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Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana 2009: Data Review and Quality Assurance

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Contents

Tables

Figures

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 rivers 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, Albeni Falls Dam, and Libby Dam during the 2009 spill season, which lasted from April 1 – September 30, 2009. 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, Albeni Falls Dam, and Libby Dam monitoring programs.

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 to 145 kcfs during this study. After the TDG study, construction on the spillway in 2009 at Chief Joseph Dam restricted the number of spillway bays available at the project to 14 out of 19 spillway bays.

Albeni Falls Dam

Albeni Falls Dam is located near the Washington-Idaho border on the Pend Oreille River at river mile 90.1. The dam became operational in 1952 and is about 2.5 miles upstream and east of the city of Newport, Washington, 26 miles west of the city of Sandpoint, Idaho, and 29 miles downstream from Lake Pend Oreille (Figure 1). Lake Pend Oreille is a natural lake that is located in a glacially scoured basin in the Purcell Trench in Northern Idaho (Fields et al. 1996). The Clark Fork is the major inflow to the lake supplying about 85 percent of the surface water inflow to the lake and the outlet arm (Frenzel, 1991). The dam is formed by two separate concrete gravity structures, a 10-bay spillway on the left or southwest side of the river and a powerhouse on the right or northeast side of the river. Total dissolved gas exchange studies conducted by Schneider (2004) concluded that spillway releases resulted in small increases in TDG pressures in the Pend Oreille River. Results showed the TDG exchange during spillway operations increased as a function of forebay TDG pressure, tailwater depth, unit spillway discharge, total head, and spillway gate submergence.

Libby Dam

Libby Dam is located at river mile 221.9 on the Kootenai River in Montana about 40 miles south of the Canadian border, as shown in Figure 1. The dam is approximately 11 miles east of the town of Libby, Montana and 221.9 miles upstream from the confluence of the Kootenai River with the Columbia River in British Columbia. Behind Libby Dam, Lake Koocanusa extends 90 miles, with about 48 miles extending into British Columbia. The dam is a straight concrete gravity gate-controlled dam, 370 feet high, with two spillway bays. Total dissolved gas exchange studies conducted by Schneider and Carroll (2003) showed that spillway releases at Libby Dam resulted in elevated TDG pressures in the Kootenai River. The TDG saturation in spillway releases increased abruptly from 104 to 129 percent saturation as the spill discharge increased from 0 to 4,000 cfs. A mild increase in TDG saturation of spillway releases of 129 to 134 percent saturation was observed as spillway discharges increased from 4,000 to 15,000 cfs.

Data Collection

Data were collected at two fixed monitoring stations at Chief Joseph Dam (CHJ and CHQW) and Albeni Falls Dam (ALFI and ALQI), and one fixed monitoring station at Libby Dam (LBQM) during the 2009 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 2009* (USCOE 2008). Data collection methods used at Chief Joseph Dam, Albeni Falls Dam and Libby Dam were slightly different and are briefly summarized below. 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.

Instrumentation at Albeni Falls Dam consisted of a Hydrolab MiniSonde 4a water quality probe, a Common Sensing TBO-L electronic barometer, a Sutron 9210 XLite DCP, a radio transmitter, and a power source. The TDG probe, DCP, and radio transmitter were powered by a 12-volt battery that was charged by either a 120-volt AC line at ALFI or a solar panel at ALQI. 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 FTP to the CROHMS database in Portland, Oregon.

Instrumentation at Libby Dam consisted of a Hydrolab MiniSonde 4a water quality probe, a Common Sensing TBO-L electronic barometer, a Sutron 9210 XLite DCP, a radio transmitter, and a power source. The TDG probe, DCP, and radio transmitter were located on the left bank of the Kootenai River and powered by a 12-volt battery that was charged by a solar panel. 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 FTP to the CROHMS database in Portland, Oregon.

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.

At Albeni Falls Dam forebay station (ALFI) the water quality probe was located in the Pend Oreille River on the left bank near the spillway. The probe was placed inside a perforated HDPE pipe that was anchored to the railroad bridge footing and extended into the river to a depth of at least 10 feet during low river level conditions (see Figure 2). At Albeni Falls Dam tailwater station (ALQI) the water quality probe was deployed along the left bank of the river, 0.5 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.

At the Libby Dam tailwater station (LBQM) the water quality probe was deployed along the left bank of the river, 0.6 miles downstream from the dam at the USGS gaging station (No. 12301933) located below Libby Dam (Figure 2). Similar to stations CHQW and ALQI, the probe was placed inside an anchored perforated PVC pipe that extended into the Kootenai River to a depth of at least 6 feet during low flow conditions.

Data Completeness

Data completeness and quality for TDG and temperature data collected in 2009 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, problems with receiving real-time hourly TDG and temperature data were encountered at all monitoring stations. Missing data for all stations in 2009 were largely due to DCP malfunctions and programming problems. In general, these problems occurred during the first 2 weeks of April and were resolved by mid April. A total of 168 hours of TDG data were rejected at station ALQI due to the probe being too shallow or out of the water, and erroneous barometric pressures. A total of 68 hours of temperature data were rejected at station ALQI due to the probe being too shallow or out of the water. Only 2 hours of TDG and temperature data were rejected at station ALFI due to the probe being out of the water during routine calibration periods. No data was rejected at station CHJ, CHQW, and LBQM.

