APPENDIX K

Walla Walla District TDG Report

(see attached CD's)

US Army Corps
of Engineers®
Walla Walla District

Quality Assurance and Quality Control for Total Dissolved Gas Monitoring - Lower Snake River, Washington; Clearwater River, Idaho; and Columbia River, Oregon and Washington Water Year 2002

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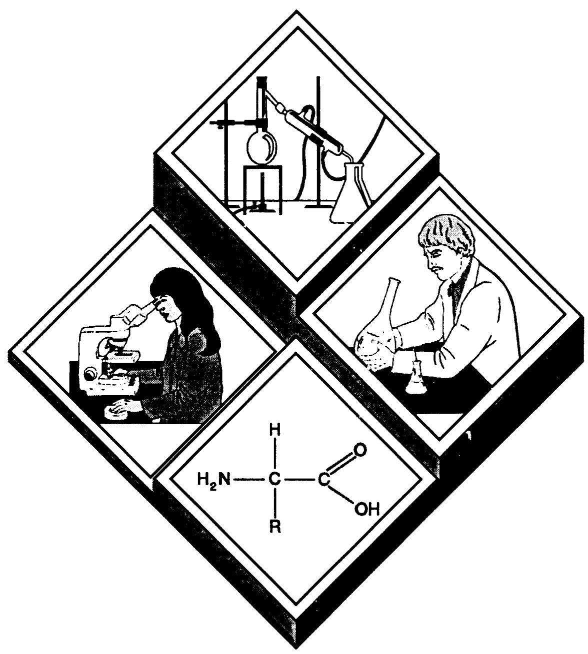

DECEMBER 2002

Quality Assurance and Quality Control for Total Dissolved Gas Monitoring - Lower Snake River, Washington; Clearwater River, Idaho; and Columbia River, Oregon and Washington, Water Year 2002

Water Quality Investigations Report 02–01

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Quality Assurance and Quality Control for Total Dissolved Gas Monitoring - Lower Snake River, Washington; Clearwater River, Idaho; and Columbia River, Oregon and Washington, Water Year 2002

By Russell D. Heaton, Gary Slack, and Phillip J. Fishella

ABSTRACT

U.S. Army Corps of Engineers (USACE), Walla Walla District (CENWW), operates 16 fixed monitoring stations (FMS) with total dissolved gas (TDG), dissolved oxygen (DO), and temperature as part of their water quality program. These stations are located on the Columbia, Lower Snake and Clearwater Rivers. This report provides the publishing of data for water and fiscal year 2003 with the corresponding quality assurance/quality control (QA/QC) data. With 245 independent QC checks, the system operated within the data quality objectives (DQO) with an overall percent passing QA/QC of 97.48 percent. This report has appendixes covering the overall station performance statistics, individual instrument control charts, missing data by hour by station, and two large portable document format (PDF) files for officially publishing the monitoring data for water year 2002. Included in the discussion are sections on variability for each parameter and proposed plans for next year's monitoring season.

INTRODUCTION

The CENWW operates six multi-purpose dams in the Columbia River, Lower Snake River, and Clearwater River basins. The drainage area above these dams is approximately 214,000 square miles. These facilities provide flood control, navigation, irrigation, recreation, hydropower, fish and wildlife habitat, and municipal and industrial water supply.

During spring runoff, air is entrained with plunging flows over the spillways and is carried deep into the stilling basin where water pressure causes the air to dissolve. Beyond the stilling basin, the river becomes shallow and the water becomes supersaturated with TDG. The U.S. Environmental Protection Agency (USEPA) has established an upper limit of 110 percent saturation for protection of freshwater aquatic life. Concentrations above this level can cause gas bubble trauma in fish and adversely affect other aquatic organisms (USEPA, 1986). Spillway deflectors have been installed on all dams in the area served by CENWW to reduce the plunging depths of spillway flows during normal water years. The CENWW collects real-time TDG data (available within about 4 hours of current time) upstream and downstream from its dams in a network of fixed station monitors known as the Total Dissolved Gas Monitoring System (TDGMS).

Real-time TDG data are vital for dam operation and for monitoring compliance within state and Federal guidelines and regulations. Water management personnel at the USACE, Northwestern Division (CENWD), maintain favorable water quality conditions, facilitate fish passage, and improve survival in the

Federal Hydropower System. HDR Engineering (HDR), under contract DACW-00-D-001 with CENWW, provided scheduled maintenance to the various instruments from the 16 fixed monitoring stations (FMS). The CENWW is responsible for operation and maintenance of the data collection system while progressively increasing levels of QA/QC. Data collection methods and QA plans have changed significantly since 1996. Water Year 2002 also included the refinement of improved tail-water FMS design and the construction of further improved FMS facilities for:

- (IDSW) Snake River at the tailwater of Ice Harbor Dam.
- (LMNW) Snake River at the tailwater of Lower Monumental Dam.
- (LGSW) Snake River at the tailwater of Little Goose Dam.
- (LGNW) Snake River at the tailwater of Lower Granite Dam.
- (ANQW) Snake River near the Anatone Gage.
- (PEKI) Clearwater River near the Peck Gage.

Background

Measurement of water quality parameters (DO, temperature, TDG, and, recently, depth of station) has evolved over the last 20 plus years. In the early 1980s, the TDG equipment used in monitoring consisted primarily of analog scaled voltage readings. The equipment averaged true accuracies of ±5 millimeters of mercury (mm Hg for TDG), ±0.7 °C, and DO was accurate to ±2 milligrams per liter (mg/L) most of the time. Maintenance was, at times, troublesome and costly. In many cases, the maintenance was done at 1- to 2-month cycles. A significant increase in reliability and accuracy required new instrumentation and a better QA program. In 1996, CENWD headquarters relinquished the task of data collection to the districts. This reorganization proved successful, and a very close partnership has developed between CENWD Water Management, the districts, and their prospective contractors such as the U.S. Geological Survey (USGS) and HDR Engineering. The USGS (Pasco Field Office) is tasked with providing rental data collection platforms (DCP) and accessories. HDR provides bi-monthly service and Quarterly QA/QC reports (appendixes A, B, and C).

Water managers use the data to maintain water quality conditions that facilitate fish passage and survival in the lower Columbia River. The official U.S. Government for the TDG, DO, and water temperature data can be found on the CENWD Web site at: http://www.nwd-wc.usace.army.mil/.

Many other government agencies and private organizations have links to our database or download portions of the database for their personal use. Data from all other sites are provisional and not considered to be complete or accurate. Some agencies use a direct link to the Water Management On-line report page but the official data site still resides at the North Pacific Regional Office Water Management Web Page.

The CENWD, North Pacific Region (NP), published reports annually from 1985 to the present containing descriptions of the methods of data collection and discussions of key factors influencing management decisions. To provide a suitable data set for managing and modeling TDG in the CENWD-NP, real-time hourly data for Water Year 2002 were reviewed in relation to measurements made during instrument calibration and quality checks. Some of the data points were assigned QA failure codes because they were not of suitable quality and did not meet the CENWW DQO. The CENWW staff for quality evaluates the reviewed hourly data Monday through Friday (except federal holidays). Data failing to meet the DQOs is flagged and included in the appendixes D, E, and F of this report.

