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Low Cost Water Quality Monitoring Needs Assessment

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Photo on front and back covers provided courtesy of Chesapeake Bay Program.

The Chesapeake Conservancy's mission is to strengthen the connection between people and the watershed, conserve the landscapes and special places that sustain the Chesapeake's unique natural and cultural resources, and encourage the exploration and celebration of the Chesapeake as a national treasure.

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LOW COST WATER QUALITY MONITORING NEEDS ASSESSMENT

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EXECUTIVE SUMMARY

The Low Cost Water Quality Monitoring Needs Assessment report was performed by Chesapeake Conservancy's Conservation Innovation Center to guide the Conservancy's entry into the water quality monitoring field. It also provided the basis for a mission-related set of findings and action recommendations made to the Conservancy. The report follows the Center's earlier investigation into precision conservation analysis tools and serves as a complementary resource guide featuring technologies available for acquisition and remote transmission of site specific water quality monitoring data. Among other goals, the Conservation Innovation Center aspires to facilitate broader citizen-based monitoring efforts in the Chesapeake Bay watershed using innovative, low cost devices.

The introductory portion of the report provides an overview of Chesapeake Bay water quality concerns and the Total Maximum Daily Load allocations that drive the need for effective best management practices and widespread water quality monitoring. It also identifies specific questions that framed the assessment and outlines the information gathering methods used. A brief review of nutrient and sediment transport pathways to ground and surface waters highlights monitoring challenges associated with physiographic, hydrological and geological conditions. Key points noted in this section include:

- Both surface and ground water monitoring are needed to understand how nonpoint source pollutants are moving through the watershed and interacting with the landscape and "best management practices" (BMP).
- Differentiating the effects that BMPs are having from other landscape factors can be difficult due to the variable hydrological, physiographic, geological, land cover and soil conditions that can influence and affect the composition and amount of pollutants entering streams and groundwater.
- Significant groundwater lag times will delay gauging the effectiveness of BMPs depending upon the regional physiographic and groundwater characteristics where they are located. In the Bay watershed, average groundwater lag times associated with dissolved nutrients are about 10 years, but a recent study of groundwater baseflow lag times in several Eastern Shore watersheds put the average closer to 30 years.
- Monitoring sediment transport and sediment flux is challenging. Most of the short-term sediment yield from the watershed to the Bay comes from sediment transported during bank full conditions, which take place on average every one to two years and during relatively large storm events. Long term sediment transport is thought to be driven by extreme climatic events that may occur only once in about every 2,500 years. While several surrogates exist for monitoring sediment flux, quantitative evaluations for the Bay are principally derived from model simulations due to the limited extent of continuous watershed sediment flux data.

Next, situation-specific water quality monitoring needs and challenges for streams and wetlands, nutrient trading related monitoring, and crowdsourcing of water quality data are addressed. This section covers: how the purpose of a monitoring program dictates equipment, training and quality assurance program needs, how monitoring challenges differ in tidal versus nontidal streams, what the programmatic context is for nutrient and Total Maximum Daily Load (TMDL) related monitoring, and an inventory of

selected crowdsourcing monitoring efforts in the Chesapeake watershed and beyond. Important monitoring needs and challenges mentioned in this section include:

- Monitoring needs for tidal versus nontidal streams are quite dissimilar due to differences in the parameters that are monitored, the physical characteristics of the two waterbodies, and the varying levels of expertise required to collect and report accurate quality controlled data.
- Nontidal stream monitoring presents significant challenges for maintaining and calibrating equipment due to major storm related changes in water flow and shallow stream depths. Also, several parameters that require accurate monitoring like sediment flux and nitrogen speciation cannot be done, at present, using low cost sensor technologies.
- Present methods for biological monitoring based on benthic macroinvertibrate sampling are time intensive and costly. However, there are strong future prospects for increased use of automated species identification using DNA sequencing technology once a well vouchered taxonomic library of macroinvertibrate species for the Chesapeake Bay watershed becomes available.
- Wetlands present unique monitoring challenges due to the many variations in wetland types and possibilities for wetland water quality criteria, alternating wet and dry conditions in some wetlands that can be problematic for monitoring sensors, and the costs to monitor wetland water quality to meet regulatory standards can be prohibitively high relative to the cost of wetland creation. Finally, most states do not rely on or use monitoring data to support wetland related designated use standards.
- Water quality monitoring standards in Maryland, Virginia and Pennsylvania are not required for purposes of verifying nutrient trading credits for specific Best Management Practices.
- The U.S. Environmental Protection Agency (EPA) Bay Program has created draft TMDL BMP verification protocols for agriculture, forestry, urban stormwater, wastewater, wetlands and stream restoration. With the exception of wastewater, it appears that verification will be done largely through programmatic and on-site visual inspections. Due to the large number of stormwater facilities that require monitoring there appears to be a role for simple water quality monitoring systems for some facilities.
- Low cost crowdsourcing of water quality data can potentially fill gaps in surface water quality information. EPA reports that nationally, less than 30 percent of the nation's surface water bodies are assessed by EPA, states and tribes partly because of the high cost of traditional water quality monitoring.
- Crowdsourcing of water quality data inventoried for this report make use of cell phone apps, parameter sensitive strips, floating multi-sensor buoy platforms, single parameter sensor monitoring in homes, and local radio networks that collect and autonomously record data.

Traditional and promising monitoring technologies are reviewed next with particular emphasis on low cost and innovative sensor technologies. An important point is made concerning the limitations of sensors in detecting a wide range of known and emerging chemicals that are potentially present in various waters. Examples of traditional water quality analytical methods for various parameters are presented in chart format. Also, in chart format, is information about selected real-time sensor technologies including fiber optic, electrochemical, biosensors, specifically-sensitive electrodes and

sensors using sound and electromagnetic field interaction. Examples of single and multi-parameter sensors and water quality equipment are presented in narrative and chart format. The need for transmitting remote monitoring data using a variety of telemetry options and related equipment is discussed. A special note about the significance of the Arduino open-source modular electronics platform is included along with examples of commercially available, interchangeable, add-on modules known as "shields." Key points in this section include:

- Low cost sensors are commercially available only for a limited number of parameters. Laboratory analysis of grab samples is still widely used in the Bay watershed. It is likely to remain that way—for the detection of toxic contaminants and the assessment of their effects on human health and wildlife. In daily use in the U.S. there are up to 70,000 known and emerging chemicals that might be present in various water resources.
- Low cost single sensor devices can play a valuable role as first warning sentinels that can signal some type of pollutant is present in the water system. Warnings can be further investigated through other more sophisticated monitoring efforts. Several parameters and toxic contaminants still require multi-step analytical techniques that are best done in a laboratory environment.
- One promising, but not fully developed technology is the lab-on-chip or LOC device made from a variety of materials which uses a combination of microfluidics and sensing capabilities. LOCs will expand the range of remote location parameter analysis capabilities in near real time and can replace certain analyses done in laboratories.
- Perhaps the most promising low-cost mobile technology encountered during this scan that is potentially viable for near term use appears to be electromagnetic wave sensors. Sensors for detection of nitrates and other pollutants has been highly successful using a combination of planar meander and interdigitated electromagnetic structure.
- The most promising low cost technology for immediate use for long-term, continuous monitoring at fixed locations is the Arduino open-source platform. The Arduino micro-controller can be outfitted with a variety of sensors and configured to work with local radio frequency wireless mesh networks to collect, record and relay sensor data.
- Using the Arduino platform at fixed locations reduces the cost of data logging and communication hardware, allowing greater spatial coverage of monitoring stations and higher quality sensors.
- The Arduino platform is supported by a worldwide network of programmers and manufacturers who provide a growing, accessible knowledge base and a constant flow of new devices.

LOW COST WATER QUALITY MONITORING NEEDS ASSESSMENT

INTRODUCTION

The Chesapeake Bay Context for Water Quality Monitoring

The Chesapeake Bay is the largest estuary in the United States supporting more than 3,600 species of plants, fish and animals and producing about 500 million pounds of seafood per year. But, many environmental stresses, directly relating to land use management practices and a population of over 17 million people in the 64,000 square mile watershed draining into the Bay, have caused serious water quality problems. Of principal concern has been decades of adverse effects from *nutrient and sediment enrichment.*

Excess plant nutrients, principally nitrogen and phosphorus, stimulate the production of algal blooms which die-off and consume oxygen, causing persistent areas of low dissolved oxygen concentration or "dead zones." Dead zones are hostile environments for living resources. For example, they reduce foraging habitat and stress or kill bottom-dwelling invertebrates that provide food sources for commercially and economically important demersal fishes (e.g., striped bass, spot, Atlantic croaker, perch, summer flounder, etc.). Dead zones can be nearly devoid of aquatic life and are often characterized by drastic declines in fish species diversity, species richness and catch rates.[1] Algal blooms and suspended sediment also reduce sunlight needed for growth of submerged aquatic vegetation that is of critical importance for the survival of many species in the Bay. Excessive sedimentation can degrade stream habitat, bury benthic organisms and may transport pathogens, toxic materials and nutrients that contaminate waterways and affect fisheries and other living resources.

Figure 1: Algae covered river

Photo provided courtesy of Chesapeake Bay Program

To address this nutrient and sediment enrichment, the U.S. Environmental Protection Agency's (EPA) Chesapeake Bay Program (CBP), in 1987, established an unprecedented practice when it first set numeric pollution reduction goals with specific deadlines to restore the Bay ecosystem. Concurrently, CBP scientists and managers have worked steadily since 1983 to improve water quality in the Bay and have developed sophisticated monitoring and modeling techniques to help translate how restoration actions are affecting water quality. In 2010, EPA took another monumental step and established a Total Maximum Daily Load (TMDL) for the Bay that specifies nutrient and sediment load allocations needed in the watershed to improve dissolved oxygen, water clarity, and chlorophyll *a* conditions in the Bay.

The TMDL requires that all pollution control measures needed to fully restore the Bay and its tidal rivers are in place by 2025, with at least 60 percent of pollution reductions completed by 2017. Watershed Implementation Plans (WIPs) detail how and when the six Bay states and the District of Columbia will meet their pollution allocations. To assess progress in reducing nutrient and sediment inputs to the Bay, the U.S. Geological Survey (USGS), EPA and state and local jurisdictions operate a CBP water quality monitoring network and associated database.

Figure 2: Algae bloom in water column

Photo provided courtesy of Chesapeake Bay Program

The TMDL has resulted in watershed management efforts going into "high gear", with state and local governments, non-profit groups and businesses searching for ways to incorporate "best management practices" (BMPs) designed to achieve pollution load allocations for nitrogen, phosphorus and sediment. Experts are continually refining the estimated nitrogen, phosphorus and sediment reduction efficiencies of dozens of BMPs, and water quality monitoring and sampling is widely occurring for a variety of other non-TMDL related purposes from wastewater discharge permit compliance to the issuance of watershed health "report cards" by local watershed groups.

Further, the cost of meeting pollution reduction targets is rising and new ways to achieve reductions are becoming complex and involve approaches such as trading nutrient "credits" and securing "offsets." A credit is a load reduction such as pounds of total nitrogen reduced per year. Offsets are used when on-site BMPs can't achieve reduction targets or when TMDL nutrient loading rates are capped. On-site BMPs which are offset are assumed to be installed and maintained in perpetuity. Tracking and verification are critical to ensure approved BMPs and activities are being implemented and maintained; and that the generator of credits meets the baseline or threshold cap allocations of the trading program.

Government agencies and others interested in knowing that real pollutant reductions are taking place could all benefit from effective "low cost" water quality monitoring technologies as a component of the verification solution. The term "low cost" when used in the context of this document simply means that the cost of the technology used for a particular water quality monitoring task is at, near or below the bottom range of what is commercially available. At the same time, a key objective is to drive the overall price range down of monitoring devices by developing more low cost monitoring options. Low cost

monitoring technologies must become more widely available, accurate and easier to operate before they can be widely used throughout the watershed for monitoring nutrient trades, offsets, stream conditions, farmland BMP effectiveness, stormwater discharges and other situations requiring reliable water quality data.

Figure 3: Woman measuring water clarity with Secchi disk.

Photo provided courtesy of Chesapeake Bay Program

Trustworthy inspection and tracking protocols for BMPs along with enhanced capabilities to provide accurate low cost water quality monitoring data will help increase public confidence in the TMDL process, facilitate technical verification needs, and EPA's determination of whether state jurisdictions are providing "reasonable assurances" that specified pollution reductions will continue to occur.

Chesapeake Conservancy's Interest in Low Cost Water Quality Monitoring Technologies

The Chesapeake Conservancy shares the concerns expressed by many environmental groups that tracking and verification are critical to ensure BMPs and restoration activities are being implemented and maintained properly in urban and agricultural landscapes. According to the EPA Chesapeake Bay Program, agricultural activities are responsible for 45% of Chesapeake Bay nitrogen loads, 44% of phosphorus loads and 65% of sediment loads.

The Conservancy, through its Conservation Innovation Center (CIC), is exploring various technologies to assess the progress and effectiveness of conservation and restoration practices along the great rivers of the Chesapeake and on other targeted landscapes. Broadly, CIC's change detection efforts include remote sensing applications and computer software programs to identify: 1) opportunities for protecting landscapes that naturally reduce pollutant loads; and 2) landscapes that are generating high pollutant loads where specific BMPs can be applied for optimum results. These desktop assessment tools perform only part of the work that is needed to evaluate watershed health and BMP effectiveness.

Figure 4: This low cost monitoring unit measures conductivity and is placed inside the home to signal potential contamination from fracking operations.

The Conservancy sees potential widespread uses for low cost water quality monitoring devices that can supplement other technologies being used to track and verify how various landscapes and BMPs are affecting water quality. Some possible monitoring applications could include:

monitoring farm level BMP's for before/after water quality changes; verifying "credits" and their effectiveness in nutrient/carbon trading transactions; conservation easement compliance; hydrological and water quality conditions at potential/actual restoration sites; crowd sourced and local water quality/biological monitoring networks; and monitoring climate change dimensions such as salt water intrusion or sea level rise.

To advance their current conservation efforts, the Conservancy has set a goal to learn more about innovative low cost monitoring technologies and the basic facts and needs related to water quality monitoring in the Chesapeake Bay watershed. To accomplish this objective, the Conservancy's scan focused on answering the following questions:

- What are the water quality monitoring needs and challenges for: 1) stream and wetland monitoring, 2) nutrient trading related monitoring, and 3) crowd sourcing of water quality data?
- What existing and emerging monitoring technologies are relevant to the Conservancy's areas of interest?
- What are the gaps between what exists and what is needed and how can they be closed?

At the outset of this study, Conservancy staff engaged in a brief period of dialogue with Intel labs staff to benefit from their experience with the creation of their own low cost water quality monitoring system that was designed to a meet a temporary permitting requirement. The most important information shared by the lab staff pertained to their use of Arduino for low cost water quality monitoring. Arduino is an open-source electronics prototyping platform based on flexible hardware and software for anyone interested in creating interactive objects or environments. Arduino is an important development discussed later in this report.

