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In Situ Optical Water-Quality Sensor Networks—Workshop Summary Report

Open-File Report 2012–1044

U.S. Department of the Interior
U.S. Geological Survey

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Abbreviations and Acronyms

CDOM	colored or chromophoric dissolved organic matter
CUAHSI	Consortium of Universities for the Advancement of Hydrologic Sciences, Inc.
DOM	dissolved organic matter
FDOM	colored or chromophoric dissolved organic matter measured by fluorescence
HIS	Hydrologic Information System
IHSS	International Humic Substances Society
LED	light-emitting diode
nm	nanometer
NSF	National Science Foundation
QAQC	quality assurance/quality control
TMDL	total maximum daily loads
UMBC	University of Maryland – Baltimore County
USGS	U.S. Geological Survey
UV	Ultraviolet

In Situ Optical Water-Quality Sensor Networks—Workshop Summary Report

By Brian A. Pellerin[1], Brian A. Bergamaschi[1], and Jeffery S. Horsburgh[2]

Executive Summary

Advanced in situ optical water-quality sensors and new techniques for data analysis hold enormous promise for furthering scientific understanding of aquatic systems. These sensors measure important biogeochemical parameters for long deployments, enabling the capture of data at time scales over which they vary most meaningfully. The high-frequency, real-time water-quality data they generate provide opportunities for early warning of water-quality deterioration, trend detection, and science-based decision support. However, developing networks of optical sensors in freshwater systems that report reliable and comparable data across and between sites remains a challenge to the research and monitoring community. To address this, the U. S. Geological Survey (USGS) and the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) convened a joint 3-day workshop (June 8–10, 2011) at the National Conservation Training Center in Shepardstown, West Virginia, to explore ways to coordinate development of standards and applications for optical sensors, and improve handling, storing, and analyzing the continuous data they produce.

The workshop brought together more than 60 scientists, program managers, and vendors from universities, government agencies, and the private sector. Several important outcomes emerged from the presentations and breakout sessions. There was general consensus that making intercalibrated measurements requires that both manufacturers and users better characterize and calibrate the sensors under field conditions. For example, the influence of suspended particles, highly colored water, and temperature on optical sensors remains poorly understood, but consistently accounting for these factors is critical to successful deployment and for interpreting results in different settings. This, in turn, highlights the lack of appropriate standards for sensor calibrations, field checks, and characterizing interferences, as well as methods for data validation, treatment, and analysis of resulting measurements. Participants discussed a wide range of logistical considerations for successful sensor deployments, including key physical infrastructure, data loggers, and remote-communication techniques. Tools to manage, assure, and control quality, and explore large streams of continuous water-quality data are being developed by the USGS, CUAHSI, and other organizations, and will be critical to making full use of these high-frequency data for research and monitoring.

Key Findings

On the basis of presentations, breakout group discussions, and other discussions among workshop participants, we have identified several key findings:

1. In situ optical sensors require improved characterization and correction methods for interferences prior to widespread use in river and stream monitoring.

2. Varying geometries and designs of optical sensors make comparison of measurements between some sensors problematic.

3. Standard solutions and protocols for sensor calibration and field checks are needed.

4. Diagnostic indicators are needed to evaluate sensor performance and data quality in real time.

5. High-priority sites for collection of continuous data by using in situ optical instruments tend to be those where water quality is episodic or otherwise highly variable over short time scales.

6. The greatest scientific value is in the deployment of optical sensors at established, fixed sites in combination with roving stations.

7. Multi-parameter data streams and development of “surrogate” measurements from these data are critical for answering process-level questions.

8. Comparing in situ optical data across the networks could be facilitated greatly through adoption of standard methods and rigorous protocols.

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9. Site logistics are a key component of successful, long-term sensor deployments and can be a constraint in sensor deployment.

10. Telemetry is key for developing long-term, continuous records from these sensors and identifying when site maintenance is needed, and is also useful for outreach and optimizing sampling routines.

11. Automated approaches are needed for storing, processing, assuring quality, and analyzing the large amounts of data produced by optical-sensor networks.

12. The full value of in situ optical data will be realized through new visualization and statistical tools and techniques yet to be developed.

Introduction and Background

Shifts in land use, population, and climate have altered hydrologic systems in the United States in ways that affect the water quality in our rivers and the function of our coastal ecosystems. Water diversions, detention in reservoirs, channelization, and changes in rainfall and snowmelt have major effects on hydrologic systems, but there also are more subtle drivers in the environment, such as changes in soil temperature, atmospheric deposition, and shifting vegetation patterns. The effects of these factors on water quality are complex and interconnected, and occur at time frames of minutes (for example, increases in constituent fluxes during flash floods) to decades (for example, reductions in nutrient concentrations with improved management practices). However, water-quality monitoring historically has relied on discrete samples collected weekly or monthly and laboratory analyses that can take days or weeks to complete. The low sampling frequency and delayed access to data do not enable a timely response during events, limit our ability to identify specific causes or actions precipitating these events, and result in poor quantification of effects at local, regional, and global scales.