Purpose and Scope

The purpose of gas monitoring is to provide managers, agencies, and interested parties with near real-time data for managing stream flows and TDG levels downstream from Federal dams. 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 data for current and future decision processes.

This report describes the data collection methods and evaluates QA/QC data for the TDGMS that includes the McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite reservoirs. Additionally, this system provided water quality data for the Clearwater River downstream of Dworshak Dam, the Columbia River near Pasco, and the Snake River near

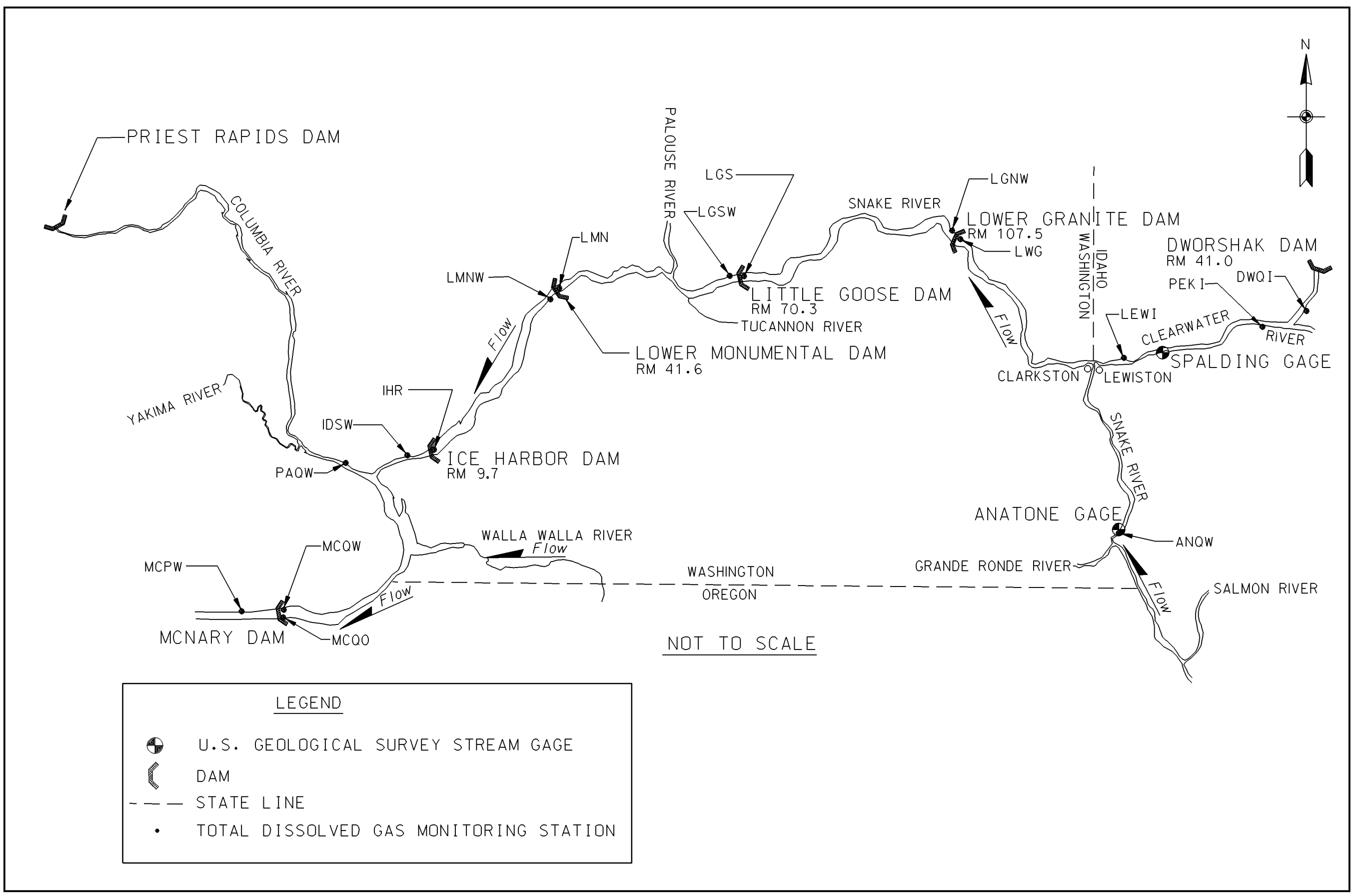

Figure 1 - Map of All Fixed Monitoring Stations.

Anatone, Washington (see table 1 and figure 1). This report was designed to document data quality of the TDGMS for Water Year 2002. Measurements include TDG pressure, DO, barometric pressure, and water temperature at 16 sites.

The QA/QC data are divided into three categories:

1. Comparative Data. This information gives CENWD-NP a means to compare CENWW data quality against their minimum DQO. The format and presentation of this comparative data allows cross comparison of data quality against similar data collected in other districts and agencies. This report also provides a beneficial means of sharing improvements between USACE districts and agencies. This data comprises the majority of numerical and graphical representations found in the main body of the report.

2. Instrument Data. These data are used to evaluate how an instrument

Station Name	Date Est	River Name	River Mile	Bank	Latitude	Longitude	Dam	Quad Map Name	Location
ANQW	1998	Snake	167	Left	46° 05' 50	116° 58' 36	Lower Granite	Limekiln Rapids, ID	River
DWQI	1994	North Fork, Clearwater	40	Left	46° 30' 11	116° 19' 18	Dworshak	Ahsahka, ID	Tailwater
IDSW	1990	Snake	6	Right	43° 14' 32	118° 56' 20	Ice Harbor	Humorist, WA	Tailwater
IHR	1984	Snake	10	Mid-River	46° 14' 58	118° 52' 42	Ice Harbor	Levey SW, Levey, & Slater WA	Forebay
LEWI	1996	Clearwater	4	Right	46° 26' 06	116° 57' 36	None	Otis Orchards, ID	River
LGNW	1990	Snake	107	Right	46° 39' 58	117° 26' 18	Lower Granite	Almota, WA	Tailwater
LGS	1984	Snake	70	Mid-River	46° 35' 05	118° 01' 32	Little Goose	Starbuck East, WA	Forebay
LGSW	1990	Snake	69	Right	46° 34' 59	118° 02' 31	Little Goose	Starbuck East, WA	Tailwater
LMN	1984	Snake	42	Mid-River	46° 33' 47	118° 32' 14	Lower Monumental	Lower Monumental Dam, WA	Forebay
LMNW	1990	Snake	41	Left	46° 33' 13	118° 32' 51	Lower Monumental	Lower Monumental Dam, WA	Tailwater
LWG	1984	Snake	108	Left	46° 39' 33	117° 25' 30	Lower Granite	Almota, WA	Forebay
MCPW	1990	Columbia	291	Right	45° 56' 00	119° 19' 30	McNary	Umatilla, OR-WA	Tailwater
MCQO	1986	Columbia	292	Left	45° 55' 58	119° 17' 43	McNary	Umatilla, OR-WA	Forebay
MCQW	1985	Columbia	292	Right	45° 56' 25	119° 17' 47	McNary	Umatilla, OR-WA	Forebay
PAQW	1998	Columbia	329	Left	46° 13' 32	119° 07' 25	McNary	Pasco, WA	River
PEKI	1996	Clearwater	36	Left	46° 32' 26	116° 23' 31	Dworshak	Southwick, ID	River

Table 1 - TDG Fixed Monitoring Stations.

performs based on the magnitude and direction that the individual sensors deviate over time from their respective laboratory standards. These relationships are measured for each sensor during the calibration procedures, which usually occur every 2 weeks. More detailed information presented can be found in the appendix B of this report and is intended for CENWW, Operations Division, use.

