Appendix F

2023 Walla Walla District TDG Report

USACE Walla Walla District QA/QC Evaluation of the 2023 Water Year FMS TDG Monitoring Data

Snake River at Anatone (ANQW)

Includes:

McNary, Ice Harbor,
Lower Monumental, Little Goose,
Lower Granite, and Dworshak Projects

USACE Walla Walla District QA/QC Evaluation of the 2023 Water Year FMS TDG Monitoring Data

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ABSTRACT

The U.S. Army Corps of Engineers (USACE), Walla Walla District (CENWW), operated fourteen fixed-monitoring system (FMS) stations (eight seasonal and six year-round) for total dissolved gas (TDG), barometric pressure (BP), and temperature as part of their 2023 water-quality program. These stations are located on the Columbia, Lower Snake and Clearwater Rivers. This report provides a summary of the 2023 water year quality assurance/ quality control (QA/QC) evaluation. Highlights include:

- Data completeness for the combined BP, TDG, and temperature data received averaged 99.2 percent for the 14 monitoring sites operated in 2023.
- The TDG data received from the individual sites ranged from 84.9 percent to 100.0 percent complete. Forty-five percent of all incomplete TDG data was due to antenna and transmission failures. The second highest cause of missing TDG data was due to sediment build-up in the deployment structure at Peck (PEKI) causing 27 percent of invalid TDG data. Defective membranes caused 19 percent of invalid TDG measurements, primarily encountered in the summer months.
- The TDG sensors from the 14 FMS stations were removed from the field and calibrated in the laboratory every three weeks from April 2023 through August 2023. From September 2022 through March 2023, the six annual FMS stations were calibrated at four-week intervals.
- The sensor pre-deployment check had calculated mean ambient pressure, ambient pressure plus 300 mmHg, and temperature differences of -0.25 mmHg, -0.04 mmHg, and 0.05 °C, respectively. The sensor post-deployment check revealed mean ambient pressure, ambient pressure plus 100 mmHg, and temperature differences of -0.04 mmHg, -0.44 mmHg, and 0.13 °C, respectively.
- The calculated median values for the 171 *in-situ* field checks with the replacement probes were:
    1. TDG; 0.1 percent with minimum and maximum station medians of -0.3 and 0.1 percent, respectively.
    2. BP; 0.00 mmHg with station medians ranging from -0.10 to 0.10 mmHg.
    3. Water temperature; -0.01 ºC with station median values ranging from -0.05 ºC to 0.05 ºC.
- Station repairs and maintenance were also completed during the 2023 water year:
    1. The Lower Granite Tailwater Station (LGNW) was rebuilt in February. Due to high flows in late May, temporary sonde deployment using a tethered cage was performed for two months. The station anchor system was revamped and finalized in early August, returning the sonde to the designated deployment structure.
    2. The Pasco station (PAQW) deployment pipe was removed, inspected, repaired, and reinstalled as part of a station rebuild in April.
    3. Sediment build-up at four of the deployment pipes was removed with compressed air on 7 separate occasions. Anatone (ANQW) and PEKI stations were primarily affected.

1.0 INTRODUCTION

Walla Walla District (CENWW) of the U.S. Army Corps of Engineers (USACE) operates six hydropower projects in the Columbia, Snake, and Clearwater River basins: McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite, and Dworshak dams. These six dams are included in the basin-wide fixed-monitoring system (FMS) network. The tailwater stations at the six projects are operated throughout the year (Figure F-1; Table F-1). The remaining eight forebay and riverine stations record hourly data from the beginning of April through 31 August, and typically bracket that period, with some exceptions noted below.

Three water-quality related parameters are monitored at these facilities. One is total dissolved gas (TDG). This parameter is of interest since gas supersaturation results when air is entrained as water flows over the spillways and plunges into the stilling basin where water pressure causes the air to go into solution. The river subsequently becomes shallow beyond the stilling basin and the result is water supersaturated with TDG relative to atmospheric conditions. The U.S. Environmental Protection Agency (USEPA) has established an upper limit of 110 percent TDG for protection of freshwater aquatic life as well. Greater than 110 percent TDG can cause gas bubble trauma in fish and adversely affect other aquatic organisms. The TDG water quality standards in Washington and Oregon were relaxed during the 2023 fish passage season (up to 125 percent for12 hours and 126 percent for 2 hours in tailwater reaches in Washington, and up to 125 percent for 12 hours and 127 percent for 2 hours in Oregon tailwater reaches [https://pweb.crohms.org/tmt/documents/fpp/2023/]) but remained unchanged in Idaho.

Barometric pressure, water temperature, and TDG measurements were completed hourly at the Columbia, Snake, and Clearwater River stations, and at 15-minute intervals at the Dworshak (DWQI) station. All data was transmitted via the Geostationary Operational Environmental Satellite Program (GOES) system to the USACE Corps Water Management System (CWMS) database. The water quality data stored in the CWMS database can be accessed at http://www.nwd-wc.usace.army.mil/ftppub/water_quality/tdg/.

2.0 PURPOSE AND SCOPE

The purpose of TDG monitoring is to provide managers, agencies, and interested parties with near real-time data for managing stream flows, spill, and percent TDG downstream from power-producing dams, as well as meeting the legal requirements of the 2020 Columbia River System Operations Biological Opinion. An additional purpose of this report is to show that CENWW complied with the USACE TDG Monitoring Plan (https://www.nwd.usace.army.mil/CRWM/Water-Quality/) during 2023. Compliance included achieving greater than 95 percent completeness for the entire data set, accomplishing the lab and field calibration using established criteria, and utilizing the primary and secondary standards called for in the plan.

As with any data collection activity, an important component that cannot be overlooked is the quality of the data. Measurement of data quality allows determination of the usefulness and relevance of the data for current and future decision processes. As such, this report:

- Describes the data collection methods.
- Evaluates QA/QC data for the FMS stations at McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite, and Dworshak hydropower projects. Additionally, this

data-collection system provided water quality information for; (a) the Clearwater River at Peck, Idaho, (b) the Columbia River near Pasco, and (c) the Snake River near Anatone, Washington (Figure F-1; Table F-1).

- The QA/QC data includes:

    1. Instrument Data: This data was used to evaluate how an instrument performed as a function of the magnitude and direction that individual sensors deviated over time from their respective laboratory standards. These relationships were determined for each sensor before and after each deployment.

    2. Station Data: These data present comparisons between an in-place instrument that was deployed at a given station for a specified cycle and a newly calibrated QA/QC instrument (field standard). The Sutron® barometers at each station were evaluated with a Novalynx® M2000 Series hand-held barometer that served as a portable field standard for barometric pressure. The hand-held barometer was checked monthly against a National Institute of Standards and Technology (NIST) traceable lab barometer. All fourteen stations were visited for routine maintenance once every three weeks between 1 April and 31 August. The six year-round stations were maintained once every four weeks for the remainder of the year.

    3. Data Completeness: The information transmitted to the databases were evaluated to determine whether they were within expected ranges.

3.0 METHODS

3.1 DATA COLLECTION

The instrumentation at each FMS station consisted of components provided by CENWW. A 12-volt battery charged by a solar panel powered each station. Forty-six Hydrolab® multi-parameter probes (*i.e.*, MS4a's and MS5's) were utilized for temperature, depth, and TDG parameters. FMS stations were equipped with Sutron® data control platforms (DCP) and barometers.

3.2 LABORATORY PROCEDURES

The TDG sensor measures the sum of the partial pressures of gaseous compounds dissolved in the water and reports the result in millimeters of mercury (mmHg). The TDG sensor requires a two-step calibration procedure (*i.e.*, adjustments are made at two points on the calibration curve) that is completed prior to and after deployment. The atmospheric pressure calibration point (Lab BP) is equal to the atmospheric pressure at the time of calibration as measured with a ParoScientific Digiquartz® barometric pressure standard that is calibrated yearly at the factory. The differences between Lab BP and the pressure measured by the sonde were recorded before and after deployment as Δ(BP). The slope of each sensor response was also evaluated to ensure that measurements were interpolated correctly over the full range of expected field values. To accomplish this task, a Heise™ PTE-2 hand-held certified pressure calibrator, calibrated yearly at the factory (primary standard), and a Ralston® pneumatic cylinder hand pump were used to apply pressure to the TDG sensor. Three hundred millimeters of mercury were added to Lab BP during the pre-deployment check and the differences between Lab BP+300 and the sensors' response were recorded as Δ(BP+300). Similar tests were completed post-deployment when 100 mmHg was added to Lab BP, and the resulting differences were recorded as Δ(BP+100). Pre-

deployment pressure tests were made without a membrane installed. Post-deployment tests were made with the dry field deployed membrane in place prior to maintenance.

Each sonde also includes a sensor for reporting water temperature in degrees Celsius (°C). Sensor thermometers are factory calibrated and cannot be adjusted. However, temperature sensor performance was evaluated pre- and post-deployment by comparing instrument readings to a NIST-traceable Fluke 1586A Super-DAQ® Precision Temperature Scanner. Thermistors reporting greater than ±0.20 °C difference from the lab standard were sent to the factory for calibration.

3.3 FIELD PROCEDURES

The differences in barometric pressure, water temperature, and TDG between a secondary standard instrument (*i.e.*, replacement sensor) and the fixed station monitors after three or four weeks of field deployment were measured and recorded as part of the field inspection and calibration procedure. These differences, defined as the secondary standard value minus the field instrument value, were used to compare and quantify the precision between two independent instruments. The station barometers were checked using hand-held digital barometer that is calibrated yearly at the factory. The water temperature and TDG comparisons were made *in situ* with the secondary standard (*i.e.*, a recently calibrated Hydrolab®) positioned alongside the field Hydrolab®.