The recent advent of commercially available, in situ sensors and data platforms—together with new techniques for data analysis—provides an opportunity to monitor water quality at time scales during which meaningful changes occur. In particular, optical sensors—those making continuous measurements of constituents by absorbance or fluorescence properties in the environment at time scales of seconds to years—have a long history in oceanography for developing highly resolved records of constituent concentrations and fluxes, but, as of yet, have not been used commonly in freshwater systems. Continuous, high-frequency optical measurements in rivers and streams can be effective sentinels of water-quality changes when combined with real-time streamflow and climate data. For example, measurements that capture the variability in freshwater systems with time help assessments of how shifts in seasonal runoff, changes in precipitation intensity, and increased frequencies of disturbances, such as fire and insect outbreaks, affect the storage, production, and transport of carbon and nitrogen in watersheds. Real-time sensors also provide tools for early trend detection, help identify monitoring gaps, and ensure timely data for science-based decision support across a range of issues related to water quality, freshwater ecosystems, and human health.

Workshop Proceedings

The 3-day workshop (June 8–10, 2011) on in situ optical sensors was convened jointly by the U. S. Geological Survey (USGS) and the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) to focus on the "full life cycle" of in situ optical measurements from sensor deployment to data analysis. A major goal of the workshop was to engage a broad community of users to begin coordinating the development of standards for deployment and applications for optical sensors, as well as for handling, storage, and analysis of the continuous data they produce. The workshop brought together more than 60 scientists, technicians, and program managers from universities, government agencies, and the private sector (*fig. 1*, *appendix 1*).

The first two days featured a mix of plenary speakers and breakout sessions focusing on sensor operation and standardization (day 1) and data management and analysis (day 2). On day 3, short "vision" talks highlighted the potential for in situ optical sensors to help answer important questions about nutrient dynamics in aquatic ecosystems, constituent transport across watershed scales, and networking real-time water-quality monitors in urban systems. Speakers for all three days represented a variety of expertise within the USGS and CUAHSI-affiliated research community, and opening remarks were made by managers from the USGS, CUAHSI, and the National Science Foundation (NSF). Evening activities included a poster session and vendor demonstrations. The workshop concluded with a "blue sky" discussion about the short- and long-term needs and goals for the in situ optical-sensor community to move technology, standardization, and information-sharing forward (*appendix 2*).

What Do Optical Sensors Measure?

Commercially available, in situ sensors measure optical properties, such as attenuation, the amount of emitted light energy removed from water by particulates; scattering, a change in direction of the emitted light path that increases the likelihood of absorption; absorption, the emitted light energy removed from water by dissolved constituents; and fluorescence, the emission of visible light by a substance that has absorbed light of a lower wavelength. These optical properties are determined by the concentration and species of materials dissolved or suspended in water. Naturally occurring

Figure 1. Participants in the USGS–CUAHSI In situ Optical Sensor workshop, June 8-10, 2011, Shepardstown, West Virginia.

organic compounds, such as colored dissolved organic matter (CDOM) and decaying organic matter; inorganic particulate matter, such as silt and clay; nutrients; phytoplankton; and contaminants all influence water optical properties and water quality.

The USGS–CUAHSI workshop focused largely on two in situ-sensor technologies—fluorometers for colored organic matter and ultraviolet (UV) spectrophotometers for nitrate—because of the high level of interest by the broader community in nitrogen and organic matter in rivers and streams. These instrument types both have a 20-year-plus history of use in oceanography but only have been adopted for use as water-quality monitors in freshwater environments in the last few years. Many of the concepts discussed during the workshop are relevant to other continuous monitors that use optical properties to measure algal pigments and particle composition. Future workshops likely will focus on instrumentation measuring attenuation and scattering because these properties are important to characterizing suspended-sediment concentration and composition.

