Chesapeake Conservancy

The Emerging Role of Technology in Precision Conservation

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Chesapeake Conservancy

The Chesapeake Conservancy's mission is to strengthen the connection between people and the watershed, conserve the landscapes and special places that sustain the Chesapeake's unique natural and cultural resources, and encourage the exploration and celebration of the Chesapeake as a national treasure.

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Executive Summary

The Chesapeake Bay watershed is home to more than 17 million residents, spans 64,000 square miles, is the largest estuary in the United States, and is one of the most productive bodies of water in the world. Conservation efforts over the last four decades have made significant progress in protecting ecologically and culturally important landscapes; however the condition of the Chesapeake Bay is still not where it needs to be and much work remains to be done. As funding sources for land conservation become increasingly scarce and the six watershed states and the District of Columbia continue to develop programs to meet the EPA's Chesapeake Bay Total Maximum Daily Load (TMDL) guidelines, it will be imperative to prioritize the conservation and restoration of high-functioning natural landscapes that have the greatest potential for maintaining or improving the water quality of the Chesapeake Bay.

Identifying landscapes that impact water quality will require the development and use of new technologies and targeting methods to ensure that the benefits of nutrient uptake and sediment retention are incorporated into decisions regarding land conservation. When combined with the land's other benefits, such as protecting critical wildlife habitat, preserving the Chesapeake's cultural history, and creating access points, this information will provide conservation organizations with a more robust and comprehensive assessment of the advantages of protecting a particular property. This advanced targeting will allow us to focus our efforts on the highest functioning parcels that will provide a balance of ecosystem services and deliver the greatest amount of benefits using the limited funding available.

For this report, the Chesapeake Conservancy interviewed and worked with researchers, industry leaders, and our partners to identify and highlight new cost-effective technologies that can rapidly and accurately determine high-functioning natural landscapes to help guide conservation targeting throughout the Chesapeake Bay watershed. Through our research, we have identified the importance, potential, and limitations of five technologies that can identify important attributes about a landscape through the evaluation of certain critical characteristics that have a substantial impact on the water quality coming off the land:

- **Headwater Stream Mapping** uses easily accessible high resolution LIDAR elevation data to identify currently unmapped stream reaches that can contribute up to 50% of downstream water, nutrients, and sediment.
- **Concentrated Flow Paths and Buffer Effectiveness** measurements compare elevation data with soil and buffer information to detect areas where water concentrates and potentially overwhelms the filtering capacity of riparian buffers and filter strips.
- **Ecosystem and Vegetative Species Determination** uses high-resolution satellite or aerial imagery to determine the location and extent of land use and land cover types to help recognize high quality natural ecosystems that can have a positive impact on water quality and should be priorities for conservation.
- **Biomass and Forest Stand Characteristics** determination uses multiple-return LIDAR data to generate estimates of biomass to approximate the nutrient uptake and carbon sequestration

potential of a landscape and can help identify areas that would qualify for crediting in ecosystem-services markets.

- **Nutrient and Sediment Loading and Restoration Potential** incorporates data from the other technologies to calculate fine-scale nutrient and sediment loads entering the water, which can be used to identify priority restoration and conservation areas.

Each of the technologies described in the first four sections can help conservation organizations identify general landscape features that have an impact on water quality. When combined using the models highlighted in the fifth section, these technologies can create a more detailed representation of where nutrients and sediment are flowing off the land and where natural systems are removing pollutants before they reach the rivers and streams flowing into the Chesapeake Bay.

Headwater stream mapping, concentrated flow paths, and ecosystem and vegetative species determination are three of the technologies with the highest likelihood of being implemented widely in the Chesapeake Bay watershed due to their ease of use and the relative accessibility of raw data, and will all provide conservation organizations with extremely useful datasets that will drastically improve conservation targeting efforts. Biomass estimations and nutrient and sediment loading also have the potential to be useful prioritization tools but the analyses required to use these technologies will likely be too complex for most organizations to complete themselves.

All of these technologies are scalable and can be applied to a range of management situations from modeling the entire Chesapeake Bay watershed to understanding what is happening on an individual parcel. As land conservation evolves and becomes more competitive, having the ability to identify and understand what characteristics make these high functioning landscapes valuable will give conservation organizations the capacity to make informed decisions about which land provides the greatest range of benefits and should be a priority for conservation.

Demonstrating the effectiveness of using these technologies to evaluate the water quality benefits of land conservation and engaging management agencies, such as the EPA and state natural resource agencies, through real-world case studies will be an important next step in promoting their wide-spread use. For all of the technologies highlighted in this report, it will also be important to develop and promote an online user community where practitioners can learn more about their implementation and interact with experts to advance the development and use of these tools.

Ultimately, using these technologies to determine a parcel's landscape characteristics provides us with a greater ability to target land that maintains water quality and helps us locate areas where restoration activities will have the greatest impact on improving water quality. These technologies will not only provide us with greater expertise for our land conservation efforts, they will ensure that conservation organizations across the Chesapeake Bay watershed have the tools they need to make wise investments that provide real results and the land that is essential to restoring the health of the Chesapeake Bay is protected.

Overview of Technologies

Technology	Potential	Limitations	Conclusions
Headwater Stream Mapping	Identifies currently unmapped stream reaches that can contribute up to 50% of downstream water, nutrients, and sediment	• Cost of software • Need for training • Access to data	Headwater stream mapping is very feasible and should be investigated more through a demonstration project
Concentrated Flow Paths and Buffer Effectiveness	Identifies areas where water concentrates and potentially overwhelms the filtering capacity of riparian buffers and filter strips.	• Access to data • Implementation considerations • Cost of software • Need for training	General hotspots could be identified using current technologies and should be investigated more. Mobile decision support tools could make it easier for users to identify potential ways to address problem areas.
Ecosystem and Vegetative Species Determination	Uses satellite or aerial imagery to determine the location and extent of land use and land cover classes to help identify high quality natural ecosystems.	• Cost of data • Cost of software • Need for training • Data/processing intensive	Image classification is a very developed technology that can provide extremely useful management information and should be investigated further in a demonstration project.
Biomass and Forest Stand Characteristics	Uses multiple-return LIDAR to generate estimates of biomass, which can be used to determine nutrient uptake and carbon sequestration potential.	• Need for training • Cost of data • Very complex analysis • Data/processing intensive	Biomass estimation is too complex for most groups but forest characteristics can improve buffer delineation and image classification. Efforts should be focused on creating tools to disseminate processed data.
Nutrient and Sediment Loading and Restoration Potential	Uses multiple data sources to calculate the expected nutrient and sediment loads entering the water and identifies priority restoration and conservation areas	• Very complex analysis • Data/processing intensive • Need for training • Access to Data	Nutrient and sediment loading calculations are too complex for most groups. Efforts should be focused on developing tools to disseminate and analyze processed data to identify priority areas.

The Emerging Role of Technology in Precision Conservation

Introduction

The Chesapeake Conservancy recognizes the importance of maintaining high-functioning landscapes along the Chesapeake Bay and its rivers that provide a multitude of benefits including not only access for recreation and open space and habitat protection, but also nutrient uptake and sediment retention that will improve water quality in the Chesapeake and its tributaries. We contend that land use is the single most profound factor affecting the Bay's water quality and numerous studies over the past thirty years have supported the link between intact natural landscapes and improved water quality (Lowrance et al 1984, Schoonover et al 2005, 2006, SCCWRP 2007). For this reason, we believe that the land's water quality and other ecosystem service benefits should be considered along with its habitat potential and cultural or historical connections when making conservation decisions. As funding sources become increasingly scarce and the six watershed states and the District of Columbia work to restore the Chesapeake Bay, this comprehensive evaluation of the land's conservation benefits will become ever more important. Prioritizing high-functioning landscapes that maintain or enhance the condition of the Bay and its tributaries will require the development and use of new technologies and targeting methods to ensure that the benefits of nutrient uptake and sediment retention are incorporated into decisions regarding land conservation.

Figure 1: The Chesapeake Bay's watershed is home to over 17 million people and drains over 64,000 square miles of land across six states and the District of Columbia. Chesapeake Bay Program 2008

In developing this report, the Chesapeake Conservancy has interviewed and worked with researchers, industry leaders, and our partners to identify and support new cost-effective technologies that can rapidly and accurately determine high-functioning natural landscapes to help guide conservation targeting throughout the watershed. These new technologies and methods allow us to perform "precision conservation"; getting the right practices in the right places, at the right time, and at the right scale (Cox 2005). Specifically, new applications of technology can help determine important attributes about a parcel of land, such as the relative nutrient and sediment reduction potential, through the evaluation of certain critical landscape characteristics including:

- Headwater stream channels and drainage density,
- Concentrated flow paths (CFPs) and buffer effectiveness,
- Ecosystem and vegetative species composition,
- Biomass and forest stand characteristics, and
- Restoration and Nutrient & Sediment loading potential

When combined with the land's other benefits, such as protecting critical wildlife habitat, preserving the Chesapeake's cultural history, and providing access points, this information will provide a more robust and comprehensive assessment of the advantages of conserving a particular property. This advanced targeting will allow us to focus our efforts on the highest functioning parcels that will provide a balance of ecosystem services and deliver the greatest amount of benefits using the limited funding available.

Going beyond the parcel level, these technologies will also help define landscape-scale conservation opportunities that transcend parcel or jurisdictional boundaries and take advantage of existing initiatives, address state and federal priorities, and engage local partners in collaborative conservation efforts. Working with multiple organizations in these priority areas has the potential to accelerate the pace and scale of regional land conservation efforts while reducing the overall project costs and improving access to financial capital (Levitt et al 2010). Using innovative technologies to identify these large, highly-functional ecosystems will allow the Chesapeake Conservancy and our partners to be more deliberate in our efforts and ensure that regional conservation efforts are coherent and complementary.

In addition to simply locating naturally high-functioning landscapes, these technologies could provide a baseline to assess the effectiveness or appropriateness of specific activities, like buffer or wetland creation, that could enhance the existing benefits of conserved land and potentially prevent additional nutrients and sediment from entering adjacent waterways. Information such as the extent of disturbed ecosystems or the location of concentrated flow paths with inadequate buffers can help evaluate under-functioning landscapes that are not reducing the nutrient and sediment load flowing into the water to their full potential. As budgets for restoration activities shrink, and as the Bay states continue to develop programs to meet the EPA's Chesapeake Bay Total Maximum Daily Load (TMDL) guidelines, it will be imperative to develop and promote technologies that can help evaluate the load reduction potential that specific restoration activities would achieve to prioritize projects with the greatest potential.

The technologies described in this report have the ability to determine which land has the potential to contribute sediment and nutrients to the Chesapeake Bay and which areas, if conserved or restored, could have the largest impact on protecting the Bay's water quality. As land conservation evolves and becomes more competitive, having the ability to identify and quantify these high functioning landscapes will give conservation organizations the capacity to make informed decisions about which land provides the greatest range of benefits and should be a priority for conservation.

Each of the technologies described in the first four sections can help conservation organizations identify critical landscape features that have an impact on water quality. When combined using the models highlighted in the fifth section, these technologies can create a more detailed representation of where nutrients and sediment are flowing off the land and where natural systems are removing pollutants before they reach the rivers and streams flowing into the Chesapeake Bay. Demonstrating the effectiveness of new technologies that can evaluate the water quality benefits of land conservation and promoting their use will not only provide us with greater expertise for our land conservation efforts, it will ensure that conservation organizations across the Chesapeake Bay watershed have the tools they need to make wise investments that provide real results and that land that is essential to restoring the Chesapeake Bay is protected.

Headwater Stream Mapping and Drainage Density

Importance

Government agencies at all levels rely on maps of stream channel networks for management efforts such as habitat surveys, general land use planning, and determining non-point source loadings of pollutants to the Chesapeake Bay. The USGS has mapped an extensive stream network in their National Hydrography Dataset (NHD), which depicts stream channels and headwater points determined from topographic maps, aerial photography, and, in some places, field verification. A large portion of the actual drainage network lengths, however, is composed of small headwater channels that aren't included in the NHD because they typically are not easily determined from aerial images or are too small to show "traditional" channel characteristics (Smith and Herrmann 2005). Headwater streams are the least well mapped, despite their abundance in the landscape, and can have a significant impact on water quality flowing downstream, contributing 40-50% of water volume and nitrogen found in fourth and higher order rivers (Alexander et al 2007). In most cases, only streams in the NHD are covered under state and federal regulations, including the Clean Water Act, leaving these unmapped upland streams open to development or alteration.

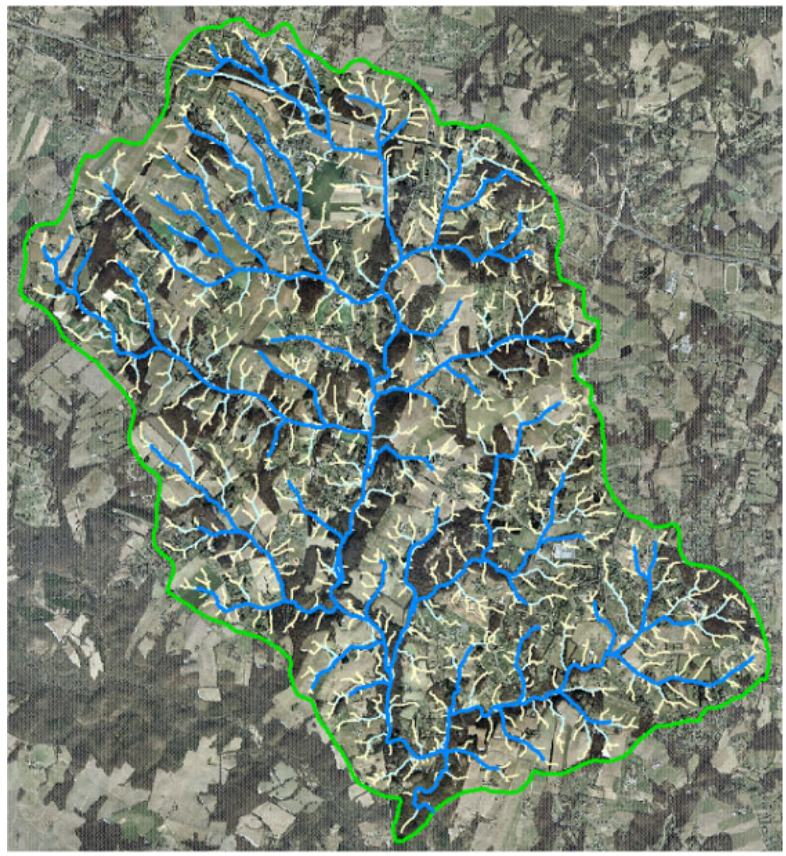


Figure 2: Cattail Creek watershed and drainage network in Howard County, MD. Blue lines represent USGS NHD streams. White lines are extended synthetically-derived head-water channels. M. Herrmann, Ecosystem Analysis Center-MD DNR

Drainage density is closely related to headwater stream channels and areas with a larger number of streams, each draining a section of land, have a higher drainage density. In most headwater areas, there is a relatively small area draining into each channel, and, theoretically, there is less chance for water to be absorbed by the land before it reaches a stream, which creates a greater potential for nutrients and sediment to be carried directly into the water (Smith and Herrmann 2005). Higher drainage densities typically occur in steeper terrain with 1st-order systems, sometimes far away from large rivers or areas that are thought of as major sources of non-point source pollution. Interestingly, these headwater streams can deliver the majority of nutrients and sediment to a river; however they also have the largest potential for denitrification when natural landscapes and buffers are intact (Alexander et al 2007). If the NHD headwater points and channels are the only landscape characteristics used in management decisions, there is potentially a large area not being accounted for in many models that, depending on land use, could play a large role in nutrient and sediment loads. Maintaining natural ecosystems and effective buffers along headwater stream channels may well be one of the most important factors to maintaining downstream water quality by keeping large sediment and nutrient loads out of the waterway.

