Identifying Market Specifications for Affordable Nutrient Sensor Technologies: User Needs Study

Submitted by

Anne S. Marsh, Ph.D.

4800 Scarsdale Rd, Bethesda, MD 20816

(301) 320-6024

marsh@asmarsh.net

June 13, 2014

Contract Number: GS-10F-0061N / EP-BPA-12-H-0035

Subcontract Number: 1110-MARSH

Table of Contents

Table of Contents……………………………………………………….……………...….2

List of Tables and Figures…………………………………………………………..……..3

Background ………………………………………………………………………………4

American University Study……………………………………………………….………..…4

Study Results……………………………………………………………...…………..…5

User Community……………………………………………………………….…5

Sensor Environment……………………………………………………………...5

Nutrient Measurements……………………………………………………….…6

Instrument Features……………………………………………………….……...6

Operation…………………………………………………………………….....…9

Cost…………………………………………………………………………..….10

Moving Towards Specifications………………………………………………..……....11

References………………………………………………………………………....….12

List of Tables and Figures

Table 1. The proportion of respondents using various sensor deployment settings…………......….6

Figure 1. The proportion of respondents seeking various upper (top graph) and lower (bottom graph) nitrogen detection limits (mg/l) in sensors……………………………………..………...7

Figure 2. The proportion of respondents seeking various upper (top graph) and lower (bottom graph) phosphorus detection limits (mg/l) in sensors……………………………………...…….8

Figure 3. The proportion of respondents interested in various levels of accuracy and precision in sensors…………………………………………………………………...………………....9

Figure 4. The proportion of respondents that identify various sensor price points as affordable…………………………………………………………………………………....…10

.

Background

Our nation's streams, rivers, lakes, estuaries and increasingly marine ecosystems are impacted by nutrient pollution, particularly from wastewater, urban and suburban stormwater, and agricultural runoff (Dubrovsky et al. 2010; The Heinz Center 2008). Nitrogen and phosphorus pollution can cause increases in the growth of algae, which in turn may reduce the concentration of dissolved oxygen in the water. This can cause fish kills as well as shifts in the composition of aquatic species. Algal blooms can diminish aesthetic and recreational values and cost businesses thousands of dollars due to the expense of de-fouling. In addition, elevated nitrogen concentrations can cause a health risk for infants if water is not treated before drinking.

Currently, monitoring data are both temporally and spatially limited because processing water samples is time consuming. Most water samples are taken back to the laboratory for analysis. The availability of affordable smart nutrient sensors that provide real time monitoring data in the field would allow for better quantification of nutrient loads, increasing monitoring efficiency and making it possible to explore the development of new market and policy tools for pollution abatement.

In January 2014, the Partnership for Technology, Innovation and the Environment (PTIE) established a workgroup to examine technologies to monitor nonpoint source pollution, barriers to their development, policies and market mechanisms to facilitate their application, and financial tools. While there are currently some smart nutrient sensor systems on the market, they tend to be cost prohibitive for many users. Many sensors also suffer from errors and uncertainty, including calibration error, network communication loss, and uncertainty in the underlying model and parameters (Goldman et al. 2007). To promote the acceleration of affordable smart nutrient sensor technologies, the workgroup is supporting a Nutrient Sensor Challenge being led by the interagency Challenging Nutrients Coalition.

American University Study

To preface the development of any sensor system specifications, American University's Center for Environmental Policy conducted an independent study of the market for nutrient sensors. In April 2014, it distributed a questionnaire to get a better sense of the user community and any features that users might demand in a smart sensor system. The questionnaire was distributed to members or contacts within of the Environmental Council of States, the National Water Quality Monitoring Council (NWQMC), the Consortium of Universities for the Advancement of Hydrologic Science, the PTIE Workgroup on Monitoring Nonpoint Source Pollutants, and the Water Keeper Alliance, as well as attendees at the NWQMC's 9th National Monitoring Conference in Cincinnati, Ohio. This report summarizes results of the American University questionnaire and recommends future lines of discussion that could be used in the development of programs to accelerate and incentivize development of nutrient sensor technology.

Study Results

User Community. Respondents to the questionnaire included 84 professionals, working in 29 states and the District of Columbia. Professionals from the academic, government (federal and state), and non-profit sectors were almost equally represented, with fewer corporate professionals (n=5). Corporate parties that manufactured sensors or sensor components were excluded from the study as were professionals working in two foreign counties due to the Partnership's focus on domestic technology development.

