Technical Memorandum

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To: Demian Ebert, PacifiCorp

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Re: Estimated correction of 2019 dissolved oxygen sonde data from Klamath River below Iron Gate (KRBI)

1. Introduction

During review of the 2019 "Klamath River below Iron Gate Dam" (KRBI) sonde data, an inconsistency in calibration protocols was identified. At times, the KRBI sonde was incorrectly calibrated with a barometric pressure of 760 millimeters of mercury (mmHg), the default value representing pressure at sea level within the sonde software. Local barometric pressure below Iron Gate dam is approximately 704 mmHg, but varies slightly depending on weather conditions (e.g., high pressure or low pressure systems). The incorrect calibrations produce incorrect dissolved oxygen (DO) concentrations. An estimation for correcting these data is provided in this memorandum, wherein corrected data are compared to reported data from this sonde. Corrected data are compared to a nearby sonde operated by the Karuk Tribe that, while located at a different location, provides an approximate analog for evaluation.

2. Background

The YSI EXO sonde deployed at KRBI has an optical DO probe that uses the Stern-Volmer equation to quantify DO percent saturation based on the quenching effect of oxygen on lifetime of luminescence within probe (YSI 2009, 2017). A simplified, linear version of this equation, shown in Equation 1, is presented in the YSI Dissolved Oxygen Handbook with a note that the true relationship has a non-linearity that becomes more pronounced at higher oxygen concentrations (YSI 2009). YSI employs a 3rd order polynomial to correct for this non-linearity. Use of the non-linear Stern-Volmer equation to calibrate similar optical DO sensors is described in detail in McNeil and D'Asaro (2014), but was not investigated further for this effort because it was not possible to acquire coefficients from the DO sensor cap used in 2019 and unknowns related to YSI proprietary information (e.g., YSI's non-linear equation).

Equation 1

$$I_0/I = 1 + k_q * t_0 * pO_2$$

where:

I_o = lifetime of luminescence without the quenching molecule (O_2)
I = observed lifetime of luminescence
k_q = quencher rate coefficient
t_o = luminescence lifetime of the chemical to be quenched
pO_2 = pressure of oxygen

3. Estimation of Correct Dissolved Oxygen

When a YSI DO sensor is calibrated using an incorrect barometric pressure, reported DO percent saturation and concentration will be incorrect throughout the subsequent deployment. Based on review of calibration worksheets for 2019 KRBI sonde data, an incorrect local barometric pressure of 760 mmHg was used in calibration over two deployment periods: April 5 18:15 through May 4 07:45 and June 23 17:06 through December 31 23:45. Corrections were made to the 15-minute reported data during these periods.

YSI technical support (personal communication, August 12, 2020 and August 20, 2020) has provided an estimation for correcting these data. Corrected DO percent saturation may be estimated from reported percent saturation using Equation 2, and corrected oxygen concentration (in milligrams per liter; mg/L) is then recalculated from these estimated percent saturation values.

Per communications with YSI technical support (personal communication, August 24, 2020), this correction should be considered an estimation. This correction is considered an estimation because it may include changes in DO membrane diffusion rates with different oxygen partial pressures and/or the non-linearity of luminescence response of the probe over the range of DO concentrations experienced in the river.

Equation 2

$$DO_{\%sat} = DO_{\%sat\_reported} * BP_{correct}/BP_{incorrect}$$

where:

$DO_{\%sat}$ = corrected DO % saturation
$DO_{\%sat\_reported}$ = DO % saturation reported by sonde ("ODO % sat")
$BP_{correct}$ = correct local barometric pressure for calibration
$BP_{incorrect}$ = incorrect barometric pressure used in calibration

Corrected DO percent saturation values were estimated using Equation 2 and local barometric pressures at the time of calibration (Table 1).

Table 1. Correct local barometric pressure for calibration and incorrect barometric pressure used during calibration for eight calibration dates in 2019.

Date	$BP_{correct}$ (mbar)	$BP_{incorrect}$ (mbar)
4/5/2019	934	1013
6/23/2019	938	1013
7/22/2019	938	1013
8/19/2019	936	1013
9/23/2019	944	1013
10/20/2019	943	1013
11/9/2019	946	1013
12/8/2019	938	1013

Corrected DO concentrations (mg/L) were then calculated as the product of corrected percent saturation and dissolved oxygen saturation concentrations taken from United States Geological Survey (USGS) DO saturation tables at a barometric pressure of 760 mmHg (1013 mbar) using sonde water temperatures and a constant specific conductance of 150 µS/cm (USGS 2020).

