Streambank and Road Erosion in Harford County

Alexander Bailor, Ellen Kortesoja, Gene Miller, Luke Savonis

Under the supervision of: Binbin Peng and Frank Zhou

URSP 688L: Recent Developments in Urban Studies: Planning Technologies
The University of Maryland – College Park
Fall 2018

PALS - Partnership for Action Learning in Sustainability
An initiative of the National Center for Smart Growth

Gerrit Knaap, NCSG Executive Director
Kimberly Fisher, PALS Director

Contents

Executive Summary

As part of the Fall 2018 URSP 688L Planning Technology class, students from the graduate Community Planning program at the University of Maryland worked with the Partnership for Action Learning in Sustainability (PALS) program to use applied computer mapping tools to address a streambank erosion project in Harford County, Maryland. Working with ArcGIS, our team identified vulnerable roadways in Harford County at risk from streambank erosion. Using the software's tools, our team identified a total of 438 vulnerable roadways, which were then ranked by their total potential risk.

Our team presented this information and ranking system so Harford County could address these roadways. It is our hope that this information proves useful to the County to address issues before they occur. We provided the County with a geodatabase that contains final spatial information, additional shapefiles that outline our technical process, and a metadata file. We also created an online presentation, which is accessible through ArcGIS Online at: https://arcg.is/1zKviX.

Background

The purpose of this project is to examine the risk that Harford County roads face from erosion and undercutting caused by nearby streams. As Harford County continues to develop and grow, roadways and streams are faced with increased stress from storm runoff, construction, and other externalities. Further pressure comes with increasing storm frequency and intensity as a consequence of climate change. Accordingly, Harford County sees a need to identify at-risk roadways. Through geographic information systems (GIS) analysis, the County hopes to identify vulnerable roads and create supplementary useful data. With this information, county officials can proactively develop solutions for mitigating streambank and roadway erosion. By extension, the hope is that this data will be used by the County to carry out focused roadway and streambank maintenance efforts to mitigate flooding and erosion damage resulting from increased stress due to climate change and other factors.

Figures 1 and 2: Examples of streambank erosion

Research Focus

During the semester, representatives from Harford County presented the project and field questions. They shared the various GIS layers that the County's office already possessed, and the data they hoped our teams could produce. The following goals were outlined.

- Identifying road segments (only roads maintained by the County) that are within 50 feet of a stream.
- Identifying the soil type in each of these areas.
- Identifying watershed drainage areas in these selected segments.

After the initial meeting with the County, the team worked with GIS data to determine how to accomplish the outlined goals. This team formulated the following research question: How can advanced GIS tools determine potential sites of road susceptibility due to stream erosion and prioritize these areas of risk?

The next sections describe the relevant variables, analysis, and methodology used to answer this question.

Methodology

This section is a detailed overview and explanation of the steps to answering the research question, beginning with ranking vulnerable roadways, the data collection process, and a detailed technical explanation of the ArcGIS steps completed and the construction of the ranking index.

Roadway Ranking

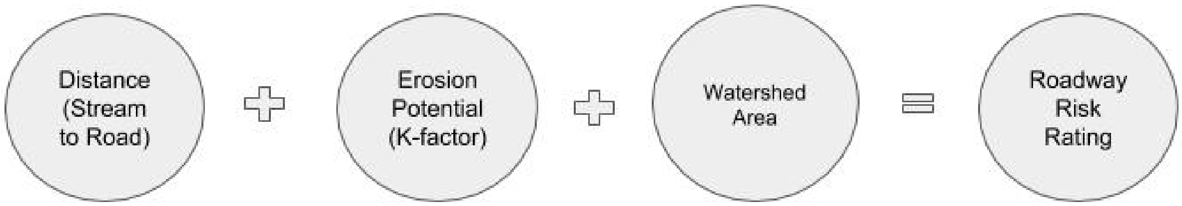
In thinking critically about the research objective and goals, the team decided to construct an index and ranking system for susceptible roadways. Using the guidance from county officials, the team ranked roadways based on a combination of factors including the distance from the stream to the road, the erosion susceptibility of the soil that underlays the road, and the watershed area of the stream. Ranking roadways using these criteria the team constructed an index that classifies roadways as severe, high, medium, and low risk. Each component in the index is weighted based on its relative importance assigned by Harford County officials. The County places the most emphasis on the distance from the stream and so, this factor is weighted most heavily.