Respondents were predominately interested in using in situ nutrient data for monitoring and research. Fewer respondents (<30%) sought to use the data primarily for regulation or other purposes, such as education, policy, and communication.

Sensor Environment. There was most demand for sensors that operated in freshwater environments (92% of respondents), but noteworthy demand for sensors that operated in brackish, marine and other environments (39%, 31% and 11% of respondents, respectively; other included groundwater, hyper-saline waters, activated sludge, and agricultural wastes). One-fifth of respondents needed sensors to operate in a full range of salinities, from freshwater to marine. Respondents operating in marine and in brackish and marine environments had comparable results to those operating exclusively in freshwater environments, perhaps because over 85% of these respondents operated in freshwaters as well. As a result, findings from this study are presented for all respondents, sampling in a range of salinities.

The primary sampling environment for many respondents was characterized by low water clarity and/or the presence of tannins. High levels of colored dissolved organic matter (CDOM) and turbidity were noted by 66% of respondents, while medium levels of CDOM and turbidity were noted by 39% of respondents.

Sensors were more frequently deployed submerged than not submerged, and more frequently deployed shoreside or unattended from a buoy that from a vessel (Table 1). Flow rates during deployment varied widely, with several recipients noting the need to take measurements at high flow.

In most cases, respondents stated that that deployment sites were easily or moderately accessible (could reach within a day or week). Only 10% of recipients said that sites would be challenging to access in less than a week.

Deployment	Submerged (%)	Non-submerged (%)
on an unattended buoy	42	0
Shoreside	58	20
from a vessel	17	6
Other	20	

Table 1. The proportion of respondents using various sensor deployment settings (n=64). Other included deployment from profiling floats, autonomous vehicles, gliders, bridges, anchors, pilings, and in wells and intermittent streams.

Nutrient Measurements. There was strong interest (>75% of respondents) in all nutrient sensors cited (nitrate & nitrite; ammonium & ammonia, total nitrogen, soluble reactive phosphorus, and total phosphorus), but greatest interest in nitrate & nitrite sensors (93% of respondents).

The upper and lower detection limits preferred by respondents for each sensor type are shown in Figures 1 and 2. The following ranges of detection satisfied the needs of 80% of respondents: 0.05 to 60 mg/l $NO_3 + NO_2$; 0.05 to 20 mg/l $NH_4 + NH_3$; 0.1 to 60 mg/l total N; 0.005 to 5 mg/l PO_4; and 0.01 to 5 mg/l total P.

Respondents were also interested in sensors that took reliable and repeatable measurements. They favored levels of accuracy (difference from calibration standard) and precision (difference in repeated measures) of 1 to 5% (Figure 3).

Instrument Features. Respondents favored sensors that were small and light weight so that they could be easily transported to field sites and handled by a single person. Larger systems were more acceptable if sensors measured multiple nutrients or were deployed at an accessible location. Respondents were also interested in including a loop or handle on the sensor housing to facilitate sensor mounting and transport.

There was a strong preference for sensors that were deployable in a variety of aquatic environments with variability in temperature, salinity, and flow. Sensors also had to account for interferences. Respondents required compensation for turbidity and colored dissolved organic matter (CDOM) and favored sensors that incorporated wipers and cleaners to limit biofouling.

There was most interest in sensors that either integrated into an existing datalogger (63% of respondents) or were stand-alone units with internal datalogging (59% of respondents). Fewer respondents sought to integrate sensors into a new commercial datalogger (22% of respondents). Preference was for data transmission by SDI-12 or RS-232.

To allow for remote monitoring and control of the system, respondents were interested in reliable data communication mechanisms. Respondents favored cellular communications (80% of

