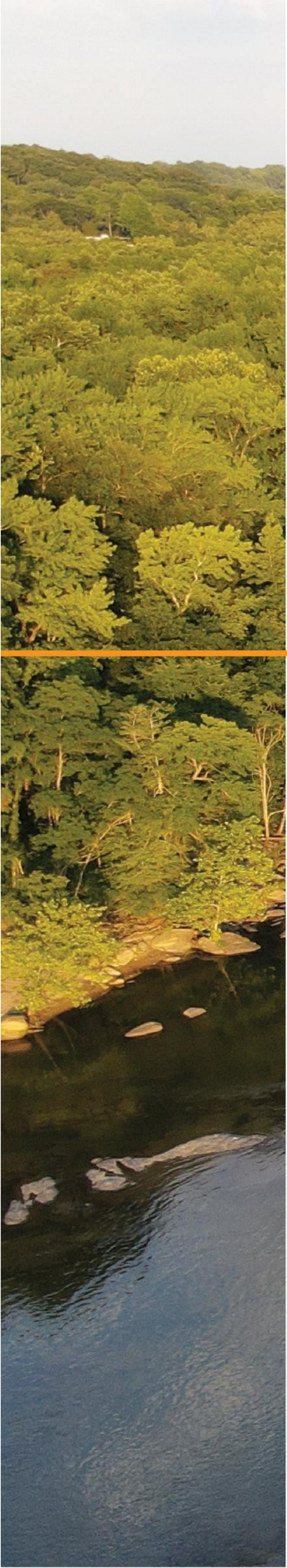

Achieving Water Quality Goals in the Chesapeake Bay: A Comprehensive Evaluation of System Response

An Independent Report from the Scientific and Technical Advisory Committee (STAC)
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Executive Summary

In 1983, the governors of Maryland, Pennsylvania, and Virginia, the mayor of District of Columbia, and the U.S. Environmental Protection Agency (EPA) administrator signed the first Chesapeake Bay Agreement. The one-page agreement acknowledged the "historical decline in the living resources of the Chesapeake Bay" and committed to addressing a major cause of the decline by pledging "to fully address the extent, complexity, and sources of pollutants entering the Bay." Subsequent Bay agreements have expanded the number of partners and the number of restoration goals, but reducing two key pollutants, nitrogen (N) and phosphorus (P), has remained a centerpiece of every subsequent Bay agreement.

Over four decades, water quality and pollutant reduction goals have been established and refined. Under authority provided by the Clean Water Act, the Bay jurisdictions and EPA adopted Bay water quality standards in 2003. The water quality standards identified living resources as the designated use of the Bay and defined numeric water quality criteria deemed necessary to support the designated use. Numeric water quality criteria were set for dissolved oxygen, water clarity, and chlorophyll *a* across five different Bay habitats: shallow water (submerged aquatic vegetation [SAV]), open water (fish and shellfish), deep water (seasonal fish and shellfish), deep channel (seasonal refuge), and migratory fish spawning and nursery.

Nutrient reduction goals were first written into the 1987 Bay agreement (and quantified in 1992 amendments). When nutrient reduction efforts failed to attain Bay water quality standards, EPA developed the country's most expansive total maximum daily load (TMDL) in 2010. The TMDL set nutrient and sediment load targets for the Bay that, if met, were predicted to achieve the water quality standards. The TMDL established that all management actions needed to achieve the target pollutant loads (214.9 million lb/yr of N, 13.3 million lb/yr of P, and 18,587 million lb/yr of sediment) should be in place by 2025. The Bay states and District of Columbia wrote watershed implementation plans (WIPs), which were approved by EPA, describing approaches to reduce nutrients and sediment to meet the load targets.

There has been progress in addressing nutrients since the first Bay agreement. The Chesapeake Bay Program (CBP) watershed model estimated that N loads to the Bay were reduced from 370 million lb/yr in 1985 to approximately 258 million lb/yr in 2021 and that P loads were reduced from 29 million lb/yr in 1985 to approximately 15 million lb/yr in 2021. Wastewater treatment plant upgrades provided the majority of these reductions. According to CBP estimates, the TMDL sediment limits have been met. Achieving these pollutant reductions in the face of significant population growth and development throughout the watershed is a noteworthy accomplishment.