Site-specific, or "local," DO percent saturation was calculated from corrected DO concentrations and dissolved oxygen saturation concentrations taken from USGS DO saturation tables at local barometric pressures at the time of calibration (Table 1) using sonde water temperatures and a constant specific conductance of 150 µS/cm (Equation 3).

Equation 3

$$DO_{\%sat\_local} = \frac{[DO]}{[DO]_{sat}} * 100$$

where:

$DO_{\%sat\_local}$ = DO % saturation at KRBI site elevation
$[DO]$ = corrected DO concentration
$[DO]_{sat}$ = DO saturation concentration at $BP_{correct}$, 150 µS/cm, and sonde water temperature (from USGS DO saturation tables)

Corrections are well within the range that might be expected over an approximate 2,000-foot elevation change and water temperatures that range from less than 10 degrees Celsius (˚C) to over 20˚C. Using the USGS DO tables, an average reported water temperature over all corrected DO data (15.1˚C), and a constant specific conductance of 150 µS/cm, the difference between saturated DO concentrations at sea level and saturated DO concentrations at the Iron Gate site can be calculated to be approximately -0.7 mg/L. Corrections are closely distributed around this average difference, ranging from -1.0 mg/L to 0.1 mg/L (-8.4% to 1.7%) (Figure 1 and Figure 2) and all common measures of central tendency for this distribution are within 0.1 mg/L of this average difference. The mean, mode, and median values of corrections (count = 21,064) are -0.7, -0.6, and -0.6 mg/L, respectively, and roughly 90% of corrections are within ± 0.3 mg/L of the mean.

Much of the variation evident in these differences is assumed attributable to changes in temperature, typical "noise" in the instrument observations, and the coarseness of USGS DO tables (presented to a single decimal place). As expected from the change in elevation, corrected DO concentrations are typically less than incorrect concentrations with few exceptions.

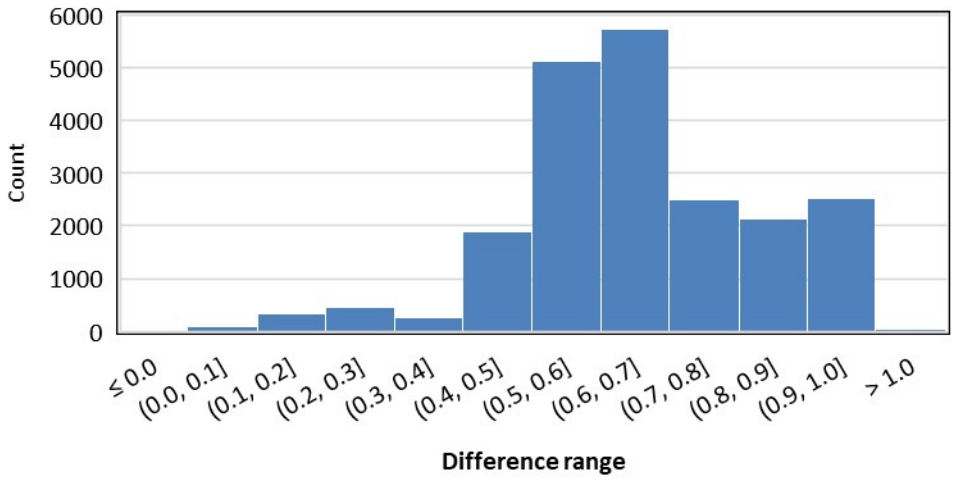

Figure 1. Histogram of corrections to KRBI sonde dissolved oxygen concentrations calculated as $[DO]_{correct}$ - $[DO]_{incorrect}$ (count = 21,064).

