Sensors Basics

An Introduction to Aquatic Sensors and the Aquatic Sensor Workgroup

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

National Water Quality Monitoring Council

Outline

- Background on using sensors for water quality monitoring
- Introduction to the Aquatic Sensor Workgroup (ASW)
- Tools developed by the ASW that lay the groundwork for sensors QA
- Future plans

Why monitor water quality continuously?

- Improves our understanding of hydrology and water quality and can lead to more effective resource management
- Provides warning for water supply and recreation
- Captures seasonal, diel, and event-driven fluctuations
- Improves concentration and load estimates with defined uncertainty (8,760 hourly values per year)
- Optimizes the collection of samples

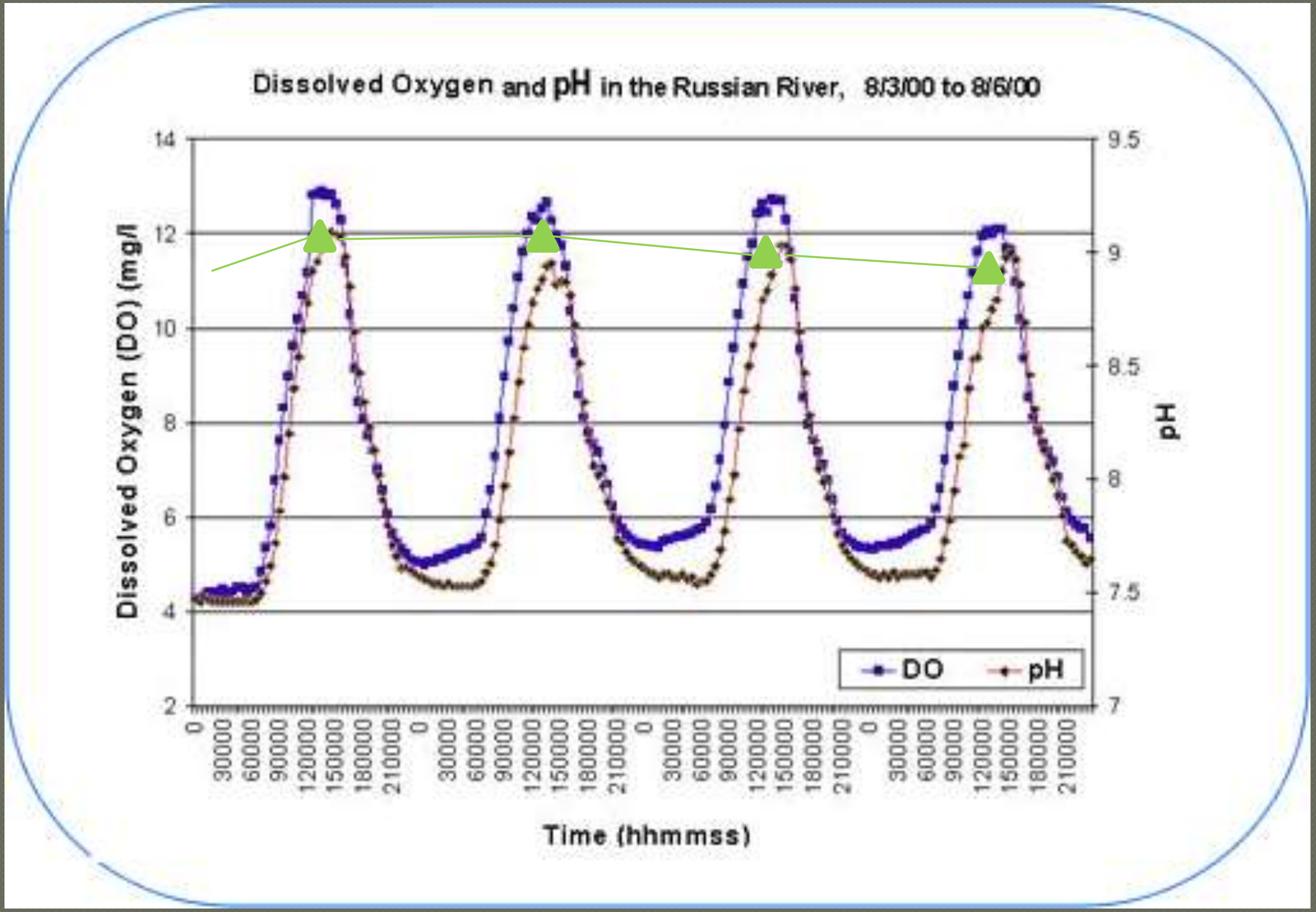
Why – (cont)

- Continuous instantaneous real-time water quality MEETS OUR INFORMATION NEEDS for time-dense information that are used to improve the quality of human life and the environment