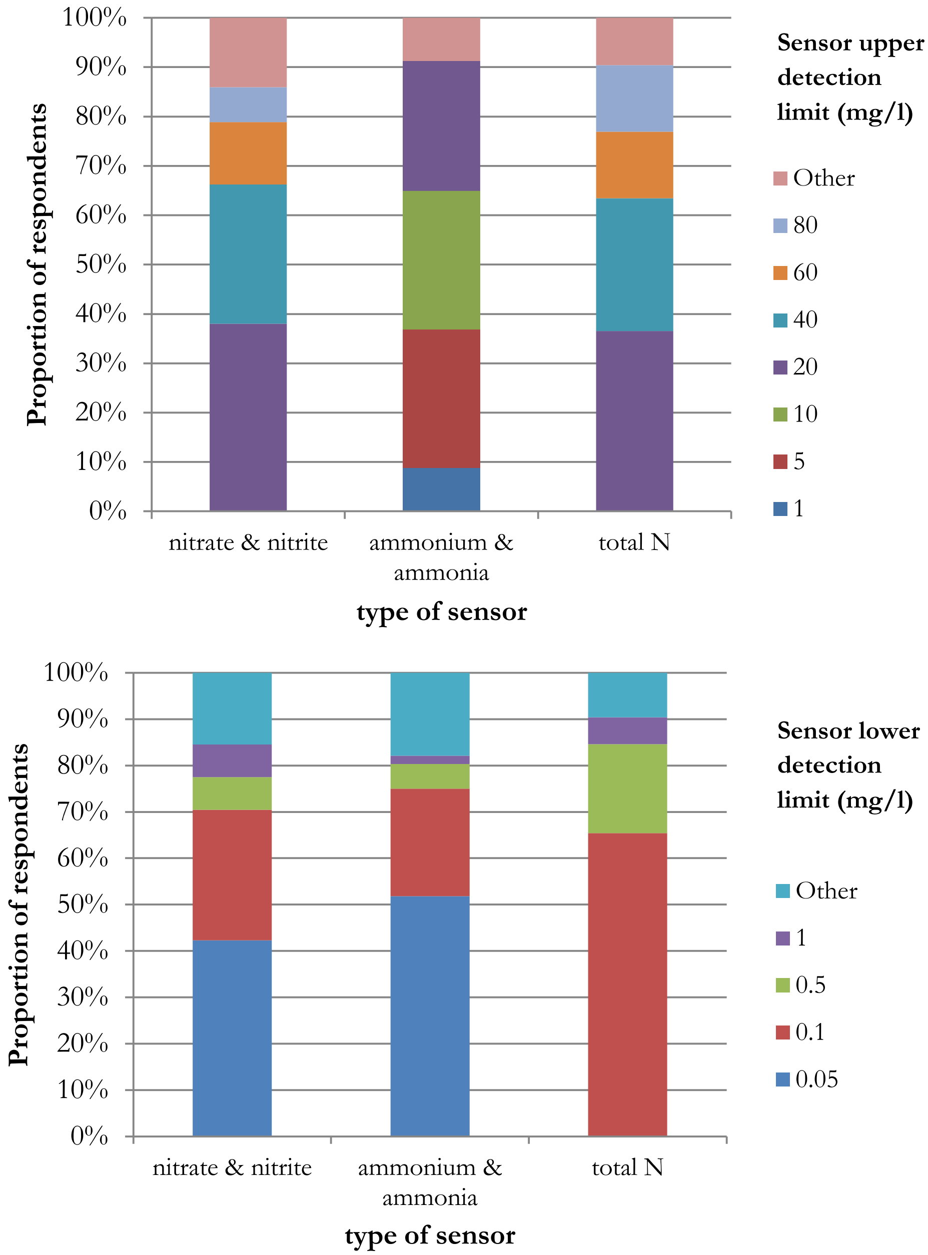

Figure 1. The proportion of respondents seeking various upper (top graph) and lower (bottom graph) nitrogen detection limits (mg/l) in sensors (Upper: nitrate & nitrite n=71 , ammonium & ammonia n=57, total n n=52; Lower: nitrate & nitriten=71, ammonium & ammonia n=56, total n n=52)

