Chesapeake Community Research Symposium 2026

Session 8: Advancing the Development and Management Applications of Next-generation Airshed, Land-use, Watershed, and Estuarine Models

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Phase 7 Models of the Chesapeake Watershed, Estuary, and Airshed – Exploring Future Challenges of Changing Environmental Conditions and Growth

The Chesapeake Bay Program is completing in 2026 a fine-scale simulation of the Chesapeake watershed, airshed, land use, and tidal waters called Phase 7. The Phase 7 Model Suite simulates the watershed and tidal Bay at a scale more than an order of magnitude greater than the previous Phase 6 version. The Phase 7 Watershed Model will be able to deliver to the tidal Bay estimated watershed loads at the NHD+ scale of about 1 km2. In Phase 7, an innovative approach to an improved simulation of the coastal plain uses nearshore tidal water quality stations to calibrate the Coastal Plain loads, a physiographic region responsible for about a third of the nutrient loads from the watershed.

The Phase 7 Main Bay Model (MBM) is also at a finer scale than previous versions allowing a better assessment of shallow water quality than previous CBP models. In addition, the MBM is augmented by Multiple Tributary Models (MTMs) that are at an even finer spatial scale. Directed toward local water quality concerns, the MTMs have already done service in the assessment of water quality planning for data centers and other water quality concerns. The MTMs included simulations of the Potomac, Choptank, Rappahannock, and Patapsco/Back Rivers. Taken together, the scale refinements along with the development of new simulation capabilities for shallow waters will enable the CBP to better assess the dissolved oxygen and other water quality standards in all Bay tributaries and in shallow water systems.

The CBP modeling tools and analyses are deeply collaborative by design and are extensively used in the CBP policy and scientific communities. But above all, the Phase 7 Models are developed and applied as state-of-the science integrated environmental models of the Chesapeake watershed and Bay to “improve the water quality and living resources in the Chesapeake Bay ecosystem” as directed by Section 117 of the Clean Water Act. The Phase 7 Model Suite uses the combination of modeling, research, and monitoring to support CBP implementation of environmental management that is environmentally protective and directed at ensuring the Chesapeake living resource-based water quality standards are achieved under the future environmental conditions of 2035 and beyond. The Phase 7 Models will be completed in 2026, reviewed by the CBP management and scientific communities in 2027, and applied to CBP planning objectives in 2028.

Joseph Delesantro (ORISE Fellow, EPA Chesapeake Bay Program Office), Isabella Bertani, Gopal Bhatt, Jessica Rigelman, Lewis Linker

Characterizing annual streamflow, nutrient, and sediment loading and drivers in the Chesapeake Bay watershed through data-driven models

Understanding how hydrology, nutrient inputs, landscape characteristics, and in-stream processes interact to control spatial and temporal variability in nutrient and sediment fluxes is critical for guiding effective and efficient watershed management. We developed a largely empirical modeling framework to characterize spatiotemporal variability in streamflow, nitrogen, phosphorus, and sediment loads across the Chesapeake Bay watershed using a Bayesian calibration approach. The model is implemented at the National Hydrography Dataset Plus (NHDPlus) catchment scale and calibrated to streamflow and constituent loads estimated at more than 210 monitoring stations across the watershed.

Model inputs incorporate detailed information compiled by the Chesapeake Bay Program describing nutrient inputs and load source loading sensitivity to inputs from multiple anthropogenic sources, including fertilizer and manure applications, atmospheric deposition, crop uptake, and point source discharges and withdrawals. Upstream catchment and stream network characteristics representing hydrologic transport, landscape delivery, channel routing, and biogeochemical attenuation processes are also incorporated as predictors. These predictors include land use and land cover, soil and physiographic properties, precipitation and runoff characteristics, stream size and travel time metrics, and the influence of reservoirs. Key parameters are calibrated within the Bayesian framework using multiple lines of evidence, integrating field level monitoring, scientific literature, and expert work group input.
We provide an overview of model structure, calibration, and performance and demonstrate application of the model to identify and parameterize drivers of spatiotemporal variability in streamflow and constituent loads across the Chesapeake Bay watershed. Results from this work are being used to inform development of the next generation (Phase 7) Chesapeake Bay Program decision-support tools and Watershed Implementation Plans.