Sensor usage today

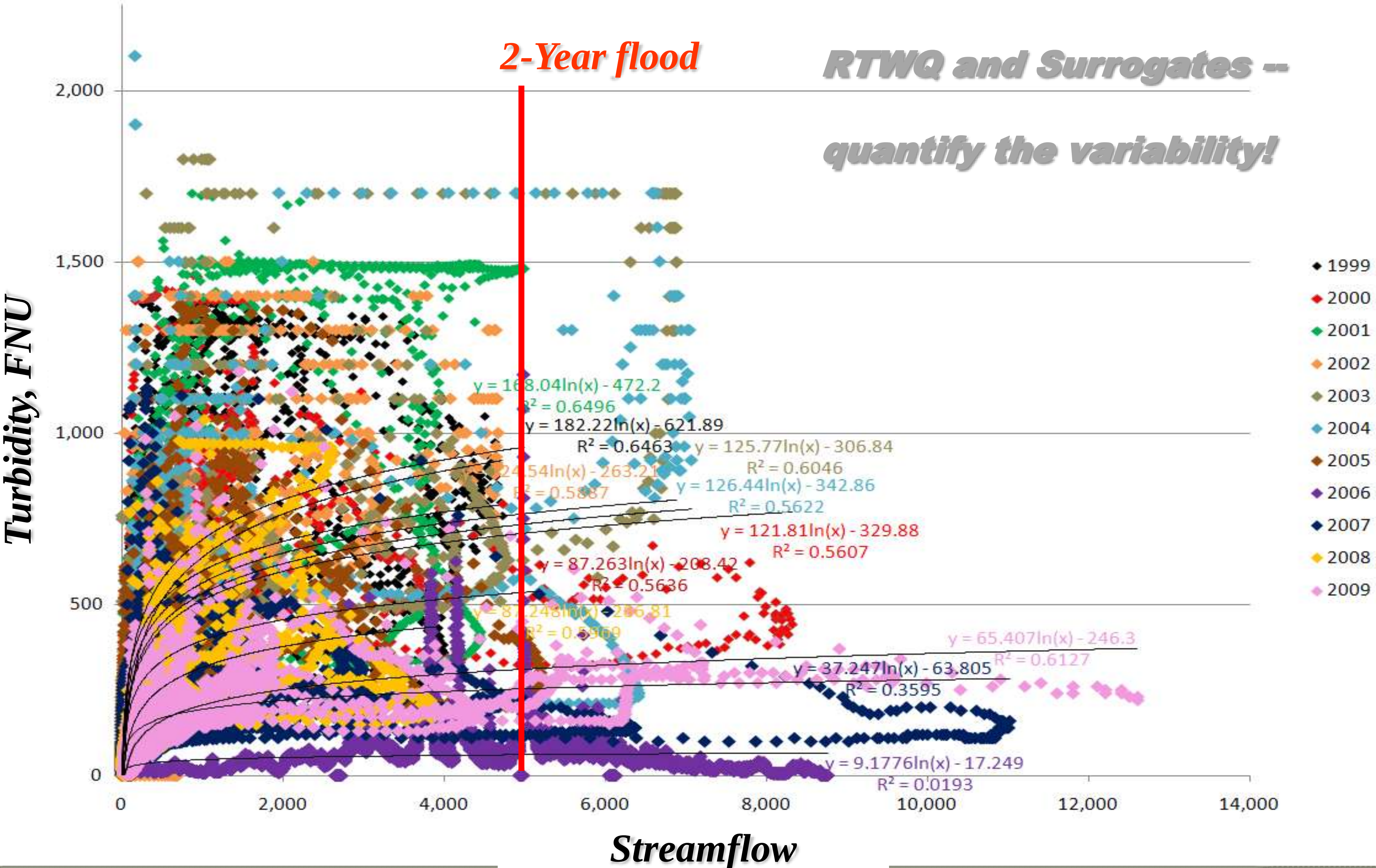
- Stage, Q, wave height, Temp, sc, pH, DO, turbidity, fluorescence, some nitrate, carbon, few others
- Wide variability in complexity of display and user ability to select information
- Surrogates

Example of real-time data



Streamflow relation to water quality is complex and variable

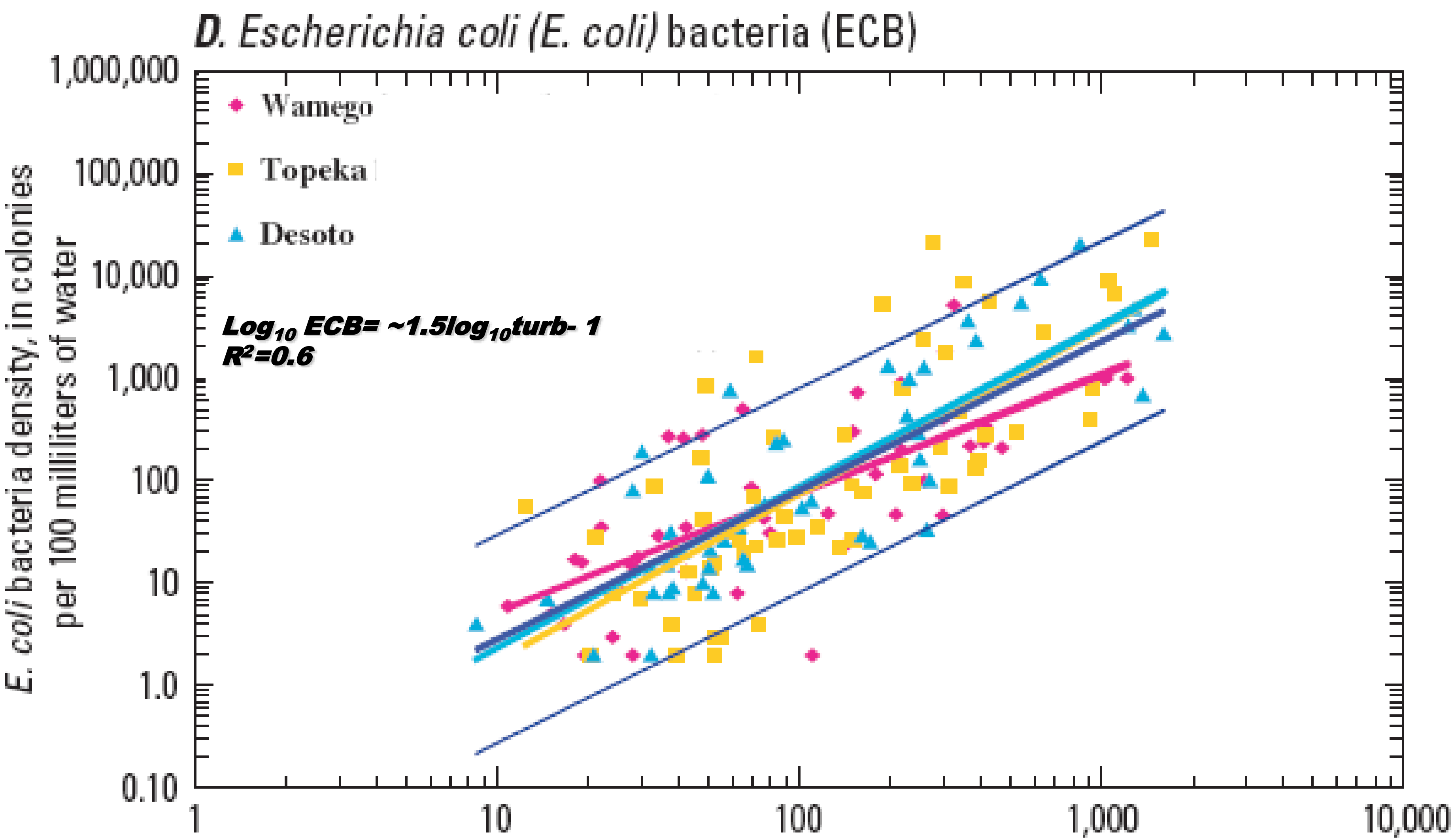
Can we capture, quantify, understand, and regulate this water-quality variability with 6 or 10 or 20 samples per year?



