A Geographic Information Systems (GIS) Approach for Estimating Runoff Characteristics for Erosion and Sediment Control Practices in the Southeastern United States

by

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ABSTRACT

Soil discharged from construction sites to nearby waterbodies have a negative impact on water quality and the aquatic ecosystem. Therefore, it is necessary to develop a stormwater pollution prevention plan (SWPPP) in accordance with the National Pollutant Discharge Elimination System (NPDES) Construction General Permit (CGP) requirements. The SWPPP dictates the erosion and sediment control practices to employ on a construction site to minimize the amount of soil leaving the site and entering a waterbody. Runoff characteristics (i.e.,, peak flow rate, total runoff volume, rainfall intensity, etc.) are required when selecting appropriate erosion and sediment control practices.

Various methods (e.g. Rational Method, Hydrograph method and etc.) have been developed to estimate peak flow rate from a watershed. For this study, the Hydrograph method is selected to estimate the peak flow rate from a 1 acre typical highway median drainage basin in Southeastern U.S. The prediction models of runoff characteristic (i.e., peak flow rate, 30/60/90 minute average flow rates, and the 24 hour total runoff volume) are developed for the entire Southeastern U.S. using Pondpack™, ArcGIS™ and Excel™.

After collecting weighted curve number (CN_W) and rainfall depth (P) for a 2-yr, 24-hr storm event data for the study area, designers can input collected data into prediction models and calculate project specific runoff characteristics for projects under consideration in the Southeastern U.S.. The prediction models can assist designers to calculate runoff characteristics from a typical highway median drainage basin or develop site-specific prediction models of runoff characteristics with specified procedures introduced later.

The prediction models of Southeastern U.S. are proved to be effective when applying on the state

of Alabama, therefore, the prediction models for entire Southeastern U.S. can be also used to predict runoff characteristics from individual States located in Southeastern U.S. In addition, by comparing two different rainfall databases (TP-40 and Atlas 14) and the prediction models generated based upon them (the prediction models for TP-40 are cited from Perez). It can be concluded that Atlas 14 rainfall database is more accurate than TP-40 and the data collected from Atlas 14 is under a raster file which can imported directly into GIS, therefore, Atlas 14 is better than TP-40 in this study.

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CHAPTER 1:

INTRODUCTION

1.1. BACKGROUND

Erosion is the process by which the land surface is worn away by the action of water, wind, ice or gravity (SWCC, 2009). Rainfall induced erosion of a land surface results in soil becoming suspended in stormwater runoff, which may be transported to nearby rivers and streams. Sediment-laden discharges into nearby waterbodies are considered nonpoint source pollution (NPS), which affects the quality of drinking water, recreation, fisheries, and wildlife habitats.

According to the National Resources Inventory (NRI) Summary Report in 2010, about 4.82 tons/acre/yr (10.75 metric tons/ha/yr) of soil loss occurs on non-federal lands in the U.S. due to sheet and rill soil erosion. The Southeast experiences 3.19 tons/acre/yr (7.11 tons/ha/yr) of eroded soil (USDA, 2010). Non-federal lands are defined as lands that are privately owned, tribal and trust lands, and lands controlled by State and local governments. Non-federal lands in the Southeastern portion of the U.S., occupy approximately 88% of total land area. Therefore, soil loss data collected on non-federal lands as part of the NRI report is highly representative for soil losses experienced in the Southeast.

Sediment discharges to nearby rivers and waterbodies that occur during earthwork activities from construction sites in urban areas result in approximately 35 to 45 tons/acre (78 to 100 tons/ha) each year (Jones, 1992). This value is much greater than the national and southeastern soil loss estimations reported by NRI, which means a construction site with poor erosion and sediment control practices will have a negative impact on the water quality of nearby streams, rivers, and waterbodies. The U.S.

Environmental Protection Agency (USEPA) in 2000 indicated that sediment discharged to nearby rivers from construction site is 10 to 20 times greater than that of agricultural lands and 1000 to 2000 times greater that naturally forested land (Zech et al., 2008). Therefore, it is necessary to design and implement a stormwater pollution prevention plan (SWPPP) to mitigate the potential risk of erosion and sediment transport off-site prior to beginning earthwork on a construction site.

To manage sediment discharges from construction sites, the USEPA established the National Pollutant Discharge Elimination System (NPDES) in 1972 to control point source water pollution discharges to nearby rivers and streams (USEPA, 2014). As part of the NPDES, the Construction General Permit (CGP) is designed for controlling pollutant discharges from construction sites that disturb 1 acre or greater (CADOT, 2003). The CGP outlines a set of regulations that construction operators must follow in order to comply with NPDES regulations. According to the CGP, construction operators must design and implement a SWPPP to control pollutant discharges from a construction site (USEPA, 2012). The SWPPP is a site-specific document that identifies the potential sources of stormwater pollution, while specifying the erosion and sediment control practices that should be employed to minimize pollutant discharges to nearby waterbodies (USEPA, 2007).

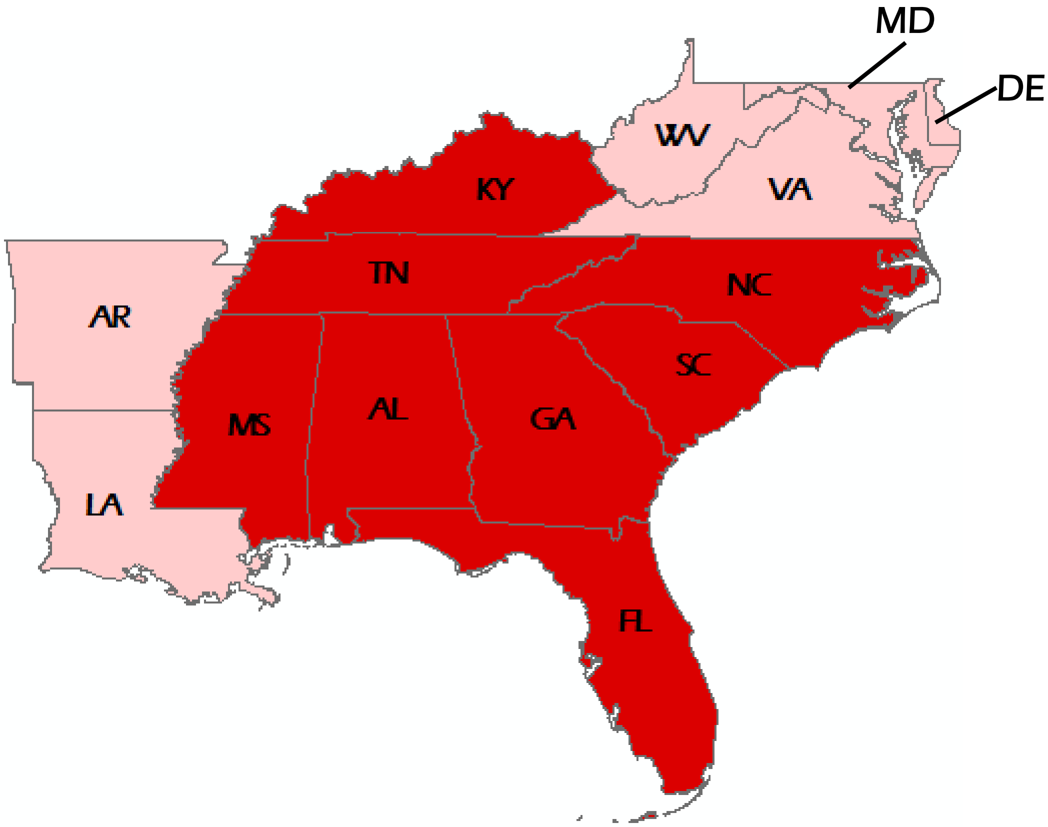
Since the average amount of money spent on highway and road construction has increased from 83 billion in 2002 (Zech et al., 2008) to 181 billion in 2014 (US Census Bureau, 2014), the percentage of the dollar spent on highway and road construction in comparison to total construction work has also increased from 7% to 18%. Moreover, the public road miles from 2000 to 2013 increased from 3.9 million miles to 4.1 million miles (FHWA, 2014) which indicates more highway construction project had been started together with higher pollutant discharge potential. In addition, the water quality standard regulations (e.g. Clear Water Act) are becoming stricter and more specific: in 1975, the first water quality standard regulation (i.e., 4O CFR 13O.17, 4O FR 55334) developed by EPA have relatively lower priority with minor requirements about water quality and criteria specified for toxic pollutants are not mentioned.

As time goes on, water quality standard regulations are revised to incorporate and complement toxic criterial requirements (USEPA, 2015). Therefore, erosion and sediment control on highway construction sites is a topic requiring further investigation to aid designers in developing effective stormwater pollution prevention plans (SWPPPs).

The best management practices (BMPs) dealing with erosion and sediment control occurring on highway construction sites are required in the project's erosion control plan (ECP). Overall there are many erosion and sedimentation control practices (i.e., straw bale barriers, filter fabrics, silt fences, sediment basins, stabilized entrances etc.) available for use on highway construction sites. While within active highway construction sites, the most commonly employed methods to control runoff in conveyance channels are ditch checks and inlet protection practices (IPP) (Perez et.al, 2014).

In this project, a 2-yr 24-hr rainfall event is chosen for the analyses since ditch checks and IPPs are generally designed to handle the soil loss and runoff generated by a 2-yr, 24-hr storm event. Also when a designer selects a return period of a rainfall event, most erosion and sediment controls used on a construction site are typically designed to withstand a 2-yr, 24-hr rainfall event (NPDES CGP, 2012). The Atlas 14 rainfall database was used throughout the study to estimate the 24 hour runoff volume (V_{24}), peak flow rates (Q_P), and for the 30, 60, and 90 minute average flow rates (Q_{p30}, Q_{p60}, Q_{p90}). The Q_{p30}, Q_{p60}, Q_{p90} represent the average flow rates of the peak volume occurring over the course of 30, 60, 90 minutes intervals, respectively.

The primary Southeastern U.S., for this study, was considered as Alabama (AL), Florida (FL), Georgia (GA), Mississippi (MS), North Carolina (NC), South Carolina (SC), Tennessee (TN) and Kentucky (KY) (USEPA, 2015). Other sources (Wikipedia, 2015) indicate that the states shaded in pink, as shown in Figure 1.1, are also considered to be located in the Southeastern U.S. and we categorized them as secondary states which include: Arkansas (AR), Delaware (DE), Louisiana (LA), Maryland (MD), Virginia (VA), and West Virginia (WV), and are shaded pink in Figure 1.1.



Note: The dark red states are usually includes the definition of Southeastern States, and light red States are considered "Southeastern States" with less frequency

FIGURE 1.1 Southeastern States in U.S.

1.2. RESEARCH OBJECTIVE

The purpose of this research is

1. To determine the hydrologic and soil data required for the development of prediction models for estimating runoff characteristics on roadway construction sites in the Southeastern U.S.
2. To list out procedures for generating prediction models with the help of computer programs (e.g. GIS^{TM}, Pondpack^{TM} and Excel^{TM}) that design practitioners can use as guidance.
3. To develop prediction models of runoff characteristics for a typical 1 acre ALDOT highway median drainage basin to aid designers in calculating various hydrologic parameters for a construction site in the Southeastern U.S. and check the application area of this models. The typical ALDOT highway

median is explained later in chapter 4.

The primary objectives of this research are:

1. To provide general hydrologic and soil related information (e.g. precipitation depth, *CN* value, etc.) for Southeastern U.S.
2. To develop specific procedures of generating prediction models of estimating runoff characteristics (Q_P, V_{24}, Q_{p30}, Q_{p60}, and Q_{p90}) for a typical 1 acre design drainage basin.
3. To generate prediction models for calculating runoff characteristics for 1 acre drainage basin in Southeastern U.S using multiple linear regression.

The secondary objectives of the research include:

1. To check whether prediction models for entire Southeastern U.S. can be applied to individual states residing in the Southeast.
2. To compare different rainfall databases (Atlas 14 vs. TP-40), including rainfall depth data and prediction models generated from these databases for the state of Alabama.

The tasks performed to accomplish the research objectives include:

Task 1: to review related literature: the purpose of this task is to identify, describe, evaluate, and critically assess methods used to estimate peak discharge from watersheds and the impact on nearby due to waterbodies the highway construction work. In addition, the role of GIS in hydrologic analysis is also clarified through site-specific case study. Upon completion of the literature review, we will be able to understand the necessary of introducing erosion control practices on construction sites and determine the method to calculate peak discharge from study area. In addition, the application of GIS in hydraulic analysis is introduced through reading case studies from GIS application literatures.

Task 2: can be divided into two steps: Step 1 - includes collecting input data (i.e., precipitation depth and hydrologic soil group information) from official databases and processing the data into uniformed raster files. Step 2 - involved using a "raster calculator" in a geographic information system (GIS) software to generate GIS maps of runoff depth and retention amount after runoff (S).

Task 3: is to list the procedures required to generate prediction models of runoff characteristics, including methods of data collection and processing, generating runoff characteristic maps, using Pondpack™ software to obtain the 24 hour flow rate, and summarizing all output data from Pondpack™ and using the data to develop prediction models of runoff characteristics using linear regression.

Task 4: was to develop prediction models along with summarized data (i.e., Q_P, Q_{p30}, Q_{p60}, Q_{p90}, and V_{24}) and collected data (i.e., CN_w and P) through regression analysis and validate the model's applicability to a project. Moreover, compare the output data from different models generated based on two different rainfall databases (i.e., Atlas 14 and TP-40) for the state of Alabama, including comparing their difference in maximum values, minimum values, average values and standard deviations of the output data.

1.3. ORGNIZATION OF THESIS

This thesis is divided into six chapters to illustrate the procedures followed to develop prediction models and the application of the prediction models. Chapter Two: *Literature Review*, discusses the impact of erosion occurring on construction sites has on nearby waterbodies, provides comparisons of various quantitative methods that can be used to estimate peak flow rates from construction sites, and the application of GIS in hydraulic analysis. Chapter Three: *Hydrologic and Soil Parameters in Southeastern U.S.*, discussed the procedures of collecting *P* and *CN* for the study area and the generation of GIS maps for hydrologic and soil parameters (i.e., runoff depth (Q) and retention amount (S)) for entire Southeastern U.S. and individual States within Southeastern U.S. Chapter Four: *Prediction Model Development*, introduces the specific procedures of developing prediction models with GIS™, Pondpack™ and Excel™. Chapter Five: *Results and Discussion*, demonstrates the prediction models for the Southeastern U.S. and

Alabama, a verification of the models applicability to a particular area, and discussions on the difference between prediction models generated based on two different rainfall databases (i.e., Atlas 14 and TP-40).

Chapter Six: *Conclusions and Recommendations,* provides conclusions regarding the application area and limitations for prediction models, moreover, recommendations for further research focusing on the development of appropriate prediction models for site specific areas are also described.

CHAPTER 2:

LITERATURE REVIEW

2.1. THE IMPACT OF EROSION ON CONSTRUCTION SITES

During the construction process, a large number of pollutant sources exist (i.e.,, waste water, fuel and oil, toxic or hazard substances). Sediment is also a pollutant that is a result of soil erosion occurring during earth-disturbing activities. Under the USEPA's the CONSTRUCTION GENERAL PERMIT, construction site operators should comply with provisions of CGP to control water pollution and minimize soil erosion (USEPA, 2012).

It had been observed that soil loss due to earthwork from highway construction site will disturb the natural drainage conditions of the area under construction and nearby woodlands (Michigan, McLeese and Whiteside, 1977). However, this conclusion is obtained by observation and recording, therefore, the degree of natural drainage conditions disturbed was not quantified in Michigan's study. A large amount of research has been conducted to determine the impact of highway construction work on the environment and ecosystem habitats. To have enough data for analysis, some researchers collected stream samples for 10 years near a construction site (Hedrick and et al., 2010) while others collected data by referencing various representative records of highway construction sites in one state (Kayhanian and Murphy, 2001). After data of samples from nearby streams had been collected, six major components (metals (total and dissolved), nutrients, conventional, oil and grease, biological, and pesticides) of collected samples were analyzed, quantified, and compared with historical records, and found out the concentrations of TSS and turbidity are caused by soils disturbed from highway construction sites

(Kayhanian andMurphy, 2001).

Other researchers such as Barrett are developing trend lines to check the amount change of analyzing components (Barrett et al., 1995). The components that researchers selected to reflect environmental conditions are not exactly the same, however, following categories are always included: total suspended solids (TSS), metals (e.g. chromium and nickel), chemicals (e.g. chloride), and nutrition facts (e.g. dissolved oxygen and phosphorus) (Hedrick and his group member, 2010). The short term analysis for 10 storm within 1 year analysis indicated that construction activities will contribute to the increasing amount of TSS by 470%, and turbidity and iron amount are also increased by 595% and 1100% (Barrett et al., 1995) respectively. According to other research results obtained from 15 typical highway construction sites in California, the highway construction period will generate more TSS, chromium, nickel, phosphorus, and turbidity pollution than during the post-construction highway operation period (Kayhanian and Murphy, 2001). Hedrick et al. (2010) were trying to determine the ecological impact associated with the highway construction period by recording the amount of variation of benthic macro-invertebrate communities within 10 years, and comparing the change of Ephemeroptera, Plecoptera, Trichoptera (EPT) on total macro-invertebrate communities. The amount of EPT decreased over the study period, but still remain above the danger threshold during construction period (4 year) and recovered after construction work had finished. The increases in TSS and turbidity observed during highway construction periods indicates more concerns should be focused on reducing the soil loss from highway construction site while designing, installing, and maintaining erosion and sediment control practices on highway construction sites.

Above all, highway construction sites have a negative impact on the water quality of nearby waterbodies and will decrease the amount of aquatic species living within those waterbodies during the construction period. However, those negative impact can be recovered after construction work is done, and longer period analysis (i.e.,, 10 or 20 years) are needed to validate the long-term impact highway construction has on nearby rivers and streams. (Hedric et al., 2012)

2.2. METHOD TO ESTIMATE RUNOFF AND PEAK FLOW RATE

Various methods had been developed to estimate the amount of runoff volume emanating from a watershed. Additionally, four methods were also evaluated that both estimate runoff volume and peak flow rate for a storm event, which include: (1) rational and modified rational method, (2) Soil Conservation Service (SCS) hydrograph method, (3) modified talbot method, and (4) United States Geological Survey (USGS) regression model.

2.2.1. Rational Method and Modified Rational Method

The Rational Method (RM) was developed by Mulvaney (1851) to estimate peak flow rates from small drainage basins in urban areas. It is considered a simple and accurate method for estimating peak flow rates for small drainage areas less than or equal to 200 acres where no significant flood storage is apparent (Dawod and Mirza, 2011). The empirical estimation formula is shown in Equation 2.1:

$$Q = CiA \quad \text{(EQ 2.1)}$$

Where,

Q = Peak flow, (ft^3/s)

C = Runoff coefficient.

i = Average rainfall intensity, (in/hr)

A = Drainage area, (acres)

A typical table used to select runoff coefficient (c) is summarized in TABLE 2.1 below.

TABLE 2.1 General Runoff Coefficient for the Rational Method

Description	Runoff Coefficient
Business	
Downtown area	0.70-0.95
Neighborhood areas	0.50-0.70
Resident	
Single-family	0.30–0.50
Multi-family detached	0.40–0.60
Multi-family attached	0.60–0.75
Residential suburban	0.25–0.40
Apartments	0.50–0.70
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yards	0.20–0.40
Unimproved areas	0.10–0.30
Drives and walks	0.75–0.85
Roofs	0.75–0.95
Streets	
Asphalt	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Lawns; sandy soils	
Flat, 2% slopes	0.05–0.10
Average, 2%–7% slopes	0.10–0.15
Steep, 7% slopes	0.15–0.20
Lawns; heavy soils	
Flat, 2% slopes	0.13–0.17
Average, 2%–7% slopes	0.18–0.22
Steep, 7% slopes	0.25–0.35

Notes: the source of table is from "The Rational Method", David B. Thompson Civil Engineering Department, Texas Tech University, 2006

The advantage of RM is its simplicity and can maintain accurate for drainage basins equal to or less than 200 acres, moreover, it had been used for over 100 years. However, RM also has its limitations, which include: (1) RM is only effective with the drainage area smaller than 200 acres, (2) it is not able to generate a hydrograph to illustrate changes in flow rate from drainage basin over the course of a rain event, (3) runoff coefficient values are selected based on engineering judgement of designers, which may lead to the inaccurate results (Iowa DOT, 2010).

The Modified Rational Method (MRM) is an extension of the rational method, and is developed by Poertner (1974) to generate geometrically simple (triangular or trapezoidal) runoff hydrographs for drainage basins (Dhakal, 2011). MRM uses the same estimation equation as RM, however the difference between the two methods is that: MRM takes rainfall duration into consideration and also accounts for moisture conditions of storms with a 25 yr, or greater recurrence intervals (Institute for Transportation at Iowa State University, 2005), therefore, the estimation formula is changed slightly as shown in Equation 2.2:

$$Q = C_a C i A \qquad \text{(EQ 2.2)}$$

Where,

Q = Peak flow, (ft^3/s)

C = Runoff coefficient.

i = Average rainfall intensity, (in/hr)

A = Drainage area, (acres)

C_a = Recommended antecedent precipitation factor

TABLE 2.2 below summarizes the recommended antecedent precipitation factors for rainfall storm with 25 year recurrence interval or greater.

TABLE 2.2 Recommended Antecedent Precipitation Factors for Modified Rational Method

Recurrence Interval	Ca
2 to 10	1.0
25	1.1
75	1.2
100	1.25

Note: 1. The product of C x Ca cannot exceed 1.0
2. Tables come from Iowa State Urban Design and specifications, chapter 2

Above all, MRM can overcome deficiencies of RM, however, MRM still use the same assumption and similar equation as RM, and the limitations (i.e., application area and accuracy) of MRM remain the same.

2.2.2. Hydrograph Method

The Hydrograph Method was created by Natural Resources Conservation Service (NRCS) in 1986, and specifically described in Technical Release 55 (TR-55). This method provides a series of equations, reference graphics, and specific procedures to assist designers in estimating the peak flow rate (Q_P) and runoff depth (Q) from a watershed. The equations used to estimate runoff depth is shown in Equation 2.3:

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \quad \text{(EQ 2.3)}$$

Where,

Q = Runoff depth, (in)

P = Cumulative Rainfall, (in)

I_a = Initial abstraction, (in)

S = Potential maximum retention, (in)

While initial abstraction (I_a) is all losses before runoff begins, including water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration (USDA NRCS, 1986). I_a is a variable with a wide range and related to the type of soil and cover parameters. Through a study on many small agricultural watersheds, I_a can be determined by the following empirical Equation (USDA NRCS, 1986):

$$I_a = 0.2 \times S \quad \text{(EQ 2.4)}$$

$$S = \frac{1000}{CN} - 10 \quad \text{(EQ 2.5)}$$

Where,

S = Retention in the soil, (in)

CN = Curve number.

Equation 2.6 can be used to estimate peak flow rate from drainage basin:

$$q = q_t A_m Q \quad \text{(EQ 2.6)}$$

Where,

q = hydrograph coordinates at hydrograph time t, (cfs)

q_t = Tabular hydrograph unit discharge, (csm/in)

A_m = Drainage area, (mi^2)

Q = Direct Runoff, (in)

Equation 2.6 is able to estimate either the peak flow rate or the flow rate at any given time over the course of the rainfall duration. Therefore, by converting the flow rate into the runoff volume (e.g., average flowrate multiply by the time period) and add runoff volumes within a rainfall duration period together, equals the total runoff volume (ft^3) for the rainfall duration under consideration.

The advantage of the hydrograph method is that it can easily estimate direct runoff (S.Gajbhiye, 2012) from a drainage basin with rainfall depth (*P*) and *CN* data for the study area and can generate hydrograph over the course of the rainfall duration by incorporating with computer program (e.g. Pondpack^TM^) or manually plotting. Moreover, there are no area limitations when applying Equation 2.3 and Equation 2.4 (USDA NRCS, 1986), which means the direct runoff amount (*Q*) of large drainage areas can also calculated according to Equation 2.3 and Equation 2.4. However, the limitation of hydrograph method include: (1) that it can't be used on the drainage basin with *CN* values less than 40, while on construction site, where the land cover condition is newly graded area without vegetation cover, the minimum CN is 77 (i.e., CN for type A soil), (2) with the complexity of drainage basin increased, the accuracy of estimation results via hydrograph method decreased, (3) when estimating direct runoff, rainfall duration and intensity are not considered, therefore, the Equation 2.3 and 2.4 are only appropriate for a single storm event (USDA NRCS, 1986).

2.2.3. Modified Talbot Method (MTM)

The Modified Talbot Method (MTM) was develop by Wilson-Murrow in 1971 to suit part of his road design project in mid-North of the Kingdom (Quraishi and Hassoun, 1996). This method is also able to estimate peak flow rate from a watershed. The MTM uses Equation 2.7 below:

$$Q = KCA^{n}R_{f}F_{f} \qquad \text{(EQ 2.7)}$$

Where,

Q = Peak flow rate, (m^3/s)

K = Constant value for various size of watersheds

A = Drainage area, (ha)

R_f = Rainfall Factor

F_f = Frequency Factor

C = Coefficient of discharge

n = Exponents value

While

$$C = c_1 + c_2 + c_3 \quad \text{(EQ 2.8)}$$

TABLE 2.3 below indicate the value of K,n, R_f, factors for Equation 2.7

TABLE 2.3 K, n, and R_f Values Corresponding to Watershed Area

Value \ Area	Median (400-1258 ha)	Large (1258-35944 ha)	Regional (over 35944 ha)
K	0.558	3.561	10.166
n	0.75	0.5	0.4
R_f	1.5	1.4	1.4

Note: the table are developed by Murrow, 1971

TABLE 2.4 below indicate the value of frequency factor for Equation 2.7

TABLE 2.4 Drainage Storm Frequency Factor for MTM

Return Periods (year)	F_f
5	0.6
10	0.8
25	1.0
50	1.2
100	1.4

Note: the table are developed by Murrow, 1971

TABLE 2.5 below indicate the value of discharge coefficient for Equation 2.7

TABLE 2.5 Discharge Coefficient Values for MTM

Coefficient	Values	Drainage nature
C_1	0.30	Mountainous area
	0.20	Semi-mountainous
	0.10	Low land
C_2	0.50	$S^1 > 15\%$
	0.40	10%<S <15%
	0.30	5%<S <10%
	0.25	2%<S <5%
	0.20	1%<S <2%
	0.15	0.5%<S <1%
C_2	0.10	S <0.5%
C_3	0.30	$W^2 = L^3$
	0.20	W = 0.4L
	0.10	W = 0.2L

Note: 1. Slope of drainage area 2. Width drainage area 3. Length drainage area
2. Table are developed by Murrow, 1971

The advantage of the MTM method is that it had no limitations on application area. However, given MTM is developed for roadway drainage design in mid-North Kingdom and the report didn't provide the basis of MTM formula (Quraishi and Hassoun, 1996). The limitations of MTM are as follows: (1) MTM considers the land cover and land use when developing MTM formula, which lead to higher error rate (compared with observed values) while estimating peak flow rate from drainage basins (Al-Shareef, 2013), (2) Murrow didn't consider 2-yr 24-hr storm event when developing TABLE 2.4.

