Appendix I

Seattle District TDG Report (Includes Albeni Falls, Chief Joseph, and Libby)

Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana 2006: 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 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 2006 spill season, which lasted from April 1 – September 30, 2006. 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 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.

Construction of spillway deflectors began at Chief Joseph Dam during 2006. Barges containing construction equipment were anchored below the Chief Joseph Dam spillway during the months of May and June which restricted the number of spillway bays available at the project. Typically, Chief Joseph Dam can spill from up to 19 spillway bays. However, during 2006 the project was only able to spill from a maximum of 11 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 2006 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 2006* (USCOE 2005). 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 Geomation 2380 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 Geomation 2380 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 Geomation 2380 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 2006 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 station CHJ, CHQW, and ALQI were largely due to DCP malfunctions and programming problems. No data were rejected from these stations. Missing data for stations ALFI were due to DCP malfunctions and programming problems, and high flows. High flows at station ALFI resulted in the real-time probe being removed from the station from May 23, 2006 at 1000 hours to June 29, 2006 at 2200 hours to avoid being damaged by high flows on the Pend Oreille River. Temperature and TDG data were missing at station ALFI from May 23, 2006 at 1000 hours to May 30, 2006 at 1400 hours when a TDG logger was deployed at the station and data were collected until station ALFI was brought online on June 29, 2006 at 2200 hours. No data were rejected at station ALFI. Missing data for station LBQM were due to DCP malfunctions and programming problems, and lightning strikes. No data were rejected at station LBQM.

Quality-Assurance Procedures

Fixed monitoring stations were calibrated every two weeks during the 2006 monitoring season following procedures outlined in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring 2006* (USCOE 2005). 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 2006 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 within 0.2 °C at all locations except the Albeni Falls tailwater station (ALQI).

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 2 percent saturation difference between the field sensor and the secondary standard, except at the Albeni Falls forebay station (ALFI) and tailwater station (ALQI). At ALFI the data were within 2 percent saturation difference except for a 6.7 percent difference on April 12, 2006. This cause of this minor outlier point was not determined and the TDG probe and membrane appeared to be operating properly. At ALQI the data were generally within 2 percent saturation difference except for a 5.1 percent difference on May 23, 2006. Similar to station ALFI, the cause of the minor outlier point was not determined and the TDG probe and membrane appeared to be operating properly.

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. In 2003 the WDOE proposed updating their 1997 water quality standards for temperature. However, the Environmental Protection Agency (EPA) has not approved these revised standards and therefore WDOE continues to use the 1997 total dissolved gas and temperature standards until EPA approval is received. The 1997 WDOE standards classified the Columbia River above and below Chief Joseph Dam as a Class A 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 Class A 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 2006 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 2006 monitoring season are presented in Figure 5. Columbia River flow volumes were moderate to high during 2006 with maximum flows generally in the 180,000 to 220,000 cfs range, with flows recorded between May 27, 2006 and May 30, 2006 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 2006 season. Spill volumes generally ranged from about 21,000 cfs to 35,000 cfs from May 25, 2006 at 2200 hours to June 16, 2006 at 2000 with a maximum spill volume of 54,500 cfs on May 29, 2006 at 2300 hours (Figure 5).

Total dissolved gas saturations at Chief Joseph forebay station (CHJ) exceeded 110 percent from about May 11, 2006 to August 10, 2006, and exceeded 115 percent from about July 5, 2006 to July 23, 2006. 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. The Chief Joseph tailwater station (CHQW) exceeded 110 percent TDG saturation from about May 11, 2006 to August 10, 2006 and exceeded 120 percent from about May 26, 2006 to June 16, 2006. The maximum TDG saturation recorded at the tailwater station was 135 percent which occurred during a 51,000 cfs spill event. Typically, Chief Joseph Dam can spill up to 35,000 cfs and stay below 120 percent TDG saturations if the spill is spread out over all 19 spillway bays. However, TDG saturations were elevated at Chief Joseph Dam during the 2006 spill season because deflector construction restricted the number of spillway bays available. Consequently, for the majority of spill events that occurred in 2006, Chief Joseph Dam was only able to spill from about 10 to 11 spillway bays which resulted in increased TDG saturations in the tailwater.

Albeni Falls Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Albeni Falls Dam during the 2006 monitoring season are presented in Figure 6. Pend Oreille River flow volumes were moderate to high during 2006 with a maximum flow of about 88,000 cfs recorded on May 25, 2006, which is similar to the historical (1952-1998) post-dam average maximum flow of about 80,000 cfs. Consequently, Albeni Falls Dam experienced moderate spill volumes during the 2006 season. Spillway flows ranged from about 0 to 88,000 cfs, with the majority of spill occurring from April 10 and June 26, 2006. Albeni Fall Dam operated on free-flow conditions from May 18, 2006 to May 30, 2006. During free flow operations, the powerhouse is taken off line and the spillway gates are raised out of the water allowing the entire river to flow freely over the spillway.

Total dissolved gas saturations at Albeni Falls forebay station (ALFI) were periodically greater than 110 percent from about May 16, 2006 to July 12, 2006 (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 April 10, 2006 to April 16, 2006, and from about May 4, 2006 to July 5, 2006 (Figure 6). The highest TDG saturation recorded was about 118 percent on June 8, 2006 during a spillway release of about 45,000 cfs. In general, the greatest increase in TDG saturations between the forebay and tailwater were measured during spillway releases that used 6 or less of the 10 possible spill bays. In general, TDG saturations decreased when the spill was spread out over at least 8 of 10 spill bays. This reduction in TDG generation by spreading the spill out over more spill bays was observed during the total dissolved gas exchange study conducted at Albeni Falls in 2003 (Schneider 2004). Additionally, little change in TDG saturations between the forebay and tailwater were measured when Albeni Falls Dam operated on free flow conditions from May 18, 2006 to May 30, 2006. The lack of an increase in TDG saturations during free flow conditions is likely because there is very little difference in elevation between the forebay and tailwater when the dam operates on free flow and all 10 spillway bays are open.

Libby Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Libby Dam during the 2006 monitoring season are presented in Figure 7. Spill at Libby Dam occurred between June 8, 2006 and June 27, 2006 with spillway discharges ranging from about 1,500 cfs to 31,000 cfs, and total discharge ranging from about 25,500 cfs to 55,000 cfs. The Libby Dam tailwater station (LBQM) exceeded 110 percent saturation during spillway releases greater than about 1,500 cfs. Total dissolved gas saturations showed an abrupt increase (107% to 123%) as a function of spillway discharges between 1,500 cfs to 6,000 cfs. Little increase was seen in TDG saturations (123% to 125%) as a function of spillway discharge from about 6,000 cfs to 15,000 cfs, while a moderate increase in TDG (125% to 132%) as a function of spillway discharge was observed between 15,000 cfs and 31,000 cfs. The highest TDG saturation recorded at LBQM was about 132% during a spillway discharge of 31,000 cfs. Total dissolved gas saturations during non spill conditions ranged from about 97 percent to 106 percent. The periodic rise and fall in TDG saturations during the non spill time periods was likely related to the use of the selective withdrawal system to supply water to the penstocks from different thermal layers in the reservoir as Lake Koocanusa begins to thermally stratify (Hoffman 2006). Because the solubility of a gas in water is inversely proportional to the water temperature, the increase and decrease in water temperature likely resulted in the rise and fall in TDG saturations measured during non spill time periods (Figure 7).

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 20 °C in early September (Figure 8). 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 July 8 through the end of monitoring on September 30, 2006, and were greater than 18 °C from July 29 through the end of monitoring on September 30, 2006. Water temperatures at the tailwater exceeded 18 °C from about July 29 through the end of monitoring on September 30, 2006.

