Stakeholder-informed scenarios to investigate the impact of land use/land change on nutrients, sediment and runoff in the Shenandoah National Park, Virginia

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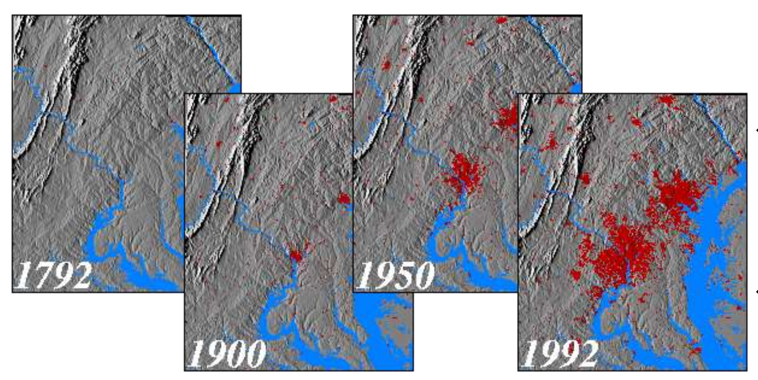
Motivation

Land use/land cover (LULC) change can negatively impact aquatic ecosystems in a variety of ways.

Chesapeake Bay Watershed

The largest estuary in North America (drainage area of 166,000 km^2) is one of the most productive and species-rich estuaries in the world. Parts of seven jurisdictions (DC, DE, MD, NY, PA, VA and WV) are located in the watershed. Water quality in the Chesapeake Bay watershed is expected to worsen with ongoing anthropogenic activities, making it more difficult for waterbodies to meet water quality standards.



