Climatic Adjustments of Natural Resource Conservation Service (NRCS) Runoff Curve Numbers: Final Report

David B. Thompson, H. Kirt Harle, Heather Keister,
David McLendon, and Shiva K. Sandrana

Department of Civil Engineering
Texas Tech University

Center for Multidisciplinary Research in Transportation

Submitted to:

Texas Department of Transportation

Report No. 0-2104-2 **October 2003**

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.: TX -00/0-2104-2	2. Government Accession No.:	3. Recipient's Catalog No.:

4. Title and Subtitle: "Climatic Adjustments of Natural Resource Conservation Service (NRCS) Runoff Curve Numbers"	5. Report Date: November 2003 6. Performing Organization Code: TechMRT
7. Author(s): David B. Thompson, H. Kirt Harle, Heather Keister, David McLendon, and Shiva K. Sandrana	8. Performing Organization Report No.0-2104-2
9. Performing Organization Name and Address Texas Tech University Department of Civil Engineering Box 41023 Lubbock, Texas 79409-1023	10. Work Unit No. (TRAIS) 11. Contract or Grant No.: Project 0-2104
12. Sponsoring Agency Name and Address: Texas Department of Transportation Research and Technology P. O. Box 5080 Austin, TX 78763-5080	13. Type of Report and Period Covered: Final Report 14. Sponsoring Agency Code:

15. Supplementary Notes:
Study conducted in cooperation with the Texas Department of Transportation.
Research Project Title: "Climatic Adjustments of Natural Resource Conservation Service (NRCS) Runoff Curve Numbers"

16. Abstract:

The purpose of this report is to present results and recommendations from Project Number 0-2104, *Climatic Adjustments of Natural Resource Conservation Service (NRCS) Runoff Curve* Numbers. The literature was reviewed for previous research pertinent to the project. Several other studies had been conducted that, while dealing with curve numbers, were not directly transferable to the subject project. However, they did provide important technology for the development of project curve numbers and the means to provide adjustments to the curve number to reflect Texas hydrology. Based on the literature and computations involving some 1600 measured rainfall-runoff events, a map was developed that can be used by TxDOT hydraulic designers to adjust the runoff curve number by geographic location. It is recommended that the tool become a part of the hydraulic design process, but not to the exclusion of other tools available to the designer.

17. Key Words: Hydrology, rainfall-runoff, NRCS curve number, SCS curve number, modeling, hydrographs	18. Distribution Statement: No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 35	22. Price

Form DOT F 1700.7 (8-72)

CLIMATIC ADJUSTMENTS OF NATURAL RESOURCE CONSERVATION SERVICE (NRCS) RUNOFF CURVE NUMBERS

FINAL REPORT

by

David B. Thompson, Ph.D., P.E.,
Graduate Students: H. Kirt Harle
Heather Keister, David McLendon, and Shiva K. Sandrana

Research Report Number 0-2104-2

conducted for

Texas Department of Transportation

by the

CENTER FOR MULTIDISCIPLINARY RESEARCH IN TRANSPORTATION

TEXAS TECH UNIVERSITY

November 2003

IMPLEMENTATION STATEMENT

This project (0-2104) resulted in the development of a map to be used by TxDOT hydraulic designers for adjustment of the NRCS runoff curve number. This tool can be used to reduce the runoff from design events for a significant portion of the state. The research findings can be used by TxDOT analysts to 1) reduce cost of new drainage facilities, 2) to assess a more reasonable estimate of the capacity of existing drainage works, and 3) to make decisions on appropriate amounts of additional hydraulic capacity, if in the judgment of the analyst such additional hydraulic capacity is warranted.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

AUTHOR'S DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view of policies of the Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PATENT DISCLAIMER

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

ENGINEERING DISCLAIMER

Not intended for construction, bidding, or permit purposes. The engineer in charge of the research study was David B. Thompson, Ph.D, Texas Tech University.

TRADE NAMES AND MANUFACTURERS' NAMES

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

(Revised September 1993)

* SI is the symbol for the International System of Units. Appropriate

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX I

CLIMATIC ADJUSTMENTS OF NATURAL RESOURCE CONSERVATION SERVICE (NRCS) RUNOFF CURVE NUMBERS: TXDOT PROJECT NUMBER 0-2104

INTRODUCTION

Background

The Natural Resource Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), developed the curve number procedure in 1954 as a method for estimating runoff. This procedure was developed for application to hydrologic design activities associated with small agricultural watersheds. Since its development, the curve number method has become a widely used procedure for estimating runoff. Because of the endorsement by NRCS as a federal agency, engineers use the procedure for a wide range of applications.

The Texas Department of Transportation (TxDOT) conducts design of a large number of drainage structures each year. For small watersheds (those with drainage areas less than 200 acres), TxDOT uses the rational method for estimation of peak hydraulic loads. For watersheds with drainage areas that exceed 20 square miles, regional regression equations are used to estimate design discharges. However, for watersheds with drainage areas between those values, hydrograph methods are used by TxDOT to estimate design discharges.

The development of a design discharge using hydrograph methods requires three components: 1) A design rainfall depth and temporal distribution, 2) a procedure for converting incoming rainfall to runoff (sometimes called effective precipitation), and 3) a unit hydrograph that represents the integrated response of a watershed to a unit pulse of effective precipitation with a particular duration. Given these three things, a tool such as HEC-HMS can be used to compute the hydrograph of runoff for the design event.

For application of the hydrograph method, TxDOT currently specifies the NRCS curve number procedure as the preferred method for sizing hydraulic structures when watershed drainage areas exceed about 200 acres but are less than about 20 square miles. As a result TxDOT engineers across the entire state of Texas have adopted this method in their designs. While curve number calculations were designed to account for variations in soil textural classification, and for variations in land use and land cover (LULC) type, they do not take into consideration the possibility that differences in effective curve number might arise in response to differences in climate, particularly rainfall. It was the opinion of some TxDOT analysts that standard estimates of curve number resulted in overprediction of runoff volume, and hence over prediction of peak discharge. There was a suspicion that effective curve number might be less than the standard values because of variations in rainfall amounts by location across Texas. Therefore, a problem statement to study the relation between climate and curve number was developed so that the effect of these variations could be studied. In response to the request for proposal, researchers from Texas Tech University and U.S. Geological Survey (USGS) prepared a proposal and won the project.

Objectives

TxDOT initiated a research project, TxDOT Project Number 0-2104, *Climatic Adjustments of Natural Resource Conservation Service (NRCS) Runoff Curve Numbers*, to investigate the need (or lack thereof) for developing a standard procedure for adjusting results of the current method of computing a NRCS curve number. Therefore, the primary objective of this study was to determine if the standard curve number is representative of rainfall-runoff processes for Texas watersheds, and, if not, to develop a method to adjust the NRCS curve number for use on Texas watersheds.

Because of the available records of rainfall and runoff for select watersheds in Texas, a task of this study was to compute the deviations between the observed curve number (calculated from rainfall-runoff data) and the NRCS curve number (or predicted curve number) for each of the select watersheds. The computed deviations were then to be analyzed with respect to geographic location of the study watershed in Texas.

The final objective of this study was to compare the deviations generated from the project and observed data to a curve number adjustment procedure developed by Hailey and McGill (1983). In their procedure, they used observations of rainfall and runoff for a large number of watersheds to compute an observed curve number. They related average annual precipitation and average annual temperature into a climatic index, and used the derived climatic index to estimate an effective curve number. This work will be brought into the discussion in the Results and Discussion section of this report.

RESEARCH METHODS

Database

The first step to achieve project objectives was to assemble the database. In addition to this project, researchers from Texas Tech University and USGS were joined by researchers from Lamar University and the University of Houston on a pair of research projects to develop a unit hydrograph (TxDOT project 0-4193) and a rainfall hyetograph (TxDOT project 0-4194) for use in executing TxDOT designs. These agencies pooled personnel resources to enter data representing 1659 storms and runoff hydrographs for 100 watersheds. These data were extracted from USGS small-watershed studies (220 paper reports) stored in USGS archives (Asquith, in press). The resulting database was housed on a Tech workstation with regular backups to USGS Austin-based computers. The majority of the study watersheds are located in west central Texas near the I-35 corridor; a few others are located in the eastern and western regions of the state, and along the Gulf coast. The locations of study watersheds are shown on Figure 1.

