Chesapeake Community Research Symposium 2024

Session 18: Examining Chesapeake Climate Change Impacts With Advances in Monitoring, Assessment Analyses, and Fine Scale Models

Lew Linker, Joseph Zhang, Gopal Bhatt, Richard Tian, Isabella Bertani, Nicole Cai, Joseph Delesantro, and Jesse Bash

Phase 7 Models of the Chesapeake Watershed, Estuary, and Airshed – Exploring Future Challenges of Climate Change and Growth

The Chesapeake Bay Program (CBP) is developing a fine-scale simulation of the Chesapeake watershed, airshed, and tidal waters called Phase 7. The Phase 7 Models will feature modeling of the watershed and tidal Bay that will be 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 to 2 km2. In addition to the Main Bay Model (MBM) used for management application to the 2010 Chesapeake TMDL, the tidal models include Multiple Tributary Models (MTMs) that are at an even finer tidal water scale and are directed toward local water quality concerns. The MTMs include simulations of the Potomac, James, 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, for the first time, to assess the dissolved oxygen water quality standards in all Bay tributaries and in shallow water systems.

Overall, the Phase 7 Models are directed at ensuring the Chesapeake living resource-based water quality standards are achieved under the future conditions of 2035 climate change and growth. The Phase 7 Models will be completed in 2025, reviewed in 2026, and applied in 2027. In addition, the increased capability of the Phase 7 Models will be able to examine the consequences of decarbonizing the economy and the commensurate reduction in atmospheric deposition of nitrogen as well as how nutrient and sediment reduction efficiencies could change for nonpoint source best management practices. Finally, the influence of climate change phenology, or how the timing of plant and animal annual life cycles may shift under climate change, on nutrient loading and water quality in the Chesapeake will be examined.

Gopal Bhatt, Isabella Bertani, Lewis Linker, Robert Burgholzer

Recent advances in the development of a fine-scale Chesapeake Bay watershed model for 2035 Climate Change Assessment

The Chesapeake Bay Program (CBP) partnership is refining its suite of land-use-, airshed-, watershed-, estuarine-, and living resource models for 2035 climate change assessment in 2027. The work plan for the Phase 7 models includes development and refinements of the models till the end of 2025 followed by a one-year period for a full review of the models by the partnership as well as any proposed changes or refinements needed in the models. Overall, the development of these models will incorporate and reflect best available data and science necessary for (a) 2035 climate change assessment, (b) setting TMDL allocations of nitrogen, phosphorus, and sediment loads, and (c) implementations of agricultural and urban management practices that will be needed for achieving water quality standards. The Phase 7 watershed model structure is being refined as a system of three linked models – (i) Chesapeake Assessment Scenario Tool, CAST, (ii) spatial model with parameter calibration, CalCAST, and (iii) Dynamic Watershed Model. This revised structure will directly address some of the key recommendations made by STAC (Easton et al. 2017, Hood et al. 2021). NHD-scale CalCAST is being 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 the monitoring stations. NHD-scale Dynamic Watershed Model (DWM) is being developed using process-based modeling principles for hourly simulation of flows and loads while applying the constraints of time-averaged response estimated by CAST or CalCAST. The Phase 7 watershed model based on 1:100,000 medium resolution NHD catchments with average area of 490 acres (2 sq km) is of substantially finer scale as compared to approx. HUC10 scale Phase 6 river segments with an average area of 42,000 acres (170 sq km). Finer scale model resolves watershed, meteorological, and monitoring data as well as watershed processes at smaller catchment scale in spatially resolving the estimates of streamflow and water quality response of the watershed for the climate change and management scenarios. The model structure and complexities of simulations at finer space and time scales is generating opportunities for evaluating the tradeoffs in implementation of the new model structure, scale, and simulation methods such that the final model will be accurate, efficient, and responsive in providing information needed by the CBP decision-makers in a timely manner.

