EFFECTS OF LAND USE ON RUNOFF CURVE NUMBERS

by

P. DeAnne Rietz

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SIGNED: 8-19-99

APPROVAL BY THESIS DIRECTORS

This thesis has been approved on the date shown below:

Richard H. Hawkins

Dr. Richard H. Hawkins
Professor of Watershed Management
Thesis Director

8/19/99
Date

Dr. Allen T. Hjelmfelt, Jr.
Research Hydraulic Engineer, ARS

8/16/99
Date

Dr. George Ball
Assistant Research Professor

8/16/99
Date

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ABSTRACT

The Runoff Curve Number method is a widely used and accepted technique for modeling runoff in ungaged watersheds. Input variables for this method include soil type, watershed condition, land use and cover density. The land use variable was isolated and evaluated at 3 scales (local, regional and national) using rainfall-runoff data from 177 small watersheds around the United States. Curve Numbers were calculated for each land use at each watershed. Differences at the 5% significance level were found in land use Curve Numbers at all three scales. Meadow usually produced the lowest Curve Number at the local and regional level. No difference could be determined between pasture and range at the regional level. At the national scale forest had the lowest Curve Number, meadow was second lowest and brush Curve Number was highest. No difference could be determined between Curve Numbers from row crops or small grain at any scale.

CHAPTER 1

INTRODUCTION

Runoff estimates from rainstorms concern engineers, land managers and hydrologists when designing hydraulic structures, performing evaluations of watershed conditions and appraising flood events. One of the most widely used techniques to estimate runoff is the SCS (Soil Conservation Service, now Natural Resources Conservation Service) Curve Number method. This is a straightforward method that incorporates soil type, watershed condition, land use and cover density to determine runoff. The land use variable and how it affects the Curve Number is the focus of this study.

1.1 Importance

The runoff Curve Number (CN) method originated from, and is documented by, the United States Department of Agriculture. It was developed as a tool to aid in the task of determining the estimated storm event runoff from ungaged small watersheds. The method has gained national and even international popularity for use in hydrologic design. Much of this popularity, according to Ponce and Hawkins (1996), is due to the support from a federal agency, and because the model is simple to use and predictable.

Runoff estimates are needed for ungaged watersheds. With the Curve Number model, an experienced professional can estimate runoff for ungaged watersheds using tables and simple equations developed by the Natural Resources Conservation Service (NRCS). These tables and equations are published in the National Engineering Handbook, Section

4, Hydrology (NEH-4) and require only basic interpretive inputs of physical watershed characteristics (soil type, land use and condition) to estimate a watershed's "Curve Number." Using this Curve Number value and NRCS equations one can easily calculate expected runoff for a given amount of rainfall on a watershed.

This method of modeling runoff in ungaged watersheds was the original intent of the Curve Number method. When using this method an accurate determination of Curve Number is vital. Hawkins (1975) contends errors in Curve Numbers are more serious than errors in rainfall if modeling runoff for rainfall depth up to 9 inches. This is supported by another sensitivity study where the effects of Curve Number variation in runoff models were found to decrease with increase rainfall (Bondelid et al., 1982).

In its modern form the Curve Number method of estimating runoff can stand alone as the simple watershed model described above, or can be used in conjunction with other models. With the advent of computer modeling the Curve Number method has been adapted for use as the internal runoff-estimating component of more complex watershed models for estimation of watershed runoff (Bonta, 1997). Examples of this include prevalent models like HEC-1, TR-20, TR-55 (Grove et al., 1998) and SPUR (Wight and Skiles, 1987).

Attention to hydrologic modeling is essential because inaccurate design can influence the cost of a project immensely. Use of the Curve Number method in hydrologic modeling of ungaged watersheds is expected to continue until there is an alternative method that can fill this niche in runoff modeling. Because the Curve Number model is so widely accepted and used it is important to verify the method, investigate inputs and understand the effects inputs may have on results.

1.2 History

During the 1940-1950's there was extensive need in the United States for research and development on soil conservation measures. In response to legislative rule set forth by the Watershed Protection and Flood Prevention Act of 1954 the Soil Conservation Service developed a hydrologic guide (Plummer and Woodward, 1998). This guide is now known as NEH-4 and contains the methodology of the SCS Runoff Curve Number Equation:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad \text{for } P \geq 0.2S, \tag{1a}$$

$$Q = 0 \qquad \text{for } P < 0.2S, \tag{1b}$$

where,

Q = direct storm runoff in inches
P = storm rainfall in inches
S = watershed storage index in inches.

In order to have a variable that was easier to work with (one that runs from 0-100 and increases with increased runoff) S was transformed into the more intuitive Curve Number with the equation:

$$CN = \frac{1{,}000}{10+S}. \qquad (2)$$

Equation (1a) has initial abstraction built in ($I_a = 0.2S$) and assumes the baseflow component, if applicable, has been separated.

The NEH-4 handbook and numerous subsequent publications contain a table of Runoff Curve Numbers for a variety of land uses, hydrologic soil groups and watershed conditions. This table, referred to as Table 9.1, was developed from data from agricultural areas of eastern and midwestern United States. Table 9.1 is a current tool used to obtain Curve Numbers for ungaged watersheds and is reproduced here in Appendix A. Even though the Curve Number table is widely used, values represented in the table are not well documented (Hawkins and Ward, 1998) and tests to verify the procedure have not been widely published (Hjelmfelt, 1980).

1.3 Objective

The basic underlying assumption of watershed management is that runoff from a watershed is affected by land use, hence one can assume the Curve Number method of modeling runoff is also affected by land use. The objectives of this study were to:

(1) develop a better understanding of the land use variable as it applies to the Curve Number method for estimating storm runoff;

(2) isolate the land use variable on a large data set of small sized watersheds;

(3) determine land use Curve Numbers for each of these watersheds;

(4) examine patterns in land use Curve Numbers at a local, regional and national scale.

Data in this study contained detailed land use information on 177 watersheds covering 2,455 years of record and 32,891 events. Resources of this magnitude were unavailable at the time Table 9.1 was developed; therefore a better understanding of the effects of land use on the Curve Number may develop. In concurrence with the assumption of watershed management, the hypothesis for this study is there will be a difference in the Curve Number of a watershed depending on its land use.

Chapter 2

Literature Review

2.1 Definition of land use

Land use on a watershed, as defined by the Natural Resources Conservation Service in Chapter 8 of NEH-4, is every kind of vegetation cover (including litter, mulch and fallow), nonagricultural uses (such as lakes, rivers and swamps) and impervious surfaces (roads, roofs, etc.). Vegetative land use is divided into three categories (1) cultivated land, (2) grassland and (3) woods and forest. These vegetative land uses are further broken down into specific land use classes that appear in NEH-4 Table 9.1. NRCS land use classes so listed include:

Cultivated lands

- *fallow* - the highest potential for runoff because the land is kept bare as possible;
- *row crop*- any crop planted in rows far enough apart to expose soil surface to rainfall impact throughout growing season (includes corn, sorghum and soy bean);
- *small grain* – planted in rows close enough so as to not expose soil surface once vegetation is established (includes wheat and oats);
- *close-seeded legumes or rotation meadow* – includes alfalfa or sweetclover that is allowed to remain for a year or more giving year-round soil protection;

Grassland

- *pasture or range* – grassland watershed that is grazed;
- *meadow* – a field of continuously grown grass, protected from grazing and usually mowed for hay;

Woods and forest

- *woods* – isolated groves of trees;
- *forest* – a watershed of which a large part is covered with trees.

This study focused on vegetative cover land use. It favored agricultural land use because the majority of quality data (with long years of record) available for analysis were from cultivated lands.

2.2 Previous land use/Curve Number studies

The Curve Number Tables in NEH-4 have been changed only slightly since their conception in 1954 and few studies have been done on land use-Curve Number relationships. Hawkins (1980) noted there are a limited number of land uses contained within Table 9.1 and most are of agricultural type from humid areas. Additional tables can be found in NEH-4 chapter 9 with Curve Number values for special climate regions of Hawaii, Puerto Rico and Contra Costa County, California. The lack of selection for vegetation types and land use in semi-arid regions or humid wildlands is obvious.

A study of runoff in Hawaii compared data derived Curve Numbers for sugarcane and pineapple to handbook table values (Cooley and Lane, 1980). The Curve Number for sugar cane was found to be slightly lower than table values, but not enough to change design criteria significantly. However, data derived Curve Number for pineapple was considerably lower than handbook values. The difference was significant enough that Cooley and Lane (1980) suggested design procedures for watersheds planted in pineapple need to be modified. They attributed these lower Curve Number values to the fact that pineapple plants provide more soil protection than expected.

Rangeland Curve Numbers were verified and documented by comparing calculated Curve Numbers for 25 Northern Great Plains watersheds to table derived values (Hanson et al., 1981). Rainfall-runoff data was used to compute an optimized Curve Number for each watershed as an indication of a range of Curve Numbers to expect. It was reported that the optimized values varied considerably, but their range always included the table-derived value. Hanson et al. (1981) concluded the NEH-4 Curve Number tables and procedures are good working tools for computing runoff from rangeland.

Another rangeland study was performed (Hawkins and Ward, 1998) using rainfall-runoff data to determine Curve Numbers for 21 rangeland plots in southern New Mexico. They compared data-defined Curve Numbers to handbook estimates and found few similarities between the two values. A reason suggested for the dissimilarity in Curve Numbers was that soil is a more important parameter than vegetation in arid regions with limited hydrology. A trend however, was observed with plant cover, higher percent cover consistently resulted in lower Curve Number values (Hawkins and Ward, 1998).

A study of seasonal variation in the runoff Curve Number examined patterns of cyclic variation in watersheds with the land use of forest, meadow and grassland (Price, 1998). A well-defined cyclic pattern was apparent in the forested watersheds where lower Curve Numbers were observed from May to October. The only seasonal variation found in Curve Numbers for cropped watersheds was for meadow during the summer.

Runoff modeling and simulation with geographic information system (GIS) has proliferated within the last several years, bringing about another application of the Curve Number method. With GIS it is a relatively easy task to assign a Curve Number to each cell or polygon in a watershed database using the soil and land use of that cell or polygon. In a study by Grove et al. (1998) a corresponding runoff depth was calculated for each cell or polygon by applying equations (1a) and (2). These depths were then averaged to determine an estimated runoff depth for the entire watershed. Grove et al. (1998) calls this method of calculating a watershed's runoff the distributive Curve Number method. Their study found the distributive Curve Number superior to the composite (area weighted) Curve Number which is currently the most common use of Curve Numbers in complex runoff modeling today.

2.3 Effects of land use on runoff

According to Chow (1964) two major groups of factors affect runoff from a watershed: climatic factors and physiographic factors. Land use is included among the physiographic factors. Table 2.1 is a list of components within these major factors.

Table 2.1: Factors affecting runoff from a watershed

Factor	Variables
Climatic	• Precipitation ▯ form, type, intensity, duration, frequency, storm movement • Interception ▯ climate dependent vegetation, seasonal effects, age, density • Evaporation ▯ temperature, wind, atmospheric pressure • Transpiration ▯ temperature, wind, solar radiation, humidity, soil moisture
Physiographic	• Basin characteristics ▯ Geometric: size, shape, slope, orientation, elevation, stream density ▯ Physical: land use, cover, infiltration, soil type • Channel characteristics ▯ Size and shape of cross section, slope, roughness, length, backwater effect

Source: Chow, 1964

In truth, any land use that triggers instability can initiate hydrological adjustment of a watershed and thus alter runoff. Small basins are very sensitive to land use (Chow, 1964). In these terms a small drainage is one where its sensitivity to land use is not depressed by channel characteristics. This could be a few acres to 1,000 acres or even up to 100 square miles.

Watershed stormflow studies usually consider land use impacts only at the watershed outlet, but the effects of land use on the magnitude of storm runoff can be diminished as the event moves downstream (Brooks et al., 1997). Many watershed characteristics remain constant; such as size, shape and slope however, the soil-plant system is dynamic and can alter the runoff response of a watershed. Brooks et al. (1997) articulated on ways in which land use will affect stormflow, some of which include:

- conversion between plants with high transpiration and interception losses and those with low transpiration and interception losses
- removal of vegetation
- any land use that alters infiltration capacity of the soil like intensive grazing, road construction and logging

The hydrological effect of land use as defined in NEH-4 (Chapter 12) is any land use that changes the volume of direct storm runoff from a watershed. Land use resulting in a change to plant or root density can alter runoff by altering infiltration capacities. For example, converting row crops to grass will increase infiltration capacities. Changes in plant interception are considered to have only a minor effect in total runoff volume.

Crop rotations are practiced in agricultural land use as a way to increase infiltration. They are planned sequences of crops on a watershed and are evaluated in terms of hydrological effects (NEH-4, Chapter 8). Rotations are given hydrological classifications of either poor or good according to the effects on infiltration. Poor rotations are usually one-crop land uses or a combination of row crops only. Good rotations are comprised of more than row crops and typically contain a crop like alfalfa (or any other close-seeded legume or grass) which will increase infiltration.

Land use associated infiltration rates are lowest for fallow and row crops and slightly higher for small grain crops. Practicing good rotation with any of these crops will improve the infiltration rate, thus decreasing the amount of storm runoff from a watershed. According to NEH-4, the highest infiltration rates are associated with land uses of meadow, woods or forest in good hydrologic condition. Hydrologic condition is based on cover effectiveness due to grazing and is evaluated by grazing intensity or air-dry weight of grass and litter. Grazing on soils, with the exception of dry soil, will cause soil compaction and lower infiltration rates because of trampling by hooves.

When Table 9.1 in NEH-4 is used to estimate a Curve Number for a watershed one must first evaluate and classify the watershed's hydrologic condition according to land use. The NRCS classification scheme for hydrologic condition on pasture and range is shown in Table 2.2 for grazing evaluation and Table 2.3 for air-dry weight evaluation. Table 2.4 is the classification of hydrological condition for woods.

Table 2.2: Classification of native pasture or range Hydrologic Condition

Vegetative condition	Hydrologic condition
Heavily grazed. Has no mulch or has plant cover on less than ½ of the area.	Poor
Not heavily grazed. Has plant cover on ½ to ¾ of the area.	Fair
Lightly grazed. Has plant cover on more than ¾ of the area.	Good

Source NEH-4 table 8.1.

Table 2.3: Air-dry weight classification of native pasture or range Hydrologic Condition

Cover density (%)	Plant and litter Less than 0.5	air-dry weight 0.5 – 1.5	(tons/ac) >1.5
Less than 50	Poor	Poor +	Fair
50 – 75	Poor +	Fair	Fair +
More than 75	Fair	Fair +	Good

Source NEH-4 table 8.2 + midway between classes

Table 2.4: Classification of Woods for Hydrologic Condition

Vegetative condition	Hydrologic condition
Heavily grazed or regularly burned. Litter, small trees, and brush are destroyed.	Poor
Grazed but not burned. There may be some litter but these woods are not protected.	Fair
Protected from grazing. Litter and shrubs cover the soil.	Good

Source NEH-4 table 8.3

2.4 The Curve Number method

The Curve Number method is a conceptual model of abstraction of storm rainfall for estimating direct runoff volume (Ponce and Hawkins, 1996). It is based on the Curve Number, a dimensionless numerical conversion of environmental inputs: land use/treatment, watershed condition, antecedent moisture condition and soil. Details of land use/treatment and watershed condition inputs are discussed in section 2.1 and 2.3 respectively. Antecedent moisture condition can be thought of as a proxy for other sources of variability, including soil moisture. Soils are classified by hydrological soil groups according to soil depth, infiltration capacity and transmission rate on a scale from A-D, where A soil has the lowest runoff potential and D soil has the highest (see Table 2.5).

Table 2.5: Definition of hydrologic soil groups

Hydrologic Soil Group	Definition
A	Deep well drained sands or gravels with high infiltration and water transmission rates
B	Moderately fine to coarse texture soils with moderate infiltration and water transmission rates
C	Moderately fine texture soils that may have a layer that impedes downward movement of water, with slow infiltration and water transmission rates
D	Clay soils with permanent high water table or shallow soils over impervious material, with very slow infiltration and water transmission rates.

Adapted from NEH-4

A complete list of hydrological soil groups is given in NEH-4 for more than 4,000 soils in the United States and Puerto Rico.

The Curve Number can be considered as a surrogate for potential retention. Values range from 0 to 100, where 0 produces no runoff and 100 results in all storm rainfall being converted to runoff. The Curve Number method was not originally intended to account for long-term losses such as evaporation or evapotranspiration nor does it take into account spatial and temporal variability of a watershed. Because of this, Ponce and Hawkins (1996) maintain the Curve Number method can only describe average trends and it is impossible for the method to be completely predicative.

Curve Numbers derived from local rainfall-runoff data are a truer estimate of a watershed's Curve Number than those obtained from handbook Tables. For data-derived Curve Numbers Hjelmfelt (1980) proposed the concept of applying frequency matching to the Curve Number technique. He followed the logic that there is a relationship between frequency distributions of rainfall and runoff. The return period rainfall is used to estimate the return period runoff; thus events of equal return period should be used in Curve Number determination.

This frequency matching method was used by Hjelmfelt (1980) to test the validity of the Curve Number method. Instead of using naturally occurring rainfall-runoff pairs as inputs into the Curve Number method the data are ordered separately by magnitude, then frequency matched by realignment to form P:Q pairs corresponding to the same recurrence probability. When calculating a return-period runoff from the same return-period rainfall in this manner, the Curve Number method is a transformation between rainfall distribution and runoff distribution.

An asymptotic determination, data-derived procedure for calculating watershed Curve Numbers was developed by Hawkins (1993) using event rainfall and direct runoff data from small watersheds. This technique uses equation (1a) to solve for S:

$$S = 5\left[P + 2Q - (4Q^2 + 5PQ)^{\frac{1}{2}}\right]. \qquad (3)$$

Frequency matched P:Q pairs (i.e., sorted separately, ordered and re-paired) are inserted into equation (3) for all P:Q pairs (0<Q<P) in the data set. Thus, a Curve Number can be calculated for each ordered P:Q pair using equation (2). When these Curve Numbers are plotted against rainfall (CN vs P) a pattern typically emerges and the Curve Number will typically approach an asymptotic constant value with increasing P.

Hawkins (1993) found several variations on the asymptotic pattern. The standard data response to this method of Curve Number determination is a decrease in Curve Number with increased rainfall, and then an approach to a constant value. To determine the asymptotic limit for ordered data pairs Hawkins (1993) adapted the Standard fitting equation:

$$CN(P) = CN_\infty + (100 - CN_\infty)e^{-k_1 P} \qquad (4)$$

where CN(P) is a P dependent Curve Number, CN_∞ is the constant value reached as P approaches ∞ and k_1 is a fitting coefficient.

Another not so common variation on the asymptotic pattern, referred to by Hawkins (1993) as Violent behavior, is characterized by a sudden rise in Curve Number with increasing P before approaching a constant asymptotic value. He attributes this violent behavior to a threshold phenomenon exhibited by the watershed at some critical rainfall depth. The fitting equation for this type of data set is:

$$CN(P) = CN_{\infty}(1 - e^{-k_2 P}) \qquad \text{for all } P > P_{\text{threshold}} \qquad (5)$$

where $P_{\text{threshold}}$ is the rainfall depth at which violent response begins and is determined by inspecting the CN-P plot, and k_2 is a different fitting coefficient.

A third variation in the pattern is a consistent decline of Curve Number values with increasing rainfall and no asymptote emerging. This is Complacent behavior and a constant Curve Number value is never reached. An asymptotic Curve Number for the watershed cannot be determined with confidence from this type of data set. But nevertheless, data of this nature can be fit to equation 4 so an estimate of Curve Number infinity (CN_{∞}). This estimate of Curve Number is performed for consistency and descriptive purposes.

Chapter 3

Methods

Land use Curve Numbers for this study were derived from local rainfall-runoff data and land use information for 179 small watersheds across the Untied States. Appendix B is a list of these watersheds, their size, location, land use and period of record. I will first enumerate data sources used in this study then explain in detail the criteria utilized for classification of different land uses. Next, I will expand upon the process by which rainfall-runoff events were extracted from data and finally explain how the Curve Number for each watershed was determined.

3.1 Data

The majority of data used here were retrieved from the Agricultural Research Service (ARS) Water Data Center. The Data Center is a division of the ARS Hydrology Lab, a research unit of the US Department of Agriculture that specializes in methods for predicting water yield, impacts of management practices and environmental changes on water resources. The Water Data Center is located in Beltsville, Maryland and maintains the ARS Water Database, a national archive of data from small experimental watersheds (ranging from 0.5 acres to 4,786 square miles) throughout the United States.

The Database is a collection of variable time-series readings of precipitation and runoff and a variety of ancillary data such as air temperature, land management practices, topography and soils information. The detail of precipitation and runoff data is such that hydrographs and hyetographs can be reconstructed. Data of individual watersheds vary from 1 to 50 years of record, some of which have been in continuous operation since the 1930's. These data are made available in several different forms; transmitted, compact disk, diskette, magnetic tape or hardcopy print (Agricultural Research Service Water Data Center, 1995). The most accessible form is transmitted data via anonymous ftp from the ARS Internet site: *hydrolab.arsusda.gov/arswater.html.* For all other forms of data media one needs only to contact the ARS Water Data Center. Table 3.1 is a list of ARS locations used for this study and the number of watersheds used within each location.

