Nutrient Sensor Challenge

Preliminary Market Outlook
for
In-water Nutrient Sensors
by

ALLIANCE FOR COASTAL TECHNOLOGIES

Abstract

This paper provides a preliminary assessment of potential U.S. markets for in-water nutrient sensor technologies being developed as part of the federally sponsored Nutrient Sensor Challenge (NSC). These NSC-based technologies are not yet fully developed, are not expected to reach markets until 2017, and will differ from one another in ways that will affect their suitability in various market segments. As a result, there is still significant uncertainty regarding potential market demand overall, in specific market segments, and for particular NSC-based technologies.

Estimates presented in this paper regarding potential sizes of markets and the timing of market development are based on ongoing research. These estimates should be considered preliminary and useful for general planning purposes. Data will be refined during 2016 and throughout the course of the NSC as new information becomes available about how particular NSC-based nutrient sensor technologies match user needs in specific market segments, and about key market drivers that will determine how rapidly these market segments are likely to grow. Key market drivers are associated with changes in water-related research priorities and federal and state water quality regulations, competing research and monitoring funding demands, public awareness and sense of urgency regarding national and regional water quality problems, and the cost and availability of competing methods of providing in-water nutrient measurements.

Preliminary assessments of existing markets related to Federal, state, university, industrial, agricultural, and non-profit research and monitoring needs suggest that overall demand for in-water nutrient sensors with characteristics specified in the NSC, over the next five years, will be 24,000 to 30,000 units. At an average market price of $5,000 per unit, this constitutes a potential U.S. market of $120 million to $150 million. These preliminary market predictions are based on the assumption that these technologies will be available in the market place in 2017 and achieve a five-year adoption rate of 25% among potential users across various market segments. They do not take into account global market potential or potential in U.S. market segments that are expected to develop as a result of the availability of NSC-based sensors. Interviews with nutrient measurement users and representatives of various market segments indicate that increasing awareness of nutrient problems and new federal and state regulations,

along with the availability of low cost sensors with NSC-specified characteristics, are likely to result in the development of significant new U.S. markets. The emergence of new U.S. markets combined with potential foreign markets can be expected to result in the overall market potential for these sensors being significantly greater than estimates presented in this paper.

Also, the preliminary market estimates presented in this paper are based on one-time purchases over a five-year period. If the average useful life of these sensor systems is approximately 5 to 10 years, the size of the overall market, over 20 years, might be expected to be two to four times larger. One key driver of new market demand will be state and county governments need for more location-specific information about in-water nutrients in order to find and validate the effectiveness of affordable ways to meet TMDLs (Total Maximum Daily Loads). The potential of these state/county TMDL-based markets could be significant, but will depend on when, where, and how TMDLs are implemented and enforced and related reporting and verification requirements. In addition, the evolution of water quality trading and offset programs, and other responses to TMDLs and other similar water quality policies in the U.S. and elsewhere could result in significant new markets.

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Section 1 Introduction

Sources of in-water nutrient pollution are widespread and include stormwater, wastewater, agricultural runoff, atmospheric deposition (e.g., from combustion of fossil fuels), and household sources (e.g., yard fertilizers, pet waste, detergents). Growing awareness of nutrient pollution and the need to find solutions is increasing interest in using location-specific in-water nutrient measurements to prioritize nutrient problems, identify their sources, compare and validate response options, verify compliance with nutrient discharge limits, and "score" water quality trades, offsets, and credits. Nutrient measurements are also used to make internal operating and management decisions involving flow rates and treatment levels at wastewater and drinking water facilities and in various types of agricultural and industrial operations.

Currently available methods of measuring in-water nutrients are based either on simple test kits which are fast and inexpensive, but too imprecise for most purposes; on water sampling and laboratory analyses which are accurate and precise, but cumbersome, time consuming, and expensive; or on in-water sensors and analyzers. Use of currently available in-water sensors has not been widespread because of their complexity, technical demands, reliability, and purchase and operating costs, as well as lag times in laboratory analysis. Market prices of currently available in-water sensor systems are in the range of $20,000 to $30,000, field deployments are limited to a few weeks, and an advanced level of training is required to operate them effectively.

It is generally recognized that the high cost of reliable measures of in-water nutrients is preventing nutrient measurements from being available to improve nutrient management decisions in many places where these decisions are becoming critical. As a result, large potential markets are expected to exist for new methods of producing accurate, precise in-water nutrient measurements at a reasonable price. The most promising methods for reaching these markets involve technologies that make use of in-water nutrient sensors. The Nutrient Sensor Challenge focuses on nitrate/nitrate and orthophosphate sensors. Some market segments require measures of nitrite only (e.g., waste water treatment); others require measures of only total nitrogen or total phosphorus.

This paper is an interim report that presents the results to date of an ongoing analysis of potential U.S. markets for nutrient sensor technologies being developed as part of the federally sponsored Nutrient Sensor Challenge (NSC). The NSC is expected to result in nutrient sensors that are: accurate, easy to use, maintenance-free, capable of remote deployments for up to three months, and available in the marketplace by 2017 at a price of $5,000 or less.

The research that forms the basis of this paper involved:

- a review of results from 2014 NSC-based surveys and interviews of likely government and university buyers;
- an assessment of generally available statistics regarding the numbers of entities in specific market segments that constitute potential buyers;

- Preliminary interviews with more than 30 current providers and users of nutrient measurements and representatives of various market segments within three general market areas: industry, government, and university.

Interviews indicate that sensors that meet the NSC challenge specifications will outcompete other available nutrient measurement methods in existing markets on the basis of price and performance. Perhaps more importantly, most interviewees believe that the availability of highly efficient, low cost nutrient sensors will result in the emergence of totally new markets associated with new types of research, expanded water quality monitoring, new ways of searching for solutions to nutrient problems, and less costly and more effective methods of monitoring and verifying compliance with nutrient discharge regulations. Programs being proposed and developed to reduce the cost of achieving nutrient discharge reduction goals, such as water quality trading and tax/subsidy programs, are also expected to generate new markets for nutrient measurements that will be needed to "score" nutrient discharge credit trades and offsets and justify nutrient-related tax/subsidy programs.

NSC-based technologies are not yet fully developed, are not expected to be marketable until 2017, and are expected to differ from one another in ways that are likely to affect their suitability in various market segments. As a result, there is still uncertainty regarding overall potential market demand for these sensors, and demand for specific sensor technologies in specific market segments. Our preliminary interviews confirmed the widespread belief that U.S. markets for NSC-based sensors will be large. However, based on what little is known about the suitability of these sensors for particular applications and the acceptance of sensor-based nutrient measurements by regulators and managers most interviewees were reluctant at this time to try to quantify how many units they, or others in the market segments they represented, are likely to purchase. Typical questions they thought would need to be answered before assessing the sizes of various market segments were related to the following:

- Accuracy, precision, and reliability of sensor operations in water with different salinities, flow rates, sludge or waste contents, or suspended solids
- Suitability for use in various settings associated with groundwater, streams, rivers, lakes, estuaries, wetlands.
- Impacts of extreme temperatures and snow and ice cover on operation and durability
- Size, portability and deployment and positioning or anchoring requirements
- Data storage, transmission and integration/communication capabilities,
- Power, maintenance, and technical support requirements
- Upfront costs, annual operating costs and leasing options
- Useful life, resale/salvage value
- Acceptability of measurements, and analyses and interpretations of measurements by federal and state regulators

Information that can be used to address the issues listed above will become available at later stages in the NSC process. Until then it is not possible to quantify the size of markets for in-water nutrient sensors with any precision. The preliminary estimates of the overall sensor market and demand in specific market segments that are presented in this paper are based on data regarding the overall number of potential buyers in various market segments and interviews with representatives of specific market segments regarding possible levels and rates of adoption. They are provided as a guide for general planning purposes only, and should be refined regularly as new information becomes available about the characteristics of particular NSC-based nutrient sensor technologies, how they match user needs in specific market segments, and how these markets are expected to respond to changes in regulations, research needs, competing technologies, and other factors.