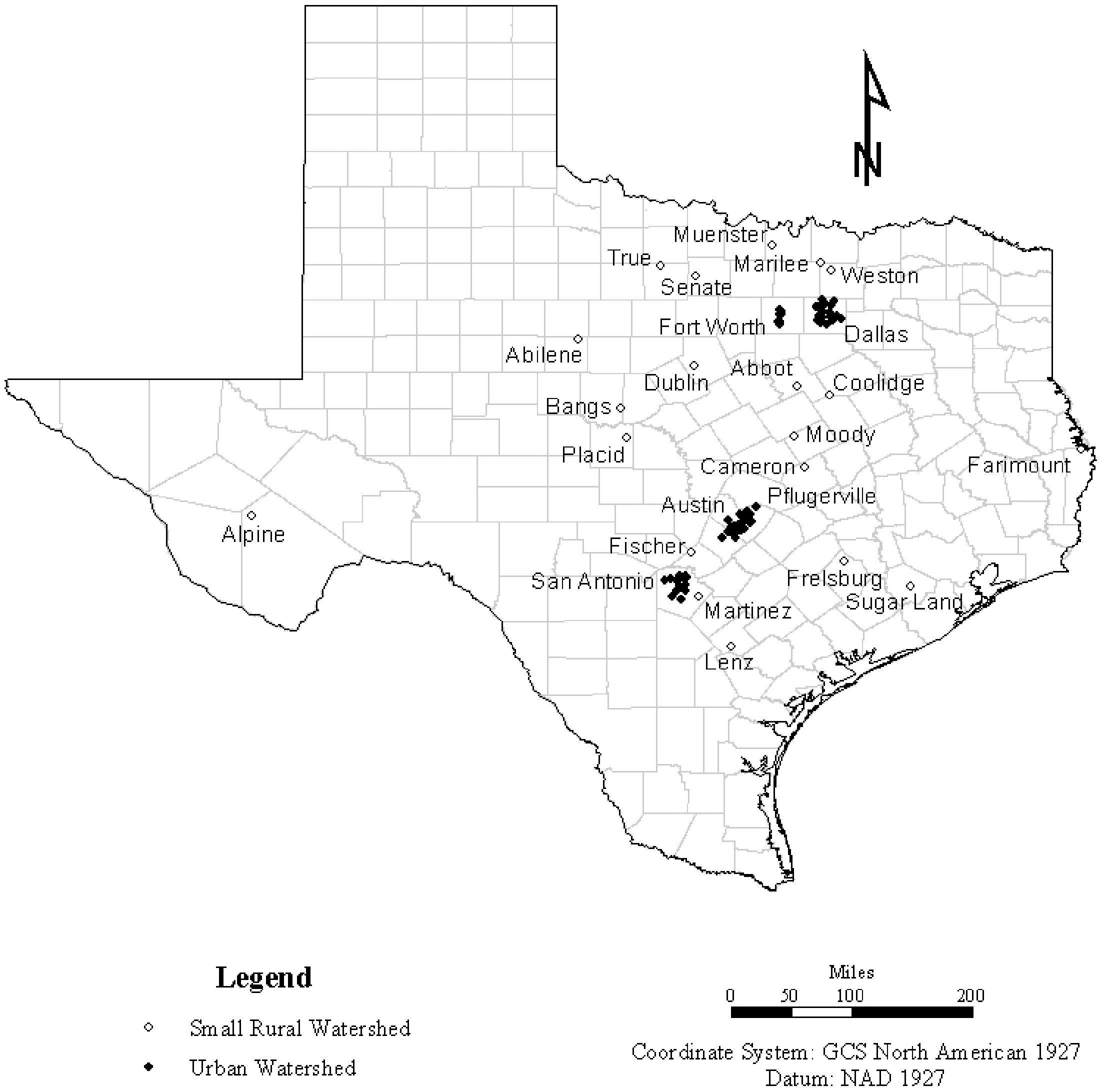

Figure 1 Location of study watersheds.

Observed Curve Numbers

For the purposes of this study, the term *observed curve number* (CN_{obs}) refers to the estimate of effective curve number for a watershed that is derived for paired observations of rainfall depth and runoff depth. Typically, CN_{obs} is estimated by inverting the NRCS rainfall-runoff relation and computing the curve number for each event. That is, the rainfall and runoff from a particular event is assumed to have the same exceedance probability. Given a number of observations from a particular watershed, then an average value can be obtained.

In the late 1970’s and early 1980’s, two researchers in particular, Allan Hjelmfelt and Richard Hawkins, were active in NRCS curve number research. They were particularly interested in inverting the curve number relation to estimate actual curve numbers from measurements of rainfall and runoff. Their approach was based on earlier work by J.C. Schaake (1967) on the rational method runoff coefficient. The essence of their approach is to pair measured values of rainfall and runoff, not on a contemporaneous basis (as described in the previous paragraph), but after sorting each component independently and then pairing rainfall and runoff on the basis of rank order. This pairing equates the frequency of rainfall and runoff. This is consistent with the approach used by designers in that the frequency of runoff is assumed to be the same as the frequency of the rainfall used to generate the runoff event.

The methods of Hjelmfelt and Hawkins[1] were applied to observations of rainfall and runoff. Each rainfall and runoff pair, associated as described in the previous paragraph, was used to compute the curve number for that pair. The set of curve numbers resulting from these computations were then plotted with curve number on the ordinate and precipitation on the abscissa. An initial estimate of CN_{obs} was determined by visual examination of the plot. Using this estimate, a threshold value for precipitation was computed using the inequality $P > 0.456S$, where P is the precipitation depth (in inches) and S is the potential maximum retention (also in inches). This threshold represents a level at which the estimate of curve number becomes inordinately sensitive to errors in measurement of either precipitation or runoff because the precipitation is close to the initial abstraction, $0.2S$.

Values of curve number resulting from precipitation depths less than the threshold were not considered in deriving a final estimate of CN_{obs} for each watershed. Those curve number values from precipitation depths that were larger than the threshold were used and a value was chosen to represent the analyst’s opinion of the most representative value. In general, those values of curve number associated with larger precipitation events were used in estimating CN_{obs}. An example of the plots used to estimate CN_{obs} is shown on Figure 2. Observed curve numbers are displayed on Figure 3. For those regions with multiple watersheds in close proximity, CN_{obs} is presented as a range of values. Tables of observed curve numbers are presented in Appendix I.

---

[1] A complete literature review is presented in Thompson (2000).

