Proceedings of the

Nutrient Sensor Challenge Workshop

September 17–18, 2014
Washington, DC

Funded by the National Oceanic and Atmospheric Administration (NOAA)
through the U.S. Integrated Ocean Observing System (IOOS)
in cooperation with the Challenging Nutrients Coalition

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Executive Summary

Cyanobacterial bloom in the Great Lakes *(source: MODIS Today* http://ge.ssec.wisc.edu/modis-today/credits.html*).*

Nutrients are essential to life. However, excess nutrients (particularly nitrogen and phosphorus) in U.S. waterways are threatening human health, ecosystem biodiversity, and the economy. Specifically, human health may be threatened when nutrient levels in water supplies violate drinking water nitrate standards and drinking water coagulation and filtration treatment standards. Similarly, excess nutrients can trigger algal blooms and biodiversity loss with consequences that affect both the economy and human health. The need for significant progress on this growing national issue has been recognized by a consortium of federal agencies working with the Alliance for Coastal Technologies (ACT) and other non-governmental partners. Their challenge has been to identify the next generation of strategies to address nutrient pollution. The Challenging Nutrients Coalition aims to incentivize new approaches using public-private partnerships, open innovation, new perspectives, and citizen input.

In November 2013, the Coalition convened a "visioneering" meeting of experts in the field of nutrient management. The meeting highlighted the need to develop affordable nutrient sensors to provide data that will better inform management decisions. This report is the outcome of a September 2014 workshop focused on accelerating the development of next-generation affordable, accurate aquatic nutrient sensors. It is anticipated that the recommendations in this report will inform the Nutrient Sensor Challenge, which will culminate in a suite of transformative, tested sensors that can be deployed for high spatial and temporal resolution *in situ* nutrient measurements.

The workshop identified desired performance parameters and usability requirements for the next generation of aquatic nutrient sensors. Developers discussed the state of technology and options for lowering costs. End-users articulated acceptable trade-offs between costs and limits of detection, accuracy, precision, and deployment length and environment. The recommendations for the Nutrient Sensor Challenge included:

- A focus on dissolved forms of nitrogen and phosphorus.
- A focus on research/monitoring grade instruments capable of remote, unattended deployment.
- The need to quantify market opportunities in target research/monitoring markets.
- Comparison of cost on the basis of cost per sample or cost per data point (to be determined).
- Sampling frequency between one minute and one hour, with 15-minute intervals meeting most needs.
- Setting cost standards to minimize lifetime costs by:
    - Keeping initial purchase price of the sensor to less than $5,000 (USD in 2014).

    - Minimizing operations and maintenance costs by reducing associated person hours and increasing ease-of-use.
    - Limiting manufacturer service intervals to annual (12 months) or longer.
    - Assuring total lifetime of at least five years (60 months).
    - Enabling unattended deployment durations of two to four months.
- The need for anti-fouling capabilities.
- The need to account for interferences.
- Accuracy and precision targets of 2 to 5 percent when measured at 20, 50, and 80 percent of the detection range.

ACT and the Challenging Nutrients Coalition will consider these recommendations in developing requirements and evaluation criteria for the Nutrient Sensor Challenge.

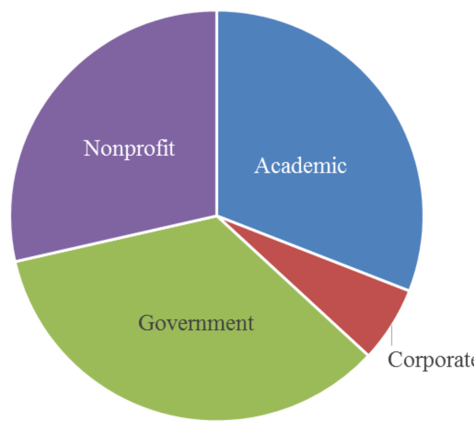
I. Introduction

Nutrients are ubiquitous and essential for the production of food, fuel, and fiber. They come from a variety of sources, including urban and agricultural runoff, sewage treatment plants and septic systems, and fossil fuel combustion. Nitrogen and phosphorus are often applied in fertilizers to supplement ambient nutrients available for crop production and livestock feed. However, excessive nutrient levels can harm human health and ecosystems and impact the economy. Potential effects include drinking water contamination and violation of national drinking water standards, harmful algal blooms, hypoxia, and biodiversity loss, among other problems.

