Reviewing and Updating Loading Sensitivity to Inputs and Phosphorous Loading Processes

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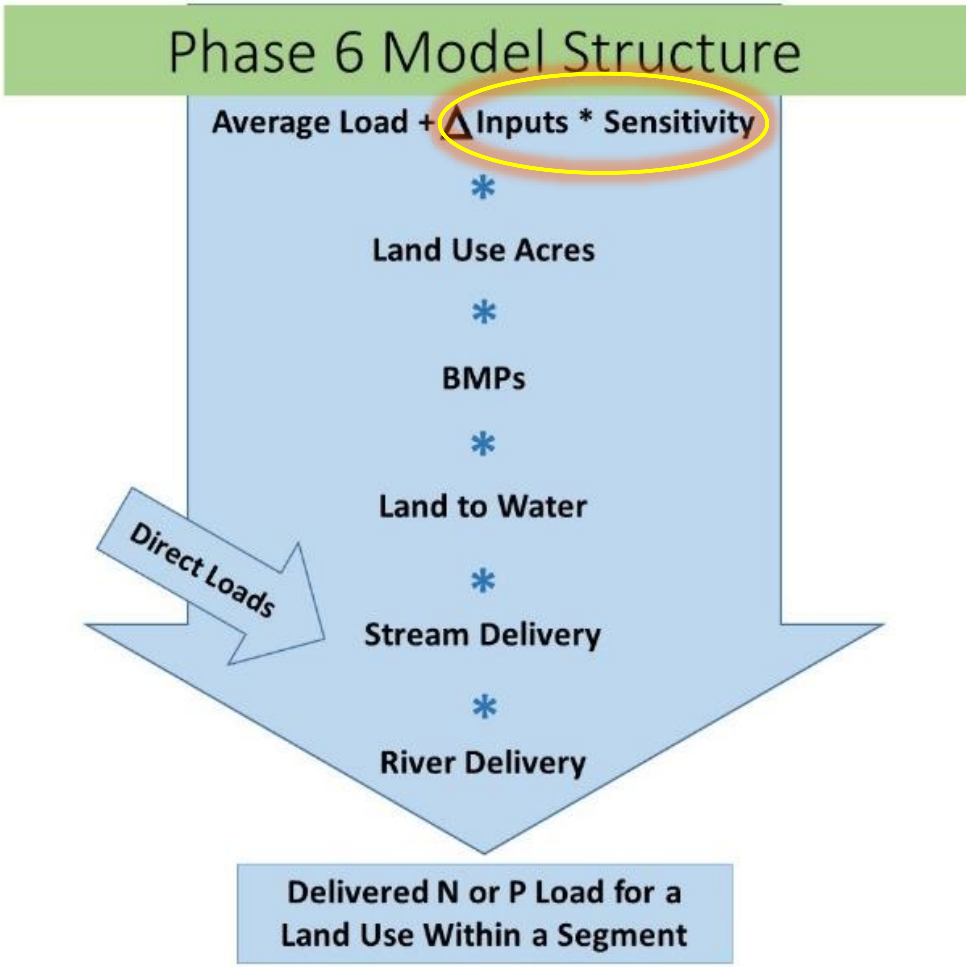
Reviewing and Updating Loading Sensitivity to Inputs

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:

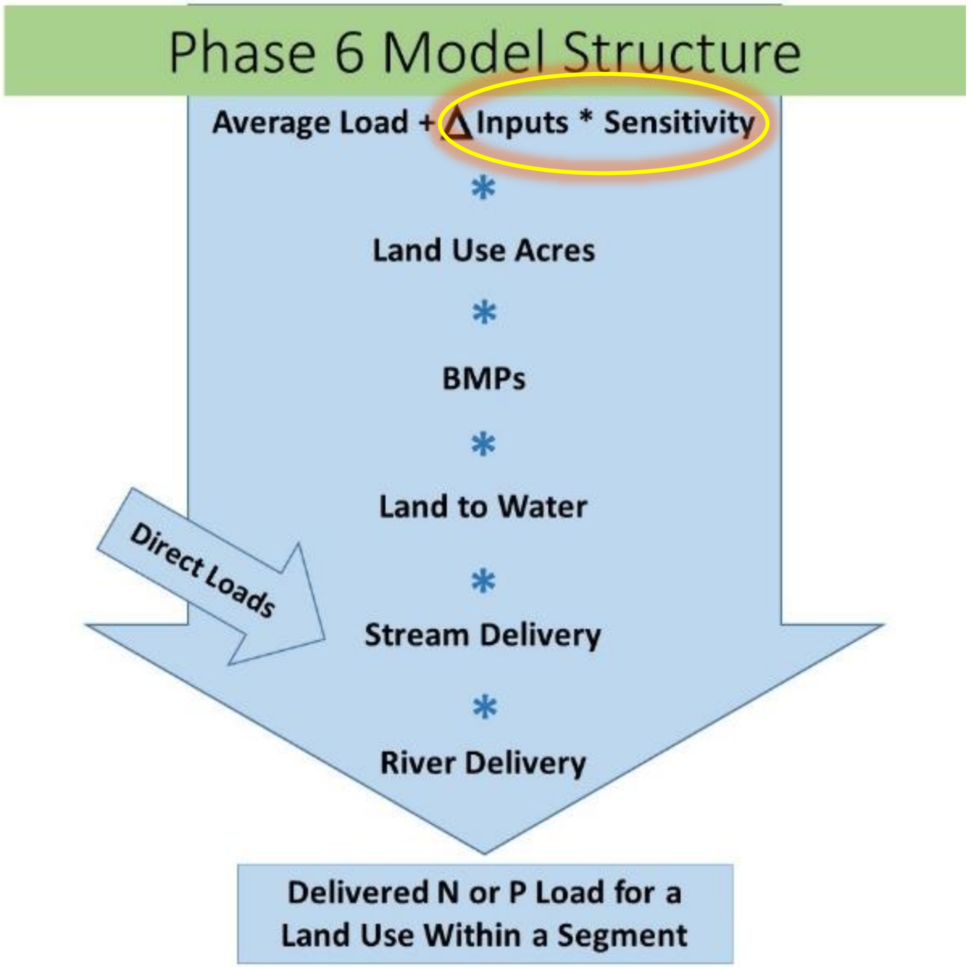
- When added to the land use average load we identify the load, by source (land use and input), which is available for export (edge of field or stream load).
- Sensitivities account for the spatial and temporal variation in the load available for export.
    - If there is no sensitivity, then the load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



