Final

# CITY OF BEND AMBIENT RIVER WATER QUALITY MONITORING: 2008-2020

## Deschutes River and Tumalo Creek

**Prepared for**

**City of Bend**

**Utility Department**

**62975 Boyd Acres Road**

**Bend, OR 97701**

**October 2021**

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# Abbreviations and Acronyms

| | |
|---|---|
| 7DADM | seven-day average maximum temperature |
| AU | assessment unit |
| AWQMS | Ambient Water Quality Monitoring System |
| BENO | Benham Falls |
| BOR | Bureau of Reclamation |
| City | the City of Bend |
| °C | degree Celsius |
| CFS | cubic feet per second |
| CM | criteria met |
| COID | Central Oregon Irrigation District |
| CWA | Clean Water Act |
| DBBC | Deschutes Basin Board of Control |
| DBHCP | Deschutes Basin Habitat Conservation Plan |
| DCMO | Deschutes County MID Canal |
| DEBO | Deschutes River Below Bend |
| DEQ | Department of Environmental Quality |
| DL | detection limit |
| DNA | deoxyribonucleic acid |
| DO | dissolved oxygen |
| DR | Deschutes River |
| EPA | Environmental Protection Agency |
| ESA | Environmental Science Associates |
| FY | fiscal year |
| IR | Integrated Report |
| ISWMP | Integrated Stormwater Management Plan |
| mg/L | milligrams per liter |
| µS/cm | microiemens per centimeter |
| mL | milliliters |
| MOU | memorandum of understanding |
| MPN | most probable number |
| MS4 | Municipal separate storm sewer system |
| NPDES | National Pollutant Discharge Elimination System |
| NTU | nephelometric turbidity units |
| OAR | Oregon Administrative Rule |
| OSP | Oregon spotted frog |
| OWRD | Oregon Water Resources Department |
| UDWC | Upper Deschutes Watershed Council |
| POR | period of record |
| PSU | Portland State University |
| QAPP | quality assurance project plan |
| QA/QC | quality assurance/quality control |
| RM | river mile |
| TC | Tumalo Creek |
| TID | Tumalo Irrigation District |
| TMDL | total maximum daily load |
| TP | total phosphorus |
| TSS | total suspended solids |
| TUMO | Tumalo Creek below Tumalo Feed Canal |
| UDWC | Upper Deschutes Watershed Council |
| UGB | urban growth boundary |
| USDA | United States Department of Agriculture |
| SM | Standard Methods |

# CITY OF BEND AMBIENT RIVER WATER QUALITY MONITORING: 2008-2020

## Deschutes River and Tumalo Creek

## Introduction

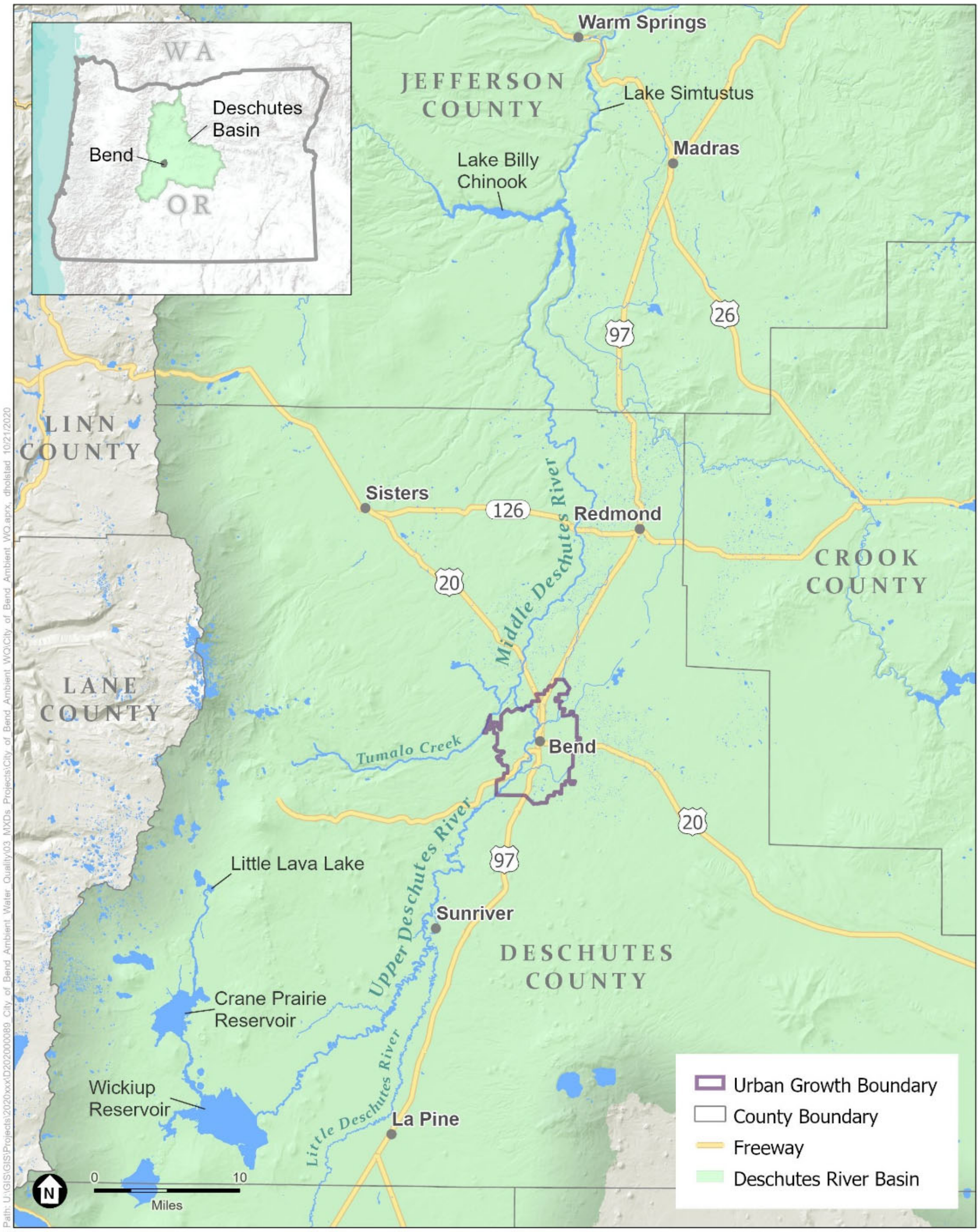
The City of Bend (the City) has been monitoring water quality from Tumalo Creek in Shevlin Park and from the Deschutes River as it enters the City near the southern urban growth boundary (UGB) to where it leaves near the northern UGB. This monitoring has occurred from 2004 through 2020, in accordance with a series of Water Quality Monitoring Plans approved by the City. These data improve understanding of changing conditions over time and data are provided to Oregon Department of Environmental Quality (DEQ). The City selected 12 sampling locations in the Deschutes River and one location along Tumalo Creek to provide a basis for understanding water quality in surface waters within the City, answer water quality questions, and inform ecological processes and protection policies regarding these waterbodies as they flow through the City. The specific objectives of this report that captures the results of the ambient monitoring program activities are to:

- Increase understanding of seasonal and annual variations for conventional water quality parameters in the Deschutes River,
- Satisfy element IX (Monitoring) of the City's *Integrated Stormwater Management Plan* (ISWMP) – a required component under the City's National Pollutant Discharge Elimination System (NPDES) permit number 102901,
- Gather legally defensible data leading to improved understanding and potentially to the listing or de-listing of local waterways under the Federal Clean Water Act Section 303(d) with the Oregon Department of Environmental Quality (DEQ) and the United States Environmental Protection Agency (USEPA),
- Gather legally defensible data to aid in establishment of DEQ's total daily maximum load (TMDL) values for the Deschutes River (and Tumalo Creek, limited data included in this study), and
- Inform staff and local authorities in addressing sediment issues in Mirror Pond on the Deschutes River.

From 2004 to 2009, water quality monitoring was performed under a memorandum of understanding (MOU) between the City and the Upper Deschutes Watershed Council (UDWC) and were summarized in *City of Bend Ambient Water Quality Monitoring: Deschutes River and Tumalo Creek 2005-2008 (Bend Oregon)* (UDWC 2010). In subsequent years, water quality data collected within the Deschutes River through the City of Bend reach and portions of Tumalo Creek were collected by the City and summarized in *City of Bend Ambient River Water Quality Monitoring: Deschutes River 2008-2017* (Environmental Science Associates [ESA] and MaxDepth Aquatics (2019). The main objective was to assess the water quality of the Deschutes River coming into, within, and leaving the City, and to further compare those results to the prior UDWC (2010) report to analyze any changes. The water quality data collected also inform the upper tier of effectiveness evaluation and assist in understanding the health of the river over time. This report builds upon previously reported data with an emphasis on data collected between 2018 and 2020. Data collected from 2008 through 2020 are generally summarized and provided graphically in Appendices. Water quality data collected between 2004 and 2007 were not available for inclusion in this reporting effort.

# Study Area

Central Oregon is located within the counties of Deschutes, Jefferson, and Crook; flanked by the Cascade Mountain Range to the west and the Ochoco Mountains to the east. Unlike most communities on the west side of the Cascades, the region is characterized by dry and sunny summers with precipitation largely falling as snow during the winter months. Average annual precipitation for Bend is 13 inches (AgACIS for Deschutes County 2021). The City of Bend is in Deschutes County and is the largest city in Central Oregon (**Figure 1**). The population of Deschutes County was 197,015 in 2020, making it the 7$^{th}$ largest county in the state (PSU 2021a). The population of the City of Bend was 92,840 in 2020, or the 5$^{th}$ largest city in the state (PSU 2021a). In 2018, the Population Research Center at Portland State University (PSU) projected the population of Bend to reach 220,708 by 2025 (PSU 2021b). Located along the bank of the Deschutes River, it was originally settled as a logging town but is now considered a gateway community to numerous outdoor activities including skiing, biking, rafting, golf, camping, tubing, and fishing – many of which are enjoyed on the Deschutes River.




SOURCE: ODOT, 2015; BLM, 2015, USGS, 2020; ESRI, 2020

D201600691.04

ESA

Study Area
City of Bend Ambient River Water Quality Monitoring

**Figure 1. Study area for the City of Bend Ambient River Water Quality Monitoring**

The Deschutes River has its headwaters along the eastern flanks of the Cascade Mountains. Its headwaters are routinely attributed to Little Lava Lake; however, groundwater that flows through porous geologic formations throughout the upper Deschutes Basin are the primary drivers of its upper watershed hydrology (Lite and Gannett 2002) (**Figure 2**).

**Figure 2. The Upper Deschutes River below Little Lava Lake, Deschutes County, Oregon**

From Little Lava Lake, the Deschutes River flows into Crane Prairie Reservoir, then Wickiup Reservoir (see **Figure 1**). Wickiup Reservoir is a productive system that can support summer algae blooms, as well as elevated primary productivity. These conditions, when combined with dramatic changes in seasonal storage and discharge, can affect and influence downstream water quality conditions (e.g., turbidity, total suspended sediments, temperature, and dissolved oxygen). Below Wickiup, the Little Deschutes River (just south of the community of Sunriver) enters the Deschutes River. Water quality conditions along the Little Deschutes are known to generate exceedances for spawning and cold water (dissolved oxygen) as well as salmon and trout rearing and migration, and bull trout spawning and juvenile rearing (temperature) (DEQ 2014). Near the City's southern UGB, a diversion canal operated by the Central Oregon Irrigation District (COID) is located at river mile (RM) 170.75 (**Figure 3**). Below the COID diversion, within the City, the river flows freely about three miles where it is flanked by the Deschutes River Trail and characterized by a series of waterfalls, riffles, and pools before Colorado Street (**Figure 4**).

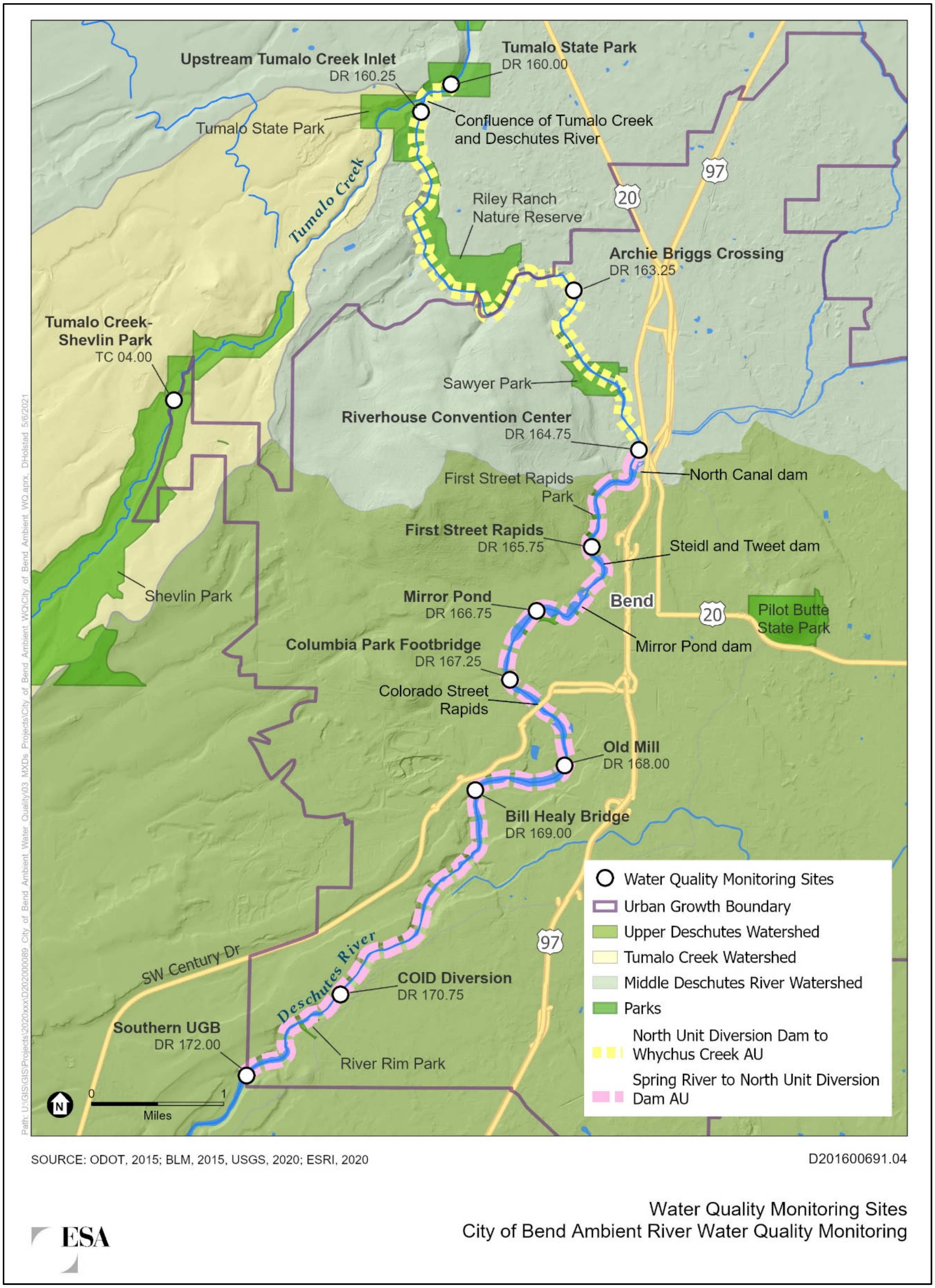



**Figure 3. Water quality monitoring sample sites, parks, and assessment units along the Deschutes River within the study area**

The Colorado Street Dam, once located at RM 167.55, was built in 1915 to serve as a mill pond for lumber mills. In 2014/2015, portions of the dam were removed and extensive improvements were made to allow for instream passage of boaters, and enhancements for fish and wildlife habitat. The Pacific Power and Light Hydroelectric Dam, located downstream from sample site DR 166.75, forms Mirror Pond, an iconic feature of the City flanked by a number of city parks, private homes, and downtown businesses (**Figure 4**). Less than a half mile downstream is the Steidl and Tweet Dam operated by Tumalo Irrigation District (TID). Approximately three quarters of a mile downstream is the North Canal Dam, which diverts water for Swalley, North Unit and Central Oregon irrigation districts. Beginning in February 2016 and again in August 2017, sections of the Pilot Butte Canal were added to the National Register of Historic Places. Beyond the city limits, Tumalo Creek joins the Deschutes River from the southwest. Further downstream, the Deschutes River is once again impounded by the Pelton Round Butte Hydroelectric Complex, a series of three dams, which in order, create Lake Billy Chinook, Lake Simtustus, and an unnamed reregulation reservoir before continuing to its confluence with the Columbia River.

**Figure 4. Example of the Deschutes River as it enters the City of Bend**

Historically, spring-fed inputs to the Deschutes River resulted in very stable hydrologic regimes on daily, monthly, and even annual timescales (USDA 1996). However, impoundments and diversions along the length of the river have dramatically altered these natural flow regimes. In the Deschutes Basin, water is legally diverted from the river to meet various water rights from early to mid-April through mid- to late October to provide for mostly agriculture demands in Central Oregon. Due to the topography of the surrounding lands, irrigation districts and related diversion points both above and within Bend, divert a substantial portion of the Deschutes River's streamflow to meet the legal water rights of the various districts and their patrons. Several of the Districts all have supplemental water rights that allow for seasonal storage in Wickiup, Crane Prairie and Crescent lakes. These combined operations result in low flows in winter months while filling reservoirs, and in summer months, release of the storage rights, create higher than historic flows upstream of Bend. The combined district diversions result in low flows downstream of Bend, most noticeably below the North Canal Dam. These large discharge swings and reductions in streamflow have contributed to degradation in streambank and fish habitat, fish passage and water quality. Within the Middle Deschutes River (between the City of Bend and Lake Billy Chinook), modern day flows are significantly lower during the summer irrigation season-though recent strides have been made by numerous stakeholders in the Deschutes Basin to increase instream flow and decrease overall fluctuations. Significant drivers of flow improvements are related to the relicensing of the Pelton project, which reintroduced listed Steelhead in 2007, and led to the start of the Habitat Conservation Plan (HCP). Steelhead were included as an experimental population which delayed the need for an incidental take permit. Later, while the HCP study was already underway, in August 2017 U.S. Fish and Wildlife Service listed the Oregon spotted frog (OSP) (*Rana pretiosa*) as threatened, and that species was added to the HCP planning.

The Deschutes Basin Habitat Conservation Plan (HCP) was finalized and approved by the U.S. Fish and Wildlife Service December 31, 2020. The HCP is a large-scale planning effort that will help the City of Prineville and the eight irrigation district members of the Deschutes Basin Board of Control (DBBC) meet their current and future water needs while enhancing fish and wildlife habitat (USFWS 2020). Conservation measures in the DBHCP are intended to minimize and mitigate impacts caused by the “take” of covered listed species (OSP, bull trout, spring Chinook salmon, sockeye salmon and steelhead) that may result from the storage, release, diversion and return of irrigation water by the member irrigation districts and the City of Prineville. Under the Proposed Action, minimum fall/winter flows in the Deschutes River below Wickiup Dam would be increased incrementally to 400 cubic feet per second (cfs) within the next 30 years.

Tumalo Creek is a tributary to the Deschutes River, the confluence is located approximately 2.5 river miles downstream of the City of Bend’s northern UGB (**Figure 3**). Tumalo Creek begins where the Middle Fork Tumalo Creek and North Fork Tumalo Creek meet in the eastern Cascade Range and travels past scenic waterfalls such as Tumalo Falls, located about 15 miles west of Bend, is a stunning 97-foot waterfall popular with tourists and photographers then skirting the westernmost boundary of the City limits as it travels through Shevlin Park (**Figure 5**) on its way to the confluence with the Deschutes River just upstream of Tumalo State Park. The Bridge Creek Fire in 1979 and subsequent salvage logging left three miles of Tumalo Creek without large woody debris for fish habitat and bank stabilization. Between 2003 and 2008, a number of partners, including the Upper Deschutes Watershed Council, the Deschutes National Forest, Oregon Watershed Enhancement Board, National Forest Foundation, City of Bend, the Deschutes River Conservancy, and the Oregon Department of Fish and Wildlife, implemented major restoration efforts to areas most affected by the fire.

**Figure 5. Tumalo Creek upstream of the confluence with the Deschutes River**

# Methods

For this analysis of ambient water quality through Bend, twelve (12) sites were monitored along the Deschutes River (DR) and Tumalo Creek (TC) within the City (**Table 1**; **Figure 3**) (one site was relocated beginning in 2015). The monitoring sites are grouped by Assessment Unit (AU) per the Oregon Department of Environmental Quality (DEQ) 2018/2020 Integrated Report (see Regulatory Framework section below). Monitoring parameters included: (1) grab samples for laboratory analysis of total coliform, *E. coli*, chloride, fluoride, sulfate, orthophosphate, total phosphate, nitrate, nitrite, and total suspended solids; (2) continuous (e.g., hourly) temperature monitoring using temperature-specific loggers, and (3) continuous (e.g., 15-minute interval) monitoring with a multi-parameter sonde for temperature, dissolved oxygen, specific conductance, and pH (**Table 2**). At the same time as grab samples were collected for laboratory analysis, a multi-parameter sonde was used to collect *in situ* measurements for temperature, dissolved oxygen (DO), specific conductance, and pH and a field meter was used to measure turbidity for comparison with the continuously monitored data as part of the Quality Assurance/Quality Control (QA/QC) procedures described later. Instrument depth for continuous monitoring probes varies by location based on conditions at each site. During some conditions, probes can be exposed to air; however; data affected by such periods have been removed from this analysis (see below for QA/QC procedures). The frequency and types of parameters measured varied slightly by site and between years but have been more consistent in recent years (**Table 2**). More specific information on analytical methods is provided in **Table 3**.

**TABLE 1. ASSESSMENT UNITS AND SAMPLE SITE NAMES AND LOCATIONS**

| 303(d) List Assessment Unit | Site No. | Site Name | Latitude | Longitude |
|---|---|---|---|---|
| Tumalo Creek | TC 04.00 | Tumalo Creek – Shevlin Park | 44.082872 | -121.376428 |
| North Unit Diversion Dam to Whychus Creek | DR 160.00[a] | Tumalo State Park | 44.117746 | -121.334802 |
| North Unit Diversion Dam to Whychus Creek | DR 160.25 | Upstream Tumalo Creek Inlet (note 1) | 44.114726 | -121.339286 |
| North Unit Diversion Dam to Whychus Creek | DR 163.25[a] | Archie Briggs Crossing | 44.095352 | -121.315838 |
| North Unit Diversion Dam to Whychus Creek | DR 164.75 | Riverhouse Convention Center | 44.077958 | -121.305693 |
| Spring River to North Unit Diversion Dam | DR 165.75 | First Street Rapids | 44.067314 | -121.313013 |
| Spring River to North Unit Diversion Dam | DR 166.75 | Mirror Pond (note 2) | 44.060242 | -121.320994 |
| Spring River to North Unit Diversion Dam | DR 167.25 | Columbia Park Footbridge | 44.05269 | -121.324939 |
| Spring River to North Unit Diversion Dam | DR 168.00 | Old Mill | 44.043359 | -121.316476 |
| Spring River to North Unit Diversion Dam | DR 169.00 | Bill Healy Bridge | 44.040564 | -121.330014 |
| Spring River to North Unit Diversion Dam | DR 170.75[b] | COID Diversion (note 3) | 44.01808 | -121.350176 |
| Spring River to North Unit Diversion Dam | DR 172.00[b] | Southern Urban Growth Boundary (UGB) | 44.009117 | -121.364307 |

NOTES:

[a] Sonde moved from DR 160.00 to DR 163.25 in 2015

[b] Sonde moved from DR 172.00 DR 170.75 in 2015

1. Site is located on the Deschutes River, above the confluence with Tumalo Creek
2. Located within the central portion of Mirror Pond
3. Located at the diversion structure

**TABLE 2. GRAB SAMPLE, CONTINUOUS TEMPERATURE, AND CONTINUOUS SONDE COLLECTION SITES AND DATES**

| Site No. | Site Name | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TC 04.00 | Tumalo Ck – Shevlin Park | — | — | — | — | — | — | — | — | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ |
| DR 160.00 | Tumalo State Park | ■ | ¤ | ¤ | ¤ | ¤ | ¤ | ¤ | ¤ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ¤ |
| DR 160.25 | Upstream Tumalo Ck. | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ |
| DR 163.25 | Archie Briggs Crossing | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ¤ | ¤ | ¤ | ¤ |
| DR 164.75 | Riverhouse Convention Center | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ |
| DR 165.75 | First Street Rapids | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ |
| DR 166.75 | Mirror Pond | ■ | ¤ | ¤ | ¤ | ¤ | ■ ◊ | ■ ▲ | ¤ | ¤ | ¤ | ¤ | ¤ | ¤ |
| DR 167.25 | Columbia Park Footbridge | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| DR 168.00 | Old Mill | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ |
| DR 169.00 | Bill Healy Bridge | ■ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ | ■ ▲ |
| DR 170.75 | COID Diversion | — | — | — | — | — | — | — | ¤ | ¤ | ¤ | ¤ | ¤ | ¤ |
| DR 172.00 | Southern UGB | — | ▲ ◊ | ¤ | ¤ | ¤ | ¤ | ¤ | — | — | — | — | — | — |

■ Grab samples + *in situ* multi-parameter sonde measurements
▲ Continuous temperature loggers
◊ Continuous multi-parameter sonde measurements
¤ All of the above

— No monitoring completed

**TABLE 3. CONTINUOUS AND GRAB SAMPLE PARAMETERS AND METHODS**

| Parameters | Analysis Technique/Equipment [a] |
|---|---|
| **Grab Sample Monitoring (Quarterly)** | |
| Coliform, Total (MPN/100 ml) | SM 9223 B |
| Coliform, E. coli (MPN/100 ml) | SM 9223 B |
| Chloride (Cl) (mg/L) | SM 4110 B |
| Dissolved Oxygen (mg/L) | Multiparameter sonde (YSI Pro DSS) |
| Fluoride (F) (mg/L) | SM 4110 B |
| Orthophosphate ($PO_4$) (mg/L) | SM 4110 B 0 |
| Nitrate ($NO_3$) (mg/L) | SM 4110 B |
| Nitrite ($NO_2$) (mg/L) | SM 4110 B |
| pH | Multiparameter sonde (YSI Pro DSS) |
| Phosphate, Total ($PO_4$) (mg/L) | SM 4500-PE |
| Specific Conductance (µS/cm) | Multiparameter sonde (YSI Pro DSS) |
| Sulfate ($SO_4$) (mg/L) | SM 4110 B |
| Temperature (°C) | Multiparameter sonde (YSI Pro DSS) |
| Total Suspended Solids (TSS) (mg/L) | SM 2540D |
| Turbidity (FNU) | Field probe HACH 2100P |
| **Ambient and Continuous Monitoring** | |
| Temperature (°C) | Multiparameter sonde (YSI EX02); continuous data logger (Vemco) |
| Dissolved Oxygen (mg/L) | Multiparameter sonde (YSI EX02) |
| Specific Conductance (µS/cm) | Multiparameter sonde (YSI EX02) |
| pH | Multiparameter sonde (YSI EX02) |
| Turbidity (NTU) | Multiparameter sonde (YSI EX02) |

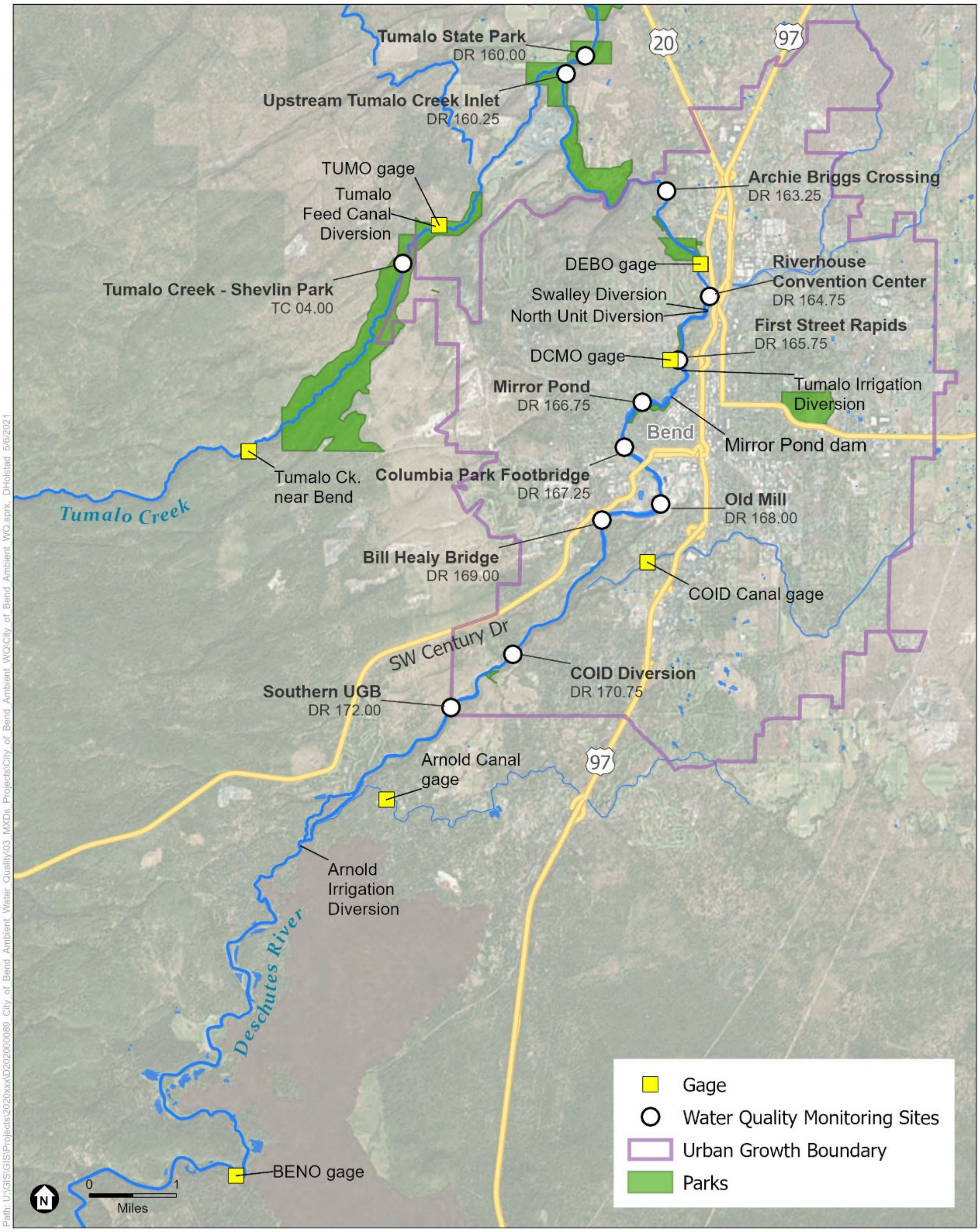
NOTES:
[a] Equipment listed are current and do not reflect improvements made over time.

Daily mean water flow data from 2008 to 2020 for the Deschutes River, Tumalo Creek, and applicable irrigation canals were taken from Bureau of Reclamation (BOR) and Oregon Water Resources Department (OWRD) gaging stations (**Figure 6**). The Benham Falls (BENO) gage is located upstream of the COID and Arnold Irrigation District diversions. Information from this gage, combined with the Arnold diversion at Lava Falls, provides an estimate of flow at the upstream UGB and is used to describe flow rates at the Southern UGB site[1] (DR 172.00) to the COID Diversion site (DR 170.25). Flows from the COID diversion were further subtracted to provide estimated rates for sites from the Bill Healy Bridge (DR 169.00) to Mirror Pond (DR 166.75). Flows from the Deschutes

[1] Monitoring at the Southern UGB site (DR 172.00) was moved farther downstream in 2015 to the COID Diversion site (DR 170.25).

County Mid Canal (DCMO) gage were further subtracted to provide estimated rates for the First Street Rapids site (DR 165.75). The Deschutes River Below Bend (DEBO) gage is downstream of all major diversions within the city. The DEBO gage was used to estimate flows below the North Unit and Swalley Irrigation District diversions but prior to the confluence with Tumalo Creek. This stretch encompasses the Riverhouse Convention Center site (DR 164.75) to the Upstream Tumalo Creek Inlet site (DR 160.25). Lastly, flows from the Tumalo Creek below Tumalo Feed Canal (TUMO) gage was added to the DEBO gage to estimate flows below the confluence of the Deschutes River and Tumalo Creek at the Tumalo State Park site (DR 160.00). Flows for the Tumalo Creek – Shevlin Park site (TC 4.00) were taken from the OWRD gage located at Skyliners Rd. A nearer gage is located downstream of TC 4.00 (but upstream of the Tumalo Feed Canal); however, the dataset was more limited compared to the gage at Skyliners Rd. It should be noted that all flow rates are based solely on previously described gage information and do not account for gains and losses from groundwater recharge, canal leakage, or evaporation as detailed in Gannett et al. (2017).

As previously mentioned, irrigation canals divert a substantial portion of the Deschutes River's streamflow, resulting in low flows in winter months, and in summer months high flows upstream of Bend and low flows downstream of Bend. **Figure 7** illustrates these seasonal changes in flow between sites for the period of 2018 to 2020. The "ramp up" process for irrigation releases is set by the OWRD and begins in April of each year with complete releases not reached until mid-May. The full period of record (POR) dataset is provided in the Appendices.




SOURCE: ODOT, 2015; BLM, 2015, USGS, 2020; ESRI, 2020

D201600691.04

ESA

River Streamflow Gauge Stations
City of Bend Ambient River Water Quality Monitoring

**Figure 6. Location of river flow gages in relation to sample sites within the study area, Deschutes County, Oregon (see text for full gage names)**

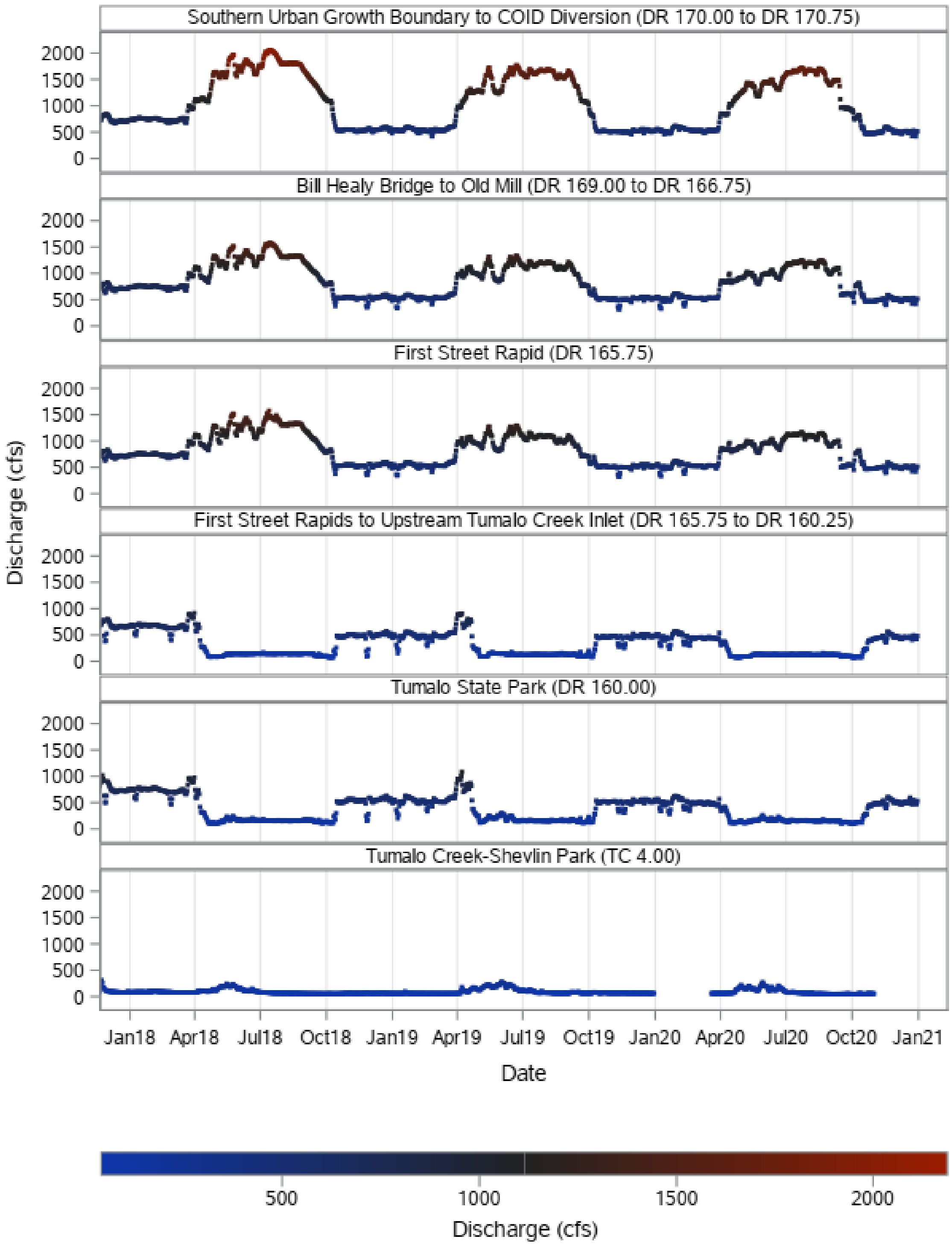



**Figure 7. Mean daily discharge (cubic feet per second, cfs) in the Deschutes River from the southern urban growth boundary (UGB) to below the northern UGB and the confluence with Tumalo Creek. Panels listed upstream to downstream (top to bottom, respectively) and includes TC 4.00 which contributes to flows at DR 160.00 - City of Bend 2018-2020**

# Quality Assurance/Quality Control

Data for this effort were collected by City staff according a *City of Bend Water Quality Monitoring Plan* (Monitoring Plan) (**Appendix A**). The continuous data were taken from (1) multi-parameter data sondes and (2) temperature-specific loggers. Continuous data were first culled for accurate deployment dates and times then carefully reviewed in order to identify anomalous data that were collected likely due to equipment error or field conditions. The Data Quality Objectives adopted by the City rely on data validation criteria developed by DEQ and include examining data points that lie outside the diurnal range for pH, temperature, and DO (included as an appendix within the Monitoring Plan). It is further laboratory policy to remove all data from a particular timestamp where errors are observed. During certain low flow periods, water levels decreased, exposing the probes to air causing erroneous data. During these periods, data sondes continued to log temperature data (i.e., air temperature), but not other parameters. Instances where air temperature was recorded is generally identified by a sharp change, usually occurring over a 15- to 30-minute period. These data were removed from further analysis, as were data for other parameters collected during these periods. Limited periods were also identified when data were skewed by equipment malfunction. These periods were typically identified by unrealistically high or low outliers observed over a period of time. These anomalies could be further confirmed by comparing output from the continuous multi-parameter sondes with one time *in situ* multi-parameter data sonde measurements collected at the same day and site when grab samples were collected and loggers were often redeployed. Where errant, these data were also removed from further consideration. Multi-parameter data sondes were calibrated according manufacturer's specifications. Only data that passed the quality assurance/quality control (QA/QC) process are included in this report. All continuous and grab data included here have been properly graded against the Oregon Water Quality Data Matrix (DEQ 2013).

# Regulatory Framework

The Federal Clean Water Act (CWA) requires Oregon to report on the quality of its surface waters every two years. Oregon surface waters are assessed to determine if they contain pollutants at levels that exceed protective water quality standards. The result of these analyses and conclusions is called the "Integrated Report" because it combines the requirements of Clean Water Act section 305(b) to develop a status report and the section 303(d) requirement to develop a list of impaired waters.

The Integrated Report assigns a Category to all assessed waterbody segments. DEQ uses data to evaluate the most common beneficial uses, such as aquatic life, drinking water or recreation. If waterbodies exceed protective water quality standards, they are placed on the 303(d) list of impaired waters. Placing a waterbody on the 303(d) list initiates the prioritization and development of a Total Maximum Daily Load (TMDL). The 303(d) list portion of the Integrated Report is submitted to the U.S. EPA for final approval.

DEQ submitted the complete 2012 Integrated Report to EPA in 2014. That portion of the Deschutes River between RM 116 to 222.2 (which includes that portion in the City of Bend) was placed on the 303(d) list of impaired waters for dissolved oxygen (DO). Specifically, the January 1 – May 15 criteria for resident trout spawning where DO should not be less than 11.0 mg/L or 95% of saturation. Between RM 168.2 and 189.4, the Deschutes River was listed for Chlorophyll *a* due to exceedances above 0.0015 mg/L during the summer months. Lastly, RM 126.4 to 162.6 were listed for pH exceedances (below 6.5/above 8.5) during all seasons.

The 2018/2020 Integrated Report (IR) relies on Assessment Units (AUs) to group stretches of river miles where impaired listings are identified. Three AUs apply to the study area: Spring River to North Unit Diversion Dam (DR 170.75 to 165.75), North Unit Diversion Dam to Whychus Creek (DR 164.75 to 160.00), and Lower Tumalo Creek (TC 4.00). The 2018/2020 IR was approved by EPA November 12, 2020. **Figure 8** and **Table 4** and summarize the applicable 303(d) listed impaired AUs in the study area. Notable delistings on the Deschutes River between the 2012 and the 2018/2020 IRs include DO (spawning and year-round), Chlorophyll *a*, and pH for the Spring River to North Unit Diversion Dam AU. These delistings apply to the following sample points within the study area of the Deschutes River: DR 170.00 (no longer monitored), DR 170.75, DR 169.00, DR 168.00, DR 167.25, DR 166.75 (Mirror Pond), and DR 165.75. Waterbodies are delisted for a variety of reasons, including:

1. current data indicate that water quality standards are attained and the waterbody is no longer impaired,
2. there is an error in the original Category 5 determination,
3. water quality standards, such as through updated science or improved measuring processes, have changed or no longer apply to a waterbody,
4. the expression of water quality standard pollutant has changed (e.g., now being measured as the dissolved fraction, when previously had been measured as the total amount of the pollutant),
5. a TMDL or other pollution control plan is in place, or
6. the impairment is caused by pollution rather than a known pollutant (i.e., flow or habitat modification) (DEQ 2020).

Water quality data used for delistings were provided to DEQ by the City of Bend Water Quality Laboratory, Deschutes River Alliance, and the Upper Deschutes Watershed Council. Details on delisting methodology may be found in DEQ (2020).