3.4 DEFINING INVALID AND MISSING DATA VALUES

The provisional real-time data were examined daily during the workweek by CENWW employees. Missing values and those that appeared to be outside the expected range were flagged. If a reasonable explanation (*e.g.*, routine maintenance/instrument inspection, DCP failure, or defective membrane) could be attributed to the incident, then the data point, or points, was not included in the final data set used for this analysis. Outlying data points that could not be attributed to a specific cause were retained.

4.0 RESULTS AND DISCUSSION

4.1 INVENTORY-WIDE SENSOR QA/QC PERFORMANCE

4.1.1 Pre-deployment

The pre-deployment evaluation of the sensors consisted of 168 individual checks for barometric pressure (Table F-2). Pre-deployment calibrations are performed without a membrane on the TDG sensor. The evaluation of the pressure sensors to the standard revealed a calculated mean of -0.25 mmHg, and a range of -1.58 to 1.09 mmHg (Table F-2; Figure F-3). TDG sensors outside of the expectable range of 2 mmHg were recalibrated. Three hundred millimeters of mercury was added to the TDG sensor in the laboratory using the laboratory barometer as the baseline standard. The difference between the TDG pressure sensor with 300 mmHg of added pressure and the instrument was compared against the expected value. The sensor pressure differences ranged from -0.18 percent to 0.13 percent with a calculated mean and median of -0.02 percent (Figure F-4; Tables F-2 and F-3).

The dissimilarities between the NIST-traceable thermometer and the sensor thermistors were also quite small. The calculated mean and median values for all the instruments were 0.05 ºC.

These calculated values were based on 168 measurements where the minimum and maximum differences for individual sensors ranged from -0.47 °C to 0.28 °C (Tables F-2 and F-3; Figure F-5). The instrument manufacturer's specification is ±0.20 °C for all instruments within a sample pool.

4.1.2 Post-deployment

The evaluation of the post-deployment QA/QC data also displayed mostly favorable results. A total of 157 data points were used for the evaluation. Post-deployment calibration checks were performed with the field deployed membrane in place. The differences between the laboratory barometric pressure and that recorded by the TDG sensors ranged from -2.24 mmHg to 10.69 mmHg, with a mean of -0.04 mmHg (Tables F-2 and F-4; Figure F-3). The range of values noted this year was attributed to a ruptured membrane. The results of the post calibration checks using barometric pressure +100 mmHg showed a calculated mean of -0.03 percent, and a range of -0.29 to 0.83 percent (Table F-2; Figure F-4).

There were 157 post deployment checks performed for the temperature evaluation. Temperature post calibration checks resulted in a calculated mean of 0.13 °C and a median of 0.04 °C, with a range of -10.88 °C to 0.25 °C (Tables F-2 and F-4; Figure F-5). The range of temperature values was caused by a defective temperature sensor.

4.2 System-wide Station QA/QC Performance

The analysis of the differences between in-place barometric air pressure, TDG pressure, and temperature instruments with secondary standards was generally favorable, albeit with a few outliers (Figures F-6 through F-8).

A total of 171 readings were used to calculate the mean and median values for barometric pressure (Table F-5). The median of all the differences between the station barometers and the secondary standards was 0.00 mmHg (Table F-5; Figure F-6). Median values for individual stations ranged from -0.10 to 0.10 mmHg (Table F-6; Figure F-6). Barometers that did not meet manufacturer's accuracy of ±0.2 mmHg they were either reset or replaced.

A total of 171 readings were used to calculate the mean and median values for TDG instrument pressure (Table F-5). The overall median for the percent TDG differences between the in-place and replacement sensors was -0.1 percent saturation (Table F-5; Figure F-7). Individual station median values ranged from -0.3 percent saturation to 0.1 percent saturation (Table F-6). The low measurement of -14 mmHg (-1.89 percent) at Lower Granite tailwater (LGNW) was the result of physical safety limitations while deploying the sonde in a cage tethered to shore.

A total of 171 readings were used to calculate the temperature differences between the in-place and replacement sondes (Table F-5). The calculated mean and median temperature differentials for the field data were -0.03 and -0.01 °C, respectively (Table F-5). The median values for individual stations ranged from -0.05 ºC to 0.05 ºC (Table F-6; Figure F-8). The manufacturer's specification for the temperature sensor is ±0.20 °C.

4.3 FMS Data Completeness and Station Statistics

Percent completeness for the real-time TDG, barometric pressure, and temperature data were 98.8, 99.4, and 99.3 percent, respectively (Table F-7; Figure F-9). The most frequent reason

attributed to missing information in the real-time data set were antenna or transmission failures (0.52 percent of the combined station performance, which is equivalent to 64.4 percent of all missing and invalid data shown in the last column of Table F-8). At the start of the new water year, the DCP IDs and Transmission Times were transitioned to ones assigned to CENWW (Table F1). Loss of data due to performing the transition/reprogramming DCPs contributed to Antenna/Transmission Failures counts. The second and third leading causes of missing/anomalous data were sediment build-up in riverine deployment structures (0.1 percent of the combined station performance or 12.9 percent of the total affected data) followed by defective membranes (0.07 percent of the combined station performance or 9.3 percent of the 1,981 hours of affected data).

4.3.1 Barometric Pressure

Barometric pressure data from the fourteen stations averaged 99.4 percent complete. Barometric pressure data was 100 percent complete at five of the fourteen FMS stations including McNary forebay (MCNA), Pasco (PAQW), Ice Harbor forebay (IHRA), Lower Monumental forebay (LMNA), and Little Goose forebay (LGSA) (Table F-7). Eight of the remaining stations were greater than 98 percent complete (Tables F-8 and F-9). The remaining station, Peck (PEKI), had 302 hours of missing data due to antenna and transmission failures.

4.3.2 Total Dissolved Gas

The TDG data from the fourteen stations averaged 98.8 percent complete (Table F-7). The station that experienced the greatest amount of data loss was Peck (PEKI), where the final data set statistic was 84.86 percent (Table F-7). While PEKI's overall data completeness was mainly affected by antenna/transmission failures, sediment accumulation in the deployment pipe was the primary cause of invalid TDG data (256 hours of the station's TDG data).

4.3.3 Temperature

The temperature data from the fourteen FMS stations averaged 99.3 percent complete. Twelve stations attained greater than 99 percent completeness (Table F-7). The two stations with the lowest percent completeness were Peck (PEKI) and Dworshak tailwater (DWQI) at 91.67 and 98.86 percent, respectively. Antenna/transmission failures were the primary cause of missing temperature data, while a defective sensor at PEKI and a DCP failure at DWQI contributed to their low data completeness percentages.

4.4 Deployment Pipe Clean-Out

Sediment build-up occurred in four tailwater deployment pipes during the 2023 water year. The presence of sediment at stations was detected and cleared out early to prevent impacts to sensors at Ice Harbor tailwater (IDSW), Lower Monumental tailwater (LMNW), and Anatone (ANQW); however, sediment build-up at Peck (PEKI) impacted data completeness. All sediment-affected stations were cleared out using compressed air. Stations LMNW and IDSW were cleared out first on 28 March 2023 and 5 April 2023, respectively. ANQW and PEKI were cleared on the same days on two occasions, 18 April 2023, and 22 May 2023. The final sediment removal maintenance was performed at ANQW on 25 July 2023.

4.5 NOTABLE STATION MAINTENANCE

The Lower Granite tailwater station (LGNW) deployment structure and electronics enclosures were rebuilt in February of 2023 due to damage caused the prior year, in June 2022. During a high flow event (139 kcfs), the deployment pipe was pushed out of place on 25 May due to anchor system failures (Figure F-10). The deployment pipe was pushed downstream into shallow water. The anchor system was revamped beginning in June 2023 with a new shore-based anchor. The deployment pipe and associated anchors/cables were reset on 3 August 2023, returning the station to a fully capable status (Figure F-11).

The Pasco (PAQW) station deployment pipe rebuild was completed on 26 April 2023. The rebuild included deployment pipe removal, inspection, repairs, and resetting (Figure F-12). The water-based anchor was replaced new and shore-based anchors/cables were upgraded/reinforced.

5.0 SUMMARY

Hourly TDG, temperature, and barometric pressure data recorded during the 2023 water year at fourteen FMS stations were evaluated. The six tailwater sites were maintained throughout the year. The seasonal riverine stations at Peck (PEKI), Anatone (ANQW), and Pasco (PAQW) were added at the beginning of April and remained active through 31 August. The forebay stations at the four lower Snake River hydroelectric projects, as well as the one at McNary Dam also came on-line 1 April. The combined data completeness for all stations and parameters was 99.2 percent.

The CENWW Hydrology Section performed routine station maintenance, completed emergency repairs, operated the DCPs, and station repairs throughout the water year. The preventative maintenance schedule provided for calibration and routine maintenance at three-week intervals during the fish spill season and once every four weeks during the rest of the year. Station performance was hampered primarily by low data values caused by sediment build-up, antenna/transmission failures, and defective TDG membranes.

The pre-deployment QA/QC checks showed a mean difference of -0.25 mmHg when the TDG sensors were compared to barometric pressure and -0.02 percent when 300 mmHg of pressure was added. The calculated means for the post-deployment evaluations were -0.04 mmHg and -0.01 percent when the TDG sensors were compared to barometric pressure and barometric pressure plus 100 mmHg, respectively. The calculated mean temperature difference was 0.05 °C for pre-deployment and -0.13 °C for post-calibration.

The 46 TDG instruments used to perform this year's monitoring met the manufacturers' specifications. Field checks completed during routine maintenance between the in-place sonde and the secondary standard demonstrated that the air barometric pressure, percent TDG, and temperature differences averaged 0.04 mmHg, -0.10 percent, and -0.03 °C, respectively.