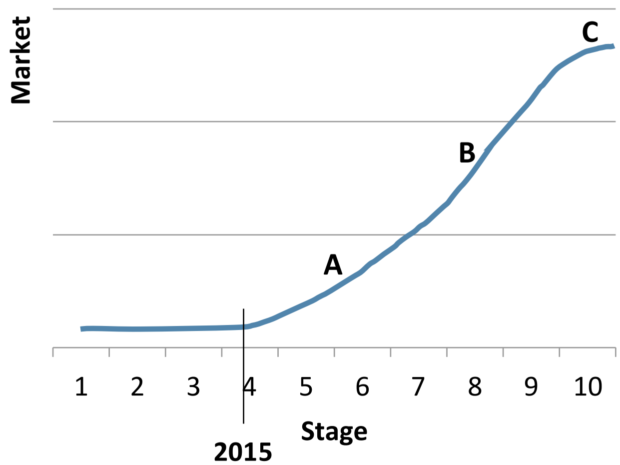
Format

After this introduction the paper has four sections. Section 2 provides some context for assessing nutrient sensor markets by describing the typical stages of technology and technology market development, and where nutrient sensors fall along a typical technology market development curve. Section 3 describes general market types and specific market segments and drivers that will determine potential U.S. markets for nutrient sensors. Section 4 presents preliminary estimates of the potential size of overall nutrient sensor markets and specific market segments and how actual market potential will be affected by various rates and levels of adoption. Section 5 presents the potential long-term outlook for nutrient sensor markets related to water quality research, industrial applications, and establishing and meeting regulatory requirements. Section 6 summarizes results, presents some conclusions, offers caveats regarding the use of preliminary market estimates presented in Section 4, and identifies some leading indicators of nutrient sensor markets that should be monitored from this point forward to help predict demand in various market segments.

Section 2 Stages of Technology Market Development

Most new technologies (e.g., tools and methods used in heart surgery, space exploration, micro-processing, and scientific investigation) tend to follow a similar sequence of development and adoption. Figure 1 shows ten typical stages of development for new technologies and technology markets depicted along a technology/market development curve which provides a useful way to characterize and track evolving markets for NSC-based nutrient sensors.

In Figure 1 new technologies are shown to start with preliminary “proof of concept” research (Stage 1) which is followed by research to clarify the underlying scientific and engineering basis of the technology (Stage 2), and then by some initial laboratory-based experimentation aimed at determining if the technology can meet certain targets (Stage 3). If the technology seems capable of meeting certain targets, this is followed by some limited field trials (Stage 4) and then some limited commercial production (Stage 5). Further refinements are often required based on the experiences of early adopters (Stage 6) which is followed by the standardization of production methods (Stage 7) and the scaling up of commercial production (Stage 8). This allows primary markets to develop (Stage 9) and may result in further refinements and adaptations to support the development of secondary markets (Stage 10).



1. Proof of concept
2. Basic science and engineering
3. Initial experimentation (Laboratory)
4. Testing and validation (Pilots/Demonstrations)
5. Limited commercial production
6. Early adoption (Limited markets)
7. Standardization of production methods
8. Scale-up of production/supply capacity
9. Adoption (Growth of primary markets)
10. Diffusion/Expansion (Growth of secondary markets)

A = Start of commercial production (Stage 5) and early adoption (Stage 6).
B = Rate of technology adoption (Annual % increase in adoption/market demand)
C = Level of technology adoption (Final % adoption/level of market demand)

Figure 1. Typical Stages of development for new technologies

Status of Nutrient Sensor Development

While existing instrumentation to measure nutrient could be considered in stage 7 or 8, next generation, NSC-based in-water nutrient sensing technologies, in late 2015, are just moving into Stage 4, which is several stages before they will generate market sales (Stages 8 through 10). Organizers of the NSC have offered beta testing and are offering verification testing to quantify instrument performance (Stage 4) in order to reduce the time and cost of moving these technologies into early stages of commercial production (Stage 5). This is hoped to be achieved in 2017. Related efforts by the NSC team and others are aimed at improving market efficiencies and reducing transaction costs to further reduce the time required for these technologies to move through Stages 6 and 7 and achieve scaled up commercial production (Stage 8), widespread adoption in primary markets (Stage 9), and diffusion into secondary markets (Stage 10). However, before the investments in production capacity are likely to be made to reach Stage 8, there needs to be some basis for expecting that potential rates and levels of adoption in primary and secondary markets in Stages 9 and 10 are significant enough to generate reasonable economic return.

This preliminary assessment of potential markets for NSC-based sensors is aimed at providing NSC-participants with at least basic information they can use to assess the size and likely development of primary and secondary markets for NSC-based sensors. This corresponds to examining factors that are likely to determine the slope of the technology market development curve in Stage 8 (marked B in Figure 1) and where markets may be expected to level off in Stage 9 and 10 (marked C in Figure 1).

The information presented here cannot be used to determine how quickly these technologies will pass through Stages 4, 5, 6 and 7 and reach Stage 8 where sensor markets start to develop and investments in sensor technologies start to yield an economic return. However, other NSC-based initiatives being undertaken over the next two years are aimed specifically at reducing the time and costs associated with moving these sensor technologies through the most difficult period of new technology development (i.e., Stages 3, 4, 5, and 6), and creating more certainty about how much sensor demand can be expected at Stages 9 and 10.

Section 3 Market Overview

Market Types and Drivers

Preliminary interviews identified several different types of potential markets for nutrient sensors that can be categorized generally as being research-driven, regulation-driven, or driven by demand to improve operational efficiencies and reduce costs in industrial facilities, such as water resource recovery facilities or drinking water treatment plants.

For purposes of characterizing these markets and their likely adoption rates, we assumed:

(1) market drivers associated with research are based on the demand for information to understand and describe nutrient problems and find solutions;
(2) market drivers associated with regulation are based on demand for nutrient measurements to design regulations, assess and compare practices, monitor compliance, and target enforcement; and
(3) market drivers associated with private sector markets are based on the use of nutrient sensors to make operations more efficient or reduce uncertainty or costs and/or meet requirements to verify and report about compliance with water quality or nutrient treatment/discharge regulations.