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 July (Figure 9). The similar water temperatures at the forebay and tailwater stations indicate well-mixed conditions in the forebay. Daily average water temperatures at the forebay were greater than 19 °C from about June 27 through September 14, 2006, while the maximum daily temperature exceeded 22 °C from about July 20 through August 29, 2006. Similarly, daily average water temperatures at the tailwater exceeded 19 °C from about June 27 through September 14, 2006, with the maximum daily temperature exceeding 22 °C from about July 20 through August 29, 2006. 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 3 °C in April to about 16 °C in September (Figure 10). 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 2006, 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 10, temperature increases and decreases during May through August represent operational changes in the selective withdrawal system, as well as periods of cool stormy weather breaking up the thermocline resulting in decreases in downstream temperatures (Hoffman 2006). The sharp decrease in temperature measured during the spillway release of 31,000 cfs was due to a rapid breaking up of the thermocline in the reservoir during this time period.

Conclusions

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

- Data completeness for TDG data ranged from 94.7 percent at the Albeni Falls Dam forebay station (ALFI) to 99.6 percent at the Albeni Falls Dam tailwater station (ALQI) and for temperature data ranged from 94.7 percent at Albeni Falls Dam forebay station (ALFI) to 99.7 percent at Albeni Falls Dam tailwater station (ALQI). Missing data were largely due to DCP malfunctions and programming problems (all stations), high river flows (ALFI), and lightning strikes (LBQM).

- 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 2 % saturation of the secondary standard TDG instrument. Total dissolved gas saturation differences of 6.7 percent at station ALFI and 5.1 percent at station ALQI could not be attributed to a TDG probe or membrane problem.

- Total dissolved gas saturations were similar between Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) stations, and exceeded 110 percent from about mid May through mid August 2006. TDG levels measured at Chief Joseph forebay (CHJ) were largely a function of TDG levels released from Grand Coulee Dam. Chief Joseph Dam experienced moderate spill volumes during the 2006 season, and generally ranged from about 21,000 cfs to 35,000 cfs from May 25, 2006 to June 16, 2006 with a maximum spill volume of 54,500 cfs on May 29, 2006. The Chief Joseph tailwater station (CHQW) exceeded 120 percent from about May 26, 2006 to June 16, 2006. The maximum TDG saturation recorded at the tailwater station was 135 percent which occurred during a 51,000 cfs spill event.

- Chief Joseph Dam tailwater station (CHQW) experienced elevated TDG saturations during the 2006 spill season because deflector construction restricted the number of spillway bays available. For the majority of spill events that occurred in 2006, Chief Joseph Dam was only able to spill from about 10 to 11 out of 19 total spillway bays which resulted in increased TDG saturations in the tailwater.

- Total dissolved gas saturations at Albeni Falls Dam forebay station (ALFI) and tailwater station (ALQI) periodically exceeded 110 percent during the 2006 spill season. TDG saturations measured at Albeni Falls Dam forebay (ALFI) were largely a function of upstream TDG saturations in the Clark Fork and Pend Oreille rivers. The highest TDG saturation recorded at the tailwater station (ALQI) was about 118 percent on June 8, 2006 during a spillway release of about 45,000 cfs. In general, the greatest increase in TDG saturations between the forebay and tailwater were measured during spillway releases that used 6 or less of the 10 possible spill bays.

- Spill at Libby Dam occurred between June 8, 2006 and June 27, 2006 with spillway discharges ranging from about 1,500 cfs to 31,000 cfs, and total discharge ranging from about 25,500 cfs to 55,000 cfs. The Libby Dam tailwater station (LBQM) exceeded 110 percent saturation during spillway releases greater than about 1,500 cfs. Total dissolved gas saturations showed an abrupt increase (107% to 123%) as a function of spillway discharges between 1,500 cfs to 6,000 cfs. Little increase was seen in TDG saturations (123% to 125%) as a function of spillway discharge from about 6,000 cfs to 15,000 cfs, while a moderate increase in TDG (125% to 132%) as a function of spillway discharge was observed between 15,000 cfs and 31,000 cfs.

- Water temperatures at the Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) were greater than 16 °C and 18 °C from about early July through September 2006 and late July through September 2006, respectively. Similarly, water temperatures at Albeni Falls Dam forebay (ALFI) and tailwater (ALFW/ALQI) were greater than 19 °C from about late June through mid September 2006. Temperatures measured at the Libby Dam tailwater (LBQM) station ranged from about 3 °C in April to 16 °C in September.

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Tables

Table 1. Fixed monitoring station locations and sampling period, spill season 2006.

Site Identifier	Station Name	Latitude	Longitude	2006 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	04/01/06 - 09/30/06
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	04/01/06 - 09/30/06
ALFI	Albeni Falls Dam Forebay	48° 10' 40"	116° 59' 52"	04/01/06 - 09/30/06
ALQI	Albeni Falls Dam Tailwater	48° 10' 39"	117° 00' 08"	04/01/06 - 09/30/06
LBQM	Libby Dam Tailwater	48° 19' 07"	115° 19' 07"	04/01/06 - 09/30/06

Table 2. Total dissolved gas data completeness for spill season 2006.

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	218	95.0	95.0
Chief Joseph Tailwater	CHQW	4392	153	96.5	96.5
Albeni Falls Forebay	ALFI	4392	231	94.7	94.7
Albeni Falls Tailwater	ALQI	4392	16	99.6	99.6
Libby Tailwater	LBQM	4392	68	98.5	98.5

Table 3. Temperature data completeness for spill season 2006.

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	217	95.1	95.1
Chief Joseph Tailwater	CHQW	4392	132	97.0	97.0
Albeni Falls Forebay	ALFI	4392	231	94.7	94.7
Albeni Falls Tailwater	ALQI	4392	12	99.7	99.7
Libby Tailwater	LBQM	4392	65	98.5	98.5

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 2006.

	Temperature	Total Dissolved Gas Pressure (% Saturation)			
	°C	100%	113%	126%	139%
N	60	60	60	60	60
Minimum	-0.4	-0.48	-0.48	-0.62	-0.76
Maximum	0.18	0.28	0.42	0.28	0.28
Median	0.01	0.06	0.06	0.06	-0.04
Average	0.01	0.02	0.04	0.02	-0.04
Standard Deviation	0.08	0.13	0.15	0.15	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	Class A: 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 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 16.0°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	Class A Special Condition: Temperature shall not exceed 20°C due to human activities. When temperature 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