Quality-Assurance Procedures

Fixed monitoring stations were calibrated every two weeks during the 2009 monitoring season following procedures outlined in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring 2009* (USCOE 2008). 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 (ten probes total) 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 2009 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 at all stations were generally within 10 mm Hg difference between the field sensor and the secondary standard with outliers ranging from 12 mm Hg at LBQM to 23 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 Idaho Department of Environmental Quality (IDEQ) determines water quality criteria for the Pend Oreille River at Albeni Falls Dam in Idaho, and the Montana Department of Environmental Quality (MDEQ) determines water quality criteria for the Kootenai River at Libby Dam in Montana. In addition, because Albeni Falls Dam is near the border of Washington State, WDOE water quality criteria are considered.

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. The IDEQ has classified the Pend Oreille River at Albeni Falls Dam as an Aquatic Life Cold waterbody, while the WDOE has classified the Pend Oreille River at the Idaho/Washington border as a Non-Core Salmon/Trout Special Condition water body. The MDEQ has classified the Kootenai River below Libby Dam as a Class B-1 water body. Water quality standards for TDG and temperature for Chief Joseph Dam, Albeni Falls Dam and Libby 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 2009 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 2009 monitoring season are presented in Figure 5. Columbia River flow volumes were moderate during 2009 with maximum flows generally in the 160,000 to 180,000 cfs range from the end of May through June. Consequently, Chief Joseph Dam only spilled three times (spill volumes ranging from 40,000 to 100,000 cfs) during this time period (Figure 5). A TDG exchange study was conducted from April 28 to May 1, 2009. Spill volumes during the study ranged from 18,000 to 145,000 cfs (Figure 5).

Total dissolved gas saturations at Chief Joseph forebay station (CHJ) exceeded 110 percent from about the beginning of June to the beginning of August 2009. 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 in early July with a maximum concentration of about 117 percent measured on July 5, 2009. Except for the spill test conducted from April 28 to May 1, 2009, the Chief Joseph tailwater station (CHQW) exceeded 110 percent TDG saturation from about the beginning of June to the beginning of August, 2009. The tailwater station exceeded 120 percent only during a 100,000 cfs spill on June 6, 2009.

Albeni Falls Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Albeni Falls Dam during the 2009 monitoring season are presented in Figure 6. Pend Oreille River flow volumes were moderate during 2009 with a maximum flow of about 76,000 cfs recorded between June 1 and June 4, 2009, which is similar to the historical (1952-1998) post-dam average maximum flow of about 80,000 cfs. Consequently, Albeni Falls Dam experienced average spill volumes during the 2009 season. Spillway flows ranged from about 2,000 to 51,000 cfs, with the majority of spill occurring between early May and late June.

Total dissolved gas saturations at Albeni Falls forebay station (ALFI) were periodically greater than 110 percent during the 2009 season, generally from late May to mid June (Figure 6). The nearest upstream project that could be a potential source of TDG to the forebay is Cabinet Gorge Dam located about 50 miles upstream on the Clark Fork River at the border of Idaho and Montana (see Figure 1). Parametrix (1999) reported that only minor degassing occurred in the Clark Fork-Pend Oreille River system between Cabinet Gorge Dam and Albeni Falls Dam during the 1998 spill season. Therefore, it is likely that Cabinet Gorge Dam was the source of the elevated TDG measured at the forebay.

Total dissolved gas saturations at Albeni Falls tailwater station (ALQI) exceeded 110 percent from about mid May to mid June (Figure 6). The highest TDG saturation recorded was about 116 percent on May 31, 2009 during a spillway release of about 45,000 cfs. Small differences in TDG concentrations between the forebay (ALFI) and tailwater (ALQI) stations were noted during these higher spillway events in late May. In general, the greatest increase in TDG saturations between the forebay and tailwater were measured in early May during spillway releases of less than 40,000 cfs. In general, TDG saturations decrease at Albeni Falls when the spill is spread out over at least 8 of 10 spill bays or when the project operates on free-flow. This reduction in TDG generation by spreading the spill out over more spill bays or on free-flow was observed during the total dissolved gas exchange study conducted at Albeni Falls in 2003 (Schneider 2007).

Libby Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Libby Dam during the 2009 monitoring season are presented in Figure 7. No spill occurred at Libby Dam in 2009. Total dissolved gas saturations ranged from about 96 percent to 110 percent, with TDG concentrations exceeding 110 percent for four hours from 1500 to 1800 hours on August 31, 2009. The increase in TDG during non-spill conditions was likely related to a decrease in outflow from Libby Dam resulting in on unit being operated at a low efficiency. To prevent the unit from running rough air was injected into the unit resulting in the spike in TDG concentrations measured at the tailwater station (Figure 7). Such TDG spikes occurring during decreased outflow events at Libby Dam were observed in 2008.

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 mid July through the end of monitoring on September 30, 2009, and were greater than 18 °C from mid August through the end of the monitoring on September 30, 2009. Water temperatures at the tailwater exceeded 18 °C from about mid August until the end of monitoring on September 30, 2009.

Albeni Falls Dam

Temperatures measured at the Albeni Falls forebay (ALFI) and tailwater (ALFW/ALQI) stations were similar, and ranged from about 5 °C in April to 24 °C in August (see Figure 6). The similar water temperatures at the forebay and tailwater stations indicate well-mixed conditions in the forebay. Daily average water temperatures at the forebay (ALFI) and tailwater (ALQI) were greater than 19 °C from about early July through mid September, while the maximum daily temperature exceeded 22 °C from about mid July to early August. Diurnal temperature cycling was minor at both the forebay station (ALFI) and the tailwater station (ALQI) and generally in the range of 1 °C.

Libby Dam

Temperature measured at the Libby Dam tailwater (LBQM) station ranged from about 4 °C in April to about 17°C in July (see Figure 7). Temperatures at Libby Dam are controlled by a selective withdrawal system. This system is operated to better reflect pre-impoundment temperature conditions in the river. In 2009, as the waters in Lake Koocanusa begin to thermally stratify in April and May, the selective withdrawal system was operated to intake water from shallower depths to increase discharge temperatures and produce more natural downstream water temperatures to benefit aquatic organisms. As seen in Figure 7, temperature increases and decreases during May through August represent operational changes in the selective withdrawal system.

