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PREDICTING ANTHROPOGENIC STREAMBED SHIFTS IN BECKLEY, WEST VIRGINIA, MODELED OVER 15 YEARS USING LANDSAT TM AND DEMS

A thesis submitted to

the Graduate College of

Marshall University

In partial fulfillment of

the requirements for the degree of

Master of Science

in

Physical and Applied Science with emphasis in Geobiophysical Modeling

by

Andrew D. Reinhardt

Approved by

Dr. Anne Axel, Committee Chairperson

Dr. Ralph Oberly, Graduate Program Director

Dr. James Leonard

Marshall University

December 2013

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Anthropogenic change of streambeds in the Beckley, West Virginia watershed region was modeled using Landsat 5 TM satellite data from 1988 and 2003, and Digital Elevation Model (DEM) data for 1969 and 2005. Comparing the 15 year land cover changes and the 36 year elevation shifts, and using a modified Universal Soil Loss Equation (USLE), in ESRI ArcMap and ERDAS Imagine, a streambed shift model was created. The model predicted land cover and elevation changes for 2018, using inputs from geospatial differencing of 2003 and 1988 land cover as well as 2003 and 1969 DEM data. Further analysis using hydrodynamic differential equations provided in depth information on stream clogging over the 15 year study period.

CHAPTER 1

INTRODUCTION

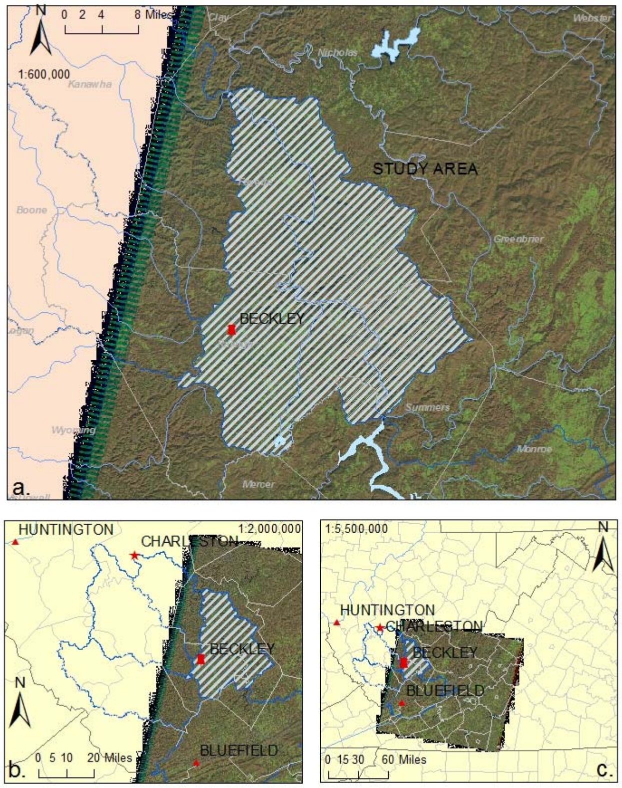
Overview

The Beckley, West Virginia watershed region has unique watershed concerns developed out of historic and ongoing anthropogenic land cover changes caused by recent suburbanization and highway construction. Changes over decadal periods to the paths of the streams, caused by changes in amount of sedimentation, water flow, and ground absorption rates, could be of great concern. Clogging of streambeds by sedimentation is a significant cause of stream redirection and subsequent flooding in mountainous regions such as the Appalachians: potential damming of streambeds due to excessive erosion of soil may cause environmental concerns ranging from stream stagnation, to eventual dam breaking and catastrophic flooding downstream.

Stream shifts over decadal periods caused by major anthropogenic changes in land cover is a problem that has not been extensively modeled previously. This thesis aims to provide a suitable model towards this question in the limited region of Beckley, West Virginia.

