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Extreme precipitation-based vulnerability assessment of road-crossing drainage structures in forested watersheds using an integrated environmental modeling approach

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ABSTRACT

The goal of this study is to develop geospatial-hydrology models incorporating design rainfall intensities and land morphologic features to identify erosion hazards and vulnerability risks to road culverts/stream crossings in three watersheds at USDA Forest Service long-term experimental forests: i) Coweeta Hydrologic Laboratory, NC, ii) Santee Experimental Forest, SC, and iii) Alum Creek Experimental Forest, AR. These models developed in an ArcGIS ModelBuilder platform were: i) Streambank Erosion Vulnerability Assessment (SBEVA) and ii) Modified Revised Universal Soil Loss Equation (MODIFIED-RUSLE) for potential erosion and streambank vulnerability estimation. The SBEVA model, developed using a Delphi-based weighted-probability scale, and MODIFIED-RUSLE were integrated to identify locations of culverts/stream-crossings morphologically vulnerable to erosion and scouring, which were ground-truthed for the SC site only. As the MODIFIED-RUSLE model does not assess streambank erosion, its integration with the SBEVA helps to develop a better decision-support tool for relevant agencies for safeguarding these road culverts/stream crossings.

1. Introduction

Climate change is expected to lead to more frequent extreme precipitation events (Kundzewicz et al., 2014), flooding, and landslides, potentially enhancing the probability of road closures and other incidents such as roads being washed away due to culverts or bridge failures, as a worst-case scenario (Kalantari and Folkeson, 2013). USDOT (2018) identified heavy precipitation and flooding as the vulnerability most closely related to the road culvert systems, among four different climate change-related vulnerabilities of forest transportation networks (Filosa et al., 2017). Projected increases in the intensity and frequency of precipitation events due to climate change (Easterling et al., 2017) may further exacerbate flooding, increasing risks of road drainage and culvert failures due to their limited carrying capacities (USDOT, 2002). Therefore, stronger demands will be placed on the functionality of road drainage systems in such extreme events (Rees et al., 2018). Urban drainage systems can be quickly assessed, while road-crossing drainage structures and stream crossings in remote forest lands will need proactive management to prevent the occurrence of such casualties due to their inaccessibility. The U.S. Department of Agriculture (USDA) Forest Service (FS) manages a road system consisting of approximately 600,000 km of roads and at least 40,000 stream crossings (i.e., road leadoff structures, fords, culverts, and bridges) (Heredia et al., 2016). These structures, most of which are located in forested headwater watersheds with small drainage areas (catchments), need an accurate estimation of peak storm discharge rates from watersheds for the design of drainage works along roadways and related infrastructure (Mannering and Kilareski 1998). According to the U.S. Department of Transportation (USDOT, 2018, most road crossings in the United States, including the ones in forested watersheds, are currently considered undersized for accommodating bankfull flow conditions that could occur about 1 or 2-years.

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Climate change-induced extreme precipitation (Jalowska and Spero, 2019) and corresponding peak discharge events including their methods of estimation could have major consequences for improperly sized stream crossing infrastructure (Amatya et al., 2021) located in headwater forested watersheds with small drainage areas. Other than the extreme discharge, the inherent scientific reasoning for such structural failures is precarious. The amount of rainfall does influence the moisture content in soil (Dawson, 2009), but the time delay between the precipitation event and the consequent subgrade moisture content increase can vary from an almost immediate effect to a delay of up to a month (Fifer Bizjak et al., 2014). This is because the soil, road surface, drainage, and surrounding conditions can all strongly affect the response of the road to rainfall and, most importantly, road scouring will increase due to this microclimatic effect (Fifer Bizjak et al., 2014). When rainfall water reaches the unbound subgrade, destabilization can take place if the drainage system is not able to remove it quickly; especially in cohesive soil, drainage clogging would occur with subsequent structural failure (Fifer Bizjak et al., 2014). This structural failure would cause significant challenges associated with increased runoff, soil erosion and sediment yields, economic losses, and disruption of stream connectivity, thereby creating barriers to aquatic organisms (Heredia et al., 2016). The FS developed an ecological stream simulation approach for designing and building road-stream crossings intended to permit free and unrestricted movements of any aquatic species (USDA 2008). The approach applies to crossing structures on any transportation network, including roads, trails, and railroads. At the same time, safe and cost-effective hydraulic design with minimum maintenance is critically important to accommodate extreme flow that may occur during the useful life of these structures (Novak et al., 2007) that could minimize siltation and scouring.

With regard to soil erosion-based vulnerability, stream bank erosion is expected to cause more infrastructure failures as forest roads are established in high-gradient watersheds and in areas receiving higher precipitation amounts than average watersheds. According to the U.S. Environmental Protection Agency (EPA, 2020), sediment from streambank erosion that contributes 80% (Cancienne et al., 2008; Langendoen and Simon, 2008; Wilson et al., 2008) of the sediment yield has been listed as one of the major and common causes of stream impairment. In forested watersheds, high precipitation on steep terrains could cause hillslope failures or landslides, exacerbated by elevated antecedent soil moisture, and debris flows that would be detrimental to the safety of road infrastructure. Soil scientists have analyzed gentle slopes and found that gully erosion, which is a form of hillslope failure, can be a significant source of stream sediment. A staggering 44% of the total soil erosion worldwide (Poesen et al., 2003) and 35% of the total soil loss in the United States (NRCS, 2020) were due to gully erosion. Historically, the emphasis of erosion research has been on sheet and rill erosion and gully erosion with a hydrologic focus on surface flow processes (NRCS, 2020); thus, the Universal Soil Loss Equation (USLE), Revised USLE (RUSLE), Modified USLE (MUSLE), and the recent version RUSLE2 are often used to assess surface flow-induced soil erosion losses. However, due to the lack of experimental observations and insufficient understanding of processes governing total runoff generation, consideration of subsurface flow contributions to such erosion processes leading to landslides and streambank erosion has largely been neglected in assessments and prediction technologies (Fox and Wilson, 2010).

Emphasized by Laniak et al. (2013) in their comprehensive review article in Environmental Modeling and Software, complex environmental issues need integrated environmental modeling (IEM) approach. IEM is inspired by contemporary environmental problems, like the one under study here, which warrant higher-order systems thinking and holistic solutions (EPA US Environmental Protection Agency, 2008; Jakeman and Letcher, 2003; Parker et al., 2002). An IEM approach to the holistic geospatial study of the dynamic and interdependent nature of forest topography, soil characteristics, antecedent soil moisture, vegetation dynamics, the extent of climate change-induced extreme precipitation, and many other environmental features that contribute to the study of physical engineering distress is needed more than ever. Laniak et al. (2013) correctly underscored that IEM concepts and early models are now more than 30 years old (Bailey et al., 1985; Cohen, 1986; Mackay, 1991; Walters, 1986). With the emergence of issues related to regional-scale spatial land-use management, climate change, and ecosystem services (Laniak et al., 2013), similar to our study, there is a critical need for a different approach to combining geospatial watershed management models such as ArcHydro, RUSLE2, and the innovative Streambank Erosion Spatial Vulnerability Assessment (SBEVA), etc., to develop a practical management decision-support system. This is explained by David et al. (2013) through their review article on the Object Modeling System in Environmental Modeling and Software.

Accordingly, the main goal of this research is to develop a comprehensive geospatial-hydrology model incorporating extreme precipitation and spatial land morphologic features, as an IEM approach, to identify erosion hazards and vulnerability of the road culverts and stream crossings employing data from three different watersheds at FS experimental forests (EFs) in the Southeastern United States. The objectives of the study are to.

i) determine spatial locations of road culverts and stream crossings using high-resolution stream networks defined by conducting hydrologic analysis of the watersheds in Arc Hydro model platform (Maidment and Morehouse, 2002);
ii) conduct on-site verifications of the geospatially determined locations of culverts using data from the FS;
iii) spatially locate/identify road culverts and stream crossings with erosion vulnerability (in low, moderate, and high scales) using the RUSLE2 model (Foster et al., 2003), modified further as MODIFIED-RUSLE and the SBEVA model developed in this study, both in the ArcGIS ModelBuilder platform; and
iv) determine the resultant scale-based vulnerable culverts and stream crossings in each of the study watersheds by combining results from both the models (MODIFIED-RUSLE and SBEVA).

2. Materials and methods

2.1. Study area

This study was conducted in three FS experimental forest watersheds in the Southeastern United States, varying in size, soils, topography, forest vegetation, and climate, and representing (i) high-relief mountains in North Carolina (NC), (ii) moderate-relief mountains in Arkansas (AR), and (iii) low-relief coastal plain in South Carolina (SC) (Fig. 1).

The study watersheds in NC (35°03′ N, 83°25’ W) are located at the Coweeta Hydrologic Laboratory (CHL) in the Appalachian Mountain Range within the Blue Ridge Physiographic Province (Fig. 1). The Coweeta Basin (1626 ha) has a humid temperate climate with a long-term average annual precipitation ranging from 1794 mm at lower elevations to 2368 mm at high elevations (Laseter et al., 2012). Soils are moderately well-drained on moderate to steep slopes. Two reference watersheds (low-elevation WS14 and high-elevation WS27) were selected for this study due to the large elevation-induced climate gradient between the two locations (Amatya et al., 2021). The mean annual precipitation in WS27 (39 ha) and WS14 (61 ha) varies widely, with 2316 mm/yr and 1842 mm/yr, respectively. The WS27 and WS14 watersheds, with mean elevations of 1254 m and 878 m, respectively, have mean slopes of 57% and 50%, respectively. The vegetation cover in both watersheds is mixed hardwood.