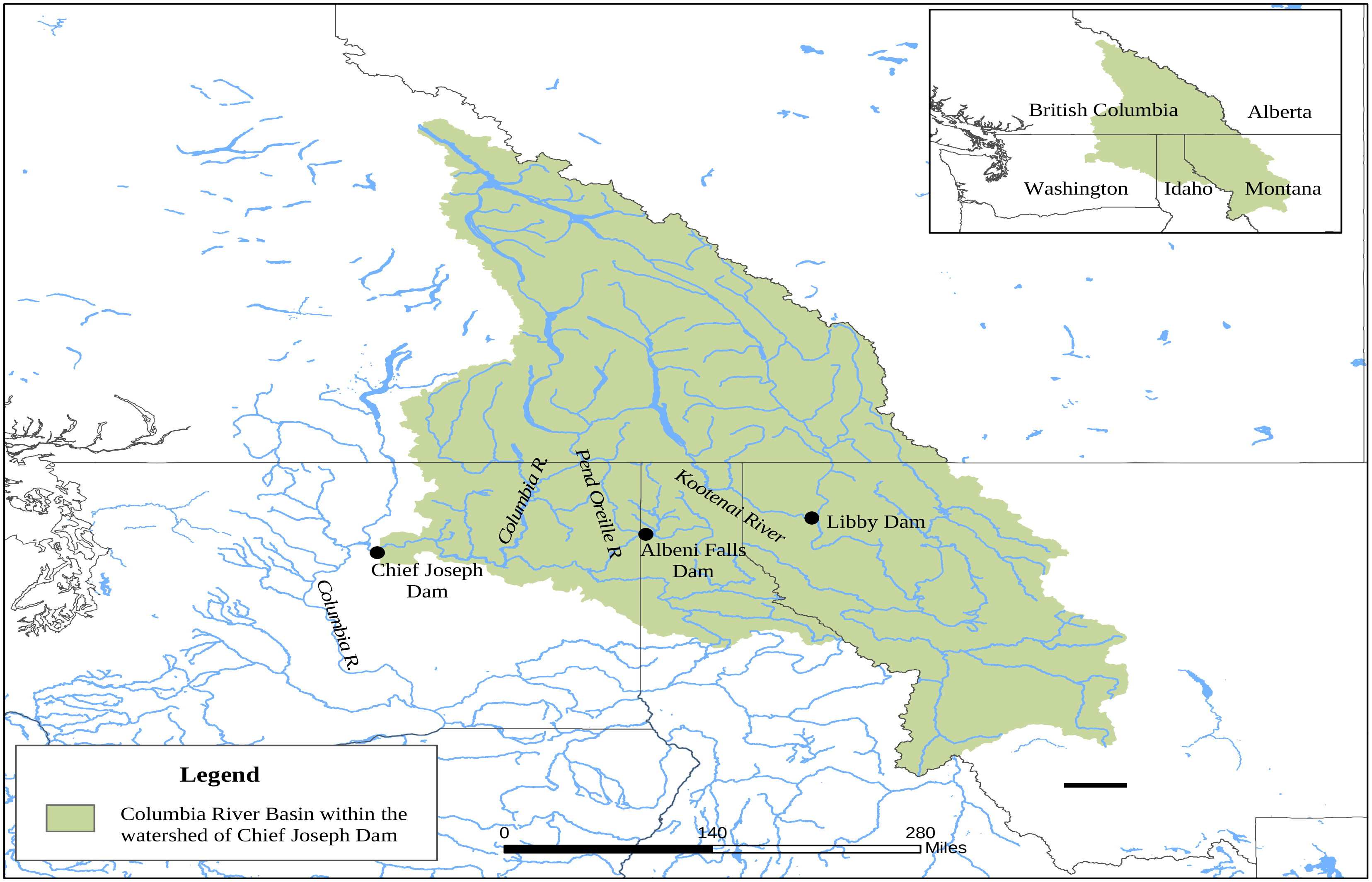


Figure 1. Location of Seattle District projects in the upper Columbia River basin.

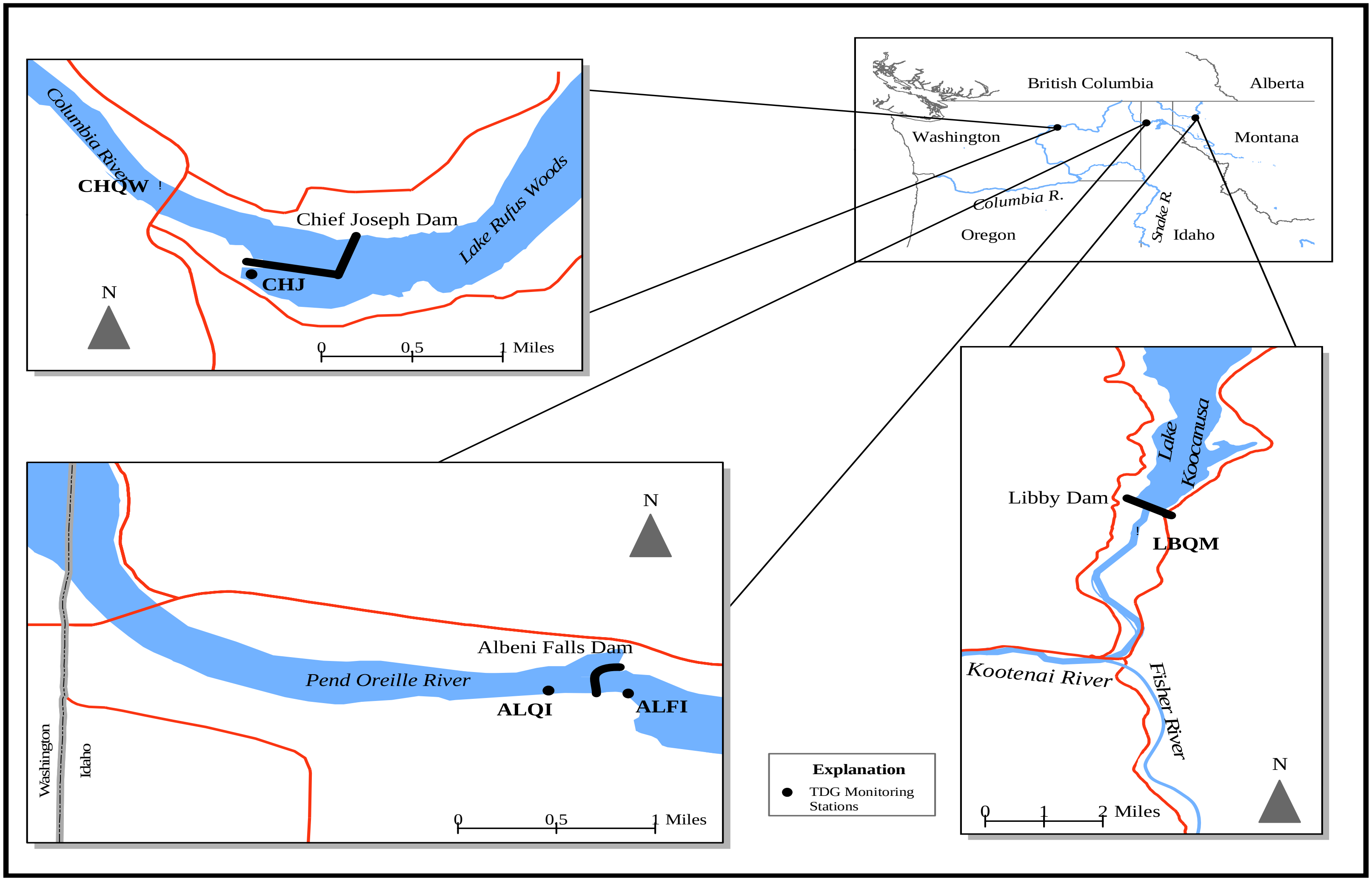
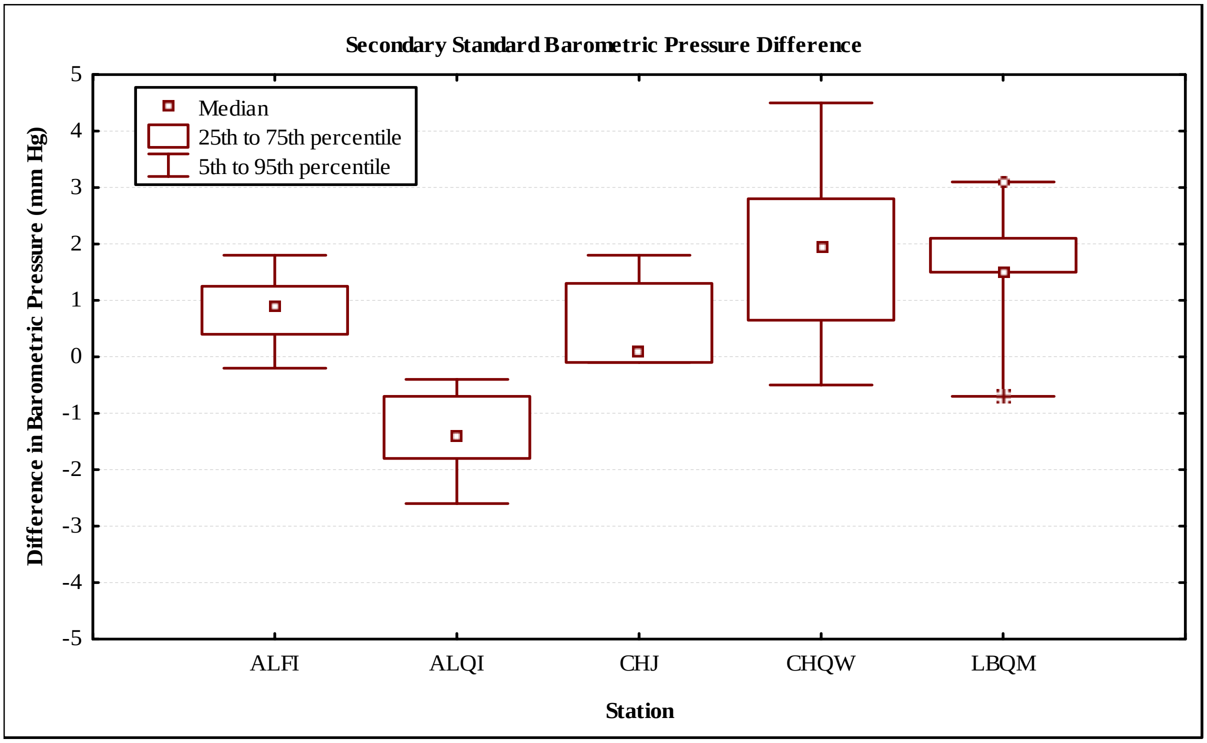