Other than this initial help from Intel labs, the information gathered during the technology scan was derived from a combination of sources including:

- Literature searches
- On-site observation of field monitoring equipment
- Telephone interviews with a variety of experts involved with water quality monitoring, data collection/analysis, or equipment prototyping
- Face-to-face meetings with water quality experts and BMP practitioners
- On-line research efforts to assess relevant technologies

Pollutant Pathways and Monitoring Challenges

To better identify the extent to which low cost water quality monitoring technologies may or may not be appropriate for or relevant to various monitoring situations, the Conservancy elected to review a few key literature sources to understand the pathways for sediment, nitrogen and phosphorus entering the Bay and its tributaries. The Conservancy focused on nitrogen, phosphorus and sediment parameters since these are the pollutants regulated by EPA under the Chesapeake Bay TMDL. Although nutrient and sediment transport is a highly complex problem, some generalizations have been well framed by USGS scientists Phillips and Lindsey, who reviewed and summarized several important research papers in a

fact sheet[2] that addresses the influence of ground water on nitrogen delivery to the Bay. Major findings included:

- There is a variable lag time between implementation of management practices and water quality improvement in the Chesapeake Bay. An important factor affecting lag time is the influence of ground water on the transport of nitrogen to streams in the Bay watershed.
- Ground water supplies about half, on average, of the water and nitrogen to streams in the watershed. Runoff and groundwater supplies, on average, the other half of the water going to streams.
- Ground water in shallow aquifers has a medium age of 10 years, but ranges from less than a year to 50 years. Runoff and shallow ground water is much younger in age–from hours to months.

Figure 5: Major storms often cause extensive stream bank erosion that carries sediment downstream.

Photo provided courtesy of Chesapeake Bay Program

Figure 6 (next page) shows relationships between nutrient sources, streams, soil water and groundwater. Table 1 (next page) also from the USGS fact sheet, shows relationships between lag time and water quality improvements. Because, monitoring of surface waters and shallow ground water (a.k.a. “soil water “ in the USGS fact sheet) can only tell part of the water quality monitoring picture—researchers and managers also use predictive modeling efforts to help evaluate pollutant loading scenarios and assess Bay restoration progress. The modeling work relies on research findings about groundwater lag time, aquifer hydraulic properties, nutrient application rates, BMPs and other data.

Figure 6: U.S. Geological Survey graphic illustrating surface and ground water relationships [3]

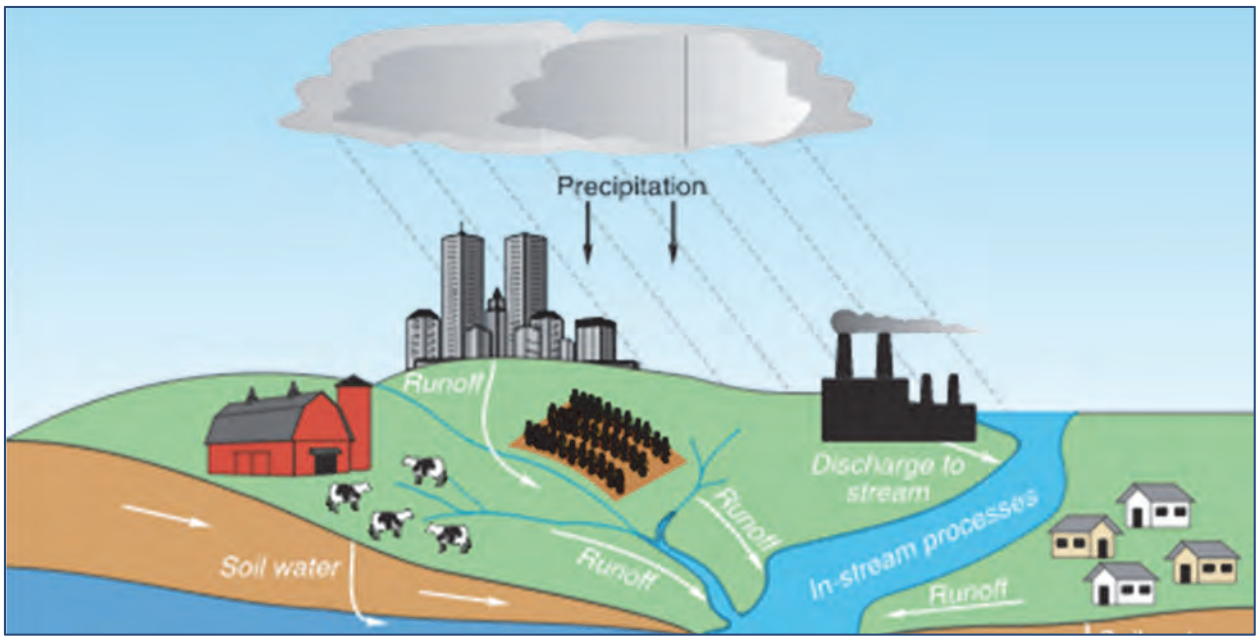


Table 1: Point and Nonpoint Pollutant Sources and Lag Times [4]

Nutrient Source	Management practice implementation time	Watershed residence time	Implications for load reductions in the Chesapeake Bay
Point sources (about 20 percent of nutrient load delivered to the Bay)	Several years	Hours to weeks	Would provide the most rapid improvement of water quality due to immediate reduction of source.
Nonpoint sources (about 80 percent of nutrient load delivered to the Bay) Dissolved nutrients	Several years	Hours to months if associated with runoff and/or soil water; years to decades if associated with ground water, with a median time of 10 years	Improvement in water quality would depend on the rate of implementation on nonpoint-source reduction and amount of nutrients still in soils. Once fully implemented, there would be a fairly rapid reduction of the load associated with runoff and soil water. Nitrogen load associated with ground water would have a median time of 10 years for water-quality improvements to be evident.
Nutrients associated with sediment	Several years	Decades or longer depending on location in watershed	Load reductions would be greatly influenced by streamflow variability. Storm events would deliver sediment and associated nutrients contained on land and in stream corridors. Loads to the Bay may not show reductions for decades due to long residence times.

A new USGS study[5] released in October 2013 of seven watersheds on the Delmarva Peninsula updates the nitrate lag times for this area, noting that the medium base-flow age of groundwater discharge in the seven watersheds is nearly 30 years, versus the Chesapeake Bay watershed estimate of 10 years. This, sadly, means that BMPs, on average, take much longer to achieve reductions on the Delmarva, unless streams with lower lag times are purposely prioritized for BMPs.

At a finer scale, researchers have been able to understand a good deal about delivery of nitrate to small streams and riparian zones using intensive monitoring and analysis techniques. One study by Bohlke, O'Connell and Prestegaard[6] is a case in point. Results from this and similar studies illustrate the critical role near-stream geomorphology and subsurface geology plays in riparian zone function and delivery of nitrate to streams in agricultural watersheds.

The first-order stream they studied was fed by a reactive stratified sedimentary aquifer where ground water was sampled vertically between recharge and discharge areas, combined with time series measurements of ground water levels and surface water flow and composition. Analyses included major element chemistry and dissolved gases, stable isotopes of nitrogen, carbon, and sulfur groundwater dating and slug tests— designed to determine aquifer hydraulic properties.

Among other observations that were made possible by the detailed monitoring and analyses approach, the research team was able to understand the balance of stream flow from shallow versus deeper water sources. For example, the team learned that out of a 15 meter thick aquifer a shallow flow system of 0 to 2 meters thick contributed most of the flow. Of additional interest was the fact that researchers learned that ground waters following shallow flow paths through the riparian forest zone were transmitted to the stream rapidly without substantial NO_3 loss largely through a network of outflow macro pores.

The researchers concluded that although seasonal correlations between stream nitrate nitrogen (NO_3) concentrations and regional water levels have been seen in many different watersheds the temporal patterns and underlying causes can vary greatly from place to place. This situation is different from more normal uniform hydraulic properties and lower hydraulic gradients near streams in many coastal plain and alluvial aquifers. However, this situation may exist in other agricultural areas with layered hydraulic and geochemical properties, such as tile-drained fields and fractured rock aquifers with permeable weathering zones.

Turning now to phosphorus, there are some significant differences in transport processes to surface waters and groundwater, compared to nitrogen. Although phosphorus is typically attached to and retained by soil through a process called adsorption (which makes phosphorus less likely to move off the farm), the *capacity of soils to store phosphorus is limited and once it is exceeded the excess will dissolve and move readily to surface waters or groundwater*.[7]

USGS recently studied agriculturally related transport in several locations, making the point that inexpensive soil tests (used to estimate fertilizer requirements) can be taken below the plant rooting zone to evaluate the potential for downward movement of phosphorus. When excess phosphorus is detected below the root zone, "the potential for groundwater transport of phosphorus can be evaluated with basic geochemical information, such as measurements of pH, dissolved oxygen and dissolved phosphorus in samples of shallow groundwater."[8]

USGS states that sometimes a vegetated stream-side buffer strip can effectively limit groundwater transport of phosphorus to a stream, but that "… it must be shown that the aquifer underlying the riparian zone is capable of adsorbing enough phosphorus to lower the groundwater concentrations."

They finally concluded that "low concentrations of iron oxides or low dissolved oxygen in the aquifer underlying the buffer strip would substantially reduce its effectiveness, and further research on the effectiveness of buffer strips for phosphorus management in a variety of agricultural settings is warranted."[9]

Figure 7: Nutrient management plans are an essential means of ensuring crops, like this corn, get the right amount of fertilizer to limit excess nutrients leaving the farm and entering local waterways.

Photo provided courtesy of Chesapeake Bay Program

Looking now at sediment transport, a few facts taken from the proceedings of a 2008 technical workshop on fine sediment and the Chesapeake Bay watershed[10] are very enlightening. First, it is important to note that although the relative contribution of upland sediment and the sediment stored in stream corridors has not been quantified in the Bay watershed, researchers know that these are the two most important sources of sediment coming from the watershed. One study in an urban setting estimated that two thirds of the sediment in the water column was from stream banks and one-third was from upland erosion. Bank full conditions, which take place on average every one to two years and during relatively large storm events, account for most of the sediment yield from the watershed to the Bay.

Figure 8: Sediment running off construction site.

Photo provided courtesy of Chesapeake Bay Program

Further, the proceedings state that the element of long term versus short term sediment transport is a very important concept to understand—particularly the magnitude of sediment derived from rare climatic events. For example, estimated long term "background" erosion rates using radio-nuclides indicate sediment yields of approximately 50t/km^2/year are more than double the short term sediment yields in the Susquehanna River basin of 22t/km^2/year. By way of explanation the proceedings note that long term erosion rates are influenced both by hydraulic transport of sediment by precipitation and mass wasting during "extreme climatic events." The implication is that infrequent massive flooding events can be responsible for much of the long-term sediment load from mountainous watersheds in the Bay watershed. "Many mountain-side (hill-top) streams have been created and shaped by low frequency, high magnitude sediment supply events that have been estimated to occur an average of once in ~2500 years in the Blue Ridge physiographic province."[11] These events have yet to be experienced in the Bay watershed.

With respect to monitoring *watershed* sediment flux—a variety of approaches are used, including:

- Sediment fingerprinting
- Calculations using data from river flow gauging and suspended sediment sampling to estimate sediment loads and their relative significance

- Surrogates for suspended sediment sampling, such as continuous turbidity measurements to estimate sediment concentrations
- Modeling to simulate rainfall runoff and related sediment flux
- Statistical relations between watershed conditions and sediment loads (e.g., USGS's SPARROW model)

Because of the limited extent of continuous watershed sediment flux data, quantitative evaluations are principally derived from model simulations.

With respect to understanding sediment conveyance through the river networks carrying sediment from hillsides to the Chesapeake Bay—this movement is controlled through complex hydraulic processes. The movement of hill slope sediment involves the passage through alluvial valleys that act as regulators of the watershed sediment yield. Fine sediment can remain stored in floodplains for an extended period of time and then become mobile at unpredictable time frames. Fluvial systems also have the capacity to store sediment in the active channel. Rivers are rarely in a "steady state" of equilibrium due to constant changes brought about by natural variations as well as anthropogenic factors. The amount and timing of sediment movement to watershed outlets in most of the tributary watersheds to the Chesapeake Bay is unknown. One of the major conclusions of the proceedings laments the overall lack of information to describe the holistic and long-term sediment flux trends on desirable ecological conditions. This, in turn, leaves watershed managers with "… generalized estimates of background and contemporary erosion rates, approximations of sediment flux, and conceptual characterizations of the hill slope and fluvial conditions associated with those rates."[12] The authors note that the lack of high resolution data that describes the relationships between sediment flux, water quality conditions and aquatic habitat limits the capacity to make watershed management decisions and investments. This, the authors cite, justifies greater expenditures to quantify sediment flux in more locations with the goal of characterizing conditions in all of the major watershed land uses and geomorphic settings in the region.

SITUATION SPECIFIC WATER QUALITY MONITORING NEEDS

This section of the report briefly addresses general water quality monitoring needs and challenges for certain categories that Chesapeake Conservancy in particular (and possibly other small NGOs) might wish to engage in. These categories include:

- Stream and wetland monitoring
- Nutrient trading related monitoring
- Crowd sourcing of water quality data

Stream and Wetland Monitoring

Monitoring Purpose Drives Needs and Requirements

Several of the experts interviewed for this study made it clear that identifying the purpose of the data collection effort is a key starting point to determining what is needed in the way of personnel, equipment, monitoring protocols and appropriate training/expertise requirements. For example, the Virginia Department of Environmental Quality's (VADEQ) Citizen Water Quality Monitoring Program recognizes five specific purposes of monitoring work that are eligible for their grant funding program[13]:

1. List and delist impaired waters on the 303(d) Impaired Waters List (note: Under section 303(d) of the Clean Water Act, states, territories, and authorized tribes are required to develop lists of impaired waters that do not meet their designated use).
2. Identify sources of pollution that may help in Total Maximum Daily Load (TMDL) development.
3. Track progress of TMDL or other restoration activities.
4. Identify waters for future monitoring by VADEQ.
5. Educating the community on local impacts to water quality and land use activities.

The Virginia Citizens Water Quality Monitoring Program also requires that an approved Quality Assurance Project Plan (QAPP) be in place for biological and/or chemical parameter field sampling. The QAPP affects both field sampling and lab processing. For instance, the program mandates that laboratory analysis costs can only be reimbursed subject to specific conditions:

1. Analyses must be conducted at a laboratory with DEQ-approved standard operating procedures and quality control/quality assurance protocols (these procedures must be submitted with the application package if they have not been submitted previously).
2. Sampling locations must not be in areas where the data are not considered useful for water quality assessments, such as in mixing zones and near discharge pipes or during spill events. Samples are representative of the stream (i.e., mid-channel just below the water surface) and are collected in safe locations on public property or where landowner permission has been obtained.
3. Data must be submitted electronically to DEQ using the online database provided by DEQ.

In Maryland, David Nemazie of the University of Maryland, Center for Environmental Science (UMCESS) makes a similar point about the scope and quality of data needed for water quality monitoring efforts

saying, "it all comes down to what you are going to use the data for."[14] UMCESS oversees the Chesapeake Bay EcoCheck watershed report card system and the operation of the Mid-Atlantic Tributary Assessment Coalition (MTAC) which is a growing coalition of watershed organizations interested in advancing the use of environmental data from local groups and citizen scientists for use in watershed report cards and assessments. MTAC has published detailed sampling and data analysis protocols to guide tidal and nontidal stream monitoring efforts of watershed organizations and their volunteer corps in an effort to ensure quality control/quality assurance.

