Appendix F

2020 Walla Walla District TDG Report

USACE Walla Walla District QA/QC Evaluation of the 2020 Water-Year 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 2020 Water-Year FMS TDG Monitoring Data

Prepared by:
Hydrology Section
Walla Walla District
U.S. Army Corps of Engineers
Walla Walla, Washington

and

Kennewick Field Office
U.S Geological Survey
Kennewick, Washington

Prepared for:
Northwestern Division Regional Office
U.S. Army Corps of Engineers
Portland, Oregon

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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 2020 water-quality program. These stations are located on the Columbia, Lower Snake and Clearwater Rivers. This report provides a summary of the 2020 water-year quality assurance/ quality control (QA/QC) evaluation. Highlights include:

- COVID-19 travel restrictions frequently delayed response time to diagnose and repair field equipment.
- Data completeness for the combined BP, TDG, and temperature data received averaged 99.5 percent for the 14 monitoring sites used in 2020.
- The TDG data received from the individual sites ranged from 95.10 percent to 99.95 percent complete. Thirty-four percent of the invalid data was due to measurements that were considered too low, primarily at the Peck (PEKI) and Lower Granite forebay (LWG) stations. The second most frequent cause of missing information was defective sondes at the Lower Monumental tailwater (LMNW) and Dworshak tailwater station (DWQI) that accounted for a combined 29 percent of the total.
- The TDG sensors from the 14 FMS stations were removed from the field and calibrated in the laboratory every three weeks from April 2020 through August 2020. From September 2019 through March 2020, 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 -0.31 mmHg, -0.44 mmHg, and 0.03 °C, respectively. The sensor post-deployment check revealed mean ambient pressure, ambient pressure plus 100 mmHg, and temperature differences of -0.03 mmHg, -1.04 mmHg, and 0.01 °C, respectively.
- The calculated median values for the 169 *in-situ* field checks with the replacement probes were:
    1. TDG; 0.0 percent with station medians ranging from -0.2 percent to 0.1 percent.
    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 -0.04 ºC to 0.03 ºC.
- Station repairs and maintenance were also completed during the 2020 water year:
    1. Repair work to the Lower Monumental Dam tailwater station damaged by fire in 2019 was completed
    2. The swing arms used to suspend the forebay TDG probes on the Lower Snake and McNary upstream navigation guidewalls were replaced.
    3. Replacement of the existing Sutron Satlink2 logger/transmitters with new Satlink3 units that are V2 compliant was completed.
    4. Sediment build-up at 7 of the deployment pipes was purged with compressed air.

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 1 April through 31 August, and typically bracket that period.

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. 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 modified for the 2020 fish passage season but remained unchanged in Idaho. In Washington, the April through June tailwater TDG in the Lower Snake River was allowed to increase to a maximum of 125 percent (calculated as an average of the 12 highest hourly measurements in a calendar day) and 126 percent calculated as an average of any two consecutive hourly measurements. During July and August the standard reverted to 115 and 120 percent in the forebay and tailwater, respectively. These values were also calculated as the average of the twelve highest measurements in a calendar day. In Oregon, the April 1 through June 15 Columbia River tailwater TDG level was allowed be as high as 125 percent as calculated using the 12 highest consecutive hourly measurements in any one day. From June 16 through August 31 the tailwater standard was reduced to 120 percent, again calculated as the average of the 12 highest consecutive hourly measurements in any one day. The State of Idaho TDG standard continued to follow the USEPA upper limit of 110 percent.

Barometric pressure, water temperature, and TDG measurements were completed hourly at the Columbia, Snake, and Clearwater River station, and at 15-minute intervals at the Dworshak station. All data was transmitted via the Geostationary Operational Environmental Satellite Program (GOES) system to USACE and U.S. Geological Survey (USGS) databases. The water quality data stored in the Corps Water Management System (CWMS) database 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 of the 2019 Columbia River System Operations Biological Opinion. An additional purpose of this report is to show that CENWW complied with the 2019-2023 TDG Monitoring Plan during 2020. 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, and at Peck, (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® hand-held barometer that served as a portable field standard for barometric pressure. 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 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-nine of these units were provided by CENWW and the remaining six 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 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-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, 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 Digi-Sense Traceable Scientific Thermistor Thermometers. 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 (completed without membrane)

The pre-deployment evaluation of the sensors consisted of 162 individual checks for barometric pressure (Table F-2). The evaluation of the pressure sensors to the standard revealed a calculated mean of -0.31 mmHg, and a range of -7.68 to 8.06 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 -1.17 percent to 0.54 percent with a calculated mean and median of -0.04 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 0.03 ºC and 0.04 °C, respectively. These calculated values were based on 162 measurements where the minimum and maximum differences for individual sensors ranged from -0.22 °C to 0.77 °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 (completed with membrane in place)

The evaluation of the post-deployment QA/QC data also displayed mostly favorable results. A total of 152 data points were used for the evaluation. The differences between the laboratory barometric pressure and that recorded by the TDG sensors ranged from -21.34 mmHg to 8.02 mmHg, with a mean of -0.03 mmHg (Tables F-2 and F-4; Figure F-3). The extreme range of values noted this year were attributed to defective membranes and sondes. The results of the post calibration checks using barometric pressure +100 mmHg showed a calculated mean of -0.06 percent, and a range of -2.79 to 0.60 percent (Table F-2; Figure F-4).

There were 152 post deployment checks available for the temperature evaluation. Temperature post calibration checks resulted in a calculated mean and median of 0.01 °C, with a range of -0.15 °C to 0.18 °C (Tables F-2 and F-4; Figure F-5).

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 169 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 0.1 mmHg (Table F-6; Figure F-6), which is within the ±0.7 mmHg published accuracy of the barometers.

A total of 169 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 0.0 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). A high value at McNary Tailwater (MCPW) with a difference of 203 mmHg (26.9%) was recorded as a result of a blown TDG membrane (Table F-6; Figure G7).

A total of 169 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 0.00 °C and -0.01 °C, respectively (Table F-6; Figure F-8). The median values for individual stations ranged from 0.04 ºC to 0.03 ºC (Table F-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 98.91, 99.95, and 99.61 percent, respectively (Table F-7; Figure F-9). While these percentages are quite good, there were instances, especially during the spring and early summer, when the response time to correct a problem was longer than usual due to travel restrictions imposed by COVID-19. The most frequent reason attributed to missing or anomalous information in the real-time data set were defective sondes (0.17 percent of the combined station performance, which is equivalent to 32.5 percent of all missing and invalid data shown in the last column of Table F-8). The second leading cause of missing/anomalous data was information considered to be too low, accounting for 0.13 percent of the combined station performance or 24.5 percent of the 1,253 hours of affected data. All stations met or exceeded the required 95 percent criterion for data completeness for all parameters. However, the TDG percent completeness at Peck (PEKI) was 95.1 percent (Table F-7). The reason for this was primarily due values that were considered too low (attributed to sediment build-up in the pipe) and COVID-19 travel restrictions previously mentioned that delayed completing the necessary field work to blow-out the pipe.

4.3.1 Barometric Pressure

Barometric pressure data from the fourteen stations averaged 99.95 percent complete. Barometric pressure data was 100 percent complete at eight of the fourteen FMS stations including McNary tailwater (MCPW), McNary forebay (MCNA), Ice Harbor tailwater (IDSW), Ice Harbor forebay (IHRA), Little Goose Tailwater (LGSW), Lower Granite forebay (LWG), Anatone (ANQW), and Peck (PEKI) (Table F-7). The six remaining stations were greater than 99 percent complete (Tables F-8 and F-9). DCP failure was the primary reason for missing barometric pressure data at Dworshak (DWQI).

