5-1980

Relationship Between Rainfall and Storm Runoff For Selected Arizona Watersheds

Robert James Anderson
Utah State University

Recommended Citation

Anderson, Robert James, "Relationship Between Rainfall and Storm Runoff For Selected Arizona Watersheds" (1980). *All Graduate Theses and Dissertations*. 6413.
https://digitalcommons.usu.edu/etd/6413

RELATIONSHIP BETWEEN RAINFALL AND STORM RUNOFF FOR SELECTED ARIZONA WATERSHEDS

by

Robert James Anderson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Watershed Science

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1980

ACKNOWLEDGEMENTS

The period of time from December of 1974 to the present has been one of considerable change and effort to produce what seems to be an ordinary thesis. Through this time I have received support and help from several people that extended simple kindnesses as well as strong grips to pull a struggling skinny kid from a quagmire of trouble.

This project began from a need recognized by Lloyd Barnett of the Coconino National Forest, which he funded. For his foresight, initiative and support I am deeply grateful. The supply of data that was used in the analysis was provided by a team of scientists and technicians from the Rocky Mountain Forest and Range Experiment Station offices in Flagstaff and Tempe, Arizona. Malcus Baker, Jess Thompsen, Jerry Gottfried and William Casner all went many extra miles in their efforts to assist me.

The members of my thesis committee also lent their help in the review of this transcript. Professor Joel Fletcher was particularly helpful in providing classwork that gave me the skills to complete this paper. He also served as my employer. Dr. Richard H. Hawkins was the greatest help in the development of a critical examination of the models examined. I can only meagerly describe the inspiration that his keenly perceptive mind has given me during the long years it has taken me to finally complete this project.

My wife has seen this work deprive her of seemingly every possible social event or family endeavor in the name of working on my thesis. I offer my love and five years of sympathy for her patience and understanding.

Robert James Anderson

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Relationship Between Rainfall and Storm Runoff For Selected Arizona Watersheds

by

Robert James Anderson, Master of Science

Utah State University, 1980

Major Professor: Richard H. Hawkins
Department: Forestry and Outdoor Recreation

The relationship between rainfall and runoff was examined for twelve selected Arizona watersheds. Expedient runoff volume model coefficients and runoff curve number model parameters were examined using standardized structure, with modifications to adjust the model for small initial abstractions and large watershed storage capacity.

Forest-land management practices were examined for their effects on curve number coefficients. The effects of rainfall characteristics were also evaluated with respect to changes they induce in curve number populations.

Evaluations included a runoff fraction, a simple multiplier of storm volume to produce runoff volume. The accuracy of this model is promising for more permeable watersheds.

(70 pages)

INTRODUCTION

Hydrology is a discipline highly oriented toward prediction. Predictions are often directed at specific phases of the hydrologic cycle, such as evapotranspiration, infiltration and runoff. These predictions are usually based on analysis of past occurrences which are used to structure a predictive model. Some models in hydrology are purely empirical and bear little analogy to the actual functioning of hydrologic processes. Developed for a specific set of circumstances, these models can produce a high amount of accuracy for the situation modeled, but extrapolation to other circumstances is dangerous. At the other end of the spectrum are models that precisely describe the processes within a watershed. Their major drawback is the large number of coefficients needed to make the model workable.

Between these types of models exist a family of relationships that are widely used by practicing hydrologists. Two of these relationships will be evaluated in this paper.

One model, developed by the United States Soil Conservation Service, is based on a generalized storm runoff mass curve. A single coefficient, Curve Number, is used to describe watershed conditions in predicting direct runoff from rainstorms. The second model also uses a single coefficient to delineate the rainfall-runoff relationship. This model, the runoff fraction, is not well documented, but is inferred from several widely accepted hydrologic concepts.

Many hydrologic models (including the Curve Number "Model") were developed for humid agricultural areas. Because of their origin, these models are not always valid for arid or semi-arid wildlands.

Wildlands may be steeper and wetter or dryer, colder and rockier or swampier than land under agriculture. These differences create conditions that result in wildland soils and vegetation which are markedly different from agricultural lands.

The potential differences between agricultural lands where models have been developed and wildlands suggest that models applied to a wildland situation should be examined for accuracy and utility. This project examined runoff Curve Numbers and runoff fraction as models in predicting rainstorm runoff volume and predicting rainstorm runoff volume from selected northern Arizona watersheds. The sub-objectives used to structure the analysis and interpretation were:

1. Development of catalog curve number values for studied watersheds.

2. Evaluation of the accuracy of existing methods of assigning curve number values to represent land condition.

3. Determination of the effects of rainfall inputs on dispersion in curve number populations.

4. Evaluation of prospective modifications in curve number technology for accuracy and utility.

5. Evaluation of runoff fraction model for accuracy and utility.

REVIEW OF LITERATURE

Background

In 1954 the United States Soil Conservation Service published a document Hydrology Guide for Use in Watershed Planning (1960) for use in small watershed treatment design and planning. This document has undergone several revisions and today is currently entitled SCS National Engineering Handbook, Section 4, Hydrology (1963), or, more briefly, NEH-4. Among the most significant and widely used portions of NEH-4 is a section which deals with determination of storm runoff volume from design rainstorms. To describe the relationship between rainfall and runoff a generalized mass curve relationship was postulated mathematically:

$$\frac{F}{S'} = \frac{Q}{P} \qquad (1)$$

where F = actual watershed retention

S'= potential watershed retention

Q = actual runoff

P = precipitation, potential maximum runoff

Since F = P - Q, (1) may be expressed as:

$$\frac{P-Q}{S'} = \frac{Q}{P} \qquad (2)$$

Then solving for Q:

$$Q = P^2/(P+S) \qquad (3)$$

This relationship (3) allows for no abstraction of rainfall prior to the initiation of flow (Q). If such an abstraction is subtracted from precipitation inputs, the relationship develops into:

$$Q = (P-Ia)^2/(P-Ia+S) \qquad (4)$$

In order to simplfy this equation experimental data were used to develop a relationship between S and Ia; i.e. re-expression. The proportion:

$$Ia = 0.2S \qquad (5)$$

was adopted. This simplifies relationships; only S is required to compute Ia. Substituting (5) into (3), results in the relationship:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (6)$$

This is the SCS runoff equation in current use. The original literature noted that the standard error for this relationship is "relatively high."

To make the parameter S more convenient for use, it was transformed into another variable, called curve number (CN), by using the definition.

$$CN = 1000/(10 + S) \qquad (7)$$

From this relationship it can be seen that CN may vary upward from 0, at S = 00 describing a watershed incapable of producing runoff to 100 at S = 0, representing an impervious watershed. This 0 - 100 spectrum of values lends itself more easily to interpretation and understanding.

Selection of Coefficients

Curve numbers have been determined experimentally for a variety of hydrologic situations and have been cataloged according to vegetative cover and soil characteristics. Although the majority of these have been developed for agricultural situations, some data is available in NEG-4 that can be used for wildlands.

Information on vegetation and soils are required before curve number selections can be made. Vegetative information requirements vary considerably. Ground cover density, cover type, and range condition class and slope are required for various catalog values. Soils descriptions required, however, are quite uniform. Generally soils are described in terms of Hydrologic Groups. These groupings are broken down descriptively in the Soil Survey Manual (1954). Brief descriptions are included in NEH-4. A short descriptive summary is given in Appendix 2. A list of several thousand soil series with their accompanying hydrologic group is given in NEH-4.

Another method of assigning curve numbers to wildlands utilizes instrumented watersheds. Runoff and precipitation data are expressed in inches. These measurements are then used to associate a curve number with a watershed by using one of several methods. Hawkins (1973) solved equation (6) for S, and then curve number. Walker (1970) and Simanton et al., (1974) used trial and error techniques as well as graphical solutions. The direct solution utilized by Hawkins seems to offer the greatest accuracy and is the most efficient to program.

Adjustment of Curve Number for Antecedent Moisture. Antecedent soil moisture is known to influence soil infiltration rates. To adjust the catalog curve number values for this situation, a method was developed by the SCS which utilizes antecedent rainfall as a soil moisture index. Three antecedent conditions are defined:

AMC I	Lowest runoff potential
AMC II	Average condition
AMC III	Highest runoff potential

Table 4.2 of NEH-4 quantifies these rather subjective criteria.

Five-day antecedent rainfall is used to select a class of antecedent watershed condition.

Table 1. Seasonal rainfall limits for AMC. (from NEH-4)

	Total 5-Day Antecedent Rainfall (In.)	
AMC Group	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

It should be noted that NEH-4 recognizes the nonspecific nature of the alterations in curve number that result from this adjustment. Chapter 4 discusses antecedent moisture indexes in general, stating:

> "Such indexes are only rough approximations . . . they don't include the effects of evapotranspiration and infiltration on watershed wetness. Therefore it is not worthwhile to try for great accuracy in computing the index described below."

The index thus referenced is the one described above, with adjustments as further shown in Table 10.1 of NEH-4, which gives a means of converting a curve number of one AMC class to another class.

These divisions may not typify wildland conditions. For example, AMC II implies that the rainfall prior to a design storm would average approximately 0.3 inches to 0.4 inches per day over a five day period. This would be uncommon in Arizona and most parts of western states. Simanton et al., 1974, found at Tombstone, Arizona, that most storms occurred when conditions described in AMC 1 were met. Antecedent moisture was found to play a positive role in increasing runoff, but the divisions described in NEH-4 weren't typical of conditions studied at the Walnut Creek Gulch Experimental Watershed near Tombstone, Arizona.

Critical Evaluation of Models

The runoff curve number method described above has been widely used by hydrology practitioners, and it has been extrapolated beyond its agricultural origins to both wildlands and urban situations. Despite this widespread application, there has been little expansion of the original technology and almost no inquire into the applicability to western wildland watersheds.

The majority of the literature references concerning runoff curve numbers are authoritative, rather than developmental or critical. Ogrosky (1960) put forth the method developed in "Hydrology Guide for Watershed Planning" and demonstrated it using a single agricultural watershed. The methodology has been presented in several technical journals. Perhaps the most widely referenced source, aside from NEH-4, is Chow's Handbook of Applied Hydrology (Chow 1964), which presents a brief overview of the method as a design tool for use on agricultural and wildland watersheds.

The curve numbers used to describe wildland watershed conditions were developed from a number of sources. Most development was by federal agencies in cooperation with the SCS. An example of this joint effort is found in Figures 9.5 and 9.6 of NEH-4, which were developed from a United States Forest Service publication entitled Handbook of Methods of Hydrologic Analysis (undated). C. H. Walker (1970) evaluated Figures 9.5 and 9.6 of NEH-4 using data from several small watersheds located in Davis County, Utah. He noted errors in curve numbers as high as 19 percent. Utilizing graphical and regression techniques, he explained a portion of the variation in curve number for watersheds and runoff plots on the Walnut Gulch Experimental Watershed. The variables found to influence experienced curve numbers included storm intensity, antecedent rainfall, watershed or plot size, land treatment and the cross-product of antecedent rainfall and storm intensity.

Chiang (1975) expressed S in terms of "Number of Wetness Curve." This is a means of describing S in terms of its relationship to bounds about a central S value determined from the original SCS curves. Chiang evaluated the variation is S by using multiple regression equations to describe S in terms of a number of dependent climatic variables. The parameters found most influential on "s" included rainfall total, an antecedent temperature and precipitation index and the base flow of the watershed when the runoff event occurred. The inclusion of the base flow rate in the model is of questionable statistical propriety. Chiang did not separate base flow from the storm induced portion of the runoff. In calculating runoff volume, the base flow component would become significant, limiting its value as a dependent variable. Chiang concluded that the SCS model should be modified to eliminate storm precipitation total as a dependent variable.