Conclusions

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

- Data completeness for TDG data ranged from 90.1 percent at the Albeni Falls Dam tailwater station (ALQI) to 99.2 percent at the Albeni Falls Dam forebay station (ALFI), and for temperature data ranged from 92.3 percent at the Albeni Falls Dam tailwater station (ALQI) to 99.4 percent at the Albeni Falls Dam forebay station (ALFI). At the majority of stations, missing data were largely due to DCP malfunctions and programming problems. A total of 168 hours of TDG data were rejected at station ALQI due to the probe being too shallow or out of the water, and erroneous barometric pressures. A total of 68 hours of temperature data were rejected at station ALQI due to the probe being too shallow or out of the water.

- 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 saturation of the secondary standard TDG instrument.

- Total dissolved gas saturations at Chief Joseph forebay station (CHJ) exceeded 110 percent from about the beginning of June to the beginning of August 2009. Forebay TDG concentrations exceeded 115 percent in early July with a maximum concentration of about 117 percent measured on July 5, 2009. Except for the spill test conducted from April 28 to May 1, 2009, the Chief Joseph tailwater station (CHQW) exceeded 110 percent TDG saturation from about the beginning of June to the beginning of August, 2009. The tailwater station exceeded 120 percent only during a 100,000 cfs spill on June 6, 2009.

- Total dissolved gas saturations at Albeni Falls forebay station (ALFI) were periodically greater than 110 percent during the 2009 season, generally from late May to mid June. Total dissolved gas saturations at Albeni Falls tailwater station (ALQI) exceeded 110 percent from about mid May to mid June. The highest TDG saturation recorded was about 116 percent on May 31, 2009 during a spillway release of about 45,000 cfs.

- Total dissolved gas saturations at Libby Dam ranged from about 96 percent to 110 percent, with TDG concentrations exceeding 110 percent for four hours on August 31, 2009. The increase in TDG during non-spill conditions was likely related to a decrease in outflow from Libby Dam resulting in on unit being operated at a low efficiency. To prevent the unit from running too rough, air was injected into the unit resulting in the spike in TDG concentrations measured at the tailwater station

- Water temperatures at the Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) were greater than 16 °C and 18 °C from about mid July through September and mid August through September, respectively. Water temperatures at Albeni Falls Dam forebay (ALFI) and tailwater (ALFW/ALQI) were greater than 19 °C from about early July through mid September, and greater than 22 °C from about mid July through early August. Temperatures measured at the Libby Dam tailwater (LBQM) station ranged from about 4 °C in April to 17 °C in July.

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Tables

Table 1. Fixed monitoring station locations and sampling period, spill season 2009.

Site Identifier	Station Name	Latitude	Longitude	2009 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	04/01/09 - 09/30/09
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	04/01/09 - 09/30/09
ALFI	Albeni Falls Dam Forebay	48° 10' 40"	116° 59' 52"	04/01/09 - 09/30/09
ALQI	Albeni Falls Dam Tailwater	48° 10' 39"	117° 00' 08"	04/01/09 - 09/30/09
LBQM	Libby Dam Tailwater	48° 19' 07"	115° 19' 07"	04/01/09 - 09/30/09

Table 2. Total dissolved gas data completeness for spill season 2009.

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	90	98.0	98.0
Chief Joseph Tailwater	CHQW	4392	93	97.9	97.9
Albeni Falls Forebay	ALFI	4392	35	99.2	99.2
Albeni Falls Tailwater	ALQI	4392	269	93.9	90.1
Libby Tailwater	LBQM	4392	54	98.8	98.8

Table 3. Temperature data completeness for spill season 2009.

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	91	97.9	97.9
Chief Joseph Tailwater	CHQW	4392	93	97.9	97.9
Albeni Falls Forebay	ALFI	4392	28	99.4	99.4
Albeni Falls Tailwater	ALQI	4392	269	93.9	92.3
Libby Tailwater	LBQM	4392	53	98.8	98.8

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 2009.

	Temperature	Total Dissolved Gas Pressure (% Saturation)			
	°C	100%	113%	126%	139%
N	77	77	77	77	77
Minimum	-0.05	-0.41	-0.28	-0.28	-0.41
Maximum	0.11	1.24	1.10	0.82	0.77
Median	0.04	0.04	0.04	0.04	-0.04
Average	0.05	0.02	0.05	0.04	-0.02
Standard Deviation	0.04	0.20	0.19	0.17	0.17

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	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: (1) Must not exceed an average of 115% as measured in the forebay of the next downstream dam. (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. (3) A maximum TDG one-hour average of 125% as measured in the tailrace must not be exceeded during spillage for fish passage.
	CCT	Shall not exceed 110% of saturation at any point of sample collection.
Albeni Falls	IDEQ	Shall not exceed 110% of saturation at any point of sample collection.
	WDOE	Shall not exceed 110% of saturation at any point of sample collection.
Libby	MDEQ	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	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.
Albeni Falls	IDEQ	Aquatic Life Cold: Water temperatures of 22°C or less with a maximum daily average less than 19°C.
	WDOE	Non-Core Salmon/Trout Special Condition: Temperature shall not exceed a 1-DMax of 20°C due to human activities. When natural conditions exceeds the criteria, no temperature increase will be allowed which will raise the receiving water by greater than 0.3°C.
Libby	MDEQ	Class B-1: A 0.6°C maximum increase above naturally occurring water temperature is allowed within the range 0°C to 18°C; within the naturally occurring range 18°C to 19°C, no discharge is allowed which causes the water temperature to exceed 19.5°C.