Table 3.1: Location of all ARS watersheds used in this study

Location	ARS ID #	Number of watersheds used from location
Watkinsville, GA	10	1
Lafayette, IN	19	2
Coshocton, OH	26	20
Cherokee, OK	34	6
Guthrie, OK	35	9
Stillwater, OK	37	3
Riesel, TX	42	21
Hastings, NE	44	25
Albuquerque, NM	47	2
Oxford, MS	62	1
Tombstone, AZ	63	7
Moorefield, WV	66	4
Reynolds, ID	68	1
Chickasha, OK	69	5
Sonora, TX	70	9
Treynor, IA	71	4

Extensive detail information concerning ARS watershed descriptions and land use was obtained from the ARS book series *Hydrologic Data for Experimental Agricultural Watersheds in the United States* (Burford, 1971 and 1972), (Burford and Clark, 1973 and 1976), (Burford, Clark, DeLashmutt and Roberts, 1979), (Burford, DeLashmutt and Roberts, 1980a, 1989b and 1981), (Burford, Thurman and Roberts, 1982, 1983 and 1985), (Hobbes. 1963 and 1968), (Hobbes and Burford, 1970), (Hobbes and Crammatte, 1965), (Thurman and Roberts, 1986 and 1989) and (USDA, 1967). These publications are better known as the "Green" or "Black" books. Land use data for ARS watersheds were also obtained from Spomer et al. (1981), USDA Central Great Plains Experimental Watershed Summary Report (1968) and USDA Washita River Watershed Research Findings (1968).

Other sources of data for this research were United States Forest Service (USFS) and United States Geological Survey (USGS). All non-ARS rainfall-runoff data, with the exception of Beaver Creek, Arizona, was received in reduced P:Q event format. Land use information was generally extracted from agency reports or published papers. Table 3.2 details the source of data for all non-ARS watershed used in this study, their geographic location and the number of watersheds used from each location.

Table 3.2: Source of non-ARS data

Watershed	Source	Number of watersheds used	Publication
Beaver Creek, AZ	USFS	3	Beaver Creek Biosphere Reserve, 1999
Badger Wash, CO	USGS	8	Lusby, 1973
Boco Mt., CO	USGS	4	Lusby, 1979
Silver Creek, ID	USFS	5	McGurk, 1982
Whitehall, GA Hubbard Brook, NH Fernow, WV Berea, KY Leading Ridge, PA Coweeta, NC Charleston, SC	USFS	1 1 1 1 1 1 2 2	Hewlett, Cunningham and Troendle, 1977 Hewlett and Fortson, 1984
Wyoming	USGS	22	Craig and Rankl, 1973 Rankl and Barker, 1977

At the onset of this study I had access to rainfall-runoff data for 391watersheds, however final analysis was done on 177 watersheds, with a size range of 0.24 - 11307 acres and a median size of 4.05 acres (see Appendix B). Reasons to eliminate a watershed from this study were (1) little or no land use information was available, (2) land use within the watershed varied spatially or (3) too few storm events in record to accurately determine a Curve Number.

3.2 Land use determination

All ancillary data was perused for land use information and in order for a watershed to be considered for this study detail land use information must exist. If land use data was fragmented or inconsistent it was assumed to be inappropriate for this study and the watershed was eliminated. Also, only watersheds in a single land use were considered, where one land use applied to at least 90% of a watershed's total area was the criteria used to define single land use.

Land uses were identified according to the NRCS land use classes as described in chapter one and then tabulated by regions. The most common land use found within the data was agronomy in nature, with only a few exceptions. Watershed land uses analyzed in this study were:

- alfalfa (close-seed legume)
- corn (row crop)
- cotton (row crop)
- desert shrub
- fallow
- forest
- grassland
- meadow
- oats (small grain)
- pasture
- range
- sage brush
- sorghum (row crop)
- soy bean (row crop)
- wheat (small grain)

Many of the cultivated watersheds had a different land use year to year due to crop rotation, for an example see Table 3.3 which is a portion of the land use table constructed for Hastings, Nebraska. Appendix C is a list, on a per land use basis, of the total number of watersheds, events and years of record used for this study.

Table 3.3: Example of land use table

			HASTINGS, NEBRASKA				
WS ID	44022	44023	44024	44025	44026	44027	44028
yr	18-H	19-H	20-H	21-H	22-H	23-H	24-H
1939	p						
1940	p						
1941	p	f	o	c	w	w	w
1942	p	w	c	o	o	c	w
1943	p	c	o	w	w	o	c
1944	p	o	w	c	c	w	o
1945	p	w	c	o	o	c	w
1946	p	c	o	w	w	o	c
1947	p	o	w	c	c	w	o
1948	p	w	c	o	o	c	w
1949	p	c	o	w	w	o	c
1950	p	o	w	c	c	w	o
1951	p	w	c	o	o	c	w
1952	p	c	o	w	w	o	c
1953	p	o	w	c	c	w	o
1954	p	w	c	o	o	c	w
1955	p						
1956			c corn				
1957	p		o oats				
1958	p		w wheat				
1959	p		f fallow				
1960	p		p pasture				
1961	p						

An inherent challenge in this process was determining at what time during the year a land use would change from one crop to another. When available, the date of planting was used for a start date; otherwise it was assumed a land use was on the watershed a full calendar year.

3.3 Reduction of data

Only a few of the data sets retrieved for this study came in event format. Any rainfall-runoff data that were in the form of instantaneous flow rates (all of ARS data) needed to be reduced to rainstorm and runoff depths in order to perform Curve Number calculations. The software program GETPQ96 was utilized to perform these calculations and produce discrete rainfall-runoff event data.

The GETPQ96 Data Reduction Program Series was developed at The University of Arizona by Dripchak (1992) and was enhanced to its present form by Simas et al. (1997). The software is actually a series of programs or modules set to perform assorted hydrological tasks:

- reduce contiguous rainfall and runoff data files from USDA/ARS Hydrologic Data Bank format into rainfall-runoff events
- produce hydrographs and hyetographs
- calculate event statistics
- calculate annual values of rainfall and runoff
- calculate erosivity index

Details of GETPQ96, the modules contained within and a hardcopy of the program itself are found in works by Simas et al. (1997) and Dripchak (1992).

Data input into GETPQ96 are limited to one raingage file and one runoff file. Therefore, if data existed for more than one raingage per watershed, a representative raingage (one assumed to give the most adequate representation of rainfall over the whole watershed) was chosen from ARS maps. Input parameters used to determine event separation were declared at the start of each program run for a watershed. These input variables were kept constant for watersheds used in this study (see Table 3.4) and were in English units to be consistent with original ARS data.

Table 3.4: Input variables for running GETPQ96

Variable	Value	Description
Watershed area	acres	as provided for each watershed
Baseflow separation slope	0.0002 in/hr/hr	separates baseflow from direct runoff
Lag time between storms	2 hr	separates storms effects on runoff generation
Max time from end of rain to start of runoff	2 hr	
Max drizzle time	20 hr	to separate storms
Drizzle intensity	0.01 in/hr	Rainfall intensity below which hydrograph is cut if goes beyond max drizzle time
Minimum depth of rainfall	0.01 in	minimum depth to be considered
Minimum depth of runoff	0.0001 in	minimum runoff depth greater than zero to be considered
Minimum peak runoff rate	0.0001 in/hr	minimum peak runoff rate greater than zero for the event to be considered

A program run of GETPQ96 will produce various output files, two of which were used in this study; the "all" file (*.all) and the "dat" file (*.dat). Examples of both files can be found in Appendix C. The *.all file is a complete event summary file containing paired rainfall-runoff events along with other statistics. Output variables contained within the all file which were relevant to this study are (1) the calendar date of each event, (2) the rainfall depth in inches and (3) its associated runoff depth in inches. The *.dat file is a data file with watershed information, values of input parameters and event information. Output variables retrieved from the *.dat file for this study were (1) the number of runoff events, (2) start year for events and (3) end year for events.

3.4 Calculation of watershed Curve Number

Curve Number analysis for each land use on each watershed was conducted utilizing one of two software programs to calculate the asymptotic constant Curve Number. One program incorporates equation (4) to analyze data displaying standard behavior and the other program uses equation (5) for data displaying violent behavior. A required input to run these programs is a text file of P:Q data. I will first illustrate how these files were created then proceed with detail on how watershed Curve Numbers were determined.

The text file consisted of P:Q event data and their corresponding calendar date. These were obtained from the *.all file of each watershed. Because some watersheds used in this study had several land uses throughout the period of record, a separate text file for each land use of each watershed was made. For instance, watershed 44024 in Hastings, Nebraska (shown in Table 3.2) was in 3 land uses throughout the period of record: oats, corn and wheat. Hence, a text file was made for each 44024o, 44024c and 44024w respectively. The P:Q data within each text file were then ordered for frequency matching.

These P:Q text files were then inputted into the standard asymptotic Curve Number program to obtain land use Curve Numbers for that watershed (see Appendix E for an example of program output). This Curve Number was then visually verified with a CN-P plot of the data. If the data were found to have Violent behavior then the Violent Curve Number program was run. Figure 3.1 is an example of data with a Standard response and Figure 3.2 is an example of data with a Violent response. If the CN-P plot displayed Complacent behavior the Curve Number was not used for analysis. Figure 3.3 is an example of a Complacent data set fitted with the Standard equation (4).

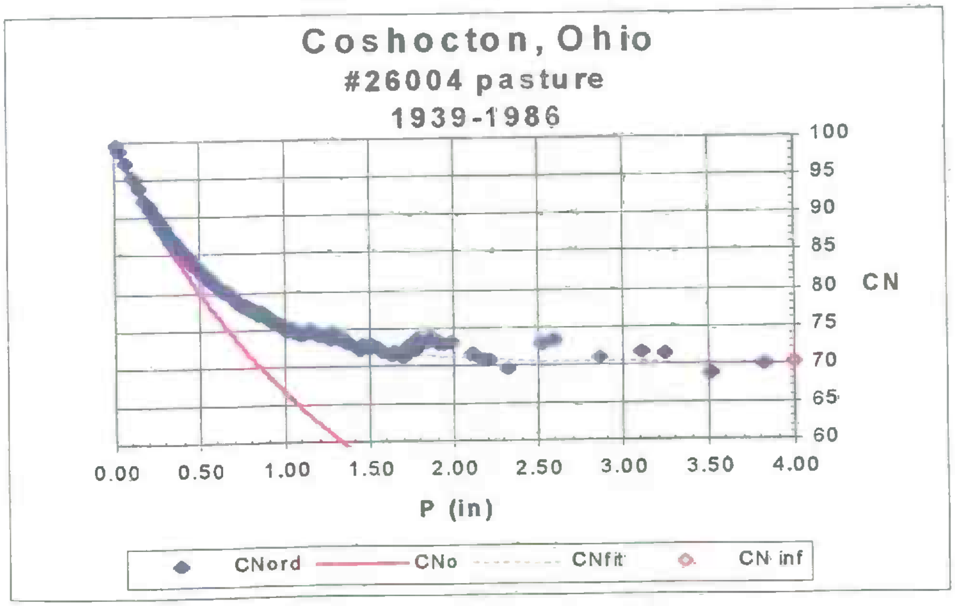

Figure 3.1: Example of standard response from ordered data

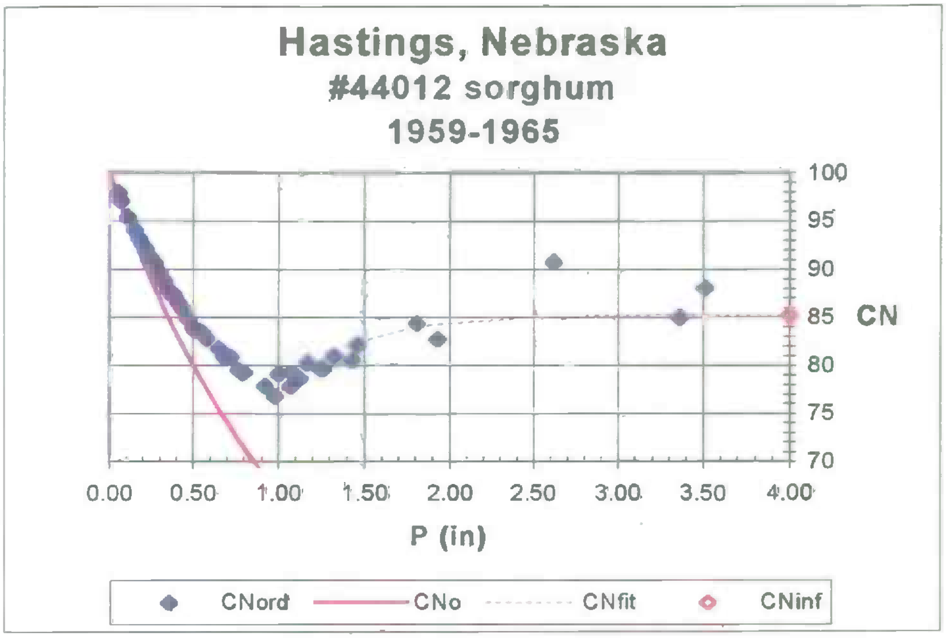

Figure 3.2: Example of violent response from ordered data

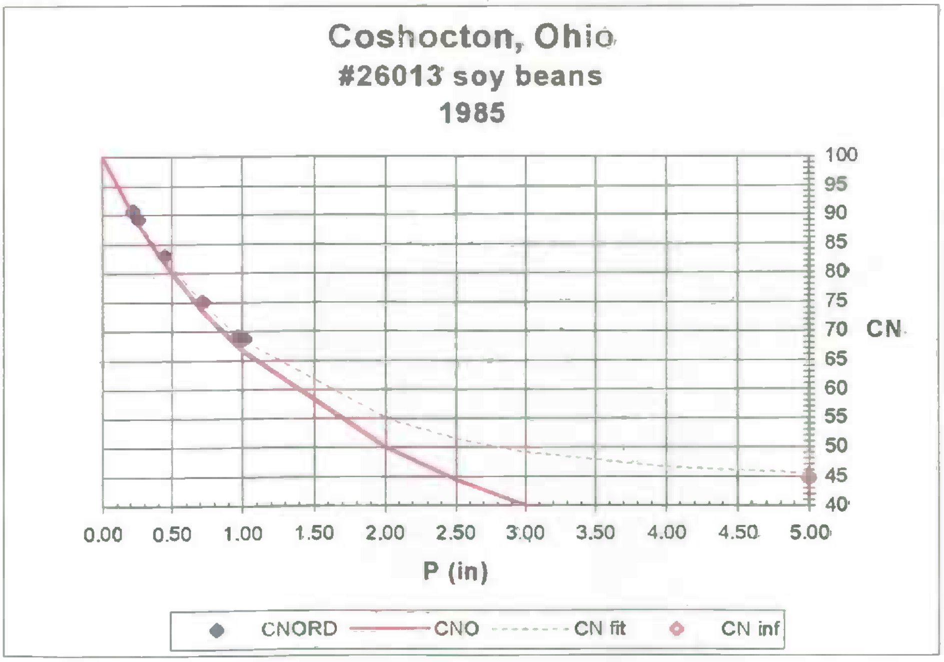

Figure 3.3: Example of complacent behavior from ordered data

In some cases the CN-P plot revealed that the Curve Number produced by either one of the asymptotic programs was not an adequate representation of the data set. In this case the asymptotic Curve Number was rejected and a Curve Number value was assigned by an eyeball fit of the data (Figure 3.4).

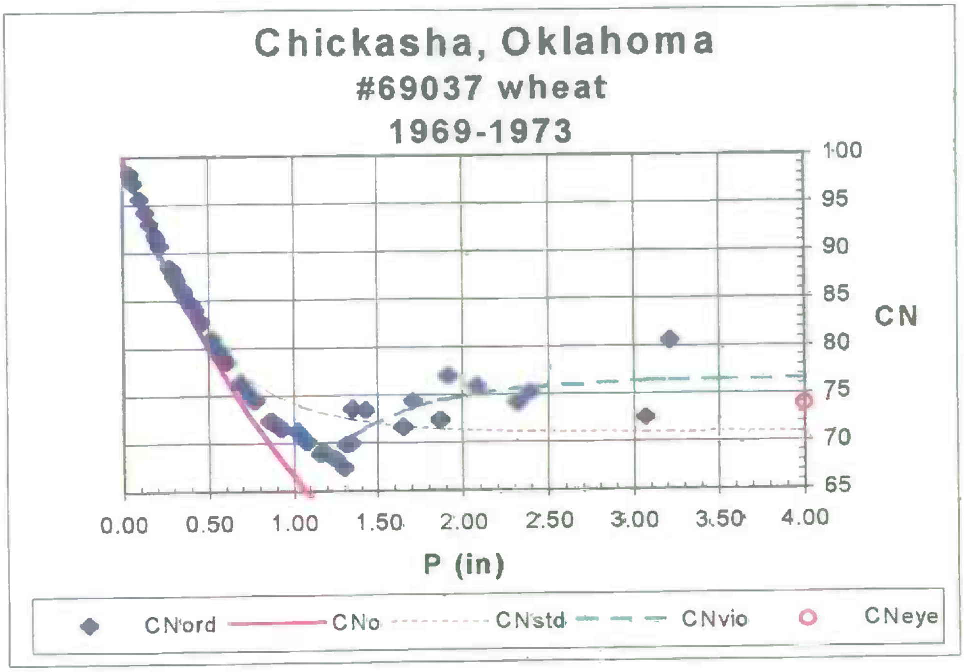

Figure 3.4: Example of fitting data by eye

This study optimized on the value of the data-derived Curve Number using ordered data. Natural data would have produced similar results (within a few Curve Numbers) except there would have been increased scatter. A table of all land use Curve Numbers used in this analysis can be found in Appendix F.

CHAPTER 4

DATA ANALYSIS

Once individual Curve Numbers for each land use on all watersheds were determined the Curve Numbers were analyzed using Winks 4.6, a statistical data analysis program. Statistical procedures used included t-test, ANOVA (Analysis of Variance), simple linear regression and graphical interpretation. Curve Number analysis was performed at three discrete scales; (1) comparison of different land uses within a single watershed, (2) comparison of the same land use between different watersheds within the same location and (3) comparison of the same land use across all watershed locations contained in this data set. The same ANOVA tests were run a second time using only those Curve Numbers with and r^2 greater than 50%.

In addition, an ancillary analysis was performed on differences in Curve Numbers as a result of treatments to the watershed such as land use conversions or extensive conservation practices. The data set contained several watersheds where this had been the case.

4.1 Differences within a watershed

One of the objectives of this study was to identify differences in land use Curve Numbers at a local scale within a watershed. Watersheds that were used for this type of analysis were those that were in rotation or that had their land use permanently converted at some point during the period of record.

An independent group ANOVA test was performed on these watersheds using summary data from their land use Curve Numbers to test the hypothesis that Curve Numbers differ because of land use (H_o: Curve Numbers are equal, H_a: Curve Numbers are not equal). Because Curve Numbers calculated from real storm data typically vary with storm depth in an asymptotic pattern (Hawkins, 1993) it was inappropriate for this study to merely average Curve Number values calculated from a data set of individual rainfall-runoff events. Thus, outputs from the asymptotic Curve Number program were used as inputs into the ANOVA test; the Curve Number infinity (CN_∞) was used as a surrogate for the mean and the standard error was assumed to be equal to the standard deviation (see Appendix E).

Land use graphs were constructed for each watershed using all the data. This graph is constructed in the CN-P plane with the watersheds different land use data overlaid separately. This type of plot illustrates behavioral patterns of each land use within a watershed and rank order of CN_∞ by land use. Regression analysis was performed and graphs were constructed for row crops and small grain crops that were planted on the same watershed.

The data were then refined to include only land use Curve Numbers having a r^2 greater than 50%. Appendix G is a list of the 47 watersheds that were eliminated from the second analysis due to a low r^2. Each ANOVA test was then revisited using the refined data to determine if it would make a difference. This procedure was done to confirm results from the analysis were not due to extremes in the data.

4.2 Differences within a location

To perform analysis within a location all land use Curve Numbers for the location were first grouped according to land use. Descriptive statistics were then used to characterize land use Curve Numbers at each location and an ANOVA test for independence was performed on each group, to test for differences in the means of land use Curve Numbers at that location. For paired watersheds a paired t-test was used for analysis.

Frequency analysis plots were developed for each location using all the land use Curve Numbers. This type of graph is similar to a flood frequency diagram in that the Curve Numbers were ranked and plotting positions were assigned. This was done separately for each land use and overlaid on the same graph to illustrate patterns and differences in land use Curve Numbers within the location.

As previously discussed considerations were made using the refined data with only land use Curve Numbers having a r^2 of greater than 50%. Descriptive statistical analysis and ANOVA tests were performed again for each location in the reduced data.

4.3 Differences across all locations

Finally, all land use Curve Numbers from all data in this study were analyzed together for significant differences. Given the limitations in this type of analysis due to variation in physiographic and climatic characteristics that exist across watersheds, this analysis was performed solely to get a general perspective of land use effects on the Curve Number.

To perform this analysis all Curve Numbers in the data set were grouped together according to land use and descriptive statistics were used to make general characterizations about land use Curve Numbers. An ANOVA test for independence was performed to test for differences in the means of the land use Curve Number.

Graphic illustrations included frequency diagrams and a regression graph using the entire data set. To display differences in all land use Curve Numbers a frequency diagram was constructed in the same manner as previously discussed. One diagram was made for each land use and overlaid with a separate frequency curve for each location. Several regression curves were made to compare land use at different locations.

Once again, the data were then reduced to those land use Curve Numbers with r^2 greater than 50%. Descriptive statistics analysis and ANOVA tests were performed across all locations a second time using the refined data.

CHAPTER 5

RESULTS AND DISCUSSION

Statistical analysis at the .05 significance level was performed on land use Curve Numbers at three different scales; (1) within the watershed, (2) across watersheds within the same location and (3) across all watersheds with the same land use. This chapter is divided into sections, each reporting the results at a different scale. The following table and charts index results of these comparisons. Discussions that follow expand upon these findings and are supplemented with graphs and charts.

5.1 Within a watershed

Of the 175 watersheds used in this study 53 were found to have more than one land use during their period of record. When ANOVA independent group tests were performed 96.23% of the watersheds (51 out of 53) were found to have significant differences among their land use Curve Numbers. Table 5.1 is an account of the watersheds used for this analysis and their respective p-value. The land use for each watershed is listed in ascending order of the land use Curve Number.

