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Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam, Washington, 2012: 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 April 1 – September 30, 2012. The purpose of the monitoring program was 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 2012 spill season (Figure 2). Fixed monitoring station location details and dates of operation are summarized in Table 1 and shown in Figure 2. 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. Corps of Engineers Plan of Action for Dissolved Gas Monitoring in 2010-2014, Updated for 2012* (USCOE 2011). Instrumentation at Chief Joseph Dam consisted of a Hydrolab MiniSonde 4a water quality probe, a Common Sensing TBO-L 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 via radio directly to the Seattle District's HEC-DSS water quality database. Data were then sent out from Seattle every hour via file transfer protocol (FTP) to the Corps of Engineers Northwestern Division (CENWD) in Portland, Oregon. The data were then stored in the Columbia River Operational Hydromet Management System (CROHMS) 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 2). 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. The probe was placed inside an anchored, perforated PVC pipe that extended into the river to a depth of at least 10 feet during low flow conditions.

Data Completeness

Data completeness and quality for TDG and temperature data collected in 2012 are summarized in Tables 2 and 3. The data were based upon the number of planned monitoring hours from April 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.

As shown in Tables 2 and 3, there were only minor problems with receiving real-time hourly TDG and temperature data encountered at Chief Joseph Dam. Missing data for stations CHJ (24 hours) and CHQW (26 hours) in 2012 were due to DCP malfunctions and programming problems. For TDG data, a total of 4 hours at CHQW and 2 hours at CHJ 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 2012 monitoring season following procedures outlined in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring in 2010-2014, Updated for 2012* (USCOE 2011). 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 2012 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 140 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 10 mm Hg for TDG pressure, 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 3. In general, the field barometer was within 2 mm Hg of the secondary standard at all locations. The temperature sensor secondary standard and the field temperature sensor results were generally within 0.2 °C at all locations.

Differences between the field TDG sensor and the secondary standard TDG sensor are presented in Figure 4. In general, the majority of TDG data were within 10 mm Hg difference between the field sensor and the secondary standard, with 90 percent of the data ranging up to 15 mm Hg 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. However, Washington allows exceedance of the 110 percent TDG criteria to facilitate fish passage spills as shown in Table 6. Chief Joseph Dam was granted a water quality criteria rule adjustment by WDOE for the 2012 spill season for the purpose of managing system spill for improved fish conditions.

Results and Discussion

Total Dissolved Gas

Chief Joseph Dam

Hourly percent TDG, river flows, and spill volumes for Chief Joseph Dam during the 2012 monitoring season are presented in Figure 5. Columbia River flow volumes were moderate during 2012 with flows generally in the 150 to 250 kcfs range. Consequently, Chief Joseph Dam experienced moderate to high spill volumes during the 2012 season. Spill at Chief Joseph during the April 1 to September 30, 2012 monitoring period ranged from about 18 kcfs to 160 kcfs (Figure 5). Due to scheduled maintenance work on the spillway and construction work on the fish hatchery, the number of spillway bays available at Chief Joseph during the 2012 season varied from 14 to 19 bays. To minimize spillway spray from impacting fish hatchery construction work on the right bank downstream of the spillway, bays 1, 2, and 3 were taken out of service from about April 3 to April 25, 2012 leaving only 16 bays operational. In general, from about April 25 to June 18, 2012, 18 to 19 bays were used, and from about June 18 to August 2, 2012 17 bays were used when possible to minimize TDG saturations. However, periodic bay shut downs for maintenance occurred from about June 18 to August 2, 2012 resulting in Chief Joseph spilling from 14 to 17 bays. Periods of reduced spill bays are shown in Figure 5 with the number of spill bays operating shown in the dashed bubbles. It is clear from Figure 5 that increased TDG saturations resulted from reductions in spillway bays.

