# Groundwater Lag-Time Estimates

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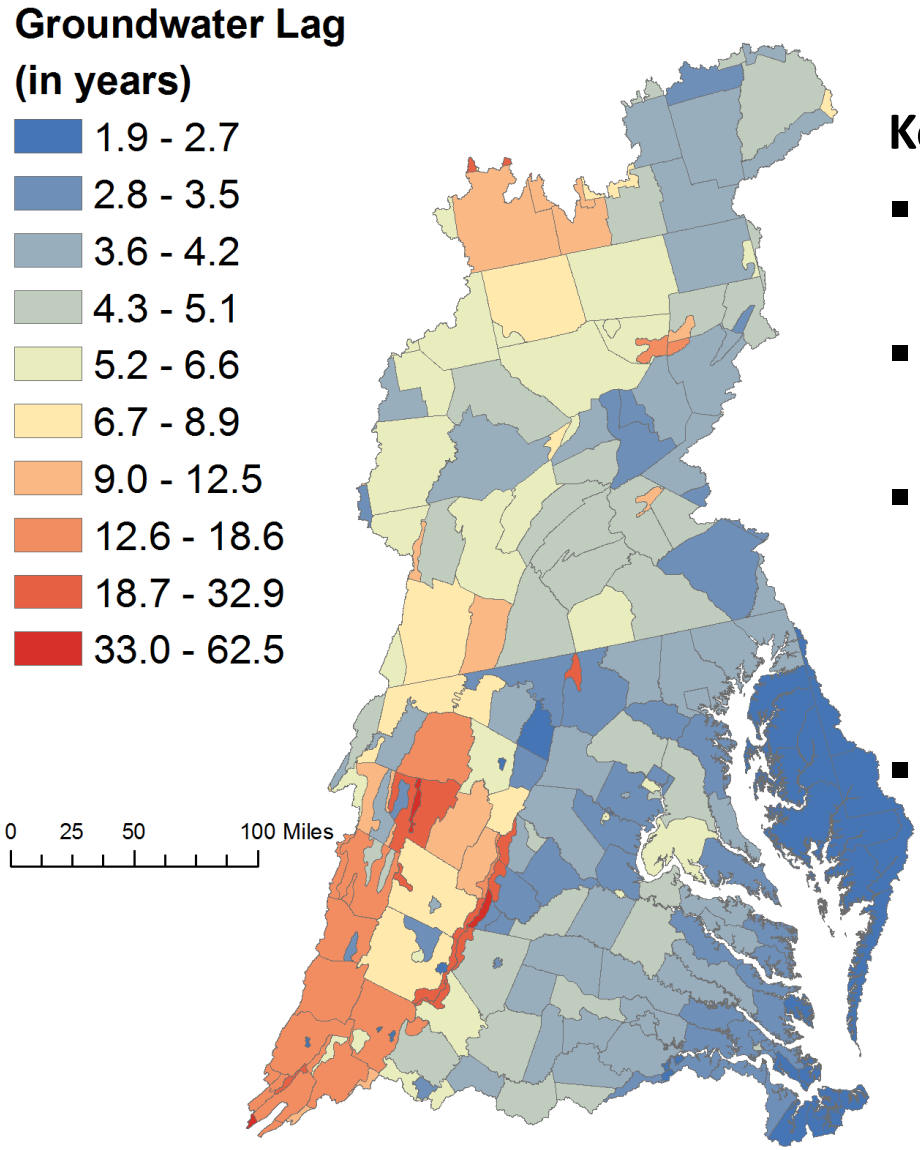
# Context

- The estimates for the lag-times do not have direct implications on the management scenarios:
  - That is because the management scenarios do not track a timeline of transition between the current to future conditions.
  - In other words, the management scenarios simulate the watershed response under the new equilibrium.

- However, the lag-times play a crucial role in the model calibration.
- It may be useful for future research work to investigate timeline related questions.

# Beta-4 estimate of groundwater lag-times




**Key issues/suggestions:**

- Verify against Potomac Model (Ward et al.)
- Eastern Shore: revise based on Ward and Pope (2013) Delmarva Study
- Western Shore: revise (a) using the ratio of aquifer storage (i.e. thickness x porosity) and recharge, (b) using eastern shore aquifer geology
- Piedmont: based on Phillips and Lindsey (2003), Lindsay et al. (2003)


Phillips, S.W. and B.D. Lindsey. 2003.The influence of groundwater on nitrogen delivery to the Chesapeake Bay. U.S. Geological Survey Fact Sheet FS–091–03, 4 pp.

Lindsey, B.D., Phillips, S.W., Donnelly, C.A., Speiran, G.K., Plummer, L.N., Böhlke, J.K., Focazio, M.J., and Burton, W.C., 2003, Residence time and nitrate transport in Groundwater discharging to streams in the Chesapeake Bay Watershed: U.S. Geological Survey Water-Resources Investigations Report 03-4035, 202 p.

Ward E.S., and Pope, J.P., 2013. Quantifying Groundwater's Role in Delaying Improvements to Chesapeake Bay Water Quality, Environmental Science & Technology, 47 (23), 13330-13338

# Brief overview and objective

- Model estimates are available for groundwater lag-time from the Upper Potomac Study (Ward et al.)
- Estimates are available for most of the Eastern Shore from the USGS Delmarva Study (Ward and Pope, 2013)
- Other estimates include Lindsey et al. 2003 (USGS report 03-4035)

- Objective: Use available information to obtain lag-time estimates for the entire Chesapeake Bay Watershed.

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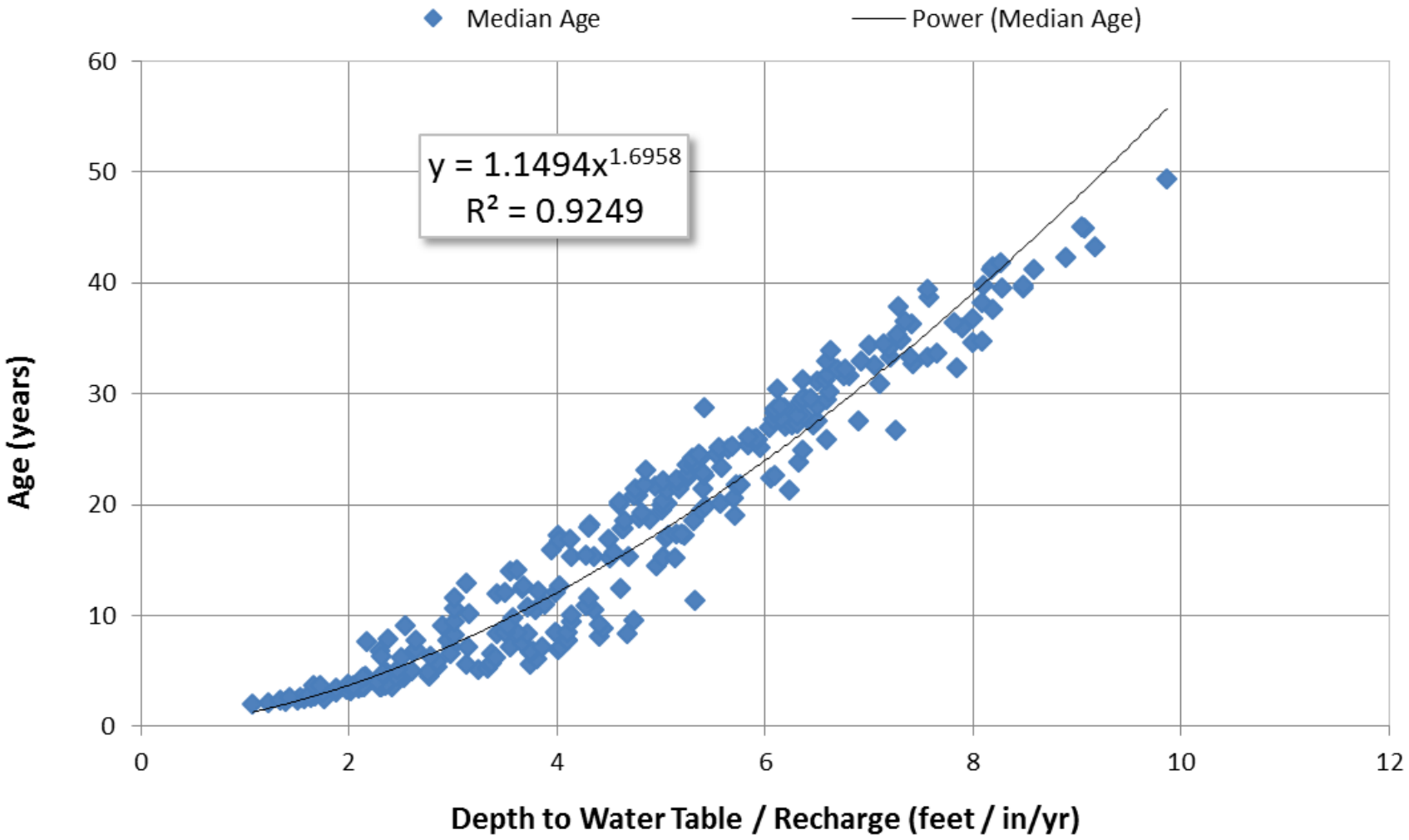
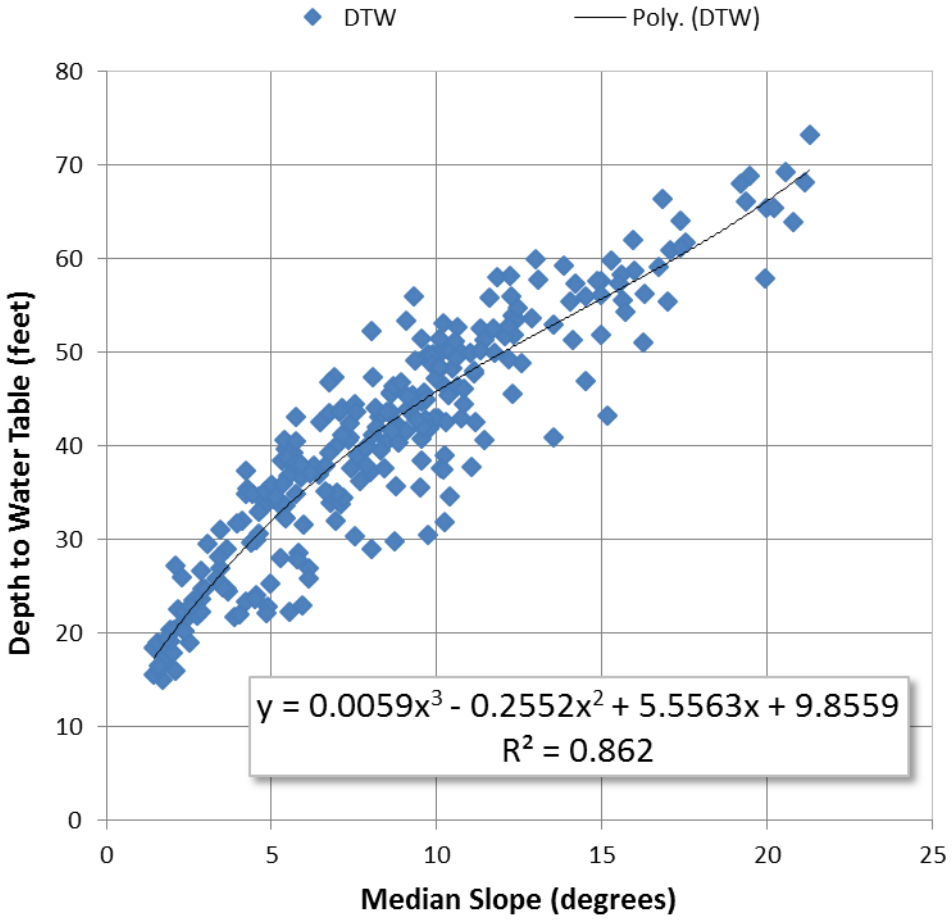
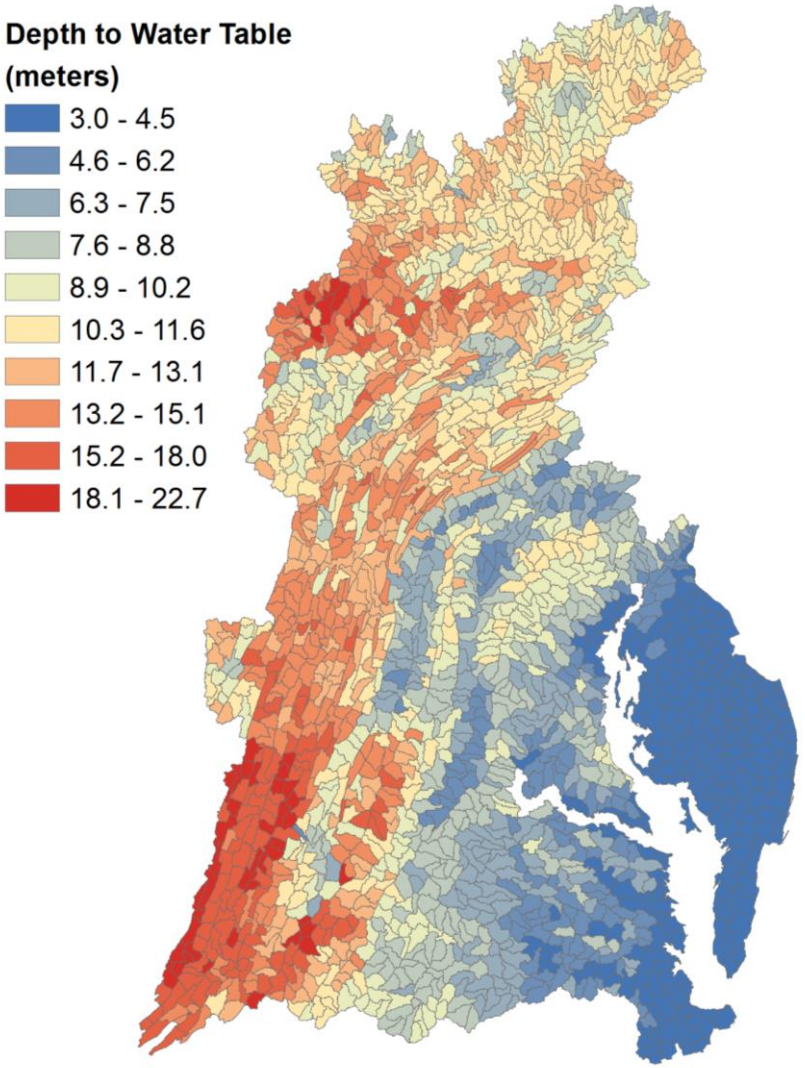
Lindsey, B.D., Phillips, S.W., Donnelly, C.A., Speiran, G.K., Plummer, L.N., Böhlke, J.K., Focazio, M.J., and Burton, W.C., 2003, Residence time and nitrate transport in Groundwater discharging to streams in the Chesapeake Bay Watershed: U.S. Geological Survey Water-Resources Investigations Report 03-4035, 202 p.

