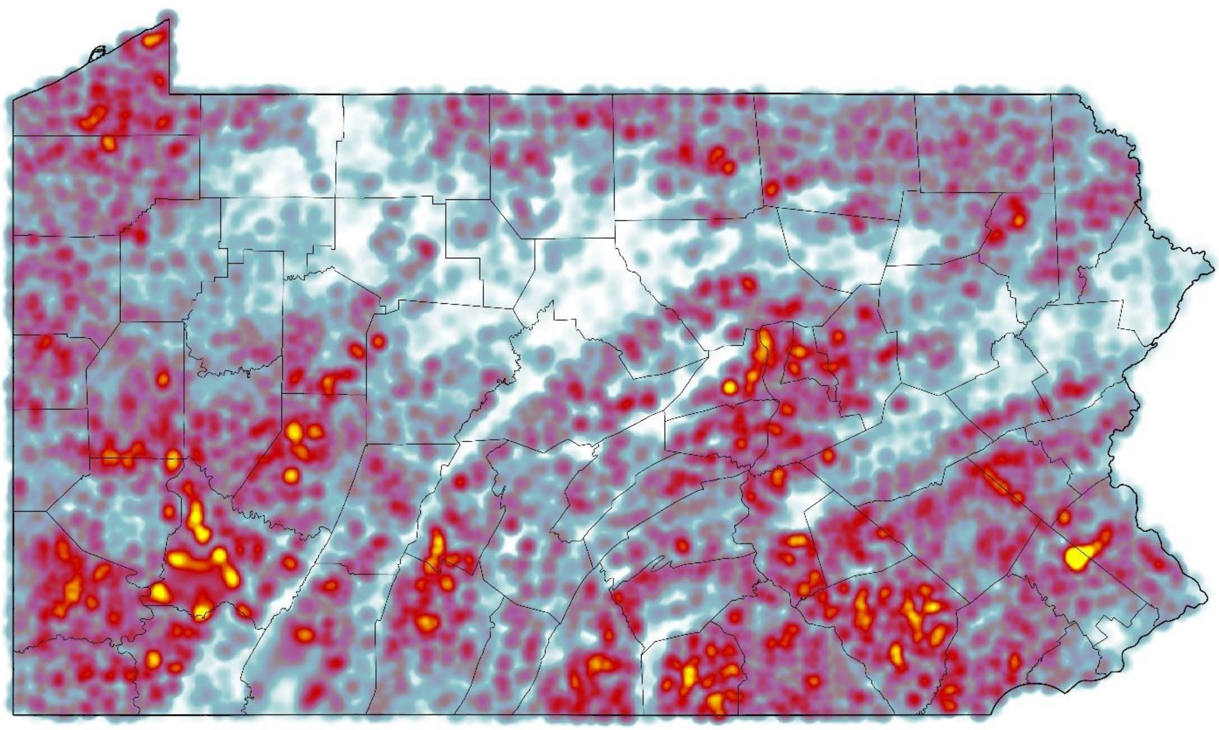
Identifying and Prioritizing Streamside Forest Planting Sites in Pennsylvania Using GIS



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PENNSYLVANIA
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ASSOCIATION

"Of the many best management practices (BMPs) used to improve the quality of waters and habitats in the Chesapeake Bay watershed, the single best BMP may be the restoration of riparian forest buffers."

– Forestry Workgroup, Chesapeake Bay Program

"He who plants a tree plants a hope."

– Lucy Larcom, poet

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Executive Summary

Streamside forests reduce nonpoint source pollution delivery to streams—especially nitrogen, phosphorous, and sediment. They are essential for healthy and safe waterways. They reduce flooding impacts, improve wildlife habitat, and enhance the stream's natural ability to break down pollutants.

As important as streamside forests are, planting them is expensive and time-consuming. Given these costs, it makes sense to prioritize streamside forest planting projects. The Pennsylvania Land Trust Association (PALTA) wanted to develop an objective way to assess potential streamside forest planting sites in Pennsylvania on their ability to improve water quality. The organization sought to answer the following questions:

1. Where are potential streamside forest planting sites?
2. Which streamside forest planting sites have the best potential to improve water quality?
3. What are the streamside forest planting opportunities on farmland, urbanized areas, and conserved properties?

To answer these questions, PALTA combined peer-reviewed methods of assessing streamside planting opportunities with new, high-resolution geographic information systems (GIS) data. The result is Pennsylvania's first statewide, comprehensive streamside planting opportunity spatial dataset. PALTA has made this dataset available publicly through a web application and the Pennsylvania Spatial Data Access (PASDA) website.[*] The application can help both planners and on-the-ground conservationists find streamside forest planting sites that will maximize water quality gains for every dollar and hour spent.

The analysis identified 217,649 potential streamside forest planting sites in Pennsylvania. These sites totaled 388,000 acres. Agricultural land offered by far the most acreage for potential plantings. More than 80% of plantable acres occurred on farmland. Urbanized areas also had significant tree-planting potential, with 43,324 plantable acres identified. Planting opportunities on conserved land were relatively low, but only because these areas already have high concentrations of streamside forests. Farmland preservation easements were an exception, combining both substantial acreage and the highest average planting site scores of any subgroup evaluated. Nevertheless, a key conclusion of this analysis is that Pennsylvania will need to expand its conservation partnerships to meet its Watershed Implementation Plan goal of planting 95,000 acres of streamside forests statewide by 2025.

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[*] The web application is available at https://palta.maps.arcgis.com/apps/webappviewer/index.html?id=432f97968b8a4ad2b2aabd8ade0ee27b. PASDA data can be downloaded at http://www.pasda.psu.edu/uci/SearchResults.aspx?originator=Pennsylvania+Land+Trust+Association.

Landscape Feature	Number of Sites	Plantable Acres	Mean Score
Along Impaired Stream	83,560	163,244	1.17
Along EV/HQ Stream	45,801	87,349	1.00
In Urbanized Area	35,983	43,324	1.16
On Agricultural Land	127,398	314,146	1.15
All Sites	**217,649**	**387,894**	**1.06**

Potential riparian planting sites on landscape features of interest. Sites can be in more than one landscape feature, so individual features sum to more than the total for all sites.

Conserved Land Type	Number of Sites	Plantable Acres	Mean Score
Federal	1,395	5,669	0.92
All State-Owned	5,043	13,758	0.80
State Forest	*1,468*	*4,192*	*0.68*
State Park	*977*	*2,605*	*0.80*
State Game Land	*2,083*	*5,234*	*0.82*
Fish & Boat Commission	*496*	*1,690*	*1.06*
Historical & Museum Commission	*19*	*37*	*0.90*
Local Government	3,578	6,003	1.15
Land Trust Owned	498	1,113	0.89
Land Trust Easement	1,946	4,856	1.15
Agricultural Easement	4,891	17,998	1.33
Other Easement	288	921	1.24
All Conserved	**17,508**	**49,784**	**1.08**

Planting site opportunities on conserved land. Due to overlap of conserved land features (example: government-owned land that also has a conservation easement), individual conserved land types sum to more than the total for all conserved land.

Background

Streamside forests are a vital component of water quality protection. They are particularly effective at reducing nonpoint source pollution delivery to streams, especially nitrogen, phosphorous, and sediment.

The wider the streamside forest, the greater the protection. A literature review by the Stroud Water Research Center in Avondale, Pennsylvania found that streamside forests 35 feet wide remove on average 65% of sediment by weight, primarily in large particles such as sand. By contrast, 100-foot-wide forests remove 85% of sediment on average and are better able to filter out fine particles like silt and clay.[1]

Width matters in particular for nitrogen reduction. Nitrogen enters streams largely through subsurface flow, which streamside forests have a harder time filtering. Even a 100-foot forest will only keep on average 48% of subsurface nitrogen from reaching streams. To remove 90% of subsurface nitrogen requires more than 300 feet, the length of a football field.[2]

Streamside forests reduce nonpoint source pollution delivery to waterways. In their literature review of more than 200 stream buffer studies, researchers from the Stroud Water Research Center found streamside forests effectively filter nitrogen, phosphorous, and sediment.