The second study site (AC04) in Alum Creek, AR is located within the 1885-ha Alum Creek Experimental Forest (34°48′ N, 93°3’ W) within the upper Lake Winona basin of the Ouachita National Forest (Fig. 1). The AC04 watershed, studied in this research, has a drainage area of 13 ha with a mean elevation of ~300 m and a mean slope of ~15% (Amatya

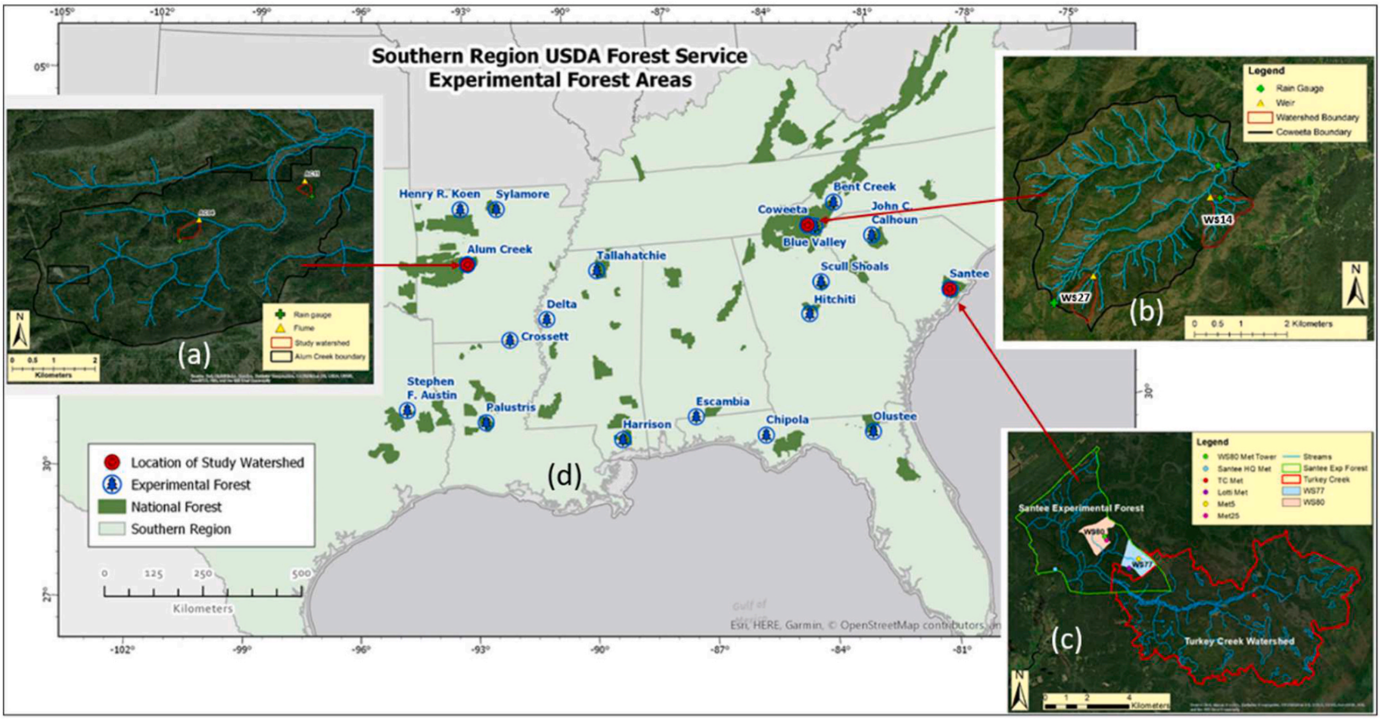


Fig. 1. Locations of the study watersheds: (a) Alum Creek Experimental Forest, Arkansas; (b) Coweeta Hydrologic Laboratory, North Carolina; (c) Santee Experimental Forest, South Carolina; and (d) regional map (Produced from Amatya et al., 2021).

et al., 2021). The AC04 watershed is characterized by a humid subtropical climate with mean annual precipitation of 1321 mm/yr. Soils are generally less than 1 m deep, with high infiltration rates. The vegetation cover in the watershed is pine hardwood. A detailed description of the watershed is provided by Adams and Loughry (2008).

The third study site is the Turkey Creek watershed (WS78) draining a third-order stream with an area of 5240 ha (Fig. 1). at Santee Experimental Forest (33° 08′ N, 79° 47’ W) within the Francis Marion National Forest (FMNF) (Amatya et al., 2015). WS78 is adjacent to the WS80 watershed studied together with the two above watersheds by Amatya et al. (2021). The watershed is the headwaters of East Cooper River, a major tributary of the Cooper River, which drains to the Charleston Harbor. The topographic elevation of the watershed varies from 3.6 m at the outlet to 14 m above mean sea level. This coastal site has a subtropical climate with hot and humid summers characterized by high-intensity, short-duration storm events and moderate wet winters generally with low-intensity, long-duration rain events. Seasonally, the summer is characterized by tropical depression storms that are not uncommon. The average annual daily temperature and average annual precipitations are 18.4 °C and 1370 mm, respectively (Amatya et al., 2015). Vegetation cover within the watershed is mostly comprised of pine forest. It is instrumented with a real-time stream gauge sensor and a rain gauge (http://waterdata.usgs.gov/sc/nwis/uv?site_no=02172035) operated and managed by the U.S. Geological Survey (USGS).

2.2. Data and software

The following data were used in the development of the three automated geospatial-hydrology models: watershed characterization using ArcHydro tool, MODIFIED-RUSLE model-based road infrastructure-related watershed erosion distribution, and SBEVA model-based streambank erosion vulnerability analysis. The sources of the data collected for the three EF watersheds are provided in parentheses:

- Precipitation (Parameter-elevation Regressions on Independent Slopes Model (PRISM), 900-m) data (USDA Natural Resources Conservation Service (NRCS) Geospatial Data Gateway, https://datagateway.nrcs.usda.gov/)
- 100-yr, 30-min. rain intensity data (NOAA Precipitation Frequency Data Server (PFDS), https://hdsc.nws.noaa.gov/hdsc/pfds/)
- gSSURGO (10 m) data (NRCS Geospatial Data Gateway, https://datagateway.nrcs.usda.gov/)
- LiDAR elevation data (1.5-m) for WS80 (SC Department of Natural Resources, https://www.dnr.sc.gov/)
- 3-m Digital Elevation Model (DEM) for Alum Creek and Coweeta watersheds (NRCS Geospatial Data Gateway, https://datagateway.nrcs.usda.gov/)
- Tiger Road 2010 data (U.S. Census Bureau, www.census.gov)
- National Agricultural Imagery Program (NAIP) 1-m land-use data (USDA Farm Service Agency, https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/)
- ArcGIS 10.3 (ESRI™, Redlands, CA)
- Arc Hydro (ESRI™, Redlands, CA)
- ArcMap ModelBuilder (ESRI™, Redlands, CA)

Other spatial data such as forest road and digitized culverts, trail network, low-resolution stream network, watershed boundaries, etc., were obtained from the FS EF geospatial database (Amatya and Trettin, 2021; Caldwell, 2019; Marion, 2019). In addition, we conducted detailed field verification of all possible road culverts and their locations using a GPS unit and mapped them for our analyses.

2.3. Procedure

This IEM approach-based study was completed with a synchronous integration of two advanced automatic geospatial models (MODIFIED-RUSLE and SBEVA) with ArcHydro tool through professional expert knowledge assimilation using Delphi-based weighted matrices. Arc Hydro model helped provide detailed stream networks, all possible road-drainage structures and stream crossing locations, and the associated catchments for each location using the LiDAR-based high-resolution DEM reconditioning and step-by-step hydrologic analyses. The Arc Hydro procedure eased the task of locating coordinates, which otherwise would have been cumbersome and time-consuming to do manually. Fig. 2 provides a comprehensive approach schematic of the entire study to achieve our research goal.

The RUSLE2 model, a modified form of a current USDA Agricultural Research Service (ARS) model, provided detailed pixel-based soil loss and total annual sediment load estimates at the locations of interest using climate change-associated and historic data-based precipitation data (NOAA Atlas 14, https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html) and detailed high-resolution land-use and soil spatial data of the studied watersheds. SBEVA model analysis provided information about streambanks that may be vulnerable due to their susceptibility to bank erosion, which could easily clog stream crossing pathways and cause subsequent scouring and ultimate failure of the road culverts.

2.3.1. Arc Hydro supported geospatial model development for stream/road crossing structures inventory development

As pointed by USDA Forest Service (USFS) and Federal Highway Authority (FHWA) field engineers, the detailed and total number of stream/road crossing structures like culverts and bridges in the forested watersheds are absent; we developed an automated geospatial model aided by ArcHydro to develop an accurate inventory. An available geospatial database for each of the EF study sites was updated using the latest remote sensing data including LiDAR, aerial photography, and localized field soil sample testing (Unpublished data) for soil database development. Arc Hydro model as an add-in to ArcGIS 10.3 was used to delineate high-resolution stream networks (which differed from National Hydrography Dataset (NHD)-created stream networks along with other digitized streams) using the high-resolution 1.5-m LiDAR-based DEM for the WS80 watershed (Photo Science, 2007) and the 3-m DEM downloaded from the NRCS Geospatial Data Gateway for other watersheds to reflect actual conditions. Arc Hydro is capable of terrain preprocessing like DEM reconditioning, fill sinks, fill pits, terrain morphology, watershed processing, attribute tools, and network tools for both vector and raster processing (Strager et al., 2010) and works efficiently for forested watersheds (Simões, 2013). The Fill Sinks tool was used to fill the depressions within the LiDAR elevation data. This was to ensure that the flow and accumulation of the stream is accurate. The Flow Direction tool was then run to create a raster flow direction from each cell to its steepest downslope neighbor. This creates the actual flow path of the channels. The Flow Accumulation tool was then run to create a flow accumulation grid from the flow direction grid. The Stream Definition tool was then used to create a stream grid with cells from the flow accumulation grid that exceeded our user-defined threshold. A threshold of 5000 cells was used to obtain a very detailed stream network configuration. Finally, the Watershed Delineation tool created the subwatersheds in the watershed. However, it was observed that the Arc Hydro-delineated subwatersheds with a defined threshold of 5000 cells did not properly represent each of the road drainage structures (culverts) mapped for the watersheds.

Together with our limited information based on an initial field visit for ground-truthing, we also developed a unique approach to identify locations of all possible culverts in each of the studied watersheds, similar to the one by Amatya et al. (2013). Analyzing detailed stream/channel networks developed using the Arc Hydro modeling, updated digitized road/trail network, and relevant GPS locations, we rasterized both layers and reclassified each pixel as a value of 1. Then the ArcGIS Plus tool provided us with pixel (cell) values of 2, which is an overlapped pixel combination of both stream and road. This analysis suggested that these pixels are road-crossing pixels. Later, our ground-truthing in the field confirmed our resultant road crossing structure locations, providing a complete updated culvert location spatial file for all the watersheds. As a next step, instead of using