Table 5.1 Results of comparing land use Curve Numbers within a watershed

WS	Land Use	Sig Dif	ANOVA p-value	
19004	m,c,sb,w	y	<.001	
19005	m,sb,w,c	y	<.001	
26002	c,p	y	0.028	
26003	m,p	y	<.001	
26010	o,w,c,m,sb	y	<.001	
26011	m,sb,w,c,o	y	<.001	
26012	sb,c,m,w	y	<.001	
26013	m,c,w,o	y	<.001	
26014	m,c,w,p	y	<.001	a = alfalfa
26015	m,w,p,c	y	<.001	c = corn
26016	sb,w,m,c	y	<.001	ct = cotton
26017	sb,m,c,w	y	<.001	db = desert brush
26018	m,w,c	y	<.001	f = fallow
26019	w,m,c,p	y	<.001	g = grass
26020	m,w,c,p	y	<.001	m = meadow
26021	m,c,w	y	0.0092	o = oats
26023	c,m,w	y	<.001	p = pasture
26025	m,w,c	y	<.001	ra = range w/live mesquite
42014	o,s,ct	y	<.001	rb = range w/dead mesquite
42016	s,ct,o	y	<.001	s = sorghum
42017	ct,o,s	y	<.001	sb = soy bean
42036	ra,rb	y	<.001	w = wheat
42037	ct,o,s	y	<.001	
42038	p,ct,o,s	y	<.001	
42039	o,s,ct	y	<.001	
42040	o,s,ct	y	<.001	
44005	m,s	y	<.001	
44006	m,p	y	<.001	
44007	s,f,w,c,o	y	<.001	
44008	o,s,w,c,f	y	<.001	
44009	f,c,s,w,o	y	<.001	
44010	f,s,w,o,c	y	<.001	
44011	s,c,w,f,o	y	<.001	
44012	w,o,c,f,s	y	<.001	
44013	w,o,c	y	<.001	
44014	w,o,c	y	<.001	
44015	o,w,c	y	<.001	
44016	w,o,c	y	<.001	
44017	o,w,c	n	0.6665	
44018	o,w,c	y	0.0123	
44019	o,w,c	y	<.001	
44020	o,c,w	y	<.001	
44021	w,c,o	y	<.001	
44023	f,c,w,o	y	0.0066	
44024	w,o,c	y	<.001	
44025	c,o,w	y	<.001	
44026	c,o,w	y	<.001	
44027	o,w,c	y	<.001	
44028	o,w,c	y	0.0022	
69037	a,w	n	0.778	
71003	p,c	y	<.001	
boco2	g,db	y	<.001	
boco4	g,db	y	<.001	

The different responses among land use were well illustrated on a CN-P plot, similar to those described in chapter 3. Examples of these graphs are contained in Figure 5.1 (watershed #26014 in Coshocton, OH), figure 5.2 (watershed #44026 in Hastings, NE) and figure 5.3 (watershed # 19005 in Lafayette, IN). Each land use contained within the watershed's period of record has a distinct identity on the graph and the land use symbol on the right axes represents the CN_∞ value assigned to that respective land use. It can be seen that the asymptotic pattern for each land use varies slightly within the same watershed after a certain value of rainfall. Land use Curve Numbers begin to diverge at approximately P = 0.4 inches in Coshocton, OH (Figure 5.1) and Hastings, NE (Figure 5.2) and at P = 0.6 in Lafayette, IN (Figure 5.3).

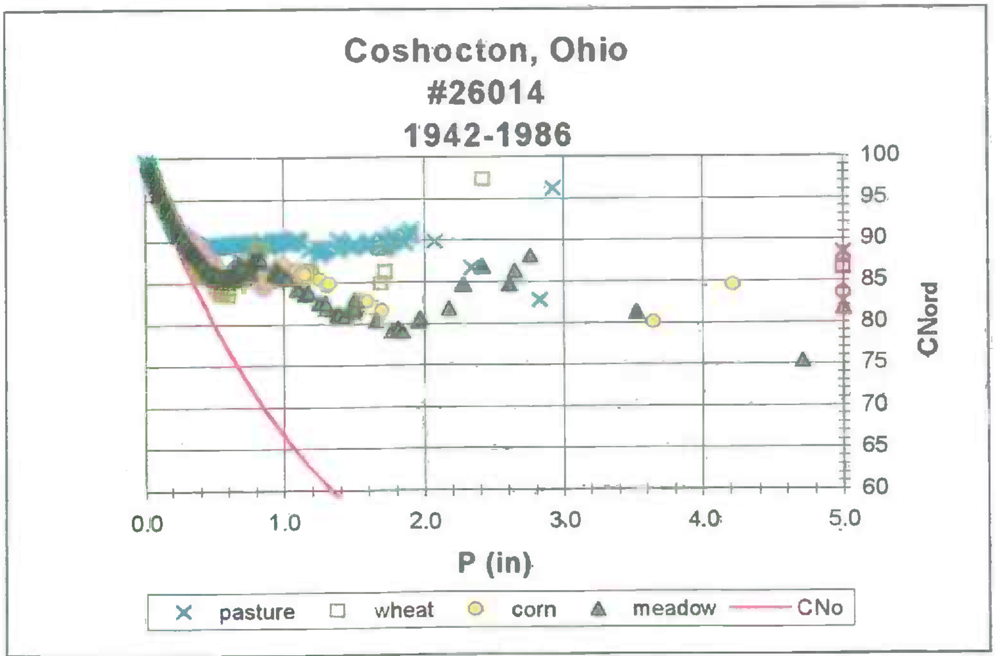

Figure 5.1: Individual land use at Coshocton #26014. Curve Number infinity (CN_∞) for each land use is shown on right axis

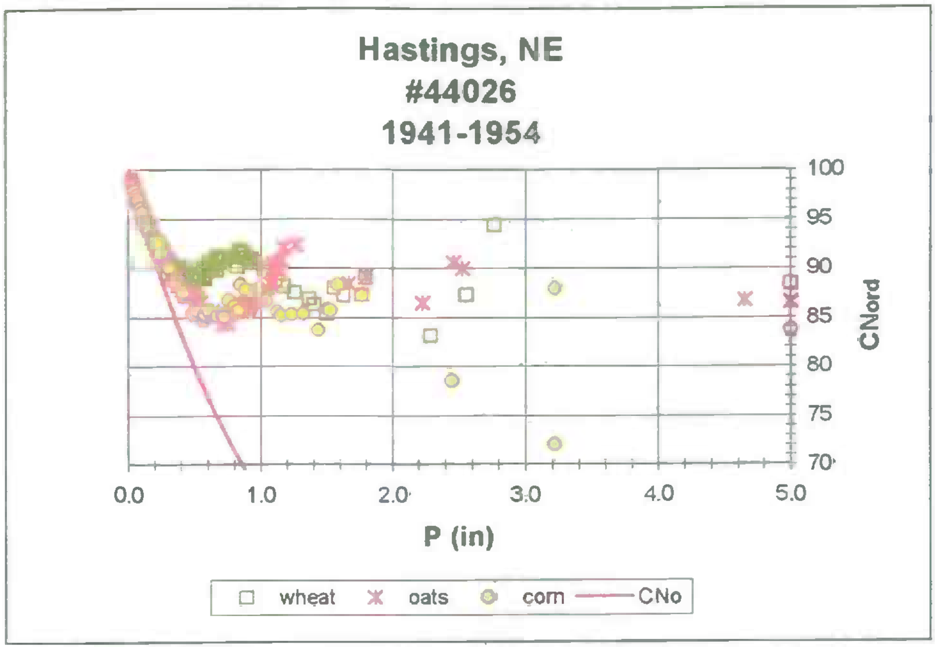

Figure 5.2: Individual land use at Hastings, NE #44026. Curve Number infinity (CN_∞) for each land use is shown on right axis

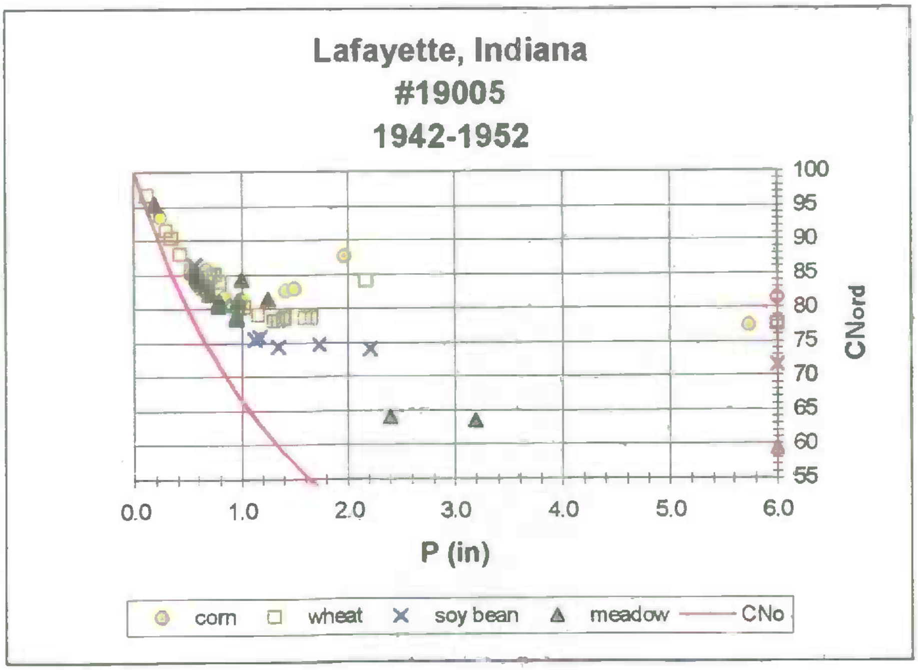

Figure 5.3: Individual land use at Lafayette, IN #19005. Curve Number infinity (CN_∞) for each land use is shown on right axis

The order of land use Curve Numbers within each watershed from Table 5.1 was examined, and although there was no repeated pattern in the ranked order there were several observations worth noting.

MEADOW

One of the most noticeable observations was that meadow Curve Numbers were almost always the lowest Curve Number for a watershed. Of the 19 watersheds that had a meadow in their crop rotation, 13 had meadow Curve Numbers significantly lower than any other land use Curve Number within that same watershed. Three others had meadow Curve Numbers that ranked second lowest. This means that over 84% (16 out of 19) of all meadow watersheds used in this study are ranked as one of the lowest Curve Numbers within their watershed. The meadow Curve Numbers begin to separate from other Curve Numbers in Figures 5.4 and 5.5 at approximately $P = 0.4$ inches.

In addition, the spread of land use Curve Number was highest in watersheds containing meadow. The difference ranged in magnitude from 1 to 22 Curve Numbers. For example, Lafayette watershed #19005 (see Figure 5.3) has a meadow Curve Number 22.01 CNs less than its highest Curve Number. Figures 5.4 and 5.5 depict watersheds whose meadow Curve Numbers are lower than the highest Curve Number by 16.48 and 15.10 CNs respectively.

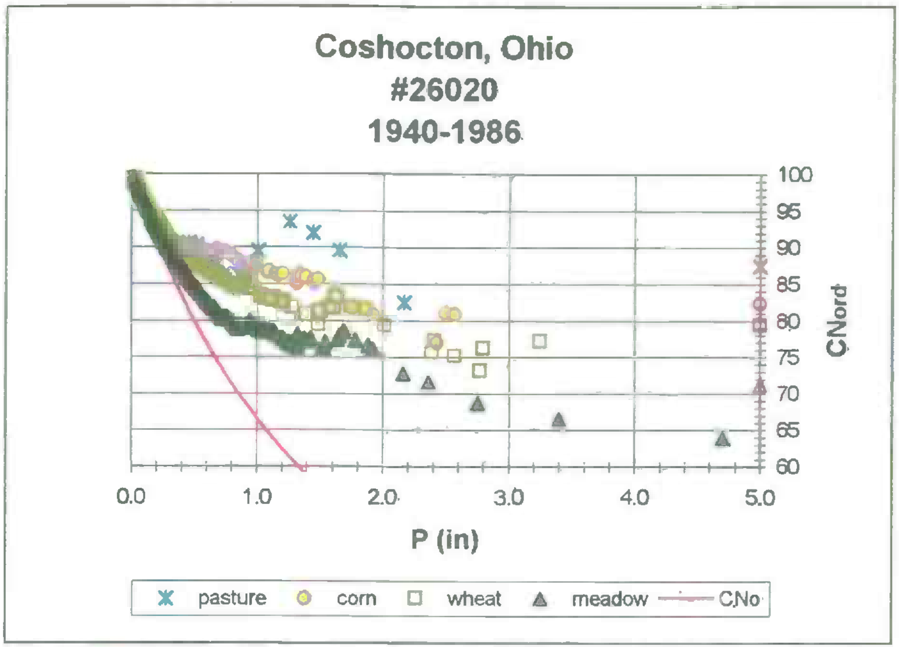

Figure 5.4: Watershed #26020 in Coshocton, OH with a difference of 16.48 between meadow and pasture Curve Numbers

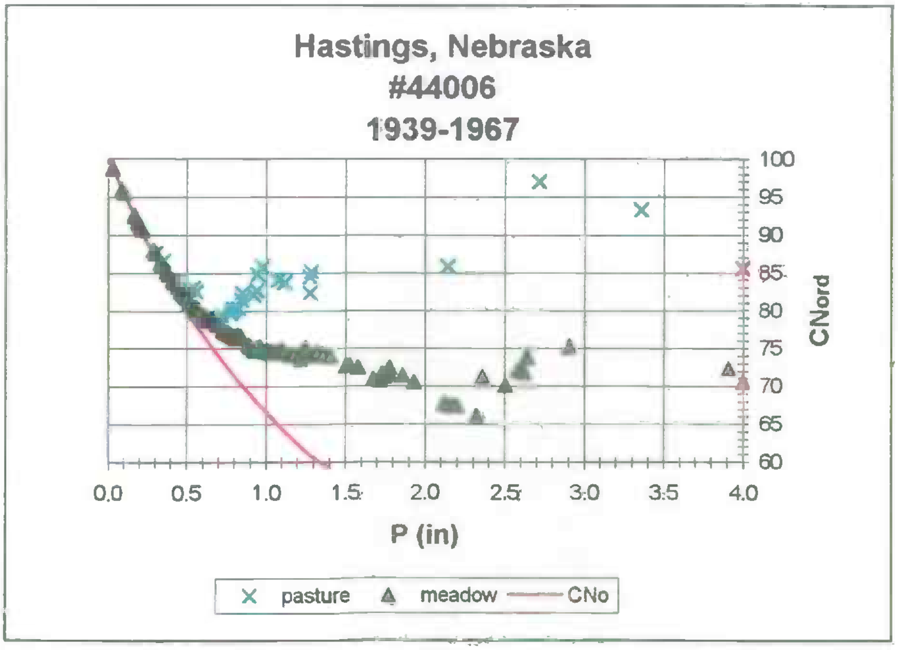

Figure 5.5: Watershed #44006 in Hastings, NE with meadow Curve Number 15.1 lower than pasture Curve Number

It can be noted that all watersheds with meadow in their rotation that did not have meadow as one of their lowest land use Curve Numbers were in Coshocton, Ohio (watershed #'s 26010, 26012 and 26016). The watersheds have several common hydrological characteristics that could prove to interact and produce high runoff: climate, soil and slope.

All three watersheds are located within a mile of each other so climate is essentially homogeneous. The dominant hydrologic soil group of each watershed is C, as determined by the aggregate aerial extent of hydrologic soil groups (Kelley et. al., 1975) and subsequent work by NRCS soil scientists (Nielsen, 1999). Soil group C is characterized as having one of the higher runoff potentials (see Table 2.5). Slope is the third factor these watersheds have in common. All 3 watersheds have at least 6-12% slopes and #26016 is reported to have slopes up to 14% in the lower third portion of the watershed. These three factors all considered may explain why land use Curve Numbers from these watersheds were frequently higher than most, including meadow.

PASTURE

Pasture land use occurred in the rotation of 8 watersheds listed in Table 5.1. Of these, pasture Curve Number was generally significantly higher (6 out of 8 times) than all other land use on a given watershed. Figure 5.6 is a representative graph of a watershed with a high pasture Curve Number. The pasture curve begins to diverge from meadow at approximately P = 0.4 and approach a constant value at approximately P = 0.5 inches. Except for some noise at P > 3 inches the pasture Curve Number is consistently higher than meadow. High pasture Curve Numbers can also be seen in Figures 5.1, 5.4 and 5.5.

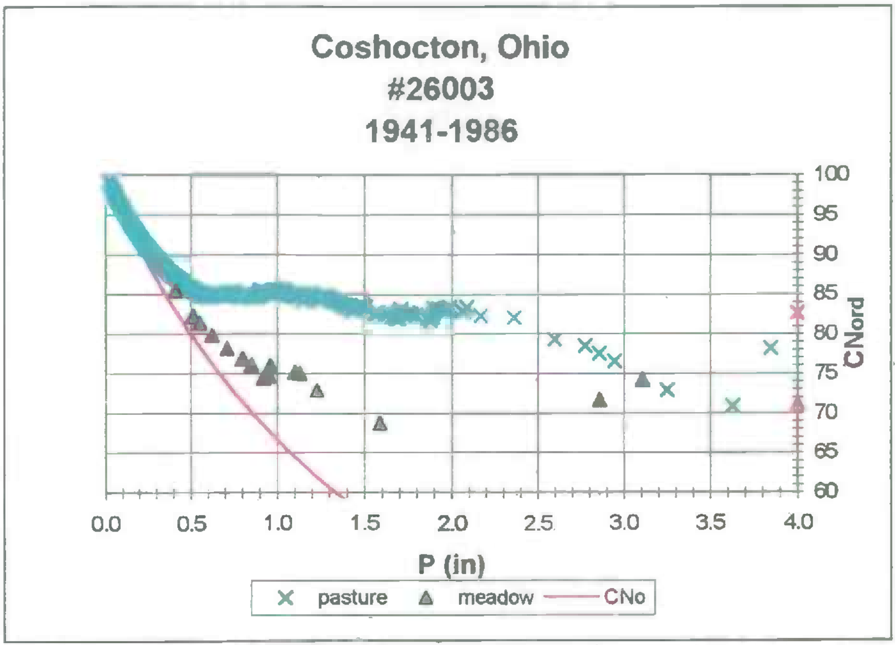

Figure 5.6: Representative graph with pasture in rotation

Pasture Curve Number is significantly lower on only 2 watersheds: in Coshocton, OH watershed #26015 pasture is lower than only one other land use but in Riesel, TX (watershed #42038) the Curve Number for pasture is significantly lower than all other land uses on that watershed. One explanation for such a low pasture Curve Number at Riesel may be because the soil is 100% Black Clay. Pasture is grazed grassland (NEH-4, Chapter 8) which typically lowers infiltration rates and thus runoff. However, grazing on clay soils could have the effect of creating depressions in clay that cause retention of rainfall and prevent it from running off the watershed.

SMALL GRAIN AND ROW CROPS

Corn, cotton, soybeans and sorghum fall under the NRCS land use class of row crop while wheat and oats are classed as small grain. One would expect row crop to yield higher runoff than small grain, and thus a higher Curve Number, because with a row crop the soil is exposed throughout the growing season. The presumption holds true in over 68% of the 44 watersheds in this study that contained both a row crop and a small grain in their rotation; 30 had at least one row crop significantly higher than a small grain.

One would, however, expect row crops to have similar Curve Numbers on the same watershed and small grains to have similar Curve Numbers. But that was not necessarily the case. In fact, only 2 out of the 19 watersheds with more than one row crop in rotation had Curve Numbers that were statistically the same at the .05 significance level. Small grain Curve Numbers were only slightly better. Twenty-four watersheds from Table 5.1 had more than one small grain crop and only 6 had no significant difference between wheat and oats Curve Number. A regression analysis was performed for row crops and small grain and the strongest correlation was found between corn and soybean (see Figures 5.7, 5.8.1 and 5.8.2). The regression equations along with corresponding r^2 and p-values are reported in Table 5.2.

