Finding Vulnerable Roads in Harford County

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Introduction

Climate change has induced more extreme weather in recent years and Harford County and the surrounding region has experienced more frequent and intense storms. Flooding in Harford County, caused by the increase in storms, generated many instances of roads washing out, which have caused severe damage and created unsafe driving conditions. The issue has necessitated considerable use of public resources.

Unfortunately, county budgets are limited, and staff resources are thin. Mitigation is the most cost-effective tool to reduce damage and associated costs; therefore, the county requires a tool that can more effectively identify vulnerable roadway segments. By working with the PALS program at University of Maryland, College Park, the county has identified an opportunity to work proactively and better meet the road safety obligations of the Public Works Department and the Division of Highways.

As part of the PALS program, the team used data processing tools and GIS mapping technology to help the county preserve their roadways. Through ongoing conversations, the county worked with the team to create a tool that meet their needs by identifying roads at risk. Vulnerable segments have been identified and prioritized so county staff can plan road reinforcement projects in a more cost-effective manner.

Along with a map of identified at-risk road segments, the team has created an interactive web app that allows an in-depth of analysis of at-risk roads, a geodatabase with watershed and soil analysis, and a presentation that reviews key findings. This report reviews the background research, the GIS methods used, the results and their implications for the county, and suggestions for moving forward. The goal, as GIS technicians and community planners, is to serve the interests of the county by providing tools to better predict instances of road failure.

Data and Background Research

Data collection primarily relied on county-supplied GIS datasets and publicly available GIS Online tools and datasets. County GIS specialists supplied GIS data packages that included: the county boundaries, centerline files that designate county roadways, contours files of elevations within the county, soils data classifications that provided a preliminary erodibility rating, land use data files, and streams data.

To make the data usable for this project the team examined the roadway, stream and soil data for errors and unnecessary information. Roadways were categorized by ownership and only roads owned and maintained by the County were used. The “shield” field in the centerline data file designates the road’s owner; “C” designates County ownership. Stream data were separated into four classifications, class 4 streams, which are the smallest and included drainage ditches and roadside water collection trenches, were eliminated from the data set prior to further analysis.

To create a useful soil erosion index the team researched and categorized the county-supplied data. Soil erosion is a factor of stream volume and the soil type’s erodibility. The erodibility of a soil type is measured by the K-factor, which reflects soil texture, permeability, structure, and organic matter content. Using the tools created by the Vermont Environmental Conservancy, the team took an average of soil composition by soil type and determined approximate K-factor values ranging from the lowest erodibility, 0.02, to the highest, 0.69. All factors being equal, the higher the K-factor, the greater the susceptibility of the soil to rill and sheet erosion by rainfall. In general, soils with greater permeability, higher levels of organic matter, and improved soil structure have a greater resistance to erosion and, therefore, a lower K-factor. The presence of silt, very fine sand, and clays with a high shrink-swell capacity tend to increase the K-factor, whereas sand, sandy loam, and loam textured soils tend to be less erodible.

To cross-check results, the team compared the output of this initial analysis with the U.S Department of Agriculture Natural Resources Conservation Service Web Soil Survey. In the Web Soil Survey, we set Harford County as our “area of interest” and collected the data that ranked the county’s soil types. This ranking was created to indicate the likelihood of soil loss from unsurfaced roads and trails. While this study addresses paved roads, Web Soil Survey information should be reliable for assessing soil loss on streambanks. The USDA rating is based on “soil erosion factor K, slope, and content of rock fragments” (U.S Department of Agriculture Natural Resources Conservation Service, 2018). Their information was limited to a ranking of slight-moderate-severe. To add this information to the Harford analysis, it was recoded to a ranking of 1-slight, 2-moderate, and 3-severe. The team’s analysis of soil type, while more specific in finding the K-factor, doesn’t consider account slope. For this analysis, the team used the Web Soil Survey information to rank roads and left the K-factor analysis as further information available for the county.

The information is combined with our watershed analysis in the web app to provide more information to users as they explore identified road segments. When roads are clicked, the available soil erodibility information is divided into three classifications: slight, moderate, and severe.

The contour data was not used to determine watershed area. For watershed analysis the team used an ArcGIS Online tool that did the calculation based on proprietary contour data. From research in soil erodibility the team determined that watershed calculations would be the only category by which to rank the road segments. The team determined that any attempt to combine the soil type and watershed area data would yield a unreliable result because the relationship cannot be accurately measured with the available data. Possible solutions to this issue are elaborated on in the Future Research section.

Even without a soil erodibility/watershed area index, the tool should still prove useful to the county because research suggests water volume is a much higher factor in erodibility than soil science could reasonably predict.

