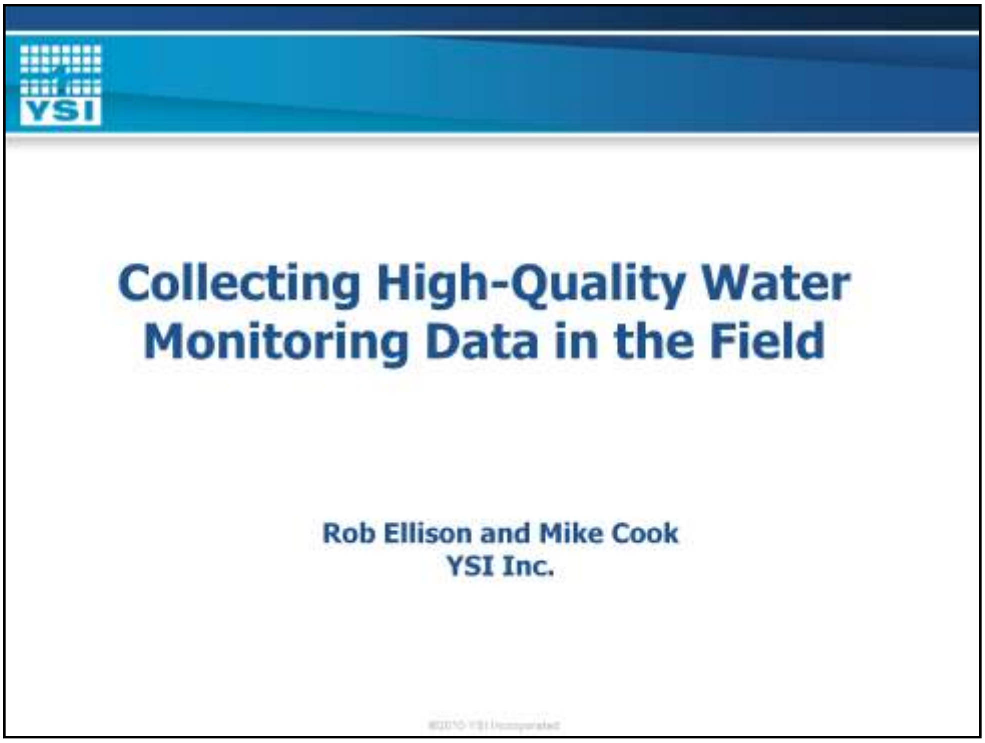


Introduce presenters:

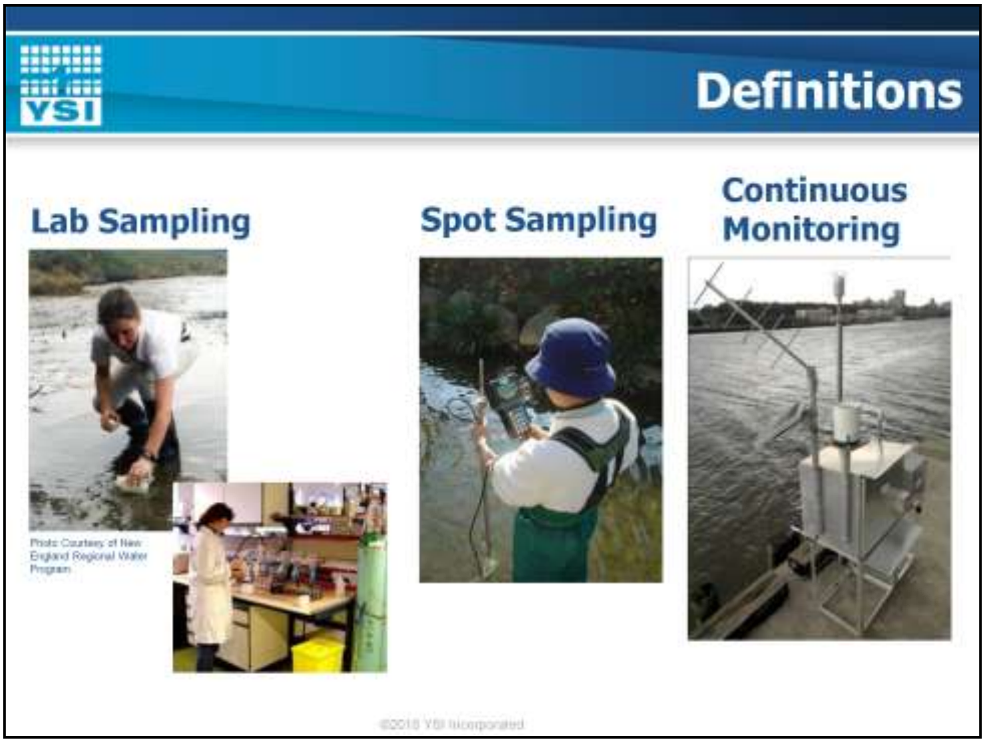
Rob Ellison. Rob has been with YSI for 5 years as the Market & Business Development Manager for environmental systems. He has a master's degree in biological oceanography and an extensive background in sensor development.

Mike Cook. Mike has been with the SonTek/YSI division for 2 years as an Applications Engineer for water quality and velocity systems. Mike has a PhD in biological and agricultural engineering, and a wealth of experience in environmental monitoring.

Agenda

1. Introduction
2. Understanding Your Instrumentation
3. Understanding Your Site
4. Data Review & Management
5. Questions

Photo by Miles Storey



This presentation will focus on the use of field sensors for measuring water quality and quantity and the means by which data quality can be determined and improved.

To make sure we are all on the same page, I would like to define some key terms we will be using:

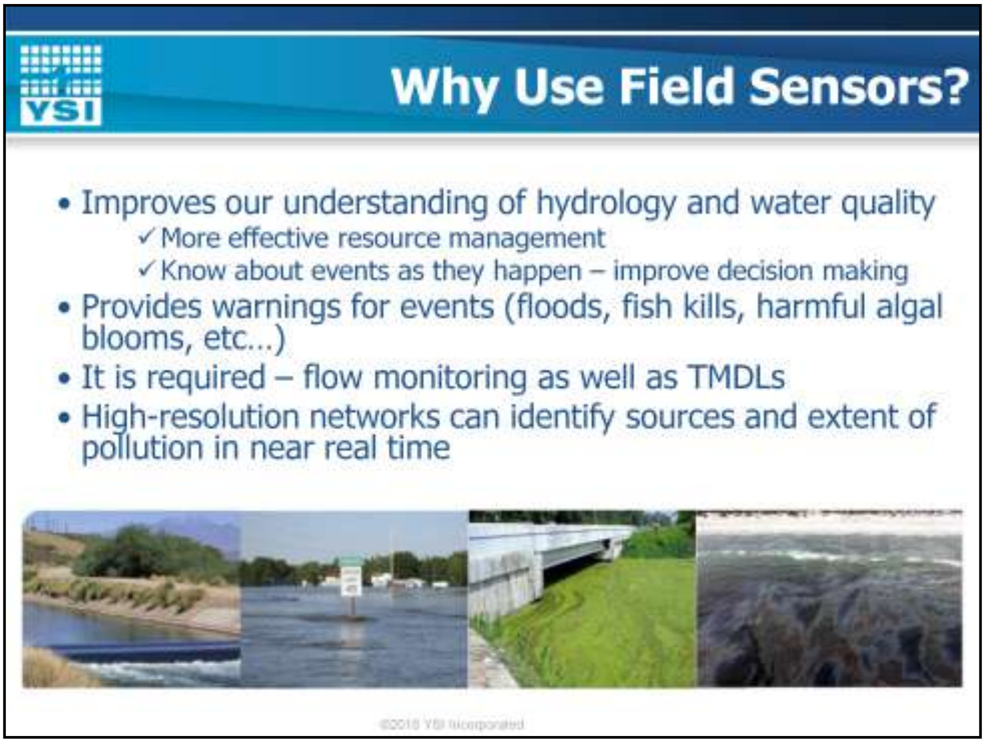
Lab Sampling is the process of collecting and transporting samples from the environment back to a laboratory for analysis. We will not be addressing this type of sampling.

In contrast, **Spot Sampling** is the process of taking measurements in the field with the use of field sensors.

Spot Sampling has unique data quality challenges such as the need to calibrate sensors prior to each trip to the field, tests to ensure the sensors have not changed in the course of a field trip, and possible effects of interfering substances on the sensors.

Continuous Monitoring is the deployment of field sensors in an autonomous mode that may or may not include telemetry of the data. Monitoring has many data quality challenges as well such as biofouling on sensors, impacts of environmental extremes on the electronics and sensing components, and damage from natural events or vandalism.

We will touch on many of challenges in the use of field sensors as well as provide you with some useful guides to get you started in collecting high quality field data.



I will not spend much time on WHY one would want to conduct field monitoring, but for anyone new to field sensors, I will quickly hit on some of the most significant advantages:

Natural ecosystems are extremely dynamic.Things change quickly. To better understand natural environments and the impact we have on them, we need systems that can monitor in relevant time scales.