Hawkins (1973) suggested a means for describing CN for some watersheds in terms of another watershed parameter. Using data from several western wildland watersheds, he showed that rainfall volume affected curve number. He proposed the use of a dimensionless curve fitting constant "K" to reduce the errors inherent in selecting curve numbers. The expression:

$$CN = 100\ (2 + K\ P)/(2 + P) \qquad (8)$$

where P = storm rainfall in inches, is used to predict CN knowing storm rainfall and the constant "K". The coefficient of determination for the above relationship on watersheds studies in Hawkins' paper ranged from 87.0 to 99.5 percent. In drawing conclusions Hawkins stated two main arguments:

1. The SCS relationship (i.e. eq (6)) does not apply easily to the wildland watersheds considered.
2. Channel precipitation may be an important source of runoff for wildland watersheds.

In another publication Hawkins (1975) presented the sole sensitivity study dealing with curve numbers. Using 10 percent errors in curve number and precipitation, he recalculated runoff for four possible non-interactive combinations of error and compared it to the true runoff value. The results of this study showed that errors in curve number are more critical than errors in precipitation for a range of precipitation values less than about nine inches.

The literature published relative to the SCS curve number method suggests several conclusions:

1. The description of a watershed's hydrology utilizing curve numbers as a tool will show significant amounts of variation in curve numbers.
2. Variation in curve number can be partially explained using climatic data as dependent variables.
3. Redesigning of curve number methodology may be necessary

to adequately describe wildland watersheds.

4. Errors in curve number are more serious than errors in rainfall.

STUDY AREA

Arizona is dependent on streamflow originating from upland plateaus for large portions of its water supply. The Beaver Creek Pilot Watershed and the Black River Barometer Watershed are hydrologically representative of large portions of this type of plateau. Figure 1 shows the location of these study areas. A summary of soils and vegetative characteristics of the study watershed is found in Table 1. A summary of the climatic data is found in Table 2.

Beaver Creek Watersheds

The Beaver Creek Pilot Watershed is located within the Coconino National Forest near Flagstaff, Arizona. This research area consists mainly of sedimentary plateaus capped by extrusive volcanic rocks and displays varying degrees of dissection and a number of different types of topography. Because the headwaters of the Verde River possess large elevational differences, it supports several vegetative zones. The hydrology of the Utah Juniper (*Juniperus osteosperma*), Alligator Juniper (*Juniperus deppeana*), and Ponderosa pine (*Pinus ponderosa*) communities will be examined here.

Utah Juniper Watersheds

Beaver Creek Watersheds 001, 002, and 003 are Utah Juniper Watersheds. These have a dwarf forest overstory that is predominantly Utah Juniper with small amounts of pinyon pine (*Pinus edulis*). Understory vegetation includes brush, grasses and forbs. The range condition of these watersheds is considered very poor (Brown 1974).

Climate. Because these watersheds are the lowest in elevation on the Beaver Creek Group, 5,200 feet to 5,500 feet (1,585 meters to 1,675 meters), they are also the warmest and the driest. The annual temperature averages 56° F (13.3° C), and the annual precipitation averages 18 inches (460 mm), most of which falls from October to April. Figure 2 shows the distribution of precipitation streamflow.

Soils. The soils of watersheds 001, 002, and 003 are predominantly Springerville, very stony clays. They are clay throughout their 44 inch (1.12 meter) profile. Basalt rock covers 30 to 50 percent of the soil surface. This series is free from lime concentrations in the surface, subsurface and upper substratum. Calcareous deposits are found near the bottom of the profile. Soil structure is massive in the zones below the surface, which is granular or platy. Infiltration of these sois varies from moderate to slow, and permeability is low in all phases of the series. Generally, these soils are very restrictive to water movement and classed as Hydrologic Soil Group D. Surface cracking is prevalent and symptomatic of soil heaving (USDA, 1967).

Hydrology. Streamflow is ephemeral in these watersheds. Runoff occurs as a result of snowmelt and in direct response to high intensity precipitation and prolonged winter rains. Little protective vegetation covers the soils. The surface is covered with rock fragments. Pronounced dissection is not common.

Land Treatment Measures. Utah Juniper Watersheds were part of a watershed rehabilitation research project. Watershed 001 was

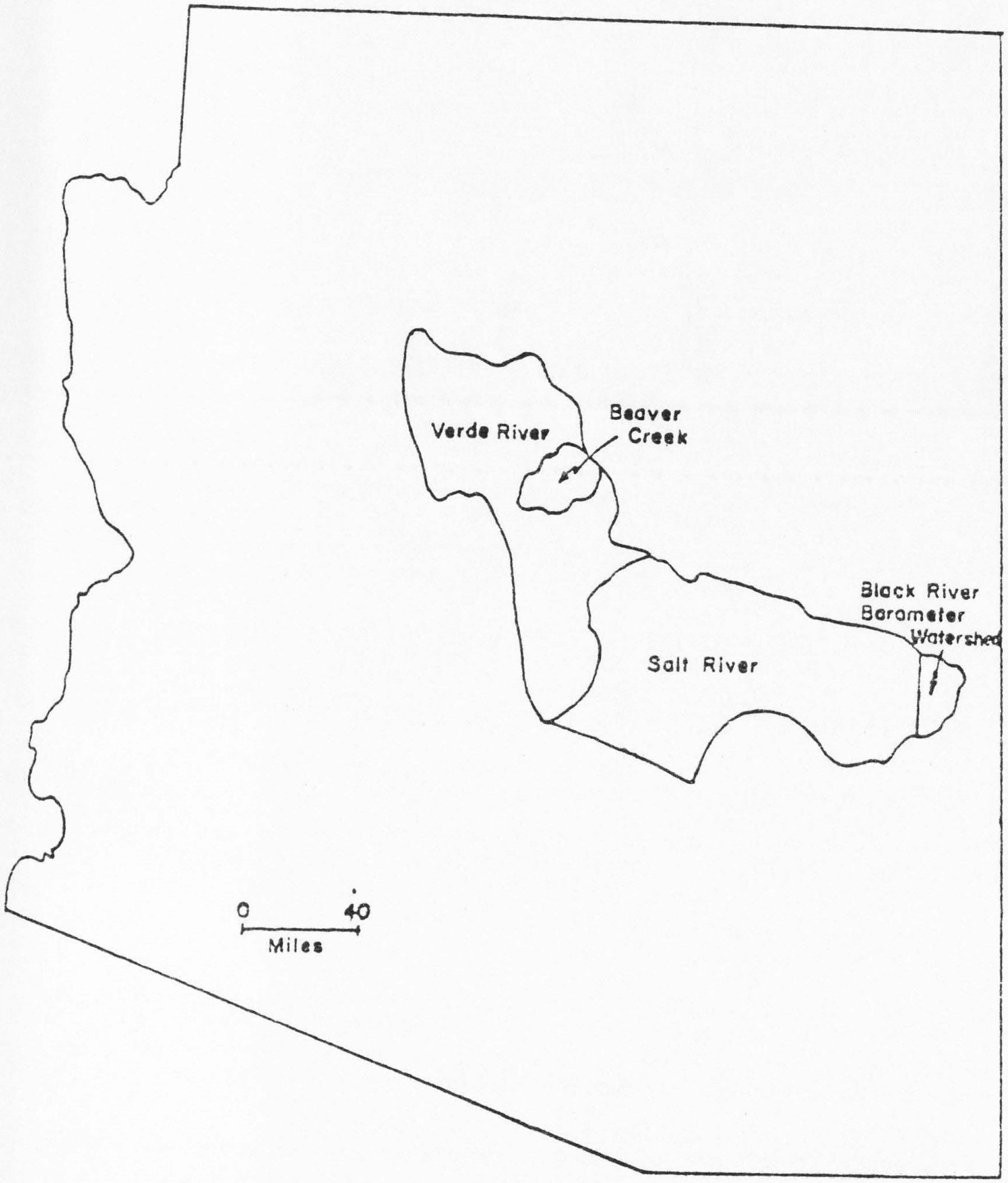

Figure 1. Location of Beaver Creek Pilot Watershed and Black River Barometer Watershed.

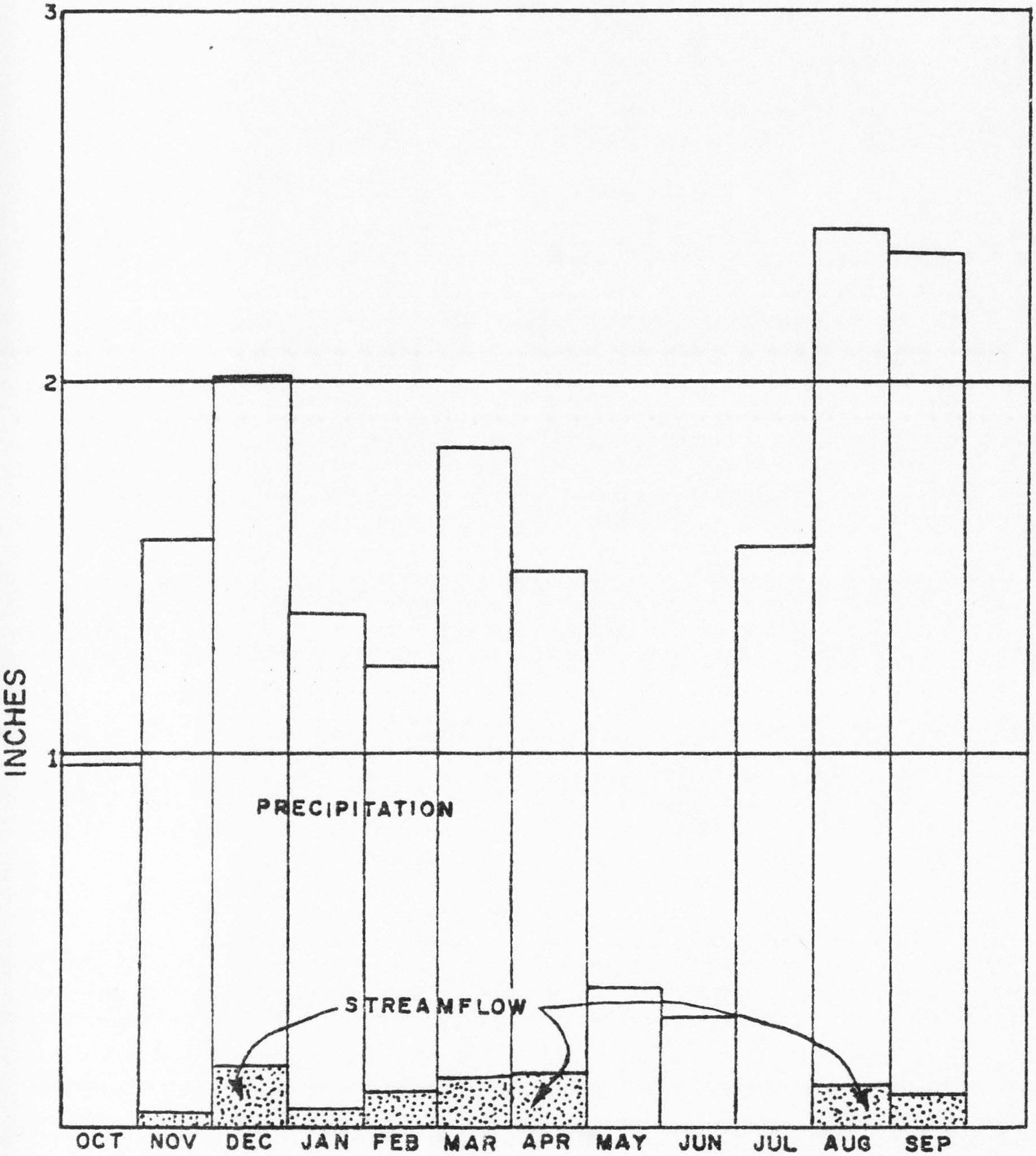

Figure 2. Distribution of Precipitation and Streamflow for Utah Juniper Watersheds.