3. Station Data: These data present the comparison between an in-place instrument that has been deployed at a given station for a 2-week cycle and a newly calibrated QA/QC instrument (field standard). The Honeywell® barometers at each station were also evaluated using the Surveyor 4® that serves as a portable field standard for barometric pressure. In the summer (1 April to 15 September), 16 stations were visited for maintenance two times per month. In the winter (16 September to 30 March), 9 stations were maintained on the same bi-weekly schedule. More detailed information can be found in the appendix C of this report and is intended for CENWW, Operations Division, use.

Acknowledgements

The authors would like acknowledge Mr. Greg Rupert, Mr. Andy Records, and Mr. Joe Bunt, our gage co-operators from the USGS, for providing the quality DCP used in transmission of our data to the Regional Database. Thanks go to Ms. Patsy Poe for her help here at the CENWW office with our life support requirements. Thanks to Mrs. LaRhonda McCauley for the assembly and publishing of the manuscript. And our very special thanks go to Mrs. Julie Dockery, Mrs. Yvonne Finely, and Mrs. Charlene Duncan from the CENWW, Contracting Division.

METHODS OF DATA COLLECTION

Methods of data collection for TDG, barometric pressure, and water temperature are described in detail in Heaton *et al.*, 2001. The instrumentation at each FMS consisted of a Hydrolab water quality probe; a Honeywell® PPT16 electronic barometer; a power supply; and a Sutron® Model 8210 DCP. A 12-volt battery that was charged by a solar panel and/or a 120-volt alternating-current line powered the barometer, probe, and DCP. Every 4 hours, the DCP transmitted the most recent logged data to the Geo-stationary Operational Environmental Satellite (GOES) system (Jones *et al.*, 1991). The data were automatically decoded and transferred to the USACE Columbia River Operations Hyudromet Management System (CROHMS) database.

The Hydrolab Minisondes used in the TDGMS are programmed to report TDG, DO, and temperature. In addition, a Surveyor 4® instrument is used as a field standard to evaluate station barometer performance. The TDG sensor measures the sum of the partial pressures of gaseous compounds dissolved in the water and reports the result in mm Hg. The TDG sensor requires a two-step calibration procedure. This means that adjustments are made at two points on the calibration curve in order to calibrate the sensor. In this report, the atmospheric pressure calibration point is referred to as Base TDG and the pressurized calibration point corresponds to Pressurized TDG (Pres TDG). For TDG sensor calibration, the base point is equal to the atmospheric pressure at the time of calibration as measured utilizing a wall-mounted mercury barometer or recently calibrated Surveyor 4® instrument. The Pres TDG point is equal to the barometric pressure plus a standard value that is chosen to include the full range of TDG values expected to be measured in the field by the sensor. In most cases, a standard of 200 and 300 mm Hg added to barometric pressure will create a slope capable of interpolating the full range of expected field values. In the winter months, the 100 and 200 mm Hg points are used for a tighter calibration curve. The Heise™ certified pressure calibrator (primary standard) is used to apply pressure to the TDG sensor.

Each sonde contains a sensor for reporting water temperature. The results are reported in degrees Celsius (°C). Sonde thermometers are factory calibrated. HDR does not make adjustments to the temperature sensor calibration. Therefore, HDR can only assess temperature sensor performance by comparing their readings to a National Institute for Standards and Traceability (NIST) mercury thermometer standard.

A DO probe measures the concentration of oxygen present in water. The sonde reports the DO results in percent of saturation (% sat) and mg/L. This report only contains an evaluation of the station comparison DO data.

Barometric pressure is used as a non-float zero point for calibrating the TDG and DO sensors. It is also an important value used in calculating the percent of TDG saturation. HDR maintains performance records for the wall-mounted mercury barometer located at HDR, the Surveyor 4® instrument used for fieldwork, and the Honeywell® barometers at each station. Calibration data is also maintained for the Surveyor 4®, which is the only barometric pressure-sensing device that is calibrated by HDR.

Calibration curves can change over time; hence, the need for calibration checks and adjustments. However, when the magnitude of the change is greater than the manufacturer specified precision limit for a sensor, this may indicate a previous calibration error or a faulty sensor. HDR does not calibrate temperature sensors.

INSTRUMENTATION PERFORMANCE CONTROL DATA

It is important to recognize the difference between calibration data and performance data. Performance Data is collected each time a sensor is compared to its standard or when two instruments are compared at a given station. These values represent the measured difference between two readings and are keyed with the term Delta. Delta values reflect the ± variation of sensor readings from their respective standard (*e.g.*, a negative value indicates that the sensor or instrument was reading below its respective standard).

INVENTORY-WIDE SONDE PERFORMANCE

A total of 90 records were included in this report’s inventory-wide summary statistics. See figure 2 for inventory-wide sonde data performance charts and summary statistics.

The results of the analyses performed on the TDG sensor performance data (table 2 and figures 2 and 4) indicate that the population of TDG sensors is continuing to meet the DQO of 2.0 mm Hg. The calculated quarterly mean and standard deviation (SDV) for Delta Base TDG were -0.1 mm Hg and 0.9 mm Hg, respectively. The calculated quarterly mean and SDV for Delta Pres TDG were -0.0 mm Hg and 0.8 mm Hg, respectively. This means that, on average, the difference between a Base TDG sensor reading and the standard (BAR) during calibration was -0.1 mm Hg for all of the TDG calibrations performed during this reporting period. Both the Base and Pres TDG monthly mean values are well within the acceptable error for the sensors.

The results of the quarterly analyses performed on the temperature sensor data indicate that the quarterly mean delta temperature was -0.1 °C with an SDV of 0.1 °C. The population of thermistors has proven to be very reliable.

The current (2002 Fourth Quarter) data confirms that there is a 95 percent confidence interval that any instrument in the inventory can be deployed at a station for 2 weeks and, when checked, will vary from the standard by -0.1 ±1.7 (2 SDV) mm Hg for Base TDG, -0.0 ±1.60 (2 SDV) mm Hg for Pres TDG, and -0.1 ±0.2 (2 SDV) °C for temperature. Both the population of TDG and temperature sensors are performing within their respective DQOs for this year; TDG ≤ ±2.0 mm Hg and temperature ≤ ±0.2 °C. The recorded precision levels for the TDG sensors and thermistors are also below the accuracy specifications set by the manufacturers.