2.2.4. USGS Regression Method

USGS regression method was developed in 1993 to estimating statewide peak flow rate of rivers and streams in the U.S.. This method was programmed in a microcomputer together with techniques of generating a typical flood hydrograph to estimate peak flow rate from ungagged rural and urban watersheds (Jennings et al., 1993). This is a kind of predicting model that makes the use of flood characteristic data from gaged watersheds in a hydrologic region to predict flood characteristics (i.e., peak flow rate for 500, 100, 50, 25, 10, 5, and 2 year intervals) of ungagged watersheds in same hydrologic region (USGS, 2007). The regression equations for each individual State are different due to their various hydrologic region, however, those equations all share the basic forms as shown in Equation 2.9:

$$Q_n = \mathrm{a}A^b B^c C^d \ldots$$

$$\mathrm{U}Q_n = a_u A_u^b SL^c (RI2+3)^c (ST+8)^d (13-BDF)^e LA^f RQ_n^g \qquad \text{(EQ 2.9)}$$

Where,

Q_n = Peak flow rate for n year recurrence interval of rural area, (ft^3/s)

a,b,c…g and a_u = Regression coefficients for each input parameters of equation

A, B, C…. = Parameters that determine peak flow rate value in rural area

UQ_n = Urban peak flow rate for n year recurrence interval, (ft^3/s)

A_u = Contributing drainage are, (mi^2)

SL = Main channel slope, (ft/mi)

RI2 = Rainfall for 2-yr, 24hr storm event, determined from TP40, (in)

ST = Basin storage, the percentage of drainage basin occupied by lakes, reservoirs, swamps and wetlands

BDF = Basin development factor

IA = Percentage of drainage basin occupied by impervious surfaces

ROT = Peak flow rate for an equivalent rural drainage basin in the same hydrologic area, for T year recurrence intervals.

The regression equation for rural area was developed by summarizing analysis reports about prediction models to estimate peak flow rate from 1973 to 1993 in U.S. In urban area, the regression model was developed based upon recorded runoff data from 199 urban basins in 56 cities and 31 State (Sauer et al., 1983) and verified by Sauer (1985). Moreover, regression equation of individual States are generated under USGS national flood frequency (NFF) program, however, the regression equations do not cover all the parameters as the statewide regression model introduced.

In the state of Georgia, the data used to generate regression equation is cited from previous analysis record provided by Golden and Price (1976). Stamey and Hess (1993) point out 10 independent factors (e.g. drainage area, main channel length, surface storage area, channel slope, etc.) that might affect peak flow rate in rural area, and performed Statistical analysis for each factor, whereas only the drainage area variable was reported to be statically significant (Stamey and Hess, 1993). Therefore, equations to estimate peak flow rate of streams in rural area of Georgia only have one parameter: drainage area. Moreover, regression equations are categorized according to hydrologic regions which are determined by major watershed boundaries (Thomas, 1993). Precipitation frequencies (or rainfall frequency) are also considered while categorizing regression equations for rural areas.

The limitations of USGS regression method is summarized by Atkins (1993): (1) the equations are less effective where dams, flood detention structures or other man made works have a significant effect on peak flow rate, (2) regression equations can't applied on streams which peak flow rate is caused by snowmelt runoff; (3) the regression model is developed to calculate peak flow rate from streams and rivers, therefore, it is not effective while applying them on construction site.

TABLE 2.6 summarized the advantages and limitations of methods to estimate peak flow rate.

TABLE 2.6 Summary of Estimation Methods

Character / Methods	Limitations of Application Area	Equation	Rainfall Frequency (year)	Advantage	Limitation
Rational Method	200	$\mathrm{Q} = \mathrm{CiA}$	2,5,10,25 50,100	(1) a simple empirical method (2)100 year usage history (3) very effective on area with simple land cover	(1) can't generate hydrograph (2)the election of coefficient C is highly variable
Modified Rational Method	30	$\mathrm{Q} = \mathrm{C_a CiA}$	2,5,10,25 50,100	estimation results is more closer to real site specific situation than rational method	selection of Coefficient C is highly variable with different engineers
Hydrograph Method	None[1]	$\mathrm{Q} = \frac{(P - I_a)^2}{P - I_a + S}$ $\mathrm{q} = q_t A_m Q$	2,5,10,25 50,100	(1) simple to estimate direct runoff with *CN* and rainfall depth (2) it is most widely used method in hydrologic analysis	(1) can't be used while *CN* is less than 40 (2) the accuracy decreased with the complexity of watershed components.
Modified Talbot Method	Unlimited	$\mathrm{Q} = \mathrm{KC}A^n R_f F_f$	5,10,25,50,100	can be applied on unlimited large area	(1) can't applied on sites with 2-yr rainfall event (2) not so accurate
USGS Regression Method	Unlimited	Rurual:$Q_n = \mathrm{a}A^b B^c C^d$ ... Urban:$\mathrm{U}Q_n = a_u A_u^b SL^c (RI2 + 3)^c (ST + 8)^d (13 - BDF)^e LA^f RQ_n^g$	2,5,10,25 50,100,500	(1) nationwide equation based on massive research data (2) regression models for each states are also provided	(1) originally developed for streams and rivers (2) can't estimate runoff caused by snow melt

Note: 1. Related reference didn't talk about the application area limitations, but the method is effective for watershed with less than 5 different sub basins

In this project, rainfall depth data from 2-yr, 24-hr storm events is selected. The MTM does not take the 2-yr storm event into consideration, therefore, MTM is not recommended. Since the study area is the drainage basin for highway construction site, USGS regression model cannot satisfy this site condition, however, regression analysis can be used to develop prediction models between *CN*, rainfall depth (*P*) and peak flow rate (Q_p). In this study, the soil type for developed drainage basin is 50% of bare soil plus 50% impervious area (pavement), and TABLE 2.1 doesn't have coefficient (*C*) values corresponding to this situation, therefore, hydrograph Method is selected as the method used to calculate peak flow rates from study area for this research.

2.3. THE ROLE OF GIS IN HYDRAULIC ANALYSIS

Geographic Information System (GIS) had been widely applied in analysis regarding spatially distributed data (Dickman and Giiven, 1997) since the development of first version of GIS (i.e., ArcView 1.0). After that, watershed hydraulic researchers introduced GIS into their analysis and applied GIS into following aspects: (1) process and organize the input data into a standard format, (2) overlaid different maplayers or spatial data into one GIS file and displayed their numerical values by attributing different colors to these values, (3) display the output hydraulic simulation results from hydraulic models(Ross and Tara,1993), (4) save manual surveying time and money while dealing with a large watershed area (Pradhan, 2010).

Melesse (2002) then specified the application of GIS in hydrologic modeling by: (1) compute input parameters (different kinds of spatial data), (2) mapping the watershed surface, and (3) distinguishing different watersheds with similar hydraulic response. In this project, the transformation and projection function in GIS will be applied to import various source of input parameters (e.g. rainfall depth (*P*), SCS rainfall distribution map and hydrologic soil group data (HSG) of Southeastern States etc.) into GIS, and projected them under a standard raster maps (100 m x 100 m raster file with "UTM_NAD1983 "projection type). Moreover, "raster calculator" tool is another function that frequently used in GIS to generate raster maps of runoff depth (*Q*) and retention amount (*S*). At last, all the hydrologic and soil parameters, including rainfall depth for 2-yr, 24-hr storm event (*P*), *CN* values, potential maximum retention amount (*S*) after runoff and runoff depth (*Q*) of urban areas in Southeastern U.S. and individual States in Southeastern U.S. will be displayed in a series of standard raster maps.

When estimating runoff depth (or direct runoff) from the watershed, NRCS-*CN* method (i.e., part of hydrograph method) were most widely used, while GIS and Remote Sensing (RS) were also introduced to increase working efficiency (Ebrahimian, 2009). GIS can provide the major computing environment to put all kinds of data inside, transforming and processing them into a standard format which is easier for further analysis. Furthermore, when all the databases are introduced and converted in GIS, engineers can manage the input parameters easily and test different combinations of input data (i.e., soil type, rainfall distribution, drainage area) to check the statistical relations of input data to peak flow rate from drainage areas (Dickman, 1997).

To overcome the difficulty of obtaining clear spatial data (i.e., land use, land cover information) from ungagged urban areas for hydraulic analysis, remote sensing (RS) technology was introduced (Ahang, Halper and Ball, 2004). This technology can be incorporated with GIS to provide high definition digital maps of the study area to assist in estimating runoff amounts from study areas (Gandini and Usunoff, 2004). In this way, land use and land cover conditions for a study area can be easily identified through analyzing digital images, therefore, it will be easier for researchers selecting the appropriate *CN* numbers of the study area. The resolution of satellite image generated by RS is an important factor because it can affect the results of simulated peak flow rate and runoff depth (i.e., all analysis was done in HEC-1™) (Zhang, Halper and Ball, 2004).

According to Equation 2.3, Equation 2.4, and Equation 2.5, *CN* values and rainfall depth (*P*) are the two major factors that determine the runoff depth (*Q*). Rainfall depth data can be obtained by referring to a rainfall database (e.g. TP-40 and Altlas 14 databases), *CN* values for the entire study area can be estimated by subdividing the entire drainage area into different parts that have their unique *CN* values (reference from TR-55) and estimate weighted *CN* for the entire study area. Other geometry characteristics, such as slope of the study area is also introduced to get more accurate *CN* values for the study area (Ebrahimian et al., 2009; Gajbhiye and Mishra, 2012). In their studies, slope-adjusted *CN* values were estimated and applied when estimating runoff depth (*Q*), compared the estimation results with *Q* values estimated with *CN* values referenced from TR-55, and finally, checking errors between observed runoff volumes and estimated runoff volumes. Through statistical analysis (i.e., p-value and percentage of error), both Gajbhiye, Mishra and Ebrahimian proved using slope-adjusted *CN* values will increases the estimation accuracy, however, the percentage of increased accuracy is minimal (the error decreased by 1% percent for Ebrahimian's study and for Gajbhiye, the error decreased by 4%). Moreover, the procedures for calculating slope-adjusted *CN* values are complex, therefore, in this study, slope-adjusted *CN* is not applied.

Most of the researchers select NRCS-CN method to estimate runoff depth of the study area for its simplicity and accuracy (Ratika Pradhan, 2010). Additionally, in order to save time and energy, GIS and Remote Sensing (RS) techniques are also introduced. GIS is mostly widely used software application for providing a uniformed estimation environment by importing various sources of data into a GIS database and overlying them onto a uniformed polygon, raster, or vector maps. Visualization of the spatial data is another important function of GIS, through this procedure, the conceptual data (i.e., rainfall depth (*P*), *CN* values) can be visualized and distinguished by attributing a series color ramps on their values, which gives researcher a visualization of the imported data.

2.4. SUMMARY

This section described the negative impact of disposed soil to nearby water bodies due to construction activities (e.g. increased TSS amount, decreased living EPT group, etc.) and discussed different methods to estimate peak discharge, including rational method, hydrograph method, modified Talbot method and USGS regression method, and finally, hydrograph method are selected for its simplicity and accuracy. In addition, the application of GIS in hydraulic analysis can save researcher’s time and money in large area hydraulic analysis.

CHAPTER 3:

HYDROLOGIC AND SOIL PARAMETERS IN SOUTHEASTERN U.S. - PHASE 1

3.1. INTRODUCTION

Most construction erosion and sediment control practices are typically designed to withstand a 2-yr, 24-hr storm event. (USEPA, 2012) A 2-yr, 24-hr storm means a storm with a duration of 24 hours with a 50% chance of occurring in any given year. Precipitation depth (or rainfall depth) is used to represent a total rainfall amount, which varies throughout the U.S. due to different regional rainfall characteristics. For example, in the Southeastern U.S., precipitation depth can range from 2.31in to 6.68 in.

The input data required to estimate runoff depth from highway construction sites in the Southeastern U.S. includes: (1) 2-yr 24-hr rainfall depth data, (2) hydrologic soil group (HSG) data, and (3) SCS-rainfall distributions. For rainfall depth data, the Atlas 14 rainfall database is selected to provide precipitation depth data that can be integrated into a geographic information system (GIS) database. The HSG data is downloaded from USDA NCRS web soil survey database. Both precipitation and HSG datasets above are the input parameters to estimate general runoff characters (i.e., runoff depth, potential maximum retention, *CN* numbers for study area, and rainfall depth for 2-yr, 24-hr design storm event) for the Southeastern U.S. This chapter aims to identify the range of *CN* values and rainfall depth for the entire Southeaster U.S. and for each state in the southeast individually (i.e., AL, AR, DE, GA, FL, KY, LA, MD, MS, NC, SC, TN, VA, and WV). Furthermore, this chapter focuses on collecting and organizing relevant data for use as input variables for prediction models. The prediction models include modeling the following: (1) peak flow rates, (2) 24 hour total runoff volume, and (3) the 30/60/90 min average flow rates for the Southeastern U.S. Moreover, runoff depth (Q) and retention amount after runoff (S) will be estimated and displayed in GIS to demonstrate general runoff potential of Southeastern U.S.

3.2. DATA COLLECTION

The input data used to estimate runoff depth and retention amounts for Southeastern U.S. includes rainfall precipitation depth, *CN* numbers for the entire study area, and various rainfall distributions associated with the regions under consideration. All of the input data can either be downloaded from an official website (e.g. National Oceanic and Atmospheric Administration (NOAA) national weather service) or created in AutoCAD (e.g. delineate rainfall distributions).

The data collected from different websites is not in a consistent, uniform format (i.e.,, raster file with 100 m X 100 m resolution, projected under “UTM_NAD 1983” datum). Therefore the data collected cannot be directly applied and used for runoff depth estimation and requires some modification. Therefore, the original dataset for the entire study area needs to be modified accordingly to generate a uniform GIS database that can be used to estimate runoff depth and retention amounts.

3.2.1. Rainfall Precipitation

The Atlas 14 rainfall database was generated by NOAA national weather service. The NOAA database is selected as the primary source of precipitation data for this study since it contains tabular rainfall precipitation frequencies estimated with associated confidence limits for the entire U.S. by individual state and is accompanied by additional information (i.e.,, temporal distributions and seasonality) (Bonnin et al., 2006). It addition to the tabular rainfall precipitation frequency data, the databased also contains precipitation depth curves for different rainfall intervals and durations. Furthermore, the data is easily downloadable and imported into a GIS databased.

The downloaded Atlas 14 files include a raster layer of rainfall precipitation for 2-yr, 24-hr storm events for the study area under consideration. This raster map is comprised into two parts: (1) the primary states being analyzed, and (2) the secondary States. Figure 3.1 illustrates the primary states under consideration highlighted with a red boundary, which includes: AL, TN, KY, NC, SC, FL, GA, and MS. The secondary states, highlighted by the blue boundary include: AL, AR, DE, MD, VA, and WV. The raster layer under UTM_NAD1983 projection has a 30 arc-seconds resolution (Perica et al., 2013). The 30 arc-seconds resolution means the sphere is divided into 360 equal by Meridian and Parallel, and each part is called 1 degree, while each degree can be divided into 60 minutes and 1 minutes can be subdivided into 60 seconds, that is where 30 arc-seconds come from. The rainfall depth for the study area ranges from 2.31 in. to 6.68 in. with the color ranges shown in a white to black spectrum. Figure 3.1 also indicate that southern Louisiana, southern Mississippi, Tennessee, South and North Carolina, and the regions along the coastline experience relatively higher rainfall depth than other areas. The image is in its original format and requires further post-processing as a required next step to add individual state boundaries, legends, changing the map colors, etc.

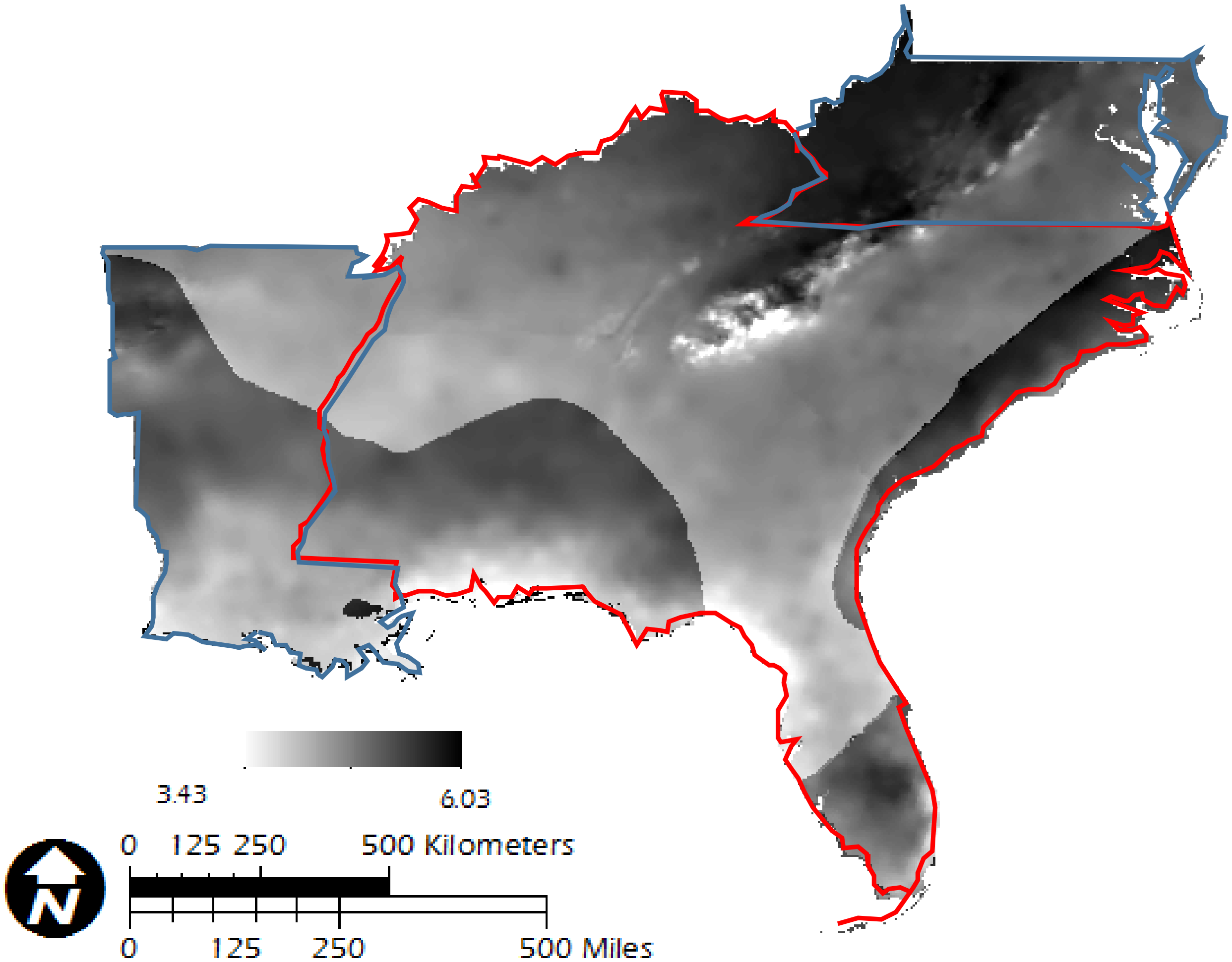


FIGURE 3.1 Original Rainfall Precipitation Data for Southeast U.S.

3.2.2. Hydrologic Soil Group (HSG)

To select appropriate range of *CN* values for the individual states in the southeast, hydrologic soil group (HSG) data are required. HSG classification is based on the premise that surface soils found within a particular climate region have similar runoff responses (Victor Mockus et al., 1972). Soils found on construction site were assigned to different HSGs depending on their infiltration rates for bare soil conditions after prolonged wetting (NRCS, 1986). Soil scientists and engineers assigned soils into classified HSG according to the following factors: (1) intake and transmission of water under the conditions of maximum yearly wetness (thoroughly wet), (2) soil not being frozen, (3) bare soil surface; and (4) maximum swelling of expansive clays. (Victor Mockus et al., 1972). The soil group classifications used in this project were derived from TR-55 are provided in TABLE 3.1

TABLE 3.1 Hydrologic Soil Group Characteristics (TR-55, 1986)

HSG	Soil Profile	Texture	Infiltration Rate	Transmission In/hr (cm/hr)
A	Deep, well to excessively drained sand or gravel.	Sand, loamy sand, or sandy loam	High (low runoff potential)	> 0.30 (0.76)
B	Moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures	Silt loam or loam	Moderate	0.15 to 0.30 (0.38 to 0.76)
C	Soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture	Sandy clay loam	Low	0.05 to 0.15 (0.13 to 0.38)
D	Consist chiefly of clay soils with a high swelling potential, soils in high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material	Clay loam, silty clay loam, sandy clay, silty clay, or clay	Very Low (high runoff potential)	< 0.05 (0.13)

Note: The source of this table is from TR-55, Appendix A

HSG data for the study area was downloaded from CONUS-Soil datasets. These datasets are divided into numerous map units and listed on a map of the U.S. Each individual map unit was assigned a percentage value of type A/B/C/D soils and water areas. As seen in FIGURE 3.2, the highlighted parts are where three map units were selected from Alabama, with the values in “HSGA”, “HSGB”, “HSGC”, “HSGD” and “HSGW” representing the percentage of area assigned a value of A, B, C, and D soil types and waterbodies within each mapunit, respectively. By identifying HSG data for the study area, *CN* values for each map unit can be calculated, which will be discussed in a later section.

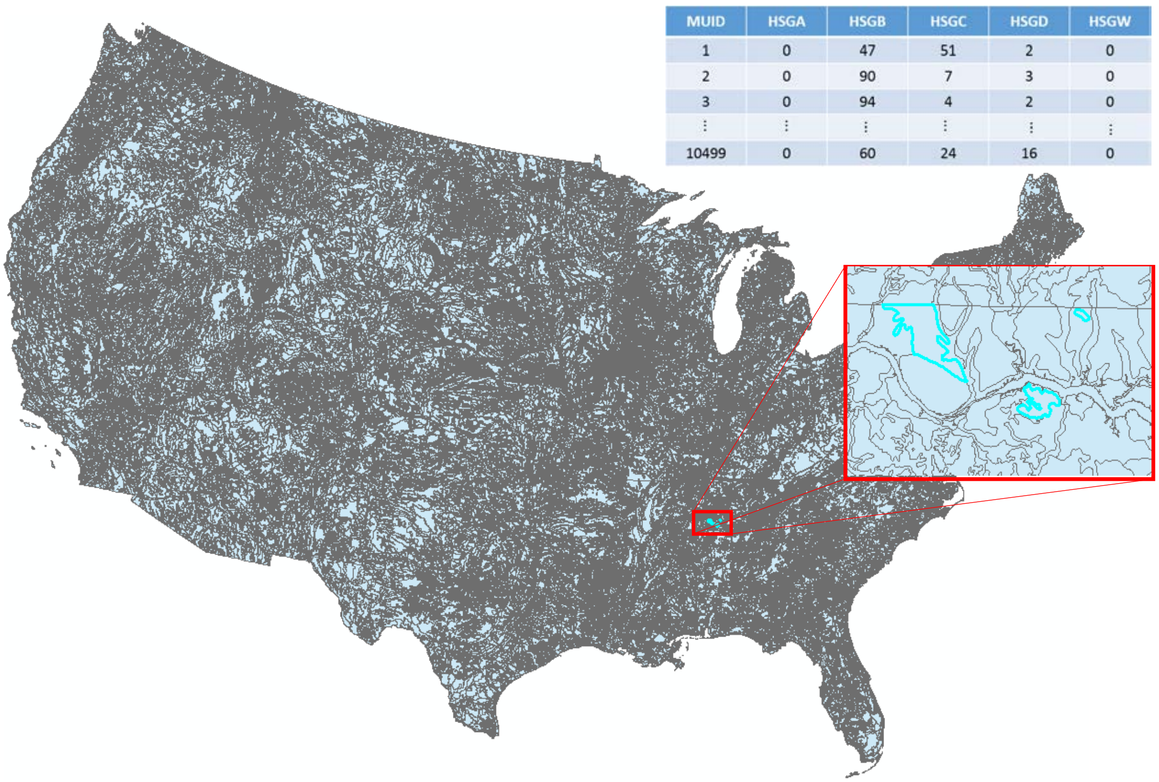


FIGURE 3.2 Original HSG Data for U.S.

3.2.3. SCS Rainfall Distribution Maps

Rainfall intensity varies throughout different geographic regions in the U.S. The NRCS has developed four different types of rainfall distributions (i.e., Type I, Type IA, Type II, and Type III). The geographical boundaries for the NRCS regional rainfall distributions are illustrated in FIGURE 3.3.

The Southeastern States included as part of this study reside within Type II or Type III rainfall distribution regions. Types I and IA represent the Pacific maritime climate with wet winters and dry summers. Type III represents Gulf of Mexico and Atlantic coastal areas where tropical storms bring large 24-hour rainfall amounts. Lastly, Type II represents the rest of the country (USDA-NRCS, 1986).

This image shown in FIGURE 3.3. is in jpeg format and it cannot be directly imported to a GIS database to represent the Type II and Type III rainfall distributions, therefore, conversion, delineation, and post processing work is required in AutoCAD.