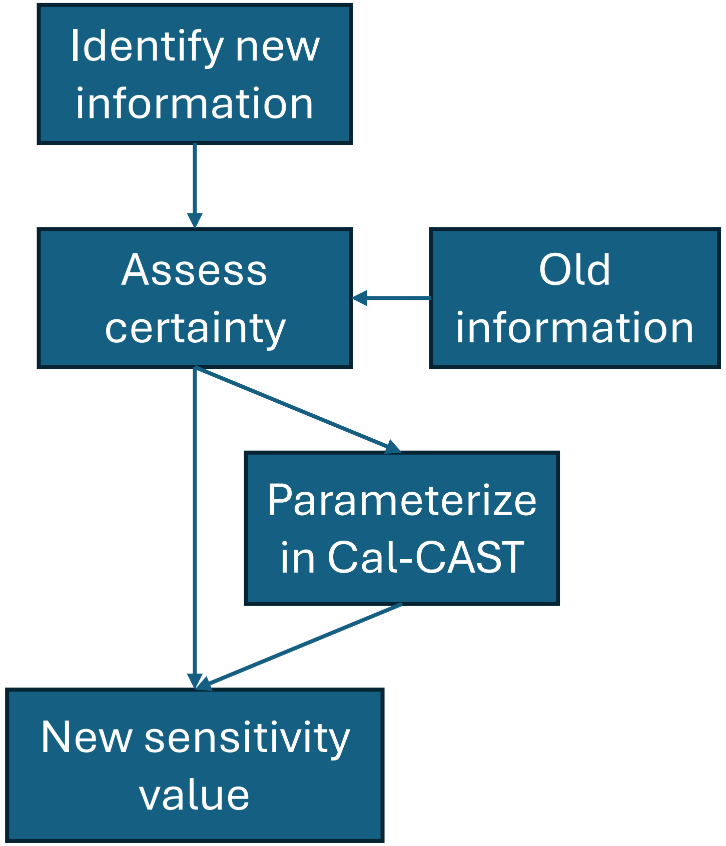
CAST Load Sensitivity to Inputs

We are reviewing these values for Phase 7

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



Addressing sensitivities



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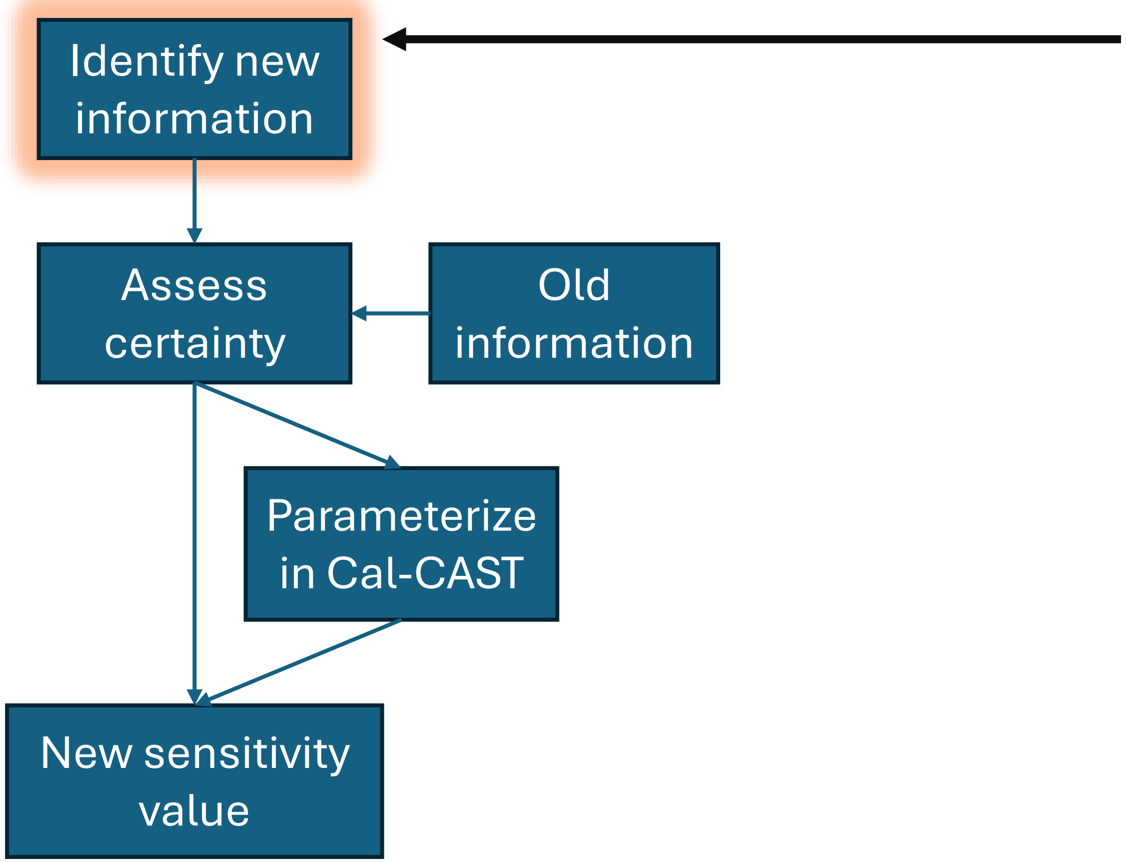
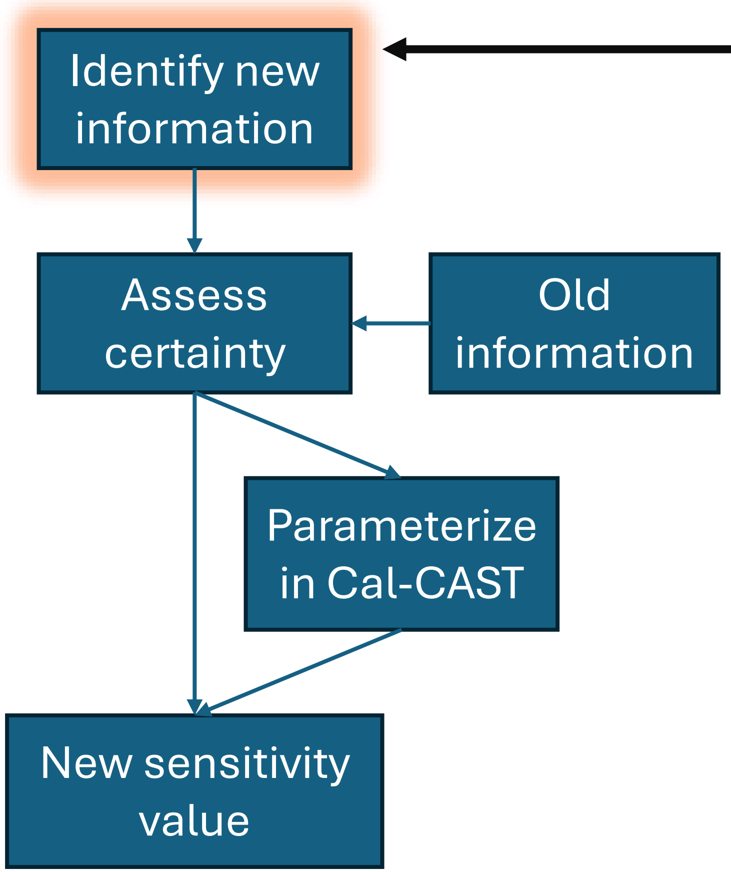