Geographic Context

Beckley, West Virginia is a small town with a population of approximately 17,000 located approximately in the central-southern portion of the state of West Virginia (37° 46’ 47” N, 81°10’ 59” W),. The watershed region to be studied is the watershed that intersects the centroid of the city of Beckley, West Virginia. This watershed region extends to the northeast of Beckley, West Virginia, emptying into the New River Gorge from both the southwest and northeast, emptying through the New River basin to the northwest into the Kanawha River basin. The total area under study is approximately 1417 km^2. The study area falls within Landsat imagery path 34 row 17. The study region is located in UTM Zone 17 N, and the projection used was WGS 1984.



Figures 1.a., 1.b., and 1.c. The study area of the thesis at varying scales. 1.a. Study area boundary. 1.b. and 1.c., respectively, the study area at regional scales.

Historical Context

Beckley, West Virginia has experienced considerable land cover changes since the mid 1980s. Artificial gullies and hills have been created to facilitate the construction of highways in the region, while mountaintop removal has become a major factor in elevation and land cover change within the past two decades. Large scale commercialization and suburbanization has taken place since the construction of the West Virginia turnpike and Interstate 64 in the late 1980s. Before that, the completion of the US 19 freeway facilitated growth and change in landscape in the 1970s. Recent projects have included a large drainage canal in the North Beckley shopping district, circa 2001, and the East Beckley Bypass, currently under construction (WV DOH).

These changes have created significant land cover changes over the study period, including greater urbanization, greater suburbanization, and a general reduction of other land cover classes in relation to these highly clustered land cover classes. Overall, land cover has changed rapidly in favor of a more urbanized and suburban, e.g. lawn, landscape, and for the purposes of this study will continue to do so throughout the predicted time period to 2018.

Hypothesis & Model

Using Landsat 5 TM differenced from 1988 and 2003 to produce land cover and DEM differenced from 1969 to 2003 to predict future changes, anthropogenic stream shifts in the Beckley, West Virginia watershed were modeled from the year 2003 projected to the year 2018. Hydrodynamic equations were used to predict soil deposition via erosion using pixel analysis. The physical model showed that significant stream clogging will occur over the 15 year study prediction period.

The purpose of this thesis is to analyze of the terrain evolution over decadal timespans of the Beckley, West Virginia watershed due to increased sedimentation caused by anthropogenic land cover and topographic changes. The analysis incorporates the preceding 15 years of land cover change and 36 years of elevation change to predict change 15 years in the future.

CHAPTER 2

RESEARCH METHODS AND TECHNIQUES

Preprocessing of Data

Using ESRI ArcGIS for initial vector analysis of the watershed boundary conditions, and to combine the raster Landsat imagery data sets by bands (1, 2, 3, 4, 5, and 7 in Landsat 5 TM for 6 band imagery raster set) into a single outputted Imagine image file (IMG), both the remaining vector and raster data was preprocessed for further modeling in ERDAS Imagine. In ERDAS Imagine, the data was processed by combining two 30 meter resolution DEMs obtained from USGS and West Virginia DEM, with the banded Landsat imagery to provide a supervised classification land cover model with 5 classes. By characterizing areas of interest (AOI) to generate a signature file for a 1988 and a 2003 Landsat 5 TM raster, supervised classification was performed to create a 5 class land cover raster including paved/urban, forested, grassy, coniferous forested, and water classes for spectral overlay onto a slope raster. The slope raster was generated using a slope process in ERDAS Imagine. The slope panchromatic rasters were subtracted from each other using the Two-Function process in ERDAS Imagine in order to provide slope change, while the land cover rasters were also subtracted from each other using the same Two-Function process in ERDAS Imagine.

The watershed boundaries shapefile was acquired from the (United States Geological Survey) USGS, while shapefiles including West Virginia towns, counties, and state boundaries, were acquired from the Marshall University College of Science GIS server. The West Virginia streams shapefile was acquired from the West Virginia GIS Data Center. All vector processing occurred, unless further noted, in ESRI ArcMap. The towns shapefile was clipped to the town of Beckley, West Virginia. The counties shapefile was clipped to the county of Raleigh, West Virginia. The watershed boundary shapefile was intersected with the Beckley, West Virginia point shapefile to select out a single watershed boundary, and clipped to that boundary. The streams shapefile was clipped to the previously clipped watershed shapefile, hereby known as the “Beckley preliminary watershed shapefile”. The Landsat imagery did not completely encompass the watershed shapefile therefore the northernmost and easternmost portion of the watershed, as well as the southernmost tip, was removed.