Joseph Delesantro (ORISE Fellow, EPA Chesapeake Bay Program Office), Conor Keitzer, Gopal Bhatt, Michelle Katoski, Lewis Linker

Closing the phosphorus modeling gap in the Chesapeake Bay watershed

Addressing the phosphorus modeling gap in the Chesapeake Bay watershed remains a critical challenge for improving confidence in watershed loading estimates and supporting nutrient management decisions. While nitrogen dynamics are generally well characterized in current modeling frameworks, phosphorus transport and attenuation processes remain more difficult to represent due to complex interactions among legacy storage, geologic sources, sediment transport, and biogeochemical cycling.

This work addresses limitations contributing to poor characterization of phosphorus transport and attenuation processes across the watershed. We synthesize monitoring data, model diagnostics, and recent research to identify key gaps in representing phosphorus dynamics and work to address limitations contributing to mischaracterization of phosphorus transport and attenuation processes across the watershed. Emphasis is placed on understanding geogenic sources, how landscape characteristics influence phosphorus hydrologic connectivity to streams, and the impact of anthropogenic activity on spatial and temporal variability in phosphorus sorption and release.

We present results from Bayesian and machine learning modeling analyses designed to identify and evaluate predictors of phosphorus loads. These analyses leverage extensive geospatial datasets, expanded stream monitoring data, and empirical and process-informed predictor variables to improve phosphorus representation in the next generation (Phase 7) Chesapeake Bay Program decision-support tools and Watershed Implementation Plans.

Gopal Bhatt (Civil & Environmental Engineering, The Pennsylvania State University), Joseph Delesantro, Lewis Linker, Robert Burgholzer, Richard Tian, Zhengui Wang, Wenfan Wu

Progress in the development and linkage of fine-scale Phase 7 Chesapeake Bay Watershed Model

The Chesapeake Bay Program (CBP) partnership is refining its suite of linked land use, airshed, watershed, estuarine, and living resource models. Overall, the development of the Phase 7 Watershed Model uses the best available data and science for (a) setting CBP nutrient and sediment target loads under future environmental conditions and growth, (b) evaluating implementation of agricultural and urban management practices that will be needed for achieving water quality standards, and (c) tracking progress in implementation of management practices in the Chesapeake watershed to achieve the nutrient and sediment targets. The Phase 7 Watershed Model uses substantially finer 1:100,000 medium-resolution NHD catchments with an average area of 490 acres (2 sq km) as compared to an approximate HUC10-scale Phase 6 river segments with an average area of 42,000 acres (170 sq km). Finer-scale modeling captures watershed, meteorological, and monitoring data as well as watershed processes at smaller catchment scales with better spatial resolution of estimated streamflow and water quality responses and how they vary over time with the management, climate, and land use scenarios. The Watershed Model structure was refined as a system of three linked models of (a) Chesapeake Assessment Scenario Tool, CAST, (b) spatial model with parameter calibration, CalCAST, and (c) Dynamic Watershed Model (DWSM). The revised structure directly addresses key recommendations made by the CBP STAC (Easton et al. 2017, Hood et al. 2021). The NHD-scale CalCAST was developed independently as a statistical model within a Bayesian calibration framework for estimating model parameters and to test and identify watershed properties that are critical in explaining variability in flow, nitrogen, phosphorus, and sediment loads at monitoring stations. The NHD-scale DWSM was developed using process-based modeling principles for the hourly simulation of flows and loads while applying the constraints of time-averaged responses estimated by CAST and CalCAST. The tightly coupled model structure and the complexities that come with simulations at finer space and time scales generated opportunities for evaluating tradeoffs in the implementation of new model structure, representation of watershed processes, and effectiveness and accuracy of simulation methods. In addition, linkage of the daily watershed loads with the Main Bay Model (MBM) estuarine model was improved, allowing the final Phase 7 Model Suite to be accurate, efficient, and responsive in providing information needed by the CBP decision-makers in a timely manner and well as improving collaboration opportunities with the Chesapeake scientific community.

