USWWG – Updates on sanitary sewer exfiltration and export sensitivity to inputs

8/18/2025

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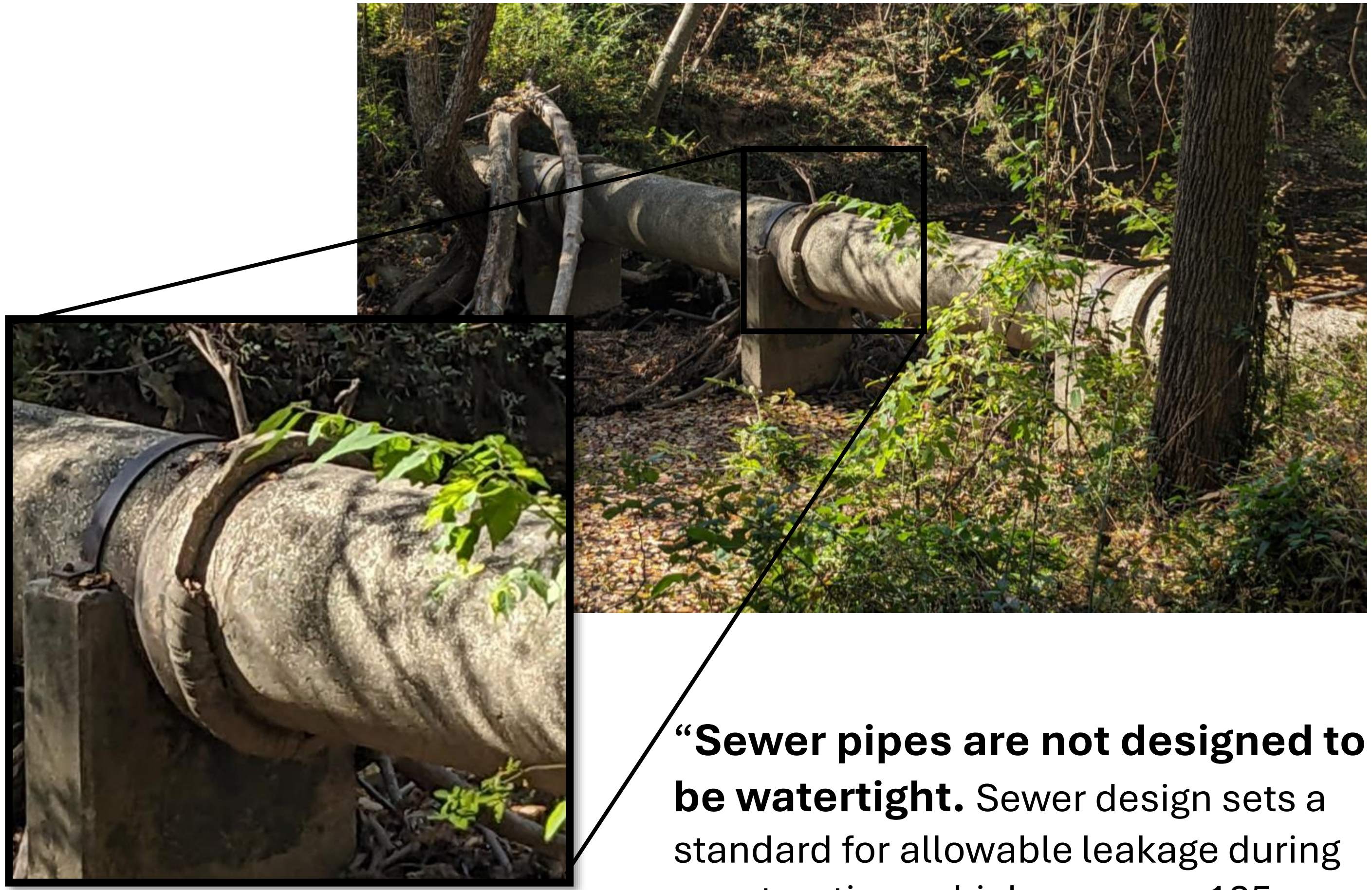
Estimating Sanitary Sewer Exfiltration



“**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”

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

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.

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.