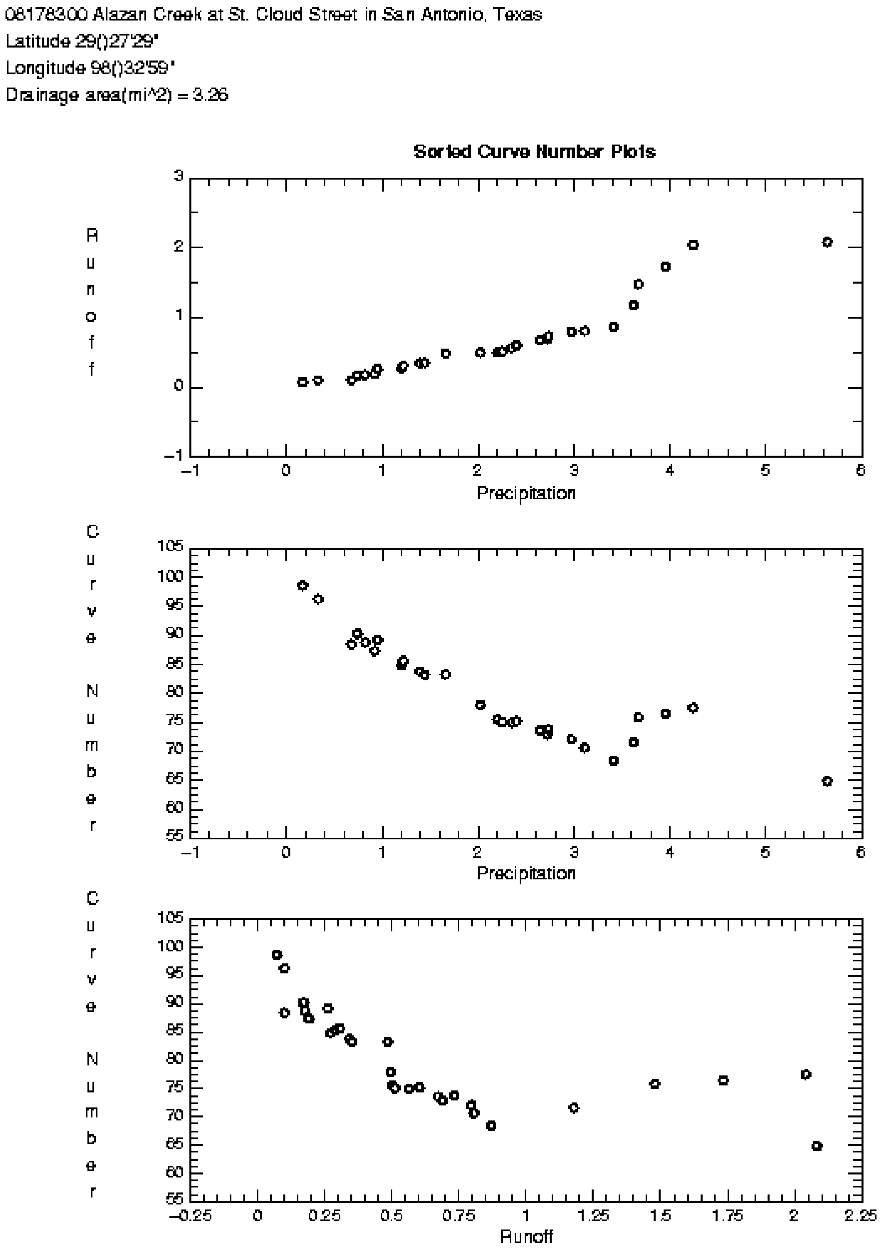

Figure 2 Plot of rainfall and runoff, rainfall and curve number, and runoff and curve number for Alazan Creek in San Antonio.

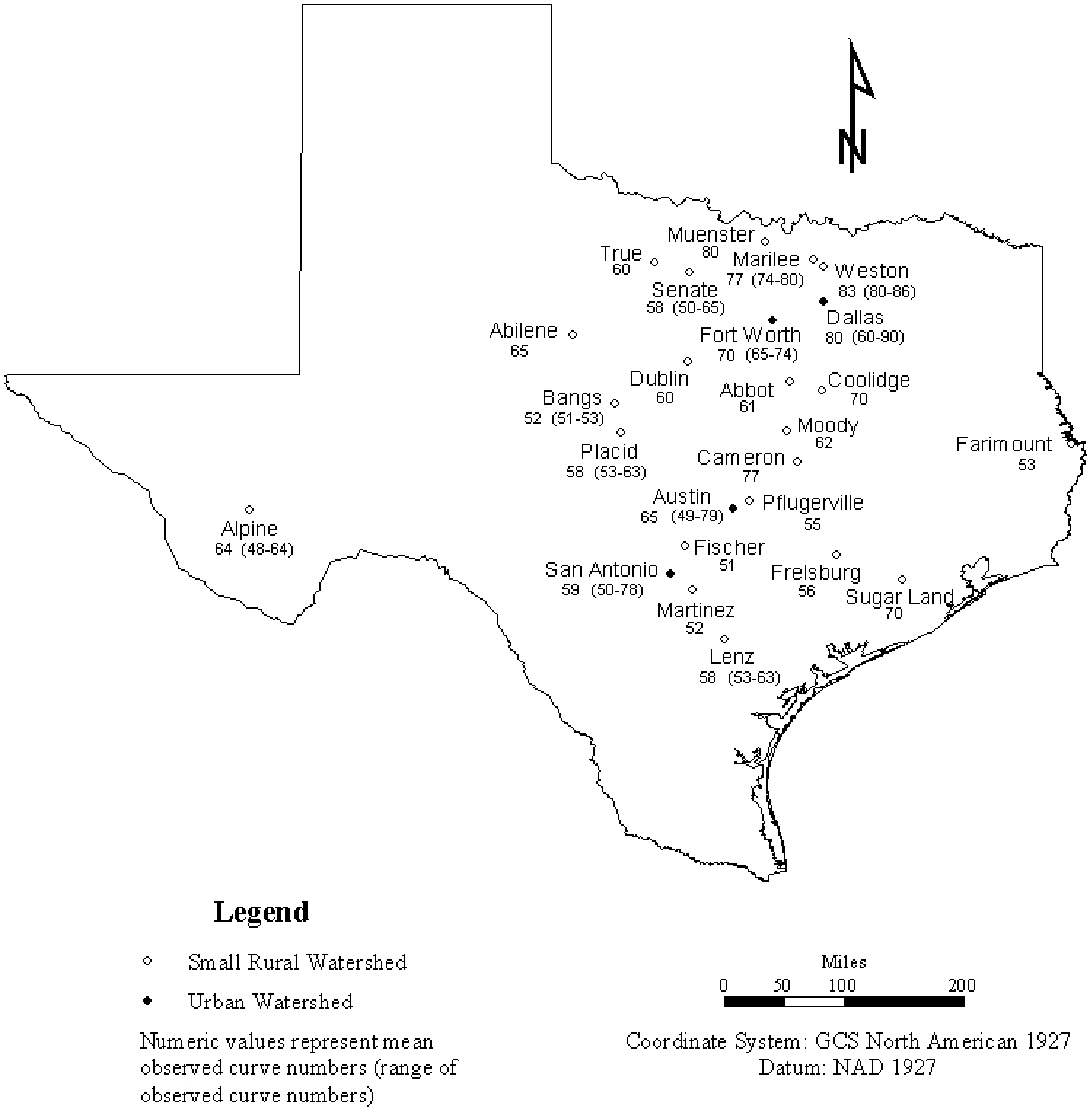

Figure 3 Observed curve numbers from study watersheds.

Predicted Curve Numbers

For the purposes of this study, the term *predicted curve number* (also CN_{pred}) refers to the standard estimate of the curve number for a watershed for the average antecedent moisture condition. The standard curve number (CN_{pred}) is derived from soil association (hydrologic soil group) and land use/land cover through a table look-up procedure. This is standard NRCS practice (Mockus, 1969). A designer would use this procedure to determine an estimate of runoff from rainfall. A total of 207 watersheds were selected for this part of the analysis. Each of these stations had, at one time, a USGS stream gaging station associated with it.

For each study watershed, the watershed boundary was hand drawn onto USGS 7-1/2 minute topographic series maps and digitized into Arc/Info. The GIS software was used to compute basin area for comparison with published USGS values. Differences of less than 10 percent were considered acceptable. The digitized basin divide was used in the GIS software as a cookie cutter to access Landsat-based LULC databases and STATSGO soils databases. The intersection of these topologies defines sub-areas of the watershed that have a common curve number. A table look-up was used to combine the LULC code with the soils identification to determine the curve number for each sub-area. An example of the output from this process is shown on Figure 4.

The sub-areas and associated curve numbers were used to compute an area-weighted average curve number. This curve numbers is CN_{pred} for the watershed. Atkinson (2000), McLendon (in press), and Sandrana (in press) present details of the procedures developed for generation of CN_{pred} for each watershed. Predicted curve numbers are displayed on Figure 5. For those regions with multiple watersheds in close proximity, CN_{pred} is displayed as a range of values. Tables of predicted curve numbers are presented in Appendix I.

Although a significant effort was required to develop the scripts used to automate the GIS procedures used in developed estimates of CN_{pred}, the level of effort was substantially reduced over what would have been required for the traditional approach. Therefore, based on this component of the study, GIS is an appropriate technology for computing CN_{pred}.

As shown of Figure 5, the geographic distribution of CN_{pred} values was nearly uniform. Urbanized areas were observed to have slightly greater CN_{pred} values because of the percentage of impervious surface assumed when the land use and land coverage tables were constructed. CN_{pred} values for the rural watersheds were mostly affected by crop cultivation practices and natural rangelands, which tend to have lower runoff-producing potential than impervious areas.

