A GIS-BASED STUDY ON THE GEOMORPHIC RESPONSES TO NATURAL FLOODS AND LAND USE/COVER CHANGE IN THE BRODHEAD WATERSHED: 2007-2011

FINAL REPORT: MARCH 2012

Based primarily on work submitted to BWA by:
Dr. Shixiong Hu, Associate Professor of Geography,
and
Dr. Jeri Jewett Smith, Associate Professor of Biology,
both of East Stroudsburg University of Pennsylvania

Submitted by:
Dr. Patricia Kennedy, on behalf of
The Brodhead Watershed Association
Box 339, Henryville Pa 18332
570-839-1120; brodheadwatershed@gmail.com
www.brodheadwatershed.org

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ACKNOWLEDGEMENTS


Dr. Jerilyn Jewett-Smith

Although many hands collected, entered and analyzed the data that contributed directly to this project and indirectly to other research projects linked with this one, the Brodhead Watershed Association (BWA) wishes to dedicate this draft final report to Dr. Jerilyn (Jeri) Jewett-Smith, formerly an Associate Professor and Director of the East Stroudsburg University's Environmental Studies Program. Jeri, a past president of the BWA, passed away on February 27, 2011 after a courageous four-year fight against cancer.

Jeri was a principal investigator and designer for this project. As part of the groundwork for this grant as well as under other DCNR grants (BRC- RC1-11-5 and BRC-RCI-13.3-506), Jeri not only provided training for students and volunteers, she tromped with them to many sites along more than 120 linear miles of watershed creeks. Sadly, Jeri was unable to see the completion of a final report on this project.

Jeri's colleague in this project was Dr. Shixiong (Shawn) Hu. Shawn was the primary force in the project's design and implementation. An expert in hydrology and an innovator enthusiastic about rapid advances in geographic information systems technology, Shawn is an Associate Professor in East Stroudsburg University's geography department. Shawn identified, installed and taught others to use the Geographic Information System (GIS) software and hardware needed to develop models that focused field efforts at sites of likely bank failure, he also supervised students who entered, interpreted, analyzed and presented the data collected.

Between 2007 and 2009, Shawn's student teams covered more than 90 linear miles of stream to collect critical data. They spent time over several semesters from 2007 through 2011 entering and analyzing the data and making presentations of the project's findings to various publics. The BWA is grateful for the data collection, compilation, mapping and the many environmental education efforts they made -- examples of which appear in the Appendices and on BWA's website.

The BWA is very grateful to Scott Collenburg, one of Dr. Hu's former graduate students, who now works for the New Jersey Bureau of Freshwater Fisheries, Division of Fish and Wildlife. Scott was an important contributor to the final draft report on this project.

And, finally, the BWA wishes to thank Edie Stevens, a longtime advocate for bringing science-based approaches to the policy making needed to protect Pennsylvania's waters, and the BWA's current vice president for administration and finance. No one familiar with the BWA's activities in support of its mission would dispute the contribution that Edie's fantastic memory and organizational assistance have made in shepherding this project toward conclusion.

Dr. Patricia M. Kennedy,
Immediate Past President and Current Secretary of The Brodhead Watershed Association

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I. **INTRODUCTION TO PROJECT STAGES AND GOALS**

This final report describes a Pennsylvania Department of Conservation and Natural Resources grant-supported project (BRC-RCP-13-9) that studied two challenges to stream bank stability: bank erosion and its relations with invasive plant spread in the Brodhead Watershed of northeastern Pennsylvania.

In the Brodhead Watershed, headwater streams flow steeply off the Pocono Plateau into the Valley and Ridge physiographic province of Pennsylvania before joining with the main stem of Brodhead Creek. Extensive, and probably natural, bank erosions were observed in stream segments transitioning from high to low gradient. Dramatic examples of such erosion can be seen on the Swiftwater Creek and Devils Hole Creek (Limbeck, 2005).

The fast development of the local community has increased the impervious cover and the risk of flash flood. Invasive plants spread at a fast rate within the watershed due to human and natural disturbance. The shallow root systems of these invasive plants increase the potential risk of future bank failure (Shaw & Seiger, 2002). The bank erosion problem has been worsened, especially by recent three 100-year floods. Private properties, public infrastructures and wetlands face major threats due to the new bank failures created by the floods. It is critical to assess the erosion sites and prioritize those sites in need of stabilization. It is also important for future management and planning to build an inventory of current bank erosion sites and predict the potential erosion sites in response to future floods by using GIS and GPS technology.

This project implements Action Item 5 under Fish and Wildlife Habitat in the Brodhead Watershed River Conservation Plan and meets the goal of "protection and enhancement of land and water resources" in the Monroe 2020 Plan. The study also meets all three goals in the DCNR action plan: 1) Improve Stewardship and Management of State Parks and Forests, 2) Promote Statewide Land Conservation and 3) Create Outdoor Connections for Citizens and Visitor.

The project, which was designed to proceed in several stages, ran from 2006 through 2011. The project's stages were:

1. The purchase and installation of high-resolution Geographic Information Systems (GIS) software, the acquisition of Trimble GPS unit, and the loading of computers at East Stroudsburg University with physical and cultural geographic data already collected and provided by such government sources as the United States Geological Survey, the Monroe County (PA) Planning Commission (MCPC), and the Monroe County (PA) Conservation District.

2. The development by researchers at East Stroudsburg University of Pennsylvania of a *predictive* model for *potential* bank erosion sites (based on materials identified in Item #1 above).

3. The development of a compressed “bank stability” index based in large part on the well-recognized Pfankuch-Rosgen (1996, 2001) scale.

4. A series of field inventories conducted specifically for this study between 2006 and 2009. Students trained by the principal researchers examined hundreds of sites, rating them using the bank stability index (identified in Item #3 above). Site locations were documented using handheld GPS units, Trimble GIS backpacks, photographs, and other survey equipment.

5. Field data collected for this study were entered for analysis, along with the data regarding invasive plant spread in the watershed collected as part of other studies supported by grants from the DCNR, East Stroudsburg University and the BWA, as well as the data from other government sources identified in Stage I. These were transferred into the GIS system’s layers, creating maps to permit spatial analysis of various elements within the watershed. Presentations of the project’s goals, methods and findings were made in a variety of academic and public venues.

The ultimate goal of the project was to generate models that would predict potential bank failure sites, validate the model in the field, and identify the major causative factors for stream bank instability in the region under study.

A longer range goal continues to be the development and calibration of a validated and enhanced tool for watershed planning and management -- one that will not only help identify areas where banks are most destabilized, but also determine and rank the causative importance of the factors that contribute to that destabilization.

Such a tool can provide a scientifically sound basis for policy decisions regarding new development and the allocation of funds for streambank protection and restoration.