Total dissolved gas at Chief Joseph forebay station (CHJ) exceeded 110 percent from about early April to late August 2012. 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. The maximum forebay TDG measured was about 123 percent in late June. Chief Joseph tailwater station (CHQW) TDG exceeded 110 percent from about early April through late August, 2012. The tailwater station exceeded 120 percent periodically from mid June through July during spillway flows ranging from about 60 to 160 kcfs. In general, TDG exceeded 120 percent only when spillway releases were from 14 to 17 spill bays out of 19, with the highest TDG saturations corresponded to periods with the fewest spill bays operating (Figure 5). The maximum tailwater TDG measured was about 126 percent during a spill of 148 kcfs from 15 spill bays.

Temperature

Chief Joseph Dam

Maximum water temperatures measured at the Chief Joseph forebay (CHJ) and tailwater (CHQW) stations were similar, and ranged from about 4°C in April to about 18°C in early September (see 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, 2012, and were only periodically greater than 18°C in early September. Water temperatures at the tailwater periodically exceeded 18°C in early September.

Conclusions

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

- Data completeness for TDG data received ranged from 99.3 percent at the tailwater station (CHQW) to 99.4 percent at the forebay station (CHJ), and for temperature data ranged from 99.4 percent at the tailwater station (CHQW) to 99.5 percent at the forebay station (CHJ). Missing data were largely due to DCP malfunctions and programming problems.

- For TDG data, at the tailwater station (CHQW) a total of 4 hours were rejected due to slow probe response time after recalibration. At the forebay station (CHJ) a total of 2 hours were rejected due to slow probe response time after recalibration. No temperature data were 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 2mm Hg of the secondary standard barometer, 0.2ºC of the secondary standard thermometer, and 10 mm Hg of the secondary standard TDG instrument.

- Total dissolved gas at Chief Joseph forebay station (CHJ) exceeded 110 percent from about early April to late August 2012. The maximum forebay TDG measured was about 123 percent in late June. Chief Joseph tailwater station (CHQW) TDG exceeded 110 percent from about early April through late August 2012, and exceeded 120 percent periodically from mid June through July 2012. In general, TDG exceeded 120 percent only when spillway releases were from 14 to 17 out of 19 spill bays.

- Water temperatures at the Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) were greater than 16°C from about late July through September. Forebay and tailwater temperatures were only periodically greater than 18°C in early September.

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Tables

Table 1. Fixed monitoring station locations and sampling period, spill season 2012.

Site Identifier	Station Name	Latitude	Longitude	2011 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	04/01/12 - 09/30/12
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	04/01/12 - 09/30/12

Table 2. Total dissolved gas data completeness for spill season 2012.

Station Name	Station Abbreviation	Planned monitoring in hours	Number of missing hourly values	Number of hourly values not passing QA	Percentage of real-time TDG monitoring data received	Percentage of real-time TDG data received and passing quality assurance
Chief Joseph Forebay	CHJ	4392	24	2	99.5	99.4
Chief Joseph Tailwater	CHQW	4392	26	4	99.4	99.3

Table 3. Temperature data completeness for spill season 2012.

Station Name	Station Abbreviation	Planned monitoring in hours	Number of missing hourly values	Number of hourly values not passing QA	Percentage of real-time Temperature monitoring data received	Percentage of real-time Temperature data received and passing quality assurance
Chief Joseph Forebay	CHJ	4392	24	0	99.5	99.5
Chief Joseph Tailwater	CHQW	4392	26	0	99.4	99.4

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
Secondary	Water Temperature	Hydrolab MiniSonde 4a

Table 5. Difference between the primary standard and the laboratory calibrated TDG instrument and thermometer for spill season 2012.

