Chesapeake Community Research Symposium 2024

Session 9: Water-quality patterns and trends in the Chesapeake Bay and its watershed: II. Novel analysis and scientific communication approaches to inform management

Gary Shenk, Qian Zhang, Gopal Bhatt, Isabella Bertani

The Chesapeake Bay TMDL indicator: Integrating monitoring and modeling information to assess progress toward nutrient reduction goals

Eutrophication has been a major environmental issue in many coastal and inland ecosystems, which is primarily attributed to excessive anthropogenic inputs of nutrients. Restoration efforts have therefore focused on the reduction of watershed nutrient loads, including in the Chesapeake Bay (USA). To facilitate watershed management, watershed models are often developed and used to assess the expected impact of scenarios of past and future management policies and practices and the impact of watershed conditions. However, the level of load reductions estimated using monitoring data often does not match with model predictions, which may cast doubt on the effectiveness of the restoration efforts, the reliability of the model, and the prospect of achieving pre-established reduction goals. To better reconcile such inconsistencies between expectation from modeling estimates and monitoring information, a watershed-wide indicator was developed for the Chesapeake Bay watershed to explicitly quantify the progress toward nutrient reduction goals in the context of the Chesapeake Bay Total Maximum Daily Load (TMDL). Results of the indicator show that since 1995 long-term progress has been made toward the TMDL planning targets for both nitrogen and phosphorus. Specifically, management practices that are implemented and realized (in monitoring data) have been increasing over time, whereas management practices that need to be implemented in the future to meet the goals have been decreasing. In addition, the progress of nutrient reduction toward meeting the goals has varied with source sectors and watershed locations: i.e., point source management has been fully or nearly fully implemented, whereas nonpoint source management has been implemented by 50%-70%. In summary, this indicator, which is largely based on monitoring data, can provide at least four benefits: (1) evaluating the validity of the modeled estimates of nutrient reductions by comparing them to monitoring information; (2) placing the monitored riverine trends into a management context; (3) comparing progress between different nutrient source sectors and watershed locations; and (4) facilitating communication of the progress to the Chesapeake Bay Program Partnership and the public. Although we focus on the indicator development and interpretation for the Chesapeake Bay watershed, the framework can be transferred to watersheds within and beyond this watershed, where similar modeling and monitoring information exists, to gauge expectations on the trajectory and pace of the progress toward meeting restoration goals.

Olivia Devereux, Helen Golimowski

Explaining Changes in Nitrogen and Phosphorus Loads Using Land Management Practice Data and How These Data Can Indicate Where Practices Could Be Targeted in the Future

We will show how management practice data correlated with CAST estimated delivery factors, nutrient loads, and how intensity of implementation can indicate effectiveness of such practices for animal and crop/pasture agricultural systems. These data establish a framework to subsequently test hypotheses and explore empirical data. We will show the percent of each area of the watershed that falls into the expected and unexpected outcomes from management practice implementation. We also will review a recent project where these data are being used to inform where outreach will occur with farmers in VA.

Keota Silaphone

An assessment of cover crop nitrogen efficiencies in the United States Coastal Plain Province, 1980 - 2022

Cover crop best management practices (BMPs) are widely implemented in the Chesapeake Bay watershed to intercept agricultural field losses of nitrogen (N) and phosphorus (P) that have fueled eutrophication in the Chesapeake Bay and fresh, estuarine and coastal waters globally. My assessment focused on 18 empirical and modeling cover crop studies in the U.S. Coastal Plain province published between 1980 and 2022. I evaluated 689 N efficiencies to test the hypothesis that cover crop N efficiencies have an adequate basis for estimating their capacity to intercept N. I found that the N efficiency was calculated as the ratio of an N interception by cover crop biomass or a reduction in soil or groundwater N divided by an N input, e.g., previous spring fertilizer or a previous soil or groundwater N concentration or flux. The use of these variables resulted in wide ranges in mean cover crop N efficiency (10-80%). The modeling approach generally resulted in N efficiencies significantly higher than the empirical approach, as did the parallel control-treatment experiments compared to the sequential before-and-after implementation method. Results indicated the cover crop N efficiencies based on soil residual N were greater thanN efficiencies based on cover crop biomass immobilization. In turn, cover crop N efficiencies based on immobilization studies were greater than N efficiencies based on groundwater nitrate studies. Because there is no standard methodology to report the effect of cover crops, standardized metadata describing the variables used in the N efficiency calculations should accompany future reported cover crop N efficiencies.