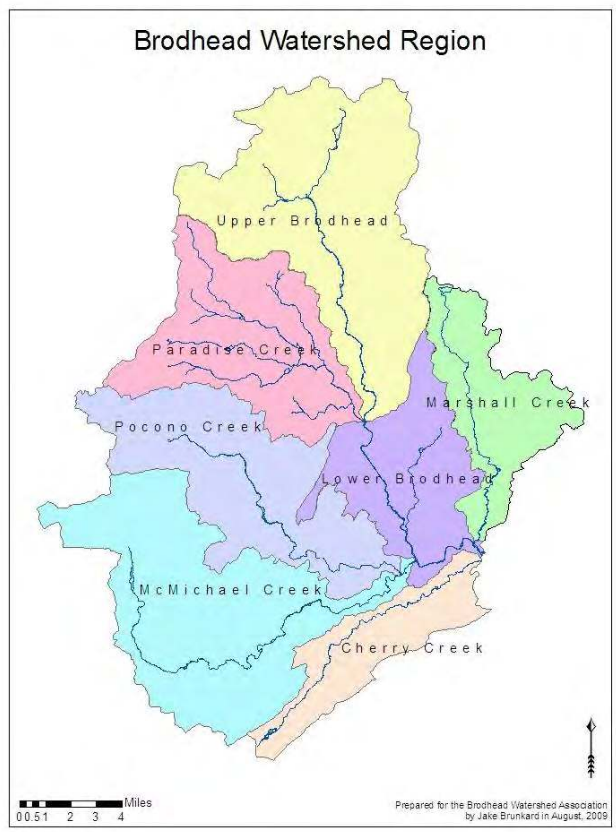

Figure 1. Map of the Brodhead Watershed Region showing major subwatersheds

With the inclusion of elements that were not specifically part of this study, data are still being analyzed.

II. BACKGROUND

The Brodhead Watershed

The study area encompasses the Brodhead Creek watershed from the creek's confluence with the Delaware River to its headwater sources in northern Monroe County and Greene Township in Pike County. The Brodhead watershed covers approximately 285 square miles, extending from Barrett Township and Mount Pocono in the north to Brodheadsville in the west to the Delaware River.

The Brodhead watershed is nearly as wide from east to west as it is long from north to south. The highest elevations (approx. 2,000 feet above mean sea level) are found in the northern and northwestern part of the watershed. Streams flow generally southeastward from the plateau to the relatively low-lying southeastern portion of the watershed. The Brodhead Creek feeds directly into the Delaware River at approximately 300 feet above sea level about two miles north of the Delaware Water Gap.

The watershed consists mostly of forested and recreation land in its headwater areas and around most of its tributaries, with urbanization increasing downstream. The Boroughs of Stroudsburg (2010 population 6674) and East Stroudsburg (2010 population 9840) are located at the base of the main stem, approximately three miles upstream of the Brodhead's confluence with the Delaware River. Through both public and private water systems, the Brodhead watershed provides potable drinking water to Monroe County. The Brodhead Creek Regional Water Authority alone provides more than 22,000 customers in five municipalities with clean public water.

Many small tributaries throughout the watershed contribute to this drainage area. All runoff in this watershed eventually flows into Brodhead Creek or the adjoining Cherry Creek, and then into the Delaware River near Delaware Water Gap, Pennsylvania. There are also other named sub-watersheds including: Paradise Creek, McMichael Creek, Pocono Creek, and Marshall's Creek. In addition, there are many smaller tributaries -- some named e.g., Swiftwater Creek, Indian Run, Cranberry Creek, Yankee Run, Devil's Hole, Forest Hills Run, Buck Hill, Sambo Creek -- as well as others that are not.

Figure 2. Typical traffic congestion on Monroe County roadways over and near creeks, 2011.

Fast population increase and suburbanization

Monroe County's 605 square miles are largely rural with rolling hills, forests and farmland dominating the landscape. It has 16 townships and 4 incorporated boroughs. In the period immediately before and during of the study reported here, Monroe county's population grew from 95709 in 1990 to over 169842 in 2010 -- an increase of nearly 56% (U.S. Census). Between 2000 and 2005 alone, the population in the Monroe County increased from 122,000 to 164,000.

The Monroe County planning department attributes this growth to "Monroe County's beautiful setting in the Pocono Mountains, bounded by the Delaware and Lehigh Rivers, and its proximity

to New York (75 miles) and Philadelphia (90 miles)," observing that "the resulting suburbanization of the landscape has brought not only the loss of open space, important natural areas, and scenic vistas, but also the rising costs of infrastructure development (such as roads and water systems)."
http://epa.gov/greenkit/monroe.htm

Much of that growth has occurred with little consideration of its impact on watershed processes. As rooftops, parking lots and streets spread across the landscape, replacing forests and fields, streams suffered. The land use/land cover changes greatly altered the local hydrological processes in the Brodhead Creek, as well as geomorphic and ecological processes.

Rain and snowmelt run rapidly off these man-made surfaces instead of soaking into the ground. This stormwater runoff carries pollutants into the streams, accelerates stream bank erosion, and raises stream temperatures.

Major floods in the period immediately preceding the study
Regional concern for riverside ecosystems in the watershed was intensified after the region experienced three 100-year floods[1] within a twenty four-month period between 2004 and 2006.

The first flood was caused by heavy rainfall (6 inches) from Hurricane Ivan on September 17-18, 2004.

The second from a combination of snowmelt (2-3 inches) and storm rainfall (5 inches) on April 6-8, 2005. The third was caused by a long duration storm on June 27-29, 2006.

Figure 3. National Park Service Building, Delaware River Flooding, 2006.

These three major flood events ripped through the Brodhead Watershed bringing great changes in the river morphology and creating many new bank erosion sites. Private property, public infrastructure and wetlands all faced major threats from the bank failures. (See, e.g., Appendix A, National Flood Insurance Claims in the Delaware River basin (by municipality) September 2004 Event - Ivan).
Although there is little pre-study baseline data, anecdotal and sporadic photographic evidence suggest that these floods may have also carried invasive vegetation to areas where few or no invasives were previously found.

[1] We use the term "100-year flood" to refer to events where water level has a one-percent chance of being equaled or exceeded each year, an event with an average recurrence interval of 100 years (Holmes & Dinocola, 2010).

Flooding continues to be a challenge, exacerbating streambank instability in the region. Annual precipitation for 2011 has set records.

Figure 4. The pavilion at Shawnee Inn during Delaware River flood conditions, Oct. 2011.

By October, more than 72 inches of precipitation had fallen, exceeding the previous record set in 1996 of just over 69 inches.

The area was hit hard by Hurricane Irene in August 2011, followed by heavy rains in September and October 2011.

III. Previous Studies: Factors known to affect stream bank stability

As streams and rivers flow they cut into the earth and form channel banks. These banks confine streamflow within their boundaries for all but the larger streamflow events in a year. The idea of stream bank stability may seem theoretical as both streams and their banks are constantly adjusting, but streams should assume some forms and functions of their natural settings and habitat (Brooks et al. 2003). Stream classification can prove useful because it provides a systematic approach for categorizing streams based on an established reference so they can be evaluated over time and with one another. Streams that deviate from their expected conditions due, for example, to human intervention, may yield obvious indicators that can be used to evaluate stream channel stability.

In addition to those factors of the Pfankuch-Rosgen (1996, 2001) bank stability assessment tool (described in detail in section VI below), the following indicators identified from previous research were considered in this study as measures of streambank stability.

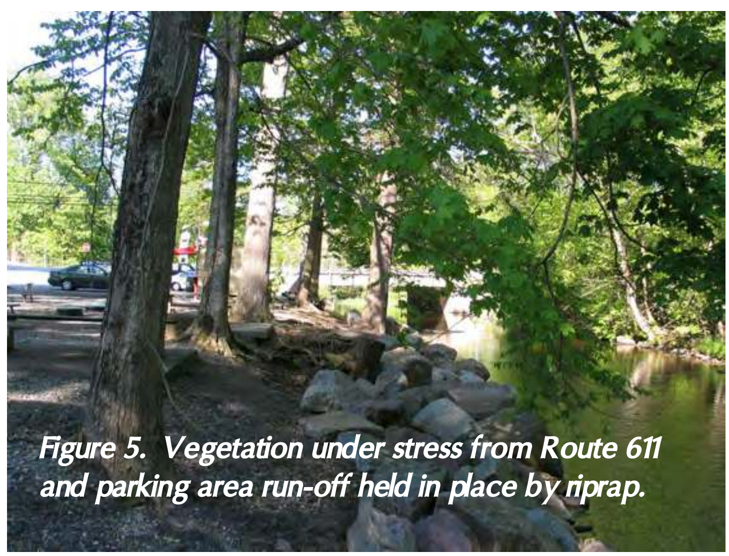

Figure 5. Vegetation under stress from Route 611 and parking area run-off held in place by riprap.