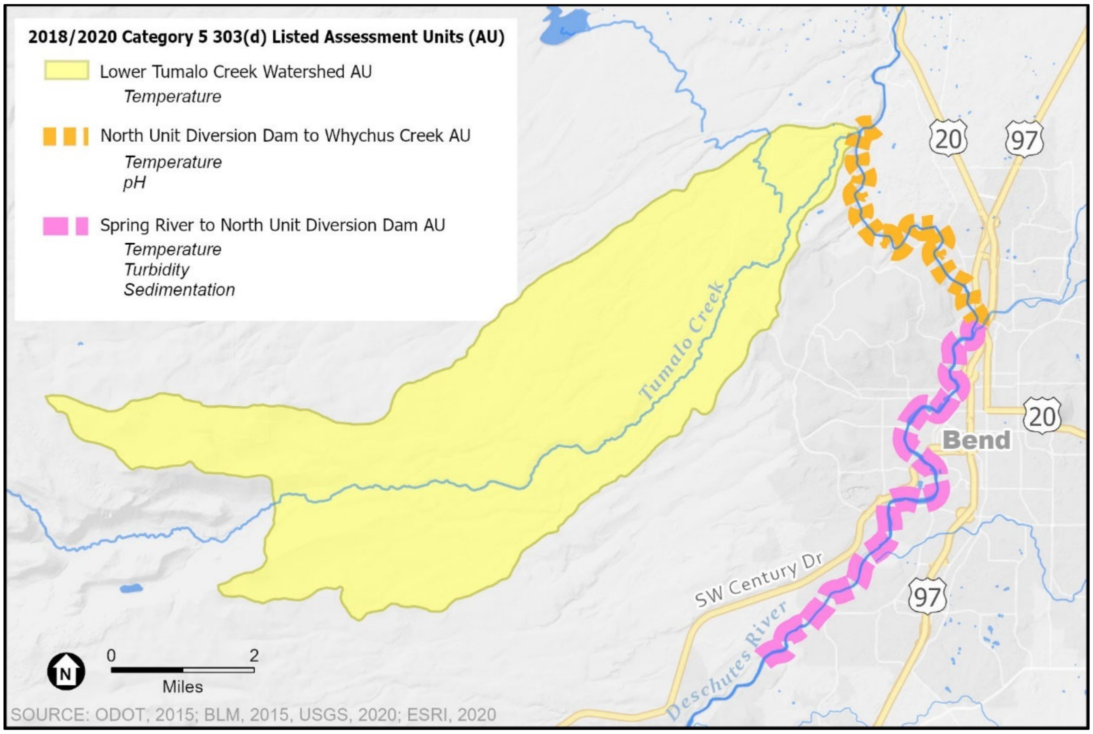



**Figure 8. 2018/2020 Category 5 303(d) Listed Assessment Units (AU) for the Tumalo Creek Watershed AU, North Unit Diversion Dam to Whychus Creek AU, and the Spring River to North Unit Diversion Dam AU**

**TABLE 4. APPLICABLE CATEGORY 5 303(D) LISTED ASSESSMENT UNITS WITHIN THE STUDY AREA**

| Parameter | Season | Criteria | Spring River to North Unit Diversion Dam (DR 170.75 to 165.75) | North Unit Diversion Dam to Whychus Creek (DR 164.75 to 160.00) | Lower Tumalo Creek (TC 4.00) |
|---|---|---|---|---|---|
| Temperature | Year Round (non-spawning) | < 18°C; 7DADM Note 1 | 303(d) | 303(d) | 303(d) |
| pH | Year Round | 6.5-8.5 | CM | 303(d) | CM |
| Turbidity | Spring/ Summer | 10% NTU increase; Note 2 | 303(d) | Insufficient data | Insufficient data |
| Sedimentation | Undefined | Note 3 | 303(d) | Insufficient data | Insufficient data |

CM = Criteria Met; N/A = Not Applicable; 303(d) = AU is listed on the 2018/2020 DEQ Integrated Report - State Final as being Category 5 303(d) listed - Impaired a TMDL is needed.

NOTES:

1. "Seven-Day Average Maximum Temperature (7DADM)" means a calculation of the average of the daily maximum temperatures from seven consecutive days made on a rolling basis (OAR 340-041-0002(56))

2. Turbidity should not increase by more than 10% during the early spring when irrigation water is released, according to the state standard. Historically, turbidity increased substantially when irrigation water is released in the spring.

3. The formation of appreciable bottom or sludge deposits or the formation of any organic or inorganic deposits deleterious to fish or other aquatic life or injurious to public health, recreation, or industry may not be allowed. Data to support evaluation of this standard was not directly evaluated under this study.

The ambient water quality data collected by the City of Bend is provided to DEQ when requests for data are made by the agency. The City is not required to collect stormwater monitoring data for the NPDES municipal separate storm sewer system (MS4) Phase II permit; however, per the permit, any data that is collected is submitted to DEQ. Between February 2, 2021 and April 2, 2021, DEQ made a call for data collected between January 2, 2016 and December 31, 2020. On behalf of the City, ESA submitted results of water quality monitoring data, summarized in **Table 5**.

### Table 5. Water Quality Monitoring Data Submitted to DEQ April 2021

| Collection Method[1,2,3] | Site Number | Site Name | Begin Date | End Date |
|---|---|---|---|---|
| Continuous multi-parameter | DR 160.00 | Tumalo State Park | 7/6/2020 | 12/17/2020 |
| Continuous multi-parameter | DR 163.25 | Archie Briggs Crossing | 10/3/2017 | 12/17/2020 |
| Continuous multi-parameter | DR 166.75 | Mirror Pond | 10/3/2017 | 12/17/2020 |
| Continuous multi-parameter | DR 170.75 | COID Diversion | 10/3/2017 | 12/17/2020 |
| Grab – laboratory analysis & multi-parameter | DR 164.75 | Riverhouse Convention Center | 6/26/2018 | 10/20/2020 |
| Grab – laboratory analysis & multi-parameter | DR 165.75 | First Street Rapids | 6/26/2018 | 10/20/2020 |
| Grab – laboratory analysis & multi-parameter | DR 166.75 | Mirror Pond | 6/26/2018 | 10/20/2020 |
| Grab – laboratory analysis & multi-parameter | DR 167.25 | Columbia Park Footbridge | 6/26/2018 | 10/20/2020 |
| Grab – laboratory analysis & multi-parameter | DR 168.00 | Old Mill | 6/26/2018 | 10/20/2020 |
| Grab – laboratory analysis & multi-parameter | DR 169.00 | Bill Healy Bridge | 6/26/2018 | 10/20/2020 |
| Grab – laboratory analysis & multi-parameter | DR 170.75 | COD Diversion | 6/26/2018 | 10/20/2020 |
| Grab – laboratory analysis & multi-parameter | TC 04.00 | Shevlin Park | 6/26/2018 | 10/20/2020 |
| Continuous water temperature | DR 160.00 | Tumalo State Park | 10/1/2017 | 12/31/2020 |
| Continuous water temperature | DR 160.25 | Upstream Tumalo Ck. Inlet | 10/1/2017 | 12/31/2020 |
| Continuous water temperature | DR 163.25 | Archie Briggs Crossing[4] | 8/29/2018 | 12/31/2020 |
| Continuous water temperature | DR 164.75 | Riverhouse Convention Center | 10/1/2017 | 12/31/2020 |
| Continuous water temperature | DR 165.75 | First Street Rapids | 10/1/2017 | 12/31/2020 |
| Continuous water temperature | DR 166.75 | Mirror Pond[4] | 10/1/2017 | 12/31/2020 |
| Continuous water temperature | DR 168.00 | Old Mill[4] | 10/1/2017 | 12/31/2020 |
| Continuous water temperature | DR 169.00 | Bill Healy Bridge | 10/3/2017 | 12/31/2020 |
| Continuous water temperature | DR 170.75 | COD Diversion | 10/1/2017 | 12/31/2020 |
| Continuous water temperature | TC 04.00 | Shevlin Park | 7/14/2016 | 12/31/2020 |

NOTES:
1 – Continuous multi-parameter = Temperature, pH, specific conductance, DO, and turbidity

2 - Grab – laboratory analysis & multi-parameter = Chloride, total coliform, *E. coli*, fluoride, nitrate, nitrite, ortho-P, TP, sulfate, TSS, temperature, pH, specific conductance, DO, and turbidity

3 - Continuous 15-minute water temperature

4 – These sites have substantial data gaps due to vandalism; lack of deployment or data did not meet QA/QC review. Gaps in data are observed in figures below.

# Results

The City has analyzed ambient river water conditions since 2004 when grab sampling began. Overtime, the program has added analytical parameters, shifted sites, and improved in situ measurement approaches and laboratory practices. The sections below summarize results of water samples collected between 2018 and 2020 to illustrate within-year variations during the most recent sampling events. Within each section, these results are further compared to the POR considered for this report (2008 to 2020) in narrative and to previous evaluations of water quality in the Deschutes River as summarized in UDWC (2010) and ESA and MaxDepth Aquatics (2019). The geographic scope of the 2010 evaluation extended beyond the limits of the City of Bend and included sites on the Upper Deschutes River, Tumalo Creek, and sites far south and north of the UGB. For comparative purposes, a brief summary of results from that study are included for each parameter at overlapping sample sites. Additionally, DEQ has an established Ambient Water Quality Monitoring System (AWQMS) sample site co-located with DR 166.75 (Mirror Pond). Results of overlapping parameters are also included for that site. Figures for the POR covering 2008 to 2020 are provided in **Appendix B**. It should be noted that the Southern UGB site (DR 172.00) was relocated to the COID Diversion site (DR 170.75) beginning in 2015 (**Table 2**).

First presented are results of parameters included in the 2018/2020 Integrated Report, followed by parameters no longer on the 303(d) list, nutrients and other parameters. Applicable numeric criteria are included on figures for temperature, pH, and dissolved oxygen. At the time grab samples were collected, water temperature, pH, turbidity, DO, and specific conductance were also measured using a multi-parameter sonde. These values were used to QC results for the continuous monitoring efforts and were submitted to DEQ as part of the call for data. The in situ data provide a "snap-shot" characterization of water quality at a more extensive network of monitoring sites compared to the continuous loggers and are presented to complement the more robust data sets provided by the continuously logged sites.

## Temperature

Temperature is a critical determinant of most biological and physiochemical processes in water, for example, chemical equilibria, water density, photosynthesis, and respiration (Wetzel 2001). By extension, water temperature determines the preferred habitat and life history of aquatic species. Excessive water temperature causes fish stress and increases vulnerability to parasites and reduced dissolved oxygen (Raleigh et al. 1984, Dorson and Touchy 1981). In Oregon, specific temperature standards have been established for waterbodies, including the Deschutes River within the City. The applicable standard within the reaches examined here include a year-round seven-day average maximum (7DADM) water temperature below 18°C for the protection of salmon and bull trout rearing and migration.

Presented are results from continuous temperature monitoring between 2018 and 2020 from (1) 10 sites using temperature-specific loggers and (2) 11 sites using data sondes at the same time grab samples were collected for laboratory analysis (**Table 2**). For the years 2009 to 2014, temperature data were collected using multi-parameter sondes and continuous temperature loggers were used for subsequent years to 2020 (POR data provided in **Appendix B**). Specific start and end times varied by site and between years; however, more recently, the continuous temperature loggers were set to a 30-minute interval. Temperature data are presented as the 7DADM and plotted by monitoring site and grouped by AU[2] (**Figure 9**) and as a percentage of times that the maximum water temperature exceeded 18°C within a month, by site (**Figure 10** and **Figure 11**). A summary of annual percent exceedances by AU, site, and year are provided in **Table 6**.

Seasonally, water temperatures at all sites ranged from at or near freezing in winter months to approximately 20°C in the summer. Substantially lower temperatures occurred in more recent years when temperature loggers were deployed over winter at some locations (**Appendix B**). On a daily basis, fluctuations in water temperature were quite low. As an example, variations in water temperature in early July 2020 at First Street Rapids (DR 165.75) were on the order of 2.5°C difference over a 24-hour period. In most years, temperature exceedances above the 18°C criteria occurred at a greater percentage of time in more downstream sites compared to upstream sites and were observed during the summer months. The greatest 7DADM exceedances between 2018 and 2020 were measured from the Deschutes River at Tumalo State Park (DR 160.00) at 20.5°C. In the Spring River to North Unit Diversion Dam AU (not including Mirror Pond), exceedances ranged from 1.5 percent at the Old Mill site (DR 168.00) in 2019 up to 17.0 percent at First Street Rapids (DR 165.75) in 2020. The greatest exceedances were generally observed in Mirror Pond (DR 166.75) between 2018 and 2020.

Exceedances in the North Unit Diversion Dam AU to Whychus Creek AU ranged from 12.6 percent at the Riverhouse Convention Center (DR164.75) in 2018 to 21.8 percent at the site Upstream Tumalo Creek Inlet (DR 160.25) in 2020. There were no exceedances measured from Tumalo Creek.

Temperatures measured during the grab sampling event with a multi-parameter sonde were within QC standards adopted by the City (**Figure 12**). Using this instrument, instances of exceedances above 18°C were measured at 12 sites across the POR (**Appendix B**); however, 11 sites have been monitored since 2015 discontinuation of the Southern UGB site.

Taken together, temperature monitoring data from the Deschutes River between 2009 and 2020 do not meet the DEQ criteria for year-round (non-spawning) 7DADM temperature criteria of 18°C and are consistent with the 2018/2020 IR 303(d) listing. Monitoring data from one site in Tumalo Creek between 2016 and 2020 were within criteria and are not consistent with the 2018/2020 IR for 303(d) listing. It is important to note that the Deschutes River at the COID Diversion (DR 170.75) site, which is located

[2] Seven-Day Average Maximum Temperature" means a calculation of the average of the daily maximum temperatures from seven consecutive days made on a rolling basis. (OAR 340-041-0002)

upstream of other irrigation diversions and urban impacts within the UGB, already exceeds the 7DADM temperature criteria of 18°C each summer.

Temperature data from 2018 to 2020 are comparable to those presented in previous summaries of ambient river conditions in the Deschutes River (**Appendix B**).

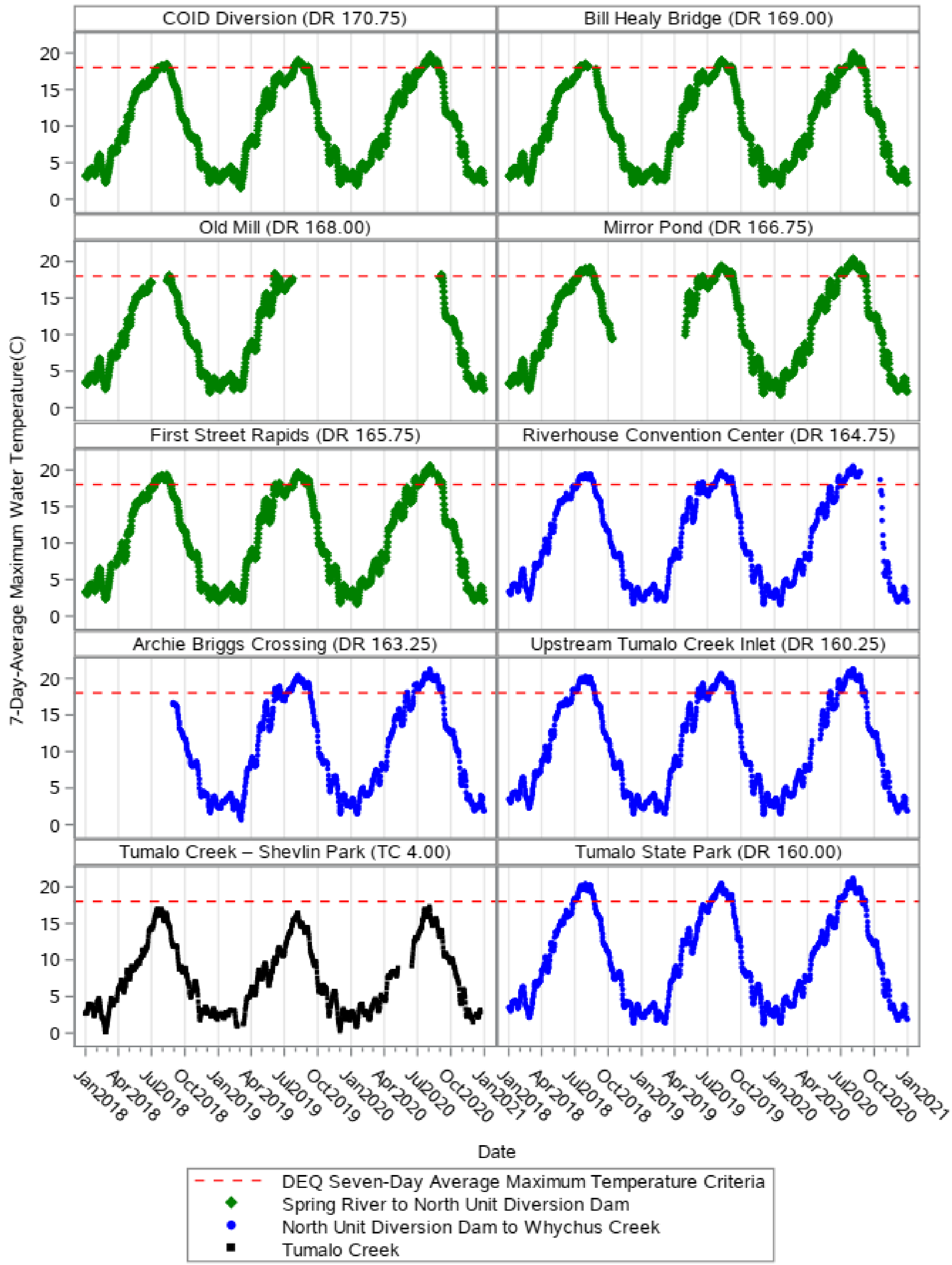



**Figure 9. The 7DADM water temperature for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green lines), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue lines) and Tumalo Creek AU (TC 4.00) (black line) - City of Bend 2018-2020. The dashed red line indicates the 18°C temperature criteria**

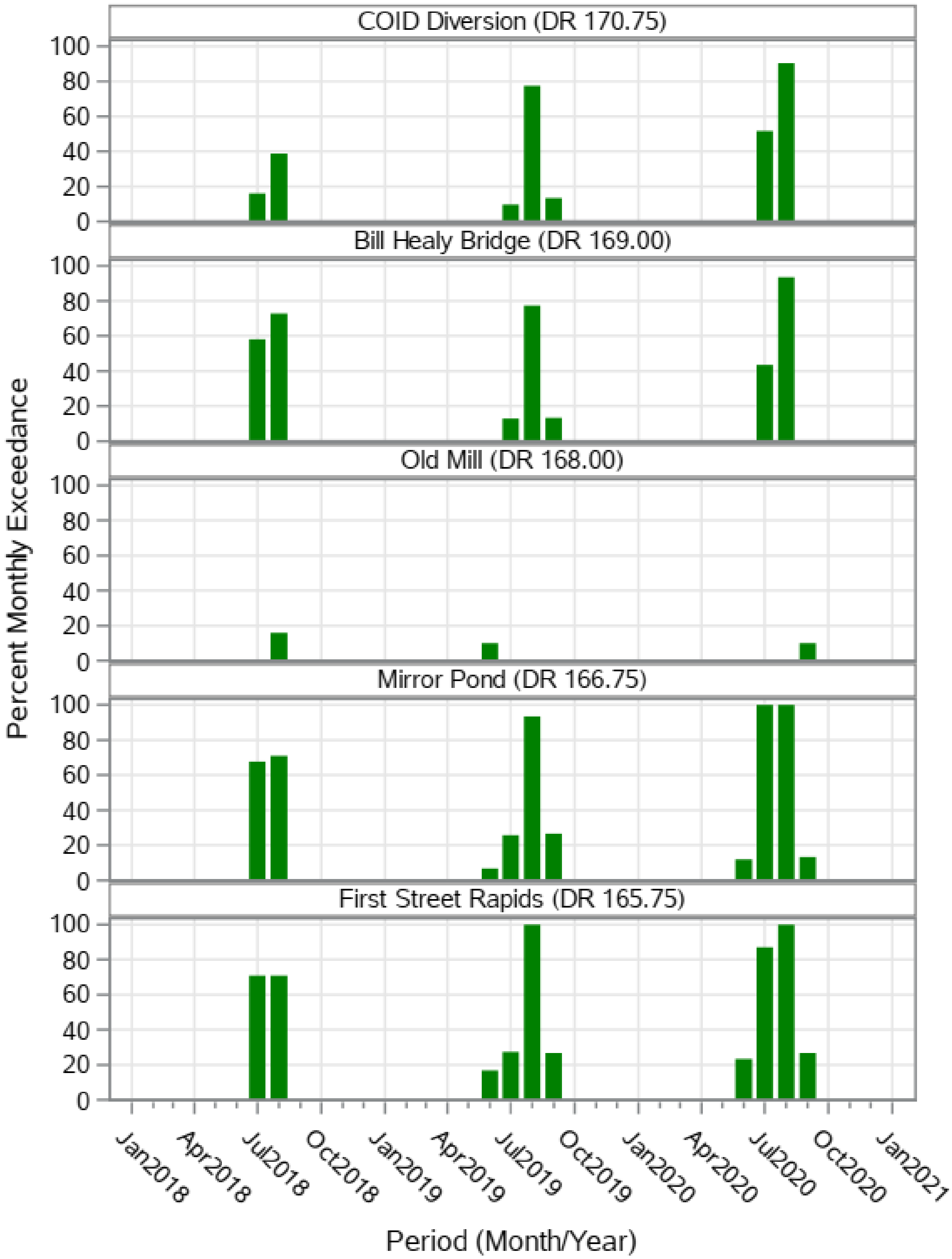



**Figure 10. Percent exceedances of the 7DADM water temperature criteria of 18°C by site and by month for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) - City of Bend 2018-2020. Note: lack of exceedances at Old Mill (DR 168.00) and Mirror Pond (DR 166.75) could also be due to lack of data**

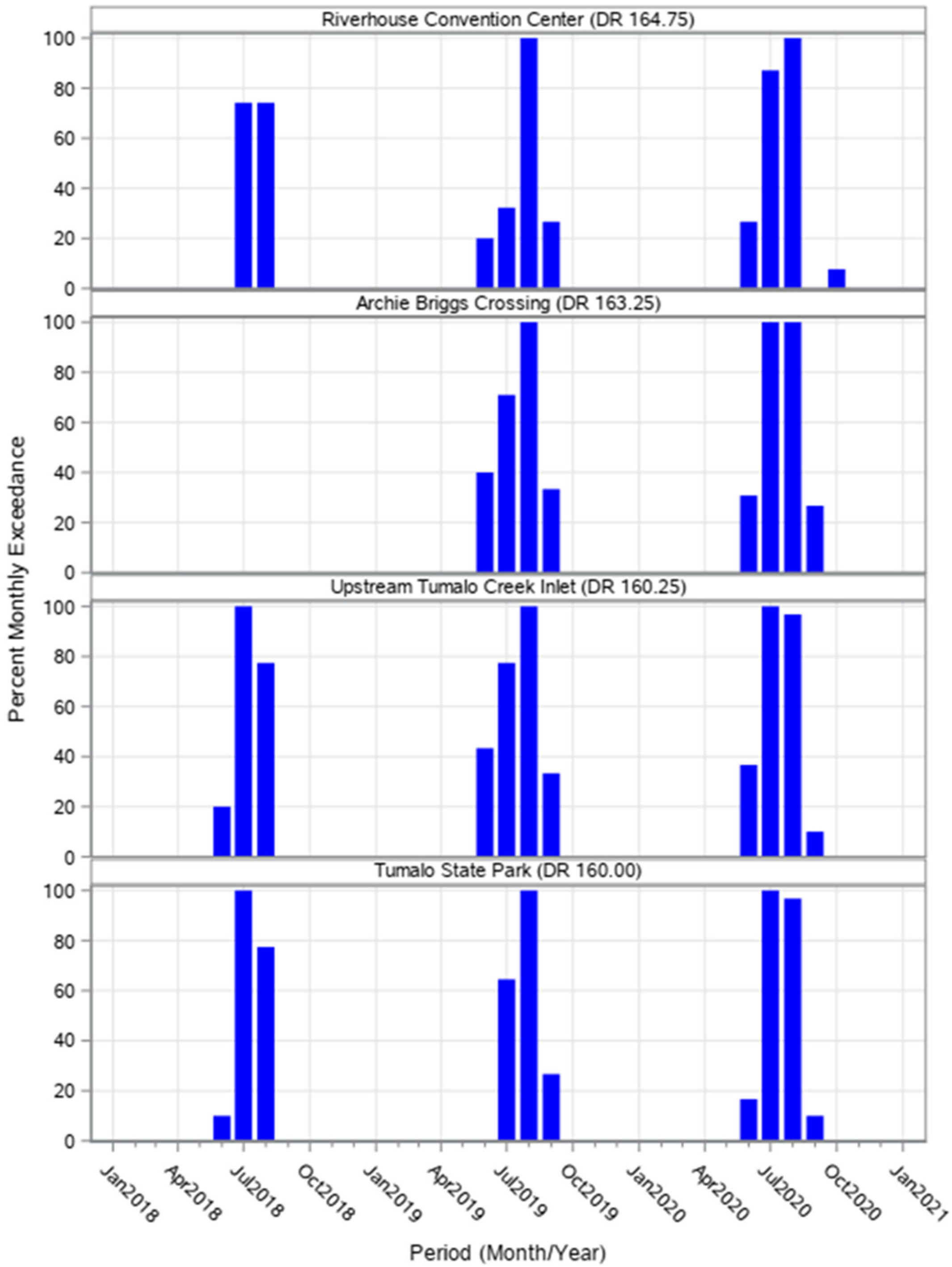



**Figure 11. Percent exceedances of the 7DADM water temperature criteria of 18°C by site and by month for the monitoring stations in the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) - City of Bend 2018-2020. Note: lack of exceedances at Archie Briggs Crossing (DR 163.25) could also be due to lack of data**

**TABLE 6. ANNUAL PERCENT EXCEEDANCES OF THE 7DADM WATER TEMPERATURE CRITERIA OF 18°C BY AU, SITE, AND YEAR BETWEEN 2018 AND 2020**

| Assessment Unit | Site | Year | Annual Percent Exceedance |
|---|---|---|---|
| Spring River to North Unit Diversion Dam | COID Diversion (DR 170.75) | 2018 | 4.7 |
| Spring River to North Unit Diversion Dam | COID Diversion (DR 170.75) | 2019 | 8.5 |
| Spring River to North Unit Diversion Dam | COID Diversion (DR 170.75) | 2020 | 12.0 |
| Spring River to North Unit Diversion Dam | Bill Healy Bridge (DR 169.00) | 2018 | 7.6 |
| Spring River to North Unit Diversion Dam | Bill Healy Bridge (DR 169.00) | 2019 | 8.8 |
| Spring River to North Unit Diversion Dam | Bill Healy Bridge (DR 169.00) | 2020 | 10.9 |
| Spring River to North Unit Diversion Dam | Old Mill (DR 168.00) | 2018 | 0.9 |
| Spring River to North Unit Diversion Dam | Old Mill (DR 168.00) (note 1) | 2019 | 1.5 |
| Spring River to North Unit Diversion Dam | Old Mill (DR 168.00) (note 1) | 2020 | 2.5 |
| Spring River to North Unit Diversion Dam | Mirror Pond (DR 166.75) (note 1) | 2018 | 15.0 |
| Spring River to North Unit Diversion Dam | Mirror Pond (DR 166.75) (note 1) | 2019 | 19.2 |
| Spring River to North Unit Diversion Dam | Mirror Pond (DR 166.75) | 2020 | 19.1 |
| Spring River to North Unit Diversion Dam | First Street Rapids (DR 165.75) | 2018 | 12.6 |
| Spring River to North Unit Diversion Dam | First Street Rapids (DR 165.75) | 2019 | 14.2 |
| Spring River to North Unit Diversion Dam | First Street Rapids (DR 165.75) | 2020 | 17.0 |
| North Unit Diversion Dam to Whychus Creek | Riverhouse Convention Center (DR 164.75) | 2018 | 12.6 |
| North Unit Diversion Dam to Whychus Creek | Riverhouse Convention Center (DR 164.75) | 2019 | 15.2 |
| North Unit Diversion Dam to Whychus Creek | Riverhouse Convention Center (DR 164.75) | 2020 | 19.6 |
| North Unit Diversion Dam to Whychus Creek | Archie Briggs Crossing (DR 163.25) | 2018 | Note 2 |
| North Unit Diversion Dam to Whychus Creek | Archie Briggs Crossing (DR 163.25) | 2019 | 20.5 |
| North Unit Diversion Dam to Whychus Creek | Archie Briggs Crossing (DR 163.25) | 2020 | 21.5 |
| North Unit Diversion Dam to Whychus Creek | Upstream Tumalo Creek Inlet (DR 160.25) | 2018 | 16.7 |
| North Unit Diversion Dam to Whychus Creek | Upstream Tumalo Creek Inlet (DR 160.25) | 2019 | 21.5 |
| North Unit Diversion Dam to Whychus Creek | Upstream Tumalo Creek Inlet (DR 160.25) | 2020 | 21.8 |
| North Unit Diversion Dam to Whychus Creek | Tumalo State Park (DR 160.00) | 2018 | 15.9 |
| North Unit Diversion Dam to Whychus Creek | Tumalo State Park (DR 160.00) | 2019 | 16.3 |
| North Unit Diversion Dam to Whychus Creek | Tumalo State Park (DR 160.00) | 2020 | 18.9 |

NOTES:

1. Substantial data gaps occur during period, annual percent exceedance based upon available data.
2. Exceedances not reported as monitoring did not begin until August 28, 2018 at this site.

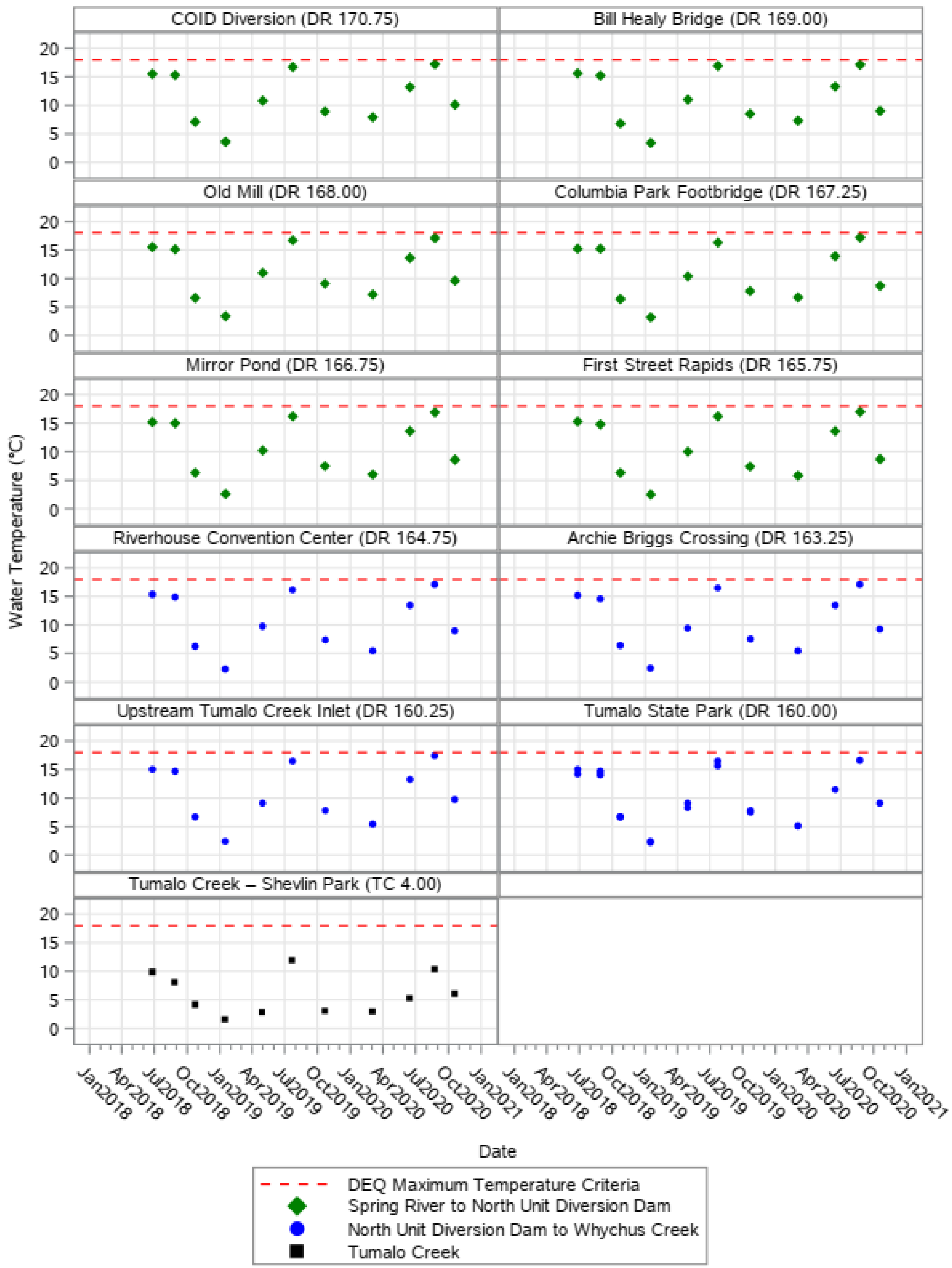



**Figure 12. Discrete in-situ water temperature readings for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2018-2020. The dashed red line indicates the water temperature criteria of 18°C (for reference only, not applicable to discrete data)**

# pH

pH describes the measurement of how acidic or basic a substance is, with values below 7.0 being acidic and above being basic. The pH of water determines the solubility and bioavailability of chemical constituents. For example, pH drives the availability and form of nutrients such as phosphorus and nitrogen, but also the solubility and toxicity of heavy metals such as lead and copper. Fluctuations in pH can occur due to phytoplankton and aquatic plants growing in the water. As these organisms photosynthesize, pH measured in the water increases. As photosynthesis declines, so does pH. In slow moving water with high photosynthetic activity, a daily pattern can be quite evident from morning (lower pH), to midday (peak pH), to evening (lowest pH). Values in pH can also be influenced by snow melt, rain, groundwater and inputs from tributaries. Most of the Deschutes River within the study area are included on the DEQ 303(d) for pH. Specifically, for pH values below 6.5 or above 8.5 (OAR 340-041-0135).

Presented are pH results from continuously logging multi-parameter data sondes between 2018 and 2020 from five sites set at 30-minute intervals (**Table 2**). Specific start and end times varied by site and between years. Also presented are results from discrete pH measurements made using a handheld multi-parameter data sonde at the same time as grab samples were collected for laboratory analysis. Measurements of pH are presented as the raw data by site and year with the DEQ 6.5 minimum and 8.5 maximum pH criteria indicated (**Figure 13**), percent monthly daily maximum exceedances by AU (**Figure 14** and **Figure 15**), and discrete in situ values collected at the same time as grab samples (**Figure 16**). A summary of annual percent daily maximum exceedances by AU, site, and year are provided in **Table 7**. Continuous pH data for the POR are provided in **Appendix B**.

Seasonally, pH values are somewhat higher in the summer, presumably due to increased photosynthetic activity. Daily fluctuations in pH were more dramatic in areas of slower moving water. For example, pH values on an average July in Mirror Pond (DR 166.75) increased by a full unit; however, upstream at the COID Diversion (DR 170.75) pH ranged by 0.5 units.

When evaluating the continuously recorded data considered in this report (2018 to 2020), average pH for all sites across all years monitored was 7.8. Exceedances of pH above 8.5 occurred at all sites at some point over the entire monitoring duration, mostly mid to late summer. Minimum pH exceedances occurred 4.4 percent of the year in 2009 in the Spring River to North Unit Diversion Dam AU (Mirror Pond - DR 166.75) and only 0.5 percent of the year (2010) in the North Unit Diversion Dam to Whychus Creek AU (at Tumalo State Park - DR 160.00). Prolonged periods of elevated pH occurred at Mirror Pond (DR 166.75) in 2010, 2012 and 2020 in which 100 percent of monthly daily maximum pH values exceeded the maximum criteria. In 2020, several concurrent months (May through October) had percent monthly exceedances above 50 percent (**Figure 12** and **Figure 13**). Daily maximum pH measurements from the Deschutes River at Archie Briggs Crossing (DR 163.25) were similarly above the maximum pH criteria 50 percent of the time in June through September 2020 as well as August 2018 (**Figure 12** and **Figure 15**). In contrast, the COID Diversion (DR 170.75) site had more frequent elevated daily maximum pH values in the summer of 2018 compared to 2020. Measurements of pH are highly correlated with photosynthetic activity which is greatest midday and could explain some variation between discrete grab sample results compared to continuous results which capture a 24-hour period.

Annual daily maximum exceedances of the maximum pH criteria (8.5) in the North Unit Diversion Dam AU to Whychus Creek AU ranged from 3.0 percent at the Tumalo State Park (DR 160.00) in 2020 to 32.9 percent at the Archie Briggs Crossing site (DR 163.25) in 2020 (Table 7). Comparatively, annual daily maximum exceedances in the Springs River to North Unit Diversion Dam AU ranged from 0.6 to 42.1 percent at the Mirror Pond site (DR 166.75) over the period 2018 to 2020.

Values of discrete in situ pH measured during the grab sampling event with a multi parameter sonde were within QA/QC standards adopted by the City (**Figure 16**). Using this instrument, exceedances above 8.5 pH units were measured at eight sites across the POR; however, two exceedances were measured between 2018 and 2020 during grab sample measurements. These exceedances occurred at the COID diversion (DR 170.75) and Mirror Pond (DR 166.75).

While monitoring data from the Deschutes River between 2009 and 2020 do not meet the DEQ criteria for year-round minimum pH criteria of 6.5, this occurred for just one site in each of the two AUs along the Deschutes River over an 11-year period (Mirror Pond [DR 166.75] and Tumalo State Park [DR 160.00]; see **Appendix B**). Observations of elevated pH compared to the maximum criteria of 8.5 are consistent with the 2018/2020 IR 303(d) listing for both AUs along the Deschutes River. The continuous monitoring of pH was not performed at the site in Tumalo Creek (TC 4.00) evaluated here; however, as noted above, no pH exceedances were measured during grab sample measurements.