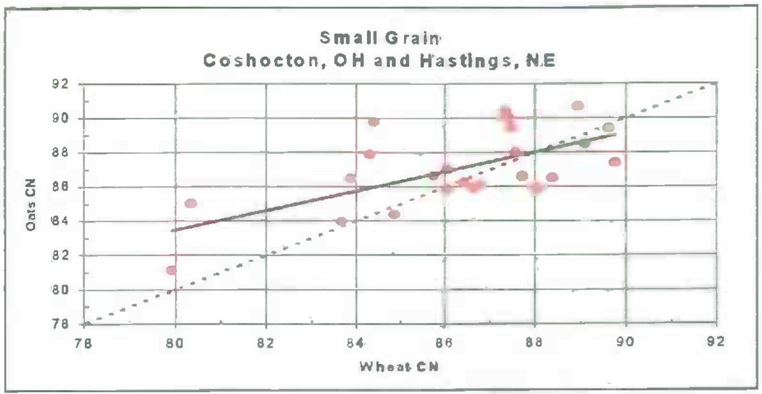

Figure 5.7: Regression of small grain crops from Coshocton, OH and Hastings, NE

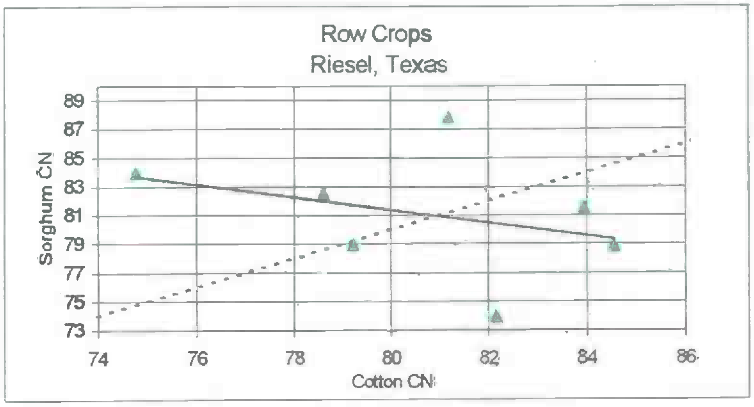

Figure 5.8.1: Regression of row crops from Riesel, TX

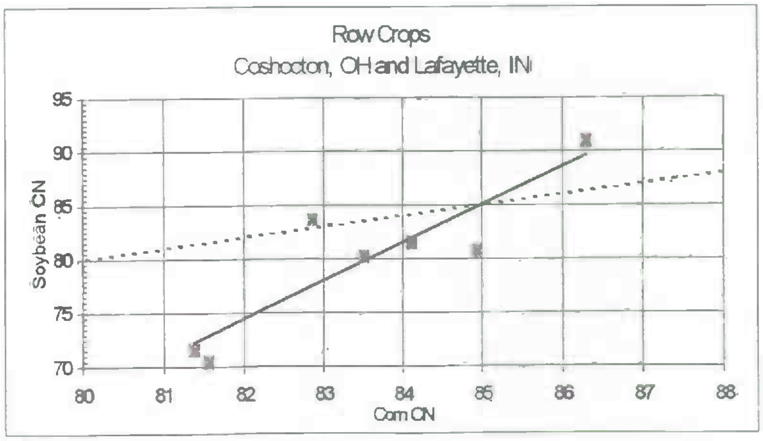

Figure 5.8.2: Regression of row crops from Coshocton, OH and Lafayette, IN

Table 5.2: Results from regression analysis of small grain and row crop Curve Numbers

Land use	Equation	R^2	p-value
Small grain	Oats = 0.563wheat + 38.483	0.4087	<.001
Row crop	Sorghum = -0.4487cotton +117.27	0.1194	0.448
Row crop	Soybean = 3.53corn – 214.96	0.787	0.008

FALLOW

The fallow data was not sufficient enough to support the theory that it will yield the highest runoff, and thus a higher Curve Number. Fallow appears in 7 of the watersheds listed in Table 5.1 but only 3 out of the 7 times fallow Curve Number is significantly higher than a most other land use Curve Numbers in that watershed.

LAND CONVERSIONS

Four watersheds (71003, Boco2, Boco4 and 42036) had a permanent (or long term) land use conversion during their period of record. Watershed #71003 in Treynor, Iowa was converted in 1972 from a continuous pasture watershed to corn (Hjelmfelt, 1989). Pasture had controlled grazing and the corn crops were planted with a conservation tillage practice. The curves for each land use on this watershed begin to diverge at approximately P = 1 inch and corn Curve Number was statistically higher than pasture by 2.67 Curve Numbers (see Figure 5.9).

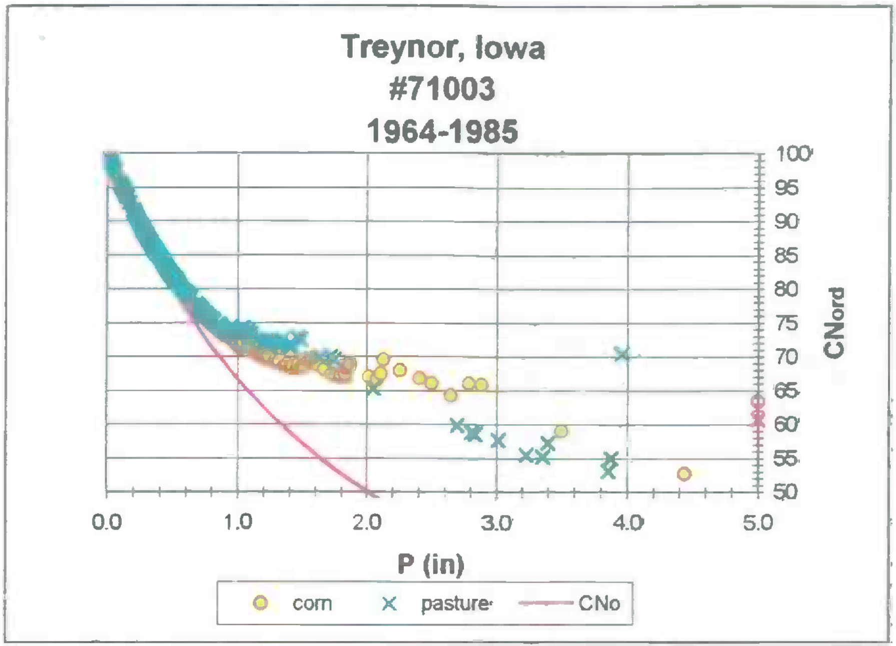

Figure 5.9: Conversion from pasture to corn at Treynor, IA #71003

Two watersheds that experienced a land conversion were at Boco Mountain, Colorado on watersheds 2 and 4. These watersheds had a natural cover in desert brush and were plowed and planted to grass in October 1967 (Lusby, 1979). As expected, on both watersheds the grass Curve Number proved to be significantly lower than desert brush. On watershed #2 the difference was 18.02 and on watershed #4 the difference between grass and desert brush Curve Numbers was 13.79 (see Figures 5.10 and 5.11).

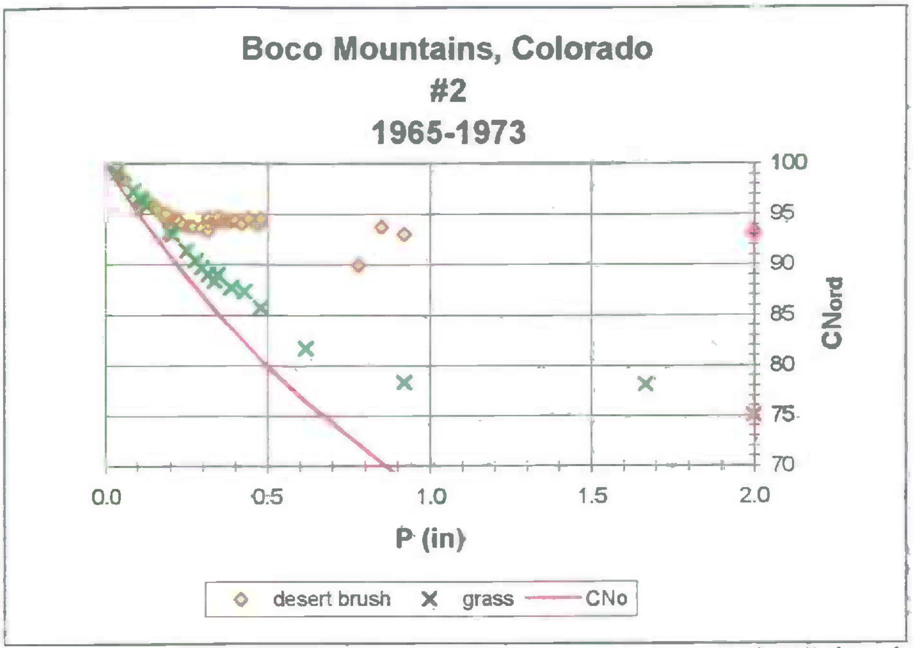

Figure 5.10: Conversion from desert brush to grass at Boco Mountain, Colorado #2

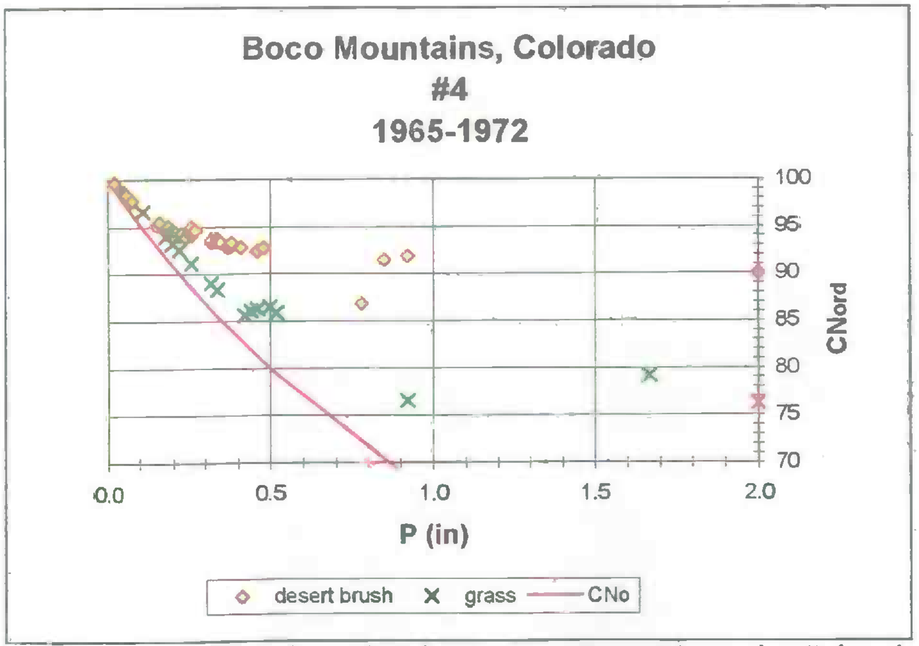

Figure 5.11: Conversion from desert brush to grass at Boco Mountain, Colorado #4

Another land use conversion of sorts was found on Riesel, Texas watershed #42036. This ARS experimental watershed was 100% rangeland that was "infested" with honey mesquite (Burford and Clark, 1976). In 1972 the watershed was treated, at which time the mesquites were killed and left standing. Curve Numbers were calculated for both before and after the treatment. The Curve Number for dead mesquites was statistically higher than for live mesquites and when plotted the data curves diverge around P = 0.4 inches (see Figure 5.12).

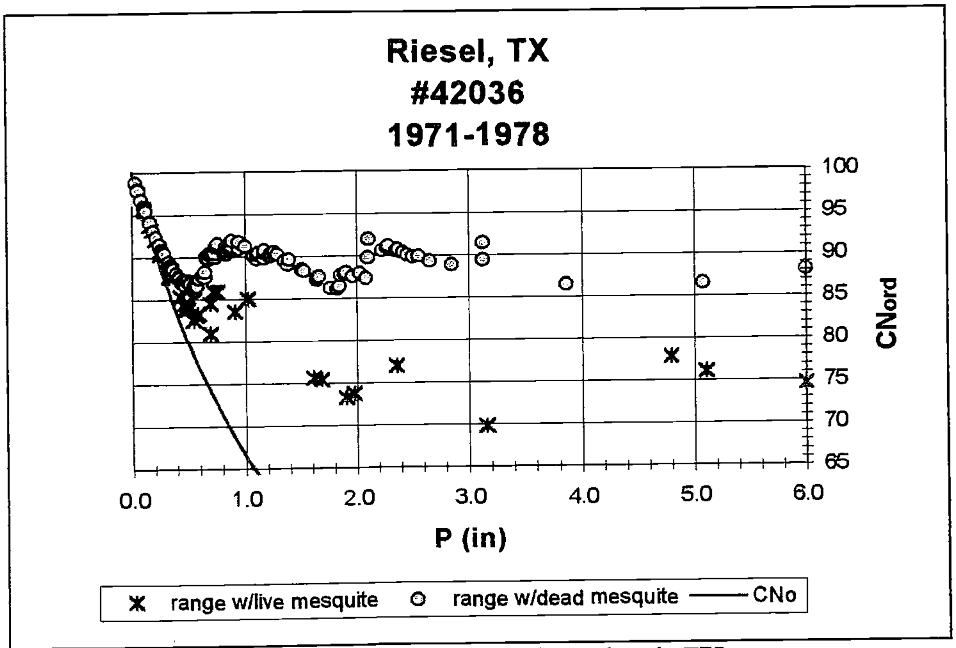

Figure 5.12: Effect of killing trees on rangeland at Riesel, TX

RESTRICTED R^2

The data were revised to include only those Curve Numbers with r^2 greater than 50% and ANOVA tests for each watershed were reviewed for possible effects. This resulted in 5 watersheds being eliminated (#'s 26002, 26018, 42017, 44005 and 69037) because only one land use was available to test. Of the remaining 48 watersheds the significance and rank order of Curve Numbers remained the same and previous observations were altered only slightly. A total of 46 watersheds had a significant difference, which translates to 95.83%. The percent of watersheds that had meadow ranked as one of their lowest Curve Numbers increased from 84% to 88.2%.

5.2 Within a location

A regional analysis was performed to determine differences, if any, between land use Curve Numbers within a location. This was when at least two land uses were both applied to at least 2 watersheds within the same location. Because climate within any given location can be considered relatively homogenous, it was hoped that with this type of analysis general statements could be made about differences in hydrologic responses of a land use within a location.

This research consisted of data from watersheds in 29 different locations around the Untied States, 10 of which proved to be appropriate for the regional analysis. When the regional analysis was performed on these 10 locations there were 6 locations whose mean land use Curve Numbers were statistically different from each other at the .05 significance level. Upon further examination it was noted that an additional 2 locations had a difference in their land use Curve Numbers at the 0.10 significance level, but the differences cannot be considered significant.

Table 5.3 is a list of these locations and their respective p-value. Land uses for each location are listed in ascending order of the average land use Curve Number for that location.

Table 5.3: Results of ANOVA test within locations. Shaded cells indicate location with significant difference among their land uses

Location	Land Use	Sig Dif	p-value	abbreviations
Tombstone,AZ	g,ds	no	0.538	
Badger Wash, CO	ungr,graz	yes	0.0266	c = corn
Boco Mt., CO	g,sh	yes	0.004	ct = cotton
Chickasha, OK	r,w,ct,p	no	0.065	ds - desert shrub
Coshocton, OH	m,sb,p,c,w,o	yes	0.046	f = fallow
Guthrie, OK	p,m	no	0.232	g = grass
Hastings, NE	m,p,s,w,f,o,c	yes	<.001	m = meadow
Lafayette, IN	m,sb,w,c	no	0.0883	o = oats
Riesel, TX	o,ct,s,r,p	yes	0.0161	p = pasture
Treynor, IA	p,c	yes	<.001	r = range
				s = sorghum
				sb = soy bean
				sh = shrub
				w = wheat
				ungr = ungrazed
				graz = grazed

HASTINGS

There was a difference at the 0.05 significance level in land use Curve Numbers at Hastings, NE. Here the Curve Number for meadow was statistically lower than all other land uses found at this location. This is probably due to the fact that all the meadow watersheds at Hastings were continuous meadow, not in rotation, throughout the period of record. This would allow for protection and a more stable condition. The watershed would not have had soil exposed to the impact of the raindrop, as is the case with plowing and planting in a crop rotation.

There were no statistical differences between the 6 other land uses found at Hastings. Figure 5.13 is a frequency analysis plot of all the land use Curve Numbers in Hastings where the percentage of watersheds are represented on a per land use basis and the average Curve Number lies at 50 percent. One can see the difference in meadow is not subtle. Meadow lies well below 75 and all other land uses are clustered together above Curve Number 80.

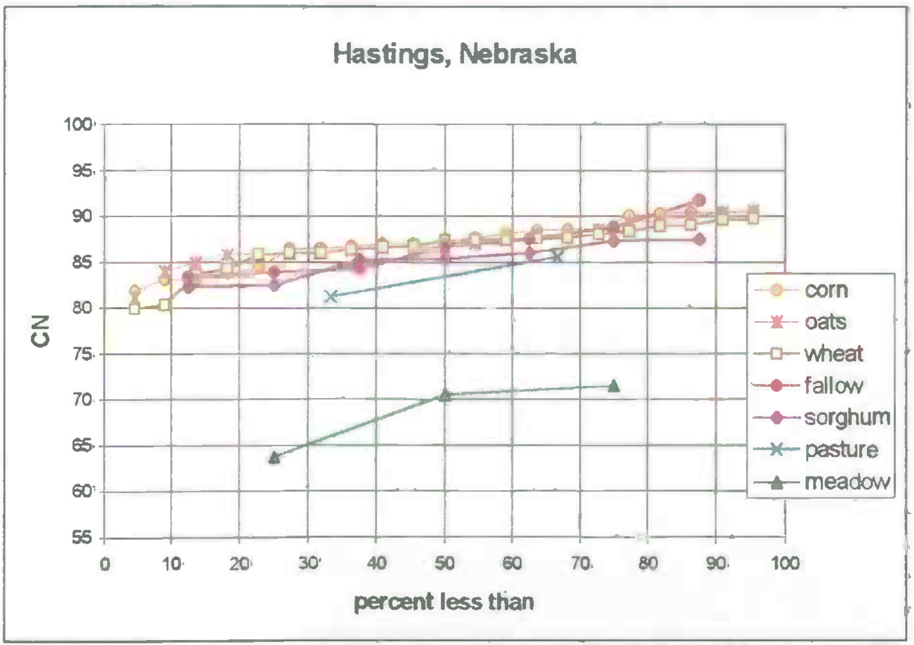

Figure 5.13: Frequency graph of all land use Curve Numbers at Hastings, NE

Meadow Curve Number was generally the lowest Curve Number at a location. This was the case in 3 out of the 4 locations from Table 5.3 that contained meadow land use. Guthrie, Oklahoma was the only location where meadow was high. In fact the hydrological response at Guthrie to pasture as well as meadow land use was exactly opposite to other locations used for this analysis. This is illustrated in Figure 5.14 which compares the difference in average Curve Number for meadow and pasture from all the locations they appear together; Guthrie, Hastings Riesel, TX and Coshocton, OH.

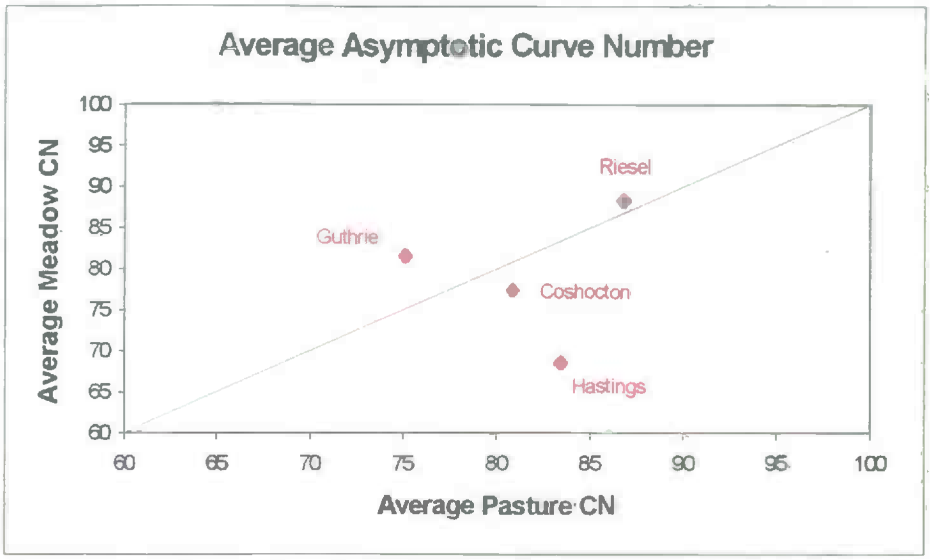

Figure 5.14: Comparison of meadow and pasture Curve Numbers at 4 locations

Guthrie lies well above the 1:1 line while Coshocton and Hastings are below. Meadow is not listed in table 5.3 as a land use for Riesel because there was only one meadow watershed at this location. Riesel, however, is used in Figure 5.14 for illustration and because it behaves similar to Guthrie.

RIESEL AND GUTHRIE

Riesel and Guthrie are similar in that they both have a propensity to produce high Curve Numbers. This can be seen in their frequency graphs (Figures 5.15 and 5.16) where 50% of all Curve Numbers at Riesel, and 40% at Guthrie, are shown to be greater than 80.

Riesel was another location where there was a significant difference among the land use Curve Numbers. The Curve Number for oats was significantly lower than pasture but all other land use Curve Numbers were not statistically different. This is the only location where oats

Curve Number is lower than pasture. Another interesting point to be made about Riesel is the radical variation of Curve Numbers, as seen in the frequency diagram (Figure 5.15). This radical pattern in the frequency curves was not observed at any other location and may be due to the black clay soil (hydrologic soil group D) which is found in all Riesel watersheds listed in Table 5.3.

