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

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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/uncertainties affect 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

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

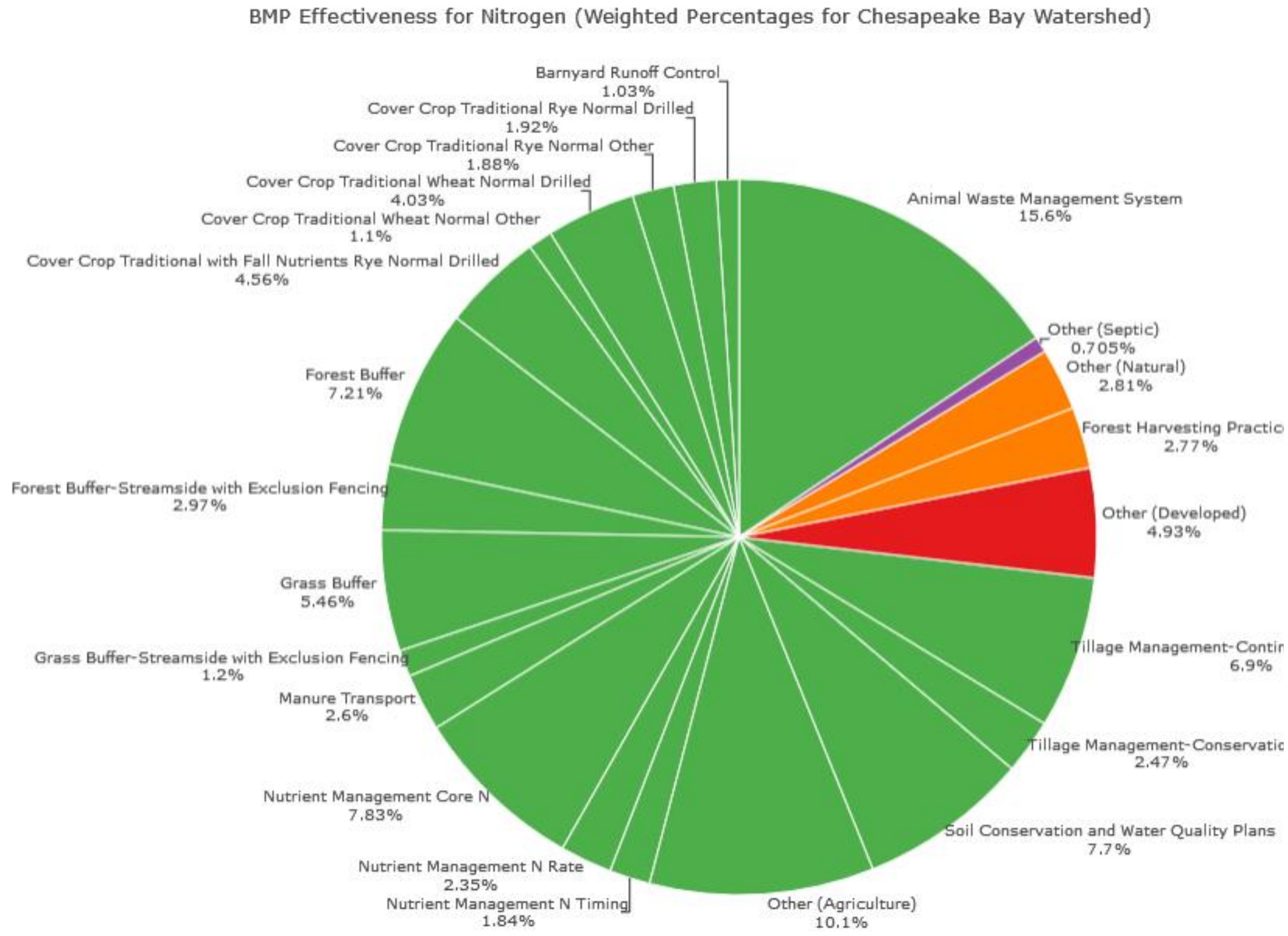
1. How do climate change and variability affect BMP performance?
   A. By what mechanisms can climate change and variability affect BMP nutrient and sediment removal efficiency?
   B. How does climate change uncertainty affect BMP performance variability?