Streamside forests provide more water quality benefits than reducing upslope pollution. Their deep, dense root networks help anchor streambanks against erosion. In a study of 748 river bends in British Columbia, major bank erosion was 30 times more prevalent on unforested bends than on forested ones.[3] In another project, deforested farm floodplains in California were 80-150% more likely to erode than floodplains with streamside forests.[4] These results are consistent with other studies finding that streams bordered by forest migrate on average half as quickly as those without trees.[5]

This reduction in streambank erosion benefits both upstream and downstream residents. For upstream landowners, a more stable stream is less likely to jump its banks and destroy a farm field. For downstream water consumers, bank erosion can contribute 50 to 90% of a stream's sediment and phosphorous load.[6] Reduce bank erosion with streamside forests, and a large portion of two major water quality pollutants is cut back.

Forested streams are better able to withstand floods with less erosion and channel migration. In this photo taken shortly after Hurricane Irene in 2011, note the devastation on the unforested left bank compared with the relatively intact forested right bank.

Streamside forests are also essential for healthy and safe waterways. In North America, nearly all streams historically had forest cover along their banks. Even in the Great Plains, trees grew along streams.[7]

Because of this historic association, aquatic wildlife are adapted for forested streams. Aquatic animals thrive in cool, shaded water. They rely on leaves, branches, logs, and root wads as the base of their food chain as well as for shelter. They count on wide, shallow streams with high variation in current speed with numerous rocks both submerged and exposed for habitat. All these features are more common in forested streams, so it comes as no surprise that these streams have both a greater abundance and diversity of invertebrates than unforested ones do.[8]

Why does stream health matter? Because a healthy stream with diverse aquatic life is itself a water quality protection tool. Plentiful invertebrates convert harmful nitrogen compounds like nitrates and ammonia into harmless nitrogen gas, which makes up 78% of air.[9] Wide, meandering, slow-flowing water also gives more opportunity for sunlight and chemical processes to break down common farm pesticides like atrazine and methoxychlor.[10]

Forested streams (left) tend to be wider, shallower, and more complex than unforested streams (right). As a result, they have more and better habitat for stream life that in turn helps break down pollutants.

Where Is the Best Place to Plant Streamside Forests?

With all the benefits of streamside forests, it's no surprise that research shows almost anywhere along a waterway is a good place for trees. Regardless of the upslope land cover, a streamside forest will improve water quality, stream habitat, and stormwater management.

Even so, some streamside forests can affect water quality more than others. Topography, soil, climate, and upland land cover all impact how much pollution a given streamside forest can filter. Considering the costs and time commitments involved in successful streamside forest planting projects, it makes sense to prioritize planting sites.

The Pennsylvania Land Trust Association (PALTA) wanted to develop an objective way to assess potential streamside forest planting sites in Pennsylvania on their ability to improve water quality. The organization sought to answer the following questions:

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To answer these questions, PALTA combined peer-reviewed methods of assessing streamside planting projects with new, high-resolution geographic information systems (GIS) data. The result is Pennsylvania's first statewide, comprehensive streamside planting spatial dataset. This dataset has been made available publicly through a web application and the Pennsylvania Spatial Data Access (PASDA) website. It will help both planners and on-the-ground conservationists find new streamside forest sites that will maximize water quality gains for every dollar and hour spent.

Methods

Identifying Potential Streamside Forest Planting Sites

Before any prioritization can occur, potential streamside forest planting sites must be identified. PALTA identified planting sites using the 1-m high resolution land cover dataset developed by the Chesapeake Conservancy in partnership with the University of Vermont. This dataset is based on 2013 aerial imagery and supplemented with additional data such as Light Detection and Ranging (LiDAR) elevation information.[11] The result provides 900 times the amount of information previously available through the National Land Cover Dataset's 30-m product.

The 1-m land cover data assigns each square meter one of twelve land classes (Table 1). For this analysis, only Value 5, "Low Vegetation" was used to identify potential planting sites. Previous projects using this dataset have included "Wetlands" and "Barren" land covers. Because this analysis focused on priority sites, though, these land covers were excluded. Wetland and Barren land covers include features such as rock fields and bogs that are impractical to establish tree cover on. Plantable acres in this analysis are thus more conservative than those in other projects.

Streamside forest locations were identified using the National Hydrography Dataset's (NHD's) High Resolution data, which is collected at 1:24,000 scale or closer and overseen by the United States Geological Survey (USGS). This dataset was chosen because it forms the basis of other state streams datasets such as Impaired Waterways and Chapter 93 designations. Using this dataset allows for greater compatibility between this analysis's final results and existing data. It is also currently the best streams data available statewide. NHD data used included:

1. NHD Flowline (for small streams)
2. NHD Area (for large streams, creeks, rivers, etc.)
3. NHD Waterbody (for lakes, ponds, reservoirs etc.)

For the NHD Waterbody layer, only features along the stream network were included. Isolated ponds and other features that are otherwise not connected with streams were removed.

Each of the three NHD layers was buffered by 100 feet. The Stroud Center literature review concluded that a 100-foot buffer was the minimum needed to protect the physical, chemical, and biological integrity of streams.[12*] The separate buffer layers were then dissolved together to create a single buffer layer for the entire state.

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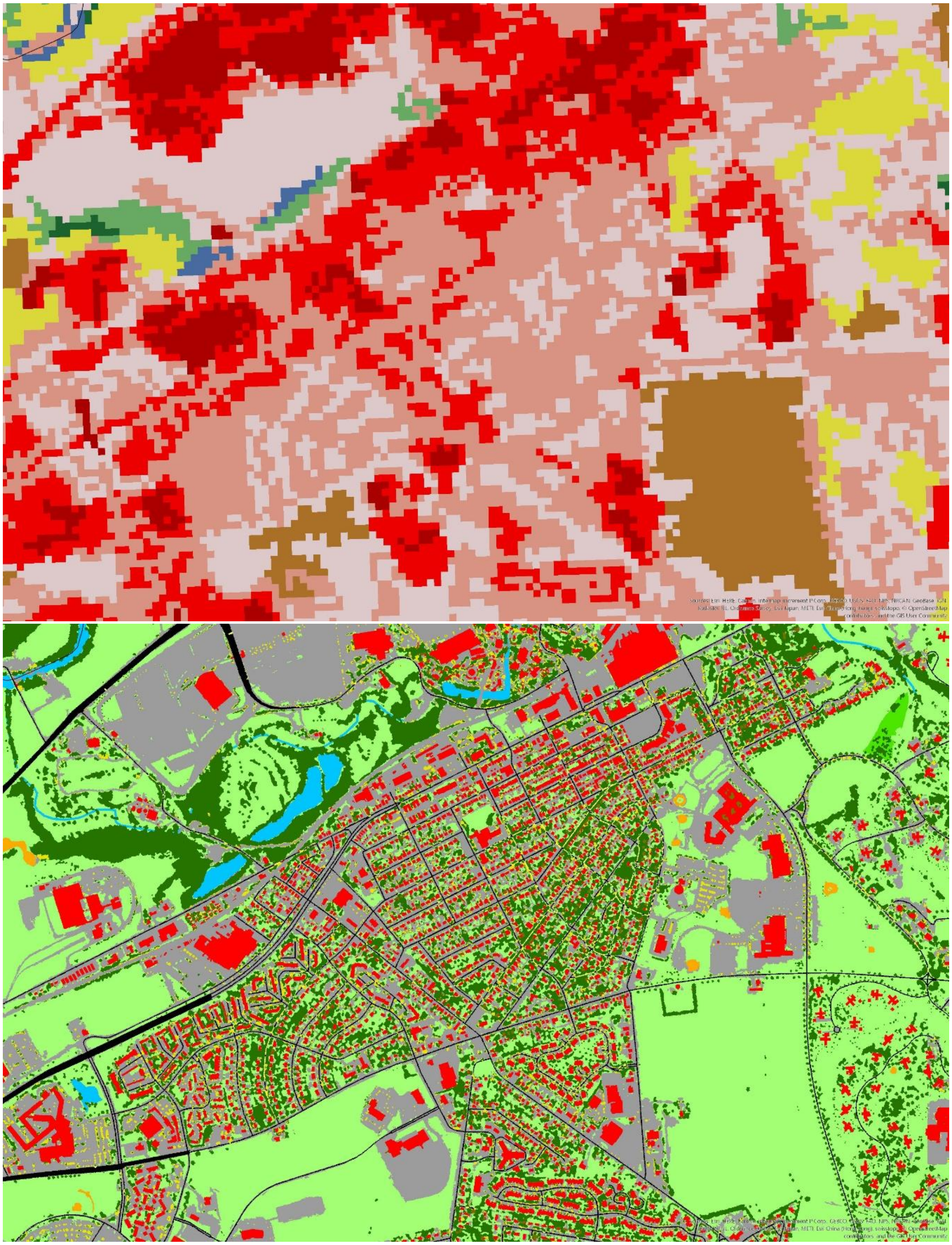
[*] Although the Stroud Center reached this conclusion, they acknowledge "that the optimal buffer width for a buffer may vary from site to site and that an ideal buffer policy might call for variable buffer widths." The 100-foot width made sense to use for this analysis, but in practice, whatever can be planted will benefit water quality. Fifteen feet is better than zero. A hundred is better than fifteen. Two hundred is better than one hundred, and so on.



