Building Environmental Intelligence

Leading the future of water quality monitoring

Acknowledgements

BACKGROUND: Building Environmental Intelligence (BEI) began as a result of a $944,000 funding cut in FY13, to the Chesapeake Bay Program funded long-term water quality monitoring networks. This funding cut was addressed in Phase I of the Scientific, Technical Assessment, and Reporting Team's (STAR) BEI work. The implications of this cut were that the current operational and funding structures for these networks are unsustainable up against economic, political, and scientific pressures.

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Science. Restoration. Partnership.

CRC

USGS
science for a changing world

Innovation for a better future
University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

Contents

Glossary and Acronyms

Adaptive Management

An ongoing, science-based process through which the Chesapeake Bay Program plans, implements and evaluates its restoration efforts.

AUV

An autonomous underwater vehicle (AUV) is a robot which travels underwater without requiring input from an operator.

BASIN

Building and Sustaining Integrated Networks (BASIN) is the former name for Building Environmental Intelligence.

BEI

Building Environmental Intelligence (BEI) is the discovery process in which the Scientific, Technical Assessment, and Reporting Team underwent to explore alternative approaches to monitoring.

BMP

Best Management Practice (BMP) is a practice intended to reduce nutrient and contaminant loads into the Chesapeake Bay.

CBIBS

Chesapeake Bay Interpretive Buoy System (CBIBS), is a network of observation buoys that give you real-time wind and weather information.

CBP

The Chesapeake Bay Program (CBP) is a regional partnership that leads and directs Chesapeake Bay restoration and protection. Bay Program partners include federal and state agencies, local governments, non-profit organizations and academic institutions.

Chesapeake 2000

On June 28, 2000, the Chesapeake Bay Program adopted Chesapeake 2000: A Watershed Partnership agreement to guide a decade of restoration in the Chesapeake Bay watershed.

Chesapeake Bay Watershed Agreement

On June 16, 2014, the Chesapeake Bay Watershed Agreement was signed. Signatories include representatives from the entire watershed, committing for the first time the Bay's headwater states to full partnership in the Bay Program. This plan for collaboration across the Bay's political boundaries establishes goals and outcomes for the restoration of the Bay, its tributaries and the lands that surround them.

Continuous Monitoring

Fixed stations that collect high frequency measurements in situ.

DATAFLOW

Collects water through a pipe ("ram") deployed on the transom of the vessel, pumps it through an array of water quality sensors, and then discharges the water overboard. The system collects samples approximately once every 3-4 seconds. The sonde transmits data collected from the sensors directly to a computer on board.

GAMs

General Additive Models (GAMs) are generalized linear models in which the linear predictor depends linearly on unknown smooth functions of some predictor variables, and interest focuses on inference about these smooth functions.

Lag Time

The period of time between stimulus and response, often describing the period of time between BMP implementation and changes in water quality conditions.

MARACOOS

The Mid-Atlantic Regional Association Coastal Ocean Observing System, covering the region from Cape Cod, MA to Cape Hatteras, NC for U.S. IOOS.

MEOWQT

Management Effects on Water Quality Trends (MEOWQT) was a workshop to solicit input and recommendations on the most promising analytical approaches and corresponding data needs for detecting linkages between management practices on the land and changes in water quality within the Bay watershed.

MOU

Memorandum of Understanding is an agreement between two or more parties, generally used for coordinated work amongst Chesapeake Bay Program partners.

MPA

The December 2010 Chesapeake Bay Total Maximum Daily Load (Bay TMDL) calls for a Mid-Point Assessment (MPA) in 2017 to review our progress toward meeting the nutrient and sediment pollutant load reductions identified in the 2010 Bay TMDL, Phase I and Phase II Watershed Implementation Plans (WIPs) and two-year milestones.

MRAT

In 2009, the Monitoring Realignment Action Team (MRAT) produced recommendations for enhancing the watershed monitoring network to align the monitoring networks with CBP partnership priorities.

NERRS

The National Estuarine Research Reserve System (NERRS) is a network of 28 coastal sites designated to protect and study estuarine systems.

NTN

Non-tidal Water Quality Monitoring Network (NTN) also known as the Watershed Monitoring Network measures water quality parameters in the Chesapeake Bay Watershed.

RIM

River Input Monitoring Program (RIM) measures nutrient and sediment loads from the major rivers flowing into the Chesapeake Bay.

SAV

Submerged Aquatic Vegetation (SAV) denotes underwater Bay grasses.

STAC

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program on measures to restore and protect the Chesapeake Bay.

STAR

The Scientific, Technical Assessment, and Reporting (STAR) Team increases the collaboration among science providers to provide monitoring, modeling, and analysis needed to update, explain, and communicate ecosystem condition and change to support the Chesapeake Bay Program Goal Teams.

TMDL

On December 29, 2010, the U.S. Environmental Protection Agency established the Chesapeake Bay Total Maximum Daily Load (TMDL). The TMDL is a historic and comprehensive "pollution diet" to restore clean water in the Chesapeake Bay and the region's streams, creeks, and rivers.

TraC

The Irish Environmental Protection Agency uses ecological quality criteria for the assessment of water quality in the transitional and coastal (TraC) waters of Europe.

Vertical Profiler

A fixed mounted system that automatically collects hourly readings of parameters (i.e. temperature, salinity, conductivity, dissolved oxygen, pH, turbidity and chlorophyll) from multiple depths along the depth profile.

WIP

Each of the seven Bay watershed jurisdictions maintain a Watershed Implementation Plan (WIP) that documents how the jurisdiction plans to partner with federal and local governments to achieve and maintain water quality standards.

WRTDS

A model for the water-quality analysis, which uses Weighted Regressions on Time, Discharge and Season (WRTDS) to describe long-term trends in both nutrient and sediment concentration and flux.

Executive Summary:
BUILDING ENVIRONMENTAL INTELLIGENCE

Building Environmental Intelligence (BEI)[1] is a three-part effort by the Chesapeake Bay Program (CBP) Partnership's Scientific, Technical, Assessment and Reporting (STAR) Team experts to discover new, smarter approaches for both sustaining and expanding the Bay Program's vast water quality monitoring networks.

Begun as a result of a funding gap, which was addressed in Phase I of STAR's BEI work, the overall BEI research soon evolved into a search for creative, progressive, long-term strategies for managing the Bay Program monitoring effort; strategies that will be effective at supporting partners' collaboration toward meeting the goals and outcomes of the Chesapeake Bay Watershed Agreement.

This report, Building Environmental Intelligence: Leading the Future of Water Quality Monitoring is the culmination of BEI's Phase II: Exploration and Discovery. It is a compilation of the innovations and new ideas that STAR experts uncovered in the course of their outreach to groups around the world, as well as wisdom gleaned during topical workshops and internal discussions. It provides STAR's best and highest recommendations for Bay Program leadership to consider in order to foster a strong and resilient monitoring network that will take the partnership into the next generation of watershed restoration.

You'll find this report divided into three clear sections.

"What We Know" focuses on the existing need for a re-envisioning of how our water quality monitoring network operates, including a call for it to be as adaptive as other management efforts supporting the Watershed Agreement. It also outlines the scientific, political and financial challenges ahead.

"What We've Learned" provides in-depth information about innovative approaches STAR has uncovered from experts within and beyond the Bay watershed, including knowledge gained from talking to monitoring groups in Ireland, Australia, and several across the United States. STAR asked colleagues in these programs about their objectives, program structures, funding, innovations and, of course, about the successes and challenges they have faced. Through this online series of discussions two things became clear: the critical value of high-quality citizen science and the myriad benefits of creative and progressive partnerships.

Finally, "What We Recommend" lays out propositions for a future in which the Bay Program Partnership "monitors SMARTer[2]". This vision and the recommendations to get there embrace new knowledge and understanding that can help us to: enable the better integration of citizen science into our work; increase collaboration across regions, organizations and programs; create closer ties to local issues and local governments; and, perhaps most importantly, build successful partnerships based on shared priorities and pooled financial and operational resources.

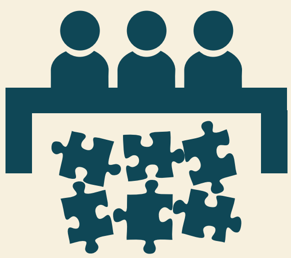
One of the hallmarks of the Chesapeake Bay Program is our continuously improving science that adjusts based on new understandings. It is a vital partnership function that makes "adaptive management" and strong decision-making possible. As we move into the next generation of work together, each of us must explore ways to build our individual and collective environmental intelligence in order for the Bay Program partnership to remain a lasting leader in the world of watershed-wide restoration.

[1]Formerly known as Building and Sustaining Integrated Networks (BASIN).

[2]Developing specific, measurable objectives and a clear picture of the results expected from program activities. SMART stands for Specific, Measurable, Attainable, Relevant, and Time bound, attributed to Peter Drucker's management by objectives concept.

STAR concluded that in order to sustain and allow for the adaptive management of the CBP water quality monitoring networks, we must focus on the implementation of recommendations that reflect six key programming elements. Summary recommendations include:

Decision Support



A User Council should be established to improve interaction between the CBP Partnership monitoring programs and decision makers. The council could serve as an advisory entity to STAR to provide guidance on monitoring and associated products.

Partnerships

The Bay Program should expand partnering opportunities with local and regional entities by co-locating monitoring efforts and enhanced coordination of shared priorities.

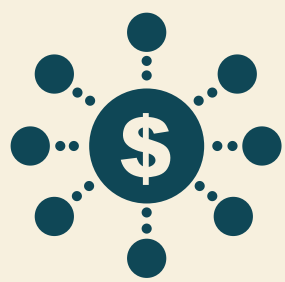
Citizen Science

Greater use of citizen science should be pursued to supplement, but not replace, Bay Program water-quality monitoring efforts in the watershed and tidal waters.

Innovations

The program should pursue cost effective technological innovations to improve the volume and frequency of data collection and consider innovative analysis techniques to improve data interpretation.

Combining Funds



Partners should contribute funding into a common pool of resources, thereby providing opportunities for efficiencies and integration of priorities.

Leadership

Continued communication with the global monitoring community could provide a mechanism to share ideas for how to build more integrated monitoring programs. Facilitation will be needed.

Why is water quality monitoring important?

In the late 1970s, Congress funded a $27 million, five-year study analyzing the Chesapeake Bay's rapid loss of wildlife and aquatic life—including major issues such as low dissolved oxygen, increased levels of phytoplankton and declines in commercially and ecologically valuable living resources. Excess nutrient pollution was identified as the main source of the Bay's degradation. These initial research findings led to the formation of the Chesapeake Bay Program as the means to restore the Bay.

In August 1984, Maryland and Virginia, in cooperation with the U.S. Environmental Protection Agency (EPA), implemented a long-term, comprehensive Chesapeake Bay water quality monitoring program with monitoring stations located throughout the mainstem Bay, its tidal tributaries and their sub-estuaries. Today, through this program, scientists collect a suite of physical, chemical and biological monitoring parameters across varied scales of space and time. The monitoring program's design focuses on meeting three objectives:

- Characterizing the status of existing water quality conditions;
- Detecting trends in water quality indicators; and
- Increasing the understanding of factors affecting Bay water quality and living resources.

Coupled with the tidal water quality monitoring program, a river input monitoring program (RIM) was also established in 1984. The RIM is critical to understanding the physical, chemical and biological dynamics of the Bay. Scientists use the data from this program to assess water flow as well as nutrient and sediment concentrations entering the Bay from nine major tributaries.

Further up in the watershed, the Chesapeake Bay the watershed water quality monitoring network has evolved significantly since coordinated sampling began in the 1970s. A 2004 Memorandum of Understanding (MOU) formalized common sampling protocols across the watershed in response to the Chesapeake 2000 agreement, in which the CBP partners agreed to improve water quality in the Bay by 2010. The original objectives of the watershed network were to:

- Measure and assess the status and trends of nutrient and sediment concentrations and loads in the tributary strategy basins across the watershed;
- Help assess the factors affecting nutrient and sediment status and trends; and
- Improve calibration and verification of partners' watershed models.

In response to a range of pressures over time—including new scientific understanding of the Bay, resource availability and evolving management priorities—the monitoring networks' objectives, elements, station selection, parameter selection and sampling frequency and distribution have been adjusted and adapted by CBP partners to meet the information needs of scientists, managers and decision-makers. In Figure 1.1 a complete picture of the monitoring program is depicted in a diagram of the Bay and Watershed and in Figure 1.2, a timeline depicts the continuous adaption of the monitoring program to management actions and new science.

