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Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana 2004: 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 2004 spill season, which lasted from April 1 – September 15, 2004. 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 and Albeni Falls Dam, and one fixed monitoring station at Libby Dam during the 2004 spill season (Figure 2). Fixed monitoring station location details and dates of operation are summarized in Table 1. 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 2003* (USCOE 2002). 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 Model 8200 data collection platform (DCP), 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 every 4 hours the DCP transmitted the data via the Geostationary Operational Environmental Satellite (GOES) system 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 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 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 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 5 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 station CHQW, 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 2004 are summarized in Tables 2 and 3. The data were based upon the number of planned monitoring hours from April 1 through September 15. However, at Albeni Falls Dam, the forebay monitoring station (ALFI) was not installed until April 20, 2004, while the tailwater monitoring station (ALFW) was not installed until May 5, 2004. 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 and deleted from the database.

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 were largely due to DCP malfunctions and programming problems. Rejected data for station CHJ were a result of DCP transmission of improper data value codes. Missing data for stations ALFI and ALFW were due to DCP malfunctions and programming problems, as well as multiple lightning strikes at Albeni Falls resulting in the failure to transmit data for short periods of time. Although no TDG data have yet been rejected from station ALFW, data collected from July 14 to August 19 are suspect due to substantially lower TDG saturations measured at ALFW compared to ALFI during low flow non-spill conditions (See Quality Assurance Procedures section below). Missing data for station LBQM were largely due to multiple lightning strikes at Libby resulting in the failure to transmit data for short periods of time until a new probe could be installed. Rejected data for station LBQM were minimal, and were a result of high TDG values immediately following redeployment of a freshly calibrated probe.

Quality-Assurance Procedures

Fixed monitoring stations were calibrated every two weeks during the 2004 monitoring season following procedures outlined in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring 2004* (USCOE 2003). 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 (six 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 2004 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.

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 tailwater station (ALFW). At ALFW the data were within 5 percent saturation difference except for a 5.2 percent difference on July 20, 2004, a 17.4 percent difference on August 5, 2004, and a 6.8 percent difference on August 19, 2004. These outlier points could not be attributed to the TDG sensor and may have been due to a worn TDG membrane or excessive algal growth on the membrane. Consequently, data collected during the July 14 to August 19, 2004 time period have been flagged as suspect and are undergoing further review to determine if any data will be deleted from the database.

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 WDOE has classified the Columbia River above and below Chief Joseph Dam as a Salmon and Trout spawning non-core rearing and migration aquatic life use water body, while 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 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 Salmon and Trout spawning non-core rearing and migration aquatic life use 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 2004 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 2004 monitoring season are presented in Figure 5. Columbia River flow volumes were low to moderate during 2004 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 2004 season, with spills of about 5,000 cfs on May 30, 30,000 cfs on June 21, and 26,000 cfs from August 30 to September 1 (Figure 5).

Total dissolved gas saturations at Chief Joseph forebay station (CHJ) were greater than 110 percent from about June 24, 2004 to August 10, 2004, 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 3 hours on May 30, 2004 and then continuously from about June 21, 2004 to August 16, 2004 and again from August 30, 2004 to September 2, 2004. This station had only 1 hour exceeding 120 percent, which occurred during a spill of 26,000 cfs on September 1, 2004.

Albeni Falls Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Albeni Falls Dam during the 2004 monitoring season are presented in Figure 6. Pend Oreille River flow volumes were low during 2004 with a maximum flow of about 52,000 cfs recorded on May 31, 2004, well below the historical (1952-1998) average maximum flow of about 80,000 cfs. Consequently, Albeni Falls Dam experienced reduced spill volumes during the 2004 season. Spillway flows ranged from about 0 to 22,000 cfs, with the majority of spill occurring from May 15, 2004 to July 1, 2004 and from August 30, 2004 to September 2, 2004.

Total dissolved gas saturations at Albeni Falls forebay station (ALFI) were periodically greater than 110 percent from about June 23, 2004 to July 2, 2004 (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 possible that Cabinet Gorge Dam was the source of the elevated TDG measured at the forebay.

Total dissolved gas saturations Albeni Falls tailwater station (ALFW) exceeded 110 percent several times during spillway operations in 2004 (Figure 6). The highest TDG saturation recorded was about 113 percent on May 11, 2004 during a spillway release of about 18,000 cfs. In general, the highest TDG saturations were measured during spillway releases that used 4 of 10 spill bays, and 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 15 percent were seen at the tailwater station during low flow conditions on the Pend Oreille River from July through September (Figure 6). During this time period, TDG saturations cycled up to 15 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 (Figure 7). Differences between forebay and tailwater TDG saturations ranged from about 5 percent during the high flow period of May through June to about 20 percent during the low flow period of July through August (Figure 7).

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 (see below) could not solely account for the up to 15 percent swings in daily TDG saturations, suggesting that other in-river processes were impacting TDG saturations. The tailwater station is located in a shallow nearshore zone that may experience slack water during low flow summer months. 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 the tailwater station suggests that an equipment problem such as a worn TDG membrane may be partly responsible for the low TDG saturations recorded at this station.

Libby Dam

Hourly total dissolved gas saturations, river flows, and spill volumes for Libby Dam during the 2004 monitoring season are presented in Figure 8. In general, total dissolved gas saturation levels increased from about 98 percent in April to about 106 percent in early June. The gradual rise in TDG saturations is likely related to the use of the selective withdrawal system during this time period to increase downstream water temperatures in the Kootenai River (Hoffman 2004). Because the solubility of a gas in water is inversely proportional to the water temperature, the increased water temperature likely resulted in the rise in TDG saturations. Total dissolved gas saturations at Libby exceeded 110 percent for 10 hours on May 24, 2004 and for 5 hours on September 5, 2004 (Figure 8). No spill occurred at Libby Dam during 2004, and these elevated TDG saturation were due to Libby Dam running a single unit on speed-no-load while performing maintenance operations. During speed-no-load operations air is injected into the turbine through a vacuum breaker valve, which would account for the rise in TDG saturations.

Temperature

Chief Joseph Dam

The seven day average maximum temperature measured at the Chief Joseph forebay (CHJ) and tailwater (CHQW) stations were similar, and ranged from about 5 °C in April to 20°C in September (Figure 9). 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 14 through September 15, 2004, and were greater than 17.5° C from August 1 through September 15, 2004. Water temperatures at the tailwater exceeded 17.5° C from about August 2 through September 15, 2004.

Albeni Falls Dam

Temperatures measured at the Albeni Falls forebay (ALFI) and tailwater (ALFW) stations were similar, and ranged from about 12 °C in May to 23°C in August (Figure 10). 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 7 through September 8, 2004, while the maximum daily temperature exceeded 22 °C from about July 21 through August 25, 2004. Similarly, daily average water temperatures at the tailwater exceeded 19 °C from about July 10 through September 7, 2004, with the maximum daily temperature exceeding 22 °C from about July 26 through August 24, 2004.

Diurnal temperature cycles of up to 3 °C were seen at the tailwater station (ALFW) during low flow conditions on the Pend Oreille River from July through September (Figure 10). Although diurnal temperature cycling was present at the forebay station (ALFI), these cycles were generally in the range of 1 °C, suggesting that the tailwater station was not representative of in-river conditions (Figure 11). The difference between forebay and tailwater temperatures ranged from about 0 °C during the high flow period of May through June to about 1.5 °C during the low flow period of July through August (Figure 11). The tailwater station is located in a shallow nearshore zone that may experience 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.

Libby Dam

Temperature measured at the Libby Dam tailwater (LBQM) station ranged from about 4 °C in April to 15°C in August (Figure 12). 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 12, temperature increases during May and June represent operational changes in the selective withdrawal system (Hoffman 2004).

