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

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# Purpose

How climate change impacts 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

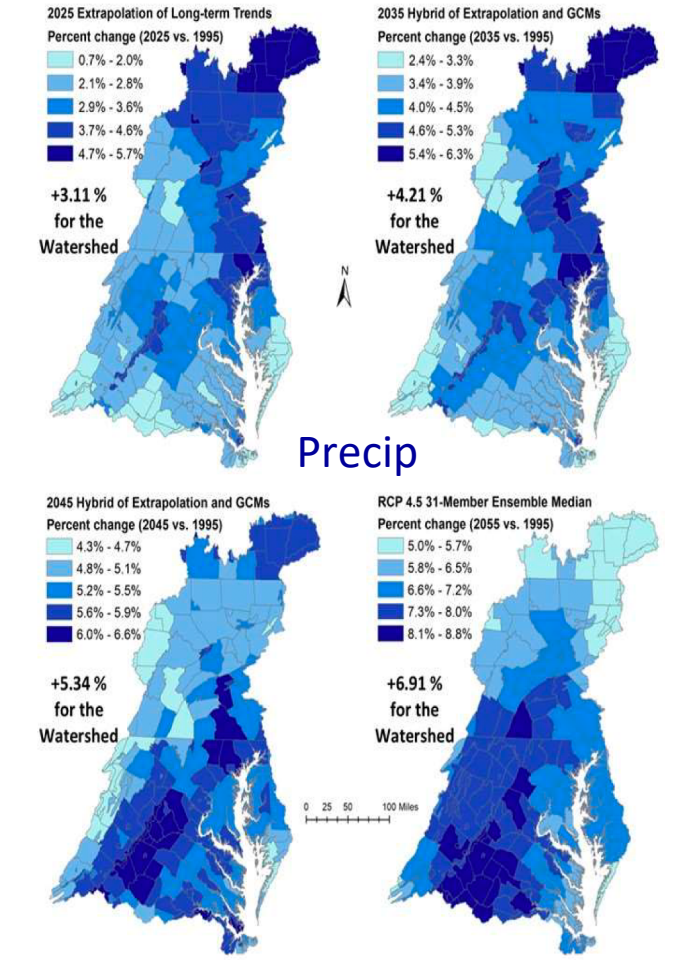
*Project Updates/Additions

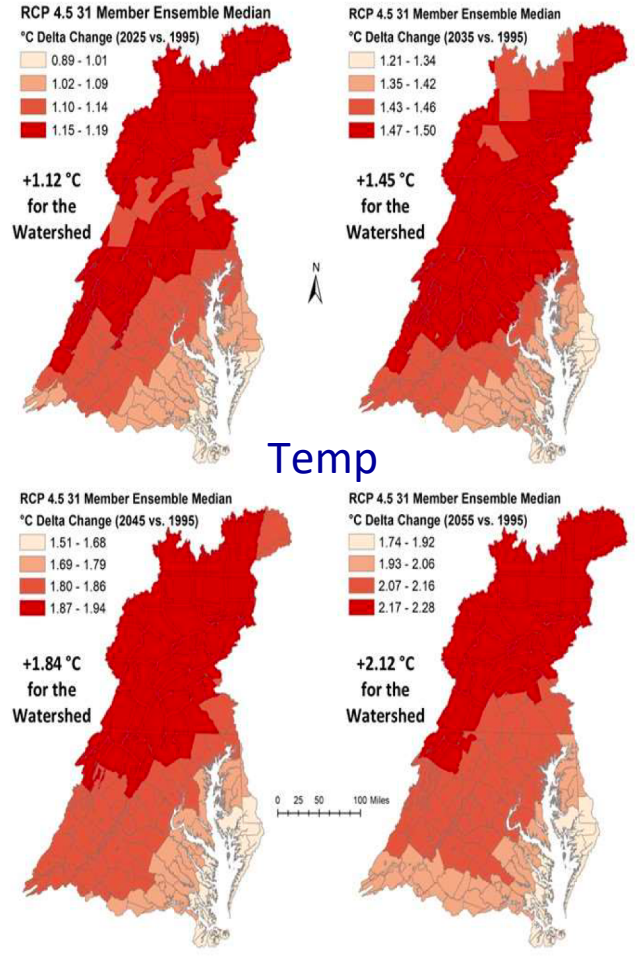
# Research Questions

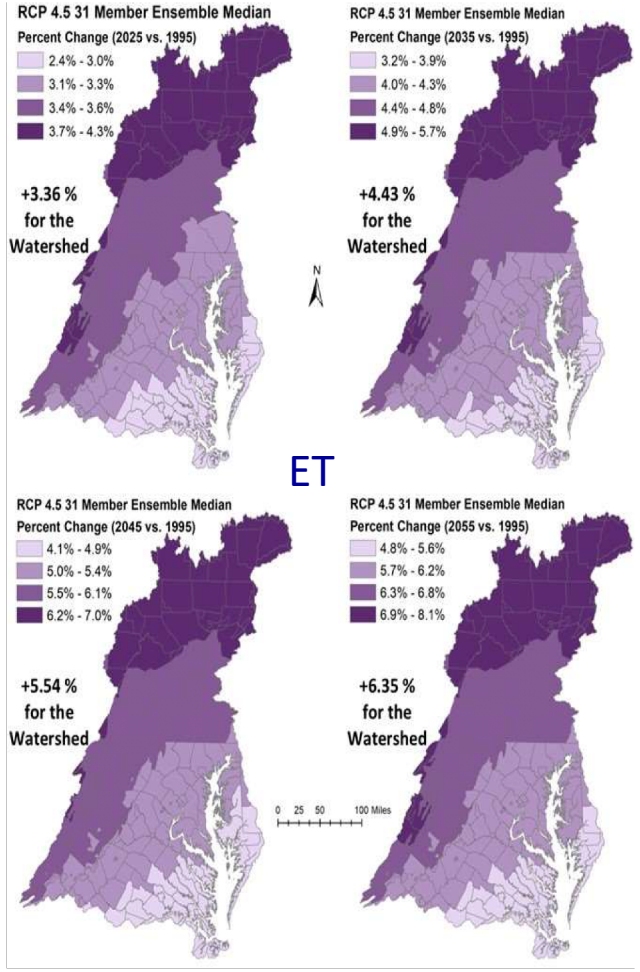
1. How do climate change and variability affect nutrient/sediment cycling in the watershed?

2. How do climate change and variability affect BMP performance?
    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?




| | 2025 | | | 2050 | | |
|---|---|---|---|---|---|---|
| **Climate scenario** | **RCP2.6** | **RCP4.5** | **RCP8.5** | **RCP2.6** | **RCP4.5** | **RCP8.5** |
| | **Precipitation Change (percent)** | | | | | |
| **10th quantile** | -1.19 | -1.19 | -2.62 | -0.51 | 0.60 | -0.75 |
| **Median** | 3.23 | 4.21 | 4.61 | 4.98 | 6.28 | 6.98 |
| **90th quantile** | **7.77** | **10.57** | **10.66** | **12.29** | **13.62** | **15.01** |
| | **Temperature Change (°C)** | | | | | |
| **10th quantile** | 0.50 | 0.61 | 0.85 | 0.7 | 1.15 | 1.80 |
| **Median** | 0.98 | 1.12 | 1.22 | 1.53 | 2.03 | 2.70 |
| **90th quantile** | **1.16** | **1.58** | **1.74** | **2.29** | **2.80** | **3.37** |

Multi-model ensemble projections of temperature and precipitation change from November 2019 draft of the Chesapeake Bay Program Climate Change Analysis: Documentation of Methods and Decisions for the 2019-2021 process. 10th and 90th quantile of 10-year average precip and temperature as projected by 31 GCMs.