Chesapeake Bay Program (CBP) also oversees the Bay-wide monitoring effort and maintains a Quality Assurance Program that tracks several environmental data sets. Water quality and living resource monitoring data is collected by over 40 agencies participating in the CBP and the quality, accuracy and consistency of this data adheres to the Chesapeake Bay Program Quality Assurance Program. There are detailed field and laboratory protocols set forth that must be followed by scientists and researchers covering tidal and nontidal monitoring, submerged aquatic vegetation, benthic and plankton methods. All monitoring programs and research projects funded by EPA or participating in CBP data collection efforts must have an EPA approved Quality Assurance Project Plan *prior to the start of monitoring or data compilation*. EPA policy is based on the American National Standard Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs (ANSI/ASQC E4-1994). The ANSI/ASQC standard describes the necessary management and technical elements for developing and implementing a quality system.

Figure 9: EPA Chesapeake Bay Program oversees Bay-wide water quality monitoring efforts that adhere to a rigorous quality assurance program.

Photo provided courtesy of Chesapeake Bay Program

The majority of small watershed organizations, who are currently doing water quality monitoring work in the tidal tributary systems of the Chesapeake Bay, are not participating in the CBP Quality Assurance Program. However, several of these same small watershed organizations participate in the EcoCheck and MTAC efforts which focus on watershed report cards that are used as an educational awareness tool for the public to track general water quality health trends. Dianna Muller, the Riverkeeper with South River Federation in Edgewater, Maryland is both a participant in EPA's CBP data monitoring and is involved with MTAC efforts and bacterial monitoring.[15] Muller is highly trained in water quality monitoring and associated lab work. She collects water quality data on: water clarity, dissolved oxygen, total nitrogen, total phosphorus, chlorophyll *a* (spring/summer), pH (surface/bottom), underwater grasses and bacteria. Muller calculates water quality scores for each numeric indicator in accordance with the Chesapeake Bay Program criteria and the Code of Maryland Regulations. Muller's level of monitoring expertise and time associated with her work as an approved CBP data provider are an example above and beyond what typical watershed organizations can commit to.

Recently, several local watershed organizations in the Chesapeake and Coastal Bays watersheds have become involved in bacterial monitoring at local beaches and popular swimming spots to improve the public's awareness of dangerous bacterial levels. According to Katie Register[16] of Clean Virginia Waterways, bacteria are the number one impairment in Virginia and there is extensive citizen interest in bacteria levels.

The Waterkeeper Alliance has developed the Swim Guide program (https://www.theswimguide.org) and app for smartphones that keeps citizens posted about the most recent bacterial count information and safety ratings for specific areas. Some Waterkeeper organizations, like the South River Federation, collect their own bacterial samples on a routine basis and post these to Swim Guide.

Different Needs and Challenges for Monitoring in Tidal Versus Nontidal Waters

The physical, chemical and biological characteristics and flow regime differences between Chesapeake Bay mainstem waters, tidal estuarine tributaries and various stream orders of nontidal waters present intuitively different monitoring needs and challenges. While these are too numerous to catalogue for the purposes of this report, some key points we learned are of particular relevance to Chesapeake Conservancy. Several important distinctions in monitoring challenges were raised by University of Maryland Research Assistant Professor Solange Filoso[17] who has done extensive research on small stream systems water quality and nutrients, in particular. Filoso points out that small and urban stream monitoring is storm flow prone and variations in flow can be substantial in a single system ranging from, for example, 1-2000 liters per second. As flow volumes increase, the force of the water becomes intensely powerful causing a number of monitoring equipment challenges.

Further, Filoso and other researchers often require flow weighted concentration sampling for various water quality parameters which is frequently paired with a controlled weir structure installed across the stream bed with "V" and rectangular shaped notches to facilitate water flow calculations. Assistant Professor Sean Smith, an expert in fluvial geomorphology and sediment, from the University of Maine, Department of Earth Sciences[18] states that flow weighted sampling versus grab sampling is needed in

small streams due to high variations in sediment and nutrient transport. Even with well-designed flow weighted sampling, Smith says that within a single storm event, water quality sampling can have too much variability to accurately assess sediment flux. In particular, he noted, water column measurements miss bed load sediment contributions that are better evaluated through sediment depth and volume tracking methods—especially in confined outlets (e.g., ponds and stormwater facilities). Further, in storm flow prone streams, weir devices can become detached from their stabilization structures and must be carefully constructed to withstand design storm flow volume and intensity. Each weir device needs to be custom fitted and installed to the stream cross-section monitoring point.

Filoso also advised that simple measures of nitrate or phosphate do not provide a complete picture of stream nutrient pollution. Filoso mentioned that researchers need to monitor the dissolved portion of phosphates not just particulate phosphorus—which is the larger portion of this nutrient. She stated that dissolved nitrogen in organic and particulate forms, especially during storms, must be accounted for to tell the complete story. She is currently authoring a paper about partitioning nitrogen in all its forms. Of great significance is a comment Filoso stated that she is not aware of sensors that have been made to detect partitioned forms of nutrients and that these are identified through expensive laboratory processing methods that involve toxic chemicals that are expensive and may require hazardous waste handling procedures. She also brought to light that in small stream sampling, timing is very important and that time series sampling at close intervals is critical during storm events. Filoso also raised the issue that turbidity meters don't work particularly well in small streams due to high turbidity conditions during storms with moving sands, stone and silt particles that also complicate instrument calibration procedures.

Figure 10: Monitoring small freshwater streams can be difficult, particularly during high storm flow volumes.

Photo provided courtesy of Chesapeake Bay Program

The issue of having flow weighted calibrations in major tidal tributary waters was not raised as a problematic issue by the interviewees. Monitoring in these large waterbodies presents other challenges, but generally there are fewer issues due to equipment calibration and malfunctioning. At the same time, there are a significant number of water quality thresholds that require monitoring based on salinity range, seasonality, water depth and living resource designated uses. These water quality thresholds are included in the Appendices portion of this document.

Biological Monitoring in Nontidal Streams

Ron Klauda, Director of Monitoring and Non-tidal Assessment Division with Maryland Department of Natural Resources[19] has overseen the highly successful Maryland Biological Stream Survey (MBSS) for many years. The MBSS group is engaged in statewide biological monitoring using both a benthic macroinvertebrate and fish index of biotic integrity—B-IBI and F-IBI, respectively, to holistically monitor the health of Maryland's streams. Biological monitoring captures the health of organisms living a life cycle and experiencing an entire range of changes in a local body of water. Monitoring of physical and chemical water quality parameters alone are insufficient to give the complete picture of how living resources are responding to water quality conditions.

The B-IBI approach is dependent upon keying out benthic organisms according to a taxonomic hierarchy of seven main ranks defined by the international nomenclature codes: kingdom, phylum/division, class, order, family, genus, and species. Klauda notes that MBSS is comfortable identifying benthic organisms to the genus level, although classifying to the species is most helpful in determining specific water quality issues such as excess nitrates and sediment. Klauda points out that oftentimes organizations only identify organisms to the order level, which, he believes is adequate for general water quality conditions categorized as "good", "fair" or "poor," for example, but will not reveal more subtle stream impacts that certain suites of organisms may be susceptible to or tolerant of. The problem with obtaining accuracy down to the species level is that it requires much greater expertise, training and experience. Maryland DNR has two full time positions available for species identification.

Klauda states that B-IBI's are easier to collect and process, but fish identification requires real time monitoring in the field with a range of 30-35 fish species commonly involved in Maryland. While B-IBI sampling can be done with two people, 6 or more may be needed for F-IBI sampling.

Eric Stein[20], with the Southern California Coastal Water Research Project is working intensely on the next generation of stream biological monitoring which involves DNA barcoding. DNA barcoding is a taxonomic method that uses a short genetic marker in an organism's DNA to identify it as belonging to a particular species. Stein collaborates with the Canadian Centre for DNA Barcoding (CCDB) at the University of Guelph in Ontario Canada to follow standard protocols in specimen collection and preparation work involved with species identification. CCDB plays a central role in training international researchers and scientists, like Stein, in the development of protocols for processing specimens and is the largest contributor of DNA sequences to the Barcode of Life Data Systems (BOLD) reference library—the central informatics hub of the DNA barcoding community.

Stein explained that a big need for mainstreaming this new monitoring technology depends on establishing a well vouchered taxonomic library of species for the geographic areas of monitoring interest. Once a reference library is established then bulk DNA sampling is possible. According to Stein, there are newer sequencing technologies that do not require species sorting and can use homogenized (ground up) samples or water column samples (pieces). Stein's lab uses a PCR (short for Polymerase Chain Reaction) machine to extract and "amplify" or copy DNA. PCR is an automated process used to focus in on a particular segment of DNA and copy it many times—in order to complete the DNA sequencing process which allows the species to be identified.

Wetland Water Quality Monitoring Needs

Addressing federal wetland water quality is a difficult issue for most states and, not surprisingly, so is wetland water quality monitoring. The Clean Water Act requires states to adopt water quality standards to protect the chemical, physical and biological integrity of U.S. waters which also includes wetlands, which are episodically subject to jurisdictional definition changes—particularly when Supreme Court rulings occur. According to EPA, natural wetlands are nearly always "waters of the U.S." and are given the same level of protection as other surface waters with regard to standards and minimum wastewater treatment requirements. According to EPA, four basic elements are required for a water quality standard[21]:

1. Designated uses of the waterbody (e.g., recreation, water supply, aquatic life, agriculture).
4. Water quality criteria to protect designated uses (e.g., numeric pollutant concentrations and narrative requirements.
2. An antidegradation policy to maintain and protect existing uses and high quality waters.
5. General policies addressing implementation issues (e.g., low flows, variances, mixing zones).

The Water Quality Standards Regulation (40 CFR 131.11(a)(1)) mandates States to adopt criteria sufficient to protect designated uses which may include general statements (narrative) and specific numerical values such as concentrations of contaminants and water quality characteristics. At the same time, EPA allows a considerable amount of flexibility in how states approach this requirement and at present very few states use monitoring data as a basis for attainment of water quality standards. Most States have criteria for various water types and designated use classes that may be applicable to wetlands. Narrative criteria are particularly important in wetlands since many wetland impacts cannot be fully addressed by numeric criteria. For example, while EPA's chemical specific human health criteria are directly applicable to wetlands, their numeric aquatic life criteria may be outside the natural background levels for specific wetlands or wetland types. Example parameters that fall into this category include dissolved oxygen, pH, turbidity, color, and hydrogen sulfide.[22]

But, according to John Kusler[23], a nationally renowned wetlands expert, adoption of wetland water quality standards has proved difficult for states and only 15 have done so. Kusler states that there are no standards for most toxics for wetlands and indices of biological indicators are challenging to establish, although a coalition of states in the Northeast is working to accomplish this goal. Kusler pointed out that many years ago the State of New York made a considerable effort to formulate IBI's for

wetlands but gave up in the end—concluding that the effort was entirely too complicated and there were too many wetlands with too many biological variables in play. Kusler stated that long term wetland restoration efforts need to look toward future conditions that may come about due to climate change and that nurse crop species should be identified, where appropriate, to fit these transitions and future conditions.

Figure 11: Due to the great diversity of wetland types, states have had difficulties in setting wetland specific water quality standards.

Photo provided courtesy of Chesapeake Bay Program

Mike Rolband[24], president of a large northern Virginia firm specializing in wetlands, indicates that wetland water quality monitoring has been an expensive and difficult proposition for his company. He believes there is no such thing as low cost water quality monitoring when it comes to wetlands. For example, Rolband recounted that for a wetland restoration project that cost his firm $50,000 to construct, it would require $250,000 (as estimated by U.S. Geological Survey) to establish valid water quality monitoring protocols, acceptable to state regulators, that included flow weighted contaminant concentrations for target water quality parameters. Rolband stated there are difficulties in measuring water flow rates and temperatures for submersible pressure transducers (sensors) when they dry out due to fluctuating water levels. He added that measuring contaminant concentrations is difficult when flow rates are often low—as they frequently are in conjunction with his firm's wetland restoration projects. Rolband would like to see easy to use sensor devices that enable him to measure water flow and contaminant concentrations that are flow weighted.

Nutrient Trading Related Monitoring

Nutrient trading in the Chesapeake Bay watershed is still evolving and a multi-jurisdictional, watershed-wide trading framework is yet to be developed. The rationale for state nutrient trading programs is, to a large degree, based on the assumption that private market forces can help reduce the cost of meeting load reductions and may accelerate the Bay restoration process. Nutrient trading and offsets required for future growth and BMP verification are all related, but distinctly different concepts. Although the protocols are still under development, it is likely that the same conservation practice will have different verification and crediting procedures in different jurisdictions for various situations. In some cases field based water quality monitoring might be required, but this would likely be an exception rather than the general rule. A brief attempt is made below to touch on some of these concepts and how they relate to TMDL programmatic and/or water quality monitoring.

All three principal Bay agreement signatory states have trading programs that existed *before* or were under development *during* the Bay TMDL public review process. A comparison of the states' approaches is enumerated in a recent white paper by Joe Maroon[25]. A few key differences, from the Maroon report are noted below.

- Pennsylvania: Is viewed by knowledgeable observers as both aggressive in allowing trades involving nonpoint sources and having the most lenient baseline that must be met before the nonpoint source is eligible to generate credits. Questions remain as to whether Pennsylvania has an adequate monitoring program to determine if nonpoint trading is actually achieving the water quality improvements the state is assuming. Pennsylvania has an online trading tool "Nutrient Net," designed by World Resources Institute that is used to facilitate and document trades.
- Virginia: Is recognized as having a strong program for water quality protection, but Virginia's Nutrient Credit Exchange Association is limited to wastewater treatment plant credit exchanges. The state uses a conservative trading ratio of 2-to-1 for nearly all point to nonpoint nutrient trades. Virginia is also considering an aggressive expansion of its program, which could alter the present conservative approach. Virginia uses a minimum "practice approach" which establishes as its nonpoint trading baseline the implementation of five priority BMPs applicable to the farm operation (Nutrient Management Plan, Cover Crops, Soil Conservation Plan, Livestock Stream Exclusion, and Riparian Buffers).
- Maryland: Presently, allows point to non-point source trades but restricts major wastewater treatment plants from purchasing credits until they meet Enhanced Nutrient Removal (ENR) standards below 4 mgl for nitrogen. Virginia and Pennsylvania, both allow point source dischargers to purchase credits to comply with annual permit limits without first reaching ENR or similar treatment levels. Maryland also has Nutrient Net as their online trading tool, although baseline standards are more stringent than Pennsylvania. [Author's note: as of 11/28/13 Maryland's Nutrient Net website lists no completed trades and 2 certified credit providers in the Potomac watershed with 9,470 and 2,600 credits available—contingent on sale.]

Closely related to, but separate from voluntary trading credits and their associated markets are requirements for "offsets" for new pollution created by growth and future development. Under the

provisions set forth in Appendix S of the Bay TMDL[26], offsets are required to account for and manage any new or increased loadings of nitrogen, phosphorus, or sediment that lack a specific allocation in the TMDL with appropriate offsets supported by credible and transparent offset programs subject to EPA and independent oversight.

To help clarify expectations for the Bay jurisdictions' offset and trading programs, EPA recently issued a draft technical memorandum for public comment in September, 2013.[27] The technical memorandum addresses the components of credit calculations that should be included in offset and trading programs for the three pollutants for which caps are set in the Bay TMDL—total nitrogen, total phosphorus, and total suspended solids. The table below summarizes the credit calculation components involved in trading and offsets.

