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Seattle District

Total Dissolved Gas and Temperature Monitoring at Chief Joseph Dam and Libby Dam, Montana 2003: Data Review and Quality Assurance

By Kent Easthouse and Amy Klein
U.S. Army Corps of Engineers, Seattle District
Hydrology and Hydraulics Section

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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 characteristic 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 and Libby Dam during the 2003 spill season from April 1 – September 15, and performed a TDG exchange study at Albeni Falls Dam from May 6 – September 1, 2003. The purpose of the monitoring program at Chief Joseph Dam and Libby Dam was to provide real-time TDG data to the U.S. Army Corps of Engineers (USCOE) to allow for the management of flow and spill at dams on the Columbia River system. The purpose of the Albeni Falls TDG exchange study was to more clearly understand total dissolved gas exchange processes associated with the operation of Albeni Falls Dam and the resultant transport and mixing in the Pend Oreille River immediately below the project.

This report describes the TDG and temperature quality assurance (QA) results and associated data for the Chief Joseph Dam and Libby Dam monitoring programs. Results from the Albeni Falls study were not available at the time of this report and should be completed by March of 2004.

Methods and Materials

Site Characterization

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 thousand cubic feet per second (kcfs). A mild increase in TDG saturation of spillway releases of 129 to 134 percent saturation was observed as spillway discharges increased from 4 to 15 kcfs.

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 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.

Data Collection

Data were collected at two fixed monitoring stations at Chief Joseph Dam and one fixed monitoring station at Libby Dam during the 2003 spill season (Figure 2). Fixed monitoring station location details are summarized in Table 1. For the 2003 spill season, Chief Joseph Dam sites were operational from April 4 through September 15, while Libby Dam was operational from April 16 through September 16. Parameters monitored at each location included hourly measurements of water temperature, barometric pressure, TDG pressure, and TDG probe depth.

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 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 Libby Dam station LIBM 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. A second DCP, barometer, and GOES transmitter were located on the right bank of the Kootenai River and powered by a 120-volt AC line. Measurements were made every hour at the monitoring station on the left bank of the river and radioed to the second DCP located on the right bank of the river. Data were then sent out every 4 hours via the GOES system to the CROHMS database in Portland, Oregon. In addition, hourly data were transmitted via radio directly to the Seattle District's HEC-DSS water quality database to provide back-up data in case of GOES transmission failures.

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 the Libby Dam tailwater station (LIBM) 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 2003 are summarized in Tables 2 and 3. The data were based upon the number of planned monitoring hours from April through September. At Chief Joseph Dam, monitoring stations CHJ and CHQW were installed on April 4, 2003, while the Libby Dam, monitoring station LIBM was installed on April 16, 2003. 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. Suspect data was then corrected if possible. For instance, data where drift occurred can be easily adjusted through software programs. 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 stations CHJ and CHQW were largely due to DCP malfunctions and programming problems. Rejected data for stations CHJ and CHQW were a result of DCP transmission of improper data value codes. Missing data for station LIBM were largely due to radio transmission errors in transmitting the data from the water quality probe station on the left bank of the river to the GOES station on the right bank of the river. In addition, two lightning strikes at Libby resulted in the failure to transmit data for a short period of time until a new probe could be installed. Rejected data for station LIBM included both DCP transmission of improper data value codes and QA/QC review of data. Data for May 21, 2003 from 1800 to 2300 were rejected because of poor water quality probe calibration data.

Quality-Assurance Procedures

Fixed monitoring stations were calibrated every two weeks during the 2003 monitoring season following procedures outlined in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring 2003* (USCOE 2002). 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 sites (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 2003 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 pressures of 0, 50, 100, 150, and 200 mm Hg above barometric pressure, which represented TDG saturations from 100 to 126% (Table 5). If any measurement differed by more than 1 mm Hg 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 1 mm Hg of total dissolved gas.

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. Calibration of the secondary barometric standard was performed in the laboratory using a NIST traceable barometric pressure gauge (Table 5). 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 0.1°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 from CHJ, CHQW, and LIBM were generally within 10 mm Hg or 2 % saturation difference between the field sensor and the secondary standard. However, at LIBM one data point of about 30 mm Hg or 4.5 % saturation difference occurred during the 2003 monitoring period. This extreme outlier point is from the May 21, 2003 field visit and represents a TDG membrane that was worn and not responding properly, resulting in incorrect TDG readings. A follow-up field visit on May 22, 2003 replaced the membrane resulting in a properly functioning TDG probe.

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, while the Montana Department of Environmental Quality (MDEQ) determines water quality criteria for the Kootenai River at Libby Dam in Montana. 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 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 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%. However, Washington allows exceedance of the 110% 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 2003 spill season for the purpose of managing system spill for improved fish conditions. For this report, compliance with only the Washington Department of Ecology water quality standards are addressed at Chief Joseph Dam.

Results and Discussion

Total Dissolved Gas

Hourly total dissolved gas saturations, river flows, and spill volumes for Chief Joseph Dam and Libby Dam during the 2003 monitoring season are presented in Figures 5 and 6, respectively. The Chief Joseph forebay station (CHJ) had no days exceeding the 12 hour average 115 % TDG saturation, and only one hour where forebay saturations exceeded 115%. 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) had no days exceeding the 12 hour average 120 % TDG saturation, and only 5 hours exceeding the 125% hourly TDG saturation standard. Exceedances of the 125% standard occurred on May 21, 2003 during a spill of approximately 18 to 26 kcfs. The May 21 exceedance was due to Chief Joseph spilling from only 8 bays, instead of spreading the spill out over 18 bays. The higher spill volume per bay resulted in abnormally high TDG levels for such a small total spill volume. Differences in TDG loading to the Columbia River from Chief Joseph Dam using 8 spillway bays instead of 18 are substantial. For example, a larger spill of about 30 kcfs on May 28, 2003 during a spill from 18 bays resulted in TDG saturations measured at CHQW from about 117% to 119%.