In the U.S. Environmental Protection Agency's (EPA's) 2014 National Summary of State Information, excess nitrogen and phosphorus were identified as leading causes of water pollution across the nation (U.S. EPA, 2014). Sixty-five percent of the nation's major estuaries display symptoms of nutrient pollution (Bricker et al., 2007). The State-EPA Nutrient Innovations Task Group estimated that approximately 14,000 water bodies are affected by excess nutrients throughout the United States, with every state affected (U.S. EPA Office of Inspector General, 2009; NOAA, 2011).

Nutrient concentrations in water are highly variable in time and space, largely due to relationships with hydrology and microbially mediated biogeochemical transformations. At present, however, nutrient measurements are typically limited to a discrete set of locations and are often collected infrequently (e.g., monthly). The responsibility of state and federal agencies to balance and manage limited water resources for the economic, environmental, and public health benefit of their constituents has exceeded the budgets of many agencies. More data are needed to inform decisions aimed at reducing excess nutrients and to track progress.

To explore the frontiers of nutrient sensor capabilities and envision next-generation sensors, the U.S. Integrated Ocean Observing System funded ACT to organize a workshop focused on accelerating the development and adoption of aquatic nutrient sensors. This effort builds on prior ACT nutrient sensor activities (e.g., needs and use assessments, workshops and instrument demonstration [see www.act-us.info]). The workshop was planned and executed with the involvement and cooperation of the Challenging Nutrients Coalition, a group of federal agencies, the Everglades Foundation, Tulane University and the Partnership on Innovation Technology and the Environment (PTIE).



PTIE user needs survey respondent characteristics (84 respondents). Report available at www.nutrients-challenge.org *(source: workshop presentation by Beth Stauffer).*

ACT convened the workshop to develop a recommended set of ideal specifications for transformative aquatic nutrient sensors in light of developer capabilities and user needs, which were identified through an online survey administered by PTIE. In particular, the workshop focused on opportunities in the user market, performance parameters, usability requirements, cost considerations, and feasibility. Ultimately, the workshop's goal was to build consensus on technical requirements and other recommendations to inform the Nutrient Sensor Challenge.

II. Background

The Nutrient Sensor Challenge is part of a broader set of activities from the Challenging Nutrients Coalition to use incentive prizes to stimulate open innovation, scientific/technological breakthroughs, partnerships, and engagement to help solve the problem of excessive nutrients. In November 2013, the group launched the "Challenging Nutrients Ideation Prize" to crowd source solutions to the nutrient problem from a worldwide audience. The ideation challenge provided a forum for international brainstorming to gather breakthrough ideas and novel approaches from citizens, physical and social scientists, and engineers. Participants were tasked with identifying "bold and innovative ideas to fundamentally transform the way we manage and recover nutrients in order to reduce pollution… within the Mississippi River Basin and its impact in the Gulf of Mexico." Sixty-one solutions were submitted from nine countries. The top three solutions were selected based on the following criteria: paradigm-shifting improvement to current nutrient management practices, scalability, user adoption, technical feasibility, and novelty. The selection committee also sought a balance between projects focused on technology and projects with a social-behavioral focus. Three prizes were awarded for technology, social, and economic solution ideas.

The ideation challenge was used to help seed, as well as supplement, an invitation-only "visioneering" meeting of 50 experts, entrepreneurs, and stakeholders. This meeting was designed to identify key gaps and extract insights and ideas to shape the next generation of strategies for addressing nutrient pollution. Two of the main needs identified in this meeting were: 1) affordable nutrient monitoring and 2) socio-economic/community-based solutions via economic incentives. The Challenging Nutrient Coalition decided to pursue a competition to spur the development of affordable *in situ* sensors and engaged two additional partners—ACT and PTIE—to play important roles in the Nutrient Sensor Challenge's development.