4.3.2 Total Dissolved Gas

The TDG data from the fourteen stations averaged 98.91 percent complete (Table F-7). The three stations that experienced the greatest amount of data loss were Lower Monumental tailwater (LMNW), Peck (PEKI), and Dworshak tailwater (DWQI) where the final data set statistics ranged from 95.1 percent to 98.3 percent complete (Table F-7). Defective sondes were the primary cause of anomalous data at LMNW and DWQI, while sediment build-up in the PEKI deployment pipe resulted in values that were considered too low (Table F-8 and F-10).

4.3.3 Temperature

The temperature data from the fourteen FMS stations averaged 99.61 percent complete. Three stations (McNary forebay [MCNA], and Lower Granite forebay [LWG], and Peck [PEKI]) attained 100 percent completeness (Table F-7). Ten of the remaining eleven stations were all greater than 99 percent complete. Lower Monumental tailwater (LMNW) had the greatest amount of missing data at 181 hours, due mainly to defective sondes and cable failures (Table F-8 and F-11).

4.4 Deployment Pipe Clean-Out

Sediment build-up occurred in several deployment pipes during the 2020 water year that resulted in measurements that were considered too low. The deployment pipe at the Pasco location (PAQW) was purged with compressed air during fall 2019. The Peck (PEKI) and Anatone (ANQW) stations were cleaned-out during April 2020, while the Dworshak (DWQI), Ice Harbor tailwater (IDSW), and Lower Monumental tailwater stations were visited during the late-spring and early-summer of 2020.

4.5 Notable Station Maintenance

The Lewiston gage (LEWI) was operated by NWW water quality staff during 2020 as a water temperature only station to support Dworshak water temperature modeling operations. It was also purged with compressed air during April 2020.

5.0 SUMMARY

Hourly TDG, temperature, and barometric pressure data recorded during the 2020 water year at fourteen FMS stations were evaluated. Six tailwater sites were maintained throughout the year and eight additional locations were added for the 1 April through 31 August fish spill season. The combined data completeness for all stations exceeded 99 percent.

The USGS Kennewick field office performed routine station maintenance, completed emergency repairs, operated the DCPs, and assisted with station 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 defective sondes, low data values, and inspections. Additionally, problems that were encountered at the field locations were exacerbated due to travel restrictions implemented as a result of COVID-19.

The pre-deployment QA/QC checks showed a mean difference of -0.31 mmHg when the TDG sensors were compared to barometric pressure and -0.04 percent when 300 mmHg of pressure was added. The calculated means for the post-deployment evaluations were -0.03 mmHg and -0.06 percent when the TDG sensors were compared to barometric pressure and barometric pressure plus 100 mmHg, respectively. The calculated mean temperature difference was 0.03 °C for pre-deployment and 0.01 °C for post-calibration.

The 45 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, 0.18 percent, and 0.00 °C, respectively.

FIGURES

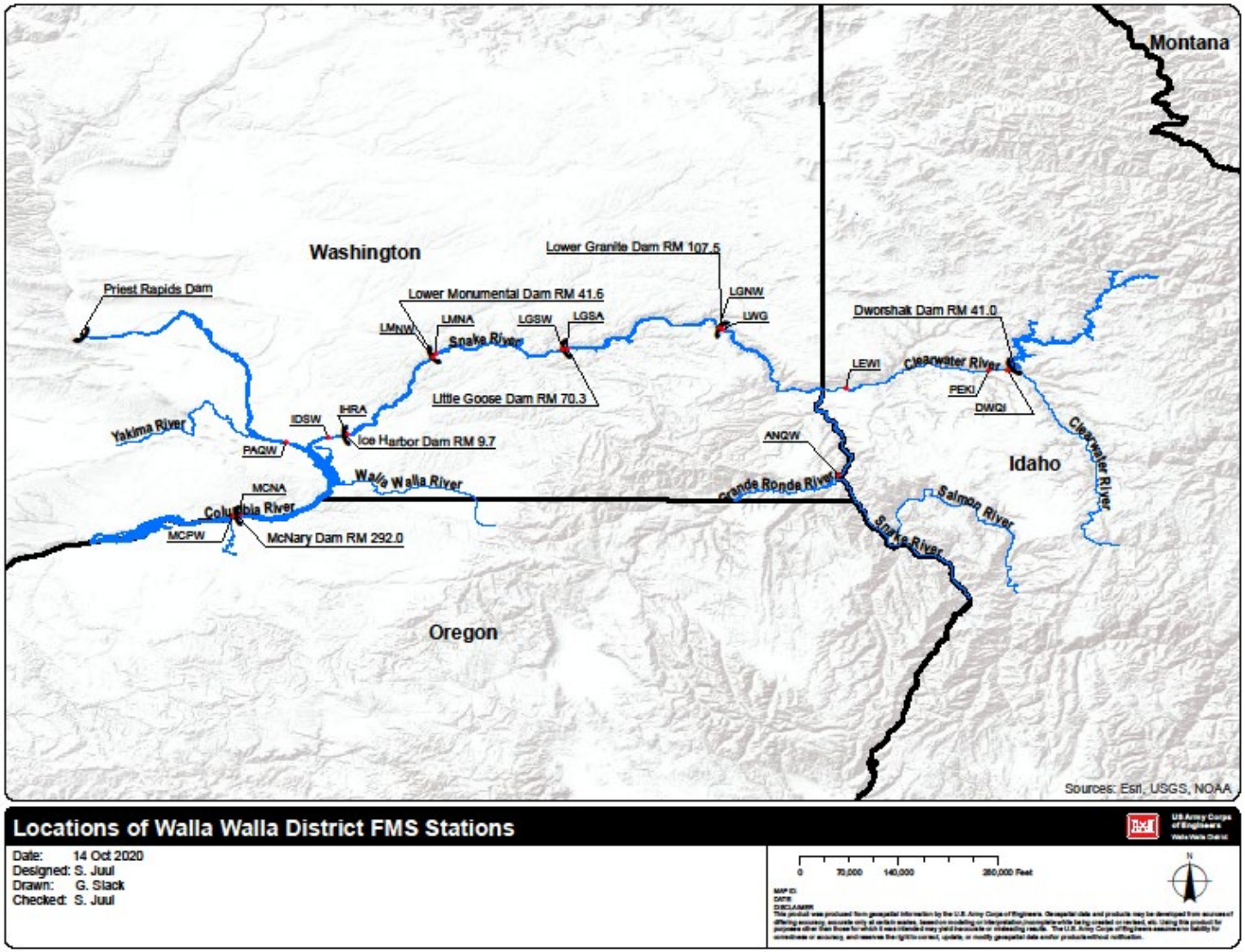

Figure F-1. Locations of Walla Walla District's FMS stations.

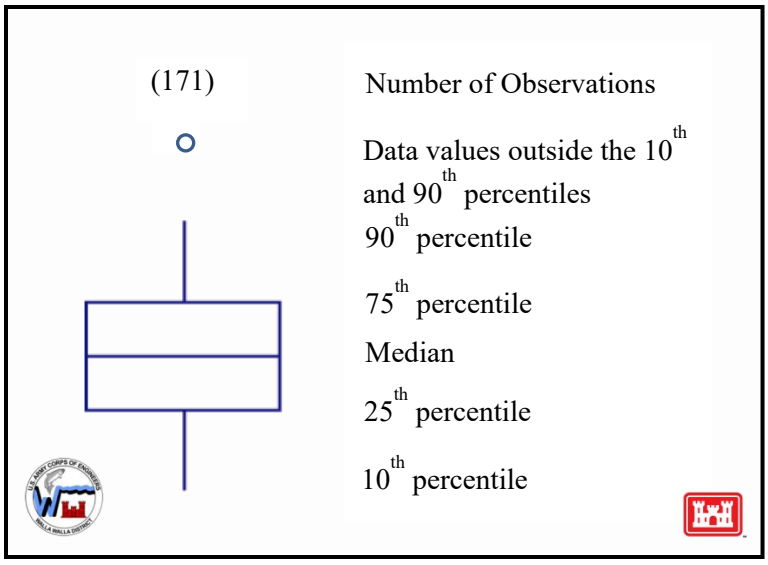

Figure F-2. Explanation key for the box plot information.