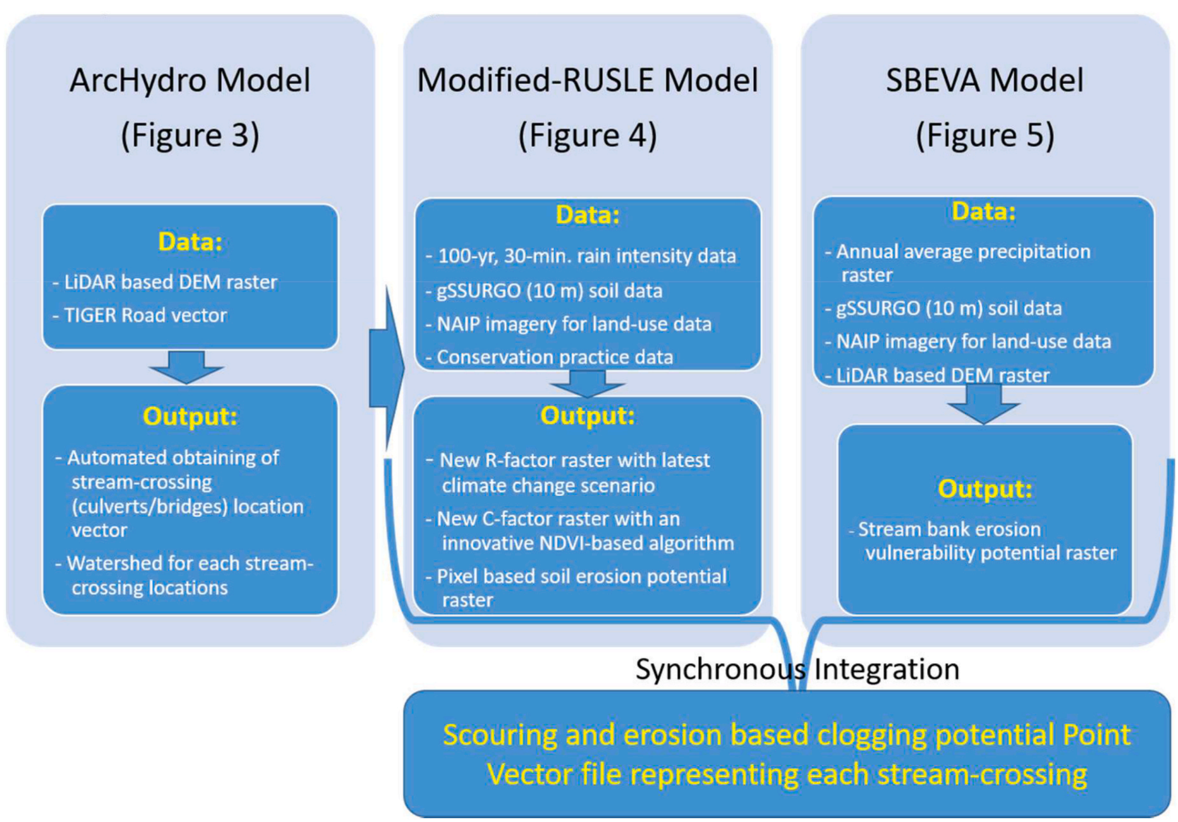


Fig. 2. Schematic diagram of the comprehensive approach followed to achieve study goal.

automatically generated subwatersheds, we used the Arc Hydro batch processing tool to delineate subwatersheds that represented each culvert location as its exit point and was present in the field. The efficacy of Arc Hydro performance was examined later when erosion-based models were developed. Fig. 3 represents the workflow process of digitizing subwatersheds for each possible culvert location in the studied watersheds.

2.3.2. MODIFIED-RUSLE model development

The RUSLE2 model is supported by six environmental factors (Renard et al., 1994) as model parameters shown in Eq. (1) below:

$$A = R\ x\ K\ x\ L\ x\ S\ x\ C\ x\ P \tag{1}$$

where, A = pixel-based soil erosion rate (t ha^{-1} yr^{-1}), R = rainfall erosivity factor (developed separately using NOAA PFDS I_{30} raster), K = soil erodibility factor (obtained from gSSURGO), L = slope length factor USLE (obtained from gSSURGO), S = slope gradient factor USLE (obtained from gSSURGO), C = crop management factor (developed with land-use map reclassification), and P = conservation practice factor (a constant value for a managed watershed). The modified form of the RUSLE2 (MODIFIED-RUSLE) model was developed for the watersheds with the uniquely developed R-factor using NOAA PFDS I_{30} raster of the study area (Panda et al., 2021) using the ARS algorithm shown in Eqs. (2) and (3). The C-factor was developed using a normalized difference vegetation index (NDVI)-based formula (Eq. (4)) (Reeves et al., 2021), and the P-factor raster was generated using the reclassified NAIP land-use-classified rasters for the studied watersheds (Reeves et al., 2021). The K-, L-, and S-factor rasters were developed from the gSSURGO data downloaded from NRCS Geospatial Data Gateway. Fig. 4 represents the schematic of the automated flow diagram for the MODIFIED-RUSLE.

$$R = KE * I_{30}, \tag{2}$$

where KE = total kinetic energy of the rainstorm, I_{30} = 30-min rainfall intensity for a 100-yr storm, and E was calculated using Eq. (3) shown below.

$$E = 916 + 331 * \log_{10}(I_{30}), \tag{3}$$

$$C = 0.1\left(\frac{NDVI + 1}{2}\right) \tag{4}$$

2.3.3. SBEVA geospatial model development

Though stream bank erosion is a natural process, often occurring as a result of changes in flow regime and sediment supply of streams and rivers, it is very detrimental to forested watersheds. For example, even a small amount of stream bank erosion can clog forest road drainage outlets and stream crossings, allowing overtopping of runoff and consequently damaging the structures. Climate change-induced extreme precipitation and/or natural catchment disturbances like soil erosion also enhance the impact of streambank erosion on the structures. It is to

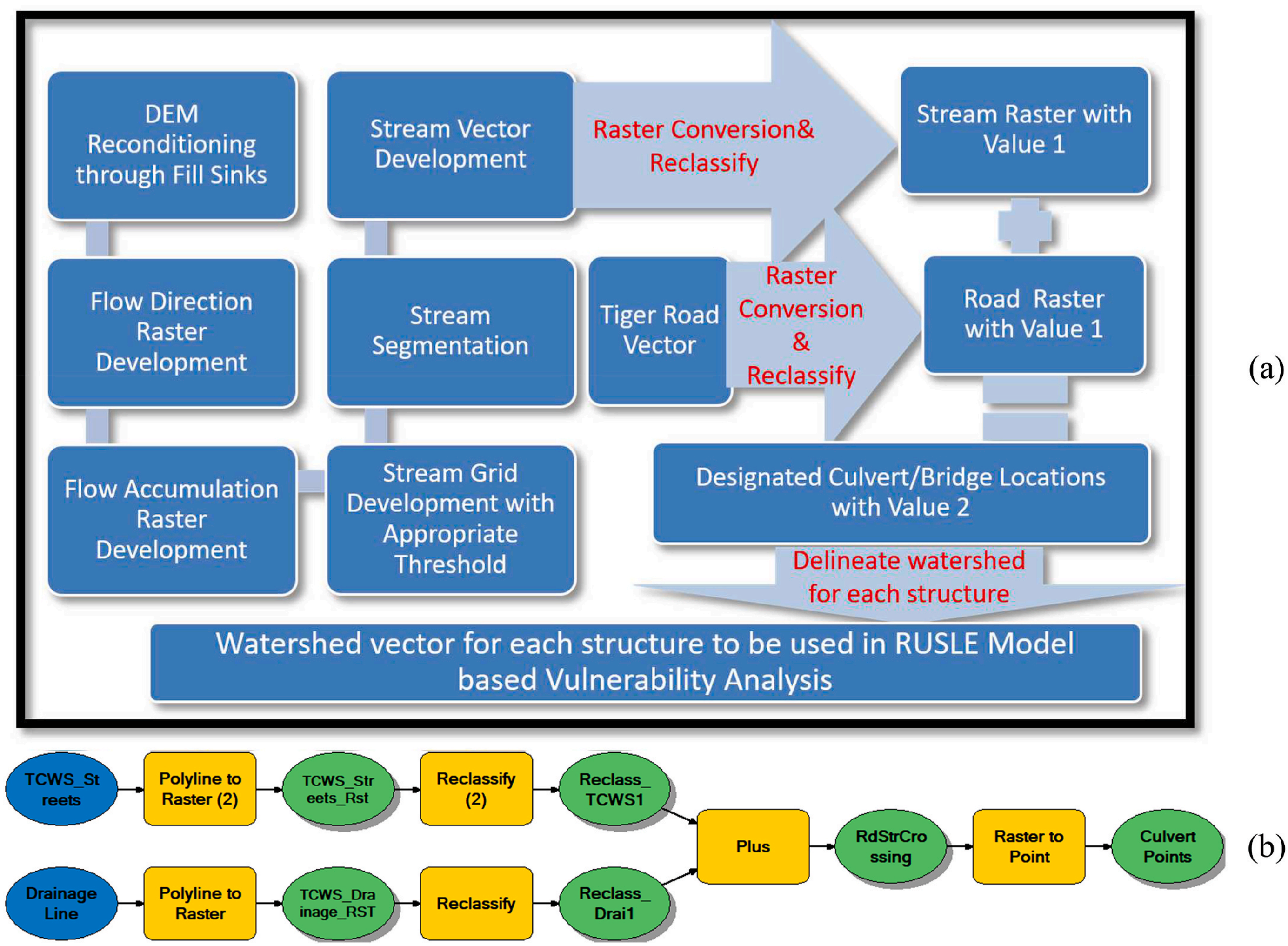


Fig. 3. (a) Schematic of the Arc Hydro modeling workflow combined with ArcGIS to delineate subwatersheds for each road crossing structure as exit points that will be used in RUSLE model-based vulnerability analysis and (b) automated geospatial model to delineate structure locations.

