Spatial Estimates of Phosphorus Transport in the Chesapeake Bay Watershed

An Application of the SPARROW model

by Scott W. Ator and Ana María García

Topics

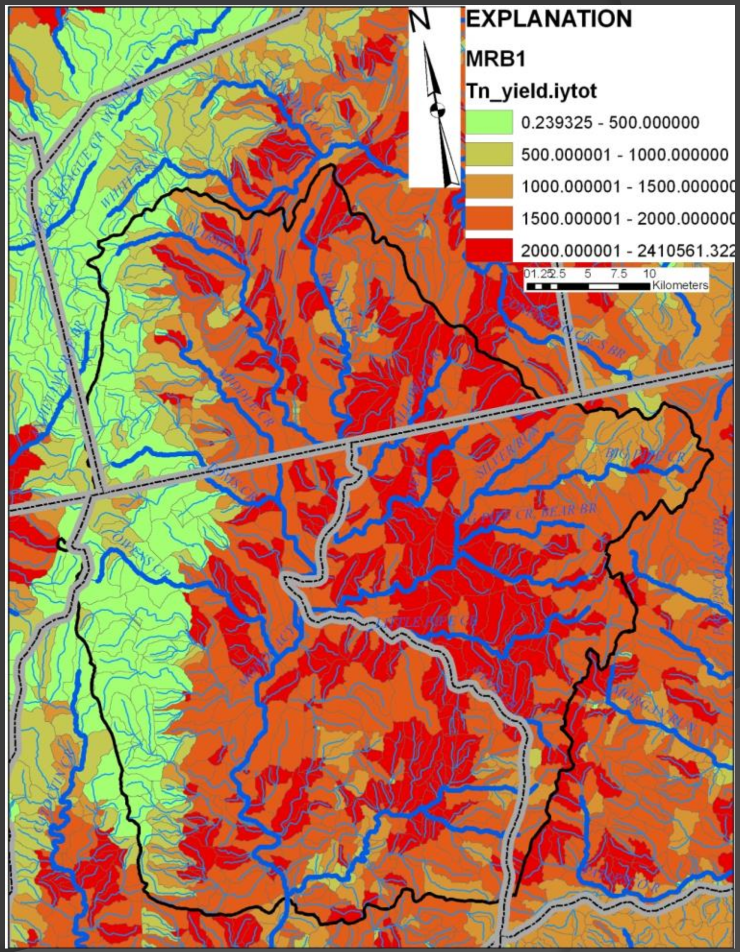
- Summary of research questions, objectives, and approach
- Preliminary results for TP
- Ideas for further investigations…

Research Questions

- Mass Budget:
  - What is the relative importance of uplands vs. stream corridors to the removal or retention of N and P between application areas and the bay?
  - How much N and P are removed or retained in upland landscapes, annually?
  - How much of a net change in N or P storage in the landscape might this represent?
- Understanding Upland Processing:
  - In what areas of the upland landscape are N or P processed/retained/transmitted differently? Why?

Conceptual Model – Budget Approach

- Over the long-term, contaminant transport from source, *n*, within a catchment, *i*, can be represented by a budget:
  - Inputs = Outputs +/- Any net change in storage
- Inputs might include natural or human applications (such as fertilizer)
- Outputs might include removal, such as through denitrification or stream flow.
- Change in storage could include sequestration in or removal from soils or biomass



Conceptual Model – Budget Approach

- Mass Balance:
  - Sni = UPLni + TAQLni + Dni
  - Sni = (UPHni + UPOni) + TAQLni + Dni

- Sni= mass of contaminant applied from source n to catchment i
- Mass of contaminant from source n applied to catchment i that:
  - UPLni = is lost within uplands in catchment i
  - UPHni = is lost to crop harvest in uplands in catchment i
  - UPOni = is lost to processes other than crop harvest in uplands in catchment i
  - TAQLni = is lost within the stream corridor within or downstream of catchment i
  - Dni = is delivered to downstream tidal (ie. terminal) waters

Conceptual Model – Budget Approach

- Mass Balance:
  - Sni = UPLni + TAQLni + Dni
  - Sni = (UPHni + UPOni) + TAQLni + Dni

- All terms are in units of mass/time (ie. kg/year)
- All terms are specific to each individual source, n
- Because they are specific to each catchment, i, they can be viewed individually or summed over subareas (like subwatersheds or hydrogeologic settings), which can be useful given the relative uncertainty in predictions for individual catchments

Conceptual Model – Budget Approach

- Mass Balance:
  - Sni = UPLni + TAQLni + Dni
  - Sni = (UPHni + UPOni) + TAQLni + Dni

Input to SPARROW (for *intensive* sources – see Schwarz et al, 2006, p. 44)

Can be computed with an independent estimate of one or the other

Can be computed from SPARROW output

Estimated by SPARROW

The budget equation can be solved for each catchment with routine output from the steady-state SPARROW model. This does not require additional model calibration or predictions.

