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EVALUATION OF DESIGN FLOOD FREQUENCY METHODS FOR IOWA STREAMS

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16 Abstract

The objective of this project was to assess the predictive accuracy of flood frequency estimation for small Iowa streams based on the Rational Method, the NRCS curve number approach, and the Iowa Runoff Chart. The evaluation was based on comparisons of flood frequency estimates at sites with sufficiently long streamgage records in the Midwest, and selected urban sites throughout the United States. The predictive accuracy and systematic biases (under- or over-estimation) of the approaches was evaluated based on forty-six Midwest sites and twenty-one urban sites. The sensitivity of several watershed characteristics such as soil properties, slope, and land use classification was also explored. Recommendations on needed changes or refinements for applications to Iowa streams are made.

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EXECUTIVE SUMMARY

Estimates of flood frequencies (e.g., the 25-year return period peak discharge) are needed for many engineering design problems in Iowa. Three design methods were evaluated for flood frequency estimation for small Iowa streams, two of which are recommended for use in urban setting by the Iowa Statewide Urban Design and Specifications (SUDAS) manual. For drainage areas of 200 acres or less, flood frequency estimates based on the Rational Method were found to significantly underpredict estimates based on streamgage data. The underprediction is greatest for undeveloped drainages in the Midwest, which are dominated by agricultural land uses; the underprediction is less for drainages in the United States with urban land uses, but still significant. Flood frequency estimates based on the NRCS curve number approach are much less biased. For urban land uses, the NRCS approach tends to overpredict flood frequencies. The Iowa Runoff Chart, developed in the 1950s, also underpredicts flood frequencies for undeveloped Midwest drainages. However, the underprediction is less than that for the Rational Method. The sensitivity of design flood frequency estimates to watershed characteristics was also explored. The Rational Method and NRCS curve number estimates depend on the runoff potential, as indicated by the hydrologic soil group; however, estimates based on streamgage data are not as sensitive to the soil group determination as these methods would imply. The differences in the biases for undeveloped and urban development sites have implications for engineering design. Since many engineering uses of design flood frequency estimates compare pre-developed and post-developed conditions, the fact that estimates for post-developed conditions are higher than for pre-developed conditions (compared to their corresponding streamgage estimates), the relative shift in flood frequency from pre- to post-development is likely overpredicted. Several methods for improving flood frequency estimation were explored. Adjusting the runoff coefficient for the Rational Method, based on the NRCS curve number for the site, can significantly reduce biases. The results also suggest that the time of concentration estimates based on SUDAS procedures may be too long, which contributes to the differences in the observed slope of estimated flood frequency curves. Future work should examine the SUDAS recommended time of concentration procedures in design flood frequency estimation.

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1. INTRODUCTION

1.1 Motivation

Estimates of flood frequencies (e.g., the 25-year return period peak discharge) are needed for many engineering design problems in Iowa. For peak discharges, flood frequency estimates are often based on regional regression equations that synthesize local flood information from gaged sites for applications at ungaged sites. For smaller rural drainages, the Iowa Runoff Chart (Bureau of Public Roads, 1950) has also been used extensively for the past 50 years. Increasingly, flood frequency estimates for small drainages are based on design approaches for applications in storm water management.

The most common design flood frequency methods used in Iowa are the Rational Method and the Natural Resource Conservation Service (NRCS) runoff curve number approach (SCS, 1986). Both methods are popular in part because they are well-documented and well-accepted methods. These methods are applied in roughly the same manner throughout the entire United States with few, if any, changes made to account for regional differences in climate or hydrology. Although standardization makes the methods simple in application, their predictive ability has not been verified for Iowa streams. In contrast, regional regression equations and the Iowa Runoff Chart were developed using local hydrologic information and can be applied with some confidence to Iowa streams.

The goal of this study is to evaluate the design approaches for flood frequency estimation and their application to Iowa streams. The evaluation is based on an empirical assessment of flood frequency estimates for small gaged streams in Iowa and the surrounding states. The evaluation quantifies the predictive accuracy and systematic biases (under- or overestimation) of the approaches and makes recommendations on necessary changes or refinements for applications to Iowa streams.

1.2 Background

Recommended urban design standards for Iowa flood flow determination are published in the Iowa Statewide Urban Design and Specifications (SUDAS) manual. The Rational Method is the recommended procedure for watersheds with drainage areas of 160 acres or less. The NRCS (SCS) runoff curve number approach is recommended for all basin sizes; however, there are two implementations of the NRCS curve number approach and the recommendation of each is determined by the drainage area. For watershed areas less than 2000 acres, the Technical Release 55 (TR-55) computer watershed model (SCS, 1986) is recommended, while the Technical Release 20 (TR-20) computer watershed model (SCS, 1983) is recommended for larger areas (SUDAS, 2004). Alternatively, one can use the Iowa Runoff Chart, adapted by the Iowa State Highway Commission (now Iowa Department of Transportation) in 1950 from the Bureau of Public Roads' Chart 1021.1 (Bureau of Public Roads, 1950). The advantage of this method is that it was developed using local hydrologic information and can be applied with some confidence to Iowa streams. This method is widely used by the Iowa Department of Transportation (Iowa DOT) for flood frequency estimation in rural watersheds with drainage areas of 1000 acres or less. Many applications in stormwater management require a complete flood hydrograph for design and/or predictions of the impact of land use changes on flood magnitudes, so flood frequency estimates for small drainages are often based on the Rational Method or NRCS curve number approach rather than the Iowa Runoff Chart.

Although both the Rational Method and the NRCS method were originally developed to predict the runoff for actual storm events generally (Mulvaney, 1851; Kuichling, 1889; Rallison, 1980), they are now used primarily as a method for flood frequency estimation. The theory is to transform the rainfall frequency curve for a watershed into a flood frequency curve. Specifically, the methods are used to predict the runoff from a *T*-year rainfall event. The resulting flow is also assumed to have a return period of *T*-years. Pilgrim and Cordery (1992) refer to this as the probabilistic approach for design flood estimation. Viewed in this way, the parameters of the methods, such as the runoff coefficient (*C*) or the runoff curve number (*CN*), should be chosen to accurately map rainfall frequencies into flood frequencies. However, standard parameter values used in design (including those in the SUDAS manual) are derived from rainfall-runoff predictions for observed events. Because of this, Pilgrim and Cordery (1992) note that there is a need to verify the methods for probabilistic applications and that parameter values derived for one region may not apply to regions with different hydrologic regimes.

Rigorous scientific evaluations of these design methods are rare. A notable exception is the study by Schaake et al. (1967), which examined probabilistic predictions of the Rational Method for 20 small urban drainages (between 0.22 and 153.4 acres) in Baltimore. They found that *C* depends on the return period *T*, and that about 20% of the estimates from local engineers (based on common design procedures) had errors of 25% or larger compared to gage estimates. In a similar study of the NRCS curve number method for five large watersheds (193 to 400 mi^2), Hjelmfelt (1980) found that a properly selected *CN* could successfully transform rainfall frequency curves into flood frequency curves at all sites except a site in the semi-arid southwestern United States. Yet in an analogous study for eastern Australia, Hoesein et al. (1989) found that the required probabilistic *CN* was markedly different from the standard *CN* based on watershed conditions. Additional studies examining probabilistic applications of the Rational Method and the NRCS curve number approach for the United States and Australia are reported by Pilgrim et al. (1989), Pilgrim (1989), and Hiemstra (1968).

Two conclusions may be drawn from these investigations: (1) the validity of design flood frequency methods needs to be evaluated on a regional basis, and (2) the evaluation must be based on the probabilistic interpretation of the methods, as this is the most common application in design. Fortunately, long flood records are available small streams in Midwestern states, enabling such an evaluation of the region. Furthermore, the availability of geographic information systems (GIS) and geospatial datasets for the United States makes it possible to rapidly and consistently analyze watershed conditions for a large number of sites. These data resources were utilized to make a rigorous scientific evaluation of design flood frequency methods for Iowa.

1.3 Objective

The objective of this project is to assess the predictive accuracy of flood frequency estimation for the Rational Method, the NRCS curve number approach and the Iowa Runoff Chart. The evaluation is based on comparisons of flood frequency estimates at sites with sufficiently long streamgage records (20 years or longer for most sites). The sensitivity of several watershed characteristics such as soil properties, slope, land use classification, and timing are evaluated. This provides a means to directly compare the Rational Method runoff coefficient with the NRCS curve number, which are both parameters that govern the proportion of runoff for a rainfall event. The result of this comparison was the development of the Iowa-modified Rational Method that effectively alters the Rational Method to get results similar to those found by using the NRCS curve number approach.

2. FLOOD FREQUENCY METHODS

2.1 Rational Method

The use of mathematical hydrologic models began late in the nineteenth century and developed in response to the civil engineering challenges of industrialized societies (Singh and Woolhiser, 2002). One of the first models for estimating peak runoff was the Rational Method, introduced by Mulvaney in the late 19th century. In this method, peak runoff is estimated by the Rational formula:

$$Q = CiA \tag{2.1}$$

where Q is the peak runoff (ft^3/s), C is the runoff coefficient (unitless), i is the rainfall intensity (in/hr), and A is the basin area (acres). Table 2.1 includes several terms and definitions that are helpful for understanding the variables and terms used in the Rational Method.

The primary advantage of the Rational Method is simplicity. It is conceptually easy to understand and apply. However, the assumptions in the Rational formula make it difficult to apply to complex or large watersheds. The assumptions in the Rational formula include:

1. Maximum runoff results from a storm where duration equals time of concentration.
2. Rainfall intensity is uniformly distributed over the entire basin.
3. The fraction of rainfall that becomes runoff is independent of rainfall intensity.
4. The fraction of rainfall that becomes runoff can accurately be predicted.

Table 2.1: Terms and acronyms used in the Rational Method.

Variable	Units	Definition	Description
Q	cfs	estimated peak runoff	Estimated volume of surface water runoff at a designated location
C	cfs	runoff coefficient	Value representing the integrated effects of evaporation, interception, retention, infiltration and flow routing. The values are presented for different surface characteristics and land uses
CN	unitless	curve number	Converts mass rainfall to mass runoff
t_c	hours	time of concentration	Time required for the surface runoff from the most remote point of the basin to reach the location being considered
i	in/hr	rainfall intensity	Average rate of precipitation for the period of maximum rainfall of a given frequency having the duration equal to the time of concentration
A	acres	basin area	Drainage area for the considered location
s	unitless	Average watershed slope	Elevation difference between the most remote location in the basin to the point of consideration divided by length of the longest flow path
t_L	hours	basin lag time	Length of time from the center of mass of the rainfall excess to the peak discharge
L	feet	hydraulic length	Distance along the path from the most remote point of the basin to the location being considered
S	unitless	potential maximum retention	Maximum amount of water that can be retained in the watershed
I_a	unitless	initial abstraction	Estimated initial abstraction before ponding, defined as 20% of the potential maximum retention
f	years	frequency	Average time between exceedances for an event
t_L	hours	basin lag time	Length of time from the center of mass of the rainfall excess to the peak discharge
HSG		hydrologic soil group	Designation developed by the National Resource Conservation Service that classifies soil based on runoff and infiltration characteristics of the bare, unfrozen soil after prolonged wetting
LULC		land use/land cover type	A classification system developed by the United States Geological Survey that divides the land surface into twenty-one categories based on surface characteristics

2.1.1 Calculating the runoff coefficient

The runoff coefficient *C* represents the integrated effects of evaporation, interception, retention, infiltration and flow routing. Average values are tabulated by different surface characteristics. Table 2.2 shows a sample of runoff coefficient values for various land use classifications, hydrologic soil groups, and slopes for a frequency of 25 years. Determining the runoff coefficient *C* requires estimation of average watershed slope (*s*), hydrologic soil group (*HSG*), land use/land cover classification (*LULC*), time of concentration (t_c), and the curve number (*CN*). Each of these variables is discussed in the following sections.

Table 2.2: Sample table of Rational Method runoff coefficients.

Land Use	HSG A Slope 0-2%	HSG A Slope 2-6%	HSG B Slope 0-2%	HSG B Slope 2-6%
Cultivated land	0.08	0.13	0.11	0.15
Pasture	0.12	0.20	0.18	0.28
Meadows	0.10	0.16	0.14	0.22
Forest	0.05	0.08	0.08	0.11

Source: McCuen, R. H. (2004), Hydrologic Analysis and Design. 3rd Ed. Prentice Hall, Upper Saddle River, New Jersey.

2.1.1.1 Average watershed slope

Using a topographical map or a digital elevation model (DEM) in a Geographical Information System (GIS), the watershed that contributes runoff to the location of concern can be delineated. With the delineated watershed, the hydraulic length (*L*) can be determined and the elevations at the endpoints of the hydraulic length provide the information necessary to calculate the average watershed slope (*s*). The hydraulic length is defined in Table 2.1. The equation for the average watershed slope *s* is:

$$s = (\text{Elevation at initial endpoint of } L - \text{Elevation at final endpoint of } L) / L \quad (2.2)$$

2.1.1.2 Hydrologic soil group

The hydrologic soil group (*HSG*), is the designation developed by the National Resource Conservation Service (NRCS) that classifies soil based on runoff and infiltration characteristics of the bare, unfrozen soil after prolonged wetting. There are four classifications of hydrologic soil groups: *A*, *B*, *C* and *D*. The NRCS defines each group as follows (National Soil Survey Handbook, 2005):

A Soils with low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well drained to excessively well-drained sands or gravels.

B Soils having moderate infiltration rates even when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures.

C Soils having slow infiltration rates even when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures.

D Soils with high runoff potential. Soils having very slow infiltration rates even when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material.

The source of the *HSG* information used in this study is soil surveys compiled into the State Soil Geographic (STATSGO) database, which is available for download from the NRCS. The data acquisition of hydrologic soil group information is discussed in Section 3.

Soils in urban areas can be more difficult to classify based on the NRCS hydrologic soil group definitions. Rawls and Brakensiek (1983) noted that determining a *HSG* based on texture in urban areas is an appropriate alternative. Table 2.3 displays Rawls and Brakensiek's classifications based on texture. The *HSG*s of the watersheds in this study were not evaluated using this approach. This would make an interesting future study, however.

Table 2.3: Soil textures for hydrologic soil groups.

HSG	Texture
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay or clay

Source: Rawls, W.J., and D.L. Brakensiek. (1983). A procedure to predict Green and Ampt. infiltration parameters. In Advances in infiltration. Proc. of the National Conference on Advances in Infiltration. Dec. 12-13. Chicago, IL.

2.1.1.3 Land use land cover

Land use land cover (*LULC*) is a classification system developed by the United States Geological Survey that divides the land surface into twenty-one categories based on surface characteristics. The source of this information is the National Land Cover Dataset (NLCD), which is a 21-category land cover classification scheme that analyzes data derived from Landsat Thematic Mapper imagery taken in the early to mid 1990s. Each land cover classification reflects electromagnetic energy differently and software is able to decipher the Landsat Thematic Mapper images and classify the surface.

2.1.1.4 Time of concentration

The time of concentration (t_c) is the estimate of the time it takes for water to travel from the hydraulically most distant location in a watershed to a point of interest, such as the streamgage (Mays, 2001). Several equations for calculating the time of concentration have been used over the last seventy years. Two of the early equations were proposed by Kirpich (1940) and Izzard (1946), who used SCS data to develop equations for rural basins. In 1975, the Soil Conservation Service (SCS) developed an equation called the SCS lag equation. It is an empirical equation specifically for determining the time of concentration in urban basins with areas less than 2000 acres (SCS, 1975). This study uses the SCS lag equation in order to calculate the time of concentration. The most critical assumption in this approach is that the time of concentration is 5/3 times the basin lag time (t_L), defined in Table 2.1. The SCS lag equation, used for time of concentration t_c calculations, is:

$$t_c = 100L^{0.8}[(1000/CN)-9]^{0.7} / 1900s^{0.5} \quad (2.3)$$

where L is the hydraulic length of the watershed in feet, CN is the NRCS runoff curve number and s is the average watershed slope.

2.1.1.5 NRCS runoff curve number

Depending on the equation used for calculating the time of concentration t_c, the curve number may or may not be required. Using the Soil Conservation Service (SCS) lag equation, the curve number is required. The curve number is discussed in detail in the NRCS curve number method (section 2.2). Therefore, at this point the curve number will be defined simply as a term that converts mass rainfall into estimated mass runoff given certain watershed characteristics.

2.1.2 Rainfall intensity

The rainfall intensity is derived from the rainfall depth-duration frequency relationship at the time of concentration for a particular drainage basin. Figure 2.1 is an example of a precipitation depth map for a given frequency and duration event. Using precipitation depth maps for various durations and frequencies allows one to calculate the rainfall intensity at the time of concentration by interpolating between the maps until the duration equals the time of concentration t_c.

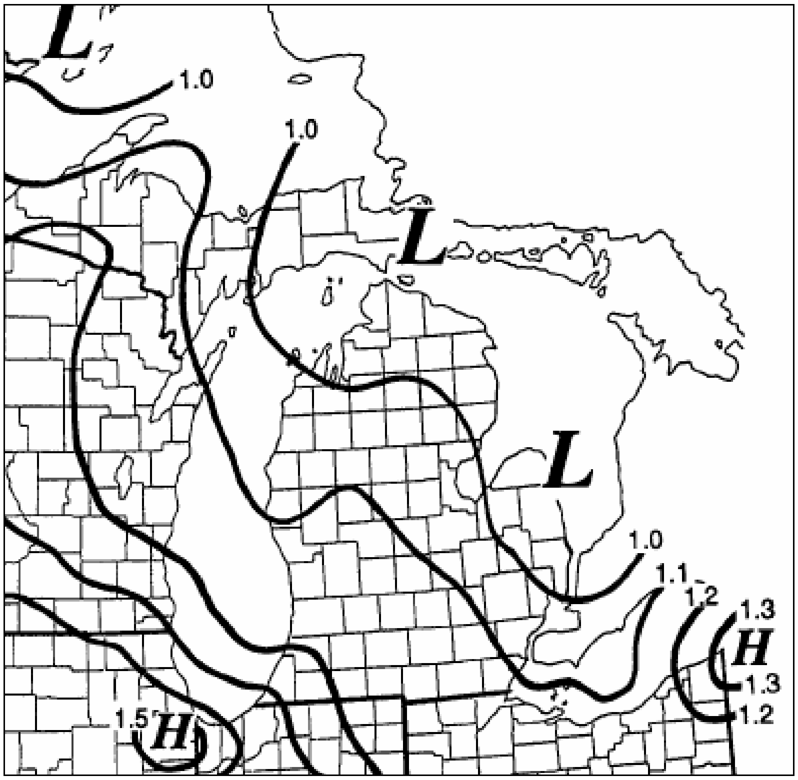

Figure 2.1: Precipitation depth map (Huff and Angel, 1992).

The Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992) contains rainfall depth-duration frequency charts for several Midwestern states used in this study including Wisconsin, Iowa, Missouri, Illinois and Indiana. This resource includes tabulated rainfall depths for given return periods, ranging from 2 months to 100 years and durations from five minutes to ten days. For the Midwestern states of North Dakota, South Dakota, Nebraska, and Kansas, rainfall frequency information was derived from NOAA Technical Paper 40 (TP 40) (Hershfield, 1961), NOAA Technical Paper 49 (TP 49) (Miller, 1964), and NOAA Technical Memorandum NWS HYDRO- 35 (Federick et al., 1977). These three publications contain collections of maps with contour lines of rainfall depth drawn on maps for frequencies from 2 to 100 years and duration of 30 minutes up to 10 days. For sites outside the Midwest, rainfall frequency information was also obtained from these NOAA publications, or more recent updated information in NOAA Atlas 14, which is available for selected regions (Bonnin et al., 2004a; Bonnin et al., 2004b).

2.1.3 Basin area

A topographical map can be used to delineate the basin and determine the drainage area. In this study, topographical maps were imported into the Geographical Information System (GIS) and the basins were delineated. The drainage areas calculated in the GIS were then compared with the drainage areas published for each basin by the USGS.

2.2 NRCS Curve Number Method

The Soil Conservation Service (SCS), predecessor to the Natural Resources Conservation Service (NRCS), was created in 1935 by Public Law 46 to address soil erosion. In 1975, the SCS published Technical Release 55 (TR-55), which documents a methodology for calculating storm runoff volume, peak rate of discharge, hydrographs, and storage volumes. The procedure was created for the analysis of small watersheds, especially urban watersheds in the United States. The current TR-55 manual was updated from the 1975 version and was published in 1986 (SCS, 1986).

A computer program implementing the TR-55 methodology was used in this project to estimate the peak discharge for various frequencies by computing the NRCS graphical peak discharge equation:

$$Q = \frac{q_u A q F_p}{640} \qquad (2.4)$$

where Q is the estimated peak discharge(ft^3/s), q_u is the unit peak discharge (csm/in), A is the drainage area (acres), q is the estimated runoff (inches), and F_p is the pond and swamp adjustment factor.

This method requires input parameters of time of concentration t_c, basin area A, 24-hour precipitation depth P, the curve number CN, and the rainfall distribution category. Table 2.4 displays the variables and acronyms used in the NRCS curve number method.

Table 2.4: Terms and acronyms used in the NRCS runoff curve number method.

Variable	Units	Definition	Description
Q	cfs	estimated peak runoff	Estimated volume of surface water runoff at a designated location
q_u	csm/in	unit peak discharge	Parameter used in the graphical peak discharge equation determined using Figure 2.2
A	acres	basin area	Drainage area for the considered location
q	in	estimated peak runoff	Parameter used in the graphical peak discharge equation
F_p		pond and swamp adjustment factor	Factoring decreasing peak runoff as proportion of pond and swamp area increases
t_c	hours	time of concentration	Time required for the surface runoff from the most remote point of the basin to reach the location being considered
P	in	24-hour precipitation	Maximum depth of precipitation over a 24-hour period for a given frequency and duration
CN	unitless	curve number	Converts mass rainfall to mass runoff
I_a	unitless	initial abstraction	Estimated initial abstraction before ponding, defined as 20% of the potential maximum retention
S	unitless	potential maximum retention	Maximum amount of water that can be retained in the watershed
s	unitless	Average watershed slope	Elevation difference between the most remote location in the basin to the point of consideration divided by length of the longest flow path
f	years	frequency	Average time between exceedances for an event
HSG		hydrologic soil group	The designation developed by the National Resource Conservation Service that classifies soil based on runoff and infiltration characteristics of the bare, unfrozen soil after prolonged wetting
LULC		land use/land cover type	A classification system developed by the United States Geological Survey that divides the land surface into twenty-one categories based on surface characteristics

2.2.1 Unit peak discharge

The unit peak discharge is calculated using Figure 2.2 given the 24-hr precipitation depth P, the initial abstraction I_a, or potential maximum retention S, and the time of concentration t_c, for the given rainfall distribution. Each of these terms is described in the following sections.