Water Quality Monitoring Networks:

Tidal Water Quality
Measures water qulaity conditions for oysters, crabs, fish, and thier habitats

Shallow Water Quality
Measures water qulaity conditions for submerged Aquatic Vegetation

Phytoplankton
Measures algal and microscop-ic plants which are indicators of the nutrient conditions and eutrophication

Zooplankton
Measures microscopic organisms that indicate the condition of the food web

Submerged Aquatic Vegetation
Measures the amount of SAV, which is important habitat for fish and food for water fowl

Benthic
Measures clams and worms which are important food sources for bottom-feeding fish and shellfish

River Input Program (RIM)
Measures the amount of nutrients and sediments entering the Bay to help assess if BMPs are having the desired impact

Watershed Water Quality
Measures the amount of nutrients and sediments throughout the Watershed to help assess if BMPs are having the desired impact

Selected Monitoring Studies:

Ecosystem Process
Study to better understand the linkage between nutrients and SAV, DO, zooplankton, and phytoplankton

Nutrient Limitation
Study to better understand the linkage between nutrients and phytoplankton (algal biomass)

Toxics Assessment
Study to document the presence of contaminants that could harm fish, and limit thier consumption by people

Figure 1.1. Elements of the Chesapeake Bay Program Water Quality Monitoring Networks, including selected monitoring studies funded throughout its history.

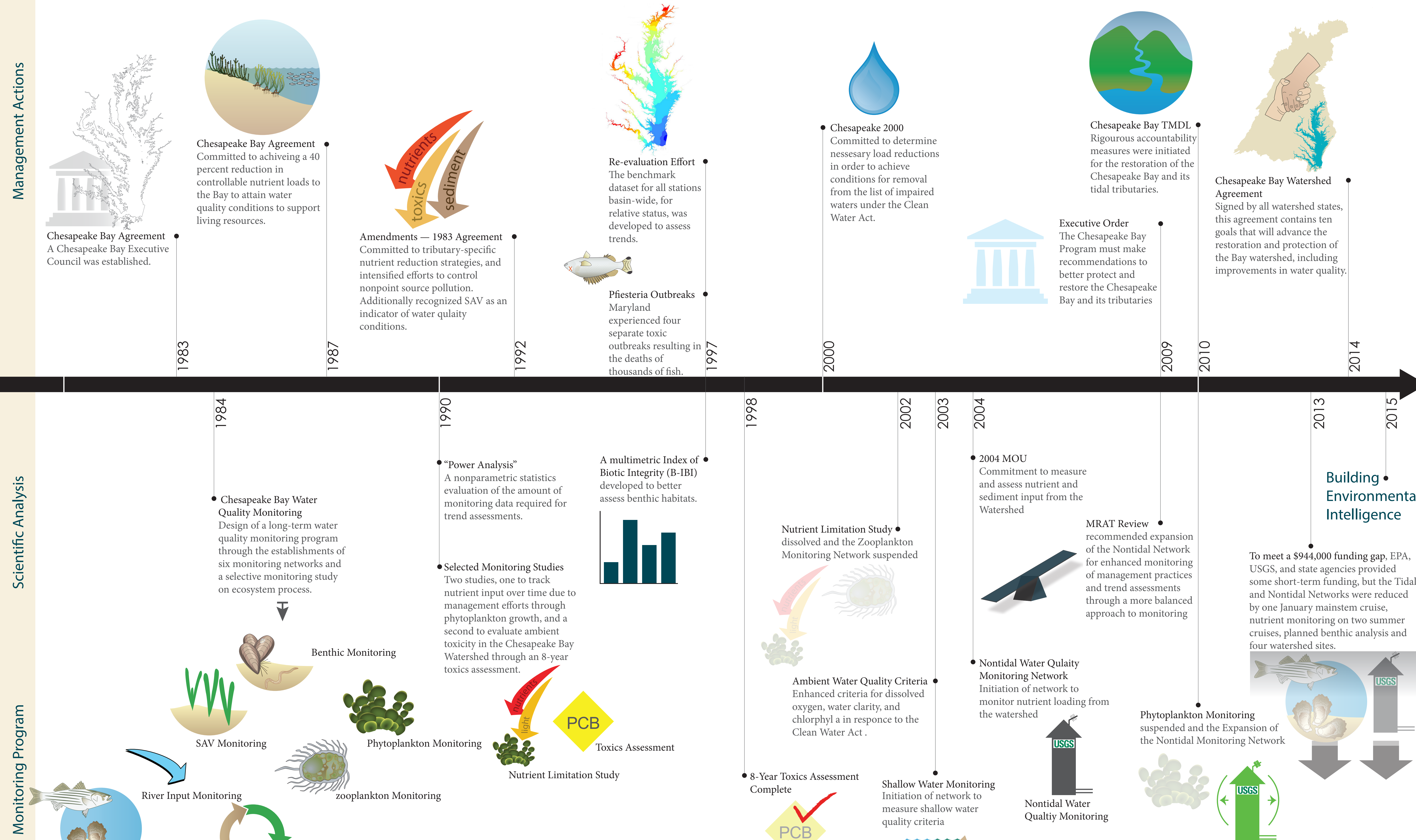


Figure 1.2. Chesapeake Bay Program water quality monitoring has changed over time as a result of Management decisions and needs, scientific analysis, changing technology, and funding. This timeline shows the history of Chesapeake Bay Program Monitoring.

What is currently being done in the Chesapeake?

The publication of the 2003 Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for Chesapeake Bay and its tributaries (U.S. EPA 2003a) codified a suite of detailed dissolved oxygen, water clarity and chlorophyll a criteria for Chesapeake Bay and its tidal tributaries and embayments. Water quality monitoring is performed to assess attainment of the criteria.

Dissolved Oxygen:

Dissolved oxygen dynamics of the Bay and its tidal tributaries have been reported on since the early 1900s (U.S. EPA 2003a). Early in the 1990s, experts further identified dissolved oxygen concentrations necessary to protect the Bay's aquatic living resources (Jordan et al. 1992). Delaware, Maryland, Virginia, and the District of Columbia have adopted the 2003 criteria published by EPA into their jurisdiction's water quality standards regulations.

The dissolved oxygen criteria shown in Figure 2.1 were tailored to each of five designated uses— migratory spawning, shallow-water bay grasses, open water, deep water, and deep channel.

These dissolved oxygen criteria include 30-day, 7-day and 1-day means along with instantaneous minima as needed to be protective of the variety of living resource species and their life stages (U.S. EPA 2003). Dissolved oxygen monitoring is performed to assess the criteria but has been considered insufficient to assess short duration criteria (temporal scales less than the 30-day mean). Additionally, there is significant uncertainty associated with the current protocols for assessing the 30-day mean criterion that are related to spatial and temporal density.

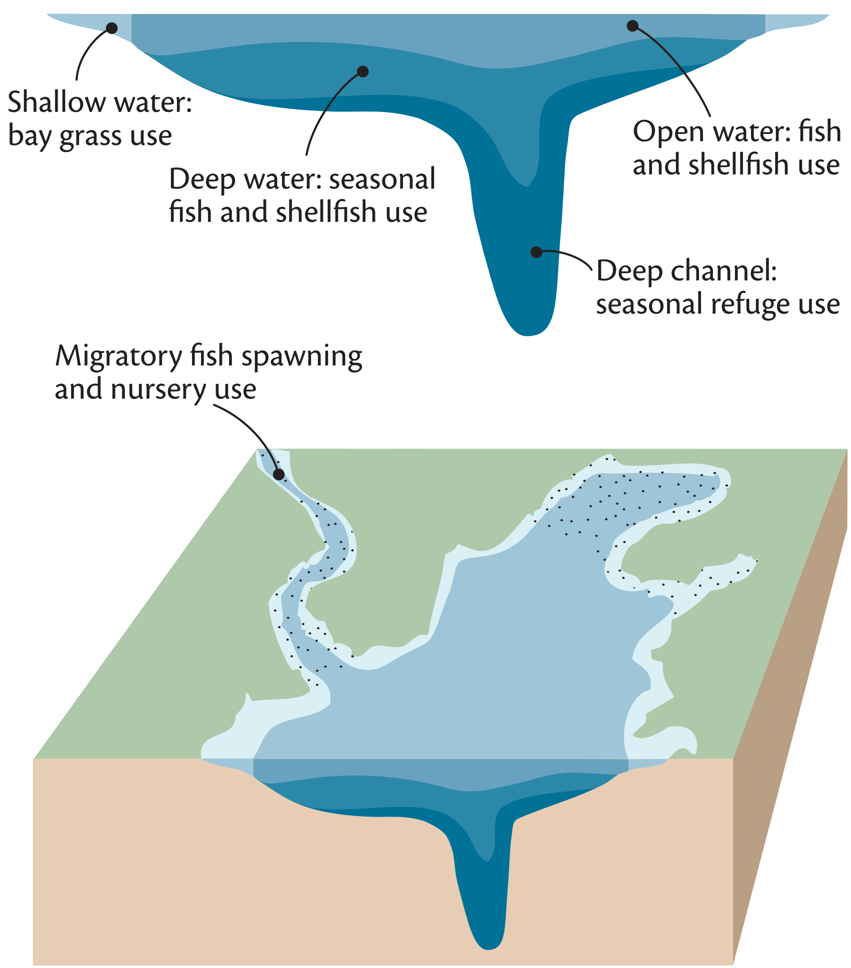
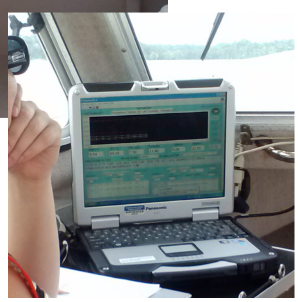


Figure 2.1. Tidal embayment diagram displaying the dissolved oxygen water quality criteria designated uses and the protection those criteria offer. (U.S. EPA2003b) Source: University of Maryland Center for Environmental Science (UMCES) Integrated Applications Network

Water clarity, Bay grasses:

Baywide, Bay grasses are assessed annually and a subset of segments is evaluated each year using the water clarity evaluations with high-speed surface water quality monitoring (DATAFLOW) deployed by a small boat operating at speeds of about 25 KT. Bay grass restoration acreage goal targets can be met in order to remove a segment from the EPA 303d impaired waters list; otherwise, the assessment is a combination of water clarity assessments and bay grass acreage. Segment assessments are based on three years of data.

Bay-wide annual assessments of the combined bay grass and water clarity assessments are desired. The DATAFLOW methodology is resource intensive. Water clarity surveys have been performed over a decade and have yet to complete a cycle of the 92 segments of the Bay.



DATAFLOW water quality monitoring sensor onboard the VIMS vessel and computer where the data is transmitted. Photos © Lea Rubin

Chlorophyll *a*:

Scientists conduct chlorophyll *a* assessments with similar methods to water clarity; however, numerical chlorophyll *a* criteria assessments are limited to waters of District of Columbia and the James River in Virginia. Analysts desire greater spatial resolution. Annual assessments on segments with numerical chlorophyll *a* criteria are made using biweekly to monthly DATAFLOW in Virginia and biweekly to monthly point sampling in the District of Columbia.

Techniques are again resource intensive, and when numerical criteria are adopted into State standards for all bay segments, resource intensive monitoring will be a further challenge to conduct annual Bay-wide assessments at high spatial and temporal resolution.

Water Quality Trends:

The Chesapeake Bay Program Office Monitoring Team works with partners to update water quality trends both in the watershed and estuary. The USGS leads updates of trends in nutrient and sediment for the watershed over two time periods: short-term (last 10 years) and long-term (since 1985). The Chesapeake Bay Program Office Monitoring Team works with Virginia and Maryland to assess attainment of water quality standards in the tidal waters. Trend updates and water quality assessment results are used to make qualitative statements about existing water quality and water quality response to nutrient and sediment reduction actions.

In 2013, the STAR Team commenced a project to measure and explain water quality trends to support the 2017 Mid-Point Assessment (MPA) of the 2010 Chesapeake Bay Total Maximum Daily Load (TMDL). Under leadership from CBP's Modeling and Monitoring Teams, USGS and University of Maryland Center for Environmental Science (UMCES), the project has four major elements:

- Analyze water quality trends in the Bay and its watershed;
- Explain factors affecting water quality trends in the Chesapeake Bay and its watershed;
- Enhance CBP models using the improved understanding of trends; and
- Inform management strategies to improve water quality.

VIMS vessel used for DATAFLOW monitoring cruises. Photo © Lea Rubin

Response to BMP Implementation:

To better understand water quality response to BMP implementation, the Chesapeake Bay Program Office Monitoring Team, UMCES, and USGS began work in 2010 to synthesize information from 40 case studies where both monitoring and information on BMP implementation were available. Three themes emerged from this research and were published in the New Insights report (2014): (1) several practices are proven effective, (2) certain challenges can impede progress and (3) more practices that target the impacts of intensified agriculture and rapid population growth are needed to improve water quality outcomes. Each theme consists of lessons that managers can use in their decision-making processes and the public can use to help raise awareness of and support for restoration efforts. Upgrades to wastewater treatment plants (WWTPs), decreases in atmospheric nitrogen deposition, and reductions in agricultural nutrient input are three major BMPs demonstrably effective in improving water quality.