CDOM Fluorometers

On the forefront of emerging water-quality sensor technologies are fluorescence-based optical sensors, designed specifically to measure dissolved organic matter (DOM) in freshwater and coastal environments. DOM includes a broad range of organic molecules of various sizes and composition that are released by all living and dead plants and animals. Measuring the fraction of light absorbed at specific UV wavelengths and subsequently released at longer wavelengths (that is, fluorescence) is diagnostic of DOM type and amount. Studies have often used the excitation and emission at 370 and 460 nanometers (nm), respectively, to quantify the fluorescent fraction of colored DOM (hereafter referred to as FDOM). Measurements of FDOM have a long history in oceanography as an indicator of terrestrial humic substances in the coastal ocean but only recently have been adapted for use as water-quality monitors in freshwater environments.

Several companies manufacture in situ FDOM sensors (including Wetlabs, Turner Designs, SeaPoint, Trios, YSI, and HobiLabs) for a range of applications in freshwater, estuary, coastal, and ocean environments. The principles behind the measurements are the same, regardless of manufacturer. Inexpensive and low-power UV light-emitting diodes (LEDs) provide nearly monochromatic excitation energy, and silicon photodiodes measure the emitted light over a specified wavelength range. Instrument designs differ, however, in some important ways—instruments either can be flow-through (for example, the sample is pumped through a quartz tube mounted through the long axis of the instrument) or use flat optical backscatter, for instance. Other differences in instruments among manufacturers include the specific wavelength for emission and detection, size, power requirements, sampling frequency, sensitivity, detection range, and the capability for automating measurements and internal logging.

Optical Nitrate Sensors

Optical nitrate sensors operate on the principle that nitrate ions absorb UV light at wavelengths less than 240 nm. Commercially available, optical nitrate sensors utilize this property to convert spectral absorption properties measured with the sensor to a nitrate concentration by using laboratory calibrations and integrated algorithms to account for interferences from other absorbing ions (such as bromide) and colored organic matter. This allows for real-time nitrate measurements without the need for chemical reagents.

Companies currently manufacturing in situ optical nitrate sensors for industrial and environmental applications include Satlantic, Hach, Trios and s::can. All manufacturers use a UV light source and a spectrometer, but instrument designs have important differences in terms of lamp type (deuterium vs. xenon), optical pathlength (1 to 35 millimeters), and the process algorithms (2-beam to full UV spectrum) used to calculate nitrate concentrations. Other differences in instruments among manufacturers include the size, geometry, accuracy, detection limit, need for proprietary controllers, maximum sampling rates, and anti-fouling techniques.

Needs and Recommendations

The needs and recommendations detailed in the following section resulted from presentations given by workshop participants, breakout-group discussions, and other discussions among workshop participants.

Standardizing Optical-Sensor Measurements

Given the goal of making comparable measurements across sites and over time, two breakout sessions identified needs and recommendations with respect to sensor qualification and validation, field checks, approaches for data collection, statistics, supporting measurements, and data corrections. Specific needs and recommendations include the following:

1. **In situ optical sensors require further characterization of interferences and development of interference correction schemes prior to widespread use in river and stream monitoring.** Optical sensor measurements can be significantly influenced by a variety of matrix effects including water temperature, inner filter effects from highly colored water, turbidity, stray light interference, air bubbles, iron interference, bromide interference, pH, and biofouling. Data suggest that these effects differ by instrument type and design and, in most cases, can be addressed through mechanical solutions (filtration, wipers), correction schemes, or both (Saraceno and others, 2009; Pellerin and others, 2011). Recommendation: Manufacturers and the user community need to evaluate optical-sensor performance under a range of conditions using standard protocols and standard materials that are representative of environmental matrices to develop robust interference correction methods.

2. **Varying optical-sensor geometries and designs can result in measurements that are not comparable.** Similar to turbidity measurements, the ability to compare data from different sensors in standardized units is limited by differences in the wavelengths or estimation techniques used. This is a particular problem for commercially available FDOM sensors, which are calibrated to a common standard (quinine sulfate), but show widely varying results in side-by-side comparisons of different instruments. Recommendations: As a first step, manufacturers should provide details on sensor design, such as instrument measurement angles, excitation-emission peaks, bandpass, sample volumes, and algorithms for constituent-concentration calculations. The user community needs to work with manufacturers to evaluate approaches for standardizing measurements through modifications to instrument designs, such as identifying an appropriate excitation-emission peak and bandpass for DOC concentrations in most aquatic systems, and evaluating standards for reporting sensor output in common units.

