Sanitary Sewer Exfiltration

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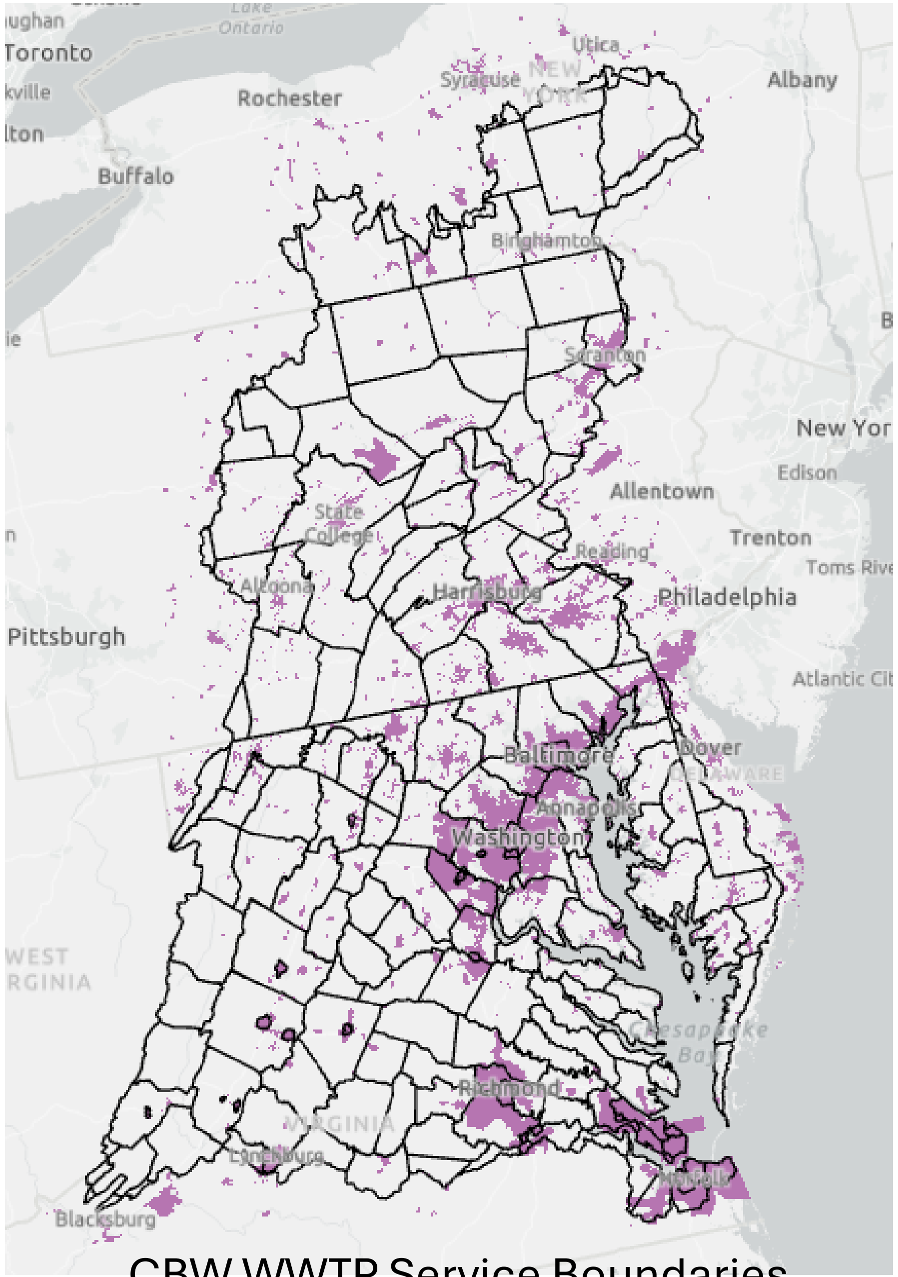


CBW WWTP Service Boundaries

“**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 calibration
- Improved targeting and crediting of management actions
- Scenario analysis (E.g., remediation, septic/sewer conversion)

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

Most of the misappropriation is likely to stormwater and lawn fertilizers. These are surface sources, and many of the management practices applied will have little to no impact on subsurface sewer exfiltration.

WWTWG Considerations

- Acknowledge interest in more accurately attributing the sources of the load.

- Prefer a conservative estimate
  - to capture the impact of small defects and joint leaks, not large structural failures which are more quickly identified and addressed,
  - and to reflect the uncertainty in estimates.

Preliminary model structure

Exfiltration Vol. = Fraction exfiltration * Annual system treatment volume (dry-weather) * Geologic coef. * Fraction gravity line * (Fraction new or rehabbed*Rehabbed coef.)

Exfiltrated nutrient mass = Exfiltration Vol. * concentration in raw WW (33 mg/L TN, 6 mg/L TP)[1]*Soil Treatment*GW Transmission

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"

- An initial default exfiltration value as a percent of treated volume will be defined by expert judgement and literature
- Spatially exfiltration will be mediated soils, geology, and by optional factors identified as drivers of exfiltration and transmission by expert judgement and literature.
  - Geologic basin as a metric of water table depth driving exfiltration vs infiltration
  - The proportion of the system which is gravity fed
  - The proportion of the system which is new or recently rehabilitated
  - Soil and groundwater transmission attenuation (?)

Literature search to focused on exfiltration as a percent of system volume

Study	% System	Observation	System flow
Nguyen and Venohr, 2021	2%	to groundwater	dry-weather
Delesantro et al., 2022	2.40%	to stream	dry-weather
Steele et al., 2025	0.60%	from pipe	total
Amik et al., 2000	11.40%	from pipe	dry-weather
Ellis et al., 2004	3-5%	from pipe	review, both
Fenz, 2003	1-5%	from pipe	dry-weather
Fens et al., 2005	1%	to groundwater	dry-weather
Karpf and Krebs 2004	2.80%	to groundwater	dry-weather
Giulianelli et al., 2003	0.24-2.96%	from pipe	dry weather
Yang et al., 1999	1-2%	to groundwater	total
CIRIA, 1995	3.00%	from pipe	total (leaky system)

Notes:

- Filtered to remove laboratory analyses which tend to be higher
- Amik et al., and CIRIA 1995 were removed as an outliers from subsequent analyses
- 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 dry-weather flow
- Dry-weather flow is generally analogous to generated wastewater

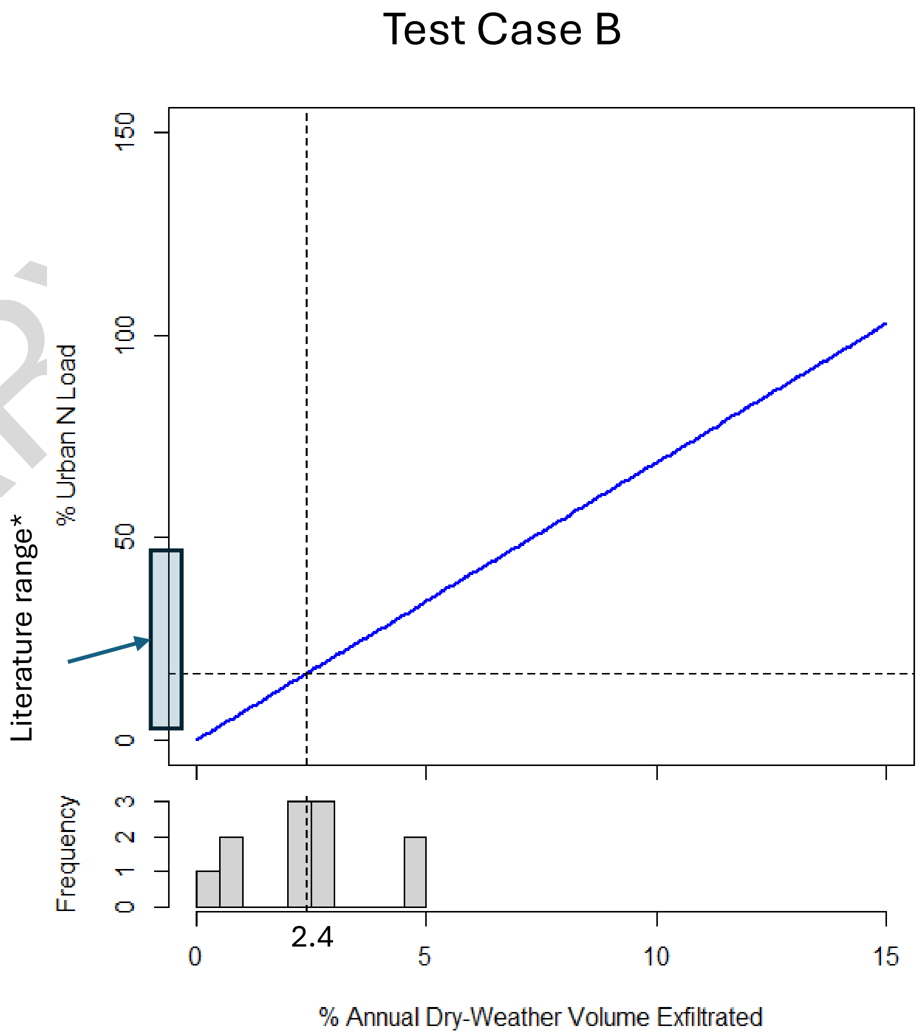
Values are generally in agreement, suggesting reasonable basis for generalization.

Exfiltration as a percent of dry-weather flow

Exfiltration Vol. = Fraction exfiltration * Annual system dry weather flow (DWF)* Fraction gravity line* Geologic coef. * New or rehabbed coef. * Soil atten. factor * GW atten. factor

- This is the initial estimate of exfiltration.
  - Additional factors will mediate this load.
- Exfiltration as a percent of dry-weather flow reduces impacts of I/I.
- The median literature value for % exfiltration of DWF was selected (2.4%)

Let's review two factors
- Mapping
- Estimating dry weather flow (DWF)



*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
Wakida and Lerner, 2005

PRELIMINARY

Mapping

- Facilities are not always linked to their service areas.
  - Facilities are assigned to the service area they reside in.
  - If a facility is not in a service area it is assigned to the service area it shares a model unit with (currently P6 LRseg, but will update to P7 HUC12).
  - When there are multiple facilities within a single service area polygon, their DWF is summed for that polygon and distributed based on model unit sewer served population.
    - CSO and MS4 polygons are always separated
  - Both the parameters and the flow/load are spatially weighted based on sewer served population estimates (currently by LRseg, but will update to P7 NHD+)
- The service boundary mapping used is static, but the sewer served population mapping varies temporally (‘84, ‘94, ‘00, ‘10, ‘13, ‘17, and P7 will add ’20 and ‘25 projection)

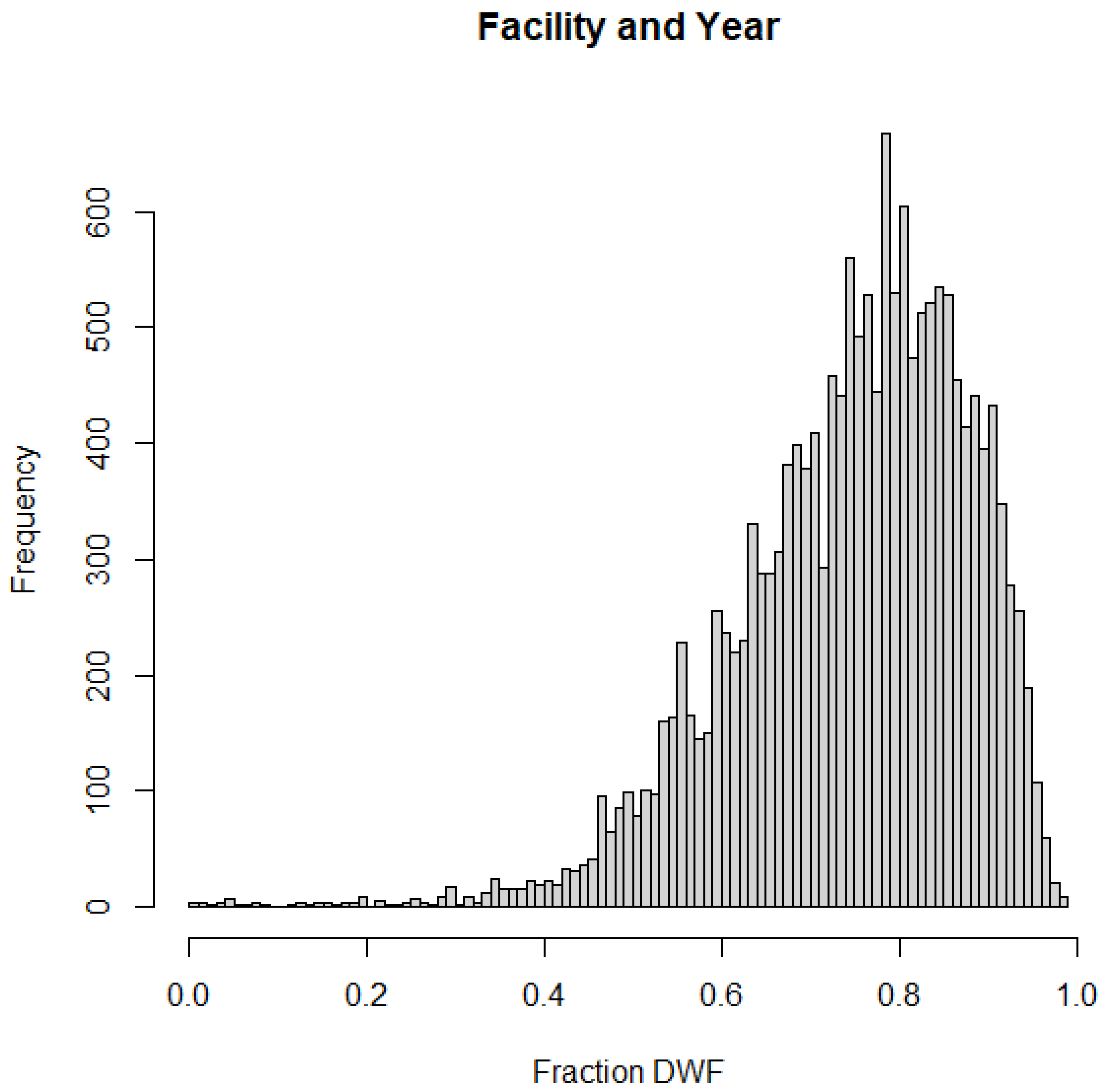
Dry Weather Flow (DWF)