	Temperature	Total Dissolved Gas Percent			
	°C	100	113	126	140
Num	70	70	70	70	70
min	-0.10	-0.69	-0.69	-0.83	-0.98
max	0.20	0.49	0.63	0.63	0.49
median	0.10	0.01	0.03	0.01	0.00
avg	0.06	0.03	0.05	0.03	-0.01
sd	0.07	0.15	0.15	0.16	0.16

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

Parameter/ Project	Regulator	Standard
Total Dissolved Gas		
Chief Joseph	WDOE	Shall not exceed 110 percent TDG at any point of sample collection, except during spill season for fish passage in which total dissolved gas shall be measured as follows: (1) Must not exceed an average of 115 percent as measured in the forebay of the next downstream dam. (2) Must not exceed an average of 120 percent as measured in the tailrace of each dam; TDG is measured as an average of the 12 highest consecutive hourly readings in any one day, relative to atmospheric pressure. (3) A maximum TDG one-hour average of 125 percent as measured in the tailrace must not be exceeded during spillage for fish passage.
	CCT	Shall not exceed 110 percent TDG at any point of sample collection.
Temperature		
Chief Joseph	WDOE	Non-Core Salmon/Trout: Shall not exceed 17.5°C as measured by the 7-day average of the daily maximum temperatures (7-DADMax) due to human activities. When natural conditions exceed a 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