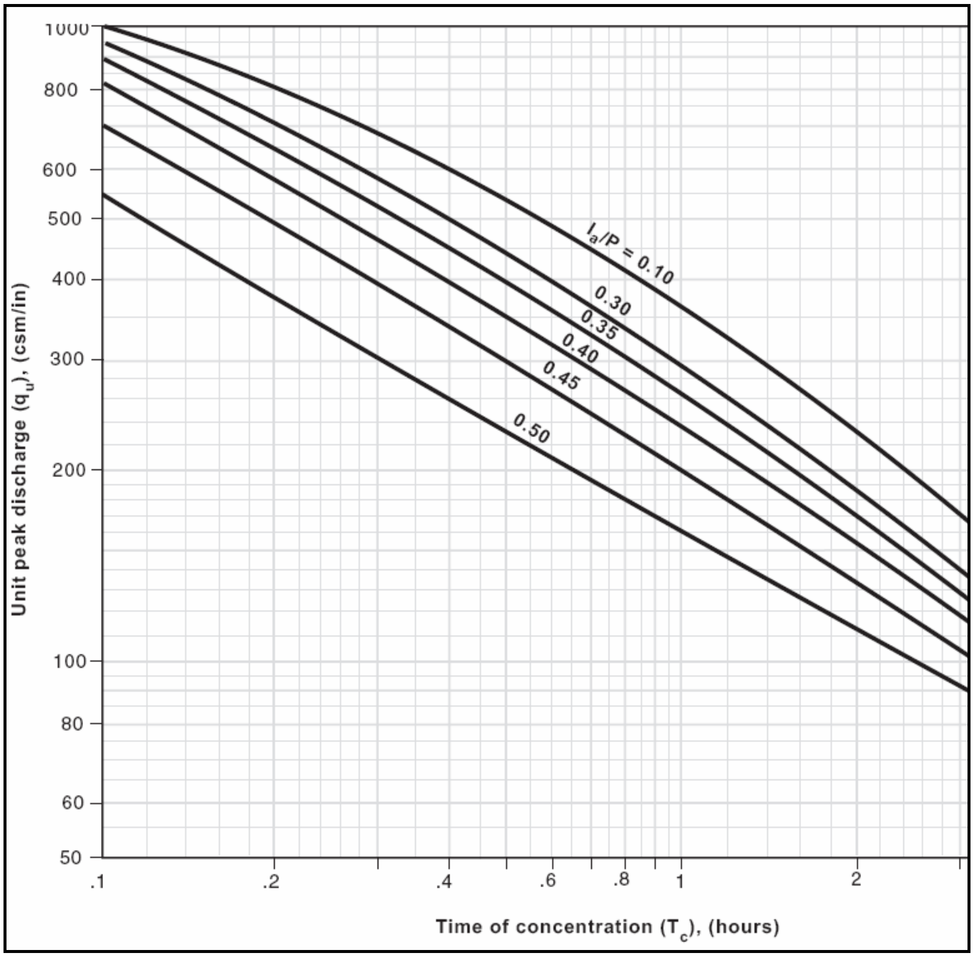

Figure 2.2: Chart used to determine the unit peak discharge (SCS, 1986).

2.2.1.1 Twenty-four hour precipitation depth

The 24-hour precipitation depth is the only duration of precipitation depth map required in the NRCS curve number method. The Rational Method requires the user to interpolate between precipitation depth maps in order to estimate the precipitation depth for the duration equal to the time of concentration t_c. The duration of 24 hours was chosen because of the general availability of the daily rainfall data. Figure 2.1 shows a precipitation depth map. The 24-hour precipitation depth at each basin must be determined by interpolating between contour lines of precipitation depths.

2.2.1.2 Initial abstraction and potential maximum retention

Initial abstraction (I_a) is defined as all losses before runoff begins, which includes water intercepted, evaporated or infiltrated. Although highly variable, I_a is highly dependent upon soil and cover parameters. Through studies of many small agricultural watersheds, I_a was found to be empirically approximated as:

$$I_a = 0.2S \qquad (2.5)$$

where S is the potential maximum retention (inches) (SCS, 1986). S is related to the soil and cover parameters through the empirically determined NRCS runoff curve number (CN).

2.2.1.3 Time of concentration

Determination of the time of concentration t_c is described in section 2.1.1.4.

2.2.1.4 Rainfall distribution

The intensity of rainfall during a storm varies depending on the region. The National Resource Conservation Service (NRCS) developed four synthetic 24-hour rainfall distribution zones for the United States in order to reflect these regional variations and more accurately portray rainfall characteristics. Type IA is the least intense, type I represents locations where the most intense precipitation comes in the form of winter storms in pacific maritime climatic areas, type II is the most intense for short durations, and type III reflects tropical storm patterns. The rainfall distribution classification by geographical region is shown in Figure 2.3. All of the sites for this study were in the type II classification.

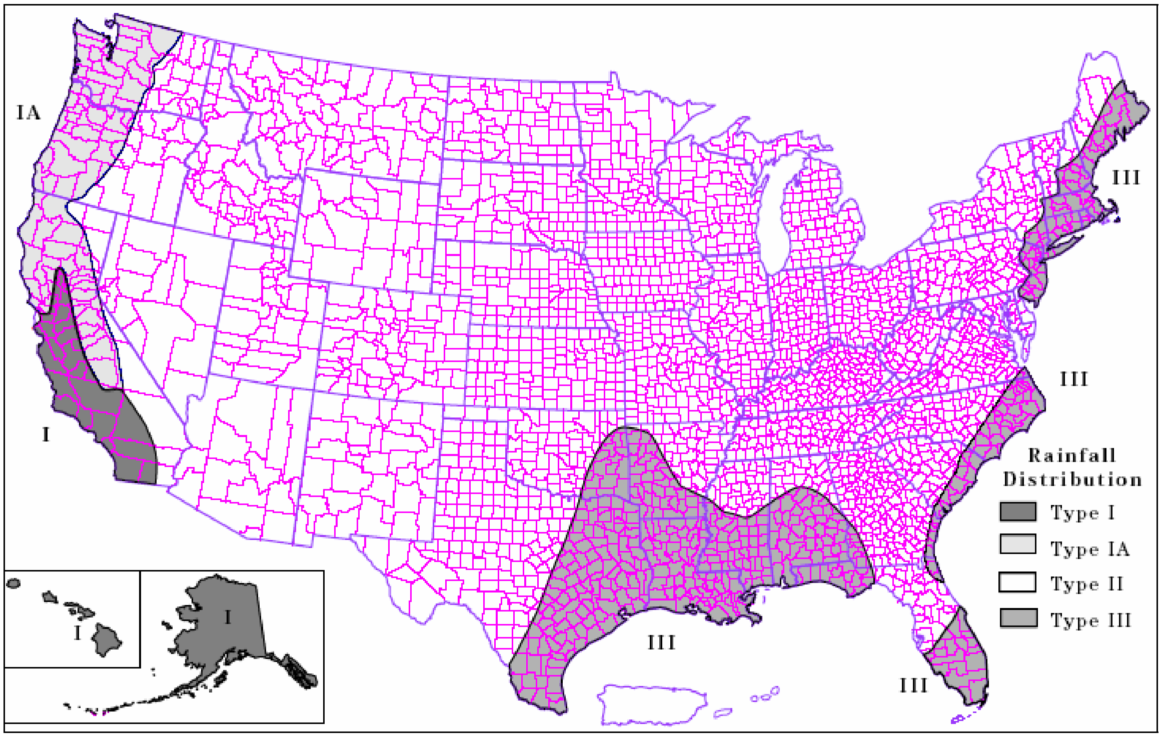

Figure 2.3: Rainfall distribution classifications (SCS, 1986).

2.2.3 Drainage area

The calculation of the drainage area is discussed in section 2.1.3.

2.2.4 Estimated runoff

The estimated runoff, q, is calculated using the SCS runoff equation:

$$q = \frac{(P - I_a)^2}{(P - I_a + S)} \tag{2.6}$$

where q is the runoff (inches), P is the 24-hr rainfall depth (inches), S is the potential maximum retention after runoff begins (inches), and I_a is the initial abstraction (inches).

2.2.5 Pond and swamp adjustment factor

If the basin has pond and swamp areas, adjustments are made in accordance with the percent of the area classified as pond or swamp. The pond and swamp adjustment factor, F_p, is determined using Table 2.5.

Table 2.5: Pond and swamp adjustment factors.

% pond and swamp areas	Adjustment factor, F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

2.2.6 SCS runoff curve number

The curve number is an empirically-based numerical representation of the watershed's soil, slope and cover conditions, which are defined by the average watershed slope (*s*), hydrologic soil group, land use land cover type, treatment and hydrologic condition. The average watershed slope, hydrologic soil group, and land use land cover type were discussed in sections 2.1.1.1, 2.1.1.2, and 2.1.1.3, respectively. Treatment is a cover type modifier that describes the management of cultivated land. It includes both mechanical and management practices of the soil. Hydrologic condition indicates the effects of cover type and treatment on runoff. Good hydrologic condition indicates that the soil has a low runoff potential. The assumptions made in this study concerning the treatment and hydrologic conditions are shown in Table 2.6.

Table 2.6: Assumptions made for treatment and hydrologic condition for applicable land use/land cover classifications.

LULC category	Treatment	Hydrologic condition
Fallow	Crop residue cover	Good
Row crops	Straight row	Good
Small grain	Straight row	Good
Meadow	Straight row	Good

With this information, the composite *CN*s for cultivated agricultural areas can be determined using Figure 2.4. Other broad land use categories in addition to cultivated agricultural land include fully developed urban land, other agricultural land, and arid/semiarid rangeland. Using a computer program implementation of the TR-55 method, the composite *CN* is calculated by importing the relative areas of each combination of parameters into a table similar to the one in Figure 2.4.

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment 2/	Hydrologic condition 3/	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Figure 2.4: SCS runoff curve number chart (SCS, 1986).

2.2.7 Method critique

The NRCS curve number approach is not free of serious criticism. Ponce and Hawkins (1996) provide an excellent summary of the history and perceived shortcomings of the method. They argue that the credibility and acceptance of the method have come into question because of its agency roots, which initially isolated it from peer review. However, disregarding the method would vitiate much of the information collected about soils for the United States since the 1940s. The specific soil data designations of hydrologic soil group, treatment and condition, which are all important aspects in the NRCS curve number approach, would become trivial (Miller and Cronshey, 1989). Ponce and Hawkins (1996) listed several perceived advantages and disadvantages of the NRCS curve number method, which are compiled in Table 2.7. Regardless of the criticism, the NRCS curve number approach has remained popular because it is simple and conceptual, and has wider applicability than empirically-based physical models (Dooge, 1977).

Table 2.7: Perceived advantages and disadvantages of the NRCS CN method.

Advantages	Disadvantages
Simple	Developed for the Midwestern United States, may be less applicable elsewhere
Relies on only parameter, the curve number, which is derived from data that has been collected since the 1940s	Very sensitive to low curve numbers and antecedent condition (Hawkins 1975; Bondelid et al. 1982; Ponce 1989)
It is well-documented and established across the United States and in many parts of the world	Method is best in agricultural sites, fair in range sites and poor in forest applications (Hawkins 1984, 1993)
Conceptual	No explicit provision for spatial scale effects
Stable	The initial abstraction ratio is fixed

Source: Ponce, V.M., Hawkins, H.H. (1996). “Runoff curve number: Has it reached maturity?” *Journal of Hydrologic Engineering*, January, 1996, pp. 11-19.

2.3 Iowa Runoff Chart Method

The Iowa Runoff Chart was adapted in 1950 by the Iowa State Highway Commision (now the Iowa Department of Transportation) from the Bureau of Public Roads’ Chart 1021.1 (Bureau of Public Roads, 1950). The advantage of this method is that it was developed using local hydrologic information, and can be applied with some confidence to Iowa streams. This method is widely used by the Iowa Department of Transportation for flood frequency estimation in rural watersheds with drainage areas of 1000 acres or less. However, a disadvantage is that the method predicts the peak discharge only, not the hydrograph, so it is not suited for stormwater management applications that require the complete flood hydrograph. The computation of the flood frequency estimation for the Iowa Runoff Chart is based on:

$$Q = LF \cdot FF \cdot Q_i \qquad (2.7)$$

where Q is the estimated peak discharge (ft^3/s), LF is the land use and slope description factor, FF is the frequency factor, Q_i is defined as $8.124*A^{0.739}$, and A is the basin area (acres). The frequency factor is determined using Table 2.8 and the land use and slope description factors by Table 2.9. Table 2.10 displays the variables and acronyms required in the Iowa runoff chart method.

Table 2.8: Frequency factor (*FF*) determination.

Frequency, years	5	10	25	50	100
Factor, *FF*	0.5	0.7	0.8	1.0	1.2

Table 2.9: Land use and slope description factor (*LF*) determination.

Land use	Description				
	Very Hilly	Hilly	Rolling	Flat	Very Flat
Mixed Cover	1.0	0.8	0.6	0.4	0.2
Permanent Pasture	0.6	0.5	0.4	0.2	0.1
Permanent Woods	0.3	0.2	0.2	0.1	0.05

The factor tables are based on subjective descriptions of Iowa terrain. However, in this study the approach is applied to sites located outside of Iowa. Consequently, the land use and slope description factors had to be adapted for this study. To accomplish this, the terms in the factor tables were subjectively defined with quantitative limits. The description factor was based on average watershed slope and the land use by 1992 National Land Cover Data classifications (EROS, 2005). Very hilly was defined as having an average watershed slope of greater than 4%, hilly 2-4%, rolling 1-2%, flat 0.5-1% and very flat 0-0.5%. Land use was considered mixed unless there was a minimum of 85% pasture/grasslands or deciduous/coniferous/mixed forests, in which case it was classified as pasture or forest, respectively.

Table 2.10: Terms and acronyms used in the Iowa Runoff Chart.

Variable	Units	Definition	Description
Q	cfs	estimated peak runoff	Estimated volume of surface water runoff at a designated location
A	acres	basin area	Drainage area for the considered location
s	unitless	average watershed slope	Elevation difference between the most remote location in the basin to the point of consideration divided by length along its longest flow path
f	years	frequency	Average time between exceedances for an event
Q_i	cfs	unscaled peak runoff	An empirical value defined as $8.124*A^{0.739}$
LF		slope description factor	Modifier that considers *s* and hydrologic soil group
FF		frequency factor	Modifier that considers *f*
HSG		hydrologic soil group	Designation developed by the National Resource Conservation Service that classifies soil based on runoff and infiltration characteristics of the bare, unfrozen soil after prolonged wetting
LULC		land use/land cover type	A classification system developed by the United States Geological Survey that divides the land surface into twenty-one categories based on surface characteristics

3. EXPERIMENTAL DESIGN

The goal of this study is to evaluate the design approaches for flood frequency estimation and their application to Iowa streams. To meet this goal, small streams with sufficient streamgage records were chosen and the flood frequency of each site was estimated. With the aid of a Geographical Information System (GIS), watershed characteristics were collected and stored for each basin. The rainfall intensities were then determined. This provided the necessary information for estimating the flood frequency based on the Rational Method and the NRCS Curve Number approach. Comparisons of the design methods were made to address the estimation differences and an alternative flood frequency estimation technique was developed in order to mitigate the differences between the two design methods.

3.1. Select sites for flood analysis

The Statewide Urban Design and Specification (SUDAS) recommends flood frequency methods based on basin area. The SUDAS manual advocates the use of the Rational Method for basins of approximately 160 acres or less and the NRCS curve number approach for larger basins. In this study, basin size was restricted to an upper bound of 200 acres (0.31 mi^2) to increase the available sample size.

For site selection, a Midwest region defined by Iowa and its surrounding states was examined. To evaluate flood frequency design techniques, all streams with a drainage area of 200 acres (0.31 mi^2) or less and sufficiently long flow records (20 years or greater) were selected. Forty-six sites in the Midwest region are available, but no Iowa sites met these criteria. However, the 46 sites within the Midwest region are considered approximately representative of the hydrologic and climatic characteristics of Iowa streams. The sites chosen are displayed in Figure 3.1 and listed in Table 3.1.

Since agricultural land uses are dominate at the 46 Midwestern sites, additional sites were examined across the United States to find those with significant urban land uses. All streams with a drainage area of 200 acres (0.31 mi^2) or less, a flow record of at least ten years for active gages, and at least 5% of the area with urban land use, were selected.

Twenty-one sites in the United States are available, including three which were selected as part of the Midwest region. Although not necessarily representative of Iowa streams, the sites are considered representative of urban streams. The sites chosen are displayed in Figure 3.2 and listed in Table 3.2.

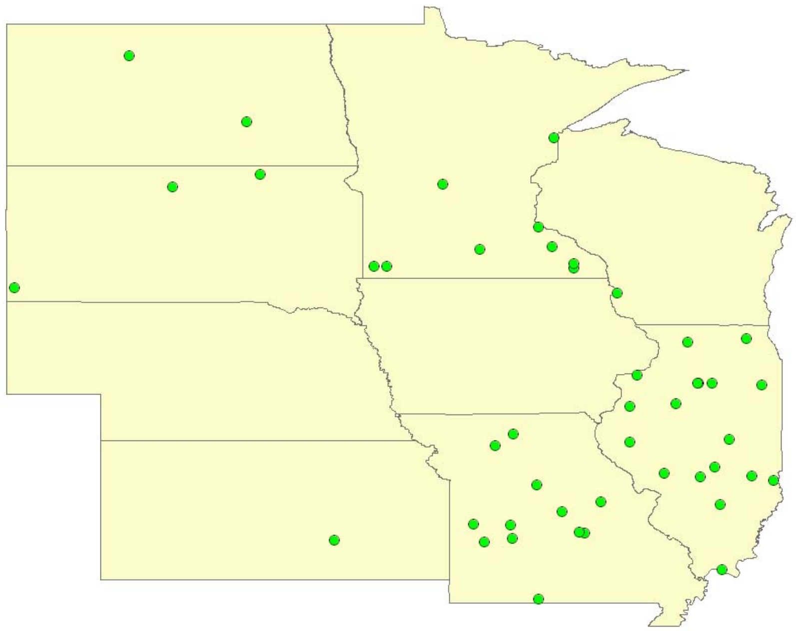

Figure 3.1: Location of Midwest USGS streamgages for streams with drainage areas of 200 acres (0.31 mi^2) or less and flow records of over 20 years.

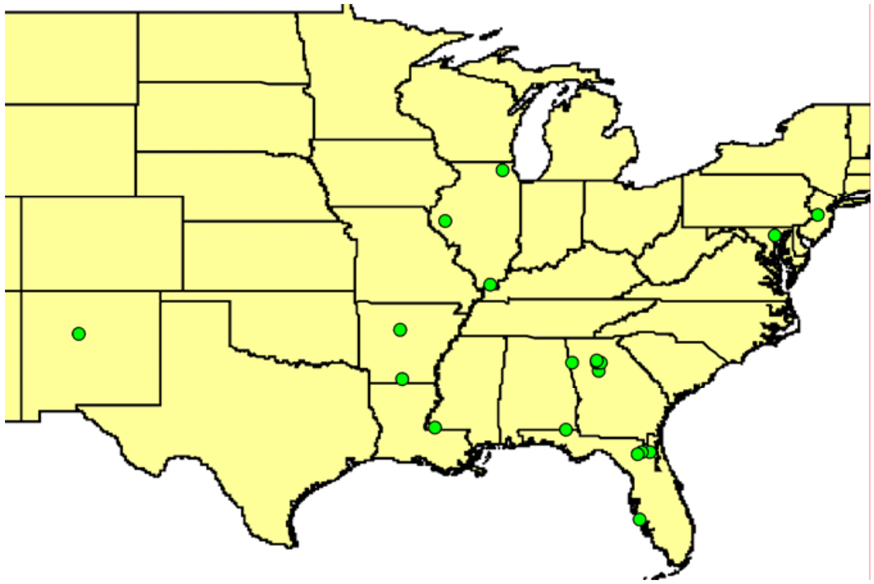

Figure 3.2: Location of urban basins with USGS streamgages for streams, with drainage areas of 200 acres (0.31 mi^2) or less, and flow records of over 10 years, and at least 5% urban land use.

Table 3.1: Site information for the Midwest basins.

USGS Site	Area (acres)	Record (years)	Site Name
3341900	26	25	Raccoon Creek Tributary near Annapolis, IL
3344250	51	25	Embarras River Tributary near Greenup, IL
3380300	51	25	Dums Creek Tributary near Iuka, IL
3612200	173	21	Q Ditch Tributary near Choat, IL
4024110	128	26	Rock Creek Tributary near Blackhoof, MN
5116100	83	22	Souris, near Burlington, ND
5270310	154	25	Sauk River Tributary #2 near St. Martin, MN
5320200	45	27	Le Sueur River Tributary near Mankato, MN
5355230	32	22	Cannon River Tributary near Welch, MN
5373350	102	24	Zumbro River Tributary near South Troy, MN
5384150	51	23	Root River Tributary near Whalan, MN
5384300	90	23	Big Springs Creek near Arendahl, MN
5388460	192	20	Du Charme Creek at Eastman, WI
5440900	96	23	Leaf River Tributary near Forreston, IL
5448050	141	25	Sand Creek near Milan, IL
5469750	166	25	Ellison Creek Tributary near Roseville, IL
5526150	122	25	Kankakee River Tributary near Bourbonnais, IL
5549900	45	23	Fox River Tributary near Cary, IL
5555400	90	21	Vermilion River Tributary at Lowell, IL
5558050	19	21	Coffee Creek Tributary near Florid, IL
5558075	141	24	Coffee Creek Tributary near Hennepin, IL
5563100	45	24	Kickapoo Creek Tributary near Kickapoo, IL
5572100	64	21	Wildcat Creek Tributary near Monticello, IL
5585700	96	21	Dry Fork Tributary near Mount Sterling, IL
5586850	13	25	Bear Creek Tributary near Reeders, IL
5592025	128	21	Mud Creek Tributary near Tower Hill, IL
5592700	90	25	Hurricane Creek Tributary near Witt, IL
6358520	192	25	Deadman Creek Tributary near Mobridge SD
6396300	58	25	Cottonwood Creek Tributary near Edgemont SD
6470200	122	28	Beaver, near Eldridge, ND
6471450	166	21	Willow Creek Tributary near Barnard SD
6482960	122	28	Mound Creek Tributary at Hardwick, MN
6483200	90	24	Kanaranzi Creek Tributary near Lismore, MN
6899600	134	23	West Fork Leakey Branch near Chillicothe, MO
6901300	83	22	Moffet Branch near Reger, MO
6909400	192	25	Cottonwood Creek Tributary at Estill, MO
6910700	83	24	Hazel Branch Tributary near Wardsville, MO
6918200	51	22	N Fork Panther Creek Tributary near Appleton City, MO
6919200	90	23	Sac R Tributary near Caplinger Mills, MO
6921400	115	21	Ferguson Branch at Nemo, MO
6922600	115	20	Little Turkey Creek Tributary near Warsaw, MO
6933700	173	24	Penzer Hollow near Rolla, MO
6934750	160	23	Little Berger Creek Tributary near Hermann, MO
7015500	141	20	Lanes Folk near Rolla, MO
7054300	147	22	Gray Branch at Lutie, MO
7147020	109	40	Whitewater River Tributary near Towanda, KS

Table 3.2: Site information for the Urban basins.

USGS Site	Area (acres)	Record (years)	Site Name
1463812	173	13	Shabakunk Creek Tributary at Texas Ave near Lawrenceville, NJ
1585225	135	12	Moores Run Tributary near Todd Ave at Baltimore, MD
2204135	179	32	Camp Creek Tributary at GA 155 near Stockbridge, GA
2206105	115	20	Jackson Creek at Angels Lane near Lilburn, GA
2206165	64	21	Jackson Creek Tributary 2 Worchester Place near Lilburn, GA
2206465	128	22	Watson Creek Tributary 2 Tanglewood Drive at Snellville, GA
2245573	103	11	Bull Creek Tributary near Middleburg, FL
2245606	134	11	Calf Branch Tributary near Middleburg, FL
2298928	128	10	Tributary to Myakka River near Venice, FL
2320978	198	11	New River Tributary near Raiford, FL
2321506	141	11	Tributary To Santa Fe River Trib near Worthington Spring, FL
2335347	122	22	Crooked Creek Tributary 2 near Norcross, GA
2365408	51	11	Poplar Springs Branch near Noma, FL
2411902	77	32	Mann Creek Tributary at GA 100 near Tallapoosa, GA
3612200	173	21	Q Ditch Tributary near Choat, IL
5549900	45	23	Fox River Tributary near Cary, IL
5585700	96	21	Dry Fork Tributary near Mount Sterling, IL
7260679	58	28	E.Fork Point Remove Creek Tributary near St.Vincent, AR
7364550	45	43	Caney Creek Tributary near El Dorado, AR
7373550	134	51	Moores Branch near Woodville, MS
8329880	77	28	Academy Acres Drain in Albuquerque, NM

3.2 USGS flow records for selected sites

For the selected sites, information concerning flood peaks was obtained. The annual maximum peak flow series was used to estimate flood frequencies at each site. This dataset is available online from the United States Geological Survey (USGS) National Water Information System (NWIS). The flow record retrieved from the NWIS for one of the basins in this study, the Kankakee River tributary near Bourbonnais, IL, is displayed in Table 3.3.