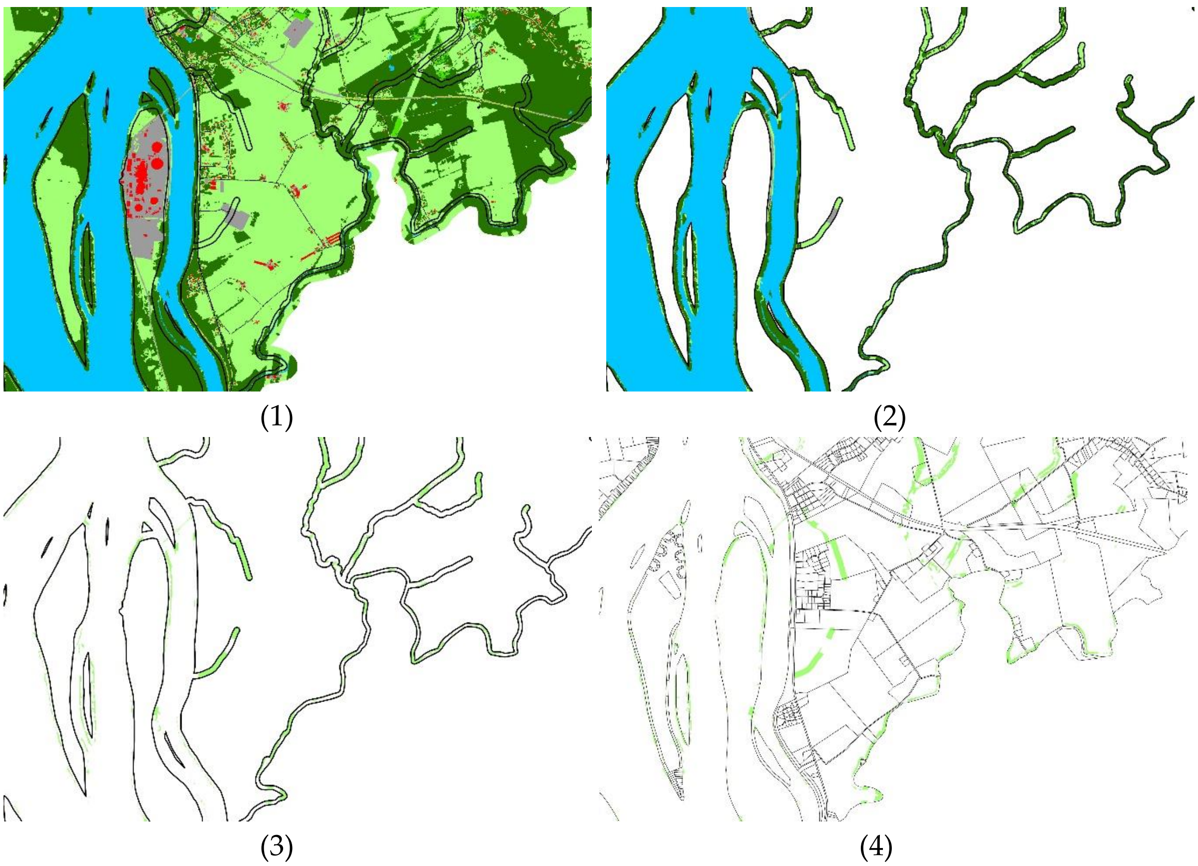
Identical views of downtown Hershey, Pennsylvania using the 30-m National Land Cover Dataset (top) and the 1-m high resolution land cover from the Chesapeake Conservancy (bottom). The 1-m dataset has 900 cells for every 1 cell in the 30-m product, allowing for far more precise and nuanced analyses.

Value	Land Class Name	Description
1	Water	All areas of open water, generally with < 25% other covers
2	Wetlands	Low Vegetation areas that intersect National Wetlands Inventory layers and are visually confirmed to have wetland characteristics
3	Tree Canopy	Deciduous and evergreen woody vegetation over approximately 5 meters in height
4	Shrubland	Deciduous and evergreen woody vegetation between approximately 2 and 5 meters in height
5	Low Vegetation	Plant material less than approximately 2 meters in height
6	Barren	Areas void of vegetation consisting of natural earthen material (ex. beaches, dirt roads, exposed bedrock, and bare ground in construction sites)
7	Structures	Human-made objects of impervious materials greater than approximately 2 meters in height
8	Other Impervious Surfaces	Human-made surfaces that water cannot pass through and that are below approximately 2 meters in height
9	Roads	Impervious surfaces used and maintained for transportation as defined in planimetric data
10	Tree Canopy Over Structures	Tree canopy that overlaps with areas classified as Structures
11	Tree Canopy Over Other Impervious	Tree canopy that overlaps with areas identified as Other Impervious Surfaces
12	Tree Canopy Over Roads	Tree canopy that overlaps with areas identified as Roads

Table 1. Land cover type descriptions for the 1-m land cover data developed by the Chesapeake Conservancy and University of Vermont.[13]

To identify planting sites, the 1-m land cover data was clipped to the single statewide buffer layer. The clipped data was then reclassified to include only locations marked as Low Vegetation. The result was then converted to a vector layer. These vectors were intersected with county tax parcel layers to break up plantable sites by ownership.*

Breaking up the land cover data by tax parcel results in hundreds of thousands of miniscule sites that would be impractical to plant. To make the final results more meaningful, a minimum planting size was established through consultation with streamside tree planting experts at the Pennsylvania Department of Conservation and Natural Resources (DCNR). This minimum size was 0.25 acres on a single tax parcel. Sites smaller than that threshold were deleted.



An example of the process for identifying potential planting sites. High-resolution land cover data (1) was intersected with 100-foot buffers around streams, rivers, and water bodies connected to the stream network (2). All land covers other than Low Vegetation were removed (3), and the results were intersected with tax parcels (4) to locate planting sites.

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* County tax parcel information was available for 65 of 67 counties. Incomplete parcel data for Clarion and Forest Counties prevented them from being analyzed in this manner. In the absence of tax parcel data, those two counties had their plantable areas segmented by NHD-Plus High Resolution Catchments, the smallest watershed delineation NHD tracks.

Assessing Streamside Planting Sites: A Three-Criteria Scoring

Numerous projects have examined ways to rank streamside plantings. Some focus on water quality. Others emphasize wildlife habitat. Still more look at social factors. This analysis stressed water quality protection. It sought to identify potential streamside forest locations that could most effectively reduce stormwater and nonpoint source pollution.

Given this water quality focus, the analysis used a three-criteria scoring that drew as much as possible on existing peer-reviewed methods. The methods used were:

1. Topographic Wetness Index (to assess the planting's ability to intercept and mitigate stormwater)
2. Sediment Trapping Efficiency (to assess the planting's ability to block nutrient delivery to streams)
3. Upslope Land Cover (to assess the need for streamside forests to act as a buffer against nonpoint source pollution)

Each method is discussed individually below. All analyses were conducted using Esri ArcGIS Pro v2.3 software. Analyses occurred at the HUC-8 watershed scale to accommodate data processing limitations. Planting sites were similarly separated by HUC-8 watershed to ensure they could be scored appropriately.

