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Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana 2005: 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 2005 spill season, which lasted from April 1 – September 30, 2005. 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 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.

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 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 ALFW/ALQI), and one fixed monitoring station at Libby Dam (LBQM) during the 2004 spill season (Figure 2). The original tailwater station at Albeni Falls Dam (ALFW) experienced data quality problems during the monitoring season due to shallow water and bed load movement in the vicinity of the station, and the station was moved about 1 mile farther upstream towards the dam to a deeper location (ALQI) at the end of July. 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 2005* (USCOE 2004). 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 and ALFW, 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 the original Albeni Falls Dam tailwater station (ALFW) the water quality probe was deployed along the left bank of the river, 1.5 miles downstream from the dam at the USGS gaging station (No. 12395500). The probe was placed inside an anchored, perforated HDPE pipe that extended into the river to a depth of at least 3 feet during low flow conditions. Due to the shallow conditions experienced at ALFW during the low flow summer period, the station was replaced in July by a deeper water station ALQI. At the new 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 2005 are summarized in Tables 2 and 3. The data were based upon the number of planned monitoring hours from April 1 through September 30, except at Albeni Falls Dam tailwater. The original Albeni Falls Dam tailwater monitoring station (ALFW) was removed on July 27, 2005, and a new tailwater monitoring station (ALQI) was installed on July 28, 2005. 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 and CHQW were largely due to DCP malfunctions and programming problems. No data were rejected from these stations. Missing data for stations ALFI, ALFW, and ALQI were due to DCP malfunctions and programming problems, probe and cable malfunctions, and lightning strikes. Temperature and TDG data were rejected at station ALFI due to erroneous data being transmitted after the probe was destroyed during high flows (June 9, 2005 at 0400 hours to 1800 hours) and data being transmitted from a probe with a torn TDG membrane (May 25, 2005 at 0600 hours to May 27, 2005 at 1100 hours). TDG data were rejected at station ALFW due to erroneous data being transmitted from a probe covered by sand and gravel (May 10, 2005 at 0400 hours to May 11, 2005 at 1000 hours), and from a probe with a torn TDG membrane (July 1, 2005 at 2300 hours to July 5, 2005 at 1100 hours). Missing data for station LBQM were due to DCP malfunctions and programming problems, and lightning strikes. High TDG saturations recorded on May 12, 2005 from 1600 hours to 2000 hours were rejected because the probe had been calibrated and redeployed at 1500 hours resulting in erroneously high TDG values until equilibrium was achieved.

Quality-Assurance Procedures

Fixed monitoring stations were calibrated every two weeks during the 2005 monitoring season following procedures outlined in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring 2005* (USCOE 2004). 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 2005 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 (ALFW).

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 (ALFW). At ALFI the data were within 2 percent saturation difference except for a 43.4 percent difference on May 27, 2005. This outlier point was due to a torn TDG membrane. Consequently, data collected at ALFI between May 25, 2005 at 0600 hours and May 27, 2005 at 1100 hours were rejected. At ALFW the data were generally within 5 percent saturation difference except for an 18.8 percent difference on May 11, 2005 and a 17.1 percent difference on July 5, 2005. The May 11, 2005 outlier point was likely due to the TDG probe being covered by sand and gravel, while the July 5, 2005 outlier point was due to a torn membrane. Consequently, data collected at ALFW between May 10, 2005 at 0400 hours and May 11, 2005 at 1000 hours, and between July 1, 2005 at 2300 hours and July 5, 2005 at 1100 hours were rejected.

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 2005 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 2005 monitoring season are presented in Figure 5. Columbia River flow volumes were low to moderate during 2005 with maximum flows generally in the 150,000 to 200,000 cfs range, well below the seven-day average 10-year return (7Q10) flood flow of 222,000 cfs. Consequently, Chief Joseph Dam experienced only small spill events during the 2005 season, with spills of about 15,000 cfs for 11 hours on May 22, 2005, 34,000 cfs for 12-hours on May 25, 2005, and 13,000 cfs for 2-hours on May 27, 2005 (Figure 5).

Total dissolved gas saturations at Chief Joseph forebay station (CHJ) periodically exceeded 110 percent from about June 16, 2005 to July 28, 2005, with no days greater than 115 percent TDG saturation. 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 for 10 hours on May 22, 2005, 8 hours on May 25, 2005, and then periodically from about June 1, 2005 to August 1, 2005. This station had only 4 hours exceeding 120 percent, which occurred during a spill of 34,000 cfs on May 25, 2005.

Albeni Falls Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Albeni Falls Dam during the 2005 monitoring season are presented in Figure 6. Pend Oreille River flow volumes were moderate during 2005 with a maximum flow of about 76,000 cfs recorded on June 9, 2005, 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 2005 season. Spillway flows ranged from about 0 to 55,000 cfs, with the majority of spill occurring between June 1 and July 1, 2005.

Total dissolved gas saturations at Albeni Falls forebay station (ALFI) were periodically greater than 110 percent from about May 27, 2005 to July 1, 2005 (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 (ALFW/ALQI) exceeded 110 percent several times during spillway operations in 2005 (Figure 6). The highest TDG saturation recorded was about 114 percent on June 10, 2005 during a spillway release of about 44,000 cfs. In general, the greatest increase in TDG saturations between the forebay and tailwater were measured during spillway releases that used 4 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).

Diurnal cycles in TDG saturations of up to 10 percent were seen at the ALFW tailwater station during moderate flow conditions on the Pend Oreille River in early May and low flow conditions during late July (Figure 6). During these time periods, TDG saturations cycled up to 10 percent during a 24 hour period. Similar TDG cycling was not seen at the forebay station suggesting that the tailwater station was not representative of in-river conditions, and that other factors such as diurnal temperature and dissolved oxygen cycling or river bed load movement were contributing to the TDG cycling.

The solubility of a gas in water is dependent on the ambient pressure of the gas, water temperature, and salinity. In general, a change in temperature of 1 °C will result in a change in TDG pressure of about 17 mm Hg or about 2 percent saturation (Schneider 2004). Therefore, diurnal temperature cycling of up to 3 °C measured at the tailwater station ALFW in late July (see below) could not solely account for the up to 10 percent swings in daily TDG saturations, suggesting that other in-river processes were impacting TDG saturations. Tailwater station ALFW is located in a shallow nearshore zone that experiences slack water during low flow conditions. These conditions may allow for considerable aquatic plant growth to occur in the river near the tailwater station possibly resulting in substantial variations in dissolved oxygen (DO) concentrations due to diurnal cycling of photosynthesis and respiration. In general, a 1 mg/L variation in DO will result in a variation in TDG pressure ranging from 12 to 17 mm Hg (about 1 to 2 percent saturation) depending on water temperatures (Schneider 2004). Lastly, quality assurance data problems (see section above) associated with tailwater station ALFW suggests that bed load movement in the vicinity of the station resulted in the probe being covered with sand and gravel during early May. The deposition of sand over the probe may have reduced the flow of water across the TDG membrane resulting in the low TDG saturations recorded during May when little to no diurnal cycling of temperature was measured.