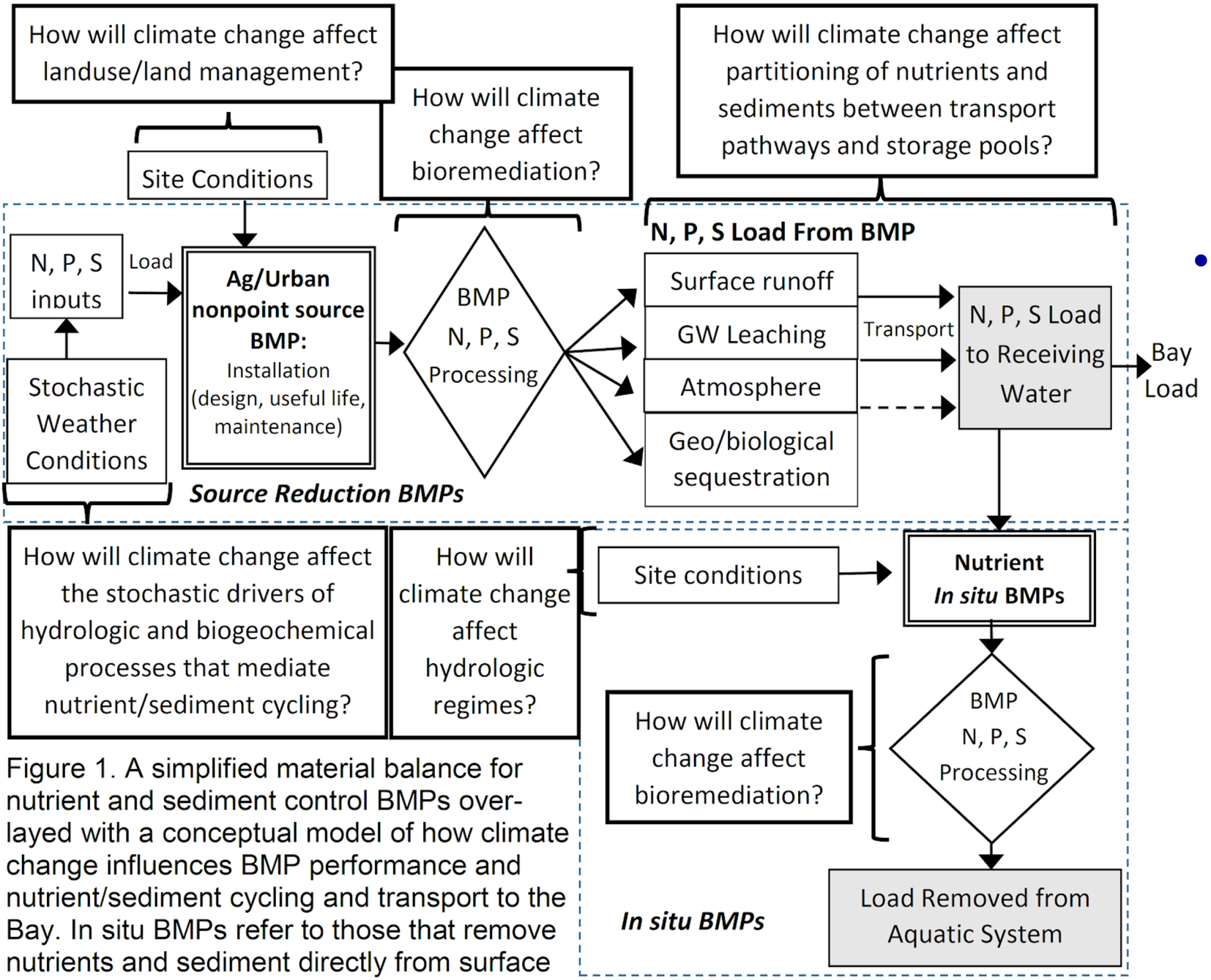



Figure 1. A simplified material balance for nutrient and sediment control BMPs over-layed with a conceptual model of how climate change influences BMP performance and nutrient/sediment cycling and transport to the Bay. In situ BMPs refer to those that remove nutrients and sediment directly from surface 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 and 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

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

- Extracted data:
  - *Geographical area: location, size, land use*
  - *Climate Projections: GCMs and ensemble method, downscaling approach, emissions scenarios, time periods, historical skill*
  - *Derivative changes to hydrology (soil moisture, partitioning of surface runoff and subsurface flow, etc.), changes to the growing season*
  - *Model used: model name, calibration and evaluation metrics, forcing data*
  - *Outputs: forecast change in N/P/sediment loads; range or uncertainty in predictions*

# 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))

  *modifications – added terms for temperature and precipitation extremes, will add NOAA BMP specific search terms

- 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

- Inclusion criteria:
  - Reports agricultural or urban bmp performance in efficiency (% removal) or removal rate (mass/time)
  - Combines data from multiple studies, multiple study sites, or multiple BMPs within a single study
  - Both empirical and modeled removal are acceptable, but empirical studies will be weighted more heavily
  - Must address practices and/or applicability to major agricultural or urban 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*
  - *Factors identified as influencing 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)
  *Modifications - will add NOAA BMP specific search terms
- 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

- Inclusion criteria:
  - Addresses how BMP effectiveness is predicted to change under climate change
  - 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, climate analogs)

- 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/ 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"))
    *Modifications - will add NOAA BMP specific search terms
- 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