3. **There is a clear need to define standard solutions and protocols for sensor calibration and field checks.** A current impediment to comparing data collected by multiple researchers is the lack of common standards and methodologies. In particular, there is a need to identify primary standards to be used in laboratory sensor calibrations and secondary-check standards to evaluate sensor performance in the lab or field. Secondary standards, in particular, need to be safe to handle in the field, stable, and relatively insensitive to changes in temperature. Recommendations: Manufacturers need to evaluate possible primary and secondary standards for fluorometers and develop protocols for their use in the lab and field. A standard methodology for the use of quinine suflate as a primary standard needs to be accepted by manufacturers and the user community, and a suite of possible secondary standards (organic-free deionized water, unacidified quinine sulfate, caffeine, International Humic Substances Society [IHSS]) standards, solid standards) need to be assessed for stability and reproducibility in the field. Standard protocols for lab and field calibrations of optical nitrate sensors need to be developed, and the user community and manufacturers should consider participation in ongoing USGS laboratory evaluations with standard reference materials.

4. **Diagnostic indicators are needed to evaluate sensor performance and data quality in real time.** The use of statistical techniques and approaches to evaluate sensor performance in real time will improve data quality and limit data gaps from field-deployed optical sensors. Common metrics, such as the rate of change, sensor ranges, and detection limits, are useful indicators of instrument performance, but advanced techniques such as "burst sampling," time series analysis, and machine-learning techniques could provide additional opportunities to ensure data quality in real time. Recommendations: The user community and manufacturers should develop protocols for collecting diagnostic data on sensor performance. Common metrics such as "rate of change" and "thresholds," should be considered, as well as the collection of "burst samples," to evaluate the variability around mean values. Manufacturers should characterize instrument "noise" in standard or blank solutions and provide this information to the user community. Automated techniques such as Bayesian analysis, should be evaluated as diagnostic tools for real-time evaluation of data.

Optical Water-Quality Sensor Networks

Several breakout sessions were tasked with identifying priorities for establishing in situ optical-sensor networks for water-quality monitoring and research. Discussions focused on sites and studies for in situ optical sensors, logistical considerations for sensor deployment, and suites of sensors for direct and "surrogate" measurements. Specific needs and recommendations include the following:

1. **High-priority sites for continuous data tend to be those where water quality is highly variable over short time scales.** While need, and the scientific questions that address those needs, is ultimately defined by the problems and concerns, the types of sites that will likely benefit from continuous water-quality data provided by in situ optical sensors include hydrologically "flashy" systems, such as urban watersheds; sites with drinking-water-quality issues, such as disinfection byproducts, high nitrate concentrations, or algal toxins; impaired sites undergoing active restoration and management of such factors as total maximum daily loads (TMDLs); and sites that drain to ecologically and economically important estuaries. Recommendations: The scientific community should continue to focus the application of in situ optical sensors on priority sites while seeking new opportunities to evaluate and demonstrate the utility and applications for water-quality studies in a broader range of aquatic environments.

The greatest scientific advances with optical sensors likely will occur through the combination of established fixed sites and relocatable stations. Coupling in situ optical-sensor deployments with established sites that have supporting data collection (discharge and discrete water-quality data) provides exciting new opportunites for calculating loads and testing hypotheses related to drivers of water-quality variability. Deploying in situ optical sensors at roving or relocatable stations in combination with data-rich, fixed site deployments in sentinel locations, however, likely would provide the greatest scientific value for monitoring and process-level understanding. Recommendations: The USGS and academic community should seek opportunities to partner—using comparable methods and instruments—to test hypotheses within broader USGS programs by developing in situ optical-sensor capabilities at fixed monitoring sites.

2. **"Surrogates" developed from multi-sensor applications will be critical for answering important water-quality questions.** Many of the water-quality challenges we face are complex and can benefit from simultaneous data characterizing a suite of parameters to answer questions of constituent sources, timing, and management. Combining observations from in situ optical sensors, physical parameters, such as discharge or temperature, and other sensor measurements, such as turbidity and specific conductance, at high temporal resolution will create opportunities to evaluate questions related to constituents whose concentrations are either measured directly or estimated through "surrogate" relationships with one or more continuously measured parameter. Recommendations: The user community should continue to couple sensors as needed to answer important water-quality questions, while

developing new methods, along with manufacturers, for using observations from different types and designs of instruments as surrogates for water-quality constituents that cannot be measured directly continuously.

3. **Standard methods are critical for comparing in situ optical data across sites, deployments, and data collectors.** Standardized sensor measurement protocols, data-collection strategies, and common quality-assurance and quality-control (QAQC) approaches will be necessary to develop an inter-calibrated network of in situ optical sensors with different agencies and users. This includes common measurement units, sensor calibration methods, and data-correction approaches. Recommendations: Developing, publishing, and sharing standard methodologies and metadata should be a high priority for the USGS, CUAHSI, and academic research community to ensure data are comparable regardless of their source. Venues to publish standard methods—including USGS Techniques and Methods reports, journal methods papers, supplemental information to scientific articles, and CUAHSI bulletins—should be explored to ensure the broad dissemination of citable information and perpetual maintenance of information in open-access venues.

