Using Local Monitoring Results to Inform the Chesapeake Bay Program's Watershed Model

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About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at http://www.chesapeake.org/stac.

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Cover graphic from: April Storm stormflows at the outfall of USGS monitoring station number 0204279245. Storm drain at Rivers Ridge Circle near Newport News, VA on April 20, 2015. Photograph by Aaron Porter, U.S. Geological Survey.

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Executive Summary

The Chesapeake Bay Program's Watershed Model (CBWM) has been used as an accounting tool for the Chesapeake Bay Total Maximum Daily Load (TMDL). However, some of the fundamental parameters that underpin the watershed model may not represent local watershed characteristics at all scales. Significant investments have been made by state and local governments, and other local stakeholders, who are interested in validating loads and progress in implementing measures to achieve the pollutant reductions called for in the TMDL through local monitoring data. For the purposes of this STAC workshop, local monitoring is considered any relevant data collected by a local, regional, state, or federal organization that has not been used previously in the development, calibration, or validation of the CBWM. Some of these local monitoring efforts have been collecting data over the past 5-10 years, with some datasets extending back over more than two decades. However, the data and the CBWM are often not directly comparable due to differences in temporal and spatial scales or because the water quality parameters being monitored are not those estimated by the model. Therefore, a Scientific and Technical Advisory Committee (STAC) workshop was convened to bring together Chesapeake Bay Program (CBP) modelers, local and state government stakeholders, and scientists who are monitoring and analyzing local water quality data to recommend ways in which local monitoring data can be used to inform the CBWM, identify gaps between modeled and monitored data, and validate model predictions at the local scale.

The workshop, "Using Local Monitoring Results to Inform the Chesapeake Bay Program's Watershed Model", was held in March 2023 to provide insight on the scope of local water quality monitoring efforts within and outside of the Bay watershed that could be used to inform the CBWM. Scientists and managers developed recommendations that could be used by modelers for either calibration or knowledge generation to inform the Phase 7 version of the CBWM currently under development for a 2028 decision by the CBP, recommendations for how local monitoring efforts could be designed or altered to better inform the CBWM, and recommendations for how monitored trends could be used in management. The preliminary presentations for the workshop provided essential background information on the CBWM and data used to parameterize it. This information was the foundation for discussions on existing data gaps, the importance of current local monitoring networks, and best practices for developing future monitoring networks. More information on this STAC-funded effort including workshop presentation slides and recordings can be accessed on the workshop webpage.

Confidence in the loading estimates of the CBWM is critical because of its role as the accounting mechanism for measuring progress toward the Bay TMDL's nutrient and sediment reduction goals. Those who are being asked or required to pay for these reductions, from state and local government managers to farmers, property owners and developers, must have confidence in the scientific validity of the CBWM's loading estimates or trust in the restoration effort could dissipate. Toward that end, several local entities have invested in extensive urban, suburban, and agricultural monitoring programs to characterize nutrient and sediment loading (among other water quality parameters) at a relatively fine scale (from a few acres to 5 square miles). Monitoring networks outside of the Bay watershed were also included as their relevance and similarities to Bay watershed landscapes, hydrology, and climate conditions can help build the body of knowledge necessary for better parameterization of the CBWM.

Local monitoring results could be analyzed for loads and trends for calibration of Phase 7, comparison against trends, informing the structure and parameterization of the model, and potentially in policy evaluation. The effectiveness of management practices at the small watershed scale is a primary question of watershed managers that could be addressed by local monitoring, but to do so study design and statistical techniques may need to be altered if these datasets are intended to inform parameterization of the Bay modeling tools. The partnership could benefit from the redesign of some existing monitoring programs so that they are hypothesis-driven, with fully described inputs, outputs, and practices. New statistical tools could be applied to evaluate the relative importance of various drivers affecting water quality and influenced by hydrogeologic setting and watershed condition.

Major Recommendations

Many consensus recommendations emerged from the breakout sessions and are captured in detail in the main report. Although breakout groups were broken into urban and agriculture sectors, the discussion and subsequent recommendations were common between both groups. The main recommendations are summarized as follows:

Recommendations to the Chesapeake Bay Program

1. Include suitable local monitoring stations in watershed model calibration
    a. Identify gaps in the current set of calibration stations.
    b. Develop criteria for the use of new or the modification of existing monitoring stations in calibration.
    c. Establish a method by which local monitoring data and loads could be reported to the Bay Program (e.g., EPA Water Quality portal).
    d. Communicate to relevant workgroups (Modeling, Urban Stormwater, Agriculture, etc.) and stakeholders how local monitoring data could be used in model calibration.
2. Include generalized knowledge from local monitoring data in development of the Phase 7 CBWM
    a. Identify the types of generalized knowledge that could be useful.
    b. Describe existing gaps in generalized data and/or issue a data call for specific information.
    c. Develop guidelines for the use of local monitoring data for generalized knowledge that include key aspects such as average loading rates and factors that modify loading rates.
    d. Conduct further research to identify and quantify potential new pollutant loading sources or new components of existing pollutant loading sources in the Phase 7 CBWM such as wastewater exfiltration from sewer pipes, illicit discharges, and waterfowl and domesticated pets.
3. Compare load change expectations under the TMDL to trends in local monitoring with potential use in Watershed Implementation Plan (WIP) and progress evaluations.
4. Explore the potential inclusion of other existing datasets, such as the monitoring required by National Pollutant Discharge Elimination System (NPDES) permits and statewide probabilistic and trend monitoring, into the watershed model.
5. Encourage discussion at the CBP policy level of potential sandboxing approaches that favor monitoring over modeling for localities that have invested in intensive monitoring.

Recommendations to Enhance Local Monitoring Programs

6. Expand existing local monitoring programs to support further estimation of loads, identification of load sources, and improve understanding of factors that influence loads and trends.
7. Design new or redesign existing monitoring programs in agricultural watersheds to address best management practice (BMP) effectiveness at the watershed scale.
    a. use hypothesis-driven design.
    b. fully describe inputs, outputs, and BMPs.
    c. develop new statistical tools to relate changes to BMPs.
8. In coordination with academics, modelers, and other practitioners, identify new statistical tools needed to derive load estimates from high frequency monitoring data.
9. Developing incentives to support long-term monitoring of BMP effectiveness that takes into account climatic factors could improve the assessment of how well the practices are performing.

Introduction

The purpose of the workshop was to explore existing local monitoring programs in the Bay region, evaluate their relevance and applicability to future upgrades of the Chesapeake Bay Watershed Model (CBWM), and identify recommendations for both modeling and monitoring efforts. For purposes of this report and the workshop, local monitoring is considered any data collected by a local, regional, state, or federal organization that has not been used in the development, calibration, or validation of the CBWM. Finer scale model development and better understanding of the effectiveness of BMPs, a recommendation from a 2019 STAC workshop (Easton et al. 2020), depend on improving the spatial resolution of model data inputs and verifying that model processes can accurately simulate loads at smaller scales.

The workshop was structured to provide an overall background of how the current Phase 6 model is constructed, what the loading sources are, and how they are simulated for delivery to the estuarine model. The Phase 7 model is now in development and background was provided to highlight where local monitoring data could be incorporated. Following the overview, case studies of existing programs were presented for urban watersheds in the Bay watershed (Fairfax County and Hampton Roads, VA) and outside the Bay watershed (the Atlanta region) and a mix of urban/suburban/agriculture (Gwynns Falls, MD). Composites of agricultural and rural monitoring programs were also presented for small Bay watersheds in PA, MD, and VA (Mahantango Creek, Conewago Creek, Upper Chester River, and Smith Creek) and outside the watershed in North Carolina. All studies ranged in watershed size, presence or absence of BMPs, and duration of monitoring; however, all had comprehensive findings leading to a better understanding of their respective watersheds.

The CBWM is not a research model whose main purpose is to understand the complex dynamics of sediment and nutrient loading in the Bay watershed. Rather, it is an applied modeling system that uses understanding generated by the large volume of available research and research-oriented models to evaluate management trade-offs. The CBWM uses a simplified structure with parameters that are well-supported by multiple lines of evidence to avoid well-known problems associated with over-parameterization and over-calibration (early discussions in Hanna 1988 and Beven 1993).