Isabella Bertani, Gopal Bhatt, Lewis Linker

Characterizing streamflow and constituent loads in the Chesapeake Bay watershed through parsimonious Bayesian modeling

The Chesapeake Bay Program is undergoing an effort to build the next-generation (“Phase 7”) of airshed, watershed, and estuarine models to support management decisions aimed at ultimately achieving water quality goals in the Bay. Understanding how landscape properties and anthropogenic factors interact in controlling variability in contaminant sources, transport, and fate is key to guide effective watershed management decisions to reduce nutrient and sediment loads. Relatively parsimonious, spatially explicit regression-based watershed models represent a flexible tool to probabilistically test hypotheses on factors related to spatio-temporal variation in constituent loads. We built a largely empirical model that characterizes spatio-temporal variability in streamflow and constituent loads across the Chesapeake Bay watershed using a Bayesian calibration framework. The model is built at the National Hydrography Dataset Plus (NHDPlus) catchment scale and is calibrated to average-annual and annual streamflow and constituent loads estimated at USGS riverine monitoring stations across the watershed. Detailed and comprehensive information gathered by the Chesapeake Bay Program on nutrient inputs from multiple anthropogenic sources across the watershed (e.g., fertilizer, manure, atmospheric deposition, crop uptake, point source discharges and withdrawals) is used as model input. Upstream catchment and stream properties that represent land and aquatic transport processes and help explain variation in streamflow and loads are also incorporated as predictors in the model. We provide an overview of the model formulation and present results of using the model as an exploratory tool to investigate drivers of spatio-temporal variability in streamflow and constituent loads across the Bay watershed. Results from this work will be used to inform the development of the next generation of Chesapeake Bay Program decision-support tools and Watershed Implementation Plans.

Qian Zhang, Joel T. Bostic, Robert D. Sabo

Regional patterns and drivers of total nitrogen and total phosphorus trends in the Chesapeake Bay watershed: Insights from machine learning approaches and management implications

Reduction of nutrient loads has long been a management focus of the Chesapeake Bay restoration, but riverine monitoring stations have shown mixed temporal trends. To better understand the regional patterns and drivers of total nitrogen (TN) and total phosphorus (TP) load trends across the Bay watershed, we have compiled and analyzed TN and TP load data from the Non-Tidal Network (NTN) stations, respectively, using clustering and random forest (RF) approaches. Cluster analysis revealed regional patterns of short-term trends and categorized the NTN stations into distinct clusters. RF models identified regional drivers of the trend clusters by quantifying the effects of major nutrient sources and watershed characteristics (i.e., land use, geology, physiography). Results show encouraging evidence that improved agricultural nutrient management has resulted in declines in agricultural nonpoint sources, which in turn contributed to water-quality improvement in our period of analysis. Results also show that water-quality improvements are less likely to occur in the Coastal Plain areas, reflecting the effect of legacy nutrients. To provide spatially explicit information for the entire watershed, including unmonitored areas, the developed RF models were used to predict TN trend clusters and TP trend clusters at the fine scale of river segments, which are more relevant to watershed planning. Across the Bay watershed, about two thirds of the river segments in the watershed had declines in TN, TP, or both. Despite such progress, continued nutrient reductions, especially from agricultural nonpoint sources, are imperative in order to achieve the

nutrient reduction goals. Overall, this work demonstrates that machine learning approaches can help better understand the regional patterns and drivers of nutrient trends in large monitoring networks, resulting in information useful for watershed management.

Sam Miller, James Webber

Evaluating nitrogen concentration – discharge patterns from agricultural Chesapeake Bay watersheds to inform management actions

Reductions from agricultural nonpoint nutrient sources are needed to meet Chesapeake Bay water-quality goals. Voluntary management practices have been used for decades to reduce nonpoint nutrient loads, but nutrient-reduction goals have not been achieved. Reducing nitrogen loads has proved particularly challenging and further nitrogen reductions will rely on addressing nonpoint sources of pollution. Analyzing the concentration-discharge (C-Q) patterns from discrete river water samples over space and time can help inform nutrient-reduction efforts. These patterns provide evidence about nutrient sources, transport, and storage and can differ based on land use, geologic setting, and nutrient inputs. This presentation will describe nitrogen C-Q patterns in selected agricultural Chesapeake Bay watersheds. Many of these watersheds showed little variability with nitrogen concentrations compared to discharge, reflecting a uniform subsurface nitrogen concentration profile likely caused by long-term accumulation of nitrogen inputs in the soil and groundwater. Significant positive relations were observed between agricultural nitrogen inputs and streamwater nitrogen concentrations, while significant negative relations were found between inputs and the slope of the log-transformed nitrogen concentration and discharge relations (b). These patterns demonstrate that watersheds with the greatest nitrogen inputs had (1) the highest stream nitrogen concentrations and (2) a dilution response that may imply low available nitrogen storage and / or decreased hydrologic connectivity. Many watersheds had significant negative declines in b over time, reflecting a change in the nitrogen-storage regime and a homogenization of the nitrogen concentration profile. These preliminary findings suggest that reductions in agricultural nitrogen inputs could eventually decrease stream nitrogen concentrations, increase b, and improve water quality conditions in the most impaired streams.