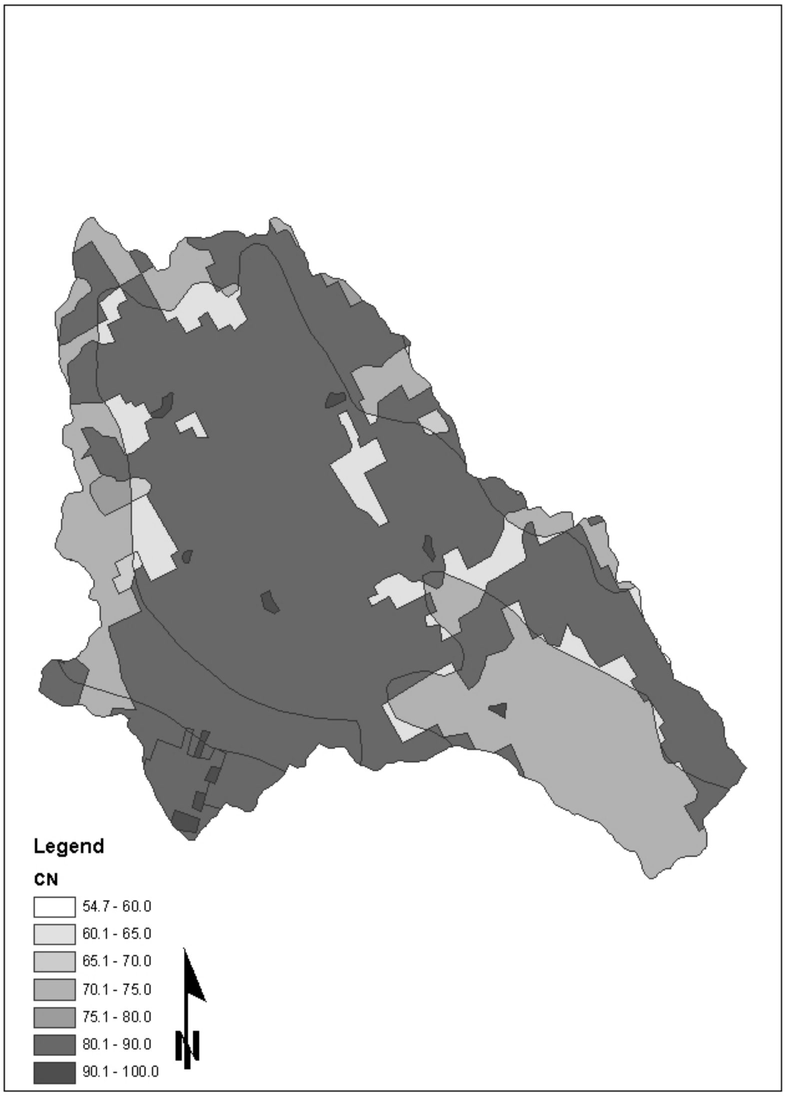

Figure 4 A watershed near Dublin, Texas with computed curve numbers derived using the automated procedures developed for this project. This figure represents results of clipping both the LULC and STATSGO databases, plus a table lookup of the underlying curve numbers. As the final step in determining CN_{pred} the values shown on this display were lumped by computing the areal average. This step was also automated. Figure after McLendon (2002).

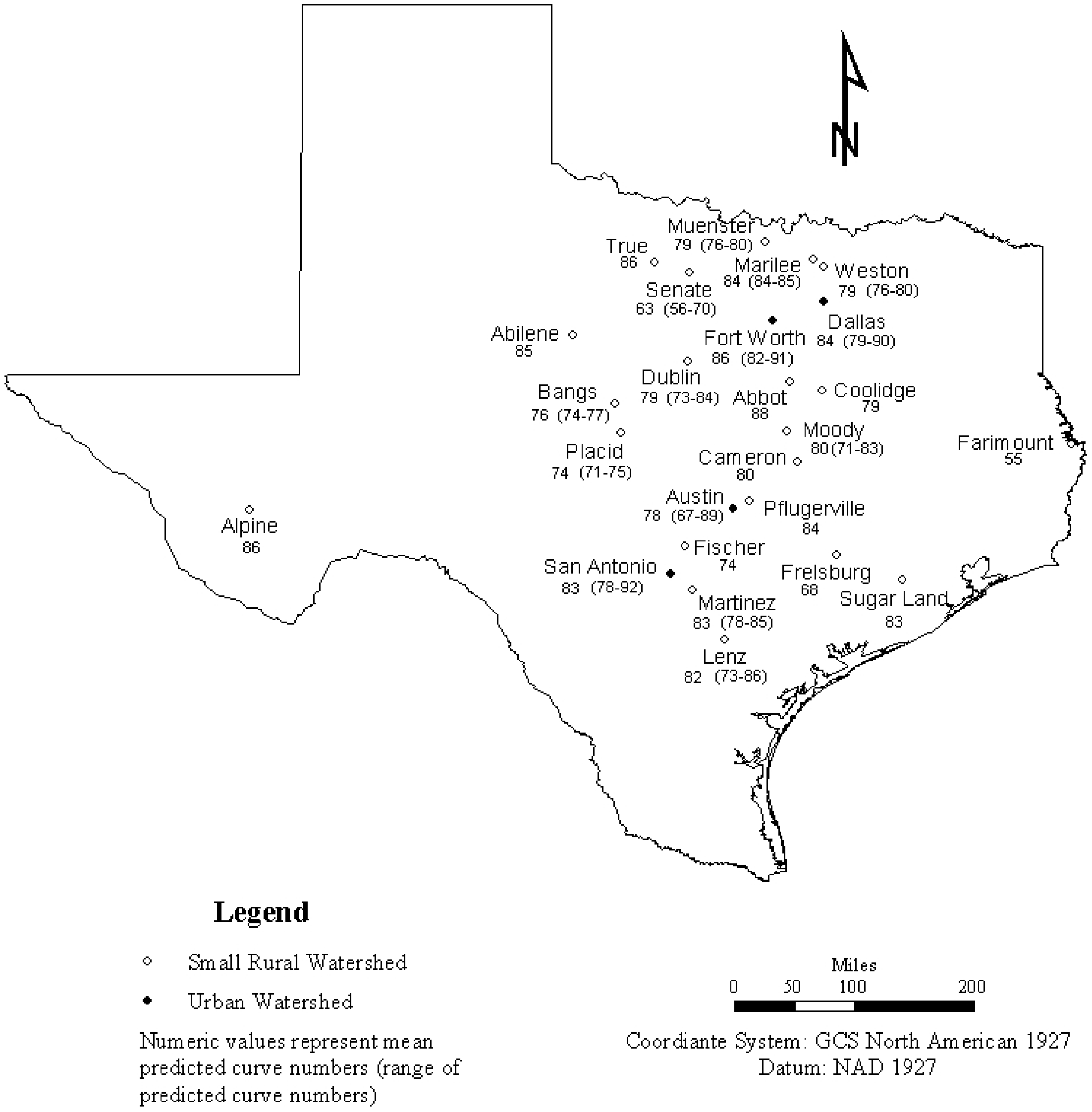

Figure 5 Predicted curve numbers from study watersheds.

RESULTS AND DISCUSSION

Predicted and Observed Curve Numbers

Estimates of CN_{obs} and CN_{pred} were developed using the procedures documented above. These results are presented on the figures preceding this section. Values of CN_{obs} and CN_{pred} were compared at common locations and the summary statistics of the curve numbers and differences between CN_{obs} and CN_{pred} are presented in Table 1 for each region. Clearly, observed curve numbers in Texas are highly variable. Statewide, CN_{obs} ranged from a minimum of 48 to a maximum of 90. Based on Figure 3, the general trend is for a decrease in CN_{obs} from east to west. Average values were greatest in the Dallas area and the least for the small rural watersheds. The statewide average CN_{obs} for all regions was about 68.

Table 1 Summary statistics of CN_{obs}, CN_{pred}, and the difference between CN_{obs} and CN_{pred}.

Statistic	CN_{obs}	CN_{pred}	Difference (CN_{obs} - CN_{pred})
Austin Region			
Range	49 to 79	67.2 to 89.1	-37.3 to 4.2
Mean	64.7	77.9	-13.2
Standard Deviation	7.3	7.5	8.3
Dallas Region			
Range	60 to 90	79.1 to 90.3	-26.5 to 7.1
Mean	79.5	84.5	-4.9
Standard Deviation	7.2	2.9	8.0
Fort Worth			
Range	65 to 74	82.3 to 91.2	-19.3 to -10.3
Mean	70.3	85.6	-15.3
Standard Deviation	3.4	3.2	3.4
San Antonio			
Range	50 to 78	78.2 to 92.3	-29.2 to -6.4
Mean	64.5	83.1	-18.5
Standard Deviation	9.5	4.5	7.1
Small Rural Watersheds			
Range	48 to 88	55.4 to 88.1	-38.7 to 9.1
Mean	62.8	76.8	-14.5
Standard Deviation	11.3	8.8	12.2
Summary			
Range	48 to 90	55.4 to 92.3	-38.7 to 9.1
Mean	67.6	80	-12.4
Standard Deviation	10.8	5.9	10.1

Predicted curve numbers are also subject to significant variability. The range of CN_{pred} values is from 55 to 92. This mimics the range of CN_{obs} closely. However, no geographic trend is visible in maps of CN_{pred}, as was observed for CN_{obs} and as shown on Figure 5. Therefore, there must be factors that affect the curve number other than those normally accounted for in the standard procedure.