The Libby tailwater station (LIBM) had no days exceeding the 110% TDG saturation standard. As seen in Figure 6, TDG saturation levels at Libby Dam increased from a low of about 96% in April to a high of about 107% in early June. The cause of the TDG increase is unknown, but may be related to the increase in water temperatures experienced in the Kootenai River during this period. Selective withdrawal systems at Libby Dam were used during the end of May and early June time period in 2003 to increase the water temperature in the Kootenai River downstream of the dam (Hoffman 2003). 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 observed at LIBM.

Temperature

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 7). The similar water temperatures at the forebay and tailwater stations indicate well-mixed conditions in the forebay. Water temperatures at both sites exceeded the WDOE criteria of 18°C from July 30 through September 15, 2003. Water temperatures at the forebay station (CHJ) exceeded the CCT Class I criteria of 16°C from June 11 through September 15, 2003.

Temperature measured at the Libby Dam tailwater (LIBM) station ranged from about 3 °C in April to 16°C in August (Figure 7). Temperatures during the 2003 monitoring season did not exceed the MDEQ water quality criteria of 18°C to 19°C. 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 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 7, temperature increases seen near the end of May and in the middle of June represents operating the selective withdrawal system to increase the temperature in the river during the late spring period (Hoffman 2003).

Conclusions

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

- Data completeness for TDG data ranged from 93.2% at the Chief Joseph Dam forebay station (CHJ) to 98.4% at the Chief Joseph Dam tailwater station (CHQW). Missing data were largely due to DCP malfunctions and programming problems. Rejected data were largely a result of DCP transmission of improper data value codes.

- In general, laboratory calibration data were good and within 0.1°C for temperature, 1 mm Hg for barometric pressure, and 1 mm Hg for total dissolved gas pressure of the primary standard.

- In general, field calibration data were good and the field barometer was within 2 mm Hg of the secondary standard and the temperature sensor was within 0.1°C of the secondary standard at all locations. Field calibration TDG data was also good, with the majority of data from all stations within 10 mm Hg or 2 % saturation of the secondary standard.

- The Chief Joseph forebay station (CHJ) had no days exceeding the 12 hour average 115 % TDG saturation, and only one hour exceeding 115%. The Chief Joseph tailwater station (CHQW) had no days exceeding the 12 hour average 120 % TDG saturation, and only 5 hours exceeding the 125% hourly TDG saturation waiver. The Libby tailwater station (LIBM) had no days exceeding the 110% TDG saturation standard.

- Temperature measured at the Chief Joseph forebay (CHJ) and tailwater (CHQW) exceeded the WDOE criteria of 18°C from July 30 through September 15, 2003. Water temperatures at the forebay station (CHJ) exceeded the CCT Class I criteria of 16°C from June 11 through September 15, 2003. Temperature measured at the Libby Dam tailwater (LIBM) station did not exceed the MDEQ water quality criteria of 18°C.

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Tables

Table 1. Total dissolved gas station locations and sampling period, water year 2003.

Site Identifier	Station Name	Latitude	Longitude	2003 Sampling Period
CHJ	Chief Joseph Dam Forebay	47° 59' 38"	119° 38' 43"	04/04/03 - 09/15/03
CHQW	Chief Joseph Dam Tailwater	48° 00' 17"	119° 39' 30"	04/04/03 - 09/15/03
LIBM	Libby Dam Tailwater	48° 19' 07"	115° 19' 07"	04/16/03 -09/15/03

Table 2. Total dissolved gas data completeness for water year 2003.

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	3962	187	95.3	93.2
Chief Joseph Tailwater	CHQW	3962	47	98.8	98.4
Libby Tailwater	LIBM	3654	63	98.3	94.6
Average					95.4

Table 3. Temperature data completeness for water year 2003.

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	3962	17	99.6	99.0
Chief Joseph Tailwater	CHQW	3962	47	98.8	98.4
Libby Tailwater	LIBM	3654	83	97.7	97.7
Average					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, barometer, and thermometer.

	Barometric Pressure mm Hg	Temperature ºC	Total Dissolved Gas Pressure (mm Hg)				
			Zero	BP+50	BP+100	BP+150	BP+200
N	42	16	17	12	12	12	17
Maximum	1.30	0.10	1.10	1.00	1.00	1.00	1.10
Minimum	-1.30	-0.05	-1.00	-1.00	-1.20	-1.20	-1.20
Median	0.10	0.02	0.00	0.00	0.00	0.00	0.00
Average	0.00	0.02	0.12	0.03	-0.05	-0.05	0.01
Standard Deviation	0.60	0.03	0.52	0.44	0.57	0.71	0.71

Table 6. Washington Department of Ecology (WDOE), 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.
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.
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 will cause the water temperature to exceed 19.5°C.