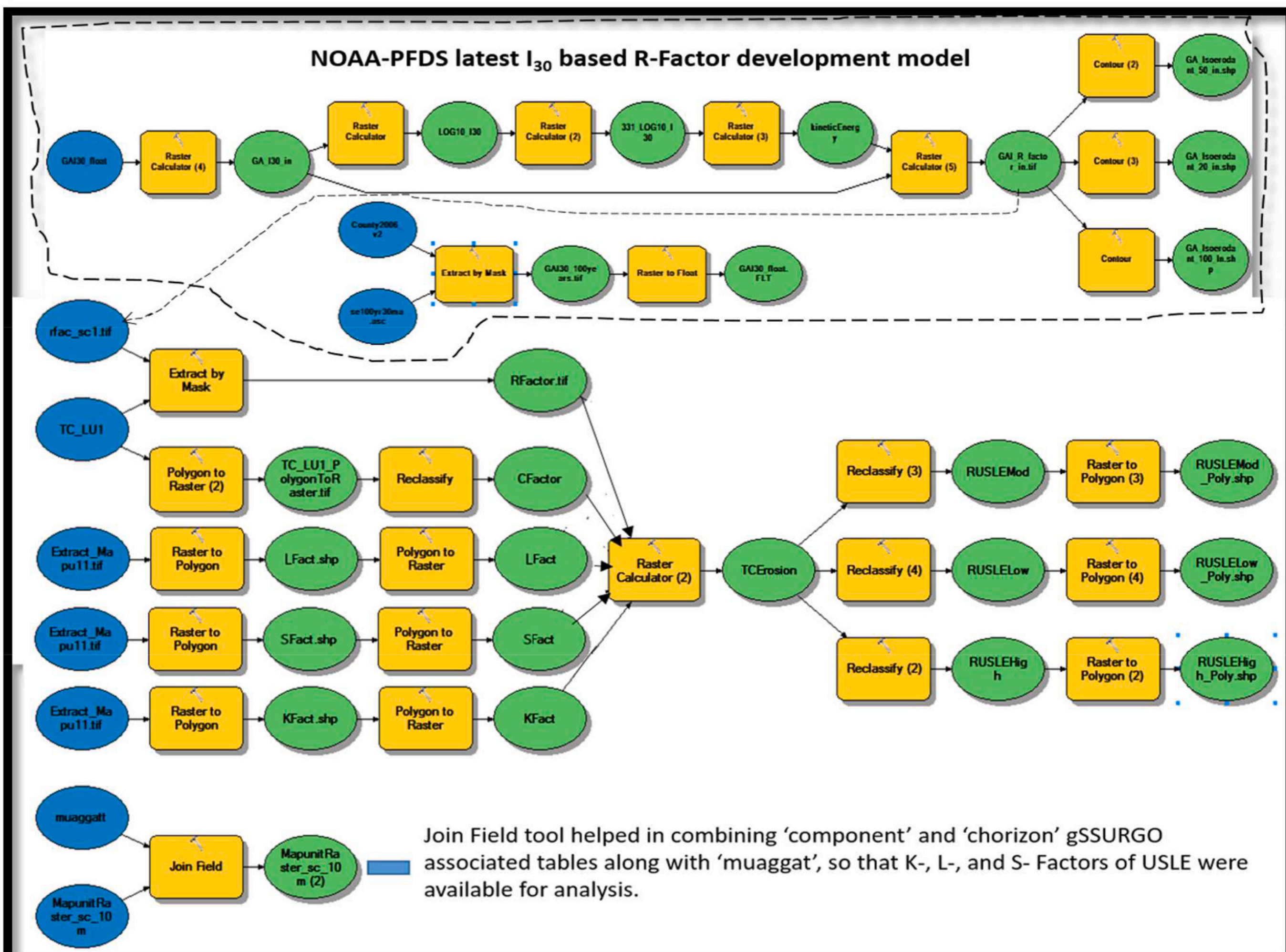


Fig. 4. Schematic of the automated MODIFIED-RUSLE Model developed in ArcGIS 10.3 ModelBuilder platform (example of Turkey Creek watershed (WS78) adjacent to WS80 watershed).

be noted, according to Hughes (2016), that streambank erosion rates increase with natural land cover changes potentially due to climate change-induced flashy regimes, changes to natural riparian vegetation, channel modification, and introduction of livestock (e.g., cattle, sheep, deer) to catchments and their unrestricted access to streams. However, most of those scenarios are not expected in forested watersheds, though streambank erosion potential is still high due to steep terrain, wildlife access to streams, and erodible soil characteristics.

We developed the SBEVA model to identify areas vulnerable to erosion at road culvert outlets, stream crossings, and stream banks of each study watershed using the PRISM precipitation raster (900 m), gSSURGO soil raster (10 m), classified NAIP imagery raster (1 m), and LiDAR-based DEM raster (1.5 m) as shown in Section 2.2 above. It is to be noted and as pointed by USFS and FHWA field engineers upon their review of this research's practicality regarding the 'real-time' precipitation data availability, we used the local weather stations (up-to-date) precipitation data to develop the Precipitation-Intensity-Duration-Frequency (PIDF) data (Amatya et al., 2021) and embedded that with NOAA created PIDF raster (https://hdsc.nws.noaa.gov/hdsc/pfds/) available for the study areas at a spatial resolution of 900 m. Each raster was pan-sharpened to a similar spatial resolution of 1 m in ArcGIS software. These 1-m spatial resolution rasters were then reclassified based on their streambank erosion vulnerability potential. The study area precipitation distribution raster was reclassified by rating the amount of precipitation (in millimeters) that occurred in an area of interest using a 1–9 scale (with 1 being the lowest and 9 being the highest). Higher precipitation was rated as a higher vulnerability for streambank erosion potential through Jenks (Natural Breaks) algorithm-based raster classification. Similarly, land-use was reclassified by its potential for streambank erosion with a scale of 1–9, i.e., dense forest along the streambank has a lower erosion potential and was assigned the lowest score (1) while bare soil along the stream bank was assigned the highest score (9). The DEM raster was converted to a slope raster and again classified using the Jenks algorithm, with nine classes. The lowest slope degree range was assigned the lowest streambank erosion vulnerability scale of 1 and vice-versa. The gSSURGO raster was also reclassified to create several streambank erosion vulnerability rasters, with five contributing soil characteristics, including k-factor, soil hydrologic group, soil texture, slope length (USLE), and drainage. Each of the characteristics was classified with a rating of 9–1; a rating of 9 was assigned to the soil with the highest potential for erosion vulnerability, and a rating of 1 was assigned to the soil with the lowest potential for erosion vulnerability. It is to be noted that the SBEVA analyses were conducted within the 50-m buffer of the entire stream network of each EF from which each road culvert on the watershed was identified for its vulnerability using the ArcGIS Zonal Statistics tool.

The streambank erosion vulnerability scale (1–9) was assigned for land-use- and soil characteristics-based rasters using the widely used Delphi method weight assignment process (Section 2.3.3.1). Once all the spatial factors contributing to the streambank erosion process were reclassified, they were assimilated through a Weighted Sum tool available in ArcGIS. The same Delphi method-based weight assignment process was used to assign percentile weights to each environmental factor during the Weighted Sum application. It is also to be noted that land-use along the stream banks influences streambank erosion more than soil drainage type. The reclassified data were given weights that determined their potential for influencing erosion vulnerability. Each of the soil characteristics was assigned a weighted score of 10%, while land-use, slope gradient, and precipitation were assigned scores of 20%, 15%, and 15%, respectively. The result of the Weighted Sum rated the areas of spatial erosion vulnerability on a scale of 1–9 (lowest to highest). The entire process was carried out for the whole stream network. Fig. 5 denotes the SBEVA model schematic as created in the ArcGIS ModelBuilder platform.

2.3.3.1. Delphi Method of vulnerability weight assignment. The Delphi method developed by the RAND Corporation in the 1950s aimed to reduce the range of group responses and to strive for expert consensus, essential in environmental modeling where vulnerability/susceptibility/probability weight assignment is crucial. The process, as described in the method, is accomplished by the feedback of individual contributions of information and knowledge as well as responses with a degree of anonymity to assign weights of vulnerability, as is applied in determining spatial probability (Adler and Ziglio, 1996; Angus et al., 1996; Linstone and Turoff, 1975; Rowe et al., 1991). Along with environmental impact assessments, the Delphi method is effective in various fields such as information systems, planning, social policy, public health, water resource use and management, and water quality assessment (Angus et al., 1996; Linstone and Turoff, 1975; Kim and Chung, 2013; Lee et al., 2013; MacMillan and Marshall, 2006; Okoli and Pawlowski, 2004). We used the Delphi Method for developing a weighted index for individual layers that are associated with our streambank erosion vulnerability model development as discussed above. The authors of this manuscript along with professional experts from USGS (Atlanta office); City of Gainesville, GA; and Institute for Environmental and Spatial Analysis and Biology and Engineering programs of the University of North Georgia were asked to provide their opinion on vulnerability weight scales for all eight layers used in the model development. Their weighted scale was compiled and a statistically derived weight scale for each layer was used in the analysis.

2.3.4. Model integration

The Arc Hydro model provided the locations of all culverts and stream crossings in each EF including the study watersheds within them. The MODIFIED-RUSLE provided pixel-based estimated erosion amounts and total summed soil erosion amounts from all pixels within a subwatershed discharged to its outlet structure (culvert or stream crossing). Each structure located in the individual EF was classified into three (low, moderate, and high) vulnerability classes based on the probable estimated erosion accumulated at that location. Similarly, the SBEVA model provided the information on a 1–9 erosion vulnerability scale for the entire stream network within each EF. The SBEVA model separated each subwatershed outlet using the ArcGIS Select tool and classified it into three (low, moderate, and high) vulnerability scales. Finally, both the MODIFIED-RUSLE and SBEVA-based scales were overlain together spatially in ArcGIS and each structure (location) was assigned a resultant scale of low (1), moderate (2), and high (3) classes based on their probable vulnerability to risks of failure due to the climate change-induced extreme precipitation events and associated soil erosion.

3. Results and discussion

Fig. 6 shows the Arc Hydro- and MODIFIED-RUSLE model-based delineated detailed stream network and the road culvert locations along with the estimated pixel-based soil erosion analysis of the Turkey Creek watershed (WS78) at Santee EF (Fig. 1). Similar results were obtained for the other two EF watersheds at Coweeta and Alum Creek. FS personnel assisted students from the University of North Georgia (UNG) (in 2010–2011) and the College of Charleston (CofC) (in 2007) in surveying each of those locations and confirmed about some of their existences as shown in Fig. 6 legend as AOI_Culverts_FSSurveyed for the WS78. It is to be noted that the NHD-based stream network in 1:24,000 scale does not show the detailed stream network as generated with the Arc Hydro model and presented in Fig. 6. Soil erosion was estimated on a pixel basis (kg/ha/yr) and grouped into three classes (green, yellow, and red being low, high, and moderate erosion amounts, respectively). Later they were summed together for individual subwatershed outlets with locations of each structure using the Zonal Statistics tool. The summed values were classified into three classes (low, moderate, and high) based on the watershed soil erosion vulnerability as discussed in Section 2.3.4.