Surrogates = calibrated sensors

- Use in-situ “surrogate” measurements when direct measurement sensors are not available
- Calibrate the in-situ sensor with samples collected over range in conditions using statistics and develop models (the simpler, the better)
- Compute concentrations, loads, uncertainty, and probability of exceeding water-quality criteria and display on web

Turbidity estimates *E. Coli* reliably



Rasmussen, Ziegler, and Rasmussen, 2005

Surrogates

Parameter measured	Parameter Computed
Gage Height/Stage/velocity	Streamflow (discharge)
Specific Conductance	Chloride, alkalinity, fluoride, dissolved solids, sodium, sulfate, nitrate, atrazine
Turbidity	Total suspended solids, suspended sediment, fecal coliform, *E. coli*, total nitrogen, total nitrogen, total phosphorus, geosmin

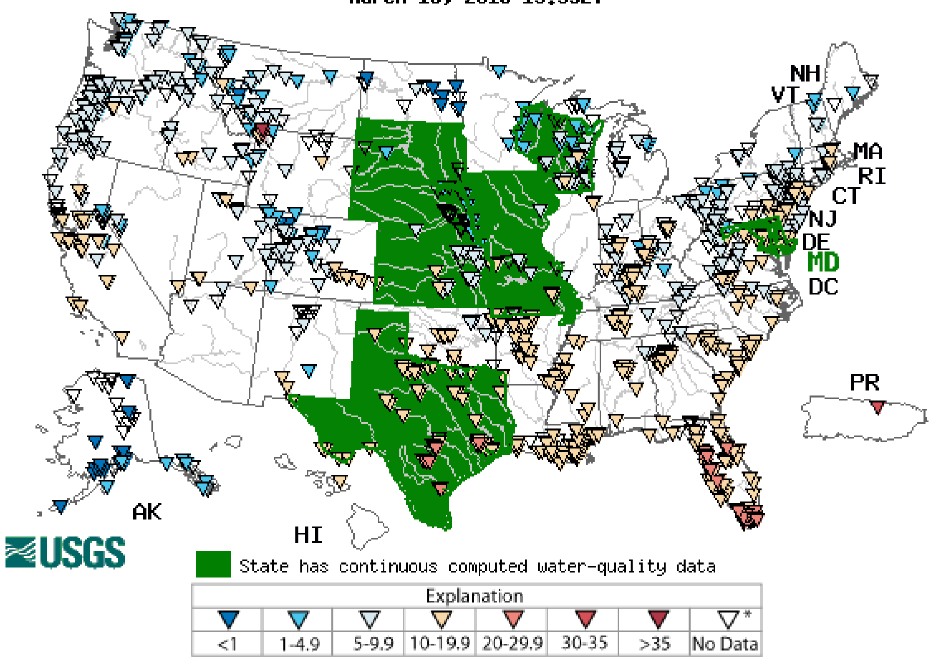
USGS NRTWQ
321 turbidity sites (90 in 2000)

US Geological Survey Real-Time Water Quality Data For the Nation

National Real-Time Water Quality

Map of Real-Time Water Temperature, in °C

March 18, 2010 15:35ET



Temp | Cond | pH | D.O. | Turb | Disch

Continuous real-time water-quality data are used for decisions regarding drinking water, water treatment, regulatory programs, recreation, and public safety. Sensors in streams typically measure streamflow, water temperature, specific conductance, pH, dissolved oxygen and turbidity. Additionally, these measurements can be used as surrogates to compute real-time concentrations and loads of other water-quality constituents.

Click the Map for Real-Time Water-Quality Data. This Will Either Show:

1. This National Real-Time Water Quality (NRTWQ) website (currently Iowa, Kansas, Maryland, Missouri, Nebraska, South Dakota, Texas, and Wisconsin) provides hourly computed concentrations and loads for sediment, nutrients, bacteria, and many additional constituents; uncertainty values and probabilities for exceeding drinking water or recreational criteria; frequency distribution curves; and all historical hourly in-stream sensor measurements.

