DESCRIPTIVE AND HYDROLOGIC CHARACTERISTICS OF THREE FORESTED WATERSHEDS IN OKLAHOMA'S KIAMICHI MOUNTAINS

By

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KIAMICHI MOUNTAINS

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CHAPTER I

INTRODUCTION

Southeast Oklahoma contains some two million hectares of commercial forestland (Figure 1). This section of the state constitutes the western extreme of the Ouachita Highlands and includes the Kiamichi mountain range (USGS, 1970). Consequently, much of the commercial forestland in this area lies within the watersheds that contribute to area rivers and lakes, via ephemeral and perennial streamflow. These natural waterways and reservoirs provide a variety of resources such as, spawning grounds and habitat for aquatic life, recreation and human consumption.

Commercial timber industry in this region began in the early 1900's. As the demand for wood and wood products increased, industrial forest policy has ultimately evolved to intensive even-aged management in order to meet this demand. Within the economic framework of even-aged forest management, harvesting methods are generally confined to clearcutting, followed by extensive site preparation.

Streamflow and precipitation are influenced by various natural elements. These elements, including climate, vegetation, soil and geologic structure, form the delicate balance of inflows and outflows of water as well as the physical charactersitics of forest watersheds (Yamamoto and Orr, 1972). Harvesting and site preparation can change these physical characteristics and alter the normal trend of water

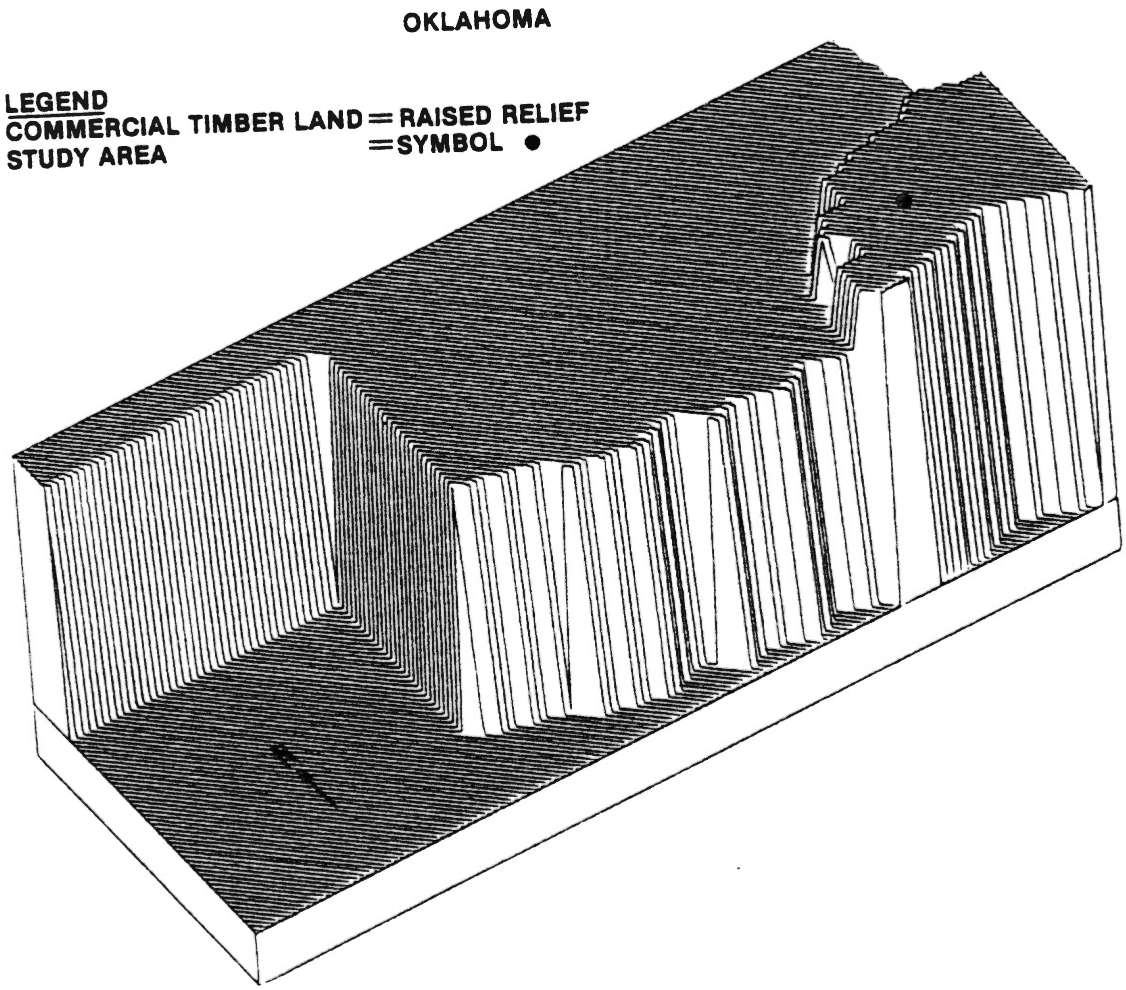

Figure 1. Commercial Forest Land in Oklahoma

movement. The result may be increased potential for sediment movement due to the change in streamflow behavior.

Forest watershed research in other parts of the country has shown that timber harvesting and site preparation can significantly change streamflow behavior. For instance, Douglas and Swank (1975) summarized that harvesting of mixed hardwood and pine on the Coweeta experimental watersheds increased streamflow in proportion to the amount cut. Kochenderfer and Aubertin (1975), also working at Coweeta, noted that streamflow duration increased with severity of the cut. Harr (1976) and Anderson et al. (1966), found that clearcutting and extensive site preparation significantly increased streamflow and peakflow rates in studies at Oregon and Hawaii, respectively. Such changes in streamflow, flow rates and flow duration can result in degradation of water quality by accelerating and prolonging the transport of suspended and dissolved solids and nutrients from the disturbed sites into waterways. Results of such research, coupled with increased environmental awareness, have focused new attention on forest management policy, and ultimately led to the classification of forest watersheds in Oklahoma as potential non-point sources of water pollution (Pope, 1977).

Precipitation and streamflow data constitute the core of hydrologic investigations (Hewlett, 1958) and are essential for an understanding of watershed behavior. Such an understanding and basic research data are lacking for Oklahoma forestland and yet could supply valuable input to conscientious forest managers. Thus, establishing a need for scientific research to evaluate commercial management of forest watersheds.

Objectives

This study was designed as part of a pretreatment watershed inventory. The primary objective of this research was to characterize the physical and hydrologic parameters of three similar, undisturbed forest watersheds in southeast Oklahoma, in order to evaluate change in these paramaters due to future harvesting. Secondary objectives were:

1. To determine if significant correlation of streamflow exists between watersheds.
2. To graphically present and compare precipitation - streamflow relationships between watersheds.
3. To identify significant interaction of watershed characteristics with streamflow.
4. To construct and compare storm hydrographs for selected storms.
5. To develop and compare mathematical models for estimating streamflow.
6. To provide basic hydrologic data for future studies concerning forest watershed management.

Definitions

The following definitions (Chow, 1964) are presented to insure that use of technical terms in this study, is consistant with current literature, and to avoid possible misunderstanding by the reader.

<u>Gross precipitation</u> is the total amount of precipitation as measured in the open or above the vegetative canopy. <u>Net precipitation</u> is that quantity actually reaching the ground; it is the sum of throughfall and streamflow. The remainder is termed <u>interception loss</u> and is the part of gross precipitation retained by the vegetation or evaporated into the atmosphere. <u>Throughfall</u> is the part of net precipitation falling directly through the vegetative foliage, including drip water from wetted leaves,

twigs and stems. Stemflow accounts for the remainder of net precipitation and reaches the ground by running down stems. Effective precipitation is that quantity contributing entirely to streamflow. The various components of precipitation are expressed either as a total amount (cm) or an intensity (cm/hr).

Streamflow is the total flow reaching the downstream end of a drainage basin. Like precipitation, streamflow is expressed as a total amount or an intensity, and has several components. Overland flow is that part of streamflow that travels over the land surface to the stream channel. Subsurface flow is that part of precipitation which infiltrates the soil surface and moves laterally to the stream channel as unsaturated (capillary) flow or saturated flow above the main groundwater table. Baseflow is lateral subsurface flow but is derived from deeper percolation of infiltrated water and may enter the permanent saturated groundwater before discharging into the stream channel. Lag-time is the difference (in hours) between peak rainfall and peak runoff. Time to peak is the time (in hours) from the beginning of rainfall to peak runoff (Viessman et al., 1977).

CHAPTER II

REVIEW OF LITERATURE

Small experimental watersheds have become the standard tool for evaluation of management practices on forested catchments. A study by Rothacher et al. (1967), summarized that hydrologic data collected from small, undisturbed forested watersheds provides the basis for determining changes that occur as a result of planned logging. Johnston and Doty (1972) suggested that watershed studies should determine whether or not sufficient correlation exists between watersheds so that the expected change in streamflow due to treatments can be detected. Hewlett (1978) and Orr and VanderHeide (1973) also identified the need for pretreatment inventory of hydrologic data to expose the effects of future land use activities on forested catchments.

Results from studies using experimental watersheds show that generally, a relationship exists between precipitation and streamflow and between contiguous watersheds that can be defined for a given set of conditions. Using three undisturbed watersheds in the Douglas-fir region of the Oregon Cascades, Rothacher et al. (1967) concluded that amounts and rates of streamflow are largely a direct reflection of rainfall patterns. Correlations with rainfall and total streamflow, rainfall and peakflow and rainfall and lowflow were high (.90) for all three study sites. Correlations were also high for comparisons of one individual watershed response to another: 96-97 percent of streamflow variation was explained by measured flow from the other two, respectively. The streamflow response of these watersheds is considered representative of the region and the variation in response is believed to be consistent.

A study in Utah's Wasatch mountains, by Johnston and Doty (1972) compared precipitation and streamflow data collected from two undisturbed, forested catchments. Aspen was the dominant tree species with Spruce and Fir accounting for three percent of the vegetation. Analysis of five years of data showed the West watershed generating nearly twice as much streamflow as the East. A linear regression model using the East and West watersheds as the independent and dependent variables, respectively, produced an R-square value of .98 for estimating annual flow on the West watershed, indicating close correlation of streamflow between the two.

Hewlett (1978) collected precipitation and streamflow data from two southeast Piedmont watersheds in Georgia for a period of about a year. Both watersheds were predominantly loblolly pine and representative of the Piedmont region. Monthly streamflow for each watershed was determined and a coefficient of correlation for streamflow was calualated. Although each watershed produced different monthly yields of streamflow, they were closely correlated with an R-square value of .98.

In most hydrologic investigations involving experimental watersheds, study sites are selected for their capacity to represent the local region. However, when comparing streamflow behavior between watersheds there remains a dissimilarity of response to precipitation even though there is close correlation. Variation between experimental units can often be attributed to unique physical characteristics of individual watersheds (Yamamoto and Orr, 1972) and the interaction of precipitation and streamflow with vegetative, edaphic, climatic, biotic and geologic elements (Hewlett, 1958). An understanding of watershed behavior necessitates an investigation of these characteristics and interactions because of their influence on the hydrologic process, from which streamflow is a product.

Precipitation is the stimulus for all hydrologic activity. Thus, it is important to examine the pathways that control the volume and intensity of precipitation reaching the forest floor. Influence by forest vegetation on precipitation, and untimately streamflow, depends on the type and distribution of vegetative canopy. Forest type was shown by Swank and Miner (1968) to be a factor influencing streamflow patterns on two southern Appalachian watersheds in North Carolina. Annual streamflow was observed to decrease significantly when a hardwood forest was converted to pine. This principal was previously demonstrated in a similar study by Hewlett (1958). Decreases in streamflow were attributed to an increase in interception due to greater canopy storage capacity of conifers. Voigt (1960) identified canopy interception as a factor in reducing streamflow, but noted that interception was a function of rainfall intensity. He found interception to vary from 100 percent of gross precipitation in very low intensity storms, to 10 percent in high intensity storms. Hewlett and Fortson (1977) further investigated the influence of rainfall intensity on streamflow. They determined that although high intensity storms decreased interception and increased total streamflow, they had little if any effect on the rate of flow.

Once precipitation reaches the forest floor as throughfall and stemflow, it becomes potential streamflow and is subject to influence by other natural elements. Undisturbed forests have a floor of accumulated organic debris that readily accepts falling water and acts as a barrier to soil water evaporation (Rowe, 1955). This surface layer has a marked effect on streamflow by influencing infiltration, surface flow and soil moisture content. Undisturbed forests in western Oregon are characterized by extremely high rates of rainfall infiltration (Harr, 1976). Due to dense forest floors, the top meter of soil is able to transmit all precipitation during most storms regardless of intensity or amount. The influence of forest litter was also demonstrated by Lowdermilk (1930). He found that removal or disturbance of the litter layer enhanced surface flow by exposing bare ground to soil particles suspended in runoff which ultimately sealed soil pores. Chapman (1948) noted the same general result from litter removal. However, he suggested that soil compaction, from falling rain, was responsible for reduced infiltration.

Because of extremely high infiltration rates, surface flow on forest land is generally considered nonexistant. This leaves subsurface flow and direct channel interception as the primary source of streamflow (Harr, 1976). The relative insignificance of surface flow in undisturbed forests was also demonstrated in watershed studies by Hoover and Hursh (1943), Whipkey (1965) and Pierce (1967). Undisturbed forest soils, in addition to high infiltration rates, lend themselves to further percolation of water through micro and macro pores resulting from root and animal activity. Aubertin (1971, p. 3) stated that "root and animal activity within natural forest soils form a network of relatively large, continuous, interconnected channels that serve as pathways for rapid movement of free water into and through soil profiles". Beasley (1976) and Dryness (1969) further supported rapid subsurface flow and concluded that movement of soil water was initiated soon enough after rainfall began to contribute appreciably to peak flow as well as total streamflow. In contrast, Dunne and Black (1970) determined that direct channel interception was responsible for most streamflow and peak flow rates since no overland flow occurred and subsurface flow was observed to be too slow for any significant contribution to the hydrograph. Freeze (1972) provided theoretical support for the Dunne and Black study, using a mathematical model to simulate runoff for rainfall events on hypothetical upstream source areas. It should be noted however, that Beasley's study was conducted in a typical upper coastal plain area with highly permeable sandy loam soils. Conversely, Dunne and Black collected data from a small watershed in Vermont, which is characterized by poorly drained valley bottoms and seeps. The contrasting results of these studies demonstrates the need to consider the soil type when characterizing streamflow on forested watersheds.

Previous research has shown there is a seasonal effect to be considered when explaining streamflow variation on forested watersheds. A study by Rogerson (1976) showed evapotranspiration, being a function of season, significantly influenced streamflow. Nearly all storm runoff from three undisturbed forested watersheds in central Arkansas, occurred from November through June when evapotranspiration was lowest. From June through October, during maximum evapotranspiration, soil water deficits increased rapidly and most precipitation contributed to soil water recharge rather than streamflow.

The amount of soil moisture or antecedent condition varies, not only by season but by storm frequency. Anderson et al. (1966), found antecedent moisture condition to be significant in explaining streamflow variation between two similar watersheds in Hawaii. Total rainfall seven days before measured storms was used as the index. Consequently, 22 percent of streamflow variation was explained by antecedent conditions prior to the storm.

Summary

A review of current literature shows that although streamflow is initiated by precipitation, it is controlled and directed chiefly by processes operating beyond the stream channels. This alone seems sufficient to justify a detailed study of the means by which precipitation is transformed into streamflow.

The volume of streamflow represented by the hydrograph at any one point is comprised of four basic parts: direct channel interception, surface flow, subsurface flow and base flow (Viessman et al., 1977). In order to understand the relationship between precipitation and streamflow, and general behavior of forest watersheds in southeast Oklahoma, an investigation of streamflow components and the influence of natural elements on the hydrologic process seems warranted.

CHAPTER III

METHODS AND MATERIALS

Study Area

The study area consists of a 1000 hectare forested watershed located approximately 13 km southeast of Clayton, Oklahoma (Figure 2). This watershed serves as the major drainage to Clayton Lake Reservoir via ephemerial and perennial streamflow. From this major drainage basin, three small headwater catchments were selected and instrumented to monitor hydrologic parameters. Hereafter, the experimental units will be referred to as Watershed 1, Watershed 2 and Watershed 3.

Watershed Characteristics

The experimental watersheds are relatively undisturbed, roadless areas and share similar physical characteristics (Table I). All three watersheds reflect past "high grade" harvesting. However, observations of stumps indicate that such activities occurred 20 - 25 years prior to this study.