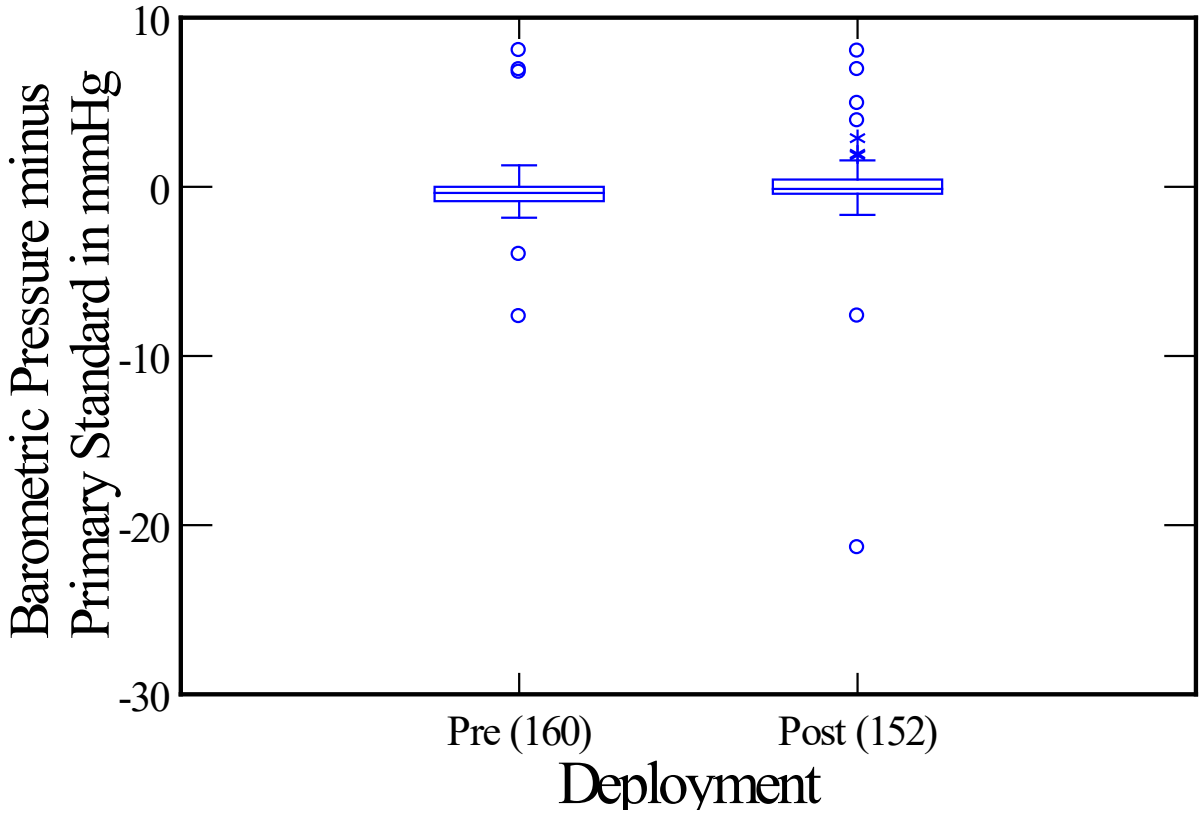

Figure F-3. Summary box plots of the pre-and post-deployment check of the barometric pressure versus the primary standard during the 2020 monitoring season.

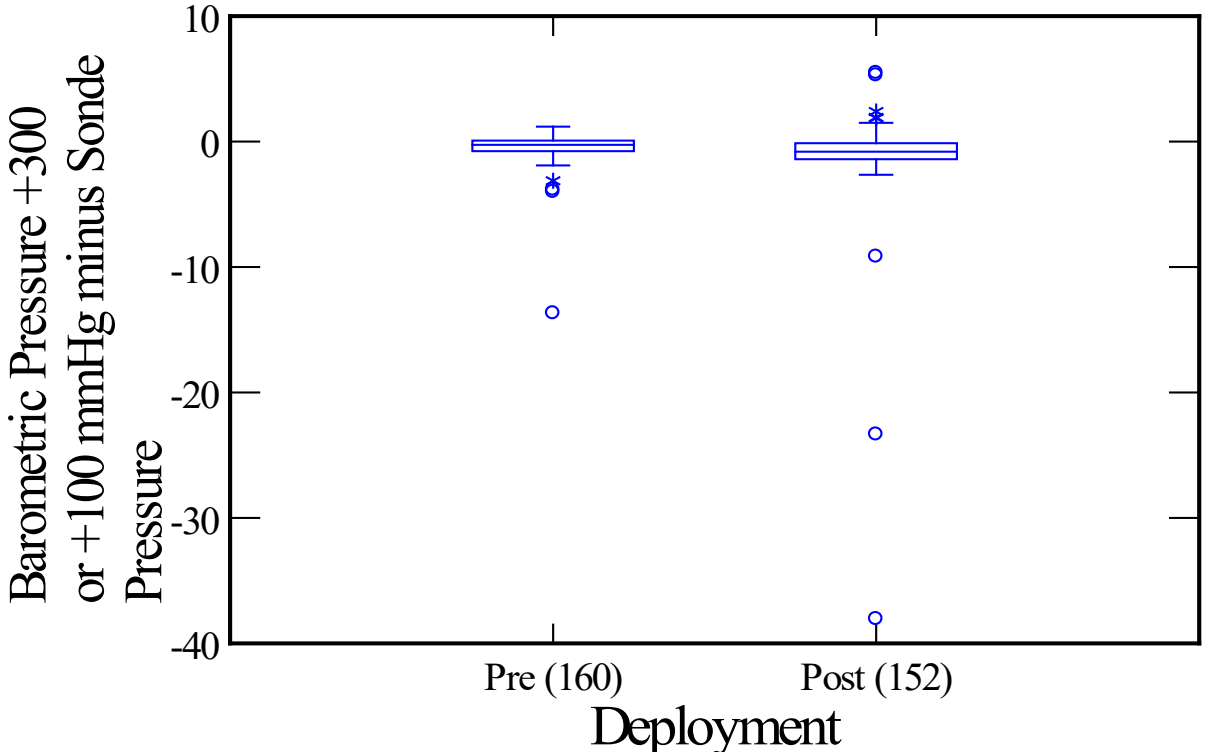

Figure F-4. Summary box plots of the pre-and post-deployment check of the Hydrolab® TDG sensors with the addition of 300 and 100 mmHg, respectively, during the 2020 monitoring season.