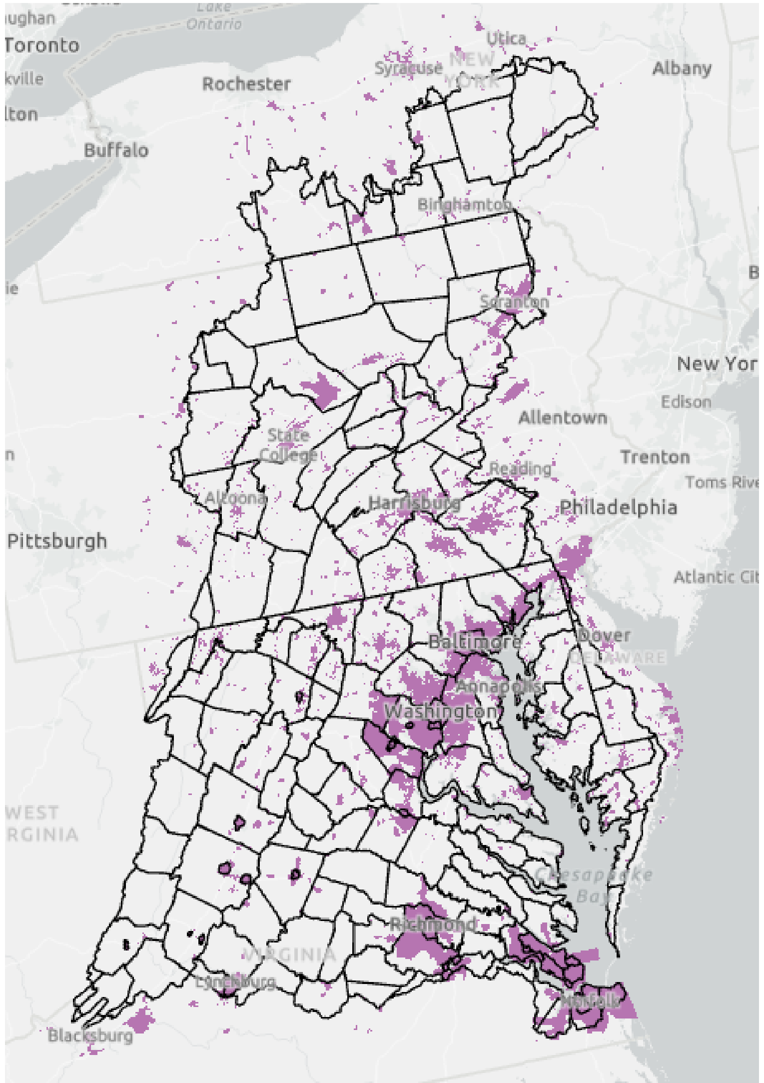
- It’s important that we not overestimate the exfiltration load.

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 * (Fraction new or rehabbed*Rehabbed coef.)

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"

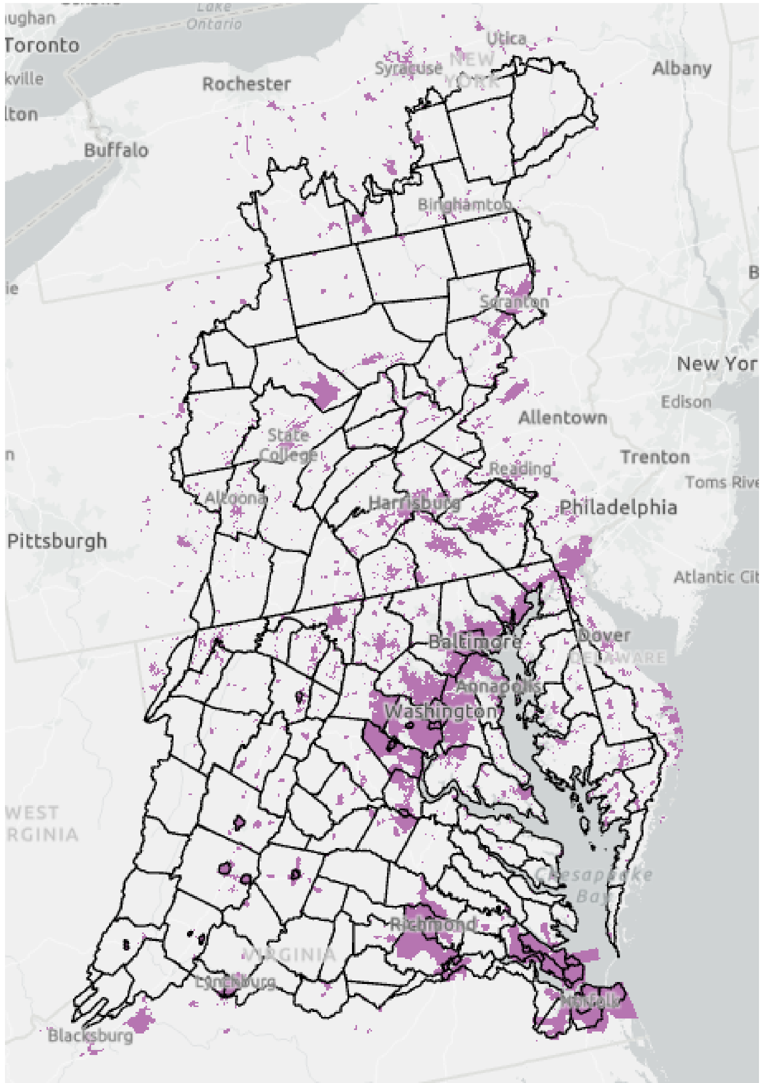
Testing

Goals:

- Evaluate whether the model can produce reasonable results given a range of inputs
- Quickly evaluate load estimates in a regional context while iterating through model formulations and parameter selection

Test cases were chosen to facilitate comparisons to urban CAST '23 load estimates.