Conclusions

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

- Data completeness for TDG and temperature data ranged from 90.2 percent at the Albeni Falls Dam tailwater station (ALFW) to 99.9 percent at the Chief Joseph Dam tailwater station (CHQW). Missing data were largely due to DCP malfunctions, programming problems, and lightning strikes. Suspect data were a result of poor quality assurance data. Rejected data were a result of DCP transmission of improper data value codes.

- 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 tailwater (ALFW). Between July 14 and August 19, TDG saturations at ALFW were between 5 percent and 17 percent different than the secondary standard. Consequently, data from this time period are suspect and may be deleted from the database.

- Total dissolved gas saturations were similar between Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) stations, and exceeded 110 percent from mid June through mid August 2004. TDG levels measured at Chief Joseph were largely a function of TDG levels released from Grand Coulee Dam, except during two small spill events that increased tailwater TDG saturations to about 120 percent.

- Total dissolved gas saturations at Albeni Falls Dam forebay station (ALFI) and tailwater station (ALFW) periodically exceeded 110 percent during the 2004 spill season. Large diurnal cycles in TDG saturations seen at the tailwater were not seen at the forebay, suggesting that the tailwater station was not representative of in-river conditions, and may be influenced by heat exchange with the river and the diurnal cycling of photosynthesis and respiration.

- Libby tailwater (LBQM) exceeded 110 percent TDG saturation standard on May 24 and September 5 during speed-no-load operations.

- Water temperatures at the Chief Joseph Dam forebay (CHJ) and tailwater (CHQW) were greater than 16 °C and 17.5 °C, respectively, from August through September 2004. Similarly, water temperatures at Albeni Falls Dam forebay (ALFI) and tailwater (ALFW) were greater than 19 °C from July through September 2004. Temperature measured at the Libby Dam tailwater (LBQM) station ranged from about 4 °C in April to 15°C in August.

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Tables

Table 1. Fixed monitoring station locations and sampling period, water year 2004.

Site Identifier	Station Name	Latitude	Longitude	2004 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	04/01/04 - 09/15/04
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	04/01/04 - 09/15/04
ALFI	Albeni Falls Dam Forebay	48° 10' 40"	116° 59' 52"	04/20/04 - 09/15/04
ALFW	Albeni Falls Dam Tailwater	48° 10' 56"	117° 02' 03"	05/05/04 - 09/15/04
LBQM	Libby Dam Tailwater	48° 19' 07"	115° 19' 07"	04/01/04 - 09/15/04

Table 2. Total dissolved gas data completeness for water year 2004.

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 passing quality assurance
Chief Joseph Forebay	CHJ	4032	163	96.0	95.9
Chief Joseph Tailwater	CHQW	4032	1	99.9	99.9
Albeni Falls Forebay	ALFI	3561	96	97.3	97.3
Albeni Falls Tailwater	ALFW	3201	313	90.2	90.2[a]
Libby Tailwater	LBQM	4032	63	98.4	98.4

Notes:
[a]Data collected between July 14 and August 19 are suspect and may be deleted from the database resulting in only 83.6 percent of data passing quality assurance.

Table 3. Temperature data completeness for water year 2004.

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 passing quality assurance
Chief Joseph Forebay	CHJ	4032	163	96.0	95.9
Chief Joseph Tailwater	CHQW	4032	1	99.9	99.9
Albeni Falls Forebay	ALFI	3561	88	97.5	97.5
Albeni Falls Tailwater	ALFW	3201	256	92.0	92.0
Libby Tailwater	LBQM	4032	63	98.4	98.4

Table 4. Total dissolved gas 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.

	Temperature	Total Dissolved Gas Pressure (% Saturation)			
	°C	100%	113%	126%	139%
N	65	65	65	65	65
Maximum	0.20	0.63	1.274	1.504	1.903
Minimum	-0.12	-1.14	-0.429	-0.429	-0.429
Median	0.020	0.026	0.067	0.067	0.000
Average	0.022	0.027	0.087	0.097	0.057
Standard Deviation	0.072	0.210	0.245	0.273	0.310

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	Measured by the 7-day average of the daily maximum temperatures. Shall not exceed 17.5°C. When temperature exceeds the criteria or is within 0.3°C of the criteria, and the condition is due to natural conditions, then human actions may not cause an increase of more 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	Water temperatures of 22°C or less with a maximum daily average less than 19°C.
	WDOE	Temperature shall not exceed a 1-day max of 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	A 0.6°C maximum increase above naturally occurring water temperature is allowed within the range of 0°C and 18°C; within the naturally occurring range of 18°C and 19°C, no discharge is allowed which causes the water temperature to exceed 19.5°C.

Figures

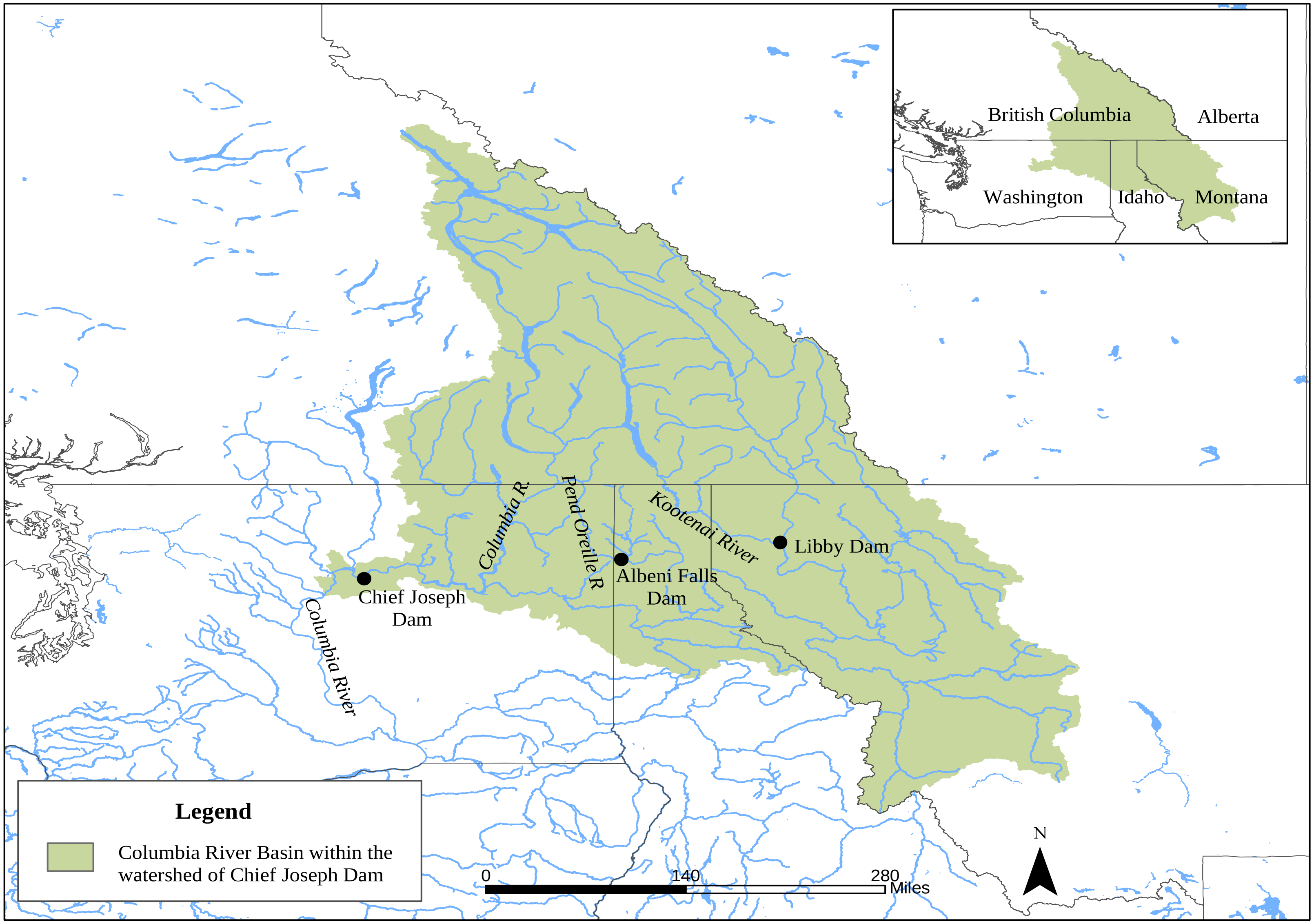


Figure 1. Location of Seattle District projects in the upper Columbia River basin.