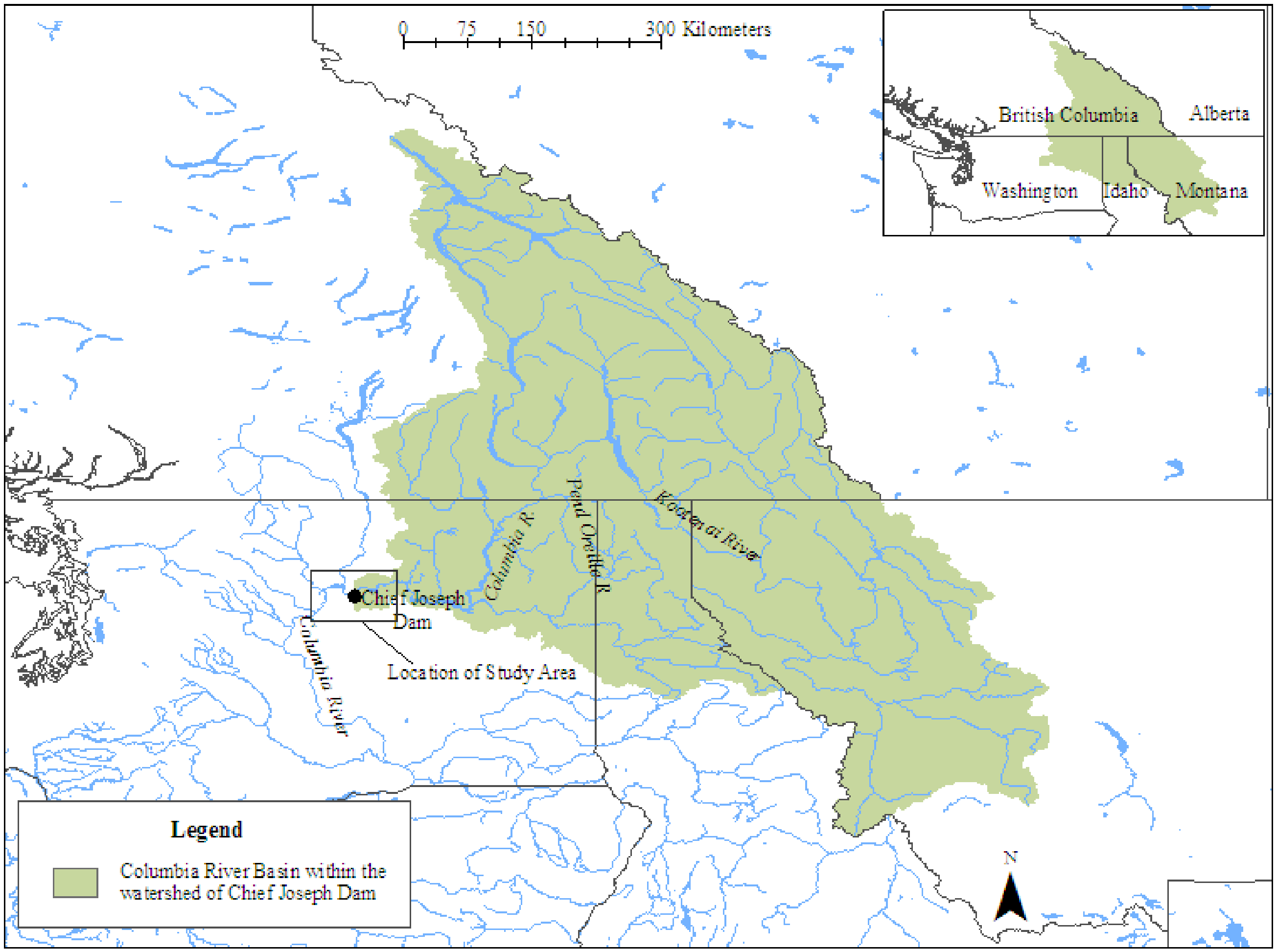

Figure 1. Location of Chief Joseph Dam in the upper Columbia River basin.

Figure 2. Locations of TDG monitoring stations in 2012 for Chief Joseph Dam, Washington.