Figures

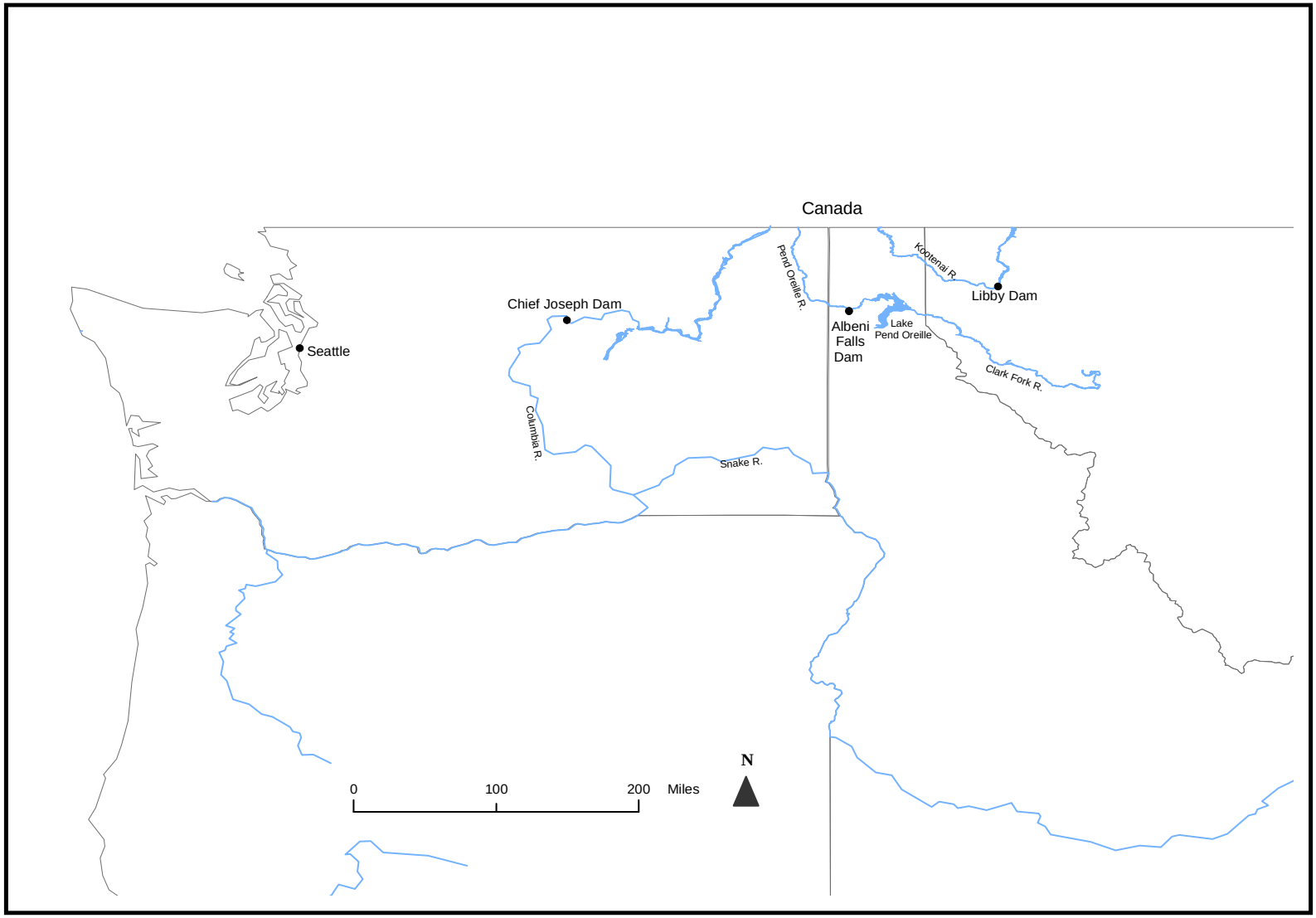


Figure 1. Location of Seattle District projects in the Columbia River system.