The weights of each factor are:

1. stream distance (SD) – 50%
2. watershed area (WA) – 25%
3. soil erosion potential (K-factor[1]) – 25%

---

[1] U.S. Department of Agriculture (USDA). *Understanding Soil Risks and Hazards: Using Soil Survey to Identify Areas with Risks and Hazards to Human Life and Property.* Washington D.C.: 2004.



This graphic illustrates the ranking system and index:

Figure 3: Visual representation of index

Data Collection

The team worked with Harford County's wealth of existing county-collected data and did not need to obtain extensive external data. The County's data was relatively straightforward to clean, manipulate, and utilize for our analyses. More difficult, was locating and manipulating other data that we (and the County) deemed potentially relevant to roadway erosion. This data includes watershed area and soil erodibility.

Watershed area is an important factor in understanding roadway erosion. It serves as a proxy for understanding potential flooding risk. For example, a stream with a large watershed area will collect more water than a smaller watershed would. In a flooding event, a larger watershed may cause a particular stream to flood more severely. The team was not given a watershed layer and we used ArcGIS Online to calculate the watershed area.

The use of ArcOnline has a potential accuracy issue. The GIS tool uses points from which it calculates drainage area. These points are calculated by GIS as centroids on line segments that represent roads. However, using a GIS tool to find the centroid of each of our susceptible segments is problematic because the mathematical centroid of each segment may not be at the actual point of drainage of a road segment (due to the point being a centroid). But this potential limitation of the data calculation would not have a major impact on the rating system and decided to move forward with this calculation method.

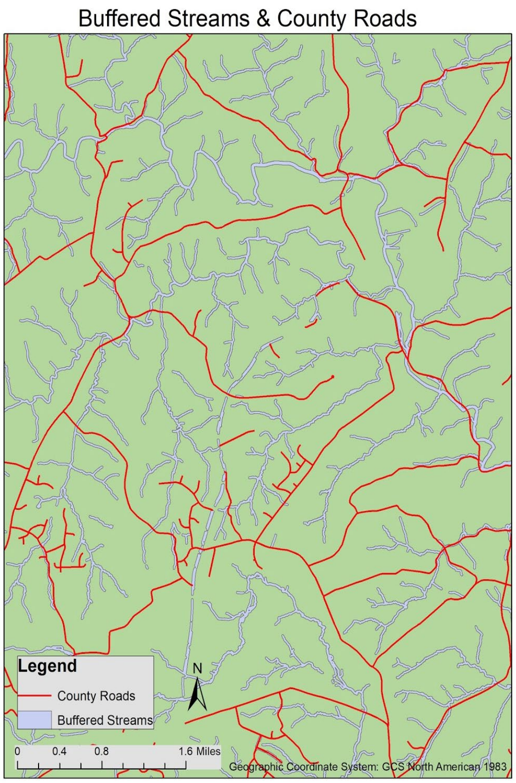
Through its research, the team determined that erodibility of soil is of particular concern when understanding streambank erosion. The Department of Agriculture describes stable streams to be in a state of “dynamic equilibrium” (US Department of Agriculture). When streambank erosion occurs, this equilibrium has been upset. This change in environment could be attributed to a number of factors: rainfall, human disturbances like construction, or animal grazing patterns.