- Service boundaries are well contained within few model units
- Minimize urban land that is not served by sanitary sewer
- Initial testing uses median and midpoint literature values for parameters, but these are only meant to be a starting point.



CBW WWTP Service Boundaries

Exfiltration as a percent of treated flow

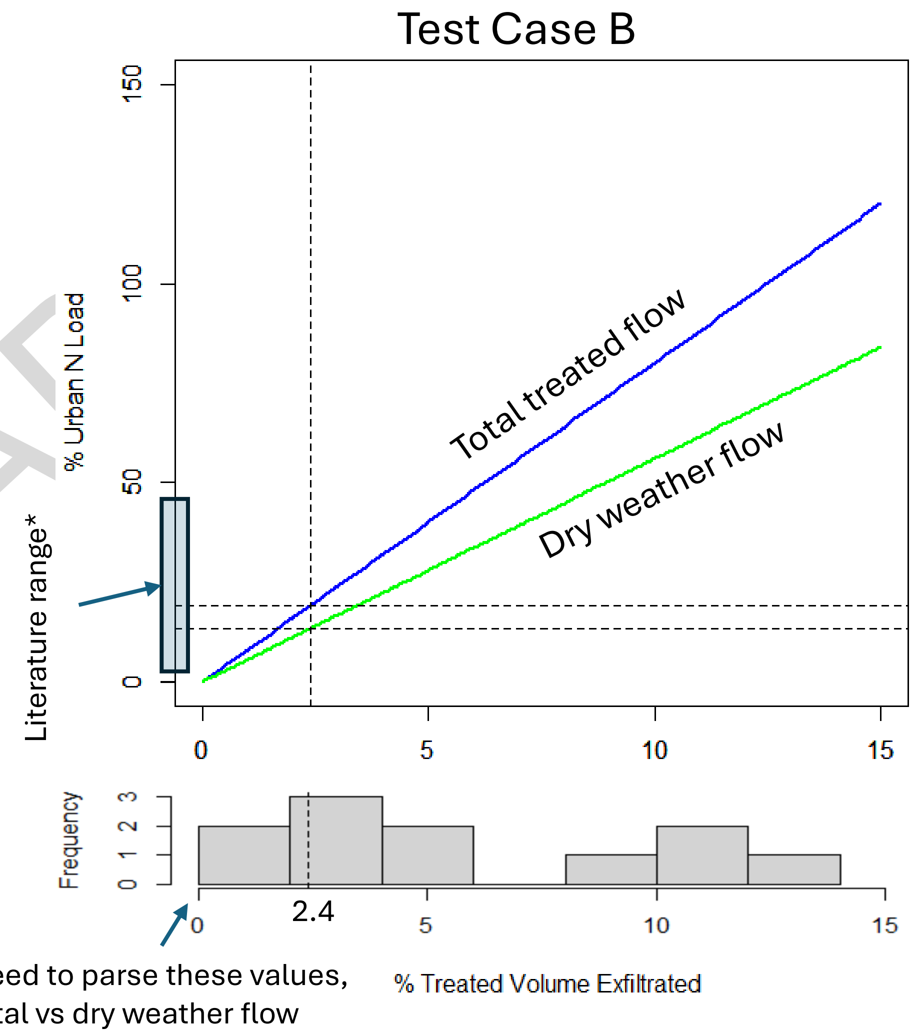
Exfiltration Vol. = Fraction exfiltration * Annual system treatment volume * Fraction gravity line* Geologic coef. * New or rehabbed coef.

- This is the default or initial estimate of exfiltration.
- Additional factors will mediate this load.
- For Test Case B, 98% of the system is gravity fed
- For Test Case B, the median of literature values was selected excluding the values greater than 10 which appear impractical.
- Compared to urban N load to streams (CAST '23)

Decisions:

- The initial/default percent exfiltrated value
- Use total treatment volume or dry weather flow

Test Case B at this step:
342277 - 488967 lbs. N/yr
13.5 - 19.2 % of Urban Load



*3-48%
Divers et al., 2013
Recommendations of the Expert Panel to Define Removal Rates for the Elimination of Discovered Nutrient Discharges from Grey Infrastructure, 2014
Nguyen and Venohr, 2021
Delesantro et al. 2022, 2024