Raster data was acquired from a variety of sources, including USGS, West Virginia DEM, WV GIS Data Center, and National Digital Elevation Mapping Center. Raster data acquired included Landsat imagery for the time period between 1988 through 2003, however, due to subsequent checking for optimal data, the Landsat imagery from 1988 and 2003 was chosen for this research. And final chosen data was imaged on November 2, 2003, and on December 26, 1988. These imagery dates are both similar in solar angle, and in seasonal land cover, making classification more straightforward. DEMs were acquired from Marshall University’s College of Science GIS Server for 30 meter resolution and from the USGS. DEM data acquired from Marshall University College of Science GIS Server was dated to 1969, DEM data acquired from USGS was dated to 2003 with revision date of 2005. Both DEMs and Landsat Imagery were clipped to the watershed boundary shapefile in ESRI ArcMap and subsequently exported to an IMG file for continued processing in ERDAS Imagine.

Slope rasters were created from the DEMs for 1969 and 2005 in ERDAS Imagine 2011. Then the slope raster for 1969 was subtracted from the slope raster for 2005 using the Two-Function intersection process in ERDAS Imagine. This processing created a differential slope raster showing the rate of change of the 36 years from 1969 to 2005 of the slope in question. For this research, it was at first assumed that the majority of this change occurred between 1988 and 2003, for modeling purposes. However, when undergoing pixel analysis of the data as well as within the physical modeling of the final data using hydrodynamic equations, a DEM time range of 1969 to 2005, and a land cover time range of 1988 to 2003, were used, accurate with the data. The assumption that nearly all slope change occurred in the 1988 to 2003 timeframe is consistent with the historical and geographic context (West Virginia Department of Transportation, October 2013). The encompassment of a final error analysis and reduction of error further improved results.

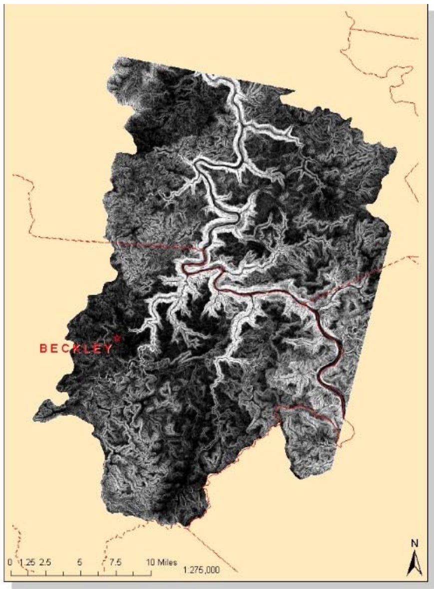


Figure 1. DEM Generated Slope Raster for 1969

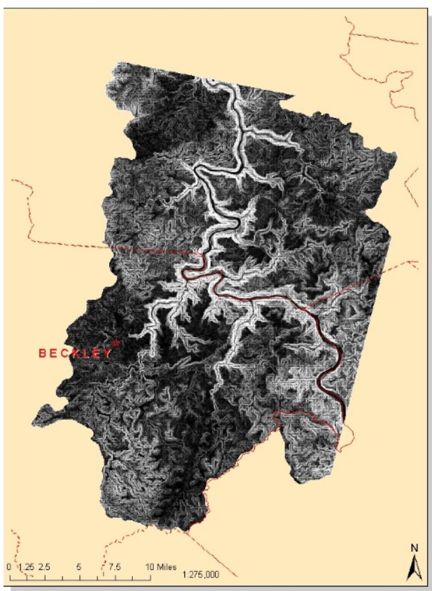


Figure 2. DEM Generated Slope Raster for 2005

Supervised classification of Landsat 5 TM imagery involved creating an area of interest (AOI) layer, and inputting the spectral data into a signature editor for saving into a signature file. Based on distinct spectral signatures, verified in Google Earth and via other Landsat imagery, five main classes were created within the Landsat 5 TM rasters for 1988 and 2003, deciduous forest, grassy areas, urban/paved, coniferous forest, and water. The land cover rasters were later recoded to merge the coniferous and deciduous forested land cover classes into a single class.