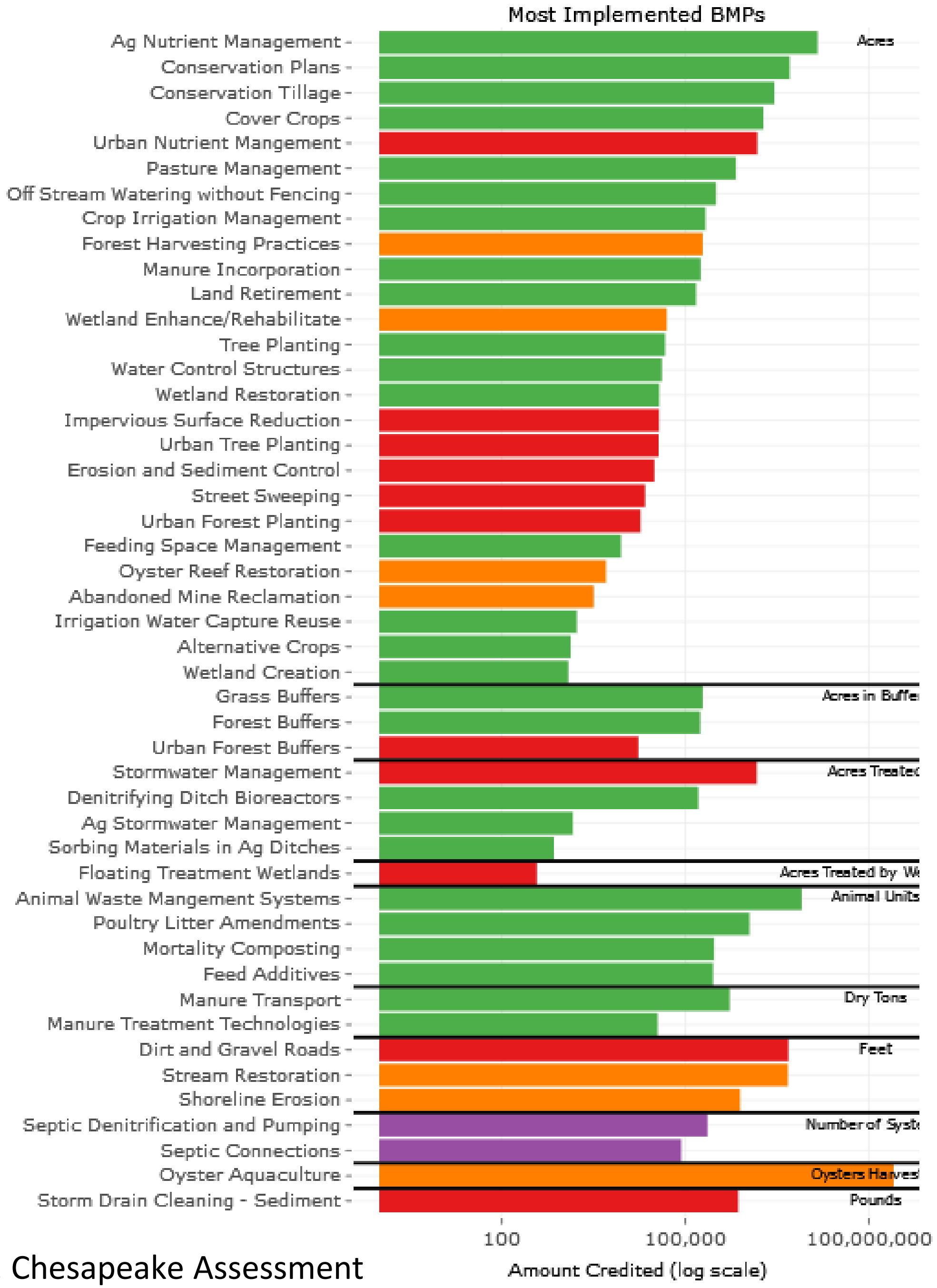
2. Which BMPs will likely result in the best water quality outcomes under climate uncertainty?

Review Questions

Using modified systematic literature reviews to inform answers and identify gaps

1. How do climate change and variability affect nutrient/sediment cycling?
   17 articles heavily supplemented by rich literature for CC and impacts
1. 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?
      61 that met criteria from search out of 412 papers
   b. How does climate change uncertainty affect BMP performance variability?
      14 articles that met criteria from search out of 172 papers
      *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
1. 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	**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)			

Ultimately, we had varying success identifying articles for such a range of BMPs, but we found at least some studies for a number of priority BMPs (we'll revisit and expand on these caveats and knowledge gaps later)

Expected climate impacts in the Bay and watershed

Changes where we have a relatively strong understanding of possible and likely futures...