However, modeling and monitoring evidence indicates that current efforts to reduce nutrient loads will not meet the TMDL targets. In addition, the CBP's ambient water quality monitoring program indicates that estuary water quality has been slow to respond to realized nutrient and sediment reductions in many regions of the Bay. The CBP has estimated that 27% of the Bay area met the water quality standards in 1985. By 2020, that figure had only risen to the mid-30% range. The consequences for living resources have not been fully evaluated.

This report summarizes the Scientific and Technical Advisory Committee (STAC) evaluation of why progress toward meeting the TMDL and water quality standards has been slower than expected and offers options for how progress can be accelerated. The report evaluates the effectiveness of current actions to reduce pollutants (N, P, and sediment) from wastewater treatment point sources and from farms and developed lands (nonpoint sources). Chapter 4 provides results from the evaluation of the water quality response in the estuary (dissolved oxygen, water clarity/SAV) to the realized nutrient and sediment reductions. Finally, chapter 5 summarizes what is known about the response of fish, shellfish, and other living organisms to changed water quality conditions. Decision-relevant uncertainties at each stage of program implementation and assessment are identified and their implications for progress considered.

Three overarching conclusions emerged from these evaluations. First, achieving pollutant reduction and water quality improvements is proving more challenging than expected. Second, the Bay system faces permanent and ongoing changes in land use, climate change, population growth, and economic development that will challenge notions of restoration based on recreating historical conditions. Third, opportunities to meet these challenges exist but efforts require changes and new approaches to implementation, planning, and decision-making. Specific findings of this evaluation supporting these conclusions and associated policy implications are summarized here.

Achieving the pollutant targets of the Bay TMDL

Finding: Existing implementation actions to reduce nonpoint sources of nutrients are insufficient to achieve the TMDL.

Meeting the TMDL depends to a significant degree on reducing nonpoint sources of pollutants. Agriculture is the largest remaining source of nutrient loads to the Bay, and urban nonpoint sources are the fastest growing. To date, CBP partner efforts to reduce nonpoint sources of nutrients have not produced sufficient levels of best management practice (BMP) implementation to meet the TMDL, and the implementation that has occurred may not be producing the pollutant reductions expected.

The CBP acknowledges the challenges of generating enough nonpoint source BMP adoption to meet nutrient reduction goals, particularly for N. Tens of millions of pounds of N reductions are needed to achieve the TMDL goal, but a decade of implementation since 2010 has produced only 2 million lb/yr of nonpoint source N reductions (as estimated by the CBP watershed model). The difference between water quality practices implemented and practices needed is termed an implementation gap and has multiple potential causes. Nonpoint source incentive programs are generally designed to encourage voluntary adoption of BMPs by covering a portion of the costs of installation. While successful at encouraging the adoption of practices that generate benefits to landowners (e.g., enhanced soil productivity), such programs do not provide sufficient incentives for adoption of practices with the largest pollutant reduction potential. Evidence also suggests that nutrient load reduction gains that have come from BMP implementation efforts are being partially offset by regional increases in imported nutrients. For example, increases in livestock numbers mean more N and P are imported into a region in the form of animal feed without corresponding increases in exports of animal products or by-products (i.e., manure). This nutrient mass imbalance leads to an accumulation of nutrients in the watershed that in turn may be transported to the Bay in runoff.

Evidence also suggests that the nonpoint source pollutant control efforts may not be as effective at producing nutrient reductions as expected by the CBP, resulting in a response gap. The existence of a response gap means that less progress is being made in meeting TMDL pollutant targets than represented by current accounting systems, and more nonpoint source controls will be needed to produce needed pollutant reductions. The response gap for phosphorus may be particularly large. While CBP modeling suggests that P reductions targeted by the TMDL are nearly achieved, analysis of water quality at riverine monitoring stations finds limited evidence of observable reductions in P concentrations. Nutrient response gaps have many potential causes, including long lag times for actions taken on the ground to produce reductions at water quality monitoring stations. However, response gaps could have a variety of other causes, including incomplete understanding of how people use nutrients on the landscape (particularly animal manures), overestimating nonpoint source practice effectiveness, incomplete or inaccurate information about nutrient inputs, landscape changes, and insufficient monitoring. Identifying and addressing response gaps is challenging, and this challenge is exacerbated by the TMDL accounting framework that tasks water quality managers with counting practices implemented and thereby diverts attention from the question of whether those practices generate the predicted pollutant reductions.