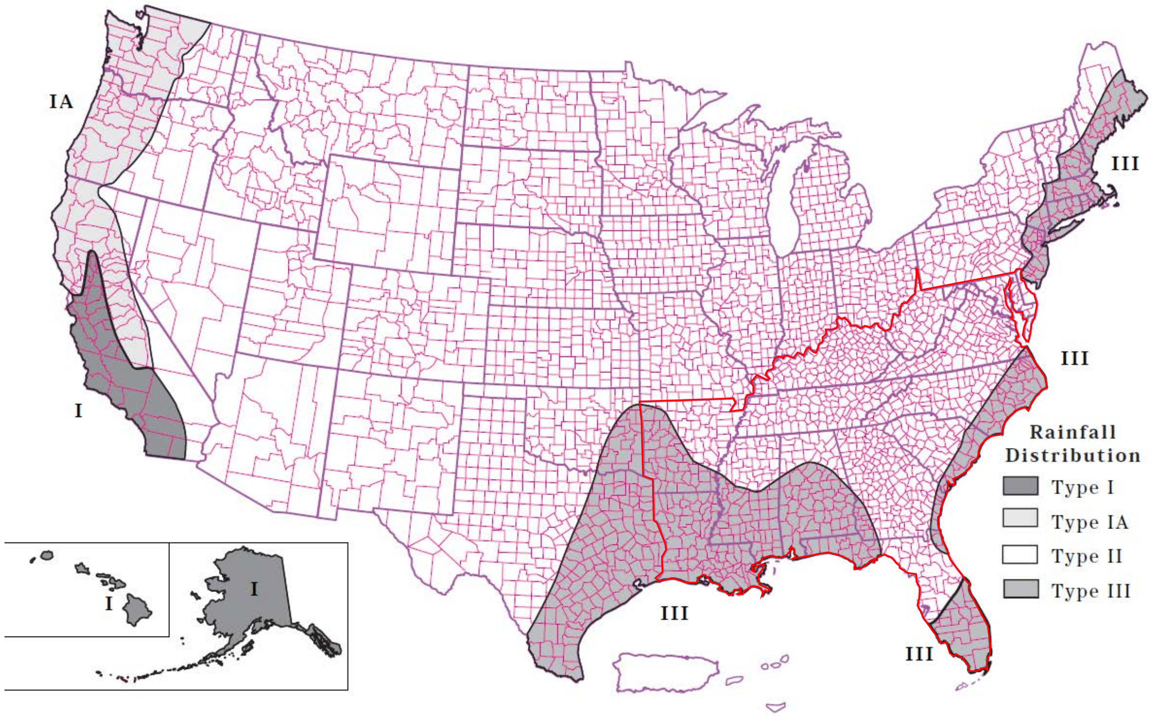


FIGURE 3.3 Geographic boundaries for NRCS rainfall distribution

3.3. DATA PROCESS

Once the abovementioned data were collected, the next step is to select and standardize input data from the original datasets before an estimate of runoff depth and retention amount can be developed. The software that will be used includes: ArcMap™, Excel™, and AutoCAD™. In ArcMap, the following procedures were performed: (1) clip and extract the study area from the original map. This process needs to be executed both on polygon and raster layers; (2) project all the maplayers under "UTM_NAD1983" datum to maintain projection consistency; (3) import and export different sources of data from ArcMap to Excel or AutoCAD; (4) display and add visual effects for hydrologic and soil parameters. In Excel, the weighted *CN* values for each polygon can be estimated according to HSG soil group information (i.e., percentage of different types of soils per map unit) and runoff *CN* table in TR-55. AutoCAD can be used to delineate boundaries of different rainfall distribution according to FIGURE 3.3 and converted back to ArcMap.

With the assistance of the software mentioned above, standard raster files of input data (e.g. rainfall depth, rainfall distributions, and *CN*s) for the study area can obtained. Therefore, runoff depth (Q) and retention amount for the study area can be estimated using the same uniform format (i.e., raster file with 100 m X 100 m resolution, projected under "UTM_NAD 1983" datum).

3.3.1. Rainfall Depth and Region

Since rainfall data of the entire Southeastern US is in a raster layer, further post-processing (i.e.,, clipping the study area out of the entire U.S. map and resetting the resolution of raster layer) is required to have uniformed input data (i.e.,, rainfall depth and rainfall boundaries for each State).

To obtain a uniform rainfall depth raster map layer for each State (i.e., raster layer with 100 m X 100 m resolution and projected under "UTM_NAD 1983" datum) it was important to execute the following stepwise process in GIS. The state of Alabama was used as an example.

Using the "Project Raster" tool to project original rainfall depth map into UTM_NAD1983 datum (Standard format), the following steps were performed.

1. Using the "Clipping" function under "Raster processing" tools to clip the original raster. An Alabama county map downloaded from the U.S. Census Bureau with a 1:20000000 resolution (U.S. Census Bureau, 2013) was used as clipping reference.
2. Using "Project Raster" tool again to convert the clipped raster layer into "UTM_NAD1983 16 zone" datum and project the Alabama county map into the same datum.
3. Add north arrow, a map legend, a scale, and select color gradients for raster layer to complete the standard Alabama 2-yr, 24-hr storm event rainfall depth map.

To delineate rainfall distributional boundaries for Alabama, the steps below were followed:

1. Export Alabama county map from GIS to AutoCAD,
2. Delineate the boundary lines of Type II and Type III regional rainfall distribution on the Alabama

county map, using FIGURE 3.3 as original data. To obtain a smooth rainfall boundary, use "SPLINE" tool to draw boundary lines. Carefully delete the Alabama county map in AutoCAD and leave the curved line created using the SPLINE tool.

3. Using the "Import from CAD" function in GIS, import the CAD file of delineated boundary line back into GIS.
4. Using "Creating Polygon" function to create different rainfall distributions with imported boundary line on Alabama county map.
5. Combine the newly created regional rainfall distribution map with the rainfall depth map created above.

Figure 3.4 (a) illustrates the rainfall distribution map of Alabama generated following the abovementioned procedure.

3.3.2. *CN* Value of Study Area

CN values represent the watershed coefficient, which is the combined hydrological effect of soil, land use, agricultural land treatment class, hydrological condition, and antecedent soil moisture condition (Nayak and Jaiswal, 2003). Furthermore, *CN* values also indicate the runoff potential of an area under consideration (i.e., higher *CN* = higher runoff potential). In the TR-55 manual (Table 2-2a, Chapter 2, TR-55, 1986), *CN* values can be selected according to soil type, land cover condition, land treatment, and hydrologic condition.

To estimate a weighted *CN* value for each polygon map unit, the *CN* value for each type of soil needs to be selected first. According to runoff *CN* table in TR-55, for construction site during earth work period, land cover is considered as "newly graded area (pervious area only, no vegetation)", therefore, the *CN* value for each soil group can be assigned to each polygon unit of HSG soil map (*CN* values are 77, 86, 91, 94 for HSG A, B, C, and D respectively). However, some polygon units may have a large percentage of water (over 40%), those areas will be removed from original HSG map because it will lower the accuracy of estimated *CN* values. Weighted average *CN* values for each polygon unit can be estimated by using Equation 3.1:

$$CN = a\% \times 77 + b\% * 86 + c\% * 91 + d\% * 94 \qquad \text{(EQ 3.1)}$$

Where,

a = percentage of group A soil.

b = percentage of group B soil.

c = percentage of group C soil.

d = percentage of group D soil.

To generate raster files of *CN* values for study area, using Alabama as an example, a user would need to execute the following stepwise procedures below:

1. Use Excel to estimate weighted *CN* for each polygon unit.

2. Clip the state of Alabama out from the original Southeastern U.S. HSG map (FIGURE 3.2). Open table of contents of Alabama HSG map in GIS, generate a new column and name it *CN*.

3.Import estimated *CN* values to new column and display it.

4.Using "conversion" tools to convert polygon to triangular irregular network (TIN) surface and then convert the TIN surface to a Raster file, because the resolution of all raster layers should set to 100 m X 100 m to maintain consistency. Then project the *CN* map to UTM_NAD1983 16 zone and add color gradient, legends, a north arrow, and scale to generate standard *CN* map for Alabama as seen in Figure 3.4 [b].

3.4. HYDROLOGIC AND SOIL PARAMETERS FOR SOUTHEASTERN U.S.

In this research, hydrologic and soil parameters of the study area includes runoff depth (*Q*) for 2-yr, 24-hr storm events, retention amount (*S*) after runoff, rainfall depth (*P*), and weighted *CN* values for the study area (e.g., Alabama). With NRCS-*CN* equations, *Q* and *S* can be estimated for the state of Alabama using input *CN* and *P* values.

Runoff depth is comprised of channel runoff, surface runoff, and subsurface flow in unknown proportions (Mockus et al., 2004). By estimating and displaying runoff depth amounts for the study area, operators can have a general idea of runoff volumes and flow rates expected for a construction site. Furthermore, designers can also set up a factor of safety (the minimum requirements of erosion control practices) and compare the effectiveness of alternative systems of measures within a watershed project according to runoff depth (Kent, 1966).

The "raster calculator" function in ArcMap can be used to estimate *Q* from the area under consideration with a given *P* (2-yr, 24-hr storm event) and *CN* value. With two raster layers of input parameters (*CN* and *P*), *Q* and *S* values can be obtained according to Equation 3.2, Equation 3.3 and Equation 3.4:

$$\mathrm{Q} = \frac{(P-I_a)^2}{(P-I_a)+S} \qquad \text{(EQ 3.2)}$$

$$\mathrm{I}_a = 0.2 * \mathrm{S} \qquad \text{(EQ 3.3)}$$

$$\mathrm{S} = \frac{1000}{CN} - 10 \qquad \text{(EQ 3.4)}$$

Where,

Q = Runoff depth, (in)

P = Cumulative rainfall, (in)

I_a = Initial abstraction, (in)

S = Potential maximum retention, (in)

CN = Curve number

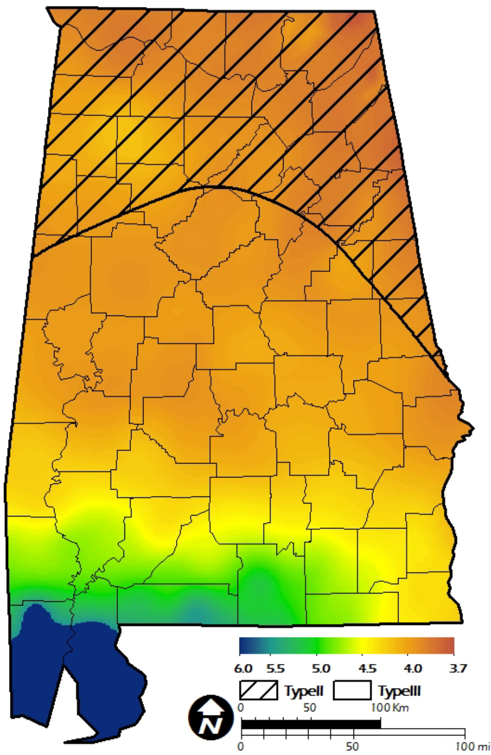
The output layer (i.e., runoff depth (*Q*) and retention amount (*S*)) is raster layer displayed in the standard format established above and can be seen in Figure 3.4 [c] and Figure 3.4 [d], respectively.

Figure 3.4 illustrates the runoff characteristics for the state of Alabama as an example. The runoff characteristics for the remaining Southeastern U.S. states can be found in Appendix B. As seen in Figure 3.4, the range of precipitation depth, *CN* values, retention rates, and runoff depth amounts can be clearly read and visualized. The waterbodies in Alabama (blanket area) are removed from all the maps, where the representative *CN* value is equal to zero. The gradual change in color means increase or decrease of displayed values (e.g. *CN*, *P, Q*, and *S*). For example, color gradient provided for precipitation depth changes from dark brown to dark blue which corresponds to the value change of precipitation depth. The range of precipitation depth various from 3.7 in to 6.0 in. Furthermore, precipitation depth in southwestern part of Alabama is larger than other areas.

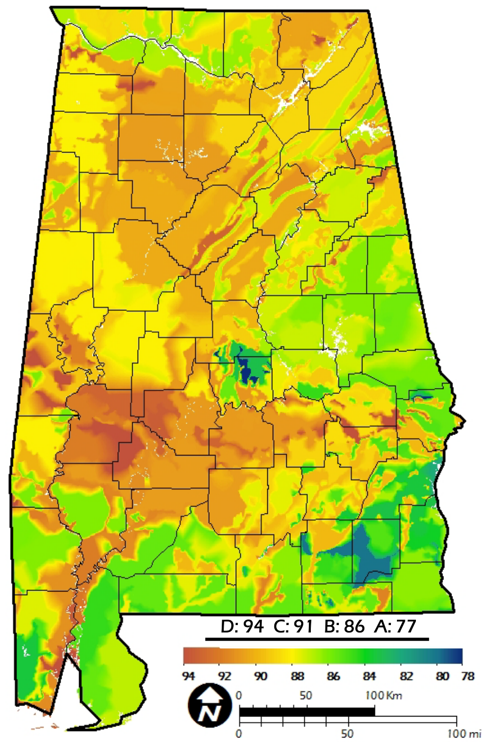
In terms of *CN* values, they range from 78 to 94. *CN* values are higher in south central Alabama, which indicates higher runoff potential of that area.

In terms of runoff depth, the southwestern portion of Alabama has larger runoff depth than other areas, which distribution is the same as precipitation depth map. Therefore, it can be concluded that precipitation depth (*P*) also have positive correlation with runoff depth amount.

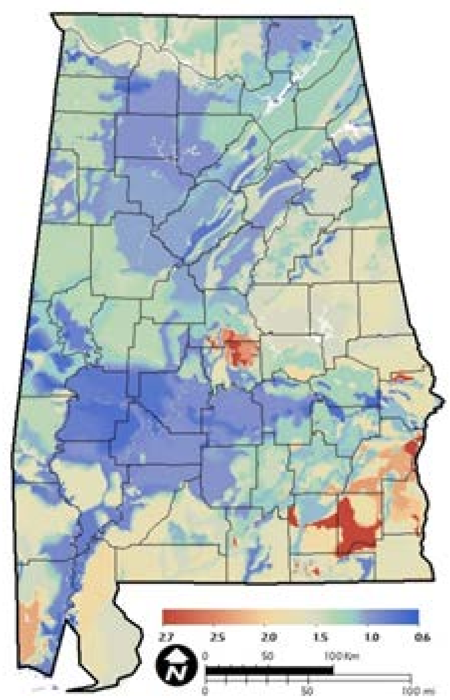
With regards to potential maximum retention, the value range of retention is from 0.6 in to 2.7 in. Since retention is estimated according to Equation 3.3, it has negative correlation with *CN* value. This explains why Figure 3.4 [b] and Figure 3.4 [c] look exactly the same while their values have negative correlation.



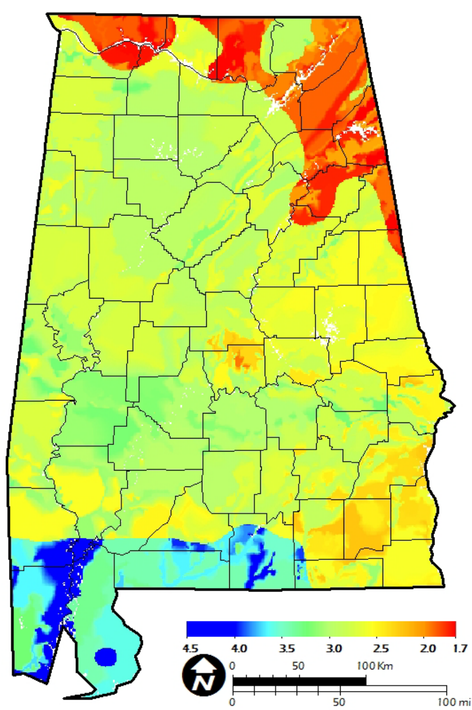
(a) 2-yr, 24-hr rainfall Distribution, in.



(b) CN values for newly graded areas



(c) potential maximum retention – S, in.



(d) runoff depth – Q, in.

FIGURE 3.4 **Hydrologic and Soil Parameters for the State of Alabama**

3.5. SUMMARY

To estimate runoff depth and retention amounts for the study area with GIS, rainfall data and soil characteristics for the study area is required. Furthermore, before entering all the data into GIS, input data need to be converted into a standard format (i.e., raster layer with 100 m X 100 m resolution and projected under "UTM_NAD 1983" datum).

TABLE 3.2 summarized the range of runoff characteristics for the state of Alabama. All the data are directly read from the table of contents for general runoff characteristic map developed in GIS (e.g. *P*, *CN*, *Q* and *S*).

TABLE 3.2 Summary of Alabama Statistic Data

AL		Statewide	Type II Region	Type III Region
P^1:2-yr 24-hr Rainfall (in.)	Max.	6.03	4.32	6.03
	Avg.	4.37	4.06	4.50
	Min.	3.68	3.68	3.99
CN	Max.	94	93.31	94
	Avg.	88.41	88.90	88.36
	Min.	78.61	85.84	78.61
CN^2_w	Max.	96	96	95.66
	Avg.	93.21	93.45	93.18
	Min.	88.31	88.31	91.92
S:Retention (in.)	Max.	2.72	1.65	2.70
	Avg.	1.30	1.25	1.33
	Min.	1.68	0.72	0.64
Q:Runoff (in.)	Max.	4.52	3.25	4.52
	Avg.	2.79	2.51	2.91
	Min.	1.66	1.66	1.72

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_W is estimated by equation CN_W=0.5**CN*+0.5*98

The range of *CN*, precipitation depth, and runoff depth amount will help with further the analysis to determine peak flow rates (Q_P), the 30/60/90 min average flow rates (Q_{p30}, Q_{p60}, and Q_{p90}), and 24 hour runoff volume (V_{24}). The Q_{p30}, Q_{p60}, Q_{p90} represent the average flow rates of the peak volume occurring over the course of 30, 60, 90 minutes intervals, respectively. By performing regression analysis, the linear models to predict Q_P, Q_{p30}, Q_{p60}, Q_{p90}, and V_{24} for 1 acre drainage basin will created. The only parameters for the model include weight *CN* values and rainfall depth (*P*) of 2-yr, 24-hr storm event of the study area. With these models, designers can select appropriate erosion and sediment control practices for highway construction sites based upon the output values from the models.

CHAPTER 4:

PREDICTION MODEL DEVELOPMENT - PHASE 2

4.1. INTRODUCTION

This chapter describes procedures followed for generating linear regression models to predict runoff characteristics (Q_P, Q_{p30}, Q_{p60}, Q_{p90}, V_{24}) from a typical 1 acre drainage basin, based on a typical ALDOT drainage basin for a highway median, in Southeastern U.S. The method used to estimate flow rates for 2-yr, 24-hr storm event from the 1 acre drainage basin is the hydrograph method. All other parameters, such as Q_{p30}, Q_{p60}, Q_{p90} and V_{24}, are obtained on the base of recorded flow rates within 24 hours in Excel™.

Three computer programs are used in this study: Geographic Information System (GIS), Pondpack™ and Excel™. Among them, GIS is used to generate raster maps for runoff characteristics; Pondpack™ is used to estimate flow rates of the simulated drainage basin over a 24 hour rainfall duration for each *CN* and *P* combination; and Excel™ is used to process output flow rates data from Pondpack, generate prediction models of runoff characteristics through regression analysis.

General procedures for developing the prediction models of runoff characteristics for the 1 acre drainage basin in Southeastern U.S. are: (1) collect rainfall data (*P*) and *CN* values for the study area, (2) generate raster maps of runoff depth (Q) and retention amount (S) in Southeastern U.S. in a standard format, (3) estimate flow rates of simulated 1 acre drainage basin over a 24 hours rainfall event in Pondpack™, and (4) post process output data in Excel and develop prediction models for runoff characteristics in Southeastern U.S.

4.2. ANALYSIS PROCEDURES

The procedures followed in this study can be divided into two phases: (1) Phase 1 aims to collect data for Pondpack (ranges of *CN* and P for the study area), and (2) Phase 2 is done to estimate flow rate for a 24 hours rainfall event for the 1 acre drainage basin and create prediction models of runoff characteristics with collected data (CN_W and *P*).

In Phase 1, rainfall depth data (*P*) are downloaded from NOAA's weather service center website and HSG data (used to estimate *CN*) are downloaded from CONUS-SOIL datasets. *CN* values are estimated by referencing TR-55 manual (NRCS, 1986) and collected HSG data. After that, runoff depth maps and retention amount maps are generated for the entire Southeastern U.S. and individual States residing in the Southeast. Since procedures for Phase 1 were described in Chapter 3, Chapter 4 will focus on Phase 2 and introducing the procedures for processing output data from Pondpack™ before using them to develop prediction models.

FIGURE 4.1 provides a flow chart of procedures followed for this research.

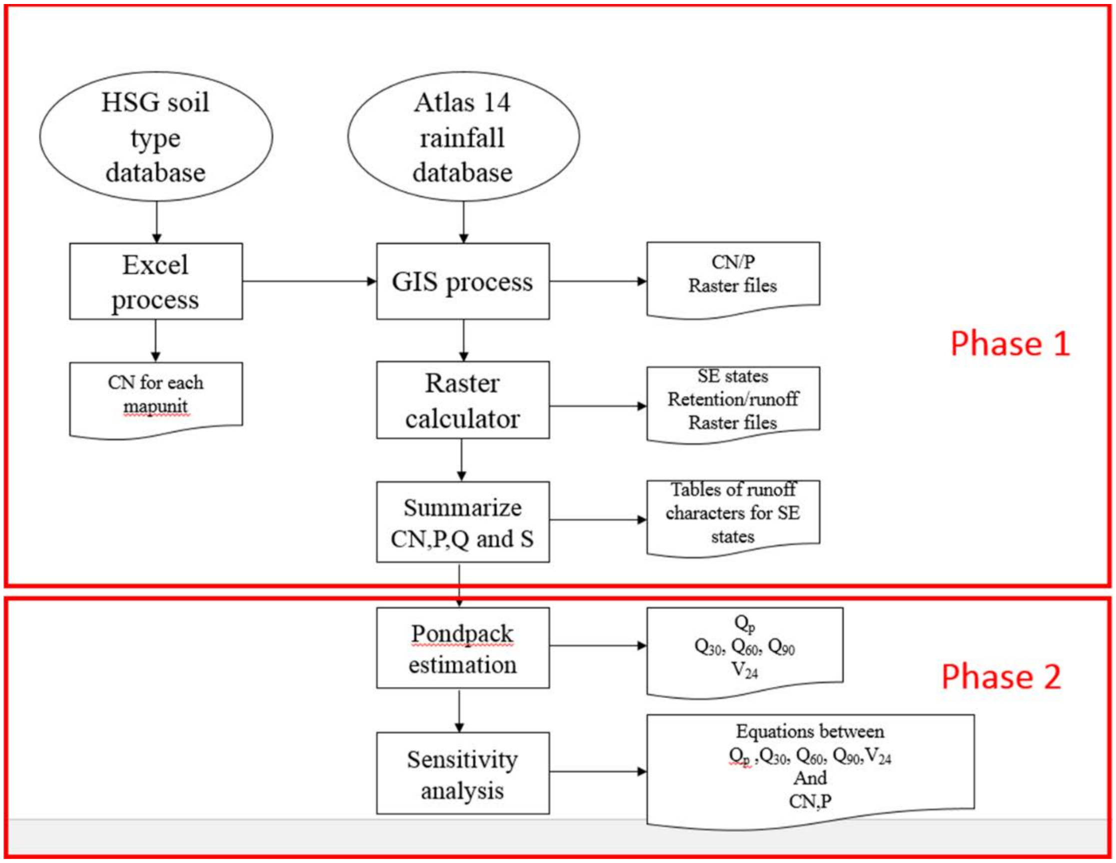


FIGURE 4.1 Procedures of the Project

4.3. PONDPACK ANALYSIS

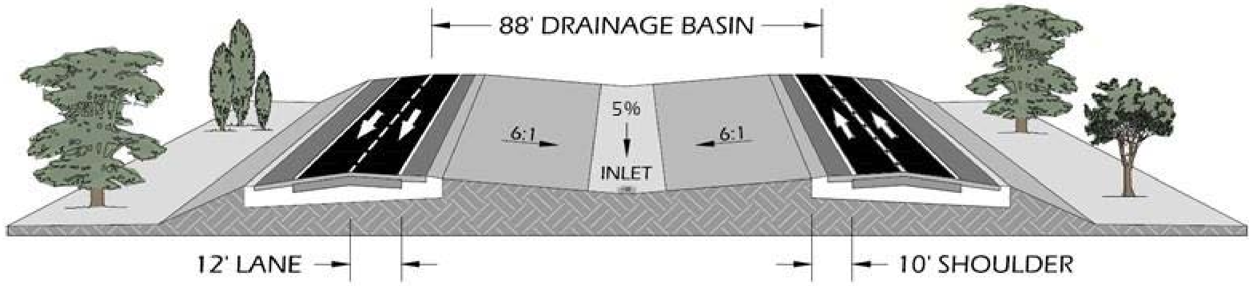
Bentley Pondpack™ is a computer program developed for hydroligic analysis. In Pondpack, the NRCS hydrograph method is used to estimate flow rates of the simulated 1 acre drainage basin (i.e., typical ALDOT drainage basin). The advantage of applying Pondpack™ is the convenience of estimating flow rates with the hydrograph method in 3 steps: (1) set up a drainage basin, rainfall storm event (i.e., 2-yr, 24-hr storm event) and rainfall type region (i.e., typeII or typeIII), (2) insert a group of CN_W and P combinations, area of drainage basin, and T_c for drainage basin, (3) click the “run” button and obtain the flow rates for a 24 hours storm event. With enough flow rate data of different CN_W/P combinations, the runoff characteristics can be estimated based on 24 hour flow rates created by Pondpack™.