The five land cover classes (2003) were subsequently modified using pixel analysis (see figure 3) based upon the Universal Soil Loss Equation, USLE, given by: $A = RCKLS$ (Equation 1) (Ustun, 2008) such that A is the amount of soil eroded, which is found by multiplying the other factors. R is the rainfall energy transfer rate, given by $R = IE$ (Equation 2) (Thrikill, 1991), where I is the seasonal rainfall rate, and E is the energy transferred per unit mass of rainfall. The average values, which were useful for this research, were already well known for the continental United States, and the value of $R = 125$ (Thrikill, 1991) was used for the watershed. C is the land cover factor in this research, which combined with the factor K, of value $K = 0.28$ (Thrikill, 1991), produced the following results.

Table 1: Landcover Classes

Class	Modified Value
Forested	0.021
Grassy areas	0.245
Paved	1
Coniferous	0.021
Water	1

Subsequently, the land cover rasters from 1988 and 2003 were combined in a matrix union processing in ERDAS Imagine, with the attribute table evaluated for comparison of values (Table 2). Spectral values for the five classes were calculated using pixel analysis.

Classes were buffered to predict the land cover changes over the 15 year study period from 2003 to 2018. The buffer zones were created by removing the water field and adding the error created in this process to each raster class. Also, each class was normalized using the following equation:

$Norm = \frac{\sqrt{(Error \times Histogram)}}{15}$ (Equation 3).

Land cover classification was followed by an ERDAS Imagine search processing of the data, in piecemeal format, to provide separate buffered class zone rasters, in order to create the 15 year timestep of the land cover data. The separate land cover rasters were then reintegrated into each other, with unsupervised classification taking place afterwards, classifying to 4 classes, ultimately. These 4 new classes include the same, old classes, less the water class, i.e. grassy areas, forested, coniferous, and paved. The newly buffered and merged land cover raster was subsequently used in the final modeling of this research.