2. WaterQualityWatch presents colorful maps of recent hourly measurements of streamflow, water temperature, specific conductance, pH, dissolved oxygen, and turbidity. The most recent 60 days of real-time data also are available for download. Similar to NRTWQ, its data are obtained from the USGS National Water Information System.

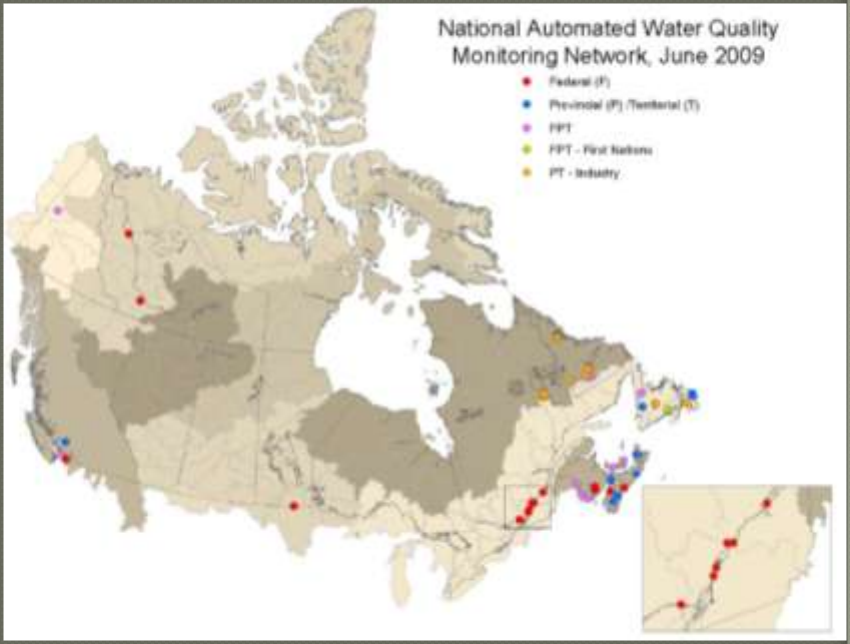
- http://nrtwq.usgs.gov/

Eye-On-Earth (EU)
Air and Bathing quality

http://eyeonearth.cloudapp.net/

Canadian National Monitoring Network

- Goal—Connect existing & implement new sites & expand w/ partners
- Maximize integration with the hydrometric network
- Benefits:
  - Demonstrate technology, cost effective, primary water quality screening, early warning, background and trend data and provide real-time information to public and more rapid intervention



http://www.env.gov.nl.ca/

Towards a National Automated Real-Time Water Quality Monitoring Network - Geneviève Tardif (Environment Canada)
Real-Time Water Quality Monitoring Workshop 2009, St. John's, NL

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- Introduction to the Aquatic Sensor Workgroup (ASW)
- Tools developed by the ASW that lay the groundwork for sensors QA
- Future plans

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.

ASW Objectives

- Develop SOPs for the calibration, QA/QC, maintenance, and deployment of field-based aquatic sensors
- Make recommendations for the creation of a database to store relevant information on sensors to allow potential users to make informed decisions on the use of sensors for their projects
- Recommend types of sensors for the National Monitoring Network

ASW milestones and members

- Formed after 2008 NMC in response to overwhelming interest in aquatic sensors
- Members from all sectors including manufacturers
- Phase I (called the "Sensors QA Initiative") products were introduced at the Conference in Denver in April, 2010

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  - Field Deployment Guide
  - QA Matrix
- Future plans

Sensors QA Initiative Products

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

Generate data of known and Documented quality

watersensors.org

asw

Aquatic Sensor Workgroup
methods and data comparability board

The Methods and Data Comparability Board is a partnership of water-quality experts whose mission is to develop water-quality monitoring approaches that facilitate collaboration and comparability amongst all data-gathering organizations. The Board develops products that enhance our ability to achieve real environmental gains while making the best use of the limited resources available for water-quality monitoring.

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...)

Field Deployment Guide

- 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

Aquatic Sensor Workgroup
methods and data comparability board

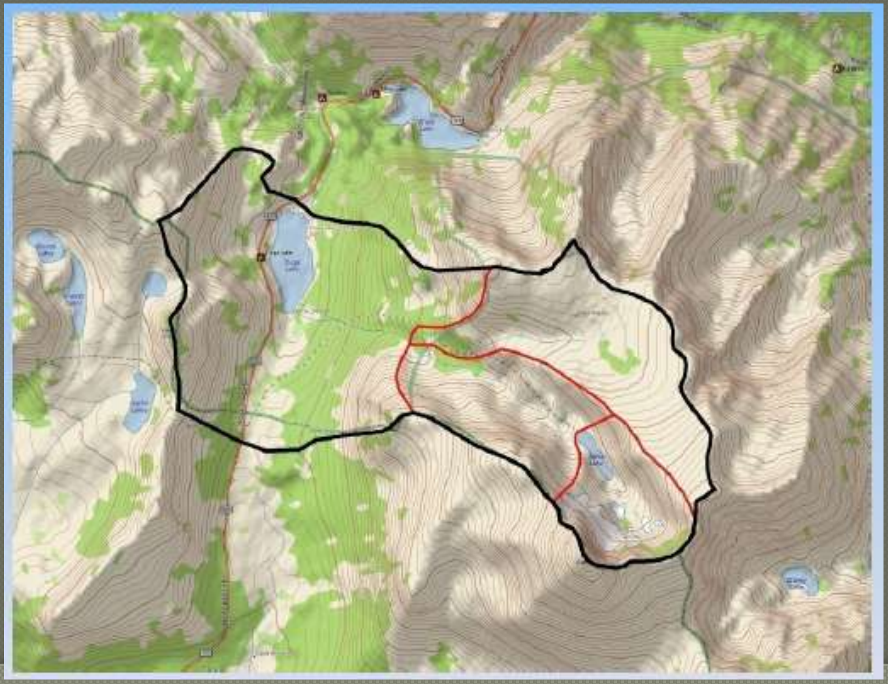
Field Deployment Guide

Checklist for Sensor Selection, Deployment, and Maintenance: **Rivers & Streams**

