S.C. Department of Health and Environmental Control

Bureau of Water
Monitoring, Protection, and Assessment Division
Surface Water Monitoring Section

STANDARD OPERATING PROCEDURE

FOR

CONTINUOUS MONITORING

OF AMBIENT SURFACE WATER

REVIEWER:	Bryan Rabon	2/13/2018 Date
SECTION MANAGER:	David Graves	2-13-18 Date
DIVISION DIRECTOR:	Rob Devlin	2/13/18 Date
ACTING BUREAU CHIEF:	Mark Hollis	2-18-18 Date

Version: February 2018

Continuous Monitoring of Ambient Surface Water
Using Multiparameter Water Quality Data Sondes

1.0 TABLE OF CONTENTS

2.0 SCOPE AND APPLICATION

This method is for the use of multiparameter data sondes for unattended measurements of water quality parameters (i.e. temperature, conductivity, salinity, pH, dissolved oxygen, chlorophyll-a, and turbidity) in ambient surface water.

3.0 SUMMARY OF METHOD

A multiparameter data sonde contains several water quality sensors. Each sensor is calibrated and validated prior to sonde deployment. At the end of each deployment, the data sonde is returned to the lab for data download, sensor verification, cleaning, and inspection and maintenance. Calibration and fouling drift corrections are presented along with quality control criteria for accepting or rejecting continuous monitoring data and data reporting requirements. This method is based on the USGS guidelines for continuous monitoring of water quality[1].

4.0 DEFINITIONS

Ambient Surface Water – a surface water body that is outside of defined National Pollutant Discharge Elimination System (NPDES) discharge zones and when the project's objective is not compliance monitoring.
Continuous Monitoring – the unattended measurement of one or more water quality parameters over periods of time from several hours to several weeks.
Data sonde or Sonde – a field monitoring device that includes a water quality sensor array and internal data storage capabilities.
Sensor Guard – a weighted cap with holes used during deployment to help keep the data sonde vertical and to protect the sensors while allowing the free exchange of water over the sensors.
Batch, Record, or Deployment – a series of measurements performed with a single calibration of the instrument.
Quality Assurance Project Plan (QAPP) – guidance document for work performed detailing the field and lab materials and methods, time frame, and quality assurance methods for a project.

5.0 INTERFERENCES

Data obtained by water quality instruments deployed over extended periods of time are subject to both calibration and fouling drift. Calibration drift is inherent to all electrical measurement devices. Fouling drift occurs during long-term deployments when the sensor's measurement surfaces are coated with a build-up of sediment and/or organic matter which affects the accuracy of the measurements.

6.0 PRE-DEPLOYMENT CONSIDERATIONS

6.1 Deployment lengths for routine monitoring are typically 2 weeks. The deployment period for a special study varies depending upon the study objectives and are detailed in the QAPP.

6.2 Continuous monitoring sites are also typically grab sample locations. Considerations for sample site selection vary with water body type (river/stream, lake, estuary/coastal water) and include:

6.2.1 Study objectives
6.2.2 Data quality objectives
6.2.3 Tributary locations (rivers/streams, or lakes)
6.2.4 Changes in bed characteristics
6.2.5 Location of saltwater/fresh water boundary and the range and period of the tide in estuarine and coastal systems
6.2.6 Turbulence
6.2.7 Location of man-made structures

Further details are available in the most recent version of Chapter 7 of the Bureau of Environmental Health Services SOP & Safety Manual: Wastewater Facility and Ambient Monitoring.

6.3 Continuous monitoring measurements are typically made at either the same depth below the surface of the water or above the bottom. Therefore, mounting a data sonde to a floating dock or within a moored oceanographic buoy is preferred. Specific deployment depths are addressed in the QAPP.

6.4 Reconnaissance of the study area is required to determine appropriate sample locations. When using a floating dock, determine the location of a dock or docks closest to the preferred sampling station. This frequently means contacting private homeowners and obtaining their permission to use their dock. When deploying a data sonde using an oceanographic buoy, permission must be obtained from the U.S. Coast Guard ATON office in Miami, Florida and the Army Corps of Engineers in the respective district. Both entities will require application forms to be completed including maps and latitude/longitude positions of the planned deployment locations. Decisions on deployment locations should be made at least 2 months prior to any planned continuous monitoring deployment so that appropriate permissions may be obtained and alternative sites selected as needed.