Zhengui Wang (Virginia Institute of Marine Science), Yinglong J. Zhang, Jian Shen, Wenfan Wu

Status of The Phase-7 Chesapeake Bay Water Quality Model

The Chesapeake Bay Program's (CBP) fully coupled physical-biological model, SCHISM-ICM, aka Phase-7 Main Bay Model (MBM), represents the CBP's cutting-edge next-generation management model for the Bay. Led by the Virginia Institute of Marine Science (VIMS) in collaboration with CBPO and UMCES, substantial progress has been made on MBM development over the past few years, including its coupling with the Phase-7 Watershed Model. In this presentation, we provide a comprehensive overview of the current status of MBM, focusing on biological processes across multiple temporal and spatial scales. We first compare MBM results with observational data as well as the previous phase-6 MBM. We then analyze key variables and parameters, such as bottom dissolved oxygen (DO), surface chlorophyll-a (CHLA), and the sediment conditions regarding sediment fluxes and nutrient dynamics. Moreover, we showcase the new shallow water modeling capability of MBM related to SAV, tidal wetlands and oyster models. Finally, we discuss the issues and challenges we have encountered during the model's development such as the linkage to the new watershed nutrient loading.

Richard Tian (UMCES), Nicole Cai

Simulation of benthic microalgae impacts on water quality in shallow water systems, Corsica River, Chesapeake Bay

Eutrophication and hypoxia represent an ever-growing stressor to estuaries and coastal ecosystems due to population growth and climate change. Understanding water quality dynamics in shallow water systems is particularly challenging due to the complex physical and biogeochemical dynamics and interactions among them. Within shallow waters benthic microalgae can significantly contribute to autotrophic primary production, generate organic matter, increase dissolved oxygen consumption, and alter nutrient fluxes at the sediment-water interface, yet they have received little attention in modeling applications. A state-of-the-art modeling system, the Semi-Implicit Cross-Scale Hydroscience Integrated System Model (SCHISM), coupled with the Integrated Compartment Model (ICM) of water quality and benthic microalgae has been implemented in the Corsica River estuary, a tributary to Chesapeake Bay, to study benthic microalgae impact on water quality in shallow water systems. The model simulation has revealed broad benthic microalgae impacts, ranging from changes in sediment-water interface fluxes, water column dynamics, with the effects observed from near-field to far-field monitoring stations. High-frequency variability and nonlinearity dominate benthic microalgae dynamics, sediment oxygen demand, and nutrient fluxes at the sediment-water interface. Resource competition and supply determine the spatial scope of benthic microalgae impacts to far-field stations and the whole Corsica embayment system. Our study shows that benthic microalgae is a significant factor in shallow water dynamics that needs adequate attention in future observations and modeling applications.

Amir Reza Azarnivand (University Of Maryland Center for Environmental Science), Jeremy Mark Testa

Modeling climate-driven flow increases on stratification in the Patuxent River Estuary: Implications for oxygen depletion

The Patuxent River, a tributary of the Chesapeake Bay, has experienced long-term climatic shifts over the past four decades, including increasing freshwater discharge, rising water temperatures, and decreasing dissolved oxygen. Understanding the relative role of increasing river flow versus temperature in driving oxygen depletion is central to ongoing efforts to improve prediction of hypoxia in Chesapeake Bay and its tributaries. As part of the broader Chesapeake Bay coupled hydrodynamic–biogeochemical modeling framework, we developed a refined, high-resolution hydrodynamic model using SCHISM for the Patuxent River Estuary that resolves its mainstem and tributary creeks. The model was run for a 10-year historical period (1991–2000) and validated against observations of temperature and salinity in both the mainstem and a tributary creek. Model performance showed strong temperature skill in the mainstem ($R2$ = 0.96 mainstem; 0.78 creeks) and moderate-to-strong skill for salinity ($R2$ = 0.81 mainstem; 0.78 creeks). Salinity RMSE across mainstem stations ranged from <0.01 PPT in the tidal freshwater reach to 2.59 PPT downstream, and from 1.25–1.83 PPT in the creeks. Temperature RMSE ranged from 1.36–3.52 °C in the mainstem and 1.43–5.43 °C in the creeks. To begin isolating the influence of climate-driven hydrologic change, we conducted a sensitivity experiment in which river discharge was increased by the observed linear trend over 1985-2023 (+0.073 m3s-1yr-1; approximately 2.8 m3s-1 over the record) and compared resulting stratification patterns to the historical simulation. Differences in seasonal stratification between scenarios are examined as a first step toward understanding how observed increases in

freshwater input may alter the physical conditions that regulate oxygen dynamics. This analysis establishes the physical framework necessary for subsequent biogeochemical simulations that will directly quantify the response of dissolved oxygen to climate-related trends in tributary estuaries.