Although presentations and breakout groups were intentionally designed to focus either on monitoring programs from the urban or agricultural sectors, the same major themes arose out of both discussions to provide overarching science-based recommendations. Monitoring programs need not be distinguished by their sector, but rather by how valuable they are in addressing knowledge gaps in the existing CBWM. To that end, many of the recommendations will require further exploration by the Bay modelers and other supporting partners in identifying those gaps. Additionally, further guidance will be needed to facilitate submission of applicable monitoring data to the Bay Program and to inform the development of future monitoring programs.

Presentations Summaries

A series of presentations provided the scientific and management background for participants prior to the breakout sessions. This information was the foundation for discussions on existing data gaps, the importance of current local monitoring networks, and best practices for developing future monitoring networks. Links to all presentations can be found on the STAC workshop page and they are linked individually through the presentation titles in this document.

The Role of Monitoring Data in Model Development – *Gary Shenk, U.S. Geological Survey (USGS)*

The Chesapeake Assessment Scenario Tool (CAST) (CBP 2020) is the watershed model used by the Chesapeake Bay Program to estimate the effects of changes in land use, management actions, point source, and atmospheric deposition on long-term loads of nitrogen, phosphorus, and sediment delivered to the tidal waters of the Chesapeake Bay. CAST is used by Chesapeake Bay Program partners in the regulatory context of the TMDL for the Chesapeake Bay and also by many stakeholders for purposes unrelated to the Chesapeake Bay TMDL such as universities, researchers, county planners for Municipal Separate Storm Sewers (MS4s), and other local watershed groups. There are approximately 2,000 CAST users.

The Phase 7 version of the CBWM, due to be completed for review in 2026 and application in 2028, has three related components: 1) CAST is the scenario tool used for management; it is run by CBP staff to generate official CBP scenarios and is also accessible by the public. Users can specify their own management scenarios and receive estimates of loads based on long-term hydrology. 2) The dynamic model, or CAST-DM, is a temporal downscaling of the long-term estimates of CAST into hourly and daily flows and constituent concentrations in rivers used to drive estuarine models. 3) CalCAST is a statistical version of CAST used to estimate optimal parameters for use in CAST during the development period. CalCAST is a new component for Phase 7. Phases prior to Phase 6 had a structure based on the process-based model Hydrologic Simulation Program—Fortran (HSPF). Draft overview documentation for phase 7 is available from the CBP. Monitoring data have three distinct uses in the CBP's suite of watershed models – calibration, comparison with trends, and knowledge generation.

Calibration is the process of ensuring, as part of model development, that the watershed models match monitoring data as well as possible. CalCAST uses loads estimated from monitoring data (Hirsch et al., 2010) at the annual or average annual temporal resolution to globally adjust parameters such that the modeled spatial pattern of loads across the entire model domain correlate to the load estimated by monitoring. CAST-DM uses observed daily flow and intermittent nutrient and sediment concentration data to match temporal patterns of flow and concentrations.

During both the development and application phases, CAST, CalCAST, and CAST-DM outputs can be compared to trends in flow-normalized loads estimated from monitoring data. Comparison of load trends during development helps the developers understand how different versions of model inputs improve predictions of change. Comparison of load trends during application assists management in understanding whether reported implementation is having the predicted effect on water quality.

Knowledge generation in the context of Phase 7 model development is the production of information relevant to model structure or parameters that can be used directly in CalCAST. CalCAST is a Bayesian spatial statistical model relating watershed inputs, natural processes, and anthropogenic properties to annual or average annual loads. The structure of CalCAST, and consequently the structure of CAST, can be informed by new source types or predictors of loads that are discovered through local monitoring. Because it has a Bayesian formulation, CalCAST can use prior descriptions of parameter distributions that can be estimated through local monitoring.

Participants in the workshop were asked to consider the three uses of monitoring data in the CBP's watershed models during the presentations on individual local monitoring studies. The remainder of the workshop time was used to understand how the data from the presentations and other monitoring studies could be used on the watershed models and how monitoring studies could be best designed for usefulness within the context of the CBP TMDL.

Chesapeake Bay Program Showcase Watersheds – *Jimmy Webber, USGS, VA-WV Water Science Center (WSC)*

Jimmy Webber presented preliminary findings about water quality responses from the Chesapeake Bay showcase watershed study. In 2010, the USGS partnered with the U.S. Department of Agriculture and the U.S. Environmental Protection Agency to establish showcase projects in small watersheds to test and monitor the benefits of a focused, partnered, voluntary approach to conservation. Three agricultural showcase watersheds received enhanced levels of management-practice investment and water quality monitoring. These are the Smith Creek watershed in Virginia's Shenandoah Valley, the Conewago Creek watershed in southern Pennsylvania, and the Upper Chester River watershed on Maryland's Eastern Shore.

The preliminary findings documented that the amount of management practices increased in each watershed and that a thorough understanding of landscape and climatic conditions is needed to evaluate the water quality effects of management practices. Monitored nutrient loads did not decrease in all watersheds and may have been affected by legacy nutrient inputs and increasing amounts of suspended sediment and agricultural nutrient inputs from manure and fertilizer. These preliminary findings highlight the value of a partnership between researchers and resource managers to understand the complex factors affecting agricultural water quality responses. Sustained investments in monitoring data, management practices, and statistical tools that evaluate cause and effect relations can help maximize information from this research and from other monitoring-based studies.

Hampton Roads Regional Stormwater Monitoring – *Aaron Porter, USGS*

Aaron Porter (USGS) presented findings about nitrogen (N), phosphorus (P), and total suspended solids (TSS) loadings from small, highly developed urban watersheds in the Hampton Roads region of Virginia (Porter, 2022). The program was developed to address a knowledge gap about such loadings in this heavily developed coastal region, and in doing so, better inform the Chesapeake Bay watershed model. Twelve monitoring stations, each located within the engineered stormwater system were installed in late 2015 and have since been continuously operated. Monitored watersheds are small (30-300 acres), highly impervious (36-80 percent), and primarily delineated by their stormwater infrastructure. The land use in each watershed is dominated by a single land use type: either commercial, high-density residential, or single-family residential.

Annual yields (load per unit area) were computed for each of the 12 monitoring stations from water year (Oct. 1 through Sept. 30) 2016 – 2022 for the following constituents: total N, total P, TSS, nitrate plus nitrite, total Kjeldahl N, total organic N, and orthophosphate. For each constituent, data will be used to develop an average annual yield representative of the common land uses in Hampton Roads.

Several mechanisms driving spatio-temporal patterns in nutrient and TSS loads, specifically hydrology, land use, nutrient speciation, and physiographic province were also discussed. Overland runoff accounts for approximately 70 percent of the surface water flowing out of these watersheds annually. Likewise, the majority of TSS and phosphorus loads were transported by stormflows. Conversely, over half of the nitrate load was transported by baseflows which had higher concentrations of nitrate compared to stormflow. Baseflows, which account for 30 percent of the annual flow, are sustained year-round by groundwater infiltrating the stormwater system. This phenomenon was discussed in the framework of “urban karst,” which refers to the network of subterranean stormwater infrastructure, which by virtue of its leakiness can provide a preferential and accelerated flow path for contaminants. Hydrology in the study watersheds was much flashier than streams in larger comparison networks consisting of a mix of developed, agricultural, and natural lands. This feature was attributed to the artificially high drainage density of these watersheds, a function of the engineered stormwater system.

Land use and land cover attributes also affect the hydrology of these watersheds. Commercial watersheds yielded more streamflow per unit rainfall than residential types. Concentrations of N, P, and TSS were highest in single-family residential watersheds; however, commercial watersheds had higher yields of these constituents. This contradiction is best explained by the higher streamflow yields in the commercial watersheds – a function of greater effective impervious cover. No difference in yield for N, P, or TSS was observed between the two residential land use types despite differences in land cover attributes. Yields in Hampton Roads (i.e., the urban Coastal Plain) were compared to monitored streams in Fairfax County, VA and Atlanta, GA (i.e., the urban Piedmont), as well as the Chesapeake Bay non-tidal network stations. N and P yields were high relative to most other networks, whereas TSS yields were much lower. Elevated N and P yields in Hampton Roads were attributed to watershed area, channel type (concrete vs earthen streams), degree of urbanization, and natural physical landscape features characteristic of the physiographic province. Low TSS yields were attributed to source limitation, channel type, soil properties, and low topographic relief in the Coastal Plain. Measured yields from this study were also compared to modeled yields from the Chesapeake Bay Watershed model.

