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Using combined prediction models to quantify and visualize stormwater runoff in an urban watershed

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ABSTRACT

Stormwater runoff can transport nutrients, sediments, chemicals, and pathogens to surface waterbodies. Managing runoff is crucial to preserving water quality in rapidly developing urban watersheds like those in Northwest Arkansas. A watershed containing the majority of the University of Arkansas campus was designated as the study area because stormwater from it drains into the West Fork of the White River, designated as an impaired waterbody due to siltation. The project objective was to develop methodology to test existing stormwater drainage infrastructure, identify potential areas of improvement, and estimate potentially contaminated runoff by combining two widely used prediction models. The U.S. Department of Agriculture's Natural Resource Conservation Service's curve number (CN) method was used to estimate runoff depths and volumes, while a flow-direction model was created that integrated topography, land use, and stormwater drainage infrastructure in a geographic information system. This study combined the CN and flow-direction models in a single geodatabase to develop flow direction/quantity models. Models were developed for 5-, 10-, 25-, 50-, and 100-year floods and varied by the antecedent moisture content. These models predicted flow directions within existing drainage infrastructure and runoff volumes for each flood, and served as a hypothetical flood analysis model. Results showed that between 24,000 m^3 (5-year flood) and 60,000 m^3 (100-year flood) of runoff would be transported to the West Fork of the White River. The methodology developed and results generated will help stormwater planners visualize localized runoff, and potentially adapt existing drainage networks to accommodate runoff, prevent flooding and erosion, and improve the quality of runoff entering nearby surface waterbodies.

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INTRODUCTION

After a precipitation event, stormwater runoff transports nutrients, chemicals, sediments, and pathogens to surface waterbodies. Managing this stormwater is crucial in preserving water quality, especially in urban watersheds under heavy development like in Northwest Arkansas, specifically Benton and Washington counties. Northwest Arkansas is the home of several large-scale corporations such as Wal-Mart, Tyson Foods, and J.B. Hunt Transportation. According to the 2000 Arkansas Census, Benton County's population experienced a 57% increase from the 1990 Arkansas Census and Washington County has experienced a 39% increase, an increase totaling over 300,000 people in both counties combined (US Census, 2000).

Washington County is also home to the University of Arkansas, the state's land-grant institution. Since 2003, more than nine buildings have been restored and more than twenty buildings have been erected at the University of Arkansas (FMPG, 2007). Of these newly constructed buildings, three dormitories were built to house the increasing student population. Like the population growth in Northwest Arkansas, student enrollment at the University of Arkansas has increased by 21%, from 15,396 in 2000 to 18,647 in 2007 (Voorhies, 2007).

The majority of stormwater runoff within the subwatershed surrounding the University of Arkansas in Fayetteville flows into the West Fork of the White River; both the White River and its West Fork are tributaries of Beaver Lake, the source for much of Northwest Arkansas' municipal water supplies. However, the West Fork of the White River has been identified as an impaired stream by the Arkansas Department of Environmental Quality due to "high turbidity levels and

MEET THE STUDENT-AUTHOR

I graduated in 2005 from the Arkansas School for Mathematics, Sciences, and the Arts in Hot Springs. I am a junior double-majoring in environmental, soil, and water science in the Dale Bumpers College of Agricultural, Food and Life Sciences and in geology in the J. William Fulbright College of Arts and Sciences. I was able to attend the University of Arkansas after receiving the Honors College Academy Scholarship in addition to several private scholarships provided by the Dale Bumpers College and the Department of Crop, Soil, and Environmental Sciences.

Keshia Koehn

I have worked two different jobs since I was a freshman, including at the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas as a GIS technician. I have also been a member of the Crop, Soil, and Environmental Sciences undergraduate student club and the National Society for Collegiate Scholars since my freshman year. After graduation, I plan on applying to a doctoral program in hydrogeology to work on groundwater system contamination and analysis.

This research was completed as part of the requirement for my undergraduate honors thesis. This project was funded by the State Undergraduate Research Fellowship (SURF) and a Dale Bumpers Research Grant. Initially, the University of Arkansas Facilities Management contracted CAST to update the existing stormwater drainage network. The task developed into the project of analyzing stormwater runoff for the majority of the campus area. I have presented this research at five conferences and won 2nd place at the Southern Branch American Society of Agronomy (ASA) Graduate Oral Symposium and 1st place at the Gamma Sigma Delta Undergraduate Oral Symposium.

excessive silt loads" that were creating an aquatic environment incapable of supporting adequate life (ADPC&E, 1998).

After the West Fork of the White River was placed on the Arkansas 303(d) list for impaired waterbodies in 1998, it was determined that sediment loads were originating from a variety of sources including stream bank erosion, local construction and development, pastures, forests, and urban areas (Formica et al., 2004). According to a best management practice (BMP) study by the US Environmental Protection Agency (EPA), average sediment contributions to surface waterbodies ranged from 213 million mg ha^{-1} yr^{-1} (190 lbs ac^{-1} yr^{-1}) in medium-density residential areas to 1.21 billion mg ha^{-1} yr^{-1} (1000 lbs ac^{-1} yr^{-1}) in commercial areas (USEPA, 1999). With the current high rate of expansion and development in Northwest Arkansas, strategic modeling and planning of stormwater runoff plays a critical role in preserving the quality of surface water.