Rashid Ansari

Analyzing Watershed Responses to Climatic and Land Use Changes: Implications for Flood Risk and Nutrient Dynamics in the Susquehanna River Basin

Managing flood risks and nutrient pollution is becoming more challenging with changing climate and land use patterns, particularly in agricultural watersheds. The Susquehanna River Basin, known for its major farming activities and ecological role in supporting the Chesapeake Bay, faces increased risks from climate change, agricultural growth, and urban development. Understanding these effects is crucial for developing informed adaptation strategies to mitigate future risks. This study aims to explore how changes in climate and land use affect flood risk and nutrient levels in the basin. We use an integrative modeling strategy to measure these risks. By applying the Soil Water Assessment Tool (SWAT) with climate scenarios from the Coupled Model Intercomparison Project Phase 6 (CMIP6) and land use forecasts, we assess trends in streamflow, sediment, and nutrients. The simulated stream flows power the LISFLOOD-FP hydrodynamic model, enhanced with flood management infrastructure, to delineate floodplains and quantify flood risk. The findings provide detailed forecasts of flood risks and nutrient distribution for both the near and distant future in this basin. These projections are crucial for the bay's future restoration efforts and managing flood risks across the commonwealth.

Andrew J. Miller, Mac S Luu

Temporal trends in watershed-average precipitation and streamflow extremes in the Baltimore metropolitan area

A changing climate disrupts many established interactions between the atmosphere and the water cycle. Warmer temperatures allow the air to hold more water vapor, enhancing moisture convergence and rain rates, thereby increasing the intensity of storm systems. Nonstationary probability analysis of radar precipitation data for a set of 4900 1-km2 grid cells used the 88 largest daily maximum 1-hour rainfall accumulations (average of four per year). Results indicate that there is an increasing trend of extreme rainfall events over 22 years of record with a median increase of 10% (Smith et. al, in review). The radar data combined reflectivity-based rainfall fields from 2000 - 2015 (HydroNEXRAD) and operational polarimetric rainfall fields from 2012 - 2021 (Digital Precipitation Rate) and were bias-corrected using a network of Baltimore-area rain gauges.

For a set of gauged watersheds within the same spatial domain, we examined watershed-average bias-corrected 60-minute radar rainfall time series for the period of April through September during the years 2000 to 2021. Nonstationary Peaks-Over-Threshold (POT) analysis was used to assess time trends in maximum rainfall accumulation for specified duration and exceedance probability. A similar nonstationary probability analysis was carried out with the 88 largest daily maxima for the U.S. Geological Survey stream gages at the outlets of those watersheds. Rainfall and streamflow results were compared to assess whether time trends in peak flow were similar to those observed for precipitation maxima over the same watershed. Trends in rainfall and runoff maxima over the sampled time period are similar and appear to be trending upwards in a majority of the watersheds studied. Coupled increases in frequency and magnitude of rainfall and streamflow extremes may have relevance for understanding of temporal trends affecting Chesapeake Bay.

Jaleel Shujath

Adapting Stormwater Management to Climate Change: Analysis of Extreme Rainfall Trends in the Chesapeake Watershed

This research delves into the changing dynamics of extreme rainfall events in the Chesapeake Watershed. Utilizing NOAA-NCDC's extensive rainfall dataset covering seven decades, the study establishes essential thresholds for defining extreme rainfall, crucial for the strategic development of stormwater infrastructure in response to climate change.

The research systematically explores trends in annual maximum daily precipitation (MAXP) and frequent heavy rainfall events. Employing sophisticated analytical techniques like linear regression and the Mann-Kendall test, it quantitatively assesses shifts in the magnitude and frequency of these events. This in-depth temporal analysis forms a solid foundation for comprehending the intensification of rainfall patterns and their implications for stormwater management.

Central to the study is the integration of climate change projections, contextualizing past data and refining future estimates for 100-year storm events. This foresight is critical for aligning with increasingly stringent environmental regulations and permit requirements. The findings are instrumental for local and regional authorities, informing updates in stormwater management practices and infrastructure design.