Measured TSS and N were much lower than modeled yields, whereas P yields were similar. The composition of N and P yields differed between the urbanized Coastal Plain in Hampton Roads and the urbanized Piedmont in Fairfax County, VA. Nitrogen loads were primarily organic in Hampton Roads and nitrate dominant in Fairfax County. Differences in N speciation were related to denitrification potential of local soils, the presence or absence of septic infrastructure, and the rate of organic matter accumulation and decomposition. Phosphorus yields were primarily particulate based in both networks; however, a larger proportion of orthophosphate was present in Hampton Roads. Factors that may affect orthophosphate in Hampton Roads are soil properties which limit adsorption, organic matter accumulation, P leaching from aging stormwater infrastructure, and soil saturation from historical fertilizer applications.

Continued monitoring could support the computation of annual loads and trends in flow-adjusted loads. In addition, further data collection efforts could provide insight 1) regarding the bioavailability of organic nitrogen in these systems, 2) on identifying and quantifying sources of N and P (e.g., pet waste, fertilizer, wastewater leaks), and 3) evaluating the efficiency of watershed management implementations.

Evaluating Water-Quality Drivers in Streams of Fairfax County, Virginia – *Aaron Porter, USGS and Jimmy Webber, USGS*

Porter and Webber presented findings about water quality responses and drivers in Fairfax County, VA from a recent 10-year period (Porter et al., 2020, Webber et al., 2023). Water quality conditions in Fairfax County streams were evaluated from 20 monitoring stations; 14 of which have been in operation since 2007. Nutrient and sediment loads were calculated at four stations. At these stations, most loads are delivered during periods of stormflow. After removing effects of streamflow, trends in load were calculated at these stations from 2009 through 2018. In general, trends in load differed among stations and constituents. Changes in load did not clearly align with the timing or expected magnitude of management-practice effects.

Drivers of changing nutrient, sediment, and salinity conditions were evaluated at 14 stations from 2009 through 2018. In general, monitored nitrogen concentrations declined, phosphorus concentrations and specific conductance increased, and suspended-sediment concentrations were unchanged during these years.

The effect of management practices on these water quality responses was evaluated. From 2009 through 2018, Fairfax County invested in stormwater retrofit practices and stream restorations.

Cumulatively, these practices were credited with thousands of pounds of nitrogen, phosphorus, and sediment reductions. These credited reductions, however, did not help explain the variability of median-annual water-quality responses. Rather, differences in water quality among stations and over time were related to a combination of landscape, stream, and climatic conditions. These patterns were evaluated using linear mixed-effect regression models.

- Total nitrogen (TN) concentrations were related to septic system density and annual differences in rainfall. TN concentrations were higher and increases over time were larger in watersheds with elevated septic-system density. Years with more heavy rainfall days typically generated higher TN concentrations.
- Total phosphorus (TP) concentrations were related to phosphorus soil storage and landscape inputs. TP concentrations were higher in watersheds with more turfgrass; concentrations were lower, but had larger increases over time, in watersheds with deeper soils (defined as depth to bedrock). Years with more rainfall typically generated lower TP concentrations.

- Suspended sediment (SS) concentrations were likely related to factors affecting streambank erosion. SS concentrations were higher in watersheds with greater stream densities and during years with colder minimum air temperatures.
- Specific conductance (SC) was likely related to the applied amount and storage of salt on the landscape. SC was higher in watersheds with more developed land use and shallower soils and during years with colder minimum air temperatures.

These findings suggest that an important consideration for future investigations of management-practice effects is how to control for water quality variability caused by geologic properties, the urban environment, precipitation, and air temperature.

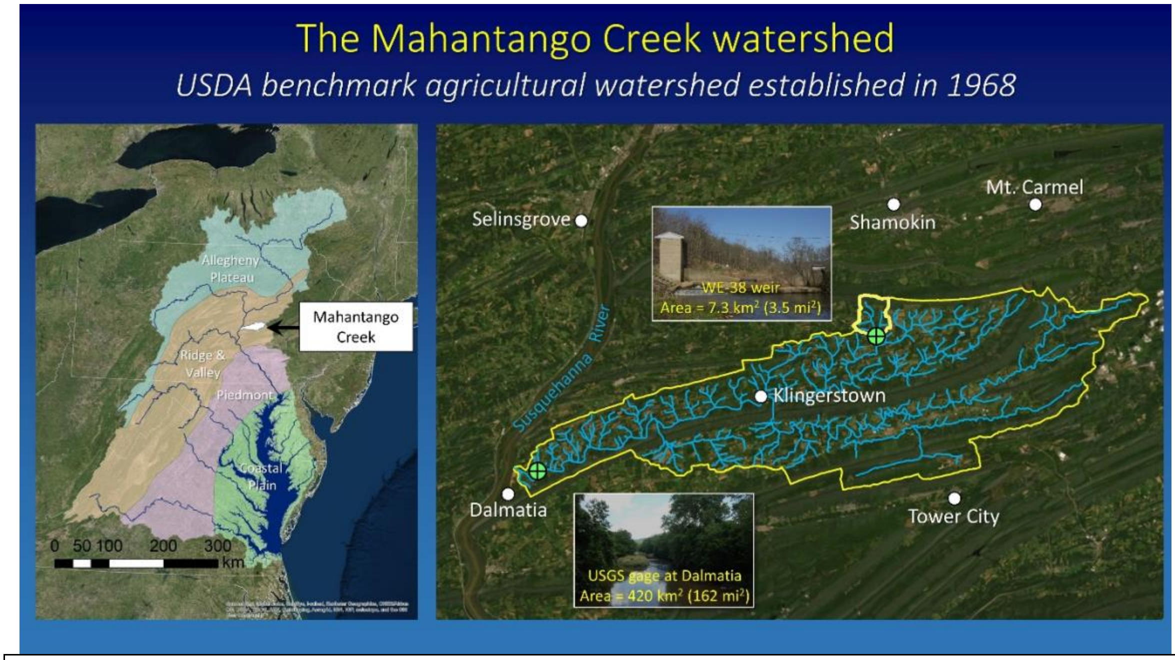
Gwynns Falls: Data on hydrology, nutrient and sediment loads and concentrations – *Jon Duncan, Penn State University (PSU)*

This presentation summarized results from the Baltimore Ecosystem Study (BES), a multi-prong effort including three National Science Foundation funded projects, the Long-Term Ecosystem Research that operated from 1998-2020, and current Long-Term Research in Environmental Biology and Urban Critical Zone Observatory (e.g. Castiblanco et al., 2023). The U.S. Department of Energy has recently funded the Baltimore Socio-Environmental Collaboratory, an Urban Integrated Field Laboratory which focuses in part on water quality and biogeochemistry. Additionally, the U.S. Forest Service has invested resources and staff into the Urban Field Station in Baltimore. In sum, these investments have enabled a broad yet detailed understanding of the processes driving hydrology and water quality in and around Baltimore, MD.

The work from Baltimore presented by Jon Duncan, included two key results for consideration by STAC for local monitoring. The first is that long-term data in addition to high-frequency sampling is required to fully understand the impact of land use and watershed management strategies on water quality loads. Long-term weekly chemistry sampling has successfully identified first order differences across watersheds of varying land use as well as trends through time that vary by watershed. Flux estimation of nitrate, phosphate, total nitrogen, and total phosphorus were estimated using Weighted Regressions on Time, Discharge, and Season (WRTDS) (Hirsch et al., 2010) for 20 years of the BES record. By examining daily fluxes for each year of the record, we see that for a given discharge value, phosphate loading is more variable across years than nitrate and that TN and TP were more variable than dissolved counterparts. This has important consequences for sampling rare events that can drive sizeable portions of total loads. High-frequency monitoring of nitrate concentrations has been important to understand the role of contrasting storm events. Although there is large variability in water quality patterns across storms, continued sampling yields important insights into typologies of storms that could help inform which storms to sample. The second important finding is that in addition to land cover metrics such as impervious surface, wastewater infrastructure (sanitary sewer and septic systems) is important to understand for predicting water quality loads. Evidence from multiple methods including modeling of in-stream metabolism, repeated spatial synoptic sampling along stream network, and dual isotopes of nitrate in stream water, suggest the source of some in-stream nitrate is derived from waste, likely leaking sanitary infrastructure.