- Precipitation
- Temp
- SLR

Changes where we still have relatively more conflicting possibilities...

- ET
- Soil moisture
- Streamflow

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.
  - The annual increase in NO_3- export is due to substantial increases in nitrification during the winter/spring and increased runoff/soil moisture.
- Phosphorus cycle changes
  - Slight to moderate increases TP yield, a result largely of increases in sediment bound P during the winter/spring
  - Warmer and wetter conditions, biomass utilizes dissolved-P rapidly and there is reduced P mineralization from fresh organic P…..consequently dissolved P levels change less.

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

Conceptual Model #1

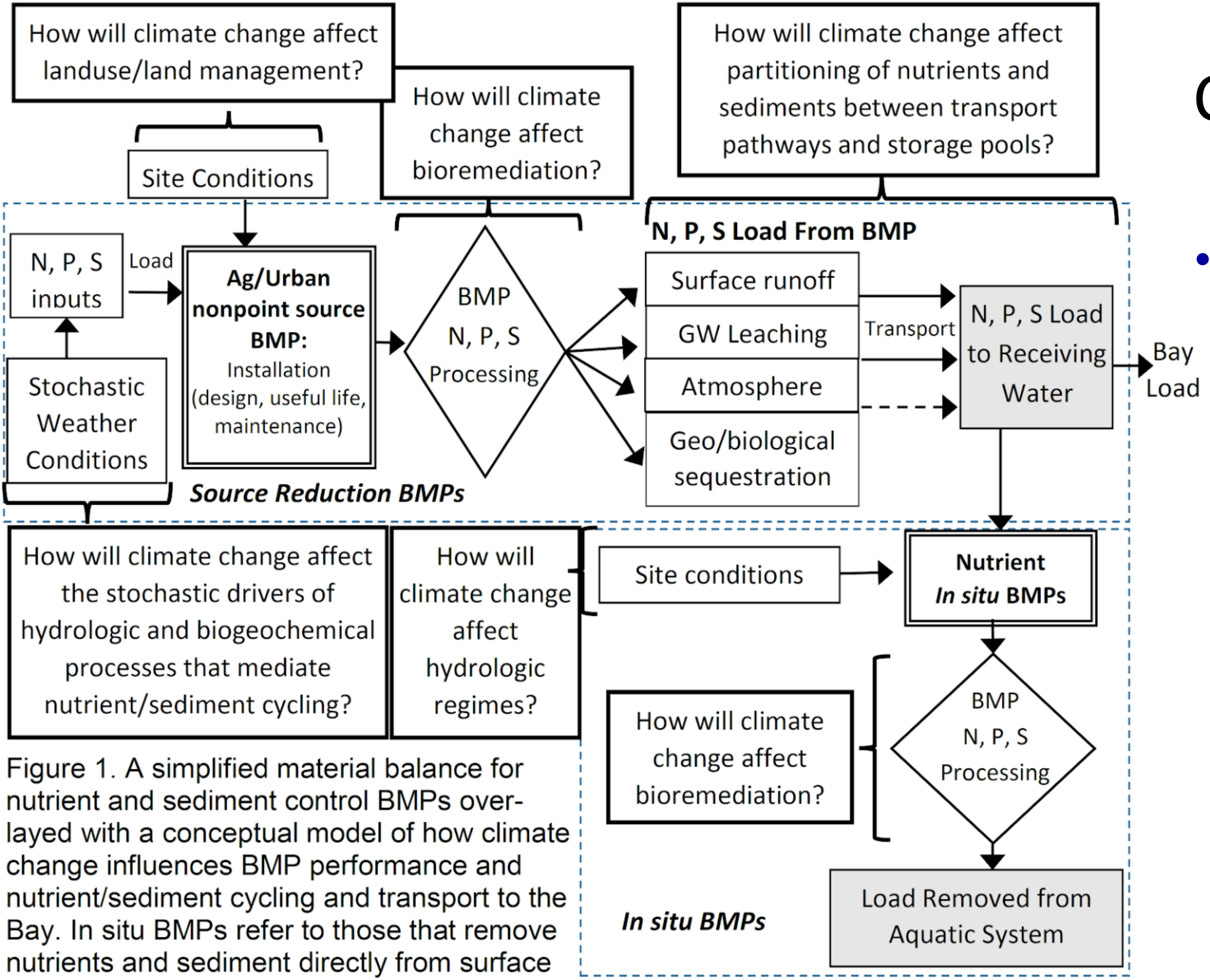


Figure 1. A simplified material balance for nutrient and sediment control BMPs over-layed with a conceptual model of how climate change influences BMP performance and nutrient/sediment cycling and transport to the Bay. In situ BMPs refer to those that remove nutrients and sediment directly from surface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

- 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 or sediment loads
  - We can do this at a smaller scale (BMP-specific; previous slide) when we have more 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 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 for stormwater BMPs (at right) can be useful for other sectors' BMPs.
  - Combined with expected or suspected future climate impacts we can begin to understand what the greatest uncertainties or concerns might be.
  - Combined with snapshot of most-implemented BMPs or BMPs with greatest overall reductions, this can help illuminate our overall question of how climate change impacts efforts to restore and protect the Chesapeake Bay.

Wood, D. 2021. Vulnerability Analysis and Resilient Design Considerations for Stormwater Best Management Practices. Chesapeake Stormwater Network. https://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2021/03/Memo-4_BMP-Vulnerability-Analysis_Final.pdf

More lessons in progress...

- Studies are only just starting to evaluate the relationship between future climate factors and (modeled) BMP performance
  - Including such analyses from Qiu et al. (2020) is necessary to strengthen our understanding.