The Challenging Nutrients Coalition is currently pursuing a three-pronged approach to develop a suite of sensors that will provide transformative tools to address the issue of nutrient pollution:

- Tulane University is leading an effort in collaboration with the U.S. Department of Agriculture (USDA) to develop in-field sensors to measure nutrient levels either directly in soil or in plants. http://tulane.edu/tulaneprize/waterprize/
- The Everglades Foundation is leading a seven-year competition to develop breakthrough technology that cost effectively measures, removes, and recovers phosphorus from surface waters. http://www.evergladesfoundation.org/breaking-news/remove-phosphorus-win-10-million/
- The Challenging Nutrients Coalition is collaborating with ACT to develop technical requirements and verification testing of the sensor technologies, while also identifying and estimating the market for the sensors. With National Oceanic and Atmospheric Administration (NOAA) and EPA involvement, this Challenge will facilitate development and testing of the next generation of affordable, accurate, and reliable nutrient sensors. A Technical Advisory Committee (see Appendix A) is supporting the Challenge, by providing insight and guidance on the Nutrient Sensor Challenge's technical aspects and expert peer-review of test protocols and final reports. www.nutrients-challenge.org

III. Workshop Overview

The Nutrient Sensor Challenge Workshop was held on September 17–18, 2014, to identify opportunities for development and adoption of the next generation of nutrient sensors for *in situ* aquatic measurement. The participants (see Appendix A) included:

- Developers from the private sector and academia.
- Subject matter experts in nutrient dynamics and excess nutrients in waterways from academic and research institutions and state and federal management agencies.
- End-users from academia, state and federal agencies, the non-profit sector, and industry.

Representatives from NOAA, EPA, USDA, the U.S. Geological Survey (USGS), the National Institute of Standards and Technology (NIST), and the White House Office of Science and Technology Policy (OSTP) attended the workshop, as did representatives of academic and non-governmental organizations (NGOs).

The workshop began with several short presentations summarizing what is known about nutrient pollution, the state of the science in monitoring, and how nutrient monitoring is being used in research, resource management, and industry (see workshop agenda in Appendix B). These presentations are available for download at www.nutrients-challenge.org.

A series of charge questions was posed to facilitate dialogue. In response, the workshop participants provided input on various aspects of aquatic nutrient sensors, including technical specifications and the need to both improve usability and reduce lifetime ownership costs. End-users provided input on needs, which included researching, meeting, and tracking state water quality regulatory requirements, and optimizing water treatment facilities. The participants discussed sensor deployment ranging from moored ocean and lake buoy observations to networks of coastal bay, river, and stream observations. Developers provided insight into the current state of the technology, feasibility of matching needs with cost, possible trade-offs, and how to motivate investments in development.

IV. Charge Questions

A series of charge questions was posed to help stimulate and guide discussion in the workshop.

Charge Question A – Who is measuring nutrients? Why or why NOT?

The participants identified the following breadth of potential *in situ* sensor users:

- Resource managers responsible for monitoring water quality status, trends, and success of restoration efforts.
- Regulated entities including industrial wastewater treatment plants, municipal water suppliers, and publicly owned water treatment plants.
- Agricultural producers who want to optimize fertilizer application and management decisions.
- Drinking water suppliers, including the bottled water industry and rural well owners.
- State agencies, tribes, and local governmental officials interested in ensuring permit compliance and demonstrating policy effectiveness.
- Aquaculture, hydroponics, aquariums, and other related efforts focused on the maintenance and growth of aquatic organisms.
- Researchers (laboratory and observing networks).
- Citizen scientists (e.g., watershed associations' volunteer water quality monitors) monitoring for problems as well as progress.
- Federal event response teams responding to storms, algal blooms, and other extreme events.
- NGOs concerned with environmental degradation and the conservation of locations, habitats, and ecosystems.
- Consultants (on behalf of their clients, listed above).

Many of these groups measure nutrients in order to inform and evaluate management decisions. Differences among groups include required level of detection, frequency of measurement, regulatory status, operations and maintenance capabilities, need to monitor in different flow conditions, and available funding. Barriers to use include the persistent issue of biofouling;[1] high level of effort to calibrate, maintain, and process data; and survey design limited by per instrument costs.

