

Appendix L

**Seattle District TDG Report
(Includes Chief Joseph Dam)**



**U.S. Army Corps
of Engineers**
Seattle District

Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam, Washington, 2010: 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 three dams in the Columbia River Basin: Chief Joseph Dam on the Columbia River in Washington, Libby Dam on the Kootenai River in Montana, and Albeni Falls Dam on the Pend Oreille River in Idaho (Figure 1). These dams are operated to provide flood control, hydropower production, recreation, navigation, and fish and wildlife habitat.

Total dissolved gas (TDG), water temperature, and associated water quality processes are known to impact anadromous and indigenous fishes in the Columbia River system. 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 Scope

The Seattle District Corps of Engineers monitored total dissolved gas (TDG) and temperature at Chief Joseph Dam during the 2010 spill season, which lasted from April 1 – September 30, 2010. 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 1,200,000 cubic feet per second (cfs) at a maximum water surface elevation of 958.8 feet. The TDG exchange characteristics for Chief Joseph Dam without spillway deflectors were determined during a comprehensive study of TDG in June 1999 (Schneider and Carroll 1999). Results showed the TDG exchange during spillway operations at Chief Joseph Dam to be an exponential function of spillway discharge, weakly related to tailwater depth of flow, and with little powerhouse entrainment.

Spillway deflector construction was completed in 2009. A spillway deflector TDG exchange study was conducted at Chief Joseph Dam from April 28 to May 1, 2009 to determine the TDG exchange characteristics for Chief Joseph Dam with deflectors. Spillway discharges ranged from 18,000 to 145,000 cfs during this study. Preliminary results showed the TDG exchange during spillway operations with deflectors was greatly reduced compared to non-deflector operations. TDG saturations were lowest for uniform spillway conditions with TDG exchange to be 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 2010 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 2010* (USCOE 2009). 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, 0.75 miles downstream from the dam. 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 2010 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 procedures occurred. First, tables of raw data were visually inspected for erroneous data resulting from DCP malfunctions or improper transmission of data value codes. Second, 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. Third, 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. Fourth, 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. Fifth, 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, no problems with receiving real-time hourly TDG and temperature data were encountered at the monitoring stations. For the 2010 season no data were missing or rejected at stations CHJ and CHQW.

Quality-Assurance Procedures

Fixed monitoring stations were calibrated every two weeks during the 2010 monitoring season following procedures outlined in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring 2010* (USCOE 2009). 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 2010 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 TDG saturations of 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 total dissolved gas 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. As shown in Figure 4, the majority of data were generally within 10 mm Hg difference between the field sensor and the secondary standard with outliers ranging up to 15 mm Hg at CHJ and 20 mm Hg at CHQW. The cause of the outlier points 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 waiver by WDOE for the 2010 spill season for the purpose of managing system spill for improved fish conditions.

Results and Discussion

Total Dissolved Gas

Chief Joseph Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Chief Joseph Dam during the 2010 monitoring season are presented in Figure 5. Columbia River flow volumes were moderate to high during 2010 with maximum flows generally in the 180,000 to 220,000 cfs range, with flows recorded between June 20, 2010 and June 22, 2010 greater than the seven-day average 10-year return (7Q10) flood flow of 222,000 cfs. Consequently, Chief Joseph Dam experienced moderate spill volumes during the 2010 season. Spill at Chief Joseph occurred between June 7, 2010 and July 2, 2010 with spill volumes ranging from about 25,000 cfs to 107,000 cfs (Figure 5).

Total dissolved gas saturations at Chief Joseph forebay station (CHJ) exceeded 110 percent from about early June to early August 2010. Because little degassing occurs during transport through Lake Rufus Woods, TDG levels measured at the Chief Joseph forebay station are likely a function of TDG levels released from Grand Coulee Dam. Forebay TDG concentrations exceeded 115 percent periodically from June 12, 2010 to July 1, 2010 with a maximum concentration of about 118 percent measured on June 23, 2010. Chief Joseph tailwater station (CHQW) exceeded 110 percent TDG saturation from about early June to early August, 2010. The tailwater station exceeded 120 percent from June 20, 2010 to June 21, 2010 during spillway releases ranging from 99,000 cfs to 107,000 cfs. A maximum TDG concentration of 124.8 percent was measured during a 107,000 cfs spill on June 10, 2010.