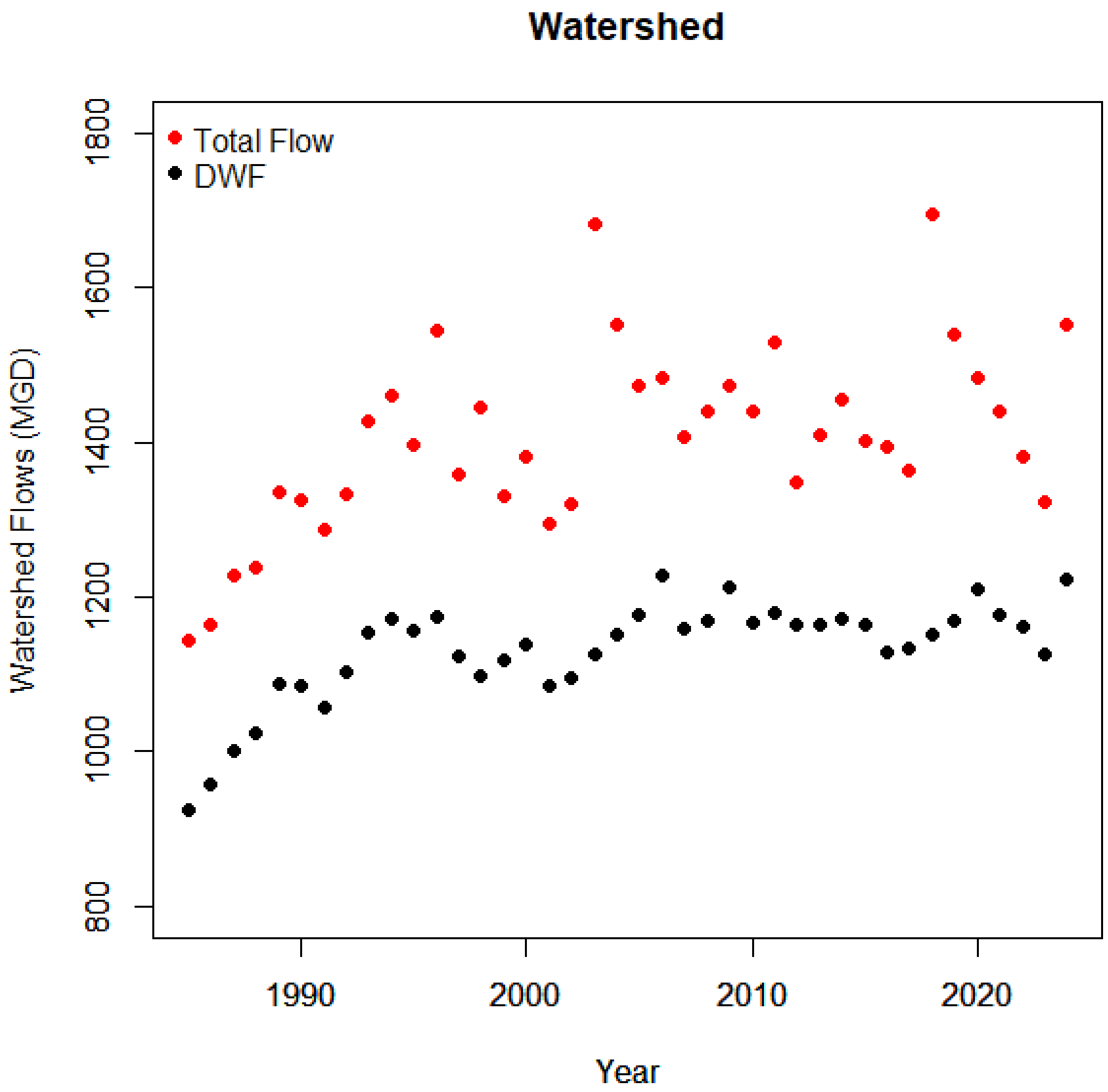
Annual dry weather flow in MGD is defined by the lowest monthly flow (in MGD)

- The precent DWF of total flow is calculated for each year and outliers are defined as exceeding the facility mean by two SD.
- Percent DWF=1are also defined as outliers (i.e., reported monthly flow = annual/12)
- DWF for years with precipitation (P6 PRISM) >1.5 SD above the mean are also defined as outliers
  - Impacts in 5 of 40 year

Outliers are interpolated (linear) or if on the leading or trailing end, they are set as the facility mean percent DWF * annual reported flow

Dry Weather Flow (DWF)





NEW- Per Capita Flow Cap

Evaluating the preliminary data, exfiltration seemed excessive to the conservative estimate approach for D.C. and other densely populated or CSS served areas.

Proposal: Cap the DWF of each model unit at 1.5 times the estimated flow based on population. Setting the max at a multiple of 1.5 allows variation in water use across the watershed and time (climate, commuter population, etc.)

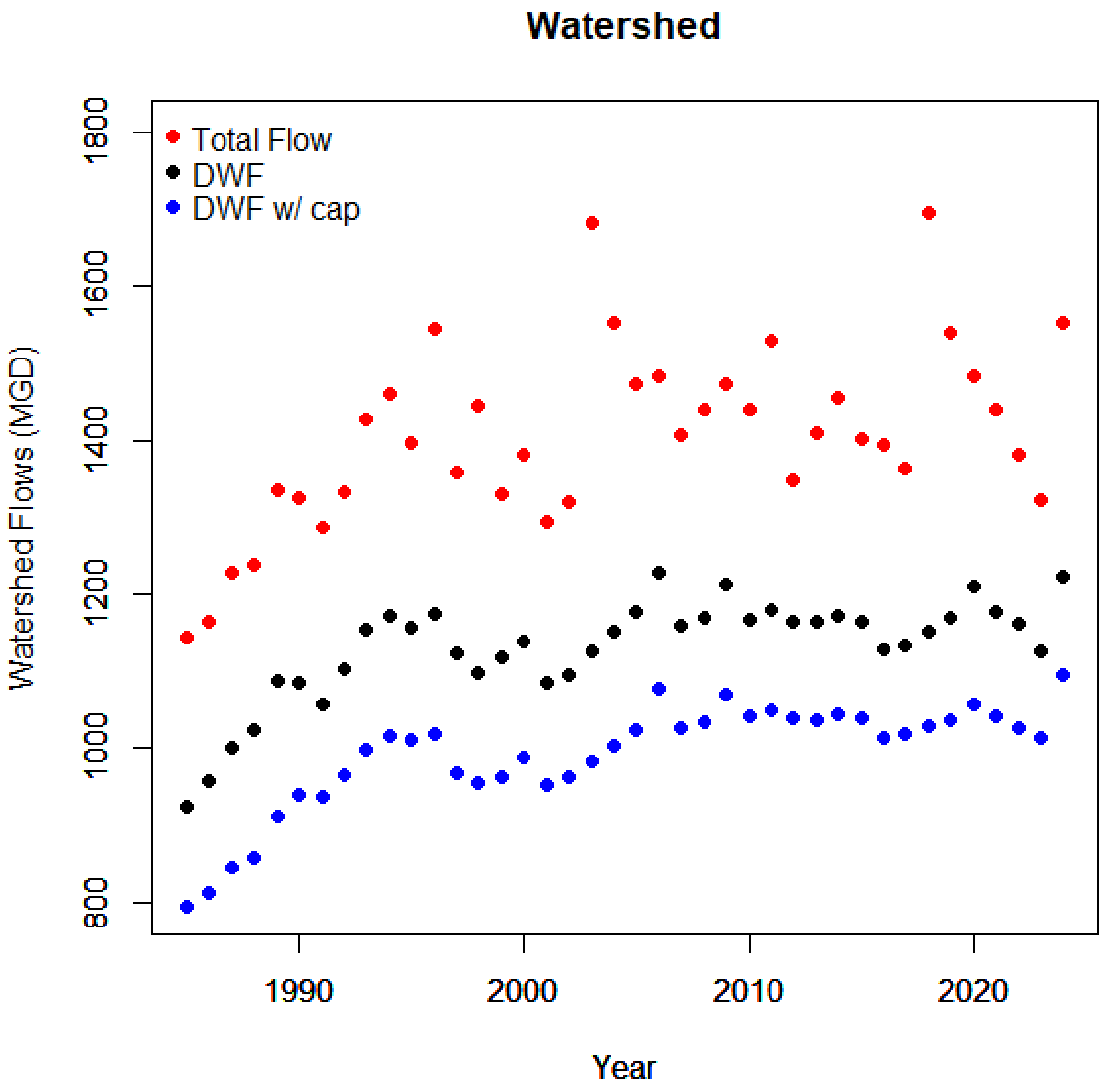
$DWF_{(model\ unit,\ year)} \le$ Per Capita DWF* Sewer Served Population $_{(model\ unit,\ year)}$ * 1.5

With P6 data, the watershed average (across space and time) per capita DWF is 81.3 gal/day/person.

NEW- Results of Per Capita Flow Cap

11.3% reduction in DWF (in testing)

Impacts 49 LR segs (in testing)



Fraction Gravity Line

Exfiltration Vol. = Fraction exfiltration * Annual system dry weather flow* Fraction gravity line* Geologic coef. * New or rehabbed coef. * Soil atten. factor * GW atten. factor

- Force mains are designed to be watertight and are less susceptible to chronic leaks

PRELIMINARY

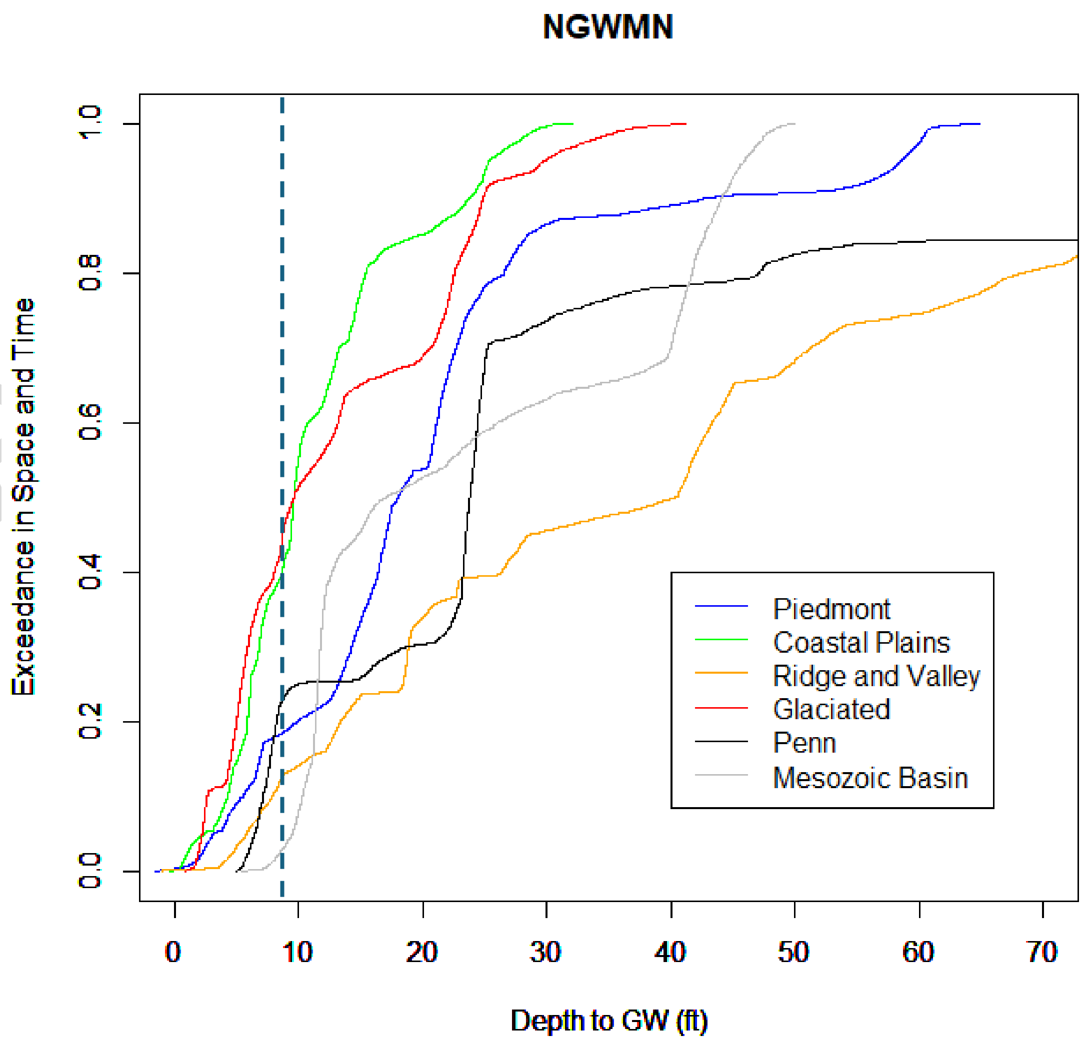
Ground-water Coefficient

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

The estimated fraction of time and space within a hydrogeomorphic basin (or corresponding aquifer system) where pipes at a depth of 9.2 ft will be inundated, and therefore not exfiltrating.

- A critical depth of 9.2 ft was selected to represent a mean invert depth. This value is based on best professional judgement and an analysis by MD.
- Where service boundaries cross multiple hydrogeomorphic basins the groundwater coefficient value is population weighted.
- Ground-water observations are queried from the National Ground-Water Monitoring Network. (https://www.usgs.gov/apps/ngwmn)
- This value is static in time.

PRELIMINARY

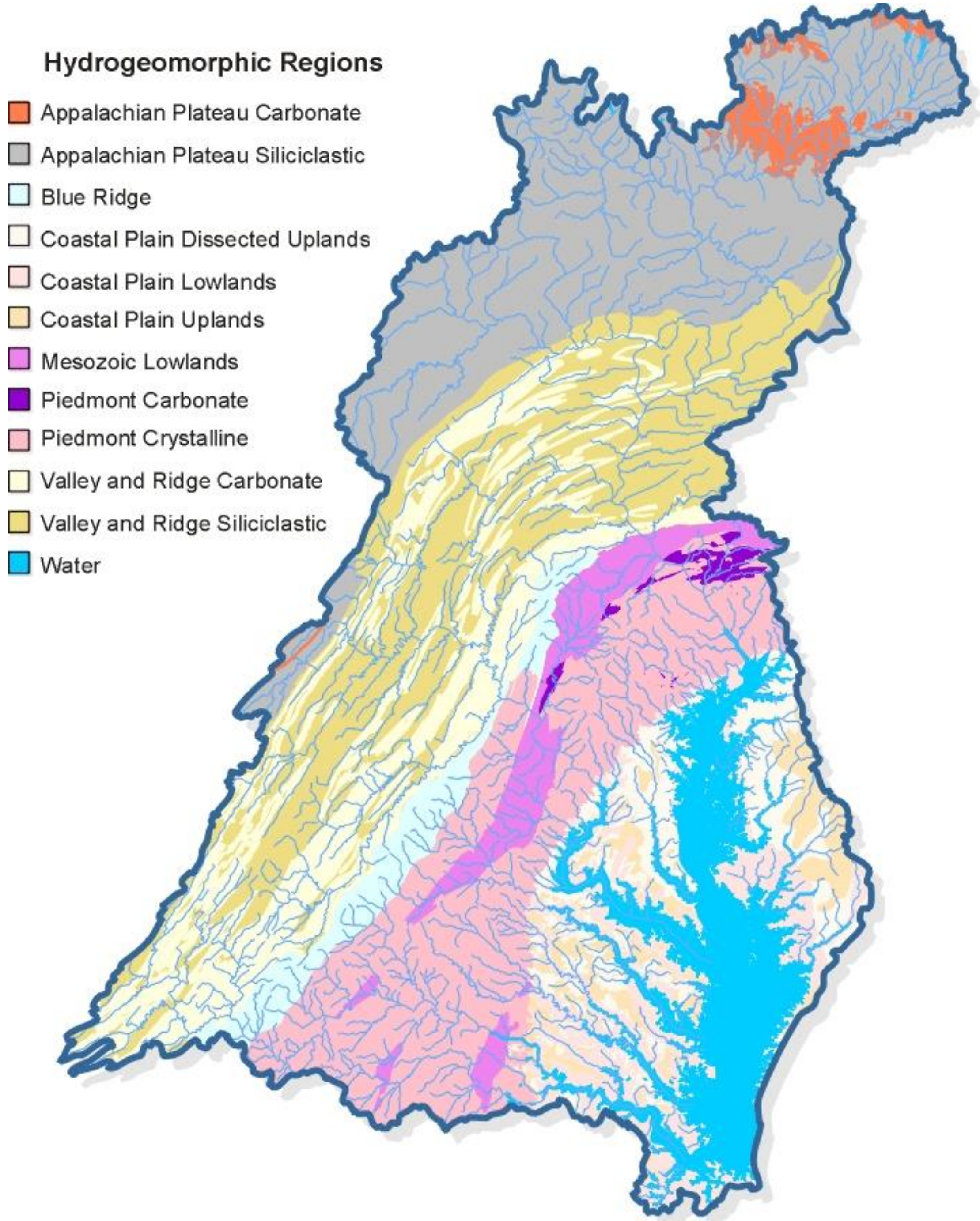


Note: Not all basins shown in this figure. There are 11.

