Appendix H

2020 Seattle District TDG Report

U.S. Army Corps
of Engineers
Seattle District

Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam, Washington, 2020: Data Review and Quality Assurance

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Introduction

The Columbia River drains over 259,000 square miles of the Pacific Northwest in the United States and Canada. The Snake, Kootenai, and Pend Oreille-Clark Fork systems are the largest tributaries of the Columbia River. The Seattle District Corps of Engineers (CENWS) operates one dam on the Columbia River, Chief Joseph Dam in Washington (Figure 1).

Water temperature, TDG, and associated water quality processes are known to impact anadromous and resident fishes in the Columbia River. Dams may alter a river's water quality characteristics by increasing TDG levels due to releasing water through the spillways and by altering temperature gradients due to the creation of reservoirs. Spilling water at dams can result in increased TDG levels in downstream waters by plunging the aerated spill water to depth where hydrostatic pressure increases the solubility of atmospheric gases. Elevated TDG levels generated by spillway releases from dams can promote the potential for gas bubble trauma in downstream aquatic biota (Weitkamp and Katz 1980; Weitkamp et al. 2002). Water temperature has a significant impact on fish survivability, TDG saturations, the biotic community, chemical and biological reaction rates, and other aquatic processes.

Purpose and Objectives

The Seattle District Corps of Engineers monitored TDG and temperature at Chief Joseph Dam from March 1 – September 30, 2020. The purpose of the monitoring program is to provide real-time TDG data to the U.S. Army Corps of Engineers (USCOE) to allow for the understanding and management of flow and spill at dams on the Columbia River system. This report describes the TDG and temperature quality assurance (QA) results and associated data for the Chief Joseph Dam monitoring program.

Methods and Materials

Site Characterization

Chief Joseph Dam

Chief Joseph Dam is located at river mile 545 on the Columbia River in Washington, about 51 miles downstream of Grand Coulee Dam (Figure 1). The dam is a concrete gravity dam, 230 feet high, with 19 spillway bays which abut the right bank. The spillway is controlled by 36-foot wide by 58-foot high tainter gates and is designed to pass releases up to 1,200 thousand cubic feet per second (kcfs) at a maximum water surface elevation of 958.8 feet. Spillway deflectors have been installed on all 19 spillway bays.

Total dissolved gas (TDG) supersaturation is generated in the Columbia River during spillway flows at Chief Joseph Dam. A detailed investigation of pre-deflector TDG exchange was conducted at Chief Joseph Dam in 1999 and an investigation of post-deflector TDG exchange was conducted in 2009 (Schneider and Carroll 1999; Schneider 2012). The pre-deflector study determined that TDG saturations in spillway flows ranged from about 111 to 134 percent and were an exponential function of spillway discharge, weakly related to tailwater depth of flow, and with little powerhouse entrainment. A post-deflector TDG study was conducted at Chief Joseph Dam from April 28 to May 1, 2009 to determine TDG exchange characteristics for Chief Joseph Dam with deflectors. Spillway discharges ranged from 18 to 145 kcfs during this study. Results showed that TDG saturations during spillway operations with deflectors were greatly reduced compared to non-deflector operations, with measured TDG saturations ranging from about 110 to 120 percent. (Schneider 2012). TDG saturations were lowest for uniform spillway conditions and influenced by tailwater depth, with higher tailwater depth resulting in greater TDG saturations.

Data Collection

Data were collected at two fixed monitoring stations at Chief Joseph Dam (CHJ and CHQW) during the 2020 spill season (Figure 2). Fixed monitoring station location details and dates of operation are summarized in Table 1 and shown in Figure 3. Parameters monitored at each location included hourly measurements of water temperature, barometric pressure, TDG pressure, and TDG probe depth.

Data Collection Methods

Data collection methods followed procedures set forth in the *U.S. Army Corps of Engineers 2019 TDG Monitoring Plan* (USCOE 2019). Instrumentation at Chief Joseph Dam consisted of a Hydrolab MiniSonde 4a/5 water quality probe, a Sutron electronic barometer, a Sutron 9210 XLite data collection platform (DCP), a radio transmitter, and a power source. The barometer, TDG probe and DCP were powered by a 12-volt battery that was charged by a 120-volt AC line.

Measurements were made every hour and the data were transmitted to the Corps Water Management System (CWMS) database.

Data Collection Locations

At the Chief Joseph Dam forebay station (CHJ) the water quality probe was located in Lake Rufus Woods near the left bank by the powerhouse. The probe was deployed directly into the water off of the boathouse's floating dock at a depth of 20 feet (see Figure 3). At the Chief Joseph Dam tailwater station (CHQW) the water quality probe was deployed along the right bank of the river, 1.3 miles downstream from the spillway (see Figure 3). Data collected at CHQW during the 2009 spillway deflector TDG exchange study showed that the TDG probe was slow to respond to changes in spill when it was place inside the anchored, perforated PVC pipe located at the station (Schneider 2012). For the 2020 spill season the TDG probe was placed directly into the water to a depth of at least 10 feet during spillway flow conditions from April through September.

