Appendix G

USACE Walla Walla District QA/QC Evaluation of the 2016 FMS TDG Monitoring Data

Includes:

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

USACE Walla Walla District QA/QC Evaluation of the 2016 FMS TDG Monitoring Data

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ABSTRACT

The U.S. Army Corps of Engineers (USACE), Walla Walla District (CENWW), operated fifteen fixed-monitoring system (FMS) stations (nine seasonal and six year round) for total dissolved gas (TDG), barometric pressure (BP), and temperature as part of their 2016 water-quality program. These stations are located on the Columbia, Lower Snake and Clearwater Rivers. This report provides a summary of the 2016 water-year quality assurance/ quality control (QA/QC) evaluation. Highlights include:

- Data completeness for the combined BP, TDG, and temperature data received averaged 96.3 percent for the 15 monitoring sites used in 2016 (nine seasonal and six year-round).
- The TDG data received from the individual sites ranged from 88.0 percent to 100.0 percent complete. Forty seven point five percent of the invalid/missing data was due to low TDG readings, primarily at the Peck (PEKI), Pasco (PAQW), Ice Harbor forebay (IHRA), Lower Granite tailwater (LGNW), and Little Goose tailwater (LGSW) stations. The second most frequent cause of missing information was data collection platform (DCP) failure at Dworshak (DWQI) that accounted for 44.5 percent of the total.
- The TDG sensors from the 15 seasonal and annual FMS stations were removed from the field and calibrated in the laboratory every three weeks between April 2016 and August 2016. From September 2015 through March 2016, the six annual FMS 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 -0.09 mmHg, -0.16 mmHg, and 0.06 °C, respectively. The sensor post-deployment check revealed mean ambient pressure, ambient pressure plus 100 mmHg, and temperature differences of 0.16 mmHg, -0.13 mmHg, and 0.04 °C, respectively.
- The median for the 157 *in-situ* field checks of TDG sensors with the replacement probes was -0.1 percent. Station median values ranged from -0.3 percent to 0.1 percent.
- The calculated median for the 158 field checks for barometric pressure was 0.00 mmHg, with station medians ranging from -0.10 to 0.10 mmHg.
- The calculated median for the water temperature field checks was -0.01 ºC. Station median values ranged from -0.08 ºC to 0.03 ºC.
- The Anatone (ANQW) deployment pipe was cleaned with compressed air to remove built-up sediment during April and had to be disassembled and rebuilt during August. The purpose of the repair was to replace a tangled deployment rope and re-anchor with larger weights.

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. Six of the stations (*i.e.*, the tailwater stations at McNary Dam, Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, Lower Granite Dam, and Dworshak Dam) are operated throughout the year (Figure G-1; Table G-1). The remaining nine stations record hourly data from 1 April through 31 August, and typically bracket that period.

Three water-quality 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. Greater than 110 percent TDG can cause gas bubble trauma in fish and adversely affect other aquatic organisms. The State of Washington rule adjustment allows the percent TDG to reach 115 percent in the forebays and 120 percent in the tailwaters when water is spilled for fish passage. The TDG criteria are not applicable when river discharge is greater than the 7Q10. Washington State TDG standards specify that the maximum TDG measurement cannot exceed 125 percent for one-hour. The State of Idaho TDG standard follows the USEPA upper limit of 110 percent. Two additional parameters that influence the percent TDG are barometric pressure (BP) and water temperature. As such, measurements for these two constituents are also recorded and stored in the database.

Measurements were completed hourly at all stations and transmitted via the Geostationary Operational Environmental Satellite Program (GOES) system to USACE and U.S. Geological Survey (USGS) databases. The Corps Water Management System (CWMS) database at the Northwestern Division (CENWD) office in Portland, Oregon can be accessed at http://www.nwd-wc.usace.army.mil/ftppub/water_quality/tdg/. The link to real-time USGS data for Washington is http://waterdata.usgs.gov/wa/nwis/current/?type =quality.

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 presented in the 2010/2014 Supplemental Biological Opinion RPA 15. An additional purpose of this report is to show that CENWW complied with the 2015-2018 TDG Monitoring Plan during 2016. 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 quality assurance/ quality control (QA/QC) data for the FMS stations at McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite reservoirs. Additionally, this data-collection system provided water quality information for; (a) the Clearwater River downstream of Dworshak Dam, at Peck, and Lewiston, (b) the Columbia River near Pasco, and (c) the Snake River near Anatone, Washington (Figure G-1; Table G-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® hand-held barometer that served as a portable field standard for barometric pressure. Fifteen 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.

3.0 METHODS

3.1 DATA COLLECTION

The instrumentation at each FMS station consisted of components provided by CENWW and the USGS Kennewick, Washington, office. A 12-volt battery charged by a solar panel powered each station. Forty-five Hydrolab® multi-parameter probes (*i.e.*, MS4A's and MS5's) were utilized. Thirty-six of these units were provided by CENWW and the remaining nine belong to the USGS.

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 Δ(BP) between Lab BP and the pressure measured by the sensor Sonde PT 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-1 hand held certified pressure calibrator, calibrated yearly at the factory (primary standard) and an Ashcroft 2089 digital test gauge, also calibrated yearly at the factory (primary standard), 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 a dry membrane in place.

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 two Oakton Acorn Temp 4 digital thermistors. Both of these instruments were checked quarterly against a National Institute of Standards and Technology (NIST) traceable Oakton Digital Temp-360 W lab thermistor.

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 Sutron® barometers were checked using a Novalynx® M2 Series 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 and/or USGS employees. Missing values and those that appeared to be outside the expected range were flagged. If a reasonable explanation (*e.g.*, routine maintenance, data collection platform [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 163 individual checks for barometric pressure (Table G-2). The evaluation of the pressure sensors to the standard revealed a calculated mean of -0.09 mmHg, and a range of -2.37 to 2.86 mmHg (Table G-2; Figure G-3). 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 barometer with 300 mmHg of pressure and the instrument was compared against the expected value. The sensor pressure differences ranged from -0.16 percent to 0.37 percent and the calculated mean and median values were both -0.02 percent (Figure G-4; Tables G-2 and G-3).

The dissimilarities between the NIST-traceable thermometer and the sensor thermistors were also quite small. The calculated average and median values for all the instruments were 0.06 ºC and 0.05 °C, respectively. These calculated values were based on 163 measurements where the minimum and maximum differences for individual sensors ranged from -0.11 °C to 0.38 °C

(Tables G-2 and G-3; Figure G-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 favorable results. A total of 151 data points were used for the evaluation. The differences between the laboratory barometric pressure and that recorded by the sensors ranged from -1.05 mmHg to 2.44 mmHg, with a mean of 0.16 mmHg (Tables G-2 and G-4; Figure G-3). The results of the post calibration checks using barometric pressure +100 mmHg showed a calculated mean of -0.02 percent, and a range of -0.14 to 0.41 percent (Table G-2; Figure G-4).

There were 151 post deployment checks available for temperature evaluation. Temperature post calibration checks resulted in a calculated mean and median of 0.04 °C with a range between -0.12 °C to 0.22 °C (Tables G-2 and G-4; Figure G-5).

4.2 System-wide Station QA/QC Performance

The analysis of the station QA/QC data showed that the in-place barometric air pressure, TDG pressure, and temperature instruments performed well when compared to the secondary standards (Figures G-6 through G-8). A total of 158 readings were used to calculate the mean and median values for barometric pressure (Table G-5). The median of all the differences between the station barometers and the secondary standards was 0.00 mmHg (Table G-5; Figure G-6). Median values for individual stations ranged from -0.1 to 0.1 mmHg (Table G-6). The published accuracy of the barometers is ±0.7 mmHg.