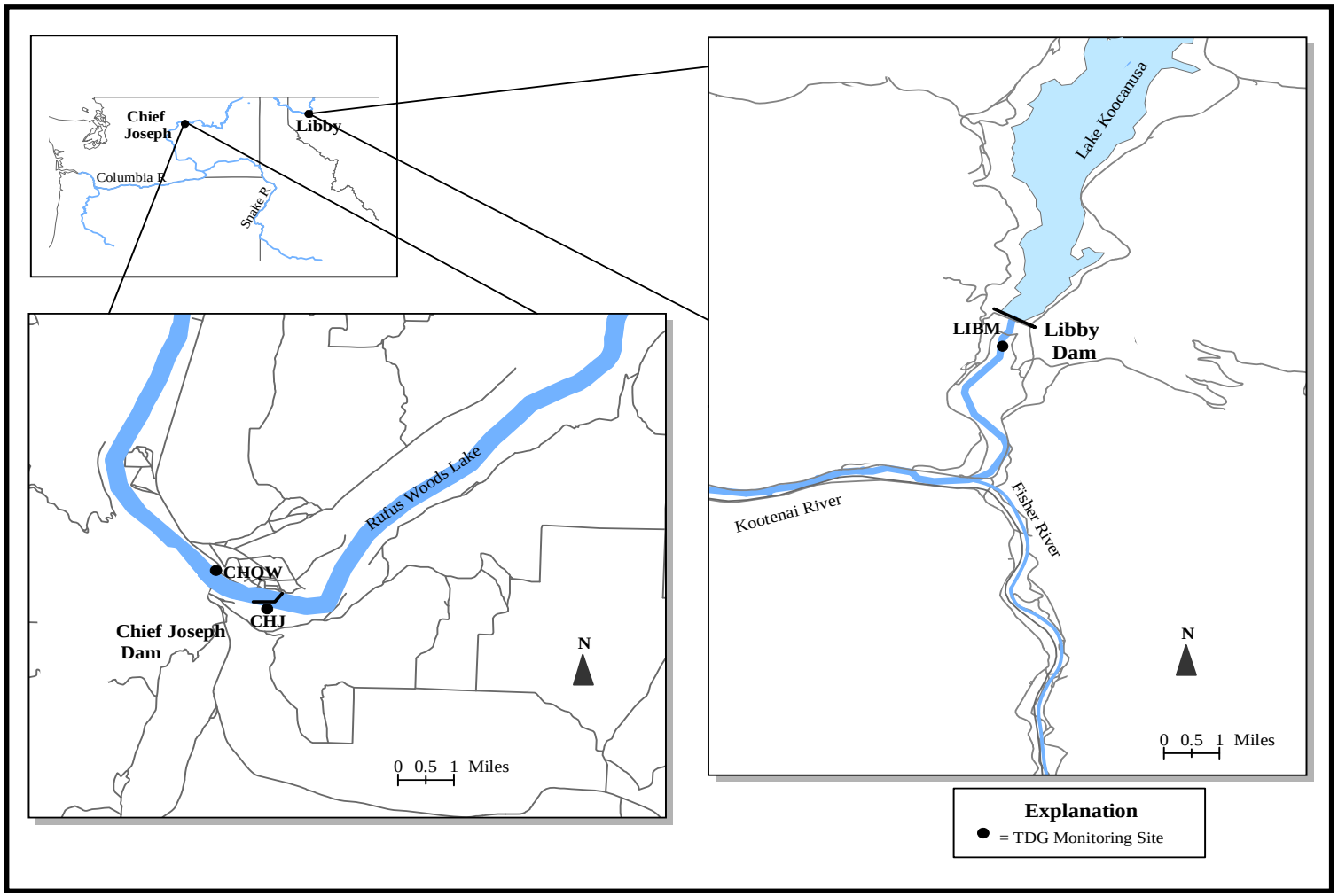
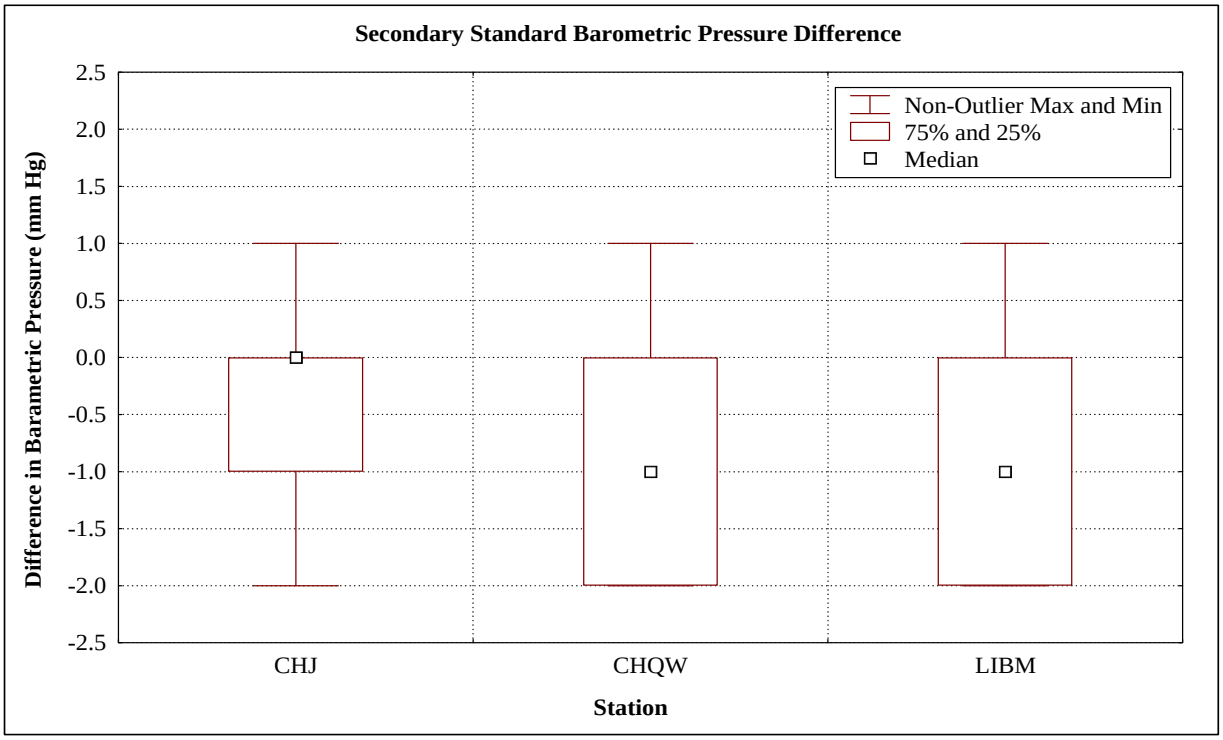


Figure 2. Locations of total dissolved gas monitoring stations in 2003 for Chief Joseph Dam, Washington and Libby Dam, Montana.