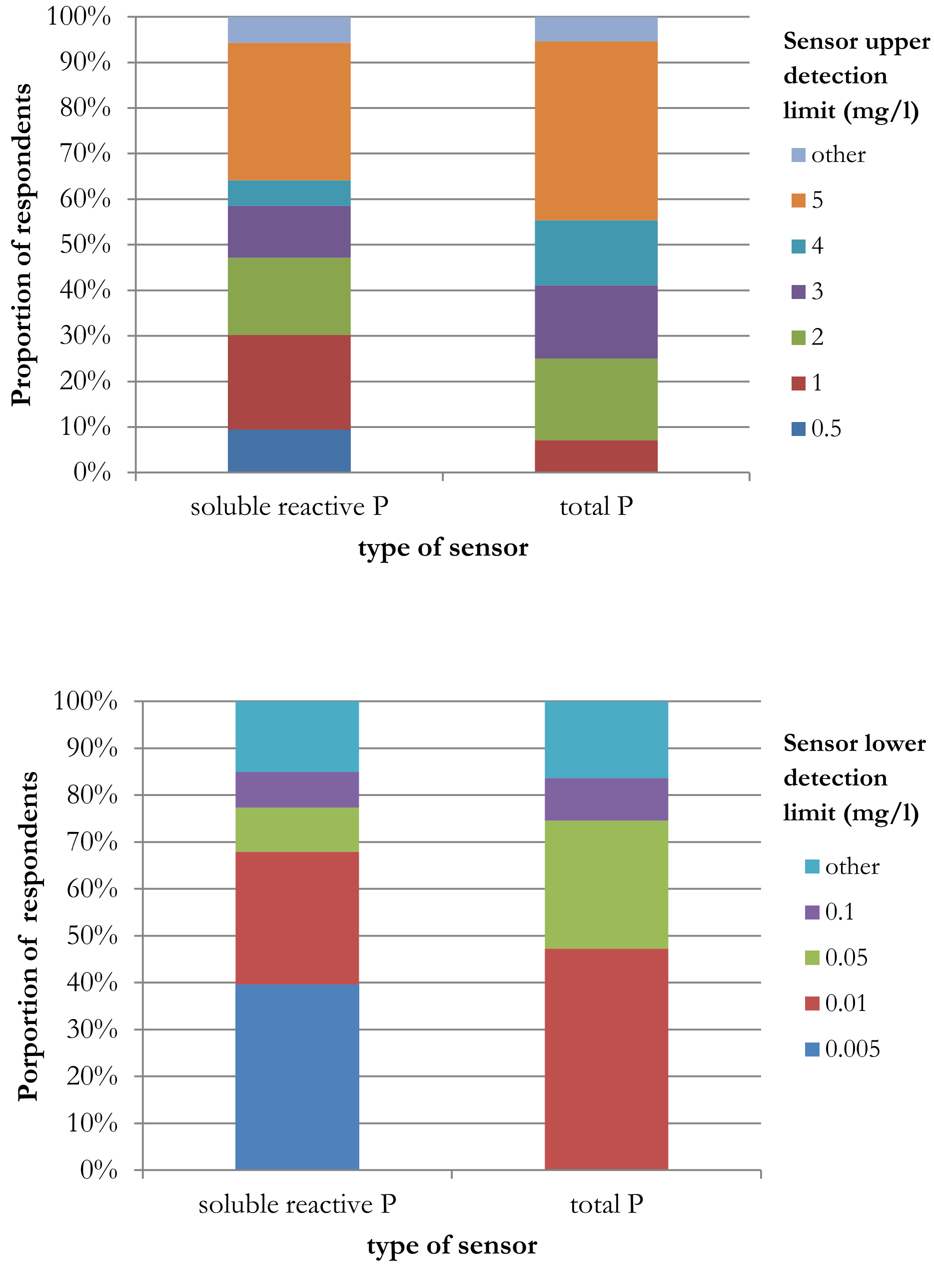

Figure 2. The proportion of respondents seeking various upper (top graph) and lower (bottom graph) phosphorus detection limits (mg/l) in sensors (Upper: soluble reactive phosphorus n=53 , total P n=56; Lower: soluble reactive phosphorus n=53, total P n=55)