Available Technologies and Techniques

There are a number of techniques and software options that could help define stream channels in upland areas and each method has distinct advantages and disadvantages, stemming from their intended audiences, differences in user interfaces, and cost (Peckham 2012, Elmore 2012, Smith 2012). All of the software packages used to define headwater stream channels primarily rely on Digital Elevation Models (DEMs), which are available at different resolutions from a number of sources. DEMs are typically "raster" datasets; essentially a geographically referenced image with each pixel containing a value that relates to the dataset. In this case, each pixel represents a square of the ground and the value represents its average elevation. The USGS has created a seamless DEM dataset for the United States with full coverage at 30m and 10m resolutions and partial coverage at 3m resolution that is currently housed and available for download from The National Map (http://nationalmap.gov/). It is possible to collect data at finer resolutions, which will create more detailed models; however the size of the datasets, as well as the processing time required to analyze the data, will expand rapidly as resolution increases.

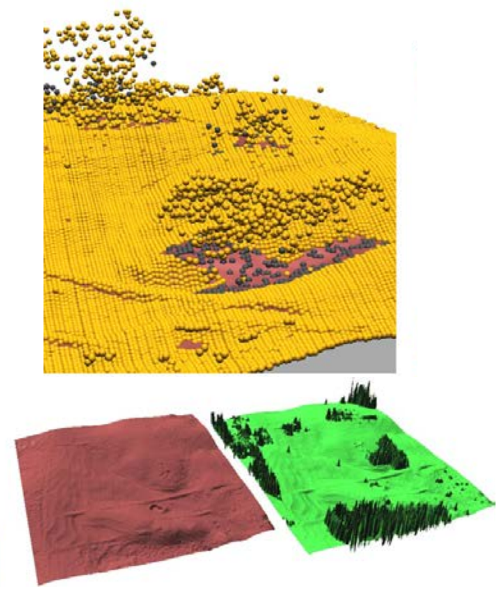


Figure 3: Visualization based on multiple return LIDAR data: (top) point cloud; (bottom) bare Earth and first return surfaces side-by-side Mitasova et al. 2012

Light Detection and Ranging (LIDAR) data consists of a point cloud with very high vertical and horizontal resolution collected by bouncing a laser beam off the ground and extrapolating the elevation from the time it takes the laser to return to the sensor. LIDAR data has been collected through various federal, state, and county initiatives for much of Pennsylvania, Maryland, Delaware, and the coastal portions of Virginia. LIDAR data for DEMs is typically collected using either fixed-wing aircraft or helicopters and requires significant processing to separate "first return" data, representing the tops of trees, buildings, etc., and "bare-Earth" data, representing the actual ground. Both datasets need to be transformed into a raster dataset where the value of each pixel represents the average height of the points within that area. Headwater stream delineation is performed using the bare-earth data to identify which direction the water flows across the landscape and determine where it accumulates. Channel formation can be estimated by calculating, based on soil data and the topography of the land, the minimum contributing area where enough flow will have accumulated to start eroding the soil the water is moving across.

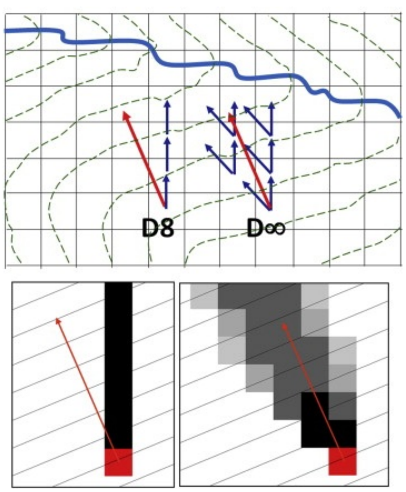


Figure 4: Difference between D8 and D∞ flow models **Tesfa et al. 2011**

There are three primary software packages used by researchers and practitioners for headwater stream delineation. Software designed to recognize flow paths perform this task in various ways, with different outcomes and accuracies for each. The most common, and simplest, method uses the "D8" algorithm, which tracks "flow" from each pixel to one of the eight neighboring pixels based on the greatest difference in elevation. The D8 method is well-suited for the identification of individual channels, river networks and basin boundaries in more defined landscapes, such as the Piedmont Plateau or Appalachian Mountains, but it is based on simplifying assumptions that do not always capture the complexity of flow in low relief areas, such as in headwater areas or in the coastal plain. Specifically, the D8 algorithm assumes each pixel has a single flow direction (SFD), which can oversimplify flow paths and incorrectly indicate a headwater channel where there isn't one (Peckham 2012). The "D-infinity" algorithm, which allows multiple flow directions (MFD), can divide the water flowing out of a pixel into two adjacent pixels and allows for more accurate determinations of when there is a transition from overland flow to channelized flow, known as the "channel head". This algorithm provides better results in areas with complex hillslope geometry and in areas with low relief.

The hydrology tools contained within ***ESRI's ArcMap Spatial Analyst*** extension are most commonly used by non-expert audiences and are likely the most accessible, as the spatial analyst extension is a common software package utilized by researchers and natural resource managers for a number of other applications (Elmore 2012). The hydrology tools in ArcMap utilize the D8 algorithm to determine flow paths and can determine the upland contributing area, a substitute for how much water is passing over the land at any given point, through a flow accumulation calculation. Based on the geologic characteristics of the land, assumptions can be made to determine the erosion potential of the soil and calculate a threshold for channel initiation that can be used to trim flow paths to the headwater channel. ESRI makes it easy for users to calculate flow paths and flow accumulation, however, any further in-depth analyses require a firm understanding of how to use the more advanced techniques of the Spatial Analyst extension and are not clearly defined as processes within the Hydrology toolbox. ArcMap has been used for stream delineation by a large number of management agencies in the past and, with proper training, can be used to determine a number of attributes related to headwater stream mapping.   For basic headwater stream mapping and broad-brush analyses, ArcMap will work well in most situations, but the processes in the Hydrology toolbox have not been updated for a number of years and since the tools rely on the D8 algorithm, the output may not correlate as closely to what is occuring on the ground in topographically complex headwater areas (Peckham 2012). ArcMap has a substantial base price, with an additional cost for the Spatial Analyst extention, but ESRI has generous options for registered non-profits, offering the software and extensions for a nominal service charge of $108, which makes the software more accessible to smaller organizations.

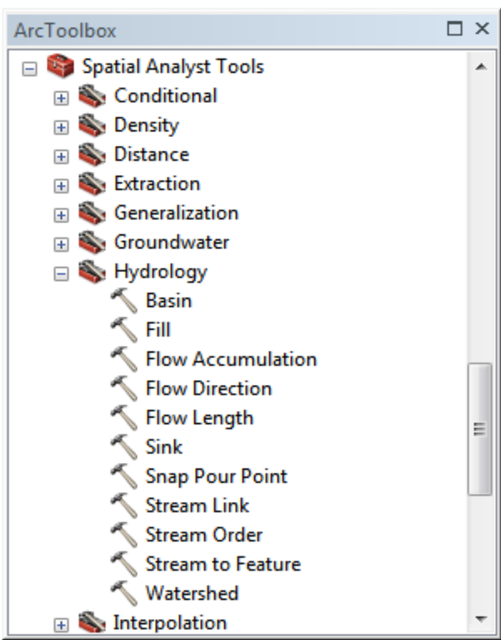


Figure 5: ESRI's ArcMap Spatial Analyst Hydrology Tools

RiverTools, recognized as one of the premier commercial software packages created specifically to identify flow paths from a topographic surface, provides analyses that use either the D8 or D-infinity algorithms (Peckham 2012). Rivertools provides a straightforward series of steps that lead users through the process of extracting flow paths and river networks from raw DEMs.   Since Rivertools was developed specifically for flow path and river network analyses, all of the tools are constructed to make critical functions, such as clipping a flow network at a minimum contributing area, easily accessible and a part of the overall process. Once the river network has been extracted, Rivertools allows the DEM and network to be displayed in a number of different ways within the program or exported to shapefiles that can be imported into GIS software, such as ESRI's ArcMap.

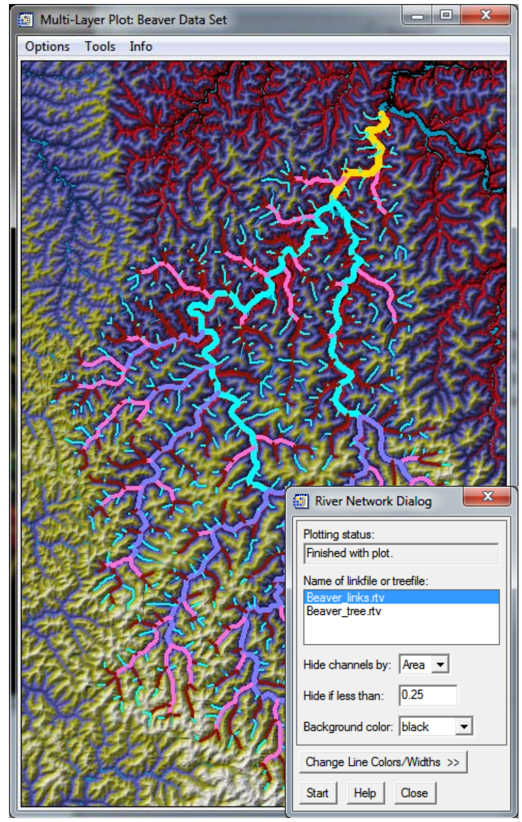


Figure 6: Screenshot from Rivertools depicting a DEM and river network that has been clipped to a 0.25 km^2 minimum contributing area

Dr. Sean Smith, a professor at the University of Maine and one of the early practitioners of headwater stream mapping in Maryland, uses RiverTools for the majority of his work determining headwater stream channels through remote sensing. While working for the Maryland Department of Natural Resources, Dr. Smith helped develop a technique to extract channel head points from elevation and soil data by identifying key values in soil grain size, surface slope, and contributing drainage area, then trimming the flow network determined by Rivertools accordingly. Dr. Smith explained that having more accurate stream lengths is vitally important for a number of management applications, particularly with regard to maintaining riparian buffers along headwater channels and improving the accuracy of Chesapeake Bay TMDL models and calculations. He stressed that headwater stream mapping has the potential to drastically improve conservation targeting methods and could act as a useful screening tool, however there will always need to be field verification to ensure that the modeled channel heads and streams correlate to what is actually on the ground (Smith 2012). While not cost prohibitive, Rivertools does require a separate license costing $500, which could make it inaccessible to smaller conservation organizations with limited budgets. The software comes with access to a number of training materials that lead new users through the process of extracting a river network and performing the analyses to determine headwater channels, reducing the amount of time and effort it takes to learn how to use the software.

The third commonly used software package for determining headwater stream channels, primarily used by researchers and academics, is an open source software package called ***Terrain Analysis Using Digital Elevation Models*** (***TauDEM)***, written by David Tarboton at Utah State University. TauDEM also uses either the D8 or D-infinity algorithm to calculate flow paths and contributing areas, as well as a number of other hydrologic calculations useful in headwater stream delineation. The software comes in two versions; one of which uses a command prompt that requires a greater knowledge of the topic as well as some basic coding experience to navigate the command prompt interface. TauDEM is also available as an ArcMap toolbox, which simplifies a number of processes into more accessible steps, however setting up the program to run in ArcMap is complex and requires administrator privileges, which could make it difficult for a smaller organization that does not have an IT professional. TauDEM can significantly improve the functionality and accuracy of using ArcMap as an analysis tool once it is set up properly. Both methods of accessing the application provide a robust set of tools for stream analyses including the capability to identify a number of factors that are useful in determining channel initiation such as the accumulated flow distance and the ability to define channel heads based on either accumulation thresholds or sudden changes in topography. TauDEM also allows users to weight flow accumulations using another raster layer, which could be helpful in determining runoff and nutrient loads coming from headwater areas.