Table 2. Soils and vegetation data for study watersheds.

	SOILS				VEGETATION
Watershed	Series	Depth	Hydrologic Soil Group	Cover Type	Ground Cover Density (%)
001	Springerville	44"	D	Utah Juniper	
002					
003					18-55
004	Springerville/	44"	D	Alligator	35-50
005	Gem	44"	C	Juniper	
016	Broliar		D	Ponderosa pine	64-76
017	Siesta		D		
018					
Seven Springs East	Cinder/Bandera		B	Grass	55-75
Seven Springs West					
Thomas Creek North	Sponseller		B	Mixed Conifer	90-95
Thomas Creek South					

Table 3. Selected climatological data for study watersheds.

		Precipitation				Temperature Degrees F		
Cover Type	Study Watersheds	Annual	Range	Winter	Study Watershed Elevation Range	Av. Annual	Av. Jan.	Av. July
Utah Juniper	001 002 003	18	12-24	11	5200-5400	56	38	76
Alligator Juniper	004 005	20	16-27	12	6200-6400	50	34	70
Ponderosa Pine	016 017 018	25	18-35	16	6800-8000	45	29	66
Grassland	Seven Springs East Seven Springs West	27	19-31	14	8500	42	26	59
Mixed Conifer	Thomas Cr. North Thomas Cr. South	28	22-37	15	8400-9200	42	26	59

NOTES: Precipitations in inches/yr. Elevations in feet.

cabled in 1963, and the small trees not uprooted by the cable were handchopped. The slash from this effort was burned. The net result of this work was a 100 percent removal of overstory trees. No significant change was noted in annual streamflow as a result of this treatment (Brown , 1974). Watershed 002 was used as a control and, therefore, was not treated. Watershed 003 was treated with herbicides. In 1968, 2.5 pounds per acre (2.8 Kg/hectare) of picloram and 5 pounds per acre (5.6 Kg/hectare) of 2,4,D was applied to kill the trees on this site. This resulted in nearly a 100 percent mortality of overstory. The dead trees were left in place to provide shade, reduce wind and prevent pits from being formed as they were on Watershed 001. Significant annual streamflow changes occurred, amounting to 0.45 inches (11.4 mm) of annual runoff (Brown , 1974).

While streamflow volume changes were small, changes in flood peaks from a 100-year storm were greatly affected by treatment. This change exceeded 250 percent on Watershed 001. Watershed 003 showed a 100 percent increase in estimated flood peak (Brown , 1974). These estimates of change are based on analysis rather than on the models considered in this evaluation.

Alligator Juniper Watersheds

Positioned above the Utah Juniper Watersheds at an elevation of 6,200 feet (1,890 meters) to 6,400 feet (1,950 meters), the studied Alligator Juniper Watersheds, 004 and 005, are significantly different from each other. Although forage production on this type of watershed is higher than under the Utah Juniper overstory, it is still considered poor range (Brown , 1974).

Climate. The Alligator Juniper vegetative zone receives about 20 inches (508 mm) of precipitation annually, varying from 16 inches (406 mm) to 27 inches (686 mm). Winter precipitation accounts for 12 inches (305 mm) of this total. Average annual temperature is 50° F (10° C), which is somewhat cooler than Utah Juniper zone. A summary of climatic data for this watershed is found in Table 2.

Soils. In addition to the Springerville very stony clay soils found in the Utah Juniper Watersheds, the Alligator Juniper zone has a significant amount of the Gem soil series. The Gem series is composed of clay loams averaging 44 inches (1.12 meters) deep. It is considered a fertile soil. No carbonate buildups occur in this soil above 37 inches (.94 meters) in depth. The structure of the series is better developed than the Springerville series. The subsoil is known to have both blocky and prismatic peds. Infiltration in this series is moderate. Permeability is generally slow. These soils are classified as Hydrologic Soil Group "C".

Hydrology. Streamflow is also ephemeral from the Alligator Juniper watersheds. While surface rock is not as abundant as on the Utah Juniper sites, more protective vegetation is present. Runoff occurs as a result of snowmelt and prolonged winter rains. High intensity thunderstorms produce brief periods of runoff.

Land Treatment. No treated Alligator Juniper Watersheds were studied.

Ponderosa Pine Watersheds

Climate. Because of a combination of physical factors, the

Ponderosa pine watersheds possess great watershed management potential. This vegetative type produces over half of the streamflow of the Verde River. Located at 6,800 to 8,000 feet (2,075 meters to 2,440 meters) in elevation, the study watersheds receive an average of 25 inches (635 mm) of precipitation annually, 64 percent of which falls between October and April. Less evaporation potential exists on these sites than on the lower juniper areas. This is reflected in the mean annual temperature.

Soils. The most extensive soil in the Ponderosa pine zone of Beaver Creek is the Broliar series. The soil possesses medium to high fertility and supports productive stands of trees. The profile, 31 inches (.79 meters) deep, is devoid of carbonate layers and is noncalcareous. The soil structure is platy at the surface and blocky in the subsurface horizon. The infiltration in the loam-silt loam surface horizons is inhibited by a clay subsurface horizon and the presence of surface rock which may cover 20 to 60 percent of the surface. Permeability of this series ranges from 0.05 to 0.8 inches per hour (1.3 to 20.3 mm/hr). Because of the inhibiting factors on the surface and in the subsurface, these soils are in Hydrologic Group "D".

The Siesta soil series is very similar to the Broliar series. This soil has slightly higher fertility and the permeability shows more variation. The texture and structure of this soil is the same as the Broliar series. One of the most noticeable differences is the presence of less rock on the surface of this series. The total profile depth averages 46 inches (1.17 meters). This series is also found in Hydrologic Group "D".

A small portion of the Ponderosa sites are in the Sponseller soil series. This series has the deepest profiles in the Ponderosa zone (52 inches) 1.32 meters). A typical profile is noncalcareous and noncarbonaceous. The surface horizon is composed of platy structured silt loams. The surface horizon of this series is usually deeper than the surface horizons of other soil series. The subsurface has firm block structure. The infiltration of these sites is moderate with moderate to slow permeability. These soils are in Hydrologic Group "B".

Land Treatment. The watershed management practices applied on the Ponderosa Pine watershed were designed to increase water yield. On Watershed 016, 65 percent of the Ponderosa pine basal area was removed. This was done by clearcutting strips that would channel snow melt waters to stream channels. Augmenting this clearcutting, selective cutting was performed between strips to obtain log size classes in short supply on the Coconino National Forest. The oak understory was cut, leaving only the trees with diameter breast height greater than 15 inches (381 mm). The precut basal area was 103 ft.^{2}/acre. Cutting reduced this to 36 ft.^{2} (8.25 m^2/hectare)/acre. This treatment increased water yield 103 percent in the year after treatment.

A thinning cut was used on Watershed 017. This cutting procedure removed 75 percent of the basal area. This removal (90 ft.^{2}/acre) (20 m^2/hectare) included all Gamble oak over 15 inches (381 mm) d.b.h. except den trees. The Alligator juniper was completely removed from this watershed. The slash was windrowed. Water yield increases in four years of post-treatment study averaged 22 percent.

Watershed 018 was not treated and was as a control.

Hydrology. Streamflow from these watersheds is intermittent. Runoff occurs after snowmelt and winter rainstorms. The high variability in soil permeability and surface infiltration causes varying responses to summer thunderstorms. Good ground cover enhances moisture retention on the watershed and diminishes surface runoff.

Black River Barometer Watershed

The Black River Barometer Watershed is located in eastern Arizona. This study area was established by the U.S. Forest Service to evaluate watershed research technology on the management level. This barometer watershed is located on the Apache-Sitgreaves National Forest in Apache County, Arizona, and lies at the headwaters of the Black River, a tributary of the Salt River. The geology is entirely volcanic with basalt and cinders comprising the parent materials. The topography of this area is characterized by high plateaus dissected by river valleys with occasional ridges and knolls. The mean annual temperatures vary from 40° F to 46° F (4.4° to 7.8° C). Annual precipitation is about 25 inches (635 mm). Approximately half of this precipitation falls between May and September. The rainfall intensities for these summer storms were described by Leven and Stender (1967) as moderate.

Grassland Watersheds

Vegetation. The Seven Springs East and Seven Springs West watersheds are high elevation grasslands. The most common species found within these paired watersheds are June grass, pine dropseed, mountain muhly and Arizona fescue.

Soils. Petrologically this area is composed of quaternary cinder deposits. The soils of this area strongly reflect the cinder influence in their development. They are primarily of the Bandera and Cinder series. The Bandera series is composed of well-drained gravelly loams. These are noncalcareous throughout their profile. The percentage of gravel increases with depth throughout the 42 inch (1.06 m) profile. Welded cinders underline this series. The Cinder series is also well-drained, but it is slightly finer in texture than the Bandera series. Cinder soils are clay loams that grade into gravelly clays as the profile deepens. They are noncalcareous throughout the four-foot deep profile. Both series are considered Hydrologic Group B soils.

Hydrology. Most of the flow record reviewed showed a base component of runoff from the grassland watersheds. Runoff records showed that the storm component occurred as a small surge of flow. Baseflow aggraded as a result of the event producing storms.

Mixed Conifer Watersheds

Vegetation. The Thomas Creek North and Thomas Creek South watersheds are covered with a variety of tree species. These species include Douglas fir, Engelmann spruce, White fir, Ponderosa pine, limber pine and blue spruce. These watersheds have high ground cover densities (85 percent). It is of interest to note that they receive approximately the same amount of annual precipitation as the grassland watersheds. Forested basal area for Thomas Creek North is 178 ft.^{2}/acre, and Thomas Creek South has 187 ft.^{2}/acre basal area.

Soils. The mixed conifer sites are underlain by soils of the Sponseller series. This series is composed of a loam surface horizon and clay subsurface components. They are deep to moderately deep, an average profile depth is 30 inches (0.76 meters). No calcareous influence is present. The fertility of this series is considered high because of the good growth shown by the conifer overstory. As much as 30 percent of the soil profile may be made up of coarse fragments, but some profiles are nearly stone-free. These soils are classified as Hydrologic Group B (Leven and Stender, 1967).

Hydrology. Thomas Creek tributaries were perennial during the observed period of record. Thomas Creek south watershed produced higher base flow rates than its counterpart. As in the grassland watersheds, baseflow was augmented by summer storms, with storm runoff consisting of a light surge of flow.

PROCEDURE

Data Development

Watersheds used for this study were selected by United States Forest Service personnel to give a stratified sample of vegetative and soils communities common to Northern Arizona. The study areas were located within two research watershed units, the Beaver Creek Pilot Watershed and the Black River Barometer Watershed. Utah Juniper, Alligator Juniper, and Ponderosa Pine communities are located in the Beaver Creek Pilot Watershed, while grassland and mixed conifer watersheds are on the Black River Barometer Watershed. Data available from these watersheds included precipitation and runoff records, in addition to soils and vegetative descriptions.

After selecting study watersheds, appropriate runoff data were reviewed either visually or by digital computer to isolate rainfall induced hydrographs. The Beaver Creek data were screened using a digital computer for hydrographs which produced streamflow peaks greater than 2.0 cfs per second per square mile. Storm hydrographs were expressed in area inches. The computer output consisted of cumulative five-minute increments of runoff.

Appropriate precipitation records were similarly included as cumulative five minute totals on the same printout sheets. Table 1 of Appendix 1 shows a typical hydrograph.