- Based on Upper Potomac River Basin study (Ward et al.), Ward found that the **Median Age** of HUC 12 catchments was strongly related to the ratio of **Depth to Water-Table** and **Recharge**.



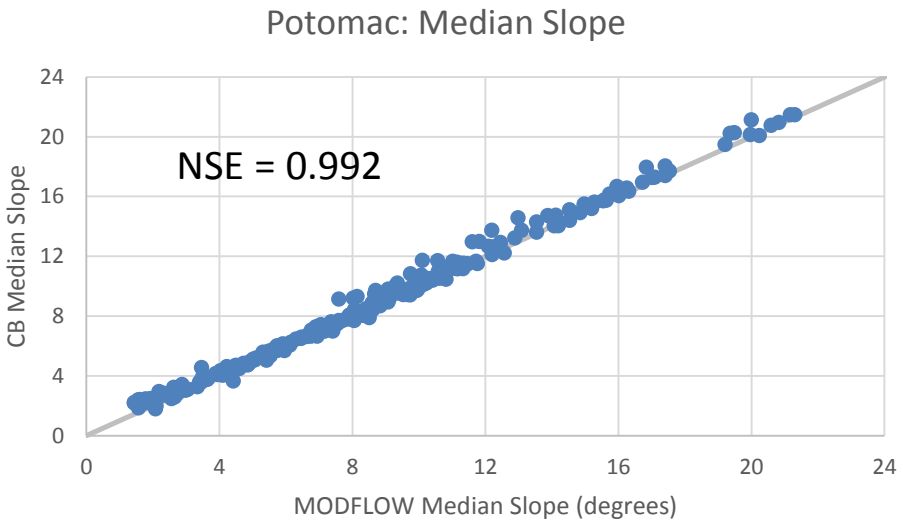
- Depth to water-table can be estimated from median topographic slope.
- USGS recharge[1] was used after adjusting them based on the recharge estimated using chemical hydrograph separation.

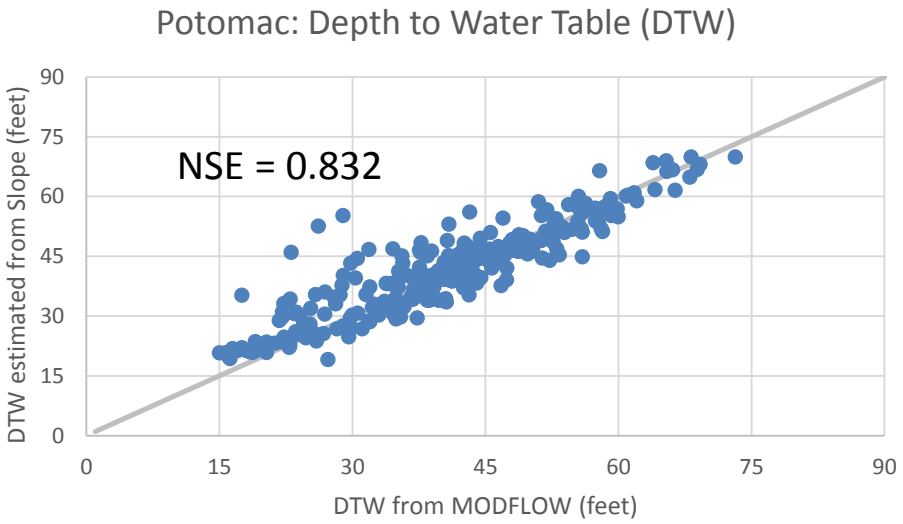


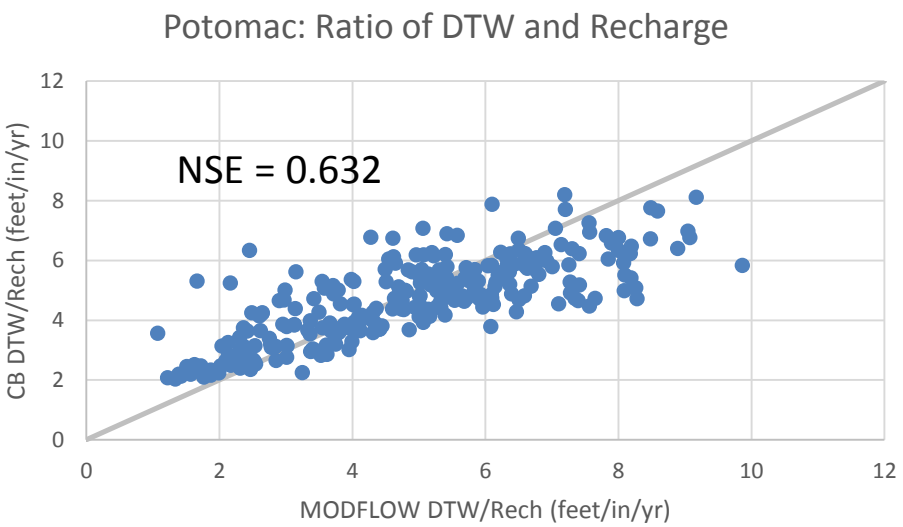



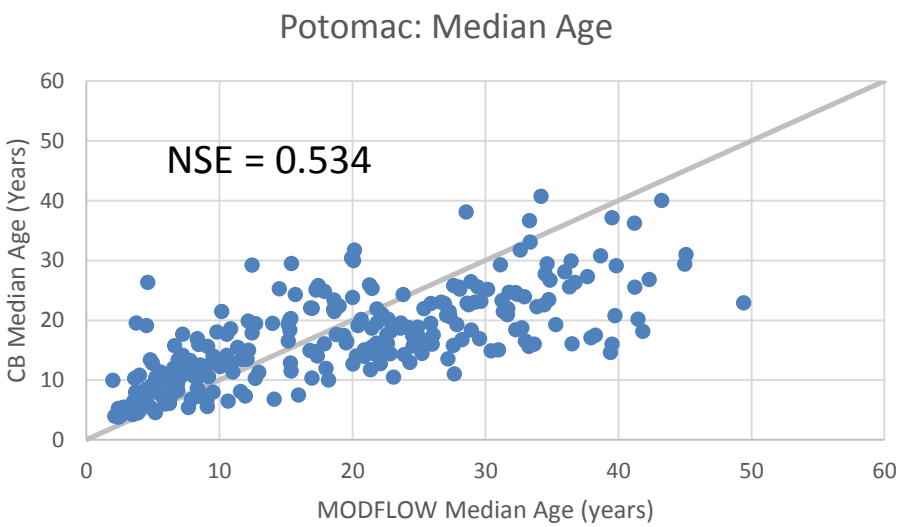

[1] Wolock, D.M., 2003, Estimated mean annual natural ground-water recharge in the conterminous United States: U.S. Geological Survey Open-File Report 03–311, digital data set, available on World Wide Web at URL http://water.usgs.gov/lookup/getspatial?rech48grd