Furthermore, our results underscore the need for adaptable stormwater management strategies. It highlights the importance of developing flexible systems, scalable treatment facilities, and innovative capture techniques to manage the heightened volumes and pollutant loads from extreme rainfall events. It also underscores the value of interagency collaboration within the Chesapeake Watershed for a unified response to climate-related challenges.

Tori Tomiczek, Liliana Velásquez Montoya, Alex Davies, Gina Henderson, Zoë Johnson, Sara Phillips, Anna Wargula, Cecily Steppe

Sea Level Rise Monitoring and Modeling at the United States Naval Academy for Flood Resilience

The United States Naval Academy (USNA) has overcome unique challenges to achieve its mission of developing future officers of the United States Navy and Marine Corps in the face of local sea level rise and climate change stressors. As sea level rise impacts manifest in the form of roadway flooding, closures, and other infrastructure effects around the installation, understanding and mitigating these flood hazards is critical for operational readiness. This presentation will describe observations of historic flood events at USNA, including Hurricane Isabel in September, 2003, which was the highest water level recorded at the Annapolis NOAA tidal station 8575512, as well as the recent record-setting high tide events occurring in October, 2021 and January, 2024. To address the increasing impacts of chronic flooding, the Superintendent created a Sea Level Rise Advisory Council (SLRAC) in 2015. This diverse group of experts and stakeholders, including the Executive Director for Strategy, USNA Architect, faculty from the departments of Ocean and Atmospheric Sciences, Naval Architecture and Ocean Engineering, Naval Facilities Engineering Systems Command (NAVFAC), and the City of Annapolis, informs observational and monitoring networks around USNA and also provides forecasting and decision-making support for future resilience and mitigation actions around the installation. Student and faculty research including short- and long- term monitoring, modeling, and forecasting efforts that support the SLRAC will be discussed. Finally, the presentation will describe the Installation's Resilience Plan, which includes multiple solutions around the Yard including exterior defenses, perimeter protections, and interior adaptations. These adaptations are planned to be implemented by 2065 in order to provide operational capacity and mission readiness to 2100.

Joseph Zhang, Jian Shen

Overview on the Phase 7 Main Bay Model

The Chesapeake Bay's fully coupled physical-biological model, SCHISM-ICM, also known as Phase 7 Main Bay Model (MBM), represents the Bay Program's cutting-edge management model to allocate TMDL (Total Maximum Daily Load) at finer scales. Led by the Virginia Institute of Marine Science (VIMS) in collaboration with the Bay Program office and UMCES, significant strides have been made in MBM's development over the past two years. During this presentation, we will offer an overview of the current status of MBM, focusing on both its physical and biological components. Moreover, we will outline our plan for the next stage of MBM development, including the incorporation of living resources and the implementation of climate scenarios. Strategy to effectively support the Bay Program Office's newly funded multiple fine-resolution tributary models (MTMs) will be outlined. These MTMs require boundary conditions and other relevant information from MBM's model configuration. The application of MBM and MTMs will enhance our understanding of the Chesapeake Bay ecosystem and support adaptive management strategies in a changing climate.

Zhengui Wang, Joseph Zhang, Jian Shen

Progress on the development of Phase 7 Chesapeake Bay Water Quality Model

The Virginia Institute of Marine Science (VIMS) has actively dedicated the past two years to working on the Bay Program's next-generation management model, known as Phase 7 MBM. In this presentation, we will provide an update on our progress in developing the MBM, with a specific focus on assessment of water quality variables. To begin, we will summarize our efforts in coding the ICM model, establishing the modeling workflow, and designing user interfaces. Subsequently, we will delve into the specifics of our model calibration regarding the ICM state variables, as well as conduct a comparative analysis between the Phase 6 and Phase 7 MBMs. We will discuss the spatial and temporal variations of key variables such as dissolved oxygen (DO) and chlorophyll-a (CHLA), and an important management question on the trend of hypoxia volume in the Bay. We will update on our progress in incorporating different submodules (e.g. living resources) into our model workflow. Furthermore, we will outline our plan to enhance the model's simulation of water quality variables and address some remaining issues related to the linkage to watershed model.