Groundwater Coefficient

HGMR	Inundation	Facility n	
Coastal Plains Upland	0.432	15	
Coastal Plains Dissected	0.432	48	
Coastal Plains Lowlands	0.432	54	
Valley and Ridge Siliciclastic	0.133	122	
Valley and Ridge Carbonate	0.133	51	
Appalachian Plateau Siliciclastic	0.482	2	
Appalachian Plateau Carbonate	0.93	1	
Piedmont Crystalline	0.191	47	
Piedmont Carbonate	0.013	20	Note: Only three wells in this basin
Mesozoic	0.041	34	
Blue Ridge	0.133	7	

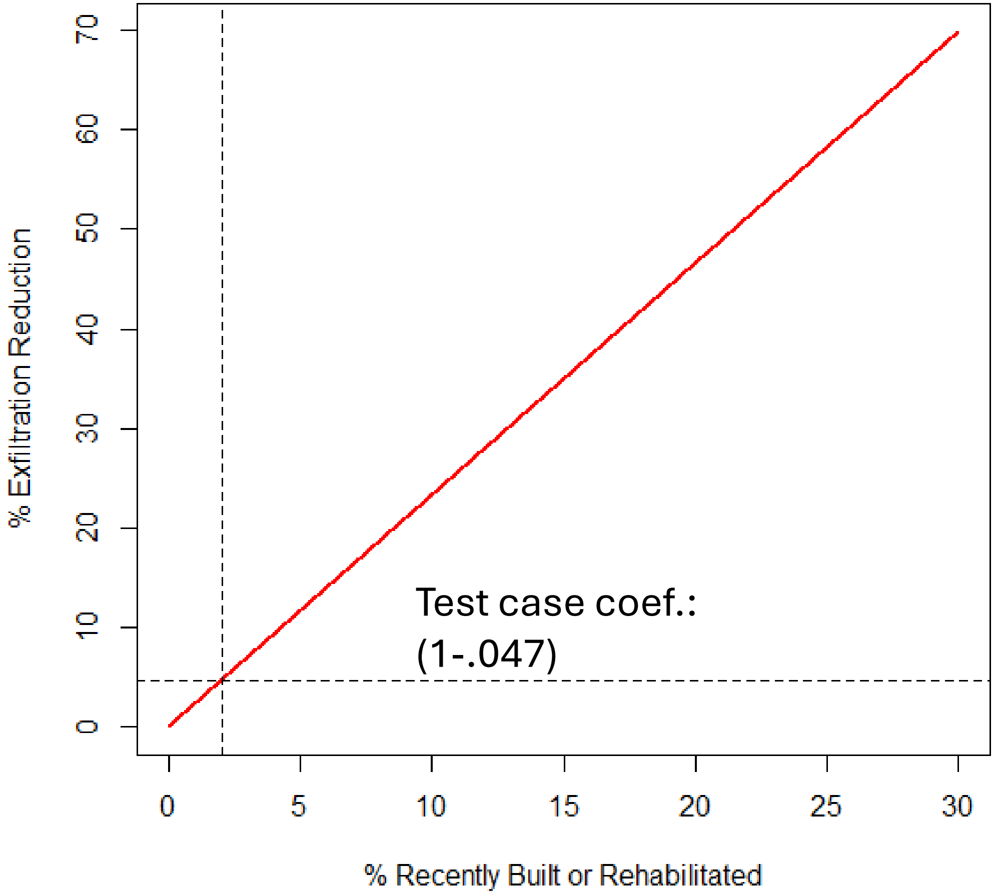
Note: The coefficient as applied would be 1- above value



New and Newly Rehabilitated Sewer Coefficient

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

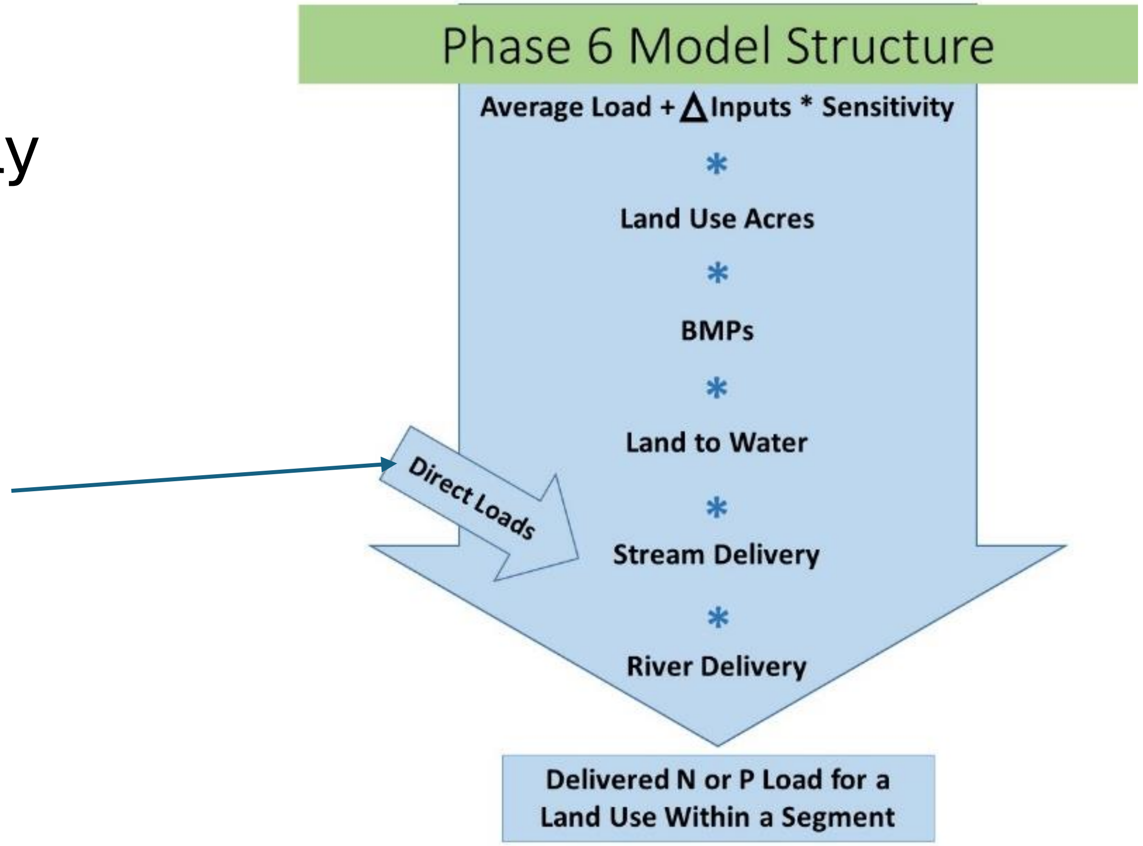
- Exfiltration primarily occurs from a fraction of the total system, 20-50%.
- Rehabilitation reduces exfiltration by 50-90%.
- Central values were selected
- A 10-year timeframe is used to define new or newly rehabilitated
- Reporting of these values is intended to be optional, and therefore the impact should be conservative



Attenuation in soil and groundwater (EOF to EOS)

Treat as a “direct load” where attenuation is defined separately (as part of the work group process).

- There are still BMPs applied to “direct loads”.



Attenuation (direct load)

Can we modify the existing framework and values for onsite wastewater attenuation for sanitary sewer exfiltration?

Yes, but some considerations:

- septic systems are generally placed in uplands while sewers are preferentially placed near streams (Delesantro et al., 2021).
- Soil mapping and classification can be less accurate in urban areas.
- Sewer exfiltration is lower in the soil column than septic effluent.
- Stormwater pipes can short circuit “attenuation zones”.
- Urban soils can be N enriched reducing total % attenuation.
- The onsite wastewater report did not address phosphorous, but recommended future consideration.

Nutrient Attenuation in Onsite Wastewater Treatment Systems - Final Report   August 2016

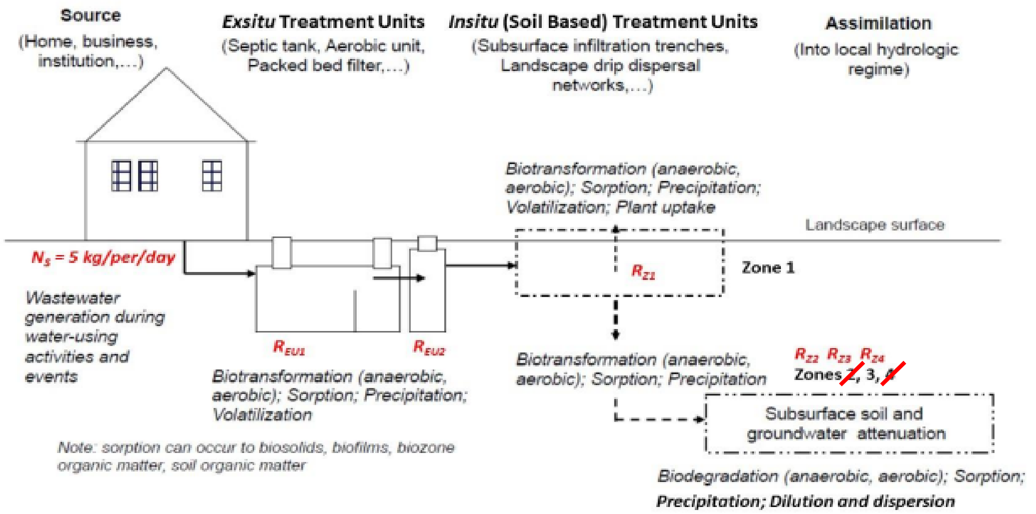


Figure 3. Nutrient Transformations associated with Treatment and Attenuation Zones (from Siegrist and Geza, 2014)

$$N_{LS} = \sum_{i=1}^{ST}\{\sum_{j=1}^{DU}[N_s(1-R_{EU1})(1-R_{EU2})(1-R_{Z1})(1-R_{Z2})(1-R_{Z3})(1-R_{Z4})]\}$$ **(Equation 1)**

Where:

N_{LS} = nutrient load from a land unit to the edge of stream (kg TN/day)
N_s = nutrient load from a source (e.g., house) (i.e., 5 kg TN/person/day)
R_{EU1} = fractional removal of TN in a 1st *exsitu* treatment unit (e.g., septic tank)
R_{EU2} = fractional removal of TN in a 2nd *exsitu* treatment unit (e.g., sand filter)
R_{Z1} = fractional removal of TN in Zone 1, Soil-Based Treatment
R_{Z2} = fractional removal of TN in Zone 2, Deep Vadose Zone
R_{Z3} = fractional removal of TN in Zone 3, Groundwater Zone
R_{Z4} = fractional removal of TN in Zone 4, Transitional Zones
ST = system type/characteristics 1, 2, 3
DU_i = dwelling units with system type *i*

The nitrogen reduction parameters referenced in Equation 1 and Figure 3 are further summarized in

Table 1, along with a brief summary of the Panel’s source of information or approach used to characterize the parameter (in the “Comments” column).

Septic example

Modification for sewers

Soil attenuation is modified to account for urban short circuiting (static coefficient) and groundwater level relative to pipes (defined by the groundwater level analysis by hydrogeomorphic basin).

Groundwater attenuation is modified to account for proximity of pipes to streams

- static factor based on the literature comparing septic and sewer locations relative to streams

Table 11. Recommended edge of Zone 1 TN load as a function of dominant soil texture for conventional onsite wastewater systems

Soil Textural Grouping	USDA Soil Textures	Zone 1 TN Reduction	TN Load at Edge of Zone 1
Sandy	Sand, Loamy Sand, Sandy Loam, Loam	16%	4.2 kg/cap/yr
Loamy	Silt loam, Clay Loam, Sandy Clay Loam, Silty Clay Loam, Silt	34%	3.3 kg/cap/yr
Clayey	Sandy Clay, Silty Clay, Clay	54%	2.3 kg/cap/yr

Table 12. Recommended Zone 3 attenuation factors for Chesapeake Bay HGMRs

Hydrogeomorphic Region[1]	Relative TN Transmission Classification	Recommended Zone 3 Attenuation Factor (Transmission Factor)
Fine Coastal Plain - Coastal Lowlands	Low	75% (25%)
Fine Coastal Plain - Alluvial and Estuarine Valleys	Low	75% (25%)
Fine Coastal Plain - Inner Coastal Plain - Upland Sands and Gravels	Medium	60% (40%)
Fine Coastal Plain - Middle Coastal Plain – mixed sediment texture	Medium	60% (40%)
Fine Coastal Plain - Middle Coastal Plain – fine sediment texture	Low	75% (25%)
Coarse Coastal Plain - Middle Coastal Plain – Sands with Overlying Gravels (also dissected)	High	45% (55%)
Coarse Coastal Plain - Inner Coastal Plain - Dissected Outcrop Belt	High	45% (55%)
Crystalline Piedmont	High	45% (55%)
Crystalline Blue Ridge	High	45% (55%)
Carbonate Piedmont	Very High	35% (65%)
Carbonate Valley and Ridge	Very High	35% (65%)
Carbonate Appalachian Plateau	Very High	35% (65%)
Siliciclastic Mesozoic Lowland	High	45% (55%)
Siliciclastic Valley and Ridge	Medium	60% (40%)
Siliciclastic Appalachian Plateau	Low	75% (25%)

[1] Generalized Geology from Greene et al., 2005; Subdivisions from Bachman et al., 1998, and Ator et al., 2005 for coastal plain

Zone 1 Attenuation

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

Reduce the TN attenuation to account for urban hydrologic connectivity and N enrichment and modify based on depth to GW via the groundwater coefficient.

For example, if the soil group is loamy and the GW factor is 0.036: 34% * 0.8 * (1-0.36) = 17.41%

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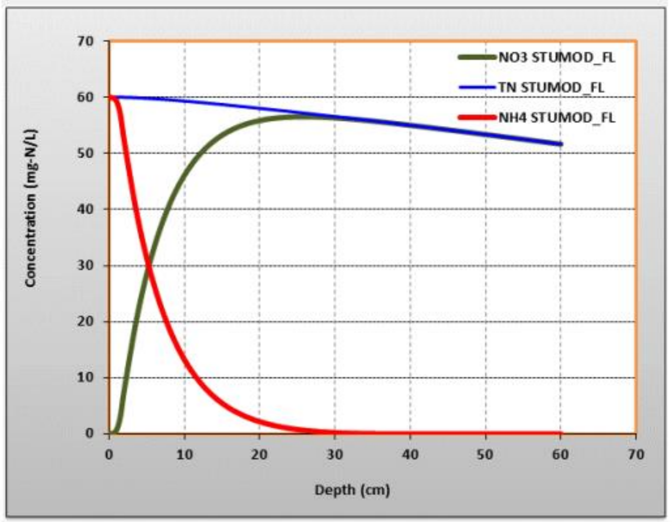

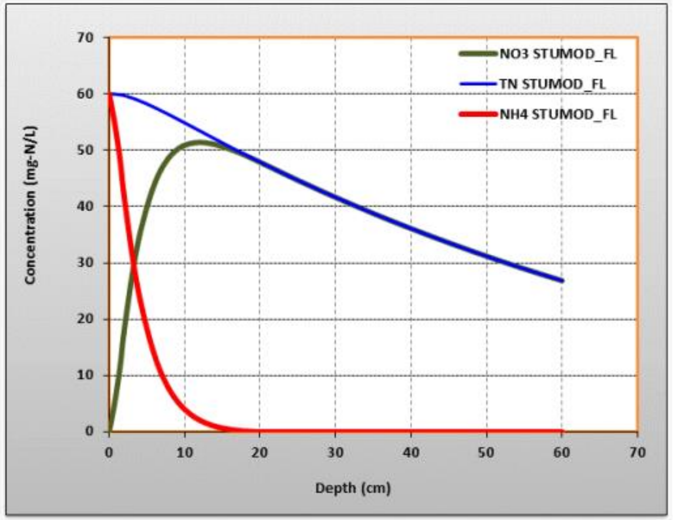

Figure 5. Concentrations from STUMOD of NH_4^+, NO_3^-, and TN as a function of depth below the infiltrative surface for a loamy sand soil (top graph) and a clay (bottom graph) for conventional systems with a water table at 60 cm and 100 percent of the design hydraulic loading rate (see Table 2).

Zone 3 Attenuation

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

In the North Carolina Piedmont, sewer lines are 36% closer to streams than septic systems (via flow path distance).

Reduce the attenuation factor based on the exponential of relative distance to streams.