The drainage system of each watershed consists of one or two well defined stream channels with several poorly developed tributaries. Basin configuration is similar for Watersheds 1 and 2, with Watershed 3 exhibiting a longer more narrow upstream reach (Figures 3, 4 and 5). All streamflow on these watersheds is ephemerial and results from storm

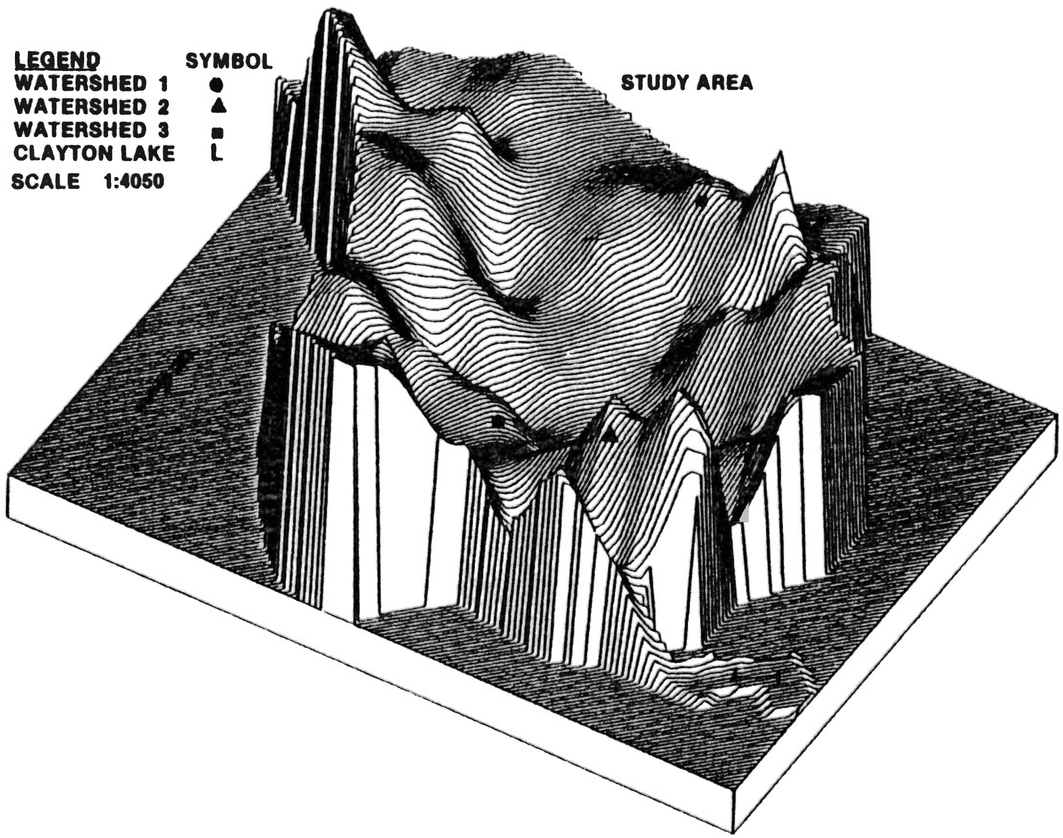

Figure 2. Study Area - Clayton Lake Watershed

ERRATA

This Errata Sheet replaces TABLE 1 on page 14; the replacement was made on September 16, 1988.

TABLE I

WATERSHED CHARACTERISTICS

Parameter	Units of Measure	Watershed 1	Watershed 2	Watershed 3
Area	Hectares	7.86	6.07	7.71
Elevation	Feet			
Maximum		418	270	378
Minimum		335	213	286
Aspect		NNW	S	SW
Slope (average[1])	Percent	16	12	14
Crown Cover[2]	Percent	90	86	88
Ground Cover	Percent			
litter		86	83	72
rock		3	8	7
tree		6	5	6
erosion		1	0	1
stream channel		4	4	13

[1]Change in elevation divided by watershed length.
[2]Crown cover was estimated from aerial photographs.

TABLE I

WATERSHED CHARACTERISTICS[1]

Parameter	Unit of Measure	Watershed 1	Watershed 2	Watershed 3
Area	Hectares	8.38	6.52	5.10
Elevation:	Feet (Meters)			
Maximum		1370(418)	1320(402)	1240(378)
Minimum		1140(348)	1140(348)	900(274)
Aspect		NW	SW	NW
Slope (average)	Percent	14	18	21
Crown Cover[2]	Percent	90	86	88
Surface Conditions:	Percent			
litter		86	81	76
rock		3	8	6
tree		6	5	6
erosion		1	0	1
stream channel		4	6	11

[1]Data were collected from sample points at 20 meter intervals on a random grid.

[2]Percent crown cover was estimated from aerial photographs.

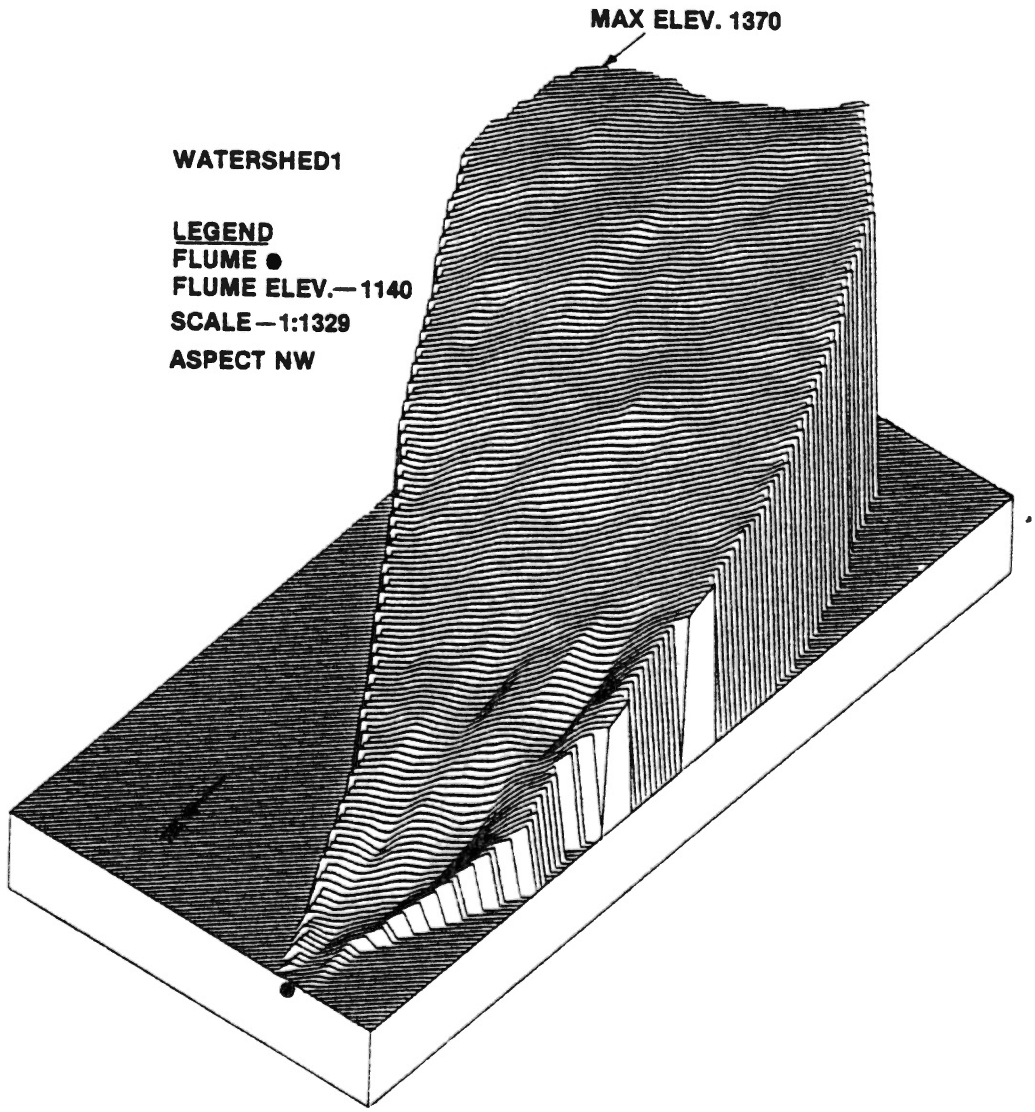

Figure 3. Watershed 1

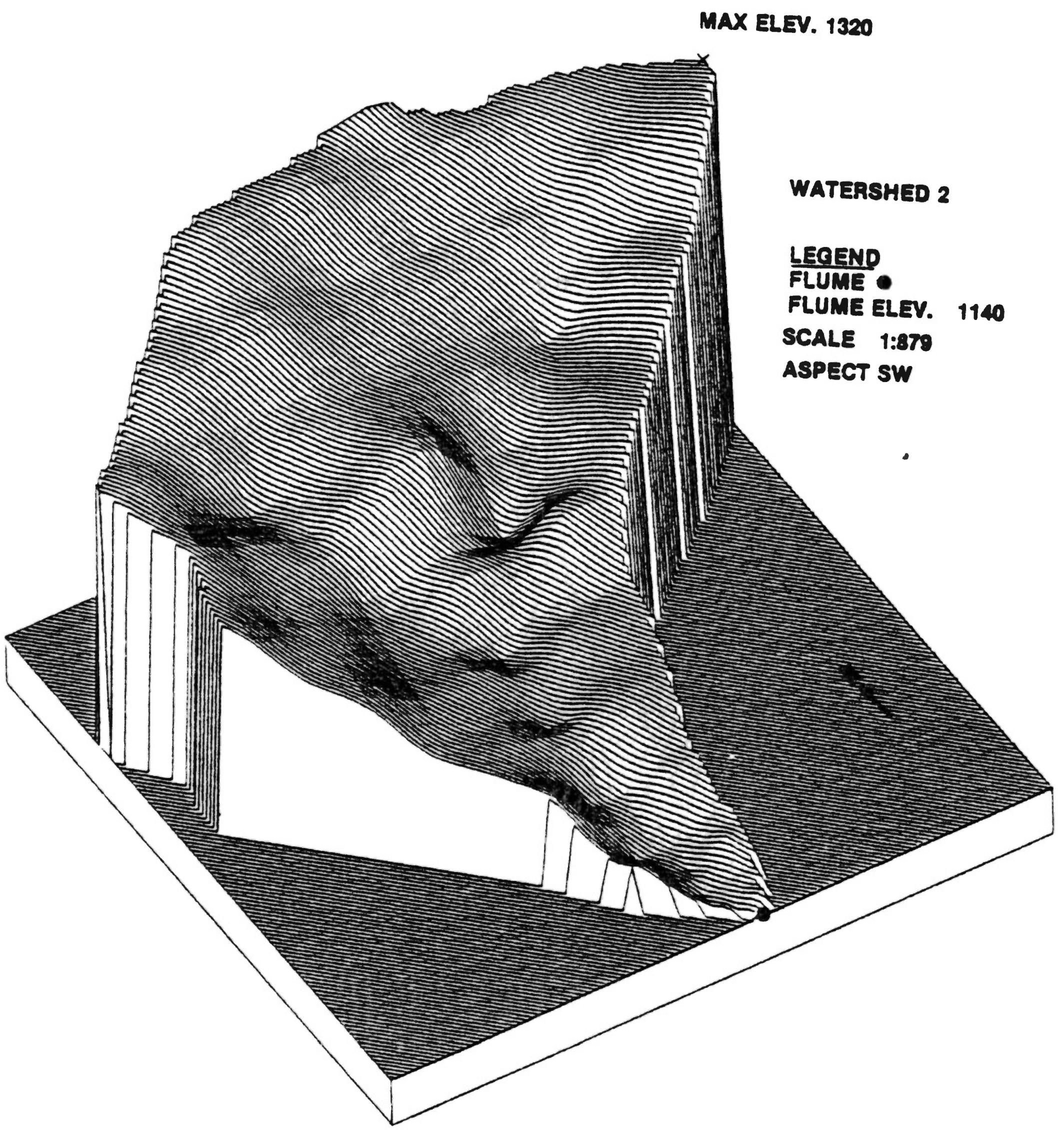

Figure 4. Watershed 2

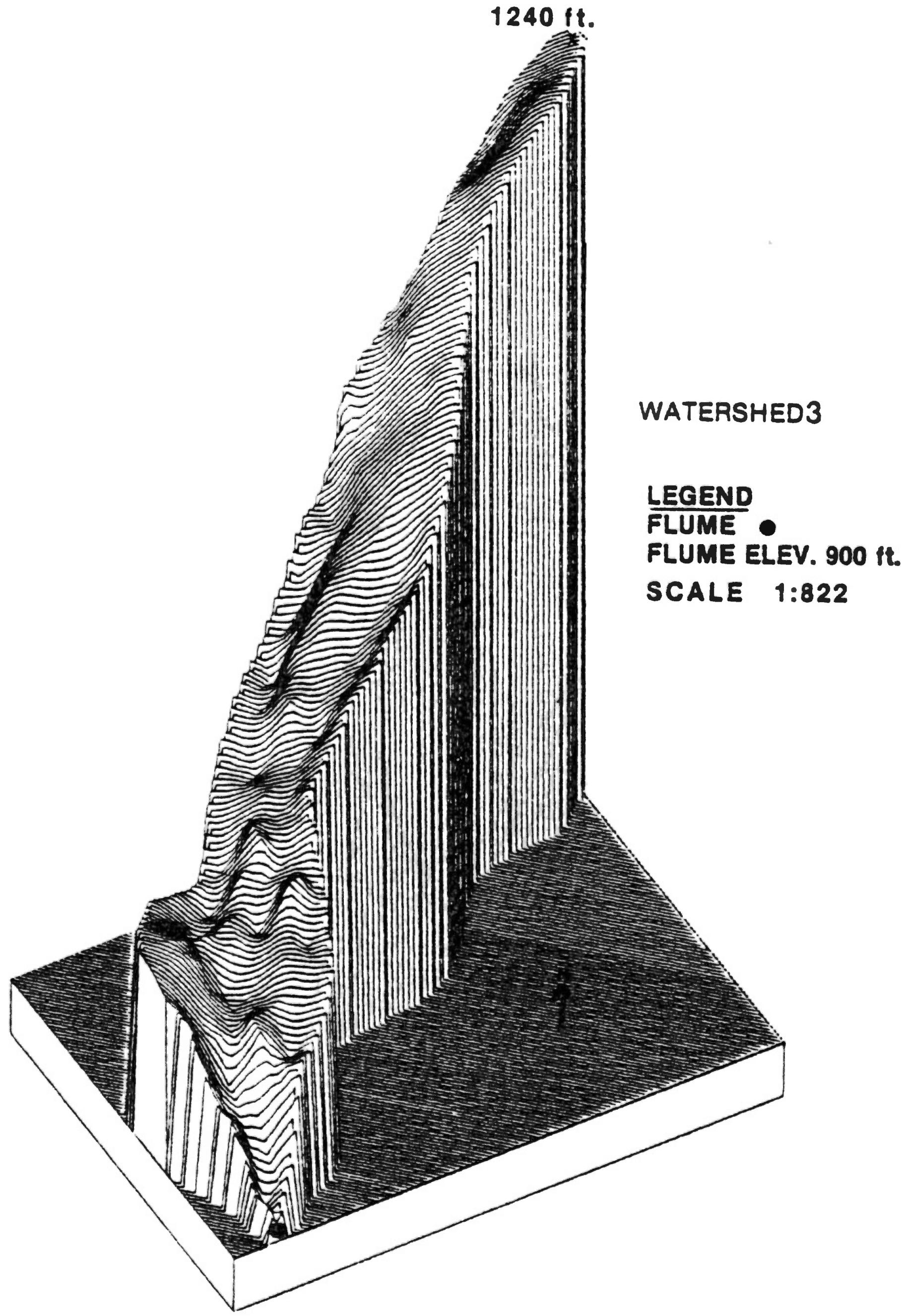

Figure 5. Watershed 3

runoff. Some base flow occurs; however, it is limited to brief periods of soil saturation.

Climate

Climate at the study area is temperate and typical of the lower coastal region. Winter and spring weather patterns are primarily influenced by frontal systems moving in from the Pacific coast, while summer storms are generally convective in nature (Donn, 1975). Prevailing winds are south, southeast bringing summer moisture from the Gulf of Mexico.

Most precipitation occurs in the spring months from March through June. Rainfall is the primary form of moisture with a mean annual amount of 119.5 cm (Bain and Waterson, 1979). A comparison of mean monthly rainfall from 1954-1979, to that during the period of study, is given in Figure 6.

Mean annual temperature for the study area is 17.2^{o}C (Bain and Waterson, 1979). Extremes may reach 40+^{o}C in the summer months and below zero in the winter. However, periods of extreme temperatures are usually brief and infrequent (Donn, 1975).

Vegetation

Primary vegetation consists of a shortleaf pine (Pinus echinata) forest with a mixed hardwood understory. Hardwoods include a typical oak-hickory (Quercus-Carya) association, elm (Ulmus) and cottonwood (Populus deltoides). The pine is a mixture of scattered old growth and dense stands of saplings from natural regeneration. Thus, age-classes are poorly distributed and the watersheds in general are understocked.

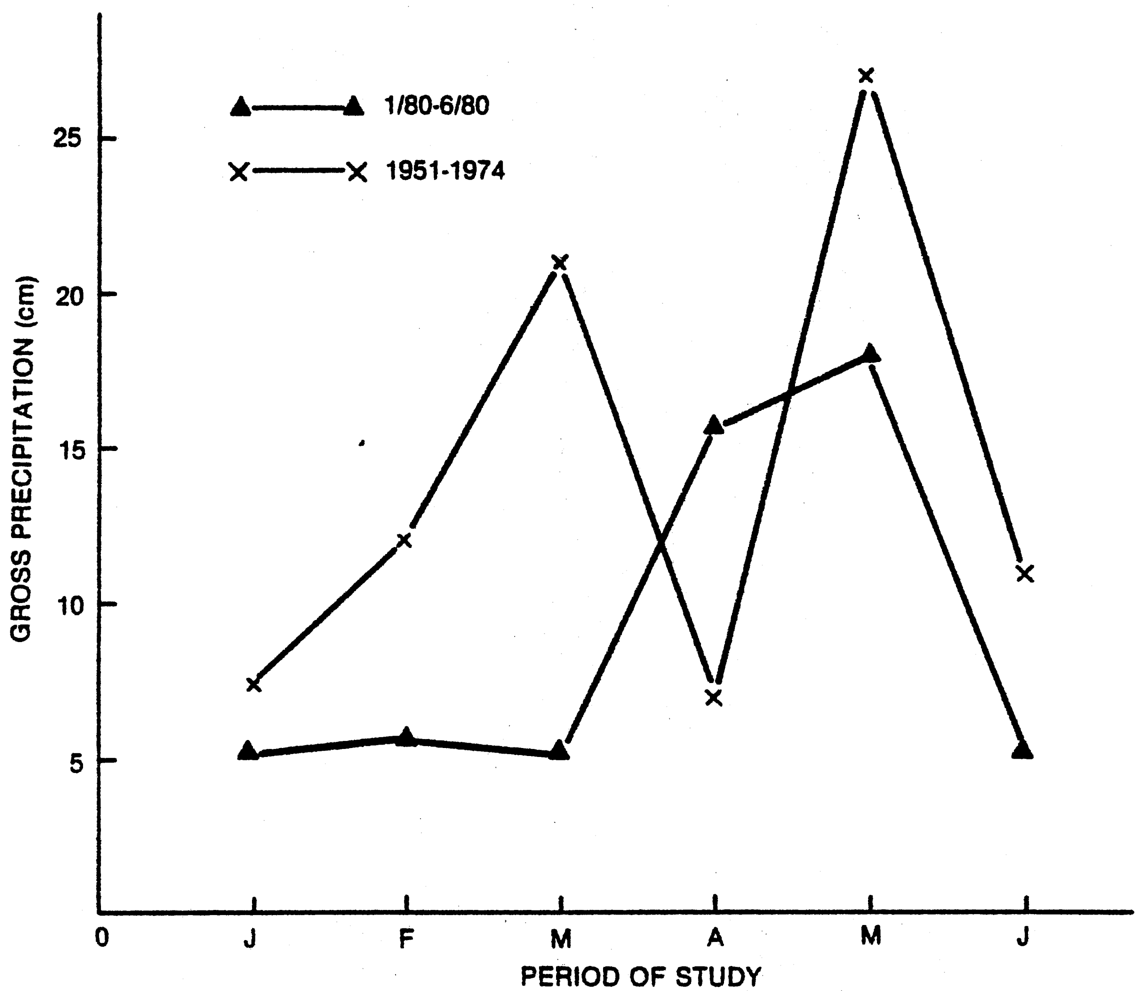

Figure 6. Comparison of Mean Monthly Rainfall

Timber inventory data for the watersheds are provided in Tables II, III and IV.