FIGURES

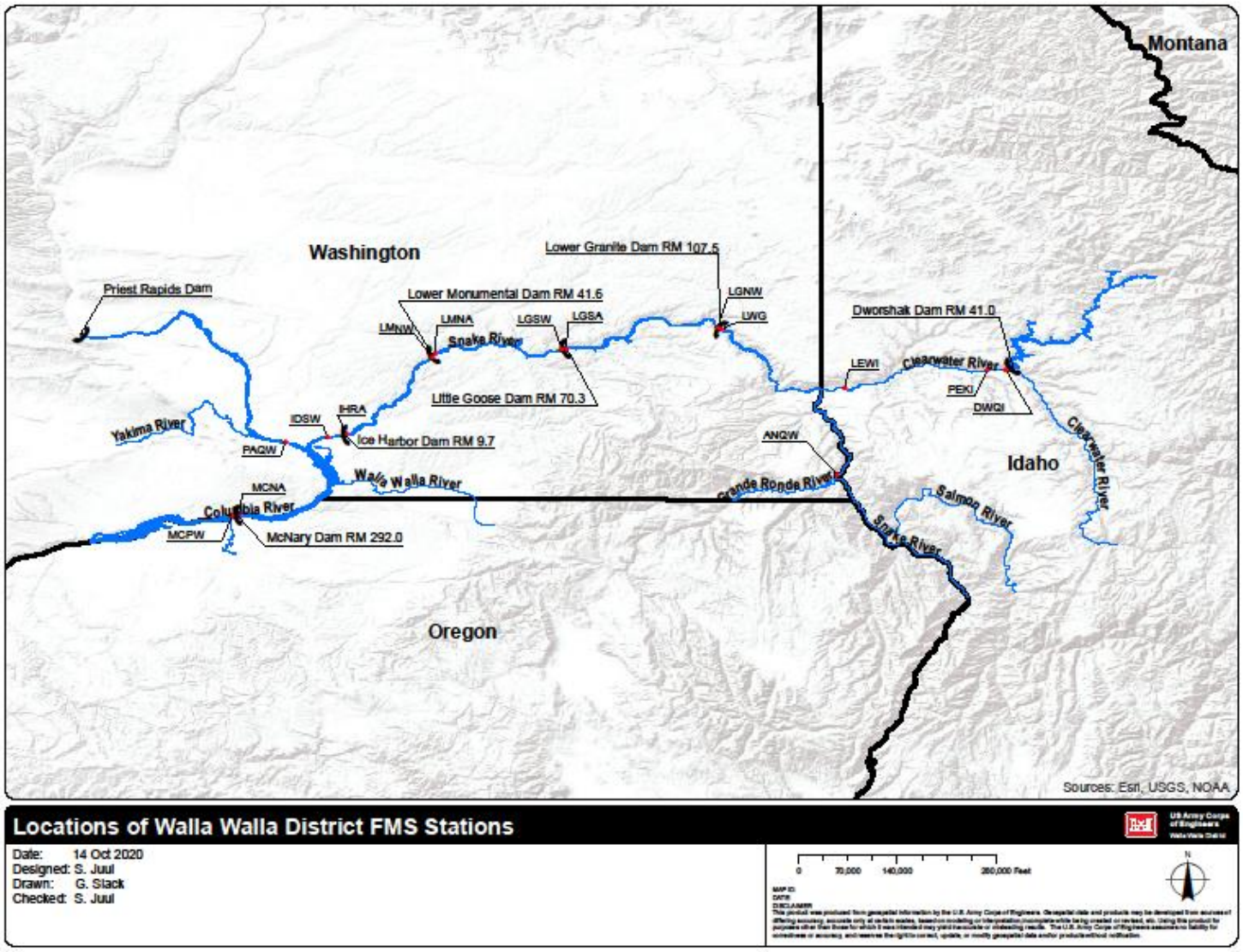

Figure F-1. Locations of Walla Walla District's FMS stations.

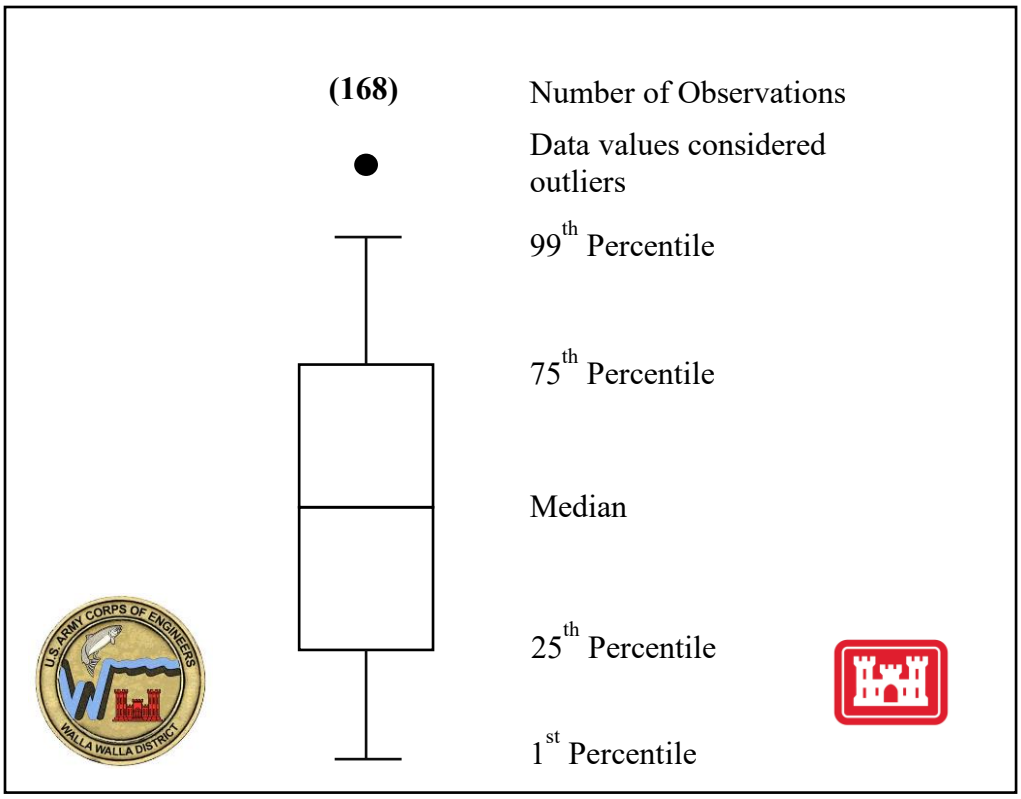

Figure F-2. Explanation key for the box plot information.

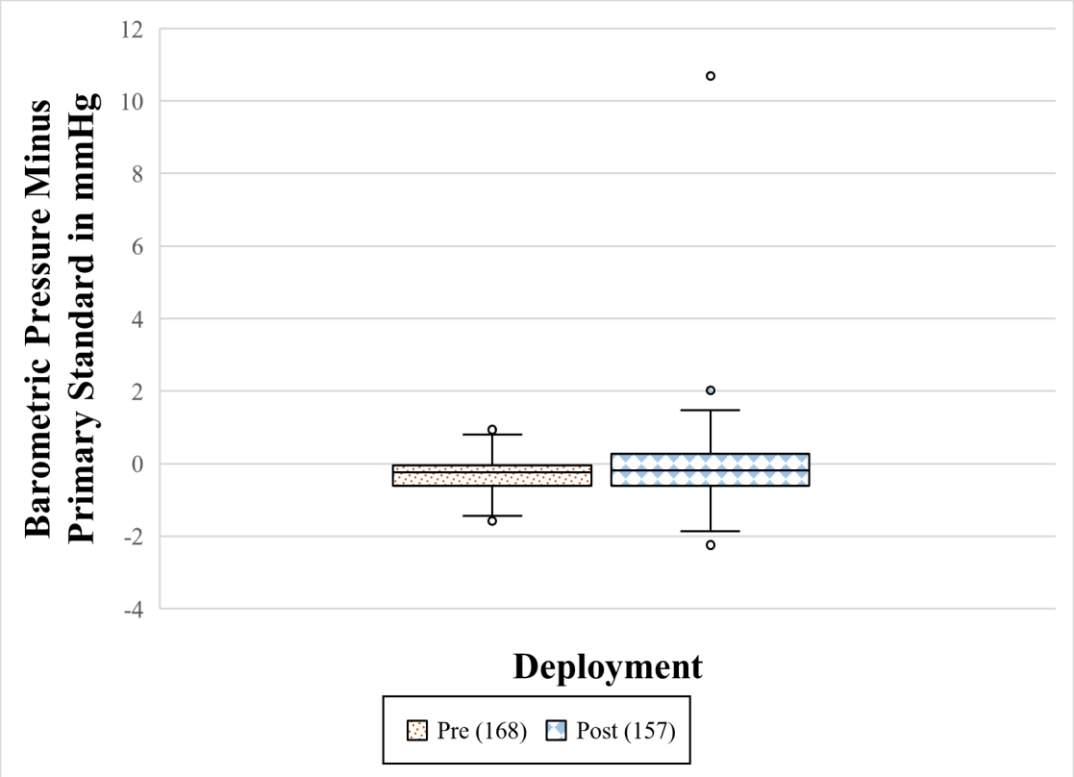

Figure F-3. Summary box plots of the pre-and post-deployment check of the barometric pressure versus the primary standard during the 2023 monitoring season.