One of the most common stormwater runoff prediction models is the U.S. Department of Agriculture's Natural Resource Conservation Service's (NRCS) curve number (CN) method (Thompson et al., 2003). Formerly known as the Soil Conservation Service (SCS) Method, the CN method calculates a net runoff depth for a specific amount of precipitation. This method is based on estimations of net runoff after initial losses of accumulated rainfall due to soil storage, interception, and infiltrated runoff (SCS, 1972).

There are several parameters that are used to determine a CN for an area. The land use of an area, or amount/type of surficial cover, can be used to determine the amount of runoff that can be intercepted and/or infiltrated. For example, a paved area would have greater runoff than a grassy area, which would have greater infiltration. Land use can also include land treatment in agricultural settings where crop rotations, contouring/terracing, and the amount of grazing and burning affect quantity of stormwater runoff (Anonymous, 2007).

Soil properties can also have an effect on depth of stormwater runoff. The hydrologic soils group (HSG) is a classification of soil moisture based on the quantity of water that is able to infiltrate the soil, which is influenced by the condition of the soil surface and the soil profile horizonation and includes slope, texture, and hydraulic conductivity (USDA, 2007). Table 1 provides the HSG classification definitions by the NRCS.

The antecedent moisture content (AMC) is another soil property that has a significant effect on quantity of stormwater runoff. AMC is defined as the level of soil moisture before a precipitation event and is divided into three classes: AMC I, AMC II, and AMC III (Anonymous, 2007). A soil with AMC I conditions is described as considerably dry, but not to the wilting point for plants. A soil having AMC II conditions is described as having an average soil moisture condition, and AMC III conditions correspond to a soil that is nearly saturated (Novotny, 1995).

The amount of precipitation, land use, HSG, and AMC are used in the CN method to calculate runoff for an area. This method operates on the assumption that each soil-land-cover combination produces a separate curve number that can be used on catchment areas up to 1000 km^2 (Williams and LaSeur 1976).

This project was designed to develop a stormwater-runoff prediction model in an effort to simulate non-point source contamination of local rivers, like the West Fork. This study sought to develop a methodology to test existing stormwater-drainage infrastructure and identify potential areas of improvement and to estimate potentially contaminated runoff volumes by combining two widely used prediction models [i.e., the NRCS CN method integrated with a geographic information system (GIS) modeling approach].

With the methodology in place, the objective of this study was to evaluate the effects of AMC on stormwater runoff for 5-, 10-, 25-, 50-, and 100-year flood events. The study area was defined as the portion of the University of Arkansas main campus in Fayetteville that contributes stormwater runoff and potential pollutants to the West Fork of the White River. It was hypothesized that the effects of AMC would increase as the flood-return period increased.

MATERIALS AND METHODS

Study area. The study area was located in the City of Fayetteville, Washington County, Northwest Arkansas, and is a delineated sub-watershed of the NRCS 12-digit Hydrologic Unit Code (HUC) Town Branch – West Fork – White River Watershed (110100010404) (Fig. 1). This sub-watershed has an area of 320 ha (~800 acres) and contains the majority of the University of Arkansas' main campus.

This site was chosen because of the availability of necessary data, the diversity of land uses within the sub-watershed, and because this area is a reasonably representative model of small-scale, rapid development. The region encompassing the actual study area is situated in the Ozark Highlands, where geologic ages of the underlying stratigraphic layers range from Late-Mississippian to Middle-Pennsylvanian sandstone with underlying sequences of shale, siltstone, and limestone. (USGS, 2007). Soil data for the study area, obtained from the NRCS Soil Survey Geographic (SSURGO) Database

(Soil Survey Staff, 2006), indicate the most common soil-surface textural class present in the study area is fine sandy loam. In this area, stormwater runoff can carry sediments from disturbed topsoil in construction zones, chemicals from paints and fertilizers used on athletic fields, pathogens from animal litter in parks and residential areas, and trash, oils, and heavy metals from parking lot runoff.

Data development. A digital elevation model (DEM) extracted from light detecting and ranging (LIDAR) data [7.62 meter (25 ft) resolution] was used for calculations in the flow-direction model. This DEM was made available by the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas and the Northwest Arkansas Regional Planning Commission (NWARPC). Aerial photography obtained in January 2007 [0.15 m (6 in.) resolution] was provided by NWARPC. Soils data for the study area were obtained from the NRCS 2007 SSURGO Database (Soil Survey Staff, 2006). Finally, a five-category impervious surface map was created from the aforementioned aerial photography. The impervious surface map was divided into five land-use categories: impervious surfaces, woodlands, grasses, bare soil, and water.

Positions of stormwater features and infrastructure for the University campus features and City of Fayetteville were identified and differentially corrected (post-processed code) using a Trimble GeoExplorer XT GPS unit (Trimble, Sunnyvale, Calif.). Collected stormwater features included intakes like storm grates, linear grates, culverts, area drains, floor drains, roof drains, and curb inlets. Outflow features included outflow pipes and culverts. Other stormwater features that did not play an active role in the flow-direction analysis of runoff included manholes and cleanout features. Locations and attributes of pipelines were provided by the University of Arkansas Facilities Management and the City of Fayetteville GIS Laboratory.

The study area was delineated from three, NRCS 12-digit HUC watershed boundaries using the LIDAR DEM. The three 12-digit HUC watershed boundaries were selected based on their spatial proximity to the central campus: the Hamestring Creek watershed (111101030203), the Town Branch – West Fork watershed (110100010404), and the Mud Creek – Clear Creek watershed (111101030202).