3.3 Estimate flood frequencies using streamgage record

Following the methodology outlined in Bulletin 17B (Water Resources Council, 1982), flood frequencies from streamgage records were estimated using HEC-WRC. For comparison, non-parametric methods were used to estimate flood frequencies for shorter return periods (e.g., for 2-, 5-, and 10-years), as these estimators are robust with sample sizes of 20-years and longer.

Table 3.3: Annual Maximum Peak Flow Series for the Kankakee River tributary near Bourbonnais, IL.

Water Year	Date	Peak discharge (cfs)
1956	Feb. 24, 1956	44
1957	Jul. 13, 1957	233
1958	Jun. 08, 1958	153
1959	Apr. 27, 1959	92
1960	Aug. 04, 1960	32
1961	Sep. 14, 1961	13
1962	Mar. 19, 1962	10
1963	Mar. 04, 1963	62
1964	Apr. 21, 1964	5
1965	Jan. 23, 1965	46
1966	Dec. 25, 1965	23
1967	May. 11, 1966	65
1968	Jun. 28, 1968	39
1969	Jul. 27, 1969	6
1970	May. 13, 1970	200
1971	Feb. 19, 1971	13
1972	Apr. 07, 1972	22
1973	Jun. 21, 1974	19
1974	Jan. 21, 1974	8
1975	May. 26, 1975	22
1976	Mar. 01, 1976	17
1977	Mar. 04, 1977	5
1978	Apr. 06, 1978	32
1979	Oct. 26, 1978	129
1980	Jun. 03, 1980	105

3.4 Watershed information for sites

Design flood frequency methods use watershed information to estimate model parameters. For the NRCS runoff method, runoff curve numbers are estimated using soil (hydrologic soil group), slope, and land use/land cover information. Similar information is also used to estimate the runoff coefficient for the Rational Method, as outlined in the Iowa Statewide Urban Design and Specifications (SUDAS) manual. In addition, both methods require topographic and stream network information to estimate travel time parameters (e.g., time of concentration).

3.4.1 Datasets from the USGS

The USGS hosts two web pages with applicable GIS data. The site http://seamless.usgs.gov/website/seamless/viewer.php gives various transportation, boundary, hydrography, orthoimagery, land cover and elevation data layers. Useful layers for runoff estimation include the state, county, street, 1992 National Land Cover Data (NLCD) and the 1/3 arc second National Elevation Dataset (NED) layers. Layers of sub-basin delineations, high density stream networks and waterbodies, aquifers and the locations of significant water-related points can be downloaded at http://nhdgeo.usgs.gov/viewer.htm.

3.4.1.1 Transportation

The Bureau of Transportation Statistics (BTS) roads layer provides the road networks for the United States and Puerto Rico. These data were published in 2002 and are intended to be displayed and analyzed at a scale of 1:100,000 or more. This information was created by digitizing line segments from topographic maps. The USGS has higher resolution and more detailed transportation maps for the United States, but they are not available for public download. The higher resolution data are currently used extensively by the Federal Highway Administration and the Census Bureau.

3.4.1.2 Land cover

The National Land Cover Data (NLCD) is a 21-category land cover classification scheme used across the country and in many parts of the world. The NLCD classification is provided as a raster data file with a spatial resolution of approximately 30 meters or 1 arc-second. Each land cover classification reflects electromagnetic energy differently and software is able to decipher the Landsat Thematic Mapper images and classify the surface. The designation of each unit of resolution is determined by the land use category with the highest percentage of area within the unit. Thirty meter resolution means that many features in the landscape cannot be resolved. Impervious areas are important in watersheds, yet many impervious areas are not accounted for because the road may not be the land use classification with the highest percentage of area within each unit of resolution.

3.4.1.3 Elevation

The National Elevation Dataset (NED) 1/3 arc-second layer is a digital elevation model with resolution of 1/3 arc-second, or around 10m. These data are currently available online for approximately 25% of the continental United States. The USGS plans to have files for the entire country available by 2008. One arc-second (approximately 30m) resolution data are currently available for the United States and Puerto Rico.

3.4.1.4 Sub-basin delineation, stream networks and waterbodies

The USGS devised a system called the hydrologic unit system, which divides and subdivides the continental United States into four nested levels of units. The largest units are called regions and represent either the drainage area of a major river or the combined drainage areas of a series of rivers ultimately draining to the same location. The successively smaller units within each region are sub-regions, accounting units, and cataloging units. Cataloging units are also known as watersheds. The unit of the basin is identified by the number of digits in the unit number. Regions have the fewest digits, and each successive unit has one additional digit. The watershed level delineation can be used to cross check basin boundaries calculated using algorithms based on digital elevation models.

Water features include streams and rivers, canals, aqueducts, lakes, reservoirs, marshes, glaciers, bays, oceans, waterfalls, dams and designated channels. The high-resolution stream networks and waterbodies layers are derived from revised Digital Line Graph (DLG) data. The source data for the DLGs is published 1:24,000-scale USGS quadrangle maps. Most of the layers have been in the current form since 2001.

3.4.1.5 Significant water-related points

The National Hydrography Database (NHD) points layer includes locations of hydraulic structures, water-related facilities or sampling locations. The locations of streamgages are shown on this layer, which can be used for verifying the USGS streamgage coordinates.

3.4.2 Datasets from the NRCS

The National Resource Conservation Service (NRCS) maintains two soil geographic databases useful at the watershed level including the Soil Survey Geographic (SSURGO) database and the State Soil Geographic (STATSGO) database. The SSURGO database provides the most comprehensive information publicly available and was designed primarily for natural resource planning and management by farmers, ranchers, landowners and local governments. This dataset is especially useful for determining areas at risk for soil erosion, reviewing contractor site development proposals, and choosing appropriate zoning classifications. The STATSGO database was designed primarily for resource planning, management and monitoring of regional, river basin, and multi-county areas. SSURGO datasets are available for download at http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/. STATSGO datasets are available at http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html.

3.4.2.1 Soil Survey Geographic (SSURGO) database

The SSURGO database contains the most detailed soil information publicly available. The information is derived from soil survey maps and the layers are digitized from mapping scales of 1:12,000 to 1:63,360. Examples of information that can be queried from a database management program such as Microsoft Access include available soil water capacity, hydrologic soil group, soil reaction, electric conductivity, land use, detailed soil classifications and flood plain delineation. The SSURGO database is currently available for about ¼ of the continental United States. Only a small portion of the Midwest included available SSURGO information, so this resource was not used in this study. However, in future research, the higher resolution data is better suited for this type of investigation. The goal of the NRCS is to have the information for the entire country available by 2008.

3.4.2.2 State Soil Geographic (STATSGO) database

The STATSGO dataset is produced from the same soil surveys as the Soil Survey Geographic (SSURGO) dataset, but it is simplified to provide a tool for broad planning and management purposes. There are 21 components in the STATSGO dataset that can be displayed in a GIS. The NRCS provides downloads directly from the Internet by state and the files are relatively small in comparison with the SSURGO files.

3.4.3 Putting the datasets together

A Geographical Information System (GIS) was used to gather and organize the watershed information for the selected sites. The advantage of using a GIS is that it allows for consistent, objective methods in estimating watershed variables and model parameters (e.g., Zhan and Huang, 2004). Soil information from the State Soil Geographic (STATSGO) database was used to determine the hydrologic soil group for the selected sites. Land use/land cover data layers were obtained from the National Land Use Dataset (NLCD). The stream network (e.g., blue lines on USGS quad maps) were determined using the National Hydrography Dataset (NHD). Slope information was obtained through the analysis of the National Elevation Database (NED) for selected basins, which contains 1/3 arc-second (10 m resolution) and 1 arc-second (30m resolution) digital elevation data. USGS quad maps were used to determine the boundaries of the watersheds and the longest flow path. The disadvantage of this approach was that it was more subjective than automated approaches (e.g., Djokic and Maidment, 1993). However, without the 1/3 arc-second resolution data for the majority of the sites, the watershed delineation could not be automated. The USGS plans to have the 10m resolution NEDs available for the Midwest by 2008, in which case watershed delineation without quad maps would be justifiable.

After collecting the data, the layers are superimposed upon one another for analysis. Figure 3.3 demonstrates how the layers are stacked. The layers from bottom to top are land use, hydrologic soil group, 10m National Elevation Dataset (NED), stream reaches, and the green dot represents the streamgage.

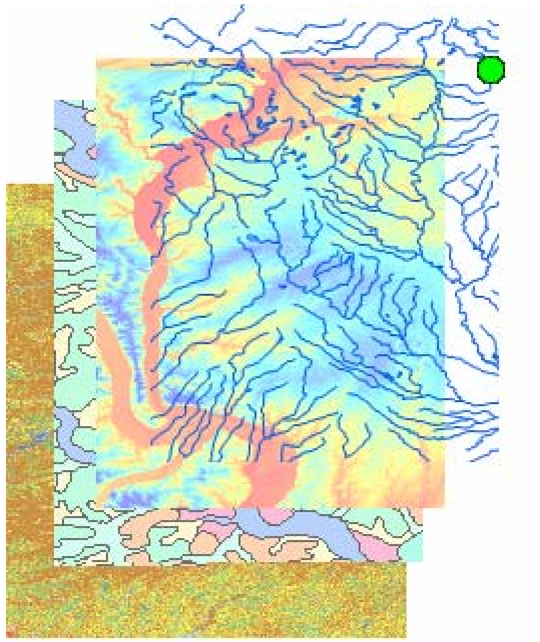

Figure 3.3: Superimposed layers in a GIS. From bottom to top: land use, hydrologic soil group, digital elevation model, stream reaches, streamgage (circle).

Figure 3.4 includes figures to demonstrate the step-by-step process for using the GIS to provide the parameters necessary for the flood frequency estimations using the design methods. Each step in Figure 3.4 is discussed below.

- Verify the location of the streamgage on the USGS 1:24,000 topographic map, in this case it is close, but not exact.
- Delineate the basin using the topographic map
- Trace out the longest travel distance the water will follow
- Ensure that roads or streams are consistent with the delineation and topographical map
- Use the NED to get the average slope and check for delineation consistency
- Import the land use land cover information
- Create polygons of land cover types to get the correct proportions
- Display the hydrologic soil group and create polygons as in part g
- Display the hydrologic soil group and create polygons as in part g

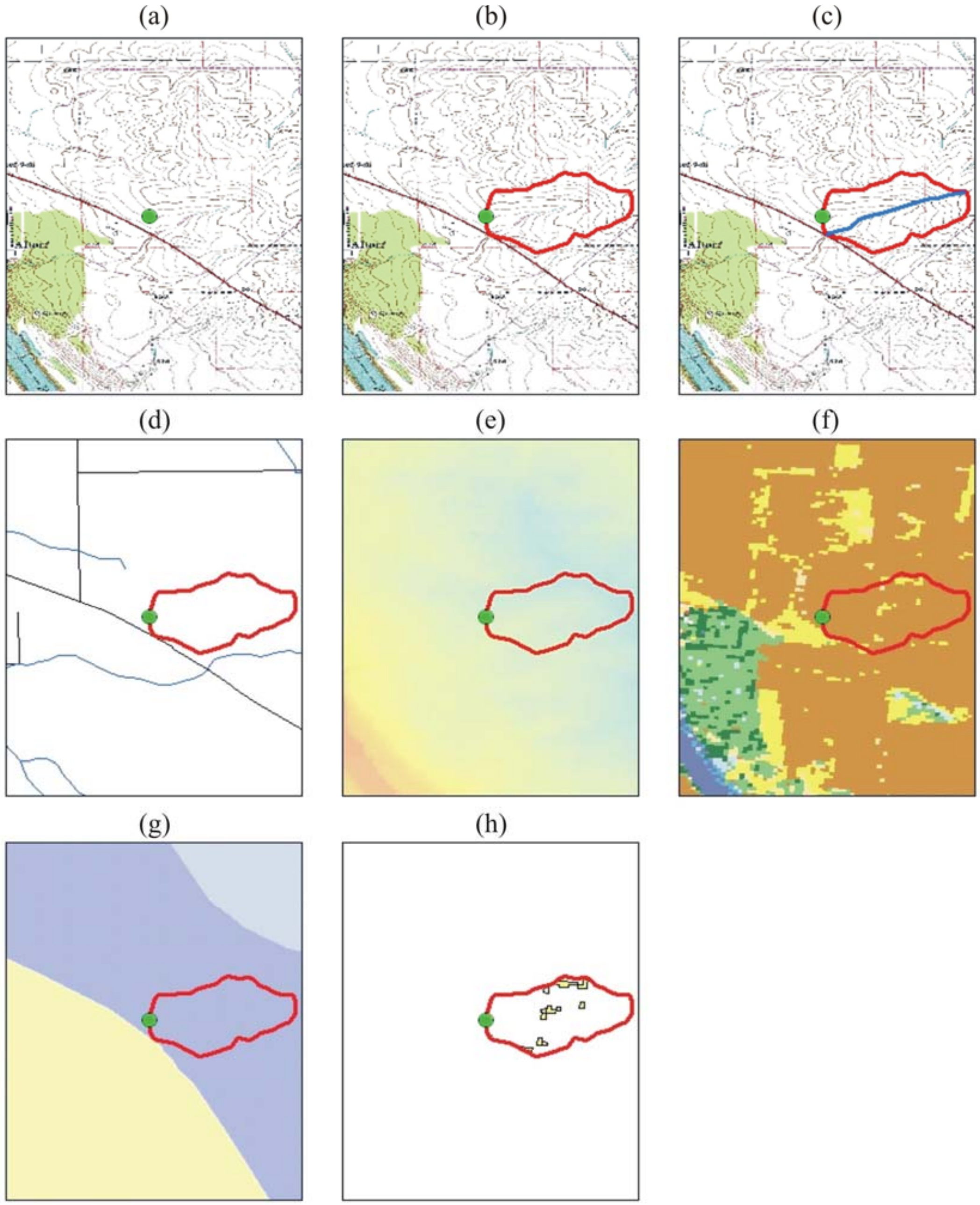

Figure 3.4: Steps for assembling the GIS for analysis

The next step is to intersect the layers and to calculate the time of concentration, t_c, the relative areas of land use and hydrologic soil group, which are necessary for determining the curve number and runoff coefficient. This information is then coupled with charts of rainfall precipitation depths to produce the necessary parameters for estimating peak discharge for the design methods.

3.5 Rainfall frequencies for selected sites

The Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992) was used to define rainfall depths for various return periods for most Midwest locations. Rainfall frequency information for other Midwest sites and Urban sites were obtained from NOAA Technical Paper 40 (TP 40) (Hershfield, 1961), NOAA Technical Paper 49 (TP 49) (Miller, 1964), and NOAA Technical Memorandum NWS HYDRO- 35 (Federick et al., 1977), or more recent updated information in NOAA Atlas 14 (Bonnin et al., 2004a; Bonnin et al., 2004b).

3.6 Estimate flood frequencies based on the Rational Method

Following the methods outlined in the Iowa Statewide Urban Design and Specifications manual (SUDAS, 2004), flood frequencies were estimated for the selected sites using the Rational Method. Estimates were made for the 2, 5, 10, 25, 50, and 100-year return periods. The Rational Method is generally accepted as applicable in small watersheds (hundreds of acres or less), although the recommended upper limit depends on the reference. For instance, the SUDAS manual recommends 160 acres as the upper limit for applications. In this analysis, basin size was restricted to an upper bound of 200 acres to increase the available sample size.

3.7 Estimate flood frequencies based on the NRCS method

Following the method outlined in Technical Release 55 (TR-55), published by the Soil Conservation Service (1986), flood frequencies were estimated for the selected sites using NRCS procedures. Estimates were made for the 2, 5, 10, 25, 50, and 100-year return periods. The SUDAS manual (2004) recommends 2000 acres as the upper limit for TR-55 methods. TR-55 methods are applicable in small drainage areas as well, so this analysis included the same set of sites used in the Rational Method analysis for comparison of the two methods. NRCS curve number procedures were used for runoff calculations and the NRCS unit hydrograph (time lag approach) was used for flow routing to the basin outlet.

3.8 Estimate flood frequencies based on the Iowa Runoff Chart method

The Iowa Runoff Chart (IRC) estimates flood frequencies using inputs of drainage area, land use, slope and return period. Land use and slope are grouped together to create a Land Use and Slope Description (*LF*) factor. The return period is used in the determinization of the Frequency (*FF*) factor. The drainage area is converted to a volume of water that is scaled by *FF* and *LF* to provide the design peak discharge for the given return period. The charts and equations necessary for this transformation are shown and discussed in section 2.3.

3.9 Comparison of the flood frequency estimates

For each site, a comparison was made between the flood frequency estimates based on the streamgage data and estimates made using the Rational Method, the NRCS curve number approach and the Iowa Runoff Chart method. The comparisons provided the information necessary to quantify the uncertainty in the design flood frequency techniques. There is also uncertainty in the estimates from the streamgage records, which was accounted for by the contribution of sampling uncertainty (a function of gage record length) in the comparison. In addition to uncertainty, biases were quantified and systematic errors (under- or over-estimation) noted. The results of these comparisons are described in Section 4.

4. RESULTS

Comparisons of the flood frequency estimates based on the streamgage data, and estimates based on the Rational Method, NCRS runoff coefficient method, and Iowa Runoff Chart were made. Exploratory data analyses were carried out in order to seek a better understanding of the discrepancies between the methods and to suggest alternatives for improved design flood frequency estimates. Specific recommendations for application of the approaches and suggestions for improving design techniques in Iowa are outlined in this Section.

4.1 Watershed Characteristics for Sites

Design flood frequency methods use watershed information to estimate model parameters. For the NRCS runoff method, runoff curve numbers are estimated using soil (hydrologic soil group), slope, and land use/land cover information. Similar information is also used to estimate the runoff coefficient for the Rational Method, as outlined in the Iowa Statewide Urban Design and Specifications (SUDAS) manual. In addition, both methods require topographic and stream network information to estimate travel time parameters (e.g., time of concentration). Table 4.1 shows some sample watershed characteristics determined using functions within the GIS for the Midwest sites. Similar information for the Urban sites is shown in Table 4.2.

Figure 4.1 shows the primary hydrologic soil group for Midwest and Urban sites. The distribution is similar for both groups. Soil B is the most common hydrologic soil group. Soil C and D account for most of the remainder of the soils. Soil A, B/C, and B/D are comparatively rare.

Table 4.1: Watershed characteristics for Midwest sites.

USGS Site	HSG	Primary Land Use	Slope (%)	CN	C 100-yr	t_c (hr)	Area (acres)
3341900	B	Pasture	0.77	72.3	0.203	1.01	26
3344250	C	Row Crops	0.30	83.8	0.214	1.88	51
3380300	C	Row Crops	1.37	81.0	0.229	0.83	51
3612200	C	Deciduous Forest	2.71	76.2	0.274	1.28	173
4024110	D	Deciduous Forest	0.89	81.9	0.198	1.53	128
5116100	B/D	Grasslands	3.58	79.7	0.391	0.91	83
5270310	B	Row Crops	2.24	74.1	0.282	1.14	154
5320200	B	Row Crops	0.97	77.4	0.165	1.16	45
5355230	B	Row Crops	0.44	76.0	0.179	1.51	32
5373350	B	Row Crops	2.11	77.2	0.209	0.96	102
5384150	B	Row Crops	4.50	74.5	0.252	0.63	51
5384300	B	Row Crops	1.02	77.7	0.248	1.10	90
5388460	B	Pasture	4.49	66.0	0.261	1.36	192
5440900	B	Row Crops	2.89	77.0	0.217	1.06	96
5448050	B	Row Crops	1.04	76.0	0.164	1.93	141
5469750	B	Row Crops	0.62	76.6	0.167	2.91	166
5526150	B/D	Row Crops	1.30	83.1	0.206	1.10	122
5549900	B	Developed/Low Intensity	1.27	80.2	0.271	1.13	45
5555400	C	Row Crops	0.71	84.0	0.217	1.61	90
5558050	B	Pasture	3.21	71.9	0.283	0.57	19
5558075	B	Pasture	2.74	70.1	0.286	1.54	141
5563100	D	Pasture	1.04	86.4	0.307	0.97	45
5572100	B	Row Crops	0.32	77.7	0.191	2.05	64
5585700	B	Row Crops	0.91	77.3	0.217	1.24	96
5586850	B	Pasture	2.27	69.3	0.287	0.59	13
5592025	B/C	Row Crops	1.28	75.4	0.172	2.02	128
5592700	D	Row Crops	0.36	87.6	0.276	1.60	90
6358520	D	Grasslands	1.86	84.0	0.370	1.24	192
6396300	D	Grasslands	4.32	83.4	0.468	0.54	58
6470200	C	Row Crops	0.96	84.7	0.198	1.27	122
6471450	D	Pasture	0.56	84.8	0.374	2.19	166
6482960	B	Row Crops	1.54	76.8	0.170	1.46	122
6483200	B	Row Crops	1.42	78.0	0.191	1.30	90
6899600	C	Pasture	1.02	80.2	0.305	1.77	134
6901300	C	Pasture	3.11	81.1	0.451	0.75	83
6909400	C	Pasture	2.00	81.4	0.230	1.18	192
6910700	B	Pasture	3.25	69.2	0.308	0.84	83
6918200	D	Pasture	1.61	85.9	0.302	0.72	51
6919200	D	Pasture	1.93	84.2	0.361	0.93	90
6921400	B	Deciduous Forest	2.05	63.1	0.168	1.71	115
6922600	B	Pasture	2.80	67.6	0.314	1.32	115
6933700	C	Deciduous Forest	3.92	73.2	0.166	1.24	173
6934750	C	Deciduous Forest	4.26	75.2	0.253	0.95	160
7015500	C	Pasture	0.92	77.7	0.248	1.47	141
7054300	C	Pasture	5.59	78.6	0.402	0.66	147
7147020	D	Grasslands	1.29	85.0	0.343	1.17	109

Table 4.2: Watershed characteristics for Urban sites.