Figures

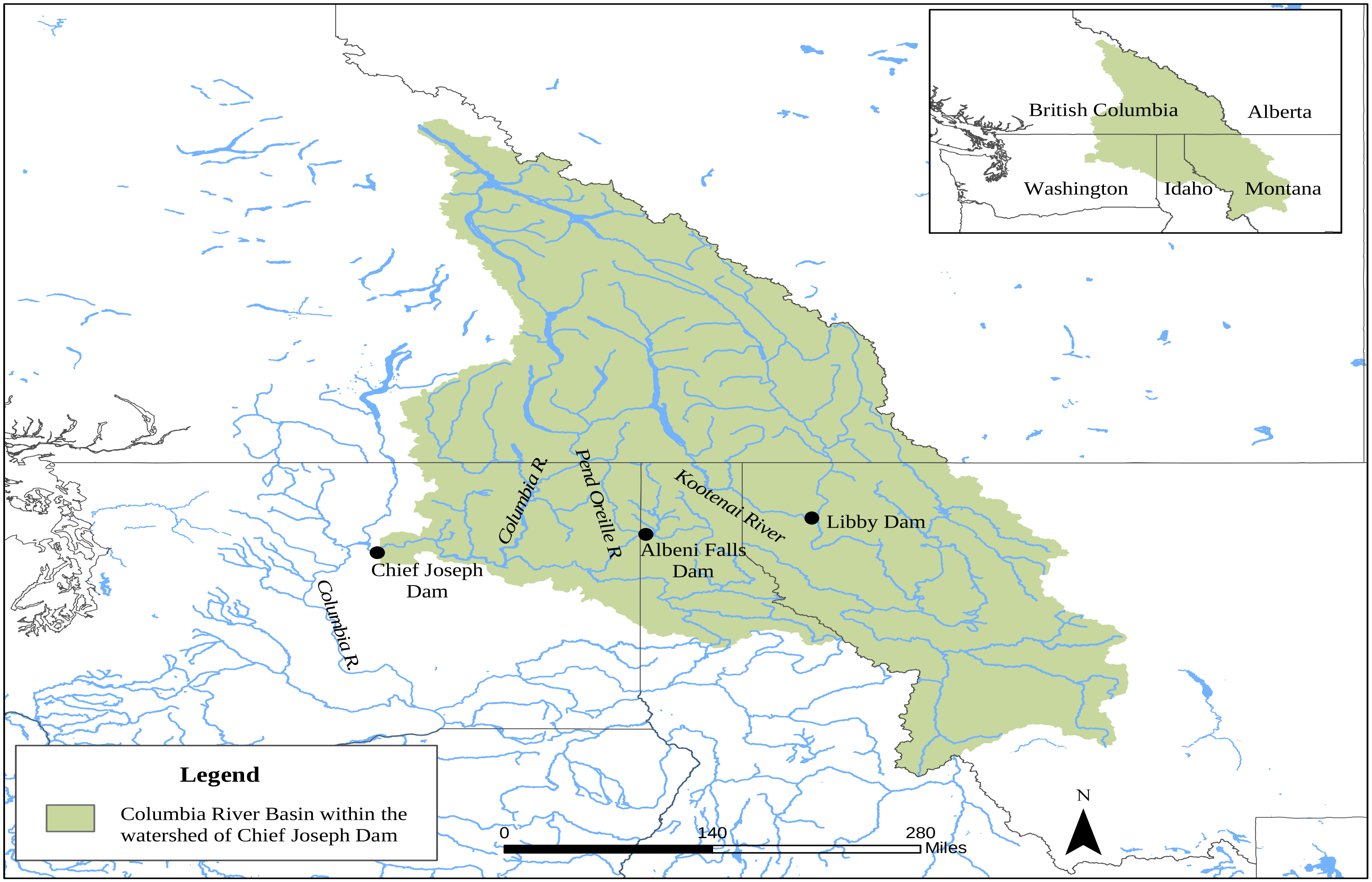


Figure 1. Location of Seattle District projects in the upper Columbia River basin.