Data Completeness

Data completeness and quality for TDG and temperature data collected in 2020 are summarized in Tables 2 and 3. The data were based upon the number of planned monitoring hours from March 1 through September 30. Any hours without TDG or barometric pressure data were considered missing data for TDG percent saturation since percent saturation is calculated as total dissolved gas, in millimeters of mercury (mm Hg), divided by barometric pressure and multiplied by 100. The percentage of real-time TDG and temperature monitoring data received was calculated from the number of missing hourly values versus the number of planned hourly values. The percent of real-time TDG and temperature data passing quality assurance represents the percent of data that was received as real-time data and passed the quality assurance review of data described below.

Once the real-time data were received and missing data were flagged, the following quality assurance review procedure occurred.

1. Tables of raw data were visually inspected for erroneous data resulting from DCP malfunctions or improper transmission of data value codes.
2. Data tables were reviewed for sudden increases in temperature, barometric pressure, or TDG pressure that could not be correlated to any hydrologic event and therefore may be a result of mechanical problems.
3. A data checklist program was used to assist in identifying erroneous data. Values outside the data checklist program range of acceptable values (0 to 30 °C for temperature, 600 to 800 mm Hg for barometric pressure, and 600 to 1000 mm Hg for TDG pressure) were flagged and reviewed to determine if the data were acceptable or an artifact of a DCP or instrument malfunction.
4. Graphs of the data were created and analyzed in order to identify unusual spikes in the data. These spikes were then further investigated in order to identify the causes of error.

5. Graphs of forebay data minus tailwater data were created and analyzed to identify erroneous data. For example, during periods of no spill if forebay and tailwater station TDG or temperature data disagreed by greater than 30 mm Hg or 3 °C, respectively, the data were flagged as suspect and reviewed to determine acceptability. Suspect data were corrected if possible. Data that could not be corrected were flagged as rejected.

Data completeness for TDG data received was 100 percent at the forebay station (CHJ) and 95.3 percent at the tailwater station (CHQW). Similarly, data completeness for temperature data received was 100 percent at the forebay station (CHJ) and 95.3 percent at the tailwater station (CHQW). As shown in Tables 2 and 3, there were several minor problems with receiving real-time hourly TDG and temperature data encountered at the Chief Joseph Dam tailwater station. Missing TDG and temperature data for station CHQW (241 hours for TDG and temperature) in 2020 were due to DCP malfunctions and programming problems. For TDG data, at the forebay (CHJ) station a total of 1 hour was rejected due to slow probe response time after recalibration. At the tailwater station (CHQW) a total of 5 hours were rejected due to slow probe response time after recalibration. No temperature data were rejected at stations CHJ and CHQW.

Quality-Assurance Procedures

Fixed monitoring stations were calibrated every two weeks during the 2020 monitoring season following procedures outlined in the *U.S. Army Corps of Engineers 2019 TDG Monitoring Plan* (USCOE 2019). Data quality assurance and calibration procedures included calibration of instruments in the laboratory and calibration of instruments in the field. Two TDG probes were assigned to each monitoring site to allow laboratory calibrations between deployments and to provide back-up sensors in the event of equipment failure.

Prior to field service visits, the secondary standard TDG probe and the replacement TDG probe were laboratory calibrated using the primary standard. All primary standards were National Institute of Science and Technology (NIST) traceable and maintained according to manufacturers recommendations. Table 4 summarizes the parameters and standards utilized for calibration during the 2020 monitoring season.

Water quality probes were laboratory calibrated using the following procedures. TDG pressure sensors were checked in air with the membrane removed. Ambient pressures determined from the NIST traceable mercury barometer served as the zero value for total pressure. The slope for total pressure was determined by adding known pressures to the sensor. Using a NIST traceable digital pressure gauge, comparisons were made at saturations corresponding to 100 percent, 113 percent, 126 percent, and 139 percent (Table 5). If any measurement differed by more than 0.5 percent saturation from the primary standard, the sensor was adjusted and rechecked over the full calibration range. As seen in Table 5, most calibrations were within 0 to 0.5 percent saturation.

A new TDG membrane was assigned to each probe at the beginning of the monitoring season. The TDG membranes were allowed to dry between deployments and tested for integrity by immersion in supersaturated water (seltzer water) prior to redeployment. A successful test was indicated by a rapid pressure increase upon immersion followed by a gradual pressure decline upon removal. Deviation indicated a problem with the membrane and the procedure was repeated with a new membrane until satisfactory results were achieved.

Laboratory calibrations of the water quality probe's temperature sensor were performed using a NIST traceable thermometer and are shown in Table 5. If the measurements differed by more than 0.2 °C the probe was returned to the manufacturer for maintenance. As seen in Table 5 most calibrations were within 0.1 °C for temperature. In addition, calibration of the secondary barometric standard was performed in the laboratory using a NIST traceable barometric pressure gauge. If the barometer was not within 1mm Hg of the primary standard, the secondary standard was re-calibrated.