4.3.1. Preparation

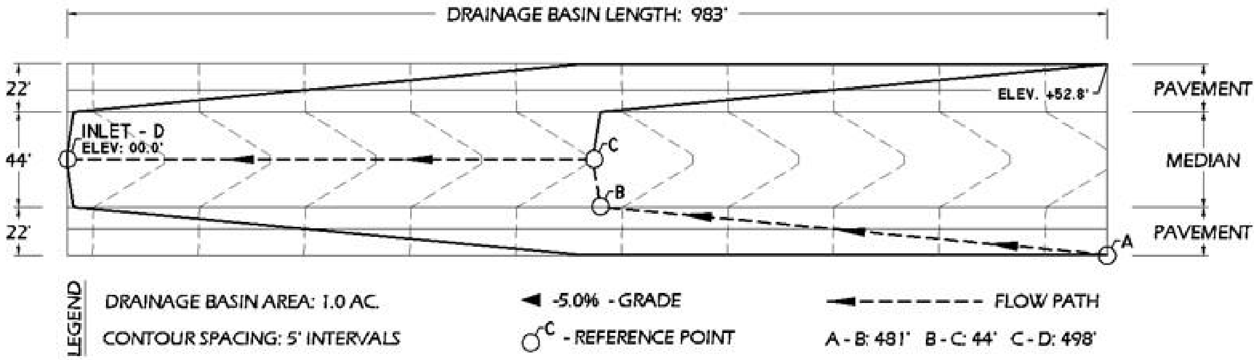
Before starting Pondpack™, following things needs to be determined: (1) geometry character of simulated drainage basin (slope, width, length etc.), (2) combination groups of *CN* and P in Southeastern U.S. ,and (3) time of concentration (T_c) for simulated drainage basin.

4.3.1.1. Drainage Basin Design

In this study, a 1 acre simulated drainage basin is developed to represent a typical ALDOT roadway median. Figure 4.2 illustrates the cross-sectional view of simulated drainage basin comprised of a two lane roadway lies beside drainage conveyance, the width of each lane is 12 ft and each shoulder is 10 ft. There are two 6:1 side slopes from the roadway shoulder to the channel located at center of drainage basin. The drainage basin is sloped longitudinally at 5% towards the outlet, which is at the lower end of the median centerline. In Figure 4 2(b), the longest flow that pass through drainage basin is A-B-C-D, with a total length of 983 ft. This flow path is divided into three parts: (1) 200 ft of sheet flow, (2) 312 ft of shallow concentrated flow, (3) 498 ft of channelized flow. The longest flow path started from point A, passing through point B and C, and discharging at point D, while the length of AB is 481 ft, BC is 44 ft and CD is 498 ft. The contour line of drainage basin have 5 ft intervals, which indicate the elevation distance between nearest contour line is 5 ft.



(a) cross section view



(b) plan view

FIGURE 4.2 Simulated Typical Drainage Basin

Note: The figure sourced from "A Geographic Information Systems (GIS) Approach for Calculating Runoff Characteristics for Erosion And Sediment Control Practices", Perez, et al, unpublished, 2014

4.3.1.2. Combinations of CN_W and P

From Figure 4.2 it can be identified that 50% of drainage basin is covered by pavement, which means the imperious area of drainage basin is 50% and the corresponding *CN* value for impervious areas is equal to 98 (USDA-NRCS, 1986). Therefore, weighted *CN* values for drainage basin can be estimated according to Equation 4.1:

$$CN_W = 0.5*CN+0.5*98 \qquad \text{(EQ 4.1)}$$

Where,

CN_W = Weighted *CN* value for study area

CN = *CN* for undeveloped area

The *CN* range for undeveloped area in Southeastern U.S. is from 77 to 94, converted them to CN_W, the range becomes 87.8 to 96. The range of rainfall depth (*P*) of study area is from 2.3 in to 6.7 in. With CN_W and *P* range in Southeastern U.S., a matrix was created to illustrate various combinations of CN_W

and P. In Figure 4.3, the combination of CN_W/P values in two rainfall distributions are demonstrated in two different matrices. Each point in the matrix represents one CN_W/P combination (e.g. P=3.0 and CN_W=88). Moreover, the increment of CN_W is 1 and rainfall depth increase 0.1 each time (e.g. CN_W can various within the range of 88, 89, 90, 91…96. and the value of P various in 2.3, 2.4, 2.5…6.7). Since the scale of CN_W range is much larger than that of P, different scales of increments for CN_W and P are used to balance their numbers, making the numbers of CN_W and P are relatively close. Above all, there are 450 combinations of CN_W and P for type II region and 270 for type III region.

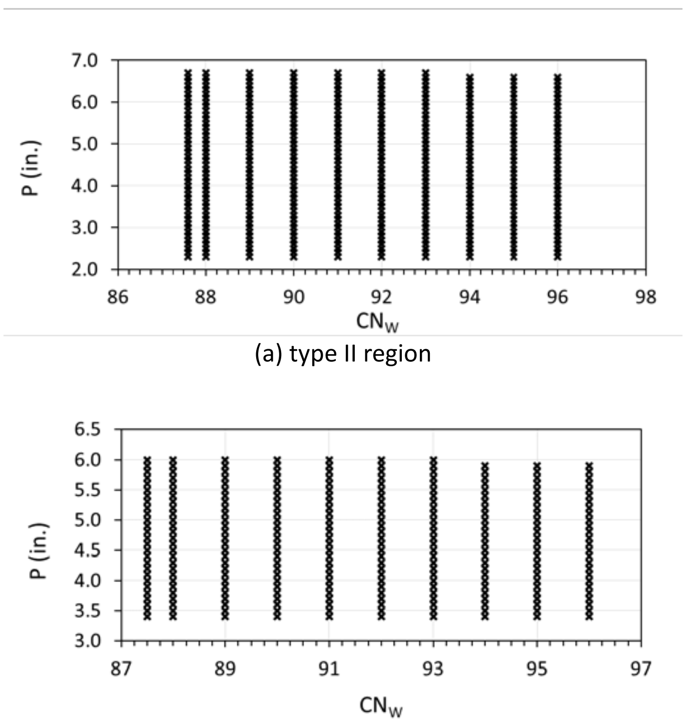


FIGURE 4.3 Combination of CN_W and P for Southeastern U.S.

4.3.1.3. Time of Concentration (Tc)

To estimate the time of concentration (*Tc*) for the drainage basin, equations in TR-55 are used. The flow passing through the drainage basin is divided into three parts: sheet flow, shallow concentrated flow and channelized flow. The maximum length of sheet flow is 300 ft for a very smooth surface, and usually 50 ft-150 ft for natural ground surface (Pitt, 2007). In this study, the surface is imperious asphalt which is smoother than natural ground surface, therefore, assume 200 ft as sheet flow length. Shallow concentrate flow started next to sheet flow and ends at point C, and channel flow starts from point C and ends in point D. T_c is the sum value of travel time (T_t) for three types of flow above, and T_t for each type of flow need to be estimated separately.

The following assumptions are made before estimating T_t of sheet flow: (1) the length of sheet flow is 200 ft, (2) the slope of pavement in flow path direction equals to the horizontal slope (s) of drainage basin, which means s = 5%. Given the Manning's roughness coefficient for sheet flow is 0.011 (smooth surface), flow length L = 200 ft and slope s = 5%, T_t for sheet flow can be estimated according to Equation 4.2:

$$T_t = \frac{0.007(\mathrm{nL})^{0.8}}{(P_2)^{0.5}S^{0.4}} \qquad \text{(EQ 4.2)}$$

Where,

T_t = travel time, (hr)

N = manning roughness coefficient, (for sheet flow)

L = flow length, (ft)

P_2 = 2-year, 24-hour rainfall depth, (in)

S = slope of hydraulic grade line, (ft/ft)

In Equation 4.2, P_2 is the only variable that depends on input rainfall depth, therefore, each time before inputting different combinations of P and CN_W, T_c needs to be recalculated before being entered into Pondpack.

Shallow concentrated flow is comprised of two segments: from the end point of sheet flow to point B, and the other is segment BC. The two segments of shallow concentrated flow need to be calculated separately with Equation 4.4 and Equation 4.5:

$$T_v = \frac{L}{V} \qquad \text{(EQ 4.3)}$$

Where,

L = flow length, (ft)

V = average velocity, (ft/s)

$$V = 16.1\sqrt{s} \text{ (Unpaved)} \quad \text{(EQ 4.4)}$$

$$V = 20.3\sqrt{s} \text{ (Paved)} \quad \text{(EQ 4.5)}$$

V = average velocity, (ft/s)

s = slope of hydraulic grade line

The first segment is shallow concentrated flow with paved surface, given s = 0.05, and L = 281 ft, therefore, T_v = 0.017 hr, and second segment is shallow concentrate flow with unpaved surface, given s = 0.09, and L = 44 ft, therefore, T_v = 0.003 hr.

To estimate T_v of channelized flow CD, the following assumptions are made: (1) side slope of open channel is 4:1; (2) the channel is made of firm soil, which indicate manning roughness coefficient n = 0.025; (3) flow cross-section area a = 24 ft^2, wetted perimeter p_w = 20.5 ft. By substituting all those values above into Equation 4.6, channel-full velocity can be obtained as:

$$V = \frac{1.49R^{\frac{2}{3}}\sqrt{s}}{n} \quad \text{(EQ 4.6)}$$

Where,

V = average velocity, (ft/s)

R = hydraulic radius which equals to a/pw, (ft)

a = cross sectional flow area, (ft2)

p_w = wetted perimeter, (ft)

s = slope of hydraulic grade line, (channel slope, ft/ft)

n = manning roughness coefficient (for open channel flow)

According to Equation 4.3, T_v = 0.009 hr

Once all travel times for the various flows types have been calculated, all individual travel times are summed to determine the time of concentration (T_c) for the drainage basin, which is a variable that is related with rainfall depth (*P*) of study area.

4.3.2. Analysis

Once all the preparation work is completed, each combination of CN_W and *P* will be imported to Pondpack™ to obtain flow rates of the drainage basin over a 24 hours period of time and output data from Pondpack™ will export to Excel™ to obtain the runoff characteristics in Southeastern U.S. 450 combinations of CN_W and *P* will be entered and analyzed in Pondpack™ for Type II rainfall distribution, and 270 combination will be entered and analyzed for for Type III rainfall distribution.

Analysis procedure for Pondpack™ are listed below:

(1) Setting the runoff estimating method as SCS unit hydrograph (hydrograph method),

(2) Generate a simulate 1-acre drainage basin in Pondpack™,

(3) Create Type II and Type III storm data group under "time-depth" column of "Storm data" window, entering rainfall depth *P*, T_c and CN_W, select storm event for the 1 acre drainage basin, and click the "compute" button ,

(4) Export computation results to Excel, repeat the procedures above, until all combinations of CN_W and *P* have computed in Pondpack™, and export the output data (flow rates for 24 hour time periods) to Excel.

4.3.3. Output

The output data from Pondpack are a series of tables representing different CN_W and *P* combinations with two columns, one of them is demonstrated in Figure 4.4. In the left column, 24 hours are divided into 2400 parts, each part represents for 0.01 hour and the right column stands for the flow correspond to the time in left column. In order to start regression analysis, 450 combinations of CN_W and *P* in the Type II rainfall distribution and 270 combinations in Type III rainfall distribution are need to be analyzed in Pondpack™ one by one, their outputs will recorded and organized in a large Excel table for the next step of the analysis. Moreover, tabular hydrographs of flow rates for each CN_W and P combination are also generated in Pondpack™. An example is illustrated in Figure 4.5. This runoff hydrograph is in Type II rainfall distribution with CN_W =96 and P =6 in. The hydrograph has a precision of 0.01 hour, peak flow rate, average 30/60/90 minute flow rates are also marked out in Figure 4.5

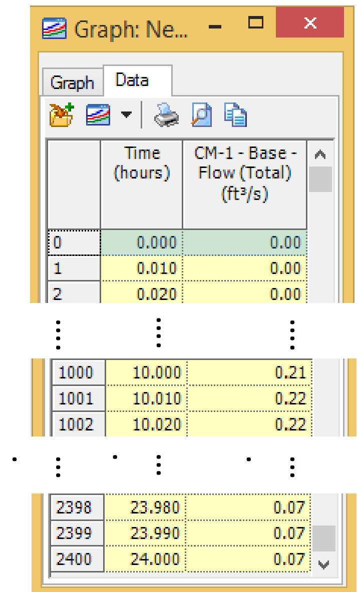


FIGURE 4.4 Output Flow Rate for One Combination (CN_W=96, P=6.0 in)

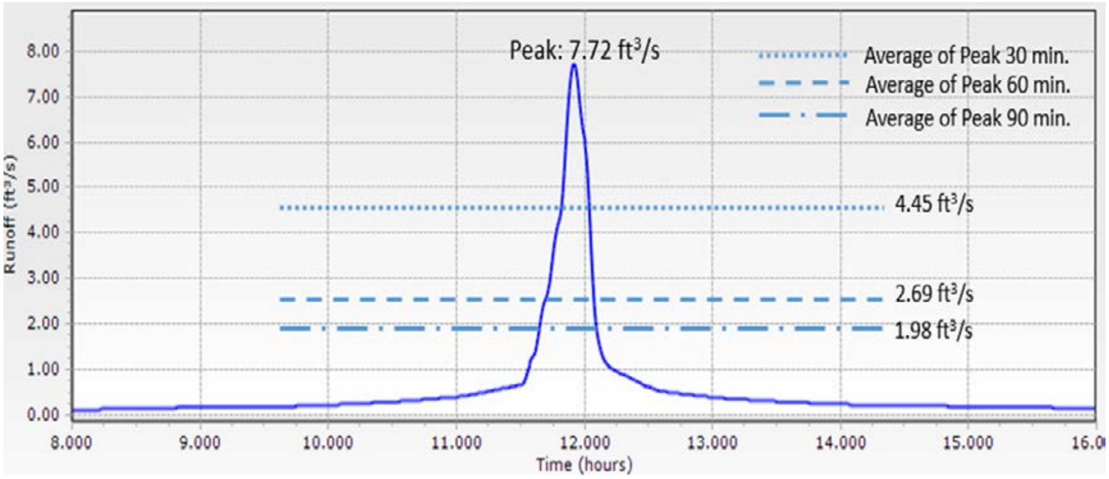


FIGURE 4.5 Example of Hydrograph Result (CN_W: 96, P = 6.0 in)

4.4. REGRESSION ANALYSIS

To generate a linear prediction model of runoff characteristics for the Southeastern U.S., regression analysis in Excel™ is performed with output data from Pondpack™ (flow rates for a 24 hour period of time) and various combinations of CN_W and P. Previous steps had recorded the flow rate occurring over the course of 24 hours for each CN_W and P combination, therefore, the next step is to estimate Q_P, Q_{p30}, Q_{p60}, Q_{p90} and V_{24} values from existing flow rates occurring over the course of 24 hours.

4.4.1. Preparation

The output data from Pondpack is a large group of flow rates for the different combinations of CN_W and P. All of that data needs to be categorized and organized before linear regression is applied to develop prediction models. Therefore, the output date are categorized into three types and prepared and categorized according to rainfall distributions in Excel (i.e., Type II and Type III): Q_P and its correlated CN_W and P, Q_{p30}, Q_{p60}, Q_{p90} and their correlated CN_W and P, and V_{24} with its correlated CN_W and P.

There are two columns for each CN_W /P combination in the output table of Pondpack™. The left column is time and right column is the flow rate corresponding to the time. Seen from Figure 4.4, 24 hours is divided into 2400 parts, each part represents for 36 seconds. Therefore, the runoff depth within each 0.01 hour interval can be estimated according to Equation 4.6 with the average flow rate within each

0.01 hour. Moreover, Q_P, Q_{p30}, Q_{p60}, Q_{p90} and V_{24} values for each CN_W /P combination can also obtained through certain data processes in Excel.

The Excel table for this analysis contains the following information: (1) the flow rate versus time for each *CN*/P combination of different rainfall distributions (i.e., Type II and Type III), (2) a summery table containing Q_P, Q_{p30}, Q_{p60}, Q_{p90} and V_{24} values for each combination of CN_W and P categorized according to different rainfall distributions, (3) regression analysis results and models for Q_P, Q_{p30}, Q_{p60}, Q_{p90} and V_{24} of each rainfall distribution.

4.4.2. Analysis

The objective of the analysis in this section is to obtain Q_P, Q_{p30}, Q_{p60}, Q_{p90} and V_{24} values for each CN_W and P combination and create prediction models using regression analysis. Q_P of each CN_W and P combination can be obtained by selecting the maximum values from all flow rates for each CN_W and P combination. The other runoff characteristics, such as Q_{p30}, Q_{p60}, Q_{p90} and V_{24}, can be estimated based upon the given runoff depth for each 0.01 hour interval.

To estimate runoff amount for each 0.01 hour interval, an assumptions has been made: the increment of flow rate in each 0.01 hour is linear, therefore, the average flow rate for 0.01 hourly interval equals to arithmetic mean of flow rates between the end of last 0.01 hour flow rate and the beginning flow rate of next 0.01 hour. A new column representing runoff amount for each 0.01 hour for each CN_W and P combination can be created. Equation 4.7 is used to estimate runoff amount for each 0.01 hour:

$$\mathrm{Q} = (\mathrm{q}_1 + \mathrm{q}_2) * 0.01 * 3600/2 \qquad \text{(EQ 4.7)}$$

Where,

Q = runoff volume for 0.01 hour, (ft^3)

q_1 = flow rate from the end of previous 0.01 hour, (ft^3/s)

q_2 = flow rate from the beginning of next 0.01 hour, (ft^3/s)

With estimated runoff volume for each CN_W and P combination, the peak 30/60/90 minutes volume can be selected from the runoff volumes within 24 hour period of time. Moreover, with peak 30/60/90 minutes volumes, the 30/60/90 minutes average flow rates can be calculated based upon the volumes divided by time. To calculate the total 24 hour runoff volume of each combination, all 0.01 hourly runoff volume need to be summed. For example, there's a group of combination which CN_W= 89 and P= 2.3 in, the flow rates and runoff volumes over a 24 hour period of time for this combination are calculated by Pondpack™, the peak flow rate (Q_P) of this combination equals to the highest flow rate within 24 hours, moreover, the highest 50, 100, and 150 runoff volumes from the total of 2400 runoff volumes (same proportion as 30/60/90 minutes to 24 hours) are selected and summed up. In this way, the highest 30/60/90 minutes runoff volumes are obtained, and finally, divide those volumes by time and converted the units to ft^3/s, the average 30/60/90 flow rates can be obtained. The summary table of analysis results is created:

TABLE 4.1 Summary of Analysis Result for Southeastern U.S.

		Type II rainfall distribution	**Type III rainfall distribution**
V_{24} (ft^3)	***min***	4256	7743
	avg	12961	13633
	max	22585	20051
	std. dev.	4658	2941
Q_p (ft^3/s)	***min***	1.86	2.19
	avg	5.30	3.62
	max	8.65	4.99
	std. dev.	1.80	0.71
Q_{p30} (ft^3/s)	***min***	1.03	1.47
	avg	3.02	2.46
	max	4.99	3.41
	std. dev.	1.04	0.49
Q_{p60} (ft^3/s)	***min***	0.63	1.01
	avg	1.34	1.71
	max	2.22	2.39
	std. dev.	0.46	0.34
Q_{p90} (ft^3/s)	***min***	0.46	0.77
	avg	1.34	1.30
	max	2.22	1.81
	std. dev.	0.46	0.26

After all runoff characteristics have been summarized, regression analysis can performed in Excel to generate prediction models for runoff characteristics applicable to the Southeastern U.S. By using prediction models developed for the Southeastern U.S, designers are able to calculate peak discharge, peak 30/60/90 minute average flow rates, and 24 hour total runoff volume from 1 acre drainage basin in any Southeastern States with CN_W and P (for 2-yr, 24-hr storm event). In addition, regression models for Q_P and other runoff characteristics (Q_{p30}, Q_{p60}, Q_{p90} and V_{24}) are also created.

4.5. SUMMARY

In this section, a massive amount of data are analyzed (CN_W, P, Q_P, Q_{p30}, Q_{p60}, Q_{p90} and V_{24}) to generate prediction models for 1 acre drainage basin in Southeastern U.S. 450 combinations of CN_W and P for Type II rainfall distribution and 270 combinations for Type III rainfall distribution are imported into Pondpack™ to generate their corresponding flow rates over a period of 24 hours, therefore, sufficient input data for regression analysis are obtained. The method used to estimate the peak flow rate is the hydrograph method. Pondpack is introduced to easily perform the calculations instead of manually calculating the peak flow rate for each CN_W and P combination. The tables of estimated flow rates from Pondpack™ are analyzed in Excel™ to obtain the value of runoff characteristics applicable to Southeastern U.S., and regression analysis is performed later to develop prediction models between runoff characteristics and CN_W and P values.

CHAPTER 5:

RESULTS AND DISCUSSION

5.1. INTRODUCTION

In this section, prediction models of peak discharge (Q_P), 30/60/90 minutes average flow rates (Q_{p30}, Q_{p60}, Q_{p90}) and total runoff volume for a 2-yr, 24-hr rainfall event (V_{24}) for Southeastern States were developed with output data from Pondpack™. The prediction models explain the relations between runoff characteristics (Q_P, Q_{p30}, Q_{p60}, Q_{p90} and V_{24}) and CN_W and P for the Southeastern U.S. The range of data used to develop prediction models are from the entire Southeastern U.S. and more detailed prediction models for individual states were not developed (e.g. the range of CN_W used to develop prediction models for southeastern U.S. are from 87.75 to 96 while in the state of Alabama, the range of CN_W is 88.3 to 91). Therefore, it is necessary to check whether prediction models for developed for the Southeastern region of the U.S. can be applied to individual States (e.g. Alabama). To achieve this goal, the first step is to create a prediction model for the state of Alabama following the same procedural methods outlined in Chapter 4. Secondly, input a series of CN_W and P combinations (value of combinations are within the state of Alabama range) into prediction models of Southeastern U.S. and the state of Alabama models separately. Finally, compare the results and compute variances of estimation results from prediction models of Southeastern U.S. and the state of Alabama.

The second objective of this section is to compare the difference between two rainfall databases: Technical Paper 40 (TP-40) and Atlas 14; each of which are developed by National Oceanic and Atmospheric Administration (NOAA) weather service center. The regression models based on the TP-40 rainfall database are developed by Perez et al. (2014) and the procedures to develop regression models are almost identical to the way the Atlas 14 prediction models were developed.

5.2. REGRESSION MODELS

5.2.1. Southeastern States

The prediction models for the entire Southeastern States are created through regression analysis in Excel and listed from Equation 5.1 to Equation 5.10 and prediction models are categorized by the two rainfall distributions: Type II and Type III.

The models for the Type II rainfall distribution are from Equation 5.1 to Equation 5.5.

$$\mathrm{V}_{24} = -36722.2 + 371(CN_{\mathrm{w}}) + 3492.1(\mathrm{P}) \quad \text{(EQ 5.1)}$$

$$\mathrm{Q}_{\mathrm{p}} = -10.29 + 0.103(CN_{\mathrm{w}}) + 1.364(\mathrm{P}) \quad \text{(EQ 5.2)}$$

$$\mathrm{Q}_{30} = -6.554 + 0.066(CN_{\mathrm{w}}) + 0.789(\mathrm{P}) \quad \text{(EQ 5.3)}$$

$$\mathrm{Q}_{60} = -3.889 + 0.039(CN_{\mathrm{w}}) + 0.475(\mathrm{P}) \quad \text{(EQ 5.4)}$$

$$\mathrm{Q}_{90} = -2.899 + 0.029(CN_{\mathrm{w}}) + 0.349(\mathrm{P}) \quad \text{(EQ 5.5)}$$

The regression equations for the Type III rainfall distribution are present from Equation 5.6 to Equation 5.10.

$$\mathrm{V}_{24} = -37749.8 + 381(CN_{\mathrm{w}}) + 3511(\mathrm{P}) \quad \text{(EQ 5.6)}$$

$$\mathrm{Q}_{\mathrm{p}} = -6.296 + 0.063(CN_{\mathrm{w}}) + 0.879(\mathrm{P}) \quad \text{(EQ 5.7)}$$

$$\mathrm{Q}_{30} = -4.667 + 0.047(CN_{\mathrm{w}}) + 0.602(\mathrm{P}) \quad \text{(EQ 5.8)}$$

$$\mathrm{Q}_{60} = -3.427 + 0.034(CN_{\mathrm{w}}) + 0.423(\mathrm{P}) \quad \text{(EQ 5.9)}$$

$$\mathrm{Q}_{90} = -2.596 + 0.026(CN_{\mathrm{w}}) + 0.32(\mathrm{P}) \quad \text{(EQ 5.10)}$$

Where,

V_{24} = Total storm volume for a 2-yr 24-hr storm, (ft^3)

Q_P = Peak flow rate, (ft^3/s)

Q_{p30} = Peak 30-minute average flow rate, (ft^3/s)

Q_{p60} = Peak 60-minute average flow rate, (ft^3/s)

Q_{p90} = Peak 90-minute average flow rate, (ft^3/s)

CN_w = Weighted Curve Number

P = 2-yr, 24-hr rainfall (in.)

All prediction models have R^2 close to 1, which indicates about 100% of dependent variable's (i.e., Q_P, Q_{p30}, Q_{p60}, Q_{p90}, and V_{24}) variations can be explained by the input variable (CN_W and P), *P-values* for CN_W and P in each model are all equal to 0, which indicates prediction models for Southeastern U.S. are reliable (statically significant) and the coefficients of CN_W and P are not obtained by chance.

Regression analysis between Q_P and other runoff characteristics (i.e., Q_{p30}, Q_{p60}, Q_{p90}, and V_{24}) are also performed in Excel. The relationship equations between and those values are listed from Equation 5.11 to Equation 5.18.