Table 2: Credit Calculation Components Involved in Trading and Offsets [28]

Credit Calculation Component	EPA Expectation
Applicable pollutants	Applicable pollutants are those addressed by the Bay TMDL —total nitrogen, total phosphorus, and total suspended solids.
Eligible parties	There are no restrictions on who can buy and sell credits. If a credit is to be used for NPDES compliance purposes or for offsets in NPDES permits, however, EPA expects that a jurisdiction will have a system in place to establish accountability for permittees trying to meet permit or offset obligations.
Eligible practices for credit generation	Credits generated using only those practices that are approved by the Chesapeake Bay Program (CBP) partnership for its annual progress review are acceptable to EPA.
Baseline requirements	Both practice-based and performance-based methods for defining baselines and calculating credits that approximate and are consistent with the Bay TMDL are acceptable to EPA as long as reductions meet allowable loads under either the Bay TMDL or a local TMDL, whichever has the most stringent restrictions.
Additionality	EPA expects a Bay jurisdiction to ensure that there is additionality – i.e., that a potential credit generating practice will result in pollutant load reductions beyond what would have occurred in the absence of a potential offset or trade.
Leakage	Leakage is defined by the CBP Partnership's Scientific and Technical Advisory Committee as occurring when a trade results in unexpected and unaccounted for net increases in loads. EPA expects a jurisdiction to address potential leakage in its offset and trading accounting practices.
Uncertainty	The Bay jurisdictions should address factors leading to uncertainty to ensure that total loads will not increase when a load reduction practice fails to generate the expected reductions.
Location adjustment	EPA expects the Bay jurisdictions to use the constant delivery factors from the CBP Partnership's Watershed Model to adjust the load between the buyer and the seller based on the relative position of each in the major river basin.
Certifying and verifying credits	The Bay jurisdictions should have a program in place to certify credits used in offset and trading programs, as well as a comprehensive system in place for credit verification whereby BMPs are routinely evaluated to ensure that they are installed, performing and maintained as designed.
Credit timeframe for buyers	EPA expects the Bay jurisdictions to provide adequate assurance of the availability of credits for the duration of the transaction.

Credit Calculation Component	EPA Expectation
Credit trading registry	Once credits are calculated, EPA expects each Bay jurisdiction to provide a publicly accessible registry that records and tracks credits available and the credits sold. All credits sold should have a unique ID that is traceable to the buyer and seller.
Reporting credits to the Chesapeake Bay Program	As part of the annual assessment toward the two-year milestone and Watershed Implementation Plan (WIP) commitments, Bay jurisdictions should report all BMPs and indicate which were certified to generate credits and those that were not sold.
Public accountability	EPA expects information on offsets or trades to be clearly articulated and available to the public at the time the credit is sold, including the methods for generating, calculating and purchasing credits

The EPA technical memorandum provides important language that suggests there may be a potential role for on-site water quality monitoring, although they state that a separate technical memorandum on verification would spell out requirements in more detail. Significantly, EPA specifies that jurisdictions may certify credits for a longer duration when a practice is permanently protected by an easement or other legal instrument that conveys with the land:

> *EPA expects that for most practices, a credit, once certified, will be valid for one year or no longer than the NPDES compliance period, whichever is shorter. However, jurisdictions may certify credits for a longer period if the practice results in a change to the landscape that reduces a pollutant load and is permanently protected by an easement or other legal instrument that conveys with the land. A jurisdiction must have a verification system in place to ensure that the practice continues to function throughout the entire period.*
>
> *EPA also expects the Bay jurisdictions to have a comprehensive system in place for credit verification whereby BMPs are routinely evaluated to ensure that they are installed, performing and maintained as designed. Verification is performed to ensure that the credit was and continues to be generated, via monitoring, inspection, reporting, or some other mechanism. The system should articulate the frequency of on-site or other monitoring and an entity able to conduct monitoring or inspections (i.e., EPA or Bay jurisdiction, or other accredited third party). Credit certification and verification are expected to be more fully addressed in a separate technical memorandum on verification.*[29]

Bay TMDL BMP Verification Protocols

Now, turning to the broader framework for verification of approved Bay TMDL BMPs, there appears to be potential for on-site water quality monitoring for certain situations and practices. As a general standard, the Chesapeake Bay Program Partnership has formally defined verification "as the process through which agency partners ensure practices, treatments, and technologies resulting in reductions of nitrogen, phosphorus and/or sediment pollutant loads are implemented and operating correctly." [30]

After a year of development work, BMP verification protocol recommendations have been completed in draft form through the efforts of six Chesapeake Bay Program source sector technical committees

covering: agriculture, forestry, urban stormwater, wastewater, stream restoration, and wetlands. The agricultural, urban stormwater and wastewater protocols are the most comprehensive of the group—with the latter two being closely tied with EPA and state regulatory processes and agriculture having strong connections with state agricultural and Federal Farm Bill programs.

Agricultural BMP Protocols:

For all agricultural BMP protocol activities, verification procedures must: 1) be established that demonstrate an 80% or greater confidence level that the subject BMP has been implemented, is currently operational, and is being maintained to meet the BMP definition for standards and requirements; and 2) be in compliance with the Chesapeake Bay Program Partnership BMP Verification Principles, including any supporting addendums. There are eight identified categories of verification based on the type of tracking assessment and the type of entity that would be collecting and verifying the data: permit issuing programs, regulatory programs, financial incentive programs, farm inventory, office records, farm records, transect survey, and CEAP (Conservation Effects Assessment Project) survey.

Figure 12: Agricultural BMPs like cover crops and no-till farming, shown here, are effective at reducing nutrient and sediment transport to local waterways.

Photo provided courtesy of Chesapeake Bay Program

Agricultural BMPs are broken into four categories:

- Annual BMPs: cover crops; commodity cover crops; dairy precision feeding; swine phytase; poultry litter transport; poultry litter injection; poultry litter treatment; poultry phytase; conservation tillage; and Interim BMPs--dairy manure injection; annual no-till.
- Structural BMPs: animal waste management system; barnyard runoff control; decision agriculture; biofilters; lagoon covers; loafing lot management; mortality composters; non-urban stream restoration; shoreline erosion control; off-steam watering without fencing; stream access control with fencing; pasture alternate watering systems; soil conservation and water quality plan elements; water control structures; wetland restoration; and Interim BMPs—dirt and gravel road erosion and sediment control; non-urban steam restoration; P sorbing materials in agricultural ditches.
- Management BMPs—Plans: enhanced nutrient management; horse pasture management; nutrient management; precision intensive rotational grazing; prescribed grazing; soil conservation and water quality plans; and interim BMPs--nutrient management as BMP only.
- Management BMPs--Practices: alternate crops; continuous no-till; forest buffers; grass buffers; land retirement; steam-side forest buffers; stream-side grass buffers; stream-side forest buffers; stream-side wetland restoration; tree planting; and interim BMPs--cropland irrigation management; irrigation water capture reuse; tree planting: vegetative environmental buffers- poultry.

There are many other supporting documents that describe how verification might work in the draft document. It is important to recognize that the draft verification procedures don't specifically mention direct water quality monitoring of the BMPs (regulated practices, as mentioned previously are the exception). The essence of the verification process relies on the development of programs and surveys which meet the 80% confidence level. Thus, state jurisdictions' verification programs could change their sampling or spot check methods in ways that increase their confidence level, depending on the approach or the practice. The protocol provides other options if a verification approach cannot meet the level of confidence for a specific practice. These statements leave the door open for possible water quality monitoring in certain instances.

It should also be noted that there is a protocol for the development, review and approval of loading and effectiveness estimates for nutrient and sediment controls used in the Chesapeake Bay Watershed Model.[31] Every BMP used in the Chesapeake Bay Watershed Model (CBWM) is reviewed and approved by the Water Quality Goal Implementation Team (WQGIT). This group works with source sector review panels and other experts to ensure the definitions and values used for both loading and effectiveness estimates are developed in a process that is consistent, transparent, and scientifically defensible. Literature reviews, and data regarding direct water quality monitoring assessments of practices along with several other considerations are incorporated into the approval process to establish nutrient and/or sediment reduction efficiency ranges for on-the-ground BMPs. This process covers any new BMP innovations that are accepted for review by the WQGIT. The efficiency ranges for a particular practice may vary in the CBWM based on its physiographic location and other factors. Water quality monitoring for a given practice, in theory, should fall within these efficiency ranges for a given parameter if the practice is working properly under design conditions.

Forestry BMP Protocols

Forestry is the largest land cover type in the watershed and yields the least pollution. Forest planting, in the form of riparian forest buffer plantings on agricultural land is one of the BMP's most relied upon to achieve water quality goals in Phase II of State Watershed Implementation Plans. Tree planting practices apply to agriculture and urban landscapes. Forest harvesting BMPs are the only BMPs applied to forest land at this time.

Figure 13: Forests are the largest land cover type in the Bay watershed and yield the least pollution.

Photo provided courtesy of Chesapeake Bay Program

Figure 14: A riparian forest buffer planted at Cool Spring Farm near Charles Town, West Virginia.

Photo provided courtesy of Chesapeake Bay Program

The table below summarizes key forestry BMP verification protocol information.

Table 3: Key Forestry BMP Verification Protocol Information[32]

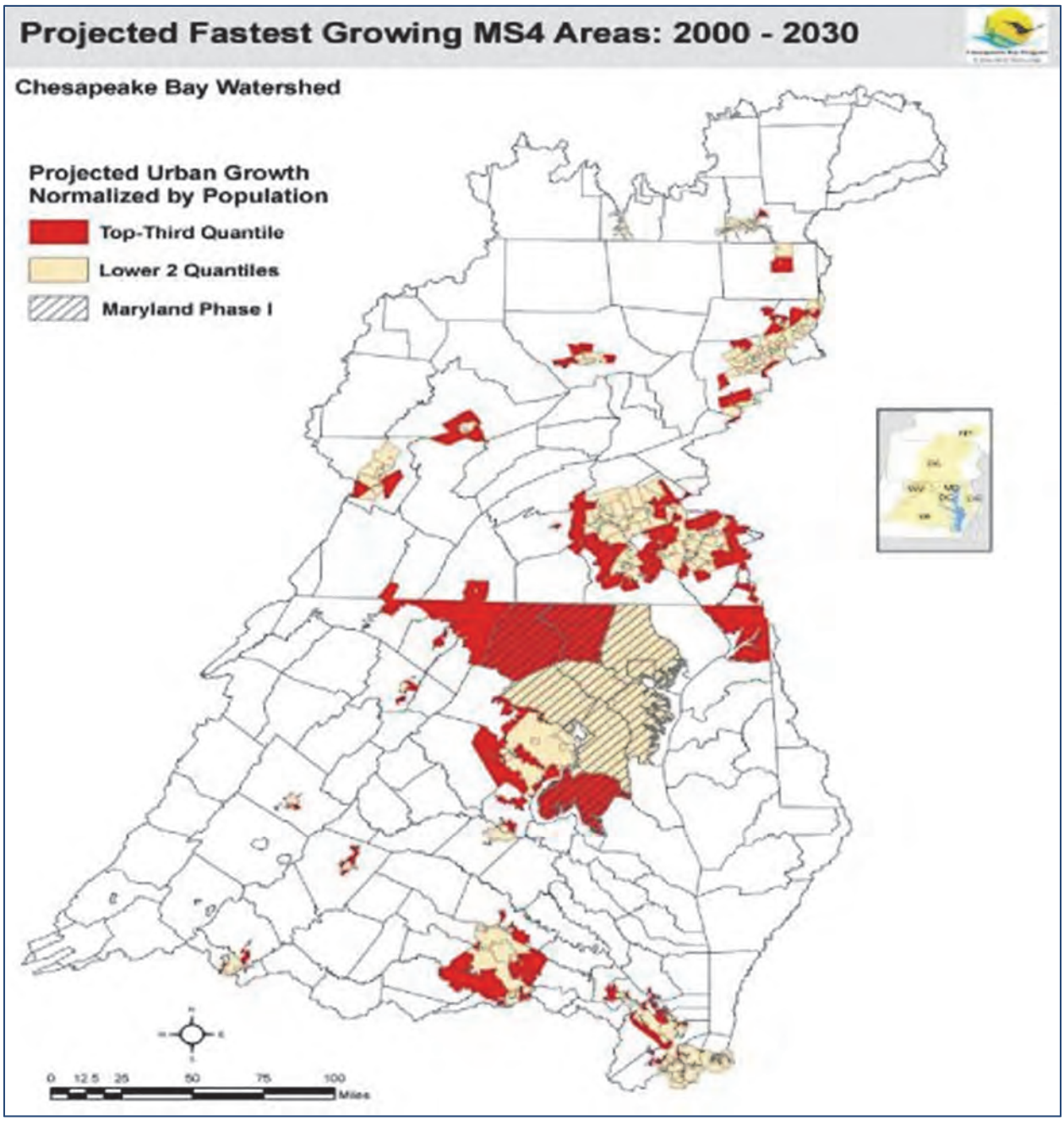
Verification Protocol	Assessment Method	Conservation Practice Category	Cost Sharing Status	Verification Methodology	Verification Issues
Expanded Urban Tree Canopy	Local and State reporting	Urban Management Practice	Not cost-shared	Professional program and satellite monitoring	Aerial sampling and accurate use of tools
Urban Riparian Forest Buffer	Local and State reporting	Urban Management Practice	Not cost-shared	Professional program and satellite monitoring	Aerial sampling and accurate use of tools
Ag Riparian Forest Buffer	Verified compliance with federal and/or state program contractual requirements.	Agricultural Management Practice	Primarily cost-shared	Through on-site contractual compliance inspections by trained agency personnel.	In frequent compliance inspections during contractual life span.
Ag Tree Planting	Verified compliance with federal or state program contractual requirements.	Agricultural Management Practice	Primarily cost-shared	Through on-site contractual compliance inspections by trained agency personnel.	Infrequent compliance inspections during contractual life span.
Forest Harvesting BMPs	Verified compliance with state and local regulations in most places.	Suite of Forest Harvesting Management Practices	Not cost-shared	Through on-site contractual compliance inspections by trained agency personnel.	Harvesting on private land is not regulated in PA, NY

Urban Stormwater Verification Protocol

Stormwater verification protocols are nearly complete for "urban BMPs", which are stormwater practices for which definitions and removal rates have been developed and approved through the Chesapeake Bay BMP review protocol. There are four broad urban BMP categories:

1. Traditional stormwater BMPs that were historically installed through a local stormwater plan review process in response to state stormwater requirements (e.g., wet ponds, dry ED ponds, bioretention, infiltration, filtering practices, bioswales, grass channels, permeable pavement).
2. New runoff reduction BMPs that will be implemented in the future to meet new state stormwater performance standards that typically go through a local stormwater review process (e.g., impervious surface disconnection, green roofs).
3. Non-structural or operational BMPs that are typically applied by a municipal agency (e.g., street sweeping, urban nutrient management, illicit discharge elimination).
4. Restoration BMPs installed by localities to treat existing impervious cover (e.g., stormwater retrofits and stream restoration).

Figure 15: Projected fastest growing MS4 areas 2000-2030 [33]



There are other categories of stormwater BMPs that will eventually be incorporated into a broader verification protocol for stormwater, but are not feasible to include at present:

- Regulated BMPs: Are those installed in jurisdictions that have a phase 1 or 2 Municipal Separate Storm Sewer System (MS4) permit. This includes most large urban areas in the watershed. See figure above.
- Semi-Regulated BMPs: Are those installed outside of a MS4 community.

- Non-regulated BMPs: Are those voluntarily installed in a community such as rain gardens built by homeowners or grant funded demonstration BMPs.
- Legacy BMPs: Are those reported to EPA for inclusion into any past version of the CBWM for sediment or nutrient reduction credit.
- Discovered BMPs: Are those that were not reported to the state or EPA and have not received nutrient credit removal.