Hydrographs for the Black River Barometer Watershed were separated from baseflow using Hewlett's (1967) method. This entails the mathematical construction of a straight line from a point on the recession limb. Hydrographs that coincided with significant storms were selected for further analysis. These were then visually analyzed to see where the recession limb of the hydrograph began to decelerate at a constant rate. Flow after stabilization of recession rate was considered to be baseflow. A straight line was drawn between the point where the rising limb started and the point where stabilization of recession rate occurred. The slope of the line was computed and noted. Separation slopes for each watershed were selected to include those storms that produced definitive storm hydrographs. Hydrographs that did not have geometry indicative of surface runoff were excluded. These hydrographs generally had a rising limb but lacked any distinct falling limb.

Since the Beaver Creek streams are ephemeral, recorded runoff was a result of the studied storms. All of the storm runoff was included in computation of coefficients. Use of the entire runoff volume meant that none of the water was extracted. Therefore the separation rate was necessarily 0.0 csm/hr.

Table 4. Storm hydrograph separation rates for Black River barometer watershed

Watershed	Separation Rate $ft^3/sec/mi^2$
TCN	2.21×10^{-3}
TCS	3.21×10^{-3}
SSE	15.96×10^{-3}
SSN	19.74×10^{-3}

Beaver Creek precipitation data was taken from computer files of the Rocky Mountain Forest and Range Experiment Station. Digitized cumulative five-minute increments of precipitation accompanied the storm hydrographs. A sample printout is found in Appendix A. Intensities for intervals greater than five minutes were computed manually. Rainfall data from the Black River Barometer Watersheds was taken from recording rain gauge charts and summarized for each storm. An example of this procedure is found in Appendix A.

Antecedent moisture conditions were compiled for all watersheds by reviewing the daily rainfall totals for each respective watershed. These totals were then summed to obtain antecedent conditions for periods up to 10 days. For example, a five-day period was computed by simple addition of all precipitation in the 120 hours prior to the beginning of the storm producing a runoff event.

Data Analysis

Computation of Model Coefficients

Runoff Fraction. Least squares methods were used to calculate coefficients for the three basic models (i.e., equations) considered. The first equation, which uses a runoff fraction is:

$$Q = CP \qquad (9)$$

where P is the rainfall depth in inches, and Q is the runoff depth in inches (although any consistent set of units may be used.

The least squares estimator of C is given by:

$$C = \Sigma(PQ)/\Sigma P^2 \qquad (10)$$

with the correlation statistics given by:

$$S_e = \frac{\Sigma\Delta^2}{N} \qquad (11)$$

and

$$r^2 = 1-(S_e/S_y)^2 \qquad (12)$$

where

$$\Delta_i = Q_i - CP_i \qquad (13)$$

and N = number of observations

S_y = standard deviation of observed runoff population.

S_e = standard deviation of estimated runoff. (Spiegel 1961)

S.C.S. Curve Number Method. Application of a least squares method to the SCS equation was done to minimize the squared errors in runoff prediction. This required the use of the expression:

$$\Delta_i^2 = (Q_i - (P_i - 0.2S)^2/(P_i + 0.8S))^2 \qquad (14)$$

where Δ_i is the error of an individual prediction in inches of storm runoff Q_i that was generated by the use of a specific S (or curve number). The summation of the squared Δ_is then yielded a value that could be minimized by varying S. This was done using a trial and error procedure on a desktop computer. Values of S_e and r^2 were also calculated as in equations (11) and (12) above and equation (14) above for Δ_i^2.

Modified SCS Method. The SCS method of estimating runoff was modified by eliminating .2S as the fixed ratio of Ia:S. A more general form α = Ia/S was substituted, and the following expression results.

$$Q = (P - \alpha S)^2/(P + (1 - \alpha)S)$$

Therefore, in a manner similar to the above,

$$\Delta_i^2 = (Q_i - (P_i - \alpha S)^2/(P + (1 - \alpha(S))^2 \qquad (16)$$

where is a dimensionless fraction of S, and P, Q, and S are as previously defined. Determination of α and S from observations required a two dimension trial and error search, which was carried out on a desktop computer. As before, a least squares fitting was done, using equations (11), (12), and (16).

Regression Analysis. A fraction of runoff from many storms can be attributed to channel precipitation. Hawkins (1973) suggested that this can be a considerable portion of the total runoff volume for some small watersheds. Since channel precipitation is not always indicative of watershed condition, it is not always an issue in land management. This component must be extracted from the analysis, if the watershed is to be evaluated. The SCS runoff equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{17}$$

also complicates the input from channel precipitation in terms of the data analysis. The channel precipitation component insures that, for practically every precipitation value, there is a runoff value and, therefore, a curve number. If the watershed lands do not contribute any runoff, curve number becomes a function of a runoff fraction and precipitation.

The relationship defining S set forth by Hawkins (1973);

$$S = 5(P + 2Q - \sqrt{4Q^2 + 5PQ}) \tag{18}$$

can be modified when a fixed portion of the watershed contributes a high proportion of runoff resulting in constant fraction of precipitation becoming runoff.

$$Q = CP \tag{19}$$

which converts "S" from (7) into

$$5P(1 + 2C - \sqrt{4C^2 + 5C}) \qquad (20)$$

This produces the situation observed by Hawkins where curve number varies in a curvilinear fashion with respect to precipitation and the runoff fraction. The watersheds studied by Hawkins produced small volumes of runoff, indicating that most of the precipitation was stored on-site. Inductively, it may be seen that the majority of precipitation was absorbed by the soil. Runoff was probably derived from channel precipitation and quick interflow.

As precipitation exceeds the infiltration rates and watersheds derive runoff from processes other than channel precipitation and interflow, additional variability in the relationship between rainfall and runoff should be expected. Variability with respect to time and space for soil, vegetation and climatic factors could contribute to the potential of various homogenous portions of a watershed to produce runoff. When the simple case of runoff originating from around the stream is expanded to include surface runoff and other processes, the flow described in (9) is increased. This may result from either increased precipitation or decreased watershed storage S because of antecedent soil moisture or other factors. Rainfall intensity may exceed infiltration rate, increasing the proportion (c) of rain that becomes runoff. These conditions lessen S and elevate curve number. The variability that ensues may be large or small, depending upon the magnitude of changes in the conditions that occur within the hydrologic cycle. Describing the variability mathematically and evaluating it statistically has been approached from several angles, as described in the Review of Literature.

Mathematical description and statistical inference on study watersheds were developed by calculating a runoff fraction for storms that were thought to have a large portion or an entirety of their runoff attributable to channel precipitation. The criteria for selecting such storms were arbitrarily selected, as storms producing less than 0.02 inches of runoff were considered.

Determination of the effects of climate variables upon curve number populations is a complex task. The curvilinear properties of curve numbers described by Hawkins and further described above require careful extraction of the portion of historic curve numbers due to climatic inputs to avoid confusing it with system variability or masking the effects of climatic parameters with estimates that have little objectivity or physical meaning.

The first step used in this phase of evaluation was to isolate the portion of runoff attributable to channel precipitation. Since this was shown to be a rather constant proportion of rainfall by Hawkins (1973), it should follow that description of curve number under hydrologic conditions that are dominated by channel precipitation should describe runoff fraction attributable to channel precipitation throughout the entire range of precipitation. Fitting a coefficient that expresses a constant ratio of runoff to rainfall was accomplished using the least squares method.

This produces the expression:

$$Q = CP$$

Where Q = runoff volume (in.)

P = precipitation volume (in.)

C = a decimal fraction of P

C may be estimated from data

$$C = \Sigma PQ/\Sigma P^2 \qquad (21)$$

Isolation of channel precipitation-dominated events was facilitated by selecting those that had runoff amounting to less than 0.02 inches and using them in the above equation to compute a C value for each watershed.

After a runoff fraction, C was estimated for each watershed, runoff attributed to channel precipitation was computed for every storm using defined coefficients. These pairs of precipitation and runoff values were associated in the equation

$$S = 5(P + 2Q - \sqrt{4Q^2 + 5PQ}) \qquad (22)$$

and curve number

$$CN = \frac{1000}{10 + S} \qquad (23)$$

where S = watershed storage

and P and Q are previously defined.

The synthesis of a population of curve numbers attributable to channel precipitation allowed comparison with the historic curve numbers. Channel precipitation - curve numbers were subtracted from historic curve numbers to obtain mathematical differences which were called: ΔCN.

The populations of ΔCN values generated for each watershed were used as dependent variables to assess the effects of climatic inputs upon curve number populations. Selection of the types of climatic variables for use in multiple regression equations was done using simple linear regression and correlation techniques. The parameters that were found to be most effective were:

Maximum sixty-minute storm intensity (I60)

One-day antecedent storm rainfall (AMC1)

Storm precipitation volume (P)

The cross product of I60 and P1.

To simplify regression analysis and interpretation, one multiple regression model using the above-mentioned variables was utilized:

$$CN = b_o + b_1P + b_2AMC1 + b_3I60 + b_4I60 \times AMC1 \quad (24)$$

The results of fitting the data to these models are found on Table 16 which gives the coefficients and Table 17 which describes the accuracy of the models.

Effects of Treatment

The assessment of the effects of treatment was done using regression analysis. The treated watersheds were subjected to regression analysis utilizing all events prior to treatment. Regression equations developed from pre-treatment data were then applied to post-treatment data. The means of regression model residual errors resulting from post-treatment data were compared statistically with the mean of residuals resulting from pre-treatment data. This analysis was facilitated by the use of the t-test for the difference between two means.

Average Error of Estimation

A final method was used to access the overall utility of the above regression procedure. The average percentage error in runoff prediction was computed for each study watershed. The equation was:

$$\frac{1}{n} \sum_{i=1}^{n} \left(\frac{Q_i - \hat{Q}_1}{Qi}\right)^2$$

where Q_i = actual runoff from event i

$\hat{Q}_i$ = predicted runoff from event i based on CN_i and the precipitation from storm i was employed to assess the relative accuracy of the model.

RESULTS

Data Population Analysis

Basic Statistics

The data used in the various phases of these analyses are found in Appendix 4. While each watershed's data have characteristics that could be considered unique, some characteristics are common to all watersheds or groups of watersheds. Those items that make the watersheds unique, while of value in intuitively assessing the data and its inter-relationships with watershed conditions, would expand this discussion to an awkward volume. Trends that occur in several watersheds will be considered here.

The mean and standard deviations of antecedent moisture conditions for the watersheds were found to be unlike those described as average in NEH-4. Five-day antecedent moisture for 11 of the 12 watersheds was below the 1.4 inch minimum required for average conditions in NEH-4. This confirms the observation of Simanton, Renard and Sutter (1974), that average moisture is below the traditional level suggested in NEH-4.

Average rainfall intensities were not extremely high, although some storms did produce substantial 60-minute intensities. The average 60-minute intensity was less than 1.0 inches per hour for all watersheds except 018 at Beaver Creek, which, coincidentally, also had the highest antecedent rainfall conditions.

Comparison of rainfall intensities with soil permeabilities reveal something of the nature of runoff. Although the average rainfall intensities were low on Beaver Creek watersheds, they were often higher than the maximum infiltration rate inferred from the hydrologic soil group. The hydrologic soil groups described for the Black River Watersheds permit rapid infiltration. The low rainfall intensities would suggest that surface runoff should have occurred infrequently. The small proportion of precipitation that was converted to runoff offers support to this supposition.

The basic statistics developed from the curve number data show that three groups of broad watershed groupings are evident. The Beaver Creek Pilot watersheds produced populations of curve numbers that ranged from 71.8 to 79.4. This is a rather limited range of coefficients when considered in light of the differences in soil and vegetation cover conditions found within these study areas. The second group comprised the Seven Springs watersheds. Both the mean curve numbers for Seven Springs exceeded the maximum range found at Beaver Creek. The Thomas Creek watersheds generated a mean curve number that was below the minimum of the averages for Beaver Creek.