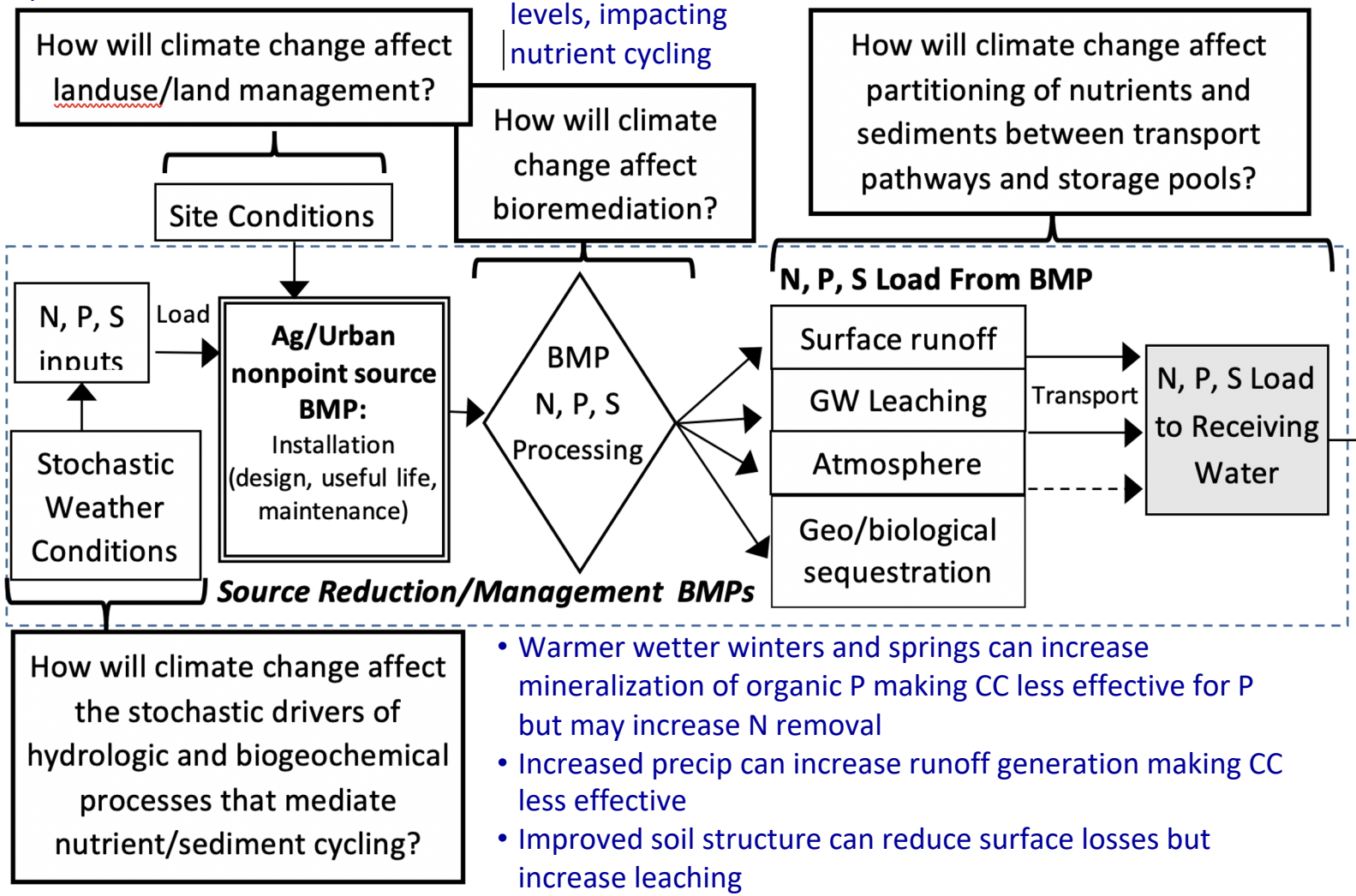
# Approach: Q3 Which BMPs will result in the best WQ outcomes under climate uncertainty?

- Originally proposed approach:
  - Identify distributions of BMP effectiveness and overlay with climate uncertainty to predict effects on performance distributions
    - But even distributions of BMP performance variability are relatively unavailable/underdeveloped and limited by very few long-term studies and incomplete metadata
- Adaptive approach:
  - Address mechanisms of climate impacts on BMP performance using the conceptual model, mapping climate influenced variables from Q2 against BMP characteristics
    - Unlikely to be able to characterize probabilities (maybe…), but can make statements about degree of certainty of impacts
  - Hypothesize/describe climate impacts on BMP performance with theoretical response functions

- Increased temps and CO2 can increase crop growth
- Changes in precipitation timing and magnitude also effect growth, esp at establishment

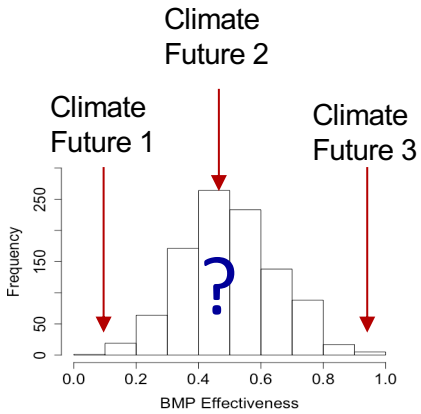
- Increased CC growth can increase soil C levels, impacting nutrient cycling

- CC may increase the ratio of organic/inorganic nutrients
- Increased plant uptake of nutrients (temporary storge pool, may be released later)
- Increased denitrification (permanent removal)




- Warmer wetter winters and springs can increase mineralization of organic P making CC less effective for P but may increase N removal
- Increased precip can increase runoff generation making CC less effective
- Improved soil structure can reduce surface losses but increase leaching
- CC can mitigate drought but can increase hydrophobicity

## Example BMP: **Cover Crops**




Take Home: Cover Crops appear to be highly sensitive to climate change, and given the uncertainty in climate projections, how the BMP performs is likewise uncertain

# 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