6.5 Steps should be taken to minimize biofouling of the sonde to the extent possible. Copper is a known anti-fouling agent and can be purchased as a roll of tape or copper mesh, for example, and applied to the outside of each sensor as well as used to cover the sensor guard. Detailed instructions for the use of copper tape or mesh are available from the manufacturer of the specific sonde used.

7.0 HEALTH AND SAFETY

A reference file of SDS sheets appropriate to the standards used when calibrating the data sondes is available in the Sims-Aycock Annex Building Room 105A as well as online at G:\COMMON_ANNEX\ANNEX Safety\Laboratory Safety.

8.0 EQUIPMENT AND SUPPLIES

8.1 Multiparameter data sondes (e.g. Hydrolab DS5x)
8.2 Computer or handheld display unit device (e.g. Hydrolab Surveyor 4a)
8.3 Calibration and field data cable
8.4 Continuous data logbook
8.5 Field logbook
8.6 Labeling tape
8.7 Permanent markers
8.8 Weighted sensor guard
8.9 500 to 1,000 mL polypropylene bottle filled with tap water
8.10 Sonde repair kit containing spare parts and tools

9.0 REAGENTS AND STANDARDS

Reagents and Standards used during data sonde calibration and verification are listed in the sonde-specific SOP.

10.0 SAMPLE COLLECTION, PRESERVATION, AND STORAGE

Not applicable: This SOP covers in-situ continuous monitoring of water quality measurements.

11.0 PERFORMANCE CRITERIA AND QUALITY ASSURANCE

11.1 Initial Demonstration of Capability (IDC): A new employee must be trained on the use of the multiparameter probes by more experienced personnel and then demonstrate proficiency by working through the calibration, validation, and verification steps successfully as detailed in the individual SOPs.

11.2 Precision Control: measurement precision for in-situ water quality instruments is accommodated during the measurement stabilization time period. Prior to recording the sensor readings, those readings must be allowed to stabilize to a median value ± 10% of the median observed.

11.3 Accuracy Checks: Linear calibrations are performed on each of the sonde's probes prior to deployment according to the manufacturer's instructions[2]. Calibration validation checks are performed for LDO, pH, and Conductivity. Temperature is factory calibrated and needs to be checked once each year using a NIST traceable thermometer. Verification checks are performed within 24 hours

of return of the sonde to the lab to check for fouling or instrument calibration drift. Calibration, validation, and verification criteria are listed in the table in Section 15.1.

11.4 Failure to meet these criteria during instrument calibration and validation requires that the calibration be performed again and possibly new standards made. A sonde that repeatedly fails calibration is not deployed and is sent to the manufacturer for testing and repair. Post deployment verification is performed prior to cleaning the sonde. If the verification fails the first time, the sonde is cleaned and the verification is performed again. If the sonde fails to verify after cleaning, then post processing of the data for Total Error is performed according to the USGS guidelines[1]. If the sonde verifies after cleaning, then the post processing of the data for Fouling Error is performed according to the USGS guidelines[1]. Adjusted data may still be used for model development. Post processing steps and evaluation criteria are outlined in Sections 13 and 15.

12.0 PROCEDURE

NOTE: Detailed instructions for the pre-deployment calibration and validation, programming, in-situ depth calibration, and post-deployment verification of a specific data sonde are available in the SOP and User's Manual for that sonde (e.g. Hydrolab DS5X, YSI EXO2).

12.1 Calibration

Continuous monitoring may involve deploying several sondes simultaneously. In order to accommodate calibration, validation, programming, transportation, and deployment times, data sondes are calibrated within 48 hours prior of the beginning of each deployment rather than at start of day.