Fig. 7 provides R-, K-, combined LS-, and C-factor rasters, developed

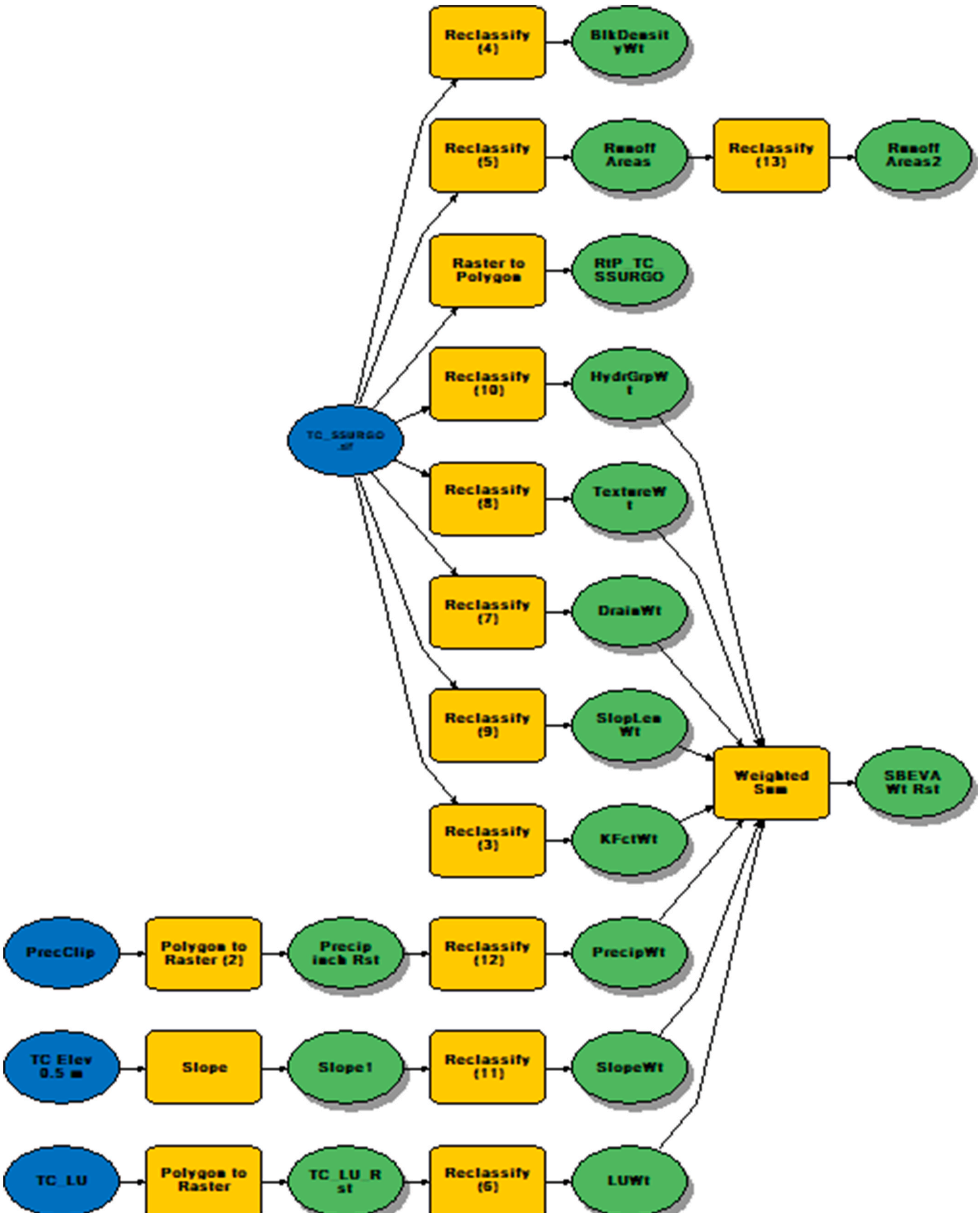


Fig. 5. Schematic of the automated SBEVA model developed in the ArcGIS 10.3 ModelBuilder platform (example of WS80 watershed model).

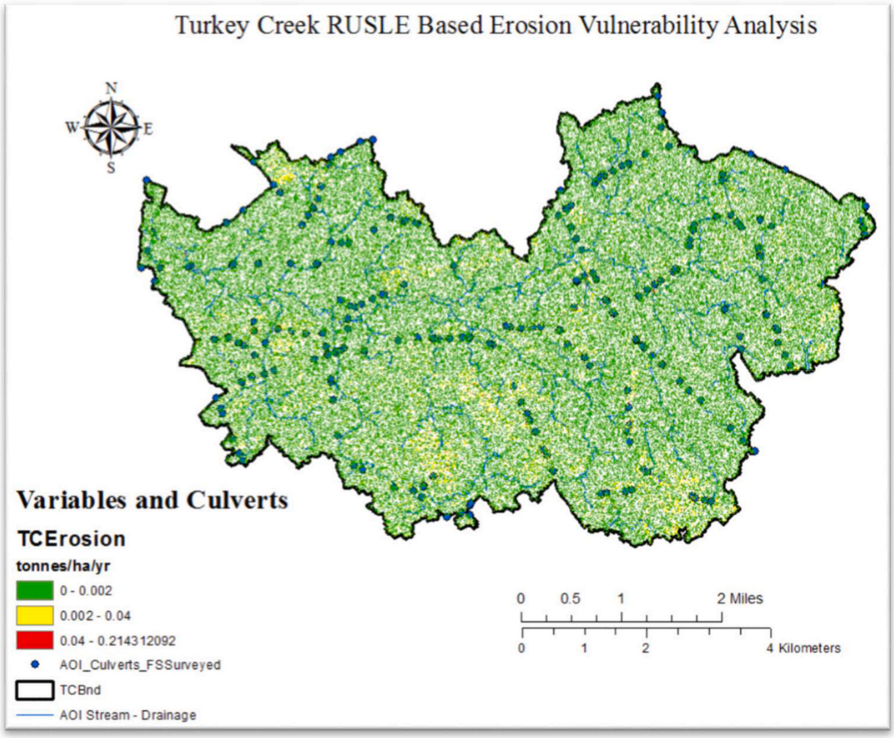


Fig. 6. Map showing Arc Hydro- and MODIFIED-RUSLE model-based detailed delineated stream network and structure locations along with pixel-based spatial soil erosion amount distribution.

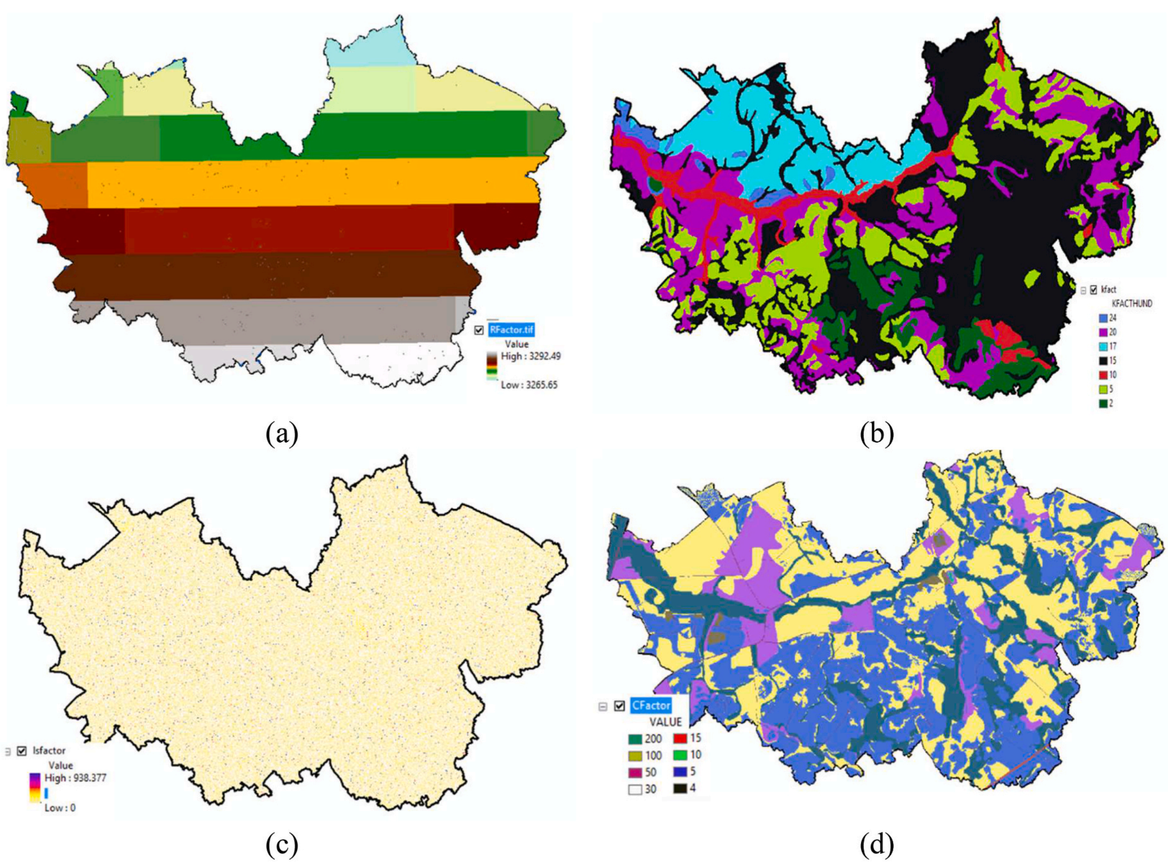


Fig. 7. Maps showing (a) R-factor raster developed using NOAA PFDS I_{30} raster using the latest storm events record, (b) gSSURGO-based K-factor raster, (c) LS-factor raster created using flow accumulation and slope rasters of the watershed, and (d) C-factor raster created with NDVI-based algorithm.

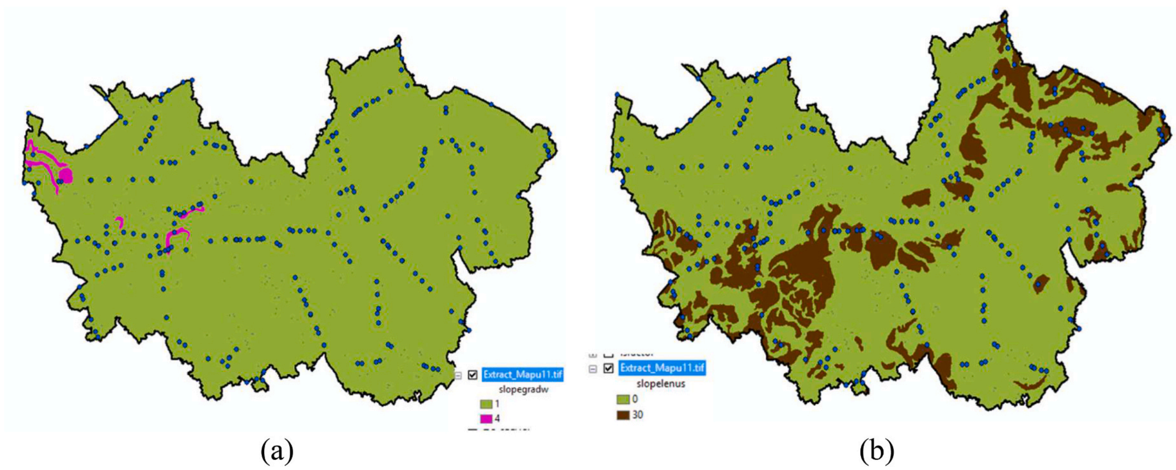


Fig. 8. Maps showing (a) L-factor and (b) S-factor rasters, developed from gSSURGO database. Most of the area has unclassified or no data (green color).