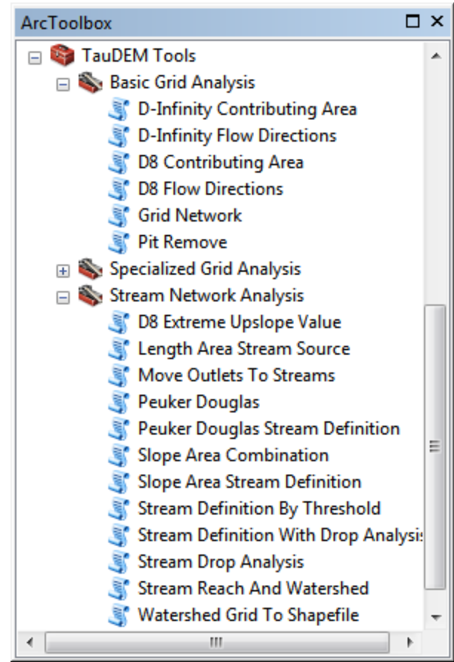


Figure 7: TauDEM's ArcMap Toolbox Interface

Dr. Andrew Elmore, a professor at the University of Maryland Center for Environmental Science's Appalachian Lab, has been working on methods of mapping headwater stream channels as well as investigating the prevalence of stream burial in upland areas. Dr. Elmore explained that his lab typically uses TauDEM to determine flow accumulation and direction. From this data, he can use the curvature of the basin and contributing area to determine where channels, and channel heads, are likely located. He explained that while it is very effective for his work, TauDEM is not a program that would be accessible for most users as it requires a solid understanding of the subject matter and some programming ability. Dr. Elmore is currently working with the Maryland Department of Natural Resources, The Nature Conservancy, and Allegany County to map headwater channels in western Maryland. He believes that creating maps of these streams and making them accessible to managers and the public is a very feasible and necessary next step that will provide protection to vulnerable areas from development and degradation and ensure that they receive the same consideration and legal protection as streams already recognized in the NHD (Elmore 2012).

Dr. Scott Peckham, the author of RiverTools, explained that there are also a number of other open-source software tools that researchers have developed to model overland flow. Many of these tools are housed in the Community Surface Dynamics Modeling System (CSDMS), an online forum composed of researchers from around the world developing innovative new models to explain how water moves across the landscape. Unfortunately, many of the models developed by the CSDMS were designed for purely academic purposes, and as such, are not user-friendly and require a significant amount of background knowledge in both surface dynamics and computer modeling to operate them. In general, Dr. Peckham stated that due to the time and effort required to make elements such as a Graphical User Interface (GUI), help documentation, and training materials, the easier a software package is to use the more it is going to cost the end user. He also explained that some of the modelers in the CSDMS have been working to develop a GUI shell in which to run some of their models, making them more accessible to the general public, however this effort has progressed slowly due to time and funding constraints (Peckham 2012). Dr. Peckham indicated that there are a number of researchers who would be willing to help develop new tools to identify high-quality lands using these technologies.

Considerations and Recommendations

Overall, due to the prevalence of available data, willingness of expert partners to collaborate, and the likelihood that most users could easily access one or more of the technologies described; headwater stream mapping holds significant promise as a technology that could be easily implemented to improve conservation targeting in the Chesapeake Bay watershed. There are a few considerations to using these tools however. Dr. Peckham and Dr. Elmore stressed the importance of working with appropriate resolution data when doing headwater stream mapping. If a manager is working with data that is too coarse, small landscape features will not be visualized or included in the river network. Conversely, if the data has too fine of a horizontal resolution, features such as raised road beds with culverts underneath begin to affect the hydrologic connectivity of a river network. Additionally, if the vertical resolution is not small enough, small inaccuracies in elevation can begin to artificially affect flow patterns, especially in flatter landscapes where there are only small changes in elevation over large distances. Researchers have generally found that using between a 5 and 10 m grid size provides an appropriate compromise between increasing resolution and the volume of data produced, with diminishing returns for finer resolutions due to inaccuracies in the resulting hydrologic networks (Zhang and Montgomery 1994, Thompson et al. 2001, Yang et al. 2001, Hancock 2005, Martinez et al 2010). Maintaining higher vertical precision will improve model accuracy regardless of changes to horizontal resolution and should be maintained by downscaling higher resolution data to a lower horizontal resolution when possible (Peckham 2012).

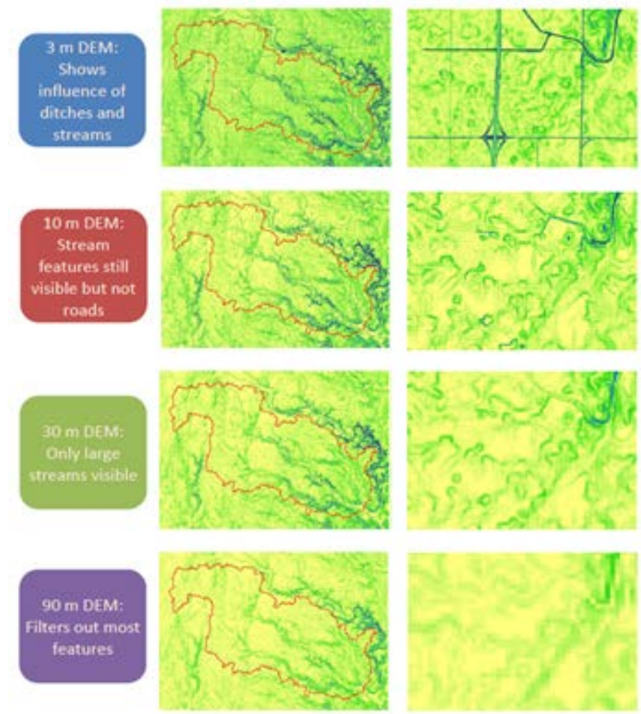


Figure 8: Spatial resolution can have a dramatic effect on the accuracy of stream networks and the features they include. Adapted from Sadeghi et al 2011

Data access is another consideration that must be taken into account when using this type of analysis. In the mid-Atlantic, there has been a considerable effort by state and county governments to collect LIDAR data for much of the area and most governments have made it publically accessible. If new data were to be collected, the cost would be fairly high for a private organization, especially if only a small target area were to be flown, but there are a number of researchers and academic organizations who would likely be interested in a cost-sharing partnership to reduce the cost of data collection for all parties involved.

While each of the software options has tradeoffs between accuracy, functionality and cost, they all require a certain level of knowledge to interpret and implement the results correctly. For an organization with the capacity to hire or train staff to do headwater stream mapping, any of the available options will provide the tools to generate this critical information. For smaller organizations, however, providing access to data generated by someone else either on demand or through an internet mapping portal will likely have the greatest impact on making headwater streams a priority for conservation efforts in the Chesapeake Bay.

Technology	Potential	Limitations	Conclusions
Headwater Stream Mapping	Identifies currently unmapped stream reaches that can contribute up to 50% of downstream water, nutrients, and sediment	• Cost of software • Need for training • Access to data	Headwater stream mapping is very feasible and should be investigated more through a demonstration project

Concentrated Flow Paths and Buffer Effectiveness

Importance

Models determining the effectiveness of filter strips and riparian buffers, as well as regulations and programs that credit them as best management practices, are typically based on the assumption that water flows evenly across the landscape and interacts with buffers equally at all points. In reality, small topographic differences in the land cause water to collect in some areas, known as concentrated flow paths (CFPs), which can easily overwhelm the filtering capacity of buffers. Researchers have been studying this issue from an agricultural and agroforestry standpoint for over a decade, and have benefited greatly from high resolution LIDAR datasets that are being collected by a number of management agencies across the country.

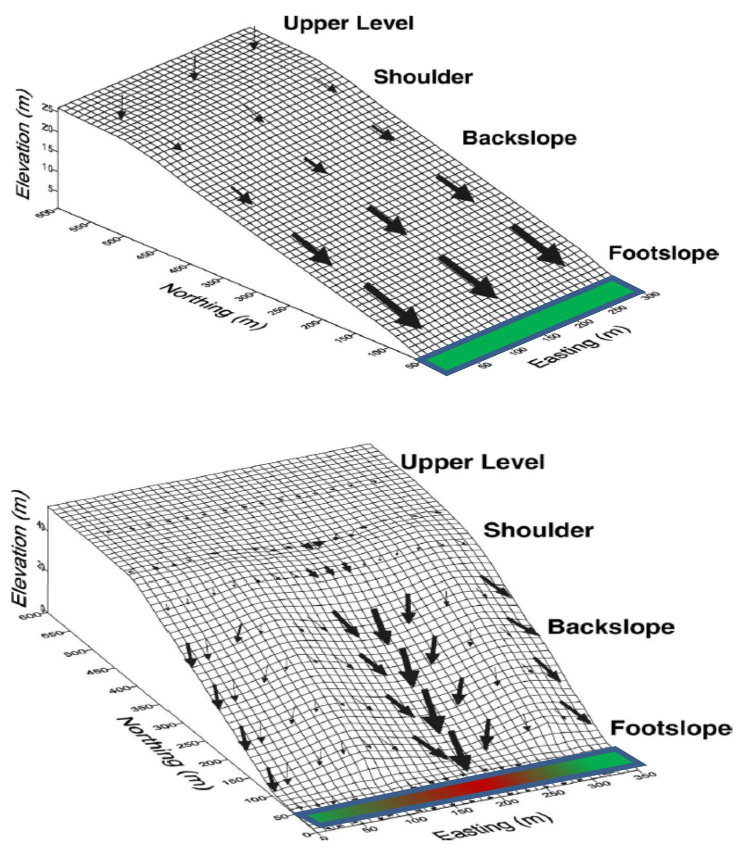


Figure 9: Topographic variation can cause water to accumulate in certain areas, overwhelming a riparian buffer's ability to filter nutrients and sediment from the water. Adapted from Pennock 2003

Research on CFPs has primarily focused on monitoring the effectiveness of agricultural buffers and analyzing spatial patterns of runoff to design variable width buffers that precisely match the needs of every location along the waterway, however it could also be applied in residential or commercial settings (Dosskey 2012). Mapping CFPs is recognized as a primary aspect of “Precision Conservation” and is seen as an integral part of reducing the impact of agriculture on downstream water quality (Cox 2005). While marginally more expensive than traditional fixed-width buffers, variable width buffers based on site-specific topographic and soil conditions can provide almost twice the cost-efficiency by providing increased ecosystem services such as water quality improvement, erosion control, and wildlife habitat improvement (Qiu and Dosskey 2012). When modeling CFP’s and buffer effectiveness there are two basic questions that could be addressed:

1) Is the existing buffer large enough to remove the nutrients and sediment flowing through it, or

2) If you want to remove a certain amount of sediment and nutrients, how big of a buffer do you need?

The first question can be answered using a fairly straight-forward analysis, however the second questions is more complex with a number of variables, including buffer width, buffer composition, and reduction efficiencies, that can result in a number of potential outcomes that would all address the issue (Dosskey 2012). Accurately modeling CFP’s and buffer efficiency could have substantial implications for proposed nutrient trading programs and existing buffer management programs around the Chesapeake Bay watershed.

Available Technologies and Techniques

Determining a buffer's effectiveness involves a multi-step process of creating flow accumulation layers through the identification of concentrated flow paths, combining these layers with sediment and nutrient accumulation data, and integrating buffer efficiency rates.

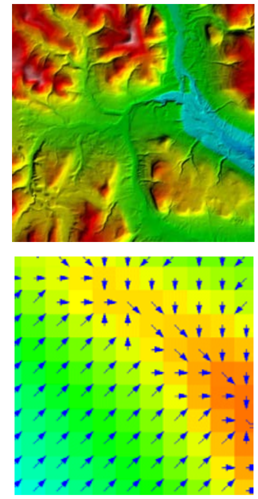


Figure 10: Flow accumulations are determined using bare-earth LIDAR data.

Concentrated flow paths can be determined using the same basic technologies as headwater stream mapping and researchers often use the same software and techniques to identify low areas where water converges as it flows across the landscape. CFP modeling uses bare-earth LIDAR data to determine flow paths and create flow accumulation layers indicating where, and how much, water is collecting. While this type of modeling can be done using a D-8 analysis, it is most accurate when using a D-infinity analysis as non-channelized flow rarely moves in a single direction downhill. Once flow paths and accumulation have been determined, areas of concentrated flow can be identified and combined with other data layers to better understand the expected impacts of runoff on water quality.

Two of the three tools highlighted in the last section, ***ArcMap's Hydrology tools*** and ***TauDEM***, have the ability to weight flow calculations and model sediment or nutrient accumulation. Additional raster layers based on soil data and agricultural practices can be used to calculate metrics for nutrient or sediment contribution. As water moves through a pixel, a specific value of nutrient or sediment contribution, based on the raster layer, is added to the accumulated amount from all of the previous pixels through which the water has flowed. Using the weighted accumulation functions in these tools is extremely easy and can be accomplished during the initial flow accumulation calculations; however, ArcMap is restricted to a D-8 analysis, based on its inherent limitations, while TauDEM can perform either a D-8 or D-infinity analysis.

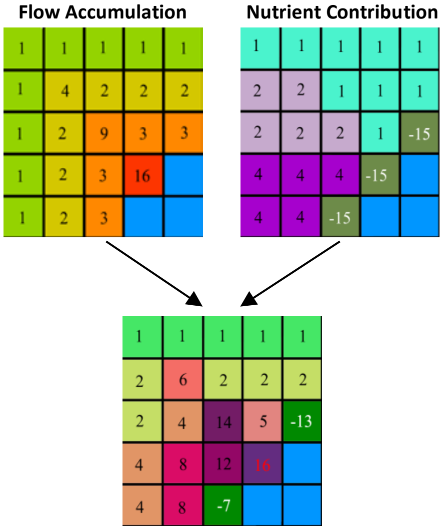


Figure 11: Flow accumulation and nutrient contribution data can be combined to determine nutrient accumulation in runoff. Incorporating the nutrient reduction efficiency of buffers can identify areas where buffers are insufficient.

Modeling the impact of CFPs on buffer effectiveness requires combining the flow and sediment and nutrient accumulation layers with further analysis that takes into account buffer efficiency rates. Once the flow path, and accumulated sediment and nutrients, reaches the buffer, the process is reversed and a specific amount is subtracted for each pixel based on a raster layer representing the reduction efficiency of the filter strip or buffer. The overall effectiveness of a buffer can be calculated by identifying areas where the accumulated nutrient and sediment levels are overwhelming the filtering capacity of the buffers through which the water is flowing. To calculate the effect of buffers on pollutant accumulation, the pollutant contribution layers and the buffer efficiency layer first need to be combined into a single raster with positive and negative values prior to the weighted flow accumulation calculation. The resulting layer can be used to help determine the effectiveness of existing buffers by determining the amount of residual nutrient and sediment accumulation that exits the buffer on the down-flow side (figure 11).