This allows us to:

-Make effective resource management decisions

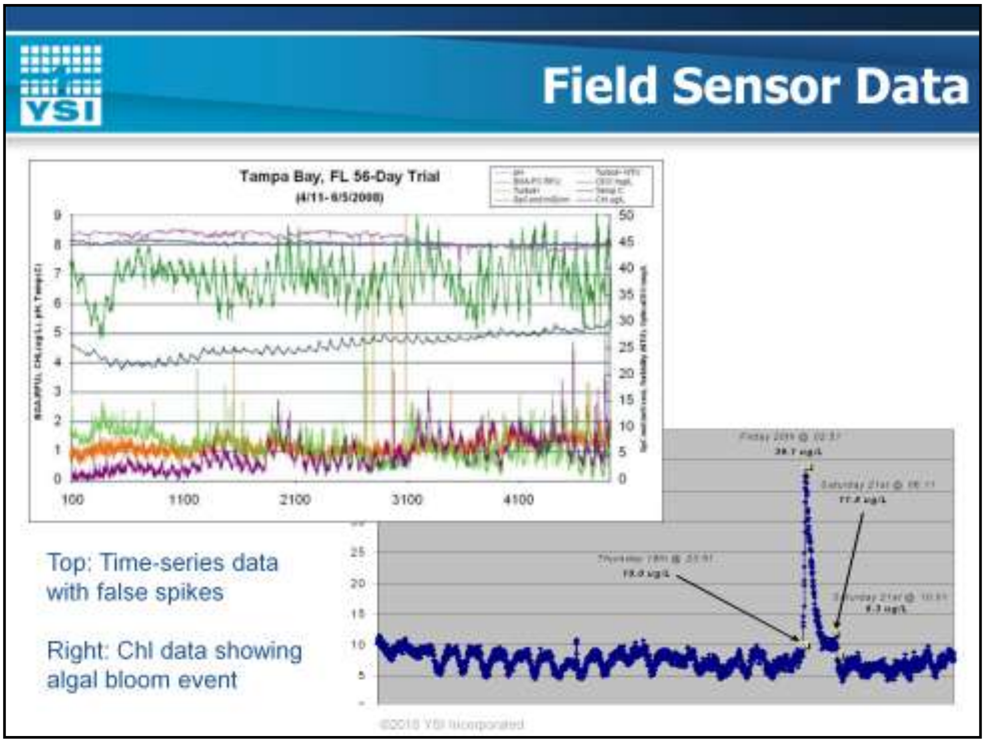
-Detect events (natural or man-made) when they are occurring

In some cases, provide warnings to events such as floods, anoxic events or HABs

In more and more instances the use of field sensors is being regulated such as for flow, TMDLs and construction monitoring

Sensor Networks can identify the sources and transport of pollution in near real time

There is a need to evolve water quality monitoring to a system as robust as weather monitoring

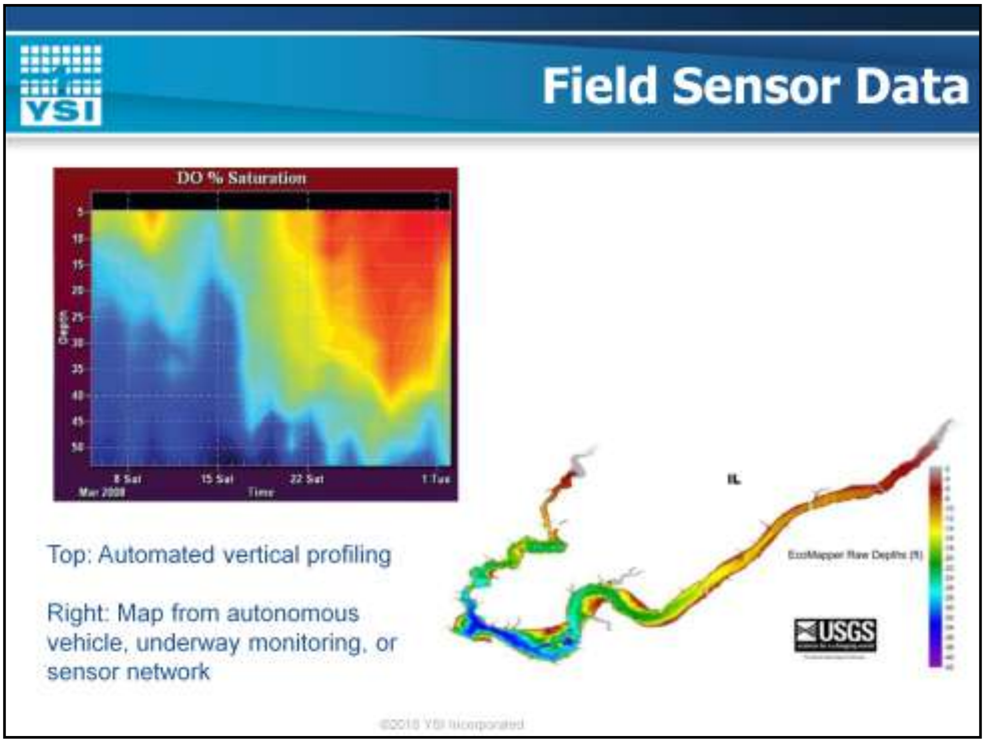


Now let's review what the data from field sensors looks like:

We have two examples of Time Series data and I would like to point out how simply looking at a time series is often the first step in checking data quality.

1) A 2-month time series in the upper left shows a number of water quality parameters, many that are tightly correlated. You can see the significant diurnal swings in this data, giving one a clear understanding of true dynamics at this site. The correlation among water quality parameters is an effective tool for identifying possible problems in a data set. If an anomaly is spotted in the data, the first thing to do is check for corresponding swings in correlated parameters. If no correlation is seen, this could be an indication of a problem with that sensor. You may be able to see some light green and orange spikes in the data from the Turbidity and BGA sensors. These sensors can be sensitive to particles in the water and occasionally a spike is seen with no data points leading up to or receding from the spike as well as no correlated spikes form the other parameters. These are relatively obvious false positives that can be removed. Statistical methods can also be used to identify spikes.

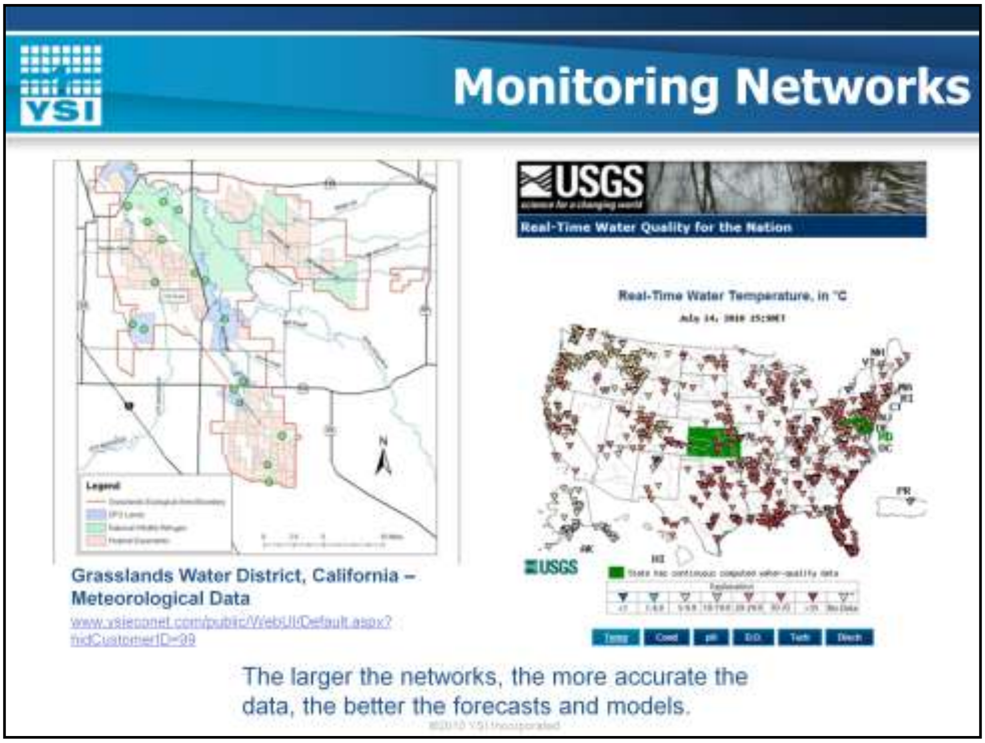
2) The second time series is of a chlorophyll data set. The user may look at this and say that something happened to the probe that caused a false spike in the data. You see the nice diurnal cycles of chlorophyll occurring in the first ¾ of the time series in a predictable pattern. However, when a user becomes experienced in looking at time series data and conducts pre and post deployment QC checks, you can determine if it is a real event or not. In this case, the spike was a real, short-term algae bloom event that did cause drinking water quality problems.



Two other types of field sensor data:

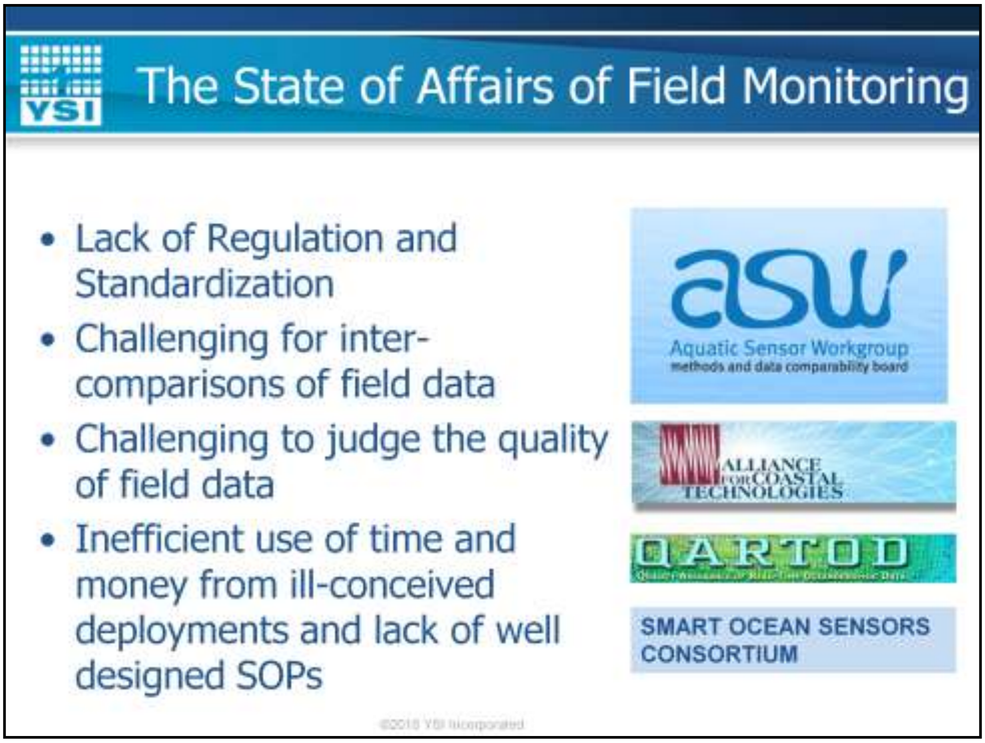
1) Top: Was collected from an automated vertical profiling system. This system generates a time series data set throughout a water column. Similar to a standard time series, data quality can be quickly checked through correlations with other parameters. For example, a rain event will often cause a decrease in conductivity and an increase in turbidity if the site is susceptible to run off. At such a site, if we see a drop in conductivity that does not show a corresponding jump in turbidity or rain event, this may be an indication of a problem with our conductivity sensor.

2) Right: This data type is a map that can be generated by autonomous vehicles, underway monitoring from boats or sensor networks. Data quality is often assessed the same way as above with sensor interactions and pre and post deployment checks.



We have reviewed data from a specific station or area. Once you install *multiple* monitoring sites you can begin to form a monitoring network that provides insight to flow and quality conditions over larger areas. Within networks it is critical that all stations utilize the same SOPs (standard operating procedures) in order to allow for inter-comparisons of the data.