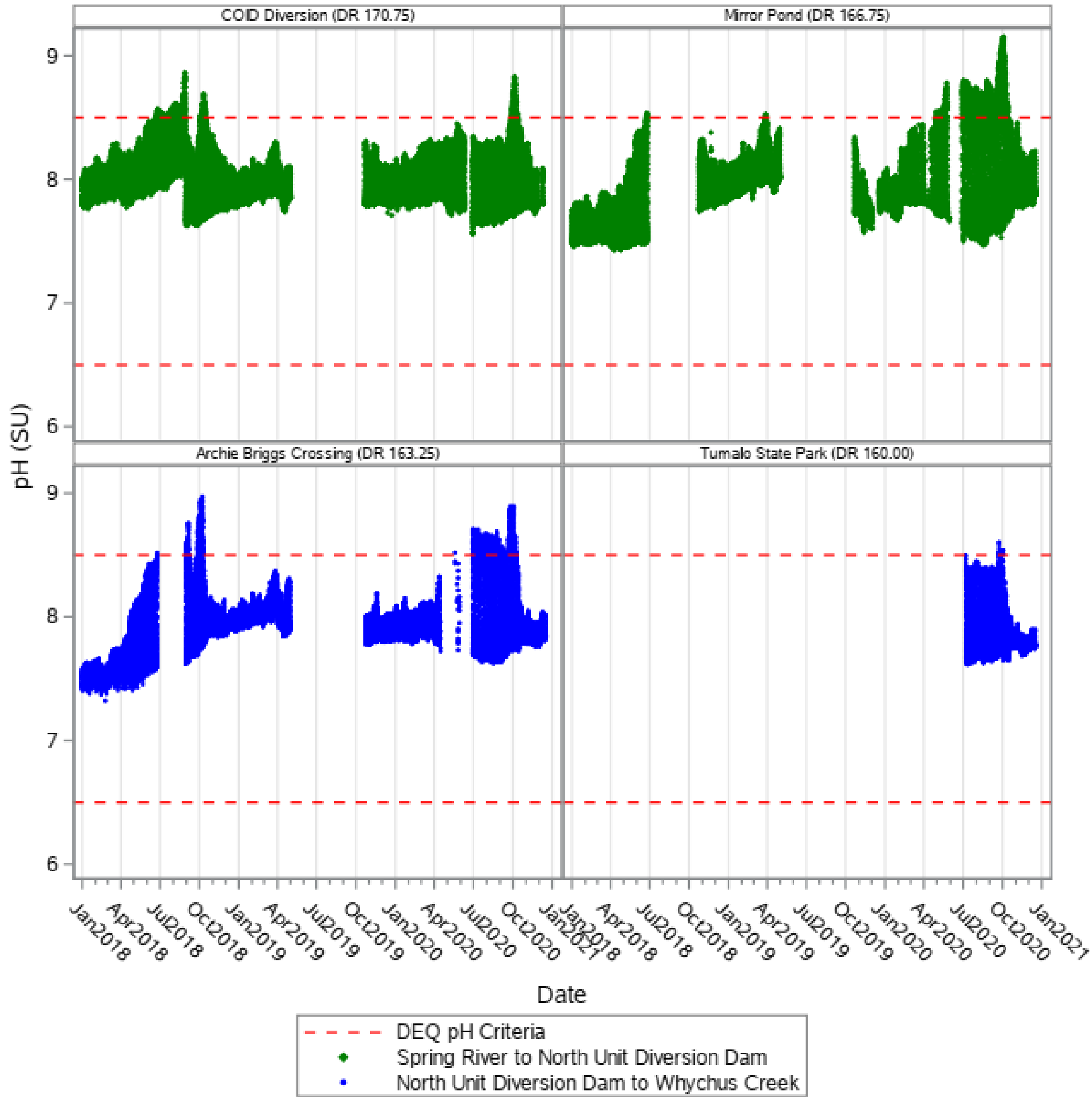



**Figure 13. Continuous pH measurements for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) - City of Bend 2018-2020. Dashed red lines indicate the minimum 6.5 and maximum 8.5 pH criteria**

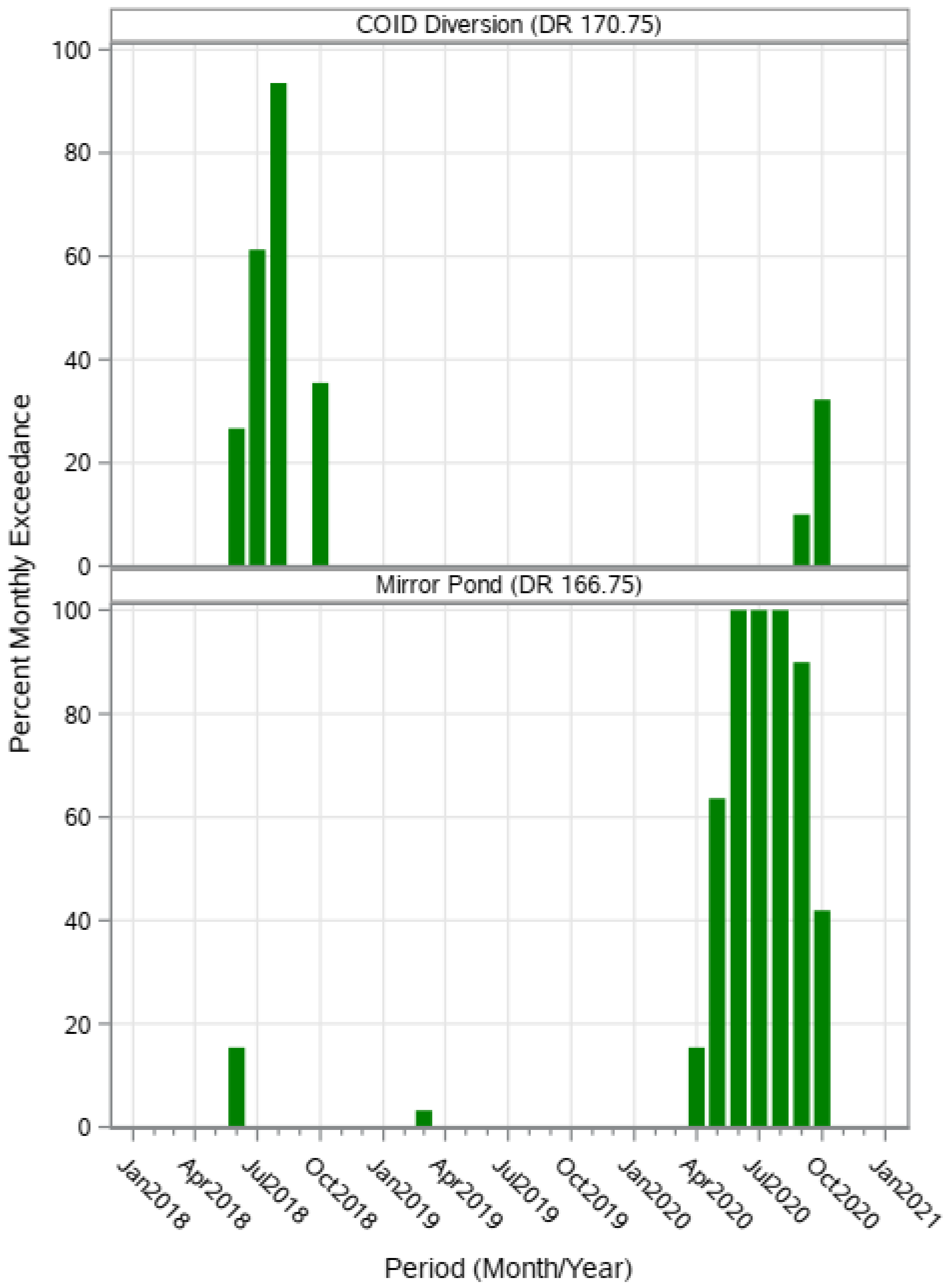



**Figure 14. Percent of daily maximum pH exceedances above 8.5 by site and by month for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) - City of Bend 2018-2020**

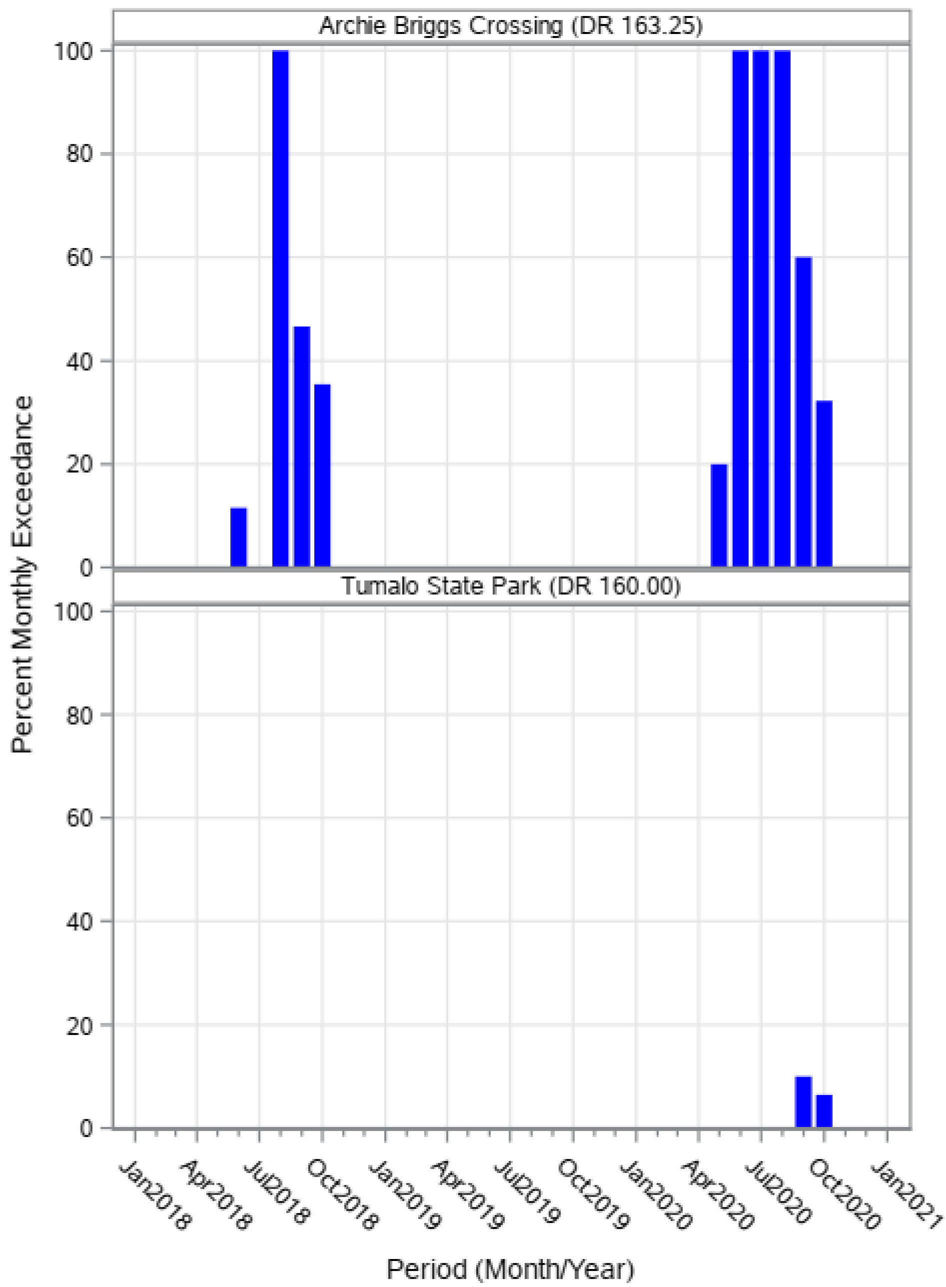



**Figure 15. Percent of daily maximum pH exceedances above 8.5 by month for the monitoring stations in the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) - City of Bend 2018-2020**

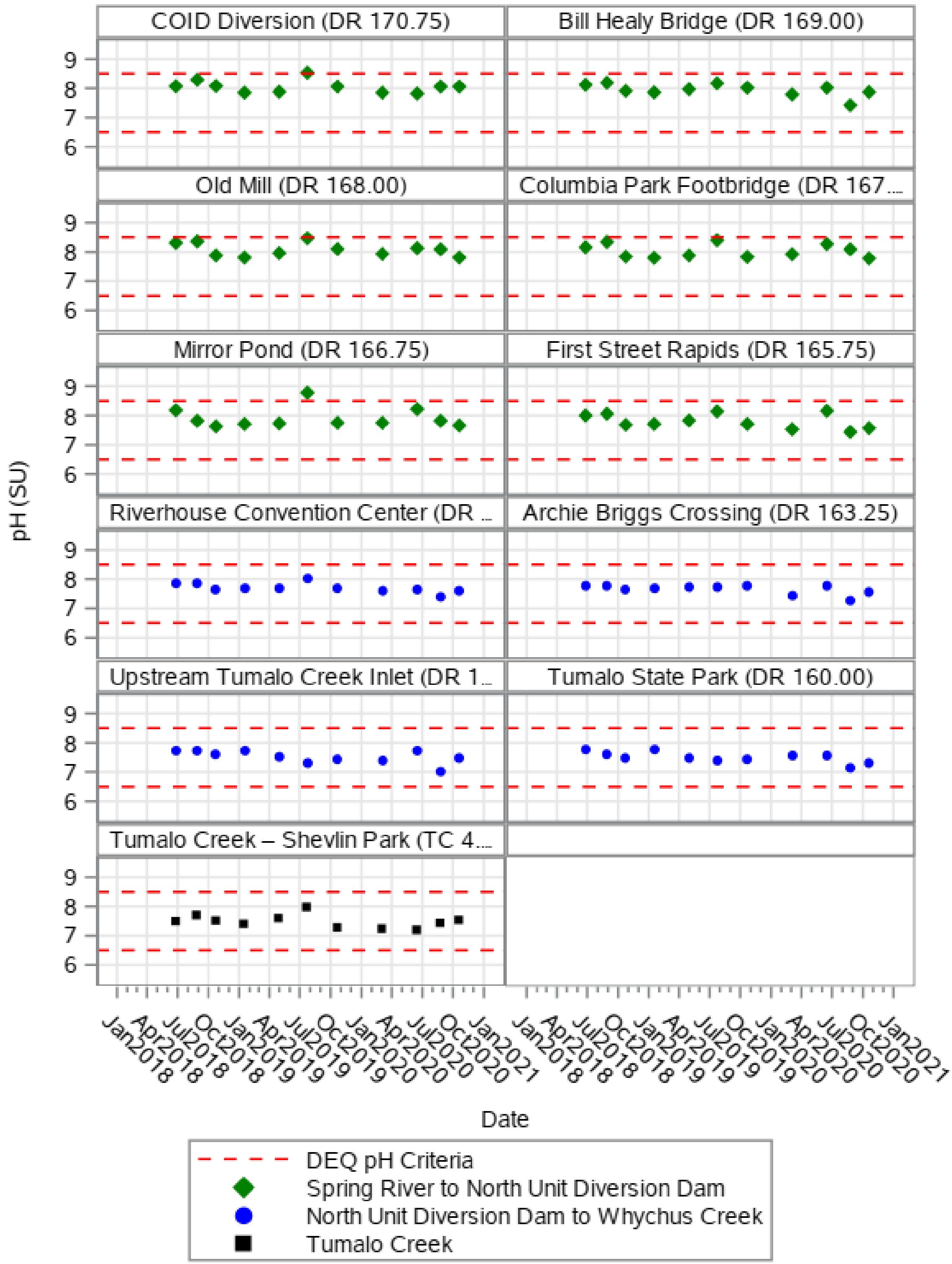



**Figure 16. Discrete in-situ pH measurements for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2018-2020. Dashed red lines indicate the minimum 6.5 and maximum 8.5 pH criteria**

**TABLE 7. ANNUAL PERCENT pH 8.5 EXCEEDANCES BY AU, SITE, AND YEAR BETWEEN 2018 AND 2020**

| Assessment Unit | Site | Year | Annual Percent Exceedance |
|---|---|---|---|
| Spring River to North Unit Diversion Dam | COID Diversion (DR 170.75) | 2018 | 18.4 |
| Spring River to North Unit Diversion Dam | COID Diversion (DR 170.75) | 2019 | Note 1 |
| Spring River to North Unit Diversion Dam | COID Diversion (DR 170.75) | 2020 | 4.1 |
| Spring River to North Unit Diversion Dam | Mirror Pond (DR 166.75) | 2018 | 1.6 |
| Spring River to North Unit Diversion Dam | Mirror Pond (DR 166.75) | 2019 | 0.6 |
| Spring River to North Unit Diversion Dam | Mirror Pond (DR 166.75) | 2020 | 42.1 |
| Spring River to North Unit Diversion Dam | Archie Briggs Crossing (DR 163.25) | 2018 | 10.3; Note 2 |
| Spring River to North Unit Diversion Dam | Archie Briggs Crossing (DR 163.25) | 2019 | Note 1 |
| Spring River to North Unit Diversion Dam | Archie Briggs Crossing (DR 163.25) | 2020 | 32.9 |
| Spring River to North Unit Diversion Dam | Tumalo State Park (DR 160.00) | 2018 | Note 3 |
| Spring River to North Unit Diversion Dam | Tumalo State Park (DR 160.00) | 2019 | Note 3 |
| Spring River to North Unit Diversion Dam | Tumalo State Park (DR 160.00) | 2020 | 3.0 |

NOTES
1 Data not available for analysis and interpretation.
2 Monitoring did not begin until August 28, 2018 at this site.
3 Exceedances not reported as monitoring did not begin until July 6, 2020 at this site.

## Turbidity

Turbidity is a visual property of water resulting from the resuspension of particles produced, for example, by erosion from the watershed or bottom sediments. The inorganic particles that result in turbidity, scatter, reflect, and refract (change direction) light penetration in the water. High levels of particulates block light for photosynthetic algae and macrophytes, can be harmful to aquatic organisms, and can attach and carry harmful pollutants. Turbidity is considered harmful to beneficial uses, including resident fish and aquatic life and water supply.

Presented are turbidity results from continuously logging multi-parameter data sondes between 2018 and 2020 from four sites set at 30-minute intervals. A fifth site was monitored from 2009 to 2014 and those data are included in **Appendix B**. Specific start and end times varied by site and between years. Also presented are results from turbidity measurements made using a field turbidity meter at the same time as grab samples were collected for laboratory analysis. The high variation in available turbidity results is largely attributed to biofouling. Vandalism and placement of the units that resulted in them being out of the water were also factors; however, these issues impacted all parameters equally and thus removed from analysis.

Overall, turbidity ranged from 0.4 NTU to 10.6 NTU in the Deschutes River and up to 11.5 NTU in Mirror Pond (DR 166.75) with an overall average of 2.9 NTU throughout the POR (**Appendix B** and **Figure 17**). Inter- and intra- annual variability was evident at all monitoring sites, with elevated maximums observed most prominently in the winter and late summer months. The discrete turbidity measurements provide a similar (general trend of decreasing turbidity from upstream to downstream as well as a decrease in variability) (**Figure 18**). These findings are in agreement with those reported by UDWC (2010) and ESA and MaxDepth Aquatics (2018). It is presumed that the dam at Mirror Pond traps sediment that would otherwise contribute to downstream turbidity. Mirror Pond has not been dredged since 1984 and is the subject of discussion for future dredging efforts. Turbidity measured in Tumalo Creek at TC 4.00 ranged from the detection limit to 1.2 NTU and an overall average of 0.6 NTU.

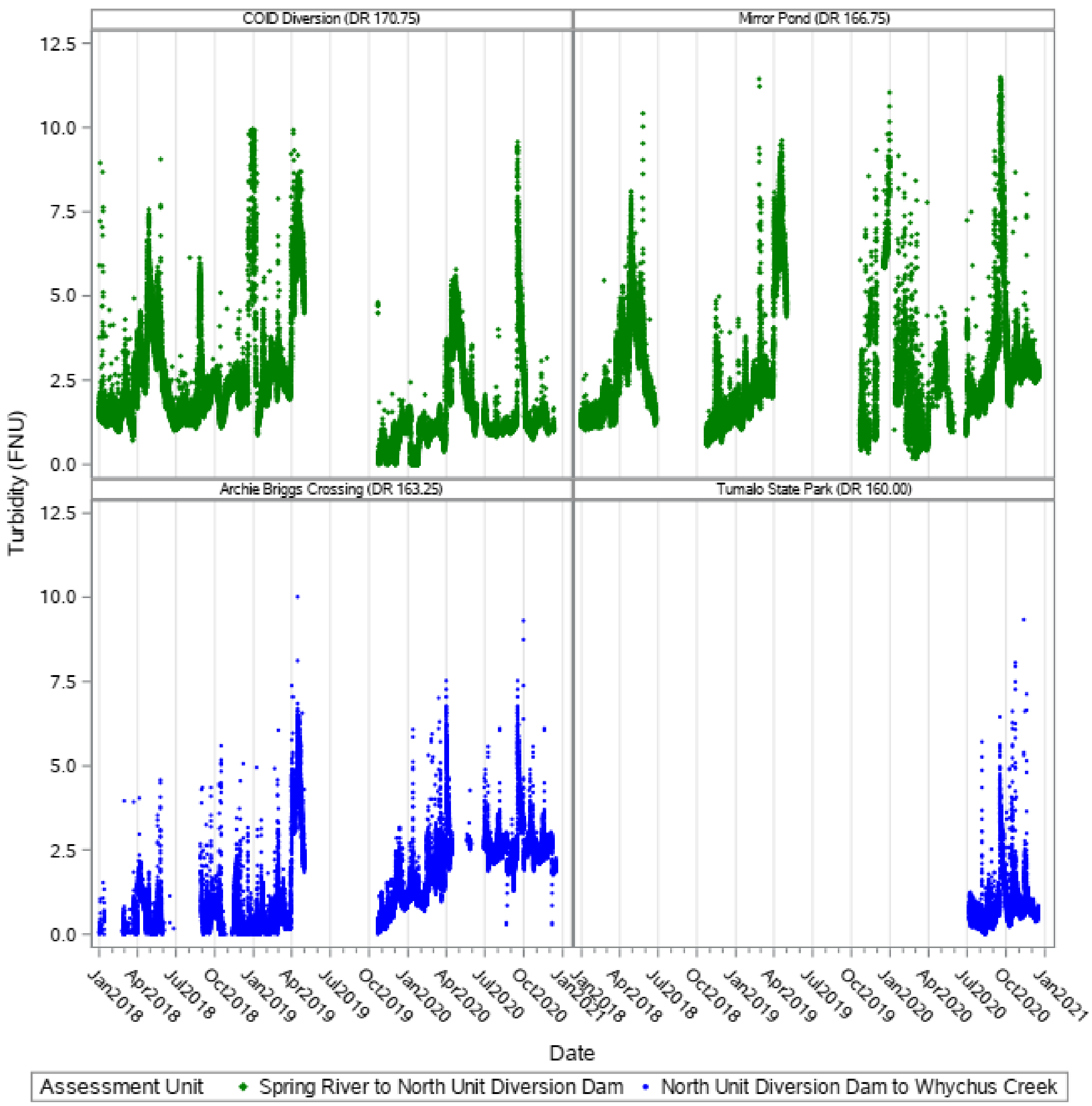



**Figure 17. Continuous turbidity measurements for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) - City of Bend 2018-2020**

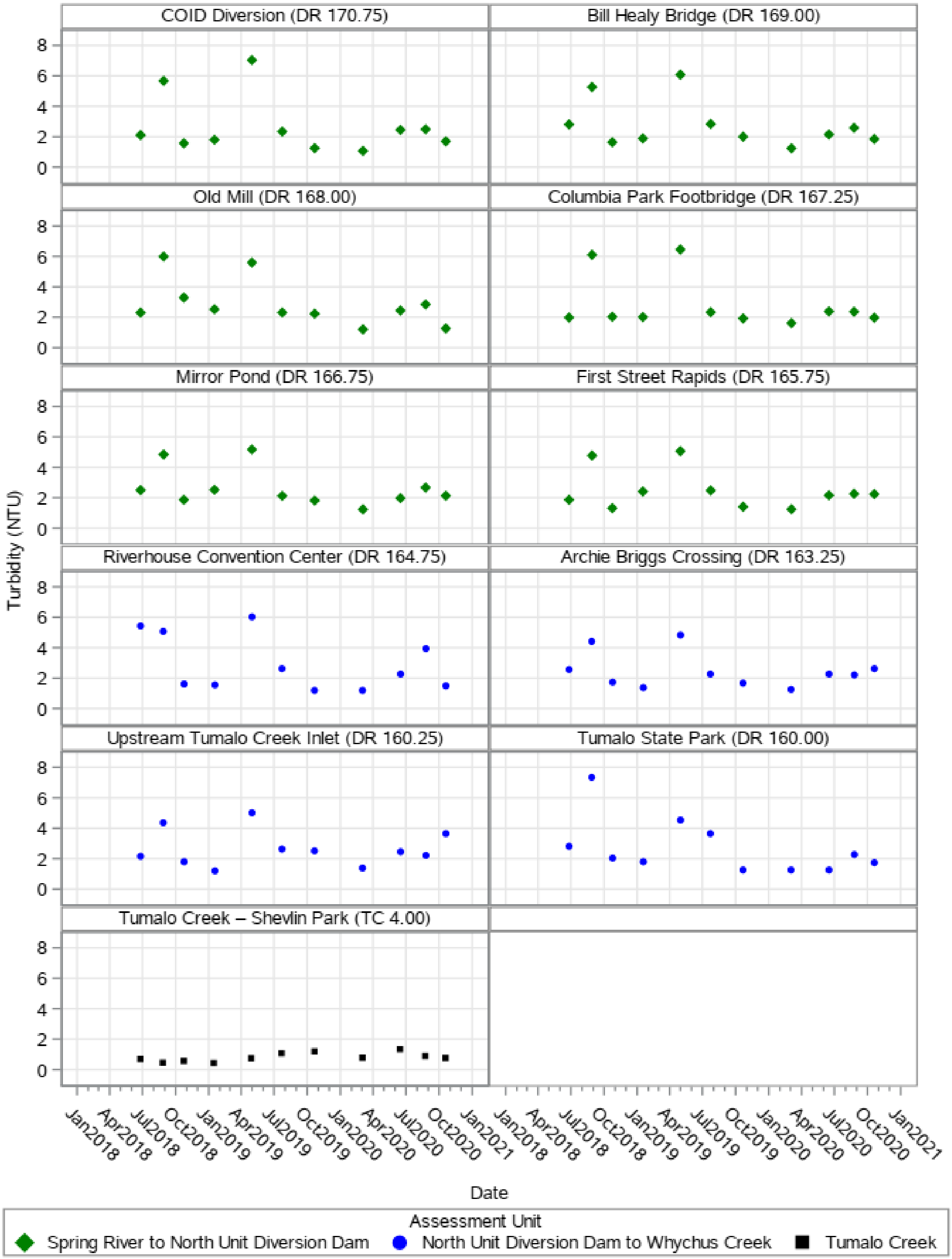



**Figure 18. Results of turbidity measurements from samples collected at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2018-2020**

Changes in turbidity from the Deschutes River have been associated with the transition to irrigation season water management practices. Examining maximum turbidity at the southern UGB (COID Diversion; DR 170.75) and northern UGB (Tumalo State Park; DR 160.00) by month, peak levels corresponded somewhat to the spring irrigation season beginning in April/early May and decline during the summer months (**Figure 19**). The difference between the spring and summer months is as much as eight times higher in the early spring. The City collected turbidity data during January through October, and the local irrigation season runs from April through October, as discussed previously. The state standard for turbidity requires that deviations from background conditions not exceed 10%. Samples collected for turbidity analysis were not collected relative to an upstream control point as described in OAR 340-041-0036.

It is important to note that the Deschutes River at the COID Diversion (DR 170.75) site, which is located upstream of other irrigation diversions and urban impacts within the UGB, already have seasonally high turbidity values and fluctuate considerably.

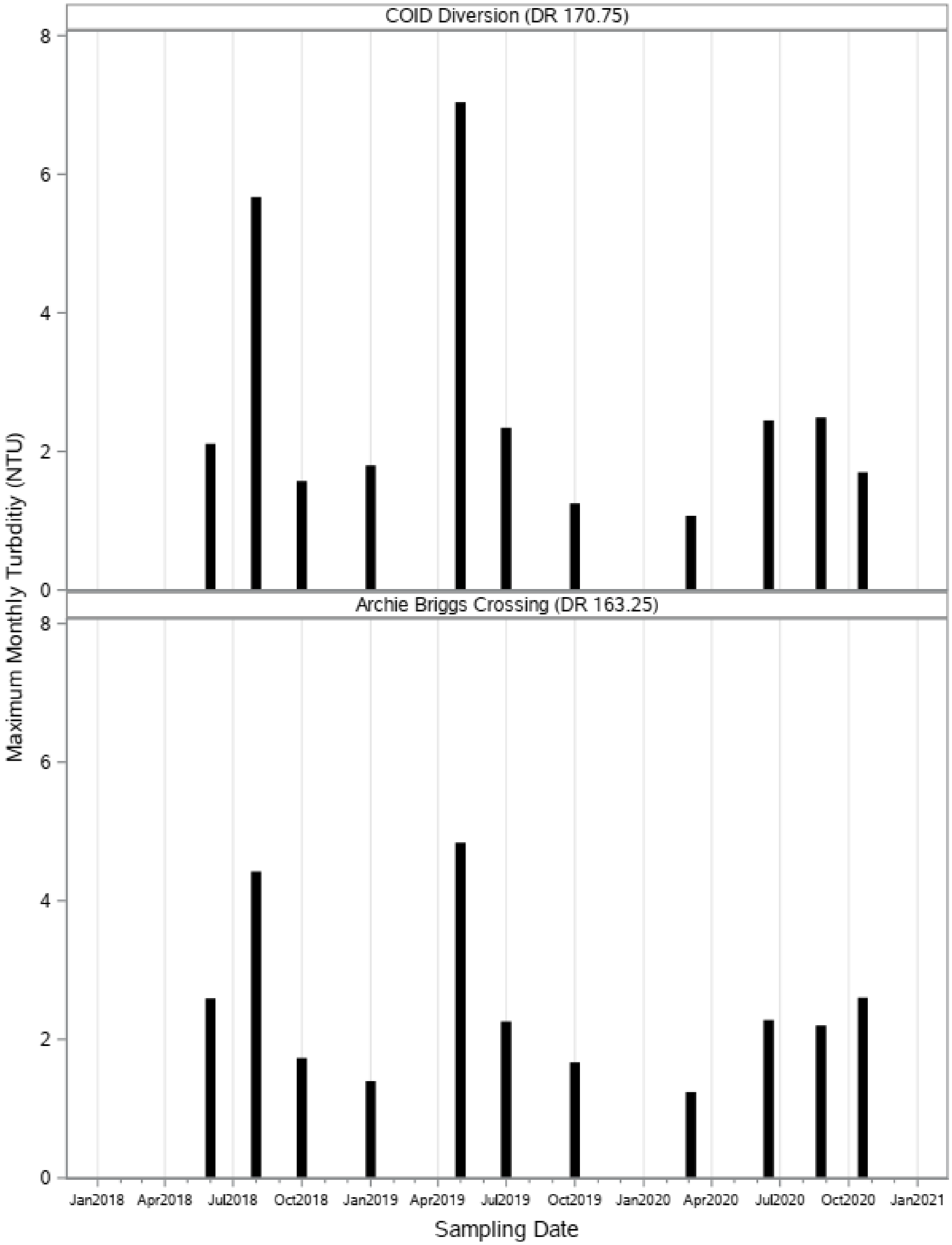



**Figure 19. Maximum turbidity measurements by month for the most upstream site in the Deschutes River (DR 170.75) that is currently monitored (top panel) and the most downstream site (DR 163.25) that has been monitored since 2019 (bottom panel) - City of Bend 2018-2020**

# Total Suspended Solids

Like turbidity, total suspended solids (TSS) are derived from similar sources, but TSS measurements include particles (including phytoplankton) greater than 0.45 microns. Therefore, generally the smaller particles that do not settle out by gravity and instead remain suspended in the water column are not incorporated in TSS and are considered total dissolved solids (TDS) (not considered here). High levels of TSS reduces photosynthesis, can increase water temperature, reduce the ability of fish to see, clog fish gills, and harm egg and larval development.

Presented are results from samples analyzed for TSS from monthly to quarterly grab samples between 2018 and 2020 (**Figure 20**). Overall, TSS ranged from 1.4 mg/L to 13.2 mg/L in the Deschutes River (including Mirror Pond) with an overall average of 4.8 mg/L TSS throughout the POR (**Appendix B**). A limited number of samples were analyzed for TSS from Tumalo Creek at Shevlin Park (TC 4.00) between April 2016 and June 2018; however, those values ranged from 0.60 to 8.10 mg/L. Similar to turbidity, there was a general trend of decreasing TSS from upstream to downstream as well as a decrease in variability, again presumably attributed to settling at Mirror Pond. These findings are in agreement with those reported by UDWC (2010) and ESA and MaxDepth Aquatics (2018).

Examining maximum TSS at the southern UGB (COID Diversion; DR 170.75) and northern UGB (Tumalo State Park; DR 160.00) by month, peak levels similarly correspond to the spring irrigation season in April/early May and decline during the summer months (**Figure 21**). The difference between the spring and summer months is similarly as much as eight times higher in the early spring.

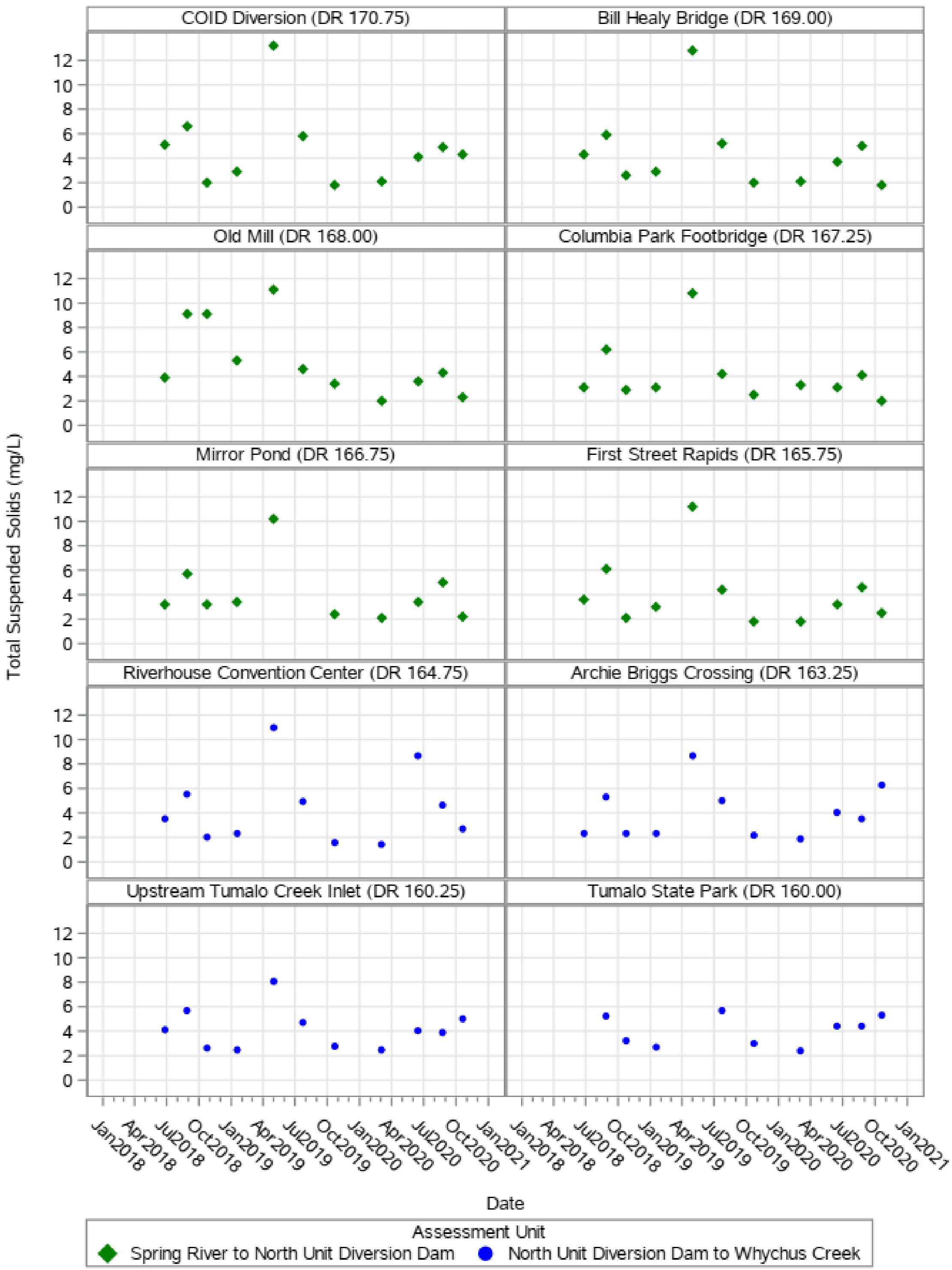



**Figure 20. Results of total suspended solids measurements from samples collected at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2018-2020**

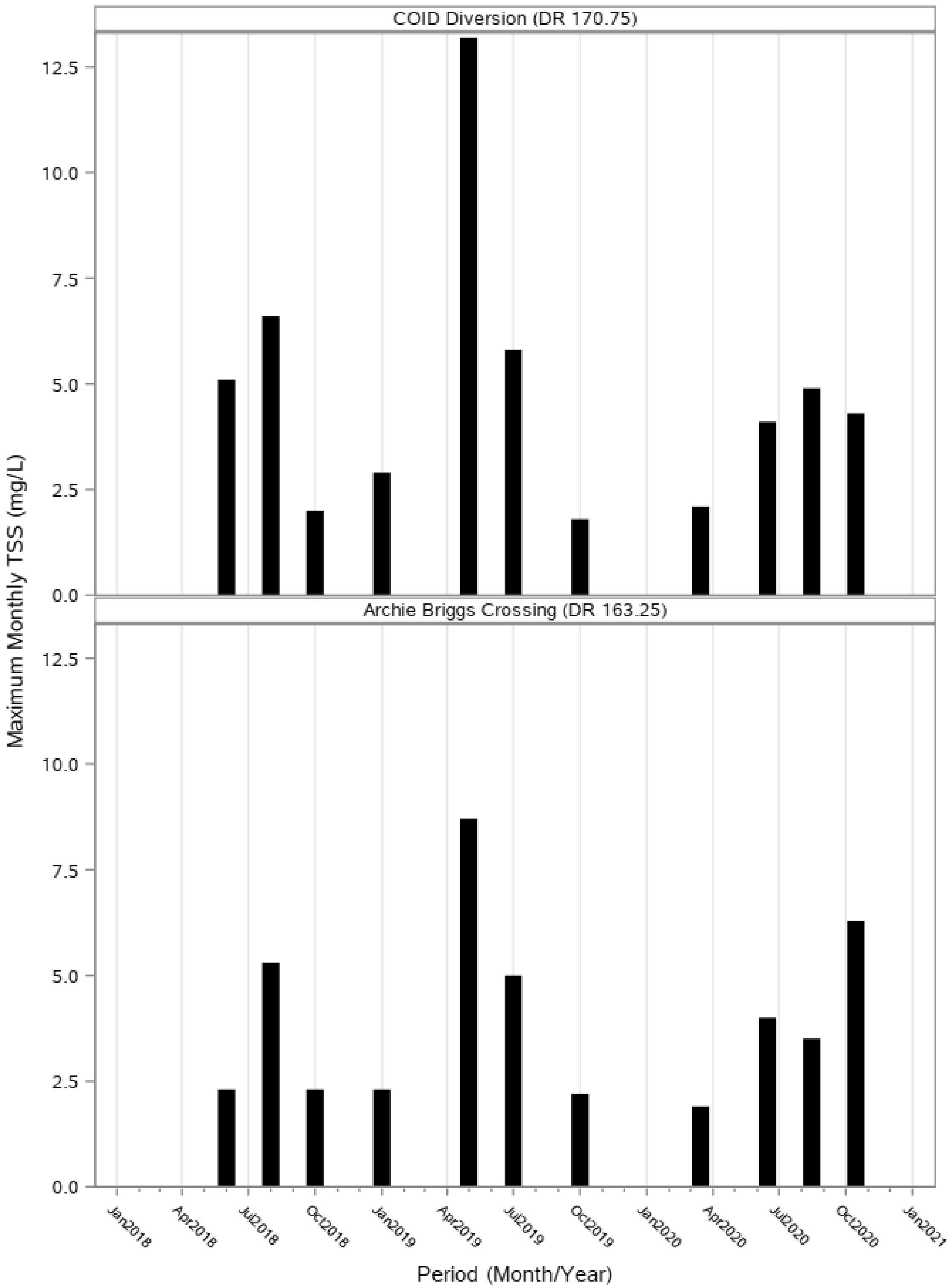



**Figure 21. Maximum total suspended solids (TSS) measurements by month for the most upstream site in the Deschutes River (DR 170.75) that is currently monitored (top panel) and the most downstream site that has been monitored since 2019 (bottom panel) - City of Bend 2018-2020**

TSS and turbidity attempt to measure similar properties in the water column, but using very different approaches. TSS is a gravimetric analytic measurement for a specific grab sample, whereas turbidity is measured by recording changes in light scattering with a continuously deployed probe. An examination of the TSS data compared to turbidity values for the City monitoring data shows reasonable agreement between the parameters (**Figure 22**). A regression of the two data sets indicates that turbidity (as the dependent variable) can predict TSS (the independent variable) with 70 percent accuracy in the Spring River to North Unit Diversion Dam AU ($p<0.0001$), but less than 50 percent in the North Unit Diversion Dam to Whychus Creek AU ($p<0.0001$) (**Figure 2**), suggesting continuous turbidity data has the potential to predict changes in TSS in the Deschutes River in the upstream AU, but less so nearer the northern UGB. It should be noted that there is twice as much data in the Spring River to North Unit Diversion AU compared to the downstream AU. Further, there is not a great deal of variation in turbidity measurements and residuals fit tests suggest better predictive power for turbidity measurements less than 6 NTU, particularly for the upriver AU (**Figure 23**)

A number of studies have sought to identify a similar predictive relationship between turbidity and TSS in an effort to apply more simplistic analytical methods with greater reproducibility (Suk et al. 1998, Hannouche et al. 2011, and Kusari and Ahmedi 2013 summarized in de Oliveira et al. 2018). While the two parameters are similar in that they describe the clarity of the water and potential impacts to aquatic organisms, a high concentration of colloidal solids (e.g., muddy water) would be included in a measurement of turbidity, but not TSS. In this scenario, the regression would not predict TSS in a meaningful manner (de Oliveira et al. 2018). Conversely, samples with low turbidity can still result in high TSS concentrations due to measurement method that could result in high variability and low predictability (Metcalf and Eddy 2014). Within the study area of the Deschutes River, the upstream AU provided much greater predictive power ($r^2$=0.70), suggesting that colloidal material interfered less with the turbidity measurements. Further analysis would be needed to better identify the factors that decrease the predictability in the downstream AU.

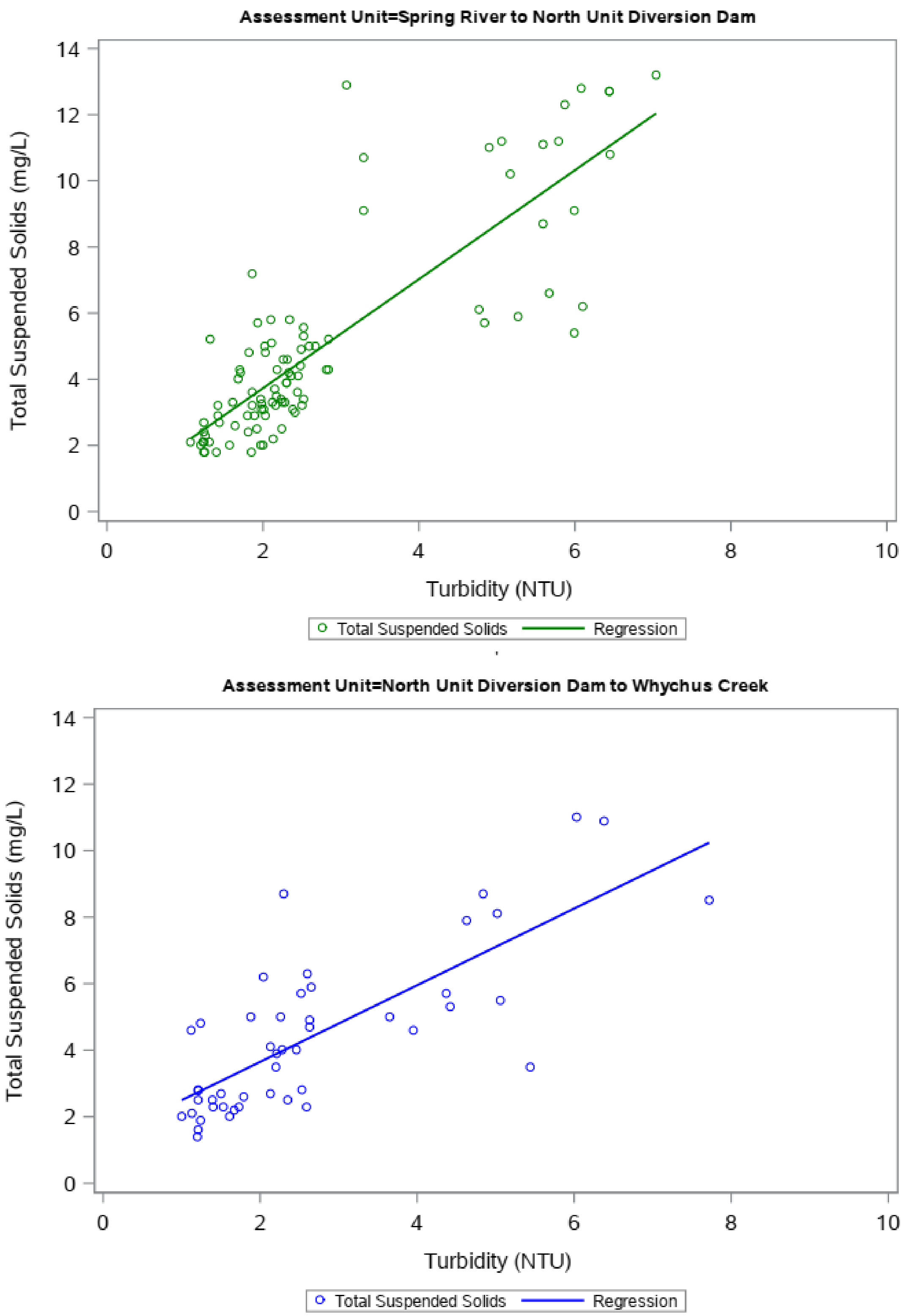
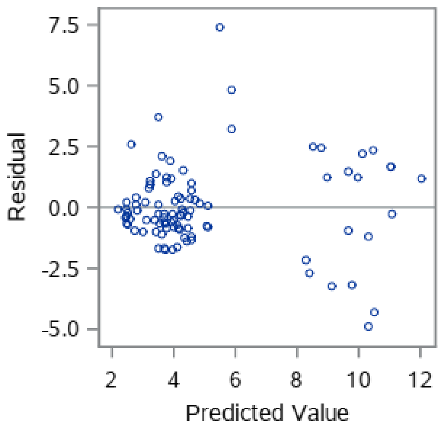



**Figure 22. Relationship between turbidity and total suspended solids (TSS) concentrations in samples collected from the Deschutes River from the Spring River to North Unit Diversion Dam AU (top panel) and the North Unit to Whychus Creek AU (bottom panel). The line represents the best fit of the observed data ($p<0.001$; $r^2 = 0.70$ [top] and $p<0.001$; $r^2 = 0.48$ [bottom]) - City of Bend 2018-2020**



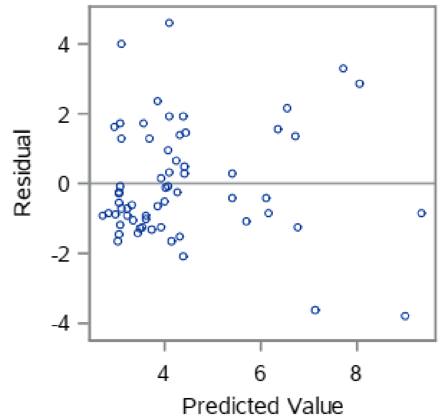




**Figure 23. Residual fits for turbidity and total suspended solids (TSS) concentrations in samples collected from the Deschutes River from the Spring River to North Unit Diversion Dam AU (left panel) and the North Unit to Whychus Creek AU (right panel) - City of Bend 2018-2020**

# Dissolved Oxygen

Dissolved oxygen (DO) is fundamental to the metabolism of aerobic organisms, including fish, invertebrates, bacteria, and plants growing in aquatic environments. DO saturation ranges are influenced by external factors such as water temperature, salinity and atmospheric pressure. As such, seasonal and regional variations are observed in the DO capacity of an aquatic system. Hydrologic influences including such as atmospheric inputs through wind mixing, and/or aeration from waterfalls and rapids, groundwater discharge, dam releases, and pumps also influence DO levels. In addition, biological factors including primary productivity, respiration, and biological and chemical degradation impact observed DO saturation and concentrations within an aquatic environment. When the DO saturation is near 100% air saturation, it is said to be in equilibrium. Lower DO saturation levels are often attributed to respiration, increased water temperature, increased salinity, and lower atmospheric pressure. Low DO concentrations can be lethal to sessile aquatic organisms that depend on DO. Conversely excessive DO levels can lead to supersaturation which has long been known to be detrimental to fish health (Weitkamp and Katz 1980). Similar to pH, fluctuations in DO commonly occur throughout the day as photosynthesis increases to a midday peak and decreases into the evening. The 2018/2020 IR provides separate criteria for the stream AUs for the Deschutes River included in the study (**Table 8**).