Figure 16: Stormwater from urban areas contains pollutants like heavy metals from roadways and industrial areas; nutrients from fertilizers, organic debris, and fuels; and various organics from oil and grease.

Photo provided courtesy of Chesapeake Bay Program

The MS4 BMPs appear to be the most feasible to capture in the verification protocol due to required permitting and reporting oversight by state and federal agencies. Based on comments made in the draft protocol report it appears as though BMP inspection guidelines will use visual indicators to verify the hydrologic performance of a practice is still adequate to achieve the intended nutrient and sediment removal rate. The visual approach was refined and tested through an extensive analysis of BMPs located in the James River Basin.

Importantly, In the case of *urban stormwater BMPs used for offsets, mitigation and trading nutrient credits, the protocol report notes that special procedures should be developed to avoid double counting and that states and localities may elect to require more frequent inspections to assure BMPs are meeting nutrient reduction objectives.* Due to the very large number of urban stormwater projects that must be inspected it appears that low cost water quality monitoring could play a role in flagging dysfunctional installations.

Wastewater, Wetlands and Stream Restoration Protocols

A review of the wastewater, wetlands and stream restoration protocols relative to low cost water quality monitoring reveals the following key points:

1. Wastewater facilities are closely regulated and permit discharge reporting effluent sampling requirements will make it fairly easy to evaluate their performance. The burden of reporting and monitoring will fall upon staff engineers and operators and there does not appear to be a role for low cost water quality monitoring.
2. Stream restoration projects will be verified based on the level of detail needed according to the stream restoration type, project objectives, size, complexity, and landscape position of the proposed project. USFWS is developing a protocol for this for Maryland Dept. of Environment. The maximum duration for which the stream restoration pollutant removal rate applies is five years, which can be renewed based on the results of the field inspection. If a project is found to be deficient, the locality will have one year to resolve the issue or the pollutant reduction rate would be eliminated. Special procedures for stream restoration projects used for offsets, mitigation and trading are recommended to avoid double counting.
3. Wetland restoration projects will be verified if they are built as designed; they are operating properly; there is a predominance of native wetland vegetation; and the hydrology is as planned. Restoration projects must also be on hydric soils. Projects have a 15-year life span unless they are enrolled in the Wetlands Reserve Program which requires maintenance in perpetuity. Inspections will be, when possible, carried out in conjunction with existing oversight programs including MS4 permitting (for urban projects) and USDA-NRCS requirements.

Crowdsourcing of Water Quality Data

Crowdsourcing of water quality data is taking on many different forms here in the Chesapeake watershed, nationally and beyond our borders. An examination of some exemplary efforts can inform the Conservancy of potential partnership models that may be prototypes for future consideration.

On the high end of crowdsourcing models in the U.S. are the six National Science Foundation funded Critical Zone Observatories—run principally by consortiums of academic and non-profit research institutions. Together they study the critical zone of the planet which includes the tree canopy layer on down to free flowing groundwater in an attempt to show how this zone operates and will respond to projected changes in climate and land use. Each observatory focuses their efforts on critical zone science issues that fit the expertise of the investigators in the specific CZO physical setting. Each CZO is heavily monitored through high tech, high cost sensors that examine a broad range of air, water, soil and geological conditions.

However, the Christina River Basin (CRB-CZO) located in southeast Pennsylvania and north Delaware is an exception. A core element of the CRB-CZO is installing a cost effective, extensive network of sensors. Researchers there have used dozens of pressure/depth transducers in streams and groundwater, as well as soil moisture sensors to measure water fluxes and storage. To understand biological and geochemical processes they have installed temperature, conductivity, redox, oxygen and carbon dioxide probes in streams and soils. The team is using sensor data communication techniques founded on the open source

electronics Arduino platform with ZigBee-based radio frequency networking. Anthony Aufdenkampe, a co-lead principal investigator and researcher with the Stroud Water Research Center in Pennsylvania says that the low cost communications network is robust and easy to use which lets them concentrate more on widespread deployment of high quality sensors rather than on data communication infrastructure. The team also uses automated stream water samplers that can be activated via a mobile phone.[34]

Figure 17: An informal display of low cost monitoring equipment at the Stroud Water Research Center in Pennsylvania.

Aufdenkampe[35] also states that a much broader citizen scientist platform called Monitor My Watershed is planned to engage citizens in monitoring the Christina River basin through a set of web-based training materials on biological, chemical and physical water quality. See more at: http://wikiwatershed.org/#sthash.MmC0x0uJ.dpuf. Aufdenkampe believes that a crowdsourcing initiative should be aimed at developing open source designs for low cost water quality sensors that can be used in conjunction with the Arduino platform. He and his co-workers at Stroud Water Research Center have been able to locate and test some inexpensive mass manufactured sensors like the turbidity sensors in dishwashing machines that can be obtained through alternative distribution channels. By a combination of mass purchasing of sensors and developing new ones through open source approaches, Aufdenkampe believes low cost water quality monitoring devices can be widely available in the not too distant future.

In the tidal waters of Chesapeake Bay, Doug Wilson[36], owner of Caribbean Winds LLC and a former oceanographer with the NOAA Chesapeake Bay office, believes there are opportunities to set up continuous monitoring platforms with telemetry and a basic array of sensors by placing floating buoys in major tidal tributary systems for relatively low cost. Wilson has already designed such a prototype and believes that low cost systems can also be achieved by crowdfunding the sponsorship of the network itself—not just achieving lower cost sensor technology. Wilson says that, based on his experience in Florida with the Sanibel-Captiva Conservation Foundation's River, Estuary and Coastal Observing

Network (RECON), the cost of telemetry equipped high end, multi-functional systems can be underwritten by recruiting sponsors for specific buoy locations.

Wilson was the coordinator for the Chesapeake Bay Interpretive Buoy System (CBIBS) and indicates there is a network of buoy operators in the Bay (Chesapeake Bay Observing System, a.k.a. CBOS) who presently maintain their own buoys but pool their information to a common data sharing platform. According to Wilson, the Chesapeake Bay Program monitoring data used in the Bay Estuary model does not make use of real time continuous monitoring data, but ultimately it could and should attempt this to more accurately track the health of the Bay. Also, Wilson made it clear that the quality assurance aspects for such crowdsourced data must be rigorous and this includes such things as making sure the buoys are functioning properly, replacing sensors, maintaining a web accessible, reliable data storage and visualization platform, etc. All of this requires management oversight if such data is intended to contribute to assuring accurate, scientifically valid information.

Figure 18: A Chesapeake Bay Interpretive buoy in Annapolis, Maryland.

Photo provided courtesy of Chesapeake Bay Program

On the lower end of the water quality crowdsourcing spectrum is the reporting of observed physical characteristics of streams and adjacent land use practices. A prime example of this in the Chesapeake Bay watershed is the Water Reporter free app available for the iPhone and iPad through Apple's App store. The Water Reporter app was initially released through the Potomac and Shenandoah Rivers Riverkeeper organizations. However the crowdsourcing network extends to all 18 local Waterkeepers in the Chesapeake Bay region and all data is reported to and stored to a common data platform managed by Chesapeake Commons--the designer of the app. App users can make either an "activity" report or a "pollution" report. An activity report is an event that the user describes verbally and can add a picture and/or video. At the same time a GPS coordinate is identified with the record and it passes on to the appropriate Riverkeeper for screening and recording after the file is reviewed. A "pollution" report is filed by selecting from an extensive menu list of items such as excessive algae, sewer, fish kill, discolored water, oil or grease, foam, trash illegal dumping, construction exposed soil, agricultural storm water, livestock in stream, eroded stream bank, etc. A pollution report can also include a photo or video.

A similar crowdsourcing, low end physical observation-based app with fewer options was developed for national use by IBM called "Creek Watch." See more at: http://creekwatch.researchlabs.ibm.com/.

This app is also available on the Apple App store and allows citizens to report:

- The amount of water: empty, some, or full.
- The rate of flow: still, moving slowly, or moving fast.
- The amount of trash: none, some (a few pieces), or a lot (10 or more pieces).
- A picture of the waterway.

Another app, designed primarily for developing countries but potentially applicable here, focuses on crowdsourcing of locally obtained low cost water quality data. An ex NASA employee and his partner designed "mWater" app for the Android platform which takes advantage of inexpensive water testing kits. The kits cost less than $5 and allow testing for sewage or presence of E. coli and don't require lab analysis. This test uses strips that change colors to indicate contamination, but more sophisticated low cost, high accuracy tests are in the development stage. One test for E. coli automates the counting of actual bacteria colonies on a test plate using a smart phone photo application. Tests for arsenic, nitrates and chlorine are being developed for the app designers by Columbia University. See more at http://www.fastcoexist.com/1681943/building-a-social-network-for-clean-water-with-apps-and-cheap-tests

Figure 19: GBF buoy at Beaver Island, Buffalo, NY[37]

A very different approach to crowdsourcing that combines human observations with sensor data was developed and tested through a project conducted by the University of Buffalo called "Another Day at the Beach."[38] Project researchers developed a prototype system that used data from a suite of distributed environmental sensors, and human experiential data collected in short interviews to create a novel metric of water

resource quality and appreciation. The data was collected by a YSI-6600V2 sonde using a battery operated buoy remotely controlled from the beach. The buoy (see Figure 19) also collected weather, sonar and GPS data and could operate for a full day. The data collected appears in the table below.

Table 4: Glass bottom float buoy data[39]

Parameter	Units	Meaning/ interpretation
Turbidity	Ntu	How clear is the water?
Chlorophyll	ug/l	How much algae are present?
pH	H+	How acidic or basic is the water?
dissolved oxygen	mg/l	How much oxygen is there in the water?
water temperature	C	How warm is the water?
Salinity	Ppt	How high is the ionic content of the water? / how salty is the water?
total dissolved solids	mg/l	How high is the combined content of inorganic and organic substances in the water?
air temperature	C	How warm or cold is the air?
wind speed	m/s	How strong are the winds?
wind direction	deg	From which direction is the wind coming?
relative humidity	%	How humid is it?
barometric pressure	mmhg	How high or low is the atmospheric air pressure?
e.coli	colonies/mL	How much e.coli contamination is in the water?
total coliform	colonies/mL	What is the sum of all forms of coliforms in the water?
water depth	m	How deep is the water where the buoy is located?
gps location	lat/long	Where is the buoy?

The researchers created indices they called swimming pleasure measures (spm) to statistically analyze how the human metrics compared with sensor data. They found that no combination of sensors from water chemistry, water biology and weather correlated significantly with the spm metric. They also found that different user groups consistently reported different results. For example, men and non-local visitors were more likely to give higher spm scores and teenagers were the most discerning beach visitors who routinely offered lower spm scores. On at least one occasion, the system was able to detect a significant E. coli related water quality problem before beach operators knew of it. The researchers were convinced that the concept of combining soft human-side data with hard sensor side data has real potential for further applications. Clearly this form of crowdsourcing requires further research and refinement, but it does suggest that human observations could potentially be calibrated sufficiently by trained personnel to achieve a useable “warning level” system with and perhaps without sensors.

Finally, in Pennsylvania, Joshua Schapiro[40] of Carnegie Mellon Create Lab reports that crowdsourcing of spikes in conductivity meters placed in homeowners toilet water reservoirs is effectively signaling potential problems associated with contamination of well water from fracking activities.

MONITORING TECHNOLOGIES

According to EPA, less than 30 percent of the nation's surface water bodies are assessed by EPA, states and tribes partly because of the high cost of traditional water quality monitoring. EPA further asserts that smart sensor technology and remote sensing through satellites will generate much more data at lower costs which, in turn, can be made readily available with telemetry and information technology.[41]

This portion of the report highlights an assortment of monitoring technologies of potential relevance to the Conservancy and other small organizations. The technology focus of interest for the Conservancy is in the realm of innovative real-time water quality monitoring versus laboratory analysis of grab samples. Real-time water quality monitoring is achieved by the use of various sensors that can detect:

- Physical characteristics (e.g., conductivity, pH, temperature, total suspended or dissolved solids, turbidity)
- Chemical parameters (e.g., alkalinity, oxygen, nitrogen and phosphorus compounds) and the presence, abundance and concentration
- Biological conditions of certain biological taxa of interest (e.g., fish, insects, algae, plants, bacteria)

Unfortunately, as we have learned through interviews and internet research, low cost sensors are available only for a limited number of parameters. Laboratory analysis of grab samples is still the dominant means of water quality monitoring in the Chesapeake watershed. It is likely to remain that way—when it comes to the detection of toxic contaminants and the assessment of their effects on human health and wildlife. In daily use in the U.S. there are up to 70,000 known and emerging chemicals that might be present in various water resources.[42]

Figure 20: Toxic contaminants are increasingly found in waterways across the U.S.

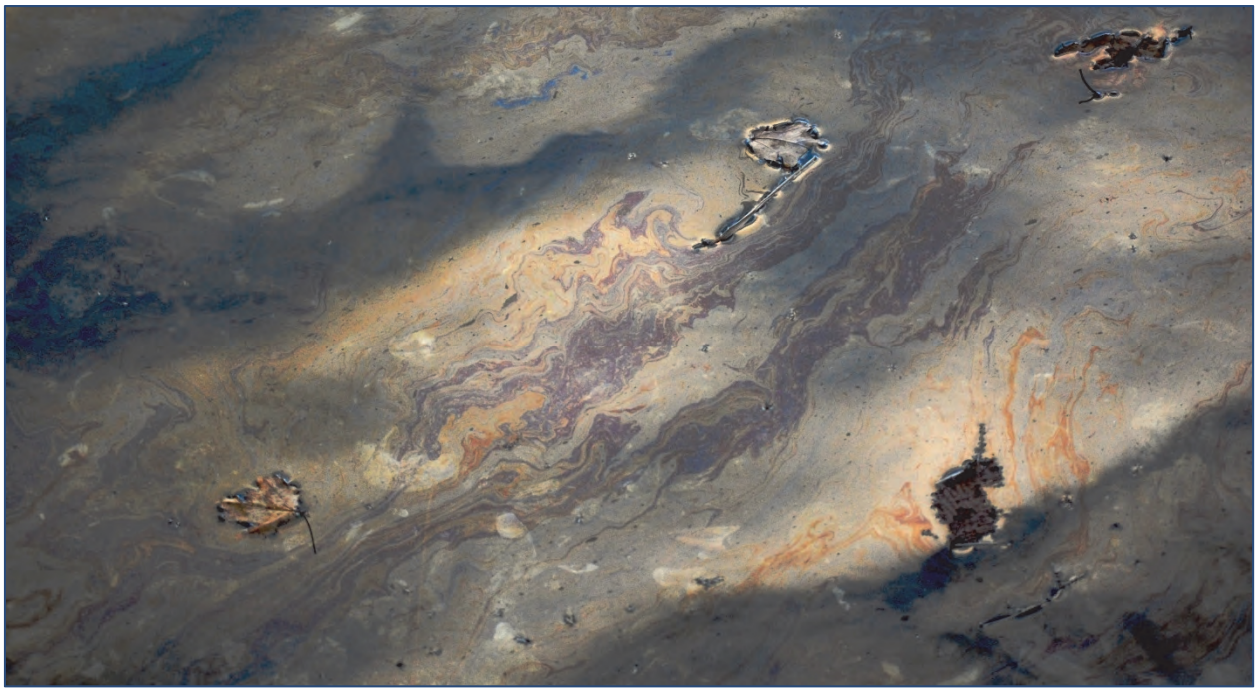


Photo provided courtesy of Chesapeake Bay Program

A contaminant category of increasing concern is called emerging contaminants (Ecs). Ecs are chemicals or materials that pose a perceived, potential or real threat to human health or the environment or because there is a lack of published health standards.[43] These contaminants are now being discovered in ground and surface waters from agricultural and urban sources that were previously not detectable. Ecs may also be classified as "emerging" because a new source or a new pathway to humans has been discovered or a *new detection method or treatment technology has been developed*. Ecs include pesticides and degradates (chemical products resulting from the degradation or breakdown of pesticide), industrial compounds, personal care products, water and wastewater treatment by-products, pharmaceuticals, and anti-inflammatory, caffeine and other "life style" contaminants. Many Ecs are of great concern to the health of wildlife and potentially human health. For example, EPA reports that two such Ecs, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are found in a wide variety of products, are extremely persistent in the environment, and they bioaccumulate and biomagnify in wildlife and have potential developmental, reproductive and systematic effects.[44] Ecs also require sophisticated and expensive lab detection methods with the capacity to detect concentrations in parts per billion.