The participants reached consensus to focus subsequent discussion on monitoring-grade instruments that can be deployed in the field for organizations engaged in water quality monitoring and/or research. However, there was also interest in simple, affordable "hand-held" instruments that would allow non-technical users, such as citizen scientists, to conduct rapid reconnaissance monitoring and determine spatial distribution of nutrients. The discussion briefly addressed the usefulness of in-plant sensors for wastewater treatment plants.

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[1] For the purposes of this discussion, biofouling is defined as biological growth that inhibits instrument operations and diminishes performance and data quality.

Charge Question B – What are the ideal performance parameters for next-generation nutrient sensors?

Present generation benchmarks/assumptions: The participants discussed limits of detection, accuracy, and precision for a variety of nutrients in environmental settings that ranged from pristine mountain streams to highly concentrated wastewater treatment side-stream flows. In most cases, the range of the desired detection limit spanned three or four orders of magnitude to cover all applications. It was suggested that, ideally, a sensor would have the ability to automatically adjust to the ambient range. Desired accuracy and precision were also application dependent. In order to compare technologies that function in environments with extreme nutrient concentrations, it was suggested that accuracy and precision be measured at 20, 50, and 80 percent of the detection range. The table in Appendix C presents a summary of values developed by workshop participants.

Although the group discussed nitrate, nitrite, ammonium, orthophosphate, total nitrogen, total phosphorus, iron, and silicate, subsequent questions focused on dissolved nitrogen and phosphorus. This focus was chosen because of the number of mature technologies currently on the market to measure such constituents and because their measurement is technologically feasible. In contrast, current methods for measuring total nitrogen and total phosphorus rely on application of heat/pressure and/or acid/bases to liberate bound constituents, making sensor development for these nutrients much more technologically constrained.

Charge Question C – What are the ideal usability requirements for next-generation nutrient sensors?

Reliability and deployment length: End-users expressed interest in sensors that could be deployed for a minimum of one month and up to12 months with confidence and minimal servicing. Users who require expensive boat time to deploy and maintain equipment prefer longer periods between calibrations, but recognize that biofouling, battery life, and reagent volume are limiting factors. Participants also discussed options for alternative power supplies. End-users requested real-time, remote indication of calibration drift with a standard solution to enable notification of data quality issues, service need, and potential for data loss.

Near-shore deployed sensor *(source: U.S. Geological Survey and Maryland Department of Natural Resources).*

Sampling frequency: End-user sampling frequency needs depend on the environment, sampling mode, and research questions. Frequency needs ranged from sub-minute for research, to one to five minutes for quick-changing streams and wastewater, to 15 to 60 minutes for routine riverine monitoring, to adaptive sampling approaches to efficiently capture episodic events. Vertical profiling deployment modes require higher sampling frequencies to allow for resolution of nutrient concentrations with depth. The participants discussed trade-offs between deployment length and sampling frequency when limited by reagent volume.

Calibration life: End-users requested sensors that maintain calibration at the deployment site for three to six months. End-users also requested the capability to service sensors at the deployment site. Adaptive calibration was suggested as a solution to variability in flow and concentration.

Remote deployed sensors on a buoy *(source: workshop presentation by Brian Pellerin).*

Maintenance/service: Offsite maintenance was determined to be acceptable every one to two years. Considerations include turn-around time at the manufacturer, cost of service, and whether the user has a designated technical staff. Clear communication of turn-around time was also noted as important. Some participants would be willing to pay higher initial costs for fewer service requirements and a longer instrument life.

Instrument lifetime: End-users requested an instrument life of five years, depending on the initial costs. Users were willing to replace an instrument more frequently if initial purchase costs were lower.

Deployment environment: End-users did not require a single instrument to be able to perform in all salinity and temperature ranges. Many would be satisfied with a sensor that performs well in their range of interest. However, others would prefer the flexibility to use a single sensor type in multiple applications and locations (freshwater to open ocean) and under a broad range of expected nutrient levels.