For example, if the service area is in the high transmission class with an attenuation factor of 45%: 1-exp(ln(0.55)*(1-.36))=0.32 or 32% attenuation factor

Nutrient Attenuation in Onsite Wastewater Treatment Systems - Final Report

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Phosphorus Attenuation

Phosphorus attenuation is effectivity 100% in the onsite wastewater. However, the literature suggests that phosphorus from leaking sewers and septic can be an important source of P in developed landscapes (Delesantro et al., 2021, Baltimore LTER, Nguyen and Venohr, 2020, Humphrey et al. 2014, Humphrey et al. 2015, Iverson et al. 2018, Humphrey et al. 2020).

Proposal: Set P attenuation proportional to the change in N attenuation from septic accounting to sewer accounting.

- Extend the N attenuation method to P assuming 100% baseline attenuation and applying the sewer discounting via the percent difference in septic to sewer N attenuation

Soil and GW attenuation in testing:

Mean N attenuation is 47%

Mean P attenuation is 89%

Preliminary Results

Notes

- You are voting on a method. In some cases, P6 input datasets are used for testing and development, these will be updated to the P7 version. Final results will vary.
- This testing does not include optional inputs, those have been tested and reported for Baltimore (city and co) and SE VA (HRSD) in previous meetings.
- 1.9% NAs in preliminary results due to mapped datasets not lining up or overlapping properly. This will need resolution in P7 with final P7 inputs.
- These values have been updated since slides were posted with the per capita flow cap

Watershed wide	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	1010642	1048515	987587	40383	42223	39817
% total EOS load	0.18%	0.20%		0.10%	0.14%	
% EOS developed load	1.35%	1.16%		0.74%	0.81%	

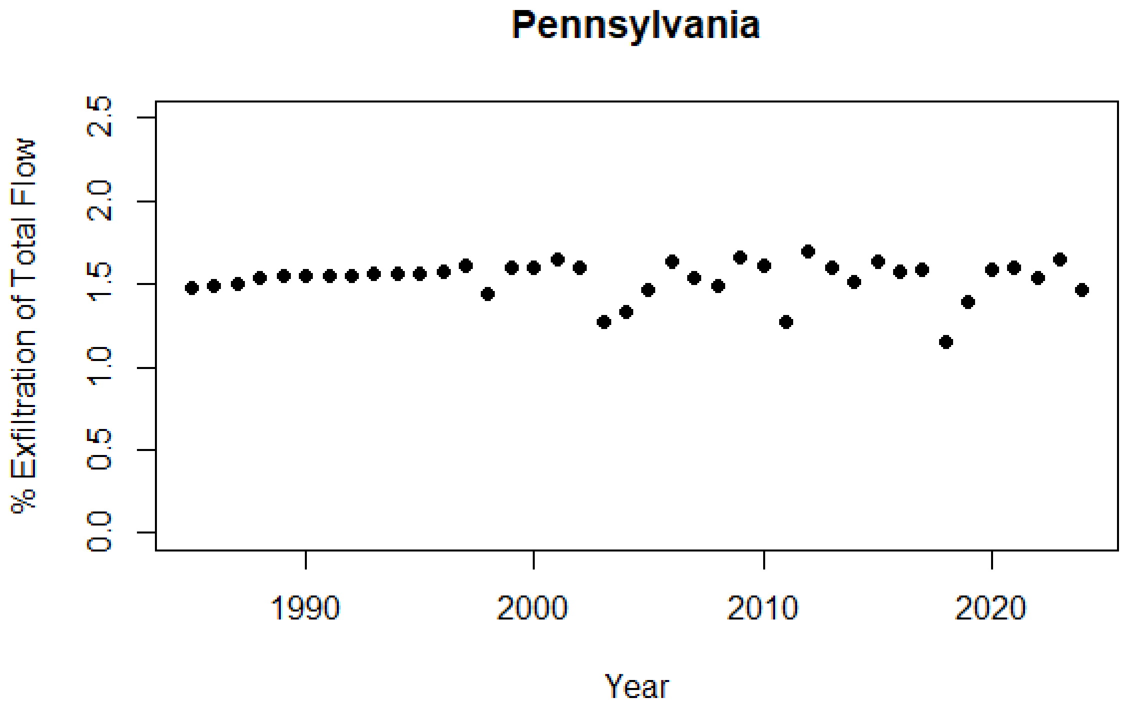
Soil and GW attenuation:

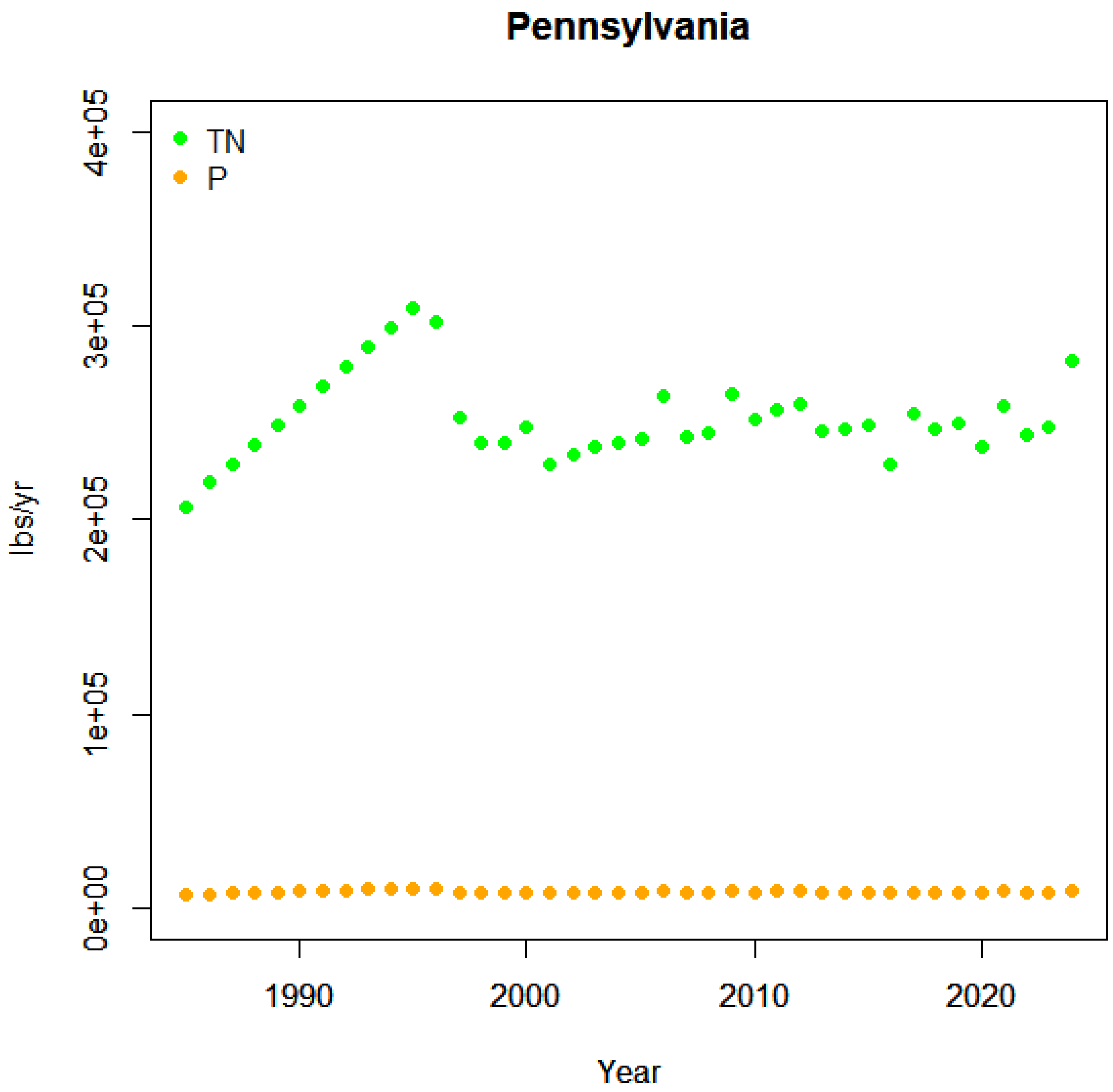
Mean N attenuation is 47%

Mean P attenuation is 89%

Preliminary Results

Pennsylvania	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	307640	237815	251813	9991	7664	8204
% developed load	1.14%	0.75%		0.76%	0.54%	

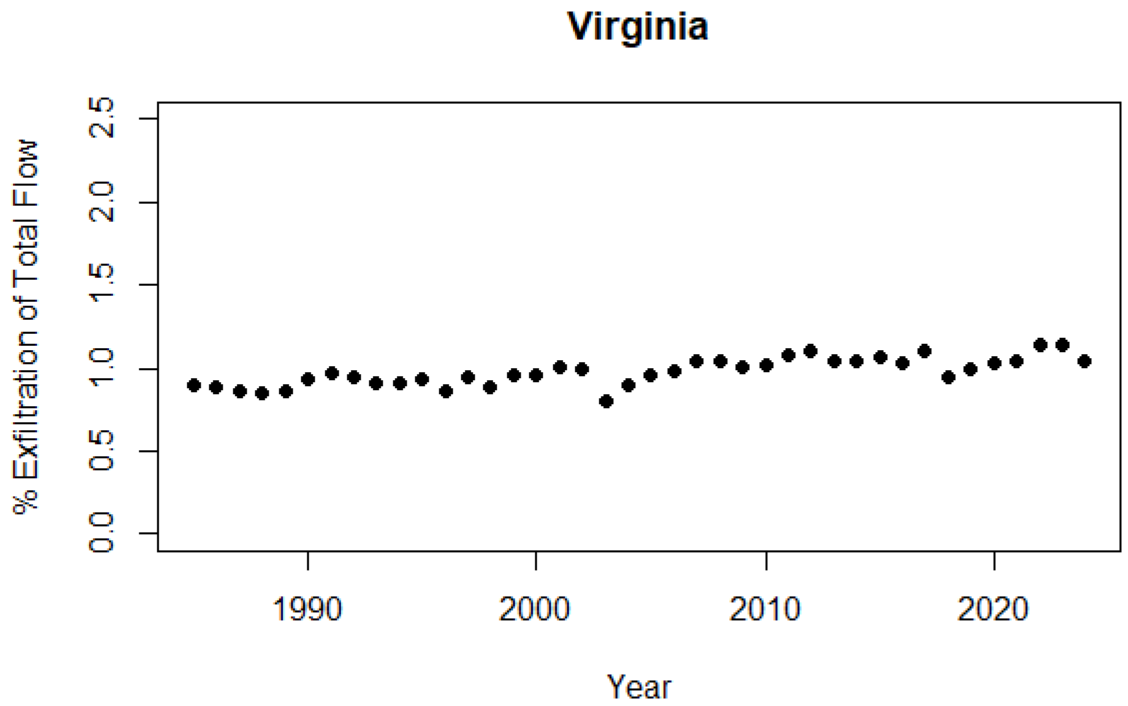


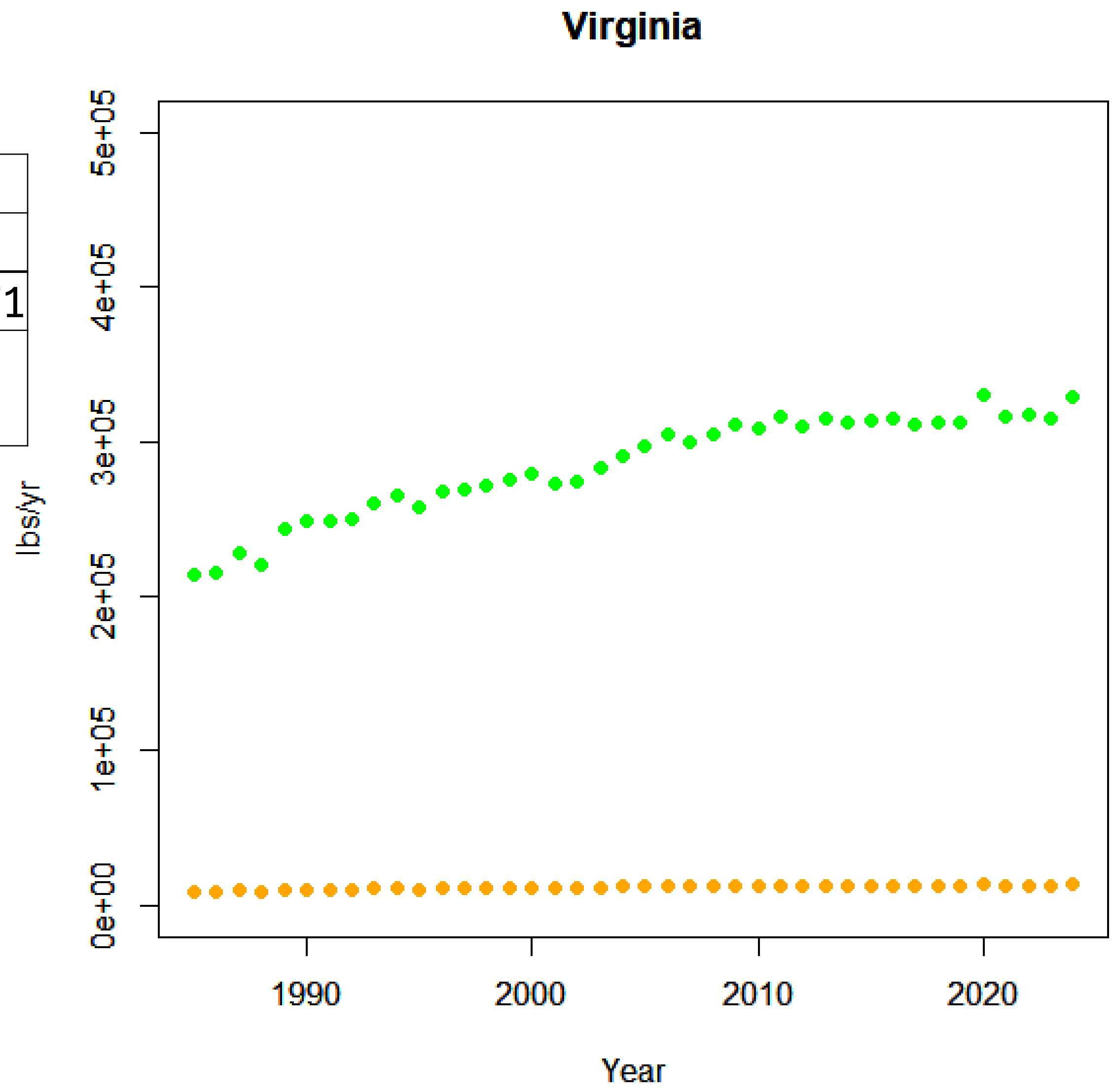


It appears that PA used a linear interpolation to report flows in early years, hence the straight-line response to '95.