In Type II rainfall distribution, the relationship equations are from Equation 5.11 to Equation 5.14

$$V_{24} = 2585.6\mathrm{Q_p} - 746.1 \quad \text{(EQ 5.11)}$$

$$Q_{30} = 0.579\mathrm{Q_p} - 0.051 \quad \text{(EQ 5.12)}$$

$$Q_{60} = 0.3495\mathrm{Q_p} - 0.024 \quad \text{(EQ 5.13)}$$

$$Q_{90} = 0.257\mathrm{Q_p} - 0.02 \quad \text{(EQ 5.14)}$$

In Type III rainfall distribution, the relationship equations are from Equation 5.15 to Equation 5.18

$$V_{24} = 4116.9\mathrm{Q_p} - 1280.8 \quad \text{(EQ 5.15)}$$

$$Q_{30} = 0.688\mathrm{Q_p} - 0.038 \quad \text{(EQ 5.16)}$$

$$Q_{60} = 0.485\mathrm{Q_p} - 0.043 \quad \text{(EQ 5.17)}$$

$$Q_{90} = 0.367\mathrm{Q_p} - 0.032 \quad \text{(EQ 5.18)}$$

Where,

V_{24} = Total storm volume for a 2-yr 24-hr storm, (ft^3)

Q_P = Peak flow rate, (ft3/s)

Q_{p30} = Peak 30-minute average flow rate, (ft^3/s)

Q_{p60} = Peak 60-minute average flow rate, (ft^3/s)

Q_{p90} = Peak 90-minute average flow rate, (ft^3/s)

CN_w = Weighted Curve Number

To obtain the values of various runoff characteristics for the Southeastern U.S., the generated prediction models and CN_W and P data were imported into GIS. Then, the "raster calculator" tools were used, from which the runoff characteristics values for a typical 1 acre drainage basin can be estimated. These values are summarized in TABLE 5.1.

TABLE 5.1 Summary of Runoff Values in Southeastern States

		Type II rainfall distribution	Type III rainfall distribution
V_{24} (ft^3)	*min*	772.6	4093.1
	avg	7176.3	11073.5
	max	16837.4	18853.1
	std. dev.	2403.9	2027.3
Q_P (ft^3/s)	*min*	0.59	1.31
	avg	3.06	3.00
	max	6.80	4.89
	std. dev.	0.93	0.49
Q_{p30} (ft^3/s)	*min*	0.29	0.86
	avg	1.72	2.03
	max	3.89	3.33
	std. dev.	0.54	0.34
Q_{p60} (ft^3/s)	*min*	0.18	0.59
	avg	1.05	1.41
	max	2.35	2.33
	std. dev.	0.32	0.24
Q_{p90} (ft^3/s)	*min*	0.13	0.45
	avg	0.77	1.07
	max	1.73	1.76
	std. dev.	0.24	0.18

5.2.2. Alabama State

The same methods were used to create regression models for Alabama:

For the Type II rainfall distribution, the relationship equations are from Equation 5.19 to Equation 5.23:

$$V_{24} = -36985 + 368.5(CN_{w}) + 3600(P) \quad \text{(EQ 5.19)}$$

$$Q_{p} = -10.609 + 0.105(CN_{w}) + 1.398(P) \quad \text{(EQ 5.20)}$$

$$Q_{30} = -6.751 + 0.067(CN_{w}) + 0.807(P) \quad \text{(EQ 5.21)}$$

$$Q_{60} = -4.001 + 0.039(CN_{w}) + 0.487(P) \quad \text{(EQ 5.22)}$$

$$Q_{90} = -2.984 + 0.029(CN_{w}) + 0.358(P) \quad \text{(EQ 5.23)}$$

For the Type III rainfall distribution, the relationship equations are from Equation 5.24 to Equation 5.28:

$$V_{24} = -38873 + 387.7(CN_{w}) + 3613.7(P) \quad \text{(EQ 5.24)}$$

$$Q_{p} = -5.225 + 0.052(CN_{w}) + 0.875(P) \quad \text{(EQ 5.25)}$$

$$Q_{30} = -3.956 + 0.039(CN_{w}) + 0.6(P) \quad \text{(EQ 5.26)}$$

$$Q_{60} = -2.938 + 0.029(CN_{w}) + 0.422(P) \quad \text{(EQ 5.27)}$$

$$Q_{90} = -2.253 + 0.022(CN_{w}) + 0.32(P) \quad \text{(EQ 5.28)}$$

Where,

V_{24} = Total storm volume for a 2-yr 24-hr storm, (ft^3)

Q_P = Peak flow rate, (ft^3/s)

Q_{p30} = Peak 30-minute average flow rate, (ft^3/s)

Q_{p60} = Peak 60-minute average flow rate, (ft^3/s)

Q_{p90} = Peak 90-minute average flow rate, (ft^3/s)

CN_w = Weighted Curve Number

P = 2-yr, 24-hr rainfall (in.)

For all prediction models developed for the state of Alabama, R^2 are all close to 1, *p-values* for each factors are all close to 0, which is the same results as prediction models for Southeastern States exhibited. It can be concluded that prediction models for state of Alabama are also reliable (statistically significant).

The relations equations between Q_P and other factors are listed below:

For type II rainfall distribution, the relationship Equations are from Equation 5.29 to Equation 5.32:

$$V_{24} = 3008.2Q_p - 198 \quad \text{(EQ 5.29)}$$

$$Q_{30} = 0.606Q_p - 0.176 \quad \text{(EQ 5.30)}$$

$$Q_{60} = 0.362Q_p - 0.085 \quad \text{(EQ 5.31)}$$

$$Q_{90} = 0.268Q_p - 0.074 \quad \text{(EQ 5.32)}$$

For Type III rainfall distribution, relationship equations are from Equation 5.33 to Equation 5.36:

$$V_{24} = 4181.7Q_p - 1267.3 \quad \text{(EQ 5.33)}$$

$$Q_{30} = 0.687Q_p - 0.026 \quad \text{(EQ 5.34)}$$

$$Q_{60} = 0.484Q_p - 0.030 \quad \text{(EQ 5.35)}$$

$$Q_{90} = 0.366Q_p - 0.025 \quad \text{(EQ 5.36)}$$

Where,

V_{24} = Total storm volume for a 2-yr 24-hr storm, (ft^3)

Q_P = Peak flow rate, (ft^3/s)

Q_{p30} = Peak 30-minute average flow rate, (ft^3/s)

Q_{p60} = Peak 60-minute average flow rate, (ft^3/s)

Q_{p90} = Peak 90-minute average flow rate, (ft^3/s)

Using the "raster calculator tool" again, Q_P, Q_{p30}, Q_{p60}, Q_{p90}, and V_{24} values of 1 acre drainage basin in the state of Alabama can be obtained and summarized in TABLE 5.2:

TABLE 5.2 Summary of runoff values in Alabama

		Type II region	Type III region
V_{24} (ft^3)	*min*	7668.4	6719.6
	avg	11378.4	11307.2
	max	14182.8	17759.6
	std. dev.	2119	1355
Q_P (ft^3/s)	*min*	2.61	1.91
	avg	3.85	3.01
	max	4.78	4.55
	std. dev.	0.7	0.32
Q_{p30} (ft^3/s)	*min*	1.41	1.29
	avg	2.16	2.04
	max	2.72	3.10
	std. dev.	0.43	0.22
Q_{p60} (ft^3/s)	*min*	0.86	0.89
	avg	1.31	1.43
	max	1.65	2.17
	std. dev.	0.25	0.16
Q_{p90} (ft^3/s)	*min*	0.63	0.67
	avg	0.96	1.08
	max	1.21	1.64
	std. dev.	0.19	0.12

The prediction models for Southeastern U.S. and the state of Alabama were developed based on 2-yr, 24-hr storm event rainfall data, and are used to estimate the runoff characteristics from 1 acre ALDOT typical drainage basin. The values summarized in TABLE 5.1 and TABLE 5.2 are estimated in GIS, while CN_W and P data are provided by raster maps for rainfall depth (P) and CN_W created in Chapter 3.

5.3. COMPARISIONS

In this section, two comparison will be made: (1) compare the difference between prediction models for Southeastern U.S. and state of Alabama, and (2) check whether prediction models for Southeastern U.S. can also applied to individual states residing in the Southeast (e.g., Alabama). Another is the comparison between two rainfall databases: Atlas 14 and TP-40. Including the difference of rainfall depth data provided by two rainfall databases and the difference between prediction models developed based on TP-40 and Atlas 14 rainfall databases will be performed.

To start the first comparison, a series of CN_W/P (within the state of Alabama range) combinations are created and introduced to prediction models for Southeastern U.S. and the state of Alabama separately. Next the variances of calculation results for each CN_W/P combination of prediction models for Southeastern U.S. and Alabama State are compared. The second comparison is performed in GIS, with the assistance of "raster calculator" tool, Q_P, Q_{p30}, Q_{p60}, Q_{p90}, and V_{24} values for two different models (TP-40 and Atlas 14) of 1 acre typical drainage basin in state of Alabama will be calculated and summarized, and the difference of calculating results can be compared.

5.3.1. Southeastern State versus the State of Alabama

To check whether prediction models developed for Southeastern U.S. are applicable to individual states in the Southeast (e.g. Alabama), prediction models of Southeastern U.S. were used to calculate runoff characteristics with the input CN_W and P combinations (within the range of individual States in Southeastern U.S.), and compared to the estimation results to the individual State model. Variances of the estimated values for both models were summarized for each CN_W and P combination. For this study, the state of Alabama was selected as an example.

A series of test data (i.e., a list of CN_W and P combinations within state of Alabama range) were generated and imported in to prediction models that are ready to compare. Another table in Excel is created to record and compare the estimated results from two prediction models (i.e., Southeastern U.S. and Alabama). The test CN_W range for Type II rainfall distribution is from 88.3 to 95, with increments of 1 and P value ranges from 3.7 in to 4.3 in, with 0.1 increments, therefore, the total number of combinations of CN_W and P for Type II rainfall distribution equals 63. In the Type III rainfall distribution, CN_W ranges from 92 to 95, with increments of 1 and the range of P varies from 3.9 in to 6 in, with increments of 0.1, therefore, there are 110 of test combinations. The percentage variance of estimation results for two models are summarized in TABLE 5.3.

TABLE 5.3 Variance Between Estimation Results Between AL[1] and SE[2] Models

		Type II rainfall distribution (%) (63 counts)	Type III rainfall distribution (%) (110 counts)
V_{24} (%)	***min***	0.10	0.01
	avg	0.54	0.37
	max	1.00	0.93
	std. dev.	0.25	0.22
Q_P (%)	***min***	0.01	0.01
	avg	0.21	0.49
	max	0.74	1.44
	std. dev.	0.16	0.39
Q_{p30} (%)	***min***	0.65	1.15
	avg	1.30	1.90
	max	2.24	2.89
	std. dev.	0.35	0.43
Q_{p60} (%)	***min***	1.43	0.21
	avg	1.69	0.80
	max	1.86	1.80
	std. dev.	0.09	0.41
Q_{p90} (%)	***min***	3.59	1.48
	avg	3.71	2.38
	max	3.90	3.55
	std. dev.	0.08	0.49

NOTE: 1.AL means Alabama State
2.SE means Southeastern States

The values in TABLE 5.3 are displayed in the form of percentage which indicate the variance of estimation results between the state of Alabama (AL) prediction models and Southeastern U.S. (SE) models for AL models, the same CN_W and P combination. For example, input one combination (CN_W=88 and P =3.7 in) into models of AL and SE separately, and minus output values from SE models with output values of AL models, divide itself, multiplied by 100% and took absolute value, the percentage of the variance for one combination is estimated. By summarizing all percentage values of various combinations together, and selecting the maximum, minimum, average and standard errors of the summarized data, categorizing them according to the rainfall distributions, TABLE 5.3 is generated.

By analyzing TABLE 5.3, the following conclusions were obtained:

1. Q_P, V_{24}, Q_{p30}, and Q_{p60} models have relatively lower variance than Q_{p90} models (average value), in all rainfall distributions.

2. The largest variance between SE and AL models are model of Q_{90} in type II region, which equals to 3.9%.
3. SE model can be applied to estimate certain values (i.e., Q_P, Q_{p30}, Q_{p60}, Q_{p90}, and V_{24}) instead of AL model.

5.3.2. TP-40 Database versus Atlas 14 Database

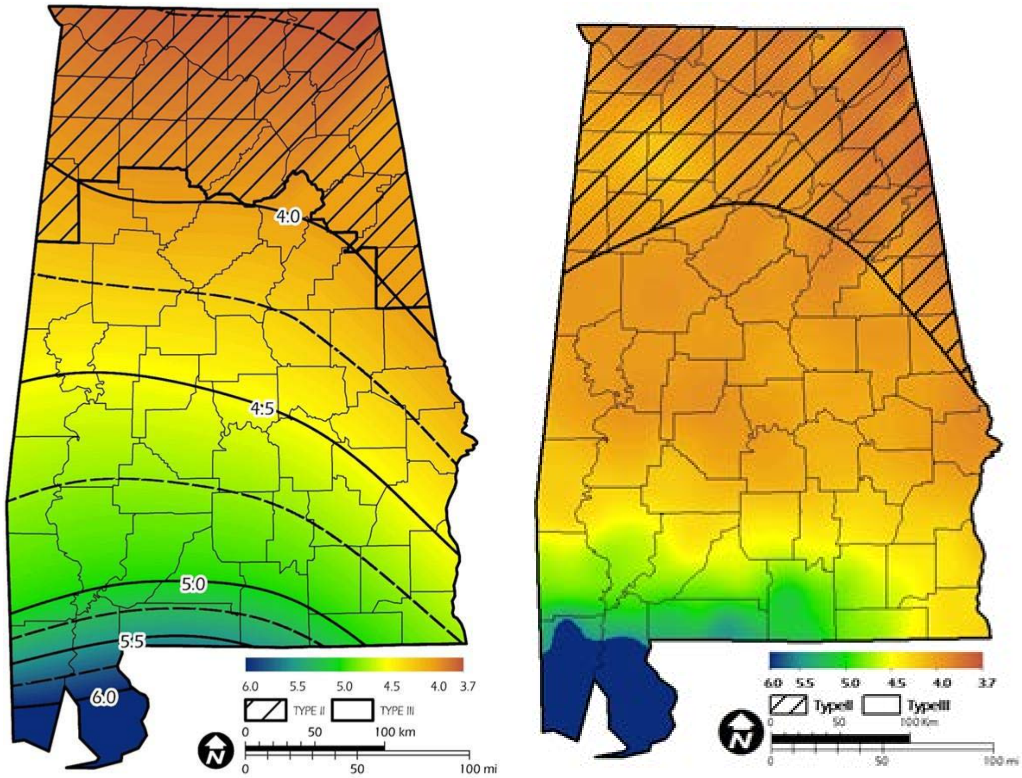
TP-40 and Atlas 14 are two rainfall datasets developed by NOAA's weather service center. Both of them can be used to demonstrate rainfall depth data of U.S. for different storm events (e.g. 2-yr, 24-hr; 5-yr, 30-min, etc.). In this study, rainfall depth data for 2-yr, 24-hr storm event is selected to develop prediction models of runoff characteristics. The following aspects of TP-40 and Atlas 14 will be analyzed: (1) the range of rainfall depth for each database, (2) models generated based on each rainfall database (i.e., Atlas 14 and TP-40), (3) output data for prediction models in GIS.

Statistical rainfall depth distribution of Alabama for both rainfall datasets are collected from GIS file and summarized in TABLE 5.4:

TABLE 5.4 Rainfall Depth of TP-40 and Atlas 14

***P*:2-yr,24-hr Rainfall (in)**	**Statewide**		**Type II**		**Type III**	
	TP-40	**Atlas14**	**TP-40**	**Atlas14**	**TP-40**	**Atlas14**
min	3.69	3.68	3.69	3.68	3.94	3.99
avg	4.44	4.37	3.89	4.06	4.64	4.50
max	6.00	6.03	4.18	4.32	6.00	6.03
std.dev	0.52	0.46	9.18	0.11	0.47	0.49

Note: Statistic data for TP-40 rainfall depths is developed by Michael A. Perez, and et.al. 2014.



(a) rainfall distribution for Tp-40 (b) rainfall distribution for Atlas 14

FIGURE 5.1 Rainfall Distribution of Different Rainfall Database in Alabama

Note: distribution map of TP-40 is developed by is Michael A. Perez, and et.al. 2014.

Seen from TABLE 5.4, Atlas 14 and TP-40 database have similar rainfall depth values with no more than 0.2 in variance. From a statewide perspective, the minimum and average rainfall depth data is smaller than that of TP-40, while their maximum value are the same. This is because the rainfall distribution of two database are different: the values of rainfall depth in Figure 5.1(a) is higher than that in Figure 5.1(b). In the Type II rainfall distribution, the maximum and average values for Atlas 14 are higher than TP-40, but its minimum value is smaller. In the Type III rainfall distribution, the Atlas 14 database has a higher minimum and maximum value of rainfall, but the average value is smaller. Figure 5.1 demonstrates the distribution of rainfall depth from the two rainfall databases in Alabama. Two figures have a common point: the rainfall depth increased from Northeastern part to Southwestern part of Alabama.

However, the rainfall distribution of the TP-40 database is gradually changed with rainfall depth isopluvial lines while Atlas 14 database is different and doesn't have the rainfall isopluvial line. This difference is caused by the source of rainfall depth data for two rainfall databases. In TP-40 database, the primary rainfall depth source are rainfall depth distribution maps for entire U.S. with different rainfall storm events. The isopluvial lines representing rainfall depth are drew based on 6000 stations recording rainfall in U.S. (Hershfield, 1961). When generating raster maps in GIS, the isopluvial lines that represent different rainfall depths will be converted raster files with "create TIN", "TIN to raster" tools in GIS (Perez, et.al. 2014). This conversion procedure will result in less accurate rainfall depth distributions by simply assuming rainfall depth is uniformly distributed between two isopluvial lines. Moreover, it will also have negative impact on estimated runoff characteristics with prediction models based on TP-40 database. For Atlas 14 database, the raster file contains rainfall depth information for the entire U.S., which means there is no need to worry about conversions and the negative impact together with conversion procedures. Moreover, the Atlas 14 rainfall depth data are created based on 7,861 station records in the U.S., which is greater than that of TP-40 database. Therefore, the Atlas 14 database is a better, more accurate and current rainfall database, in comparison to the TP-40 rainfall database.

Two types of prediction models (i.e., Atlas 14 and TP-40) for the state of Alabama are displayed in TABLE 5.5 and they are really close with each other: the difference between their interceptions, coefficients for CN_W and P are not significant (e.g., 0.197 vs 0.105, 0.063 vs 0.066, etc). Moreover, the prediction models for estimating the Q_{p30}, Q_{p60}, and Q_{p90} values, the coefficient of CN_W and P have negative correlation with time (e.g., for TP-40 of Type II rainfall model, the coefficient of CN_W decreased from 0.063 to 0.028 while time increased from 30 minutes to 90 minutes), while the interception value for these models have positive correlation with time (e.g. for TP-40 of Type II rainfall model, interception value increased from -6.262 to -2.808).

Above all, prediction models for TP-40 and Atlas 14 database share a common trend: coefficient for CN_W and P of Q_{p30}, Q_{p60}, and Q_{p90} decreased with time increasing (i.e., from 30 minutes to 90 minutes), and the interceptions increased with time changed from 30 minutes to 90 minutes. By comparing the coefficients and interception values, it can be concluded that the difference between these models are not significant, therefore, further analysis about the output data from two types of prediction models needs to be performed.

TABLE 5.5 Prediction Models Based on Different Rainfall Datasets

	Type II		Type III	
	TP-40	Atlas14	TP-40	Atlas14
Q_p	Q_P= -9.620 + 0.097(CN_W)+1.349(P)	Q_P= -10.609 +0.105(CN_W)+1.398(P)	Q_P= -6.065 + 0.061(CN_W) + 0.876(P)	Q_P= -6.296 + 0.063(CN_W) + 0.879(P)
V_{24}	V_{24}= -38198 + 383.2(CN_W)+3560 (P)	V_{24}= -36722.2+371(CN_W)+3492.1(P)	V_{24}= -38566+383.7(CN_W)+3533(P)	V_{24}= -37749.8+381(CN_W)+3511(P)
Q_{p30}	Q_{p30}= - 6.262 +0.063(CN_W)+0.782(P)	Q_{p30}= -6.554 + 0.066(CN_W) +0.789(P)	Q_{p30}= -4.525+0.045(CN_W)+0.600(P)	Q_{p30}= -4.667+0.047(CN_W)+0.602(P)
Q_{p60}	Q_{p60}= - 3.718+0.037(CN_W) +0.472(P)	Q_{p60}= -3.889 + 0.039(CN_W) +0.475(P)	Q_{p60}= -3.335+0.034(CN_W)+0.422(P)	Q_{p60}= -3.427+0.034(CN_W)+0.423(P)
Q_{p90}	Q_{p90}= - 2.808 + 0.028(CN_W)+0.347(P)	Q_{p90}= -2.899 + 0.029(CN_W)+0.349(P)	Q_{p90}= -2.534+0.025(CN_W)+0.319(P)	Q_{p90}= -2.596+0.026(CN_W)+0.32(P)

Note: Models of TP-40 database are cited from "A Geographic Information Systems (Gis) Approach For Calculating Runoff 1 Characteristics For Erosion And Sediment Control Practices", Michael A. Perez, and et.al. 2014.

To compare the results between these models, use "raster calculator" tool in GIS and summarize the output data from GIS in TABLE 5.6

TABLE 5.6 Output Data of the Models

		Type II rainfall distribution		Type III rainfall distribution	
		TP-40	**Atlas14**	**TP-40**	**Atlas14**
V_{24} (ft^3)	***min***	10410	7668.4	10450	6719.6
	avg	11440	11378.4	13490	11307.2
	max	12770	14182.8	19450	17759.6
	std. dev.	436.7	2119	1622	1355
Q_P (ft^3/s)	***min***	4.33	2.61	3.01	1.91
	avg	5.15	3.85	5.03	3.01
	max	4.68	4.78	3.66	4.55
	std. dev.	0.14	0.70	0.40	0.32
Q_{p30} (ft^3/s)	***min***	2.46	1.41	1.99	1.29
	avg	2.67	2.16	2.44	2.04
	max	2.94	2.72	3.39	3.10
	std. dev.	8.53	0.43	0.27	0.22
Q_{p60} (ft^3/s)	***min***	1.45	0.86	1.46	0.89
	avg	1.57	1.31	1.78	1.43
	max	1.74	1.65	2.46	2.17
	std. dev.	5.11	0.25	0.19	0.16
Q_{p90} (ft^3/s)	***min***	1.06	0.63	1.02	0.67
	avg	1.16	0.96	1.27	1.08
	max	1.28	1.21	1.78	1.64
	std. dev.	3.79	0.19	0.15	0.12

NOTE: Output data of TP-40 database are developed by Michael A. Perez, and et.al. 2014.

In TABLE 5.6, the average values of runoff characteristics from Atlas 14 models, including V_{24}, Q_P, Q_{p30}, Q_{p60}, and Q_{p90}, are smaller than that of TP-40 models. This is because the value of rainfall depth (P) data from TP-40 database are larger than Atlas 14 database, therefore, the runoff characteristics estimated by Atlas 14 prediction models are smaller than TP-40 prediction models. While in Type II rainfall distribution, the maximum V_{24} and Q_P values from Atlas 14 are larger than those values obtained from TP-40 models and the minimum value of V_{24} and Q_P from Atlas 14 models are smaller than the same values from TP-40. This is also cause by different rainfall depth data provided by two rainfall databases (e.g. in Type II rainfall distribution, maximum rainfall depth (P) data of Atlas 14 are larger than that of TP-40 and minimum rainfall depth). For Q_{p30}, Q_{p60}, and Q_{p90} in two rainfall distributions, a common trend is observed: the maximum and minimum values from Atlas 14 models are all smaller than the values from TP-40 database. However, in the Type III rainfall distribution, the values of P are different: the minimum P from Atlas 14 models is smaller than minimum P value from TP-40 but, the maximum value of it is larger than that from TP-40 models.

Above all, two regular patterns can be summarized from TABLE 5.6: (1) the average values of all output data from Atlas 14 are smaller than the values from TP-40 models, and (2) the values of Q_{p30}, Q_{p60}, and Q_{p90} from Atlas 14 models are all smaller than those values from TP-40 models. Regular patterns 1 and 2 are caused by difference of rainfall distributions of the two database (i.e., the average rainfall depth in statewide range of Atlas 14 is smaller than TP-40), which means the smaller average P data results in smaller average runoff characteristics within the statewide range.

5.4. SUMMARY

In this chapter, the prediction models of peak flow rate (Q_P), 24 hour total runoff volume (V_{24}), and 30/60/90 minutes average flow rates (Q_{p30}, Q_{p60}, and Q_{p90}) for Southeastern U.S. and the state of Alabama are generated and discussed. The prediction models for the state of Alabama are generated and compared with prediction models of Southeastern U.S. to prove that Southeastern U.S. models are also applicable to individual states within Southeastern area. Another comparison is between the regression models generated based on two rainfall databases: Atlas 14 and TP-40. By comparing their difference of rainfall distribution, and output data in GIS, two regular patterns are summarized: (1) The average values of all output data from Atlas 14 are smaller than the values from Tp-40 models, (2) The values of Q_{p30}, Q_{p60} and Q_{p90} from Atlas 14 models are all smaller than those values from TP-40 models. All of these regular patterns are caused by the difference of rainfall distribution of two rainfall databases (i.e the average rainfall depth provided by Atlas 14 are smaller than that of TP-40), since the rainfall data provided by Atlas 14 is collected from 7861 stations in U.S. and had already processed into raster files. Therefore, it is recommended for designers to select Atlas 14 database rather than TP-40 because Atlas 14 have more collecting stations and the rainfall data provided by Atlas 14 is in raster file which can be directly imported into GIS for further analysis.

CHAPTER 6:

CONCLUSIONS AND RECOMMENDATIONS

6.1. INTRODUCTION

Runoff characteristics, including the peak flow rate (Q_P), 24 hour total runoff volume (V_{24}), and the 30, 60 and 90 minute average flow rates (Q_{p30}, Q_{p60}, and Q_{p90}), are important variables for designers to consider while developing storm water pollution prevention plans (SWPPPs). Designers need to have an understanding of site specific runoff characteristics when selecting appropriate erosion and sedimentation control practices to implement on a construction site. As part of this research effort, predictions models were developed to aid design practitioners in determining site specific runoff characteristics for the Southeastern U.S. The developed runoff characteristic prediction models have the ability to calculate runoff volumes and flow rates directly with the knowledge of site specific curve numbers (*CN*) and rainfall depths (*P*) for a given study area. Therefore, the prediction models can save practitioners time by importing processed CN_W and *P* data from a GIS database rather than manually observations on-site. This study generated prediction models that can be applied to the entire Southeastern U.S. for a 1 acre typical drainage basin that experiences a 2-yr, 24-hr rainfall event occurring on a highway construction site. An example application of the developed prediction models was applied to a typical drainage basin in the state of Alabama. Procedures used to develop the prediction models could provide future guidance to researchers as a reference to develop similar models for other geographic areas in the U.S. beyond the Southeast.