Market Segments

Within each general market type - government, research, and industry - we identified several distinct market segments for NSC-based nutrient sensor technologies and used available data and results from preliminary interviews to examine three factors that will determine their potential size:

(1) the maximum number of entities in the market sector that might buy,
(2) typical numbers of units that would be purchased by entities that do buy; and
(3) ranges of possible adoption rates (i.e., the percent of potential buyers who can be expected to buy)

Within each market segment, actual adoption rates will be determined by two factors: how nutrient measurements can be used to improve decisions in ways that reduce costs or risks or increase some measure of benefits (e.g., revenues, productivity, nutrient discharge reductions, water quality improvements, ecosystem services); and differences between the cost of generating nutrient measurements using NSC-based sensor technologies and the cost of other methods. NSC sensor target features (e.g. accuracy, precision, deployment length, etc.) were developed with input from primarily research and monitoring market segments. In time, more information will become available about how close NSC-based technologies come to meeting needs in various market segments—and how flexible the sensors are for uses outside of intended market segment targets. This information could then be used in surveys and interviews of potential buyers to provide a basis for assessing likely rates and levels of adoption in each market segment. For now, however, we decided to start with information about the potential size of various market segments and use a broad range of possible levels of adoption within each of them, including 5% (low), 25% (medium), and 75% (high).

For example, published data for 2014 indicate that there are more than 16,000 waste water treatment facilities or water resource recovery facilities (WRRFs) treating sewage water in the United States. More than 500 of these WRRFs treat more than ten million gallons of waste water per day and currently measure nutrients in treatment tanks to manage internal water flow and treatment operations. During interviews, representatives of groups that represent these large WRRFs who were presented with available information about NSC-based technology characteristics indicated that at a price of $5,000 per unit each of these large WRRFs might purchase 10 to 20 units. That would imply that large entities within the WRRF market segment might represent a market for 5,000 to 10,000 units or about $25 to $50 million. If the level of adoption in this market segment turns out to be 5%, 25%, or 75% (low, medium or high using our standards), this market segment would be proportionately smaller at 250 to 500 units (low), 1,250 to 2,500 units (medium), or 3,750 to 7,500 units (high). It should be possible to develop reasonable estimates of likely adoption rates and market segment sizes once more information is available about NSC-based technologies to focus interviews of likely buyers.

Section 4 Preliminary Market Assessment

Survey of Government/University Users

In 2014, American University's Center for Environmental Policy conducted an independent study of the potential nutrient sensor market (Marsh 2014). To assess user needs and gain an initial understanding of the potential research and monitoring market, a questionnaire was distributed to professionals in the academic, Federal and state government, non-profit, and corporate communities. Key findings from questionnaire respondents include the following:

- Ninety-two percent of respondents preferred sensors that work in freshwater, but there was also demand for sensors that work in brackish, marine, and other environments, with 20% of respondents needing sensors to operate in a full range of salinities.
- More than 75% of respondents indicated that there was demand for a range of nutrient sensors for nitrate and nitrite; ammonium and ammonia, total nitrogen and total phosphorus, and soluble reactive phosphorus. However the biggest interest (93%) was in nitrate and nitrite sensors.
- Cost was cited as a key factor that will determine demand, with the majority of respondents indicating that a price point under $5,000 would make the sensors affordable to many likely government/university users.

Analysis of Potential Demand by Market Segment

The potential size of markets for new technologies can be estimated by determining the numbers of entities in various market segments that could be buyers, and then projecting levels of adoption in each market segment (e.g. the percent of potential buyers who will actually make purchases). Where data are available, rates and levels of adoption of a technology can often be based on estimates of how potential buyers in each market segment can use the technology to reduce costs or risks, or increase some measure of benefits. For users who are required to collect and report nutrient data and can use NSC-based technologies to lower cost resulting cost savings can provide a basis for attaching a monetary measure of value to these new technologies. In some cases, these cost savings can be used to predict adoption rates and market development for new technologies by projecting payback periods or returns on investment that users in various market segments can expect when they purchase the new technology. Currently, however, nutrient sensors provide information that is used mostly to make decisions that generate public benefits (e.g., improved water quality) that cannot be translated easily into monetary measures of value and cannot be used effectively to predict how many buyers exist in various market segments and their "willingness to pay".

After using generally available statistics to identify the number of entities in each market segment (e.g., businesses, government agencies, research institutions), we asked interviewees familiar with these market segments general questions about how the use of sensors might reduce costs and/or risks or increase some measure of benefits from the perspective of decision-makers in each market segment. Answers to these general questions and some quantitative estimates of market potential offered by interviewees formed the basis of our preliminary estimates of potential levels of adoption in various market segments (see Appendix for summary of interviews).

Overview of Interview Results

Preliminary interviews with more than 30 representatives of different market segments indicated that likely rates and ultimate levels of adoption in each market segment are difficult to project at the present time for the following reasons:

- The technologies are not yet fully developed. Demand in various market segments will depend in critical ways on specific product characteristics that have not yet been determined.
- Few industrial or household sectors use nutrient related information to make decisions that have the potential to reduce costs or risks, or increase benefits other than those associated with demonstrating compliance with government regulations.
- Although awareness of nutrient problems and the need for regulating nutrient discharges is growing, the nature of nutrient-related regulations, their implementation and enforcement, and compliance monitoring and reporting requirements are not fully developed.

Results

Table 1 presents preliminary estimates of potential sizes of U.S. markets for in-water nutrient sensors based on the approximate number of potential buyers in each market segment, interview-based estimates of the number of units that might be purchased by individual buyers in each market segments, and low, medium and high (5%, 25%, and 75%) levels of adoption. Based on this preliminary and very crude characterization of potential demand, the potential market for in-water nutrient sensors across all market segments in the U.S. ranges from 24,000 to 30,000 at a 25% adoption rate. At an average market price of $5,000 per unit this constitutes a potential U.S. market of $120 million to $150 million. NSC target features for nutrient sensor technologies were determined based on input from representatives of primarily research and monitoring market segments. Therefore, it is possible that sensors developed as part of the NSC may lack features desirable for certain other market segments (e.g., aquaculture). It is possible, therefore, that even the low adoption rate estimates for some market segments are overly optimistic. Additionally, interviewees from some market segments (e.g., non-profit) expressed interest in potentially sharing sensors. If sensor sharing is widespread in those market segments, adoption rate in those segments would be somewhat lower.

In addition to U.S. markets, these sensors have potential foreign markets that are likely to be at least as large as, and may be many times larger, than U.S. markets. However, this preliminary review focused only on U.S. markets. Data to provide even preliminary estimates of possible or likely rates and levels of adoption and market penetration of NSC-based sensors in various foreign market segments are not available at this time.

