Reviewing and Updating Loading Sensitivity to Inputs, Phosphorous Loading Processes, and Updates on Representing Sanitary Sewer Exfiltration

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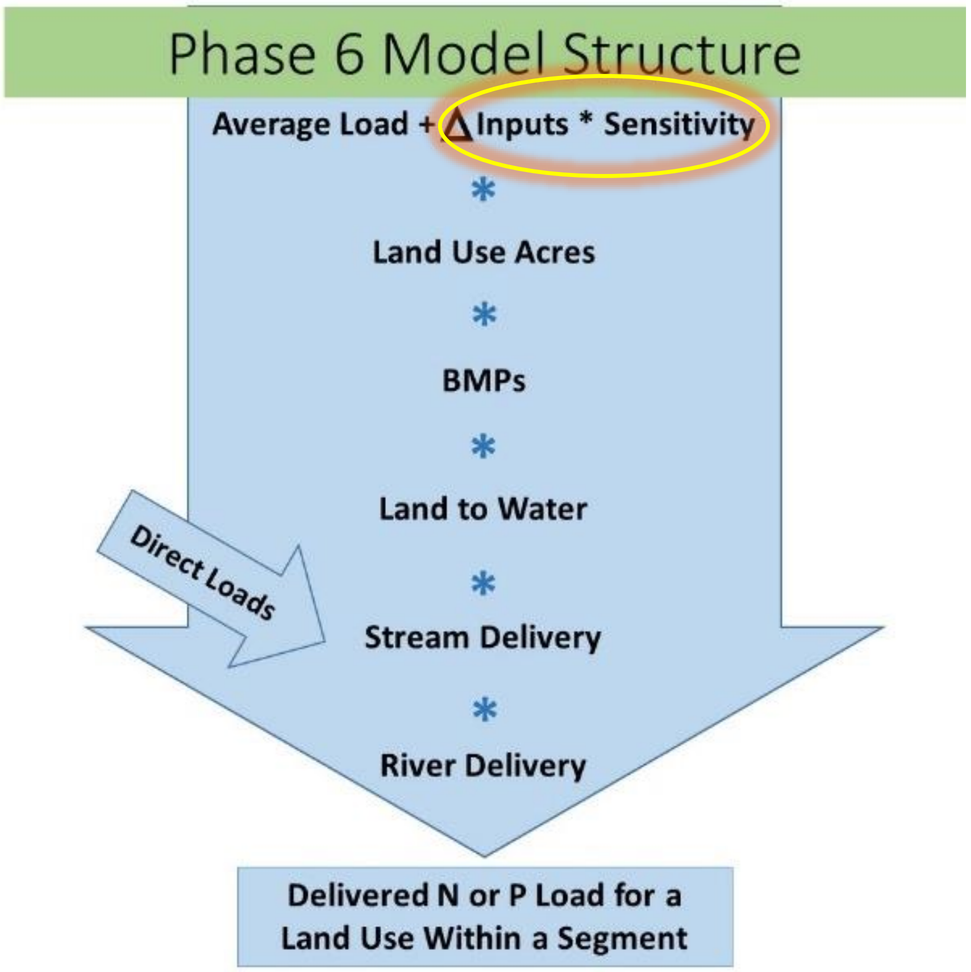
Reviewing and Updating Loading Sensitivity to Inputs

CAST Load Sensitivity to Inputs

Sensitivity (S) is defined as the change in export load per change in input load. If inputs change by Δ, the export will change by S*Δ (S=Δ Export/Δ Input).

In other words:

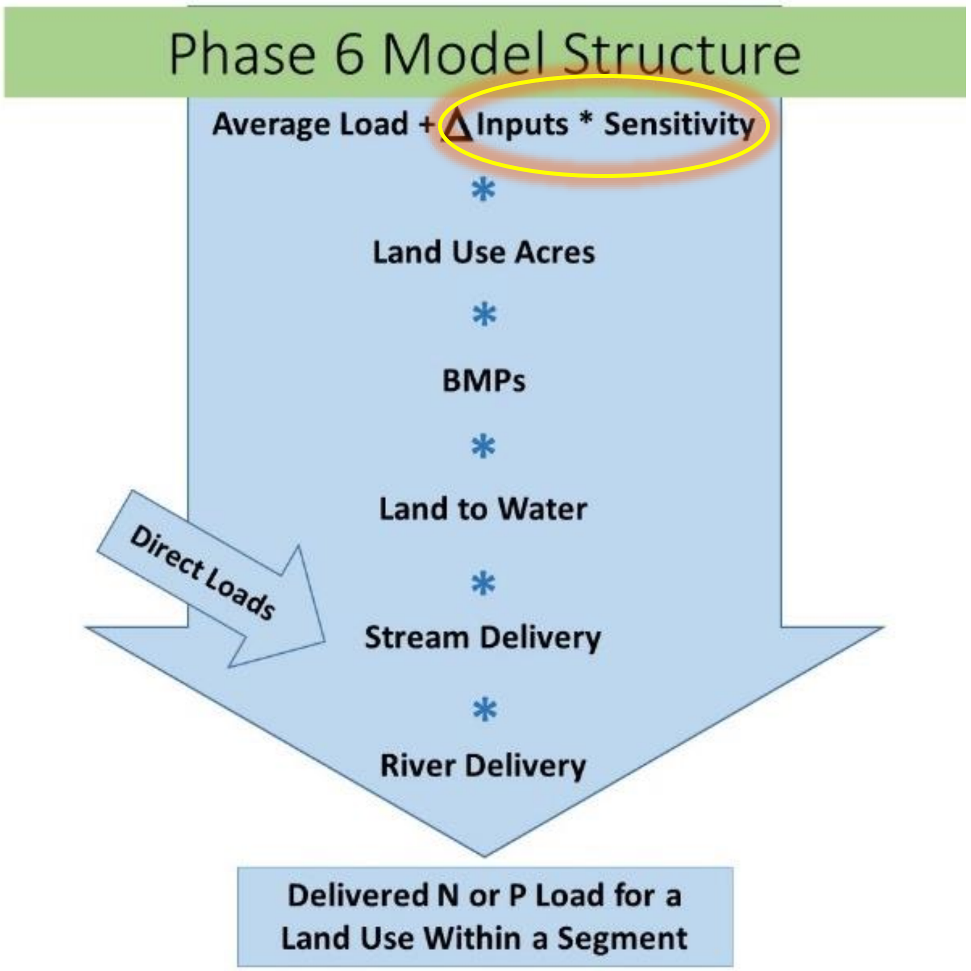
- When added to the land use average load we identify the load, by source (land use and input), which is available for export (edge of field or stream load).
- Sensitivities account for the spatial and temporal variation in the load available for export.
    - If there is no sensitivity, then the load available for export is constant in space and time for that land use.



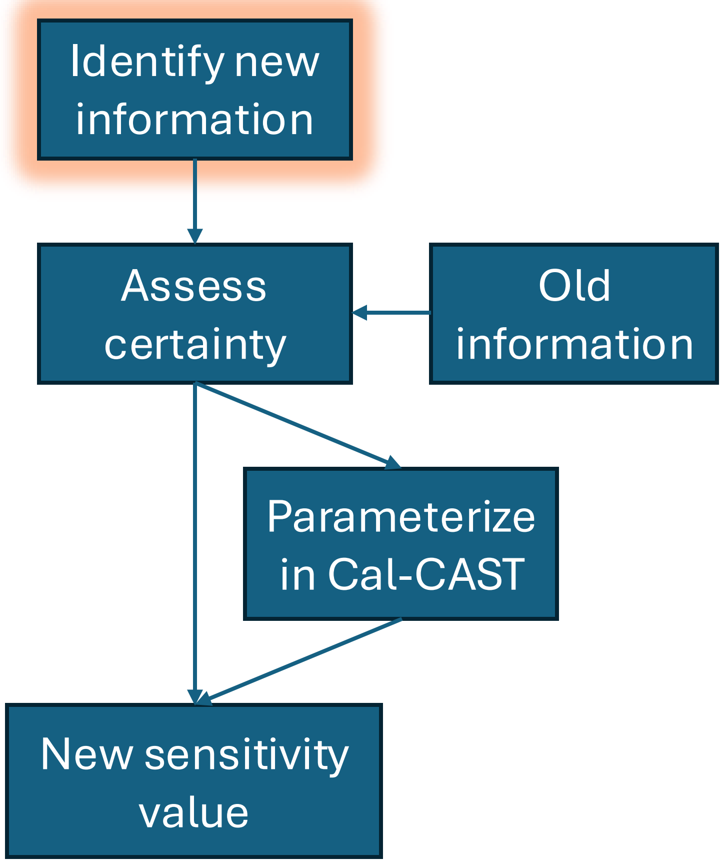
CAST Load Sensitivity to Inputs

We are reviewing these values for Phase 7

- Consistent with the best available science
- Validated by multiple sources including observation when possible