# Validation: Upper Potomac River Basin

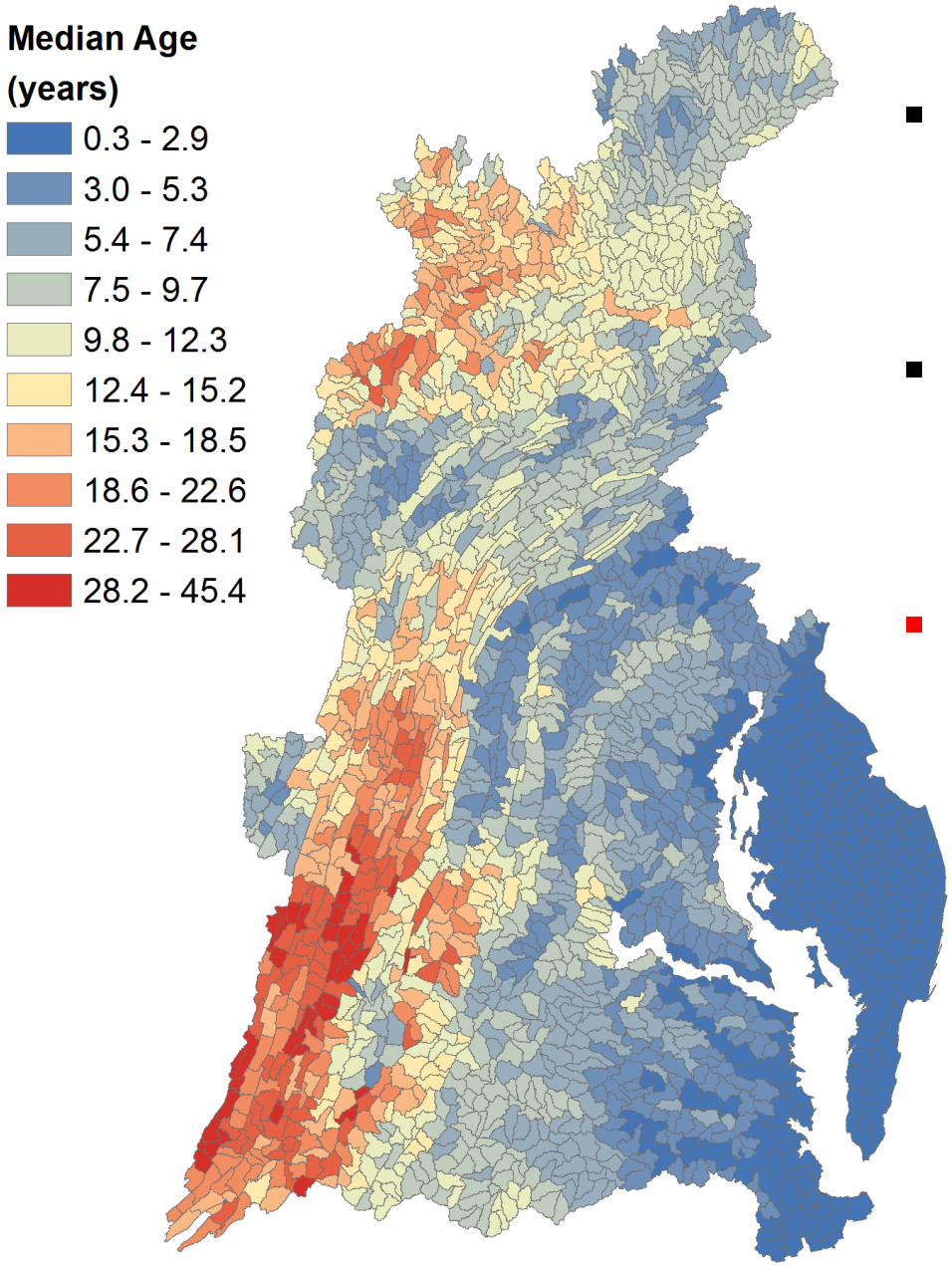


# Revised lag-time estimates



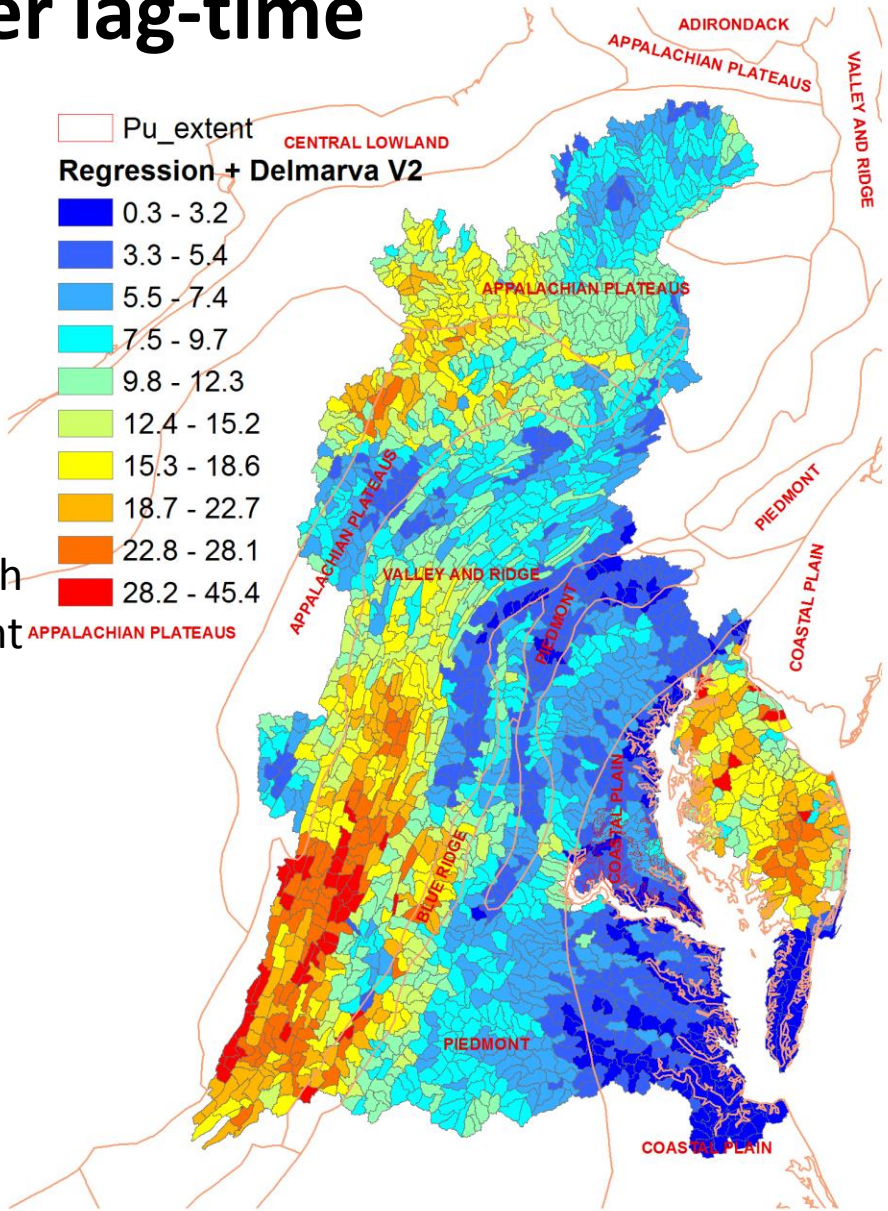

- Revised calculations were made at HUC12 scale, so that the estimates can be directly compared against others (e.g. Potomac, Delmarva studies).
- The estimates can be aggregated to Land segments for Phase 6 application.

- **The estimates are reasonable except for the Coastal Plain.**

# Coastal plain groundwater lag-time

- Estimates for the Eastern Shore were substituted with better information using Delmarva Study (Ward and Pope, 2013).

- **What about rest of the costal plains?**
  - Perform statistical analysis.
  - Some of the standard techniques such as Generalized Linear Model, Gradient Boosted Trees [1][2], and Principal Component Analysis were used.

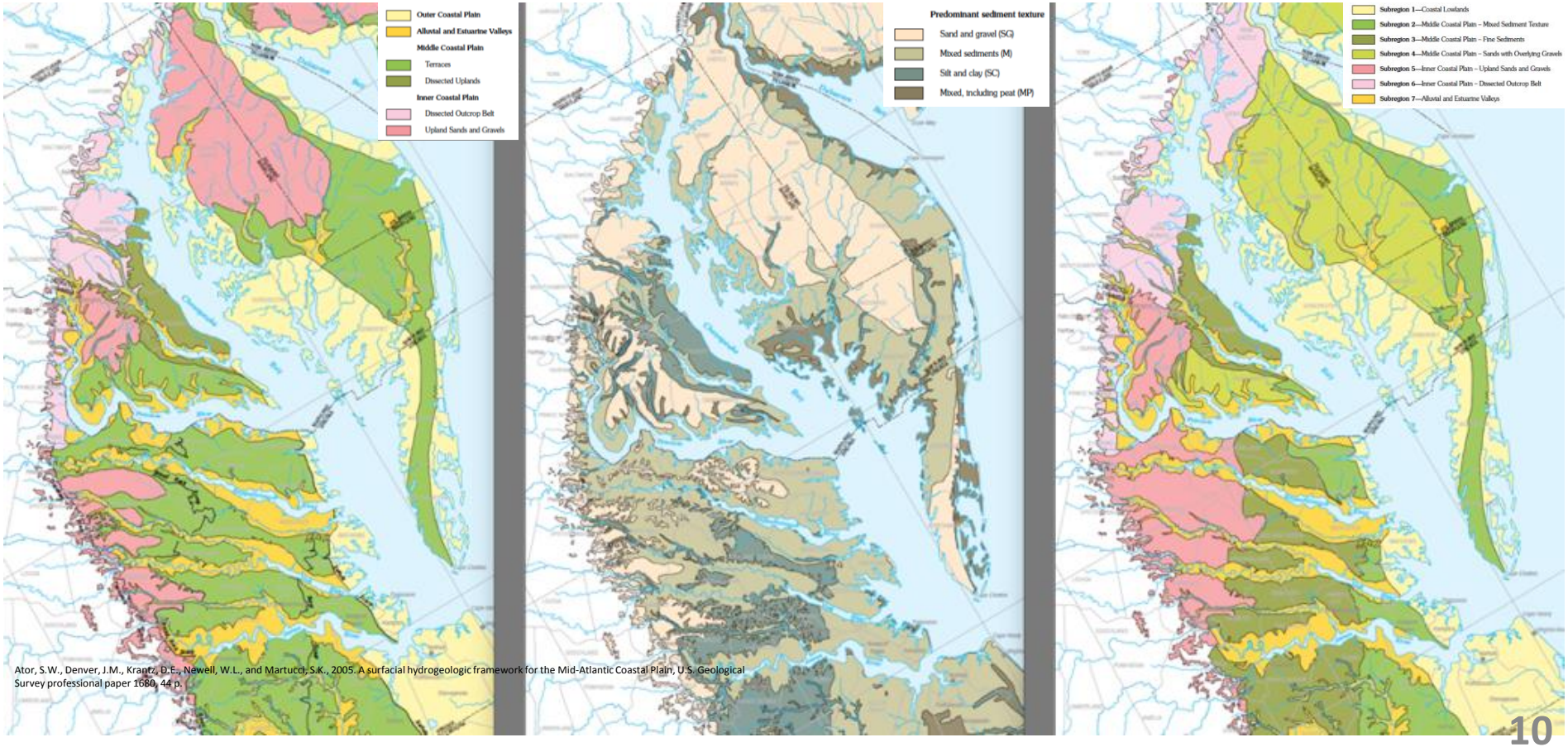



[1] https://en.wikipedia.org/wiki/Gradient_boosting
[2] http://xgboost.readthedocs.io/en/latest/model.html

Ward E.S., and Pope, J.P., 2013. Quantifying Groundwater's Role in Delaying Improvements to Chesapeake Bay Water Quality, Environmental Science & Technology, 47 (23), 13330-13338

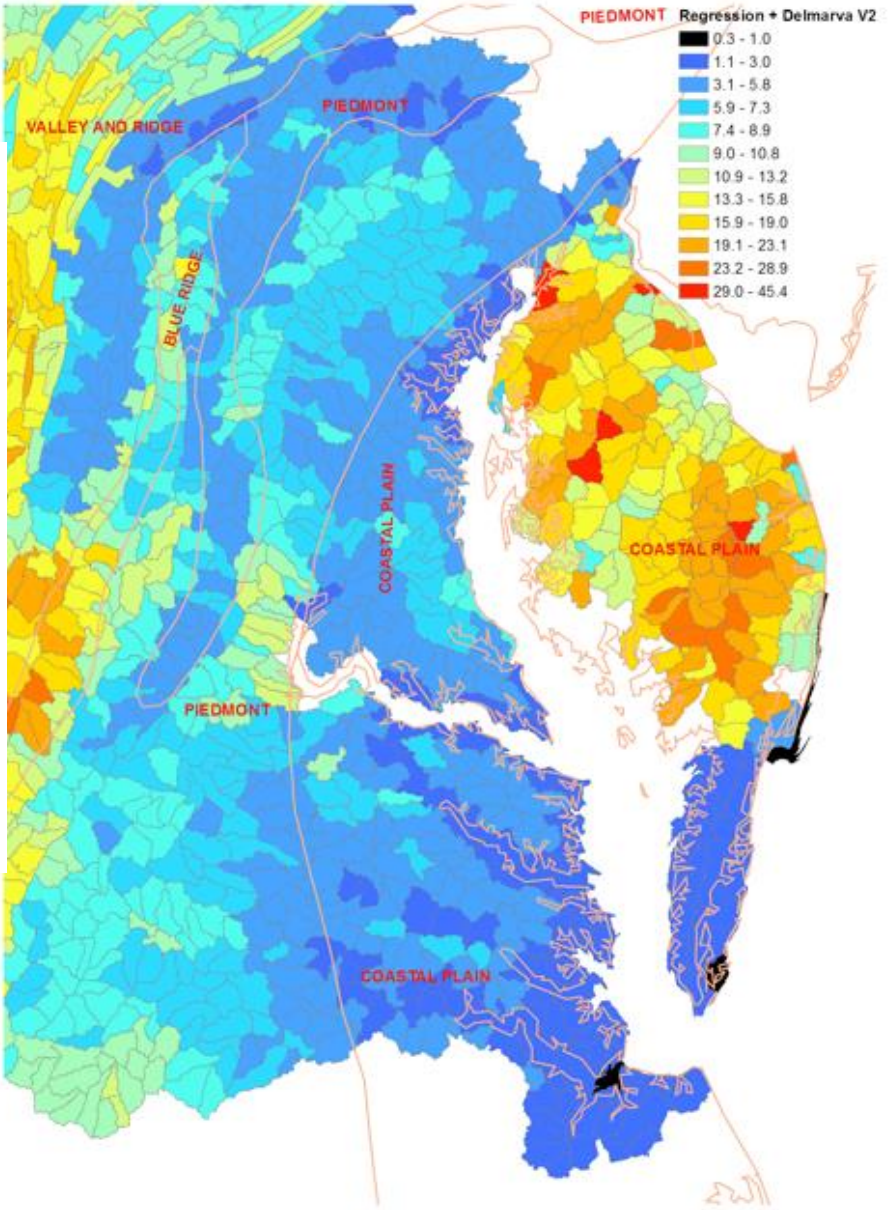
# Gather additional data for statistical analysis

- Ator et al. (2005) – USGS publication on surficial hydrogeologic framework for the Mid-Atlantic coastal plain.
- Based on this dataset several ***watershed attributes*** for HUC12 catchments were calculated – 6 physiographic providences, 7 physiographic frameworks, 4 lithology classes, 12 surficial geology, and 16 sub-cropping geology.



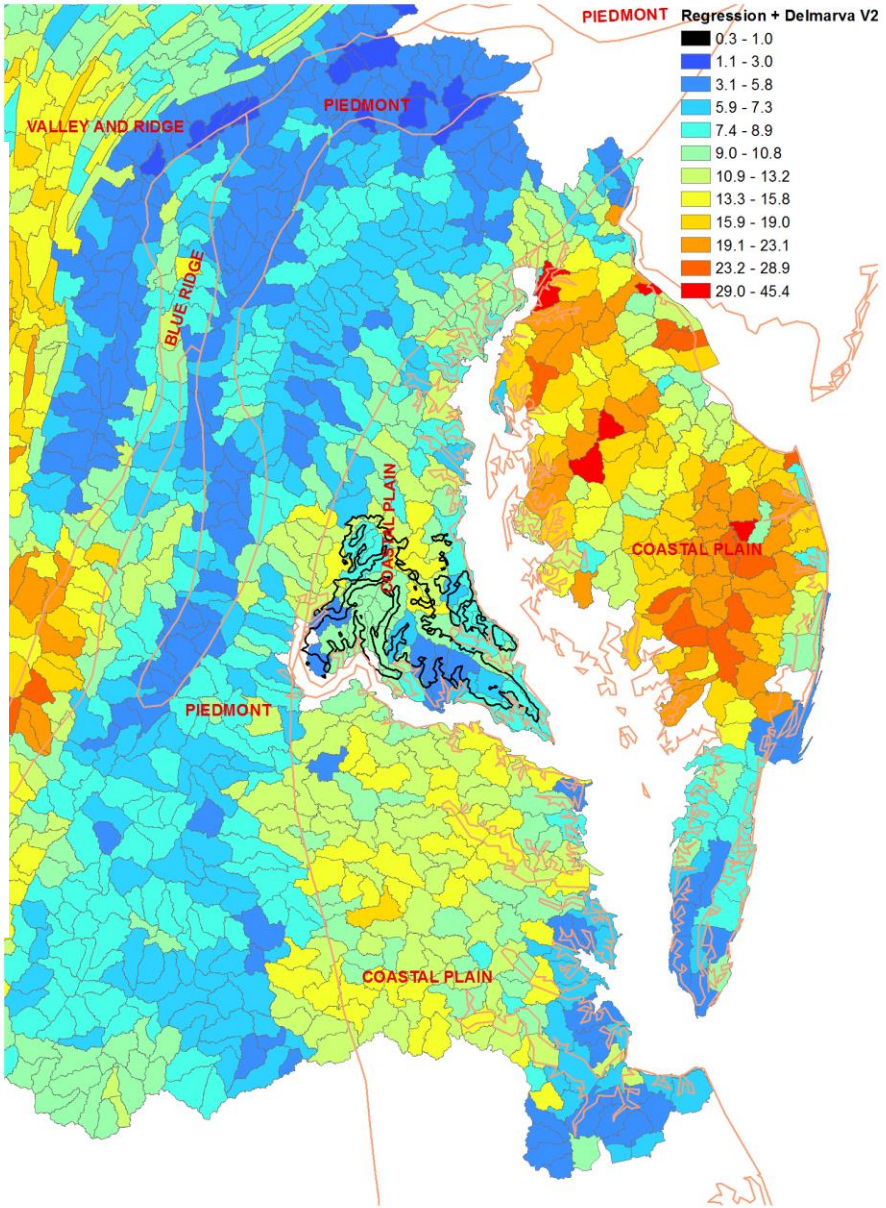

Ator, S.W., Denver, J.M., Krantz, D.E., Newell, W.L., and Martucci, S.K., 2005. A surficial hydrogeologic framework for the Mid-Atlantic Coastal Plain, U.S. Geological Survey professional paper 1680, 44 p.