Table 1. Estimates of potential nutrient sensor market

Market Segment	Number of entities	Potential # to purchase	Overall Market Potential (100% Adoption)	Level of Adoption Illustration		
				5%	25%	75%
Industry - Large WRRFs (>10 MGD)	533	20	10,660	533	2,665	7,995
Industry - Medium WRRFs (1-9 MGD)	2,665	10	26,650	1,333	6,663	19,988
Industry - Small WRRFs (<1 MGD)	13,057	2	26,114	1,306	6,529	19,586
Industry – Drinking Water Facilities	419[a]	1 to 3	419 to 1,257	21 to 63	105 to 314	314 to 943
Industry – Other (e.g., NPDES permit holders)	3,487[b]	1 to 2	3,487 to 6,974	174 to 349	872 to 1,744	2,615 to 5,230
Commercial – Aquaculture	3,093[c]	1	3,093	155	773	2,320
Commercial – Agriculture (operations with fertilizer expenses)	1,011,896	1 to 2	3,272 to 6,543 (See Agricultural Markets section)			
Commercial – Hydroponics/aquaponics	71[c]	1	71	4	18	53
Government – Federal research and monitoring	NA	700[d]	700	35	175	525
Government – State research and monitoring	51	3 to 13[e]	153 to 663	8 to 33	38 to 166	115 to 497
Government – Local research and monitoring	5,904[f]	1 to 2	5,904 to 11,808	295 to 590	1,476 to 2,952	4,428 to 8,856
Academic research – e.g.NAML/OBFS and/or LTER	500[g]	10	5,000	250	1,250	3,750
Non-profits (e.g., River Keepers)	1,200[h]	1 to 2	1,200 to 2,400	60 to 120	300 to 600	900 to 1800
		TOTAL	**86,723 to 101,933**	**7,445 to 11,313**	**24,135 to 30,391**	**65,860 to 79,086**

[a] There are 419 Community Water Systems in the US that each serve a population >100,000. These systems serve 46% of the US population (US EPA 2013a). There are approximately 4,000 CWS serving populations of 10,000-99,999; we have not estimated sensor adoption for these smaller systems, although some may be interested in using this technology.
[b] According to EPA, there are 6,685 major dischargers (>1 MGD) with individual or general NPDES permits. This value represents the total less large and medium WRRFs (US EPA 2015a).
[c] 2013 Census of Aquaculture (USDA 2013)
[d] We believe this to be a conservative estimate for federally operated research programs. This value is based on interviews with federal agency personnel, but does not necessarily capture the full breadth of federal programs that could utilize these sensors (i.e., NOAA, EPA, USGS). Programs funded but not operated by NSF, NOAA, or other agencies are captured elsewhere (i.e., academic research, non-profits, etc.).
[e] This is the average number of N sensors and P sensors likely to be purchased over the next 5 years per state according to the respondents in the ACWA survey.
[f] This value is the total number of N and P-related TMDLs (EPA 2015b). P = 3,714; N = 2,190.
[g] Billick et al., 2013.
[h] Rough estimate based on: 129 Waterkeepers in the US (Waterkeeper Alliance 2015), plus anywhere from a few dozen to a few hundred watershed associations per state, plus large, well-funded NGOs like TNC, CBF, Trout Unlimited, etc. The estimate is based on 20 watershed associations/state + RiverKeepers + large NGOs ≈1200.

Agricultural markets – A special case

The 2012 Census of Agriculture estimated a total of 1,011,896 farms operating in the U.S. with fertilizer-related expenses, and that, nationwide, fertilizer-related expenses make up 8.7% of overall farm expenses (USDA 2014). More than 327,000 operations (32.3%) spend $10,000 or more on fertilizer annually (with almost 72,000 operations spending $100,000 or more). By allowing the monitoring of the amount of nutrients that run off farm fields into adjacent water bodies, the use of affordable, accurate in-water nutrient sensors has the potential to help farmers apply fertilizers more efficiently and result in cost-savings as well as water quality improvements.

However, many methods other than in-water nutrient sensors can be used to generate information about in-soil nutrients, nutrient uptake by crops, and nutrient runoff in order to adjust fertilizer applications, optimize crop growth, manage fertilizer costs, and reduce edge-of-field nutrient runoff. As a result, it is not possible at this time to predict how many farms may be situated in ways that make in-water nutrient monitoring useful, or to predict how many farmers might purchase low-cost in-water nutrient sensors if they were available. However, it is reasonable to expect that at least a small portion of U.S. agricultural operations with fertilizer expenses may purchase or finance the purchase of one or more NSC-based nutrient sensors once they become available, especially if the sensors were able to be used to document "creditable" nutrient discharge reductions as part of nutrient credit trading programs. For sake of illustration, assume that 1% of operations with greater than $10,000 in annual fertilizer expenses will purchase one or two sensors to improve fertilizer application decisions. This level of adoption would result in the sale of 3,272 to 6,543 units which, at a unit price of $5,000, would represent a market segment worth $16.4 million to $32.7 million.

Section 5 Long-term Market Outlook

The previous section focused on potential markets for in-water nutrient sensors based on their expected capacity to outcompete other methods of measuring nutrients in existing U.S. markets, and the likelihood that their reliability and low cost will cause those existing U.S. markets to grow. In conventional economic terms, these reflect both outward movements along the demand curve in existing markets (demand increasing because of declines in price) as well as an expected upward shift in the demand curve in those markets (more demand at any given price).

However, many interviewees indicated that they believed the availability of reliable, low cost in-water nutrient sensors will result in the development of totally new and potentially large markets. For example, under section 303(d) of the Clean Water Act, all states must develop lists of impaired waterbodies (i.e., those that do not meet their designated use criteria due to one or more pollutants), and develop TMDLs (Total Maximum Daily Loads) for relevant pollutants being discharged into these waterbodies. Of the 68,496 TMDLs currently being developed nationwide, 6,047 specify limits on nutrient discharges (US EPA 2015b). As a result, many states and counties are being required to describe what changes in land and water use and other management practices they plan to undertake to meet their allocated nutrient discharge reduction targets and show that they are or will be effective.

In the Chesapeake Bay watershed, for example, an overall TMDL for the Bay was established by EPA in December 2010 that sets overall annual limits of 185.9 million pounds of nitrogen and 12.5 million pounds of phosphorus entering the watershed (US EPA 2013b). This overall TMDL, which is to be achieved by 2025, was subsequently divided into 92 TMDLs for specific river basins. The seven jurisdictions that make up the watershed (Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and Washington, DC) have each developed Watershed Implementation Plans (WIPs), and assigned specific nutrient discharge reduction goals to individual counties and/or sectors (e.g., wastewater, agriculture, forestry, etc.).

One significant problem facing county governments and other jurisdictions in the region that have developed or are developing WIPs is that the cost of implementing them has been estimated for many jurisdictions to be in the hundreds of millions or even billions of dollars. As part of its Phase II WIP, for example, Maryland estimated in 2012 that the cost of achieving its target nitrogen, phosphorus, and sediment reductions by 2025 would be about $14.4 billion dollars (University of Maryland et al. 2012).