<u>Bank material and plants</u>

Riparian bank materials and vegetation -- depending on various factors including root strength and depth -- can help armor and stabilize a channel or the reverse.

Generally speaking, though, the removal of vegetation instigates channel entrenchment as the channel deepens and banks steepen. Slope failures begin to occur and channel banks start to fail. Soil erodes from the streambank and fills the channel.

Bank erosion and stream shape in local creeks are closely related to bank material. The basic material along streambanks in the Brodhead region is till left by glacial retreat during last ice age. The ratio between silt and sand can control width/depth ratio and sinuosity, and further affect the stability of stream bank.

The size of the sediment in transport is assumed to be reflected in the size of the sediment constituting the channel bed and banks. Studies have shown that there is a strong negative relation between width/depth ratio and the percent of silt and clay in the channel bed and banks. It also showed that there is a strong positive relation between the sinuosity ratio and the percent of silt and clay in the channel bed and banks.[2]

This study chose the percent of silt and clay in the stream bank material as one measure of bank materials. Details of how this analysis was conducted are described in a later section of this report.

Figure 6. Multiflora Rose at streamside on the McMichael Creek

Invasive plants

Invasive plant species have begun to displace many of the native species found in the Brodhead watershed. The problems associated with invasive plant species begin when replacement of native species results in inhibiting the channel's ability to shift morphology. Another problem occurs when invasive species are less resistant to flooding and results in destabilization of the channel banks. Causes of erosion can come from invasive plant species as well. For instance, Multiflora Rose and Autumn Olive can shade out desirable bank stabilizing native ground cover leaving the streambanks vulnerable to erosion.

The model contemplated for this study derived its data on the identity, location and density of invasive plant species from data collected primarily under DCNR grant (BRC-RCI-11-5).

Wetness Index

The wetness index is calculated by combining local upslope contributing area and

2 Schumm (1977), for example, found the relation could be expressed as: F =255M^1.08.

slope. The wetness index can be used to understand the topographic control on hydrologic processes. Streamflow, runoff, erosion, and a number of other hydrological characters and their reactions can be inferred from calculating the wetness index. Theoretically, a high wetness index represents wet soil that is easy to be fluidized during the flood or storm.

In this study, wetness index was calculated with TauDEM. [3]The wetness index is a major controlling factor for bank stability and was considered as a substitute of soil moisture in the bank material.

River/Stream bed slope

One factor known to impact stream flow is the slope of the river or stream bed. This bed slope has a strong physical relationship with mean flow velocity and deposit characteristics such as thickness and composition (Paricio et. al., 2010).

Figure 7. Erosion of steeply sloped bank near Route 611, Tannersville, Pa.

River/stream bed slope results in straightening a stream channel, impacting river bottom scouring and bank erosion, and increasing the process of erosion resulting in destabilized streambanks.

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[3] Wetness index, also called topographic index, is expressed as ln (a/tanB), where, a – contributing upslope area/per unit contour line, and B – local slope angle. In general, high ln(a/tanB) means more wetness and the values 9 – 16 were assigned. The low ln(a/tanB) means less wetness or drier areas, and the values 2 – 5 were assigned.

In this study, researchers chose to use the river/stream bed slope to represent the flow velocity. The streambed slope used for this study was derived from Digital Elevation Models (DEM) using Landserf software described below.

Sinuosity

A sinuous stream channel is one with many curves, bends, or turns. A more stable stream is more sinuous because it carries stream flow on a longer, slower path as it travels. Around bends water deposits sediment it carries creating habitat for native plants to grow and stabilize the channel banks. Large woody debris increases sinuosity in streams, helps stabilize banks, and create side channels. A sinuous stream channel supports a wider variety of habitat types and creates a more stable environment.

Figure 8. Erosion on steep bank downstream from bridge and meander on McMichael Creek, Stroud Township, Pa.

The sinuosity is the ratio of real stream length over the straight distance of two locations between two locations. A meander in general is a bend in a sinuous watercourse or river. A meander is formed when the moving water in a stream erodes the outer banks and widens its valley. A stream of any volume may assume a meandering course, alternately eroding sediments from the outside of a bend and depositing them on the inside. The result is a snaking pattern as the stream meanders back and forth across its down-valley axis. Previous research indicated that there is a strong positive relation between the sinuosity ratio and the percent of silt and clay in the channel bed and banks.

Sinousity was considered a causative factor for bank stability. Student teams collected the data of sinuosity for this study in the field.

Human disturbance

Of any land use conversion, urbanization and suburbanization can bring about some of the most dramatic changes in streamflow. Increasing the impervious surfaces in a watershed influences several factors, including the extent of soil erosion and sediment delivery. This greatly increases the risk of channel instability. However, each channel's morphology depends on its resilience to new flow regimes, such as, riparian conditions, erodibility of stream beds and banks, mode of sediment transport, and status of stream conditions to geomorphic thresholds (Brooks et. al. 2003). Bledsoe and Watson (2001) found that the hydrologic effects of urbanization impact stream channel stability as imperviousness increases. This impact is due to the increase in annual peak flows from impervious surface runoff.

Figure 9. Debris piling up under bridge over Pocono Creek after severe rain event, 2010

Although the geology of a region determines the bank material and plants found there, urbanization impacts the riparian buffer close to any stream and can directly influence soil erosion and sediment delivery downstream.

Intensive agricultural development, stream channelization, and other land use changes have resulted in stream channel instability. Channel degradation in the local watershed has resulted in $1.1 billion of damage to bridges, pipelines, and adjacent lands since the early 1900s.

Human disturbance in this study was measured by the percentage change of imperviousness above the assessment site.

Figure 10. Impervious surface beside pond developed from Pocono Creek, Tannersvile, Pa.

IV. Stage 1: Purchase and installation of GIS software

As an early element of this study, the researchers not only identified factors known (or hypothesized) to impact bank stability, but also identified sources for already existing data either measured the identified factors or could serve as a proxy for those measurements.

A geodatabase design was created with the goal of adding information -- as it was acquired from either existing databases or from the field -- to be held in a system, accessible to multiple viewers and large enough to store the significant amounts of data that were developed.