Methods and Methodology

Once collected, the county data was organized to ensure that everything needed was available. The team then looked at where road and stream segments interacted, separating out the county-maintained roads from the centerline file and eliminating the bridges from the road segments. Since the stream sections were split into four separate files the team used a “spatial join” to merge all four files. A further review of the data showed that the fourth stream file contained data that wasn’t helpful for the analysis and it was culled from the combined stream file. To account for the amount of water at each road segment we used the ArcGIS Online “watershed” tool to calculate the watershed area.

Streams

Stream data appeared in four files, roughly by size of stream. Stream file four was discarded because it was mostly stormwater management infrastructure and gullies only temporarily filled with water. The other three streams files were combined with a “spatial join” to create one shapefile (see Figure 1).

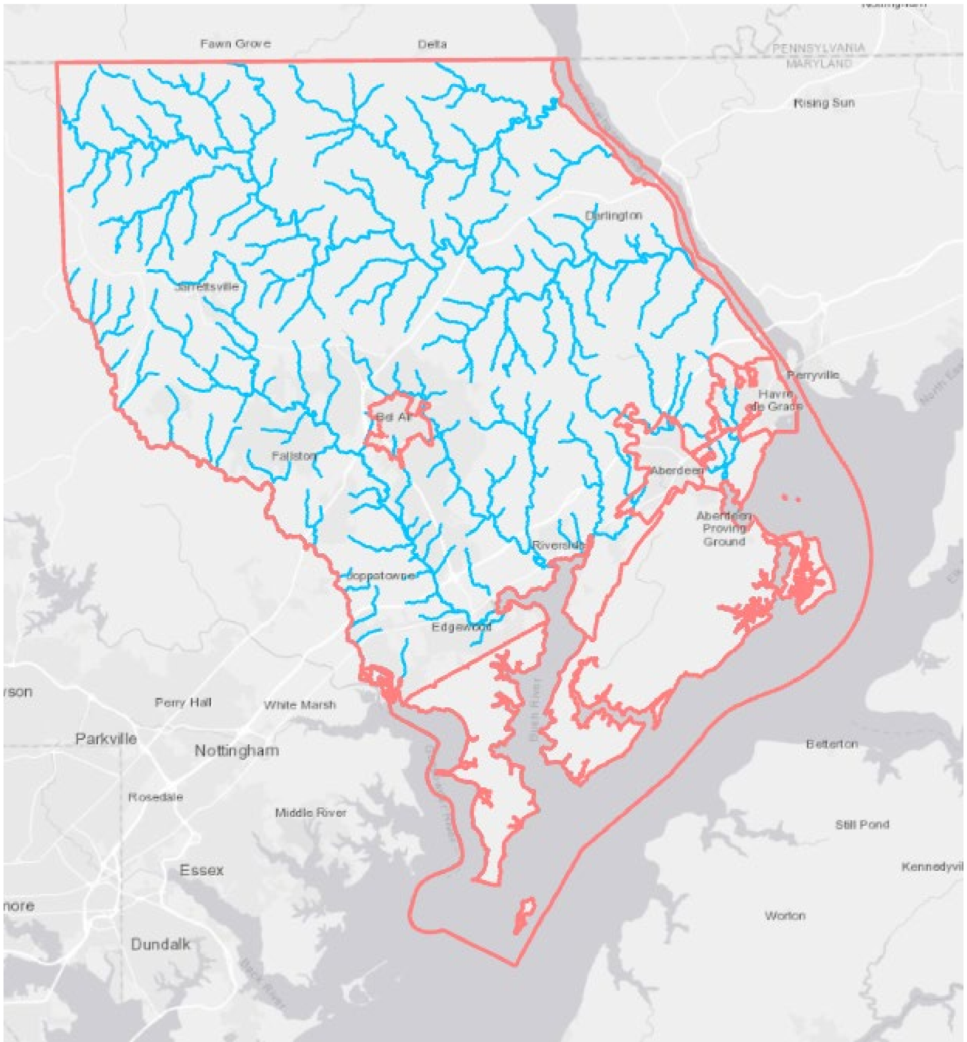

Figure 1: Combined stream data files

In the finalized stream file, a 50-foot buffer was applied the stream line segments to determine road segments that were within 50 feet of a stream (see Figure 2).

Figure 2: 50-foot buffer applied to a stream segment

Roads

Data on Harford County roads was provided in a centerline file that contained all roads in the county. This project only analyzed the county-owned roads maintained by Harford County Public Works Department. To determine ownership of the 14,754 road segments the “shield” attribute was sorted with 10 different ownership codes (1,027 segments were blank) (see Figure 3).

