Impacts of Climate Change and Uncertainty on Watershed Processes, Pollutant Delivery, and BMP Performance

Jeremy Hanson, Chesapeake Research Consortium
Emily Bock, Consultant
Binyam Asfaw, Virginia Tech
Zachary Easton, Virginia Tech

Modeling Workgroup
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For today

- ➔ Purpose and methods
- ➔ Expectations, climate impacts and uncertainty
- ➔ Conceptual framework
- ➔ Working conclusions, knowledge gaps
- ➔ Discussion

Purpose

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

Key Considerations

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

Review Questions

Using modified systematic literature reviews to inform answers and identify gaps

1. How does climate change affect nutrient/sediment cycling?

   17 articles heavily supplemented by rich literature for climate impacts

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

      61 that met criteria out of 412 papers identified

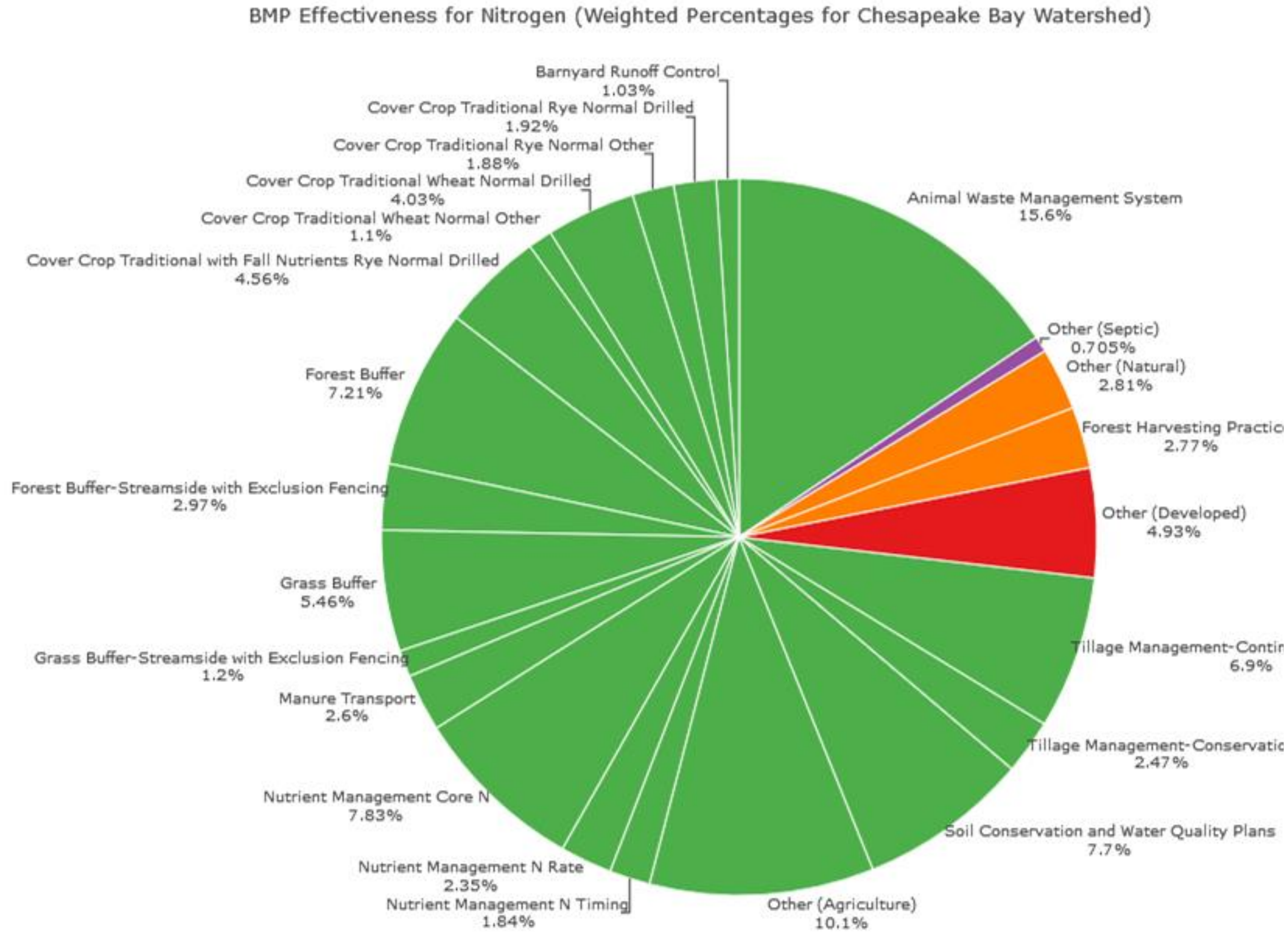
   b. How does climate change uncertainty affect BMP performance?

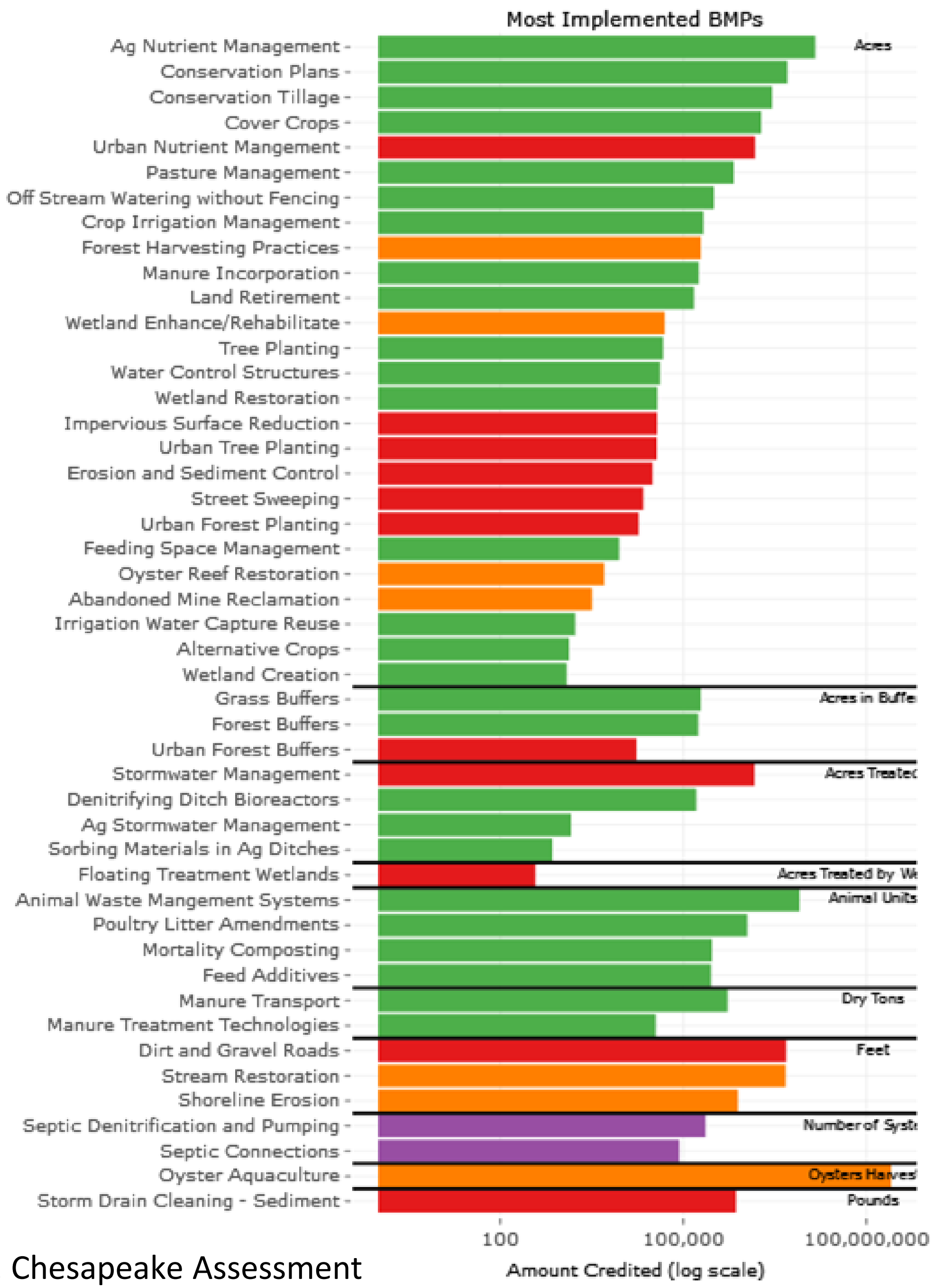
      14 articles that met criteria out of 172 papers identified