INSTRUMENTATION CALIBRATION DATA

Calibration procedures only take place after recording the performance data described above. Calibration Data reflects the actual adjustments that take place when a sensor is calibrated to correct for drift. These values are keyed with the term Adjustment because they represent an actual adjustment to the

Reporting Period	(n)*	Mean Delta Base TDG (mm Hg)	Stdev Base TDG (mm Hg)	Mean Delta Pres TDG (mm Hg)	Stdev Pres TDG (mm Hg)	Mean Delta Temp (ºC)	Stdev Temp (ºC)
1st Quarter	14	-0.3	0.6	-0.3	0.6	-0.1	0.1
2nd Quarter	42	-0.1	1.1	-0.1	1.1	-0.1	0.1
3rd Quarter	99	-0.2	0.5	-0.2	0.5	-0.1	0.1
4th Quarter	90	-0.0	0.9	-0.0	0.9	-0.1	0.1
Cumulative '02	245	-0.1	0.8	-0.1	0.8	-0.1	0.1
Cumulative '01	274	0.0	0.7	0.0	0.7	-0.1	0.0
Cumulative '00	204	0.1	1.1	0.3	1.1	-0.0	0.1

* (n) = total number of records entered in a month; not all records are complete for all parameters

Table 2 - Total Sonde Inventory Cumulative Control Chart Data for TDG and Temperature Parameters, Water Year 2002.

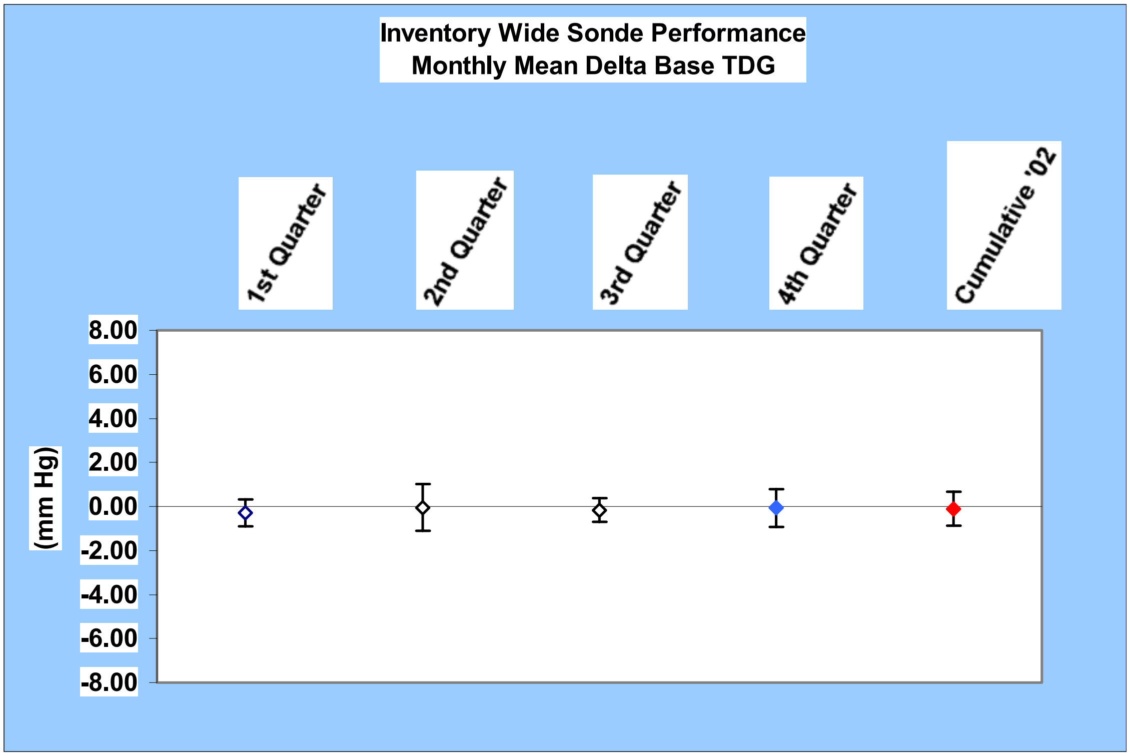

Figure 2 - Cumulative Adjustments of Offset Points from the Total Sonde Inventory, Water Year 2002.

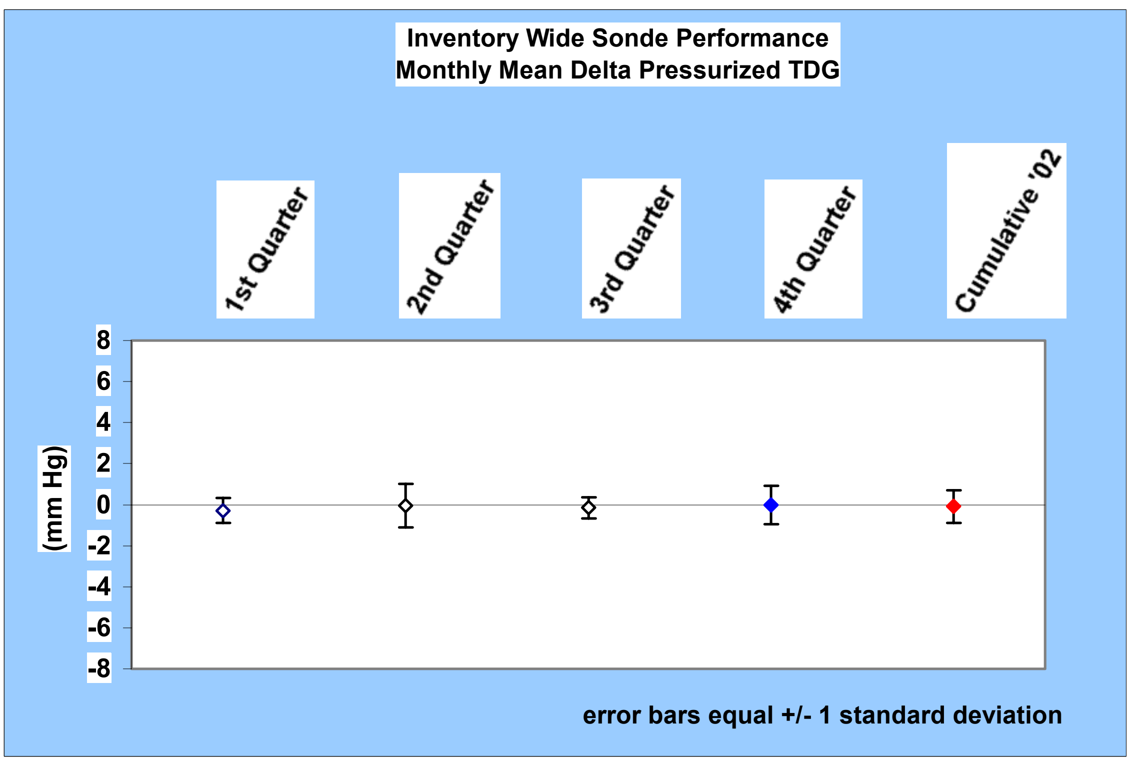

Figure 3 - Cumulative Adjustments of Slope Points from the Total Sonde Inventory, Water Year 2002.