Identify new information

- Data, literature, or expert judgement demonstrating that there is spatial or temporal variation in the edge of stream load from a given source
- Data, literature, or expert judgement identifying the input(s) responsible for said variation
- Chesapeake Bay watershed wide data on the spatial and/or temporal variation in the input
- The edge-of-stream loading sensitivity to the input

Addressing sensitivities



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Identifying new information

- 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
- Empirical analysis
  - Via Cal-CAST or other statistical analysis of existing data

Prioritizing assessment and update of sensitivities

Identifying priorities

- P6 model review
- STAC workshops
- Modeling Workgroup guidance
- Other technical workgroups
- Model assessment

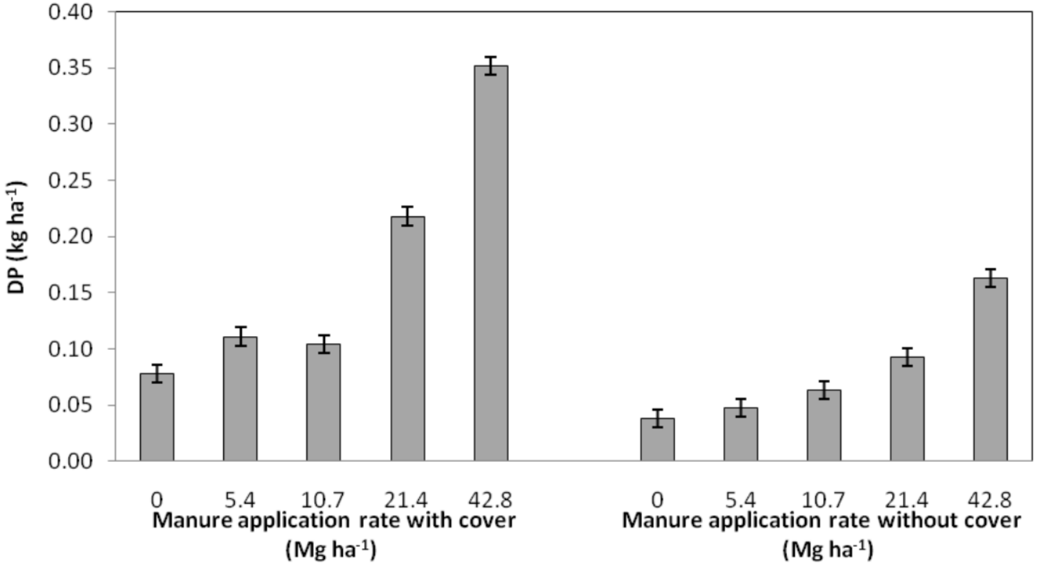
Identified priorities

- Greater use of field data and literature validation
- Agricultural and urban P
- Manure and fertilizer
- Urban N
- Effect of phenology changes due to climate change

Agricultural Sensitivities

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
- Many factors prevent direct interpretation and comparison of some values from the literature.
  - Results are impacted by variation in land-use, hydrology, tillage, history, soil N+P, etc., etc.…
  - Many studies report loss ratios rather than sensitivities
  - The delta of input may not be representative of CBW conditions
  - Input units may be reported in raw fertilizer or manure rather than N species
  - Results are not speciated
  - Inputs are more variable at smaller scales
- HOWEVER, these values can still be used to approximate CAST sensitivities.
  - Preliminary values need vetting!



Gilley et al., 2012

Manure literature values, preliminary

Where methods are comparable there is decent agreement across models and field studies.

Nitrogen (TN, NO3, Org N)

- Range: 0.014-0.28
  - Note: Not a true range because models and meta-analyses often report a CI.
- Median: 0.094
- Mean: 0.099
- The range encompasses P6 sensitivities.
- The range of P6 ensemble model sensitivities was greater than in the literature.
- Median literature sensitives exceeds P6 median (0.04).

Phosphorus (MinP, WEP, SRP)

- Range: 0.009-0.08
  - Note: Not a true range because models and meta-analyses often report a CI.
- Median: 0.026
- Mean: 0.0332

Fertilizer literature values, preliminary

There is a large range in reported values with less agreement than for manure

Nitrogen (TN, NO3, NH3)

- Range: 0.03-0.39
  - Note: Not a true range because models and meta-analyses often report a CI.
- Median: 0.11
- Mean: 0.13
- Very close to current values, however the large range in values requires additional review and possibly calibration.