Background – SPARROW Coefficients

- Source coefficients
  - Intensive or extensive
  - Estimate mean proportion or yield delivered to streams
- Land-to-water coefficients
  - Allow for spatial variability in delivery to streams
  - Positive or negative
- Stream decay coefficients

RMSE=0.4741, R^2=0.9510, yieldR^2=0.7300

Phosphorus Model	Estimate	p
Sources		
Point sources (kg/yr)	0.877	<0.0001
Urban land (km^2)	49	<0.0001
Fertilizer (kg/yr)	0.0377	0.0014
Manure (kg/yr)	0.0253	0.0002
Siliclastic rocks (km^2)	8.52	<0.0001
Crystalline rocks (km^2)	6.75	0.0009
Land to Water Transport		
Soil erodibility (k factor)	6.25	0.0002
Ln(% well drained soils)	-0.100	0.0019
Ln(precipitation (mm))	2.06	<0.0237
Coastal Plain (area)	1.02	<0.0001
Aquatic Decay		
Impoundments	54.3	0.0174

Ator et al., 2011

Computing Upland Loss (UPL_{ni})

- $UPL_{ni} = S_{ni} (1 – LDR_{ni})$
- LDR_{ni} = Landscape delivery ratio, or the proportion of contaminant from source n in catchment i that reaches the local stream (Hoos and McMahon, 2009):

$$LDR_{ni} = \alpha_n DVF_i$$
$$= \alpha_n \exp(\Sigma_m(\omega_{mn} Z_{mi} O_m))$$

α_n = model-estimated coefficient for source n. This is also the mean LDRni.

DVF_i = delivery variation factor or "delivery factor" (Schwarz et al, 2006), or "relative upland erosion vulnerability" (Ator et al., 2010)

m = individual land-to-water term in the model

ω_{mn} = interaction between source n and land-to-water term, m (0,1)

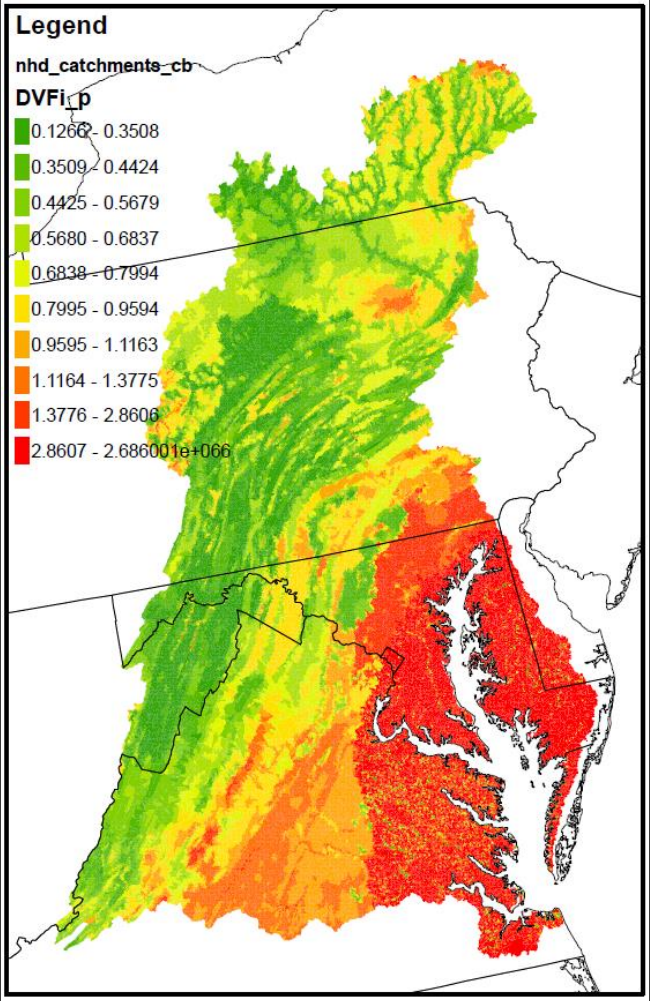
Z_{mi} = mean-adjusted value of term m in catchment i

O_m = model-estimated coefficient for land-to-water term m

Some Preliminary Results…

- Question: In what areas of the upland landscape is P processed or transmitted differently? Why?
- Approach: Look at the $DVF_i = \exp(\Sigma_m(\omega_{mn} Z_{mi} O_m))$
  - A continuous function of land-to-water terms demonstrated by the model to be significant to transport from uplands to stream corridors
  - Allows for spatial variability of land-to-water transport among catchments in SPARROW models

Delivery Variation Factor (DVF_i)