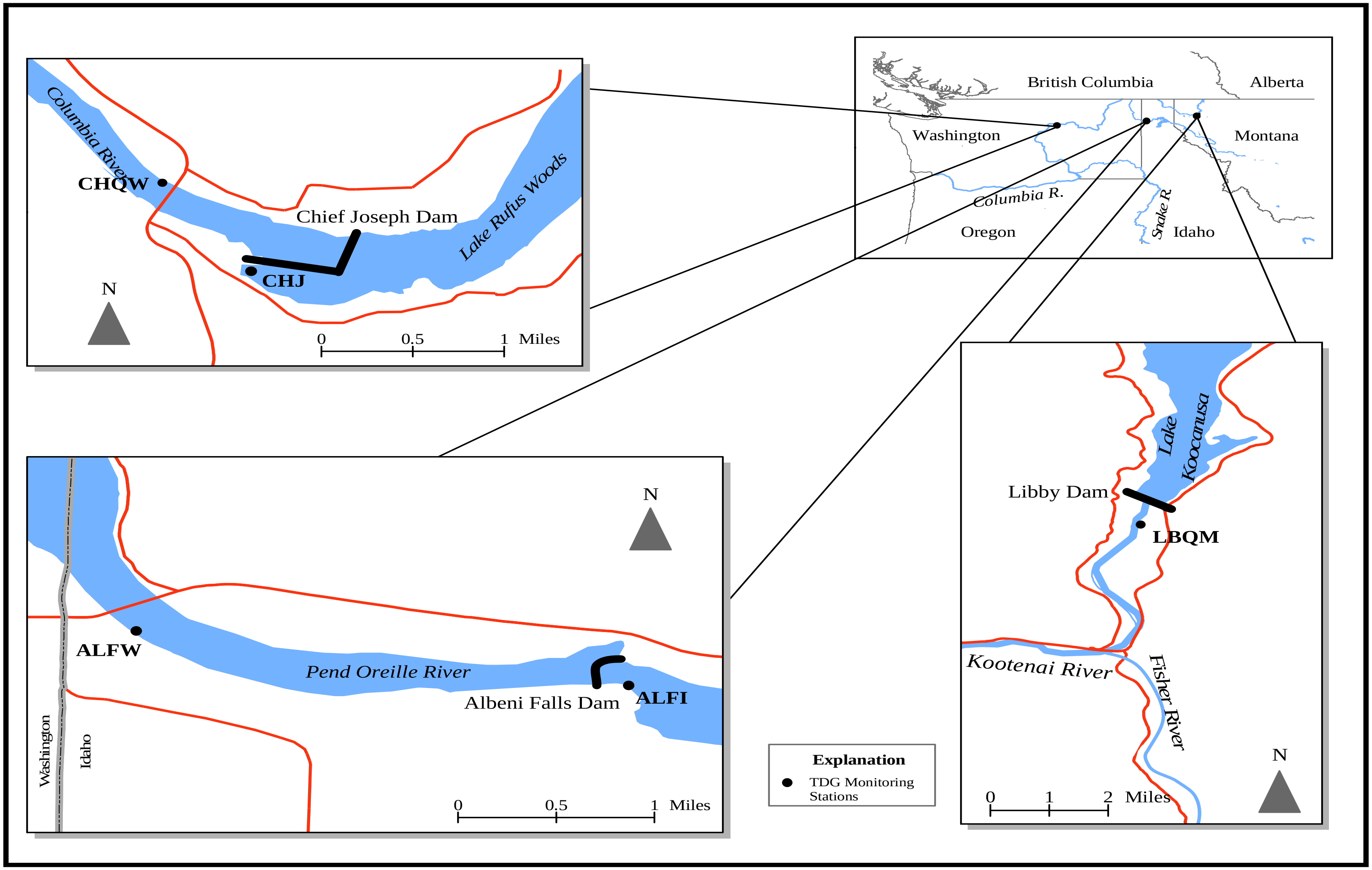


Figure 2. Locations of total dissolved gas monitoring stations in 2004 for Chief Joseph Dam, Washington, Albeni Falls Dam, Idaho and Libby Dam, Montana.

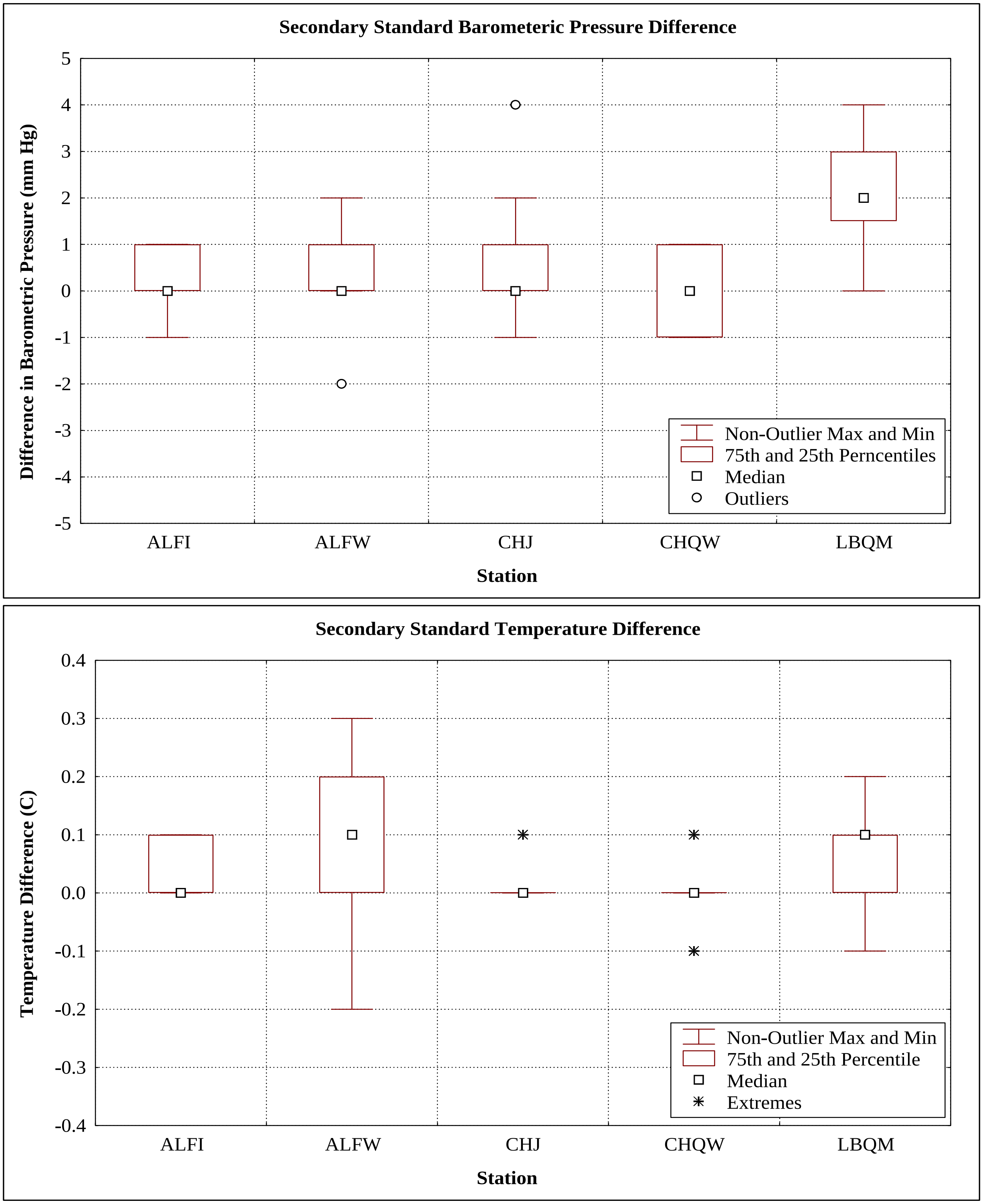


Figure 3. Difference between the secondary standard and the field barometers and field thermometers.

