SEDIMENT-PRECIPITATION-RUNOFF RELATIONSHIPS
FOR THREE EPHEMERAL FORESTED WATERSHEDS
IN SOUTHEASTERN OKLAHOMA

By

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IN SOUTHEASTERN OKLAHOMA

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CHAPTER I

INTRODUCTION

Clean, high quality water has been and is important to the growth and development of the United States. In some areas, growth has outpaced the available water resources. Fresh, clean water has become a necessity for large scale agriculture. Many industries require clean water as part of the manufacturing process or in the maintenance of equipment (Sawyer and McCarty, 1978). Another use is for human needs. As the human population increases and becomes more concentrated, the need for clean, treatable water will grow. A standard of quality must be maintained to keep the quality of health high and to provide water for agricultural purposes, industrial uses, and other multiple uses such as recreation and wildlife habitat. The increased multiple demands on water have increased the concern for maintaining a supply of clean, usable water.

In response to the need to maintain a high standard of water quality, Congress passed the Clean Water Act, Public Law 92-500 and its subsequent amendment, Public Law 95-217. Section 208 of Public Law 92-500 and sections of Public Law 95-217 address the need to limit the amount of pollutants entering streams from nonpoint sources. These sources include silvicultural practices as well as other land uses such as mining and agriculture. One program established to control nonpoint source pollution has been the development of Best Management Practices (BMP's).

A major area of concern in developing BMP's is the control of sediment due to nonpoint sources.

Water quality can be seriously reduced by increased sediment loads (Sawyer and McCarty, 1978). Sediment from land erosion is considered to be the primary source of suspended solid pollution in this nation's waterways (Grissinger and McDowell, 1970). Sediment from land erosion can be due to a variety of nonpoint sources including urban development, road construction, agriculture, and silvicultural practices.

In recent years, intensive forest management has begun in southeastern Oklahoma. Large tracts of land are being managed for a variety of wood products. Large areas are being converted to pine plantations. To make these areas productive, intensive site preparation is required which can lead to potential increased sediment loads in area streams. These potential increased loads can be caused by associated road construction or land clearing techniques conducted during the actual site preparation.

In addition to a great potential for forest products, southeastern Oklahoma has areas well suited for recreational activities such as hunting and camping. Clean water is abundant and streams have important sport fisheries. Careful management and stewardship is necessary for the coexistence of water resources, recreational activities, and silvicultural operations.

In response to the growth of intensive forestry in southeastern Oklahoma and its possible detrimental effects on water resources, the Oklahoma Forestry Division has developed BMP's for silvicultural activities. Development of effective BMP's requires an understanding of cause and effect relationships of nonpoint pollutants and being able to identify quantities of a pollutant which constitutes a problem. To address this need for information, field research is required. A need for this type of research has been identified in southeastern Oklahoma and several studies have been initiated in response to this need. This project examines relationships among sediment, runoff, and precipitation of three small, ephemeral, forested watersheds in southeastern Oklahoma.

The study is presented in two parts. The first part looks at surface runoff sources and process, and then relates these processes to sediment production for the watersheds. The second part investigates sediment loading of streams of three ephemeral watersheds and relationships between precipitation and runoff. The objectives of this project are:

1. To determine basic relationships among sediment, stormflow, and precipitation for three small, forested ephemeral watersheds in southeastern Oklahoma.

2. To determine the variability and source areas of surface runoff of a small, forested, ephemeral watershed in southeastern Oklahoma.

3. To determine relationships among sediment, surface runoff, and precipitation for three small, forested, ephemeral watersheds in southeastern Oklahoma.

4. To develop predictive models for sediment, precipitation, and stormflow among three small, forested, ephemeral watersheds in southeastern Oklahoma.

CHAPTER II

LITERATURE REVIEW

Stormflow

In an ephemeral forested watershed, the source of streamflow is due to precipitation. There is no flow resulting from groundwater discharge. The route precipitation takes in reaching a channel is important to forest management, potentially influencing the amount of erosion within the watershed. Understanding the processes by which precipitation reaches a channel can aid in preventing damage to a watershed.

Theories

For many years Hortonian overland flow was thought not to occur typically in forested watersheds (Dunne et al., 1975; Kirkby and Chorley, 1967). Horton's theory proposed that surface runoff will not occur unless rainfall intensity exceeds the infiltration rate (Horton, 1945). In most forested watersheds, infiltration rates are so great that overland flow due to high rainfall intensity rarely occurs (Kirkby and Chorley, 1967).

Therefore, subsurface stormflow was believed to be the main route water traveled in reaching a stream channel (Rowe, 1955). However, recent studies have indicated subsurface stormflow may not adequately explain hydrograph characteristics of some forested watersheds. Pierce (1967) suggested other processes may contribute to streamflow during a storm event. For runoff events Pierce studied in New Hampshire, the times to peak flow were much too short and volume of discharge too large to be attributed to subsurface stormflow alone. Freeze (1972) also suggested subsurface stormflow could not produce enough volume to achieve some of the observed peak flows for the events he studied in the northeastern United States.

The variable source area concept has been presented as an alternative to Horton's model to explain stormflow for forested watersheds (Hewlett and Hibbert, 1967; Dunne and Black, 1970). According to this concept, the sources of stormflow from watersheds with large infiltration capacities, such as forested catchments, are a combination of subsurface stormflow, direct precipitation on water surfaces, and types of overland flow. The variable source area concept suggests there are saturated and moist soils along stream channels which can contribute to surface runoff during a storm event (Freeze, 1972; Dunne and Black, 1970). Runoff source areas can be variable sized swales, concave areas, flat areas adjacent to a channel and other points where water can accumulate and lead to saturation of the soil.

The size of the saturated and moist areas varies with the length of rain storm and the intensity and amount of precipitation. At the start of a storm the saturated areas are immediately adjacent to a channel. With elapsed time the channel expands, incorporating these initial saturated areas. As channel expansion occurs, the size of the saturated area expands into the watershed (Satterlund, 1972). The area directly contributing to runoff grows during a storm and decreases at the end of a precipitation event as the water in the saturated soil drains into the channel.

To further explain and to expand the variable source area concept, Dunne et al. (1975) presented a runoff-producing zone concept which states that streamflow resulting from a precipitation event is caused by a combination of three processes: subsurface stormflow, return flow, and direct precipitation on saturated areas. Return flow is subsurface flow which returns to the surface in a saturated area near the stream channel or some area where water can accumulate and cause saturation. Direct precipitation on saturated areas is rainfall falling directly on a saturated area, resulting in surface runoff. Dunne et al. (1975) determined there were zones in which the degree of wetness generally decreases with distance from the channel. The occurrence of the three processes depends on the degree of wetness within a zone.

To adequately determine the potential runoff-producing zones requires extensive field mapping. Such factors as soil type and vegetation can be good indications of potential runoff-producing zones. In addition, monitoring soil moisture over time can be useful in estimating the potential size of runoff-producing zones (Dunne et al. 1975). Other factors and watershed characteristics may also be important in the consideration of sources of stormflow and the possibility of overland flow in certain zones. Some of these factors include: soils, topography, antecedent moisture, storm size including precipitation intensity and amount of vegetation, and ground cover (USFS and SCS, 1940; Ursic, 1965; Rowe, 1955; Bowie et al., 1975; Betson and Marius, 1969; and Dunne et al., 1975).

Factors Affecting Stormflow

Soils. Studies conducted by Betson and Marius (1969) indicated one important soil characteristic that influences the amount of runoff is depth of A horizon. The A horizon, the mineral horizon nearest the soil surface, is the area of maximum leaching and eluviation (Brady, 1974). The A horizon can be divided into different layers, but for the purposes of this study it will be discussed as one unit. Deep A horizons composed of very permeable soils have large infiltration capacities and less occurrence of surface runoff than soils with shallow, less permeable A horizons. Shallow A horizons with low infiltration capacity require less water to reach saturation, increasing the potential for surface runoff.

Soil type is important to runoff production. Ursic (1965) found that loess soils have high total runoff volumes. Bowie et al. (1975) support the importance of soil type to runoff. Fine textured soils such as silt loams tend to produce greater quantities of surface runoff than coarse soils. Coarse soils, such as sands, have high percentages of macropore spaces, allowing for increased permeability and infiltration capacity. Fine soils, such as clays and silts, have low percentages of macropore spaces, resulting in reduced permeability and infiltration capacity (Brady, 1974). Incorporation of organic matter into a soil can affect the potential of a soil to produce surface runoff. Organic matter incorporation can change soil structure, creating more macropore space. The increased macropore space improves permeability and infiltration capacity, decreasing the potential for surface runoff.

Forest soils typically have very large infiltration capacities (Lull and Reinhart, 1972; Hoover, 1950). The percent pore space is large for forested soils due to animal activity and the presence of fibrous roots in the upper soil horizons. In addition, microbial breakdown of organic material can increase the total pore space of the upper soil horizons (Pritchett, 1979). Due to the high permeabilities and infiltration capacities of most forest soil, the amount of surface runoff which can occur during a precipitation event is limited (Lull and Reinhart, 1972).