Deployment mode: End-user needs varied by environment and application, including moored, profiling, flow-through (e.g., surface mapping), and quick deployment of hand-held devices for spot-checking. Flexibility in operational mode, from continuous to semi-continuous, was preferred. There was also a strong preference for the nutrient sensors to simply be added to existing integrated water quality sensor packages as an additional parameter. Some participants expressed concerns about large, obvious equipment attracting unwanted attention from vandals or thieves.

Size: Some end-users requested diameters less than 3 or 4 inches for use in a stream or well/ground water. However, it was agreed that nutrient sensors need to be of a size and weight that can easily be handled by one person for remote deployments in the field. In fact, small nutrient sensors that can be added to existing water quality instrument packages would be extremely attractive.

Data management/display: End-users requested real-time quality control capability for viewing the data, as well as automated self-diagnosis to trigger warnings. Diagnostics are often already recorded, but not accessible to the user in real-time. Users expressed preference for capability to integrate new sensors to measure an additional parameter with existing multi-parameter water quality systems, data loggers, and communication systems, particularly with an eye to the future integrated sensor networks.

Charge Question D – What are the cost considerations for nutrient sensors?

User perspective: Some end-users were limited by the purchase price of the sensors currently on the market and appropriate for prolonged field deployment ($15,000 to $25,000 [USD in 2014]) and by the replacement costs should theft/failure occur. Others had budgets to purchase equipment, but no budget for additional operation and maintenance staff. In the latter case, low maintenance requirements are needed to sustain a network of sensors. Some users were willing to pay significantly more if the sensor could integrate with their existing system. Others would regularly buy additional sensors as spares to swap out during maintenance, especially if sensors were available at lower cost, in order to achieve uninterrupted records.

Participants were enthusiastic that affordable sensors would allow for an increased numbers of sensors. A hierarchy, of sorts, was discussed:

- At a purchase price above $25,000, sensors are and would continue to be a rare luxury.
- At a purchase price below $10,000, *in situ* nutrient monitoring would be much more accessible and provide an enhanced understanding of nutrient dynamics.
- At a purchase price below $5,000, sensors would transform monitoring practices and begin to address spatial and temporal heterogeneity.
- At a purchase price below $1,000, sensors would allow for comprehensive, high spatial and temporal frequency monitoring networks. A researcher might initially pair a low-cost sensor with a more expensive one.

End-users discussed $10,000 as a threshold upper-end cost for funding agencies and for risk of loss or damage. Users also mentioned $7,000 as an upper-end cost threshold for non-profit organizations, which might be willing to compromise on accuracy, precision, and detection limits for reconnaissance-level monitoring.

Developer perspective: Developers noted that costs are limited by available technology and parts. Current pump and lamp technology is over a decade old and can cost several thousand dollars. More recently developed technology may result in cost and energy savings. Reducing power requirements and sending the signal outside the instrument for memory and analytics are other ways to reduce costs. Compromises in parameters such as accuracy, range, selectivity, and precision may be needed to achieve cost targets. Additional cost savings could be made by bundling multiple sensors into one unit, which would share the data logger. Developers also suggested that grants or other small subsidies which offset research and development costs would provide important incentives to smaller companies to participate in the Challenge.

Charge Question E – What's audacious yet feasible?

Technological barriers to advancement: Developers concluded that the solid state physics required to develop LEDs capable of deep UV light in the spectrum necessary for optical instruments was unlikely to mature during the Nutrient Sensor Challenge's time frame. However, fluid-handling components in microfluidics could significantly decrease the unit cost and save energy in reagent-based systems. These components include pumps and particularly valves that can be fully integrated into the microfluidic channels and are more biomimetic in nature (i.e., based on soft polymer actuators rather than conventional micromachined components).

Flexible requirements: Users were willing to compromise to some extent on accuracy, precision, and detection limits to lower life-cycle costs. Users were also willing to compromise flexibility, opting for a more specialized and affordable instrument that operates well under a specific range of conditions. Some users were willing to pay higher initial costs to reduce servicing costs over the long term.

Charge Question F – What are the next steps in supporting innovations and the next generation of nutrient sensors?