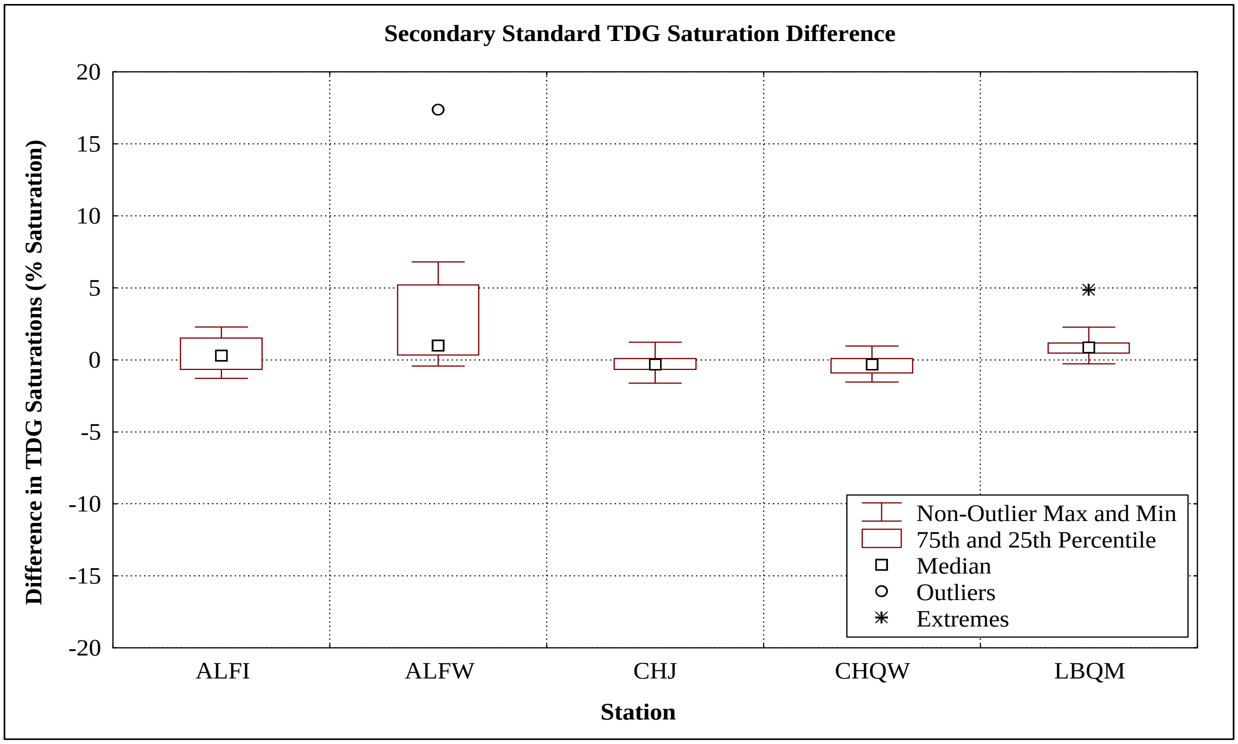


Figure 4. Difference between the secondary standard and the field total dissolved gas instrument for TDG pressure.

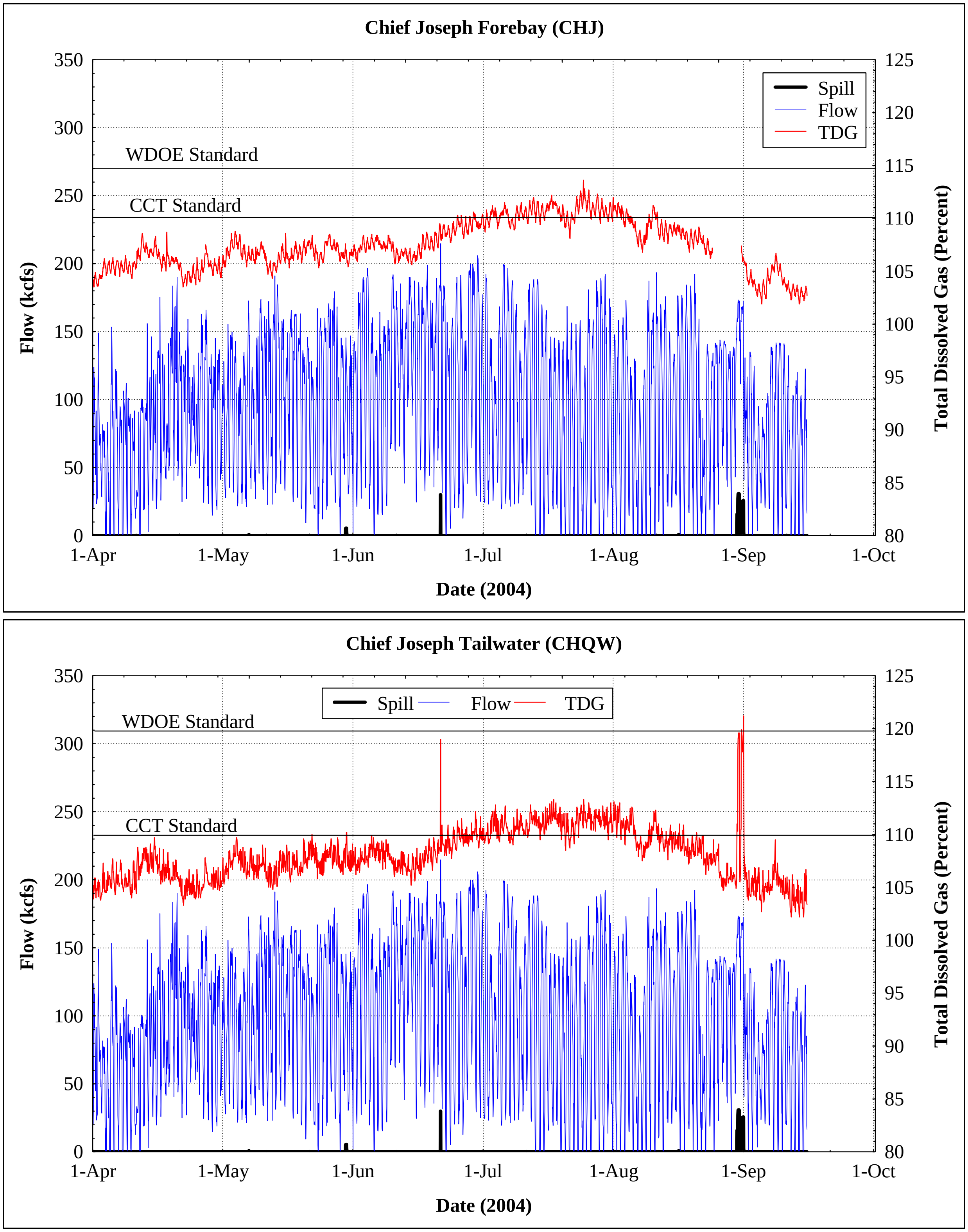
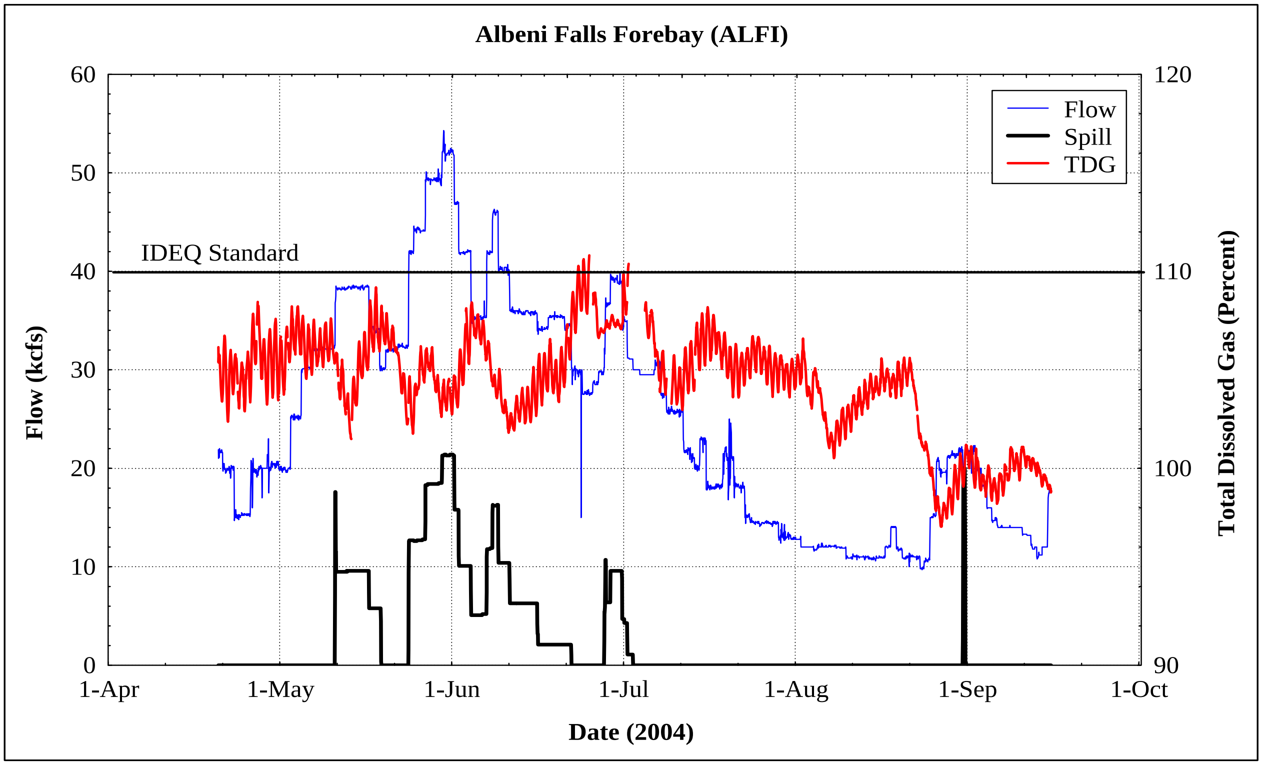