Libby Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Libby Dam during the 2005 monitoring season are presented in Figure 7. In general, total dissolved gas saturation levels increased from about 98 percent in April to about 108 percent in mid May, decreased back to 98 percent in late May and increased again to about 108 percent in early June. From mid June through September, TDG saturations gradually decreased from about 108 percent to about 100 percent. The gradual rise and fall in TDG saturations during the April to June time period 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 2005). A period of cool stormy weather at the end of May resulted in the breakup of temperature stratification at Libby Dam, which caused a decrease in water temperatures for a short period of time (see below). 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 the April to June time period. Total dissolved gas saturations at Libby did not exceed 110 percent during 2005 and no spill occurred during 2005 (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 5 °C in April to 19 °C in late August (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 12 through the end of monitoring on September 30, 2005, and were greater than 18 °C from August 5 through the end of monitoring on September 30, 2005. Water temperatures at the tailwater exceeded 18 °C from about August 7 through the end of monitoring on September 30, 2005.

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 (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 July 12 through September 11, 2005, while the maximum daily temperature exceeded 22 °C from about July 26 through August 23, 2005. Similarly, daily average water temperatures at the tailwater exceeded 19 °C from about July 8 through September 11, 2005, with the maximum daily temperature exceeding 22 °C from about July 23 through August 22, 2005.

Diurnal temperature cycles of up to 3 °C were seen at tailwater station ALFW during low flow conditions on the Pend Oreille River in late July (Figure 9). Although diurnal temperature cycling was present at the forebay station (ALFI), these cycles were generally in the range of 1 °C, suggesting that tailwater station ALFW was not representative of in-river conditions. Tailwater station ALFW was located in a shallow nearshore zone that likely experienced slack water during low flow summer months. Such conditions would allow for considerable heat exchange within the river during the day and night resulting in larger diurnal cycles of temperature than measured at the forebay. After the tailwater station was moved upstream to a deeper location (ALQI) on July 29, 2005 diurnal temperature cycling was similar to the forebay and generally in the range of 1 °C, indicating that the new tailwater station ALQI was representative of in-river conditions (Figure 9).

Libby Dam

Temperature measured at the Libby Dam tailwater (LBQM) station ranged from about 4 °C in April to 16 °C in August (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. As the waters in Lake Koocanusa begin to thermally stratify in April and May, the selective withdrawal system can be operated to intake water from various depths to produce more natural downstream water temperatures to benefit aquatic organisms. As seen in Figure 10, temperature increases and decreases during May and June 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 2005).

Conclusions

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

- Data completeness for TDG and temperature data ranged from 81.0 percent at the Albeni Falls Dam tailwater station (ALFW) to 99.0 percent at the Chief Joseph Dam tailwater station (CHQW). Data completeness for TDG and temperature at the new Albeni Falls Dam tailwater station (ALQI) were greater than at ALFW and ranged from 96.6 percent to 97.7 percent, respectively. At all stations, missing data were largely due to DCP malfunctions, programming problems, probe and cable malfunctions, and lightning strikes.

- Temperature and TDG data were rejected at station ALFI due to erroneous data being transmitted after the probe was destroyed during high flows and data being transmitted from a probe with a torn TDG membrane. TDG data were rejected at station ALFW due to erroneous data being transmitted from a probe covered by sand and gravel, and from a probe with a torn TDG membrane. TDG data were rejected at station LBQM due to a calibrated and redeployed probe transmitting erroneously high TDG values until equilibrium was achieved.

- The original tailwater station at Albeni Falls Dam (ALFW) experienced data quality problems during the monitoring season due to shallow water and bed load movement in the vicinity of the station and the data were not representative of in river conditions. Consequently, the station was moved about 1 mile farther upstream towards the dam to a deeper location (ALQI) at the end of July. Data collected at ALQI were determined to be more representative of in river conditions.

- In general, laboratory calibration data were good for all parameters. Field calibration data were good for all parameters and stations except for TDG saturation data from Albeni Falls Dam forebay (ALFI) and tailwater (ALFW) stations. At ALFI the data were within 2 percent saturation difference except for a 43.4 percent difference on May 27, 2005. This outlier point was due to a torn TDG membrane. At ALFW the data were generally within 5 percent saturation difference except for an 18.8 percent difference on May 11, 2005 (due to the probe being covered by sand and gravel) and a 17.1 percent difference on July 5, 2005 (due to a torn membrane).

- Total dissolved gas saturations were similar between Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) stations, and exceeded 110 percent from about mid June through mid August 2005. TDG levels measured at

Chief Joseph were largely a function of TDG levels released from Grand Coulee Dam, except during three small spill events in May that increased tailwater TDG saturations above 110 percent.

- Total dissolved gas saturations at Albeni Falls Dam forebay station (ALFI) and tailwater station (ALFW/ALQI) periodically exceeded 110 percent during the 2005 spill season. Large diurnal cycles in TDG saturations seen at tailwater station ALFW were not seen at the forebay or at the new tailwater station ALQI, suggesting that ALFW was not representative of in river conditions, and was influenced by heat exchange with the river and the diurnal cycling of photosynthesis and respiration.

- Libby tailwater (LBQM) did not exceed 110 percent during 2005.

- 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 2005 and early August through September 2005, respectively. Similarly, water temperatures at Albeni Falls Dam forebay (ALFI) and tailwater (ALFW/ALQI) were greater than 19 °C from about mid July through mid September 2005. Large diurnal cycles in temperature seen at tailwater station ALFW were not seen at the forebay or at the new tailwater station ALQI suggesting that ALFW was not representative of in-river conditions. Temperatures measured at the Libby Dam tailwater (LBQM) station ranged from about 4 °C in April to 16 °C in August.

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Tables

Table 1. Fixed monitoring station locations and sampling period, spill season 2005.

Site Identifier	Station Name	Latitude	Longitude	2005 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	04/01/05 - 09/30/05
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	04/01/05 - 09/30/05
ALFI	Albeni Falls Dam Forebay	48° 10' 40"	116° 59' 52"	04/01/05 - 09/30/05
ALFW	Albeni Falls Dam Tailwater	48° 10' 56"	117° 02' 03"	04/01/05 - 07/27/05
ALQI	Albeni Falls Dam Tailwater	48° 10' 39"	117° 00' 08"	07/28/05 - 09/30/05
LBQM	Libby Dam Tailwater	48° 19' 07"	115° 19' 07"	04/01/05 - 09/30/05

Table 2. Total dissolved gas data completeness for spill season 2005.

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	89	98.0	98.0
Chief Joseph Tailwater	CHQW	4392	96	97.8	97.8
Albeni Falls Forebay	ALFI	4392	36	99.2	97.4
Albeni Falls Tailwater	ALFW	2820	360	87.2	81.0
Albeni Falls Tailwater	ALQI	1552	52	96.6	96.6
Libby Tailwater	LBQM	4392	149	96.6	96.4

Table 3. Temperature data completeness for spill season 2005.

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	81	98.2	98.2
Chief Joseph Tailwater	CHQW	4392	44	99.0	99.0
Albeni Falls Forebay	ALFI	4392	35	99.2	98.6
Albeni Falls Tailwater	ALFW	2820	316	88.8	88.8
Albeni Falls Tailwater	ALQI	1552	36	97.7	97.7
Libby Tailwater	LBQM	4392	79	98.2	98.2

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 2005.