Workshop participants agreed that their recommendations for the next generation of nutrient sensors are transformative, challenging but feasible, and should serve as a foundation for the ACT Nutrient Sensor Challenge. It was also clear that both the ongoing market assessment and opportunities for no-risk beta testing and verification testing of next-generation nutrient sensors are critical for supporting targeted innovations. Growth in comprehensive, sustainable environmental monitoring networks and continued support from state and federal agencies will also convey the commitment needed to drive innovation.

V. Recommendations

The workshop participants made the following recommendations in order to inform the Nutrient Sensor Challenge. The recommendations below will be considered, along with input from the PTIE survey and other sources, to develop Challenge requirements and targets. User criteria for a particular parameter often spanned a range depending on use, environment, and technology cost; they are included in the summary table in Appendix C. The requirements will set a minimum standard that all submissions must meet and points will be awarded for exceeding those requirements according to predetermined weights. The award structure for the Challenge will take both into account.

The workshop participants recommended that the Nutrient Sensor Challenge:

1. Focus the Challenge initially on dissolved forms of nitrogen and phosphorus.
2. Focus on research/monitoring grade instruments capable of remote, unattended deployment.
3. Quantify, to the extent possible, market opportunities in target markets: state agencies, others engaged in routine monitoring, and basic research.
4. Encourage users to think in terms of cost per sample or per data point when comparing sensors to traditional sampling methods.
5. Set a sampling frequency of one minute to one hour, with 15-minute intervals meeting most needs.
6. Set the Challenge's cost standards to minimize lifetime costs by:
    - ✓ Keeping initial purchase price to less than $5,000.
    - ✓ Reducing operations and maintenance costs by reducing associated person hours and increasing ease-of-use.
    - ✓ Limiting maintenance intervals to annually or less.
    - ✓ Assuring total lifetime of at least five years.
7. Set a required minimum deployment length capability of two to three months.
8. Require anti-fouling capabilities.
9. Require the ability to compensate for interferences (such as high turbidity, colored dissolved organic matter, etc.).
10. Set accuracy and precision targets of 2 to 5 percent when measured at 20, 50, and 80 percent of the detection range.

Appendix C presents a summary of recommendations from the workshop discussions.

VI. Conclusions

Excessive nutrients in streams, rivers, lakes, and coastal water are a serious environmental, economic, and human health concern. However, comprehensive nutrient monitoring networks (at appropriate temporal and spatial scales) have not been widely established, due in large part to the costs and complexities associated with the use of current *in situ* instrumentation. Nutrient sensors that can meet the specifications and requirements listed above would transform our understanding of nutrient dynamics and provide the foundation for efficient and effective management and mitigation efforts. Although they provide a challenge for technology developers, instruments meeting most or all targets described above are possible over the next three years. To facilitate the creation of the next generation of sensors, the Nutrient Sensor Challenge will provide technology developers with resources, opportunities, and incentives, while minimizing market uncertainties and risks.

VII. References

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Appendix A: Technical Advisory Committee and Workshop Participants

Technical Advisory Committee

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Nutrient Sensor Challenge Workshop Participants

Appendix B: Workshop Agenda

Alliance for Coastal Technologies and the Challenging Nutrients Coalition
Nutrient Sensor Challenge Workshop

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17 September 2014
Lincoln Room, White House Conference Center (WHCC)
726 Jackson Place NW, Washington, DC

9:00 a.m.	Coffee and continental breakfast
Overview and background	
9:30 a.m. – 9:45 a.m.	Welcome, Workshop Outline and Objectives, Participant Introductions (Tamburri ACT)
9:45 a.m. –10:00 a.m.	Opening Remarks, Interagency Challenging Nutrients Coalition (Rodan, OSTP)
10:00 a.m. – 10:15 a.m.	Open Innovation in the Federal Government: a tool to break down barriers (Dorgelo, OSTP)
10:15 a.m. – 10:35 a.m.	Presentation: State of the Science, on nutrient pollution (Boynton, CBL/MCES)
10:35 a.m. – 10:50 a.m.	Break
10:50 a.m. – 11:10 a.m.	Presentation: The state of the science on nutrient and water monitoring and management (Pellerin, USGS)

Charge Question A – Who is measuring nutrients? Why or why NOT?