But, as shown in Figure 2.2, delays between BMP implementation and observable water quality improvements, as well as counteracting influences, have impeded progress despite the implementation of BMPs. Continuing suburbanization and intensified agriculture are driving forces of declining water quality in the Bay watershed. Increased use of fertilizers, higher livestock densities and greater impervious surface area are major factors that can reduce BMP impact. Based on these challenges, managers need to be diligent in how and where both proven and innovative pollution-reducing practices are put in place, as well as in monitoring how well they work.

The results of the 2017 MPA project will be used by the Bay Program's Water Quality Goal Implementation Team (WQ GIT) and other partners to consider the adaptations needed to:

- Help prepare the jurisdictions' Phase III Watershed Implementation Plans (WIPs);
- Inform which practices to implement where in carrying out the WIPs; and
- Evaluate progress toward improving water quality.

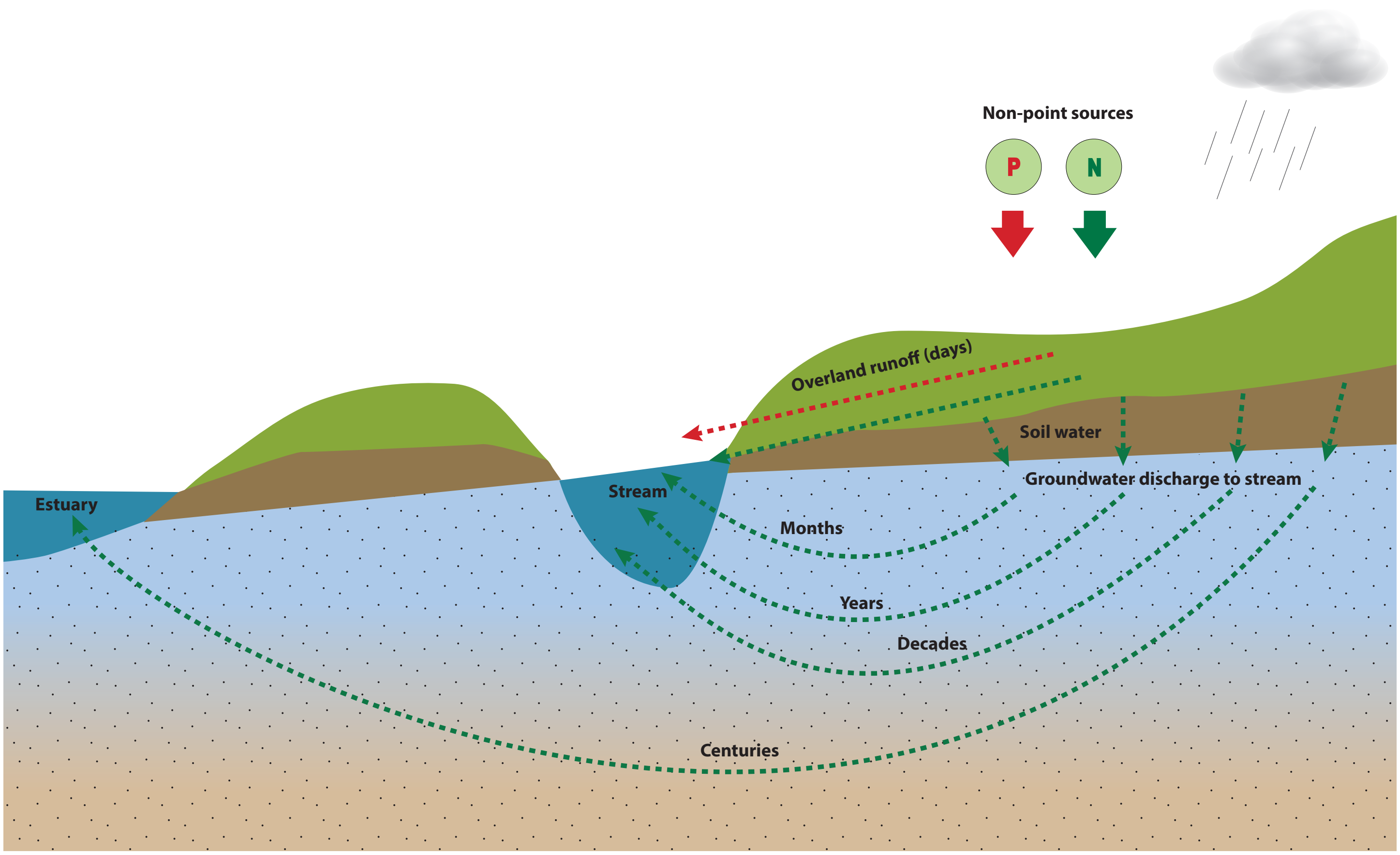


Figure 2.2. Simplified conceptual diagram of the water cycle and major sources of nitrogen, phosphorus, and sediment pollution to the Chesapeake Bay. Once in groundwater, nitrogen can take from months to years to be transported to rivers and then to the Chesapeake Bay which, combined with variable water quality and precipitation, can make detecting improvements difficult (adapted from Ator 2013, New Insights 2014)

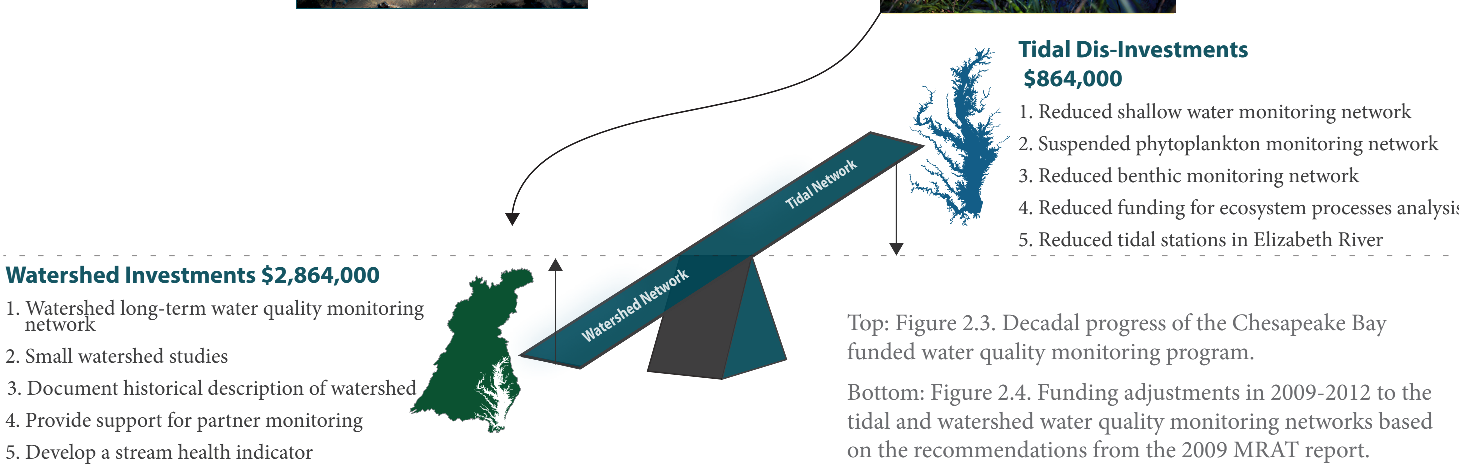
Adjusting to funding pressures:

The CBP has made numerous adjustments in the past in response to funding pressures and re-prioritization. Figure 2.3 shows the timeline of different monitoring elements of the program and how they have changed since 1985. Among the significant changes that can be seen in Figure 2.3 are the cessation of the zooplankton monitoring program in 2002 and the phytoplankton monitoring program in 2010 as the result of funding pressure, and the initiation of the shallow water monitoring program in 2003 to close a significant gap in monitoring in the tidal portion of the Bay that had been identified.

One of the largest changes in water quality monitoring for the Bay Program Partnership has been the expansion of watershed water quality monitoring beyond the primary RIM sites. This expansion was begun in 2004 and greatly accelerated after the 2009 Monitoring Realignment Action Team (MRAT) Report to the CBP Management Board. Figure 2.4 shows the recommendations of the MRAT report which led to a strategic increase of watershed water quality network sites to support assessment of the effects of management actions in a more quantitative fashion in the future.

There was also an increase in small watershed monitoring after 2009 in order to synthesize lessons learned and integrate these results into communication products to support watershed assessments and management decisions. The re-balancing of the funding support for the tidal and watershed water quality networks led to the expansion of the watershed monitoring sites to those displayed in Figure 2.5.

The CBP will need to maintain flexibility in the future to continue to make these kinds of changes to meet management needs and help in decision making in an adaptive management framework.



Top: Figure 2.3. Decadal progress of the Chesapeake Bay funded water quality monitoring program.

Bottom: Figure 2.4. Funding adjustments in 2009-2012 to the tidal and watershed water quality monitoring networks based on the recommendations from the 2009 MRAT report.

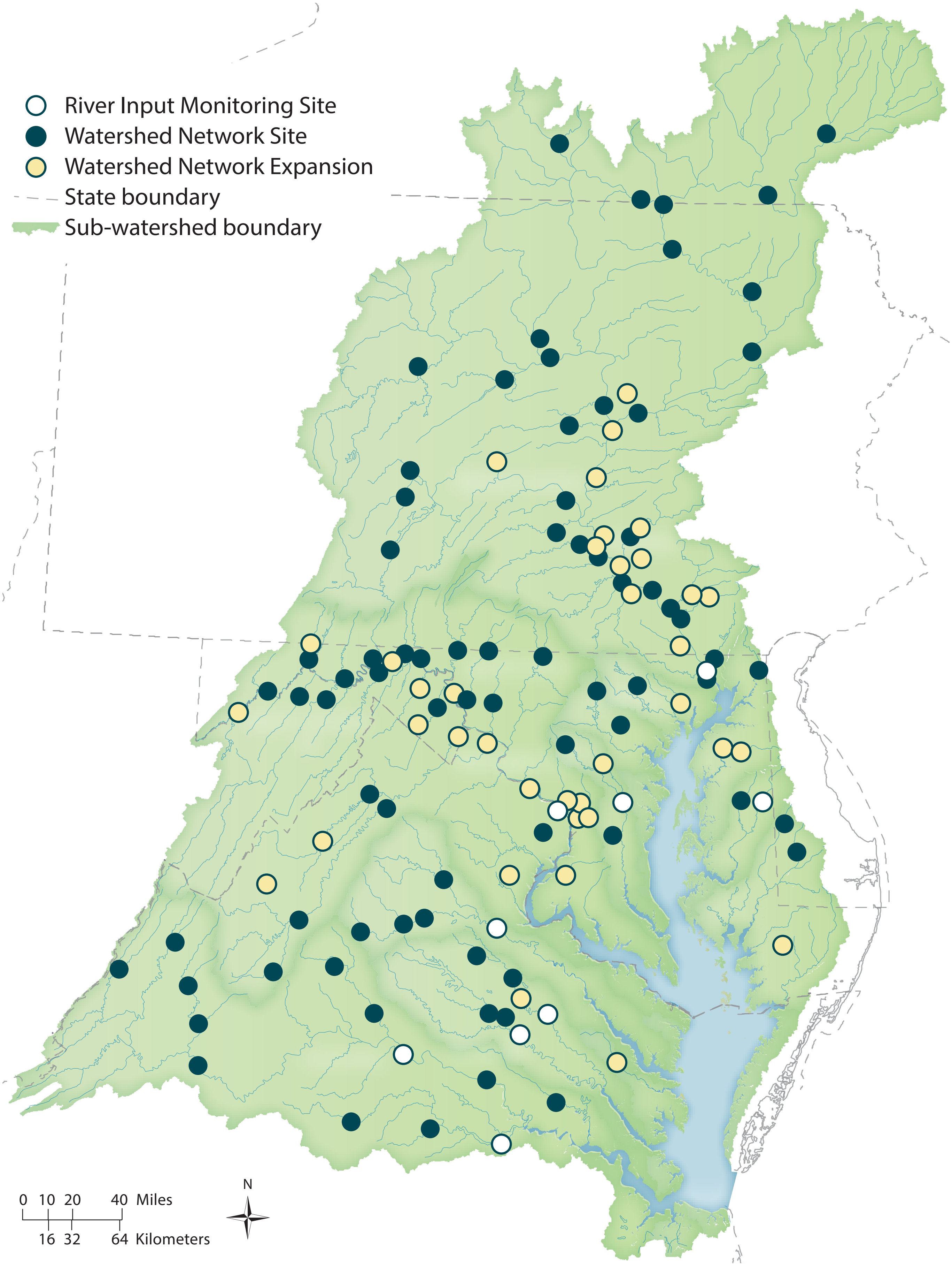


Figure 2.5. A map of the long-term (2004 and earlier) watershed water quality monitoring network sites and the expansion of the watershed network from 2009-2012 based on the recommendations from the 2009 MRAT report. The expansion sites were focused on the need for monitoring of specific land uses, with intensions to measure BMP effectiveness, and small watershed studies.