Vegetation and Ground Cover. Forest litter is another factor which influences total runoff and surface runoff. Rowe (1975) determined soils covered with less than one-half inch of litter usually produced higher surface runoff volumes than soils with thicker litter layers. Litter type can affect runoff production. Surface runoff has been found to be higher on sites with poorly developed hardwood litter than for pine-hardwood litter (Ursic, 1965). On a site with a well developed forest floor, surface runoff is low due to animal and microbial activity associated with litter decomposition increasing the pore space. As discussed previously, increased pore space can increase soil permeability and infiltration capacity.

Precipitation and Antecedent Moisture. Antecedent moisture and precipitation, in the form of rainfall, are important factors to consider when looking at surface runoff and total stormflow production (Betson and Marius, 1969). High antecedent moisture can result in reduced infiltration capacity, allowing rainfall intensity to more readily exceed the infiltration rate. However, other work suggests total rainfall coupled with antecedent moisture may be more important to surface runoff and total stormflow production (Hewlett and Forsten, 1977). High antecedent moisture at the beginning of a storm reduces the amount of rainfall required to bring a soil to saturation. Once saturation is reached the remaining rainfall can result in surface runoff.

Antecedent moisture frequently varies spatially within a watershed due to soil characteristics and topography (Kirkby and Chorley, 1967; Betson, 1964). Variation of antecedent moisture and infiltration capacity within a watershed can affect the distribution of saturated areas during a storm. Spatial variation of saturated areas will determine the relative importance of the three stormflow processes: subsurface flow, return flow, and direct precipitation into saturated areas as sources of storm runoff.

Topography. Areas with gentle slopes can have large numbers of shallow, concave areas or small swales which can become saturation points leading to surface runoff (Dunne et al., 1975). There are fewer rapid gradient changes on gentle sloping areas so water movement in the soil may be slowed, resulting in reduced permeability during storms. Areas with steep slopes tend to have more rapid water movement through the soil due to steeper gradients. Since water moves through the soil faster, there is less chance of saturated zones occurring. However, soil characteristics must be considered. As mentioned in preceding sections, soil depth and permeability are factors in determining the amount of water a soil is capable of holding and how water will move through a soil.

Determining and classifying the relationships among runoff processes and the factors influencing them is important in a forested watershed because these processes determine the amount of water and source of flow discharged from the watershed. The factors affecting runoff are interrelated and must be studied together to determine their relative effects on runoff and potential resultant erosion.

Sediment Sources and Causes

In an undisturbed, forested watershed the three main causes of sediment entering a stream are channel erosion, bank erosion, and surface erosion, with channel and bank erosion being the primary contributors (Lull and Reinhart, 1972; EPA, 1973). Surface erosion contributes the least amount of sediment. However, the processes and factors affecting surface erosion are important to the understanding of total sediment production in a forested watershed.

Total sediment produced from forested watersheds has been found to range between 2.24 kg per ha per year to extremes of 7.392 kg per ha per year (Fowler and Hardy, 1981). The highest sediment loads were reported to be in the northwest and southern United States. The lowest erosion rates for forested lands tend to be in areas which receive 30 inches or more of precipitation a year (Satterlund, 1972). Patric (1976) and Yoho (1980) found that soil losses between 122 to 224 kg per ha per year were common for most undisturbed forested watersheds of the eastern and southern United States, which were less than normal geologic rates of 403 kg to 672 kg per ha per year or typical rates from agricultural lands of 2240 kg to 11200 kg per ha per year (Table I). The large range in sediment production is due to specific characteristics of individual watersheds and regions (Patric, 1976).

Sediment produced from a watershed is due to three variables. These variables are: the inherent watershed characteristics such as soil type, channel density, and topography, the nature of precipitation events, and

TABLE I

EROSION RATES FROM FORESTED PLOTS AND SMALL WATERSHEDS IN THE EASTERN UNITED STATES

State	Site Size (Acres)	Erosion Rate kg/Ha/Year	Source
Arkansas	Watersheds, 1.3-1.6	6.7-29.1	Rogerson (48)
Kentucky	Watershed, 540	44.8	Collier (14)
Maryland	Watershed, 95	67.2	Cleaves et al. (12)
Maryland	Watershed, 140	336.3	Cleaves et al. (13)
Mississippi	Plot, 0.0009	112.1	Meginnis (43)
Mississippi	Watersheds, 3.3-4.6	22.4-89.7	Ursic & Dendy (59)
Mississippi	Watershed, 2.6	67.2	Ursic (58)
New Hampshire	Watershed, 3.0	89.7	Bormann et al. (7)
North Carolina	Plot of Unknown Size	4.5	Bennett (5)
North Carolina	Watershed, 6.0	717.4	Copley et al. (15)
North Carolina	Watershed, 23	160.0	Dils (19)
North Carolina	Watershed, 31	31.4	Johnson & Swank (35)
North Carolina	Watershed, 33	80.7	Johnson & Swank (35)
Ohio	Watershed, 2.2	22.4	Borst et al. (8)
Oklahoma	Plot, 0.01	22.4-112.1	Daniet et al. (17)
Pennsylvania	Watershed, 174,000	224.2	Williams & Reed (63)
Tennessee	Watershed, 1715	67.2	TVA (55)
Wisconsin	Watershed, 11.5	22.4	Hayes et al. (22)

Source: J. H. Patric (1976).

land use patterns such as vegetation and cover (Anderson, 1957; Leaf, 1966). The amount of surface erosion usually results from a combination of these variables and the specific factors listed with each variable. The factors affecting surface runoff and stormflow discussed in the previous section also are important factors affecting surface erosion. The processes which produce surface runoff are much the same as those producing surface erosion since surface runoff causes surface erosion (Leaf, 1966; Kirkby and Chorley, 1967; Rowe, 1955; USFS and SCS, 1940). It is necessary to expand on certain aspects of these factors to better understand the causes of surface erosion and the relationships of these factors to the forested watershed.

Precipitation

The impact of falling rain is the greatest force of moving water on most watersheds (Satterlund, 1972). This force is very important to the occurrence of surface erosion on a watershed. Raindrops can be destructive to soil aggregates (Meyer et al., 1975; Satterlund, 1972). This destructive force is a function of the kinetic energy produced by a falling raindrop. As a raindrop falls, its size and mass increase and the velocity increases until terminal velocity is reached. The kinetic energy also increases until terminal velocity is reached (Satterlund, 1972). At the point of impact, the energy is transferred, resulting in destruction of soil aggregates and movement of soil particles. The destruction and movement of soil aggregates and particles is a function of the stability of the aggregates and size of particles. Sometimes the impact of the raindrops can result in moving soil particles several feet. This movement is termed splash erosion (Satterlund, 1972).

Storm intensity affects the overall erosive force of rainfall. Leaf (1966) determined that the erosive force of rainfall increases as rain intensity increases. The increase in erosive force is due to a positive relationship between raindrop size and rainfall intensity; the median size of a raindrop increases as rain intensity increases up to three inches per hour (Wischmeier and Smith, 1958). Increasing drop size results in a greater mass per drop and an increased terminal velocity and greater kinetic energy. The actual erosive force exerted on the soil by rainfall is a function of the amount of mineral soil exposed to direct raindrop impact.

Ground Cover

The presence of ground cover in a watershed minimizes the impact of raindrop energy on a soil. An undisturbed forest floor usually has very few spots which are not covered with a layer of litter and humus. Litter serves as a buffer against the erosive forces of rainfall (Pritchett, 1979). The energy of the raindrop is dissipated before it can disturb the mineral soil. The thickness of the litter layer is also important to surface erosion. Erosion tends to be higher in areas with thin litter layers than those with thick layers (Rowe, 1955; USFS and SCS, 1940).

Soils

The texture and organic matter content are two main factors determining a soil's potential erodibility (Wischmeier and Smith, 1978; Wischmeier and Mannering, 1969; Leaf, 1966; Satterlund, 1972). High percentages of silt will lead to high potential erodibility in soils (Wischmeier and Smith, 1978). Leaf (1966) determined that large percentages of loose, fine material within a soil results in higher erosion rates. If not sufficiently covered with litter or otherwise protected, these soils are more susceptible to the erosive forces of rainfall. Wischmeier and Mannering (1969) determined an increase in the percentage of incorporated organic matter in a soil decreased the erosion potential. The decreased erosion is due to increased permeability, infiltration capacity, and the development of soil aggregates which can resist the erosive forces of rainfall.

Forest soils have a high amount of incorporated organic matter contributed from the litter cover leading to a reduction of the erosion potential (Dissmeyer and Foster, 1980). In addition, forested soils typically have a dense mat of fibrous roots in the upper inches which serve as protection against the erosive forces of rainfall and surface runoff. Other factors which are important to the erosive response of forested soils include on-site storage and residual binding (Dissmeyer and Foster, 1980). The root mat discussed above and the large amount of organic matter incorporated in forested soils tend to bind the soil into stable aggregates which can resist erosion. Natural depressions such as stumpholes provide a certain amount of storage, reducing the overall total runoff and leading to a possible reduction of erosion.

