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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Abstract

Land use/land cover (LULC) change could adversely affect watershed health by elevating nutrients and sediment levels and intensifying the risk of flooding. In this study, a spatially-explicit LULC change modeling framework was coupled with the Chesapeake Bay Watershed Model (CBWM) to investigate the impact of LULC change on nutrients (total nitrogen and total phosphorous), sediment and runoff volume in the watersheds surrounding Virginia's Shenandoah National Park, U.S. Four stakeholder-informed scenarios alongside a Recent Trends LULC change scenario were studied. The stakeholder-informed LULC change scenarios, which differed in consideration of future planning and population growth, were developed through several meetings with stakeholders. To develop the Recent Trends, the historical LULC trend from 2001 to 2011 was analyzed. Using 2011 as a baseline scenario, the spatio-temporal patterns of LULC change were estimated as influenced by physiographic and socio-economic drivers 50 years in the future (2061). The projected LULCs were fed into the CBWM to predict the change in average annual loading of nutrients, sediment and runoff volume. While the changes in loads at the full study area were not substantial ($< 0.9\%$), changes became more pronounced at finer spatial scales. Expectedly, the LULC change scenario with ad-hoc planning and high population growth resulted in the largest increase in runoff volume. However, the scenario with ad-hoc planning and low population growth showed the largest increase in the simulated pollutants. This was because while this scenario projected less development, it projected more increases in agricultural LULCs that export more nutrients and sediment than other changing LULCs. This implied that sole land use planning based on urban development is not sufficient for watershed protection and agricultural LULCs need to be incorporated in concert in our future planning. This further suggested that land use planning plays a more critical role than population growth rate in water quality management. The results have implications for the Chesapeake Bay total maximum daily load and could help well-informed future land use planning and watershed protection by incorporating the impact of future LULC change on water quality and quantity.

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College of Agriculture and Life Sciences
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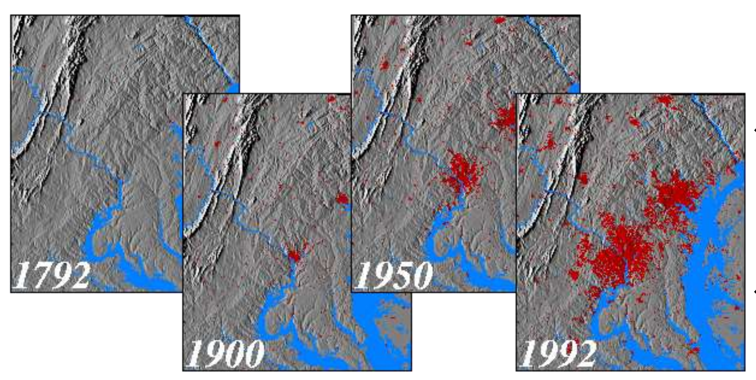
Motivation

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.



