STAC Science Synthesis: Impacts of Climate Change and Uncertainty on Watershed Processes, Pollutant Delivery, and BMP Performance

Zachary Easton and Jeremy Hanson

Biological Systems Engineering, Virginia Tech

Climate Resiliency Workgroup
April 19, 2021

Purpose

Evaluate how climate change impacts efforts to restore and protect the Chesapeake Bay?

Key Considerations

- How climate change/uncertainties affect watershed processes and BMP performance
- Identify opportunities for risk-based decision-making given future climate uncertainties
- Identify additional research needed to support robust landscape management

Project Structure

- Project Elements
  - Analysis and synthesis of available data and published results
  - Identify, characterize, and suggest means of addressing knowledge gaps
  - Inform additional research
  - Place scientific information in a management-relevant context
- Steering Committee
  - Zach Easton, Virginia Tech
  - Ray Najjar, Penn State
  - Julie Shortridge, Virginia Tech
  - Kurt Stephenson, Virginia Tech
  - Lisa Wainger, UMCES

*Emily Bock was primary researcher and will continue in advisory role now that she’s taken a new position

Review Questions

1. How do climate change and variability affect nutrient/sediment cycling?

2. How do climate change and variability affect BMP performance?
   1. By what mechanisms can climate change and variability affect BMP nutrient and sediment removal efficiency?
   2. How does climate change uncertainty affect BMP performance variability?