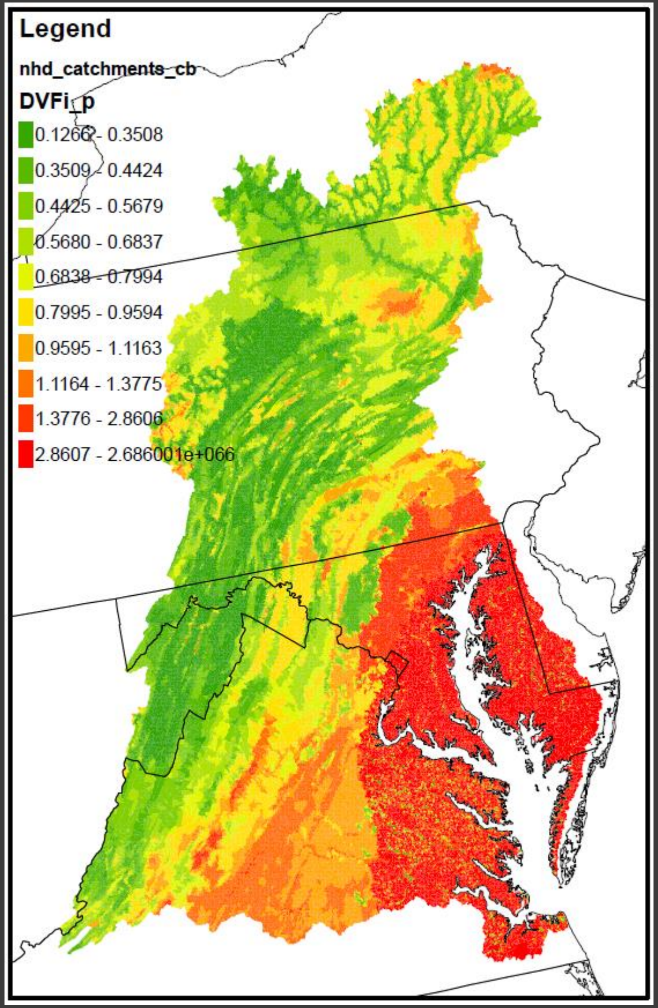


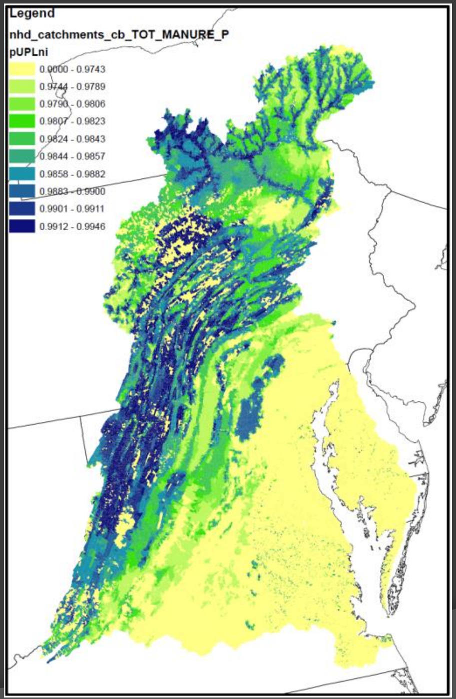
- Is independent of source*, a function only of land-to-water specification
- TP terms
  - Soil erodibility (+)
  - Soil drainage (-)
  - Coastal plain area (+)
  - Precipitation (+)

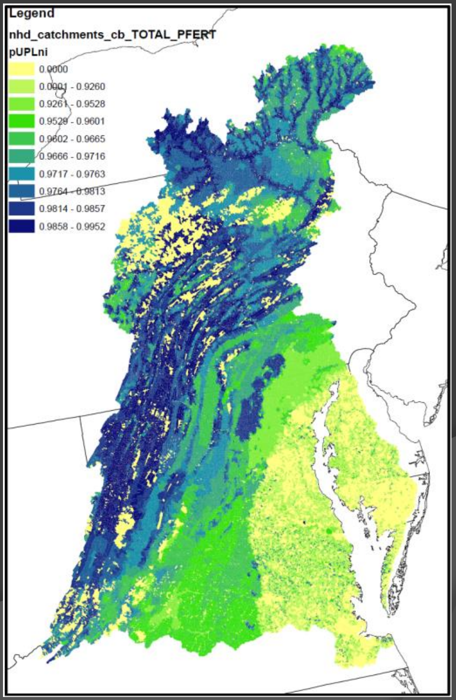
*$DVFi = \exp(\Sigma_m(\omega_{mn} Z_{mi} O_m))$, for sources interacting with same land-to-water terms

Relative Losses

- Proportion of TP from that is lost in uplands
- This is really just a function of DVFi, as:
  - UPLni = Sni (1 – LDRni)
  - UPLni / Sni = 1- LDRni
  - UPLni / Sni = 1 – αn DVFi