Phosphorus (MinP, SRP, WEP)

- Range: 0.011-0.12
  - Note: Not a true range because models and meta-analyses often report a CI.
- Median: 0.032
- Mean: 0.043

Manure and fertilizer comparison

- Manure and fertilizer sensitivity are likely more comparable than represented in P6.
  - In P6, fertilizer was 3-5 times more sensitive than manure.

Fertilizer N S:Manure N S

- Range: 0.8-4
  - Note: Only calculated from studies which evaluate both.
- Median: 1.2
- Mean: 1.4

Sensitivity across load sources

- Most of the literature reports values for cropland or generic “agricultural lands”, but there is reporting which may allow differentiation of hay and pasture from row crop. More work is needed.

Uptake

- There are various new (relative to P6) literature sources for evaluating crop uptake.
  - E.g., Hong et al., 2011, 2013; University of California Davis., 2016; USDA, 2010, 2011; Geisseler & Horwath, 2014, etc…
- There is literature supporting uptake variation over time for corn.
- New crop yield calculation methods will allow uptake calculations using yields from more crops than used in P6.
- I can’t compare today, because I messed up the units…

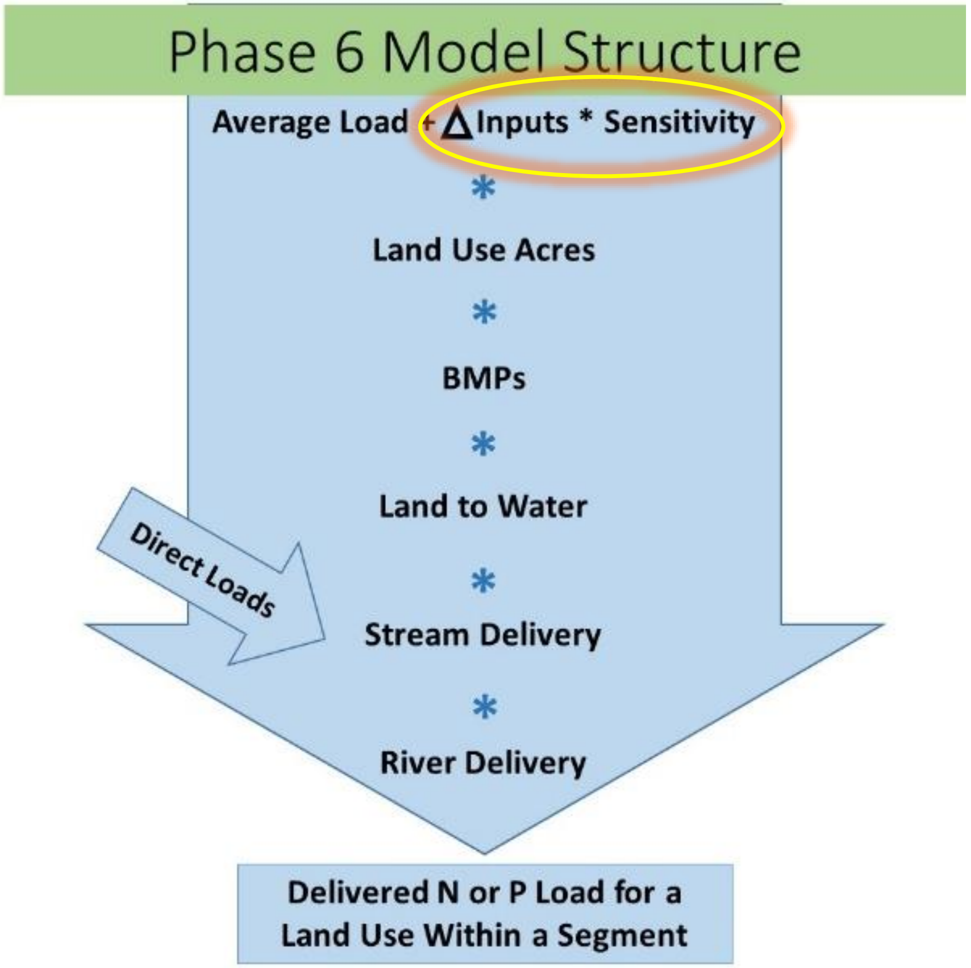
Preliminary findings on agricultural sensitivities

- There is substantial literature with which to review and update many agricultural sensitivities.
- Generally, the literature suggests values which are higher or comparable to P6, with less difference between fertilizer and manure.
- Additional review is needed particularly for uptake, and other sensitivities to stormflow, WEP, and fixation will also be reviewed.

Urban Sensitivities

Urban literature rarely assesses export sensitivity to input

- Because inputs are often not well known.
- In agricultural lands, fertilizer, manure, ad yields are highly managed and the sensitivity to these inputs and removal are well studied…
- In urban environments, inputs are often highly uncertain, and the literature focuses on land-use loading and delivery factors.
- There are exceptions…