Figure 5. Total dissolved gas, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during water year 2004.



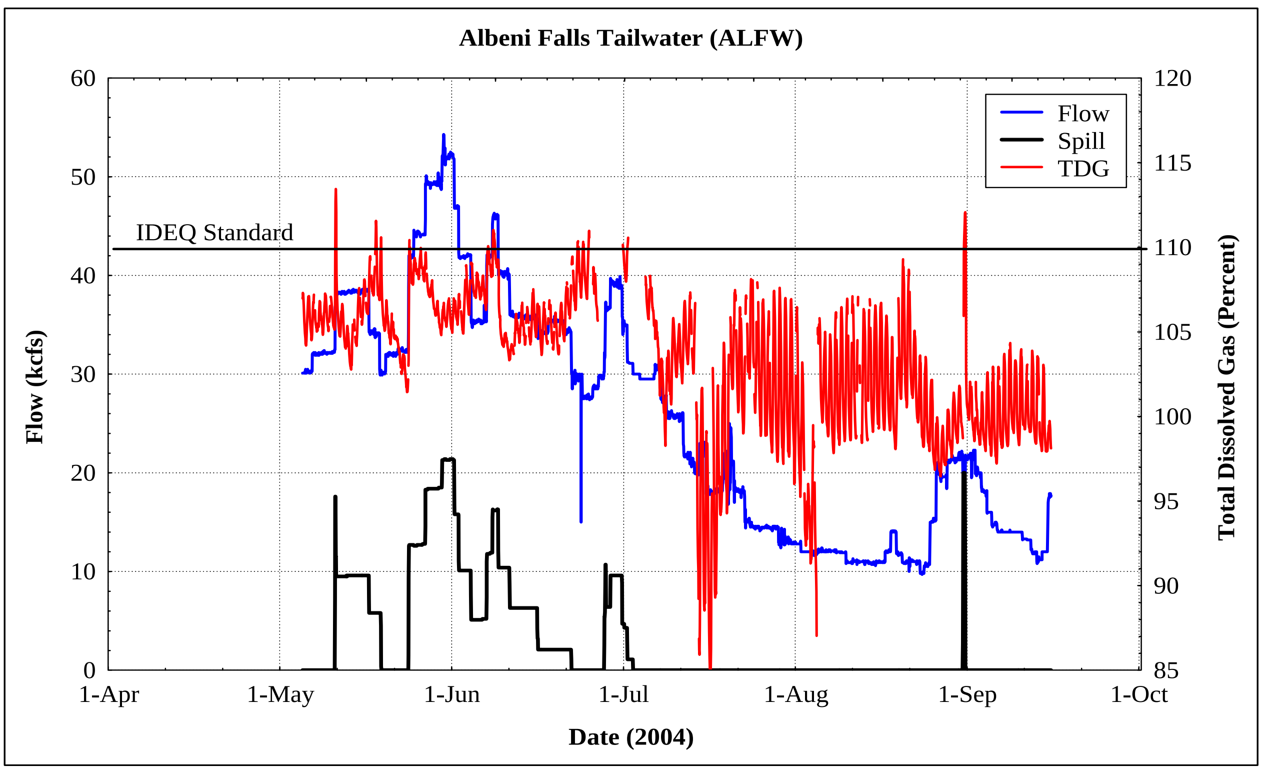


Figure 6. Total dissolved gas, spill, and flow at Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALFW) stations during water year 2004.