Soils

Principal soil type on all three watersheds is the Carnasaw series (Bain and Waterson, 1979). This soil was formed from weathered shales and sandstone and is relatively deep and well drained. Permeability rates are classified as slow (0.15 to 0.45 cm/hr) due to the clay content. Carnasaw soils are geographically closely associated with the Pirum, Clebit and Stapp series, all of which have less clay in the control section than Carnasaw. Direct observations on all three watersheds identified frequent occurrences of Pirum and Stapp soils; however the Carnasaw series was dominant. Generally, the A horizon is 0 - 18 cm and consists of a stoney, sandy loam. The B horizon is 18 - 90 cm and is predominantly clay.

Carnasaw and the associated soil series make up 53 percent of Pushmataha County soils and are classified as medium, with respect to woodland use (Bain and Waterson, 1979). The percentage of stones, a high shrink swell and relatively low rate of percolation are the major limitations for site potential.

Hydrologic Inventory - Precipitation

Gross precipitation was measured throughout the period of study by two Belfort universal raingages. Gages were equipped with 12 inch dual traversing pens and 48 hour gears. The 48 hour time frame was selected to reduce error in time increment interpretation from the charts. Since only two recording gages were available for this study, they were located

TABLE II

TIMBER INVENTORY OF WATERSHED 1[1]

Diameter Class (cm)	Trees/ha		Basal Area (M^2/ha)	
	Pine	Hardwood	Pine	Hardwood
5	132.00	37.09	1.59	0.46
10	16.56	19.87	0.82	0.98
15	22.08	7.36	2.46	0.82
20	19.87	0.83	3.94	0.16
25	11.13	0.53	3.44	0.16
30	2.58	0.87	1.15	0.39
35	1.08	-	0.66	-
40	-	-	-	-
45	0.49	0.33	0.49	0.33
50	0.13	0.13	0.16	0.16
55	0.11	-	0.61	-
Total	206.03	66.99	15.32	3.47

[1]Data were collected from sample points at 20 meter intervals on a random grid.

TABLE III

TIMBER INVENTORY OF WATERSHED 2[1]

Diameter Class (cm)	Trees/ha		Basal Area (M^3/ha)	
	Pine	Hardwoods	Pine	Hardwoods
5	136.00	37.09	1.68	0.46
10	15.38	18.55	0.77	0.92
15	4.12	8.24	0.46	0.92
20	2.32	4.64	0.46	0.92
25	2.47	1.98	0.77	0.61
30	2.75	0.34	1.22	0.15
35	1.50	0.51	0.92	0.31
40	3.08	0.19	2.45	0.15
45	0.61	-	0.61	-
50	0.12	-	0.15	-
55	-	-	-	-
Total	168.35	71.54	9.54	4.44

[1]Data were collected from sample points at 20 meter intervals on a random grid.

TABLE IV

TIMBER INVENTORY OF WATERSHED 3[1]

Diameter Class (cm)	Trees/ha		Basal Area (M^3/ha)	
	Pine	Hardwoods	Pine	Hardwoods
5	98.93	37.09	1.22	0.46
10	18.55	15.46	0.02	0.77
15	4.12	15.11	0.46	1.68
20	4.64	11.59	0.92	2.30
25	3.46	5.94	1.07	1.84
30	1.37	1.03	0.61	0.46
35	1.01	0.76	0.61	0.46
40	0.58	0.58	0.46	0.46
45	0.76	-	0.77	-
50	0.12	0.12	0.15	0.15
55	-	-	-	-
Total	133.54	87.68	7.19	8.58

[1]Data were collected from sample points at 20 meter intervals on a random grid.

at Watersheds 1 and 3, respectively. Rainfall on Watershed 1 was assumed to be equal to that on Watershed 2, since the two watersheds were in close proximity and at approximately equal elevations. Both gages were placed in open areas to eliminate interference from forest vegetation. As a precaution against equipment failure, a four inch standard rain can was installed at both recording gage sites. Standard cans were charged with oil and antifreeze to prevent evaporation and freezing.

All instruments were serviced within 48 hours of a rainfall event. Standard can readings were made in the field and used as a check for gross precipitation on the recording gages.

Hydrologic Inventory - Streamflow

Stage was measured on each watershed with a Belfort stage recorder. Stage recorders were mounted on four-foot, flat surfaced H flumes. H flumes were selected to take advantage of the critical depth - minimum energy phenomenon, i.e. to provide critical velocities at all depths of stage since changes in stage are approximately equal to changes in specific energy (Chow, 1959). For a given energy then, discharge can be related to depth of flow by the equation: $q = \sqrt{2g(y^2E-y^3)}$, where q = discharge per unit area, y = depth of flow, g = acceleration constant and E = specific energy.

Flumes were installed on each watershed at a downstream control section which provided enough change in elevation to eliminate the possibility of tailwater. Wing walls were erected at 45 degree angles from the flume approach pads to direct all flow through the control section. Control section area and zero level on the stage recorder charts were established by a series of measurements, with precalibrated rods, at several points along the flume throat.

Stage recorders were serviced after each storm, and streamflow (discharge) was determined, using stage as the input parameter. Three equations, corresponding to three levels of flow, were employed to equate stage to discharge cfs (Gwinn and Parsons, 1976). The empirical equations are as follows:

1. Lowflow (<0.1 ft)

   $$Q = A_o\ (2B_o + B_1\ H)\ H\ (H - 0.01)^{A_1}$$

2. Transition - flow (0.1 - 0.2 ft)

   $$Q = (K_o\ B_o + K_1\ B_1\ H)\ \sqrt{2g}\ H^{3/2}$$

3. Main - flow (<0.2 ft)

   $$Q = [(E_o + E_1\ D)\ B_o + (F_o + F_1\ D)\ B_1\ (H + V^2/2g)]\ \sqrt{2g}\ (H + V^2/2g)^{3/2}$$

   where Q = discharge cfs, A = area ft, H = stage ft and V = velocity fps.

Values for equation constants for each watershed are given in Table V. Explanation of all equation terms and symbols are given in Table IX, Appendix A.

From these equations, a discharge rating table was developed for each flume, providing a value of Q at depths of stage ranging from 0.01 to 4.0 feet and incrementing by 0.01 ft. Rating tables are given in Appendix A, Tables X, XI and XII.

Quantitative Analysis

Rain gage and hydrograph charts were analyzed in the laboratory, using a Lascio digital planimeter. Amounts of precipitation and

TABLE V

VALUES FOR DISCHARGE EQUATIONS

Coefficient	Watershed I	Watershed 2	Watershed 3
A_o	3.1400	3.1400	3.1400
A_1	0.4860	0.4860	0.4860
B_o	0.20881	0.20085	0.20007
B_1	0.40817	0.49883	0.50004
K_o	0.7132	0.7133	0.7133
K_1	0.6158	0.6059	0.6044
E_o	0.6120	0.6120	0.6120
E_1	0.2090	0.2090	0.2090
F_o	0.4090	0.4090	0.4090
F_1	-0.0240	-0.0240	-0.0240
D[1]	1.0000	1.0000	1.0000

[1]If $D > 1.0$ ft., use $D = 1.0$ ft.

streamflow were determined from the charts at 15 minute intervals throughout each storm. Precipitation data were keypunched and entered into the rainfall reduction program (Shanholtz and Burford, 1967), which generated by storm: gross precipitation (P), maximum precipitation intensity (MPI) and storm duration (SD).

Streamflow data were also keypunched and entered, along with the respective rating tables, into the runoff reduction program (Shanholtz and Burford, 1967), which generated by storm: total streamflow (TS), flow duration (FD) and maximum flow rate (MFR).

Other variables measured were: mean maximum temperature prior to storm beginning (T) and days between runoff producing storms (DY). Two indices were also calculated in an attempt to measure antecedent conditions: API1 = P/DY(T) and API2 = P(SD)MPI/DY(T). All variables were converted to their metric equivalent, and are given by watershed, in Tables XIII, XIV and XV, Appendix B.

Statistical Analysis

Data were compiled and sorted by watershed and storm, using Statistical Analysis Systems (SAS) programming language (Barr and Goodnight, 1979). SAS procedures were further employed to generate: correlation coefficients for streamflow and precipitation, and for streamflow between watersheds, stepwise regressions to identify sources of variation in streamflow and general linear models to provide equations for streamflow estimation. Independent variables considered in the stepwise regressions were: total streamflow, gross precipitation, days between storms, temperature, storm duration and both antecedent indices.

Several linear models were developed for each watershed, with streamflow as the dependent variable in each case. Independent variables were selected from the stepwise regressions, based on their significance (at the 0.05 level) in explaining streamflow variation. Each model generated the coefficients for and equation to estimate streamflow, along with the statistics. By using several models, each with different independent variables or combinations of variables, it was presumed that a best fit model would be obtained.

CHAPTER IV

RESULTS AND DISCUSSION

Precipitation

Hydrologic data were collected throughout a six month period, beginning January 1 and ending June 30, 1980. Twenty-three individual storms were measured during this period, ranging in magnitude from 0.17 to 7.32 cm. Gross precipitation for the entire period of study averaged 54.6 cm, with total amounts of 50.8 and 58.4 cm occurring at Watersheds 1 and 3, respectively.

Since two rain gages at different locations were used, a linear regression model was run, regressing precipitation at Watershed 1 with precipitation at Watershed 3. This procedure produced an R-square value of .90 (Table VI). Testing the hypothesis that the slope of this regression line was equal to one, yielded a "t" value less than the tabulated t at the 0.05 significance level. The conclusion was; not to reject the hypothesis. However, direct observations of precipitation data show a difference in gage readings for some storms. This difference is attributed to gage location, and is most likely due to micro-climatic factors and local geographic features.

With respect to this analysis, and recognizing the importance of rainfall amounts in generating streamflow, gage records at Watershed 3 were assigned exclusively to that area. The other gage was assigned to represent both Watershed 1 and Watershed 2, with respect to gross

TABLE VI

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING PRECIPITATION AT WATERSHED 1 WITH PRECIPITATION AT WATERSHED 3

Source	DF	Sum of Squares	Mean Square	F Value	OSL	R^2
P	1	82.669	82.669	203.29	.0001	.906
Error	21	8.540	0.407			
Total	22	91.208				

P_3 = Precipitation at Watershed 3
P_1 = Precipitation at Watershed 1
Dependent Variable = Precipitation at Watershed 1
$P_1 = 0.1099 + 0.8247(P_3)$
Standard error for intercept = 0.1982
Standard error for β_1 = 0.0578

precipitation. The alternative was to use an average of the two gages for all three watersheds, which would most likely introduce more error in relating streamflow to precipitation.

As described in the previous chapter, standard can readings were made after every storm, and used as a check for gross precipitation on the recording gages. These readings were taken and compared with the chart records in the field. No equipment failures were observed throughout the study period. Standard can readings were consistently accurate to within 0.01 cm of gage records.

Streamflow

Twenty-three storms, during the period of study, produced 19 runoff events on Watershed 1, 14 on Watershed 2 and 17 on Watershed 3. Total streamflow for the period of study was 12.7 cm, 7.6 cm and 19.6 cm for Watersheds 1, 2 and 3, respectively. Monthly discharge volumes are compared in Figure 7. Whenever storms produce runoff on all three watersheds, the total discharge was different from each individual catchment. A two-way classification analysis of variance also determined that this difference was not consistent for all events. Using watershed and storm as independent variables, an F statistic was calculated to test the hypothesis that the streamflow averages were not different. This hypothesis was rejected at the 0.05 significant level (Table VII).

Identifying this variation of streamflow in terms of a variable, or combinations of variables, was accomplished through a series of stepwise regressions. Two separate regressions were run for each watershed, with streamflow as the dependent variable in each case. Streamflow from one of the other two watersheds, respectively, was included in each procedure

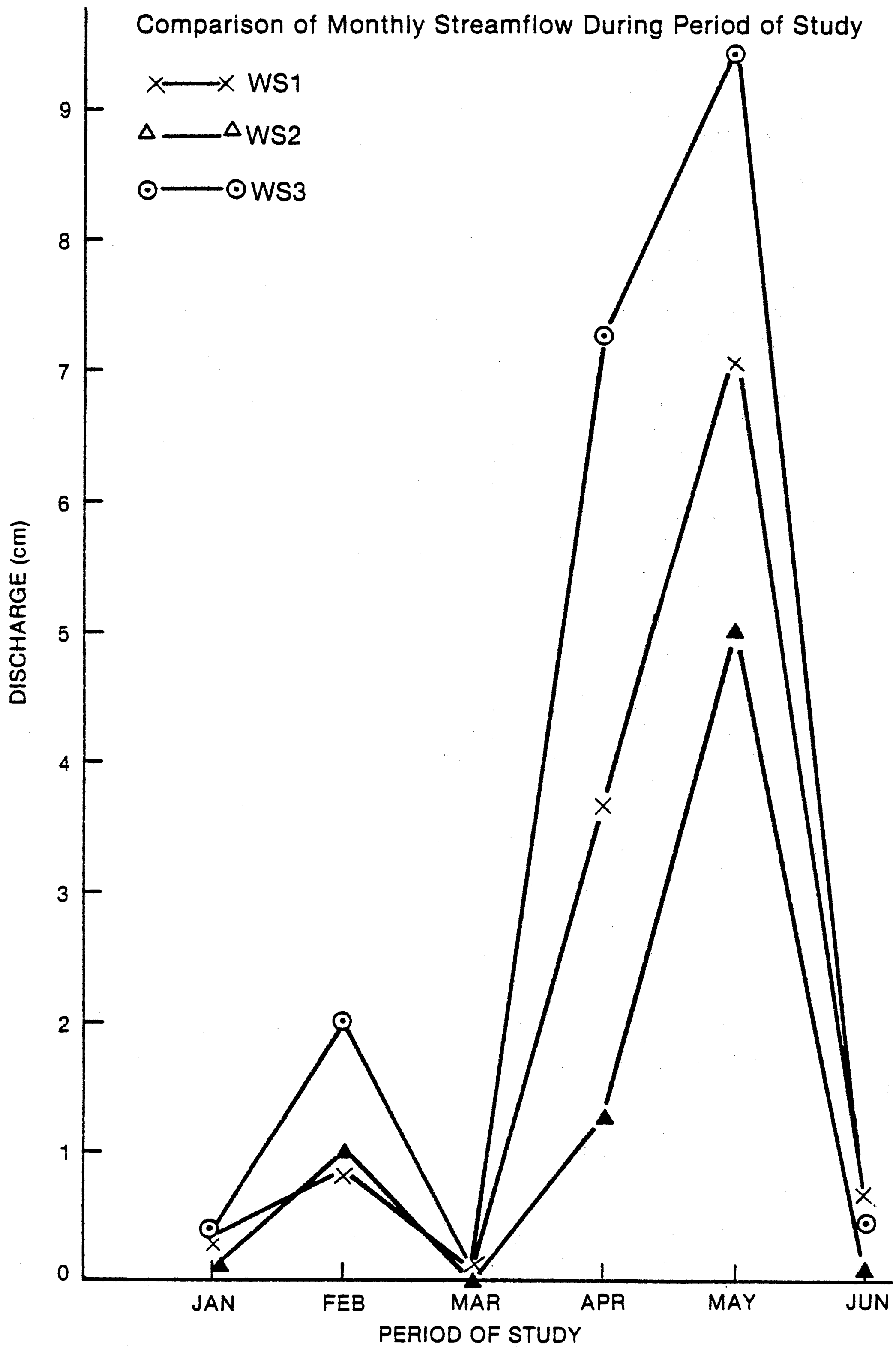

Figure 7. Comparison of Monthly Streamflow for the Study Period

TABLE VII

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE
FOR STREAMFLOW

Source	DF	Sum of Squares	Mean Square	F Value	OSL
WS	2	1.284	0.642	8.97	0.0005
Storm	22	17.263	0.078	10.96	0.0001
Error	44	3.149	0.072		
Total	68	21.696			

WS = Watershed

Error = WS * Storm

as the first independent variable. Other independent variables considered were: gross precipitation, maximum precipitation intensity, storm duration, days since last storm, temperature and both antecedent precipitation indices, API1 and API2.