Local Monitoring in Mahantango Creek – *Tony Buda, U.S. Department of Agriculture (USDA)*

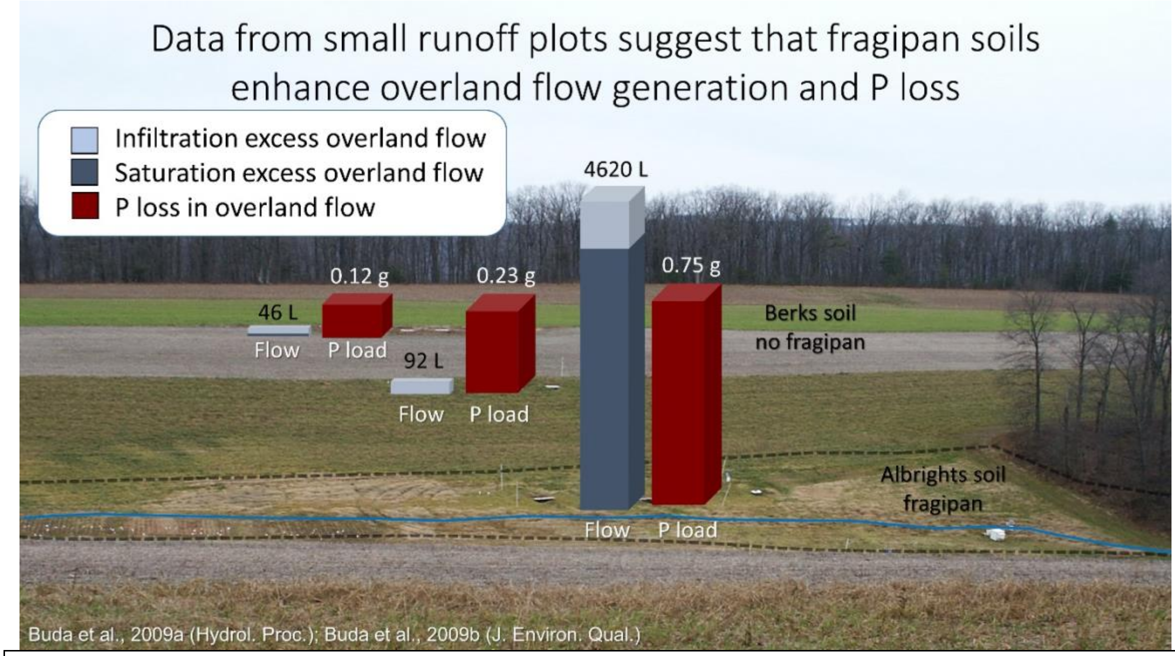
Reducing nutrient export from agricultural watersheds is essential to improving water quality conditions in the Chesapeake Bay. This presentation highlighted local hydrologic and water quality monitoring efforts in the Mahantango Creek watershed near Klingerstown, PA, (Figure 1) that have served to illuminate critical source areas of phosphorus (P) and nitrogen (N) losses from agriculture. Mahantango Creek is one of 23 benchmark experimental watersheds operated by the U.S. Department of Agriculture's Agricultural Research Service (ARS), and long-term records in the watershed date back to 1968 (Bryant et al., 2011). ARS selected Mahantango Creek to represent the non-karst regions of the Ridge and Valley physiographic province.


The Mahantango Creek watershed

USDA benchmark agricultural watershed established in 1968

Figure 1: The Mahantango Creek Watershed. Green circles indicate monitoring stations

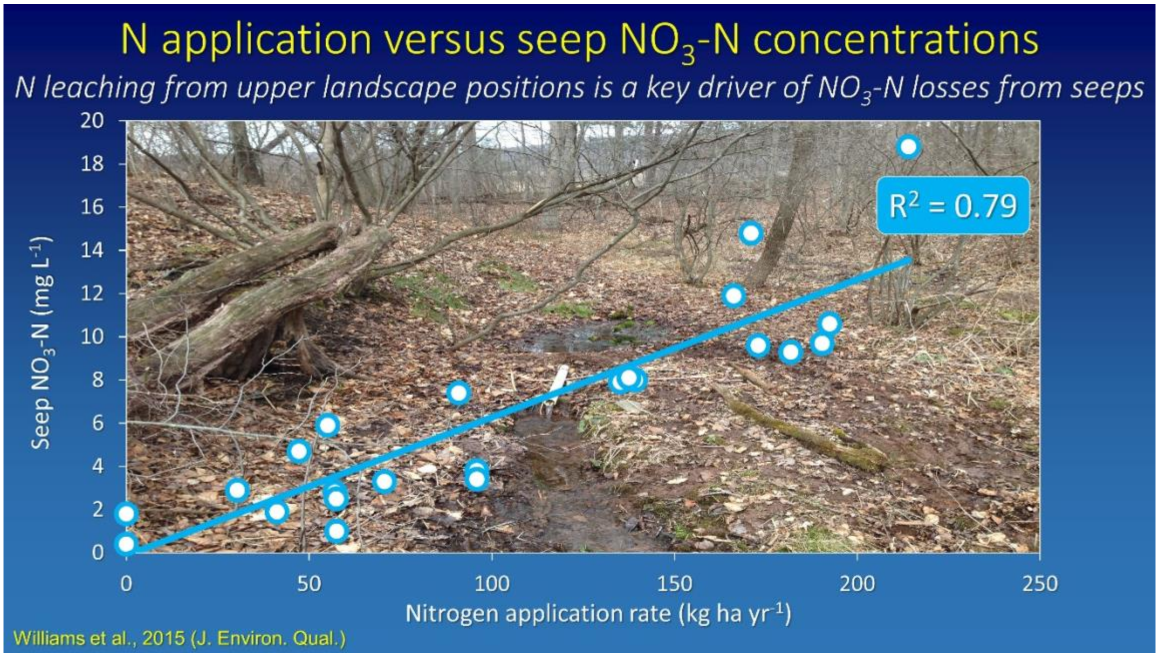
Interflow and surface runoff serve as the primary pathways of P loss from sloping agricultural landscapes in Mahantango Creek. Data from a series of hillslope monitoring studies (Kleinman et al., 2007; Buda et al., 2009a, b; Sharpley et al., 2013) reveal that P transfers are greatest in footslope positions where the presence of soil restrictive layers (e.g., fragipans) favors the largest amounts of interflow and surface runoff (Figure 2). Findings from these studies affirm the importance of critical source area management in hydrologically active areas that overlap with legacy P sources in soils. Results also have implications for watershed modeling, as realistic representations of P critical source areas are essential to improving simulations of P fate and transport in agricultural watersheds of the Upper Chesapeake Bay. Details of the monitoring methods are in the associated publications.(Buda et al., 2009a, Buda et al., 2009b)


Data from small runoff plots suggest that fragipan soils enhance overland flow generation and P loss

Buda et al., 2009a (Hydrol. Proc.); Buda et al., 2009b (J. Environ. Qual.)

Figure 2: Variable source P runoff in a small watershed

Riparian seeps, a common feature in many upland agricultural watersheds, are an important source of nitrate-N to streams. Results from a field study in Mahantango Creek (Williams et al., 2015) show strong positive relationships between N applications in upslope fields and nitrate-N concentrations in riparian seeps, indicating that nitrate-N levels in seeps are largely controlled by N leaching processes in well-drained upslope soils and ridge-top locations (Figure 3). A positive association between seep and stream nitrate-N concentrations further suggests that seeps control nitrate-N in stream baseflow. Collectively, these findings highlight important links between agricultural management, groundwater nitrogen legacies, and nitrate-N fluxes from riparian seeps to headwater streams in the Upper Chesapeake Bay region.



N application versus seep NO_3-N concentrations

N leaching from upper landscape positions is a key driver of NO_3-N losses from seeps

Williams et al., 2015 (J. Environ. Qual.)

Figure 3. Relationship between Nitrogen application rates and seep concentrations

Controls on Nitrogen Loading Along the Exurban-urban Gradient of the North Carolina Piedmont – *Joseph Delesantro, PSU*

Nonpoint source urban nutrient loading into streams and receiving water bodies is widely recognized as a major environmental challenge and contributor to eutrophication. Wastewater is the largest potential source of nitrogen in urban areas owing to the import of food for human consumption (Bernhardt et al., 2008). Across the 6,975 km^2 study area in the North Carolina Piedmont, population density of developed sub catchments was low and there was a large overlap in the population density served by septic systems and sanitary sewers. Regionally, 25% of the population was served by septic systems, and sanitary sewers were preferentially placed near streams (Delesantro et al., 2021). To determine how nitrogen is transported to streams in developed watersheds we asked: what are the dominant flow paths of nitrogen delivery, what are the primary nitrogen sources, and what landscape features control nitrogen loading? In-situ monitoring of nitrogen flux from five catchments in the North Carolina Piedmont spanning a rural to urban gradient indicated that subsurface flows contributed a large portion of the total nitrogen load, between 39% and 78% (Delesantro, 2021).