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 19 °C in early September (see Figure 5). 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, 2010, and were greater than 18 °C from mid to late August through the end of the monitoring on September 30, 2010. Water temperatures at the tailwater exceeded 18 °C from about mid to late August until the end of monitoring on September 30, 2010.

Conclusions

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

- Data completeness for both TDG and temperature data at Chief Joseph Dam was 100 percent at CHJ and CHQW. No data were missing or rejected at either stations CHJ or 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, 0.2°C of the secondary standard thermometer, and 10 mm Hg saturation of the secondary standard TDG instrument.
- Total dissolved gas saturations at Chief Joseph forebay station (CHJ) exceeded 110 percent from about early June to early August 2010. Forebay TDG concentrations exceeded 115 percent periodically in late June with a maximum concentration of about 118 percent measured on June 23, 2010. Chief Joseph tailwater station (CHQW) exceeded 110 percent TDG saturation from about early June to early August, 2010. The tailwater station exceeded 120 percent from June 20, 2010 to June 21, 2010 during spillway releases ranging from 99,000 cfs to 107,000 cfs. A maximum TDG concentration of 124.8 percent was measured during a 107,000 cfs spill on June 10, 2010.
- Water temperatures at the Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) were greater than 16 °C and 18 °C from about late July through September and mid to late August through September, respectively.

References

Schneider, M.L. and Carroll, J.C. 1999. TDG exchange during spillway releases at Chief Joseph Dam, near-field study, June 6-10, 1999. Prepared for the Seattle District Corps of Engineers by the U.S. Army Waterways Experiment Station, Vicksburg, MS.

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Weitkamp, D.E. 1980. A review of dissolved gas supersaturation literature. *Transactions of the American Fisheries Society*, 109:659-702.

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Tables

Table 1. Fixed monitoring station locations and sampling period, spill season 2010.

Site Identifier	Station Name	Latitude	Longitude	2010 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	04/01/10 - 09/30/10
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	04/01/10 - 09/30/10

Table 2. Total dissolved gas data completeness for spill season 2010

Station Name	Station Abbreviation	Planned monitoring in hours	Number of missing hourly values	Percentage of real-time TDG monitoring data received	Percentage of real-time TDG data received and passing quality assurance
Chief Joseph Forebay	CHJ	4392	0	100.0	100.0
Chief Joseph Tailwater	CHQW	4392	0	100.0	100.0

Table 3. Temperature data completeness for spill season 2010.

Station Name	Station Abbreviation	Planned monitoring in hours	Number of missing hourly values	Percentage of real-time Temperature monitoring data received	Percentage of real-time Temperature data received and passing quality assurance
Chief Joseph Forebay	CHJ	4392	0	100.0	100.0
Chief Joseph Tailwater	CHQW	4392	0	100.0	100.0

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 total dissolved gas instrument and thermometer for spill season 2010.

	Temperature	Total Dissolved Gas Pressure (% Saturation)			
	°C	100%	113%	126%	139%
Num	42	42	42	42	42
min	-0.10	-0.21	-0.21	-0.21	-0.21
max	0.17	0.27	0.34	0.34	0.27
median	0.03	0.04	0.08	0.08	0.02
avg	0.04	0.03	0.06	0.06	0.01
sd	0.06	0.11	0.12	0.12	0.12

Table 6. Washington Department of Ecology (WDOE), Idaho Department of Environmental Quality (IDEQ), Montana Department of Environmental Quality (MDEQ), and Colville Confederated Tribe (CCT) water quality standards.