Independent variables were entered by the procedure in order of highest to lowest significance, until all variables meeting the 0.05 significance level were included.

Of the independent variables considered, only four were identified as significant in the regressions. Storm duration was the most frequent variable selected, occurring in four of the six regressions. Gross precipitation, maximum precipitation intensity and API2 followed, occurring in three regressions each.

The significance of these three variables seems to follow the conclusion by Rothacher et al. (1967), that amounts of streamflow are largely a reflection of rainfall patterns.

Linear models were developed to show the relationship between precipitation and streamflow, to compare streamflow between watersheds and to generate equations for estimating streamflow. Single variable models were developed, followed by a multivariate approach, using several independent variables identified in the regressions. All models with equations and statistics are shown in Table VIII.

The relationship between precipitation and streamflow is presented graphically for each watershed in Figures 8, 9 and 10. Using precipitation as a single independent variable, the models failed to produce statistics that would suggest reliable predicted values from the equations. Although there appears to be a linear trend, the R-square values and correlations were relatively low. Precipitation explained only 73

TABLE VIII

COMPARISON OF LINEAR MODELS FOR ESTIMATING STREAMFLOW

Model: Dependent Variable	Model: Independent Variable(s)	R^2	r	Standard Deviation	Equation
Streamflow (TS_1)	P	.73	.85	.398	TS_1 = -0.141 + 0.315 (P)
	TS_2	.78	.88	.363	TS_1 = 0.149 + 1.199 (TS_2)
	TS_2, MPI, P	.92	.96	.221	TS_1 = -0.104 + 0.668 (TS_2) + 0.202 (MPI) + 0.107 (P)
	TS_3	.81	.90	.331	TS_1 = 0.095 + 0.539 (TS_3)
	TS_3, SD, P, API2	.91	.95	.246	TS_1 = 0.053 + 0.217 (TS_3) - 0.007 (SD) + 0.138 (P) + 0.179 (API2)
Streamflow (TS_2)	P	.53	.73	.384	TS_2 = -0.099 + 0.198 (P)
	TS_1	.78	.88	.267	TS_2 = -0.021 + 0.647 (TS_1)
	TS_1, MPI	.81	.91	.249	TS_2 = 0.025 + 0.828 (TS_1) - 0.148249 (MPI)
	TS_3	.66	.81	.327	TS_2 = 0.033 + 0.357 (TS_3)
	TS_3, SD, P	.75	.86	.312	TS_2 = 0.367 + 0.180 (TS_3) - 0.007 (SD) + 0.263 (P)
Streamflow (TS_3)	P	.57	.76	.837	TS_3 = -0.178 + 0.405 (P)
	TS_1	.81	.90	.553	TS_3 = 0.015 + 1.510 (TS_1)
	TS_1, SD, API2	.89	.94	.448	TS_3 = 0.170 + 1.158 (TS_1) - 0.0139 (SD) + 0.321 (API2)
	TS_2	.66	.81	.745	TS_3 = 0.225 + 1.855 (TS_2)
	TS_2, SD, API2, MPI	.90	.95	.441	TS_3 = 0.126 + 1.297 (TS_2) - 0.014 (SD + 0.320 (API2) + 0.196536 (MPI)

P = Precipitation; TS = Total Streamflow; MPI = Maximum Precipitation Intensity; SD = Storm Duration; API = Antecedent Precipitation Index; Subscripts refer to watershed

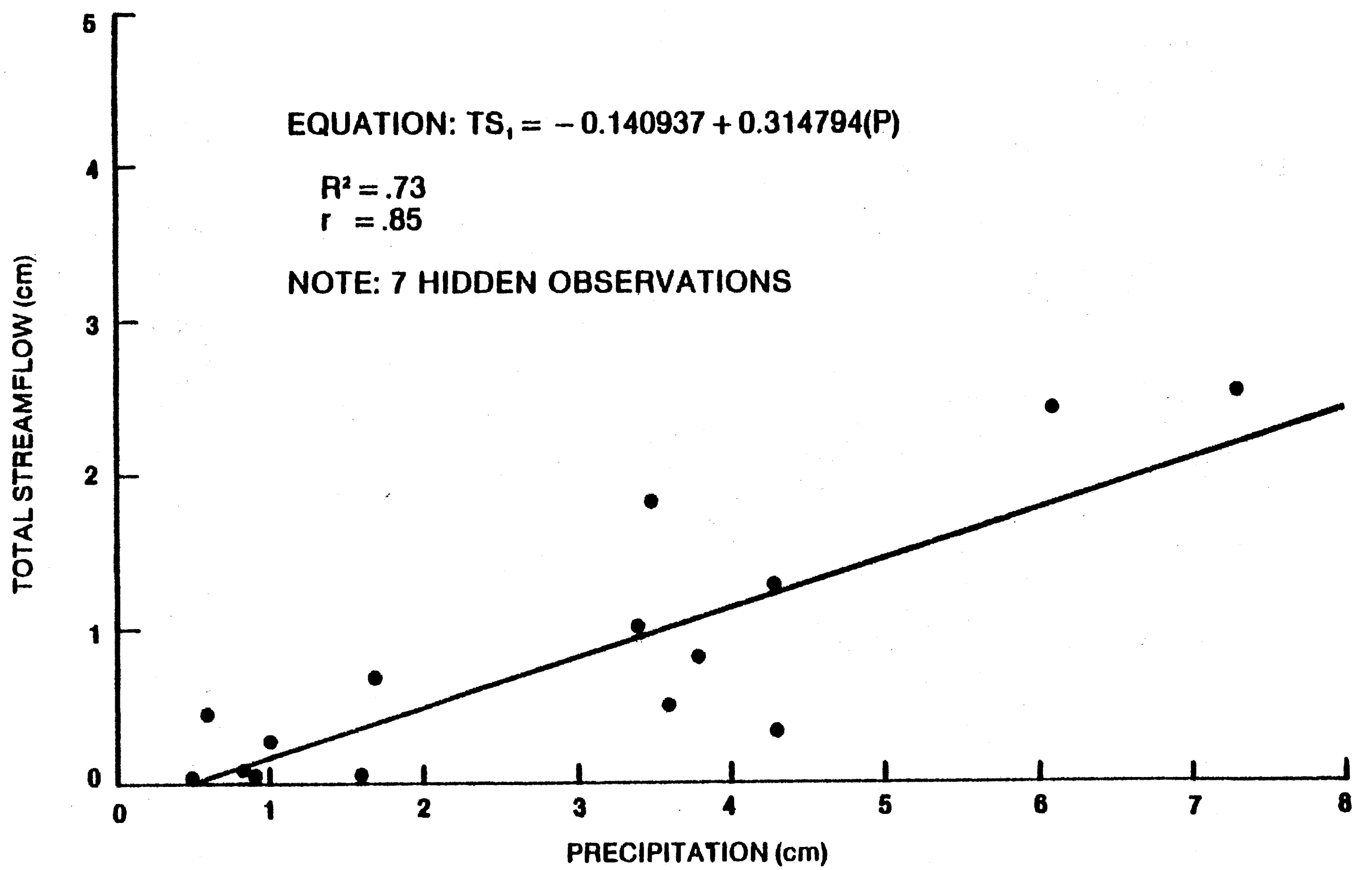

Figure 8. Relationship Between Precipitation and Streamflow for Watershed 1

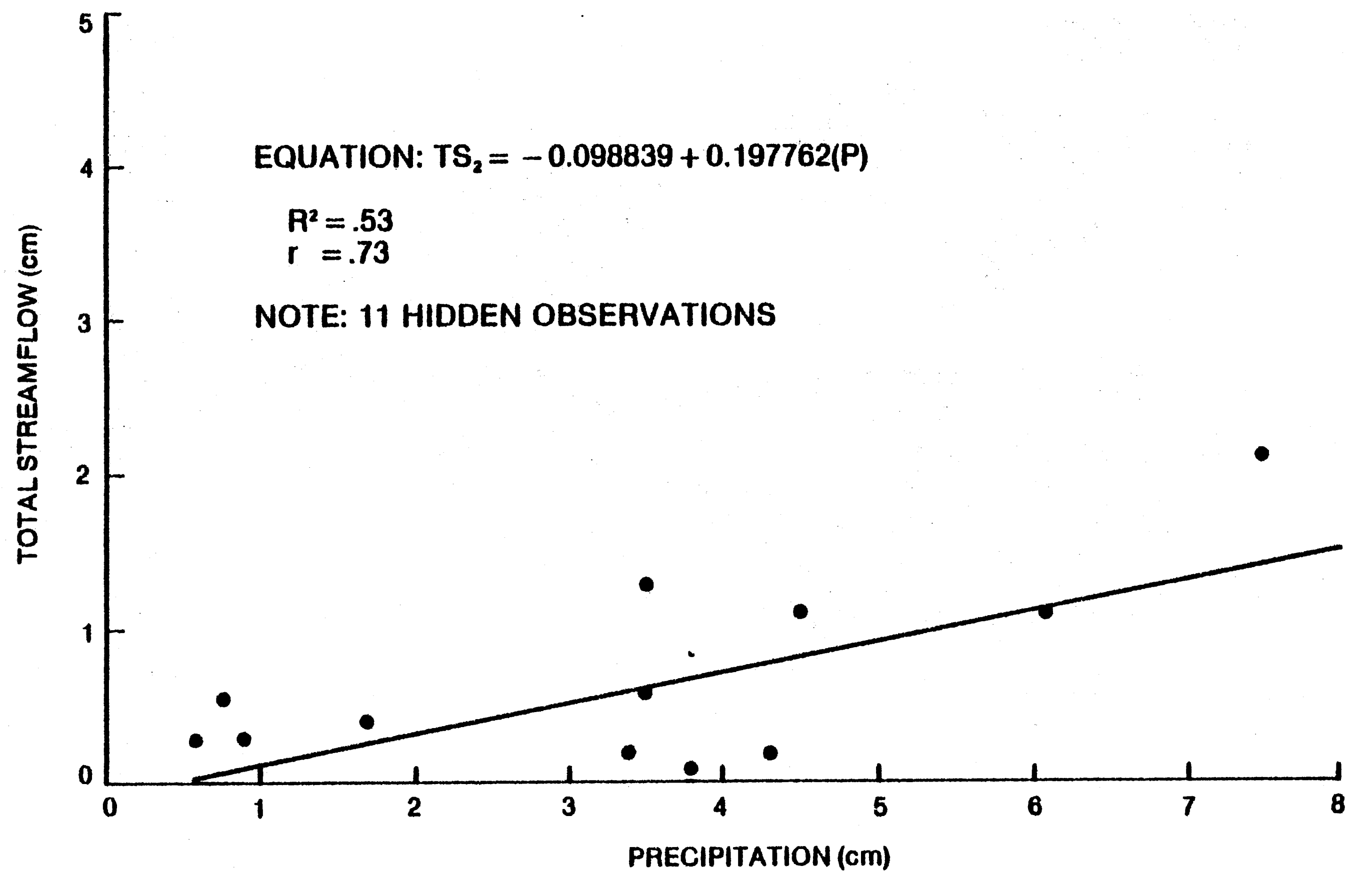

Figure 9. Relationship Between Precipitation and Streamflow for Watershed 2

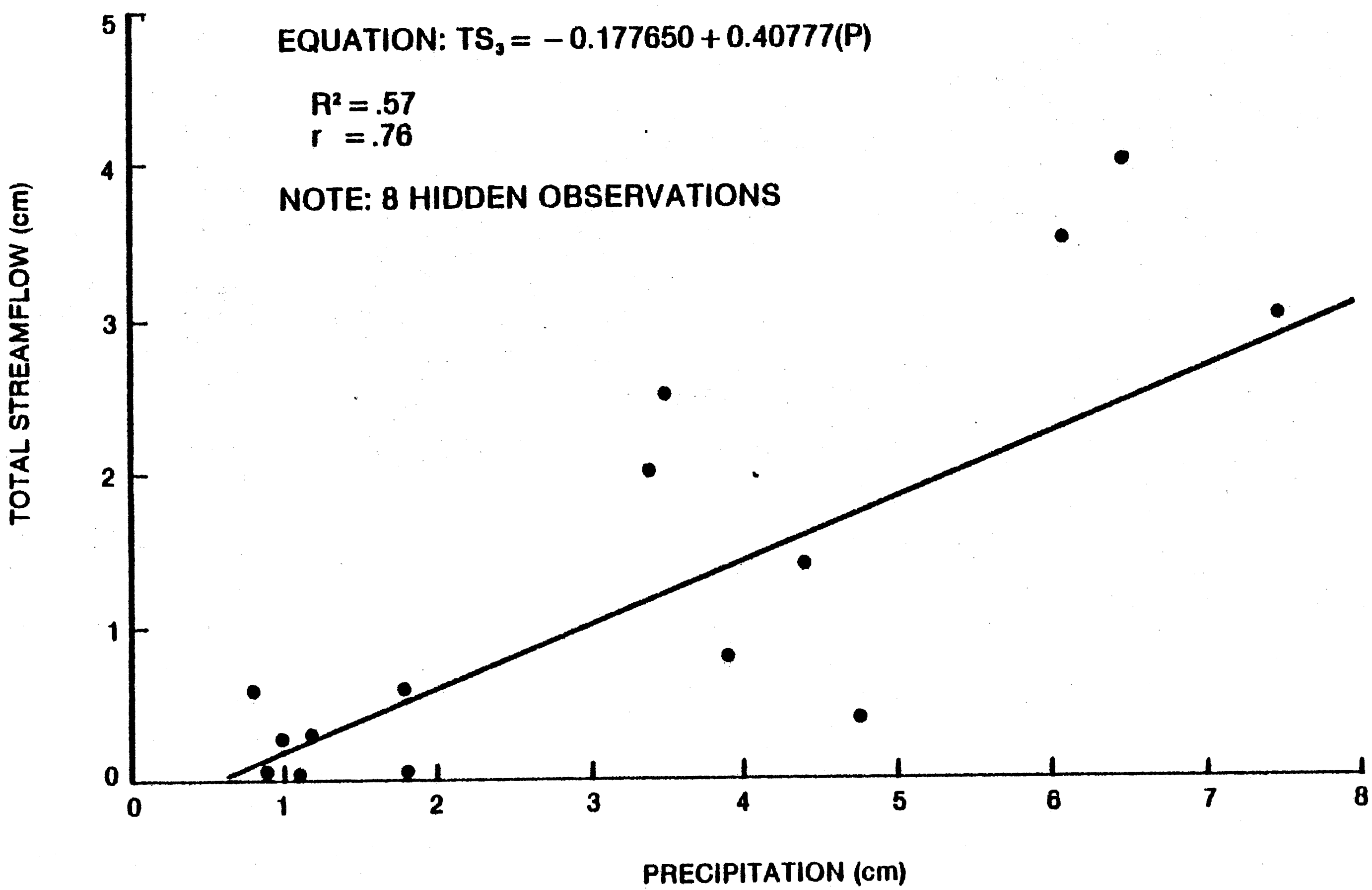

Figure 10. Relationship Between Precipitation and Streamflow for Watershed 3

percent of streamflow variation on Watershed 1, 53 percent on Watershed 2 and 57 percent on Watershed 3. Analysis of variance for streamflow versus precipitation are given for each watershed in Tables XVI, XVII and XVIII, Appendix C. Results of this analysis indicate that precipitation accounts for a portion of streamflow variation. However, with precipitation as a single independent variable, the models do not do a good job of estimating streamflow.

Additional single variable models were developed by pairing each watershed with the other two, respectively. The relationship between watersheds, with respect to streamflow, are presented graphically in Figures 11 through 16. These models produced substantially higher R-square values than the models using precipitation as a single independent variable. When pairing Watersheds 1 and 3, streamflow was closely correlated (.90). However, when Watershed 2 was included with either of the other two watersheds, the level of significance decreased substantially. The analysis of variance for each watershed pair is given in Tables XIX through XXIV, in Appendix C.

At best, the single variable models indicate that the majority of streamflow variation can be accounted for by gross precipitation alone, or measured flow from one of the other watersheds. However, they do not provide equations for estimating streamflow, while maintaining a reasonable level of accuracy, in all cases.