Flow-direction analysis. The first stage of synthesizing the model was to establish flow directions of stormwater runoff within the existing drainage infrastructure. A flow-direction model will provide a way for planners to assess areas needing improvement and will aid in tracing potential contamination pathways.

Spatial and physical connectivity between stormwater pipelines and features was established after creating a geometric network using ArcGIS version 9.2 [Environmental Systems Research Institute (ESRI), Redlands, Calif.]. Geometric network development enabled the complex linear edges and point features of the existing stormwater-drainage network to operate as a complete system. Weights were added to the geometric network such as pipe lengths, diameters, and elevations. In addition, the material used to construct the infrastructure was recorded. Using ArcHydro, and extension of ArcGIS, these weights were used to design a set of algorithms that were able to establish flow direction within the desired stormwater-drainage network.

After determining flow directions of stormwater runoff within the drainage network, the Utility Network Analyst toolset of ArcGIS was used to determine sample contamination pathways in addition to lengths of hypothetical contamination pathways.

Runoff depth and volumetric quantification. It was necessary to generate a set of spatially distributed CN for the entire study area in order to estimate the potential amount of stormwater runoff for a specific precipitation event. Curve numbers were generated using the NRCS CN method, an impervious surface map, surface topography data from the DEM, soils information for the area, and local precipitation data.

Volumes of runoff were calculated in 50 sub-watersheds using runoff depths from the CN method. ArcHydro [Environmental Systems Research Institute (ESRI), Redlands, Calif.] was used to delineate sub-watersheds based on the stored flow directions within stormwater pipelines and key outflow storm features. Because the stormwater drainage network was used instead of a surface water network, sub-watersheds were developed based on flow directions within the pipelines. The precipitation amount, initial abstraction (ie., amount of runoff lost to infiltration, interception, and possible evaporation), and potential maximum subsurface storage were inserted as additional sub-watershed attributes. These parameters were used to estimate runoff using the CN method. Precipitation data were derived for Northwest Arkansas for five flooding recurrence intervals, 5 (142 mm), 10 (159 mm), 25 (184 mm), 50 (203 mm), and 100 year (225 mm), provided by the U.S. Weather Bureau (1958). These precipitation data were used in the CN method to provide a base level for net runoff.

Potential maximum flood model analysis. The potential maximum flood model was designed to be a hypothetical scenario, created in order to visualize runoff movement through the watershed. To assess potential maximum flooding depths, it was necessary to generate a flood environment confined by the study area boundaries. The initial model assumed no addition of runoff water from surrounding watersheds and no loss of runoff water from the study area to surrounding watersheds. The depth of ponding in this model was used to visualize localized runoff and to determine areas that had volumetrically high runoff.

ArcScene (ESRI) was used to create a three-dimensional, seamless model capable of representing the advance and retreat of runoff water in the study area, assuming it was a confined environment. The depressionless DEM, aerial photography, and the sub-watershed and study-area vector boundaries were imported into ArcScene (NAD State Plane 1987 FIPS 301 Feet, Coordinate System). The base heights for the photography and vector boundaries were set equal to the heights of the DEM in order to achieve a seamless, three-dimensional model.

The base heights for the "flood" layer were not set to that of the DEM, but to the minimum elevation of the study area. This boundary created a moveable, planar layer that was able to simulate the flooding capacity of runoff within the study area. This height of the "water" layer was set to the starting position of "No Flooding." For each corresponding flood interval, this layer's base height increased relative to the maximum height of ponded water. ArcScene was also used to model the maximum depth of ponded water for 5-, 10-, 25-, 50-, and 100-year flood recurrence intervals.

RESULTS AND DISCUSSION

Flow direction tracing. The flow-direction prediction model that was developed for this study is important for planning officials at the University of Arkansas and City of Fayetteville at a small scale. However, even though the study area only covered approximately 320 ha (800 acres), the methodology used to develop this flow-direction prediction model can be repeated for larger scales. Since transportation routes of potentially contaminated runoff can be visualized, the model can be used to trace accidental spills, re-route runoff to treatment facilities, and identify locations near outflow features that may be particularly sensitive to contamination.

Curve number analysis. A composite CN map was generated for each level of AMC (AMC I, II, and III) using the impervious surface and soils maps (Fig. 3). Each land-use/soil-group polygon was assigned a CN to be used to calculate a weighted CN average for each sub-watershed. Weighted CN that were calculated for each of the 50 sub-watersheds were used to determine the impact of land use and soils on the amount of direct runoff. The CN maps generated for each AMC condition illustrate not only the abundances of low-permeable land uses in the study area, but also the effects these land uses have on the volume of runoff water being transported into the West Fork of the White River.

Upon observation of the weighted, sub-watershed CN map with reference to the impervious surface map, areas that have the same land-use category, but different HSG, have different local CN. This is shown in the Western quadrant of the study area within the wooded land-use area. This situation can be compared to a sandy soil and a clayey soil under tree cover, because each soil texture has different infiltration and water-holding capacities that affect the amount of runoff. The HSG of an area has a direct effect on the CN-runoff relationship—sandy soils are capable of being more permeable than clayey soils, thus sandy soils have a greater capacity to filter runoff water. These areas are particularly important in filtering contaminated stormwater runoff and are comparable to the drain field of a septic system. Increasing areas that have the capability of runoff infiltration and decontamination can decrease contaminant loading to nearby surface waterbodies, such as the West Fork of the White River.