A related problem is widespread uncertainty about estimates of WIP implementation costs because of significant uncertainty about what types of projects in what locations will be most effective at reducing nutrient discharges and helping achieve TMDL targets. One cause of uncertainty about cost-effective projects to achieve TMDL targets is the fact that the high cost of measuring nutrients has resulted in most jurisdictions using estimates of the effectiveness of nutrient reduction options (e.g., best management practices or BMPs) that are based on generally accepted “BMP efficiencies.” These BMP efficiencies were often estimated based on average site conditions and landscape contexts across the watershed or on modeling results rather than location-specific information from within each jurisdiction (see State and Local Research and Monitoring Programs in the Appendix for more information). The high cost of obtaining nutrient measurements has also resulted in states and counties not having sufficient data to justify and validate the basis for establishing innovative nutrient discharge treatment and offset and credit trading programs that could be used to reduce the cost of meeting TMDL nutrient discharge targets. Having location-specific nutrient data to determine where BMPs are most cost-effective and least cost-effective rather than using average values over all locations or model results has the potential to result in counties and states achieving significant cost savings and making it more likely that they will be able to achieve TMDL targets.

Potential cost savings - the 1% rule

Based on preliminary interviews, it is reasonable to assume that state and county governments could use more reliable, low-cost, location-specific nutrient measurements to identify cost-effective ways of meeting TMDL targets, validate the results of their nutrient discharge reduction efforts, and design and manage other location-specific water quality and habitat improvement projects. However, since potential cost savings from using sensors cannot be measured at this time, it is not possible to predict if and when government agencies may decide to purchase sensors or to purchase nutrient measurement data provided by contractors who will produce them using NSC-based sensors.

Rather than ignore this uncertain but significant long-term market potential it seems reasonable to use a conventional rule of thumb that has been used in many similar situations, which is that significant improvements in information that form the basis of production and investment decisions can be expected to result in cost savings equal to about 1% (Nordhaus 1986). For example, if investments required to meet the State of Maryland's nutrient-related TMDL targets account for about half of the state's estimated WIP costs, or about $7 billion over ten years, applying this 1% rule implies, hypothetically, that average cost savings associated with improvements in in-water nutrient measurements to help target, design, and validate nutrient discharge reductions would be worth about $70 million. Hypothetically, similar cost savings might be expected in other states in the Bay watershed and in other watersheds across the U.S. where investments of tens of billions of dollars will be made over the next ten years or so to meet nutrient-related TMDL targets.

The 1% cost savings exercise described above obviously provides no hard prediction about long-term in-water nutrient sensor markets, and absolutely no evidence that the search for less costly ways to implement WIPs and achieve TMDL goals will result in significant new markets for nutrient measurements or NSC-based nutrient sensors. However, it does provide some context for considering the potential impact of potential long-term driver of markets for nutrient sensors. At a unit price of $5,000 for NSC-based sensors, it is reasonable to expect that many government agencies will determine that purchasing them and using them to improve the mix of management practices being used to meet TMDL targets will result in significant cost savings. In many cases this will result in a positive economic return from investing in NRC-based sensors. Interviews suggest that this forms the basis of a highly favorable long-term outlook for these sensors in these regulation-driven U.S. markets. Similar nutrient pollution problems around the world indicate that similar market drivers may result in significant long-term market potential outside of the U.S.

Potential Cost Savings – Using Cost-effectiveness and Incremental Cost Analysis

Because WIPs will be costly to implement, most jurisdictions in the Chesapeake Bay watershed and elsewhere that are developing WIPs will be using some type of cost-effectiveness analysis (CEA) to compare options, and some type of incremental cost analysis (ICA) to determine how to prioritize options in order to minimize costs as they attempt, over time, to meet their nutrient discharge reduction targets.

For planning purposes most of these jurisdictions will have some standard measures of the unit costs of BMPs (e.g., cost per acre or stream mile or level of treatment) and will use them with "BMP efficiencies" to assess and compare the cost-effectiveness of BMP options. However, within a state and within counties, the effectiveness of implementing any particular BMP (e.g., % reduction in nutrient discharges) will range around standard measures of "BMP efficiencies" with BMPs undertaken at favorable sites achieving greater than average results, and at unfavorable sites achieving lower than average results. If information is available to select the most favorable sites first, the "marginal" cost of implementing any given BMP will increase from below average to above average as a BMP is applied at more sites. As a result, having information about locations where BMPs can be expected to be more or less effective can result in the selection of a more cost-effective or more "optimal" mix of BMPs for implementing county WIPS. Use of Challenge-based nutrient sensors might also indicate that BMPs are demonstrably more efficient at certain times or during certain weather conditions.

This is illustrated in Figure 2a and b, which presents overlapping marginal cost curves for three BMPs. The individual cost curves for each BMP show them applied first at favorable sites with relatively low costs, and then being applied at less favorable sites with incrementally higher costs. As Figure 2a illustrates, it is possible, and in some cases likely, that applying BMPs with higher average unit costs at some sites with especially favorable conditions that make them more effective will be more cost-effective than applying some other BMP with a much lower average unit cost at some difficult and relatively costly site.

The dashed curve on Figure 2a connects the lowest cost combination of BMPs for achieving incrementally higher levels of nutrient discharge reduction and represents the least cost "expansion path" or what is often called an "incremental cost effectiveness curve." Estimating this curve, which depicts the most cost-effective way to meet TMDL targets, requires measuring differences in how site conditions and landscape contexts influence the effectiveness of various BMPs at reducing nutrient discharges. Estimating this least cost incremental cost curve and justifying investments that are determined to be on this curve requires more location-specific nutrient measurements than are generally available at the current time.

The curve presented in Figure 2b depicts the combination of least cost options depicted by the thick curve in Figure 2a. This is the "optimal expansion path" or "cost-effective/incremental cost curve" for using BMPs to achieve any particular level of nutrient discharge reduction. Based on increasing marginal costs of reducing nutrient discharges using each type of BMP, as shown in Figure 2a, this curve can be expected to involve a mix of BMPs that includes some with relatively high average costs implemented at favorable sites where costs are not only below average, but lower than the cost of implementing a BMP with lower average unit cost that can only be applied at a relatively expensive site.

Figure 2b illustrates the cost savings of not relying on average or typical BMP efficiencies and how location-specific nutrient measurements can be used to reduce the cost of achieving various nutrient discharge reduction targets. BMPs with combinations of costs and nutrient reductions that fall above the incremental cost curve (e.g., BMP X) are <u>**wasteful**</u> because another option (e.g., BMP A) is a lower cost way to achieve the same level of nutrient reduction. Projects that fall below the curve in Figure 2b are designated as <u>**unattainable**</u> because if a project was available that achieved the same incremental reduction in nutrient discharges as a project on the curve at a lower cost, it would replace that project on the curve and the project currently on the curve would be above the curve and classified as <u>**wasteful**</u>.

CEA and ICA are standard and widely acceptable methods for assessing and comparing options for achieving environmental goals in situations where it is not possible to use conventional cost benefit analysis (BCA) because the benefits of achieving those environmental goals cannot be monetized. (Robinson et al. 1995; Brandreth and Skaggs 2002; U.S. Army Corps of Engineers 2015). The point of the illustrations in Figures 2a and 2b is that having location-specific nutrient measurements to improve how BMP options are assessed and compared (e.g., location-specific BMP efficiencies) can be expected to allow significantly greater precision when measuring and comparing the cost-effectiveness of alternative urban and rural BMPs. This can be expected to result in fewer projects that are **wasteful** (above the curve) being chosen and fewer projects that are **unattainable** (below the curve) being attempted.

