Identifying Sediment and Nutrient Hotspots in the Chesapeake Bay Watershed Using ENVI and Object-Based Classification

Taylor Holden, Austen Kelso, Andrew Pericak, Todd Lookingbill, Kimberley Klinker, and Jeffrey Allenby
Department of Geography and the Environment, University of Richmond, VA 23173

UNIVERSITY OF RICHMOND

Chesapeake Conservancy

Abstract

The Chesapeake Bay watershed stretches across six states and the District of Columbia and includes areas which are highly urbanized, agricultural and forested. The scale and ecological diversity of the watershed present a challenge for conservation managers charged with improving the health of the Bay itself. Localities could target best management practices (BMPs) toward making the most positive impact. We demonstrate the utility of geographic information systems (GIS) and remote sensing to locate hotspots of sediment and nutrient pollution by investigating two separate sub-watersheds of the James River: one centered around the City of Lynchburg and the other in a more agricultural landscape around Totier Creek **(Figure 1, 2)**. Using National Agriculture Imagery Program (NAIP) 1 m 4-band imagery, we conducted high resolution land cover classifications and concentrated flow path mapping to identify potential pollutant hotspots. Results revealed the combined impact of land cover and topography on nutrient and sediment entry into the Bay's waterways. While our analysis readily identified concentrated flow paths with the potential for poor water quality, interpretation by local conservation managers remains an important final step to close the loop on this project.

Precision Conservation

Local municipalities seek ways to reduce their input into waterways in response to the Environmental Protection Agency's total maximum daily load (TMDL) requirements for sediment and nutrient pollution. Conservation efforts face limits from time and financial resources and benefit from efficient and cost-effective pollution-reduction strategies such as strategic riparian buffer placement (precision conservation). Identifying hotspots for sediment and nutrient pollution reduction through precision conservation offers municipalities an efficient way to choose the right places and scales for conservation efforts. Ultimately, such methods help localities target efforts in places where they will have the most positive impact on water quality with the least cost.

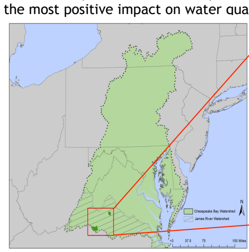

Figure 1. Study Area. The Chesapeake Bay Watershed stretches over 64,000 square miles from Virginia to southern New York. Our analysis investigated areas in the watershed's southernmost portion.

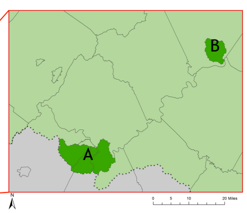

Figure 2. Study Watersheds. Lynchburg (A) and Totier Creek (B) both fall within the James River watershed; the Lynchburg watershed has relatively more urbanization when compared to the more agricultural Totier Creek watershed.

Acknowledgements

- Jeffrey Allenby and the Chesapeake Conservancy for supplying us with data, ENVI software assistance, and continued support throughout the entire project.
- John Scrivani and the Virginia Geographic Information Network for supplying LIDAR data and hydrology mapping support.
- Exelis VIS for providing us with ENVI 5, the remote sensing software necessary to complete the land-cover classifications.

Methods

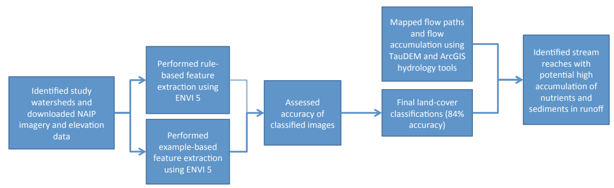

Figure 3. Project Flow Chart. Prioritizing buffer placement uses a combination of three processes: land-cover classification, accuracy assessment, and concentrated nutrient and sediment flow path mapping.

1) Land Cover Classification

We used both example- (**Figure 4**) and rule-based (**Figure 5**) classification methods for feature extraction of the NAIP imagery. These object-based methods analyze groups of pixels with similar spatial, spectral, and textural characteristics rather than classifying by individual pixels. We classified the 1 m, 4-band NAIP imagery into seven distinct land-cover classes that have differing influences on water quality: rural open, tilled agriculture, water, impervious surfaces, deciduous forest, coniferous forest, and barren.