Shuyu Y Chang, Qian Zhang, Nandita B Basu, Kimberly J Van Meter

Past trajectories and future horizons of water quality in the Chesapeake Bay reservoir system

The Chesapeake Bay Watershed is home to more than 1400 dams and reservoirs, from small mill dams to the large Conowingo Dam on the lower Susquehanna River. But despite the importance of reservoirs to water quality and aquatic ecosystems, we continue to have a limited understanding of how these hydrologic structures impact the sink and flow of legacy contaminants, and of how these effects may change under future scenarios, including a warming climate, aging infrastructure, and dam removal. The research so far to study the impacts of river damming on nutrients in the Chesapeake Bay has been limited to either solely focusing on single dams on a small scale, or intensively relying on in-situ measured data and

therefore lack of appropriate modeling approach. We addressed this knowledge gap by designing a parsimonious process-based model to put the reservoir into the river routing system together to account for the effects of dams cascades to downstream water quality. Our work suggests the construction of reservoirs elevated the residence time of surface water in the Chesapeake Bay from 20 days for the James River to more than 200 days for the Pamunkey River since 1930, as a function of both reservoir residence and water depth; and their corresponding annual nutrient retention percentage to date range from 2% to 26%. Overall, the Chesapeake Bay Watershed reservoirs prevent approximately 9 kilotons of nitrogen from reaching the Chesapeake Bay estuaries. Our future scenarios indicate that reservoirs could potentially be better operated through manipulating the reservoir residence time to maximize their water quality benefits.

Sabrina Mehzabin, Kurt Stephenson, Daniel Fuka, Zachary Easton

Environmental and management impacts of legacy nitrogen remediation using bioreactors

This study addresses the critical issue of legacy nitrogen remediation from emergent groundwater, by a novel application of denitrifying bioreactors. Our study site is a large spring in the Shenandoah Valley, Virginia. Discharging nitrate-N concentrations of approximately 7.5 mg/L, and flow rates of between 1000-3000 m3/d. Over two years (2022-2023), the bioreactor's nitrogen load removal performance was evaluated under a range of conditions, including manipulations to the hydraulic residence time, ambient bed temperature, bioreactor age, and ground water nitrogen concentrations. A combination of laboratory-based analysis and high-frequency nitrate sensors provided comprehensive NO3-N concentration data in the bioreactor's influent and effluent. Inflow rates into the bioreactors range between 295 m3/day and 845 m3/day with a mean of 635 m3/day, and nitrate concentrations between 6 and 8 mg/L. The bioreactor consistently reduces N concentrations by 2 mg/L, across a range of flow rates. The calculated nitrogen load removal amounted to an average of kg/year with daily removal rates ranging from 0.14 kg/day to 1.6 kg/day, and a mean of 0.82 kg/day. A crucial aspect of our research was exploring opportunities to optimize nitrogen removal. By manipulating the bioreactor's water level, we effectively tested the impact of varying hydraulic residence times (HRT), an important control on N removal. Our findings demonstrate that operating the bioreactor at lower HRTs (<5 hours) significantly enhances nitrogen load removal rates, compared to higher HRTs (>8 hours). This operational strategy led to an estimated nitrogen removal rate of 927 kg/year at lower HRTs, and considerably greater than removal rates under higher HRTs. These results indicate that appropriately sizing bioreactors for available flow is critical to optimizing nitrogen load removal rates. Oversizing bioreactor is substantially more expensive to install and potentially maintain, and it results in lower removal rates than an appropriately sized bioreactor that maintains the HRT below 8 hours.