Every two weeks a currently operating field probe was replaced with a laboratory calibrated probe, which also operated as the secondary standard for the field probe. Prior to replacement, every probe was field calibrated using the following methods. First, the laboratory calibrated probe (secondary standard) was placed in supersaturated water (seltzer water) to test for the integrity of the probe and the responsiveness of the membrane. If the membrane was not responding properly it was replaced and re-tested. Second, the difference in barometric pressure, TDG pressure, and temperature between the field probe and the laboratory calibrated probe (secondary standards) were measured *in-situ* and recorded. If the field probe disagreed with the secondary standard probe by more than 0.2°C for water temperature or 2% for TDG saturation, the probe was removed and rechecked to field standards. If the field barometer disagreed with the secondary standard barometer by more than 1 mm Hg, the barometer was adjusted and rechecked.

The comparisons of the field barometer and the secondary barometric pressure standard, and the field temperature and the secondary standard temperature are shown in Figure 4. In general, the field barometer was within 1 mm Hg of the secondary standard at all locations. The temperature sensor secondary standard and the field temperature sensor results were generally within 0.1 °C at all locations. Differences between the field TDG sensor and the secondary standard TDG sensor are presented in Figure 5. In general, the majority of TDG data were within 1 percent saturation difference at both CHJ and CHQW. The cause of the differences between the field sensor and the secondary standard were likely due to the secondary standard probe not being left in the water long enough to reach equilibration.

Water Quality Criteria

The Washington Department of Ecology (WDOE) and the Colville Confederated Tribe (CCT) determines water quality criteria for the Columbia River at Chief Joseph Dam in Washington. The CCT has classified the Columbia River as a Class I water body above Chief Joseph Dam and a Class II water body below the dam. The WDOE classified the Columbia River above and below Chief Joseph Dam as a Non-Core Salmon/Trout water body. Water quality standards for TDG and temperature for Chief Joseph Dam are presented in Table 6. At Chief Joseph Dam, the State of Washington and the Colville Tribe have a similar TDG standard of 110 percent.

Results and Discussion

Total Dissolved Gas

Chief Joseph Dam

Hourly percent TDG, river flows, and spill volumes for Chief Joseph Dam during the 2020 monitoring season are presented in Figure 6. Columbia River flow volumes at Chief Joseph Dam were moderate during 2020 with flows generally in the 120 to 220 kcfs range, with peak flows of about 240 kcfs in mid May. Consequently, Chief Joseph Dam experienced moderate spill volumes during the 2020 season. Spill at Chief Joseph during the March 1 to September 30, 2020 monitoring period ranged from 0 to about 140 kcfs (Figure 6). Total dissolved gas at Chief Joseph forebay station (CHJ) exceeded 110 percent during the 2020 season from early-June to late-July, with a maximum value of about 117 percent on May 17, 2020. Because little degassing occurs during transport through Lake Rufus Woods, TDG measured at the Chief Joseph forebay station are largely a function of the TDG released from Grand Coulee Dam. In general, Chief Joseph tailwater station (CHQW) TDG saturations were slightly lower than forebay saturations during periods of low to moderate spill when forebay TDG was elevated. Tailwater TDG was greater than 110 percent from late-May to late-July, with a maximum tailwater TDG of about 118.5 percent on May 31, 2020 during a spill of 140 kcfs.

Temperature

Chief Joseph Dam

Maximum water temperatures measured at the Chief Joseph forebay (CHJ) and tailwater (CHQW) stations were similar, and ranged from about 3°C in March to about 19°C in early-September (Figure 6). The similar water temperatures at the forebay and tailwater stations indicate well-mixed conditions in the forebay. Water temperatures at the forebay were greater than 16°C from about late-July through the end of monitoring on September 30, 2020, and were greater than 18°C from about mid-August through the end of monitoring on September 30, 2020. Similarly, water temperatures at the tailwater exceeded 18°C from about mid-August through the end of monitoring on September 30, 2020.

Conclusions

Evaluation of the Quality Assurance and monitoring results yielded the following conclusions:

- Data completeness for TDG data received was 100 percent at the forebay station (CHJ) and 95.3 percent at the tailwater station (CHQW). Data completeness for temperature data received was 100 percent at station CHJ and 95.3 percent at station CHQW. Missing TDG and temperature data at both stations were largely due to DCP malfunctions and programming problems.

- For TDG data, at the forebay (CHJ) station a total of 1 hour was rejected due to slow probe response time after recalibration. At the tailwater station (CHQW) a total of 5 hours were rejected due to slow probe response time after recalibration. No temperature data was rejected at stations CHJ and CHQW.

- Laboratory calibration data were good and within 0.1°C for temperature and 1 percent saturation for TDG. Field calibration data were good and generally within 1mm Hg of the secondary standard barometer, 0.1ºC of the secondary standard thermometer, and 1 percent saturation of the secondary standard TDG instrument.

- The TDG sensors were removed from the field after 2 weeks of deployment and calibrated in the laboratory.

- A total of 27 out of 27 (100%) in-situ field checks of total-dissolved-gas sensors with a secondary standard were within ± 2 percent after 2 weeks of deployment in the river.

- A total of 27 out of 27 (100%) in-situ field checks of barometric pressure were within ±2 mm Hg of a secondary standard, and 26 out of 27 (96%) water temperature field checks were all within ±0.2°C.