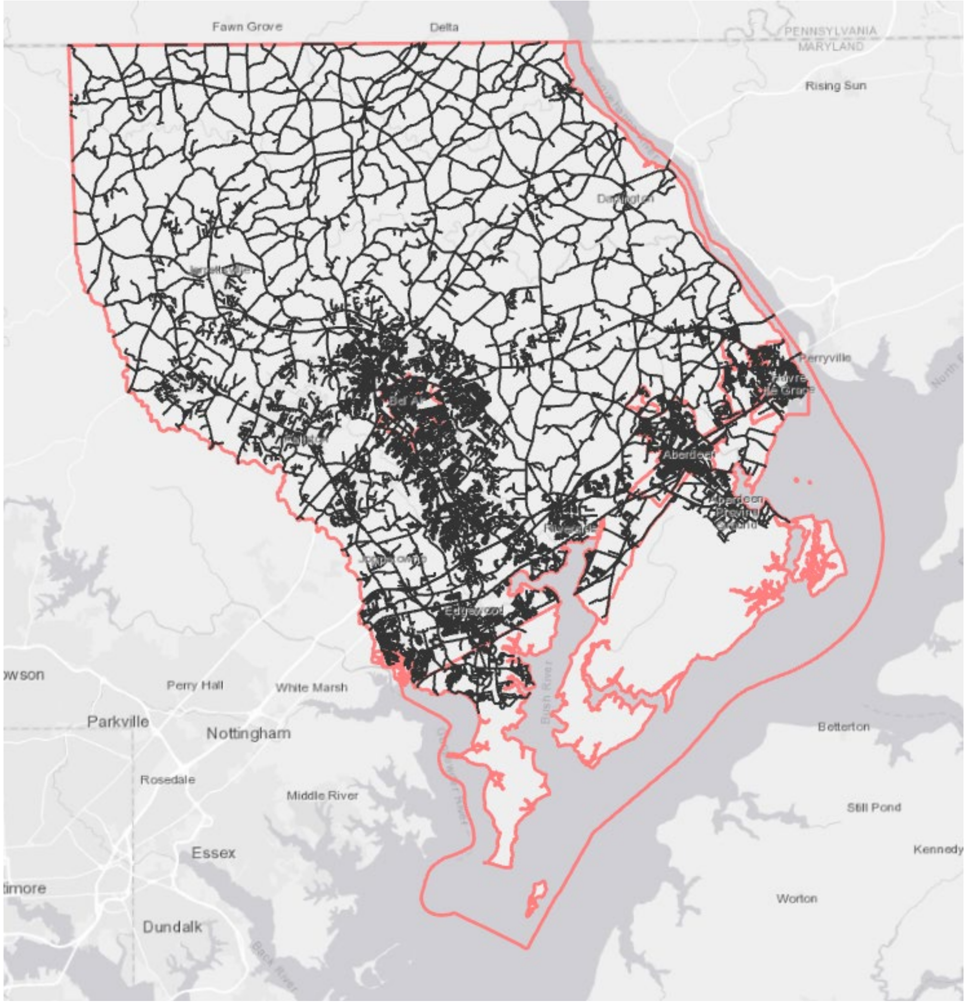

Figure 3: All road segments in Harford County

County roads were designated with a “c” in the “shield” field and exported as a separate shapefile showing 7,395 road segments with a total length of 5,701,927.721 feet, more usefully, 1,079.91 miles (see Figure 4).