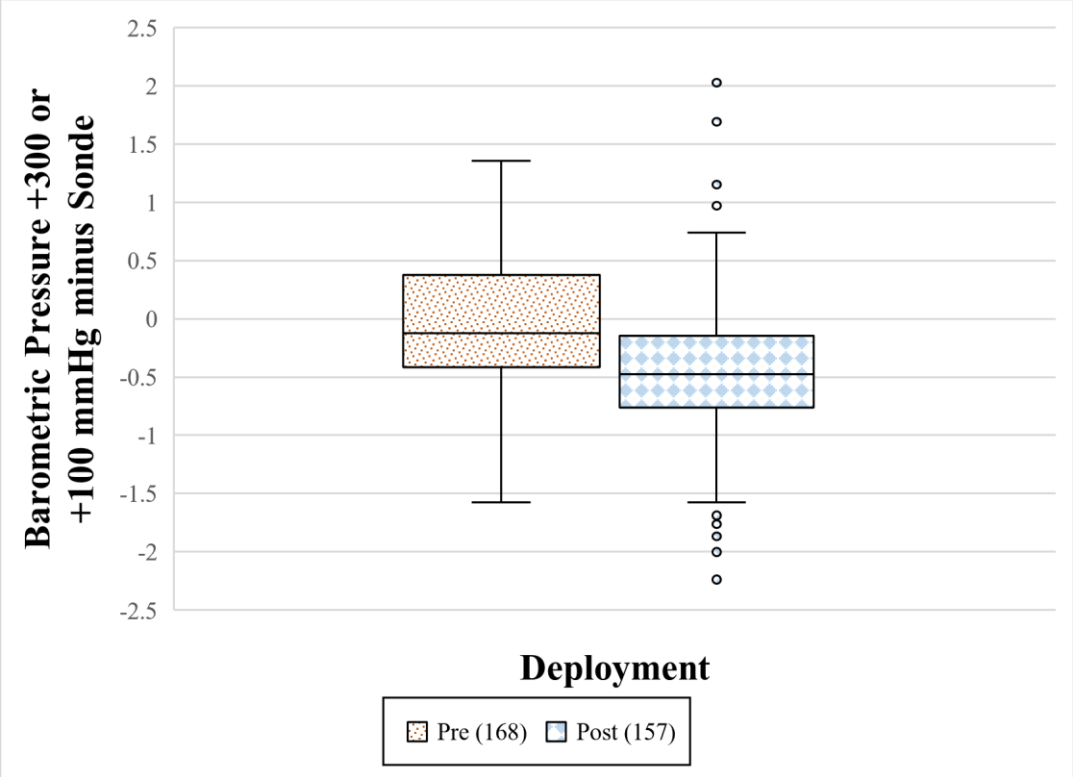

Figure F-4. Summary box plots of the pre-and post-deployment check of the Hydrolab® TDG sensors with the addition of 300 and 100 mmHg, respectively, during the 2023 monitoring season.

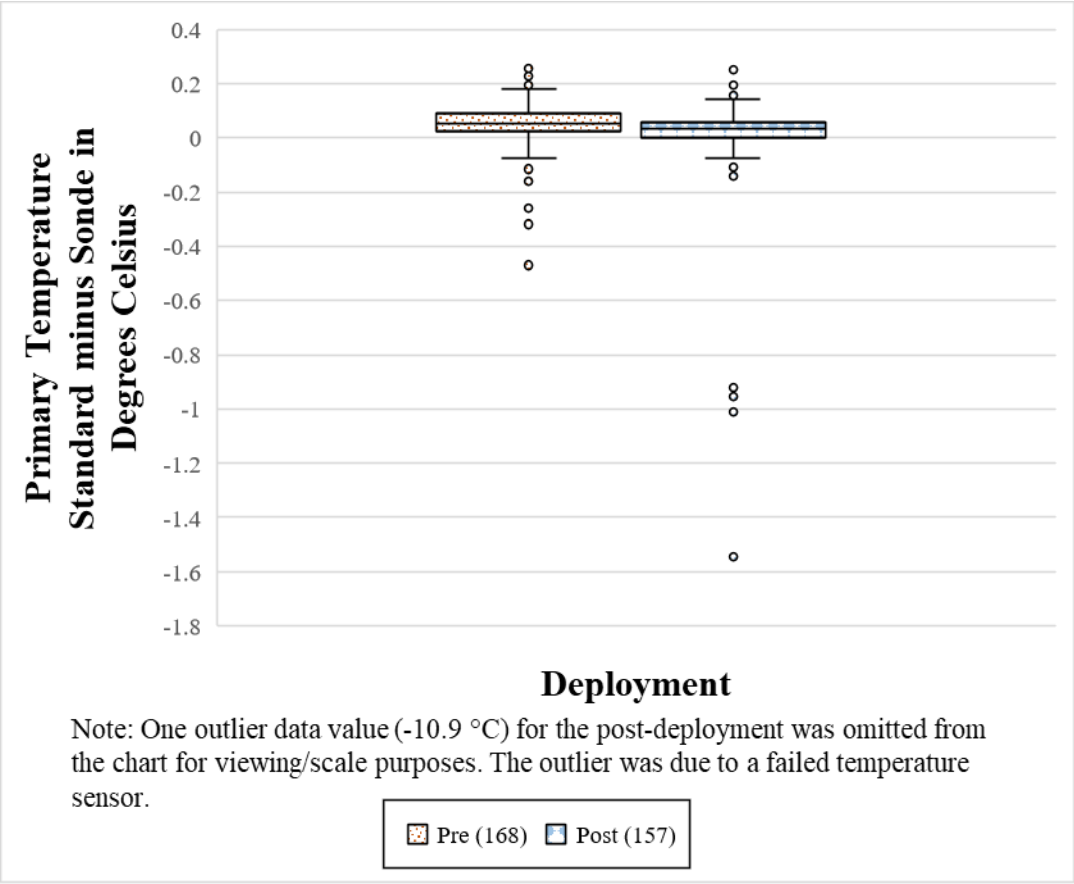

Figure F-5. Summary box plots of the pre- and post-deployment check of the Hydrolab® temperature sensors during the 2023 monitoring season.

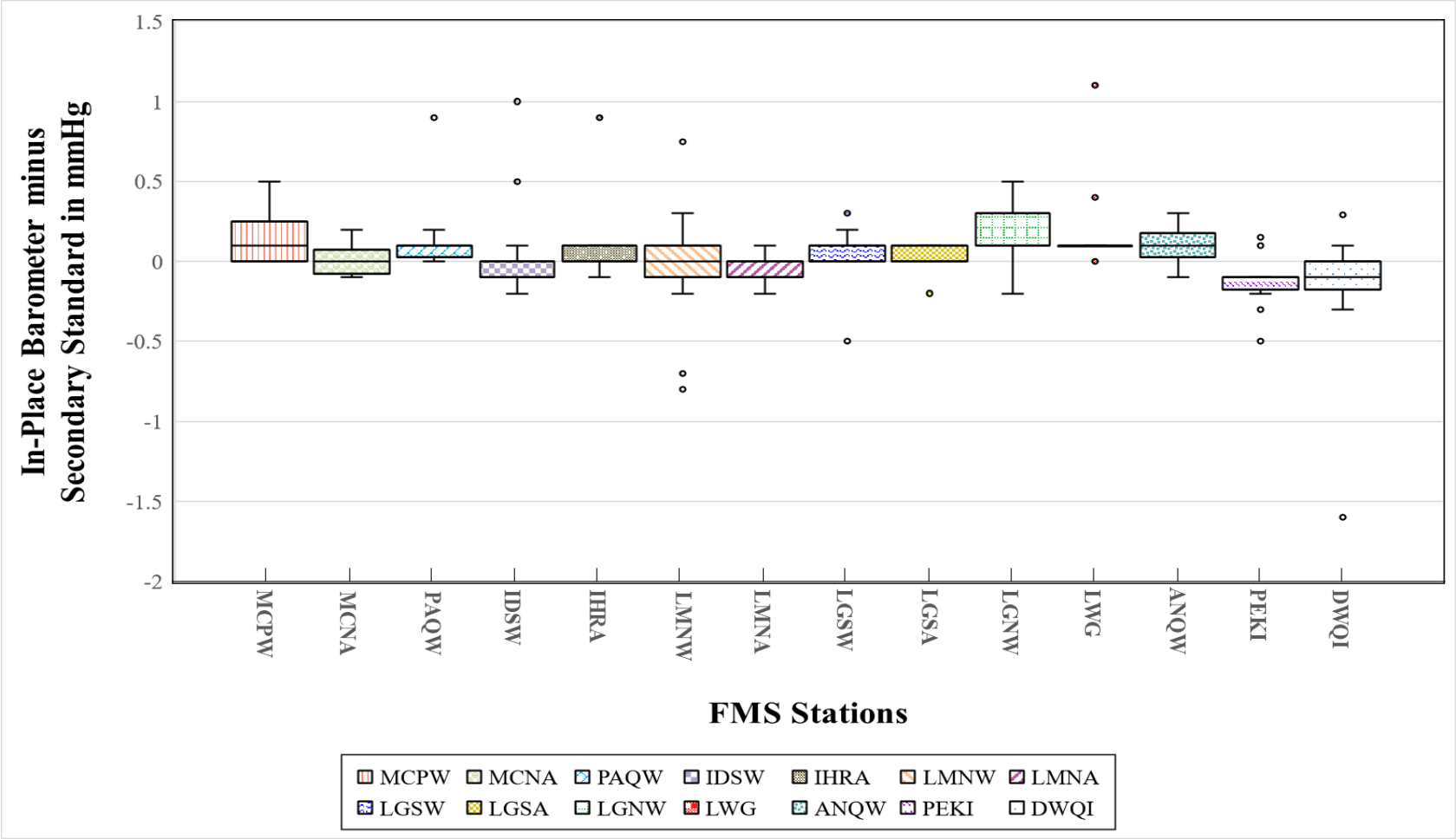

Figure F-6. Box plots of the field barometric pressure sensors check in mmHg by site during the 2023 monitoring season.