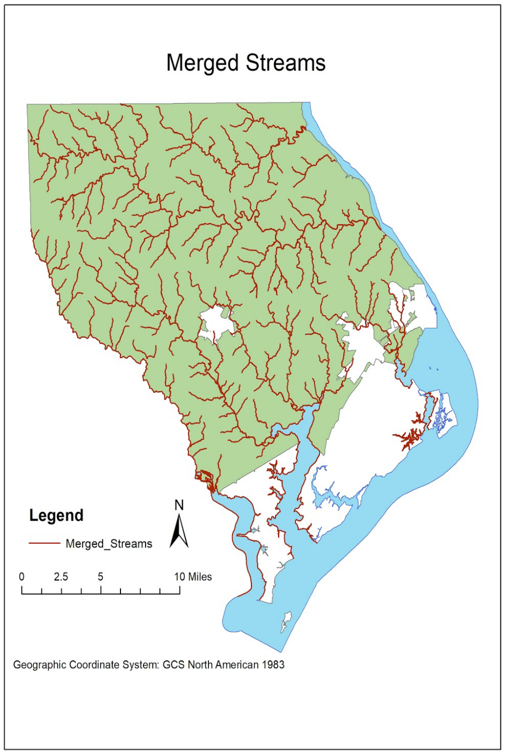
Soil erodibility information, or the K-factor, was obtained from the United States Department of Agriculture’s Web Soil Survey. A soil’s K-factor is a measure of both susceptibility to erosion and a soil’s rate of runoff (U.S. Department of Agriculture). Using this number allowed the team to assess how vulnerable a soil type is to erosion and to include it in the index. In sum, the team utilized already existing data from Harford County for the main analysis, and relied on further research, as necessary, to obtain additional relevant data for the index.

Technical Strategy

This section explains the steps taken to create the index and how County and other source data was manipulated.

The team's first step was to create a single streambank file from the multiple files the County provided. This was accomplished using the "merge" function, which combined three of the four streambank layers provided by the County. We next created a 50-foot buffer around the combined streambank file by using the "buffer" tool. The buffer distance was specified by the County.[2]