Monitoring to support Adaptive Management

Addressing the needs of the Bay Program partners to address the Bay TMDL and associated water quality standards requires a strong emphasis on adaptive management to inform decision makers. The Bay Program adopted an adaptive management framework to improve decision making (Fig. 3.1), which has these components: (1) articulating program goals, (2) describing factors influencing goal attainment, (3) assessing current management efforts and gaps, (4) developing a management strategy, (5) developing the monitoring program, (6) assessing performance and (7) revising these components based on new insights to improve program performance. The information generated from the decision framework will help formulate management strategies, evaluate progress toward goals and reduce uncertainty for decision making.

The water quality goals under the Watershed Agreement are to implement the Bay TMDL (reduce nutrients and sediment entering tidal waters) and to achieve water quality standards in the tidal waters. WIPs provide strategies for improving water quality.

The monitoring component of the CBP framework is an integrated approach that assesses progress through three primary pieces of information:

- Reporting of water quality management practices and predicting pollutant load reductions via modeling;
- Analyzing trends of nitrogen, phosphorus and sediment in the watershed; and
- Measuring attainment of dissolved oxygen, chlorophyll *a*, and water clarity/SAV criteria in tidal waters.

The monitoring is conducted for all three of these items and used each year to assess the number of practices implemented and the resultant water quality changes in the watershed and estuary. The decision framework will be a primary tool to use science to inform the management strategies. These strategies will be evaluated every two years, so that there are opportunities to continuously inform decision makers through monitoring results and new scientific insights.

Figure 3.1. Adaptive Management is the decision framework used by the CBP Partnership.

What pressures are affecting the Water Quality Monitoring Networks?

The three primary pressures affecting the CBP monitoring networks are economic, political and scientific. Geopolitical and socioeconomic dynamics—ranging from local to global—affect funding availability, funding distributions and buying power (e.g., oil price volatility affects gas prices, impacting travel costs in monitoring efforts). Political pressures include changes in CBP management priorities, such as the 2010 Chesapeake Bay Total Maximum Daily Load (TMDL) and the Chesapeake Bay Watershed Agreement, signed in June of 2014. Scientific pressures include adjusting networks to account for new scientific understanding of ecosystems and improved metrics for detecting ecosystem response to management actions.

Economic:

Economic pressures include both inflation and availability of funding for monitoring. Inflation in the U.S. has increased at an average of about 2.3% per year since the 1980s. Figure 4.1 shows the inflation rate fluctuations over the last decade. The result of inflationary pressures is that the value of a dollar to purchase goods and services declines over time. Therefore, level funding is rarely a viable long term funding strategy to support monitoring programs. When projecting funding needs out to 2025, using constant average annual inflation rates, the funding needed is about $2 million more than the approximate $5 million in core federal funding for maintaining the present tidal and non-tidal water quality monitoring operations.

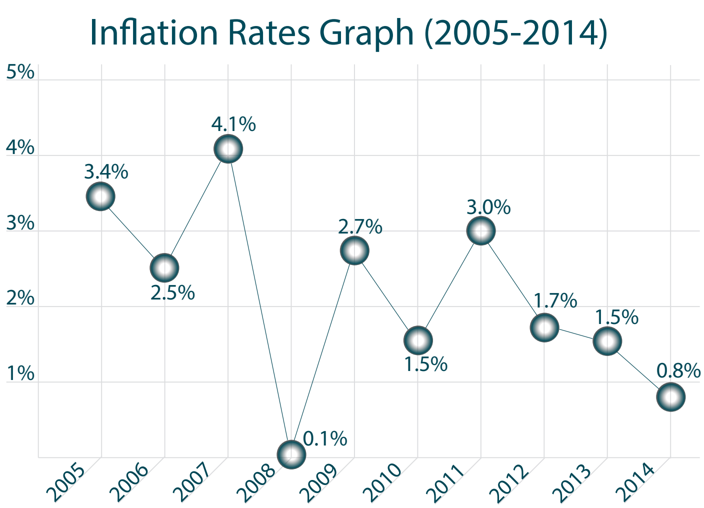


Figure 4.1. The inflation rate has fluctuated over the last decade with an average of 2.1% based on data from the U.S. Bureau of Labor Statistics. Source: Recreated from CoinNews Media Group LLC

Political:

Policy agreements such as the Bay TMDL can generate expectations of tracking and accountability while garnering attention that drives new funding into a monitoring program. Coincident with the TMDL and community-expressed needs for information in the watershed, $2 million in new funding to the Bay Program over two years supported watershed monitoring network expansion and new data analysis, helping to fill monitoring gaps.

Changing leadership can also affect management priorities and resource distribution. Policy actions place expectations on monitoring programs to assess current status and trends, as well as how management actions influence environmental health. Commitments tied to initiatives such as with the *Chesapeake Bay Watershed Agreement*, further create a need for monitoring to support decision-making and adaptive management. The evolving needs of the policy and management communities can therefore influence funding availability and impact local, state and federal distribution priorities.

Public pressure on policy and economics can further lead to adjustments in monitoring program support. For example, "*Pfiesteria* hysteria"—resulting from putatively toxic harmful algal bloom linked to human health—impacted the regional economy in 1999-2000 due to local and regional food security issues. New monitoring network designs, metrics, analysis and reporting were put in place to support assessments and feedback to managers, policy-makers and the public.

Evolving Technology

Photo © UMCES

Scientific:

Changes in scientific understanding provide insights to management and policy-makers. Since the 1970s, nutrient enrichment has become a focal point of estuarine coastal science. New and historic observations have been used to patch together an emerging concept of how anthropogenic enrichment causes changes in coastal zones (Cloern 2001), and models of eutrophication and anticipated recovery have further been developed (Kemp et al. 2004). Case studies of ecosystem recovery in the Bay watershed have demonstrated the responsiveness of the estuary and its tributaries across geographic and temporal scales (Lyerly et al. 2014). Venues that bring scientists, managers and policy-makers together to discuss new science and its implications are crucial for sustaining monitoring programs that meet a clear set of objectives understood by all parties. The interplay between science and monitoring provides a focus on measures of status and response to management actions against the backdrop of other environmental pressures, such as climate change.

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Photo © NOAA

Monitoring technology is constantly evolving and creating oppertunities for better science. Grabbing water samples off of a dock or bridge was an appropriate method for collecting water samples until in-situ sampling proved to be a more accurate method for collecting representative data. Now, there are new technologies such as continuous monitors that can collect high frequency data in-situ and remotely transmit the data to a computer. Photos on the right show examples of evolving technology.

An introduction to Building Environmental Intelligence

Building Environmental Intelligence (BEI) is an effort to meet the needs of the Partnership by discovering new approaches to sustain and expand Chesapeake Bay Program monitoring activities.

Initially, a review of the CBP water quality monitoring networks was conducted to compensate for a $944,000 gap in the budget for FY13. After the 2013 review, the CBP Partnership realized a longer term solution was needed to maintain existing water quality networks and to expand monitoring to address the new monitoring needs associated with the upcoming *Chesapeake Bay Watershed Agreement*. The CBP Management Board directed the discovery process be carried out in three phases as shown in figure 5.1.

Phase I was the short-term review of the networks to recommend possible cutbacks and gap-filling solutions to maintain the integrity of the networks during the FY13 budget shortfall. The final list of potential watershed network monitoring site losses included 18 stations. Fortunately, additional funding from the EPA ($300,000), the U.S. Geological Survey ($100,000) and state partners reduced the network losses to a total of four sites for FY13. The tidal network sustained a loss of one mainstem cruise, nutrient sampling on two summer cruises and the elimination of a planned benthic index of biological integrity analysis.

Phase II of the process—the focus of this report—was to develop approaches to sustain and enhance the water quality monitoring networks by looking for efficiencies and recommending future steps for addressing funding uncertainties (i.e., inflation and budgetary changes). Phase II began with a series of webinars to gain insights from monitoring programs around the globe. Phase II continued with topical workshops and internal meetings evaluating opportunities for sustaining and growing the CBP monitoring networks. Recommendations from this report will be used to evolve the CBP water quality monitoring networks.

Phase III is the ongoing effort to catalog monitoring needs for supporting the *Chesapeake Bay Watershed Agreement* and to develop recommendations addressing the need for increasing capacity. The Bay Program's Scientific, Technical Assessment and Reporting (STAR) Team led Phase I and Phase II of the process and is working with the Scientific and Technical Advisory Committee (STAC) and the six Goal Implementation Teams to carry out Phase III.

Figure 5.1. Building Environmental Intelligence is made up of three phases. Starting with Phase I and II which targeted the water quality needs of the CBP Partnership, led to Phase III, a means to find support for the CBP Partnership with the signing of the *Chesapeake Bay Watershed Agreement* which stretches beyond water quality.

Phase I — Water Quality Monitoring
Phase II — Water Quality Monitoring
Phase III — Chesapeake Bay Watershed Agreement

Short-Term: $944,000 Budget Cut

Purpose

To find solutions for the opperation of the CBP-funded water qulaity monitoring networks for FY13 while experienceing a significant budget cut.

Synopsis

Proposed cuts:
$55,000 to the Tidal and $700,000 to the Nontidal Water Quality Monitoring Networks.

Expected losses:
1) One January mainstem cruise
2) Nutrient monitoring on two summer cruises
3) Planned benthic analysis
4) 18 nontidal network stations

Gap-filling solutions:
Contributions from the EPA, USGS, and state partners, reduced the network losses to four nontidal network stations. The reductions to the tidal network remained the same.

Implications

The current operational and funding structures of the water qulaity monitoring networks are not sustainable.

Discovery: BEI

Purpose

To develop long-term recommendations to sustain and enhance water quality monitoring in responce to economic, political, and scientific pressures.

Synopsis

Global Webinar Series:
Nine monitoring programs from around the globe addressed our questions on monitoring network opperations, from design, and technology, to citizen science and funding.

Innovative Approaches to Monitoring Workshop:
The goal of this workshop was to explore innovative approaches to measure the attainment of water qulaity standards in the Tidal Bay using insights gathered from the Global Webinar Series.

Shallow Water Monitoring Action Team Established to develope a future vision for the Shallow Water Monitoring Program.

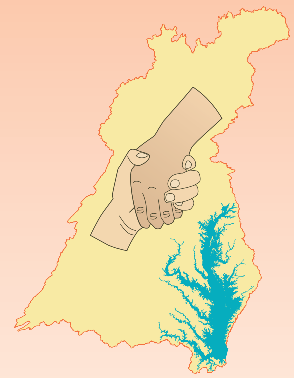
Implications

The implications from Phase II are found within this Building Environmental Intelligence report.

Expanding Efforts: Beyond Water Quality

Purpose

To enhance science support to address the priorities of the Chesapeake Bay Watershed Agreement



Synopsis

STAR Re-organization:
STAR Workgroups are now organized to support the enhanced monitoring, modeling, GIS, research needs, citizen science, and the inclusion of climate change.

2015 STAC Workshops:
Two STAC Workshops will occur in 2015 to support the integration of monitoring networks to support the assessment of outcomes in the Chesapeake Bay Watershed Agreement, as well as the integration of Climate Change.

Implications

Phase III will be an ongoing process to align integrated monitoring networks with the priorities of the Chesapeake Bay Program Partnership

What We Learned: Based on the Chesapeake Bay Program Partnership's experience with long-term monitoring

One of the hallmarks of the Chesapeake Bay Program is our continuously improving science that adjusts based on new understandings. The STAR Team has focused on three key themes for this report based on the current priorities of natural resource managers in the Chesapeake Bay Watershed.

Attainment

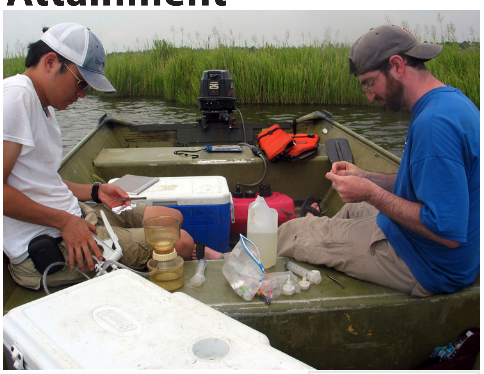


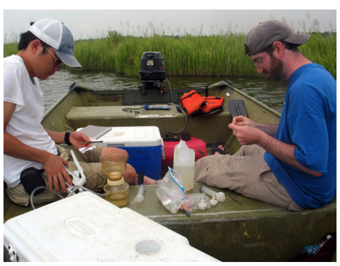
Photo © UMCES

Response

Photo © Aaron Volkening

Support

Photo © ALLARM



Monitoring for Water Quality Standards Attainment

Dissolved oxygen criteria attainment assessments. The temporal density of measurements supporting dissolved oxygen criteria attainment assessments remains the same as in 2003. The assessments rely on the biweekly to monthly water quality cruise assessments. Shallow-water, high-frequency continuous monitoring data is being collected. Assessment approaches that incorporate high temporal density data are under evaluation by the Chesapeake Bay Program.

Vertical resolution of water quality remains the same as in 2003. However, vertical profiling technology—which increases vertical and temporal data resolution for a site—has been used successfully in several regions (e.g., York and Rappahannock Rivers in Virginia, Harris Creek and Choptank River in Maryland). The technology is expensive, and its successful use has thus far been limited to more protected sites of tidal tributaries. There are no successful applications of the technology yet in the open, mainstem Bay.