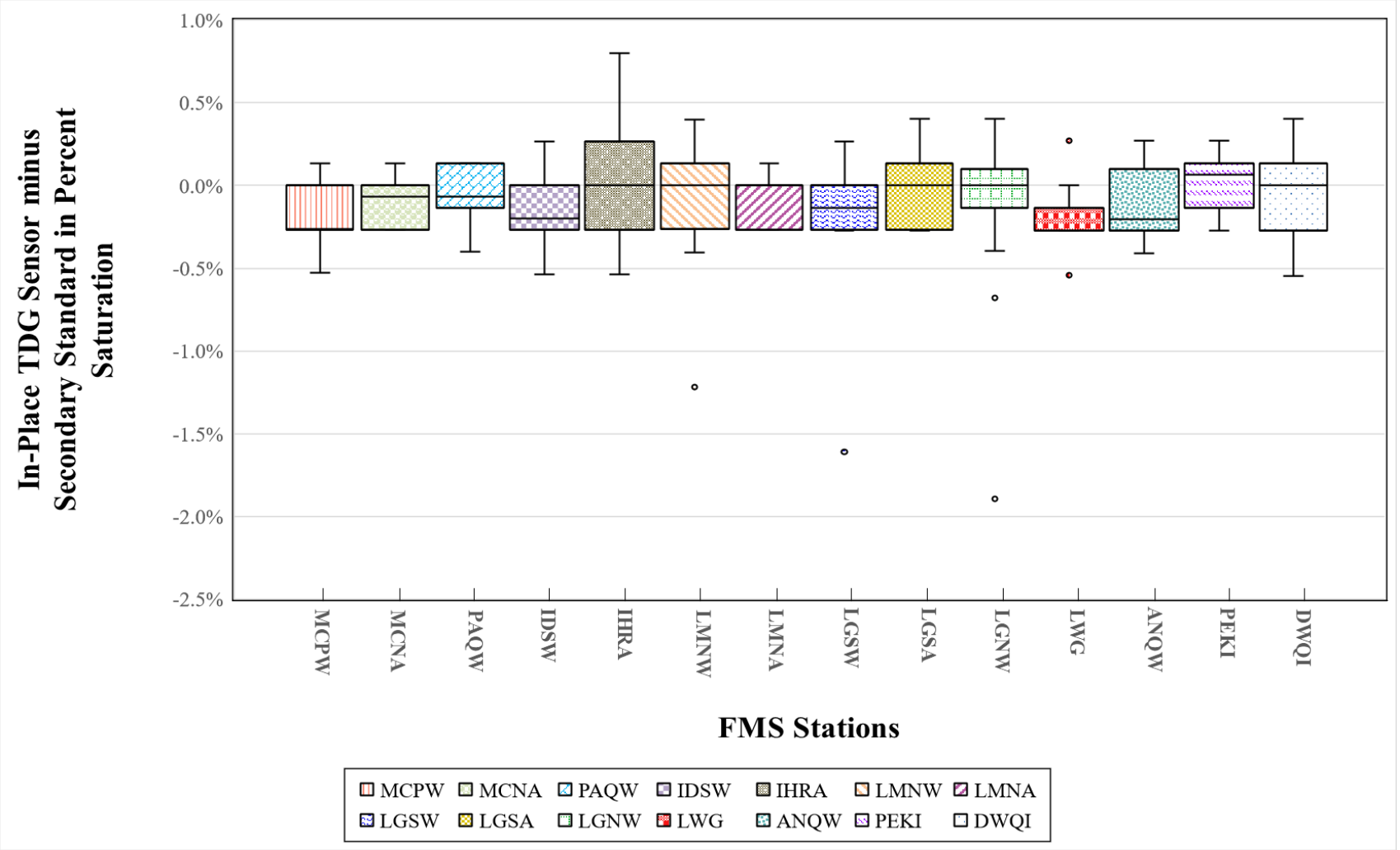

Figure F-7. Box plots of the field total dissolved gas sensor check verses secondary standard in percent saturation by site during the 2023 monitoring season.

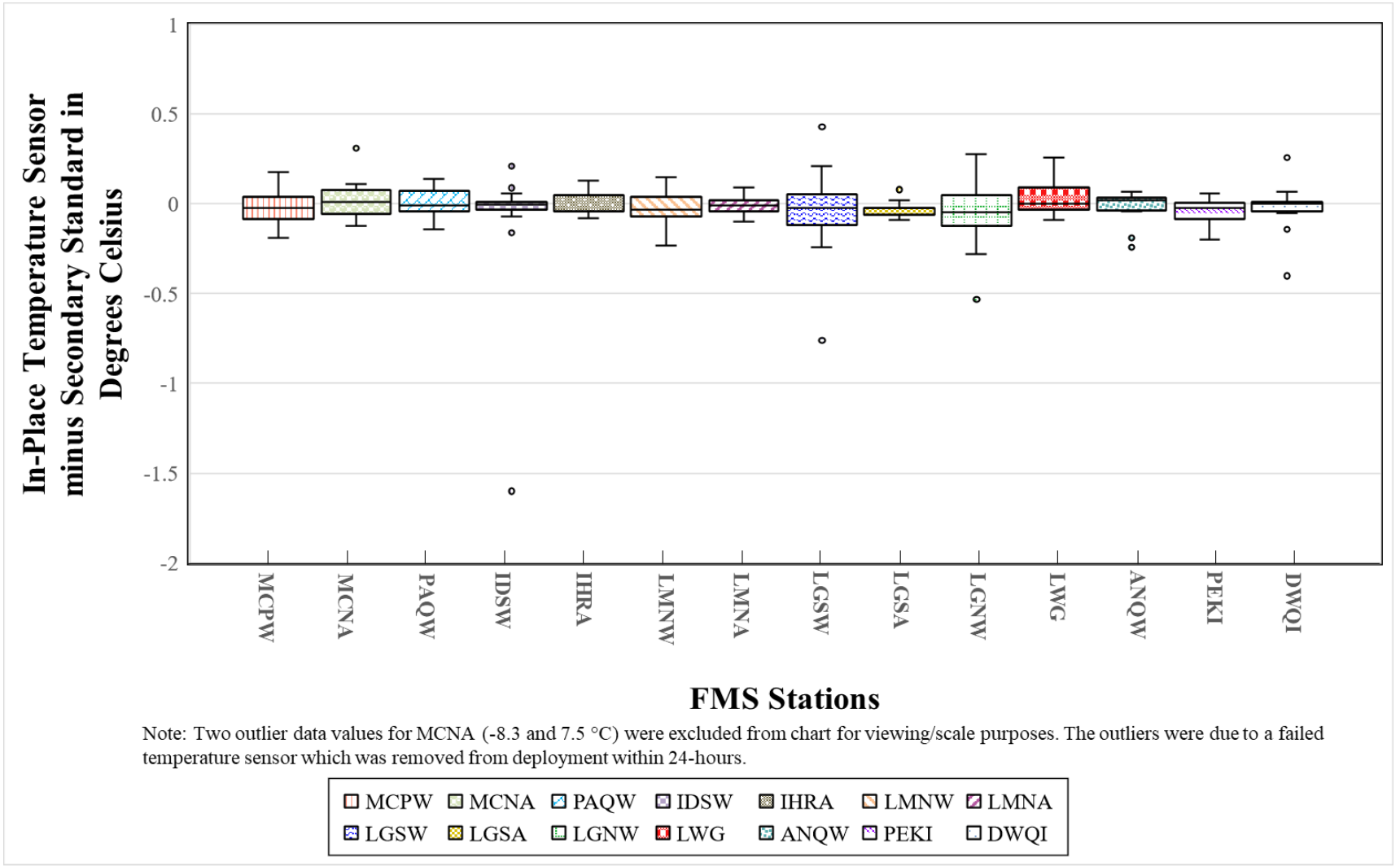

Figure F-8. Box plots of the field temperature sensors check verses secondary standard in degrees Celsius by site during the 2023 monitoring season.

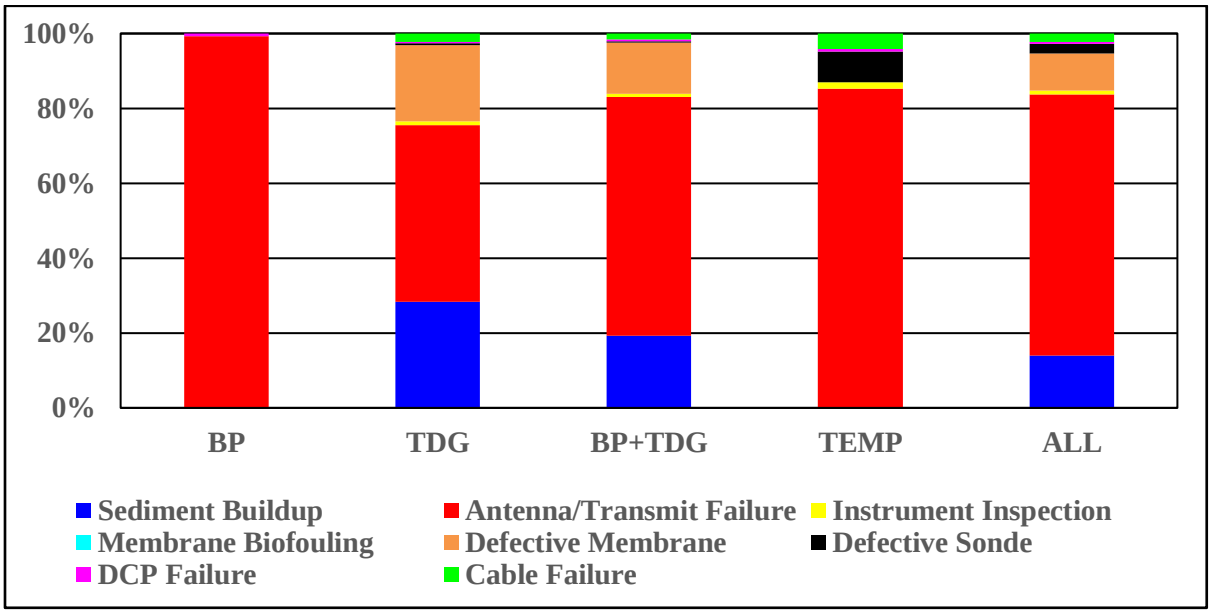

Figure F-9. Percentages for the reasons invalid or anomalous barometric pressure, TDG, and temperature data were removed from the databases during the 2023 monitoring season.