USGS Site	HSG	Primary Land Use	Slope (%)	CN	C 100-yr	t_c (hr)	Area (acres)
1463812	C	Developed/Low Intensity	0.95	84.8	0.372	1.53	173
1585225	D	Developed/Low Intensity	2.68	90.7	0.533	0.61	135
2204135	B	Pasture	2.87	67.1	0.280	1.30	179
2206105	B	Developed/Low Intensity	2.42	76.5	0.388	0.97	115
2206165	B	Developed/Low Intensity	4.48	78.1	0.342	0.50	64
2206465	B	Developed/Open Space	3.34	77.3	0.449	0.83	128
2245573	C	Evergreen Forest	0.99	76.5	0.227	1.29	103
2245606	A	Developed/Open Space	1.41	68.3	0.290	1.60	134
2298928	B	Woody Wetlands	0.56	92.1	0.805	0.72	128
2320978	D	Grasslands	0.24	85.1	0.392	2.77	198
2321506	D	Pasture	1.01	84.1	0.334	1.19	141
2335347	B	Developed/Low Intensity	3.11	82.4	0.456	0.83	122
2365408	A	Evergreen Forest	1.59	48.0	0.200	1.75	51
2411902	B	Deciduous Forest	3.17	67.2	0.228	0.94	77
3612200	C	Deciduous Forest	2.71	76.2	0.274	1.28	173
5549900	B	Developed/Low Intensity	1.27	80.2	0.271	1.13	45
5585700	B	Row Crops	0.91	77.3	0.217	1.24	96
7260679	B	Evergreen Forest	2.54	74.2	0.278	0.67	58
7364550	C	Developed/Low Intensity	3.91	82.4	0.343	0.39	45
7373550	B	Pasture	1.25	71.3	0.219	1.62	134
8329880	B	Developed/Low Intensity	2.29	87.5	0.578	1.03	77

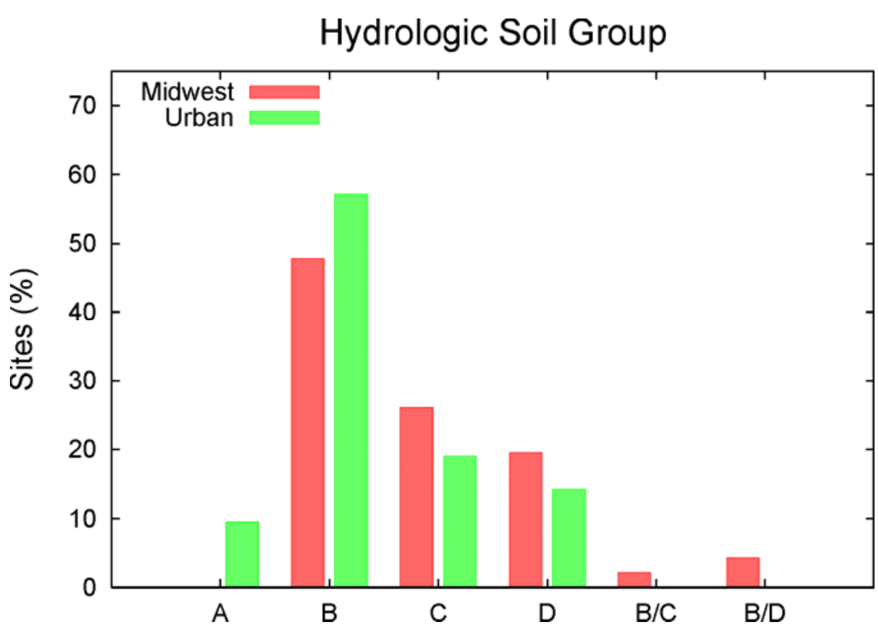

Figure 4.1: Primary hydrologic soil group category for Midwest and Urban sites.

Figure 4.2 shows the primary land use for the Midwest and Urban sites. For the Midwest group, agricultural categories are the dominate land use. For the Urban group, developed land use categories dominate, although some sites have forest or agricultural land use as their primary category.

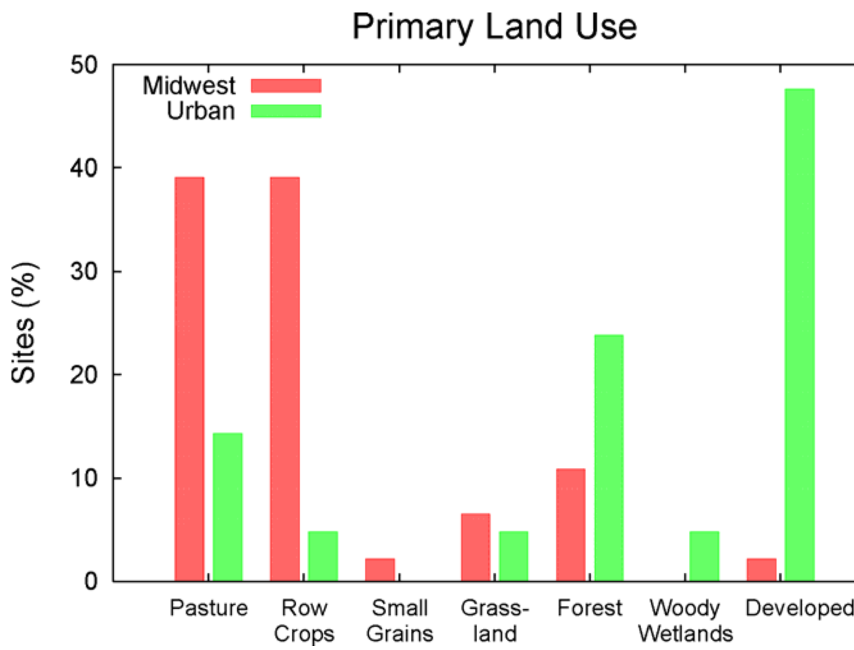

Figure 4.2: Primary land use category for Midwest and Urban sites.

Figure 4.3 shows the average watershed slope along the flow path from the hydraulically furthest point to the streamgage. The average slopes are generally mild (less than 2%). Higher slopes in the 2-4% range are more common for the Urban sites, which has a majority of basins outside the Midwest.

Figure 4.4 shows the composite NRCS curve numbers; the higher the curve number, the greater the amount of runoff. For the Midwest group, the composite curve number range from 63 to 88, with a peak between 76 and 80. The distribution for the Urban group is similar. The peak is also between 76 and 80, but the range wider, extending up to a curve number of 92.

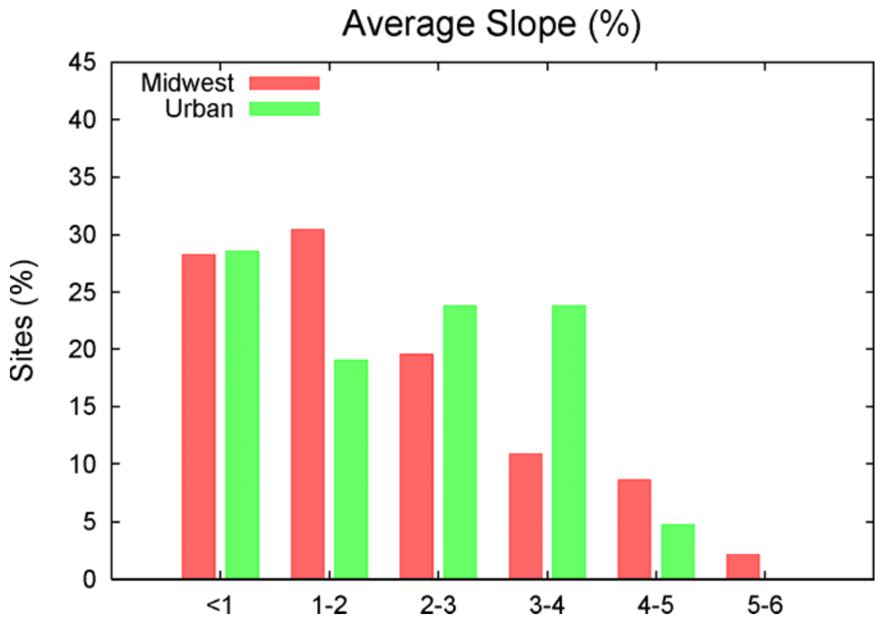

Figure 4.3: Distribution of the watershed average slope (in %) for Midwest and Urban sites.

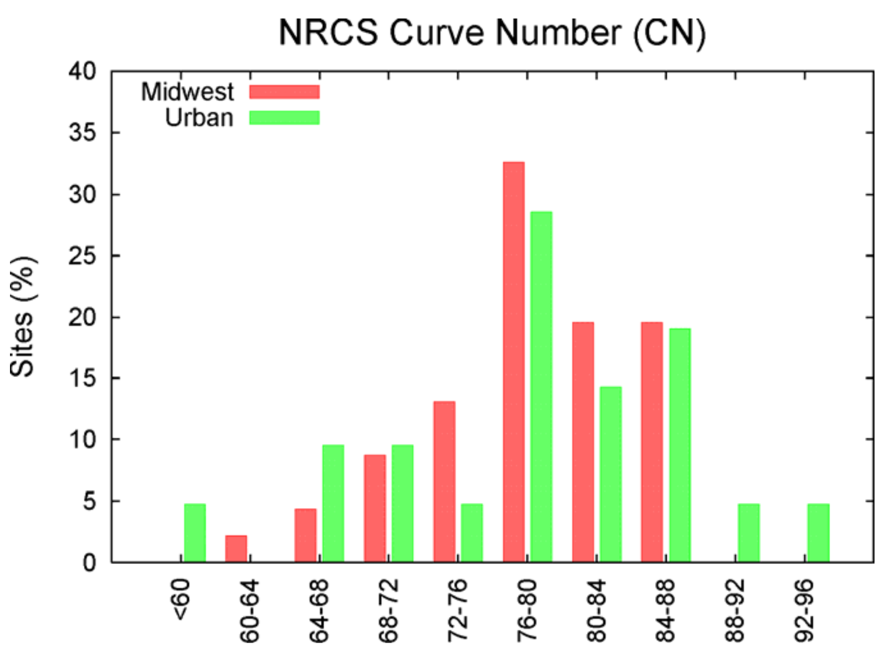

Figure 4.4: Distribution of the NRCS runoff curve number for Midwest and Urban sites.

Figure 4.5 shows the Rational Method runoff coefficients for return periods of 25 to 100 years. For the Midwest group, the runoff coefficients range from 0.16 to 0.47, with the majority less than 0.30. The distribution for the Urban group is shifted to higher values; the coefficients range from about 0.20 to 0.81.

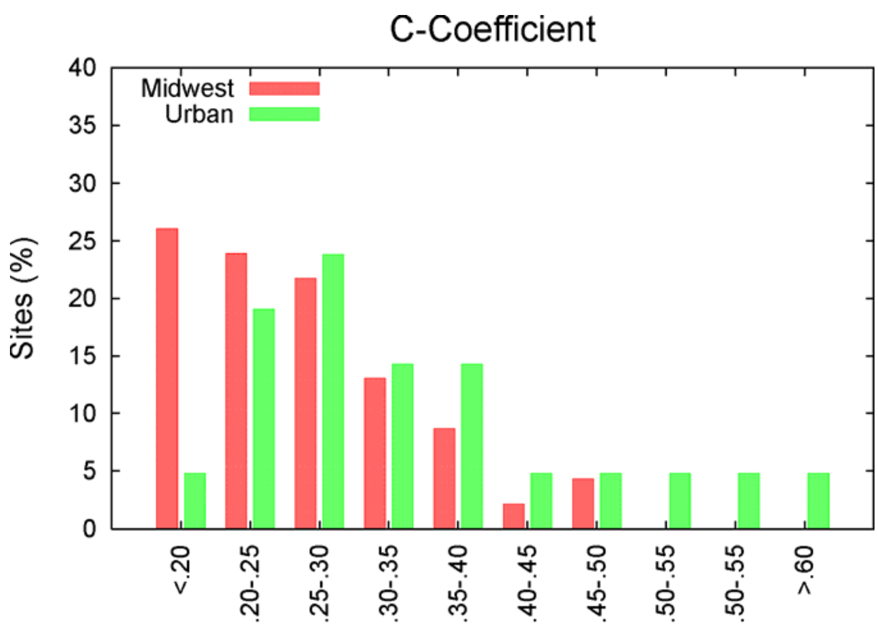

Figure 4.5: Distribution of the Rational Method runoff coefficient for Midwest and Urban sites.

Figure 4.6 shows the time of concentration for the sites. The distribution is similar for both the Midwest and Urban groups. About 70 to 75% of the sites have a time of concentration of less than 1.5 hours. The average time of concentration for the Urban group (1.15 hours) is slightly less than that for the Midwest group (1.27 hours). In this study, the time of concentration was calculated using the SCS lag equation (SCS, 1986) and the sensitivity was not evaluated. This is one parameter that should be explored in greater depth in a future study to better understand the sensitivity of the timing.

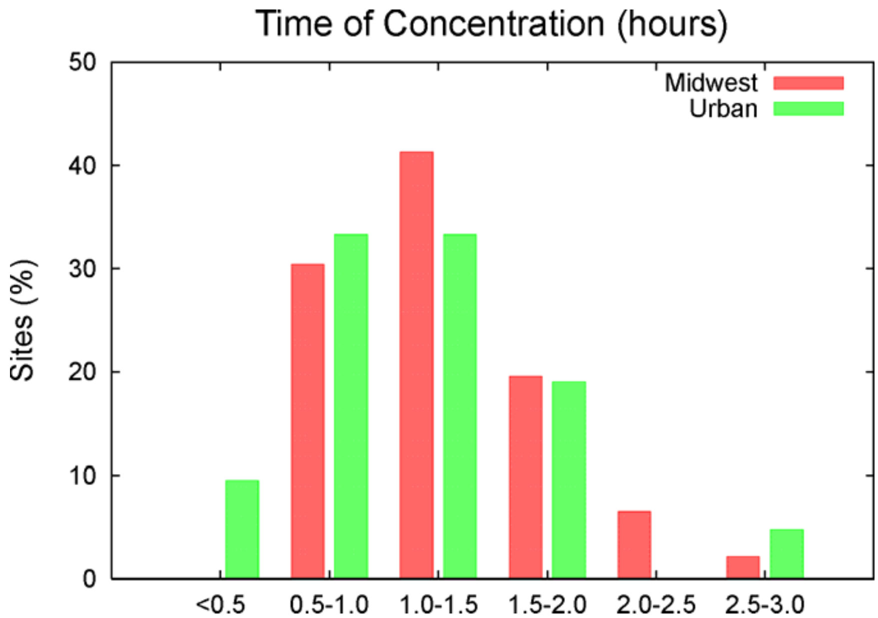

Figure 4.6: Distribution of the time of concentration (in hours) for Midwest and Urban sites.

4.2 Comparisons of the Design Approaches

For the Midwest region, the two design methods and the Iowa Runoff chart systematically underestimate flood frequencies compared to the flood frequency based on the streamgage data. Figure 4.7 shows the average flood frequency estimate per unit area (in/hr) of the three approaches for all 46 sites, as well as the estimates based on the streamgage data. On average, an unbiased estimator would equal the average estimate based on the streamgage data. The Rational Method is the poorest estimator. The Iowa Runoff chart is somewhat less biased. The estimates based on the NRCS curve number are unbiased for the 2-year return period, but estimates at higher return periods are less than streamgage flood frequencies. Overall, the NRCS curve number methods is the least biased. On average, all three methods systematically underestimate flood frequencies for nearly all return intervals.

For the Urban sites, the Rational Method flood frequency estimates are again systematically less than those based on the streamgage data (see Figure 4.8). However, the magnitude of the bias for Urban sites is less than for the agricultural-dominated land uses in the Midwest region. The NRCS estimates are slightly higher than those based on streamgage data, except at the 100-year return period. Overall, the NRCS method is again less biased than the Rational Method. Since the Urban sites generally outside the Midwest region, the Iowa Runoff Chart method was not applied for comparison.

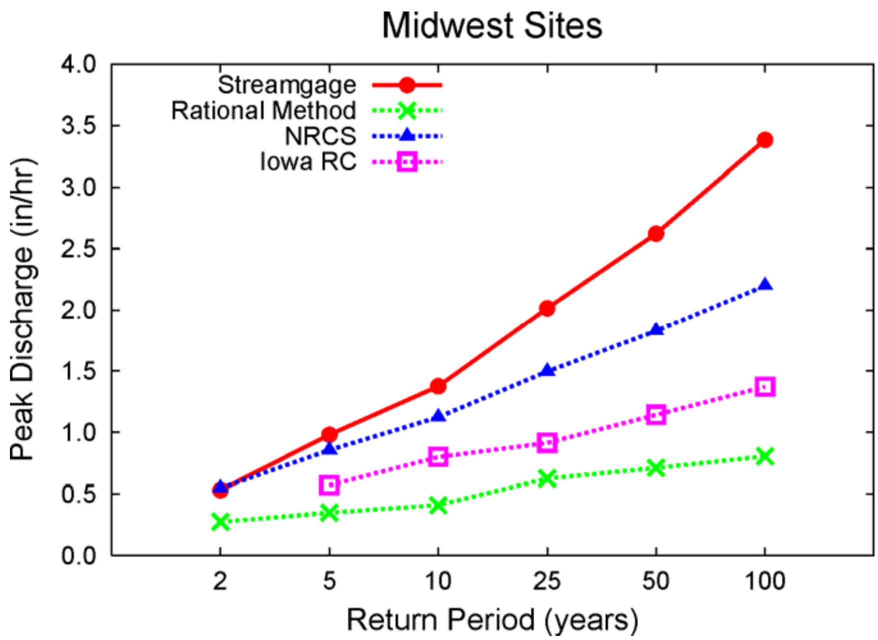

Figure 4.7: Average flood frequency estimates for the 46 Midwest sites based on streamgage data, the Rational Method, the NRCS curve number method, and the Iowa Runoff Chart. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

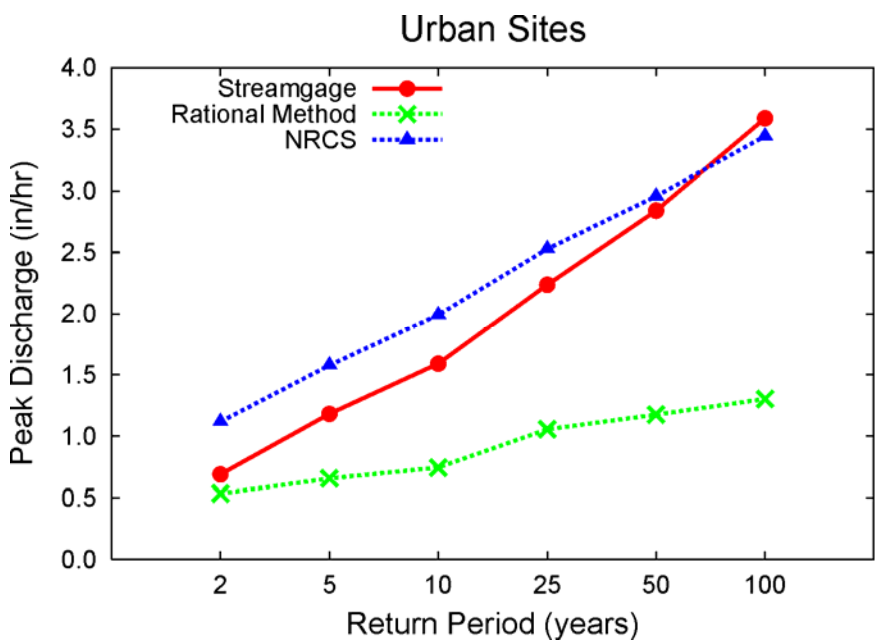

Figure 4.8: Average flood frequency estimates for the 21 Urban sites based on streamgage data, the Rational Method, the NRCS curve number method, and the Iowa Runoff Chart. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

The range of variability of the estimates is shown for the Midwest sites in Figure 4.9. Results are shown for the 10-year return period estimates, but the overall results are similar for all return periods. The spread is the largest for the estimates based on the streamgage data; this makes sense because the design methods do not exhibit the sampling uncertainty that exists with short flood records from a streamgage. While the range for the NRCS method falls within that for the streamgage estimates, the underestimation biases of the Rational Method and (less so) the Iowa Runoff Chart are obvious.

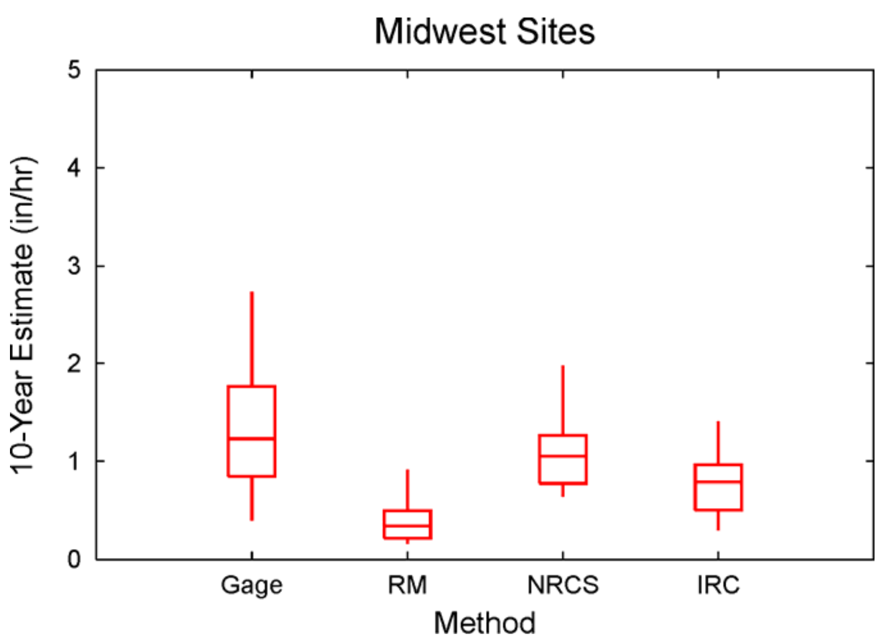

Figure 4.9: Range of 10-year return period flood frequency estimates for the 46 Midwest sites based on streamgage data, the Rational Method, the NRCS curve number method, and the Iowa Runoff Chart. The peak discharge per unit area (in/hr) is shown to facilitate comparison. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

The range of variability of the estimates for the Urban sites is shown in Figure 4.10. Compared with the Midwest sites, the range of 10-year estimates is much larger for the Urban sites. This is to be expected, as urban development produces greater runoff amounts. Although the overall range of variability is largest for the streamgage estimates, the boxes containing 50% of the results is slightly larger for the NRCS method. The estimates for the NRCS show its overestimation bias and large sensitivity, while those for the Rational Method show its underestimation bias and small sensitivity.

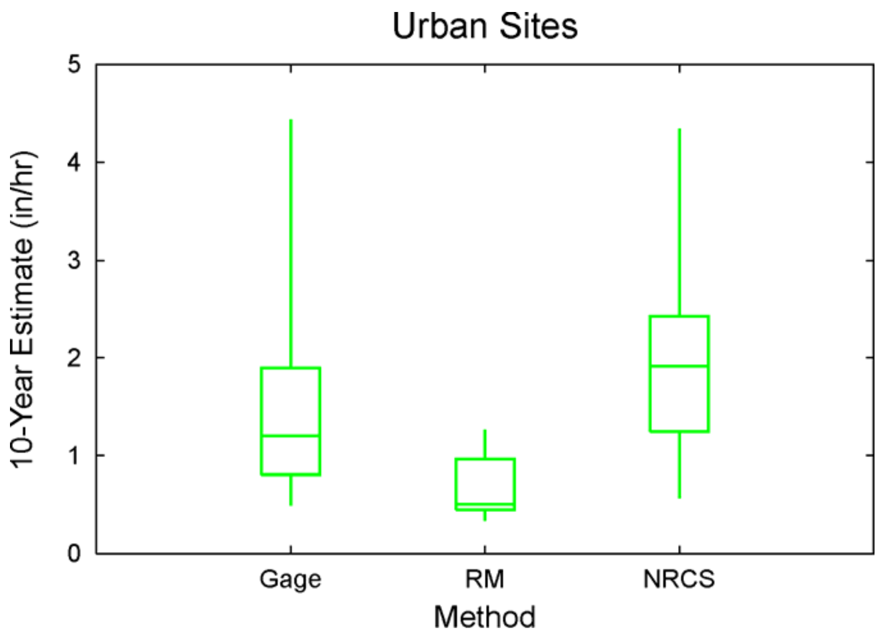

Figure 4.10: Range of 10-year return period flood frequency estimates for the 21 Urban sites based on streamgage data, the Rational Method, and the NRCS curve number method. The peak discharge per unit area (in/hr) is shown to facilitate comparison. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

Although the design methods underestimate the peak discharge on average for each of the return intervals, the estimates for individual sites exhibit a large amount of scatter. Figure 4.11 compares the 10-year return period estimates for the Rational Method with those from the streamgage. If the design method estimates are the same as the gage estimates, points fall on the 1:1 line. Points above the line represent overestimation by the design method, and points below the line are underestimates. Clearly, the Rational Method systematically underestimates the 10-year return period peak discharge; nearly all the points fall below the 1:1 line. The correlation between the estimates is higher for the Urban sites (0.66) than for the Midwest sites (0.40).