Addressing sensitivities



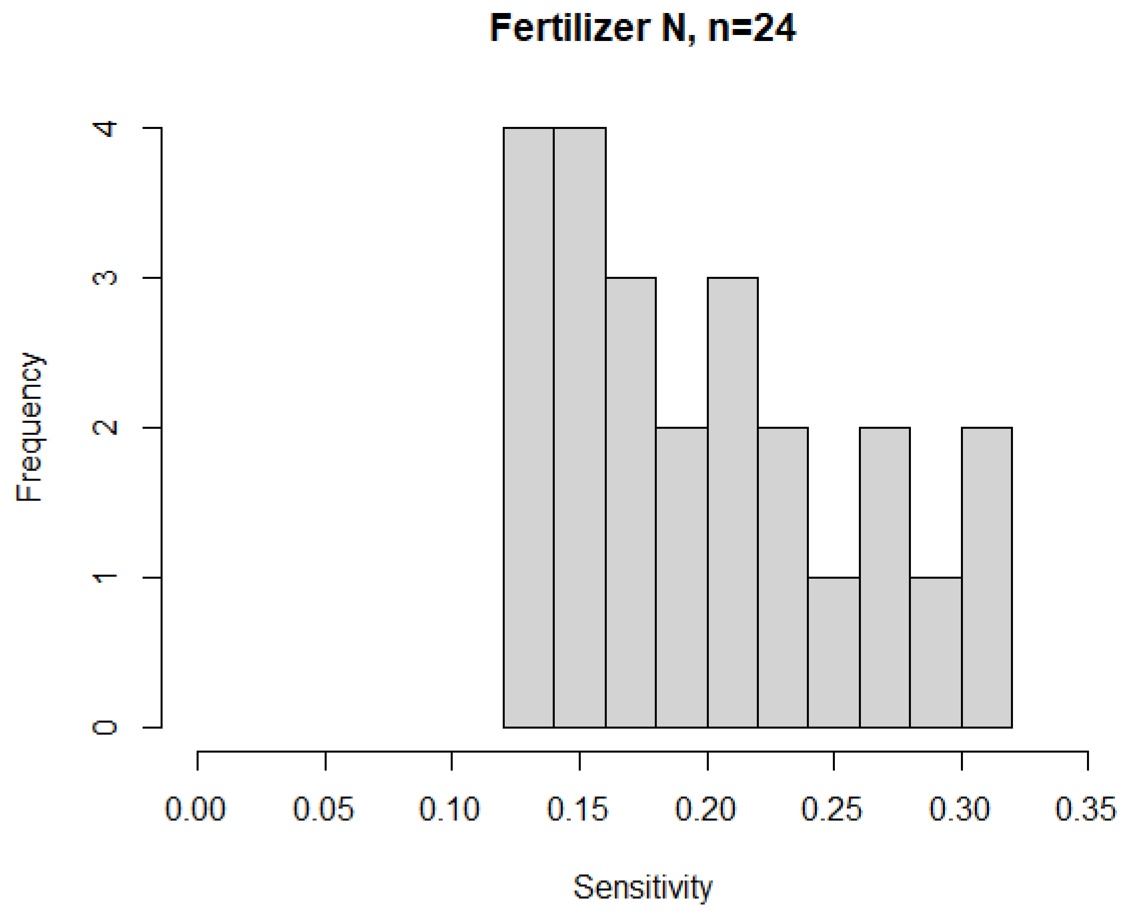
- Direct measures of sensitivity from the literature
  - Look for agreement across studies or to other information
- Modeled values from the literature
  - Values from other calibrated models (other than P6 assessment)
- Non-direct measure from the literature
  - Assumptions are required to convert to a CAST sensitivity value
  - I.e., measurements are catchments scale or involve other variables which occlude direct calculation of sensitivity
- Process knowledge from literature
  - Provides further understanding of the processes affecting sensitivity which improves expert judgement

Manure and fertilizer literature

- Plot scale studies
  - Over 50 relevant studies
  - Both field studies and highly calibrated plot scale models
- Watershed models
  - Over 30 models, mostly SPARROW, SWAT
- The literature and models are evaluated to identify the most relevant values to CAST sensitivities.
- Relevant values are normalized for difference in land-use to be more comparable to CAST sensitivities.
  - CAST and the literature suggests that N application to high intensity ag. is 1.5-1.6 times the N applied other cropland types.
  - Normalized values based on the percent study area that is high intensity ag. assuming 1.6 times application.
    - Where studies did not report ag. land composition values were extracted from the USDA Census.

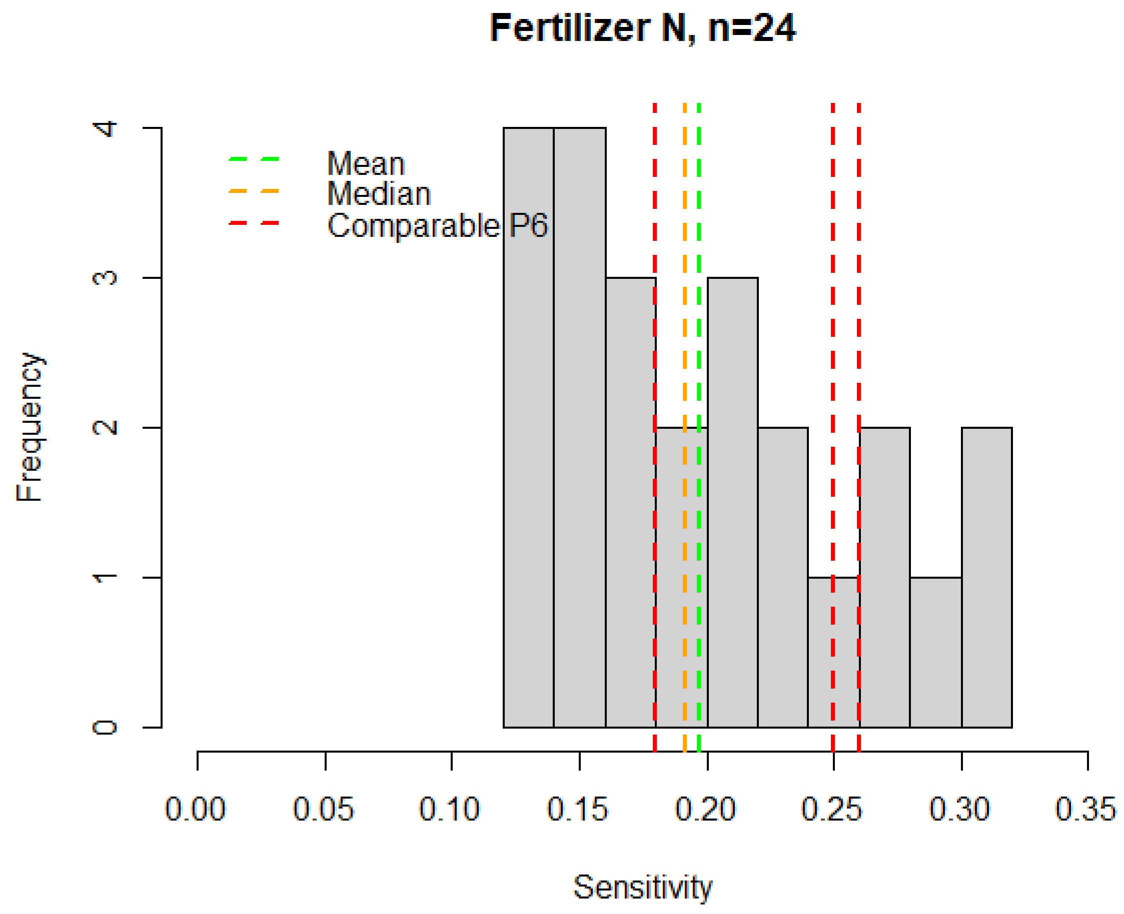
Fertilizer N literature values

- 24 CAST comparable values from the literature
- Not a well-defined mode, but a clear range to inform calibration.



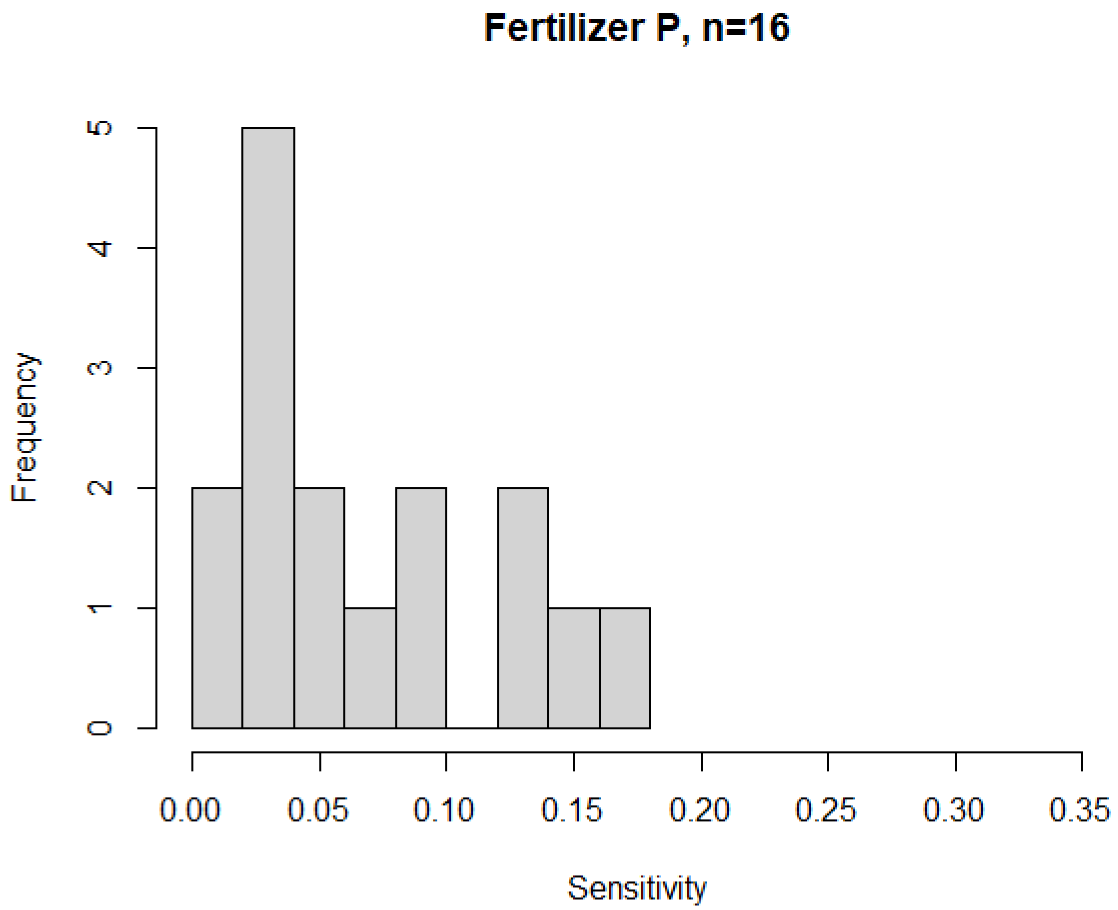
Fertilizer N literature values

Value	TN
Literature Mean	0.20
Literature Median	0.19
P6 Grain w/ Manure	0.26
P6 Specialty Crop High	0.25
P6 Grain w/o Manure	0.18