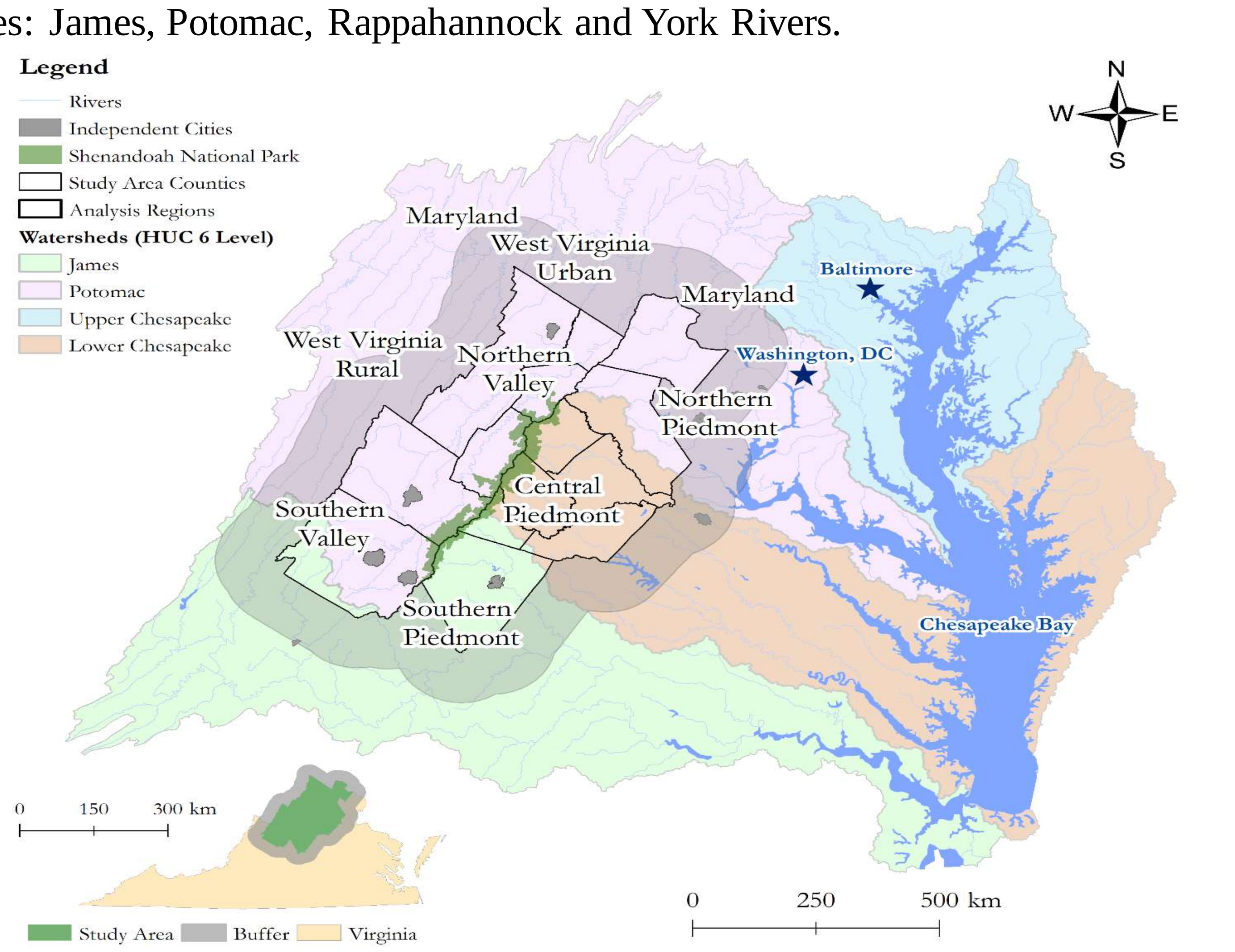
LULC change in the Chesapeake Bay

Chesapeake Bay Program

The Chesapeake Bay total maximum daily load (TMDL) was issued in 2010. The TMDL specifies that all pollution control measures needed to meet nutrient and sediment target load reductions are to be implemented by 2025. Under the TMDL, jurisdictions are expected to develop watershed implementation plans (WIPs) that are the roadmap for how they will achieve the Bay TMDL allocations.

Study Area

The ~17900 km^2 area includes parts of four physiographic provinces in Virginia, West Virginia and Maryland. The dominant LULC is forest (> 55%) followed by agricultural and urban LULC. The area includes portions of four major Chesapeake Bay tributaries: James, Potomac, Rappahannock and York Rivers.



Primary Objective

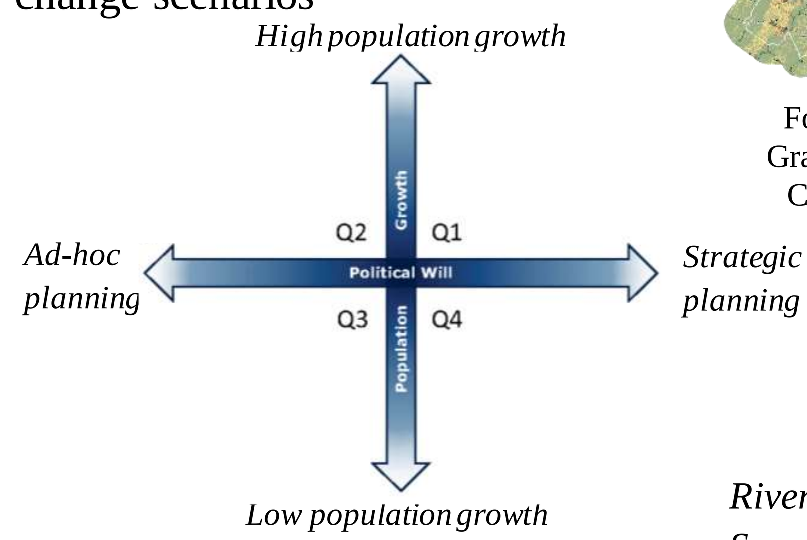
To study the impact of LULC change on nutrients, sediment and runoff volume in areas surrounding Shenandoah National Park in Virginia.