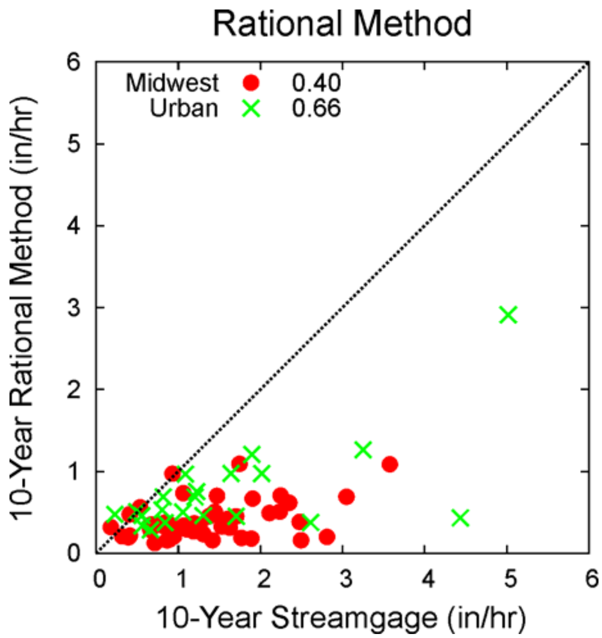

Figure 4.11: Estimates of the 10-year return period peak discharge based on the Rational Method and streamgage data for the 46 Midwest sites and the 21 Urban sites. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

Figure 4.12 compares the 10-year return period estimates for the NRCS runoff curve number methods with those from the streamgage. The points are distributed both above and below the 1:1 line. For the Midwest sites, the deviations below the 1:1 are greater than those above the line, resulting in a slight underestimation bias (see Figure 4.7). The opposite is true for the Urban sites, resulting in an overestimation bias (see Figure 4.8). The correlation between the estimates is higher for the Urban sites (0.62) than for the Midwest sites (0.42).

Figure 4.13 compares the 10-year return period estimates for the Iowa Runoff Chart with those from the streamgage for the Midwest sites. Points are distributed both above and below the 1:1 line, with large deviations below the line (underestimates) for the large peak discharge, resulting in an overall underestimation biases (see Figure 4.7). The correlation for with the streamgage estimates for the Iowa Runoff Chart (0.32) is lower than for the NRCS (0.38) and Rational Method (0.40) for the Midwest sites.

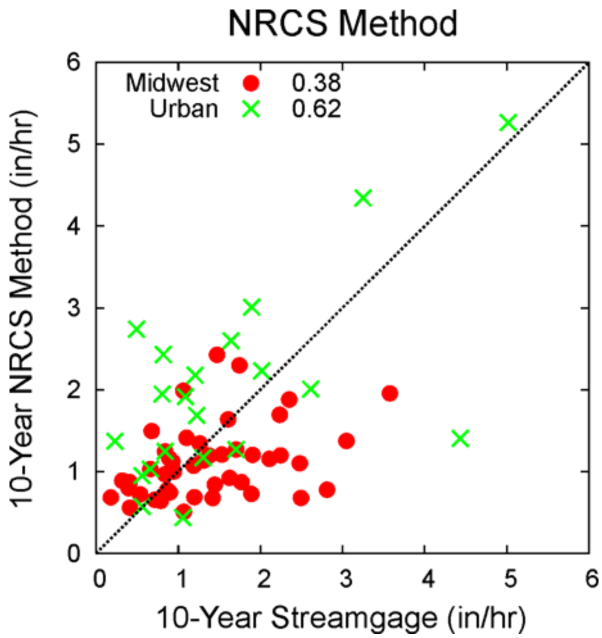

Figure 4.12: Estimates of the 10-year return period peak discharge based on the NRCS runoff curve number method and streamgage data for the 46 Midwest sites and the 21 Urban sites. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

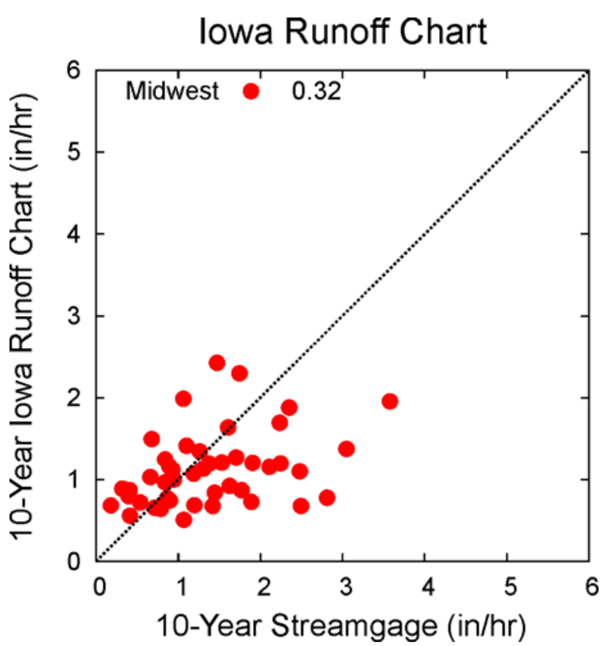

Figure 4.13: Estimates of the 10-year return period peak discharge based on the Iowa Runoff Chart and streamgage data for the 46 Midwest sites. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

In the following sections, the sensitivity of the flood frequency estimates to watershed characteristics is explored. Comparisons were made for all return periods; however, discussion is limited to the 10-year return period, as it adequate summarizes the sensitivity observed.

4.2.1 Comparison by drainage area

The differences between the 10-year return period estimates by the Rational Method, and those based on the streamgage data, are shown versus the basin drainage area in Figure 4.14. The differences do not appear to be strongly related to the drainage area, although the largest deviations are observed for drainage areas nearer the 200 acres upper limit.

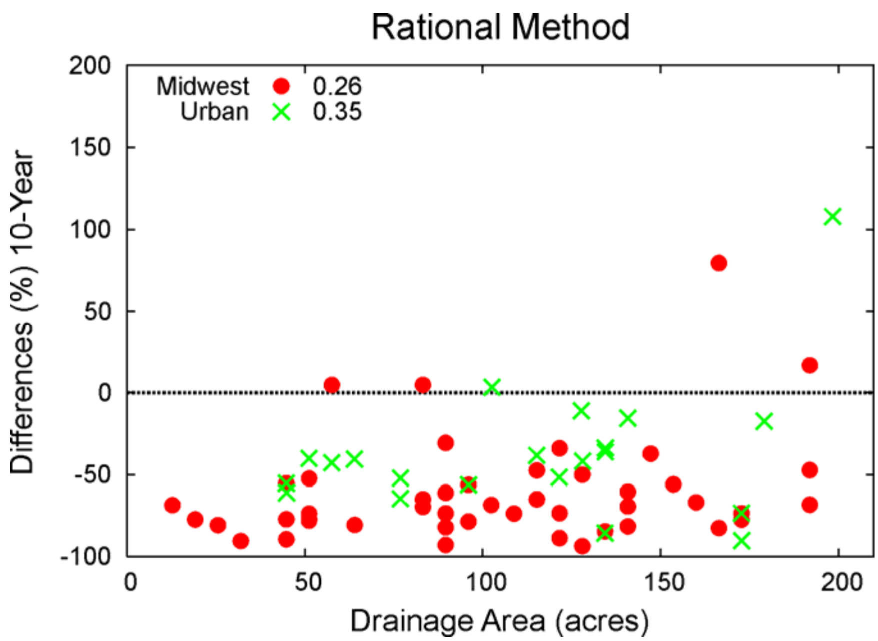

Figure 4.14: Differences (%) in estimates of the 10-year return period peak discharge based on the Rational Method and streamgage data for the 46 Midwest sites and 21 Urban sites versus basin drainage area (acres). The correlation between the differences and drainage area are shown in the legend.

The differences for the NRCS method are shown in Figure 4.15. Again, the differences do not appear to be strongly related to drainage area, but again, the larger deviations occur at larger drainage areas. Also, for the NRCS method, some very large positive differences are observed, with some approaching a 500% overestimation. Note that the differences are bounded below by -100% for underestimation, but unbounded above for overestimation; since the NRCS is less biased that the Rational Method, the large percentage differences do occur with overestimation. For the Urban sites, the two largest differences (both above 400%) are for nearby locations in northeastern Florida. But sites have relatively high runoff potential, with hydrologic soil groups of type C and D, and relatively low levels of urban development (less than 20%). Therefore, sites may be less representative of Urban sites than other locations.

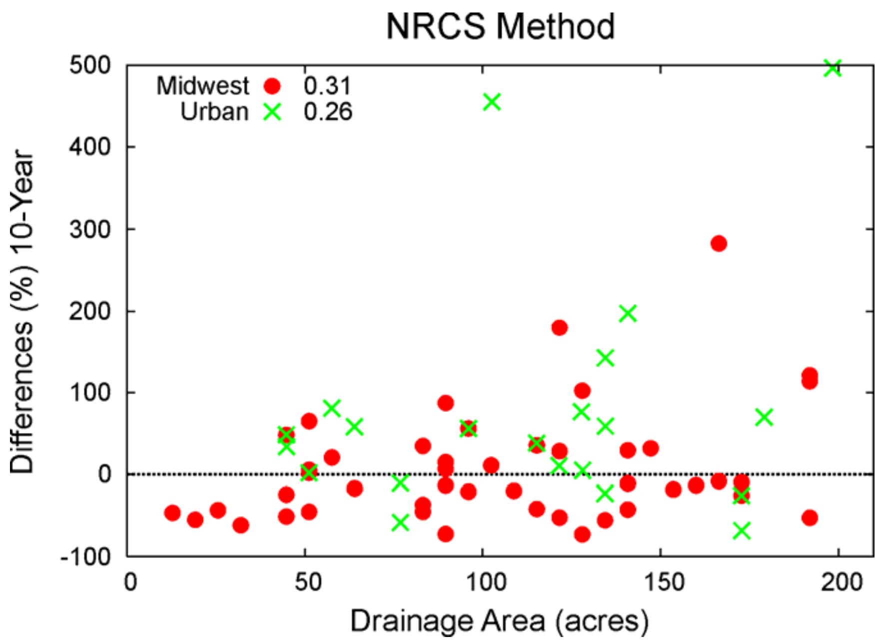

Figure 4.15: Differences (%) in estimates of the 10-year return period peak discharge based on the NRCS method and streamgage data for the 46 Midwest sites and 21 Urban sites versus basin drainage area (acres). The correlation between the differences and drainage area are shown in the legend.

The differences for the Iowa Runoff Chart are shown for the Midwest sites in Figure 4.16. Compared to the other methods, the differences for the Iowa Runoff Chart are the least related to the drainage area (correlation of 0.11). One reason appears may be that the Iowa Runoff Chart uses only the slope and land use/cover information, and not the soil type, to characterize the watershed.

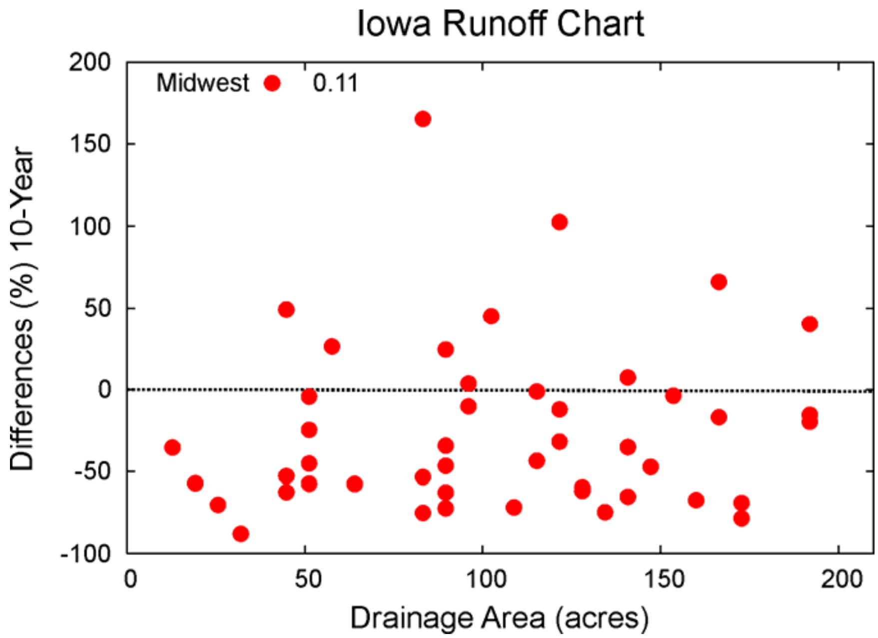

Figure 4.16: Differences (%) in estimates of the 10-year return period peak discharge based on the Iowa Runoff Chart and streamgage data for the 46 Midwest sites versus basin drainage area (acres). The correlation between the differences and drainage area are shown in the legend.

4.2.2 Comparison by hydrologic soil group

The sensitivity of the estimates to the hydrologic soil group is shown for the Rational Method in Figure 4.17. The figure shows the range of the differences (in %) between the Rational Method and streamgage estimates of the 10-year return period peak discharge; deviations for individual hydrologic soil group from the results for all the sites is an indication of the sensitivity. For both the Midwest and Urban sites, the differences for soil group D are the most sensitive; the range of differences is larger than for all sites. Furthermore, the estimates are systematically higher. For the Rational Method, this means that the estimates are the least biased for soil group D, though the tendency still remains to underestimate 10-year return period peak discharges.

The sensitivity of the estimates to the hydrologic soil group is shown for the NRCS Method in Figure 4.18. For the Midwest sites, there is a clear transition from underestimation for sites with soil group B (low runoff potential), to overestimation for soil group D (highest runoff potential). For the Urban sites, the range of variation is higher for soil group C and D, but an overestimation bias is only apparent for soil group

D. These trends indicate that the sensitivity of estimates to soil group is greater than observed by the streamgage data. This outcome may suggest that the soil group identification of runoff potential is not as good a predictor as one might hope; the distinction is important for the NRCS (and Rational Method) parameters, but leads to systematic differences with streamgage estimates.

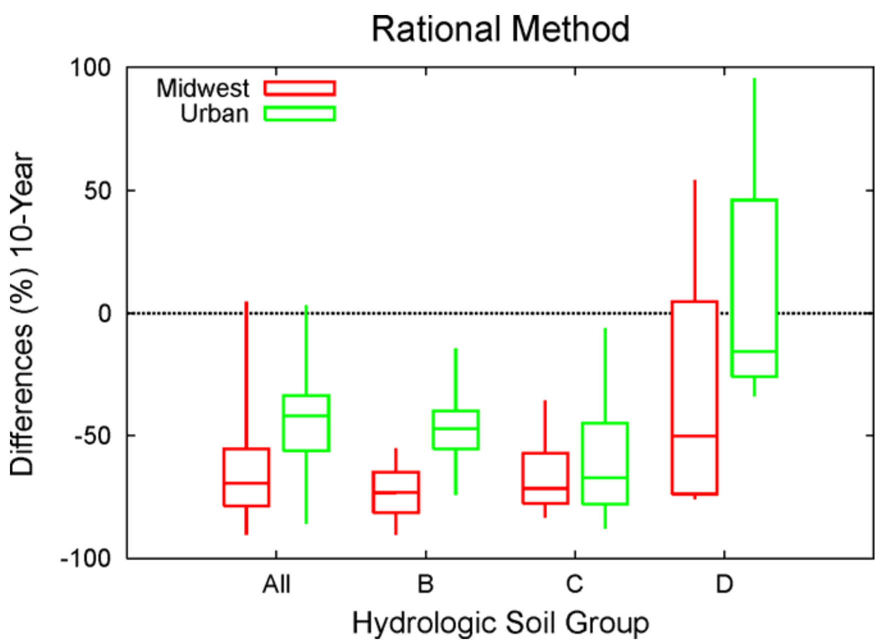

Figure 4.17: Range of 10-year return period flood frequency estimates for the Rational Method by hydrologic soil group. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites and the 21 Urban sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

This conclusion is confirmed somewhat based on the sensitivity to hydrologic soil group for the Iowa Runoff Chart, shown in Figure 4.19. This method does not utilize hydrologic soil group for estimation, and the differences show smaller deviations by soil group than the Rational Method and NRCS method. The tendency is for soil group C and D slightly greater underestimation differences than soil group B, as one might expect based on their runoff potential, but the significance of making the soil group distinction is not as great as implied the other two methods.

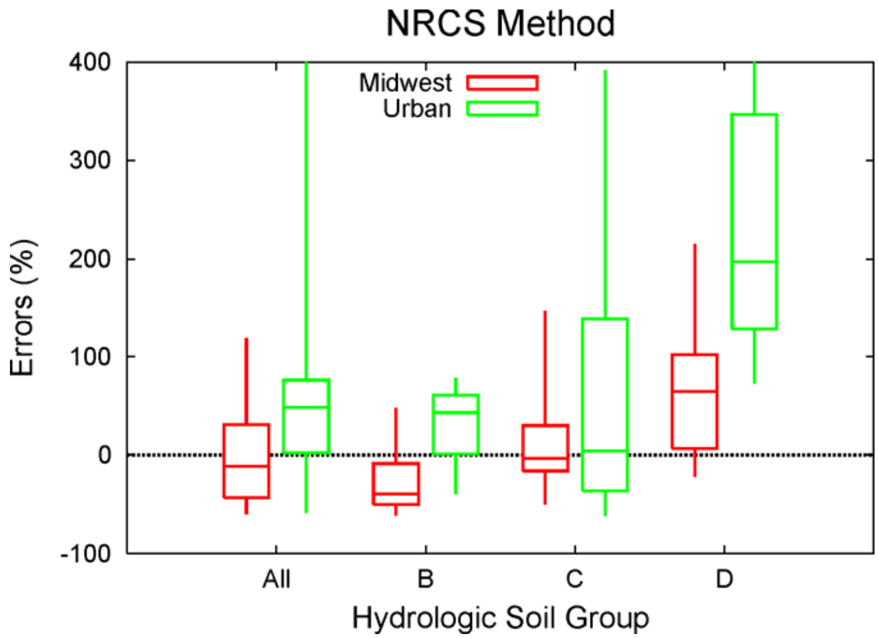

Figure 4.18: Range of 10-year return period flood frequency estimates for the NRCS Method by hydrologic soil group. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites and the 21 Urban sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

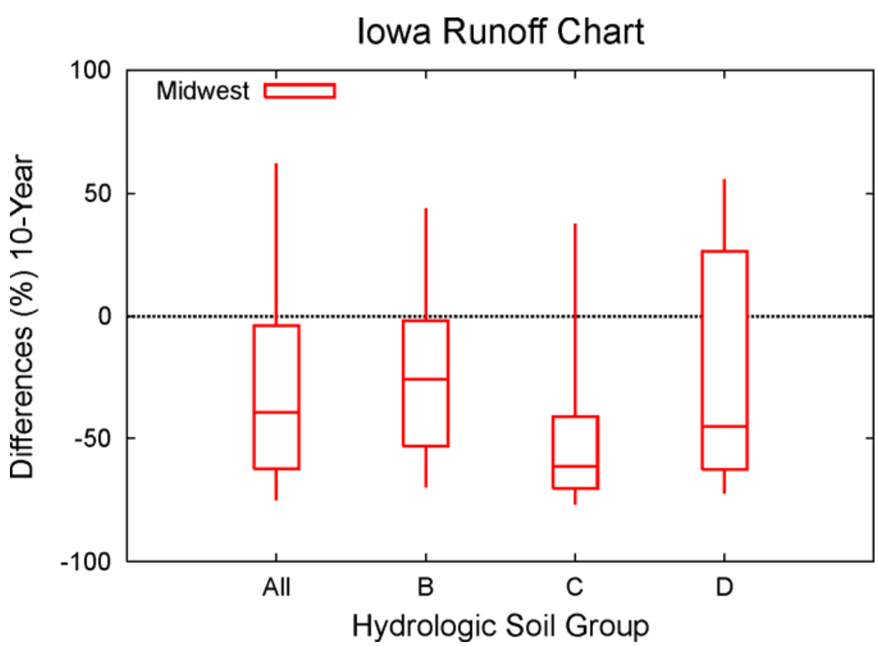

Figure 4.19: Range of 10-year return period flood frequency estimates for the Iowa Runoff Chart by hydrologic soil group. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

4.2.3 Comparison by slope

For the purpose of sorting sites by slope, a mild slope was defined as having an average watershed slope of less than or equal to 2%. A site with an average watershed slope greater than 2% was defined as a steep slope. Many design charts are divided into three classes by slopes of 0-2%, 2-6% and over 6% (e.g. McCuen, 2004). There were no sites in our study with slopes over 6%, so the basins were only defined as steep or mild. A more detailed delineation of the sites by slope is given in Figure 4.3, which shows that the majority of sites have slopes of 0.5-1.5%.

The sensitivity of flood frequency estimates to the average watershed slope for the Rational Method (Figure 4.20), the NRCS method (Figure 4.21), and the Iowa Runoff Chart (Figure 4.22) were evaluated. For both the Midwest and Urban sites, the results are insensitive to slope. Slope is a major factor for the Iowa Runoff Chart, but the range of differences is virtually identical for mild and steep slopes. For both the Rational Method and the NRCS method, the range is larger for mild slopes, but there are no systematic shifts in the median differences.