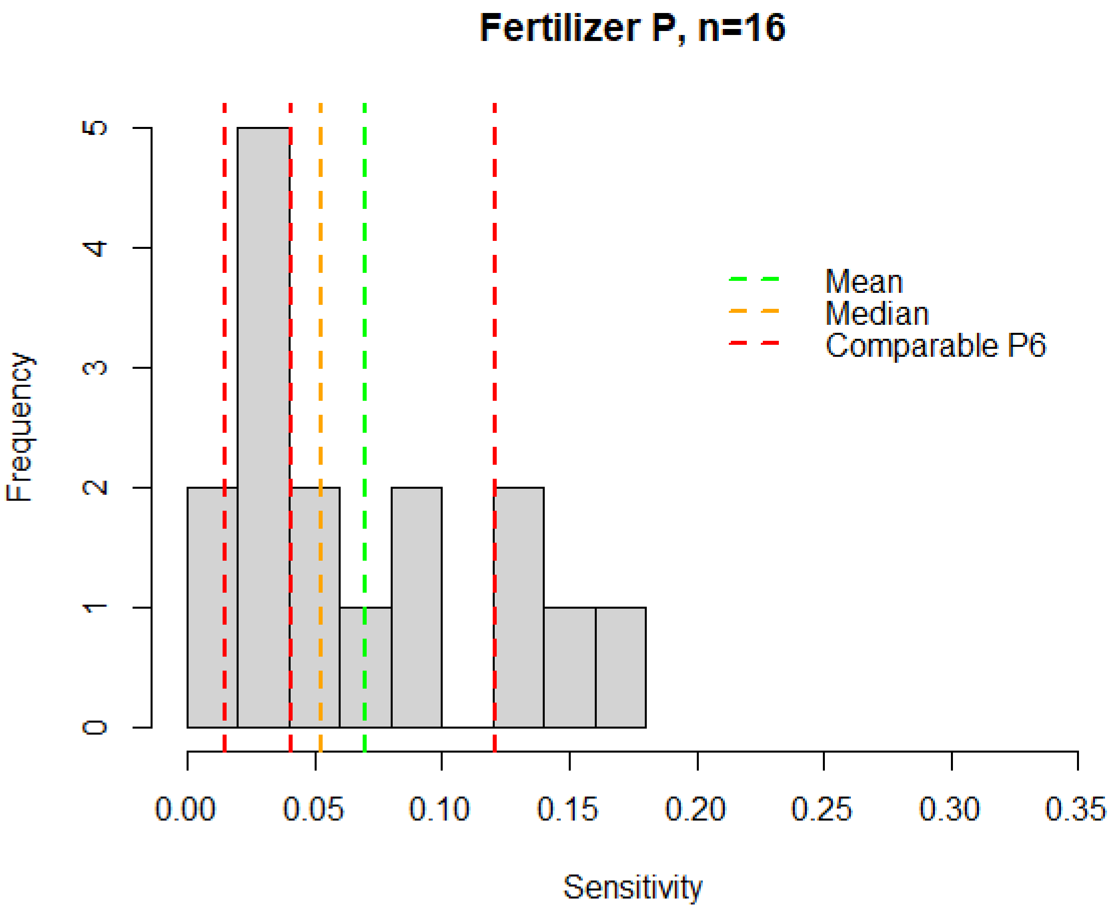
Fertilizer P literature values

- 16 CAST comparable values from the literature
- More variation in field and modeling methods with comparison to N



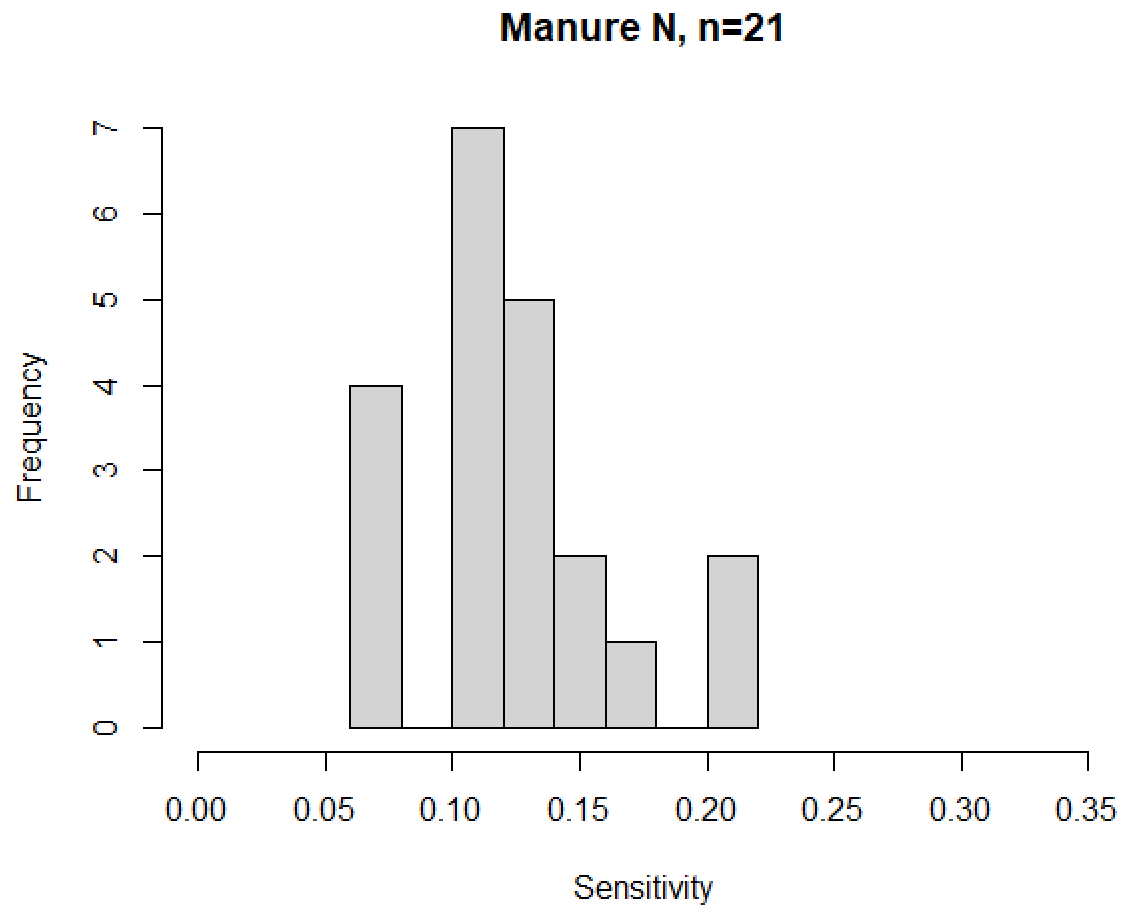
Fertilizer P literature values

Value	P	WEP	Storm -water	Sediment
Literature Mean	0.07			
Literature Median	0.05			
P6 Grain w/ Manure	-	0.015	0.041	0.121
P6 Specialty Crop High	-	0.015	0.041	0.121
P6 Grain w/o Manure	-	0.015	0.041	0.121