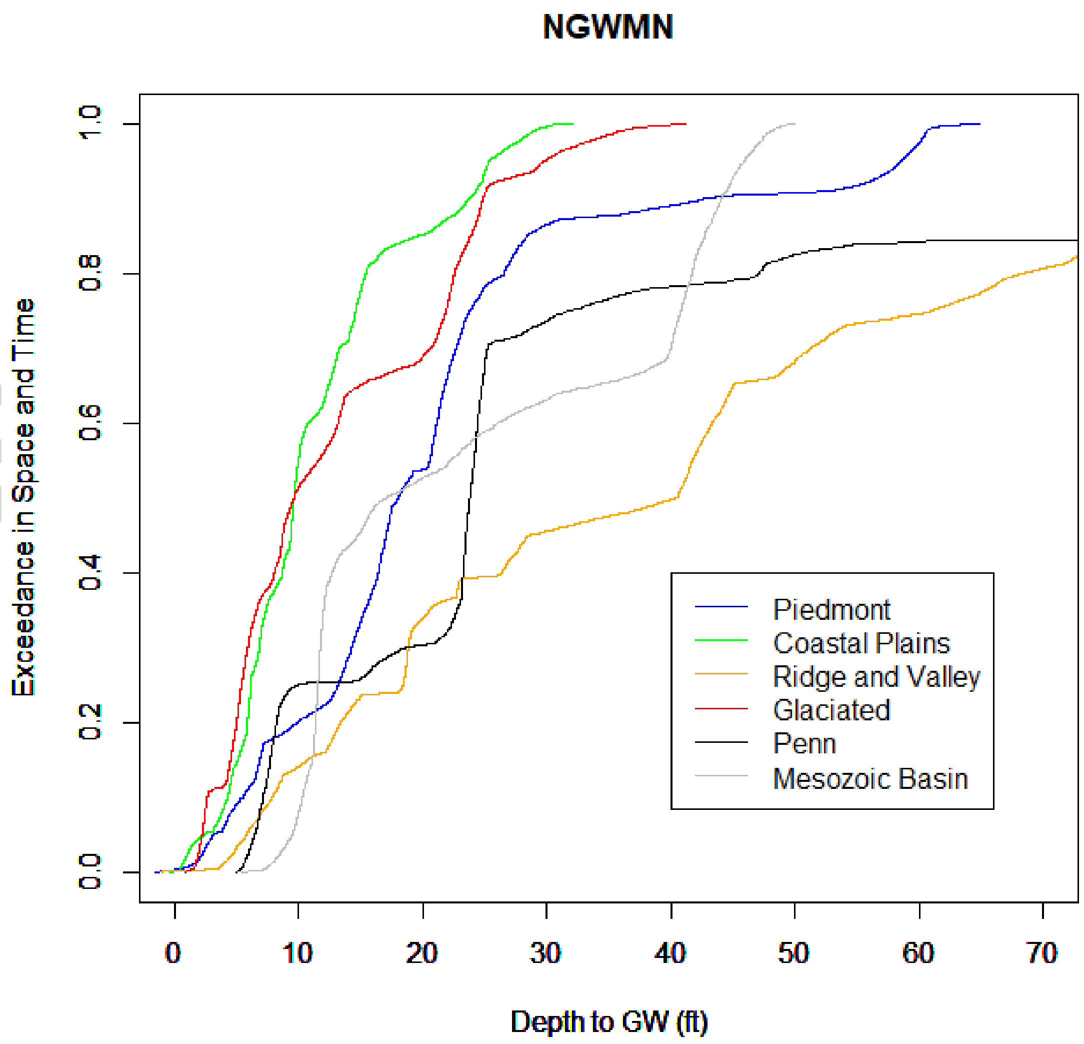
Groundwater Coefficient

Exfiltration Vol. = Fraction exfiltration * Annual system treatment volume * Fraction gravity line* Geologic coef. * New or rehabbed coef.

The depth to groundwater fraction exceedance in space and time has been calculated for each Geobasin. This value represents the fraction of time/space that is inundated at a given depth to GW.

Decisions

- Selection of Depth to GW critical value or range over which to average the inundation period.
- Where service boundaries cross multiple geobasins: area weighted, or population weighted
- Mean groundwater depth taken from the entire Geobasin or other geographic subset (ecoregion, state, etc.)



For initial test, I used a critical value of 8 ft for which the test case region fraction exceedance was 0.28. Coef.=(1-0.28)