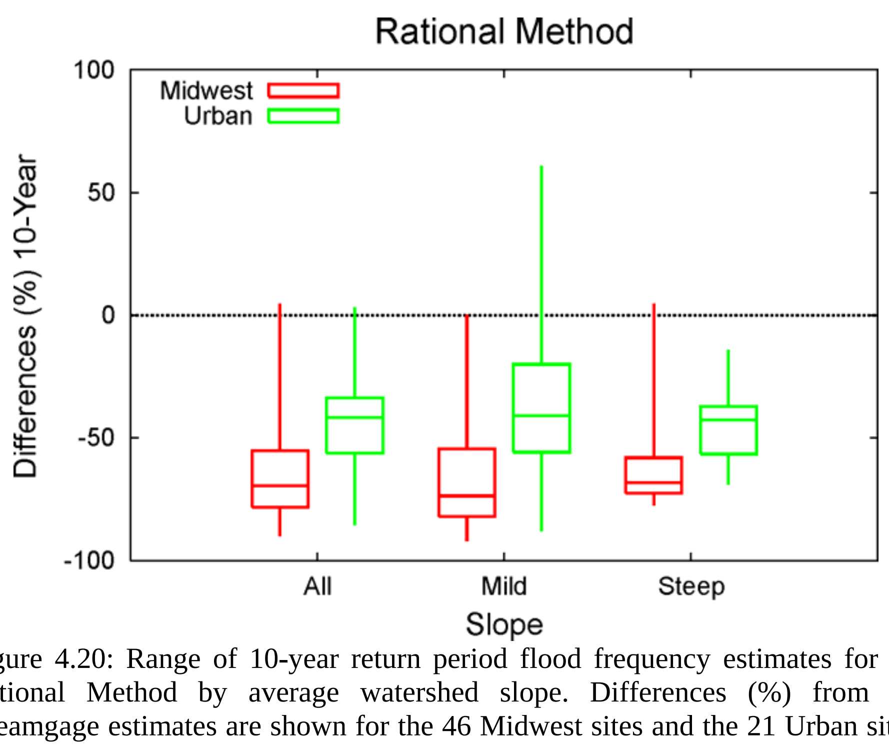

Figure 4.20: Range of 10-year return period flood frequency estimates for the Rational Method by average watershed slope. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites and the 21 Urban sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

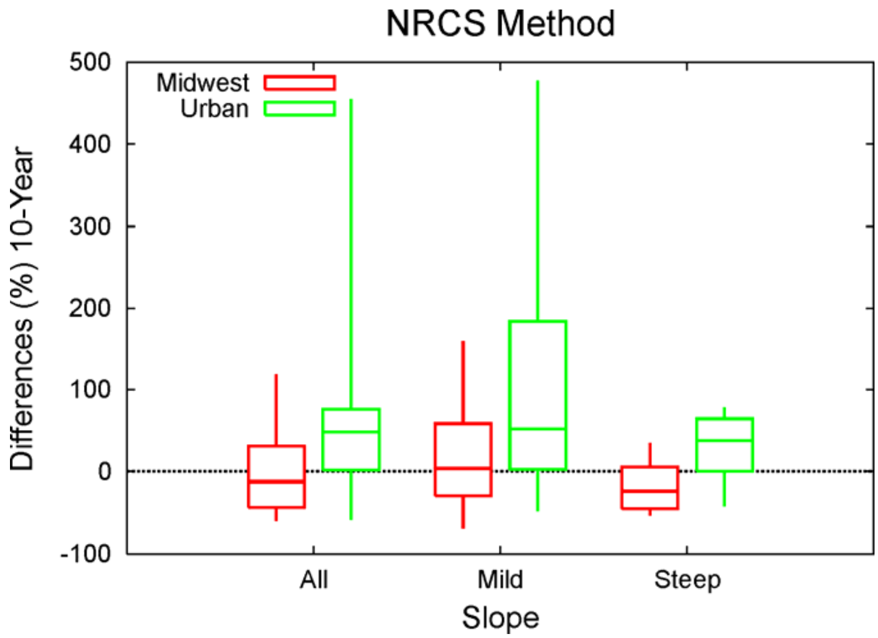

Figure 4.21: Range of 10-year return period flood frequency estimates for the NRCS method by average watershed slope. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites and the 21 Urban sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

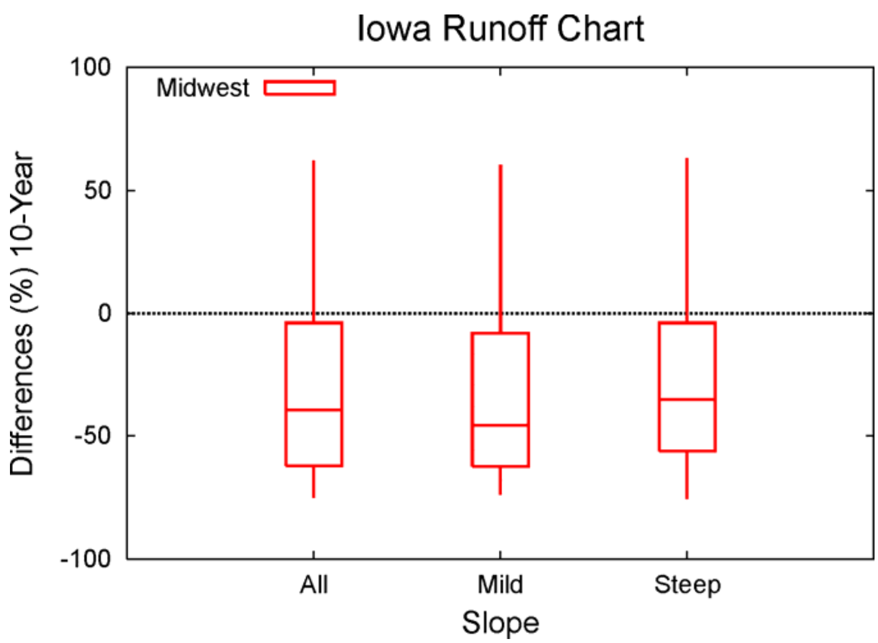

Figure 4.22: Range of 10-year return period flood frequency estimates for the Iowa Runoff Chart by average watershed slope. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

4.2.4 Comparison by land use/land cover

To compare flood frequency estimates by land use/land cover, the primary land use was categorized as an agricultural, forest, or developed land use/land cover. For the Midwest sites, agricultural is the dominant land use; only five of the 46 sites are forest, and one is developed. For the Urban sites, developed is the dominate land use; only three of the 21 sites are agricultural, and eight are forest.

The sensitivity of the estimates to land use/land cover for the Rational Method is shown in Figure 4.23. The sensitivity for the Midwest sites is low; the few forest and the one developed land uses have similar differences to the majority agricultural sites. For the Urban sites, the agricultural estimates tend to be slightly higher, and the forest estimates show more variability, than those for the majority developed sites.

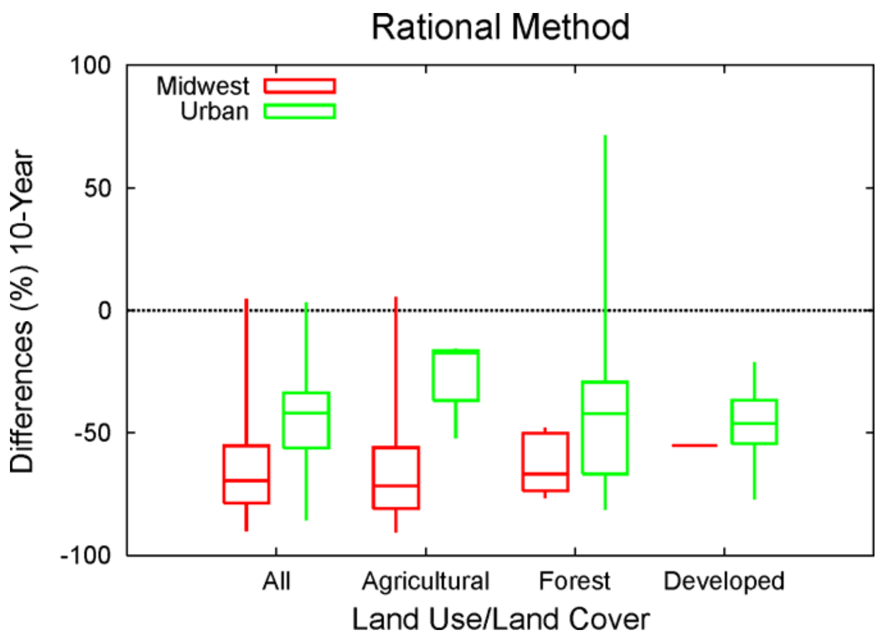

Figure 4.23: Range of 10-year return period flood frequency estimates for the Rational Method by land use/land cover. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites and the 21 Urban sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

As shown in Figure 4.24, the results for the NRCS follow similar trends as those for the Rational Method. Ponce and Hawkins (1996) argued that the NRCS curve number "generally does poorly in applications to forest sites". Contrary to these findings, the performance for forest sites is similar to other land use, although the variability is much higher for the set of Urban sites.

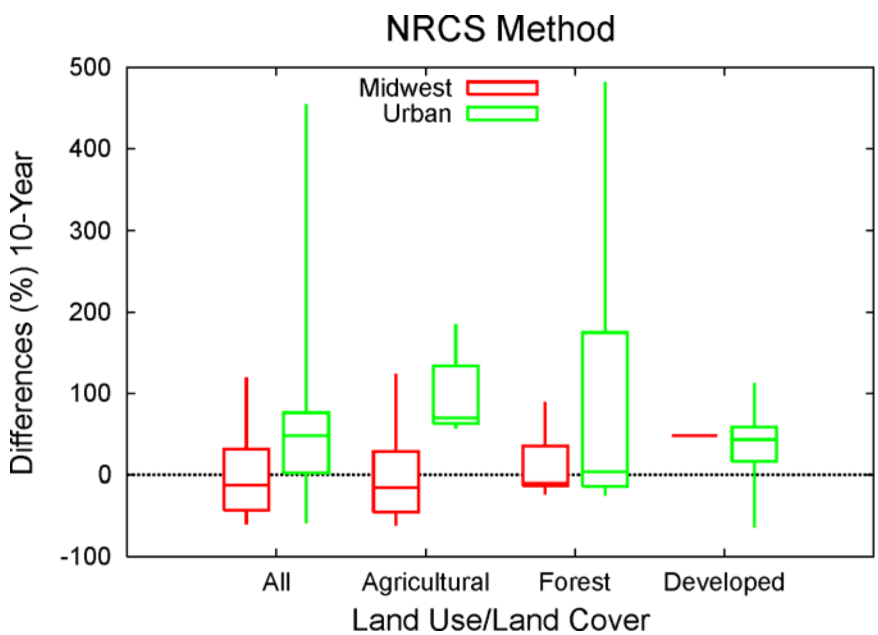

Figure 4.24: Range of 10-year return period flood frequency estimates for the NRCS method by land use/land cover. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites and the 21 Urban sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

The sensitivity of the estimates to land use/land cover for the Iowa Runoff Chart is shown in Figure 4.25. Unlike the Rational Method or the NRCS method, the few forest land use sites tend to be lower (greater underestimation) than the majority agricultural sites. The land use/land cover is represented by the land use and slope description factor (*LF*). The results suggest that coefficients for the permanent woods land use are anomalously low for the Midwest sites examined.

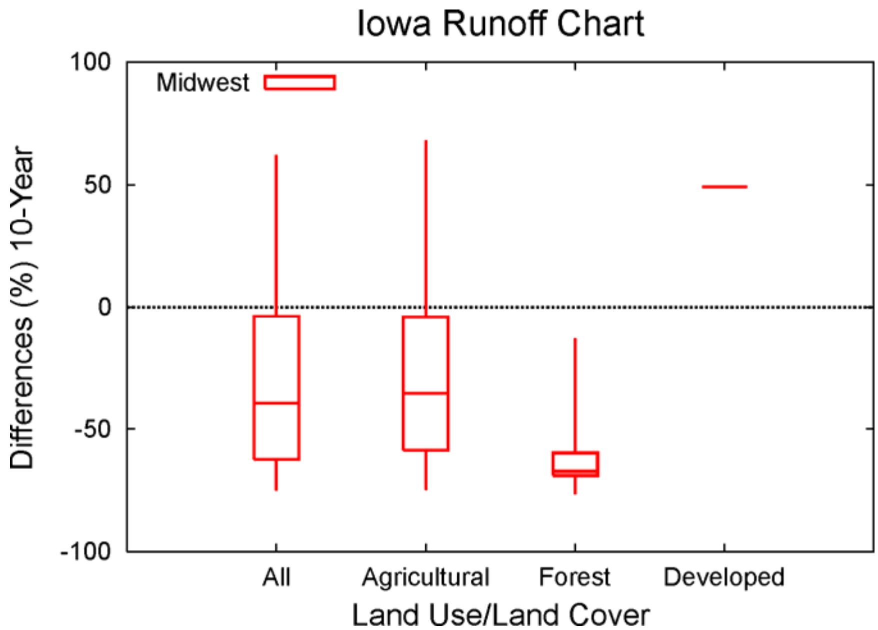

Figure 4.25: Range of 10-year return period flood frequency estimates for the Iowa Runoff Chart by land use/land cover. Differences (%) from the streamgage estimates are shown for the 46 Midwest sites. The boxes contain 50% of the estimates; 90% of the estimates fall within the range shown by the bars. The median is indicated by the horizontal line within the boxes.

4.3 Evaluation of design flood frequency techniques

Many of the same parameters are used in the Rational Method and the NRCS curve number approach, yet the estimates vary greatly. A technique proposed by McCuen and Bondelid (1981) was used to investigate the discrepancies between the two design methods. The technique involves equating the two methods and solving for the runoff coefficient in terms of the curve number. Because the NRCS curve number approach involves the intensity duration frequency (IDF) curve for the region of concern, the curve number cannot be universally converted to a runoff coefficient. The curve number may be universally converted for a particular region where a single IDF curve is representative of the rainfall characteristics throughout the basin. Central Iowa was chosen as the representative IDF curve for the analysis of the 46 sites located in seven nearby states. Although the rainfall characteristics at each site may not be identical to central Iowa, the sites were chosen for their similar climatic and hydrologic regimes, making the central Iowa region an appropriate choice. The outcome of equating the two design approaches resulted in a new method, named the Iowa-modified Rational Method. This approach takes advantage of the simplicity of the Rational formula as well as the generally better flood frequency estimation of the NRCS curve number approach. The explanation of the development and the implications of this new method are outlined in the following section.

4.3.1 Iowa-modified Rational Method

The Rational Method and the NRCS curve number approach use many of the same watershed and rainfall characteristics yet come to very different estimates. McCuen and Bondelid (1981) equated the two methods for Baltimore, Maryland and suggested the ability to convert a curve number to a Rational Method runoff coefficient for any given return interval. In this study, this approach was used for the central Iowa region and allows the Rational Method equation to be used to get estimations that closely resemble the NRCS curve number approach. The transformation was made by equating the estimated discharge for both methods and solving for the runoff coefficient in terms of the curve number. The NRCS curve number approach is based on the TR-55 graphical method:

$$Q = q_u A_1 V \tag{4.1}$$

where Q is the peak discharge (cfs), q_u is the unit peak discharge (cfs/mi^2/in of runoff), A_1 is the drainage area (square miles), and V is the runoff volume (inches) computed as:

$$V = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{4.2}$$

where P is the 24-hour precipitation depth (inches) and

$$S = \frac{1000}{CN} - 10 \tag{4.3}$$

where CN is the NRCS curve number. Equating the Rational Method equation with the TR-55 graphical method equation and solving for C yields:

$$C = \frac{q_u V}{i} \tag{4.4}$$

where i is the rainfall intensity for the given return interval and time of concentration. Therefore:

$$V = f(P, CN) \tag{4.5}$$

$$q_u = f(P, CN, t_c) \tag{4.6}$$

$$i = f(t_c) \tag{4.7}$$

$$C = f(P, CN, t_c) \tag{4.8}$$

The Iowa-modified runoff coefficient can be applied to a particular region, thereby customizing the runoff coefficient for the region. The conversion is not universal because the transformation involves the interpolation of intensity duration frequency curves, which vary by region. The result of this technique is the ability to convert any curve number into a runoff coefficient that can be used in the Rational Method to produce results similar to the results that would have been generated using the NRCS curve number approach. In short, the curve number can be used in place of the runoff coefficient in the Rational formula to get an improved flood frequency estimation.

Figure 4.26 shows the relationship between the Rational Method runoff coefficient and the curve number for central Iowa. Table 4.3 can be used to substitute published values of runoff coefficients with new values determined from the equivalent curve numbers. The result of this transformation is shown in Table 4.4, which is a detailed table of runoff coefficients derived from the equivalent curve numbers. In many cases, the numbers are different from the published values of runoff coefficients shown in Table 4.5. Tables 4.4 and 4.5 include 21 land use classifications, 4 hydrologic soil groups and 2 return intervals. The same charts with 6 return periods are included in Appendix B. The modified runoff coefficients generated from the equivalent curve numbers for central Iowa are referred to as Iowa-modified runoff coefficients. There were instances where the Iowa-modified runoff coefficients exceeded 1.0 in the conversion of curve numbers to Iowa-modified runoff coefficients. Because runoff cannot possibly exceed the amount of rainfall over a specified time interval, the coefficients were capped at 0.99. The computed Iowa-modified runoff coefficients where this was an issue involved land uses with high curve numbers at larger return intervals, such as commercial and fallow land uses at 25, 50 and 100-yr return periods. The small percentage of land use in these categories in the

46 basins of this study resulted in negligible effects on peak flow estimation when the Iowa-modified runoff coefficients were capped.

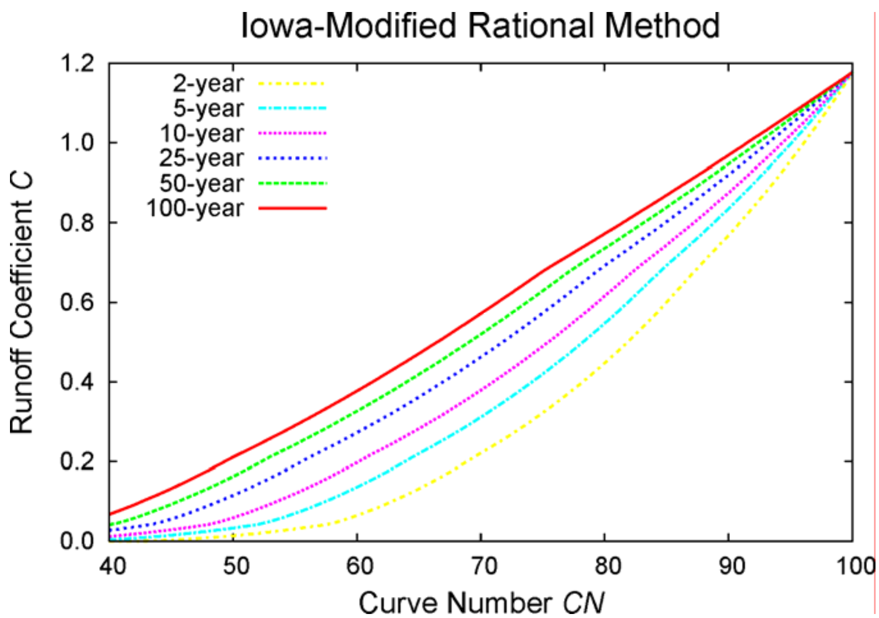

Figure 4.26: CN versus The Iowa-modified runoff coefficient for Central Iowa for various return periods (t_c = 1 hr).

Figure 4.27 shows the average peak discharge estimates using the Rational Method, the NRCS curve number approach, the Iowa-modified Rational Method for time of concentration 1 hour, and the peak flow determined from the streamgage data. The NRCS curve number approach and the Iowa-modified Rational Method procedures produce roughly the same average. The Rational Method estimates a much smaller discharge. Estimates are also made using the Iowa-modified Rational Method assuming a time of concentration of 30 minutes and 1.5 hours; the results are indistinguishable from those based on a 1 hour time of concentration. Hence, the Iowa-modified runoff coefficient for the time of concentration of one hour is assumed to be representative of all sites with times of concentration of 30 minutes to 2 hours. The distribution of time of concentration values by site is shown in Figure 4.6 and suggests that using 1 hour as the representative time of concentration is within reason since the majority of the t_c values for the 46 sites are within 30 minutes of 1 hour.

Table 4.3: Direct conversion from curve numbers to Iowa-modified runoff coefficients using a time of concentration of 1 hour.

	Iowa Modified Rational Method *C* Coefficients					
CN	2-year	5-year	10-year	25-year	50-year	100-year
40	0.000	0.004	0.012	0.028	0.041	0.067
41	0.000	0.006	0.015	0.032	0.048	0.079
42	0.000	0.008	0.018	0.036	0.058	0.091
43	0.001	0.010	0.022	0.040	0.069	0.105
44	0.002	0.013	0.025	0.046	0.080	0.118
45	0.003	0.015	0.029	0.056	0.093	0.132
46	0.005	0.019	0.033	0.066	0.106	0.147
47	0.006	0.022	0.038	0.077	0.119	0.162
48	0.009	0.026	0.042	0.089	0.133	0.177
49	0.011	0.029	0.049	0.102	0.147	0.194
50	0.014	0.033	0.059	0.115	0.162	0.211
51	0.017	0.038	0.070	0.129	0.178	0.226
52	0.020	0.042	0.081	0.143	0.194	0.241
53	0.023	0.050	0.093	0.158	0.211	0.257
54	0.027	0.059	0.106	0.174	0.227	0.273
55	0.031	0.070	0.120	0.190	0.242	0.290
56	0.035	0.082	0.134	0.207	0.258	0.306
57	0.040	0.094	0.148	0.223	0.275	0.323
58	0.045	0.107	0.164	0.239	0.291	0.341
59	0.054	0.121	0.180	0.255	0.308	0.359
60	0.065	0.136	0.197	0.272	0.326	0.377
61	0.076	0.151	0.215	0.289	0.344	0.395
62	0.089	0.167	0.231	0.306	0.362	0.413
63	0.102	0.184	0.247	0.324	0.380	0.432
64	0.117	0.202	0.264	0.343	0.399	0.451
65	0.132	0.220	0.282	0.361	0.418	0.471
66	0.148	0.237	0.300	0.381	0.438	0.490
67	0.165	0.254	0.319	0.400	0.458	0.510
68	0.183	0.272	0.338	0.420	0.478	0.530
69	0.202	0.291	0.358	0.441	0.499	0.551
70	0.221	0.311	0.378	0.462	0.520	0.571

Table 4.3 (continued): Direct conversion from curve numbers to Iowa-modified runoff coefficients using a time of concentration of 1 hour.

	Iowa Modified Rational Method *C* Coefficients					
CN	2-year	5-year	10-year	25-year	50-year	100-year
71	0.239	0.331	0.399	0.483	0.541	0.592
72	0.259	0.352	0.421	0.505	0.562	0.613
73	0.279	0.374	0.443	0.527	0.584	0.634
74	0.300	0.396	0.466	0.550	0.606	0.656
75	0.322	0.419	0.489	0.573	0.629	0.678
76	0.345	0.443	0.513	0.596	0.651	0.697
77	0.369	0.468	0.538	0.620	0.674	0.715
78	0.394	0.494	0.563	0.644	0.695	0.734
79	0.420	0.520	0.589	0.669	0.715	0.753
80	0.447	0.547	0.615	0.692	0.735	0.772
81	0.475	0.575	0.642	0.714	0.756	0.791
82	0.504	0.603	0.669	0.736	0.776	0.811
83	0.535	0.633	0.695	0.758	0.797	0.830
84	0.567	0.663	0.719	0.780	0.818	0.850
85	0.600	0.693	0.744	0.803	0.839	0.869
86	0.634	0.720	0.769	0.826	0.860	0.889
87	0.670	0.748	0.795	0.849	0.882	0.909
88	0.703	0.776	0.821	0.872	0.903	0.929
89	0.735	0.806	0.848	0.896	0.925	0.949
90	0.769	0.836	0.875	0.920	0.947	0.969
91	0.804	0.866	0.903	0.945	0.969	0.989
92	0.839	0.898	0.931	0.970	0.990	0.990
93	0.877	0.930	0.960	0.990	0.990	0.990
94	0.915	0.963	0.989	0.990	0.990	0.990
95	0.955	0.990	0.990	0.990	0.990	0.990
96	0.990	0.990	0.990	0.990	0.990	0.990
97	0.990	0.990	0.990	0.990	0.990	0.990
98	0.990	0.990	0.990	0.990	0.990	0.990
99	0.990	0.990	0.990	0.990	0.990	0.990
100	0.990	0.990	0.990	0.990	0.990	0.990

Table 4.4: Iowa-modified runoff coefficients.

HSG	A	A	A	B	B	B	C	C	C	D	D	D
Slope %	0-2	2-6	6+	0-2	2-6	6+	0-2	2-6	6+	0-2	2-6	6+
Open Water												
10-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100-yr	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Perennial Ice/Snow												
10-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100-yr	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Low Intensity Residential												
10-yr	0.11	0.11	0.11	0.38	0.38	0.38	0.61	0.61	0.61	0.74	0.74	0.74
100-yr	0.27	0.27	0.27	0.57	0.57	0.57	0.77	0.77	0.77	0.87	0.87	0.87
High Intensity Residential												
10-yr	0.54	0.54	0.54	0.74	0.74	0.74	0.88	0.88	0.88	0.93	0.93	0.93
100-yr	0.72	0.72	0.72	0.87	0.87	0.87	0.97	0.97	0.97	0.99	0.99	0.99
Commercial/Industrial/Transportation												
10-yr	0.85	0.85	0.85	0.93	0.93	0.93	0.99	0.99	0.99	0.99	0.99	0.99
100-yr	0.95	0.95	0.95	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Bare Rock/Sand/Clay												
10-yr	0.51	0.51	0.51	0.74	0.74	0.74	0.85	0.85	0.85	0.90	0.90	0.90
100-yr	0.70	0.70	0.70	0.87	0.87	0.87	0.95	0.95	0.95	0.99	0.99	0.99
Quarries/Strip Mines/Gravel Pits												
10-yr	0.51	0.51	0.51	0.74	0.74	0.74	0.85	0.85	0.85	0.90	0.90	0.90
100-yr	0.70	0.70	0.70	0.87	0.87	0.87	0.95	0.95	0.95	0.99	0.99	0.99
Transitional												
10-yr	0.54	0.54	0.54	0.77	0.77	0.77	0.90	0.90	0.90	0.99	0.99	0.99
100-yr	0.72	0.72	0.72	0.89	0.89	0.89	0.99	0.99	0.99	0.99	0.99	0.99
Deciduous and Evergreen Forest												

Table 4.4 (continued): Iowa-modified runoff coefficients.