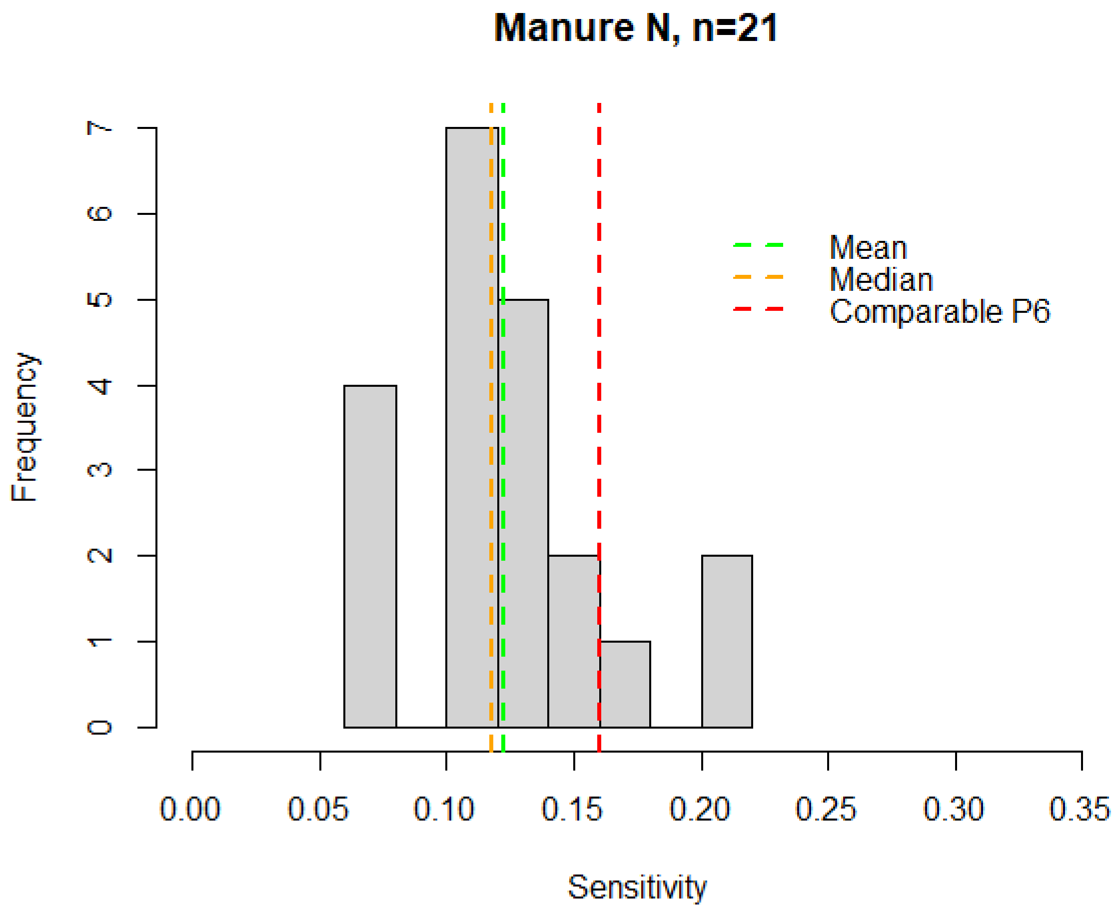
Manure N literature values

- 21 CAST comparable values from the literature
- Variation across studies in how inputs from prior year or period manure N is accounted for
- Fairly clear mode in values



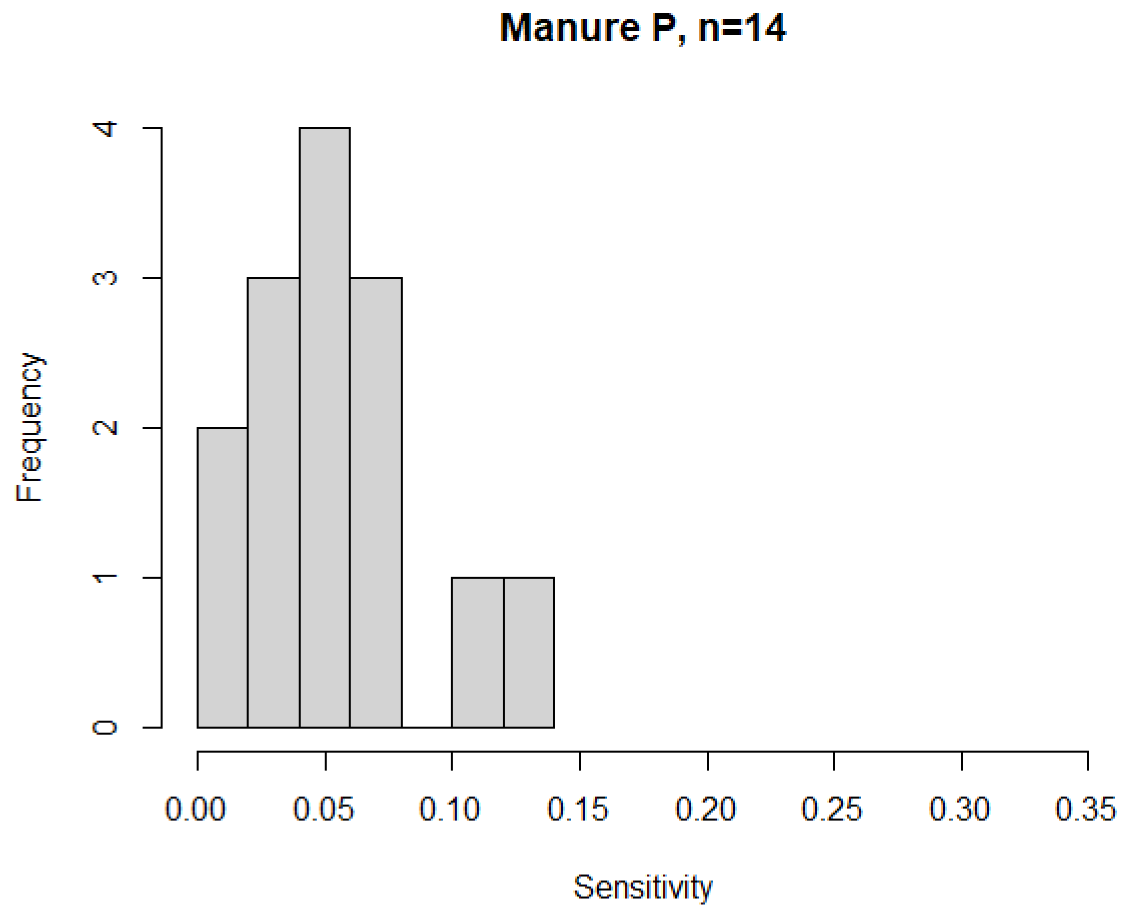
Manure N literature values

Value	TN
Literature Mean	0.122
Literature Median	0.118
P6 Grain w/ Manure	0.16
P6 Specialty Crop High	0.16



Manure P literature values

- 14 CAST comparable values from the literature
- Fairly clear mode in values



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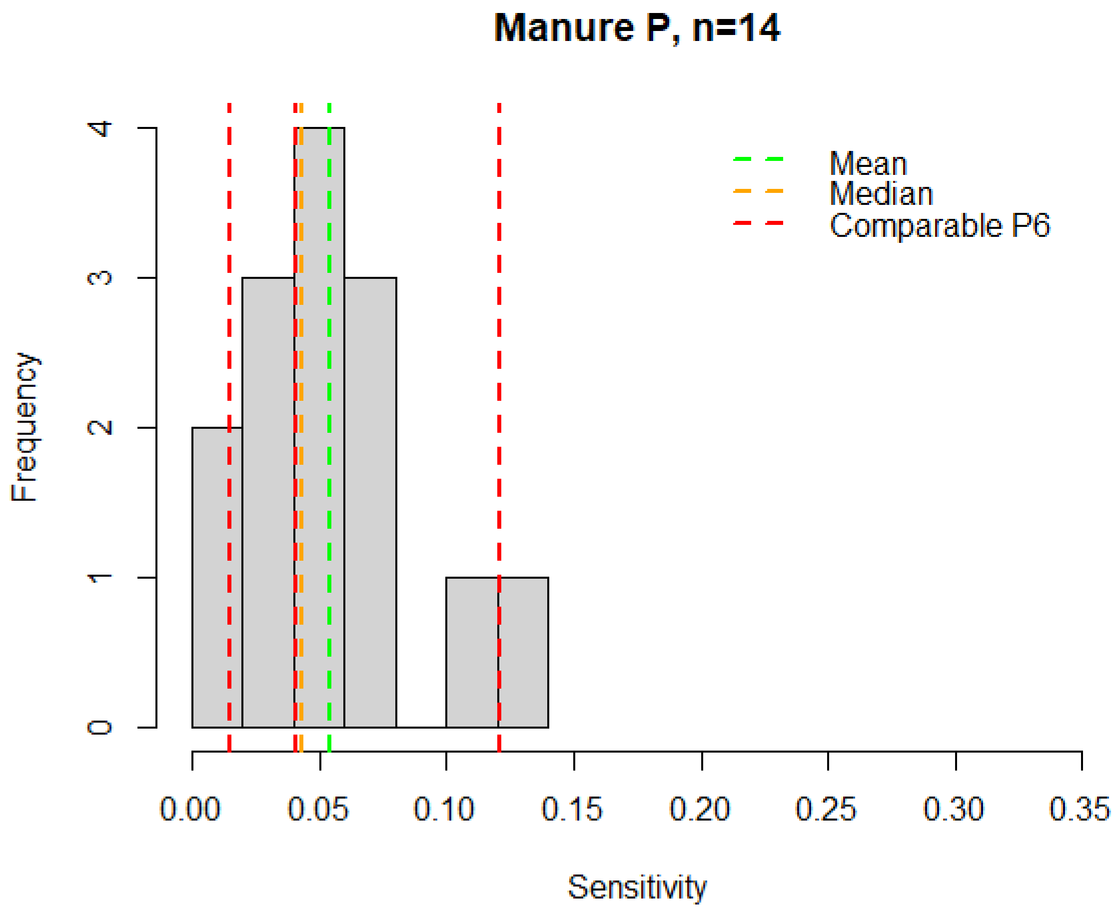
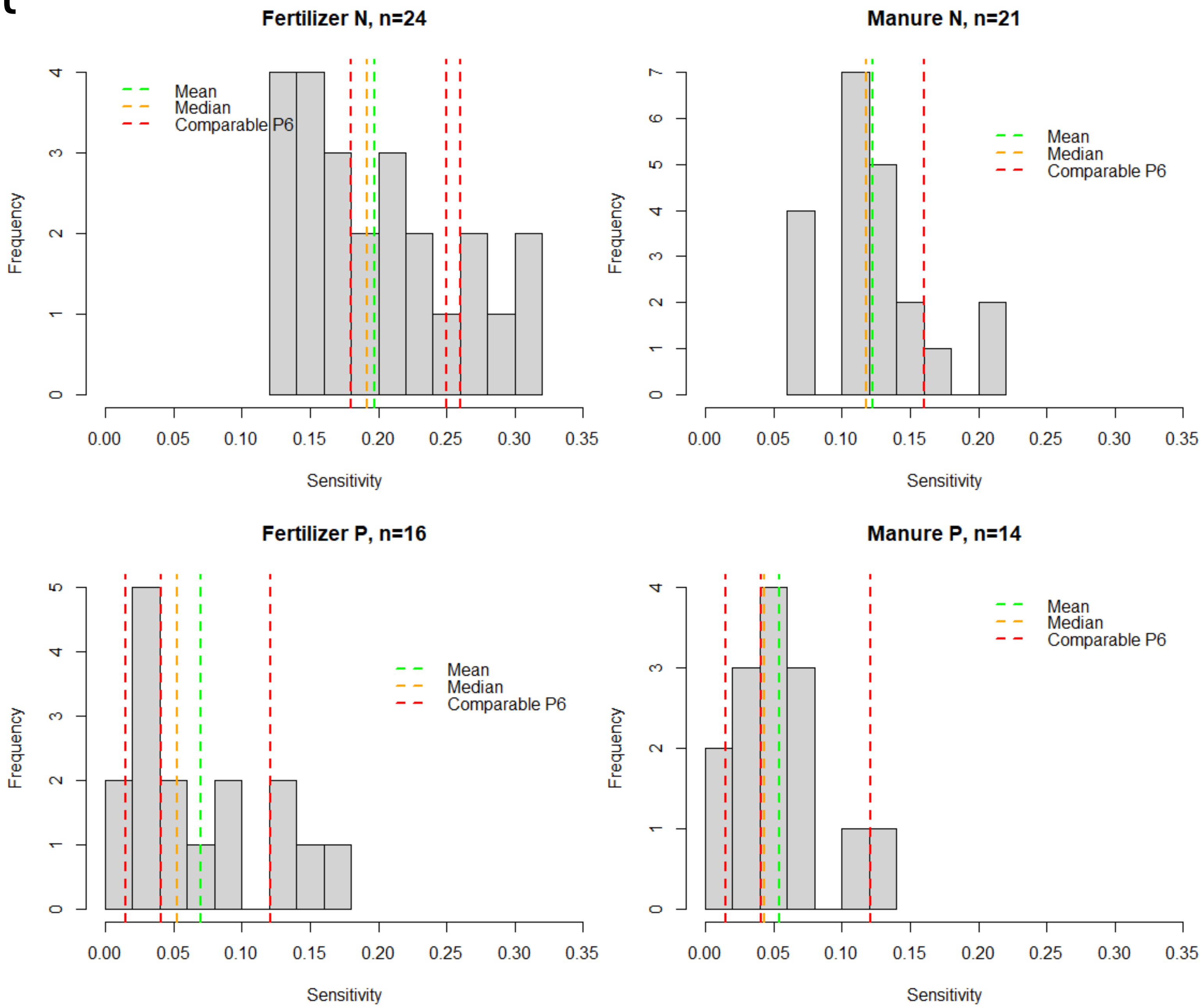