- Total dissolved gas at Chief Joseph forebay station (CHJ) exceeded 110 percent from early-June to late-July, with a maximum value of about 117 percent on May 17, 2020. Tailwater (CHQW) TDG was greater than 110 percent from late-May to late-July, with a maximum tailwater TDG of about 118.5 percent on May 31, 2020 during a spill of 140 kcfs. In general, tailwater station (CHQW) TDG saturations were lower than forebay saturations during periods of low to moderate spill.

- Water temperatures at the Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) were greater than 16°C from about late-July through the end of

September. Forebay and tailwater temperatures were greater than 18°C from mid-August through the end of September.

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Tables

Table 1. Fixed monitoring station locations and sampling period, spill season 2020.

Site Identifier	Station Name	Latitude (NAD 83)	Longitude (NAD 83)	2020 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	03/01/20 - 09/30/20
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	03/01/20 - 09/30/20

Table 2. Total dissolved gas data completeness for spill season 2020.

Station Name	Station Abbreviation	Planned monitoring in hours	Number of missing hourly values	Number of hourly values not passing quality assurance	Percentage of real-time TDG monitoring data received	Percentage of real-time TDG data received and passing quality assurance
Chief Joseph Forebay	CHJ	5134	0	1	100.0	100.0
Chief Joseph Tailwater	CHQW	5134	241	5	95.3	95.2

Table 3. Temperature data completeness for spill season 2020.

Station Name	Station Abbreviation	Planned monitoring in hours	Number of missing hourly values	Number of hourly values not passing quality assurance	Percentage of real-time Temperature monitoring data received	Percentage of real-time Temperature data received and passing quality assurance
Chief Joseph Forebay	CHJ	5134	0	0	100.0	100.0
Chief Joseph Tailwater	CHQW	5134	241	0	95.3	95.3

Table 4. Total dissolved gas and temperature calibration standards.

Standard	Parameter	Instrument
Primary	Atmospheric Pressure	NIST traceable mercury barometer
Primary	Total Pressure	NIST traceable digital pressure gage
Primary	Water Temperature	NIST traceable mercury thermometer
Secondary	Atmospheric Pressure	Electronic barometer
Secondary	Total Pressure	Hydrolab MiniSonde 4a/5
Secondary	Water Temperature	Hydrolab MiniSonde 4a/5

Table 5. Difference between the primary standard and the laboratory calibrated TDG instrument and thermometer for spill season 2020.

	Temperature °C	100% TDG	113% TDG	126% TDG	139% TDG
Num	29	29	29	29	29
min	-0.11	-1.10	-1.10	-1.10	-1.10
max	0.02	0.90	0.80	0.80	0.80
median	-0.02	0.10	0.00	-0.10	-0.10
avg	-0.03	0.06	0.02	-0.01	-0.01
sd	0.04	0.43	0.40	0.38	0.38

Table 6. Washington Department of Ecology (WDOE) and Colville Confederated Tribe (CCT) general water quality standards.

Parameter/ Project	Regulator	Standard
Total Dissolved Gas		
Chief Joseph	WDOE	Salmonid Spawning/Rearing: Shall not exceed 110 percent TDG at any point of sample collection.
	CCT	Class I and II: Shall not exceed 110 percent TDG at any point of sample collection.
pH		
Chief Joseph	WDOE	Salmonid Spawning/Rearing: pH shall be within the range of 6.5 to 8.5 with a human-caused variation within the above range of less than 0.5 units.
	CCT	Class I and II: Shall be within the range of 6.5 to 8.5 with a man-caused variation within a range of less than 0.5 units.
Dissolved Oxygen		
Chief Joseph	WDOE	Salmonid Spawning/Rearing: Lowest 1-day minimum of 8.0 mg/L.
	CCT	Class I: Shall exceed 9.5 mg/L. Class II: Shall exceed 8.0 mg/L.
Chief Joseph	WDOE	Salmonid Spawning/Rearing: Shall not exceed 17.5°C as measured by 7-day average of the daily maximum temperatures (7-DADMax) due to human activities. When natural conditions exceed 7-DADMax of 17.5°C, no temperature increase will be allowed which will raise the receiving water 7-DADMax temperature by greater than 0.3°C.
	CCT	Class I: Shall not exceed 16.0°C due to human activities. When natural conditions exceed 16.0°C, no temperature increase will be allowed which will raise the receiving water by greater than 0.3°C. Class II: Shall not exceed 18.0°C due to human activities. When natural conditions exceed 18.0°C, no temperature increase will be allowed which will raise the receiving water by greater than 0.3°C.