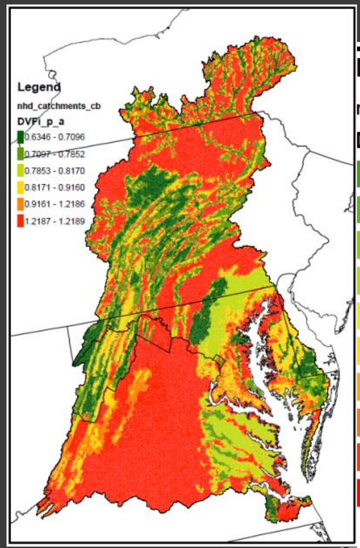


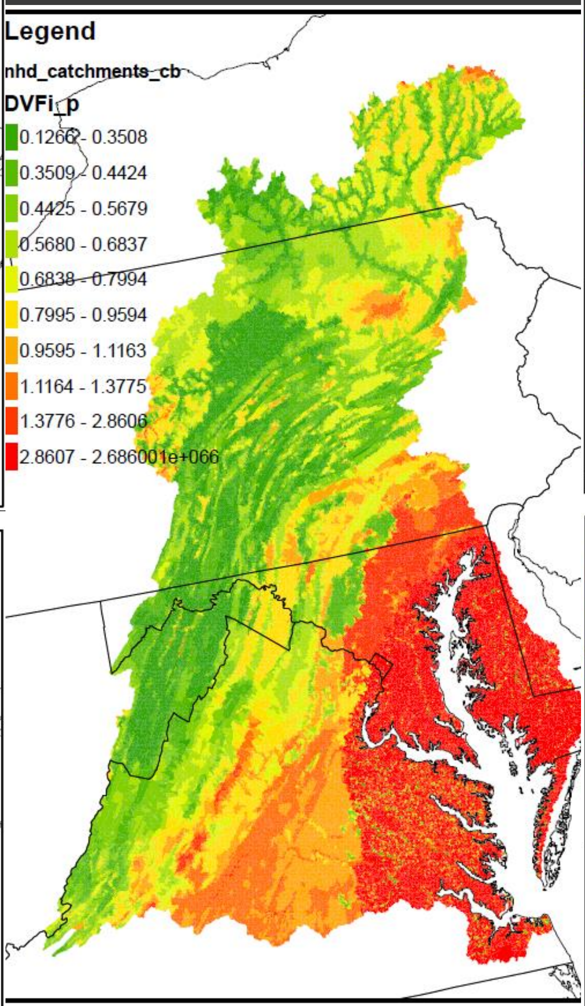




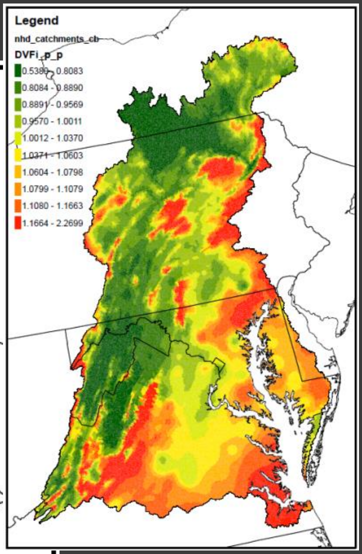
Explaining DVF_i - Phosphorus

Type A Soils (-)

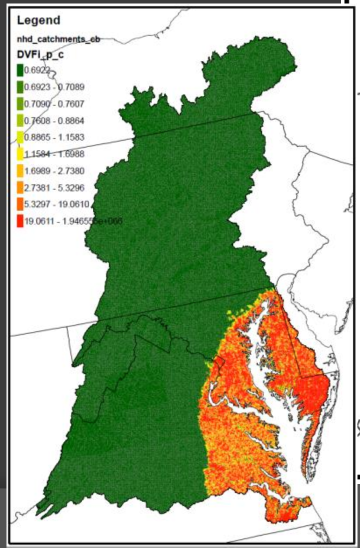




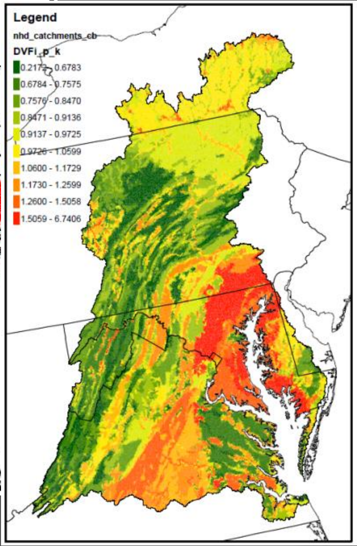
Precip (+)