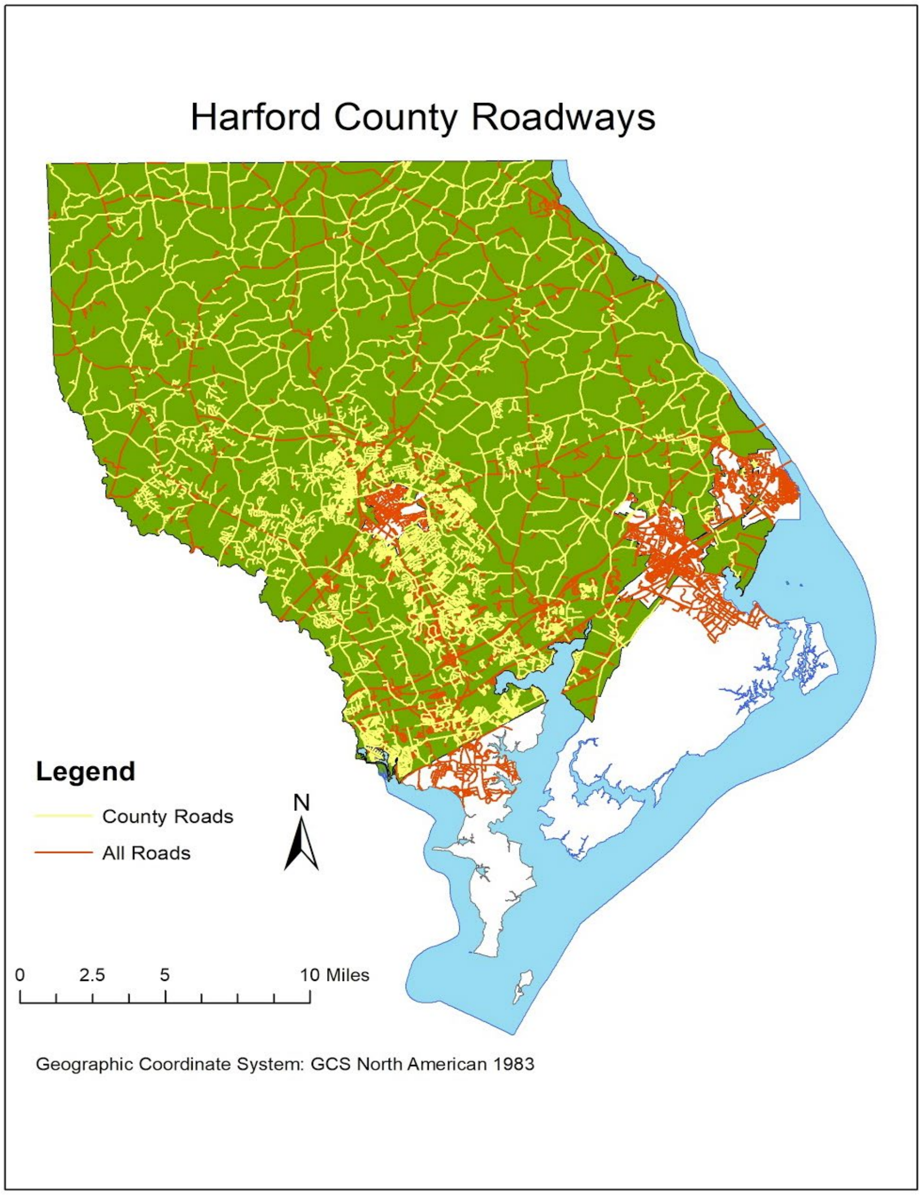




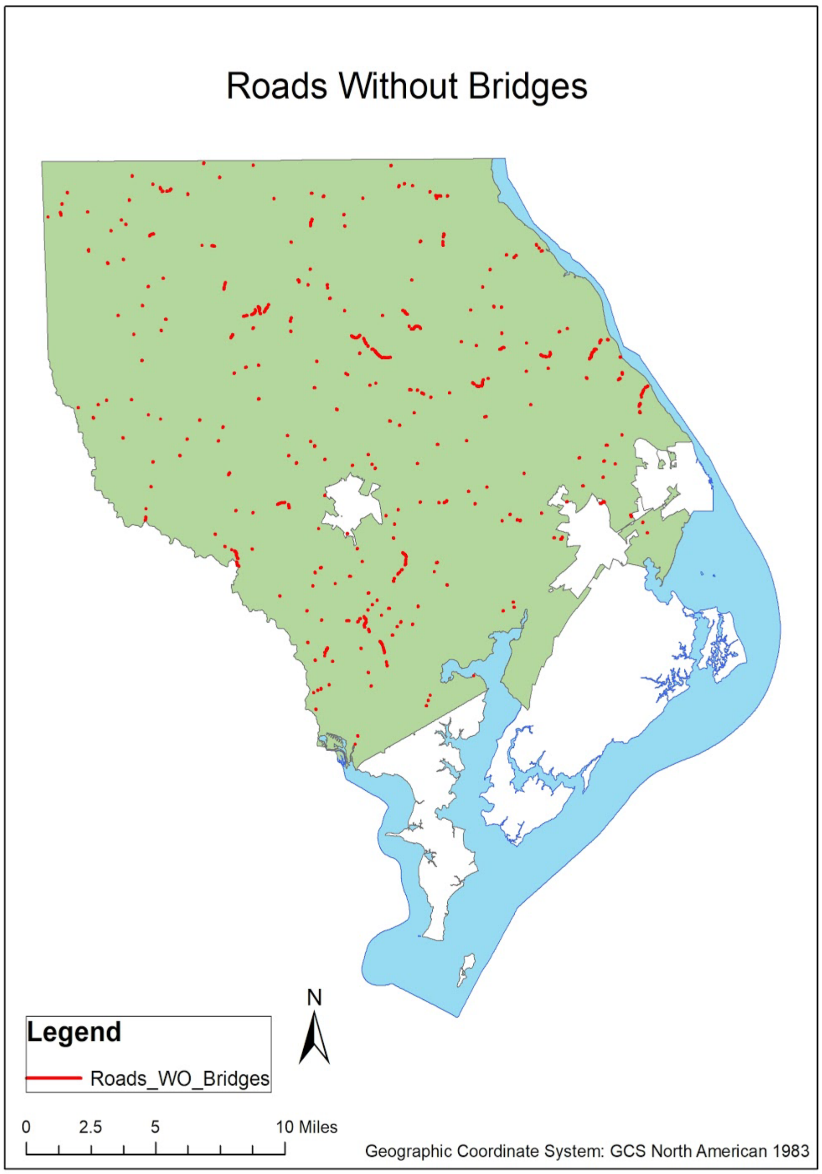
We next worked with the County's "centerline" file to identify only county-maintained roads. We achieved this by using the "select by attribute" tool directing ArcMap to select only roads identified as "C" in the "Shield" field in the Attribute Table. This selection was exported into a new shapefile and then overlaid with the existing buffered streams file. To identify roadways within the buffered zone, the team used ArcMap's "intersect" feature, which identified