	Temperature	Total Dissolved Gas Pressure (% Saturation)			
	°C	100%	113%	126%	139%
N	82	82	82	82	82
Minimum	-0.12	-0.63	-0.27	-0.27	-0.28
Maximum	0.09	1.14	1.27	1.50	1.90
Median	0.00	0.02	0.04	0.04	0.00
Average	-0.01	0.02	0.07	0.07	0.04
Standard Deviation	0.05	0.18	0.21	0.24	0.28

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 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	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

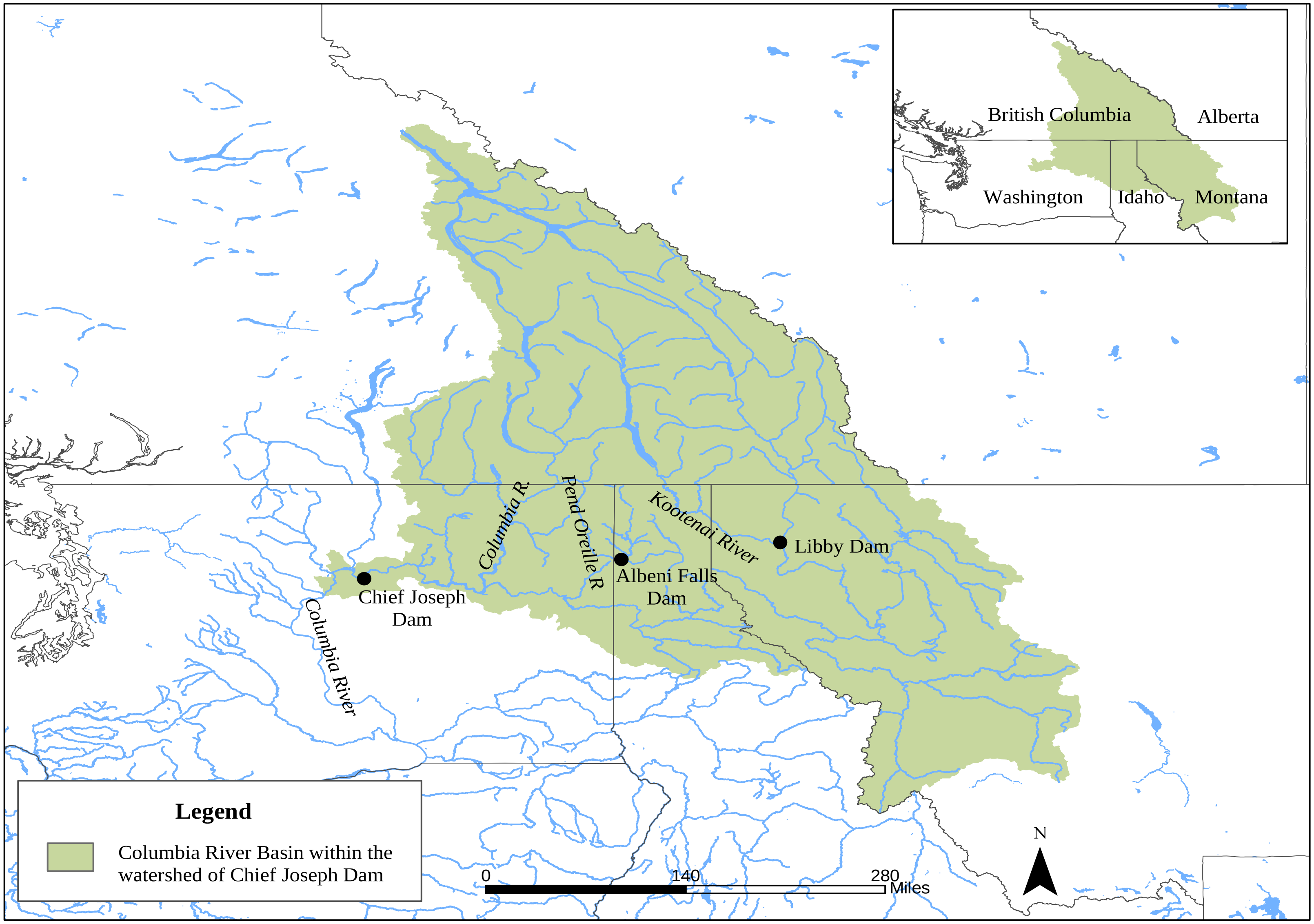


Figure 1. Location of Seattle District projects in the upper Columbia River basin.