Once an analysis has been completed to estimate which parts of a buffer needs to be enhanced, reducing the amount of nutrients and sediment in runoff can be accomplished by either making a filter strip or vegetated buffer wider, by increasing its efficiency, or by doing a combination of both. There has been extensive research to determine the efficiency of various widths and compositions of buffers and integrating this data with the previous analysis can create a "buffer calculus" to determine the best buffer design that would accomplish a desired percentage reduction of runoff load (Dosskey et al 2002, Duzant 2008).

In many cases, ***decision support tools*** are extremely effective at determining which combinations of increased width and composition can help achieve desired pollutant reductions in the most cost-effective manner. The United Kingdom's Department for Environment, Food, and Rural Affairs (DEFRA) has supported research on variable width-buffers to reduce the environmental impact of agriculture. As part of this effort, DEFRA has created a number of worksheets that help farmers understand what conditions exisit on their property and what impacts their land might be creating as well as tables depicting the relationship between buffer structure and buffer efficiency to help decide the most appropriate balance between width and composition (Duzant 2008).

FIELD CLASSIFICATION		PERCENTAGE COVER WITHIN VFS (%)				
Class	Soil	<20%	20-40%	40-60%	60-80%	80-100%
HEAVY	C	137 m	63 m	47 m	30 m	24 m
HEAVY	ZC	99 m	53 m	28 m	**20 m**	14 m
MEDIUM	ZCL	67 m	29 m	18 m	**12 m**	8 m
MEDIUM	SCL	51 m	24 m	14 m	**10 m**	6 m
LIGHT	ZL	8 m	4 m	2 m	**2 m**	2 m
LIGHT	SL	4 m	2 m	2 m	**2 m**	2 m

Figure 12: Buffer selection table developed for the DEFRA Decision Support System. The widths represent the buffer width required to reduce the net soil loss to less than 2t/ha/yr. Duzant 2008

Dr. Michael Dosskey, a research ecologist with the USDA Forest Service's National Agroforestry Center in Lincoln, Nebraska, has studied the effect of CFPs on buffer effectiveness for over a decade and is one of the pioneers of promoting variable-width buffers in agricultural settings. He explained that while buffer composition and quality certainly matter in determining reduction efficiencies, most research indicates that width plays a much larger role than composition in determining the effectiveness of a buffer (Dosskey et al 2011). Dr. Dosskey has developed a design aid that can help identify the width needed to achieve certain reduction percentages based on soil type, slope, modeled contribution factors, and pollutant types. This tool allows a user to input information about their site and determine which trapping efficiency curve has the most similar landscape conditions to their site. To accommodate differences in the four base conditions, the user can adjust from an initial reference line to a final selected line using a set of rules based on how much the actual site conditions differ from the reference conditions. The expected efficiency can then be calculated using the ratio between the buffer width and the drainage area that passes through that section of buffer. Increasing the width of the buffer will raise the ratio, which in turn will improve the expected efficiency (Dosskey 2011). Dr. Dosskey stressed the importance of transitioning from a system where we build buffers indepedant of the landscape to a system where we are locating and designing buffers to specifically meet a program's goals, such as nutrient and sediment reduction requirements (Dosskey 2012).

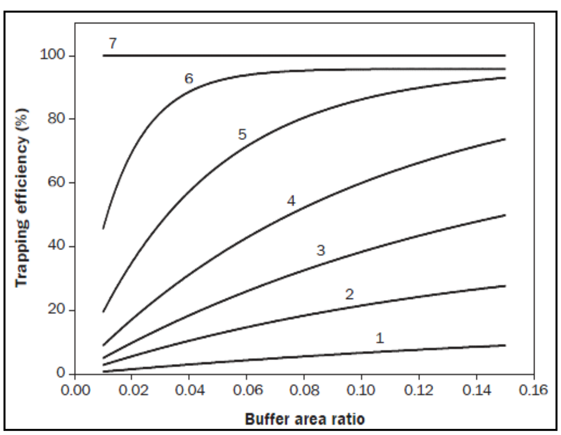


Figure 13: Relationships between pollutant trapping efficiency and buffer area ratio for seven different simulated site conditions. Dosskey 2011

It is also useful to be able to visualize and explore the impact of various buffer configurations on water quality. Autodesk's ***AutoCAD Civil 3D*** software is typically used by civil engineers developing models for transportation, land development, and water projects, however its tools can also be used to investigate and analyze runoff patterns and buffer effectiveness. The Storm and Sanitary Analysis extension of the software is specifically designed to model stormwater flow and can incorporate nutrient and sediment contribution information as well as buffer width and composition to estimate the effectiveness of potential buffer designs. The functionality of this tool is particularly appealing because it incorporates the EPA's Stormwater Management Model (SWMM) and quickly and easily allows a user to modify a potential buffer design to determine its impact on overall pollutant reduction effectiveness. Josh Kehs and Brian Young, who create stormwater and low impact development solutions for Autodesk, described a number of situations where AutoCAD Civil 3D has been used to physically model pollutant loads in an urban setting or associated with construction projects and explained that the same tools could be applied in an agricultural or residential setting. Autodesk is also developing a "River Analysis" extension for the Civil 3D software that allows users to perform complex water surface analyses and automates a number of tools that could be used to determine the effectiveness of buffers. In the interview, Mr. Kehs stressed that the AutoCAD software is designed for engineers and that this level of modeling would require expert level knowledge of water quality and stormwater management practices. Additionally, the cost of the Autodesk Infrastructure Design Suite Premium, which includes Civil 3D and the Storm and Sanitary extension, costs $7,345 and there is no non-profit discount, which likely makes it inaccessible to many organizations (Kehs and Young 2012). Most local governments do have engineers on staff in their Department of Planning or Department of Public Works and potentially already have access to the software and have had training using AutoCAD for this type of analysis, which could make the use of this software an option for a larger number of government users.

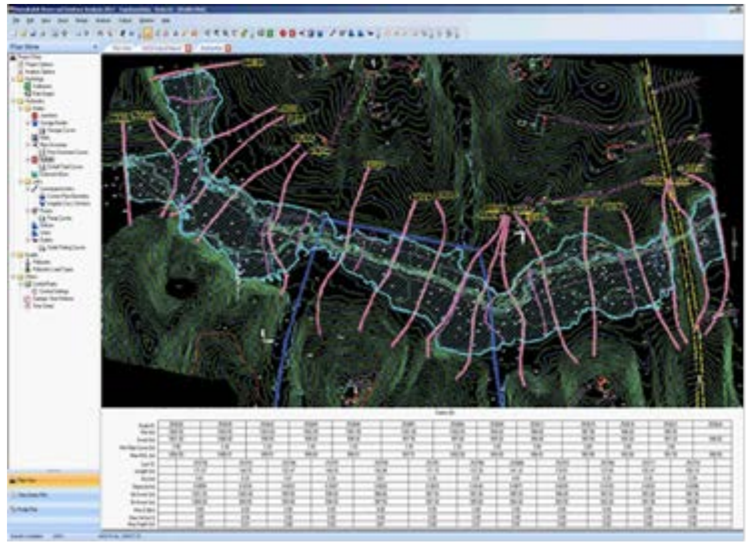


Figure 14: Screenshot from Autodesk's Civil 3D software showing a river analysis

Considerations and Recommendations

In general, concentrated flow path mapping and buffer effectiveness calculations have large-scale implications for targeting conservation land that will have a substantial impact on improving water quality in the Chesapeake Bay. Many of the same considerations and recommendations for headwater stream mapping apply to CFP and buffer effectiveness modeling, especially with regard to using an appropriate resolution for elevation data. CFP modeling inherently addresses areas with low relief where small inaccuracies in elevation data can potentially create misleading information. Higher resolution LIDAR elevation data will provide more accurate results and using a D-infinity algorithm is recommended to reduce the impact of small errors in the modeled landscape. The increase in processing power and storage needed to analyze high-resolution data could potentially prohibit a CFP analysis for a larger watershed, however, there should be no issues conducting a sub-watershed or multi-parcel analysis with a moderately powerful computer (Dosskey 2012).

Flow accumulation and its relative impact on buffer effectiveness can be calculated using readily available datasets, however, accurate soil data, farming practice data, and buffer extent and composition data as well as previously calculated reduction efficiencies used by models, such as the Chesapeake Bay TMDL, are also needed to model nutrient and sediment accumulation and the specific effectiveness of buffers. Soil data is available for free from the USDA's Natural Resources Conservation Service, however agricultural practices, such as fertilizer application or tillage methods, must be collected individually from farmers and may be difficult to obtain. Information regarding lost opportunity costs from farmland that is being converted to buffers will also play a role and ultimately influence the decision of farmers choosing between enhancing buffers or changing farming practices to reduce the amount of nutrients and sediment entering the water from their land.

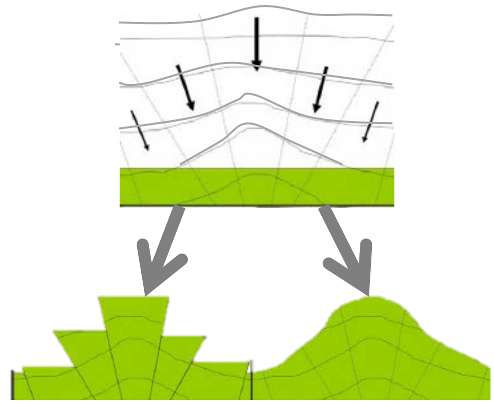


Figure 15: In addition to data needs, there are implementation concerns with regard to how easy it is to farm around variable width buffers. From a crop planting and harvesting perspective, curved boundaries are often harder to maneuver around. Adapted from Dosskey et al 2005

Some state programs have collected data in areas where buffers are being credited or were constructed using state funding, however, for most of the watershed there is no data detailing this information. There are a number of techniques that can be used to determine the extent of riparian buffers using remotely sensed data, of which two will be described in the next sections. Models will produce more accurate results with higher resolution data; however, medium resolution data can also be used if it is not available. Field verification is also recommended to ensure that modeled data matches what is actually on the ground, especially if restoration efforts will be based on this information (Dosskey 2012).

There are still significant barriers to data availability that will initially prevent complex analyses from determining site-specific priorities, but if an organization has qualified staff, the current technology is at a level where general hotspots can be identified for further on-the-ground study and targeted for restoration or protection efforts. For most conservation organizations, however, the cost of the software and the complexity of the analysis used to evaluate fine-scale buffer effectiveness will still be prohibitive. To facilitate the use of this information in targeting high value areas for protection and restoration, management organizations at the state or federal level with a greater capacity to monitor and collect information regarding buffers and agricultural practices could process the raw data and distribute the results to conservation organizations through a web mapping application. There are also opportunities to develop new decision support tools or mobile software packages that allow users to quickly and easily understand the water quality impact that various buffer designs will have on their land.

Technology	Potential	Limitations	Conclusions
Concentrated Flow Paths and Buffer Effectiveness	Identifies areas where water concentrates and potentially overwhelms the filtering capacity of riparian buffers and filter strips.	• Access to data • Implementation considerations • Cost of software • Need for training	General hotspots could be identified using current technologies and should be investigated more. Mobile decision support tools could make it easier for users to identify potential ways to address problem areas.

Ecosystem and Vegetative Species Determination

Technology Overview

One of the most important factors affecting water quality is the land use within a watershed. Beginning with the Landsat 1 satellite, launched in 1972, the United States has been gathering satellite images that have been used to classify the earth's surface into distinct land use and land cover (LULC) categories. This information has proved extremely useful in a number of applications including regional planning, ecosystem management, and global change analysis. Over the last forty years the technology used to gather this data has improved significantly and provides scientists and planners with access to information about natural and man-made landscapes that would have required enormous amounts of time and money to collect manually (Nosakhare et al 2012).

Users can get detailed information about how the landscape is changing over time by studying multiple time periods of LULC data. Identifying how impervious cover has increased, what areas have been converted from cropland or forests to suburban neighborhoods, and if there have been significant changes in the composition of natural ecosystems will provide conservation organizations and local governments with a better understanding of what land has the highest ecologic value and what areas may be in need of increased protection or restoration efforts (Ramsey et al 2001). High resolution data has also improved the ability of resource managers to identify important ecosystems, determine where development is encroaching on the extent of natural areas, and even determine the impact of sediment and nutrient pollution in the water.

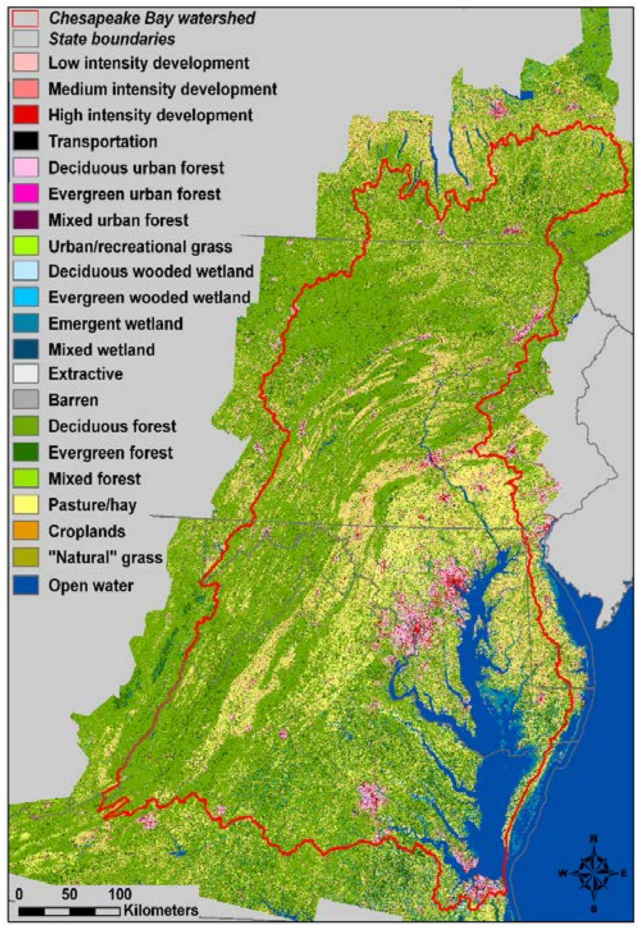


Figure 16: An example of a classified multispectral image depicting the Chesapeake Bay watershed's land cover developed using Landsat 7 TM imagery. Woods Hole Research Center 2000

Precise LULC data also has numerous uses within conservation targeting and can help a user determine information such as what ecosystems a parcel contains, the width and extent of buffers along streams, and even what plant species are growing in a wetland or forest (Klemas 2011). LULC data is also used in models such as the Chesapeake Bay TMDL to calculate non-point source pollution loads and credit best management practices (Ramsey et al 2001). These models are dependent on data sources that provide accurate classifications of the land and higher resolution data will lead to more precise estimates of the type and amount of contaminants flowing off the land. Ultimately, collecting and using high-resolution LULC data will give managers the knowledge they need to make informed decisions about what ecosystems are on the ground, how they contribute to the Chesapeake Bay's water quality, and what needs to be protected.