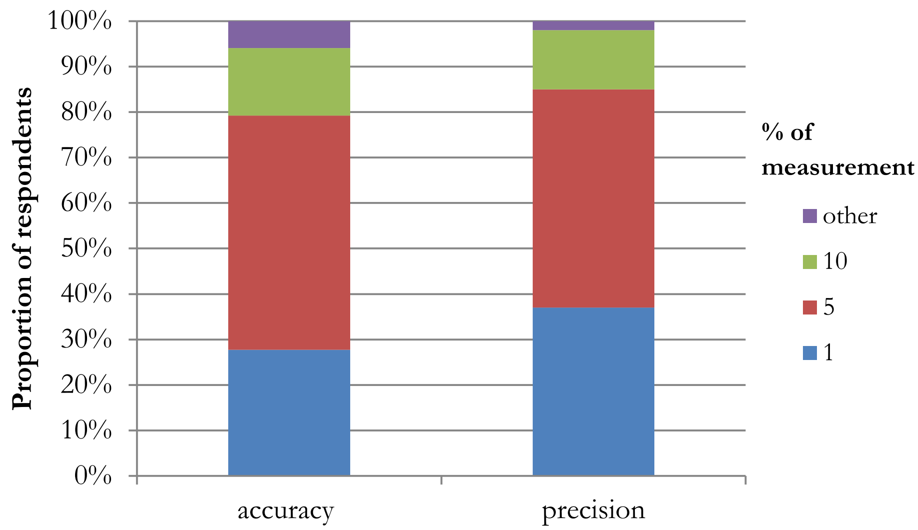

Figure 3. The proportion of respondents interested in various levels of accuracy and precision in sensors (accuracy n=54, precision n=53).

respondents), but also showed preference for other forms of communication, including WiFi (36% of respondents), satellite (27% of respondents) and HF radio (17% of respondents).

Respondents wanted systems that were easy to download from the unit or datalogger, and provided data in accessible formats (e.g. Water ML.2 compliant). There was also an interest in being able to provide metadata to the system and set flags to trigger sensor operation.

Low power requirements were seen as critical and the provision of a sleep mode helpful in maintaining power. Those respondents that commented on power (n=11), tended to favor systems with a 12 VDC or internal power supply and the ability to use solar panels to power sensor systems. To ensure users that the instrument was powered and operating, two respondents requested a light indicating operation or LED data acquisition interface.

Operation. Respondents desired sensor systems that had sufficient memory, sensor stability, and power to sample on an hourly basis and have the option for more frequent bursts of activity. The ability to maintain and calibrate the instrument under these sampling conditions varied, but was typically at least on a monthly (55% of respondents) or seasonal (31% of respondents) basis. Respondents were willing to send the instrument to the manufacturer for maintenance and calibration once every 1 to 2 years (77% of respondents). The majority of respondents thought that sensor components should last at least 2 to 4 years (39% of respondents) or 4 to 6 years (29% of respondents) before being replaced at the owners cost.

Technical support for QA/QC of sensor data was available to most but not all respondents, with almost equal numbers having dedicated versus non-dedicated (less than half time) technical support. Twenty-two percent of respondents had little or no technical support.

Cost. There was a strong desire for reliable sensor systems with a lower price point than those currently on the market. As once respondent stated: "If a field verified total P or total N sensor costs less than $5000 and met specs for more than 2 to 3 years, you would have a very large interest from a variety of organizations."

The majority of respondents indentified the $1000 to $5000 price range as affordable for their purposes and/or organization (Figure 4). Respondents identifying <$1000 as an affordable price range were predominantly from non-profit organizations. Almost two-thirds of all respondents and all respondents in the <$1000 category were willing to consider using sensors with a slightly lower precision and/or accuracy if the sensor were significantly less expensive.