- The figure shows <u>initial estimates</u> (i.e. before the statistical analysis) for the coastal plain. The estimates are based on the Potomac Model Regression, as well as a portion of the Eastern Shore was substituted using data from the Delmarva Study.
- Statistical analysis can be used for revising the estimates for remaining coastal plain.



- First, principle component analysis (PCA) was performed on the *watershed attributes*. And then, the principle components were used in the statistical analysis [1][2].

*Results from this particular analysis matched well with the empirical estimates for a section (highlighted using black polygon) as well as rest of the Western Shore.*

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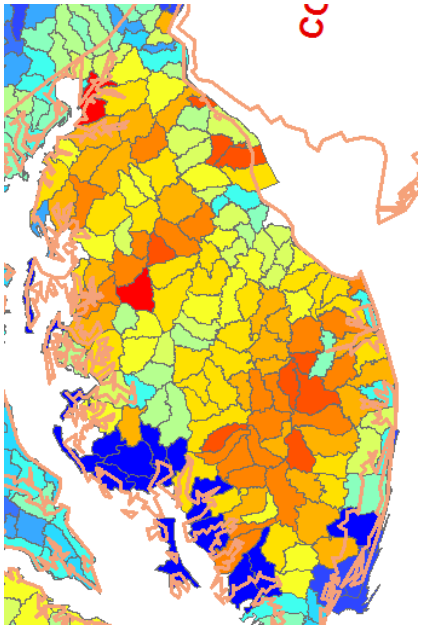
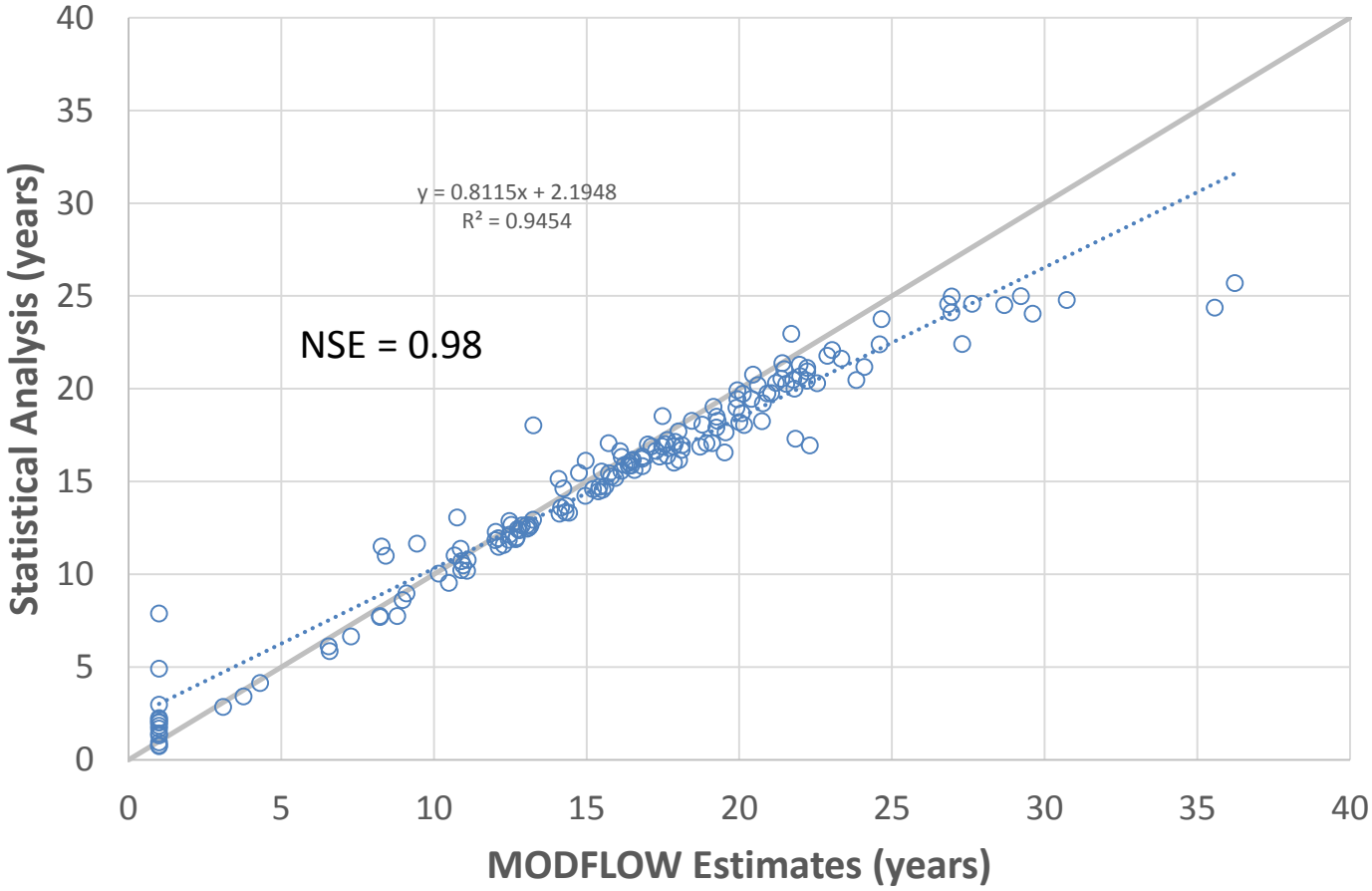
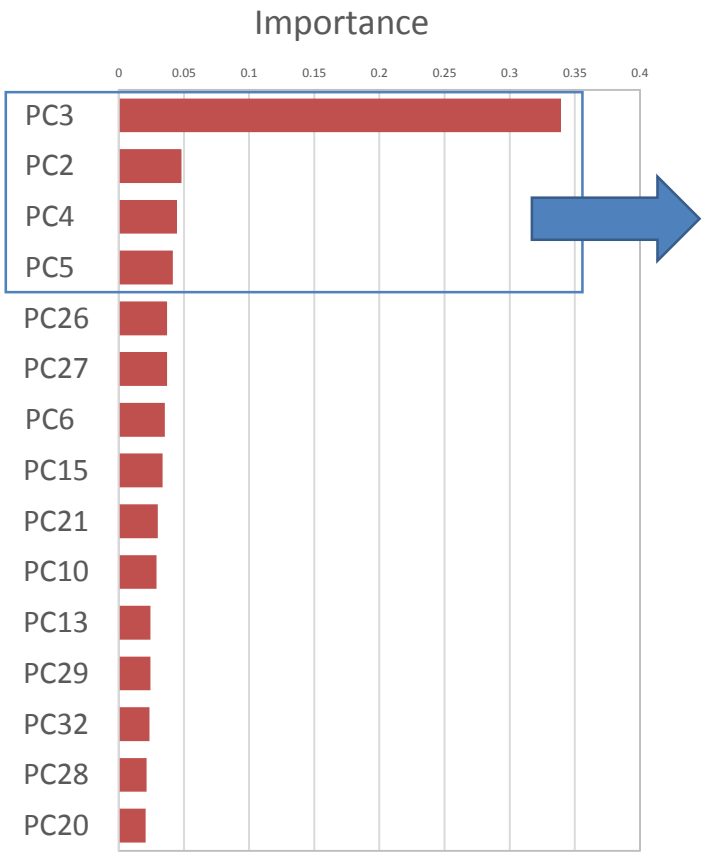
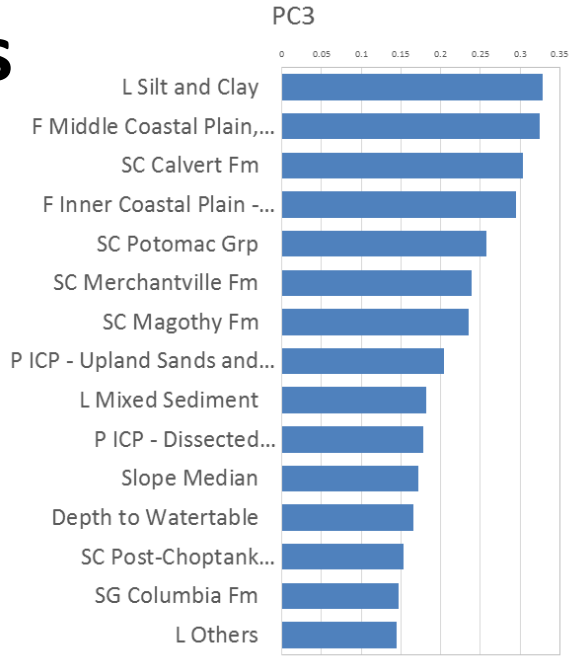
# Performance of the statistical model

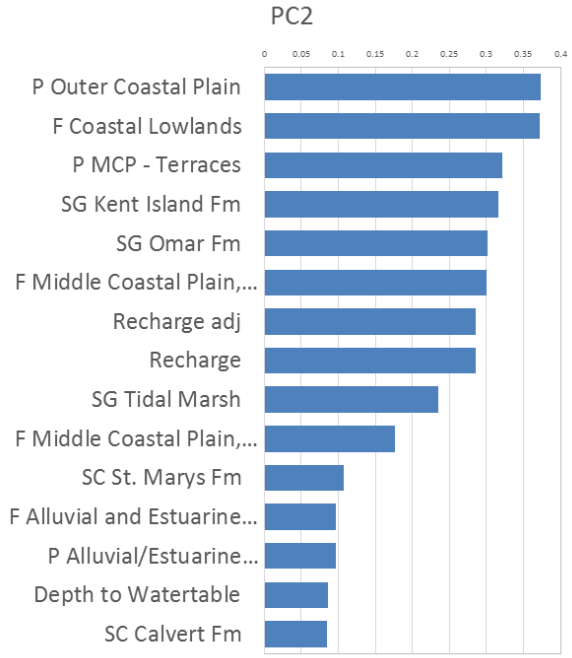


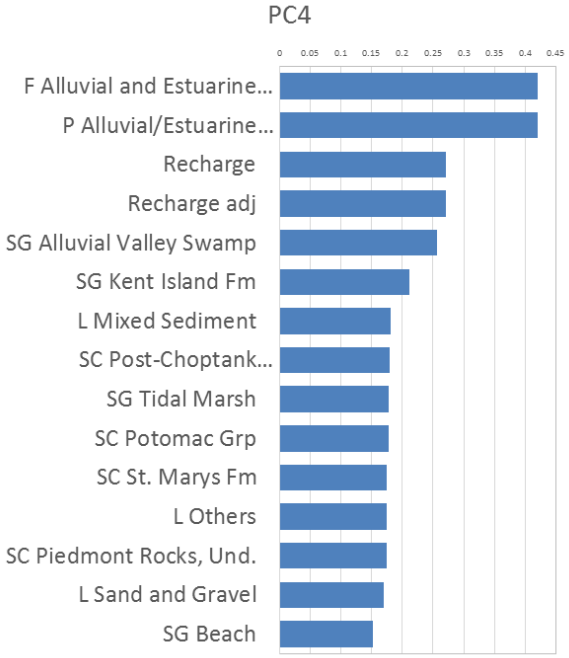


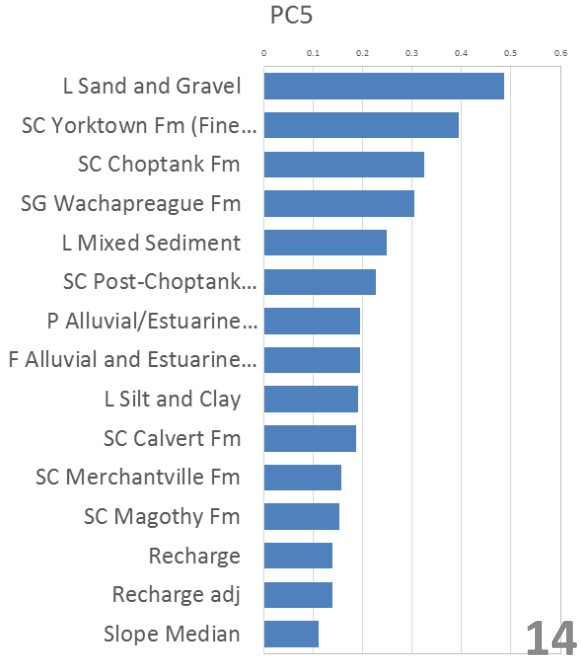
# Important variables identified by the statistical model