The multivariate models provided the best mathematical models for estimating streamflow. Using combinations of variables, two models were generated for each watershed. Each model included streamflow from another watershed as the first independent variable. Other independent

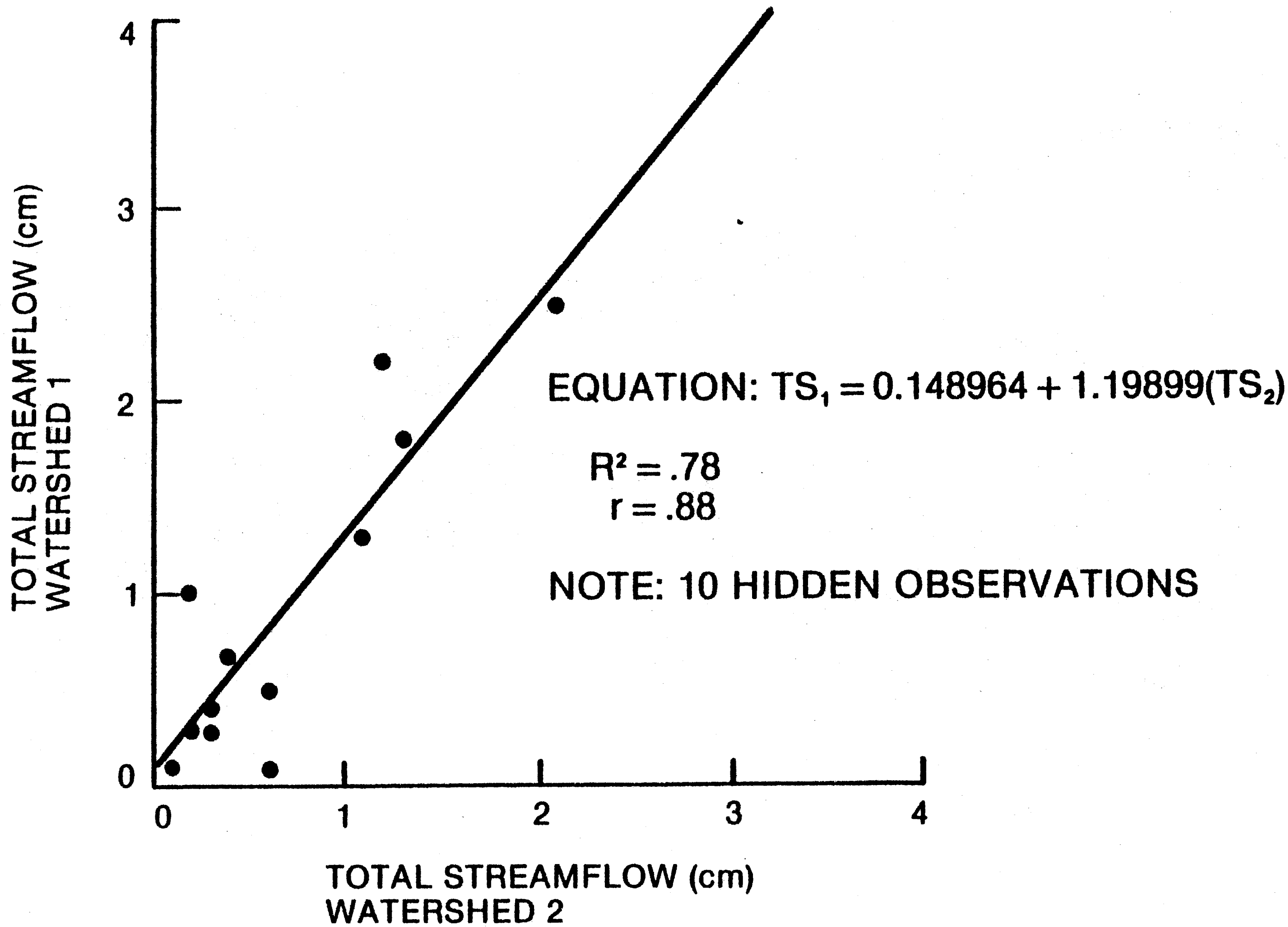

Figure 11. Linear Regression of Streamflow on Watershed 1 with Watershed 2

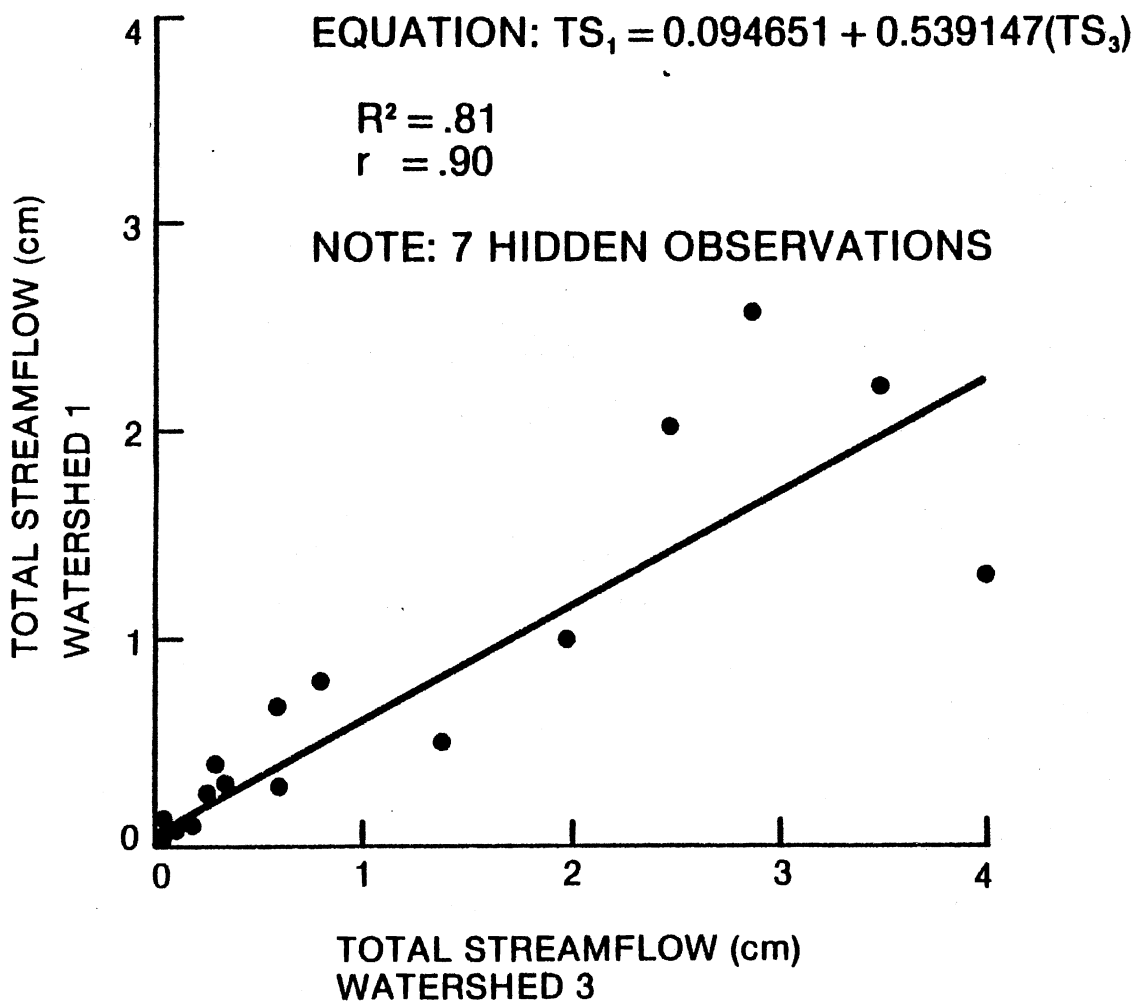

Figure 12. Linear Regression of Streamflow on Watershed 1 with Watershed 3

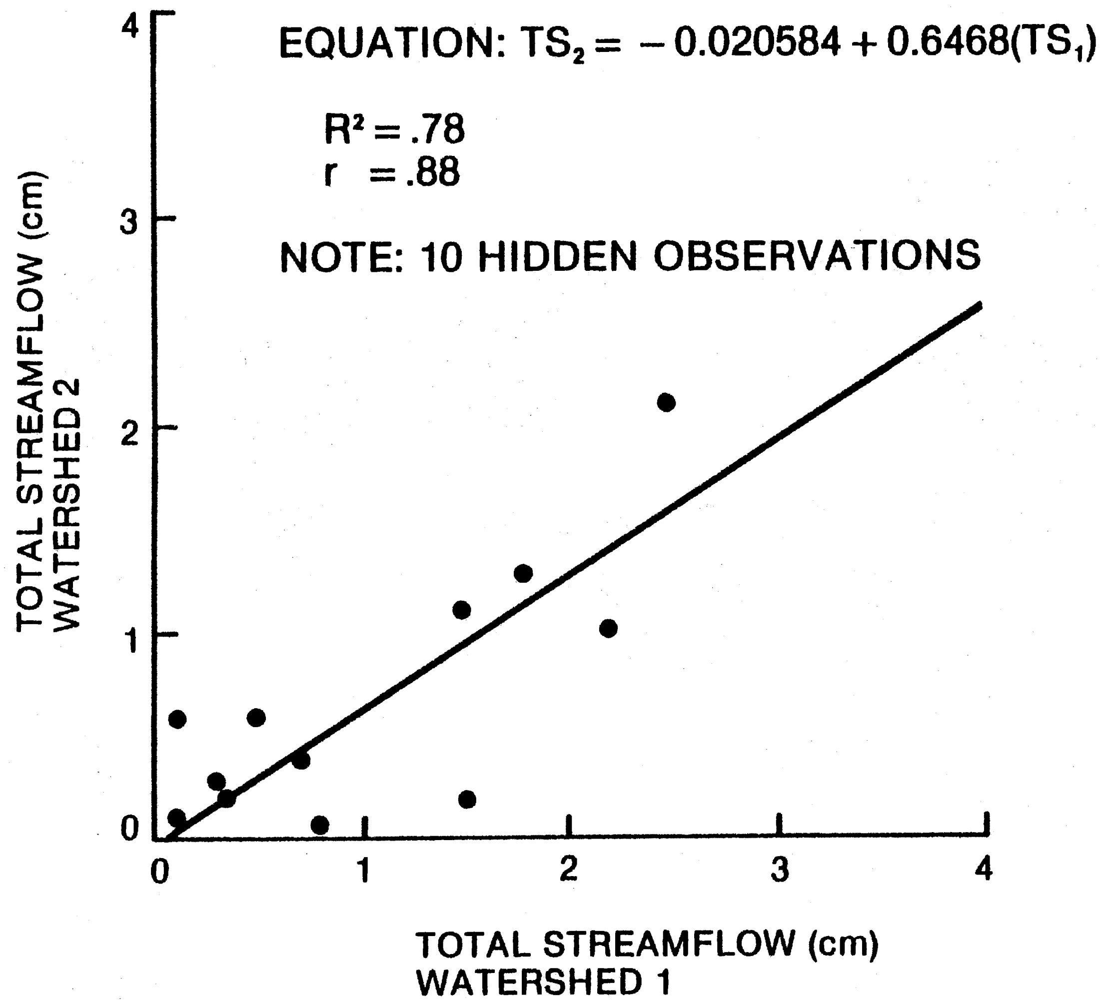

Figure 13. Linear Regression of Streamflow on Watershed 2 with Watershed 1

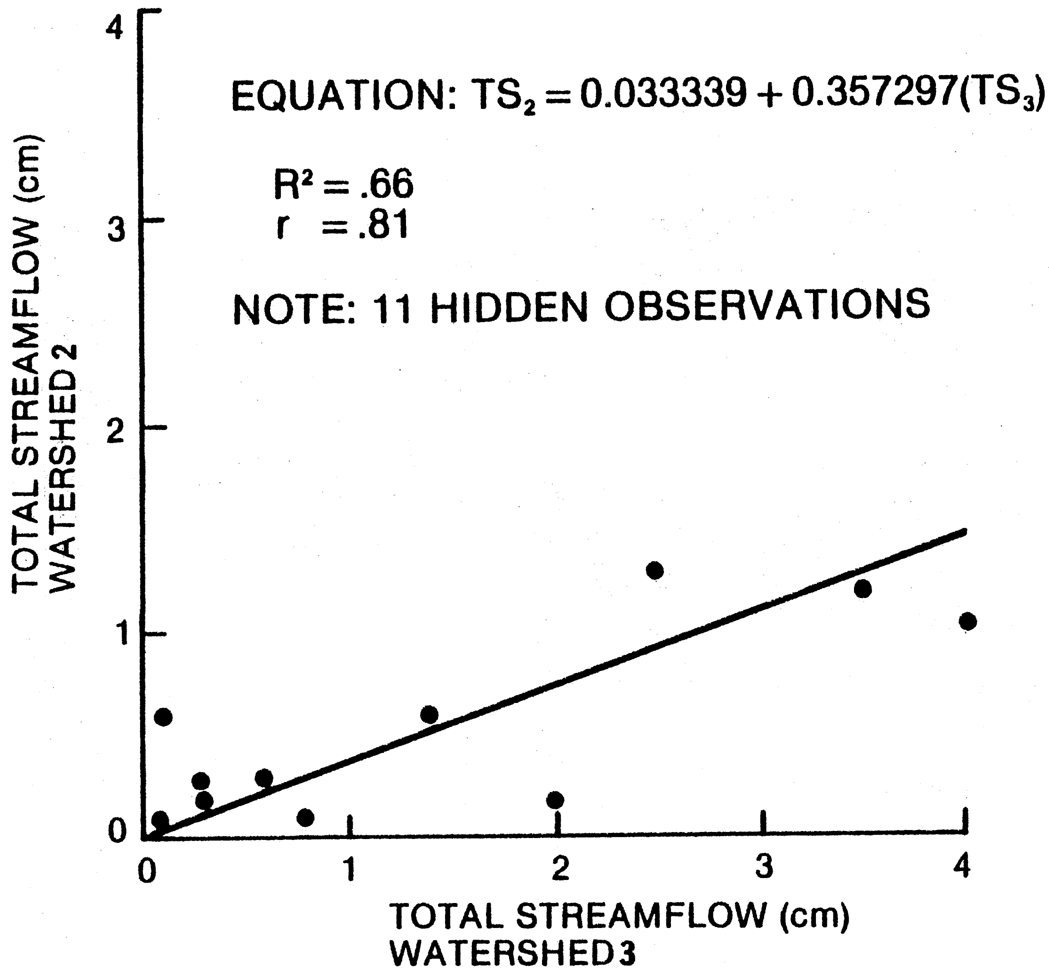

Figure 14. Linear Regression of Streamflow on Watershed 2 with Watershed 3

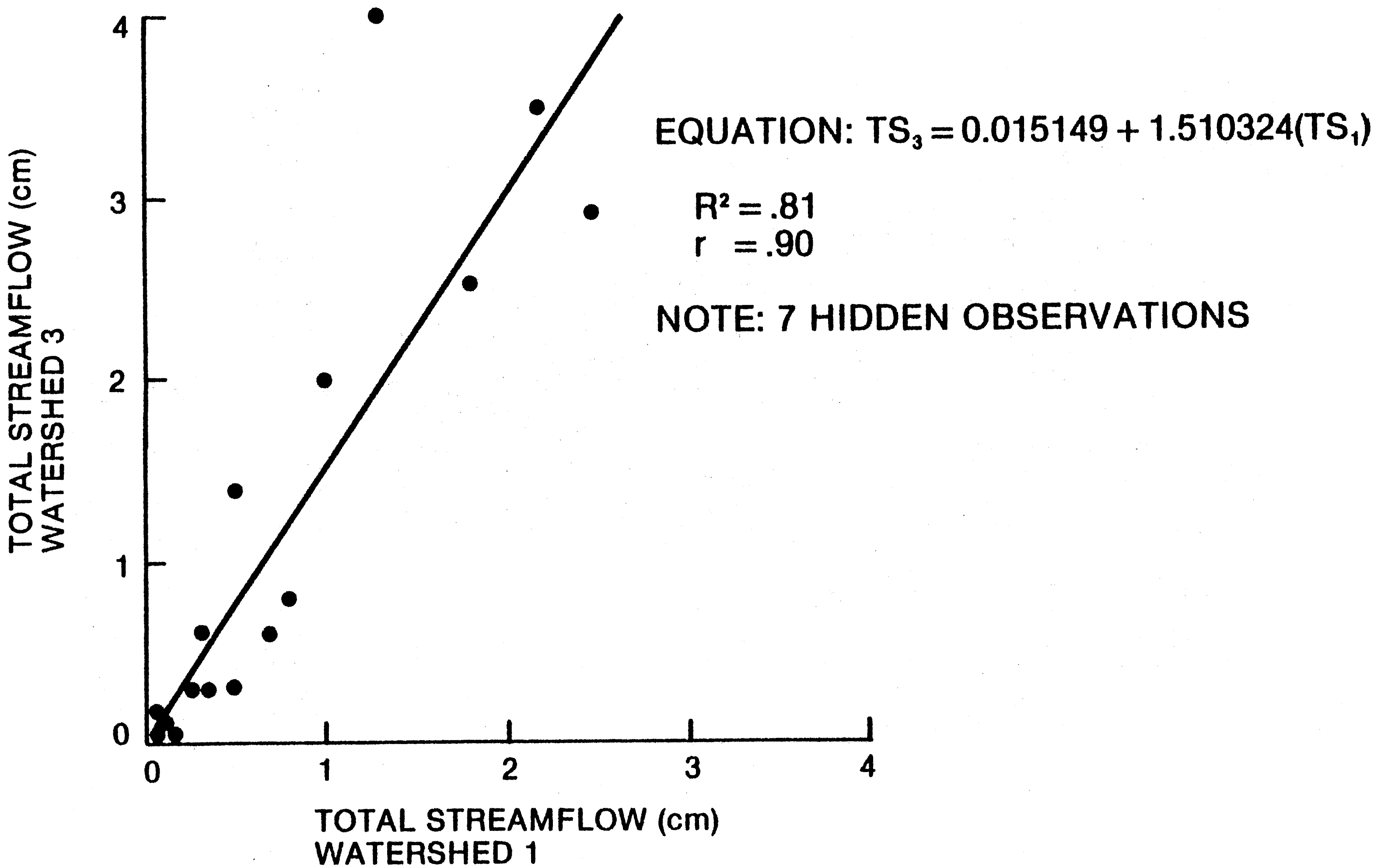

Figure 15. Linear Regression of Streamflow on Watershed 3 with Watershed 1

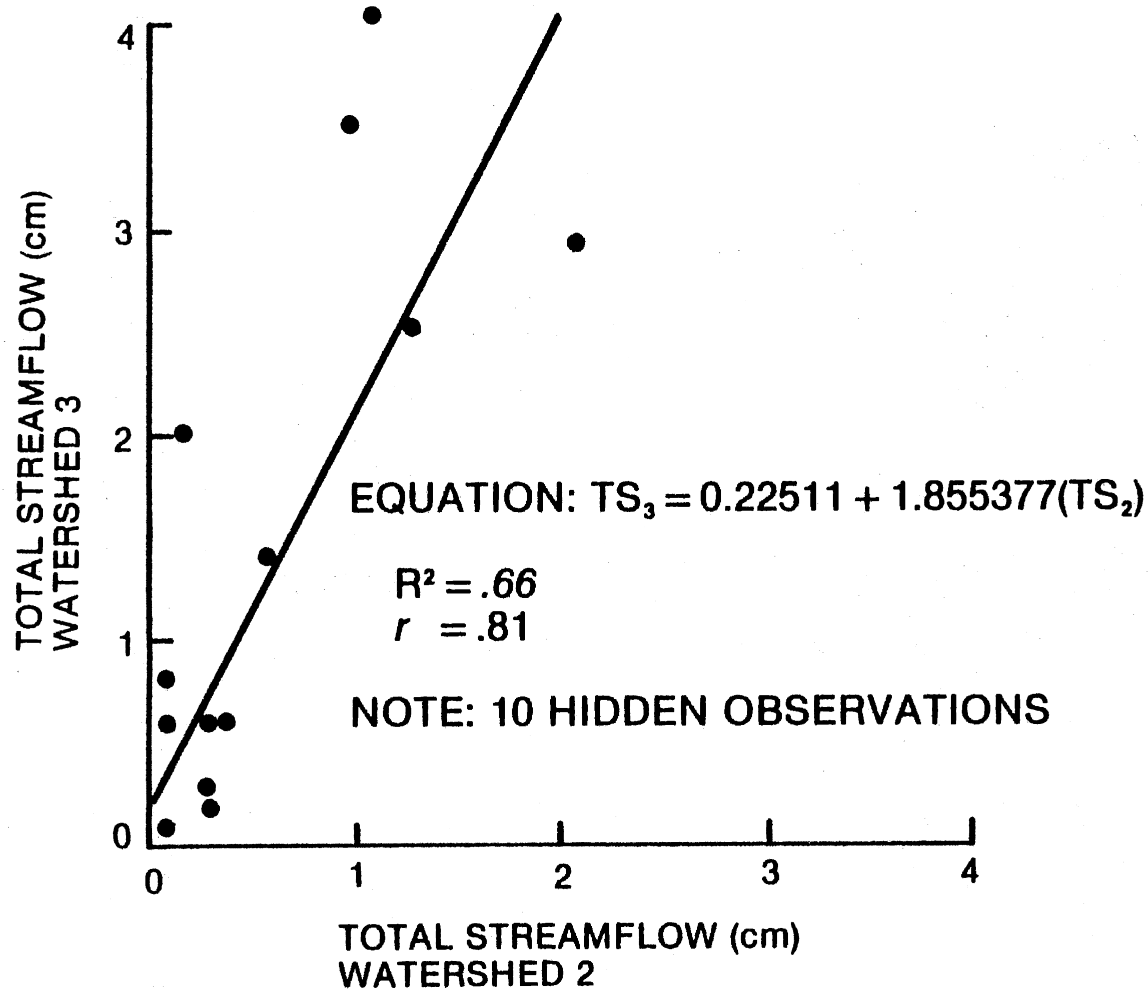

Figure 16. Linear Regression of Streamflow on Watershed 3 with Watershed 2

variables were selected by their significance, as determined by the stepwise regressions.

The introduction of several independent variables increased the accuracy of the models substantially. Modeling streamflow on Watershed 1, using as independent variables, streamflow from Watershed 2, maximum precipitation intensity and gross precipitation produced an R-square of .92 (Table XXV, Appendix C) and a standard deviation of .22. Using streamflow on Watershed 3, storm duration, gross precipitation and API2 as independent variables, an R-square of .91 (Table XXVI, Appendix C) and standard deviation of .24 were obtained.

Modeling for streamflow on Watershed 3 produced comparable results. Streamflow on Watershed 1, storm duration, maximum precipitation intensity and API2 as independent variables, produced an R-square of .89 (Table XXVII, Appendix C) and standard deviation of .44. Streamflow on Watershed 2, storm duration, maximum precipitation and API2 as independent variables, produced an R-square of .90 (Table XXVIII, Appendix C) and a standard deviation of .44. The multivariate models for Watershed 2 also improved in accuracy over the single variable models. However, when compared with the multivariate models for Watersheds 1 and 3, the R-square values indicate that predicted streamflow would be less reliable. An R-square of .81 and standard deviation of .24 were obtained when streamflow on Watershed 1 and maximum precipitation intensity were used as independent variables (Table XXIX, Appendix C). With streamflow from Watershed 1, storm duration, gross precipitation and API2 as independent variables, an R-square of .75 and standard deviation of .31 were calculated (Table XXX, Appendix C).

The statistical analysis indicates a relatively strong correlation of streamflow between watersheds, particularly when comparing Watershed 1 with 3. Also, the majority of streamflow variation on all watersheds was explained by several significant variables identified in the stepwise regressions. Combinations of these variables, applied to multivariate modeling techniques, produced reasonably accurate equations for estimating streamflow, in most cases. However, notice is given to the fact that the combinations of variables selected in the regressions were different for each watershed model. Seemingly, a variable or combination of variables, found to be significant in streamflow behavior, should be consistant for all watersheds. Such was not the case for this study, hence some question may be raised as to the application of the models.

Storm Analysis

Variables considered in the statistical analysis were time related variables, i.e. variables subject to seasonal changes. Hoover and Hursh (1943) suggested that "fixed" variables such as topography, size, shape, vegetation and soil profile are the principal sources of variation in hydrologic behavior of different drainage areas. Clearly, from Figures 3, 4 and 5, and from Table I, these watersheds exhibit substantial differences as well as similarities.