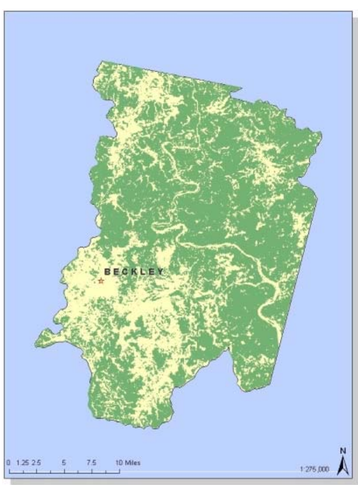


Figure 3 Deciduous forest land cover change predicted over 15 years to 2018

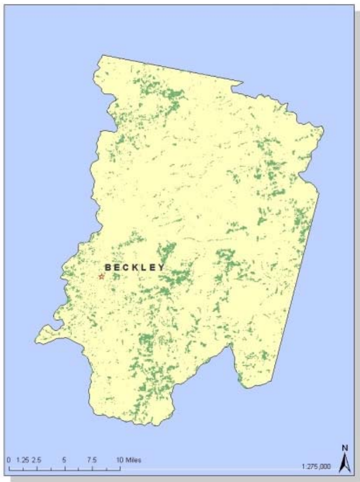


Figure 4 Coniferous forest land cover change predicted over 15 years to 2018

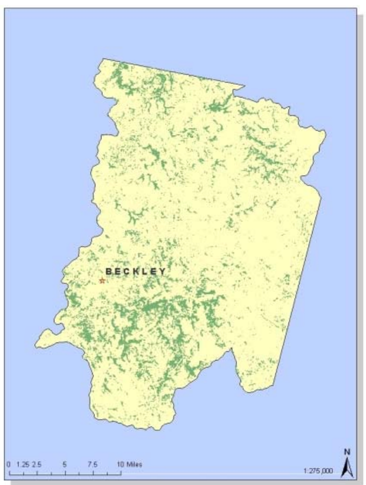


Figure 5 Grassy areas land cover change predicted over 15 years to 2018

Figure 6 Urban land cover change predicted over 15 years to 2018

In order to further model the soil deposition, mathematical and physical analysis of the data was performed using hydrodynamic equations. These hydrodynamic equations provided the means to model physically and more quantitatively what is happening with this research.

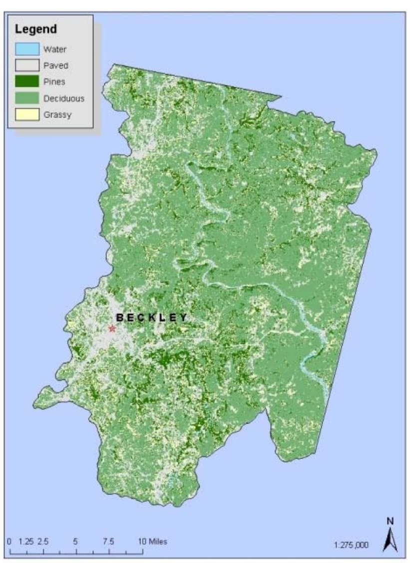


Figure 7 The predicted land cover types for 2018.

Modeling

Further pixel analysis was performed on the classes of the merged land cover raster, as shown in Table 3. The merged and opacity modified land cover raster was then combined with the slope rasters for 1969 and 2005, respectively, using the Two-Function modulus (MOD) union process on ERDAS Imagine, to provide a timestep of 15 years preliminary to merging for final modeling and analysis. Finally, the two merged preliminary rasters, containing modified land cover and slope covering an approximate 15 year period, were merged using the Two-Function subtract via union process in ERDAS Imagine, to provide the final raster model. This raster model then underwent histogram analysis in order to seek out secondary maxima and minima angles of the slope through an exported DAT file imported into MS Excel. This data provided the bounds on the stream well in terms of general angular position.

The process for pixel analysis is well described by ERDAS (ERDAS Field Guide, 2010), and will not be gone over again here. However, the preceding Table 5 lists the opacity values for each class used in modeling. Physically speaking, pixel analysis was conducted on the basis of allotting greater or lesser convergence in merge functions with the slope raster, with the basis of equation 1, $A = RKCLS$, where *LS* is the slope raster, and *RKC* is the opacity modified land cover raster, however a new model was created on the basis of a differential equation, as follows: $A = \int_{t_0}^{t} \frac{dL_1}{dS_1} - \frac{dL_2}{dS_2} dt$ (Equation 4), where L is the land cover raster and S is the slope raster, and t is time elapsed. Thus, by merging the two raster sets using the appropriate formula in ERDAS Imagine Two-Function process, a raster set that could be merged using similar means to provide a final model was developed.

The land cover and slope raster sets were individually merged for the 1988/1969 and 2003/2005 modeling years, to provide a hybrid model of slope and land cover change, using the modulus two-function process in ERDAS Imagine. The result of this was two panchromatic rasters, which were then merged into each other using the subtract two-function tool in ERDAS Imagine. The resulting raster had only 4 classes with pixel values. These 4 classes could be defined both by histogram count and location fairly straightforwardly (see Table 2).

Figure 8 The final modeling raster. Green represents the most likely location of hydrology changes due to slope and land cover shift.

CHAPTER 3

DATA AND ANALYSIS

The modeling raster showed that a small yet significant fraction of the watershed area of interest exhibited both slope and land cover change over the period in question, see Table 6 for details. This data was pulled from the final raster histogram, which was exported to a DAT file and imported to MS Excel. The data showed that 2.26% of the watershed underwent both land cover and slope change. The remaining 97.74% of the watershed either underwent land cover change alone, slope change alone, or neither. Of this, 47.29% underwent no change, 39.60% underwent land cover change alone, and 10.83% underwent slope change alone.