[2] After an initial merge of the four shapefiles, the team noticed that many stream banks mimicked the route of major roadways. We raised this issue with the county and it was determined that the fourth stream bank layer included drainage ditches alongside major highways. The team then excluded this fourth layer from the analysis.

roadways that intersected the buffer zone and exclude those which did not. After performing this action, the team created a new shapefile that included only these roadways.



In the course of the project, the County informed the team that it should exclude road segments with bridges because the County already has existing data on these particular roads. To exclude these bridge locations, the team applied a planometric file of bridge locations (supplied by the County) to susceptible areas data and then selected roadways that intersect a bridge using ArcMap's "select by attribute" function. A new shapefile excluded these segments. The total number of roadways identified as susceptible to streambank erosion was 438.



Next, to determine the distance between the roadway and the stream within the buffer zone the team used ArcGIS's "near" function, which calculates the distance from the closest point on the roadway to the stream. For files with a distance of "0," it was determined that these segments cross the stream. Upon investigation the team determined that these segments cross the stream using a culvert or some other structure (as bridges were identified and excluded).

The team then worked on the third variable, identifying soil erodibility. First, to identify soils that are more susceptible to erosion the team split the county-supplied soils layer into two layers based on their description as either "moderately eroded" or "severely eroded." Using ArcMap's "Select by Attributes" feature the team built a query expression that selected soils based on their Feature ID. However, upon further research, the team determined it needed to consider more soil type attributes than either "moderately eroded" or "severely eroded."