      *Additionally, NOAA funding enabled additional search focused more on BMPs of interest for tidal and habitat purposes; reviewed an additional 33 articles based on search results of 205 papers

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

   Will use information from reviews for the other questions





Many ways to look at BMPs' effectiveness or priority status

Both images are from CAST using jurisdictions' Phase 3 WIPs, accessed October 15, 2021 (https://cast.chesapeakebay.net/Documentation/wipbmpcharts); Chesapeake Bay Program, 2020. Chesapeake Assessment and Scenario Tool (CAST) Version 2019.

Most implemented	NOAA
By units planned implementation/treatment	
Ag Nutrient Management	Living shoreline
Tillage Management	Tidal wetland restoration
Cover Crops	Oyster restoration
Urban Nutrient Management	Oyster aquaculture
Pasture Management	stream restoration
Forest Harvesting	
Manure Incorporation	
Land Retirement	
Wetland Rehabilitation	
Tree Planting	
Wetland Restoration	
Grass Buffers	
Forest Buffers	
Animal Waste Management Systems (AWMS)	

Examples of other BMPs discussed in the reviewed lit:

veg. buffers or filter strips;
drainage water management;
bioretention

Red→ N=0 studies (does not mean no studies of these BMPs, just no climate change related studies)
Orange→ N was relatively low, may include high quality reviews, but overall less literature than desired
Green→ N was relatively high or high quality

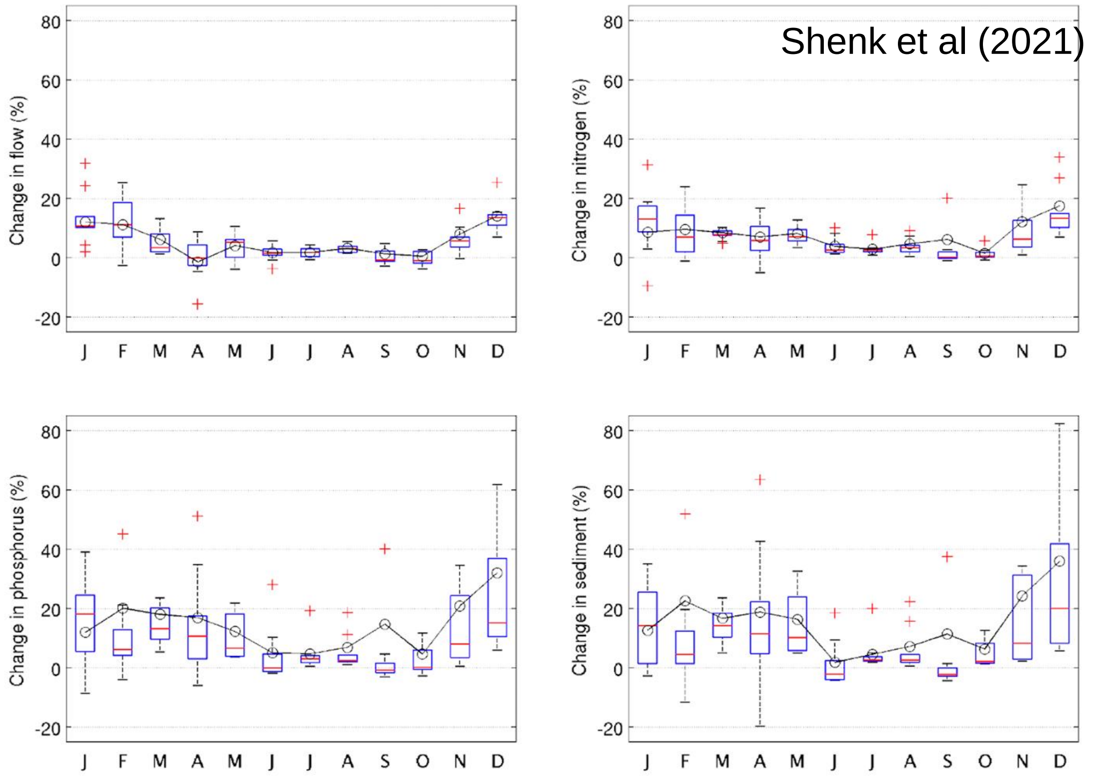
Expected climate impacts in the Bay and watershed