A total of 157 readings were used to calculate the mean and median values for TDG instrument pressure (Table G-5). The overall median for the percent TDG differences between the in-place and replacement sensors was -0.1 percent saturation (Table G-5; Figure G-7). Individual median station values ranged from -0.3 percent saturation to 0.1 percent saturation (Table G-6).

A total of 157 readings were used to calculate the temperature differences between the in-place and replacement sondes (Table G-5). The calculated mean and median temperature differentials for the field data were both -0.01 °C (Table G-5; Figure G-8). The median values for individual stations ranged from -0.08 to 0.03 ºC (Table G-6). 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 97.5, 99.4, and 99.4 percent, respectively (Table G-7). The most frequent reason attributed to missing or anomalous information in the real-time data set was low TDG pressure (1.74 percent of the combined station performance, which is equivalent to 47.5 percent of all missing and invalid data shown in the last column of Table G-8). The second leading cause of missing/anomalous data was DCP failure, accounting for 1.63 percent of the combined station performance or 44.5 percent of the 3,130 hours of affected data. Thirteen of the fifteen stations exceeded the required 95 percent criterion for data completeness for all parameters. The exceptions were the TDG data for Pasco (PAQW) and Peck (PEKI) which were 90.8 and 88.0

percent complete for TDG, respectively, as well as the barometric pressure, TDG, and temperature data for Dworshak (DWQI) which all came in at 94.6 percent (Table G-7).

4.3.1 Barometric Pressure

Barometric pressure data was 100 percent complete at eleven of the fifteen FMS stations (Table G-7). Three of the remaining four stations were greater than 99 percent complete. The Dworshak station (DWQI) had the lowest completeness at 94.6 percent. The primary difficulty at DWQI was DCP failure that accounted for 464 omitted hours (Tables G-8 and G-9).

4.3.2 Total Dissolved Gas

The TDG data from the fifteen stations averaged 97.5 percent complete (Table G-7). The Little Goose forebay (LGSA) station was 100 percent complete, followed very closely by Lower Monumental forebay (LMNA), McNary forebay (MCNA), Lower Monumental tailwater (LMNW), and Lewiston (LEWI). The three stations that experienced the greatest amount of data loss were Peck (PEKI), Pasco (PAQW), and Dworshak (DWQI) where the final data set statistics ranged from 88.0 percent to 94.6 percent complete (Table G-7). Data collection platform failure was the primary cause of missing data at DWQI while the low readings at PEKI were attributed to sediment accumulation in the deployment pipe (Table G-8 and G-10).

4.3.3 Temperature

The temperature data from the fifteen FMS stations averaged 99.4 percent complete. Seven stations (McNary forebay [MCNA], Lower Monumental forebay [LMNA], Little Goose tailwater [LGSW], Little Goose forebay (LGSA), Lower Granite tailwater [LGNW], Lewiston [LEWI], and Peck [PEKI]) attained 100 percent completeness (Table G-7). Seven of the remaining eight stations were all greater than 99 percent complete. Dworshak (DWQI) had the greatest amount of missing data at 471 hours – again due mainly to DCP failure (Table G-8 and G-11).

4.4 Deployment Pipe Clean-Out

Sediment build-up occurred in the deployment pipes at Anatone, Lewiston, and Peck that resulted in low TDG measurements and/or difficulty retrieving the sonde. The Anatone and Lewiston stations were purged with compressed air on 11 April 2016, followed by Peck on 12 April.

4.5 Anatone Deployment Pipe Repair

The Anatone deployment pipe on the Snake River was again rebuilt during the 2016 water year. Following the pipe cleanout on 11 April, it was still difficult to remove and re-deploy the sonde. During the next scheduled maintenance on 27 April the sonde could not be removed from the pipe. A pipe camera was brought on-site the following month and the examination revealed that the deployment rope was tangled. A length of PEX tubing was subsequently used to install and retrieve the sonde until the flows in the Snake River diminished to the point where it was safe to operate a boat to complete the repair. River discharge was consistently less than 20 kcfs by the latter part of July, and the repair was scheduled to occur between 17-19 August. The pipe was

disassembled so the tangled rope could be removed, and the pipe was repositioned with new anchors and rope.

5.0 SUMMARY

Hourly TDG, temperature, and barometric pressure data recorded during the 2016 water year at fifteen FMS stations were evaluated. Six tailwater sites were maintained throughout the year and nine additional locations were added for the 1 April through 31 August fish spill season. The combined data from all stations exceeded the 95 percent criterion.

The USGS Kennewick field office performed routine station maintenance, completed emergency repairs, operated the DCPs, and assisted with deployment pipe repairs under a cooperative agreement with Walla Walla District. 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 TDG values and DCP malfunctions, followed by defective sondes and membranes.

The pre-deployment QA/QC checks showed a mean difference of -0.09 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 0.16 mmHg and -0.02 percent when the TDG sensors were compared to barometric pressure and barometric pressure plus 100 mmHg, respectively. The calculated mean temperature difference was 0.06 °C for pre-deployment and 0.04 °C for post-calibration.

The 46 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 -0.02 mmHg, -0.2 percent, and -0.01 °C, respectively.

The Anatone deployment pipe was again repaired during August 2016. The problem was a tangled retrieval rope inside the pipe.