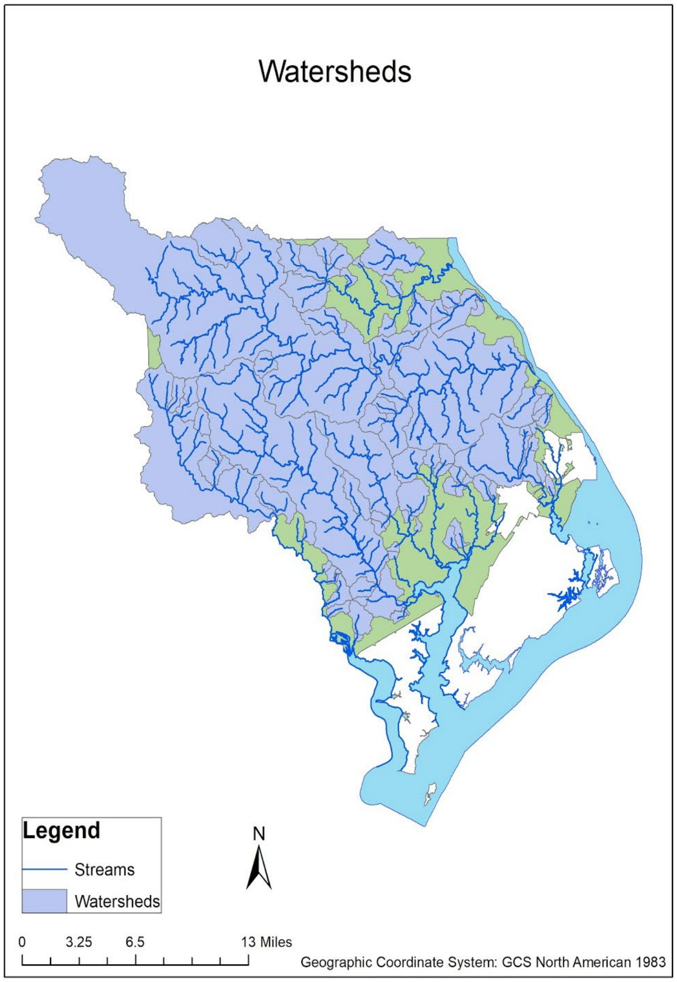
Using the USDA's Web Soil Survey, the team found Harford County soils data that includes a nationally standardized soil ranking system of relative susceptibility and erosion—the K-factor. This dataset compiles the soil type (on a scale based on whether the soil detaches from itself easily), the human activity with that soil (disturbing the soil wears it down faster and it washes away), and the plant density (roots hold the soil together). Together, these three factors are a more thorough approach to classifying soil than the county-supplied data. K values range from 0.02 to 0.69, with a higher K value indicating greater erodibility (see Appendix A).

From this database, the team gathered the K-factor of each soil type available for Harford County. This data was entered into excel and then loaded into ArcMap. It was then joined to the USDA soil layer and made into a new shapefile to preserve the join. Next, the team performed a "spatial join" with the roadway shapefile to match roadways to their underlying soil type. This join matched the soil polygons to lines and was a many-to-one join. Where a roadway crossed multiple soil types, the spatial join averaged the K-factor. The team acknowledges that there may be more elegant ways to capture information for each road's soil type, however, given the data and ArcMap limitations, we chose to proceed with an average rating where necessary.

At this point, the shapefile contained data and information on roadways within 50-feet of a stream and the team calculated the distance from the roadway to the stream as well as the average erodibility of the soil underlying each stream.

The team next tackled the watershed calculation portion of the rating system. To calculate watershed areas, the team first converted line segments (the roads layer) into centroids using the “Feature to Point” tool from ArcMap’s Data Management toolbox. A centroid is the geometric center of a feature. Using these centroid points, the team uploaded the shapefile layer into an ArcGIS Online map where the watershed area could be calculated using the “Create Watersheds” tool, which uses a built-in digital elevation model (DEM) to create water catchment areas.

To add the watershed data to the table of existing shapefiles containing roadway distance and erodibility, the team imported the watershed data into ArcGIS and joined that data to the already existing file, which had relevant distance and K-factor criteria. The join was based on the common variable, the “RDNameLOCA” field, in the attribute table. The joined file was exported into a new shapefile to preserve the join. This operation created the final workable shapefile for analysis.



The following section is a discussion of using each value's weighted Z-score to add the salient criteria together to achieve a total score for each susceptible area—which would indicate the priority roads susceptible to failures in Harford County.

Index Construction

To compile the three criteria with different units of measurement in this analysis the variables needed to be standardized. To aggregate this data and construct an index, the team, in discussion with Professors Peng and Zhou, decided to use Z-scores for each variable. Z-scores are a statistical tool that indicate the number of standard deviations a certain data point is from the mean. By using Z-scores, each variable can be standardized and then aggregated to create an index. The scores will vary around the mean or “0” value. Higher scores indicate a higher risk for streambank erosion and lower scores indicate lower risk.