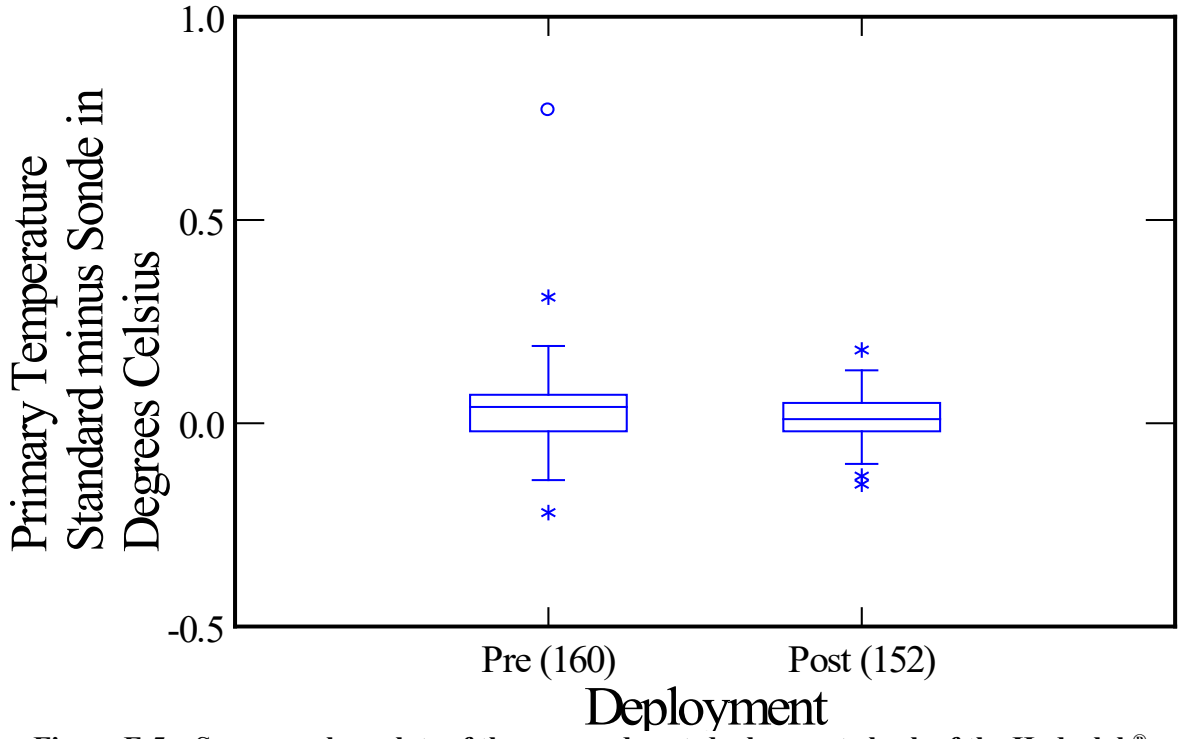

Figure F-5. Summary box plots of the pre- and post-deployment check of the Hydrolab® temperature sensors during the 2020 monitoring season.

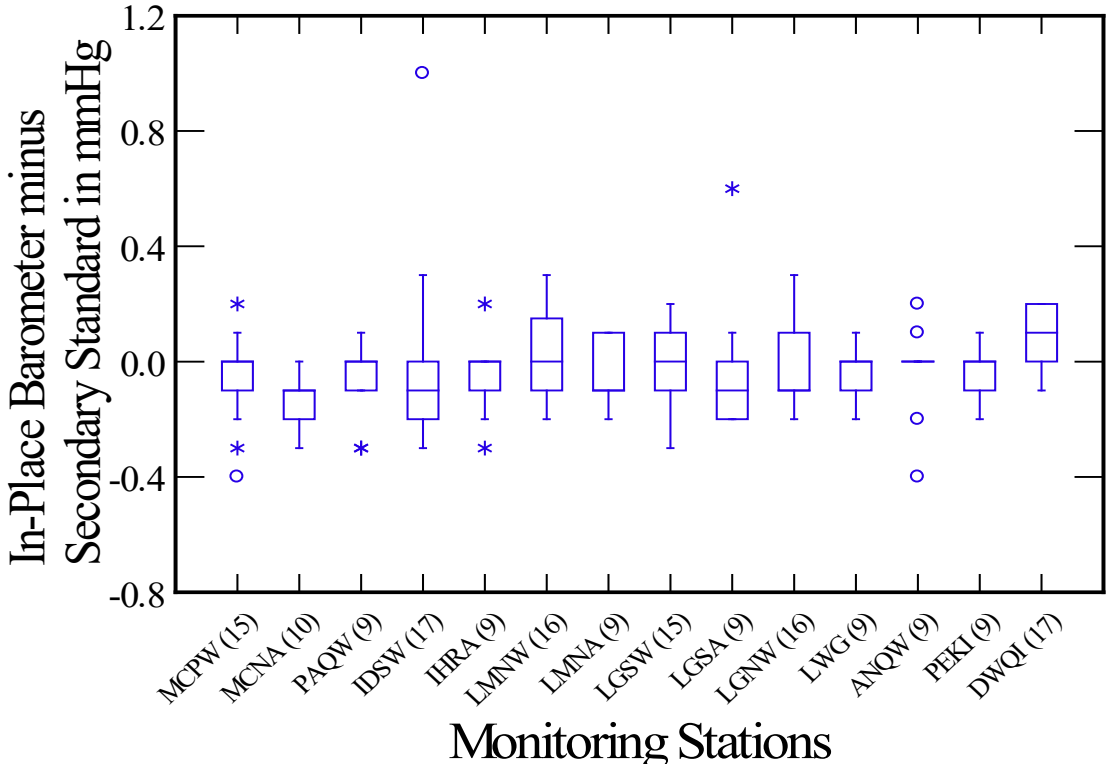

Figure F-6. Box plots of the field barometric pressure sensors check in mmHg by site during the 2020 monitoring season.

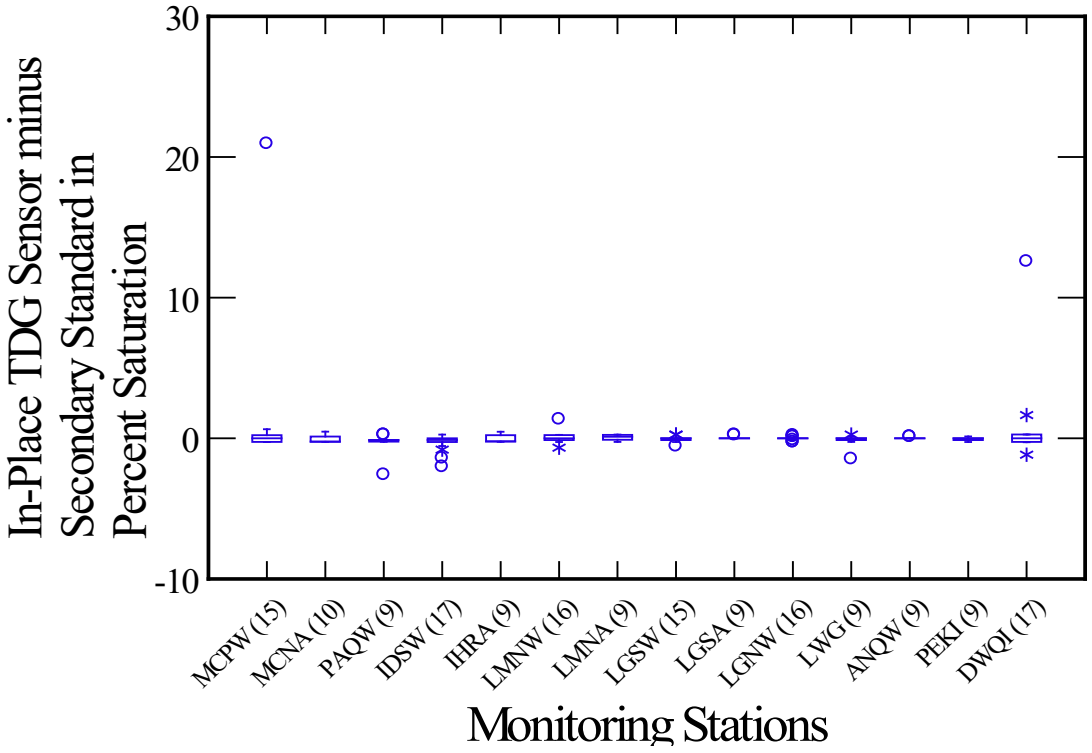

Figure F-7. Box plots of the field total dissolved gas sensor check verses secondary standard in percent saturation by site during the 2020 monitoring season.