Wenfan Wu (Virginia Institute of Marine Science, William & Mary), Zhengui Wang, Jian Shen, Y Joseph Zhang, Jeremy M Testa, Richard Tian, Lewis C Linker

Disentangling Drought-induced Algal Blooms in Tidal Freshwater Zones with an Interpretable Bloom Risk Index

Tidal freshwater zones (TFZs), typically situated in the upper reaches of estuaries, support high biodiversity and are closely intertwined with human activities. However, these systems are increasingly threatened by climate change, and the ecological responses remain poorly understood. Using the TFZs of the Patuxent River as a case study, we examined a series of rare and intense algal blooms triggered by the severe drought in summer 2007, based on extensive in-situ observations and an interpretable bloom risk index. This index effectively reproduced observed chlorophyll-a fluctuations in the TFZs across intraseasonal, seasonal, and interannual timescales, suggesting that drought modulates the algal blooms via the synergistic responses of atmospheric, hydrological, and anthropogenic drivers. During the 2007 drought, precipitation deficits reduced cloud cover, markedly enhancing downward solar radiation, while reduced river flow lowered water turbidity and extended water residence time. Meanwhile, the reduced dilution capacity under low-flow conditions amplified the role of nutrient inputs from the upstream WWTP, sustaining sufficient phosphorus supply during the drought. These synergistic responses collectively fueled the explosive growth of phytoplankton at the early stage of the drought. As the drought persisted, however, the seasonal decline in solar radiation, and the nutrient depletion related to phytoplankton uptake, jointly reduced bloom intensity at the later stage, despite the exceptionally long residence time then. This study demonstrates that TFZs are exposed to multi-faceted stressors from climate extremes, and the novel index offers an effective tool to inform management in the future and provides process-based validation for the developing Main Bay Model.

Anand Gnanadesikan (Johns Hopkins University), Rui Jin, Marie-Aude Pradal, Pierre St-Laurent

CDOM Absorption by Phytoplankton Modulates the distribution of Hypoxia in Chesapeake Bay

Recent limnological research has highlighted the role of Chromophoric Dissolved Organic Matter (CDOM) in modulating hypoxia in freshwater systems. In estuarine systems, this influence is less well understood. This study explores the interactions between CDOM and hypoxia in Chesapeake Bay by implementing a nitrogen-based biogeochemical model with an improved light attenuation parameterization that explicitly represents CDOM as a function of

riverine refractory dissolved organic carbon (DOC). Chesapeake Bay's estuarine structure—featuring salinity stratification and a deep axial channel—makes it an ideal testbed. Removing CDOM-associated absorption increases light availability and alters productivity and nutrient dynamics, with regionally distinct outcomes. In the upper Bay, CDOM removal stimulates surface productivity, increasing detritus by about 10% and leading to correspondingly elevated respiration and hypoxia. In contrast, in the middle and lower Bay, light-enhanced productivity shifts deeper in the water due to surface nutrient depletion, deepening oxygen production and increasing both oxygen supply and remineralization in the deep channel. The net effect is to reduce the time-integrated hypoxic volume by 8.8-27%, depending on streamflow. Hypoxic volume during dry years shows a strong response to CDOM removal, whereas in wet years, the effects are more muted. Other metrics of hypoxic stress used for fisheries management are consistent with these results. The fact that CDOM-associated light absorption can either intensify or mitigate hypoxia depending on hydrographic context highlights the need for its explicit representation in estuarine models of water quality.