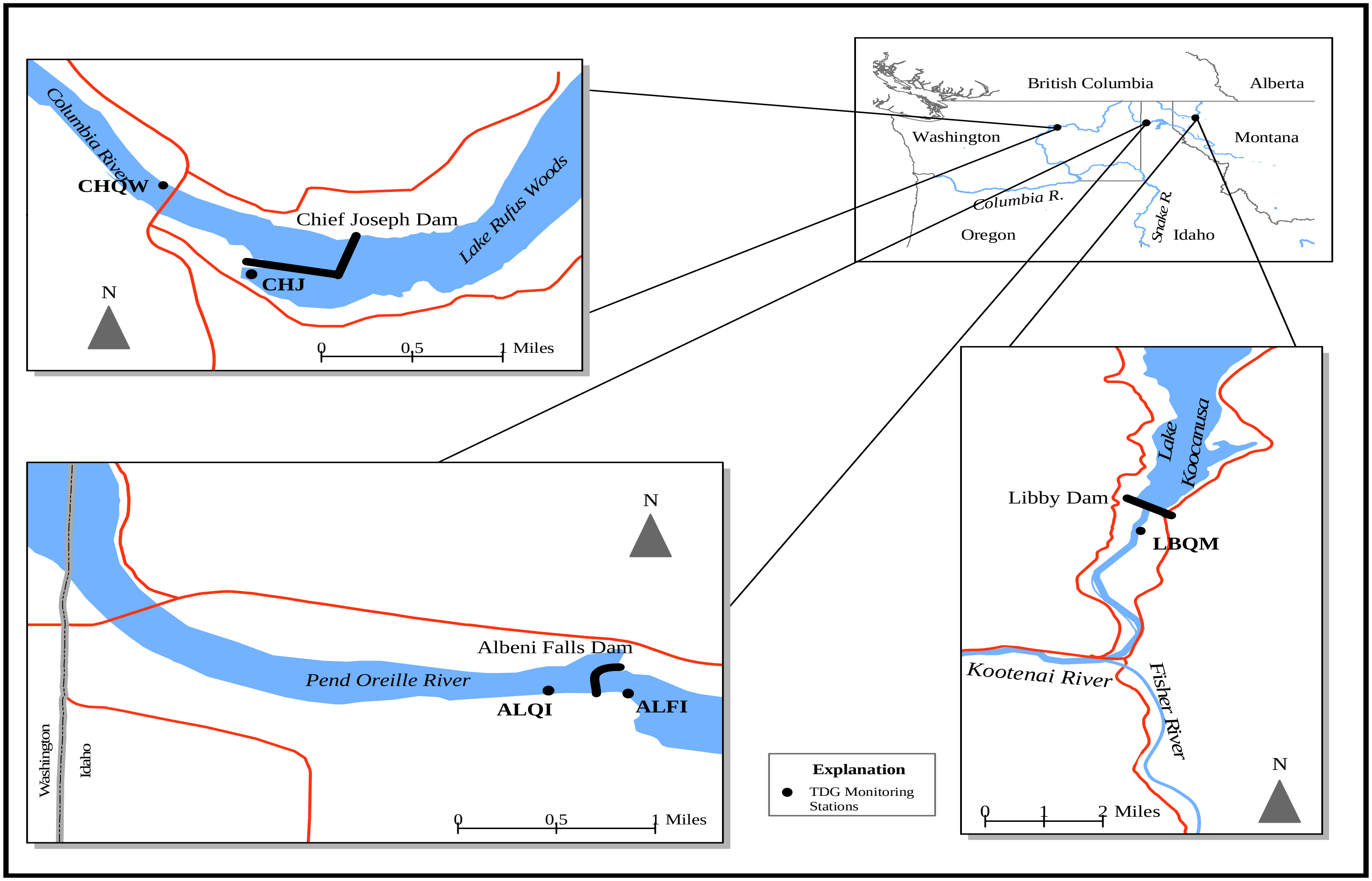
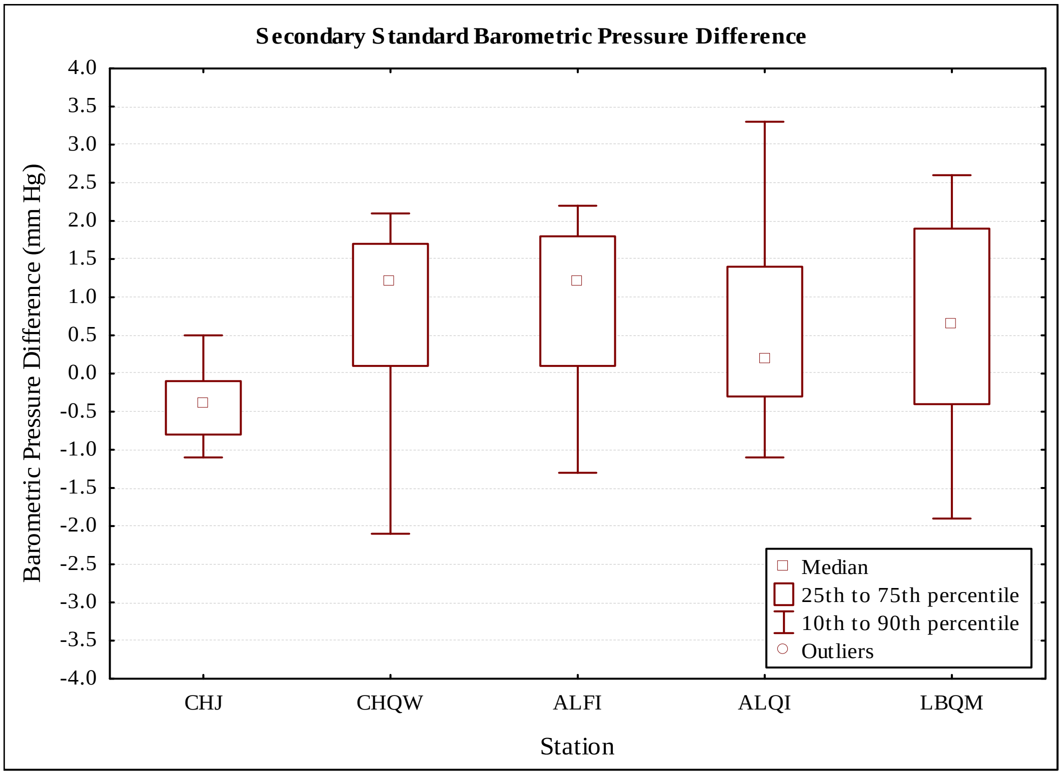


Figure 2. Locations of total dissolved gas monitoring stations in 2009 for Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana.