FIGURES

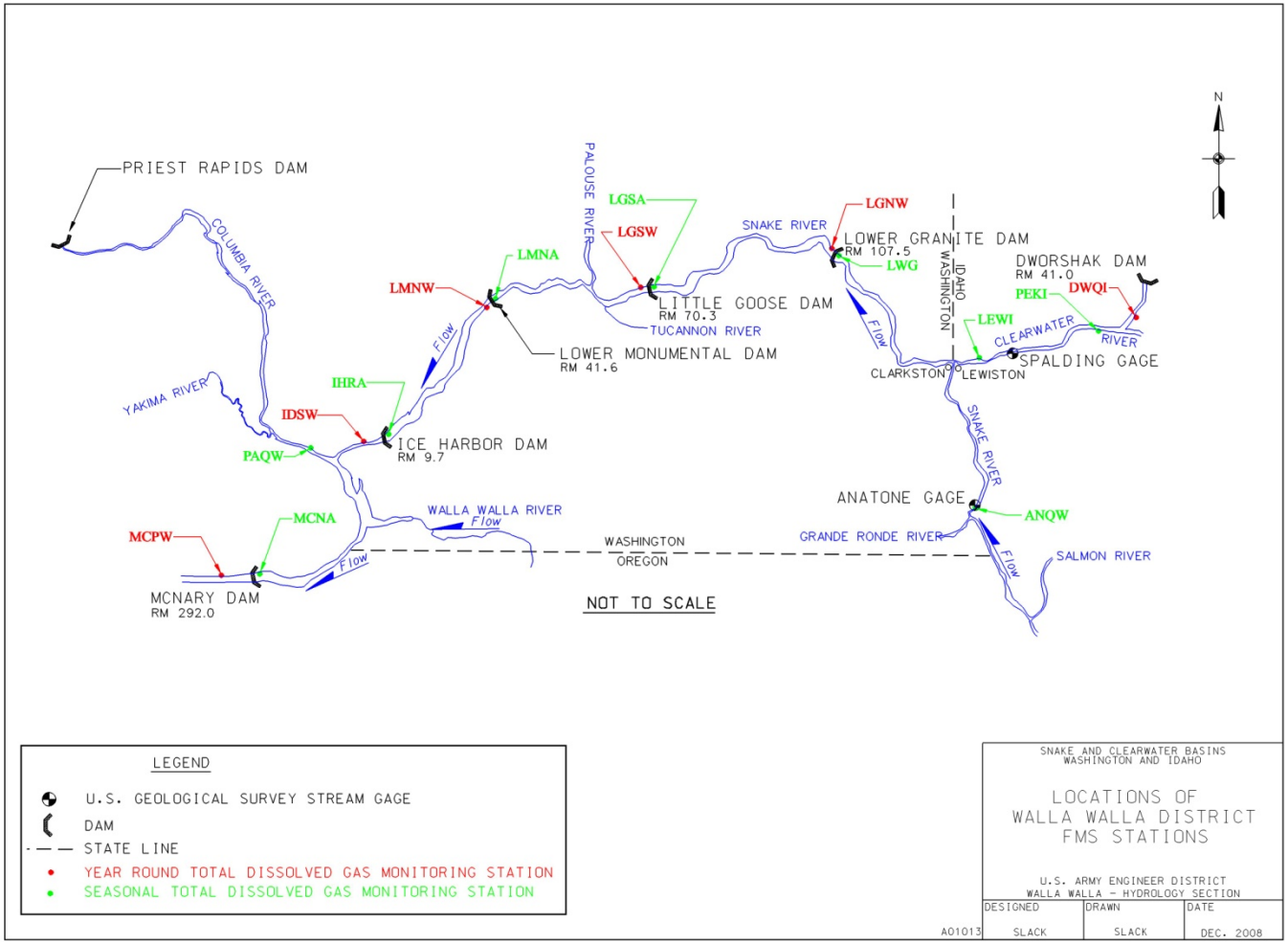

Figure G-1. Locations of Walla Walla District's FMS stations.

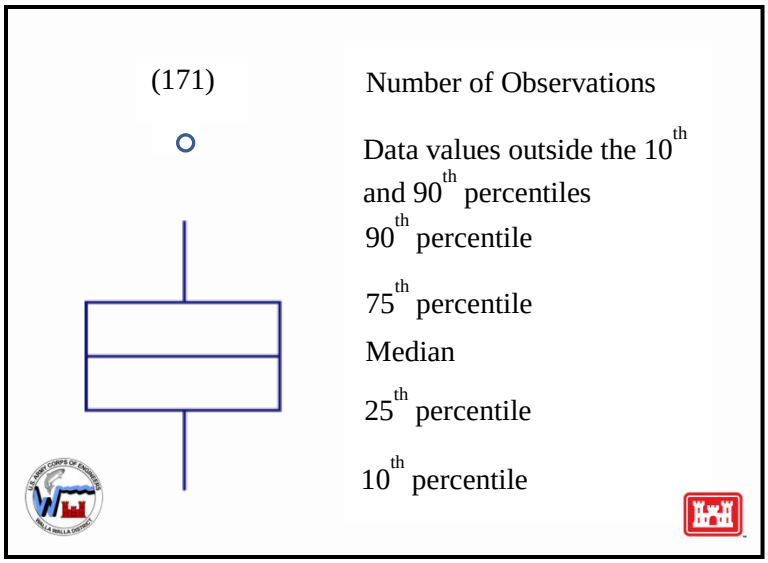

Figure G-2. Explanation key for the box plot information.

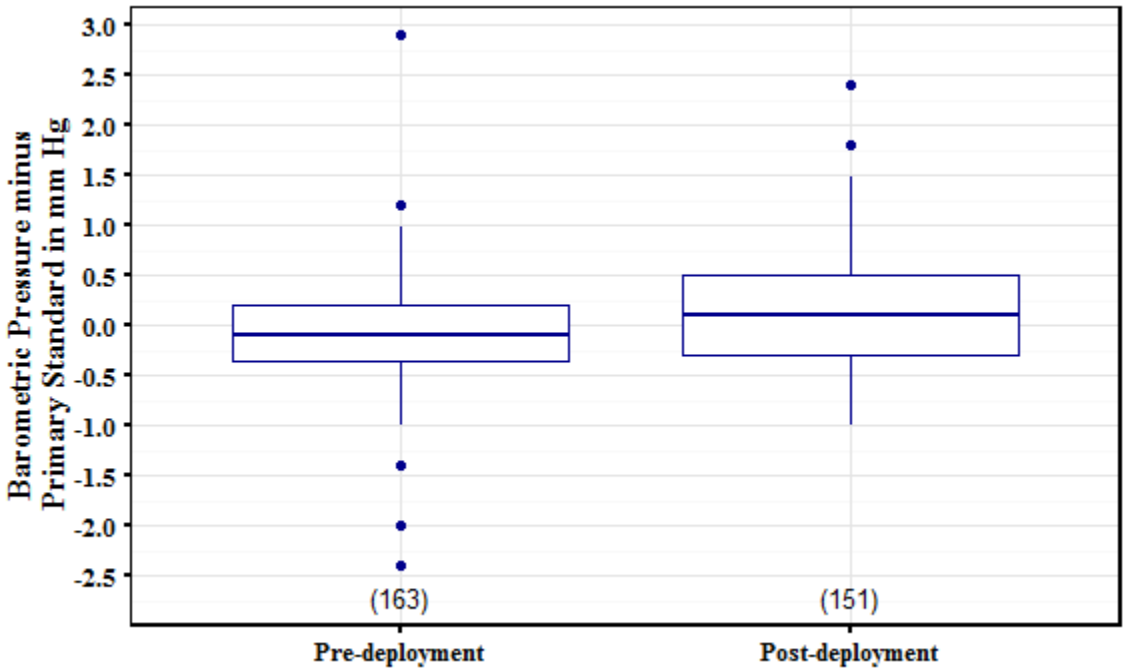

Figure G-3. Summary box plots of the pre-and post-deployment check of the barometric pressure versus the primary standard during the 2016 monitoring season.

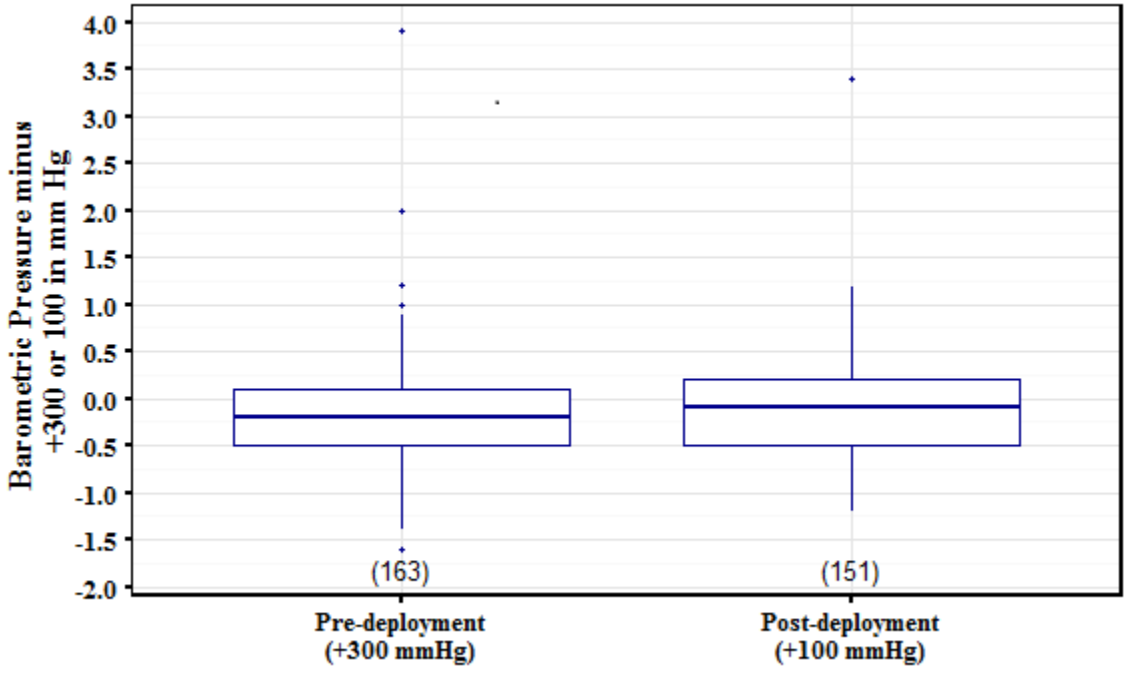

Figure G-4. Summary box plots of the pre-and post-deployment check of the Hydrolab® TDG sensors with the addition of 100 and 300 mmHg during the 2016 monitoring season.