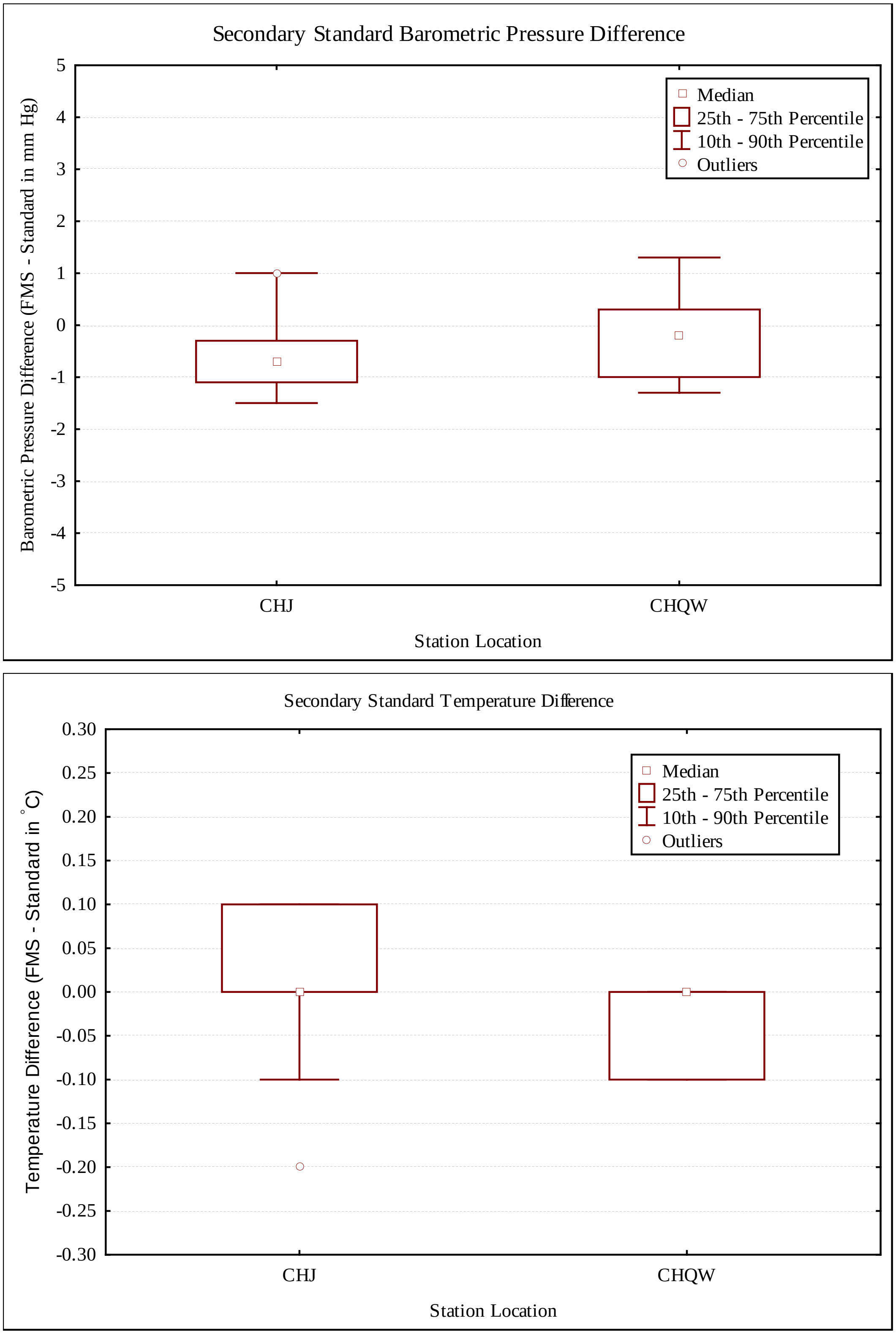

Figure 3. Difference between the secondary standard and the field barometers and field thermometers during spill season 2012.

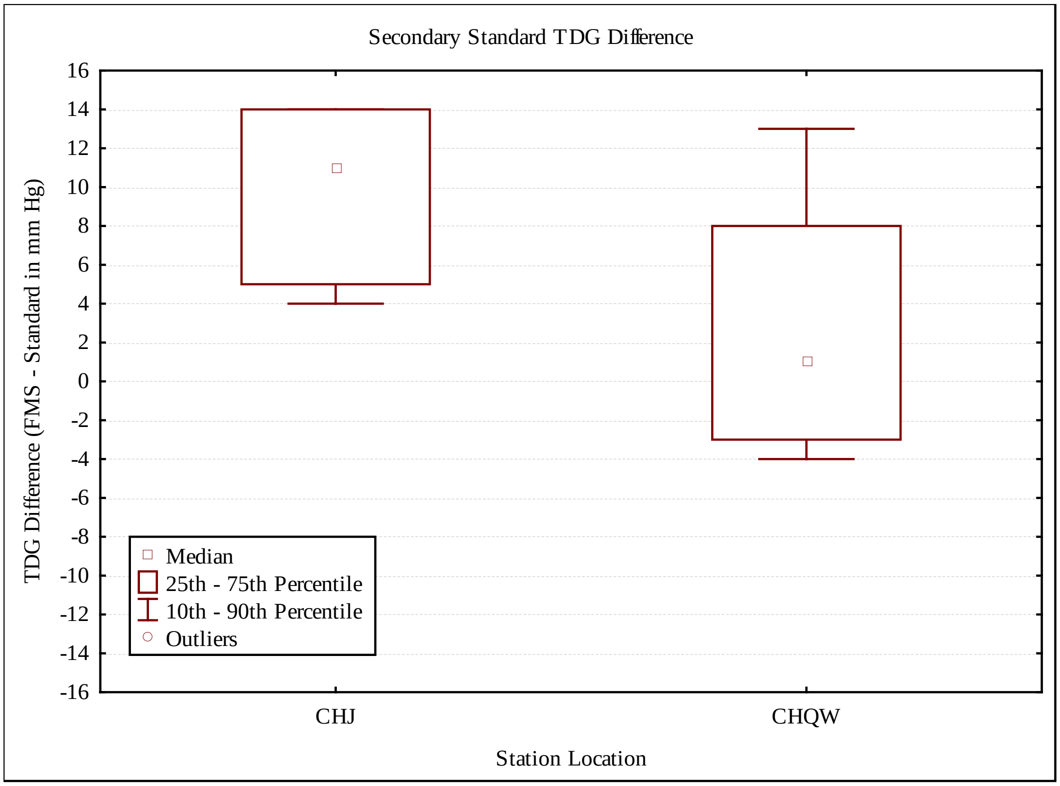

Figure 4. Difference between the secondary standard and the field TDG instrument for TDG pressure during spill season 2012.