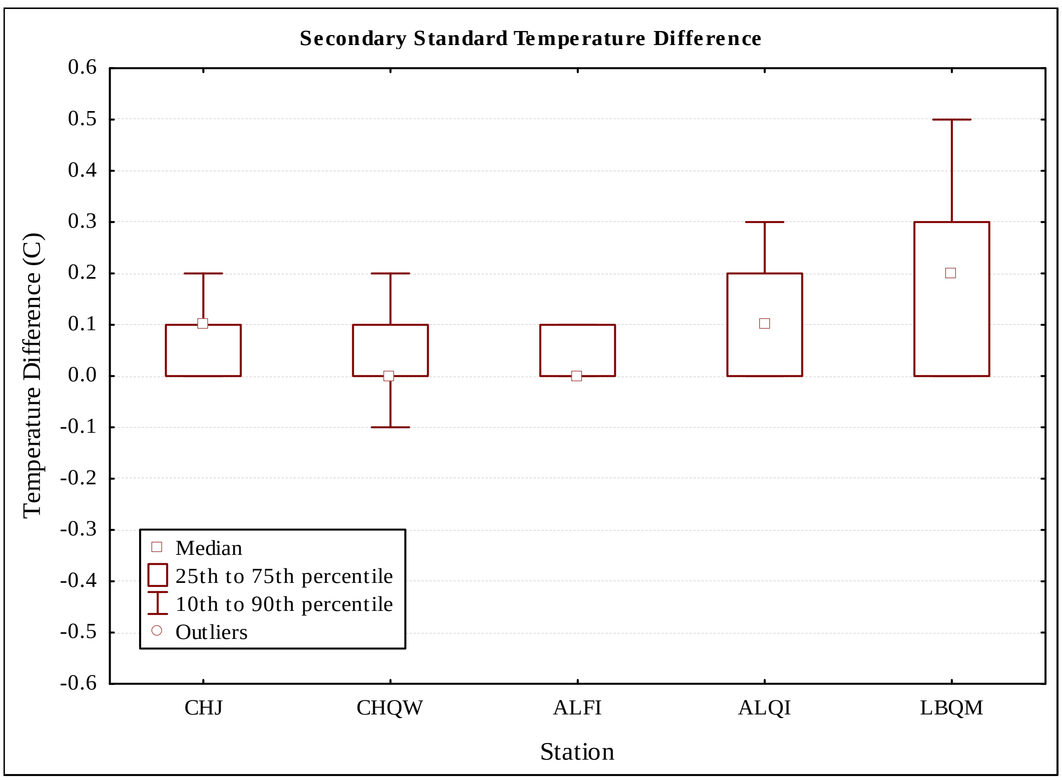


Figure 3. Difference between the secondary standard and the field barometers and field thermometers during spill season 2009.

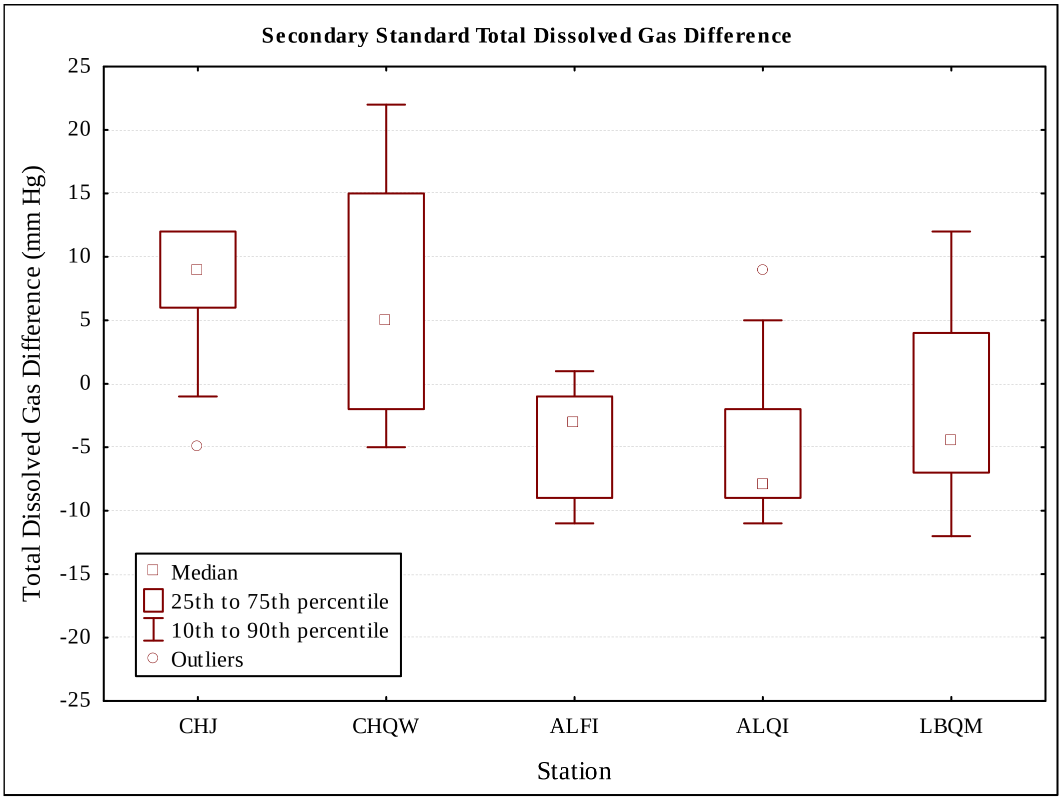


Figure 4. Difference between the secondary standard and the field total dissolved gas instrument for TDG pressure during spill season 2009.