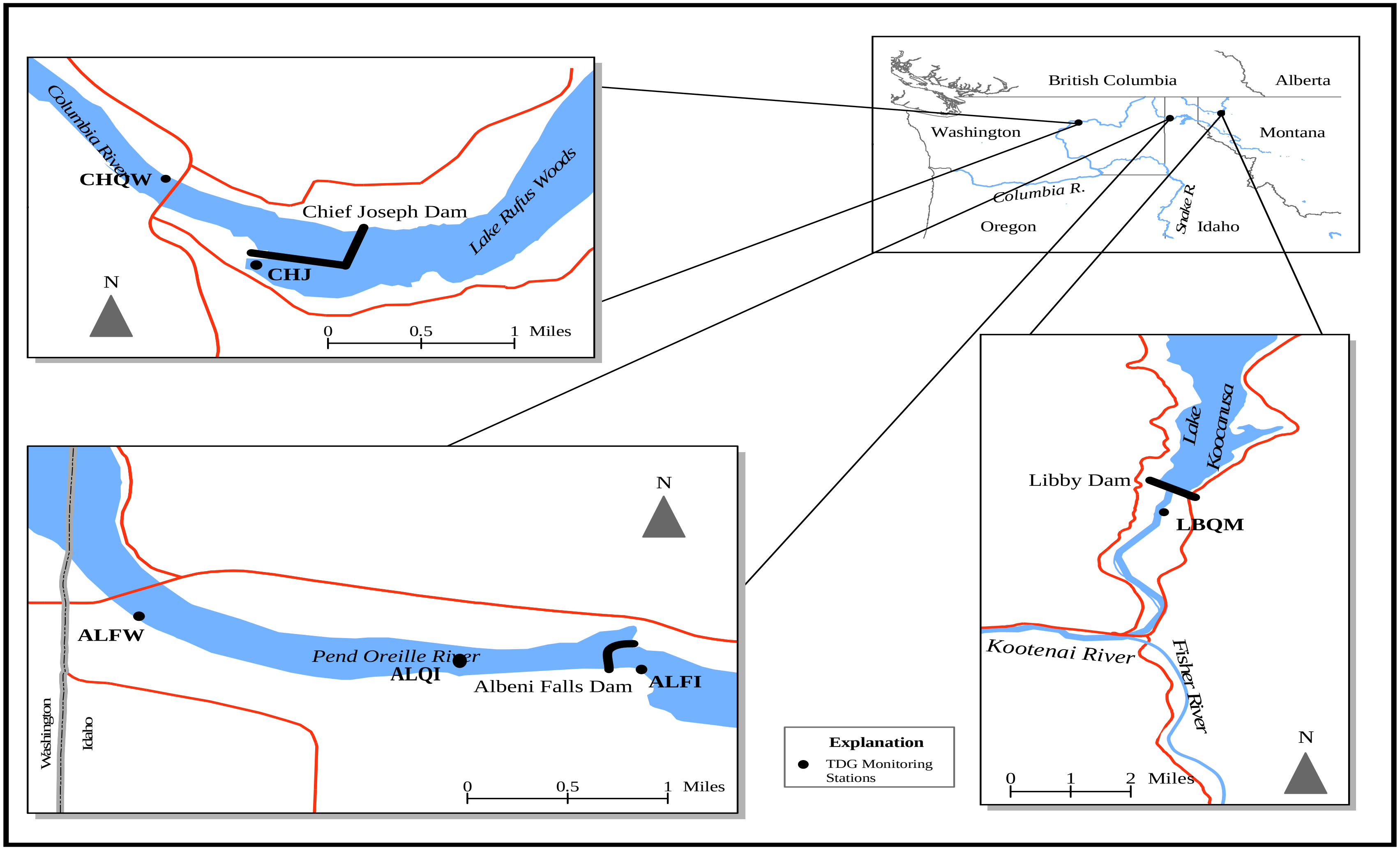
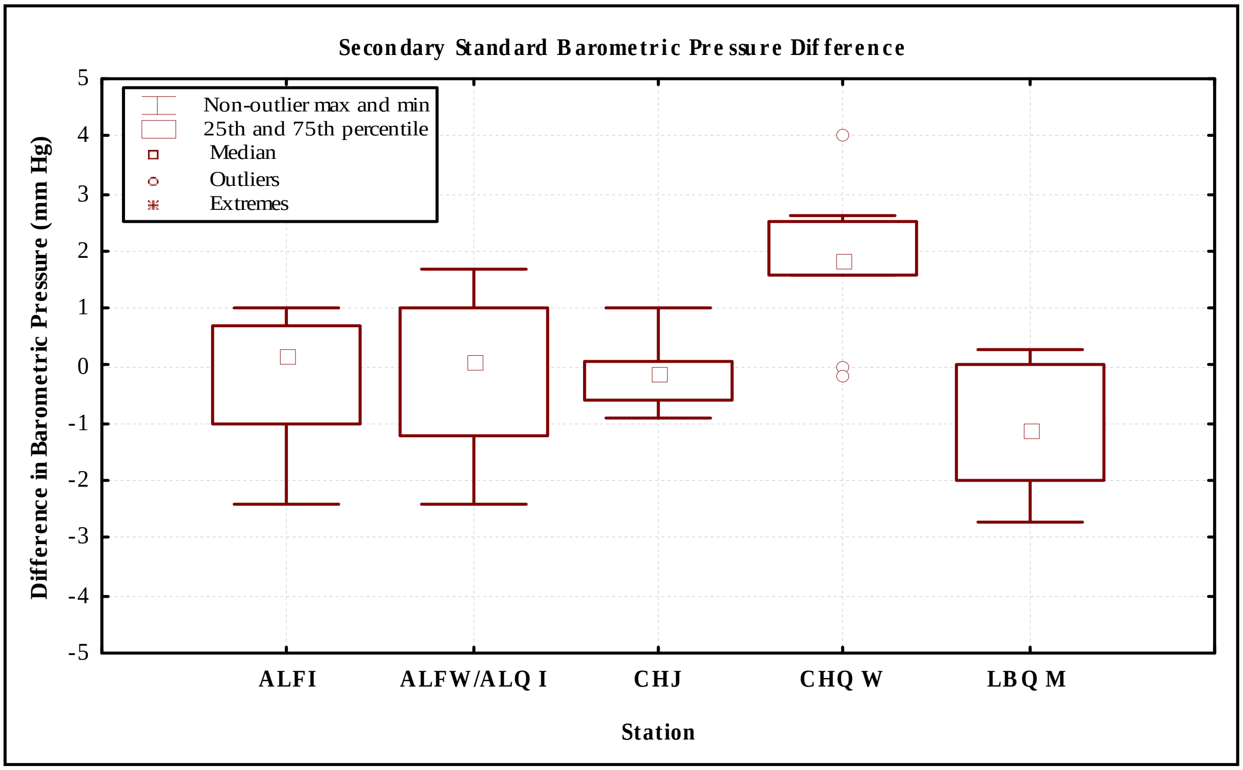


Figure 2. Locations of total dissolved gas monitoring stations in 2005 for Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana.



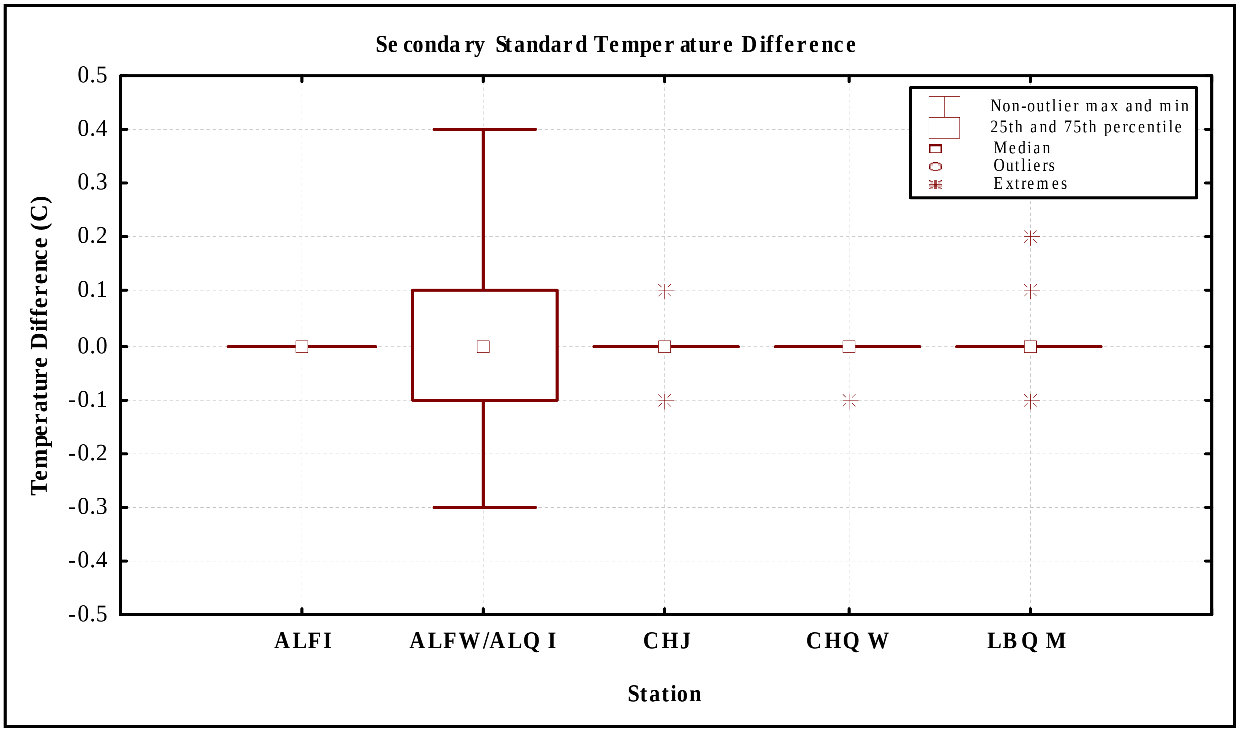


Figure 3. Difference between the secondary standard and the field barometers and field thermometers during spill season 2005.