Figure 2. Locations of total dissolved gas monitoring stations in 2006 for Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana.



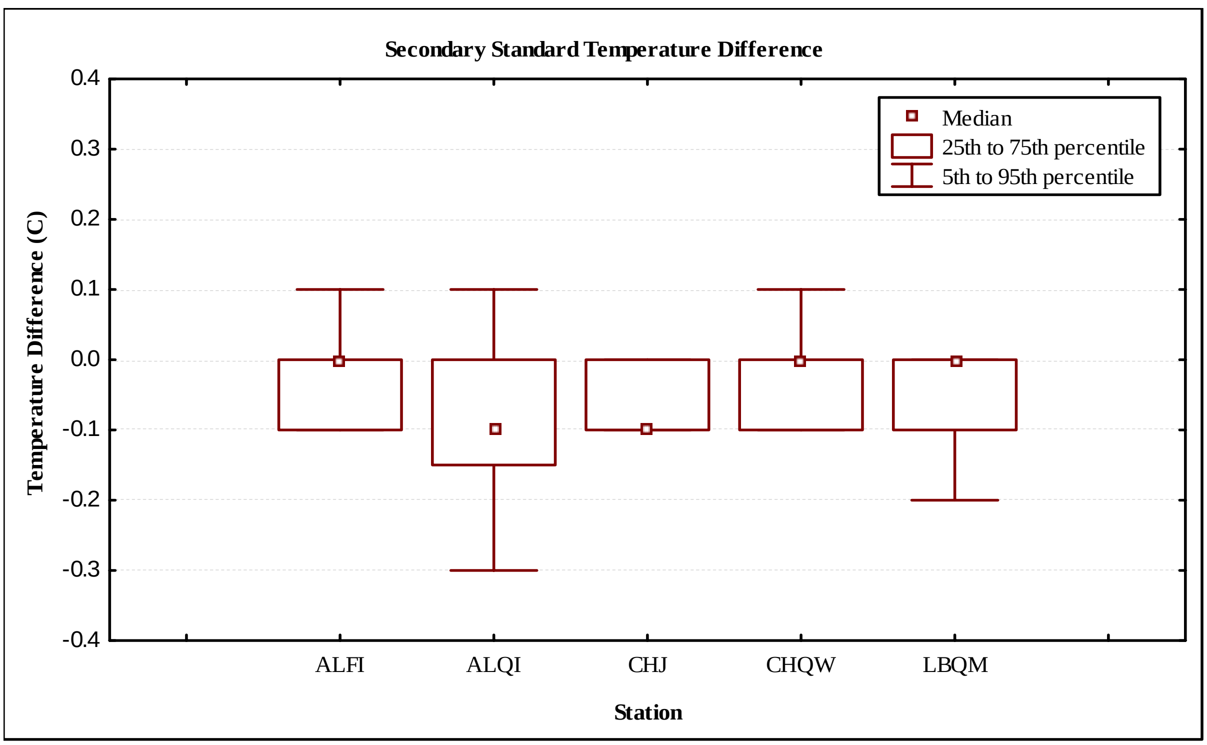


Figure 3. Difference between the secondary standard and the field barometers and field thermometers during spill season 2006.

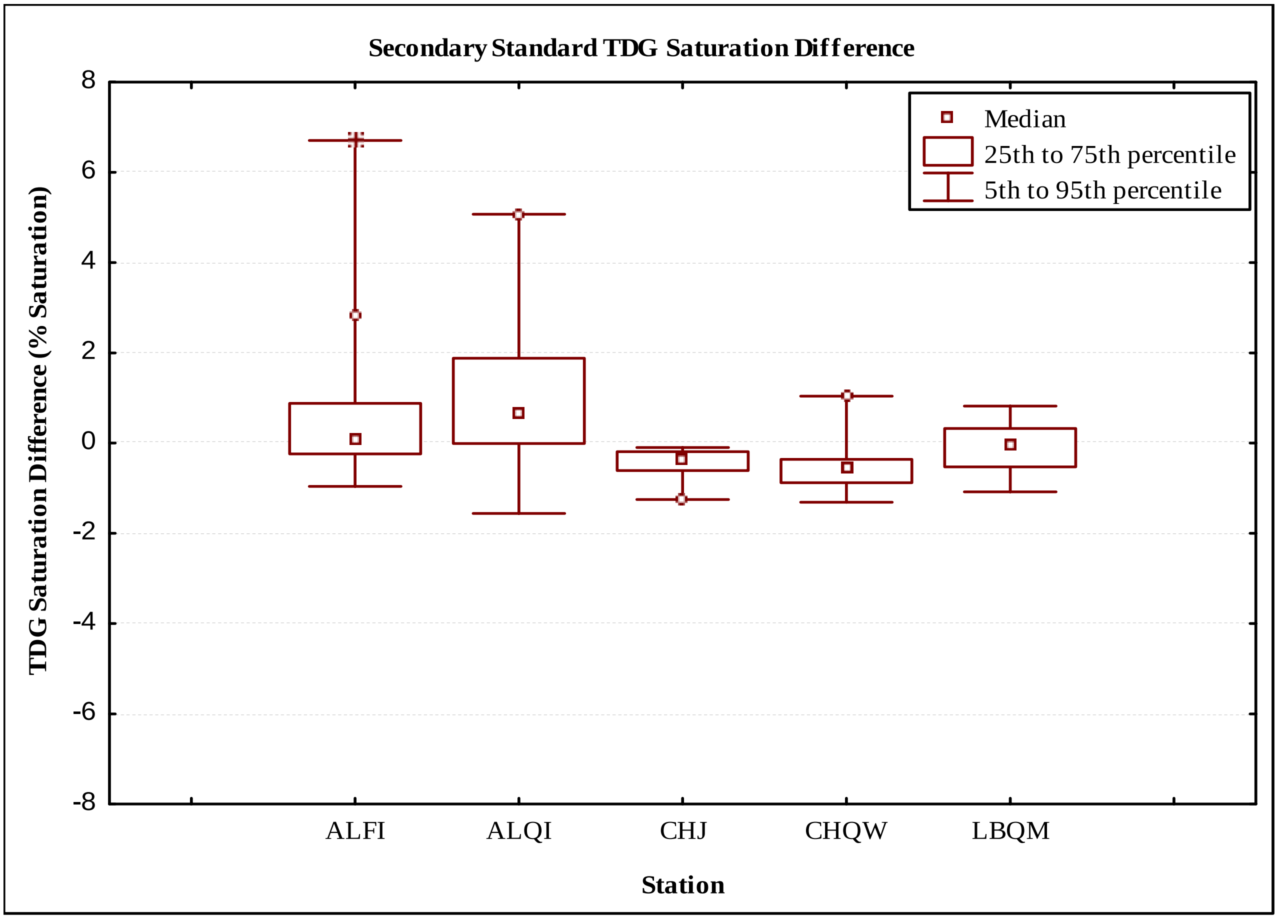


Figure 4. Difference between the secondary standard and the field total dissolved gas instrument for TDG pressure during spill season 2006.