Accordingly, we focused our investigation on baseflow and selected 27 NHD+ (National Hydrography Dataset Plus) (Wieczorek et al, 2018) scale catchments for twice monthly baseflow sampling which represents the regional distribution of metrics of land cover, infrastructure, and population (Delesantro et al., 2022). A subset of 13 catchments were sampled for isotopic nitrate. Nitrate made up 73% of total dissolved nitrogen (TDN) and analysis of nitrate isotopes indicates that wastewater was the probable primary source for both septic and sanitary sewer served catchments (Figure 4). Of the 27 study catchments, 13 had significant linear baseflow concentration- discharge (CQ) relationships ($p<0.1$). The baseflow CQ slopes were positive for all developed study catchments meaning that as baseflow increased, rising groundwater and higher soil saturation facilitated the export of additional nitrogen. The CQ slope, or the degree to which concentration increased relative to flow was well described by the hydrogeomorphic position of sanitary infrastructure. This suggests that nitrogen from sanitary infrastructure in wet locations, was more readily transported by increases in flow and shallow groundwater tables and more hydrologically connected to streams than nitrogen from sanitary infrastructure in dry locations (Figure 5). Consequently, the single best predictor of mean catchment TDN loading across the 27 study catchments was the topographic wetness index at the location of sanitary sewers. Catchment footslope area and convergent sloping area, both metrics which represent areas of high saturation and may promote higher baseflow were the next best predictors of baseflow TDN loading followed by household density, which represent the probable source of wastewater nitrogen. From these predictors we generate a conceptually informed, parsimonious empirical model of baseflow N loading which explains 78% of the variation across study catchments. We extend this model across the region’s developed NHD+ catchments and estimate that 39% of baseflow loading regionally was attributed to sanitary infrastructure in wet areas of the landscape. In summary, we found that baseflow and subsurface flows contribute most N loading across the most common low and moderate development intensity landscapes and that subsurface N, originating from wastewater, is abundant and the position of sanitary infrastructure within the terrestrial flow field largely governed loading.

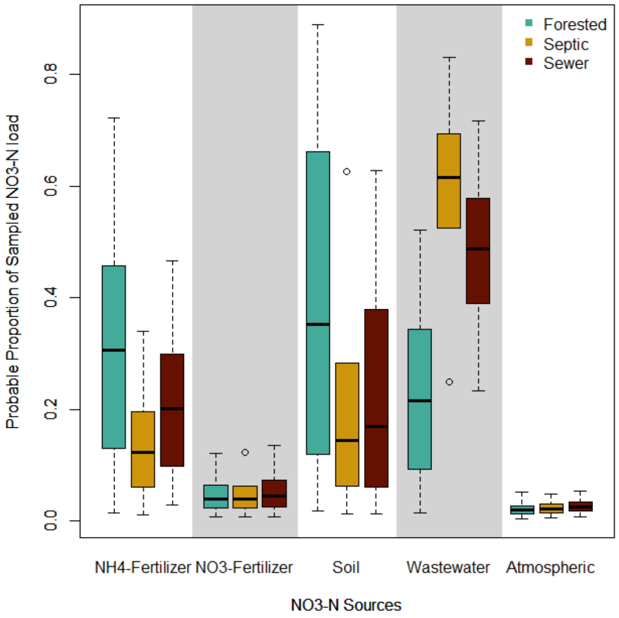


Figure 4. Boxplots of the probability distribution for the proportion by mass of nitrate sources for primarily forested, septic served, and sanitary sewer served catchments across baseflow. Analysis was conducted from dual nitrate isotopes using a Bayesian approach to solve standard mixing equations (Delesantro et al., 2022).

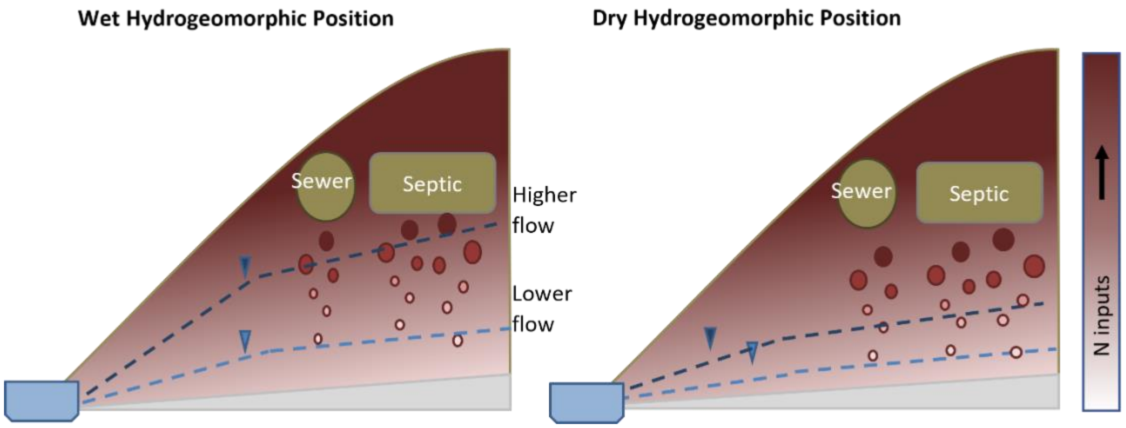


Figure 5. Conceptual depiction of a hillslope cross section under different flow conditions and at different hydrogeomorphic positions. Nitrogen from sanitary infrastructure in wet locations is more readily transported by increases in flow and shallow groundwater tables and more hydrologically connected to streams than nitrogen from sanitary infrastructure in dry locations (Adapted from Delesantro et al., 2022).

Atlanta-Area Piedmont Watersheds – *Brent Aulenbach, USGS*

- Atlanta Urban Studies Bibliography. For Chesapeake Bay Program STAC Local Monitoring workshop, March 2023. Indented references are data releases associated with prior listed report 2/15/2023 (Brent Aulenbach, btaulenb@usgs.gov).

The USGS, in cooperation with Gwinnett County Department of Water Resources and the DeKalb County Department of Watershed Management, established long-term streamflow and water-quality monitoring programs in 1996 and 2012, respectively, for select suburban to urban watersheds in Gwinnett and DeKalb Counties near Atlanta, Georgia. Each county's monitoring program consists of 15 watersheds monitored for streamflow, precipitation, continuous water-quality, and baseflow and stormflow composite stream water-quality samples analyzed for a similar set of 20+ constituents. Watersheds vary from about 1+ to 161 square miles, and have been characterized by land cover/use, imperviousness, population density, basin slope, and implementation of infrastructure including storm and sanitary sewers, septic systems, detention ponds, and building density. Loads and yields were estimated using a turbidity-surrogate regression model approach when there were moderate to strong relations between constituent concentration and streamflow or turbidity, and the Beale ratio estimator for cases where concentration relations were weak. Annual loads and yields were estimated for Gwinnett County for 12 constituents for water years 2003-20 and for DeKalb County for 15 constituents for calendar years 2012-16. These constituents include sediment (TSS and suspended-sediment concentration (SSC)) and nutrients ((TN), nitrate plus nitrite [NO_3+NO_2], TP, and dissolved phosphorus (DP)), which are constituents of concern to the Chesapeake Bay Program. The study area has experienced reoccurring droughts that affect annual loads and could result in trends.

Higher watershed stormflow runoff and lower baseflow were strongly correlated to higher percentage of watershed imperviousness. Suspended sediment concentrations were one to two orders of magnitude higher in stormflow composite samples than baseflow samples. Concentrations were also significantly ($p<.05$) higher in stormflow samples for TP, DP, and total ammonia plus organic nitrogen, but differences varied by watershed for other nitrogen species.