It is not unreasonable to expect that individual counties could save millions or tens to hundreds of millions in WIP implementation costs if they perform CEA and ICA based on more reliable nutrient measurements than they have now. This should provide a basis for assessing their willingness to pay for in-situ nutrient sensors if they meet the NSC-challenge and become the least cost way of generating reliable location-specific nutrient measurements.

In general, future markets for in-water nutrient sensors will depend on how the information they provide can be used to improve private sector and public sector decisions in ways that reduce costs and/or risks or increase some measure of benefits. The types of decisions that may be improved as a result of having sensor-based nutrient information differ significantly from one watershed to another and among market segments and differ among potential users within each market segment. In some cases, nutrient measurements might be useful by themselves to improve decisions, for example when monitoring to assess and compare how alternative nutrient treatment methods are performing. In other cases, using them to improve decision-making may require the information they provide to be integrated with other information, for example with data that can be used to link nutrient measures to flow rates, treatment levels, rainfall, or proximity to potential sources or treatments.

Value of Information (VOI) analysis is a well-developed field of economic research (McCauley 2005; Hagan et al. 2009). Showing how nutrient sensor-based information can help decision-makers select cost-effective nutrient reduction projects and avoid choosing wasteful projects or attempting unattainable projects, as illustrated in Figures 2a and 2b, is a fairly typical application of VOI analysis. Once NSC-based nutrient sensors are more fully developed and proven, it will be possible to examine the types of relationships depicted in Figure 2a, use them to estimate an incremental cost curve as shown in Figure 2b, and use resulting estimates of cost savings associated with using sensors to estimate likely size of markets for the information these sensors provide and project how quickly they are likely to develop. Based on the current NSC schedule it should be possible to perform this type of VOI analysis and help assess and promote markets for NSC-based technologies as early as the spring of 2016.