The larger the networks, the more accurate the data will be, the better forecasts and models we will be able to develop.



To conclude the Introduction, I would like to restate that field instrumentation is capable of providing data of high temporal and spatial resolution with significantly less effort and cost than laboratory methods. However, in many instances, standard methods have not been developed for the various steps involved in collecting and analyzing field data.

YSI has been actively involved in a number of groups working towards standardization of field monitoring methods and technologies.

The importance of this work is:

• To allow the inter-comparability of data

• Collecting data of known quality

• Efficient use of monitoring time and resources to collect as much important environmental data as possible

We will focus on documents developed by the Aquatic Sensor Workgroup.

Understanding Instruments

Let's take a look at some of the typical water quality and water quantity sensors and a few examples of sensor-specific details used to measure or impact data quality.

Temperature

Robust sensor that does not require calibration but should be verified periodically with a NIST traceable thermometer. This verification is critical given the fact that all of the sensors use the temperature sensors for temperature compensation in the field. Problems with this sensors are almost always related to physical damage to the sensor.

Conductivity

Often conductivity sensors have internally housed electrodes that must be kept free of fouling and debris. The conductivity cell constant is a good diagnostic tool to check conductivity performance.

pH

This electrochemical sensors is one of the more sensitive field sensors and should be calibrated frequently. The slope of the sensor output should always be checked during calibration as an indication of sensor health. Care should be taken when cleaning these sensors since they can be easily damaged. These sensors must also remain hydrated.

Optical Dissolved Oxygen

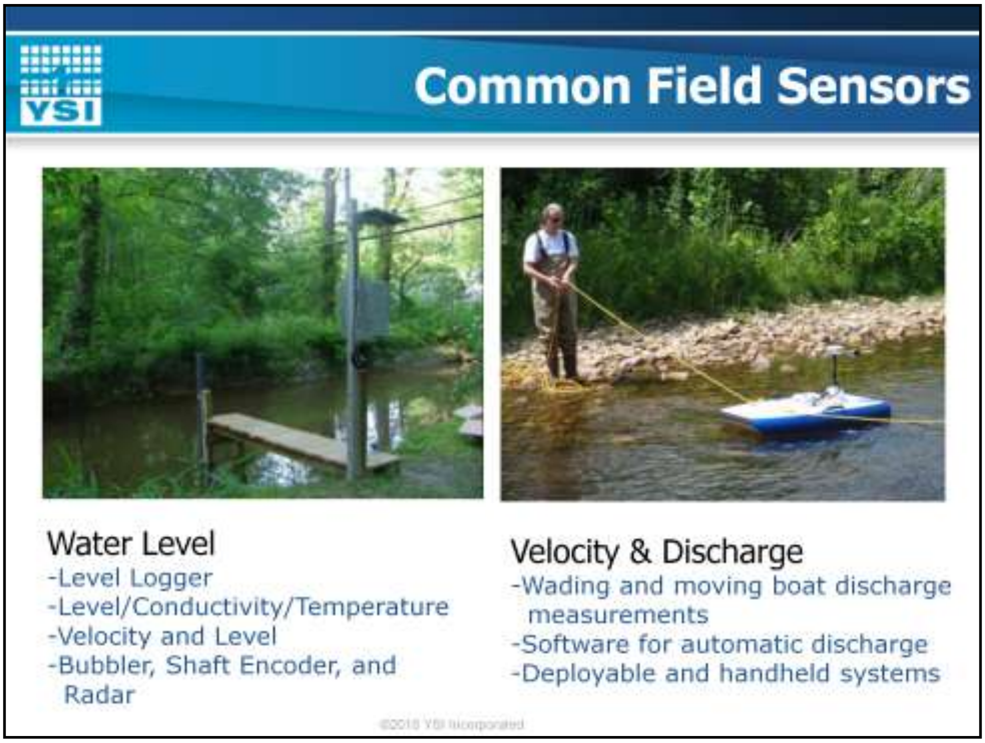
Care must be taken in calibrating the sensor to ensure complete Oxygen saturation and done near the ambient temperature. Also, optical DO membranes should be fully saturated prior to calibration and deployment.

Turbidity

Like most optical sensors, care must be given to the optical surface since scratches in the optical windows can create offsets. Also, with turbidity great care should be taken during calibration to avoid contamination of the calibration blank to avoid negative readings in the field.

MET Sensors

Cannot be calibrated by the user, but should be returned for annual calibration by manufacturer.



Other Sensors include Water Level sensors, where there is a variety of sensing technologies with their unique features, as well as Acoustic Velocity and Discharge Instruments.

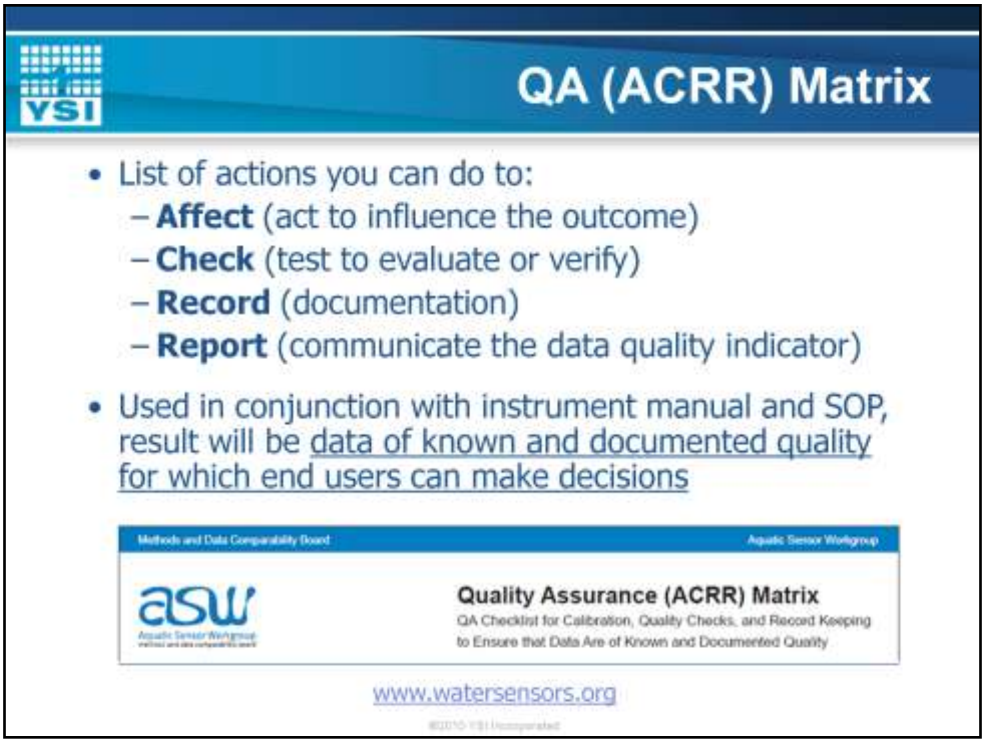
Wading Discharge Measurements

Ensure sampling volumes are clear of debris or boundaries. In the case of Sontek's FlowTracker, the system includes a Smart QC program that detects boundaries and anomalies in your measurement automatically and provides feedback so you can make the best measurement possible.

Moving Boat Discharge Measurements

A user must configure the instrument for cell sizes and specific sampling intervals based on site conditions. In the case of Sontek's River Surveyor, the system automates these steps so the user can focus on the measurement. This is especially useful in challenging conditions such as a Flood Event where there is a shallow flood plain as well as deeper sections in the main stream. This system allows you to collect accurate data in both conditions without having to change instrument settings.

As instrument developers, our goal is to make system with effective QA/QC data and to automate these steps when possible.



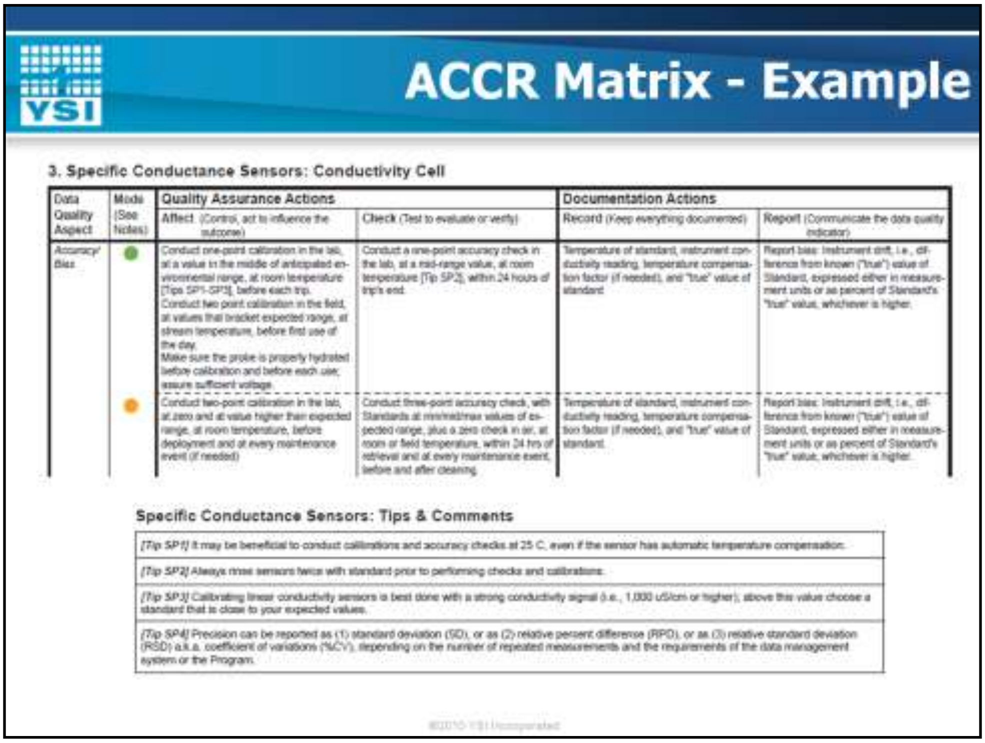
Now I would like to get into some specific resources available to you that can help to measure and improve data quality.

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.

One of the four products that the ASW has developed is called the QA Matrix.

The purpose of this matrix is to provide users of field sensors with the information they need to collect data of known quality (good or bad).

The current rev of the QA Matrix has been Completed for the core water quality parameters (CTD, DO, pH, TURB)



ACCR Matrix - 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	● (green)	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.
	● (orange)	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.