Parameter/ Project	Regulator	Standard
Total Dissolved Gas		
Chief Joseph	WDOE	<p>Shall not exceed 110% of saturation at any point of sample collection, except during spill season for fish passage in which total dissolved gas shall be measured as follows:</p> <p>(1) Must not exceed an average of 115% as measured in the forebay of the next downstream dam.</p> <p>(2) Must not exceed an average of 120% 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.</p> <p>(3) A maximum TDG one-hour average of 125% as measured in the tailrace must not be exceeded during spillage for fish passage.</p>
	CCT	Shall not exceed 110% of saturation 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	<p>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.</p> <p>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.</p>

Figures



Figure 1. Location of Seattle District projects in the upper Columbia River basin.



Figure 2. Locations of total dissolved gas monitoring stations in 2010 for Chief Joseph Dam, Washington.

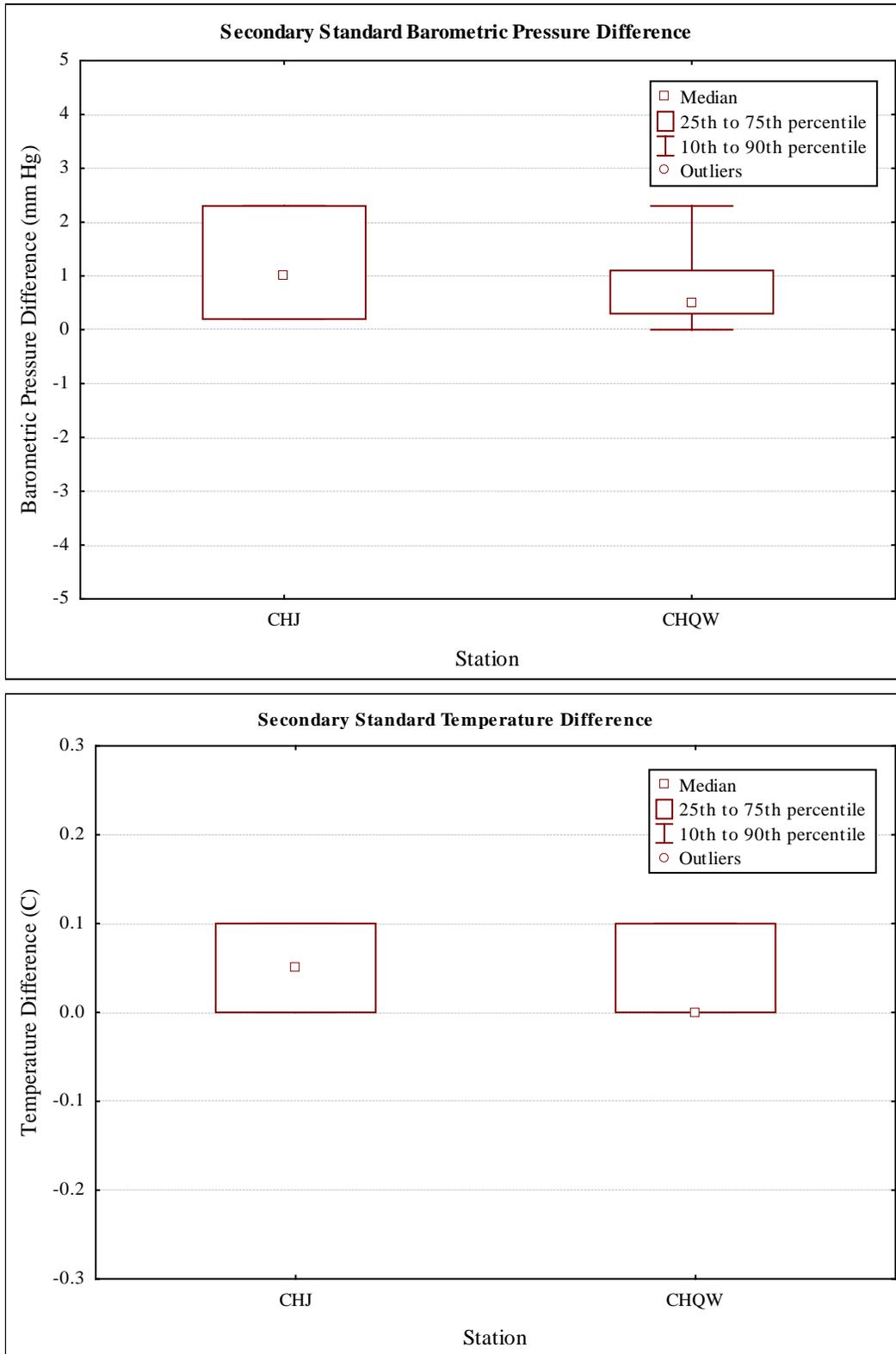


Figure 3. Difference between the secondary standard and the field barometers and field thermometers during spill season 2010.

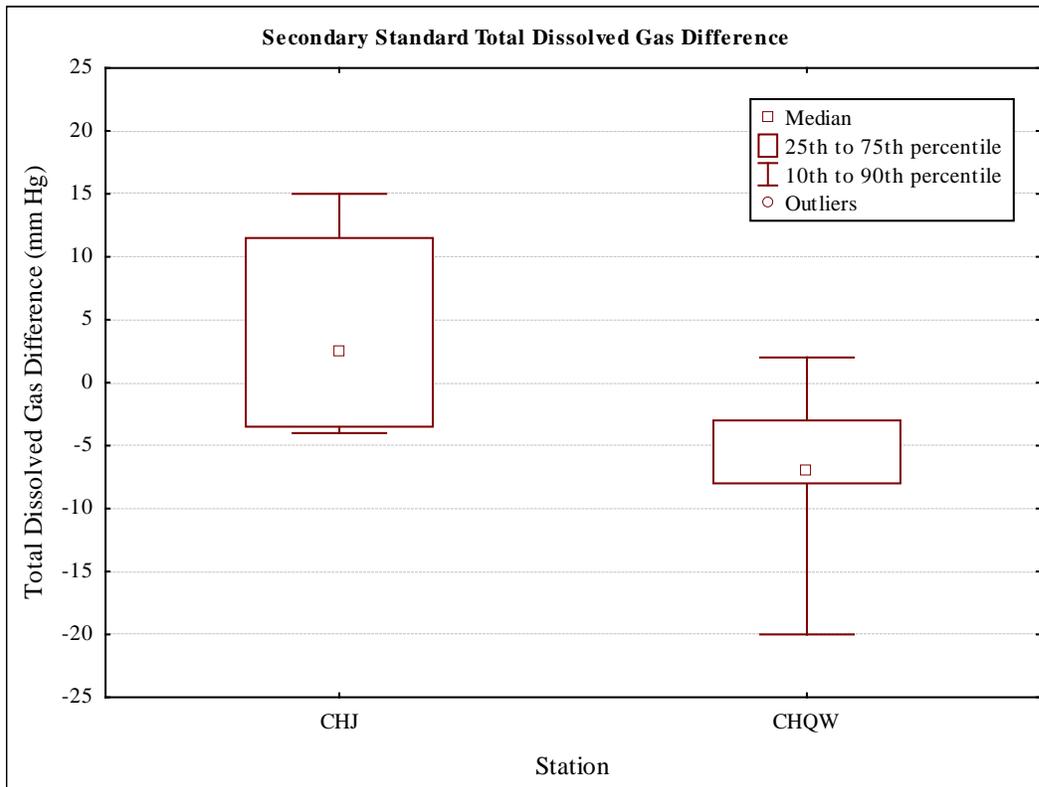


Figure 4. Difference between the secondary standard and the field total dissolved gas instrument for TDG pressure during spill season 2010.