Annual loads generally varied with annual runoff. Concentration enhancement at higher flows results in a several-fold increase (3.5 to 4.8 times based on Gwinnett County watersheds) in annual TSS, SSC, and TP loads relative to increases in annual runoff, based on the ranges in annual loads and runoff. Several moderate to strong positive correlations were noted between nutrient yields and developed medium and high intensity land cover types and watershed imperviousness. Watershed sediment yields were not significantly correlated ($p<.05$) to any watershed characteristics. The Stone Mountain Creek watershed had among the lowest sediment and nutrient constituent yields and reflected the percentage of drainage area upstream of reservoirs. DeKalb County watersheds, which developed earlier than Gwinnett County, had significantly higher TSS, TP, and DP yields. Four of the Gwinnett County watersheds and six of the DeKalb County watersheds had significantly higher SSC versus TSS loads ($p<.05$), indicating more coarser grained sediment that may reflect differences in watershed sediment sources or transport processes.

Gwinnett County watersheds, which had a longer record that allowed for more in-depth analysis, had more decreasing trends than increasing trends in sediment, TN, and NO_3+NO_2 concentration and loads over its study period. This indicates improving water quality despite continued development over this period. Higher-than-expected annual sediment loads occurred in years that also had some of the highest peak flows during the period, suggesting that large storms are responsible for much of the sediment transport. A few years with high sediment loads appear to be the result of large land development projects in proximity to streams. Year-to-year patterns in annual sediment loads indicated that eight watersheds exhibited a transport-limited behavior, one watershed exhibited a supply-limited behavior, and four watersheds exhibited a mixed behavior. Higher sediment loads following droughts at six watersheds are indicative of the flushing of sediment that accumulated during droughts. The long-term dataset and the incorporation of continuous turbidity into the load estimation methodology that captured deviations from the average concentration-streamflow relations provide insights into sediment transport within these watersheds.

Breakout Group Discussions

Questions for Breakout Groups

With a better understanding of how current modeling data are used in the CBWM, and examples and findings from existing monitoring studies in urban and agricultural landscapes, workshop participants were divided into three breakout groups to formulate recommendations for the Chesapeake Bay Program. The following initial list of questions was provided by the steering committee.

- What current monitoring data can be used to inform watershed model processes?
- How representative of watershed-wide conditions are these data?
- What additional analyses of existing monitoring data would allow them to be generalized across the Chesapeake watershed?
- What changes to existing monitoring programs would make their data more useful for informing watershed model processes in the future?

Results of the Three Breakout Group Discussions

The in-person workshop participants were organized into breakout groups focused on either urban or agricultural landscapes. A separate breakout group among the virtual participants focused on both. Breakout group discussion comprised the bulk of the agenda and was facilitated by members of the Steering Committee, who presented their groups' recommendations on the final day of the workshop. As informed by a final plenary discussion among all participants, these recommendations are discussed in detail in the following section. Bold font is used below to highlight top-level recommendations for paragraphs in which it occurs.

Recommendations

Urban Monitoring Recommendations

The two breakout groups focused on urban monitoring (later combined into one group) discussed how current monitoring data are used in the model. It was determined that monitoring data are used for the purposes of model calibration or providing generalizable knowledge. Discussions centered around these two main themes – calibration and new load sources.

Calibration

Based on explanations provided by the modeling team, the first recommendation was to **include suitable local monitoring stations in watershed model calibration.** Urban landscapes are currently under-represented in the Bay Program's non-tidal monitoring network (NTN). The NTN mostly samples larger mixed-use watersheds or ones dominated by agricultural land use. There are currently only six stations that sample predominantly urban watersheds. Several of the stations in the Fairfax County monitoring network and the aggregated stations in Hampton Roads were identified as potential candidates. Further discussions will be needed with modelers and the local partners who have funded the data collection efforts to determine if this is the appropriate use for these datasets. The Hampton Roads stations are characterized by land use in the Coastal Plain physiographic province, a geography underrepresented in the NTN. However, the longevity and size of this program may mean its results are not yet suitable for calibration. Further discussion among the CBP modelers, the USGS monitoring scientists, the local government managers supporting these programs, and jurisdictional partners should be held to address these questions. The primary criterion for inclusion in calibration is the ability to calculate a load for a specific watershed for a defined period of time.

New Load Sources

Local monitoring programs in Hampton Roads and Fairfax County and others discussed at the workshop also could **provide generalized knowledge to inform the model.** The Bayesian analysis process being used in the Phase 7 model development facilitates the incorporation of prior knowledge into the development of model parameters given sufficient information. Several new potential load sources were discussed at the workshop, urban 'karst', residential groundwater pumping, illicit discharges, waterfowl, and domesticated pets. A potentially substantial previously unaccounted for source for evaluation in Phase 7 is exfiltration of wastewater from sewer pipes. The monitoring studies also provided new insights on septic loads. Local datasets from Gwynns Falls, the North Carolina Piedmont, and Fairfax County support the potential inclusion of a new source to represent contributions from wastewater collection systems. Additionally, results from several local studies support a re-evaluation of the way septic loads are currently characterized in the model. The Fairfax County studies provide quantitative estimates of the extent of nitrate loading to streams due to septic infrastructure. The North Carolina Piedmont data provide estimates of both wastewater and septic infrastructure loading (Figure 4).

Septic systems are modeled as a separate load source in the CBWM; however, the Fairfax data could improve this simulation by focusing on the age and density of septic systems. Wastewater infrastructure, as a separate source from urban runoff and wastewater permitted discharges could potentially be added as a new source to Phase 7. To use this as a new source, the Bay Program will need more data to quantify loads in various geographic areas, and to consider how these loads could be affected by the age and maintenance status of wastewater collection systems. Further consideration and evaluation of this as a possible source to include in the Phase 7 model should engage a range of stakeholders, including local governments and municipalities, jurisdictional representatives as well as Bay Program staff and modelers.

Current reductions for wastewater exfiltration loads can be credited in the CAST model through the "Advanced Grey Infrastructure Discharge Elimination Sewage Pipe Exfiltration" BMP although no Bay partner jurisdiction has reported its use as of 2023. Other credits are available if the following discharges are eliminated: laundry washwater, commercial car washing, floor drains, miscellaneous high nutrient non-sanitary discharges, drinking water transmission loss, and dry weather Sanitary Sewer Overflows (SSOs). The credits apply to developed land in general because there is no explicit source for these loads which would require further evaluation. Stable isotopes were used in the NC Piedmont study and may be a valuable tool to use in existing or new monitoring networks with dense sewage or septic infrastructure.

The wastewater discussion led to a related longer-term recommendation: to **investigate potential changes to wastewater overflows.** The current CAST/CBWM modeling for climate change includes the effect of climate on the frequency and severity of combined sewer overflows through the existing combined sewer overflow model at the CBP. Sanitary sewer overflows would also be affected and should be investigated through literature reviews and by examining local and state records across the jurisdictions, potentially leading to revised data input and flow-driven deliveries for each watershed.

The Hampton Roads monitoring network, although small, could be used to provide general knowledge for "urban karst" or networks of artificial subsurface pathways (Bonneau et al., 2017), in the Coastal Plain physiographic province. There are notable differences in TN, TP, and TSS yields between the Coastal Plain and the urban Piedmont studies that could be useful in calibration and quantifying a new load source. The regional data could also be representative and provide generalizable knowledge of municipal separate storm sewer system (MS4) loads that have no BMPs and are not influenced by non-tidal streams.

Local Monitoring Guidance

To provide support for the use of local monitoring data in the model, the breakout group thought it was necessary to **establish a process for the submission of data and a set of guidelines for how data can be used in calibration or as generalized knowledge.** The generalized knowledge used to inform Phase 6 has several gaps noted by workshop participants that local monitoring data could address in future model iterations. Such gaps include refinement of sensitivity analyses, delivery factors for nutrient species, the impact of soil depth and composition on nutrient loading, and transport and lag time for delivery of phosphorus. In addition, as noted previously, several potential load sources in urban areas lack quantifiable data.

To facilitate this goal, the Bay Program should:

- identify gaps in the current set of calibration stations.
- describe existing gaps in generalized data and/or issue a data call for specific information.
    - communicate to relevant workgroups (Modeling, Urban Stormwater, Agriculture, etc.) and stakeholders how local monitoring data could be used in model calibration.
- develop criteria to establish new or modify monitoring stations to be used in calibration.
- develop criteria for the use of local monitoring data for generalized knowledge.
    - include existing frameworks for data quality criteria and reporting that are being established within the Partnership.
- establish a portal by which local monitoring data could be reported (e.g., EPA Water Quality portal).
- develop protocols for how monitoring programs can address different aspects of the watershed model, such as calibration, land use loading rates, climate impacts, and BMP effectiveness.

