A SYSTEMATIC REVIEW OF CHESAPEAKE BAY CLIMATE CHANGE IMPACTS AND UNCERTAINTY: WATERSHED PROCESSES, POLLUTANT DELIVERY, AND BMP PERFORMANCE

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STAC-sponsored Science Synthesis Project for the CBP Partnership

- Purpose
- Project Structure
- Research Questions
- Approach
- Continued Efforts
- Connecting to Decision-Making

Purpose

How may climate change impact on-going efforts to restore and protect the Chesapeake Bay?

Key Considerations

- How climate change uncertainties affect CBP's capacity to predict watershed responses and achieve desired outcomes
- 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*

Research Questions

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

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

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

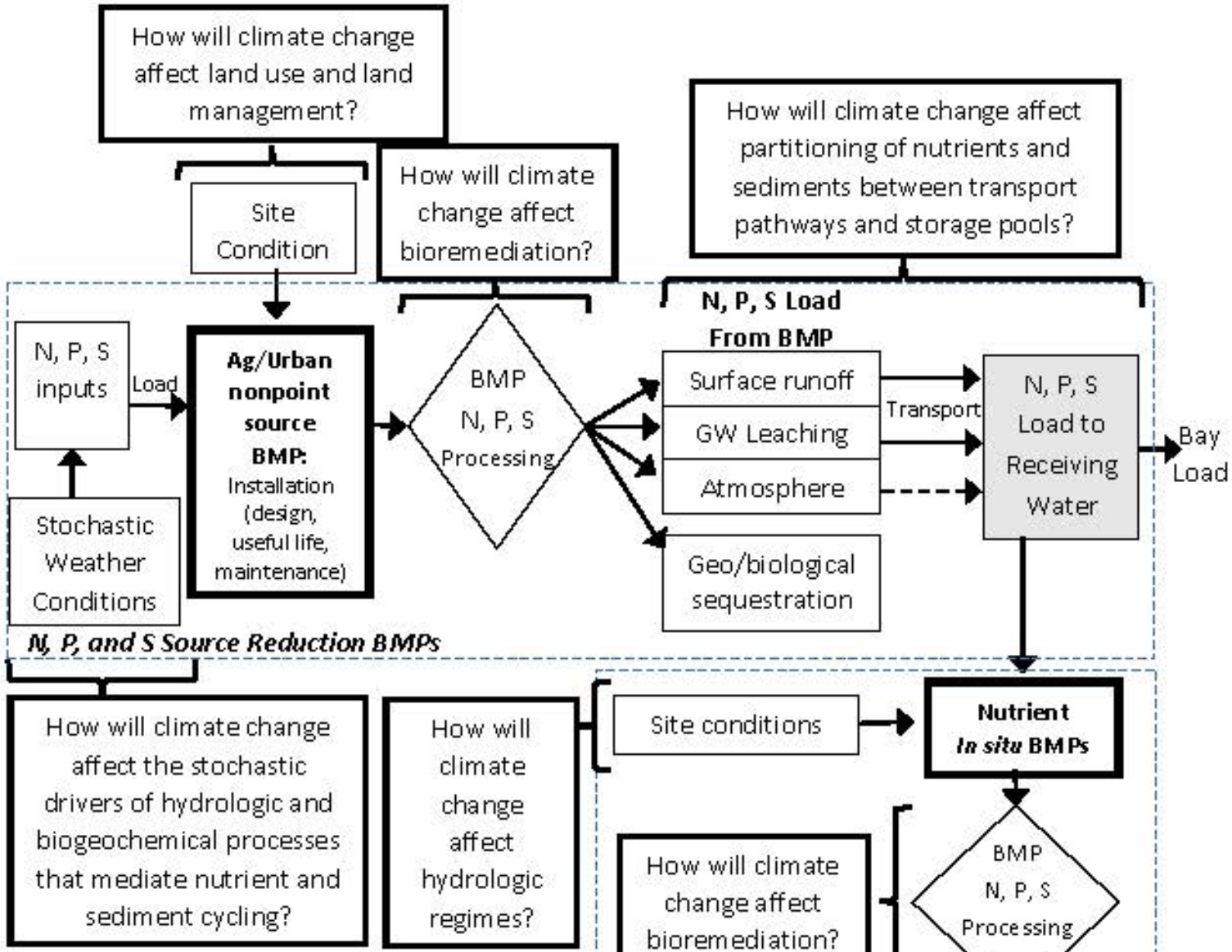

Figure 1. A simplified material balance for nutrient and sediment control BMPs over-layed with a conceptual model of how climate change can influence BMP performance and nutrient and sediment cycling and transport to the Bay.