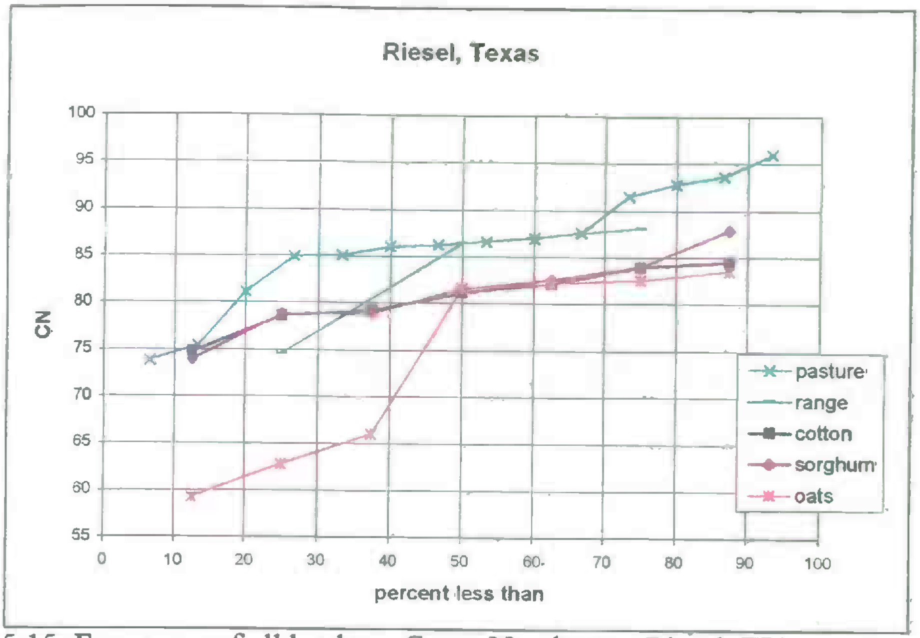

Figure 5.15: Frequency of all land use Curve Numbers at Riesel, TX

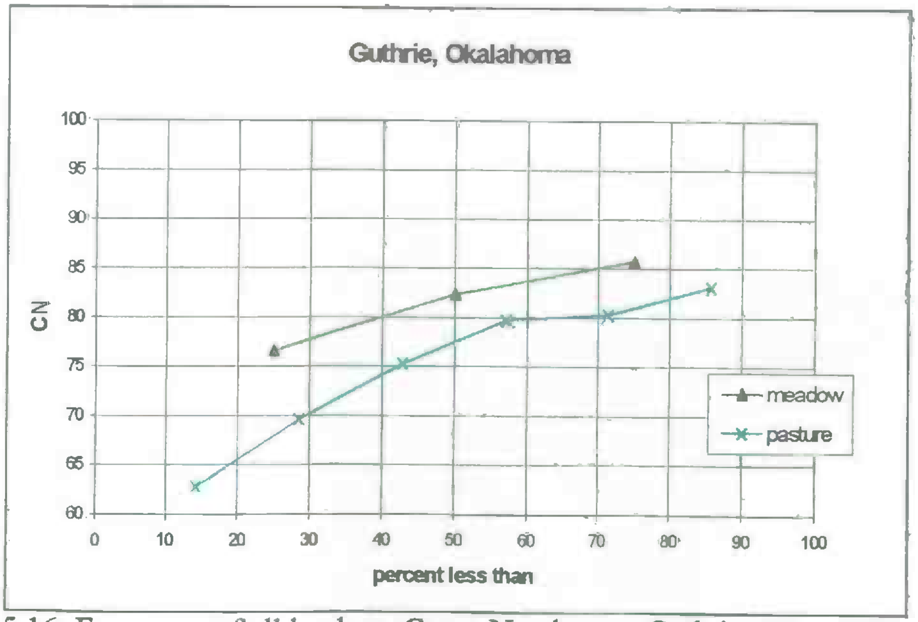

Figure 5.16: Frequency of all land use Curve Numbers at Guthrie, OK

TREYNOR AND BOCO MOUNTAIN

Two of the regions that had a significant difference in their land use Curve Numbers were land conversion watersheds previously discussed; Treynor, IA and Boco Mountain, CO. It can be said that pasture Curve Number was significantly lower than corn at Treynor and grass Curve Number was significantly lower than desert shrub at Boco Mountain. Since this analysis included all watersheds within a given location it offers credence to the significant difference found in the first analysis. Not only did these land use conversions have an effect on the Curve Number within the watershed, they were statistically different from all other land use Curve Numbers in their respective locations. Figure 5.17 includes the Curve Number frequency of both locations in Colorado and it can be seen that the grass Curve Number was the lowest in all of Colorado. Other interesting points to note about desert shrubs on the Colorado frequency graph. As would be expected all desert shrubs are grouped together and are high, most well above 85.

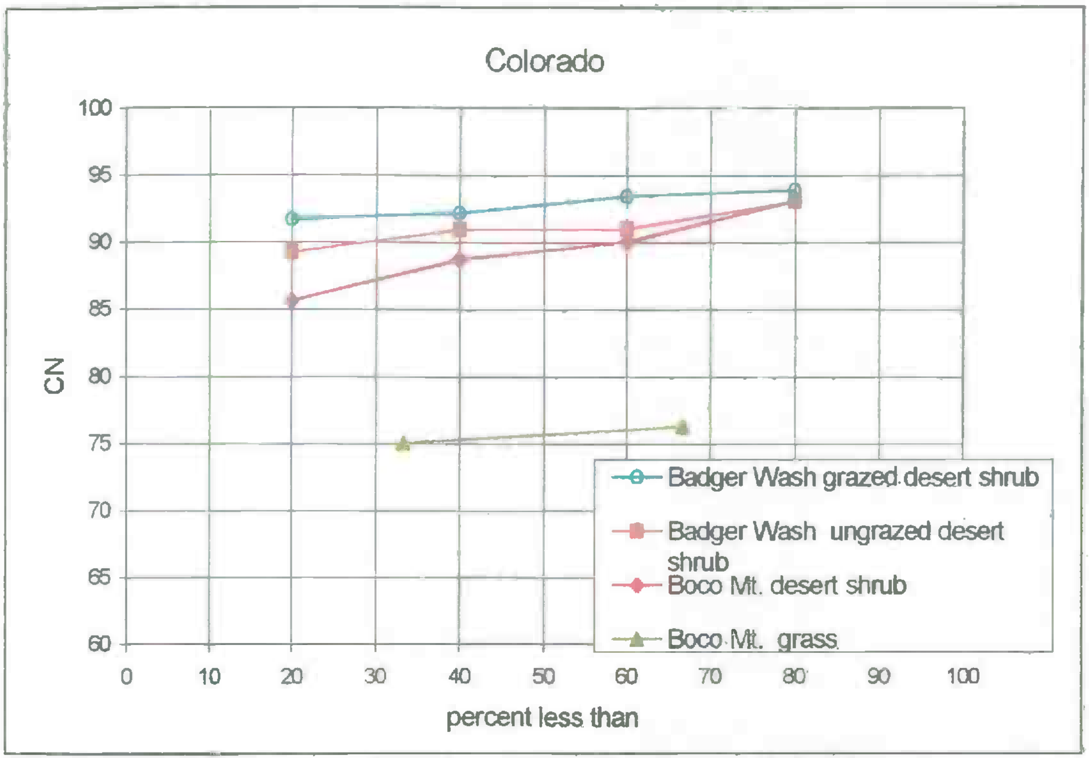

Figure 5.17: Frequency of all land use Curve Numbers in Colorado

The frequency of Curve Numbers at Badger Wash is shown in Figure 5.17. Badger Wash data were from a 20 year paired watershed study on the effects of grazing where one watershed from each pair was grazed and the other was ungrazed (Lusby, 1973). Because the watersheds were paired, a paired t-test was appropriate for comparing grazed land to non-grazed. Curve Numbers from the grazed watersheds were significantly higher than ungrazed Curve Numbers. This is in keeping with the supposition that grazing will result in lowering of infiltration rates (NEH-4, Chapter 8). For an arid region such as Badger Wash, grazing typically would have the most effect on runoff in riparian areas of the watershed where soil is moist and subject to compaction by hooves.

RESTRICTED R^2

When the ANOVA tests were run a second time with the restricted data Tombstone, AZ could not be tested because it was limited to only one land use. Data from Boco Mt. and Treynor were not affected by restricting the data and the same 5 watersheds showed a significant difference among their land use Curve Numbers.

Using the restricted data resulted in changes to 2 items, the p-values and the rank order of land uses within watersheds. The p-values were typically stronger in the second run. Watersheds with a statistical difference either had a lower p-value or it remained near the same, and for watersheds with no difference the p-value went up (see Table 5.4).

Table 5.4: ANOVA test results using only Curve Numbers with $r^2 > 50\%$. Land use categories are listed in ascending order of Curve Number. Shaded cells indicate a change from when all Curve Numbers were used.

Location	Land Use	Sig Dif	ANOVA p-value
Badger Wash, CO	ungraz,graz	yes	0.0413
Boco Mt., CO	g,sb	yes	0.004
Chickasha, OK	r,w,ct	no	0.1924
Coshocton, OH	m,sb,c,w,p,o	no	0.1014
Guthrie, OK	p,m	no	0.283
Hastings, NE	m,p,s,w,c,o,f	yes	<.001
Lafayette, IN	m,sb,w,c	no	0.0667
Riesel, TX	o,s,ct,p	yes	<.001
Treynor, IA	p,c	yes	<.001

The rank order of Curve Number changed at Coshocton, Hastings and Riesel. This is not considered unusual since the number of watersheds eliminated from each location were 9, 8 and 14 respectively. At Coshocton pasture land use was ranked second highest of all land uses, but there was still no significant differences among the land uses. The order of land use at Hastings was almost exactly as expected, meadow Curve Number ranked lowest and fallow ranked highest. Meadow however, remained the only Curve Number that was statistically different from other land uses at Hastings. At Riesel the range Curve Number was lower, but oats was still the only land use that was significantly lower. The data changed such that pasture could not be evaluated at Chickasha.

5.3 Across all locations

Interpreting results from more than one location is complicated by regional differences in climate, ecosystems and physiographic factors. Keeping this in mind, an analysis was performed which entailed a very basic comparison of all land use Curve Numbers from the entire data set. General inferences about land use Curve Numbers were made as to rank order of the means, variances and reasons for differences in Curve Numbers across regions.

In order to compare land use Curve Numbers across all locations a land use had to have been applied in more than one location, which was found to be the case with 11 single land uses. Seven of these 11 land uses (63.6%) exhibited a significant difference. This difference can be attributed to variation in locations, discussions of which are to follow. Descriptive statistics for land use Curve Numbers used in this analysis are listed in Table 5.5 in ascending order of the average value for asymptotic Curve Numbers.

Table 5.5: Descriptive statistics of Curve Numbers for land uses found in more than one location. Shading indicates significant difference among land uses

Land Use	CN_{avg}	var	CN_{med}	N	Sig Dif	ANOVA p-value
forest	63.65	360.475	66.83	17	yes	0.0013
meadow	75.86	53.927	76.55	26	yes	0.0014
range	78.45	130.642	81.13	38	no	0.0472
cotton	80.19	9.207	80.30	10	no	0.516
pasture	81.12	60.271	81.39	41	yes	0.0059
soy bean	81.92	64.289	82.58	4	no	0.379
corn	83.09	48.605	84.04	44	yes	<.001
sorghum	83.15	15.566	83.23	14	yes	0.046
wheat	83.57	27.606	85.66	47	yes	<.001
oats	84.10	57.948	86.26	31	yes	<.001
brush	90.60	7.618	91.20	18	no	0.1898

The rank order of Curve Numbers was somewhat as expected: forest and meadow were among the lowest average Curve Number, row crops or small grain were in mid-range and desert brush exhibited the highest average Curve Number. Also, as anticipated small grains (wheat and oats) were grouped together as were row crops (soybean, corn and sorghum). It was surprising however, that the average Curve Number for range was the third lowest average Curve Number and that row crops had a lower average Curve Number than small grains.

FOREST

Forest had the lowest over all average Curve Number of all land uses considered. Forested watersheds were used in this study only if they had not been cut or treated. The low forest Curve Number therefore is likely due to stable vegetation cover and/or the deep soil typically associated with untreated forests. Coweeta, North Carolina and Silver Creek, Idaho were the only two locations that were found to have different Curve Numbers and they were significantly lower than all other locations that had forest land use. The deep sandy loams which typify watersheds in Coweeta (Hewlett and Fortson, 1984) are in hydrological soil group B (see Table 2.5) which can explain the significantly lower Curve Numbers at Coweeta.

The Silver Creek watersheds are very steep with shallow soils (McGurk, 1982), factors that would usually produce high runoff, but the low Curve Number here may be attributed to soil texture and vegetation. The soil texture is coarse loamy sand, usually associated with high infiltration rates, and the watersheds are densely vegetated forests with heavy undergrowth (willow, aspen, cherry, grasses and ferns) which help to lessen runoff from rain.

Forest Curve Numbers ranged from 36.81 (Coweeta 14, North Carolina) to 92.33 (Berea 6, Kentucky) with a variance of 369.77, the largest of any variance recorded. This large variance is exemplified well in the frequency graph for all forested watersheds of the data set (see Figure 5.18).

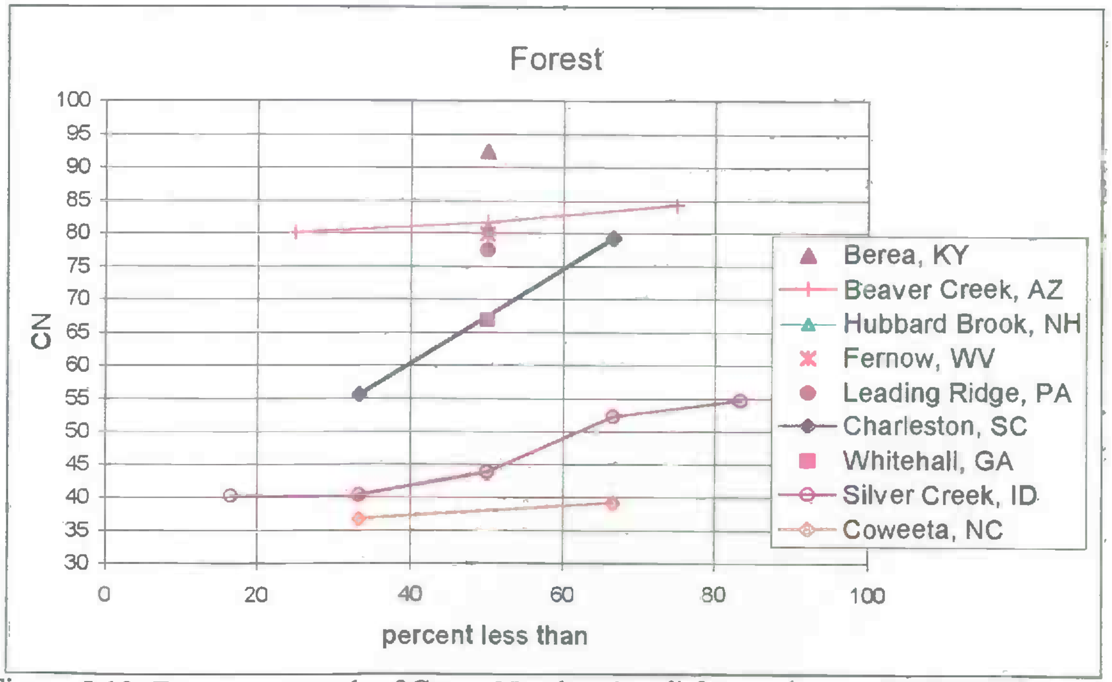

Figure 5.18: Frequency graph of Curve Number for all forested watersheds

Average Curve Numbers from Berea, Kentucky and Beaver Creek, Arizona are among the highest of all forest Curve Numbers calculated. Berea is an Oak-Hickory forest on a very shallow soil classified as a hydrological soil group B/C (Hewlett and Fortson, 1984). This classification has a higher runoff potential than that of a B group and may be the reason for higher Curve numbers at Berea. A high Curve Number was not a surprise from Beaver Creek, an Alligator juniper forest in a semi-arid climate (Beaver Creek Biosphere Reserve, 1999).

MEADOW

The next lowest Curve Number was meadow, second only to the average of forested watersheds. This is as expected, again because of the consistent vegetative cover meadow land use has to offer. Curve Numbers from Lafayette, Indiana and Hastings, Nebraska were significantly lower than all other meadow Curve Numbers. The significantly low Curve Numbers at these locations may be explained by well-drained soils in Lafayette and continuous meadow land use on B soils in Hastings. Continuous meadow, as opposed to meadow in crop rotation, would influence the hydrological response of a watershed by providing protective vegetative cover at all times with no soil exposed to the impact of rainfall due to plowing and harvesting.

Figure 5.19 is the frequency graph for Curve Numbers from all meadow watersheds in this data set. It is interesting to note the even spacing of the curves on this diagram. This is unlike any pattern seen on all land use frequency diagrams.

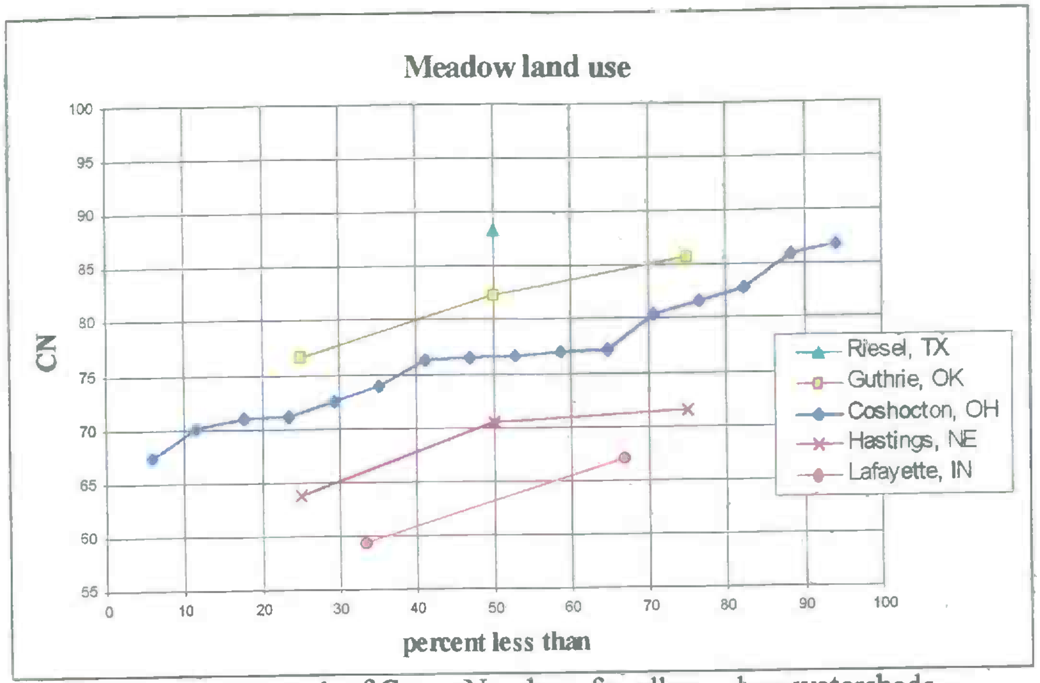

Figure 5.19: Frequency graph of Curve Numbers for all meadow watersheds

All the meadow watersheds at Coshocton, Ohio were in C soils (higher run of potential) and a majority of them were in rotation, not continuous meadow. This may explain why the average meadow Curve Number at Coshocton was statistically higher than Curve Numbers in Lafayette or Hastings. Furthermore, the meadow Curve Number at Coshocton was not statistically different from any other remaining meadow Curve Numbers. Riesel, Texas had the highest average Curve Number for meadow, presumably because of its black clay soils (D soil) which has the highest runoff potential.

RANGE

Surprisingly, range land use Curve Numbers were the next lowest average Curve Number, lower even than pasture or crops. Even though rangelands are grazed, as are pastures, they are different in that ranges typically have sparse vegetative cover, variable soils and are in areas of low rainfall. There was a difference between the rangeland Curve Numbers from this study but it was not significant. This is probably due to the high variance of range Curve Numbers (130.642) that was second only to the variation seen in forest Curve Numbers. Figure 5.20 illustrates the variation in Curve Numbers from this study.

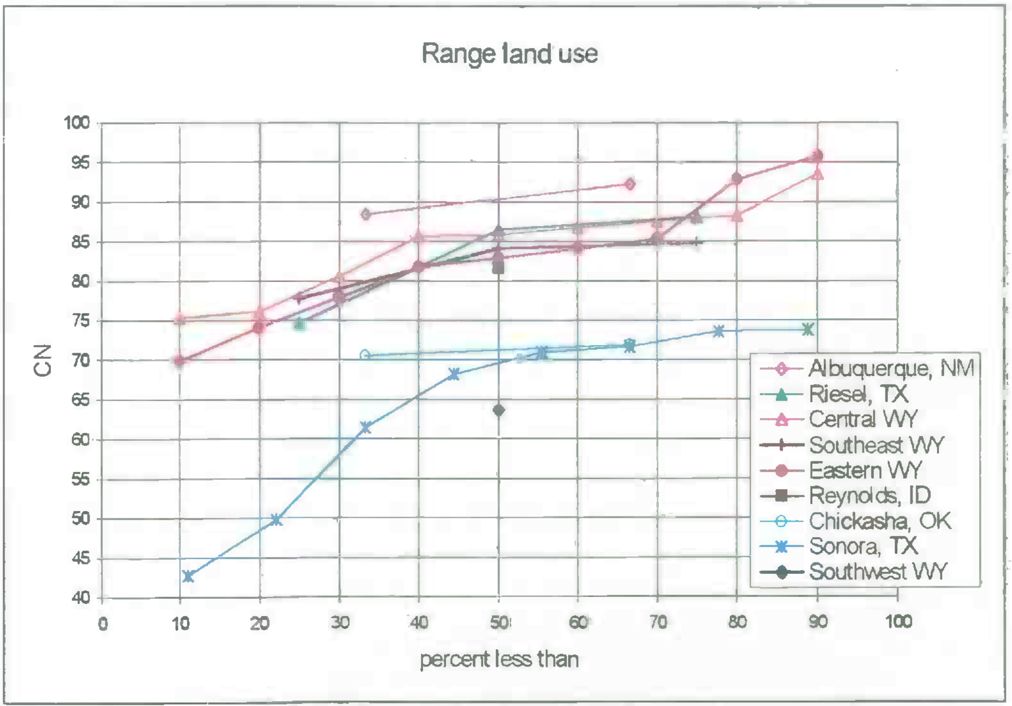

Figure 5.20: Frequency graph of Curve Numbers for all range watersheds

Sonora, Texas has the largest variation of range Curve Number within any one location. The difference of 31.06 CNs (73.76 - 42.70) is most likely a result of differences in hydrologic soil groups. The 3 Sonora watersheds with the lowest range Curve Numbers have C soil while the remaining 5 watersheds are D soil.

Variations such as this have been found characteristic of rangeland watersheds because of fluctuations in range production from year to year caused by climatic variability (Gifford and Hawkins, 1978). A given amount of grazing could have a substantially different hydrologic impact on the range depending if it was a high or low production year.

PASTURE AND CORN

Pasture and corn land use were the next in rank order of Curve Numbers with a statistical difference. Average Curve Numbers at Treynor, Iowa were significantly lower than Riesel, Texas for pasture and significantly lower than all other locations for corn (see Figures 5.21 and 5.22).