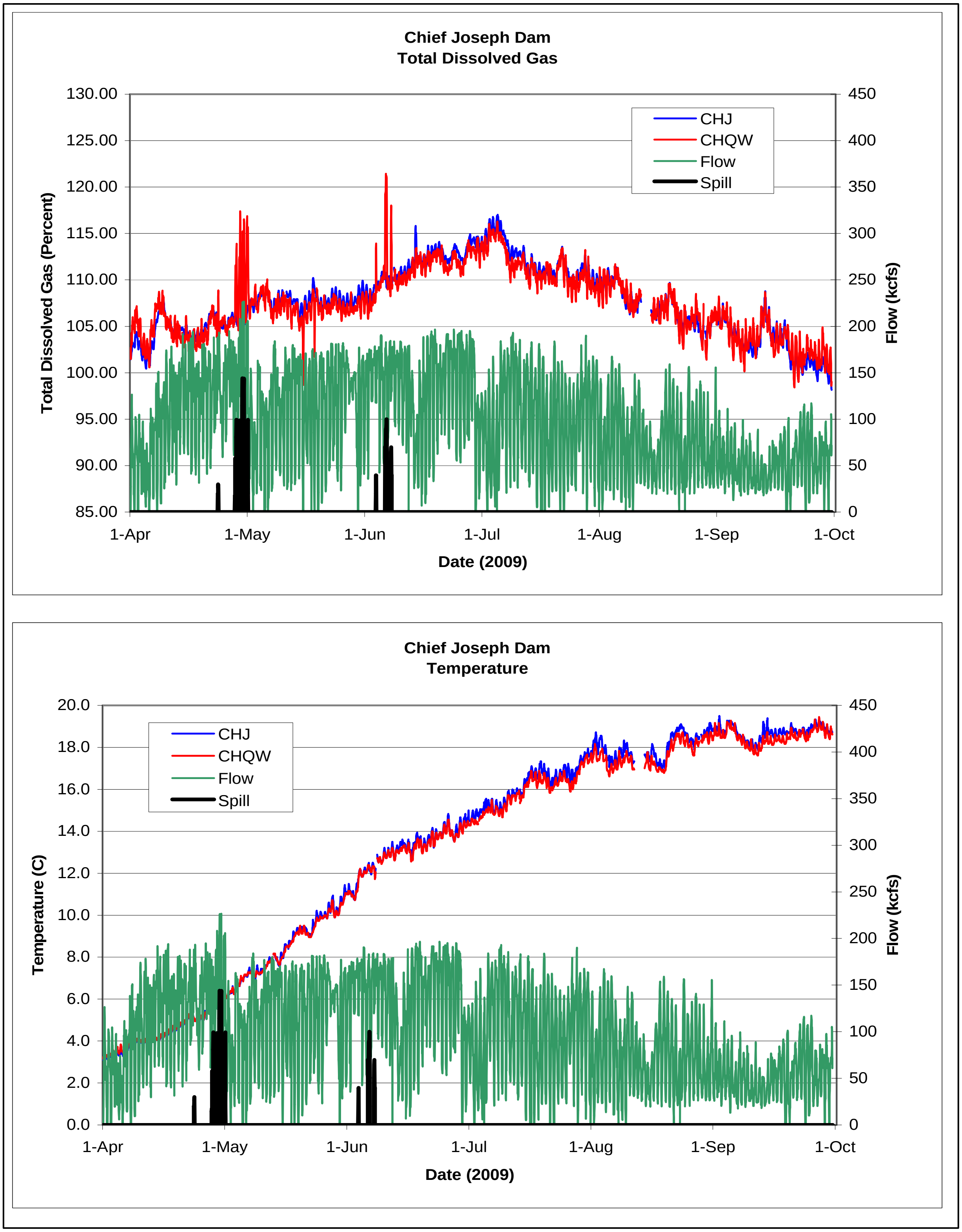


Figure 5. Total dissolved gas, spill, and flow (upper panel) and temperature, spill, and flow (lower panel) at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2009.