The average runoff values produce the same groups of watersheds as the average curve number values. Comparison of runoff values shows that watershed groups that have similar curve number populations also have similar runoff characteristics. The Beaver Creek catchments, with the largest storm volumes and least permeable soils, produced the largest unit area runoff volumes. The Seven Springs Watersheds produced much less runoff than the Beaver Creek study area. They have more permeable soils and, thus, a greater potential to allow precipitation to infiltrate and to become stored within the soil profile. The Thomas Creek watersheds' hydrologic soil groups are the same as those found on Seven Springs, but differences in infiltration rates and storage capacity probably exist. Additionally, the tree canopy found on Thomas Creek possesses substantial interception potential. Forest litter may also provide additional soil profile storage for precipitation prior to infiltration into mineral soil.

The data generally suggests that the differences in watersheds may be described using curve numbers methods, yet a more refined look at individual storms is necessary. Examination of the population parameters can cause significant errors in forecasting effects of land condition because the lack of uniformity in inputs clouds the effects of the hydrologic processes on the outputs. Beaver Creek watersheds averaged substantially more runoff for the events considered than any of the Black River watersheds. Seven Springs drainages averaged several times more runoff than those from Thomas Creek.

While the Thomas Creek watersheds were subjected to nearly the same average precipitation inputs as the Beaver Creek watersheds, the Seven Springs watersheds received about half or a third as much mean precipitation from storm events. The runoff from Thomas Creek averaged less than the grassland watersheds, but the area received higher inputs. This suggests that watershed storage potential is greater at Thomas Creek. Beaver Creek, with the greatest storm inputs, had the greatest outputs. Also, the variability of the outputs was much greater at Beaver Creek than at Black River.

Selection of model coefficients to describe conditions on the studies watersheds is difficult. Production of storm runoff from a watershed appears to be related to watershed conditions. The choice of four soil categories to represent a continuation of soils conditions that ranges from nearly impervious to extremely porous was not effective in terms of the data for studied watersheds. While Seven Springs and Thomas Creek have identical hydrologic soil groups, they produce quite different runoff populations. Some of this difference is probably due to the lack of sensitivity that current catalog values of curve numbers ascribe to differences in soils. The ability of mean curve numbers to predict mean runoff is poor. A range of less than eight curve numbers encompasses the means of all eight pilot watersheds from Beaver Creek. The work by Hawkins (1975) showed that accuracy in selection of curve numbers is more important than accuracy in selection of a design storm size. The differences between two watersheds may be described as differences in curve number, but this offers little hope for extrapolation to other watersheds. Hawkins showed that arithmetic differences in curve number may produce geometric differences in runoff for certain ranges, yet these are inconsequential changes in other ranges. The sensitivity of this coefficient may be difficult to grasp intuitively, as it varies widely over combinations of precipitation and runoff. Changes in outputs described as changes in model coefficients tend to ignore the real function of the model. Similar effects have been described in predicting runoff peaks using logarithmically transposed frequency distributions. The slope of the flood probability curve is determined by the parameters of the frequency distribution that describe dispersion of the population logarithms. The effects of changes in the coefficients at one point in the curve are grossly different on outputs than they are at another point on the curve, even though the magnitude of the transposed variable, usually the standard deviation, is identical. When the parameter S, which isn't linear with respect to precipitation and runoff, is transposed again into a convenient index, the soundness of the index to present differences in land conditions becomes greatly clouded.

Primary Model Calibration and Evaluation

Least Squares Curve Number Fitting

The curve numbers developed for the study watersheds using the least squares method were substantially different from arithmetic means of curve number populations presented in Tables 4 through 15. The least squares curve numbers presented in Table 16 were lower than the mean curve numbers. This is due in part to the tendency of curve numbers to vary inversely (because of channel interception) with storm precipitation total that was described by Hawkins (1973). As the precipitation increases, runoff also increases. Curve number, however, decreases. The least squares method is designed to minimize the effects of large deviations in runoff. The storms producing the largest amounts of runoff were, therefore, more influential in selecting a coefficient that would describe a population of runoff events than they were in the arithmetic mean method. These large events had lower curve numbers. Consequently, the least squares coefficients were lower than the average curve numbers. The standard error of the least squares curve number is quite high. It was roughly equivalent to the mean runoff value. The standard deviation of the runoff values exceeded the mean values (coefficients of variation > 1) for all watersheds. This suggests that the least squares curve numbers did eliminate some of the error that would have resulted without the use of the model.

Least Squares Fitting of the Modified Curve Number Method

Table 4 presents the results of the least squares fitting of α and S coefficients for the modified curve number method. The use of the modified model resulted in lower standard errors than the curve number model in current use. These error reductions were a small percentage of the residual standard errors for the Beaver Creek watersheds. The largest reduction, which occurred at Watershed 001, amounted to 17 percent of the standard error for the modified model. Black River watersheds were much more suited to this type of modified model. The application of the modified SCS method to the Seven Springs and Thomas Creek watersheds resulted in reduction of standard errors by as much as 99%. This was possible because the Black River watersheds cannot be accurately described by a relationship that has a sizeable initial abstraction and low storage potential. These drainages produced small runoffs regardless of (although in proportion to) storm size. The initial abstraction of 0.2S does not allow runoff under these situations without varying S. The soils on the Black River watersheds had higher infiltration rates than the Beaver Creek watersheds. This would mean that greater amounts of precipitation would be absorbed by the soil mantle, accounting for the high watershed storage factors. The more permeable soils also would mean that interflow from the riparian zone would be faster than in a tighter soil. The net effect would be to have a quicker delivery of precipitation falling near the channel to the stream suggesting a smaller initial abstraction. In restrictive soils, such as those found in Beaver Creek watersheds, small storms may not contribute significant interflow, or they may also contribute it so slowly that it would not create a hydrograph that would have met the criteria set for selecting runoff events at Beaver Creek.

Runoff Fraction Model Fitting

The runoff fraction model generated high standard errors for the Beaver Creek watersheds, but was quite usefully applied to the Black River watersheds. With the exception of Watershed 001, the standard errors for the runoff fraction model were higher than that of the least squares curve number for Beaver Creek drainages.

The Black River watersheds were generally better suited to the runoff fraction model than the least squares curve number. The Seven Springs East watershed was the exception to this case (see Table 5). The modified curve number method was superior to the runoff fraction method for all watersheds. The runoff fraction model apparently is quite similar to the modified curve number model when α is close to zero and S is relatively high.

Regression Analysis

General. Much of the variation in curve number populations was explained as a result of the regression analysis. The use of climatological data reduced the variation that is portrayed in Appendix 4. The regression equations are presented in Table 6. The statistics that describe the accuracy of the regression equations are found in Table 7.

Table 5. Least squares coefficients for curve number and modified curve number models.

Watershed	Curve Number $\alpha = 0.2S$	Standard Error (in)	Modified Curve Number Method		
			α	S (in)	Standard Error (in)
001	58.32	0.1592	0.000	36.00	0.1363
002	60.46	0.2325	0.000	18.41	0.2142
003	66.75	0.1844	0.334	3.70	0.1769
004	67.90	0.1115	0.210	4.60	0.1114
005	66.10	0.2828	0.208	5.02	0.2828
016	69.93	0.6868	0.237	4.07	0.6830
017	82.19	0.4670	0.387	1.69	0.4478
018	68.46	0.2847	0.063	6.40	0.2819
TCS	63.44	0.0398	0.000	1287.00	0.0012
TCN	59.21	0.0690	0.000	2523.00	0.0007
SSE	77.09	0.0419	0.000	38.97	0.0095
SSW	78.58	0.0346	0.000	110.50	0.0091

NOTES: Above cofficients for use in the equation:

$$Q = (P - \alpha S)^2/(P + (1 - \alpha)S), \text{ where} \qquad (26)$$

Q = runoff (in)
P = storm precipitation
S = total potential watershed retention
α = coefficient of initial abstraction as a fraction of S

Table 6. Regression model coefficients Model: $CN = CN_c + \Delta CN$

$CN_c = 100/(1+(P/2)(1+2c=-\sqrt{4c^2+5c^1})$ $\Delta CN = b_o+b_1P=B_2AMC1+b_3I60+b_4I60xAMCI$

Watershed	"c"	b_o	b_1	b_2	b_3	b_4
001	.006676199	-3.41398	1,97635	3.82802	4.89384	1.37036
001 Treated		-0,95250	1.64241	-2.11022	0.13973	20.59023
002	.010607816	-2.81652	1,96970	1,24389	6.68598	3,52768
003	.009060898	-2,59740	5.80776	-.79598	-2,2635	14.48768
003 Treated		-.64342	2,40804	-0,68861	1,42714	12.40410
004	.006193433	-1.91545	8.35395	-3.53331	-3.78774	-1.28635
005	.005364220	-3,91793	7,34762	2.76378	-4.60269	13.21183
016	,000668829	4.15288	6.01562	-1,56429	-16,83882	17.86702
017	.008250679	-4,56678	8.519033	6.28023	-7,72632	-0.92734
017 Treated		-1,28248	7.99465	6.00517	-7.79770	-0.40572
018	,004914450	-28,71566	11.30367	22,01584	17.54361	-40.84116
SSE	.000060	-1,28902	-.82426	0,53035	3.58826	-7.75217
SSW	,000366	0.54014	-3.49050	,86617	3.023462	-7.23585
TCN	.00716	0,56010	0.15754	0.42560	0.56661	-1.06328
TCS	.001012	-1,69622	0.85688	0.48874	0.504631	1.87257

Statistical tests. The effects of climatic inputs upon curve number were examined using a pair of statistical tests to determine the strength an individual parameter adds to the multiple regression model. Correlation was used to determine the amount of variation that was attributable to each variable. The r value was used instead of r^2 because it retained the positive and negative sign descriptor that is absent from r^2. The correlation coefficients were tested using the F-test to determine whether the correlation was truly significant or possibly attributable to chance. Further constraints were placed upon interpretation of the data by combining watersheds with common vegetation types. When correlation and significance were common throughout a negative type, inferences were drawn for that vegetative category.

Rainfall. More types of watersheds were significantly correlated with precipitation than any other factor. The strength of correlation increased with storm size. Insignificant correlation was observed on the grassland watersheds and one Utah juniper watershed had marginal effects ($.50 < p < .75$). The strongest correlation came from the Ponderosa Pine watersheds where the mean precipitation volume was the greatest. Physical causes of this trait probably stem from the tending for the streamside zone that often produces runoff to expand with increased rainfall (Hewlett and Nutter). This would also indicate that the most effective antecedent moisture is that which falls in the same storm as that which eventually produces runoff.

Rainfall intensity and Antecedent rainfall. Antecedent rainfall and rainfall intensity showed nearly identical strengths and weaknesses in relation to changes in curve number. Distinctive weakness was observed for both parameters in the Alligator Juniper and Ponderosa Pine watersheds. The correlation was significant but accounted for very little of the variation. This may result from the absence of a wide range of independent variables. The Utah Juniper, grassland and mixed conifer watersheds showed mixed results. This may be also due to a lack of sufficient inputs to activate the hydrologic processes to the point that they would produce significant correlation. The lack of sufficient inputs may be a moot point as other work (Simanton et al., 1974) indicate that these inputs do not occur historically. The assessment of this type of question could be better addressed on watersheds that have a longer period of record. Suitable watersheds for longterm studies would include Sierra Ancha, Tombstone and Great Basin Experiment Station. As more data is collected at Beaver Creek, the relationships may become more clearly defined if additional analysis is undertaken.