Flowing Water

Laminar Flow. The erosive potential of flowing water is a function of velocity. Water moving at high velocity is more capable of detaching and transporting soil particles (Satterlund, 1972; EPA, 1973; Meyer, 1975). Important factors affecting surface runoff velocities are slope length and slope gradient. The amount of soil loss due to erosion per unit area generally increases with an increase in slope length (Wischmeier and Smith, 1978). Long slopes allow greater accumulation of surface runoff which increases detachment and transport capabilities of the runoff. Surface runoff occurring on steep slopes can obtain high flow velocities, resulting in increased soil detachment capabilities (EPA, 1973). Flow resistance of the surface which the water moves over will affect the velocity of the flow. A broken surface will offer more resistance to flow than a smooth surface, resulting in slower flows and a reduction of the erosive potential of flowing water (Wischmeier and Smith, 1978). To determine the erosive potential of surface flow, it is important to look at the above mentioned variables together.

Channelized Flow. The factors affecting the erosive potential of channelized flow are similar to those discussed in the laminar flow section. An increase in flow velocity increases the carrying power of channel flow (Hewlett and Nutter, 1969; Satterlund, 1972). Also, increased total flow leads to increased erosion in a channel because of increased carrying power and a greater area of channel exposed to flow (Hewlett and Nutter, 1969). Factors which can limit the erosive force of flow are the smoothness and straightness of a channel. Smoothness of a channel includes the amount of vegetation in the channel and the composition of the channel bottom and sides. A rocky channel or vegetated channel will have increased resistance to flow than a smooth channel with few obstructions. Increased resistance results in decreased velocity reducing the carrying power (Leopold et al., 1964). A combination of factors must be considered when looking at channel flow as was the case with laminar flow.

Sediment-Runoff-Precipitation Relationships

Sediment loading in streams is directly related to storm magnitude and certain runoff characteristics. Knowledge of relationships between storm magnitude and sediment loading can aid in the understanding of sediment movement in a stream channel. Determining these relationships for forested watersheds aids in determining if silvicultural treatments adversely alter these relationships and result in increased sediment loads in streams.

Sediment and Rainfall Quantity and Intensity

Work by Guy (1964), which examined several drainage basins with different land uses in the eastern United States, indicated sediment loads increased as total rainfall increased with high volume of rainfall, tending to cause large volumes of streamflow which can lead to increased carrying powers and greater erosive potential as discussed previously.

Guy (1964) also determined that increases in rainfall intensity result in higher sediment loads. Work by Paustrian and Beschta (1979) support the relationship between intensity and sediment loading. As discussed earlier, the erosive force of rainfall increases as rain intensity increases. The increased erosive force can result in making more soil particles available to contribute to sediment loading. Also, storm intensity can be a factor in the time of rise to peak flow during a storm. As the slope of the rise to peak flow increases, the probability of larger sediment loads increases (Paustrian and Beschta, 1979).

Sediment Loading and Time of Rainfall

The time of year a storm occurs affects the relationship between sediment and precipitation. In some areas there is a defined storm season. The storm season is when the majority of the yearly precipitation occurs. Paustrian and Beschta (1979) determined a flushing of fine sediment particles can occur early in a storm season, resulting in higher sediment loads during early season storms. During drier periods, fine particles are replaced by deposition during low flows by soil creep, dry ravel, and bank failure (Paustrian and Beschta, 1979).

Storm magnitude can also vary with season. High intensity convective storms are common in some areas in the spring and summer months. The increased erosive potential of high intensity rainfall can affect sediment loading on a seasonal basis.

Sediment and Storm Variability

Doty et al. (1981) determined that for forested watersheds in Hawaii, two or three major storms can be the major sediment producers for a year. These storms are of greater magnitude than the average storm of an area. They determined that 80 percent of the total sediment produced during the study period was produced during 2 percent of the total storm time accumulated for the study period. Other studies involving other land uses besides undisturbed forests support these findings (Wilber and Hunter, 1977; Randall et al., 1978).

Sediment concentrations can be highly variable within an individual storm. Peak sediment concentrations often occur before or at the peak discharge of a stream during a runoff event (Paustrian and Beschta, 1979). High flow velocities and early removal of easily detached fine particles are factors affecting sediment concentrations. As the flow recedes, many of the fine particles have been removed by the initial rise in flow and the larger particles settle out as velocity decreases, resulting in lower sediment concentrations. Sediment concentrations are also lower for subsequent peak flows after the initial peak during storm flows of more than one peak. Early removal of fine particles may influence the concentration reduction for subsequent peaks. The relationships among sediment, runoff, and precipitation are complex and depend on factors that can vary regionally.

CHAPTER III

MATERIALS AND METHODS

Study Area

General Description

The study was conducted on three forested, ephemeral watersheds which are part of the drainage basin of Clayton Lake. The watersheds are located at Latitude 34°41'45", Longitude 95°20'00", approximately 13 km southeast of Clayton, Oklahoma (Figures 1 and 2). The three watersheds range in size from 6.07 ha to 7.86 ha (Table II). The drainage pattern for the watersheds is generally composed of two or three main channels with dendritically branching tributaries (Figure 3). Other information on general watershed characteristics is included in Table II. These watersheds will be referred to as WS-1, WS-2, and WS-3 for the remainder of this study.

The watersheds are maintained and monitored by the Oklahoma State University Department of Forestry as part of a study to determine the effects on water quality of forest management practices currently being implemented in southeastern Oklahoma. The watersheds have been made available for this study by Weyerhaeuser Company and Nekoosa Papers Company.