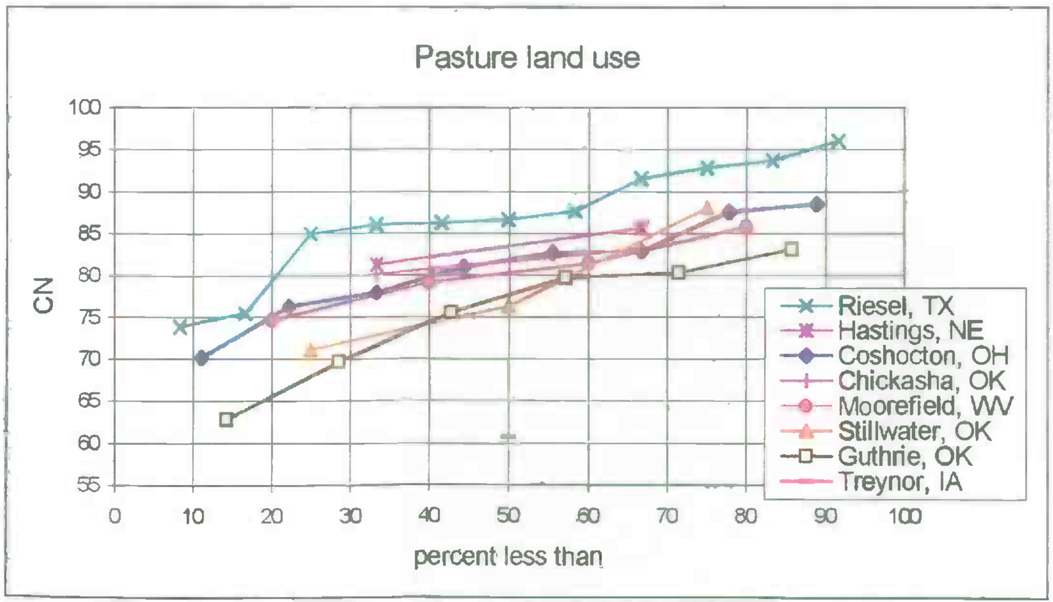

Figure 5.21: Frequency diagram of Curve Numbers for all pasture watersheds

Low Curve Numbers at Treynor can be explained by controlled grazing on the pasture (watershed #71003) and the use of concentrated conservation practices and terracing of corn watersheds (#71003 and 71004) (Spomer et al, 1981). However, a low Curve Number for corn at Treynor watershed #71004 does not necessarily reflect how corn land use affects runoff from a watershed, instead it is a direct result of terraces that were constructed in 1964 and 1972.

The frequency diagram of corn land use Curve Numbers is shown in Figure 5.22. The highest corn Curve Number is in Oxford, Mississippi where the watershed had moderate to steep slopes and was in continuous corn for 7 years on C soil. Treynor #71003 had the lowest corn Curve Number while #71004 was not represented on the corn graph because of the terracing effect.

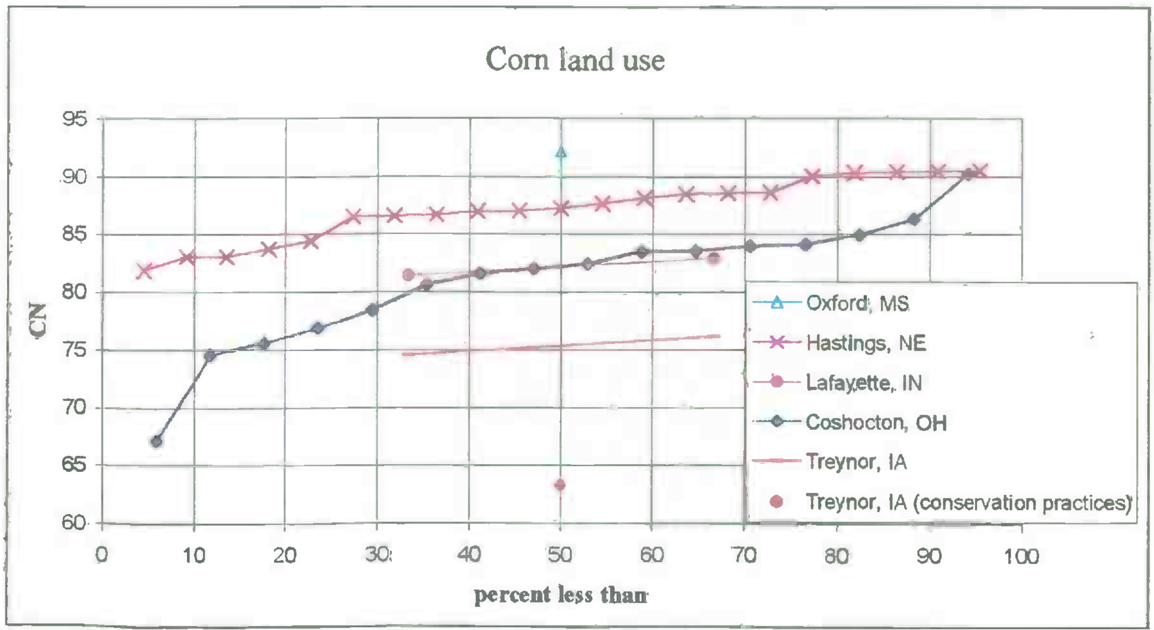

Figure 5.22: Frequency graph of Curve Numbers for all corn watersheds

SORGHUM, WHEAT AND OATS

Sorghum, wheat and oats were the last of the land use categories to have a significant difference among all their Curve Numbers. The Curve Number for wheat was statistically lower at Chickasha, Oklahoma than all other wheat Curve Numbers (see Figure 5.23). Previous studies have shown that runoff from 2 of the Chickasha watersheds in wheat (#'s 69031 and 69037) are very low compared with other watersheds at that location (Nicks et al, 1968).

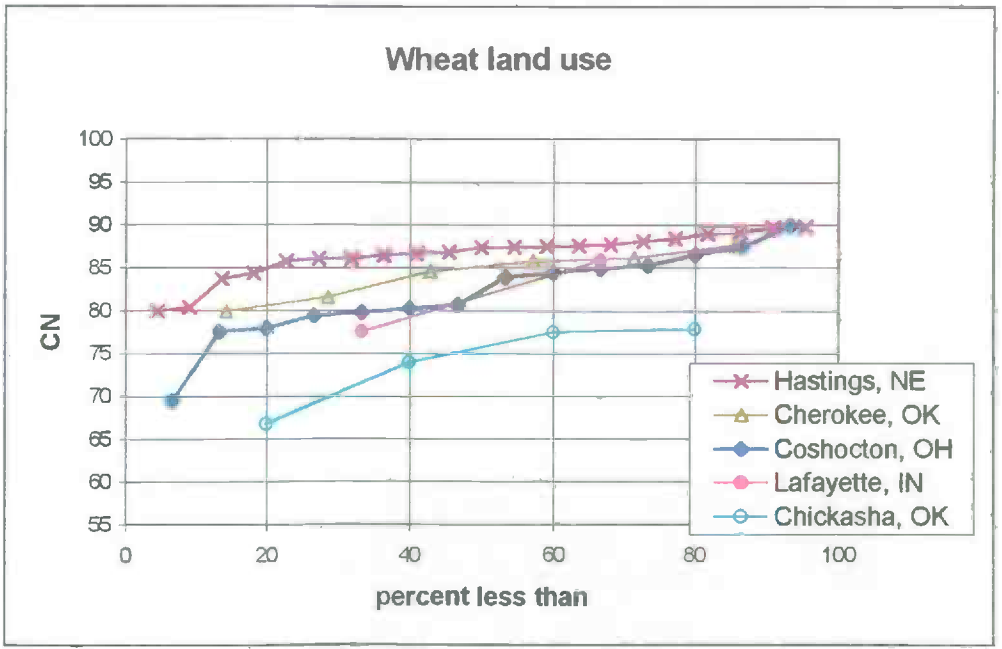

Figure 5.23: Frequency graph of Curve Numbers for all wheat watersheds

Sorghum was planted in 2 locations and oats were planted in 3, the Curve Numbers for both land uses were significantly lower at Riesel, Texas than at Hastings, Nebraska.

Figure 5.24 contrasts the 4 land uses found in common at these 2 locations and is a good illustration of the differences between locations. All land uses, especially oats and meadow, lie away from the 1:1 line. It is also interesting to note that meadow stands apart from other land uses on both watersheds.

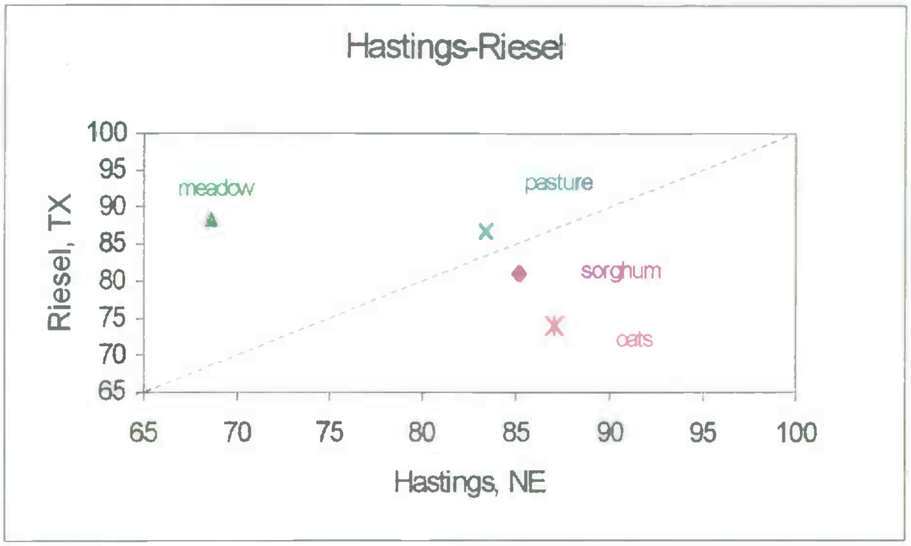

Figure 5.24: Contrast of Curve Number for common land uses at Hastings, NE and Riesel, TX

RESTRICTED R^2

When ANOVA tests were run on only data with r^2 greater than 50% soybean could not be tested because only one watershed remained. Cotton data were not affected by the reduction of data. All land uses that showed a significant difference between locations in the first ANOVA test did so in the second test, except for pasture. Slight changes occurred in p-values, descriptive statistics and overall rank order of the average of asymptotic Curve Numbers. Table 5.6 details results of the second ANOVA run.

Table 5.6: Results of ANOVA test using only data with $r^2 > 50\%$. Land use categories are listed in ascending order of Curve Number. Shaded cells indicate change from when all data were used.

Land Use	CN_{avg}	var	CN_{med}	Sig Dif	ANOVA p-value	N
forest	59.49	332.2582	55.10	yes	<.001	14
meadow	75.68	55.27243	76.49	yes	0.0018	25
range	76.49	119.0808	77.76	no	0.179	33
pasture	78.91	61.5964	80.63	no	0.1651	26
cotton	80.19	9.207	80.30	no	0.516	10
corn	82.19	49.84273	83.52	yes	<.001	38
sorghum	82.85	17.811	83.94	yes	0.005	11
wheat	83.54	26.2161	85.20	yes	<.001	43
oats	83.80	71.6953	86.49	yes	<.001	24
brush	90.34	7.79748	90.95	no	0.2701	16

The most notable difference between the two ANOVA tests was in pasture. This was due to the elimination of 9 pasture watersheds located in Riesel with $r^2 < 50\%$. In the first ANOVA run pasture at Riesel was significantly higher than pasture at Treynor but in the second run pasture was no longer statistically different across locations.

The p-values were stronger in the second run, those land uses with a significant difference had a smaller p-value or it remained the same and those land uses with no difference had a larger p-value. The descriptive statistics of course changed with the elimination of data, but only slightly. The variance was still the highest for forest land use and second highest for range. The overall rank of average land use Curve Numbers also changed slightly because the average pasture Curve Number was lowered. This placed all row crops together (cotton, corn and sorghum) and all small grain land use together (wheat and oats). The average Curve Number for forest remained the lowest, meadow second lowest and brush the highest. When the summary statistics from Table 5.6 were input into an ANOVA test of independence there was a significant difference between the average land use Curve Numbers (p-value < .001).

CHAPTER 6

CONCLUSIONS

This study examined the effects and differences of land use on Curve Number at three distinct scales: (1) locally within a watershed; (2) regionally within a location; and (3) nationally across all locations. Differences in Curve Numbers were tested for at the 5% significance level and several conclusions can be draw from this study. They are highlighted in this chapter and recommendations for future work are discussed.

6.1 Within a watershed

Results at this scale were the most robust because spatial and climatic variations do not apply. Land uses tested at this level were alfalfa, brush, corn, cotton, fallow, grassland, meadow, oats, pasture, sorghum, soybean, and wheat.

- More than 95% of the watersheds tested showed a significant difference in their land use Curve Numbers.
- The response from meadow had a tendency to be the lowest Curve Number within a watershed.
- Curve Number is affected by land conversions.
- Expected response in Curve Numbers from row crops, small grain and fallow could not be verified.

6.2 Within a location

Results at this scale had a built in bias because each location will only support a certain type of land use (e.g. crops could be planted in humid locations but this is not an option in semi-arid locations). Land uses tested at this level were brush, corn, cotton, desert shrub, fallow, grassland, range (grazed and ungrazed), meadow, oats, pasture, sorghum, soybean and wheat.

- Land use made a significant difference in the Curve Number at 50% of the locations tested.
- Meadow was generally the lowest Curve Number within a location.
- Expected response in Curve Numbers from row crops and small grains could not be verified.
- A significant difference was found between Curve Numbers from grazed and ungrazed-paired watersheds.

6.3 Across all locations

There is high variability of climate and physiographic characteristics at this level, but general statements can be made about the results from this scale and average land use Curve Numbers. Land uses tested at this level were brush, corn, cotton, forest, meadow, oats, pasture, range, sorghum, soybean and wheat.

- The response from different land uses across all watersheds had a tendency to be different in at least one location.

- The average response from all land uses produced Curve Numbers in rank order as expected. Curve Numbers in order from least to highest were forest, meadow, range, pasture, cotton, corn, sorghum, wheat, oats and brush:
  - forest Curve Numbers were variable but statistically lowest,
  - meadow had a tendency to produce higher Curve Numbers than forest but lower than any other land use,
  - range and pasture Curve Numbers were not statistically different,
  - row crop Curve Numbers (cotton, soybean, corn and sorghum) were not statistically different,
  - small grain Curve Numbers (wheat and oats) were not statistically different,
  - brush had the highest Curve Numbers.

6.4 Future Work

As long as the Curve Number method continues to be used to estimate runoff it is important to understand the variables that go into the model. Areas of study that could be explored are as follows:

- Soil was found to be an important variable when trying to explain differences in land use Curve Numbers. A relationship between soil and land use Curve Number would be appropriate to investigate.
- Many of the agricultural watersheds in the data used for this study were part of a paired set of 3 used for crop rotation. It would be interesting to compare and analyze land use Curve Numbers from these watersheds at a paired watershed level.

- This study did not consider area of the watershed. It would be interesting to investigate differences in land use Curve Numbers using P and Q standardized to watershed area, or volume of runoff per land use.

APPENDIX A

Copy of Table 9.1

“Runoff Curve Numbers for hydrologic soil-cover complexes”

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Table 9.1. Runoff curve numbers for hydrologic soil-cover complexes (Antecedent moisture condition II, and $I_a = 0.2S$)

Land use	Cover		Hydrologic soil group			
	Treatment or practice	Hydrologic condition	A	B	C	D
Fallow	Straight row	---	77	86	91	94
Row crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	"and terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	"and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes 1/ or rotation meadow	Straight row	Poor	66	77	85	89
	" "	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	"and terraced	Poor	63	73	80	83
	"and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	71	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		----	74	84	90	92

1/ Close-drilled or broadcast.

2/ Including right -of-way.

APPENDIX B

This is a listing of watersheds used in this analysis. The headings for the table are:

- WS ID -Watershed identification,
- LOCAL ID - Local identification of watershed if different from WS ID,
- TOWN - name of closest town to watershed,
- STATE - state in which watershed is located,
- TOT YRS - total number of years of record for watershed,
- DA - drainage area in acres,
- COMMENTS.

WS ID	LOCAL ID	TOWN	STATE	TOT YRS	DA	COMMENTS
10001	W-1	Watkinsville	GA	4	19.2	continuous pasture
19004	W-5	Lafayette	IN	12	2.87	ws in rotation
19005	W-6	Lafayette	IN	11	2.79	ws in rotation
26001	102	Coshocton	OH	44	1.26	ws in rotation until 1973
26002	104	Coshocton	OH	20	1.33	
26003	129	Coshocton	OH	46	2.71	ws in rotation
26004	135	Coshocton	OH	44	2.69	mostly pasture
26005	130	Coshocton	OH	19	1.63	continuous meadow
26010	123	Coshocton	OH	48	1.37	ws in rotation
26011	115	Coshocton	OH	36	1.61	ws in rotation
26012	127	Coshocton	OH	26	1.65	ws in rotation
26013	109	Coshocton	OH	46	1.69	ws in rotation
26014	103	Coshocton	OH	39	0.65	ws in rotation
26015	110	Coshocton	OH	42	1.27	ws in rotation
26016	113	Coshocton	OH	20	1.45	ws in rotation
26017	118	Coshocton	OH	41	1.96	ws in rotation
26018	111	Coshocton	OH	10	1.18	ws in rotation
26019	121	Coshocton	OH	45	1.42	ws in rotation
26020	106	Coshocton	OH	46	1.56	ws in rotation
26021	188	Coshocton	OH	28	2.05	ws in rotation
26023	185	Coshocton	OH	28	7.4	ws in rotation
26024	187	Coshocton	OH	30	7.2	ws in rotation
26025	192	Coshocton	OH	28	7.59	ws in rotation
34001	W-1	Cherokee	OK	14	2.23	continuous wheat
34002	W-2	Cherokee	OK	7	4.82	
34006	W-6	Cherokee	OK	15	1.75	continuous wheat
34007	W-7	Cherokee	OK	15	1.99	continuous wheat
34008	W-8	Cherokee	OK	15	4.72	continuous wheat
34013	W-13	Cherokee	OK	8	1.99	continuous wheat
35002	W-2	Guthrie	OK	10	3.21	continuous meadow
35003	W-3	Guthrie	OK	8	3.13	continuous meadow
35005	W-5	Guthrie	OK	9	5.28	continuous meadow
35006	W-I	Guthrie	OK	6	2.5	continuous pasture
35007	W-II	Guthrie	OK	7	5.09	continuous pasture
35008	W-III	Guthrie	OK	7	9.09	continuous pasture
35009	W-IV	Guthrie	OK	7	13.4	continuous pasture
35010	W-V	Guthrie	OK	7	15.7	continuous pasture
35011	W-VI	Guthrie	OK	7	94.8	continuous pasture
37001	W-1	Stillwater	OK	10	16.7	continuous pasture
37002	W-3	Stillwater	OK	20	92	pasture 2 yrs @ a time
37003	W-4	Stillwater	OK	5	206	pasture 2 yrs @ a time
42007	W-2	Riesel	TX	2	130	
42008	W-6	Riesel	TX	23	42.3	pasture 3 yrs @ a time
42010	W-10	Riesel	TX	12	19.7	continuous pasture

WS ID	LOCAL ID	TOWN	STATE	TOT YRS	DA	COMMENTS
42014	Y-6	Riesel	TX	12	20.9	ws in rotation
42015	Y-7	Riesel	TX	6	40	continuous pasture
42016	Y-8	Riesel	TX	11	20.8	ws in rotation
42017	Y-10	Riesel	TX	11	21	ws in rotation
42023	SW-11	Riesel	TX	8	3.23	continuous pasture
42024	SW-12	Riesel	TX	11	2.97	continuous meadow
42028	SW-17	Riesel	TX	12	2.99	continuous pasture
42031	P-1	Riesel	TX	1	0.24	pasture w/mod-heavy grazing
42032	P-2	Riesel	TX	1	0.24	pasture w/mod-heavy grazing
42033	P-3	Riesel	TX	1	0.24	
42034	P-4	Riesel	TX	1	0.24	
42035	SW-19	Riesel	TX	10	3.25	continuous range
42036	SW-20	Riesel	TX	9	3.21	continuous range
42037	Y-13	Riesel	TX	9	11.3	ws in rotation
42038	Y-14	Riesel	TX	8	5.6	ws in rotation
42039	W-12	Riesel	TX	9	9.9	ws in rotation
42040	W-13	Riesel	TX	10	11.3	ws in rotation
44005	1-H	Hastings	NE	26	3.62	continuous mead until 1962
44006	2-H	Hastings	NE	26	3.4	continuous mead until 1963
44007	3-H	Hastings	NE	26	3.95	ws in rotation
44008	4-H	Hastings	NE	26	3.84	ws in rotation
44009	5-H	Hastings	NE	27	3.93	ws in rotation
44010	6-H	Hastings	NE	28	4.16	ws in rotation
44011	7-H	Hastings	NE	27	4.15	ws in rotation
44012	8-H	Hastings	NE	26	3.93	ws in rotation
44013	9-H	Hastings	NE	16	3.78	ws in rotation
44014	10-H	Hastings	NE	16	3.98	ws in rotation
44015	11-H	Hastings	NE	16	3.85	ws in rotation
44016	12-H	Hastings	NE	16	3.66	ws in rotation
44017	13-H	Hastings	NE	16	3.41	ws in rotation
44018	14-H	Hastings	NE	16	3.35	ws in rotation
44019	15-H	Hastings	NE	16	3.62	ws in rotation
44020	16-H	Hastings	NE	16	3.57	ws in rotation
44021	17-H	Hastings	NE	16	3.96	ws in rotation
44022	18-H	Hastings	NE	22	3.74	continuous pasture
44023	19-H	Hastings	NE	14	4.1	ws in rotation
44024	20-H	Hastings	NE	14	4.05	ws in rotation
44025	21-H	Hastings	NE	14	3.94	ws in rotation
44026	22-H	Hastings	NE	14	3.83	ws in rotation
44027	23-H	Hastings	NE	14	4.2	ws in rotation
44028	24-H	Hastings	NE	14	4.21	ws in rotation
44029	25-H	Hastings	NE	5	2.24	continuous meadow
47002	W-II	Albuquerque	NM	31	40.1	continuous range
47003	W-III	Albuquerque	NM	31	155	continuous range
62014	WC-2	Oxford	MS	2	1.45	