6.2. RAINFALL ANALYSIS

To satisfy the first objective of this research, rainfall (*P*) and curve number (*CN*) values for entire Southeastern U.S. are collected from the NOAA website and USDA NCRS web soil survey database separately, and then imported and manipulated in a GIS database to provide uniform input data for generating prediction models of runoff characteristics. Furthermore, the *P* data representing a 2-yr, 24-hr rainfall event for the entire Southeastern U.S. were segmented into 14 parts according to individual State boundaries considered as part of this study. The *CN* values were derived from the HSG map for the U.S. that was obtained from USDA NCRS web soil survey database and imported into the GIS database and further categorized according to the individual State boundaries. Finally, a series of uniform GIS maps (i.e., raster files with 100 m x 100 m resolution, projected under "UTM_NAD 1983 zones") for the Southeastern U.S, and the individual States (e.g. Alabama, Georgia, North Carolina, South Carolina, etc.) are created to develop hydrologic and soil parameters (i.e., rainfall distributions, *CN* values, retention amounts, and runoff depth). The range of *P* and *CN* values for each individual State and the entire Southeastern U.S. are summarized into tables separately and shown in Appendix A.

6.3. ANALYSIS METHOD

The second objective of this study is to create the methods for developing prediction models to calculate site specific runoff characteristics. The procedures were divided into two phases: (1) collecting and transforming input data (CN_W and *P*) used to develop prediction models, and (2) the generation of prediction models using linear regression based upon output data from Bentley's Pondpack™ software.

Before the generation of prediction regression models in Excel, the time of concentration (T_c) for the site specific study area is required. To illustrate the specific procedures for calculating the T_c, a 1 acre typical drainage basin within the state of Alabama is used as a case study. The step-by-step procedures for gathering, organizing, and processing the required input data (*CN* and *P*) and the programs used (i.e., GIS™, Pondpack™ and Excel™) to obtain site-specific runoff characteristics, along with the development of the prediction models are described. With the developed procedures, researchers and practitioners will have the ability to generate site specific runoff prediction models for a 2-yr, 24-hr rainfall event occurring in a 1 acre drainage basin located in Southeastern U.S.

6.4. PREDICTION MODELS

The last objective of this study is to generate runoff characteristic prediction models, including models to calculate peak flow rate (Q_P), 24 hour total runoff volume (V_{24}), and 30, 60 and 90 minutes average flow rates (Q_{p30}, Q_{p60} and Q_{p90}). All the regression models have a R^2 = 1, and *p*-values for all models and each parameter (CN_W and P) are reported less than 0.05, which indicates these models are statistically significant and the coefficients for P and CN_W are not obtained by chance.

Moreover, the secondary objectives also satisfied, since the prediction models for Southeastern U.S. are generated based upon the regional data (CN_W, P, calculated Q_P, V_{24}, Q_{p30}, Q_{p60} and Q_{p90}), they are only effective for construction sites residing in the Southeastern U.S., rather than other geographic areas of the the U.S. Therefore, it is necessary to check the applicability of the developed prediction models on a particular site at the State level to be used as an example. In order to verify the application area of Southeastern U.S. models, prediction models for the State of Alabama are created separately, using statewide data, and compared with the prediction models developed for entire Southeastern U.S. The verification procedures include: (1) inputting the same group of CN_W and P values (the range of CN_W and P are within Alabama State) into the two different models separately, (2) compare the difference of their outputs (Q_P, V_{24}, Q_{p30}, Q_{p60}, and Q_{p90}). The results show that the difference between two models (Southeastern and Alabama models) are negligible, since the difference between output values is 3% or less. These results indicate that the prediction models developed for the Southeastern U.S. are also effective on the individual States within that region.

Furthermore, another secondary objective is been accomplished by comparing models generated based on two different rainfall depth databases (i.e.,, Atlas 14 and TP-40) for the State of Alabama. To illustrate the difference of two types of rainfall databases, the “raster calculator” tool is used in GIS to estimate runoff characteristics for Alabama for the two types of prediction models using the following steps: (1) introducing the two types of rainfall models into GIS separately, (2) use “raster calculator” to estimate runoff characteristics with the same CN_W and P data in Alabama. The difference between two rainfall databases can be observed from Figure 5.1, the rainfall depth data in Alabama provided by Atlas 14 database is lower than TP-40, this is because Atlas 14 database is developed based on collected rainfall data from 7800 stations in U.S. while TP-40 database only provide the rainfall distribution map which needs to be converted into raster files before generating prediction models. Therefore, the input rainfall depth data from Atlas 14 is more reliable because it has been prepared into raster file and ready to use, in addition, the number of stations used to collect rainfall data for Atlas 14 are larger than TP-40. The estimation results of two rainfall databases are summarized in TABLE 5.6. Two distinct patterns are observed: (1) the average values of all output data (Q_P, V_{24}, Q_{p30}, Q_{p60} and Q_{p90}) of Atlas 14 models are smaller than that of TP-40 models, and (2) Q_{p30}, Q_{p60} and Q_{p90} values of Atlas 14 models are all smaller (including maximum, minimum and average values regardless of rainfall distributions) than those values from TP-40 models. The difference of average rainfall depth for Alabama is the primary reason to the patterns, and Atlas 14 is recommended as the source of rainfall data in this study for its accuracy.

Above all, all the objectives are satisfied through analysis work in this project: (1) raster maps for *CN*, *P*, *S*, *Q* are generated for entire Southeastern U.S. and individual States located in Southeastern U.S., all of them are attached in Appendix B, (2) specific procedures of developing prediction models are recorded in Chapter 3 and Chapter 4, (3) prediction models for entire Southeastern U.S. are demonstrated in Chapter 5 and their application area are verified to satisfy the first secondary objective, (4) another secondary objective are achieved by comparing different rainfall database (TP-40 and Atlas 14) in Chapter 5, and indicate Atlas 14 is a better rainfall database than Tp-40.

6.5. PREDICTION MODEL LIMITATIONS

The study generated prediction models for determining runoff characteristics on individual construction sites that are located in the Southeastern U.S. using CN_W and *P* values of the geographic region. With the knowledge of CN_W and *P*, designers are able to use prediction models to obtain Q_P, V_{24}, Q_{p30}, Q_{p60} and Q_{p90} values for any 1 acre drainage basin under consideration in Southeastern U.S. easily. This procedure is easier, more convenient, and consumes less time to perform in comparison to applying TR-55 procedures for sites under consideration to determine runoff characteristics.

Several limitations of this study are also apparent and include: (1) the limited of study area (i.e.,, Southeastern U.S. and 1-acre drainage basin), (2) the limitation of design storm event (i.e.,, only modeled the 2-yr, 24-hr storm event), and (3) the reliability of regression models.

The first limitation is the type of study area and its size. The developed prediction models are generated to evaluate values of runoff characteristics for typical 1 acre drainage basin. Since the time of concentration (T_c) is an important factor to estimate peak discharge from a drainage basin using the hydrograph method, the size and geometrical conditions of drainage basin will greatly affect the value of T_c. Therefore, if a designer was planning to apply the prediction models on other drainage basins larger than 1 acre and with different geometrical characteristics, T_c would need to be recalculated. Therefore, if designers have the ability to develop site-specific prediction models with site-specific data according to the methods documented in Chapter 3 and 4, the developed prediction models would also work.

The second limitation relates to the return intervals of rainfall data (or precipitation data). Given that the rainfall data (*P*) used to generate the prediction models is a 2-yr, 24-hour rainfall event, the input *P* data must be rainfall depth corresponding to a 2-yr, 24-hr rainfall event. If a designer needs to use a different return period, other than the 2-yr, 24-hr rainfall event, new predictions models would need to be developed.

The prediction models are generated through software analysis, including generate *CN* and *P* raster maps in GIS™, estimate flow rate within 24 hour for a simulated drainage basin (1 acre typical drainage basin for a highway construction site) in Pondpack™, and perform regression analysis in Excel™. Which means, the prediction models are developed based upon digital data (i.e., downloaded *CN* and *P*, estimated Q_P, V_{24}, Q_{p30}, Q_{p60}, and Q_{p90}) without comparing with site observed data. Therefore, the availability of prediction models needs to be verified by observed runoff characteristics data of a 1 acre, typical highway median drainage basin, however, it will be difficult and cost a lot of money to find out an ideal typical highway median drainage basin and collect runoff characteristics data during 2-yr, 24-hr storm event.

6.6. RECOMMENDATIONS FOR FURTHER RESEARCH

To deal with limitations of this study, several recommendations are proposed for further researchers: (1) develop prediction models for larger area drainage basin, (2) develop prediction models for individual States in Southeastern U.S., (3) collect runoff characteristics data from real 1 acre typical highway median drainage basin and compare the different between output data from prediction models and site collected data.

Firstly, prediction models for wider area typical highway median drainage basins (e.g. 5 acres, 10 acres or 20 acres typical drainage basin) can be developed to fulfill the needs of designers with various area of drainage basin, furthermore, if the drainage basin are not typical highway median drainage basin, designers can also generate site-specific prediction models according to the method introduced in Chapter 3 and 4 with collected T_c data from drainage basins of highway construction sites.

Second, even the prediction models in Southeastern U.S. are proved to be effective in Alabama State, however, Alabama State can't represent all individual States in Southeastern U.S., therefore, prediction models for each individual States in Southeastern U.S. can be generated to give detailed information of runoff characteristics in individual States of Southeastern U.S.

Finally, the runoff characteristics collected from a 1 acre typical highway median drainage basin for a highway construction site in the Southeastern U.S (if exists) can compared with the output data from prediction models. By comparing the difference between prediction values and observed values, the prediction models will be more reliable and convincing.

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APPENDIXS

Appendix A: Tables of runoff characteristics for individual States in Southeastern U.S.

Appendix B: Figures of general runoff characters for individual States in Southeastern U.S.

Appendix A:

Tables of runoff characteristics for individual States in Southeastern U.S.

Statistical Data of Hydrologic and Soil Parameters for Alabama

AL		Statewide	Type II Region	Type III Region
P^1:2-yr 24-hr Rainfall (in.)	***Max.***	6.03	4.32	6.03
	Avg.	4.37	4.06	4.50
	Min.	3.68	3.68	3.99
CN	***Max.***	94	93.31	94
	Avg.	88.41	88.90	88.36
	Min.	78.61	85.84	78.61
CN^2_w	***Max.***	96	96	95.66
	Avg.	93.21	93.45	93.18
	Min.	88.31	88.31	91.92
***S*:Retention (in.)**	***Max.***	2.72	1.65	2.70
	Avg.	1.30	1.25	1.33
	Min.	1.68	0.72	0.64
***Q*:Runoff (in.)**	***Max.***	4.52	3.25	4.52
	Avg.	2.79	2.51	2.91
	Min.	1.66	1.66	1.72

Note: 1. Rainfall depth came from Atlas14 rainfall database

2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Arkansas

AR		Statewide	Type II Region	Type III Region
P^1:2-yr 24-hr Rainfall (in.)	***Max.***	5.05	4.37	5.05
	Avg.	4.16	4.02	4.31
	Min.	3.59	3.59	3.78
CN	***Max.***	93.78	93.76	93.78
	Avg.	90.61	90.64	90.58
	Min.	80.76	80.76	80.76
CN^2_w	***Max.***	95.89	95.88	95.89
	Avg.	94.31	94.32	94.29
	Min.	89.38	89.38	89.38
***S*:Retention (in.)**	***Max.***	2.38	2.38	2.38
	Avg.	1.04	1.04	1.04
	Min.	0.66	0.67	0.66
***Q*:Runoff (in.)**	***Max.***	3.88	3.30	3.88
	Avg.	2.72	2.57	2.87
	Min.	1.33	1.78	1.33

Note: 1. Rainfall depth came from Atlas14 rainfall database

2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Delaware

DE		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	3.45	3.45	-
	Avg.	3.33	3.33	-
	Min.	3.18	3..18	-
CN	***Max.***	93.15	93.15	-
	Avg.	87.74	87.74	-
	Min.	81.49	81.49	-
***CN*[2]$_w$**	***Max.***	95.58	95.58	-
	Avg.	92.87	92.87	-
	Min.	89.75	89.75	-
***S*:Retention (in.)**	***Max.***	2.27	2.27	-
	Avg.	1.41	1.41	-
	Min.	0.74	0.74	-
***Q*:Runoff (in.)**	***Max.***	2.27	2.27	-
	Avg.	1.81	1.81	-
	Min.	1.35	1.35	-

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Florida

FL		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	6.02	5.28	6.02
	Avg.	4.66	4.49	4.79
	Min.	3.87	4.12	3.87
CN	***Max.***	94	94	94
	Avg.	89.46	87.79	90.75
	Min.	77.27	77.27	77.80
***CN*[2]$_w$**	***Max.***	96	96	96
	Avg.	93.73	92.90	94.38
	Min.	87.64	84.64	89.90
***S*:Retention (in.)**	***Max.***	2.94	2.94	2.85
	Avg.	1.21	1.43	1.04
	Min.	0.64	0.64	0.64
***Q*:Runoff (in.)**	***Max.***	5.26	4.31	5.26
	Avg.	3.08	2.81	3.28
	Min.	1.28	1.83	1.28

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Georgia

GA		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	5.85	5.85	5.01
	Avg.	3.95	3.90	4.36
	Min.	3.20	3.20	3.99
CN	***Max.***	94	94	94
	Avg.	88.20	88.19	88.29
	Min.	79.88	79.88	79.88
CN^2_w	***Max.***	96	96	96
	Avg.	93.10	93.10	93.15
	Min.	88.94	88.94	88.94
***S*:Retention (in.)**	***Max.***	2.52	2.52	2.52
	Avg.	1.35	1.35	1.34
	Min.	0.64	0.64	0.64
***Q*:Runoff (in.)**	***Max.***	3.79	3.79	3.42
	Avg.	2.14	2.07	2.77
	Min.	1.24	1.24	1.93

Note: 1. Rainfall depth came from Atlas14 rainfall database

2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Kentucky

KY		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	3.88	3.88	-
	Avg.	3.21	3.21	-
	Min.	2.56	2.56	-
CN	***Max.***	93.67	93.67	-
	Avg.	89.21	89.21	-
	Min.	81.61	81.61	-
CN^2_w	***Max.***	95.84	95.84	-
	Avg.	93.61	93.61	-
	Min.	89.81	89.81	-
***S*:Retention (in.)**	***Max.***	2.25	2.25	-
	Avg.	1.21	1.21	-
	Min.	0.68	0.68	-
***Q*:Runoff (in.)**	***Max.***	2.32	2.32	-
	Avg.	1.66	1.66	-
	Min.	0.63	0.63	-

Note: 1. Rainfall depth came from Atlas14 rainfall database

2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Louisiana

LA		Statewide	Type II Region	Type III Region
P^1:2-yr 24-hr Rainfall (in.)	***Max.***	3.88	3.88	-
	Avg.	3.21	3.21	-
	Min.	2.56	2.56	-
CN	***Max.***	93.67	93.67	-
	Avg.	89.21	89.21	-
	Min.	81.61	81.61	-
CN^2_w	***Max.***	95.84	95.84	-
	Avg.	93.61	93.61	-
	Min.	89.81	89.81	-
***S*:Retention (in.)**	***Max.***	2.25	2.25	-
	Avg.	1.21	1.21	-
	Min.	0.68	0.68	-
***Q*:Runoff (in.)**	***Max.***	2.32	2.32	-
	Avg.	1.66	1.66	-
	Min.	0.63	0.63	-

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Maryland

MD		Statewide	Type II Region	Type III Region
P^1:2-yr 24-hr Rainfall (in.)	***Max.***	3.52	3.52	-
	Avg.	3.15	3.15	-
	Min.	2.34	2.34	-
CN	***Max.***	94	94	-
	Avg.	88.30	88.30	-
	Min.	81	81	-
CN^2_w	***Max.***	96	96	-
	Avg.	93.15	93.15	-
	Min.	89.5	89.5	-
***S*:Retention (in.)**	***Max.***	2.35	2.35	-
	Avg.	1.34	1.34	-
	Min.	0.64	0.64	-
***Q*:Runoff (in.)**	***Max.***	3.52	3.52	-
	Avg.	1.70	1.70	-
	Min.	2.34	2.34	-

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Mississippi

MS		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	6.00	4.45	6.00
	Avg.	4.52	4.23	4.71
	Min.	3.30	3.93	4.08
CN	***Max.***	94	94	94
	Avg.	90.07	90.52	89.78
	Min.	81.98	84.66	81.98
CN*[2]*w	***Max.***	96	96	96
	Avg.	94.04	94.26	93.89
	Min.	89.99	91.33	89.99
***S*:Retention (in.)**	***Max.***	2.20	1.81	2.2
	Avg.	1.11	1.05	1.14
	Min.	0.64	0.64	0.64
***Q*:Runoff (in.)**	***Max.***	4.31	3.32	4.31
	Avg.	3.05	2.97	3.10
	Min.	1.73	1.73	2.26

Note: 1. Rainfall depth came from Atlas14 rainfall database

2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for North Carolina

NC		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	6.68	6.68	4.95
	Avg.	3.74	3.62	3.98
	Min.	2.51	2.51	3.43
CN	***Max.***	94	93.46	94
	Avg.	88.93	87.23	90.22
	Min.	80.45	80.45	80.56
CN*[2]*w	***Max.***	96	95.93	96
	Avg.	93.47	92.62	94.11
	Min.	89.23	89.23	89.28
***S*:Retention (in.)**	***Max.***	2.43	2.43	2.41
	Avg.	1.35	1.47	1.10
	Min.	0.64	0.70	0.64
***Q*:Runoff (in.)**	***Max.***	4.46	4.46	3.32
	Avg.	2.02	1.84	2.40
	Min.	0.85	0.85	1.30

Note: 1. Rainfall depth came from Atlas14 rainfall database

2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for South Carolina

SC		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	5.49	5.49	4.84
	Avg.	3.76	3.65	4.06
	Min.	3.43	3.43	3.52
CN	***Max.***	94	94	94
	Avg.	87.82	87.04	89.94
	Min.	78.78	78.78	78.80
CN*[2]*w	***Max.***	96	96	96
	Avg.	92.91	92.52	93.97
	Min.	88.39	88.39	88.40
***S*:Retention (in.)**	***Max.***	2.69	2.69	2.69
	Avg.	1.40	1.50	1.13
	Min.	0.64	0.64	0.64
***Q*:Runoff (in.)**	***Max.***	3.55	3.55	3.32
	Avg.	2.02	1.81	2.58
	Min.	1.18	1.18	1.23

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Tennessee

TN		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	5.01	5.01	-
	Avg.	3.62	3.62	-
	Min.	2.40	2.40	-
CN	***Max.***	93.67	93.67	-
	Avg.	88.9	88.9	-
	Min.	80.22	80.22	-
CN*[2]*w	***Max.***	95.84	95.84	-
	Avg.	93.45	93.45	-
	Min.	89.11	89.11	-
***S*:Retention (in.)**	***Max.***	2.47	2.47	-
	Avg.	1.25	1.25	-
	Min.	0.68	0.68	
***Q*:Runoff (in.)**	***Max.***	5.01	5.01	-
	Avg.	1.86	1.86	-
	Min.	2.40	2.40	-

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation CN_w=0.5*CN+0.5*98

Statistical Data of Hydrologic and Soil Parameters for Virginia

VA		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	4.96	4.96	3.75
	Avg.	3.19	3.18	3.68
	Min.	2.32	2.32	3.60
CN	***Max.***	94	94	94
	Avg.	88.36	88.25	92.94
	Min.	81.35	81.35	84.84
***CN*[2]$_w$**	***Max.***	96	96	96
	Avg.	93.18	93.13	95.12
	Min.	89.68	89.68	91.42
***S*:Retention (in.)**	***Max.***	2.29	2.29	1.79
	Avg.	1.32	1.34	0.76
	Min.	0.64	0.64	0.64
***Q*:Runoff (in.)**	***Max.***	2.94	2.94	2.35
	Avg.	1.62	1.61	2.25
	Min.	0.71	0.71	1.58

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation $CN_w=0.5*CN+0.5*98$

Statistical Data of Hydrologic and Soil Parameters for West Virginia

WV		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	3.04	3.04	-
	Avg.	2.61	2.61	-
	Min.	2.31	2.31	-
CN	***Max.***	93.70	93.70	-
	Avg.	89.18	89.18	-
	Min.	79.12	79.12	-
***CN*[2]$_w$**	***Max.***	95.85	95.85	-
	Avg.	93.59	93.59	-
	Min.	88.56	88.56	-
***S*:Retention (in.)**	***Max.***	2.64	2.64	-
	Avg.	1.22	1.22	-
	Min.	0.67	0.67	-
***Q*:Runoff (in.)**	***Max.***	2.09	2.09	-
	Avg.	1.05	1.05	-
	Min.	0.53	0.53	-

Note: 1. Rainfall depth came from Atlas14 rainfall database
2. Weighted curve number CN_w is estimated by equation $CN_w=0.5*CN+0.5*98$

Statistical Data of Hydrologic and Soil Parameters for Southeastern U.S.

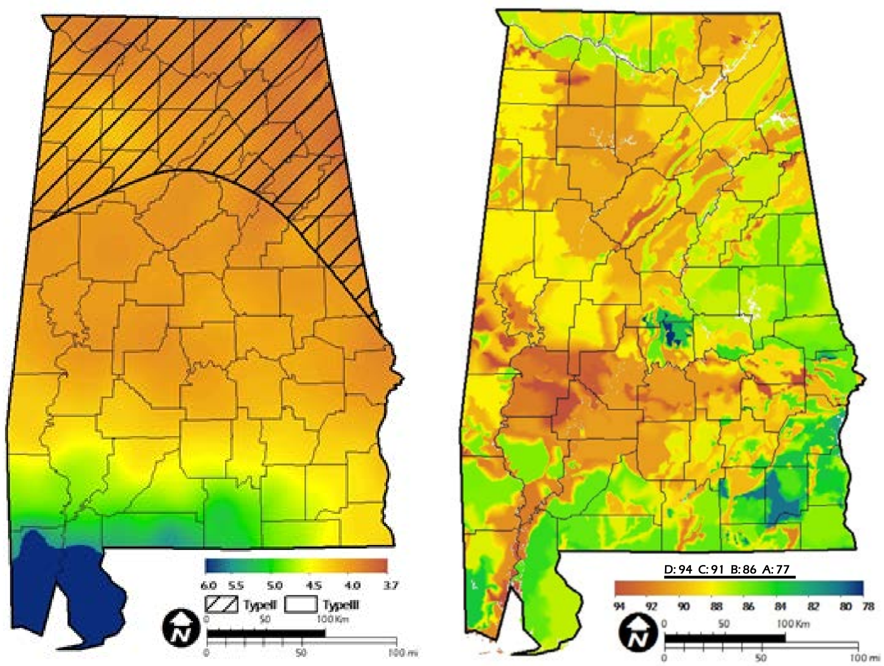
SE		Statewide	Type II Region	Type III Region
***P*[1]:2-yr 24-hr Rainfall (in.)**	***Max.***	6.68	6.68	6.02
	Avg.	3.99	3.92	4.44
	Min.	2.31	2.31	3.43
CN	***Max.***	94	94	94
	Avg.	89.03	87.1	87.37
	Min.	77.05	77.27	77.05
CN^2_w	***Max.***	96	96	96
	Avg.	93.52	92.55	92.69
	Min.	87.75	87.64	87.53
***S*:Retention (in.)**	***Max.***	2.98	2.94	2.98
	Avg.	1.24	1.55	1.52
	Min.	0.64	0.64	0.64
***Q*:Runoff (in.)**	***Max.***	5.27	5.01	5.26
	Avg.	2.35	2.45	2.67
	Min.	0.53	0.53	1.23

Note: 1. Rainfall depth came from Atlas14 rainfall database

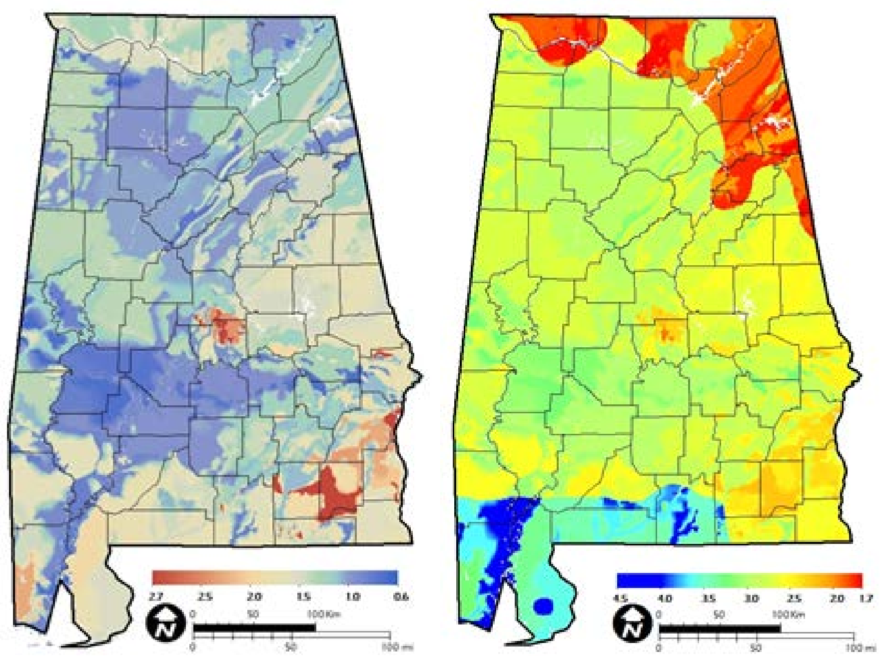
2. Weighted curve number CN_w is estimated by equation $CN_w=0.5*CN+0.5*98$

Appendix B:

Figures of general runoff characters for individual States in Southeastern U.S.