Specific Questions

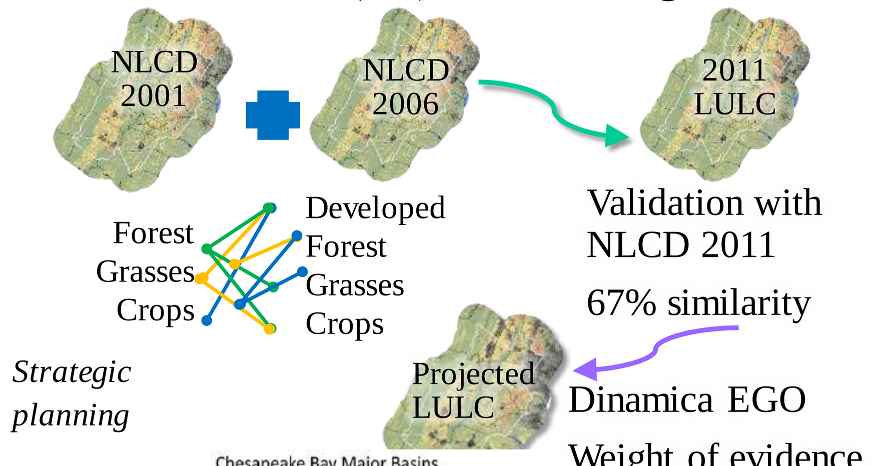
1. Are TN, TP, TSS or runoff (water quality constituents) sensitive to alternative future LULC change scenarios?
2. Are changes in water quality constituents spatio-temporally uniform?
3. How does LULC change affect ongoing watershed protection efforts (Chesapeake Bay TMDL and watershed implementation plans)?