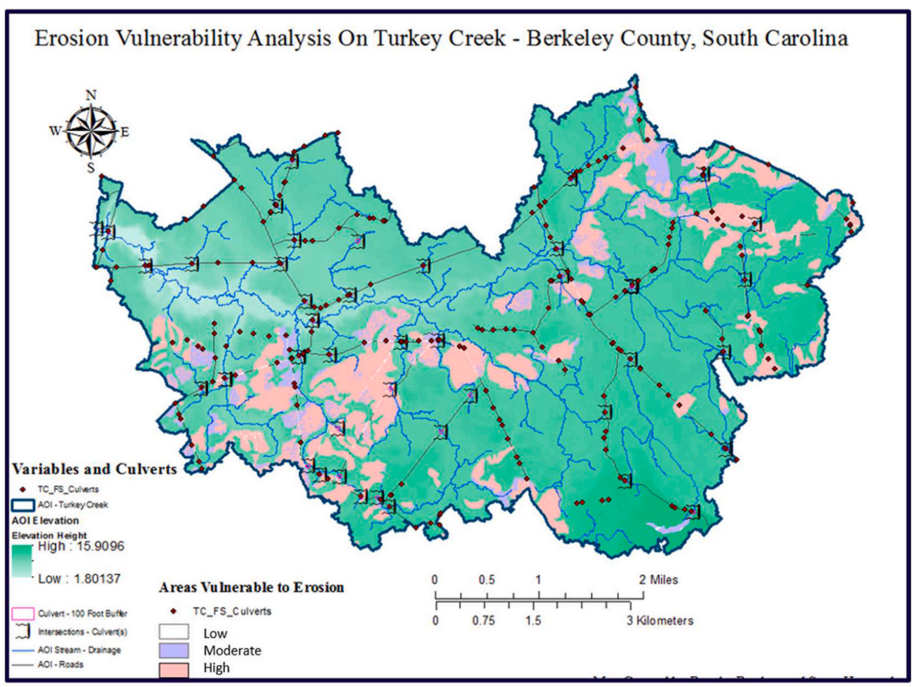
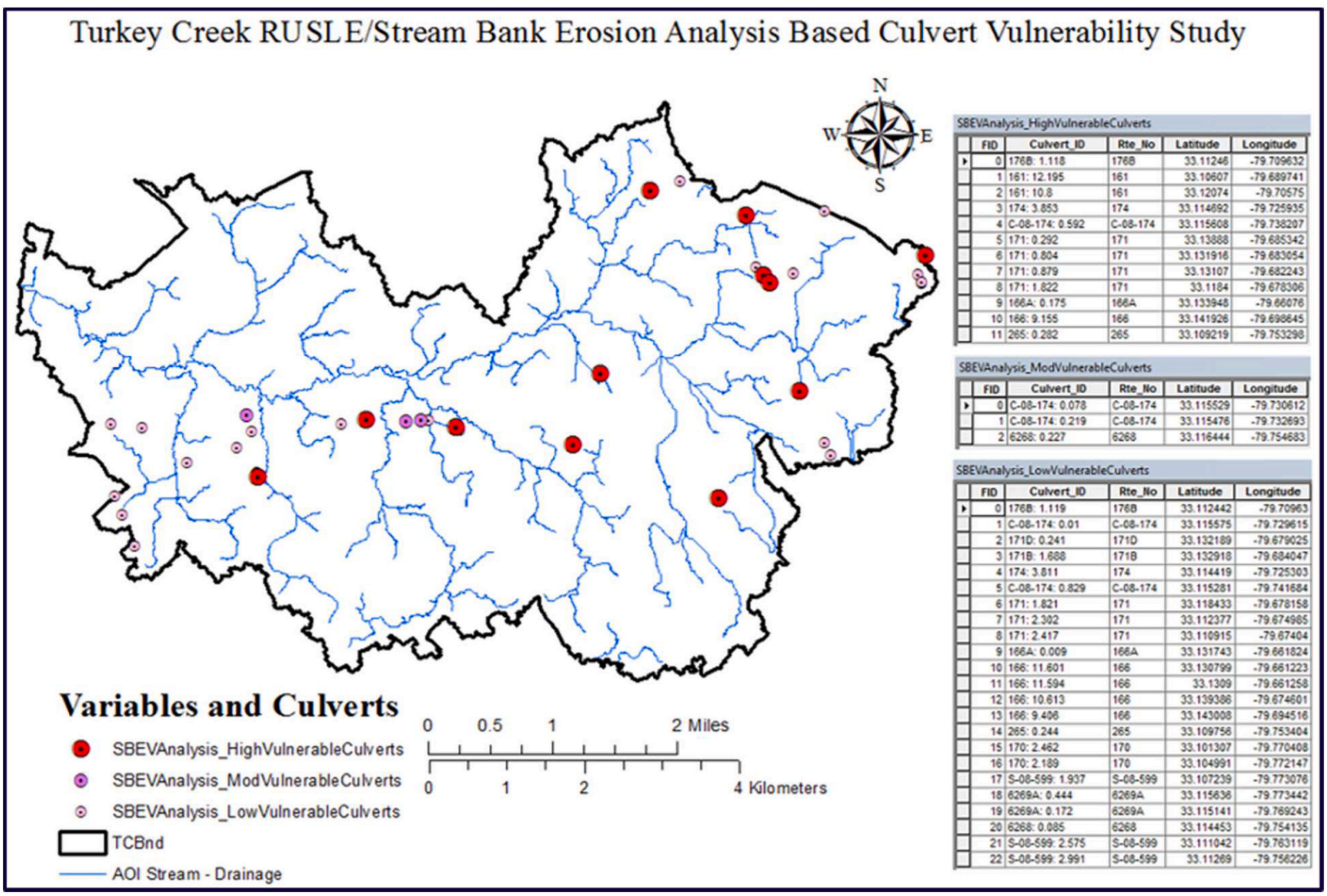


Fig. 9. Streambank erosion vulnerability along the streams (roads and culvert locations shown on map) in the Turkey Creek watershed.

using an innovative approach, that ultimately were combined in ArcGIS using the Raster Calculator tool. It should be noted that although L- and S-factor rasters (Fig. 8) were individually created from gSSURGO reclassification, we found more than 70% of the Area of Interest having no data or provided as unclassified. This paucity of data is attributed to the fact that the Turkey Creek watershed is on low-gradient forested wetlands on the lower coastal plain where soil mapping and data were obtained from SCS (1980), in which many soil characteristics were broadly defined or were not completed (Ramcharan et al., 2017). Therefore, another ARS algorithm (Eq. (5))-supported approach was followed to create the combined LS-factor raster that uses the flow accumulation and slope rasters of the watershed, which were developed with the Arc Hydro model. The studied forested watersheds are within FS national forests and are well-managed sites; therefore, we used a value of 0.9 for all the three watersheds.

LS-factor raster = (Pow([fac] * (28.36 / 22.13), 0.4) * Pow(Sin([Slope] / 0.0896), 1.3) (5)

Fig. 9 shows streambank erosion vulnerability along with the streams crossings and road culvert locations in the Turkey Creek watershed (WS78) classified into three vulnerability classes (low, moderate, and high) as described in Section 2.3.4. As the next step, the SBEVA- and Modified RUSLE-based vulnerability classes were combined and/or overlain together. The culvert locations at the intersection of these two layers were classified into three final categories low (1), moderate (2), and high (3) vulnerability based on scouring, clogging of culvert openings, and flood runoff overtopping that was partially ground-truthed. Accordingly, Fig. 10 provides these three categories for culverts/bridges along with other stream crossings with low vulnerability, due to their locations at the headwaters of the entire watershed. The ArcGIS Select tool was used to separate such locations belonging to each vulnerability category and separate databases were created for individual categories with the locational coordinate information (shown on the right side of Fig. 10 as examples). The culvert/bridge structures with scaled vulnerability are presented on the Turkey Creek watershed with Point Variation format (Fig. 10). Culverts and their on-site condition



SBEVAnalysis_HighVulnerableCulverts

FID	Culvert_ID	Rte_No	Latitude	Longitude
0	176B: 1.118	176B	33.11246	-79.709632
1	161: 12.195	161	33.10607	-79.689741
2	161: 10.8	161	33.12074	-79.70575
3	174: 3.853	174	33.114692	-79.725935
4	C-08-174: 0.592	C-08-174	33.115608	-79.738207
5	171: 0.292	171	33.13888	-79.685342
6	171: 0.804	171	33.131916	-79.683054
7	171: 0.879	171	33.13107	-79.682243
8	171: 1.822	171	33.1184	-79.678306
9	166A: 0.175	166A	33.133948	-79.66076
10	166: 9.155	166	33.141926	-79.698645
11	265: 0.282	265	33.109219	-79.753298

SBEVAnalysis_ModVulnerableCulverts

FID	Culvert_ID	Rte_No	Latitude	Longitude
0	C-08-174: 0.078	C-08-174	33.115529	-79.730612
1	C-08-174: 0.219	C-08-174	33.115476	-79.732693
2	6268: 0.227	6268	33.116444	-79.754683

SBEVAnalysis_LowVulnerableCulverts

FID	Culvert_ID	Rte_No	Latitude	Longitude
0	176B: 1.119	176B	33.112442	-79.70963
1	C-08-174: 0.01	C-08-174	33.115575	-79.729615
2	171D: 0.241	171D	33.132189	-79.679025
3	171B: 1.688	171B	33.132918	-79.684047
4	174: 3.811	174	33.114419	-79.725303
5	C-08-174: 0.829	C-08-174	33.115281	-79.741684
6	171: 1.821	171	33.118433	-79.678158
7	171: 2.302	171	33.112377	-79.674985
8	171: 2.417	171	33.110915	-79.67404
9	166A: 0.009	166A	33.131743	-79.661824
10	166: 11.601	166	33.130799	-79.661223
11	166: 11.594	166	33.1309	-79.661258
12	166: 10.613	166	33.139386	-79.674601
13	166: 9.406	166	33.143008	-79.694516
14	265: 0.244	265	33.109756	-79.753404
15	170: 2.462	170	33.101307	-79.770408
16	170: 2.189	170	33.104991	-79.772147
17	S-08-599: 1.937	S-08-599	33.107239	-79.773076
18	6269A: 0.444	6269A	33.115636	-79.773442
19	6269A: 0.172	6269A	33.115141	-79.769243
20	6268: 0.085	6268	33.114453	-79.754135
21	S-08-599: 2.575	S-08-599	33.111042	-79.763119
22	S-08-599: 2.991	S-08-599	33.11269	-79.756226

Fig. 10. Streambank erosion vulnerability along the streams (roads and culvert locations shown on map) in the Turkey Creek watershed.

information on the WS78 reported by the C of C and UNG students with assistance from the Santee EF personnel were used for ground-truthing of the geospatial model-based vulnerability assessment results (Appendix A). Even with our previous ground-truthing, we observed 80% accuracy on the vulnerability results obtained from our study with sampled sites verified. Our earlier assessments on the WS78 could not follow a detailed protocol on the “Culvert Inventory and Assessment” prepared by the Center for Aquatic Technology Transfer team only in 2011 (CATT, 2011). In a separate related streambank erosion vulnerability model study, detailed ground-truthing found 100% accuracy on nine sampled locations (Panda et al., 2017), which are provided in Appendix B.