3. Which BMPs will likely result in the best water quality outcomes under climate uncertainty?

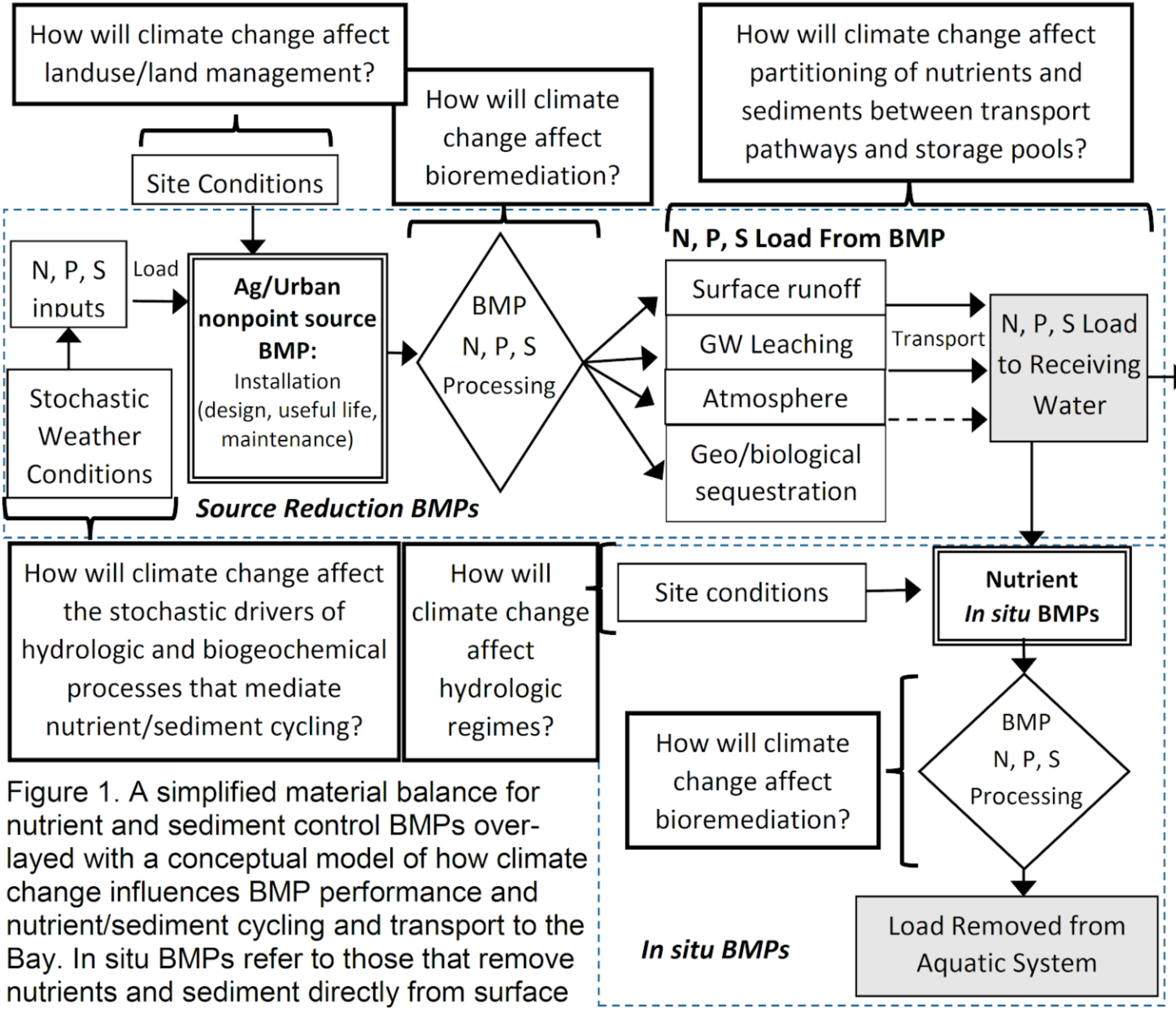


Figure 1. A simplified material balance for nutrient and sediment control BMPs over-layed with a conceptual model of how climate change influences BMP performance and nutrient/sediment cycling and transport to the Bay. In situ BMPs refer to those that remove nutrients and sediment directly from surface waters (e.g., stream restoration), as opposed to source reduction BMPs, which intercept pollutants before they reach water bodies (e.g., cover cropping, nutrient management).

Conceptual Model

- Climate change factors include changes in
  - Air temperature
  - Precipitation (volume, intensity, seasonality)
  - Atmospheric CO_2 concentration
  - Likelihood of occurrence of extreme weather events
  - Sea level rise, and saltwater inundation
  - Derivative hydrological impacts (soil moisture, partitioning of surface runoff and subsurface flow, etc.) and changes to the growing season

Most implemented	Most effective TN	Most Effective TP	NOAA
By units planned implementation/treatment	By reductions	By reduction	
Ag Nutrient Management	AWMS	AWMS	Living shoreline
Tillage Management	Tillage Management	Tillage Management	**Tidal wetland restoration**
Cover Crops	Nutrient Management	Forest Buffers	Oyster restoration
Urban Nutrient Management	Forest Buffers	Grass Buffers	Oyster aquaculture
Pasture Management	Grass Buffers	Nutrient Management	Forest buffers
Forest Harvesting	Cover Crops	Stream Restoration	
Manure Incorporation		Wet Ponds and Wetlands	
Land Retirement			
Wetland Rehabilitation			
Tree Planting			
Wetland Restoration			
Grass Buffers			
Forest Buffers			
Animal Waste Management Systems (AWMS)			

Summary of BMP implementation and effectiveness from Sekellick et al. 2019 and the Phase 3 WIPs (https://cast.chesapeakebay.net/Documentation/wipbmpcharts). Includes priority BMPs requested by the partnership, in addition to the practices specified by NOAA.

Approach: A Modified Systematic Review

- Systematic review elements
  - Transparent search plan
  - Defined inclusion/exclusion criteria
  - Critical appraisal of data quality (peer-reviewed, sufficient detail to evaluate methodological rigor, model skill metrics)
- Modifications
  - Adaptive/iterative search development, changes documented
  - Targeting of key resources recommended by steering committee, gray literature
  - Initial inclusion determinations by single researcher

Approach: Q1 How do climate change and variability affect nutrient/sediment cycling