4. **The success of long-term sensor deployments requires careful consideration of site logistics.** Site access, security, deployment infrastructure, and solutions to reduce biofouling need to be carefully considered to ensure the collection of high-quality in situ optical data at long-term monitoring sites. Recommendations: The user community should share information on successful (and unsuccessful) deployments of optical sensors, including techniques for mounting sensors in flowing waters, reducing biofouling, preventing vandalism, and establishing site communication. A list of logistical considerations and supplies for sensor deployment was discussed as part of this workshop and is available in VerHoef and others (2011). Manufacturers should work more closely with the user community to establish protocols for sensor deployments that maximize the likelihood of high-quality data collection, such as guidelines on the physical orientation of sensors, mounting hardware, and tools for remote data access.

Data Management and Analysis

Given the goals of the workshop to consider the full “life cycle” for optical sensor deployments, several breakout sessions focused on the collection, management and analysis of large water-quality datasets. Specific topics included telemetry and communication hardware, tools and software for the analysis of continuous data, and systems for data storage and retrieval. Specific needs and recommendations include the following:

1. **Telemetry and real-time communication is essential for site maintenance, outreach, and optimizing sampling routines.** The ability to monitor and deliver data in real time provides numerous benefits, including monitoring sensor performance, providing an early warning of water-quality issues, allowing for adaptive sampling, and increasing public awareness. Several different technologies are available for real-time data transmission, including acoustic, radio, cellular telephone, and satellite, and the optimized infrastructure is based on study needs, available site infrastructure (power, cellular telephone, and satellite coverage), and sensor network design. Recommendation: A workgroup has begun developing a comprehensive list of existing telemetry options and the coincident benefits and challenges for use in a water-quality sensor network. CUAHSI and USGS should continue to support and encourage this group and facilitate the compilation and publication of the information produced.

2. **Management of continuous, optical measurements should rely heavily on automated approaches for acquisition, processing, quality assurance, storage, querying, and display of data.** Recent advances in sensor technology and software for automated data collection have improved the availability of software that automates storing, retrieving, and displaying data. For example, the CUAHSI Hydrologic Information System (HIS) tools and other recent developments using open-source technology allow for broad access to large streams of data generated by multiple sensors within networks, while minimizing the opportunity for human error associated with data management. Recommendations: The user community should work with software developers to continue development of tools for automating QAQC, storage and retrieval, and visualization of real-time in situ optical-sensor data and statistics. Development and adoption of standard metadata for describing optical sensor data will facilitate compari-

son of data across networks, and the use of data repositories, such as the HIS, for sharing data would benefit the broader community.

3. **New visualization and statistical tools and techniques are needed to fully utilize continuous water-quality data.** Advanced visualization and statistical analysis can help in evaluation of trends in concentrations, fluxes, and yields across space and time. Long-term data are needed for many of these analyses, with the length of the dataset determining the phenomena or processes that can be investigated. However, new tools and techniques that are readily available and well documented are needed by the water-quality community to fully utilize continuous data in watershed models and water-quality management. Recommendations: The user community needs to invest more directly in tools that are both readily accessible and well documented for the visualization and analysis of large datasets. Approaches used in other fields, such as atmospheric and computer science, should be investigated, given the large data streams generated by these fields. New statistical techniques for data analysis also should be investigated as longer-term, in situ optical datasets become available.

Future Directions

The general consensus of the workshop participants was that in situ optical sensors for water quality (particularly for FDOM and nitrate) will be increasingly important to understanding water quality in a complex landscape influenced by climate variability and land-use change. The group also felt that the in situ optical-sensor technology was sufficiently developed to warrant its broader application in rivers and streams after some of the key, but solvable, issues, such as standards and corrections, are resolved. Future directions will include closer collaboration between the USGS, academia, and manufacturers to advance and document the development of instruments, standards, quality-assurance techniques, and data-management tools. Workshop attendees were invited to join an online community sharing experiences at *http://www.watersensors.org*, and continued activities for several smaller work groups were planned.

Acknowledgements

This summary represents the effort of a large number of people who planned and participated in the workshop. In particular, we thank the plenary speakers and breakout session leaders, as well as the workshop sponsors (Consortium of Universities for the Advancement of Hydrologic Science, Inc., National Science Foundation, and the U.S.Geological Survey Office of Water Quality).