10-yr	0.00	0.00	0.00	0.20	0.20	0.20	0.44	0.44	0.44	0.59	0.59	0.59
100-yr	0.04	0.04	0.04	0.38	0.38	0.38	0.63	0.63	0.63	0.75	0.75	0.75
Mixed Forest												
10-yr	0.00	0.00	0.00	0.20	0.20	0.20	0.44	0.44	0.44	0.59	0.59	0.59
100-yr	0.04	0.04	0.04	0.38	0.38	0.38	0.63	0.63	0.63	0.75	0.75	0.75
Shrubland												
10-yr	0.03	0.03	0.03	0.28	0.28	0.28	0.51	0.51	0.51	0.67	0.67	0.67
100-yr	0.12	0.12	0.12	0.47	0.47	0.47	0.70	0.70	0.70	0.81	0.81	0.81
Orchards/Vineyards/Other												
10-yr	0.03	0.03	0.03	0.28	0.28	0.28	0.51	0.51	0.51	0.67	0.67	0.67
100-yr	0.12	0.12	0.12	0.47	0.47	0.47	0.70	0.70	0.70	0.81	0.81	0.81
Grasslands/Herbaceous												
10-yr	0.00	0.00	0.00	0.21	0.21	0.21	0.47	0.47	0.47	0.72	0.72	0.72
100-yr	0.04	0.04	0.04	0.39	0.39	0.39	0.66	0.66	0.66	0.85	0.85	0.85
Pasture/Hay												
10-yr	0.05	0.05	0.05	0.36	0.36	0.36	0.59	0.59	0.59	0.72	0.72	0.72
100-yr	0.19	0.19	0.19	0.55	0.55	0.55	0.75	0.75	0.75	0.85	0.85	0.85
Row Crops												
10-yr	0.32	0.32	0.32	0.56	0.56	0.56	0.74	0.74	0.74	0.85	0.85	0.85
100-yr	0.51	0.51	0.51	0.73	0.73	0.73	0.87	0.87	0.87	0.95	0.95	0.95
Small Grains												
10-yr	0.25	0.25	0.25	0.49	0.49	0.49	0.70	0.70	0.70	0.80	0.80	0.80
100-yr	0.43	0.43	0.43	0.68	0.68	0.68	0.83	0.83	0.83	0.91	0.91	0.91
Fallow												
10-yr	0.54	0.54	0.54	0.77	0.77	0.77	0.90	0.90	0.90	0.99	0.99	0.99
100-yr	0.72	0.72	0.72	0.89	0.89	0.89	0.99	0.99	0.99	0.99	0.99	0.99
Urban/Recreational Grasses												

Table 4.4 (continued): Iowa-modified runoff coefficients.

10-yr	0.01	0.01	0.01	0.21	0.21	0.21	0.47	0.47	0.47	0.61	0.61	0.61
100-yr	0.06	0.06	0.06	0.39	0.39	0.39	0.66	0.66	0.66	0.77	0.77	0.77
Woody Wetlands												
10-yr	0.00	0.00	0.00	0.20	0.20	0.20	0.44	0.44	0.44	0.59	0.59	0.59
100-yr	0.04	0.04	0.04	0.38	0.38	0.38	0.63	0.63	0.63	0.75	0.75	0.75
Emergent Herbaceous Wetlands												
10-yr	0.00	0.00	0.00	0.21	0.21	0.21	0.47	0.47	0.47	0.72	0.72	0.72
100-yr	0.04	0.04	0.04	0.39	0.39	0.39	0.66	0.66	0.66	0.85	0.85	0.85

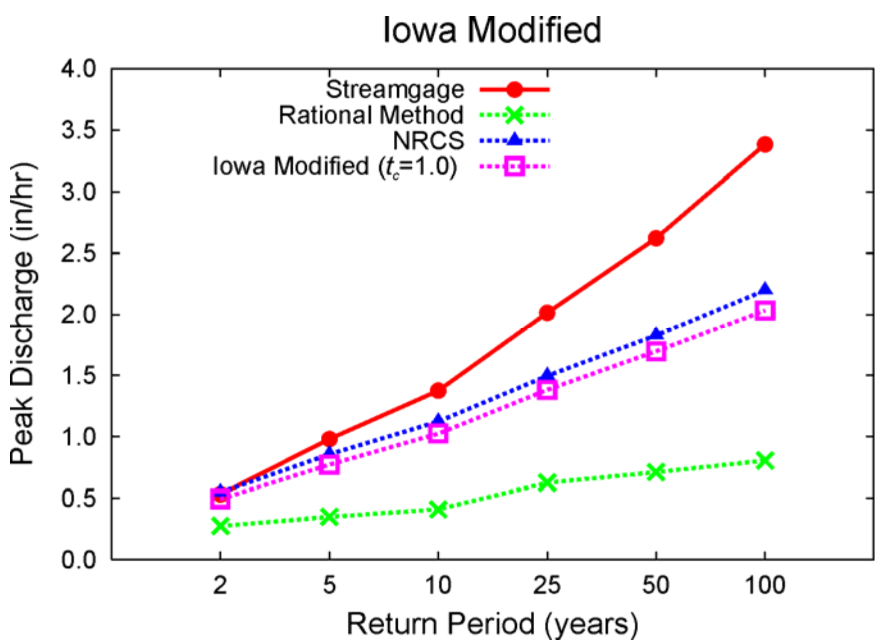

Figure 4.27: Average flood frequency estimates for the 46 Midwest sites based on streamgage data, the Rational Method, the NRCS curve number method, and the Iowa-modified Rational Method. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

Table 4.5: Accepted values for runoff coefficients.

HSG	A	A	A	B	B	B	C	C	C	D	D	D
Slope	0	2	6	0	2	6	0	2	6	0	2	6
Open Water												
10-yr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
100-yr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Perennial Ice/Snow												
10-yr	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
100-yr	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Low Intensity Residential												
10-yr	0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
100-yr	0.25	0.29	0.32	0.28	0.32	0.36	0.31	0.35	0.42	0.34	0.38	0.48
High Intensity Residential												
10-yr	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
100-yr	0.30	0.34	0.37	0.33	0.37	0.42	0.36	0.40	0.47	0.38	0.42	0.52
Commercial/Industrial/Transportation												
10-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
Bare Rock/Sand/Clay												
10-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
Quarries/Strip Mines/Gravel Pits												
10-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
Transitional												
2-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
Deciduous Forest												
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20

Table 4.5 (continued): Accepted values for runoff coefficients.

100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Evergreen Forest												
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Mixed Forest												
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Shrubland												
10-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
100-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Orchards/Vinyards/Other												
10-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
100-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Grasslands/Herbaceous												
10-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
100-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
Pasture/Hay												
10-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
100-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
Row Crops												
10-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
100-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Small Grains												
10-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
100-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Fallow												
10-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
100-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
Urban/Recreational Grasses												
10-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40

Table 4.5 (continued): Accepted values for runoff coefficients.

100-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Woody Wetlands												
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Emergent Herbaceous Wetlands												
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25

Source: Soil Conservation Service (SCS). (1986). Urban Hydrology for Small Watersheds. Technical Release 55 (TR-55), 2nd Edition, Department of Agriculture, Washington, D.C.

In summary, the Rational Method is well-established, simple, and is the standard approach in Iowa for engineering designs in basins of less than 160 acres. However, the derived curve number equivalent values for the runoff coefficient enable the engineer to continue using this simple equation, while at the same time taking advantage of the better estimation ability of the NRCS curve number approach.

4.3.2 Optimized composite curve numbers

The NRCS curve number approach provides a better estimate of the flood frequency than the Rational Method. The Iowa-modified Rational Method provides a technique for getting the predictive accuracy of the NRCS curve number approach while continuing to use the Rational formula. However, it would be improved if the curve numbers converted to a runoff coefficient that led to flood frequency estimations more closely resembling the flood frequency based on the streamgage data. To address this situation, an optimization code was developed resulting in the creation of an optimized curve number for each individual site. The goal of this optimization function was to determine the curve number that resulted in the best flood frequency estimation and compare the optimized composite curve number with the composite curve number calculated from published values.

The mean absolute error function was used to optimize the data for each return period. The criteria for the mean absolute error function included the constraint such that the optimized value would not exceed a 10% over- or under-estimation of the streamgage estimation for each return period. The averages for return intervals of 2, 5,10, 25, 50 and 100 years for the Rational Method, the NRCS curve number approach, and the optimized Iowa-modified Rational Method are shown in Figure 4.28. Although the estimates are improved, there remains a systematic underestimation of the streamgage flood frequencies, especially for long return period. The overall improvement is more clearly seen in Figure 29, where the 10-year estimates better match those from the streamgage than the NRCS approach without optimization (see Figure 12).

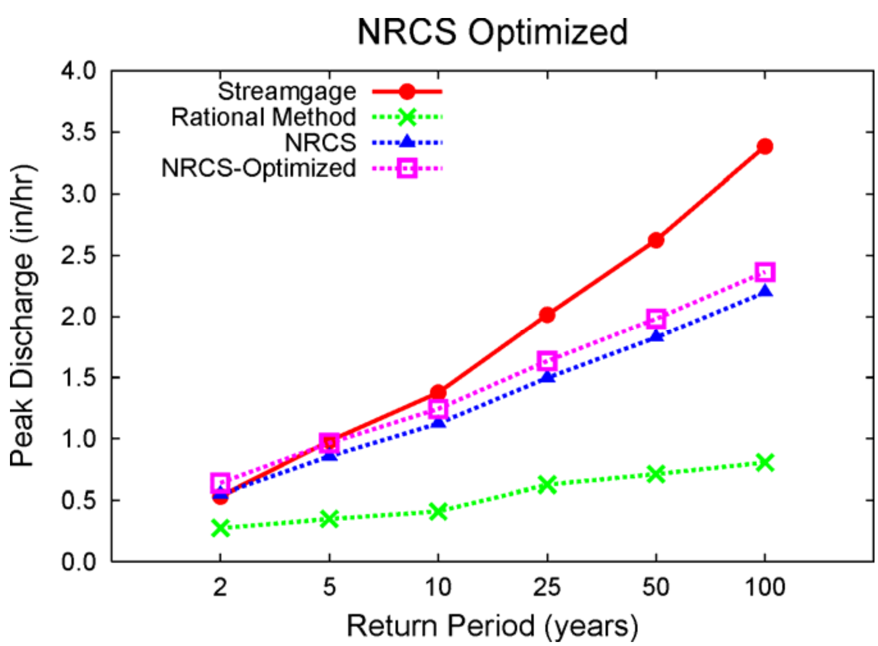

Figure 4.28: Average flood frequency estimates for the 46 Midwest sites based on streamgage data, the Rational Method, the NRCS curve number method, and an optimized NRCS curve number method. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

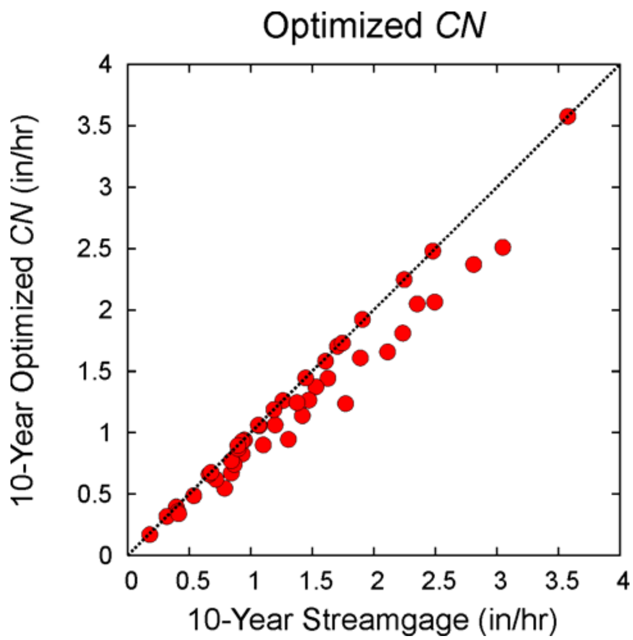

Figure 4.29: Estimates of the 10-year return period peak discharge based on the optimized NRCS runoff curve number and streamgage data for the 46 Midwest sites. The peak discharge per unit area (in/hr) is shown to facilitate comparison.

The relationship between the curve numbers derived from watershed characteristics, and the optimized curve numbers, is shown in Figure 4.30. The NRCS method systematically underestimated flood frequencies, so one might expect that the optimized curve numbers would systematically increase. This was not the case. On average over the 46 sites, the optimal curve number only increased by 1. Therefore, the optimization appears to account for random errors in curve number estimation, rather than systematic errors for Midwest sites. Hence, the range of variability observed for the NRCS method flood frequency estimates are indicative of the inherent uncertainty with the methodology. With optimized curve numbers, the only other parameters determining the flood frequencies are the 24-hour precipitation and the time of concentration (t_c). Hence, the failure of a single optimized curve number to provide an unbiased estimate would suggest that the time of concentration, which determines the slope of the flood frequency curve, may be overestimated using the SUDAS procedures.

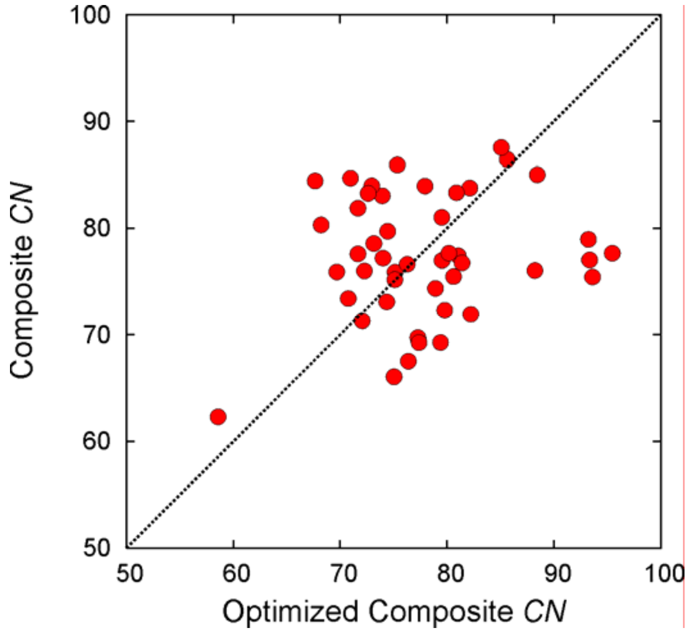

Figure 4.30: Composite curve numbers versus optimized composite curve numbers.

4.4 Limitations of the datasets used in the GIS

The curve number and runoff coefficient are sensitive to topography, land use land cover classification, and the hydrologic soil group. The datasets used to determine these parameters have important limitations. All sites studied had 30m resolution digital elevation models available, but only a small fraction had 10m resolution models. This limitation required the manual basin delineation using scanned 1:24,000 USGS topographic maps. In relatively flat basins, basin delineation presented some difficulties. Had the 10m resolution data been available, functions within the GIS could have been used to objectively and systematically delineate the basins without the necessity of the scanned maps.

The land use land/cover information was collected in the early to mid 1990s. Changes in land use in the study region over the last 10-15 years have resulted from various modifications in agricultural practices and urbanization. More recent land cover information is available from the USGS for some areas, but remains at low resolutions without the number of distinctions necessary for accurate curve number and runoff coefficient calculations.

The Soil Survey Geographical (SSURGO) database is ideal for providing spatial hydrologic soil group information. However, it is not publicly available for the majority of the Midwest. Consequently, the best resource available was the State Soil Geographical (STATSGO) dataset that generalizes the SSURGO information by assuming areas up to several tens of square miles have the same soil properties. For small basins, this generalization may result in the use of the wrong hydrologic soil group simply because the STATSGO information is too general.

As the SSURGO information and 10m resolution digital elevation modes become available within the next decade, more accurate determinations will be possible. There is no time table set for updated land use information, and this will become the limiting factor in the most accurate determination of the necessary parameters.

4.5 Central Iowa as representative of the Iowa and the Midwest

This study provides tables of Iowa-modified runoff coefficients and conversion charts from curve numbers to runoff coefficients based on the hydrologic characteristics of central Iowa. Regionalizing the tables is a function of the ratio of initial abstraction to the 24-hour precipitation depth and the intensity duration frequency (IDF) curve for the region. To compute the I_a/P ratio, a computer code was developed to interpolate between the curves of Figure 2.2. As long as the IDF curves are similar between regions, the Iowa-modified runoff coefficients (adjusted for central Iowa) are applicable throughout Iowa and the surrounding states. As an example, Figure 4.31 shows the 10-year IDF curves for six Midwestern states. With the exception of parts of Missouri, all of the states shown have IDF curves similar to Iowa, so the Iowa-modified runoff coefficients are applicable.

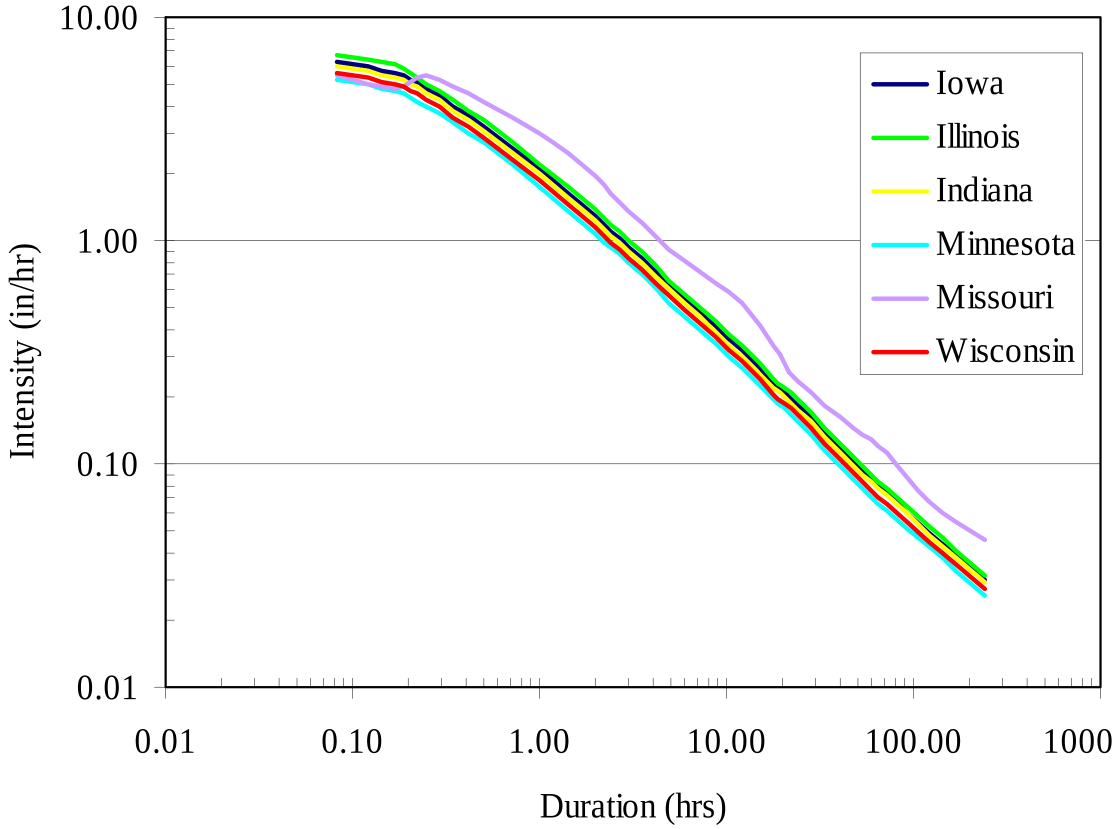

Figure 4.31: 10-year IDF curves for six Midwestern states.

5. CONCLUSIONS AND RECOMMENDATIONS

Estimates of flood frequencies based on design methods were evaluated for small Iowa streams (200 acres or less). The evaluation is based on a comparison of the design method flood frequency estimates, with those based on streamgage records. Sites in the Midwest with at least 20 years of annual maximum peak discharge records were examined. Since these 46 sites represent mostly pre-development agricultural land uses, a second set of sites with significant urban developed were also examined. These 21 additional Urban sites are located throughout the United States.

The Rational Method is one of the most popular design flood frequency methods for small drainage areas, in large part because it is easy to apply. Using the procedures outlined in the Iowa Statewide Urban Design and Specifications (SUDAS) manual, the flood frequency estimates based on the Rational Method systematically underestimate peak discharges based on streamgage data for the Midwest sites. The average differences are on the order of -50 (2-year return period) to -75% (100-year return period). For the Urban sites, the Rational Method still underestimates peak discharge, but the underestimation is less. The differences range from about -25% (2-year return period) to -50% (100-year return period).

The NRCS curve number approach is also a popular method for small to medium-sized drainage areas, and its procedures are also outlined in the SUDAS manual. Like the Rational Method, the NRCS curve number approach also tends to underestimate peak discharges for the Midwest sites. However, the underestimation is significantly less. For the 2-year return period, the NRCS estimates are nearly unbiased, but the differences grow to about -25% for the 100-year return period. For Urban sites, the NRCS method overestimates peak discharge at shorter return periods by as much as 50%, but estimates are nearly unbiased at longer return periods.

The Iowa Runoff Chart, developed in the 1950s by the Iowa State Highway Commission (now Iowa Department of Transportation), is widely used throughout the state for flood frequency estimation on rural watersheds with drainage areas of 1280 acres (2 mi^2) or less. The Iowa Runoff Chart was developed using local hydrologic information and has been applied with some confidence to Iowa streams. Still, the evaluation for the Midwest sites shows that the Iowa Runoff Chart also underestimates flood frequencies for small drainages (less than 200 acres). The underestimation is on the order of -30 to -50%, smaller than that of the Rational Method, but greater than that of the NRCS method.

The sensitivity of flood frequency estimates to watershed characteristics was examined. The results show some sensitivity to the hydrologic soil group, an important parameter for both the Rational Method and NRCS curve number approach. For high runoff potential soils (types C and D), the Rational Method and NRCS methods produce higher flood frequency estimates than for low runoff potential soils (types A and B). However, the magnitude of increase for high runoff potential soils appears to be greater than that observed at streamgages. These results suggest that the hydrologic soil group is not as good a predictor of flood potential as one might expect. Indeed, the Iowa Runoff Chart, which does not make any distinction between hydrologic soil groups (it uses only land cover and slope factors), does not display the sensitivity to hydrologic soil group as seen (and predicted) by the Rational Method and NRCS curve number approaches.

The design method flood frequency estimates are less sensitive to other watershed characteristics. For example, the average watershed slope is an important parameter for all design methods, but no significant trends were observed between flatter and steeper watersheds. Although there were slight differences between estimates for agricultural, forest, and developed land uses, the differences were not strong or consistent for the Midwest and Urban sites. The one exception is for the Iowa Runoff Chart, where the underestimation for predominantly forest land use was greater than for agricultural land use sites.