- Targeted search
  - Contextualize current CBP approach to evaluating climate change impacts
  - Characterize climate modeling advancement in Bay watershed over last decade
- Systematic search
  - Obtain observational and modeling studies that assess the impact of climate change/ variability on nutrient and sediment cycling (i.e., transport, storage, and nutrient species transformations)
  - Core review of modeling studies predicting N, P, and/or sediment loads
- Analysis
  - Assess the relationships between change/uncertainty in observations/predictions of climate drivers and N, P, and sediment loading
  - Characterize output variability across all studies, to the degree possible, to evaluate the relative uncertainty/variability

Approach: Q1 How do climate change and variability affect nutrient/sediment cycling

- Search string: TS=((watershed simulation* OR hydrologic* model* OR biophysical model* OR process*based model* OR watershed model*) AND (climate change OR climate variability OR climate uncertainty OR global warming) AND (nitrogen OR phosphorus OR sediment OR nonpoint source pollution OR water quality) AND (Chesapeake Bay))
- Search results:
  - 92 hits, 12 articles included (plus one published dataset), 27 retained as supplemental
- Preliminary findings:
  - Since 2010 climate impacts on CB review of Najjar et al., 12 modeling studies of change in NPS pollution loading within the Chesapeake Bay watershed
  - Dozens of recent studies on modeling advancement (e.g., GCM ensembles, higher certainty N deposition projections, more reports of output variability)
  - Climate impacts on landscape processes, basis to infer NPS response

Approach: Q2 How climate change/ variability affect BMP performance

- Targeted search:
  - Determine current BMP efficiency assumed by CBP and extract accompanying quantitative or qualitative description performance variability/uncertainty
  - Develop mechanistic descriptions of BMP types and identify environmental variables affecting BMP performance (CBP, NRCS, International Stormwater Database resources, etc.)
- Systematic search:
  - Part 1: Previous reviews of BMP performance
  - Part 2: Simulation studies of BMP performance under future climates
- Analysis:
  - BMP performance data summarized, and knowledge gap identified
  - Ultimately, climate change impacts on relevant environmental variables will be mapped to conceptual models of BMP performance

Approach: Q2 How climate change/ variability affect BMP performance

Part 1: Previous Reviews of BMP Performance

- Search string: (review OR meta-analysis OR meta analysis OR synthesis) AND (best management practices OR conservation practices OR stormwater management) AND (removal OR efficiency OR performance) AND (nitrogen OR phosphorus OR sediment)
- Search results:
  - 412 hits, 49 articles included, 62 supplemental, 301 excluded
- Preliminary findings:
  - BMP performance highly variable, known to be affected by design, site/environmental variables, and maintenance, but these are inconsistently reported
  - Relatively few long-term studies
  - Several high-quality review papers despite data limitations

Approach: Q2 How climate change/ variability affect BMP performance

Part 2: BMP Performance Under Future Climates

- Search string:
    - Search Terms: (("climate change" OR "climate uncertainty" OR "climate extremes" OR "climate variability") AND ("best management practice" OR "conservation practice" OR "stormwater management") AND ("nitr*" OR "phosphorus" OR "sediment" OR "water quality" OR "nonpoint source pollution" OR "diffuse pollution"))
- Search results:
    - 172 hits, 14 articles included, 6 supplemental, 152 excluded
- Preliminary findings:
    - Few studies that examine change in BMP impacts under climate change, even without geographic restriction
    - NPS loads often predicted to increase while BMP performance predicted to decrease at watershed scale under climate change, often driven by increase in precipitation/runoff
    - Different BMPs affected differently for different pollutants and by season

Approach: *Q2 Climate change resilience of tidally-influenced BMPs

Inclusion criteria:

- Reports bmp performance in efficiency (% removal) or removal rate (mass/time)
  - BMPs of interest include living shoreline, wetland restoration, oyster practices, forest buffers
- Combines data from multiple studies, multiple study sites, or multiple BMPs within a single study (preferred, not required)
- Both empirical and modeled removal are acceptable, but empirical studies weighted more heavily
- Addresses how BMP effectiveness is predicted to change under climate change
  - CC impacts of interest include changes in temp, precip, atmos. CO_2, extreme weather, SLR, saltwater intrusion, acidification