Findings on agricultural sensitivities

- There can be a large range in values in the literature, even after review and vetting of methods and models.
- Literature value distribution will be used as priors to CalCAST for nitrogen.

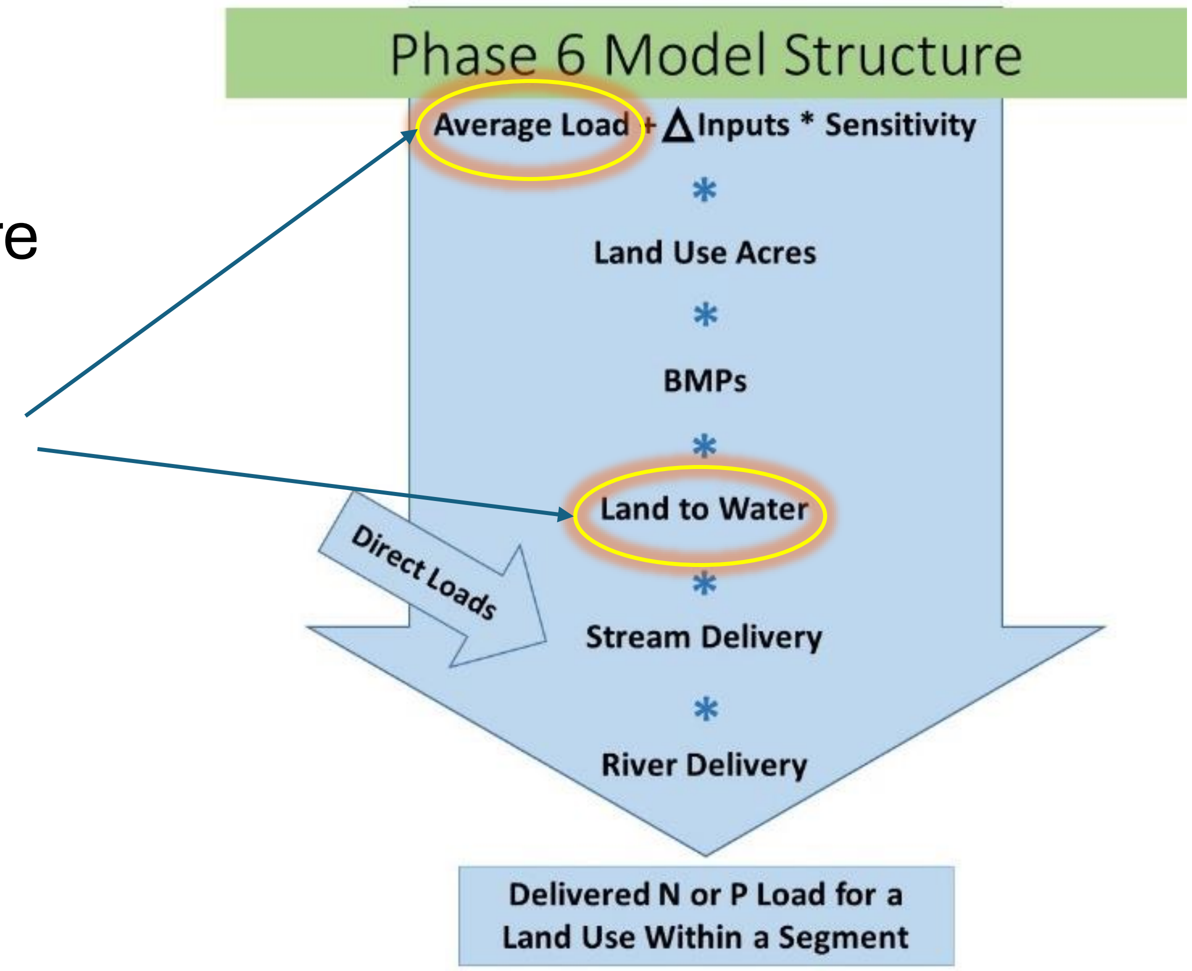
Moving forward…

- Further discussion is needed regarding P which is currently derived from Annual P Loss Estimator (APLE) and accounts for soil and sediment partitioning and accumulation.
- Should literature values be weighted based on model performance or size of datasets?



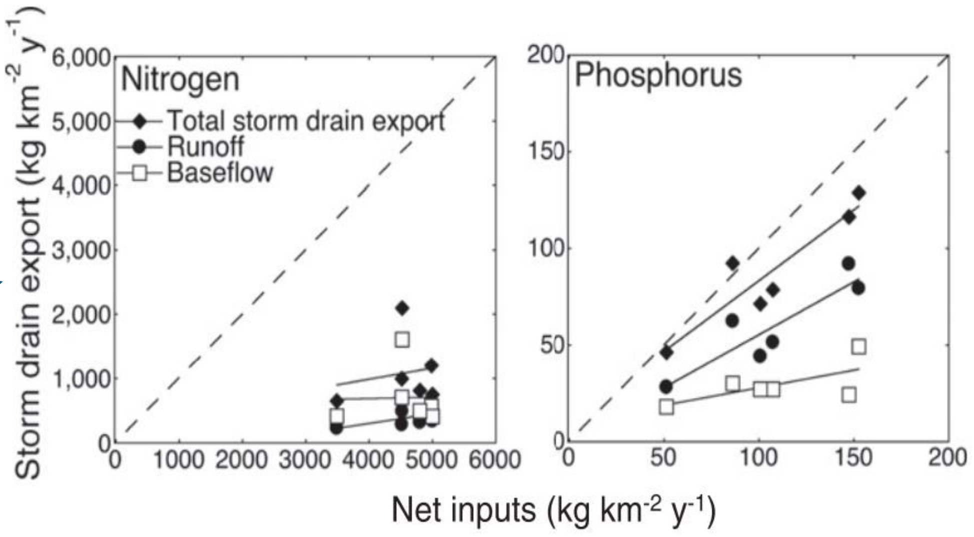
Urban literature rarely assesses export sensitivity to input

- Inputs are often not well known
- In urban environments, inputs are often highly uncertain, and the literature focuses on land-use loading and delivery factors.



Urban literature rarely assesses export sensitivity to input

- Inputs are often not well known
- In urban environments, inputs are often highly uncertain, and the literature focuses on land-use loading and delivery factors.
- There are exceptions…
- In this next quarter I will be discussing this issue with the Urban Nutrient Management Pannel and other experts.



Hobbie et. al., 2017

Ongoing work on additional sensitivities

Not prepared to provide an update today, but I will be working evaluate additional sensitivities this quarter.