The team used the following formula to calculate the Z-score for each variable:

$$Z = \frac{X - \mu}{\sigma}$$

Where *X* is the value***,*** *u* is the mean, and *o* is the standard deviation. Each variable’s data was entered into this formula to calculate their Z-scores. Once calculated, each score was weighted by an appropriate amount, and the resulting data was summed to create the final index. The mathematical representation of the equation is:

Rating= ∑KFactor*.25, WA*.25,- [SD*.40]

Note that the distance is subtracted in the equation because it has an inverse relationship to the other variables (a lesser distance has greater impact on the score because the roadway is closer to the stream).

To calculate the index, the team exported the attribute data from our “Complete_Final_Data” shapefile into Microsoft Excel for easy calculation and aggregation. Once completed, we re-loaded the file into Excel and did a join to match the data. This data was then cleaned (duplicate and erroneous fields were removed to present a readable and workable attribute table) and visualized. Extra fields were removed using the “Fields” tab under the “Layer Properties” dialog box. Visualization was created by using the Jenks classification tool to create four categories (explained below) and the field calculator was used to create string names in the attribute table (the “Risk Rating” field).

Using the indexed data, the team visualized the susceptible roadways in ArcMap using four categories in the “Risk Rating” field:

1. Low Risk (Blue line)
2. Medium Risk (Green line)
3. High Risk (Orange line)
4. Severe Risk (Red line)

The next section explores the indexing results and explains final deliverables.

Research Outcomes and Final Deliverables

The research outcomes were a breakdown of at-risk roads and resulting products—this report, a story map presentation, and a map attached to geodatabase with metadata. These products provide the information and instruction necessary to understand and reconstruct the analysis steps.

The ArcGIS map is a tool that automatically visualizes data that is pre-loaded into the map—called a "map pack." This makes working with the data simple, requires less ArcGIS know-how and provides options to change the view of road segments. The report and presentation show how to remake the tool to make adjustments. Finally, the database, named "Complete_Final_Data," contains metadata (spelling out the names of attributes in analysis), shapefile source information, and shapefile purpose.

According to calculations, the breakdown of 438 at-risk roads is 13.7 percent low-risk (60 roads), 32.2 percent medium-risk (142 roads), 22.6 percent high-risk (98 roads), and 31.5 percent severe (138 roads). Thus, a majority of road segments, 54 percent (236 road segments), are at high or severe risk of erosion. However, given this large number, these sites should be further ranked to use county resources effectively. With the hot spots identified, a hydrology (or other) expert may believe that the effect of nearby watershed are undervalued for some segments, and may view the results differently.

Conclusions and Recommendations

One way to make this data more useful to Harford County is a GIS map that allows the client to easily locate each susceptible area while in the field. Because the County has a GIS specialist, we created all search functionality within ArcGIS. One could bookmark each susceptible area allowing the user to get results up-close. It would be necessary to understand the County's technology to go in the field and find the identified areas. For example, could the map data easily convert into GPS coordinates to dispatch field operators? Each searchable area could include the distance from the road to the stream, the soil rating of relevant soil types, any watershed considerations, and possibly a steepness or slope evaluation. Then, in this layer's attribute table, the rating system could show the priority for each area.

Further research could also explore soil data for Harford County. A deeper analysis would examine more factors that impact soil stability. For example, given stronger storms created by climate change, are there soil types or traits that need attention? Some plant species are used in cities because of their effectiveness at holding soil together (and withstanding flooding). What plants match the soil types in Harford County? Is planting a viable option given financial and ecological considerations? Some cities are using planting enthusiastically because plant roots can hold soils together for decades.

Additionally, using the County's DEM (Digital Elevation Model) to calculate how steep the hills are that roads are built into could help understand water movement and speed, and give some indication of how much water moves down the hill. This is another indication of vulnerability. However, producing an operational slope layer in ArcMap proved to be a task beyond class limits.