Extracted Data (draft):

- *Geographical area: location, watershed area, land use*
- *Climate Projections: GCMs and ensemble method(s) if applicable, downscaling approach(es), emissions Scenarios, future time periods, skill with historical simulations*
- *Watershed model: model name, calibration and evaluation metrics*
- *Outputs: forecast change in N/P/sediment loads; range or uncertainty in predictions*
- *BMPs: types, change in efficiency, predicted load reductions with implementation extent, major conclusions*
- *Ecosystem(s) of interest and relevant findings*

* Modification to original Q2 to include NOAA BMPs

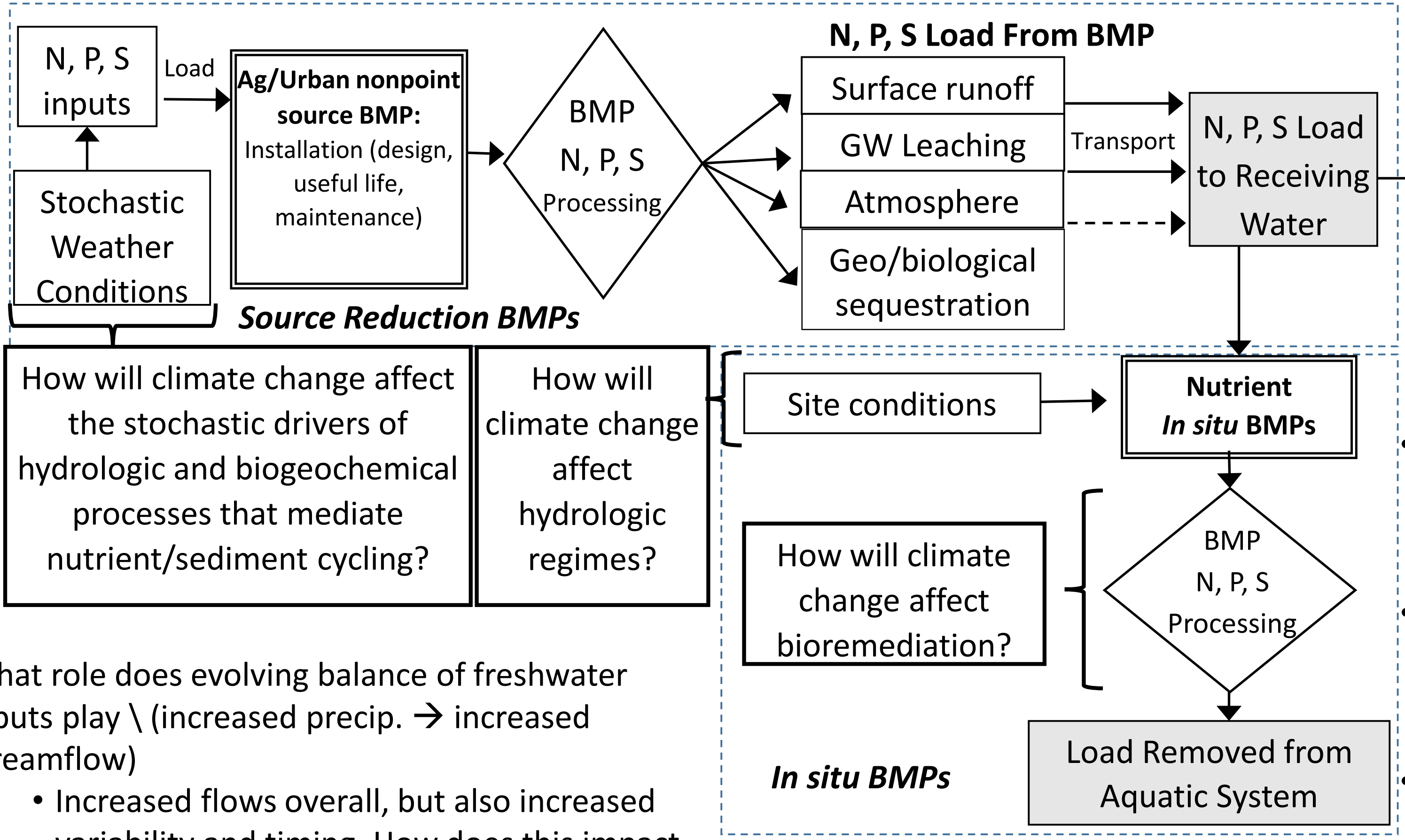
Approach: Q4 Climate change resilience of tidally-influenced BMPs