Available Technologies and Techniques

Satellite and aerial imagery are commonly used as the base data from which LULC classifications are determined. There are a number of ways that this data can be collected and analyzed but imagery datasets are created using sensors that measure the intensity of different sections, or "bands", of the visible and infrared spectrums reflecting off the earth's surface. Each band is measured as a separate raster dataset, with individual pixels containing the reflectance intensity of that section of the spectrum. Individual datasets are geographically referenced and then are layered together to create a multi-band image. Each sensor collects a unique number and combination of bands but in general there are two categories that sensors fall into: multispectral sensors and hyperspectral sensors (Ranson 2012).

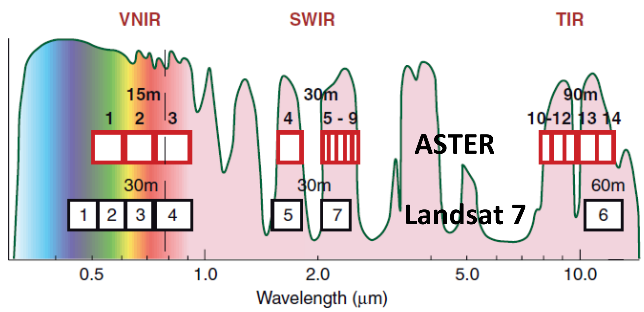


Figure 17: Multispectral sensors, such as the Landsat 7 satellite, measure distinct bands of light along the electromagnetic spectrum. Adapted from Raup et al 2006

Most multispectral sensors typically collect between three and six spectral bands within the visible to middle infrared region of the electromagnetic spectrum; however some sensors can measure up to fifteen bands (Klemas 2012). Depending on the sensor, each band measures between 50-270nm of wavelength and may not be contiguous to the other bands being collected. Band combinations are typically chosen to collect specific reflectance patterns that allow for land classes of particular interest to be easily distinguished. Multispectral sensors are effective at determining general land classes such as water, vegetation, and development, but may have a harder time discriminating smaller differences within a class, such as the difference between a corn field and a wheat field.

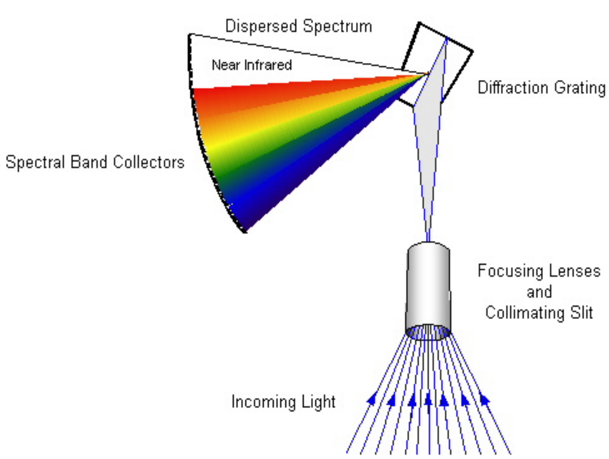


Figure 18: Hyperspectral sensors collect a continuous range of reflectance values with a very high spectral resolution throughout the visible and infrared spectrums. This allows them to identify precise land use and land cover classifications. Civil Air Patrol 2007

In contrast, hyperspectral sensors typically collect over 200 very narrow, contiguous spectral bands throughout the visible, near-infrared, mid-infrared, and thermal infrared portions of the electromagnetic spectrum. Having such a high spectral resolution, often only a few nanometers of wavelength per band, allows for a more precise classification of land types. Most hyperspectral sensors can distinguish sub categories within a general land class, including individual plant species. Because they can identify such minute differences in intensity, small variances in reflectance based on environmental conditions, such as seasonality or nutrient availability, can potentially impact the resulting classification and make it difficult to identify common reflectance patterns within an image (Govender et al 2007). Hyperspectral images provide the best results using high-resolution data but typically an expert is needed to interpret them (Irani 2012).

Different materials, such as soil or plants, absorb and reflect various wavelengths of light in unique ratios that create a distinctive reflectance pattern called a "spectral signature". To classify a raw multi-band image, an analyst must identify the reflectance values that are indicative of a particular land class for each band and then select all of the pixels in the image that have a similar signature (Ranson 2012). There are three techniques that are typically used to classify spectral signatures within multi and hyperspectral images. Two of the more common processes are similar and employ training data to manually determine the spectral signatures of individual pixels in the image which are then applied to the whole dataset. The third looks at groups of pixels to determine a range of spectral signatures and uses pattern recognition to determine other areas that belong to the same class.

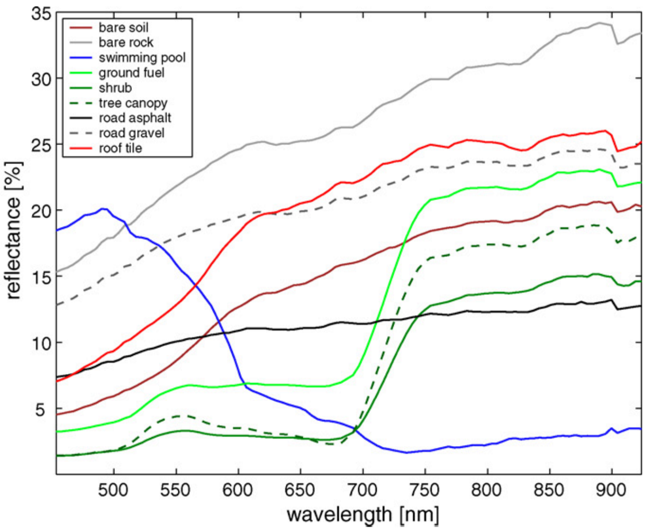


Figure 19: Spectral signatures can help classify the land in a satellite or aerial image by identifying pixels that have similar reflectance values. Koetz et al 2008

The first technique, supervised classification, relies on an analyst to choose a set of training points from the image that represent specific land classes and have been identified using either field verification or high resolution aerial imagery. From these points, the spectral signatures for each land class is determined and extrapolated to the rest of the image based on the likelihood that similar signatures belong to the same land class. Unsupervised classification uses a similar principle but breaks the image into a specified number of spectral classes based on an analysis that groups statistically similar reflectance signatures. These clusters of signatures are then classified by comparing points that are related to each grouping with data from field verification or aerial imagery to identify which land class it represents. During an unsupervised classification the image is often divided into more clusters than are needed to increase the accuracy of the analysis and the groups are then combined into the larger final classes (Huang and Klemas 2012).

Object-oriented classification, the third commonly used technique, uses a process called "image segmentation" to divide the image into visually similar, contiguous "objects" based on their reflectance values. Using these groups of pixels, this process uses pattern recognition to identify similar groupings of pixels in the image and then "grows" the initial area to encompass all the surrounding pixels that have similar characteristics. Existing geographic data, such as road or river lines, can also be incorporated to identify objects as a specific land class that could be excluded from the subsequent analysis. Object-oriented classification tends to have a higher accuracy than pixel-based classification because it identifies a specific range of spectral signatures for each land class instead of relying on a statistical estimation (Gao Yan et al. 2006).

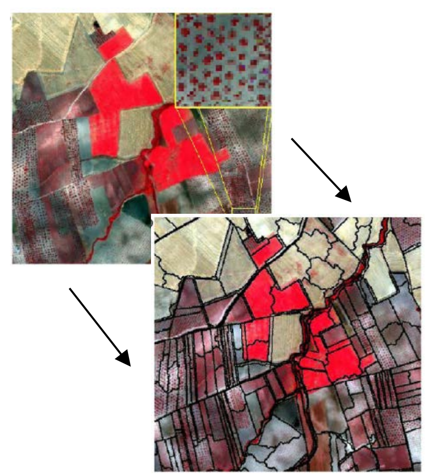


Figure 20: Object-oriented image analysis divides an image into areas with similar characteristics then identifies other areas that belong to the same land class. Adapted from Castillejo-Gonsalez et al 2009

A number of commercial image analysis software packages have been developed and refined over the last thirty-five years and provide a variety of options and capabilities. Pixel-based image classification has been used since the first Landsat satellite was launched and has traditionally been the primary classification tool used in commercial products. Object-oriented classification has seen increased use over the last decade as computer processing abilities have increased. Of the commercial products available to users, four software packages are commonly used by practitioners to develop LULC datasets from aerial and satellite imagery.

ERDAS Imagine is one of the oldest image classification software tools, orginally developed in 1978, and is used by a large number of academics and management agencies around the world. Imagine primarily uses pixel-based classification and is intended to process multi-spectral imagery. The software comes with extensive training materials and has easy to use tools that guide users through the unsupervised or supervised classfication processes. Although the software comes in three product tiers, most users would need at least the middle level to perform the techniques described in this report. The "Professional" version of the software also includes the ability to use image segmentation and contains a suite of hyperspectral image analysis tools. Imagine also includes tools for conducting a number of other raster analyses such as change detection, topographic analyses, and image preperation and interpretation although it requires a thorough understanding of the subject matter to conduct more advanced analyses (Klemas 2012). While extremely powerful, Imagine will not be affordable for many conservation organizations due to its cost, a minimum of $2400 for the middle tier and $4200 for the professional tier with non-profit pricing.

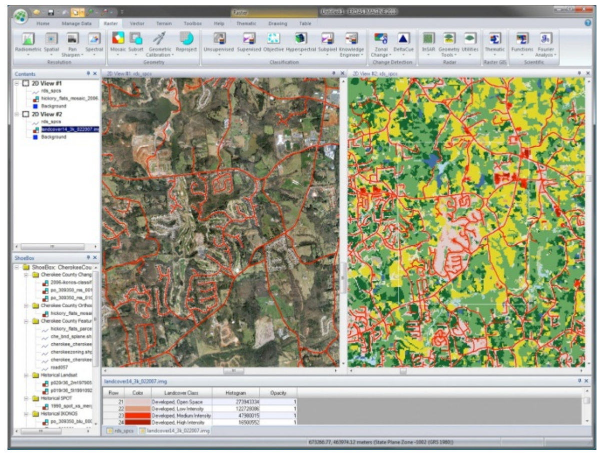


Figure 21: Screenshot from ERDAS Imagine showing pixel-based classification from satellite imagery.

Exelis ENVI 5 is another commercial software package available to users that provides robust tools to process raw imagery data into LULC data. ENVI focuses more on image classification and does not include as many additional raster analysis tools as ERDAS Imagine, however it does have the capability of conducting both pixel-based and object-oriented analyses to classify satellite and aerial imagery. Many of the most common workflows in ENVI have been automated to allow users to get useful data products from raw data quickly and easily. The software includes tools for both multispectral and hyperspectral data analysis, however the tools for multispectral analysis are better developed and easier to use. ENVI's toolset can also be imported into ESRI's Arcmap, significantly extending that program's image analysis capabilities. For many new, non-expert users, ENVI's automated workflows make this software option extremely accessible and the special pricing for conservation non-profits makes it a viable option for all organizations.

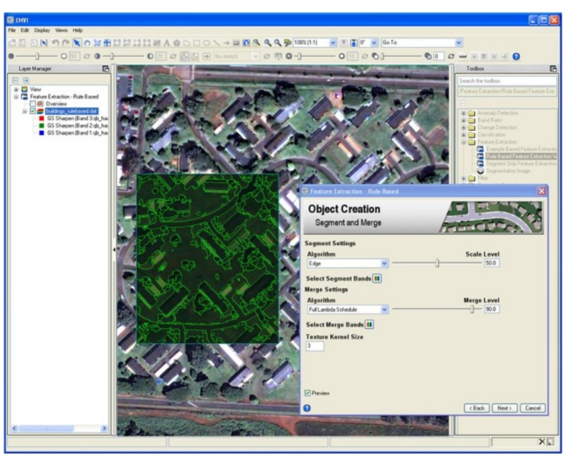


Figure 22: Screenshot from Exelis ENVI 5 showing its automated object-oriented classification tool.

Trimble eCognition was one of the first commercial software tools to specifically use object-oriented classification in image analysis. There are two versions of the software, Developer and Architect, which were created to offer more flexibility and deliver a product that is tailored to users needs. Developer is intended for an expert audience and allows greater flexibility in developing workflows and rule sets that can be used for vegetation mapping, feature extraction, change detection and object recognition. Architect was created for non-technical professionals, such as resource managers, urban planners, or foresters, and relies on pre-packaged toolboxes that automate and simplify most object-oriented analyses. Workflows that were created in Developer can also be exported as a pre-defined tool for Architect which allows custom, complex analyses to be created and made accessible to non-expert users. ECognition's toolsets are also built to handle both multispectral and hyperspectral image analysis. Although eCognition is one of the more technically accessible options for non-expert users once workflows have been established, a steep initial learning curve and the cost of the software may prevent some organizations from being able to use it for their analysis.