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Appendix 1. Workshop Participants

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Appendix 2. Workshop Agenda

USGS (U.S. Geological Survey) – CUAHSI (Consortium of Universities for the Advancement of Hydrologic Sciences, Inc.), In situ Optical-Sensor Networks Workshop
(June 8-10, 2011, National Conservation Training Center, Shepardstown, WV)

TUESDAY, JUNE 7, 2011
Arrive at the National Conservation Training Center, 698 Conservation Way, Shepherdstown, WV 25443-4024

WEDNESDAY, JUNE 8, 2011
8:30 AM Welcome / Introductions – *Rick Hooper, CUAHSI; Robert Mason, USGS*

9:00 AM **PLENARY TALK:** The need for continuous water quality data: Examples from headwaters to the coast – *Brian Pellerin, USGS*
In order to understand and respond to changes in hydrology and water quality, scientists and managers need accurate and early indicators, as well as the ability to assess possible mechanisms and likely outcomes. The recent advent of commercially available in situ sensors and data platforms - together with new techniques for data analysis - provides the opportunity to monitor water quality on the time scales in which changes occur. This talk will provide a number of examples where continuous data has transformed our ability to understand drivers and trends in water quality across a range of environments.

9:40 AM **PLENARY TALK:** What do in situ optical sensors measure? – *Emmanuel Boss, University of Maine*
Demonstration of the principles of optical measurements including attenuation, scattering, absorbance and fluorescence, as well as interference from particles and inner filtering.

10:30 AM **CONCURRENT BREAKOUT SESSIONS**

Breakout 1: How optical sensors work – a hands on demonstration of the principles and problems with optical sensors
Breakout Leaders: Emmanuel Boss, University of Maine; Brian Bergamaschi, USGS
The purpose of this breakout is to provide a guided, hands-on opportunity for people unfamiliar with optical sensors to see what they measure, how they work, and what interferes. Absorbance, attenuation, and scattering will be covered as it relates to making good measurements using sensors with different power, sensors tuned to different wavelengths, and sensors with different geometries.

Breakout 2: How optical sensors work – considerations for field deployment of optical sensors *Breakout Leaders: Brian Downing, USGS; Claire Welty, University of Maryland – Baltimore County*
The purpose of this breakout is to acquaint users with the infrastructure and design of field deployment of optical sensors for water quality studies. Topics to be discussed include robust mounting in flowing systems, considerations of light and turbidity interference, sensing volume, temperature control, bubbles, cabling, signal transmission, etc.

Breakout 3: How optical sensors work – principles and basics of nitrate sensors *Breakout Leaders: Matt Cohen, University of Florida; John Saraceno, USGS; Janice Fulford, USGS*
There has been a great deal of interest recently in the ability to make in situ optical nitrate measurements in rivers and streams. However, the principles, operation and state of the technology are not widely understood. This breakout session will provide an overview of the theory behind optical nitrate measurements, basics of operation, data generation and analysis, and design differences between manufacturers.

12:30 PM **LUNCH**

1:30 PM **PLENARY:** Why standardize measurements? Examples from intentional or ad hoc comparisons – *George Aiken, USGS*
Results of a recent comparison study for lab optical measurements (absorbance and fluorescence) that demonstrates the needs and challenges of making standardized measurements.

2:10 PM **PLENARY:** From the lab to the field: Challenges for collecting high quality optical sensor data in situ – *Brian Bergamaschi, USGS*
The advent of commercially-available field photometers and fluorometers over the last twenty years provides an opportunity to revolutionize how we do science. However, the challenges that we need to overcome in collecting high quality data in the field —particularly in rivers, streams and estuaries—are in many cases just emerging. This talk will highlight some of the challenges inherent in making intercalibrated and consistent measurements with in situ optical sensors under field conditions.

2:40 PM The National Environmental Methods Index – *Dan Sullivan, USGS*

3:10 PM **CONCURRENT BREAKOUT SESSIONS**

Breakout 4: The need for in situ optical sensors in freshwater and coastal systems: Where is the greatest "bang for the buck"? *Breakout leaders: Wil Wollheim, University of New Hampshire; Brian Pellerin, USGS*
The goal of this breakout is to identify the highest priority opportunities for answering important questions and monitoring trends with respect to the deployment of in situ optical sensors. In particular, the group will identify the value of deploying optical sensors in remote locations, opportunities related to watershed size (headwaters vs. large coastal basins), freshwaters vs. coastal systems, freshwater (lakes, rivers) vs. coastal systems, process studies vs. monitoring, site with regulatory issues and those dedicated to long-term trends. While all sites are important, we can't make optical measurements everywhere. So, where is a focused effort likely to yield the greatest results?