Traditional and Promising Analytical Technologies

Traditional methods for water quality analysis are numerous and incorporate sensors and laboratory procedures that have been well documented by many organizations. The methods used to determine contaminant thresholds vary by the parameter of concern and the preferred analysis technique—which can be limited by the laboratory equipment available at a given location, staff expertise or other factors. A table of water quality analytical methods used for various parameters has been prepared below. The table is based on edited excerpts from a United Nations manual listing many other parameters.[45]

Table 5: Traditional Water Quality Analytical Methods

Parameter	Units	Analytical method
Ammonia	mg/L N	Ion Selective Electrode
Ammonia	mg/L N	Alpha – Naphthol Method (Colourimetry)
Cadmium — Dissolved	mg/L Cd	AAS –Solvent Extraction
Calcium — Dissolved	mg/L CaCO3	Ion Chromatography
Chlorophyll A	mg/L	Colourimetry
Clarity	M	Horizontal Black Disc
Dissolved Oxygen	mg/L O2	Winkler Method
Dissolved Oxygen	mg/L O2	Dissolved Oxygen Meter
Electrical Conductivity	µs/cm	Conductivity Meter
Fecal Coliform Bacteria	No./100 ml MF	Multiple Test Tube
Fecal Coliform Bacteria	No./100 ml MPN	Membrane Filtration
Mercury — Total	µg/L Hg	AAS — Flameless
Nitrite	mg/L N	Colourimetry (Sulfanilamide)
Nitrogen Organic — Particulate	mg/L N	CHN Analyzer

Parameter	Units	Analytical method
Nitrogen — Total	mg/L N	Alkaline Persulphate Digestion
PCBS	µg/L	Gas – Liquid Chromatography
pH	pH Units	Colorimetric Method
Phosphorus – Total Dissolved	mg/L P	Colourimetry
Poly Aromatic Hydrocarbons	µg/L	Fluorescence Spectrophotometry FLUORESCENCE SPECTROPHOTOMETRY
SALINITY	Ppt	TDS-Salinity-Conductivity Meter at 25° C
Turbidity Light Penetration	Metre	Secchi Depth
Turbidity	NTU	Nephelometric - HACH

Modern, real-time water quality monitoring using sensors is a very complex and rapidly emerging field. The table below, characterizing selected categories of the most promising real-time monitoring technologies and sensors, has been interpreted or restated by the author from information appearing in [42] and [46] and a few miscellaneous Internet sources.

Table 6: Selected Real-time Sensor Technologies for Water Quality Monitoring

Category	Description	Use Information	Comments
Fiber optic	Fiber optic sensors are glass or polymeric fibers doped with dye or rare earth metal or activated with transition metal	Used in combination with UV-VIS (ultraviolet-visible light spectrum) spectroscopy to detect a larger range of compounds	Coating of fiber governs sensitivity & selectivity of the sensor—research underway to develop new materials to suit the sensing task
Electrochemical sensors: potentiometric, amperiometric and conductometric	These sensors are electrochemical cells that employ a 2 or 3 electrode arrangement. The electrochemical measurement can be made in a steady-state or transient mode which is chosen to enhance sensitivity or selectivity	Potentiometric sensor— may be used to determine the analytical *concentration* of some components of the analyte gas or solution. Amperiometric sensor—measures the *current-potentia*l relationship of the electrochemical cell Conductometric sensor—measures the *conductivity change* of the electrochemical cell in the presence of a given solute concentration (the solute is often the sensing species of interest).	Amperometric & conductimetric sensors widely used Potentiometric sensing appears to be more portable & cost effective—may be limited in sensitivity range for some parameters. E.g., dissolved oxygen (DO).
Biosensors	Analytical devices which convert a biological response into an electrical signal using a bioreceptor and a transducer to produce a measureable signal	A bio receptor can be a tissue, microorganism, organelle, cell enzyme, antibody, nucleic acid & biomimic, etc. and the transduction may be optical electrochemical, thermometric, piezoelectric, magnetic and micromechanical or combinations of one or more of these techniques	Molecular sensing methods are used to conduct rapid, sensitive, quantitative detection of specific taxa, genes or gene expression—requires DNA sequence information to process

Category	Description	Use Information	Comments
Systems based on specifically-sensitive electrodes	microelectrodes in conjunction with electrochemical detection, MEMs and Lab-on-chip sensors have miniaturization & efficiency advantages	Microelectrodes for phosphate detection: uses a micro-sized cobalt-based phosphate ion sensitive 'working" electrode & an isolated cell as the reference electrode to detect the concentration of phosphate by an electrochemical method. MEMs: micro-electro mechanical systems. MEMs have arrays of individual microelectrodes that can increase robustness and possibilities for multi-analyte detection. Lab-on-chip sensors: are complex systems that combine amperometric & conductimetric sensors, microelectrodes and MEMs arrays	Electrochemical sensors are suitable platforms for the development of microsystems for remote pollution detection & monitoring. Lab-on-chip and MEMs are often used with microfluidic technology to minimize the volume of reagent & sample required. Lab-on-chip sensors hold promise for remote analysis applications. Analyses that require reagent processing may limit true real-time applications.
Sensors using sound & electromagnetic field interaction	low-power ultrasonic measurement, electromagnetic wave sensors and microwave spectroscopy	Ultrasonic measurement: uses ultrasound & infrared waves emitted from equipment isolated from the target. Used in food & water analysis—is sensitive to particles between 10nm-1,000mm r. Electromagnetic wave sensors: detection of nitrates & other pollutants has been highly successful using a combination of planar meander & interdigitated electromagnetic structure.[47] Microwave sensing: an object under test produces unique electromagnetic waves in the GHz range that can be correlated with the properties of the material.	Ultrasonic measurement is non-destructive & non-invasive. Electromagnetic wave sensors have considerable potential for commercialization. Microwave sensing can measure materials non-destructively, without contact from a short distance, using penetrating waves, without health hazards to people.

Brief Overview of Commercial Water Quality Instruments and Sensor Products

There are a wide array water quality instruments and sensor products available for purchase and in active use by watershed organizations, consulting firms, academic and government researchers and others interested in user friendly sensors. In general, water quality monitoring devices can be designed to accommodate a variety of situations from short term or spot sampling of water quality to long-term, unattended monitoring and analysis. Small portable water quality instruments that connect to laptops or hand-held monitoring computers are a popular choice for in-field data collection—and are relatively affordable, but limited in sensor options. Commercially available, multi-parameter unattended monitoring stations designed as floating platforms (buoys) or long term fixed stations with flow controls and mini wet labs are at the high end of the cost spectrum. This section of the report presents a few examples of multi-parameter and single sensor equipment; and monitoring telemetry options and related equipment.

Figure 21: Dissolved oxygen monitoring.

Photo provided courtesy of Chesapeake Bay Program

Multi-Parameter Water Quality Instruments and Sensors

Some local organizations we talked to prefer portable multi-parameter water quality instruments that combine convenience and affordability. This equipment is often referred to as a "sonde." A sonde (French for probe) is a water quality monitoring instrument that may be stationary or may move up and down a water column, measuring parameters such as temperature, conductivity, salinity, dissolved oxygen, pH, turbidity, and depth. This option conveniently combines multiple sensors into a single unit.

Figure 22: YSI MDS multiparameter display and data logger system (right) and Furuno navigational data organizer (left).

Photo provided courtesy of Chesapeake Bay Program

In Maryland, the West/Rhode Riverkeeper organization in Maryland uses a 2009 YSI 600QS sonde. This instrument monitors dissolved oxygen, temperature, conductivity, salinity, specific conductance, resistivity, depth, pH, oxidation reduction potential (ORP), and total dissolved solids (TDS). A similar model built by YSI powers itself and the sonde continuously for approximately 30 hours and has a rechargeable battery pack and a memory option with 150 data sets, time and date stamped and downloadable to a PC.

Figure 23: Volunteers monitoring water quality on the West River in Maryland.

Photo provided courtesy of Chesapeake Bay Program

A $3,610 2013 Horiba model U52 multi-parameter instrument measures the same parameters as the YSI, but reflects improvements in technology like automatic calibration for pH, conductivity, dissolved oxygen, turbidity and depth. It also features individually replaceable electrodes for pH and ORP (a cost saving measure) and an ultra-sensitive turbidity meter with a wiper for convenience/accuracy.

A good deal of cost savings can be achieved through the purchase of multi-sensor kits that can be assembled by those with sufficient knowledge of electronics. As mentioned previously, the open source electronics Arduino platform facilitates the assembly of individual sensors, but communications, data logging, in-field ruggedization of equipment and several other considerations come into play when taking this approach. A five sensor kit called the ENV-SDS (Star Dot Star), is manufactured by Atlas Scientific, and includes all the equipment needed to build a monitoring unit. The kit has pH, oxidation reduction potential (ORP), dissolved oxygen (DO), conductivity and environmental temperature sensors and costs $595.

Single Parameter Instruments and Sensors

Single parameter measuring instruments (e.g., meters) or sensors can be used, at a lower cost than multi-parameter instruments, by themselves or in combination with other single sensors to zero in on a particular problem(s) of research interest. Table 7 (next page) provides selective examples of the importance of monitoring particular parameters.

Figure 24: A volunteer uses a single parameter sensor to measure water salinity.

Photo provided courtesy of Chesapeake Bay Program

Table 7: Water Quality Parameter Importance[48]

Parameter	Importance
Temperature	Affects the ability of living organisms to resist certain pollutants. Some organisms cannot survive beyond certain temperature ranges. The demand of dissolved oxygen increases when temperature is high.
Dissolved Oxygen (DO)	Dissolved oxygen is breathed by fish and zooplankton and is needed for survival. Fish in low DO environments are susceptible to disease or mortality below 4 ppm.
Salinity	Certain fish species require specific salinity ranges to survive. Others can tolerate a range of salinities at some phase of their life cycle. Abrupt changes in salinity can be lethal.
pH	Water bodies with 6.5 to 9.0 pH concentrations are appropriate for most fish—reproduction outside of this range decreases. Acid death appears with values below 4.0 and alkaline death in values above 11.
Nitrogen/Ammonia	Inorganic nitrogen in water is chiefly present as unionized ammonia-NH_3 or ionized ammonia-NH_4, and nitrate-NO_3 and nitrite-NO_2. For fish, safe levels for NH_3 (most toxic form of ammonia) are less than 0.1mg/l and for total ammonia is less than 1.0mg/l. Optimal levels for NO_3 are from 400 to 800ug/l. The safe concentration for NO_2 is from 0.4 to 0.8mg/l.
Conductivity	Conductivity in streams and rivers is mainly affected by the geology of the area through which the water flows. Inland fresh waters supporting good mixed fisheries range between 150-500 micromhos/centimeter (uhos/cm). Each stream tends to have a relatively constant range of conductivity that can be used as a baseline for comparison with regular conductivity measurements. Significant changes in conductivity could indicate a discharge or some source of pollution has entered the stream.

The price, function and quality of single parameter water quality monitoring equipment vary widely. Examples of single parameter monitoring instruments and sensors appear in the table below. Note, again the cost saving potential between ready-to-use single parameter meters and their corresponding sensors.

Table 8: Selected Examples of Single Parameter Meters and Sensors

Parameter	Item	Features	Source	Price Estimate
Turbidity	Meter	Accuracy +/- 5%. Portable. Incandescent Lamp. Four-Point Calibration. Auto-range. Digital Readout.	Hach Co. Model 2100P	$775
Turbidity	Sensor	Sensor measures the turbidity of fresh-water or seawater samples in NTU (Nephelometric Turbidity Units, the standard unit used by most water collection agencies and organizations)	Vernier http://www.vernier.com/products/sensors/trb-bta/	$112
Flow	Meter	Working velocity range <0.2 ft/sec.	Advanced Measurement and Controls model: Price AA and Pygmy meters	$550 – 750
Conductivity	Meter	Accuracy +/- 0.5% full scale. Automatic Temperature Compensation. Digital Readout.	Fisher Yellow Springs Instruments Model 30.	$625
Conductivity	Sensor	Replace your old uncalibrated sensor with these NEW high quality sensors, compatible with any meter on the market.	Atlas Scientific https://www.atlas-scientific.com/product_pages/sensors/ec-sensor.html	$105
pH	Meter	Instrument + Probe accuracy of +/- 0.2 Digital Readout to 0.01 SU Two-point Calibration. Automatic Temperature Compensation	Fisher Example: Orion 210A meters with accessory ATC probe.	$450
Water Temperature	Data Logger	Accuracy +/- 0.5 C or Better. Waterproof Sealed Unit. Delayed Start-up. 8K memory	Vemco "Minilog-TR"	$135
Dissolved Oxygen	Sensor	Designed for use with galvanic dissolved Oxygen meters, transmitters and controllers. Ideal for lab or portable use, fresh water and salt water capable.	Atlas Scientific https://www.atlas-scientific.com/product_pages/sensors/do-sensor.html	$160
Salinity	Sensor	Sensor easily and precisely measures the total dissolved salt content in an aqueous solution. Measure water with a wide variety of salinities, from brackish water to ocean water, and hyper-saline environments.	Vernier http://www.vernier.com/products/sensors/sal-bta/	$92.00

Monitoring Telemetry Options and Related Equipment

Data collected from remote field locations will potentially require wireless telemetry in order for researchers and environmental professionals to access the data. Real-time data access reduces the time and expense required to visit sites and manually upload data. It also permits interested parties to monitor remote sites to diagnose potential problem situations with environmental conditions or possible equipment issues, which may otherwise go undetected for weeks or months—resulting in a possible loss of data. Wireless telemetry options include:

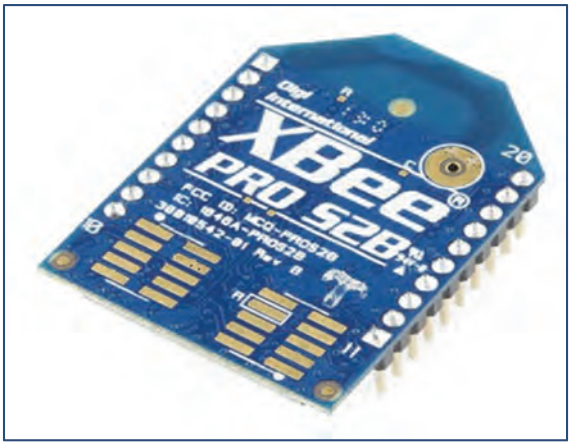


Figure 25: XBee modules allow simple communications between microcontrollers, computers, or anything with a serial port and operate on ZigBee industrial, scientific and medical (ISM) radio bands--915MHz in the USA.