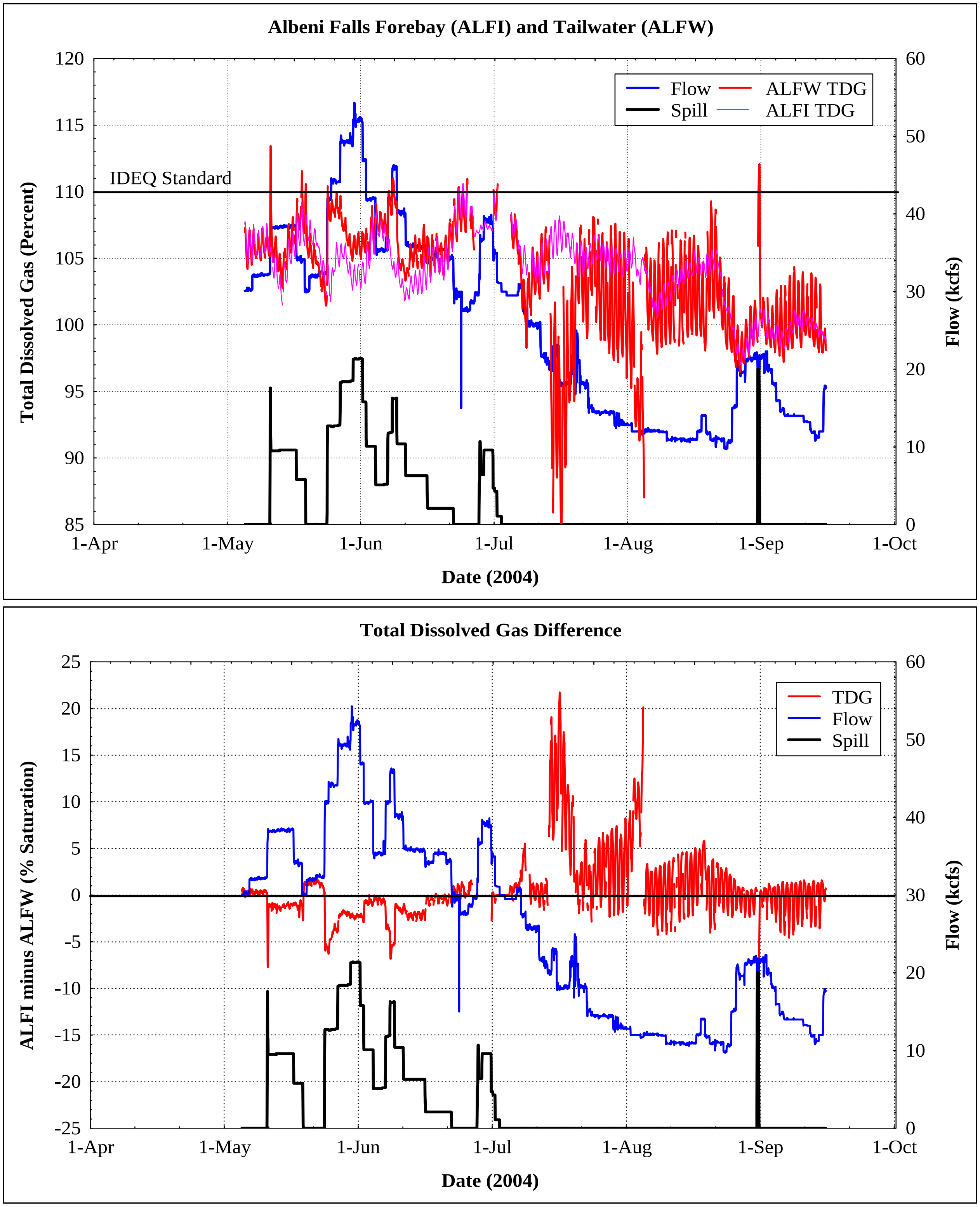


Figure 7. Comparison of Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALFW) TDG during water year 2004.

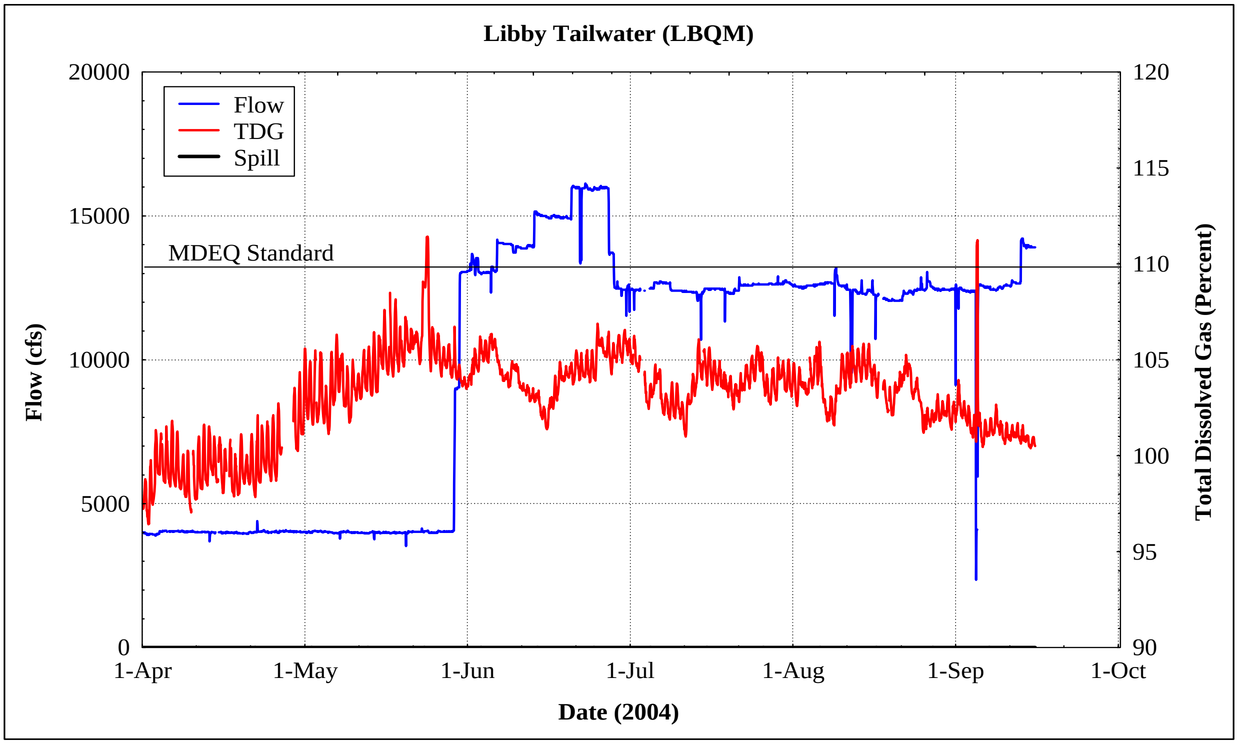
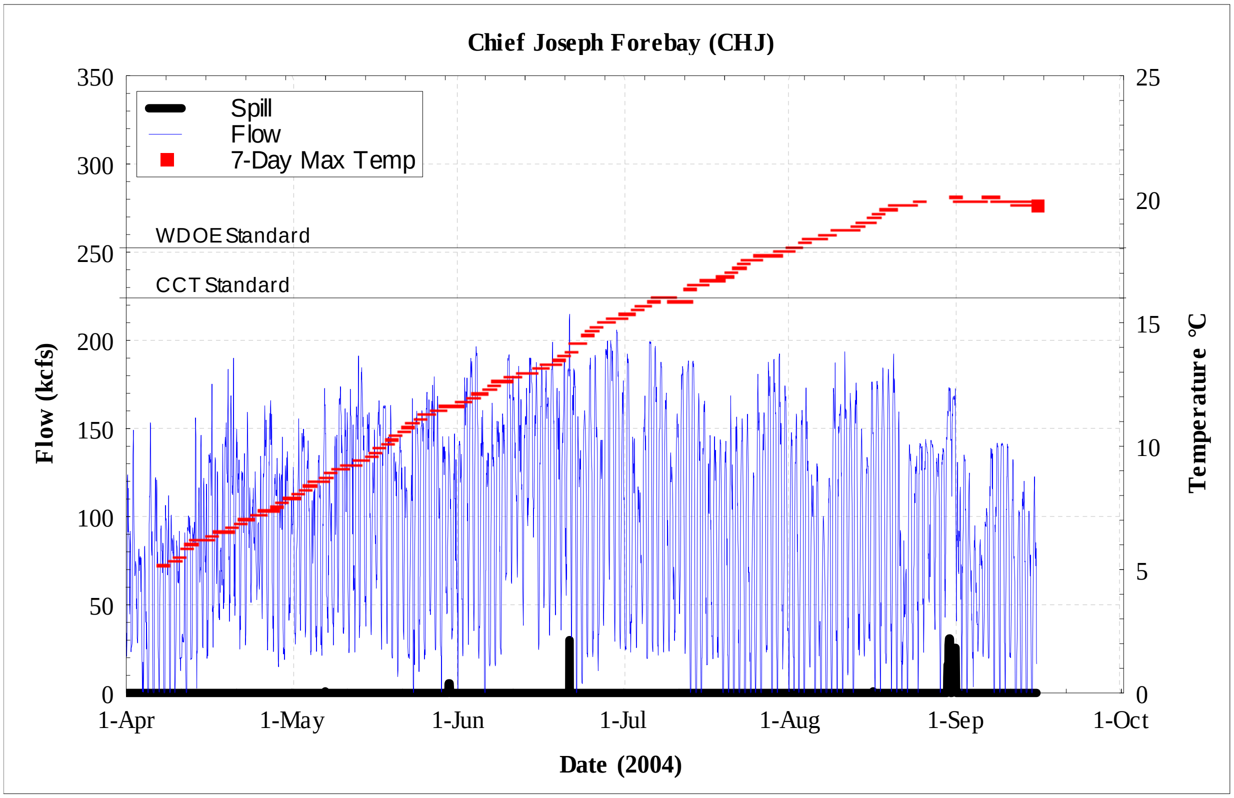


Figure 8. Total dissolved gas, spill, and flow at the Libby Dam Tailwater (LIBM) station during water year 2004.