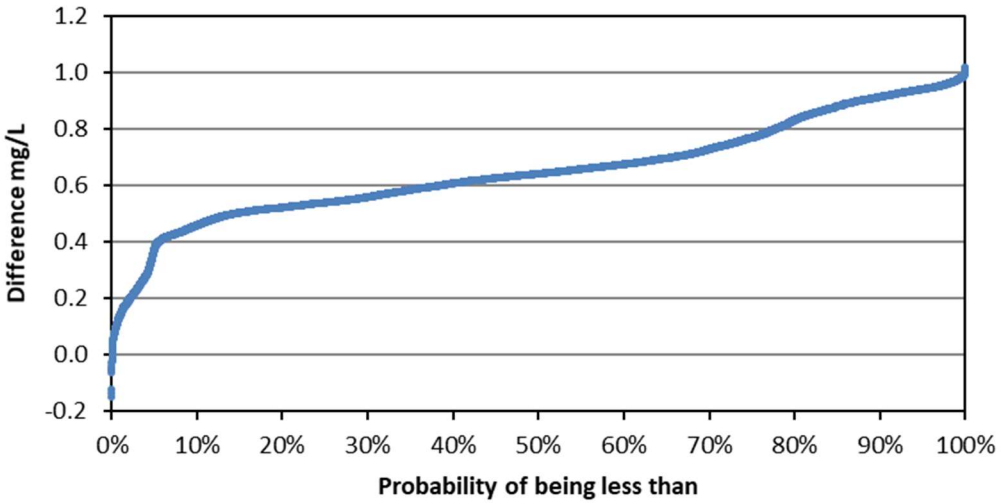

Figure 2. Probability plot of corrections to KRBI sonde dissolved oxygen concentrations calculated as $[DO]_{correct}$ - $[DO]_{incorrect}$.

4. Data Comparisons

Differences between corrected and uncorrected DO percent saturation and concentration are evident only for periods during which corrections were made (early April through early May and late June through the end of the year) with corrected data being lower than uncorrected data during these periods (Figure 3 and Figure 4, respectively).

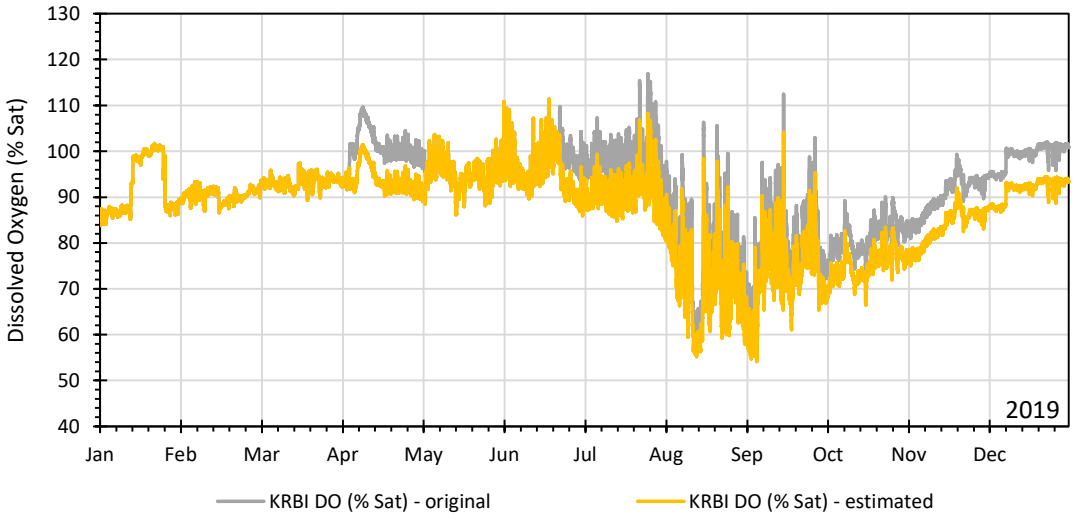

Figure 3. Original and corrected (estimated) dissolved oxygen percent saturation from the PacifiCorp Klamath River below Iron Gate (KRBI) sonde. Note that data from January through early April and early May through late June did not require correction.

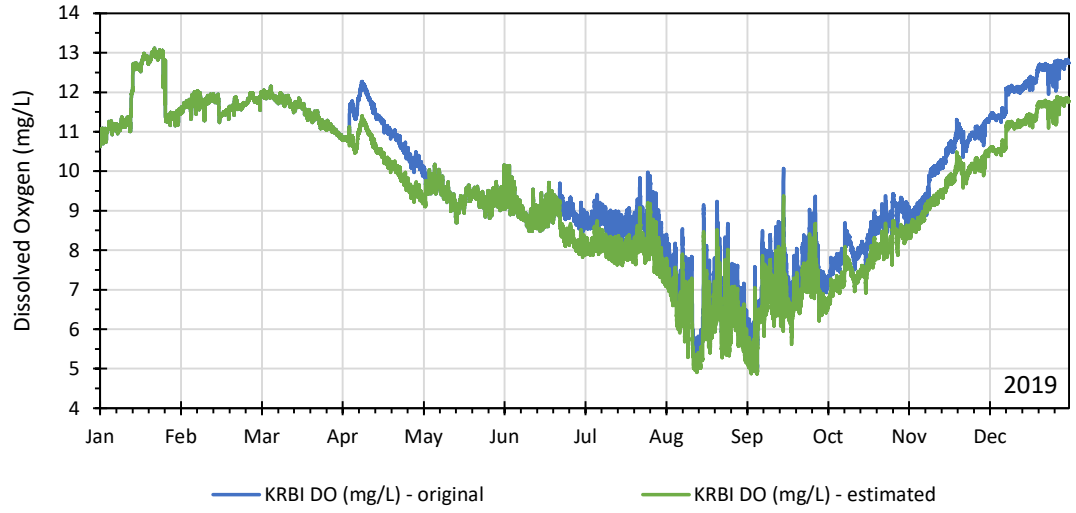

Figure 4. Original and corrected (estimated) dissolved oxygen concentrations from the PacifiCorp Klamath River below Iron Gate (KRBI) sonde. Note that data from January through early April and early May through late June did not require correction.