Spatial resolution support of dissolved oxygen measures remains similar to 2003. There is some additional data collected from calibrations sites of the shallow water monitoring network. Some citizen monitoring data in the South River, Maryland enhanced the density of data from one site to approximately 20 sites. Additionally, some citizen monitoring data is incorporated into the 30-day mean dissolved oxygen criteria attainment assessments in Virginia. In 2014, an EPA RFP supporting greater contributions by the citizen science community led to a 2015 award anticipated to provide additional citizen monitoring coordination and potential contributions to dissolved oxygen criteria attainment assessments. Similarly, the U.S. Navy has demonstrated the potential for using autonomous underwater vehicles (AUVs) and shown CBP partners successful three-dimensional water quality mapping in protected small tributaries or sub-embayments of the South and Severn Rivers in Maryland.

Analytical options are expanding as CBP workgroups have pursued new approaches to incorporating high frequency data streams into the assessment framework.

Explaining Response to Management Actions

To develop new ideas to explain water quality trends, the Scientific and Technical Advisory Committee (STAC) and the Harry R. Hughes Center for Agro-Ecology co-sponsored the Management Effects on Water Quality Trends (MEOWQT) workshop to solicit input and recommendations on the most promising analytical approaches and corresponding data needs for detecting linkages between management practices on the land and changes in water quality within the Bay watershed. Select findings and recommendations from the workshop report (STAC 2015) include:

Trend Detection

I. Finding:

The Weighted Regressions on Time, Discharge, and Season (WRTDS) method is appropriate for estimating medium- to long-term trends (i.e., greater than 5 years) in nitrogen, phosphorus, and sediment loads at a majority of the watershed network sites.

Recommendation:

The Bay Program should prioritize work that adds the ability to estimate uncertainty to the WRTDS method.

II. Finding:

Methods (such as General Additive Models or GAMs) for detecting and describing trends in estuarine waters require further development. The inability to automate interpretation of GAM results currently limits its utility.

Recommendation:

The Bay Program should continue to develop and apply GAMs to the appropriate response variables in tidal waters, and should develop a process of "artificial intelligence" that enables automated application of GAMs.

Information Needed to Better Explain Trends

I. Finding:

Incomplete and/or inaccurate reporting of BMP implementation continues to constrain the partnership's ability to quantify BMP impact on water quality at both the local and watershed scales. Some practices—such as voluntary efforts—are not well tracked, and reporting of other practices is suspect in some cases and lacks the geographic resolution needed to help explain trends. Furthermore, the assumptions and decision rules that must be applied in order to process these datasets constrain its interpretability.

Recommendation:

CBP partners should continue efforts to improve reporting and tracking of BMPs. Bay Program leadership and staff should ensure that any partnership-derived assumptions and decision rules are applied transparently in the processing of reported BMP data.

II. Finding:

A better understanding of BMP effectiveness requires more edge-of-field, farm-scale flow and concentration data, including a more complete inventory of all pollutant sources (such as livestock populations) encompassing a greater number and variety of watersheds.

Recommendation:

The CBP should prioritize more comprehensive and improved monitoring of BMP effectiveness. This includes assessing BMP effectiveness over time, both with and without proper operation as well as required periodic maintenance.

III. Finding:

Although the existing body of water quality monitoring data for the Chesapeake Bay and its watershed is among the most robust in the world, additional continuous monitoring of water quality parameters would reduce uncertainty and improve assessment of trends in water quality. In the watershed, continuous monitoring of phosphorus and sediment loads may be more valuable than that of nitrogen.

Recommendation:

The CBP should implement continuous monitoring for locations, times, and constituents that maximize utility for improving the assessment of effectiveness of management actions.

Integrated Approaches to Explain Trends

I. Finding:

It is often more feasible to identify and explain the effects of management actions in small watersheds because of the limited number of influencing factors and pollutant transport processes relative to larger watersheds. In addition, explaining change at smaller scales addresses citizens' concerns regarding local water quality. Trends from larger watersheds can be used to assess the collective benefit of many different types of practices on downstream water quality. Efforts to link management actions with trends in water quality at the scale of small watersheds should incorporate and be complemented by studies that aim to discern trends and their drivers at regional and basin-wide scales. However, care should be taken in extrapolating findings from small watershed studies to explain trends in water quality at larger scales across the Chesapeake Bay watershed. Isolating the effects of management actions on water quality across both spatial and temporal scales will require novel approaches and the application of new analytical techniques.

Recommendation:

The Bay Program should engage in a concerted effort to energize the academic and federal research communities to conduct collaborative studies using the most capable and feasible techniques. A number of techniques hold promise for application at a range of scales, or even for integrated application across scales from small watersheds to the entire Chesapeake Bay drainage basin. Multiple tools and approaches were suggested both for small watershed studies and regional analysis in the MEOWQT workshop report. These approaches need to be evaluated to explain observed water quality changes.

Opportunities for Supporting the Water Quality Monitoring Networks

Addressing inflationary pressure for the network over time provides a significant obstacle that must be anticipated and managed by the partnership. Failure to account for the reduced purchasing power for the same investment will result in significant reductions in current levels of data collection. The solution to this problem cannot simply be to expect funding to increase given the growing expectations of monitoring due to the increased number of CBP priorities (Figure 6.1). A multi-faceted approach is required that includes prioritization, use of available technologies, partnerships, leveraging of funding and other non-traditional approaches.

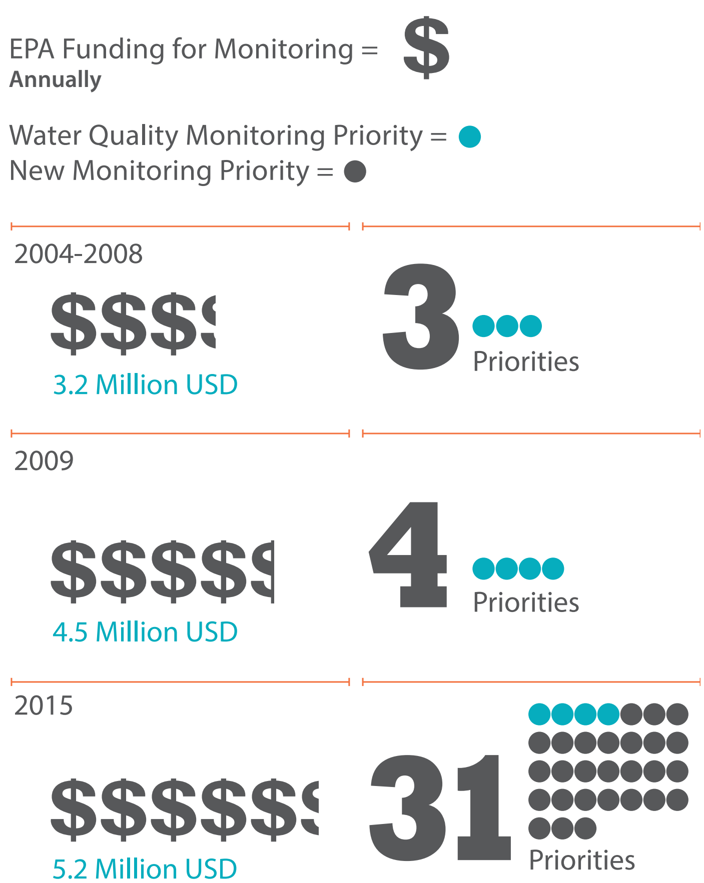


Figure 6.1. The CBP monitoring budget does not match the increasing number of monitoring priorities. Included in the graphic above is an EPA grant awarded in 2015 for the integration of citizen science and nontraditional partner data to supplement the CBP monitoring networks.

What We Learned: Based on the Global Seminar Series: Monitoring Programs from Across the United States, Ireland, and Australia

Insights on Water Quality and Ecosystem Monitoring

The STAR Team organized a seminar series to gain information about the operation and challenges of other large-scale ecosystem monitoring programs. Having information from diverse monitoring programs will help STAR consider ways to enhance monitoring to meet the needs of the *Chesapeake Bay Watershed Agreement*. In addition, citizen science and technological innovation offer ways to enhance the monitoring effort and perhaps defray some of the inflationary and budgetary pressures. Findings from the seminars were used to develop recommendations for sustaining the Chesapeake Bay Program monitoring efforts.

STAR solicited case studies from a wide range of spatial scales—from a hundredth of the size of the Chesapeake Bay watershed to twenty times larger—in order to better understand monitoring in the context of the Bay's geographic scale.

Figure 7.1 shows the location and size of the monitoring programs consulted for this activity.

A series of five questions were posed to each case study:

1. What are your monitoring network objectives and design?
2. Can you describe your operations model, including innovations?
3. Can you describe your business model?
4. What is your governance model?
5. Can you describe your monitoring successes and challenges?

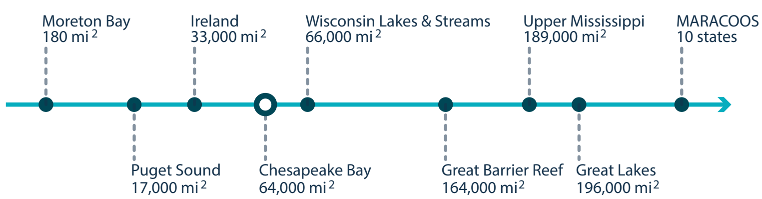


Figure 7.1. The Global Seminar Series was hosted by STAR for the purpose of exploring the operations and funding structures of other monitoring programs from Ireland, Australia, and across the United States. This map and scale of the monitoring programs who shared their insights with the Chesapeake Bay Program brings some perspective of size, as well as geographical significance of the efforts.

Findings

Every case study had similar monitoring objectives: responding to federal directives, informing decision makers, and providing support for measuring restoration progress. The priorities of decision makers were aligned with the needs of the region—such as toxics, emerging contaminants, and non-point source pollution in the Great Lakes region. Aligning priorities with stakeholder interests such as improving the safety and efficiency of maritime operations in the Mid-Atlantic, helped the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) leverage more resources for monitoring.

Challenges: Decreasing Resources

The challenge of decreased monitoring resources coupled with sustained or growing expectations for providing decision support appeared in several case studies. In the Great Lakes region, the USGS budget for monitoring toxics, emerging contaminants, and nutrients has decreased by almost half, as they are facing an emphasis on project implementation spending and de-emphasis on monitoring. The Puget Sound Partnership has to continue to find creative ways to monitor the recovery of even its iconic Pacific Salmon. The most important insights from the case studies came from unique attributes of their monitoring designs implemented to overcome some of these challenges. Several new and unique themes appeared during the seminar series: operational models, innovations, business models, partnerships and citizen science.

Photo © UAS Ground Operations

Operational Models and Innovations:

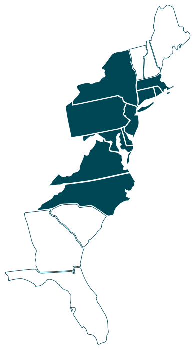
Innovations enable new insights and gain efficiencies, but many can be resource intensive.

In Ireland, for effective, focused decision-making, scientists give consideration to the contrasting physical settings present in Ireland and the associated variation in risk to water. Therefore, Ireland's National Transitional and Coastal Waters Monitoring Program (TraC) divided their monitoring effort into three networks: (1) operational, (2) surveillance and (3) investigative monitoring networks. The investigative monitoring network uses risk assessment tools to characterize the risk of water bodies, allowing for the establishment of environmental objectives and level of investment for specific waters.

In the Great Lakes, scientists and experts practice selective monitoring. The coordinated science and monitoring program rotates intensive sampling to one lake per year. In response to the monitoring budget decline for routine sampling, program managers limit the number of stations in order to maintain higher frequency sampling. Continued investigation into measuring physical, chemical and biological variables using real-time sensors (e.g., nitrogen sensors at edge-of-field sites) and the development of surrogate regression equations will potentially reduce the cost of long term monitoring.

Additionally, the Great Lakes Restoration Initiative identified five priority watersheds where best management practice (BMP) implementation was anticipated. The timely investment provided the installation of edge-of-field monitoring stations before BMPs were implemented. Therefore, monitoring took place before, during, and after implementation to document the effectiveness of the practice. There is interest in using this data to increase the accuracy of modeling BMP implementation.

To inform management actions on sewage BMPs in the Moreton Bay, Australia, the Ecosystem Health Monitoring Program utilizes sewage plume mapping by deploying stable isotopes in macroalgae around the bay to assess the nitrogen plume. This case study was able to track a decrease in sewage plumes as a response to nitrogen reducing actions. TraC also performs a macroalgal assessment on the Dublin Bay. Their approach involves the deployment of a hovercraft from the Ireland Environmental Protection Agency as a sampling platform.