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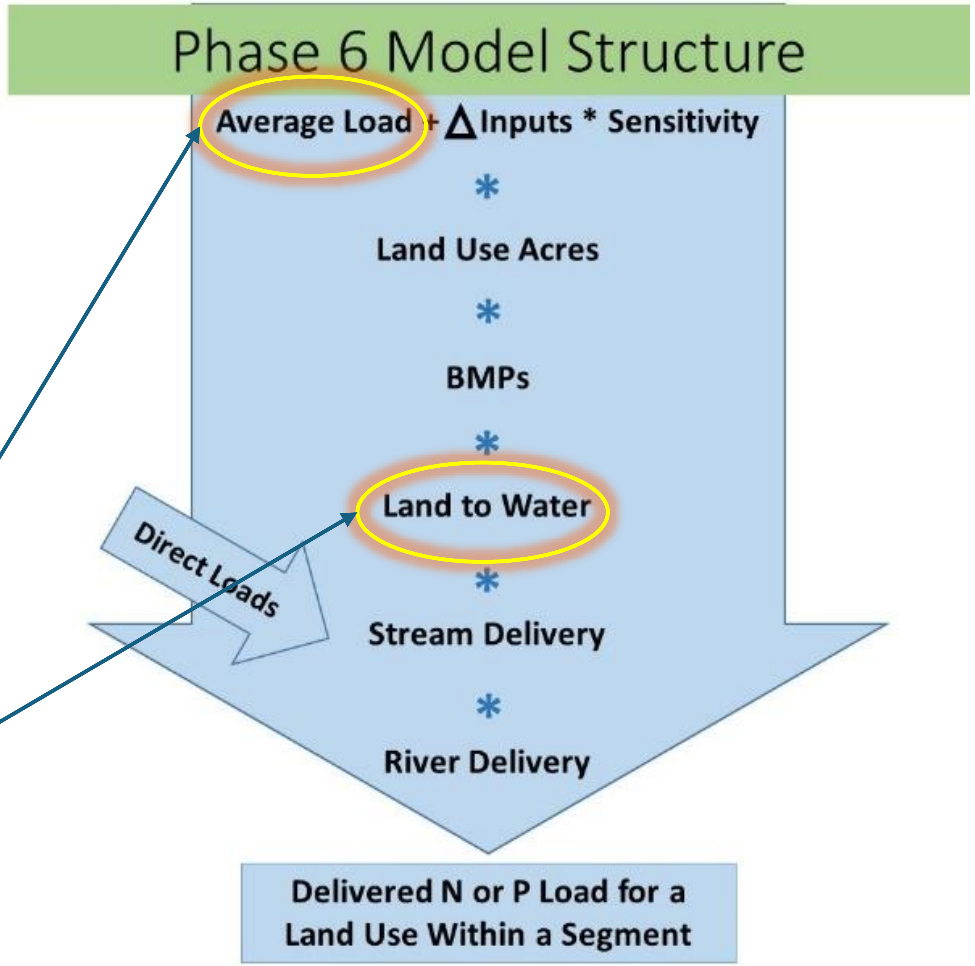
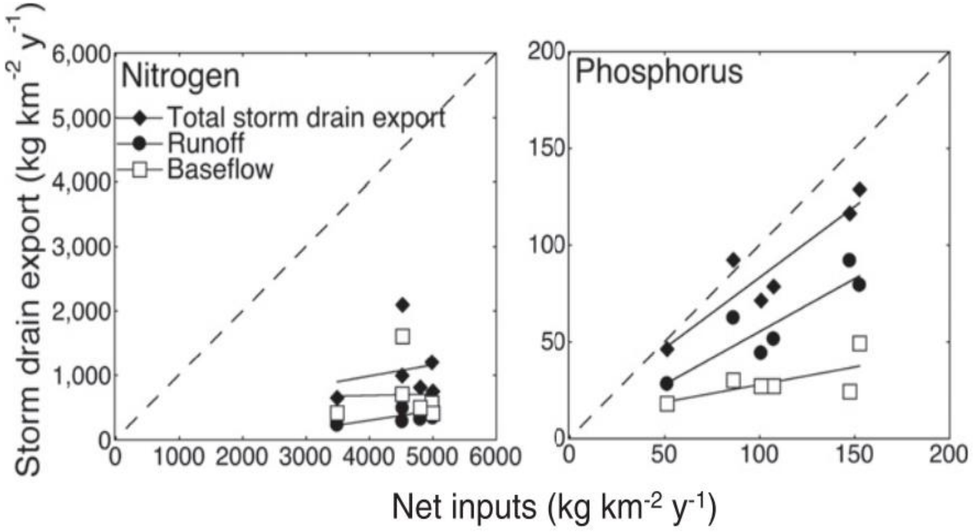


Urban studies of export sensitivity to input

- Baltimore LTER
    - Baltimore lawn lysimeter study
    - Raciti, Groffman, Belt work
    - Neely and Law Lawn Fertilizer work
- Mass balance projects
- Values range from 0.06 to 0.75 and are generally higher than represented in P6
- P sensitivity is generally greater than N. This is different from ag. sources, but is consistent with P6 values.

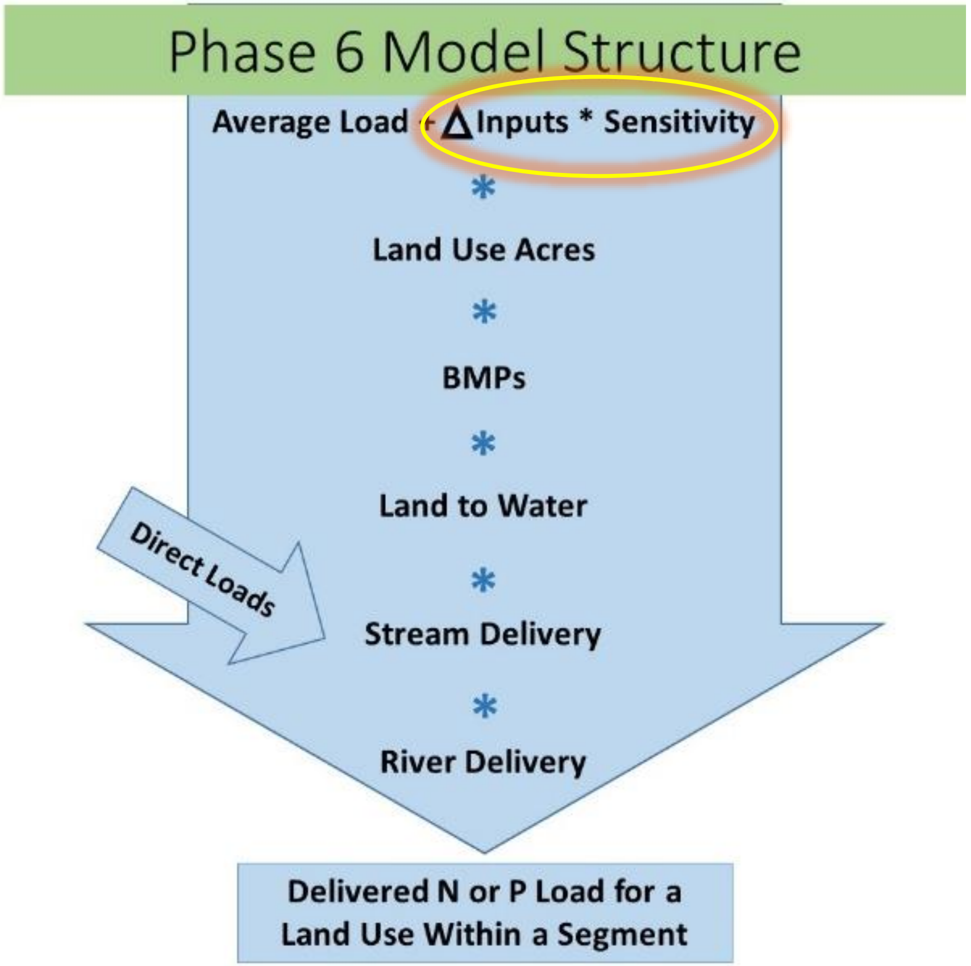


Hobbie et. al., 2017

Comparing the P6 approach to literature values

- Given the high uncertainty in urban inputs, P6 uses conservative sensitivity values.
  - With some exceptions like atm. dep. on impervious surfaces.
- Although the literature suggests true sensitivity values may often be higher, relevant studies are limited, and results are highly variable.