Every potential planting site received a score for each criterion. These scores were normalized using feature scaling to have a value from 0–1, with 0 being the worst and 1 being the best. The three values were summed to develop a final score for each planting site. A score of 3 indicates the best possible planting site according to this analysis, while a score of 0 indicates the worst.

Critically, a low-scoring site does not mean a streamside forest is unwarranted or valueless at that location. As noted in the Background section, streamside forests benefit water quality regardless of location. The scoring helps identify areas where streamside forests will be most effective at protecting water quality. It should be used to help decide which areas to plant first, not to exclude sites from planting altogether.

Scores also should not be considered exclusively when selecting planting sites. Despite the robustness of the analysis, there is no substitute for evaluating potential planting sites in the field. Those using the results of this analysis are cautioned to use the information as a guide, and to make any final choices on site selection only after onsite reviews.

Sidebar: Qualitative Attributes and Filters

The three-criteria scoring focuses on environmental factors such as soils, elevation, slope, and land cover. It does not factor in social information that can be helpful in selecting planting sites. To assist users of the final dataset in site selection, qualitative attributes were added for each planting site. These attributes were determined by intersecting the planting sites with common geographic and landscape features users may want to focus on. The result allows users to narrow their site search without diluting the environmentally-focused score. Users can filter planting sites by whether they are any combination of the following:

1. Along an impaired stream as designated by the Pennsylvania Department of Environmental Protection (DEP)
2. Along a "High Quality" or "Exceptional Value" stream as designated under Pennsylvania Chapter 93
3. In agricultural land cover as determined by the National Agricultural Statistics Service's 2017 farmland layer
4. In an urbanized area as determined by the 2010 US Census
5. On conserved land as determined by PA Conserved Land, 2019 edition

Users can also filter based on geographic regions of interest including counties and HUC-8, -10, and -12 Watersheds. Finally, planting sites on conserved land received additional attributes from PA Conserved Land, including owner or easement holder name and type. This information is available in the full data download on PASDA.

Scoring Criterion 1: Topographic Wetness Index

Topographic Wetness Index (TWI) was developed in 1991.[14] It was adapted for use in prioritizing streamside tree planting in 2003 by soil scientists at the US Department of Agriculture.[15]

TWI is derived from two facts. First, streamside forests that have a large upslope contributing area per unit of stream length provide a greater potential water quality benefit than those with small contributing areas. Second, to be most effective, streamside planting sites need shallow slopes so water passes through them as a distributed rather than channelized flow. Distributed flow more efficiently allows for water infiltration into the soil and for plants to uptake water and pollutants. TWI is calculated as shown:

$$TWI = \ln \frac{A_s}{\tan \beta}$$

Where:

TWI = Topographic Wetness Index

A_s = upslope contributing area per unit grid cell width

β = land slope in degrees (*tan β* thus represents percent slope divided by 100)

Calculating TWI in GIS begins with a digital elevation model (DEM). This analysis used 3-m DEMs derived from LiDAR data collected through the PAMAP Program. These statewide data were collected between 2006 and 2008. Although more recent national LiDAR data were available, PAMAP was chosen because of its higher resolution. PAMAP also has 1-m data, but that data proved too large to work with for this analysis. The 3-m data balanced precision with data processing efficiency.

A drawback to the DEM's precision is that it contains noise. The data has erroneous "sinks" where single cells appear at a lower elevation than they actually are. These sinks were first corrected using the Fill tool. The result, called a "filled DEM" was used for all subsequent analyses.

A slope raster was created using the Slope tool on the filled DEM. This raster was used for the *tan β* portion of the TWI equation.

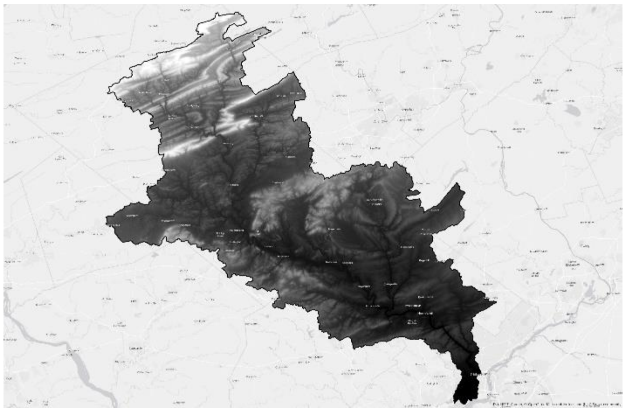
To generate A_s, the Flow Direction tool was run on the filled DEM. Flow Direction identifies the path water takes from one cell to the next based on changes in elevation. This analysis used the

D-8 method of assigning flow direction. More advanced flow direction modeling approaches exist such as D-Infinity (which allows water to flow into multiple cells), but since this analysis occurred at a statewide level, D-8 was considered to be of sufficient quality. It also greatly accelerated processing speed.

The Flow Accumulation tool was next applied to the flow direction raster. This tool uses the flow direction results to plot the course of water across the landscape. Water starts out diffuse in relatively higher elevations and gradually accumulates as it flows downhill. Eventually enough water accumulates that it forms recognizable streams. Flow Accumulation traces the pathways water takes to assemble into those streams. For every cell in the raster, it calculates the number of other cells that have water flowing through it. The result, when symbolized, looks like a highly detailed streams layer.

Flow Accumulation in ArcGIS software does not include the cell being calculated in its own sum. This results in many cells having a flow accumulation of 0. Because the equation $ln(0)$ is undefined, Raster Calculator was used to add 1 to every cell in the Flow Accumulation raster. This 1 reflects the precipitation that lands on that cell. A_s was then calculated for each cell in the flow accumulation raster as the value of that cell multiplied by 3, since the cells are a 3-m resolution.

TWI was calculated for every 3-m cell in Pennsylvania. The TWI for a given planting site was the average of all the TWI scores for each cell in that site.



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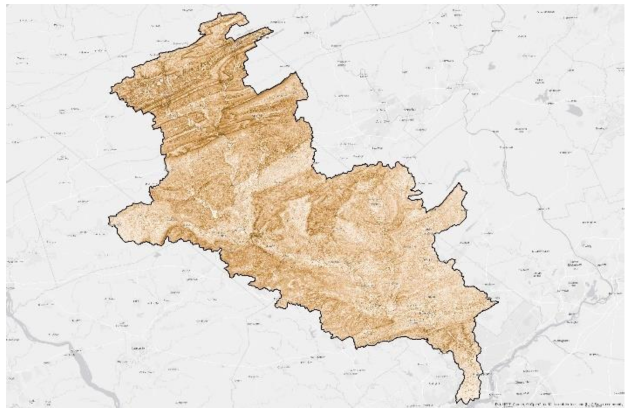

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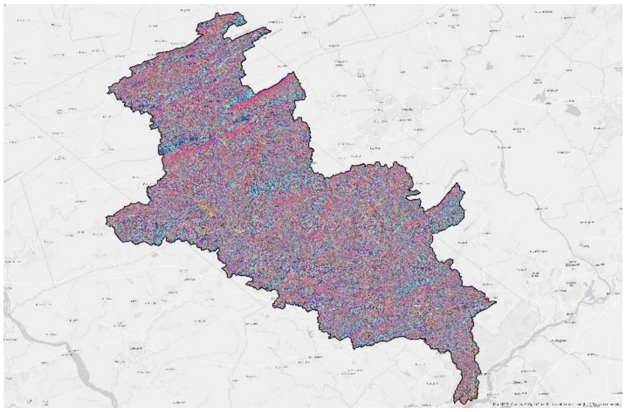

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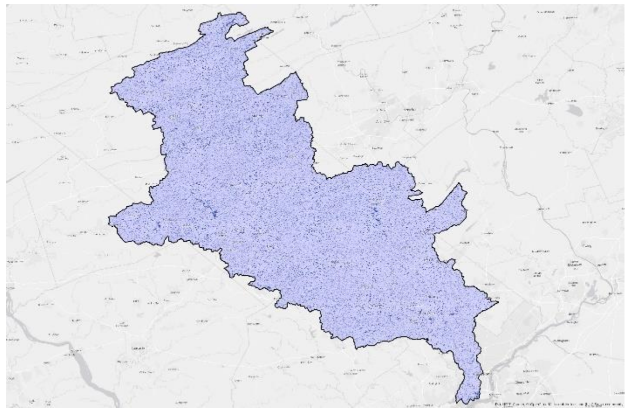