- Uptake
- Forested Atmospheric Deposition

Update on Phosphorus Loading Processes

Last time on Modeling Quarterlies…

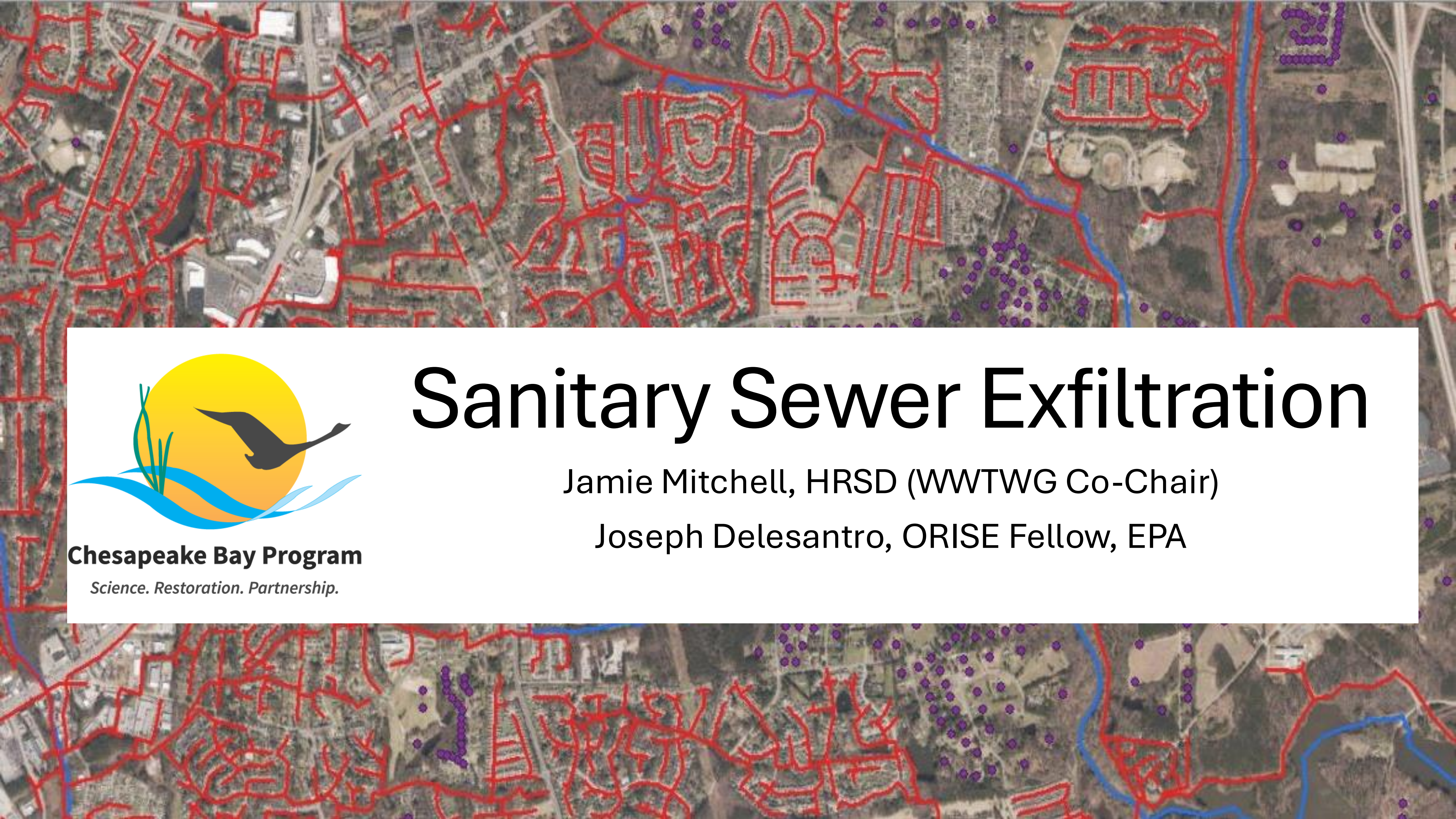
Major unaccounted for controls on P loading:

- Hydrologic connectivity of landscapes and sources (Land-to-water factors)(work of Michelle Katoski)
  - Inverse Euclidean distance to NHD Medium Resolution Flowline (mean, median, mode, std)
  - Inverse flow distance to Medium Resolution Flowline (mean, median, mode, std)
  - TWI (mean, median, mode, std)
  - SedIC to Medium Resolution Flowline (mean, median, mode, std)
  - Summaries repeated within mask extents of Phase 6 LULC classes
  - Road length and density for Census TIGER/Line 2023 Roads

- Biogeochemical controls on P mobility (Stream/River Delivery)
  - Alkaline desorption
  - Saltwater intrusion
  - Road salting
  - Increasing temperature
  - Increasing residence time
  - Anoxic conditions

The GIS team is currently working to finalize hydrologic connectivity metrics.

I am working to assess datasets for stream and river pH and conductivity.



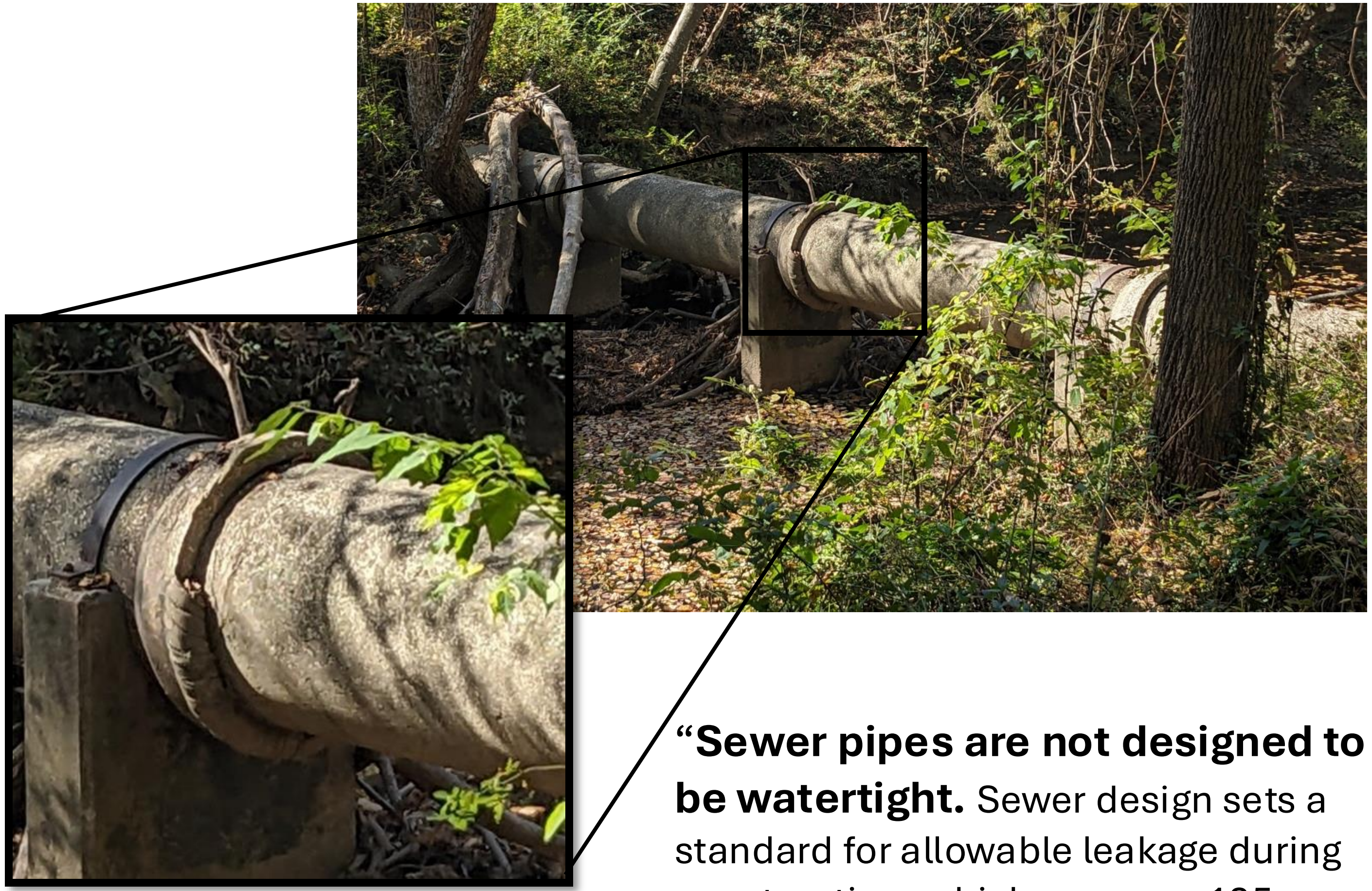
Chesapeake Bay Program

Science. Restoration. Partnership.

Sanitary Sewer Exfiltration

Jamie Mitchell, HRSD (WWTWG Co-Chair)

Joseph Delesantro, ORISE Fellow, EPA



"**Sewer pipes are not designed to be watertight.** Sewer design sets a standard for allowable leakage during construction, which averages 125 gallons per 400 feet of pipe, which is the standard distance between sewer manholes (ASTM, 2009), or about 1,650 gallons per mile of standard sewer pipe."

Chesapeake Bay Program, (2014). "Final Expert Panel Report on Removal Rates for the Elimination of Discovered Nutrient Discharges from Grey Infrastructure"

Why does this matter for the model?

- Proper appropriation of loads
- Improved targeting and crediting of management actions
- Scenario analysis (E.g., remediation, pipe ageing, etc.)