Preliminary Results

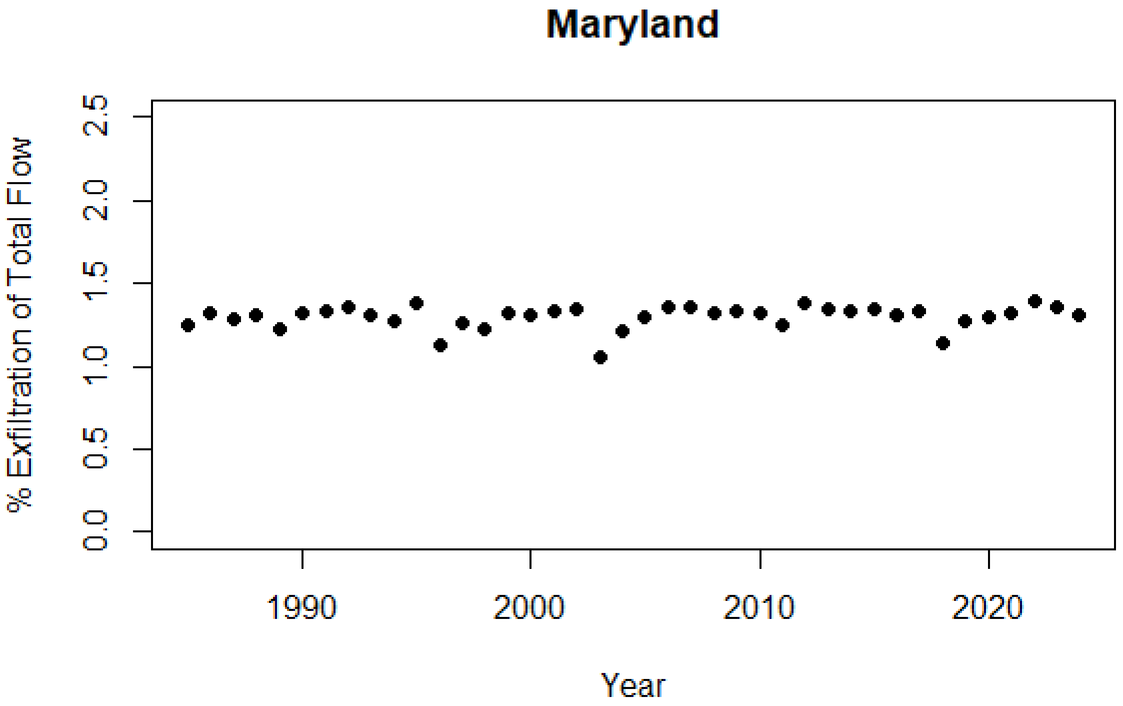
Virginia	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	257629	329797	296464	10710	13453	12271
% of developed load	1.66%	1.63%		0.56%	0.68%	

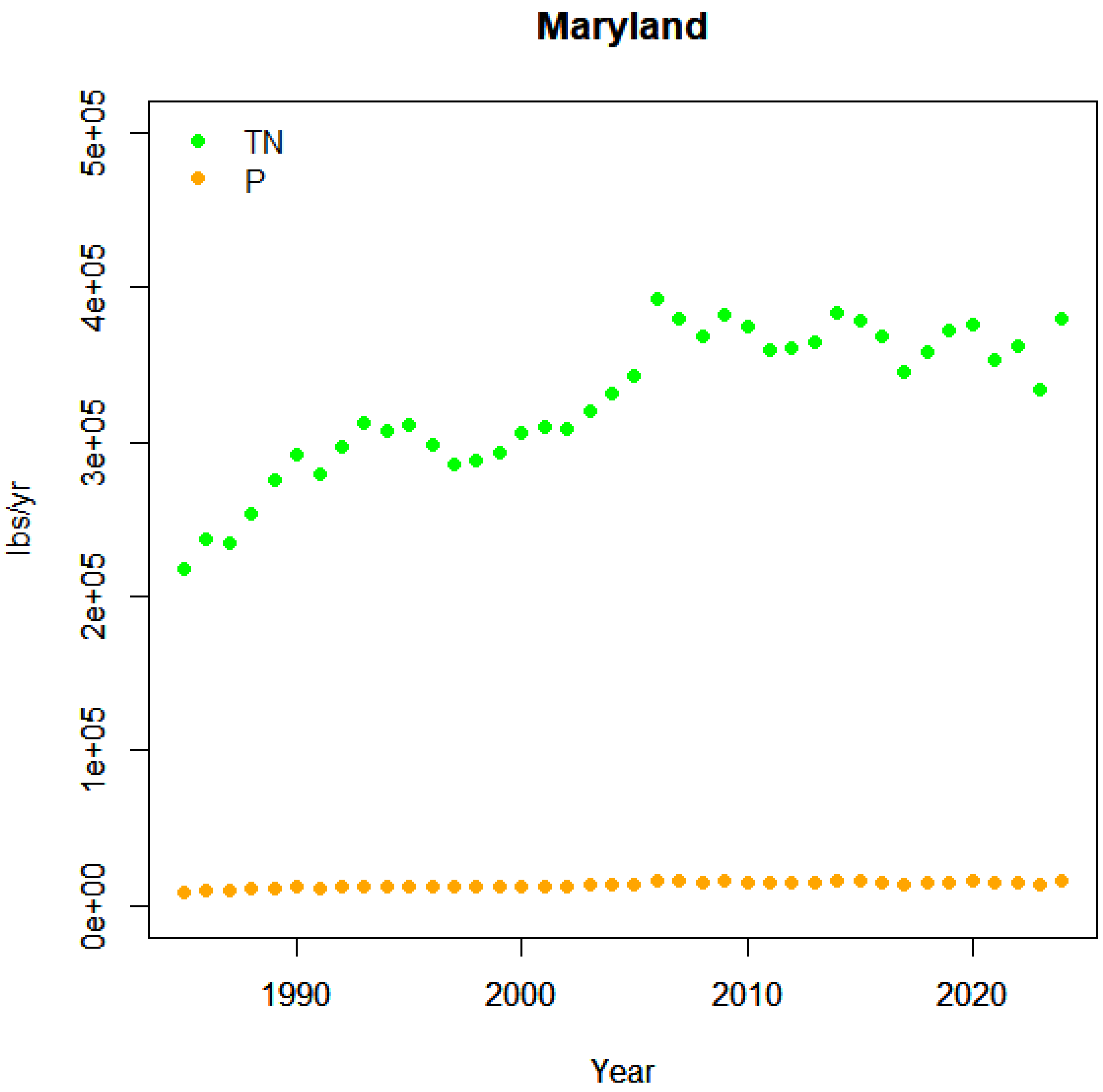




Preliminary Results

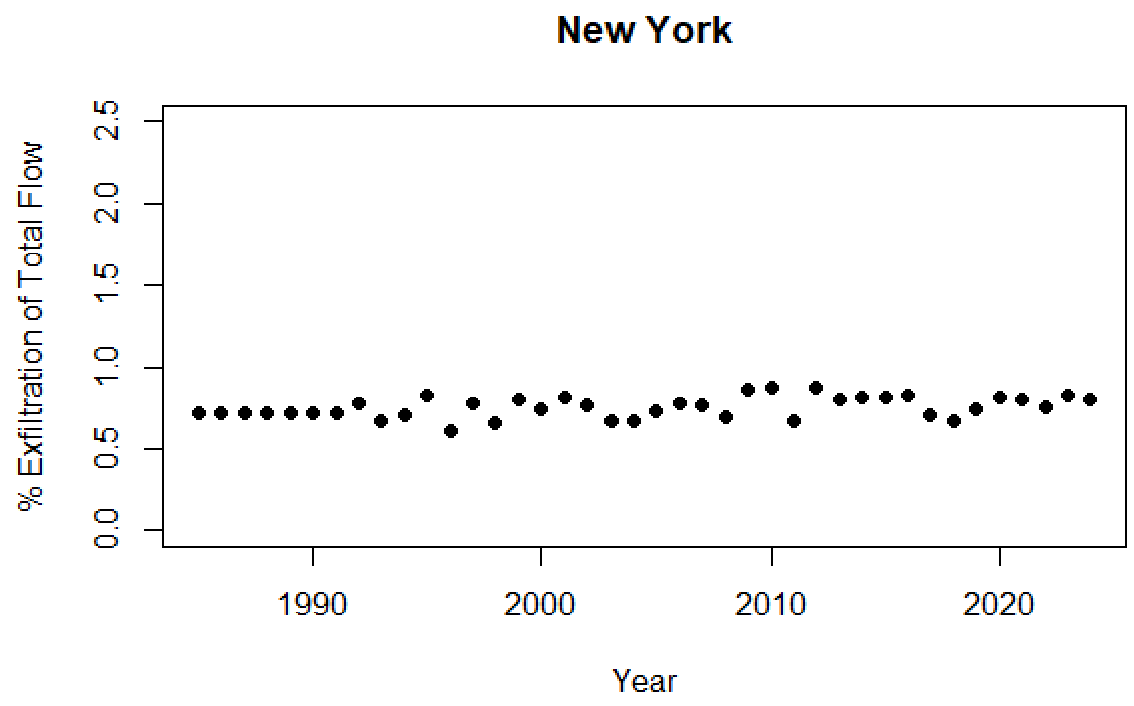
Maryland	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	312664	363168	325787	13226	15452	13762
% developed load	2.10%	2.13%		1.07%	2.24%	

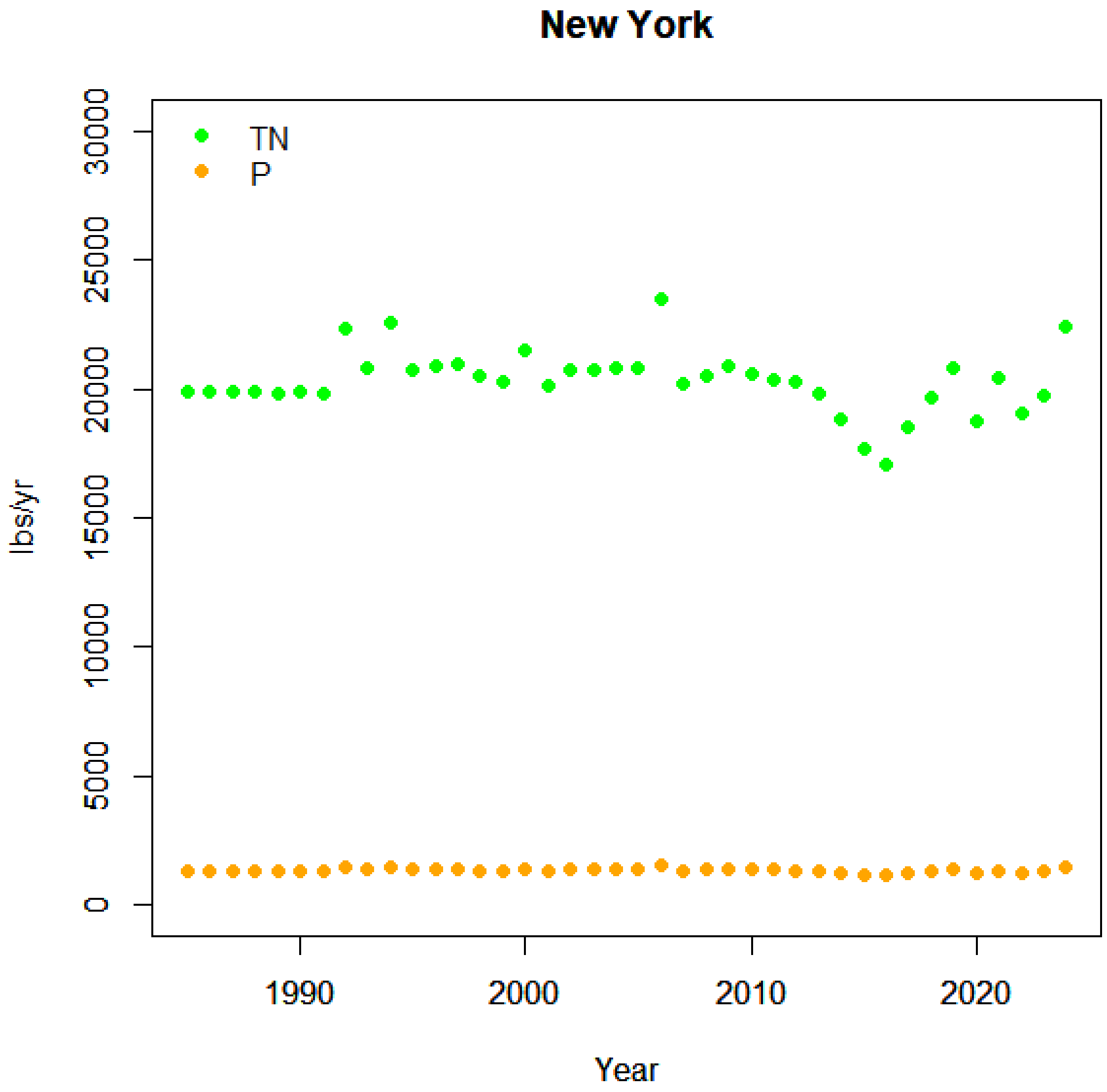




Preliminary Results

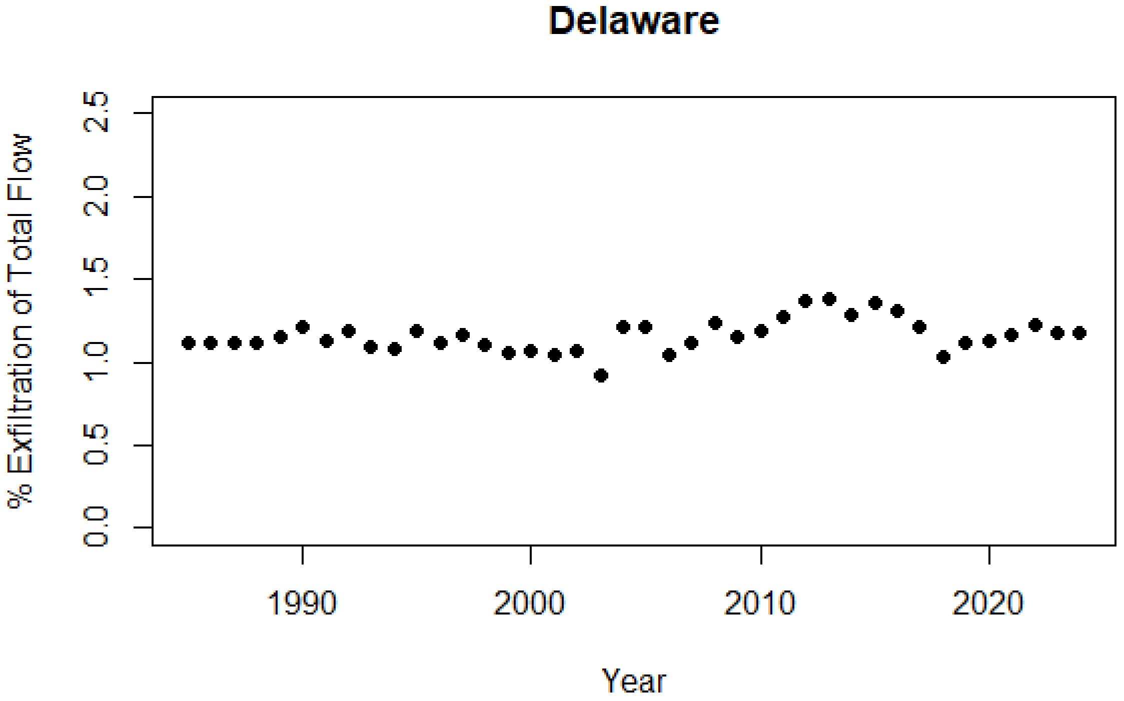
New York	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	20754	18720	20294	1349	1220	1319
% developed load	0.20%	0.16%		0.23%	0.21%	