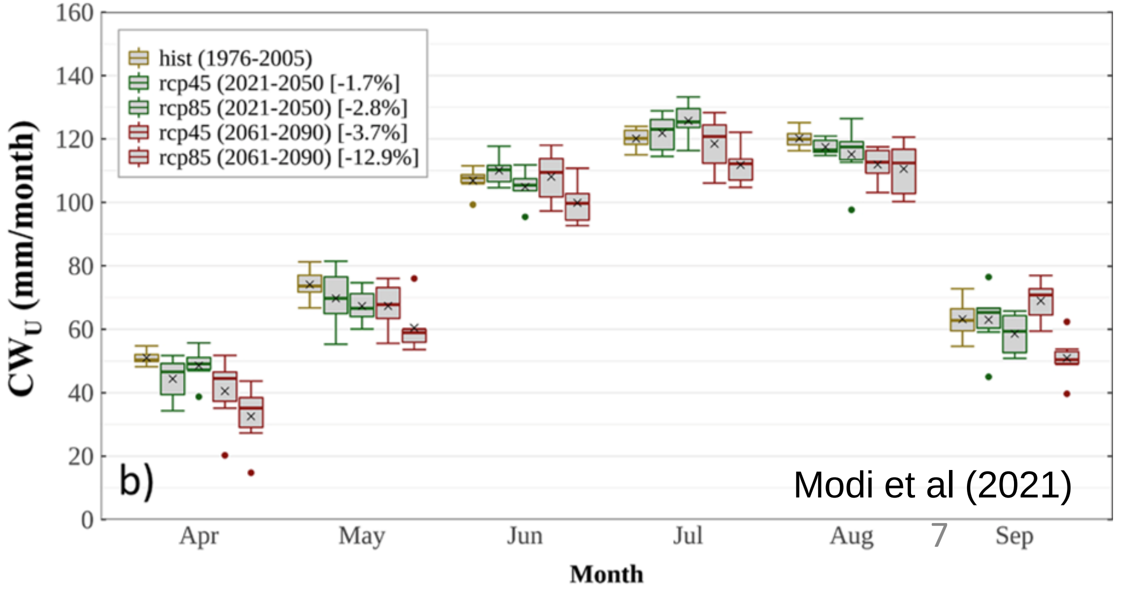
Changes where we have a relatively strong understanding of likely futures…

- Precipitation (increase but variable)
- Temp (increase)
- SLR (increase)

Changes where we still have more conflicting possibilities…

- ET (depends on CO_2)
- Streamflow (increase but variable)
- Soil moisture (variable)
- Nutrient/sediment cycling and export (increase but variable)



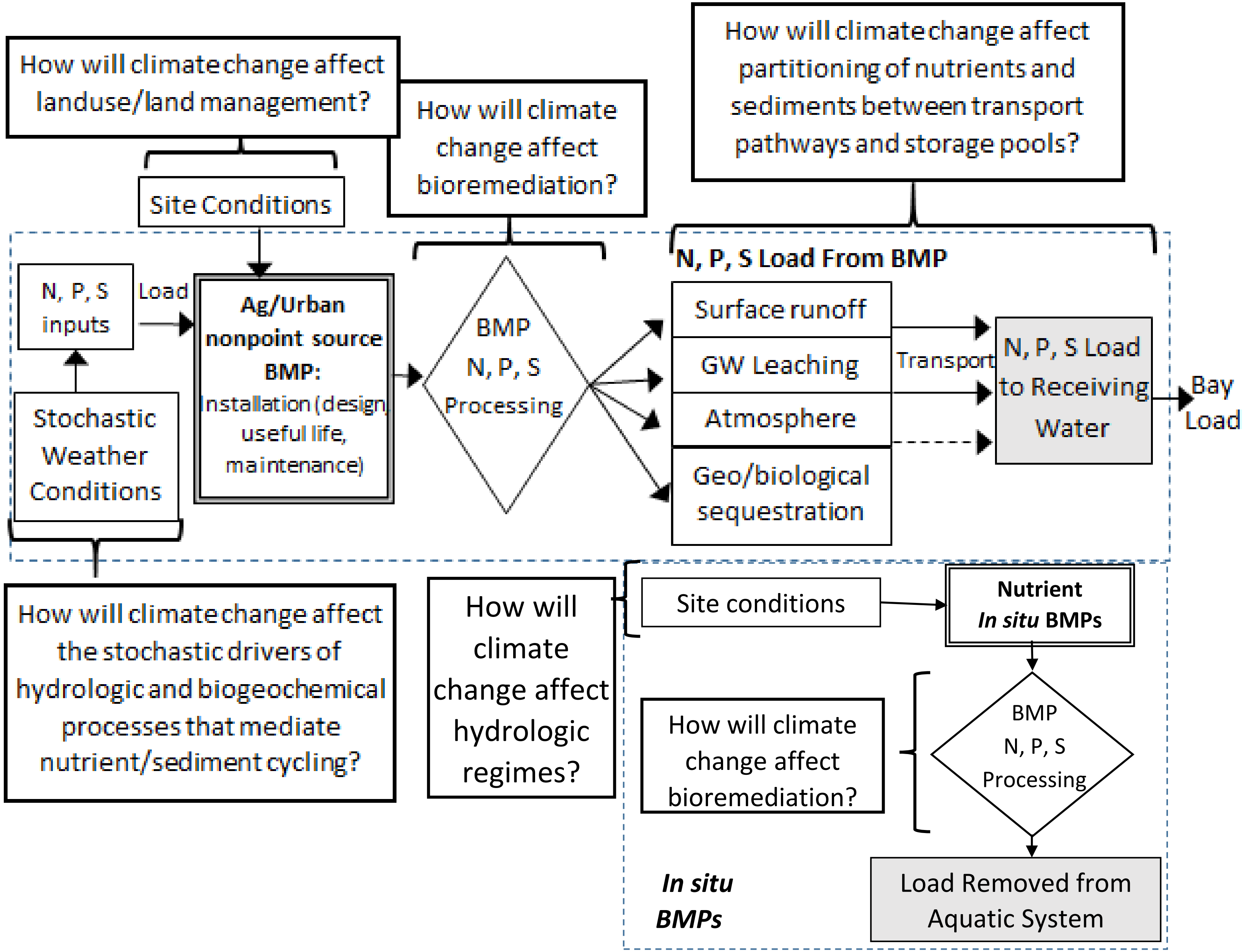


Expected climate impacts in the Bay and watershed

- Warmer, wetter winters and springs
- Nitrogen cycle changes
  - Increased temp → increases in mineralization and nitrification, generally results in greater N yields
  - Increases in NO_3- export due to substantial increases in nitrification (Temp effect) during the winter/spring and increased runoff (Precip effect)
- Phosphorus cycle changes
  - Slight to moderate increases Total P yield, a result largely of increases in sediment bound P during the winter/spring (Precip effect)
  - Warmer and wetter conditions, increase biomass utilization of dissolved-P, reducing P mineralization from fresh organic P…..consequently dissolved P levels change less (Temp effect)

<u>Bottom line: BMPs will have to deal with greater fluxes and more variability</u>