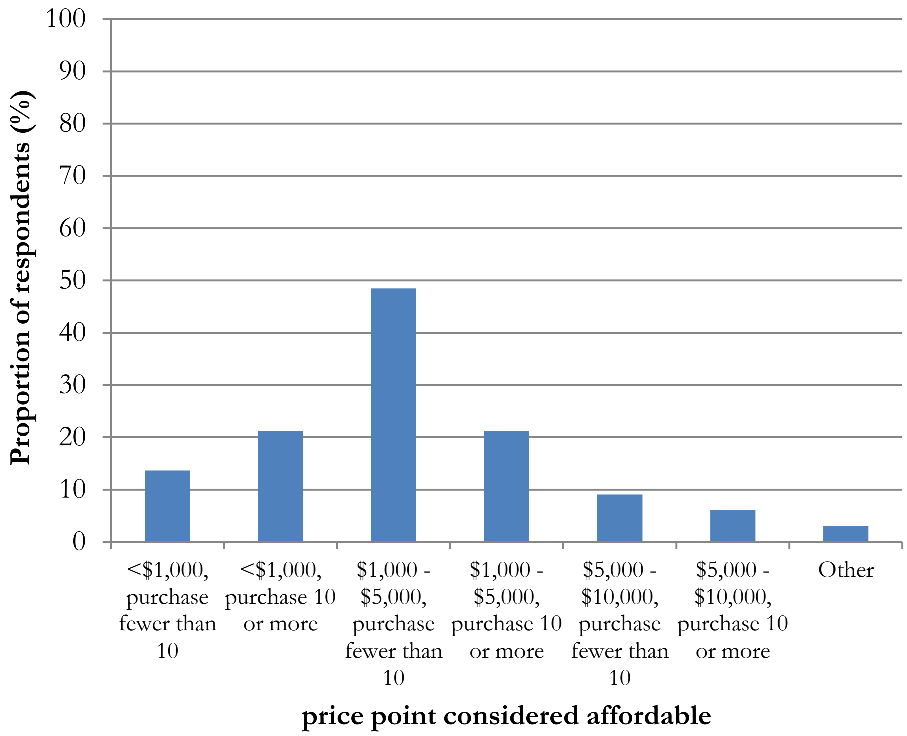

Figure 4. The proportion of respondents that identify various sensor price points as affordable (n=66).

Moving Towards Specifications

Findings from the American University questionnaire provide an excellent foundation for understanding user needs for smart nutrient sensor systems; however, further information is needed in order to draft specifications for a nutrient challenge. EPA and the PTIE workgroup would benefit from additional, more specific data on system parameters (electrical, mechanical and operational) and a better understanding of technical challenges and alternatives in sensor manufacturing. Issues that should be further explored include:

1. **Nutrient focus.** Should the challenge focus on a single parameter (e.g. nitrate & nitrite) exclusively or a combination of nitrogen and/or phosphorus sensors? Are there fundamental technological obstacles to focusing on some of the other nutrient parameters? What are the greatest challenges in ensuring reliability and repeatability in variable deployment settings?
2. **Freshwater focus**. Could affordability, reliability and repeatability of measurement be more easily achieved if a sensor system were developed solely for freshwater or potentially freshwater and brackish water deployment?
3. **Nutrient detection limits.** Which lower and upper detection limits are most challenging to achieve and maintain between calibrations? Are there limits that could be easily raised or lowered? How do we use this information to identify specifications for detection limits?
4. **Interferences.** Based on the specified deployment setting, what compensation should be required? What if any limits to compensation should be specified?
5. **Sensor integration**. What are the pros and cons of built-in datalogging and communication? What cost savings are achieved (if any) when existing datalogging systems are used?
6. **Ease of use**. Is it possible to provide data and metadata formats and maintenance/calibration protocols that meet the needs of technical experts as well as those with less sophisticated technical backgrounds ?
7. **Communications.** How difficult would it be to build in compatibility with multiple types of communication (e.g. cellular, WiFi, etc.)?
8. **Power**. What are the trade-offs in batter life, frequency of measurement, calibration/maintenance schedules, and transmission of data? What challenges (if any) are there in integrating solar power into deployments?
9. **Deployment environment**. In what range of depths, temperatures, and flow rates would the sensors need to operate? Are there temperature storage parameters for the instrument?
10. **Installation**. What are the installation equipment requirements (e.g shelters, pumps) for particular sensor systems?
11. **Features**. Given the trade-offs, what size, weight, and dimensions are optimal? Are there innovative approaches to make the instrument more durable and resistant to biofouling?

References

Goldman, Jeff, Nithya Ramanathan, Richard F. Ambrose, David A. Caron, Deborah Estrin, Jason C. Fisher, Robert Gilbert, Mark H. Hansen, Thomas Harmon, Jennifer Jay, William J. Kaiser, Gaurav S. Sukhatme, and Yu-Chong Tai. 2007. Distributed Sensing Systems for Water Quality Assessment and Management. Woodrow Wilson Center for International Scholars.

Heinz Center. 2008. *State of the Nation's Ecosystems 2008*. Washington, DC: Island Press.

Dubrovsky, Neil M., Karen R. Burow, Gregory M. Clark, Jo Ann M. Gronberg, Pixie A. Hamilton, Kerie J. Hitt, David K. Mueller, Mark D. Munn, Bernard T. Nolan, Larry J. Puckett, Michael G. Rupert, Terry M. Short, Norman E. Spahr, Lori A. Sprague, and William G. Wilber. 2010. The Quality of Our Nation's Water—Nutrients in the Nation's Streams and Groundwater, 1992–2004. U.S. Geological Survey, National Water-Quality Assessment Program, Circular 1350.