In addition to the datasets presented at the workshop, the CBP should **explore the potential inclusion of other existing datasets, such as the monitoring required by NPDES permits, electronic discharge monitoring reports (eDMR) system, and statewide water quality attainment programs, including probabilistic monitoring, into the watershed model.**

Participants noted that extensive datasets extending over many years in various watersheds have been collected by local and state agencies. These data typically include nutrient and sediment concentrations, but not necessarily loads. Although these data were not explicitly examined at the workshop, it was noted as a potential source for generalized knowledge. The publication of criteria for use of generalized knowledge in the watershed model could provide local and state program managers with better understanding of whether the data could be analyzed for such purposes.

Workshop participants identified that support is needed to identify new statistical tools to derive load estimates from high frequency monitoring data. Local monitoring efforts are increasingly using continuous sensors to better estimate loads for parameters that vary greatly with streamflow, for example, nitrate. However, load estimation methods are not as well developed for continuous data as they are for discrete data. Further, historical datasets could be mined for more information by using continuous datasets as models for data interpretation.

To facilitate this goal, the Bay Program and its monitoring partners should work together to support funding for new statistical techniques for load estimation from continuous sensor data.

Incentives to long-term monitoring of BMP effectiveness that takes into account climatic factors could improve the assessment of how well the practices are performing. BMP effectiveness over the lifetime of most practices, including the impacts of changing precipitation patterns driven by climate change, is not well established. The small scale of local monitoring programs makes them better suited to quantifying BMP effects than the larger scale of the average NTN station. In its 10 years of data collection, the Fairfax County network has not shown that the BMPs installed in these watersheds have produced the expected load reductions. The study identified several factors in addition to climate change that may be masking the estimation of BMP performance.

To facilitate incentivization of long-term, climate-centered, load monitoring, the Bay Program and its monitoring partners should:

- Encourage more monitoring efforts that seek to quantify factors such as precipitation intensities, groundwater age, and depth to water table that can impact load estimates and BMP performance.
- Advocate that long-term monitoring be required under pay-for-performance programs as a new method for crediting nutrient and sediment reductions.
- **Lead a future STAC workshop on BMP efficiency monitoring.**

Agricultural Monitoring Recommendations

The breakout group on local monitoring in agricultural areas discussed ways that existing local monitoring data could be used in the development and application of the Phase 7 watershed model and how monitoring strategies could be adjusted in the future to tailor outcomes more to modeling and management needs. The participants were asked to make recommendations of findings from local monitoring studies that were ready to be used in watershed modeling or could be used with additional analyses. They were also asked to consider how local monitoring in agricultural areas could be more effective with changes to monitoring methods. Further, participants chose to discuss potential ways that local monitoring could be used in policy.

The uppermost question for management remains a demonstration and quantification of the effectiveness of management practices at the watershed scale. As evidenced by the workshop presentations, many prior attempts to monitor BMP effectiveness have been inconclusive or had mixed results (e.g., Hyer et al., 2016). Phosphorus remains more difficult than nitrogen to model (Kleinman et al., 2019). A recipe for success in any statistical analysis is to have high confidence in the measurement of dependent and independent variables, a solid conceptual model, and an appropriate analysis method. Monitoring programs that are redesigned to be hypothesis-driven, with fully described inputs, outputs, and practices may be more successful. New statistical tools may be needed to extract knowledge.

The workshop did not identify any results from local monitoring in agricultural areas that suggest substantial changes to the structure of the CBWM or define parameter distributions. Findings from monitoring studies re-emphasized the existing understanding that meter-scale and field-scale hydrologic properties tend to dominate transport considerations.

Improved monitoring design could better evaluate BMP effectiveness at the watershed scale. Planners of small watershed monitoring projects could use hypothesis-driven design to select monitoring sites and monitoring frequencies to answer specific management-related questions. Monitoring methods and frequencies, including continuous monitors, should be appropriate to deliver the needed accuracy in load or concentration estimates. Carefully tracked watershed inputs and properties will allow greater understanding of the causes of monitored results. Using the quality of information on watershed inputs as a criterion for locating monitoring stations will lead to better results.

The development of new statistical tools is needed to better understand management practice effects.

Currently available statistical tools are not sufficient to determine causes of loads and trends in small watershed data. The development of new methods could improve the determination of the relationship between monitored water quality results and the associated inputs, practices, and physical properties in small watersheds. New statistical methods may also allow the CBP to make use of synoptic data that have been collected throughout the watershed but have not been brought to bear on scientific questions related to the CBWM. Methods to make use of synoptic data could improve access to important sources of data and create meaningful involvement for stakeholders in community science projects.

Using local monitored loads in the calibration of the Phase 7 Watershed Model could improve the model and stakeholder confidence in the model.

Use of additional monitoring stations in the calibration of the CBWM generally improves the entire model by helping to identify parameters and distributions that best describe load variability throughout the model domain. Participants in the agricultural breakout section discussed their experience that stakeholder confidence in the model was increased if local data were used in the calibration and if loads were closely matched. For this to occur, total annual loads must be calculated for a watershed or set of watersheds that match the spatial segmentation in the model.

Compare load change expectations under the TMDL to trends in monitoring.

The modeling done for the Chesapeake TMDL estimates the necessary change in loads delivered to the Chesapeake since 1995 to achieve water quality standards. Looking at trends over time to judge the effectiveness of the monitored watershed is consistent with the calculations in the TMDL and can be applied to local areas to determine if policies aimed at reducing nutrients and sediment are being successful. Robust statistical methods and long-term data are necessary for producing reliable output at this scale.

The CBP Partnership could use counties as policy laboratories.

Monitoring is expensive, but so is the implementation and reporting of management practices. Policies that give credit based on monitored results rather than modeled results could incentivize more monitoring, potentially funded by cost savings in managing counting and verification of BMPs (Easton et al., 2020). STAC has advocated for allowing local governments regulatory flexibility including the ability to test the effectiveness of policies at the local level for potential large-scale implementation. STAC refers to this method as ‘sandboxing’ in their Comprehensive Evaluation of System Response report (STAC 2023).

Virtual Breakout Group Recommendations: Combined agricultural and urban areas

A virtual breakout group was convened concurrently with the two in-person breakout groups. The virtual group consisted of agricultural, urban, modeling, and monitoring experts. As was the case in the other breakout sessions, members of the virtual breakout group were impressed by the monitoring presentations. They recognized that these represented a gold standard that had identified potential new sources such as wastewater exfiltration in urban areas, but also that most local entities do not have the resources to conduct the same level of monitoring. The discussion centered around two general ideas: how to combine more sparse monitoring from different areas to make it more useful for model purposes and how to design effective monitoring studies in areas where resources support more intensive monitoring.

Combine local data from areas of less intensive monitoring.

Many state and local programs have collected data on flow, nutrients, and sediment for various purposes throughout the recent past. These often do not qualify for inclusion in the NTN due to low frequency of collection, lack of storm sampling, short length of record, or lack of flow data with water quality. While these data may not be of high enough quality to quantify loads for a particular site, many small datasets could be combined in a statistical analysis that would inform generalized knowledge about the Bay watershed. The development and dissemination through a data portal of a set of minimum standards for inclusion in such a statistical analysis to local and state monitoring officials could result in the generation of useful new data and the utilization of existing datasets.

Improve design for intensive monitoring products to assess the effects of BMPs

The presentations from the workshop showed that the impact of BMPs was difficult to determine through monitoring, given the impact of other drivers that are difficult to control, such as climate-driven precipitation changes and changing land use. A more consistent approach is needed in collecting landscape variables, meteorologic inputs, and other information, as well as updated statistical methods to find sources and causes. It was also noted that implementation plans tend to focus on headwaters that are easier to restore while monitoring is typically conducted further downstream in watersheds. Monitoring at the scale of implementation may produce clearer results of BMP implementation. Further, highly intensive monitoring of individual BMPs over time may yield insights into life-cycle mass balances of pollutants and understanding of the causes of BMP success and failure.