Breakout 5: Long-term deployments of optical sensors: considerations and needs. *Breakout Leaders: Claire Welty, University of Maryland – Baltimore County; Jon Morrison, USGS*
The ability to make high quality in situ optical measurements requires careful consideration of factors other than just the sensors. In particular, site access, sensor infrastructure, and power are key considerations. The goal of this breakout is to update the Wagner and others, 2006 USGS report for in situ optical sensors. Key considerations include: What infrastructure is needed in the field (power, gage house, etc.), what are the key components of site communication and logging, and what are the key needs for site access (maintenance and sampling).

Breakout 6: How can we test that sensors are measuring what we expect them to measure? *Breakout Leaders: Emmanuel Boss, University of Maine; Dan Sullivan, USGS*
Given the goal of our science is to make comparable measurements across sites and over time, the purpose of this breakout is to identify protocols needed for aligning the user communities' activities with respect to sensor qualification and validation (including instrument characterization for data handling, range, temperature, measurement properties, blanks), field checks (blanks, calibration solutions), approaches for data collection (burst sampling, statistics), supporting measurements (lab and field), and data corrections (biofouling, temperature, inner filter effects, particle concentration and size).

5:30 – 7:30 PM **POSTERS**

THURSDAY, JUNE 9, 2011
8:30 AM The need for continuous monitoring: The academic and research perspective – *Tom Torgersen, National Science Foundation; Rick Hooper, CUAHSI*

9:00 AM **PLENARY:** Statistical analysis of concentration and flux over time: Thinking about change at multiple temporal scales – *Bob Hirsch, USGS*
An overview of methods being used for analysis with traditional river sampling strategies, the questions and uncertainties that arise from them, and a discussion of the potential role of in situ sensors in resolving scientific puzzles and regulatory problems.

9:40 AM **PLENARY:** Management of sensor datasets: Experiences from an Urban Environmental Observatory – *Mike McGuire, University of Maryland – Baltimore County*
Recent advances in sensor technology and automated data collection have improved the ability to monitor urban environmental systems and are making the idea of an urban environmental observatory a reality. This talk focuses on the management of sensor data from a prototype urban environmental observatory based at the Baltimore Ecosystem Study National Science Foundation Long Term Ecological Research site (BES LTER). Details will include a discussion of the use of Hydrologic Information System (HIS) tools developed by the Consortium of Universities for the Advancement of Hydrologic Sciences Inc. (CUAHSI) and recent developments using open source technology.

10:30 AM **CONCURRENT BREAKOUT SESSIONS**

Breakout 7: New and existing tools for data analysis and visualization. *Breakout Leaders: Bob Hirsch, USGS; Laura Toran, Temple University*
The purpose of this breakout is to discuss the benefits and difficulties of interpreting high frequency data sets, including improved trend detection. Breakout participants will identify current methods and resources for mining this data, and recommend standards for reporting, publishing, and serving this data to downstream users.

Breakout 8: Techniques and needs for quality assurance and quality control. *Breakout Leaders: Stewart Rounds, USGS; Matt Cohen, University of Florida*
The ability to collect, store and use large amounts of data from in situ optical sensors require new techniques and approaches for quality assurance/quality control (QAQC). In particular, tools that automate QAQC procedures will improve the intercalibration of sensor networks and proxy measurements across a range of systems. The goal of this breakout is to identify the broad suite of issues that affect sensor data quality, identify current QAQC gaps that need new tools and make recommendations for how to standardize QAQC across an intercalibrated network.

Breakout 9: Community-based requirements for a distributed sensor data management system. *Breakout Leaders: Mike McGuire, University of Maryland – Baltimore County; Robert Mason, USGS*
One of the unavoidable consequences of real-time high frequency data collection is the large volume of data generated. As this data accumulates over time, it becomes more important to store the data in a system that makes the data easily accessible. Advancements in distributed computing have made it possible to manage sensor data by using network-based services which make the data accessible through standard interfaces. Examples include the CUAHSI HIS and the Open Geospatial Consortium Sensor Web Enablement (SWE). The purpose of this breakout is to inform the development of next generation distributed sensor data management systems by developing a set of community-based requirements.

12:30 PM **LUNCH**

1:30 PM **PLENARY: Sensors, cyberinfrastructure, and water quality in the Little Bear River: Adventures in continuous monitoring** – *Jeff Horsburgh, Utah State University*
Process-based understanding of short- and longer-term behavior of catchments is important to our ability to predict hydrologic system response. The time scale of many processes is on the order of minutes to hours, not weeks to months, and understanding the linkages between catchment hydrology and water quality requires measurements on a time scale consistent with these processes. This presentation describes the development of a sensor network within the Little Bear River Utah, USA, that provides continuous, high frequency streamflow and water quality observations aimed at improving understanding of the hydrologic and water quality response of the watershed; the timing, duration, and sources of water quality constituent fluxes; and development of the observing infrastructure and cyberinfrastructure needed to better quantify these fluxes.