**TABLE 8. DISSOLVED OXYGEN CRITERIA BY ASSESSMENT UNIT**

| Season[1] | Criteria | Spring River to North Unit Diversion Dam [1] (DR170.75 to DR165.75) | North Unit Diversion Dam to Whychus Creek [1] (DR164.75 to DR160.00) | Lower Tumalo Creek (TC4.00) |
|---|---|---|---|---|
| Year Round (Non-spawning) | "Cool water" Not less than 6.5 mg/L as an absolute minimum | N/A | CM | Insufficient data |
| Year Round (Non-spawning) | Minimum 6.5 mg/L of the 30 consecutive-day floating averages of the calculated daily mean dissolved oxygen concentration (OAR 340-041-0002) | N/A | CM | Insufficient data |
| Year Round (Non-spawning) | Minimum 5.0 mg/L of the seven consecutive-day floating average of the calculated daily mean dissolved oxygen concentration (OAR 340-041-0002) | N/A | CM | Insufficient data |
| Year Round (Non-spawning) | Absolute minimum 4.0 mg/L for surface samples when applying the averaging period, spatial median of IGDO[2] (OAR 340-041-0016) | N/A | CM | Insufficient data |
| Year Round (Non-spawning) | "Cold water" Not less than 8.0 mg/L as an absolute minimum | CM | N/A | Insufficient data |
| Year Round (Non-spawning) | 8.0 mg/L as a 30-day mean minimum | CM | N/A | Insufficient data |
| Year Round (Non-spawning) | 6.5 mg/L as a 7-day mean minimum | CM | N/A | Insufficient data |
| Year Round (Non-spawning) | 6.0 mg/L absolute minimum | CM | N/A | Insufficient data |
| Jan 1 - June 15 (Spawning) | Not less than 11.0 mg/L 7-day mean minimum | CM | N/A | Insufficient data |
| Jan 1 – May 15 (Spawning) | Not less than 11.0 mg/L 7-day mean minimum | N/A | CM | Insufficient data |

CM = Criteria Met; N/A = Not Applicable; 303(d) = AU is listed on the 2018/2020 DEQ Integrated Report - State Final as being Category 5 303(d) listed - Impaired a TMDL is needed.

1. Dissolved oxygen criteria for resident trout spawning is applied differently between Assessment Units (AU).
2. "Spatial Median" means the value that falls in the middle of a data set of multiple intergravel dissolved oxygen (IGDO) measurements taken within a spawning area. Half the samples should be greater than and half the samples should be less than the spatial median. (OAR 340-041-0002).

Presented are DO results from continuously logging multi-parameter sondes between 2018 and 2020 from four sites set at 30 –minute intervals. (**Table 2**). A fifth site was monitored from 2009 to 2014 and those data are included in **Appendix B**. Specific start and end times varied by site and between years. Also presented are results from DO measurements made using a handheld multi-parameter data sonde at the same time as grab samples were collected for laboratory analysis. Measurements of DO are presented as the 30-day mean minimum (**Figure 24**) and seven-day mean minimum (**Figure 25**) by

AU and the raw data by site and year from data sondes deployed at the same time as grab sample collection (**Figure 26**).

No instances of falling below the 30-day mean minimum of 8.0 mg/L or 6.5 mg/L criteria for the Spring River to North Unit Diversion Dam or the North Unit Diversion Dam to Whychus Creek AUs were observed, respectively, though DO in Mirror Pond (DR 166.75) was very near 8.0 mg/L on numerous occasions prior to 2015 (see **Appendix B**). That is, monitoring data from the Deschutes River between 2009 and 2019 meet the DEQ criteria for year-round (non-spawning) 30-day mean minimum DO criteria.

In addition to the year-round non-spawning DO criteria, each assessment unit has a seven-day mean minimum spawning criteria of 11.0 mg/L which coincide with specific time periods. For the Spring Creek to North Unit Diversion Dam AU, the spawning period extends from January 1 to June 15 whereas the period ends one-month sooner in the North Unit Diversion Dam to Whychus Creek AU (January 1 to May 15) within a respective year. For all sample sites in both AUs, the seven-day mean minimum of 11.0 mg/L was exceeded at some point during the study period (**Figure 25**). In 2019, two monitoring locations (Mirror Pond; DR 166.75 and COID Diversion DR 170.75) in the Spring Creek to North Unit Diversion Dam AU reported 30.0 and 22.5 percent of calculated values below the spawning criteria, respectively. Only one monitoring site in the North Unit Diversion Dam to Whychus Creek AU (Archie Briggs Crossing; DR 163.25) had seven-day mean minimum concentrations below 11.0 mg/L in 33.8 percent of calculated values during the spawning period.

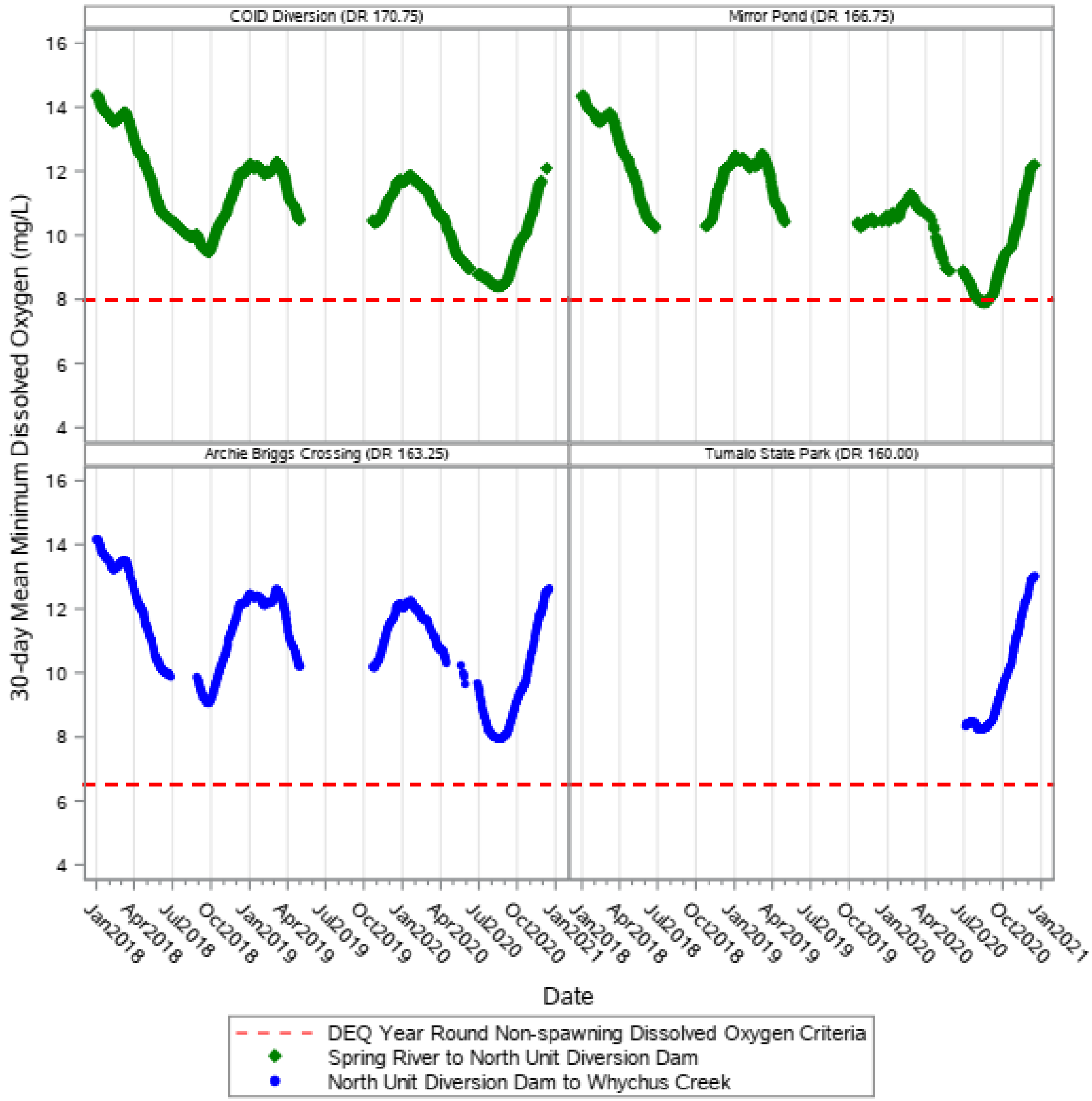



**Figure 24. The 30-day mean minimum dissolved oxygen concentrations for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green lines) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue lines) - City of Bend 2018-2020. The red line indicates the DEQ 8.0 mg/L year-round non-spawning for the Spring River to North Unit Diversion Dam AU (top panels) and the 6.5 mg/L yea- round non-spawning criteria for the North Unit Diversion Dam to Whychus Creek AU**

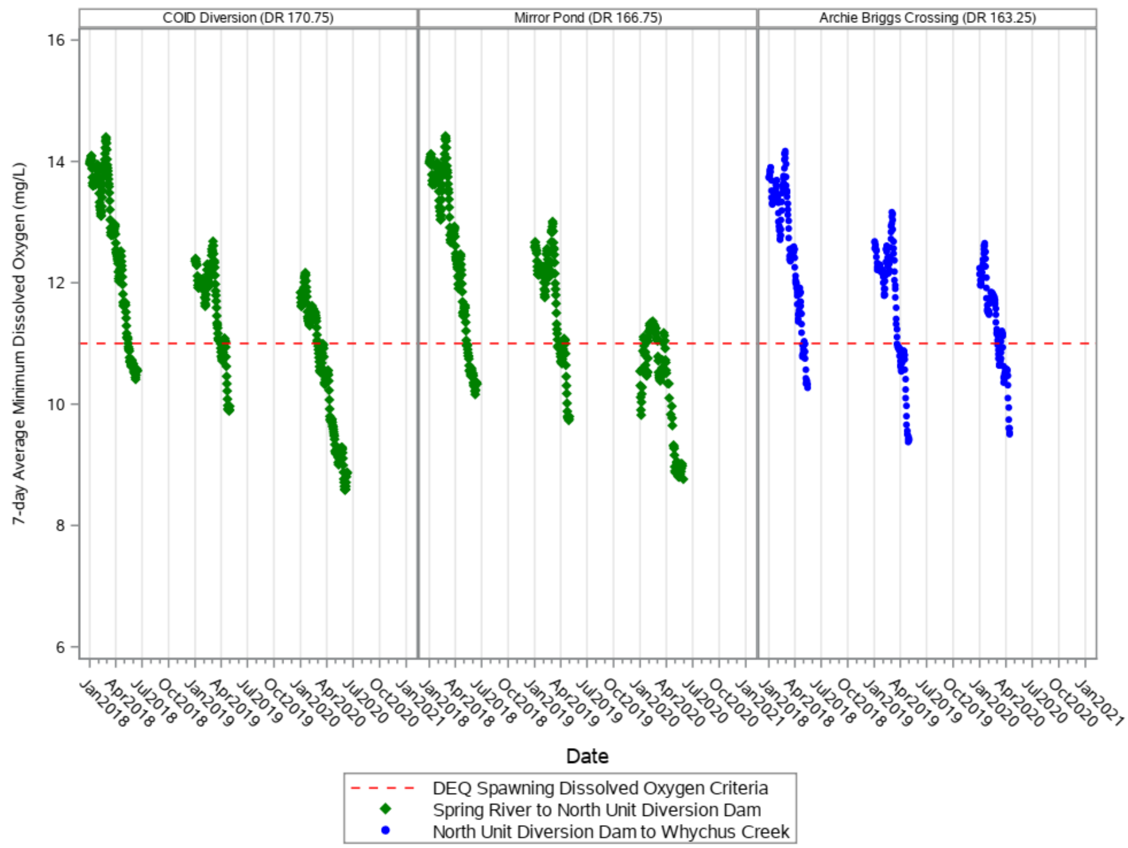



**Figure 25. The seven-day mean minimum dissolved oxygen concentrations for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (left and middle in green) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (right panel in blue) - City of Bend 2018-2020. The red line indicates the DEQ 11.0 mg/L spawning criteria for the Spring River to North Unit Diversion Dam AU (January 1 to June 16) and the North Unit Diversion Dam to Whychus Creek AU (January 1 to May 15)**

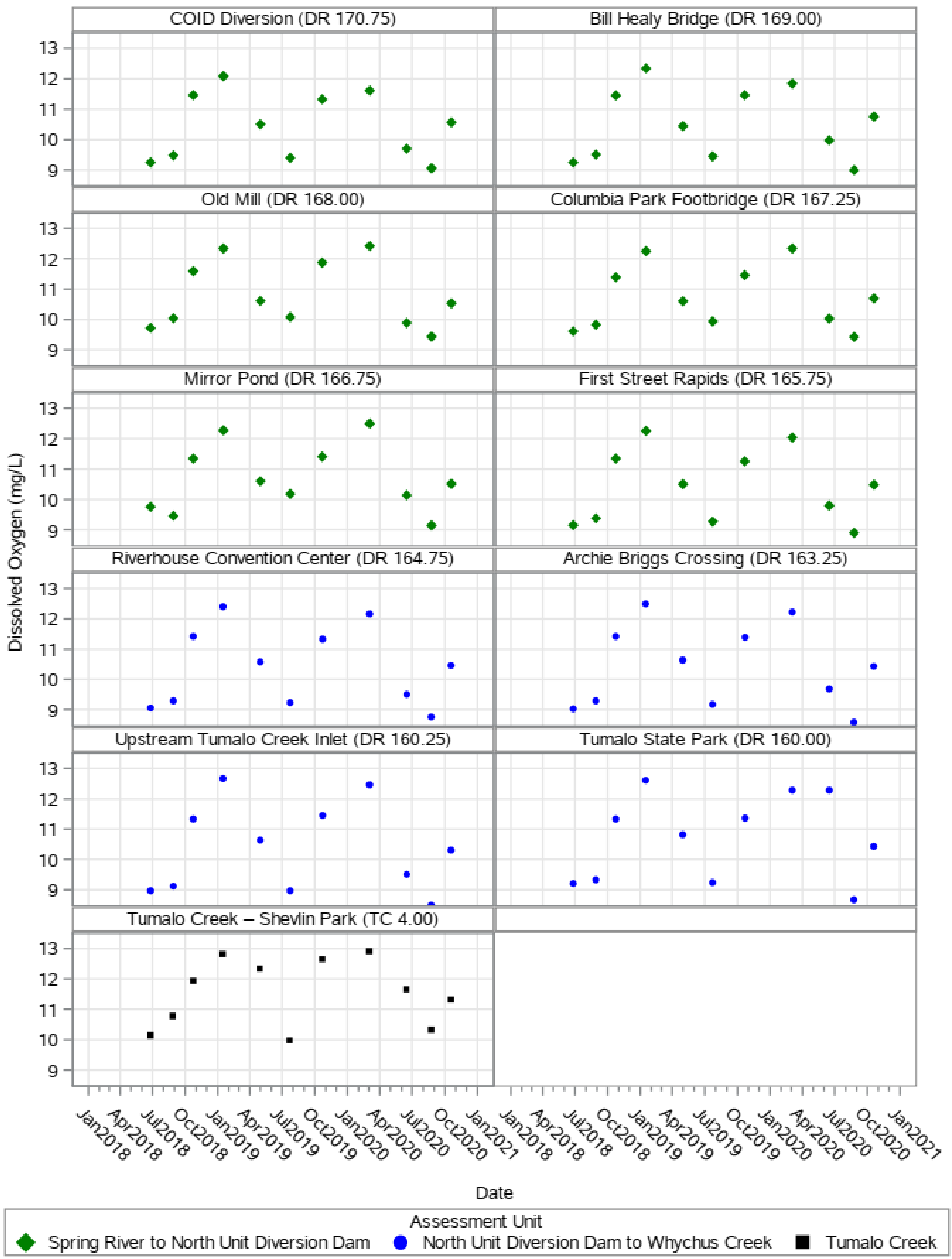



**Figure 26. Discrete in-situ dissolved oxygen measurements collected at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2018-2020**

## Specific Conductance

The specific conductance of water is highly correlated to the concentration of major ions in the water such as calcium, magnesium, sodium, et cetera. Natural sources of these major ions are weathering of soil and rock in the watershed, the atmosphere, and regional climate, but pollutant discharges can also lead to notable changes in conductance due to the high levels of chloride, phosphate or nitrate which would appreciably raise conductance above ambient levels.

Presented are specific conductance results from continuously logging multi-parameter sondes between 2018 and 2020 from four sites set at 30 –minute intervals (**Table 2**; **Figure 27**). A fifth site was monitored from 2009 to 2014 and those data are included in **Appendix B**. Specific start and end times varied by site and between years. Also presented are results from specific conductance measurements made using a handheld multi-parameter data sonde at the same time as grab samples were collected for laboratory analysis (**Figure 28**).

Prior to the confluence with Tumalo Creek, specific conductance in the Deschutes River across all years and all sites averaged 64.0 µS/cm with marked seasonal variation (**Figure 27**). Based on a more limited number of samples taken at the same time as grab samples, average conductance in Tumalo Creek was 39.4 µS/cm. Below the confluence at Tumalo State Park (DR 160.00), specific conductance in the Deschutes River declined substantially with an average of 58.1 µS/cm at DR 160.00. In fact, the lowest specific conductance levels measured from DR 160.00 corresponded with the summer irrigation season when the contribution of water from Tumalo Creek accounts for over 60 percent of instream flow at that site resulting in dilution of specific conductance.

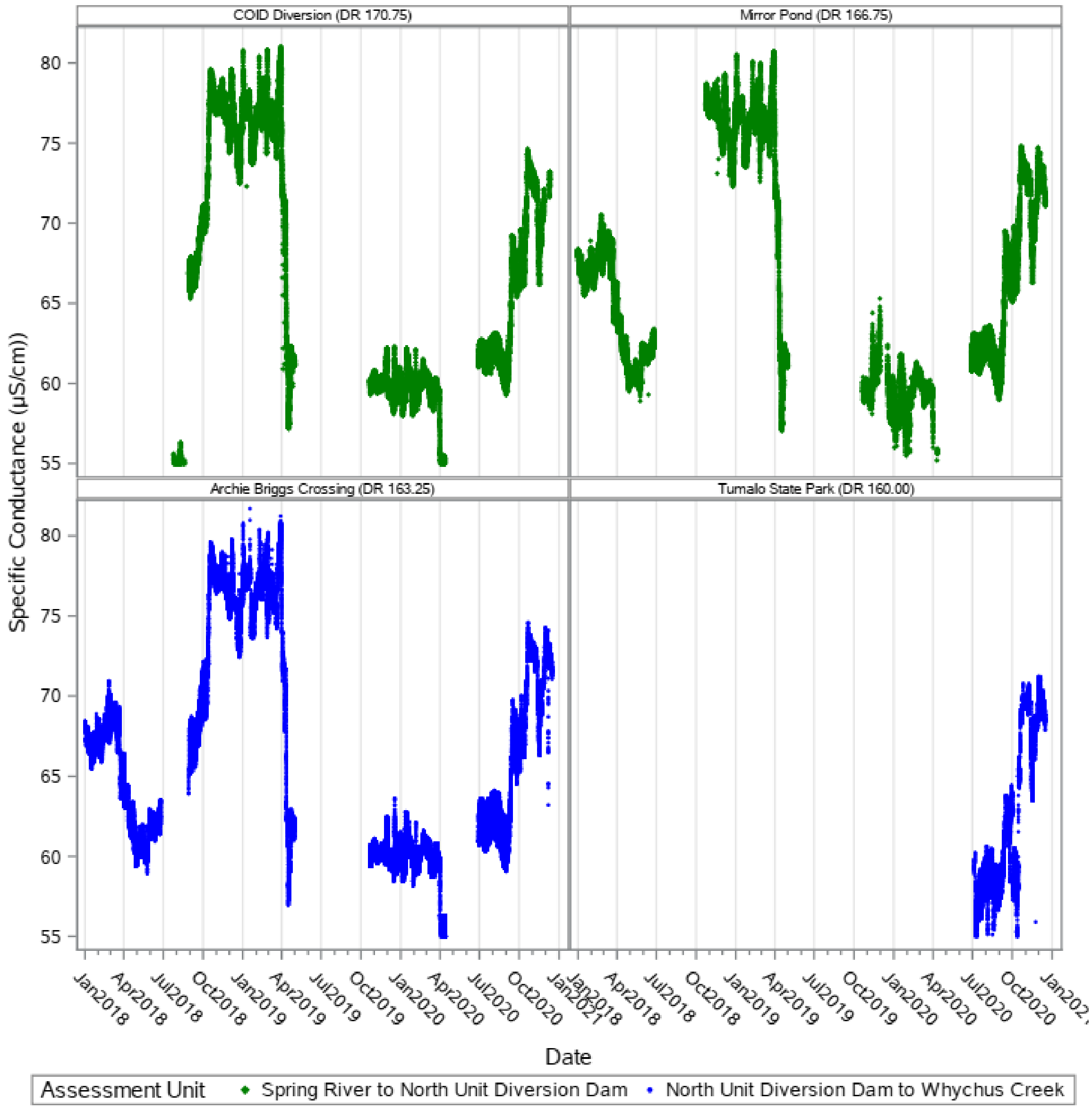



**Figure 27. Continuous specific conductance measurements for the monitoring stations over period of 2018 to 2020 in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) - City of Bend 2018-2020**

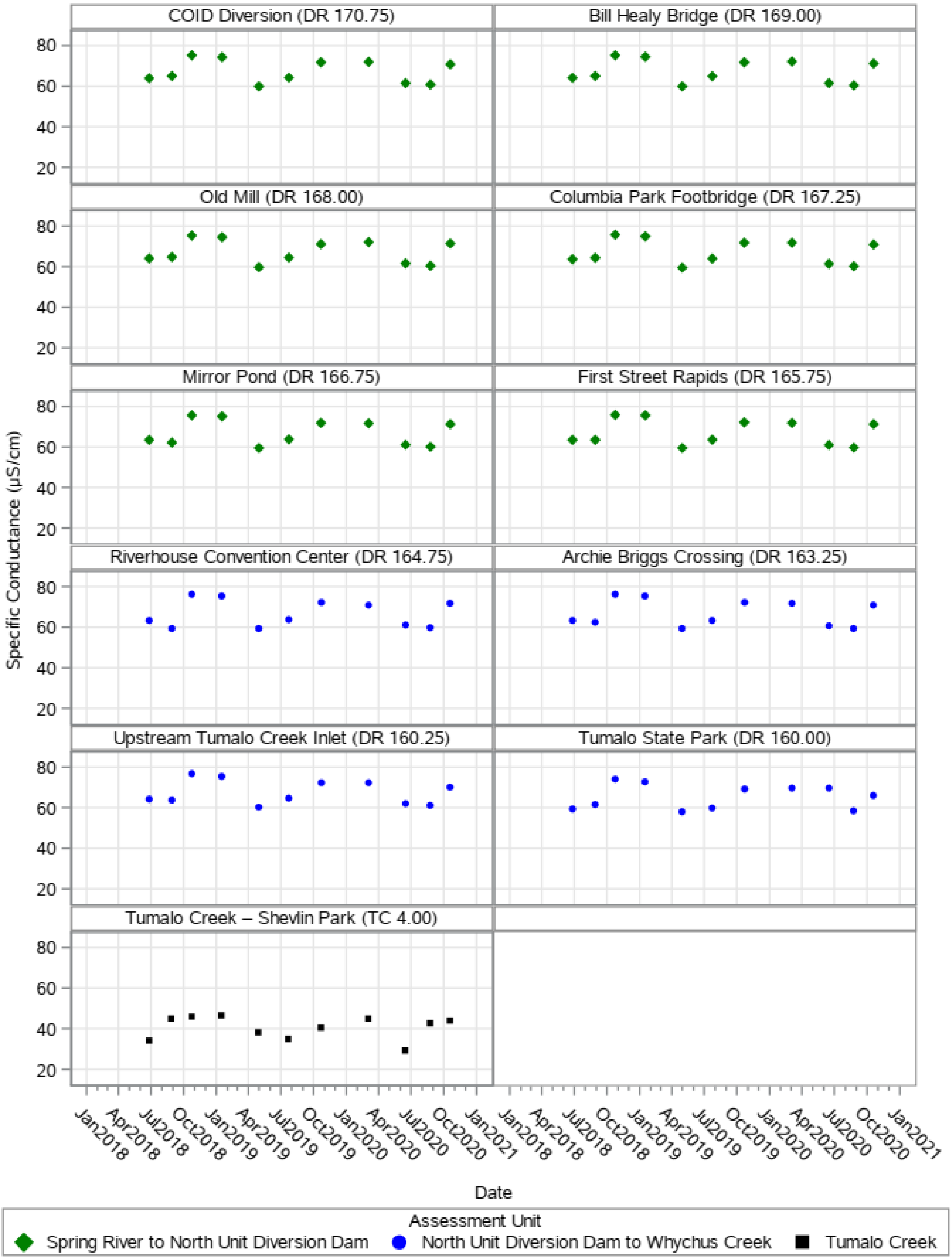



**Figure 28. Discrete in-situ specific conductance concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2018-2020**

## Nitrate-Nitrogen

Nutrients such as nitrate-nitrogen ($NO_3$ - N) are essential for plant and animal growth. Natural sources of nitrate-nitrogen occur from nitrogen fixing bacteria and the oxidation of other forms of nitrogen (e.g., ammonia); however, runoff from fertilizers, sewage, animal manure can lead to excessive nitrogen in surface and groundwater. Excess nitrogen in surface water can lead to a number of problems, including excessive growth of algae and aquatic plants which can subsequently deplete DO upon decomposition. The Deschutes River is known to be nitrogen-limited (Jones 2003), thus rapidly consumed in primary production.

Grab samples were collected monthly for nitrate-nitrogen analysis from 2010 to 2020. Concentrations were routinely at or below detection limits (DL), particularly between May 2010 and July 2013 (thus no figures are included for this parameter and are instead summarized in narrative). While detected concentrations were still quite low (on the order of 0.11 to 0.13 mg/L), the frequency of detections increased at all sites after 2013. It is likely that improvements in laboratory analytical methods lowered DL, resulting in more instances of results above previous analytical limits. Mean nitrate-nitrogen across all sites in the Deschutes River and all years was 0.015 mg/L. In more recent years, values have been quite low and nearer DL. Out of 14 samples collected from TC 4.00 between 2016 and 2019, only one detection at 0.11 mg/L was reported. EPA (2000) provides guidance on total nitrogen for Ecoregions II and III but not nitrite- or nitrate-nitrogen.

## Phosphorus

Phosphorus is essential to biological metabolism, including cellular DNA, yet it is often the nutrient most limiting to primary productivity (e.g., algae growth). Despite this, excess loading can occur to aquatic ecosystems and result in algae blooms and subsequent cascading events (e.g., low DO, aesthetics, taste and odor problems, and harmful algae). While sources of phosphorus can be naturally occurring, anthropogenic loading can result from run-off (urban, pastures, croplands), streambank erosion, and sewage seepage. Phosphorus is available in organic (organic biomass) and inorganic (orthophosphate) forms. Inorganic phosphorus is the preferred form for primary productivity as it is readily available for biological uptake requiring minimal energy utilization. Total phosphorus (TP) is the combination of all forms of phosphorus in the water column.

Presented are results from samples analyzed for orthophosphate and as TP from monthly grab samples between 2018 and 2020 (**Figure 29** and **Figure 30**, respectively). Orthophosphate concentrations ranged from non-detect (ND) to 0.12 mg/L (measured at DR 163.25 in October 2018). Mean orthophosphate across all sites in the Deschutes River and all years was 0.047 mg/L with little notable variation over time. Orthophosphate at TC 4.00 ranged from the detection limit to 0.07 mg/L (mean 0.02 mg/L). Temporal variability in orthophosphate availability is observed throughout the

Deschutes River, with reduced concentrations in the late-spring to early-summer periods. This orthophosphate depletion may be attributed to increased primary productivity, warmer water temperatures and solar irradiance.

TP concentrations ranged from 0.02 mg/L to 0.19 mg/L, exceeding guidance values for EPA Ecoregions II and III in all reported observations (453 [number of exceedances]/453 [total number of observations]) (**Table 9**; **Figure 31**). However, it should be noted, that the 0.19 mg/L measurement occurred in May 2009 from just one site (Columbia Park Footbridge; DR 167.25) and subsequent measurements were at or below 0.10 mg/L. Further, observed elevated phosphorous values are likely derived primarily from natural sources, due to weathering of phosphorous-rich volcanic rocks (mostly basalt). This process drives naturally high phosphorous measurements across much of central and eastern Oregon. Bedrock geology has been mapped for the entire Pacific Northwest and it documents the importance of basalt and other rocks of volcanic origin for this region (Johnson and Raines 1995). The weathering products from basalts are well known and show a disproportionately high rate of weathering of phosphorus from these rocks by hydrolysis (Krauskopf 1979; Colman 1982). The weathering of phosphorus is readily apparent in all three major tributaries to Lake Billy Chinook, including from the Deschutes River (Eilers and Vache 2020). As previously mentioned, excess TP concentrations can lead to cascading environmental events such as depleted DO due to algae growth followed by decomposition. A regression analysis between TP and DO was applied using data from the upstream and downstream AUs on the Deschutes River. While the relationship was significant ($p<0.001$), the ability of TP to predict DO was very week ($r^2<0.20$).

The UDWC (2010) report indicated exceedances in 91 percent of reported values (354 exceedances out of 389 total observation) of the TP ecoregion thresholds, with the highest concentrations (0.40 mg/L) measured at a site further downriver than was evaluated in this report.

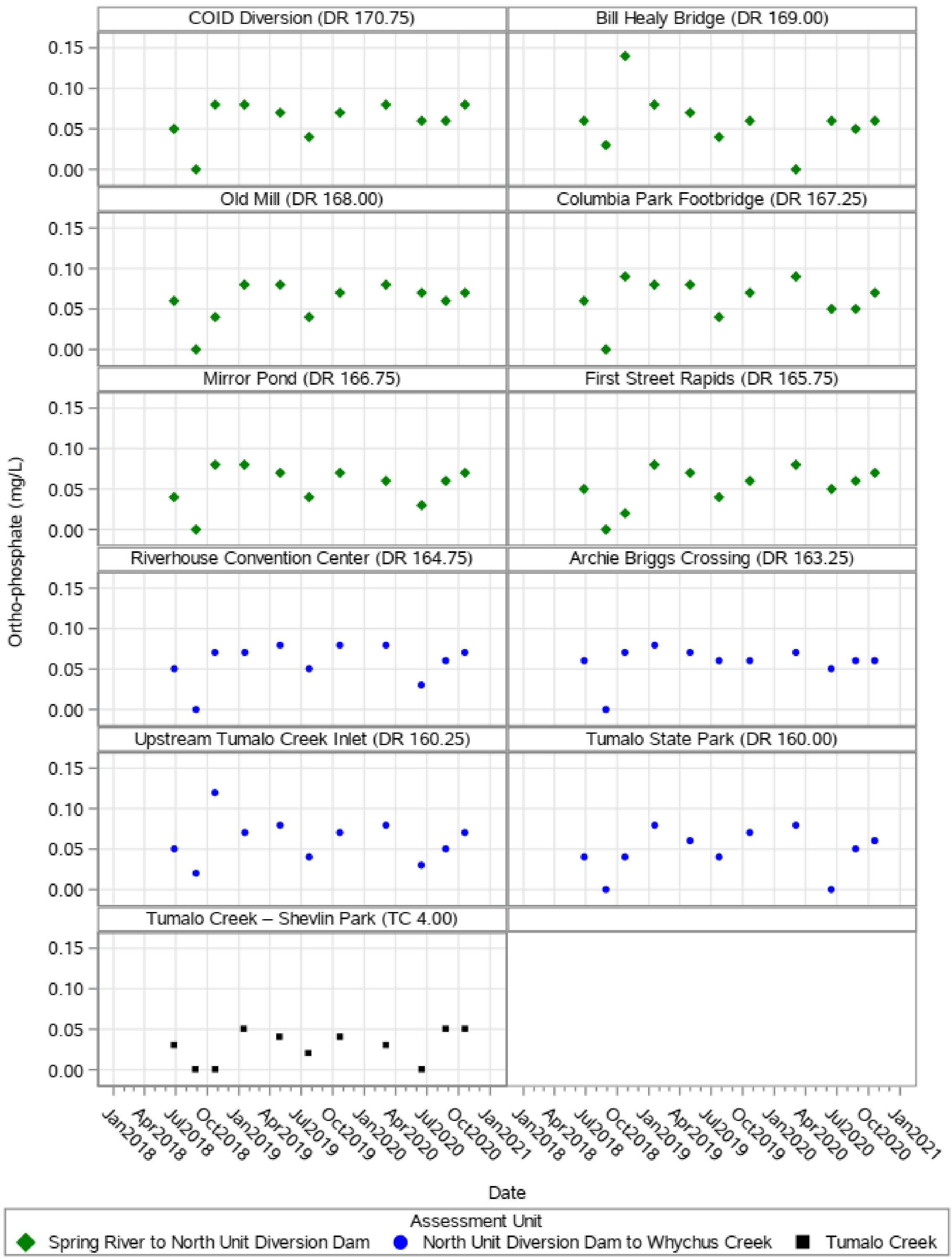



**Figure 29. Deschutes River orthophosphate concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots)- City of Bend 2018 to 2020**

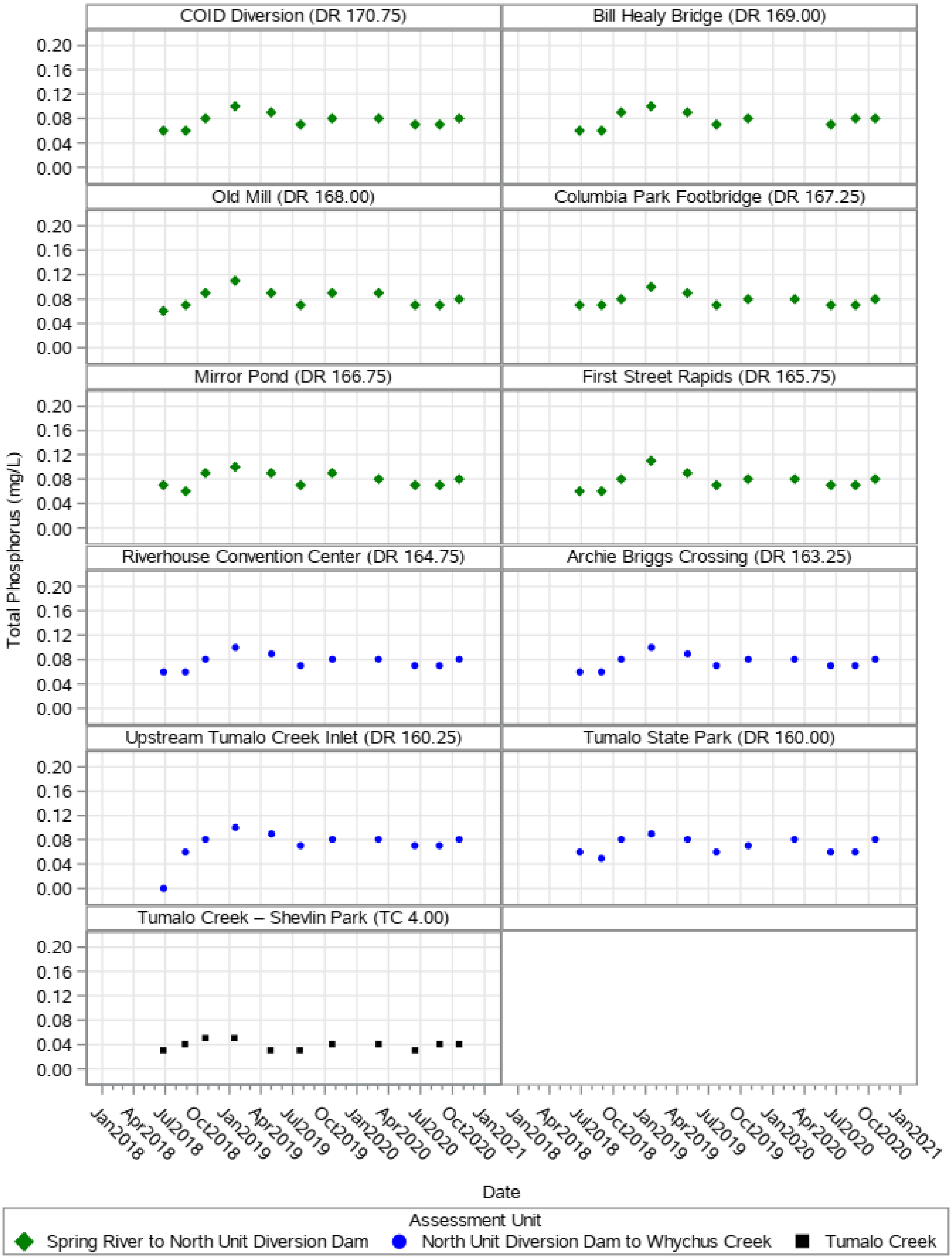



**Figure 30. Deschutes River total phosphorous concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2018 to 2020**

## Chloride, Fluoride, and Sulfate

Chloride is not generally a dominant anion in non-maritime environments where atmospheric deposits generally increase its concentration in adjacent ambient freshwaters. However, anthropogenic sources include run-off from road salting and wastewater discharge can harm aquatic life by disrupting osmoregulation (the process by which biological organisms maintain proper levels of salt). Presented are results from grab samples collected monthly between 2018 and 2020 and analyzed for chloride. Measurements ranged from 0.03 mg/L to 2.88 mg/L in the Deschutes River and averaged 0.44 mg/L in Tumalo Creek at Shevlin Park (TC 4.00) (**Figure 31**).

Fluorides are naturally occurring through geologic processes but can also be released directly to the environment through a number of human activities, including a number of industrial manufacturing processes, the use of fluoride-containing pesticides, and fluoride in drinking water (though fluoride is not provided in the City of Bend's drinking water). Naturally occurring levels of fluoride in fresh surface waters is generally less than 1 part per million (ppm or 1 mg/L). Substantially higher levels can be found in groundwater. Presented are results from grab samples collected monthly between 2018 and 2020 and analyzed for fluoride. Measurements ranged from detection limits to 0.22 mg/L in the Deschutes River and averaged 0.05 mg/L in Tumalo Creek at Shevlin Park (**Figure 32**).

Sulfate also naturally occurs from the breakdown of organic material and geological processes and atmospheric deposition. Specific anthropogenic sources may include runoff from pulp mills or agricultural areas. All living organisms utilize forms of sulfur, depending on the redox status of the cycle (sulfate being bonded with oxygen); including bacteria responsible for decomposing organic matter and contribute to the cycling of other nutrients in ecosystems (Wetzel 2001). Presented are results from grab samples collected monthly between 2018 and 2020 and analyzed for sulfate. Measurements ranged from 0.26 mg/L to 2.96 mg/L in the Deschutes River and averaged 0.52 mg/L in Tumalo Creek at Shevlin Park (**Figure 33**). The sulfate result of 2.96 mg/L at DR 164.75 (Riverhouse Convention Center) is highly anomalous as the mean across all sites along the Deschutes is 0.5 mg/L and this data point is not shown in **Figure 33**.

No exceedances were reported for the subject parameters in UDWC (2010) and ESA and MaxDepth Aquatics (2018) and all were within EPA guidance (**Table 9**).