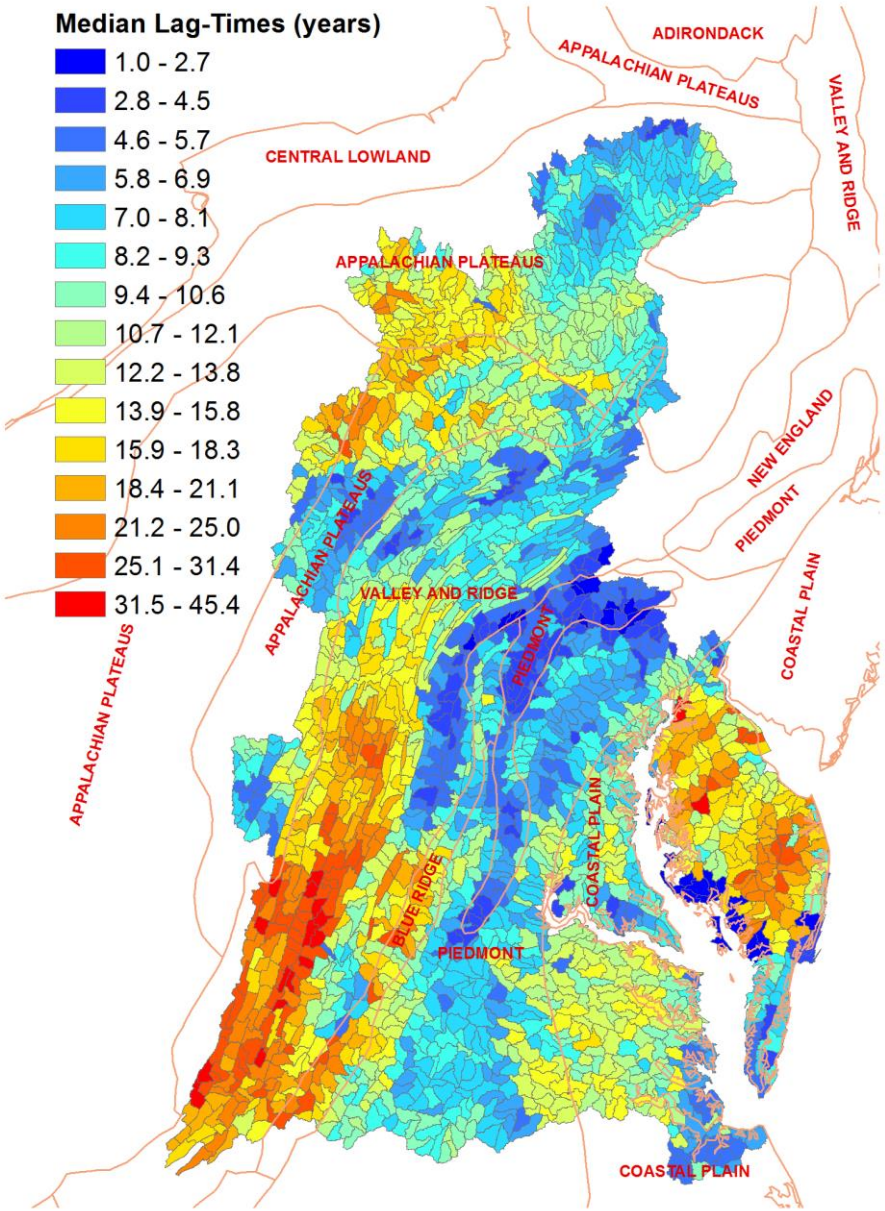



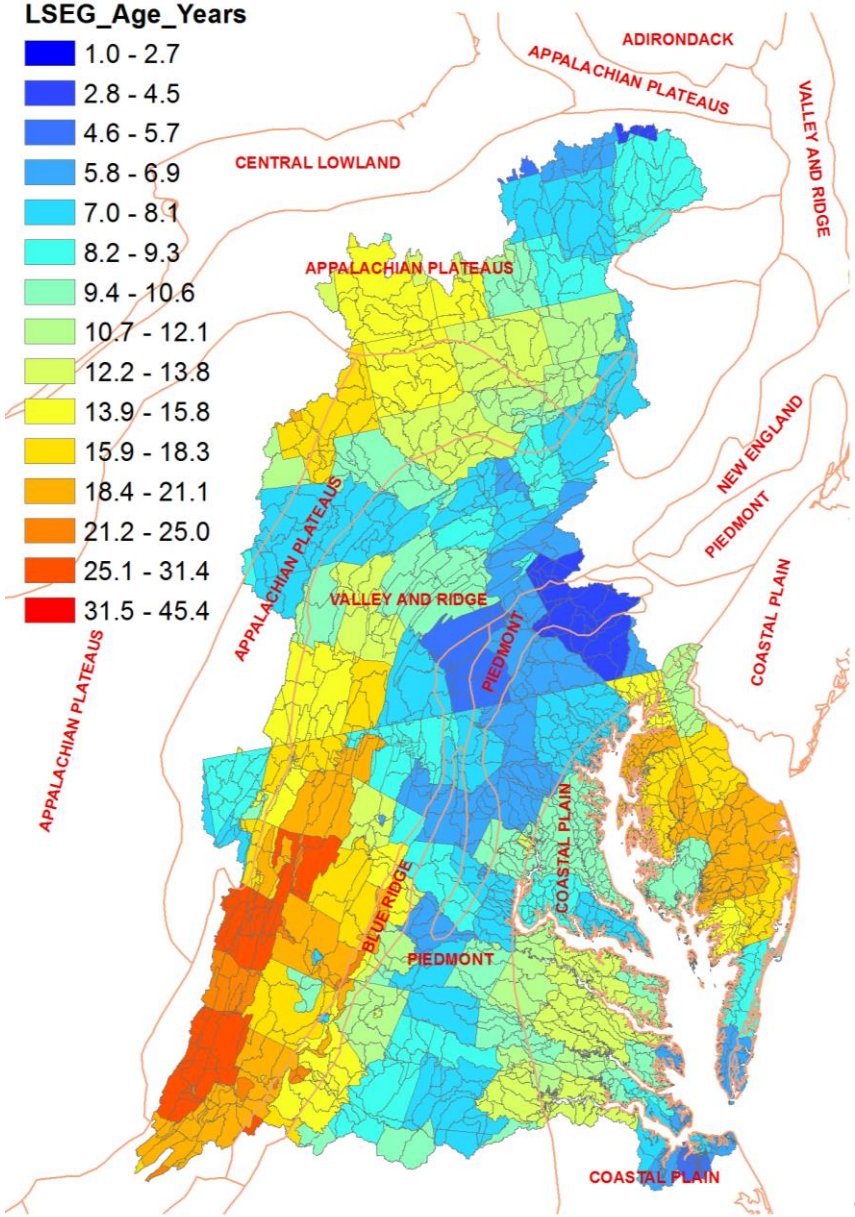




L = Lithology
F = Physiographic framework
P = Physiographic providence
SG = Surficial geology
SC = Sub-cropping geology

# Revised groundwater lag-times estimates



# Conclusions

- CBPO received several reviews of the Beta 4 groundwater lag-time estimates pointing out some of the shortcomings of the data product.
- Groundwater lag-time estimates were revised to address those issues, as well as reviewed by the experts.
- These estimates does not have direct implications on the management scenarios.
- They are important for bettering our understanding of nutrient transport, and have a meaningful influence on the model calibration.

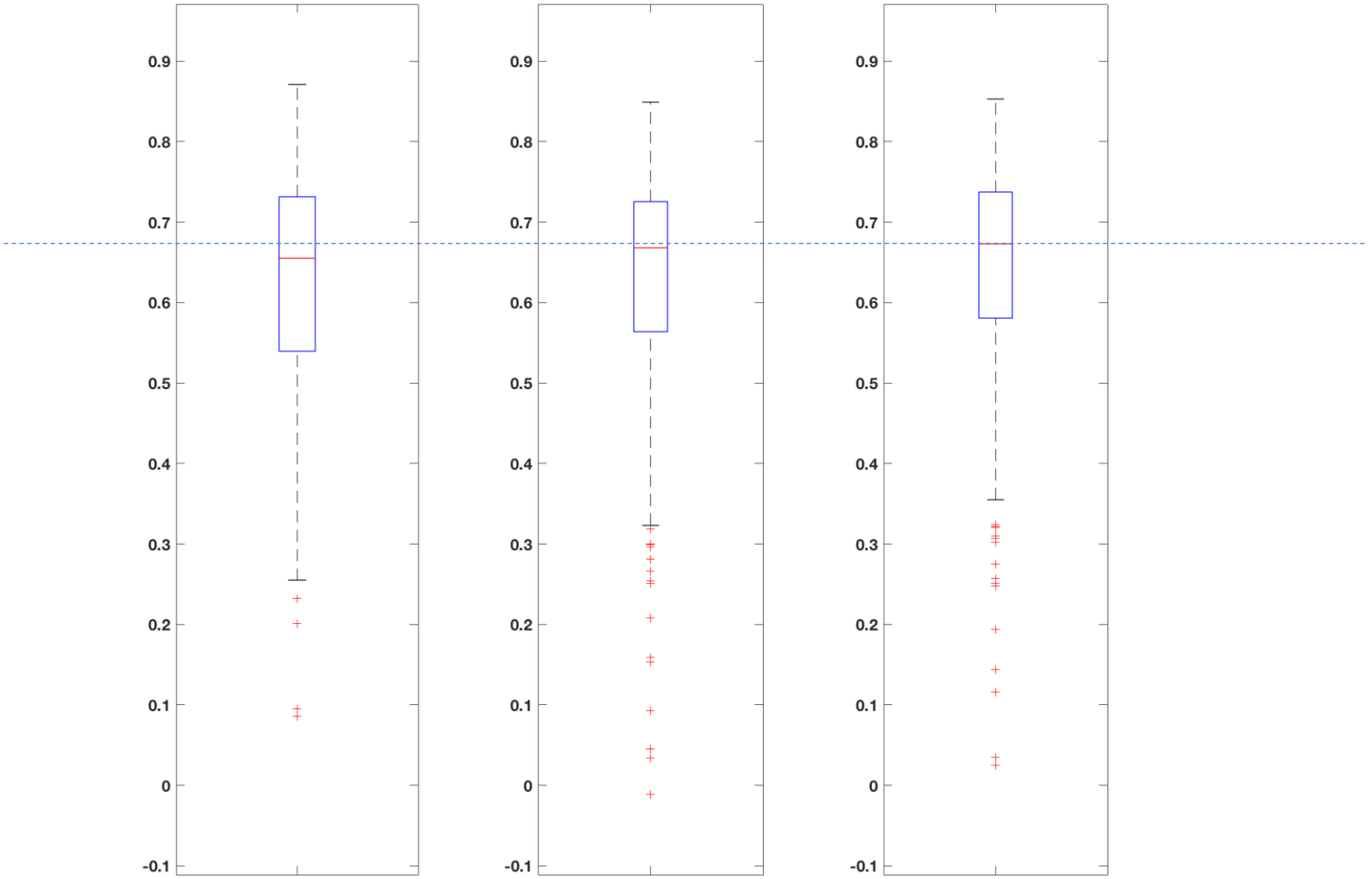
- **We are seeking an approval to this Chesapeake Bay groundwater lag-time estimate.**