- Land-line telephone
- Cellular—analog cellular modems, GSM digital cellular modems
- Wi-Fi
- Ethernet
- Bluetooth
- ZigBee—a specification for local area networks built from small, low-power digital radios
- VHF
- UHF
- Spread spectrum radio
- Satellite – geostationary satellites (GOES, Inmarsat) or low earth orbit satellites (ORBCOMM, Argos, IRIDIUM)

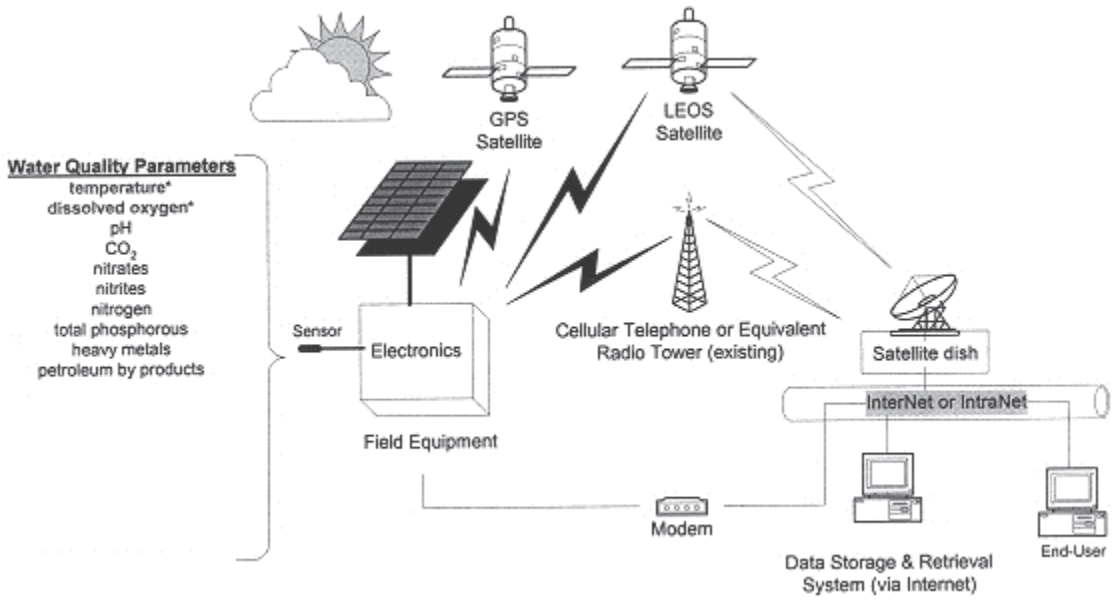
Typically, budgetary constraints, site conditions and location will determine the most feasible alternative. Ethernet is relatively inexpensive and effective for very close range systems. Wi-Fi ranges are reported up to 100 meters.[49] ZigBee has a range of up to 70 meters and Bluetooth up to 100 meters, depending on the radio class.[50] Cellular works well anywhere there is reliable service from a provider, but requires a cellular account subscription. Spread spectrum radio has a 5 mile range and VHF/UHF is 30 miles.[51] Once outside the range of these communications networks, a variety of geostationary or low earth orbit satellites can provide coverage options.

Wireless communication architectures include a modem on each end that emits or receives a defined radio frequency (options listed above) and an antenna. Engineers design appropriate communications systems to take advantage of the different propagation characteristics of the frequency bands of radio waves or signals. Ideally, the characteristics of a cost effective remote monitoring system would have the following elements:

- A network of strategically placed sensors, reliably recording data for parameters of specific regulatory or research interest at sufficient time intervals and during specified weather/climatic events

- A portable, durable, low profile capable of operating autonomously for several weeks or months on battery and/or solar support
- Real-time data collection, and reporting from remote locations to a central web server where data can be effectively processed, stored, visualized within parameter thresholds, and automated warning protocols are displayed and/or communicated to key personnel via email or telephone

Figure 26: This figure shows a theoretical relationship of communication links in a remote monitoring system.



An important concept to understand for local communications networks is mesh networking—where each data node with a network transceiver must both capture and disseminate its own data and serve as a relay for other nodes, until the information reaches its destination.

> According to Wikipedia, *"… a wireless mesh network (WMN) is a communications network made up of radio nodes organized in a mesh topology. Wireless mesh networks often consist of mesh clients, mesh routers and gateways. The mesh clients are often laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gateways which may, but need not, connect to the Internet. The coverage area of the radio nodes working as a single network is sometimes called a mesh cloud. Access to this mesh cloud is dependent on the radio nodes working in harmony with each other to create a radio network. A mesh network is reliable and offers redundancy. When one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more intermediate nodes."*

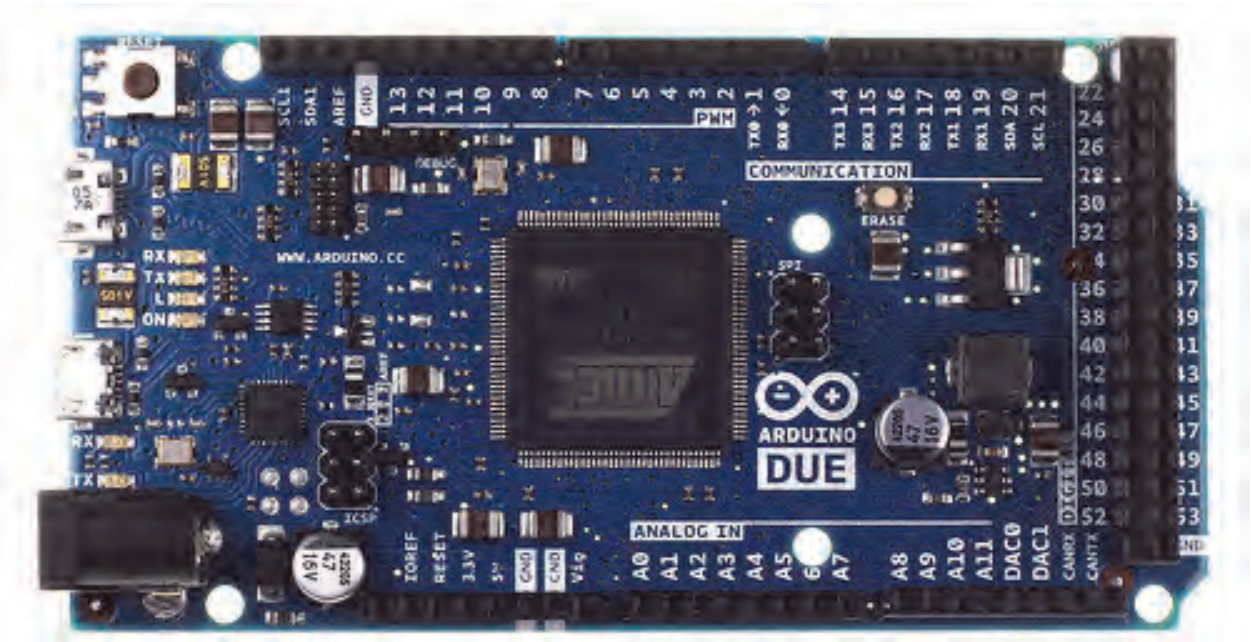
Arduino

A special acknowledgement is justified regarding the importance of having the ZigBee local area radio network platform in combination with the popular open-source modular electronics Arduino (single-board microcontroller) platform. The staff at Stroud Water Research Center introduced the Conservancy

to this significant development in technology. Selected information taken from a poster[52] they prepared underscores the perceived value this group of researches places on this technology development.

1. Implementation of open-source electronics hardware will transform our ability to deploy sensors, field instruments and other electronic "eyes and ears" to unprecedented levels.
2. Almost any device that outputs data can be interfaced with an Arduino-based circuit, and that data can be instantly transmitted through the wireless mesh network.
3. By significantly decreasing the cost of the data logging and communication hardware, resources can be focused on installing more high-quality sensors for greater spatial coverage.
4. Researchers, students, and individuals can easily build and deploy customized inexpensive data loggers without the need for electronics experience, complicated software, or specialized tools.

Figure 27: The Arduino Due is the newest microcontroller board from Arduino with two on-board USB ports and a micro-USB to connect peripherals.



According to Wikipedia, an important aspect of the Arduino is the standard way that connectors are exposed, allowing the CPU board to be connected to a variety of interchangeable add-on modules known as shields. Some shields communicate with the Arduino board directly over various pins, but many shields are individually addressable via an I²C serial bus, allowing many shields to be stacked and used in parallel.

A few examples of Arduino "shields" that can be used directly with official Arduino or Arduino compatible circuit boards are profiled in Table 9 (next page). The newest Arduino board called "Due" is also listed.

Table 9: New Arduino Microcontroller Board and Shield Examples

Item	Features	Source	Price
Xbee Networking Module	Digi International Xbee® & Xbee-PRO® 802.15.4 RF Modules are embedded solutions providing wireless end-point connectivity to devices. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking. Xbee 802.15.4 modules are ideal for low-power, low-cost applications.	Link: http://goo.gl/rjXtph Manufacturer: Digi International	$19.00
Xbee Wireless Kit Retail RTL-11445	Connect one Xbee to the shield and your Arduino, connect the other Xbee to the Explorer board and your computer, and you'll be able to seamlessly pass serial data to and from your Arduino wirelessly! Using this connection, you can transmit remote sensor data, or send data from your computer to activate remote devices.	Xbee Kit- Sparkfun https://www.sparkfun.com/products/11445	$94.95
Assembled Data Logging shield ID: 1141	New 'assembled' version of this shield, with all the components pre-soldered. NOTE: You will only need to solder on either plain 0.1" headers (included) or stacking headers (not included) to attach to your 'duino.	AdaFruit http://www.adafruit.com/products/1141#Description	$19.95
Arduino "Due" Board SKU:-ARD12264M	Newest Arduino microcontroller board—based on a 32 bit ARM core processor, the Atmel SAM3X8E ARM Cortex-M3 MCU. Has 54 digital input/output pins (of which 12 can be used as PWM outputs, with selectable resolution), 12 analog inputs with 12 bit resolution, 4 UARTs (hardware serial ports), and two DAC outputs (digital to analog converter), 84 MHz crystal oscillator, two USB connections, power jack, an ICSP header, JTAG header, and reset button. Maximum voltage I/O pins can provide or tolerate is 3.3V. The Due has two USB connectors to connect compatible external USB peripherals to the board, such as a mouse, keyboards, or smartphones. Due also has a USB port with a type B connector for debugging use.	Arduino/ SeeedStudio http://www.seeedstudio.com/depot/arduino-due-p-1333.html?cPath=6_7	$74.90

A FORWARD LOOK AT LOW COST WATER QUALITY MONITORING

For many years sophisticated water quality monitoring efforts, coordinated by the EPA Chesapeake Bay Program, have been ongoing in both tidal and freshwater environments throughout the Chesapeake Bay watershed. These efforts have provided critically important data—allowing citizens and scientists alike to better understand how our aquatic ecosystems and the living resources that depend on them are responding to our collective actions to restore the Bay. The monitoring and research data together help EPA to construct model simulations about how the Bay might respond in future years based on various scenarios about population growth, land use, best management practices and other information.

The potential roles that low cost water quality monitoring can play to inform these sophisticated efforts may be limited in the near term due to a combination of technology constraints and our abilities to accurately monitor and interpret beneficial or harmful landscape scale changes. However, it is clear that monitoring technologies are rapidly advancing and as they do, we can expect increasing deployment of low cost sensors to provide the Bay community with a wealth of environmental data that did not exist previously. We can anticipate monitoring costs to be driven down by innovative open source electronic platforms and more sophisticated sensors that automatically transmit data from fixed locations around the watershed. We can also reasonably project a growing role for crowdsourcing of water quality monitoring data via cell phone-based mobile sensor technologies. With this increase in the quantity and quality of data, coupled with innovative visualization tools to map and interpret this information in real and near real time, we will inevitably gain a fuller sense of what is happening to our environment and accordingly, how we can adjust our actions to better sustain it.

[1] Malquist, David. "VIMS study shows "dead zone" impacts Bay fishes." William and Mary, Virginia Institute of Marine Science; July 8, 2013. Retrieved from: http://www.vims.edu/newsandevents/topstories/buchheister_fish_hypoxia.php

[2] Phillips, Scott W. and Bruce D. Lindsey. "The Influence of Ground Water on Nitrogen Delivery to the Chesapeake Bay." US Department of Interior, USGS Fact Sheet FS-091-031, 2003.

[3] *Id.*

[4] *Id.*

[5] Sanford, Ward E. and Jason P. Pope. "Quantifying Groundwater's Role in Delaying Improvements to Chesapeake Bay Water Quality. Environmental Science & Technology, American Chemical Society. October, 2013.

[6] Bohlke, J.K., M.E. O'Connell and K.L. Prestegaard. "Ground water stratification and delivery of nitrate to an incised stream under varying flow conditions." Journal of Environmental Quality; Apr 5;36(3):664-80. 2007 May-Jun.

[7] Domagalski, Joseph L and Henry Johnson. "Phosphorus and Groundwater: Establishing Links Between Agricultural Use and Transport to Streams." US Department of Interior, USGS Fact Sheet 2012-3004, January 2012.

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APPENDICES

List of Interviewees

1. Ben Grumbles, President U.S. Water Alliance, Washington, D.C. Related Expertise: Former Assistant Administrator for Water at U.S. EPA from 2004 through 2008; Serves on Water Science and Technology Board of the National Academy of Sciences; and Water Resources Adaption to Climate Change Workgroup of the Federal Advisory Committee on Water Information; excellent perspective of high level water quality monitoring needs.
2. Mike Rolband, President Wetlands Studies and Solutions, Gainesville, VA. Related Expertise: Civil and environmental engineering, geotechnical expertise; runs consulting firm with large practice specializing in wetlands; wetlands mitigation; wetlands monitoring; hydrology; stormwater management.
3. David Nemazie, University of Maryland, Center for Environmental Science, Cambridge, MD. Related Expertise: Marine and estuarine ecology; coastal pollution; watershed management; environmental policy and development; general knowledge of EcoCheck's expertise in report cards and ecological health assessments and related water quality monitoring protocols for data gathering and reporting at watershed level.
4. Chris Trumbauer, Riverkeeper and Executive Director of West and Rhode Riverkeeper, Shady Side, MD. Related Expertise: Chemistry, biology, water quality monitoring; formerly coordinated Maryland Department of Natural Resources statewide water quality monitoring program; Critical Areas Commission for the Chesapeake and Atlantic Coastal Bays.
5. Dianna Muller, Riverkeeper, South River Federation, Edgewater, MD. Related Expertise. 20 years of riverine and estuarine water quality, chemistry, marine science, microbiologist, water quality laboratory manager, lab QA/QC specialist; Chesapeake Bay Long Term Monitoring Project; sampled most of the Chesapeake Bay watershed, from the Susquehanna River to the Bay mouth; certified by EPA Bay program for water quality data collection.
6. Andrew Muller, Associate Professor of Oceanography, United States Naval Academy, Annapolis, MD. Related Expertise: Three dimensional, multi-parameter water quality monitoring and modeling of Chesapeake Bay rivers; familiarity with high end monitoring equipment; laboratory sampling processes; autonomous sampling methods.
7. Doug Levin, Deputy Director, Washington College Center for Environment and Society, Chestertown, MD. Related Expertise: Marine science/geology/biology; former program manager for Coastal Ocean Modeling Test Bed Program a for NOAA's U.S. Integrated Ocean Observing System; assembly of low cost basic water quality monitoring buoys for classrooms and wide scale deployments; operates high end, field monitoring sensor systems.
8. Bernard W. Sweeney, President, Director, Senior Research Scientist, Stroud Water Research Center, Avondale, PA. Related Expertise: Head of Freshwater Surveillance Group, International Barcode of Life Project; water quality monitoring in conservation, population and community ecology of temperate aquatic invertebrates; pollution assessment in temperate streams using macroinvertebrates.