March 24, 2010 acwi.gov/methods

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 <u>representative</u> of conditions in that stream while measuring the inherent <u>variability</u>



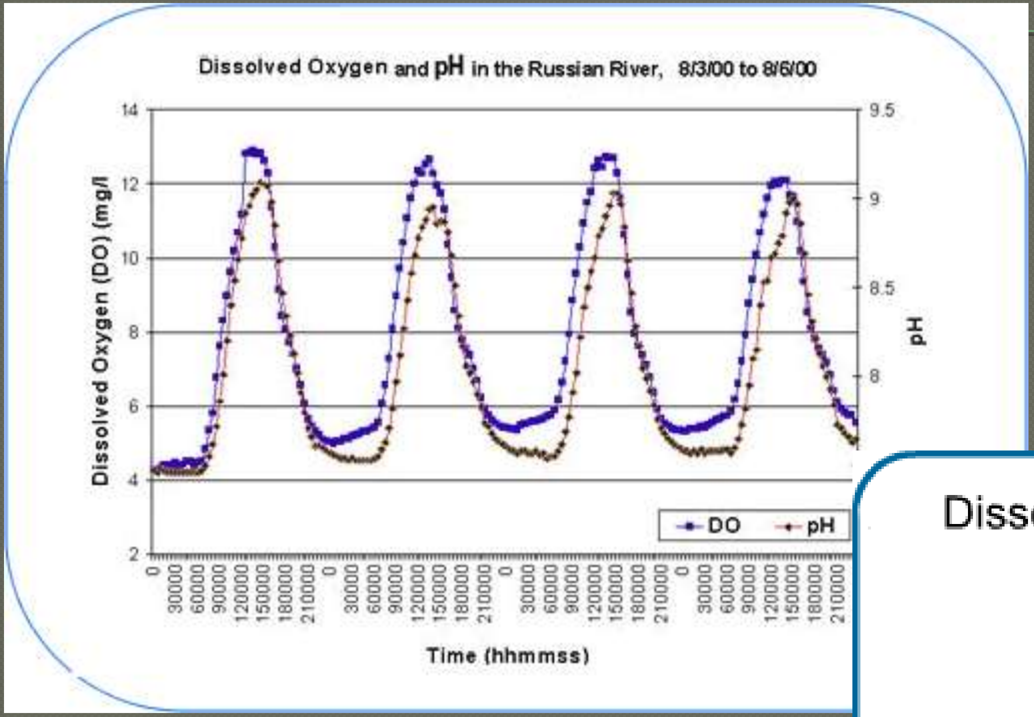
Representativeness

- A measurement is taken at one point in a stream: one point in time & space
- Water quality varies in time & space
- What does that measurement represent?
- Where you put the sensor is very important!

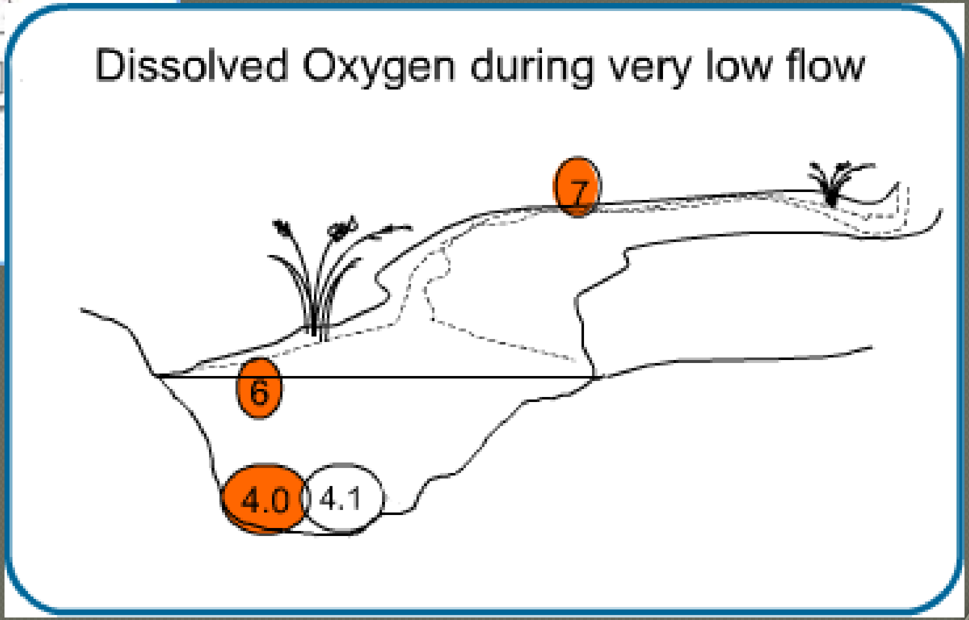
Variability

- Variability is inherent in the aquatic environment (otherwise, why bother to monitor?)
- How do you separate inherent variability from sampling error?
- Cross-section surveys
- It does matter where you deploy your sonde…