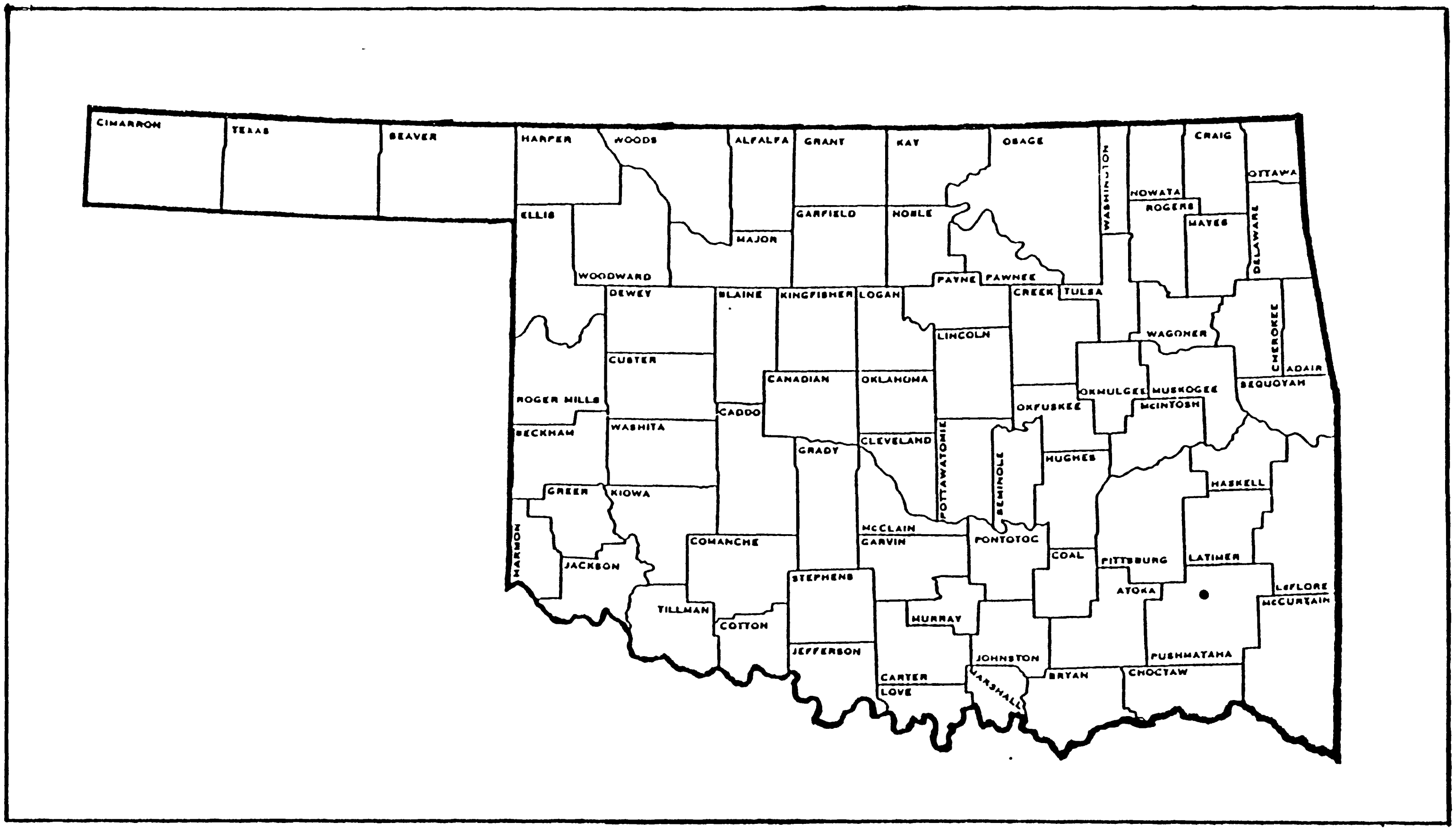


Figure 1. Location of Clayton Lake Watershed Research in Oklahoma

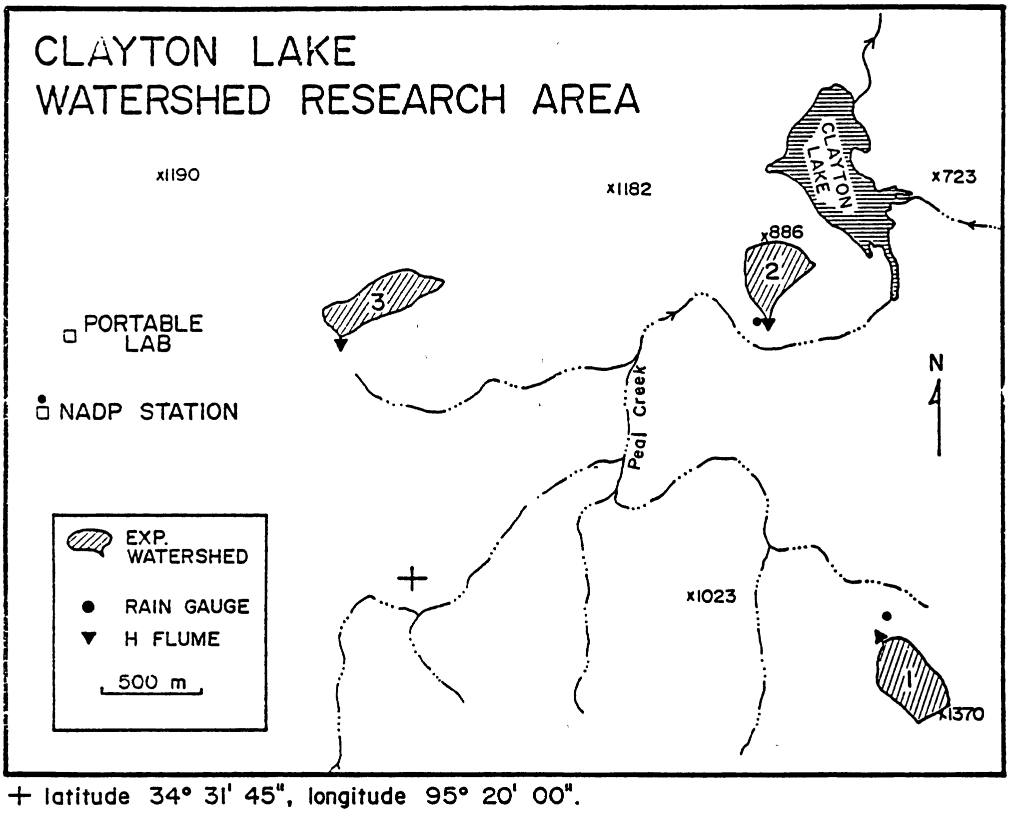


Figure 2. Clayton Lake Watershed Research Area

ERRATA

This Errata Sheet replaces TABLE 2 on page 22; the replacement was made on September 16, 1988.

TABLE II

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.

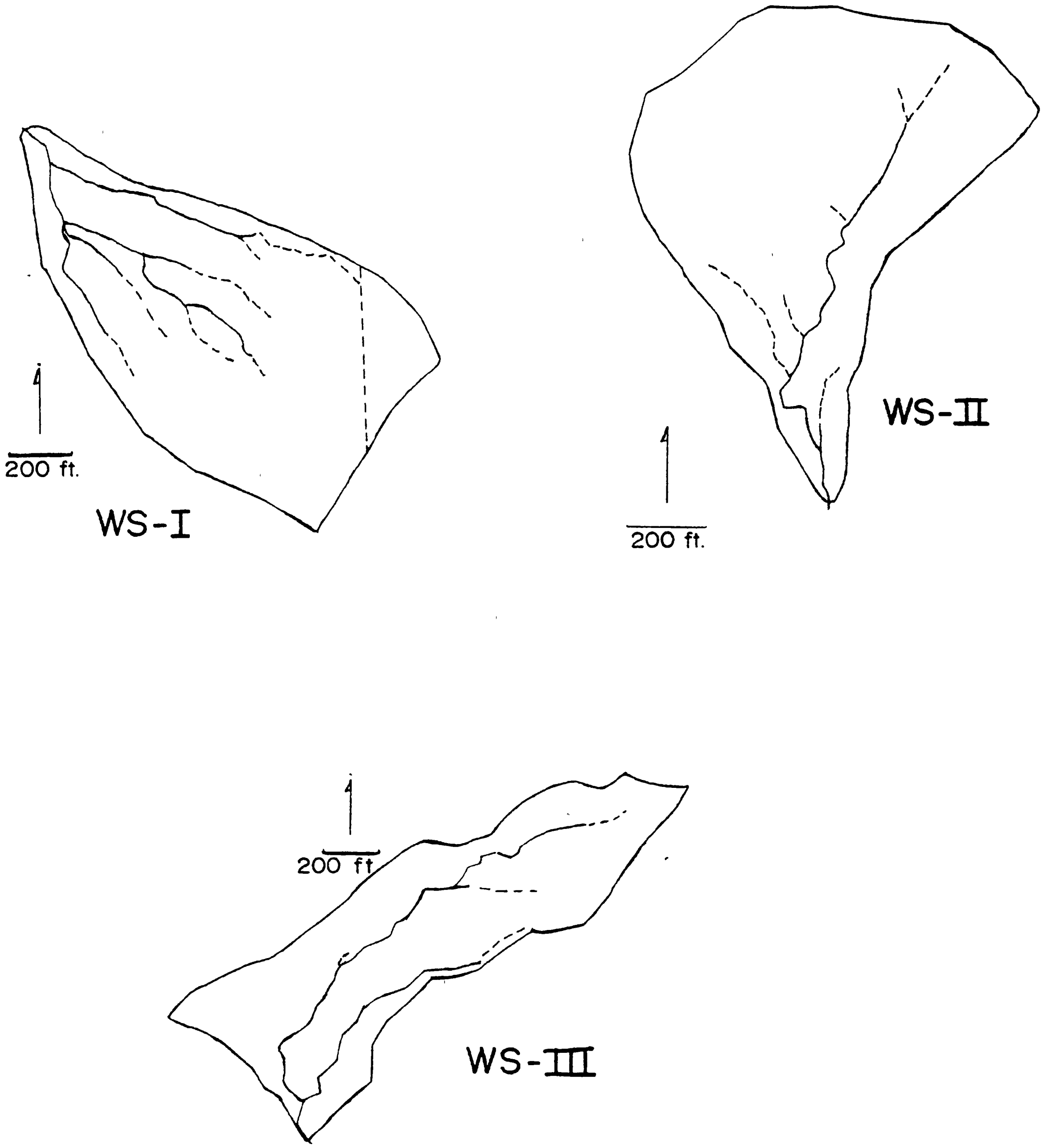


Figure 3. Drainage Patterns of the Three Study Watersheds

Soils and Geology

The soils found on the study are formed from sandstone and shale bedrock of the Jackfort Unit which developed during the Pennsylvania Period. The major soil association is the Carnasaw-Pirum-Clebit, moderately steep (Bain and Waterson, 1979). These sites have slopes averaging 12 to 20 percent with extremes up to 40 percent. Colluvial soils such as the Octavia series are also present with the Carnasaw-Pirum-Clebit association on the study watersheds (Bain and Abernathy, 1984).

The Carnasaw soil series is a clayey, mixed, thermic Typic Hapludults with a sandy loam texture in the A horizon. A horizon depth averages 8.9 cm. This series is typically found on slopes between 8 and 20 percent. Carnasaw soils are deep, well drained, and have slow permeability. Soil pH ranges from 4.5 to 5.5 and natural fertility is low.

The Clebit soil series is a loamy-skeletal, siliceous, thermic Lithic Dystrochrept with a stony, very fine sandy loam A horizon. A horizon depth averages 6.4 cm. Clebit soil series is commonly found on upland sites with slopes ranging from 8 to 45 percent. Clebit soils are shallow, well drained with moderately rapid permeability. Soil pH ranges from 5.1 to 6.5 and natural fertility is low.

The Pirum soil series is a fine loamy, siliceous, thermic Typic Hapludult with a stony fine sandy loam A horizon. A horizon depth ranges between 0 to 25 cm. This soil typically occupies upland sites with slopes ranging between 12 and 30 percent. Pirum soils are moderately deep and well drained with moderate permeability. Soil pH ranges from 4.5 to 5.5 and natural fertility is low.

The Octavia soil series is a fine-loamy, silaceous, thermic typic Paleudults with a stony fine sandy loam A horizon. A horizon depth averages 7.6 cm. The Octavia soil series is found on foot slopes or colluvial benches with slopes ranging between 3 to 45 percent. Octavia soils are deep, well drained with moderately slow permeability. Soil pH ranges from 5.6 to 6.0 and natural fertility is low.

Vegetation

The three watersheds are predominantly covered with pine-hardwood forests (Tables XXV, XXVI, and XXVII, Appendix B). Shortleaf pine (*Pinus echinata*), hickory (*Carya sp.*), and oak (*Quercus sp.*) comprise a majority of the canopy trees. In some isolated areas immediately adjacent to stream channels on WS-1, blackgum (*Nyssa sylvatica*) is present in the canopy. A shrub layer comprised of members of the Rosaceae, Ericaceae and of other shrub families are present. Also, a low ground cover comprised of blueberry (*Vaccinium sp.*), poison ivy (*Rhus radicans*), bluestems (*Andropogon sp.*) and other ground vegetation occurs over much of the sites. The litter layer is fairly uniform across the watersheds except where rock is exposed (Table II).