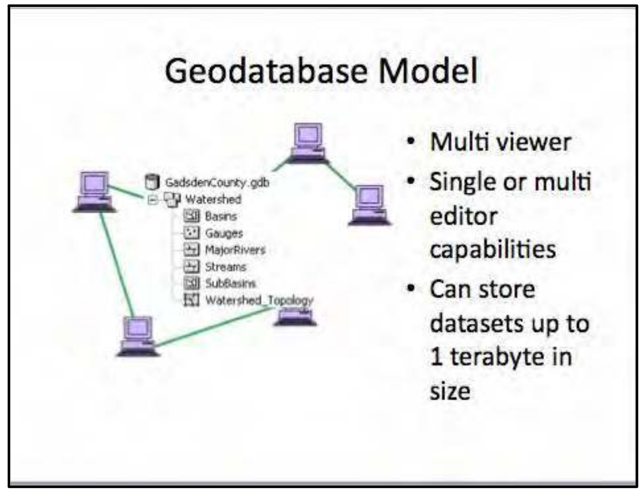
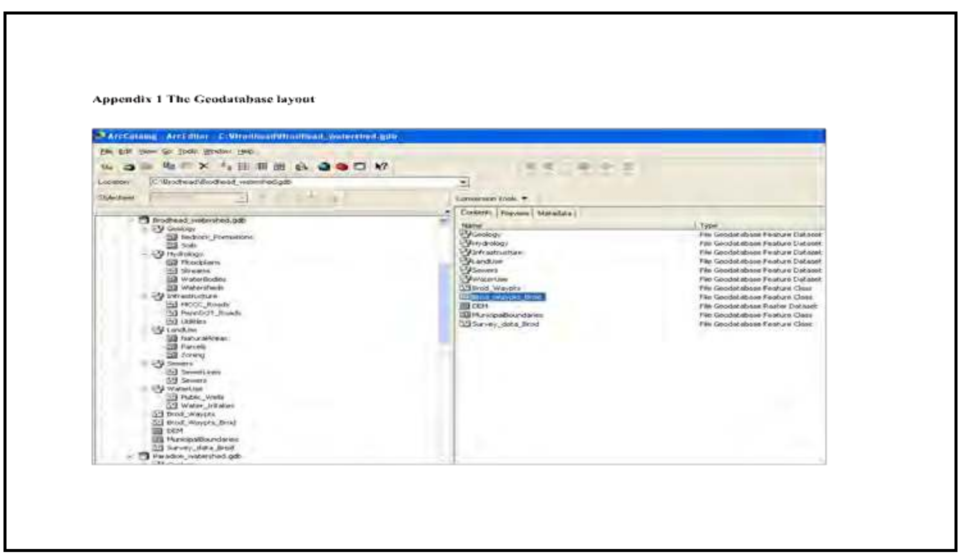


Figure 11. An element of a student presentation reporting on this project, illustrates the multiuser concept.

The initial geodatabase, shown on ***Figure 12 (below)*** regrettably in small font format, includes such factors as:

- *Geology* (Bedrock formations, soils),
- *Hydrology* (Floodplains, streams, water bodies, watersheds),
- *Infrastructure* (MCCC roads, PennDot Roads, Utilities),
- *Land Use* (Natural Areas, Parcels, Zoning),
- *Sewers* (Sewer lines, sewers),
- *Water Use* (Public wells, water intakes),
- *Brodhead waypoints*,
- *DEM*,
- *Municipal boundaries,*
- *Survey data* (BRDHhead, Paradise, Marshalls Creek).



To assist in the development of this geodatabase, the researchers obtained and installed the following software and data:

A. TauDEM

TauDEM is a software suite of Digital Elevation Model (DEM) tools for the extraction and analysis of hydrologic information from topography called TauDEM (Terrain Analysis Using Digital Elevation Models).[4] TauDEM provides the following capabilities:

- Development of hydrologically correct (pit removed) DEMs using the flooding approach;
- Calculation of the slope/area ratio that is the basis for the topographic wetness index.

More specifically, researchers used TauDEM to calculate the wetness index. Wetness index, as previously discussed, is measure of water content in streambank soil materials.

B. SINMAP

SINMAP (Stability Index MAPping) is an Arc GIS extension that implements the computation and mapping of a slope stability index based upon geographic information, primarily digital elevation data. SINMAP has its theoretical basis in the infinite plane slope stability model with wetness (pore pressures) obtained from a topographically based steady state model of hydrology.

Digital elevation model (DEM) methods are used to obtain the necessary input information (slope and specific catchment area). Parameters are allowed to be uncertain following uniform distributions between specified limits. These may be adjusted (and calibrated) for geographic "calibration regions" based upon soil, vegetation or geologic data.

More specifically, SINMAP was used in this study to extract the valley slope index alone the creeks in local watershed.

C. LandSerf

LandSerf is a freely available Geographical Information System (GIS) software used for the visualization and analysis of surfaces. Applications include visualization of landscapes; geomorphological analysis; gaming development; GIS file conversion; map output; archaeological mapping and analysis; surface modeling and many others. LandSerf runs on any platform that supports the Java Runtime Environment (e.g., Windows, MacOSX, Unix, Linux etc.)

More specifically, project researchers applied Landserf in this study to generate the bed slope for the Digital elevation model (DEM), which was used as a substitute or proxy for the measurement of flow velocity.

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[4] This software was developed by David Tarboton, a professor at the Utah Water Research Laboratory and Department of Civil and Environmental Engineering, Utah State University, the Director of Utah State University Water Initiative, and an Adjunct Professor in Aquatic Watershed and Earth Resources and Geology departments.

D. Data collected from and/or produced by government sources
The GIS data layers of geology, hydrology, land use, road, flood plain and DEM were collected through the USGS (United States Geological Survey), MCPC (Monroe County Planning Commission), the MCCD (Monroe County Conservation District) and DRBC (Delaware River Basin Commission).

The Digital Elevation Model (DEM) used in this study, which permits 10 feet resolution, was downloaded from the USGS website .

V. Stage 2: On-going development of GIS-based statistical models for projecting bank failure sites

The software and data described above were used to develop models that could be used to predict the likelihood of bank failure for creeks and streams in the watershed. The maps that follow provide an example of the process.

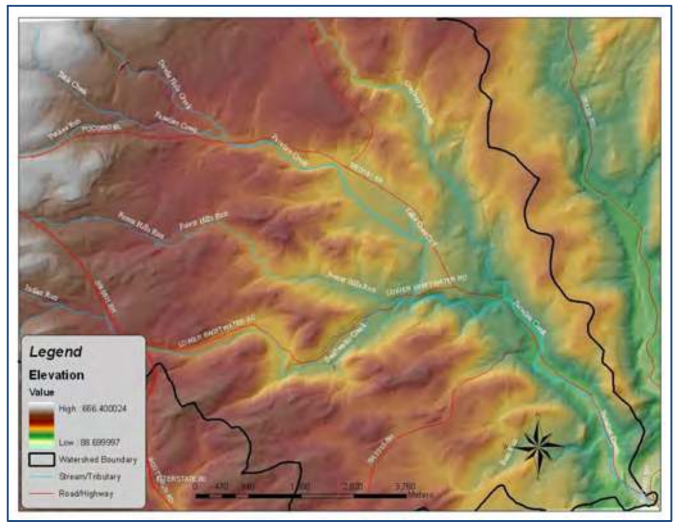


Figure 13 (right) shows the relative elevations for the Paradise Creek subwatershed.

The legend colors indicate the elevation in meters in relation to the named creek beds shown, with white indicating the highest areas and green the lowest.

Figure 14 (below) shows the stream channel slope generated by Landserf.