Natalie Schmer, Hilary Dozier, John Clune, Lisa Carper, Matthew Conlon, Joseph Duris, Matthew Gyves

Science communication tools of surrogate regression modeling designed to meet stakeholder needs

The U.S. Geological Survey Pennsylvania Water Science Center has been working with resource managers to develop real time loads using surrogate modeling at 11 stations in lower Susquehanna basin of the Chesapeake Bay watershed. Excess loading of nutrients and sediment has negatively impacted environmental resources in the Chesapeake Bay watershed, and water resource managers need water quality information that is relevant to management time-scales. Advances in water-quality monitoring instrumentation have made it possible to compute nutrient and sediment loads in near-real-time (every 15 minutes), and publishing real time loads will improve our ability to connect management practices with changes in water quality. High frequency data can estimate discrete concentrations through regression models known as surrogate modeling. This process pairs the continuous water quality records and discrete water-quality sampling analytical results and relates the data using linear regression. A workflow was developed to streamline calculating regressions, concentrations, and loads which allows publication of modeled parameters as real-time concentrations and loads on the National Water dashboard. A combination of R programming scripts were used and web-based communication products are being developed. Examples of a proposed interactive dashboard that will utilize the publicly available data from the USGS National Water Information Systems will be demonstrated. The planned dashboard will provide daily updates for real-time constituent concentrations, loads, and yields displayed with each monitoring location. These data visualizations are easily customized to adapt to evolving needs of stakeholders. Results of this study and associated communication products will help water resource managers to adaptively manage nutrient and sediment pollution from entering nearby waterways and serve as a comparison of progress to the wider Chesapeake Bay Model.

Kaylyn Gootman, Breck Sullivan, Alex Gunnerson

CBP Tributary Summaries: Communication tool on water quality changes to inform management decisions

The Chesapeake Bay Program (CBP) and its partners compile tributary basin summaries for 12 major tributaries or tributary groups in the Chesapeake Bay Watershed. These documents summarize and compile the monitoring and research data federal, state, and academic partners do all in one place. The Tributary Summaries are technical documents made for technical managers within jurisdictions and local watershed organizations to help them answer the overall questions: 1) How does tidal water quality changes over time?; 2) How do factors that drive those changes change over time?; and, 3) What is the current state of the science on connecting change in aquatic conditions to its drivers? The Tributary Summary documents include a suite of monitored tidal water quality parameters (i.e., surface total nitrogen (TN), surface total phosphorus (TP), spring and summer surface chlorophyll a, summer bottom dissolved oxygen (DO) concentrations, and Secchi disk depth) and associated potential drivers to those trends for the time period 1985 – 2018. These documents will be updated on a rotating basis to provide the up-to-date results that can drive the direction for future management actions. The Tributary Summary documents are available on the Chesapeake Assessment Scenario Tool (CAST) website, and the CBP is looking to disseminate these documents to managers and planners to use as a tool to measure actual progress and transform the monitoring findings into actionable information. Continuing to track water quality response and investigating influencing factors are important steps to understand water quality patterns and changes in the Bay tributaries.

Joseph Tamborski, Margaret Mulholland

Nutrient loading via submarine groundwater discharge to the lower tributaries of Chesapeake Bay

The Chesapeake Bay and its lower tidal tributaries are subject to eutrophication and seasonally recurring harmful algal blooms. At present, the significance of submarine groundwater discharge (SGD) as a nutrient vector is largely unknown. Here we investigated two estuaries with contrasting hydrogeomorphic characteristics, an estuary fed by two rivers (York), and an urbanized estuary that only receives freshwater inputs via stormwater, runoff, and groundwater (Lafayette). Radon surveys were performed in each tidal river to assess inputs of SGD at the embayment-scale during spring and fall 2021. Probability distributions were determined for known 222Rn sources and sinks, including groundwater 222Rn activity, and total SGD was determined from a 222Rn mass balance and Monte Carlo simulations. Rates of SGD between the two estuaries differed by a factor of two during spring (Lafayette = 11 ± 17 cm d-1; York = 6 ± 10 cm d-1) and by a factor of six during fall (Lafayette = 19 ± 27 cm d-1; York = 3 ± 7 cm d-1). Hydrogeologic assessments suggest that the fresh, terrestrial fraction of SGD is less than 0.5 cm d-1 for the Lafayette and 1.5-2.4 cm d-1 for the York. Groundwater N concentrations and flux varied seasonally in the York (4 - 7 mmol m-2 d-1). In the Lafayette seasonal N fluxes (22 - 37 mmol m-2 d-1) were driven by seasonality in water exchange rather than N concentrations, likely the result of recurrent saltwater intrusion. SGD derived nutrient fluxes were several orders of magnitude greater than riverine inputs and storm runoff. Sediment N removal by denitrification and anaerobic ammonium oxidation in these systems would only attenuate ~1 - 11% of DIN supplied by SGD. Seasonal nutrient loads from total SGD should be considered in the nutrient budgets and total maximum daily loads of Chesapeake Bay’s lower tributaries.