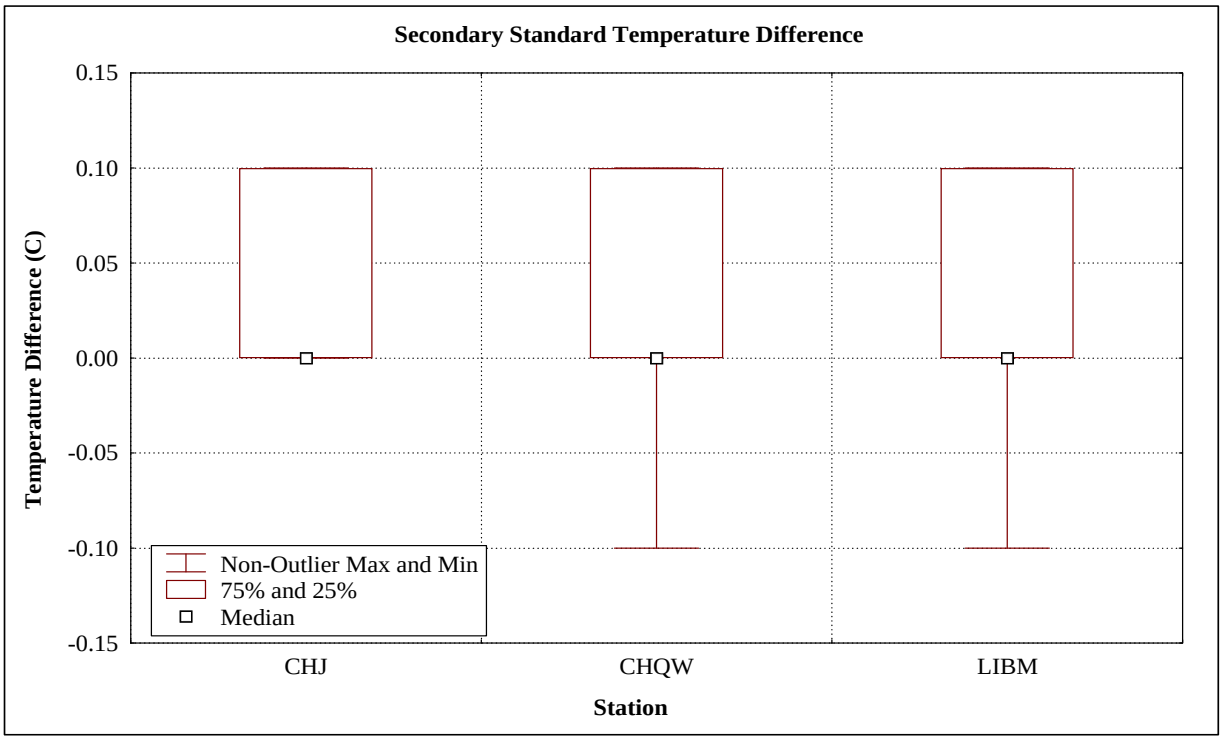
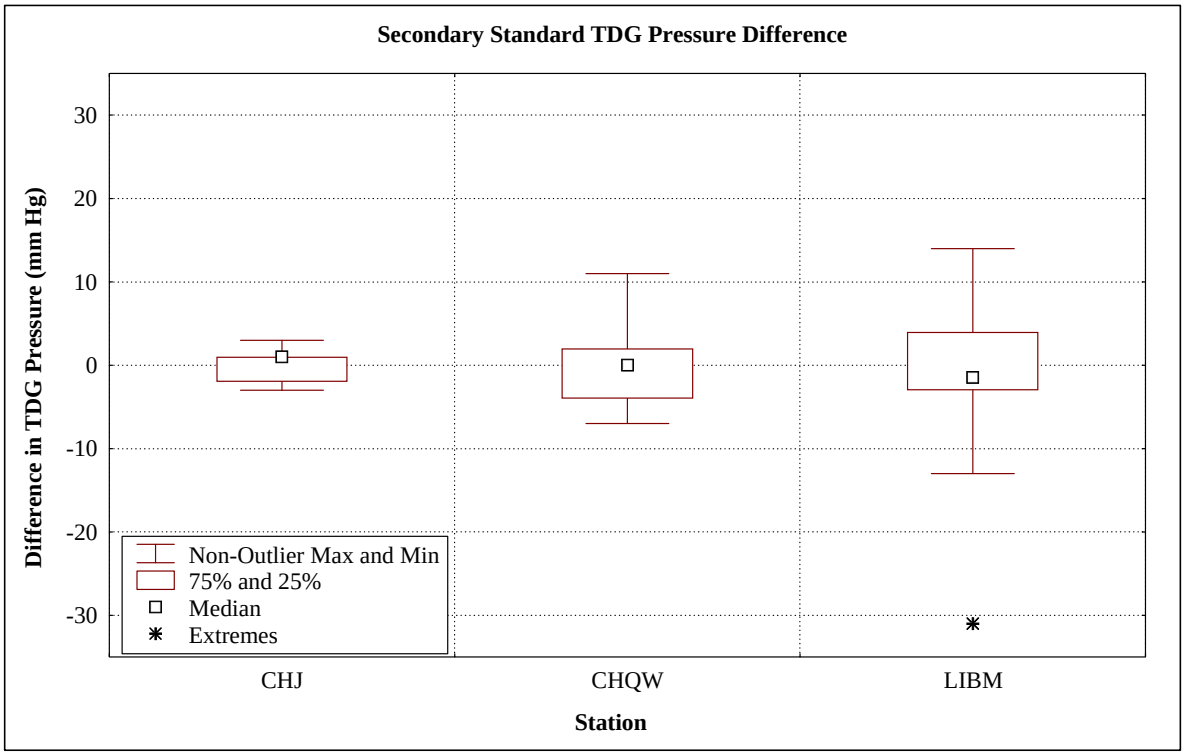


Figure 3. Difference between the secondary standard and the field barometers and field thermometers.