9. Anthony K. Aufdenkampe, Principal Investigator, Organic and Isotope Geochemistry Group, Stroud Water Research Center, Avodale, PA. Related Expertise: organic matter cycling throughout watersheds — from soils to rivers to estuaries; synthesizing observation and theory into quantitative models to guide new experiments and theory; low cost water quality monitoring using open source licensing and Arduino micro-controller compatible frameworks; familiarity with low cost water quality monitoring sensors, telemetry configurations, data collection and internet data management.
10. Kathleen Register, Executive Director, Clean Virginia Waterways, Longwood University, Farmville, VA. Related Expertise: Co-author of U.S. EPA's Estuary Monitoring: A Methods Manual and Virginia's Water Resources: A Tool for Teachers; long term experience managing low cost adult volunteer and student monitoring programs; coordinates International Coastal Cleanup in Virginia.
11. Jeanne Christie, Executive Director, Association of State Wetland Managers, Windham, ME. Related Expertise: Knowledge of U.S. wide wetland issues; status of wetland water quality monitoring and condition assessment activities of states; water quality standards for wetlands; TMDLs and wetlands.
12. Solange Filoso, Research Assistant Professor, University of Maryland, Center for Environmental Science, Chesapeake Biological Laboratory, Solomon, MD. Related Expertise: Limitations of current small stream sensor technology, biogeochemistry and nutrient dynamics in aquatic ecosystems; impacts of land use change, urbanization, and energy production on water resources; effectiveness of stream restoration and other best management practices at improving water quality of small streams.
13. Sean Smith, Assistant Professor, University of Maine, Department of Earth Sciences, Bryand Global Sciences Center, Orono, Maine. Related Expertise: Watershed geomorphology, stream channel morphology and stability, surface flow patterns in headwater drainage basins, watershed sediment budgets, quantification and explanation of human impacts on landscapes--particularly those that govern the flux of water, sediment and nutrients in contemporary landscapes. Extensive experience working in Chesapeake Bay watershed, co-editor of "A summary report of sediment processes in Chesapeake Bay and watershed." USGS Water Resources Investigations Report 03-4123.
14. Mario Tamburri, University of Maryland, Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, MD. Related Expertise: Environmental sensor technologies, green ship technologies, chemical ecology of aquatic organisms, non-native species, larval settlement and recruitment, and partner liaison with Alliance for Coastal Technologies (note, ACT is a partnership of research institutions, resource managers, and private sector companies dedicated to fostering the development and adoption of effective and reliable sensors and platforms for use in coastal, freshwater and ocean environments).
15. Govind Rao, Professor of Chemical & Biochemical Engineering and Director of the Center for Advanced Sensor Technology, University of Maryland, Baltimore County, MD. Related Expertise: Development of advanced sensors for industry; applications of fluorescence spectroscopy to bioprocess engineering; low-cost non-invasive monitoring of oxygen, pH and pCO2 in bioreactors; next generation of ultra-sensitive, ultra-fast sensors based on surface plasmon

coupled fluorescence. Note: surface plasmon–coupled emission (SPCE) arose from the integration of fluorescence and plasmonics, two rapidly expanding research fields. SPCE-based analytical platforms have applications in DNA sensing and the detection of other biomolecules and chemicals.

16. Logan Liu, Principal Investigator and Assistant Professor, Micro and Nanotechnology Lab, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urban, Illinois. Related Expertise: Design, modeling, and fabrication of nanoelectronic and nanophotonic devices and their biomedical applications; developing nanobionics by integrating solid-state optoelectronic nanodevices with functional biomolecules and studying the properties of electrons, photons and ions in the hybrid system; creating nanobionic systems for health care, energy harvesting and environment protection.
17. Ron Klauda, Director of Monitoring and Non-tidal Assessment Division, Maryland Department of Natural Resources, Annapolis, MD. Related Expertise: aquatic ecology and fisheries biology; small stream, river and estuarine water quality and ecological health monitoring; aquatic and terrestrial/aquatic invasive species threat assessment; Maryland Biological Stream Survey and Sentinel Site Network; effects of acid deposition and other contaminants on the eggs and larvae of striped bass, American shad, blueback herring, alewife, and yellow perch.
18. Eric Stein, Principal Scientist, Director of Biology Department, Southern California Coastal water Research Project (A Public Agency for Environmental Research), Costa Mesa, California. Related Expertise: biology, environmental science and engineering; benthic macro invertebrate species collection, taxonomy and DNA extraction and amplification; in-stream and coastal water quality, hydro modification, development of biological indices, and assessment of wetlands and other aquatic resources.
19. Jon Kusler, Founding Director of Association of State Wetland Managers, Windham, ME. Related Expertise: Scientist, lawyer, internationally recognized wetlands expert who has played a pivotal role in defining key directions in wetland science and demonstrating how sound science can improve public policy. Consultant to U.S. Water Resources Council, author of over 50 publications, including Wetland Creation and Restoration, Status of the Science and Wetland Water Quality Standards for States.
20. James McElfish, Director of Sustainable Use of Land Program, Environmental Law Institute, Washington, D.C. Related Expertise: Nationally recognized authority on NEPA and former litigator with DOI; extensive knowledge of water laws and policies of Chesapeake Bay states, nonpoint source water pollution control strategies at federal, state, and local levels; examining how watersheds and resources can be evaluated, used, conserved, and restored.
21. Joshua Schapiro, Robotics Research Engineer, CREATE Lab, Carnegie Mellon, Pittsburg, PA. Related expertise: Mechanical engineering, design of low cost water quality monitoring systems for in-home water supplies and streams, design of sophisticated environmental data loggers, wireless data transfer protocols, mechanical and electrical system design for numerous robotics applications.
22. Doug Wilson, Owner, Caribbean Wind LLC, Annapolis, MD. Related expertise: Ocean sciences, physical oceanography, observing systems, design of Basic Observation Buoy System “BOBS”, estuarine monitoring, project leader for NOAA Chesapeake Bay Interpretive Buoy System

"CBIBS", project coordinator for IOCARIBE-GOOS (Intergovernmental Oceanographic Commission for the Caribbean and Adjacent Regions-- Global Ocean Observing System).

23. Hank Zygmunt, Resource Dynamics, Yardley, PA. Related expertise: EPA Bay Program Best Management Practices Verification Committee, former EPA Mid-Atlantic Office Agricultural Advisor leading EPA's Agriculture Work Group for State Phase I Watershed Implementation Plans/TMDL, CAFO rule development, Science Advisor to EPA for Federal toxics and water quality legislation.
24. Bob Gallagher, West and Rhode Riverkeeper Board of Directors, Shady Side, MD. Related expertise: 30+ year law practice, water quality/conservation policy, environmental advocacy, nutrient trading committee chair for ad hoc NGO conservation group, co-founder Anne Arundel Chapter of Maryland League of Conservation Voters, Scenic Rivers Land Trust Board of Directors, Chesapeake Environmental Protection Association, Trustee.
25. Nick Dilks, Ecosystem Investment Partners, Baltimore, Maryland. Has extensive experience in land conservation finance and real estate. Formerly, Vice President for Real Estate with The Conservation Fund, completing some of TCF's most complex and innovative transactions. Familiar with nutrient trading, offsets, stream and wetland mitigation projects and associated monitoring requirements.

Chesapeake Bay Water Quality Thresholds*

Dissolved Oxygen

Migratory Fish Spawning and Nursery Designated Use: Aims to protect migratory finfish during the late winter/spring spawning and nursery season in tidal freshwater to low-salinity habitats. This habitat zone is primarily found in the upper reaches of many Bay tidal rivers and creeks and the upper mainstem Chesapeake Bay and will benefit several species including striped bass, perch, shad, herring and sturgeon.
7-Day Mean: >= 6mg/l
Instantaneous Minimum >=5mg/l

From February - May 31
Shallow-Water Designated Use: Designed to protect underwater bay grasses and the many fish and crab species that depend on the shallow-water habitat provided by grass beds.
30-Day Mean >=5.5mg/l (Tidal Fresh)
30-Day Mean>=5.0mg/l (saline waters)
7-Day Mean >= 4mg/l, (saline waters)
Instantaneous minimum >=3.2mg/l

Year Round
Open-Water Fish and Shellfish Designated Use: Designed to protect water quality in the surface water habitats within tidal creeks, rivers, embayments and the mainstem Chesapeake Bay year-round. This use aims to protect diverse populations of sportfish, including striped bass, bluefish, mackerel and seatrout, bait fish such as menhaden and silversides, as well as the listed shortnose sturgeon.
30-Day Mean >=5.5mg/l (Tidal Fresh)
30-Day Mean>=5.0mg/l (saline waters)
7-Day Mean >= 4mg/l, (saline waters)
Instantaneous minimum >=3.2mg/l

Year Round
Deep-Water Seasonal Fish and Shellfish Designated Use: Aims to protect living resources inhabiting the deeper transitional water column and bottom habitats between the well-mixed surface waters and the very deep channels during the summer months. This use protects many bottom-feeding fish, crabs and oysters, as well as other important species, including the bay anchovy.
30-Day Mean >= 3mg/l
1-Day Mean >=2.3mg/l
Instantaneous Minimum >=1.7mg/l

June 1 - September 30

Deep-Channel Seasonal Refuge Designated Use: Designed to protect bottom sediment-dwelling worms and small clams that act as food for bottom-feeding fish and crabs in the very deep channel in summer. The deep-channel designated use recognizes that low dissolved oxygen conditions prevail in the deepest portions

Instantaneous >=1mg/l, June 1 to September 30
30-Day Mean >=5.5mg/l (Tidal Fresh), October 1 to May 31

30-Day Mean>=5.0mg/l (saline waters)
7-Day Mean >= 4mg/l, (saline waters)

Water Clarity

Water Clarity Thresholds are based on what salinity regime and for SAV growth:

SAV Acreage Restoration Goals.

Segment Description[1]	Segment Designator	SAV Acreage Restoration Goal	Secchi Application Depth
Northern Chesapeake Bay	CB1TF2	12,149	2 meters
Northern Chesapeake Bay	CB1TF1	754	1.0 meters
Lower Pocomoke River Mesohaline	POCMH	877[2]	1.0 meters
Manokin River Mesohaline	MANMH1	4,294	2.0 meters
Manokin River Mesohaline	MANMH2	59	0.5 meters
Big Annemessex River Mesohaline	BIGMH1	2,021	2.0 meters
Big Annemessex River Mesohaline	BIGMH2	22	0.5 meters
Tangier Sound Mesohaline	TANMH1	24,683[2]	2.0 meters
Tangier Sound Mesohaline	TANMH2	74	0.5 meters
Middle Nanticoke River Oligohaline	NANOH	12	0.5 meters
Lower Nanticoke River Mesohaline	NANMH	3	0.5 meters
Wicomico River Mesohaline	WICMH	3	0.5 meters
Fishing Bay Mesohaline	FSBMH	197	0.5 meters
Middle Choptank River Oligohaline	CHOOH	72	0.5 meters
Lower Choptank River Mesohaline	CHOMH2	1,621	1.0 meters
Mouth of Choptank River Mesohaline	CHOMH1	8,184	2.0 meters
Little Choptank River Mesohaline	LCHMH	4,076	2.0 meters
Honga River Mesohaline	HNGMH	7,761	2.0 meters
Eastern Bay	EASMH	6,209	2.0 meters
Upper Chester River Tidal Fresh	CSHTF	1	0.5 meters
Middle Chester River Oligohaline	CHSOH	77	0.5 meters
Lower Chester River Mesohaline	CHSMH	2,928	1.0 meters
Chesapeake & Delaware (C&D) Canal	C&DOH	7	0.5 meters
Northeast River Tidal Fresh	NORTF	89	0.5 meters
Bohemia River Oligohaline	BOHOH	354	0.5 meters
Elk River Oligohaline	ELKOH1	1,844	2.0 meters
Elk River Oligohaline	ELKOH2	190	0.5 meters
Sassafras River Oligohaline	SASOH1	1,073	2.0 meters
Sassafras River Oligohaline	SASOH2	95	0.5 meters
Bush River Oligohaline	BSHOH	350	0.5 meters
Gunpowder River Oligohaline	GUNOH2	572	2.0 meters
Mouth of Gunpowder River	GUNOH1	1,860	0.5 meters
Middle River Oligohaline	MIDOH	879	2.0 meters

Segment Description[1]	Segment Designator	SAV Acreage Restoration Goal	Secchi Application Depth
Back River Oligohaline	BACOH	30	0.5 meters
Patapsco River Mesohaline	PATMH	389	1.0 meters
Magothy River Mesohaline	MAGMH	579	1.0 meters
Severn River Mesohaline	SEVMH	455	1.0 meters
South River Mesohaline	SOUMH	479	1.0 meters
Rhode River Mesohaline	RHDMH	60	0.5 meters
West River Mesohaline	WSTMH	238	0.5 meters
Upper Patuxent River Tidal Fresh	PAXTF	205	0.5 meters
Middle Patuxent River Oligohaline	PAXOH	115	0.5 meters
Lower Patuxent River Mesohaline	PAXMH1	1,459	2.0 meters
Lower Patuxent River Mesohaline	PAXMH2	172	0.5 meters
Lower Patuxent River Mesohaline	PAXMH4	1	0.5 meters
Lower Patuxent River Mesohaline	PAXMH5	2	0.5 meters
Lower Potomac River Tidal Fresh	POTTF	2,142[2]	2.0 meters
Piscataway Creek Tidal Fresh	PISTF	789	2.0 meters
Mattawoman Creek Tidal Fresh	MATTF	792	1.0 meters
Lower Potomac River Oligohaline	POTOH1	1,387[2]	2.0 meters
Lower Potomac River Oligohaline	POTOH2	262	1.0 meters
Lower Potomac River Oligohaline	POTOH3	1,153	1.0 meters
Lower Potomac River Mesohaline	POTMH	7,088[2]	1.0 meters
Upper Chesapeake Bay	CB2OH	705	0.5 meters
Upper Central Chesapeake Bay	CB3MH	1,370	0.5 meters
Middle Central Chesapeake Bay	CB4MH	2,533	2.0 meters
Lower Central Chesapeake Bay	CB5MH	8,270[2]	2.0 meters

Nutrients:

Guidance for nutrients is 0.037 mg/l for Total Phosphorus, and 0.65 mg/l for Total Nitrogen

Bacteria:

In accordance to the Beaches Act the bacteria guidelines are for "recreational beaches", which is 104cfu/100ml daily instantaneous, or 35 cfu/100ml geometric mean of 5 days continuous.

I use the daily instantaneous—

* **Source:** Diana Muller, South River Federation, Waterkeeper, Edgewater, Maryland

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