Approach: a modified systematic review

- Balancing
  - *Addressing a broad topic, the need to be effective and efficient*
  - *Best practices of systematic review methodology (to avoid bias and omission in literature and data selection)*
- 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*
  - *Web of Science as most complete database*
  - *Inclusion determinations by single researcher*

Approach: Q1 climate change impacts on 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 in the Bay watershed that assess the impact of climate change and/or 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 and uncertainty in observations/predictions of climate drivers and N, P, and sediment loading*
  - *Characterize output variability across all studies to evaluate the relative uncertainty/variability using qualitative or quantitative methods*

Approach: Q1 climate change impacts on nutrient/sediment cycling

- Inclusion criteria:
  - *Climate relevance to the Chesapeake Bay Watershed*
  - *Addresses change in nonpoint source pollution loading under climate change*
  - *References retained as supplemental: does not predict change in NPS loads, but does address climate effects on relevant landscape processes, land use, or technological/methodological advances in predicting future climate impacts on water quality*
- Extracted data:
  - *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*

Approach: Q1 climate change impacts on 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))*
  - *Planed modification – add terms for temp and precipitation extremes*
- Search results:
  - *92 hits, 12 articles included (plus one published dataset), 27 retained as supplemental, 52 excluded*
- 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 and 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 onto conceptual models of BMP performance*

Approach: Q2 how climate change and variability affect BMP performance

Part 1: Previous reviews of BMP performance

- Inclusion criteria:
  - *Reports agricultural or urban bmp performance in efficiency (% removal) or removal rate (mass/time)*
  - *Combines data from multiple studies or multiple study sites within a single study*
  - *Both empirical and modeled removal are acceptable for inclusion, but the evidence of performance from empirical studies will be weighted more heavily*
  - *Must address widely used practice and/or applicability to major agricultural production systems or municipal stormwater systems*
- Extracted Data:
  - *BMP type/definition*
  - *Number of sites/studies*
  - *Number of site/study years*
  - *Study locations*
  - *Pollutants addressed*
  - *Central tendency and range of pollutant removal efficiencies/rates (specify concentration or load reduction)*
  - *Whether performance variability was quantified and report if so*
  - *Factors original authors identify as influencing BMP performance*

Approach: Q2 how climate change and 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, screening in progress: 9 articles included, 1 supplemental, 41 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 and variability affect BMP performance

Part 2: Simulation studies of BMP performance under future climates

- Inclusion criteria:
  - *Addresses how BMP effectiveness is predicted to change under climate change at the field or watershed scale*
  - *No geographical restriction*
  - *References retained as supplemental: not a projection of BMP performance under climate change, but does provide a conceptual basis to anticipate BMP behavior (e.g., performance response to extreme precipitation events)*
- Extracted Data:
  - *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*

Approach: Q2 how climate change and variability affect BMP performance

Part 2: simulation studies of 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:
  - *Relatively 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: Q3 BMPs with the best outcomes under climate uncertainty

- Originally proposed approach:
  - *Identify distribution of N, P, and sediment removal efficiency for specific BMPs and overlay with climate uncertainty do predict effects on performance distributions*
  - *But even distributions of BMP performance variability are relatively unavailable/underdeveloped and limited by paucity of long-term studies and incomplete metadata*
- Adaptive approach:
  - *Address mechanisms of climate impacts on BMP performance using mapped impact on relevant environmental variables from Q2.*
  - *Unlikely to be able to characterize probabilities, but aim to make statements about degree of certainty of impacts*
  - *Categorizing BMPs by pollution removal mechanism to draw conclusions about related BMPs as strategy to overcome data limitations*
  - *Hypothesize/describe climate impacts on BMP performance with theoretical response functions*

Continued Efforts

- Identifying further sources of relevant information
  - *BMP studies under extreme events (storms, droughts, temperature extremes)*
  - *Observational studies of climate analogs for the Bay watershed*

- Evaluate approaches to describe relative BMP performance uncertainty and sensitivity to climate impacts
  - *Explore possible metrics of robustness*
  - *Assess strength and completeness of evidence*

- Identify key knowledge gaps
  - *What avenues of research might effectively address BMP and climate uncertainty?*
  - *What a modeling strategies would support a quantitative evaluation of the impact of these uncertainties?*

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?*

Thank you

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Key Resources: Q1

1. Chesapeake Bay Program Climate Change Analysis: Documentation of Methods and Decisions for the 2019-2021 Process (CBP, 2019)
2. Najjar et al. 2010 (previous climate synthesis)
3. Climate Science Special Report: Fourth National Climate Assessment, Volumes I and II (Global Change Research Program, 2017 and 2018)
4. Journal articles and reports provided by Steering Committee

Key Resources: Q2

1. Easton, Z., D. Scavia, R. Alexander, L. Band, K. Boomer, P. Kleinman, J. Martin, A. Miller, J. Pizzuto, D. Smith, C. Welty. 2017. Scientific and Technical Advisory Committee Review of the Phase 6 Chesapeake Bay Watershed Model. STAC Publication Number 17-007, Edgewater, MD. 47 pp.
2. Simpson, T., and S. Weammert. 2009. Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed. Final Report
3. Chesapeake Bay Program. 2018. Chesapeake Bay Program Quick Reference Guide for Best Management Practices (BMPs): Nonpoint Source BMPs to Reduce Nitrogen, Phosphorus and Sediment Loads to the Chesapeake Bay and its Local Waters.
4. CBP Expert Panel BMP Reports
5. Stephenson, K., C. Hershner, B. Benham, Z. Easton, J. Hanson, S. Julius, and E. Hinrichs. 2018. Consideration of BMP Performance Uncertainty in Chesapeake Bay Program Implementation. STAC Publication Number 18-003, Edgewater, MD. 33 pp
6. Easton, Z.M., K., Stephenson, A. Collick, P.M. Fleming, E. Kellner, J. Martin, M. Ribaudo, and G. Shenk. 2020. Increasing Effectiveness and Reducing the Cost of Non-Point Source Best Management Practice Implementation: Is Targeting the Answer? STAC Publication Number 20- 002.