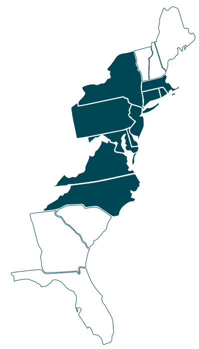
MARACOOS believes that in addition to innovative technologies, an innovative operational model is a driver of their success. MARACOOS reaches across ten states and five estuaries, with a distinct cross-jurisdictional operational model that the Chesapeake region can learn from. The research sector provides information and tools to the operations sector, often providing meaningful products that operational partners had yet to conceive. Operations staff provide feedback to help drive research and product development to address their needs more effectively. To build a more formal framework for delivering feedback from operations to the research community, MARACOOS found success holding stakeholder workshops, implementing a User Council and deploying a Stakeholder Liaison.

In undertaking the wishes of the operations community, MARACOOS invested in continuous monitoring technology. Experts use a network of underwater radars to monitor a spectrum of parameters. They believe this to have a 7-to-1 annual return on investment because of the information the monitoring program is able to deliver to their stakeholders.

Photo © Evan Schneider

Funding Models:

Inflation and availability of funding is a challange, there is no universal solution, but many creative approaches.



MARACOOS has surpassed the standard in leveraging resources within water quality monitoring systems. MARACOOS enhances collaboration across the Mid-Atlantic while maintaining the unique focus that is required by individual end users. This model allows for funding to come from a particular source for a particular theme, but then inform other themes for other end users. By leveraging data for other purposes, every federal dollar provided to MARACOOS is matched with funding support from other sources that benefits the observing system and its capabilities. MARACOOS also draws on new partners to strengthen grant proposals for collaborative monitoring . This funding model is a function of clear and effective communication between the data providers and the end users. MARACOOS also charges an annual membership fee.

On the other coast, in the Puget Sound, state and local governments imposed monitoring requirements on individual permittees through municipal stormwater permits, which resulted in significant duplication of efforts and greater overall costs. This operational model was not working for municipalities, because they were not seeing how data collected was used to inform decisions; they wanted to participate in a more meaningful way. Municipalities were encouraged by the Regional Stormwater Monitoring Program—a product of the Puget Sound Partnership Stormwater Workgroup to pool funding resources from permittees. By creating a system that allows permittees to contribute to a common funding pool, individual costs are reduced and a much more robust regional monitoring program was designed.

In response to the need for salmon recovery monitoring, the Puget Sound Partnership, Salmon Recovery Funding Board (SRFB) has provided, for nearly a decade, a minimum of 10% of its annual state-wide allocation for monitoring purposes.

Taxes are a funding source that both Ireland's TraC and Healthy Waterways monitoring of Moreton Bay have tapped into. In Ireland, an environmental fund derived from levies on plastic bags and landfills supports a suite of environmental and educational work. Ireland's TraC program receives roughly $13 million annually from the approximate $90 million fund (2012 values). Moreton Bay is evolving towards a "user pays" system similar to MARACOOS, as well as pooling funds from industries (i.e., paper, utilities and farms) similar to Puget Sound's pooling framework. Additional resources for Moreton Bay monitoring come from municipalities taxed on a per capita basis and industries taxed by per ton of nitrogen.

Photo © ALLARM

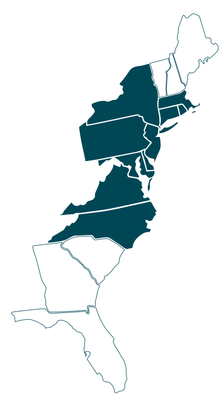
Partnerships:

Partnerships can expand capacity and diversify funding, but institutional obstacles require effort.

The USGS Great Lakes, MARACOOS and the Puget Sound Partnership have found effective methods for building partnerships. Partnering provides support whereby the overall cost of the monitoring effort is reduced, as compared to if the monitoring were done independently.

The USGS Great Lakes program formed partnerships based on shared priorities and incentivized support.

- In coordination with NOAA and NASA, USGS performs remote sensing for toxic algal bloom forecasting.
- State and local level agencies now monitor sixty beaches that were historically monitored by EPA, NOAA and State Health Departments
- The Great Lakes Observing System has been successful with gaining sponsorship for buoys for example, energy companies and universities, in exchange for public recognition (i.e. advertising approach).
- Local charter boats have installed monitors to support the Great lakes monitoring network.



MARACOOS and the Puget Sound Partnership have formed partnerships founded in their strength of communication. MARACOOS does extensive outreach activities using their Stakeholder Liaison, a position specifically designed to reach out to stakeholders. Puget Sound Partnership has designed an indicator framework geared towards managers, not scientists—including nine indicators directly monitoring management response. The Puget Sound Partnership hired social scientists to help balance their reporting framework resulting in more successful engagement of new partners.

Photo © National Park Service

Citizen Science:

It has a long, rich history of contributing to scientific discovery for environmental monitoring purposes and has tremendous potential, but it requires coordination, training and continuity.

Citizen science is a growing approach for expanding monitoring efforts through crowd sourcing science and coordinated volunteer programs. Most case studies had some element of citizen science, but the Wisconsin Citizen-Based Monitoring Program distinguished itself among the rest. The Lake and Stream Monitoring Networks—established in 1986 and 1996, respectively—in partnership with Wisconsin Department of Natural Resources, obtain high quality water resources data useful for decision-making. They also built a network of informed citizens who take action to protect natural resources.

The citizen-based monitoring program has been funded over time through EPA, UW-Extension state funds and competitive grants. They partner with nonprofits, counties, universities, municipal districts and businesses. Ultimately, the support of regional and local coordinators is key in the operation of the citizen-based programs.

Some of their greatest successes include:

- Building a network of trusted volunteers who are well-trained and willing to assist with the collection of high quality data;
- Collecting additional samples as needed for DNR water quality modeling; and
- Saving Wisconsin DNR $1,585,782 since 1986 with its secchi volunteers alone, based upon a $12.00/hour would-be-compensation.

Photo © ALLARM

Photo © WI Dept. of Natural Resources

ALLARM and the Wisconsin Citizen-Based Monitoring Program are two examples of citizen groups that are well-trained and willing to assist with the collection of high quality data.

Summary

The Global Seminar Series demonstrated that there are different approaches to operating a successful monitoring program. However, the overarching theme seen in these case studies is the critical need to connect monitoring results with management actions. It is something that most case studies feel they have yet to achieve in a satisfactory way, and they strive to improve ways for monitoring to inform management actions.

The findings from the seminar series have been grouped into three categories to help develop recommendations for the CBP:

- Innovation: We recognize that funding is going to be an ongoing battle and that we must maintain diligence and find innovative solutions.
- Partnerships: Technological innovation provides for new partnership opportunities. Partnering effectively creates new opportunities for data acquisition and shared costs.
- Citizen Science: There is a need for broader engagement, including the integration of citizen science.

Finally, sharing of monitoring approaches can be enhanced. There is a very elaborate and highly evolved scheme of trading research methods through scientific journals, conferences, and workshops. However, much less effort has been invested in sharing methods for operating monitoring networks. There should be an organized framework to share lessons learned, and new approaches to opperating and funding monitoring networks.

Implications for Monitoring in the Chesapeake Bay

The first installment of identifying alternative approaches to monitoring the Chesapeake Bay following the insights gained from the seminar series occurred on December 8, 2014. A co-sponsored workshop by STAR and STAC focused on addressing part of the challenge—monitoring the tidal Bay.

The workshop resulted in the following questions and recommendations for the CBP monitoring and management community:

Which current or emerging technologies are most cost-effective and easily utilized by an evolving Chesapeake Bay Program criteria assessment? Subsequently, how do we interpret and analyze the new data?

Recommendation:

Incorporate emerging technologies into the overall monitoring effort in order to positively redirect resources for a more comprehensive effort. This must be useful and cost-effective, and there will be a need to develop methods for interpreting data brought in by new technology.

How can we design a more efficient monitoring network to assess water quality standards attainment?

Recommendation:

Use simulation modeling and interpolation modeling techniques to develop a targeted monitoring program that measures the water quality response to management actions and environmental stressors while considering cost-effectiveness, management priorities and uncertainties.

How do we ensure that management needs are being met while maintaining sufficient confidence levels in the monitoring program? What is the role of citizen science?

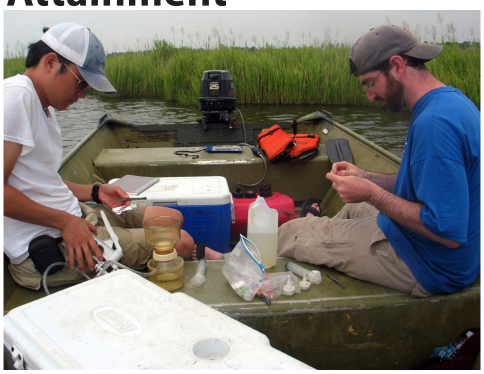
Recommendation:

A User Council—made up of monitoring providers, resource managers, citizen science representatives and the scientific community—that regularly coordinates with the monitoring team is essential in order to create and maintain a productive dialogue.

Opportunities for Enhancing the Chesapeake Bay Program Partnership's Water Quality Monitoring Networks

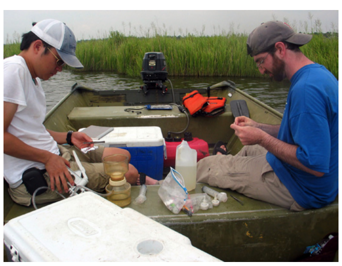
Focused on the three key themes, STAR examined current challenges facing the CBP monitoring networks. Using the lessons learned through the experience of the Chesapeake community and the discoveries from the Global Seminar Series, these are the opportunities for sustaining and enhancing the monitoring network to meet the needs of the Chesapeake Bay Program Partnership.

Attainment



Response

Support



Challenge

The Chesapeake Bay long-term, fixed-station tidal water quality monitoring program was designed to capture long-term trends, as well as seasonal and interannual variation in water quality conditions (U.S. EPA 2003a). The existing program supports 30-day mean assessments for each Bay segment; however, it was considered insufficient on its own to assess short-duration dissolved oxygen criteria (Bay Program-STAC 2012 Umbrella Criteria Report), i.e., it was poorly suited for supporting Clean Water Act 303d listing assessments of the new water quality criteria that included 7-day mean, 1-day mean, and instantaneous minimum dissolved oxygen criteria (p.177, U.S. EPA 2003a). Assessment of short-duration criteria might be accomplished using statistical methods that estimate probable attainment (p.179, U.S. EPA 2003a). Additionally, the 30-day mean dissolved oxygen assessment for a segment is based on two and sometimes a single sample per month from one to three stations; in some locations the spatial density is augmented by other monitoring programs (e.g., Shallow Water Monitoring Program) and sometimes citizen monitoring programs (e.g., Alliance for the Chesapeake Bay in Virginia, South River Federation in Maryland). There is great uncertainty surrounding estimates of the water quality conditions for the purposes of tracking progress and measuring attainment based on such low sample numbers. Further evaluation of water quality monitoring and assessment options to support measurements of Chesapeake Bay water quality standards attainment is needed.

Key issues:

- Temporal density of measurements
- Vertical resolution of measurements
- Spatial resolution of measurements
- Analytical options to make better use of existing information to inform assessments
- Resources to support any or all of the above

Approaches

Innovation

Vertical water quality profilers, or other technologies that can similarly accomplish the task (e.g. AUVs for three-dimensional monitoring assessments), are needed to support greater spatial resolution of dissolved oxygen and possibly chlorophyll *a* patterns for more accurate assessments. Some Bay segments appear near attainment for dissolved oxygen standards, but the low resolution of sampling in space and time means a greater change in water quality is necessary to detect the effect of management actions. Higher resolution sampling may also more conclusively demonstrate the attainment status of water quality criteria.

Partnerships

The National Estuarine Research Reserve System (NERRS) network, as well as NOAA's Chesapeake Bay Interpretive Buoy System (CBIBS), provides leveraging opportunities with existing infrastructure to further support status and trend assessments in water quality standards attainment.

MARACOOS is at the cusp of dedicating resources to move into the Chesapeake Bay estuary. Buoys with water quality profiling capacities may provide supplemental data for network needs and criteria attainment assessment data for Bay Program partners.

Citizen Science

Citizen scientists equipped with the same basic sensors used by state agencies to monitor water quality allow for enhanced water quality monitoring—spatially and temporally—at local scales. South River Federation has already demonstrated enhanced spatial assessment abilities. The Severn, Magothy, and Chester Riverkeepers have similarly had higher numbers of sampling stations than are feasible with the Bay Program sponsored program. Coordination is needed to seasonally enhance temporal intensity at select sites to address short-duration water quality criteria attainment assessments.

Example: The NOAA Sentinel Site Program is an Existing Infrastructure Utilizing Innovative Technology

The Chesapeake Bay area, located in National Oceanographic and Atmospheric Administration's (NOAA) Northeast Region, provides an excellent opportunity to showcase the benefit of integrating existing sentinel stations and sentinel sites into NOAA's Sentinel Site Program. The Chesapeake Bay Sentinel Site Cooperative provides integrated observations across a host of environmental monitoring programs within the Bay area. The goal of the cooperative is to provide information to Chesapeake Bay communities and managers who need to address challenges such as storm flooding, long term, local sea level rise, barrier island movement, degraded water quality and wetland loss. The information will also be useful to federal and state restoration planners and living resource managers who are addressing these challenges.