This load is in the bay, the load is in the model, but it is currently misappropriated.

The majority of misappropriation is likely to other urban load sources such as stormwater and lawn fertilizers.

Potential impacts of SS Exfiltration in the CBW

Conservative estimated contribution to the CBW from literature:

- 665,392 – 2,217,974 lb N/year
- 0.23 - 0.76% of the total N load to the CB
- 1.51 - 6.04% of the WW load to the CB
- 3.28 - 10.93% of the urban load to the CB
- 0.60% – 48.9% of the load from individual urbanized catchments to CBW**
- 13 - 47.5% of the measured load from individual urbanized residential catchments in the NC Piedmont*

Note: Values derived from the mean of studies or study regions (Delesantro et al., 2022; Nguyen and Venohr, 2021)

Assuming 30mg/l N in raw WW

Delesantro et al., 2022: Assuming NO_3^- proportion from WW ~ TN proportion from WW

*Assuming stormflow WW exfiltration loading from mean of Delesantro et al., (in review) urban catchments and baseflow WW exfiltration from Delesantro et al., 2022

** using full range in exfiltration values reported from Nguyen and Venohr, 2021

Comparing across studies

Good agreement despite very different methods, regions, and scales.

Study	Exfiltration Vol.	Exfiltrated N	% treated volume
Nguyen and Venohr, 2021	228 gal/day/km	20.8 lb N/year/km	2%
Delesantro et al., 2022	365 gal/day/km	33.2 lb N/year/km	2.40%
Steele et al., in review	630 gal/day/km	56.6 lb N/year/km	0.60%
Lerner and Halliday, 1994	246 gal/day/km	22.5 lb N/year/km	
Amik et al., 2000			11.40%
Ellis et al., 2003			5-10%
Wakida and Lerner, 2005			13%
Fenz, 2003			1-5%
Rieckermann et al., 2005			11%
Karpf and Krebs, 2004			2.80%

Notes:

- Values are the mean for each study or study region
- N load may be estimated assuming 30mg/l N in raw WW
- Delesantro et al., 2022: Assuming NO_3^- proportion from WW ~ TN proportion from WW
- Studies estimate exfiltration from pipe, to GW, or to streams
- Studies may estimate treated volume based on total flow or DWF

This suggests that generalizing sanitary sewer exfiltration loads is reasonable.

WWTWG Considerations

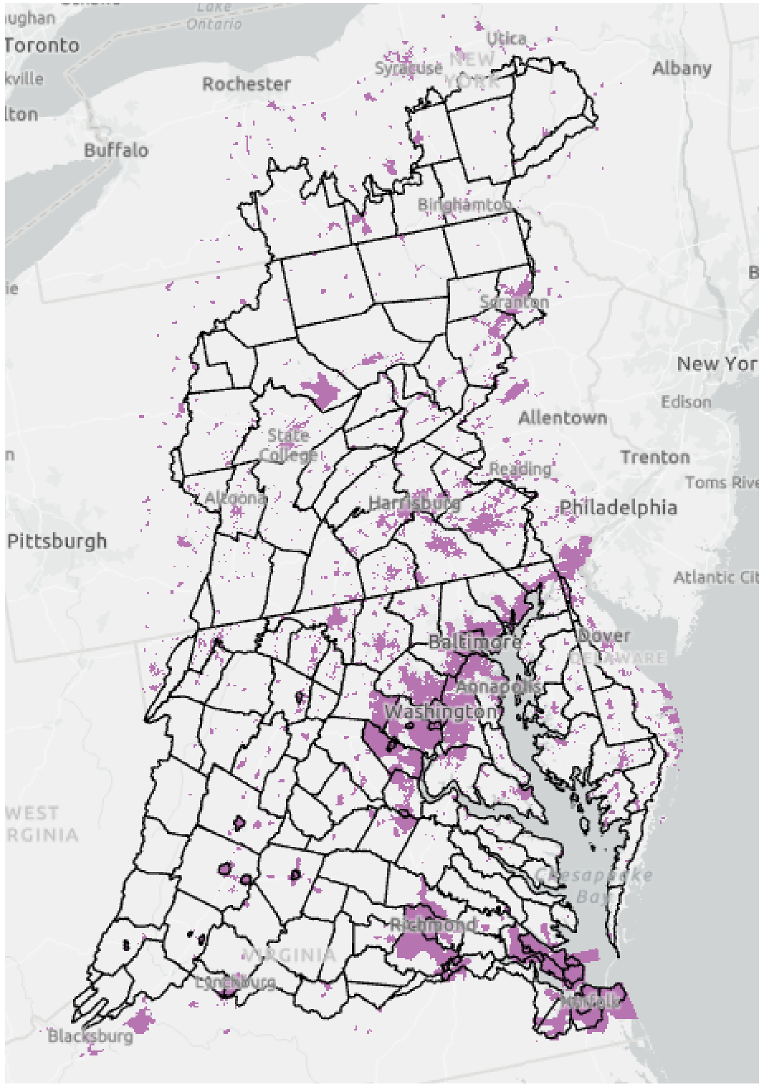
- Acknowledge interest in more accurately attributing the sources of the load.
- Default values risk overestimating loads due to differences in collection systems, surrounding geology, and on-going rehabilitation efforts.
- It’s important that we not overestimate the exfiltration load.

Potential modeling of sanitary sewer exfiltration

- Several options for modeling sanitary sewer exfiltration have been discussed.

Link to previous meeting materials: Wastewater Treatment Workgroup

- A sub workgroup is testing and evaluating a preliminary model structure applied at a limited scale.



CBW WWTP Service Boundaries

Preliminary model structure

- A default exfiltration value as a percent of treated volume will be defined by expert judgement and literature
- Spatially exfiltration will be mediated by optional factors identified as drivers of exfiltration by expert judgement and literature.
  - Geologic basin as a metric of water table depth
  - The proportion of the system which is gravity fed
  - The proportion of the system which is new or recently rehabilitated

Exfiltration Vol. = Fraction exfiltration * Annual system treatment volume * Geologic coef. * Fraction gravity line * 1/fraction new or rehabbed

Exfiltrated nutrient mass = Exfiltration Vol. * concentration in raw WW[1]

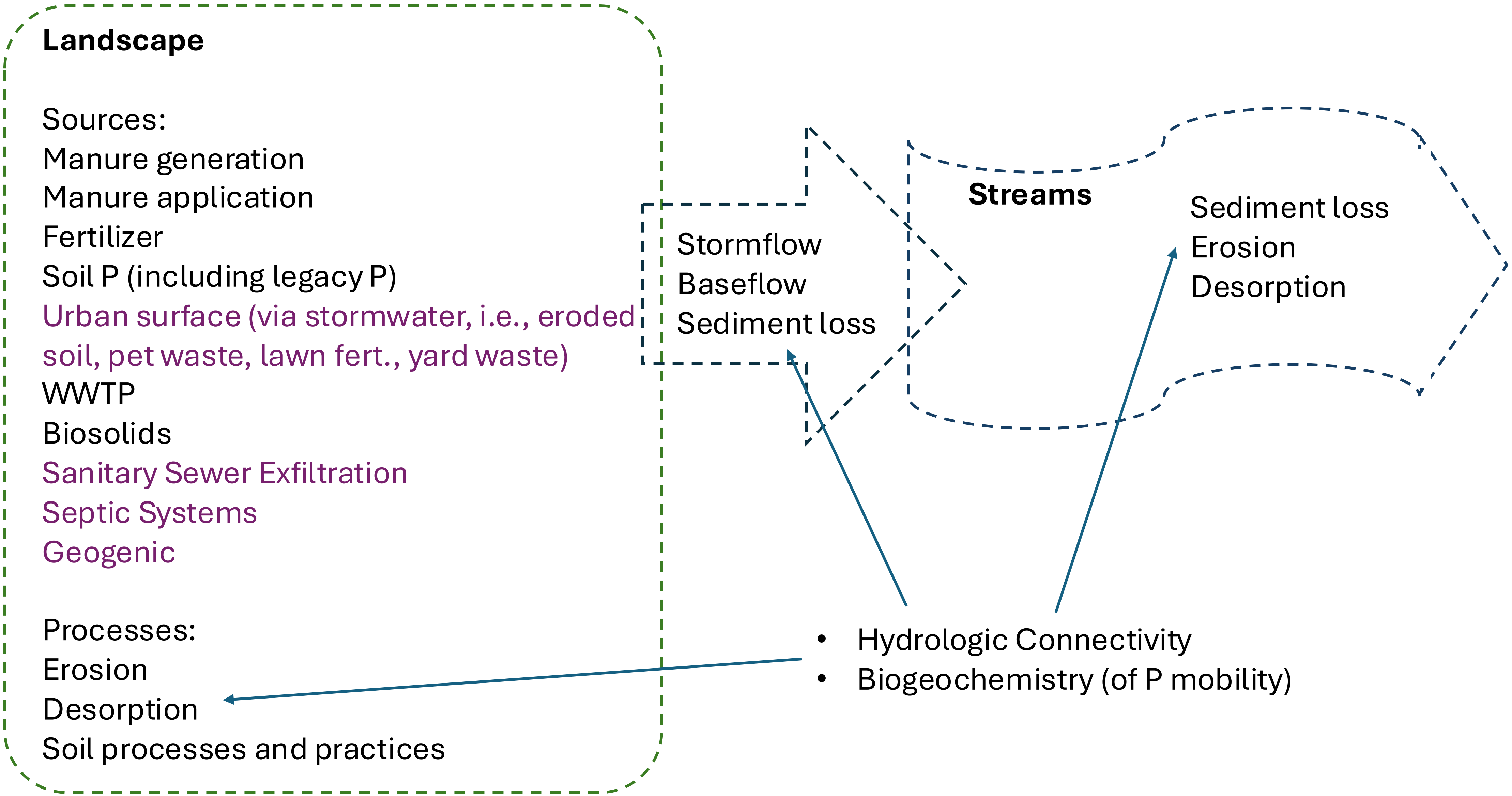
Workgroup Defined, Required State Provided Input, Optional State Provided Input

[1]Chesapeake Bay Program, (2014). "Final Expert Panel Report on Removal Rates for the Elimination of Discovered Nutrient Discharges from Grey Infrastructure"

Schedule

November	December	January	February	March	April
Testing of preliminary model		Evaluate preliminary results	Refine model	Work group model recommendation	Seek feedback or approval from the WQGIT

Discussion



Purple sources are not explicitly accounted for in P6 but are captured to some extent in LU.