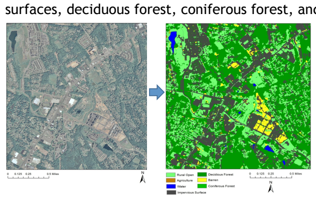

Figure 4. Lynchburg. Comparison of NAIP image of an urban area of the Lynchburg watershed to its example-based classification.

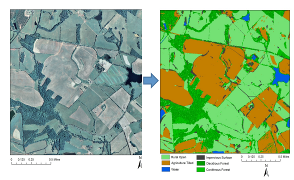

Figure 5. Totier Creek. Comparison of NAIP image of a rural area of the Totier Creek study watershed to its rule-based classification.

2) Accuracy Assessment

Using 30-50 random samples per class in a confusion matrix, we calculated overall accuracy, user accuracy, producer accuracy, and the kappa coefficient of each classified image.

3) Concentrated Flow Path Mapping

We assigned weights to each land cover type based on whether it generally increases or diminishes nutrients or sediments in runoff. Then using digital elevation models paired with the D-Infinity flow direction model from the TauDEM toolset for ArcGIS, we calculated and mapped flow direction for all pixels in the watersheds (**Figure 6**). We weighted these flow paths by land-cover type to produce our final flow accumulation maps.

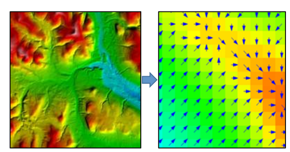

Figure 6. Flow Paths. Mapping flow paths and flow accumulation makes it easier to visualize where riparian buffers could have the greatest impact in improving the water quality of runoff from surrounding areas.

Results

1) Land Cover Classification Accuracy

The classifications had overall accuracies lower than our target of 80% **(Table 1)**. The greatest difficulties involved discriminating between Agricultural and Rural Open as well as Deciduous Forest being classified as Coniferous **(Table 2)**.

Table 1. Accuracy Assessment Summary Table.

Site	Overall Accuracy	Kappa Coefficient
Lynchburg	73%	0.81
Totier Creek	79%	0.79

Table 2. Lynchburg Confusion Matrix. Columns provide ground truth observations; rows provide classified pixels. Gray cells represent pixels classified correctly. Final columns and rows show user and producer accuracy.

Class	Agriculture	Barren	Coniferous	Deciduous	Impervious	Rural Open	Water	Grand Total	User Accuracy
Agriculture	22	2	0	1	1	24	0	50	44%
Barren	0	28	0	1	6	1	1	37	76%
Coniferous	0	2	30	13	3	2	0	50	60%
Deciduous	1	0	3	45	0	1	0	50	90%
Impervious	0	3	0	3	41	3	0	50	82%
Rural Open	0	0	0	2	4	44	0	50	88%
Water	0	0	0	5	6	3	36	50	72%
Grand Total	23	35	33	70	61	78	37	246	
Producer Accuracy	96%	80%	91%	64%	67%	56%	97%		73%

2) Pollutant Hotspots Over Concentrated Flow Paths

We weighted the hydrologic flow paths using the classified land cover maps to identify areas of potentially high flow accumulation of sediments and nutrients (red in **Figure 7**).

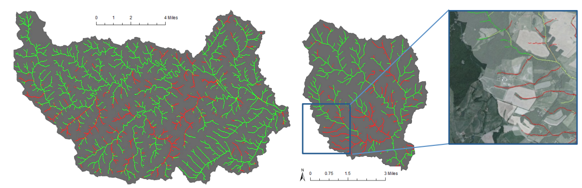

Figure 7. Weighted Accumulation Maps. Lynchburg (left) and Totier Creek (right). Green stream segments experience good buffering from forested upslope areas; red stream segments have high accumulation of runoff from urban and agricultural lands. The enlarged section of the Totier Creek watershed provides an example of the analysis results overlaid back on the NAIP imagery for the site.

Discussion and Conclusion

The combination of high resolution land cover classification and concentrated flow path mapping presents an efficient way to pinpoint areas that would most benefit from conservation efforts. Interpretation by local conservation managers remains an important final step to close the loop on this project; analysts must carefully interpret the final maps in context.

As a continuation of this project, students in our Advanced Spatial Analysis class completed a similar analysis for two watersheds closer to the Chesapeake Bay. ENVI 5.1 update allowed for the saving of example data which has increased accuracy. Students ran the Feature Extraction and then collected more examples for classes that were not accurately being classified. In addition the use of more classes mitigated the confusion between rural, barren, and agriculture classes.