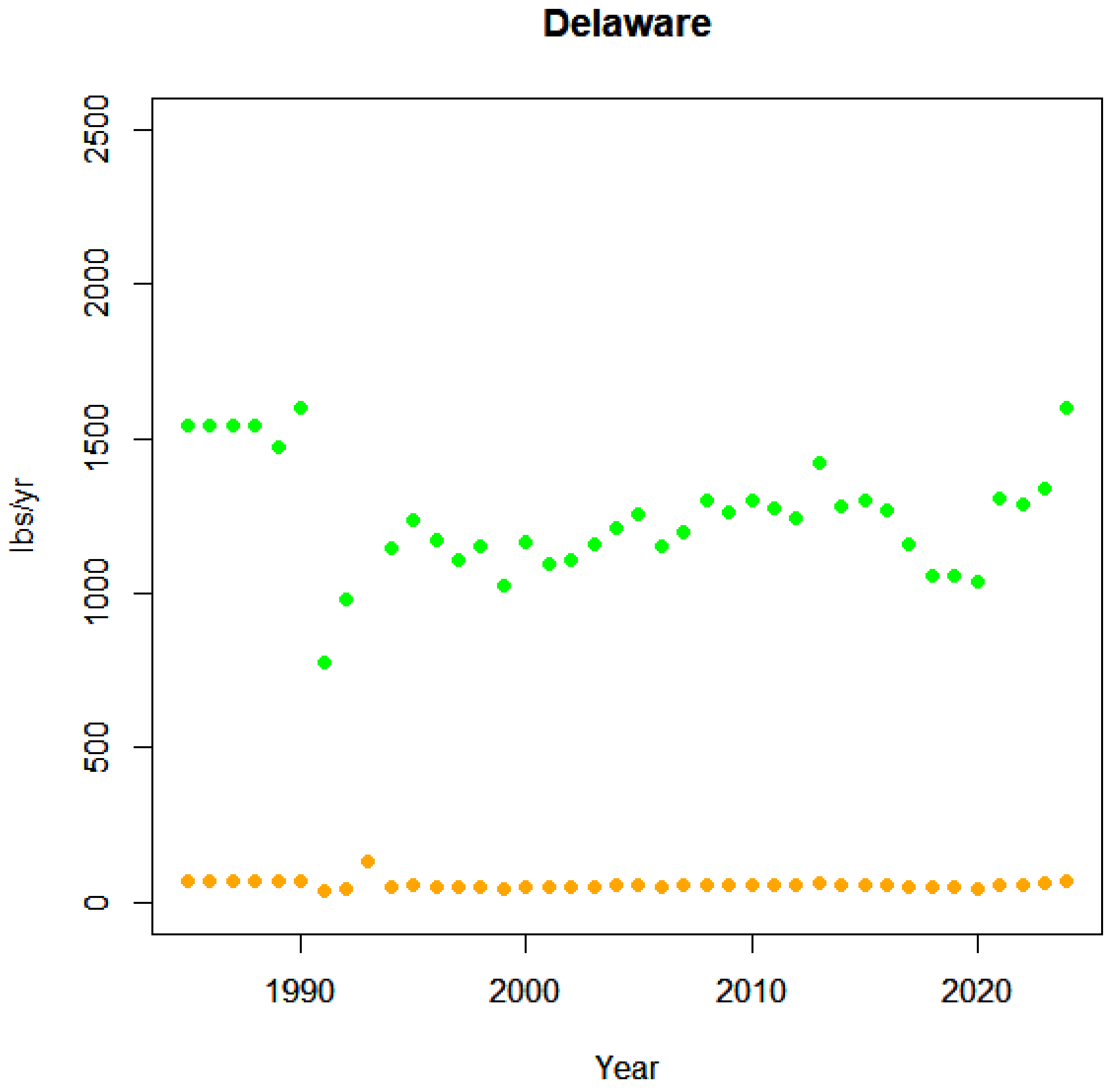




Preliminary Results

Delaware	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	1236	1041	1292	56	47	58
% of developed load	0.04%	0.02%		0.03%	0.02%	

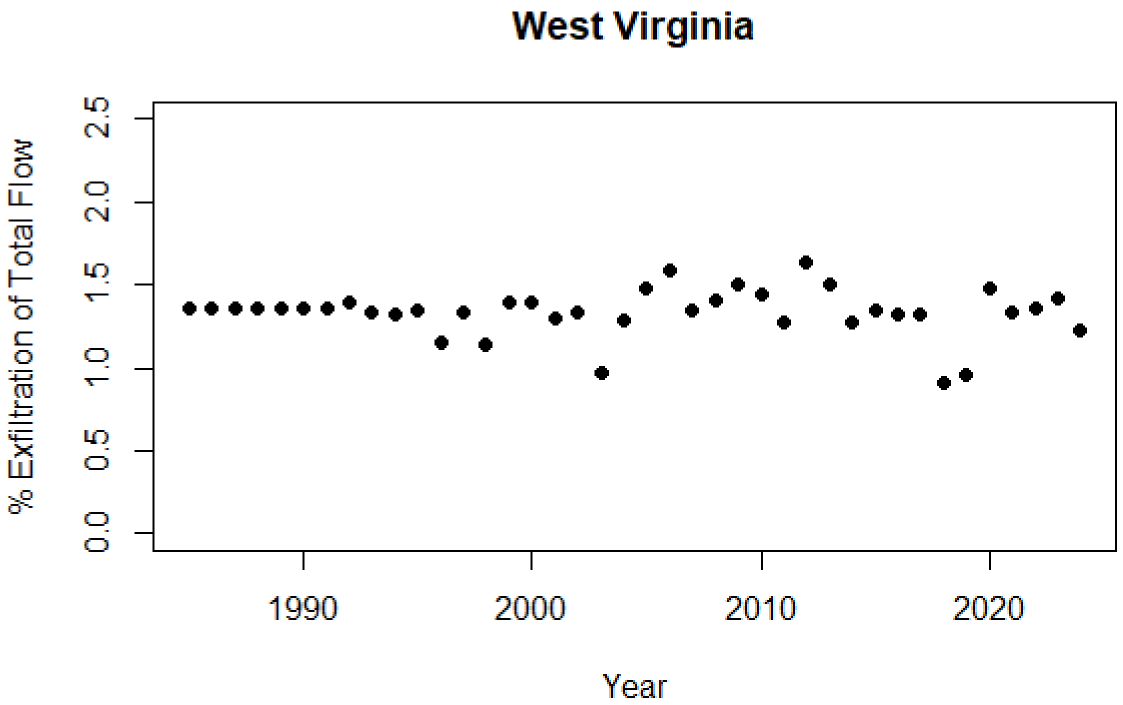


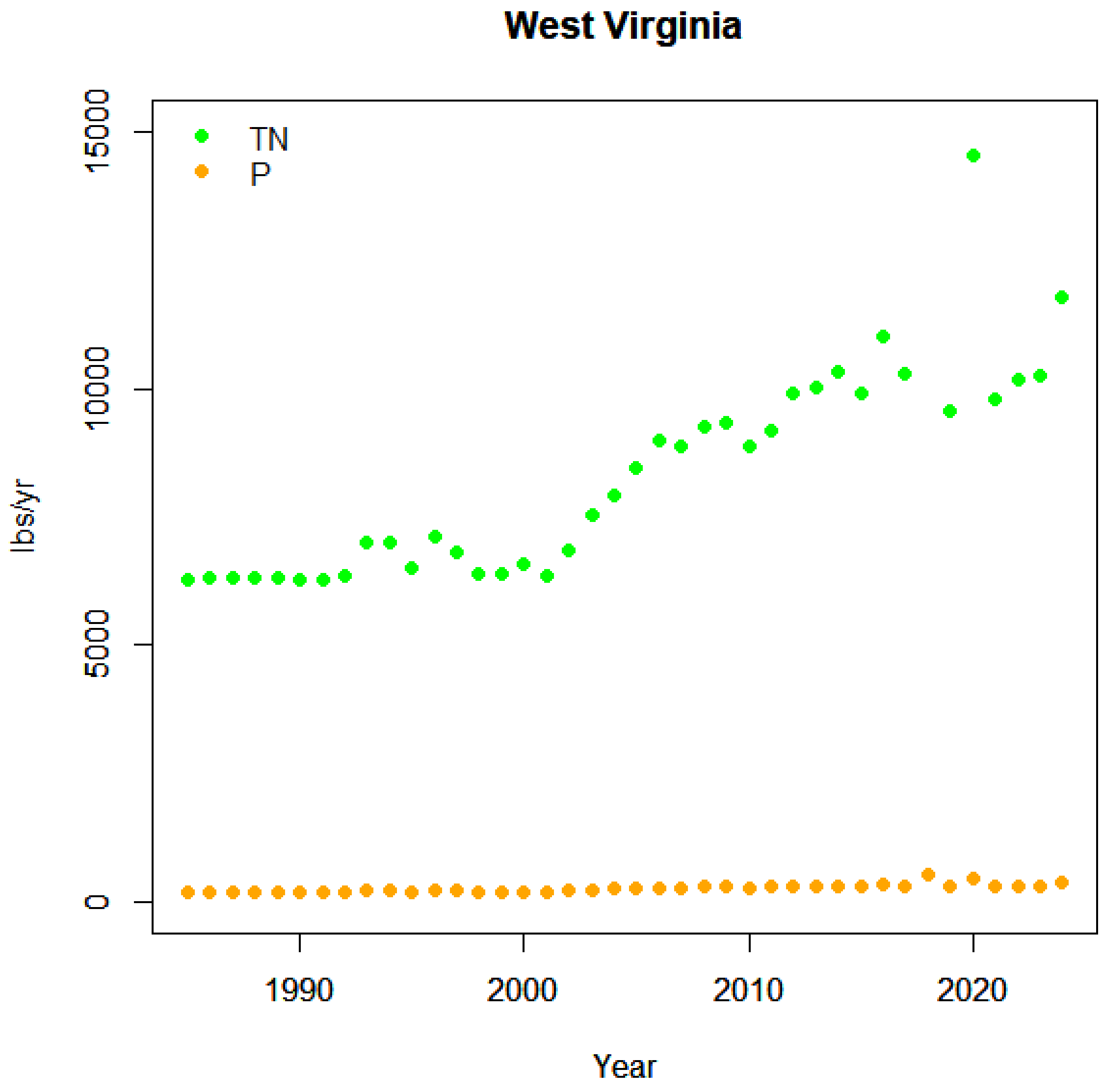


Outfalls may be outside the watershed?

Preliminary Results

West Virginia	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	6513	14546	8510	203	447	264
% developed load	0.37%	0.67%		0.20%	0.35%	

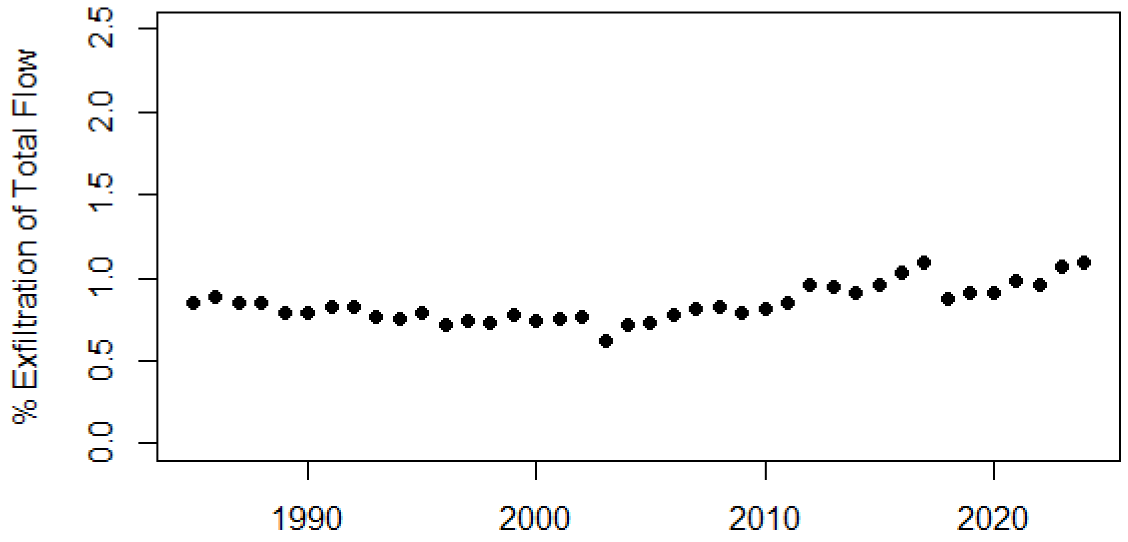


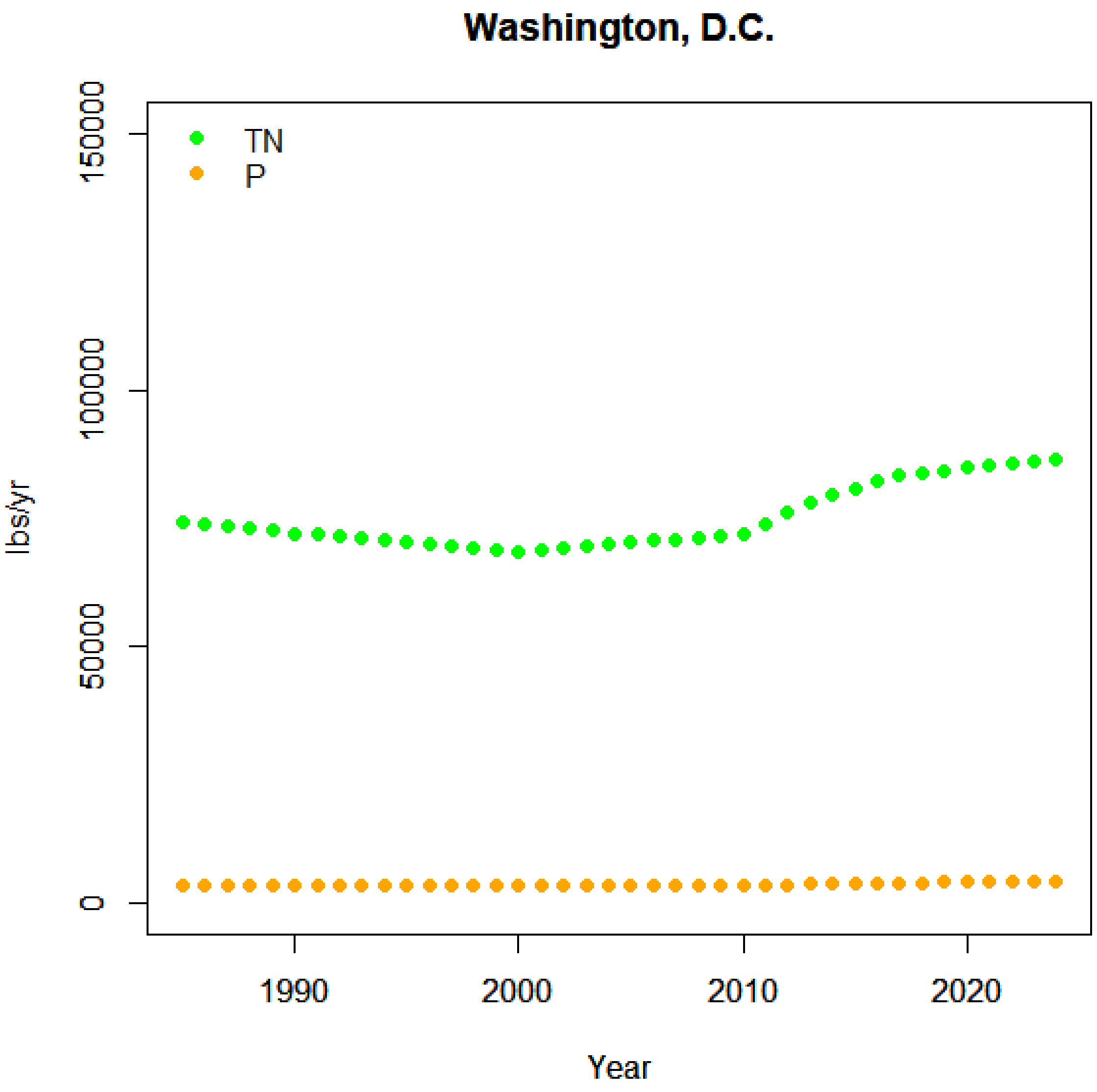


Preliminary Results

Washington D.C.	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	70342	84757	74870	3321	4002	3535
% developed load	25.81%	39.00%		9.55%	22.98%	

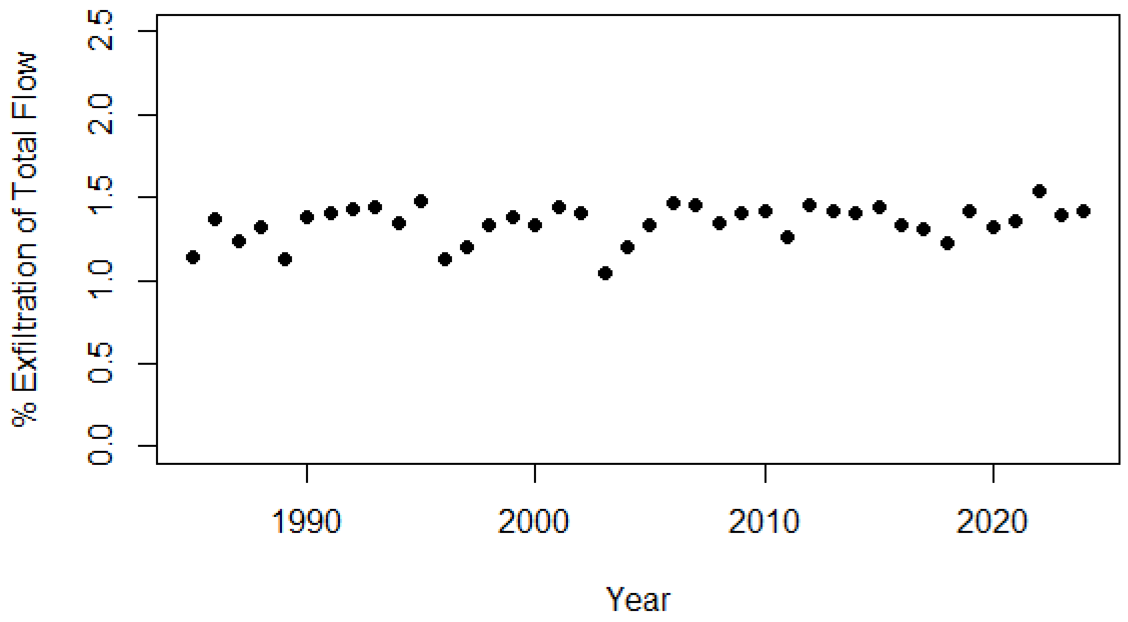
Note: The SSE load is consistent with similar areas, but the % of developed is high because the CAST estimated dev. load is small.