Richard Tian, Zhengui Wang, Gopal Bhatt, Joseph Zhang, Larry Sanford and Lewis Linker

Modeling Wave-driven Shoreline Erosion in the Corsica and Choptank Estuaries, Chesapeake Bay

Shoreline erosion constitutes a fundamental challenge to the coastal communities and is becoming more acute under climate change conditions. Over the years scientists have explored ways to quantify shoreline erosion and progress has been made during recent decades that shoreline erosion is related to wind wave power, bank height, water depth, and the shoreline erodibility. We have parameterized these new findings into the state-of-the-art model system, the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM), coupled with the new generation wind wave model WWMIII. SCHSIM employs an unstructured grid with high resolution and is particularly suitable for coastal dynamics simulations. We have applied the coupled system to the Corsica River and Choptank estuaries (Chesapeake Bay) where field observations on bank height and property are available. In addition to the observation data, the Maryland USGS has digitized historical coastline cartographs based on which shoreline recession rate computed. The model has successfully reproduced the cartographic estimates of shoreline erosion. The simulation revealed that shoreline erosion occurred more in winter and fall, due to more frequent strong winds, than during summer. In general, the southern shorelines experienced stronger wind induced wave impacts due to the predominantly northernly winds, leading to more severe bank erosion than northern banks in the region. Also, the lower estuaries experienced higher shoreline erosion than in the upper estuaries where the wind fetch is more limited. Detailed model parameterization and simulation results will be presented at the conference.

Kyle Hinson, Marjorie A.M. Friedrichs

Response of hypoxia to future climate change is sensitive to methodological assumptions

Climate-induced changes in hypoxia are among the most serious threats facing estuaries, which are among the most productive ecosystems on Earth. Future projections of estuarine hypoxia typically involve long-term multi-decadal continuous simulations or more computationally efficient time slice and delta methods that are restricted to short historical and future periods. We make a first comparison of these three methods by applying a linked terrestrial–estuarine model to the Chesapeake Bay, a large coastal-plain estuary in the eastern United States. Results show that the time slice approach accurately captures the behavior of the continuous approach, indicating a minimal impact of model memory. However, increases in mean annual hypoxic volume by the mid-21st century simulated by the delta approach (+19%) are approximately twice as large as the time slice and continuous experiments (+9% and +11%, respectively), indicating an important impact of changes in climate variability. Our findings suggest that system memory and projected changes in climate variability, as well as simulation length and natural variability of system hypoxia, should be considered when deciding to apply the more computationally efficient delta and time slice methods.

Colin Hawes, Marjorie A.M. Friedrichs, Pierre St-Laurent, Raymond G. Najjar, Kyle Hinson

Projected impacts of climate-induced changes in the ocean, land, and atmosphere on mid-21st century Chesapeake Bay hypoxia

Hypoxia is impacted by many climate-induced changes. These include atmospheric warming and solar radiation which exacerbate deoxygenation by decreasing gas solubility and enhancing

phytoplankton growth and respiration, and changes in precipitation, winds and sea level which can influence hypoxia via nutrient availability and estuarine circulation. To project the impacts of such future climate changes on hypoxia in Chesapeake Bay, a 3-D coupled hydrodynamic–biogeochemical model was linked with the Chesapeake Bay Program's Phase 6 watershed model. A control experiment simulated the early 1990s while mid-21st century projections were generated by applying downscaled outputs of three Earth System Models (ESMs) according to a "business as usual" emissions scenario. Using the median ESM (in terms of future warming and precipitation increases), projections estimated mid-century annually integrated hypoxic volume (for O2 < 3 mg L–1) will increase by 23% ± 9% (mean ± standard deviation), depending on the year analyzed. Climate forcings from additional ESMs provided larger estimates of uncertainty on future hypoxic volume increase (21±19%), depending on the ESM used. Future changes to hypoxia were seasonally variable, with the greatest increases predicted early in the hypoxic season (May–June) and no change or decreases in mid-summer. Finally, experiments with subsets of modified climate forcings revealed that air temperature accounted for the majority (72±18%) of the total increases in annually integrated hypoxic volume. Next most impactful were changes to watershed inputs (21±31%) and sea level (-1±24%). Both of these impacts were highly dependent on freshwater discharge, with wetter years showing more hypoxia. Finally, changes to solar radiation, winds, direct precipitation on the Bay, and ocean temperature cumulatively accounted for only small future increases in hypoxia (5±3%). To reach regulatory water quality goals despite these competing impacts of climate change, future nutrient management actions will likely need to be more aggressive.