12.2 Programming for Deployment

At the end of the calibration process, each sonde is programmed to autonomously measure several water quality parameters simultaneously. The data sonde will need to be programmed with the following information:

12.2.1 *The start date/time and end date/time for the deployment.* The start date/time is set so that the sonde begins recording during the morning of the deployment day. The length of time programmed should exceed the anticipated length of the deployment of the sonde. For example, set the start and end date/time to be 4 weeks apart for a planned deployment of 2 weeks. This ensures that data will continue to be collected if weather or other circumstances delay the retrieval of the sonde.

12.2.2 *Sampling interval (dependent upon deployment environment and study requirements).* The sampling interval is the frequency with which the data sonde records the water quality measurements to its internal memory. The sampling interval for routine ambient monitoring is 15 minutes. The

sampling interval for Special Studies varies depending on the objective of the study and is described in the QAPP.

12.2.3 *The selection of water quality parameters to be measured.* This selection will depend on the requirements of the study and the sensors available in the data sonde.

12.2.4 *Logbook Record.* The written record for the deployment of each sonde should include the filename (internal sonde data file), continuous monitoring Station ID, sample interval, program duration (start/stop), and anticipated deployment length. The format for the file name should be the alphanumeric Station ID followed by the 4-digit year, 2-digit month, and 2-digit day (AA-NN-YYYY-MM-DD).

12.3 In the Field

12.3.1 Calibrate depth on the data sonde just prior to placing it in the deployment tube or buoy cage.

12.3.2 Secure the sonde in the dock deployment tube or buoy cage and record the deployment date and time in the Field Logbook. Also, record the retrieval date and time of any sonde removed from that location.

12.3.3 For each continuous monitoring station visited, begin the steps again from 11.3.1.

12.3.4 A mid-deployment inspection of the sonde and download and review of the data can reveal instrument failure, power loss, and other mechanical problems. At that time, batteries may be replaced and any needed repairs may be made in the field. A mid-deployment verification is conducted at this time (Section 12.4.1). Read the data from both sondes and record them in the field logbook.

12.4 Verification

Continuous monitoring sonde verification occurs more than once. The first verification occurs in the field at roughly the mid-point of the deployment. NOTE: for deployments longer than 2 weeks, this field verification may occur more than once. The second verification occurs when the sonde is returned to the lab at the end of its deployment.

SC DHEC considers data from a single deployment in segments: 1) from initial deployment to field verification, 2) from field to end-of-deployment verification, and 3) between field verifications (if needed).

12.4.1 The field verification is a comparison of the current continuous monitoring sonde readings with those of an identical instrument, calibrated that morning, used to collect instantaneous water quality readings at that site.

12.4.1.1 If the variance between the continuous monitoring and the instantaneous sonde readings (Section 13.3) are within the calibration criteria (Section 15.1), field personnel record that calculation result in the field logbook and leave the continuous monitoring sonde at its deployment location until the next field verification or the end of its planned deployment.

12.4.1.2 If the variance for pH, dissolved oxygen, or conductivity exceed the calibration criteria, then the deployed sonde is pulled from its location. A freshly calibrated spare sonde will be deployed if one is available at that time.

12.4.1.3 If the variance for turbidity or chlorophyll *a* exceed the calibration criteria, but the variance for pH, dissolved oxygen, and conductivity are all within the calibration criteria, it is up to the discretion of the field personnel whether or not to retrieve and replace the sonde at that location.

12.4.1.4 The instantaneous water quality sonde is verified in the lab at the end of the day. Verification failure is noted and the variance information used during post-processing of Segment 1 data (Section 12.4).

12.4.2 Post-deployment verification of the data sondes must be performed within 24 hours of returning the instrument to the laboratory. This pertains to sondes that were retrieved mid-deployment as well as those retrieved at the end of a planned deployment. The verification is first performed prior to cleaning the data sondes. If the verification values fall within the criteria listed in the table in Section 15.1, then no data adjustments will be made, and the data sondes cleaned and stored to be ready for the next deployment.

12.4.3 If any of the pre-cleaned verification values fall outside of the stated criteria, then the data sondes will be cleaned, and the verification process performed a second time for any sensors that did not meet the verification criteria. If the post-cleaning verification data falls within acceptable data tolerances, then the data will be adjusted linearly for fouling error as a percent. If the post cleaning verification data falls outside of the acceptable data tolerances, then the data will be adjusted linearly for total error as a percent (see Section 13.0).