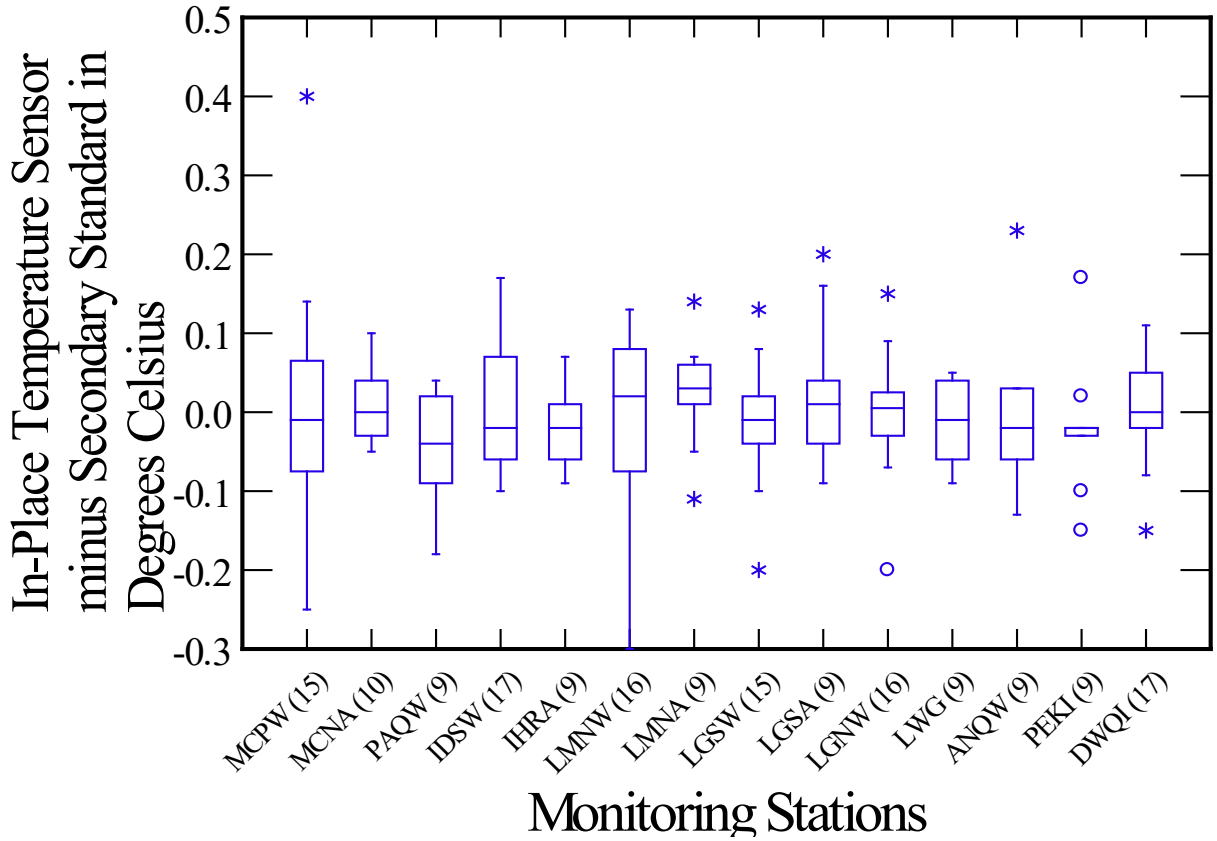

Figure F-8. Box plots of the field temperature sensors check verses secondary standard in degrees Celsius by site during the 2020 monitoring season.

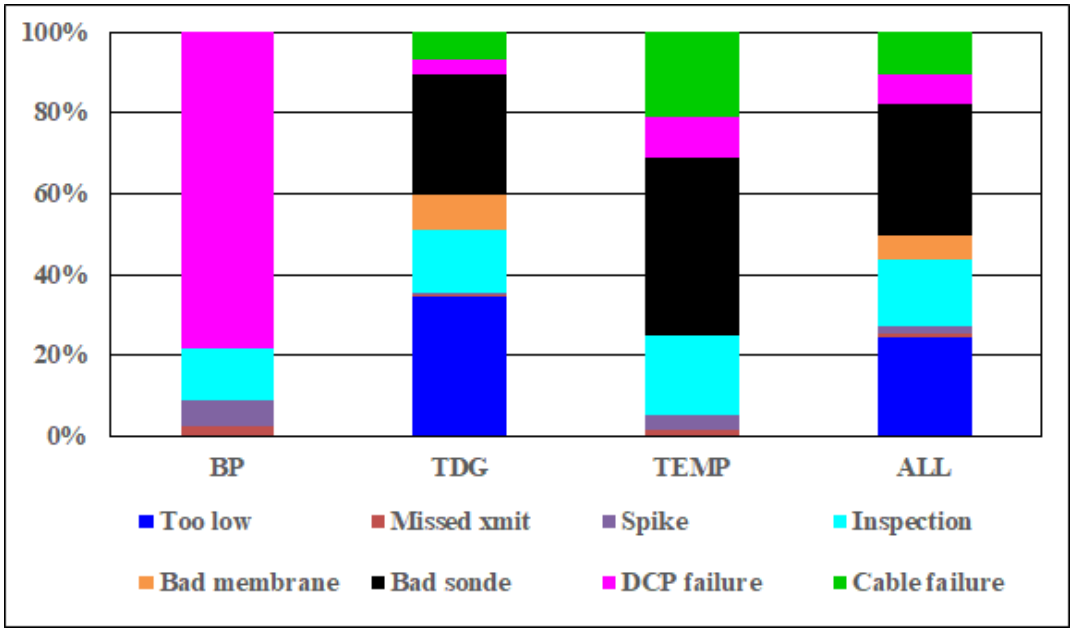

Figure F-9. Percentages for the reasons invalid or anomalous barometric pressure, TDG, and temperature data were removed from the databases during the 2020 monitoring season

TABLES

Table F-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	DE90FB26	0:03:05*
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

Note: * Indicates the station transmits at 15-minute intervals as opposed to the standard hourly rate of transmission.

Table F-2. Summary of the laboratory results evaluating the overall differences between laboratory standards and the sensors pre- and post-deployment during the 2020 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 (°C)
Pre	Number	162	162	162	162	----	----	162
	Minimum	-7.68	-1.03	-13.68	-1.17	----	----	-0.22
	25 Percentile	-0.85	-0.11	-0.75	-0.08	----	----	-0.02
	Median	-0.37	-0.05	-0.26	-0.04	----	----	0.04
	75 Percentile	0.00	0.00	0.07	-0.01	----	----	0.07
	Maximum	8.06	1.08	1.19	0.54	----	----	0.77
	Mean	-0.31	-0.04	-0.44	-0.04	----	----	0.03
Post	Number	152	152	----	----	152	152	152
	Minimum	-21.34	-2.84	----	----	-38.05	-2.79	-0.15
	25 Percentile	-0.41	-0.05	----	----	-1.40	-0.09	-0.02
	Median	-0.13	-0.02	----	----	-0.81	-0.04	0.01
	75 Percentile	0.43	0.06	----	----	-0.13	0.00	0.05
	Maximum	8.02	1.09	----	----	5.48	0.60	0.18
	Mean	-0.03	0.00	----	----	-1.04	-0.06	0.01

Table F-3. Pre-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2020 water year.