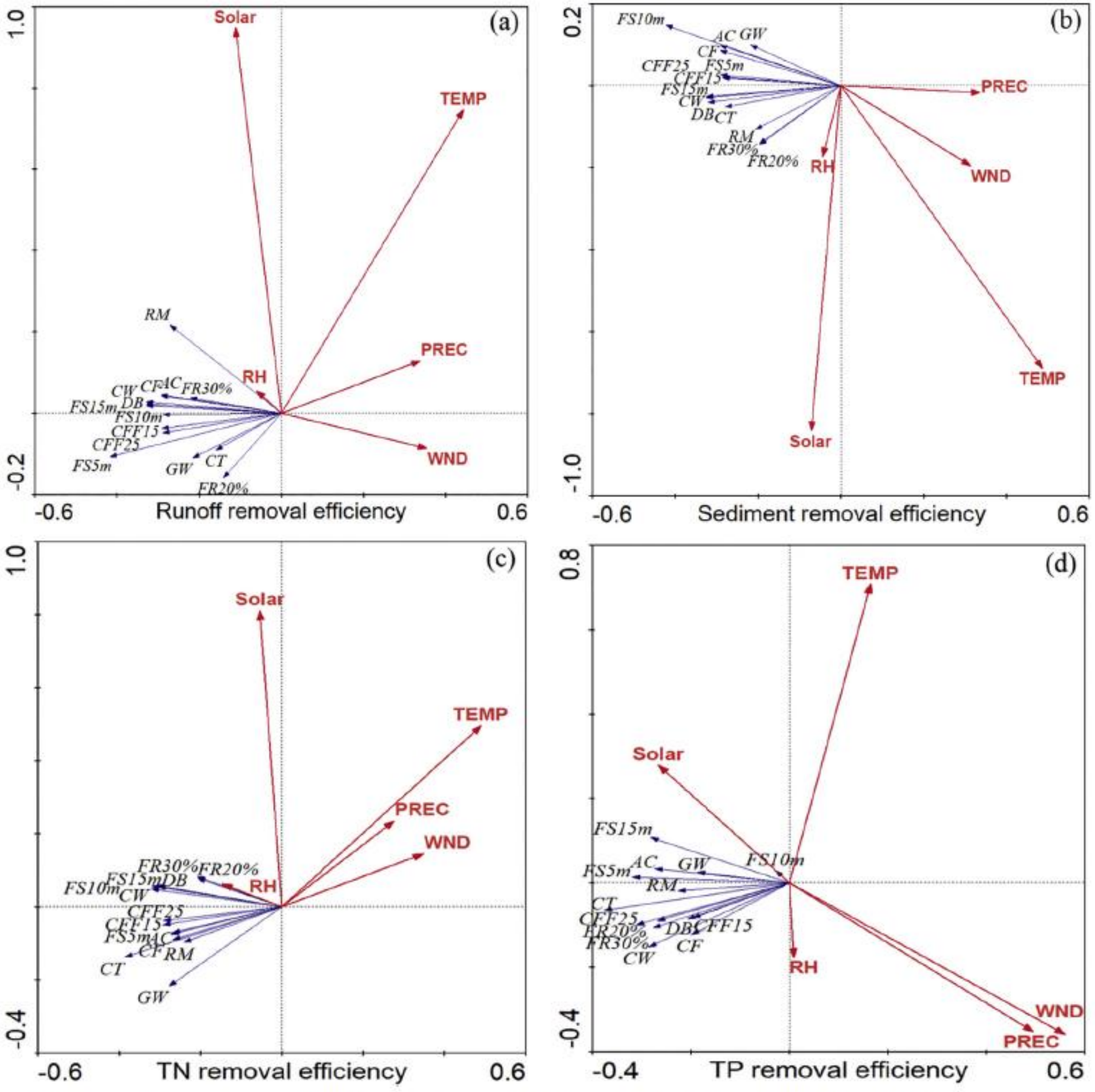