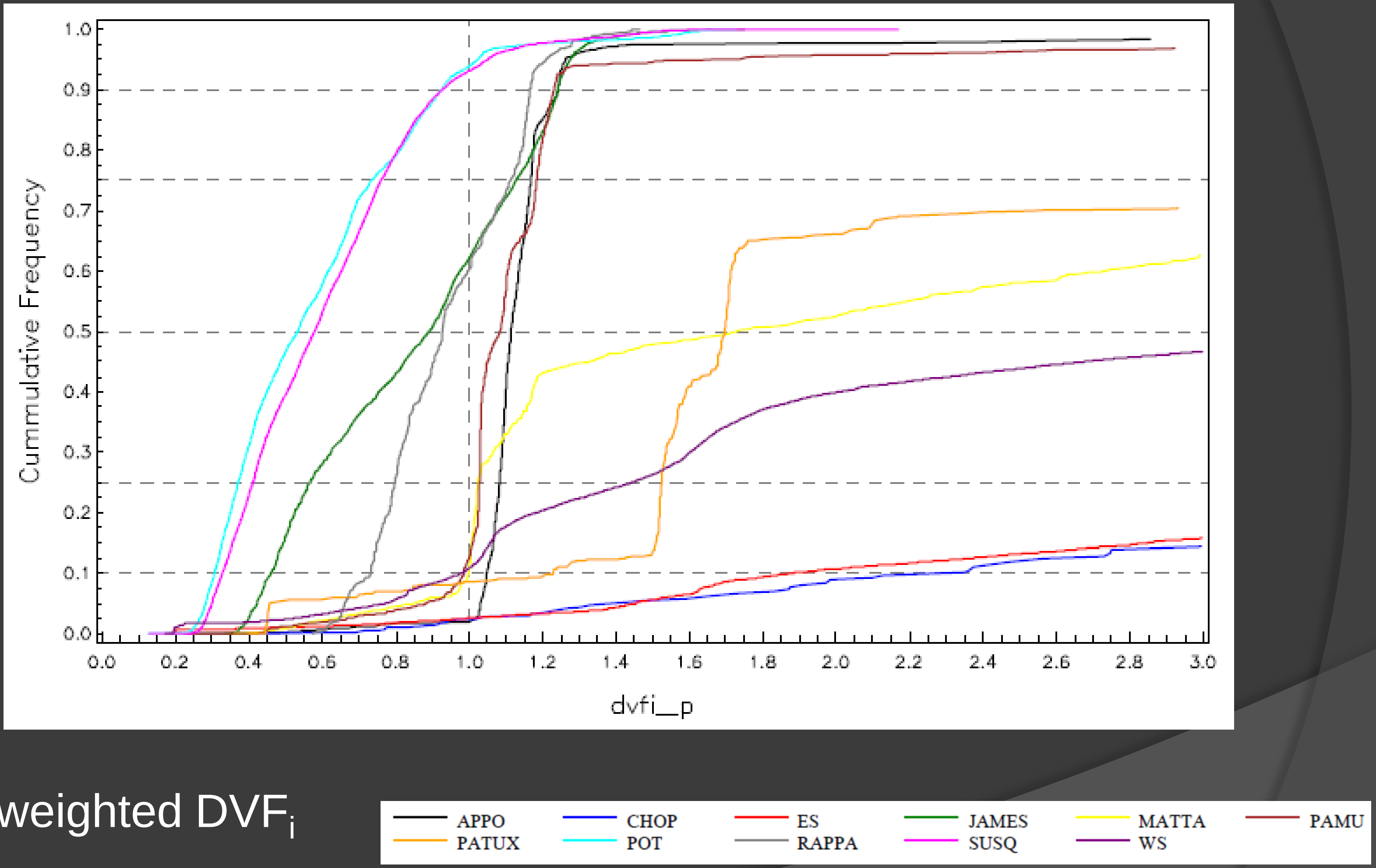
Coastal Plain (+)



Soil K-factor (+)



Delivery Variation Factor (DVF_i)

