Water quality monitoring: Sensors Basics

An Introduction to the Aquatic Sensor Workgroup

Dan Sullivan, USGS co-chair, Methods and Data Comparability Board

National Water Quality Monitoring Council
Introduction to the Aquatic Sensor Workgroup (ASW)

Tools developed by the ASW: laying the groundwork for sensors QA

Data Management

Specifications
Aquatic Sensor Workgroup (ASW)

- The ASW is a subcommittee of the *Methods and Data Comparability Board*, a workgroup of the National Council
- Objective: to convene a workgroup of experts to consider efforts to address challenges:
  - SOPs have not kept pace with technology
  - No central repository for information about SOPs, sensor performance, etc.
Formed after 2008 NMC in response to overwhelming interest in aquatic sensors

Members from all sectors including manufacturers

“Sensors QA Initiative” products were introduced at the Nat’l. Monitoring Conference in Denver in April, 2010
Sensors QA Initiative Products

- Website
- Deployment Guide
- QA (ACRR) Matrix
- Data Elements
- Glossary

Generate data of known and Documented quality
Welcome to watersensors.org

The Aquatic Sensor Workgroup is a public-private partnership of water-quality monitoring agencies, industry, and academia. Our mission is to ensure that water-quality data collected by sensors are of known and documented quality.

QA (ACRR) Matrix

The Sensor QA (ACRR) Matrix is a checklist of actions you can do to Affect, Check, Record, and Report the quality of your Sensors' measurements. A number of data quality aspects are addressed. The Matrix reflects... (Read more and download files here...)

Field Deployment Guide

The ASW Field Deployment Guide is intended to be used as a checklist of considerations to guide both new and experienced users in the deployment of water-quality monitoring systems using sensors. The Guide is organized in four sections: (Read more and download files here...)

Data Elements

The Sensors Data Elements list includes the information that documents the "who, what, when, where, how, and why" associated with your monitoring results. (Read more...)

http://watersensors.org
Assumptions/Overview of the Guide

- Your site has been selected (e.g., “Black Earth Creek at Cross Plains, WI”)
- The guide will help ensure that measurements you take at that “point” are representative of conditions in that stream while measuring the inherent variability
Data quality considerations
- Representative of conditions
- Capture natural variability
- Ensure data of known quality – useful for decision-making, sharing

Informative tool
- New users
- Experienced users

Aid to system and site selection
- Checklist to evaluate site conditions
A measurement is taken at one point in a stream: one point in time & space

What does that measurement represent?

Water quality varies in time & space

Where you put the sensor is very important!
Variability

Source: SWAMP Field Modules (2005)
1) System Selection
   - Attended Monitoring
   - Unattended Monitoring
   - Flow-through systems

2) Site Selection
   - Location within the channel
   - Flow and Stage

3) Installation and Maintenance
   - Access and safety
   - Equipment location
   - Infrastructure
   - Extreme conditions
   - Service intervals

4) Documentation
   - Installation
   - On-going site visits
1. System Selection

- **Attended monitoring**
  - Infrequent discrete samples
  - Multiple points in the cross section

- **Unattended monitoring**
  - Continuous data from a fixed point
  - Low power requirements - internal-logging systems

- **Flow-through monitoring system**
  - High power requirements
  - Typically tied to telemetry
2. Site Selection

- Location within channel/reach

*Photo: Jerrod Wheeler, USGS*

*Faith Fitzpatrick, USGS*
2. Site Selection

- Flow and stage
3. Installations

Shelters, sondes, intakes

Flood & debris damage

Laura Flight, USGS
3. Installations
Service Intervals

Rasmussen, USGS
4. Documentation

- Written documentation
  - USGS National Field Manual Chapter 6 (online)
  - Record every field visit
  - Log books/electronic files for every instrument

- Photo documentation
  - A picture says a thousand words
  - Pictures provide perspective
Quality Assurance (ACRR) Matrix

QA Checklist for Calibration, Quality Checks, and Record Keeping to Ensure that Data Are of Known and Documented Quality
The basic sensors that are in wide use for monitoring (NPS “Vital Signs”):

- Temp.
- SC
- D.O.
- pH
- Turbidity
- Depth
- ORP (Oxidation Reduction Potential)
List of actions you can do to:

- **Affect** (act to influence the outcome)
- **Check** (test to evaluate or verify)
- **Record** (documentation)
- **Report** (communicate the data quality indicator)

Used in conjunction with users manual, result will be **data of known and documented quality**.
Aspects of Data Quality

- Accuracy/Bias
- Precision
- Lack of interference or contamination
## QA Matrix – Accuracy/Bias example