12.5 Data Retrieval

12.5.1 Once the sonde verification process is complete, stop the current program and transfer the data file stored on the sonde to the common computer drive (G:\COMMON_ANNEX...). Always make sure that the data file

was transferred successfully to the common drive prior to deleting the file from the sonde. This raw data is maintained separately from any post-processing files that are created according to Section 13.0.

13.0 CALCULATIONS, DATA REPORTING, AND QUALITY CONTROL

13.1 The data sonde firmware calculates salinity from temperature and conductivity and makes any needed temperature adjustments to DO readings. Notification of updated firmware is pushed to the end-users by the manufacturer and is installed to the data sondes by SC DHEC personnel.

13.2 Results are reported as follows. The number of significant digits is dictated by the sensor precision of each measurement. Please see the data sonde-specific SOP.

13.2.1 Temperature – °C
13.2.2 Conductivity –µS/cm
13.2.3 Salinity – PPT (estuarine and salt water systems only)
13.2.4 pH – Standard Units
13.2.5 LDO – mg/L
13.2.6 Chlorophyll *a* – µg/L
13.2.7 Turbidity – NTU

13.3 The variance for the calibration and verification criteria is calculated as either a percent (specific conductance, turbidity, and chlorophyll *a*):

$$\%\text{Variance} = [(\text{Measured Value}/\text{Standard Value}) - 1] \times 100 \quad \text{(Eq. 1)}$$

or as the difference between the stated standard value and the current sonde measurement. For the mid-deployment verification, the instantaneous measurement sonde reading is used in place of the standard value.

13.4 Error propagation is performed on any final calculated quantity reported. The method used depends on the calculation. For sums and differences, the final error reported is the square root of the sum of the squares:

$$R \pm \delta R = (A \pm a) + (B \pm b) + \cdots + (I \pm i) \quad \text{(Eq. 2)}$$

$$\delta R = \sqrt{a^2 + b^2 + \cdots + i^2} \quad \text{(Eq. 3)}$$

Where R is the sum (or difference), δR is the propagated error value, and A ± a etc. is each measurement with its associated measurement error.

Mean values are calculated as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{(Eq. 4)}$$

and

$$\bar{x} \pm \delta R \qquad \text{(Eq. 5)}$$

where $\bar{x}$ is the mean and δR is calculated from the individual measurement error as shown above.

13.5 Initial post processing of the data is conducted according to a modification of the USGS Guidelines for Continuous Monitoring[2]. If the end-of-deployment verification exceeds the calibration criteria listed in Table 15.1, it is processed as described in Sections 13.5.1 to 13.5.5.

13.5.1 Initial Data Evaluation
Verify the accurate transfer of raw field data from the data sonde to a folder on the shared drive (G:\COMMON_ANNEX\…) named for the year in which the data was collected. Evaluate and identify erroneous data.

13.5.2 Removal of Erroneous Data
NOTE: Complete mechanical failure of a sensor or the sonde while deployed is obvious when examining the stored data (see example in Section 15.2). This data is not capable of being post processed and is, therefore, excluded from further review.

13.5.3 Error Calculations
For continuous monitoring data sondes, total error (E_T) is the combination of sensor fouling error (E_f) plus calibration drift error (E_c).

$$E_T = E_f + E_c \qquad \text{(Eq. 6)}$$

Total error is equivalent to variance (Section 13.3), but is broken into its component parts in order to assess whether more rigorous fouling control measures are needed or whether instrument repair is needed.