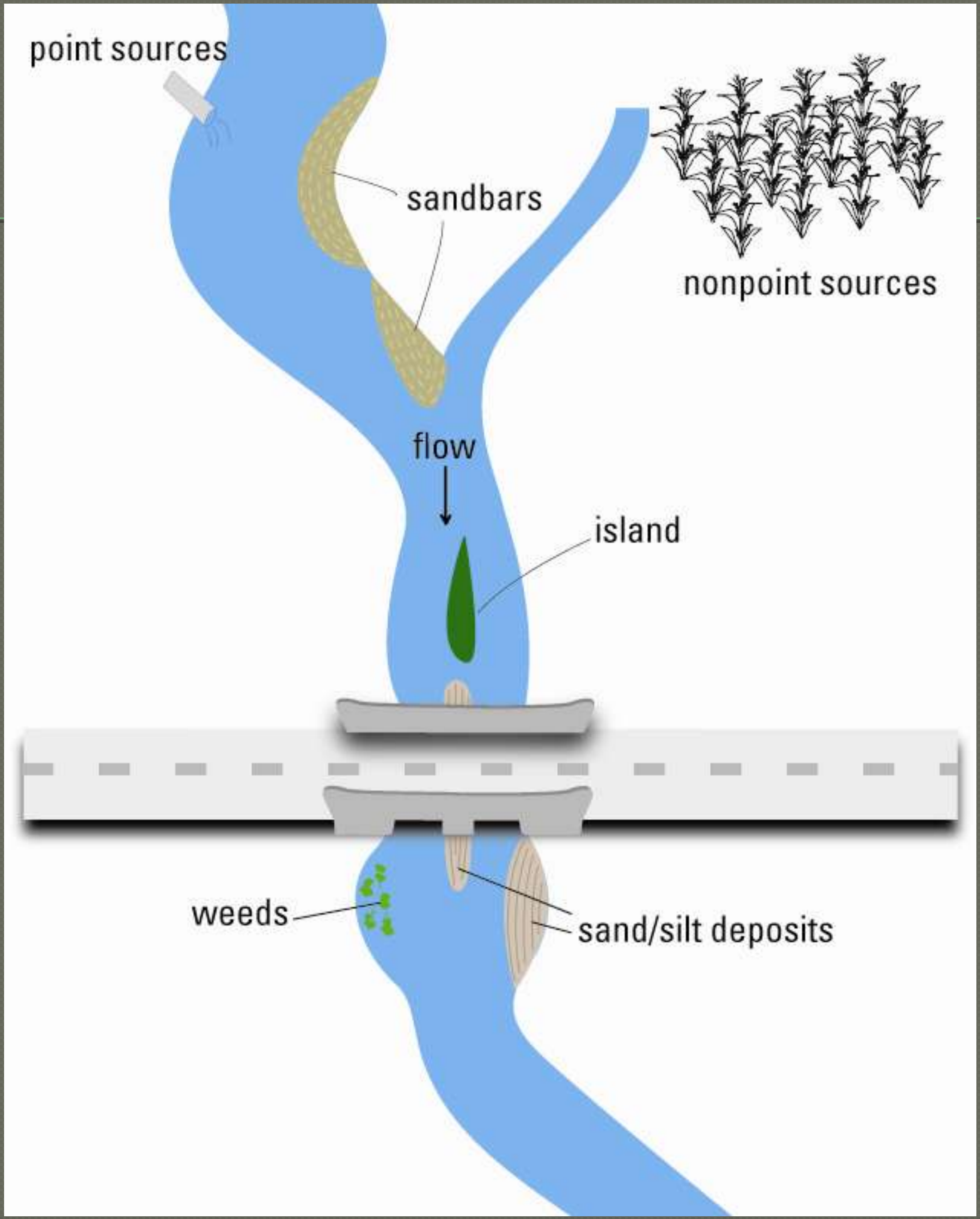
Variability



Modified from SWAMP, 2010



Variability



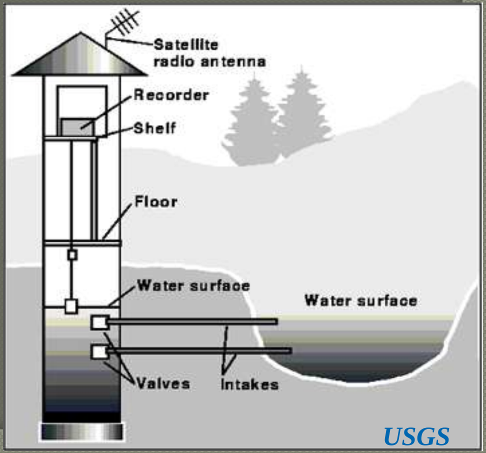
Deployment Guide Outline

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



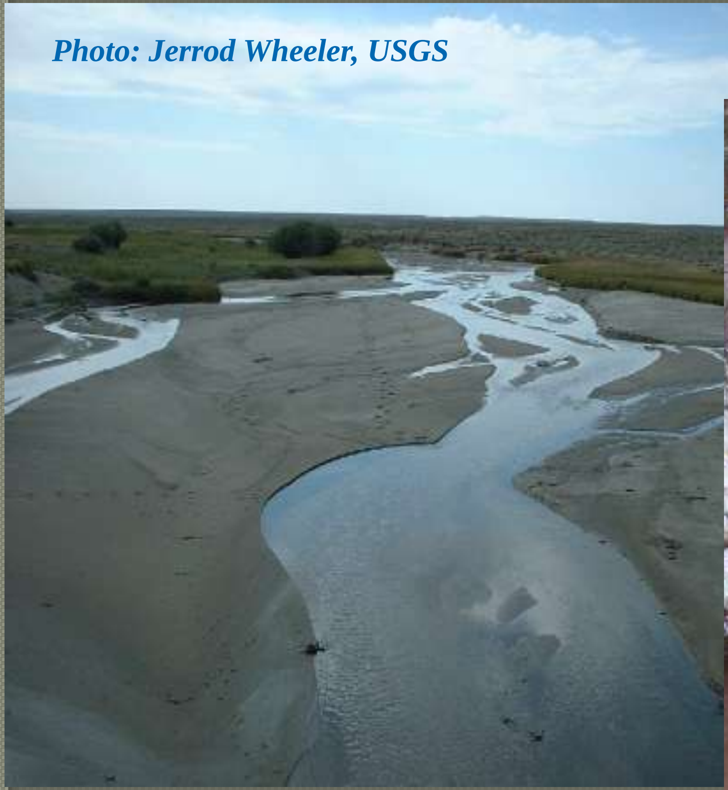
1. System Selection

	Advantages	Disadvantages
Attended Monitoring	Calibration should be done right before data are collected, ensuring data of the highest, known quality. Vandalism not an issue. No need for expensive shelters.	Does not take full advantage of new technology. Each data point is expensive.
Unattended: In-situ Monitoring System	Remote locations are possible. Small shelters can be used. No power is needed to pump water, and electrical hazards are reduced. With satellite telemetry, data can be transmitted to an office location. System can be monitored remotely for problems. No pump maintenance.	Sensors are susceptible to vandalism. Sensors are more prone to fouling than in flow-through system. Servicing sensors during flooding can be difficult. In shallow bank or poorly mixed installations, properly locating intakes or sensors in the cross section is difficult. Sensors are susceptible to debris or high flow. Shifting channels may require adjustments to sensor placement. Susceptible to freezing.
Unattended: Internal-logging Monitoring System	Location options are flexible. No electrical hazards. Exposure to vandalism may be reduced. No pump maintenance.	