Interaction between rainfall intensity and antecedent rainfall. Significant correlation was observed between the cross product of rainfall intensity and storm runoff and curve number on the Utah Juniper watersheds. During dry periods, vertisols produce prominent cracks which swell shut when soil moisture levels increase. Open cracks add to surface retention capacity until they swell shut. This additional surface detention differs from pits and similar items because it varies with soil moisture content. Springerville soils have very low permeabilities (hydrologic soil group D) which predicate high runoff rates when surface retnetion is low. Runoff would increase with rainfall intensity if it were greater than the permeability rate after surface detention is satisfied. An increase in the runoff rate would elevate the percentage of rainfall that becomes runoff because less moisture can be absorbed by the soil. The lack of strong correlation between the cross product and dependent variable on the other watersheds logically follows from the above discussion. Vertisols activated the hydrologic processes occurring on watersheds 001, 002, and 003, provided surface retention of rainfall until the cracks swelled shut and left the impermeable soil profile with little means of abstracting large amounts of precipitation. Infiltration rates and transmission rates were low to very low. The soils on the other watersheds were not as prone to change during a multiple day storm because they lacked the dynamic properties caused by the high shrink swell potential of Springerville series. Only minimal surface cracking existed and the transmission rates more closely approximated the infiltration rates. This caused less change as the profile was wetted by a storm. When little change occurs between wet and dry conditions, insignificant coefficients representing this situation should be expected.

Table 7 displays some rather pronounced trends. The standard error of estimates for the Beaver Creek watersheds were rather uniform. No marked variation exists in the entire group of watersheds or in any vegetative cover grouping of watersheds. The Black River watersheds produced much lower standard errors of estimation than the Beaver Creek Pilot watersheds. When this was viewed in light of the low coefficients of variation that the Black River watershed regression equations produced, a point soon became clear. The variation in the curve number population after transposition by the channel runoff fraction was small. This should have been expected in light of the low standard errors in runoff generated by the runoff fraction model. The use of F tests and average percentage error of estimate methods to describe the utility of the regression models seemed rather mute in light of their apparent contradiction with the standard error of estimate. The use of the percentage error seemed to be impractical. This is probably due to the sensitivity of the curve number model at a point where the runoff volume is small. A similar observation was made by Hawkins (1975). The F test loses some meaning because the regression model was actually a combination of two models. The runoff fraction used to synthesize the ΔCN populations may have explained most of the variation in ΔCN prior to the actual application of the regression analysis.

Effects of Treatment

The three watersheds that were treated showed post-treatment changes in mean curve numbers. Watershed 001 showed an increase in mean curve number of 2.7 curve numbers. This difference was significant at the .95 level based on a t-test that compared the two means. The difference in curve numbers would be expected based on the work of Gifford (1973) which showed that infiltration rates commonly decline in areas that have had mechanical removal of pinyon juniper overstory.

Watershed 003 exhibited a decrease in mean curve number after treatment with herbicides. The mean curve number after treatment was 1.5 curve numbers lower than the pre-treatment regression residuals. This was significant at the 0.75 level. This difference in mean post-treatment curve number between Watersheds 001 and 003 may be ascribed to the differences in the land surface caused by treatment. The sprayed watershed had no soil disturbance due to treatment. The tree canopy was also left standing. These soil disturbance differences may have resulted in increased infiltration rates after treatment. The standing trees may be more effective in intercepting rainfall than the residual debris resulting from chaining. Watershed 017 showed the greatest effect from treatment. The mean curve number after treatment was depressed 9.0 curve numbers below pre-treatment levels. This depression may be as a result of windrowed slash acting as a barrier to delivery of runoff to a stream. The change of curve number seems to contradict the annual increases in annual watershed yield that were experienced since treatment. Possibly this may result from a higher base flow produced by increased infiltration and subsurface flow that was not seen as part of the runoff hydrograph.

Evaluation of Field Methods

The field estimates of curve number differed markedly from the least squares calculated values. The most obvious difference is that, with the exception of Watershed 017, the field estimates were much too high. Secondly, the variation between least squares curve numbers is not reflected in the field estimates which show a great amount of uniformity.

It is evident that the use of the existing methods for estimating curve number do not give reasonable results. Use of these methods without checking the results with gaged watersheds or infiltrometer studies will produce results that may be a poor estimate of reality.

Table 7. Comparison of field estimate curve numbers - vs. - least squares curve number.

Watershed	Predicted Curve Numbers	Actual Curve Number (Least Squares)
001	90.4	58.32
002	89.8	60.46
003	89.5	66.75
004	89.0	67.90
005	88	66.10
016	77	69.93
017	77	82.19
018	76	68.46

Table 8. Regression model correlation -- accuracy statistics.

Watershed		b_1	b_2	b_3	b_4	Multiple R^2	Standard Error	Multiple F	% significance
001	r	0.318	0.625	0.576	0.747	0.836	4.6439	6.38	
	F	1.3722	1.0008	2.6572	17.6728				
	% signif.	0.50<P<.75	.50<P<.75	0.90	0.999				0.99
002	T	0.408	0.481	.696	.708	0.844	5.5231	10.9	
	F	0.0671	0.0007	8.0471	12.0501				
	% signif.	P<.50	P<.50	0.99	0.995				0.99
003	r	0.646	0.346	0.483	0.676	0.889	5.2815	10.3	
	F	18.6306	0.4813	0.2109	11.7562				
	% signif.	0.999	P<.50	P<.50	0.999				0.99
004	r	0.832	-0.043	0.539	0.525	0.863	5.5025	20.2	
	F	40.5219	.4856	1.8881	.6393				
	% signif.	0.999	P<.50	0.75	P<.50				0.999
005	r	.762	.339	.213	.501	0.850	6.4747	13.0	
	F	31.8291	10.0477	0.2968	0.4374				
	% signif.	0.999	0.999	P<.50	P<.50				0.999
016	r	.942	-0.238	0.015	-0.189	0.983	5.6864	29.1	
	F	55.462	5.0932	4.0045	0.0022				
	% signif.	0.99	0.90	0.75	P<.50				0.99
017	r	0.926	0.118	-0.085	0.104	0.963	5.7515	54.8	
	F	120.9440	9.2141	5.8082	0.0447				
	% signif.	0.999	0.999	.995	P<.50				0.999

Table 8. (Continued)

Watershed		b_1	b_2	b_3	b_4	Multiple R^2	Standard Error	Multiple F	% significance
018	r	0.820	0.067	.036	0.208	0.991	5.6986	13.7	
	F	8.1903	14.4674	.9071	1.2891				
	% signif.	0.75	.75	P<.50	P<.50				0.75
SSW	r	-0.159	-0.058	0.014	0.134	0.261	2.096	.0274	
	F	0.4674	0.0160	0.6251	0.1254				
	% signif.	P<.50	P<.5	P<.5	P<.5				P<.5
SSE	r	0.599	-0.365	0.503	-0.203	0.702	1.8286	5.11	
	F	13.4530	2.8747	1.6558	0.9253				
	% signif.	0.999	0.95	0.75	0.5<P<0.75				0.99
TCS	r	.401	0.554	0.561	0.679	0.848	0.5077	4.48	
	F	7.0007	0.1270	.4879	8.5424				
	% signif.	0.975	P<.50	P<.50	0.99				.90
TCN	r	0.380	-0.367	0.457	0.308	0.574	0.4177	.491	
	F	0.0351	0.1012	1.8498	0.8751				
	% signif.	P<.50	P<.50	.50<P<.75	P<.50				P<.50

infiltration, it is not a measure of infiltration.

3. Many of the existing catalog values use even more subjective criteria than described above. Subjective terms such as good, fair and poor are coupled with descriptives such as woods and range, then assigned curve numbers according to hydrologic soil group. This type of practice, although expedient, must be viewed with scepticism.

Precipitation characteristics greatly affected dispersion of curve number populations. Precipitation affects runoff volume as a watershed begins to produce runoff from a fairly constant area near stream channels. As watershed wetness increases and the near-channel sources expand, precipitation volume becomes the most important factor influencing runoff. Precipitation intensity and antecedent storms, although significant at times on certain watersheds, lack consistency in producing runoff. The interaction of rainfall intensity and antecedent rainfall is important when surface storage fluctuates with changes in soil moisture.

Modifications of the curve number methodology produced more accurate results than the existing technology. Changes in the initial abstraction coefficient improved accuracy from a few percent to several orders of magnitude greater. The improvement was most noticeable on the watersheds with more permeable soils. The modified method was quite similar to the runoff fraction method when the initial abstraction approached zero and the storage factor became large. The modified curve number method had slightly greater accuracy than the runoff fraction method, because it could account for increasing proportions of rainfall becoming runoff as storm

SUMMARY AND CONCLUSIONS

The analysis of the data from selected Northern Arizona watersheds generated information which was summarized in some basic conclusions. Catalog values of curve numbers were generated for all watersheds studied. The catalog values for curve numbers at Beaver Creek showed insufficient dispersion to demonstrate the differences in watershed condition. Characteristics of the Black River Barometer Watershed catchments showed distincting differences between types of watersheds and minor differences between paired watersheds.

Error which is associated with this method of predicting runoff was quite high. Portions of this error are explainable, given rainfall characteristics, but a significant element remains random and unexplained.

The existing methods for assigning curve number coefficients to represent watershed conditions at Beaver Creek were inaccurate. The differences between estimated coefficients and least squares curve number were large enough to suggest that the catalog values should be used with a great amount of caution.

Potential problems which made representation of hydrologic condition with the existing system of ground cover, vegetation type and hydrologic soil group inaccurate include:

1. Discrete categories of soils which make large differences in coefficients from subjective selection criteria.
2. Reliance upon indirect methods of measuring soil surface characteristics. Although ground cover density has been shown to be a very important factor in controlling

size increased.

Use of the runoff fraction model was effective only on watersheds with low rainfall amounts. This situation precluded large scale expansion of the streamside zone producing runoff. The use of this model on the Beaver Creek watersheds would be ineffective because of the large initial abstractions which characterized most of those areas.

The effects of treatment on land condition as manifest in changes in curve number were detectable for all treated watersheds which produced runoff after treatment. The Utah juniper watershed, which was cabled, produced elevated mega curve number coefficients after treatment. The herbicide treated alligator juniper watershed produced lower curve numbers as a result of treatment. Finally, the strip cut Ponderosa pine watershed produced a lower post-treatment curve number population. Because the mean curve number residuals were compared after climatic data were considered as independent variables, the tests should not be markedly influenced by circumstances other than treatment.

Table 9. Effect of treatment

Watershed	$\bar{x}$	$\bar{y}$	n_1	n_2	t	$1-\beta$	Effect of Treatment
001	.000182	2.713	11	5	1.898	.95	CN Elevated
003	.00009	-1.499	11	5	0.95	.75	CN Depressed
017	.11945	-0.201	19	5	5.91	.99	CN Depressed

Ho: $M_1 - M_2 = D$

$$t = \frac{\bar{x} - \bar{y}}{\dfrac{n_1 \Sigma X_i^2 - \bar{X}^2 + n_2 \Sigma Y_i^2 - \bar{Y}^2}{n_1 + n_2 - 2}}$$

x_i = Observations of pre-treatment storms

y_i = Observations of post-treatment storms

D = Difference between means

n_1 = Number of pre-treatment observations

n_2 = Number of post-treatment observations

t = T statistic where $D = \bar{x} - \bar{y}$

$1-\beta$= Maximum level of significance

LITERATURE CITED

Brown, H. E. 1974. Opportunities in increasing water yields and other multiple use values in ponderosa pine forestlands. USDA Forest Service Research Paper RM 219. 36 pp.

Chiang, S. L. 1975. Prediction of flood volume from small humid region watersheds. Journal of the Hydrolics Division, Am. Soc. Civ. Eng. HY7:817-828.