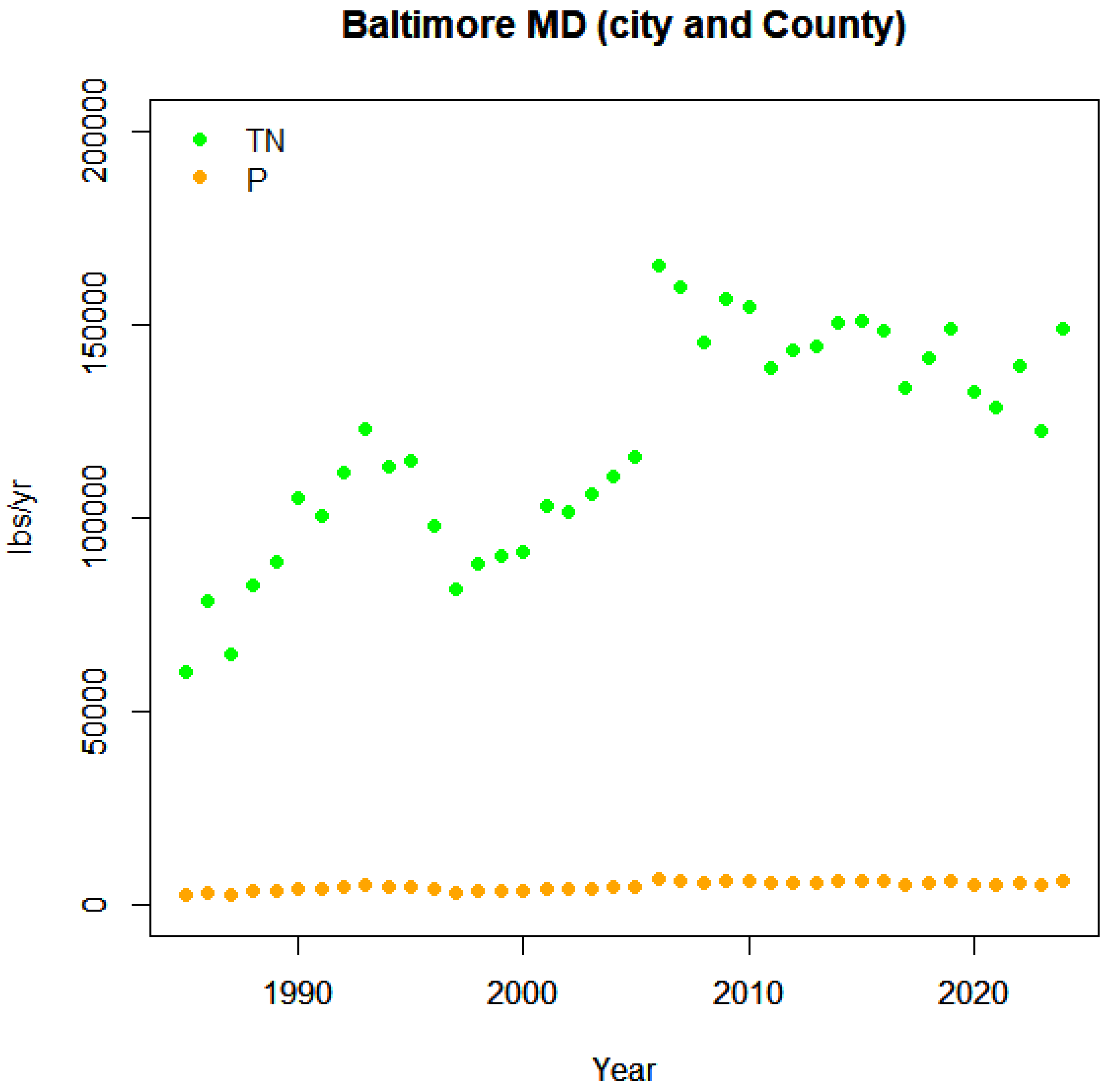




Preliminary Results

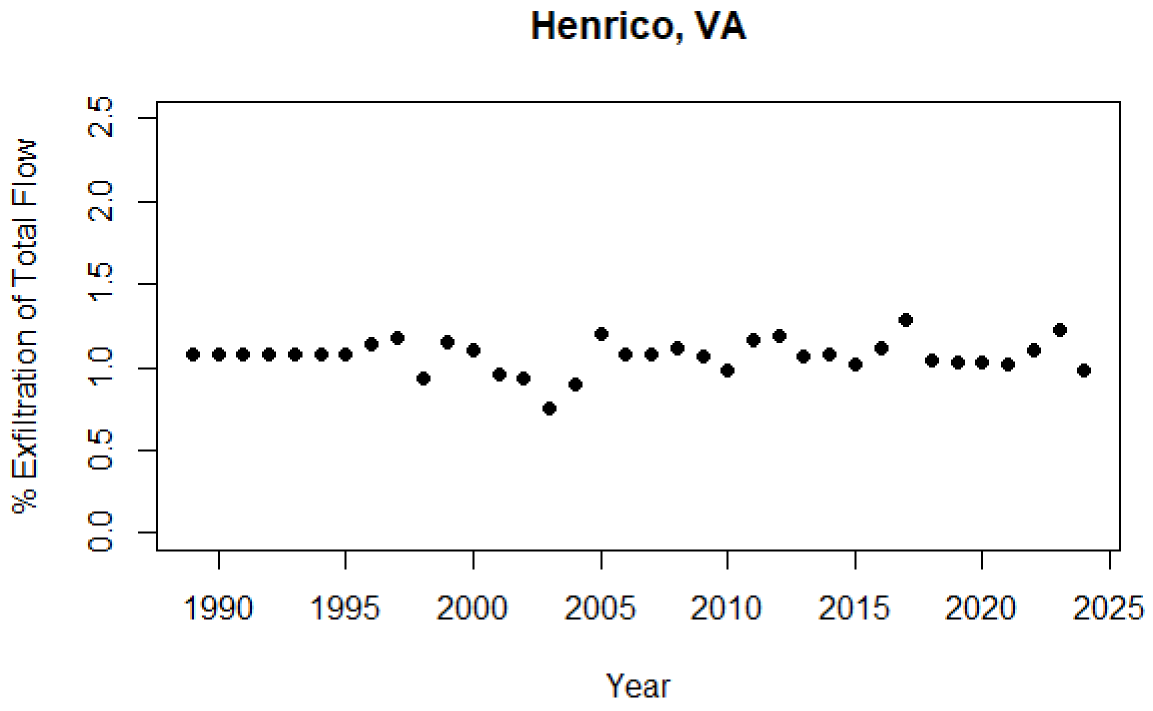
Baltimore (city+county)	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	114785	132735	119597	4549	5223	4730
% of developed load	5.73%	6.35%		2.71%	5.74%	

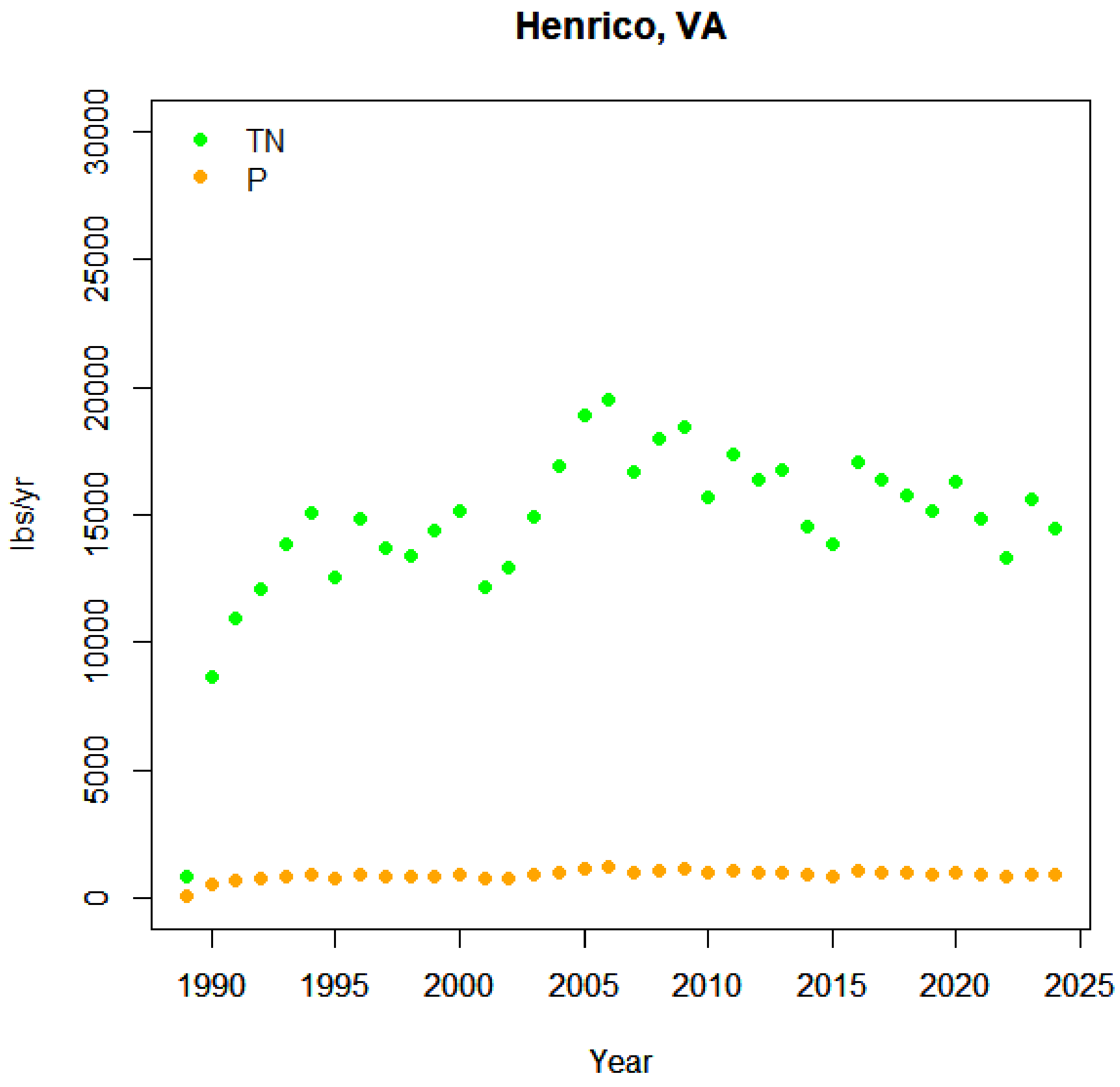




Preliminary Results

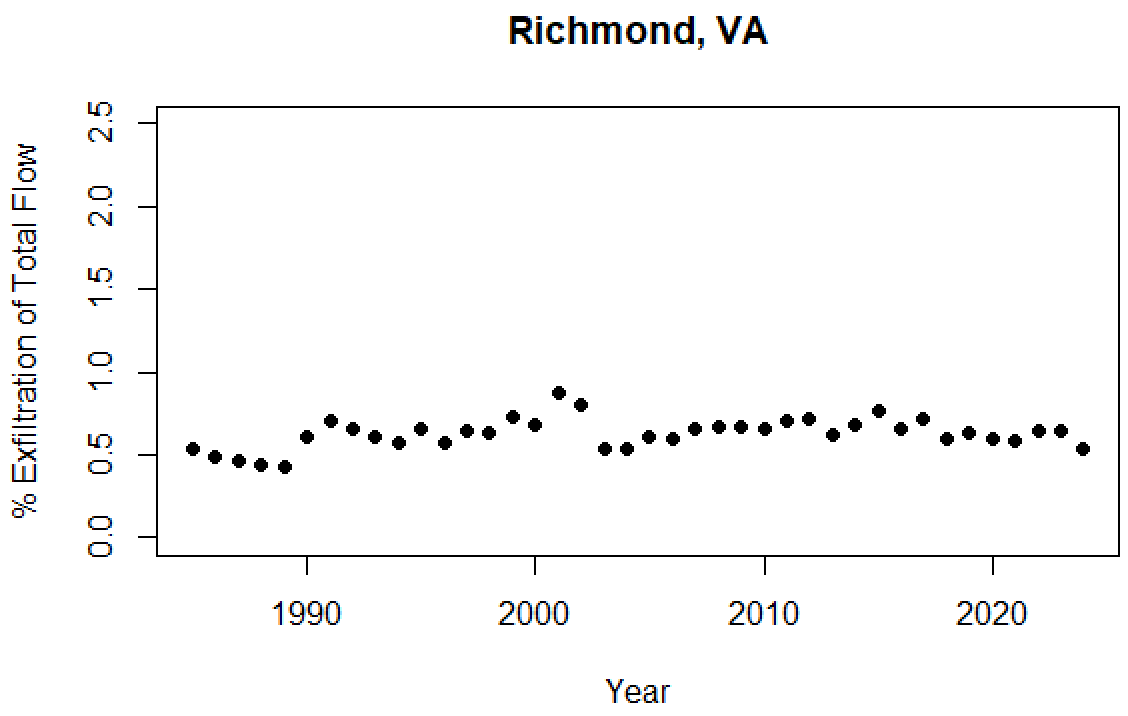
Henrico, VA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	12568	16257	14635	760	984	886
% of developed load	2.51%	2.49%		1.37%	1.72%	