Finally, exploring traffic volume could further prioritize at-risk roadways according to their annual average weekday traffic. For example, assuming that risk factors are the same, one could prioritize the maintenance of a road that sees more vehicular traffic over a less traveled route.

This project used traffic volume data for the entire state from the Maryland State Highway Administration (SHA) and cut it to only show Harford County roadways. A deeper analysis of SHA data showed only one of the County's roadways had recorded traffic data. Many of the roadways identified are rural and traffic volume on these roads may be too low for the SHA to track. This discovery nullified the use of traffic volume in our final risk index.

This report is intended to help Harford County staff find and repair roads threatened by erosion. Harford County has 438 roads at some risk and 236 (54 percent) at high or severe risk with a weighted index of road segments based on distance to a stream, watershed, and soil erodibility.

Segments within 50 feet of a stream were assigned an importance of 50 percent, calculated watershed area that made up 25 percent, and K-factor of soil that was also 25 percent. These parameters were entered into ArcGIS to generate a map that can filter and adjust the settings. The report and shapefiles are tools to deconstruct and recreate the process. The database is named "Complete_Final_Data" and metadata describe the variables.

Appendix A

Whole Rock K-factor Description

“Erosion factor K indicates the susceptibility of a soil to sheet and rill erosion by water. Factor K is one of six factors used in the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) to predict the average annual rate of soil loss by sheet and rill erosion in tons per acre per year. The estimates are based primarily on percentage of silt, sand, and organic matter and on soil structure and saturated hydraulic conductivity (Ksat). Values of K range from 0.02 to 0.69. Other factors being equal, the higher the value, the more susceptible the soil is to sheet and rill erosion by water” (Geospatial Dataset).

The erosion factor Kw (whole soil), indicates the erodibility of the whole soil. The estimates are modified by the presence of rock fragments.

Appendix B

Top 10 Roadways Presenting High Risk Rating

Street Name	Zipcode	Total	Risk Rating
LEESWOOD RD	21014	0.15080478	High Risk
WHITAKER MILL RD	21085	0.217349005	High Risk
ROCK RUN RD	21078	0.029287385	High Risk
GUYTON RD	21047	-0.042554294	High Risk
FRANKLIN CHURCH RD	21034	-0.038141778	High Risk
FRANKLIN CHURCH RD	21034	-0.038141778	High Risk
WHITE HOUSE RD	21015	-0.044430315	High Risk
WHITE HOUSE RD	21015	-0.044430315	High Risk
HARFORD CREAMERY RD	21161	-0.019383084	High Risk
WESLEYAN DR	21028	0.035158624	High Risk
OLD JOPPA RD	21085	0.307829102	High Risk

Works Referenced

All shapefiles were obtained from Harford County Planning & Zoning.

"Geospatial Dataset - (Code: 2198017)." National Parks Service, U.S. Department of the Interior, irma.nps.gov/DataStore/Reference/Profile/2198017.

Maryland Department of Transportation (MDOT) State Highway Administration (SHA). "Maryland Annual Average Daily Traffic - Annual Average Daily Traffic (SHA Statewide AADT Lines)". http://data.imap.maryland.gov/datasets/maryland-annual-average-daily-traffic-annual-average-daily-traffic-sha-statewide-aadt-lines. (accessed November 15, 2018).

U.S. Department of Agriculture (USDA). Understanding Soil Risks and Hazards: Using Soil Survey to Identify Areas with Risks and Hazards to Human Life and Property. Washington D.C.: 2004.

U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NCRS). "Web Soil Survey". https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. (accessed November 15, 2018).

U.S. Department of Agriculture (USDA). Understanding Soil Risks and Hazards: Using Soil Survey to Identify Areas with Risks and Hazards to Human Life and Property. Washington D.C.: 2004.

RUSLE - An online soil erosion assessment tool. (2002). K Factor (I., Ed.). Retrieved November 14, 2018, from http://www.iwr.msu.edu/rusle/kfactor.htm