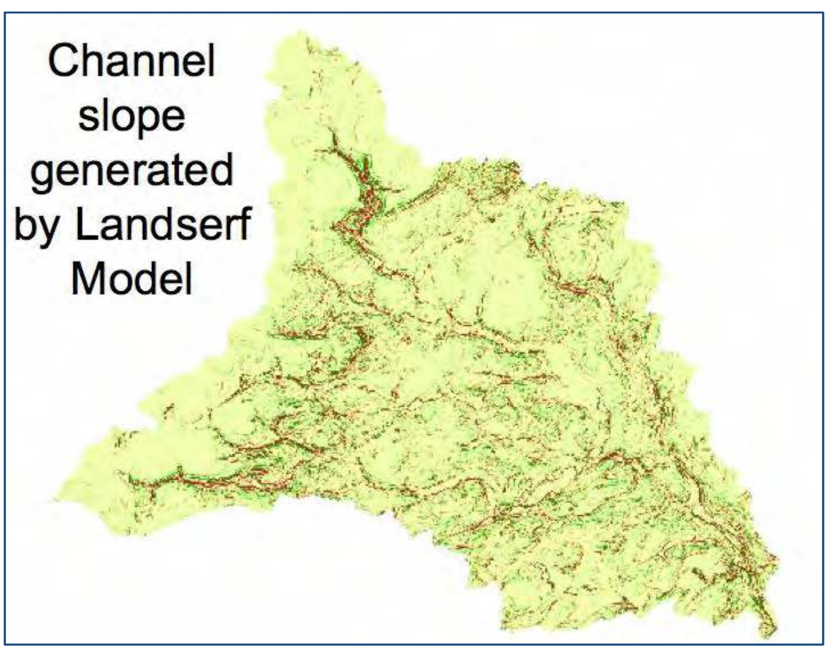


Figure 15 (below right) shows the relative topographical slope (ranging from 0 to 53%) for the Paradise Creek subwatershed.

The legend colors indicate the degree of slope in relation to the named creek beds shown, with red indicating the steepest areas and dark green the least steep.

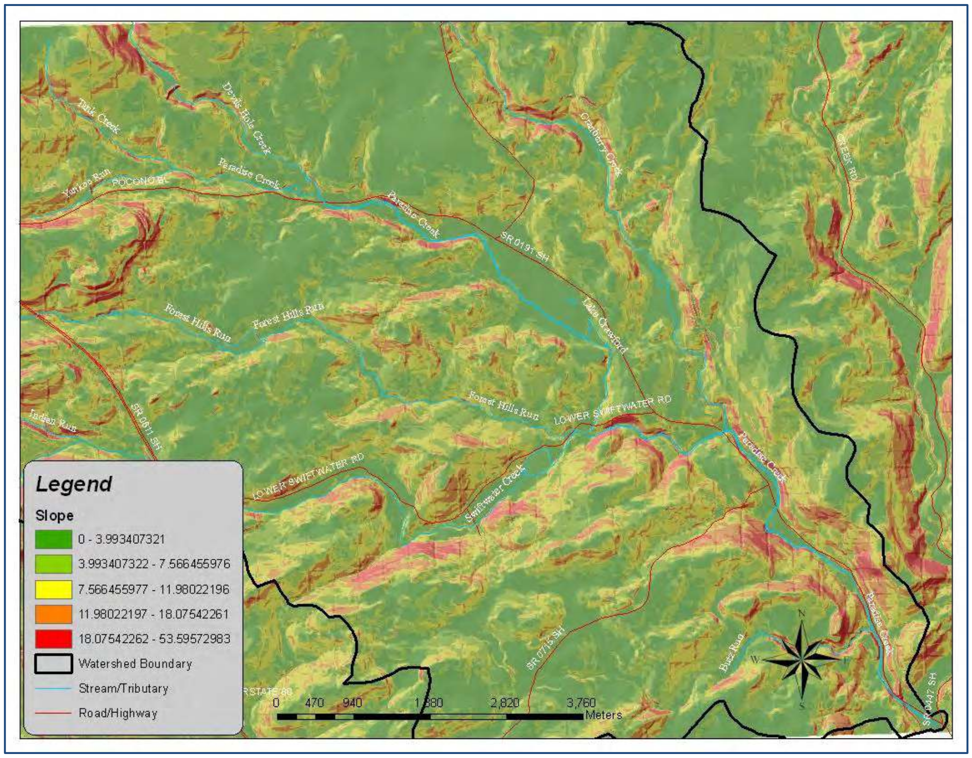


Figure 16 (below) shows the introduction of two additional variable layers to the mapping process: wetness index and stability index.

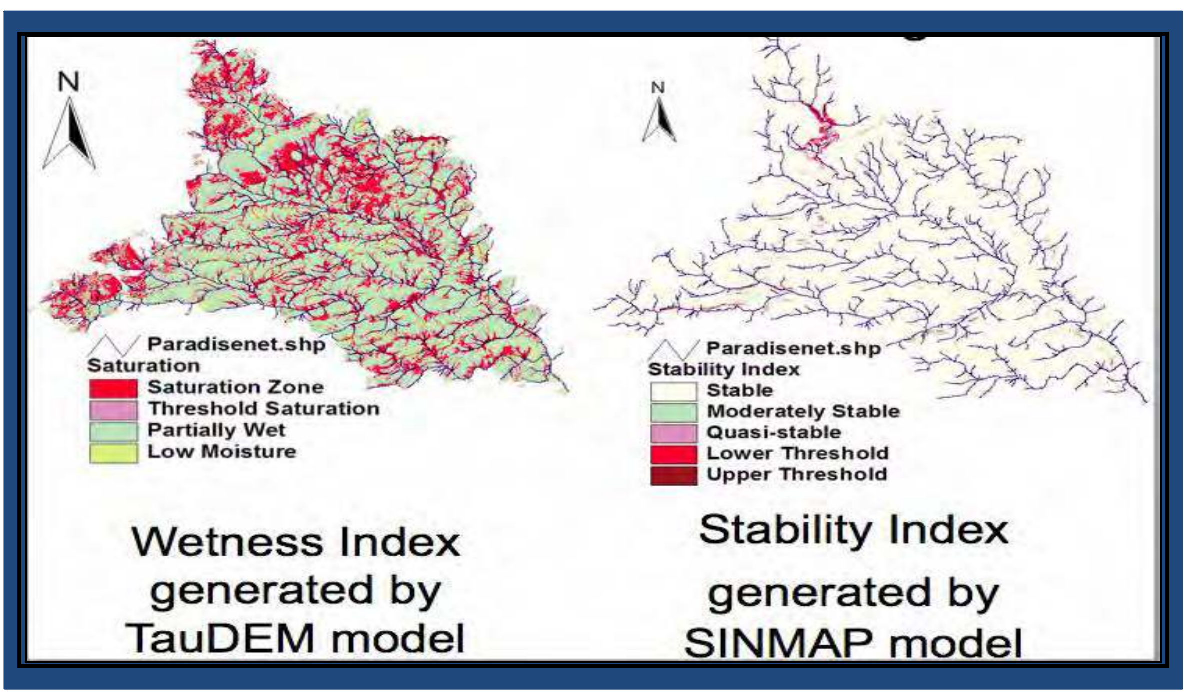
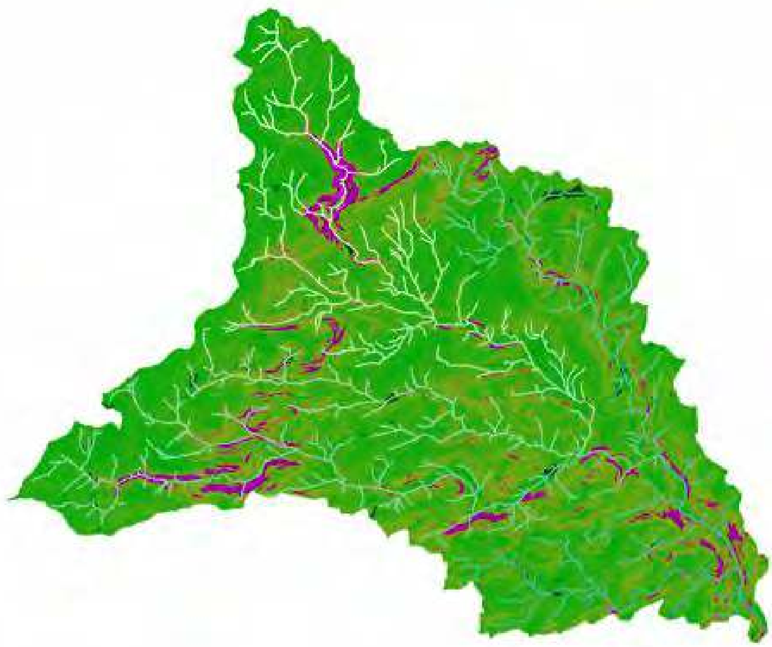


Figure 17 (below) shows map information from various layers (channel slope, wetness index and stability index) integrated to create a model that "predicts" the most likely location for bank failure based on the factors included.