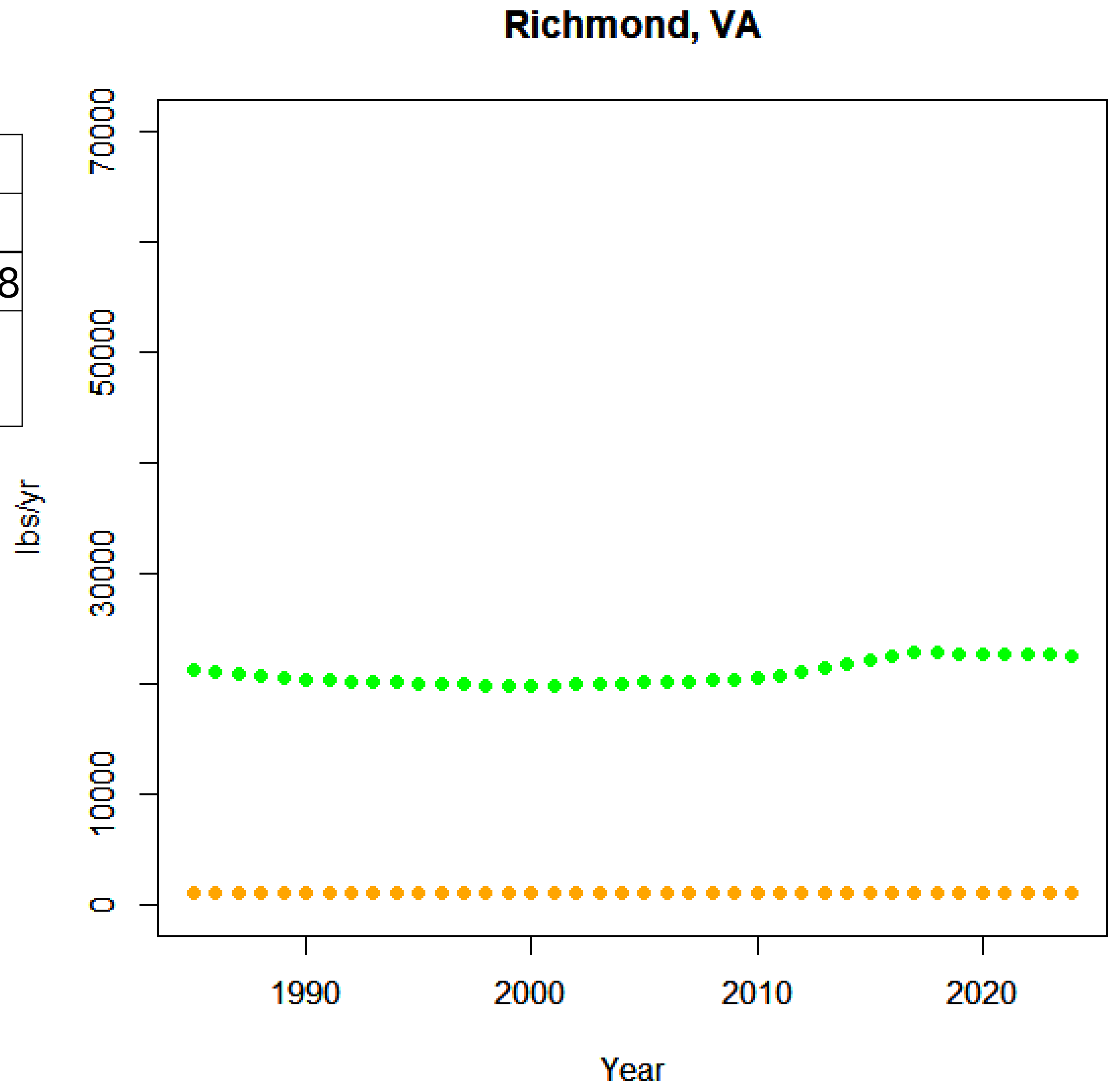




Preliminary Results

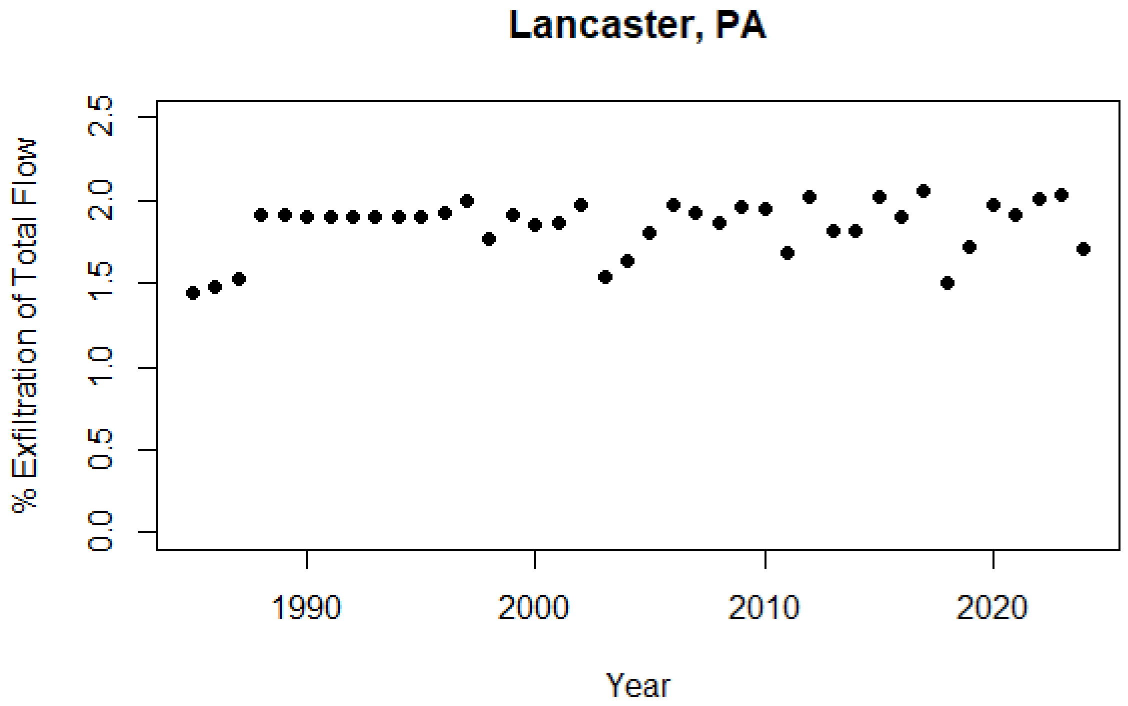
Richmond, VA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	20041	22789	22741	994	1130	1128
% developed load	5.67%	6.27%		2.43%	2.95%	

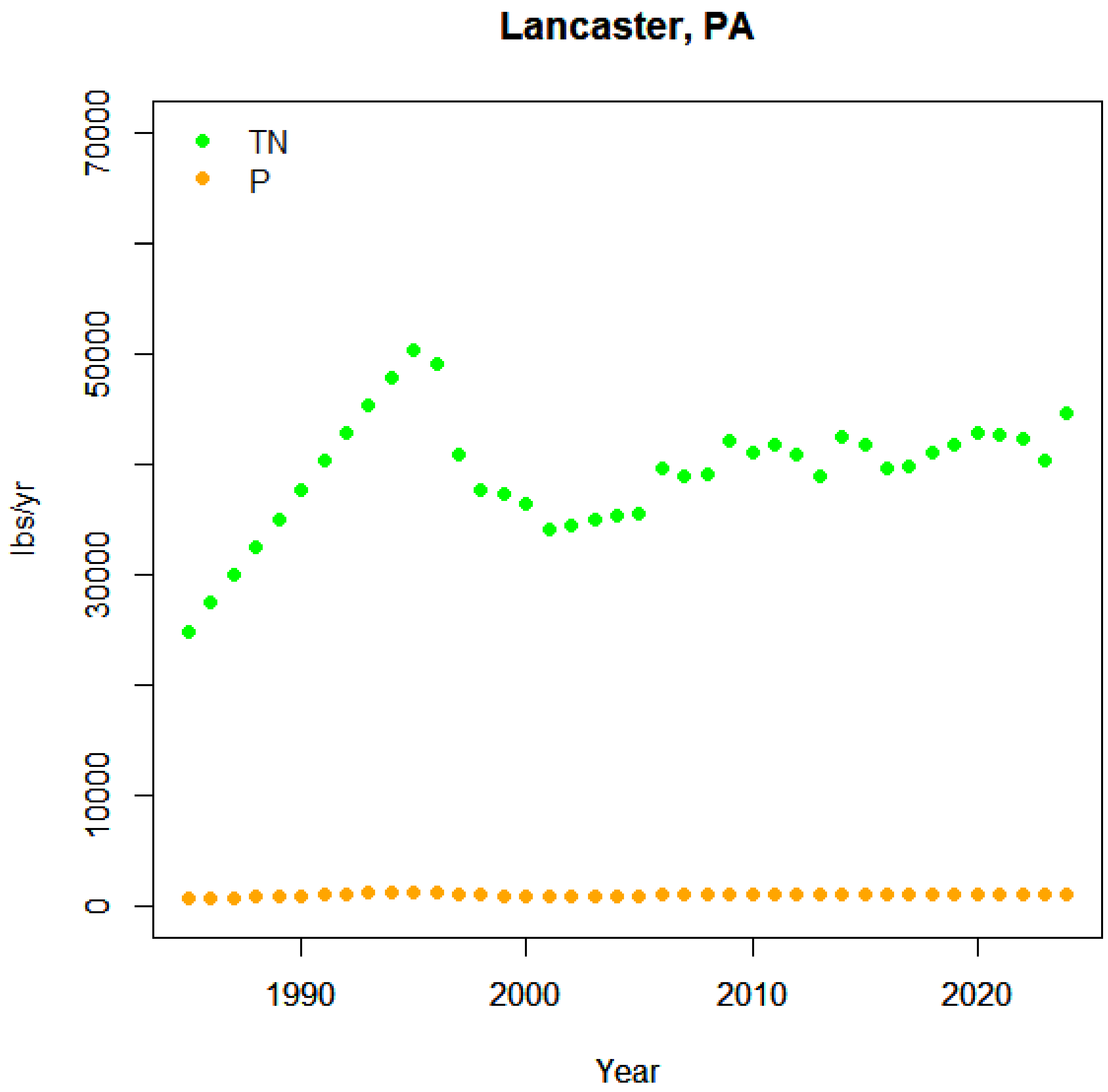




Preliminary Results

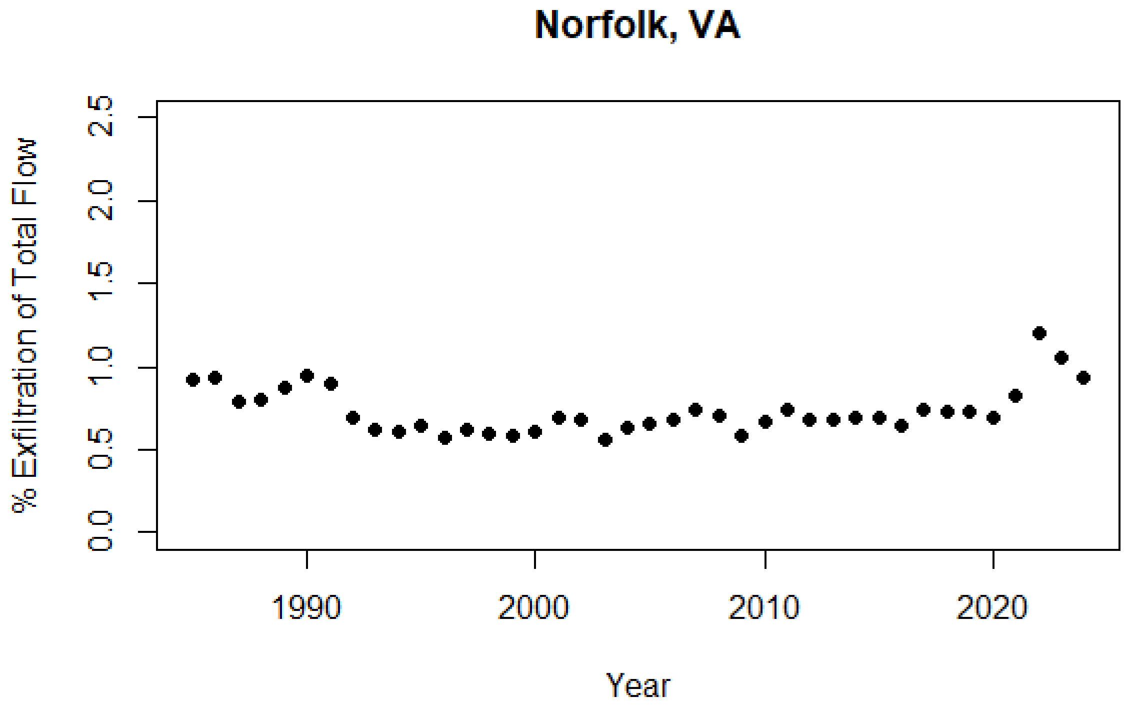
Lancaster, PA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	50334	42858	39285	1283	1084	999
% of developed load	1.69%	1.15%		1.30%	0.97%	

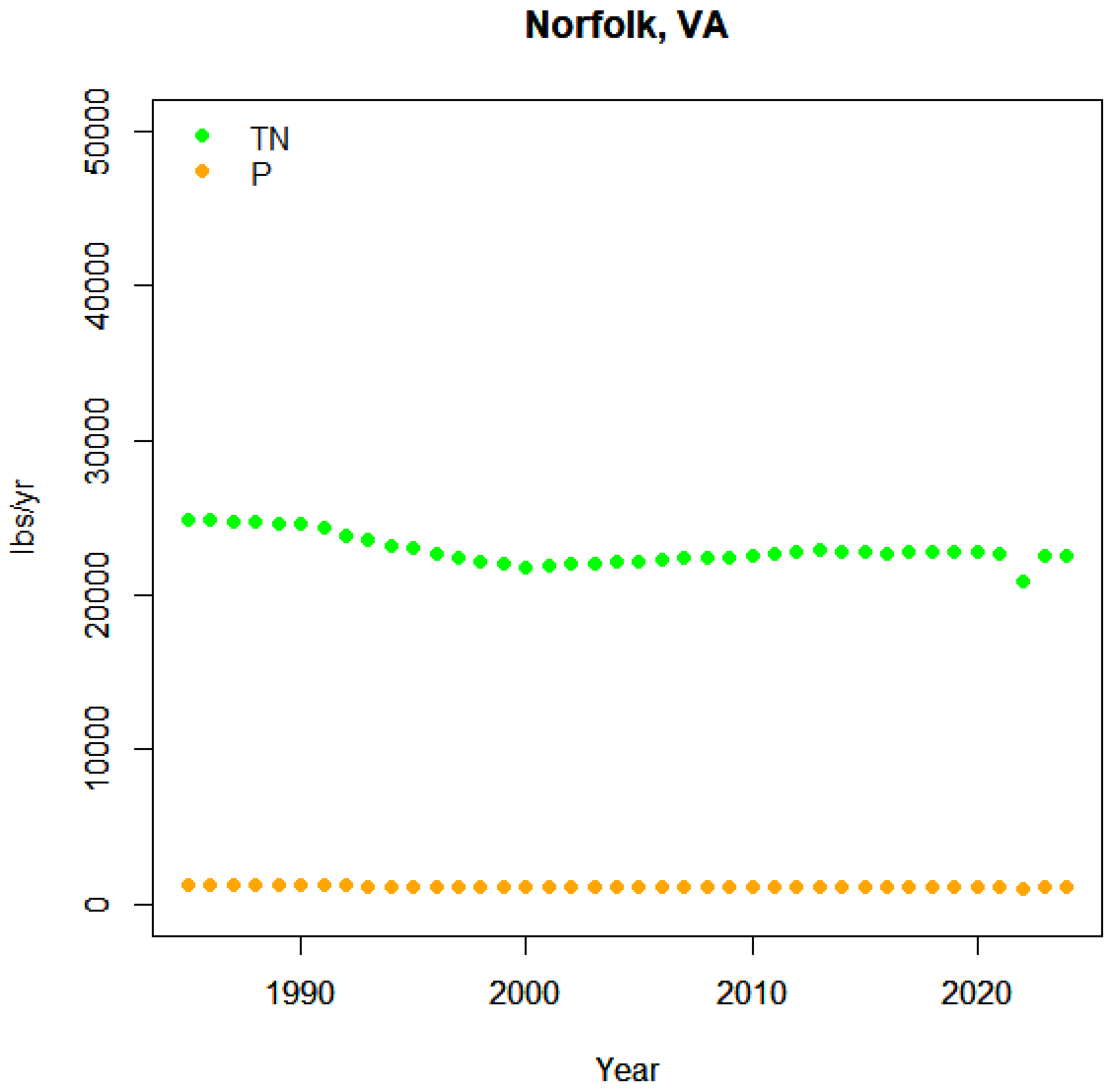




Preliminary Results

Norfolk, VA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	23015	22862	22814	1160	1150	1148
% developed load	6.86%	6.55%		4.07%	4.64%	





Discussion

Decision

The methodology detailed in this presentation should be used to estimate the baseline exfiltration and edge of stream delivery of nitrogen and phosphorus from sanitary sewers.

Exfiltration Vol. = Fraction exfiltration * Annual system treatment volume (dry-weather) * Geologic coef. * Fraction gravity line * (Fraction new or rehabbed*Rehabbed coef.)

Exfiltrated nutrient mass = Exfiltration Vol. * concentration in raw WW (33 mg/L TN, 6 mg/L TP)[1]*Soil Treatment * GW Transmission

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