LULC Modeling

Four stakeholder-informed LULC change scenarios

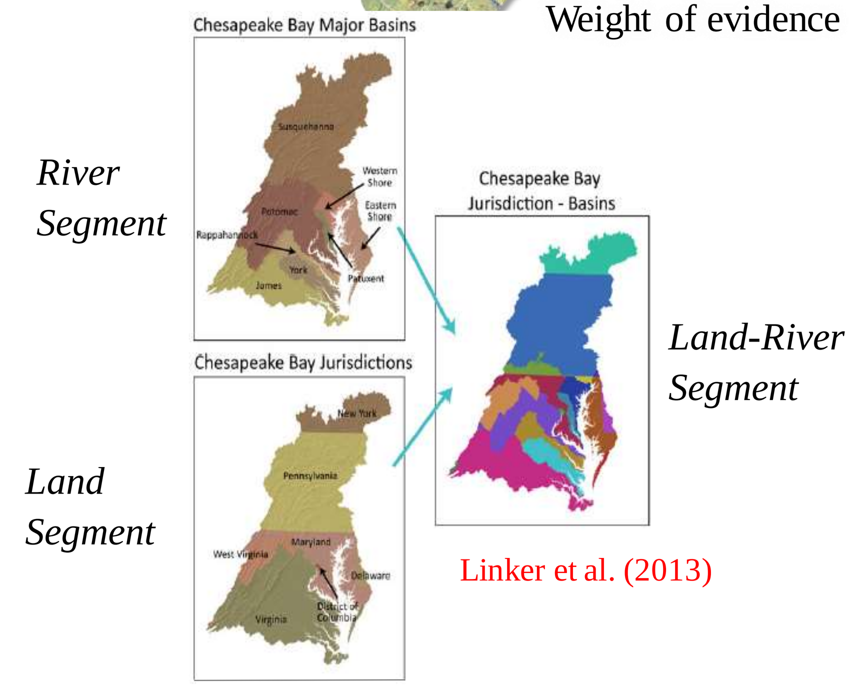


A recent trends (RT) LULC change scenario



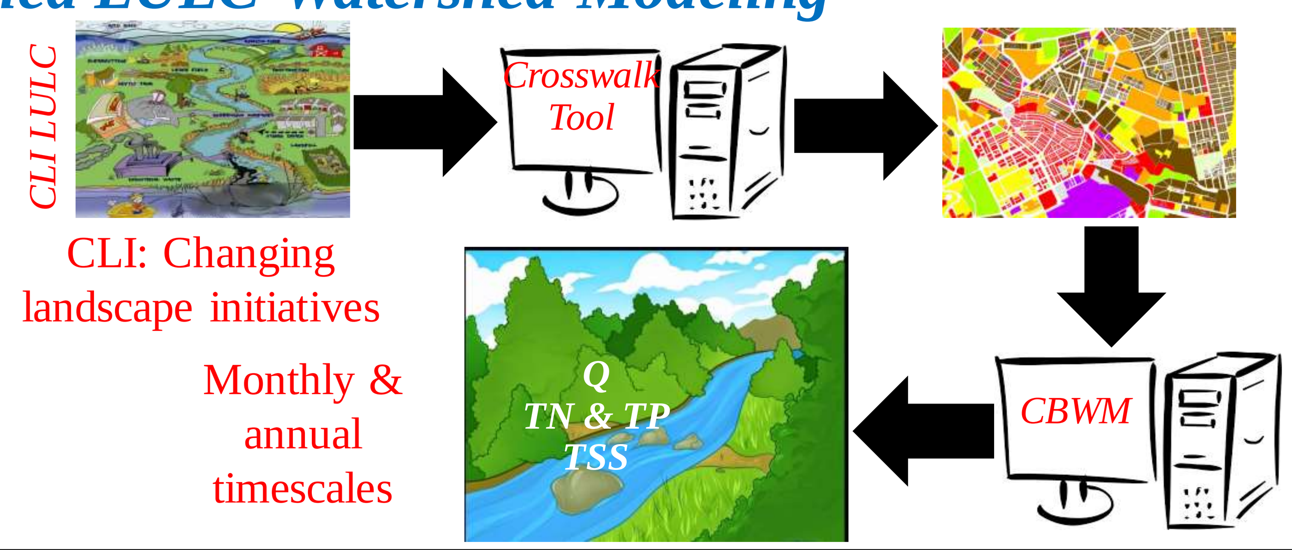
Watershed Modeling

- Chesapeake Bay Watershed Model (CBWM) Phase 5.3.2
- LULC area changes over time
- LULC unit area loads kept constant



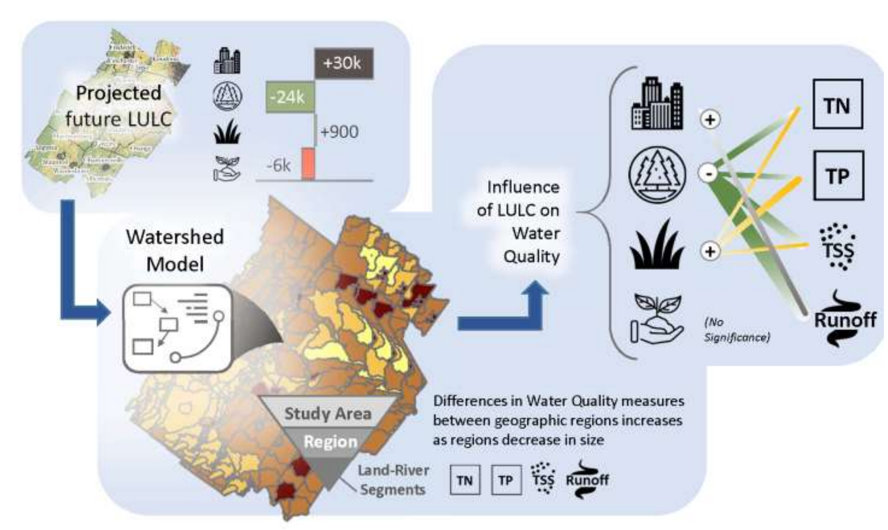
Linker et al. (2013)