Biofouling errors are calculated as:

$$E_f = M_c - M_f \qquad \text{(Eq. 7)}$$

where M_c is the value measured after the data sonde has been cleaned and M_f is the value measured prior to cleaning at the end of a deployment period. The calibration drift error (E_c) is calculated as the value of the standard solution (V_s) minus the post-deployment, clean sensor reading of the standard solution (M_c as in Eq. 7) obtained during the verification process:

$$E_c = V_s - M_c \qquad \text{(Eq. 8)}$$

Post deployment verification begins prior to cleaning the data sondes. If the verification values fall within the tolerances listed in Section 15.1, then no data adjustments will be made, and the data sondes cleaned and calibrated again prior to the next deployment. However, if the pre-cleaned verification values fall outside of the stated criteria, then the data sondes will be cleaned immediately, and the data verification performed a second time. If the post-cleaning verification data falls within acceptable data tolerances, then the data will be adjusted linearly for fouling error as a percent.

$$\%E_f = 100 \times \left(\frac{M_c - M_f}{M_f} \right) \qquad \text{(Eq. 9)}$$

If the post-cleaning verification data do not meet acceptable data tolerances, then the data will also be adjusted linearly for calibration drift error as a percent.

$$\%E_c = 100 \times \left(\frac{V_s - M_c}{M_c} \right) \qquad \text{(Eq. 10)}$$

In this case, the fouling error (E_f) is calculated as the difference between the total error (E_T) and the calibration drift error (E_c), with the total error calculated as the difference between the pre-cleaned verification value and the value of the standard solution. Total error is the variance found during the end-of-deployment verification process.

13.5.4 Data Adjustment, Accuracy Ratings, and Adjustment Limits
If post-deployment verification results exceed the stated calibration criteria, then Data Correction is applied.

A linear equation (y = mx + b) is developed between the two points consisting of the date and time of calibration and verification (x-values) and the ratios of the stated standard values to the sensor readings at that time (y-values). NOTE: the successful calibration ratio is assumed to be 1, the verification ratio may be greater than or less than 1. The linear equation is then applied to the data segment of interest with "x" being the date/time stamp during the deployment and the resulting "y" value the ratio as it changes through time. The resulting "y" value for each date/time stamp of the segment is then applied to the raw sensor data to create the adjusted column of data.

Once data adjustments are applied, then each recorded data point is compared to the original, unadjusted record. It is assigned an accuracy rating according to the table in Section 15.3. If any part of the data

segment exceeds the Rejection criteria, that segment is eliminated from further analysis but will be used for informational purposes.

13.5.5 Data will then be analyzed using descriptive statistics, boxplots, and outlier tests to determine whether any additional data points should be removed from further analysis[3].

14.0 WASTE MANAGEMENT

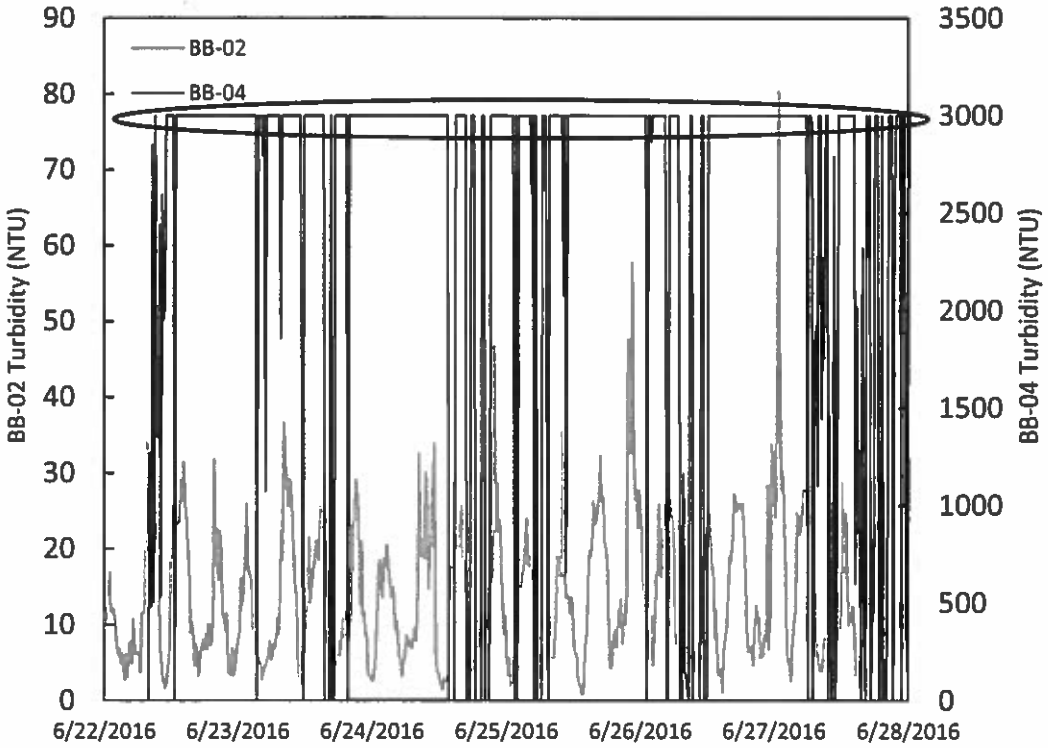
Not applicable to this SOP. Waste management of the reagents and Standards used in the calibration of individual sensors is detailed in the SOP for each sensor.