Together the implementation and response gaps represent significant challenges to the CBP's ability to achieve the nonpoint source pollutant load reductions as required by the TMDL. Uncertainty and complexity of nonpoint source-generating behaviors and processes confound assessment of these gaps. These challenges are not unique to the CBP, with many large-scale eutrophication management efforts (e.g., Great Lakes, Gulf of Mexico, Baltic Sea) also facing similar challenges for reducing watershed-scale nonpoint source pollutants.

Policy implication: There are opportunities to further reduce nutrients from nonpoint sources, but changes to programs and policies need to be considered.

Additional funding of existing implementation efforts is unlikely to produce the intended nutrient reduction outcomes. Achieving and sustaining substantial nonpoint pollutant reductions will likely require development and adoption of new implementation programs and tools.

Nonpoint source implementation efforts could be improved by shifting the focus from a census of implemented practices to an accounting of load reductions. Finer spatial scale modeling and monitoring could further identify high nutrient loss areas and operations and be used to consider more effective treatment options. Additionally, new financial incentive programs such as pay-for-performance or pay-for-success programs offer opportunities to reward treatment of high-loss areas or operations and to encourage adoption of highly effective practices that land managers may not consider under standard cost-share programs. These approaches would provide both the identification of high-value opportunities and the incentives for landowners to take advantage of them.

Achieving large-scale reductions in nonpoint sources of nutrients depends on adequately addressing regional nutrient mass imbalances. Many regions of the Bay watershed exhibit mass imbalances, where nutrient imports to a region (animal feed, fertilizer, atmospheric deposition) exceed nutrient exports from the region (agricultural products harvested, manure transport). The problem is particularly acute in areas of intensive livestock production. A variety of options is available to address these imbalances, including implementing technologies that reduce nutrient inputs, improving manure distribution (from surplus to deficit areas), and exporting nutrients from the watershed.

Most nonpoint source policies are based on allowing land managers to decide whether or how to reduce nonpoint source pollution. Such an approach is often reasonable given the number and diversity of people involved in producing nonpoint pollutants. However, the extensive history of nonpoint policy illustrates the limits of relying on voluntary actions. New and refined requirements in case-specific circumstances may be necessary to achieve substantial progress in reducing nonpoint source loads. Such requirements need not be overly costly to land managers if land managers are given flexibility in how to meet the pollutant control requirements and are provided financial assistance (similar to how some states are upgrading wastewater treatment plants).

Given uncertainties around the complexity and diversity of nonpoint source pollutant processes, not all alternatives will work as expected. Nevertheless, program change, innovation, and experimentation are needed. Institutional innovation could be facilitated by considering ideas such as sandboxing. Sandboxing is a formalized way to test and evaluate the efficacy of new rules and programmatic approaches to nonpoint source or water quality management without disrupting the operation of existing implementation efforts. Sandboxing also requires a commitment from management agencies to make larger programmatic changes if the sandboxed change demonstratively improves outcomes.

Achieving the water quality standards

Finding: Preliminary analyses suggest that nutrient load reductions have not produced the expected level of improvement in estuary water quality, and this response gap is particularly pronounced in the Bay's deep channel.

Evidence indicates that the nutrient and sediment load reductions realized to date have led to improved water quality conditions in some portions the Bay, but these nutrient load reductions have not produced the expected level of increased dissolved oxygen in most of the Bay's habitats. This shortfall, or water quality response gap, is particularly pronounced in the Bay's deeper waters and could have significant consequences because of the large nutrient reductions required to achieve the dissolved oxygen criteria in the deep water and deep channel habitats. Quantification of a response gap for water clarity is not possible because of the absence of a formal predictive model, but progress in improving water clarity and expanding SAV remains below the stated goal.

A variety of factors may explain the response gap in water quality conditions to pollutant load reduction. For example, recent studies suggest that higher water temperatures offset roughly 6–34% of the water quality improvement from N reductions. Furthermore, Bay water quality response will differ across habitats and may be nonlinear in some. That is, water quality response to pollutant loads may occur fairly slowly until conditions are sufficient to accelerate improvements. The thresholds where conditions more rapidly improve are often called tipping points.