Michael Mallonee, Rikke Jepsen

Biological stream health in the Chesapeake Bay watershed

Statistical estimates indicate a net 6.1% improvement in stream macroinvertebrate “health” between 2006 – 2011 (baseline) and 2012 – 2017 (first interval) in the Chesapeake Bay watershed. Harmonized raw sample counts collected by twenty-four federal, state, and other institutional monitoring programs at 26,752 small streams (1st – 4th Strahler order) were used to calculate the multi-metric Chesapeake Benthic Index of Biotic Integrity, or “Chessie BIBI.” The random-stratified sampling designs of state agencies, the largest data providers, facilitated use of a novel statistical method to estimate the percentage of stream miles with Chessie BIBI ratings of excellent, good, and fair (“healthy”). The results are compared to those derived with fewer than 100 random samples (National River and Stream Assessment) and from more than 105,000 model-based, catchment-scale predictions (Maloney et al. 2022). Linkages to various land use/land cover and stream geomorphic features are also explored.

David Secor

Advancing complex science and natural history in advocating for Maryland’s only sturgeon population

Despite their evolutionary resilience, sturgeons are particularly sensitive to human impacts. Indeed, sturgeon protections drive the most stringent of Chesapeake Bay dissolved oxygen thresholds. In the Nanticoke River, a collaborative twelve-year study by UMCES, state, and federal scientists revealed habitat dependencies, spawning behaviors, and demographics using an integrated sonar and telemetry assessment. We discovered a very small spawning population (<100 adults), spawning seasons that were curtailed by summer warming and fall storms, and a nursery habitat that was overrun by invasive blue catfish predators. In 2022, the proposed siting of a large recirculating salmon plant within sturgeon spawning habitat (Federalsburg, Maryland) caused a sudden demand for public access to our team’s science. State and federal protections were insufficient and managers unresponsive, requiring science advocacy. Unexpectedly, the path towards successful removal of the plant’s threat was not ‘advancing the best available science’ but rather came about as feedbacks among multiple stakeholder groups, overt advocacy, and scholarship that led to a changed understanding of key threats to this population. Chief among these threats was the role of salinization in degrading sturgeon spawning habitats.

Pierre St-Laurent, M.A.M. Friedrichs

An Atlas for Physical/Biogeochemical Conditions in the Chesapeake Bay

Over the past four decades, the monitoring programs of the Chesapeake Bay have contributed to making this coastal ecosystem one of the most data-rich in the world. This continuous data collection simultaneously allowed for the development and calibration of increasingly capable 3D hydrodynamical-biogeochemical models of the estuary. Such models have the advantages of: (a) integrating the environmental variables into a cohesive whole, (b) extrapolating these variables across time, depths, and locations throughout the Bay, and (c) providing additional variables that are never sampled or had their sampling discontinued. These capabilities of models were exploited to generate a climatological atlas of conditions in the Chesapeake Bay based on a 1985-2023 hindcast simulation with ROMS-ECB. This particular model has been in continuous development at VIMS over the past 10 years and is the backbone of the Chesapeake Bay Environmental Forecasting system (CBEFS). The climatological atlas offers both surface/bottom conditions for each month of the year in a format adapted for rapid visualization and data extraction in Geographic Information Systems (GIS) and other popular software. The atlas serves as a baseline for the Bay against which year-to-year variability or long-term changes (such as coastal acidification) can be assessed. We anticipate the atlas will become a useful reference for researchers, managers and other stakeholders whose livelihood depend on water quality conditions in the Bay.

Rebecca Murphy, August Goldfischer, Jon Harcum, Elgin Perry, Breck Sullivan, Peter Tango

Spatial-temporal interpolation tool for dissolved oxygen in Chesapeake Bay

Our collaborative team is developing a spatial-temporal interpolation tool to aid in Chesapeake Bay dissolved oxygen water quality criteria assessment. To-date, not all the water quality criteria that apply to Chesapeake Bay tidal waters can be assessed due to lack of enough high frequency data and/or analysis techniques to reasonably estimate dissolved oxygen at shorter time intervals than a monthly average. This is a critical gap that needs to be addressed because these criteria were designed to protect different species and life stages of the bay's living resources. Our focus is on building statistical tools that leverage and combine the rich information contained in multiple types of data sets including long-term fixed station monitoring, high-frequency shallow water continuous monitoring, and new continuous vertical profilers in the deeper waters. This presentation will provide an overview of the analysis and interpolation tool being developed, with a focus primarily on example output from our first step of using Generalized Additive Models to estimate average daily dissolved oxygen across space and time in the Chesapeake Bay. Ultimately, those estimates will be combined with output from additional components of the tool to generate hourly estimates and a measure of variability. This project is under development, and we wish to share progress with the community and solicit feedback.