Watershed Instrumentation

Each of the three watersheds was equipped with a 1.21 m H-flume. Stream stage was recorded using a Belfort water level recorder for continuous stage monitoring. Stage was converted to discharge using rating curves developed for each watershed (Vowell, 1980). Water samples for suspended solids determination were obtained using an Isco automatic pump sampler, model 1680. Approximately 500 ml discrete samples were obtained at 3.05 cm stage intervals by the pump sampler linked to a stage activated triggering mechanism (Turton and Wigington, in press).

A weighing bucket rain gage was located on each watershed for continuous monitoring of precipitation. Storm duration, precipitation intensity, and total precipitation were obtained using data collected from each rain gage.

A rain gage was not available for WS-2 for part of the study period. Using data for periods when WS-2 was monitored, multiple linear regression models were developed using precipitation data from WS-1 and WS-3 to predict precipitation on WS-2. A coefficient of determination (R^2) of 0.97 was obtained for WS-1 and WS-2, and a R^2 of 0.85 was obtained for WS-3 and WS-2 (Table XXIV, Appendix A). WS-1 precipitation data were used for estimating WS-2 precipitation for the unmonitored periods.

Climate

The study area receives an average of 127 cm of precipitation yearly (Bain and Waterson, 1979). The majority of this precipitation occurs in the winter and spring (Figure 4), resulting from frontal systems moving from the Pacific. Winter storms tend to be low intensity and long duration and spring storms are a series of frontal and convective showers. Summer rainfall is due mainly to convective storms and tends to be widely scattered.

Average daily temperature ranges between 6.5°C in the winter and 26.8°C in the summer. Extremes range from -16°C in the winter to 40°C in the summer (Bain and Waterson, 1979).

Hydrology

The period of largest runoff volumes is in late spring with May usually having the greatest monthly runoff (Figure 5). High spring runoff

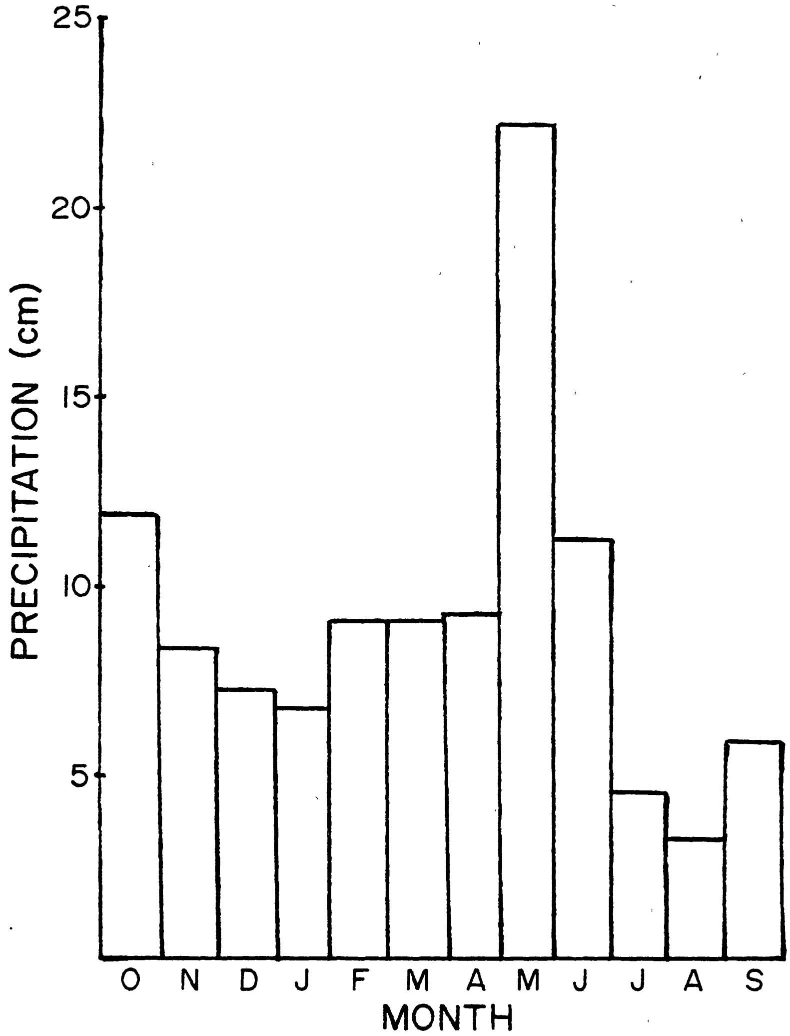


Figure 4. Average Monthly Precipitation for Clayton Lake Watershed Research Area for 1979-83

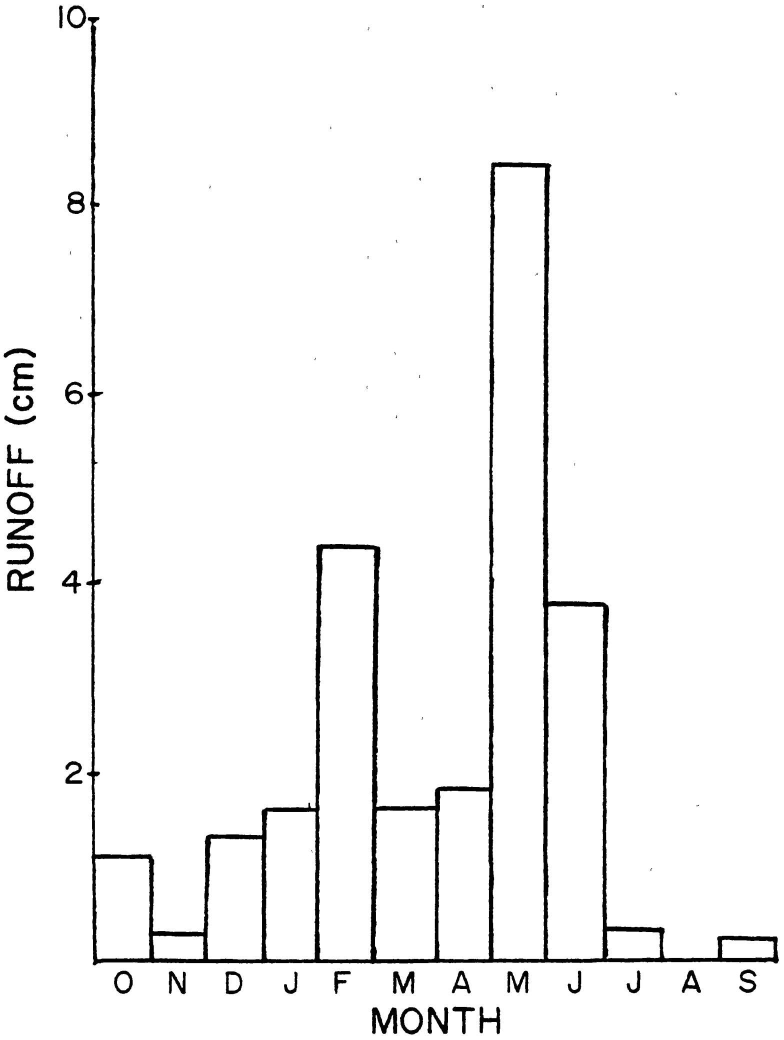


Figure 5. Average Monthly Runoff for the Three Study Watersheds for 1979-83

coincides with the periods of greatest precipitation (Figure 4). During the summer months runoff is limited due to hot and dry conditions and high evapotranspiration potentials. Runoff occurrence increases in the fall and winter as basin recharge occurs and precipitation events become more frequent.

Large Plot Surface Runoff and Erosion

Surface runoff was monitored on the three watersheds using six large runoff plots. The large plots were utilized to measure surface runoff occurrence under natural watershed conditions. Variables such as slope length, slope angle, ground cover, and vegetation would be more representative of actual watershed conditions in a large plot where typical slope lengths and ground cover variations may be taken into consideration. Relationships established between surface runoff, precipitation, and surface erosion on these large plots may provide a basis to explain processes on the whole watershed. In addition, surface runoff and sediment production variability among the plots will provide an estimate of variability within each watershed and among the watersheds.

Sampling Layout

Two runoff plots were established on each watershed. Plot sizes ranged between 25 m^2 to 249 m^2 (Table III). For WS-2 and WS-3, one plot was placed in the lower portion of the watershed near the point of discharge and the second plot was placed in the upper part of the drainage. On WS-1, both plots were placed in the middle of the watershed (Figure 6).