Based on on-site ground-truthing, it was observed that out of more than 100 culverts, only 11 and three culverts in the Turkey Creek watershed (WS78) were found to be in the high and moderate vulnerability scales, respectively, with the rest of the structures either in the low or zero vulnerability categories. This is attributed to the topographic condition of the watershed, mostly a flat to low-gradient one with minimal soil erosion losses. Appelboom et al. (2002) noted that low slope along the road length and coarser textured soils in the coastal plain forest lands result in less erosion and sedimentation potential (Forestry Best Management Practices Manual, 1989). However, it was found that a higher percentage (>30%) of the forest road culverts/bridges/stream crossings in the Coweeta and Alum Creek watersheds were under the high vulnerability category (Not shown). Both of these watersheds are on highly undulated and moderate-to high-gradient topography. In addition, the Coweeta watershed is within the highest precipitation zone of the United States. On the other hand, the Alum Creek watershed has soils that are more vulnerable to erosion compared to the other two watersheds.

3.1. Uncertainty and limitations

In general, error propagation is the persistence of an error in new datasets calculated or created using datasets that originally contained errors during geospatial data analysis and model development (Goodchild, 2018, 2020; Wechsler et al., 2019). Cumulative error propagation is certainly a big concern throughout a series of data processing operations, such as those conducted in this geospatial modeling study that used aerial imageries, LiDAR data-supported DEM, on-site surveys, and GIS-analyzed gSSURGO data in addition to instrumentation for measurements of NOAA-PFDS-supported precipitation data. NAIP aerial images used in this study were downloaded directly from the NRCS Geospatial Data Gateway, which may contain radiometric errors, although we have corrected them for geometrical errors. LiDAR data collected a few meters above the ground were not corrected for atmospheric interference, which may potentially lead to some elevation errors. Similarly, gSSURGO data may contain human-induced errors and other geospatial data development process errors. Precipitation raster data obtained from the NOAA-PFDS was not corrected either for any human or satellite (RADAR)-based errors. All these spatial and temporal data with such potential errors were used in the modeling process and automated model building. Therefore, both error propagation and accumulation are inherent and should be acknowledged. However, these errors are minimal, and in environmental modeling, such small errors can easily be ignored (Goodchild, 2018). Therefore, we believe results from this study with a more subjective approach should be acceptable for a vulnerability assessment-based decision-support system.

We could not include any culverts/bridges structural vulnerability analysis based on serious structural failure due to debris flow to the structure opening and clogging it. Boulders and tree debris can make the erosion based clogging process faster and thus subsequent overtopping off and scour could happen. We will update our vulnerability analyses modeling approach in future works as suggested by USFS and FHWA engineers to include the Debris-Flow modeling based analysis into the model to make it more comprehensive and efficient.

3.2. Software and models

With this study, three automated geospatial models (ArcHydro based stream-crossing watershed development model; modified RUSLE model to determine eroded soil amount at stream-crossings; and SBEVA model to determine stream-crossing location scouring potential) were developed. They are available at UNG Institute for Environmental Spatial Analysis (IESA) program’s ESRI portal (https://iesa-ung.maps.arcgis.com/home/gallery.html?view=grid&sortOrder=desc&sortField=relevance&focus=applications-dashboards). It is password protected and will be available to readers/users at request. However, as explained the schematic of the models shown in Figs. 3–5 can be replicated with knowledge in ESRI ModelBuilder application. We also have developed basic Python scripts for each model as supported by ESRI ModelBuilder and the codes would be available for public use in the GitHub site (https://github.com/drsudhanshupanda/Software). Appendix C contains an example of the ArcGIS ModelBuilder created Python script that can be replicated on modification by other researchers.

4. Summary and conclusions

This study provides an initial assessment of the vulnerability of forest road culverts and stream crossings) due to climate change-induced extreme precipitation events which can result in their complete failure due to flooding (undersized), siltation, scouring, and even washout. The study described a step-by-step methodology of developing geospatial technology-based hydrology models incorporating design rainfall intensities to identify erosion hazards and vulnerability risks of forest road culverts and stream crossings in one of three study watersheds with varying areas, topography, soils, and land-use. The modeling approach used the Arc Hydro model in creating detailed stream networks with the LiDAR-based high-resolution DEM combined with digitized forest road networks, culverts, and stream crossings. A MODIFIED-RUSLE utilizing design precipitation intensity and SBEVA geospatial-hydrology models were developed and integrated to obtain erosion vulnerability on a scale of high, moderate, and low using the Delphi method. The combined vulnerability estimates from both the SBEVA and MODIFIED-RUSLE models established the most vulnerable locations of the structures, which were ground-truthed based on 2007 photos (Appendix A) to be 80% accurate for culvert and streambank erosion conditions in the Turkey Creek watershed.

It is to be noted that the RUSLE2 model alone does not assess streambank erosion, so integration of the SBEVA model helps develop a more reliable decision-support tool for assessing the vulnerability of these forest road culvert and stream crossing structures. Finally, this study and associated geospatial models provide decision-support tools for forest managers, engineers, and hydrologists to identify, analyze, and prioritize culvert design, restoration, and adaptation options, substantively informing their management decisions on road infrastructure planning. This can serve as a rapid assessment tool for the vulnerability of road culverts at these pilot EFs in NC, SC, and AR, with a possibility of its extension to other EFs and federal lands (e.g., national forests, national parks, lands managed by the Bureau of Land Management (BLM)) under current and future climatic conditions. For example, an earlier version of this geospatial modeling assessment was shared with the transportation engineer at FS Region 8 in Tallahassee, FL, and the FMNF staff, SC for their initial assessment of the culverts to support their timely management and on-ground restoration work, if needed. Similar geospatial modeling analyses were conducted in two other EFs in NC and AR as well (Fig. 1). It is expected that this study will also facilitate forest managers and landowners in locating inaccessible and not easily traceable road culverts and stream crossings that require repair/restoration and upgrades. Finally, this geospatial modeling study can be replicated in other forested or non-forested watersheds as it is an integration of automated environmental models (hydrology and morphology-based) to provide forest structure management decision support.

Future studies should explore multiple on-site data for enhancing the scaling factors of the Delphi-based weighted approach. In addition, future work also should explore the FS Water Erosion Prediction Program (WEPP) model, as an alternative to RUSLE, for evaluating the erosion potential of small catchments within the watersheds. The SBEVA model should also consider adding an antecedent soil moisture parameter among the existing parameters as it plays a critical role in affecting peak discharges as well as sediment export. In that context, there is great potential to explore the use of NASA's recently available Soil Moisture Active Passive (SMAP)-based soil moisture data (Ayres et al., 2021; Colliander et al., 2020). In future, we would update our vulnerability analyses including a Debris-Flow model based on Borga et al. (2014) suggested parameters and others, such as PIDF (>24 h duration), geologic data (Rock Type 1 and 2), and SMAP/ECOSTRESS satellites supported soil moisture data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to acknowledge Robert Gubernick, Watershed Restoration Geologist and Team Lead at US Forest Service National Stream and Aquatic Ecology Center, for reviewing the manuscript and providing constructive suggestions that helped improve the quality of the manuscript. In addition we are thankful to Elizabeth Haley, former graduate student and her advisor Dr. Timothy Callahan both at the College of Charleston and Jose Martin former undergraduate student of University of North Georgia for helping conduct extensive survey of road culverts at the Turkey Creek study site, and Stephanie Worley Firley and Shawna Reid both at Forest Service Southern Research Station for edits and GIS map, respectively. The authors would like to acknowledge the USDA Forest Service Southern Research Station (SRS) and Region 8 for funding this study. Furthermore, the authors extend thanks to the reviewers and editorial board members for this manuscript's review and publication.

Appendix A

Photographs (Figure A1 below provides spatial location reference of each photograph to show their condition) taken in the Turkey Creek during the stream survey during 2007 as an example of stream crossings damaged that corroborates to our recent geospatial-hydrology integrated model based results.

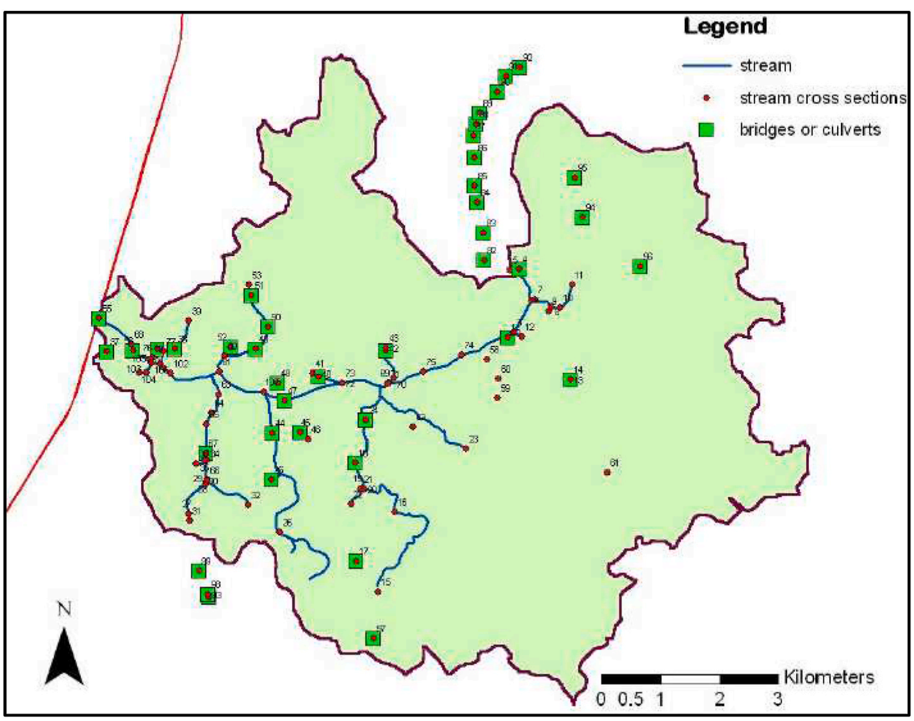


Fig. A1. Stream crossings (Culverts/Bridges) surveyed in the year 2007 by E.B. Haley as part of her postgraduate research. Photographs below shows the condition of few culverts that are found to be moderately or highly vulnerable to extreme precipitation based erosion/scouring.

Photographs (Credit: Beth Haley, College of Charleston, SC, 2007).

Photo A-1: Photograph taken January 11, 2007 of a tributary emerging from a metal culvert at point 13 on map in Figure A1.

Photo A-2: Photograph taken January 12, 2007 of a floodplain in one of the tributaries at point 19 on map in Figure A1.

Photo A-3: Photograph taken January 31, 2007 of a tributary flowing through a concrete culvert under a gravel road at point 40 on map in Figure A1.

Photo A-4: Photograph taken January 31, 2007 of metal culverts in poor condition at point 38 on map in Figure A1.

(*continued on next page*)

(*continued*)

Photo A-5: Photograph taken February 16, 2007 of a metal culvert at point 54 on map in Figure A1.

Photo A-6: Photograph taken February 16, 2007 of metal culvert at point 50 on map in Figure A1.

Photo A-7: Photograph taken February 16, 2007 of metal culvert beginning to collapse at point 48 on map in Figure A1.