The mean weighted CN for the sub-watersheds increased with each increase in AMC level. Three maps were developed depicting the weighted CN for each sub-watershed varied by the level of AMC (Fig. 4). The three maps show an increase in the average weighted CN for each increase in AMC level supported by the areal extents of higher CN. There is a clear relationship between the weighted CN and the AMC level—as the soil water content (i.e., AMC) increases, the weighted CN for a watershed also increases, meaning more runoff will occur because the soil has a decreasing capacity to store more infiltrating water as the water content approaches saturation (i.e., AMC III).

The minimum calculated curve numbers for AMC I, II, and III conditions were 52, 71, and 85, respectively. The maximum calculated curve numbers for AMC I, II, and III conditions were 93, 98, and 99, respectively. Average curve numbers for AMC I, II, and III conditions were 79, 89, and 94, respectively.

Runoff depth and volume analysis. The CN method was used to determine net runoff for each sub-watershed for a specific single-storm event. Net runoff increased for each increase in flooding-recurrence interval. As expected, for each increase in precipitation amount, there was a corresponding increase in runoff because of decreasing soil storage capacity. Modeling depths of runoff from precipitation data is important in visualizing the quantity of stormwater being transported by existing infrastructure, given the soil moisture condition (i.e., AMC I, II, or III) at the time of the event.

Also shown by the weighted sub-watershed CN map, for each increase in AMC level, there was a corresponding increase in net runoff for the same precipitation event. Table 2 summarizes the effects of increasing precipitation on the stormwater runoff in each sub-watershed per AMC level.

Net runoff depths calculated from precipitation data were used to calculate volumes of water associated with a specific precipitation event. Runoff data showed that each increase in precipitation was associated with an increase in the volume of runoff water. In addition, the increasing trend in the volume of stormwater runoff was directly related to depths of runoff and to the soil moisture condition (i.e., AMC level). Calculated stormwater runoff volumes were combined with the flow-direction model to visualize maximum flood water retention within the study area.

Maximum flood water retention. In order to model maximum flooding depths of ponded water within the area of study, a hypothetically closed-"bowl" system was constructed to eliminate runoff volume additions and losses to and from surrounding watersheds. Antecedent moisture condition I provided the least areal extent of flooding with increasing flood area in AMC II and AMC III conditions, respectively (Fig. 5). This is directly related to decreasing soil storage capacity as the AMC increases.

For each increase in AMC level, there was an increase in the areal extent covered by ponded water. For lower-magnitude flood-recurrence intervals (i.e., 5 and 10 year), there was a smaller range of area covered by runoff water. For greater-magnitude storm events (i.e., 25-, 50-, and 100-year floods), there is a greater range of areas covered by ponded water (Table 3).

The average height of rise of flood water in the hypothetical closed-"bowl" study area was 0.95 meters (3.11 feet). This is a relatively shallow depth of water, but its magnitude increases greatly when distributed over a low-relief region of the study area. As previously described, this model was conceived in a hypothetically closed system and was able to represent the height of rise and areal extent covered by ponded runoff water. In reality, there would also be simultaneous additions and losses of runoff water in the study area that likely keep maximum flooding depths lower than those predicted by the model.

Significance of research. This project's objective was to develop a methodology to test existing stormwater-drainage infrastructure and identify potential areas of improvement and to estimate volumes of potentially contaminated runoff by combining two widely used prediction models. Using these developed models as a guide, planners at the University of Arkansas and City of Fayetteville can work to improve the quality of runoff water being transported to the West Fork of the White River. Using the flow-direction model and estimated runoff volumes, stormwater-drainage infrastructure can be improved in sub-watersheds that have been shown to contribute the largest volumes of runoff from the study area and in areas experiencing or predicted to experience localized flooding and soil erosion on land and along stream banks.

Currently, stormwater-drainage infrastructure within the study area releases untreated runoff water directly into College Branch Creek, which is a tributary of the West Fork of the White River. During storm events, nutrients, chemicals, sediments, and pathogens are ultimately carried through the drainage network to the West Fork of the White River. The southern reach of College Branch Creek is presently showing severe erosion, and thus is transporting sediment-laden runoff to the West Fork (Fig. 6). This model can help planners re-route runoff away from College Branch Creek, thus likely reducing sediment loads transported to the West Fork.

Future implications. Surficial soil properties and land use have been shown to have an impact on the amount of runoff directly discharging from an area. Models of runoff quantity and flow direction were not only created to determine the quantity of stormwater runoff and its flow through a watershed, but also to develop a reproducible methodology for visualizing small-scale, urban stormwater runoff.

The runoff flow-direction model of the existing stormwater-drainage network is particularly useful for tracing possible point-source contamination. In the case of accidental spills or leaks, planners can accurately trace the contamination pathway through the pipeline infrastructure. In addition, drainage infrastructure surrounding potentially hazardous areas can be modified to transport contaminated water away from surface waterbodies in the likelihood of a spill or leak. Finally, the runoff flow-direction model can be used to decrease localized flooding by re-routing runoff water away from low-relief areas that have greater potential to accumulate runoff from a precipitation event.

Because of the current rate of expansion at the University of Arkansas, construction sites are prevalent throughout much of central campus and contribute to the sediment loading of the West Fork after precipitation. The amount of sediment in stormwater runoff could be decreased by instituting various BMPs that increase the percentage of permeable land, such as permeable pavement and green roofs and a series of detention ponds or grassy swales to slow the water velocity and allow sediment to drop out of suspension before entering College Branch Creek. By constructing monitoring stations along key points in the stormwater-drainage network, areas with high sediment or contaminant loads could be re-routed using the flow-direction model within the existing drainage infrastructure.