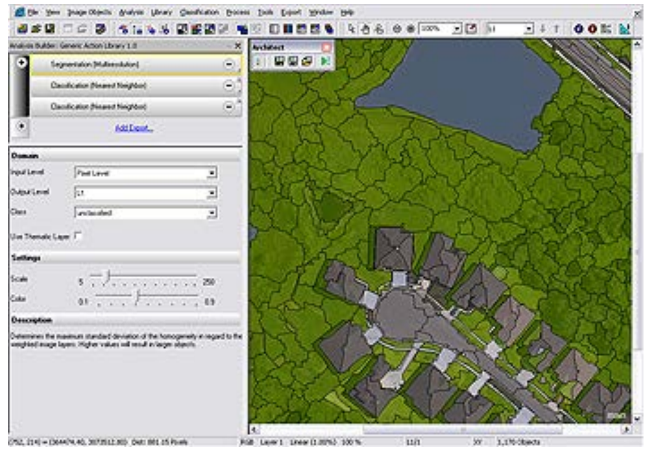


Figure 23: Screenshot from Trimble's eCognition software showing object-oriented classification from aerial imagery

Overwatch's Feature Analyst is another commercial object-oriented image analysis tool that runs as an extension to ESRI's ArcMap software. Feature Analyst uses advanced algorithms and processes, such as hierarchical learning and spatial pattern recognition, to identify the boundaries of visually similar features from aerial and satellite imagery. The software is capable of extracting LULC from either multispectral or hyperspectral datasets and processes raw imagery data quickly. Feature Analyst is extremely easy to use and its feature extraction tools are simple and straightforward, especially for users who are already familiar with ArcMap. Feature Analyst also comes with a tutorial which walks new users through the process of creating training polygons and identifying particular land classes. There is little to no learning curve involved with Feature Analyst and the software would be accessible to almost all users from a technical standpoint. The software does have a base price of about $400 with an annual maintence fee of $1,250, which would likely make the software an impractical investment for smaller organizations who are not going to be doing a signficant amount of land classification. Additionally, because Feature Analyst runs as an extension to Esri's ArcMap, that software must also be purchased for an additional fee.

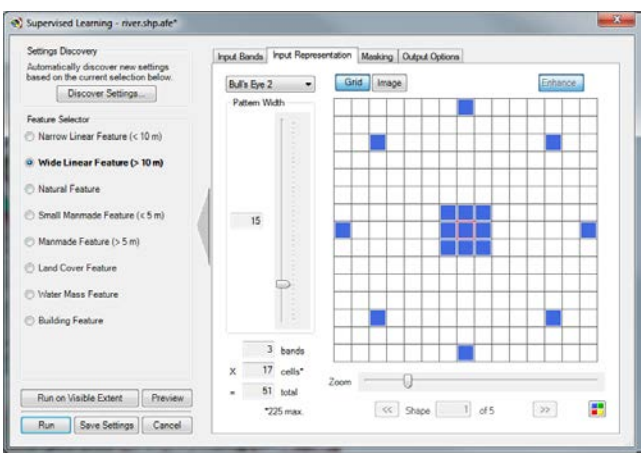


Figure 24: Screenshot of Overwatch's Feature Analyst showing its object-oriented image classification tool.

Considerations and Recommendations

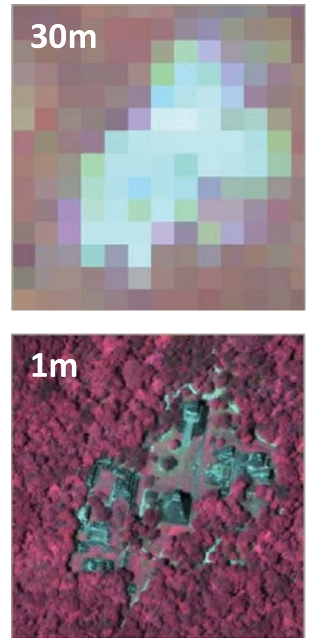


Figure 25: The impact of resolution on a users' ability to identify landscape characteristics is noticeable when comparing Landsat 7 (30m) and Ikonos (1m) data. T.L. Sever, NASA/ Marshall Space Flight Center

Ecosystem and vegetative species composition analysis using high resolution land use and land cover data is potentially one of the most useful datasets that could be obtained for the Chesapeake Bay watershed (Claggett 2012). This data would be valuable in calculating more accurate nutrient and sediment loads used in the Chesapeake Bay TMDL, in monitoring the location, composition and extent of riparian buffers, and in better understanding development trends and what areas are most at risk.

Much like LIDAR elevation data, using an appropriate resolution for data collection is one of the most important aspects of ecosystem and vegetative species composition analysis. For many of the analyses described in this report, high resolution data would be needed to obtain the level of precision required to identify changes in land type over such a small geographic area. Due to the cost and processing power required to collect and analyse high-resolution data, Dr. Victor Klemas, a professor at the University of Delaware, recommends analyzing previously collected medium resolution data throughout the entire watershed to identify potential hotspots. After these focal areas are identified, higher-resolution data can be used to conduct targeted analyses to determine important landscape characteristics, such as buffer extent or forest cover, with higher precision only where it is needed (Klemas 2011).

Fred Irani, a geographer from the United States Geological Survey working with the Chesapeake Bay Program, also recommended that multi-spectral image analysis will likely provide better results for most users due to the complexity of working with hyperspectral data and the fact that it requires higher resolutions to be effective at separating vegetation at the species level. Because much of this data is collected for specific academic projects, collecting hyperspectral data for a larger area will be prohibitive for most organizations due to the cost and amount of storage needed to maintain such a large dataset (Irani 2011).

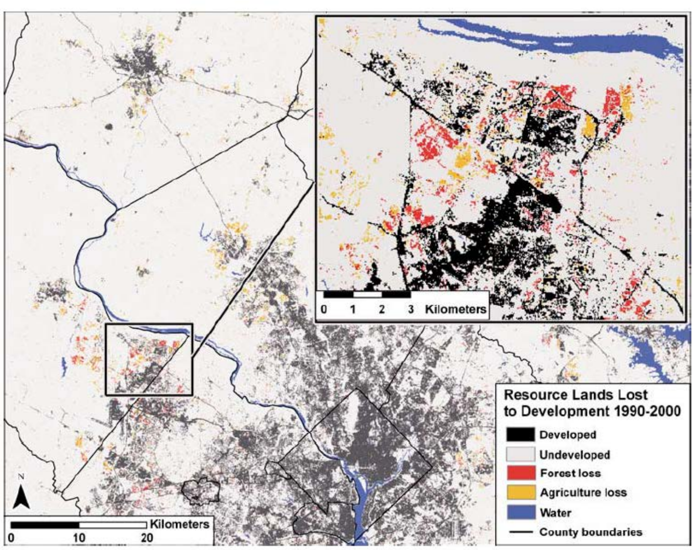


Figure 26: High-resolution imagery can improve mapping efforts of natural ecosystems to better understand how they are changing. Jantz et al 2005

In addition to identifying what is on the ground with better precision, high resolution LULC data will be extremely useful for conducting land cover change analyses. Dr. K. Jon Ranson, Branch Head for the Biospheric Sciences Branch at NASA Goddard Space Flight Center, explained the importance of having strong LULC data from multiple time periods to understand how the land around us is changing. He explained that the ability to monitor and credit restoration efforts and the implementation of best management practices to reduce sediment and nutrient loads entering the water and to determine areas that have been negatively impacted will be increasingly important to Chesapeake Bay restoration efforts (Ranson 2012). Remotely determining the extent and composition of forested buffers or filter strips and confirming that conservation easements are being implemented will greatly expand the ability of conservation organizations and government agencies to effectively manage conservation land. While high-resolution LULC data will not completely replace field verification, it will allow organizations to use this data as a primary verification tool and subsequently spot check various areas to ensure that the information is accurate. Remotely monitoring conservation efforts could reduce the cost and time involved with field monitoring and lessen resource constraints experienced by many conservation organizations.

Cost will ultimately be the largest barrier to widespread implemention of image analysis as a management tool. Typically, medium resolution imagery, such as Landsat 7 data, has been collected by the government and is available for free. The majority of high-resolution data is collected by private companies and sold commercially, however, and prices range from $0.33 to over $30 per km^2 depending on if the imagery is archived or if it needs to be acquired. Furthermore, satellite imagery is often sold in "scenes" which could potentially contain over 250 km^2 and cost more than $10,000 (Klemas 2012). Many of the companies providing high-resolution data have a minimum scene size of 25km^2 with a corresponding price of between $250-350. The price of various commerical software options can cost up to $4,000 for non-profits and many software packages require annual maintence fees, increasing the cost to organizations who will use the software on an ongoing basis. Initally, a small number of organizations collecting and processing imagery data and distributing the final product to other organizations may be the most effective model to reduce the overall cost of obtaining high quality LULC and land change data for the Chesapeake Bay Region.

Image classification is one of the oldest and most developed technologies discussed in this report. Because it has had time to mature, there are a number of tools that are readily available to analyze imagery data, all of which produce high quality datasets with minimal effort, and there is a tremendous amount of privately collected imagery that can be purchased in various spatial and spectral resolutions. For conservation organizations with capable staff and the resources to purchase imagery data, high quality classification data could signficantly improve their ability to identify landscape characteristics that would maintain or improve water quality and monitor changes, both positive and negative, in their area to prioritize land that needs to be protected. For most conservation organizations, however, affording the data and software will still be a barrier. To make high quality image classification more accessible to conservation organizations in the Chesapeake, there will likely need to be a regionally coordinated effort, lead by either a state or federal management agency or a conservation organization with the ability to collect and process large quantities of data, that can operate using economies of scale and disburse the processed data to indivdual organizations at a more reasonable cost.

Technology	Potential	Limitations	Conclusions
Ecosystem and Vegetative Species Determination	Uses satellite or aerial imagery to determine the location and extent of land use and land cover classes to help identify high quality natural ecosystems.	• Cost of data • Cost of software • Need for training • Data/processing intensive	Image classification is a very developed technology that can provide extremely useful management information and should be investigated further in a demonstration project.

Biomass and Forest Stand Characteristics

Technology Overview

Ecosystem service markets, such as nutrient and carbon trading, are an increasingly important motivation for conserving high quality land and can greatly influence the decision to protect natural areas around the Chesapeake Bay. With public and private financing for conservation efforts declining in most areas, capitalizing on these markets will decrease the cost of protecting important landscapes and could provide funds to enhance restoration efforts across the watershed. To date, crediting conservation land in ecosystem markets has seen little interest due to the difficulties of quantifying the nutrient uptake or carbon sequestration potential of a parcel with any amount of precision. Traditionally, this information had to be collected manually through field measurement and was costly and labor intensive. New technologies, including LIDAR data interpretation, are improving the ability of managers to remotely quantify the biomass in ecosystems and improve the estimates of nutrient and carbon reductions attributed to these natural areas.

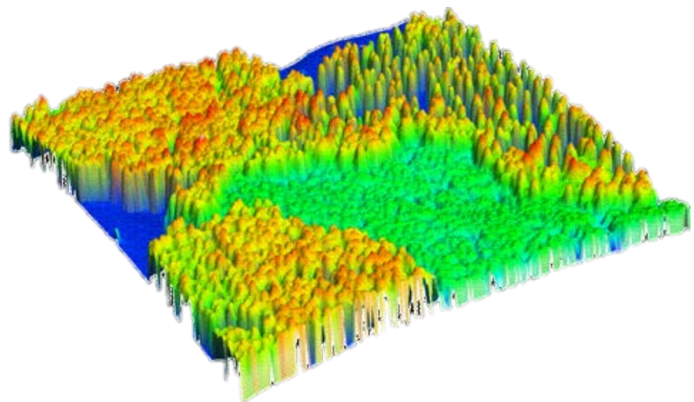


Figure 27: LIDAR-derived forest characteristics can provide important information used in biomass estimations and ecosystem services markets. Adapted from USDA 2012

Forests and wetlands both have a high potential for nutrient uptake and carbon sequestration that is dependent on their structure and composition. LIDAR-derived forest characteristics have been used by foresters over the last decade to determine stand metrics related to logging, such as tree density and wood volume, but the technology is increasingly being applied to other ecosystems, particularly wetlands, to determine factors relating to biomass and nutrient uptake and carbon sequestration rates (van Leeuwen and Nieuwenhuis 2010). Characteristics such as height, canopy cover, and planting density can also be extrapolated from full-waveform LIDAR data and can be used to determine the overall biomass of a system.

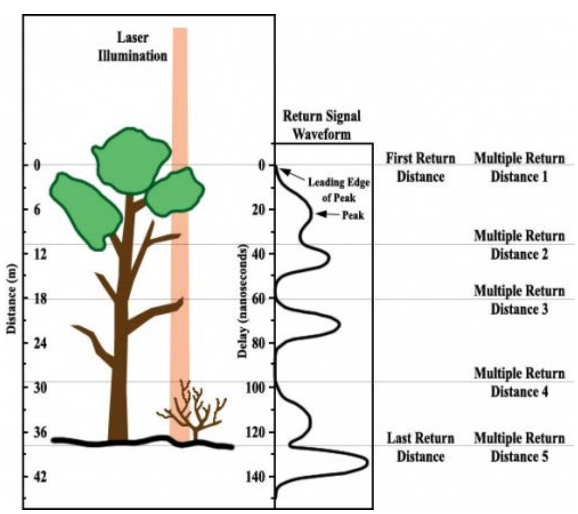


Figure 28: A laser used to collect LIDAR data creates multiple returns when it bounces off a tree's canopy, its branches, and the ground. ASPRS

Forest canopy maps derived from the LIDAR data can be used to estimate the volume, age, and structure of a forest, which is used to determine an accurate estimate of total biomass for the system (Treuhaft et al 2004). Similar information can be used to determine the biomass of wetlands by combining the height of the plants above the ground with species information. To determine the water quality benefits a forest or wetland would provide if it remains protected, resource managers can use commonly accepted rates of nutrient uptake and carbon sequestration for a given species of a certain age and biomass to extrapolate the expected reductions that the ecosystem is expected to deliver. Collecting and analyzing this data, although complex and potentially expensive, could provide resource managers with important information about the reduction benefits of a parcel that could be used to justify crediting within an ecosystem services market.

Available Technologies and Techniques

As discussed in previous sections, LIDAR elevation data is collected by bouncing a laser off the ground at high speed and measuring the time it takes to return. If there is any obstacle between the sensor and the ground, such as the top of a tree, the laser will return sooner than a point representing the ground. Every time the laser beam encounters an object between the sensor and the ground it will create a "return", or a point in the point cloud, representing that elevation. The resolution of a LIDAR dataset is determined by its pulse density, which corresponds to the number of times the laser was bounced off a specific area; a higher pulse density creates higher resolution datasets. By displaying every return of the laser, the structure of forests and wetlands can be visualized and initial attributes, such as the general shape of trees, can be determined. From this data, other information can begin to be extracted including volume, height and canopy cover (Naesset et al 2004). A tree's crown can be determined by draping a surface over the point cloud to create a "canopy map" that shows the tops of trees and structure of the canopy on the way down. This information can be used to calculate the volume of the tree. Resource managers can determine the location of individual trees by performing a "local maxima" analysis that identifies and separates the highest points in the point cloud to represent each tree. Managers can also calculate the height of trees, or other wetland species, by subtracting the elevation of the bare-earth data from the first return data representing the tops of the trees. Determining the percentage of first returns that are located above a specified height can help managers determine the canopy cover in both forests and wetlands (Swatantran 2012, van Leeuwen 2012). With the correct information, biomass can be calculated with up to 92% accuracy using complex regression analyses that relate common species characteristics to the individual plant metrics derived from the LIDAR point cloud (Lefsky et al 2005). Carbon flux and nutrient uptake for a system can subsequently be calculated using commonly accepted values based on species, age, and biomass.