11:10 a.m. – 11:25 a.m	Presentation: Examples from Research (Johengen, ACT/U of Michigan)
11:25 a.m. – 11:40 a.m.	Presentation: Examples from Resource Management (Michael, Maryland DNR)
11:40 a.m. – 11:55 a.m.	Presentation: Examples from Industry (Bott, Hampton Roads WWTP)
11:55 a.m. – 1:00 p.m.	Group Discussion 1. What is the breadth of *in situ* nutrient sensor end users? 2. What are similarities/differences in the main users of nutrient sensors? 3. What are some of the main barriers to use?
1:00 p.m. – 2:00 p.m.	Lunch

2:00 p.m. – 2:15 p.m. Presentation: The Nutrients Sensor Challenge – overview and timeline (Shaw, US EPA)

2:15 p.m. – 2:30 p.m. Presentation: Results from User Surveys – needs for the next generation of nutrient sensors (Stauffer, AAAS Fellow, US EPA)

Charge Question B – What are the ideal performance parameters for next-generation nutrient sensors?

2:30 p.m. – 3:45 p.m. Group Discussion

1. Limits of detection
2. Accuracy / Precision
3. Reliability
4. Other

3:45 p.m. – 4:00 p.m. Break

Charge Question C – What are the ideal usability requirements for next-generation nutrient sensors?

4:00 p.m. –5:15 p.m. Group Discussion

1. Deployment environment
2. Deployment mode
3. Deployment length
4. Sampling frequency
5. Calibration life
6. Maintenance / servicing expectations
7. Size/weight
8. Time and expertise required to operate/maintain
9. Other

5:15 p.m. Adjourn

5:30 p.m. – 7:30 p.m. Cash Bar Reception Offsite (Laughing Man Tavern, 1306 G St. NW, Washington, DC 20005, http://laughingmantavern.com

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18 September 2014
Georgetown Room, Hilton Garden Inn Downtown
815 14th Street NW, Washington, DC

8:30 a.m. – 9:00 a.m. Coffee and continental breakfast

9:00 a.m. – 9:15 a.m. Review of day one and goals of day two (Tamburri, ACT/UMCES)

Charge Question D – What are the cost considerations for nutrient sensors?

9:15 a.m. – 10:30 a.m. Group Discussion

1. User perspective
    a. Sensor purchase cost
    b. O&M costs (incl. technical personnel)
    c. Other (E.g. telecom, data management, etc.)
2. Developer perspective
    a. Market indicators needed for lower price point
    b. What other indicators prioritize R&D investment?
    c. Other

10:30 a.m. – 10:45 a.m. Break

Charge Question E – What's audacious yet feasible?

10:45 a.m. – 12:00 p.m. Group Discussion

1. Technical barriers to advancement
2. Requirements that cannot be compromised?
3. Requirements that are more flexible?
4. Other

12:00 p.m. – 1:00 p.m. Lunch

Charge Question F – What are the next steps in supporting innovations and the next generation of nutrient sensors?

1:00 p.m. – 1:15 p.m. Presentation: Beta-testing and validation of sensor performance (Tamburri, ACT/UMCES)

1:15 p.m. – 2:30 p.m. Group Discussion

1. Considerations around no-risk beta testing
2. Considerations around validation testing
3. Bringing end-user partners into the testing process
4. Explore post sensor validation, end-to-end nutrient monitoring systems demonstration

2:30 p.m. – 2:45 p.m. Break

2:45 p.m. – 3:15 p.m. Other activities to further stimulate development, adoption, and use of next-generation sensors?