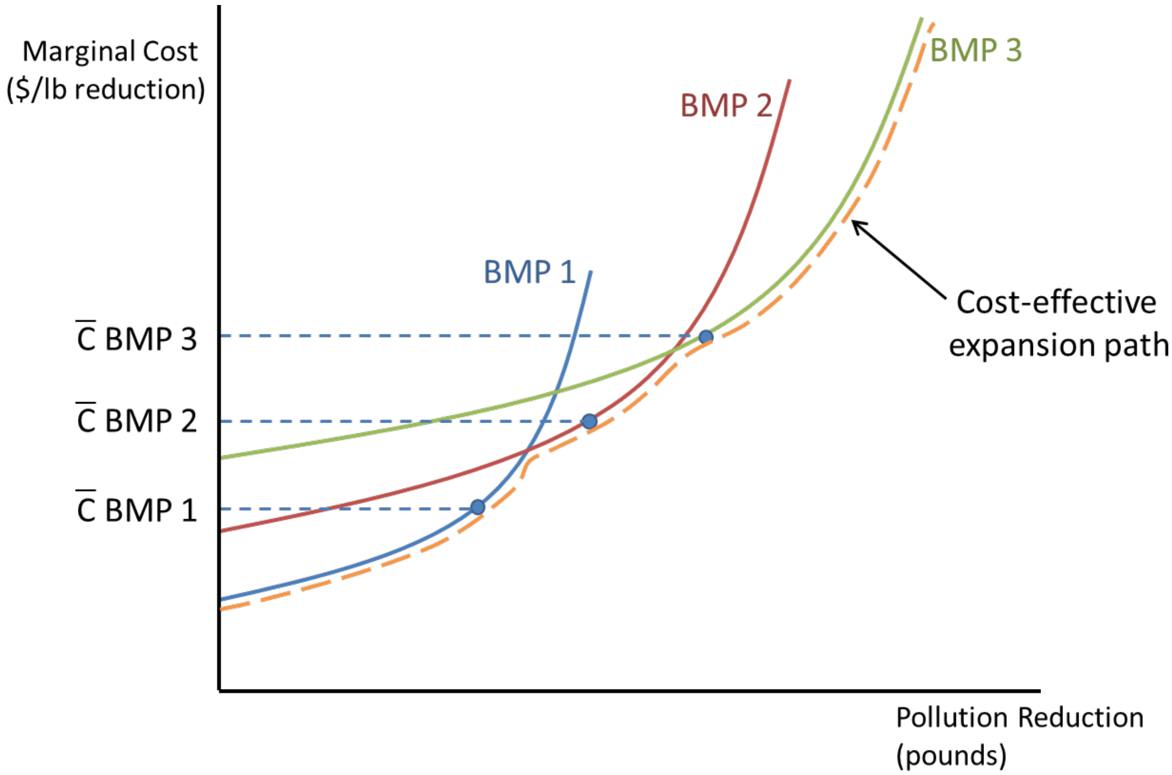


Figure 2a. Cost-effective expansion path for several nutrient reduction BMPs

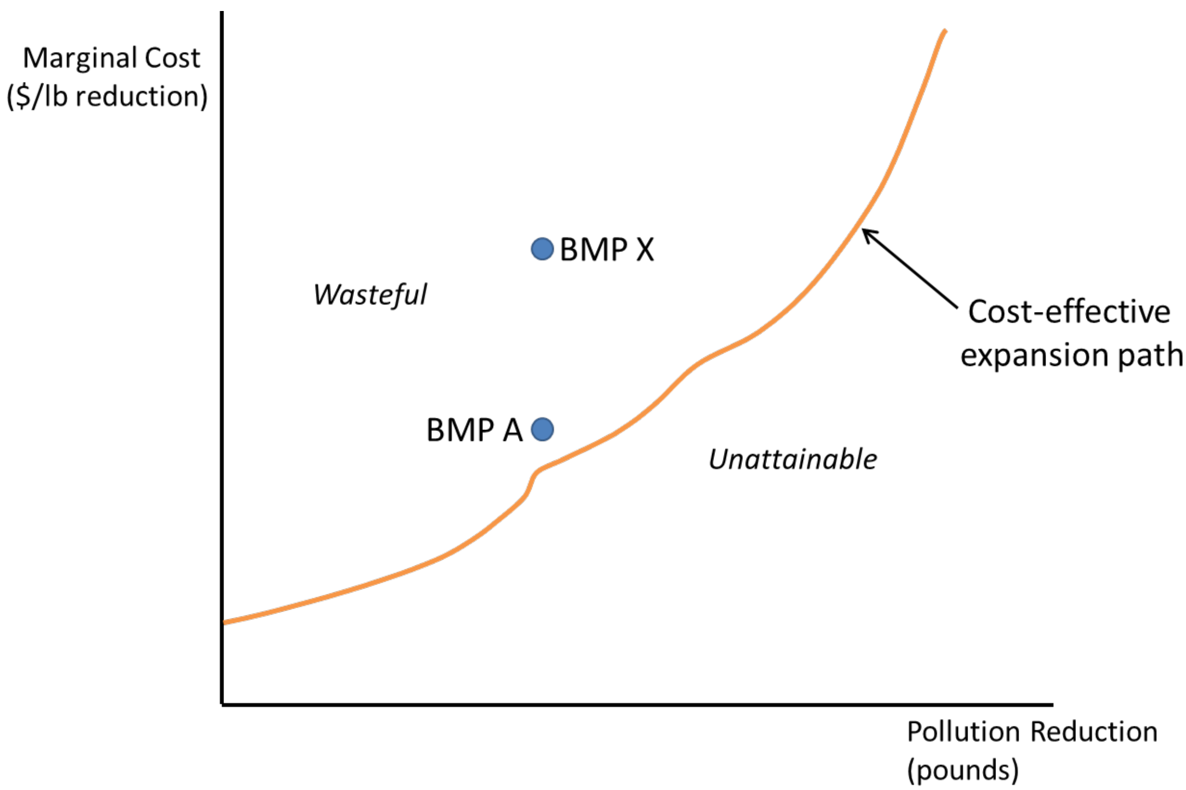


Figure 2b. Cost effective/incremental cost curve

References

Billick I., I Babb, B. Kloeppel, J.C. Leong, J. Hodder, J. Sanders, and H. Swain. 2013. Field Stations and Marine Laboratories of the Future: A Strategic Vision. National Association of Marine Laboratories and Organizations of Biological Field Stations. Available online at: www.obfs.org/fsml-future

Brandreth, B. and L.L. Skaggs. 2002. Lessons Learned from Cost Effectiveness and Incremental Cost Analyses: Final Report. U.S. Army Corps of Engineers Investment and Management Decision Making Research Program. IWR Report 02-R-5. Available online at: http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/02r5cost_eff.pdf

Chesapeake Bay Program. 2015. Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model. Available online at: http://www.chesapeakebay.net/documents/CBP_BMP_Expert_Panel_Protocol_WQGIT_approved_7.13.15.pdf

Hagan, P., D. King and E. Price. 2009. Increasing use and growing value of ocean observing systems in fisheries: with illustrations from the U.S. Mid-Atlantic (MARCOOS) region.

Marsh, Anne S. 2014. Identifying Market Specifications for Affordable Nutrient Sensor Technology: User Needs Study. Available online at: http://www.american.edu/spa/cep/projects/upload/Sensor-Needs-Report_Final.pdf

Macauley, Molly. 2005. The Value of Information: A Background Paper on Measuring the Contribution of Space-Derived Earth Science Data to Natural Resource Management. RFF Discussion Paper 05-26.

Nordhaus, William D. 1986. "The Value of Information," in Richard Krasnow, ed., Policy Aspects of Climate Forecasting (Washington, DC, Resources for the Future), RFF Proceedings, March 4, 129-134.

Robinson, Ridgley, William Hansen and Kenneth Orth. 1995. Evaluation of Environmental Investments Procedures Manual Interim: Cost Effectiveness and Incremental Cost Analysis. U.S. Army Corps of Engineers Water Resources Support Center, Institute for Water Resources Report 95-R-1. Available online at: http://planning.usace.army.mil/toolbox/library/IWRServer/95r01.pdf

Schueler, Tom, Cecelia Lane and Bill Stack. 2014. Recommendations of the Expert Panel to Define Removal Rates for the Elimination of Discovered Nutrient Discharges from Grey Infrastructure. Available online at: http://www.chesapeakebay.net/documents/GREY_INFRASTRUCTURE_Expert_Panel_Report_FINAL_LONG.pdf

U.S. Army Corps of Engineers Chicago District. 2015. Bubbly Creek, South Branch of the Chicago River, Illinois Integrated Feasibility Report and Environmental Assessment. Available online at: http://www.lrc.usace.army.mil/Portals/36/docs/projects/bubblycreek/Bubbly_Creek_NEPA%20public%20comment%20report_14%20Apr%202015.pdf

USDA. 2013. 2013 Census of Aquaculture. National Agricultural Statistics Service. Available online at: http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Aquaculture/

USDA. 2014. 2012 Census of Agriculture QuickStats. Available online at: http://quickstats.nass.usda.gov/

US EPA. 2013a. Fiscal Year 2011 Drinking Water and Ground Water Statistics. Office of Water. March 2013. Available online at: http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/upload/epa816r13003.pdf

US EPA. 2013b. Fact Sheet: Chesapeake Bay Total Maximum Daily Load (TMDL): Driving Actions to Clean Local Waters and the Chesapeake Bay. Available online at: http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/BayTMDLFactSheet8_26_13.pdf

US EPA. 2015a. Action towards Limiting Total Nitrogen, Total Phosphorus, and Total Inorganic Nitrogen Loads from NPDES-Permitted Facilities. Available online at: http://www2.epa.gov/nutrient-policy-data/action-towards-limiting-total-nitrogen-total-phosphorus-and-total-inorganic

US EPA. 2015b. National Summary of Impaired Waters and TMDL Information website. Available online at: http://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T

University of Maryland, Maryland Department of Planning, Maryland Department of Agriculture, Maryland Department of the Environment, and Maryland Department of Natural Resources. 2012. Maryland's Phase II Watershed Implementation Plan for the Chesapeake Bay TMDL. Available online at: http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Pages/FINAL_PhaseII_WIPDocument_Main.aspx

Waterkeeper Alliance. 2015. Waterkeeper Alliance website. http://waterkeeper.org

Appendix: Interview Notes

The sections below provide brief descriptions of some of the interviews we conducted as part of this project.

Industry Market Segments

A potentially significant market segment for nutrient sensors includes industrial water treatment facilities, including water resource recovery facilities (WRRFs) treating sewage; drinking water treatment plants; and other sources of nutrient discharges that are covered by NPDES permits.

Water resource recovery facilities represent perhaps the largest market for nutrient sensors with demand based on both permit compliance and reporting requirements and internal process control purposes. The estimates provided in Table 1 should be used with caution, however, because our initial interviews with WWRF representatives revealed a range of opinions about potential uses and/or effectiveness of in-water nutrient sensors in these operations.

One senior manager of a major WRRF (treating more than 10 million gallons per day) suggested that nutrient sensors meeting challenge requirements would have huge potential not only for regulatory compliance, but also for internal process control. Currently, the WRRF this individual manages conducts on-site analysis of nutrient data collected using probes that cost about $60,000 and require expensive maintenance. If Challenge-based sensors prove to have the linear range and anti-biofouling mechanisms required by these applications, they would not only reduce up-front and maintenance costs, but would save significant operator time, freeing up that staff time to focus more effectively on process control.

Several contacts and interviewees associated with WRRF noted that there will be a range of potential levels of adoption based on geography, with some areas of the country, such as the Great Lakes and Chesapeake Bay watersheds, likely to have more regulatory drivers of demand than other parts of the country. One manager noted that non-coastal or Great Lakes areas of the country with WRRFs releasing discharges into smaller, more sensitive bodies of water might have higher incentive to gather more timely information for process control purposes than WRRFs operating in other areas where receiving water bodies are larger, have strong tidal flushes, or contain habitats and ecosystems that are generally less sensitive to nutrient discharges

Drinking Water Facilities

The drinking water treatment sector is difficult to characterize, for a number of reasons. Nitrate is a big concern for many drinking water facilities in various areas of the country, including ones using groundwater or surface water sources, as elevated levels of nitrate have been linked to blue-baby syndrome. In other areas, elevated phosphorus levels have resulted in harmful algal blooms affecting drinking water supply. While relatively large systems that provide water to populations of 100,000 or more (more than 400 systems nationwide) are typically treating surface water, there are many more relatively small facilities (more than 4,000 nationwide) providing service to populations in the 10,000 to 99,000 range, which typically use groundwater sources. Nutrient monitoring needs differ significantly between these two groups and within each group based on regional differences in landscape conditions and regulatory contexts.