Coupled LULC-Watershed Modeling

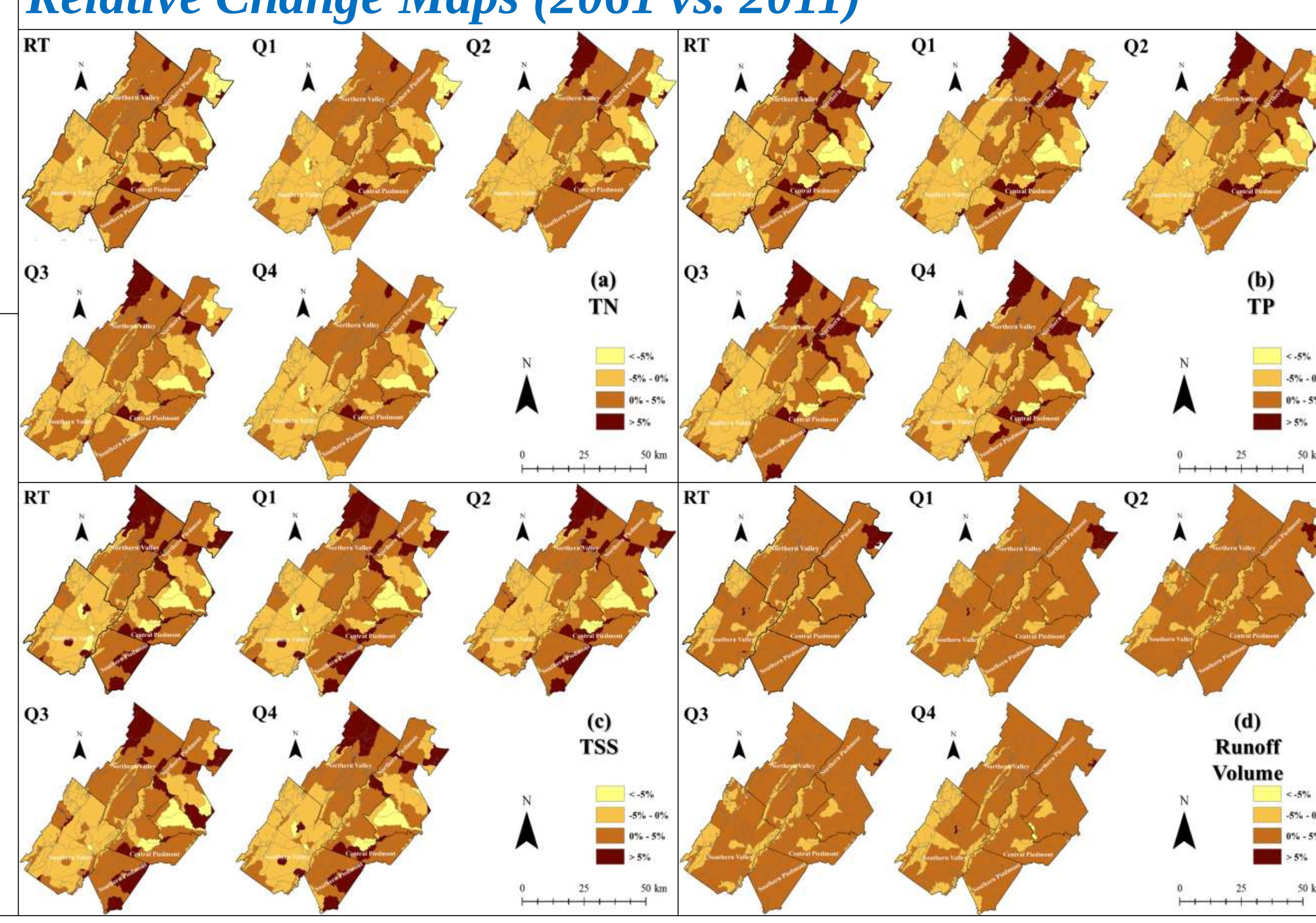


Watershed Analyses

- Three spatial scales (full study area, five regions and 216 segments)
- Three temporal scales (annual)
- Correlation between LULC and the constituents
- Sensitivity of changes with respect to current LULC distribution
- Comparison with the Bay TMDL