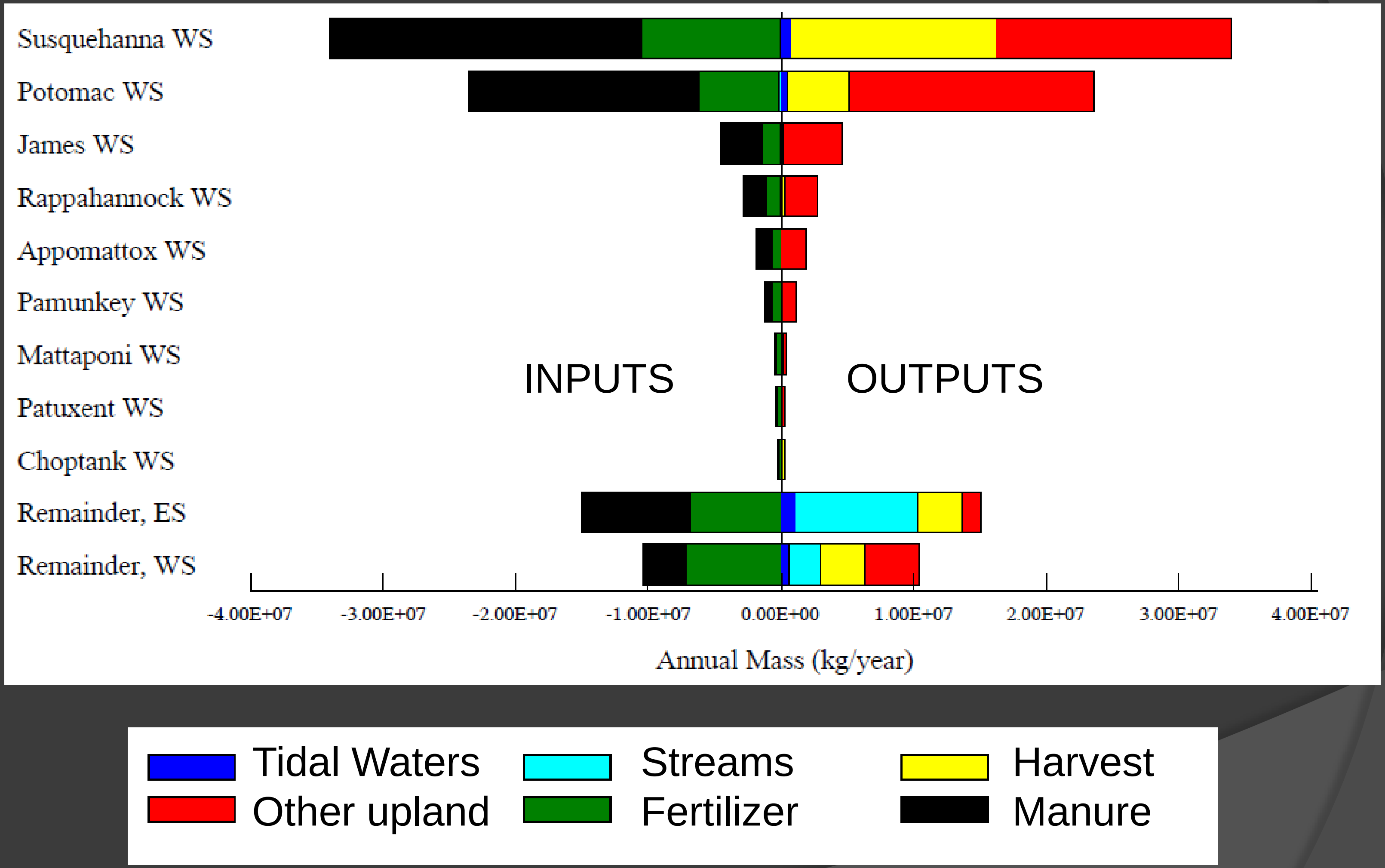


* area-weighted DVF_i

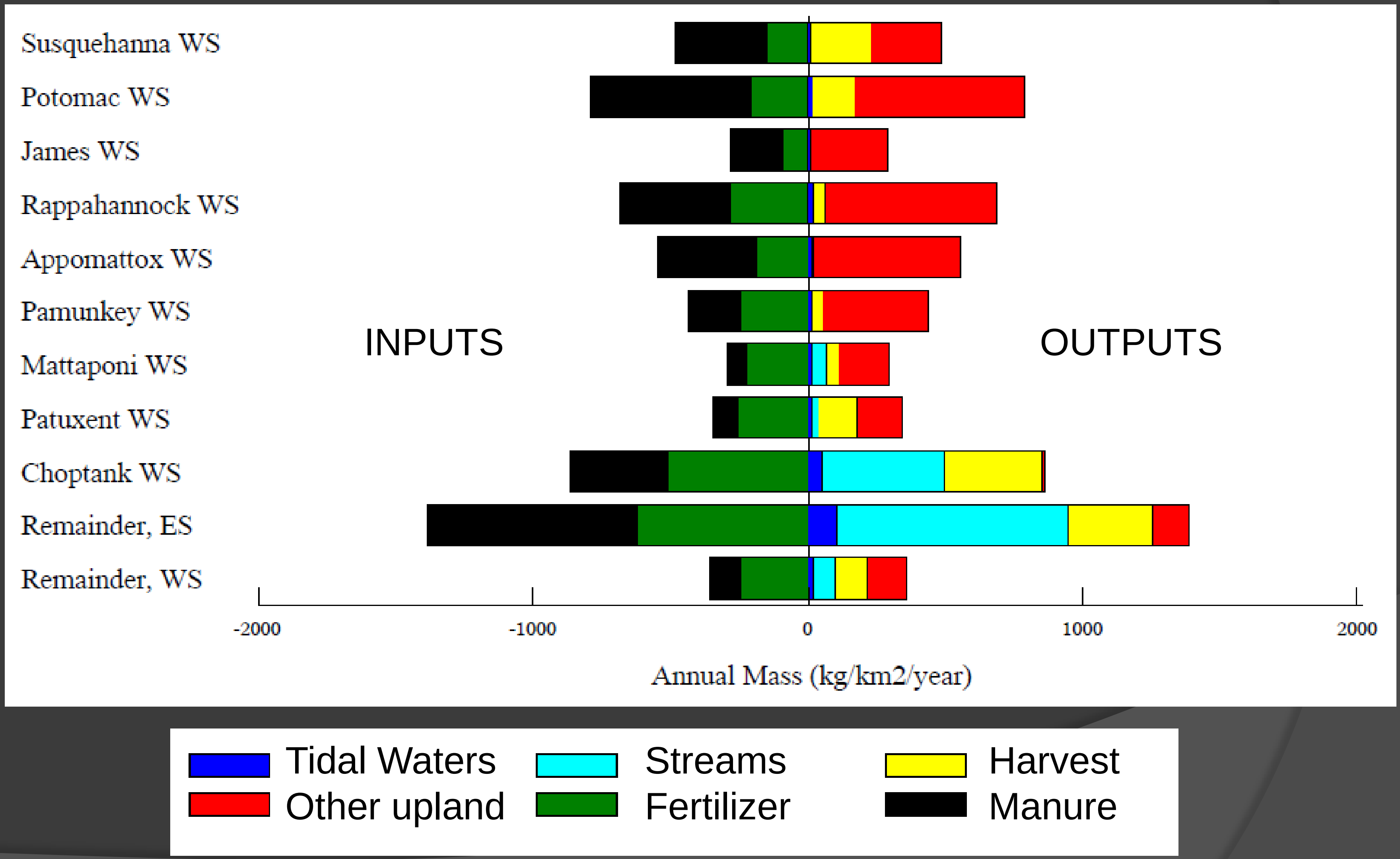
Some Preliminary Results…

- Question: How much annual net N and P losses (retention?) occur during transport from upland source areas to tidal waters
  - In uplands
  - In stream corridors
- Approach: Look at the mass balances of inputs and outputs over different areas of interest:
  - Major watersheds
  - Hydrogeologic settings
  - Land-use settings