Since hydrograph shape and peak flow timing are related to watershed characteristics (Taylor and Schwarz, 1952 and Viessman et al., 1979), several individual storms were selected to compare watersheds with respect to these parameters. Storm 16, 18 and 21 seemed best suited for making the comparison, since variation in raingage readings for all three events was minimal (Tables XIII, XIV and XV, Appendix B), indicating uniform rainfall.

Storm 16 began April 30 at 2200 hours, and was preceded by 4.5 days without precipitation. Rainfall continued until May 2 at 1100 hours.

Streamflow began on all three watersheds at 2300 hours April 30. Three distinct hydrograph peaks were identified in response to rainfall patterns throughout the storm.

In comparing hydrographs, Figure 17 shows discharge rates on Watershed 3 consistantly higher at each peak. Discharge on Watershed 2 was lowest at the first peak, then rose above Watershed 1 at subsequent peaks. Maximum discharge rate occurred during the first peak for Watershed 1 and during the third peak for Watersheds 2 and 3.

Peak flow for each rise in the hydrograph occurred at approximately the same time for Watersheds 1 and 3. Watershed 2 was slower to peak in each case. Streamflow on Watershed 1 continued until 0800 hours on May 12. Streamflow ceased on Watersheds 2 and 3 much sooner; May 6 at 1600 hours and May 9 at 2200 hours, respectively.

Storm 18 began at 0050 hours May 15 and ended at 2150 hours the same day. only 2.6 days without precipitation preceeded this storm. The hydrographs for storm 18 show two distinct peaks occurring on each watershed (Figure 18). Discharge on Watershed 3 was again consistently higher at each peak. Maximum discharge for all three watersheds occurred during the second peak. Peak flow rates for Watersheds 1 and 3 occurred at the same time with Watershed 2, slower in response.

Recessions for storm 18 were intercepted by streamflow from the following storm, thus stage did not return to zero.

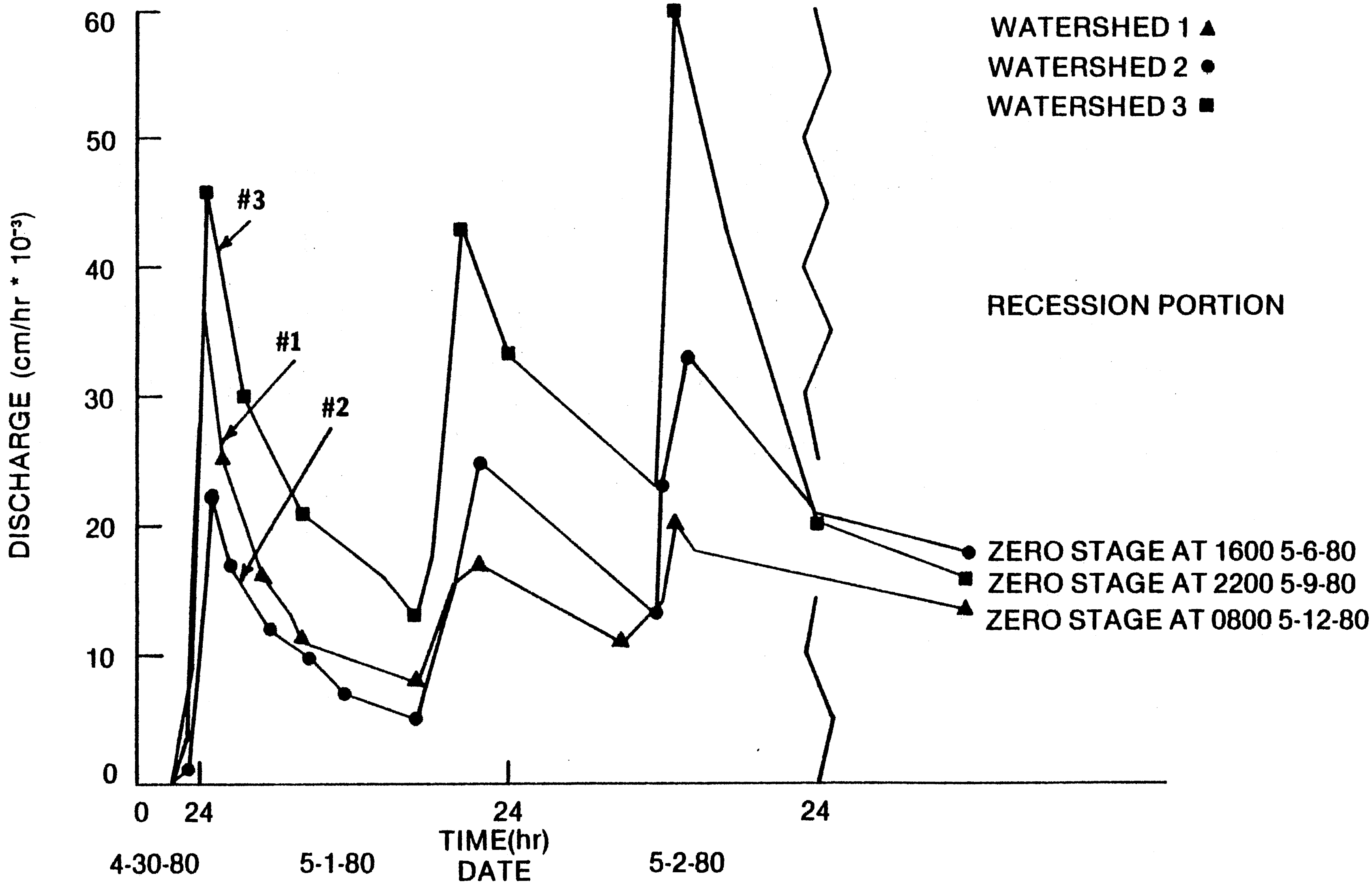

Figure 17. Hydrographs for Storm 16

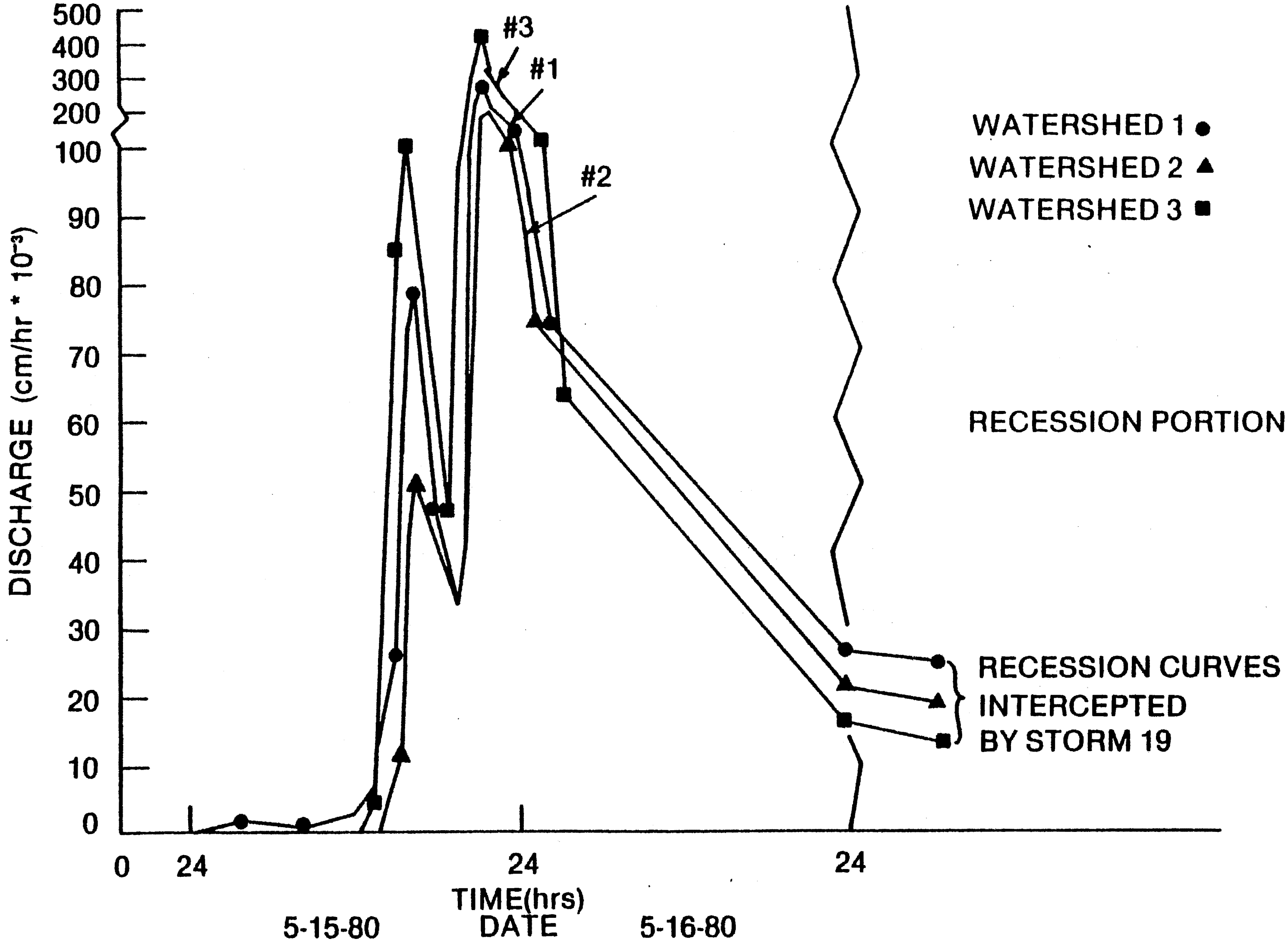

Figure 18. Hydrographs for Storm 18

Storm 21 began May 29 at 0550 and continued to 0950 May 30. Approximately eight days without precipitation preceded storm 21.

One significant hydrograph peak occurred for each watershed (Figure 19). As in the previous two storms, Watershed 3 maintained the higher discharge rate, followed by Watersheds 1 and 2, respectively. Peak flow rates on Watersheds 1 and 3 occurred at the same time. Watershed 2 was again slower to peak than the other two.

The recession curve for Watershed 1 ended June 8 at 0400 hours. Recessions for Watersheds 2 and 3 ended at 1700 hours June 1 and 1100 hours June 5, respectively.

Analysis of storms 16, 18 and 21 indicates a close correlation of hydrograph shapes and peak flow timing, particularly when comparing Watershed 1 with 3. This seems to follow the same pattern as the results of statistical analysis. However, the statistical analysis considered only total discharge, and thus does not reflect variation in streamflow mechanics.

Total discharge for a given amount of precipitation is basically a function of two parameters; flow rate and flow duration. From the hydrograph analysis, there is a substantial difference between watersheds with respect to these parameters.

In all three storms, Watershed 3 produced higher rates of discharge than Watersheds 1 or 2. Also, Watershed 1 maintained streamflow considerably longer than the other two. This most likely reflects the difference in physical characteristics between watersheds.