### 3. Specific Conductance Sensors: Conductivity Cell

<table>
<thead>
<tr>
<th>Data Quality Aspect</th>
<th>Mode (See Notes)</th>
<th>Quality Assurance Actions</th>
<th>Documentation Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy/Bias</td>
<td></td>
<td>Affect (Control, act to influence the outcome)</td>
<td>Check (Test to evaluate or verify)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conduct one-point calibration in the lab, at a value in the middle of anticipated environmental range, at room temperature [Tips SP1-SP3], before each trip. Conduct two point calibration in the field, at values that bracket expected range, at stream temperature, before first use of the day. Make sure the probe is properly hydrated before calibration and before each use; assure sufficient voltage.</td>
<td>Conduct a one-point accuracy check in the lab, at a mid-range value, at room temperature [Tip SP2], within 24 hours of trip’s end.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conduct two-point calibration in the lab, at zero and at value higher than expected range, at room temperature, before deployment and at every maintenance event (if needed)</td>
<td>Conduct three-point accuracy check, with Standards at min/ mid/ max values of expected range, plus a zero check in air, at room or field temperature, within 24 hrs of retrieval and at every maintenance event, before and after cleaning.</td>
</tr>
</tbody>
</table>

### Specific Conductance Sensors: Tips & Comments

[Tip SP1] It may be beneficial to conduct calibrations and accuracy checks at 25 C, even if the sensor has automatic temperature compensation.

[Tip SP2] Always rinse sensors twice with standard prior to performing checks and calibrations.

[Tip SP3] Calibrating linear conductivity sensors is best done with a strong conductivity signal (i.e., 1,000 uS/cm or higher); above this value choose a standard that is close to your expected values.

[Tip SP4] Precision can be reported as (1) standard deviation (SD), or as (2) relative percent difference (RPD), or as (3) relative standard deviation (RSD) a.k.a. coefficient of variations (%CV), depending on the number of repeated measurements and the requirements of the data management system or the Program.
- Guides are designed as checklists
- Important to know site details/specific sensor requirements
- Maintenance intervals – data quality
- Document everything
“Water Quality – Anytime, Anywhere” (B. Hirsch)

Capabilities, reliability, and deployment of sensors will continue to increase

Several networks in planning stages
- Mississippi River Basin sediment pilot
- Great Lakes Restoration Initiative
- NAWQA

Areas of need:
- Data management
- Specifications
- Data analysis
ASW Initiatives FY11-

- NEMI-ACT web portal
- Data Management
- Specifications
- Data Quality Objectives
Access traditional analytical and sampling methods from NEMI along with sensors information from ACT

- Over 4,000 sensors in ACT database
- Side-by-side comparisons
- Format for standardizing performance criteria for sensors
  - w/in single manufacturers, reported performance for a given analyte can be different for different models
### ACT data linked with NEMI methods

<table>
<thead>
<tr>
<th>Name</th>
<th>Analyte Name</th>
<th>Method No</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMT Deep Water pH Sensor</td>
<td>pH</td>
<td>150 1</td>
</tr>
<tr>
<td>AMT Deep Water pH Sensor</td>
<td>pH</td>
<td>8156</td>
</tr>
<tr>
<td>AMT ORP-Combined Shallow Water Sensor</td>
<td>Electromotive force</td>
<td>NFM 6.5</td>
</tr>
<tr>
<td>AMT Shallow Water DO Micro-sensor</td>
<td>Dissolved Oxygen</td>
<td>350 1</td>
</tr>
<tr>
<td>AMT Shallow Water DO Micro-sensor</td>
<td>pH</td>
<td>150 1</td>
</tr>
<tr>
<td>AMT Shallow Water pH Sensor</td>
<td>pH</td>
<td>8156</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments Oxygen Optodes 3835/4130/4175</td>
<td>Dissolved Oxygen</td>
<td>350 1</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments Temperature Sensor 4086</td>
<td>Temperature</td>
<td>170 1</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments Turbidity/Temperature Sensor 3712</td>
<td>Turbidity</td>
<td>180 1</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments Water Level/Temperature Sensor</td>
<td>Water level</td>
<td>D5413B</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments pH Sensor</td>
<td>pH</td>
<td>150 1</td>
</tr>
<tr>
<td>Aquamatic Data Instruments pH Sensor</td>
<td>pH</td>
<td>8156</td>
</tr>
<tr>
<td>Aquamatic Oxygen Sensor</td>
<td>Dissolved Oxygen</td>
<td>350 1</td>
</tr>
<tr>
<td>Aquamatic pH Sensor</td>
<td>pH</td>
<td>150 1</td>
</tr>
</tbody>
</table>