Figure F-10. Lower Granite tailwater (LGNW) deployment pipe pushed into downstream into shallow water during May 2023 high flows.

Figure F-11. Lower Granite tailwater (LGNW) station rebuild completed August 2023.

Figure F-12. Pasco (PAQW) station rebuild – during the deployment pipe inspection and repair.

TABLES

Table F-1. CENWW FMS station identification and location information.

Station Name	Station ID	Latitude (NAD 83)	Longitude (NAD 83)	Elevation (NGVD 29)	River Mile	DCP ID	XMIT Time
Columbia River at Pasco, WA	PAQW	46 13 23.9016 N	119 06 59.04 W	345	329.1	CE681730	00:12:00
Snake River Near Anatone, WA	ANQW	46 05 50.7579 N	116 58 41.2382 W	807	167.5	CE68FA10	00:12:05
N.F. Clearwater River at Dworshak Hatchery, ID*	DWQI	46 30 11.6464 N	116 19 16.4090 W	1,150	0.5	CE6906BC	0:06:05
Clearwater River Near Peck, ID	PEKI	46 30 00.9396 N	116 23 32.4163 W	930	37.4	CE692E82	00:12:15
Lower Granite Dam Forebay, WA	LWG	46 39 34.1727 N	117 25 34.8564 W	738	107.5	CE6993DE	00:12:25
Lower Granite Dam Tailwater, WA	LGNW	46 39 58.0726 N	117 26 19.2595 W	645	106.7	CE69CD70	00:12:30
Little Goose Dam Forebay, WA	LGSA	46 34 58.3188 N	118 01 32.9831 W	638	70.3	CE69F8EA	00:12:35
Little Goose Dam Tailwater, WA	LGSW	46 35 00.5280 N	118 02 37.4186 W	560	69.6	CE6A275E	00:12:40
Lower Monumental Dam Forebay, WA	LMNA	46 33 44.6559 N	118 32 08.3477 W	540	41.6	CE6A7722	00:12:45
Lower Monumental Dam Tailwater, WA	LMNW	46 33 04.5051 N	118 32 58.9500 W	445	40.4	CE6A79F0	00:12:50
Ice Harbor Dam Forebay, WA	IHRA	46 15 05.2792 N	118 52 43.0096 W	440	10	CE6AA14A	00:12:55
Ice Harbor Dam Tailwater, WA	IDSW	46 14 27.5868 N	118 57 13.7130 W	340	6.1	CE6AAF98	00:13:00
McNary Dam Forebay, WA	MCNA	45 56 28.9200 N	119 17 35.4400 W	340	292	CE6AD908	00:13:05
McNary Dam Tailwater, WA	MCPW	45 56 02.7775 N	119 19 35.4628 W	240	290.7	CE6BD520	00:13:10

Note: * Indicates the station records data at 15-minute intervals as opposed to the standard hourly rate.

Table F-2. Summary of the laboratory results evaluating the overall differences between laboratory standards and the sensors pre- and post-deployment during the 2023 water year.

Deployment	Observations	Statistic			Delta BP mmHg (%)	Delta (BP+300) mmHg (%)	Delta (BP+100) mmHg (%)	Delta Temp. °C
Pre	168	Minimum	-1.58	-(0.21)	-1.58 (-0.21)	-1.58 (-0.18)	----	-0.47
		25 Percentile	-0.60	-0.08	-0.6 (-0.08)	-0.42 (-0.05)	----	0.02
		Median	-0.21	-0.03	-0.21 (-0.03)	-0.13 (-0.02)	----	0.05
		75 Percentile	-0.04	-0.01	-0.04 (-0.01)	0.37 (0.01)	----	0.09
		Maximum	1.09	0.15	1.09 (0.15)	1.35 (0.13)	----	0.28
		Mean	-0.25	-0.03	-0.25 (-0.03)	-0.04 (-0.02)	----	0.05
Post	157	Minimum	-2.24	-0.30	-2.24 (-0.3)	----	-2.24 (-0.29)	-10.88[(a)]
		25 Percentile	-0.60	-0.08	-0.6 (-0.08)	----	-0.76 (-0.08)	0.00
		Median	-0.20	-0.03	-0.2 (-0.03)	----	-0.47 (-0.03)	0.04
		75 Percentile	0.31	0.04	0.31 (0.04)	----	-0.15 (0)	0.06
		Maximum	10.69	1.46	10.69 (1.46)	----	2.03 (0.83)	0.25
		Mean	-0.04	-0.01	-0.04 (-0.01)	----	-0.44 (-0.03)	-0.13

Note: (a) Due to possible defective sensor

Table F-3. Pre-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2023 water year.

	Δ (PT – BP)			Δ [PT- (BP+300)]			Δ (Water Temperature)		
Sensor ID	Obs. (#)	Range (mmHg)	Median (mmHg)	Obs. (#)	Range (mmHg)	Median (mmHg)	Obs. (#)	Range (º C)	Median (º C)
1972	5	-0.2 to 0.4	-0.12	5	-1.2 to 0.4	-0.12	5	0.0 to 0.1	0.06
1973	6	-0.6 to 0.3	-0.27	6	0.0 to 0.8	0.47	6	0.1 to 0.3	0.10
1975	6	-1.4 to -0.3	-0.50	6	-0.4 to 0.7	0.25	6	0.0 to 0.1	0.02
1976	6	-0.7 to 0.3	-0.10	6	0.2 to 0.6	0.32	6	-0.1 to 0.0	-0.03
1977	6	-1.3 to 0.9	0.39	6	-1.3 to 0.9	0.39	6	0.0 to 0.2	0.02
1978	6	-0.8 to 0.0	-0.43	6	-0.5 to 0.2	-0.26	6	0.0 to 0.0	0.03
1979	7	-0.7 to 0.2	-0.18	7	-0.8 to 0.0	-0.20	7	0.1 to 0.2	0.06
2009	3	-0.5 to -0.1	-0.16	3	-1.1 to -0.2	-0.52	3	0.1 to 0.2	0.08
2010	3	-0.7 to -0.3	-0.45	3	-0.7 to -0.3	-0.45	3	-0.2 to 0.0	0.02
2011	2	-0.8 to 0.4	-0.16	2	-0.8 to 0.4	-0.16	2	-0.5 to 0.0	-0.23
2012	4	-0.3 to 0.1	-0.24	4	-0.3 to 0.1	-0.24	4	0.0 to 0.1	0.03
2431	2	-1.1 to -1.0	-1.06	2	-1.1 to -1.0	-1.06	2	0.1 to 0.1	0.09
2433	4	-1.6 to -0.5	-1.10	4	-1.6 to 0.5	-0.60	4	0.1 to 0.1	0.08
2435	3	-0.7 to -0.1	-0.60	3	-0.7 to -0.1	-0.60	3	0.1 to 0.2	0.13
3064	4	-0.3 to -0.1	-0.25	4	-0.3 to -0.1	-0.25	4	0.0 to 0.2	0.03
3065	4	-0.7 to -0.2	-0.36	4	-0.7 to 0.8	-0.36	4	0.0 to 0.1	0.02
4382	4	-0.5 to 0.4	0.00	4	0.4 to 1.2	0.61	4	0.1 to 0.2	0.11
5131	1	0.6 to 0.6	0.55	1	0.6 to 0.6	0.55	1	0.1 to 0.1	0.12
6685	4	-0.3 to 0.4	-0.13	4	-0.3 to 0.4	-0.13	4	0.0 to 0.0	0.03
6688	2	-0.7 to 0.5	-0.13	2	0.3 to 0.5	0.37	2	0.0 to 0.1	0.05
7494	2	-1.0 to -0.2	-0.61	2	-1.0 to -0.2	-0.61	2	0.0 to 0.0	-0.01
7896	5	-0.5 to 0.4	-0.14	5	-1.2 to -0.1	-0.62	5	0.1 to 0.1	0.07
7897	5	-1.0 to -0.2	-0.45	5	-1.0 to -0.2	-0.45	5	-0.3 to 0.0	0.02
7944	5	-1.3 to -0.5	-0.76	5	-0.5 to 0.3	0.07	5	-0.1 to 0.0	-0.02
7945	2	-0.2 to 0.3	0.06	2	-0.2 to 0.3	0.06	2	0.0 to 0.2	0.09
7947	6	-0.8 to 0.1	-0.14	6	-0.8 to 0.4	-0.08	6	-0.3 to 0.1	0.08
7949	5	-1.1 to -0.1	-0.29	5	-0.6 to -0.1	-0.17	5	0.0 to 0.1	0.05
8101	4	-0.8 to -0.4	-0.49	4	-0.5 to 1.2	0.57	4	0.0 to 0.0	-0.04
8496	2	-0.3 to 0.4	0.01	2	0.7 to 1.4	1.01	2	0.1 to 0.2	0.14
8497	5	-1.3 to 0.4	-0.53	5	-0.6 to 0.4	-0.30	5	0.1 to 0.2	0.12
8498	6	-0.2 to 0.5	-0.14	6	-0.5 to 0.3	-0.19	6	0.1 to 0.3	0.20
8499	4	-1.3 to 0.1	-0.63	4	-0.3 to 1.1	0.37	4	0.1 to 0.3	0.14
9522	5	-1.3 to -0.1	-0.65	5	0.2 to 1.4	0.71	5	0.0 to 0.1	0.05
9523	2	-0.2 to 0.2	-0.03	2	-0.2 to 0.2	-0.03	2	0.0 to 0.3	0.15
9524	3	-0.1 to 0.8	0.62	3	0.6 to 0.9	0.81	3	0.1 to 0.1	0.09
9525	4	0.2 to 1.1	0.59	4	0.2 to 1.1	0.59	4	0.0 to 0.1	0.06
022A	4	-1.2 to -0.2	-0.88	4	-1.2 to -0.2	-0.88	4	-0.1 to 0.1	0.05
113B	4	-0.8 to -0.1	-0.58	4	-0.1 to 0.6	0.18	4	0.0 to 0.1	0.04
113C	1	0.4 to 0.4	0.40	1	0.4 to 0.4	0.40	1	0.1 to 0.1	0.05
522A	4	-1.1 to -0.2	-0.62	4	-1.1 to 0.3	-0.36	4	0.0 to 0.1	0.05
522B	1	-0.3 to -0.3	-0.30	1	-0.3 to -0.3	-0.30	1	0.0 to 0.0	-0.02

Table F-3. Pre-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2023 water year (continued).

