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Runoff Using a Combined Geographic Information System and Curve Number Approach

Keshia M. Koehn
University of Arkansas, Fayetteville

RUNOFF USING A COMBINED GEOGRAPHIC INFORMATION SYSTEM AND CURVE NUMBER APPROACH

By Keshia M. Koehn
Department of Crop, Soil and Environmental Science

Faculty Mentor: Kristofor R. Brye
Department of Crop, Soil and Environmental Science

Abstract

Stormwater runoff can transport nutrients, sediments, chemicals, and pathogens to surface water bodies. Managing runoff is crucial to preserving water quality in rapidly developing urban watersheds like Northwest Arkansas. A watershed containing much of the University of Arkansas campus was identified as the target area for this study because stormwater from this location drains into the West Fork of the White River, designated as an impaired water body due to siltation. The project objective was to develop a 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 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, runoff volumes for each flood, and a hypothetical flood analysis model. Results showed that between 24,000 m³ (5-year flood) and 60,000 m³ (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 water bodies.

Introduction

After a precipitation event, stormwater runoff transports nutrients, chemicals, sediments, and pathogens to surface water bodies. Managing this stormwater is crucial in preserving water quality, especially in urban watersheds under heavy development typified by Benton and Washington Counties in Northwest Arkansas. 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 and Washington County experienced a 39% increase from the 1990 Arkansas Census, adding more than 300,000 people in both counties (US Census, 2000).

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

All stormwater runoff within the watershed surrounding the University of Arkansas in Fayetteville flows into the West Fork of the White River, a tributary of Beaver Lake, the source for much of Northwest Arkansas' drinking water. 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 excessive silt loads" that were creating an aquatic environment incapable of supporting adequate life (ADPC&E, 2007).

After the West Fork of the White River was placed on the Arkansas 303(d) list for impaired water bodies 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 Environmental Protection Agency (EPA), average sediment contributions to surface water bodies 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} y^{-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).

Several parameters are used to determine the 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 result in 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 the quantity of stormwater runoff (Anonymous, 2007).

Soil properties can also have an effect on the 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 in turn is influenced by the condition of the soil surface and the soil profile horizonation. Also included would be values for slope, texture, and hydraulic conductivity (USDA, 2007). Table 1 provides the HSG classification definitions by the NRCS.

Antecedent moisture content (AMC) is another soil property that has a significant effect on the 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 plant. 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).

Table 1. **Natural Resource Conservation Service hydrologic soils group (HSG) classification descriptions (USDA, 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.

The amount of precipitation, land use, HSG, and AMC are used in the CN method to calculate the net runoff for an area. This method is based upon 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, 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 of the White River. This study sought to develop a methodology to test existing stormwater drainage infrastructure, identify potential areas of improvement, and 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 effect 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.

Methodology

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). This sub-watershed has an area of 320 ha (~800 acres) and contains most of the University of Arkansas' main campus.