- Search string: TS=((climate change OR climate variability OR climate extremes OR climate uncertainty OR global warming OR future climate OR saltwater intrusion OR saltwater inundation OR acidification OR sea level rise OR resilience OR adaptation) AND (living shoreline OR veg* shoreline OR wetland restoration OR marsh restoration OR oyster restoration OR oyster aquaculture OR forest buffer OR nature-based OR green engineering OR green infrastructure OR natural infrastructure OR engineering with nature OR reef balls OR reef maker OR rock sill OR coir logs OR oyster castles OR wave abatement) AND (removal OR efficiency OR performance OR effect*) AND (nitrogen OR phosphorus OR sediment OR water quality OR nonpoint source pollution OR diffuse pollution) AND (tidal OR Chesapeake Bay OR estuar*) NOT (mangrove)) AND AD=(United States OR USA)
  - Years: 2000-present
- Search results:
  - 204 hits, currently screening for inclusion (thus far: 12 included, ~20 supplemental)

- Upland watershed and shoreline management can impact sediment and nutrient quality and availability for tidal marsh – how might CC impact these processes

- Warmer wetter winters and springs and increased soil moisture can increase mineralization of organic P making wetlands less effective for P but may increase N removal via denitrification
- Increased temps and CO_2 affect growth of marsh vegetation (greater nutrient uptake and temporary storage)
- What do changes to soil chemistry and biogeochemical functions mean for wetlands
  - Wetter and warmer environment speeds up nutrient cycling in general
- Increases in salinity can enhance flux of NH_4 to water column which can then be exported with tides. Export of soil NH_4 decreases N supply for coupled nitrification-denitrification in coastal wetlands

Example BMP: **Tidal wetland "restoration"**



- What role does evolving balance of freshwater inputs play \ (increased precip. → increased streamflow)
  - Increased flows overall, but also increased variability and timing. How does this impact wetland hydrology
  - Timing of extreme events like droughts can change form of nutrients

- Saltwater intrusion may have significant impacts, and rising sea levels and increased storm surge can threaten coastal wetland systems
  - Are these balanced by increased freshwater flows
- Sediment accretion influenced by many factors; which are the most impactful?
  - Liu et al 2021 suggests sediment availability is driver for success of coastal wetland restoration
- Interaction with living shorelines or natural barriers (oyster reefs) can improve accretion rates and resiliency of tidal marsh

Connect Synthesis Findings to CBP Decision-Making

- Research and communication framework inspired by Robust Decision-Making, an analytical process for decision making under deep uncertainty

- Identify BMP implementation/landscape management strategies that are effective across many possible climate futures
  - Which BMPs appear to the be most robust to climate change and BMP performance uncertainty? Which are the most sensitive?

- Characterize the vulnerabilities of these strategies (under what conditions do they fail?)
  - Which uncertainties dominate the CBP's ability to predict nutrient and sediment delivery to the Bay for a future climate?

Questions? Input?

- Are there key authors/researchers whose peer-reviewed or gray lit publications might supplement lit search?
- Does the CRWG know of tidal/coastal analogs that are of most interest or relevance? E.g., North Carolina bays > Gulf > SF Bay or points north?

Photo: CBP

Thank You

Contact:
Jeremy Hanson
jchanson@vt.edu

Photo: CBP