One overall consistent trend for the Rational Method and NRCS curve number approach is the change in systematic differences between the Midwest and Urban sites. If the results for Midwest sites are indicative of pre-developed conditions, and results for the Urban sites are indicative of post-developed conditions, then changes in flood frequency due to land development would tend to be overpredicted for both methods (even if the absolute flood magnitudes are underpredicted). The change in flood frequency from pre-development to post-development is often a benchmark for engineering design, where the goal is to reduce the post-development flood frequencies to pre-development levels through engineered systems. The implication is that the larger predicted relative changes in flood frequencies by the two methods would lead to more conservative and costly engineered solutions than is required.

Given the more accurate estimation of flood frequencies by the NRCS curve number approach, this method should be the first choice of engineers for design estimation, even for small streams. Since SUDAS procedures recommend estimation of the curve number (*CN*) to evaluate the the time of concentration (t_c), even when using the Rational Method, then in some sense, it is straightforward to simply continue with the uses of NRCS curve number procedures for flood frequency estimation. Alternatively, we have developed an Iowa-modified Rational Method, which directly calculates appropriate runoff coefficients (*C*) based on the *CN* estimates. Using the Iowa-modified Rational Method conversion charts, where the runoff coefficient is determined from the equivalent curve number, or by using the Iowa-modified runoff coefficient charts, an estimate of the flood frequency can be made with less bias than the Rational Method. This method allows engineers to continue using the Rational Method as suggested by the SUDAS manual, but with peak discharge estimation accuracy on the order of the NRCS approach.

We also explored improving the NRCS estimates, by finding the optimal *CN* for each site, and examining the deviations from the *CN* determined from watershed characteristics. The optimization demonstrated that the errors in curve number estimation are random, and not systematic errors that could be corrected. Hence, the variability observed for NRCS flood frequency estimates are indicative of the inherent uncertainty with the methodology for Iowa streams. The only other remaining parameter that could be adjusted to correct flood frequency estimates is the time of concentration. Since the slope of the estimated flood frequency curves are shallower than those observed, it suggests that the time of concentration may be systematically overestimated (the time to too high). Further research is needed to examine whether improved estimation of the time of concentration is possible; the data sets for the Midwest and Urban sites, and examination of the typical hydrologic response times based on their streamgage hydrographs, are avenues for exploring the role of time of concentration estimation for both the Rational Method and NRCS approaches.

There are also avenues for improving estimation based on the Iowa Runoff Chart. With the longer streamgage records that now exists, recalibration of the frequency factor (*FF*) and land use and slope description factor (*LF*) is possible. Such an effort would seem to be worthwhile, given that the hydrologic soil group determination has less predictive ability than implied by the Rational Method and NRCS curve number approach.

This study focused on basin areas of 200 acres or less. For larger basins, the SUDAS manual suggests the use of the NRCS curve number approach for estimating peak runoff on basins with drainage areas up to 10 mi^2 in area. Future study may be aimed at comparing the flood frequency estimates determined by using the NRCS curve number method to the flood frequency estimation based on the gage records in drainage areas of 10 mi^2 or less. By doing this, the predictive accuracy of the NRCS curve number method can be determined for basins up to 10 square miles. Within the Midwest region considered in the present study, there are 457 sites (and 37 in Iowa) with drainage areas of 10 mi^2 or less with flow records of over 20 years. Still, as in this study, the region may need to be expanded to obtain an adequate sampling of basins with urban land uses.

APPENDIX A: METADATA FOR GIS DATASETS

This section provides the web addresses for exploring the GIS datasets used in this investigation. It also includes file names and folders corresponding to the metadata for the datasets at the time they were utilized.

Gage Locations

The information in the table used to display the gage locations comes from the USGS Peak Streamflow for the Nation webpage available at:
http://nwis.waterdata.usgs.gov/nwis/peak?introduction.

The webpage http://nwis.waterdata.usgs.gov shows the location where the information for the 46 sites was extracted.

Map of the Midwest

The metadata for this layer can be found online at:
http://nhdgeo.usgs.gov/help/Layers.html.

State Land Use Land Cover

The metadata for this layer can be found online at:
http://www.mrlc.gov/index.asp.

Streets

The metadata for this layer can be found online at:
http://nhdgeo.usgs.gov/help/Layers.html.

Rivers and water bodies

The metadata for this layer can be found online at:
http://nhdgeo.usgs.gov/help/Layers.html.

10 m and 30m Digital elevation model

Metadata regarding the National Elevation Datasets (NEDs) used can be found online at: ftp://edcftp.cr.usgs.gov/pub/data/ned/documents/NED_Release_Notes_Dec04.pdf.

STATSGO-Hydrologic soil group

The metadata for this layer can be found online at: http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/data/index.html.

USGS 1:24,000 Topographical map

The topological maps used are scanned from paper maps that are projected in Transverse Mercator, NAD 27, and the corresponding UTM zone.

Map of Counties

The metadata for this layer can be found online at: http://nhdgeo.usgs.gov/help/Layers.html.

APPENDIX B: IOWA-MODIFIED RUNOFF COEFFICIENTS.

Table B.1: Complete table of the Iowa-modified runoff coefficients.

HSG	A	A	A	B	B	B	C	C	C	D	D	D
Slope %	0-2	2-6	6+	0-2	2-6	6+	0-2	2-6	6+	0-2	2-6	6+
Open Water												
2-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-yr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50-yr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
100-yr	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Perennial Ice/Snow												
2-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-yr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50-yr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
100-yr	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Low Intensity Residential												
2-yr	0.03	0.03	0.03	0.22	0.22	0.22	0.45	0.45	0.45	0.60	0.60	0.60
5-yr	0.06	0.06	0.06	0.31	0.31	0.31	0.55	0.55	0.55	0.69	0.69	0.69
10-yr	0.11	0.11	0.11	0.38	0.38	0.38	0.61	0.61	0.61	0.74	0.74	0.74
25-yr	0.17	0.17	0.17	0.46	0.46	0.46	0.69	0.69	0.69	0.80	0.80	0.80
50-yr	0.23	0.23	0.23	0.52	0.52	0.52	0.74	0.74	0.74	0.84	0.84	0.84
100-yr	0.27	0.27	0.27	0.57	0.57	0.57	0.77	0.77	0.77	0.87	0.87	0.87
High Intensity Residential												
2-yr	0.37	0.37	0.37	0.60	0.60	0.60	0.77	0.77	0.77	0.84	0.84	0.84
5-yr	0.47	0.47	0.47	0.69	0.69	0.69	0.84	0.84	0.84	0.90	0.90	0.90

Table B.1: Continued.

10-yr	0.54	0.54	0.54	0.74	0.74	0.74	0.88	0.88	0.88	0.93	0.93	0.93
25-yr	0.62	0.62	0.62	0.80	0.80	0.80	0.92	0.92	0.92	0.97	0.97	0.97
50-yr	0.67	0.67	0.67	0.84	0.84	0.84	0.95	0.95	0.95	0.99	0.99	0.99
100-yr	0.72	0.72	0.72	0.87	0.87	0.87	0.97	0.97	0.97	0.99	0.99	0.99
Commercial/Industrial/Transportation												
2-yr	0.74	0.74	0.74	0.84	0.84	0.84	0.92	0.92	0.92	0.95	0.95	0.95
5-yr	0.81	0.81	0.81	0.90	0.90	0.90	0.96	0.96	0.96	0.99	0.99	0.99
10-yr	0.85	0.85	0.85	0.93	0.93	0.93	0.99	0.99	0.99	0.99	0.99	0.99
25-yr	0.90	0.90	0.90	0.97	0.97	0.97	0.99	0.99	0.99	0.99	0.99	0.99
50-yr	0.93	0.93	0.93	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
100-yr	0.95	0.95	0.95	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Bare Rock/Sand/Clay												
2-yr	0.34	0.34	0.34	0.60	0.60	0.60	0.74	0.74	0.74	0.80	0.80	0.80
5-yr	0.44	0.44	0.44	0.69	0.69	0.69	0.81	0.81	0.81	0.87	0.87	0.87
10-yr	0.51	0.51	0.51	0.74	0.74	0.74	0.85	0.85	0.85	0.90	0.90	0.90
25-yr	0.60	0.60	0.60	0.80	0.80	0.80	0.90	0.90	0.90	0.94	0.94	0.94
50-yr	0.65	0.65	0.65	0.84	0.84	0.84	0.93	0.93	0.93	0.97	0.97	0.97
100-yr	0.70	0.70	0.70	0.87	0.87	0.87	0.95	0.95	0.95	0.99	0.99	0.99
Quarries/Strip Mines/Gravel Pits												
2-yr	0.34	0.34	0.34	0.60	0.60	0.60	0.74	0.74	0.74	0.80	0.80	0.80
5-yr	0.44	0.44	0.44	0.69	0.69	0.69	0.81	0.81	0.81	0.87	0.87	0.87
10-yr	0.51	0.51	0.51	0.74	0.74	0.74	0.85	0.85	0.85	0.90	0.90	0.90
25-yr	0.60	0.60	0.60	0.80	0.80	0.80	0.90	0.90	0.90	0.94	0.94	0.94
50-yr	0.65	0.65	0.65	0.84	0.84	0.84	0.93	0.93	0.93	0.97	0.97	0.97
100-yr	0.70	0.70	0.70	0.87	0.87	0.87	0.95	0.95	0.95	0.99	0.99	0.99
Transitional												
2-yr	0.37	0.37	0.37	0.63	0.63	0.63	0.80	0.80	0.80	0.92	0.92	0.92
5-yr	0.47	0.47	0.47	0.72	0.72	0.72	0.87	0.87	0.87	0.96	0.96	0.96
10-yr	0.54	0.54	0.54	0.77	0.77	0.77	0.90	0.90	0.90	0.99	0.99	0.99
25-yr	0.62	0.62	0.62	0.83	0.83	0.83	0.94	0.94	0.94	0.99	0.99	0.99

Table B.1: Continued.

50-yr	0.67	0.67	0.67	0.86	0.86	0.86	0.97	0.97	0.97	0.99	0.99	0.99
100-yr	0.72	0.72	0.72	0.89	0.89	0.89	0.99	0.99	0.99	0.99	0.99	0.99
Deciduous Forest												
2-yr	0.00	0.00	0.00	0.06	0.06	0.06	0.28	0.28	0.28	0.42	0.42	0.42
5-yr	0.00	0.00	0.00	0.14	0.14	0.14	0.37	0.37	0.37	0.52	0.52	0.52
10-yr	0.00	0.00	0.00	0.20	0.20	0.20	0.44	0.44	0.44	0.59	0.59	0.59
25-yr	0.01	0.01	0.01	0.27	0.27	0.27	0.53	0.53	0.53	0.67	0.67	0.67
50-yr	0.02	0.02	0.02	0.33	0.33	0.33	0.58	0.58	0.58	0.72	0.72	0.72
100-yr	0.04	0.04	0.04	0.38	0.38	0.38	0.63	0.63	0.63	0.75	0.75	0.75
Evergreen Forest												
2-yr	0.00	0.00	0.00	0.06	0.06	0.06	0.28	0.28	0.28	0.42	0.42	0.42
5-yr	0.00	0.00	0.00	0.14	0.14	0.14	0.37	0.37	0.37	0.52	0.52	0.52
10-yr	0.00	0.00	0.00	0.20	0.20	0.20	0.44	0.44	0.44	0.59	0.59	0.59
25-yr	0.01	0.01	0.01	0.27	0.27	0.27	0.53	0.53	0.53	0.67	0.67	0.67
50-yr	0.02	0.02	0.02	0.33	0.33	0.33	0.58	0.58	0.58	0.72	0.72	0.72
100-yr	0.04	0.04	0.04	0.38	0.38	0.38	0.63	0.63	0.63	0.75	0.75	0.75
Mixed Forest												
2-yr	0.00	0.00	0.00	0.06	0.06	0.06	0.28	0.28	0.28	0.42	0.42	0.42
5-yr	0.00	0.00	0.00	0.14	0.14	0.14	0.37	0.37	0.37	0.52	0.52	0.52
10-yr	0.00	0.00	0.00	0.20	0.20	0.20	0.44	0.44	0.44	0.59	0.59	0.59
25-yr	0.01	0.01	0.01	0.27	0.27	0.27	0.53	0.53	0.53	0.67	0.67	0.67
50-yr	0.02	0.02	0.02	0.33	0.33	0.33	0.58	0.58	0.58	0.72	0.72	0.72
100-yr	0.04	0.04	0.04	0.38	0.38	0.38	0.63	0.63	0.63	0.75	0.75	0.75
Shrubland												
2-yr	0.00	0.00	0.00	0.13	0.13	0.13	0.34	0.34	0.34	0.50	0.50	0.50
5-yr	0.01	0.01	0.01	0.22	0.22	0.22	0.44	0.44	0.44	0.60	0.60	0.60
10-yr	0.03	0.03	0.03	0.28	0.28	0.28	0.51	0.51	0.51	0.67	0.67	0.67
25-yr	0.05	0.05	0.05	0.36	0.36	0.36	0.60	0.60	0.60	0.74	0.74	0.74
50-yr	0.24	0.24	0.24	0.42	0.42	0.42	0.65	0.65	0.65	0.78	0.78	0.78
100-yr	0.12	0.12	0.12	0.47	0.47	0.47	0.70	0.70	0.70	0.81	0.81	0.81

Table B.1: Continued.

Orchards/Vinyards/Other											
2-yr	0.00	0.00	0.00	0.13	0.13	0.13	0.34	0.34	0.34	0.50	0.50	0.50
5-yr	0.01	0.01	0.01	0.22	0.22	0.22	0.44	0.44	0.44	0.60	0.60	0.60
10-yr	0.03	0.03	0.03	0.28	0.28	0.28	0.51	0.51	0.51	0.67	0.67	0.67
25-yr	0.05	0.05	0.05	0.36	0.36	0.36	0.60	0.60	0.60	0.74	0.74	0.74
50-yr	0.24	0.24	0.24	0.42	0.42	0.42	0.65	0.65	0.65	0.78	0.78	0.78
100-yr	0.12	0.12	0.12	0.47	0.47	0.47	0.70	0.70	0.70	0.81	0.81	0.81
Grasslands/Herbaceous												
2-yr	0.00	0.00	0.00	0.08	0.08	0.08	0.30	0.30	0.30	0.57	0.57	0.57
5-yr	0.00	0.00	0.00	0.15	0.15	0.15	0.40	0.40	0.40	0.66	0.66	0.66
10-yr	0.00	0.00	0.00	0.21	0.21	0.21	0.47	0.47	0.47	0.72	0.72	0.72
25-yr	0.01	0.01	0.01	0.29	0.29	0.29	0.55	0.55	0.55	0.78	0.78	0.78
50-yr	0.02	0.02	0.02	0.34	0.34	0.34	0.61	0.61	0.61	0.82	0.82	0.82
100-yr	0.04	0.04	0.04	0.39	0.39	0.39	0.66	0.66	0.66	0.85	0.85	0.85
Pasture/Hay												
2-yr	0.01	0.01	0.01	0.20	0.20	0.20	0.42	0.42	0.42	0.57	0.57	0.57
5-yr	0.03	0.03	0.03	0.29	0.29	0.29	0.52	0.52	0.52	0.66	0.66	0.66
10-yr	0.05	0.05	0.05	0.36	0.36	0.36	0.59	0.59	0.59	0.72	0.72	0.72
25-yr	0.10	0.10	0.10	0.44	0.44	0.44	0.67	0.67	0.67	0.78	0.78	0.78
50-yr	0.15	0.15	0.15	0.50	0.50	0.50	0.72	0.72	0.72	0.82	0.82	0.82
100-yr	0.19	0.19	0.19	0.55	0.55	0.55	0.75	0.75	0.75	0.85	0.85	0.85
Row Crops												
2-yr	0.16	0.16	0.16	0.39	0.39	0.39	0.60	0.60	0.60	0.74	0.74	0.74
5-yr	0.25	0.25	0.25	0.49	0.49	0.49	0.69	0.69	0.69	0.81	0.81	0.81
10-yr	0.32	0.32	0.32	0.56	0.56	0.56	0.74	0.74	0.74	0.85	0.85	0.85
25-yr	0.40	0.40	0.40	0.64	0.64	0.64	0.80	0.80	0.80	0.90	0.90	0.90
50-yr	0.46	0.46	0.46	0.70	0.70	0.70	0.84	0.84	0.84	0.93	0.93	0.93
100-yr	0.51	0.51	0.51	0.73	0.73	0.73	0.87	0.87	0.87	0.95	0.95	0.95
Small Grains												
2-yr	0.10	0.10	0.10	0.32	0.32	0.32	0.53	0.53	0.53	0.67	0.67	0.67

Table B.1: Continued.

5-yr	0.18	0.18	0.18	0.42	0.42	0.42	0.63	0.63	0.63	0.75	0.75	0.75
10-yr	0.25	0.25	0.25	0.49	0.49	0.49	0.70	0.70	0.70	0.80	0.80	0.80
25-yr	0.32	0.32	0.32	0.57	0.57	0.57	0.76	0.76	0.76	0.85	0.85	0.85
50-yr	0.38	0.38	0.38	0.63	0.63	0.63	0.80	0.80	0.80	0.88	0.88	0.88
100-yr	0.43	0.43	0.43	0.68	0.68	0.68	0.83	0.83	0.83	0.91	0.91	0.91
Fallow												
2-yr	0.37	0.37	0.37	0.63	0.63	0.63	0.80	0.80	0.80	0.92	0.92	0.92
5-yr	0.47	0.47	0.47	0.72	0.72	0.72	0.87	0.87	0.87	0.96	0.96	0.96
10-yr	0.54	0.54	0.54	0.77	0.77	0.77	0.90	0.90	0.90	0.99	0.99	0.99
25-yr	0.62	0.62	0.62	0.83	0.83	0.83	0.94	0.94	0.94	0.99	0.99	0.99
50-yr	0.67	0.67	0.67	0.86	0.86	0.86	0.97	0.97	0.97	0.99	0.99	0.99
100-yr	0.72	0.72	0.72	0.89	0.89	0.89	0.99	0.99	0.99	0.99	0.99	0.99
Urban/Recreational Grasses												
2-yr	0.00	0.00	0.00	0.08	0.08	0.08	0.30	0.30	0.30	0.45	0.45	0.45
5-yr	0.00	0.00	0.00	0.15	0.15	0.15	0.40	0.40	0.40	0.55	0.55	0.55
10-yr	0.01	0.01	0.01	0.21	0.21	0.21	0.47	0.47	0.47	0.61	0.61	0.61
25-yr	0.02	0.02	0.02	0.29	0.29	0.29	0.55	0.55	0.55	0.69	0.69	0.69
50-yr	0.04	0.04	0.04	0.34	0.34	0.34	0.61	0.61	0.61	0.74	0.74	0.74
100-yr	0.06	0.06	0.06	0.39	0.39	0.39	0.66	0.66	0.66	0.77	0.77	0.77
Woody Wetlands												
2-yr	0.00	0.00	0.00	0.06	0.06	0.06	0.28	0.28	0.28	0.42	0.42	0.42
5-yr	0.00	0.00	0.00	0.14	0.14	0.14	0.37	0.37	0.37	0.52	0.52	0.52
10-yr	0.00	0.00	0.00	0.20	0.20	0.20	0.44	0.44	0.44	0.59	0.59	0.59
25-yr	0.01	0.01	0.01	0.27	0.27	0.27	0.53	0.53	0.53	0.67	0.67	0.67
50-yr	0.02	0.02	0.02	0.33	0.33	0.33	0.58	0.58	0.58	0.72	0.72	0.72
100-yr	0.04	0.04	0.04	0.38	0.38	0.38	0.63	0.63	0.63	0.75	0.75	0.75
Emergent Herbaceous Wetlands												
2-yr	0.00	0.00	0.00	0.08	0.08	0.08	0.30	0.30	0.30	0.57	0.57	0.57
5-yr	0.00	0.00	0.00	0.15	0.15	0.15	0.40	0.40	0.40	0.66	0.66	0.66
10-yr	0.00	0.00	0.00	0.21	0.21	0.21	0.47	0.47	0.47	0.72	0.72	0.72

Table B.1: Continued.

25-yr	0.01	0.01	0.01	0.29	0.29	0.29	0.55	0.55	0.55	0.78	0.78	0.78
50-yr	0.02	0.02	0.02	0.34	0.34	0.34	0.61	0.61	0.61	0.82	0.82	0.82
100-yr	0.04	0.04	0.04	0.39	0.39	0.39	0.66	0.66	0.66	0.85	0.85	0.85

Table B.2: Complete table of the accepted runoff coefficients.

HSG	A	A	A	B	B	B	C	C	C	D	D	D
Slope	0	2	6	0	2	6	0	2	6	0	2	6
Open Water												
2-yr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5-yr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10-yr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
25-yr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
50-yr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
100-yr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Perennial Ice/Snow												
2-yr	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
5-yr	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
10-yr	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
25-yr	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
50-yr	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
100-yr	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Low Intensity Residential												
2-yr	0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
5-yr	0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
10-yr	0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
25-yr	0.25	0.29	0.32	0.28	0.32	0.36	0.31	0.35	0.42	0.34	0.38	0.48
50-yr	0.25	0.29	0.32	0.28	0.32	0.36	0.31	0.35	0.42	0.34	0.38	0.48
100-yr	0.25	0.29	0.32	0.28	0.32	0.36	0.31	0.35	0.42	0.34	0.38	0.48
High Intensity Residential												
2-yr	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
5-yr	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
10-yr	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
25-yr	0.30	0.34	0.37	0.33	0.37	0.42	0.36	0.40	0.47	0.38	0.42	0.52

Table B.2. Continued.

50-yr	0.30	0.34	0.37	0.33	0.37	0.42	0.36	0.40	0.47	0.38	0.42	0.52
100-yr	0.30	0.34	0.37	0.33	0.37	0.42	0.36	0.40	0.47	0.38	0.42	0.52
Commercial/Industrial/Transportation												
2-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
5-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
10-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
25-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
50-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
Bare Rock/Sand/Clay												
2-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
5-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
10-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
25-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
50-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
Quarries/Strip Mines/Gravel Pits												
2-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
5-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
10-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
25-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
50-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
Transitional												
2-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
5-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
10-yr	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
25-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
50-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90
100-yr	0.88	0.88	0.89	0.89	0.89	0.89	0.84	0.89	0.90	0.89	0.89	0.90

Table B.2. Continued.

Deciduous Forest												
2-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
5-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
25-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
50-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Evergreen Forest												
2-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
5-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
25-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
50-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Mixed Forest												
2-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
5-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
25-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.2	0.25
50-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.2	0.25
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.2	0.25
Shrubland												
2-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
5-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
10-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
25-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
50-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
100-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Orchards/Vinyards/Other												
2-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40

Table B.2. Continued.

5-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
10-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
25-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
50-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
100-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Grasslands/Herbaceous												
2-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
5-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
10-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
25-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
50-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
100-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
Pasture/Hay												
2-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
5-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
10-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
25-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
50-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
100-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
Row Crops												
2-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
5-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
10-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
25-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
50-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
100-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Small Grains												
2-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
5-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
10-yr	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31

Table B.2. Continued.

25-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
50-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
100-yr	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Fallow												
2-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
5-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
10-yr	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
25-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
50-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
100-yr	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.57
Urban/Recreational Grasses												
2-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
5-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
10-yr	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
25-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
50-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
100-yr	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Woody Wetlands												
2-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
5-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
25-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
50-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Emergent Herbaceous Wetlands												
2-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
5-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
10-yr	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
25-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
50-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25

Table B.2. Continued.

100-yr	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25

Source: Soil Conservation Service (SCS). (1986). Urban Hydrology for Small Watersheds. Technical Release 55 (TR-55), 2nd Edition, Department of Agriculture, Washington, D.C.

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