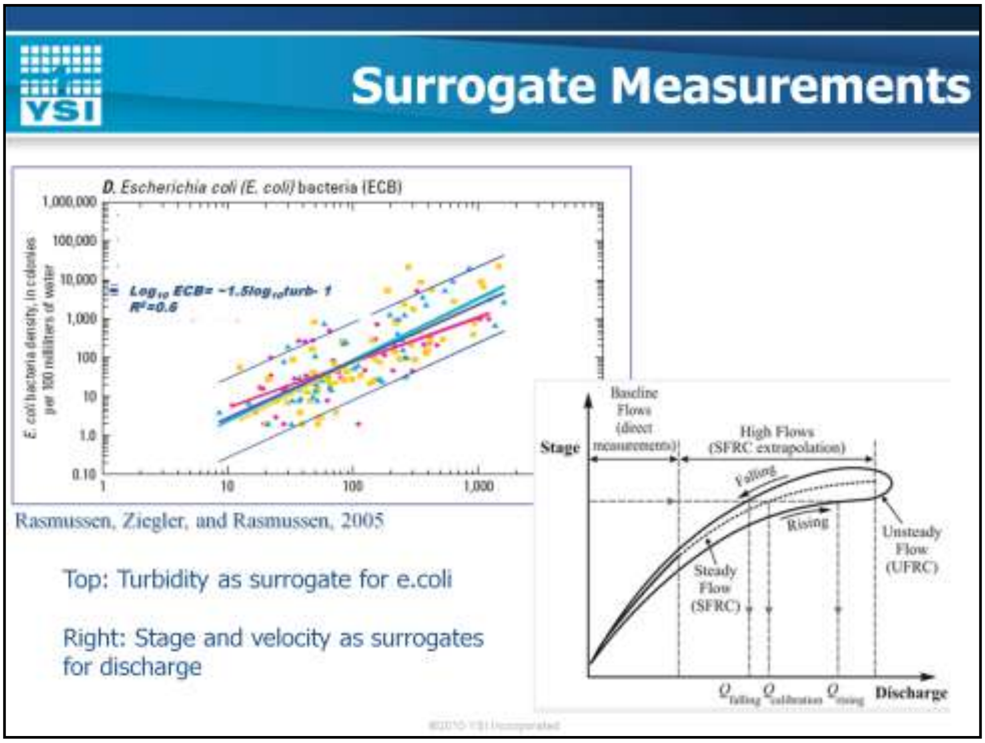
Specific Conductance Sensors: Tips & Comments

[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.

This example is the section for Conductivity Sensors. The guide has sensor specific information of the essential steps of collecting data of known quality: AFFECT CHECK RECORD REPORT

In this example the guide provides the recommended calibration procedures for a conductivity sensor (AFFECT), tells you how to check that accuracy of that calibration (CHECK), tells you what data to collect such as samples temp, temp compensation factor etc… at the time of calibration (RECORD), and what data to collect upon completion of a study in order to calculate a data quality indicator (REPORT).

In addition there are sensor specific tips and comments. In the case of conductivity an example is to calibrate sensors with a strong conductivity standard (1000uS/cm or higher) to minimize chances of standard contamination leading to poor accuracies.



Finally in the Instrument section of the presentation, I would like to mention surrogate measurements.

- The use of in-situ "surrogate" measurements can be powerful tool when direct measurement sensors are not available
- The process requires calibration of the in-situ sensor with samples collected over range of conditions, using statistics and models (the simpler, the better)
- This then allows one to compute concentrations, loads, uncertainty, and probability of exceeding water-quality criteria that can be transmitted and displayed in near real-time

- The first example is using turbidity measurements as a surrogate for e. coli.
- The best way to get quality data of e. coli is to take a sample and send to a lab
- However, this cannot be done at high resolutions or in real-time. Above is an example of turbidity and e. coli correlations at 3 different sites. This is not quantitative data but can be effective at showing trends, events, etc…

The second example is of water discharge calculations.
Historically people have used STAGE to calculate discharge but it is not always a reliable surrogate because one water level can correspond to two different flows.

If you use an acoustic device, you measure stage and velocity that are used to calculate discharge, allowing you to better define these complex flow situations and thus better understand the site.

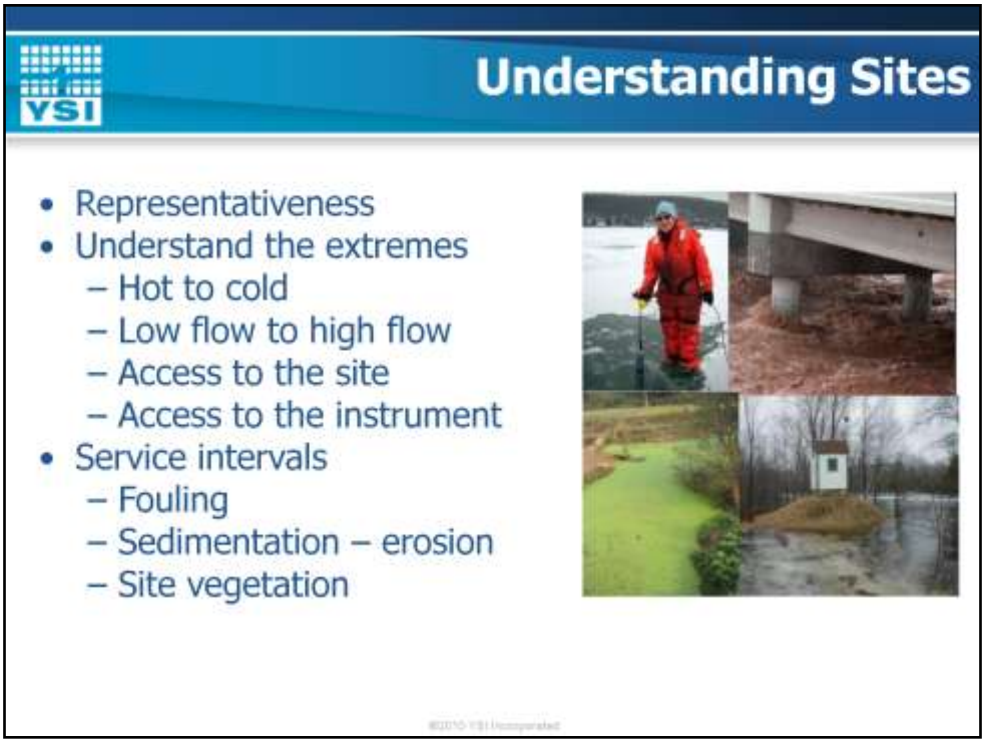
The bottom right graph is an example of discharge during a flood event. If you just measure STAGE, you use the middle line which is a linear regression that calculates an estimated discharge. But if you can measure VELOCITY and STAGE you get that extra information that so you can detect variations in discharge patterns during different stages of an event.

Common Surrogates

Parameter measured	Parameter Computed
Stage/velocity	Streamflow (discharge)
Specific Conductance	dissolved solids, salts
Turbidity	Total suspended solids, suspended sediment, fecal coliform, *E. coli*, total nitrogen, total nitrogen, total phosphorus

Here are a couple examples of parameters used for surrogate measurements

Understanding monitoring sites is an important aspect for collecting quality data, particularly for instrument installation, service intervals and data interpretation.

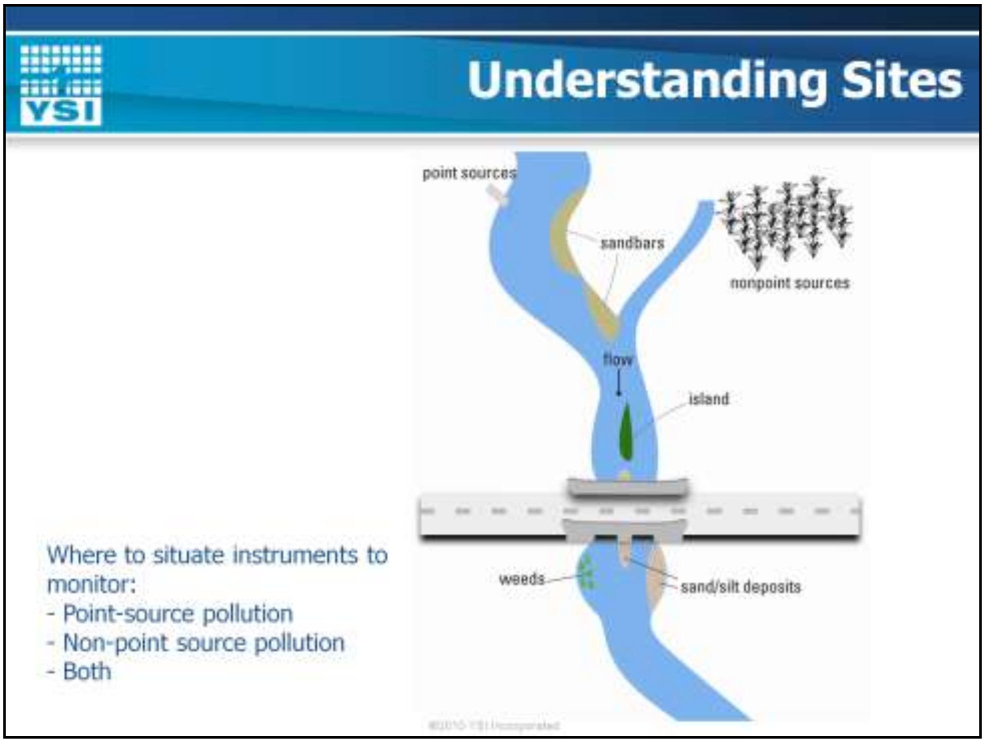


One of the biggest challenges at a site is to ensure that the data collected is representative – that is to say that the data collected by the instrument represents what is occurring at the site. This is crucial for making decisions based on the data.

Understanding extremes is an important concept for all aspects of data collection – Often the best way to understand the monitoring site is to evaluate historical data to to get an idea of what the instrument will have to endure. The range of hot and cold and high and low flow are important components for preparing to go to the field, accessing the site and the instrument selected for monitoring.

The photos to the right highlight some conditions that are often faced. The first image highlights sampling in a frigid environment, this requires special transport to the field, personal gear to stay warm and tools to have access to the water. The next images highlights a flooding event – installations must be robust enough to withstand peak events and still collect data – these are the events that monitoring programs are waiting for to better understand site dynamics – it is important to note that sometimes conditions can be really tough – the photo in the bottom right show a gage house well prepared for the event – however arriving to the site will be difficult, water covered ice is never fun!. The third picture highlights an algae bloom – issues here are safety, access to the sonde for maintenance and can the sensor package handle the extreme – this photo will be an important factor for data interpretation– one can expect to see large daily variations in dissolved oxygen from the data at this site.