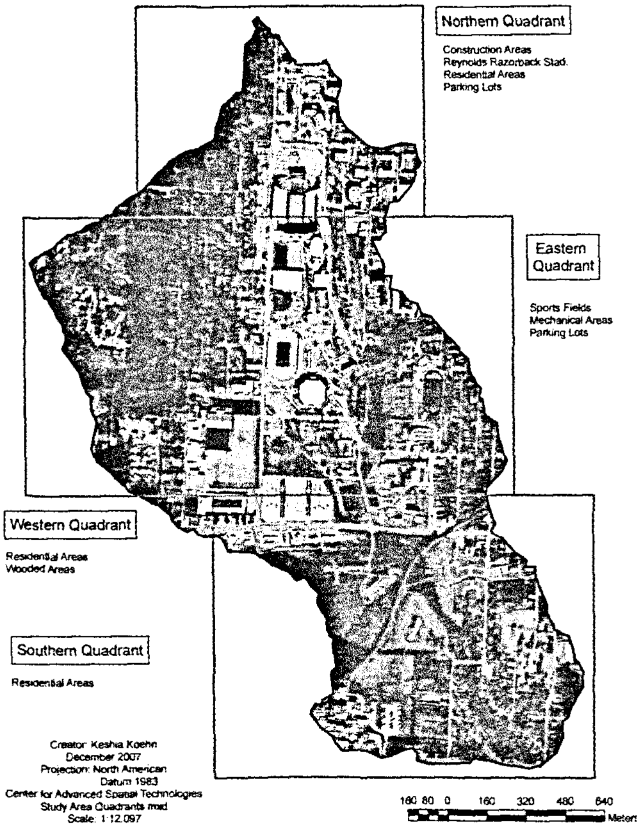
This site was chosen because of the availability of necessary data, the diversity of land uses within the sub-watershed, and the fact that this area is a reasonably representative model of small-scale, rapid development. The region encompassing the actual study area is situated in the Ozark Highlands, where geologic ages of the underlying stratigraphic layers range from the Late-Mississippian to the 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.

The area of study was divided into four quadrants; the Northern, Western, Eastern, and Southern regions. Stormwater runoff from these quadrants flows into College Branch Creek and is transported to the West Fork of the White River (Figure 1).

The Northern region of the study area is characterized by many construction zones, residential areas, parking lots, and sports facilities, including Reynolds Razorback Stadium. This region's stormwater runoff may contain sediments from disturbed topsoil in construction zones, chemicals from paints and fertilizers used in the stadium, pathogens from animal litter in parks and residential areas, and trash, oils, and heavy metals from parking lot runoff.

The Western region contains residential areas in addition to large wooded areas. Stormwater runoff from residential areas can transport pathogens from animal litter, chemicals from drained pools, oil and heavy metals from leaking vehicles, trash, and yard waste to surface water bodies. Wooded areas without development can transport leaf litter in runoff water that can clog stormwater drains. Clogged stormwater drains become a problem when runoff is forced to flow over the land surface, contributing to surficial erosion and

Figure 1. **Land use quadrants within the study area and characterized by potential sources of runoff contamination. These sources include parking lots, construction zones, residential areas, and athletic fields.**



to sediment loading of nearby streams, such as the West Fork of the White River.

The Eastern region contains a number of the University of Arkansas' additional sports fields, parking lots, and mechanical areas. Runoff from these areas can transport paint chemicals, oils, heavy metals, and fertilizers. The majority of the Southern region is residential and has the capability of runoff containing animal litter, oils, sediments, and fertilizers.

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.

Finally, a five-category impervious surface map was created from the NWARPC aerial image. The impervious surface map was divided into five land-use categories: impervious surfaces, woodlands, grasses, bare soil, and water. These five land uses are defined as follows: impervious surfaces include paved parking, building infrastructure, and major roadways; woodlands include light woods, wood-grass combination, and tree farms; grasses include parks, golf courses, greenways, and grazed pastures; bare soil includes gravel parking, quarries, and land under development; and water corresponds to any open surface water body (Halley, 2007).

Positions of stormwater features and infrastructure for the University campus and City of Fayetteville were identified and differentially corrected (post-processed code) using a Trimble GeoExplorer XT GPS unit. 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 which 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. These three 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 the flow direction of stormwater runoff within the existing drainage infrastructure. A flow direction model provides a way for planners to assess areas needing improvement and to 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, CA]. 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 the flow direction of stormwater runoff within the drainage network, the Utility Network Analyst toolset of ArcGIS was used to determine sample contamination pathways in addition to the 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 the net runoff depths from the CN method. ArcHydro [Environmental Systems Research Institute (ESRI), Redlands, CA] was used to delineate sub-watersheds based on the stored flow direction of the 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 (i.e., 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 (1948). 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 to visualize runoff movement through the watershed. To assess the potential maximum flooding depth, 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.