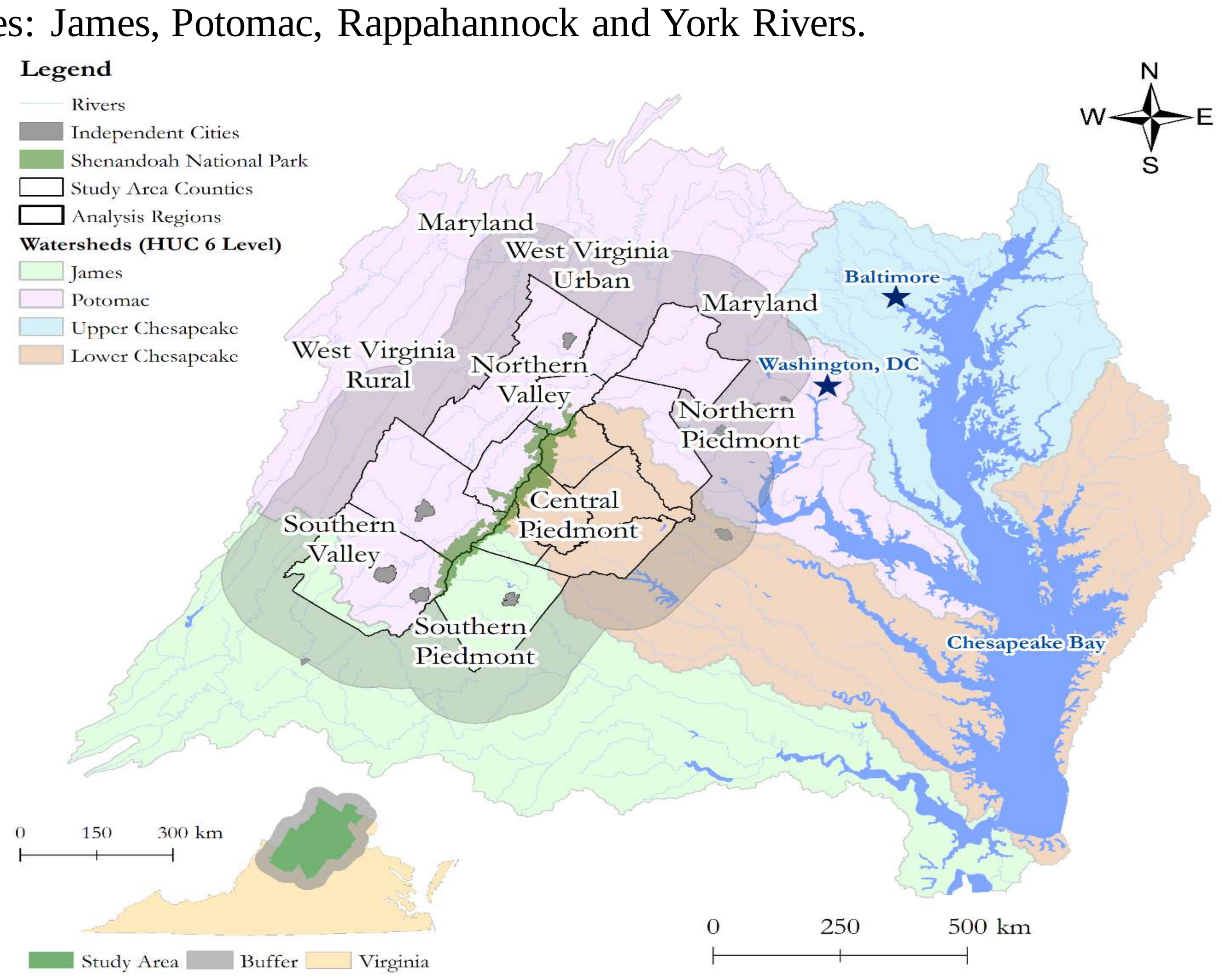
LULC change in the Chesapeake Bay

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

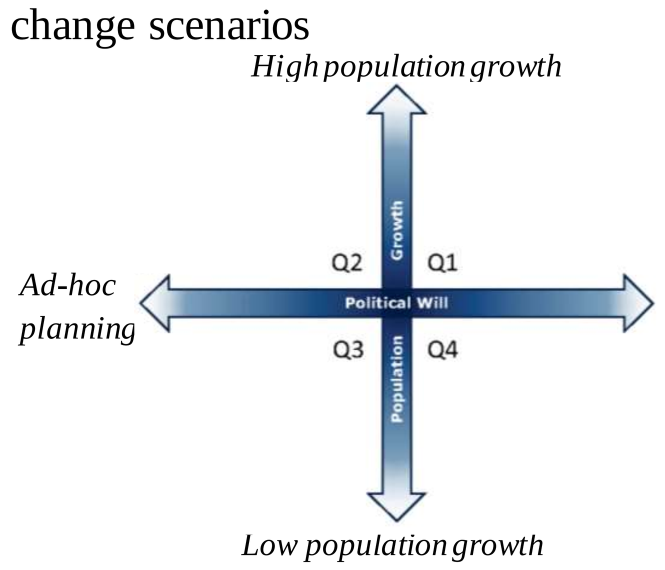
To study the impact of LULC change on nutrients, sediment and runoff volume in areas surrounding Shenandoah National Park in Virginia.