Mass Balance of TP

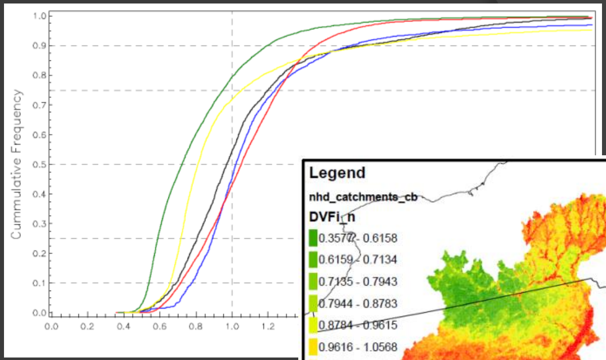


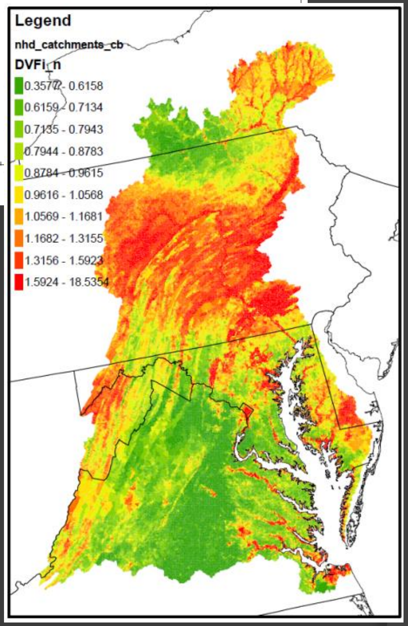
Mass Balance of TP

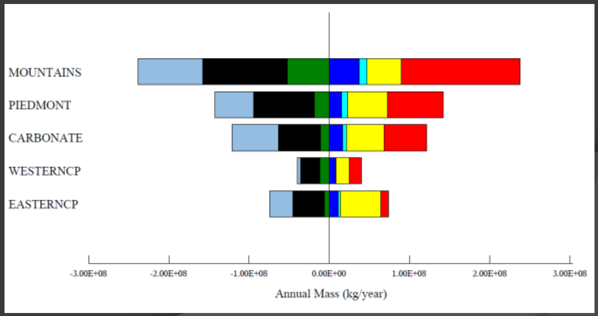


Summary

- Review of DVFi allows for us to visualize and explain why and how different areas of the watershed process or transmit N and P from uplands to streams differently
- We can also quantify relative upland processing retention in different areas