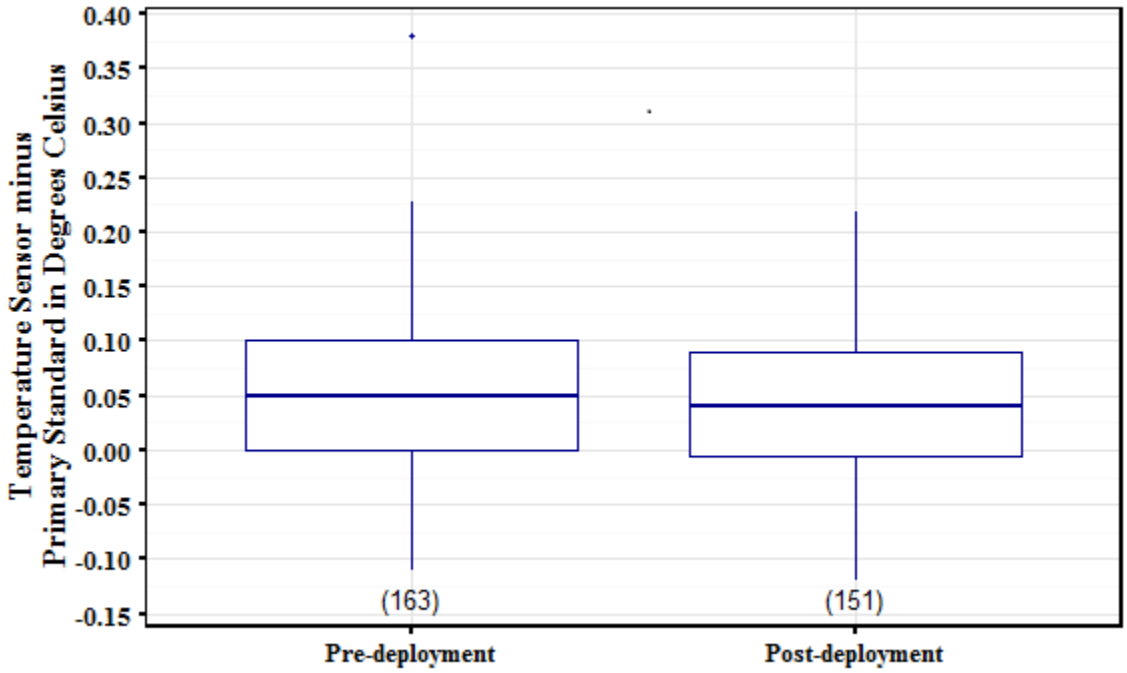

Figure G-5. Summary box plots of the pre- and post-deployment check of the Hydrolab® temperature sensors during the 2016 monitoring season.

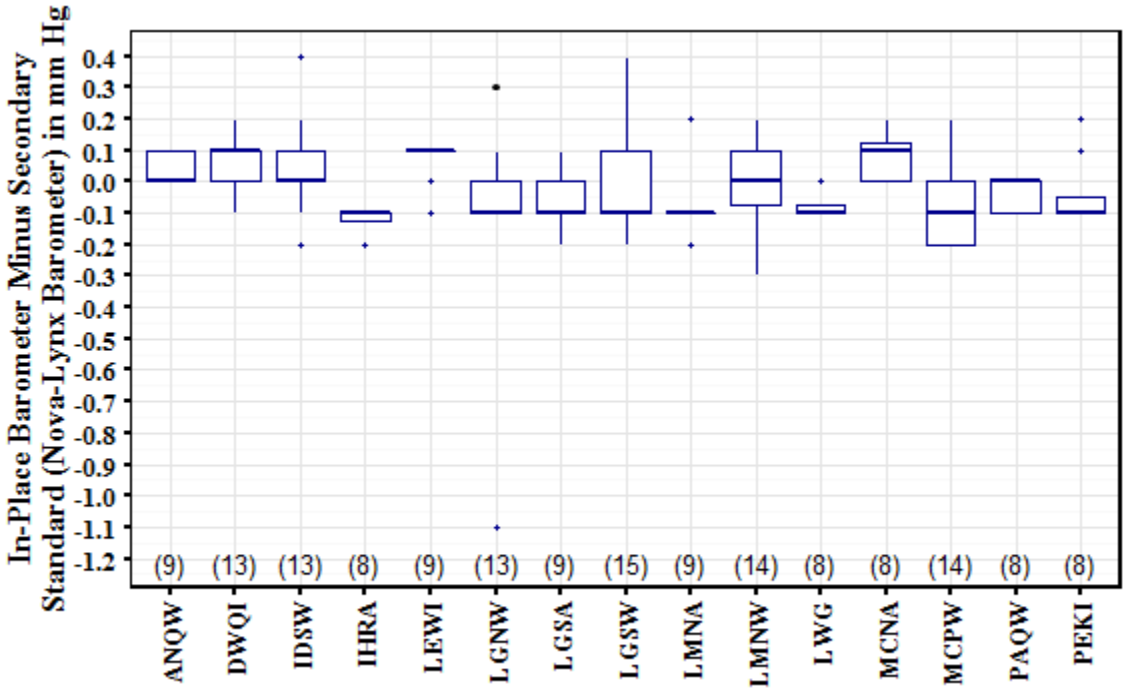

Figure G-6. Box plots of the field barometric pressure sensors check in mmHg by site during the 2016 monitoring season.

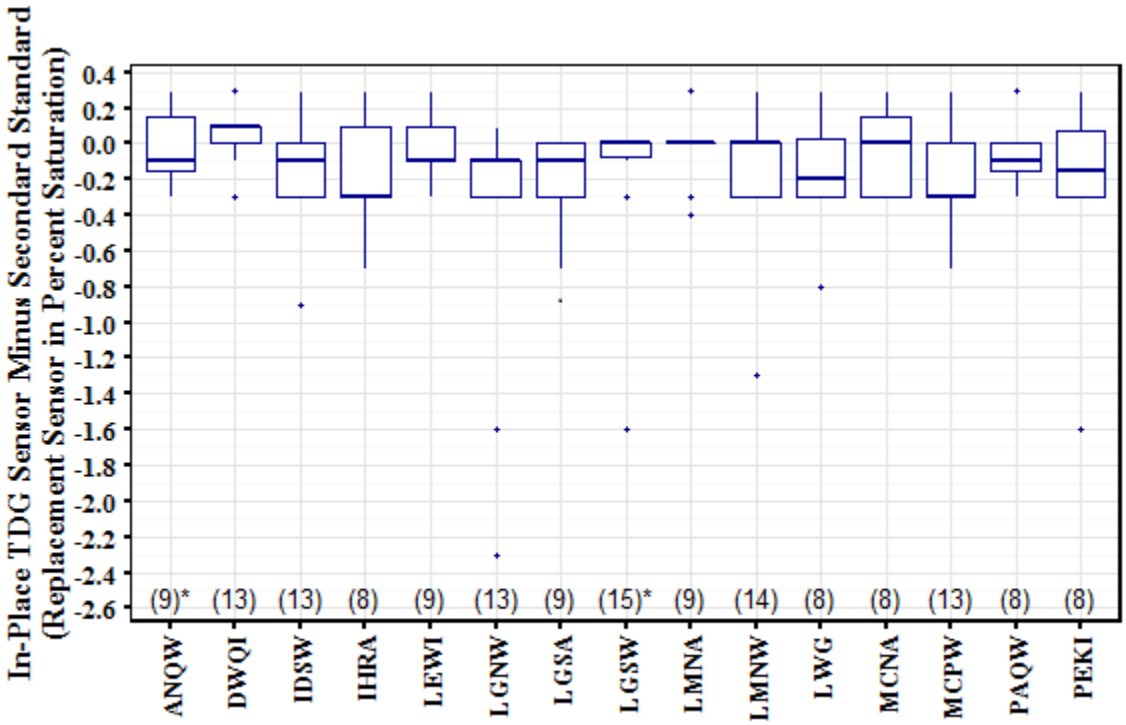

Figure G-7. Box plots of the field total dissolved gas sensor check verses secondary standard in percent saturation by site during the 2016 monitoring season.