Jiangtao Xu (NOAA/NOS/CO-OPS), Lixia Wang, Aijun Zhang, Wei Wu, Qichun Xu, Siqi Li, Lu Wang, Changsheng Chen, Lucila Houttuijn Bloemendaal, Ed Myers, Tom Shyka

Update on NOAA's New Operational Forecast System for the Northeast US

NOAA's National Ocean Service (NOS) has been collaborating with the University of Massachusetts - Dartmouth (UMASS) to develop and implement a new Operational Forecast System (OFS) for US Northeast coastal waters to provide short-term (3-5 days) forecast guidance of water level, 3D currents, water temperature, and salinity for this regional navigation and coastal community. This system is based on the Finite Volume Community Ocean Model (FVCOM) and has been developed by the UMASS-WHOI research team in collaboration with the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS). The model domain extends from Bald Head Island, North Carolina northeastward to Nova Scotia, Canada. NOS plans to replace 4 existing models, including the New York and New Jersey OFS (NYOFS), Chesapeake Bay OFS (CBOFS), Delaware Bay OFS (DBOFS), and Gulf of Maine OFS (GoMOFS), with this new regional OFS. It is currently being transitioned from UMASS to NOAA and undergoing performance evaluations, intercomparisons with existing NOS models, and semi-operational tests to prepare the model for operational implementation. The results from the experimental semi-operational runs will be made available to all interested users for further evaluation and validation of its usefulness, accessibility, and assessment of impacts to any downstream applications. An overview of NECOFS, the project timeline, hindcast results, and preliminary results of the semi-operational simulations will be presented. NOS welcomes feedback from potentially-impacted users in anticipation of the upcoming changes to the OFS operational products, and strongly encourages the community to become further engaged in the ongoing development of this critical regional model.

Robin Glas (US Geological Survey)

When Is “Typical” Typical? Re-evaluating Hydrologic Base and Critical Periods for Chesapeake Bay Program Models

Accurate representation of hydrologic variability is central to the Chesapeake Bay Program’s (CBP) Watershed Model, particularly through the selection of base and critical periods to characterize long-term and stress-condition freshwater inputs to Chesapeake Bay. Careful consideration of these periods is critical to the CBP because these hydrologic conditions determine the modeled loads of nitrogen, phosphorus, and sediment delivered to the Bay. The current hydrologic base and critical periods are centered around 1995 and were established more than a decade ago using methods documented in EPA’s Chesapeake Bay Total Maximum Daily Load (TMDL) report. Since that time, longer records and improved analytical tools motivate a re-evaluation of these periods to update our understanding of freshwater inputs to the Bay.
The U.S. Geological Survey initiated a study in fiscal year 2026 (FY26), in partnership with the CBP, to assess historical freshwater inputs to the Chesapeake Bay and identify candidate base and critical periods that are representative of modern hydrologic conditions. The analysis evaluates rolling 10-year and 3-year windows of multiple hydrologic metrics, including lower- and upper-tail flow quantiles (Q05, Q10, Q90, and Q95). The current CBP model starting in 1985 motivates emphasis on post-1975 hydrology when evaluating candidate base and critical periods. Using post-1975 streamflow records also limits the skewing effects of rare, severe droughts, such as those experienced in the 1930s and 1960s, thereby improving the representativeness of the resulting hydrologic summaries.

We will present preliminary results that summarize the rolling-window evaluation, discuss sensitivity to historical extremes, and outline implications for defining hydrologic periods that balance representativeness, stability, and stress relevance for future model applications. The presentation will conclude with an overview of how study results will be shared with the CBP in FY26, allowing the partnership to decide on potential changes to the modeled hydrologic periods.

Gopal Bhatt (Civil & Environmental Engineering, The Pennsylvania State University),
Lewis Linker, Richard Tian, Jesse Bash, Chris Nolte

Initial assessment of future energy scenarios in Chesapeake airshed, watershed, and tidal bay nitrogen loads