	Δ (PT – BP)			Δ [PT- (BP+300)]			Δ (Water Temperature)		
Sensor ID	**Obs. (#)**	**Range (mmHg)**	**Median (mmHg)**	**Obs. (#)**	**Range (mmHg)**	**Median (mmHg)**	**Obs. (#)**	**Range (º C)**	**Median (º C)**
BP6911	1	-0.2 to -0.2	-0.16	1	-0.2 to -0.2	-0.16	1	0.1 to 0.1	0.05
BP6912	1	-0.1 to -0.1	-0.09	1	-0.1 to -0.1	-0.09	1	0.0 to 0.0	-0.05
BP7492	2	-0.2 to 0.2	0.00	2	-0.2 to 0.2	0.00	2	0.0 to 0.0	0.00
BP8715	1	0.2 to 0.2	0.23	1	0.2 to 0.2	0.23	1	0.0 to 0.0	0.03
BP914A	2	-0.7 to -0.4	-0.57	2	-0.7 to -0.4	-0.57	2	0.1 to 0.1	0.07

Table F-4. Post-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2023 water year.

	Δ (BP – PT)			Δ [PT - BP+100)]			Δ (Water Temperature)		
Sensor ID	Obs. (#)	Range (mmHg)	Median (mmHg)	Obs. (#)	Range (mmHg)	Median (mmHg)	Obs. (#)	Range (º C)	Median (º C)
1972	5	-1.2 to 0.8	-0.32	5	-1.2 to 0.7	-0.55	5	-1.5 to 0.1	0.05
1973	6	-0.6 to 0.3	-0.22	6	-2.0 to 0.7	-0.25	6	0.0 to 0.1	0.08
1975	5	-1.3 to 0.7	-0.36	5	-1.0 to -0.3	-0.36	5	0.0 to 0.1	-0.02
1976	6	-0.7 to 0.4	-0.06	6	-0.7 to 0.1	-0.46	6	0.0 to 0.0	-0.04
1977	6	-0.6 to 1.3	-0.13	6	-0.7 to -0.1	-0.40	6	0.0 to 0.1	0.00
1978	6	-1.4 to 0.3	-0.63	6	-1.8 to -0.4	-1.27	6	0.0 to 0.0	0.02
1979	7	-0.8 to 0.5	-0.40	6	-0.8 to 0.5	-0.51	7	-0.1 to 0.1	0.04
2009	2	-0.1 to 0.0	-0.08	2	-1.0 to -0.1	-0.58	2	0.0 to 0.1	0.07
2010	3	-0.5 to 0.0	-0.34	3	-1.0 to -0.3	-0.50	3	0.0 to 0.0	0.02
2011	2	-0.6 to 1.4	0.39	2	-0.6 to -0.6	-0.61	2	-10.9 to 0.0	-5.44
2012	3	-0.9 to 0.5	-0.18	3	-0.9 to -0.2	-0.47	3	-0.1 to 0.1	0.02
2431	1	-1.6 to -1.6	-1.58	1	-1.6 to -1.6	-1.58	1	0.1 to 0.1	0.08
2433	4	-2.2 to -1.0	-1.46	4	-2.2 to 1.0	-1.46	4	-0.9 to 0.1	0.05
2435	3	-1.1 to -0.1	-0.65	3	-1.1 to -0.1	-0.65	2	0.0 to 0.1	0.06
3064	4	-0.9 to 0.1	-0.44	4	-0.9 to 0.1	-0.44	4	-0.1 to 0.0	-0.01
3065	4	-0.9 to 0.1	0.03	4	-0.9 to 0.1	0.03	4	0.0 to 0.0	0.02
4382	4	-0.9 to 0.4	-0.21	4	-1.9 to 0.4	-0.21	4	0.0 to 0.2	0.09
5131	0[(a)]	-	-	0[(a)]	-	-	0[(a)]	-	-
6685	4	-1.3 to 0.1	-0.31	4	-0.9 to -0.2	-0.34	4	0.0 to 0.2	0.03
6688	1	-0.8 to -0.8	-0.75	1	-0.8 to -0.8	-0.75	1	0.1 to 0.1	0.06
7494	2	-0.8 to -0.4	-0.63	2	-0.8 to -0.4	-0.63	2	-0.1 to 0.0	0.00
7896	5	-0.2 to 0.5	0.01	3	-1.0 to 0.4	-0.09	5	0.0 to 0.1	0.04
7897	4	-1.2 to 0.5	-0.48	4	-1.2 to -0.4	-0.53	4	-0.1 to 0.0	0.01
7944	4	-0.6 to 0.4	-0.04	4	-0.7 to -0.4	-0.56	4	-0.1 to 0.1	0.02
7945	2	0.7 to 10.7	5.71	2	-1.3 to 1.7	0.21	2	0.0 to 0.0	-0.02
7947	6	-0.5 to 1.5	0.31	5	-1.2 to 0.1	-0.46	6	0.0 to 0.1	0.04
7949	5	-0.9 to 0.3	-0.58	5	-1.7 to 0.4	-0.72	5	0.0 to 0.1	0.07
8101	4	-1.9 to 0.0	-0.78	3	-1.9 to 0.2	-0.75	4	-0.1 to 0.0	-0.07
8496	2	0.2 to 0.5	0.32	2	-0.8 to 0.5	-0.18	2	0.0 to 0.0	-0.01
8497	5	-0.6 to 1.3	-0.19	5	-1.2 to 0.6	0.34	5	0.0 to 0.2	0.12
8498	6	-0.8 to 0.7	-0.19	6	-1.4 to 0.7	-0.23	6	0.0 to 0.3	0.11
8499	4	-0.7 to 1.4	0.68	3	-1.0 to -0.6	-0.66	4	-0.1 to 0.2	0.09
9522	5	-1.4 to 0.6	-0.15	5	-1.4 to -0.1	-0.69	5	0.0 to 0.0	0.03
9523	2	-0.6 to 0.4	-0.08	2	-0.6 to -0.6	-0.58	2	0.0 to 0.1	0.05
9524	3	-0.1 to 1.4	1.15	3	-0.6 to 1.2	-0.07	3	0.0 to 0.1	0.06
9525	4	-0.2 to 2.0	0.50	4	-0.2 to 2.0	0.50	4	0.0 to 0.1	0.05
022A	3	-0.9 to 0.0	-0.58	3	-0.6 to 0.1	-0.04	3	-1.0 to 0.1	0.01
113B	3	-0.3 to 0.3	-0.20	3	-0.7 to -0.2	-0.30	3	0.0 to 0.0	0.03
113C	1	0.5 to 0.5	0.53	1	-0.5 to -0.5	-0.47	1	0.0 to 0.0	0.05
522A	4	-1.0 to -0.2	-0.57	4	-1.0 to -0.2	-0.57	4	0.0 to 0.1	0.04
522B	1	0.9 to 0.9	0.94	1	-0.1 to -0.1	-0.06	1	0.0 to 0.0	-0.02

Note: (a) Post calibration not performed due to failed instrument. Instrument sent directly for repairs.

Table F-4. Post-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2023 water year (continued).

	Δ (BP – PT)			Δ [PT - BP+100)]			Δ (Water Temperature)		
Sensor ID	Obs. (#)	Range (mmHg)	Median (mmHg)	Obs. (#)	Range (mmHg)	Median (mmHg)	Obs. (#)	Range (º C)	Median (º C)
BP6911	1	0.7 to 0.7	0.75	1	-0.3 to -0.3	-0.25	1	0.1 to 0.1	0.05
BP6912	1	-0.7 to -0.7	-0.75	1	-0.7 to -0.7	-0.75	1	0.1 to 0.1	0.07
BP7492	2	0.2 to 0.3	0.22	2	0.3 to 1.2	0.72	2	0.0 to 0.0	-0.01
BP8715	1	-0.3 to -0.3	-0.33	1	-0.3 to -0.3	-0.33	1	-1.0 to -1.0	-1.01
BP914A	1	-0.6 to -0.6	-0.65	1	-0.6 to -0.6	-0.65	1	0.1 to 0.1	0.06

Table F-5. Summary of the field results for the differences between the in-place and replacement sensors during 2023 water year.

Statistic	Delta BP (mmHg)	Delta TDG (% sat)	Delta Temp (°C)
Number of Inspections	171	171	171
Min	-1.6	-1.9	-8.34
Max	1.1	0.8	7.47
Mean	0.04	-0.1	-0.03
Median	0.00	-0.1	-0.01

Table F-6. Summary of the field results for the differences between the in-place and replacement sensors by station during 2023 water year.