- I believe the P6 approach is sensible given the uncertainty in urban inputs.
- We will continue to look for additional information and test literature values, time permitting.

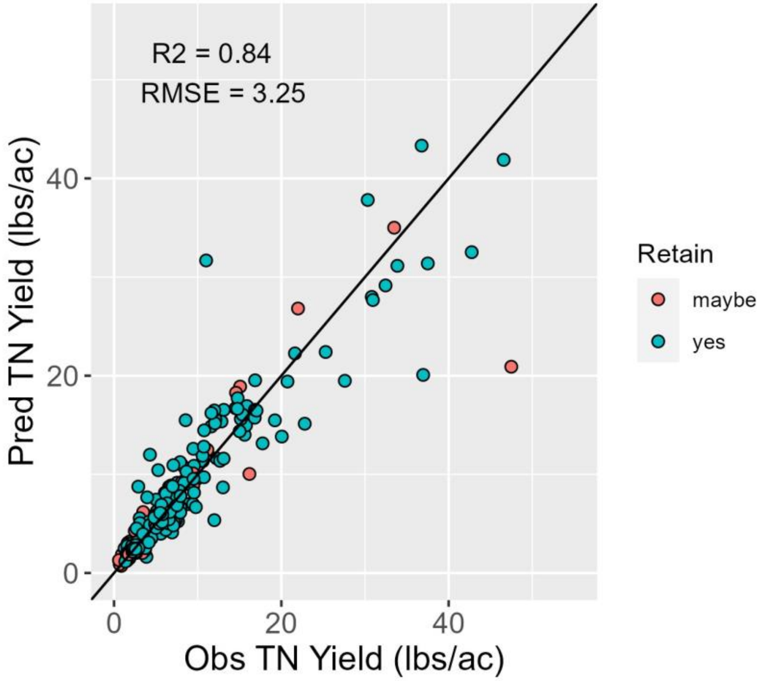


Phosphorus Loading Processes

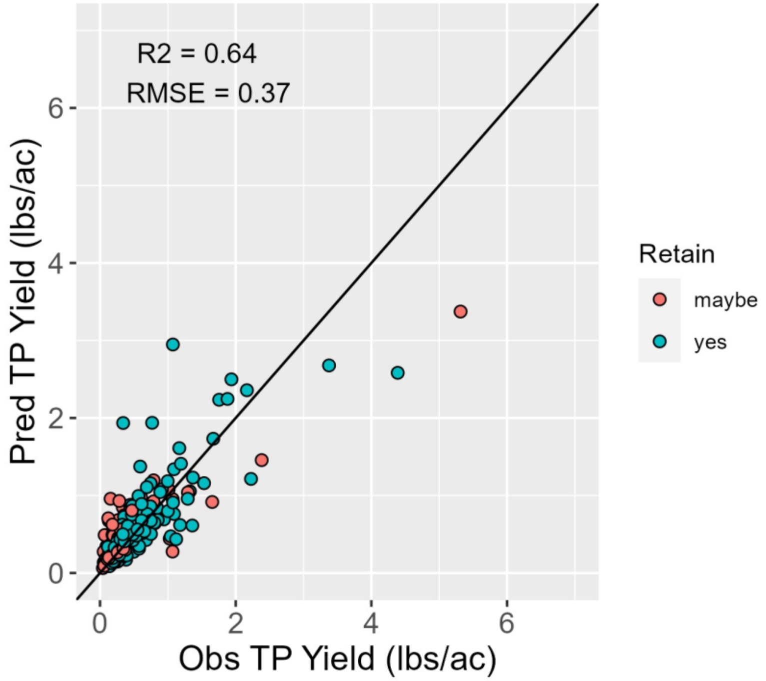
What additional processes may help improve P modeling?