*one more thing…*

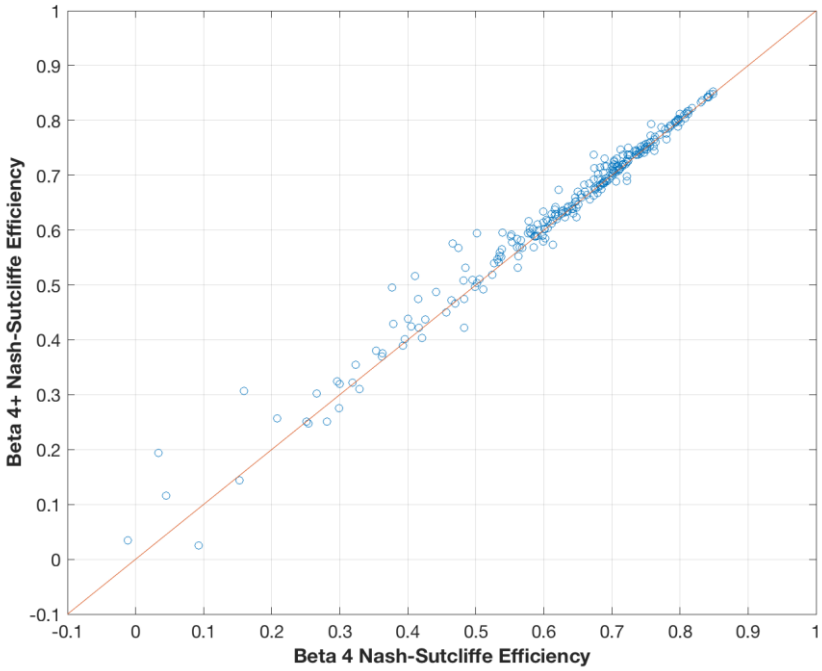
# Hydrology calibration

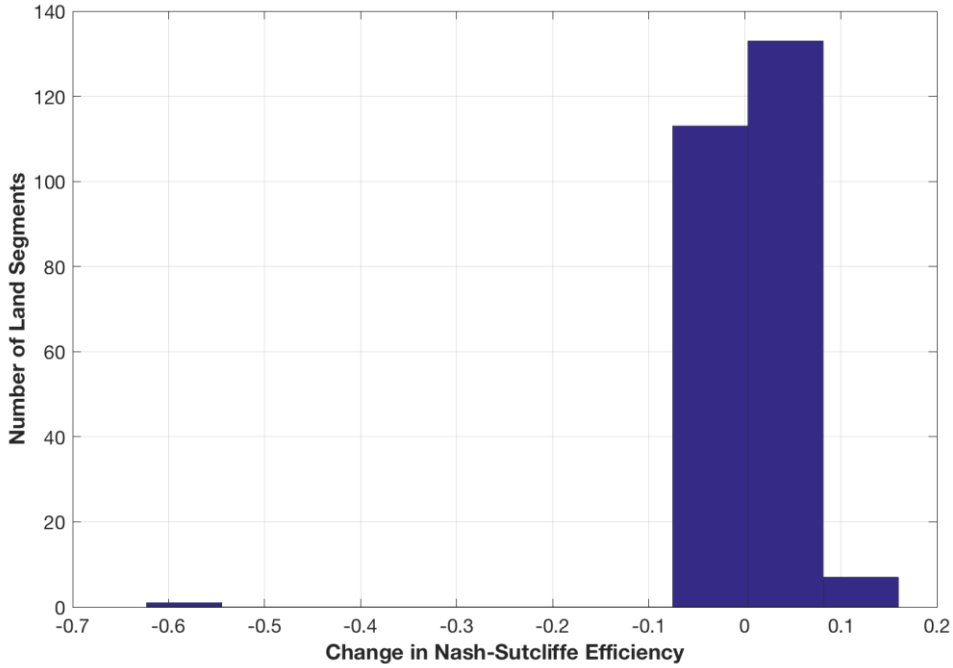
- Beta 4+ is based on hi-res land cover data (most up to date land-use)

***Nash-Sutcliffe Efficiency* at 221 Calibration Stations**



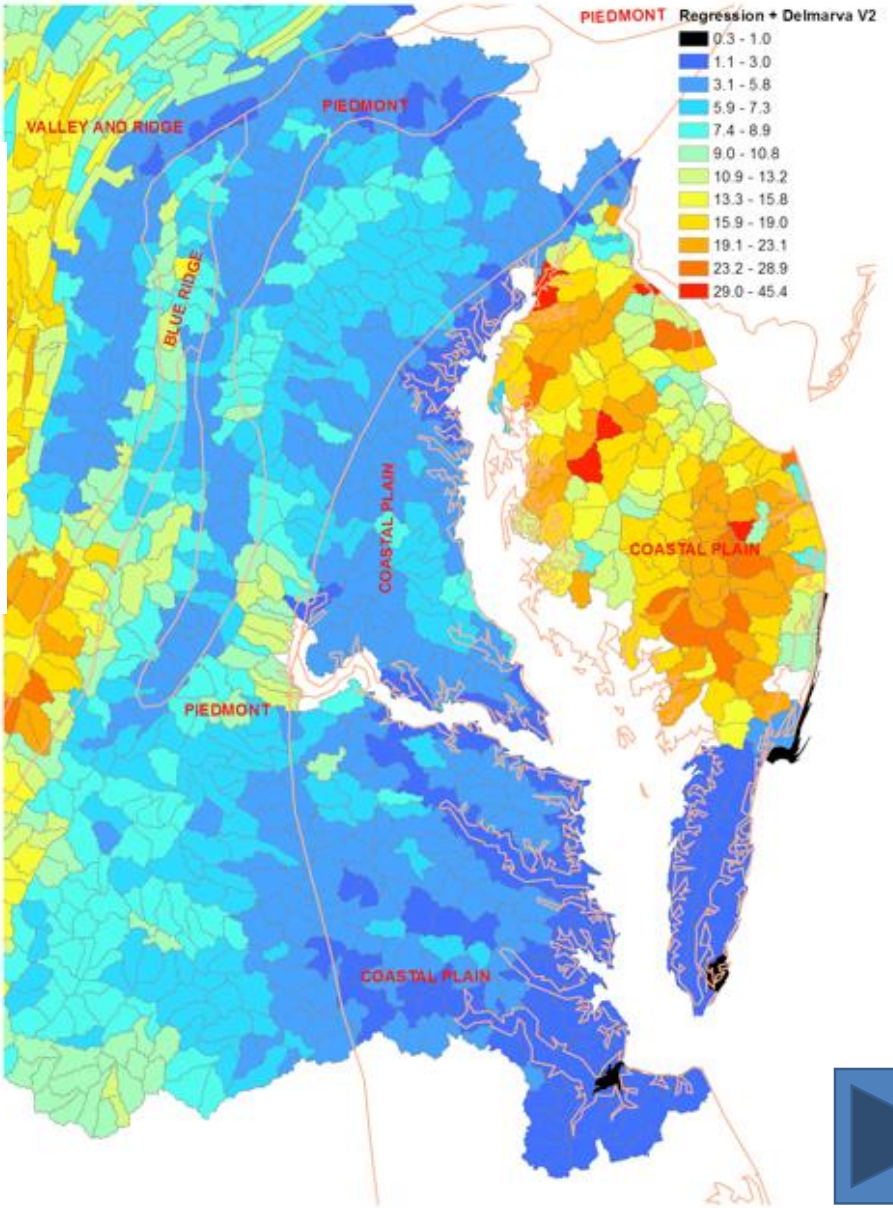
# Was any particular river segment impacted severely?




- No, and further analysis is not warranted.

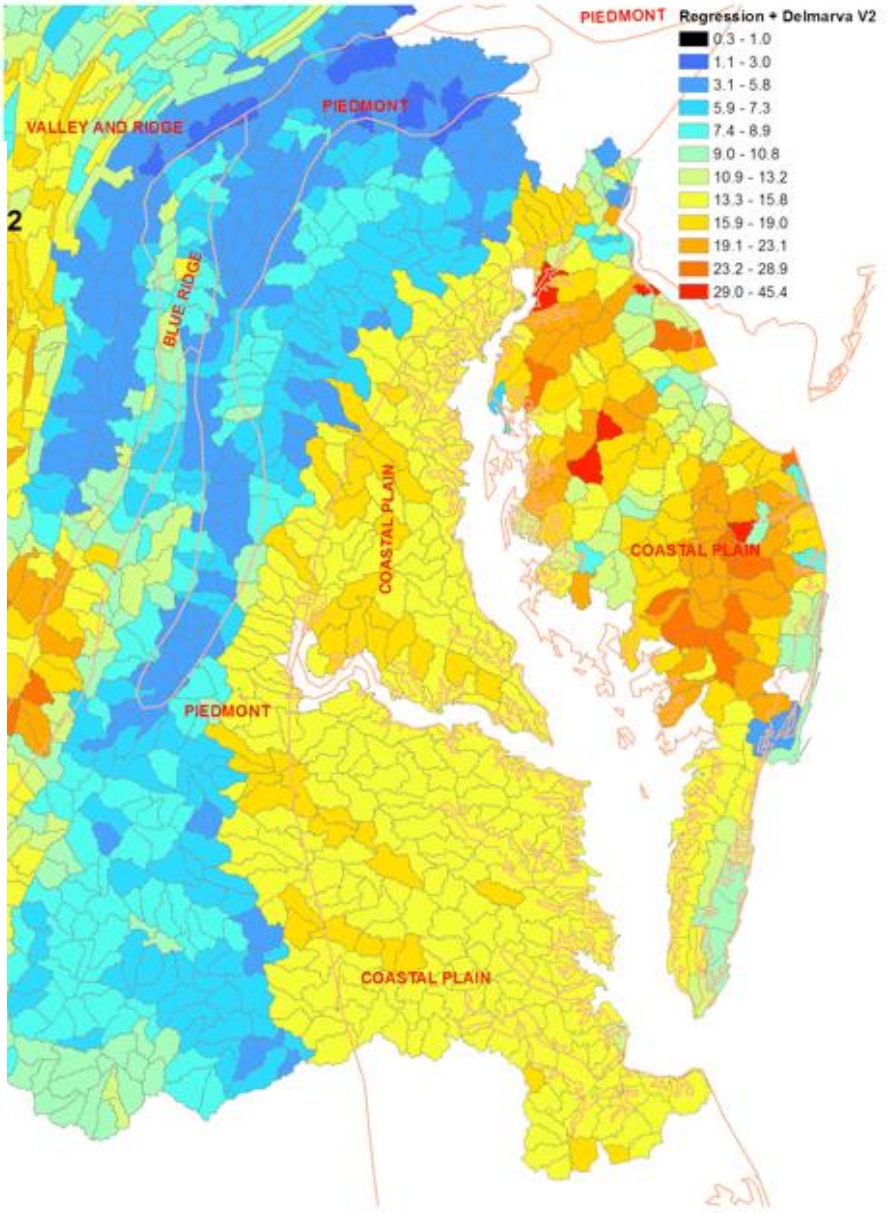
(1) the starting point for the coastal plain, where predictions are based on Potomac Model Regression but the portion of the Eastern Shore was substituted using Delmarva Study. The estimates for the remaining coastal plain needed revisions.



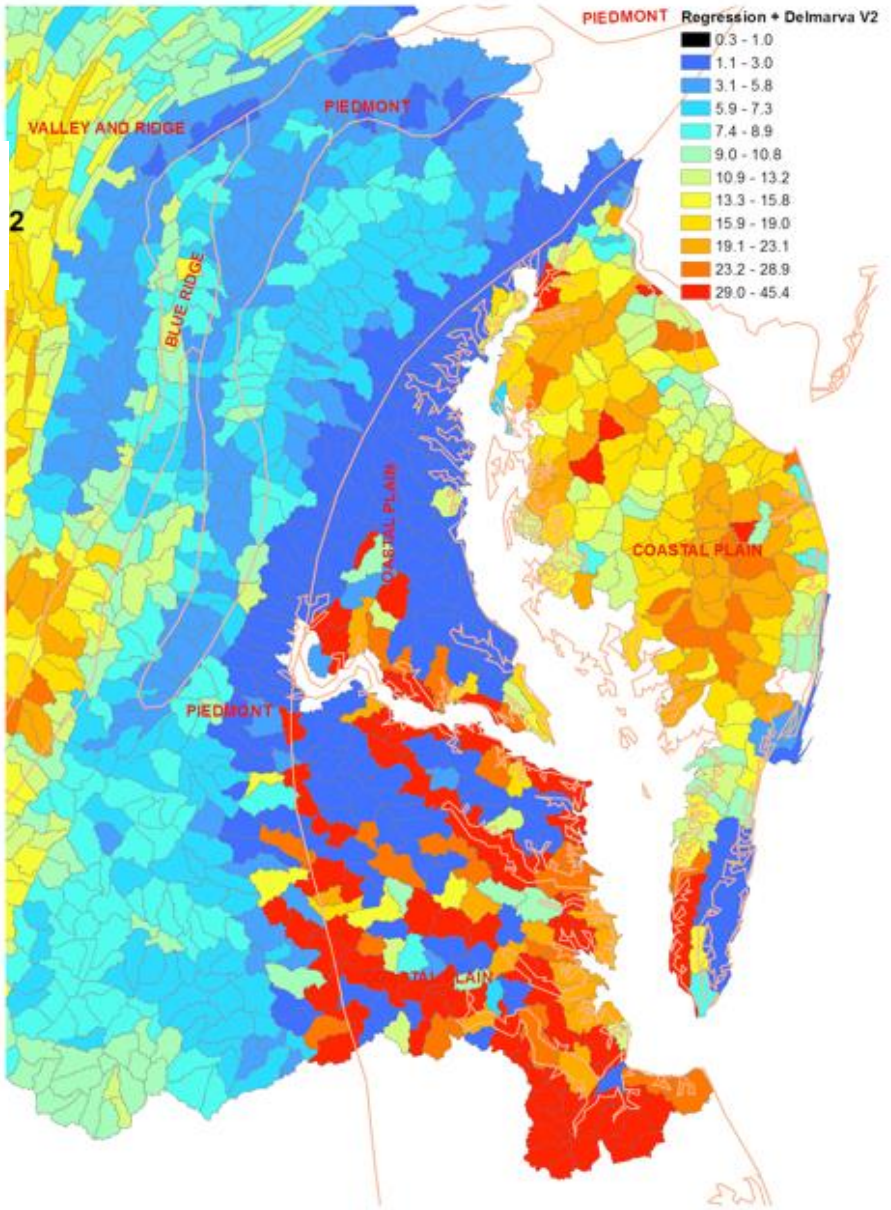
(2) If spatial means were to be used, the surficial geology performed best in the Delmarva region (R2 = 0.28).

Spatial means analysis for physiographic providence, physiographic framework, lithology, surface geology, and sub-cropping geology were performed.