Chow, V. T. 1964. Handbook of applied hydrology. Ven Te Chow, McGraw-Hill, Inc., New York. 1418 pp.

Gifford, G. F. 1973. Runoff and sediment yields from runoff plots on chained pinyon-juniper sites in Utah. J. of Range Management. 26:440-443.

Hawkins, R. H. 1973. Improved prediction of storm runoff in mountain watersheds. Am. Soc. Civ. Eng. 99(1R4):519-523.

Hawkins, R. H. 1975. The importance of accurage curve numbers in the estimation of storm runoff. Water Resource Bulletin 11(5):887-891.

Hewlett, J. D. 1967. A. hydrologic response map for the state of Georgia. Water Resources Bulletin Vol. 13, p. 4-20.

Leven, A. A. and P. J. Stender. 1967. Comprehensive hydrologic survey and analysis, Black River barometer watershed, Apache National Forest. Region 3, USDA Forest Service, Springerville, Arizona. 200 pp.

Ogrosky, H. O. 1960. Hydrologic technique in watershed planning. Transactions. Am. Soc. Civ. Eng., Special Soils Water Edition, 3(1).

Simanton, J. R., K. G. Renard and N. G. Sutter. 1974. Procedures for identifying parameters affecting storm runoff volumes in a semi-arid environment. ARS-W-1, USDA ARS Southwest Range Watershed Research Center. 12 pp.

Speigel, M. R. 1961. Theory and Problems of Statistics. Schaum Publishing Co., New York, 359 pp.

USDA. 1954, et sew. Soil survey manual, USGPO, Washington, D.C.

USDA. undated. Handbook of methods of hydrologic analysis, USGPO, Washington, D.C.

USDA. 1963. Nat. engineering handbook. Section 4, Hydrology, USGPO, Washington, D.C.

USDA. 1967. Soil survey Beaver Creek area, Arizona. USGPO, Washington, D.C.

Walker, C. H. 1970. Estimating the rainfall-runoff characteristics of selected small Utah watersheds, MS Thesis. Utah State University. 120 pp.

APPENDICES

APPENDIX 1

Hydrologic Soil Groups After NEH-4 Chapter 7

A. (Low Runoff Potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep well to excessively drained sands and gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High Runoff Potential). Soils having very slow infiltration rates when thorogghly wetted and consisting chiefly of clay soils with high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a slow rate of water transmission.

APPENDIX 2

Data Summaries

Symbols used in the following data presentation:

P:	Storm rainfall, inches
Q:	Storm hydrograph runoff, inches
P5:	Five day rainfall prior to storm, inches
P1:	One day rainfall prior to storm, inches
I60:	Maximum 60 minute storm intensity, inches per hour
CN:	Realized curve numbers, as calculated from P and Q
CNC:	Realized curve number corrected for antecedent rainfall (by SCS NEH-4 methods)
AMC:	Antecedent moisture condition as calculated by SCS NEH-4 Criteria from P5

The data summary does not include several events in Black River watersheds with P1 and P5 information missing.

Watershed 001

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
10 31 57	3.01	0.0547	0.86	0.00	0.50	47.55	47.55	2
9 12 58	2.54	0.0830	0.73	0.42	0.50	54.55	73.55	1
9 28 58	0.76	0.0815	1.38	0.44	0.76	85.35	94.17	1
9 2 60	0.77	0.0142	1.73	0.45	0.60	78.03	78.03	2
9 10 60	0.80	0.0030	0.00	0.00	0.80	74.17	87.58	1
7 16 61	0.92	0.0031	0.62	0.05	0.92	71.25	85.62	1
8 22 61	2.61	0.0970	0.58	0.18	0.98	54.61	73.61	1
9 8 61	0.91	0.0061	0.00	0.00	0.35	72.59	86.59	1
9 17 61	1.52	0.0733	0.13	0.00	0.68	68.82	84.41	1
9 28 62	0.62	0.0050	0.00	0.00	0.60	79.83	90.91	1
8 2 64	2.72	0.4007	0.40	0.19	2.33	65.50	81.75	1
8 3 64	1.65	0.4575	3.12	2.72	1.65	82.72	66.59	3
8 4 64	0.53	0.1350	4.77	1.65	0.52	93.29	83.94	3
8 23 61	0.89	0.0166	2.30	1.72	0.15	75.48	57.23	3
1 25 69	0.83	0.0264	0.20	0.20	0.06	78.50	90.25	1
8 26 71	1.14	0.0029	0.03	0.03	1.14	66.28	82.28	1
MEAN	1.38	0.0912	1.05	0.50	0.78	71.78	79.00	1.5
ST DEV	0.84	0.1384	1.34	0.80	0.56	12.09	12.70	0.8

N = 16

Watershed 002

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
8 22 61	2.63	0.1399	0.58	0.23	1.12	56.73	74.86	1
8 23 61	0.84	0.0181	2.38	1.78	0.32	76.97	58.97	3
8 2 64	2.99	0.5855	0.56	0.29	2.51	67.13	83.13	1
8 4 64	0.54	0.2016	4.94	1.40	0.50	95.12	87.69	3
9 12 58	2.79	0.1114	0.76	0.47	0.70	53.38	72.38	1
9 29 58	0.63	0.1977	1.30	0.38	0.63	93.33	97.77	1
9 2 60	0.78	0.0141	1.78	0.50	0.74	77.76	77.76	2
9 3 61	0.87	0.0070	0.00	0.00	0.29	73.82	87.41	1
9 17 61	1.74	0.2287	0.16	0.00	0.72	73.67	87.33	1
9 24 64	0.71	0.0074	0.00	0.00	0.43	78.06	90.03	1
9 25 64	0.48	0.0010	0.71	0.71	0.30	82.20	92.60	1
9 5 70	4.11	0.7667	0.53	0.47	1.39	59.02	77.02	1
8 3 64	1.40	0.6854	3.54	2.98	1.39	91.45	80.37	3
8 10 71	1.03	0.0029	0.74	0.00	0.63	68.64	84.32	1
MEAN	1.53	0.2119	1.28	0.65	0.83	74.81	82.26	1.5
ST DEV	1.14	0.2683	1.43	0.85	0.60	13.14	9.76	0.8

N = 14

Watershed 003

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
8 2 64	2.86	0.4645	0.55	0.29	2.38	65.58	81.79	1
9 2 60	0.75	0.0122	1.70	0.48	0.75	78.15	78.15	2
7 16 61	1.02	0.0088	0.61	0.03	1.02	70.79	85.39	1
8 22 61	1.43	0.0243	0.54	0.19	0.90	65.38	81.69	1
8 23 61	0.67	0.0101	1.96	1.42	0.26	79.83	79.83	2
9 8 61	0.89	0.0052	0.00	0.00	0.33	72.78	86.78	1
9 17 61	1.73	0.1730	0.00	0.00	0.75	71.30	85.65	1
9 12 58	2.87	0.1938	0.82	0.49	0.72	56.40	74.70	1
9 29 58	0.57	0.1429	1.31	0.38	0.57	92.74	97.58	1
1 25 69	0.81	0.0558	0.50	0.18	0.12	82.19	82.19	2
8 7 69	1.11	0.0078	0.00	0.00	1.11	68.56	84.28	1
8 26 69	0.84	0.0053	0.03	0.00	0.84	74.04	87.52	1
11 15 69	1.31	0.0124	0.27	0.27	0.36	65.60	81.80	1
9 5 70	3.91	1.2826	0.55	0.48	1.24	70.20	85.10	1
8 4 64	0.54	0.2798	4.75	1.34	0.51	96.81	91.21	3
8 3 64	1.33	0.5265	4.75	1.34	1.31	89.44	77.17	3
MEAN	1.41	0.2003	1.14	0.43	0.82	74.99	83.80	1.4
ST DEV	0.97	0.333	1.52	0.49	0.54	10.95	5.56	0.7

N = 16

Watershed 004

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
8 18 57	0.37	0.0155	0.62	0.24	0.28	89.73	96.36	1
8 3 64	0.62	0.0028	1.29	0.76	0.58	78.98	90.49	1
8 5 57	0.92	0.0035	0.16	0.16	0.72	71.43	85.71	1
8 3 58	1.10	0.0046	0.01	0.01	1.08	67.79	83.79	1
9 12 58	2.33	0.1252	0.74	0.30	0.60	59.75	77.75	1
9 29 58	0.11	0.0055	1.19	0.46	0.11	96.85	98.95	1
7 13 59	0.65	0.0038	0.54	0.54	0.65	78.54	90.27	1
9 2 60	2.53	0.1531	1.11	0.18	2.34	58.62	76.62	1
9 17 61	2.11	0.1267	0.50	0.00	0.81	62.89	79.89	1
8 27 63	0.75	0.0155	0.56	0.08	0.75	78.80	90.40	1
9 25 64	0.74	0.0081	0.65	0.65	0.49	77.44	89.72	1
7 26 68	0.89	0.0053	0.81	0.29	0.55	72.81	86.81	1
7 28 68	0.73	0.0089	1.64	0.25	0.70	77.92	77.92	2
8 2 68	0.68	0.0494	0.79	0.00	0.49	84.84	92.92	1
11 15 69	1.67	0.0108	0.33	0.33	0.41	58.98	76.98	1
9 5 79	4.74	1.9194	0.38	0.34	1.86	70.96	85.48	1
8 11 57	1.51	0.0089	0.00	0.00	1.27	61.20	78.60	1
8 4 68	0.80	0.1112	0.68	0.00	0.77	86.23	94.61	1
8 27 70	1.64	0.0008	3.02	0.60	1.49	56.17	36.17	3
8 20 57	0.74	0.0064	0.99	0.04	0.63	76.97	89.48	1
MEAN	1.28	0.1292	0.80	0.26	0.82	73.34	84.00	1.1
ST DEV	1.04	0.4243	0.66	0.23	0.54	11.37	13.17	0.4

N = 20

Watershed 005

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
10 31 57	3.12	0.1782	0.46	0.00	0.64	53.03	72.03	1
9 9 63	0.25	0.0098	0.06	0.00	0.21	92.71	97.57	1
8 2 64	0.67	0.0051	1.53	0.92	0.63	78.45	78.45	2
5 13 65	0.68	0.0008	0.40	0.40	0.33	76.06	89.03	1
8 16 65	0.89	0.0016	0.34	0.00	0.82	71.20	85.60	1
11 22 65	4.60	0.9487	0.38	0.38	0.44	57.87	75.87	1
8 14 66	0.82	0.0026	0.59	0.00	0.82	73.48	87.24	1
9 19 66	0.67	0.0042	0.00	0.00	0.44	78.14	90.07	1
12 5 66	2.02	0.4812	0.63	0.00	0.18	77.61	77.61	2
7 28 68	0.70	0.0070	1.56	0.24	0.67	78.22	78.22	2
8 2 68	0.44	0.0054	0.72	0.00	0.32	85.42	94.21	1
8 20 57	1.13	0.0015	0.69	0.02	1.01	65.77	81.88	1
8 15 58	1.13	0.0063	0.59	0.00	1.00	67.71	83.71	1
9 12 58	2.18	0.0403	0.70	0.35	0.55	55.66	74.33	1
9 2 60	2.71	0.0966	1.10	0.19	2.53	53.43	72.43	1
8 17 61	0.75	0.0024	0.51	0.00	0.60	75.19	88.19	1
8 19 61	0.66	0.0040	1.26	0.00	0.65	78.34	98.17	1
9 17 61	2.15	0.1430	0.37	0.00	0.82	63.21	80.21	1
8 12 63	0.43	0.0009	0.50	0.00	0.43	83.76	93.38	1
8 27 63	0.72	0.0092	0.58	0.08	0.72	78.26	90.13	1
11 15 69	1.73	0.0131	0.00	0.00	0.42	58.50	76.50	1
9 5 70	4.58	2.3715	0.36	0.33	1.78	78.14	90.07	1
9 25 64	0.70	0.0055	0.66	0.66	0.57	77.76	89.88	1
11 24 65	0.86	0.5303	3.73	2.69	0.26	96.37	90.12	3
MEAN	1.42	0.1947	0.70	0.25	0.71	72.77	87.34	1.2
ST DEV	1.20	0.5062	0.75	0.56	0.50	11.53	7.28	0.5