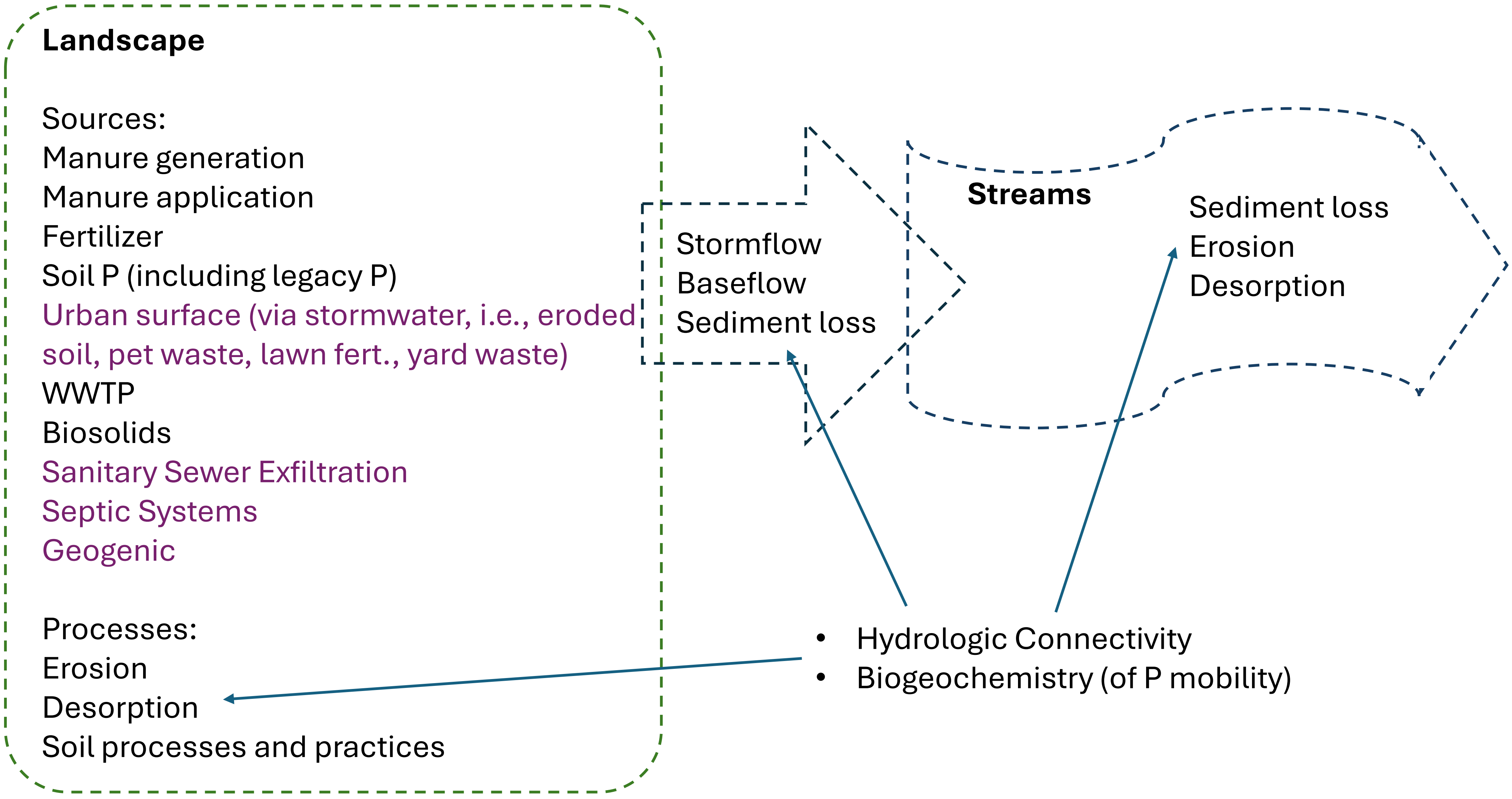
Working parallel to sensitivities, we will be evaluating all aspects of P modeling.

Nitrogen



Phosphorus



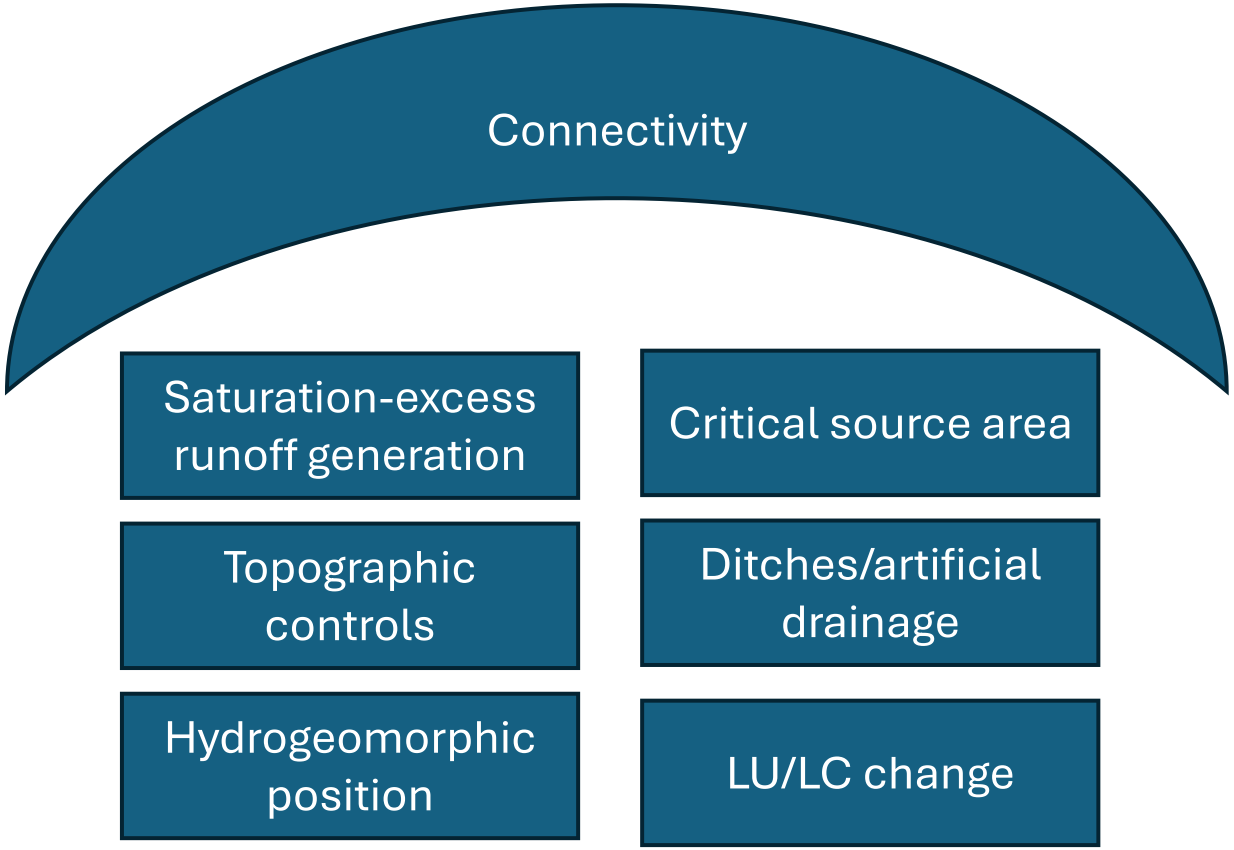


Purple sources are not explicitly accounted for in P6 but are captured to some extent in LU.

Connectivity: Landscape controls

Model review, STAC, and literature review identify several processes related by their influence on landscape connectivity of sources to streams.

We are working with the Geospatial team to better capture connectivity in model Land to Water factors.