Conceptual Model #1



Climate change factors include changes in

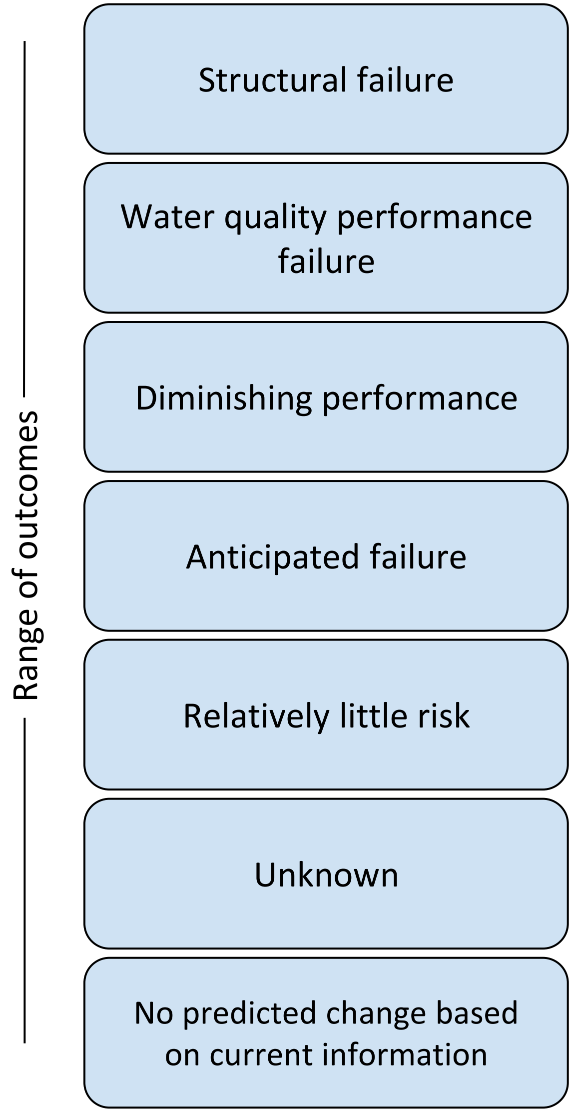
- Air temperature
- Precipitation (volume, intensity, seasonality)
- Atmospheric CO_2 concentration
- Likelihood of occurrence of extreme weather events
- Sea level rise, and saltwater inundation
- Derivative hydrological impacts (soil moisture, partitioning of surface runoff and subsurface flow, etc.)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

Conceptual frameworks

- It helps to consider the mechanisms of how the BMPs remove, transform, or otherwise reduce nutrients and sediment loads
  - We can do this at a smaller scale (BMP-specific; previous slide) when we have adequate information, especially from field/empirical studies
  - We can also do this more easily and for more BMPs at a higher level, which may help reinforce understanding of gaps and research priorities

Leveraging other conceptual frameworks

- We can apply our framework alongside other conceptual models to characterize risks and uncertainty, and to better understand our knowledge gaps and needs.
  - For example, CSN's risk spectrum (Wood 2021) for stormwater BMPs can be useful for other sectors' BMPs, with modifications Given level of available info: we combine expected future climate factors (CO_2, temp, precip) with generalized conceptual model of BMP primary mechanisms
  - To identify mechanisms and BMPs most at-risk, compared with snapshot of most-implemented BMPs or BMPs with greatest overall reductions, this can help illuminate the overall question of how climate change impacts efforts to restore and protect the Chesapeake Bay.



Wood, (2021) https://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2021/03/Memo-4_BMP-Vulnerability-Analysis_Final.pdf

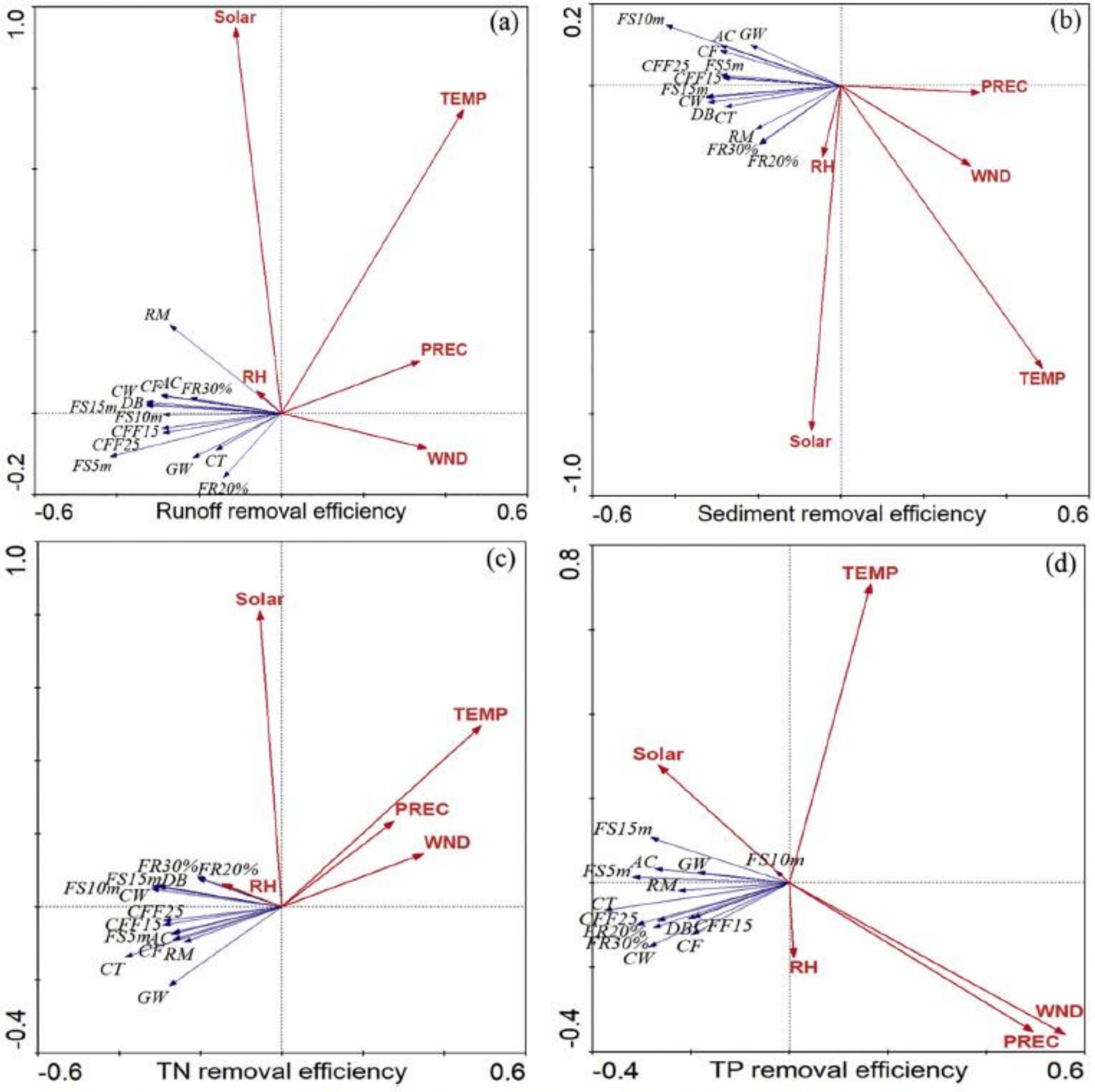


Fig. 5. Relationships between annual runoff (a), sediment (b), TN (c), and TP (d) removal efficiencies of 14 BMPs with climate factors, including precipitation (PREC), temperature (TEMP), solar radiation (Solar), relative humidity (RH), and wind speed (WND), during 2020–2099. Abbreviations of BMPs are given in Table 1.