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Appendix A: Workshop Agenda

Chesapeake Bay Program's (CBP)
Scientific and Technical Advisory Committee (STAC) Workshop

Using Local Monitoring Results to Inform the
Chesapeake Bay Program's Watershed Model
March 7-8, 2023
Workshop Webpage
Northern Virginia Regional Commission | Fairfax, VA

Objectives:

1. Identify current monitoring data that can be used to inform watershed model processes under Phase 7 of the model
2. Determine how representative the monitoring data is of watershed-wide conditions
3. Determine if any additional analyses of existing data would make it useful for informing the watershed model
4. Identify potential changes to current local monitoring programs that would make their data more useful for informing watershed model updates in the future

Tuesday, March 7th, 2023

8:30 am	**Coffee & Light Breakfast (Provided)**
9:00 am	**Workshop Overview (Steering Committee Presenter) –** *Rachel Tardiff, facilitator*
9:20 am	**Watershed Model Framework: What Knowledge is Needed –** *Gary Shenk (USGS)* Recording
10:00 am	**CBP Showcase Watersheds (Mix Urban/Ag) –** *Jimmy Webber (USGS)* Recording Data on hydrology, nutrient and sediment loads and concentrations in selected watersheds.
10:40 am	**Break**
10:50 am	**Hampton Roads (Urban) –** *Aaron Porter (USGS)* Recording Data on hydrology, nutrient and sediment loads and concentrations in selected watersheds.
11:20 am	**Fairfax (Urban) –** *Aaron Porter (USGS), Jimmy Webber (USGS)* Recording Data on hydrology, nutrient and sediment loads and concentrations in selected watersheds.
11:50 am	**Gwynns Falls (Urban) –** *Jon Duncan (Penn State), Claire Welty (UMBC)* Recording Data on hydrology, nutrient and sediment loads and concentrations in selected watersheds.
12:20 pm	**Lunch (provided)**
1:10 pm	**Mahantango Creek (Ag) –** *Tony Buda (USDA ARS)* Recording Data on hydrology, nutrient and sediment loads and concentrations in selected watersheds.
1:40 pm	**NC Piedmont Nutrient Study (Urban)** Recording **–** *Joseph Delesantro (Penn State), Jon Duncan (Penn State)* Recording Grab sampling (n=37) and continuous monitoring (n=5) of hydrology, nutrient loads and

concentrations across representative catchments selected by geospatial analysis of watershed composition and structure.

2:10 pm **Atlanta-Area Piedmont Watersheds (Urban) –** *Brent Aulenbach (USGS)* Recording
Hydrology and stream water-quality concentrations and loads from 30 suburban to urban watersheds in the Atlanta-area. Spatial and temporal relations between hydrology, water-quality, and watershed characteristics.

2:40 pm **Q&A on Presentations –** *Rachel Tardiff, facilitator*

3:00 pm **Break**

3:15 pm **Plenary Breakout Instructions** – *Rachel Tardiff, facilitator*

3:25 pm **Breakout Groups** – *led by Steering committee member(s)*
The goal of the breakouts is to develop recommendations for how the Bay Program modeling team can use current local monitoring information and how local monitoring programs could be modified to better inform model processes in the future.

Breakout kick-off to address key workshop goals:

1. What current monitoring data can be used to inform watershed model processes?
2. How representative of watershed-wide conditions is this data?
3. What additional analyses of existing monitoring data would allow it to be generalized across the Chesapeake watershed?
4. What changes to existing monitoring programs would make their data more useful for informing watershed model processes in the future?

Each breakout will have two chairs who will lead and facilitate discussion, and a notetaker. The chairs will be responsible for writing up the recommendations section of the workshop report. The goal of the afternoon is for each breakout to produce 2 items:

1. List of draft recommendations, with focus on the top consensus priorities
2. Longer list of thoughts and notes from discussion, for inclusion in workshop report

4:45 pm **Plenary Check-in & preview Day 2**

5:00 pm **Recess**

6:00 pm **Group Dinner (Optional)**

Wednesday, March 8th, 2023

8:30 am **Coffee & Light Breakfast (Provided)**

8:50 am **Review of Day 1; Objectives for Day 2** – *Steering committee member*
The early morning break-out session will focus on each breakout group reaching consensus on their recommendations.

9:00 am **Continued Breakout Discussions**
Breakout groups reach consensus on their recommendations for answering the workshop's goals that can be communicated to the plenary group on a set of presentation slides. Begin work on longer descriptions of draft recommendations.

10:15 am	**15-minute break**
10:30 am	**Plenary Presentation of Breakout Proposals** – *led by Steering committee member* 20-minutes per breakout. All participants will reconvene and breakout group leaders will briefly present their recommendation slides.
11:30 am	**Lunch (provided)**
12:00 pm	**Group Discussion: Report recommendations** – *Steering Committee* Breakout group leaders and Steering Committee members will meet to reconcile the recommendations from each breakout group in a facilitated discussion. A final set of recommendations for incorporation in a final report will be produced. The longer descriptions of thoughts from each breakout group will subsequently be captured in the final report on the workshop.
1:40 pm	**Workshop Wrap-up and Next Steps** – *led by a Steering committee member* The workshop steering committee will synthesize workshop findings and recommendations provided by participants.
2:00 pm	**Workshop Adjourns**
2:00 pm	**Steering Committee Meets**

Appendix B: Workshop Participants

Name	Affiliation	Name	Affiliation
Aaron Porter	U.S. Geological Survey	**Jon Duncan**	Pennsylvania State University
Allie Wagner	Northern Virginia Regional Commission	**Jonathan Leiman**	Maryland Department of the Environment
Amalia Pleake-Tamm	Calvert County Gov	**Jonathan Witt**	Fairfax County
Brent Aulenbach	U.S. Geological Survey	**Josh Lookenbill**	Pennsylvania Department of Environmental Protection
Bruce Weckworth	Hampton Roads Sanitation District	**Karl Berger**	Metropolitan Washington Council of Governments
Bryant Thomas	Virginia Department of Environmental Quality	**Karl Blankenship**	Bay Journal
Cassandra Davis	New York State Department of Environmental Conservation	**KC Filippino**	Hampton Roads Planning District
Claire Welty	University of Maryland, Baltimore County	**LeAnne E Astin**	Fairfax County
Cynthia Ross	University of Maryland Center for Environmental Science	**Leon Tillman**	U.S. Department of Agriculture-Natural Resources Conservation Service
Doug Liang	University of Maryland Center for Environmental Science	**Lew Linker**	U.S. Environmental Protection Agency-Chesapeake Bay Program Office
Doug Moyer	U.S. Geological Survey	**Lisa Beatty**	Pennsylvania Department of Environmental Protection
Douglas Moyer	U.S. Geological Survey	**Lora Harris**	University of Maryland Center for Environmental Science
Efeturi Oghenekaro	Department of Energy & Environment	**Mark Brickner**	Pennsylvania Department of Environmental Protection
Elizabeth Beatty	Pennsylvania Department of Environmental Protection	**Matt Kofroth**	Lancaster Conservation
Felicia Dell	York County Planning Commission	**Matt Monroe**	West Virginia Department of Agriculture
Gary Shenk	Chesapeake Bay Program	**Melissa Fagan**	Chesapeake Research Consortium
Greg Noe	U.S. Geological Survey	**Michael Lookinbill**	Pennsylvania Department of Environmental Protection
Guido Yactayo	Maryland Department of the Environment	**Natalie Schmer**	U.S. Geological Survey
Isabella Bertani	Chesapeake Bay Program	**Norm Goulet**	Northern Virginia Regional Commission
James Webber	U.S. Geological Survey	**Peter Tango**	U.S. Geological Survey
Jamie Shallenberger	Susquehanna River Basin Commission	**Qian Zhang**	University of Maryland Center for Environmental Science
Jason Hill	Virginia Department of Environmental Quality	**Robert Sabo**	U.S. Environmental Protection Agency - Office of Research and Development
Jeff Chanat	U.S. Geological Survey	**Scott Heidel**	Pennsylvania Department of Environmental Protection
Jenny Reitz	Hampton Roads Sanitation District	**Shirley Clark**	Pennsylvania State University
Joe Duris	U.S. Geological Survey	**Solange Filoso**	University of Maryland Center for Environmental Science
John Clune	U.S. Geological Survey	**Sophia Grossweiler**	Maryland Department of the Environment
John Seitz	York County Planning Commission	**Whitney Katchmark**	Hampton Roads Planning District Commission

Appendix C: List of Figures