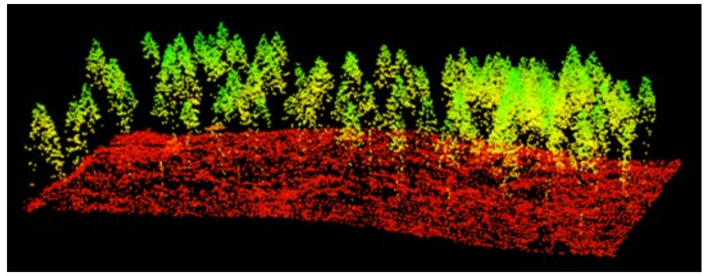
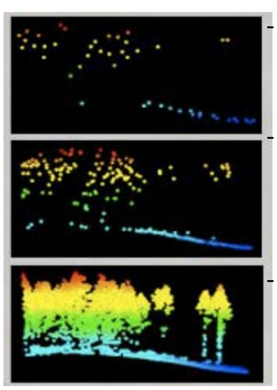


Figure 29: LIDAR point clouds make it easy to visualize forest structure and identify individual trees.

Combining LIDAR data with high-resolution imagery can often provide an initial determination between coniferous and deciduous trees, which can be used for biomass estimations (van Leeuwen 2012). There has also been some success creating automated tools that combine object-oriented classification of high resolution imagery with small area LIDAR transects to extrapolate forest characteristics across large areas for a lower cost (Chen and Hay 2010). It is important to remember, however, that while LIDAR data can help determine discrete metrics about a forest or wetland, accurately estimating biomass relies heavily on having correct species data and crown structure that often needs to be collected manually (Gleason and Im 2012).



- Low Pulse Density (≤ 1 pulse/m^2)
  - Product: Moderate resolution topographic products (≥ 2m grid)
- Moderate Pulse Density (1-3 pulses/m^2)
  - Product: Stand level vegetation metrics (canopy height, % cover) and high-resolution topographic products
- High Pulse Density (≥ 3 pulses/m^2)
  - Product: Forest Structure (Modeling and ***field data collection required***)

Figure 30: Pulse density can have a significant impact on what data can be determined from LIDAR datasets. Adapted from USDA 2012

The majority of LIDAR-derived biomass estimations are still conducted in an academic setting using custom scripts written in programming languages without a visual interface (van Leeuwen 2012, Swatantran 2012). There are a few software options available that allow resource managers to view and extract relevant information from LIDAR data; but translating this information from raw metrics to biomass estimations and nutrient uptake and carbon sequestration rates is a complex task that requires an expert level understanding of the subject matter. Using LIDAR point clouds to determine forest structure has only received increased attention over the last decade so software and other analysis applications have not had time to mature to the level of other technologies, such as imagery classification. Consequently, the available software packages tend to be somewhat undeveloped, requiring basic programming skills, or rely on applying software intended for another use.

The United States Department of Agriculture's Remote Sensing Applications Center created a free LIDAR analysis tool for forests called ***FUSION***. This program is a standalone application that allows users to input LIDAR point cloud data and reference it to imagery and other data from the same area. Visualizing the point cloud is very easy and the software provides a 3-D environment in which a user can rotate and analyze subsets of the data. FUSION also allows users to calculate detailed forest metrics as well as extract bare-earth surfaces and canopy models from the LIDAR data, however these capabilities can only be accessed through a command prompt interface that may be difficult for users who aren't used to this format. FUSION also allows users to export the resulting datasets in formats that work with other GIS applications. This software is free and there are training materials available to walk new users through the program's installation and operation as well as a detailed manual describing the functionality of more advanced features making it an attractive option for smaller organizations.

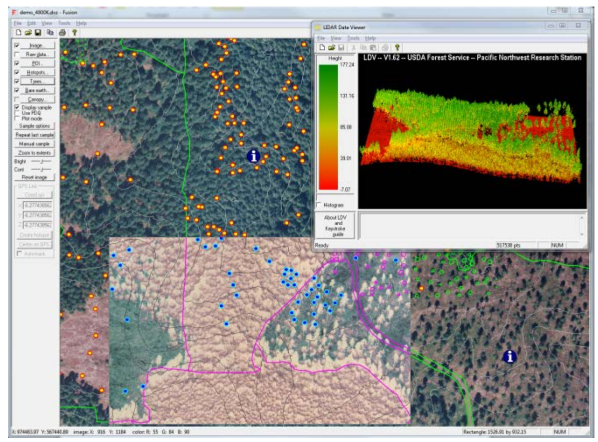


Figure 31: FUSION allows managers to easily view 3D point clouds and extract forest structure information from LIDAR data.

Overwatch's LIDAR Analyst is a commercial software product that can be used to extract information from raw LIDAR data. LIDAR Analyst, like its partner application Feature Analyst, operates as an extension to ESRI's ArcMap software and cannot function as a standalone program. LIDAR Analyst includes streamlined workflows to extract bare-earth data, define building footprints, and determine the location and basic characteristics of trees, such as height and crown width, from raw LIDAR data. The software is easy to use and comes with a tutorial that leads new users through each data processing step. LIDAR Analyst also includes the ability to delineate entire forested areas, in addition to extracting individual trees, which would be extremely useful in determining the extent of buffers or other natural areas. This extension is designed to work in conjunction with Feature Analyst to enhance both programs abilities to determine LULC classifications and define the location of developed and undeveloped areas with extremely high precision and accuracy. LIDAR Analyst has a fairly high price, $400 with an annual maintenance fee of $1,250, making it a software package that might not be attainable for most small organizations that are only going to be doing occasional analyses.

Considerations and Recommendations

Overall, LIDAR-derived biomass estimation has the potential to be a valuable tool for estimating the value of land conservation and restoration efforts in ecosystem-services markets and can provide additional incentives to protect ecologically valuable landscapes. However, in the near future it is unlikely that this technology will be used outside of academia or larger government agencies due to the high cost of data collection and the difficulty of transforming raw data into final products. LIDAR data can determine the width and even composition of riparian buffers and could be used to facilitate nutrient reduction calculations on agricultural land (Akay et al 2012). LIDAR data and forest structure metrics can also improve LULC classifications when combined with high-resolution aerial imagery leading to more accurate nutrient uptake and carbon sequestration estimates (Cook et al 2009).

LIDAR datasets typically consist of hundreds of millions of returns creating significant limitations in terms of storage and processing (Cook 2012). The size of a dataset is directly related to the number of returns stored for each pulse and the pulse density at which the data was collected. Most LIDAR datasets that have been collected by states and counties for elevation mapping have a moderate pulse density, between 1-3 pulses per square meter, and are not suitable for modeling individual trees. Assessments about stand level vegetation and the location of forested buffers can still be made using this data, but to create more defined estimates of biomass, carbon sequestration, and nutrient uptake, high density data must be collected.

Dr. Anuradha Swatantran, a research professor at the University of Maryland, is working with other faculty at the University of Maryland and NASA Goddard Space Flight Center to develop new techniques to estimate carbon stocks and sequestration potential from multi-sensor high-resolution data. While explaining her work, Dr. Swatantran described the amount of effort that goes into estimating biomass and carbon sequestration potential from LIDAR data and how this type of analysis is likely beyond the abilities of most non-experts.

The cost of collecting and processing new LIDAR data can be quite high and is dependent on the distance the equipment must travel, the size of the area being sampled, and the amount of post-processing that needs to be done (Cook 2012). Relatively accessible software options that can provide baseline metrics describing forested areas are available, but translating this information into biomass estimations and nutrient uptake or carbon sequestration potential will be beyond the capabilities of most organizations and agencies. Spreading the cost of collecting new datasets among interested government agencies, academic institutions and conservation organizations could facilitate access to new data in areas where it would be infeasible for an organization to work individually. With time LIDAR technology and analysis software may evolve to a level where it is feasible for groups to process their own data, but for the present, only universities and federal agencies have the expertise and capabilities to extensively model biomass. This information is still important for conservation organizations and future efforts should be focused on developing new ways for organizations to access the final processed data.

Technology	Potential	Limitations	Conclusions
Biomass and Forest Stand Characteristics	Uses multiple-return LIDAR to generate estimates of biomass, which can be used to determine nutrient uptake and carbon sequestration potential.	• Need for training • Cost of data • Very complex analysis • Data/processing intensive	Biomass estimation is too complex for most groups but forest LIDAR can improve buffer delineation and image classification. Efforts should be focused on creating tools to disseminate processed data.

Nutrient and Sediment Loading and Restoration Potential

Technology Overview

Models describing nutrient and sediment loading are used for a number of management applications from identifying field scale agricultural best management practices to creating watershed wide estimates of sediment and nutrient contributions for the EPA's Chesapeake Bay TMDL. Effective nutrient and sediment management in support of Chesapeake Bay restoration efforts will require a comprehensive understanding of the sources, fate, and transport of nitrogen, phosphorus, and sediment in the watershed, which is only available through models (Altor et al 2012).

Data relating to hydrology, elevation and topography, soil attributes, land cover and land use, vegetation (NDVI), and precipitation can all be combined to estimate the erosion potential of the land and identify hotspots where nutrients and sediment are most likely entering the water. Integrating this information with high-resolution land use/land cover and forest structure data can help determine where these nutrients and sediment are being removed prior to reaching waterways and where natural landscapes may not be functioning to the best of their ability.

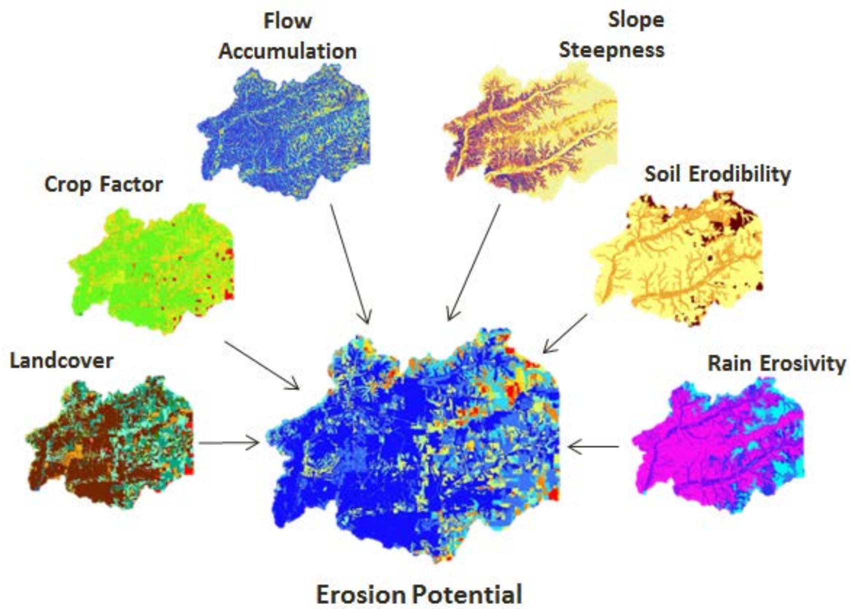


Figure 32: Data from a number of sources can be combined to determine the erosion potential of the land. This data can be used to identify nutrient and sediment loading hotspots and areas that need additional protection. Storm et al 2006

Maximizing the impact of increasingly limited restoration and management resources will require a solid understanding of the quantity and location of nutrient and sediment sources, the conditions that can affect pollutant levels entering the water, and the most vulnerable or valuable ecosystems that need to be protected (Castro et al 2003). Having high quality data relating to nutrient and sediment loading and restoration potential can drastically improve the ability of resource managers and conservation organizations to target their protection and restoration efforts towards landscapes that will have the largest impact on improving the quality of the water flowing into the many rivers and streams emptying into the Chesapeake Bay.

Available Technologies and Techniques

Modeling nutrient and sediment loading and restoration potential is a complex task that incorporates data from a number of sources including elevation and hydrology information extracted from multiple-return LIDAR, land use and land cover classification based on satellite or aerial imagery, and precipitation measurements, soil attributes and farming practices collected from field stations and manual field work. Information from these layers is combined using models that estimate the soil erosion potential and amount of surface runoff expected from a watershed. These models can address long-term trends and contributions as well as the expected impact of

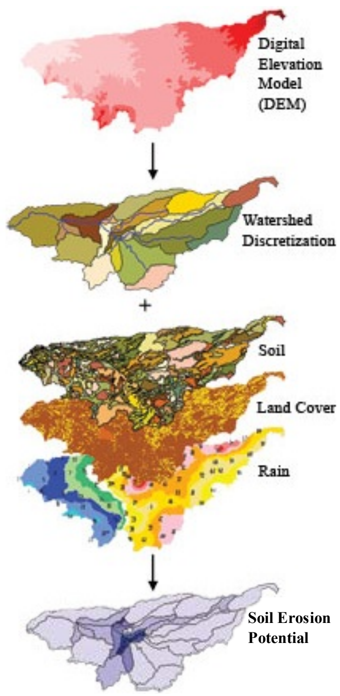


Figure 33: Soil erosion potential for individual sub-watersheds can be calculated using numerical models that incorporate elevation and hydrology data with soil attributes, land cover and precipitation values. US EPA 2012

individual storms and are scalable, meaning they can estimate nutrient and sediment loads from areas the size of few square kilometers up to the entire Chesapeake Bay watershed.