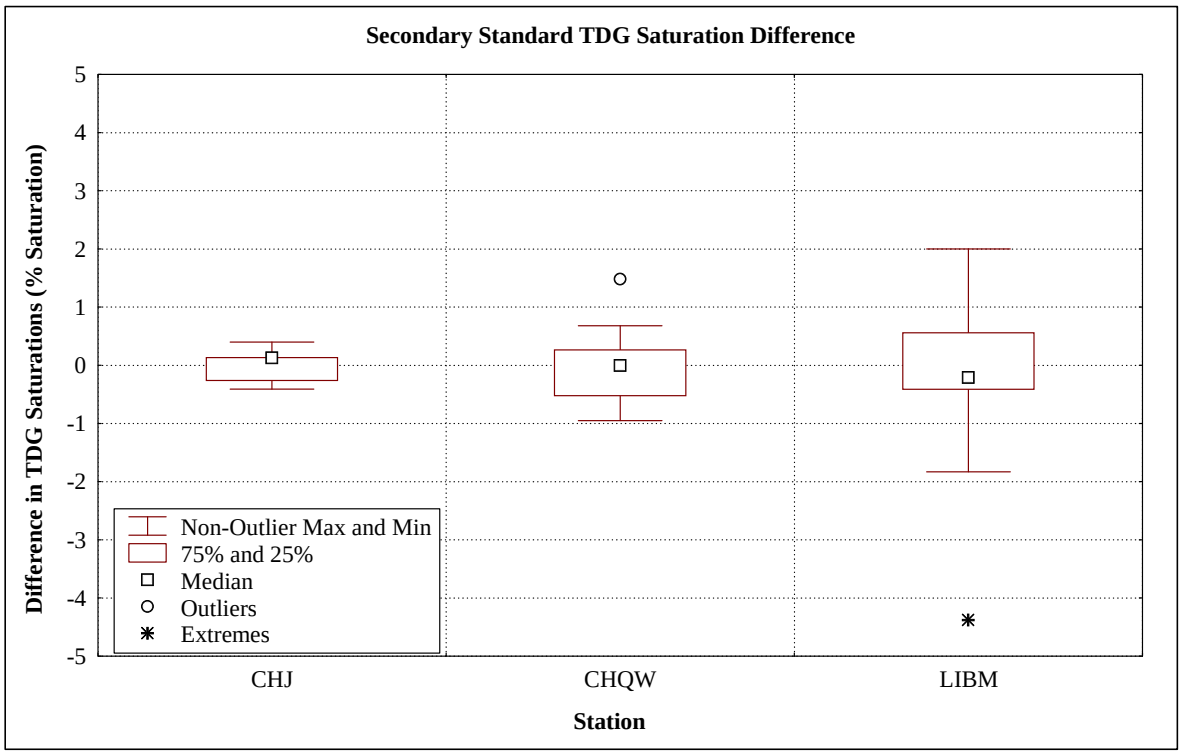
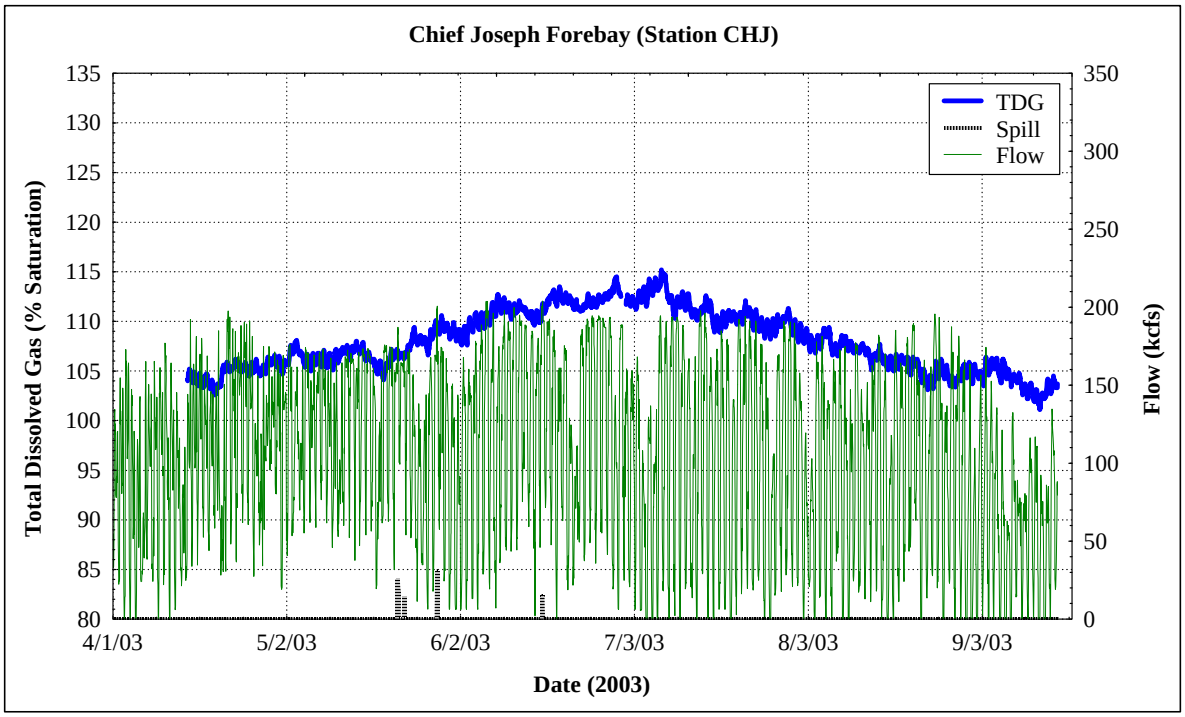


Figure 4. Difference between the secondary standard and the field total dissolved gas instrument for TDG pressure and TDG saturations.



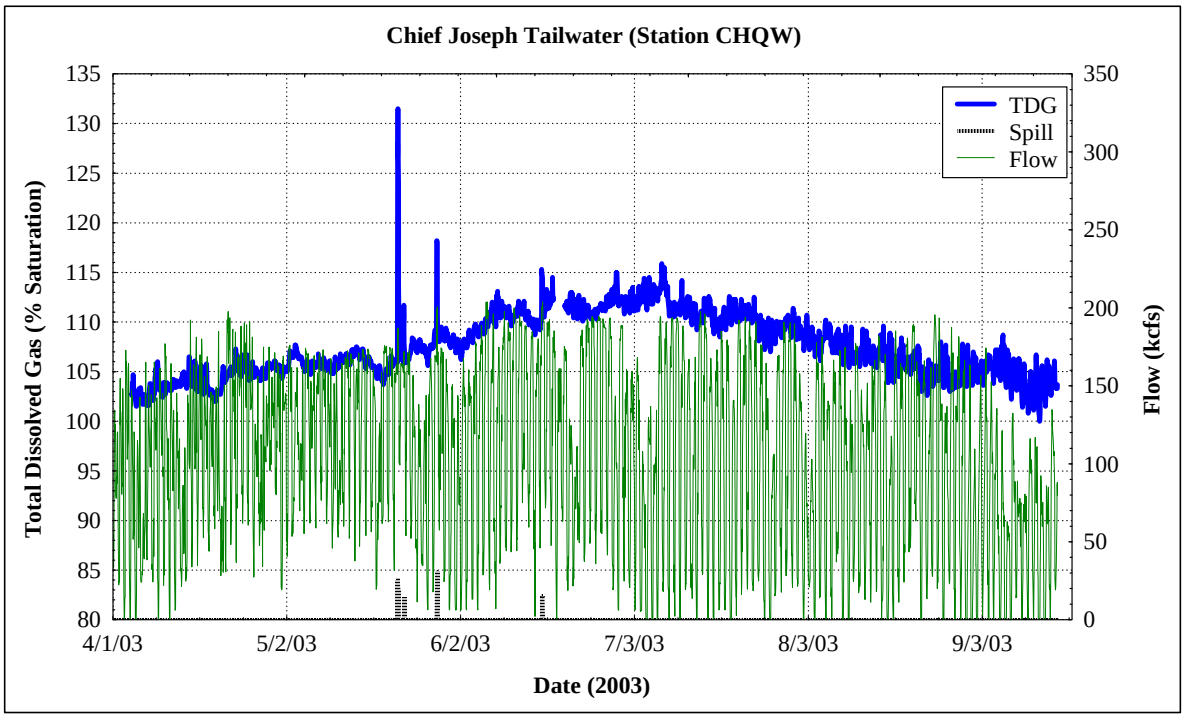


Figure 5. Total dissolved gas, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during water year 2003.