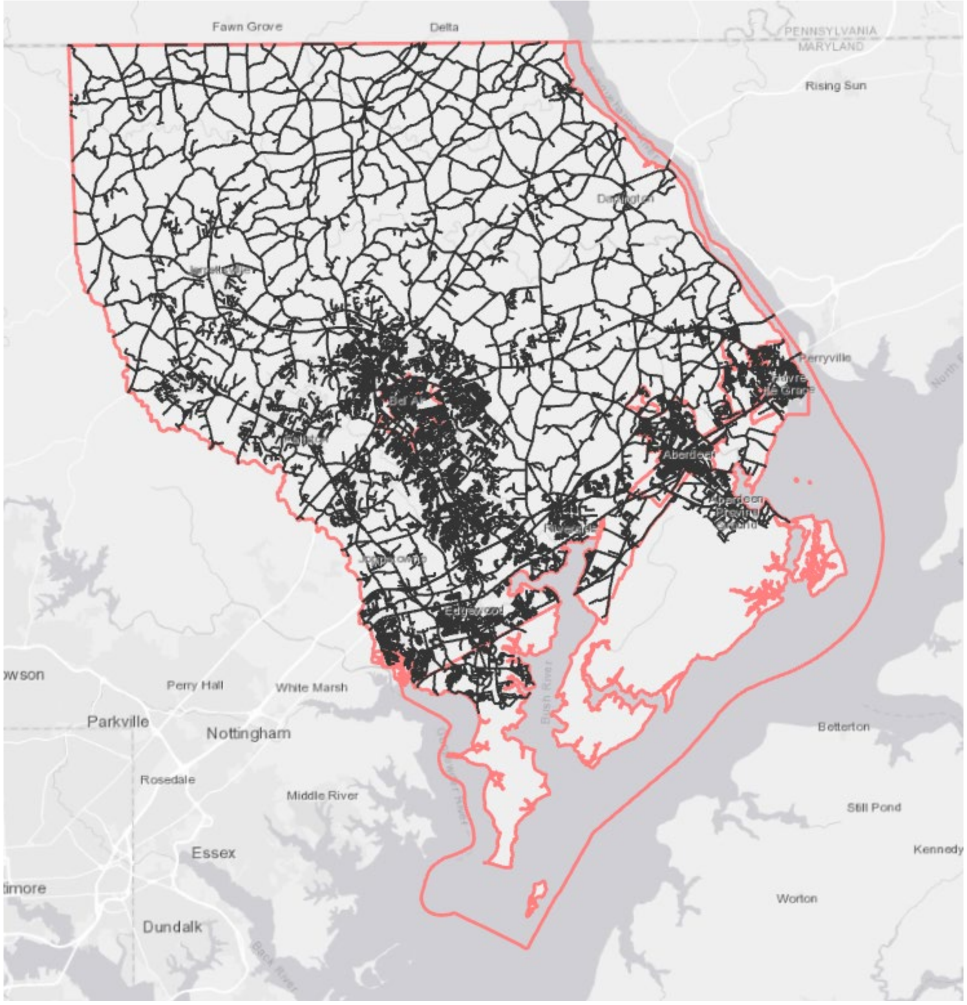

Figure 4: County roads after applying a “select by” tool

Next, bridges data file was imported and marked with 50-foot buffers around all bridges (see Figure 5). The team then used that buffered file to clip the county-owned road sections to eliminate the bridges from at-risk road sections and to prevent bridges from qualifying as road segments within 50 feet of streams (see Figure 6). After clipping out the bridges, there were 7,380 road segments.

Figure 5: Bridges with a 50-foot buffer applied

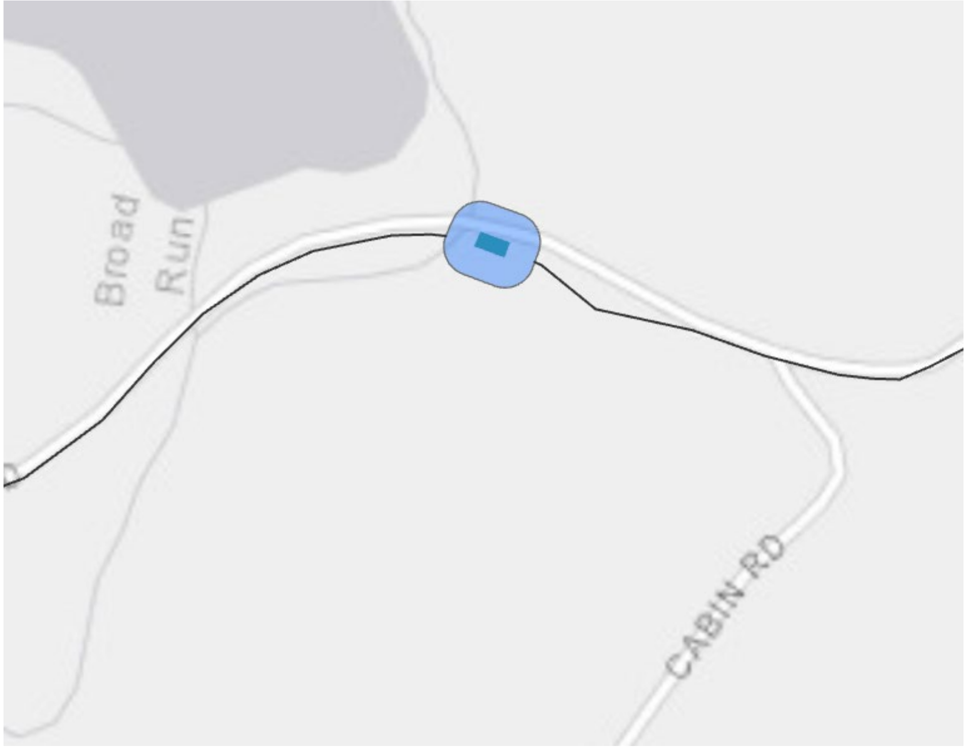

Figure 6: Road segment clipped by bridge with 50-foot buffer

The next step was to find the remaining road sections within 50 feet of a stream. The team used the stream file with a 50-foot buffer to clip the 7,380 road segments, resulting in 310 segments (see Figure 7).