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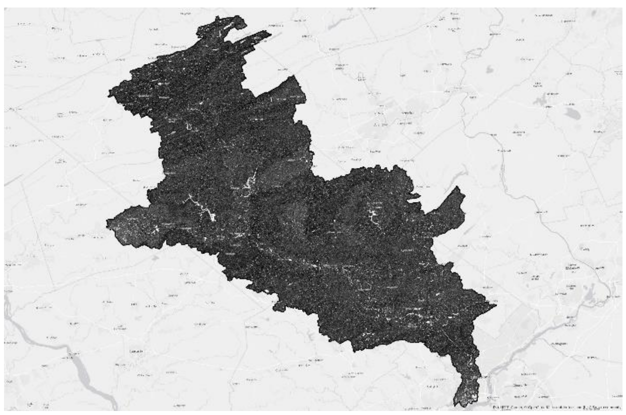


(5)

Calculating TWI for the Schuylkill River Watershed. A filled DEM (1) is used to generate slope (2) and flow direction (3) rasters. Flow direction is used to create a flow accumulation raster (4). Raster Calculator is then used to calculate TWI (5) from the slope and flow accumulation rasters. In image 5, higher TWI values are symbolized with lighter colors.

Scoring Criterion 2: Sediment Trapping Efficiency

Sediment Trapping Efficiency (STE) was developed in 2005 as a companion to TWI.[16] Where TWI assesses a planting site's ability to manage runoff, STE models the ability of a planting site to capture nonpoint source pollutants contained in that runoff.

STE is an output variable from the Vegetative Filter Strip Model (VFSMOD).[17] It estimates the percent of input load that will be deposited in a buffer.

STE is derived from elements of the Revised Universal Soil Loss Equation (RUSLE). These elements are combined to produce a "sediment index" (SI), which is then used in a regression equation to calculate STE. The two step equation is:

$$SI = \frac{D_{50}}{R * K * LS}$$

$$STE = 84.6 * (1.17 - e^{-1320SI})$$

Where:

SI = Soil Index
D_{50} = median particle diameter of surface soil
R = RUSLE rainfall and runoff erosivity factor
K = RUSLE soil erodibility factor
LS = RUSLE slope length and steepness factors
STE = Sediment Trapping Efficiency expressed as a percent (0 – 100)

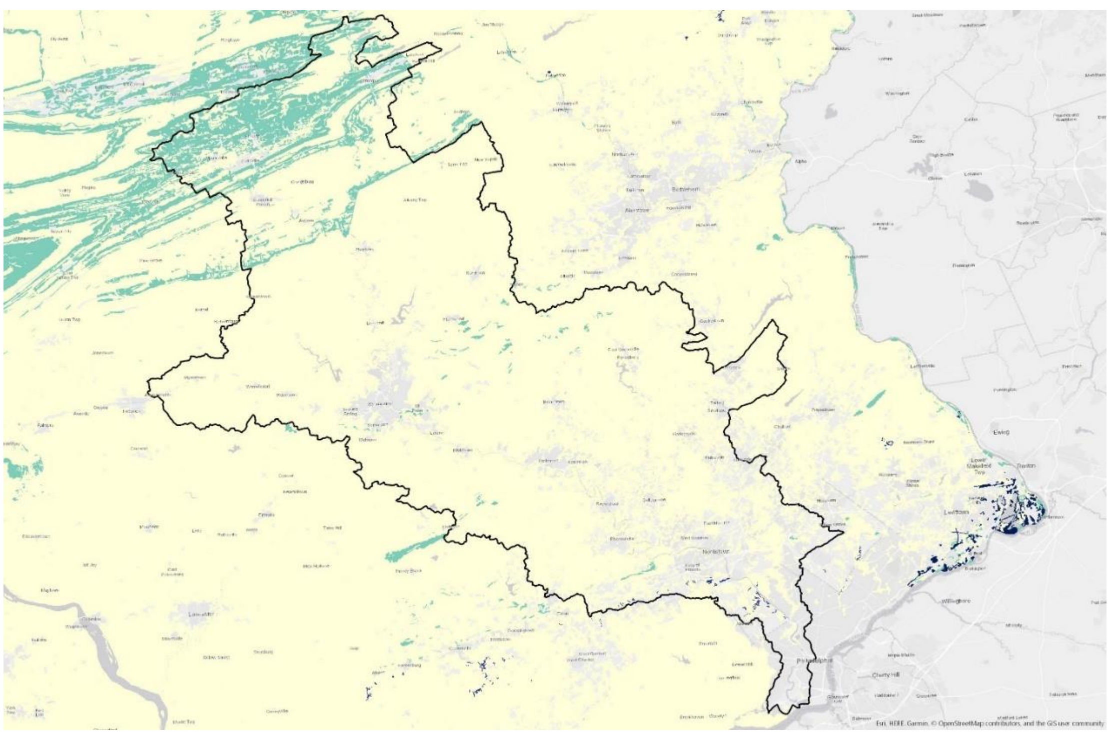
For this analysis, the four parts of SI were calculated as follows:

<u>D_{50}</u>

D_{50} was calculated using the 10-m raster soil data from the US Natural Resources Conservation Service (NRCS) Gridded Soil Survey Geographic Database (gSSURGO). The median particle size was identified through a six-step process:

1. For each soil map unit, the dominant component was identified based on which component had the highest "Component Percentage – Representative Value." In case of a tie, the component with the highest "Slope Gradient – Representative Value" was used. The dominant component's key number was joined to the corresponding map unit in the raster.

2. The surface horizon for each dominant component was identified. This horizon was found in the “chorizon” table by selecting the horizon with a “Top Depth – Representative Value” of 0. This horizon’s key number was joined to the raster using the component key identified in Step 1.
3. The horizon texture group was identified for the surface horizon. This group was found in the “chtexturegrp” table. The texture group selected was the one with an “RV?” value of “Yes,” indicating that horizon texture group was representative of the horizon. The horizon texture group’s key number was joined to the raster using the horizon key number identified in Step 2.
4. The horizon texture group’s Texture was joined to the raster data using the horizon texture group key number identified in Step 3. Texture was found in the table “chtexture.”
5. The Texture entry was used to enter a median particle size based on the D_{50} chart for the VFSMOD.
6. Where Texture was not available, the “Particle Size” field from the “component” table was joined to the raster. The description in the component table and the soil’s name were used to estimate D_{50} according to the VFSMOD table.



D_{50} results for southeastern Pennsylvania, with the Schoharie River Watershed outlined. Green areas indicate larger median soil particle sizes.

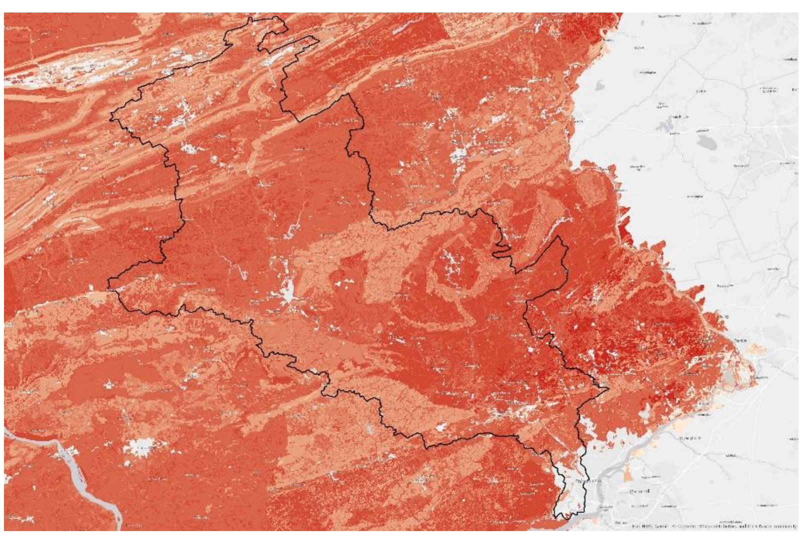
R Factor

R Factor values were provided by the USGS through their supplemental attributes for NHDPlus catchments.[18] Since these values were provided in vector form through catchments, they were converted to a 30-m raster for analysis purposes.