2:10 PM **PLENARY: You can't measure everything: Using 'surrogates' to compute continuous concentrations and loads** – *Pat Rasmussen, USGS*
This will be a presentation of approaches for continuous monitoring of parameters that can be computed directly from field-sensor measurements using linear regression. Examples of surrogate relations with a range of uncertainties will be presented with some thoughts on how they can be documented, disseminated, and improved.

3:00 PM **CONCURRENT BREAKOUT SESSIONS**

Breakout 10: Designing continuous monitoring networks. *Breakout Leaders: Jamie Shanley, USGS; Rick Hooper, CUAHSI*
The ability to link monitoring sites and individual networks with sensor measurements will provide a powerful approach to studying water quality at regional to global scales. However, a number of key considerations need to be addressed to further develop these networks. This breakout will be a discussion of the following considerations: What kinds of sites should be included in a large-scale network? Should a network focus on a particular size watershed (for example, small watershed as in NEON; large river basins as in NASQAN) or be driven at least in part by a set of questions (climate trends in the HBN)? What are the key variables that need to be measured at every site? What are the key components that make the network "inter-calibrated"?

Breakout 11: Sensor network telemetry and communication. *Breakout Leaders: Jeff Horsburgh, Utah State University; Bridget Benson, University of Massachusetts – Boston*
Technology now permits communication with in situ sensors remotely, in real-time, and in ways that improve our ability to understand and manage water quality. However, the set of tools for doing so is diverse and the techniques are not well defined or understood by scientists, especially for water quality sensors. This breakout will focus on the following key issues: what is the "state of the art" in remote communication with instruments and stations? What does having optical sensor data available in real-time enable scientists to do that cannot be done with offline data? What are the characteristics of the optimum communication network (hardware and software, reliability, availability, connectivity, bandwidth, etc.) and do currently available technologies satisfy these needs? How do we maximize the power of infrastructure, loggers and communications for in situ optical sensor networks? [BP]

Breakout 12: Integrating optical measurements with other water quality data to improve predictions and understand patterns. *Breakout Leaders: Wil Wollheim, University of New Hampshire; Pat Rasmussen, USGS*
Real-time water-quality measurements are typically made to assist in the characterization of environmental conditions and contaminant transport. Although it is difficult and expensive to periodically or continuously monitor for many contaminants, contaminant presence or concentrations can often be inferred from individual or groups of measurements (for example, "surrogates" or "proxies") that track sources and/or environmental processes. Further, multiple measurements provide the prospect of developing biogeochemical signatures that could be used to identify dominant source locations in space and time. The purpose of the breakout is to identify the suites of measurements potentially suitable for these purposes, identify resources for development and application of multi-measurement surrogates or signatures, and identify what protocols are needed to better apply these types of models over diverse settings

5:30 – 7:30 PM **VENDOR DEMONSTRATIONS**
Vendors attending include Hach, YSI, Wetlabs, Turner Designs, Campbell Scientific, Satlantic, s::can, Aquatic Informatics, and Eureka Scientific

FRIDAY, JUNE 9, 2011
8:30 AM The Need for Continuous Monitoring: The USGS Perspective – *Donna Myers, USGS; Jared Bales, USGS*

9:00 AM – 11:00 AM: **VISION TALKS**
Matt Cohen, University of Florida – *Emergent inference: High resolution sensing for understanding ecosystem processes*

Jamie Shanley, USGS – *Application of optical sensors to small watershed research*

Wil Wollheim, University of New Hampshire – *Continuous in situ data and models: Towards mechanistic understanding of biogeochemical dynamics in watersheds*

Brian Bergamaschi, USGS – *Proxy measurements with in situ fluorometers*

Bob Chen, University of Massachusetts – *Water quality forecasting—using a network of optical sensors to better understand and predict water quality, carbon cycling, and climate change*

Casey Lee, USGS – *The future for optical sensors in national and regional water-quality assessment*

Claire Welty, University of Maryland – Baltimore County *An end-to-end vision for environmental data collection and analysis in an urban ecosystem*

Nate Booth, USGS – *Sensors and geospatial tools*

11:00 AM **SYNTHESIS AND "BLUE SKY" DISCUSSION**

12:30 PM **END**

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USGS

Pellerin and others—**In Situ Optical Water-Quality Sensor Networks—Workshop Summary Report**—Open-File Report 2012–1044