Julia Abrao Teixeira, Xun (Nicole) Cai, Piero L.F. Mazzini, Qubin Qin, Y. Joseph Zhang

Connectivity, Distribution, and Fate of Microplastics from Mid-Atlantic Bight Estuaries: A Lagrangian Particle Tracking Approach

Microplastic pollution (≤5 mm) has emerged as a globally recognized issue in water systems. Due to their great durability, plastics persist in marine ecosystems for hundreds to thousands of years, leading to a wide range of negative impacts on wildlife, human health, habitats, and economies. Land-based sources are the primary contributors to microplastic pollution in the ocean, and estuaries serve as significant conduits for transporting microplastics to the ocean. Thus, it is imperative to conduct investigations connecting estuaries and the coastal ocean to further understand the pathways, dispersion, and accumulation areas of microplastics. To advance our understanding of this persistent problem, coupled ocean hydrodynamics and Lagrangian particle-tracking models serve as invaluable tools. This project will utilize a Lagrangian particle tracking method coupled with a validated 3D hydrodynamic model of the Mid-Atlantic Bight (MAB) region using the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM). The overall goal of this study is to obtain a comprehensive understanding of the pathways, distribution, and fate of microplastics originating from the major estuaries in the Mid-Atlantic Bight (MAB): Chesapeake Bay, Delaware Bay, Hudson River, and Long Island Sound. We will present preliminary results about the dispersion patterns of microplastics and identify regions with a high probability of accumulation under multiple driving forces. Additionally, we will estimate the connectivity between microplastic sources from estuaries in the MAB and their potential impact on pollution in the Chesapeake Bay. This research will generate valuable insights into microplastic pathways and potential accumulation hotspots, thereby offering guidance for the management of microplastic pollution in the Mid-Atlantic Bight and Chesapeake Bay.

Harry Wang, Jeremy Testa, Gopal Bhatt, Zheng Jing, Breanna Maldonado, and David Forrest

Fine-scale Patapsco River Tributary Model for Simulating Effect of Sanitation Sewage Overflow under Climate Change Conditions

In recent years, the increased frequency of sanitation sewage overflow (SSO) in Baltimore has caused millions of gallons of sewage to flood into the urban streams. In 2018 alone, Baltimore City recorded more than 5000 SSO occurrences, especially during heavy precipitation events. Hurricane Irene of 2011 set new records for both the water level and reported SSO in many parts of Maryland. Based on the climate model prediction, increasing temperatures will cause flooding events to be more common which will trigger the stormwater and groundwater to overload the system causing SSO to flow out of the collection system. When that happens, extremely high concentrations of nutrient loads discharged into the stream can potentially set off an environmental crisis. Although SSO was not included in Bay's water quality model in the past, given that climate change has the footprint of increasing the frequencies of flood and urban SSO, analysis and assessment of SSO's potential impact is warranted in addressing 2035 climate change risk in the Patapsco/Back River basin. As EPA CBP's phase 7 watershed model already has the National Hydrography Dataset catchments for the Baltimore metropolitan area that contain pour points for terminal streams, the interface between watershed and estuarine model can be achieved by resolving fine-scale streams in the estuarine model to handle the spatial linkage for the flow and loads generated by the watershed model. As such, efforts were made to explicitly include the Herring Creek, Jones Falls, Gwynns Falls, and the non-tidal portion of the Patapsco River into the model domain such that the SSO loads can be added through these streams and be further used for sensitivity scenarios. The research will help to understand the process of SSO transport, its fate, and the influence on water quality through the fine-scale 3D tributary model for Patapsco/Back Rivers.