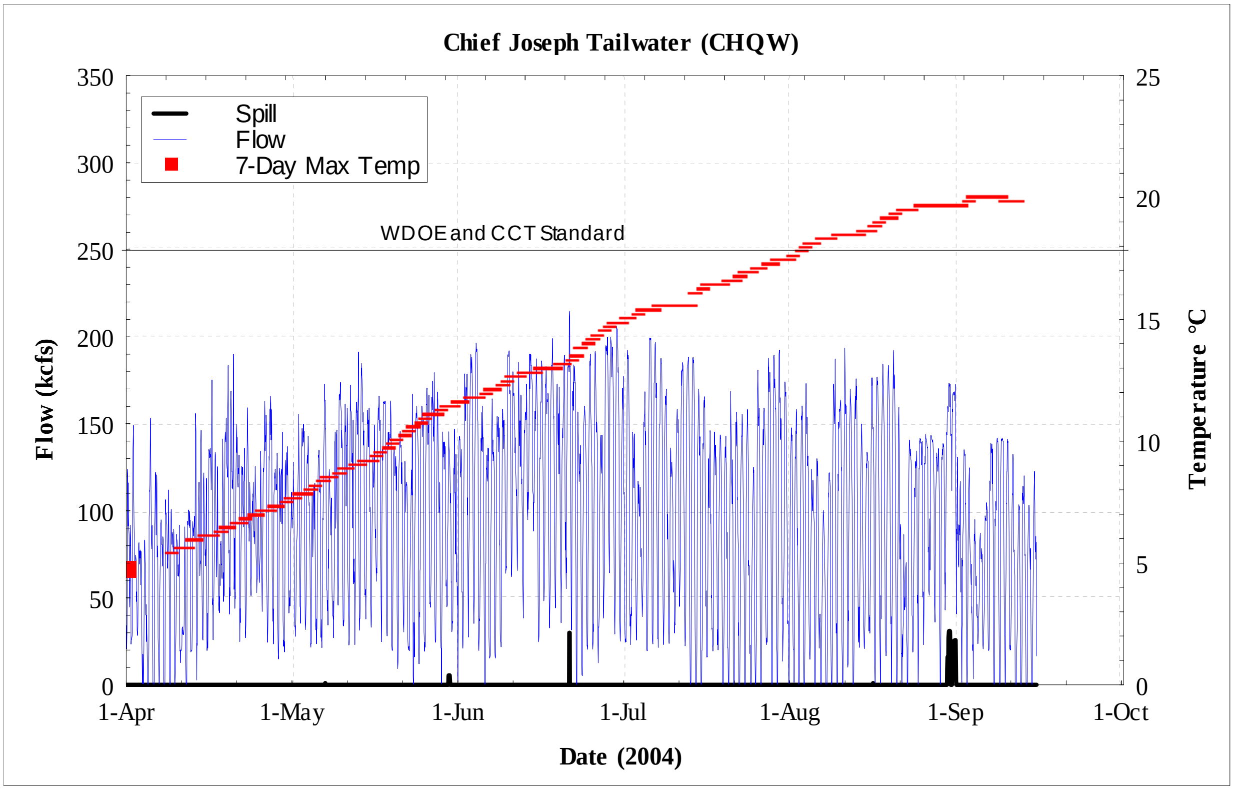


Figure 9. Temperature, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during water year 2004.

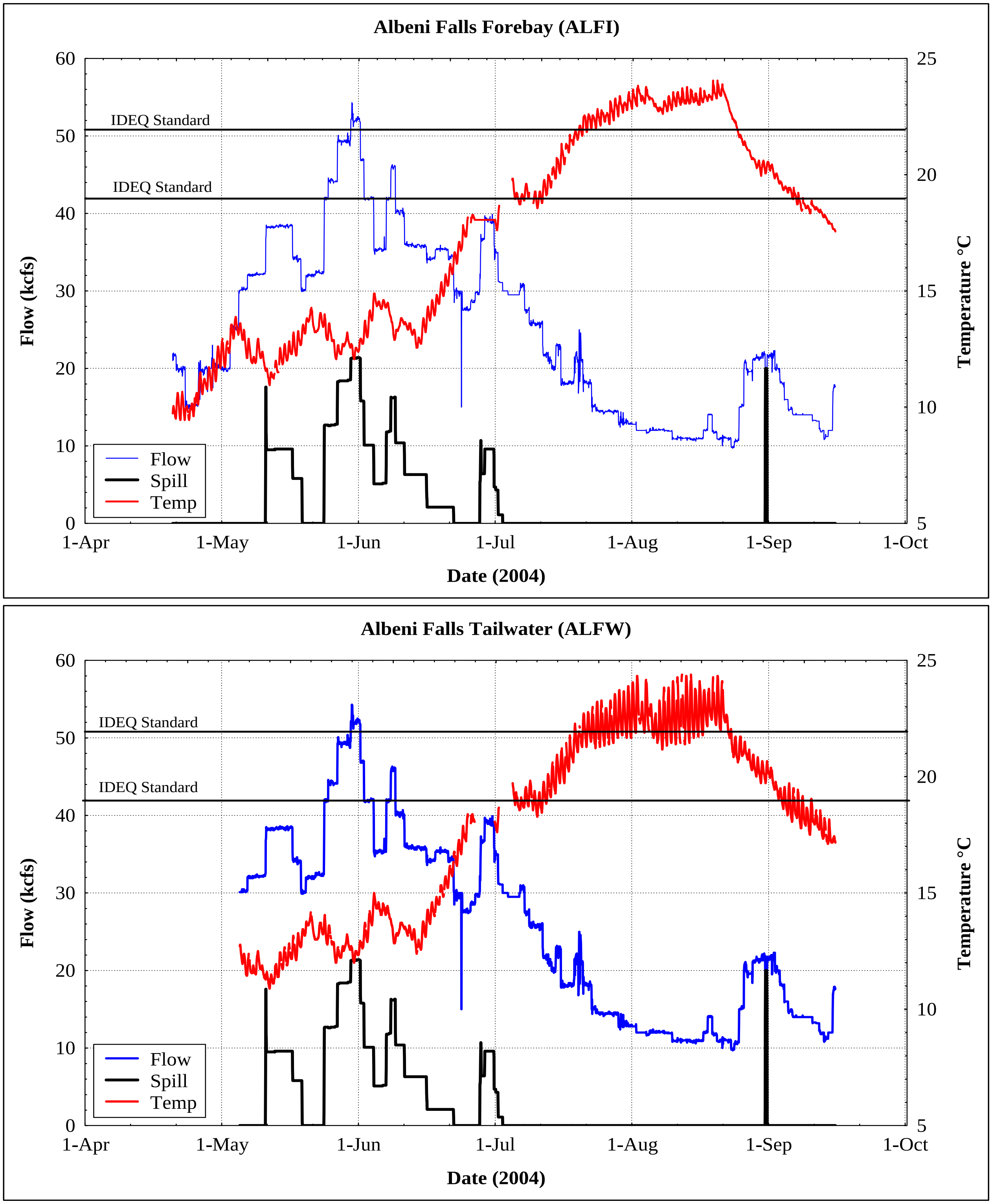


Figure 10. Temperature, spill, and flow at Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALFW) stations during water year 2004.