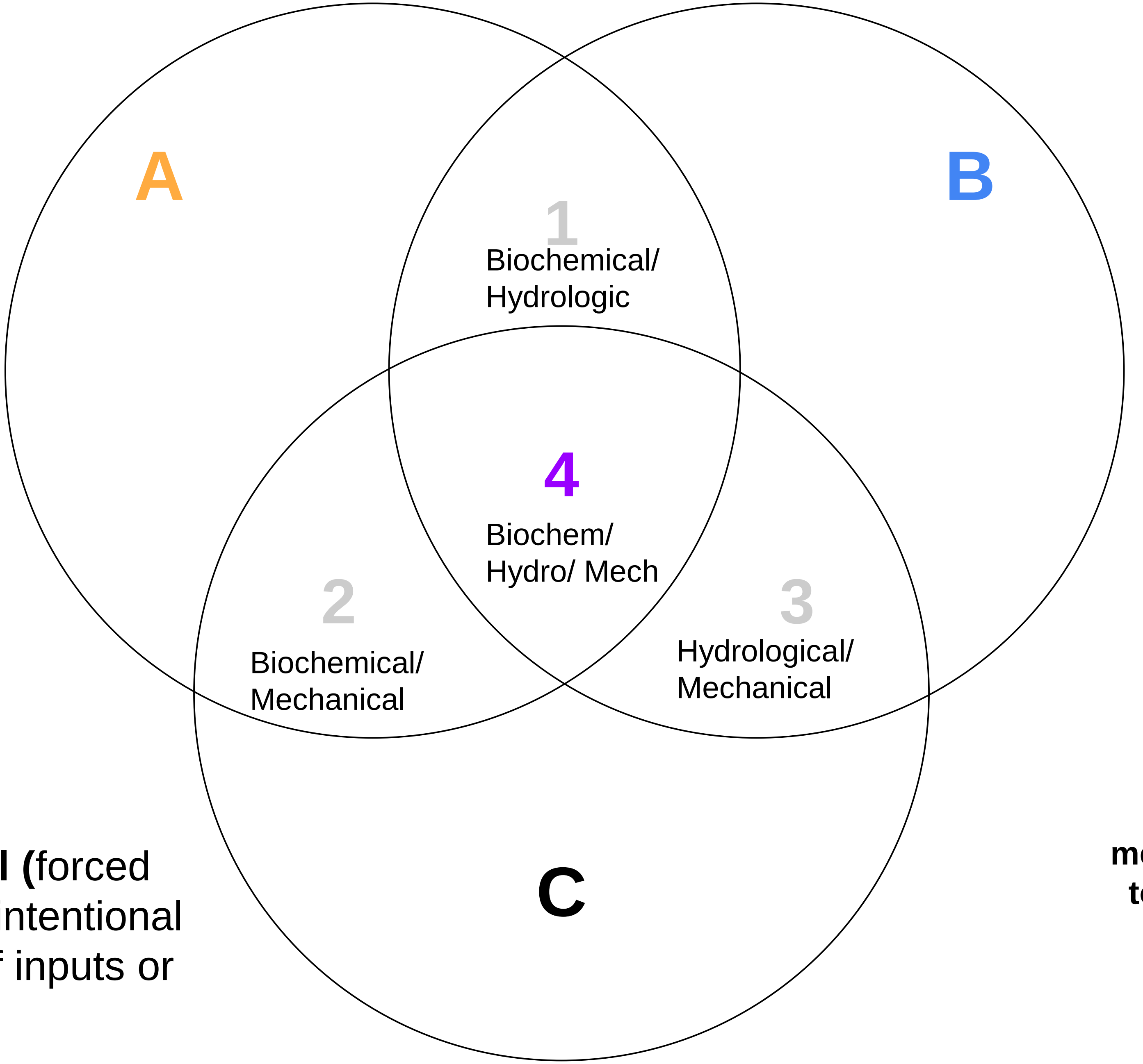