See http://oceanservice.noaa.gov/sentinelsites/chesapeake.html for more details.

Challenge

The Bay TMDL is focused on implementing practices to reduce nutrient and sediment loads to achieve water quality standards in the Bay and its tidal waters. Water quality standards in estuary waters are based on levels of dissolved oxygen, water clarity, SAV and chlorophyll a needed to support fisheries such as crabs, oysters and finfish. Water quality monitoring information is needed to assess criteria attainment in tidal waters and in the watershed to document the response of rivers to nutrient and sediment reduction efforts. Explaining the relationship between best management practices, model predictions and monitoring conditions is critical to help inform the TMDL and carry out the associated WIPs.

Approaches

Innovation

Improved Interpretation. The activities conducted to measure and explain water quality changes for the Mid-Point Assessment should consider all the findings from the STAC Management Effects on Water Quality Trends Workshop Report (2015) and implement as many recommendations as feasible. The most applicable recommendations that should be pursued include:

- Adopt the enhanced techniques to report trends, which is WRDTS for the watershed and the GAMs method for estuary waters.
- Focus on explaining changes in nutrients and sediment in distinct source sectors, including wastewater treatment plants, agriculture, urban/suburban areas and atmospheric loads of nitrogen. States are proposing that 70% of the TMDL load reduction will come from agriculture, so this sector should be the highest priority.
- Better integrate modeling tools, BMP data and research on ecosystem response (including living resource response) to explain monitoring results. Use the findings to enhance model simulations of the results.
- Continue efforts to include additional investigators from academia, federal agencies, states and NGOs to help relate changes in sources sectors to watershed and estuary water quality changes.
- Inform management strategies and biennial workplans to improve water quality. Interact with the CBP's WQ GIT and other partners to provide implications for Phase III WIPs, inform implementation of practices to carry out the WIPs and evaluate progress toward water quality milestones for the TMDL.

Monitoring Design Innovations.

- Further incorporate new technologies into networks. Possibilities include continuous monitoring both in the tidal waters and watershed. Continuous monitoring can improve load estimates to the Bay. This could be initially targeted at the RIM stations in the three largest rivers emptying into the Bay (Susquehanna, Potomac and James) to improve load estimation and understanding of nutrient and sediment delivery. If determined effective, use of the technology could be expanded to other RIM stations and to the targeted smaller watersheds.
- Enhance monitoring in distinct source sectors. Many of the monitoring stations in the watershed network include different types of land use, so it can be difficult to interpret response to practices associated with a particular source sector and very challenging to assess individual BMP effectiveness. More emphasis should be placed on monitoring in smaller watersheds with distinct land uses. The stations added to the CBP monitoring network in 2010-2012 will help meet this purpose, but there are more opportunities to reach out to academic institutions and local government partners to have a network of small watersheds addressing different types of source sectors and BMPs.
- Select sentinel sites for continuity and longevity. The sentinel sites should include those sites that can integrate results over large areas and ones in distinct source sectors, also with demonstrable effects on living resources in both tidal waters and the watershed. Bay Program models can be instructive in prioritizing locations for potential sentinel sites.

Partnerships and Combining Funds

PartnershipsFunding for monitoring is typically managed by individual agencies and designed to meet specific program mandates. Pooling funding resources provides opportunities for efficiencies and integration of priorities.

Recommendations include:

Creating a common fund. Individual costs are reduced and more robust monitoring programs are designed. For example, sugar cane growers contribute to fund a monitoring program for the Great Barrier Reef in Australia. The Puget Sound Partnership has implemented a regional monitoring program funded through contributions by individual municipal storm-water permittees. The Chesapeake Bay Trust, in cooperation with the Maryland Department of Natural Resources and EPA, is exploring this type of opportunity in Maryland, which could be a model for other areas in the Chesapeake. Figure 8.1 shows a potential conceptual diagram for pooling funds in the Chesapeake.

Leveraging monitoring data for multiple purposes to provide partnership opportunities. MARACOOS utilizes a network of stakeholder liaisons to broaden individual users' needs into a regional theme. Partners in the regional network see benefits beyond their individual contributions through leveraging.

Working more closely with local governments. Many local jurisdictions have developed monitoring programs to assess conditions and effects of publically financed improvements. The counties surrounding major metropolitan areas are good opportunities to form monitoring consortiums.

Better coordinating federal and state efforts. EPA, USGS, NOAA and other national monitoring organizations have multiple programs to address different monitoring needs. There are opportunities to better integrate these efforts to meet needs of the Bay Program .

All of these types of partnerships can result in more robust monitoring, but typically require increased management. They also require that government entities think beyond their individual programs and what is required to support them. The benefit is an integrated monitoring program, but care must be given that the initial monitoring objectives of the funding are met and communicated.

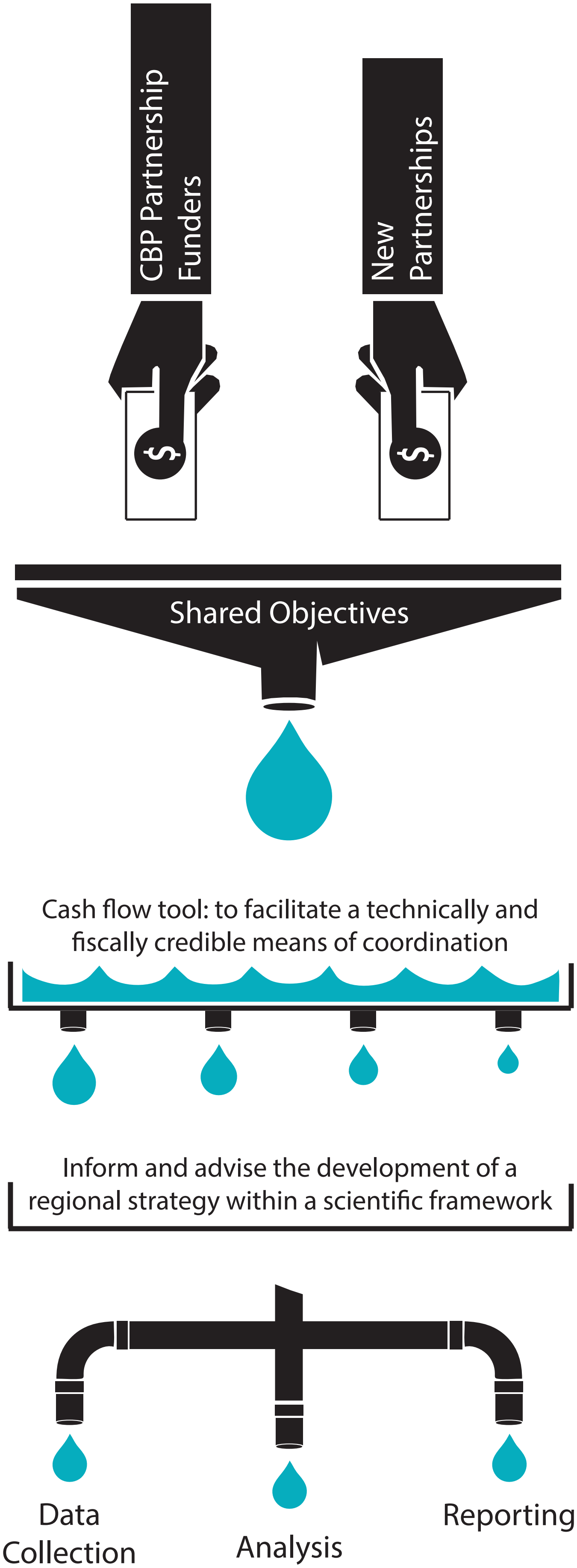


Figure 8.1. Conceptual diagram for combining funds in the Chesapeake Bay Program Partnership through enhanced partnerships

Citizen Science

Citizen science has tremendous potential but requires coordination, training and continuity. There is a trend of increasing citizen science activity with varying degrees of data incorporation into the Bay Program's monitoring programs. It is evident from the case studies that citizen science data is not free, but requires coordination and training to be sustainable. Expanding the use of citizen scientists has multiple benefits: allowing for more frequent data collection at more sites, providing more trained eyes observing the ecosystem and enhancing community engagement. The need to integrate the citizen science data with that collected by trained personnel was found important as well. Recommendations include:

Implement the Bay Program enhanced citizen science program. The new project, led by the Alliance for the Chesapeake Bay, provides a comprehensive and robust approach to use citizens monitoring and nontraditional partners. The program will: (1) set up a process to integrate monitoring partners in the Bay Program Partnership; (2) develop consistent collection methods, data management, reporting procedures and analysis; (3) coordinate and conduct training and support for monitoring program integration; and (4) coordinate with the Chesapeake Bay Program.

Use citizens monitoring to better assess local conditions. Citizen monitoring can provide enhanced information on local conditions, which is a gap in the current Bay Program networks.

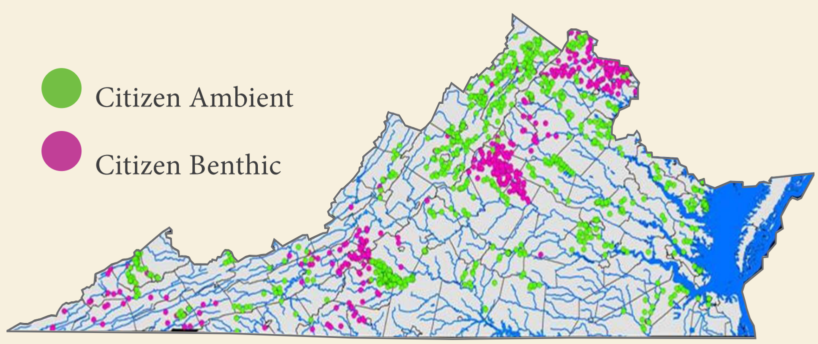
Example: Virginia Department of Environmental Quality Uses Citizen Science

The Virginia Department of Environmental Quality (VADEQ) utilizes citizen monitoring data to produce their bi-annual 305(b)/303(d) Integrated Water Quality Assessment Report. The 305 (b) report is a report on the health of all of the waters in a state. From the 305(b) report the 303(d) list of impaired and threatened streams is developed. The use of citizen monitoring data allows VADEQ to significantly increase the number of data collection sites and stream miles covered in the 305(b) assessment.

James Beckley of VADEQ leading a sampling method training session for citizen scientists. Photo © VADEQ

VADEQ qualifies citizen monitoring data into two categories for use in the report. Level III data is equivalent to water quality data samples collected by VADEQ; Level II data does not meet VADEQ collection standards, but is still useful data for prioritizing waters needing DEQ sampling.

The latest citizen monitoring activity report issued by VADEQ showed 27 Level III citizen volunteer organizations collecting data at 695 sites. There were an additional 91 Level II organizations collecting data at 748 sites. VADEQ determined that 4,124 stream miles, 40 square miles of estuaries and 27,975 acres of lakes and reservoirs were monitored by citizens groups at either Level II or III. The data being collected include benthic macroinvertebrates, dissolved oxygen, pH, temperature and E. coli.



Map of Citizen Science sites in Virginia. Photo © VADEQ

Challenge

How can the Chesapeake Bay Program's water quality monitoring networks sustain or improve the quality of monitoring data while facing inflationary pressures and funding uncertainties?

Concern over sustainable funding for the water quality networks initiated the Building Environmental Intelligence process. Federal funding and state match funding, in general, is being reduced or at best continued at a level ceiling. The CBP needs to be proactive in its long-term outlook in funding the needed monitoring or the program is at risk of not having the necessary information for tracking progress towards goals and for understanding why change is or is not occurring.

Inflationary pressure alone is a constant threat to effectiveness of the monitoring network over the long-term. As shown in Figure 8.2, by the year 2025 the current network funding will have lost almost 40% of its value with a projected 3% annual inflation rate. Inflation alone will create an almost $2 million deficit in funding the current network.