Table 2. Merged land cover and slope raster classes over 15 year time period with change percentages.

Class	Change %
No change	47.29%
Slope only	10.83%
Land cover only	39.60%
Both	2.26%

The land cover-slope changes provide intriguing questions for further analysis. Notably, first among these is what does a 2.26% change in both slope and land cover mean for the hydrology of the region? Is there a way to quantify this measurement into something more valuable? This analysis will attempt to reach those conclusions.

It was found that a 2.26% change is the slope and land cover for the period of interest, 15 years into the future from 2003, should occur using the model in question. This model provided a good estimate of the combined slope/land cover change, and thus soil erosion. Physically speaking, the 2.26% value is the most likely class to see soil erosion change. However, this project is interested in soil deposition, which will require some transformation of the data in question from a soil erosion model to a soil deposition model.

First, it must be understood that the 2.26% change is a differential value. This allows the following mathematical model to be used: $\frac{dA}{dt} = \frac{dL_1}{dS_1} - \frac{dL_2}{dS_2}$ (Equation 5), where

L is the land cover raster, S is the slope raster, and A is the fractional time undergone in change in years, and t is time. Thus, $A = \int_{t_0}^{t} \frac{dL_1}{dS_1} - \frac{dL_2}{dS_2} dt$ (Equation 4). Thus, we know that : $A = \int_0^{15} 0.0226\, dt = 0.339\, yrs$. The differential slope can be used to develop, in conjunction with the total histogram value for the area under study, $Q = \frac{1}{H} \frac{dm}{dA} \frac{dS}{dz}$ (Equation 6), where Q is the soil deposition mass density per unit time, S is the slope raster, H is the total watershed area under study, $\frac{dm}{dA}$ is the mass flow rate, $\frac{dS}{dz}$ is the differential thickness of the watershed. The mass flow rate is estimated by using the total soil mass per total time. This can be found by modifying the previous equation into the following form: $\dot{\rho} = \frac{1}{Hdz} \frac{dm}{dA}$ (Equation 7). Thus, the soil deposition equation becomes: $Q = \dot{\rho} dS$ (Equation 8). In order to find the mass eroded, $M(Q) = \int_{t_0}^{t} \int_{v_o}^{v} \dot{\rho} dV dA = \int_{t_0}^{t} \int_{z\, sin(S_{min})}^{z\, sin(S_{max})} QHdz\, dA$ (Equation 9), which becomes when evaluated: $M(Q) = QHz[\sin(S_{max}) - \sin(S_{min})](t - t_0)$ (Equation 10). The slope raster is roughly centered at '0', tapering off to approximately 90 degrees. However, the core of the slope raster histogram represents values that do not change significantly for this research.