Sensors are susceptible to vandalism. Sensors are more prone to fouling than in flow-through system. Servicing sensors during flooding can be difficult. In shallow bank or poorly mixed installations, properly locating intakes or sensors in the cross section is difficult. Data are available only during site visits. Sensors are susceptible to debris or high flow. Shifting channels may require adjustments to sensor placement. Status of equipment can only be checked while servicing. Site visit required to view data and assess data loss. Susceptible to freezing.
Flow-through System	Unit can be coupled with chlorinators to reduce membrane fouling. Expensive sensor systems can be secured in vandal-resistant shelters. Sample water from more than one measuring point can be pumped to a single set of sensors. With satellite telemetry, data can be transmitted to an office location. System can be monitored remotely for problems. Freeze protection can be provided to the sensors.	110-volt AC power source is needed. Large shelters are required, incurring higher installation costs. Pumps in streams can clog from algal fouling or high sediment loads. In shallow bank or poorly mixed installations, properly locating intakes or sensors in the cross section is difficult. Electrical shock protection is required. Pumps may be damaged by sediment or corrosive waters. Pump maintenance may be necessary. Pumping may cause changes in water quality.

Most of the information in this table is from Wagner et al, 2006.

2. Site Selection

- Location within channel/reach



2. Site Selection

- Flow and stage

3. Installations

- Access & Safety
- Equipment location
- Available infrastructure
- Extreme conditions
- Service intervals