Specific Questions

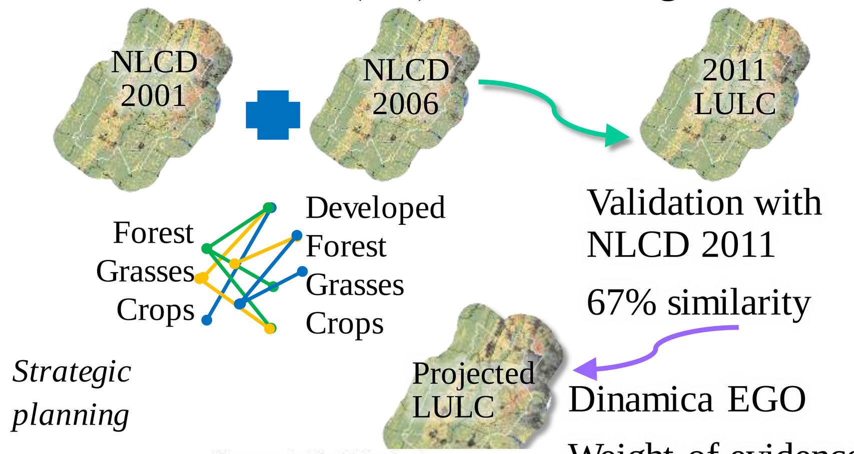
1. Are TN, TP, TSS or runoff (water quality constituents) sensitive to alternative future LULC change scenarios?
2. Are changes in water quality constituents spatio-temporally uniform?
3. How does LULC change affect ongoing watershed protection efforts (Chesapeake Bay TMDL and watershed implementation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