Test Case B at this step:
246440 - 352057 lbs. N/yr
11.8 – 16.8 % of Urban Load

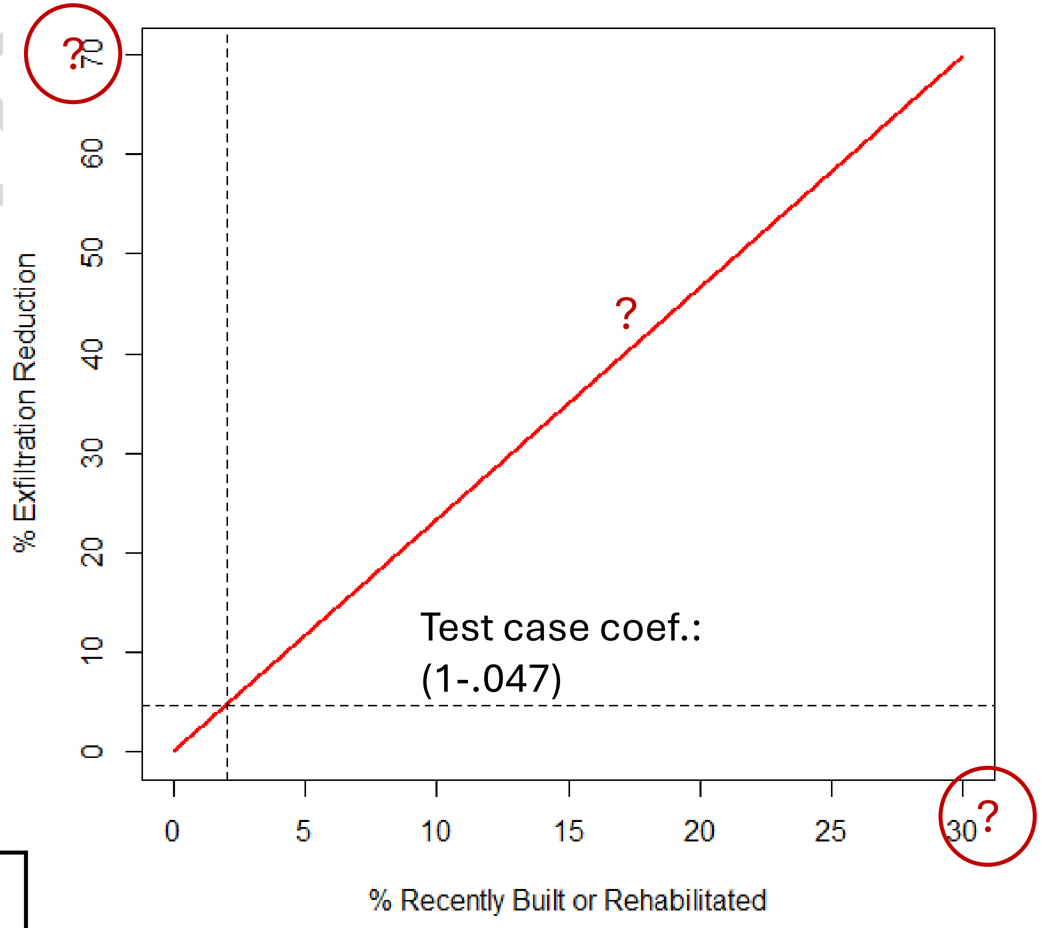
New and Newly Rehabilitated Sewer Coefficient

Exfiltration Vol. = Fraction exfiltration * Annual system treatment volume * Fraction gravity line* Geologic coef. * New or rehabbed coef.

- Exfiltration primarily occurs from a fraction of the total system, 20-50%.
- Rehabilitation reduces exfiltration by 50-90%.
- Example uses 10-year timeframe

Decisions

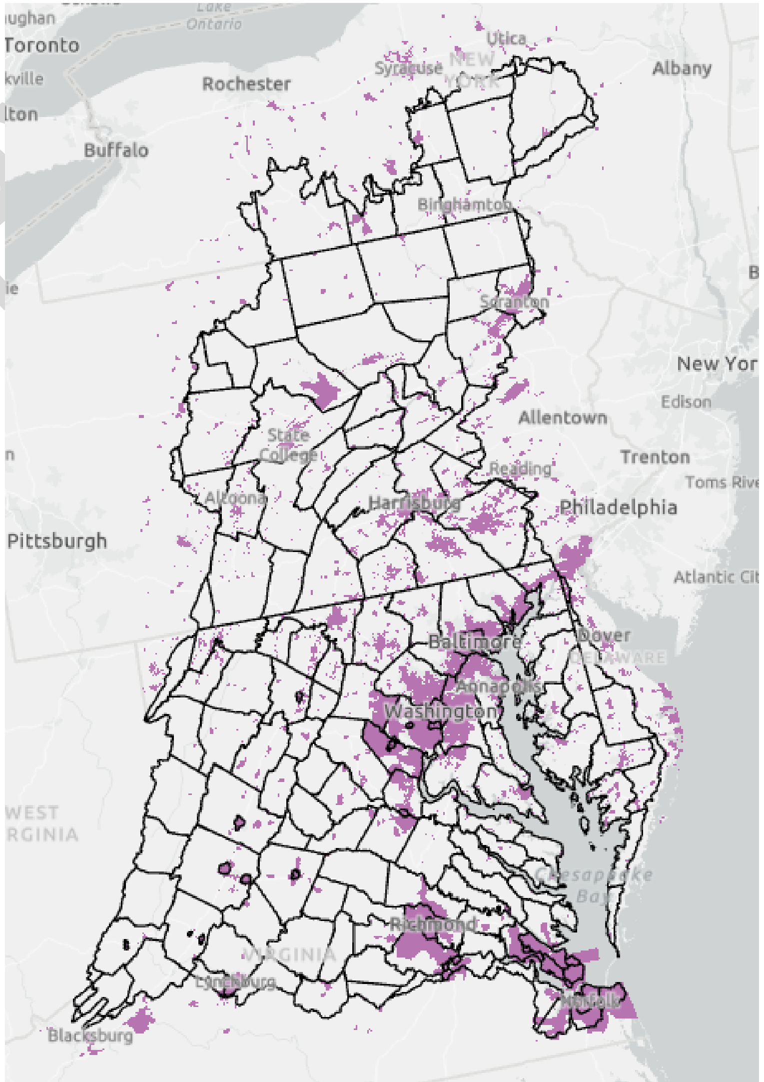
- How does this interact with BMPs
- Timeframe
- Max reduction and max system percent rehabilitated
- Numerical function