Channel slope, wetness index and stability index combined to predict possible bank failure sites (shown in purple)

Appendix B of this report describes preliminary efforts at producing both linear and non-linear statistical models for predicting bank instability (the dependent variable) based on a multiple regression using data collected for six independent variables (Spreadsheets, Appendix C and D):

- stream sinuosity,
- terrain stability,
- topographic index,
- stream bed slope,
- terrain saturation index, and
- soil composition.

It is anticipated that the models will be refined with the inclusion of additional data in the future.

VI. Stage 3: Field Tools for Assessing Streambank Stability

Pfankuch-Rosgen Bank Stability Assessment Methods.
To analyze the state of stream bank stability on sites throughout the Brodhead Watershed the Pfankuch-Rosgen method was used. The Pfankuch-Rosgen method is a stream bank rating procedure that evaluates the upper bank, lower bank, and the streambed for high amounts of erosion or deposition (Rosgen, 2001).

Upper →

Lower→

Streambe d →

Figure 18: Stream in Brodhead watershed overlaid to display the separate sections analyzed using the Pfankuch-Rosgen method

For each part of the stream channel, certain parameters were applied and rated. The cumulative score from the ratings were then used to categorize the stability of the bank:

Upper Bank *ratings were based on:*

1. *Landform slope – increased gradient increases stream flow and increases the chance of erosion (>60% grade is considered poor for stream bank stability)*
2. *Mass wasting – slumping of banks or falling debris is a sign of instability*
3. *Debris Jam Potential – a stream that is able to move organic material is considered stable*
4. *Vegetative Protection – densely vegetated channels were rated as stable*

Lower Bank *ratings were based on:*

1. *Channel capacity – overbank flows were indicative of instability*
2. *Bank rock content – if large substrate along lower bank was present then stream bank is considered unstable*
3. *Flow obstructions – cross-cutting of channel, new obstructions, and sufficient sediment deposition that causes channel migration are signs of instability*
4. *Degree of bank cutting –eroded, high raw banks indicate instability*
5. *Deposition – enlarged point bars and mid-channel bars composed of mainly fine sediments is a sign of instability*

Streambed ratings *were based on:*

1. *Angularity of stream bottom rocks – sharp edges and corners indicate stability*
2. *Brightness of stream bottom rocks – stable channel has > 35% dull or stained rocks*
3. *Consolidation of bottom deposits – tightly packed rocks indicated stable banks*
4. *Distribution of bottom particle size – greater than 80% of stream bottom particles should be stable*
5. *Scouring and deposition – stable if <5% affected by scour and deposition*
6. *Aquatic vegetation – greater amounts of algae, moss, and detritus indicates stable banks*

To varying degrees, depending on the students assigned to the project, these fifteen parameters were used with variable scoring with different weights to determine a numeric score, the higher the rating, the higher the risk of instability. Rosgen's modification to Pfankuch's scoring converts these numeric scores to "excellent, good, fair, or poor" according to stream type.

VII. Stage 4: Field Data Collection

<u>Sites studied</u>

Intermittently between the summer of 2006 and through the fall of 2007, then again in 2009, ESU students were tasked with assessing the upper banks, lower banks, and streambed every 250 meters for more than 90 linear miles. Sites that were given initial attention were those determined by the GIS-based predictive model to have high potential for bank failure.

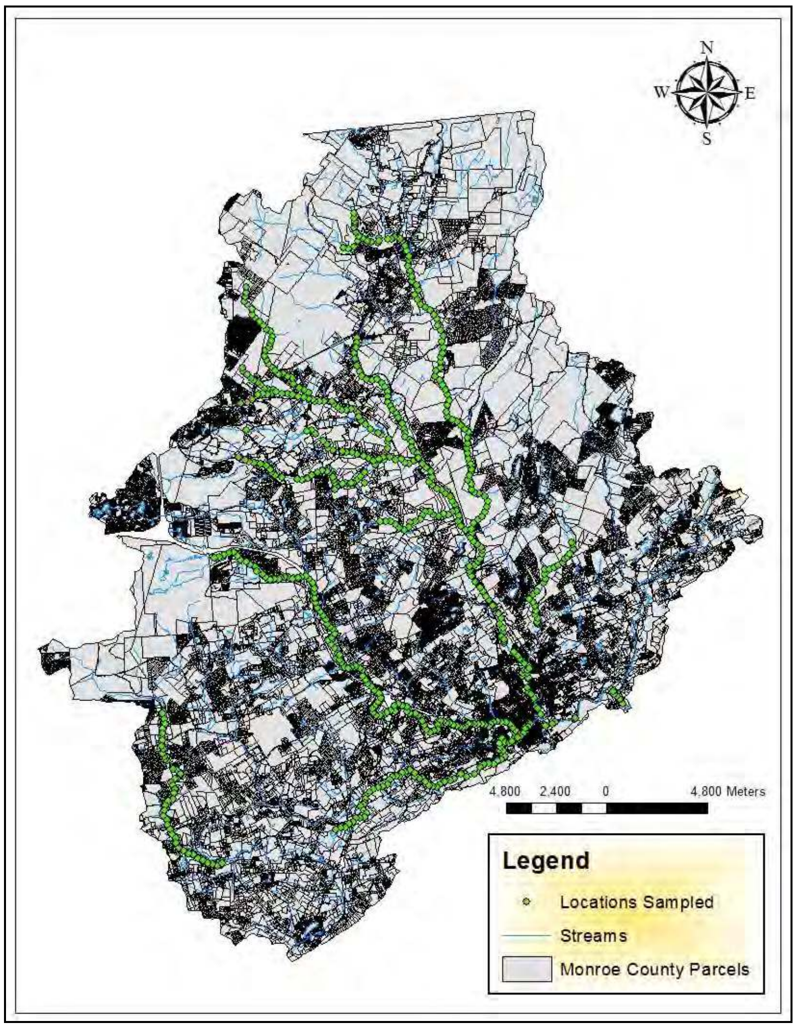
Waypoints at each site inspected were recorded with a Trimble GPS unit to create spatial data to be integrated into the geodatabase. ***(Figure 19 (right).***

In all, 812 sites (treated as units of analysis) were identified by longitude and latitude (waypoints) for possible inspection. Of these, 434 were assessed for bank stability. However, full data sets using all fifteen elements of the modified Pfankuch-Rosgen method are not available for all sites. Appendices C and D to this report show the data for each site for the variables collected.

Invasive plant density data are available for 485 sites. The waypoint locations for both bank stability and invasive species inventory data were the same in Paradise Creek and upper Brodhead Creek. Waypoint locations in other creeks differed slightly.

Examples of the bank stability and invasive plant data collection sheets appear in the Appendices E and F.