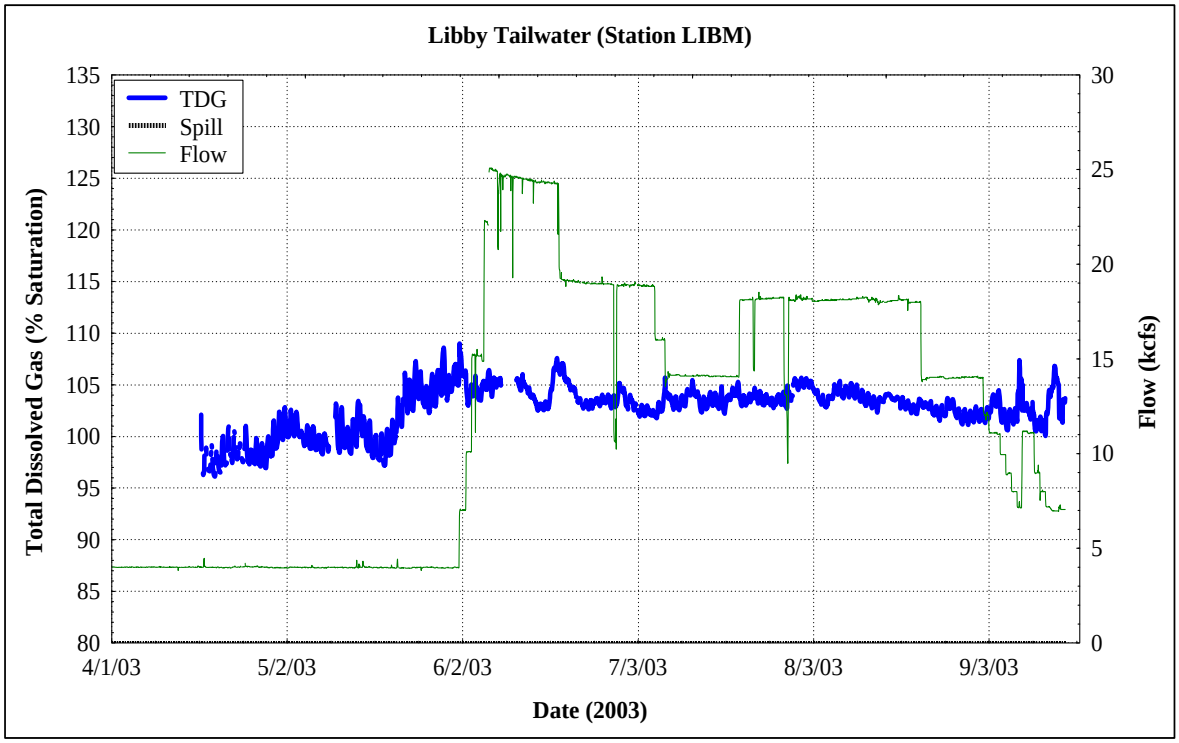
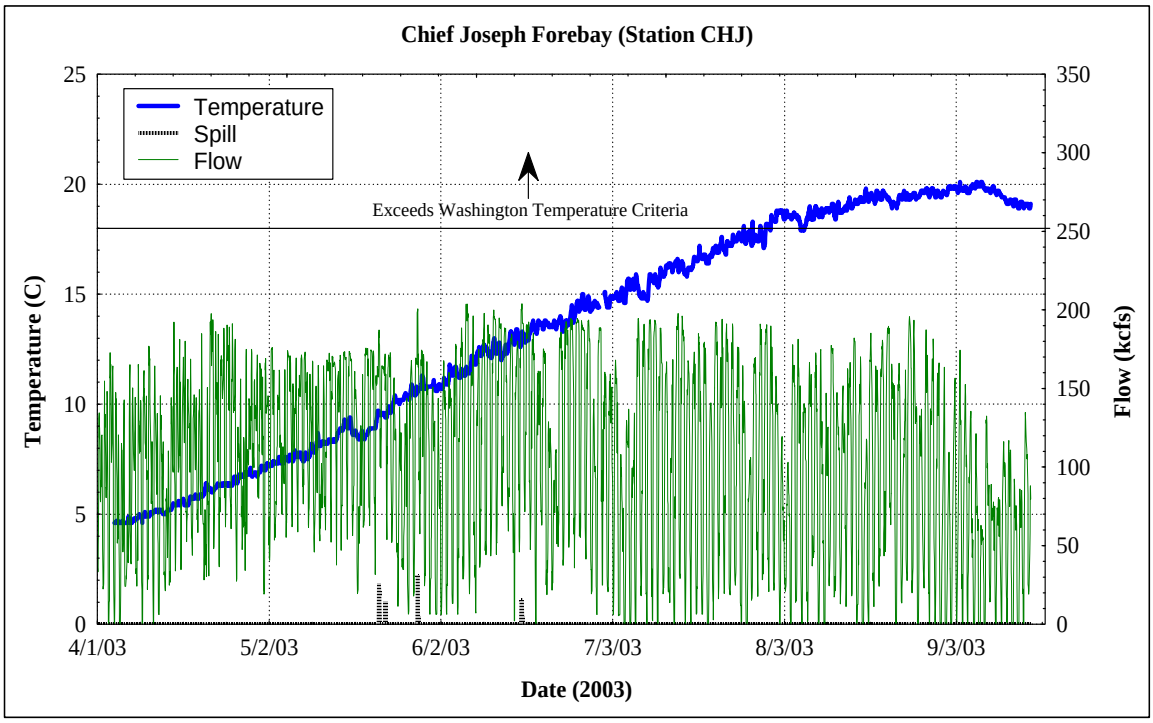


Figure 6. Total dissolved gas, spill, and flow at the Libby Dam Tailwater (LIBM) station during water year 2003.