LULC Modeling

Four stakeholder-informed LULC change scenarios

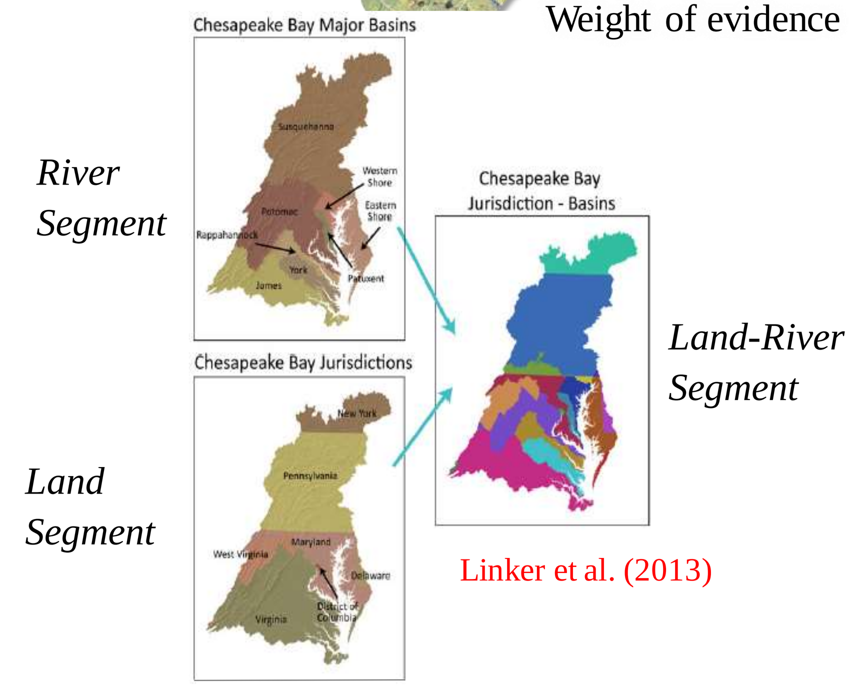


A recent trends (RT) LULC change scenario



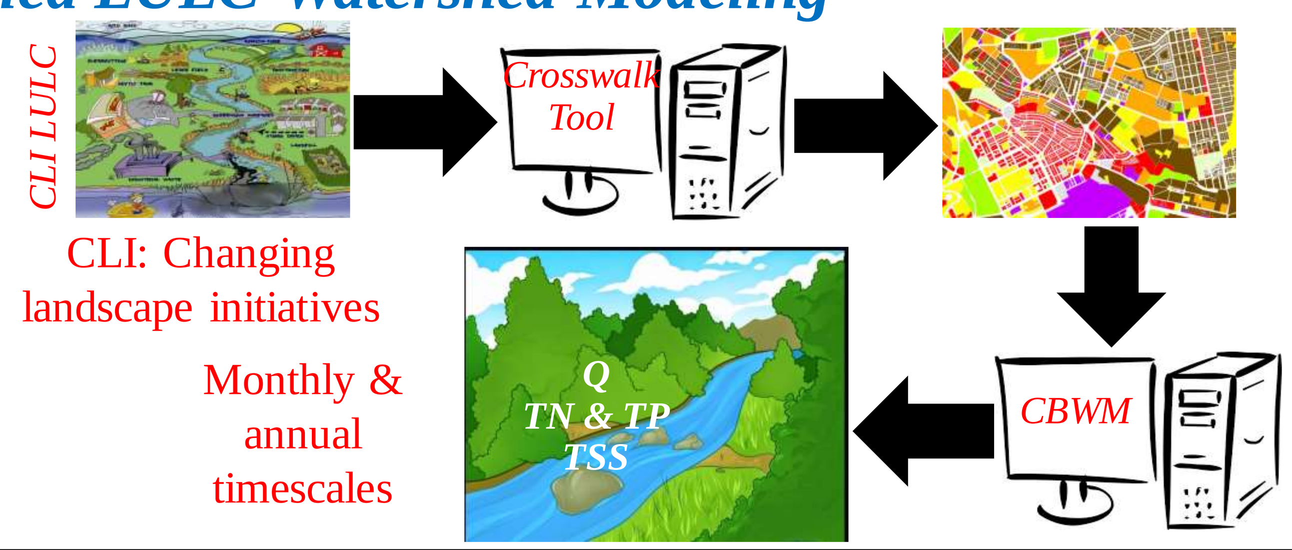
Watershed Modeling

- 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

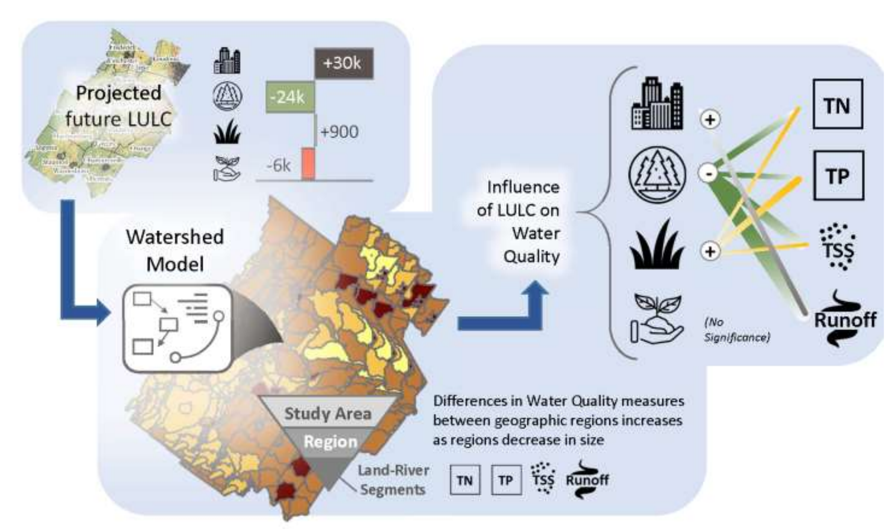


CLI: Changing landscape initiatives