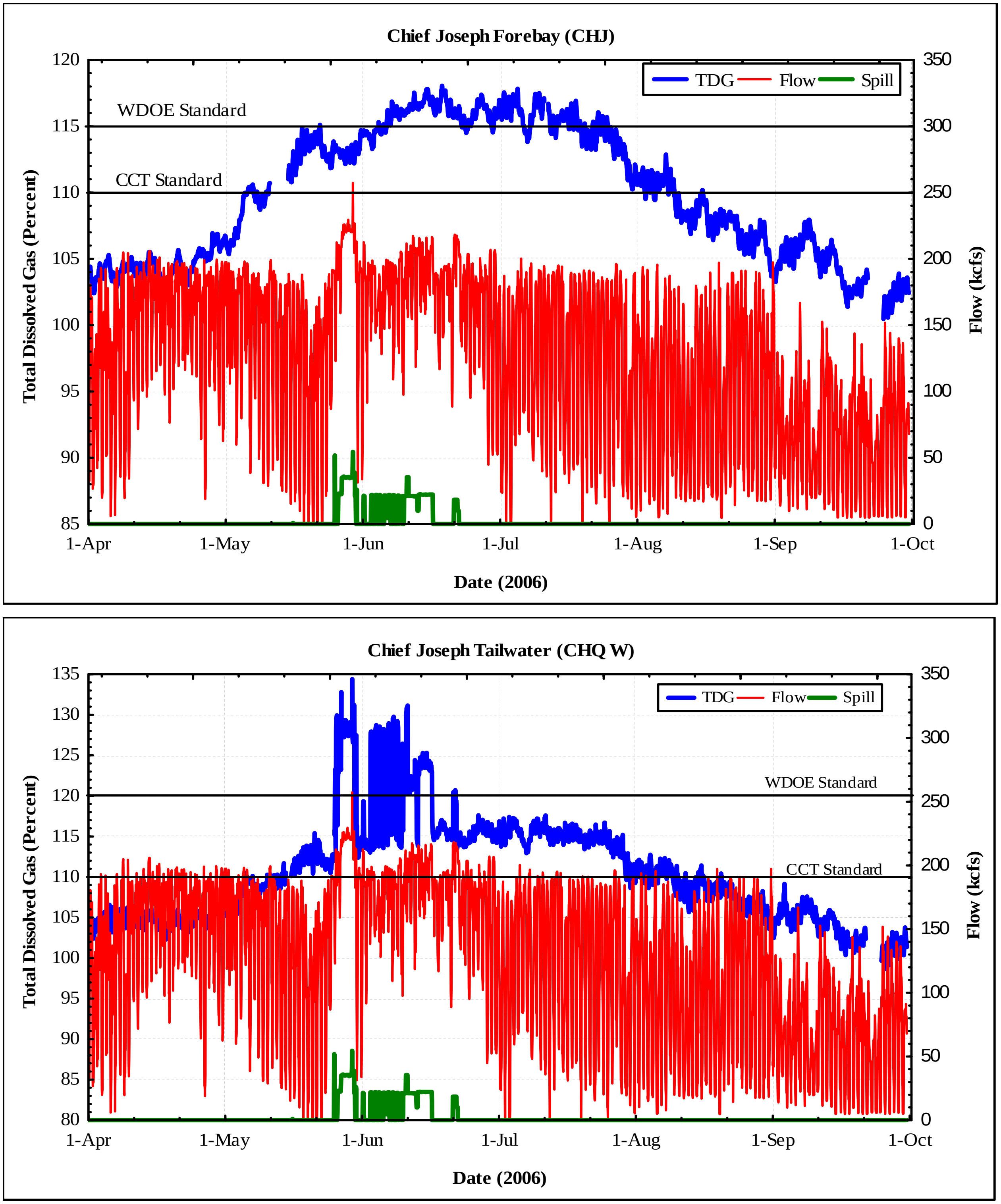
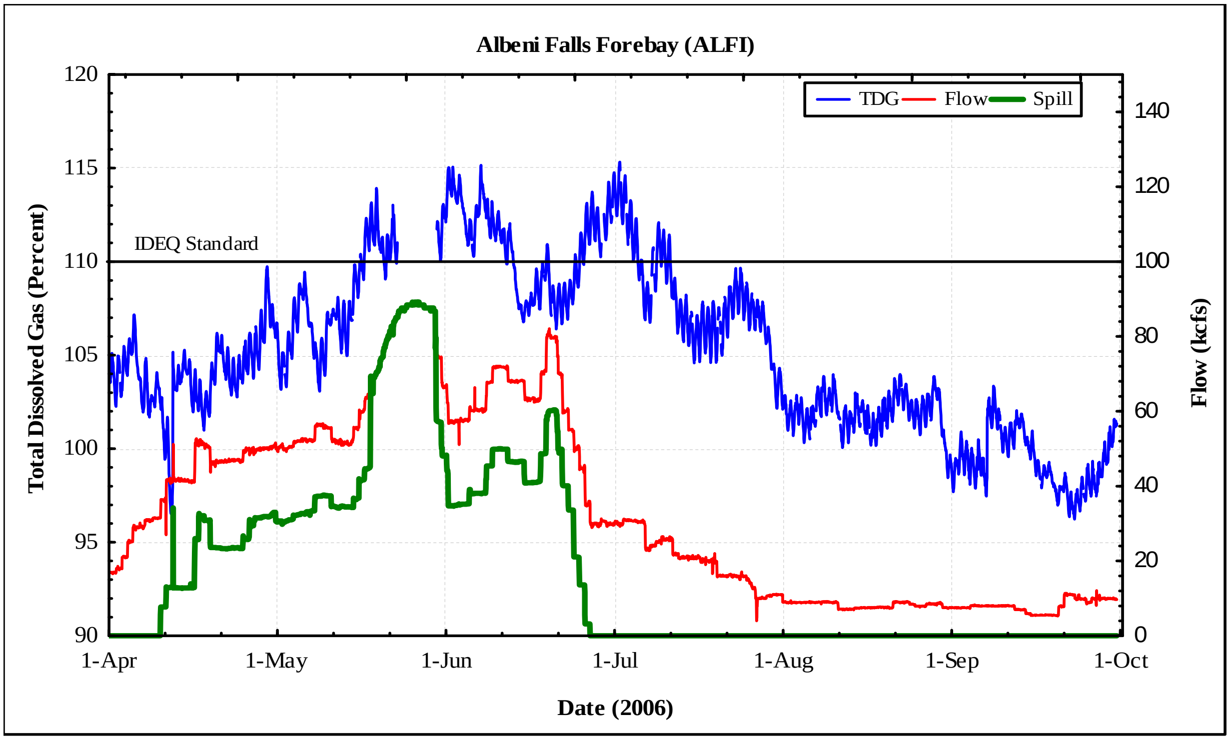


Figure 5. Total dissolved gas, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2006.