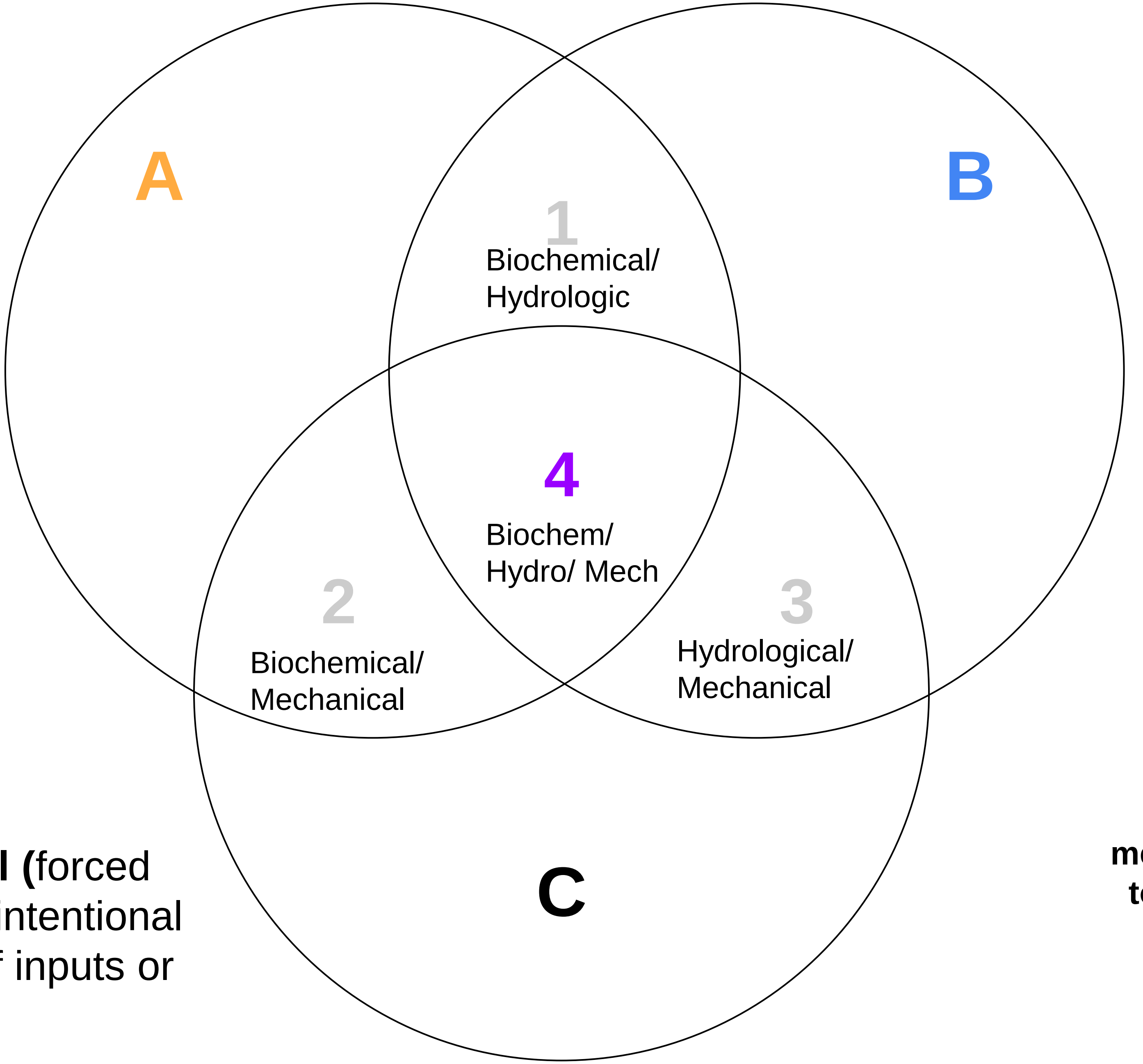
Qiu et al (2020)

More lessons in progress…

- Studies are only just starting to evaluate the relationship between future climate factors and (modeled) BMP performance
  - Including such analyses is necessary to strengthen our understanding of causal impacts of climate on BMP performance

Biological or chemical (e.g., plant uptake, denitrification, soil or water biochemical processes)

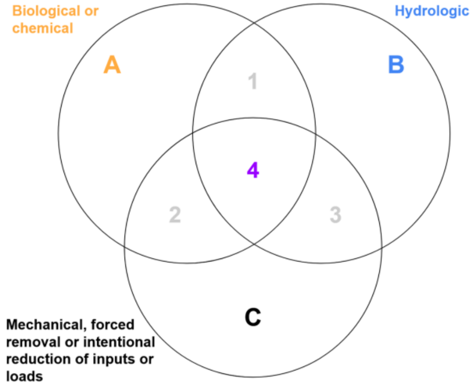
Hydrologic (e.g., water capture, retention, infiltration)



Mechanical (forced removal or intentional reduction of inputs or loads)

Conceptual model of BMP categorization based on mechanisms and processes used to reduce, remove or transform nutrients or sediment

BMP or BMP group	Assignment
Ag Nutrient Management	4 or C (rate/core only)
Tillage Management	B
Cover Crops	1 or A
Urban Nutrient Management	4
Pasture Management	1
Forest Harvesting	B
Manure Incorporation	1 or B
Land Retirement	1 or 4
Wetland Rehabilitation	A or B
Tree Planting	A
Grass Buffers	1
Forest Buffers	1
Animal Waste Management Systems (AWMS)	C
Stream restoration	1
Wet ponds and wetlands	1
Tidal wetland restoration	1
Nontidal wetland restoration	1
Living shoreline	1
Oyster restoration or aquaculture	2