15.0 TABLES, DIAGRAMS, FLOWCHARTS

15.1 Calibration, Validation, and Verification Criteria

Parameter	USGS Calibration Verification Criteria (Wagner et al., 2006)	BOW Calibration Verification Criteria
Temperature	± 0.2 °C	Verify with NIST thermometer at least once during field season. ± 0.1 °C
Specific Conductance	± 5 µS/cm or ±3 % of the measured value, whichever is greater	±10%
Dissolved oxygen	± 0.3 mg/L	± 0.2 mg/L
pH	± 0.2 pH unit	± 0.2 unit
Turbidity	± 0.5 NTU or ± 5% of the measured value, whichever is greater	± 10%
Chlorophyll *a*	None	± 10%

15.2 Erroneous Sonde Data Example



Continuous monitoring Turbidity data from within the same field area. The record from Station BB-04 site is the result of turbidity sensor failure during deployment and is typical of obviously erroneous data. Please note the extreme difference in Turbidity scales between the primary and secondary vertical axes as well as the flat shape of the BB-04 profile across the top highlighted by the red circle.

15.3 Data Accuracy Ratings and Maximum Allowable Data Adjustments

Parameter	Excellent	Good	Fair	Adjustment Rejection Limit
Specific Conductance (%)	≤ ± 10%	> ± 10% to ≤ ± 15%	> ± 15 % to < ± 20%	≥ ± 20%
Dissolved Oxygen (mg/L)	≤ ± 0.2 mg/L	> ± 0.2 to ≤ ± 0.8 mg/L	> ± 0.8 to < ± 1.5 mg/L	≥ ± 1.5 mg/L
pH (Standard Unit)	≤ ± 0.2 Unit	> ± 0.2 to ≤ ± 0.6 Unit	> ± 0.6 to < ± 1.0 Unit	≥ ± 1.0 Unit
Turbidity (%)	≤ ± 10%	> ± 10% to ≤ ± 15%	> ± 15 % to < ± 20%	≥ ± 20%
Chlorophyll *a* (%)	≤ ± 10%	> ± 10% to ≤ ± 15%	> ± 15 % to < ± 20%	≥ ± 20%

16.0 REVISION HISTORY

Date	Rev. No.	Section	Description of Change
Feb 2018	1.0	11.3	Section 14.1 corrected to read Section 15.1
Feb 2018	1.0	13.5.3	Section 14.1 corrected to read Section 15.1
Feb 2018	1.0	Cover	Revision number added to cover, revision history section added to document, sections re-numbered.

17.0 REFERENCES

[1] Wagner, R.J., R.W. Boulger Jr, C.J. Oblinger, and B.A. Smith (2006). Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1-D3, 51p. + 8 attachments; accesses March 24, 2017. http://pubs.water.usgs.gov/tm1d3.

[2] Hach Company (2006). Hydrolab DS5X, DS5, and MS5 Water Quality Multiprobes User Manual. OTT Hydromet GmbH Document number 55.495.000.B.E 02-0511. Edition 3, February 2006.

[3] US EPA (2006). Data Quality Assessment: Statistical Methods for Practioners. EPA QA/G-9S, February 2006.