### NEMI Methods

<table>
<thead>
<tr>
<th>NEMI Method</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.1</td>
<td>Asbestos in Water by TEM</td>
</tr>
<tr>
<td>100.2</td>
<td>Asbestos in Water by TEM</td>
</tr>
<tr>
<td>100.29</td>
<td>E. coli by m-CoilBlue24 Broth Procedure for Membrane Filtration</td>
</tr>
<tr>
<td>110.1</td>
<td>Color by Spectrophotometry</td>
</tr>
<tr>
<td>110.2</td>
<td>Color by Spectrophotometry</td>
</tr>
<tr>
<td>110.3</td>
<td>Color by Spectrophotometry</td>
</tr>
<tr>
<td>1103.1 (modified)</td>
<td>Membrane filtration plating of E. coli on modified mTEC agar</td>
</tr>
<tr>
<td>1106.1</td>
<td>Enterococci in water by MF using mE-EI Agar</td>
</tr>
<tr>
<td>120.1</td>
<td>Conductance by Conductivity Water</td>
</tr>
<tr>
<td>130.00</td>
<td>Capillary gas chromatography analysis for organic contaminants in marine sediments.</td>
</tr>
<tr>
<td>130.01</td>
<td>Organic contaminants in marine animal tissues by GC-FPD</td>
</tr>
<tr>
<td>130.1</td>
<td>Total Hardness by Spectrophotometer</td>
</tr>
<tr>
<td>130.10</td>
<td>Organic contaminants in marine sediments by GC-ECD</td>
</tr>
<tr>
<td>130.11</td>
<td>Organic contaminants in marine animal tissues by GC-ECD</td>
</tr>
<tr>
<td>130.2</td>
<td>Total Hardness of Water by Titrimetry</td>
</tr>
</tbody>
</table>

### Sensors Table - no join to NEMI methods or analytes

<table>
<thead>
<tr>
<th>Name</th>
<th>Keywords</th>
<th>Analyte Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMT CTD/O2 Fast Profiling Probe</td>
<td>CTD, DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>AMT Dissolved Oxygen Sensor for Deep Sea</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>AMT Dissolved Oxygen Sensor for Deep Sea</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>AMT Shallow Water DO Micro-sensor</td>
<td>DO, dissolvedoxygen</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments Oxygen Optodes 3830/3930/3975</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments Oxygen Optode 4330/4330F</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments Oxygen Optode 3835/4130/4175</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Aaenderaa Data Instruments pH Sensor</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Aquamatic Oxygen Sensor</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Aquamatic pH Sensor</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Campbell Scientific CS511-L Dissolved Oxygen Probe</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Centre for Microcomputer Applications Dissolved Oxygen Sensor</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Coastal-USA MacQual</td>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Common Sensing Model TBO-F</td>
<td>dissolvedgases, DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Common Sensing Wireless Probe WDGL-3</td>
<td>dissolvedgases, DO</td>
<td>Dissolved Oxygen</td>
</tr>
</tbody>
</table>
The water quality monitoring community needs better data management procedures to deal with the large amount of data generated by remotely-deployed sensors. Sensors provide unique challenges in almost every phase of data management, from what data should be collected and stored (the content of the data) to data transfer.
Data Management

- SOP for basic data verification, validation, and error calculation to connect the outcome of quality checks with the data, plus a standardized set of data qualifiers
- List of data elements/data fields that need to be recorded (*DRAFT long list is complete)
- Recommendations for a streamlined process of sensors’ data correction, i.e., alteration to correct for drift and fouling, using consistent procedures/algorithms and consistent categories for the extent of corrections
Specifications

- Technology performance standards and test criteria designed specifically for field sensors and natural environmental conditions are required to allow inter-comparison of sensor specifications and the data generated by field sensors.
- Need for EPA-accepted criteria for sensors for ambient monitoring.
Specifications

- ASTM D-19 workgroup – standard reference samples
  - ASW will provide input and comments
  - First meeting Jan. 19

- Working with EPA’s Forum on Environmental Measurements to move forward on ambient monitoring standards for sensors
Questions and Comments

Dan Sullivan
(608) 821-3869
djsulliv@usgs.gov
A unique public-private partnership have collaborated on the products described herein, including:

**Core Workgroup Members:**

- Revital Katzenelson, PhD
- Dan Sullivan, USGS Co-chair
- Gayle Rominger, YSI, Co-chair
- Chuck Spooner, EPA
- Chuck Dvorsky, Texas CEQ
- Mike Sadar, Hach Co.
- Cristina Windsor, In-Situ
- Mike Cook and Rob Ellison, YSI
- Janice Fulford, USGS

**Review Board:**

- Pete Penoyer, Nat’l. Park Service
- Mario Tamburri, Alliance for Coastal Technologies
- Eva DiDonato, Nat’l. Park Service
- Jami Montgomery, EPA
- Rick Wagner, USGS
- Eli Greenbaum, Oak Ridge Nat’l. Laboratory
- Tamim Younos, Virgina Tech. U.