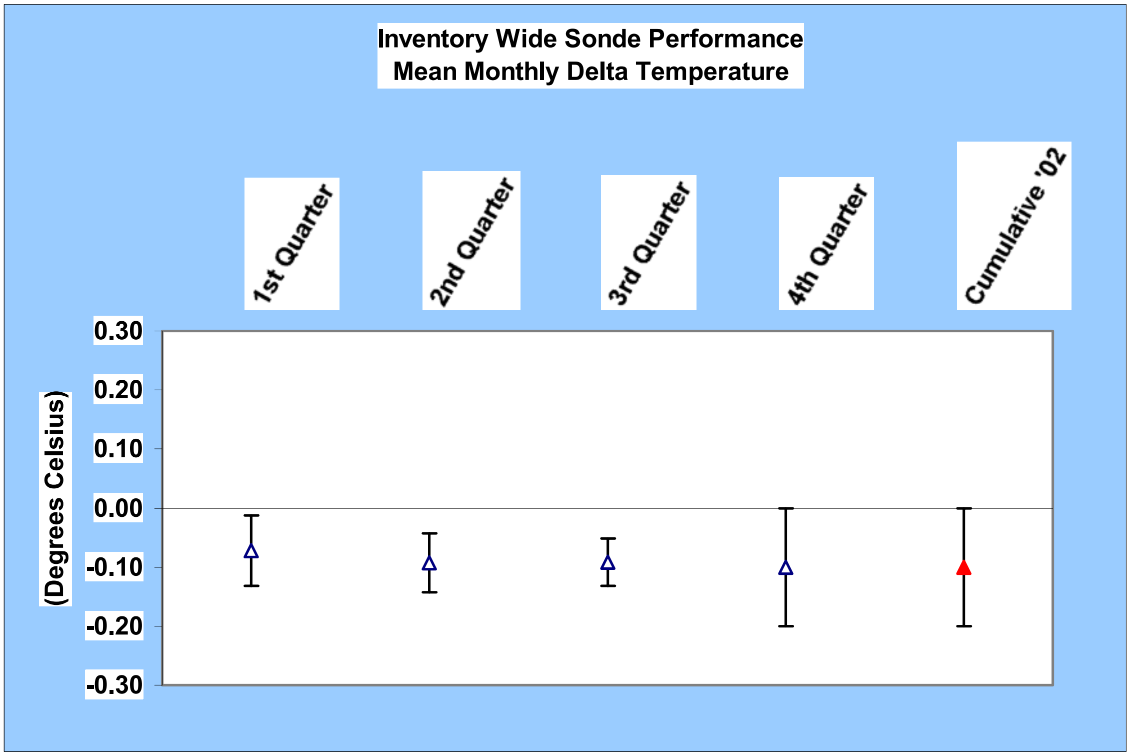

Figure 4 - Analysis of Variance of Temperature Quality Control Charts from the Total Sonde Inventory, Water Year 2002.

calibration curve. A positive adjustment indicates that the sensor was reading below the standard (equivalent to a negative performance value) and required a positive adjustment. Adjustment and Delta values will always have opposite signs but should be the same number.

SYSTEM-WIDE STATION PERFORMANCE

A total of 90 records were included in this report's system-wide summary statistics. The system-wide sonde data, performance charts, and summary statistics can be found in appendix C. The results of the analyses performed on the station comparison data indicate that the quarterly mean delta for TDG comparisons was -0.53 mm Hg with an SDV 3.12 mm Hg. These values meet the DQO of ≤ ±4 mm Hg TDG for station comparisons.

The quarterly mean delta value for DO was calculated to be -0.17 mg/L with an SDV of 0.70 mg/L. Thirty-two of the 90 DO delta values exceed the DQO for DO of ≤ ±0.50 mg/L. This seems to result from dirty deployment systems. The high DO readings are a result of significant algal growth in the deployment pipes of the forebay stations and the filling of the tailwater stations with sediment and algae. This problem is somewhat fixed by the new deployment systems.

The quarterly mean delta value for temperature was calculated to be -0.0 °C with an SDV of 0.1 °C. This is well below the DQO of ≤ ±0.2 °C for station temperature comparisons.

The quarterly mean delta value for station BAR was calculated to be +1.2 with an SDV of 1.8 mm Hg.

Reporting Period	(n)*	Mean Base Delta TDG (mm Hg)	Stdev Base TDG (mm HG)	Mean Delta DO (mg/L)	Stdev DO (mg/L)	Mean Delta Temp (ºC)	Stdev Temp (ºC)	Mean Delta BAR (mm Hg)	Stdev BAR (mm Hg)
1st Quarter	14	-0.1	1.6	-0.33	0.51	0.0	0.1	1.6	4.2
2nd Quarter	42	-0.2	1.3	-0.21	0.50	-0.0	0.1	0.5	3.3
3rd Quarter	99	0.1	1.7	-0.24	0.69	-0.0	0.1	0.4	1.3
4th Quarter	90	-0.5	3.1	-0.17	0.70	0.0	0.1	1.2	1.8
Cumulative '02	245	-0.2	2.3	-0.21	0.65	0.0	0.1	0.8	2.8
Cumulative '01	274	-0.1	1.8	-0.28	0.59	-0.0	0.1	0.5	2.2
Cumulative '00	240	0.1	2.4	n/a	n/a	0.0	0.1	n/a	n/a

* (n) = total number of records entered in a month; not all records are complete for all parameters
n/a - not applicable

Table 3 - All Fixed Monitoring Stations Cumulative Control Chart Data for TDG, DO, BAR, and Temperature Parameters, Water Year 2002.

The performance data for the station barometers is up from last quarter. All the station barometers were calibrated at the beginning of the third quarter.

The calibration of the barometers brought a significant decrease in the delta values between the second and third quarter and now the delta values are starting to rise again.

After collecting a full year's worth of data, it will tell how often the station barometers need to be calibrated.

The current (2002 Fourth Quarter) data confirms that, within a 95 percent confidence interval during simultaneous comparison at any station, the in-place instrument will vary from a QC instrument by -0.5 ±6.2 (2 SDV) mm Hg for TDG, -0.0 ±0.2 (2 SDV) °C for temperature, and -0.17 ±1.40 (2 SDV) mg/L for DO.

MONTHLY QUALITY CONTROL CHARTING AND CALCULATIONS

The volume of data collected for any specific instrument or station on a monthly basis is not sufficient to perform meaningful calculations. To increase the number of values (n) for each statistical analysis, all of the station data entered into the QA/QC database in a particular month are combined to evaluate "System-Wide Station Performance." Likewise, all of the instrument data points entered into the QA/QC database in a particular month are combined to evaluate the "Inventory-Wide Sonde Performance."

Inventory-wide sonde performance control charts evaluate the performance data for the entire population of TDG sensors and thermometers. Delta values are calculated for each parameter by subtracting the appropriate standard from the observed pre-calibrated sensor reading collected during instrument calibration. Once the delta values are calculated, they are averaged on a monthly basis to calculate a monthly mean delta for each parameter. The standard deviation is also calculated for each parameter on a monthly basis. The following equations summarize the above description.

- Delta Base TDG = [Pre-Calibrated Base TDG] - [Atmospheric Pressure]
- Delta Pres TDG = [Pre-Calibrated Pres. TDG] - [Pressurized Standard]
- Delta Temperature= [Sonde Temperature] - [NBS (National Bureau of Standards) Standard Temperature]
- Monthly Mean Delta = [Sum of Deltas for X] / (n) where n = number of delta for parameter X values for parameter X from entire sonde inventory
- Standard Deviation = (SDV)

$$\sqrt{\frac{n\sum x^2 - \left(\sum x\right)^2}{n(n-1)}}$$

Where *x* = Delta for any parameter

The monthly sonde performance control charts display the monthly mean delta values plotted for each parameter versus time (calibration date). Each chart represents one parameter and contains one data point per month. The y-error bars presented on the charts represent ±1 standard deviation for the corresponding mean. The monthly inventory-wide sonde performance data, charts and tables are contained in table 2 and figure 2.