Figures

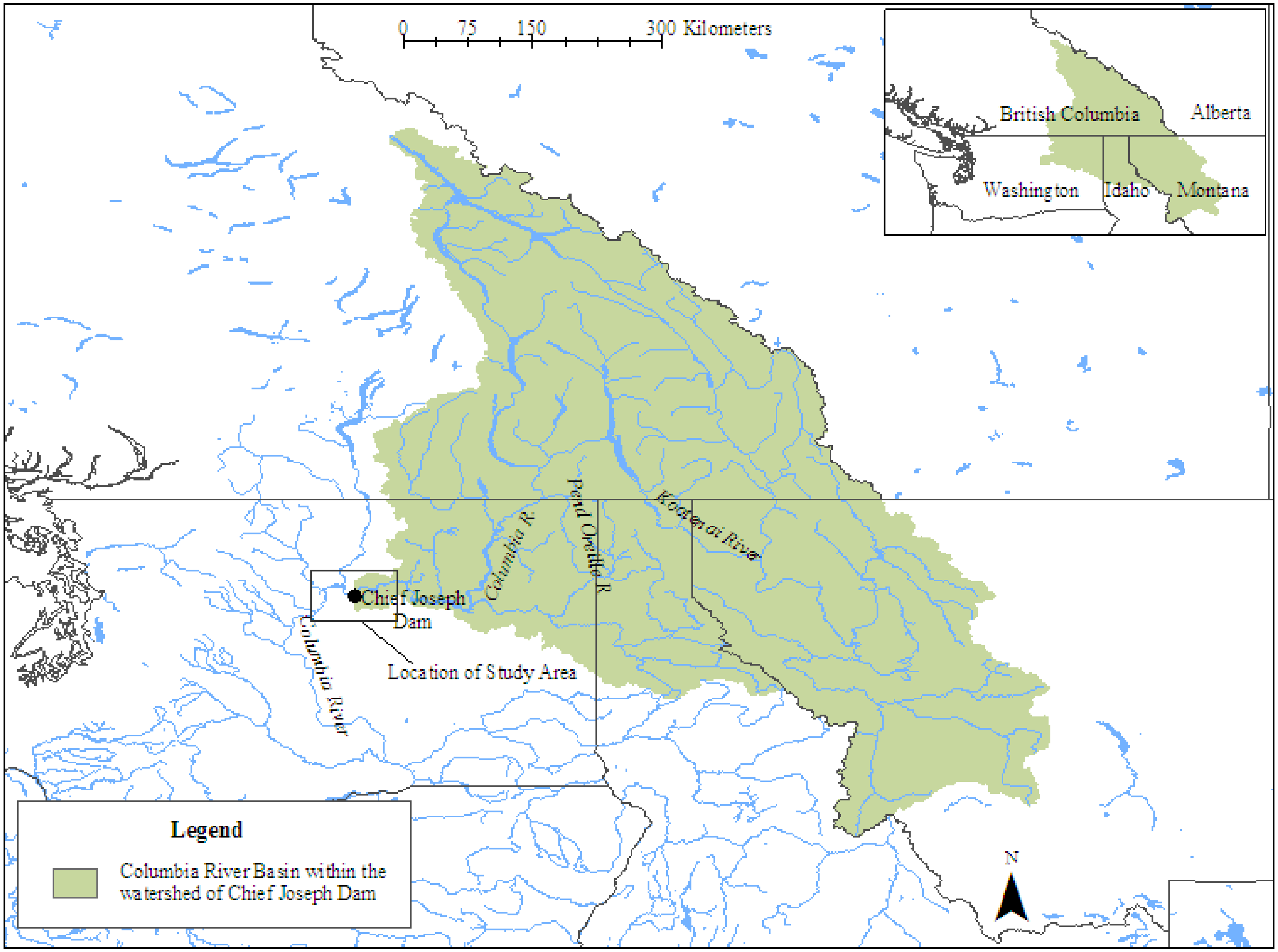


Figure 1. Location of Chief Joseph Dam in the upper Columbia River basin.

Figure 2. Locations of TDG monitoring stations in 2020 in Rufus Woods Lake, Chief Joseph Dam, Washington.