Where priority BMPs fit

Pros

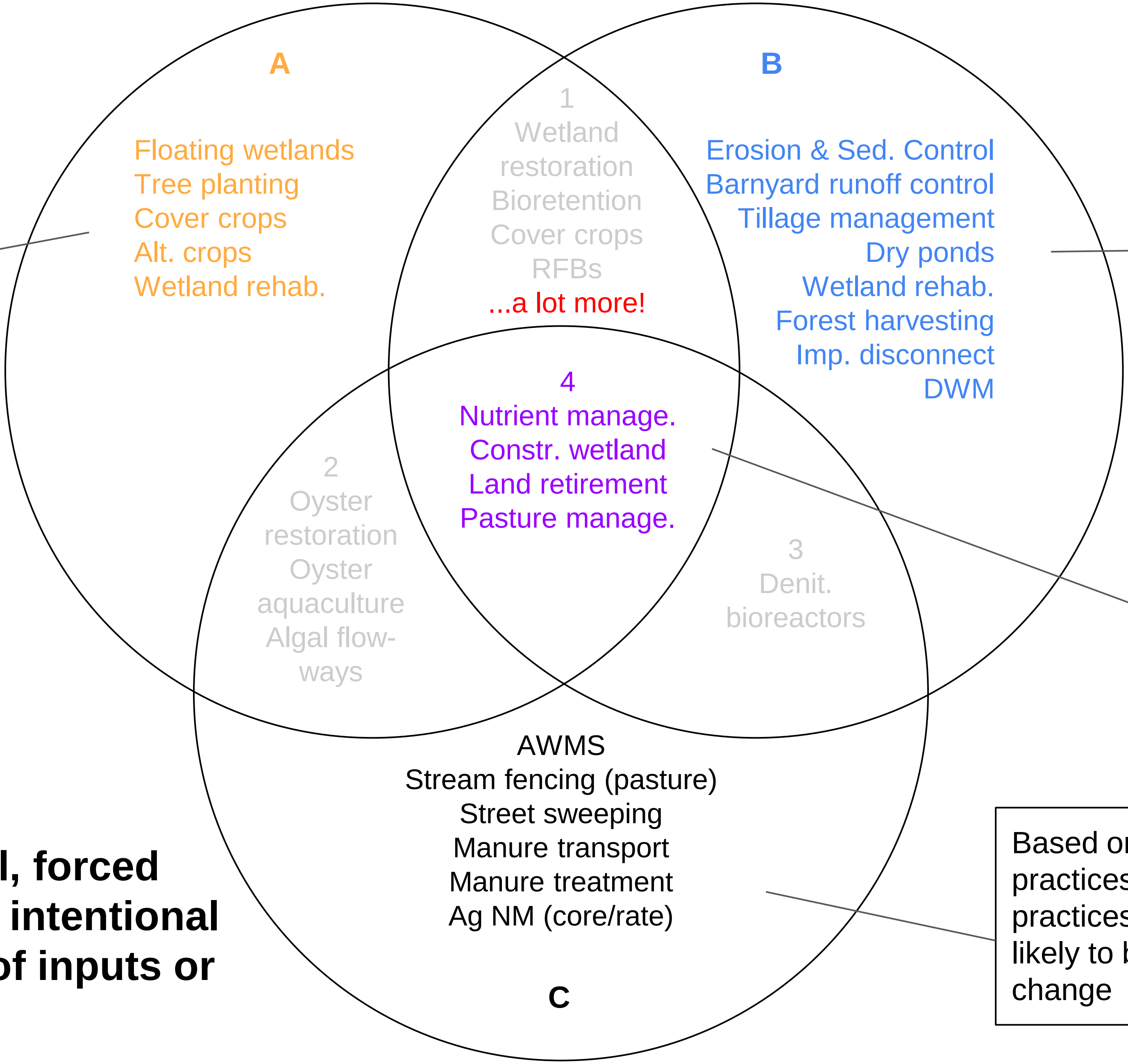
- Enables us to think through some of the relative uncertainties and complexities between different practices, or within the same practice, more easily
- Helps to separate out some practices and identify vulnerabilities more easily

Cons and caveats

- This lumps a lot of unique processes together. Same goes for complexity of the BMPs
- This is illustrative. It is neither comprehensive nor definitive
- A lot of BMPs fall in zone 1
- Subjective

Biological or chemical

Greater variability expected for these practices, given the complexity of the processes, but adaptable



Hydrologic

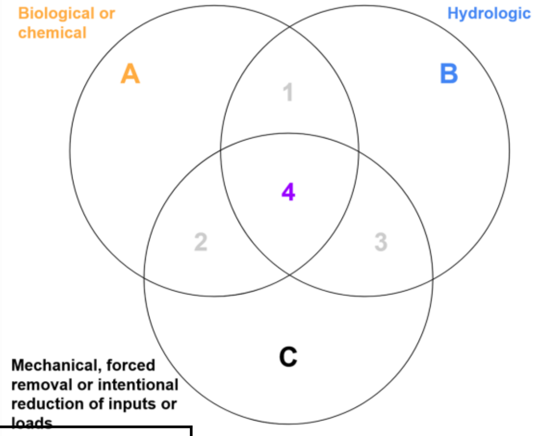
There may be a better understanding of potential hydrologic changes relative to biochemical changes, and there tend to be design changes that can be made to increase size, capacity, or function

Some element of control, although still vulnerable to climate change, also some element of adaptability

Mechanical, forced removal or intentional reduction of inputs or loads

Based on how we know these practices work, many of the practices here are the least likely to be impacted by climate change

Application of classification scheme



Summary of BMPs' key performance, relevant climate factors, expected risks under future climate and identification of possible interventions or adaptations; for BMPs with primarily biological or geochemical pollutant removal/prevention mechanism (Area A from Venn diagram)