Sensor ID	Obs (#)	Δ (PT – BP) Range (mmHg)	Δ (PT – BP) Median (mmHg)	Δ [PT-(BP+300)] Range (mmHg)	Δ [PT-(BP+300)] Median (mmHg)	Δ (Water Temperature) Range (ºC)	Δ (Water Temperature) Median (ºC)
13b	1	-0.28 to 0.28	-0.28	-0.28 to -0.28	-0.28	-0.13 to -0.13	-0.13
26	4	-0.35 to 0.61	-0.13	-0.35 to -.94	0.21	-0.03 to 0.05	0.02
27	3	0.08 to 0.89	0.17	-0.11 to 0.17	0.08	0.08 to 0.17	0.12
29	3	-1.11 to -0.35	-1.09	-1.11 to -0.35	-1.09	-0.08 to 0.07	-0.06
32	3	-0.19 to 0.19	0.03	-1.19 to 1.19	1.03	0.08 to 0.10	0.09
33	2	0.58 to 1.13	0.86	-0.42 to 1.13	0.36	0.06 to 0.06	0.06
34	3	-0.76 to -0.08	-0.66	-0.76 to 0.34	-0.08	-0.22 to 0.04	0.01
35	6	-7.68 to 6.77	0.13	-13.68 to 0.36	-0.31	-0.09 to 0.31	-0.01
36	4	-0.29 to 0.01	-0.14	-1.00 to -0.28	-0.64	-0.07 to 0.02	0.00
37	4	-1.12 to -0.19	-0.86	-3.82 to -1.19	-2.51	-0.02 to 0.11	0.01
39	4	-0.91 to 0.16	-0.58	-0.61 to 1.16	0.27	-0.10 to 0.06	-0.02
41	3	-0.21 to 0.00	-0.17	-0.17 to 1.00	0.79	0.00 to 0.10	0.09
42	5	-1.05 to -0.71	-0.86	-0.05 to 1.03	0.17	-0.14 to 0.03	-0.02
43	4	-0.92 to -0.43	-0.75	-0.92 to 0.15	-0.54	-0.04 to 0.01	-0.03
44	3	-0.86 to -0.32	-0.85	-0.85 to 0.14	-0.32	-0.08 to 0.09	0.06
45	5	-1.14 to -0.38	-0.68	-0.98 to -0.14	-0.39	-0.06 to 0.06	0.02
47	3	-0.40 to -0.31	0.11	-0.69 to 0.11	-0.40	-0.02 to 0.09	0.08
48	3	-1.83 to -0.03	-0.45	-0.83 to -0.03	-0.45	0.05 to 0.06	0.06
49	5	-1.14 to 1.27	-0.59	-0.73 to -0.14	-0.59	-0.07 to 0.07	-0.01
50	6	-1.32 to -0.23	-0.72	-1.23 to -0.23	-0.72	0.07 to 0.19	0.11
51	4	-0.45 to -0.07	-0.12	-1.07 to -0.10	-0.29	-0.09 to 0.09	0.00
52	2	0.08 to 0.57	0.33	0.08 to 0.57	0.33	0.09 to 0.10	0.09
53	5	-1.83 to 0.11	-0.10	-1.10 to -0.07	-0.83	0.04 to 0.08	0.05
54	3	-0.61 to 0.13	-0.07	-0.61 to 0.13	-0.07	-0.07 to 0.09	0.05
55	3	-1.12 to -0.74	-1.06	-1.12 to 0.06	-0.74	0.03 to 0.09	0.05
56	6	-1.23 to 1.15	0.33	-0.69 to 1.15	-0.03	-0.11 to 0.77	0.04
57	5	-1.24 to -0.92	-1.14	-1.14 to -0.01	-0.24	-0.11 to 0.06	0.05
58	4	-0.71 to 0.14	-0.38	-1.56 to -0.71	-1.03	-0.13 to 0.10	0.04
60	3	-0.81 to 0.45	-0.15	-0.55 to 0.19	-0.15	0.04 to 0.12	0.05
61	2	-0.71 to -0.38	-0.55	-1.38 to -0.71	-1.05	-0.09 to 0.05	-0.02
62	6	-1.24 to -0.07	-0.69	-0.85 to 0.73	-0.07	-0.04 to 0.09	0.01
63	4	-0.94 to -0.10	-0.65	-0.94 to 0.21	-0.30	0.05 to 0.08	0.07
64	7	-1.14 to 8.06	-0.68	-1.10 to 0.00	-0.20	-0.02 to 0.04	0.01
65	3	-0.70 to -019	-0.45	-0.70 to 0.19	-0.45	-0.01 to 0.05	0.01
32431	2	-0.16 to 0.18	0.01	-0.16 to 0.18	0.01	-0.12 to 0.04	-0.04
32432	3	-0.13 to 0.06	-0.11	-0.94 to -0.11	-0.13	-0.03 to 0.07	0.03
32435	1	0.04 to 0.04	0.04	0.04 to 0.04	0.04	-0.01 to -0.01	-0.01
35131	2	-0.95 to 0.08	-0.52	-0.92 to 1.05	0.99	0.02 to 0.05	0.03
36902	1	-0.17 to -0.17	-0.17	-0.17 to -0.17	-0.17	0.07 to 0.07	0.07
USGS #1	1	-0.64 to -0.64	-0.64	-0.64 to -0.64	-0.64	0.03 to 0.03	0.03
USGS #2	4	-0.20 to 0.29	-0.08	-0.71 to -0.05	-0.16	-0.04 to 0.04	0.03
USGS #4	3	-4.00 to 0.92	0.48	-4.00 to 0.92	0.48	0.06 to 0.14	0.07
USGS #5	2	-1.83 to 6.92	2.54	-1.83 to -1.08	-1.45	-0.02 to 0.10	0.04
USGS #6	4	-1.09 to -0.81	-0.91	-1.90 to -0.09	-0.87	0.05 to 0.08	0.07
USGS #9	6	-0.44 to 0.13	-0.28	-0.91 to 0.64	-0.28	-0.05 to 0.08	0.00

Table F-4. Post-deployment quality assurance data for the individual sensors utilized at the FMS stations during the 2020 water year.