Test Case B at this step:
234956 - 335650 lbs. N/yr
11.3 – 16.1 % of Urban Load

Summary

- Values are within the literature range as a percent of the urban load, however there is a lot of opportunity for refinement.
- Need to consider the load source within CAST modeling. Is it a NPS subject to land-to-water factors, or a new direct load (similar to septic)?
- Should systems report N and P concentrations, or should different defaults be set for combined and separate systems?
- The percent exfiltration relative to treatment volume or dry weather flow will have the most leverage
- Rehabilitation sensitivity will need to be determined with consideration of available BMP credits



CBW WWTP Service Boundaries

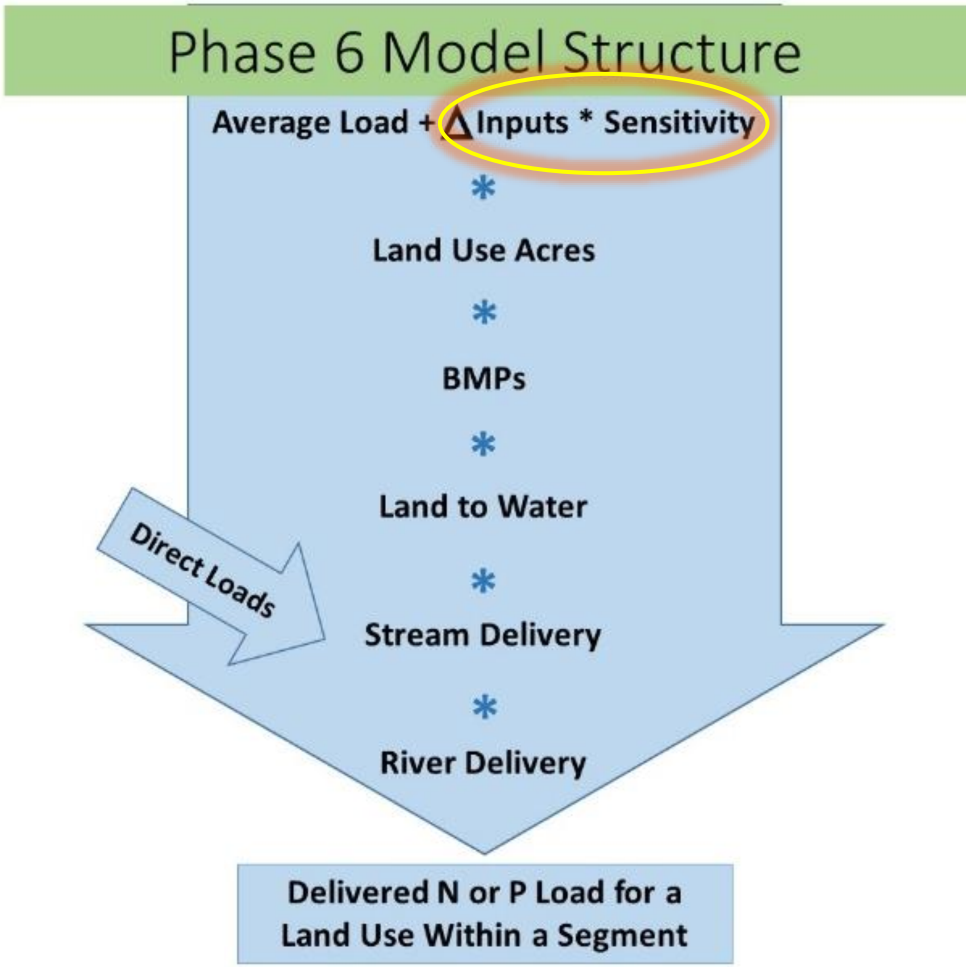
Urban nutrient export sensitivity to inputs

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).