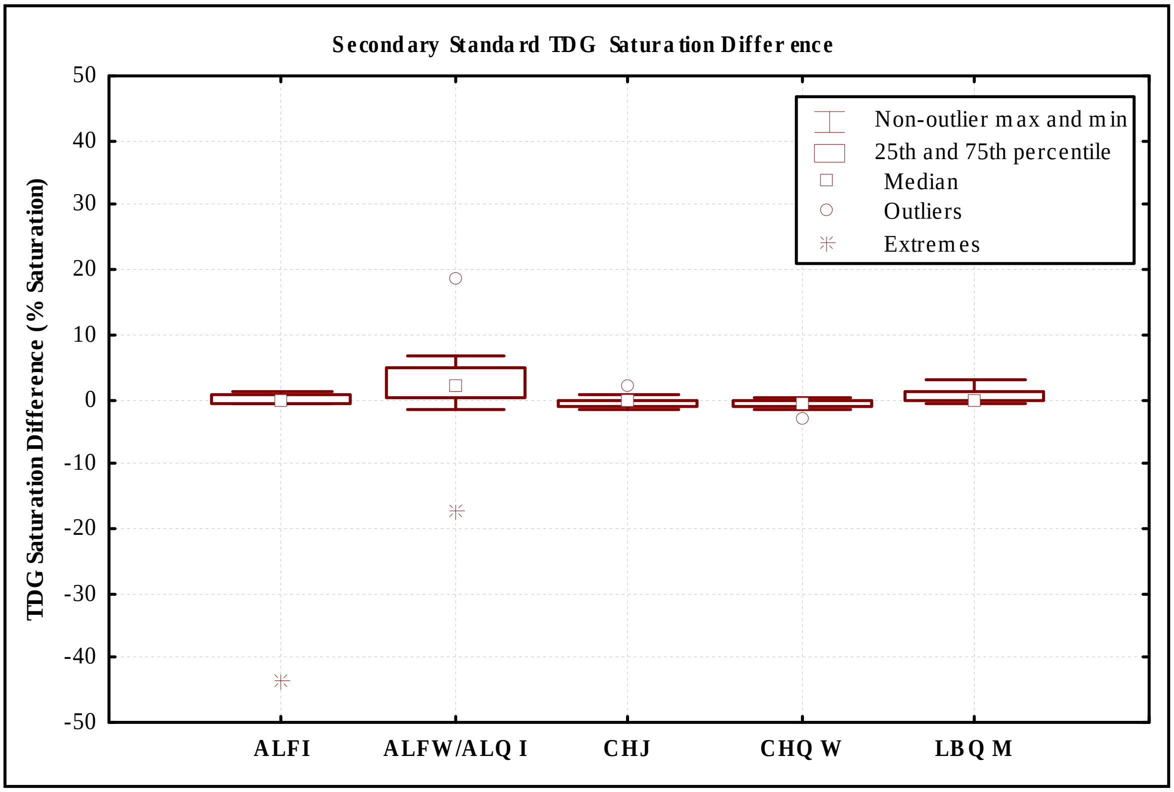
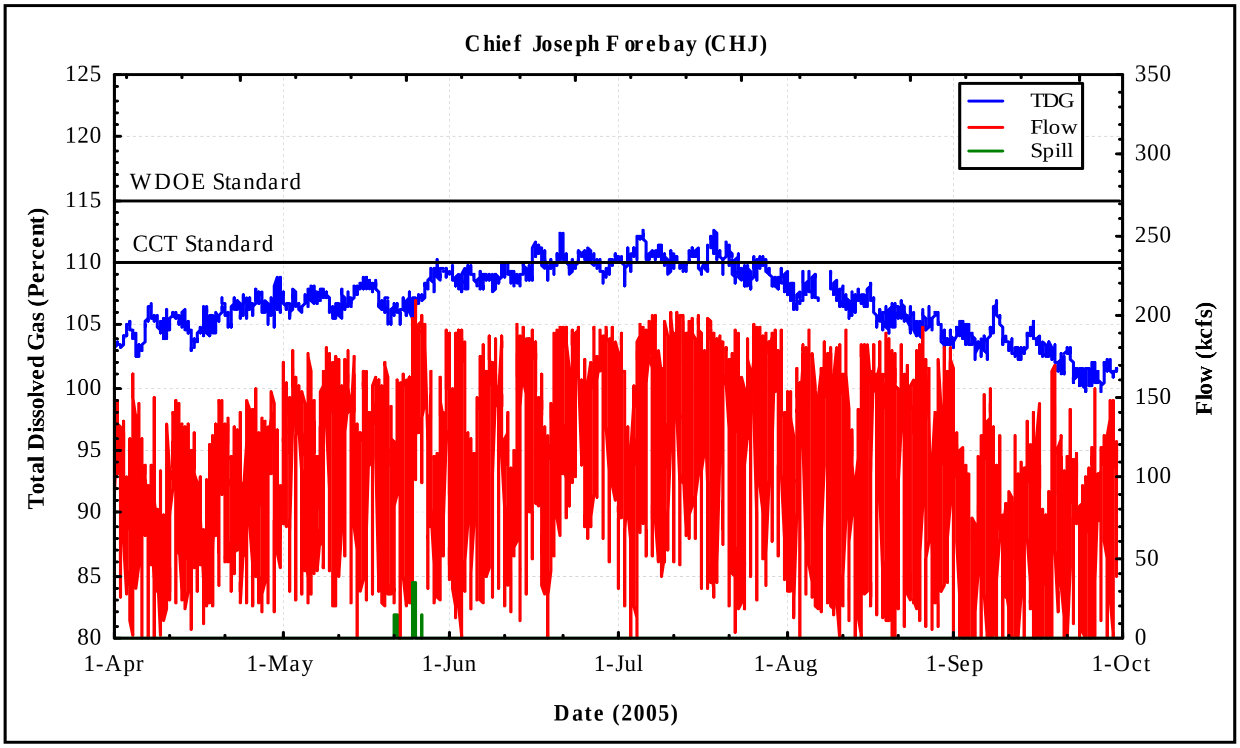


Figure 4. Difference between the secondary standard and the field total dissolved gas instrument for TDG pressure during spill season 2005.