Sensor ID	Obs (#)	Δ (PT – BP) Range (mmHg)	Δ (PT – BP) Median (mmHg)	Δ [PT - BP+100)] Range (mmHg)	Δ [PT - BP+100)] Median (mmHg)	Δ (Water Temperature) Range (ºC)	Δ (Water Temperature) Median (ºC)
13b	1	0.13 to 0.13	0.13	1.13 to 1.13	1.13	0.06 to 0.06	0.06
26	4	-0.83 to 0.89	0.30	-1.85 to -1.11	-1.68	0.02 to 0.05	0.04
27	3	-0.01 to 0.52	0.48	-1.48 to 0.99	-0.52	0.06 to 0.08	0.06
29	3	-1.66 to -0.25	-0.52	-1.52 to -0.52	-1.25	0.04 to 0.06	0.05
32	2	-0.06 to 0.22	0.08	-1.78 to 5.48	1.85	0.01 to 0.02	0.02
33	2	0.76 to 1.08	0.92	-0.24 to 0.08	-0.08	-0.01 to 0.02	0.01
34	1	-1.57 to -1.57	-1.57	-0.57 to -0.57	-0.57	0.07 to 0.07	0.07
35	4	-21.34 to 1.95	0.30	-38.05 to 0.25	-12.50	-0.05 to 0.12	-0.02
36	4	-0.25 to 0.45	0.19	-0.76 to 0.45	-0.05	-0.10 to 0.05	-0.03
37	3	-1.12 to -0.31	-0.78	-0.12 to 0.69	0.22	-0.05 to 0.04	-0.01
39	3	-0.31 to 0.16	-0.24	-0.84 to 0.76	-0.31	-0.02 to 0.00	-0.02
41	2	0.28 to 0.31	0.29	-0.69 to 1.28	0.29	-0.06 to 0.04	-0.01
42	5	-0.99 to 0.69	-0.85	-1.60 to 0.10	-0.99	-0.06 to 0.03	0.01
43	4	-0.34 to 1.36	-0.23	-9.16 to 5.30	1.06	-0.04 to 0.01	-0.02
44	5	-0.67 to -0.35	-0.40	-1.70 to -0.28	-1.40	-0.06 to 0.08	0.01
45	5	-1.00 to -0.15	-0.49	-1.26 to 0.00	-0.49	0.00 to 0.02	0.01
47	2	0.24 to 1.56	0.90	-1.44 to 0.24	-0.60	-0.07 to 0.07	0.00
48	3	0.64 to 4.93	1.12	-1.88 to -0.07	-1.36	-0.04 to 0.04	0.03
49	5	-0.60 to 0.25	-0.24	-1.87 to -0.60	-1.24	-0.01 to 0.08	0.04
50	6	-0.56 to 0.90	-0.27	-1.90 to -0.17	1.39	-0.01 to 0.18	0.09
51	4	-0.33 to -.92	-0.03	-1.78 to -0.08	-0.81	-0.06 to 0.06	-0.01
52	2	-0.65 to 0.18	-0.24	-1.82 to -1.65	-1.74	-0.09 to -0.02	-0.05
53	6	-1.07 to 0.51	-0.25	-2.07 to -0.84	-0.43	-0.05 to 0.06	0.01
54	4	-0.82 to 1.86	1.12	-1.97 to -0.14	-0.81	-0.04 to 0.02	0.02
55	3	-0.90 to 0.34	-0.78	-1.66 to 0.10	-0.66	-0.03 to 0.13	0.01
56	5	-0.29 to 1.05	0.46	-1.29 to 0.46	-0.95	-0.05 to 0.07	-0.01
57	5	-1.54 to -0.13	-0.49	-0.63 to -0.13	-0.49	-0.10 to 0.08	0.03
58	4	-0.50 to 0.46	0.06	-1.63 to 0.50	-1.39	-0.01 to 0.06	0.02
60	4	-0.41 to 1.04	0.14	-0.96 to 0.43	-0.27	-0.02 to 0.04	0.02
61	3	-0.12 to 3.90	1.40	-1.60 to -1.10	-1.12	-0.01 to 0.09	0.00
62	6	-1.05 to 0.07	-0.30	-1.93 to -0.05	-0.88	-0.09 to 0.02	0.00
63	4	-0.74 to -0.01	-0.10	-0.74 to -0.01	-0.10	0.00 to 0.05	0.02
64	6	-0.80 to 6.93	-0.31	-1.80 to 1.93	-1.31	-0.15 to 0.02	-0.01
65	2	-1.27 to 0.89	-0.19	-1.27 to -1.11	-1.19	0.02 to 0.02	0.02
32431	2	0.25 to 0.61	0.43	-1.00 to 0.61	-0.19	0.11 to 0.13	0.12
32432	3	-0.26 to 0.32	-0.05	-0.68 to 0.74	-0.05	-0.05 to 0.06	0.05
32435	1	-0.21 to -0.21	-0.21	-0.21 to -0.21	-0.21	-0.10 to -0.10	-0.10
35131	2	-0.24 to -0.14	-0.19	-1.14 to 0.76	-0.19	-0.06 to 0.00	-0.03
36902	1	0.93 to 0.93	0.93	-1.07 to -1.07	-1.07	0.03 to 0.03	0.03
USGS 2	4	-0.15 to 0.69	0.13	-1.31 to 1.12	-1.00	-0.06 to 0.04	0.01
USGS 4	3	0.50 to 2.87	1.38	1.62 to 1.87	1.50	0.04 to 0.07	0.06
USGS 5	2	-7.64 to 8.05	0.19	-2.64 to 1.00	-0.82	-0.05 to 0.00	-0.03
USGS 6	3	-0.60 to -0.11	-0.60	-1.60 to -1.11	-1.60	-0.07 to 0.06	0.00
USGS 9	5	-0.14 to 0.79	0.28	-1.72 to 0.43	-0.85	-0.13 to 0.13	-0.06

Table F-5. Summary of the field results for the differences between the in-place and replacement sensors during 2020 water year.

Statistic	Δ BP (mmHg)	ΔTDG (% sat)	Δ T (ºC)
Number	169	169	169
Minimum	-0.40	-4.8	-0.30
Maximum	1.00	26.9	0.40
Mean	-0.02	0.18	0.00
Median	0.00	0.00	-0.01

Table F-6. Summary of the field results for the differences between the in-place and replacement sensors by station during 2020 water year.

Station ID	# Obs	Δ Barometric Air Pressure Range (mmHg)	Δ Barometric Air Pressure Median (mmHg)	Δ Total Dissolved Gas Range (mmHg)	Δ Total Dissolved Gas Median (mmHg)	Δ Total Dissolved Gas Range (% Sat)	Δ Total Dissolved Gas Median (% Sat)	Δ Water Temperature Range (ºC)	Δ Water Temperature Median (ºC)
MCPW	15	-0.4 to 0.2	0.00	-2.0 to 203.0	0.0	-4.8 to 26.9	0.1	-0.25 to 0.40	-0.02
MCNA	10	-0.3 to 0.0	-0.10	-2.0 to 4.0	-2.0	-0.3 to 0.5	-0.3	-0.05 to 0.10	0.00
PAQW	9	-0.3 to 1.0	0.00	-21.0 to 2.0	-1.0	-2.7 to 0.3	-0.1	-0.18 to 0.04	-0.04
IDSW	17	-0.3 to 1.0	-0.10	-15.0 to 2.0	1.0	-2.0 to 0.3	-0.1	-0.10 to 0.17	-0.02
IHRA	9	-0.3 to 0.2	0.00	-2.0 to 4.0	-2.0	-0.3 to 0.5	-0.3	-0.09 to 0.07	-0.02
LMNW	16	-0.2 to 0.3	0.00	-5.0 to 10.0	0.0	-0.7 to 1.3	0.0	-0.30 to 0.13	0.02
LMNA	9	-0.2 to 0.1	-0.10	-2.0 to 2.0	1.0	-0.3 to 0.3	0.1	-0.11 to 0.14	0.03
LGSW	15	-0.3 to 0.2	-0.00	-4.0 to 2.0	0.0	-0.5 to 0.3	0.0	-0.20 to 0.13	-0.01
LGSA	9	-0.2 to 0.6	-0.10	0.0 to 2.0	0.0	0.0 to 0.3	0.0	-0.09 to 0.20	0.01
LGNW	16	-0.2 to 0.3	-0.10	-2.0 to 2.0	0.0	-0.3 to 0.3	0.0	-0.20 to 0.15	0.00
LWG	9	-0.2 to 0.1	0.00	-11.0 to 2.0	0.0	-1.5 to 0.3	0.0	-0.09 to 0.05	-0.01
ANQW	9	-0.4 to 0.2	0.00	0.0 to 1.0	0.0	0.0 to 0.1	0.0	-0.13 to 0.23	-0.02
PEKI	9	-0.2 to 0.1	0.00	-2.0 to 1.0	0.0	-0.3 to 0.1	0.0	-0.15 to 0.17	-0.02
DWQI	17	-0.1 to 0.2	0.10	-9.0 to 96.0	0.0	-1.2 to 13.1	0.0	-0.15 to 0.11	0.00

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 2020 water year.