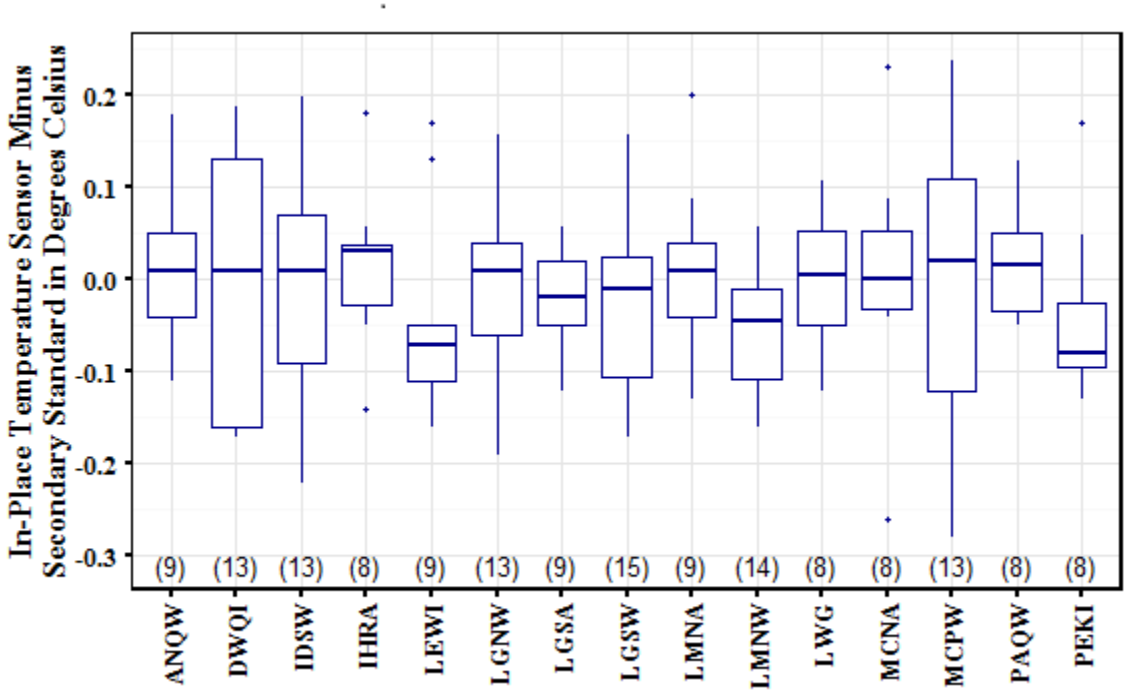

Figure G-8. Box plots of the field temperature sensors check verses secondary standard in degrees Celsius by site during the 2016 monitoring season.

TABLES

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

Station Number	Station Name	Station ID	Latitude (NAD 83)	Longitude (NAD 83)	Elevation (NGVD 29)	River Mile	DCP ID	XMIT Time
12514400	Columbia River at Pasco, WA	PAQW	46 13 26.2851 N	119 06 57.3388 W	345	329.1	17D6E32C	0:27:10
13334300	Snake River Near Anatone, WA	ANQW	46 05 50.7579 N	116 58 41.2382 W	807	167.5	17D63544	0:16:10
13341000	N.F. Clearwater River at Dworshak Hatchery, ID	DWQI	46 30 11.6464 N	116 19 16.4090 W	1,150	0.5	17D600DE	0:13:10
13341050	Clearwater River Near Peck, ID	PEKI	46 30 00.9396 N	116 23 32.4163 W	930	37.4	17D613A8	0:14:10
13343000	Clearwater River Near Lewiston, ID	LEWI	46 25 52.0867 N	116 56 43.9589 W	750	5.0	17D62632	0:15:10
13343590	Lower Granite Dam Forebay, WA	LWG	46 39 34.1727 N	117 25 34.8564 W	738	107.5	17D643D4	0:17:10
13343595	Lower Granite Dam Tailwater, WA	LGNW	46 39 58.0726 N	117 26 19.2595 W	645	106.7	17D650A2	0:18:10
13343855	Little Goose Dam Forebay, WA	LGSA	46 34 58.3188 N	118 01 32.9831 W	638	70.3	17D66538	0:19:10
13343860	Little Goose Dam Tailwater, WA	LGSW	46 35 00.5280 N	118 02 37.4186 W	560	69.6	17D6764E	0:20:10
13352595	Lower Monumental Dam Forebay, WA	LMNA	46 33 44.6559 N	118 32 08.3477 W	540	41.6	17D686CA	0:21:10
13352600	Lower Monumental Dam Tailwater, WA	LMNW	46 33 04.5051 N	118 32 58.9500 W	445	40.4	17D695BC	0:22:10
13352950	Ice Harbor Dam Forebay, WA	IHRA	46 15 05.2792 N	118 52 43.0096 W	440	10.0	17D6A026	0:23:10
13353010	Ice Harbor Dam Tailwater, WA	IDSW	46 14 27.5868 N	118 57 13.7130 W	340	6.1	17D6B350	0:24:10
14019220	McNary Dam Forebay, WA	MCNA	45 56 28.9200 N	119 17 35.4400 W	340	292.0	17D6D6B6	0:26:10
14019240	McNary Dam Tailwater, WA	MCPW	45 56 02.7775 N	119 19 35.4628 W	240	290.7	17D5F754	0:12:10

Table G-2. Summary of the laboratory results evaluating the overall differences between laboratory standards and the sensors pre- and post-deployment during the 2016 water year.

Deployment	Statistic	Δ (BP) (mmHg)	Δ (BP) (%)	Δ (BP+300) (mmHg)	Δ (BP+300) (%)	Δ (BP+100) (mmHg)	Δ (BP+100) (%)	Δ T (ºC)
Pre	Number	163	163	163	163	----	----	163
	Minimum	-2.37	-0.32	-1.64	-0.16	----	----	-0.11
	25 Percentile	-0.35	-0.05	-0.46	-0.04	----	----	0.00
	Median	-0.12	-0.02	-0.17	-0.02	----	----	0.05
	75 Percentile	0.16	0.02	0.13	0.01	----	----	0.10
	Maximum	2.86	0.38	3.86	0.37	----	----	0.38
	Mean	-0.09	-0.01	-0.16	-0.02	----	----	0.06
Post	Number	151	151	----	----	151	151	151
	Minimum	-1.05	-0.14	----	----	-1.21	-0.14	-0.12
	25 Percentile	-0.26	-0.03	----	----	-0.50	-0.06	0.00
	Median	0.06	0.01	----	----	-0.10	-0.01	0.04
	75 Percentile	0.47	0.06	----	----	0.21	0.02	0.09
	Maximum	2.44	0.33	----	----	3.44	0.41	0.22
	Mean	0.16	0.02	----	----	-0.13	-0.02	0.04