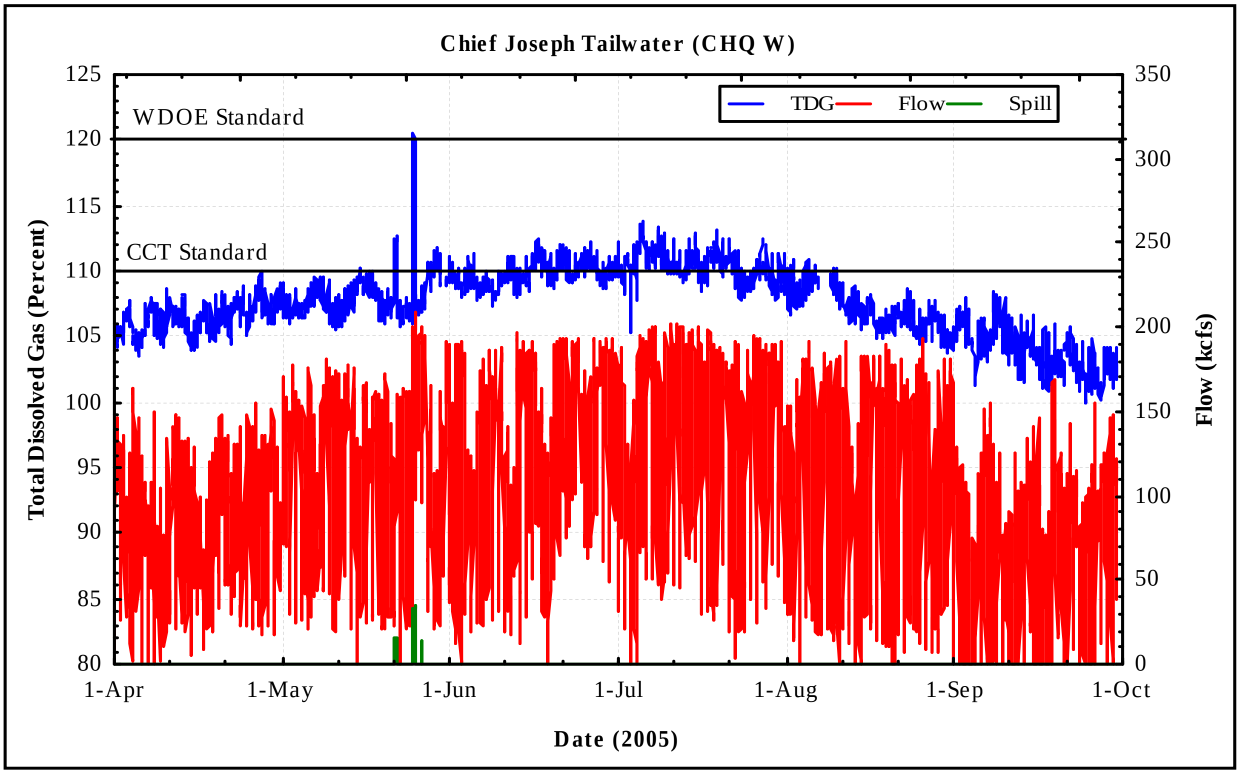


Figure 5. Total dissolved gas, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2005.

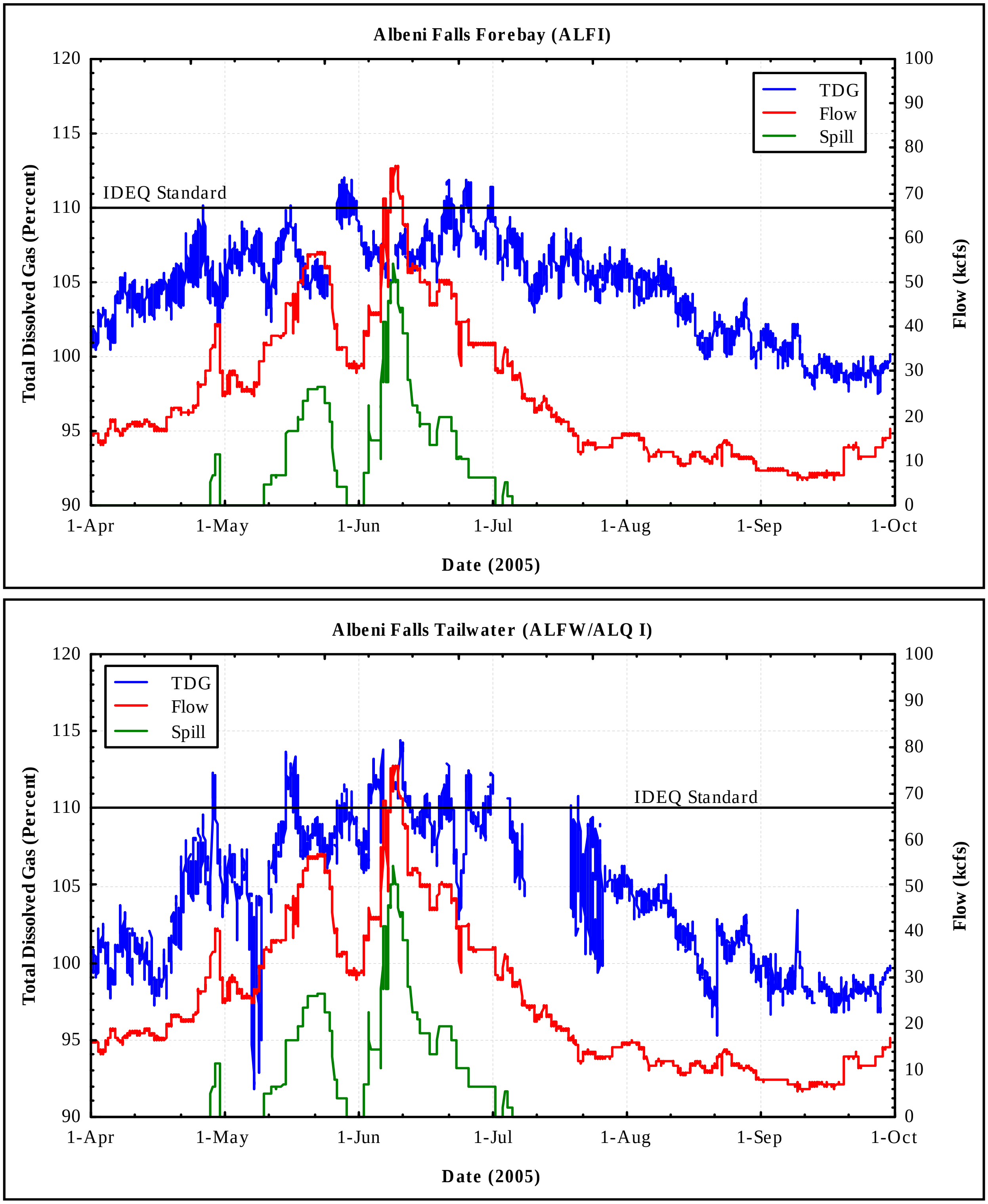


Figure 6. Total dissolved gas, spill, and flow at Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALFW/ALQI) stations during spill season 2005.