Bank stability data were collected by accessing more than 620 individual parcels, shown on ***Figure 20 below***). In some cases, sites where the predictive model suggested high likelihood of bank failure could not be inspected because the property owner would not grant access.



The bank stability data were collected as part of this grant project. Although some invasive plant data were collected during this project, the bulk of these data were

collected under other DCNR grants as well as grants from East Stroudsburg University of Pennsylvania.
Students conducted field observations to collect data from the following creeks on the dates shown on Table 1 below.

Table 1. Bank Stability and Invasive Plant field sites by creek name, number of sites per creek and dates collection occurred.

Creek	Bank Stability Number of Sites	Bank Stability Dates	Invasive plants Number of Sites	Invasive plants Dates
Brodhead				
• lower[5]	0	N/A	61	2006: 8/9& 10
• upper	55	2007: 6/18-6/26	52	2007: 6/18-26
Griscom	0	N/A	9	TBD[6]
McMichael	33	2007: 6/29-7/25	31	2007: 6/13-20
Paradise				
• Lower	37	2006: 7/26-8/17	37	TBD
• Upper	19	2006: 7/26-8/17	18	TBD
• Tank	18	2006: 7/26-8/17	17	TBD
• Cranberry	30	5/19-6/16/07	30	2007: 5/15-6/30
• Swiftwater	40	5/18/06-7/27-06	36	TBD
• Forest Hills Run	7	2006: 5/05-6/17	24	TBD
• Devil's Hole	31	2006: 6/18-7/27	41	TBD
Pocono	85	2007: 9/8-10/27	116	2007: 5/4-6/7
Total	**355[7]**		**485**	

Training:
Threats to the reliability of the data gathering were reduced by extensive classroom and field training. Only data collected by students or BWA volunteers trained for performing the bank stability and invasive plant assessments were included in the study. Photographs were taken of sites visited and remain a part of the study file (see, e.g., ***Figure 21 (left)*** Dr.Hu in the field with student Brian Peeters).

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[5] *During the intial phases of the study, bank stability inspections were not performed in the lower Brodhead because:*
1) Most banks are "armored" as part the flood control design created by the Army Corps of Engineers, and 2) the relative inaccessibility of the stone canyon areas below Stroudsburg.
However, in the fall of 2011, a student did inspect four sites in the Lower Brodhead and reported his findings (Weinman, 2011). These data have not yet been added to the database, but the report can be provided upon request.
[6] *TBD = To Be Determined. Data information to be obtained from report on related grant.*
[7] *Full data sets are not currently available for all sites.*

Bank stability assessment

For bank stability analysis training, students were first introduced to the Pfankuch-Rosgen method, described above, in the classroom. Photographs were used to explain the differences in ratings. Students were then tested for consistency and accuracy in the field by one of the principal investigators for this study -- Dr. Shixiong Hu, Associate Professor of Geography at East Stroudsburg University, a watershed specialist with extensive experience in bank stability analyses. Students trained by Dr. Hu then trained other students.

Soil data collection

Soil texture data were collected in the field and used to estimate the ratio of sand over silt and clay in bank material. The soil samples were collected every 750 meters along the streambanks.

Three classes of soils were identified and classified as: Sand 2.0-0.05mm; Silt: 0.05-0.002mm; Clay: < 0.002mm.

In the laboratory, the texture of the soil was found using Soil Flocculating Reagent and Texture Dispersing Reagent.

- 15mL of the soil sample was added to the Soil Separation Tube "A."
- 1mL of Texture Dispersing Reagent was added followed by a dilution of tap water to the 45mL line.
- The sample was capped and mixed by shaking for two minutes.
- After two minutes tube "A" was placed on the rack undisturbed for 30 seconds.
- After 30 seconds, the solution was poured into Soil Separation Tube "B" and placed on the rack for 30 minutes undisturbed.
- After 30 minutes the solution within tube "B" was poured into tube "C."
- 1ML of Soil Flocculation was added to solution in tube "C" and placed on the rack for 24 hours.
- After 24 hours remaining soil content within the tube was measured, divided by 15, and multiplied by 100. This recorded the percentage of sand in tube silt in tube "B", and clay in tube "C."

From these procedures, the percentage of sand, silt and clay was obtained.

Invasive plant identification and density training

As previously indicated, the invasive plant identification and density training were conducted as part of a separate study. Details of the invasive plant density assessment training and reports of the results of that study can be found on the BWA website.[8] However, training for the field inventories was similar in many respects to that use for bank stability inspections.

Students and other volunteers were initially shown photographs and samples of the invasive plants most likely to be found in the region, then tested for consistency and

[8] *http://www.brodheadwatershed.org/invasivespeciesmanagement.html*

accuracy of plant recognition and measuring the extent of an invasion in the field by one of the principal investigators for this study -- Dr. Jeri Jewett-Smith, Associate Professor of Biology at East Stroudsburg University, a botany specialist with extensive experience in invasive plant identification.

Students were trained to recognize and measure the density of the following plants: Phragmites (Common Reed), Garlic Mustard, Japanese Barberry, Japanese Knotweed, Stiltgrass, Multiflora Rose, Morrows Honeysuckle, Loosestrife, Knapweed, Russian Olive, Tree of Heaven, Crown Vetch, Oriental Bittersweet, Norway Maple, English Ivy.

Data regarding the invasive plants were collected with the support of another DCNR grant. Both left and right banks were observed with canopy cover and soil moisture being noted.

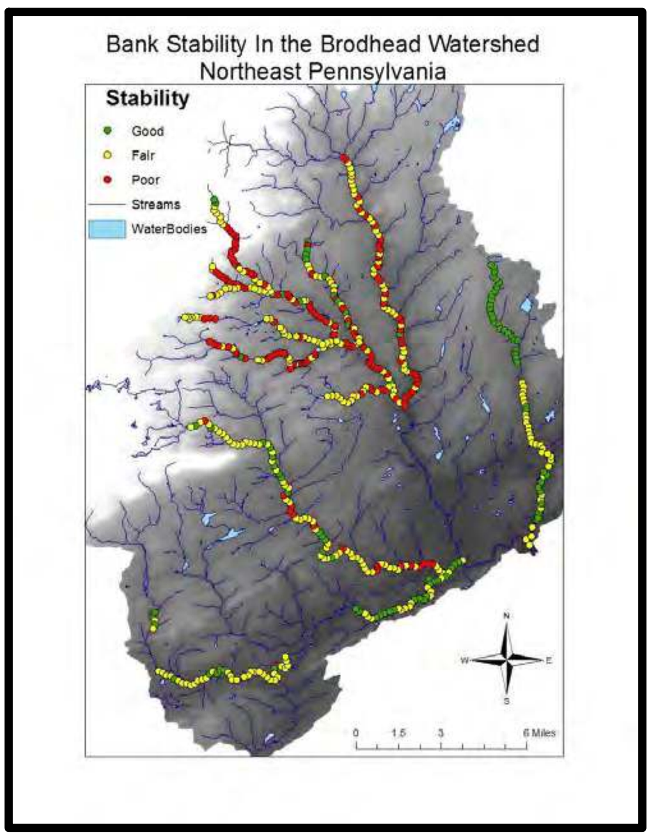
In 250-meter reach increments, the relative densities of invasive plants were measured. The presence and density of invasive flora were noted using a modified Braun-Blanquette range (0 - 4): 0 = none present; 1 = rare, single plants; 2 = small patches, easily counted; 3 = large patches; 4 = dense, continuous stretches.