Furthermore, the regional mean values of CN_{pred} are not as variable as those of CN_{obs}. Regional mean CN_{pred} ranged from 76 to 86 while regional mean CN_{obs} ranged from 63 to 80. The difference in variability is further evidenced by the standard deviations of the curve numbers. A statewide value of the standard deviation for CN_{obs} was 10.8 while that of CN_{pred} was 5.9. Again, clearly there are differences between predicted and observed curve numbers.

This observation is reinforced by examining the difference between CN_{obs} and CN_{pred}. The difference between CN_{obs} and CN_{pred} was calculated for each watershed where observed data were available. By computing this difference, the standard procedure for calculating curve numbers can be validated. If CN_{pred} is representative of actual watershed runoff producing potential, the difference between CN_{obs} and CN_{pred} should be close to zero. A value different from zero would indicate that CN_{pred} is not the best approximation for design purposes. The difference between CN_{obs} and CN_{pred} is also presented on Table 1. The range in the difference is from -38.7 to 9.1, the mean difference is -12.4, and the standard deviation is 10.1. Therefore, statewide, observed curve number is about 12 points less than the design value and the variability, as measured by standard deviation, is nearly as large the mean difference. The difference between CN_{obs} and CN_{pred} is shown on Figure 6.

From Figure 6, there appears to be a trend in the difference between CN_{obs} and CN_{pred}. The difference is approximately zero in the northeast portion of the state, increasing in the negative direction from east to west. Superimposed on Figure 6 are contours of average annual rainfall. Rainfall trends in the decreasing direction from east to west. This pattern reflects the differences between CN_{obs} and CN_{pred}.

The difference between CN_{obs} and CN_{pred} is also shown on Figure 7. Superimposed on Figure 7 is also mean annual temperature. Contours of average annual temperature curve from east to west, indicating that the temperature gradient is from the north to the south (increasing mean annual temperature). This direction is nearly orthogonal to the gradient observed in the difference between CN_{obs} and CN_{pred}; therefore temperature does not seem to be a significant factor influencing the difference.

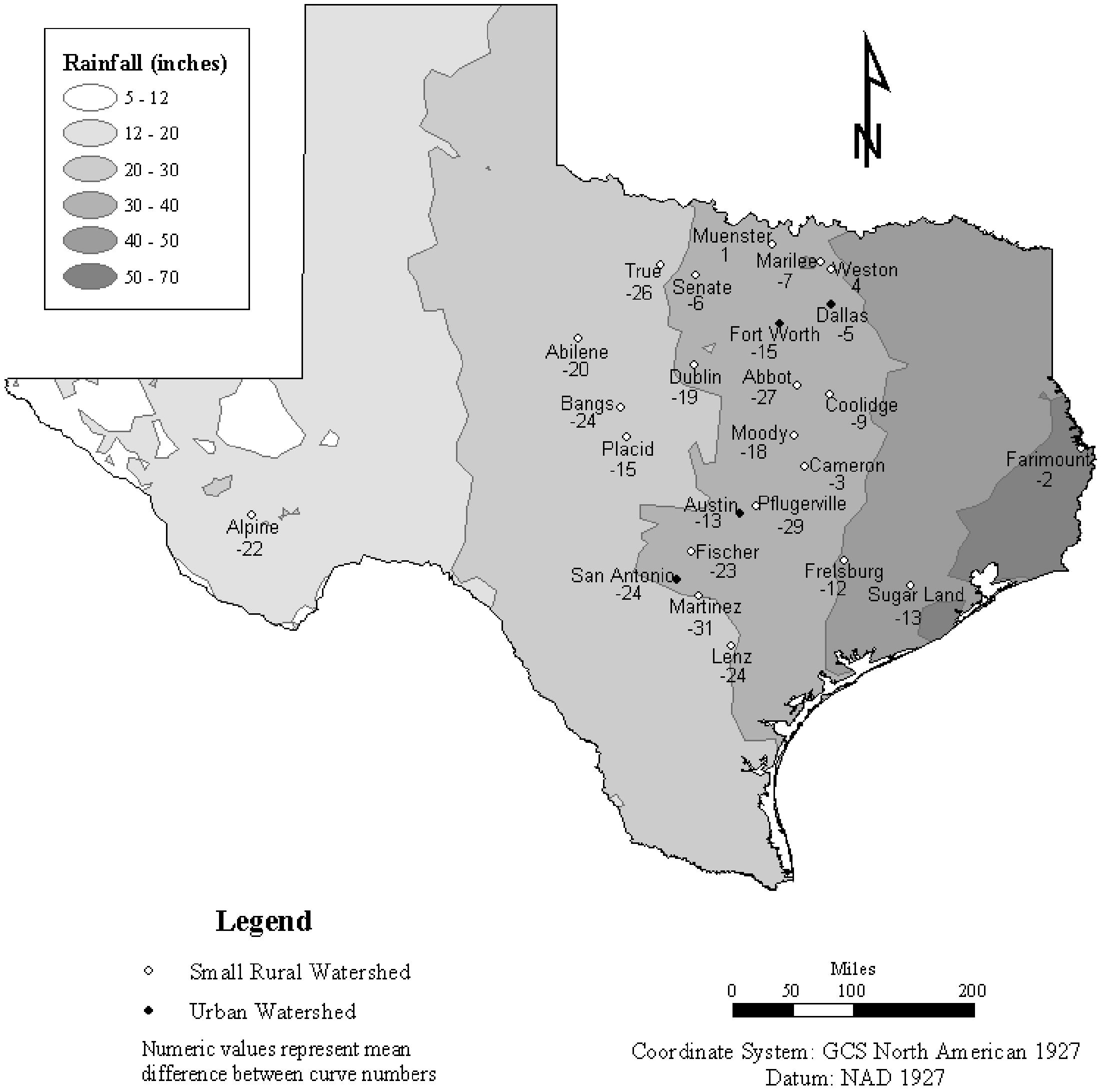

Figure 6 Mean difference between CN_{obs} and CN_{pred} overlain on map of average annual precipitation. Negative values indicate that CN_{obs} is less than CN_{pred}.