The performance QC of an FMS is measured by comparing two instruments at a specific FMS at the same time, then subtracting the QA/QC sonde (standard) readings from the in-place instrument readings to calculate the delta values for TDG, DO and temperature. The QA/QC sonde is considered the standard because, of the two instruments being compared, it was the one most recently calibrated in the lab. The Honeywell® barometers at each station are also evaluated by subtracting the Surveyor 4® readings (transfer standard) from the station barometer readings. Once the delta values are calculated, they are averaged on a monthly basis to calculate a monthly mean delta for each parameter. The standard deviation is also calculated for each parameter on a monthly basis. The following equations summarize the above description.

- Delta TDG = [In-place Sonde TDG] - [QA/QC Sonde TDG]
- Delta DO mg/L = [In-place DO mg/L] - [QA/QC DO mg/L]
- Delta Temp = [In-place Temperature] - [QA/QC Temperature]
- Delta BAR = [FMS Honeywell® BAR] - [Surveyor 4 BAR]
- Monthly Mean Delta = [Sum of Deltas for X] / (n) where n = number of delta for parameter X values for parameter X from entire TDGMS
- Standard Deviation = (SDV)

$$\sqrt{\frac{n\sum x^2 - \left(\sum x\right)^2}{n(n-1)}}$$

Where *x* = Delta for any parameter

The system-wide FMS performance control charts display the monthly mean deltas plotted for each parameter versus time (deployment date). Each graph represents one parameter and contains one data point per month. The y-error bars presented on the charts represent ±1 standard deviation for the corresponding mean. The monthly system-wide station performance data, charts, and tables are contained in appendix C.

SONDE-SPECIFIC PERFORMANCE

As of print, 28 sondes are active in the TDGMS inventory and are numerically designated #1 through #30. Of these, 22 are fully operational and 3 are in need of repair. Of the 3 sondes that need repair, 1 is down with a bad DO sensor, and the other 2 are down with temperature sensors that are reading out side of the DQO. Sonde #24 has been permanently removed from the inventory. Sonde #9 and sonde #22 are being parted out and eventually will be removed from the inventory. The ghost (assembled from spare parts) is being added to the inventory as sonde #30.

Control charts are plotted for instruments that have accumulated three or more completed data sheets between the beginning of the monitoring year and the end of the current reporting period. At the close of the fourth quarter of 2002, 19 of the instruments met this criterion. Sonde-specific performance charts are included in appendix B. Eight sondes do not have performance charts as explained by the table included in appendix B.

QUARTERLY CONTROL CHARTING AND CALCULATIONS

Quarterly reports contain a sufficient quantity of data to evaluate the performance of an individual instrument or station. The TDG sensor calibration data and thermometer performance data for each instrument are plotted versus time (calibration date) in order to evaluate "Sonde-Specific Performance." Likewise, the station performance data collected at individual stations are plotted to evaluate "Station-Specific Performance."

A sonde-specific control chart is plotted for each instrument that has accumulated three or more completed data sheets between the beginning of the monitoring year and the end of the current quarter. Each sonde control chart contains thermometer *performance* data and TDG sensor *calibration* data. The Base and Pres TDG *Net Cumulative Adjustment* (Net Cum Adj.) data are also represented on the graph, each as a line. The Net Cum Adj. calculation reflects the cumulative adjustments made over time to the base and pressurized points of a particular TDG sensor's calibration curve. Plotting this trend provides insight about the bias of a sensor (tendency to drift over time in a particular direction in relation to the standard).

The *Delta* calculation is performed on the temperature data because the user does not calibrate the thermometers (no adjustments are made). An *Adjustment* calculation is performed on the TDG calibration data. The Adjustment values represent the magnitude and direction that the base and pressurized points of a TDG calibration curve are adjusted to match their respective standards. The adjustment value is calculated by subtracting the pre-calibrated TDG readings from the calibrated TDG readings. The Net Cum Adj. value is calculated by adding each new Base or Pressurized TDG Adjustment value to the sum of the values above them in their respective columns. The same equations previously mentioned were used to calculate the statistical numbers.

Appendix B contains the sonde-specific performance charts. Each chart represents one instrument and displays the actual delta Temp and TDG adjustment values plotted over time (calibration date). Net Cum Adj. calculations are represented as lines on the chart.

The FMS control charts plot the delta values calculated for each parameter compared between the in-place and QA/QC instruments during site visits at individual stations. Again, the QA/QC sonde is used as the standard to compare TDG, DO, and temperature with the in-place instrument, while the Surveyor 4® is used as a standard for barometric pressure to evaluate the precision of the barometers at each station. An FMS control chart is plotted for each station that has accumulated three or more completed data sheets between the beginning of the monitoring year and the end of the current quarter. The following equations summarize the above description.

- Delta TDG = [In-place Sonde TDG] - [QA/QC Sonde TDG]
- Delta DO mg/L = [In-place DO mg/L] - [QA/QC DO mg/L]
- Delta Temp = [In-place Temperature] - [QA/QC Temperature]
- Delta BAR = [Station Honeywell® BAR] - [Surveyor 4 BAR]

Appendix C contains the station-specific performance charts. Each chart represents one station and displays the actual delta values for each parameter plotted versus time (deployment date).

DEFINING AND USING OUTLYING, INVALID, AND MISSING DATA VALUES

An outlying data point is any parameter value that exceeds the DQO for that parameter. These values reflect correctible or inherent sources of error in the maintenance procedures, instruments, standards, or stations. All of the outlying data values are included in the QA/QC summary statistics.

The CENWW used the following DQOs: For sonde calibration delta values, the DQOs are delta TDG $\leq \pm 2$ mm Hg and delta Temp $\leq \pm 0.10$ °C. Station comparison DQOs are $\leq \pm 4$ mm Hg for delta TDG, $\leq \pm 0.20$ °C for delta Temp, and $\leq \pm 0.50$ mg/L for delta DO. The DQOs for the barometers were set at $\leq \pm 2$ mm Hg.

Not all data reported by the instruments are included in the QA/QC summary statistics. A class of data, designated as invalid data, includes data values associated with malfunctioning sensors or other inoperative conditions. The technician is responsible for identifying these occurrences. Although not included in QA/QC summary statistic calculations, invalid data values are plotted on sonde-specific and station-specific charts and are listed in tables 2 and 3 for reference.

In some cases, particular data points may not be collected during instrument calibration or site visits. For example, stations that go off-line in the winter do not contain an in-place instrument at the beginning of the summer maintenance season; therefore, a comparison cannot be performed during the initial site visit. Another instance occurs when a sensor fails prior to site visitation preventing a value for that parameter from being recorded. Missing data values are designated with the symbol *(ND)* on tables 2 and 3. Blanks created in the record are not included in QA/QC summary statistics. A description of each missing data value is listed in appendix F.