One executive of a large multi-location facility treating surface water in a Midwest state noted that data from Challenge-based sensors deployed near these facilities would be a great supplement to data they already obtain from USGS sensors located upstream. Water tested by these USGS sensors has a travel time of three to eight days before it reaches treatment facilities. Additional sensors in closer proximity to the facilities and on selected tributaries would help characterize a broader range of facility-based water quality control options.

The potential for use of sensors within the facilities themselves depends to a large degree on the type of water treatment that is taking place. Reverse osmosis treatment, for example, would not require sensors, as the treatment removes nitrate, but other treatment methods would benefit from location specific nutrient measurements within tanks to help optimize water flow and treatment.

Use of sensors for groundwater monitoring might increase demand in this market segment, but an industry executive pointed out that this depends to a large degree on regulatory changes, as groundwater has largely been left alone by regulators.

Commercial Market Segments

Interviews with representatives of sectors with potential commercial applications for in-water nutrient sensors revealed a variety of potential uses. One interviewee was a researcher working on the design and operating procedures for oyster aquaculture. He noted that currently oyster aquaculture is considered by federal regulators to be a “Class III BMP” and in order to generate marketable credits to sell in a nutrient credit trading program would need to “move up” to a “Class I BMP”. The interviewee saw potential for oyster growers to use NSC-based sensors to verify their nutrient discharge reductions and the nutrient removal properties of oysters in order to achieve this designation change which would facilitate the direct involvement of oyster aquaculture in this type of trading and generate new income sources for aquaculture businesses.

Individuals who represent different parts of the commercial finfish aquaculture industry were also interviewed. Prior to these interviews, we envisioned two potential uses of NSC-based sensors in aquaculture operations: monitoring water quality for fish health and improve product quality, and monitoring discharge to meet regulatory requirements. In most aquaculture farms, however, dissolved oxygen and ammonia need to be monitored, but nitrate is not as much of a concern. Discharge practices vary with different types of farms (e.g., ponds, recirculating systems, etc.) and government-mandated monitoring and reporting requirements vary in different regions of the U.S. There is an aquaculture-based market for the type of in-water nutrient sensors being developed as part of the Challenge, but predicting the size of this market is very difficult at the present time.

Two people were interviewed regarding potential use of in-water nutrient sensors in hydroponic and aquaponics applications. Although the overall market in these sectors is small, both interviewees saw potential uses for NSC-based sensors. In a hydroponic operation where fertilizer is stored in large tanks, nutrient levels are currently estimated through electrical conductivity. A university researcher speculated that more frequent and accurate measures of nutrient concentration could yield more growth and a better quality product, thereby having a positive impact on profits. Aquaponics is currently a small but rapidly developing industry sector and potential sensor market. One interviewee, a member of a national aquaponics association, indicated that in a few years, when government food safety audit standards for this sector are finalized, the aquaponics sector could grow significantly as farmers look to diversify their operations in ways that mitigate the uncertain impacts of changes in precipitation regimes and flood threats that are expected to accompany climate change.

Government Market Segments

Federal Research and Monitoring Programs

Federal research and monitoring programs, such as those conducted by USGS, EPA, and NOAA, represent a significant source of potential demand for NSC-based sensors. One interviewee noted in particular that the lower price point targeted by the challenge is critical, not only for Federal programs, but for academic and non-profit institutions as well. Many potential uses of these sensors for research and monitoring by universities, non-profits and for-profit companies will also be funded by federal grants and contracts.

State and Local Research and Monitoring Programs

With more than 6,000 nutrient TMDLs nationwide, there is an increasing need for state and local jurisdictions in areas subject to TMDLs, such as those in the Chesapeake Bay watershed, to gain a better understanding of nutrient sources. One expert in the Chesapeake Bay region emphasized that finding and removing or reducing sources of nutrient discharges may have TMDL-credit benefits for regulated communities. An example of how nutrient measurements are used to make determinations about levels of nutrient removals and the “creditworthiness” associated with particular types of projects is an October 2014 recommendation of the Chesapeake Bay Program’s “Expert Panel to Define Removal Rates for the Elimination of Discovered Nutrient Discharges from Grey Infrastructure”. (Schueler et al. 2014).

The Chesapeake Bay watershed is one of the most active regions of the country in terms of TMDL development, and can be viewed as a model for other regions, and for how Challenge-based sensors might help inform ongoing refinement of watershed cleanup models and best management practices (BMPs). The Chesapeake Bay Program (CBP) Water Quality Goal Implementation Team (WQGIT) is responsible for approving loading estimates to quantify expected amounts of nutrients (nitrogen and phosphorus) or sediment loads to water from specific land uses or point sources. The CBP has developed a protocol (CBP 2015) that outlines specific procedures for its best-management-practice Expert Panels to follow so the process is consistent, transparent, and scientifically defensible.

The protocol notes that changes in estimated loads from a particular piece of land can occur in a number of ways, including: 1) A change in the land use (e.g. forest instead of grassland), 2) an adjustment based on an estimate of effectiveness of a BMP, 3) a measured reduction in direct load to the land use, and 4) a measured reduction from a treatment process. The CBP uses these effectiveness estimates and measures of direct load reductions to modify estimates of existing baseline loading for particular land uses and practices.

The WQGIT is responsible for approving the loading rate reductions, and percentage adjustments to these rates, used in the Chesapeake Bay Watershed Model (CBWM). The 2014 Chesapeake Bay Watershed Agreement includes the commitment to meet two-year milestones that accelerate the pace of Chesapeake Bay restoration, and the need to quantify impacts of practices to be used in Watershed Implementation Plans (WIPs) to achieve TMDL allocation targets.

Other Market Segments

Academic researchers interviewed for this project were, in general, excited by the prospect of NSC-based products and how they could be used to identify the sources and impacts of water quality problems and find cost-effective solutions. More than one academic researcher was optimistic that the market among their peers would be strong, indicating that at a unit price of less than $5,000 each of them might purchase as many as 10 NSC-based sensors as part of the research grants they currently manage. However, without doing some research they were not willing to provide estimates about how large the overall research market was likely to be. A researcher in the Chesapeake Bay watershed indicated that the availability of sensors that can take samples, regardless of weather conditions, will greatly reduce uncertainty about how projects affect nutrient discharges and improve general understanding of how watershed systems work. For example, in large storm events, it is generally understood that nutrient concentrations change rapidly. However, because researchers cannot safely take water samples at some locations except before and after a severe storm the “snapshots” of conditions they are able to collect tell only part of the story. Although this researcher believed the potential research market for NSC-base sensors would be large, he was, understandably, unwilling to predict how large.