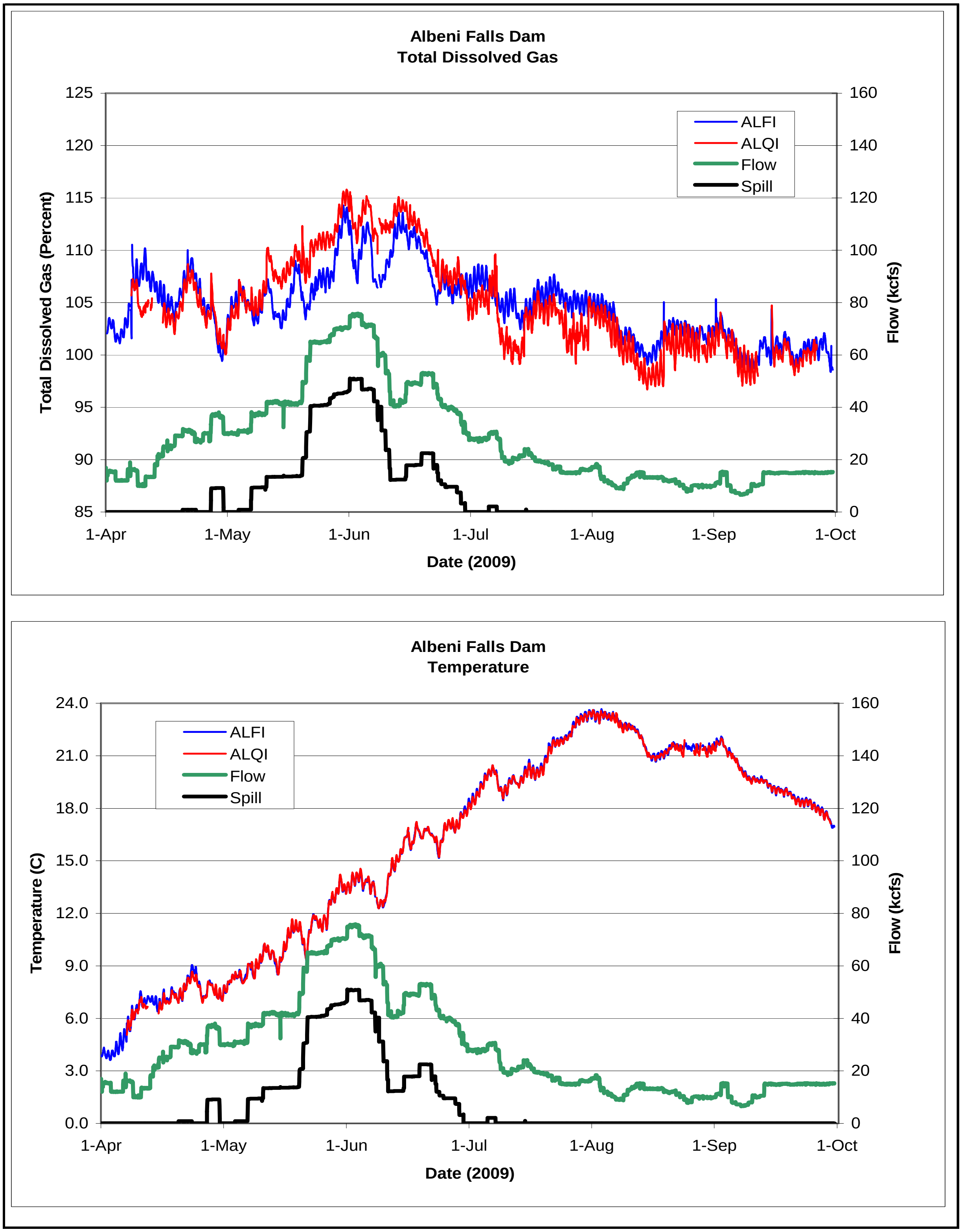


Figure 6. Total dissolved gas, spill, and flow (upper panel) and temperature, spill, and flow (lower panel) at Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALQI) stations during spill season 2009.

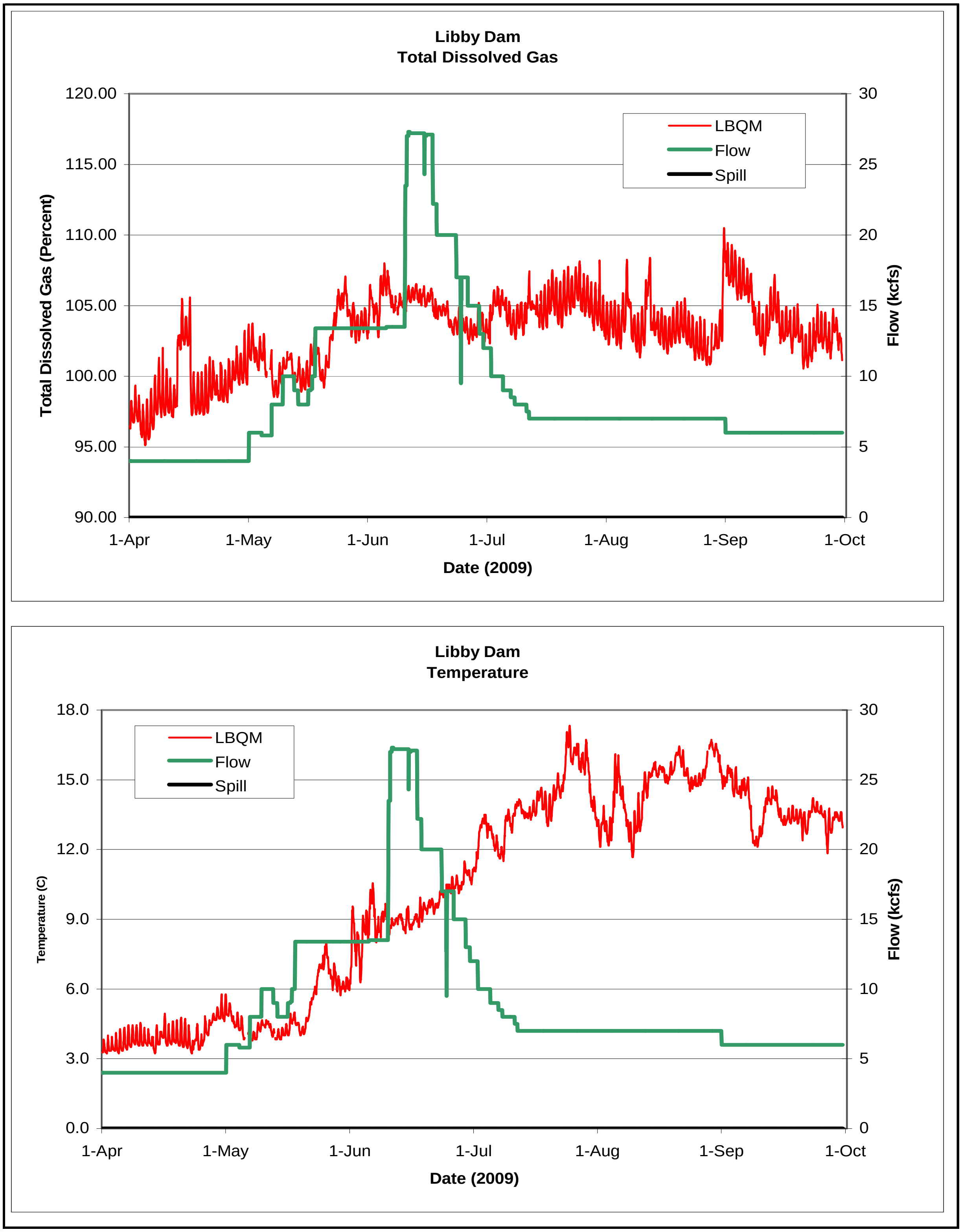


Figure 7. Total dissolved gas, spill, and flow (upper panel) and temperature, spill, and flow (lower panel) at the Libby Dam Tailwater (LBQM) station during spill season 2009.