Whenever possible, plots were placed so natural drainage boundaries could be utilized to delineate flow areas. Each plot was constructed

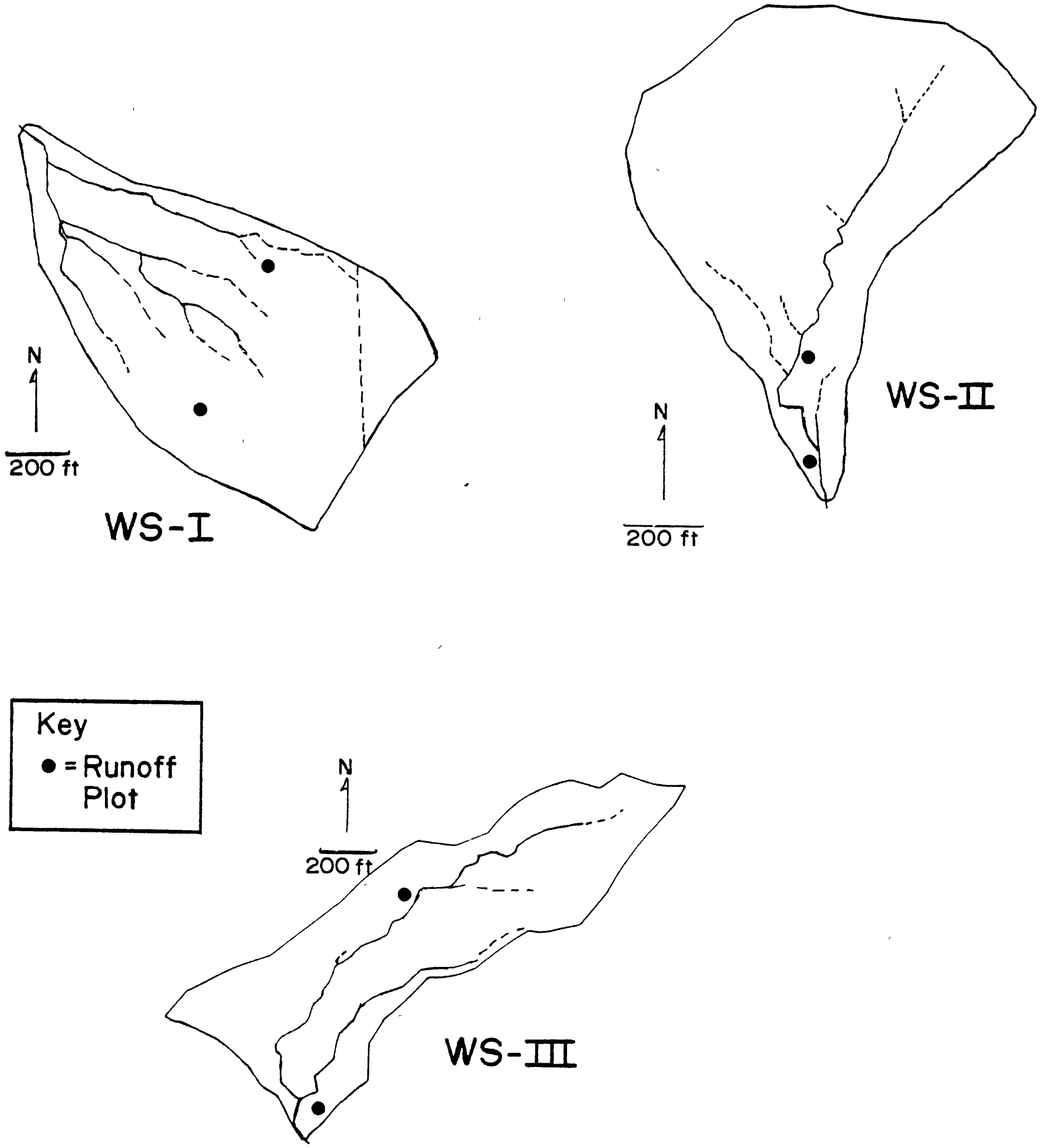


Figure 6. Location of Large Surface Runoff Plots Within the Three Watersheds

using a 1.52 m section of gutter at the base to serve as a surface runoff collector. The gutter was placed in the ground so the lip was just below the mineral soil surface. Disturbance was kept to a minimum. Attached to the gutter was a 2.54 cm diameter hose which ran to a 250 l holding tank. Metal flashing was placed into the soil approximately 2 to 4 cm deep along portions of the natural boundary to prevent leakage around the gutter (Figure 7). Flashing was also used to define plot boundaries where natural topographic boundaries were not available at a sampling site.

Five throughfall collectors were placed within or immediately adjacent to each plot. Throughfall was used as an estimate of the total precipitation reaching each plot.

TABLE III

LARGE PLOT AREAS AND LENGTHS

	Watershed 1		Watershed 2		Watershed 3	
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2
Area (m^2)	182	25	81	52	119	249
Length (m)	55	8	25	19	37	76

Sampling Method

The plots were monitored on an individual storm basis, from April, 1983, through June, 1983. After each precipitation event, two 500 ml

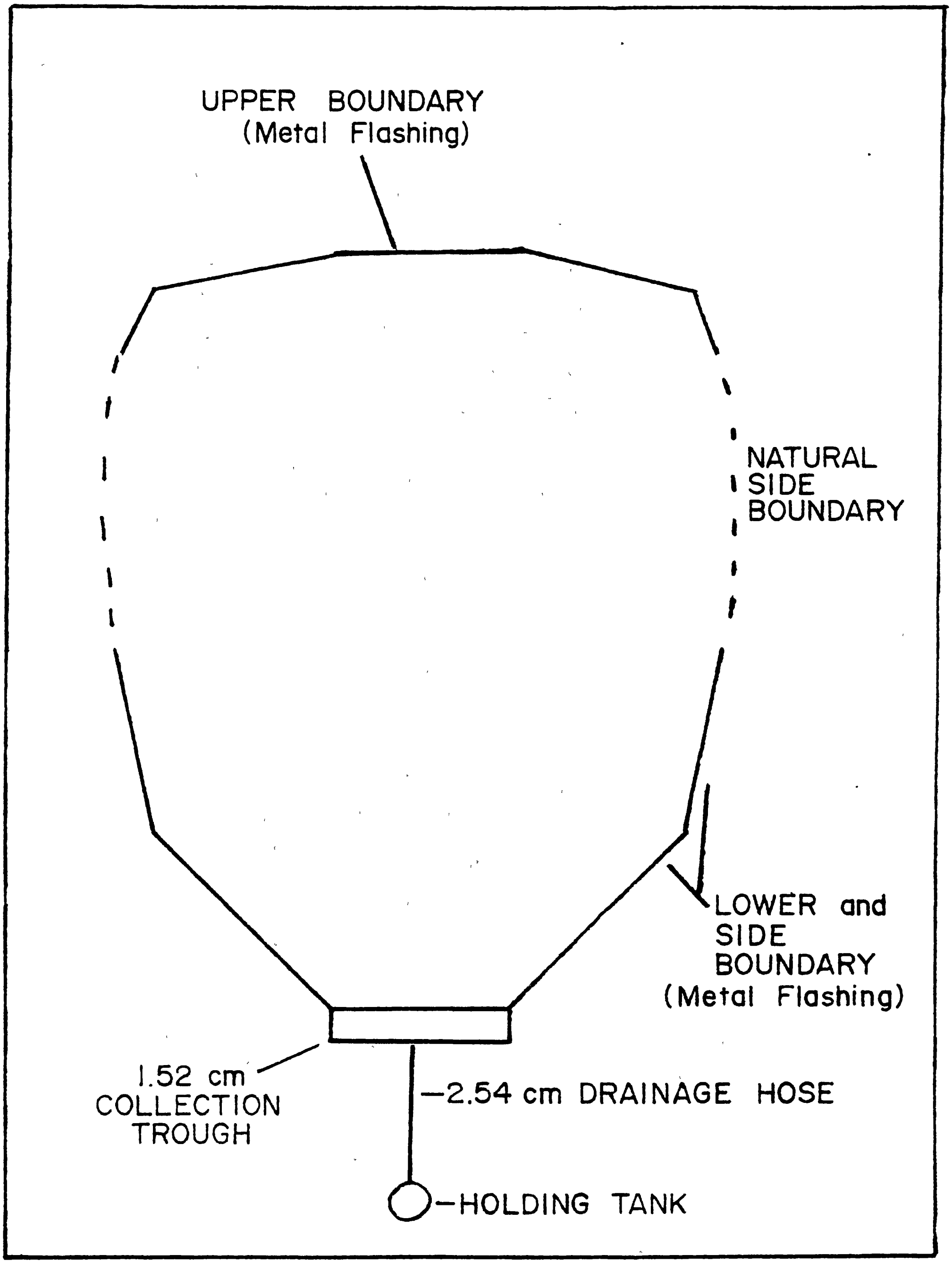


Figure 7. Plan View of Large Surface Runoff Plot

grab samples were obtained from each holding tank to analyze for total suspended solids. The water collected in each holding tank was thoroughly mixed prior to obtaining the grab samples to resuspend any solid material which may have settled to the bottom of the holding tank. The mixing insured an unbiased grab sample of surface runoff.

After the grab samples for suspended solids analysis were obtained, the total volume of surface runoff in each tank was determined. Water was bailed from each tank using a one-gallon bucket and measured using a 2000 ml graduated cylinder. After all the water was measured, the holding tank was rinsed.

Grab samples were returned to the laboratory and total suspended solid concentration was determined by procedures described by EPA (1979). Total suspended solid concentration was used as an estimate of sediment concentration. Sediment loading for each plot on a storm-by-storm basis was determined by multiplying the average sediment concentration of the two grab samples by corresponding surface runoff volumes.