Table G-3. Pre-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2016 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 (ºC)	Median (ºC)
1b	3	-0.5 to 1.2	0.33	3	-0.5 to 1.2	-0.33	3	0.10 to 0.19	0.13
13b	4	-0.1 to 0.5	-0.05	4	-0.1 to 0.9	0.25	4	0.07 to 0.20	0.08
26	5	-0.3 to 0.4	0.00	5	-0.2 to 0.8	0.10	5	-0.01 to 0.18	0.12
27	6	-2.0 to 0.3	-0.27	6	-1.4 to 0.3	-0.27	6	0.00 to 0.18	0.10
29	5	-0.3 to 0.5	-0.02	5	-0.3 to 0.5	-0.02	5	-0.04 to 0.11	0.04
32	5	-0.5 to -0.1	-0.28	5	-0.5 to -0.1	-0.28	5	0.03 to 0.16	0.10
33	4	-0.6 to 0.2	-0.16	4	-1.3 to 0.2	-0.29	4	0.00 to 0.09	0.04
34	4	-0.4 to 0.5	-0.10	4	-0.4 to 0.5	-0.10	4	0.00 to 0.15	0.07
35	4	-0.5 to 0.3	-0.05	4	-0.5 to 0.3	-0.05	4	0.01 to 0.10	0.03
36	5	-0.4 to 0.4	0.13	5	-0.4 to 0.3	0.13	5	0.02 to 0.10	0.05
37	5	-0.3 to 0.2	-0.18	5	-0.3 to 0.2	-0.18	5	-0.03 to 0.08	-0.01
39	5	-0.8 to 0.1	-0.35	5	-0.8 to 0.1	-0.35	5	0.00 to 0.11	0.05
40	6	-1.0 to 0.7	-0.11	6	-1.0 to 0.2	-0.21	6	0.00 to 0.13	0.04
41	4	0.0 to 1.0	0.25	4	-0.7 to 0.2	-0.03	4	-0.03 to 0.12	0.03
42	2	-0.9 to -0.4	-0.69	2	-1.4 to -0.9	-1.18	2	0.01 to 0.02	0.01
43	3	-0.5 to 0.3	0.09	3	-0.5 to 0.3	0.09	3	-0.07 to -0.03	-0.05
44	2	-0.7 to 0.0	-0.33	2	-0.7 to 0.0	-0.33	2	0.02 to 0.23	0.12
45	4	-2.4 to 0.1	-0.17	4	-0.4 to 0.1	-0.17	4	-0.03 to 0.18	0.10
47	2	-0.5 to -0.2	-0.39	2	-0.5 to -0.2	-0.39	2	0.10 to 0.16	0.13
48	3	-0.2 to 0.1	-0.16	3	-0.2 to 0.1	-0.16	3	0.05 to 0.18	0.06
49	3	-0.6 to 0.4	-0.26	3	-1.3 to 0.3	-0.58	3	0.07 to 0.18	0.12
50	2	-0.5 to 0.8	0.11	2	-0.5 to -0.2	-0.39	2	0.06 to 0.14	0.10
51	3	-0.6 to -0.2	-0.42	3	-1.6 to -1.2	-1.42	3	0.02 to 0.14	0.09
52	4	-0.7 to 0.3	-0.14	4	-0.7 to 0.3	-0.14	4	0.08 to 0.17	0.10
53	1	-0.3 to -0.3	-0.28	1	-1.3 to -1.3	-1.28	1	0.03 to 0.03	0.03
54	2	-0.5 to 0.5	0.00	2	-0.5 to -0.5	-0.50	2	0.02 to 0.09	0.05
55	4	-0.2 to 0.2	-0.09	4	-1.2 to 0.2	-0.59	4	0.01 to 0.13	0.05
57	2	0.1 to 0.1	0.11	2	-0.9 to 0.1	-0.39	2	0.08 to 0.10	0.09
58	2	-0.2 to 2.9	1.35	2	-0.2 to 3.9	1.85	2	0.10 to 0.19	0.15
60	1	-0.1 to -0.1	-0.14	1	-0.1 to -0.1	-0.14	1	-0.01 to -0.01	-0.01
61	4	-0.6 to 0.3	-0.35	4	-0.6 to 0.3	0.35	4	0.01 to 0.15	0.08
32434	4	-0.9 to 0.2	-0.37	4	-0.9 to 0.2	-0.37	4	-0.11 to 0.38	0.01
32435	4	-0.2 to 0.0	-0.09	4	-1.2 to 2.0	-0.10	4	-0.10 to 0.08	0.04
32444	4	-0.4 to 0.4	0.11	4	-0.6 to 0.4	-0.29	4	-0.04 to 0.17	-0.02
35131	4	-0.4 to 0.2	0.01	4	-0.9 to 0.2	-0.23	4	-0.03 to 0.08	0.01
36902	2	0.2 to 1.0	0.58	2	-0.8 to 1.0	0.09	2	0.10 to 0.19	0.15
38110	2	0.2 to 1.0	0.58	2	0.2 to 1.0	0.59	2	-0.07 to 0.00	-0.04

Table G-3. Pre-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2016 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 (ºC)**	**Median (ºC)**
USGS 1	2	0.2 to 0.3	0.26	2	0.2 to 0.3	0.26	2	0.03 to 0.03	0.03
USGS 2	5	-0.1 to 0.8	0.14	5	-0.7 to 0.1	-0.12	5	-0.10 to 0.08	-0.07
USGS 3	7	-0.8 to 0.9	0.04	7	-0.3 to 0.9	0.04	7	-0.02 to 0.11	0.03
USGS 4	6	-0.5 to 0.2	-0.17	6	-0.5 to 0.8	-0.11	6	-0.08 to 0.14	0.09
USGS 5	5	-0.6 to 0.9	0.01	5	-1.0 to 0.0	-0.12	5	-0.04 to 0.12	0.07
USGS 6	3	-0.8 to 0.0	-0.48	3	-0.5 to 0.2	0.01	3	-0.08 to -0.02	-0.03
USGS 7	2	-0.8 to -0.4	-0.63	2	-0.8 to -0.4	-0.63	2	-0.05 to -0.04	-0.04
USGS 8	2	-0.7 to -0.5	-0.59	2	-0.5 to 0.3	-0.09	2	-0.03 to 0.00	-0.02
USGS 9	2	-0.4 to -0.4	-0.40	2	-0.4 to 0.6	0.10	2	-0.07 to -0.06	-0.07