In order to calculate the total volume, or volumetric capacity, of individual sub-watersheds, ArcHydro was used to determine the volume of an empty sub-watershed based on the summation of a series of volumetric slices calculated from the original DEM at 1-m contour intervals. The calculated empty-basin volumes were added to the sub-watershed attribute table. In addition to the empty basin volumes, the maximum and minimum elevations were also appended to each sub-watershed's attribute table.

After calculating the volumetric capacity of the study area and flow direction of runoff, the percent volume filled by runoff water in the sub-watersheds was calculated using the volumes of each empty sub-watershed basin. These volumes were determined from the DEM volumetric slice analysis and each corresponding volume of runoff calculated by the CN method. By calculating the percent of each subwatershed filled by runoff water, the maximum elevation attained by ponded water in the "bowl" environment could be calculated.

Using the maximum fill elevations for the study area as the reference, 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 instead 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 on 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 to 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. Each land-use/soil-group polygon was assigned a CN to be used to calculate a weighted CN average for each sub-watershed. The weighted CNs 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 water bodies, 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 (Figure 2). 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.

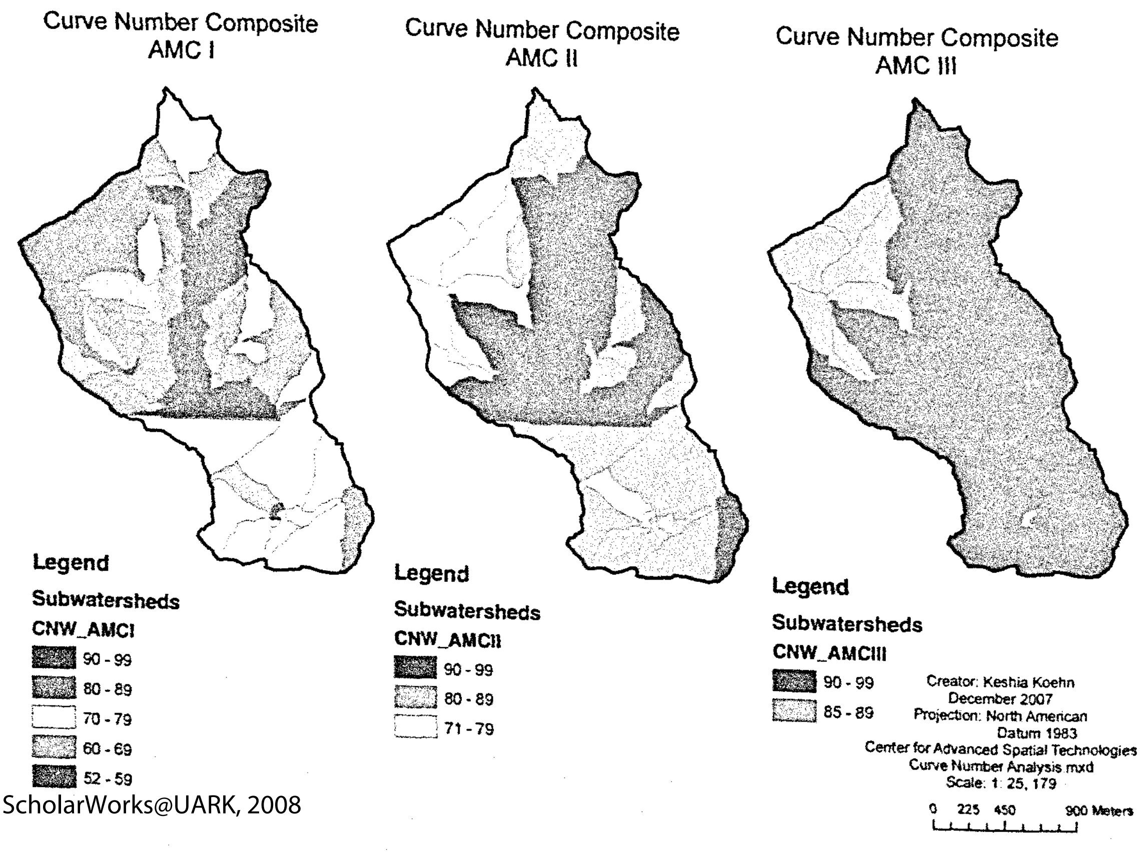
Runoff Depth and Volume Analysis

The CN method was used to determine the amount of 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 the 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.