Fig. 5. Relationships between annual runoff (a), sediment (b), TN (c), and TP (d) removal efficiencies of 14 BMPs with climate factors, including precipitation (PREC), temperature (TEMP), solar radiation (Solar), relative humidity (RH), and wind speed (WND), during 2020–2099. Abbreviations of BMPs are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

Qiu et al. 2020..

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	Best approx. 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 might fit

Pros

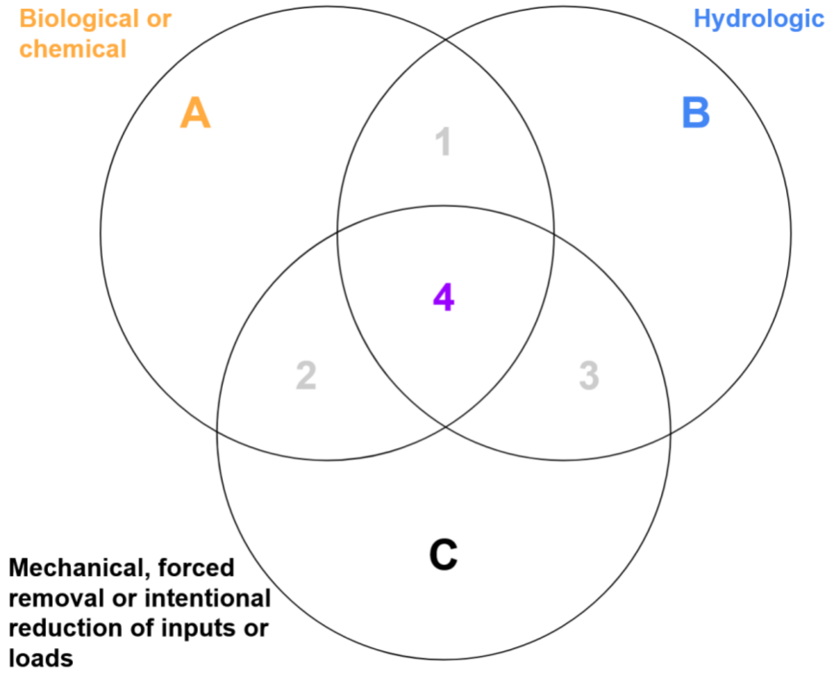
- It enables us to think through some of the relative uncertainties and complexities between different practices, or within the same practice, more easily.
- This helps to separate out some practices and identify possible lessons more easily.