N = 25

Watershed 016

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
9 3 65	0.16	0.0069	1.37	0.99	0.25	95.31	98.43	1
9 18 56	2.01	0.2970	0.67	0.67	0.35	72.01	86.01	1
9 19 65	0.63	0.1216	2.68	2.68	0.35	90.57	78.85	3
11 22 65	7.62	3.4005	0.53	0.00	0.49	63.25	63.25	2
9 19 66	1.45	0.0005	1.46	0.06	0.70	58.98	58.98	2
9 5 70	6.62	2.2838	1.11	0.63	1.22	59.41	77.41	1
5 24 65	1.52	0.0414	0.00	0.00	0.20	65.88	81.94	1
7 27 67	1.58	0.0008	0.57	0.39	1.45	57.10	75.10	1
MEAN	3.44	1.4747	0.93	0.60	0.62	71.57	79.14	1.4
ST DEV	3.43	2.4496	0.84	0.85	0.43	14.32	12.64	0.7

N = 9

Watershed 017

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
8 16 63	0.42	0.0137	1.48	0.99	0.37	87.88	87.88	2
8 18 63	0.21	0.0013	1.51	0.10	0.20	91.93	91.93	2
8 17 63	0.09	0.0006	1.61	0.42	0.09	96.39	96.39	2
9 13 63	0.56	0.0142	0.74	0.00	0.28	83.78	93.39	1
8 30 63	0.13	0.0090	0.89	0.45	0.09	96.64	98.88	1
8 31 63	0.41	0.0224	1.02	0.13	0.24	89.45	96.22	1
7 17 65	0.22	0.201	0.90	0.90	0.14	94.95	98.31	1
9 3 65	1.81	0.1181	1.77	1.27	0.97	66.98	66.98	2
9 18 65	2.33	0.2788	0.44	0.44	0.62	66.64	82.64	1
11 22 65	5.14	2.3106	0.52	0.00	0.29	72.05	72.05	2
11 24 65	1.21	0.6434	5.13	3.47	0.31	93.40	84.21	3
8 17 66	0.75	0.0196	1.14	0.00	0.75	79.51	90.75	1
9 14 66	1.52	0.0047	0.01	0.00	0.69	59.87	77.87	1
9 19 66	0.92	0.0136	1.53	0.00	0.54	74.19	74.19	2
12 5 66	9.26	8.5100	0.92	0.00	0.20	93.78	93.78	2
8 29 67	1.18	0.0024	0.00	0.00	0.67	65.23	81.61	1
8 9 68	0.90	0.0012	1.85	0.03	0.74	70.69	70.69	2
8 10 68	1.57	0.0580	0.98	0.90	1.41	66.43	82.63	1
11 15 69	1.66	0.0271	0.41	0.00	0.19	61.78	78.89	1
8 6 70	1.85	0.0394	0.75	0.33	1.63	60.24	78.12	1
9 5 70	5.11	3.3708	0.77	0.61	0.91	83.99	2.49	1
8 29 63	0.45	0.0370	0.44	0.00	0.45	89.84	96.42	1
MEAN	1.71	0.7052	1.12	0.45	0.53	79.36	85.79	1.4
ST DEV	2.17	1.9357	1.03	0.77	0.41	13.10	9.81	0.5

N = 22

Watershed 018

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
9 18 65	2.04	0.0073	0.39	0.39	0.56	52.89	71.89	1
11 22 65	5.18	2.1009	0.54	0.00	0.40	69.14	69.14	2
11 24 65	1.19	0.5399	5.18	3.50	0.28	91.85	81.28	3
8 9 68	0.95	0.0002	0.09	0.04	0.82	68.50	84.25	1
9 5 70	5.33	2.1278	0.79	0.63	0.99	68.12	84.06	1
9 19 65	0.66	0.0181	2.37	1.98	0.34	81.66	64.98	3
MEAN	2.55	0.7990	1.56	1.09	0.56	72.02	75.93	1.8
ST DEV	2.13	1.0394	1.94	1.38	0.28	13.32	8.32	0.9

N = 6

Seven Springs West

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
7 31 64	0.58	0.0094	0.68	0.08	0.37	82.21	92.60	1
8 3 64	0.30	0.0015	0.88	0.10	0.30	88.67	95.83	1
8 5 64	0.60	0.0007	1.11	0.06	0.60	78.26	90.13	1
9 23 64	0.60	0.0014	0.75	0.02	0.09	78.80	90.40	1
7 10 65	1.00	0.0010	0.80	0.09	0.74	68.23	84.11	1
7 20 65	0.37	0.0008	0.77	0.00	0.29	85.72	94.36	1
7 23 65	0.50	0.0021	1.27	0.00	0.30	82.24	92.62	1
7 26 65	0.56	0.0092	1.51	0.00	0.38	82.75	82.75	2
7 30 65	0.30	0.0274	0.93	0.25	0.28	93.24	97.74	1
8 3 65	0.65	0.0274	0.97	0.00	0.65	83.28	93.14	1
8 9 65	0.17	0.0034	0.05	0.00	0.17	94.22	98.07	1
8 14 65	0.33	0.0025	0.57	0.04	0.21	87.90	95.45	1
8 16 65	0.12	0.0003	0.55	0.00	0.10	94.91	98.30	1
9 8 65	0.40	0.0016	0.00	0.00	0.08	85.23	94.11	1
9 18 65	0.70	0.0076	0.00	0.00	0.29	78.38	90.19	1
7 31 67	0.20	0.0001	1.48	0.43	0.10	91.31	91.31	2
8 9 67	0.50	0.0001	1.52	0.13	0.33	80.50	80.50	2
8 27 67	0.73	0.0006	0.75	0.00	0.57	74.50	87.75	1
9 16 67	0.75	0.0057	0.72	0.07	0.32	76.48	89.24	1
8 29 69	1.00	0.0025	1.48	0.26	0.48	69.13	69.13	2
MEAN	0.51	0.0052	0.83	0.07	0.33	82.80	90.39	1.2
ST DEV	0.24	0.0081	0.47	0.11	0.19	7.62	7.01	0.4

N = 20

Seven Springs East

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
7 31 64	0.58	0.0124	0.68	0.08	0.37	82.86	92.92	1
8 2 64	0.30	0.0012	0.88	0.10	0.30	88.49	95.74	1
9 14 64	0.34	0.0003	1.41	0.43	0.11	86.28	86.28	2
9 23 64	0.60	0.0161	0.75	0.02	0.86	82.98	92.99	1
7 10 65	1.00	0.0139	0.80	0.09	0.74	72.39	86.39	1
7 18 65	0.42	0.0045	0.52	0.35	0.24	85.78	94.39	1
7 20 65	0.37	0.0041	0.77	0.00	0.29	87.30	95.15	1
7 21 65	0.17	0.0003	1.17	0.40	0.50	92.82	97.60	1
7 23 65	0.50	0.0094	1.27	0.00	0.30	84.58	93.79	1
7 24 65	0.30	0.0023	1.30	0.60	0.82	89.05	96.02	1
7 26 65	0.56	0.0106	1.51	0.00	0.38	83.06	83.06	2
7 30 65	0.30	0.0012	0.93	0.25	0.28	88.49	95.74	1
8 3 65	0.65	0.0244	0.97	0.00	0.65	82.88	92.94	1
8 9 65	0.17	0.0016	0.05	0.00	0.16	93.62	97.87	1
8 14 65	0.35	0.0051	0.57	0.04	0.09	88.29	95.64	1
8 16 65	0.12	0.0004	0.55	0.00	0.10	94.99	98.33	1
9 8 65	0.40	0.0028	0.00	0.00	0.08	85.81	94.40	1
9 18 65	0.70	0.0093	0.05	0.00	0.29	78.82	90.41	1
7 26 66	1.35	0.0654	1.14	0.00	1.28	71.33	85.66	1
8 1 66	0.95	0.0030	0.71	0.16	0.73	70.51	85.25	1
7 31 67	0.20	0.0011	1.48	0.43	0.20	92.21	92.21	2
8 10 67	1.08	0.0053	1.43	0.48	0.76	67.48	68.46	2
9 16 67	0.75	0.0333	0.72	0.07	0.32	81.40	92.20	1
8 1 68	0.35	0.0018	0.70	0.58	0.35	87.05	95.02	1

Seven Springs East (Continued)

8 5 68	0.60	0.0063	1.35	0.00	0.28	80.82	91.82	1
8 29 69	1.00	0.0261	1.48	0.26	0.48	74.42	74.42	2
MEAN	0.54	0.0100	0.89	0.16	0.42	83.64	90.95	1.1
ST DEV	0.31	0.0142	0.44	0.20	0.29	7.29	7.11	0.4

N = 26

Thomas Creek South

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
7 18 65	1.00	0.0000770	0.61	0.06	0.45	67.10	83.10	1
7 23 65	0.55	0.0000843	1.10	0.07	0.44	78.89	90.44	1
7 18 64	0.85	0.0000924	0.27	0.00	0.79	70.66	85.33	1
7 25 64	1.12	0.0005666	0.32	0.20	0.80	65.25	81.62	1
8 11 63	0.81	0.0001042	0.17	0.08	0.78	71.69	85.84	1
8 16 63	0.93	0.0003545	1.22	0.07	0.93	69.20	84.60	1
9 10 63	1.31	0.0015891	0.13	0.03	1.11	62.28	79.28	1
8 20 66	0.65	0.0003928	1.25	1.15	0.55	76.48	89.24	1
9 20 66	1.92	0.0024477	0.35	0.02	1.06	53.02	72.02	1
7 25 70	0.90	0.0001787	2.19	0.79	0.81	69.63	49.95	3
8 15 70	1.22	0.0008966	0.49	0.44	1.08	63.53	80.53	1
8 16 70	1.05	0.0044288	1.69	1.29	1.00	68.82	68.82	2
MEAN	1.02	0.0009343	0.81	0.35	0.81	68.05	79.23	1.2
ST DEV	0.35	0.0013185	0.66	0.46	0.23	6.75	11.18	0.6

N = 12

Thomas Creek North

DATE	P (IN)	Q (IN)	P5 (IN)	P1 (IN)	160 (IN/HR)	CN	CNC	AMC
6 28 66	0.83	0.0003155	0.25	0.15	0.79	71.57	85.78	1
9 20 66	1.92	0.0024827	0.35	0.02	1.06	53.04	72.04	1
7 29 65	0.60	0.0003458	0.90	0.40	0.32	77.86	89.93	1
9 8 65	0.76	0.0002344	0.90	0.00	0.38	73.24	87.12	1
7 25 70	0.90	0.0002346	2.19	0.79	0.81	69.73	50.09	3
7 26 69	1.15	0.0010391	1.73	0.39	1.15	65.04	65.04	2
8 30 68	0.95	0.0005800	0.60	0.00	0.66	68.99	84.49	1
8 8 67	1.55	0.0017337	1.70	0.00	1.55	58.18	58.18	2
9 3 74	2.35	0.0009964	0.35	0.07	1.42	47.12	67.12	1
MEAN	1.22	0.0008846	0.99	0.20	0.90	64.97	73.31	1.4
ST DEV	0.59	0.0007797	0.70	0.27	0.42	10.14	14.24	0.7

N = 9