Alkaline desorption

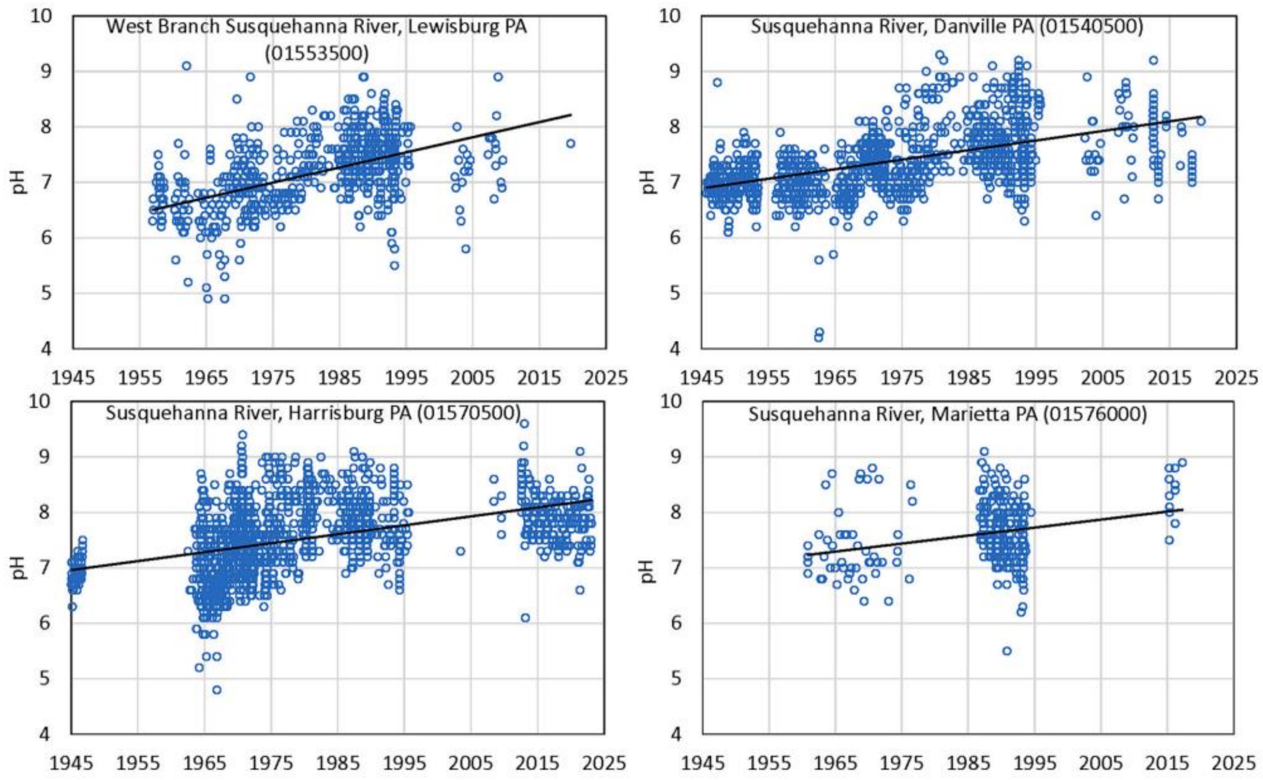


Fig. 5. Time-series showing pH of discrete samples for historical and current conditions on the West Branch Susquehanna River at Lewisburg (USGS station no. 01553500) and the Susquehanna River at Danville (USGS station no. 01540500), which merge downstream to form the lower Susquehanna River, represented by the Susquehanna River at Harrisburg (USGS station no. 01570500) and Marietta (USGS station no. 01576000). A positive trend in pH, with current baseline pH ~8, is indicated for all these stations. For any given year, pH variability by ~3 units reflects variations in flow conditions. Data retrieved from the U.S. Geological Survey (2023a) National Water Information System database; station locations are shown in Fig. 1.

Alkaline desorption and transport of phosphorus from legacy sediments is a potential source of P, but quantifying the export requires addition work.

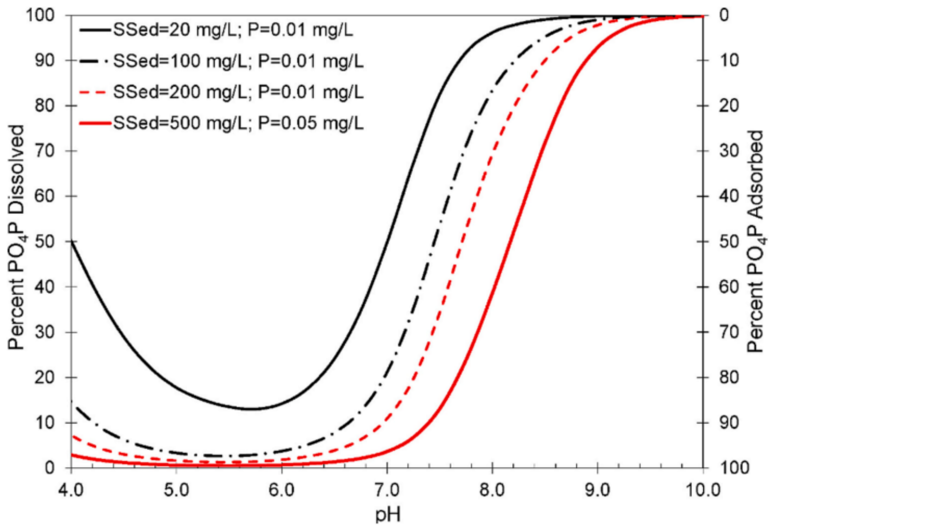


Fig. 4. Equilibrium fractions of initial concentration of phosphate (0.01 or 0.05 mg/L as P) that may be dissolved or adsorbed by suspended sediment (Ssed) composed of 6.7 % Fe (HFO; with a specific surface area (Asp) of 600 m^2/g), 0.5 % Mn (HMO; with Asp of 746 m^2/g), and 2.8 % Al (HAO; with Asp of 68 m^2/g). Upper three curves consider PO_4 = 0.01 mg/L as P and vary sorbent concentration from 20 to 200 mg/L, whereas lower curve considers PO_4 = 0.05 mg/L as P and sorbent concentration of 500 mg/L. Additional details and model results are shown in Figs. S1 and S2.

Legacy sediment as a potential source of orthophosphate: Preliminary conceptual and geochemical models for the Susquehanna River, Chesapeake Bay watershed, USA

Charles A. Cravotta III[a,*], Travis L. Tasker[b], Peter M. Smyntek[c], Joel D. Blomquist[d], John W. Clune[e], Qian Zhang[f], Noah M. Schmadel[g], Natalie K. Schmer[h]

Saltwater intrusion and road salting

- Ions in saltwater and road salting displace bound phosphate and increase P in solution.

Examples of recent literature:

Lucas, E., Kennedy, B., Roswall, T. et al. Climate Change Effects on Phosphorus Loss from Agricultural Land to Water: A Review. Curr Pollution Rep 9, 623–645 (2023). https://doi.org/10.1007/s40726-023-00282-7

Weissman, D. S., & Tully, K. L. (2020). Saltwater intrusion affects nutrient concentrations in soil porewater and surface waters of coastal habitats. Ecosphere, 11(2), e03041.

Foley, E., & Steinman, A. D. (2023). Urban lake water quality responses to elevated road salt concentrations. Science of the Total Environment, 905, 167139.

Increasing temperatures, residence times, and anoxic conditions

- Higher temperatures with climate change may increase instream mobilization of P but may also increase watershed uptake.
- Land use change and climate change generally increase hydrologic flashiness, resulting in higher high flows and lower low flows.
- Decreasing flows during inter-storm periods may increase the desorption of P which then flushes during storm events.

Examples of recent literature:

Duan, S., Kaushal, S. S., Groffman, P. M., Band, L. E., & Belt, K. T. (2012). Phosphorus export across an urban to rural gradient in the Chesapeake Bay watershed. Journal of Geophysical Research: Biogeosciences, 117(G1).

Anderson, H. S., Johengen, T. H., Miller, R., & Godwin, C. M. (2021). Accelerated sediment phosphorus release in Lake Erie's central basin during seasonal anoxia. Limnology and Oceanography, 66(9), 3582-3595.

Phosphorus processes in summary

- Hydrologic connectivity likely has a large effect on P export as demonstrated extensively in the literature.
  - We are pursuing representation in P7.

- Biogeochemical processes may have increased importance on P export with climate change, but the magnitude of the effect is largely unknown.
  - We can test drivers of these processes as potential delivery factors.
  - Results will be highly sensitive to how well soil, sediment, and legacy P are accounted for.