Conclusions and recommendations for Nutrient Sensor Challenge and the next generation of nutrient sensors

3:15 p.m. Briefing on a related in-field sensor challenge

3:30 p.m. Adjourn

Appendix C: Discussion Summary Table

<table>
<tr><th>Environment</th><th>Range (mg/L)</th><th>Acc</th><th>Prec</th><th>Instrument Life</th><th>Deployment Length</th><th>Ease of Use</th><th>Cost of Sensor Ownership (Purchase Price)</th></tr>
<tr><td>Remote Deployment</td><td rowspan="2">Nitrate: 0.001–60
Nitrite: 0.001–60
Ammonium: 0.001–20
Phosphate: 0.002–5
Silicate: 0.05–170 µM
Iron: 0.01uM–50µM
TotN: 0.1–60
TotP: 0.01–5</td><td rowspan="2">2%*</td><td rowspan="2">2%*</td><td>5 years with no more than annual serving accessibility.</td><td>4 months:
prevent fouling, self-diagnostics, power, 2-way data and meta data telecommunication calibration life, instrument drift. Flexibility in application (shorter term, mobile)

O&M critical issues: servicing efficiency</td><td>Portable, self diagnostics, non-dedicated technician, level of effort (person hours <0.5 day), data accessibility, redundancy</td><td>$1K (sacrifice LOD for quantity)
<$5K ideal
$5–10K ok
$20K (loss issues)
Lower cost=more units<hr>O&M
Plugs into existing system</td></tr>
<tr><td>Hand-Held</td><td>5 years</td><td>Daily Deployment Length: (per use); Daily calibration; plug in and recharge; no fouling issues; no power issues, no data telemetry issues.</td><td>Citizen science friendly;
Real time display and data log;
Date/time & location stamp;
portable (one person), rugged, verifiable for legal purposes</td><td>Grant funding typically $1–5K</td></tr>
<tr><td>Industrial</td><td>Nitrate: 0.01–3000**
Nitrite: 0.1–100
Ammonium: 0.05–20
Phosphate: 0.5–1000</td><td>2%*</td><td>2%*</td><td></td><td></td><td></td><td></td></tr>
</table>

Acc= Accuracy; LOD= Limit of Detection; O&M= Operations and Maintenance; Prec= Precision; TotN= Total Nitrogen; TotP= Total Phosphorus; µM= micrometer

* Accuracy and precision will be measured at 20, 50, and 80% of the detection range.
**Note that ranges of detection vary from very low levels needed in research and pristine settings to very high levels needed in side-streams of industrial plants.

Appendix D: Factsheet

Nutrient Sensor Challenge

There are **CHALLENGES** underway to accelerate the development of new affordable technologies for measuring nutrients. **WHY?**

Nutrients are essential for ecosystems and many products we need. But **TOO MUCH** nitrogen and phosphorus in water can cause algal blooms, contaminate drinking water, and kill fish. These wide-ranging effects mean:

Nutrient pollution is one of America's **BIGGEST** environmental problems.

65% of assessed estuaries and coastal areas have moderate to high **WATER QUALITY IMPACTS** from nutrient pollution.

Freshwater nutrient pollution costs the nation **$2.2 BILLION PER YEAR**.

Reported drinking water violations for nitrates have nearly **DOUBLED** in the last decade.

How can we address this problem? For one thing, we need more information. We need to **REDUCE THE HIGH COST** and **COMPLEXITY**of collecting data, so we can measure nutrients and track progress.

Federal agencies, the Alliance for Coastal Technologies (ACT), and other partners **CHALLENGE YOU** to join the effort to develop **AFFORDABLE, ACCURATE,** and **RELIABLE NUTRIENT SENSORS!**

Nutrient Sensor Challenge

My organization wants to
DEVELOP
a nutrient sensor

The Nutrient Sensor Challenge will mobilize markets and provide laboratory and field verification at no cost to you—and an opportunity to showcase your innovation.

My organization wants to
MEASURE
nutrients

The sensors developed through this challenge will let you cost-effectively measure and track nutrients and provide better data to evaluate approaches for nutrient management.

Nutrient Sensor Features

- Measures dissolved nitrogen and/or phosphorus
- Provides real-time data
- Affordable
- Capable of unattended measurements
- Highly accurate and precise

Nutrient Sensor Challenge Schedule

Launch:
Winter 2014

Testing:
Summer 2015 – Fall 2016

Awards:
Winter 2016

Learn more at: www.nutrients-challenge.org
Send questions to: info@nutrients-challenge.org

ALLIANCE FOR COASTAL TECHNOLOGIES