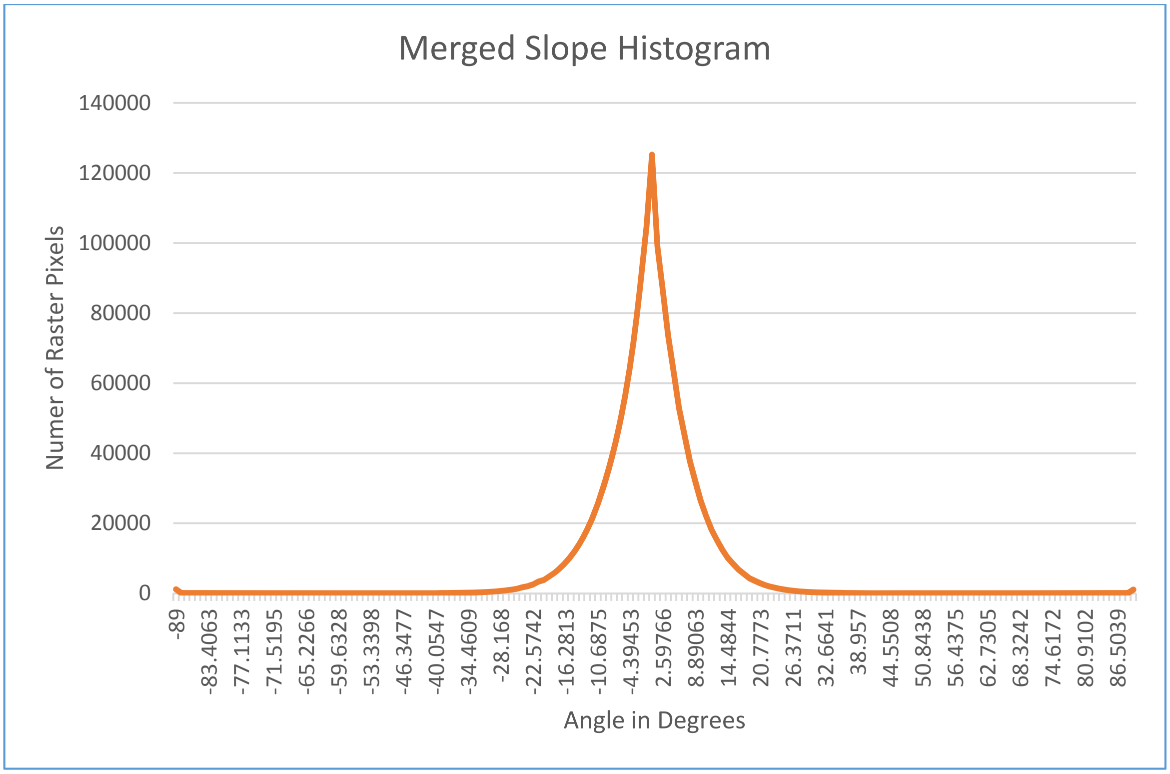


Figure 9 Slope raster histogram, clearly showing the peak of the histogram centered around an angle of '0'.

There is an obvious inflection point in each case, averaging the values will give the minimum value wanted, when subtracted from the maximum value at 90 degrees. Thus, at 52 degrees and at -53 degrees there are inflection points. Averaging the absolute values of these angles provides an inflection point of 52.5 degrees. Thus, the equation above becomes, for the purposes of this research, $M(Q) = QHz[\sin(90°) - \sin(52.5°)](15 - 0)$. It was shown that $Q = \dot{\rho}dS$, thus we know that $M(Q) = 15\dot{\rho}Hz[1 - \sin(52.5°)]\, dS = \rho Hz[1 - \sin(52.5°)]\,^2 = 1531\ {}^{kg}/_{m^3}\,(1.417 \times 10^9 m^2)(0.015m)(0.04270) = 1.389 \times 10^9\ kg$. This can be converted to more useful units, tons, which then becomes 631600 tons potential erosion, or 42,106 tons per year. We know that the area of deposition is approximately 32 km^2, as found in using the modeling process described in the previous chapter of this this thesis. Thus if the material were deposited evenly across all the surfaces, $\frac{r}{QA} = z_{new}$, where r is the area of the raster pixel, 900 m^2, z is the surface deposition height, and where Q and A have been previously defined above. Thus, the surface deposition is, on average, 0.5878 m in height. However, since even deposition is a simplistic argument, a better argument would assume a well of shape: $z = z_{new} \cos \theta^2$, such that it can be assumed that $\theta = range(\theta, \frac{\pi}{2}, 0)$, which is programmable into a scientific programming language such as python. Taking the range of values of the new well height, the deposition was found to be more of a range of values, with a maximum value of 0.5878 meters and a minimum of approximately 0. Thus, the average value of deposition is more of the value of $z = 0.1332\ m$, which seems considerably more reasonable than the 0.5878 value. Assuming that any increase over 1 meter will clog most streams in a period of 15 years in this particular watershed, and subsequently cause a streambed shift, it was found through analyzing the histogram that the streambed will clog at merged slope values of $\pm 60°$. This means, physically speaking, that the change in slope has to be greater than 60° or less than -60° in order for there to be a significant shift in the streambed. This amounts to 4291 raster pixels. Ratioing this value with the value for all raster pixels of interest in generating a slope differential, 35,675, provides the area percentage that will undergo deposition in this model. This is 12% of the deposition basin. Thus, 12% of the deposition basin, an area of approximately 3.8 km^2, should experience erosional deposition great enough to clog the watershed.