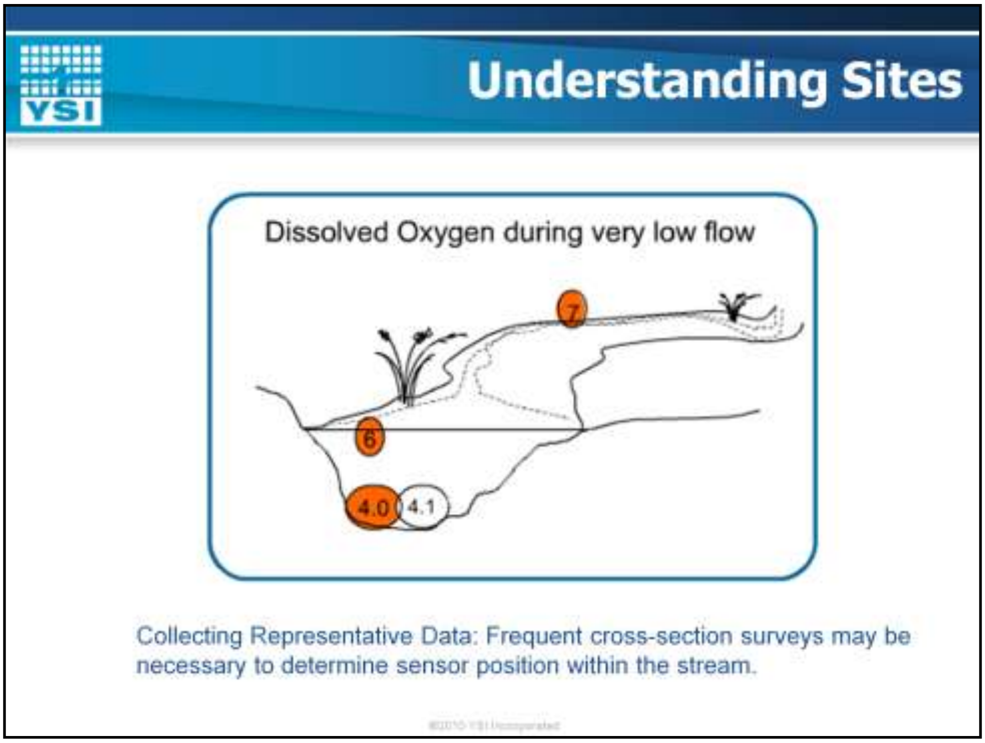
The pictures discussed here also relate to service intervals – fouling, sedimentation and site vegetation all effect data quality. The important consideration here is that site conditions change frequently and regular service intervals are required maintain data quality.



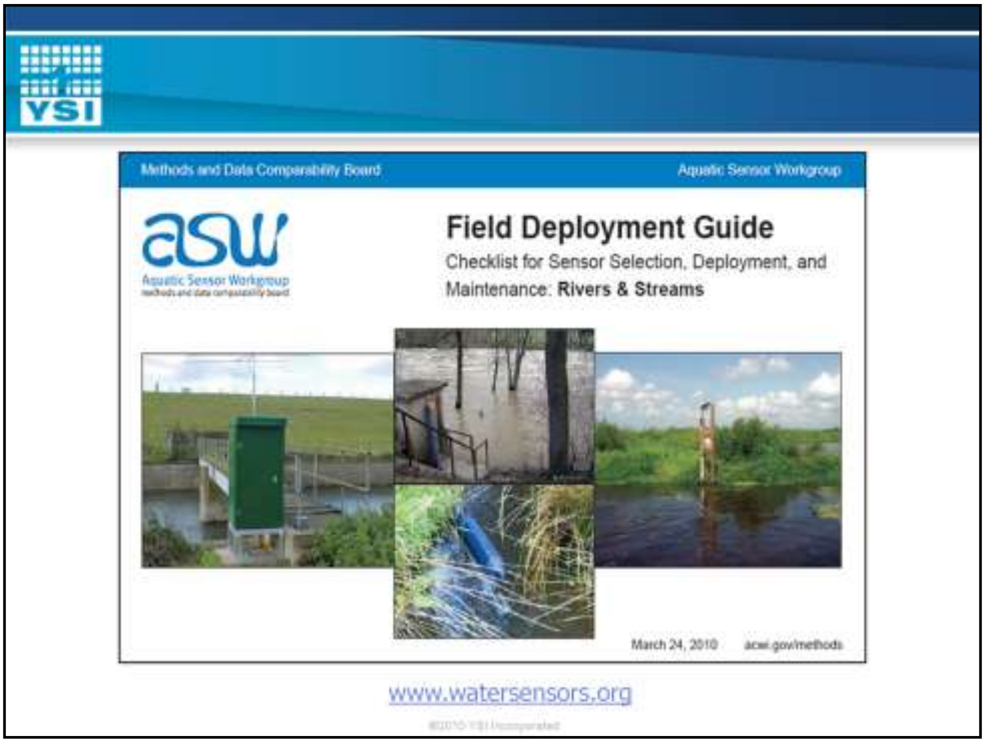
This diagram presents monitoring site considerations – for example, where you position the sonde is a function of your monitoring goals.

If the primary interest is to monitor non-point sources, then the high order stream on the far left bank or right side of the side is the best option. However, if the monitoring goal is to evaluate point source pollution, then installing the instrument down stream of the point source is the best location.

However, should the goal be to evaluate both sources, things become a little more complicated – but not impossible. Initially the bridge piling in the center of the stream would be a logical choice, but turbulence and sedimentation are issues for this example as indicated by the sand deposits. A likely candidate site would be downstream of the weeds and sand and silt deposits near the bottom of the slide. Bear in mind that in many instances, the weeds and sedimentation issues will not likely be present during initial site visits, so it is important to plan and understand potential site dynamics.



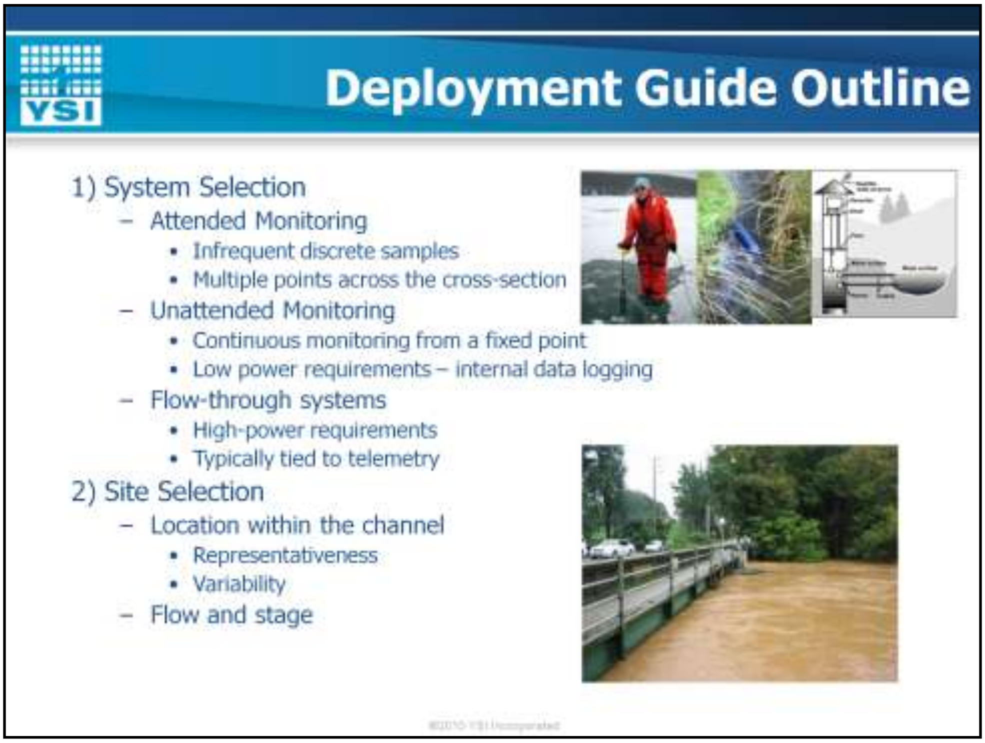
Sensor installation is not only important based on site conditions but also the physical location within the stream. This diagram highlights the distribution of dissolved oxygen concentrations in a stream. This data is used to determine the proper location of the sensor in the stream in order to obtain data that is representative for the site. The idea is to collect representative data, so the position of the sensor that provides the most representative data over a wide range of conditions is ideal. Periodic cross-section surveys are necessary to determine appropriate sensor placement as well as provide information that can be used to correlate to representative conditions.



To aid in the process of collecting high quality data, the Methods and Data Comparability Board and the Aquatic Sensor Workgroup developed a deployment guide.

This particular guide is geared toward rivers and streams with additional guides planned for lakes and reservoirs, coastal areas as well as others. The overall goal of these groups is to provide guidance and a framework so that users of all levels of experience are informed on how to collect reliable data of know confidence.

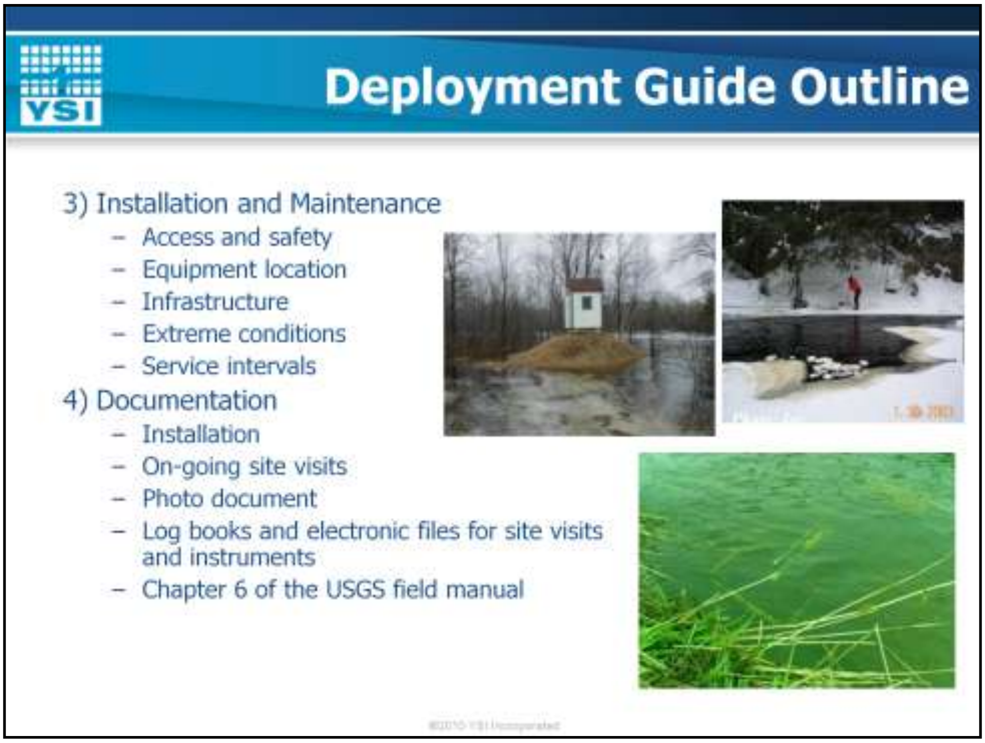
www.watersensors.org



The deployment guide is divided into 4 sections – the first two sections are presented in this slide and the last two sections in the next slide.