R Factor values for southeastern Pennsylvania. Darker blues indicate greater rainfall and runoff potential.

K Factor

K Factor values were provided by the USA Soils Erodibility Factor layer from Esri.[19] This dataset is a 30-m raster and is derived from NRCS soils data.



K Factor values for southeastern Pennsylvania. Darker reds indicate more erodible soils.

LS Factor

There are multiple ways to calculate the LS Factor. This analysis used the Unit Stream Power Erosion and Deposition (USPED) method, because it uses flow accumulation and slope rasters and is therefore practical to apply in a GIS setting. The same 3-m Slope and Flow Accumulation rasters created for TWI were used to calculate the LS Factor.

The factor's L portion is the ratio of soil loss from a slope length relative to the standard erosion plot length of 22.1m. The actual slope length is converted to the L Factor through the following equation:

$$L = (m+1)\left(\frac{\lambda_A}{22.1}\right)^m$$

Where:

L = L Factor

λ_A = area of upland flow (determined using the Flow Accumulation raster)

m = the ratio of rill to interill erosion (commonly 0.4, which is what was used in this analysis)

The factor's S portion assesses the effects of slope steepness on erosion. It is calculated as the ratio of the actual slope to an experimental slope of 9%. The S Factor is calculated as follows:

$$S = \left(\frac{\sin(0.01745 \times \theta_{deg}}{0.09}\right)^n$$

Where:

S = S Factor

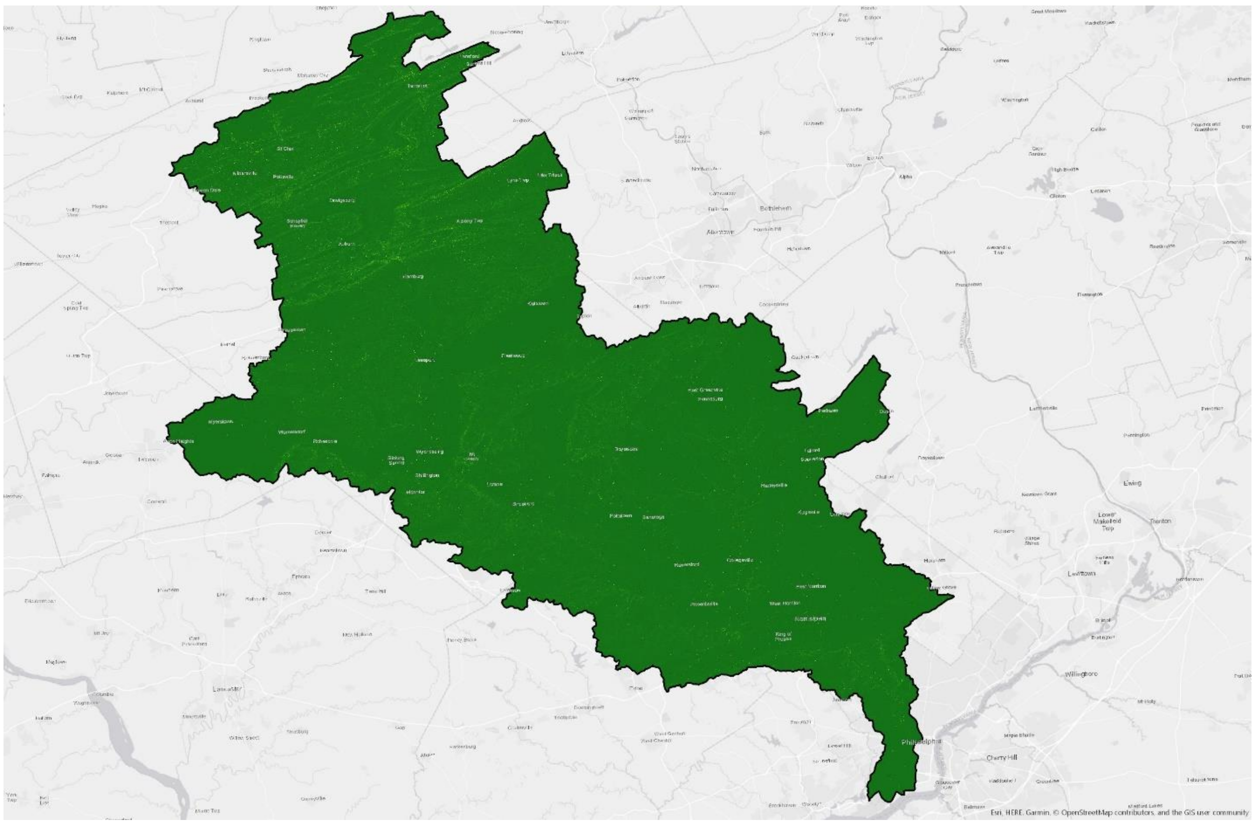
θ_{deg} = slope in degrees

0.01745 = a conversion factor from degrees to radians

0.09 = slope gradient constant

n = an adjustable value depending on the soil's susceptibility to erosion. A typical value is *n*=1.4, which is what was used in this analysis.

The L and S Factors were multiplied together using Raster Calculator to obtain the LS Factor.

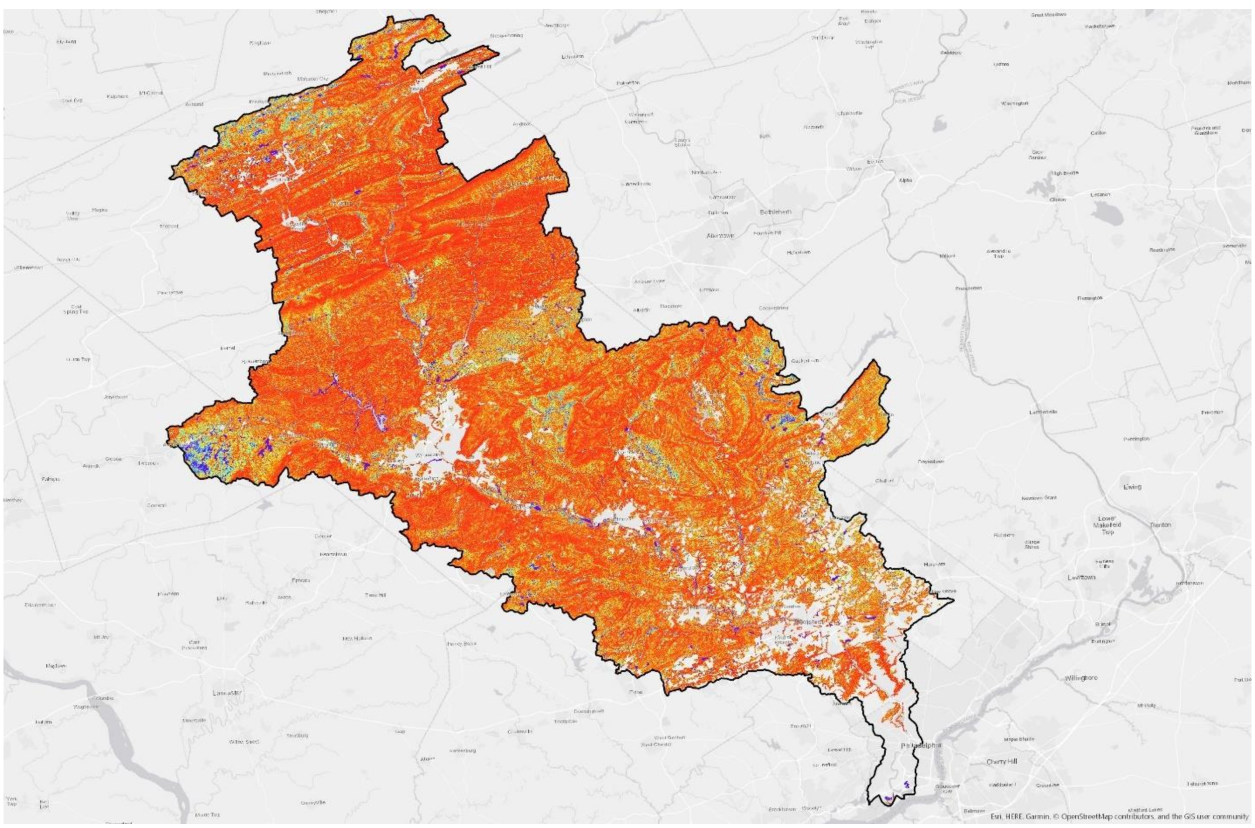


LS Factor calculated for the Schuylkill River Watershed. Dark green indicates lower slope length and steepness. Lighter greens, yellows, and reds indicate longer slope lengths and steeper slopes.