Identifying response gaps and their potential causes is limited by the design of the CBP monitoring networks. The current estuary monitoring program is more attuned to assessing attainment of water quality criteria than understanding processes underlying water quality response. For example, nonlinear interactions (tipping points) have been identified at the scale of subsystems in the Bay, but monitoring to determine the thresholds associated with either degradation or restoration is not currently done. Monitoring designs may need to be modified, and coupled with research and modeling efforts, to better understand the range of conditions and relationships between stressors and water quality standards attainment.

Policy implication: Additional nutrient reductions will improve water quality, but water quality criteria may be unattainable in some regions of the Bay under existing technologies.
The CBP is trying to achieve water quality standards in a highly altered environment that will continue to change in ways with no historical precedent. Climate change is producing increases in water temperature and changing precipitation patterns that confound efforts to achieve water quality goals. The deep channel dissolved oxygen level has proven to be relatively intransigent to load reduction efforts, but this area often serves as the primary policy focus for CBP work. This reality may necessitate assessing the costs and tradeoffs of attaining numeric water quality criteria in specific situations and locations and adapting numeric goals if desired.

Managing water quality to enhance living resources

Finding: Significant enhancement of living resources can be achieved through additional management actions without complete achievement of water quality standards across all habitats.
The Bay water quality criteria were selected based on chemical and physical conditions (dissolved oxygen and water clarity) necessary, but not sufficient alone, to support fish and invertebrate species living in different habitats and at different life stages. For instance, the presence of adequate dissolved oxygen in a habitat does not guarantee that organisms will fully populate that habitat. Direct evidence of the impact of water quality changes on various classes of living resources is mixed, partly because of the confounding multiple changes occurring and complex ecological interactions, and partly because there have not been substantial system-wide changes in some criteria, like dissolved oxygen. As a result, quantifying living resource

responses to any specific management and restoration action is a significant analytical challenge. While the CBP employs a suite of models to predict the impacts of management actions on chemical conditions in the estuary (particularly nutrient levels and dissolved oxygen), the CBP does not use models to relate changes in dissolved oxygen and habitat to the composition or abundance of living resources.

Living resource benefits may occur without full attainment of water quality criteria across all habitats and in every region of the Bay. The location and timing of water quality improvements will influence the composition and abundance of living resources. The five habitats demonstrate different patterns and trajectories of attainment of water quality criteria, and attaining the criteria is expected to be most difficult in the deep channel habitat. The shallow water and open water habitats, however, more directly influence the life cycles of most fish species. Habitat types also differ in their sensitivity to local management actions that can enhance living resource response. For example, actions in shallow waters such as creating living shorelines and improving benthic habitat can greatly increase the living resource response to water quality conditions.

The living resource outcomes that can be expected from incremental attainment of water quality criteria depend greatly on a host of other factors. Structural aquatic habitat, nearshore habitat (wetlands, shoreline), commercial and recreational harvest, disease, and water conditions (temperature, salinity) are all significant drivers of the composition and abundance of living resources. Research points to the importance of specific habitats (particularly shallow water) and nearshore conditions for many important species. Improvements in dissolved oxygen may not increase the abundance of desirable fish species if these other factors are already limiting populations. Thus, focusing investments on these other factors could improve composition and abundance of living resources for any given level of water quality improvement.

Policy implication: The legal requirements of the Clean Water Act (the water quality goal) divert attention away from considering multiple means of improving living resources (support of aquatic life as the designated use) as articulated in the Chesapeake Bay Watershed Agreement.

The TMDL framework presents challenges to focusing management attention and resources on improving living resource outcomes. The Chesapeake Bay Watershed Agreement lists 10 goals and 31 desired outcomes. Water quality is only one of the goals, but it is the only legally enforceable goal (under the Clean Water Act). This means that the benefits of restoration actions tend to be expressed primarily in terms of nutrient reductions rather than benefits for living resources. For example, benefits of restoring wetlands or living shorelines are often framed in terms of the TMDL rather than improved habitat. Yet these investments can substantially improve Bay living resources. A broader policy challenge for the CBP is how to allocate restoration funds and efforts to generate the largest living resource impacts for the most stakeholders.