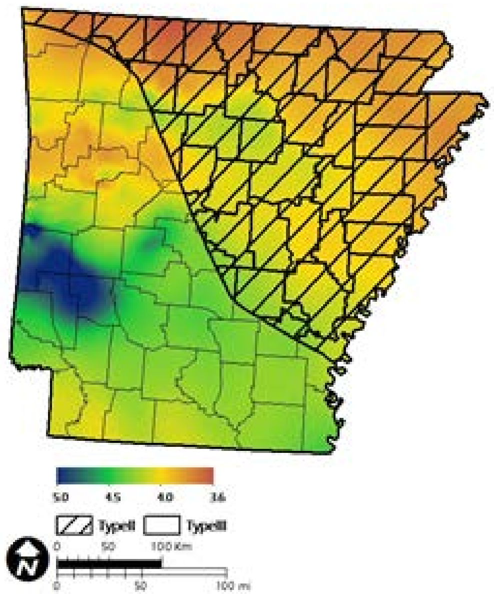


(a) 2-yr, 24-hr rainfall distribution, in. (b) *CN* for newly graded areas

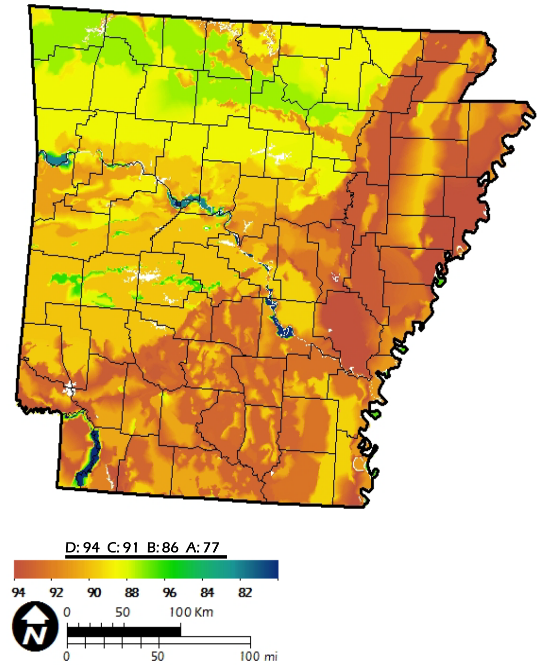


(c) potential maximum retention – S, in. (d) runoff depth – Q, in.

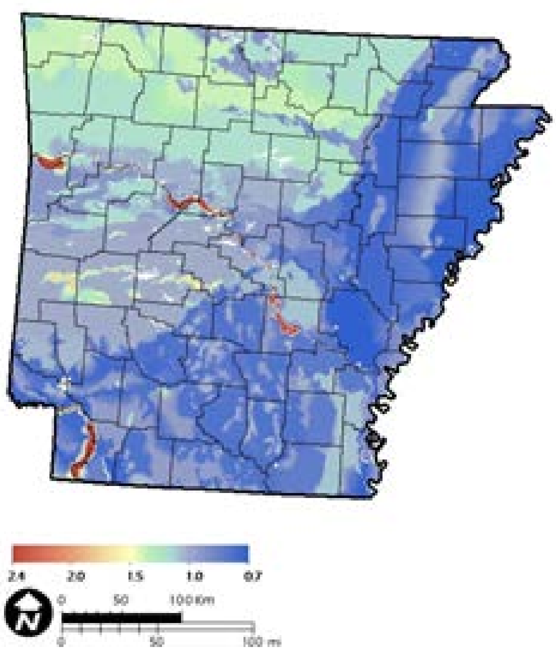
Hydrologic and Soil Parameters for the State of Alabama



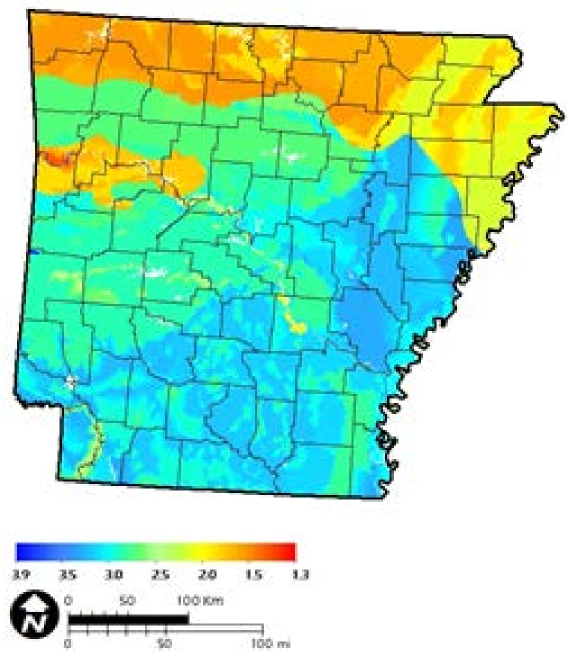
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

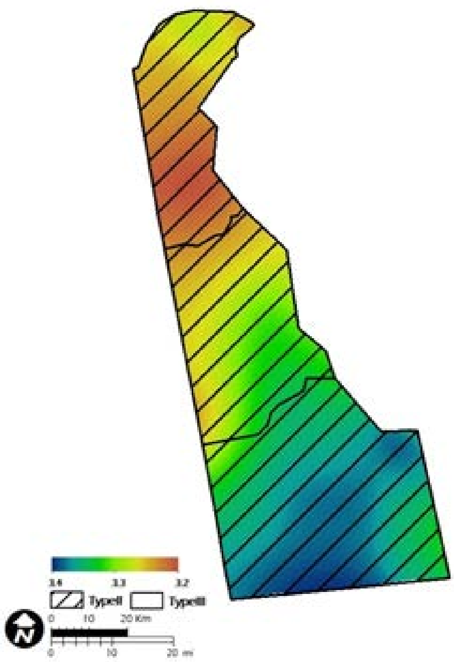


(c) potential maximum retention – S, in.

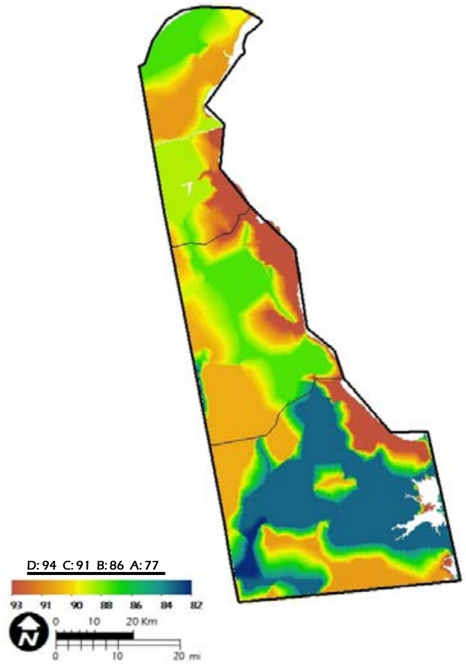


(d) runoff depth – Q, in.

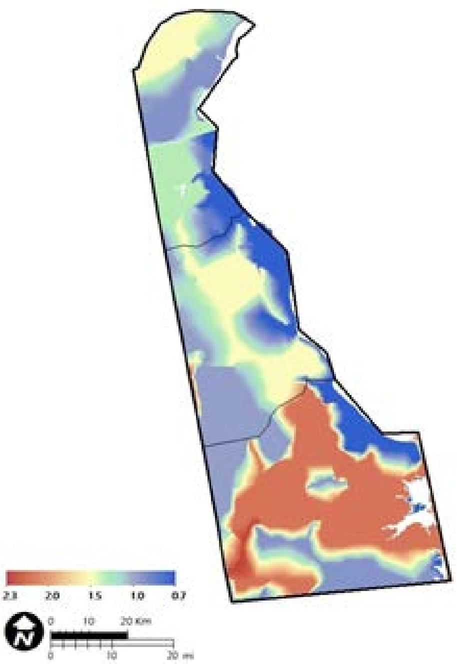
Hydrologic and Soil Parameters for the State of Arkansas



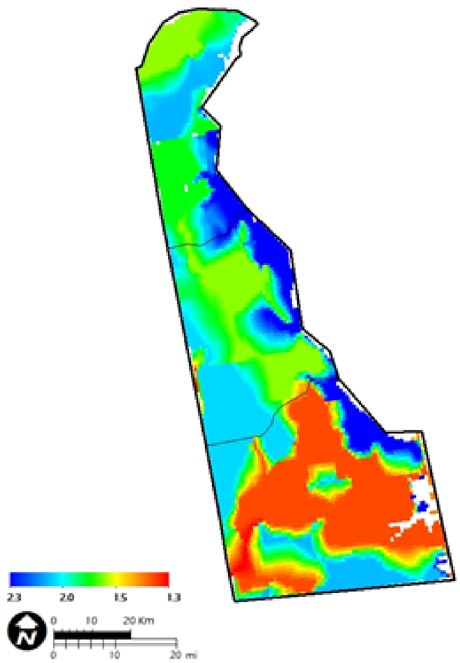
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

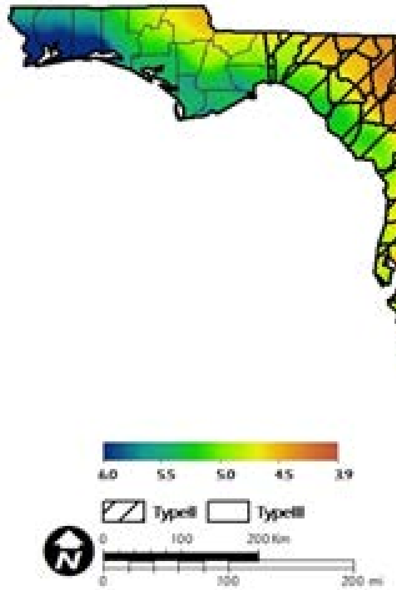


(c) potential maximum retention – S, in.

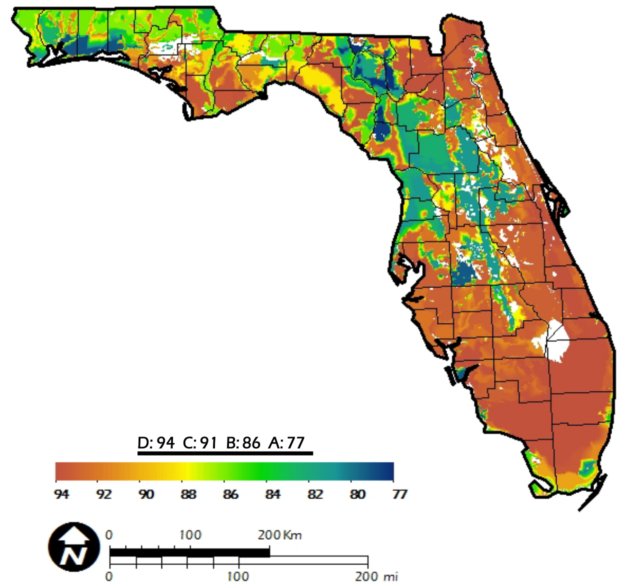


(d) runoff depth – Q, in.

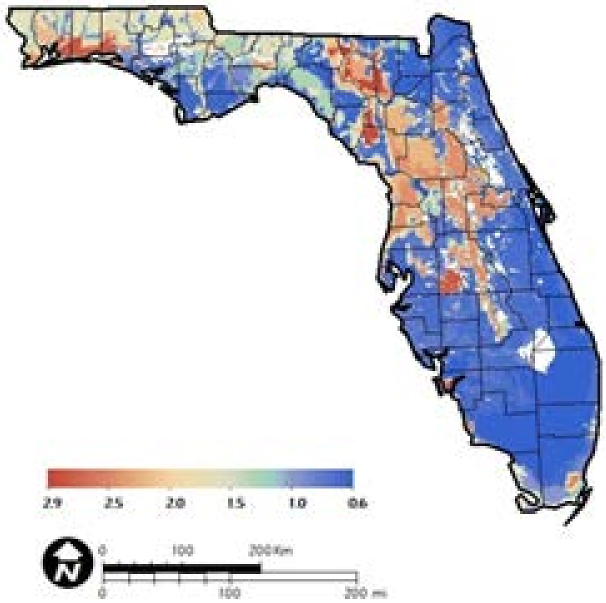
Hydrologic and Soil Parameters for the State of Delaware



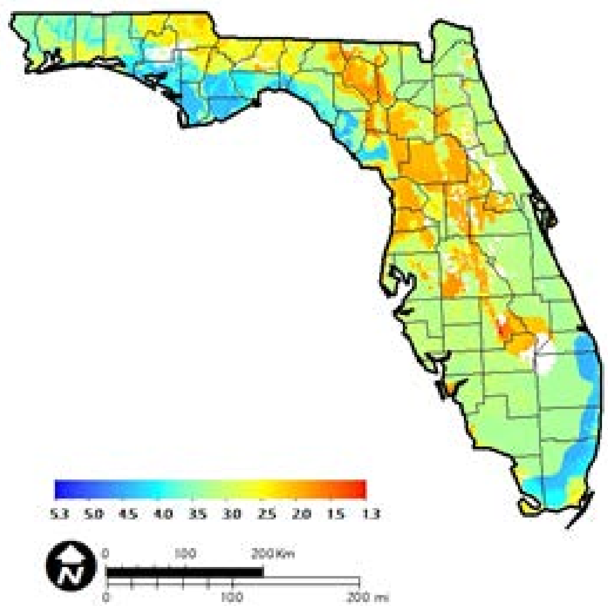
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

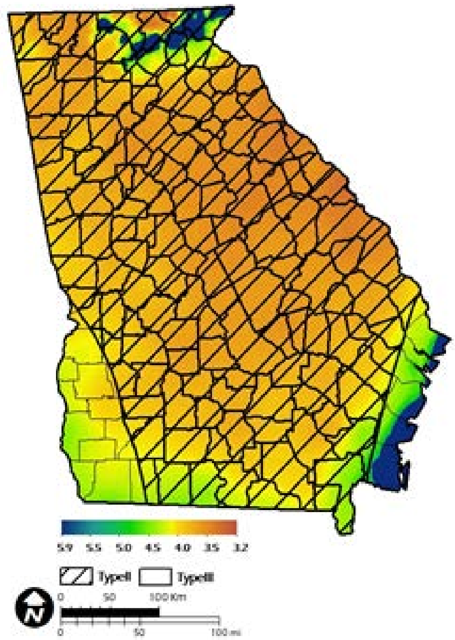


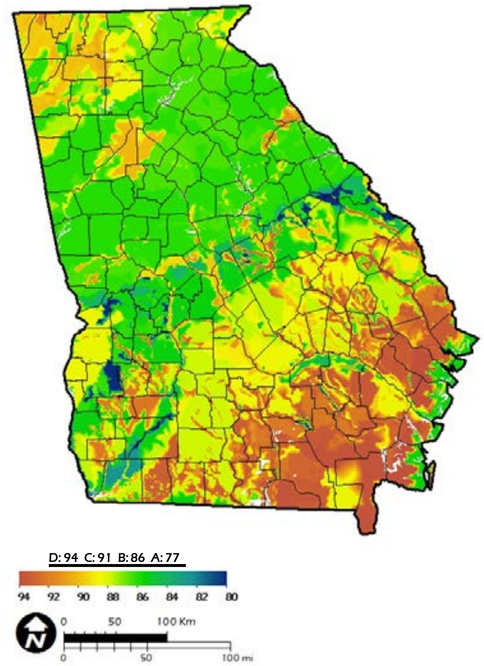
(c) potential maximum retention – S, in.



(d) runoff depth – Q, in.

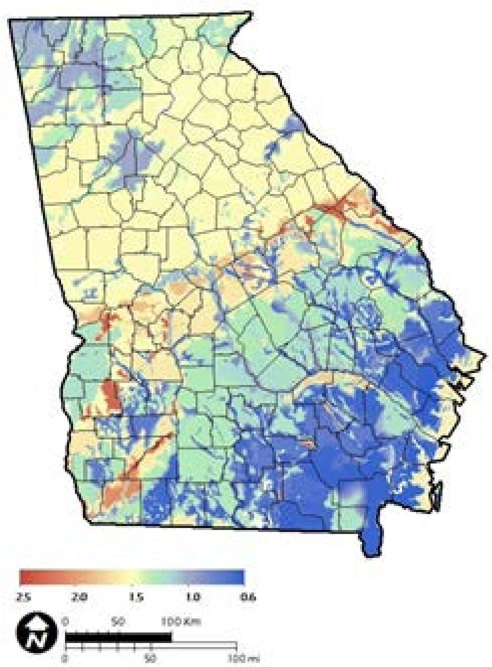
Hydrologic and Soil Parameters for the State of Florida

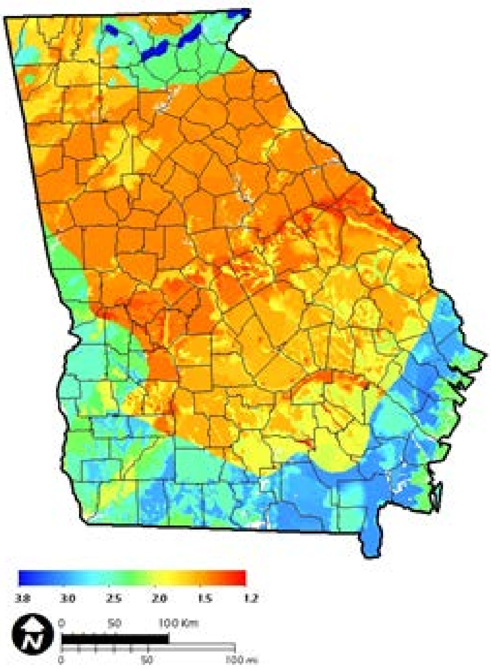




(a) 2-yr, 24-hr rainfall distribution, in.

(b) *CN* for newly graded areas

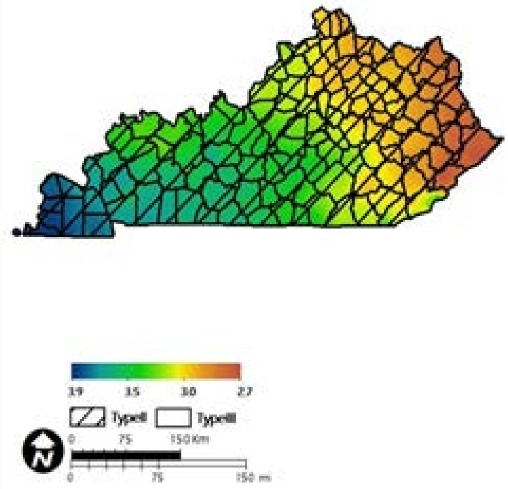




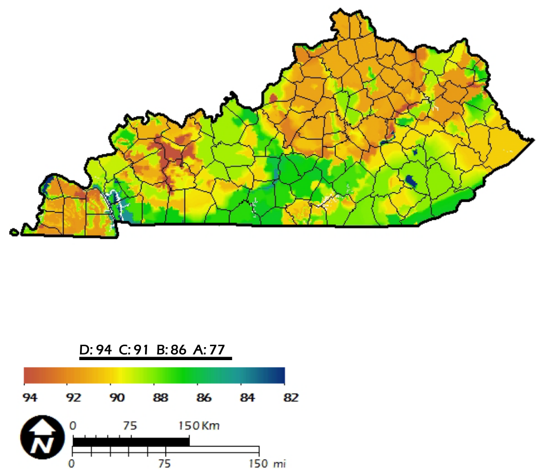
(c) potential maximum retention – S, in.

(d) runoff depth – Q, in.

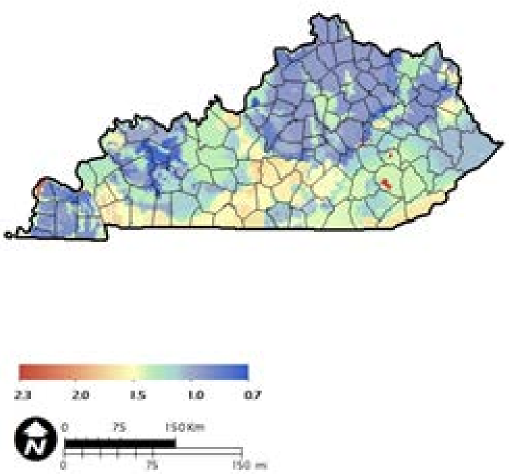
Hydrologic and Soil Parameters for the State of Georgia



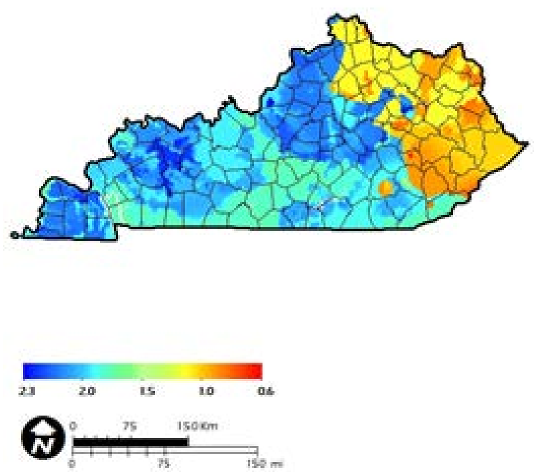
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

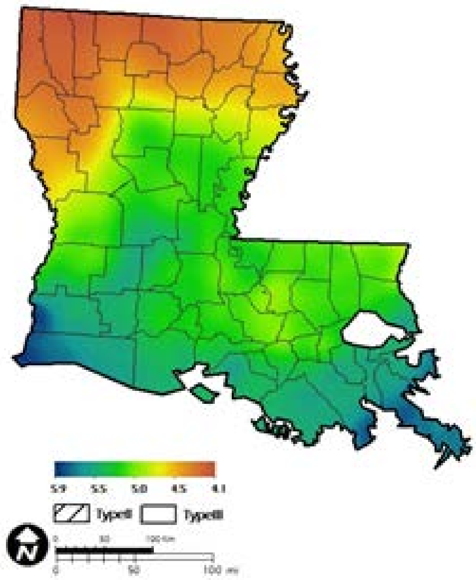


(c) potential maximum retention – S, in.

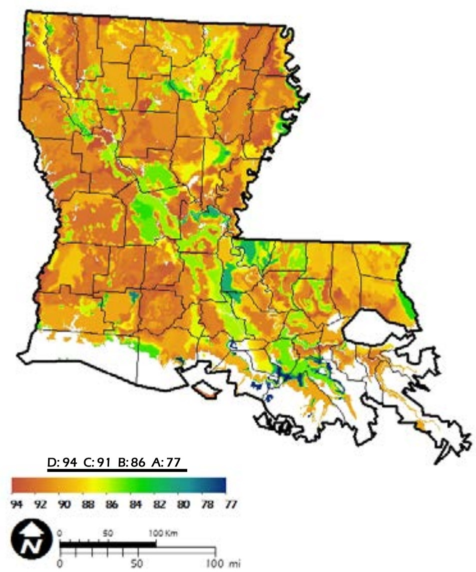


(d) runoff depth – Q, in.

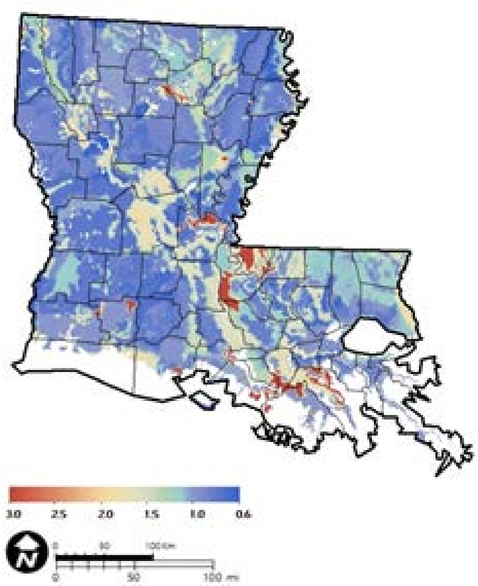
Hydrologic and Soil Parameters for the State of Kentucky



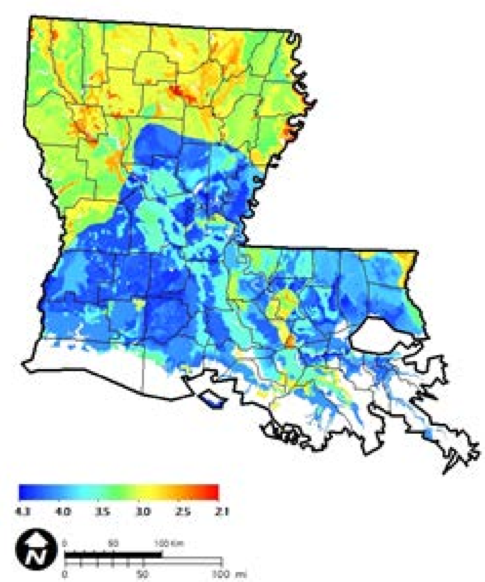
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

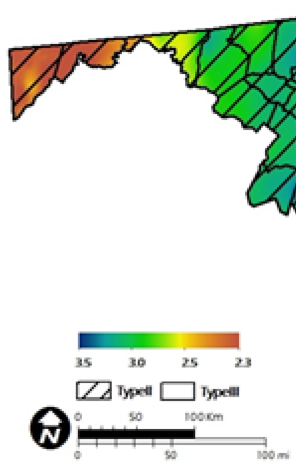


(c) potential maximum retention – S, in.

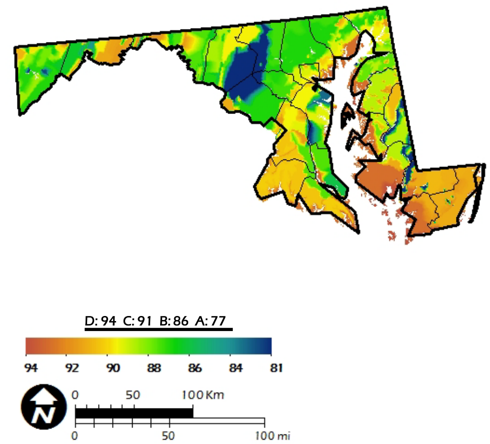


(d) runoff depth – Q, in.