Qubin Qin, Jian Shen; Xun Cai; Zhengui Wang; Pierre St-Laurent

The transport and retention conditions in the middle-lower Rappahannock River

The Rappahannock River, Virginia's longest free-flowing river, remains relatively understudied in terms of its ecosystem and water quality. It has been suggested that the presence of a shallow region in the middle river plays a crucial role in influencing gravitational circulation, affecting transport and retention conditions in the middle-lower Rappahannock River. This, in turn, has implications for biogeochemical processes, including nutrient deposition and hypoxia. This study uses a well calibrated 3D SCHISM model to reevaluate the aforementioned suggestion by investigating local transport and retention conditions in the middle-lower Rappahannock River.

Through numerical dye experiments and particle tracking methods, we analyze conditions for both conservative materials, such as dissolved nutrients, and nonconservative materials with varying vertical velocities, like sediment and particulate nutrients. Our results shed light on the impact of hydrodynamics on water quality in the Rappahannock River and inform strategies for its management and preservation.

Jian Zhao, Jiabi Du

Fine scale numerical simulations of the Choptank River in the Chesapeake Bay

The Choptank River is a major tributary of the Chesapeake Bay and the largest river on the Delmarva Peninsula. Its watershed is a low-gradient coastal plain with characteristic agricultural and forested landscape, which is typical of many coastal plain systems, both in the region and beyond. The Choptank ecosystem has been in decline due partly to excessive nutrient and sediment loads from agriculture. In addition, the potential effects of climate change are widely reported in the Chesapeake, however, whether the impacts are heterogeneous in space and time, especially in tributary regions, are still unclear.
To elucidate the factors affecting the water quality in the Choptank River and assess the responses to climate change, a numerical tool with fine scale resolution is imperative. Here, we develop a high-resolution unstructured grid hydrodynamic-water quality model to represent the specific characteristic of the Choptank River. The model is based on the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM), which also is adopted by Chesapeake Bay Program (CBP) Main Bay Model (MBM) project. Our tributary model successfully captures the hydrodynamics in the Choptank River. The simulated water quality variables display distinct variations on time scales from synoptic to seasonal and interannual. Their behaviors are consistent with the CBP observations.

Kenneth A Rose, Mark Monaco, Lee McDonnell, Denice Waldrop

More Consideration of Living Resources in Chesapeake Bay Restoration: “Hail to CESR” or “CESR Salad”

The policy implications contained in the recent Comprehensive Evaluation of System Response (CESR) report prepared by the Scientific and Technical Advisory Committee advocated for more explicit consideration of living resources responses in CBP planning and actions. A supporting document to CESR entitled “A Proposed Framework for Analyzing Water Quality and Habitat Effects on the Living Resources of Chesapeake Bay” presented a strategy for using existing data and models to quantify responses to the TMDL and other restoration actions within the context of complex life cycles and multiple factors and stressors. Management questions to be addressed include: (1) What is the expected (projected) response of living resources to water quality and habitat conditions in the Bay under alternative combination of management actions and plausible futures under climate change? (2) Given the current state or condition, how can the analyses inform what types and magnitude of changes in water quality and habitat are needed to evoke an agreed-upon target set of the desired living resources’ responses? (3)

Where spatially within the Bay would we focus management actions to generate critical improvements in habitat and therefore living resources? We will provide an overview of CESR as it relates to living resources and these management questions and highlight opportunities for adapting and developing habitat, population, and multi-species models. The process will be illustrated with an example of a work plan for a habitat analysis that uses the CESR documents. We will try to bring clarity to how the many implications arising from the CESR report affects and offer opportunities for advancing living resource modeling in the Chesapeake Bay.