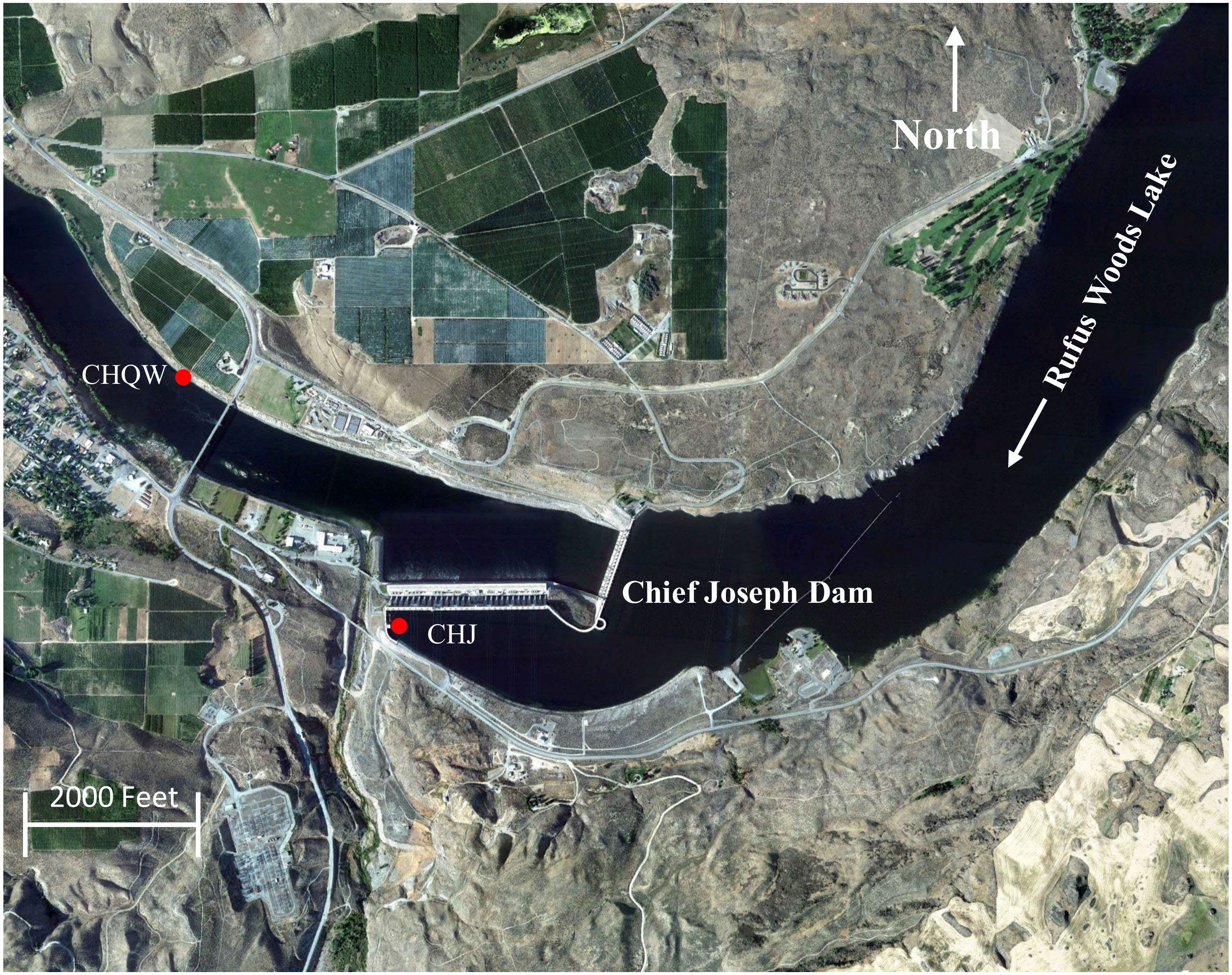


Figure 3. Locations of TDG monitoring stations in 2020 for Chief Joseph Dam, Washington.