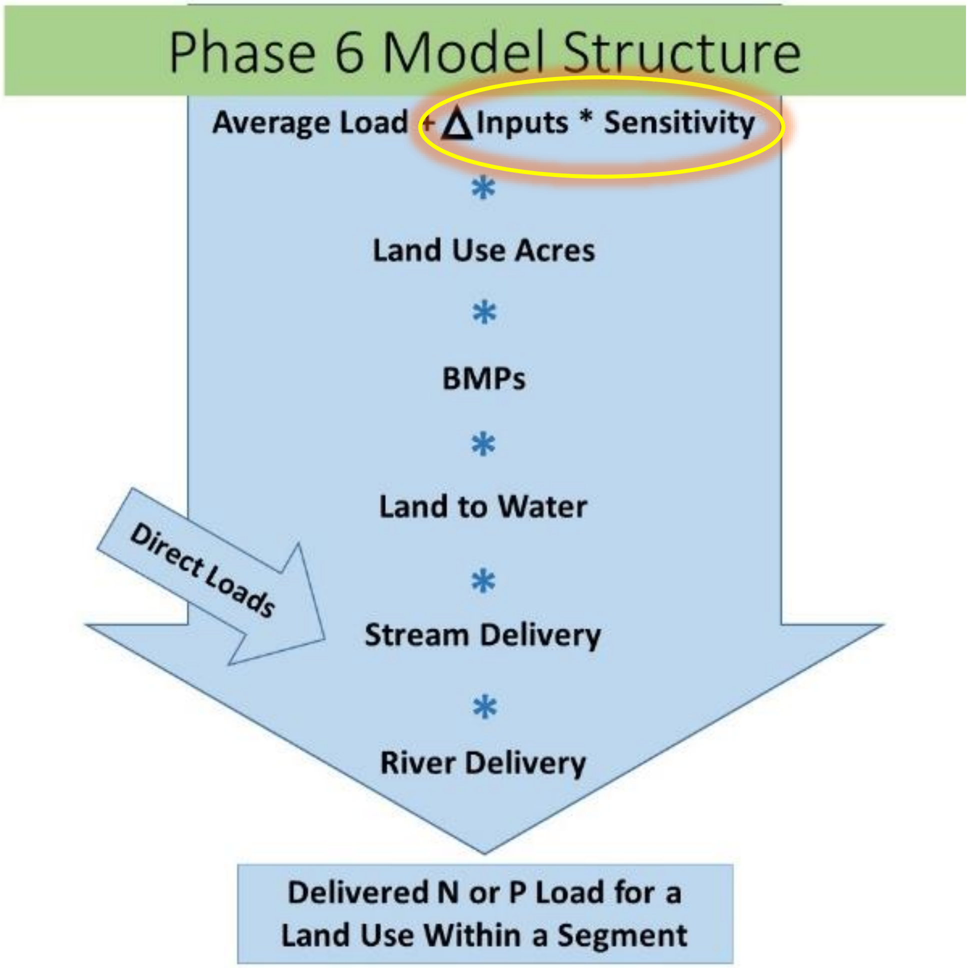
In other words:

- 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.



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 rates and delivery factors.
- There are exceptions…



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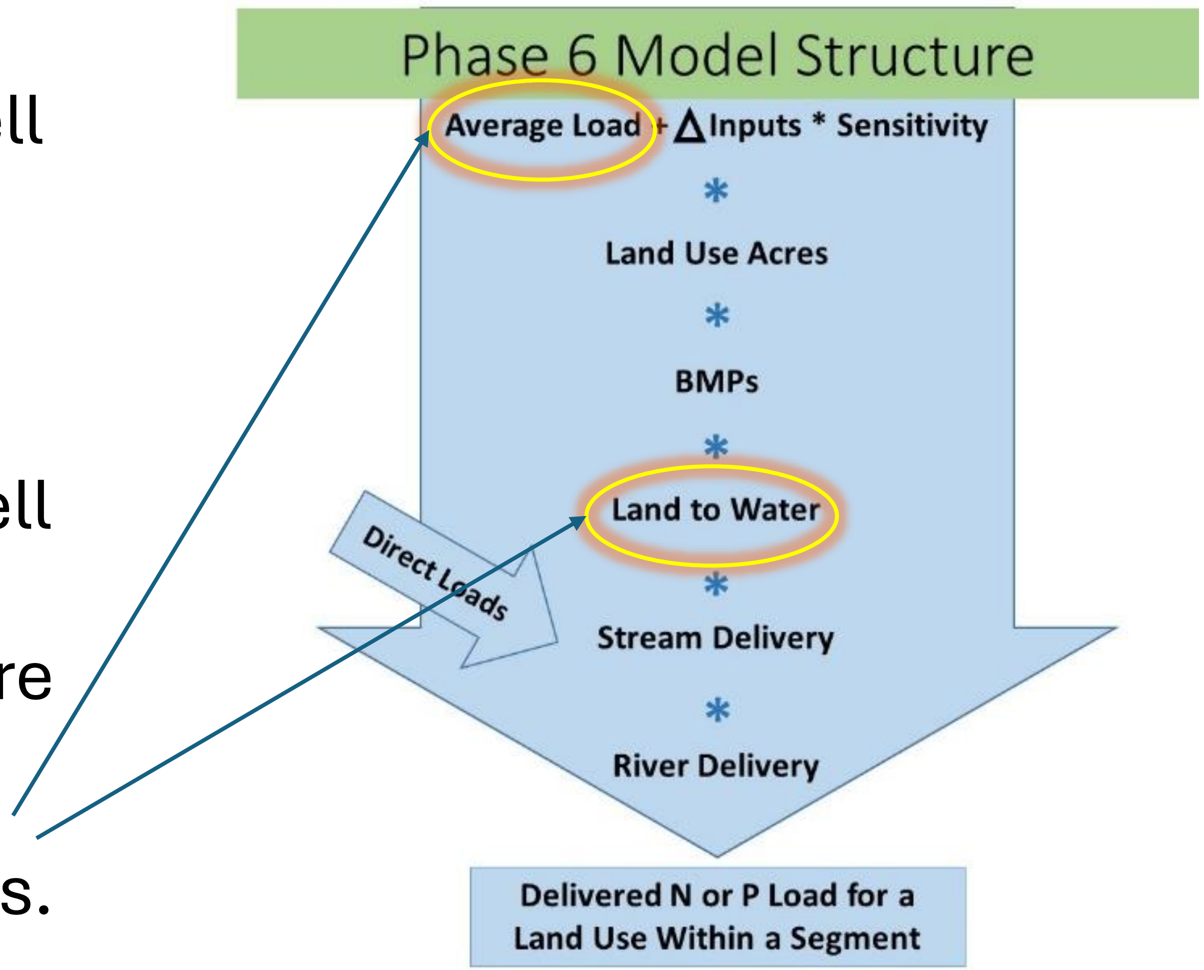