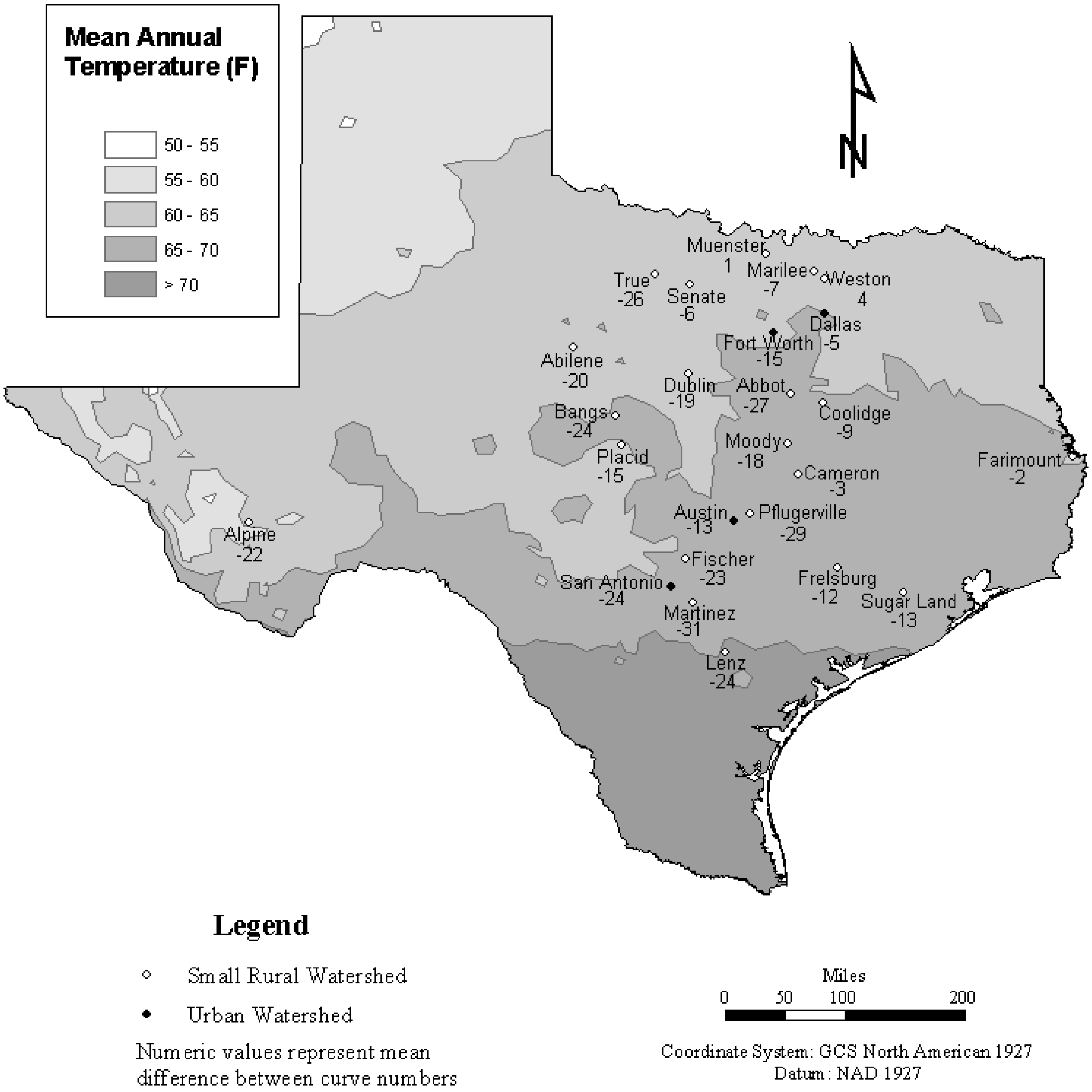

Figure 7 Mean differences between CN_{obs} and CN_{pred} and mean annual temperature. Negative values indicate that CN_{obs} is less than CN_{pred}.

Hailey and McGill

Some TxDOT analysts use the work of Hailey and McGill (1983) to adjust CN_{pred}. One of the project objectives is to compare results of this research project with those of Hailey and McGill. A portion of the database that Hailey and McGill used intersects with the project database. They reported observed curve numbers, so these values were extracted and a comparison of Hailey and McGill (H&M) observed curve numbers with CN_{obs}, and the difference between their observed curve numbers and CN_{obs} is shown on Table 2.

Table 2 Comparison of project CN_{obs} with observed curve numbers computed by Hailey and McGill (1983). Negative differences indicated that CN_{obs} is less than the Hailey and McGill observed curve number.

USGS Gage ID	Location	CN_{obs}	H&M Observed Curve Number	Difference (CN_{obs} - H&M Curve Number)
8058000	Weston	86	81.7	4.3
8057500	Weston	80	83	-3.0
8052700	Aubrey	74	78.1	-4.1
8063200	Coolidge	70	74	-4.0
8098300	Rosebud	88	79.4	8.6
8108200	Yarrelton	77	79.2	-2.2
8050200	Freemound	80	82.6	-2.6
8096800	Bruceville	62	72.3	-10.3
8042700	Lynn Creek	50	70.4	-20.4
8187000	Lenz	53	59.6	-6.6
8187900	Kenedy	63	63.8	-0.8
8136900	Bangs West	51	69.7	-18.7
8137000	Bangs West	52	72	-20.0
8137500	Trickham	53	69.6	-16.6
Range		51 to 86	59.6 to 82.6	-20.4 to 8.6
Mean		67	74.0	-6.9
Standard Deviation		13.9	7.11	9.09

There are differences in observed curve numbers used by the two studies. Of the 14 common watersheds, project CN_{obs} was less than the Hailey and McGill observed curve number in 12 cases. That is, CN_{obs} was greater than the Hailey and McGill value only for two watersheds. Furthermore, the mean difference was about –7. Clearly project CN_{obs} tends to be less than the observed curve number that Hailey and McGill used. Therefore, it appears that their adjustment procedure would produce adjustments not as strong as suggested by this study CN_{obs}.

Furthermore, another comparison of the two procedures was suggested, that is, to compare results of application of the Hailey and McGill adjustment procedure to study watersheds with study CN_{obs}. To accomplish this task, the Hailey and McGill procedure was applied to CN_{pred} for study watersheds for comparison with CN_{obs}. The adjustment of CN_{pred} using the Hailey and McGill procedure results in an adjusted curve number, termed $CN_{H\&M}$. The adjusted curve number, $CN_{H\&M}$, was subtracted from CN_{obs} and the results are presented on Figure 7. Superimposed on Figure 7 are the isolines that represent the adjustment procedure presented in Hailey and McGill (1983) as their Figure 4. Based on these comparisons, $CN_{H\&M}$ is conservative, that is, $CN_{H\&M}$ exceeds project CN_{obs} by an average amount of about 7 points. From Figure 7, that deviation varies depending on geographic location within the state. Furthermore, it should be possible to produce an adjustment procedure that will produce curve numbers commensurate with observed values. However, in areas where the current study has fewer datapoints, the Hailey and McGill procedure will allow a downward adjustment of the curve number. This means that the analyst can choose to reduce the runoff volume if he or she decides it is appropriate.

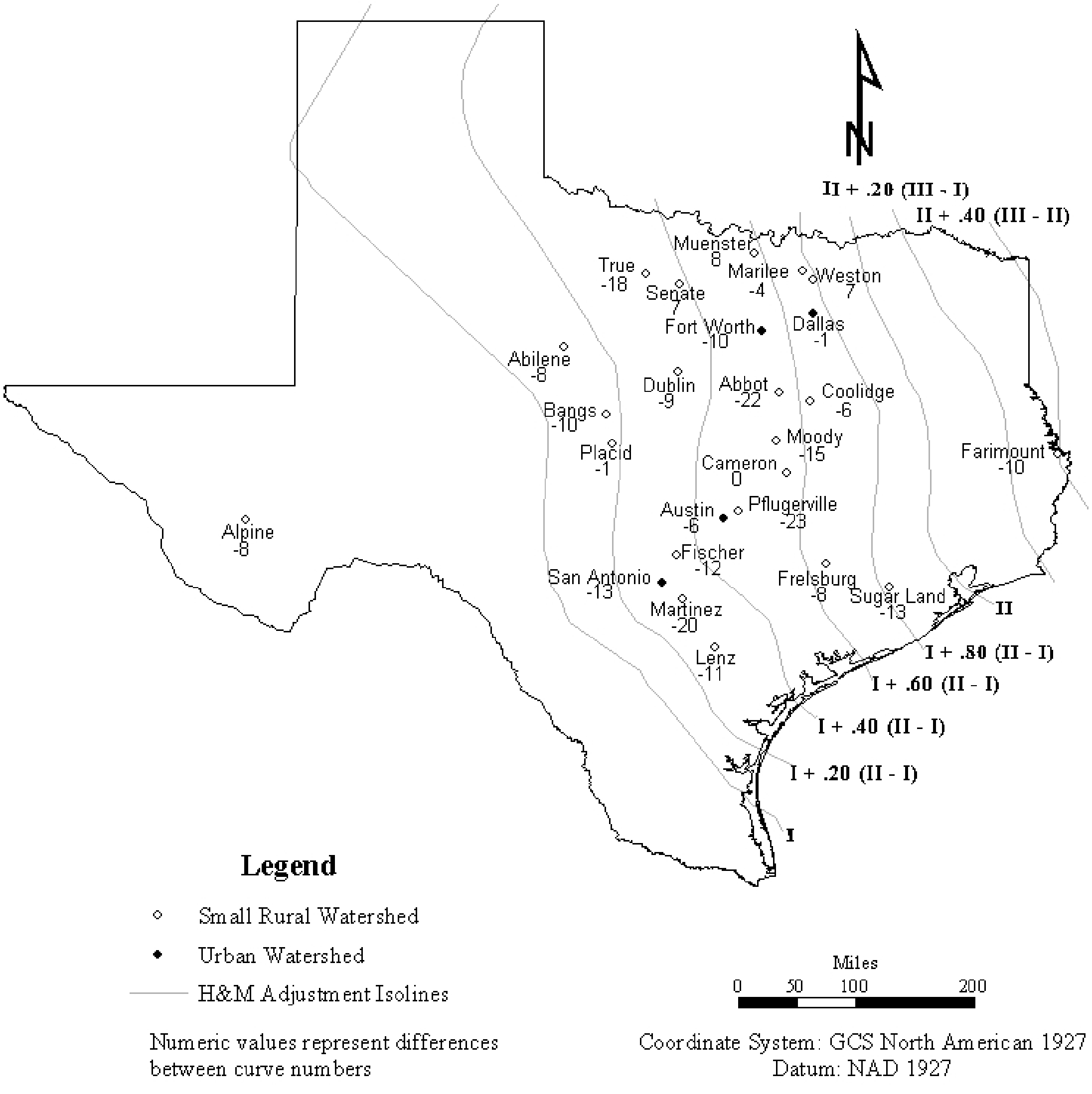

Figure 8 Comparison of Hailey and McGill adjusted curve numbers, $CN_{H\&M}$, with CN_{obs}. Negative differences indicate that $CN_{H\&M}$ is larger than CN_{obs}. Also shown are the lines of equal adjustment to curve number from Hailey and McGill's (1983) Figure 4.