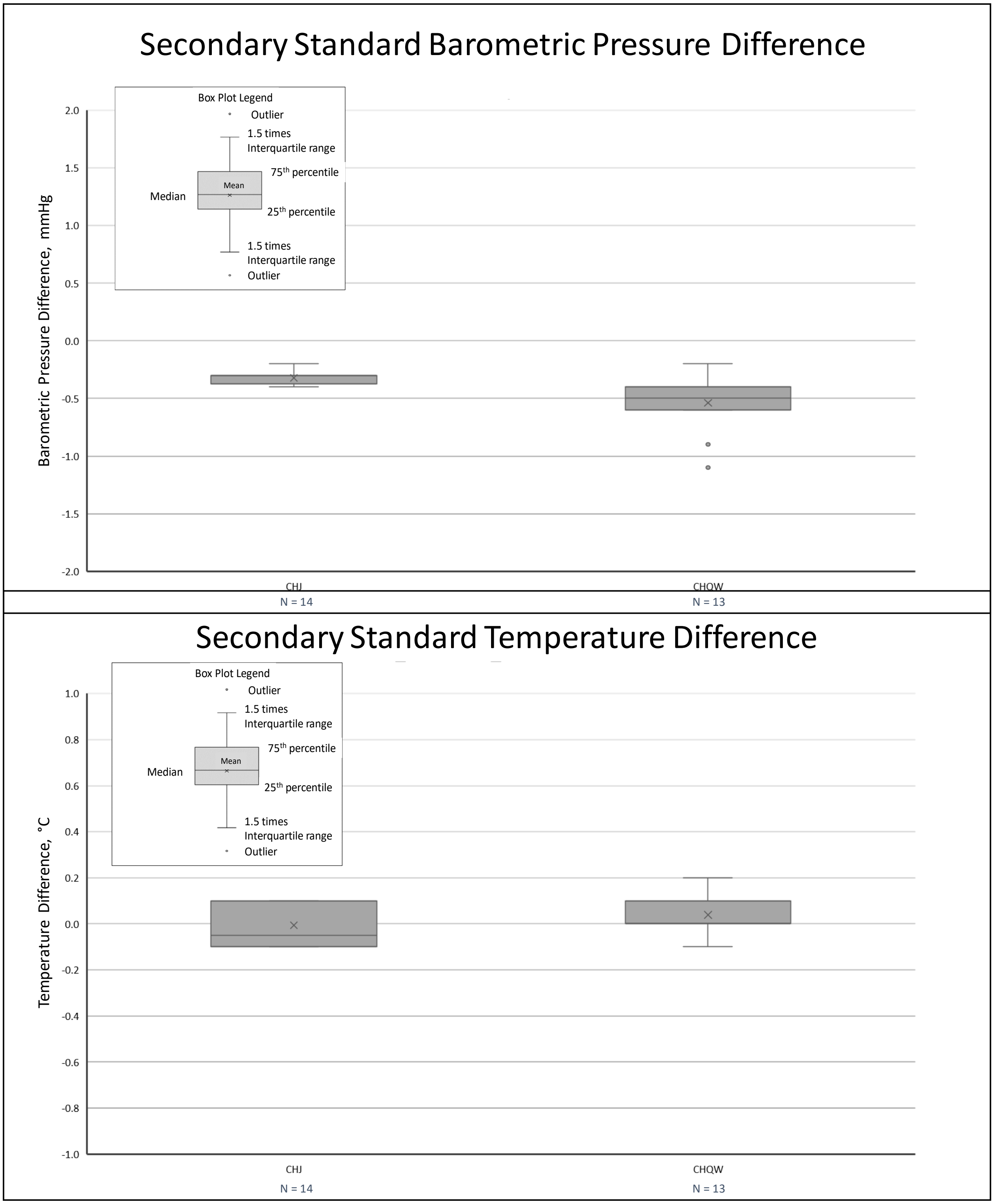


Figure 4. Difference between the secondary standard and the field barometers and field thermometers during spill season 2020.

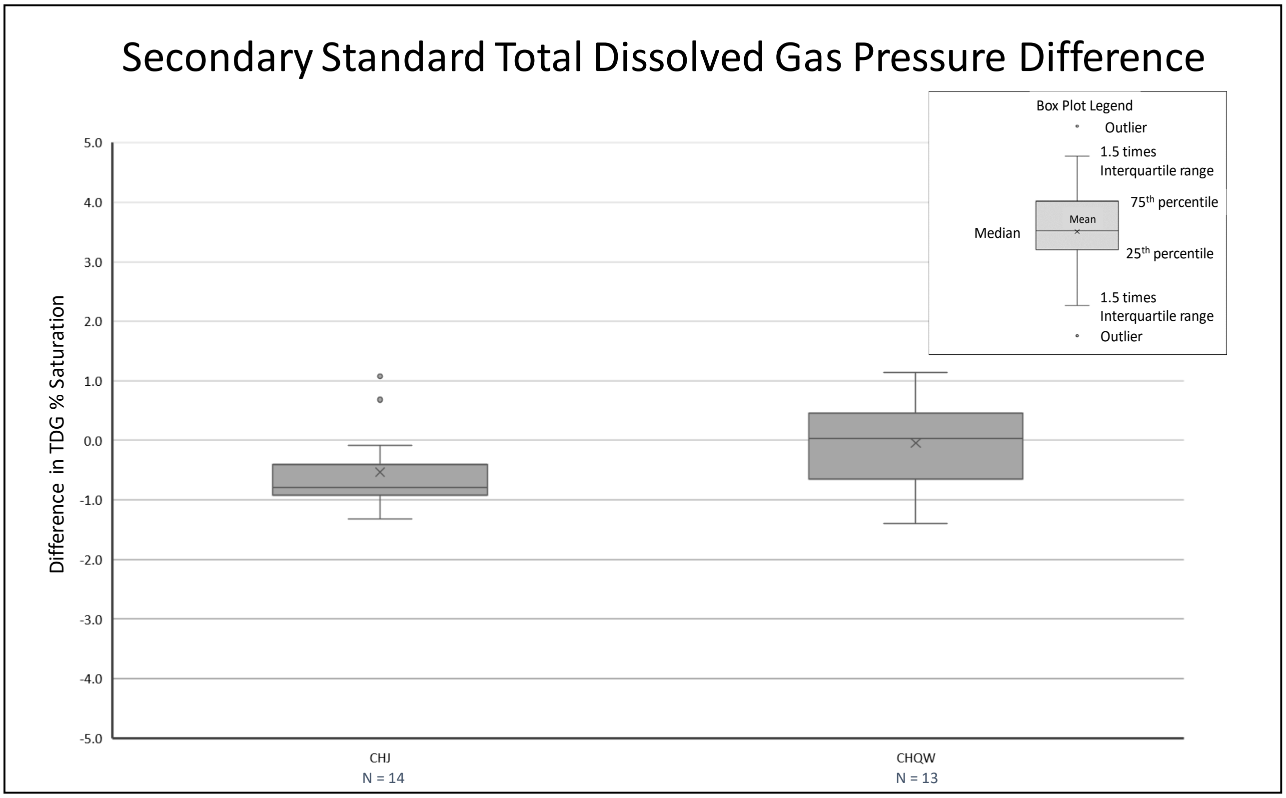
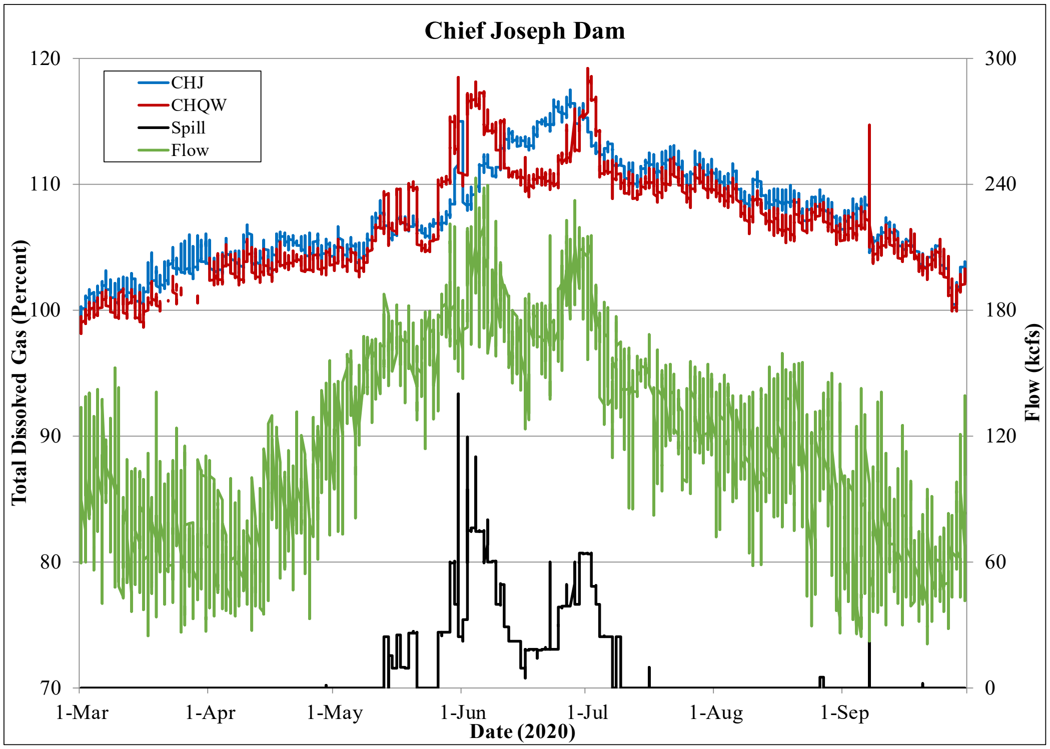