Station ID	Delta Barometric Air Pressure			Delta Total Dissolved Gas				Delta Water Temperature		
	# Obs.	Range (mmHg)	Median (mmHg)	# Obs.	Range (mmHg)	Median (mmHg)	Range (% Sat)	Median (% Sat)	# Obs.	Range (^{o}C)	Median (^{o}C)
MCPW	15	0.00 to 0.50	0.10	15	-4.0 to 1.0	-2.00	-0.53 to 0.13	-0.3%	15	-0.19 to 0.18	-0.02
MCNA	10	-0.10 to 0.20	0.00	10	-2.0 to 1.0	-0.50	-0.27 to 0.13	-0.1%	10	-8.34[a] to 7.47[(a)]	0.01
PAQW	10	0.00 to 0.90	0.10	10	-3.0 to 1.0	-0.50	-0.40 to 0.13	-0.1%	10	-0.14 to 0.14	-0.01
IDSW	16	-0.20 to 1.00	-0.10	16	-4.0 to 2.0	-1.50	-0.54 to 0.27	-0.2%	16	-1.60 to 0.21	0.00
IHRA	9	-0.10 to 0.90	0.00	9	-4.0 to 6.0	0.00	-0.53 to 0.80	0.0%	9	-0.08 to 0.13	0.05
LMNW	17	-0.80 to 0.75	0.00	17	-9.0 to 3.0	0.00	-1.22 to 0.40	0.0%	17	-0.23 to 0.15	-0.03
LMNA	9	-0.20 to 0.10	0.00	9	-2.0 to 1.0	0.00	-0.27 to 0.14	0.0%	9	-0.10 to 0.09	-0.01
LGSW	15	-0.50 to 0.30	0.10	15	-12.0 to 2.0	-1.00	-1.61 to 0.27	-0.1%	15	-0.76 to 0.43	-0.02
LGSA	9	-0.20 to 0.10	0.00	9	-2.0 to 3.0	0.00	-0.27 to 0.41	0.0%	9	-0.09 to 0.08	-0.02
LGNW	18	-0.20 to 0.50	0.10	18	-14.0 to 3.0	0.00	-1.89 to 0.40	0.0%	18	-0.53 to 0.28	-0.05
LWG	9	0.00 to 1.10	0.10	9	-4.0 to 2.0	-2.00	-0.54 to 0.27	-0.3%	9	-0.09 to 0.26	0.00
ANQW	10	-0.10 to 0.30	0.10	10	-3.0 to 2.0	-1.50	-0.41 to 0.27	-0.2%	10	-0.24 to 0.07	0.02
PEKI	10	-0.50 to 0.15	-0.10	10	-2.0 to 2.0	0.50	-0.27 to 0.27	0.1%	10	-0.20 to 0.06	-0.02
DWQI	14	-1.60 to 0.29	-0.10	14	-4.0 to 3.0	0.00	-0.55 to 0.40	0.0%	14	-0.40 to 0.26	0.00

Note: (a) Sensor failed

Table F-7. Database completeness with the number and percent of all missing or invalid barometric pressure, total dissolved gas, and temperature points for each FMS station during the 2023 water year.

Station ID	Monitoring Period	Barometric Pressure		Total Dissolved Gas		Temperature	
		Number Missing/ Anomalous	Percent Complete	Number Missing/ Anomalous	Percent Complete	Number Missing/ Anomalous	Percent Complete
MCPW	1 Oct – 30 Sep	27	99.69	35	99.60	31	99.65
MCNA	1 Apr – 31 Aug	**0**	**100.00**	**0**	**100.00**	26	99.29
PAQW	1 Apr – 31 Aug	**0**	**100.00**	58	98.42	**0**	**100.00**
IDSW	1 Oct – 30 Sep	3	99.97	24	99.73	24	99.73
IHRA	1 Apr – 31 Aug	**0**	**100.00**	**0**	**100.00**	5	99.86
LMNW	1 Oct – 30 Sep	3	99.97	82	99.06	5	99.94
LMNA	1 Apr – 31 Aug	**0**	**100.00**	**0**	**100.00**	**0**	**100.00**
LGSW	1 Oct – 30 Sep	3	99.97	3	99.97	3	99.97
LGSA	1 Apr – 31 Aug	**0**	**100.00**	**0**	**100.00**	**0**	**100.00**
LGNW	1 Oct – 30 Sep	30	99.66	87	99.01	34	99.61
LWG	1 Apr – 31 Aug	2	99.95	2	99.95	2	99.95
ANQW	1 Apr – 31 Aug	8	99.78	8	99.78	12	99.67
PEKI	1 Apr – 31 Aug	302	91.78	556	84.86	306	91.67
DWQI	1 Oct – 30 Sep	100	98.86	100	98.86	100	98.86

Table F-8. Summary of the total hours of barometric pressure, total dissolved gas, and temperature data that were missing or considered invalid in the 2023 water year.

Reason	BP Hours (%)	TDG Hours (%)	BP+TDG Hours (%)	Temp. Hours (%)	All Hours (%)
Sediment Build-up		256 (0.31)	256 (0.16)		256 (0.10)
Missed Transmit	50 (0.06)	50 (0.06)	100 (0.06)	50 (0.06)	150 (0.06)
Antenna/Transmit Failure	425 (0.52)	427 (0.52)	852 (0.52)	425 (0.52)	1277 (0.52)
Instrument Inspection		10 (0.01)	10 (0.01)	8 (0.01)	18 (0.01)
Membrane Biofouling					
Defective Membrane		184 (0.22)	184 (0.11)		184 (0.07)
Defective Sonde		4 (0.00)	4 (0.00)	41 (0.05)	45 (0.02)
DCP Failure	3 (0.00)	3 (0.00)	6 (0.00)	3 (0.00)	10 (0.00)
Cable Failure		21 (0.03)	21 (0.01)	21 (0.03)	42 (0.02)
Totals	478 (0.58)	955 (1.17)	1433 (0.87)	548 (0.67)	1981 (0.81)

Table F-9. Number and percent of all missing or invalid barometric pressure data for each FMS station during the 2023 water year, along with the reasons for those designations.

Station ID	Sediment Build-up # (%)	Missed Transmit # (%)	Antenna/ Transmit Failure # (%)	Instrument Inspection # (%)	Membrane Biofouling # (%)	Defective Membrane # (%)	Defective Sonde # (%)	DCP Failure # (%)	Cable Failure # (%)
MCPW	-	3 (0.03)	24 (0.27)	-	-	-	-	-	-
MCNA	-	-	-	-	-	-	-	-	-
PAQW	-	-	-	-	-	-	-	-	-
IDSW	-	3 (0.03)	-	-	-	-	-	-	-
IHRA	-	-	-	-	-	-	-	-	-
LMNW	-	3 (0.03)	-	-	-	-	-	-	-
LMNA	-	-	-	-	-	-	-	-	-
LGSW	-	3 (0.03)	-	-	-	-	-	-	-
LGSA	-	-	-	-	-	-	-	-	-
LGNW	-	30 (0.34)	-	-	-	-	-	-	-
LWG	-	-	2 (0.05)	-	-	-	-	-	-
ANQW	-	8 (0.09)	-	-	-	-	-	-	-
PEKI	-	-	302 (8.22)	-	-	-	-	-	-
DWQI	-	-	97 (1.11)	-	-	-	-	3 (0.03)	-

Table F-10. Number and percent of all missing or invalid total dissolved gas data for each FMS station during the 2023 water year, along with the reasons for those designations.

Station ID	Sediment Build-up # (%)	Missed Transmit # (%)	Antenna/ Transmit Failure # (%)	Instrument Inspection # (%)	Membrane Biofouling # (%)	Defective Membrane # (%)	Defective Sonde # (%)	DCP Failure # (%)	Cable Failure # (%)
MCPW	-	3 (0.03)	24 (0.27)	4 (0.05)	-	-	4 (0.05)	-	-
MCNA	-	-	-	-	-	-	-	-	-
PAQW	-	-	-	-	-	58 -	-	-	-
IDSW	-	3 (0.03)	-	-	-	-	-	-	21 (0.24)
IHRA	-	-	-	-	-	-	-	-	-
LMNW	-	3 (0.03)	4 (0.05)	2 (0.02)	-	73 (0.83)	-	-	-
LMNA	-	-	-	-	-	-	-	-	-
LGSW	-	3 (0.03)	-	-	-	-	-	-	-
LGSA	-	-	-	-	-	-	-	-	-
LGNW	-	30 (0.34)	-	4 (0.05)	-	53 (0.61)	-	-	-
LWG	-	-	2 (0.05)	-	-	-	-	-	-
ANQW	-	8 (0.22)	-	-	-	-	-	-	-
PEKI	256 (6.97)	-	300 (8.17)	-	-	-	-	-	-
DWQI	-	-	97 (1.11)	-	-	-	-	3.25 (0.04)	-

Table F-11. Number and percent of all missing or invalid temperature data for each FMS station during the 2023 water year, along with the reasons for those designations.

Station ID	Sediment Build-up # (%)	Missed Transmit # (%)	Antenna/ Transmit Failure # (%)	Instrument Inspection # (%)	Membrane Biofouling # (%)	Defective Membrane # (%)	Defective Sonde # (%)	DCP Failure # (%)	Cable Failure # (%)
MCPW	-	3 (0.03)	24 (0.27)	-	-	-	4 (0.05)	-	-
MCNA	-	-	-	-	-	-	26 (0.71)	-	-
PAQW	-	-	-	-	-	-	-	-	-
IDSW	-	3 (0.03)	-	-	-	-	-	-	21 (0.24)
IHRA	-	-	-	-	-	-	5 (0.14)	-	-
LMNW	-	3 (0.03)	-	-	-	-	2 (0.02)	-	-
LMNA	-	-	-	-	-	-	-	-	-
LGSW	-	3 (0.03)	-	-	-	-	-	-	-
LGSA	-	-	-	-	-	-	-	-	-
LGNW	-	30 (0.34)	-	4 (0.05)	-	-	-	-	-
LWG	-	-	2 (0.05)	-	-	-	-	-	-
ANQW	-	8 (0.22)	-	4 (0.11)	-	-	-	-	-
PEKI	-	-	302 (8.22)	-	-	-	4 (0.11)	-	-
DWQI	-	-	97 (1.11)	-	-	-	-	3 (0.04)	-