Relative Change Maps (2061 vs. 2011)



Statistical Analyses Results

Constituent	Range of Relative Change		
TN	-25.9 to +42.2%	-1.3 to +1.9%	-0.1 to +0.1%
TP	-38.1 to +181.4%	-2.1 to +3.5%	-0.6 to -0.1%
TSS	-32.0 to +91.2%	-1.5 to +4.9%	+0.5 to +0.9%
Runoff volume	-4.1 to +9.9%	+0.1 to +1.5%	+0.4 to +0.7%
Spatial scale	Segment	Region	Full Study Area

Changes in the constituents become less pronounced in larger scales.

Correlation between LULC and Constituents

	Pearson's r			
LULC	TN	TP	TSS	Runoff Volume
Developed	-0.11	-0.05	-0.04	0.25*
Forest	-0.37**	-0.27*	-0.55**	-0.91**
Grasses	0.18*	0.36**	0.23*	-0.02
Crops	0.11	0.06	0.06	-0.06

*Significant correlation **Strongest correlation
Significance level $\alpha = 0.01$

- Results of the correlation analysis were not different when other correlation measures such as Kendall's τ were used.

- *Forest* had a significant correlation with all the modeled constituents;
- *Developed* had a strong correlation with runoff volume;
- *Grasses* had a significant correlation with all the modeled pollutants;
- *Crops* had no significant correlation with any of the modeled constituents.

Discussion and Conclusions

- Overall, TP and runoff experienced the greatest increase and decrease, respectively.
- In full study area, TSS and runoff volume increased in all the LULC change scenarios; TP always decreased, while TN either increased in some but decreased in others.
- Increases in the area of Grasses produced the greatest increase in TP load, while loss of Forest increased TN, TP and runoff volume.
- The greater the proportion of Developed or smaller proportion of the Forest in the 2011 scenario, the more the runoff production sensitivity to additional LULC change.
- The results of the RT scenario were not substantially different from the stakeholder-informed scenarios, implying the usefulness of such a LULC trend analysis for the study area in the absence of resources to engage stakeholders' opinions.
- The LULC change scenario with ad-hoc planning and high population growth resulted in the largest increase in runoff volume, while the scenario with ad-hoc planning and low population growth showed the largest increase in the modeled pollutants.
- Political will plays a more critical role than population growth rate in watershed management.

Implications for the Chesapeake Bay TMDL: Under the LULC change scenarios investigated here, less effort is required to achieve TP TMDL but more for TSS. Required efforts to meet TN TMDL might either increase or decrease.

Future Direction

- ✓ Considering changes in the unit area loads of the LULCs over time;
- ✓ Considering changes in BMPs and nonpoint sources over time;
- ✓ Exploring the impact of LULC change on the required BMPs to meet water quality goals;
- ✓ Studying other constituents (e.g., carbon and bacteria);
- ✓ Coupled LULC-climate change model to better project future changes.

Acknowledgments

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References

1. Lacher I, Ahmadisharaf E, Fergus C, Akre T, McShea W, Benham BL, Kline KS (2019) Scale-dependent impacts of urban and agricultural land use on sediments and pollution. *Sci Total Environ* (652): 611-622
2. Linker LC, Batiuk RA, Shenk GW, Cerco CF (2013) Development of the Chesapeake Bay watershed total maximum daily load allocation. *J Am Water Resour Assoc* 49(5): 986-1006.