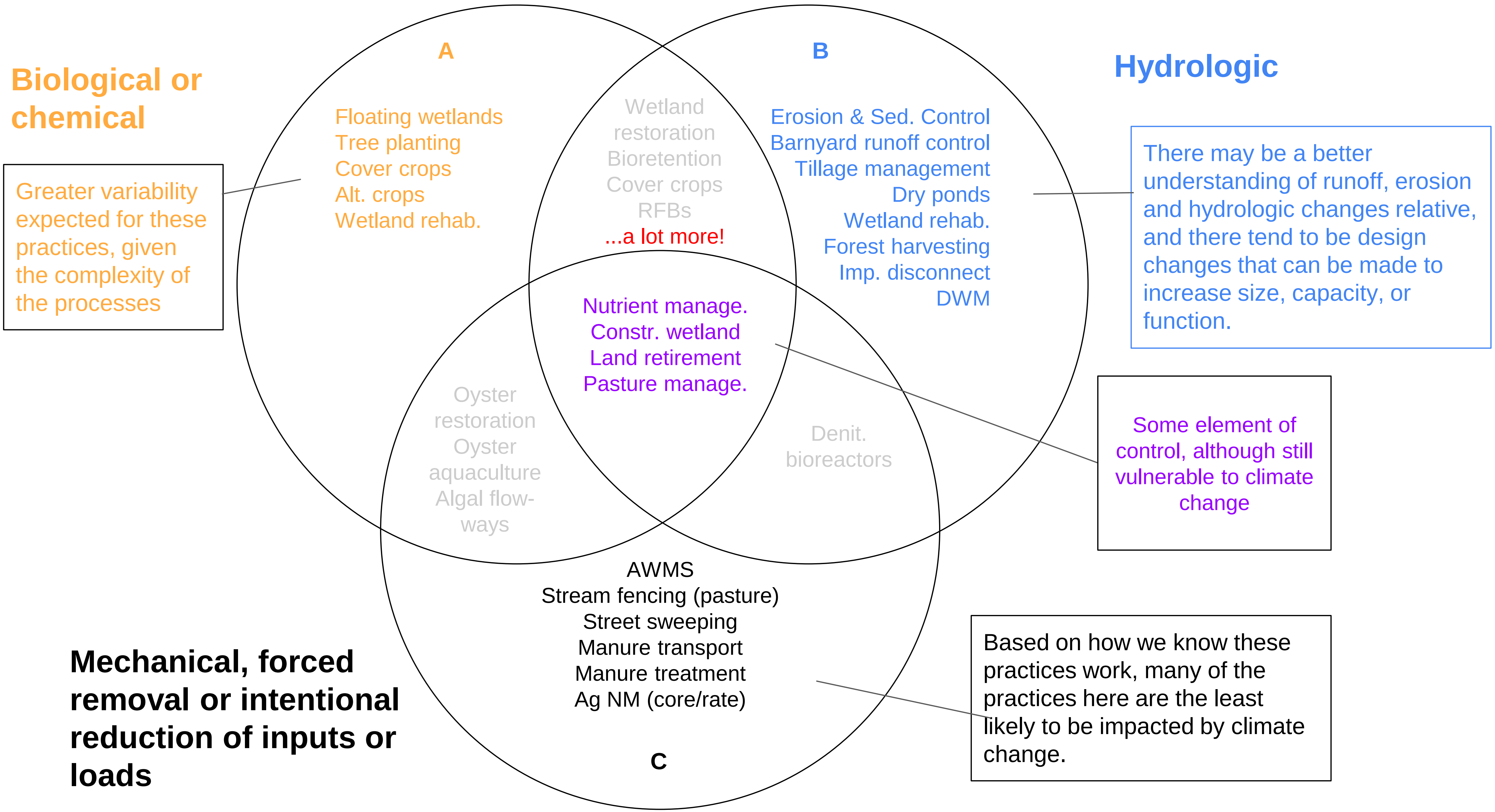
Cons and caveats

- 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.

BMP or BMP group	Best approx. assignment
Bioretention	1
Erosion & Sediment Control (construction)	B
Dry ponds	B
Rooftop or imp. disconnection	B
Barnyard runoff control	B
Denitrifying bioreactors	3 or 4
Algal flow-ways	2
Stream fencing	C
Street sweeping	C
Manure treatment	C
Manure transport	C
Constructed wetland	4
Drainage water management	B