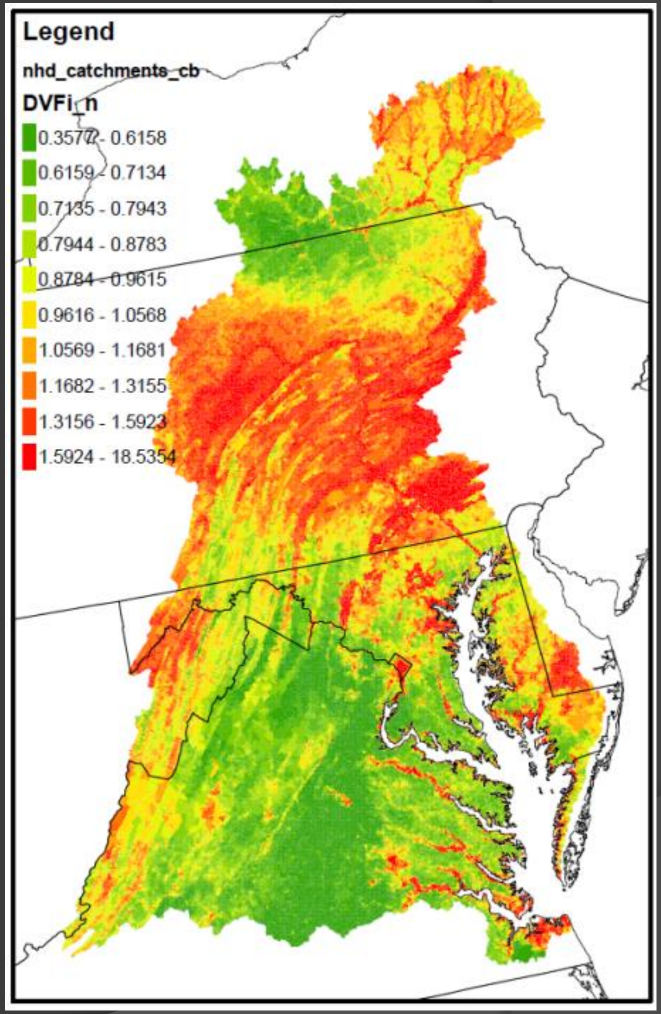


One Limitation

- Math only works for *intensive* sources in the SPARROW models. For TN/TP, this includes fertilizer/fixation, manure, atmospheric (86% of non-point TN flux to bay, 63% of non-point TP flux to bay).
- For *extensive* sources, α_n when "*combined*" with the land-to-water delivery factor is the "*mean quantity of contaminant mass per unit area that is delivered to streams*" (Schwarz et al., 2006, p. 45).
  - $\alpha_n \, DVF_i = (S_{ni} - UPL_{ni}) / A_n$
- So we could compute (Sni – UPLni), but we don't know either of those terms, individually.

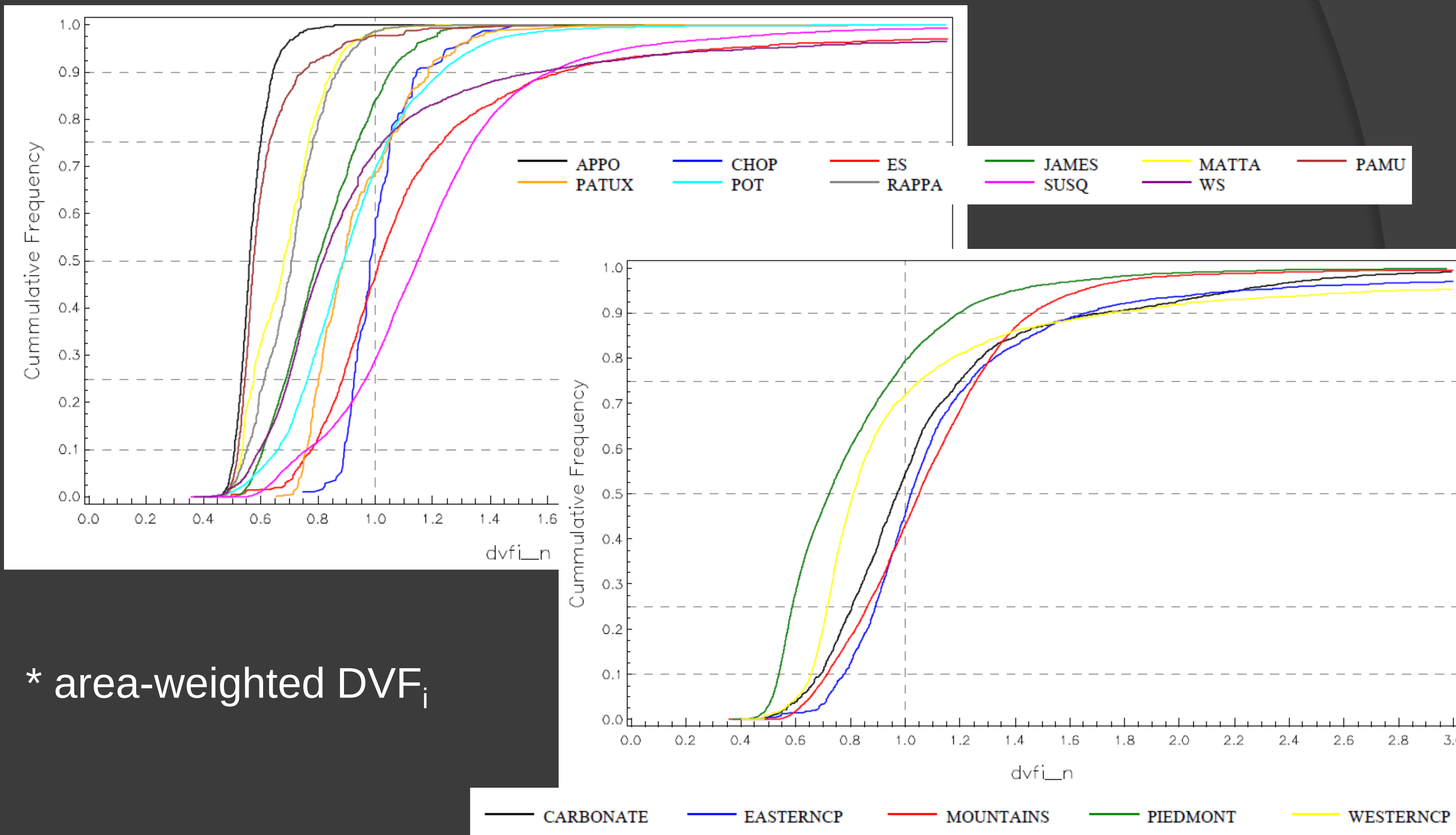
Status

- The method seems to work very well with the CBTN_v4 model. We are preparing a paper for JAWRA presenting the approach and demonstrating it for the case of TN in the Chesapeake Bay watershed.
- We can then try different calibrations of the Bay TN and TP models to provide the most useful output for understanding fate and transport



?

Delivery Variation Factor (DVF_i)



* area-weighted DVF_i

Delivery Variation Factor (DVF_i)