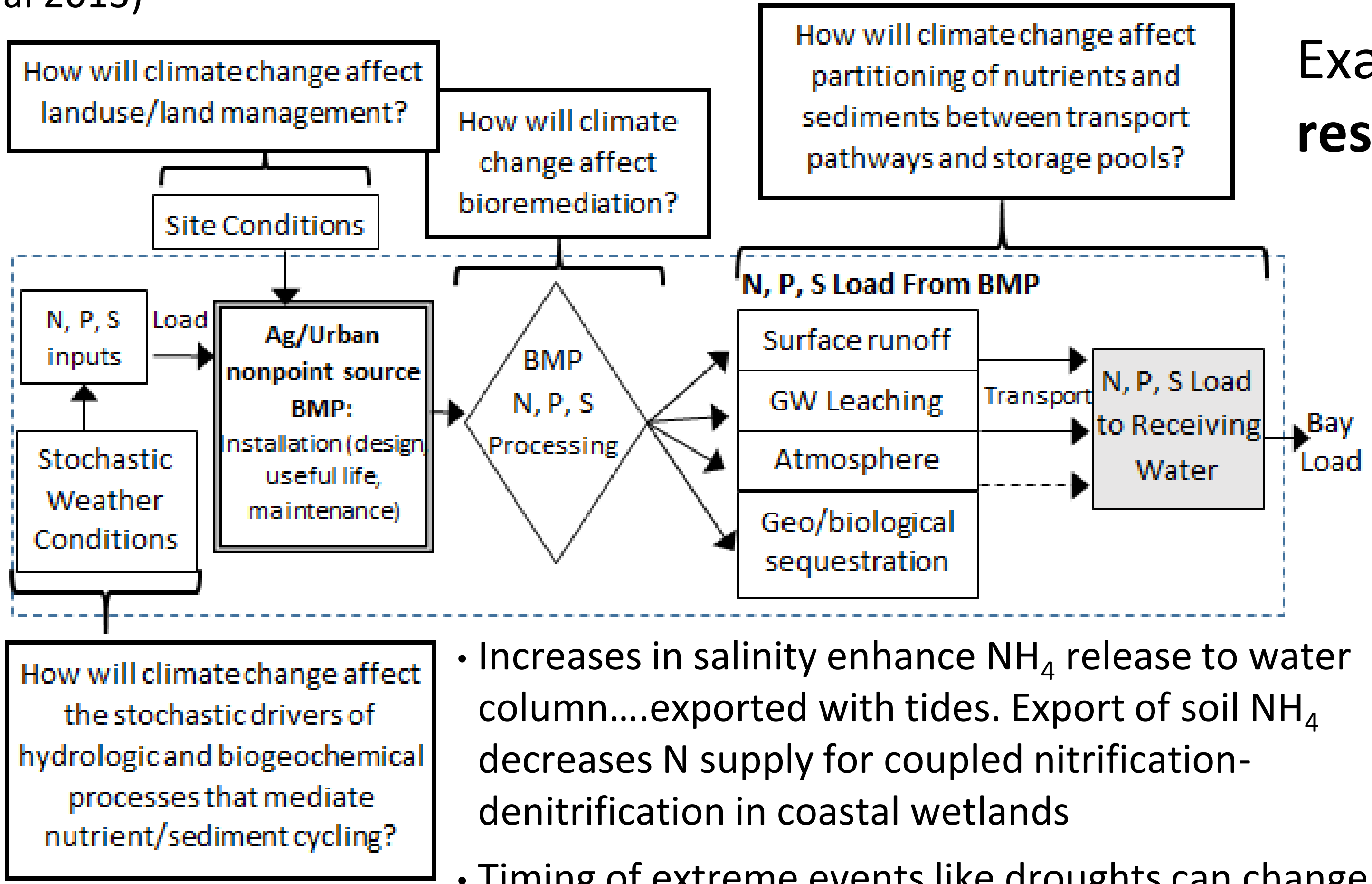
BMP or BMP group	Class	Performance depends on	Relevant Climate Factors	Expected risks under future climate	Possible intervention
Cover Crops	1 or A	Crop species or mixture; planting date and method; establishment	Precipitation variability/intensity; altered growing season; Increased temps and CO_2	Diminishing performance from increased variability, but countered by increased plant biomass from CO_2 effect[1]	Continued research to improve species selection, timing, planting recommendations
Wetland Rehabilitation	A or B (or 1)	Landscape position; design; complex factors, time	Precipitation variability/intensity; Increased temps and CO_2	Diminishing performance from increased water balance but countered by increased plant biomass from CO_2 effect[1]	Monitoring; inspect and maintain, update designs and recommendations, develop more adapted species
Tree Planting	A	Planting density and survival; upkeep or maintenance	Precipitation variability/intensity; altered growing season; Increased temps and CO_2	Diminishing performance from increased variability but countered by increased plant biomass from CO_2 effect[1]	Monitoring; develop more adapted rapidly maturing species

[1] Although evidence exists that many of these natural type BMPs may function better under higher temperatures and CO_2 concentrations as long as moisture and nutrients are not limiting (this also depends on plant type, C3 or C4 species).

- Upland management impacts sediment quality/ availability– how does climate impact these processes?
- Restoring tidal hydrology may enable salinity to travel farther inland…. Ag land use exposed to low levels of salinity can release NH_4 (Ardon et al 2013)

- Increased temps and CO_2 affect growth of vegetation (greater N uptake and temporary storage)
- What role does evolving balance of freshwater inputs play? (increased precip… increased streamflow) - inconclusive
- What does the literature say about changes to soil chemistry and biogeochemical functions? Short answer: it's complicated and varies by wetland type, site factors

Example BMP: **Tidal wetland restoration**



- Increases in salinity enhance NH_4 release to water column….exported with tides. Export of soil NH_4 decreases N supply for coupled nitrification-denitrification in coastal wetlands
- Timing of extreme events like droughts can change form of exported N

- Saltwater incursion into historically freshwater wetland systems impact microbial communities; restoring freshwater may not fully restore microbial function but can improve sensitives (Huang et al 2021)
- Rising sea levels and increased storm surge threaten coastal wetland systems
- Sediment accretion influenced by many factors
  - Liu et al (2021) suggests sediment availability is driver for success of coastal wetland restoration
- Interaction with nature-based BMPs (living shorelines) or natural barriers (oyster reefs) can slow marsh retreat (Ridge et al 2017)