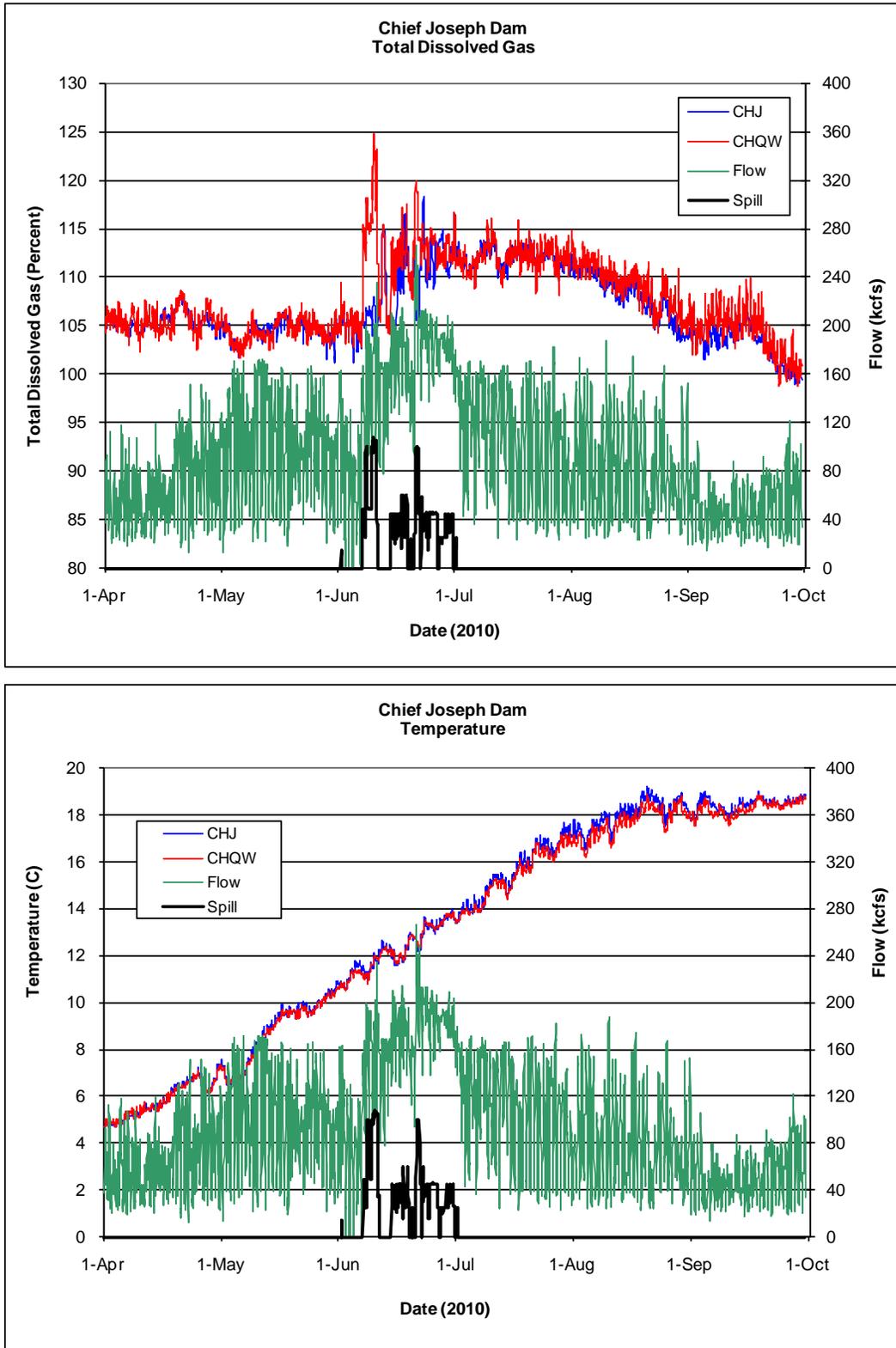


Figure 5. Total dissolved gas, spill, and flow (upper panel) and temperature, spill, and flow (lower panel) at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2010.