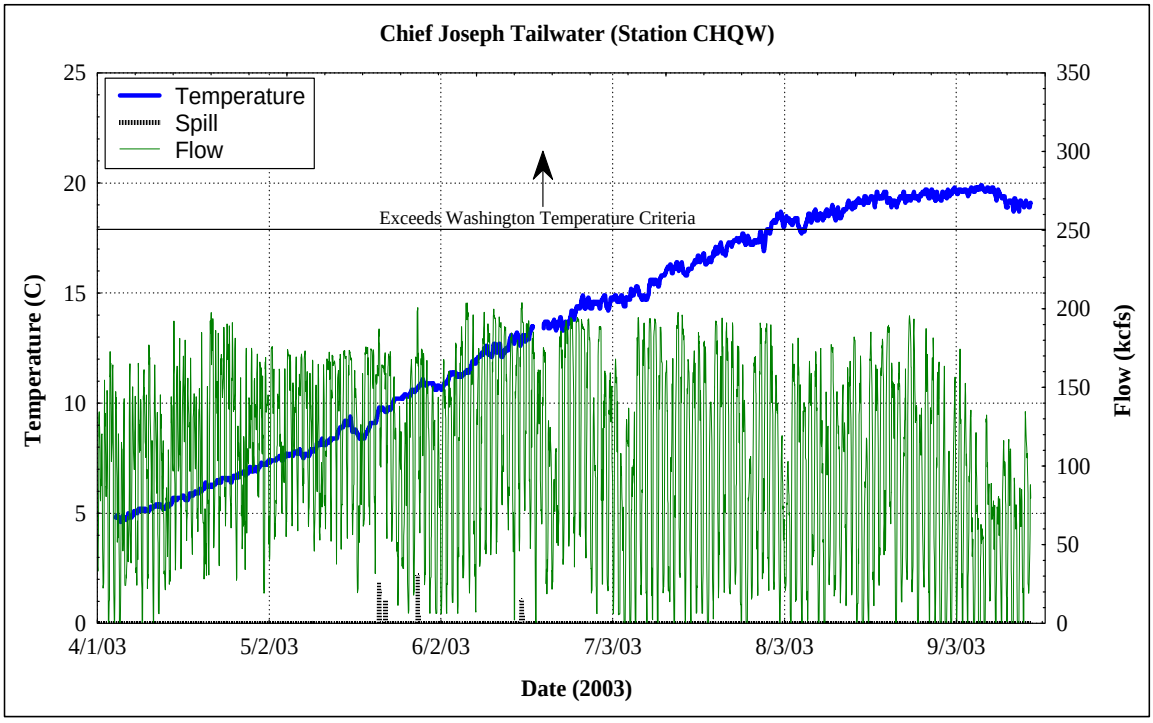


Figure 7. Temperature, spill, and flow at Chief Joseph Dam Forebay (CHJ) and Chief Joseph Dam Tailwater (CHQW) stations during water year 2003.

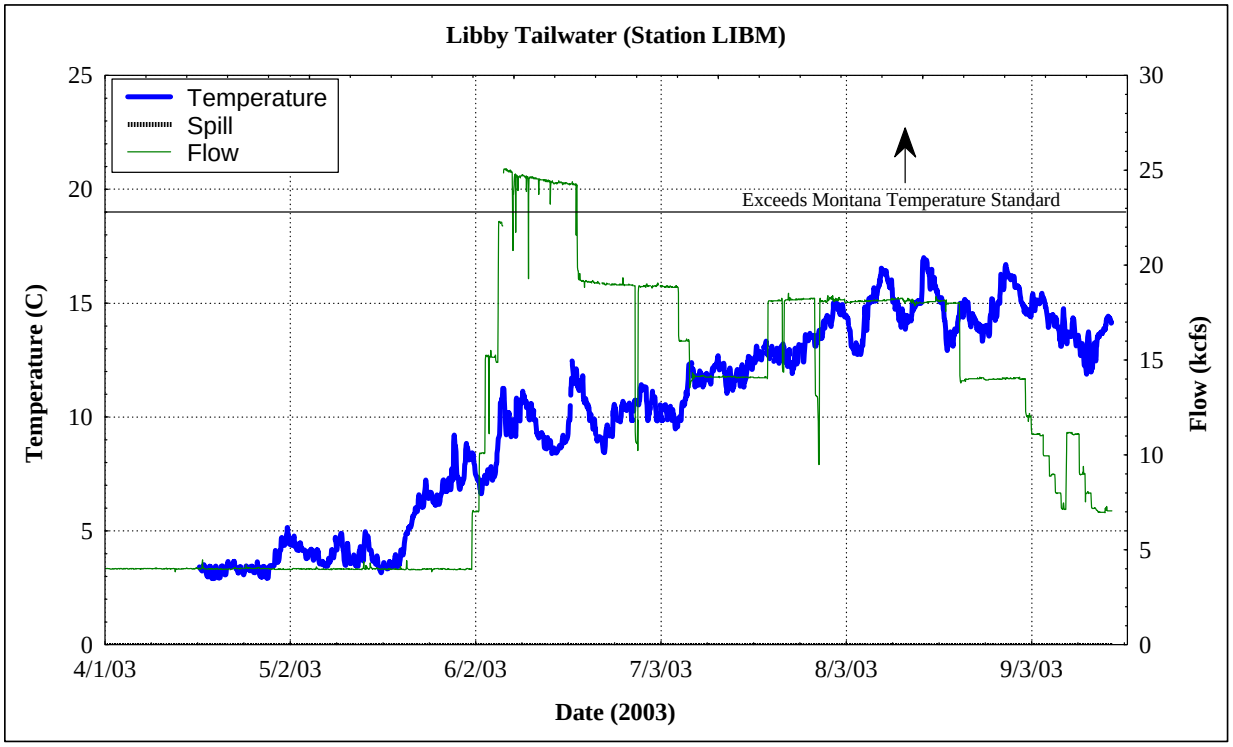


Figure 8. Temperature, spill, and flow at the Libby Dam Tailwater (LIBM) station during water year 2003.