Since forest soils exhibit extremely high infiltration rates, very little surface runoff occurs. When soil on these watersheds is wet to field capacity, water moves down slope as direct channel interception,

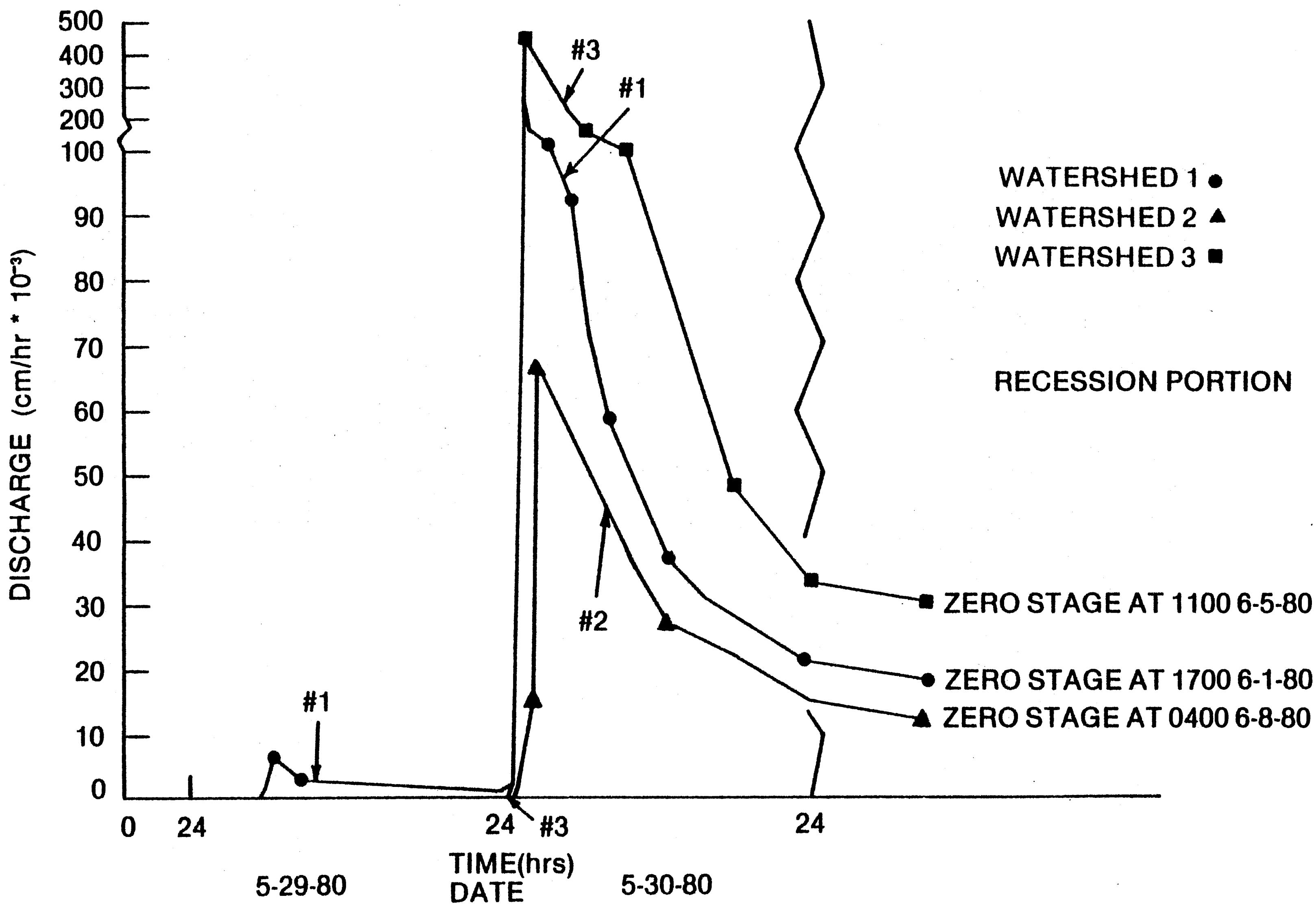

Figure 19. Hydrographs for Storm 21

or as subsurface flow. Some of this subsurface flow reaches the stream channel. The remainder may percolate to the ground water table and become temporarily stored. Outflow from this storage can add appreciably to storm hydrographs, however the rate of storage outflow is largely a function of slope (Hoover and Hursh, 1943).

The higher average slope on Watershed 3 may account for the rapid discharge of storm water and stored water, as well as the relatively shorter recession. Also, because of the shape and area of Watershed 3, storm water has less distance to travel to reach stream channels. On a percentage basis, Watershed 3 also has less ground cover (litter) and more stream channel area (Table I).

In storms 16 and 21, where stage returned to zero, Watershed 1 maintained flow considerably longer than the other two watersheds. Thus, Watershed 1 appears to store infiltrated water and discharge that storage at a slower rate, possibly due to the lower average slope. Also, drip water from canopy interception may account for part of the longer recessions since Watershed 1 has nearly twice as much basal area per acre of pine than Watershed 2 or 3 (Table I).

Watersheds 1 and 3 have north aspects, whereas Watershed 2 faces predominantly south. During periods of dry weather, Watershed 2 may generate substantially higher soil moisture deficits due to comparatively higher solar insolation. This may account for the relatively slower response to rainfall patterns since the soil on Watershed 2 would take longer to wet up.

CHAPTER V

SUMMARY AND CONCLUSIONS

Twenty-three storms occurred during the period of study, producing 19 runoff events on Watershed 1, 14 on Watershed 2 and 17 on Watershed 3. Total streamflow, as a percent of gross precipitation, averaged 25 percent, 15 percent and 33 percent for Watersheds 1, 2 and 3, respectively.

Relationships between gross precipitation and streamflow, and streamflow between watersheds, were determined by developing single variable linear models. The models using precipitation alone, or measured flow from another watershed as independent variables, produced statistics that suggest unreliable predicted values for streamflow. R-square values ranged from .53 to .81, along with equations and statistics.

Stepwise regressions identified storm duration, gross precipitation, maximum precipitation intensity and antecedent precipitation index (API2) as significant variables accounting for streamflow variation. Using these variables in combination with measured flow from one of the other watersheds, respectively, two multivariate models for each watershed were developed to estimate streamflow. R-square values for the multivariate models ranged from .75 to .92. Single variable and multivariate models were presented and compared in Table VIII.

Three individual storms were selected for hydrograph analysis, to compare watersheds with respect to discharge rates, flow duration and peak flow timing. In all three storms, Watershed 3 generated higher discharge rates than Watershed 1 or 2. Watershed 1 maintained substantially longer recession flow than the other two watersheds, and Watershed 2 was consistantly slower to peak, while Watersheds 1 and 3 peaked at the same time in almost all cases.

Several watershed characteristics were discussed as to their influence on these parameters. Fixed variables such as slope, basin configuration, vegetation and aspect were cited as probable sources of variation, which ultimately produced differences in total storm discharge between watersheds.

The objectives of this study were met. The collection and analysis of hydrologic data will provide the basis for determining the timing and type of treatment imposed, as well as the evaluation of post treatment effects.

Future studies with the Clayton experimental watersheds should include a continued streamflow calibration period in conjunction with measurements of sediment loading in runoff. Some relationships most likely exist between discharge, discharge rates and sediment movement, and should be documented. Information combining flow characteristics with the movement of suspended and dissolved solids from these watersheds will complete the pretreatment analysis, and provide a basis for evaluating forest management practices, with respect to non-point source pollution.

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APPENDIXES

APPENDIX A

DISCHARGE EQUATION RATING TABLES AND SYMBOLISM

TABLE IX

EXPLANATION OF TERMS AND SYMBOLS FOR DISCHARGE EQUATIONS

Symbol	Explanation of Term
Q	discharge (cfs)
H	stage (ft)
D	maximum depth of flume (ft)
V	average velocity (ft/sec)
g	acceleration by gravity (ft/sec/sec)
$\frac{V^2}{2g}$	velocity head (ft/sec)
B_o	1/2 bottom width of flume outlet (ft)
B_1	slope of outlet wall (ft)
k_o	draw down and fluid friction constant[1]
k_1	draw down and fluid friction constant[1]
E_o	draw down and fluid friction constant[1]
E_1	draw down and fluid friction constant[1]
F_o	draw down and fluid friction constant[1]
F_1	draw down and fluid friction constant[1]
A_o	draw down and fluid friction constant[1]
A_1	draw down and fluid friction constant[1]
α	velocity distribution coefficient[2]

[1]Experimentally obtained constants

[2]Velocity distribution coefficient α is assumed to be 1.

TABLE X

DISCHARGE RATING TABLE FOR WATERSHED 1[1]
DISCHARGE (cfs)

Head (H) (feet)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.000	0.000	0.002	0.006	0.010	0.014	0.019	0.025	0.031	0.038
0.1	0.045	0.053	0.061	0.070	0.080	0.090	0.101	0.113	0.125	0.137
0.2	0.150	0.163	0.177	0.191	0.205	0.220	0.235	0.251	0.268	0.285
0.3	0.303	0.320	0.338	0.357	0.377	0.397	0.417	0.438	0.460	0.482
0.4	0.504	0.527	0.551	0.575	0.600	0.625	0.651	0.677	0.704	0.732
0.5	0.760	0.788	0.818	0.847	0.878	0.908	0.940	0.972	1.004	1.038
0.6	1.072	1.106	1.141	1.176	1.213	1.249	1.287	1.324	1.363	1.402
0.7	1.442	1.482	1.523	1.565	1.607	1.650	1.693	1.737	1.782	1.827
0.8	1.873	1.920	1.967	2.015	2.064	2.113	2.163	2.214	2.265	2.317
0.9	2.369	2.422	2.476	2.531	2.586	2.642	2.699	2.756	2.814	2.873
1.0	2.932	2.992	3.053	3.114	3.176	3.239	3.303	3.367	3.432	3.498
1.1	3.564	3.631	3.699	3.768	3.837	3.907	3.978	4.050	4.122	4.195
1.2	4.269	4.343	4.419	4.495	4.572	4.649	4.727	4.807	4.886	4.967
1.3	5.048	5.131	5.214	5.297	5.382	5.476	5.553	5.640	5.728	5.816
1.4	5.905	5.995	6.086	6.178	6.271	6.364	6.458	6.553	6.649	6.745
1.5	6.843	6.941	7.040	7.140	7.240	7.342	7.444	7.547	7.652	7.756
1.6	7.862	7.969	8.076	8.185	8.294	8.404	8.515	8.627	8.739	8.853
1.7	8.967	9.082	9.199	9.316	9.433	9.552	9.672	9.793	9.914	10.036
1.8	10.160	10.280	10.410	10.530	10.660	10.790	10.920	11.050	11.180	11.310
1.9	11.440	11.580	11.710	11.850	11.980	12.120	12.260	12.400	12.540	12.680

TABLE X (Continued)

Head (H) (feet)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
2.0	12.82	12.96	13.10	13.25	13.40	13.54	13.69	13.84	13.99	14.14
2.1	14.29	14.44	14.60	14.75	14.91	15.06	15.22	15.38	15.54	15.70
2.2	15.86	16.02	16.18	16.35	16.51	16.68	16.85	17.02	17.19	17.36
2.3	17.53	17.70	17.88	18.05	18.23	18.40	18.58	18.76	18.94	19.12
2.4	19.30	19.49	19.67	19.85	20.04	20.23	20.42	20.61	20.80	20.99
2.5	21.18	21.37	21.57	21.77	21.96	22.16	22.36	22.56	22.76	22.97
2.6	23.17	23.37	23.58	23.79	23.99	24.20	24.41	24.63	24.84	25.05
2.7	25.27	25.48	25.70	25.92	26.14	26.36	26.58	26.81	27.03	27.25
2.8	27.48	27.71	27.94	28.17	28.40	28.63	28.87	29.10	29.34	29.57
2.9	29.81	30.05	30.29	30.53	30.78	31.02	31.27	31.51	31.76	32.01
3.0	32.26	32.51	32.77	33.02	33.28	33.53	33.79	34.05	34.31	34.57
3.1	34.84	35.10	35.36	35.63	35.90	36.17	36.44	36.71	36.98	37.26
3.2	37.53	37.81	38.09	38.37	38.65	38.93	39.22	39.50	39.79	40.07
3.3	40.36	40.65	40.94	41.24	41.53	41.83	42.12	42.42	42.72	43.02
3.4	43.32	43.63	43.93	44.24	44.54	44.85	45.16	45.48	45.79	46.10
3.5	46.42	46.74	47.05	47.37	47.70	48.02	48.34	48.67	49.00	49.32
3.6	49.65	49.99	50.32	50.65	50.99	51.32	51.66	52.00	52.34	52.69
3.7	53.03	53.38	53.72	54.07	54.42	54.77	55.13	55.48	55.84	56.20
3.8	56.55	56.92	57.28	57.64	58.01	58.37	58.74	59.11	59.48	59.85
3.9	60.23	60.60	60.98	61.36	61.74	62.12	62.50	62.89	63.28	63.66
4.0	64.05									

[1]Water Conservation Structures Laboratory, Stillwater, OK, September 16, 1980.

TABLE XI

DISCHARGE RATING TABLE FOR WATERSHED 2[1]
DISCHARGE (cfs)

Head (H) (Feet)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.000	0.000	0.002	0.005	0.009	0.014	0.019	0.024	0.034	0.037
0.1	0.044	0.051	0.059	0.068	0.078	0.087	0.098	0.109	0.121	0.133
0.2	0.146	0.158	0.171	0.185	0.199	0.213	0.228	0.244	0.260	0.276
0.3	0.293	0.311	0.329	0.348	0.367	0.386	0.406	0.427	0.448	0.469
0.4	0.491	0.514	0.537	0.561	0.585	0.610	0.635	0.661	0.688	0.715
0.5	0.742	0.770	0.799	0.828	0.858	0.888	0.919	0.950	0.982	1.015
0.6	1.049	1.082	1.117	1.152	1.187	1.223	1.260	1.297	1.335	1.374
0.7	1.413	1.453	1.493	1.534	1.576	1.618	1.661	1.704	1.748	1.793
0.8	1.838	1.881	1.931	1.978	2.026	2.075	2.124	2.174	2.225	2.276
0.9	2.328	2.380	2.433	2.487	2.542	2.597	2.653	2.710	2.767	2.825
1.0	2.884	2.943	3.003	3.064	3.125	3.188	3.250	3.314	3.378	3.113
1.1	3.509	3.576	3.643	3.711	3.779	3.849	3.919	3.990	4.061	4.134
1.2	4.207	4.280	4.355	4.430	4.506	4.583	4.661	4.739	1.818	1.888
1.3	1.070	5.060	5.142	5.225	5.309	5.394	5.479	5.565	5.652	5.740
1.4	5.828	5.917	6.008	6.098	6.190	6.283	6.376	6.470	6.565	6.661
1.5	6.758	6.855	6.953	7.052	7.152	7.253	7.355	7.457	7.560	7.664
1.6	7.769	7.875	7.982	8.089	8.198	8.307	8.417	8.528	8.640	8.753
1.7	8.866	8.981	9.096	9.212	9.329	9.447	9.566	9.686	9.807	9.928
1.8	10.050	10.170	10.300	10.420	10.550	10.680	10.800	10.930	11.060	11.190
1.9	11.330	11.460	11.590	11.730	11.860	12.000	12.130	12.270	12.410	12.550

TABLE XI (Continued)

Head (H) (Feet)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
2.0	12.69	12.84	12.98	13.12	13.27	13.41	13.56	13.71	13.86	14.01
2.1	14.16	14.31	14.46	14.61	14.77	14.92	15.08	15.24	15.40	15.56
2.2	15.72	15.88	16.04	16.20	16.37	16.53	16.70	16.87	17.04	17.21
2.3	17.38	17.55	17.72	17.90	18.07	18.25	18.42	18.60	18.78	18.96
2.4	19.14	19.32	19.51	19.69	19.88	20.06	20.25	20.44	20.63	20.82
2.5	21.01	21.21	21.40	21.60	21.79	21.99	22.19	22.39	22.59	22.79
2.6	22.99	23.20	23.40	23.61	23.81	24.02	24.23	24.44	24.66	24.87
2.7	25.08	25.30	25.51	25.73	25.95	26.17	26.39	26.61	26.81	27.06
2.8	27.29	27.51	27.74	27.97	28.20	28.43	28.67	28.90	29.14	29.37
2.9	29.61	29.85	30.09	30.33	30.57	30.81	31.06	31.31	31.55	31.80
3.0	32.05	32.30	32.55	32.81	33.06	33.32	33.57	33.83	34.09	34.36
3.1	34.61	34.88	35.14	35.41	35.68	35.94	36.21	36.48	36.76	37.03
3.2	37.31	37.58	37.86	38.14	38.42	38.70	38.98	39.27	39.55	39.84
3.3	40.12	40.41	40.70	41.00	41.29	41.58	41.88	42.18	42.48	42.78
3.4	43.08	43.38	43.68	43.99	44.29	44.60	44.91	45.22	45.54	45.85
3.5	46.16	46.48	46.80	47.12	47.44	47.76	48.08	48.41	48.73	49.06
3.6	49.39	49.72	50.05	50.39	50.72	51.06	51.39	51.73	52.07	52.42
3.7	52.76	53.10	53.45	53.80	54.15	54.50	54.85	55.20	55.56	55.92
3.8	56.27	56.63	56.99	47.36	57.72	58.09	58.45	58.82	59.19	59.56
3.9	59.91	60.31	60.69	61.07	61.45	61.83	62.21	62.59	62.98	63.37
4.0	63.76									

[1]Water Conservation Structures Laboratory, Stillwater, OK, September 16, 1980.