For each increase in AMC level, as shown on the weighted sub-watershed CN map, there was a corresponding increase in the 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 the 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 the net depth 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.

Figure 2. **Sub-watershed weighted curve numbers for varied AMC levels. For each map, left to right, the AMC was increased, increasing the average sub-watershed CN and runoff depths.**



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

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 (AMC I) provided the least areal extent of flooding with increasing flood area in AMC II and AMC III conditions, respectively (Figure 3). This is directly related to the decreasing soil storage capacity as the AMC increases.

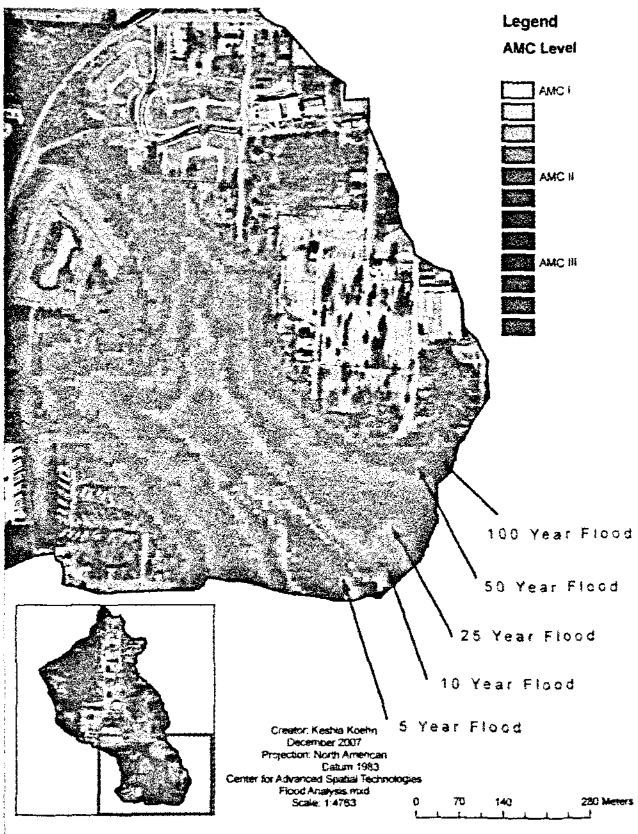


***Figure 3.* Maximum flooding extent for varied AMC levels showing the locations of potential flooding on aerial photography of the southern quadrant of the study area.**

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

***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

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 would keep maximum flooding depths lower than that predicted by the model.

Significance of Research

This project's objective was to develop a methodology to test existing stormwater drainage infrastructure, identify potential areas of improvement, and estimate the volume 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 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, transporting sediment-laden runoff to the West Fork (Figure 4). The model developed in this study can help planners re-route the flow of stormwater runoff away from College Branch Creek, reducing sediment loads transported to the West Fork.

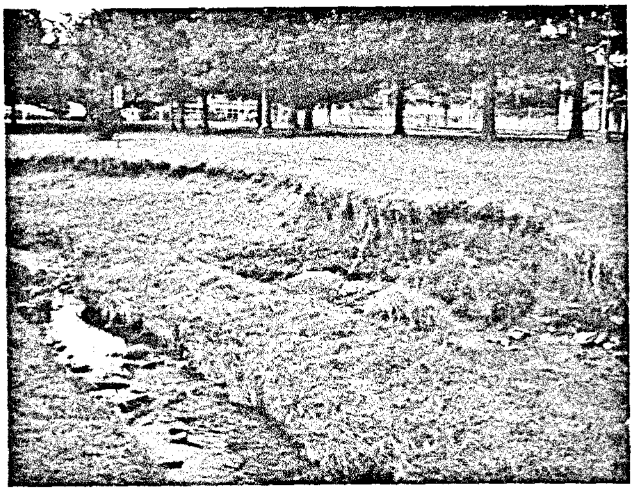


Figure 4. **Picture of southern reach of College Branch Creek showing significant soil erosion**