Photo A-8: Photograph taken March 7, 2007 of three concrete culverts in Turkey Creek watershed at point 65 on map in Figure A1.

Photo A-9: Photograph taken of a second beaver dam also near Whittley Bridge on the main channel of Turkey Creek near point 67 on map in Figure A1.

Appendix B

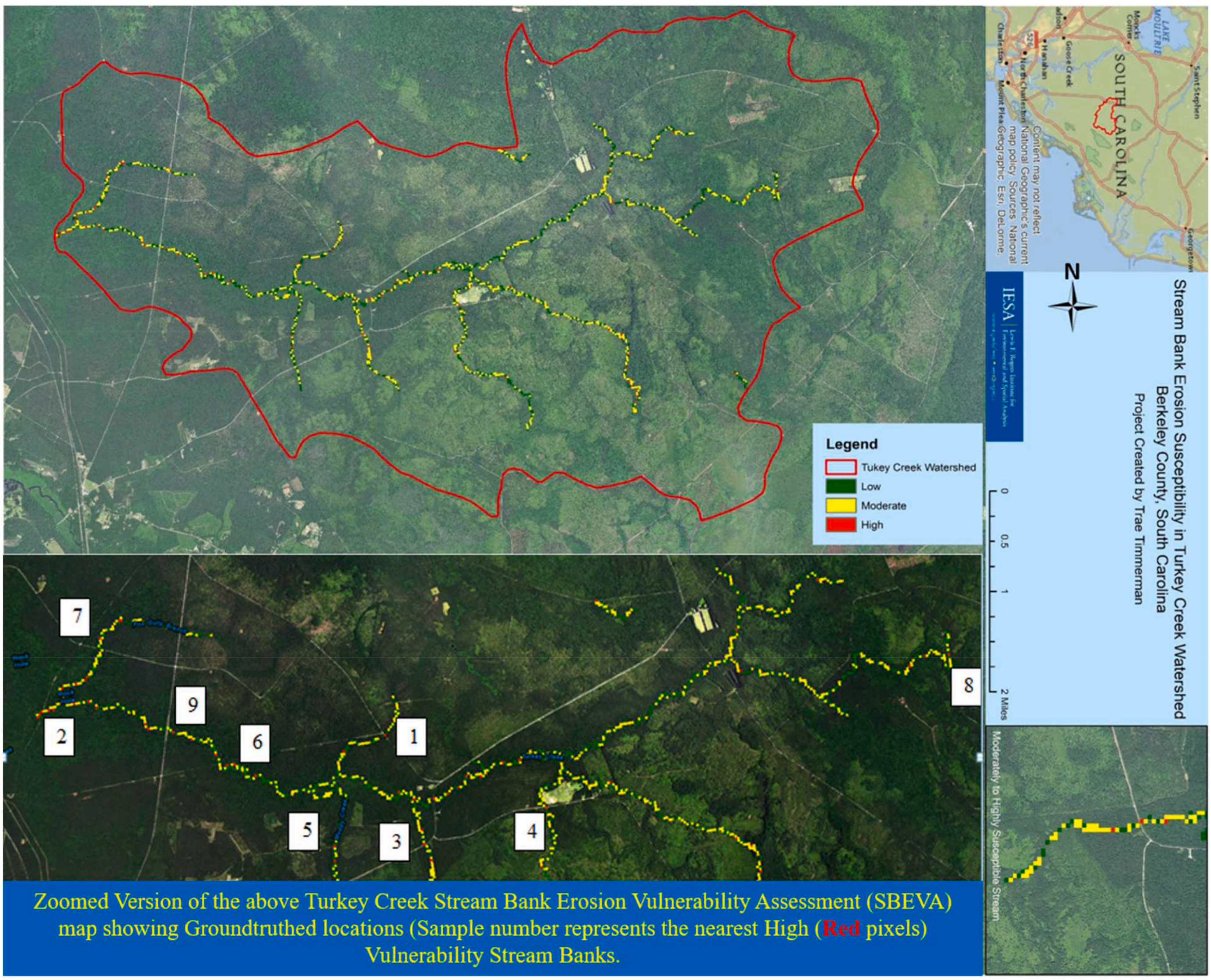
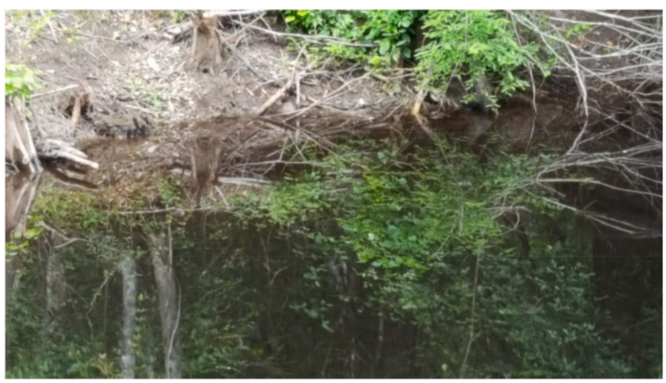


Fig. B1. Turkey Creek watershed SBEVA model result showing the ground-truthed locations with 100% accuracy obtained. (Note: Field photographs confirming the ground-truthed locations' actual field conditions are shown below.)

(Photograph Location #1).



(Photograph Location #2).

(Photograph Location #4).

(Photograph Location #7).

(Photograph Location #9).

Appendix C

Python script sample example of SBEVA model created with data stored in local folder as generated by ArcGIS ModelBuilder and can be replicated by researchers with modification.

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# SBEVA Model.py
# Created on: 2022-02-25 09:51:04.00000
#   (generated by ArcGIS/ModelBuilder)
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy


# Local variables:
KFACT_shp =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\soils_
SSURGSDM_sc015_3166549_01\\KFACT.shp"
Stream_Buff_Fin =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Strea
mBankErosionOutput.gdb\\Stream_Buff_Fin"
StreamBuffer50 =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Strea
mErosion2.gdb\\StreamBuffer50"
KFACT_BUFF =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Strea
mErosion2.gdb\\KFACT_BUFF"
…………………………

SLOPESUS_1FT =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Strea
mErosion2.gdb\\SLOPESUS_1FT"
STRMBNKEROS_FIN =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Strea
mErosion2.gdb\\STRMBNKEROS_FIN"

# Set Geoprocessing environments
arcpy.env.scratchWorkspace =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Eman
uel_Soil_Project\\OutputData.gdb"
arcpy.env.workspace =
"U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Eman
uel_Soil_Project"
```

```
# Process: Buffer
arcpy.Buffer_analysis(Stream_Buff_Fin, StreamBuffer50, "50 Feet", "FULL", "ROUND",
"ALL", "", "PLANAR")

# Process: Clip (5)
arcpy.Clip_analysis(KFACT_shp, StreamBuffer50, KFACT_BUFF, "")

# Process: Polygon to Raster
arcpy.PolygonToRaster_conversion(KFACT_BUFF, "kffact", KFACT_BUFF_RAST2,
"CELL_CENTER", "NONE", "10")

# Process: Extract by Mask
arcpy.gp.ExtractByMask_sa(JM_2011_TC_agreedem, AOIWS_shp, DEM_AOI)

# Process: Slope
arcpy.gp.Slope_sa(DEM_AOI, SLOPE_AOI, "DEGREE", "1", "PLANAR", "METER")

# Process: Reclassify
arcpy.gp.Reclassify_sa(SLOPE_AOI, "Value", "0 2 0;2 4 0;4 6 0;6 20 1;20 77.929459 2",
SLOPE_SUS, "DATA")

# Process: Extract by Mask (3)
arcpy.gp.ExtractByMask_sa(SLOPE_SUS, StreamBuffer50, SLOPESUS_50FT)

# Process: Extract by Mask (4)
arcpy.gp.ExtractByMask_sa(NLCD_AOI, StreamBuffer50, NLCD_BUFF50)

# Process: Reclassify (3)
arcpy.gp.Reclassify_sa(NLCD_BUFF50, "Land_Cover", "'Developed, Open Space' 1;'Evergreen
Forest' 0;Shrub/Scrub 0;Hay/Pasture 1;'Woody Wetlands' 0;'Emergent Herbaceuous Wetlands'
0", NLCD_SUS_50FT, "DATA")

# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(KFACT_RAST, "kffact", ".15 0;.05 0;.20 1;.24 1;.02 0;.17 0;.10 0",
KFACT_SUS, "DATA")

# Process: Extract by Mask (6)
arcpy.gp.ExtractByMask_sa(MapunitRaster_sc_10m1_tif, StreamBuffer50, GSSURGO_AOI)

# Process: Reclassify (5)
arcpy.gp.Reclassify_sa(GSSURGO_AOI, "flodfreqdc", "None 0", FLOODFREQ_SUS,
"DATA")

# Process: Reclassify (6)
arcpy.gp.Reclassify_sa(GSSURGO_AOI, "hydgrp", "C/D 1;B/D 1;B 0;C 0;A/D 1",
HYDGRP_SUS, "DATA")
```

. (*continued*).

```
# Process: Weighted Sum
arcpy.gp.WeightedSum_sa("U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConf
erence_2016\\Project\\StreamErosion2.gdb\\SLOPESUS_50FT Value
0.2;U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Str
eamErosion2.gdb\\NLCD_SUS_50FT Value
0.2;U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Str
eamErosion2.gdb\\KFACT_SUS Value
0.2;U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Str
eamErosion2.gdb\\FLOODFREQ_SUS Value
0.2;U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConference_2016\\Project\\Str
eamErosion2.gdb\\HYDGRP_SUS Value 0.2", WTSUM50FT)

# Process: Buffer (2)
arcpy.Buffer_analysis(Stream_Buff_Fin__2_, StreamBuffer1, "1 Feet", "FULL", "ROUND",
"ALL", "", "PLANAR")

# Process: Extract by Mask (7)
arcpy.gp.ExtractByMask_sa(WTSUM50FT, StreamBuffer1, EROS_SUM_1FT)

# Process: Extract by Mask (5)
arcpy.gp.ExtractByMask_sa(NLCD_AOI, StreamBuffer1, NLCD_BUFF1)

# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(NLCD_BUFF1, "Land_Cover", "'Developed, Open Space' 1;'Evergreen
Forest' 0;Shrub/Scrub 0;'Woody Wetlands' 0;'Emergent Herbaceuous Wetlands' 0",
NLCD_SUS_1FT, "DATA")

# Process: Extract by Mask (2)
arcpy.gp.ExtractByMask_sa(SLOPE_SUS, StreamBuffer1, SLOPESUS_1FT)

# Process: Weighted Sum (2)
arcpy.gp.WeightedSum_sa("U:\\Shared\\GIS\\Projects\\USFS_Biomass_Panda\\EcoStreamConf
erence_2016\\Project\\StreamErosion2.gdb\\EROS_SUM_1FT VALUE
0.2;U:\\Shared\\GIS\\Projects
```

. (*continued*).

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