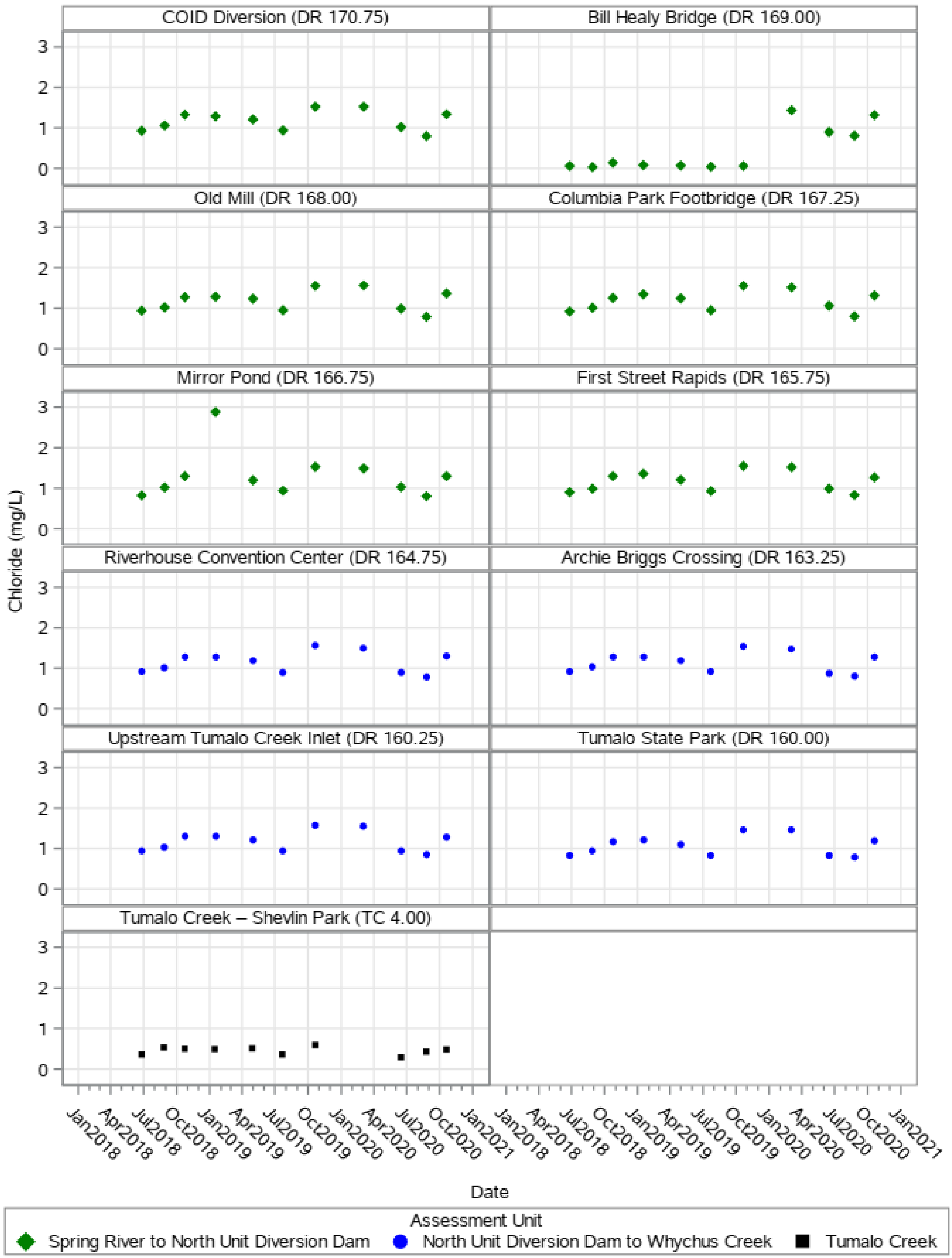



**Figure 31. Deschutes River chloride concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2018 to 2020**

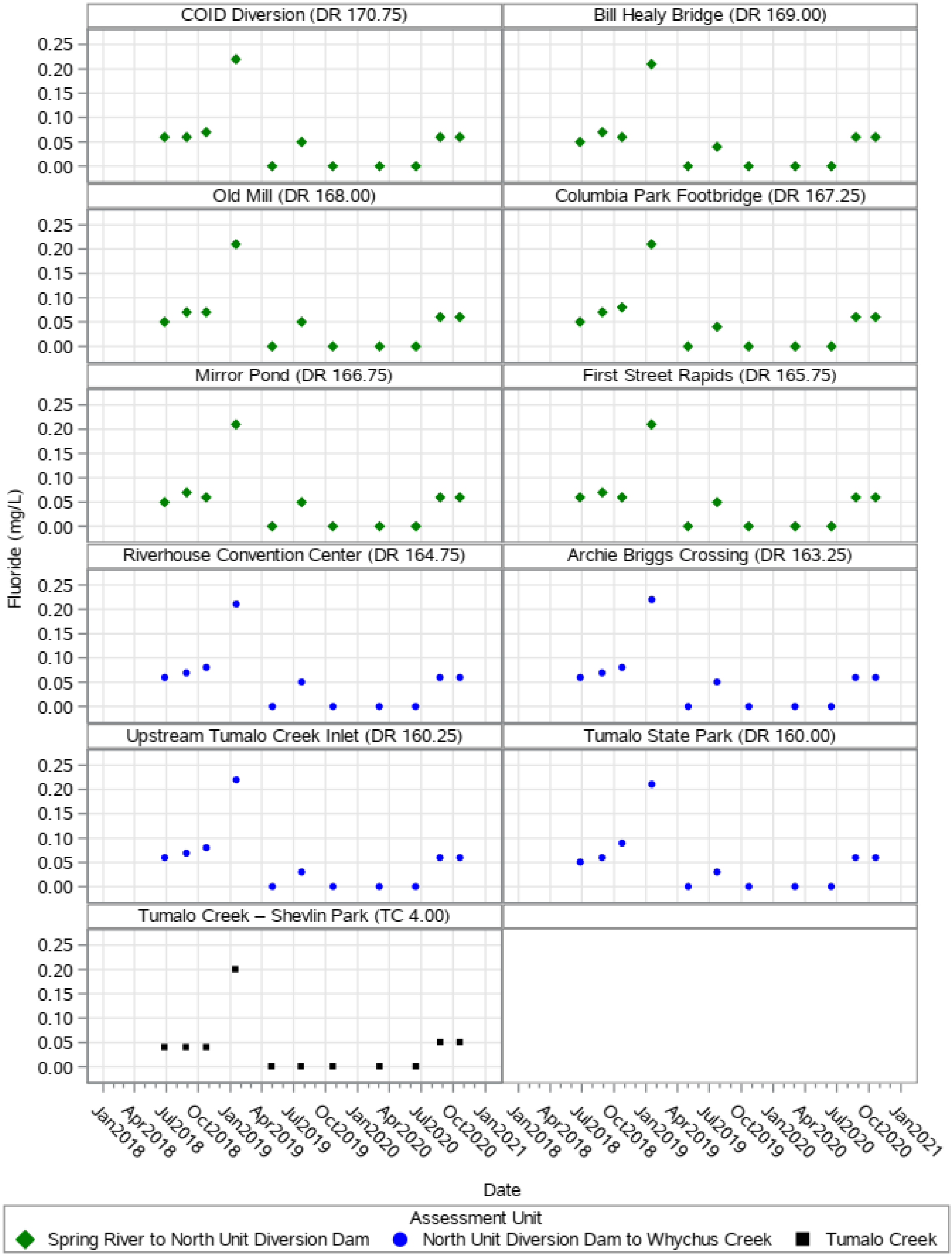



**Figure 32. Deschutes River fluoride concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2018 to 2020**

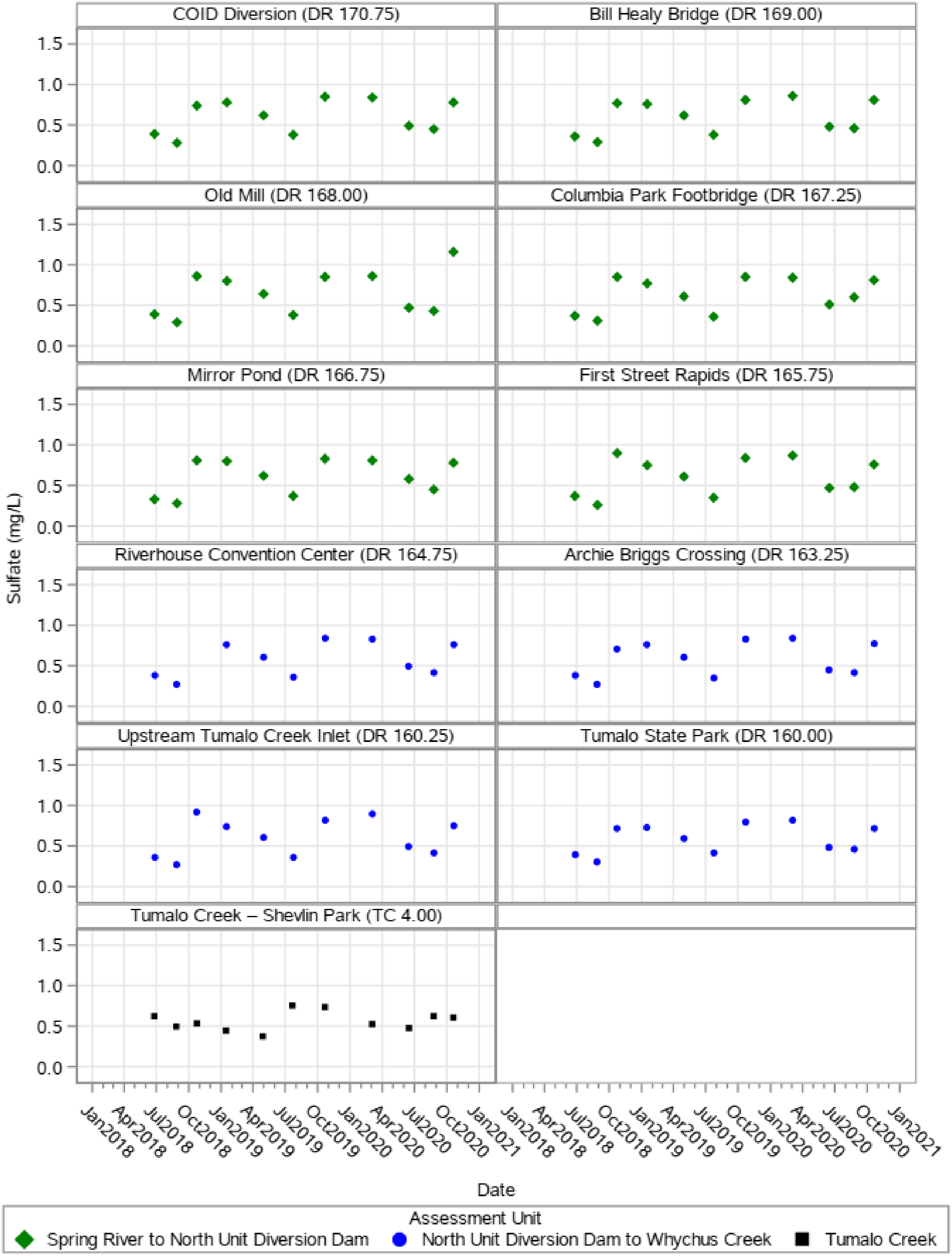



**Figure 33. Deschutes River sulfate concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2018 to 2020. Note: Y-axis is truncated not displaying an elevated anomalous value at DR 164.75 (Riverhouse Convention Center)**

## Total Coliform and *E. coli*

Total coliforms are a group of bacteria that exist in soil and water and are used as an indicator for other potential pathogens because they are relatively easy to identify, commonly occur in large numbers and generally respond to the environment in the same way as more detrimental pathogens. *Escherichia coli* (*E. coli*) is a major species that make up total coliforms and is found in the large intestines of humans and other warm-blooded animals. *E. coli* is used as an indicator for fecal contamination and subsequently whether pathogenic or disease-causing organisms may also be present.

Samples were analyzed for total coliform and *E. coli* monthly from 2018 to 2020 with sampling occurring more frequently in the summer months. Monthly maximums were routinely observed during summer months.

Total coliform concentrations ranged from 36.8 most probably number per 100 mL (MPN/100 mL) to 2,420 MPN/100 mL (the upper quantification limit) in the Deschutes River and were roughly three times higher at the northern end of the UGB compared to the southern UGB (**Figure 34**). Total coliform ranged from 9.8 to 866 MPN/100 mL and averaged 197 MPN/100 mL in Tumalo Creek.

Monthly maximums of *E. coli* ranged greatly from no detections to 88 MPN/100 mL in the Deschutes River and averaged 7.2 MPN/100 mL in Tumalo Creek (**Figure 35**). Distinct peaks were observed at the Old Mill site (DR 168.00) and Mirror Pond (DR 166.75) during summer 2018. The numeric criteria for *E. coli* for freshwater contact recreation is a 90-day geometric mean of 126 organisms100 mL and a single sample of 406 organisms/100 mL (DEQ 2018) (**Table 9**). Previous UDWC (2010) report indicated two exceedances out of 513 total samples with the highest concentration measured at 387 MPN/100 mL; however, that exceedance occurred in 2011 and no exceedances were reported for the subject parameter by ESA and MaxDepth Aquatics (2018) and criteria were met during the current study period through 2020.

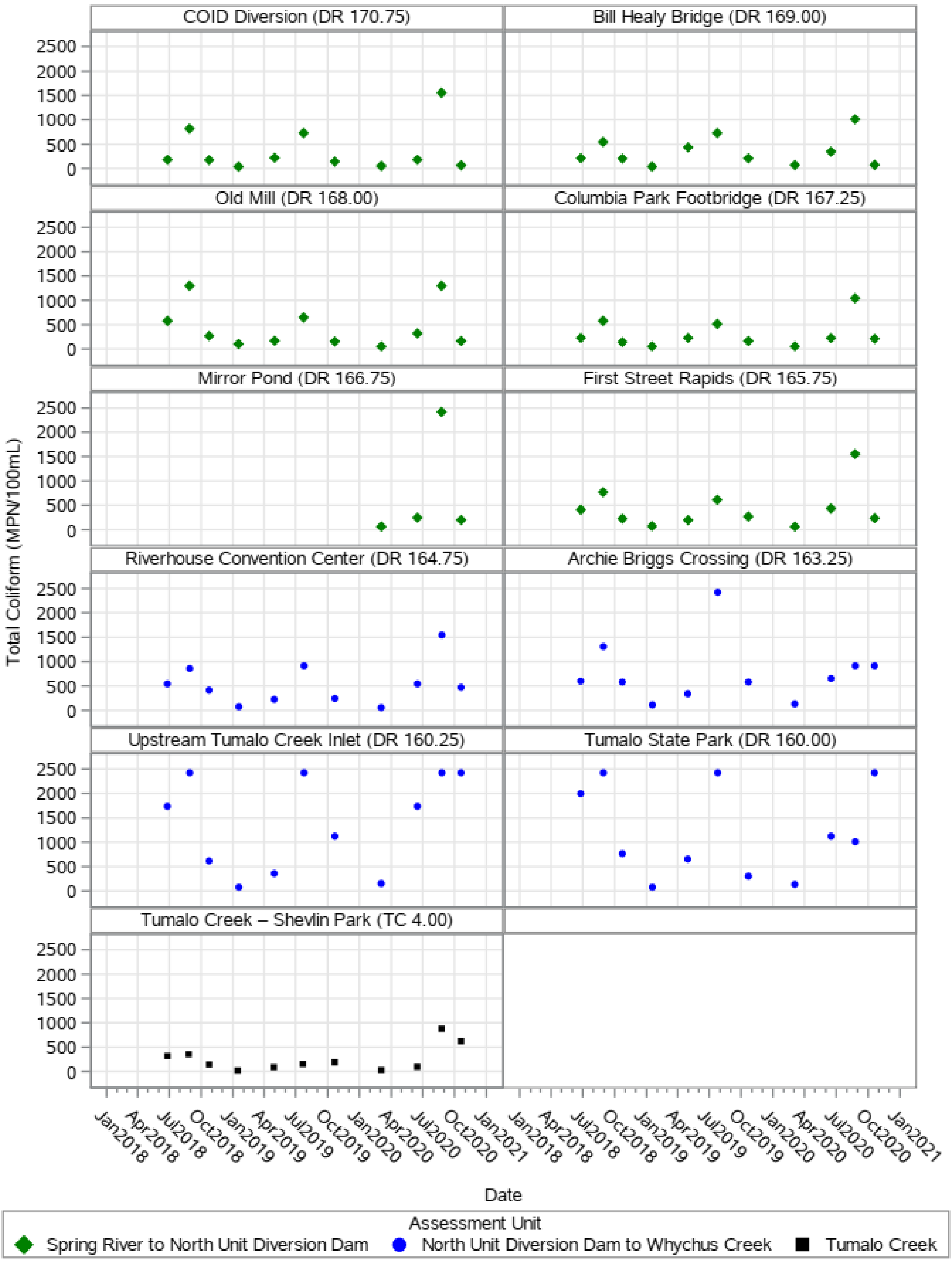



**Figure 34. Deschutes River total coliform levels (most probable number, MPN per 100 mL) at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2018 to 2020**

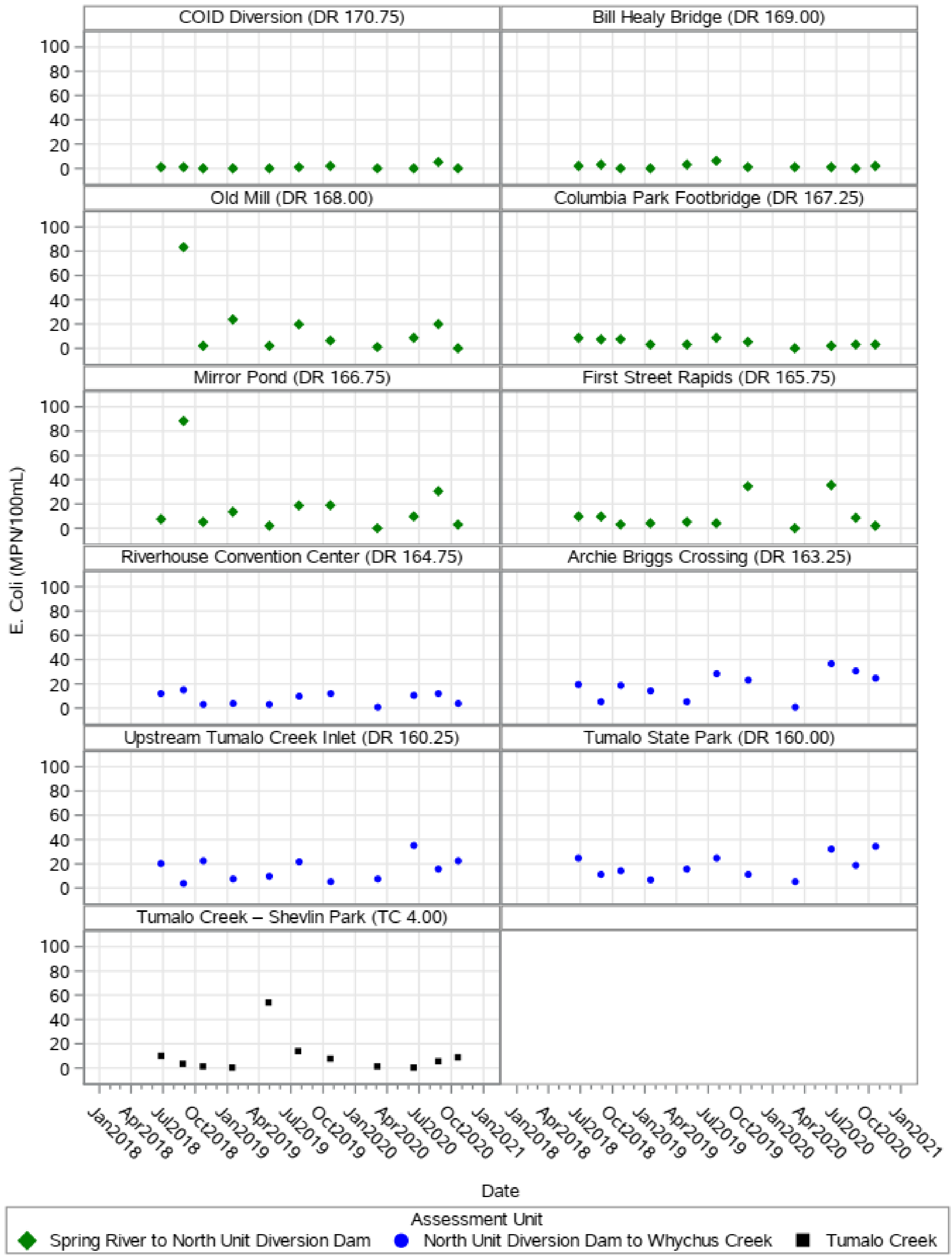



**Figure 35. Deschutes River *E. coli* levels (most probably number, MPN per 100 mL) at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2018 to 2020**

**TABLE 9. GUIDANCE/STANDARDS SUMMARY WITHIN THE STUDY AREA**

| Parameter | Exceedances/ Observations | ORDEQ Standard/ EPA Guidance | Max Observed | Station Name | Date of Max. Concentration |
|---|---|---|---|---|---|
| Total phosphorus (mg/L)[a] | 453/453 | TP (II) = 0.01<br>TP (III) = 0.02 | 0.19 | Columbia Park Footbridge (DR 167.25) | 5/20/2009 |
| Chloride (mg/L)[b] | 0/322 | 860.0 (acute)<br>230.0 (chronic) | 2.88 | Drake Park (DR 166.75) | 1/17/2019 |
| Fluoride (mg/L)[c] | 0/322 | 0.50 | 0.23 | Drake Park (DR 166.75) and Columbia Park Footbridge (167.25) | 6/14/2011 (both) |
| Sulfate as $SO_4$ (mg/L) | 0/322 | 250[d] | 2.96 | Riverhouse Convention Center (DR 164.75) | 10/24/2018 |
| *E. coli* (MPN/100mL)[b] | 0/475 | 126 (90-day mean); 406 (single sample) | 387 | First Street Rapids (DR 165.75) | 9/28/2011 |

MPN = Most Probable Number
SOURCES:
[a] Guidance, EPA (2000); monitoring stations upstream of RM 164.75 are located within EPA Ecoregion II and sites below are in Ecoregion III.
[b] Standard, DEQ (2018)
[c] Guidance, Carmago (2003)
[d] Guidance, EPA (2003); secondary maximum contaminant level (SMCL) based on aesthetic effects (i.e., taste and odor)

# Summary and Recommendations

The City of Bend has been collecting ambient water quality from the Deschutes River since 2004 and this report summarizes results of grab samples and in situ monitoring from 2018 to 2020. Results from grab samples collected since 2008 and in situ monitoring since 2009 are provided in **Appendix B**. Water quality data collected from 2004 to 2007 were not available for incorporation in this report. It is anticipated that this report will be updated annually to include results from the previous year. While there have been minor shifts in monitoring locations, improvements in analytical methods and equipment upgrades have greatly increased data reliability by decreasing instrument drift, lowering method detection limits, and reducing sensor fouling. This dataset spans an important time in the City as it sideboards an era of rapid population growth, important restoration efforts, and changes in water allocation. The 2012 IR listed impaired river reaches whereas the 2018/2020 IR groups areas in terms of AUs presented in a very user friendly "story map". Of particular interest is the delisting in the 2018/2020 IR for DO (spawning and year-round), Chlorophyll *a*, and pH for the Spring River to North Unit Diversion Dam AU which apply to the following sites that are currently monitored: DR 170.75, DR 169.00, DR 168.00, DR 167.25, DR 166.75 (Mirror Pond), and DR 165.75. Key findings and recommendations from the review of data collected from 2018 to 2020 include the following:

## Water Temperature

- Water temperatures in the Deschutes River measured between 2018 and 2020 had exceedances above the 18°C criteria in both AUs in the summer, occurring at a greater percentage of the time in more downstream sites compared to upstream sites (see **Figure 9**).
- Water temperatures in the Deschutes River within the study area do not meet the DEQ criteria for year-round (non-spawning) seven-day moving average maximum temperature criteria of 18°C and are consistent with the 2018/2020 IR 303(d) listing. Two years of monitoring data from one site in Tumalo Creek were within criteria and not consistent with the 2018/2020 IR for 303(d) listing, indicating this reach of Tumalo Creek was cooler than the criteria (see **Figure 9**).

## pH

- Exceedances of pH above 8.5 occurred at all sites at some point over the entire monitoring duration, mostly mid to late summer, which is consistent with the 2018/2020 IR 303(d) listing for both AUs along the Deschutes River. No minimum pH 6.5 exceedances occurred between 2018 and 2020 (**Figure 13**).

## Turbidity/TSS

- There was a general trend of decreasing turbidity and TSS in the Deschutes River from upstream to downstream as well as a decrease in variability. Consistent with other reports (USFS 1995 cited in DEQ 2014), peak turbidity levels corresponded to the spring irrigation season in April/early May and decline during the summer months. Turbidity and TSS were fairly consistent in Tumalo Creek, ranging from 0.00 to 1.31 mg/L and 2.0 and 6.0 mg/L, respectively.

- Using data from the Deschutes River and applying a simple regression model, turbidity measurements predict TSS with 70 percent accuracy in the Spring River to North Unit Diversion Dam AU, but less than 50 percent in the North Unit Diversion Dam to Whychus Creek AU. This suggests continuous turbidity data has the potential to predict changes in TSS in the Deschutes River in the upstream AU, but based on existing data, not nearer the northern UGB.
- There are no further TSS monitoring recommendations; however, if the City intends to use continuous turbidity measurements to predict TSS, then it is strongly recommended that additional TSS samples be collected to increase the robustness of the correlation dataset. At present, only monthly to quarterly TSS measurements are available.

## Dissolved Oxygen

- Between 2018 and 2020, DO concentrations met DEQ criteria for year-round (non-spawning), specifically, the 30-day mean minimum DO concentration of 8.0 mg/L and 6.5 mg/L for the Spring River to North Unit Diversion Dam and the North Unit Diversion Dam to Whychus Creek AUs, respectively. Though the DR 166.75 in Mirror Pond site was very near 8.0 mg/L on numerous occasions prior to 2015, more recent conditions are well above 8.0 mg/L.
- For the seven-day average minimum DO concentration criteria of 11.0 mg/L, all sample sites exceeded at some point during the current study period (2018 to 2020) for the respective AU. In 2019, there was only one monitoring location in the North Unit Diversion Dam to Whychus Creek AU during the spawning period (DR 163.25) which reported seven-day average minimum DO concentrations below 11.0 mg/L in 33.8 percent of seven-day average minimum DO concentrations. In the Spring Creek to North Unit Diversion Dam AU, two monitoring locations (DR 166.75 and DR 170.75) reported 30.0 and 22.5 percent of the seven-day calculated average minimum DO concentrations below the spawning criteria.

## Specific Conductance

- Across the years and sites, specific conductance in the Deschutes River above the confluence with Tumalo Creek ranged from 55 µS/cm to approximately 81 µS/cm and was generally lower in the summer months compared to winter months. Specific conductance in Tumalo Creek ranged from 22 to 46 µS/cm with an average of39.4 µS/cm and far less seasonal variation. Below the confluence with Tumalo Creek, values subsequently decreased in the Deschutes, with an average of 58 µS/cm with some, albeit less, seasonal variation. The low specific conductance contribution of Tumalo Creek to the Deschutes River is evident by the substantially lower specific conductance below the confluence of the two waterbodies, particularly when flows in the Deschutes are low.

## Nutrients

- Nitrite-nitrogen measurements were routinely at the DLs for all sites sampled. Mean nitrate-nitrogen across all sites in the Deschutes River and all years was 0.015 mg/L. Improvements in analytical methods have likely resulted in increased instances of detections, but these levels remain quite low.

- Mean orthophosphate across all sites in the Deschutes River and all years was 0.047 mg/L with little notable variation over time. Orthophosphate at TC 4.00 ranged from the detection limit to 0.07 mg/L (mean 0.02 mg/L). TP concentrations ranged from 0.02 mg/L to 0.09 mg/L with no EPA exceedances between 2018 and 2020.

- It is recommended that where results are at the MDL, that this value be recorded and qualified such that zeros are not reported in the data set.

## Other Parameters of Interest

- Chloride ranged from 0.53 mg/L to 2.88 mg/L, fluoride from detection limits to 0.23 mg/L, and sulfate from 0.03 mg/L to 2.96 mg/L. Mean chloride levels in Tumalo Creek were 0.63 mg/L, 0.22 mg/L for fluoride, and 0.56 mg/L sulfate with little variation over the study period at this site from 2018 to 2020. No exceedances were reported for the subject parameters and all were within EPA guidance. Similar to nutrients, it is recommended that where results are at the MDL, that this value be recorded and qualified such that zeros are not reported in the data set.

- Between 2018 and 2020, monthly maximums of total coliform ranged greatly from 36.8 to 2,240 MPN/100 mL in the Deschutes River and 9.8 to 866 MPN/mL in Tumalo Creek with the lowest monthly maximums observed in January and the highest monthly maximums routinely observed during summer months.

- Between 2018 and 2020, monthly maximums of *E. coli* ranged greatly from no detections to 88 MPN/00 mL in the Deschutes River and from no detections to 53.7 MPN/100 mL in Tumalo Creek. No exceedances were reported for the subject parameter and criteria were met during the current study period through 2020. It is recommended that field notes accompany sample collections to document presence of flora or fauna that could be contributing *E. coli.*

- There has been interest internally as well as from the public advisory group to further investigate potential harmful algae blooms (HABs) and the conditions that could trigger a bloom in the Deschutes River. Generally, HABs are more common in slow moving water and less common in higher velocity areas. At this time, the City will follow the lead of federal agencies in the area that routinely monitor HABs. If observations increase, then the City will consider implementing more rigorous testing for total nitrogen (which is a limiting nutrient in the Deschutes) and chlorophyll a.

## General

- The expansion of the quarterly grab sampling schedule to monthly is recommended from April to October to better characterize seasonal changes in water quality resulting from diversions and resulting changes in flows. An increase in sampling intensity during this period would assist in identifying the system response and drivers which influence water quality conditions.

- Evaluation of the existing available water quality data indicate that there are select parameters which reported elevated or depressed values in comparison to the respective criteria. There are spatial and temporal variations in the data which should be evaluated through a more comprehensive assessment of the potential influencing factors resulting in depressed DO during the spawning season, elevation in TP, increases in water temperature and fluctuations in pH. Further, it should be noted that a number of parameters with criteria exceedances occur at the most upstream site at the COID diversion located just inside the UGB but upstream of urban influences.

- Development of a statistically-based exceedance frequency curve for each constituent could be used to estimate the likelihood of (not) exceeding water quality criteria and improve understanding of the system response to any improvements in upstream conditions.

- Comprehensive water quality monitoring programs such as the one that the City of Bend implements provide an extensive amount information which can be difficult to present to interested stakeholders and residents. An interactive Story Map, or similar, is recommended as a platform to present technical information in a stream-lined, easy to understand environment to better connect the watershed-users with the natural resource they interact with on a daily basis.

- Further evaluate influences on water quality degradation through statistical correlations associated with natural productivity in the Deschutes River and Tumalo Creek and potential anthropogenic influences such as dam releases, agricultural practices, recreational uses, etc.

- Evaluate spatial and temporal trends that indicate changes in reach water quality. Spatial trends could include relationships between monitoring locations on the River and specific locations such as diversions. Temporal trends could include seasonal relationships and specific events such as dam releases.

- A variety of factors are evaluated as part of the Quality Assurance / Quality Control (QAQC) review of the continuous recorder data including equipment calibration records, verification of proper deployment (e.g., review of water depth to ensure equipment sensors are adequately submerged) or values reported out of acceptable range (e.g., pH >15). It is recommended that a data qualifier library be developed and implemented to support the management of a comprehensive water quality database. This recommendation would require the re-structuring of the database to allow for parameter-specific data qualifying which allows the flexibility to review each parameter independently. In addition to the incorporation of parameter-specific data qualifiers, it is recommended that data are not omitted from the water quality database. With the utilization of data qualifiers, data users are able to include/exclude data based upon the type of analysis completed.

- Long-term deployment of continuous recorder equipment can be subject to harsh environmental conditions, vandalism and/or malfunction. The regular, routine calibration and maintenance of the equipment is important to minimize data gaps. An increase in the frequency of calibration/verification efforts is recommended to avoid sensor drift and data confidence.

- Algal monitoring can provide valuable information on the status and trends of phytoplankton concentrations in the river system. It is recommended that paired discrete chlorophyll-a samples are performed routinely to validate the reported fluorescent values provided by the continuous recorder (data not included in this report).

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# Appendix A:
## City of Bend Water Quality Monitoring Plan

ESA

CITY OF BEND

# City of Bend Water Quality Monitoring Plan

NPDES Watershed Monitoring

## City of Bend

**2021**

This Quality Assurance Project Plan was prepared by: Nicholas Jenness & Matthew Sanders

# Approval Sheet

| | | | |
|---|---|---|---|
| Prepared By: | Nicholas Jenness, City of Bend<br>Field Sampling and Measurement Operation | Date | 03-25-2021 |
| Prepared By: | Matthew Sanders, City of Bend<br>Field Sampling and Measurement Operation | Date | 03-25-2021 |
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# 1. Project Management

## 1.1. Requirements and programs related to water quality monitoring list

The City of Bend Water Quality Monitoring Program (WQMP) was developed in 2003 in cooperation with the Upper Deschutes Watershed Council in an effort to fulfill the monitoring suggestions described in USGS report 00-386, “Framework for Regional, Coordinated Monitoring in the Middle and Upper Deschutes River Basin, Oregon.”

**Table 1. Overview of requirements and programs related to water quality monitoring**

| Program Name/Activity | Permit/Criteria | Permit/Document Number(s) |
|---|---|---|
| Storm water | City of Bend Integrated Storm water Management Plan (ISWMP) 2012-2022 | Bend ISWMP 2022 |
| Stormwater | National Pollutant Discharge Elimination System (NPDES) MS4 Phase II Permit No. 102901 Stormwater Management Plan | NPDES 102901 |
| Stormwater | Water Pollution Control Facilities (WPCF) Permit No. 103052 For Class V Stormwater Underground Injection Control System (UIC) | WPCF 103052 |
| Drinking Water | Watershed Control Plan | (plan update pending) |
| Drinking Water | Special Use Permit (SUP) – Bend Municipal Watershed (BMW) with United States Forest Service | BEN1158 |
| Total Maximum Daily Loads (TMDLs) Program | Oregon Department of Environmental Quality (DEQ) Total Maximum Daily Load and Water Quality Management Plan, Deschutes Basin | (in development) |
| Federal Clean Water Act (CWA) list of waters identified under Section 303(d) as water quality limited and needing a TMDL | Oregon Department of Environmental Quality (DEQ) Integrated Report and 303(d) List | Oregon’s 2012 Integrated Report and 303(d) List |

Data collected is also distributed to multiple agencies that have a vested interest in the water quality and condition of the Deschutes River.

## 1.2. Acronyms

| | |
|---|---|
| BMW | Bend Municipal Watershed |
| CCV | Continuing Calibration Verification |
| CFR | Code of Federal Regulations |
| COC | Chain of Custody |
| COID | Central Oregon Irrigation District |
| CWA | Clean Water Act |
| DEQ | Oregon Department of Environmental Quality |
| DMR | Discharge Monitoring Report |
| DQO | Data Quality Objective |
| EPA | Environmental Protection Agency |
| FQRO | Facility Quality Assurance Officer |
| FRO | Facility Responsible Officer |
| HUC | Hydrologic Unit Code |
| ICV | Initial Calibration Verification |
| ISWMP | Integrated Stormwater Management Plan |
| LCS | Laboratory Control Sample |
| LIMS | Laboratory Information Management System |
| LOQ | Limit of Quantitation |
| LPM | Laboratory Project Manager |
| MB | Method Blank |
| MDL | Method Detection Limit |
| MRL | Method Reporting Limit |
| MS | Matrix Spike |
| NPDES | National Pollutant Discharge Elimination System |
| PM | Project Manager |
| QA | Quality Assurance |
| QAO | Quality Assurance Officer |
| QC | Quality Control |
| QAPP | Quality Assurance Project Plan |
| QMP | Quality Management Plan |
| RPD | Relative Percent Difference |
| SOP | Standard Operating Procedure |
| SUP | Special Use Permit |
| UIC | Underground Injection Control System |
| WPCF | Water Pollution Control Facilities |

## 1.3. Definitions

**Monitoring Sites:** Site locations among the three bodies of water the City of Bend samples.

**Continuous Monitoring Sites:** Site locations where multiparameter sondes are deployed in the river or steam to measure analytes on a continuous basis.

**Sampling Event**: A group of samples collected and/or shipped under a single Chain of Custody (COC), by an individual or sampling team (usually a single day's sampling activity).

**Reference Material**: A material or substance that is sufficiently homogenous, stable, and well established to be used for calibration of an instrument or assessment of a method.

**Metadata**: A subset of data that describes and gives information about other data (e.g. collection date or sample location)

## 1.4. Task Organization

### Key duties and responsibilities are listed below:

Facility Responsible Official –FRO

- Responsible for the implementation of permit and certification requirements.

Facility Quality Assurance Officer FQAO

- Responsible for QA/QC of all self-monitoring required under the permit.
- Responsible for water quality analysis, including sampling and shipping of samples to third-party laboratories.
- Responsible for generating water quality reports and data integrity.
- Responsible for QA/QC of water quality analyses under federal and state certification.
- Responsible for water quality analytical analysis and adhering to specific analytical method rules and analytical reports

**Table 2. Task Responsibilities**

| Name | Project Title | Responsibility |
|---|---|---|
| Jeff Buystedt | Facility Responsible Official | Implementation of the Permit and the certification requirements |
| Nicholas Jenness | Facility Quality Assurance Officer | QA/QC of all self-monitoring required under the permit, water quality analysis, including sampling and shipping of samples to third-party laboratories and water quality analyses under federal and state certification |
| Matt Sanders | Facility Quality Assurance Officer | QA/QC of all self-monitoring required under the permit, water quality analysis, including sampling and shipping of samples to third-party laboratories and water quality analyses under federal and state certification |
| Stefan Dangona | Facility Quality Assurance Officer | Water quality analysis and adhering to specific analytical method rules and analytical reports |

## 1.5. Background Information

The Clean Water Act requires point source surface water dischargers to obtain a National Pollutant Discharge Elimination System (NPDES) permit. The NPDES permit will describe what discharges are allowed to surface water, monitoring and data reporting requirements, as well as other provisions deemed necessary to protect receiving waters. Monitoring conducted as part of the permit compliance must be conducted in a manner that complies with Federal Regulations (40 CFR Part 136) and the requirements of the NPDES Permit. This WQMP ensures that all data collected and analyzed under an NPDES permit are valid and verifiable and can be used to satisfy the requirements of the permit.

The City of Bend will complete extensive water quality monitoring along the Deschutes River, Tumalo Creek, and Bridge Creek for the 2021 calendar year. Sixteen sampling locations were selected to provide the basis for the understanding of the watershed within the City, answer water quality questions, and inform processes regarding the Deschutes River and Tumalo Creek as they flow within the city limits. The specific objectives of the monitoring program include:

- Increase understanding of seasonal and annual variations for conventional water quality parameters in the Deschutes River and Tumalo Creek.
- Satisfy element IX (monitoring) of the City's Integrated Stormwater Management Plan (ISWMP) –a required component under the City's NPDES permit number 102901.
- Gather legally defensible data leading to the listing or de-listing of local waterways under the Federal Clean Water Act Section 303(d) with the Department of Environment Quality.
- Gather legally defensible data to aid in establishment of DEQ's total daily maximum load (TMDL) values for the Deschutes River and Tumalo Creek
- Inform the process for local authorities to deal with the sedimentation problem in Mirror Pond in the Deschutes River
- Split sampling project with the state's Department of Environmental Quality Ambient Water Quality Monitoring Program for increased confidence in data integrity

The City of Bend is the county seat of Deschutes County and is the largest city in Central Oregon. With a population at 94,520 in 2017, it is one of the fastest growing cities in the state. Bend is located along the bank of the Deschutes River, originally settled as a logging town but is now considered a resort community to numerous outdoor activities. Many of these outdoor activities directly impact the Deschutes River.

Data is primarily collected within three different zones listed in USGS 00-386 – zones 5,6, and 7 – for monitoring of the Deschutes River as it flows through the City of Bend, as well as Tumalo Creek from Tumalo Falls to the confluence with the Deschutes River.

## 1.6. Task Description

The sampling events will consist of collecting samples at 16 monitoring sites to be analyzed for as many of the listed analytes as practical throughout the year. The minimum requirement is on a quarterly basis. The grab sample analytes includes:

### Table 3. Grab Analyte List

| Grab Sample Analyte List |
|---|
| Temperature, pH, Specific conductance, Turbidity, Total Suspended Solids (TSS), Dissolved Oxygen (DO), Total Coliform Bacteria, E. coli, Chloride (Cl), Fluoride (F), Sulfate (SO4), Ortho-phosphate (O-PO4), Nitrate (NO3), Nitrite (NO2), Total Phosphate (T-PO4) and Ammonia (NH3). In development: Chlorophyll A (Only at DR 166.75), heavy metals (Only at DR 160.00 Tumalo State Park, DR 163.25 Archie Briggs Crossing, DR 166.75 Mirror Pond, DR 170.75 COID Diversion). Possible additions in the future: pesticides. |

Vemco temperature loggers will be placed at all applicable monitoring sites but will exclude sites without a secure deployment apparatus and sites with a history of vandalism and/or theft. The deployed loggers will log the water temperature every half hour, 24 hours a day. They will be deployed in the Deschutes River and Tumalo Creek from July to June to capture full season temperature profiles.

At the continuous monitoring sites, the city's multiparameter sondes will be deployed in the river or stream to measure the listed analytes on a continuous basis. Analyses will be recorded in the sondes' memory on a 15-minute interval and downloaded as often as practical with our field equipment. Sonde data will be audited and compared with our handheld field meters to ensure data integrity. Audit data will be collected every month to assure the sonde is working and maintaining its accuracy. When sondes need maintenance or calibration, they will be brought back to the satellite laboratory.

The City of Bend Laboratory will perform the standard analytical tests required by this permit. See the NPDES permit and other sampling requirements in the permit for the parameters, sample locations, sample frequency, and sample type for all self-monitoring required.

## 1.7. Quality Objectives and Criteria for Measurement of Data

To be acceptable for use, environmental data must meet established QC control limits. This section defines criteria for measuring or estimating the potential error of monitoring results and how to interpret the QC data as it applies to the reported environmental data.

EPA's Guidance for the Data Quality Objectives Process (QA/G-4, EPA 2006) defines two sources of error: Sampling Error (Field Variability) and Measurement Error (Measurement Variability), which each contribute to the total error.

Sampling (field) error – This error is influenced by the inherent variability of the contaminant over geographic space and time, the sample collection design, and the number of samples. It is usually impractical to measure the entire space, and limited sampling may miss some features of the natural variation of the measurement. Sampling design error occurs when the sampling does not capture the complete variability within the environment, to the extent appropriate for making conclusions. Sampling design error can lead to random error (i.e., variability or imprecision) and systematic error (bias) in estimates of contaminant concentrations.

Measurement error – This error is the result of imperfections in the measurement and analysis system. Random and systematic measurement errors are introduced in the measurement process during sample collection, sample handling, sample preparation, sample analysis, data reduction, transmission, and storage.

**Specific QA Objectives are:**

Collect a sufficient number of samples, sample duplicates, and field blanks to evaluate the sampling and measurement error.

Analyze a sufficient number of QC Standards, blanks and duplicate samples in the Laboratory to effectively evaluate results against numerical QA goals established for precision and accuracy.

Implement sampling techniques in such a manner that the analytical results are representative of the media and conditions being sampled.

Evaluate Data quality through the use of these Data Quality Indicators:

- Precision
- Accuracy/Bias
- Sensitivity
- Representativeness
- Comparability
- Completeness

Table 5 in section 2.4 lists precision and accuracy control limits for each parameter of concern.

### 1.7.1 Precision

Precision is estimated by measuring the variability of duplicate measurements. The best estimate of precision is the comparison of duplicate samples. The variability in the results obtained from duplicate samples is the sum of the sampling and analytical variability (measurement error).

The control limits for the duplicate samples collected in the field are +/- 20% RPD. For sample duplicate results that are less than 5 times the method detection limit this control limit does not apply.

In accordance with the control limits, sample blanks are collected after rinsing the sampling apparatus. If there are any significant detects within any of the analytical parameters, data should be qualified and improvements should be made in the sampling process and the sampling event should be repeated.

### 1.7.2 Accuracy/Bias

Accuracy is a measure of the error between reported test results and the true sample concentration. This error, called “bias” is made up of the two types of error, sampling error and measurement error. Accuracy is estimated by measuring the bias of measurement error, even though bias is due to both systematic error in sampling and measurement variability.

Systematic error attributable to sampling design must be minimized by following the procedures described in section 2. This will generally result in acceptable levels of bias.

To minimize bias, all instruments must be calibrated using appropriate reference materials. The accuracy of these materials must be documented and maintained by the City of Bend and any third party laboratories. The instrument’s response to the reference material (initial calibration) shall also be documented and must fall within method control limits. Immediately following the initial calibration a second source standard must be used to verify the accuracy of the calibration reference material. This must be done every time after the initial calibration.

Laboratory Control Samples (LCS) prepared with each batch of samples will be used to estimate accuracy and where applicable, matrix spikes will be used in conjunction with the LCS.

### 1.7.3 Sensitivity

The analytical methods used must be sufficiently sensitive to determine compliance with permit limits. Analytical results should be reported to the Method Detection Limit (MDL) (40 CFR 136, Appendix B) when possible. At a minimum, the data will be reported to the specified Quantitation Limit (QL) listed in the permit. These QLs have been determined to be sufficiently sensitive by Oregon DEQ. The permit lists the parameters of interest for this facility and the target QL for each parameter.

If matrix interference or other analytical issue prevents the data from being reported to the sufficiently sensitive QL, the permittee will work with the permittee’s lab and Oregon DEQ to demonstrate the matrix effects according to procedures described in EPA's "Solutions to Analytical Chemistry Problems with Clean Water Act Methods," March 2007.

Blank results must be less than the QL for each analyte listed in the permit. Laboratory Method Blanks (MB) must be prepared along with each LCS. MB results will be used to assess the sensitivity of the method. If corrective action measures fail to resolve MB errors, results batched with the MB will be flagged with the appropriate data qualifier when reported.

### 1.7.4 Significant Figures and Rounding

Calculations must be made following Oregon DEQ's guidance documents for significant figures and for rounding, unless directed otherwise by Oregon DEQ.

### 1.7.5 Representativeness

Representativeness is a qualitative term used to determine whether measurements are made and physical samples are collected in such a manner that the resulting data appropriately reflects the media and phenomenon measured or studied.