Conclusions. In rapidly developing urban watersheds, improperly managed stormwater runoff can degrade surrounding surface waterbodies. In Northwest Arkansas, sediment-laden stormwater runoff is transported to the West Fork of the White River, a surface waterbody impaired by siltation. This project established a repeatable protocol that resulted in a stormwater prediction model that was varied by potential soil moisture conditions in an effort to simulate non-point source contamination of local rivers, such as the West Fork, from urban stormwater drainage networks. The AMC of the soils studied had a direct effect on the amount of stormwater runoff from the study area because the soil had a decreasing capacity to store additional infiltrated water as the soil water content approached saturation.

The methodology developed by this research project can be used to test existing stormwater-drainage infrastructure and identify potential areas of improvement and to estimate the volume of potentially contaminated runoff. The runoff flow-direction model will be particularly useful in tracing point-source contamination within the stormwater drainage network. Volumes of runoff water from specific storm events, calculated using the CN method, can be used to gauge the effects semi-permeable land uses have on the quantity and quality of runoff transported to surface waterbodies.

Designing a stormwater runoff prediction model that includes both the water flow direction and quantity of water transported is essential for not only urban stormwater management planners, but also for city utility officials and urban developers. In Northwest Arkansas, larger-scale replicates of these prediction models could play a crucial role in improving and preserving the quality of surface waterbodies like the West Fork tributary. With the advent of cost-effective monitoring programs, BMP construction, and education to improve water quality, the West Fork of the White River could eventually be removed from the impaired waterbodies list and have its biological productivity return to normal.

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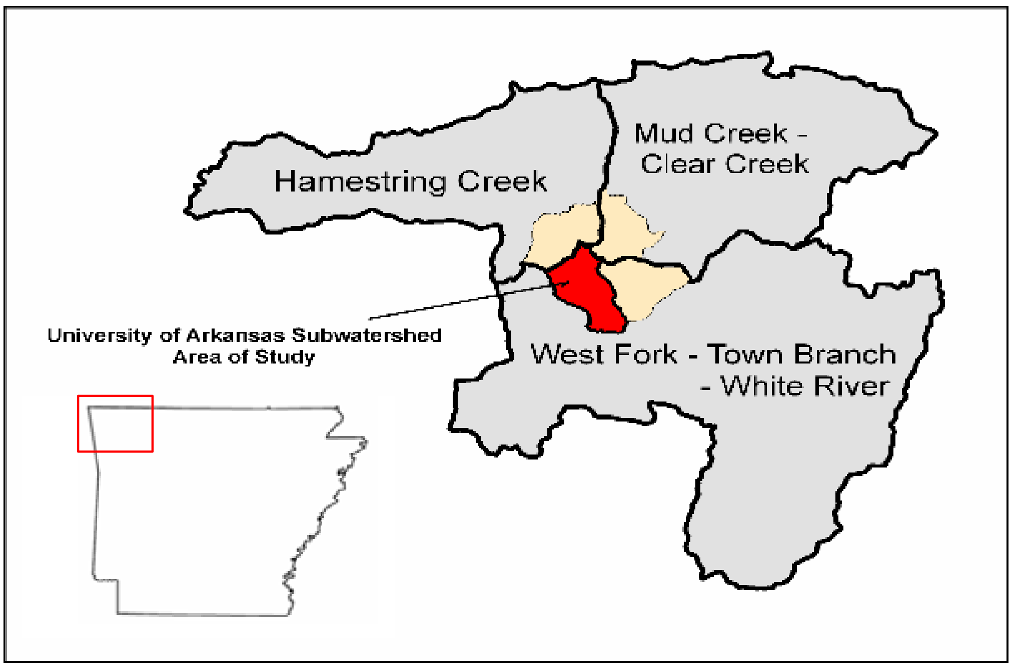

Fig. 1. Delineated University of Arkansas sub-watershed with surrounding NRCS HUC 12-Digit watershed boundaries. The study area was delineated from the West Fork – Town Branch – White River Watershed.