Precipitation intensity and duration information were obtained from weighing bucket rain gage data collected after each precipitation event. The rain gage data were reduced and converted to intensity and duration utilizing computer programs. Total throughfall was determined by measuring the volume of each of the five collectors per plot with a 2000 ml graduated cylinder and calculating the average of the five collectors.

A ground cover survey was conducted on each plot using a line-plot sampling system. An X,Y axis system was established for each plot and five sets of X,Y coordinates were randomly chosen using a computer (Figure 8). Each coordinate position was located within the plot and a measuring tape was extended at a random angle 3.05 m from each coordinate

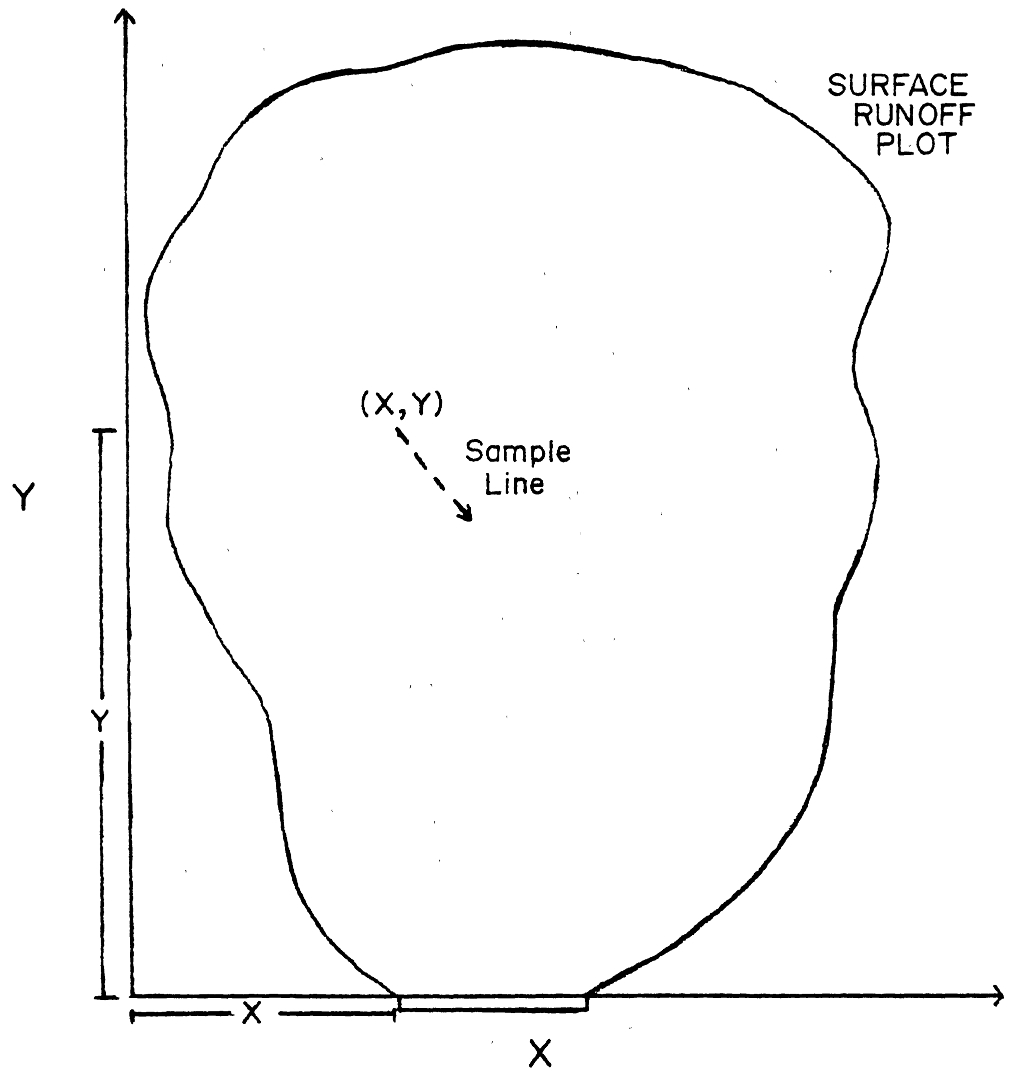


Figure 8. Example of X,Y Coordinate System Utilized for the Line-Point Ground Cover Survey Implemented on Each Large Surface Runoff Plot

point. At 0.15 m intervals along the tape the ground cover type was determined for a point directly beneath the tape. Ground cover was defined in four categories: rock, litter, branches and logs, and bare ground. The total number of points counted for each of the four categories was determined and a percentage relative to the total number of observations was obtained for each category. This percentage was used to estimate the occurrence of each of the four categories in each plot. A 100 percent timber cruise was conducted for each plot to determine the percent ground occupied with trees.

Data Analysis

A randomized block analysis of variance was used to test for significant difference in total sediment production and total surface runoff among the six surface runoff plots (Dixon and Massey, 1969; Snedecor and Cochran, 1967). Each runoff producing event was considered a block with the plots being the treatments. A Pearson correlation procedure was utilized to test for relationships between total sediment and total precipitation, average precipitation intensity, maximum precipitation intensity, and surface runoff (Graybill, 1976). Also tested, using a Pearson correlation procedure, were relationships between total surface runoff and total precipitation and average precipitation intensity.

Variable Source Study

The areas contributing to the surface runoff portion of stormflow can vary within a watershed. Hewlett and Hibbert (1967), Betson (1964), and Dunne et al. (1975) have determined that there are zones within watersheds that contribute to stormflow via surface runoff. On WS-1, three surface runoff producing zones were hypothesized based on topography in an attempt to identify the main source of surface runoff and the variability of surface runoff within the watershed. Eighteen surface runoff plots were placed within the three zones and monitored for surface runoff production and soil moisture. Surface runoff and soil moisture were used to test for significance differences among the hypothesized zones. Identification of specific zones could be useful for determining areas which could be potential areas with high surface erosion if disturbed.

Sampling Layout

On WS-1, three runoff producing zones were delineated based on topography and field observation (Figure 9). The zones were identified as Zone I, Zone II, and Zone III. Zone I was defined as the areas which were immediately adjacent to the stream channels and the lower slopes above the stream channels. Zone II was composed of the ridge tops between the stream channels and the upper slopes of the ridges. Zone III was defined as the upper part of the watershed. There were no stream channels present in Zone III and the topography was gentle and broadly undulating to flat.

Seven surface runoff plots were placed randomly in Zones I and II and four plots were randomly placed in Zone III. A greater number of plots were placed in Zones I and II due to greater slope variability within the zones. Plots were randomly placed based on an X,Y coordinate system established on the watershed. Computer generated random pairs of X,Y coordinates were used to identify the position of plots within each zone (Figure 10).