Connectivity: Hydrologic controls

- P has greater sensitivity to stormflow and extreme events relative to N
- Climate change increases hydrologic connectivity by increasing stormflows and total runoff.
- Increased scouring flows transport legacy P in stream and stream valleys, particularly of agricultural or formerly ag. catchments.
- In urban environments the positive relationship between P export and impervious surface cover can be almost entirely be accounted for by increased stormflow (Duan et al., 2012; Carpenter et al., 2018).

Biogeochemical controls on P mobility

- Alkaline desorption
- Saltwater intrusion
- Road salting
- Increasing temperature
- Increasing residence time
- Anoxic conditions

These processes potentially control export from the landscape but are also drivers of instream internal loading.

Their effect on loading will then be very sensitive to instream sediment and legacy P.

While these processes are well documented, their potential impact on watershed scale P loading is not.

Alkaline desorption

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

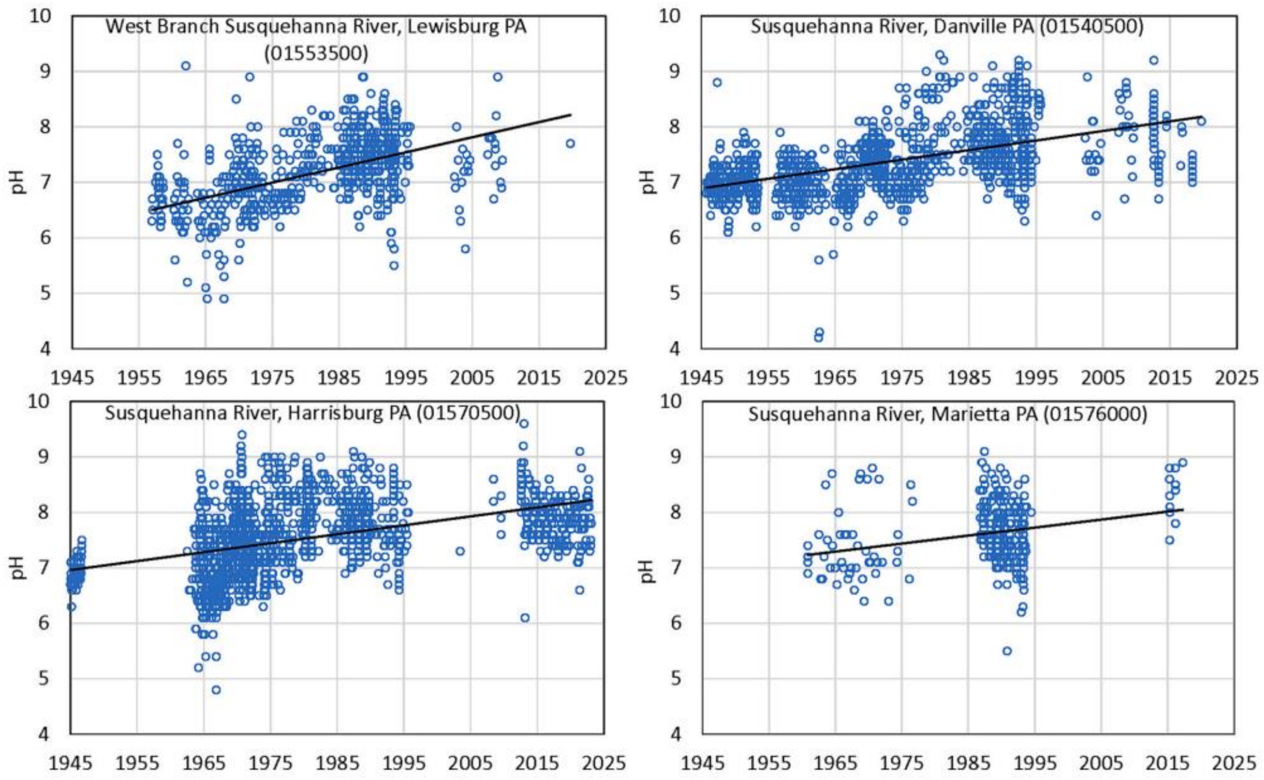


Fig. 5. Time-series showing pH of discrete samples for historical and current conditions on the West Branch Susquehanna River at Lewisburg (USGS station no. 01553500) and the Susquehanna River at Danville (USGS station no. 01540500), which merge downstream to form the lower Susquehanna River, represented 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.

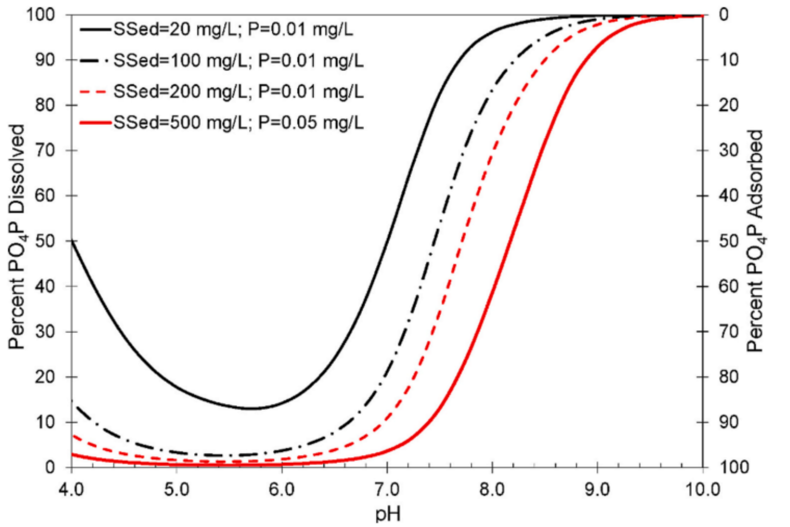


Fig. 4. Equilibrium fractions of initial concentration of phosphate (0.01 or 0.05 mg/L as P) that may be dissolved or adsorbed by suspended sediment (Ssed) composed of 6.7 % Fe (HFO; with a specific surface area (Asp) of 600 m^2/g), 0.5 % Mn (HMO; with Asp of 746 m^2/g), and 2.8 % Al (HAO; with Asp of 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.

Discussion