Additional BMPs that we think fit nicely in this framework

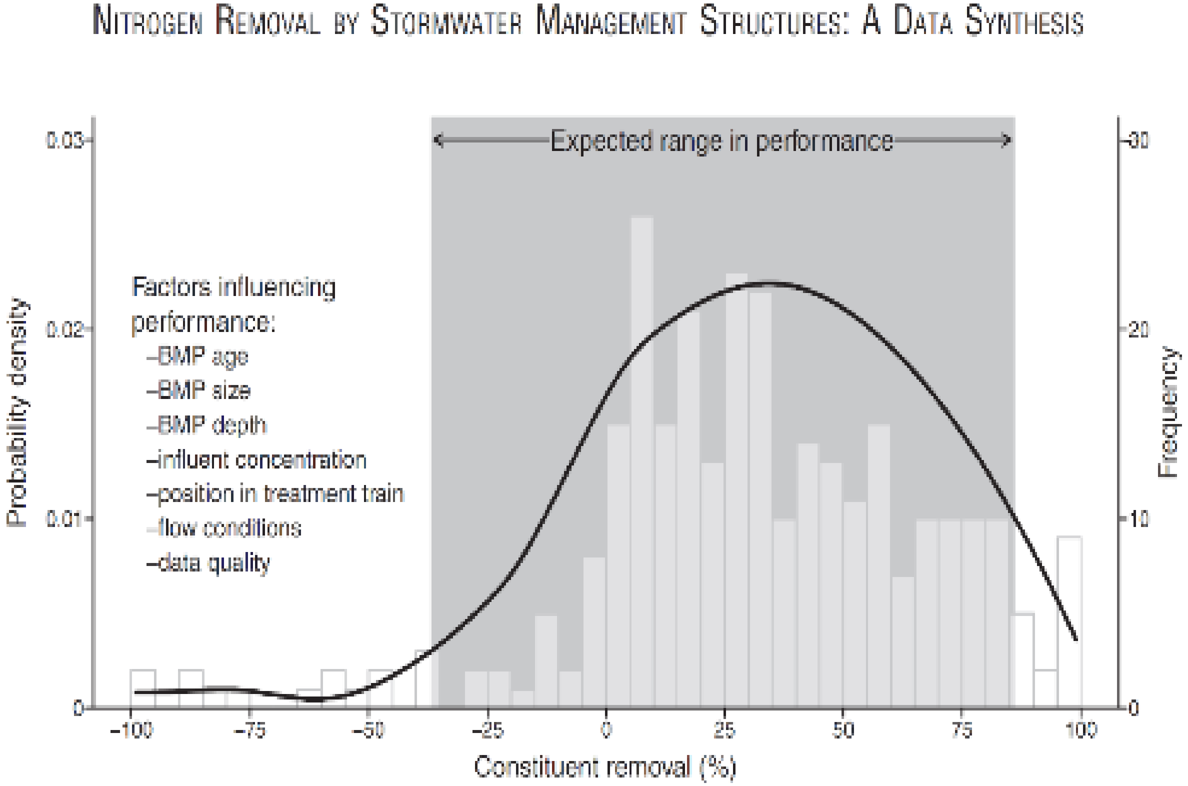



Biological or chemical
Greater variability expected for these practices, given the complexity of the processes
A
Floating wetlands
Tree planting
Cover crops
Alt. crops
Wetland rehab.
Wetland restoration
Bioretention
Cover crops
RFBs
...a lot more!
B
Erosion & Sed. Control
Barnyard runoff control
Tillage management
Dry ponds
Wetland rehab.
Forest harvesting
Imp. disconnect
DWM
Hydrologic
There may be a better understanding of runoff, erosion and hydrologic changes relative, and there tend to be design changes that can be made to increase size, capacity, or function.
Nutrient manage.
Constr. wetland
Land retirement
Pasture manage.
Some element of control, although still vulnerable to climate change
Oyster restoration
Oyster aquaculture
Algal flow-ways
Denit. bioreactors
AWMS
Stream fencing (pasture)
Street sweeping
Manure transport
Manure treatment
Ag NM (core/rate)
C
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.

Preliminary findings or conclusions (in progress)

- Impacts on watershed processes
  - Precipitation and temperature increase
  - Streamflow overall increase, less in summer
  - Nitrogen yields largely mimics streamflow (increases), changes to N cycling rates
  - Phosphorus yields increase due to increased sediment bound P (more than dissolved P)
- Impacts on BMP performance
  - BMPs in Zones A/1 (high uncertainty) can be offset by adaptability in the case of annual practices
  - BMPs in Zone C are considered cost effective and high impact, can be built bigger and better
  - BMPs in Zone B may have variable performance but moderate changes to BMP design and implementation may result in more certain performance

Knowledge gaps (in progress)



Koch et al. 2014

- More long term studies of BMPs are needed (always), but especially for BMPs that are particularly vulnerable to climate change (Sectors A, 1, 4)
- Literature rarely describes maintenance or upkeep of longer term practices
- Studies on the non-linear responses of the system to climate variability/change, and their interaction with other anthropogenic stressors
  - The primary mechanisms/processes are highly uncertain and highly sensitive to expected future climate impacts

Discussion

Thank You

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Photo: Chesapeake Bay Program