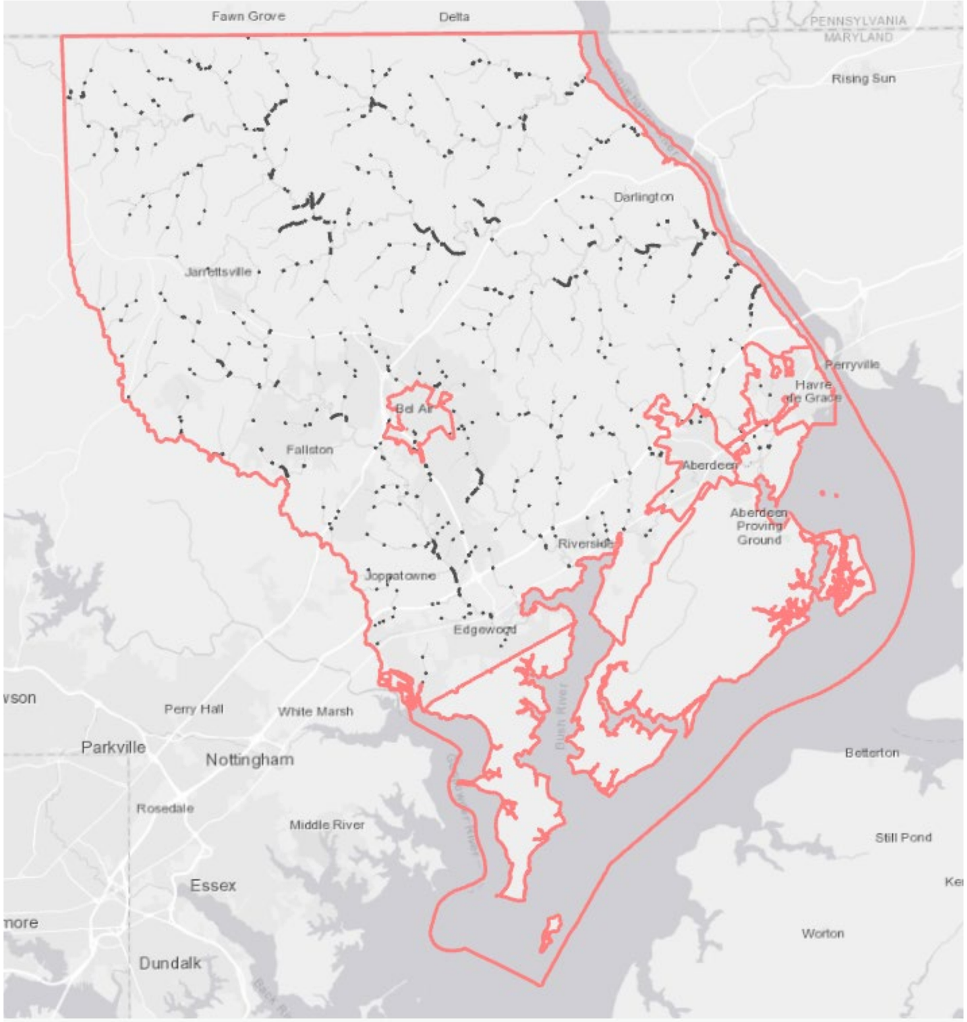

Figure 7: The 310 county-owned road segments within 50 feet of a stream

Watersheds

Once the team determined the 310 county-owned road segments within 50 feet of a stream, it needed to determine the watershed area of each segment, using the ArcGIS Online "watershed" tool, which uses a point feature to calculate watersheds (the upstream contributing drainage area) for each point. To calculate a point for each road line segment the team used the “feature to point” tool, which created a feature class designating the centroid of the line segment as a point (see Figure 8).