Figure 5. Difference between the secondary standard and the field TDG instrument for TDG pressure during spill season 2020.



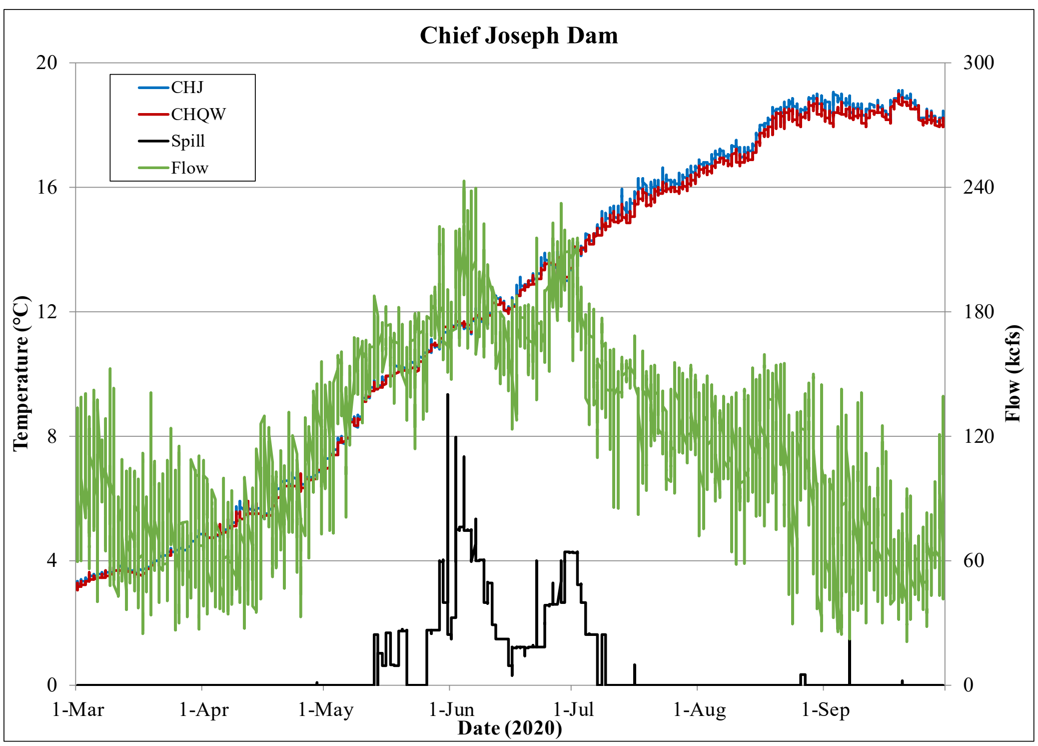


Figure 6. Percent TDG, spill, and flow (upper panel) and temperature, spill, and flow (lower panel) at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2020.