WS ID	LOCAL ID	TOWN	STATE	TOT YRS	DA	COMMENTS
63101	LUCK.H.1	Tombstone	AZ	9	3.2	
63102	LUCK.H.2	Tombstone	AZ	13	3.6	
63103	LUCK.H.3	Tombstone	AZ	10	9.1	
63104	LUCK.H.4	Tombstone	AZ	11	11.2	
63105	LUCK.H.5	Tombstone	AZ	13	0.45	
63106	LUCK.H.6	Tombstone	AZ	13	0.85	
63112	KENDALL2	Tombstone	AZ	13	4.6	
66001	W-1	Moorefield	WV	10	0.25	continuous pasture
66002	W-2	Moorefield	WV	10	10.06	continuous pasture
66004	W-4	Moorefield	WV	10	6.32	continuous pasture
66005	W-5	Moorefield	WV	10	9.55	continuous pasture
68014	W-14	Reynolds	ID	12	33	continuous range
69030	C-1	Chickasha	OK	10	17.83	continuous cotton
69031	C-2	Chickasha	OK	8	38.1	continuous wheat for 4 yrs
69032	C-3	Chickasha	OK	9	44.26	continuous cotton
69033	C-4	Chickasha	OK	10	29.93	continuous cotton
69034	C-5	Chickasha	OK	10	12.75	continuous wheat
69035	C-6	Chickasha	OK	10	13	continuous wheat
69037	C-8	Chickasha	OK	11	27.28	ws in rotation w/ alfalfa
69042	R-5	Chickasha	OK	10	23.72	continuous pasture
69043	R-6	Chickasha	OK	10	27.22	continuous range
69044	R-7	Chickasha	OK	10	19.19	continuous pasture
69045	R-8	Chickasha	OK	10	27.55	continuous pasture
70004	S-11	Sonora	TX	5	10787	heavily grazed range
70006	S-13	Sonora	TX	4	686	heavily grazed range
70007	W-1	Sonora	TX	5	5466	continuous range
70009	W-3	Sonora	TX	3	6.7	continuous range
70010	W-4	Sonora	TX	3	4.5	continuous range
70011	W-5	Sonora	TX	4	7.2	heavily grazed range
70012	W-6	Sonora	TX	3	6.9	heavily grazed range
70013	W-7	Sonora	TX	4	12.2	continuous range
71001	W-1	Treynor	IA	16	74.5	contin corn paired w/71002
71002	W-2	Treynor	IA	22	82.8	contin corn paired w/71001
71003	W-3	Treynor	IA	22	107	contin corn paired w/71004
71004	W-4	Treynor	IA	22	150	contin corn paired w/71003
86002	2	Beaver Creek	AZ	24	126	Utah juniper, USFS data
86004	4	Beaver Creek	AZ	16	346	Alligator juniper, USFS data
86005	5	Beaver Creek	AZ	16	66	Alligator juniper, USFS data
6233360	*	Hudson	WY	9	5267.2	
6238760	*	Riverton	WY	9	441.6	
6238780	*	Riverton	WY	8	1184	
6256670	*	Lysite	WY	10	3750.4	
6266320	*	Grass Creek	WY	8	832	
6266460	*	Grass Creek	WY	8	1484.8	
6267260	*	Worland	WY	9	2912.8	

WS ID	LOCAL ID	TOWN	STATE	TOT YRS	DA	COMMENTS
6267270	*	Worland	WY	8	1350.4	
6274190	*	Basin	WY	9	966.4	
6312910	*	Midwest	WY	8	979.2	
6312920	*	Midwest	WY	8	857.6	
6313050	*	Edgerton	WY	8	3481.6	
6313180	*	Midwest	WY	19	518.4	
6316480	*	Buffalo	WY	5	2124.8	
6382200	*	Lance Creek	WY	8	3264	
6631150	*	Medicine Bow	WY	9	6912	
6634910	*	Hanna	WY	9	1926.4	
6634950	*	Hanna	WY	9	1267.2	
6644840	*	Casper	WY	9	1292.8	
6648720	*	Orpha	WY	9	505.6	
6648780	*	Orpha	WY	9	883.2	
9221680	*	Lyman	WY	9	5651.2	
bad1a	1-A	Badger Wash	CO	20	42	paired w/1b grazed nov-may ea yr
bad1b	1-B	Badger Wash	CO	21	54	ungrazed paired with 1a
bad2a	2-A	Badger Wash	CO	20	107	paired w/2b grazed nov-may ea yr
bad2b	2-B	Badger Wash	CO	21	101	ungrazed paired with 2a
bad3a	3-A	Badger Wash	CO	20	38	grazed nov-may ea yr
bad3b	3-B	Badger Wash	CO	21	31	ungrazed paired with 3a
bad4a	4-A	Badger Wash	CO	20	14	grazed nov-may ea yr
bad4b	4-B	Badger Wash	CO	21	12	ungrazed paired with 4a
boco1	1	Boco Mts.	CO	9	7.41	
boco2	2	Boco Mts.	CO	9	9.69	plowed & planted to grass Oct 67
boco3	3	Boco Mts.	CO	9	5.1	
boco4	4	Boco Mts.	CO	8	8.13	plowed & planted to grass Oct 67
c_creek	*	Silver Creek	ID	9	460	USFS dense forest
cabin	*	Silver Creek	ID	9	271	USFS dense forest
d_creek	*	Silver Creek	ID	10	292	USFS dense forest
ditch	*	Silver Creek	ID	7	252	USFS dense forest
eggers	*	Silver Creek	ID	10	318	USFS dense forest
hew1	*	Whitehall	GA	9	59.3	
hew11	1	Leading Ridge	PA	5	303.9	
hew14	14	Coweeta	NC	44	145.8	
hew3	3	Hubbard Brook	NH	14	103.8	
hew34	34	Coweeta	NC	22	81.5	
hew4	4	Fernow	WV	24	96.3	
hew6	6	Berea	KY	8	246.6	
hew77	77	Charleston	SC	8	378	swamp and forest
hew78	78	Charleston	SC	8	11307	swamp and forest

APPENDIX C

This is a list of all land uses used in this study and their associated totals. The headings for the table are:

- LANDUSE – single land use as described in chapter 3
- TOTAL WS - total number of watersheds found to have that land use
- TOTAL N - total number of events per land use
- TOTAL YR - total number of years of record per land use.

LANDUSE	TOTAL WS	TOTAL N	TOTAL YR
alfalfa	**1**	**65**	**5**
corn	**44**	**8001**	**326**
cotton	**10**	**882**	**47**
desert shrub	**14**	**991**	**233**
fallow	**8**	**354**	**22**
forest	**17**	**2252**	**243**
grassland	**3**	**124**	**22**
meadow	**26**	**3555**	**298**
oats	**33**	**2164**	**127**
pasture	**39**	**6208**	**375**
range	**39**	**1475**	**353**
sage brush	**4**	**220**	**24**
sorghum	**14**	**877**	**52**
soy bean	**8**	**172**	**10**
wheat	**48**	**5522**	**315**

APPENDIX D

An example of two outputs with data from the GETPQ96 data reduction program.

Format of *.ALL file

N	YY	MO	DY	TIME	P (in)	PDUR (hr)
1	38	1	30	934	0.62	14.57
2	38	2	6	1000	0.72	6.83
3	38	2	18	1100	0.4	8.5
4	38	2	19	1316	0.34	6.9

IA (in)	IMAX (iph)	IMAXDUR (hr)	TQLAGP (hr)	Q (in)	QDUR (hr)	QBASE (iph)
0.012	0.1667	0.3	1.27	0.1187	19.83	0.0013
0.01	2.4	0.02	0.5	0.2391	19.5	0.0025
0.016	0.3	0.07	2	0.0392	13	0.0018
0.311	0.6	0.03	5.73	0.0667	14	0.0037

QPPS (iph)	QP (iph)	AMC-5 (in)	AMC-2 (in)	AMC-1 (in)	Imax05 (iph)	Imax10 (iph)
0.0215	0.0178	0.06	0.06	0.06	0.1667	0.1667
0.0884	0.0847	0	0	0	1.3198	0.8628
0.0146	0.0115	0	0	0	0.2469	0.1411
0.0164	0.0119	0.4	0.4	0.4	0.3002	0.2001

Imax15 (iph)	Imax20 (iph)	Imax25 (iph)	Imax 30 (iph)	Imax35 (iph)	Imax40 (iph)	Imax45 (iph)
0.1667	0.1633	0.1573	0.1533	0.1505	0.1486	0.1489
0.6443	0.535	0.4695	0.4258	0.3946	0.3711	0.3529
0.1333	0.1333	0.1333	0.1333	0.1333	0.1295	0.1258
0.1721	0.174	0.1712	0.156	0.1452	0.137	0.1307

Imax50 (iph)	Imax55 (iph)	Imax60 (iph)	PBAR (hr)	PSD (hr)	PSkew (-)	PKurt (-)
0.1493	0.1479	0.1467	8.803	3.146	-0.474	3.095
0.3384	0.3265	0.3165	4.228	1.776	-0.379	1.827
0.1227	0.1202	0.1182	5.433	1.802	-0.685	2.811
0.1256	0.1215	0.118	2.283	1.999	0.762	2.332

Qbar (hr)	QSD (hr)	QSkew (-)	QKurt (-)	Tpeak (hr)	PI (-)	Lag (hr)
10.935	2.742	0.402	3.148	11.5	0.3957	3.399
7.792	2.896	1.149	4.359	6.083	0.3811	4.063
7.362	1.898	0.529	3.025	6.3	0.3608	3.929
5.191	2.545	0.676	2.871	4.117	0.6691	8.641

CN (-)	EI ft*tonf /ac
90.66	0.533
92.83	0.728
91.42	0.261
94.73	0.305

Example of *.DAT file

```
**********************  GETPQ 96  **********************
                     ver. October 28, 1996
Date of test run --------------------------------> 06-11-1997
Time of test run --------------------------------> 14:16:03
Watershed ID ------------------------------------> WS44022
Watershed Name ----------------------------------> Hastings, NE
Input Directory ---------------------------------> D:\GETPQ96\44022&RG
Output Directory --------------------------------> D:\GETPQ96\44022&RG
<H>ydrograph or <B>oth --------------------------> B
Output in ARS Format (Y/N)-----------------------> N
Watershed Area (acres) --------------------------> 3.74
Rainfall File -----------------------------------> RGRGPB33.WDC
Runoff File -------------------------------------> WS44022.WDC
Baseflow Separation Slope (iph/hr)---------------> .0002
Lag Time Between Storms (hr) --------------------> 2
Max Time from End of Rain to Start of Runoff (hr)-> 2
Max. Drizzle Time to Separate Storms (hr) -------> 2
Drizzle Intensity (iph) -------------------------> .01
Minimum Depth of Rainfall (in)-------------------> .001
Minimum Depth of Runoff (in)---------------------> .01
Minimum Peak Runoff Rate (iph)-------------------> .01
Calculation of Annual Yields --------------------> Y
Calculation of Annual Erosivity -----------------> Y
Calculation of moments and rainfall intensities --> Y
Name of Operator --------------------------------> SEATON CLAGGETT
Events Start at Year ----------------------------> 40
Events End at Year ------------------------------> 62
Number of Runoff Events -------------------------> 166
Number of Erosivity Events ----------------------> 1415
```

The *.DAT file contains the values of the input parameters for the sample run on data from Hastings, NE #22.

APPENDIX E

Example of an output from the standard asymptotic Curve Number computer program:

```
Run performed by pdr
 12-30-1998    13:28:37
Standard Asymptotic Fit        Standard Asymptotic Fit   on CN
Version of June 10, 1997       Comparative results for file  26019w

Asymptotic CN LS fit to CN(P)=CN(inf)+(100-CN(inf))*exp(-k*P)
Minimizes Sum(CN-CNcalc)^2 in the above function for CN(inf) and k

              Minimum   Mean(Std Dev)     Maximum
             -----------------------------------------
      P       0.010     0.5634(0.5622)    3.2400
      Q       0.0003    0.0473(0.1044)    0.7571
    CN nat             87.0740(10.281)
    CN ord             87.5237( 7.449)
      N =    199

 Item                 NATURAL             ORDERED
 -------------------------------------------------------
CN(inf)               55.29               69.42
k (1/in)               0.7180              1.2785
 R2  (%)              81.64               97.83
 SE  (CN)              4.4059              1.0961
on Q r2  (%)          38.43               96.63
     se  (in)          0.0819              0.0192

At 90% ordered P       1.380 in            1.380 in
 CNP90 (CN)           71.89               74.65
 Stability  (%)       62.87               82.87
 Slope dP/dQ  (%)      9.29               20.26
 CN(max)              90.22               90.50
 P/S(inf)              0.1707              0.3132
 K'=k*S(inf)           5.8059              5.6331

At P=0
 dCN/dP  (CN/in)     -32.10              -39.10
 P  limited to >       0.1487              0.1487
 CN limited to <     100.00              100.00
-----------------------------------------------------------

Fitted Performance Summary  12-30-1998    13:28:37  File 26019w.prn
          ------- N A T U R A L ------    ------- O R D E R E D ------
  P       CN    Qcalc    P-Q     dQ/dP     CN     Qcalc    P-Q     dQ/dP
-------------------------------------------------------------------------
 0.50   86.51  0.0203  0.4797    4.70    85.55  0.0142  0.4858    5.15
 1.00   77.10  0.0488  0.9512    6.89    77.93  0.0576  0.9424   12.74
 1.50   70.52  0.0910  1.4090   10.17    73.91  0.1458  1.3542   22.79
 2.00   65.93  0.1522  1.8478   14.47    71.79  0.2865  1.7135   33.45
 2.50   62.72  0.2369  2.2631   19.54    70.67  0.4790  2.0210   43.36
 3.00   60.48  0.3484  2.6516   25.09    70.08  0.7177  2.2823   51.87
 3.50   58.91  0.4881  3.0119   30.83    69.76  0.9952  2.5048   58.87
 4.00   57.82  0.6565  3.3435   36.48    69.60  1.3043  2.6957   64.55
-------------------------------------------------------------------------
Infin   55.29          9.7031  100.00    69.42          5.2872  100.00
```

APPENDIX F

This is a list of all the watersheds used for analysis broken down by land use and their corresponding Curve Number. The symbol * indicates no data was available. Headings for the table are:

- WS ID – watershed identification,
- TOWN – closest town to the watershed,
- STATE – state in which watershed is located,
- LAND USE – land use > 90% of watershed area,
- CN – Curve Number of watershed in stated land use,
- R^2 – statistic from asymptotic Curve Number program in (%),
- STAB – relative closeness of fitted CN for the 90th percentile sampled rainfall from asymptotic Curve Number program reported in %,
- N – number of events in stated land use,
- LU YRS – number of years of record watershed in stated land use.

WS ID	TOWN	STATE	LAND USE	CN	R^2	STAB	N	LU YRS
10001p	Watkinsville	GA	pasture	72.61	57.98	99.78	32	4
19004c	Lafayette	IN	corn	82.86	86.98	91.19	23	3
19004m	Lafayette	IN	meadow	66.97	85.43	89.35	21	4
19004sb	Lafayette	IN	soy bean	83.67	45.35	99.90	18	2
19004w	Lafayette	IN	wheat	85.80	85.33	97.76	42	3
19005c	Lafayette	IN	corn	81.38	56.04	100.00	11	3
19005m	Lafayette	IN	meadow	59.37	89.95	86.98	15	3
19005sb	Lafayette	IN	soy bean	71.55	89.68	96.60	7	2
19005w	Lafayette	IN	wheat	77.47	86.89	96.60	21	3
26001p	Coshocton	OH	pasture	77.97	0.02	*	295	31
26002c7	Coshocton	OH	corn	74.54	93.67	99.16	17	5
26002p	Coshocton	OH	pasture	76.24	0.01	*	242	14
26003m	Coshocton	OH	meadow	71.02	89.67	99.67	17	3
26003p	Coshocton	OH	pasture	82.67	93.47	98.07	755	37
26004p	Coshocton	OH	pasture	70.17	99.35	94.47	333	44
26005m	Coshocton	OH	meadow	76.24	98.44	94.29	202	19
26010c	Coshocton	OH	corn	86.29	25.38	95.81	466	19
26010m	Coshocton	OH	meadow	86.77	77.03	99.93	189	17
26010o	Coshocton	OH	oats	84.38	83.17	98.97	23	1
26010sb	Coshocton	OH	soy bean	90.98	41.73	99.96	16	1
26010w	Coshocton	OH	wheat	84.87	80.50	98.43	131	8
26011c	Coshocton	OH	corn	84.94	91.80	98.78	282	11
26011m	Coshocton	OH	meadow	80.42	0.02	*	170	14
26011o	Coshocton	OH	oats	89.75	21.82	99.95	30	1
26011sb	Coshocton	OH	soy bean	80.74	90.34	99.43	10	1
26011w	Coshocton	OH	wheat	84.40	90.64	97.58	185	8
26012c	Coshocton	OH	corn	84.12	93.22	99.18	218	8
26012m	Coshocton	OH	meadow	85.91	88.57	99.73	203	11
26012sb	Coshocton	OH	soy bean	81.49	95.09	94.88	48	1
26012w	Coshocton	OH	wheat	87.43	74.40	97.16	87	5
26013c	Coshocton	OH	corn	75.63	95.06	97.80	312	20
26013m	Coshocton	OH	meadow	67.30	95.25	93.64	98	14
26013o	Coshocton	OH	oats	86.47	83.13	99.25	21	1
26013w	Coshocton	OH	wheat	83.88	64.17	98.31	107	8
26014c	Coshocton	OH	corn	83.53	90.54	96.86	90	7
26014m	Coshocton	OH	meadow	81.69	87.64	98.11	133	14
26014p	Coshocton	OH	pasture	88.44	81.89	99.94	399	11
26014w	Coshocton	OH	wheat	86.52	6.05	*	73	7
26015c	Coshocton	OH	corn	83.96	91.94	97.23	127	8
26015m	Coshocton	OH	meadow	76.49	91.97	93.02	182	15
26015p	Coshocton	OH	pasture	80.93	95.76	95.80	300	12
26015w	Coshocton	OH	wheat	80.62	96.50	95.47	97	7
26016c	Coshocton	OH	corn	83.51	88.38	97.11	206	9
26016m	Coshocton	OH	meadow	82.89	81.02	95.08	69	7

WS ID	TOWN	STATE	LAND USE	CN	R^2	STAB	N	LU YRS
26016sb	Coshocton	OH	soy bean	80.23	93.49	95.00	18	1
26016w	Coshocton	OH	wheat	80.23	85.06	98.56	18	2
26017c	Coshocton	OH	corn	81.56	97.03	95.76	369	13
26017m	Coshocton	OH	meadow	77.06	96.71	92.84	311	18
26017sb	Coshocton	OH	soy bean	70.45	99.22	81.11	48	1
26017w	Coshocton	OH	wheat	85.20	91.24	98.50	269	8
26018c	Coshocton	OH	corn	90.23	24.76	100.00	33	2
26018m	Coshocton	OH	meadow	77.23	80.97	66.42	43	5
26018w	Coshocton	OH	wheat	89.91	48.84	100.00	27	2
26019c	Coshocton	OH	corn	80.61	97.35	92.36	210	10
26019m	Coshocton	OH	meadow	73.96	97.56	86.99	219	15
26019p	Coshocton	OH	pasture	82.84	85.75	96.03	93	2
26019w	Coshocton	OH	wheat	69.42	97.83	82.87	199	9
26020c	Coshocton	OH	corn	82.38	67.56	87.33	275	8
26020m	Coshocton	OH	meadow	71.18	62.67	90.37	328	17
26020p	Coshocton	OH	pasture	87.50	69.01	99.53	51	1
26020w	Coshocton	OH	wheat	79.40	95.34	89.65	258	8
26021c	Coshocton	OH	corn	76.89	88.65	97.42	64	8
26021m	Coshocton	OH	meadow	76.65	94.92	95.43	102	13
26021w	Coshocton	OH	wheat	77.47	71.38	73.83	136	6
26023c	Coshocton	OH	corn	67.15	96.58	86.51	43	2
26023m	Coshocton	OH	meadow	72.48	95.72	82.51	53	2
26023w	Coshocton	OH	wheat	77.84	73.80	96.01	20	1
26024c	Coshocton	OH	corn	78.50	97.45	98.90	67	3
26025c	Coshocton	OH	corn	82.03	94.08	93.67	157	7
26025m	Coshocton	OH	meadow	70.17	95.33	83.88	307	14
26025w	Coshocton	OH	wheat	79.77	97.37	90.26	158	7
34001w	Cherokee	OK	wheat	86.10	81.29	99.97	225	14
34002w	Cherokee	OK	wheat	87.61	77.99	100.00	7	7
34006w	Cherokee	OK	wheat	84.53	92.21	99.92	240	15
34007w	Cherokee	OK	wheat	85.66	89.08	99.99	236	15
34008w	Cherokee	OK	wheat	81.58	95.00	99.88	207	15
34013w	Cherokee	OK	wheat	79.92	80.50	99.17	52	8
35002m	Guthrie	OK	meadow	82.37	91.54	98.20	151	10
35003m	Guthrie	OK	meadow	85.69	68.83	100.00	107	8
35005m	Guthrie	OK	meadow	76.60	94.93	97.29	128	9
35006p	Guthrie	OK	pasture	75.48	*	*	32	6
35007p	Guthrie	OK	pasture	62.84	97.61	94.53	35	7
35008p	Guthrie	OK	pasture	80.32	93.77	99.70	129	7
35009p	Guthrie	OK	pasture	83.12	94.70	99.92	120	7
35010p	Guthrie	OK	pasture	79.70	95.01	99.78	113	7
35011p	Guthrie	OK	pasture	69.59	97.22	96.58	99	7
37001p	Stillwater	OK	pasture	88.00	*	*	185	10
37002p	Stillwater	OK	pasture	76.26	72.32	99.79	60	4