A series of models ranging from a Global Change Analysis Model, (GCAM) and models of the Chesapeake Bay Program (CBP) airshed, watershed, and tidal Bay were used to estimate atmospheric deposition loads of nitrogen to the Chesapeake Bay and its watershed under future emission conditions. The future energy scenarios included a scenario of limited greenhouse gas (GHG) mitigation, a scenario of State GHG emission reduction, and an estimated national, economy-wide CO_2 cap of net-zero carbon emission by 2050. The estimate of atmospheric N-deposition loads in the Chesapeake Bay watershed and direct to tidal waters for the future scenarios were compared to estimates of historic loads of 2016 and estimates for 2030 used in the development of Chesapeake Bay Program Phase 3 Watershed Implementation Plan. The emissions were estimated by source and by state in the GCAM and deposition of nitrogen loads to the watershed and tidal waters by the Community Multistate Air Quality (CMAQ) airshed model, and changes in delivery to the Chesapeake Bay and impact on hypoxia were simulated by the Phase 6 CBP watershed and estuarine models, respectively. Overall, the findings are that atmospheric deposition loads of nitrogen are estimated to continue to decrease in the Chesapeake watershed and tidal Bay until midcentury with estimated midcentury reductions in the watershed and Bay of 33 Mlb-N and 1 Mlb-N, respectively, as compared to that for 2030. The additional nitrogen reductions of about 2.9 Mlb-N loads delivered to Bay beyond the 2030 N-delivery estimates - with 1.9 Mlb-N from the watershed and 1 Mlb-N directly to tidal open waters - reduced deep-channel and deep-water hypoxia by about 35 Mm3 (i.e., about 3% decrease) where hypoxia is defined as volume of water with <1 mg/l dissolved oxygen during the months of June to September over 10-year average hydrology period, and by about 57 Mm3 (i.e., about 1.3% decrease) where hypoxia is defined as volume of water with <3 mg/l dissolved oxygen.

Garett Pignotti (ICPRB), Stephanie Nummer, Carlington Wallace

Modeling Water Quality Response of Urban Watersheds to Future Management Scenarios

Addressing the environmental impacts of nutrient and sediment pollution requires robust modeling to support assessment and scenario analysis. Future land use and associated management actions are expected to place additional stress on water resources, particularly in urban watersheds, with highly variable responses given their engineered, heterogeneous characteristics. To understand these potential impacts to water quantity and quality, we evaluated the response of four Maryland watersheds (Jones Falls, Gwynns Falls, Prettyboy Reservoir, Rocky Gorge Reservoir) under future management scenarios using the Soil and Water Assessment Tool (SWAT), with and without urban best management practices (BMPs). Specifically, we explicitly incorporated stormwater management practices (e.g., wet ponds, detention ponds, wetlands) and calibrated the models using observed streamflow. In general, we found that urban BMPs substantially reduced stormflow and decreased pollutant loads, although response varied among watersheds. Potential increased precipitation increased stormflow with associated increases in nutrient and sediment loads. For example, sediment loads increased by a range of 13,000 to 24,000 tons per year from 2025 to 2050. Although BMPs reduced projected loads, their long-term effectiveness under intensified stress remains uncertain. By capturing and improving predictive understanding of watershed responses, such ongoing modeling efforts will enhance the capacity of management strategies to mitigate the adverse consequences of projected increases in nutrient and sediment pollution.

Lewis C. Linker (U.S. EPA Chesapeake Bay Program Office), Gopal Bhatt, Richard Tian, and Raymond Najjar

Estimated Impacts of Environmental Change on Water Quality in the Chesapeake Bay Beyond Midcentury

To set the Midpoint Assessment nutrient and sediment load targets in 2020 for the Chesapeake Bay, projections of changing environmental conditions to 2055 and their effects on water quality have been considered. The assessment was done to set additional nutrient and sediment reductions required to maintain water quality standards under 2025 environmental conditions. Analysis for the Midpoint Assessment used four decadal periods centered on 2025, 2035, 2045, and 2055, conditions that are three, four, five, and six decades, respectively, beyond the end year of the 1993–1995 critical period, and the 1991-2000 base hydrology and nutrient loads used to set the 2010 Chesapeake TMDL allocations.

The analysis is now expanded to changing environmental conditions beyond midcentury to 2085. Under the CMIP5 RCP 4.5 ensemble scenario, temperature and precipitation trends for the Chesapeake Bay watershed prior to midcentury have a rate of change more than twice that of the post midcentury trend. Prior to midcentury, runoff and nutrient loading to the Bay are projected to increase. In this analysis, model simulations suggest the trend of increasing runoff may be reduced post midcentury. The combined effect of a reduced increase in the trend in temperature and precipitation post midcentury in the RCP 4.5 scenarios with estimated sea level rise continuing well beyond 2100 leads to a decreasing trend in Chesapeake hypoxia post midcentury resulting in a leveling off of dissolved oxygen water quality degradation during that period with reduced hypoxia beyond the close of this century.