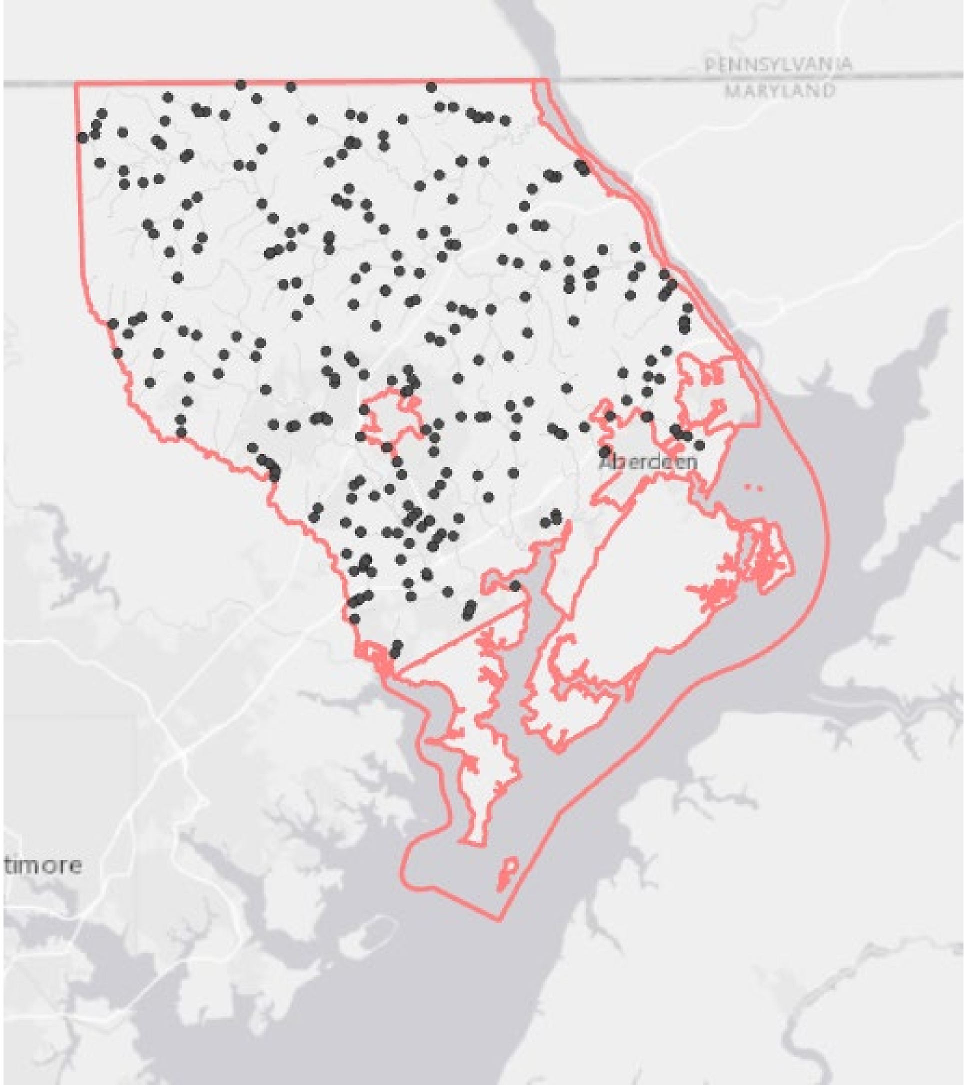

Figure 8: Centroid point of each road segment

The file containing the centroid of each road segment was loaded into ArcGIS Online’s “watershed” tool. According to the software: “If your input points are located away from a drainage line, the resulting watersheds are likely to be very small and not of much use in analysis, such as determining the upstream source of contamination. In most cases, you want your input point to snap to the nearest drainage line in order to find the watersheds that flows to a point located on the drainage line. To find the closest drainage line, specify a search distance. If you do not specify a search distance, the tool will compute and use a conservative search distance."

The team didn't designate a specific distance but allowed the tool to designate the closest drainage line. According to ESRI, within the "watershed" tool "for analysis purposes, drainage lines have been precomputed by ESRI using standard hydrologic models." There was very minimal movement from the team's points to the designated points used by the "watershed" tool (see Figure 9).

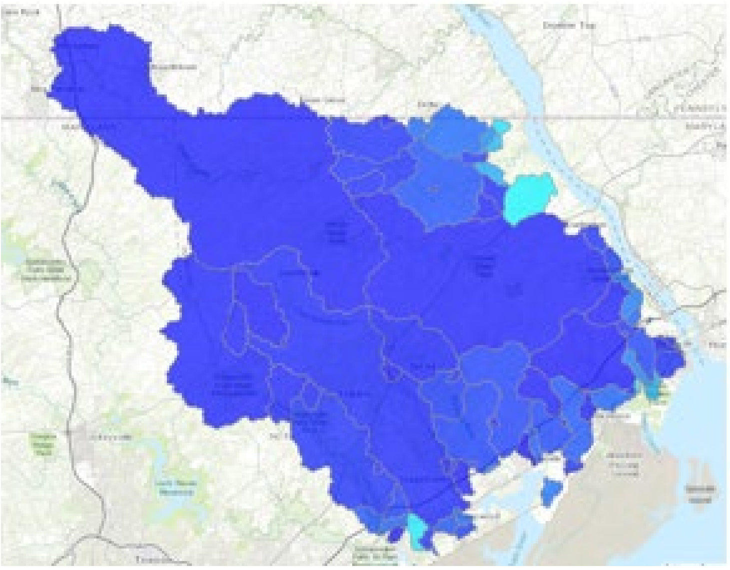

Figure 9: "Watershed" tool output

Results

Our group used a few tools to provide the county with information to make as informed decisions as possible. At the county's request, the team provided a static map that can be used for simple, quick reference or trend analysis. With the static map, users can interpret trends like clustering of higher risk roads that follow major waterways. The web app allows more flexibility regarding data input. The static map used a 50-foot buffer on the roadways and trimmed those roadways where they intersected with a bridge. The web app allows for a custom input of road distance from a stream, watershed area, and soil erodibility level based on a soil risk index. This flexibility should allow the county more insight than the static map. The web app also leaves room in the initial analysis for any updates to the county's future research. Finally, the team's web map would be the tool most useful to the county. It has the same information as the static map but also allows department staff to interact with the results. Clicking on a segment will bring up key information including the road's name, soil erodibility, soil type, and watersheds.