Table G-4. Post-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2016 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 (ºC)	Median (ºC)
1b	2	0.0 to 1.5	0.75	2	0.0 to 0.5	0.25	2	-0.01 to 0.13	0.06
13b	4	0.0 to 0.7	0.27	4	-1.0 to 0.7	0.27	4	0.00 to 0.17	0.05
26	5	-0.3 to 1.2	0.39	5	-0.7 to 0.4	-0.20	5	0.05 to 0.21	0.10
27	5	-0.6 to 0.3	0.00	5	-0.9 to 0.3	-0.20	5	0.03 to 0.19	0.07
29	3	0.2 to 1.4	1.33	3	0.2 to 0.4	0.33	3	-0.01 to 0.12	0.06
32	5	-0.3 to 0.5	0.37	5	-0.3 to 0.5	0.37	5	-0.08 to 0.20	0.08
33	4	-0.5 to 0.3	-0.06	4	-0.5 to 0.3	-0.06	4	-0.02 to 0.15	0.07
34	5	-0.1 to 0.7	0.59	5	-1.1 to 0.6	-0.34	5	0.03 to 0.20	0.08
35	5	-0.4 to 0.2	0.04	5	-1.0 to 0.0	-0.41	5	-0.01 to 0.11	0.01
36	5	-0.3 to 1.8	0.66	5	-0.3 to 0.7	-0.18	5	0.00 to 0.11	0.04
37	4	-0.2 to 0.7	0.12	4	-0.9 to 0.7	-0.05	4	-0.03 to 0.03	-0.01
39	4	-0.5 to 1.8	0.14	4	-0.5 to 0.3	-0.12	4	0.06 to 0.10	0.06
40	6	-0.4 to 0.5	-0.24	6	-1.2 to 0.0	-0.36	6	-0.01 to 0.22	0.12
41	4	0.0 to 0.9	0.41	4	-1.0 to 0.5	0.10	4	-0.04 to 0.11	0.02
42	2	-0.5 to -0.1	-0.31	2	-0.5 to -0.1	-0.31	2	-0.02 to 0.00	-0.01
43	3	-0.6 to 0.3	-0.38	3	-0.8 to -0.4	-0.57	3	-0.09 to 0.01	0.00
44	3	-0.7 to -0.1	-0.33	3	-1.1 to -0.3	-0.73	3	0.05 to 0.17	0.06
45	3	-0.5 to 0.7	-0.50	3	-0.5 to 0.7	-0.50	3	0.02 to 0.11	0.04
47	1	-0.3 to -0.3	-0.34	1	-0.3 to -0.3	-0.34	1	0.16 to 0.16	0.16
48	4	0.1 to 0.6	0.19	4	-0.8 to 0.2	-0.18	4	0.00 to 0.19	0.07
49	2	-1.0 to -0.2	-0.63	2	-1.2 to -1.0	-1.13	2	0.06 to 0.16	0.11
50	2	0.0 to 0.0	0.00	2	0.0 to 0.0	0.00	2	0.04 to 0.09	0.07
51	2	-0.5 to -0.5	-0.50	2	-0.5 to -0.5	-0.50	2	-0.02 to 0.08	0.03
52	3	-0.4 to 0.3	-0.05	3	-0.4 to 0.3	-0.05	3	0.07 to 0.09	0.08
53	1	0.0 to 0.0	0.00	1	0.0 to 0.0	0.00	1	0.02 to 0.02	0.02
54	2	-0.2 to 1.1	0.47	2	-1.2 to 0.1	-0.53	2	0.04 to 0.07	0.05
55	3	-0.6 to -0.2	-0.61	3	-0.2 to 0.4	0.37	3	0.02 to 0.05	0.04
57	2	0.9 to 1.1	1.01	2	-0.9 to -0.1	-0.49	2	0.06 to 0.07	0.07
58	2	1.0 to 2.4	1.72	2	1.0 to 3.4	2.22	2	0.02 to 0.10	0.06
60	2	-0.7 to 0.0	-0.33	2	-0.7 to 0.0	-0.33	2	0.01 to 0.03	0.02
61	3	-0.6 to 0.1	-0.52	3	-0.6 to 0.1	-0.52	3	0.00 to 0.07	0.06
32434	4	-0.7 to 0.1	-0.28	4	-1.2 to -0.4	-0.79	4	-0.09 to 0.09	-0.06
32435	4	0.0 to 0.9	0.21	4	-0.1 to 0.3	0.07	4	-0.12 to 0.09	-0.02
32444	3	0.4 to 1.0	0.64	3	0.0 to 0.6	0.37	3	-0.07 to 0.10	-0.02
35131	4	0.0 to 0.9	0.40	4	-0.2 to 0.9	-0.01	4	-0.03 to 0.09	0.02
36902	2	-0.1 to 1.0	0.45	2	-0.1 to 0.0	-0.05	2	0.07 to 0.11	0.09
38110	1	0.9 to 0.9	0.90	1	-0.1 to -0.1	-0.10	1	-0.07 to -0.07	-0.07

Table G-4. Post-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2016 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 (ºC)**	**Median (ºC)**
USGS 1	2	0.4 to 0.5	0.44	2	-0.5 to 0.4	-0.06	2	-0.02 to 0.03	0.01
USGS 2	4	0.0 to 0.5	0.13	4	-0.7 to 0.5	0.00	4	-0.09 to 0.01	-0.05
USGS 3	6	-0.2 to 1.2	0.21	6	-0.9 to 1.2	0.05	6	0.00 to 0.13	0.02
USGS 4	4	-0.7 to 0.2	-0.22	4	-0.7 to 0.2	-0.22	4	0.06 to 0.17	0.09
USGS 5	5	-0.3 to 0.4	0.33	5	-0.6 to 0.4	0.31	5	-0.03 to 0.14	0.07
USGS 6	3	-0.8 to 0.2	-0.69	3	-0.7 to 0.3	0.19	3	-0.09 to -0.08	-0.09
USGS 7	3	-0.6 to 0.0	-0.59	3	-0.6 to 0.0	-0.59	3	-0.07 to -0.04	-0.06
USGS 8	2	0.0 to 0.6	0.30	2	-0.4 to 0.0	-0.20	2	-0.04 to -0.04	-0.04
USGS 9	3	-0.5 to 0.6	0.40	3	-0.5 to 0.4	-0.35	3	-0.04 to 0.02	-0.02

Table G-5. Summary of the field results for the differences between the in-place and replacement sensors during 2016 water year.

Statistic	Δ BP (mmHg)	ΔTDG (% sat)	Δ T (°C)
Number	158	157	157
Minimum	-1.10	-7.1	-0.28
Maximum	0.40	0.3	0.24
Mean	-0.02	-0.2	-0.01
Median	0.00	-0.1	-0.01

Table G-6. Summary of the field results for the differences between the in-place and replacement sensors by station during 2016 water year.

	Δ Barometric Air Pressure			Δ Total Dissolved Gas					Δ Water Temperature		
Station ID	**# Obs**	**Range (mmHg)**	**Median (mmHg)**	**# Obs**	**Range (mmHg)**	**Median (mmHg)**	**Range (% Sat)**	**Median (% Sat)**	**# Obs**	**Range (ºC)**	**Median (ºC)**
MCPW	14	-0.2 to 0.2	-0.10	13	-5 to 2	-2.0	-0.7 to 0.3	-0.3	13	-0.28 to 0.24	0.02
MCNA	8	0.0 to 0.2	0.10	8	-2 to 2	0.0	-0.3 to 0.3	0.0	8	-0.26 to 0.23	0.00
PAQW	8	-0.1 to 0.0	0.00	8	-2 to 2	-1.0	-0.3 to 0.3	-0.1	8	-0.05 to 0.13	0.01
IDSW	13	-0.2 to 0.4	0.00	13	-7 to 2	-1.0	-0.9 to 0.3	-0.1	13	-0.22 to 0.20	0.01
IHRA	8	-0.2 to -0.1	-0.10	8	-5 to 2	-2.0	-0.7 to 0.3	-0.3	8	-0.14 to 0.18	0.03
LMNW	14	-0.3 to 0.2	0.00	14	-10 to 2	0.0	-1.3 to 0.3	0.0	14	-0.16 to 0.06	-0.04
LMNA	9	-0.2 to 0.2	-0.10	9	-3 to 2	0.0	-0.4 to 0.3	0.0	9	-0.13 to 0.20	0.01
LGSW	15	-0.2 to 0.4	-0.10	15	-53 to 0	0.0	-7.1 to 0.0	0.0	15	-0.17 to 0.16	-0.01
LGSA	9	-0.2 to 0.1	-0.10	9	-5 to 0	-1.0	-0.7 to 0.0	-0.1	9	-0.12 to 0.06	-0.02
LGNW	13	-1.1 to 0.1	-0.10	13	-17 to 1	-1.0	-2.3 to 0.1	-0.1	13	-0.19 to 0.16	0.01
LWG	8	-0.1 to 0.0	-0.10	8	-6 to 2	-1.5	-0.8 to 0.3	-0.2	8	-0.12 to 0.11	0.00
ANQW	9	0.0 to 0.1	0.00	9	-37 to 2	-1.0	-5.0 to 0.3	-0.1	9	-0.11 to 0.18	0.01
LEWI	9	-0.1 to 0.1	0.10	9	-2 to 2	-1.0	-0.3 to 0.3	-0.1	9	-0.16 to 0.17	-0.07
PEKI	8	-0.1 to 0.2	-0.10	8	-12 to 2	-1.0	-1.6 to 0.3	-0.1	8	-0.13 to 0.17	-0.08
DWQI	13	-0.1 to 0.2	0.10	13	-2 to 2	1.0	-0.3 to 0.3	0.1	13	-0.17 to 0.19	0.01