SI and STE

Once all the factors were calculated, Raster Calculator was used to combine them into SI, and from SI to STE. As with TWI, STE was calculated for every cell in Pennsylvania. The STE for a given planting site was the average of all the STE scores for each cell in that site.

Null values complicated STE calculations. Both D_{50} and K Factors were absent from some locations. This data gap was usually caused by the underlying "soil" not being soil at all but a different ground type such as Muck, Urban, or Rock. While it makes sense that, for example, solid rock would not have a median particle size, the resulting null values caused the STE Raster Calculator to produce incalculable cells in the STE raster. To address these gaps, any incalculable cells were reclassified to have an STE of 0. This conversion allowed for average STE scores to be calculated on the entire planting site, which gave a more accurate view of the site's potential effectiveness than if only cells with non-null values counted toward the average.



STE calculated for the Schuylkill River Watershed. Blue indicates high STE, while red shows low STE. Incalculable cells show as gray in this map (where the basemap shows through). These cells were reclassified to have an STE of 0.

Scoring Criterion 3: Upslope Land Cover

While STE models a planting site's potential effectiveness at reducing nonpoint source pollution, it does not estimate how much of that pollution there is to remove in the first place. There are several methods available for estimating this "need" for a planting site to act as a buffer for upslope uses. For example, the website Model My Watershed, an initiative of the Stroud Water Research Center, uses the MapShed model to estimate nitrogen, phosphorous, and sediment delivery for individual catchments or HUC-12 watersheds.[20] In another approach, TWI can be modified by applying weights during the Flow Accumulation step. These weights can reflect different amounts of pollutant contribution from different land covers such as impervious surface or farmland.

Unfortunately, none of these methods proved practical on a statewide assessment. Processing time rendered them impossible to use on the equipment available and at the scale required.

Even so, it makes sense to include some measure of need for pollution control in a streamside forest planting prioritization. The method below was developed for this analysis and satisfied that requirement. However, there are likely more accurate methods available for assessing this need. Those wishing to replicate this analysis in other locations may want to examine those methods, particularly when working at smaller scales or with better processing equipment.

For this analysis, the simple assumption was made that agricultural and urban land runoff will have more nonpoint source pollution than runoff from natural covers like forests and wetlands. Based on that assumption, the 1-m land cover data was reclassified into a binary, 0-1 raster. Low Vegetation (reflecting features like agriculture and lawns) and all impervious surface types were reclassified to 1, and all other surface types were reclassified to 0. This raster was then overlaid with the NHD-Plus catchments layer. The percent area of Low Vegetation and impervious surfaces was calculated for each catchment using Zonal Statistics. The Upslope Land Cover score for each planting site was then determined by calculating a weighted average of the percent area of Low Vegetation and impervious surfaces from each catchment that planting site was part of. The weighted average was based on the following equation:

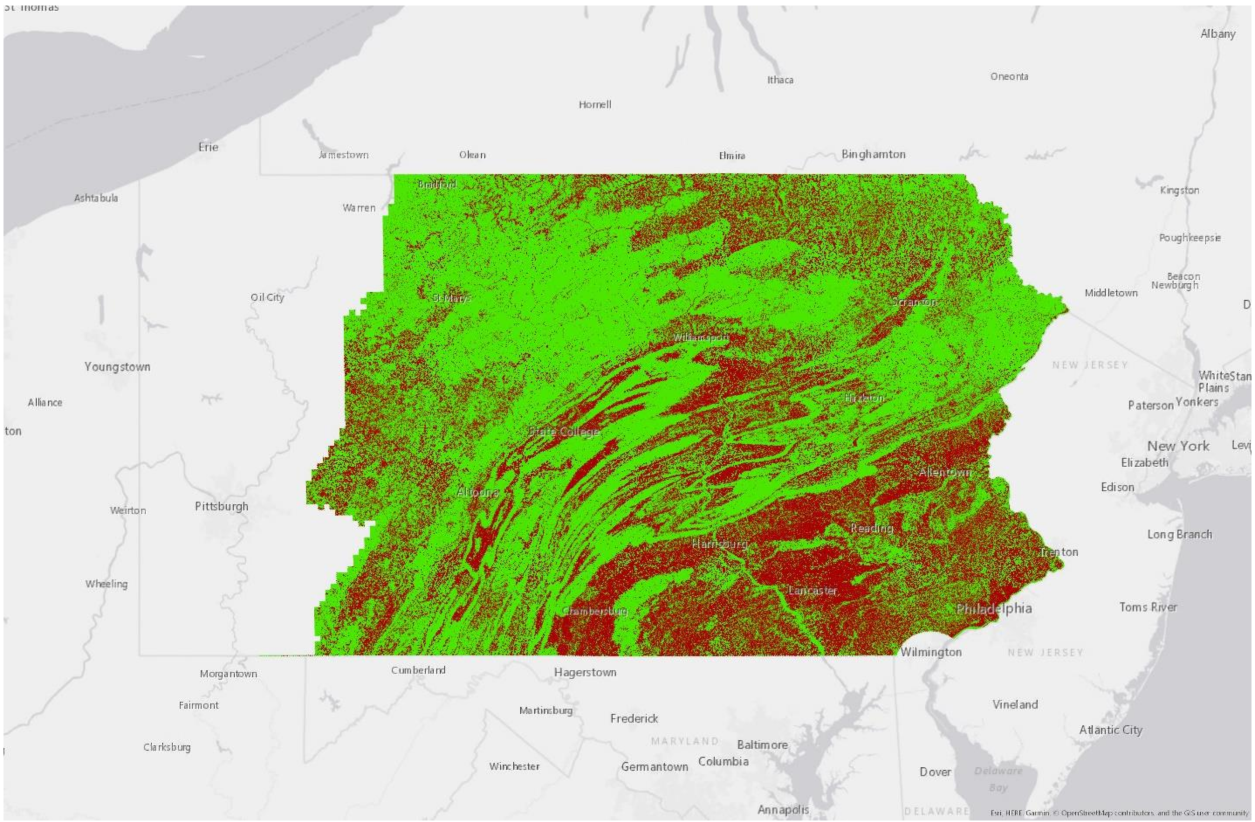
$$ULC = \frac{\sum_{n=1}^{n} P_n A_n}{\sum_{n=1}^{n} A_n}$$

Where:

ULC = Upslope Land Cover

P_n = the percentage of impervious surface and Low Vegetation area in catchment *n*

A_n = the area of catchment *n* located within the planting site



The 1-m land cover data for the Delaware and Chesapeake Bay Watershed counties reclassified so all Low Vegetation and impervious surfaces have a value of 1 (red), and other land cover types have a value of 0 (green).

Results

The analysis identified 217,649 potential streamside forest planting sites in Pennsylvania. These sites totaled 387,894 acres. The sites ranged in size from 0.25 acres (the minimum for inclusion in the analysis) to a maximum of 270 acres (a planting site on federal land around Raystown Lake). Most planting sites were small; the median site size was 0.8 acres.

Planting prioritization scores had a theoretical range of 0–3. Actual scores ranged from 0.11 to 2.69. The mean score was 1.06, while the median was slightly lower at 1.04. Most planting sites scored between 0.5 and 1.5. Only 3,440 sites (16%) scored higher than 2.

Agricultural land offered by far the most acreage for potential streamside forest plantings. More than 80% of plantable acres occurred on land identified as agricultural by the National Agricultural Statistics Service (Table 2).