There are two primary types of soil erosion models that are commonly used by resources managers to estimate erosion: 1) empirical models that use mathematical equations to estimate erosion potential based on soil conditions, land cover, and precipitation levels and 2) process-based models that simulate the conditions necessary to cause erosion by solving partial differential equations relating to soil attributes and overland flow. Empirical models, such as the Soil Water Assessment Tool (SWAT) tool, tend to work better with long-term cumulative estimates in larger watersheds, while process-based models, including the Kinematic Runoff and Erosion (KINEROS2) model, give better estimations for single-storm events in smaller watersheds. To reduce the processing time and storage needed to compute complex equations, empirical erosion models divide watersheds into Hydrologic Response Units (HRUs), which are expected to have similar erosion levels based on common soil types, land uses and slope classes. When coupled with modeled nutrient and sediment levels on the ground, these erosion values can provide an estimate of the pollutant loads that are entering the water throughout the modeled watersheds (Naik et al 2009).

Comparing erosion estimates with the location of riparian buffer data, generated using high-resolution satellite or aerial imagery or LIDAR data, can help managers identify areas where high sediment and nutrient loads are expected to enter the water unimpeded and which areas are successfully stopping pollutants from entering the water. By evaluating the effectiveness of riparian buffers at all potential sites within a watershed, resource managers can optimally place newly constructed buffers in targeted areas and focus conservation efforts towards intact natural systems to generate the greatest environmental benefit per dollar spent (Storm et al 2010).

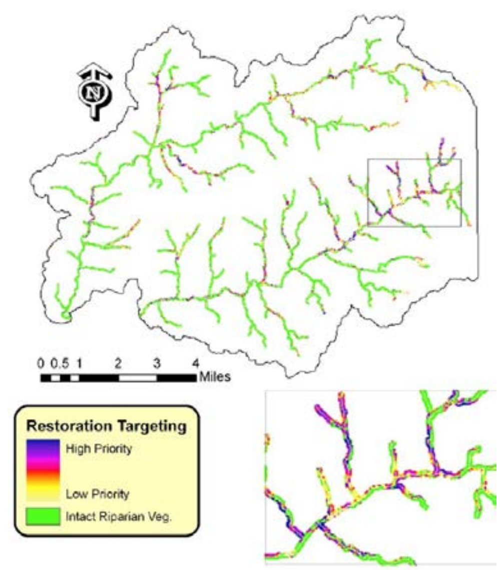


Figure 34: Combining erosion potential data with riparian buffer quality can help managers identify priority restoration areas where efforts will have the greatest impact on water quality. Storm et al 2010

Both process-based models and empirical models provide insight into the response of watersheds to land-cover and resource management changes, provided they are used properly, but applying raw models to estimate erosion potential requires high level statistics and mathematics knowledge and can be both time-consuming and computationally complex (Miller et al 2007). To make these models more accessible to resource managers, a few tools have been created that automate much of the data extraction, are compatible with commonly available GIS data layers, and can be used to compare the potential effectiveness of proposed best management practice implementation and restoration efforts.

The ***Automated Geospatial Watershed Assessment (AGWA)*** tool was created jointly by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA) Agricultural Research Service. This free tool operates as an extension to ESRI's ArcMap software and uses commonly available data to run either the SWAT or KINEROS2 models to estimate soil erosion potential. AGWA automatically extracts information from a digital elevation model (LIDAR DEM), a polygon soil map (U.S. STATSGO, U.S. SSURGO data), and a classified LULC layer and exports the parameters into the specified mathematical models. Using precipitation information from nearby weather stations, the models estimate the amount of erosion that can be expected based on local conditions. After the model has run, AGWA imports the results back into the GIS software as a shapefile showing the individual sub-watersheds and their erosion potential. The software also includes tools to modify the LULC layer to simulate the effect of enhanced buffers or restoration efforts, allowing users to understand the water quality impacts of various management decisions. AGWA comes with a detailed manual that explains both the theory behind the models and software as well as instructions on how to run the program making it a useful and powerful tool for conservation organizations and management agencies.

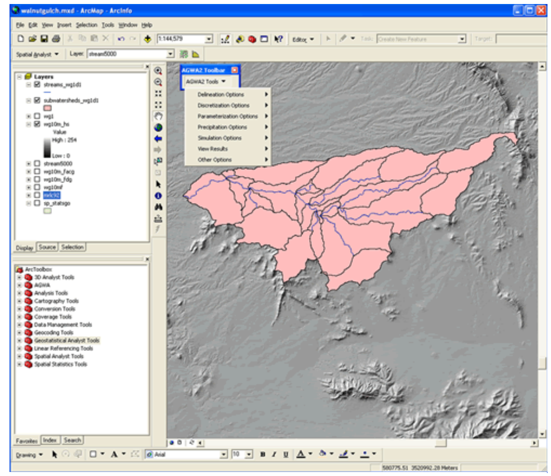


Figure 35: AGWA is a free tool developed by the EPA and USDA to automate soil erosion models using commonly available data.

The ***Spatially Referenced Regression on Watershed Attributes (SPARROW)*** model was developed by the USGS and is one of the primary tools used to estimate nutrient and sediment loads in the EPA's TMDL program. SPARROW uses statistical methods to explain in-stream measurements of water quality (pollutant mass or load) in relation to upstream sources and watershed properties (soil characteristics, precipitation amounts, and land cover). Based on these relationships, the model is used to predict water quality in unmonitored streams for an entire region. SPARROW can help determine water quality metrics including source contributions to stream loads and nutrient and sediment yields and concentrations. Although the model is freely available, it is complex and requires a significant amount of knowledge and training to use in addition to having large processing time and power needs. Most organizations will not be able to use SPARROW because it requires the SAS statistics software and some programming knowledge to run, however the EPA has generated results for the entire Chesapeake Bay watershed, providing them to the public, and continues to update and improve its calculations in support of the TMDL. These results, while useful for making calculations for the Chesapeake Bay TMDL, can only estimate a sub-watershed's contribution, and are not at a resolution that could identify the contribution of individual parcels or landscapes and would not be helpful for small scale management decisions.

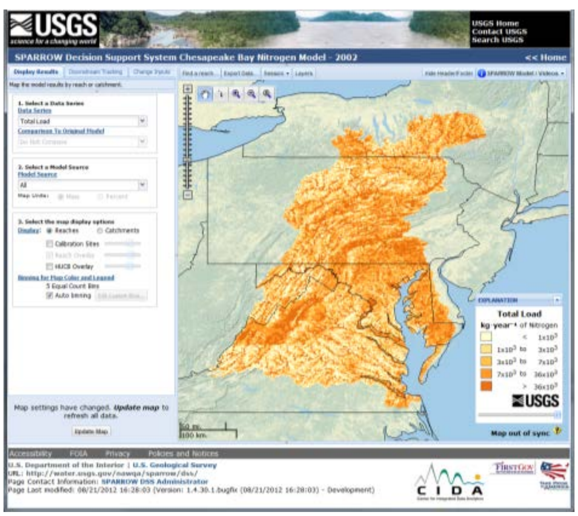


Figure 36: Screenshot of USGS web portal providing access to SPARROW data

Considerations and Recommendations

Overall, nutrient and sediment loading and restoration potential modeling can provide useful information to conservation organizations detailing the impact the land has on water quality. Like many other types of analysis, the accuracy and limitations of nutrient and sediment loading and restoration potential calculations are greatly affected by the scale of the source data. Higher resolution data allows resource managers to develop more precise models and target specific areas that are impacting water quality but using this data creates significant tradeoffs in terms of processing and storage constraints. For this reason, many scientists who engage in this type of modeling begin with broad-brush analyses using medium resolution data to determine potential hotspots and then re-run the analysis in specific areas using higher resolution data to obtain more accurate results (Claggett 2012).

The time-scale of the analysis can also impact potential management decisions based on these models. Event-driven models can help determine inadequacies of riparian buffers or best management practices and are useful at modeling small watersheds while long-term models can help determine landscape scale implications of land management practices that are contributing or preventing nutrients and sediment loads from entering the water at a much larger scale. Both types of models are important tools that can be used to determine the potential impact of management decisions on water quality, but a solid understanding of the inherent limitations of a model is vital to ensure that managers choose the right tool for the management issues being addressed (Miller et al 2007).

Another consideration is the amount of uncertainty that goes into these models. All models are imperfect representations of reality and calculations inherently reflect uncertainties in the available source data sets. The estimates of nutrient and sediment loading created by these models are being extrapolated from limited information, so small errors in the source data can be compounded as it is applied to a much larger area. As better data is collected for large areas, such as high-resolution LULC and LIDAR elevation data, the accuracy of the results will improve because there will be less extrapolation. To prevent the misinterpretation of a model's results and to ensure that uncertainty is accounted for in management decisions, these tools should be run by users with a high level of knowledge of the subject and an appreciation for each models' underlying assumptions (Claggett 2012).

Accurate information about which land is potentially affecting the amount of pollutants entering the water will be critical when prioritizing land conservation efforts. Due to the complexities of the underlying models used to estimate nutrient and sediment loading, this data will likely need to come from high level sources, such as the Chesapeake Bay Program or academic institutions. Once this baseline information has been generated, however, users with a solid understanding of GIS and access to high quality LULC data can identify areas that have a high potential for restoration or conservation using commonly accessible software options. Consequently, future efforts should be focused on developing ways for conservation organizations and management agencies to access processed nutrient and sediment loading data that has been developed by a trusted source.

Technology	Potential	Limitations	Conclusions
Nutrient and Sediment Loading and Restoration Potential	Uses multiple data sources to calculate the expected nutrient and sediment loads entering the water and identifies priority restoration and conservation areas	• Very complex analysis • Data/processing intensive • Need for training • Access to Data	Nutrient and sediment loading calculations are too complex for most groups. Efforts should be focused on developing tools to disseminate and analyze processed data to identify priority areas.

Conclusions

Individually, the technologies described in this report can provide conservation organizations and resource managers with unprecedented access to information about the landscapes surrounding the Chesapeake and a greater understanding of how they impact water quality in the Bay. When they are combined, these technologies can deliver a level of detail that could be used to credit land conservation in ecosystem-services markets and identify specific areas that are contributing or preventing nutrients and sediment from entering the water. These technologies can significantly improve our ability to conserve and restore high-functioning natural landscapes that have the greatest potential for maintaining and improving the water quality of the Chesapeake Bay.

All of the technologies highlighted in this report are scalable and can be applied to a range of management situations from modeling the entire Chesapeake Bay watershed to understanding what is happening on an individual parcel. Although they can handle various sized datasets, a significant consideration for each tool is the amount of data storage and processing power needed to handle high-resolution data. As resolution increases, the amount of data contained in a file increases exponentially; for example, a satellite image with 1m resolution contains 900 times the number of pixels as an image of the same area with 30m resolution. While these new sensors are providing increasingly useful datasets, large-scale storage solutions and more powerful computers with increased processing capacity will need to be purchased to handle the data that are being collected. For organizations at all levels, this will be a major constraint that plays a large role in determining whether or not these technologies will be implemented.

Each tool has distinct benefits and limitations that will have to be weighed by conservation organizations to determine whether it is something they want to invest their time and money into, or if it is something that they would rather pay someone else to do. While it is not currently feasible for all of the technologies described in this report to be employed by conservation organizations in their targeting efforts, some of them do have significant promise.

- Headwater stream mapping and concentrated flow path mapping have the greatest potential for wide-spread use because there is previously collected, high quality LIDAR elevation data available for the majority of the watershed and the software options used to process these datasets are relatively inexpensive and easy to use. Additionally, some of the leading researchers on this topic have already expressed an interest in partnering on projects of this type in the Chesapeake Bay watershed in the near future. The data these tools can generate is extremely important as it identifies landscapes that are not legally protected under current environmental regulations but contribute up to half the sediment and nutrients flowing into the bay.
- High-resolution land cover mapping also has a high likelihood of success and is something that we should invest our time and energy into. Imagery data are easily accessible, with an associated cost, and there are extremely powerful software packages that are available for a reasonable cost. High-resolution land cover data would have tremendous implications for conservation organizations and would significantly improve our ability to target intact, high-value natural landscapes that provide substantial water quality benefits in addition to other ecosystem services.

Like all new technologies, the effectiveness of these tools and the applicability of their products will need to be established for them to be accepted and widely used within the conservation community. Demonstrating their “proof of concept” through real-world case studies will be an important next step in promoting their use as worthwhile investments that can enhance an organization’s ability to target high-functioning natural landscapes. Furthermore, engaging management agencies in charge of implementing the Chesapeake Bay TMDL, such as the EPA and state agencies, in a pilot project’s development will help reinforce that these technologies are appropriate tools for high-level tasks such as landscape targeting, best management practice monitoring and crediting, and nutrient and sediment loading estimation.

Educating conservation organizations about the use of these technologies will be another challenge that needs to be overcome if they are going to be used to incorporate the benefits of nutrient uptake and sediment retention into decisions regarding land conservation. The Chesapeake Conservancy is working with its partners to develop an online portal that will contain the information from this report as well as resources that can help users get started with these technologies and gain access to data, tools, trainings, and examples of how these assessments have been used in other areas. As part of this effort, we are also developing and promoting an online user community where practitioners and experts can interact with each other to advance the development and use of these tools. Another essential role for the portal will be providing access to online and in-person trainings that teach interested conservation organizations how to conduct these assessments on their own.

Due to the cost and effort required to purchase software, acquire training, and transform raw data into useful products, many of the technologies described in this report will not be accessible to all organizations. There is an opportunity, however, for an organization such as the Chesapeake Conservancy to collect and process regional datasets that could be subset and distributed to other organizations at a reduced cost. Consolidating these efforts and benefiting from economies of scale would ensure that conservation organizations have the capability of make informed decisions about which areas should be a priority for conservation because they provide the greatest range of benefits while minimizing the expenditure of the limited resources needed to protect these high-functioning landscapes.

The technologies highlighted in this report have the capacity to determine a parcel’s landscape characteristics and provide us with the ability to target land that maintains water quality and identify areas where restoration activities will have the greatest impact on improving water quality in the Chesapeake Bay and its tributaries. As land conservation evolves and becomes more competitive, having the ability to identify and understand what characteristics make these high functioning landscapes valuable will give conservation organizations the capacity to make informed decisions about which land provides the greatest range of benefits and should be a priority for conservation. Ultimately, these technologies will not only provide us with greater expertise for our land conservation efforts, they will ensure that conservation organizations across the Chesapeake Bay watershed have the tools they need to make wise investments that provide real results and that land that is essential to restoring the health of the Chesapeake Bay is protected.

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