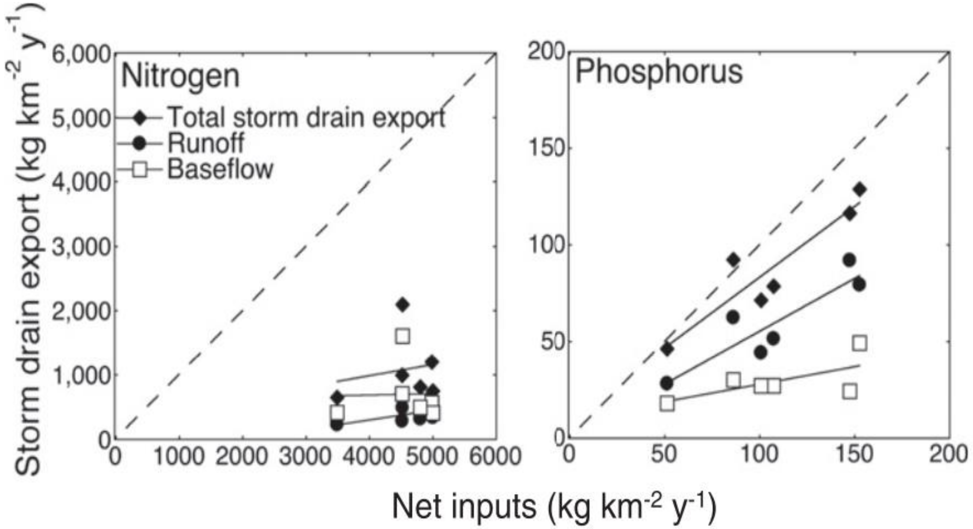
Table 1. Summary of nonlinear least-squares calibration results for CBTN_v4, the Chesapeake Bay watershed total nitrogen model.

[MSE, mean squared error; RMSE, root mean squared error; kg, kilogram; yr, year; km^2, square kilometer; EVI, enhanced vegetative index; AWC, available water capacity; m, meter; mm, millimeter; d, days; WY02, water year 2002 (October 2001 through September 2002); MAQ, mean annual flow; $m^3 s^{-1}$, cubic meters per second; T30, mean annual maximum temperature from 1971 through 2000; °C, degrees Celsius; <, less than; >, greater than; ≤, less than or equal to]

Total Nitrogen, 2002 (n = 181, MSE = 0.0836, RMSE = 0.289, flux R^2 = 0.978, yield R^2 = 0.858)					
Explanatory variables	**Estimate**	**Units**	**90-percent confidence interval**	**Standard error**	**p[1]**
Sources					
Point sources (kg yr^{-1})	0.774		0.375 – 1.17	0.242	0.0008
Crop fertilizer and fixation (kg yr^{-1})	0.237		0.177 – 0.297	0.0363	< 0.0001
Manure (kg yr^{-1})	0.0582		0.0138 – 0.103	0.0269	0.0157
Atmospheric deposition (kg yr^{-1})	0.267		0.179 – 0.355	0.0533	< 0.0001
Urban[2] (km^2)	1,090	kg km^{-2} yr^{-1}	707 – 1,480	234	< 0.0001

Urban studies of export sensitivity to input

- Very few true measure or models of sensitivity in the lierature
- 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.
- Land use loading rates largely define export
- Due to high uncertainty in urban inputs, limited literature on export sensitivity to input, and high variation in reported values, updating urban sensitivity values based on the literature does not appear feasible.
- Time permitting… We will continue to look for additional information and test literature values.