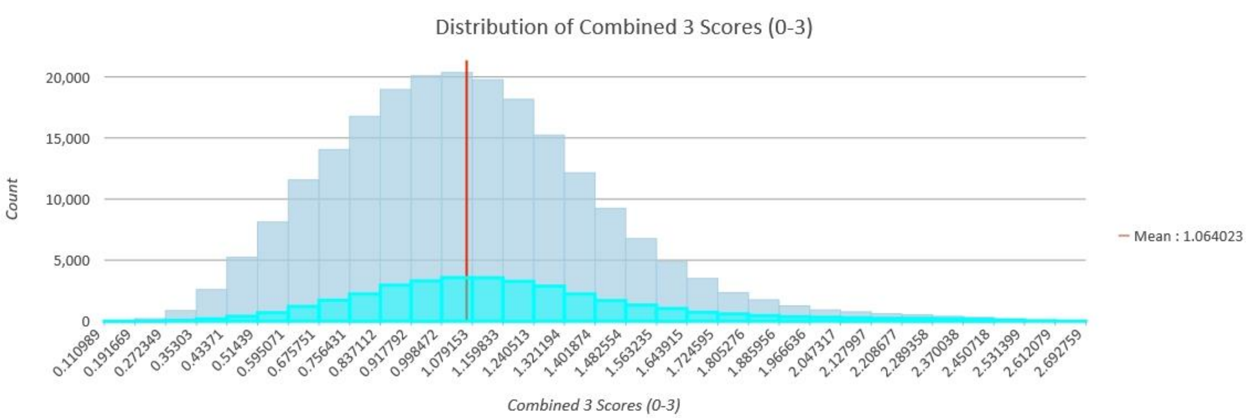
Urbanized areas also offered surprising water quality improvement opportunity. These areas of high population density are defined by the US Census Bureau and used by the US Environmental Protection Agency to stipulate which municipalities are regulated under Municipal Separate Storm Sewer System (MS4) Phase II Stormwater Permits. Together they account for just over 3 million acres in Pennsylvania, about 10% of the state's land. The analysis found substantial streamside forest planting potential within them—more than 43,000 acres, 11% of the total plantable area. Moreover, urban sites had similar score distributions to the statewide totals, suggesting that even in urban areas, streamside forests can play an important role in managing stormwater and improving water quality.

Conserved land offered relatively fewer planting opportunities. Based on the PA Conserved Land database, about 20% of Pennsylvania acres have some level of protection such as government ownership or a conservation easement. Similarly, 19% of stream miles in Pennsylvania flow through conserved land. However, conserved land provided only 13% of potential streamside forest planting acres (Table 3). This discrepancy is due to conserved land having an above-average rate of existing streamside forests.

Of the conserved land types, agricultural easements acquired through the Pennsylvania Agricultural Easement Purchase Program offer the greatest opportunity for water quality improvement. Not only did these easements have more potential streamside forest acres than any other conserved land category, they also had the highest mean score of any subgroup analyzed in the study (1.33).

Landscape Feature	Number of Sites	Plantable Acres	Mean Score
Along Impaired Stream	83,560	163,244	1.17
Along EV/HQ Stream	45,801	87,349	1.00
In Urbanized Area	35,983	43,324	1.16
On Agricultural Land	127,398	314,146	1.15
All Sites	**217,649**	**387,894**	**1.06**

Table 2. Potential riparian planting sites on landscape features of interest. Sites can be in more than one landscape feature, so individual features sum to more than the total for all sites.



Distribution of scores across all planting sites (tall bars) and those in urbanized areas (short bars).

Conserved Land Type	Number of Sites	Plantable Acres	Mean Score
Federal	1,395	5,669	0.92
All State-Owned	5,043	13,758	0.80
State Forest	*1,468*	*4,192*	*0.68*
State Park	*977*	*2,605*	*0.80*
State Game Land	*2,083*	*5,234*	*0.82*
Fish & Boat Commission	*496*	*1,690*	*1.06*
Historical & Museum Commission	*19*	*37*	*0.90*
Local Government	3,578	6,003	1.15
Land Trust Owned	498	1,113	0.89
Land Trust Easement	1,946	4,856	1.15
Agricultural Easement	4,891	17,998	1.33
Other Easement	288	921	1.24
All Conserved	**17,508**	**49,784**	**1.08**

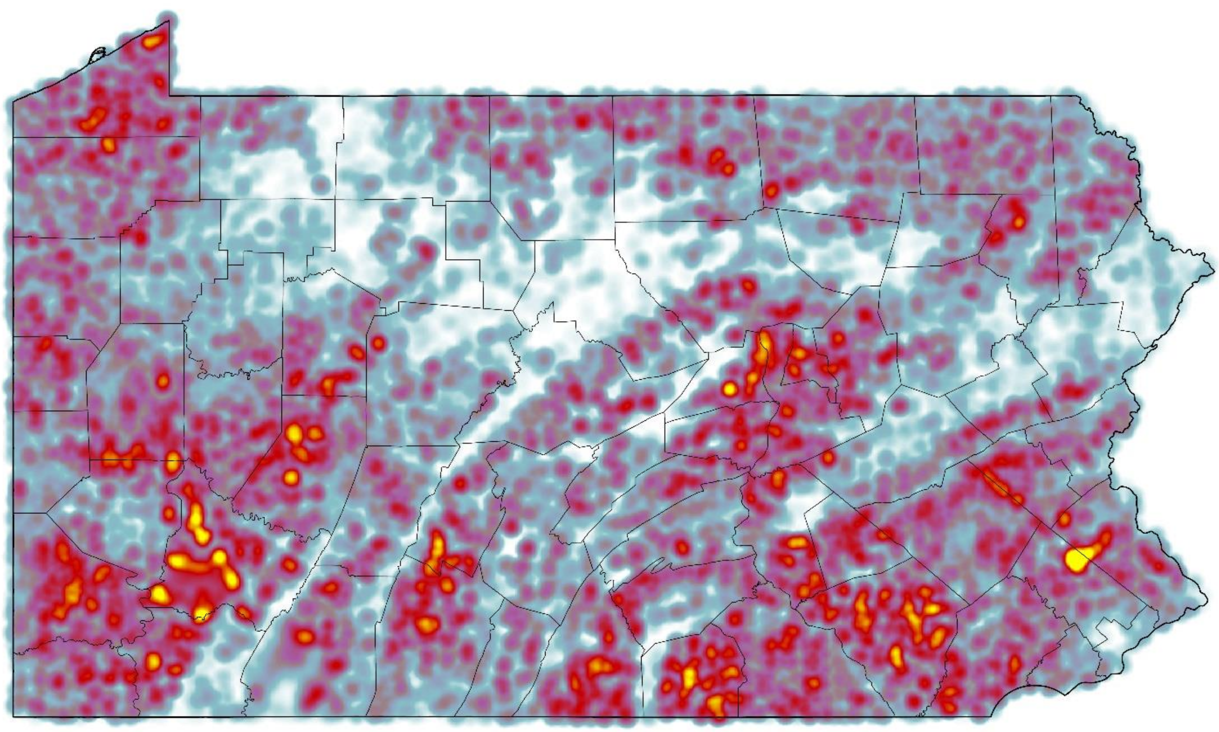
Table 3. Potential riparian planting sites on conserved land. Due to overlap of conserved land features (example: government-owned land that also has a conservation easement), individual conserved land types sum to more than the total for all conserved land.

Conclusions

Even though high-scoring locations made up only 16% of planting sites, they appeared across the state. A "hot spot" map was created to identify clusters of high-scoring sites. It can aid in identifying where to concentrate planting to maximize water quality return on investment.

As expected, Lancaster County stood out for its numerous high-priority sites. This result helped give confidence that the scoring method worked as intended. Other areas with many high-priority sites included Adams County, western Westmoreland County, the border between Bucks and Montgomery Counties, and the region around the confluence of the North and West Branches of the Susquehanna River.

Perhaps the most important conclusion of this study, however, came from the analysis of conserved acres. In its Watershed Implementation Plan, Pennsylvania set a goal of planting 95,000 acres of streamside forests statewide by 2025. Conserved land is seen as a priority for planting because the land is not at risk for development. While conserved land will be critical in meeting the 2025 goal, this analysis revealed that conserved land alone is insufficient to achieve the state's water quality objectives. Even if every streamside forest planting site on conserved land was planted, the state would only be halfway to its 2025 goal. The state will need to expand its conservation partnerships to achieve the Watershed Implementation Plan's target.



Statewide heat map of potential streamside forest planting sites. Yellow areas indicate clusters of high-scoring sites.

Endnotes

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