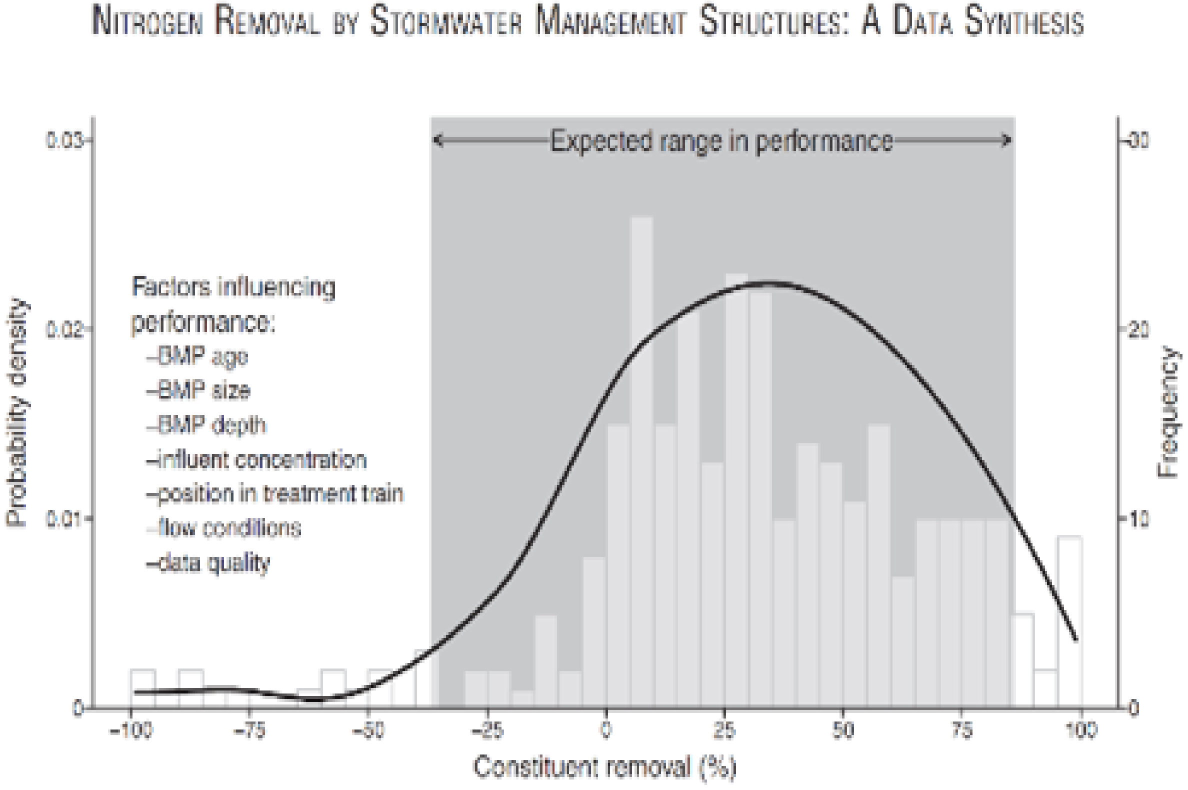
Preliminary findings or conclusions

- Impacts on watershed processes
  - Precipitation and temperature increase
  - Streamflow overall increase, more in winter, less in summer
  - Nitrogen yields largely mimics streamflow (increases), but also changes to N cycling rates
  - Phosphorus yields increase due to increased sediment bound P (more than dissolved P)
- Impacts on BMP performance
  - We still lack comprehensive or detailed understanding of individual BMPs' functioning, even for the most-studied/most-reviewed BMPs, to the extent needed to describe explicit impacts of future climate conditions on BMP performance
  - This is due to a number of factors, e.g., inconsistent reporting of key data in empirical studies, reliance on models to evaluate BMP performance under future climates, lack of information about management factors (maintenance, failure, skill/knowledge)

Preliminary findings or conclusions

- Lit confirmed what we already knew: empirical studies show BMPs range from net negative to positive removal (can be a source or a sink), but average contribution is *usually* net removal for desired pollutant
  - No conclusive evidence that any specific BMP currently assumed to have average net removal (sink) will shift to average net load increase (source) under future climate conditions, but this is more of a knowledge gap than exoneration
  - Individual sites can certainly make this shift, so maintenance and verification are vital
- BMP performance "resilience" is something we can conceptualize even without comprehensive information
  - For example: similarities between resilient stormwater BMP principles from Wood (2021) and factors that increase/decrease resilience for aquatic ecosystems (Pelletier et al 2021)
    - Contributing factors include: functional redundancies; heterogeneity/complementary BMPs (complexes, treatment trains)

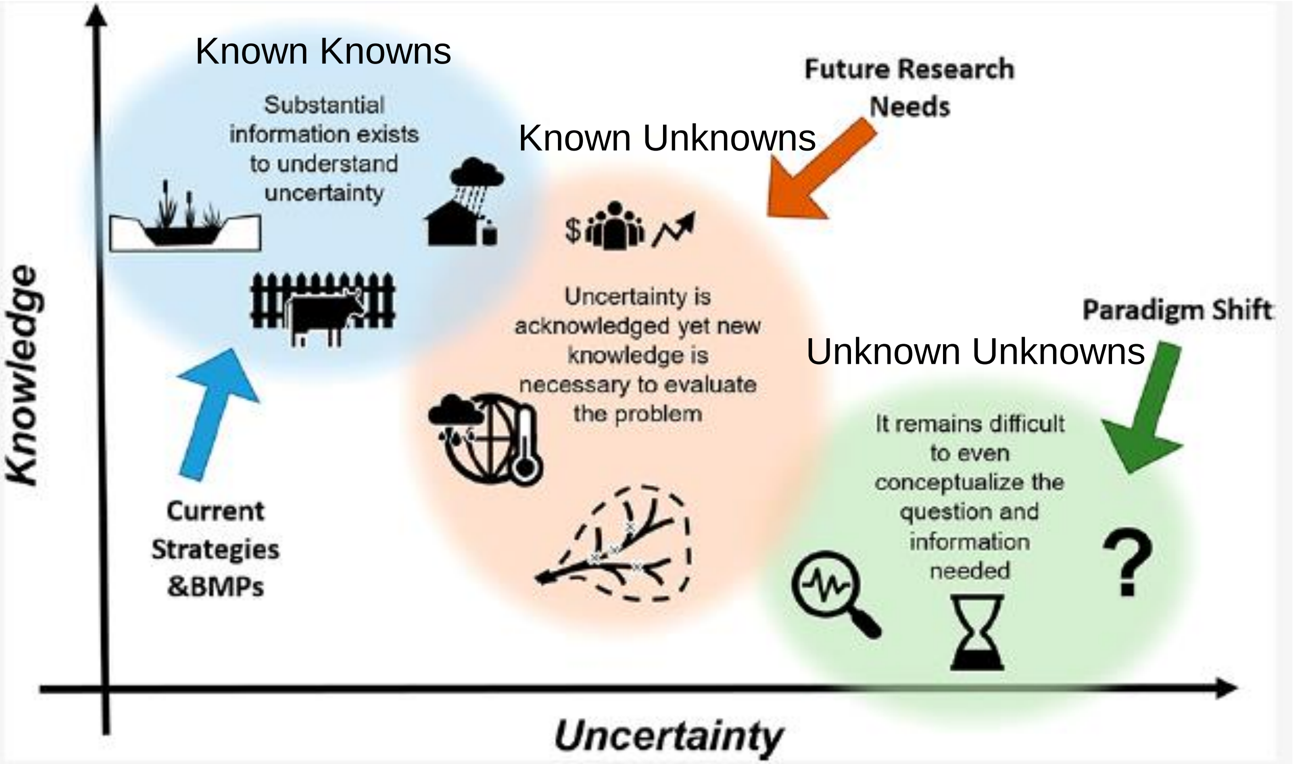
Knowledge gaps (abridged - part 1)



Koch et al (2014)

- More long term studies of BMPs are needed (always), but especially for BMPs that are particularly complex or are vulnerable to climate change
- Literature rarely describes maintenance or upkeep of longer term practices; almost never considers BMP failure
- Studies on the non-linear responses of the system to climate variability/change, and their interaction with other anthropogenic stressors

Knowledge gaps (abridged - part 2)



Lintern et al (2020)

- Modeling studies of BMPs under future conditions - by necessity - do not account for population growth, land use change, or other socioeconomic factors that will drive significant changes to the landscape in which BMPs operate. There may be time horizons appropriate for combining land use change projections into future BMP performance modeling studies
- Closely related infrastructure systems (e.g., storm sewers) were not addressed in our review, but offer opportunities for cross-sector collaboration
- Social science linkages are a critical next step (especially w.r.t. improved implementation, appropriateness of individual/complexes of BMPs)

Discussion

Thank You

Contact:

Jeremy Hanson
hansonj@chesapeake.org

Zach Easton
zeaston@vt.edu

Photo: Chesapeake Bay Program