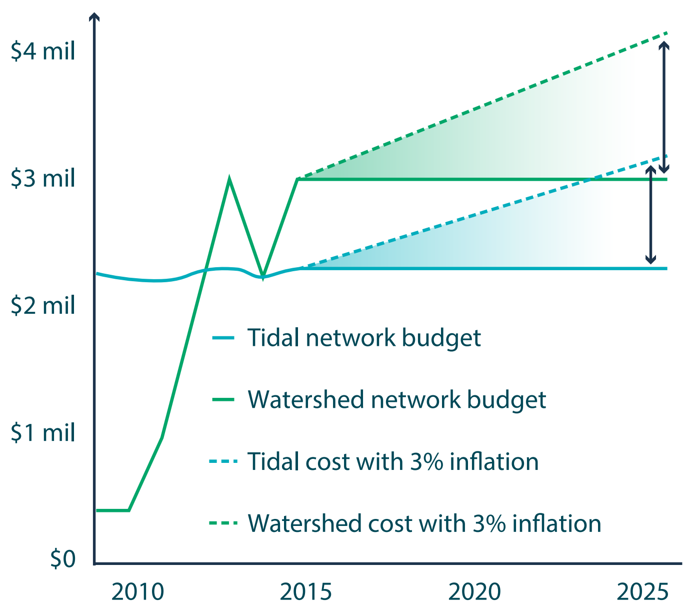


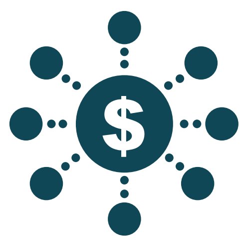
Figure 8.2. Graph of the projected inflationary pressure facing the CBP tidal and watershed water quality monitoring networks leading up to the Chesapeake TMDL reporting year, 2025. The estimated 3% inflation rate is the rounded rate of change from the initiation of the CBP funded monitoring program using data from the U.S. Bureau of Labor Statistics.

Approaches

A number of insights were gained from the Global Seminar Series that may help to address future shortfalls in funding of the monitoring networks and the analysis and interpretation of data.

Innovation and Combinging Funds

Innovative Technologies. Technology related to the collection of water quality data has evolved rapidly over the last decade. Reliable sensors that may be deployed and collect data continuously have been developed for many water quality constituents. These sensors can collect huge volumes of data that greatly expand our understanding of water quality changes that occur both in space and time. Although these sensors collect data in an automated fashion, they do require maintenance to assure that the quality of data being collected is maintained. They also provide huge amounts of data that must be processed and analyzed.



Innovative Funding. Current trends in federal agency and partner funding suggest that increases allowing the water quality monitoring networks to keep pace with inflation are unlikely. Opportunities for supplemental resources to those provided by government agencies were examined in the Global Seminar Series.

The Puget Sound Partnership implemented a regional monitoring program funded through contributions by individual municipal storm-water permittees. By creating a common fund, individual costs are reduced and more robust monitoring program was designed. Similarly, sugar cane growers contribute to fund a monitoring program for the Great Barrier Reef in Australia. A portion of the funding for Ireland's coastal monitoring program comes from fees for using plastic bags. An advantage of these approaches is that the cost of monitoring is distributed to multiple entities, which makes the overall funding for the network more resilient.

Grants and windfalls are not seen as a way to fund the backbone of the monitoring effort or offset inflation, but may provide opportunities for shorter duration studies or analysis of data that already exists.

There is an acknowledged gap in the analysis of data that is collected by the CBP. Taking advantage of grants and windfalls should be encouraged and may be a way to grow academic involvement.

Certain elements of the monitoring networks may be cyclical and not require annual funding. It may be possible to shift to semi-annual data collection in some instances. This could help with overall shortfalls in funding for the monitoring network, and also help with other known gaps such as funding for analysis and development of communication products.

Citizen Science

Citizen science and non-traditional partners may or may not be an option in future years for helping to meet funding shortfalls caused by spending cuts or inflation. The current funding available enables the Chesapeake Bay Program and its partners to operate what we consider to be the backbone of the water quality network. This is monitoring that is essential to the program and in some cases the current effort falls short of what would be recommended. Operation of the network often requires specialized equipment or collection of data in conditions and from locations that can prove dangerous without specialized training. An example of this is sampling on large rivers from bridges or during storm conditions. It is not realistic that this type of monitoring entirely be offset by citizen monitoring; however, there may be opportunities where citizen volunteers could be utilized.

Decision Support

In order to budget funds efficiently, there should be constant and clear communication between the data users and data providers. This was accomplished successfully by MARACOOS with their use of a User Council and Stakeholder Liaison. Prioritization of monitoring expectations will be difficult; however with regular input from stakeholders the monitoring networks can adapt based on the stakeholder's needs.

Partnerships

The Chesapeake Bay Program should consistently look for partnering opportunities with local and regional entities. Some of this already occurs. Partnering can provide efficiencies whereby each partner benefits by co-locating monitoring efforts and the overall cost of the monitoring effort is reduced as compared to if the monitoring were done independently. Ultimately, the monitoring effort may be more stable because multiple entities are contributing smaller amounts. These types of partnering opportunities should be sought out, but do require flexibility and may require certain changes in approach in order to accommodate all partners.

Example: The Habitat Goal Implementation Team has a creative partnership appraoch for Brook Trout Monitoring

The CBP Habitat Goal Team reached out to new partners to enhance monitoring for Brook Trout across the Chesapeake watershed. The Eastern Brook Trout Joint Venture (EBTJV) worked with the University of Massachusetts Amherst (UMass) to develop a monitoring approach (described in Conservation Genetics, 2012, issue 13: 625-637) to estimate Brook Trout populations across the Northeast. The CBP provided a grant to UMass to coordinate the same type of monitoring among 5 states in the Chesapeake Bay watershed to ensure a consistent approach in reporting of progress toward the CBP brook trout outcome.

Photo © UMCES

Summary of Water Quality Recommendations in Phase II of Building Environmental Intelligence

STAR concluded that in order to sustain and allow for the adaptive management of the CBP water quality monitoring program, we must focus on the implementation of the following six key elements: Decision Support, Partnerships, Citizen Science, Innovations, Combining Funds, and Leadership.

The vision and implementation of the recommendations from Phase II of Building Environmental Intelligence will help to guide the Chesapeake Bay Program Partnership in Phase III – to support the Partnership in being accountable to the *Chesapeake Bay Watershed Agreement*.

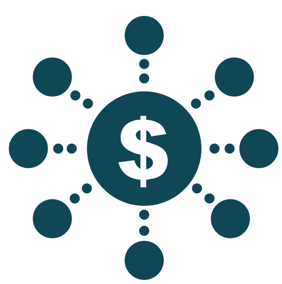
Decision Support

Partnerships

Citizen Science

Innovations

Combining Funds



Leadership

Decision Support

The monitoring and analysis to explain water-quality change will primarily focus on supporting the TMDL and attainment of standards. Addressing the needs of CBP partners to address the Bay TMDL and associated water quality standards requires monitoring to support adaptive management and communication of results to inform decision makers. The monitoring results will be used by the CBP's Water Quality Goal Implementation Team and other partners to consider adaptations needed to evaluate progress toward improving water quality, help prepare Phase III watershed implementation plans and inform implementing practices to carry out the WIPs.

A User Council should be established to improve interaction between the CBP monitoring programs and decision makers. The council could serve as an advisory entity to provide guidance on monitoring and associated products most important for addressing outcomes in the *Chesapeake Bay Watershed Agreement*. The membership should include: (1) Chesapeake Bay Program Goal Team Chairs and Coordinators as decision makers with (2) STAR and state agency monitoring leads representing the data providers. The council would facilitate ongoing communication for the end users and those who rely on the groups that provide monitoring data and products.

Citizen Science

Photo © ALLARM

Citizen science has tremendous potential but requires coordination including oversight and quality control, training, and continuity. There is a trend of increasing citizen science activity with varying degrees of data incorporation into monitoring programs. It is generally felt that expanding the use of citizen scientists has multiple benefits: allowing for more frequent data collection at more sites, providing more trained eyes observing the ecosystem and enhancing community engagement.

Citizen science can help supplement Chesapeake Bay Program water-quality monitoring efforts in the watershed and tidal waters. Utilization of citizen science for measuring and tracking water quality could help identify areas of high nutrients and sediment to better target local implementation of practices. Areas of poor tidal water quality can be further identified. However, citizen science cannot replace CBP networks due to specialized equipment that can be required and safety issues for sampling during storm events.

The Alliance for the Chesapeake Bay starting in 2015 will receive about $2.5 Million over the next six years to integrate citizen science and nontraditional partner data into the CBP monitoring networks. This EPA investment will add approximately $400,000 more per year to support monitoring in the Chesapeake Bay and watershed.

Innovations

Photo © Konny Zucher

Technological innovations are beneficial from two aspects: improved interpretation of the monitoring information and improvements in the frequency and collection of data. Inferred water quality attainment approaches illustrate how present monitoring results for dissolved oxygen at one time scale can provide effective understanding of water quality at other time scales (STAC Umbrella Criteria report 2012). New statistical techniques such as WRTDS and GAMS are new approaches that will improve our ability to analyze and understand water-quality trends in the bay and its watershed. Other analysis techniques may allow for more detailed data collection at fewer sites without a loss in analytical power. The CBP should consider several opportunities to utilize new technologies and innovative analysis techniques, including:

- Continuous monitoring, which can improve load estimates of some nutrients and sediment to the bay and should be considered for the major rivers entering into the bay (such as the Susquehanna, Potomac and James or all of the RIM stations).
- Improve measurements of dissolved oxygen in tidal waters. Vertical water quality profilers, or another technology that can similarly accomplish the task (e.g., Navy demonstrated the use of AUVs to get 3-dimensional monitoring assessments) are needed to support greater spatial resolution of dissolved oxygen patterns for more accurate assessments and attainment of standards.
- Enhanced monitoring in distinct source sectors. Many of the monitoring stations in the watershed network include multiple types of land use so it can be difficult to interpret response to practices associated with a particular source sector and very challenging to assess individual BMP effectiveness. More emphasis should be placed on monitoring in distinct source sectors and monitoring smaller watersheds with distinct land uses.
- Sentinel sites to assess long-term changes in water quality as practices are implemented should be considered for the watershed and tidal waters.

Partnerships


Photo © ALLARM

The Chesapeake Bay Program should expand partnering opportunities with local and regional entities. While the CBP has effectively partnered between federal and state agencies on water quality networks, there are opportunities to expand by working with local and other regional groups. Opportunities that should be pursued include:

- Working more closely with local governments. Many local jurisdictions have developed monitoring programs to assess conditions and effects of publically financed improvements. The counties surrounding major metropolitan areas are good opportunities to form monitoring consortiums.
- The NERRs and CBIBS networks provide leveraging opportunities with existing infrastructure to further support status and trend assessments in water quality standards attainment.
- The Chesapeake Bay Program is well positioned to serve as a bridge between the research communities, resource managers and monitoring communities. In order to identify and translate needs that lead toward the development and successful communication of meaningful information, the CBP should function as a facilitator of these enhanced partnerships.

The CBP should identify opportunities to expand monitoring partnerships that can increase monitored locations, coordinate collection efforts and share data. Some partnership opportunities were explored during the MRAT process in 2009, recommendations can be found in the Monitoring Needs and Partnership Opportunities Assessment.

Combining Funds

Having agencies contribute funding into a common pool of resources provides opportunities for efficiencies and integration of priorities. This will be a change from the current method of individual agencies managing to meet specific program mandates and would allow the water quality monitoring networks to better keep pace with inflation. By creating a common fund, individual costs are reduced and a more robust monitoring program is possible. An advantage of these approaches is that the cost of monitoring is distributed to multiple entities, which makes the overall funding for the network more resilient.

Leadership

All of these recommendations can result in more robust monitoring, but typically require increased management to succeed. The CBP has an opportunity to show leadership to improve monitoring through the five previous recommendations. Leadership will be needed within the CBP so government entities think beyond their individual programs and recognize wider partnership benefits. Continued communication with the global monitoring community will also provide a mechanism to share ideas of how to build more integrated monitoring programs.

Considerations for Next Steps in Phase III of Building Environmental Intelligence

The *Chesapeake Bay Watershed Agreement* will require a broad range of monitoring to assess progress toward its goals and outcomes. Some outcomes have very well developed indicators and associated monitoring programs (e.g., water quality standards attainment, land conservation). However, as of the spring in 2015, many outcomes in the Watershed Agreement do not have associated indicators with sufficient monitoring networks and assessment protocols to support effective accountability in tracking change over time. Given the high cost of monitoring, the Chesapeake Bay Program needs to identify ways to better leverage existing networks and work with new partners.

STAR has begun to work with the Goal Implementation Teams to identify the monitoring needed to support the outcomes of the *Chesapeake Bay Watershed Agreement*. This is the first step of the BEI Phase III process. STAR and STAC will be leading an "Integrating Monitoring Networks" Workshop in the spring of 2016 to focus on monitoring and assessing progress of the Chesapeake Bay Watershed Agreement outcomes. The goal of this workshop is to develop approaches and recommendations on how to leverage existing Chesapeake Bay Program Partnership monitoring networks, filling gaps and creating efficiencies for measuring and reporting on the outcomes. Workshop results will help the CBP identify opportunities to provide new and sustainable monitoring support for tracking progress of the outcomes.

The CBP Partnership committed to work towards the progress of the 31 outcomes in the *Chesapeake Bay Watershed Agreement* such as Fish Passage, Protected Lands, and Climate Resiliency. As part of the Adaptive management decision framework of the CBP, all outcomes must include a monitoring component. Phase II of BEI will help to develop and enhance monitoring to support this new monitoring effort.

Chesapeake Bay Program
Science. Restoration. Partnership.

This report summarizes the opportunities available to the Chesapeake Bay Program Partnership to Build Environmental Intelligence

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