Table G-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 2016 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	0	100.0	**69**	**99.2**	**3**	**100.0***
MCNA	1 Apr – 31 Aug	0	100.0	**2**	**99.9**	0	100.0
PAQW	1 Apr – 31 Aug	0	100.0	**338**	**90.8**	**1**	**100.0***
IDSW	1 Oct – 30 Sep	0	100.0	**73**	**99.2**	**1**	**100.0***
IHRA	1 Apr – 31 Aug	0	100.0	**174**	**95.3**	**3**	**99.9**
LMNW	1 Oct – 30 Sep	**3**	**100.0***	**15**	**99.8**	**3**	**100.0***
LMNA	1 Apr – 31 Aug	0	100.0	**1**	**100.0***	0	100.0
LGSW	1 Oct – 30 Sep	0	100.0	**246**	**97.2**	0	100.0
LGSA	1 Apr – 31 Aug	0	100.0	0	100.0	0	100.0
LGNW	1 Oct – 30 Sep	**1**	**100.0***	**169**	**98.1**	0	100.0
LWG	1 Apr – 31 Aug	**1**	**100.0***	**36**	**99.0**	**3**	**99.9**
ANQW	1 Apr – 31 Aug	0	100.0	**112**	**97.0**	**3**	**99.9**
LEWI	1 Apr – 31 Aug	0	100.0	**21**	**99.4**	0	100.0
PEKI	1 Apr – 31 Aug	0	100.0	**441**	**88.0**	0	100.0
DWQI	1 Oct – 30 Sep	**471**	**94.6**	**470**	**94.6**	**471**	**94.6**

Notes:

* Denotes value that was rounded up to 100 percent

Bold font highlight cases where there were one or more anomalous/missing values

Table G-8. Summary of the total hours of barometric pressure, total dissolved gas, and temperature data that were missing or considered invalid in the 2016 water year.

	BP		TDG		BP+TDG			Temperature		All	
Reason	**hours**	**%**	**hours**	**%**	**hours**	**% of hours**	**% of bad data**	**hours**	**%**	**hours**	**%**
Too Low	0		1,486	1.74	1,486	1.74	56.25	0		1,486	1.74
Missed transmit	0		0		0			0		0	
Missing data	5	0.01	4	0.01	9	0.01	0.36	4	0.00	14	0.02
Spike	0		0		0			0		0	
Inspection	7	0.01	21	0.02	39	0.05	1.48	16	0.02	44	0.05
Defective membrane	0		89	0.10	89	0.10	3.37	0		89	0.10
Defective sonde	0		99	0.12	99	0.12	3.74	0		99	0.12
DCP failure	464	0.54	464	0.54	928	1.08	35.12	464	0.54	1,392	1.63
Cable failure	0		3	0.00	3	0.00	0.10	3	0.00	5	0.01
Totals	**476**	**0.56**	**2,166**	**2.53**	**2,642**	**3.09**	**100.00**	**488**	**0.57**	**3,130**	**3.66**

Table G-9. Number and percent of all missing or invalid barometric pressure data for each FMS station during the 2016 water year, along with the reasons for those designations.

Station ID	Too Low		Missed Transmit		Missing DCP Data		Spike		Inspection		Defective Membrane		Defective Sonde		DCP Failure		Cable Failure	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
MCPW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MCNA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PAQW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IDSW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IHRA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LMNW	-	-	-	-	-	-	-	-	3	0.03	-	-	-	-	-	-	-	-
LMNA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGSW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGSA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGNW	-	-	-	-	1	0.01	-	-	-	-	-	-	-	-	-	-	-	-
LWG	-	-	-	-	-	-	-	-	1	0.03	-	-	-	-	-	-	-	-
ANQW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LEWI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PEKI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DWQI	-	-	-	-	4	0.05	-	-	3	0.03	-	-	-	-	464	5.30	-	-

Table G-10. Number and percent of all missing or invalid total dissolved gas data for each FMS station during the 2016 water year, along with the reasons for those designations.

Station ID	Too Low		Missed Transmit		Missing DCP Data		Spike		Inspection		Defective Membrane		Defective Sonde		DCP Failure		Cable Failure	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
MCPW	-	-	-	-	-	-	-	-	3	0.03	66	0.75	-	-	-	-	-	-
MCNA	-	-	-	-	-	-	-	-	2	0.05	-	-	-	-	-	-	-	-
PAQW	320	8.71	-	-	1	0.03	-	-	1	0.03	16	0.44	-	-	-	-	-	-
IDSW	71	0.81	-	-	1	0.01	-	-	1	0.01	-	-	-	-	-	-	-	-
IHRA	173	4.71	-	-	-	-	-	-	1	0.03	-	-	-	-	-	-	-	-
LMNW	11	0.13	-	-	-	-	-	-	4	0.05	-	-	-	-	-	-	-	-
LMNA	-	-	-	-	-	-	-	-	1	0.03	-	-	-	-	-	-	-	-
LGSW	167	1.90	-	-	-	-	-	-	1	0.01	-	-	78	0.89	-	-	-	-
LGSA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGNW	169	1.93	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LWG	33	0.90	-	-	-	-	-	-	3	0.08	-	-	-	-	-	-	-	-
ANQW	109	2.97	-	-	-	-	-	-	3	0.08	-	-	-	-	-	-	-	-
LEWI	-	-	-	-	-	-	-	-	-	-	-	-	21	0.57	-	-	-	-
PEKI	434	11.81	-	-	-	-	-	-	-	-	7	0.19	-	-	-	-	-	-
DWQI	-	-	-	-	2	0.03	-	-	1	0.01	-	-	-	-	464	5.30	3	0.03

Table G-11. Number and percent of all missing or invalid temperature data for each FMS station during the 2016 water year, along with the reasons for those designations.

Station ID	Too Low		Missed Transmit		Missing DCP Data		Spike		Inspection		Defective Membrane		Defective Sonde		DCP Failure		Cable Failure	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
MCPW	-	-	-	-	-	-	-	-	3	0.03	-	-	-	-	-	-	-	-
MCNA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PAQW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IDSW	-	-	-	-	1	0.01	-	-	-	-	-	-	-	-	-	-	-	-
IHRA	-	-	-	-	-	-	-	-	3	0.08	-	-	-	-	-	-	-	-
LMNW	-	-	-	-	-	-	-	-	3	0.03	-	-	-	-	-	-	-	-
LMNA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGSW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGSA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGNW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LWG	-	-	-	-	-	-	-	-	3	0.08	-	-	-	-	-	-	-	-
ANQW	-	-	-	-	-	-	-	-	3	0.08	-	-	-	-	-	-	-	-
LEWI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PEKI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DWQI	-	-	-	-	3	0.04	-	-	1	0.01	-	-	-	-	464	5.30	3	0.03