Methodology Sensitivity and Sources of Error

No model is created without error and every model is only as accurate as its least accurate parameter. Each of the steps executed to achieve the project objective was subjected to a source of error, whether it was human error, systematic error of equipment, or methodology sensitivity. The spatial data accuracy of the collected stormwater features was determined by the accuracy of the GPS unit used. Pipeline data acquired from the University of Arkansas Facilities Management and the City of Fayetteville were subjected to a coordinate system transformation, skewing the original computer aided drawings by a set of spatial algorithms. The CN method has known sensitivity to initial CN selection. Curve numbers were derived from the impervious surface map which had an 89% accuracy assessment between permeable and non-permeable land uses, possibly skewing the CN composites calculated for the sub-watersheds. In addition to the impervious surface map, the accuracy of the aerial photography and the LIDAR DEM were also important in developing a precise runoff model.

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 created not only 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 water bodies 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, contributing to the sediment loading of the West Fork after precipitation. The amount of sediment in stormwater runoff could be decreased by installing 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 of the existing drainage infrastructure.

Conclusions

In rapidly developing urban watersheds, improperly managed stormwater runoff can degrade surrounding surface water bodies. In Northwest Arkansas, sediment-laden stormwater runoff is transported to the West Fork of the White River, a surface water body 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 soil 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 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 water bodies.

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 city utility officials and urban developers. In Northwest Arkansas, larger-scale replicates of these prediction models could play a crucial role in preserving the quality of surface water bodies like the West Fork of the White River. 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 water bodies list and have its biological productivity return to normal.

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Mentor Comments

Dr, Kristofor Brye underscores the interdisciplinary nature of Keshia Koehn's work and draws attention to the originality of her approach and practical impact of her findings.

Ms. Koehn undertook a rigorous project for an undergraduate that was only possible because of Ms. Koehn's unique combined background in soils, environmental science, hydrology, and GIS. Very few undergraduates possess the abilities Ms. Koehn has acquired while still being an undergraduate. Ms. Koehn is a highly independent student. As such she worked independently on her research project getting only minor assistance from a few colleagues she works with in the Center for Advanced Spatial Technology (CAST). Ms. Koehn conducted a significant amount of field work to validate electronic data she used in her study and protocol development.

The nature of Ms. Koehn's research project was significant in that it demonstrated the usefulness of combining various types of information in a GIS to analyze several very real, potential harmful, environmental scenarios. The end product of Ms. Koehn's research project was a working model for land-use planners to use and an adaptable *template that can be applied to similar, but yet somewhat different, scenarios and conditions for preparing for and managing storm water runoff in an urban setting. The model she developed will be implemented and used by Facilities Management to improve existing storm water infrastructure and minimize potential contaminant transport from entering the West Fork of the White River that may be originating from the University of Arkansas's main campus area.*

Ms. Koehn's accomplishments with this research project are highly unique and original in that this approach had not been attempted previously due to the lack of time and resources. Ms. Koehn's work on this project will have saved Facilities Management a substantial amount of time and money and will likely make a significant impact on how storm water and potential contaminants from the U of A campus are managed. Ms. Koehn developed her research topic on her own with little guidance from me. The area of research that she pursued was tangential to my area of expertise and interest, but we decided early on in the process that we would go through this process together, as a team, learning along the way and hopefully making the right decisions. Ms. Koehn's was true to this from the beginning as she asked many questions and thought about every decision that needed to be made along the way.