CHAPTER 4

CONCLUSIONS

An area of approximately 3.8 km^2 will be filled in streambeds within the Beckley, West Virginia watershed over the next 15 years, out of a study area of 1417 km^2. The study area includes several vital feed channels to the Kanawha River, and subsequently major feed channels to the Ohio and Mississippi water basins. Blocking these channels, or adding significant sedimentation, could have implications well beyond the modeling area. The hydrology of the area in question is likely the change over the next 15 years, and a significant (by at least a factor of 4) reason for this is land cover changes, most of which in this watershed region can be attributed to anthropogenic causes. In this study, it was found that the primary land cover changes between 1988 and 2003 were caused by urbanization, deforestation, and mountaintop removal, each of which provided its own unique change in land cover classification between the years in question. Specifically, urbanization both increased paved surface areas and the grasslands classification, as well as decreased classification areas for other classes in a tight cluster around nuclei of urban activities. Forested areas were buffered to compensate, but lost out to urban and grassy areas near these already urbanized areas, as well as near mountaintop removal sites, which were created and subsequently converted to grassy areas meadows between 1988 and 2003. However, by removing the top of a mountain, a large elevation shift occurred in many places with a large land cover change as well. This was a major factor in the high levels (42,601 tons per year) of erosion, enough to cause all slope shifts with 60° slope differential or greater to have greater than a 1 meter increase in sedimentation over 15 years.

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USGS Earth Explorer

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USGS National Elevation Data (NED)

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West Virginia GIS Data and Technical Center

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APPENDIX A

GLOSSARY OF TECHNICAL TERMS

Land cover – Compound scientific term often used as a synonym for land usage, e.g. urban, forested, meadow.

DEM – Digital Elevation Model, a GIS-based model produced to two or three dimensionally model terrain elevation.

Attribute table – GIS data format that when read provides the metadata for reading and writing the GIS formatted file

Vector – GIS data format based upon a set of shapes, points, or lines, tied to an attribute table

Raster – GIS data format based upon a grid of pixels rather than vectorized information

ERDAS Imagine – GIS software platform with advanced raster modeling capabilities

ESRI ArcGIS – GIS software platform with advanced vector modeling capabilities

ERDAS – Software company that distributes the Imagine software platform.

ESRI – Software company that distributes the ArcGIS software platform.

USGS – United States Geologic Survey, a federal government agency involved in mapping, geology, and related services.

Watershed – The smallest discrete, and cohesive individual part of a water basin.

APPENDIX B

LIST OF EQUATIONS

APPENDIX C

IRB REVIEW EXEMPTION LETTER

MARSHALL UNIVERSITY®
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Office of Research Integrity

October 3, 2013

Andrew D. Reinhardt
2619 S. 7th Street
Ironton, OH 45638

Dear Mr. Reinhardt:

This letter is in response to the submitted thesis abstract entitled *"Anthropogenic Streambed Shifts in Beckley, West Virginia, Modeled Using 15 Year Dual Landsat TM and 36 Year Dual DEM."* After assessing the abstract it has been deemed not to be human subject research and therefore exempt from oversight of the Marshall University Institutional Review Board (IRB). The Code of Federal Regulations (45CFR46) has set forth the criteria utilized in making this determination. Since the information in this study does not involve human subjects as defined in the above referenced instruction it is not considered human subject research. If there are any changes to the abstract you provided then you would need to resubmit that information to the Office of Research Integrity for review and a determination.

I appreciate your willingness to submit the abstract for determination. Please feel free to contact the Office of Research Integrity if you have any questions regarding future protocols that may require IRB review.

Sincerely,

Bruce F. Day

Bruce F. Day, ThD, CIP
Director

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