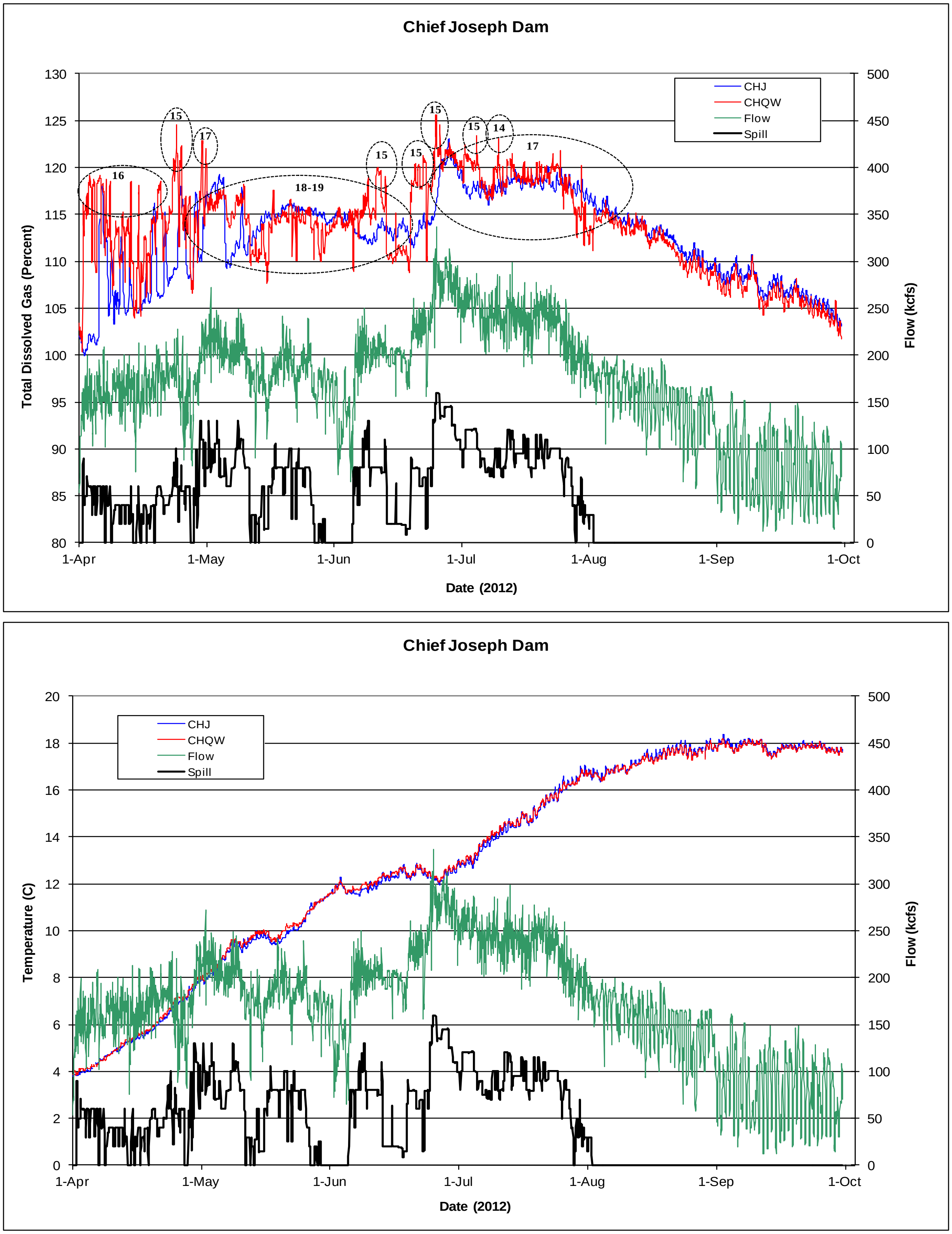

Figure 5. Percent TDG, spill, and flow (upper panel) and temperature, spill, and flow (lower panel) at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2012.