Analysis of Static Map

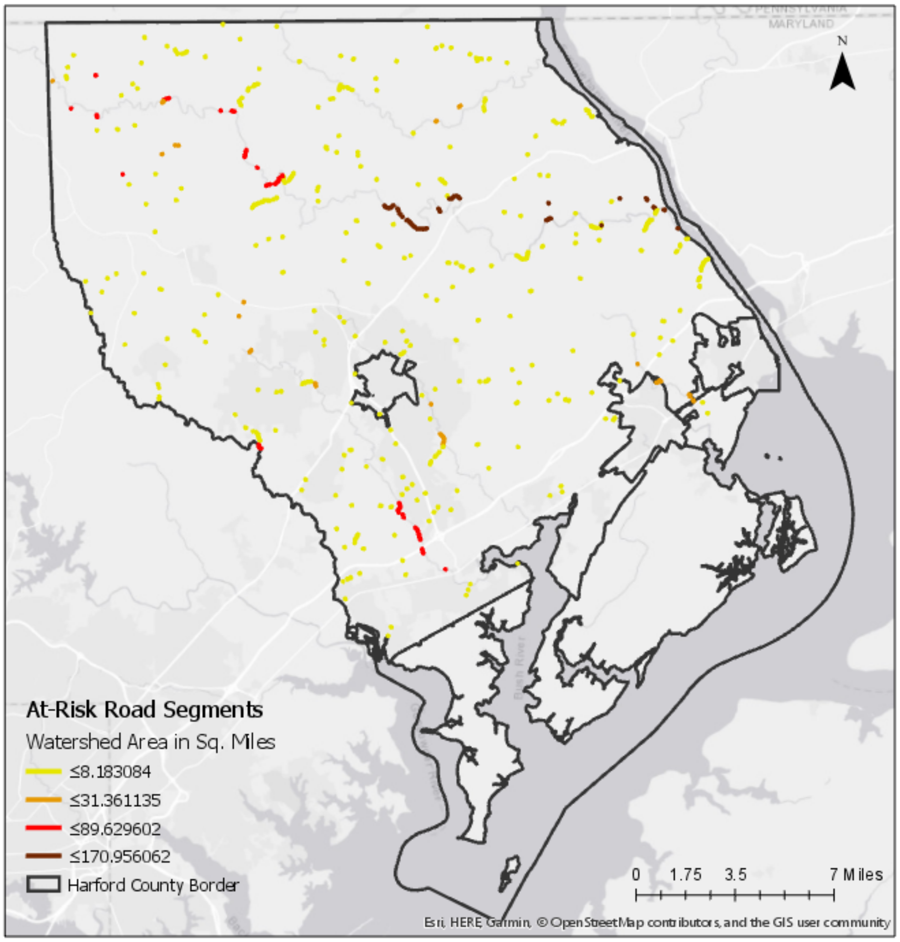

Figure 10: Static map of at-risk road segments

The static map shows significant clusters of high-risk segments, which generally follow major waterways, consistent with the team's hypothesis. The ranking is based the fact that in a larger watershed, the impact of a storm has a higher impact increasing water volume and speed. Table 1 shows the watershed area of each risk category, separated into four categories by the natural breaks (Jenks Breaks) method.

Table 1: Description of watershed area range in each risk category

Rank	**Watershed Area (Sq-mi)**
Low	0.0 - 8.2
Mild	8.3 - 31.4
Moderate	31.5 - 89.6
Severe	89.7 - 171.0

Roadways near major waterways should be at highest risk. In Harford, smaller waterways to the south and tributary waterways in the west show a similar clustering pattern. Most road segments were categorized as low risk. They don't cluster as tightly as high-risk segments. The scattered pattern also follows in line with the team's hypothesis. These segments are parts of roads abutting creeks or small tributaries that are scattered throughout the county. These roads may not need to be prioritized due to the relatively small watershed that feeds them and a lower capacity to cause quick erosion and road degradation.

Recommendations

Figure 11 shows the scope of the road risk relationship demonstrated by the static map.