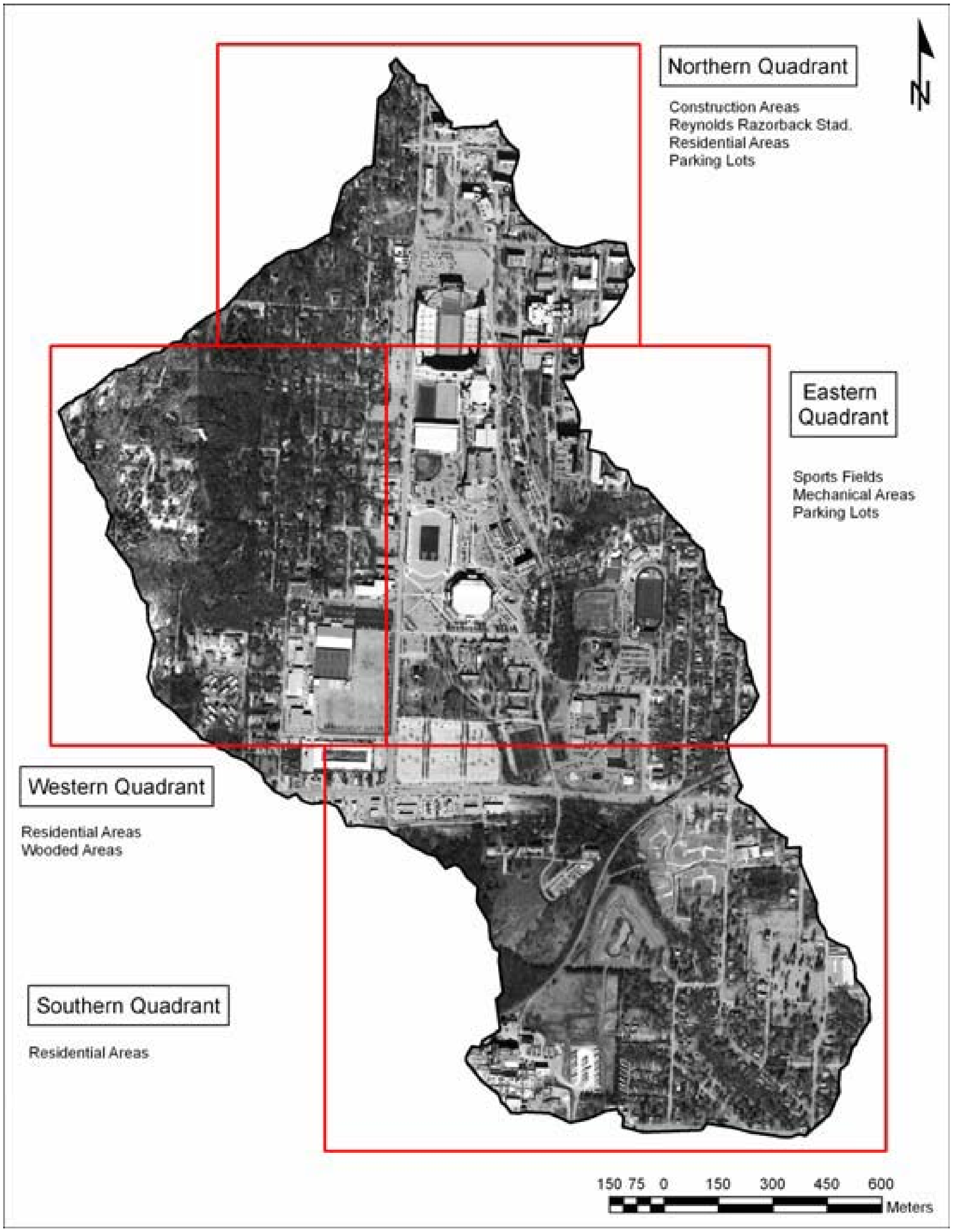

Fig. 2. Land-use quadrants within the study area are characterized by potential sources of runoff contamination. These sources include parking lots, construction zones, residential areas, and athletic fields.