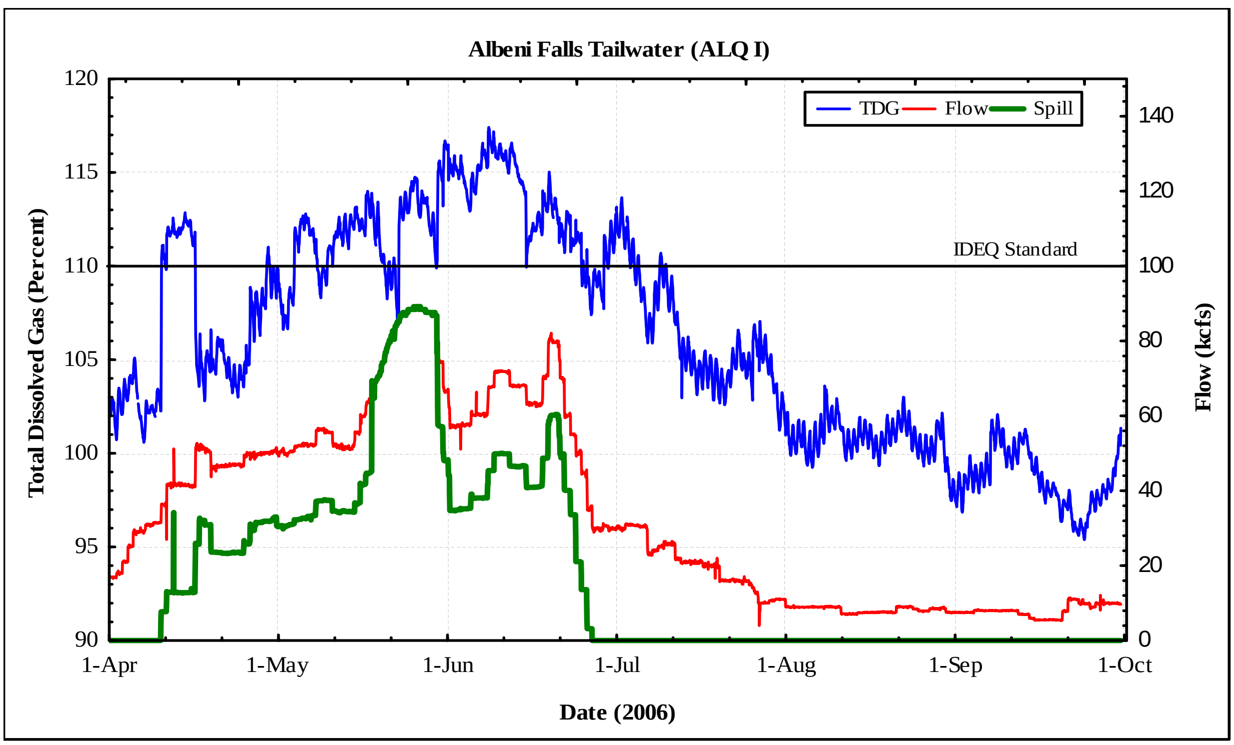


Figure 6. Total dissolved gas, spill, and flow at Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALQI) stations during spill season 2006.

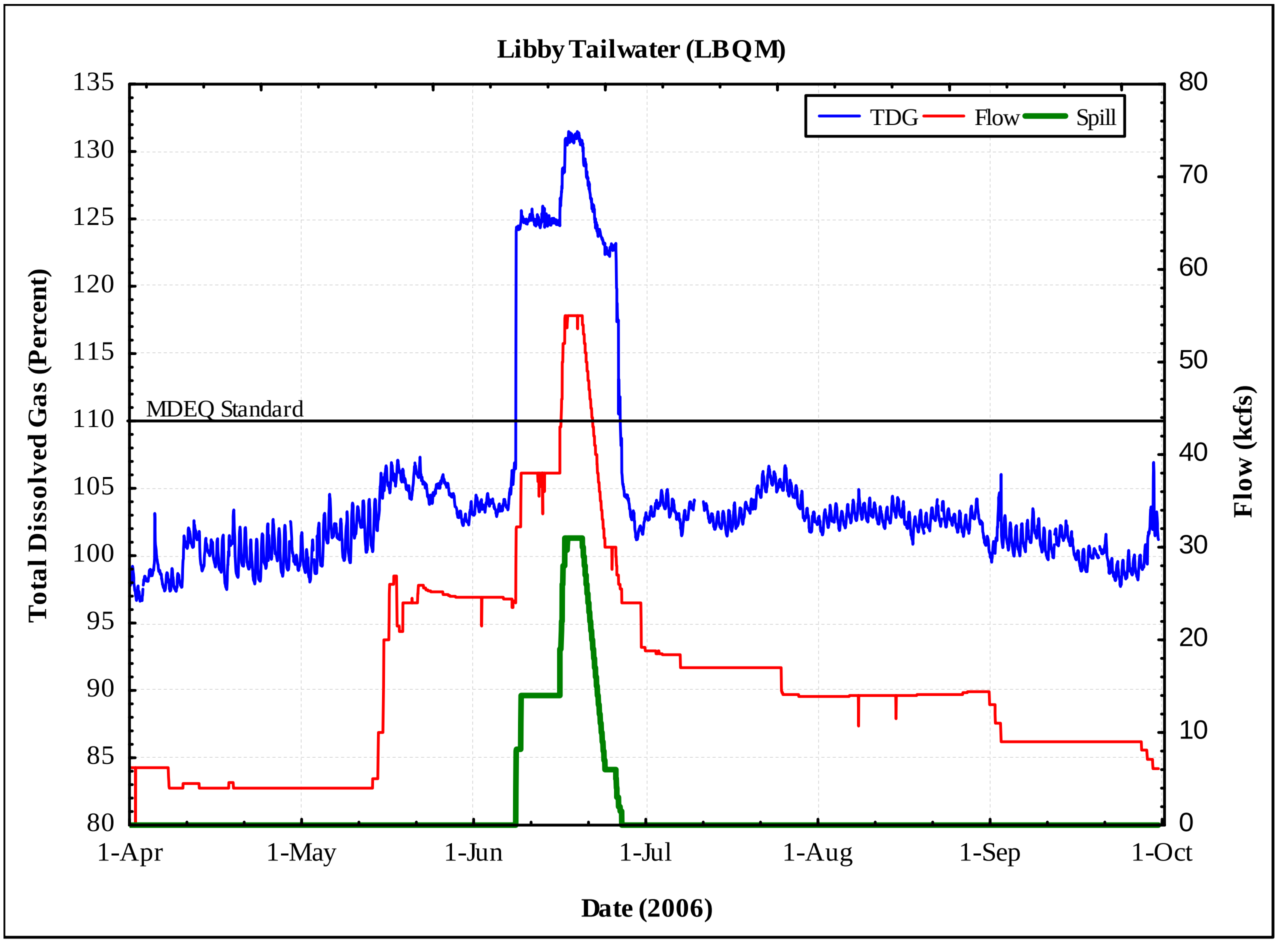
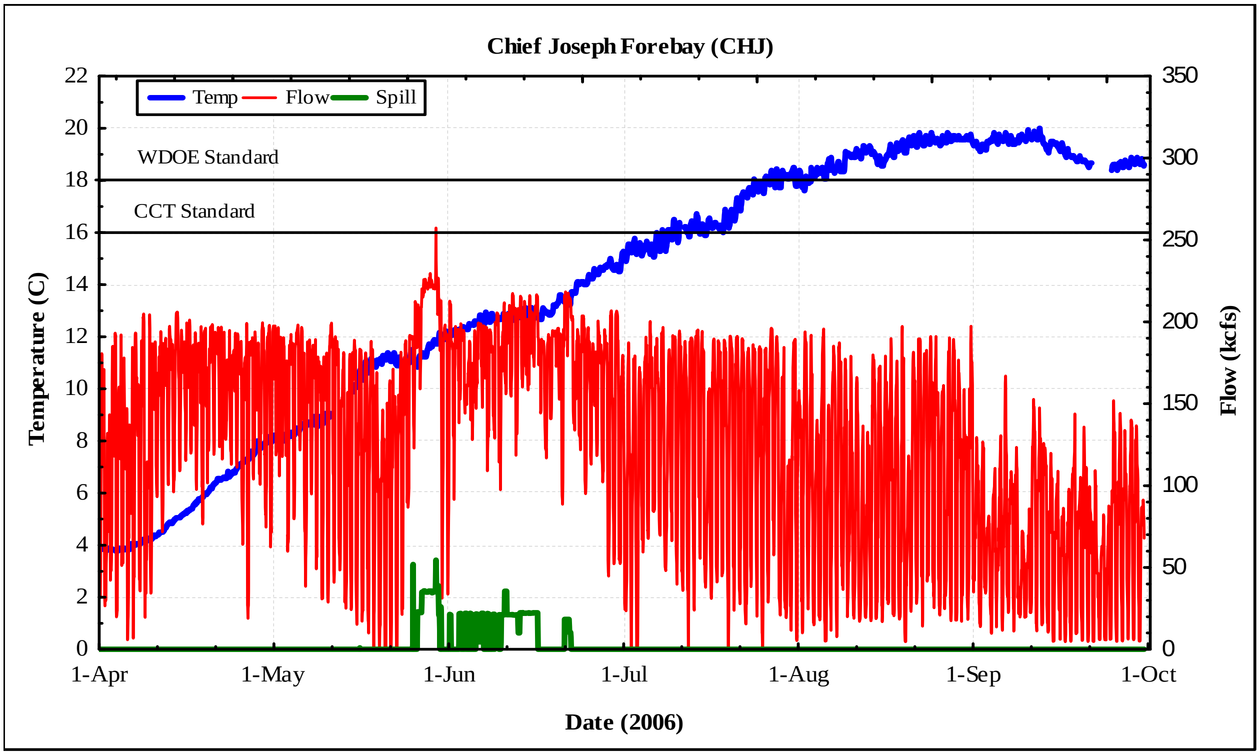