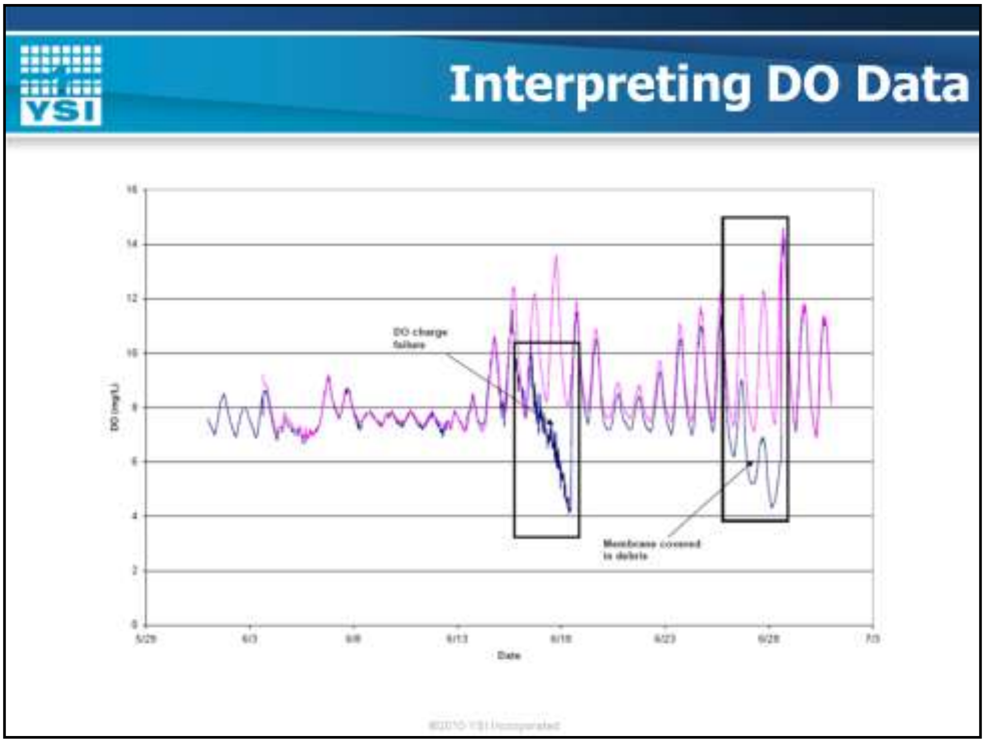
System selection will be based on data objectives and budget as this portion of the guide deals with the purchase of instruments for the field. There are three types of systems used – attended monitoring or sampling, unattended monitoring and flow through systems. Attended monitoring primarily deals with going to the field at regular intervals to collect data – this allows for low resolution trending for a site, but does allow for multiple points across the cross-section – this type of monitoring is highlighted by the picture on the top left. Unattended monitoring allows for continuous monitoring from a fixed point. These sites are battery operated with internal data logging. An example of an unattended monitoring site is presented in the top middle of the slide. Lastly, an example of a flow through system presented in the top right. These systems typically have high power requirements due to pumps and other devices such as telemetry.

The guide assumes that a monitoring location has already been selected and that the **specific site** of the sensor needs to be determined. For example the monitoring location of the picture in the bottom of the slide is the bridge, the site selection is the one of the bridge pilings. Important considerations for the site are representativeness of the data (which can be determined by a cross-section survey) and if the installation can capture the variability of the site. Flow and stage are the two primary drivers for site selection – as the sensors need to measure over the entire range observed in the field and the installation must be robust enough withstand all conditions.



The third section of the Deployment Guide is **installation and maintenance**. If an instrument package is not properly serviced then the data will not be reliable. Considering this, users need safe access to the site and the equipment – it is one thing to have safe access to the site and another to have safe access to the sonde. Available infrastructure is an important consideration – if the monitoring goals require a flow-through system, then it is likely that the site will require AC power. However you may be able to achieve your monitoring goals with unattended monitoring which may be as simple as a budgetary decision.

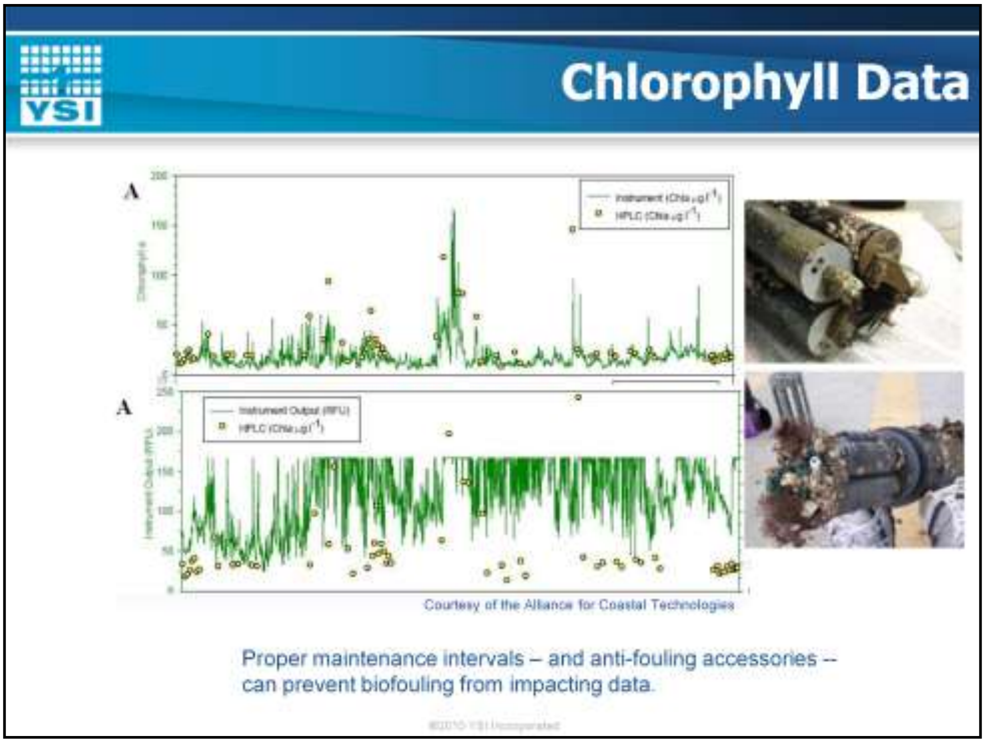
The last section and probably the most under-rated section is **documentation**. Simply put, the more documentation about the site and data collection the better. Photo documentation for the installation and site visits as well as a log book and electronic files should be kept based on station or instrument. Chapter 6 of the USGS field manual provides an excellent resource for documentation.



So, putting it all together: Knowing your sites and instruments allows users to make informed decisions when **interpreting data**.

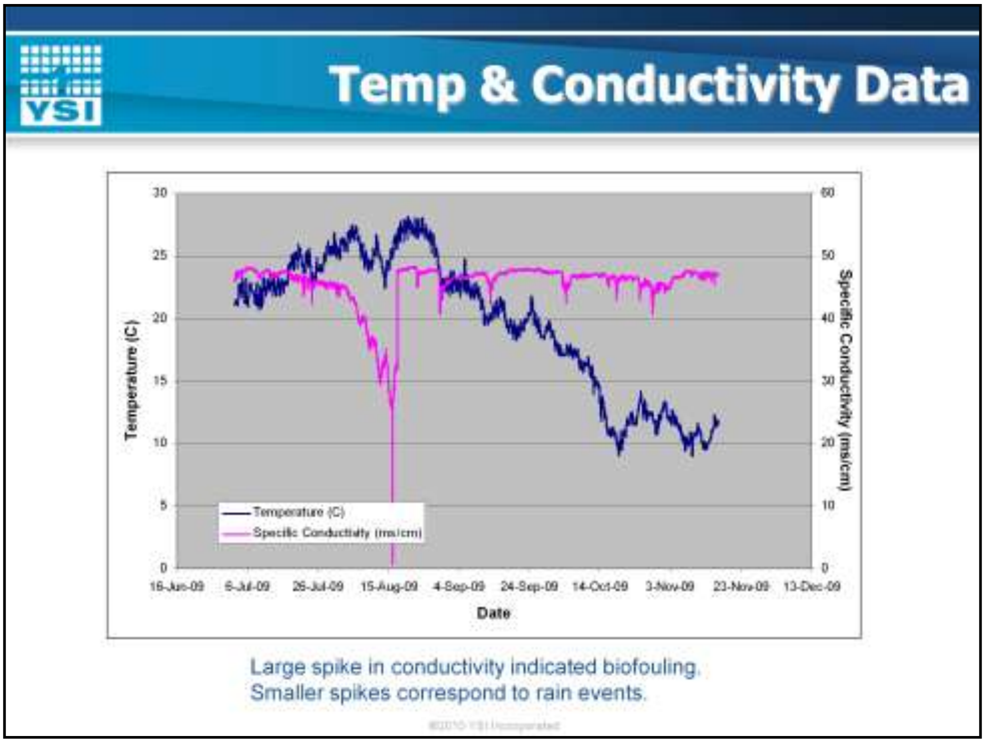
The data set presented is for two dissolved oxygen sensors installed in parallel – the pink line or trace presents un-biased data from the site while the blue trace presents data that has experienced a couple of problems. The data in the middle section shows a DO charge failure, likely due to a tear in the DO membrane, thus a rapid decrease in DO concentration due to a sensor malfunction.

The second issue (on the far right) shows a slow response to the environment – which is likely due to the DO membrane being covered by debris.