3. Installations

Laura Flight, USGS

Shelters, sondes, intakes

Flood & debris damage

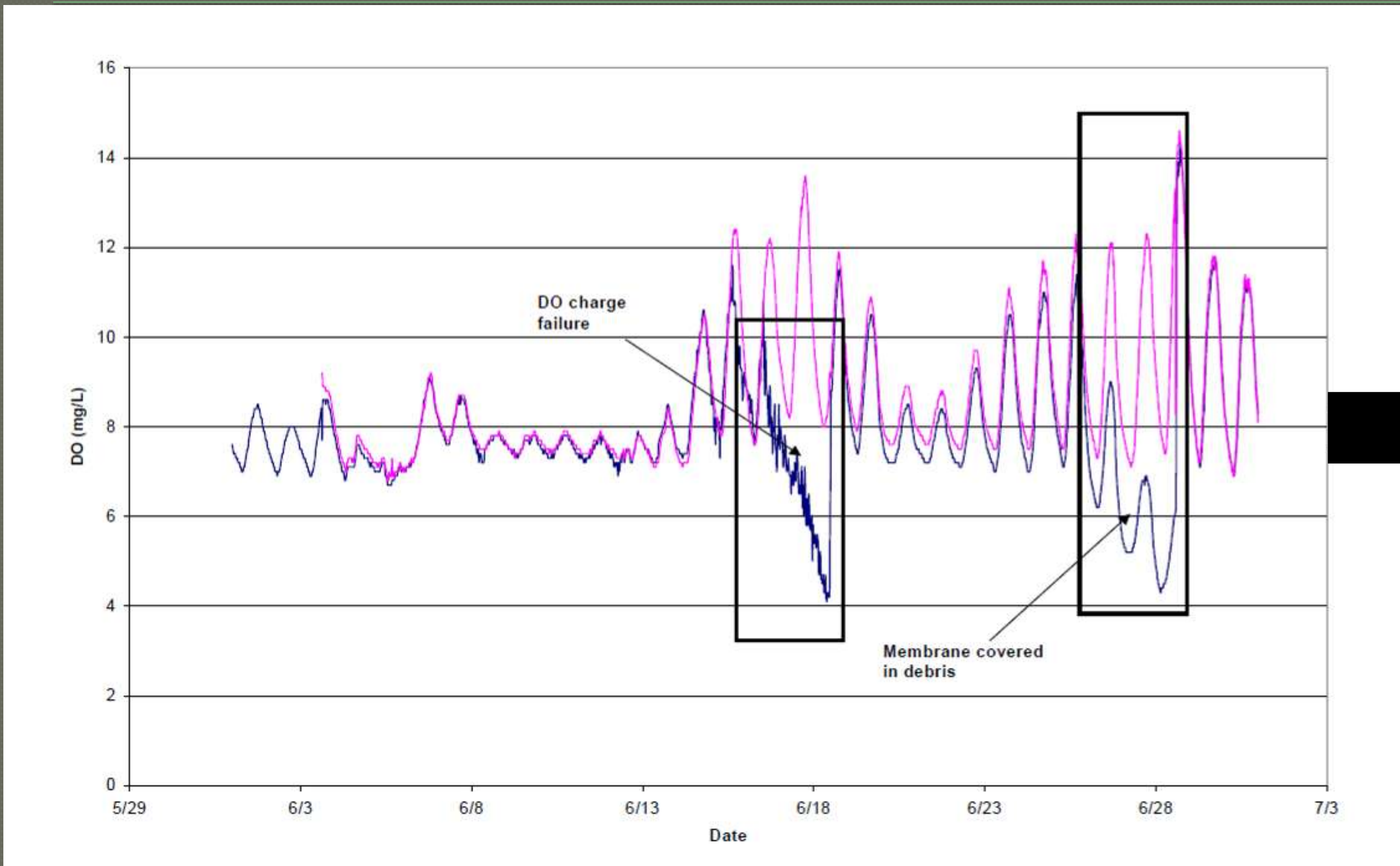
3. Installations

Extreme Conditions

Photo: Joe Zanka, 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

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Quality Assurance (ACRR) Matrix

QA Checklist for Calibration, Quality Checks, and Record Keeping to Ensure that Data Are of Known and Documented Quality

April 19, 2010 acwi.gov/methods

What's in the Matrix?

- The basic sensors that are in wide use for monitoring today:

- Temperature
- Specific conductance
- Dissolved oxygen
- pH
- Turbidity
- Depth
- ORP (Oxidation Reduction Potential)

QA (ACRR) Matrix

- 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 <u>data of known and documented quality</u>

Quality Assurance Matrix

- Format is designed to let you print out only the pages you need
- First section is applicable to all sensors; subsequent pages are sensor-specific
- Front page for each sensor is guidance; back page has tips and comments

QA Matrix

1. General: All Sensors

Data Quality Aspect	Mode (See Notes)	Quality Assurance Actions		Documentation Actions	
		Affect (Control, act to influence the outcome)	**Check** (Test to evaluate or verify)	**Record** (Keep everything documented)	**Report** (Communicate the data quality indicator)
Operator's compe-tence	*All*	Train, refresh, supervise.	Run proficiency tests, review work products.	Record operator name, test/review date, and Test outcome or review summary.	Pass/fail procedure-specific proficiency tests (by individual).
Accuracy/ Bias	*All*	Use certified non-expired Standards for calibration and accuracy checks.	Compare previous lot/batch of standards with new lot with a high-resolution instru-ment.	Reading of standard solutions from the two lots.	Report "Standard Solution Drift," the difference between values measured in solutions of the two lots.
	All	Calibrate the instrument at the project's prescribed values and intervals and under the prescribed conditions.	Conduct accuracy checks at the project's prescribed values and intervals and under the prescribed conditions.	Instrument reading, value of standard, temperature /pressure /salinity as rel-evant [Tips A1-A2], electrode voltage, cell constant, and other diagnostics as rel-evant, including their acceptable ranges.	Report bias: Instrument drift, i.e., differ-ence from known ("true") value of stan-dard, expressed either in measurement units or as percent of Standard's "true" value, whichever is higher [Tip A3].
	All	Calibrate the instrument after every service event and after instrument has been subject to an impact (e.g., during transport or deployment).	Conduct and accuracy check after every service event and after the instrument has been subject to an impact (e.g., dur-ing transport or deployment).	Instrument reading and value of stan-dard.	Report bias: Instrument drift, i.e., differ-ence from known ("true") value of stan-dard, expressed either in measurement units or as percent of standard's "true" value, whichever is higher.
	●	Avoid switching the power off or discon-necting the sensor from its display unit between sites.	Check accuracy after turning the instru-ment on again [Comment A1].		

QA Matrix – SC example

3. Specific Conductance Sensors: Conductivity Cell

Data Quality Aspect	Mode (See Notes)	Quality Assurance Actions		Documentation Actions	
		Affect (Control, act to influence the outcome)	Check (Test to evaluate or verify)	Record (Keep everything documented)	Report (Communicate the data quality indicator)
Accuracy/ Bias		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.	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.	Temperature of standard, instrument conductivity reading, temperature compensation factor (if needed), and "true" value of standard	Report bias: Instrument drift, i.e., difference from known ("true") value of Standard, expressed either in measurement units or as percent of Standard's "true" value, whichever is higher.
		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)	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.	Temperature of standard, instrument conductivity reading, temperature compensation factor (if needed), and "true" value of standard.	Report bias: Instrument drift, i.e., difference from known ("true") value of Standard, expressed either in measurement units or as percent of Standard's "true" value, whichever is higher.

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.

Summary

- Guides are designed as checklists
- Important to know site details/specific sensor requirements
- Maintenance intervals – data quality
- Document everything

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The Future of Sensors?

- "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
- Areas of need:
  - data & databases
  - statistics

Future Plans – Sensor Workgroup

- Specifications – need for EPA-accepted criteria for sensors for ambient monitoring
- Data Management – widespread need for better, faster, easier ways to download, manage and store sensors data
- Statistics – in conjunction with Water Information Strategies

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Questions and Comments

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