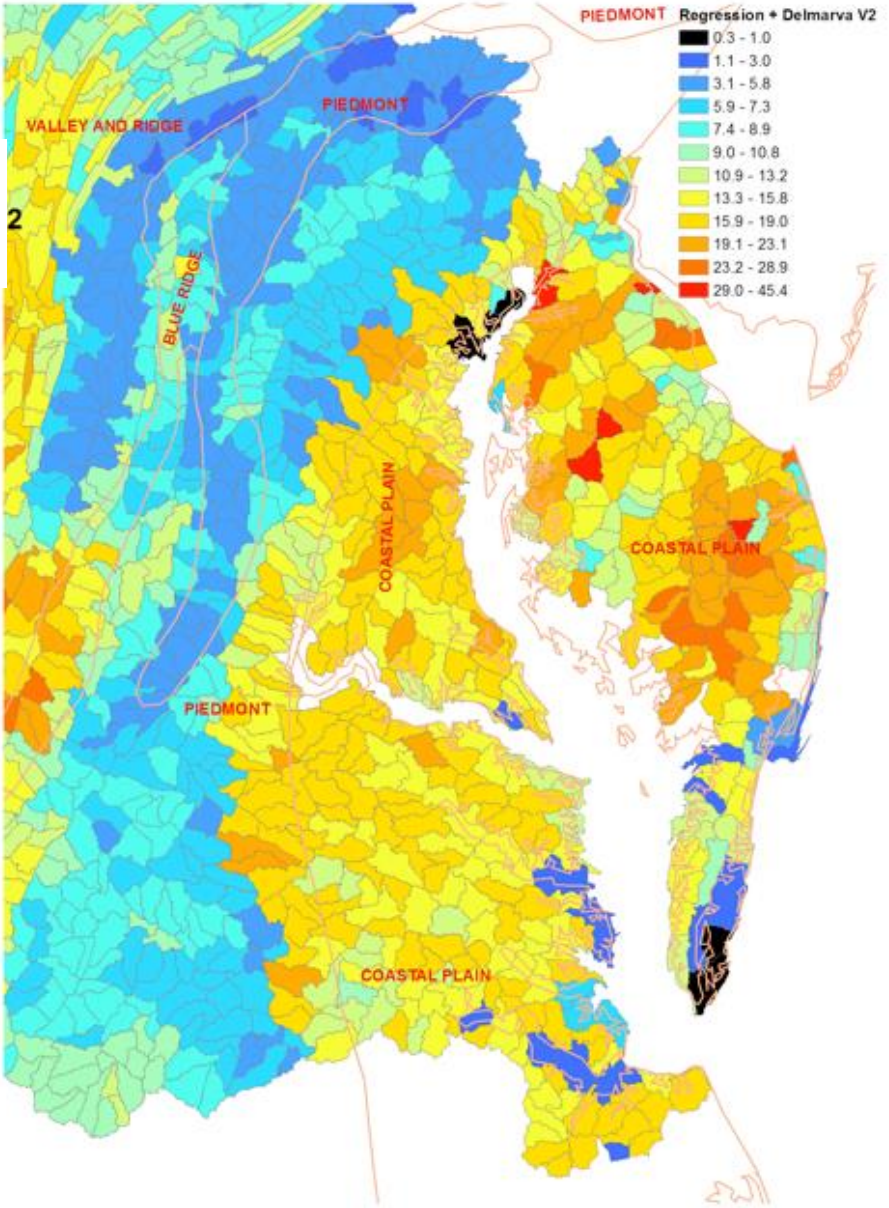
Figure shows (a) Ward & Pope results for the Delmarva, (b) statistical prediction for remaining of the coastal plain, and (c) rest of the watershed using the regression model that was developed based on the Potomac Model.



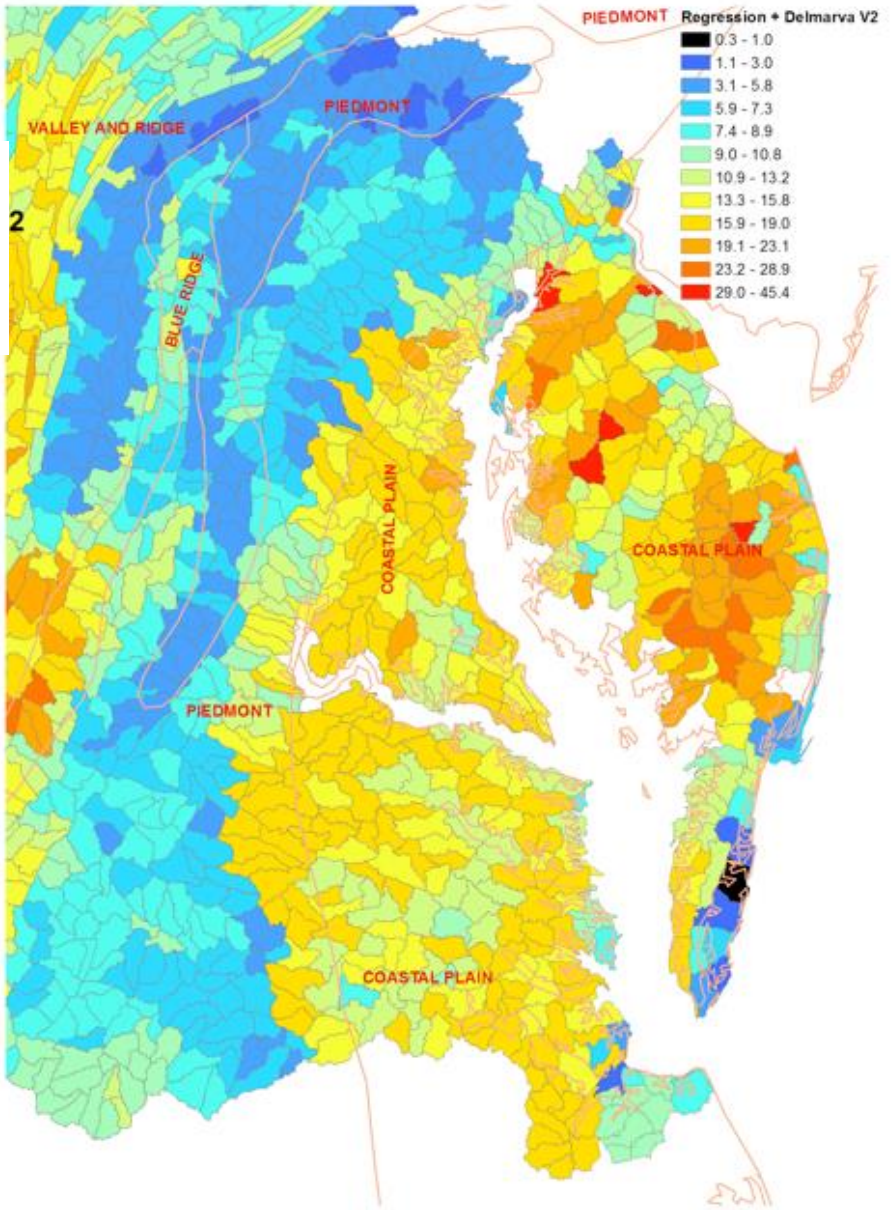
(3) Generalized Linear Model (GLM) did not perform well.



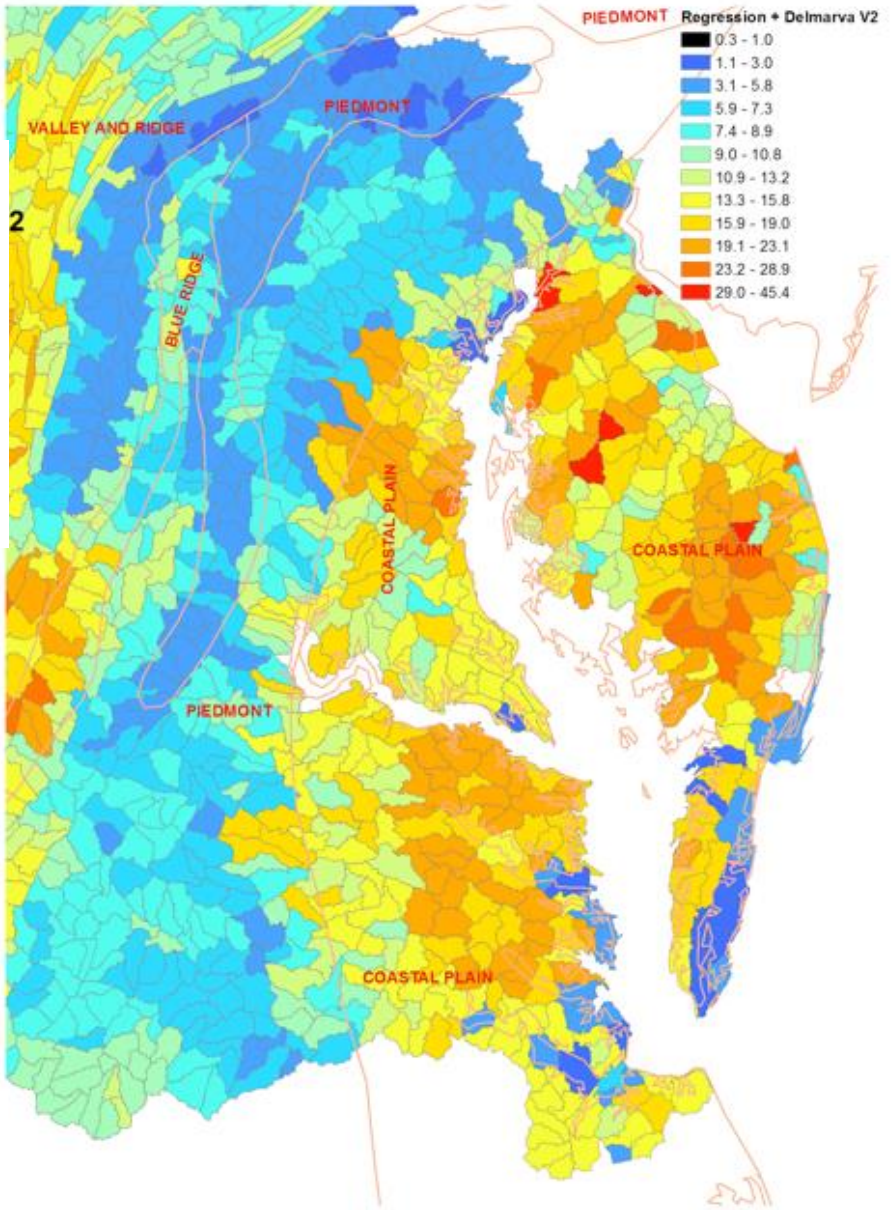
(4) Using all 52 watershed attributes in the statistical analysis.



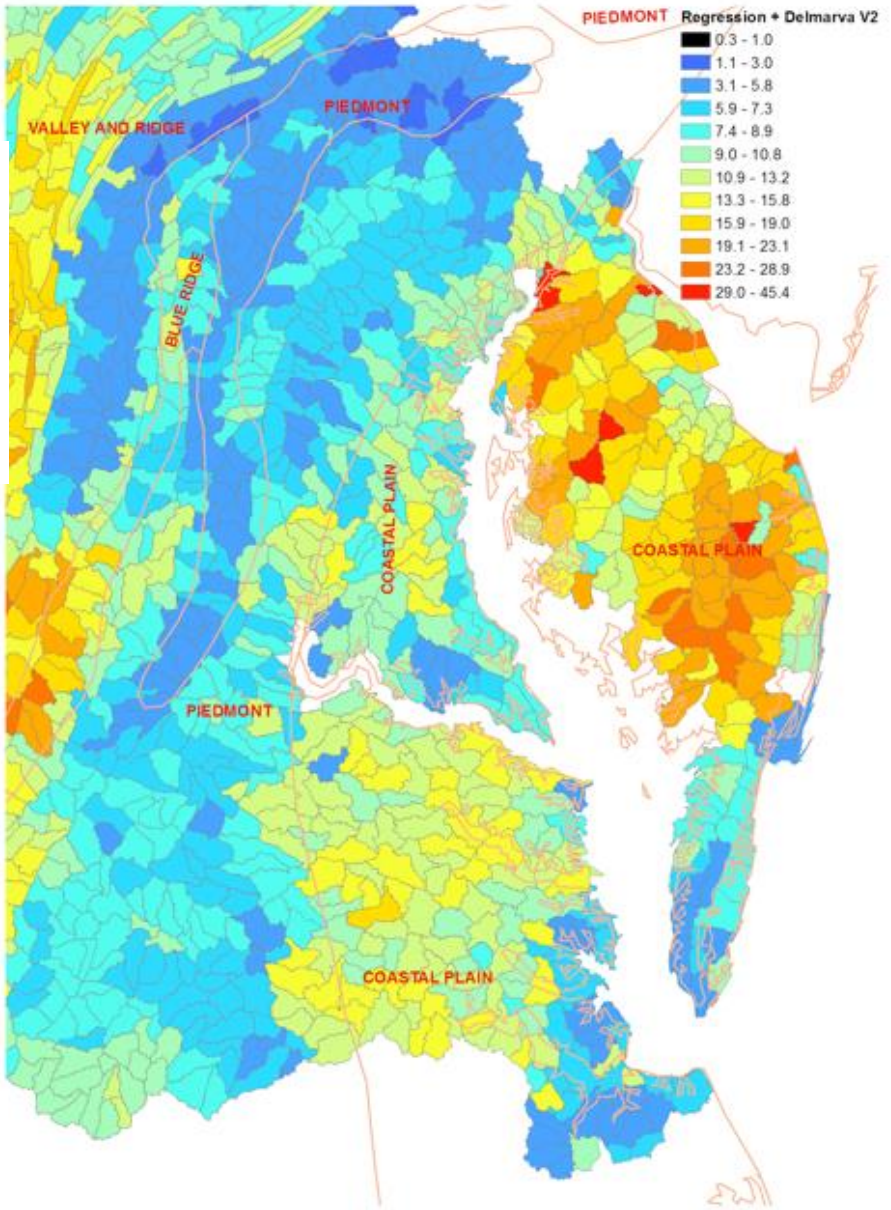
(5) Using all watershed attributes other than slope and depth to water table:



(6) Some of the attributes were dropped using ‘regularization’ statistical analysis, where the objective function consisting of a loss function based on RMSE and a penalty for complexity was minimized.