Chlorophyll data – the green trace is data measured in-situ by a sensor while the yellow dots are data determined from laboratory analysis. The top graph shows a good relation between the two data types, while the graph at the bottom shows good agreement initially, however over time this relationship breaks down with data from the in-situ sensor becoming very erratic. After further evaluation it was determined that biofouling was the culprit for the problems with the data.

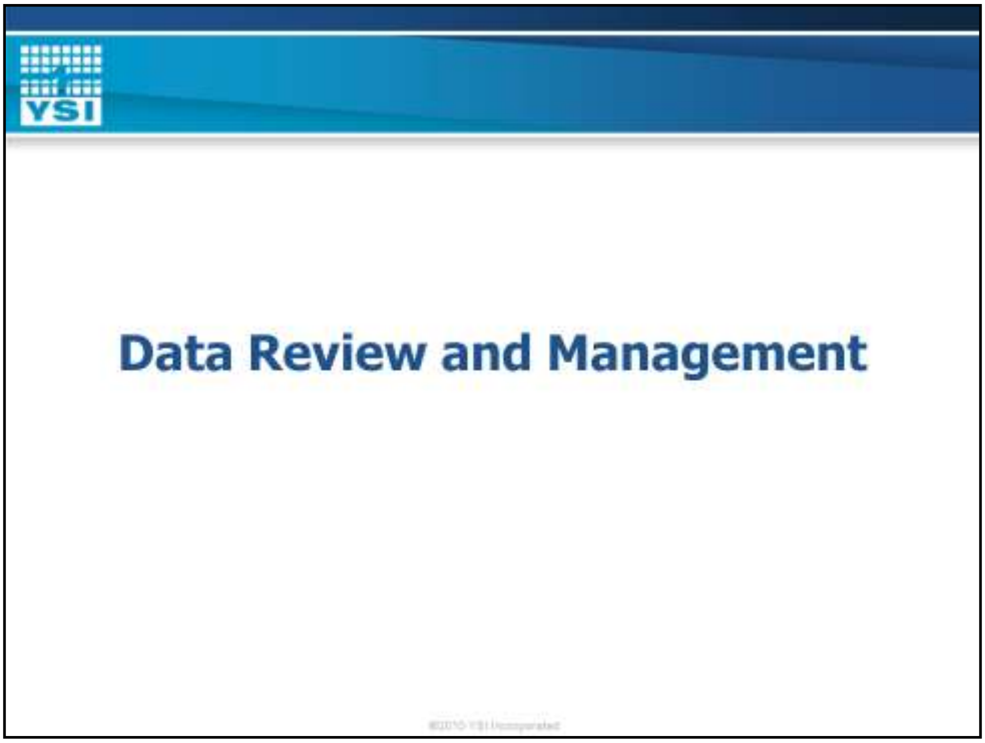
The pictures on the far right display the physical effect of fouling on sensors. Proper maintenance intervals can provide high quality data. In this case data collected with a sonde with an antifouling kit provided much more reliable data than the standard sonde.



The next data set highlights time series data with temperature data on the left-y axis and specific conductivity on the right y- axis. The temperature data corresponds well with what is to be expected at the site, while the conductivity data displays good data initially but is followed by a gradual downward trend followed by a spike. Fortunately a site visit occurred right after the spike – it was determined that there was a mass of algae growing inside the conductivity sensor housing thus isolating sensor from the natural environment thus biasing the data. After sensor maintenance the data returned to trends that are normal for the site. The small downward spikes at the tail end of the deployment correspond to rain events for the shallow subsurface deployed sonde.

Biofouling can be a tough issue for data collection. YSI has focused on providing solutions to combat antifouling - whether it is the integration of mechanical wipers and brushes, copper alloy sonde bodies and guards, mesh screens or the newest antifouling product C-spray -- all sensors are protected to ensure longer deployments with unbiased data.

The pictures on the bottom show the effects of a sonde with a copper alloy sonde guard and copper tape applied to the sensor bodies that also use mechanical wipers and brushes to fight fouling compared to a sonde that had no antifouling protection . Both pictures are taken after a 30 day deployment. The antifouling equipped sensor provided clean data for the 30 days while the unprotected sensor collected only 11 days of viable data. This provides important economic savings to end users – maintenance trips every 11 days as opposed to every 30 days is a big deal.

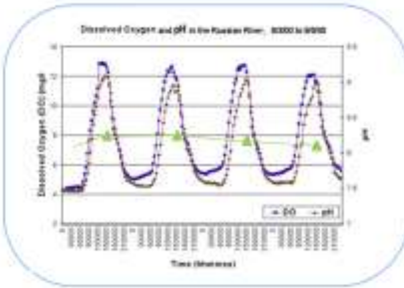


Data review and management are the next aspects of the talk and are topics that rely heavily documentation.

Data management deals with a variety of issues but the key word is consistency. It is important for monitoring programs to maintain a consistent date/time stamp and to have consistent file names. Using a consistent time reference is important know what is going on at a site and when, while consistent file names are important uploading data to a continuous record. Data review and correction procedures should be applied consistently to all data – in other words all data is created equally. Applying these procedures in a consistent manner will remove any uncertainties when making decisions based on the data. The last bullet deals with saving data versions. Depending what programs are used for data analysis there can be various versions of the data created – therefore always save the raw data file. This is the best way to “undo” any error and start your analysis from zero. This is often a support issue and the best advice that we can offer is… Always save the raw data!

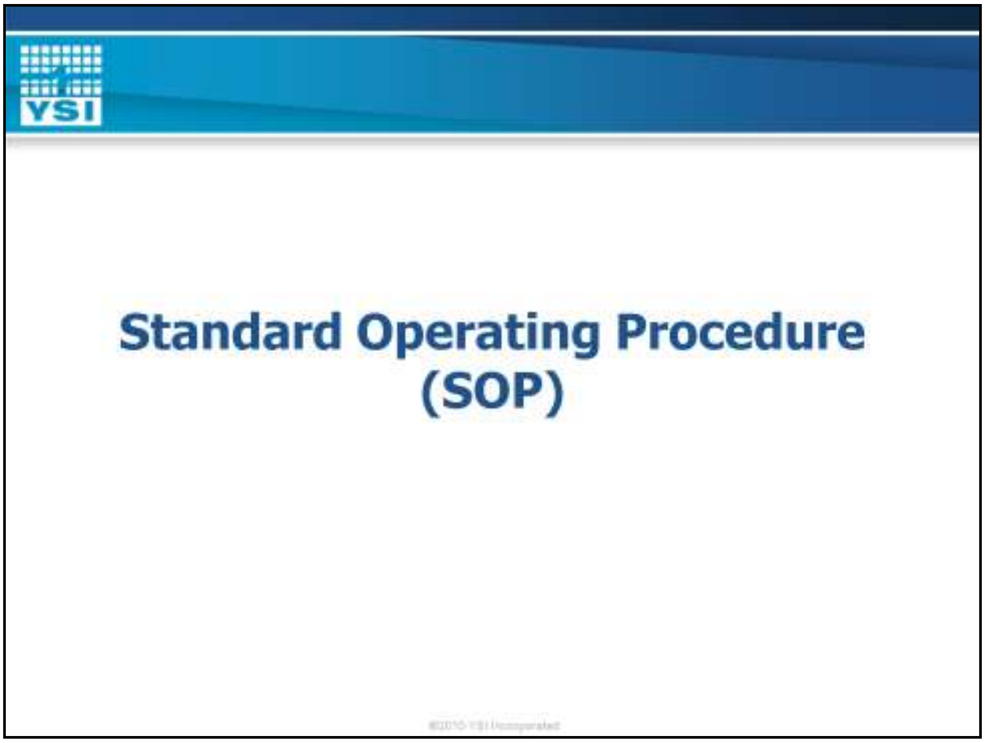
Data Management

***Example*: One site with four parameters**

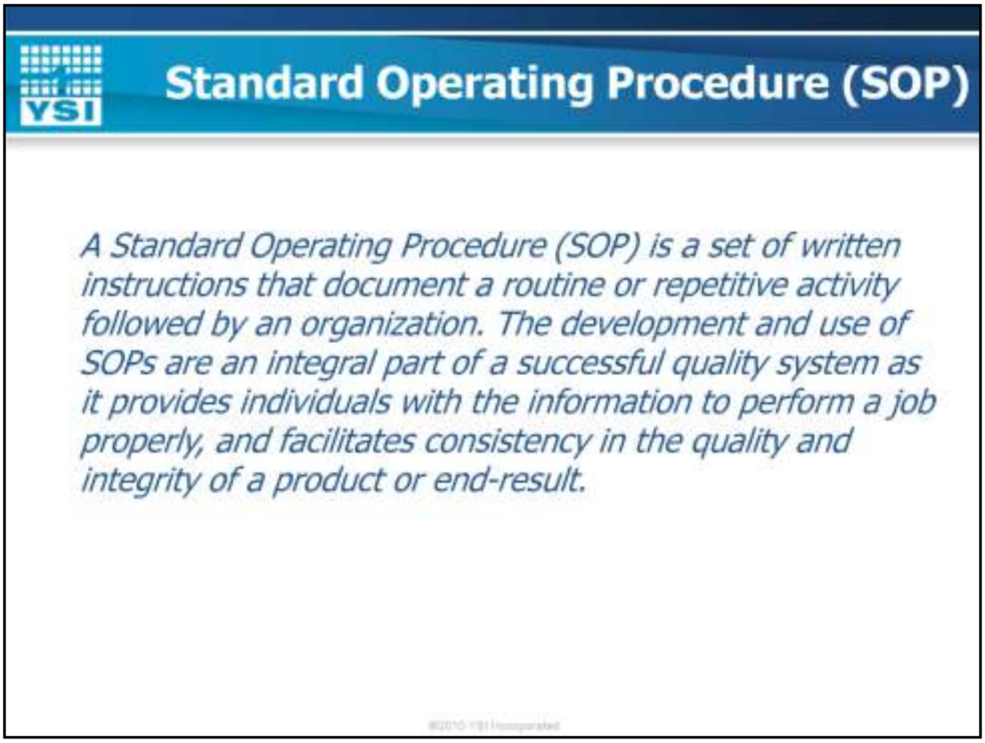


Sample Interval	Number of parameters	Total number of points/ yr
Weekly	4	208
15 min	4	35040