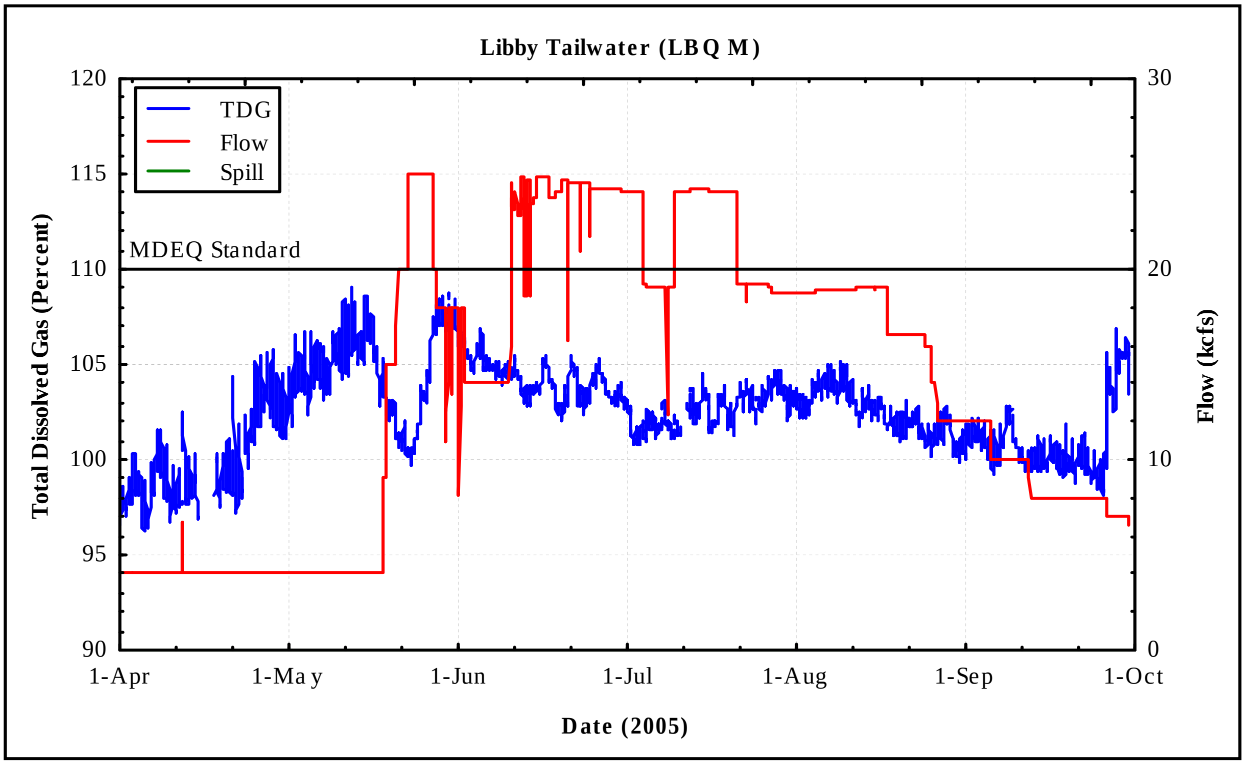
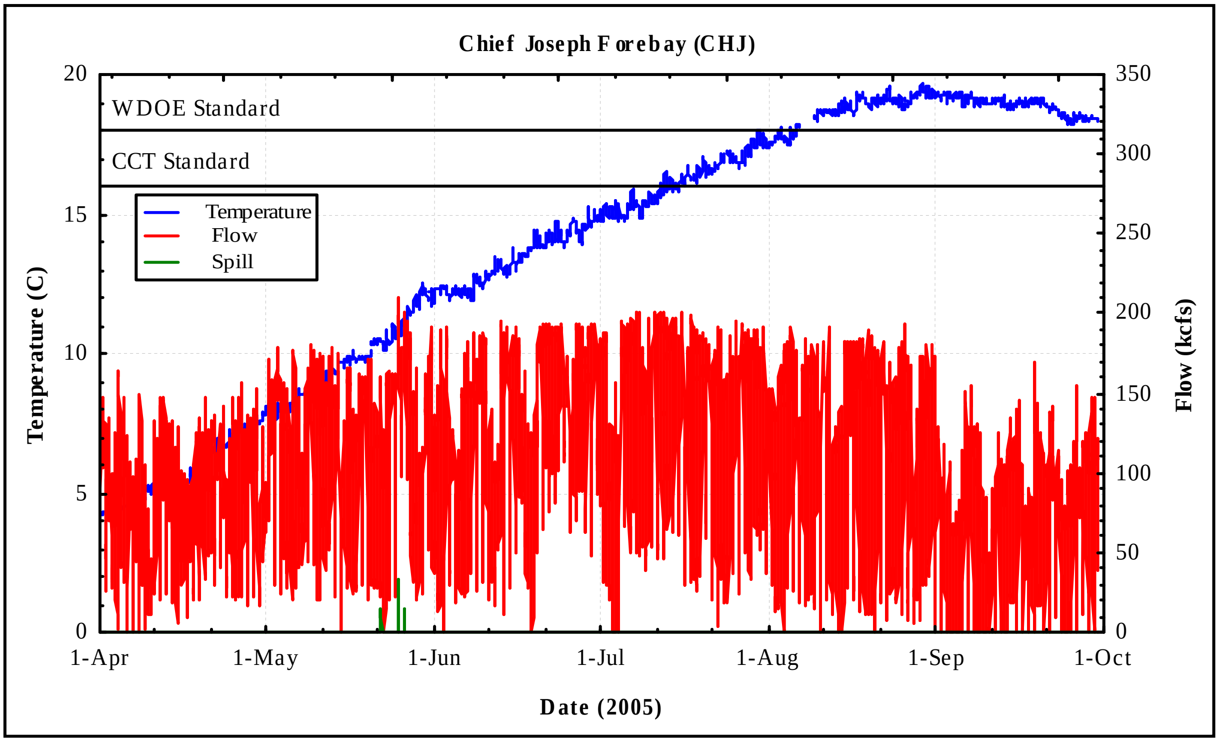


Figure 7. Total dissolved gas, spill, and flow at the Libby Dam Tailwater (LBQM) station during spill season 2005.



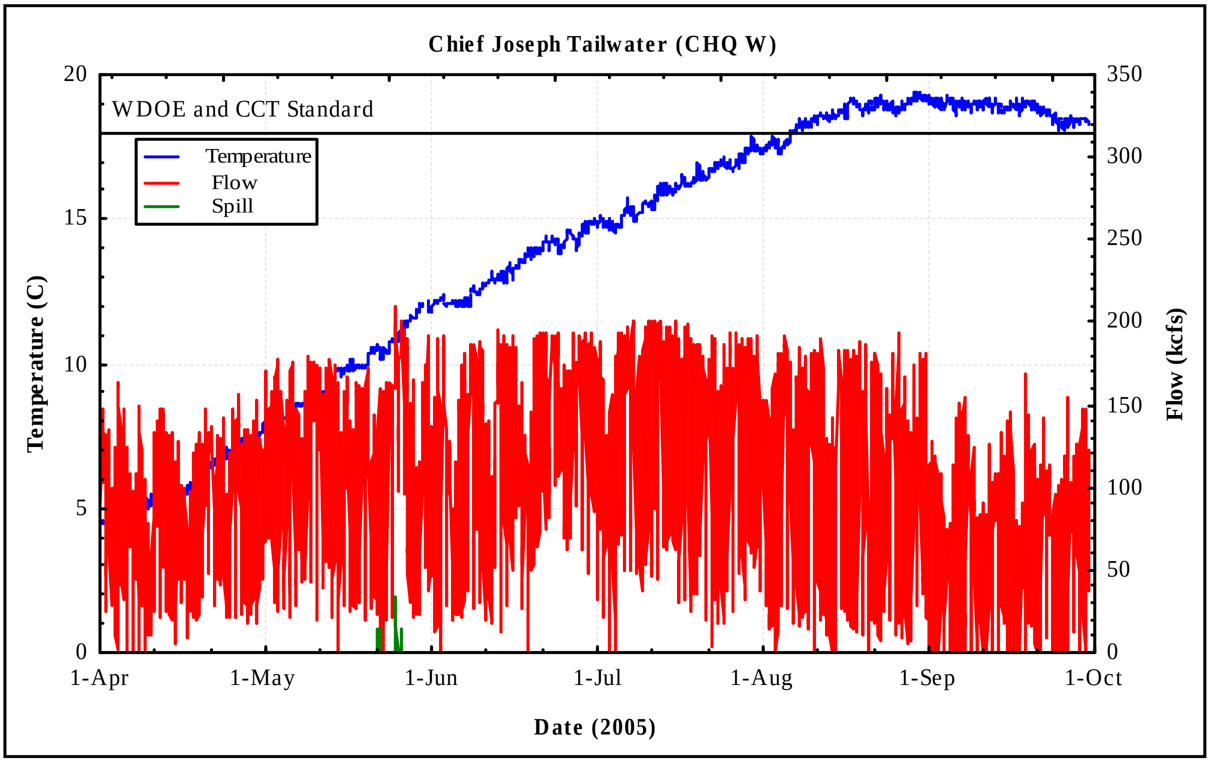


Figure 8. Temperature, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during spill season 2005.