Figure 7. Total dissolved gas, spill, and flow at the Libby Dam Tailwater (LBQM) station during spill season 2006.



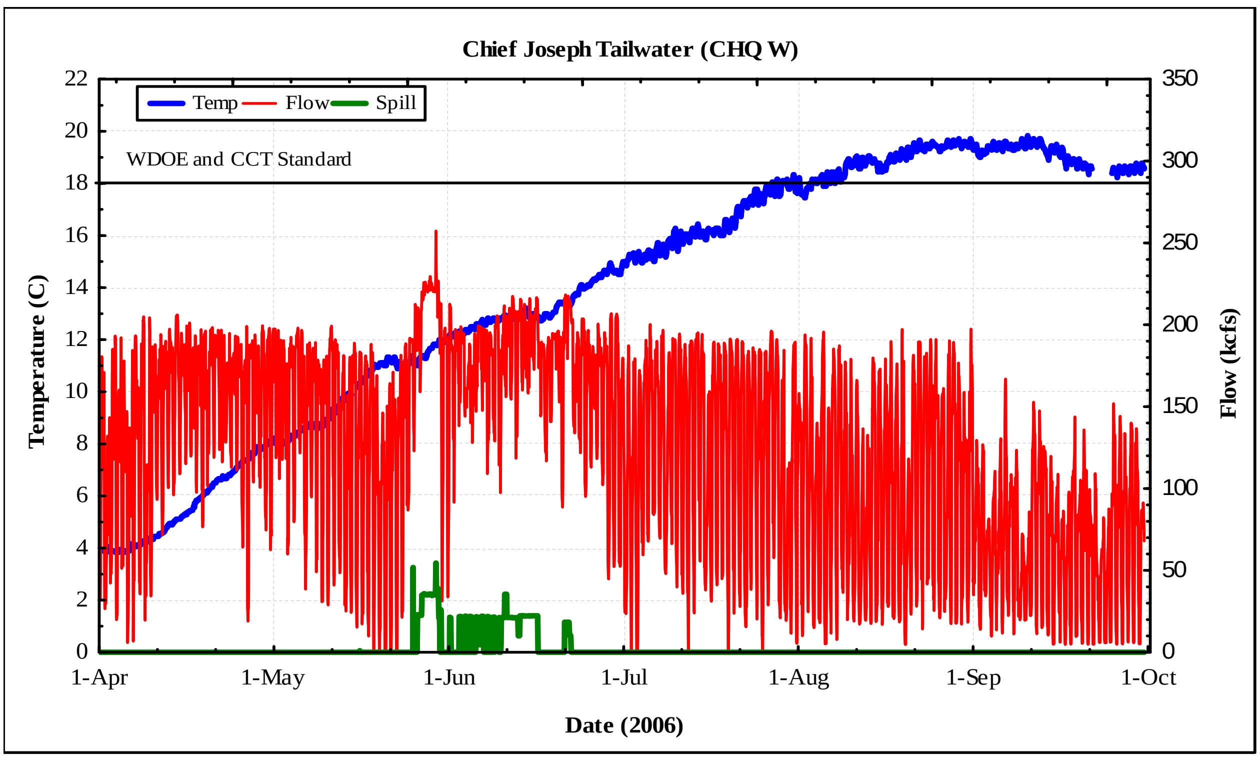
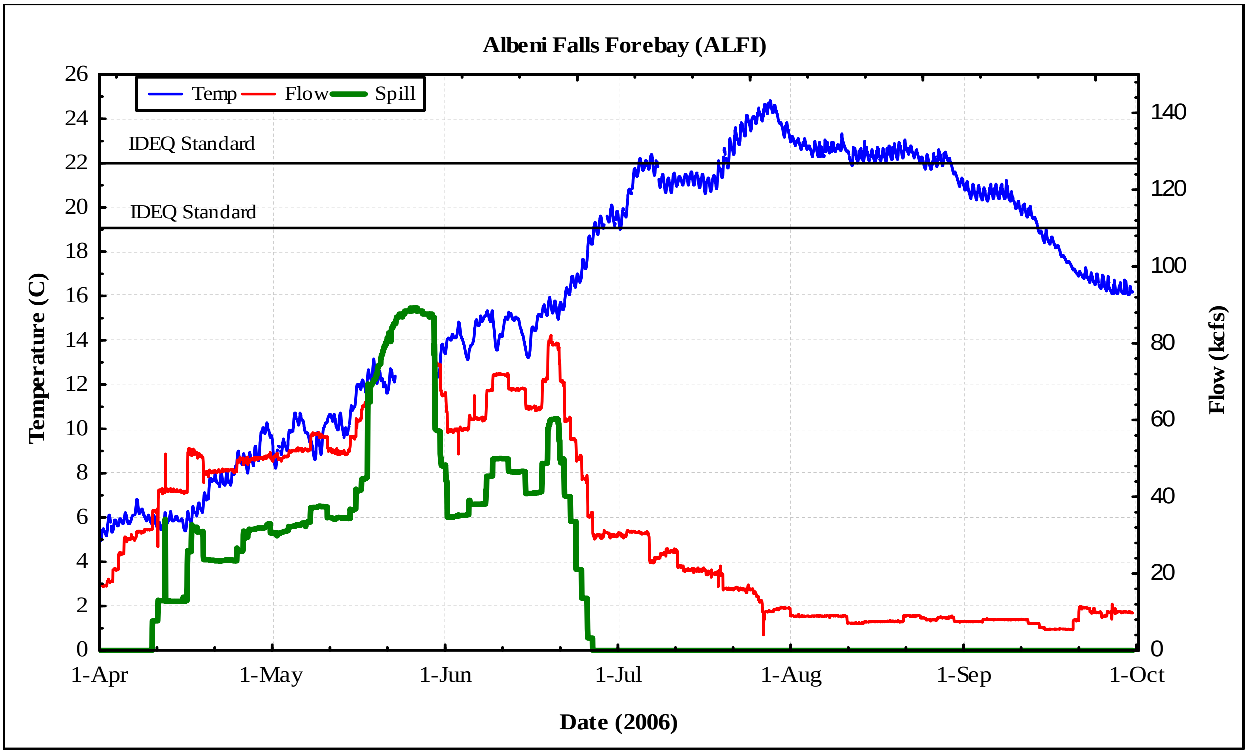


Figure 8. Temperature, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2006.