Design Tool

Given the differences between CN_{obs} and CN_{pred}, it is possible to construct a general adjustment to CN_{pred} such that an approximation of CN_{obs} can be obtained. The large amount of variation in CN_{obs} does not lend to smooth contours or function fits. There is simply an insufficient amount of information for these types of approaches. But, a general adjustment can be implemented using regions with a general adjustment factor. Such an approach was taken and is presented in Figure 8.

The bulk of rainfall and runoff data available for study were measured near the I-35 corridor. Therefore, estimates for this region are the most reliable. The greater the distance from the majority of the watershed that were part of this study, then the more uncertainty must be implied about the results. For the south high plains, that area south of the Balcones escarpment, and the coastal plain, there was insufficient data to make any general conclusions.

Application of the tool is straightforward. For areas where adjustment factors are defined (see Figure 8), the analyst should:

1. Determine CN_{pred} using the normal NRCS procedure.

2. Find the location of the watershed on the design aid (Figure 9). Determine an adjustment factor from the design aid and adjust the curve number.

3. Examine Figure 8 and find the location of the watershed. Use the location of the watershed to determine nearby study watersheds. Then refer to Figure 8 and Appendix I and determine the difference between CN_{pred} and CN_{obs} for study watersheds near the site in question, if any are near the watershed in question.

4. Compare the adjusted curve number with local values of CN_{obs}.

5. The result should be a range of values that are reasonable for the particular site.

6. As a comparison, the adjusted curve number from Hailey and McGill (Figure 10) can be used.

7. A lower bound equivalent to the curve number for AMC I, or a curve number of 60, which ever is greater, should be considered.

Judgment is required for application of any hydrologic tool. The adjustments presented on Figure 8 are no exception. A lower limit of AMC I (dry antecedent conditions) may be used to prevent an overadjustment downward. For areas that have few study watersheds, the Hailey and McGill approach should provide some guidance on the amount of reduction to CN_{pred} is appropriate, if any.

Furthermore, application of the tool is not meant to be used to adjust the risk associated with a particular event. It is intended to provide a more realistic estimate of the curve number, and hence an estimate of the peak discharge, expected at a particular site. The risk of exceedence is defined by the choice of return interval for the design.

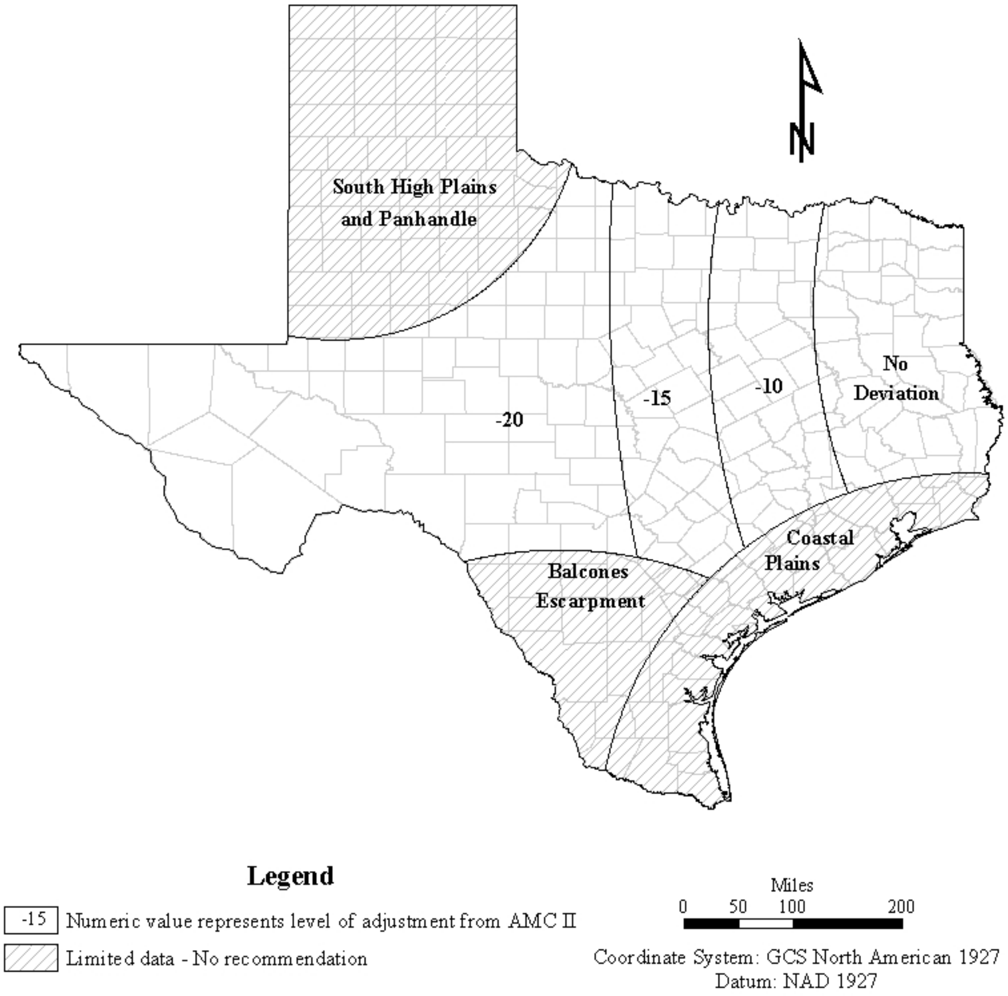

Figure 9 Suggested design aide based on difference between CN_{obs} and CN_{pred}.

Conclusions and Recommendations

The objectives of this research study were: 1) to determine if the standard curve number is representative of rainfall-runoff processes for Texas watersheds; 2) if not, to develop a method to adjust the NRCS curve number for use on Texas watersheds; and 3) to compare the deviations generated from the project and observed data to a curve number adjustment procedure developed by Hailey and McGill (1983).

Based on review of measured rainfall-runoff data from about 100 watersheds and approximately 1600 events, CN_{pred} is greater than CN_{obs} for much of the state of Texas. That is, an adjustment of CN_{pred} is required to avoid inflating the runoff volume associated with a particular design rainfall depth at a particular recurrence interval. Therefore, differences between CN_{obs} and CN_{pred} were computed and used as the basis for a simple adjustment procedure. Basically, the adjustment amounts to a subtractive amount between 0 and 20 points.

This procedure was compared with the procedure developed earlier by Hailey and McGill (1983). In general, the curve numbers produced by the study procedure are less than those produced by the Hailey and McGill method. That is, estimates of runoff produced using curve numbers adjusted according to the study method will be less than or equal to estimates of runoff produced using the Hailey and McGill approach.

It is the recommendation of the investigators that the study approach be adopted for testing by TxDOT.

GIS technology is appropriate for computation of CN_{pred}. This is especially true when Landsat and STATSGO databases have appropriate resolution for the watersheds being study and when a large number of watersheds are under investigation such that an economy of scale can be achieved using automated procedures.

Finally, in the process of executing this research project, it became clear to the investigators that hydrologic measurements of watershed behavior on small watershed basically ceased in Texas about 20 years ago. The development and assessment of hydrologic methods depends on the availability of such data. Large areas of Texas have had no small watershed studies executed in those regions. Therefore, it is difficult to measure the effectiveness of methods like the NRCS curve number procedure for hydrologic modeling in those areas. Clearly, then, it is in the interest of TxDOT that such data be collected. It is the recommendation of the investigators that avenues to encourage such a data collection program be opened and executed.