Station ID	Monitoring Period	BP Number Missing/ Anomalous	BP Percent Complete	TDG Number Missing/ Anomalous	TDG Percent Complete	Temp. Number Missing/ Anomalous	Temp. Percent Complete
MCPW	1 Oct – 30 Sep	**0**	**100.00**	60	99.32	2	99.98
MCNA	1 Apr – 31 Aug	**0**	**100.00**	21	99.43	**0**	**100.00**
PAQW	1 Apr – 31 Aug	3	99.92	30	99.17	28	99.24
IDSW	1 Oct – 30 Sep	**0**	**100.00**	83	99.05	27	99.69
IHRA	1 Apr – 31 Aug	**0**	**100.00**	3	99.92	1	99.97
LMNW	1 Oct – 30 Sep	2	99.98	192	97.81	181	97.94
LMNA	1 Apr – 31 Aug	1	99.97	9	99.76	5	99.86
LGSW	1 Oct – 30 Sep	**0**	**100.00**	58	99.34	22	99.75
LGSA	1 Apr – 31 Aug	2	99.95	2	99.95	1	99.97
LGNW	1 Oct – 30 Sep	2	99.98	6	99.93	3	99.97
LWG	1 Apr – 31 Aug	**0**	**100.00**	83	97.74	**0**	**100.00**
ANQW	1 Apr – 31 Aug	**0**	**100.00**	20	99.46	17	99.54
PEKI	1 Apr – 31 Aug	**0**	**100.00**	180	95.10	**0**	**100.00**
DWQI	1 Oct – 30 Sep	30	99.66	149	98.30	31	99.65

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 2020 water year.

Reason	BP (hours)	BP (%)	TDG (hours)	TDG (%)	BP+TDG (hours)	BP+TDG (%)	Temp.(hours)	Temp. (%)	All (hours)	All (%)
Too Low			307.8	0.38	307.8	0.19			307.8	0.13
Missed transmit	1.0	0.00	6.5	0.01	7.5	0.00	4.5	0.01	12.0	0.00
Missing data										
Spike	2.5	0.00	4.2	0.01	6.7	0.00	11.2	0.01	18.0	0.01
Inspection	5.0	0.01	138.9	0.17	143.9	0.09	63.9	0.08	207.8	0.08
Defective membrane			76.9	0.09	76.9	0.05			76.9	0.03
Defective sonde			267.4	0.33	267.4	0.16	139.9	0.17	407.3	0.17
DCP failure	31.0	0.04	32.0	0.04	63.0	0.04	32.0	0.04	95.0	0.04
Cable failure			62.0	0.08	62.0	0.04	65.9	0.08	127.9	0.05
Totals	**39.5**	**0.05**	**895.7**	**1.09**	**935.1**	**0.57**	**317.5**	**0.39**	**1,252.7**	**0.51**

Table F-9. Number and percent of all missing or invalid barometric pressure data for each FMS station during the 2020 water year, along with the reasons for those designations.

Station ID	Too Low (#)	Too Low (%)	Missed Transmit (#)	Missed Transmit (%)	Missing DCP Data (#)	Missing DCP Data (%)	Spike (#)	Spike (%)	Inspe-ction (#)	Inspe-ction (%)	Defective Membrane (#)	Defective Membrane (%)	Defective Sonde (#)	Defective Sonde (%)	DCP Failure (#)	DCP Failure (%)	Cable Failure (#)	Cable Failure (%)
MCPW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MCNA	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
PAQW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	0.08	-	-
IDSW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IHRA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LMNW	-	-	-	-	-	-	-	-	2	0.02	-	-	-	-	-	-	-	-
LMNA	-	-	-	-	-	-	-	-	1	0.03	-	-	-	-	-	-	-	-
LGSW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGSA	-	-	-	-	-	-	-	-	2	0.05	-	-	-	-	-	-	-	-
LGNW	-	-	1	0.01	-	-	1	0.01	-	-	-	-	-	-	-	-	-	-
LWG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANQW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PEKI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DWQI	-	-	-	-	-	-	2	0.02	-	-	-	-	-	-	28	0.32	-	-

Table F-10. Number and percent of all missing or invalid total dissolved gas data for each FMS station during the 2020 water year, along with the reasons for those designations.

Station ID	Too Low (#)	Too Low (%)	Missed Transmit (#)	Missed Transmit (%)	Missing DCP Data (#)	Missing DCP Data (%)	Spike (#)	Spike (%)	Inspe-ction (#)	Inspe-ction (%)	Defective Membrane (#)	Defective Membrane (%)	Defective Sonde (#)	Defective Sonde (%)	DCP Failure (#)	DCP Failure (%)	Cable Failure (#)	Cable Failure (%)
MCPW	-	-	-	-	-	-	-	-	4	0.05	54	0.62	2	0.02	-	-	-	-
MCNA	-	-	-	-	-	-	-	-	1	0.03	20	0.54	-	-	-	-	-	-
PAQW	-	-	-	-	-	-	-	-	27	0.75	3	0.08	-	-	-	-	-	-
IDSW	51	0.58	-	-	-	-	-	-	32	0.37	-	-	-	-	-	-	-	-
IHRA	-	-	-	-	-	-	-	-	3	0.08	-	-	-	-	-	-	-	-
LMNW	-	-	-	-	-	-	-	-	18	0.21	-	-	157	1.79	-	-	17	0.19
LMNA	-	-	4	0.11	-	-	-	-	-	-	-	-	-	-	-	-	5	0.14
LGSW	-	-	-	-	-	-	-	-	31	0.35	-	-	-	-	-	-	27	0.31
LGSA	-	-	-	-	-	-	-	-	2	0.05	-	-	-	-	-	-	-	-
LGNW	-	-	2	0.02	-	-	1	0.01	3	0.03	-	-	-	-	-	-	-	-
LWG	83	2.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANQW	-	-	-	-	-	-	-	-	3	0.08	-	-	-	-	4	0.11	13	0.35
PEKI	174	4.73	-	-	-	-	-	-	6	0.16	-	-	-	-	-	-	-	-
DWQI	-	-	1	0.01	-	-	3	0.04	9	0.10	-	-	109	1.24	28	0.32	-	-

Table F-11. Number and percent of all missing or invalid temperature data for each FMS station during the 2020 water year, along with the reasons for those designations.

Station ID	Too Low (#)	Too Low (%)	Missed Transmit (#)	Missed Transmit (%)	Missing DCP Data (#)	Missing DCP Data (%)	Spike (#)	Spike (%)	Inspe -ction (#)	Inspe-ction (%)	Defective Membrane (#)	Defective Membrane (%)	Defective Sonde (#)	Defective Sonde (%)	DCP Failure (#)	DCP Failure (%)	Cable Failure (#)	Cable Failure (%)
MCPW	-	-	-	-	-	-	-	-	-	-	-	-	2	0.02	-	-	-	-
MCNA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PAQW	-	-	-	-	-	-	-	-	28	0.76	-	-	-	-	-	-	-	-
IDSW	-	-	-	-	-	-	1	0.01	26	0.30	-	-	-	-	-	-	-	-
IHRA	-	-	-	-	-	-	-	-	1	0.03	-	-	-	-	-	-	-	-
LMNW	-	-	-	-	-	-	8	0.09	7	0.08	-	-	138	1.57	-	-	28	0.32
LMNA	-	-	2	0.05	-	-	-	-	-	-	-	-	-	-	-	-	3	0.08
LGSW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	0.25
LGSA	-	-	-	-	-	-	-	-	1	0.03	-	-	-	-	-	-	-	-
LGNW	-	-	1	0.01	-	-	1	0.01	1	0.01	-	-	-	-	-	-	-	-
LWG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANQW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	0.11	13	0.35
PEKI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DWQI	-	-	2	0.02	-	-	1	0.01	-	-	-	-	-	-	28	0.32	-	-