WS ID	TOWN	STATE	LAND USE	CN	R^2	STAB	N	LU YRS
37003p	Stillwater	OK	pasture	71.10	89.91	96.46	23	2
42007p	Riesel	TX	pasture	85.00	*	*	20	21
42008p	Riesel	TX	pasture	73.81	77.39	99.70	25	3
42010p	Riesel	TX	pasture	87.61	48.96	100.00	181	12
42014cot	Riesel	TX	cotton	83.94	82.63	99.99	71	3
42014o	Riesel	TX	oats	66.03	89.30	94.66	33	3
42014s	Riesel	TX	sorghum	81.56	89.56	99.96	83	4
42015p	Riesel	TX	pasture	86.03	53.83	100.00	99	6
42016cot	Riesel	TX	cotton	82.16	91.82	99.88	102	4
42016o	Riesel	TX	oats	83.52	39.80	*	79	3
42016s	Riesel	TX	sorghum	73.95	93.81	97.89	57	4
42017cot	Riesel	TX	cotton	81.18	77.16	99.65	54	4
42017o	Riesel	TX	oats	81.65	34.90	99.99	22	2
42017s	Riesel	TX	sorghum	87.86	6.36	*	56	3
42023p2	Riesel	TX	pasture	86.60	0.01	*	73	7
42024m	Riesel	TX	meadow	88.26	70.26	100.00	252	11
42028p	Riesel	TX	pasture	86.24	78.39	100.00	263	12
42031p1	Riesel	TX	pasture	96.00	*	*	15	1
42032p1	Riesel	TX	pasture	93.66	25.03	*	21	1
42033p	Riesel	TX	pasture	92.82	57.60	99.96	17	1
42034p	Riesel	TX	pasture	91.48	11.92	99.98	19	1
42035ra	Riesel	TX	range	86.48	22.30	100.00	146	10
42036ra	Riesel	TX	range	74.62	88.46	99.52	33	2
42036rb	Riesel	TX	range	88.07	36.39	100.00	120	7
42037cot	Riesel	TX	cotton	74.78	86.76	99.60	21	2
42037o	Riesel	TX	oats	82.56	0.01	*	31	2
42037s	Riesel	TX	sorghum	83.94	66.05	100.00	62	5
42038cot	Riesel	TX	cotton	78.61	52.69	96.16	25	1
42038o	Riesel	TX	oats	82.19	33.87	100.00	33	2
42038p	Riesel	TX	pasture	75.46	56.80	99.69	14	2
42038s	Riesel	TX	sorghum	82.52	30.21	100.00	38	3
42039cot	Riesel	TX	cotton	84.55	68.79	*	50	2
42039o	Riesel	TX	oats	59.25	95.06	90.42	26	2
42039s	Riesel	TX	sorghum	78.83	84.01	99.99	79	5
42040cot	Riesel	TX	cotton	79.22	79.08	99.96	44	2
42040o	Riesel	TX	oats	62.77	95.55	96.00	27	2
42040s	Riesel	TX	sorghum	78.97	81.69	99.99	103	6
44005m	Hastings	NE	meadow	63.78	96.78	93.75	105	25
44005s	Hastings	NE	sorghum	82.34	48.25	99.99	24	2
44006m	Hastings	NE	meadow	70.50	97.52	97.49	124	22
44006p	Hastings	NE	pasture	85.60	74.61	*	25	4
44007c	Hastings	NE	corn	90.42	63.27	99.92	104	5
44007f	Hastings	NE	fallow	88.82	54.52	99.98	30	3
44007o	Hastings	NE	oats	90.65	70.31	99.96	106	5

WS ID	TOWN	STATE	LAND USE	CN	R^2	STAB	N	LU YRS
44007s	Hastings	NE	sorghum	87.55	77.97	99.48	88	3
44007w	Hastings	NE	wheat	88.95	76.31	99.76	169	8
44008c	Hastings	NE	corn	88.46	87.22	99.84	106	6
44008f	Hastings	NE	fallow	91.72	60.45	99.92	84	3
44008o	Hastings	NE	oats	85.86	45.26	97.01	91	5
44008s	Hastings	NE	sorghum	87.35	81.76	99.57	71	4
44008w	Hastings	NE	wheat	88.06	85.00	99.59	163	8
44009c	Hastings	NE	corn	84.42	87.78	98.02	99	5
44009f	Hastings	NE	fallow	84.21	94.46	98.54	63	4
44009o	Hastings	NE	oats	87.00	79.69	99.13	101	5
44009s	Hastings	NE	sorghum	85.41	86.71	99.31	49	3
44009w	Hastings	NE	wheat	86.04	90.76	98.82	203	8
44010c	Hastings	NE	corn	90.30	62.80	*	95	5
44010f	Hastings	NE	fallow	83.36	90.28	97.52	63	4
44010o	Hastings	NE	oats	89.47	79.54	99.86	124	6
44010s	Hastings	NE	sorghum	86.03	80.37	99.15	48	3
44010w	Hastings	NE	wheat	87.48	76.77	99.40	154	8
44011c	Hastings	NE	corn	83.06	81.82	99.30	65	4
44011f	Hastings	NE	fallow	87.50	88.38	99.44	67	3
44011o	Hastings	NE	oats	87.88	73.30	99.98	96	6
44011s	Hastings	NE	sorghum	82.50	94.39	97.53	67	4
44011w	Hastings	NE	wheat	84.31	88.22	97.34	129	8
44012c	Hastings	NE	corn	81.89	88.22	99.62	67	6
44012f	Hastings	NE	fallow	83.95	46.39	99.93	19	3
44012o	Hastings	NE	oats	81.14	85.67	97.94	70	5
44012s	Hastings	NE	sorghum	85.24	82.68	*	52	3
44012w	Hastings	NE	wheat	79.91	95.04	97.71	147	9
44013c	Hastings	NE	corn	86.53	67.35	99.78	93	6
44013o	Hastings	NE	oats	83.97	85.60	98.89	71	5
44013w	Hastings	NE	wheat	83.68	84.18	97.97	84	5
44014c	Hastings	NE	corn	86.69	63.45	99.76	106	6
44014o	Hastings	NE	oats	85.00	67.62	99.80	68	4
44014w	Hastings	NE	wheat	80.34	89.95	98.45	58	4
44015c	Hastings	NE	corn	88.56	76.79	99.67	100	4
44015o	Hastings	NE	oats	85.88	81.41	99.14	93	6
44015w	Hastings	NE	wheat	86.04	68.90	99.33	60	4
44016c	Hastings	NE	corn	90.52	65.04	99.89	96	5
44016o	Hastings	NE	oats	90.02	52.36	99.98	90	6
44016w	Hastings	NE	wheat	87.41	74.78	99.07	123	5
44017c	Hastings	NE	corn	86.49	68.08	99.74	78	5
44017o	Hastings	NE	oats	86.26	88.62	99.57	95	5
44017w	Hastings	NE	wheat	86.42	4.66	91.72	88	4
44018c	Hastings	NE	corn	87.00	16.74	90.65	76	5
44018o	Hastings	NE	oats	86.13	65.86	99.85	66	5

WS ID	TOWN	STATE	LAND USE	CN	R^2	STAB	N	LU YRS
44018w	Hastings	NE	wheat	86.80	82.73	99.77	94	4
44019c	Hastings	NE	corn	90.47	58.17	100.00	105	6
44019o	Hastings	NE	oats	89.41	57.02	99.87	85	5
44019w	Hastings	NE	wheat	89.62	55.82	99.95	113	5
44020c	Hastings	NE	corn	88.13	49.06	99.98	66	4
44020o	Hastings	NE	oats	87.37	64.73	99.97	67	5
44020w	Hastings	NE	wheat	89.76	58.94	99.97	86	5
44021c	Hastings	NE	corn	88.58	69.89	99.73	97	5
44021o	Hastings	NE	oats	90.42	28.14	99.97	110	6
44021w	Hastings	NE	wheat	87.34	79.06	99.62	114	5
44022p	Hastings	NE	pasture	81.28	89.30	99.70	320	22
44023c	Hastings	NE	corn	87.20	87.19	99.60	75	4
44023f	Hastings	NE	fallow	86.72	62.32	99.66	26	1
44023o	Hastings	NE	oats	88.03	66.05	99.92	63	4
44023w	Hastings	NE	wheat	87.57	64.85	99.88	94	5
44024c	Hastings	NE	corn	87.64	54.17	99.82	90	5
44024o	Hastings	NE	oats	86.64	71.54	99.38	103	5
44024w	Hastings	NE	wheat	85.76	53.69	98.69	71	4
44025c	Hastings	NE	corn	83.05	60.42	97.79	69	5
44025o	Hastings	NE	oats	86.59	79.38	99.00	90	5
44025w	Hastings	NE	wheat	87.72	82.06	99.66	79	4
44026c	Hastings	NE	corn	83.73	76.37	99.61	58	4
44026o	Hastings	NE	oats	86.51	74.27	99.79	81	5
44026w	Hastings	NE	wheat	88.39	73.42	99.96	102	5
44027c	Hastings	NE	corn	90.04	31.84	100.00	99	5
44027o	Hastings	NE	oats	88.49	77.12	99.89	81	4
44027w	Hastings	NE	wheat	89.10	53.59	99.98	97	5
44028c	Hastings	NE	corn	87.01	78.74	99.78	80	4
44028o	Hastings	NE	oats	85.92	72.41	99.77	72	4
44028w	Hastings	NE	wheat	86.63	75.82	99.61	117	6
44029m	Hastings	NE	meadow	71.51	69.11	99.95	16	5
47002r	Albuquerque	NM	range	92.33	55.49	99.82	240	31
47003r	Albuquerque	NM	range	88.44	68.40	99.59	132	31
62014c	Oxford	MS	corn	91.14	24.45	99.83	53	2
6233360	Hudson	WY	range	75.32	94.50	80.54	11	9
6238760	Riverton	WY	range	88.37	63.01	98.44	17	9
6238780	Riverton	WY	range	86.73	72.55	99.80	13	8
6256670	Lysite	WY	range	76.16	98.86	62.62	20	10
6266320	Grass Creek	WY	range	93.60	10.64	97.66	14	8
6266460	Grass Creek	WY	range	85.62	89.95	78.21	23	8
6267260	Worland	WY	range	85.87	92.68	89.78	19	9
6267270	Worland	WY	range	80.60	99.01	90.73	16	8
6274190	Basin	WY	range	87.50	80.39	84.10	15	9
63101	Tombstone	AZ	desert shrub	91.41	16.09	99.96	70	9

WS ID	TOWN	STATE	LAND USE	CN	R^2	STAB	N	LU YRS
63102	Tombstone	AZ	desert shrub	91.65	69.38	99.65	132	13
63103	Tombstone	AZ	desert shrub	88.82	79.16	99.82	94	10
63104	Tombstone	AZ	desert shrub	90.55	82.09	99.44	83	11
63105	Tombstone	AZ	desert shrub	83.08	93.77	84.91	63	13
63106	Tombstone	AZ	desert shrub	92.34	67.18	99.47	102	13
63112	Tombstone	AZ	grassland	88.71	45.58	99.71	87	13
6312910	Midwest	WY	range	95.80	4.89	100.00	21	8
6312920	Midwest	WY	range	77.93	91.11	41.78	21	8
6313050	Edgerton	WY	range	81.82	80.05	92.36	17	8
6313180	Midwest	WY	range	92.89	42.17	97.67	37	19
6316480	Buffalo	WY	range	82.92	85.41	97.77	12	5
6382200	Lance Creek	WY	range	84.09	91.24	75.57	25	8
66001p	Moorefield	WV	pasture	85.75	85.31	97.04	169	10
66002p	Moorefield	WV	pasture	79.07	2.20	2.156	288	10
66004p	Moorefield	WV	pasture	74.56	98.71	82.35	389	10
66005p	Moorefield	WV	pasture	81.39	96.15	95.87	244	10
6631150	Medicine Bow	WY	range	77.76	93.42	68.56	21	9
6634910	Hanna	WY	range	84.15	84.36	95.43	23	9
6634950	Hanna	WY	range	84.77	86.38	87.59	20	9
6644840	Casper	WY	range	74.09	91.71	87.32	13	9
6648720	Orpha	WY	range	85.39	72.67	95.64	12	9
6648780	Orpha	WY	range	69.89	76.15	80.80	12	9
68014r	Reynolds	ID	range	81.67	94.24	92.72	31	12
69030cot	Chickasha	OK	cotton	76.90	87.89	99.02	161	10
69031w	Chickasha	OK	wheat	66.72	96.79	91.03	42	5
69032cot	Chickasha	OK	cotton	81.13	81.47	99.63	198	9
69033cot	Chickasha	OK	cotton	79.47	79.12	99.78	156	10
69034w	Chickasha	OK	wheat	77.39	85.87	99.36	94	10
69035w	Chickasha	OK	wheat	77.82	88.99	99.32	116	10
69037a	Chickasha	OK	alfalfa	73.69	86.19	98.02	65	5
69037w	Chickasha	OK	wheat	73.9	*	*	58	4
69042r	Chickasha	OK	range	71.93	93.53	99.16	85	10
69043r	Chickasha	OK	range	70.53	95.08	96.99	127	10
69044p	Chickasha	OK	pasture	83.14	27.13	93.74	225	10
69045p	Chickasha	OK	pasture	80.07	94.41	97.92	250	10
70004r1	Sonora	TX	range	61.40	72.30	98.68	12	5
70006r1	Sonora	TX	range	71.66	82.38	99.89	14	4
70007r	Sonora	TX	range	73.76	67.24	99.92	25	5
70009r	Sonora	TX	range	70.92	60.14	99.99	18	3
70010r	Sonora	TX	range	49.82	91.18	98.33	9	3
70011r1	Sonora	TX	range	73.56	68.88	99.81	41	4
70012r1	Sonora	TX	range	68.15	83.43	99.93	15	3
70013r	Sonora	TX	range	42.70	99.73	85.12	17	12
71001c1	Treynor	IA	corn	74.51	97.97	88.54	908	16

WS ID	TOWN	STATE	LAND USE	CN	R^2	STAB	N	LU YRS
71002c1	Treynor	IA	corn	76.12	97.74	90.19	1120	22
71003c2	Treynor	IA	corn	63.34	99.21	80.60	490	14
71003p1	Treynor	IA	pasture	60.67	96.48	79.43	246	8
71004c2	Treynor	IA	corn	60.63	84.43	94.51	636	22
86002f	Beaver Cr	AZ	forest	80.03	93.73	91.09	100	24
86004f	Beaver Cr	AZ	forest	84.28	64.60	96.94	58	16
86005f	Beaver Cr	AZ	forest	81.64	64.10	98.70	60	16
9221680	Lyman	WY	range	63.62	88.41	33.65	20	9
bad1a_db	Badger Wash	CO	desert shrub	92.19	77.21	97.34	54	20
bad1b	Badger Wash	CO	desert shrub	90.99	60.37	98.67	37	21
bad2a_db	Badger Wash	CO	desert shrub	91.74	64.79	96.10	66	20
bad2b	Badger Wash	CO	desert shrub	89.26	81.19	94.38	55	21
bad3a_db	Badger Wash	CO	desert shrub	93.89	40.14	99.89	66	20
bad3b	Badger Wash	CO	desert shrub	93.04	52.28	99.64	62	21
bad4a_db	Badger Wash	CO	desert shrub	93.43	55.74	99.44	56	20
bad4b	Badger Wash	CO	desert shrub	90.91	65.66	98.62	51	21
Boco1	Boco Mts.	CO	sage brush	85.66	65.66	94.87	61	9
boco2_db	Boco Mts.	CO	sage brush	93.07	74.08	96.56	39	3
boco2_g	Boco Mts.	CO	grassland	75.05	97.58	75.18	22	5
Boco3	Boco Mts.	CO	sage brush	88.73	86.89	93.25	82	9
boco4_db	Boco Mts.	CO	sage brush	90.02	85.16	85.26	38	3
boco4_g	Boco Mts.	CO	grassland	76.23	93.49	89.97	15	4
c_creek	Silver Creek	ID	forest	54.65	98.74	70.13	29	9
cabin	Silver Creek	ID	forest	43.82	99.50	65.00	43	9
d_creek	Silver Creek	ID	forest	52.21	99.76	73.44	30	10
ditch	Silver Creek	ID	forest	40.37	99.80	63.78	27	7
eggers	Silver Creek	ID	forest	40.25	99.94	58.37	38	10
hew1	Whitehall	GA	forest	66.83	69.24	99.13	142	9
hew11	Leading Rdg	PA	forest	77.47	88.04	88.20	52	5
hew14	Coweeta	NC	forest	36.81	80.18	92.63	901	44
hew3	Hubbard Brk	NH	forest	80.63	*	*	77	14
hew34	Coweeta	NC	forest	39.12	91.31	95.79	491	22
hew4	Fernow	WV	forest	79.80	74.79	97.41	50	24
hew6	Berea	KY	forest	92.33	80.20	*	86	8
hew77	Charleston	SC	forest	79.27	43.57	99.49	38	8
hew78	Charleston	SC	forest	55.54	91.99	87.07	30	8

APPENDIX G

Watersheds with r^2 less than 50%

WS ID	Town	State	Landuse	CN	R2 (%)
19004sb	Lafayette	IN	soy bean	83.67	45.35
26001p	Coshocton	OH	pasture	77.97	0.02
26002p	Coshocton	OH	pasture	76.24	0.01
26010c	Coshocton	OH	corn	86.29	25.38
26010sb	Coshocton	OH	soy bean	90.98	41.73
26011m	Coshocton	OH	meadow	80.42	0.02
26011o	Coshocton	OH	oats	89.75	21.82
26014w	Coshocton	OH	wheat	86.52	6.05
26018c	Coshocton	OH	corn	90.23	24.76
26018w	Coshocton	OH	wheat	89.91	48.84
35006p	Guthrie	OK	pasture	75.48	0.00
37001p	Stillwater	OK	pasture	88.09	0.00
42007p	Riesel	TX	pasture	84.93	0.00
42010p	Riesel	TX	pasture	87.61	48.96
42016o	Riesel	TX	oats	83.52	39.80
42017o	Riesel	TX	oats	81.65	34.90
42017s	Riesel	TX	sorghum	87.86	6.36
42023p2	Riesel	TX	pasture	86.60	0.01
42031p1	Riesel	TX	pasture	96.00	*
42032p1	Riesel	TX	pasture	93.66	25.03
42034p	Riesel	TX	pasture	91.48	11.92
42035ra	Riesel	TX	range	86.48	22.30
42036rb	Riesel	TX	range	88.07	36.39
42037o	Riesel	TX	oats	82.56	0.01
42038o	Riesel	TX	oats	82.19	33.87
42038s	Riesel	TX	sorghum	82.52	30.21
44005s	Hastings	NE	sorghum	82.34	48.25
44008o	Hastings	NE	oats	85.86	45.26
44012f	Hastings	NE	fallow	83.95	46.39
44017w	Hastings	NE	wheat	86.42	4.66
44018c	Hastings	NE	corn	87.00	16.74
44020c	Hastings	NE	corn	88.13	49.06
44021o	Hastings	NE	oats	90.42	28.14
44027c	Hastings	NE	corn	90.04	31.84
62014c	Oxford	MS	corn	91.14	24.45
6266320	Grass Creek	WY	range	93.60	10.64
63101	Tombstone	AZ	desert shrub	91.41	16.09
63112	Tombstone	AZ	grassland	88.71	45.58
6312910	Midwest	WY	range	95.80	4.89
6313180	Midwest	WY	range	92.89	42.17
66002p	Moorefield	WV	pasture	79.07	2.20
69037w	Chickasha	OK	wheat	73.90	*
69044p	Chickasha	OK	pasture	83.14	27.13
bad3a_db	Badger Wash	CO	desert shrub	93.89	40.14
hew3	Hubbard Brk	NH	forest	80.63	*
hew6	Berea	KY	forest	92.33	0.80
hew77	Charleston	SC	forest	79.27	43.57

APPENDIX H

GLOSSARY OF ACRONYMS

a	alfalfa
ANOVA	Analysis of Variance
ARS	Agricultural Research Service
c	corn
CN	Curve Number
CN_{avg}	average Curve Number
CN_{eye}	Curve Number determined by eye
CN_{fit}	fitted Curve Number
CN_{inf}	Curve Number infinity
CN_{med}	median Curve Number
CN_o	Curve Number at threshold of runoff
CN_{ord}	ordered Curve Number
CN_{std}	standard Curve Number
CN_{vio}	violent Curve Number
ct	cotton
db	desert brush
f	fallow
GIS	Geographic Information System
graz	grazed
I_a	Initial abstraction
k	fitting coefficient
m	meadow
N	sample size
NEH-4	National Engineering Handbook, Section 4, Hydrology
NRCS	Natural Resource conservation Service
o	oats
P	rainfall in inches
p	pasture
Q	runoff in inches
r^2	coefficient of determination
ra	range with live mesquite
rb	range with dead mesquite
s	sorghum
S	watershed storage index in inches
sb	soybean
SCS	Soil Conservation Service
sh	shrub
sig dif	significant difference

ungr	ungrazed
USDA	United States Department of Agricultural
USFS	United States Forest Service
USGS	United States Geological Survey
var	variance
w	wheat
WS	watershed

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