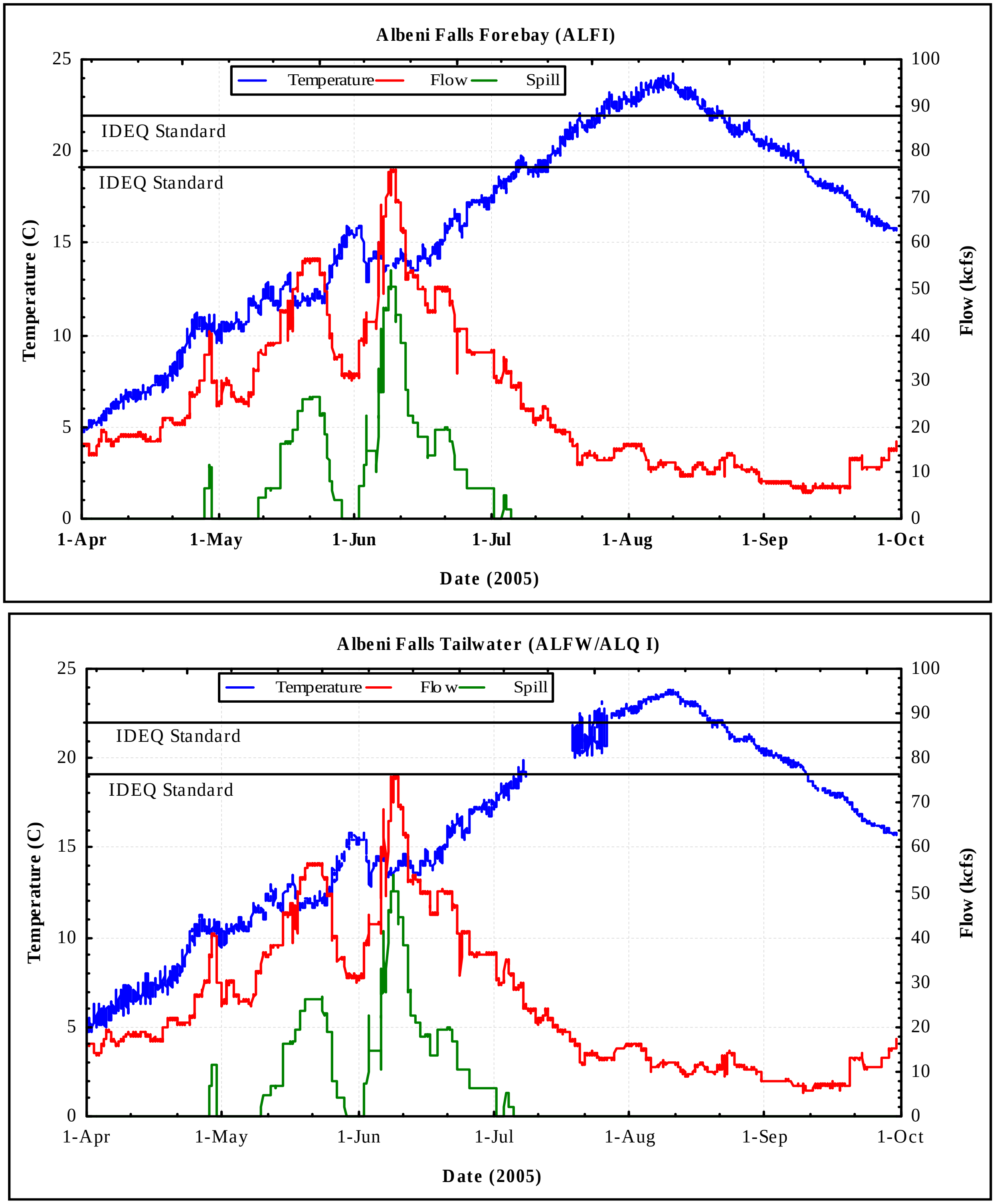


Figure 9. Temperature, spill, and flow at Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALFW) stations during spill season 2005.

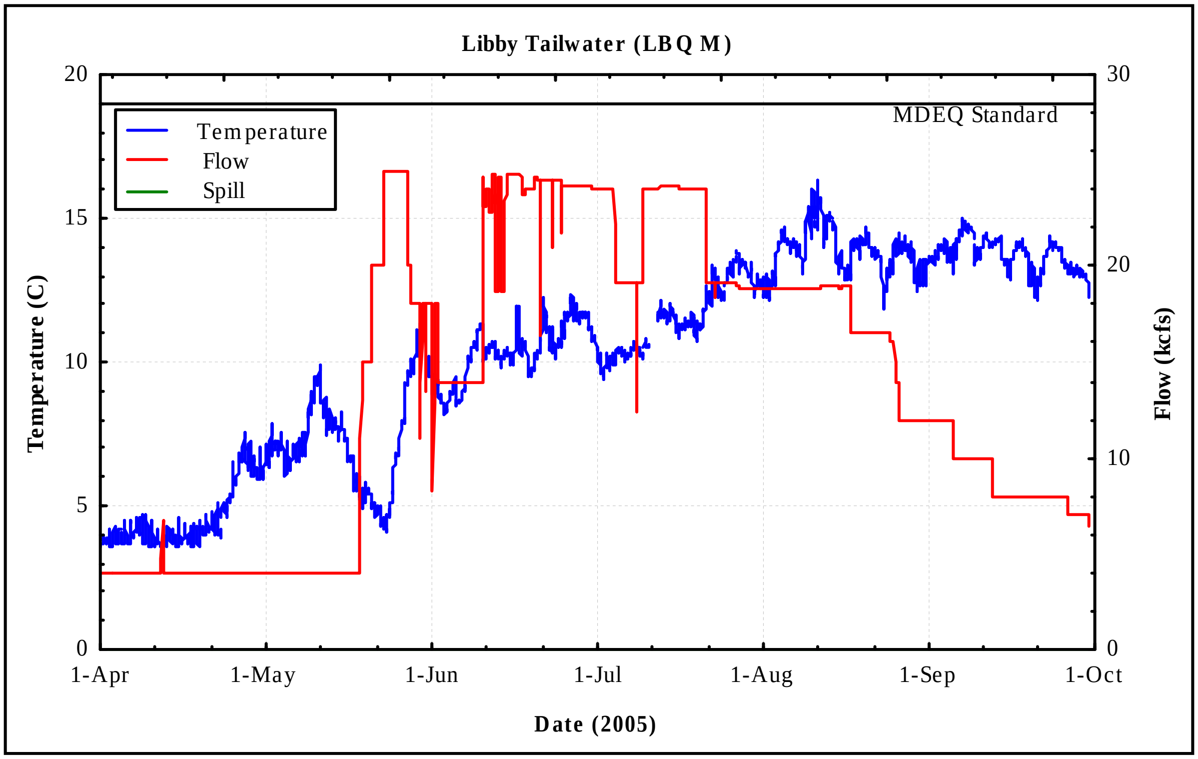


Figure 10. Temperature, spill, and flow at the Libby Dam Tailwater (LIBM) station during spill season 2005.