Call Letters	Station Name	Possible Hours	Percent of realtime data received within 24hrs	Percent of Data Passing QA/QC
MCPW	McNary tailwater	8760	99.65	99.45
MCQO	McNary Oregon forebay	8760	99.53	97.81
MCQW	McNary Washington forebay	8760	99.85	99.53
PAQW	Columbia River at Pasco	8760	99.33	97.48
IDSW	Ice Harbor tailwater	8760	98.46	97.44
IHR	Ice Harbor forebay	8760	98.84	97.72
LMNW	Lower Monumental tailwater	4560	99.91	99.61
LMN	Lower Monumental forebay	4560	100.00	99.56
LGS	Little Goose forebay	4560	100.00	99.89
LGSW	Little Goose tailwater	4560	99.91	99.74
LGNW	Lower Granite tailwater	8760	99.46	98.74
LWG	Lower Granite forebay	8760	93.76	92.72
ANQW	Snake River at Anatone	4560	82.59	82.19
LEWI	Clearwater River at Lewiston	4560	100.00	98.87
PEKI	Clearwater River at Peck	4560	100.00	99.78
DWQI	Dworshak tailwater	8760	99.53	99.2
	Average		98.18	97.48

Table 4 - Completeness Table.

It is important to have the ability to view trends that may occur between outlying data points and any particular instrument or station. Being able to identify these trends is what turns this entire data management system into a dynamic management tool. To accomplish this, it is necessary to view a column of delta values, sorted by magnitude, adjacent to the appropriate reference information. For example, it might be useful to see if all of the outlying delta TDG values can be correlated with a particular instrument or group of instruments.

SUMMARY OF DATA COMPLETENESS AND QUALITY

Year-end summaries of water year 2002 TDG data completeness and data quality are shown in table 4. Data in this table are based on the total amount of hourly TDG data and barometric pressure data that could have been collected during the scheduled monitoring season (appendixes G and H). At all part-year stations, more data were collected than were scheduled because the monitors were set up early to ensure correct operation. Any hour without TDG-pressure data or barometric pressure data was counted as an hour of missing data for TDG in percent saturation (which is calculated as TDG pressure in millimeters of mercury, divided by the barometric pressure, in millimeters of mercury, multiplied by 100). The percentage of real-time data received and shown in table 4 represents the data that were received via satellite telemetry at the Corps' satellite downlink called the DOMSAT.

At each FMS, most of the data was received 99 percent of real-time by the DOMSAT downlink, with an overall average of 98.18 percent (table 4). Problems with the amount of real-time data received at the Lower Granite forebay FMS was due to interference with another GOES user transmitting on the same frequency, channel, and transmit time slot belonging to this FMS for the purpose of the TDGMS. Instrument malfunctions or mistakes in programming of the data-collection platform were but a small percentage of the documented data gap.

The Anatone FMS came off-line in the last part of August and remained off-line the rest of its operational season. Several factors contributed to the problem. Heavy silt buildup and fractures in the polyvinyl chloride (PVC) protective instrument pipe well caused the pipe to fail in two locations during early spring periods of high flow. The instrument then was outside of the pipe for the rest of the season. During the month of September, the data cable at Anatone was severed at the overhead run to the instrumentation house on the opposite side of the road. With the extent of damage to the station, this FMS remained off-line for the rest of the monitoring season. The Anatone FMS was completely reconstructed in late September with the exception of the overhead data cable run.

QUALITY ASSURANCE

Data collection for TDG, barometric pressure, water temperature, and DO included several QA procedures, such as the calibration of instruments in the field and in the laboratory, daily checks of the data, and data review and archival. After field deployment for 2 weeks, the TDG sensors were calibrated in the laboratory. First, the unit was tested, with the membrane in place, for response to increased pressure and to supersaturation conditions. The membrane was then removed from the sensor and allowed to dry for at least 24 hours. The CENWW lab has a ratio of 2.4:1 membrane cartridges to sondes to ensure enough spares and availability of dry membranes for deployment. Before installing the dried membrane, the TDG sensor was examined independently. The calibration test procedure involved reading the TDG sensor at the barometric pressure (100 percent saturation) and, using the Heise™ certified digital pressure calibrator (primary standard), at added pressures of 100, 200, and 300 mm Hg (approximately 113 percent, 126 percent, and 139 percent saturation, respectively).

The accuracy of the TDG sensors was calculated by computing the difference between the expected reading and the Hydrolab TDG sensor reading for each of the test conditions. The differences in barometric pressure, water temperature, and TDG between a secondary standard instrument and the fixed-station monitors after 2 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. For water temperature, DO and TDG, the measurements were made in situ with the secondary standard (a recently calibrated Hydrolab) positioned alongside of the field Hydrolab in the river.

The DO sensor at the end of their 2-week deployment received a fresh membrane and potassium chloride electrolyte recharge in the lab prior to recalibration. Each of the recharged DO sensors was allowed to soak for 24 hours in standard tap water to ensure the membrane and electrolyte equilibrated with anode's electrical potential. Under the controlled laboratory conditions, the sensor is calibrated in 100 percent saturated water at 25 °C ±0.1 inside a barometric pressure stable room. Random sonde units are selected from the pre-deployment instrument pool and evaluated for stability and accuracy by Winkler (Pomeroy modification) titration. Both normal and supersaturated tap water is used in this QA random check.

The ancillary parameters to the TDG and DO parameters receive their own QA checks. Temperature sensors were checked against the NBS sensors in the laboratory prior to deployment. Sensors failing QA tests were not used and were sent to the manufacturer for repair or rehabilitation. Calibration of the depth sensor consisted of zeroing at ambient barometric pressure and checks at 1 and 2 feet. Substantial damage to the tailwater FMS were identified during routine QA checks. The extent of the bias that occurred under some conditions will be discussed later.

DISCUSSION

Charts of temperature, DO, and TDG saturation were constructed using a simple plotting program written in Pascal. The charts were then used to develop the most relevant topics for discussion of the measurements for water year 2002. The discussion is arranged by the parameters in order of the corresponding appendix I with the topic of the site-specific considerations and planned actions for next water year.

Variability of Dissolved Oxygen in the Forebays

The comparisons of Lower Granite FMS, other Lower Snake River FMSs, and the Anatone FMS sites, demonstrated the expected diurnal change associated with photosynthetic activity in the forebays. The DO concentration also increased ratio-metrically with the TDG concentration increases due to spill. The DO concentrations on the Lower Snake River are of relevance due to the aquatic life dependent upon a reasonable level of oxygen saturation for their survival just as humans require oxygenated air to breath and survive. From March through June, oxygen concentrations ranged from 13 mg/L to 9 mg/L. In July, it was expected that photosynthetic activity would maintain a higher DO concentration in the forebays. In August and September, the Lower Granite FMS oxygen measurements increased with the expected seasonal succession of algal communities. The comparisons of the tailwater concentration of DO plots show a relative stable DO concentration from March to middle June. After middle June, the tailwater DO concentrations steadily decrease until late August and September, and the concentration falls as low as 6.0 mg/L. This could be a significant water quality problem for CENWW and should be further evaluated. The Hydrolab® DO sensors have several limitations that prevent the authors from fully quantifying the variation of oxygen concentrations vertically and spatially. There were no limnology data collection this year to capture the change and variation in the algae and chemical variations resulting in the physical effects measured by the TDGMS. What is needed for next year is limnology data and vertical seasonal profiles of the forebay FMS sites. None of this can be accomplished with the current Hydrolab® DO sensors since the

DO measurements are currently outside the DQO for this program.