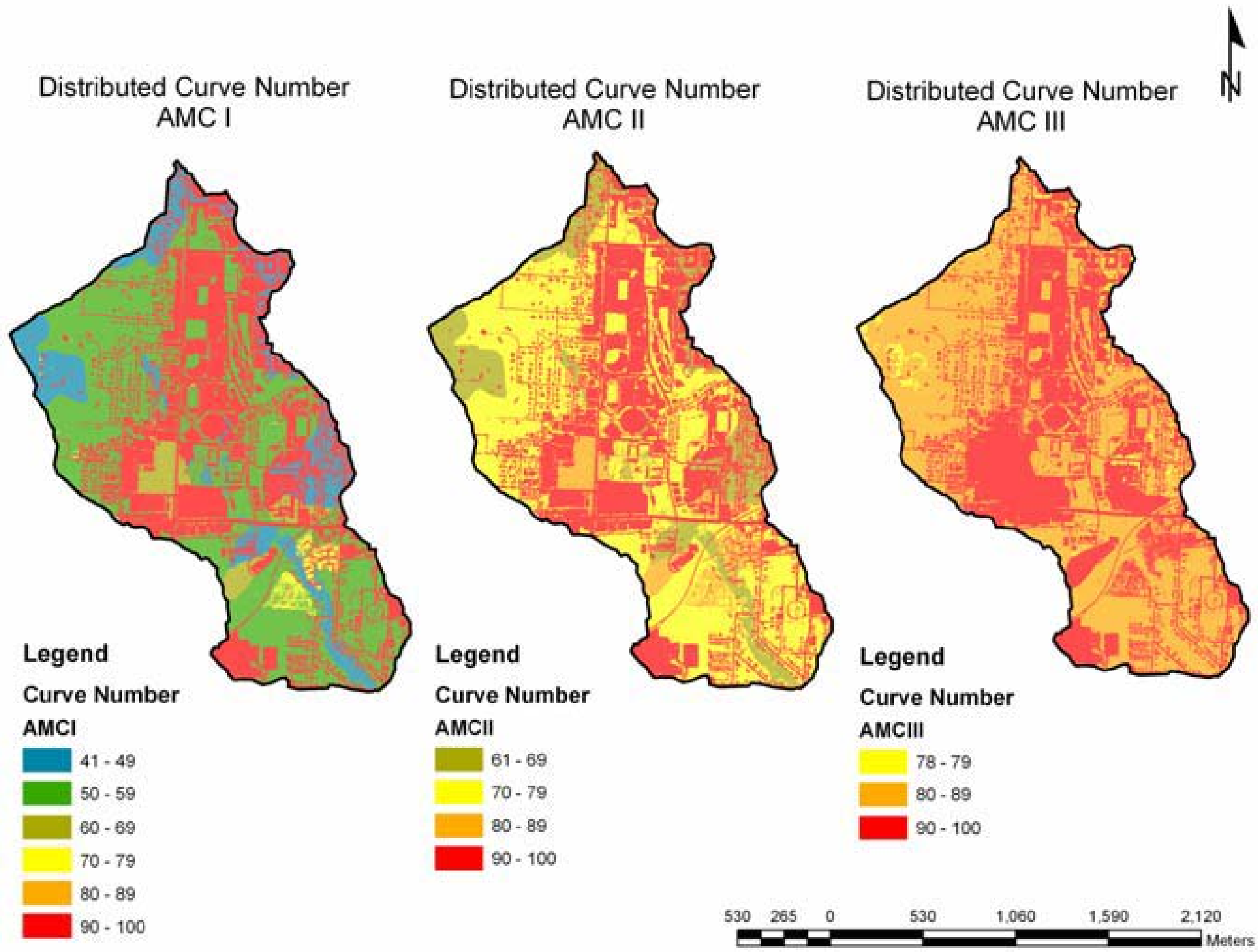

Fig. 3. Study area curve number analysis varied by AMC I, II, and III conditions. For each figure, the AMC was increased, increasing the spatially distributed CN and runoff depths.

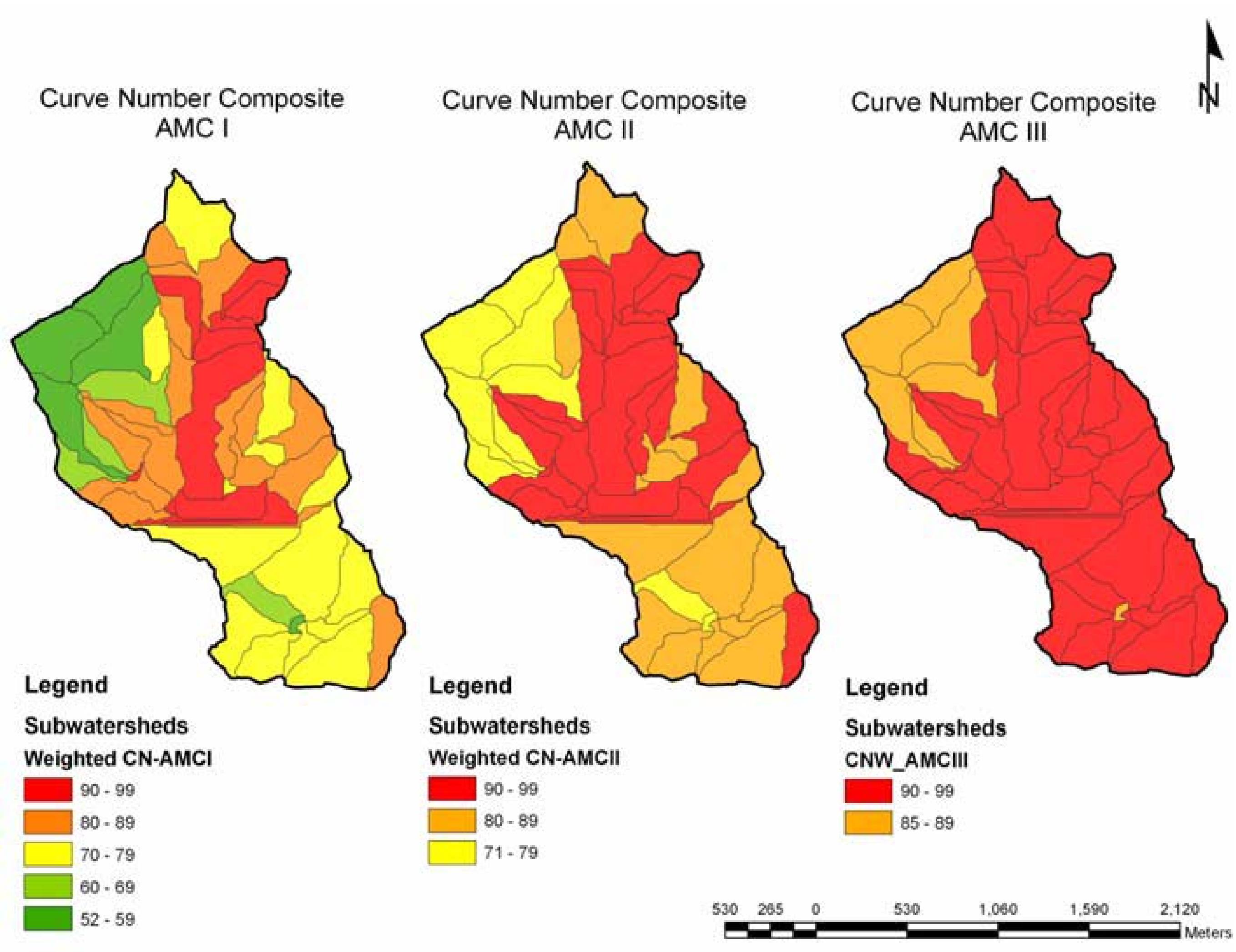

Fig. 4. Sub-watershed weighted curve numbers (CN) for varied AMC levels. For each map, left to right, the AMC was increased, thus increasing the average sub-watershed CN and runoff depths.