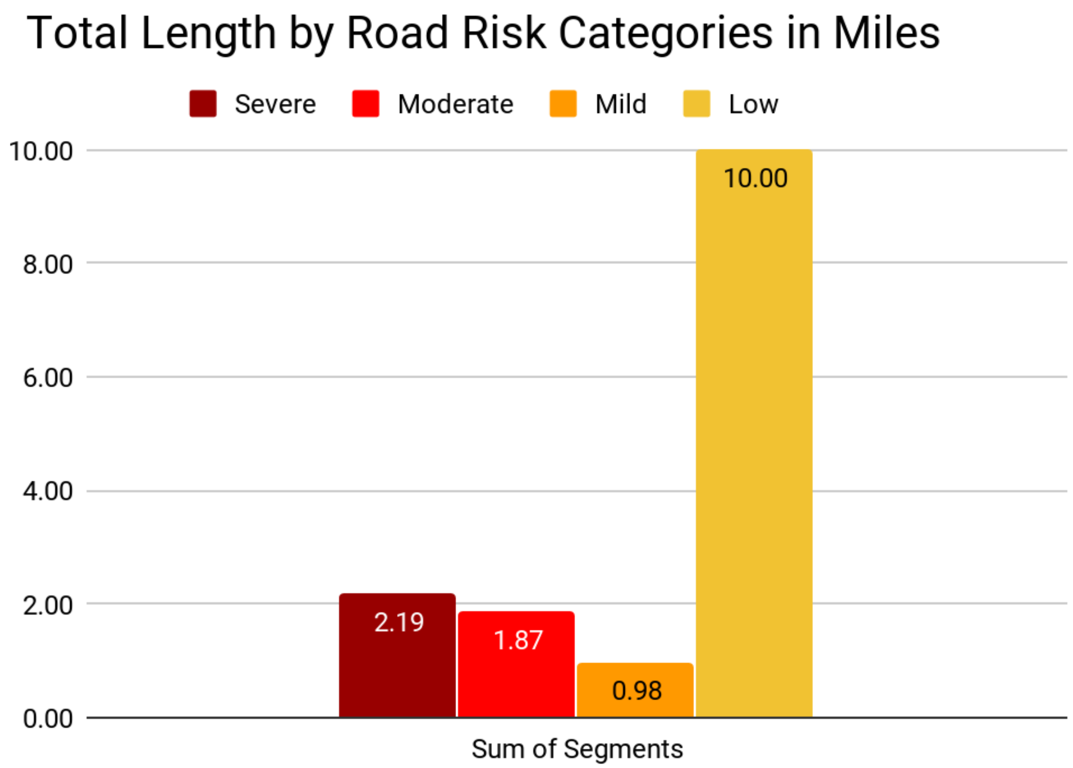

Figure 11: Graph of total length of at-risk roads by risk category

The graph shows the total distance of roads by category. The severe category, which may necessitate survey by field technicians, encompasses 2.19 miles of county roads. This area is highly clustered, which is helpful logistically. Roads classified as moderate risk may also require surveillance and total 1.87 miles. Roads at mild risk cover .98 miles. Due to the total length and spatially scattered nature of low-risk roads, the county must decide how much can be monitored. The team was asked to include the top 200 road segments, however, due to the nature of the data we believe this graph is more useful to the county to conceptualize the scale of public resources required to address the roads most at risk.

Table 2: Statistics of related road risk categories

	Risk									
	Severe		Moderate		Mild		Low		**Total**	
Mean	0.27mi	1444ft	0.12mi	657ft	0.05mi	259ft	0.04mi	201ft	0.05mi	**258ft**
Sum	2.19mi	11549ft	1.87mi	9848ft	0.98mi	5179ft	10mi	52774ft	15.03mi	**79356ft**
Minimum	0.01mi	36ft	0mi	1ft	0mi	2ft	0mi	0ft	0mi	**0ft**
Maximum	0.69mi	3639ft	0.71mi	3758ft	0.36mi	1922ft	0.52mi	2766ft	0.71mi	**3758ft**
Count	**8**		**15**		**20**		**263**		**307**	

Table 2 shows that the mean segment length of roads of all risk types is 258 feet. This is an important observation for understanding the high segment count. Most of the segments are specific points on roads rather than large segments of roads. The results are careful here to not dismiss low-risk roads, as an analysis of watersheds is not the same as floodplains. Lower risk segments may have a small watershed but if they feed into an area of severe risk, they could still face flooding, which will impact the roads. The static map is useful for understanding the spatial relationship of proximity and waterways, which could have the highest impact on road degradation but does not consider every factor.

Opportunities for Future Research

Information on Instances of Failure

To improve outcomes the county can improve data collection in a few areas. Foremost would be to track the locations and conditions of future road failure sites. The next team of GIS researchers can geocode the locations and extract a trend of watershed size, soil type, stream proximity, and floodplain location. The team's geodatabase includes information on the soil index and water drainage areas. Proximity can then be calculated by the program. With tracked instances of road failure, GIS' linear regression function can show the relative weight of each variable and allow a more accurate predictive map to be created. The process would require having location points as a dependent variable and the watershed area, soil index, stream proximity, and floodplain location as independent variables. This map will become more useful as more data becomes available. It would be worthwhile to examine county records to find and track locations that have needed repairs in the past.

Citizen Scientists

To improve monitoring of low-risk roads in rural areas the county can lead workshops and offer information online about being a Citizen Scientist. Citizen Scientists are volunteers who, with some introductory training, can provide high quality data. They could check on identified areas and can provide more thorough information on instances of road failure. More information on how to start such a project can he found at http://citsci.org/ .

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