The distribution of invasive plants, by site, was tracked via Trimble GPS units. XY coordinate data (waypoints) were imported from the GPS units into ArcMap software.

These data were joined with the Digital Elevation Model of bank stability to analyze the features of the stream networks and surrounding landforms.

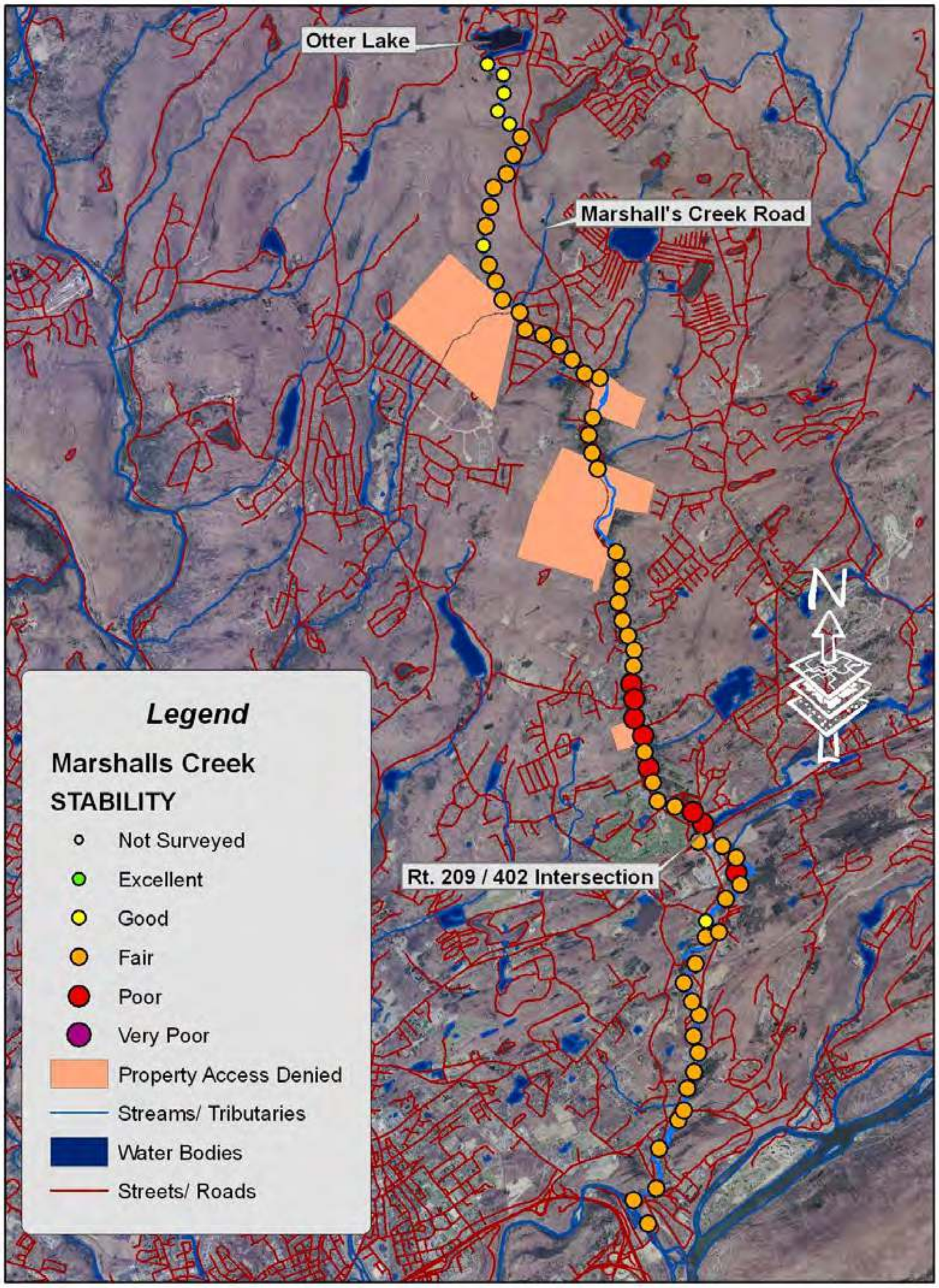
VIII. Stage 5: Data Analysis:

<u>Bank Stability Findings</u>
Preliminary analyses of the bank stability, as shown on ***Figure 22 (right)*** suggests that although bank erosion is present in moderate to severe amounts throughout the entire Brodhead Watershed, there is substantial variation along and within the subwatersheds.



For example, as can be seen on ***Figure 23 (on the following page),*** the stability of banks in Marshall's Creek -- at least for those areas where researchers had permission to enter -- was primarily in the "fair" range, with a few sections where the banks were "poor."

Marshall's Creek Bank Stability Survey



Map Prepared by Michal Niemoczynski

In most areas, sharp bends and meanders in the streambed show excessive cutting.

Figure 24 (photo above), for example, shows serious cutting that occurred below a meander in a bank where residential construction was only a few feet from the bank.

Additional findings include these:

- Headwaters' banks were found to be more stable than downstream banks.
- Middle sections of streams showed the most severe instability.
- Sections with bends and meanders were more heavily eroded.
- High elevation relief areas showed more severe erosion.

Some lower portions of the watershed have yet to be fully assessed for bank stability. In this non-surveyed area the streambed broadens, accommodating more peak flow. However, much of this area lies along the lower section of Brodhead Creek where the banks were artificially armored by the Army Corps of Engineers to permit channelization.

Invasive Vegetation Presence and Density Findings (from related grant).
The five prevailing invasive species found in the watershed are:

- Japanese barberry was found throughout the entire watershed with patches observed in almost every stream, and hot spots observed in a few areas in the upper watershed.

- Japanese knotweed. Although, the southwestern portion of the watershed observed few specimens of Japanese knotweed, this invasive occurred the most and was the most dense of the invasive species.

- Multiflora rose was found throughout the entire watershed in abundant numbers, but few very dense areas were observed.

- Japanese stiltgrass was scattered with some patches throughout the northern areas of the watershed. Stiltgrass was found to be more dense in the southern areas of the watershed, and hotspots were more common.

- Garlic mustard was observed scattered throughout the southern areas of the watershed. In the northern reaches, garlic mustard was rare with scattered plants growing in the northern most areas.

Maps of the relative density of each invasive can be found in "*The Invasive Plants Management Plan for the Brodhead Watershed of Pike and Monroe Counties, PA"* at: http://www.brodheadwatershed.org/invasivespeciesmanagement.html [accessed on 3.3.12].

Conclusions
This study suggests that GIS software can be a very helpful tool for collecting various types of spatial data and analyzing such data for watershed management. What has been determined thus far, as shown in Appendices B-D is that some major controlling factors for bank stability include: wetness index, terrain stability index, river bed slope, and sinuosity.

Limitations of the study
There are gaps in the data caused by several factors: 1) the inability to access to some properties, 2) in spite of intense training, weather conditions, difficulties transporting equipment to even permitted sites, the use of student researchers who varied over several years, several courses and several semesters led to some data entry and recording omissions and errors, and 3) methods have not yet been developed for measuring, for example, the percentage of imperviousness along any particular section of stream bank in a way that would link that variable to bank erosion likelihood.

Suggestions for future management
Many hot spots have been identified for future watershed management. With that information, additional work is needed to educate local and regional decision-makers and to make the geodatabase accessible and understandable for them. Two steps in that direction include the postershown on the BWA website and the publication of this report and various elements from it in such public locations as the BWA's website: http://www.brodheadwatershed.org/BankStability.html.

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