Representativeness is controlled by using well defined sampling and sample handling standard operating procedures (SOP). SOP's must be designed so that results are representative of the matrix being sampled. Sample handling protocols for storage, preservation, and transportation must be developed to preserve the representativeness of the collected samples. Proper documentation will establish that protocols have been followed with sample identification and sample integrity assured. If it is determined that sample integrity has been compromised, data must be flagged with the appropriate data qualifier.

Sample locations will be referenced to latitude and longitude using a Global Positioning System device. In-stream samples are best collected at or near the center of the stream channel if applicable, where the water is well mixed and representative of the ambient conditions. For every sample collected, the date and time at which measurements are made will be recorded and all efforts will be made to confirm the accuracy of this metadata. In-stream samples will be collected at a location that is free of the influence of the confluence of tributaries or point source discharges.

Quality analytical measurements with poor field duplicate precision may point to sampling problems or heterogeneous samples and thus not representative of ambient conditions. To ensure the representative data quality indicator is correct, field duplicates must be collected within 15 minutes and 15 meters of each other, where the sample matrix is assumed to be homogeneous. Evaluation of field duplicate, lab duplicate, and accuracy data will provide information if there is error in the hypothesis that the sample is homogeneous. If field duplicate data exceeds precision limits but lab duplicate and accuracy data is acceptable, the sampling design may be in error and the data may not represent the environmental conditions for which it was collected. If field duplicate data indicates representativeness is acceptable, data users may assume other project data meet representativeness objectives.

### 1.7.6 Comparability

To ensure data will be comparable to similar environmental data collected at other facilities, procedures for sampling, sample handling, and sample analysis will be documented and written to comply with 40 CFR 136. The City of Bend and any third party laboratories should follow the analytical methods cited in Table 5, which are promulgated methods in 40 CFR Part 136 and the sampling procedures described in section 2.

### 1.7.7 Completeness

It is expected that samples will be collected from all sites described in this QAPP unless seasonal-related events or safety issues prevent sampling. Oregon DEQ may require re-sampling to obtain more information of qualified data.

## 1.8. Special Training and Certification

Facility laboratory personnel will be trained in sampling methods, sample handling, COCs, sample transport, and field and laboratory measurements. The PM and/or the QAO are responsible for the training of staff who perform sampling, sample handling, and analysis activities. Records will be kept on file of these training activities and may be reviewed by Oregon DEQ.

## 1.9. Records

Field logbooks, notebooks and/or data sheets will be filled out using waterproof or weather resistant ink and should not be erased. Changes must be made by crossing out errors and adding correct information. Logbooks should be bound with numbered pages.

Laboratory data results must be recorded on laboratory data sheets, bench sheets and/or in laboratory logbooks for each sampling event. These records along with control charts, equipment maintenance logbook, calibration and quality control checks, preparation and use of standard solutions, inventory of supplies and consumables, equipment check-ins, equipment parts, and chemicals should be kept on file at the laboratory.

Any procedural or equipment problems must be recorded along with data results. Any deviation from this QAPP must be noted. Additional sampling and analyses should be performed when results fall outside the specified range and when the Data Quality Objectives (DQO) are not met. Data results submitted to Oregon DEQ will include information on field and/or laboratory QA/QC problems and corrective actions.

COCs or Transmission forms will be kept with the sample transport, and will accompany data results sent to Oregon DEQ.

Training records and data review records will be kept on file in the facility’s laboratory and will be available on request by Oregon DEQ.

All records and documents must be kept according to the schedule specified in the permit at the facility’s laboratory and are available to the EPA and Oregon DEQ for inspection at any time.

### 1.9.1 Analytical Reports

Permittees must submit data to Oregon DEQ as required by the facility permit.

Electronic versions of the final laboratory analytical reports must be e-mailed to the distribution list specified in Section 1.1 in a Portable Document Format (PDF).

Analytical reports must contain sufficient information to unambiguously link sample collection information to the group of analytical parameters. The following elements should be addressed in the report:

- COC Documentation
- Holding Times
- Method Detection Limits
- Blank Analysis
    - Field (Trip and Equipment)

  - Method
- Quality Control
  - Spike Recovery
  - Field Duplicates
  - Laboratory Duplicates
- Data Use and Limitations

**NOTE**: Include tables or narratives that clearly identify all data where DQOs were not met and a discussion of the significance of each case. Data flags must be used to qualify data that do not meet quality requirements to indicate potential bias. Qualifying flags must be clearly defined in the laboratory report.

### 1.9.2 Field Documentation

The sampling team uses the COC/field data sheets to document the record of significant events, observations, and measurements during field investigations. This record may include water level data, field measurements, personnel, significant weather observations, and physical conditions should they exist. All entries in the COC/field data sheets should be signed and dated. The COC/field data sheets will be kept as a permanent record.

# 2. Data Generation and Acquisition

## 2.1. Sampling Process Design

All samples must be collected in the appropriate sample containers and preserved as identified in the appropriate reference methods. Samples must also arrive to the analytical laboratory within the appropriate sample holding times, with the appropriate documentation, and under the appropriate sample transport conditions. In cases where an external analytical laboratory analyzes samples for the permittee, the external lab assumes no responsibility for the quality of data resulting from samples that were collected, shipped, or stored under inappropriate conditions.

The locations to be sampled are summarized in Table 4.

**Table 4. Summary of sampling locations**

| Site No. | Site Name | Description | Latitude | Longitude |
|---|---|---|---|---|
| DR 160.00 | Tumalo State Park | Downstream of the Mouth of Tumalo Creek | 44.117746 | -121.334802 |
| DR 160.25 | Upstream Tumalo Creek Inlet | Immediately upstream of the mouth of Tumalo Creek | 44.114726 | -121.339286 |
| DR 163.25 | Archie Briggs Crossing | Footbridge maintained by the City of Bend | 44.095352 | -121.315838 |
| DR 164.75 | Riverhouse Convention Center | Downstream of COID impoundment | 44.077958 | -121.305693 |
| DR 165.75 | First Street Rapids | Downstream of PP&L dam | 44.067314 | -121.313013 |
| DR 166.75 | Miror Pond | Mirror Pond | 44.060242 | -121.320994 |

| | | | | |
|---|---|---|---|---|
| DR 167.25 | Columbia Park Footbridge | Adjacent to Columbia Park | 44.05269 | -121.324939 |
| DR 168.00 | Old Mill | Downstream end of the Mill log pond | 44.043359 | -121.316476 |
| DR 169.00 | Bill Healy Bridge | At the southern crossing, Bill Healy Bridge | 44.040564 | -121.330014 |
| DR 170.75 | COID Diversion | Immediately upstream of COID diversion intake facility | 44.01808 | -121.350176 |
| TC 000.25 | Mouth Tumalo Creek | Where creek empties into Deschutes River | 44.115950 | -121.339290 |
| TC 003.25 | Tumalo Feed Canal/Stag Drive | Immediately downstream of Tumalo Irrigation withdrawal from creek | 44.040564 | -121.330014 |
| TC 004.00 | Shelvin Park | Upstream of Shevlin Road Bridge | 44.082873 | -121.376368 |
| TC 007.50 | FS 4606 Bridge Crosing | Near the South Boundary of Shevlin Park | 44.051480 | -121.411349 |
| TC 014.50 | Skyliner Road Bridge | Skyliner’s Road Bridge | 44.032310 | -121.520430 |
| TC 017.25 | Tumalo Falls FS Day Use Area | Across from USFS stream gauge | 44.031218 | -121.564654 |

These sites will be collected on a quarterly basis. The analyte list for each of these quarterly sampling events are summarized in Table 3. All of the Tumalo Creek sampling events omit total suspended solids due to the low level of that specific analyte.

Every quarterly sampling event will include an equipment blank to be analyzed after a randomly assigned location.

## 2.2. Sampling Methods

Samples and measurements taken as required by the permit must be representative of the volume and nature of the monitored discharge. When a sample is collected using a peristaltic pump or portable sampler, a volume of water equal to at least ten times the volume of the sample line will first be discharged through the line to clear it of standing water and possible contamination. If there is no discharge line port, the sampler may take the sample from the final effluent chamber at the designated sample location, taking all safety and contamination-prevention precautions.

Where site locations safely allow, receiving water samples should be collected from the center of the main channel, at a depth of one foot. This ensures a sample representative of environmental conditions. If access to the center of the channel dos not exist, the sample will be collected where there is clear flow within the receiving waters.

A stainless steel sampling container is used to hold the sample containers as they are filled in the receiving waters. To avoid excess solid debris, the stainless steel sampling container is only used at locations that it can be safely lowered in to the sampling site.

Samples will be identified as “grab” on COC forms and in field logbooks and field data sheets.

**Grab Samples**

Grab samples are discrete samples taken at one location and time. Depending on the analyte of interest there may be volume, sample collection, or sample preservation requirements (see Table 5). Consult the analytical method (see Table 6) or third-party laboratory for proper collection and preservation requirements for each analyte.

The sample time to be listed on the COC and sample bottle will be the time of the sample collection.

**Cleaning**

All sampling equipment and sample containers must be cleaned prior to use, according to the equipment specifications or the analytical method, SOPs and/or the manufacturer's recommendations.

Rinse the bottles three times with sample to clean out any containment. This does not apply to the sterilized bottles due to the added preservative in the bottle.

## 2.3. Sample Handling and Custody Procedures

Sample handling, preservation, and holding times will follow those approved by EPA 40 CFR 136.3. Sample container, minimum sample volume, preservation, and maximum storage requirements for each parameter are listed in Table 5 below. When samples are transferred to an outside contracted laboratory, COC forms must be filled out and accompany the samples sealed inside the cooler, until received by the laboratory. When samples are transferred between personnel, such transfer will be indicated on the COC with a signature and date and time of transfer. The COC will remain with the samples at all times, samples and sample containers must be maintained in a secure environment from the time the bottles leave the facility until the time the samples are received at the laboratory. Contracted laboratories will maintain custody of bottles and samples using their normal custody procedures.

A summary of the sampling containers, preservation requirements, and holding times is presented in **Error! Reference source not found.** 4.

### Table 5. Summary of analytical parameters

| Analytical Parameters | Container | Preservation | Holding Time |
|---|---|---|---|
| Coliform, Total (No./100 mL) | Sterile 125-mL plastic bottle | Sodium Thiosulfate, Cool to 0 - 6°C | 8 hours |
| Coliform, E. Coli (No./100 mL) | Sterile 125-mL plastic bottle | Sodium Thiosulfate, Cool to 0 - 6°C | 8 hours |
| Chloride (Cl) (mg/L) | 125-mL plastic bottle | Cool to 0 - 6°C | 28 days |
| Copper (Cu) (mg/L) | 250-mL plastic bottle | Nitric Acid, Cool to 0 - 6°C | 6 months |
| Fluoride (F) (mg/L) | 125-mL plastic bottle | Cool to 0 - 6°C | 28 days |
| Lead (Le) (mg/L) | 250-mL plastic bottle | Nitric Acid, Cool to 0 - 6°C | 6 months |
| Ortho-phosphate ($PO_4$) (mg/L) | 125-mL plastic bottle | Cool to 0 - 6°C | 48 hours |
| Nitrate ($NO_3$) (mg/L) | 125-mL plastic bottle | Cool to 0 - 6°C | 48 hours |
| Nitrite ($NO_2$) (mg/L) | 125-mL plastic bottle | Cool to 0 - 6°C | 48 hours |
| Phosphate, Total (T-$PO_4$) | 250-mL plastic bottle | Sulfuric Acid, Cool to 0 - 6°C | 28 days |
| Sulfate ($SO_4$) (mg/L) | 250-mL plastic bottle | Cool to 0 - 6°C | 28 days |
| Total Suspended Solids (mg/L) | 1-L plastic bottle | Cool to 0 - 6°C | 7 days |
| Zinc | 250-mL plastic bottle | Nitric Acid, Cool to 0 - 6°C | 6 months |

One of the difficulties in measuring pollutants in environmental samples is preventing sample contamination during collection and transport. "Clean Hands/ Dirty Hands" sampling techniques will provide the level of protection necessary to prevent contamination of the samples.

The clean sampling methodology requires that a two-member team participate in the collection of the samples. The "Clean Hands" member is responsible for all procedures involving direct contact with the samples and the sample container. The "Dirty Hands" member is responsible for preparing the sample containers for collection, operates samplers and takes out the Nalgene samplers from the sampling containers and any other activity that could lead to potential contamination of the sample.

Some guidelines for "Clean Hands/ Dirty Hands" sampling techniques:

**Dirty Hands**

- Does not touch the sample source
- Does not touch the primary inner sample bag
- Does not touch the sample containers
- Does not touch clean sampling equipment
- Handles all dirty materials
- Arranges sampling materials
- Opens/closes secondary-outer sample bags
- Opens/closes sample cooler
- Operates pump equipment and pole sampler
- Pulls out the Nalgene sample container from the sample apparatus
- Pours sample from the Nalgene sample bottle into the clean sample bottle
- Wears nitrile gloves

**Clean Hands**

- Does not touch dirty materials
- Does not touch the secondary-outer sample bags
- Does not touch the sample cooler
- Handles all clean materials
- Assembles the clean sampling equipment
- Handles any tubing from samplers
- Directly contacts the sample source
- Opens/closes primary-inner sample bags
- Directly comes in contact with the clean sample bottle
- If needed submerges container and collects sample
- Wears double nitrile gloves. If the outer glove gets contaminated, they can easily take off the contaminated glove and still have on a clean glove.
- Labels sampling containers and fills out logbooks and chain of custody forms

## 2.4. Analytical Methods

Contaminants of concern for this project are listed in the permit. All laboratories involved with compliance monitoring for this facility must make analytical SOPs available upon request. The laboratories' analytical SOPs must cite EPA-approved methods as found in 40 CFR Part 136.3 or its updates.

Field analytical measurements will be graded using the Oregon DEQs Data Validation Criteria for Water Quality Parameters Measured in the Field. (Appendix A)

A summary of the analytical parameters, the analytical methods used, and their precision and accuracy values is provided in **Error! Reference source not found.** 6.

## Table 6. Summary of analytical parameters and methods

| Analytical Parameters | Reference Method | Precision (RPD) | Accuracy | | | |
|---|---|---|---|---|---|---|
| | | | MS | LCS | CCV | ICV |
| **Grab Sample Monitoring (Quarterly)** | | | | | | |
| Coliform, Total | SM 9223 D | 0.6(log) | N/A | Positive Confirmation | N/A | N/A |
| Coliform, E.coli | SM 9223 B | 0.6(log) | N/A | Positive Confirmation | N/A | N/A |
| Chloride (Cl) | SM 4110B | ±20% | ±20% | ±10% | ±10% | ±10% |
| Copper, Total (Cu) | SM 3125 | ±20% | ±20% | ±10% | ±10% | ±10% |
| Dissolved Oxygen | Field probe: Pro DSS | ±20% | N/A | N/A | ±0.5 (mg/L) | ±0.5 (mg/L) |
| Fluoride (F) | SM 4110B | ±20% | ±20% | ±10% | ±10% | ±10% |
| Lead, Total (Pb) | SM 3125 | ±20% | ±20% | ±10% | ±10% | ±10% |
| Orthophosphate ($PO_4$) | SM 4110B | ±20% | ±20% | ±10% | ±10% | ±10% |
| Nitrate ($NO_3$) | SM 4110B | ±20% | ±20% | ±10% | ±10% | ±10% |
| Nitrite ($NO_{2)}$ | SM 4110B | ±20% | ±20% | ±10% | ±10% | ±10% |
| pH | Field Probe: Pro DSS | ±0.2 pH | N/A | ± 0.1 pH | ± 0.2pH | ±0.1pH |
| Phosphate Total | SM 4500-P E | ±20% | ±20% | ±10% | ±10% | ±10% |
| Specific Conductance | Field Probe: Pro DSS | ± 10% | N/A | ± 5% | ±5% | ±5% |
| Sulfate | SM 4110B | ± 20% | ± 20% | ± 10% | ±10% | ±10% |
| Temperature | Field Probe: Pro DSS | ± 0.1˚C | N/A | ± 0.1 ˚C | ±0.1˚C | ±0.1˚C |
| Total Suspended Solids (TSS) | SM 2540D | ± 20% | N/A | ± 10% | N/A | N/A |
| Turbidity | Field Probe: HACH 2100P | ± 10% | N/A | ± 10% | ± 10% | ± 10% |

| | | | | | | |
|---|---|---|---|---|---|---|
| Zinc, Total (Zn) | SM 3125 | ±20% | ±20% | ±10% | ±10% | ±10% |
| **Continuous Temperature Monitoring** | | | | | | |
| Temperature | Vemco loggers | ± 0.1˚C | N/A | ± 0.1 ˚C | ±0.1˚C | ±0.1˚C |
| **Continuous Multiparameter Sonde Monitoring** | | | | | | |
| Dissolved Oxygen | Field Probe; EXO2 | ±20% | N/A | N/A | ±0.5 (mg/L) | ±0.5 (mg/L) |
| pH | Field Probe; EXO2 | ±0.2 pH | N/A | ± 0.1 pH | ±0.2pH | ±0.1pH |
| Specific Conductance | Field Probe; EXO2 | ± 10% | N/A | ± 5% | ±5% | ±5% |
| Temperature | Field Probe; EXO2 | ± 0.1˚C | N/A | ± 0.1 ˚C | ±0.1˚C | ±0.1˚C |
| Turbidity | Field Probe; EXO2 | ± 10% | N/A | ± 10% | ± 10% | ± 10% |

## 2.5. Quality Control

At least once during each quarterly sampling event, the FQAO will take one field duplicate sample. The field duplicate will be randomly assigned to a sampling site within the event and will rotate each quarter. One field blank will be taken every quarterly sampling event.

With knowledge of an unacceptable error in the QC measurement (as defined in Table 6 above), environmental samples within the QC batch must either be reprocessed (if possible) after improvements are made to minimize the observed error, or the data must be flagged as not meeting the quality control standard. If more than one of the same QC is performed in the batch only the environmental data preceding the failed QC must be qualified (flagged). Batch QC control limits are summarized in Table 6.

All monitoring performance evaluation results are required records and must be put in safekeeping at the facility to be made available for review by the Oregon DEQ upon request.

### 2.5.1 Location:

All environmental data generated from samples collected at a station may be flagged based on observations made by the sampling team and supporting data. The sampling station should appear to be indicative of normal homogeneous ambient conditions. Access to the sample location within the stream should not be impaired. The sampling team will note on their field sheet if an obstacle prevents collecting the sample at the specified location and time.

## 2.6. Instrument/Equipment Testing, Inspection, and Maintenance

All analytical equipment must be maintained and inspected in accordance with the analytical method's SOPs, and/or the manufacturer's recommendations.

The laboratories will keep maintenance logs on all analytical equipment. Laboratories are expected to conduct routine maintenance procedures and follow the manufacture's advice. Personnel conducting peer review will find it helpful to use maintenance logs during corrective action procedures.

## 2.7. Instrument Calibration and Frequency

All analytical and field equipment will be calibrated in accordance with the procedures test method SOPs.

If instruments cannot be calibrated as required, the analyst will flag data as appropriate.

## 2.8. Inspection/Acceptance of Supplies and Consumables

The FQAO will be responsible for maintaining records of traceability for all reagents and standards. The FQAO must validate the usability of standards and reagents upon receipt and when expiration dates are exceeded.

## 2.9. Data Management

Data will be entered onto field data sheets, bench sheets, and into laboratory logbooks. The FQAO or appointed designee will submit data to DEQ based on requirements outlined in the permit. The following is a list of data information records that are kept available at the facility's laboratory for Oregon DEQ review upon request:

- Training Records
- Field equipment and chemicals maintenance, cleaning and calibration records
- Field logbooks and/or field data sheets
- COC forms
- Laboratory equipment and reagents maintenance, cleaning and calibration records
- Laboratory bench sheets, control charts
- Laboratory SOPs
- Records of QA/QC problems and corrective actions (field and/or laboratory)
- Laboratory data QC records
- Duplicate, split sample, performance evaluation records and other QA/QC control records (field and laboratory)
- Assessment records, such as Proficiency Test results
- Data review, verification and validation records

Whenever possible data results will be entered electronically and transferred electronically to avoid transcription errors.

# 3. Assessment and Oversight

## 3.1. Assessment and Response Actions

The FQAO will ensure that the field and laboratory forms are complete. Approximately 10% of the data sheets or logbook entries with the Discharge Monitoring Report (DMR) entries should be inspected for inaccuracies. If any errors are found the FQAO will verify correct entry by comparing another 10% of the data sheets.

Should the sampling staff, laboratory personnel or FQAO find errors in sampling or analysis, the FQAO will notify the FRO and the party responsible for the error or deficiency, and will recommend methods of correcting the deficiency. The responsible party will then take action to correct the problem and will report corrections to the FQAO and FRO. See above for how this information is recorded and reported

The FQAO will monitor the duplicate sampling and analysis activities and will review these results. The FQAO will keep these assessment records available for review by Oregon DEQ.

Additionally, the facility is inspected and/or audited regularly by Oregon DEQ or EPA.

## 3.2. Reports

The data reporting schedule is specified in the permit. Monitoring results are summarized on the DMR, included in the permit and are submitted to Oregon DEQ each month. Refer to permit for the reporting schedule for Tier I/Tier II monitoring and Copper BLM/Aluminum BLM monitoring (if applicable).

Any improvements to QA and/or QC will be implemented as necessary. Records of changes will be available for Oregon DEQ review.

# 4. Data Validation and Usability

The FQAO will perform at least quarterly quality checks of data to detect correctable problems. Any problems noted will be immediately brought to the attention of the FRO. Items to be checked include data sheets, logbooks, data entry, DMR's, calibration logs, and custody/transmission forms.

The Vemco data processing is focused on ensuring the temperature profile for each site passes quality control and has been culled of data that is observably or obviously not representative of the actual temperature at the site. The primary reasons for culling data are because of QC failure by the sensor, the sensor being frozen in water, or the sensor being pulled out of the water entirely. The data is graded based on the Continuous Field Temperature Measurement SOP. If the Vemco passes the check in and check out it procedures will be graded as level "A" data. If the data does not meet the criteria it will be qualified appropriately.

The multiparameter data processing is focused on ensuring the profile for each parameter at each site passes quality control and has been culled of data that is observably or obviously not representative of the actual conditions at the site. The primary reasons for culling data are because of QC failure by the sensor, the sensor being frozen in water, or the sensor being out of the water entirely. The data is graded based on the audits performed while the sonde was deployed and the check in and check out procedures. If any of the parameters do not meet the acceptance criteria it will be qualified appropriately.

## 4.1. Data Review, Verification and Validation

The FQAO will check the accuracy and precision of data to ensure that data quality objectives are being met and that the program conforms to CFR 136.7 and the conditions outlined in the permit

Data sheets and/or logbooks must be completely filled out and signed at the time of sampling and analysis. The FQAO will review data sheets and/or logbooks for accuracy, precision, missing or illegible information, errors in calculation and values outside the expected range.

The WQMP will be reviewed on a yearly basis and updated accordingly.

When data quality indicators do not meet specifications (see Table 6) the cause of the failure will be evaluated. If the cause is equipment failure, calibration and maintenance procedures will be reassessed and improved. If the problem is procedural error, the FQAO will review methods used. If accuracy and precision goals are frequently not being met, QC procedures will be reviewed and, subject to Oregon DEQ approval, may be revised.

The FQAO or appointed designee will review and initial equipment maintenance logs, sample custody forms and equipment/supply inventory and inspection forms on a quarterly basis.

Verification of data accuracy will be made by the FQAO during quarterly quality control checks, replicate analysis and split sampling checks. The FQAO during the quarterly review process will make calculations and determinations for precision and completeness. Results of accuracy, precision, and completeness calculations will be kept on file at the laboratory. Upon submission and review, data to be flagged will be in accordance of the DEQ field data qualifier list. (Table 7)

### Table 7. DEQ Field Data Qualifiers

| Result Measure Qualifier | |
|---|---|
| **Code** | **Allowed Value** |
| FDC | Drift check, failed |
| PBH | Estimated, Continuous probe biased high |
| PBL | Estimated, Continuous probe biased low |
| R | Rejected; The sample results are unusable due to the quality of the data generated because certain criteria were not met. The analyte may or may not be present in the sample. |
| SUS | Result value is defined as suspect by the data owner. |

## 4.2. Reconciliation with User Requirements

Problems with quality sampling and analysis will be discussed with Oregon DEQ to ensure that permit requirements and QAPP data quality objectives are met. Modifications to monitoring required by permit will require modifications to the approved QAPP.

# 5. Revision History

### Table 8. Revision History

| Revision | Date | Changes | Editor |
|---|---|---|---|
| | | | |
| | | | |

# Appendix A

Data Quality Matrix
DEQ04-LAB-0003-QAG
Version 5.0

Oregon Department of Environmental Quality
May 03, 2013
Page 1 of 2

Data Validation Criteria for Water Quality Parameters Measured in the Field

| Data Quality Level | Quality Assurance Plan | Water Temperature Methods | pH Methods | Dissolved Oxygen Methods | Turbidity Methods | Conductivity Methods | Bacteria Methods | Data Uses |
|---|---|---|---|---|---|---|---|---|
| **A** | Approved QAPP | Thermometer Accuracy checked with NIST standards<br>A ≤ ± 0.5ºC<br>P ≤ ± 0.5ºC | Calibrated pH electrode<br>A ≤ ± 0.2 S.U.<br>P ≤ ± 0.3 S.U. | Winkler titration<br>A ≤ ± 0.2 mgL<br>P ≤ ± 0.3 mgL<br>Calibrated oxygen meter/LDO<br>Accuracy:<br>≤ + 0.4 mgL<br>≥ - 0.3 mgL<br>P ≤ ± 0.3 mgL | Nephelometric Turbidity meter<br>A ≤ ± 10% Standard value<br>P ≤ ± 20% (± 3 NTU if NTU < 20) | Meter with temp correction to 25ºC<br>A ≤ ± 7% of standard value<br>P ≤ ± 10% | DEQ Approved Methods<br>Absolute difference between log-transformed values<br>P ≤ 0.6 log | Regulatory, permitting, compliance (e.g., 303(d) and 305(b) assessments) |
| **B** | Minimum Data Acceptance Criteria Met | Thermometer Accuracy checked with NIST standards<br>A ≤ ± 1.0ºC<br>P ≤ ± 2.0ºC | Any Method<br>A ≤ ± 0.5 S.U.<br>P ≤ ± 0.5 S.U. | Winkler titration or Calibrated oxygen meter/LDO<br>A ≤ ± 1 mgL<br>P ≤ ± 1 mgL | Any Method<br>A ≤ ± 30%<br>P ≤ ± 30% | Meter with temp correction to 25ºC<br>A ≤ ± 10% of standard value<br>P ≤ ± 15% | DEQ Approved Methods<br>Absolute difference between log-transformed values<br>P ≤ 0.8 log | Regulatory, permitting, compliance (e.g., 303(d) and 305(b) assessments) <u>with professional judgment</u> |
| **C** | | A > ± 1.0ºC<br>P > ± 2.0ºC | A > ± 0.5 S.U.<br>P > ± 0.5 S.U. | A > ± 2 mgL<br>P > ± 2 mgL | A > 30%<br>P > 30% | A > ± 10%<br>P > ± 15% | Absolute difference between log-transformed values<br>P > 0.8 log | **<u>Not</u> to used for 303(d) and 305(b) assessments**<br>Based on project manager judgment, the data may be **Voided** with a DQL of D. |
| **D** | | Missing or voided data | Missing or voided data | Missing or voided data | Missing or voided data | Missing or voided data | Missing or voided data | Missing or voided data |
| **E** | No QAPP provided | No precision or accuracy checks available | Any Method<br>No precision or accuracy checks available | Any Method<br>No precision or accuracy checks available | Any Method<br>No precision or accuracy checks available | Meter without routine calibration<br>No precision or accuracy checks available | Any Method<br>No precision or accuracy checks available | Informational purposes only |
| **F** | See definitions table | See definitions table | See definitions table | See definitions table | See definitions table | See definitions table | See definitions table | See definitions table |

## Notes:

***QA definitions of Data Quality Levels***

| |
|---|
| **A – Data of known quality**; meets QC limits established in a DEQ approved QAPP. |
| **B – Data of known but lesser quality**; Data may not meet established QC but is within marginal acceptance criteria; or data value may be accurate, however controls used to measure Data Quality Objective (DQO) elements failed (e.g., batch failed to meet blank QC limit); the data is generally usable for most situations or in supporting other, higher quality data. **(Equivalent to the "J" (estimated) qualifier used by EPA).**<br><br>**Note:** Statistics for **turbidity, conductivity,** and **bacteria** are concentration-dependent; thus low-concentration B level data may be considered acceptable for all uses. |
| **C – Data of unacceptable quality;** Generally due to QC failures but may be related to other known information about the sample. Data should not be used for quantitation purposes but may have qualitative use. (Equivalent to the "R" (rejected) validation qualifier used by EPA) |
| **D – No data available**; No sample collected or no reportable results. Samples are either voided or canceled. |
| **E – Data of unknown quality;** Insufficient QA/QC or other information available to make determination. Data could be acceptable; however, no evidence is available to prove either way. |
| **F – Exceptional event;** "A" quality data (data is of known quality), but not representative of sampling conditions as required by the project plan.(e.g., a continuous water quality monitor intended to collect background environmental conditions collects a sample impacted by a fire that created anomalous conditions to the |

*Data Quality Level Grading Criteria:*

**A** = Accuracy as determined by comparison with standards, e.g., during equipment calibration or pre- and post-deployment checks

**P** = Precision as determined by replicate measurements, e.g., during field duplicates, field audits, or split samples

# Appendix B:
## Results of Water Quality Monitoring from 2008 to 2020

ESA

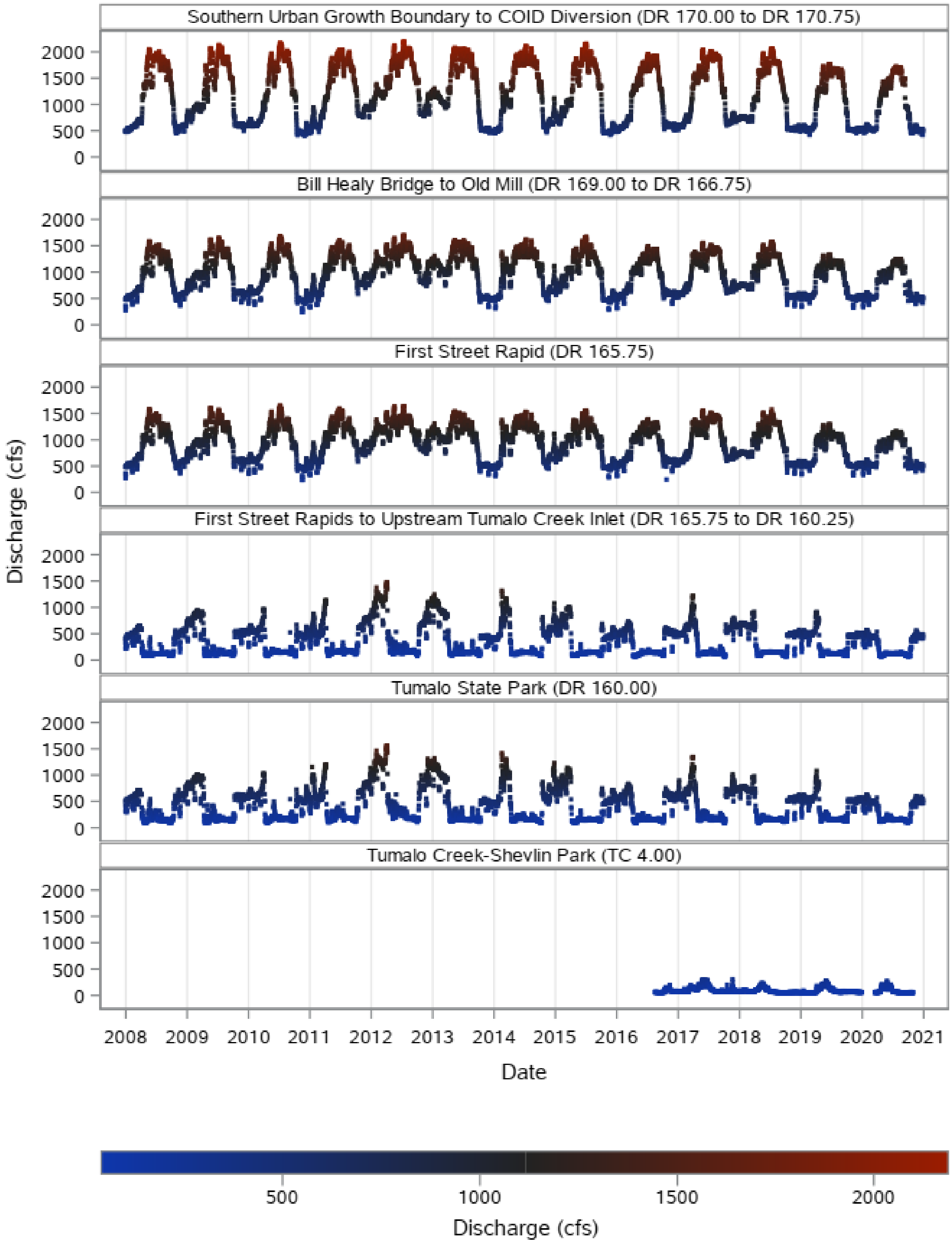


**Figure B-1. Mean daily discharge (cubic feet per second, cfs) in the Deschutes from the southern urban growth boundary (UGB) to below the northern UGB and the confluence with Tumalo Creek. Panels listed upstream to downstream (top to bottom, respectively) and includes TC 4.00 which contributes to flows at DR 160.00 – City of Bend 2008 – 2020.**

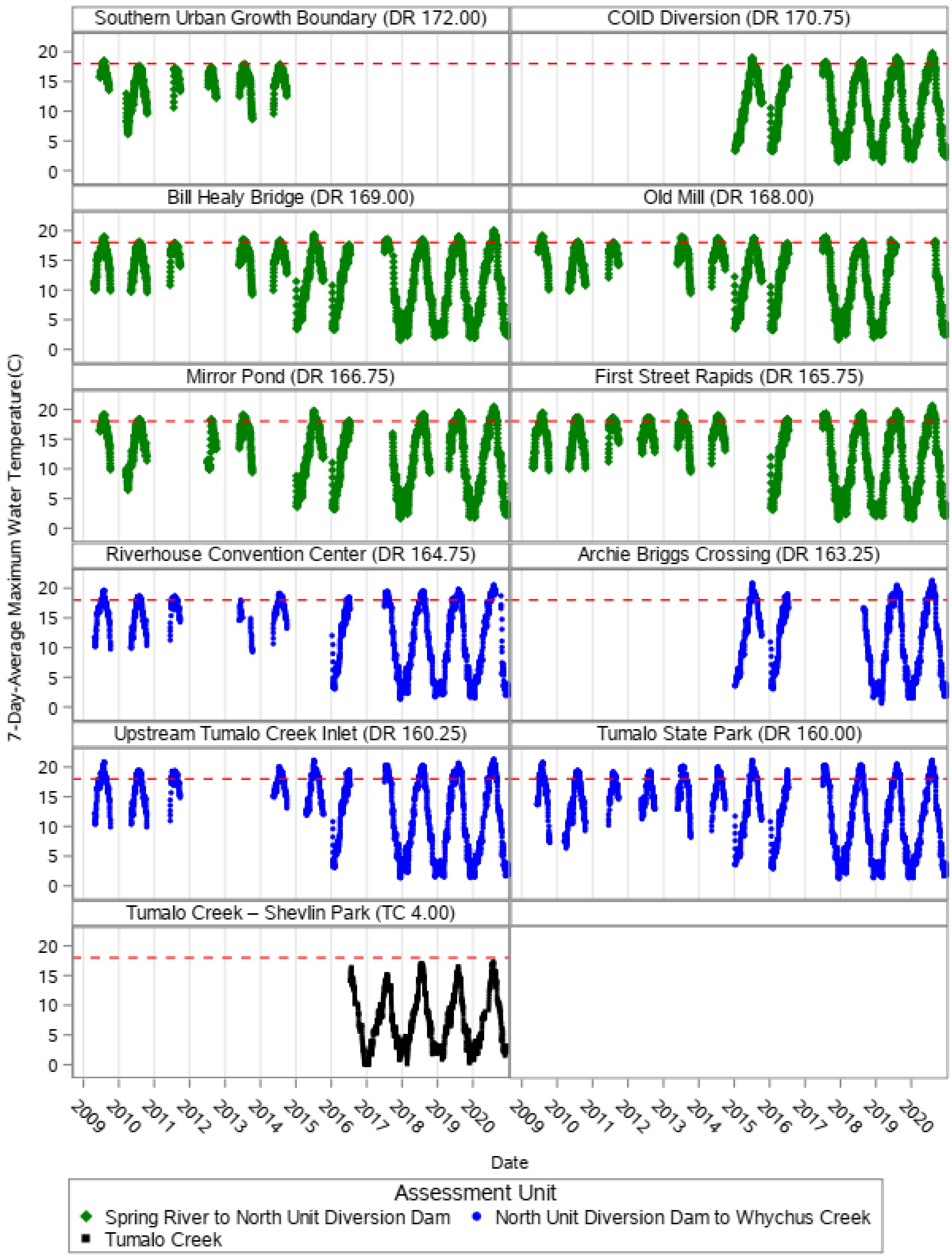


**Figure B- 2. The 7DADM water temperature for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green lines), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue lines) and Tumalo Creek AU (TC 4.00) (black line) - City of Bend 2009-2020. The dashed red line indicates the 18°C maximum temperature criteria.**

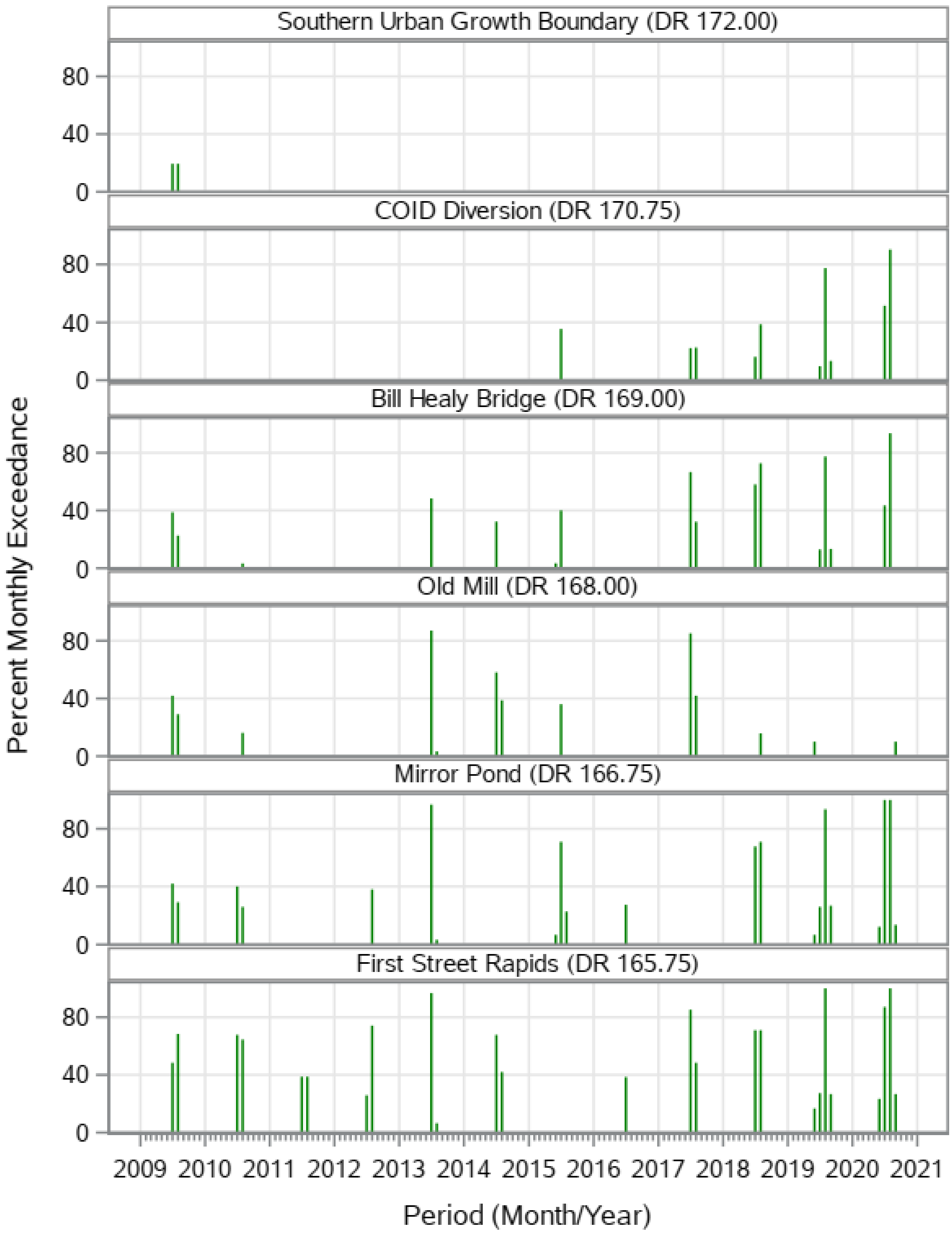


**Figure B- 3. Percent exceedances of the 7DADM water temperature criteria of 18°C by site and by month for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) - City of Bend 2009-2020.**

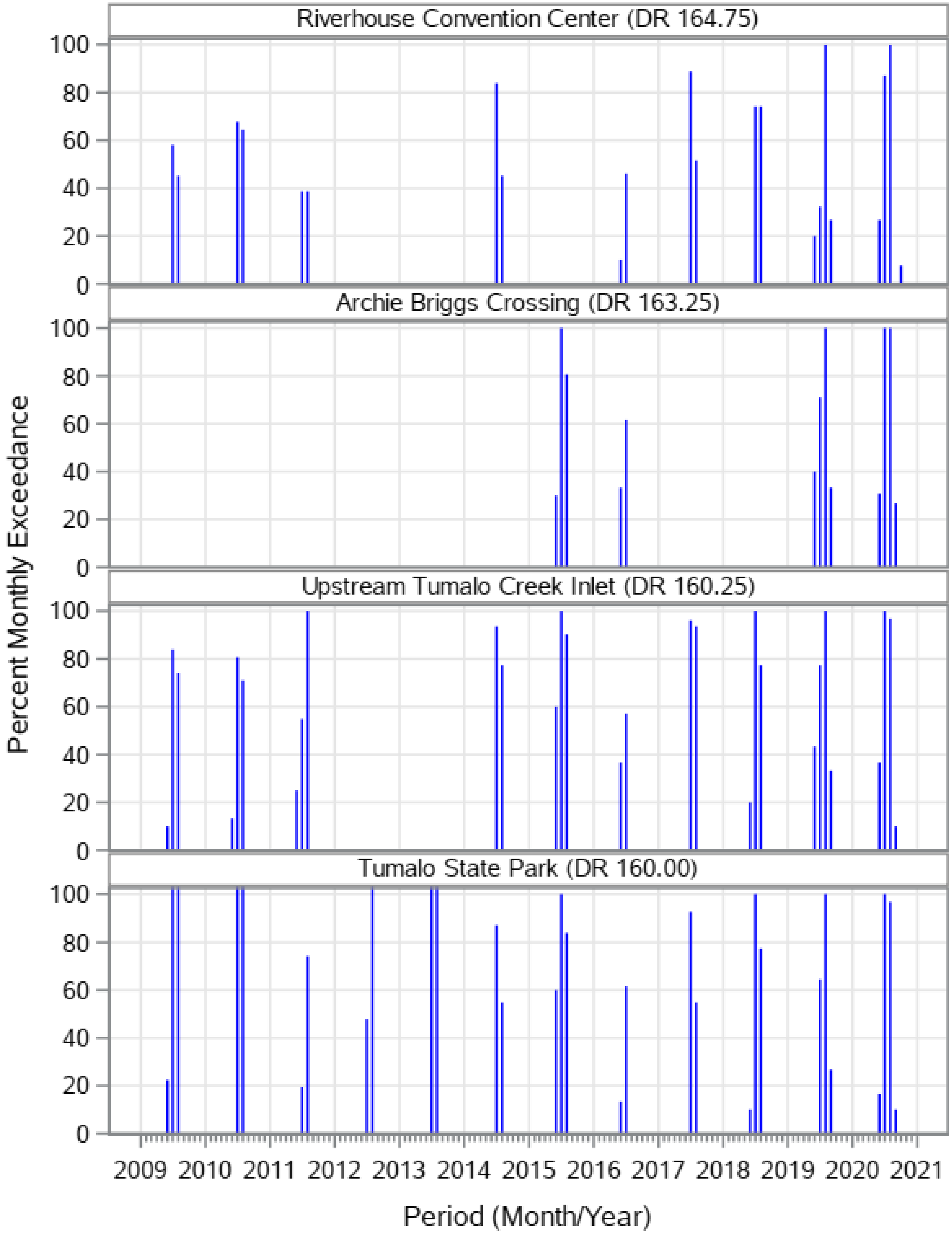


**Figure B- 4. Percent exceedances of the 7DADM water temperature criteria of 18°C by site and by month for the monitoring stations in the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) - City of Bend 2009-2020.**