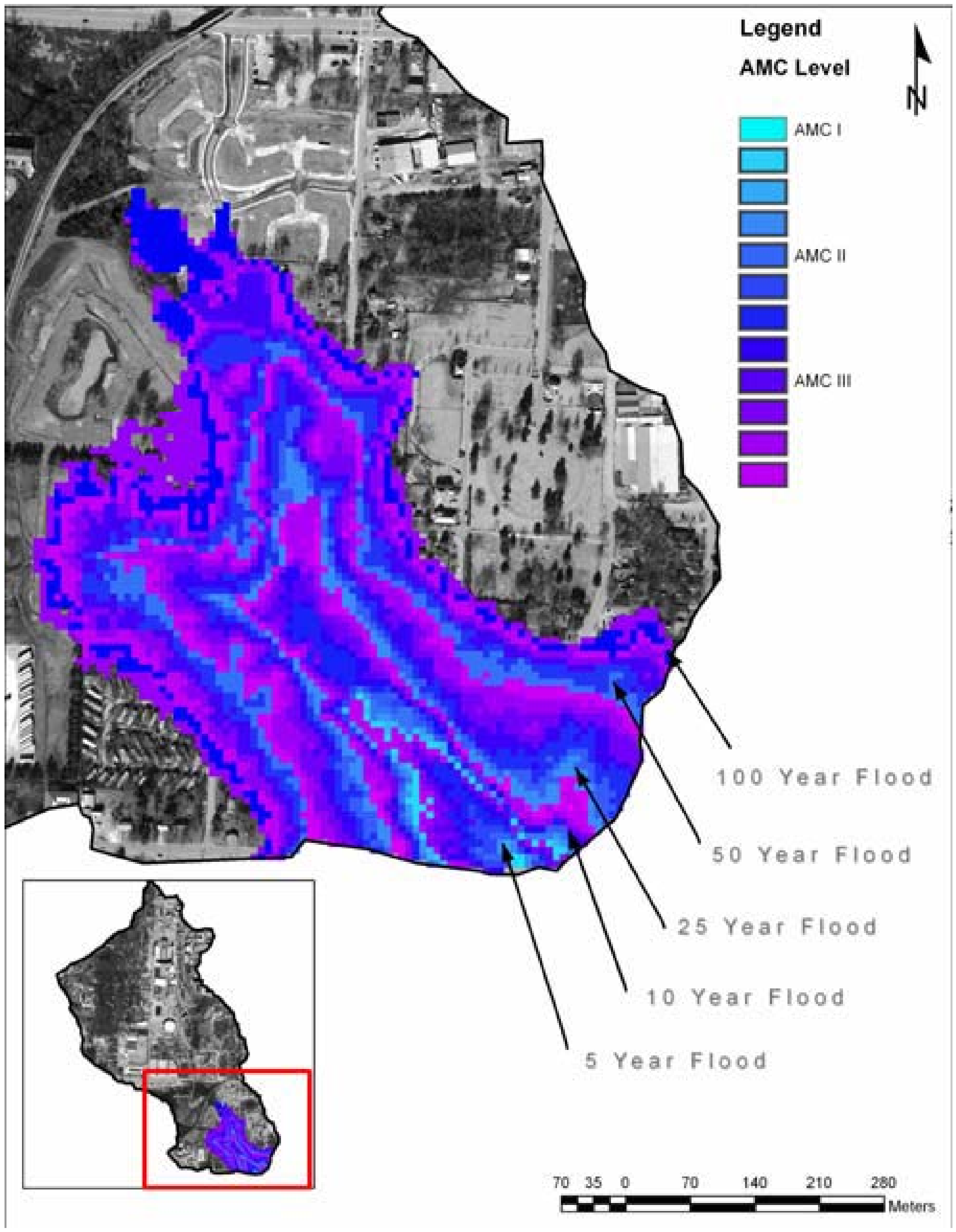

Fig. 5. Maximum flooding extent for varied AMC levels showing the locations of potential flooding on aerial photography of the southern quadrant of the study area.

Fig. 6. Picture of southern reach of College Branch Creek showing significant soil erosion.

Table **1**. Natural **R**esource Conservation Service hydrologic soils group (**H**S**G**) classification descriptions (**U**S**D**A, **2007**)

HSG	Description of Classification
A	Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
B	Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
C	Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
D	Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have high shrink-swell potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Table 2. Statistical information for the net runoff from the sub-watersheds based on curve number calculations

Statistic/ AMC level	5-yr Flood	10-yr Flood	25-yr Flood	50-yr Flood	100-yr Flood
Minimum			- mm -		
AMC I	28	36	51	63	77
AMC II	66	79	100	116	135
AMC III	100	115	139	158	179
Maximum					
AMC I	122	138	163	182	203
AMC II	136	153	178	197	219
AMC III	139	155	181	200	221
Mean					
AMC I	86	100	123	140	160
AMC II	110	126	150	169	190
AMC III	126	142	167	186	208

Table 3. Cumulative runoff depths and volumes for study area calculated by combining GIS calculations with the curve number method

Variable	5-yr Flood	10-yr Flood	25-yr Flood	50-yr Flood	100-yr Flood
Depth			- m -		
AMC I	4313	5031	6159	7021	8011
AMC II	5509	6297	7520	8443	9495
AMC III	6289	7105	8363	9308	10381
Volume			- m^3 -		
AMC I	24758	28975	35625	40716	46571
AMC II	32167	36851	44127	49627	55893
AMC III	37210	42083	49602	55252	61668