Policy implication: Opportunities exist to adjust approaches to prioritize management actions that improve living resource response.

Possible changes to TMDL implementation could help prioritize water quality investments that have greater and more immediate impacts on living resources. The TMDL as currently structured directs management attention toward meeting an aggregate nutrient load limit that is largely driven by dissolved oxygen conditions in the Bay. A tiered approach to TMDL implementation would identify the locations or habitats expected to achieve pollutant reduction limits first. Shallow water habitats in specific regions of the Bay may offer significant opportunities to produce living resource responses. These are also areas with significant stakeholder engagement because of their status as primary areas of recreational use, their cultural significance, and their visibility as iconic Chesapeake landscapes. Reevaluation of water quality criteria may also include consideration of new criteria (e.g., water temperature, toxic and emerging contaminants of concern) or new frameworks for devising criteria (e.g., indicators of resilience). Exploring such policy options would be enhanced with additional analytical capacities and analyses capable of more fully articulating potential living resource responses to water quality management.

Enhancing adaptive management

Finding: The Chesapeake Bay Program's current portfolio of adaptive management processes is inadequate to address the uncertainties and response gaps described in this report.

Moving forward, the CBP enters a new era of management. The Bay of the future will be different from the Bay of the past because of permanent and ongoing changes in land use, climate change, population growth, and economic development. Refining restoration goals over time should be considered as knowledge evolves about what future conditions are possible, what local communities and the partnership at-large see as priorities, and what is required to attain those possible futures. Uncertainty is inherent in each of these.

The CBP has built a sophisticated TMDL implementation and accounting process premised on the use of deterministic predictive and planning models to secure a desired pollutant reduction and water quality response. The CBP's decision framework and associated Strategy Review System (SRS) assesses and evaluates progress toward achievement of specific CBP goals and adjusts implementation based on these assessments. The water quality goal also adds an accountability framework. However, the deterministic models providing single estimates of pollutant loads for all inputs, land uses, and management actions are not well suited for evaluating and addressing uncertainty. Such modeling approaches make it difficult to assess the performance risk of different BMPs, inform decision makers of uncertainties, or assess the robustness of management actions to underlying assumptions or changing environmental conditions. The CBP has limited capacity to assess the potential of management alternatives for improving living resources. The critical question is not simply: Are planned actions being undertaken? Rather, are the actions producing load reductions and improved estuary conditions?

Policy implication: Expanding the scope of adaptive management could address critical uncertainties and response gaps.

A formalized adaptive management approach currently exists: the SRS, complemented by the TMDL accountability framework. It is used to refine the existing implementation programs and accounting structure. However, the system does not provide adequate insights into potentially necessary policy changes at multiple levels ranging from devising new programs, rules, and accountability systems to making budgetary and funding decisions and revising goals. Enhancing adaptive management for water quality improvement suggests the CBP consider ways to include more decision makers who have influence in broader scale potential changes to the programs and policies.

To respond effectively to the issues raised in this report, the current adaptive management process for water quality could be enhanced in several ways. Decision science offers processes to integrate complex technical analyses with the planning processes used by those with the authority to make choices about goals, programs, and budgets. A number of tools and processes are available to identify and reduce decision-relevant uncertainties. Such approaches aim to identify those uncertainties that pose the greatest risk to achieving management objectives, identify how much a given outcome could be improved if a given uncertainty was resolved, and identify the cost of error. These tools can be used for a variety of purposes including supporting program design, implementation, and prioritization of research needs.

Conclusion

Four decades of efforts to manage nutrient and sediment pollutants have improved water quality conditions in some portions of the Chesapeake Bay, but results are mixed. Additionally, changing conditions from population growth, land use, and climate will make future restoration more challenging. However, opportunities exist to improve the effectiveness of pollution reduction efforts and accelerate improvements in living resources by building on the data, knowledge, and experience gained over decades of effort. Capitalizing on these opportunities will require adoption of new policies, procedures, and programs and expanded capacities to address uncertainties around system response in decision-making. Finally, achieving reductions in pollutants and realizing improvements in water quality and living resources in a system as large, diverse, and complex as the Bay watershed and estuary calls for patience as changes are planned and implemented and the system responds