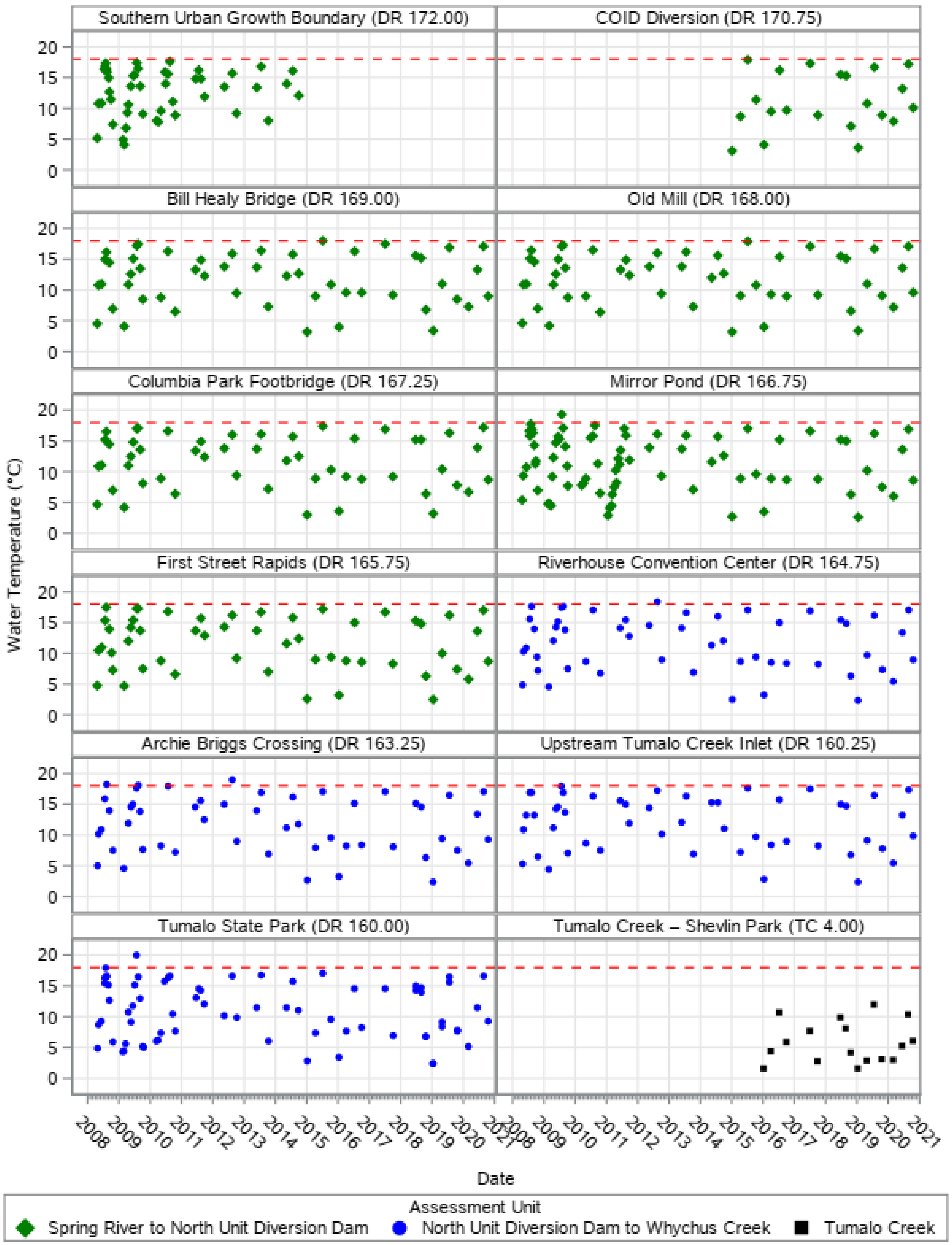


**Figure B- 5. Discrete in-situ water temperature readings for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2008-2020. The dashed red line indicates the 18°C maximum temperature criteria.**

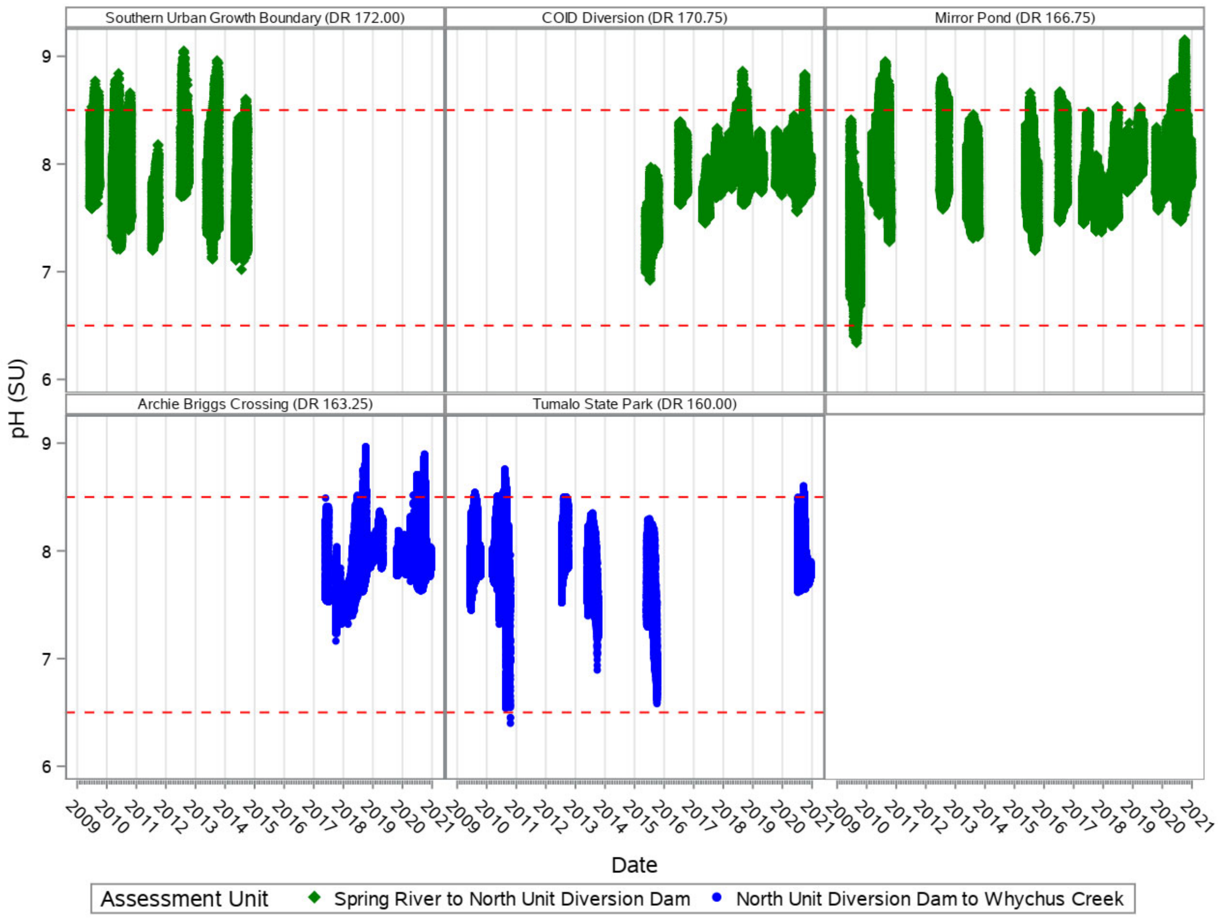


**Figure B- 6. Continuous pH measurements for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75) (green dots) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) - City of Bend 2009-2020. Dashed red lines indicate the minimum 6.5 and maximum 8.5 pH criteria**

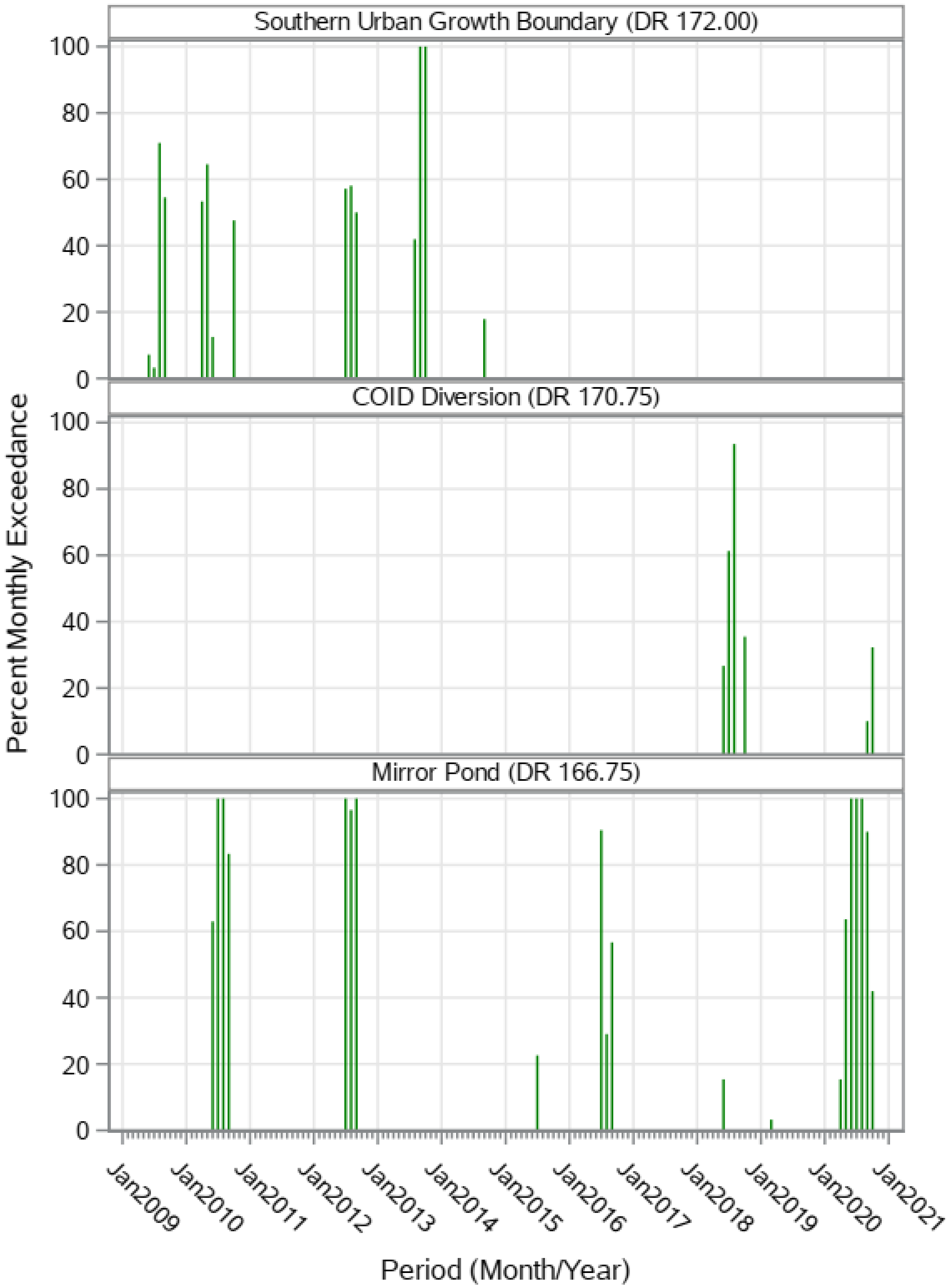


**Figure B- 7. Percent of daily maximum pH exceedances above 8.5 by site and by month for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) - City of Bend 2009-2020.**

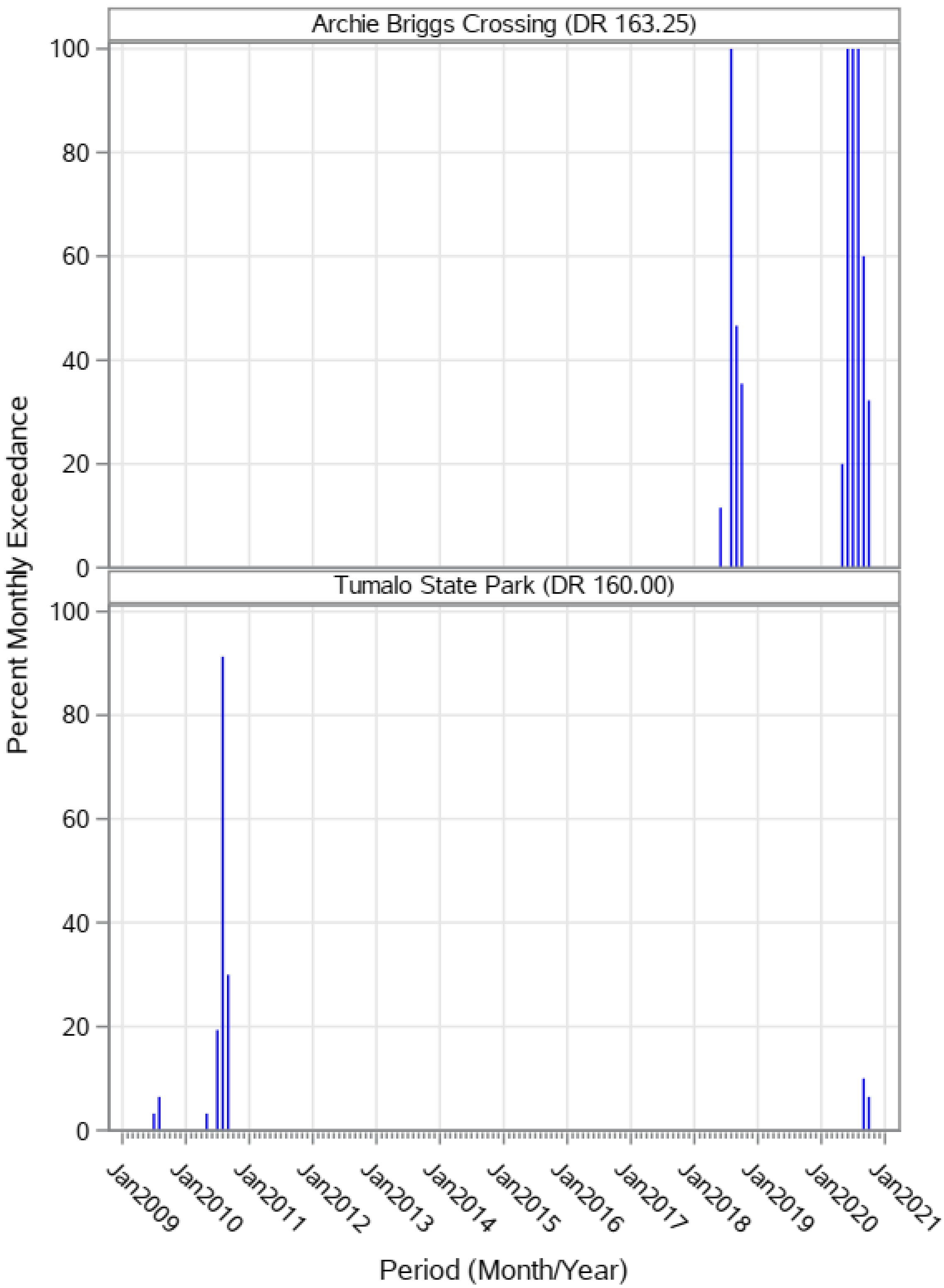


**Figure B- 8. Percent of daily maximum pH exceedances above 8.5 by month for the monitoring stations in the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) - City of Bend 2009-2020**

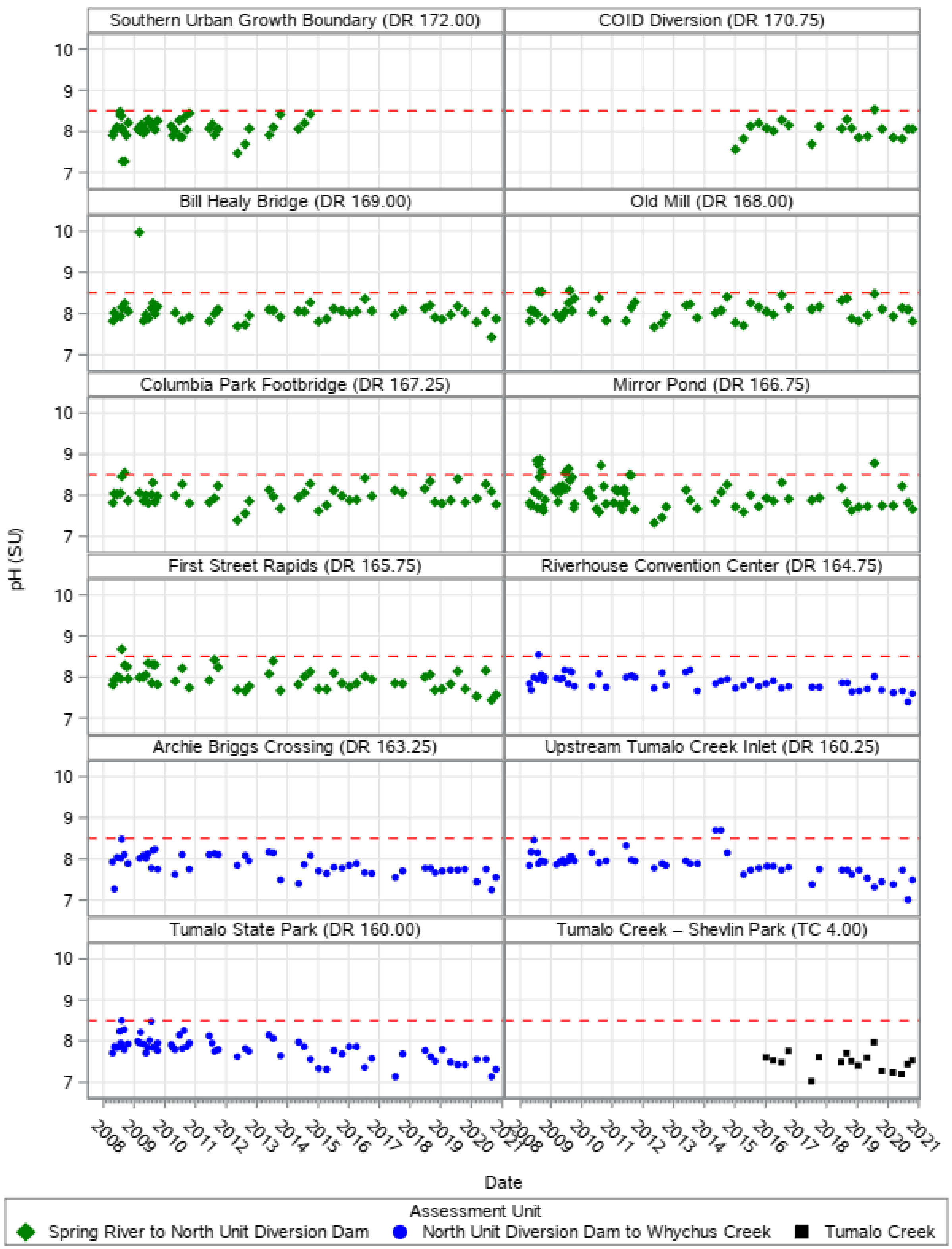


**Figure B- 9. Discrete in-situ pH measurements for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2008-2020. Dashed red lines indicate the minimum 6.5 and maximum 8.5 pH criteria.**

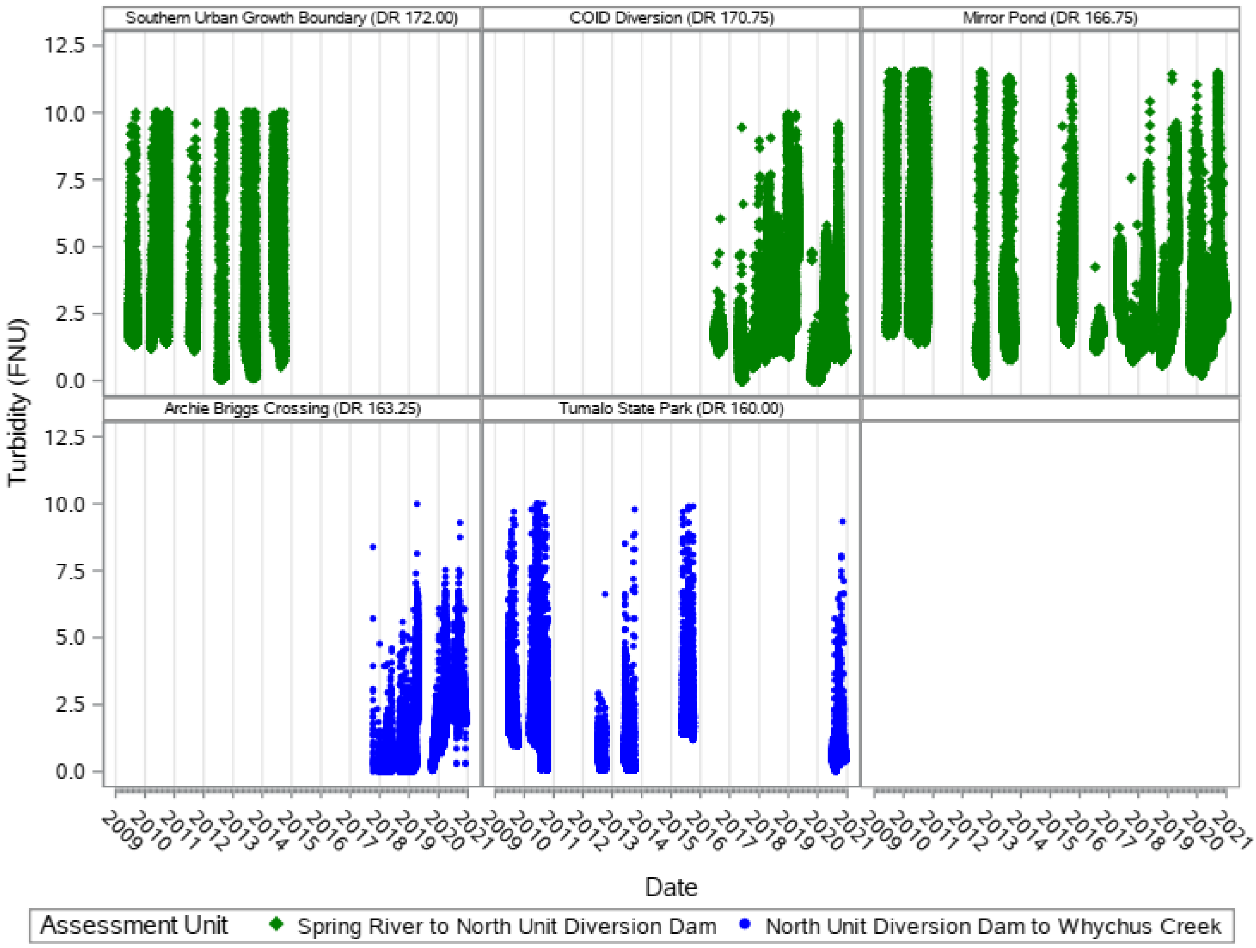


**Figure B- 10. Continuous turbidity measurements for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) - City of Bend 2009-2020.**

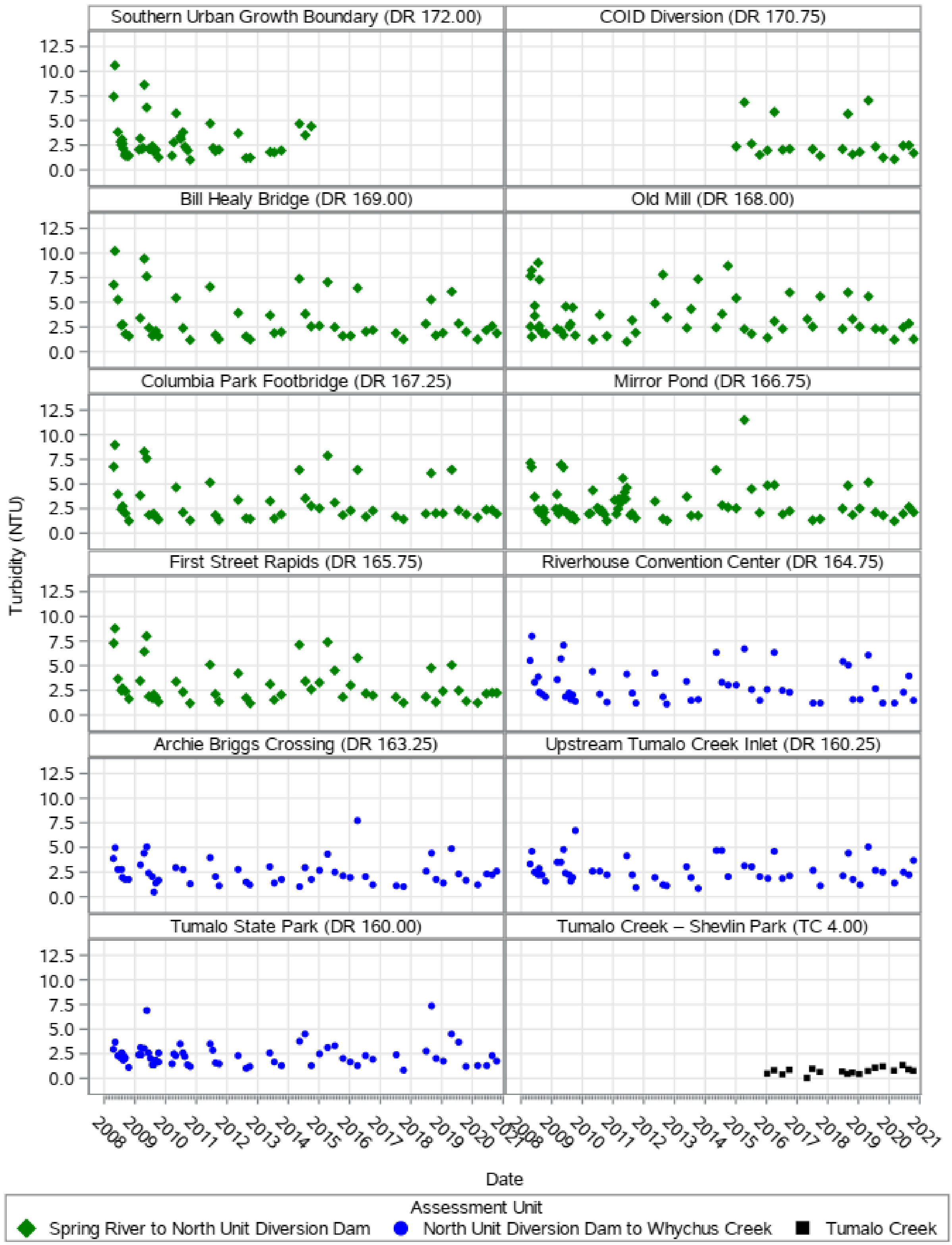


**Figure B- 11. Results of turbidity measurements from samples collected at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2008-2020.**

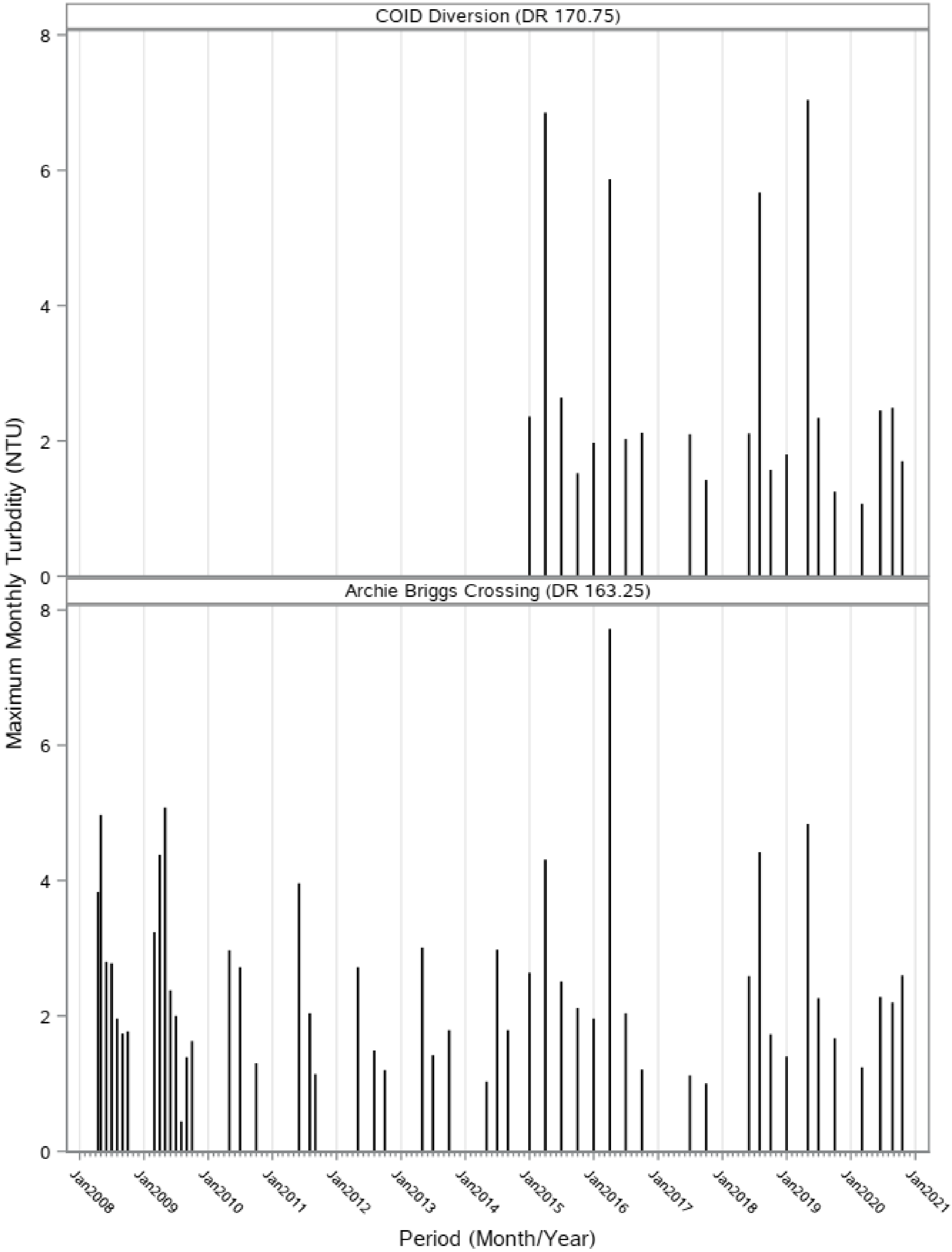


**Figure A- 12. Maximum turbidity measurements by month for the most upstream site in the Deschutes River (DR 170.75) that is currently monitored (top panel) and the most downstream site (DR 163.25) that has been monitored since 2019 (bottom panel) - City of Bend 2008-2020.**

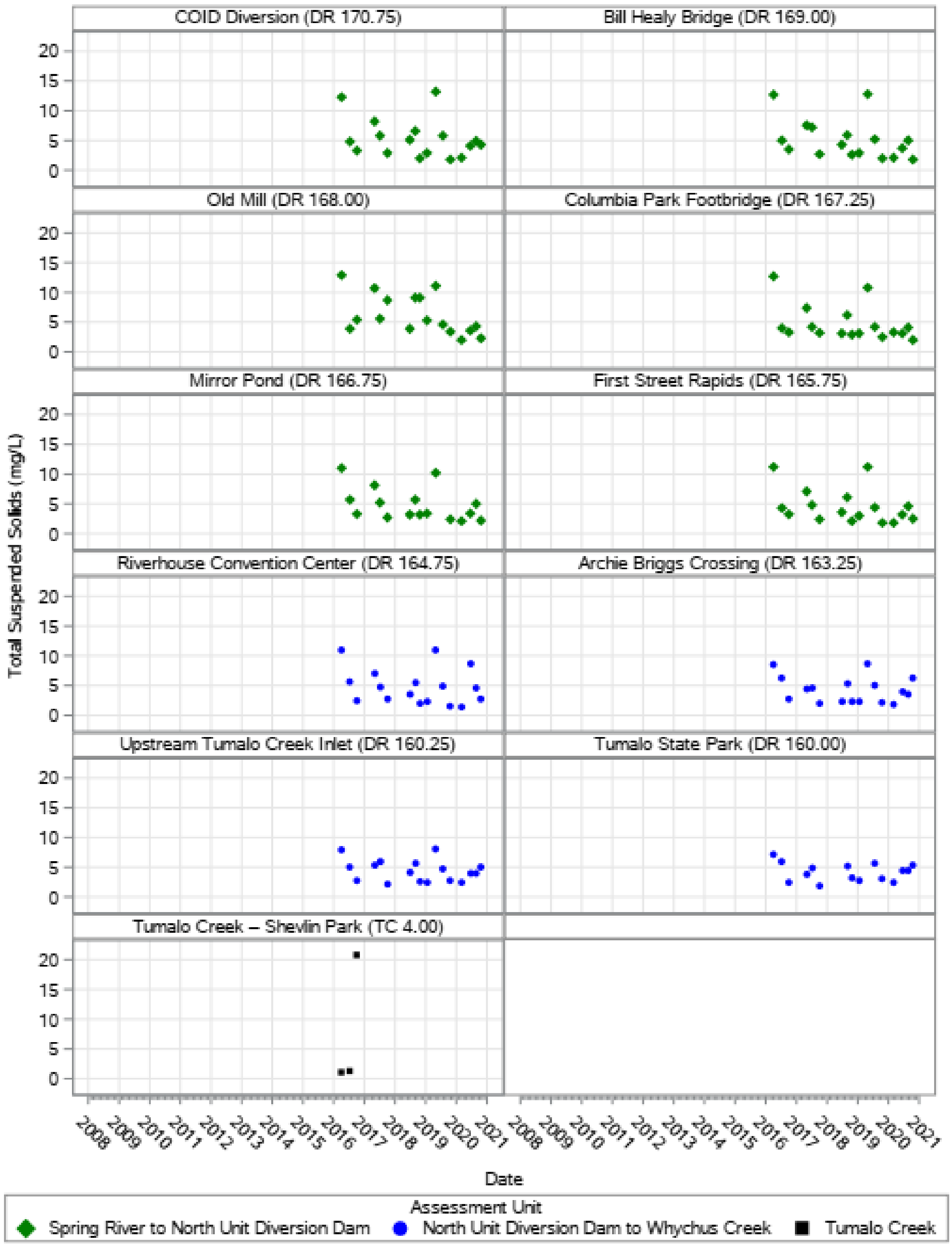


**Figure B- 13. Results of total suspended solids measurements from samples collected at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2008-2020.**

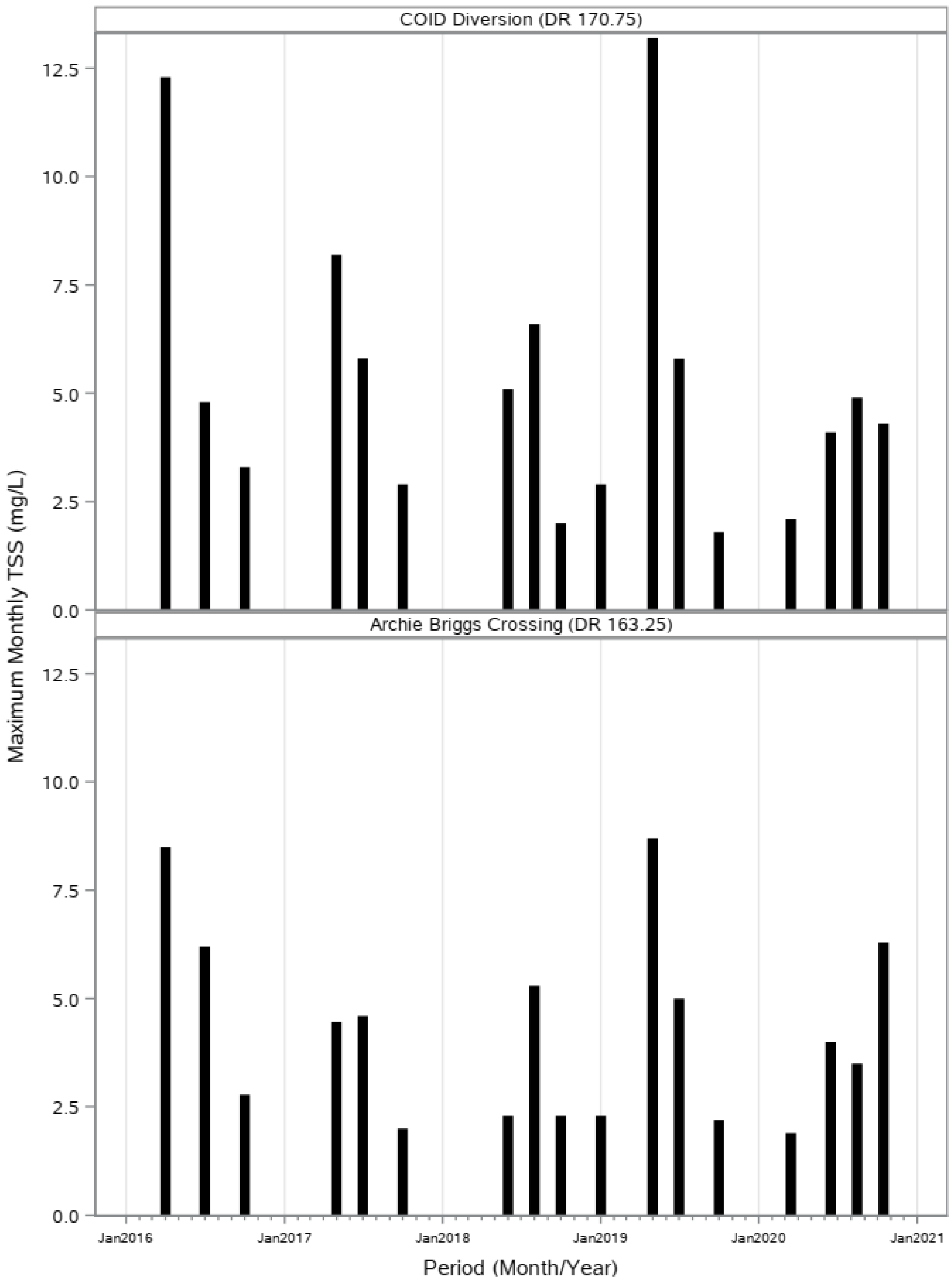


**Figure B- 14. Maximum total suspended solids (TSS) measurements by month for the most upstream site in the Deschutes River (DR 170.75) that is currently monitored (top panel) and the most downstream site that has been monitored since 2019 (bottom panel) - City of Bend 2016-2020**

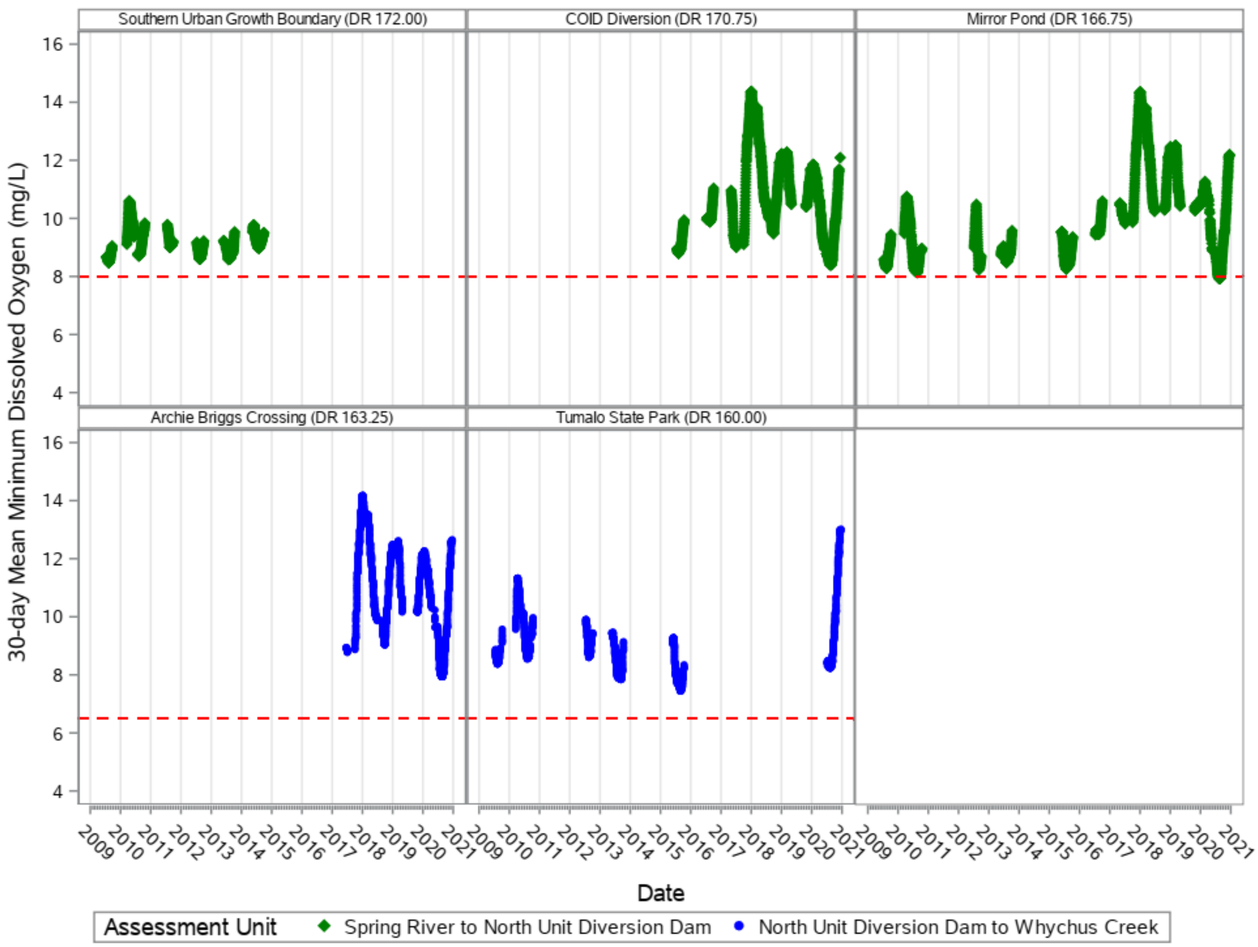


**Figure B- 15. The 30-day mean minimum dissolved oxygen concentrations for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green lines) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue lines) - City of Bend 2009-2020. The red line indicates the DEQ 8.0 mg/L year round non-spawning for the Spring River to North Unit Diversion Dam AU (top panels) and the 6.5 mg/L year round non-spawning criteria for the North Unit Diversion Dam to Whychus Creek AU.**