TABLE XII

DISCHARGE RATING TABLE FOR WATERSHED 3[1]
DISCHARGE (cfs)

Head (H) (Feet)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.000	0.000	0.002	0.005	0.009	0.014	0.018	0.024	0.030	0.036
0.1	0.013	0.051	0.059	0.068	0.077	0.087	0.098	0.109	0.120	0.132
0.2	0.145	0.158	0.171	0.184	0.198	0.213	0.228	0.243	0.259	0.276
0.3	0.293	0.310	0.328	0.347	0.366	0.385	0.405	0.426	0.447	0.468
0.4	0.191	0.513	0.536	0.560	0.584	0.609	0.634	0.660	0.686	0.713
0.5	0.741	0.769	0.798	0.827	0.8568	0.887	0.918	0.949	0.981	1.014
0.6	1.047	1.081	1.115	1.150	1.186	1.222	1.259	1.296	1.334	1.372
0.7	1.411	1.451	1.491	1.532	1.574	1.616	1.659	1.703	1.747	1.791
0.8	1.837	1.883	1.929	1.977	2.025	2.073	2.123	2.172	2.223	2.274
0.9	2.326	2.379	2.432	2.486	2.540	2.596	2.652	2.708	2.766	2.824
1.0	2.882	2.942	3.002	3.063	3.124	3.186	3.249	3.313	3.377	3.442
1.1	3.508	3.574	3.642	3.710	3.778	3.848	3.918	3.989	4.060	4.133
1.2	4.206	4.280	4.354	4.430	4.506	4.583	4.660	4.739	4.818	4.898
1.3	4.978	5.060	5.143	5.225	5.309	5.394	5.479	5.565	5.652	5.740
1.4	5.828	5.918	6.008	6.099	6.191	6.283	6.377	6.471	6.566	6.662
1.5	6.759	6.856	6.954	7.054	7.154	7.254	7.356	7.459	7.562	7.666
1.6	7.771	7.877	7.984	8.092	8.200	8.309	8.420	8.531	8.643	8.756
1.7	8.869	8.984	9.099	9.216	9.333	9.451	9.570	9.690	9.811	9.932
1.8	10.050	10.180	10.300	10.430	10.550	10.680	10.810	10.940	11.070	11.200
1.9	11.330	11.460	11.600	11.730	11.870	12.000	12.140	12.280	12.420	12.560

TABLE XII (Continued)

Head (H) (Feet)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
2.0	12.70	12.84	12.99	13.13	13.27	13.43	13.57	13.72	13.86	14.01
2.1	14.16	14.32	14.47	14.62	14.78	14.93	15.09	15.25	15.41	15.57
2.2	15.73	15.89	16.05	16.22	16.38	16.55	16.71	16.88	17.05	17.22
2.3	17.39	17.56	17.74	17.91	18.09	18.26	18.44	18.62	18.80	18.98
2.4	19.16	19.34	19.52	19.71	19.89	20.08	20.27	20.46	20.65	20.84
2.5	21.03	21.22	21.42	21.16	21.81	22.01	22.21	22.41	22.61	22.81
2.6	23.01	23.22	23.42	23.63	23.04	24.05	24.26	24.47	24.68	24.89
2.7	25.11	25.32	25.54	25.76	25.98	26.20	26.42	26.64	26.86	27.09
2.8	27.32	27.54	27.77	28.00	28.32	28.46	28.70	28.03	29.17	29.40
2.9	29.64	29.88	30.12	30.36	30.60	30.85	31.09	31.34	31.59	31.84
3.0	32.09	32.34	32.59	32.84	33.10	33.36	33.61	33.87	34.13	34.39
3.1	34.66	34.92	35.18	35.45	35.72	35.99	36.26	36.53	36.80	37.08
3.2	37.35	37.63	37.90	38.18	38.46	38.75	39.03	39.31	39.60	39.89
3.3	40.17	40.46	40.76	41.05	41.34	41.64	41.93	42.23	42.53	42.83
3.4	43.13	43.44	43.74	44.05	44.35	44.66	44.97	45.28	45.60	45.91
3.5	46.23	46.54	46.86	47.17	47.50	47.82	48.15	48.47	48.80	49.13
3.6	49.46	49.79	50.12	50.46	50.79	51.13	51.47	51.81	52.15	52.49
3.7	52.83	53.18	53.53	53.87	54.22	54.58	54.93	55.28	55.64	56.00
3.8	56.35	56.72	57.08	57.44	57.81	58.17	58.54	58.91	59.28	59.65
3.9	60.03	60.40	60.78	61.16	61.54	61.92	62.30	62.69	63.08	63.46
4.0	63.85									

[1]Water Conservation Structures Laboratory, Stillwater, OK, September 16, 1980.

APPENDIX B

DATA TABLES

TABLE XIII

WATERSHED 1 HYDROLOGIC DATA

Date	Storm #	P	TS	SD	MPI	DY	T	API 1	API 2
1-19-80	1	4.32	0.34	94.5	0.34	5.0	15.3	5.64	1.83
1-30-80	2	0.79	0.10	48.0	0.71	6.9	11.6	0.98	0.33
2-07-80	3	3.56	0.46	18.0	0.40	6.3	10.7	5.28	0.38
2-10-80	4	0.99	0.28	3.0	0.57	1.9	3.1	16.86	0.29
2-26-80	5	0.33	0.00	24.0	0.02	15.6	17.2	0.12	0.00
3-11-80	6	1.00	0.00	4.5	0.68	31.3	20.0	0.16	0.01
3-16-80	7	0.75	0.00	3.0	0.54	4.9	19.2	0.79	0.01
3-19-80	8	0.17	0.00	21.5	0.01	2.7	13.8	0.45	0.00
3-23-80	9	1.62	0.04	22.0	0.60	5.4	21.1	1.42	0.19
3-27-80	10	0.93	0.02	9.0	0.51	3.5	11.9	2.24	0.10
3-29-80	11	0.34	0.04	1.5	0.22	1.3	17.2	1.49	0.01
4-02-80	12	3.43	1.05	3.0	3.02	4.4	22.7	3.44	0.31
4-11-80	13	3.86	0.84	41.0	0.43	8.4	24.3	1.89	0.33
4-17-80	14	0.89	0.34	18.5	0.54	4.0	22.3	1.01	0.10
4-24-80	15	4.34	1.30	38.0	2.15	6.9	28.6	2.20	1.80
4-30-80	16	3.52	1.81	39.0	2.82	4.5	25.7	3.04	3.35
5-12-80	17	0.28	0.05	3.0	0.27	9.8	27.9	0.10	0.00
5-15-80	18	7.32	2.52	21.0	1.56	2.6	27.7	10.16	3.33
5-18-80	19	0.62	0.47	8.0	0.40	2.5	23.9	1.04	0.03
5-21-80	20	1.71	0.72	4.0	0.60	2.5	27.5	2.48	0.06
5-29-80	21	6.15	2.24	49.5	4.82	7.8	28.9	2.73	6.51
6-08-80	22	0.47	0.01	1.5	0.31	8.4	31.2	0.18	0.00
6-19-80	23	3.36	0.09	27.5	1.10	10.7	31.2	1.00	0.30

P = Gross Precipitation (cm); TS = Total Streamflow (cm); SD = Storm Duration (hrs); MPI = Maximum Precipitation Intensity (cm/hr); DY = Days Between Runoff Producing Storms (Days); T = Average Maximum Temperature Prior to Storm (°C); API 1 = Antecedent Precipitation Index; API 2 = Antecedent Precipitation Index.

TABLE XIV

WATERSHED 2 HYDROLOGIC DATA

Date	Storm #	P	TS	SD	MPI	DY	T	API 1	API 2
1-19-80	1	4.32	0.01	94.5	0.34	5.0	15.3	5.69	1.83
1-30-80	2	0.79	0.58	48.0	0.71	6.9	11.6	0.98	0.33
2-07-80	3	3.56	0.57	18.0	0.40	6.3	10.7	5.27	0.38
2-10-80	4	0.99	0.26	3.0	0.57	1.9	3.1	16.86	0.29
2-26-80	5	0.33	0.00	24.0	0.02	15.6	17.2	0.12	0.00
3-11-80	6	1.00	0.00	4.5	0.68	30.3	20.0	0.17	0.01
3-16-80	7	0.75	0.00	3.0	0.54	35.4	19.2	0.11	0.00
3-19-80	8	0.17	0.00	21.5	0.01	38.2	13.8	0.03	0.00
3-23-80	9	1.62	0.00	22.0	0.60	41.8	21.1	0.18	0.02
3-27-80	10	0.93	0.00	9.0	0.51	46.2	11.0	0.17	0.01
3-29-80	11	0.34	0.00	1.5	0.22	47.9	17.2	0.04	0.00
4-02-80	12	3.43	0.15	3.0	3.02	52.3	22.7	0.28	0.03
4-11-80	13	3.86	0.02	41.0	0.43	8.4	24.3	1.89	0.33
4-17-80	14	0.89	0.00	18.5	0.54	4.0	22.3	1.00	0.10
4-24-80	15	4.34	1.11	38.0	2.15	10.2	28.6	1.49	1.22
4-30-80	16	3.52	1.26	39.0	2.82	4.5	25.7	3.04	3.35
5-12-80	17	0.28	0.00	3.0	0.27	9.8	27.9	0.10	0.00
5-15-80	18	7.32	2.11	21.0	1.56	12.5	27.7	2.11	0.69
5-18-80	19	0.62	0.29	8.0	0.40	2.5	23.9	1.04	0.03
5-21-80	20	1.71	0.39	4.0	0.60	2.5	27.5	2.48	0.06
5-29-80	21	6.15	1.02	49.5	4.82	7.8	28.9	2.73	6.51
6-08-80	22	0.47	0.00	1.5	0.31	8.4	31.2	0.18	0.00
6-19-80	23	3.36	0.01	27.5	1.10	19.1	31.3	0.56	0.17

P = Gross Precipitation (cm); TS = Total Streamflow (cm); SD = Storm Duration (hrs); MPI = Maximum Precipitation Intensity (cm/hr); DY = Days Between Runoff Producing Storm (Days); T = Average Maximum Temperature Prior to Storm (°C); API 1 = Antecedent Precipitation Index; API 2 = Antecedent Precipitation Index.

TABLE XV

WATERSHED 3 HYDROLOGIC DATA

Date	Storm #	P	TS	SD	MPI	DY	T	API 1	API 2
1-19-80	1	4.78	0.37	59.0	1.00	5.0	15.3	6.25	3.71
1-30-80	2	0.93	0.01	47.0	0.21	8.4	11.6	0.96	0.09
2-07-80	3	4.43	1.41	17.0	0.60	6.3	10.7	6.57	0.67
2-10-80	4	0.83	0.62	2.5	0.67	1.9	3.1	14.10	0.23
2-26-80	5	0.34	0.00	25.0	0.01	15.6	17.2	0.13	0.00
3-11-80	6	1.16	0.00	5.0	0.74	30.4	20.0	0.19	0.01
3-16-80	7	0.69	0.00	2.5	0.35	35.4	19.2	0.10	0.00
3-19-80	8	0.17	0.00	21.5	0.00	38.2	13.8	0.03	0.00
3-23-80	9	1.79	0.01	13.0	0.89	41.9	21.1	0.20	0.02
3-27-80	10	1.15	0.05	9.0	0.50	3.9	11.0	2.47	0.11
3-29-80	11	0.32	0.03	2.5	0.26	1.3	17.2	1.42	0.01
4-02-80	12	3.42	2.04	3.0	4.53	4.0	22.7	3.76	0.51
4-11-80	13	3.91	0.82	40.5	0.81	8.2	24.3	1.96	0.64
4-17-80	14	1.23	0.32	17.5	1.02	3.7	22.3	1.49	0.27
4-24-80	15	6.56	4.01	39.5	3.81	7.0	28.6	3.28	4.93
4-30-80	16	3.57	2.54	37.5	2.79	4.5	25.7	3.08	3.23
5-12-80	17	0.17	0.00	3.0	0.01	9.8	27.9	0.06	0.00
5-15-80	18	7.32	2.92	21.0	1.56	12.6	27.7	2.09	0.69
5-18-80	19	0.95	0.31	8.0	0.64	2.5	23.9	1.58	0.08
5-21-80	20	1.83	0.60	13.5	0.53	2.5	27.5	2.66	0.19
5-29-80	21	6.15	3.51	44.0	4.82	7.3	28.9	2.92	6.19
6-08-80	22	0.51	0.00	1.5	0.34	8.4	31.2	0.19	0.00
6-19-80	23	6.28	0.01	27.5	4.23	19.1	31.3	1.05	1.22

P = Gross Precipitation (cm); TS = Total Streamflow (cm); SD = Storm Duration (hrs); MPI = Maximum Precipitation Intensity (cm/hr); DY = Days Between Runoff Producing Storms (Days); T = Average Maximum Temperature Prior to Storm (^{o}C); API 1 = Antecedent Precipitation Index; API 2 = Antecedent Precipitation Index.

APPENDIX C

ANALYSIS OF VARIANCE

TABLES

TABLE XVI

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING PRECIPITATION WITH STREAMFLOW ON WATERSHED 1

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
P	1	0.038	9.038	56.98	0.0001	0.731
Error	21	3.331	0.159			
Total	22	12.369				

Parameter	Estimate
Intercept	-0.141
P	0.315

P = Gross Precipitation

TABLE XVII

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING PRECIPITATION WITH STREAMFLOW ON WATERSHED 2

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
P	1	3.567	3.567	24.12	0.0001	0.535
Error	21	3.106	0.148			
Total	22	6.673				

Parameter	Estimate
Intercept	-0.099
P	0.198

P = Gross Precipitation

TABLE XVIII

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING PRECIPITATION
WITH STREAMFLOW ON WATERSHED 3

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
P	1	19.913	19.913	28.38	0.0001	0.575
Error	21	14.737	0.702			
Total	22	34.650				

Parameter	Estimate
Intercept	-0.178
P	0.405

P = Gross Precipitation

TABLE XIX

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING WATERSHED 1 WITH WATERSHED 2

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_2	1	9.593	9.593	72.55	0.0001	0.776
Error	21	2.777	0.132			
Total	22	12.370				

Parameter	Estimate
Intercept	0.149
TS_2	1.199

TS = Total Streamflow

Subscripts refer to Watersheds

TABLE XX

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING WATERSHED 1 WITH WATERSHED 3

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_3	1	10.072	10.072	92.08	0.0001	0.814
Error	21	2.297	0.109			
Total	22	12.369				

Parameter	Estimate
Intercept	0.095
TS_3	0.540

TS = Total Streamflow
Subscripts refer to Watersheds

TABLE XXI

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING WATERSHED 2 WITH WATERSHED 1

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_1	1	5.175	5.175	72.55	0.0001	0.776
Error	21	1.498	0.071			
Total	22	6.673				

Parameter	Estimate
Intercept	-0.021
TS-1	0.647

TS = Total Streamflow
Subscripts refer to watershed

TABLE XXII

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING WATERSHED 2 WITH WATERSHED 3

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_3	1	4.424	4.424	41.30	0.0001	0.663
Error	21	2.249	0.107			
Total	22	6.673				

Parameter	Estimate
Intercept	0.033
TS-3	0.357

TS = Total Streamflow
Subscripts refer to watersheds

TABLE XXIII

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING
WATERSHED 3 WITH WATERSHED 1

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_1	1	28.215	28.215	92.08	0.0001	0.814
Error	21	6.435	0.306			
Total	22	34.650				

Parameter	Estimate
Intercept	0.015
TS_1	1.510

TS = Total Streamflow
Subscripts refer to watersheds

TABLE XXIV

ANALYSIS OF VARIANCE FOR LINEAR MODEL REGRESSING WATERSHED 3 WITH WATERSHED 2

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_2	1	22.971	22.971	41.30	0.0001	0.663
Error	21	11.680	0.556			
Total	22	34.651				

Parameter	Estimate
Intercept	0.225
TS_2	1.855

TS = Total Streamflow
Subscripts refer to watersheds

TABLE XXV

MULTIVARIATE MODEL ANALYSIS OF VARIANCE FOR
WATERSHED 1 INCLUDING WATERSHED 2

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_2	1	9.593	9.593	196.09	0.0001	0.925
MPI	1	1.465	1.465	29.95	0.0001	
P	1	0.382	0.382	7.81	0.0116	
Error	19	0.929	0.049			
Total	22	12.369				

Parameter	Estimate
Intercept	- 0.104
TS_2	0.668
MPI	0.202
P	0.106

Subscripts refer to watersheds
P = Gross Precipitation
MPI = Maximum Precipitation Intensity

TABLE XXVI

MULTIVARIATE MODEL ANALYSIS OF VARIANCE FOR
WATERSHED 1 INCLUDING WATERSHED 3

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_3	1	10.072	10.072	165.43	0.0001	0.911
SD	1	0.016	0.016	0.26	0.6159	
P	1	0.671	0.671	11.02	0.0038	
API 2	1	0.514	0.514	8.45	0.0094	
Error	18	1.096	0.061			
Total	22	12.369				

Parameter	Estimate
Intercept	0.063
TS_3	0.217
SD	-0.007
P	0.138
API 2	0.179

TS = Total Streamflow; SD = Storm Duration; API2 = Antecedent Precipitation Index; Subscripts refer to watersheds

TABLE XXVII

MULTIVARIATE MODEL ANALYSIS OF VARIANCE FOR WATERSHED 3 INCLUDING WATERSHED 1

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_1	1	28.215	28.215	140.55	0.0001	0.890
SD	1	0.051	0.051	0.260	0.6192	
API2	1	2.569	2.569	12.800	0.0020	
Error	19	3.814	0.201			
Total	22	34.649				

Parameter	Estimate
Intercept	0.170
TS_1	1.158
SD	-0.014
API2	0.321

TS = Total Streamflow; SD = Storm Duration; API2 = Antecedent Precipitation Index; Subscripts refer to watersheds

TABLE XXVIII

MULTIVARIATE MODEL ANALYSIS OF VARIANCE FOR
WATERSHED 3 INCLUDING WATERSHED 2

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_2	1	22.971	22.971	118.070	0.0001	0.899
SD	1	0.418	0.418	2.150	0.1601	
API2	1	6.815	6.815	35.030	0.0001	
MPI	1	0.945	0.945	4.860	0.0408	
Error	18	3.502	0.195			
Total	22	34.651				

Parameter	Estimate
Intercept	0.126
TS_2	1.297
SD	-0.014
API2	0.320
MPI	0.197

TS = Total Streamflow; SD = Storm Duration; MPI = Maximum Precipitation Intensity; API2 = Antecedent Precipitation Index; Subscripts refer to watersheds

TABLE XXIX

MULTIVARIATE MODEL ANALYSIS OF VARIANCE FOR WATERSHED 2 INCLUDING WATERSHED 1

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_1	1	5.175	5.175	83.09	0.0001	0.813
MPI	1	0.252	0.252	4.05	0.0578	
Error	20	1.246	0.062			
Total	22	6.673				

Parameter	Estimate
Intercept	0.025
TS -1	0.828
MPI	-0.148

TS = Total Streamflow
MPI = Maximum Precipitation Intensity
Subscripts refer to watershed

TABLE XXX

MULTIVARIATE MODEL ANALYSIS OF VARIANCE FOR WATERSHED 2 INCLUDING WATERSHED 3

Source	DF	Sum of Squares	Mean Square	F	OSL	R-Square
TS_3	1	4.424	4.424	45.29	0.0001	0.751
SD	1	0.000	0.000	0.00	0.9841	
P	1	0.155	0.155	1.59	0.2246	
Error	19	1.661	0.098			
Total	22	6.240				

Parameter	Estimate
Intercept	-0.367
TS -3	0.180
SD	-0.007
P	0.263

P = Gross Precipitation; TS = Total Streamflow; SD = Storm Duration; Subscripts refer to watersheds

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VITA

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