References

Asquith, W. H., in press. “Modeling of runoff-producing rainfall hyetographs in Texas using L-moment statistics,” Ph.D. dissertation, University of Texas, Austin, Texas.

Hailey, James L. and McGill, H.N., 1983. “Runoff curve number based on soil-cover complex and climatic factors,” *Proceedings 1983 Summer Meeting ASAE*, Montana State University, Bozeman, MT, June 26-29, 1983, Paper Number 83-2057.

McLendon, D. M., in press. “Use of automated procedures for computation of NRCS curve numbers,” M. S. thesis, Texas Tech University, Lubbock, Texas.

Mockus, V., 1964. “National engineering handbook, Section 4, hydrology,” USDA, Soil Conservation Service, reprinted with minor revision 1969.

Sandrana, S. K., in press. “Development of a curve number design tool for TxDOT applications,” M. S. thesis, Texas Tech University, Lubbock, Texas.

Schaake, J. C., Jr., Geyer, J. C., and Knapp, J. W., 1967. “Experimental examination of the rational method,” *Journal of the Hydraulics Division*, ASCE 107(HY3), 651-653.

Thompson, D. B., 2000. “Climatic Influence on NRCS Curve Numbers Literature review.” Texas Department of Transportation Research Study Number 0-2104, Civil Engineering Department, Texas Tech University, Lubbock, Texas, 20pp.

APPENDIX I

APPENDIX I: OBSERVED AND PREDICTED CURVE NUMBERS

Table I.1 Observed and predicted curve numbers for the Austin region.

USGS Gage ID	Quad Sheet Name	CN_{obs}	CN_{pred}	Difference
8154700	Austin West	59	68.9	-9.9
8155200	Bee Cave	65	70.7	-5.7
8155300	Oak Hill	64	69.8	-5.8
8155550	Austin West	50	87.3	-37.3
8156650	Austin East	60	83.6	-23.6
8156700	Austin East	78	86.6	-8.6
8156750	Austin East	66	86.8	-20.8
8156800	Austin East	66	87	-21
8157000	Austin East	68	88.3	-20.3
8157500	Austin East	67	89.1	-22.1
8158050	Austin East	71	83.9	-12.9
8158100	Pflugerville West	60	72.6	-12.6
8158200	Austin East	62	75.6	-13.6
8158400	Austin East	79	88.9	-9.9
8158500	Austin East	71	85.6	-14.6
8158600	Austin East	73	76.7	-3.7
8158700	Driftwood	69	74.5	-5.5
8158800	Buda	64	73.3	-9.3
8158810	Signal Hill	64	69.8	-5.8
8158820	Oak Hill	60	67.9	-7.9
8158825	Oak Hill	49	67.2	-18.2
8158840	Signal Hill	74	69.8	4.2
8158860	Oak Hill	60	68	-8
8158880	Oak Hill	67	79.4	-12.4
8158920	Oak Hill	71	77.5	-6.5
8158930	Oak Hill	56	75.2	-19.2
8158970	Montopolis	56	77.7	-21.7
8159150	Pflugerville East	63	78.8	-15.8
Range of values		49 to 79	67.2 to 89.1	-37.3 to 4.2
Mean value		64.7	77.9	-13.2
Standard deviation		7.3	7.5	8.3

Table I.2 Observed and predicted curve numbers for the Dallas region.

USGS Gage ID	**Quad Sheet Name**	***CN_{obs}***	***CN_{pred}***	**Difference**
8055580	Garland	85	85.2	-0.2
8055600	Dallas	82	86.1	-4.1
8055700	Dallas	73	85.5	-12.5
8056500	Dallas	85	85.8	-0.8
8057020	Dallas	75	85.5	-10.5
8057050	Oak Cliff	75	85.7	-10.7
8057120	Addison	77	80.2	-3.2
8057130	Addison	89	82.9	6.1
8057140	Addison	78	86.8	-8.8
8057160	Addison	80	90.3	-10.3
8057320	White Rock Lake	85	85.7	-0.7
8057415	Hutchins	73	87.8	-14.8
8057418	Oak Cliff	85	79.1	5.9
8057420	Oak Cliff	80	81	-1
8057425	Oak Cliff	90	82.9	7.1
8057435	Oak Cliff	82	81.1	0.9
8057440	Hutchins	67	79.1	-12.1
8057445	Hutchins	60	86.5	-26.5
8061620	Garland	82	85	-3
8061920	Mesquite	85	86	-1
8061950	Seagoville	82	85.3	-3.3
Range of values		60 to 90	79.1 to 90.3	0.2 to 26.5
Mean value		79.5	84.5	-4.9
Standard Deviation		7.2	2.9	8.0

Table I.3 Observed and predicted curve numbers for the Fort Worth region.

USGS Gage ID	**Quad Sheet Name**	***CN_{obs}***	***CN_{pred}***	**Difference**
8048520	Fort Worth	72	82.3	-10.3
8048530	Fort Worth	69	86.7	-17.7
8048540	Covington	73	88	-15
8048550	Haltom City	74	91.2	-17.2
8048600	Haltom City	65	84.3	-19.3
8048820	Haltom City	67	83.4	-16.4
8048850	Haltom City	72	83	-11
Range of values		65 to 74	82.3 to 91.2	-19.3 to -10.3
Mean value		70.3	85.6	-15.3
Standard deviation		3.4	3.2	3.4

Table I.4 Observed and predicted curve numbers for the San Antonio region.

USGS Gage ID	**Quad Sheet Name**	CN_{obs}	CN_{pred}	**Difference**
8177600	Castle Hills	70	84.8	-14.8
8178300	San Antonio West	72	85.7	-13.7
8178555	Southton	75	84.2	-9.2
8178600	Camp Bullis	60	79.7	-19.7
8178640	Longhorn	56	78.4	-22.4
8178645	Longhorn	59	78.2	-19.2
8178690	Longhorn	78	84.4	-6.4
8178736	San Antonio East	74	92.3	-18.3
8181000	Helotes	50	79.2	-29.2
8181400	Helotes	56	79.8	-23.8
8181450	San Antonio West	60	87.3	-27.3
Range of values		50 to 78	78.2 to 92.3	-29.2 to -6.4
Mean value		64.5	83.1	-18.5
Standard deviation		9.5	4.5	7.1

Table I.5 Observed and predicted curve numbers for the small rural watersheds.

USGS Gage ID	Quadrangle Sheet Name	CN_{obs}	CN_{pred}	Difference
8025307	Fairmount	53	55.4	-2.4
8083420	Abilene East	65	84.7	-19.7
8088100	True	60	85.9	-25.9
8093400	Abbott	61	88.1	-27.1
8116400	Sugarland	70	82.9	-12.9
8159150	Pflugerville East	55	83.7	-28.7
8160800	Frelsburg	56	67.8	-11.8
8167600	Fischer	51	74.3	-23.3
8436520	Alpine South	64	86.4	-22.4
8435660	Alpine South	48	86.7	-38.7
8098300	Rosebud	88	80.5	7.5
8108200	Yarrelton	77	79.9	-2.9
8096800	Bruceville	62	80	-18
8094000	Bunyan	60	78.4	-18.4
8136900	Bangs West	51	75.8	-24.8
8137000	Bangs West	52	74.5	-22.5
8137500	Trickham	53	76.5	-23.5
8139000	Placid	53	74.6	-21.6
8140000	Mercury	63	74.4	-11.4
8182400	Martinez	52	80	-28
8187000	Lenz	53	83.8	-30.8
8187900	Kenedy	63	73.3	-10.3
8050200	Freemound	80	79.6	0.4
8057500	Weston	80	78.2	1.8
8058000	Weston	86	80.1	5.9
8052630	Marilee	80	85.4	-5.4
8052700	Aubrey	74	84.1	-10.1
8042650	Senate	59	63.4	-4.4
8042700	Lynn Creek	50	62.5	-12.5
8042700	Senate	56	62	-6
8042700	Senate	65	55.9	9.1
8063200	Coolidge	70	79.4	-9.4
Range of values		48 to 88	55.4 to 88.1	-38.7 to 7.5
Mean value		62.8	2.0	-14.5
Standard deviation		11.3	8.8	12.2