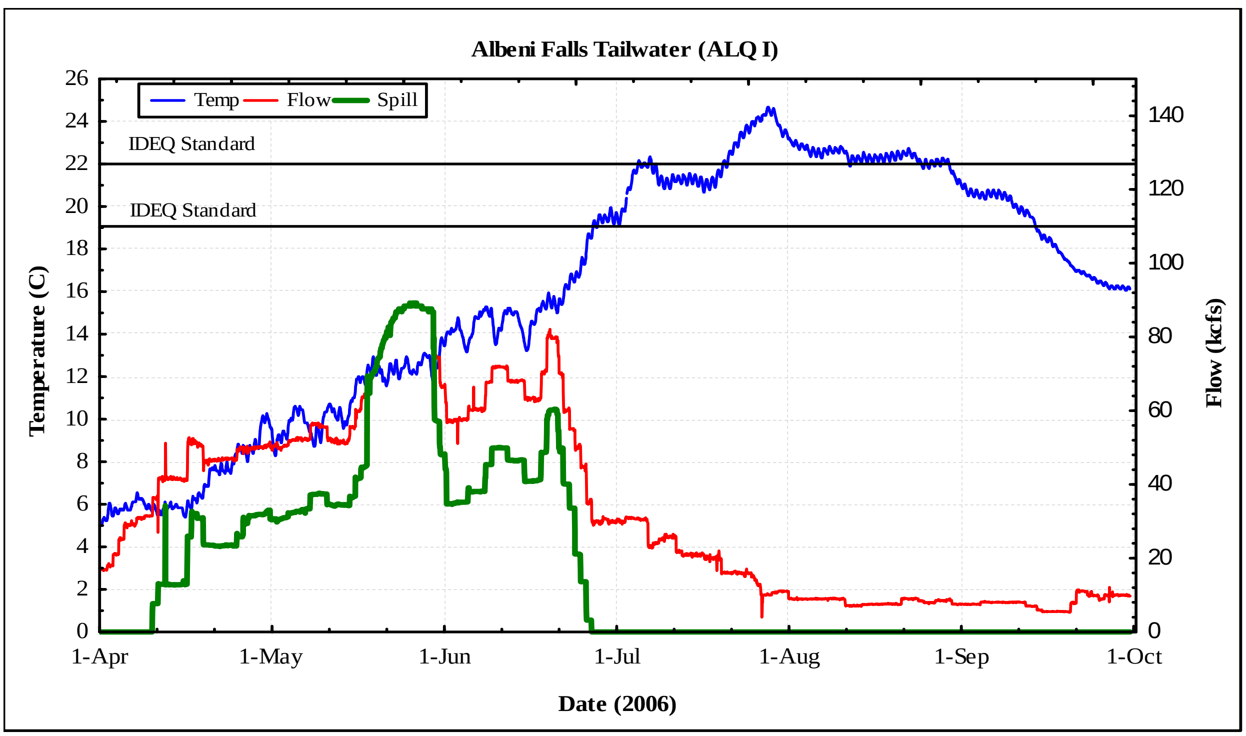


Figure 9. Temperature, spill, and flow at Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALQI) stations during spill season 2006.

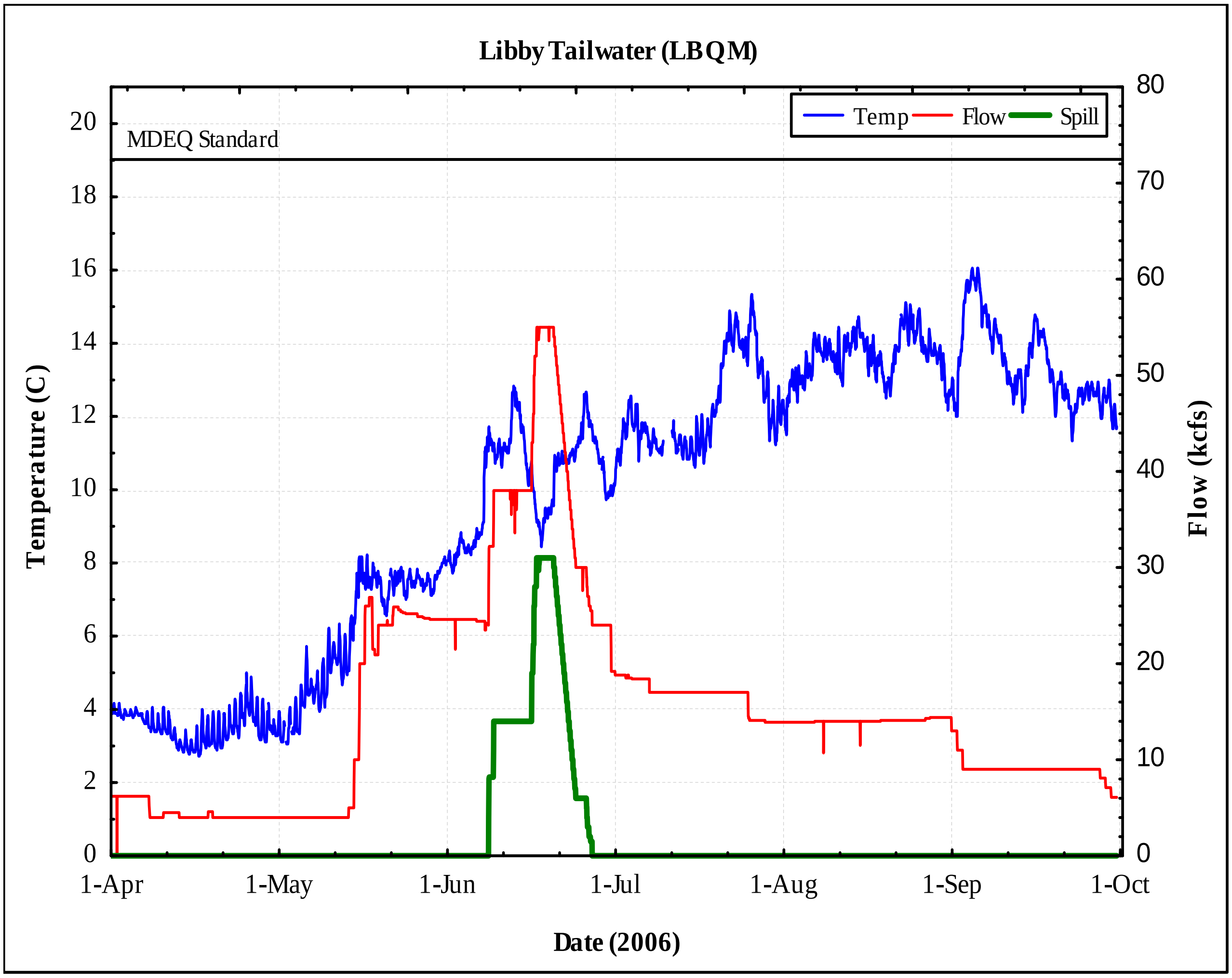


Figure 10. Temperature, spill, and flow at the Libby Dam Tailwater (LIBM) station during spill season 2006