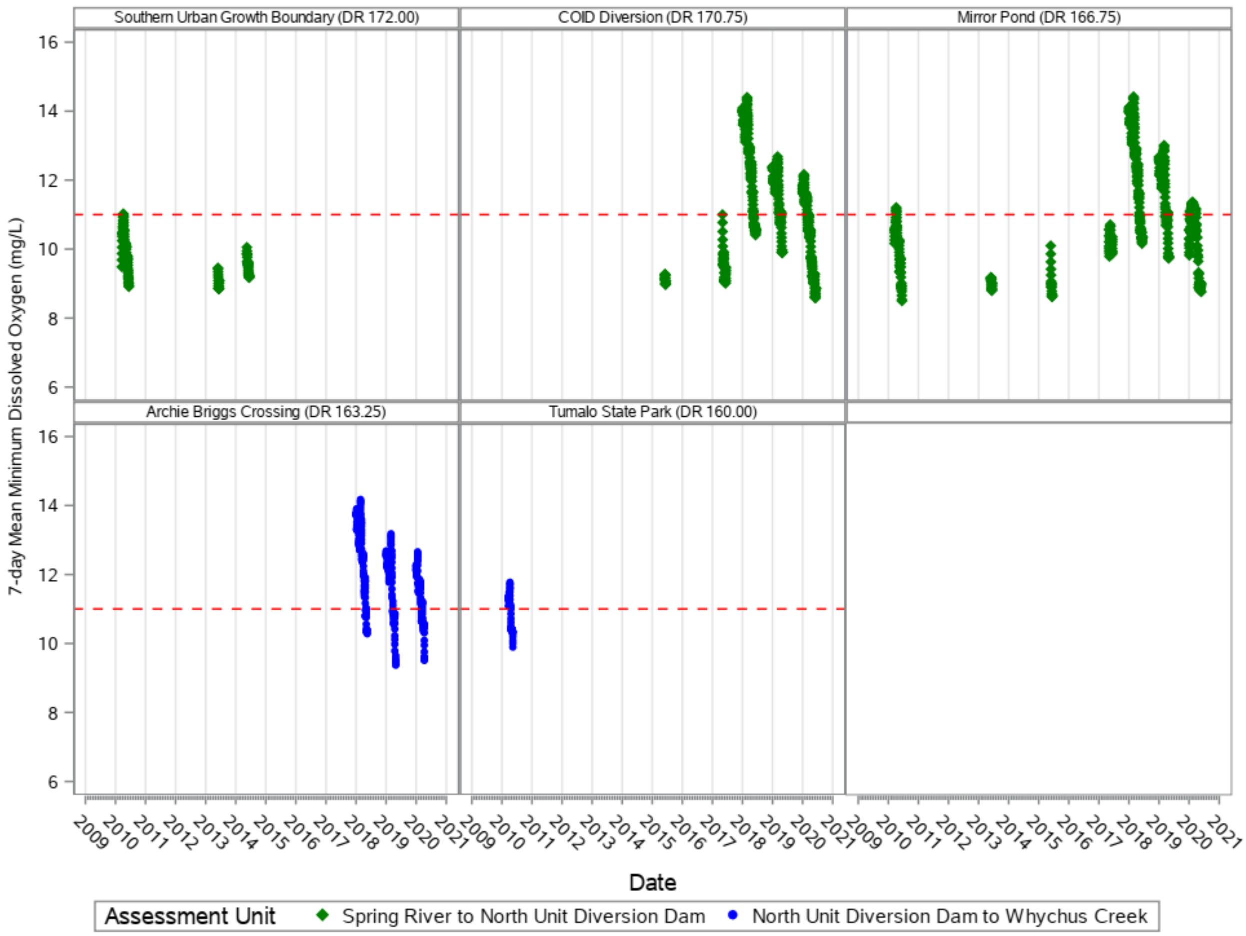


**Figure B- 16. The seven-day mean minimum dissolved oxygen concentrations for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (left and middle in green) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (right panel in blue) - City of Bend 2009-2020. The red line indicates the DEQ 11.0 mg/L spawning criteria for the Spring River to North Unit Diversion Dam AU (January 1 to June 16)) and the North Unit Diversion Dam to Whychus Creek AU (January 1 to May 15).**

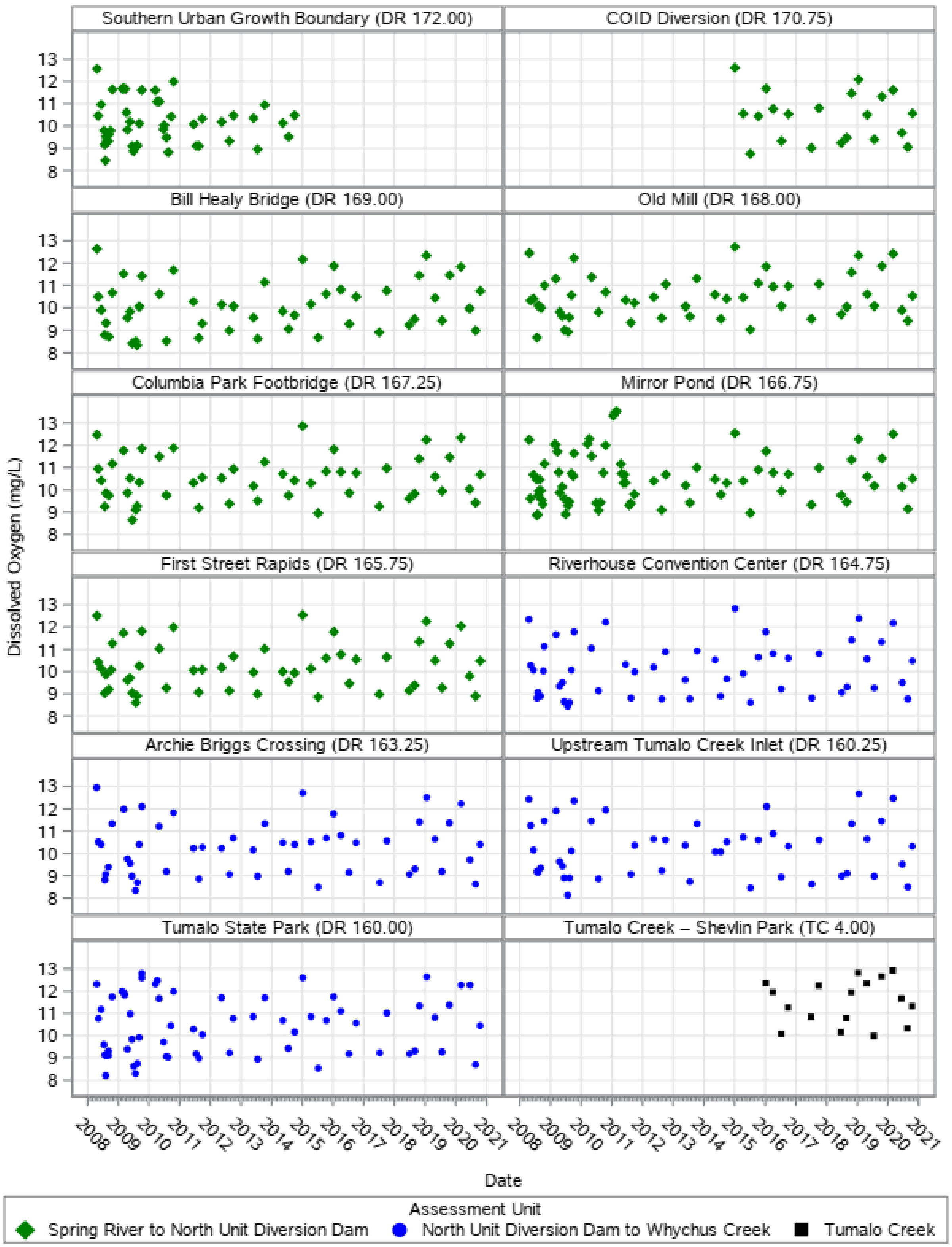


**Figure B- 17. Discrete in-situ dissolved oxygen measurements collected at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2009-2020.**

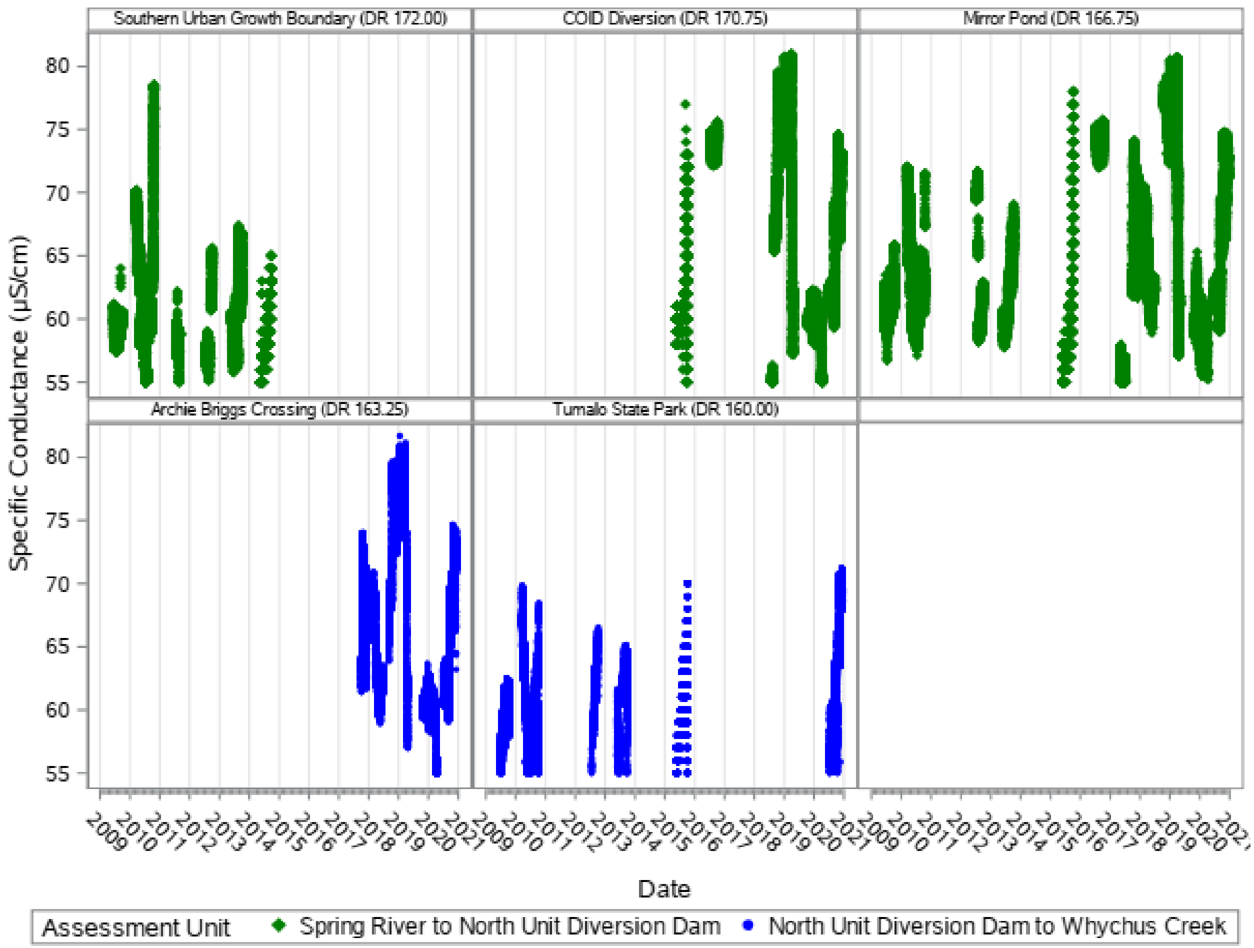


**Figure B- 18. Continuous specific conductance measurements for the monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots) and the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots) - City of Bend 2009-2020.**

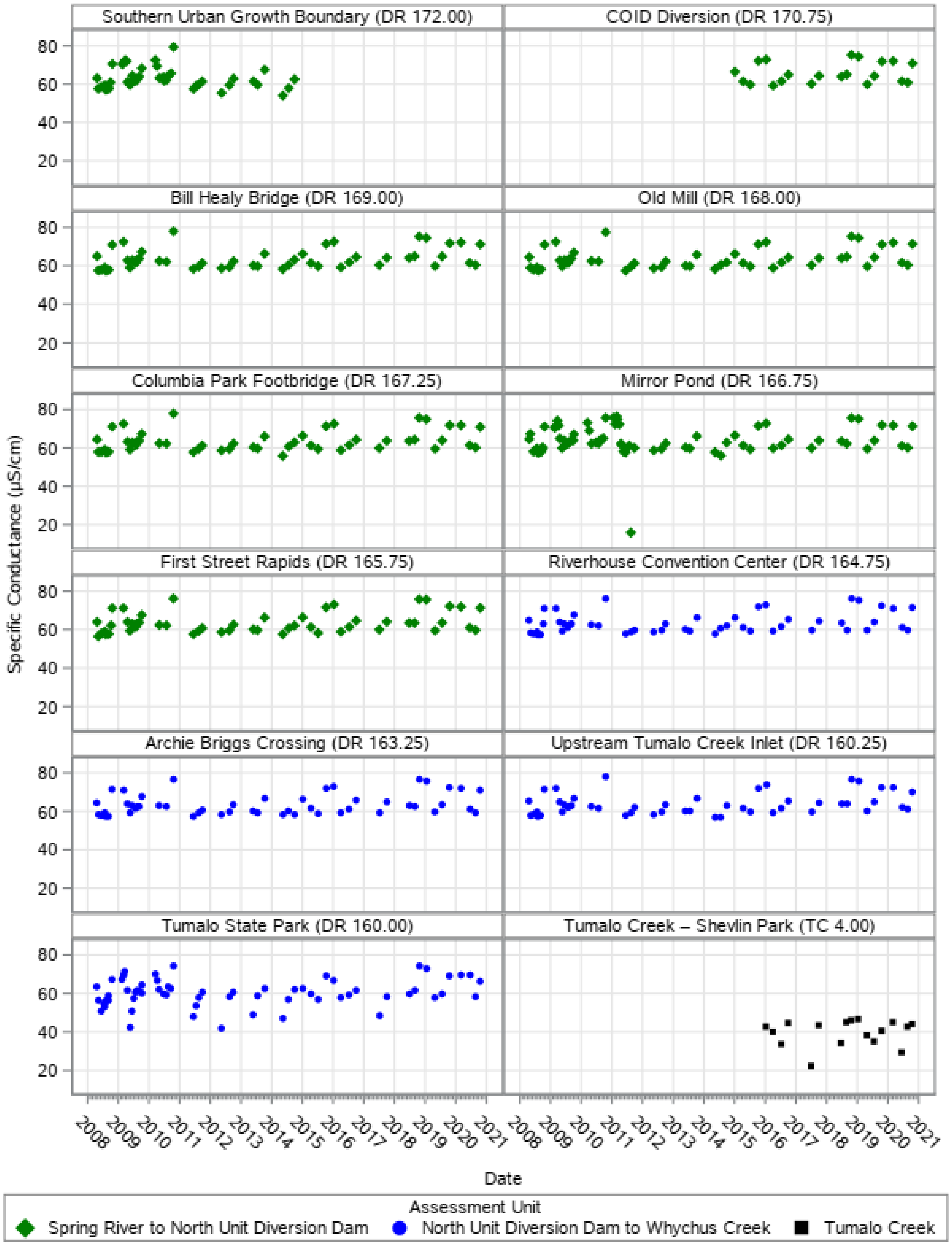


**Figure B- 19. Discrete in-situ specific conductance concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots) - City of Bend 2008-2020.**

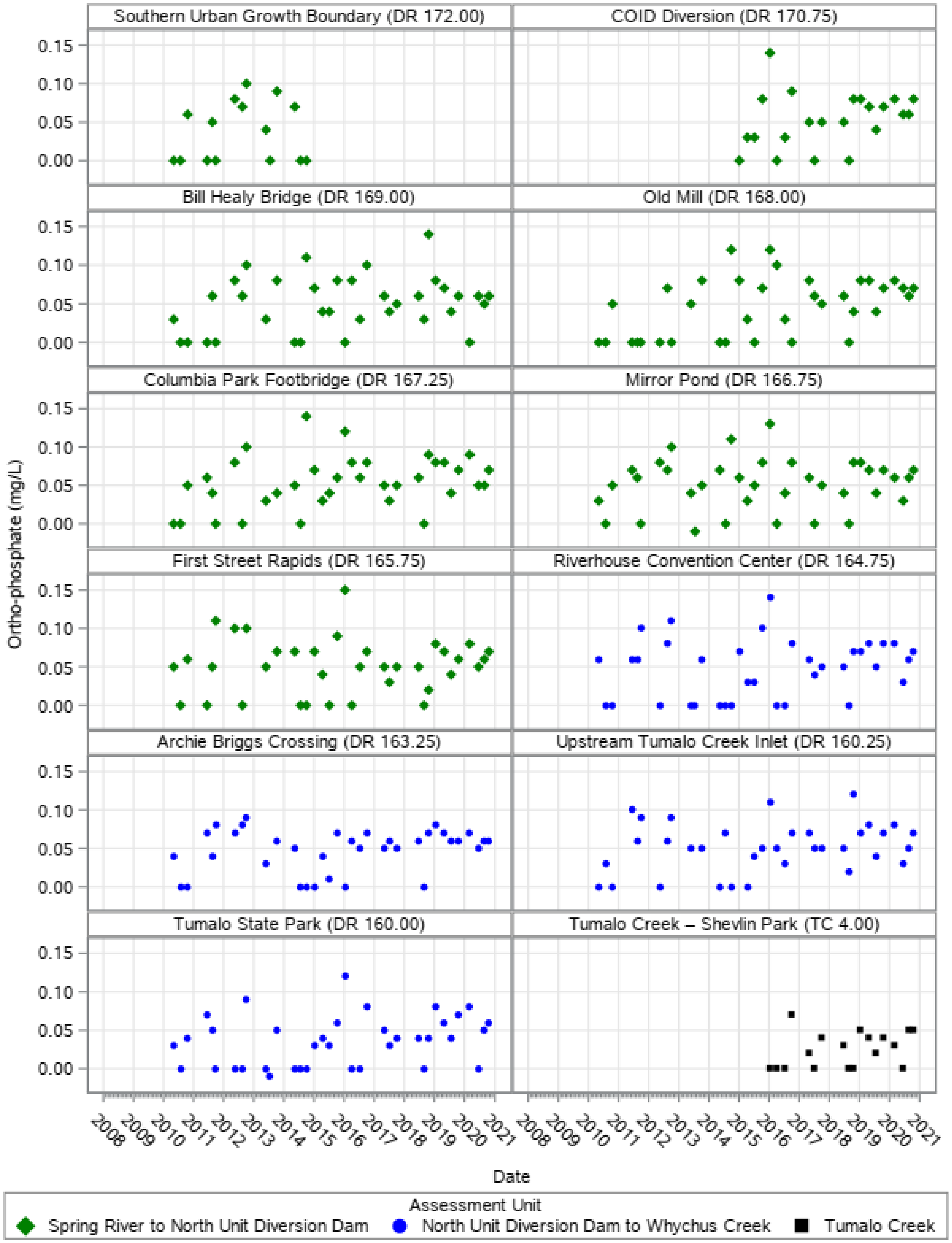


**Figure B- 20. Deschutes River orthophosphate concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75) (green dots), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00) (blue dots), and Tumalo Creek AU (TC 4.00) (black dots)- City of Bend 2008 to 2020.**

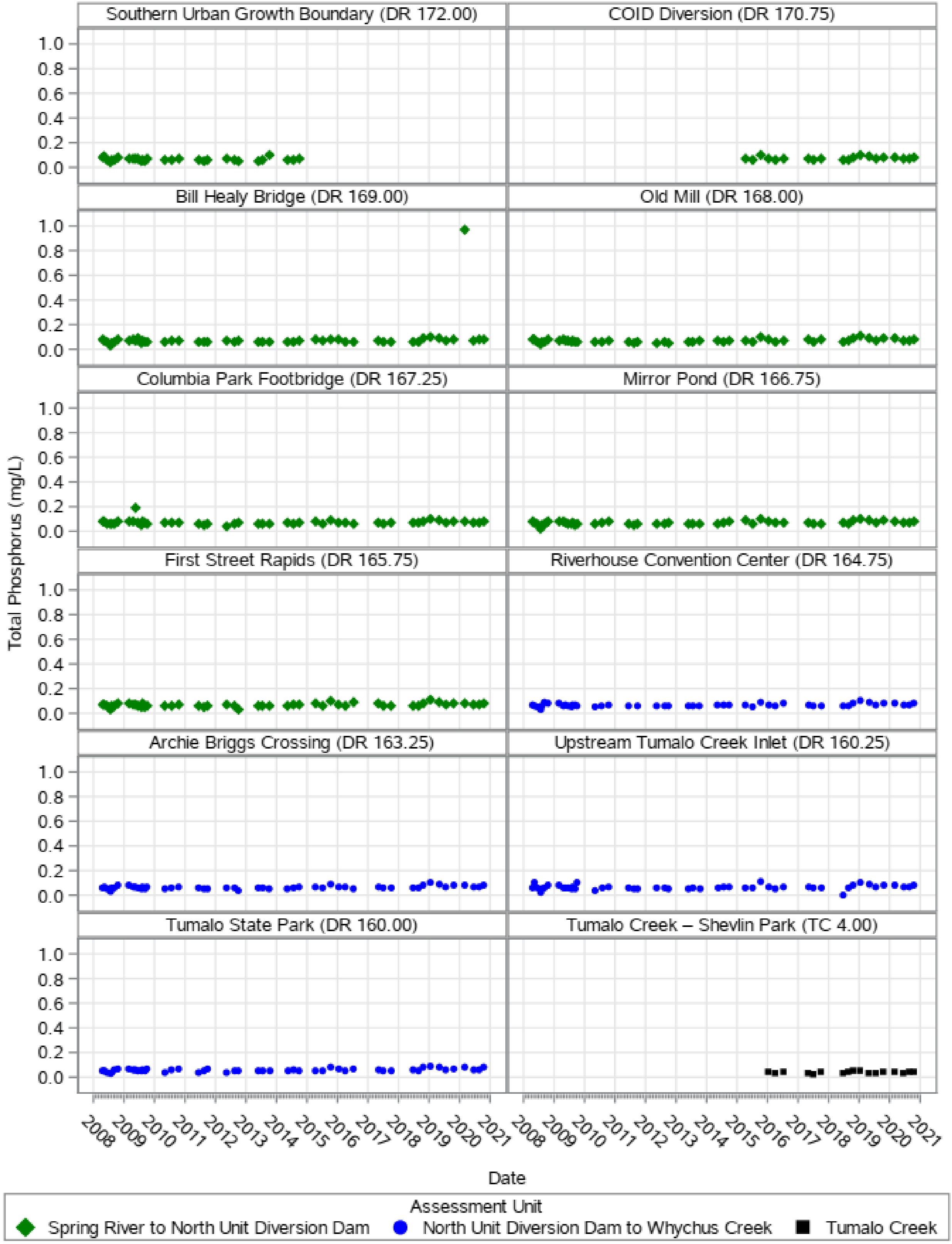


**Figure B- 21. Deschutes River total phosphorous concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2008 to 2020.**

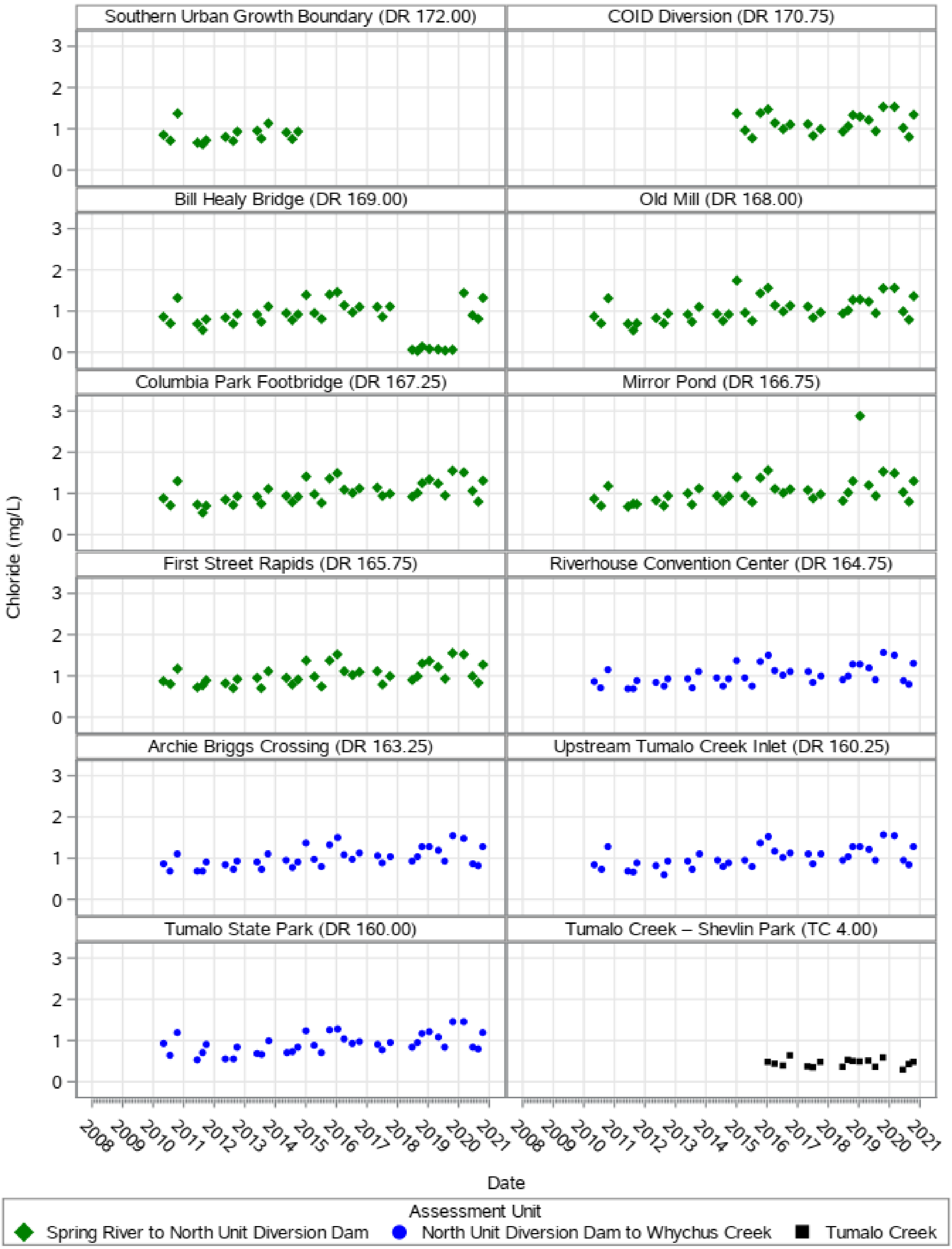


**Figure B- 22. Deschutes River chloride concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2008 to 2020.**

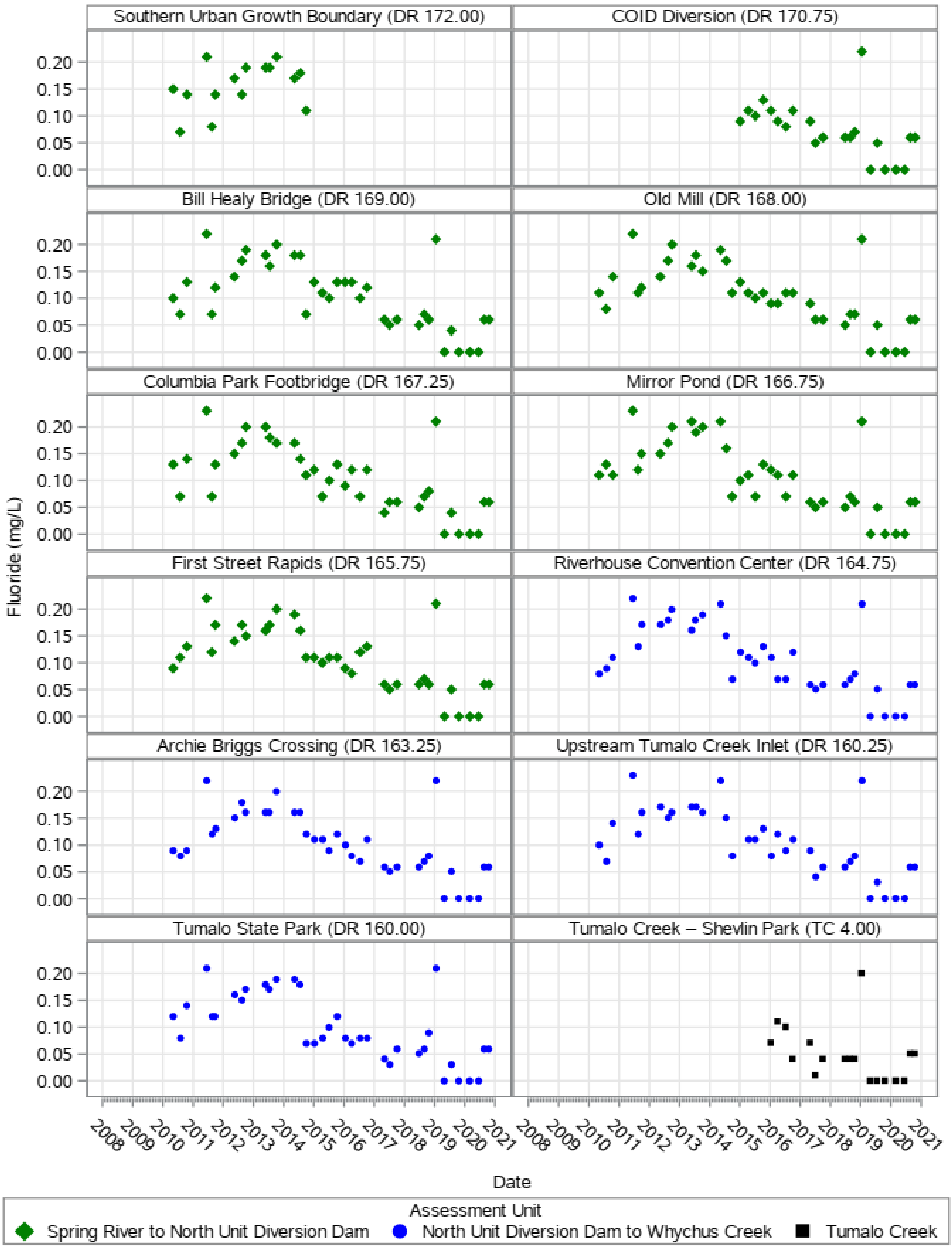


**Figure B- 23. Deschutes River fluoride concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2008 to 2020.**

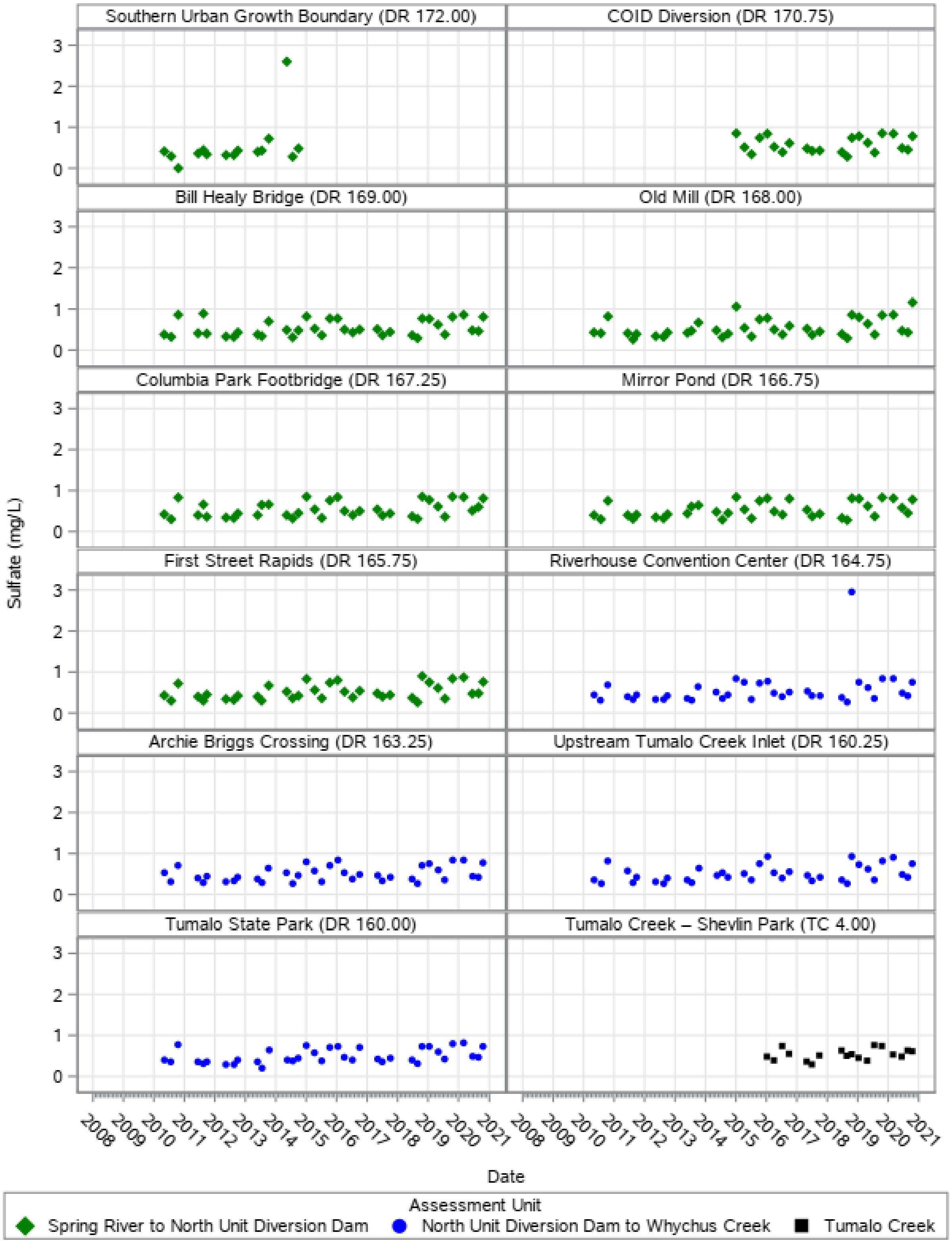


**Figure B- 24. Deschutes River sulfate concentrations at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2008 to 2020.**

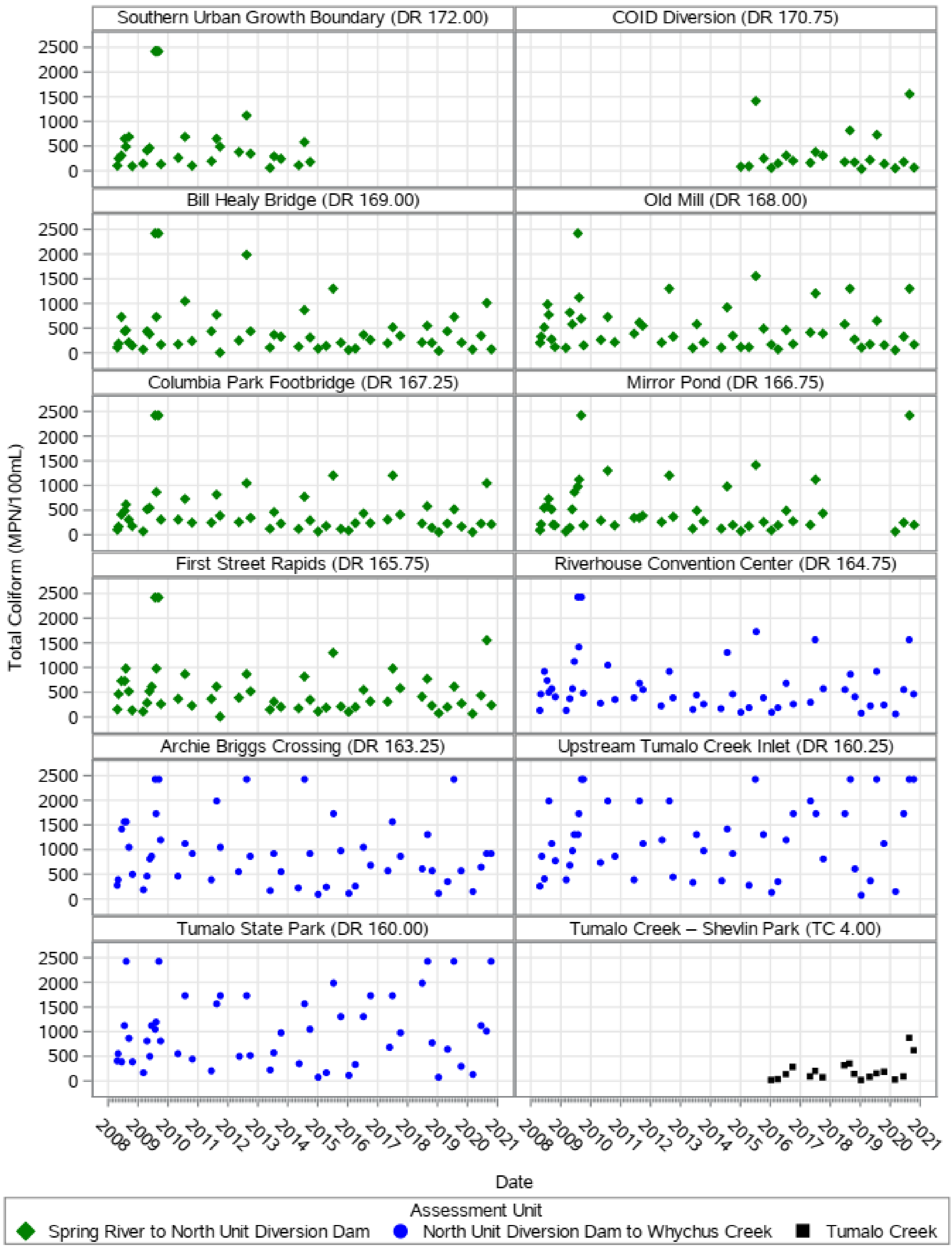


**Figure B- 25. Deschutes River total coliform levels (most probable number, MPN per 100 mL) at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR 166.75), the**

**North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2008 to 2020.**

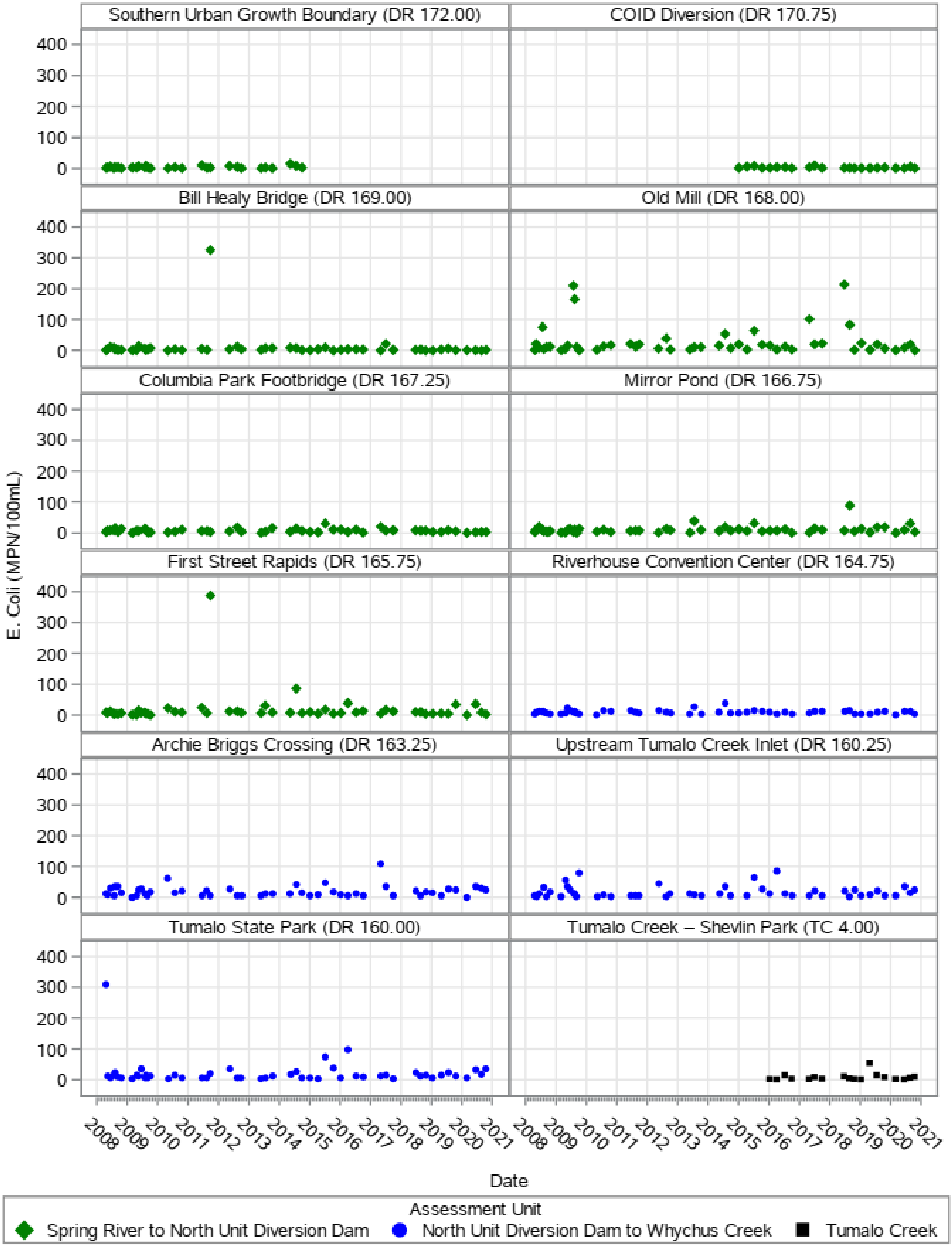

**Figure B- 26. Deschutes River *E. coli* levels (most probably number, MPN per 100 mL) at monitoring stations in the Spring River to North Unit Diversion Dam Assessment Unit (AU) (DR 170.75 to DR166.75), the North Unit Diversion Dam to Whychus Creek AU (DR 163.25 to 160.00), and Tumalo Creek AU (TC 4.00) - City of Bend 2008 to 2020.**