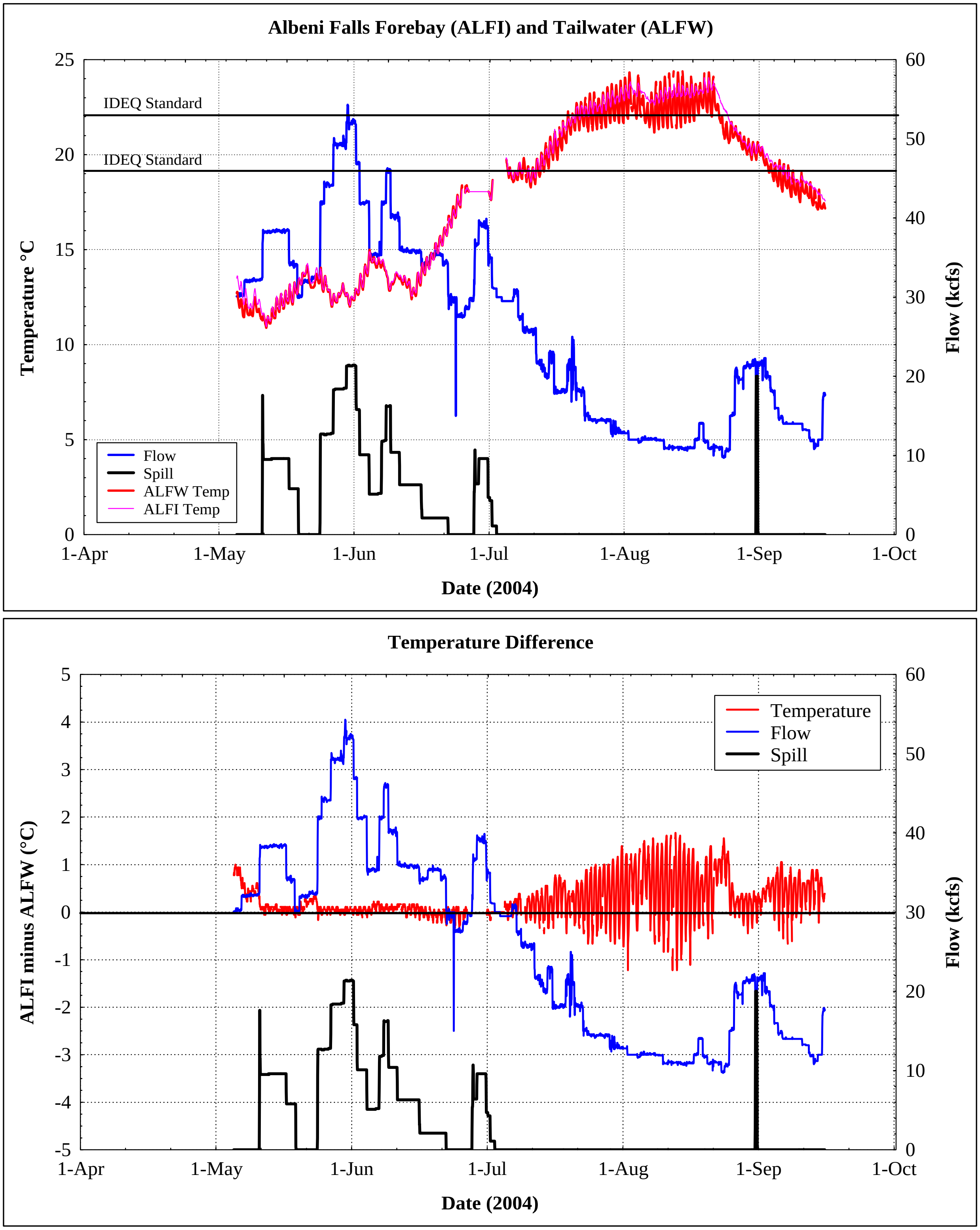


Figure 11. Comparison of Albeni Falls Dam Forebay (ALFI) and Albeni Falls Dam Tailwater (ALFW) temperature during water year 2004

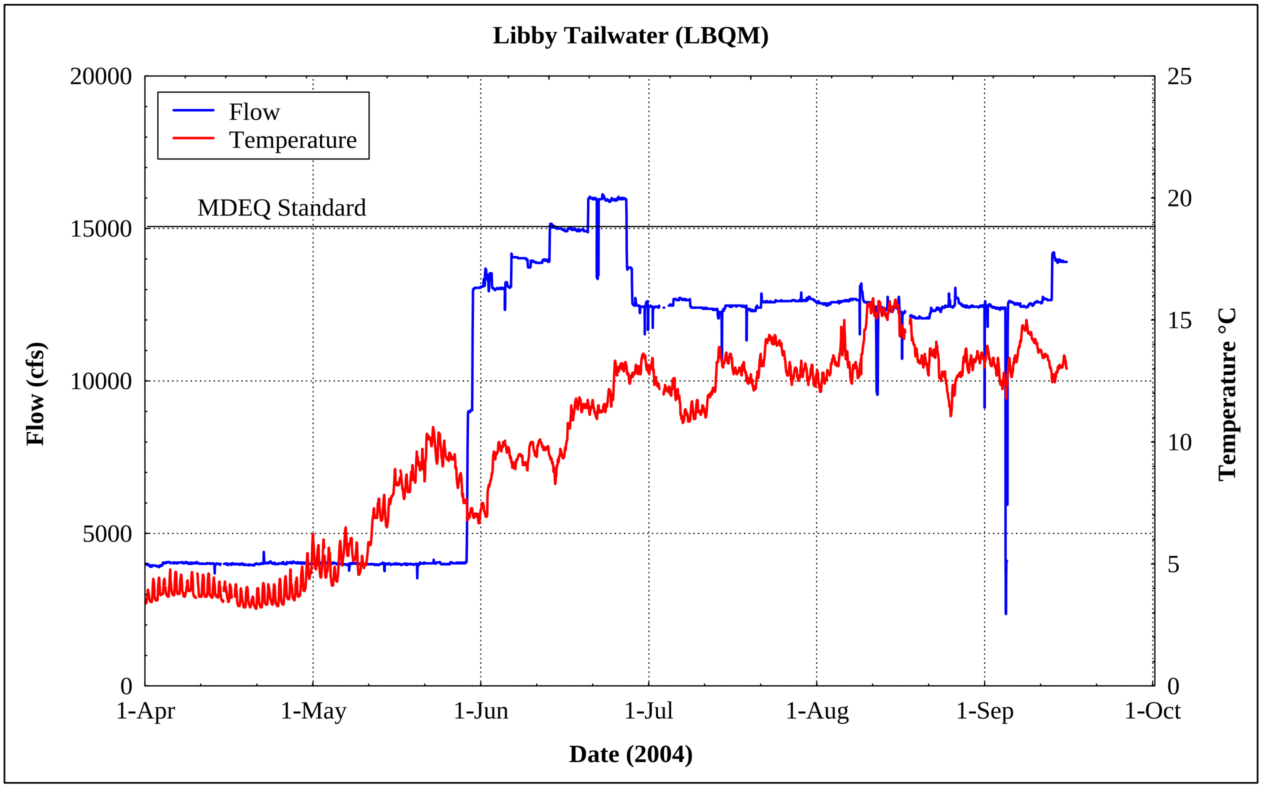


Figure 12. Temperature, spill, and flow at the Libby Dam Tailwater (LIBM) station during water year 2004.