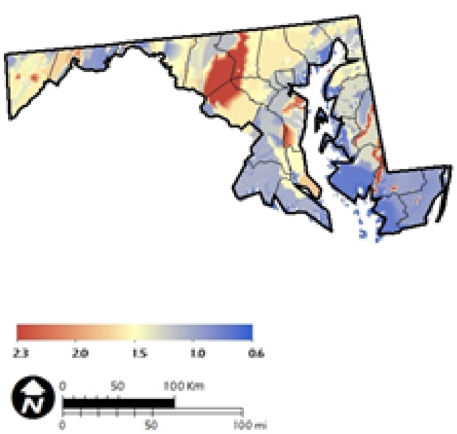
Hydrologic and Soil Parameters for the State of Louisiana



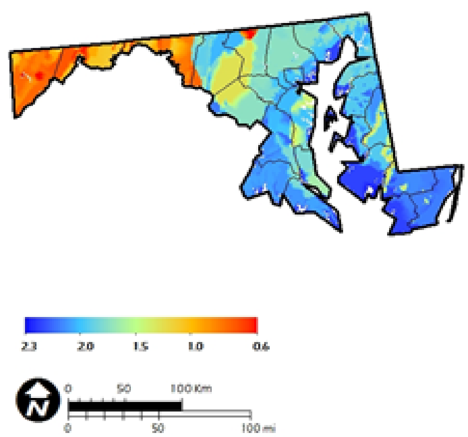
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

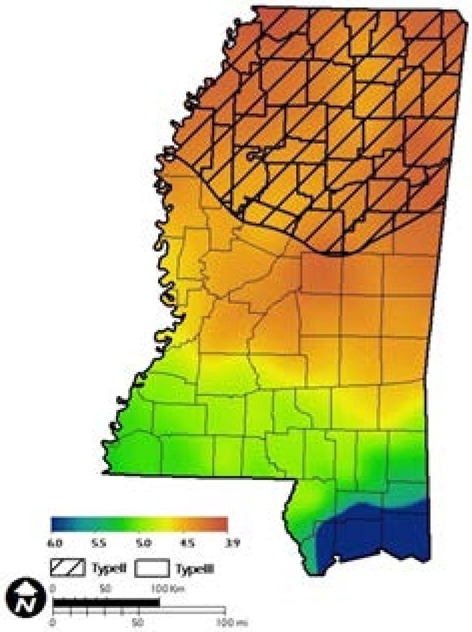


(c) potential maximum retention – S, in.

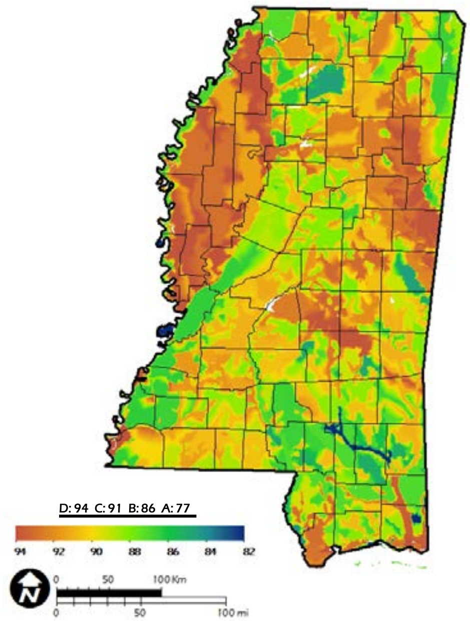


(d) runoff depth – Q, in.

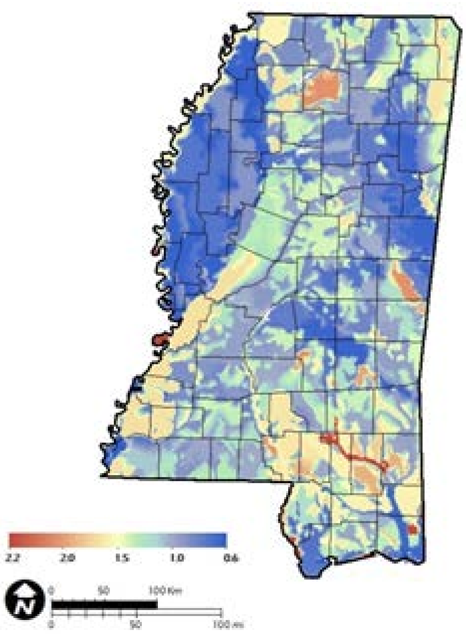
Hydrologic and Soil Parameters for the State of Maryland



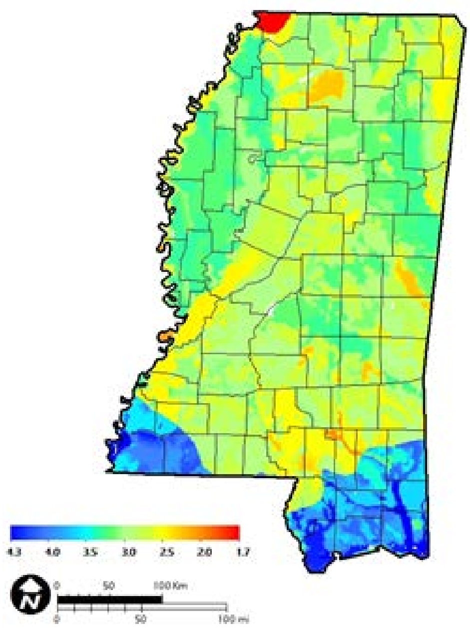
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

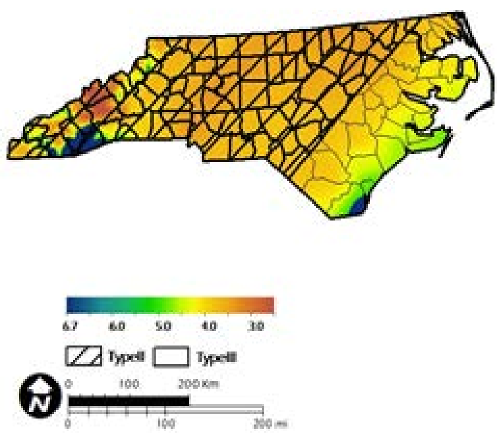


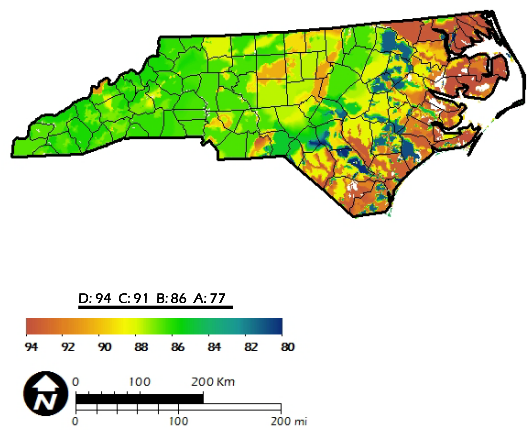
(c) potential maximum retention – S, in.



(d) runoff depth – Q, in.

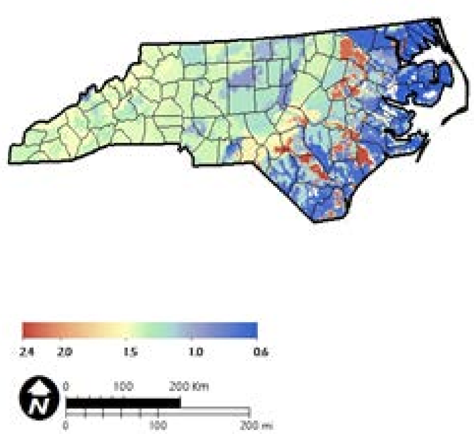
Hydrologic and Soil Parameters for the State of Mississippi

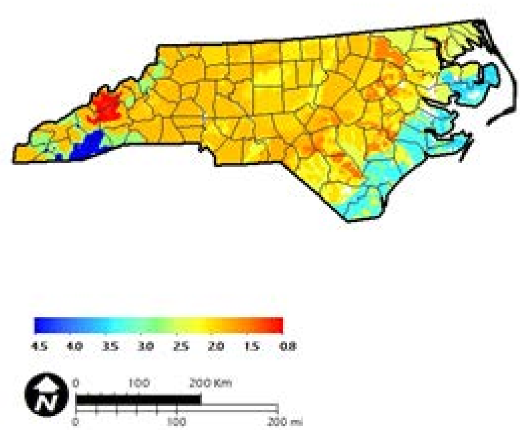




(a) 2-yr, 24-hr rainfall distribution, in.

(b) *CN* for newly graded areas

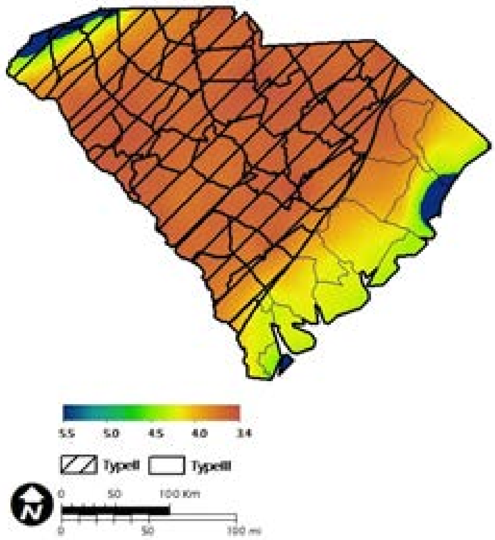




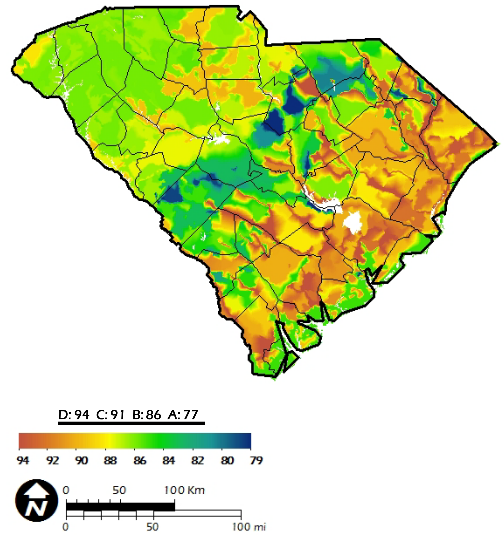
(c) potential maximum retention – S, in.

(d) runoff depth – Q, in.

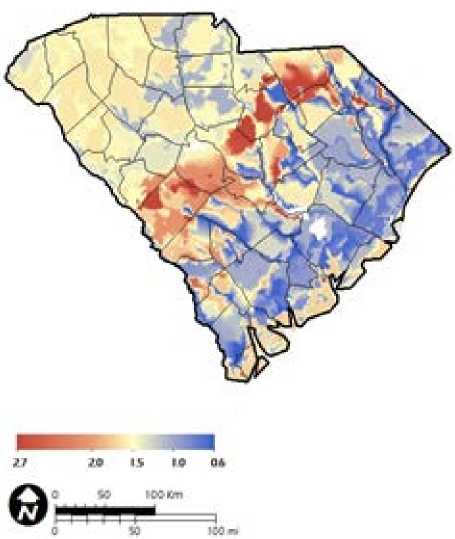
Hydrologic and Soil Parameters for the State of North Carolina



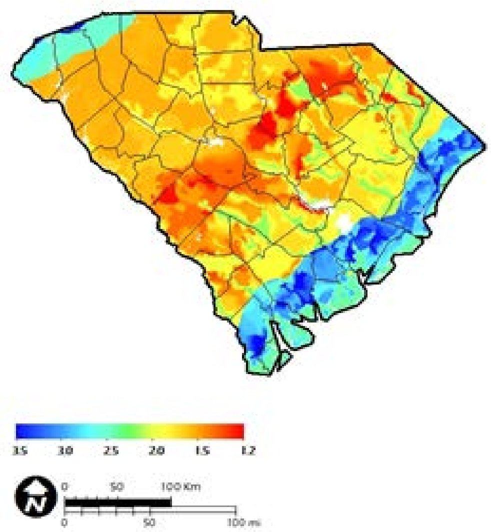
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

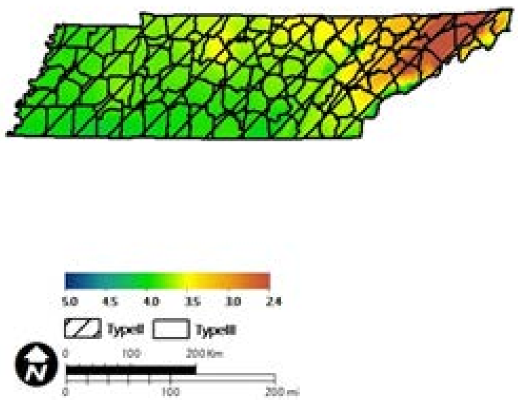


(c) potential maximum retention – S, in.

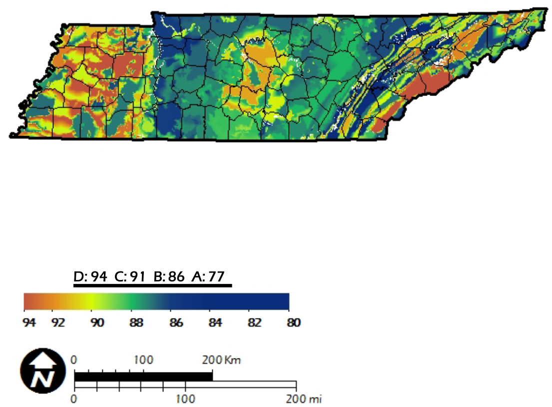


(d) runoff depth – Q, in.

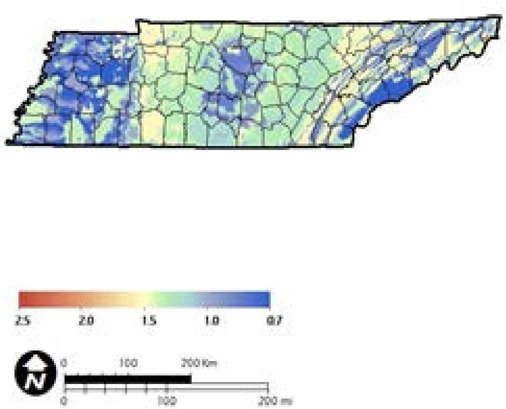
Hydrologic and Soil Parameters for the State of South Carolina



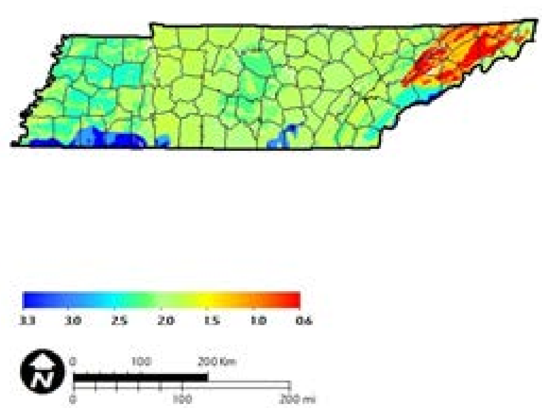
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

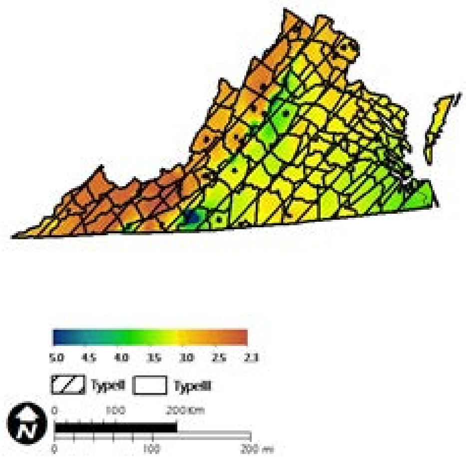


(c) potential maximum retention – S, in.

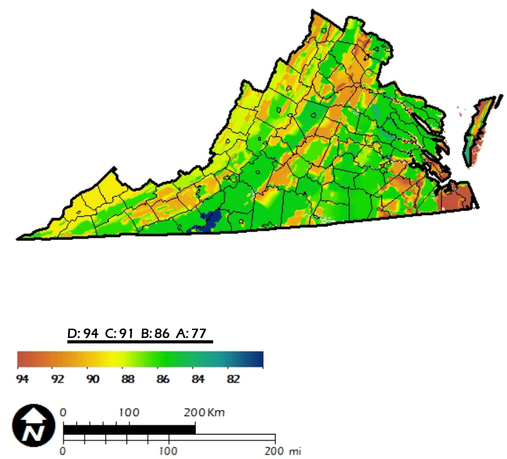


(d) runoff depth – Q, in.

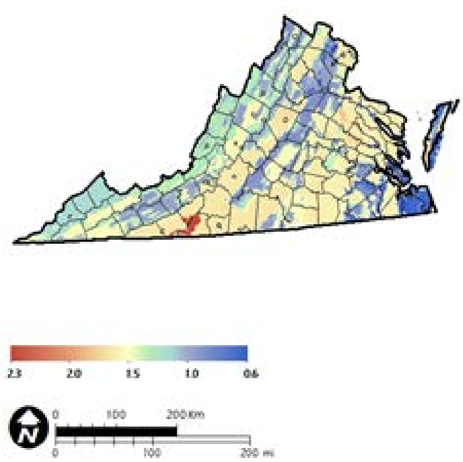
Hydrologic and Soil Parameters for the State of Tennessee



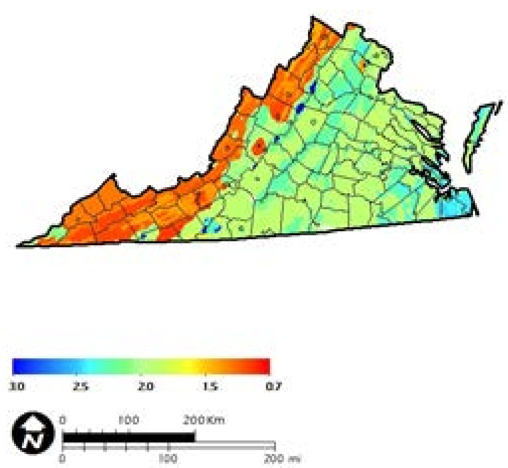
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

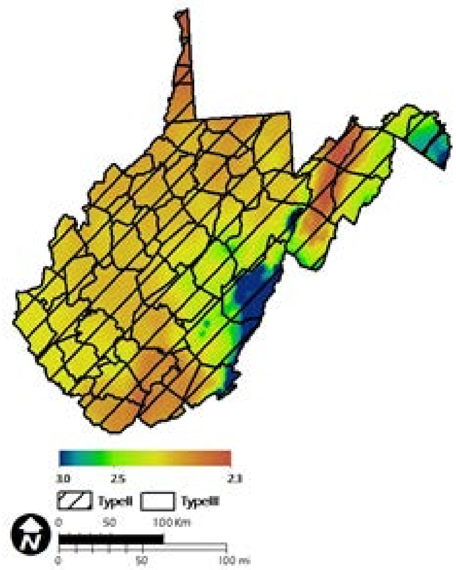


(c) potential maximum retention – S, in.

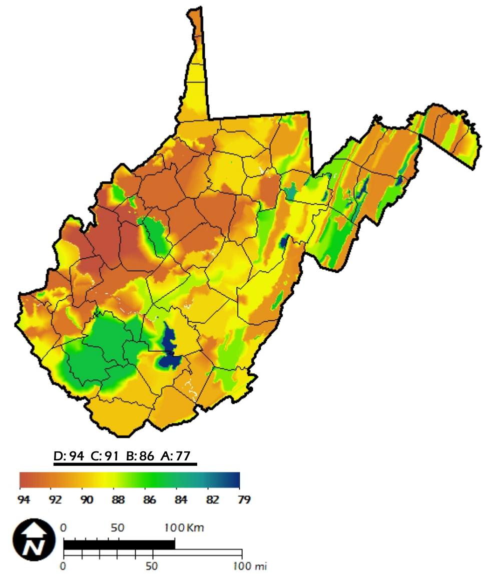


(d) runoff depth – Q, in.

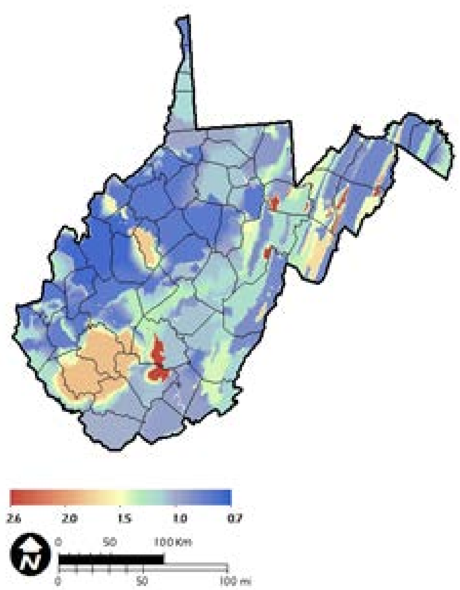
Hydrologic and Soil Parameters for the State of Virginia



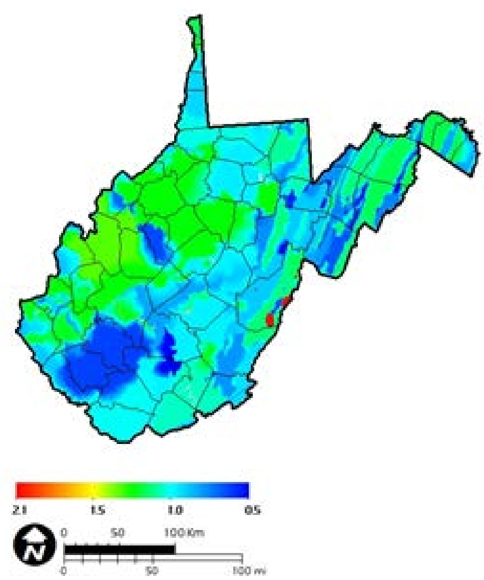
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas

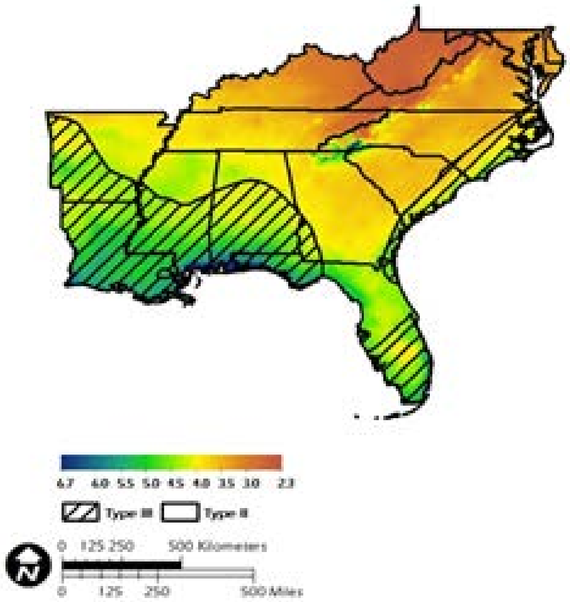


(c) potential maximum retention – S, in.

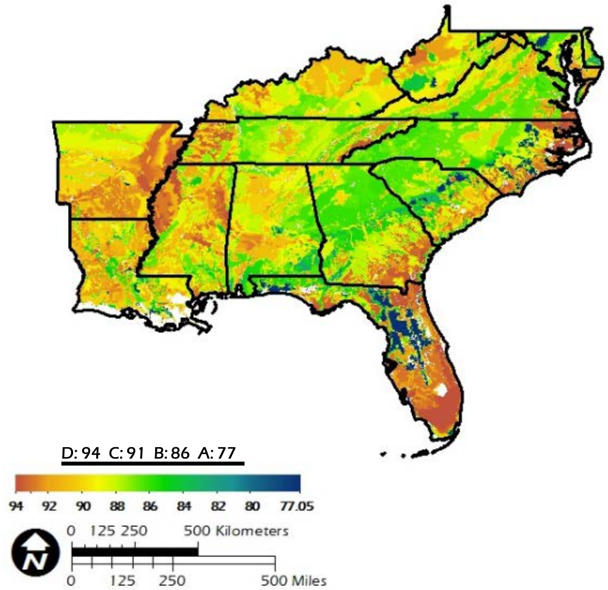


(d) runoff depth – Q, in.

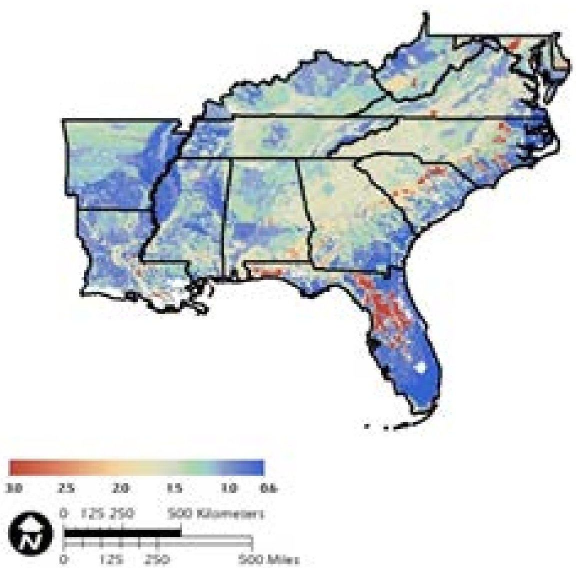
Hydrologic and Soil Parameters for the State of West Virginia



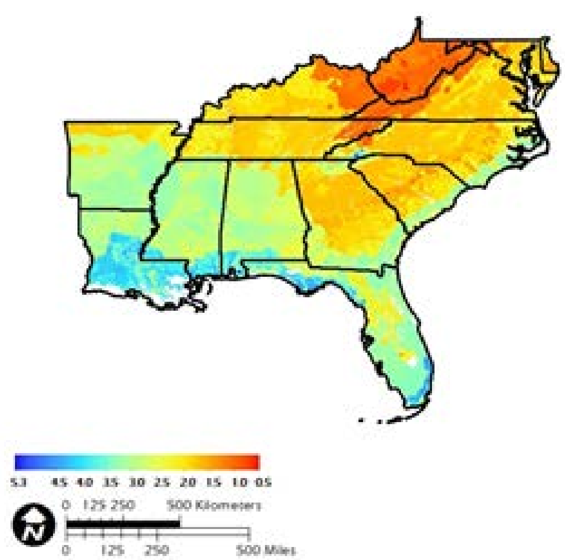
(a) 2-yr, 24-hr rainfall distribution, in.



(b) *CN* for newly graded areas



(c) potential maximum retention – S, in.



(d) runoff depth – Q, in.

Hydrologic and Soil Parameters for the State of Southeastern U.S.