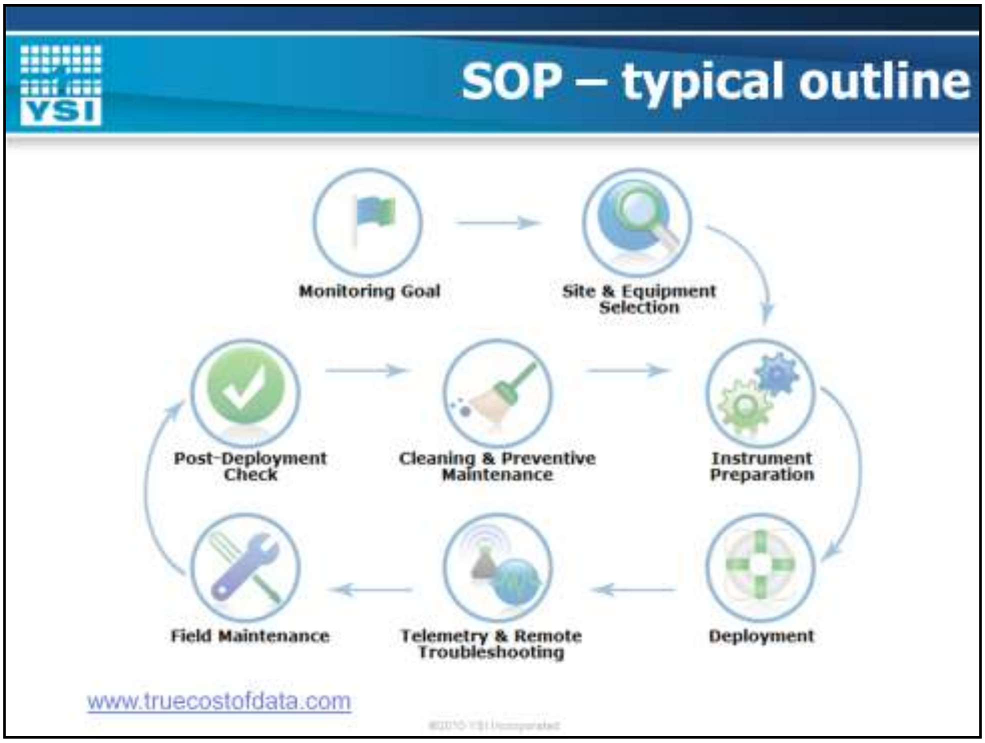
Another important issue of data management is the overall volume of data. As Rob highlighted earlier, there is a big difference in the resolution of data collected with weekly sampling and data via continuous monitoring. This slide emphasizes this point not only with the graphic above, where site variation is detected with continuous monitoring but the table below presents the increase in the volume of data generated by continuous monitoring. To take this point a step further – what is the time required to QA/QC 208 data points when compared to 35000? Bear in mind theoretically this is one monitoring site.



When summing up the information presented thus far, it is important to document everything related to the monitoring program as well as manage data in a consistent manner. To do this in an efficient way, monitoring programs should develop a standard operating procedure or SOP.



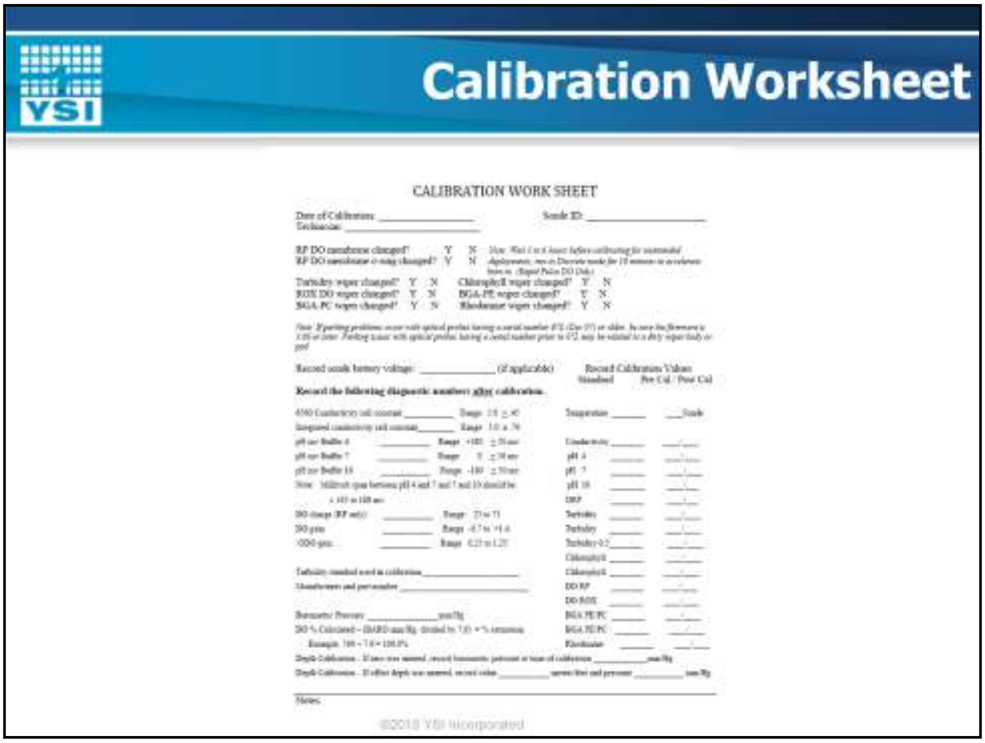
The bottom line is that an SOP, if followed, will ensure data quality.



This slide describes components of an SOP and how they relate to each other. Everything starts with monitoring goals--this will help drive decisions ranging from equipment selection to maintenance intervals. From there protocols for instrument preparation and deployment are necessary so that things are done consistently and correctly each time the site is visited. Troubleshooting and field maintenance procedures should be well documented so that a continuous data record can be maintained. The post deployment check and maintenance step ensure data quality. These steps annotate any differences observed in the field which can be used to correct the data. Proper maintenance keeps the sensor performance at an optimal state ensures the best quality data.

- Clearly defined procedures for data collection –Step by step
  - Monitoring goals
  - Data quality objectives
  - Documentation
- Pre-deployment procedures
  - Preparation
  - Calibration
    - Calibration sheet
- On-site data collection - retrieval
  - File names
  - Notes (site conditions, battery, fouling)
- Post deployment
  - Post-calibrations and data corrections
  - Data management
  - Maintenance
  - Storage requirements

  http://www.truecostofdata.com



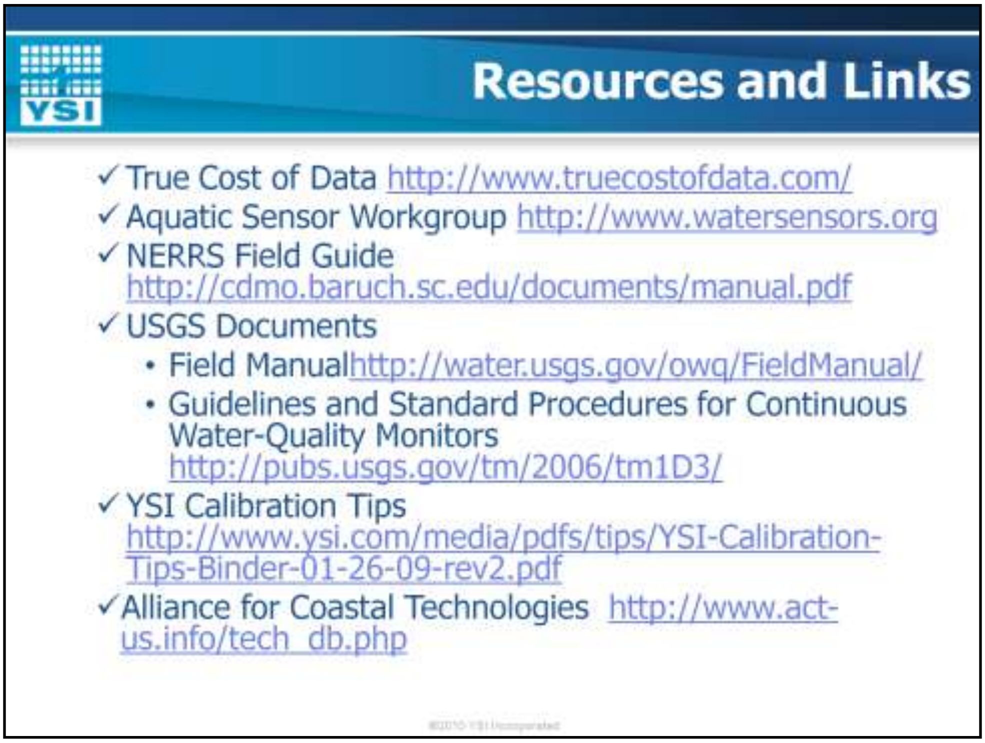
As mentioned before, documentation is an important factor for collecting reliable data. Site visit templates and log books should be incorporated in an SOP. Another important component is a calibration worksheet. As you can see in the slide the calibration worksheet guides users in documenting to document important sonde maintenance and sensor calibration procedures. For example, mechanical wiper changes battery voltages as well as sensor readings for calibration standards are all documented. This information can be used to evaluate data as well as be used for correcting data for electronic drift and even fouling.

Calibration, Maintenance & Troubleshooting Tips for YSI 6-Series Sondes and Sensors

http://www.ysi.com/media/pdfs/YSI-Calibration-Maintenance-Troubleshooting-Tips-6-Series-Sondes-2-8-10.pdf

Summary and Conclusions

1. Understanding instruments is essential to get the most for your money
   - Know limitations of the technology and the monitoring group
   - Realize the potential of surrogates
2. Understanding the monitoring site
   - Understanding maintenance intervals and effort
   - Critical to maintaining data quality
3. SOP is critical for:
   - obtaining monitoring goals
   - maintaining data quality



The goal is to continue to support the development and acceptance of field monitoring.

It is an absolutely essential component in developing a better understanding of our environment and making the best management decisions.

Here are some links to resources that will provide detailed information and will also allow you to get involved in efforts to further develop field monitoring standards.

- ✓ True Cost of Data http://www.truecostofdata.com/
- ✓ Aquatic Sensor Workgroup http://www.watersensors.org
- ✓ NERRS Field Guide http://cdmo.baruch.sc.edu/documents/manual.pdf
- ✓ USGS Documents
  - Field Manualhttp://water.usgs.gov/owq/FieldManual/
  - Guidelines and Standard Procedures for Continuous Water-Quality Monitors http://pubs.usgs.gov/tm/2006/tm1D3/
- ✓ YSI Calibration Tips http://www.ysi.com/media/pdfs/YSI-Calibration-Maintenance-Troubleshooting-Tips-6-Series-Sondes-2-8-10.pdf
- ✓ Alliance for Coastal Technologies http://www.act-us.info/tech_db.php