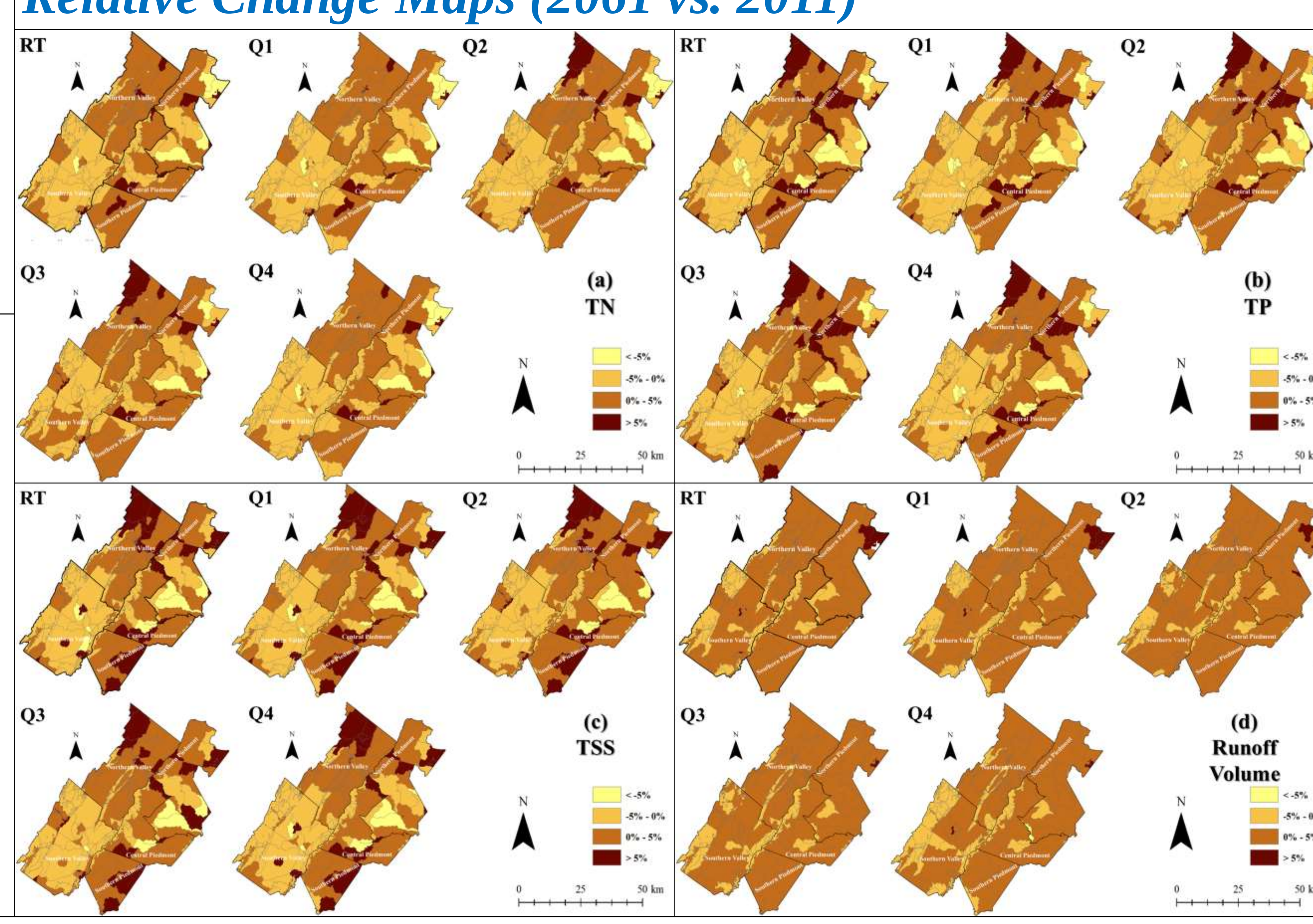
Monthly & annual timescales

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

LULC	Pearson's *r* 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.

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References

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