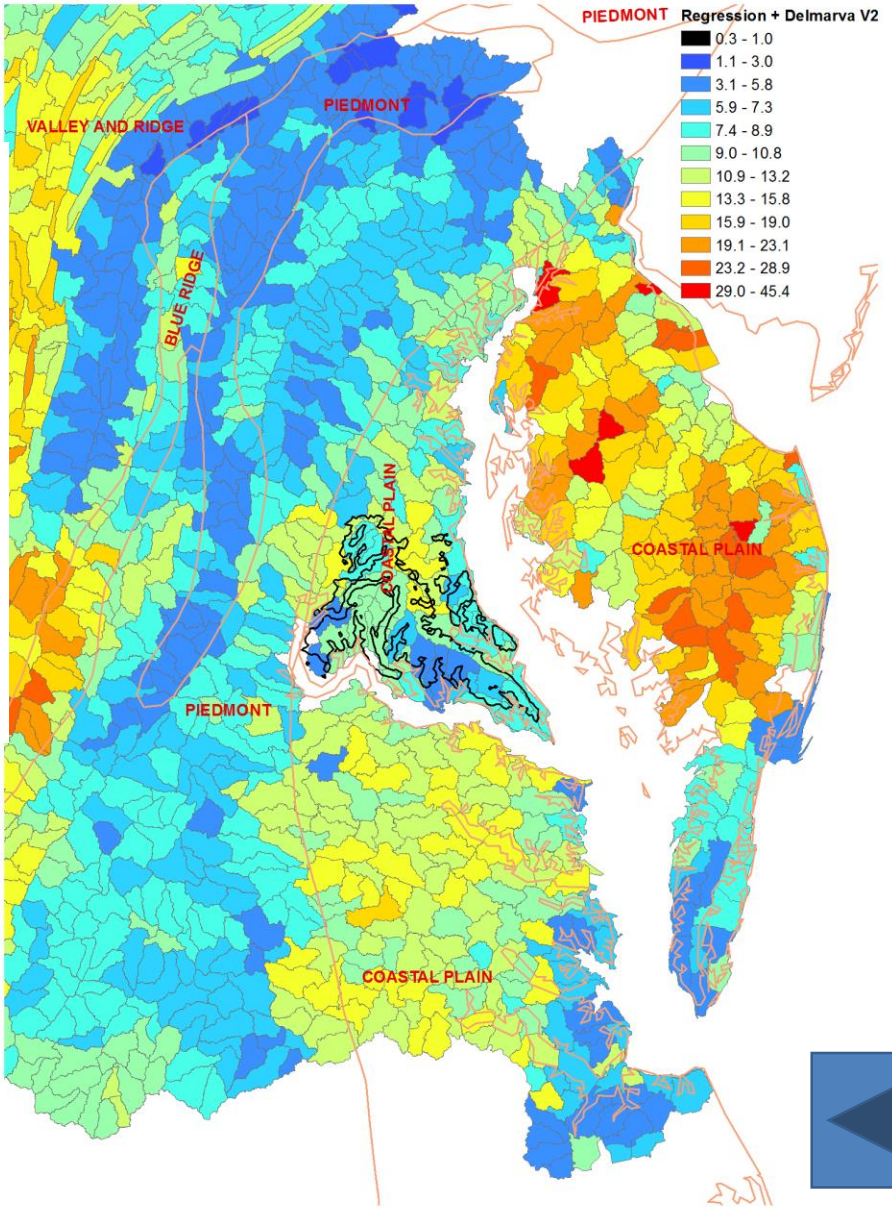


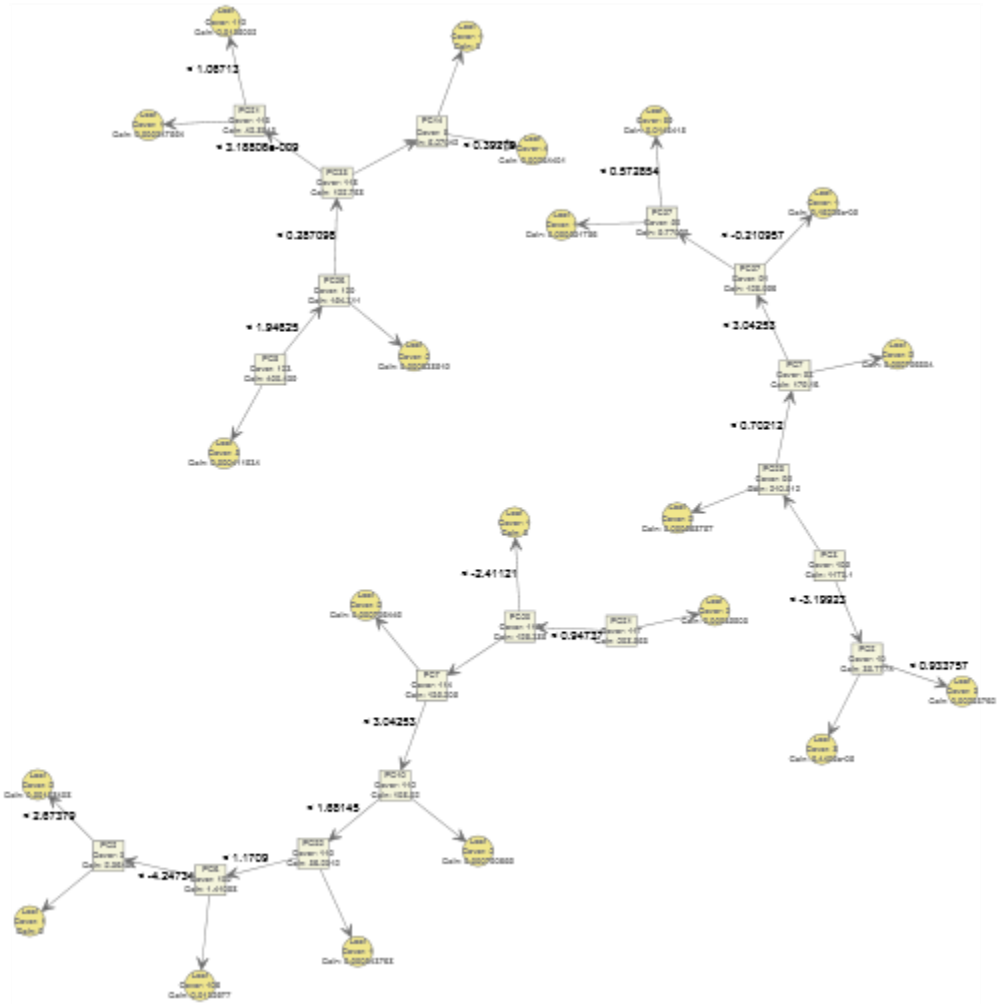
(7) First, principle component analysis (PCA) on the watershed attributes was performed. And then principle components were used in the statistical analysis.

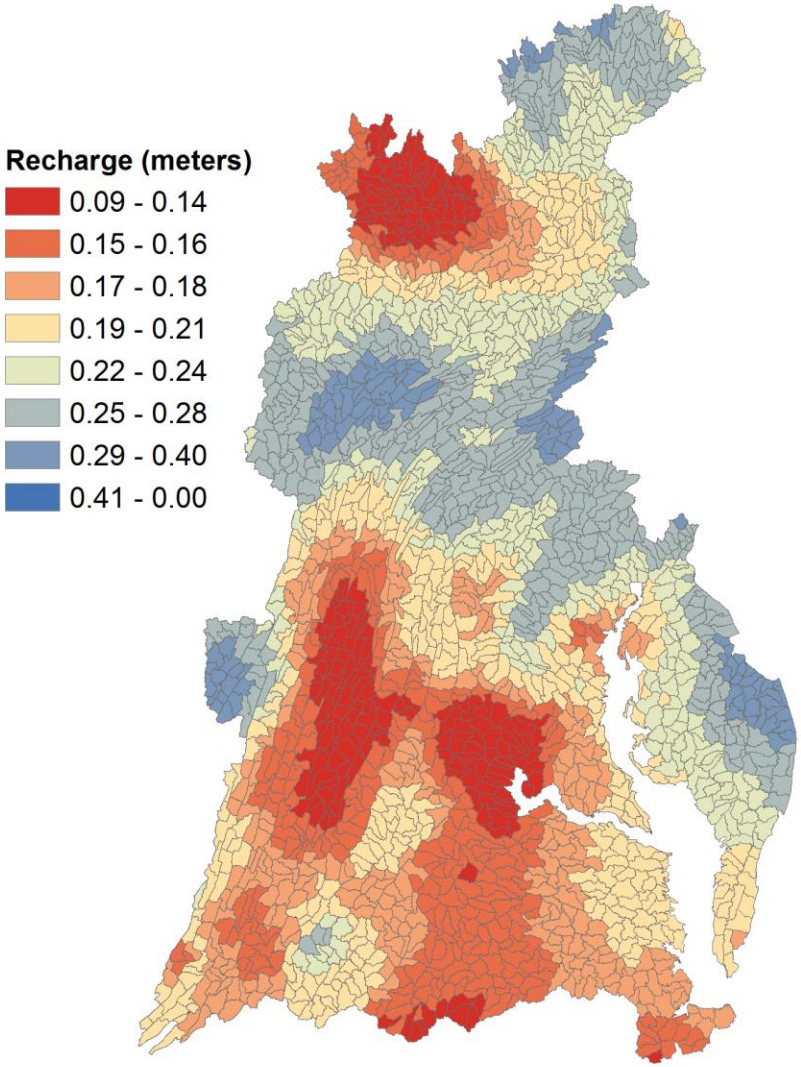


(7) First, principle component analysis (PCA) on the watershed attributes was performed. And then principle components were used in the statistical analysis.

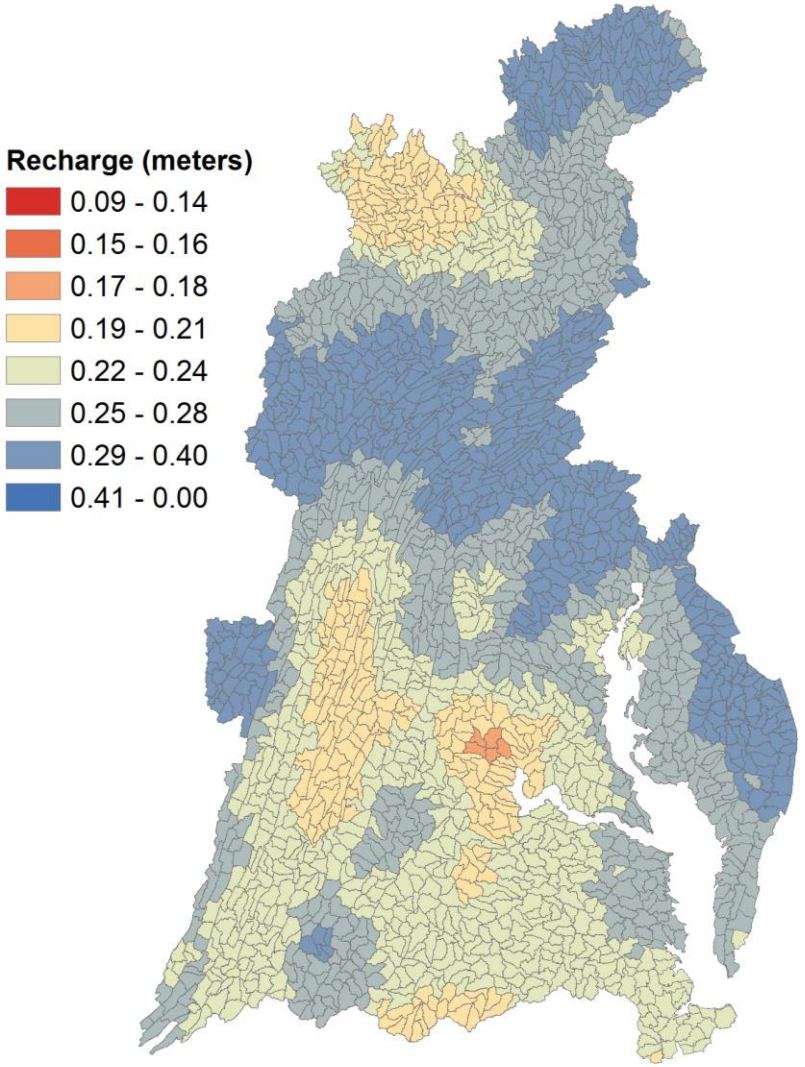
*Results from this particular analysis matched with the empirical estimates for a section of Western Shore.*








USGS Recharge [1]




After adjustment made based on recharge estimated using chemical hydrograph separation.

[1] Wolock, D.M., 2003, Estimated mean annual natural ground-water recharge in the conterminous United States: U.S. Geological Survey Open-File Report 03–311, digital data set, available on World Wide Web at URL http://water.usgs.gov/lookup/getspatial?rech48grd