Original and corrected DO concentrations from the KRBI site are qualitatively compared to DO concentrations from the Karuk sonde site, co-located with the USGS streamflow gage approximately 0.4 river miles downstream of the PacifiCorp sonde. Generally, the two time series' mirror one another (Figure 5). These two sites should not necessarily match because of reaeration and primary production that occurs between the sondes. Overall, corrections appear to be supported by data from the Karuk sonde.

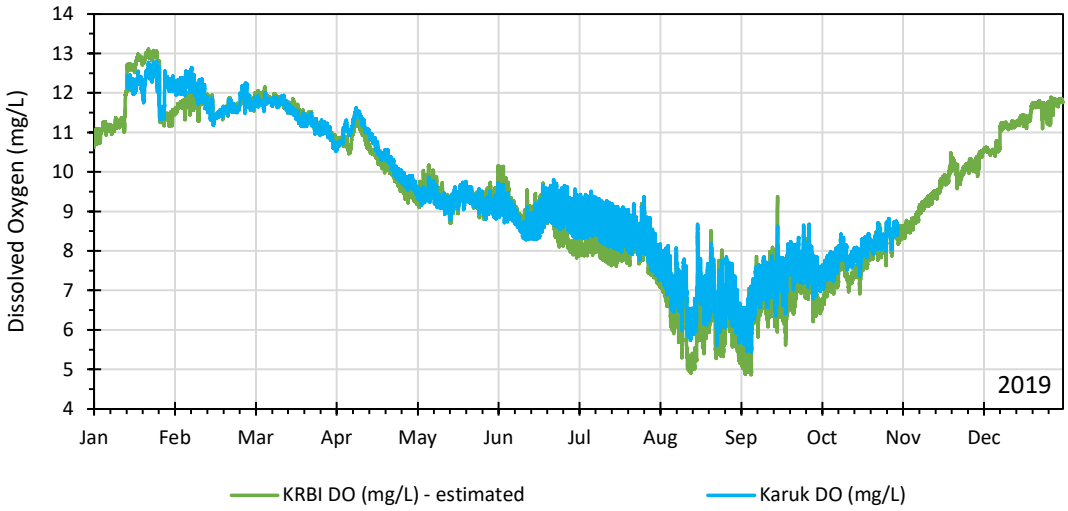

Figure 5. Corrected (estimated) dissolved oxygen concentrations from the PacifiCorp Klamath River below Iron Gate (KRBI) sonde and the Karuk sonde approximately 0.5 river miles downstream.

5. Conclusions

If calibration is performed with an incorrect (i.e., not local) barometric pressure reading, a manufacturer-suggested correction, given in Equation 2, can be used to estimate corrected DO percent saturation values. A corrected concentration can be recalculated from these estimated DO percent saturation values.

During two periods of 2019, a data sonde deployed downstream of Iron Gate dam (KRBI) was found to have been incorrectly calibrated to the wrong barometric pressure. Consequently, reported DO concentrations during those periods have been assumed to be incorrect. These data were corrected using a correction factor provided by the sonde manufacturer, YSI. Corrected data were compared to data reported by a downstream sonde and found to reasonably match. As a result, DO concentrations reported at KRBI during 2019 are assumed to have been successfully corrected and the record is assumed to correctly represent field conditions throughout the year.

6. Recommendations

A number of recommendations were developed during the review and correction of the 2019 KRBI sonde data.

- A standard protocol should be developed for sonde calibrations and referenced during calibrations to prevent errors and to ensure consistency between calibrations.

- The sonde should be cleaned prior to calibrations and sensors should be rinsed at least three times with deionized or distilled water, prior to calibrating.

- The DO sensor should be dried with a lint-free cloth or droplets shaken off the sensor and left to equilibrate in water-saturated air for at least 10 to 15 minutes prior to calibrating (an air-saturated water or a mg/L calibration can also be performed, see the YSI manual for more details).

7. References

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