Variability of the Temperature Measurements throughout the Total Dissolved Gas Monitoring System

The CENWW measured water temperature at the various stream gage sites at the tributaries of the Snake and Columbia Rivers. A large body of knowledge relevant to the seasonal variations is available to the Hydrology Section. Included in the (appendix I) temperature plots is a single summary Lower Snake River temperature plot for water year 2002. The comparison charts of the four Snake River dam's tailwater were similar [within a few degrees Fahrenheit (°F)]. By June the Lower Snake River water temperature showed that the Anatone FMS recorded as much a 7 degrees increase over the Lower Snake River dams. The temperature sites provided data that suggests earlier temperature findings are statistically sustained.

Variability of Total Dissolved Gas Measurements

The comparison charts in appendix I were used to evaluate and discuss the physical TDG components, summarily called effects. Charts for all the Lower Snake River dams were plotted to compare the forebay and tailwater and evaluate the cumulative effects. The month of April 2002, showed the best view of the variability of the comparisons. Subsequent months were usable but other factors that could not be quantified exacerbated the process of comparison. The plots suggest by comparing the forebay to tailwater TDG ratio, there could be a cumulative effect as the water moves through the Lower Snake River. This does not agree with other reports and should be further evaluated in subsequent CENWWs TDG monitoring reports. It should be noted that the plots the authors used to make the evaluation were cross-compared to discharge and spill hydrologic data directly correlated by time and date.

The Pasco and Anatone FMS were installed 4 years ago to measure the saturation of the waters flowing into the CENWW TDGMS. Comparisons were plotted for McNary versus Pasco FMSs and Anatone versus Lower Granite FMSs. The charts plotted for May, June, and July 2002 showed the Anatone and Pasco stations with TDG readings above 110 percent. This demonstrates that water with higher TDG concentrations enter into CENWWs TDGMS monitoring site already supersaturated.

At this time, we cannot account for other sources of error or bias in the measurement. Barometric pressure is used in the calculation of the TDG percent saturation. The standard error in the measurement compounds both environmental bias and instrument variability. Before a further explanation can be made, it is necessary to install new barometer instrumentation at the FMS sites. The current Honeywell® units have been used for 7 to 8 years and reached their effective life span. The manufacturer no longer services the instruments, and they are in need of service. Another problem with the barometers is the use of the Hydrolab Surveyor 4® as a transfer standard. However, the most significant limitation in the comparisons is the use of percent saturations as a measurement. Most experts in this field all recognize the best scale of measurement for the total gas pressure is the use of the delta pressure (Δp) (D'Aoust, 1975, Weitcamp Katz, 1980, APHA 1998).

SITE-SPECIFIC CONSIDERATIONS

There are two types of site-specific considerations relevant to the QA of the TDGMS measurements. The first type is the bias produced through instrumentation use and physical considerations of the FMS measurement apparatus itself. The second type of site-specific consideration is the influences of the environment the measurement is extracted from. An example of these are: altitude influences on barometers; nutrient and phytoplankton influences on DO; or the watershed riparian foliage affecting the thermal loads to streams, thus, influencing water temperature readings. If an error exists associated with the type one consideration, you cannot quantify the error in the type two site-specific consideration. The CENWW TDGMS needs to overhaul a majority of their tailwater stations and evaluate the efficacy of its forebay stations for applicability and representation of the average condition. While the instrumentation bias is accurately quantified in this report, some amount of bias exists due to fractured pipes. The silt buildup in some pipes have contributed to a potential problem with flow.

PROPOSED CHANGES AND PLANS FOR NEXT WATER YEAR

As previously stated in the introduction of this report, 6 out of the 10 tailwater/gage FMSs were rebuilt at the end of the monitoring season. Next year, the remaining four will be rebuilt to the same standard as the other six: Columbia River at Pasco (PAQW); McNary tailwater (MCPW); Clearwater at Lewiston (LEWI); and Dorsal tailwater (DWQI). Upon completion of the CENWW TDGMS overhaul, a report will be produced for general circulation to other data collectors and users. This report will provide other individuals a chance to consider the technological advances developed during this task. Next water year, the forebay stations will be evaluated under the same conditions used to review the USACE, Portland District, station in accordance with the Federal Power Operation BiOP measure RPA 132. A report of these findings will be published at the end of water year 2003. The six-forebay stations are scheduled for overhaul in water year 2004. The CENWW procured a new set of instrumentation using tighter specifications to fulfill the CENWD redundant monitoring requirement. This procurement provided for replacement barometer units to include real-time pressure compensation to the depth and TDG sensors. The new sonde procurement includes both redundant instruments and replacements for some of the Hydrolab® sondes that have reached the end of their TDGMS service life. A full documentation and service trial test results will be provided in a separate report for next year's season. Some of the Hydrolab® instruments will continue to be used in water year 2003. A complete replacement and redundant supply will be completed in water year 2004 and will include in-service spares. The CENWW plans to procure a set number of program replacements in water year 2005 for protection against block obsolescence and large cyclic replacements requiring capitalization. The CENWW plans to use the TDGMS telemetry backbone architecture to collect temperature data in the forebay of all its operating Snake, Clearwater, and Columbia River dams. The CENWW will send the CENWD, Water Management Office, a revised Quality Assurance Project Plan that will incorporate the new equipment manufacturer's calibration procedures.

REFERENCES CITED

American Public Health Association. 1998. Standard Methods for the Examination of Water and Wastewater, APHA, Washington DC, 1,085 p.

Colt, J. 1984. Computation of dissolved gas concentrations in water as functions of temperature, salinity, and pressure: American Fisheries Society Special Publication Number 14, 154 pages.

Heaton, R.D., Seiple, T., Slack, G., and Miller, T.D. 2001. Quality Assurance and Quality Control for the Total Dissolved Gas Monitoring - Lower Snake River, Washington, Clearwater River, Idaho; and Columbia River, Oregon and Washington, Walla Walla, Washington. 29 pages with appendixes.

Jones, J.C., Tracey, D.C., and Sorensen, F.W., eds. 1991. Operating manual for the U.S. Geological Survey's data-collection system with the Geo-stationary Operational Environmental Satellite: U.S. Geological Survey Open-File Report 91–99, 237 pages.

U.S. Environmental Protection Agency (USEPA). 1986. Quality criteria for water: Washington, D.C., EPA-440-5-86-001.

D'Aoust, B.G., R. White and H. Siebold. 1975. Direct Measurement of Total Dissolved Gas Partial Pressure. Undersea Biomedical Research, 2:141.

HDR Engineering. 2002. Total Dissolved Gas Monitoring System, 2002 Fourth Quarter Report.

Weitkamp, D.E and M. Katz. 1980. A review of dissolved gas Supersaturation literature, Transactions of the American Fisheries Society, 109:659.

U.S. Army Corps of Engineers (USACE). 2002. Corps of Engineers Plan of Action For Dissolved Gas Monitoring in 2002, CENWD Portland, Oregon, 14 p.