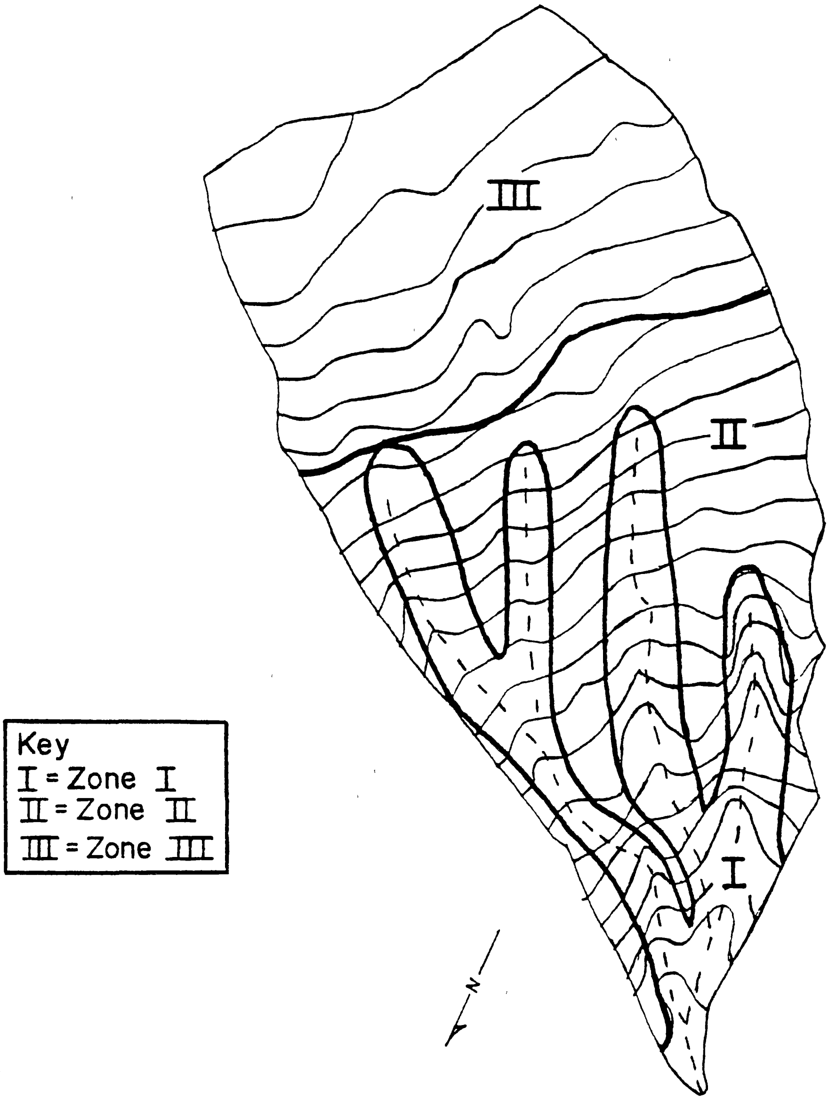


Figure 9. Clayton Lake Watershed 1, With
Runoff Zone Delineation

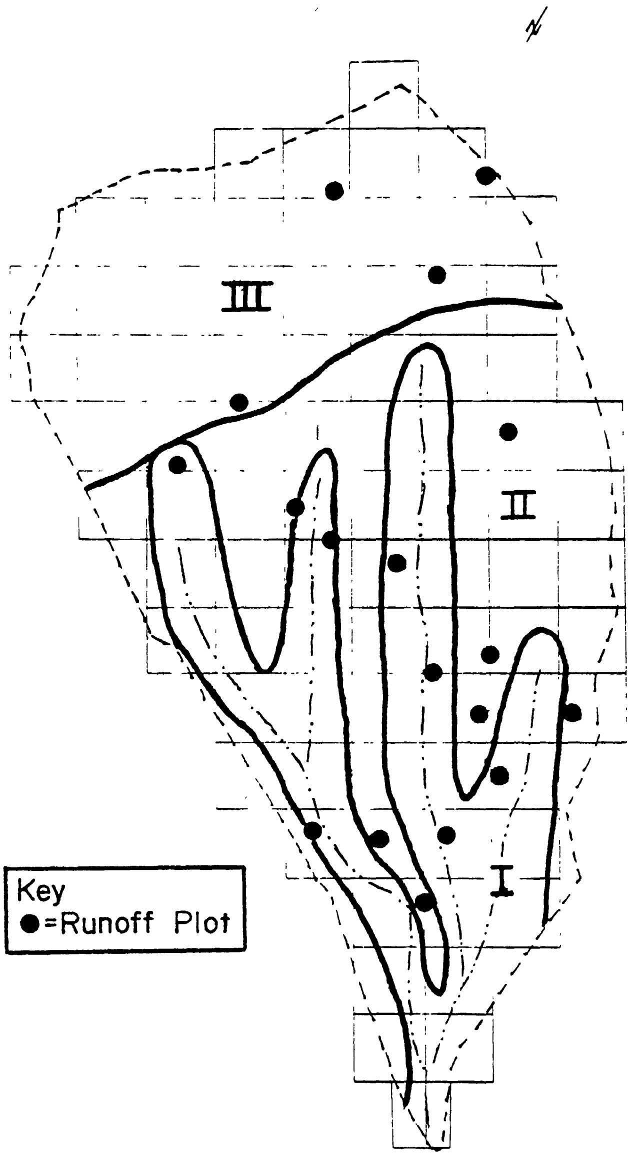


Figure 10. Surface Runoff Plot Placement
Within Runoff Zones

The surface runoff plots were 3 m^2. 2.54 cm by 10 cm boards with metal flashing attached were used to delineate plot boundaries (Figure 11). The flashing was placed so that 2 to 4 cm of metal was in the ground to prevent entrance of surface runoff from outside sources and loss of surface runoff from seepage. A 1 m gutter trough was placed at the base of each plot to collect surface runoff. The gutter lip was placed in the mineral soil to prevent loss of surface runoff. A 0.64 cm diameter hose drained surface runoff from the trough to an 18.9 l covered holding tank.

Each plot was equipped with a throughfall collector. The collectors were placed immediately adjacent to the back boundary of each plot. Throughfall was used to estimate total precipitation reaching each plot.

Sampling Method

Surface Runoff and Sediment. On a storm-by-storm basis, total surface runoff, throughfall, and sediment production were monitored for a period from April, 1983, through June, 1983. The surface runoff in the holding tanks was thoroughly mixed to resuspend all solids which may have settled to the bottom of the tank. A 500 ml grab sample was obtained immediately following mixing to be used for total suspended solids analysis. Mixing the water in the holding tank insured that an unbiased sample of the material transported by the surface runoff could be obtained.

After obtaining the grab sample, the volume of the remaining surface runoff was determined using a 2000 ml graduated cylinder. Water was transferred directly from the tank to the graduated cylinder.

The grab samples were returned to the laboratory and total suspended solids concentrations were determined by the procedure described by

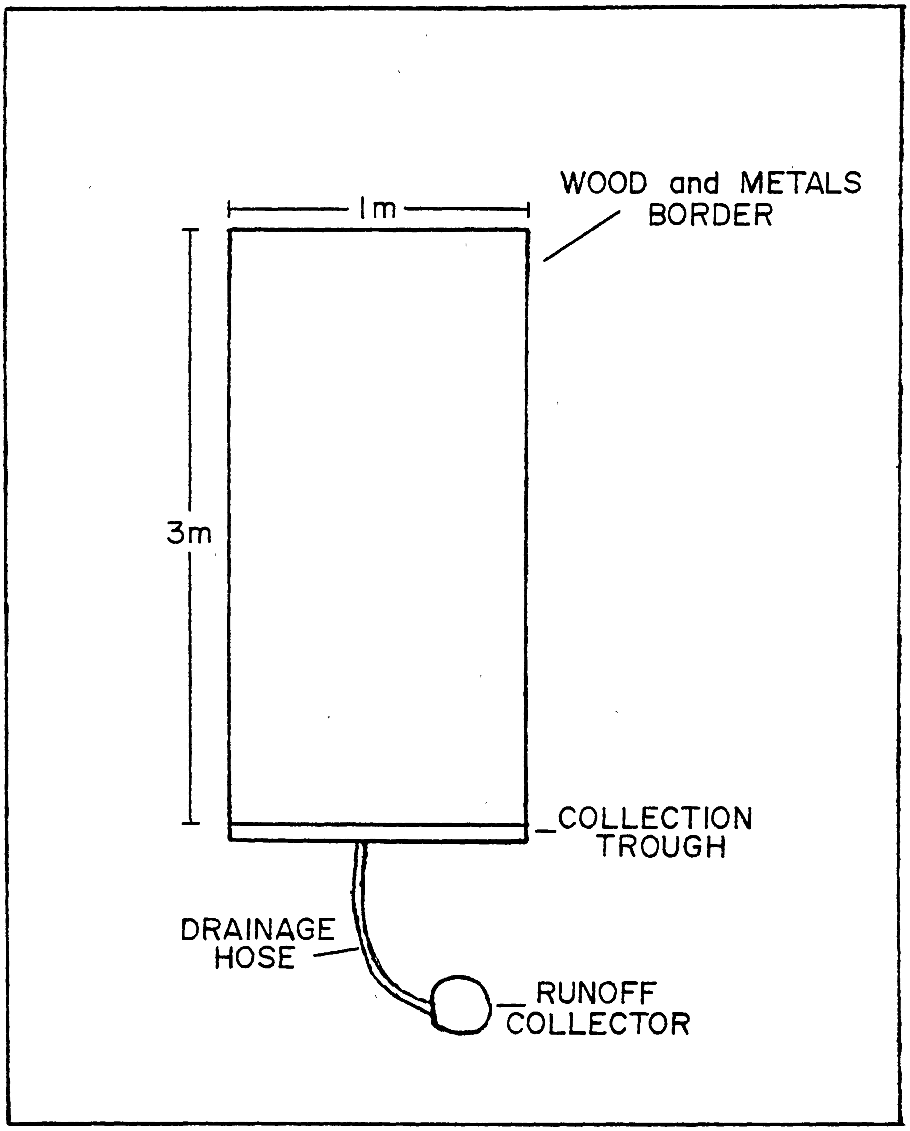


Figure 11. Plan View of Surface Runoff for
Variable Source Area Study

EPA (1979). Total suspended solids concentrations were used as estimates of sediment concentrations. Sediment loading was calculated by multiplying each sediment concentration by the corresponding runoff volume.

Throughfall was measured after each storm using a 2000 ml graduated cylinder. Throughfall was used as an estimate of the total precipitation reaching each plot. Precipitation intensities were determined by the same procedure described in the previous sections.

Soil Moisture. Soil moisture of the upper soil horizon was measured at each plot every seven to ten days. Soil samples were obtained, using a punch tube, in the area immediately adjacent to each plot. Five to six samples were collected in a plastic bag and mixed thoroughly. Organic material was removed during the mixing process. After mixing, a sample was collected from the bag and placed in a 136 ml soil can which was sealed and transported back to the laboratory. The percent soil moisture for each plot was determined gravimetrically in the laboratory (Gardner, 1965).

Data Analysis

Significant differences in surface runoff and percent soil moisture among the three hypothesized zones were tested using a split-plot design analysis of variance and a Duncan's multiple comparison procedure (SAS, 1982). Each runoff event was a block, with differences in surface runoff among zones tested with plots nested within zones. A ranking procedure was applied to the data before the tests were conducted to account for possible non-normality of the data.

Pearson's correlation test was used to determine possible associations between (1) average sediment load per zone and average total runoff per zone, (2) average sediment load per zone and total precipitation, (3) average surface runoff per zone and total precipitation, and (4) average surface runoff per zone and average precipitation intensity (Graybill, 1976). Total precipitation per zone was obtained by averaging the throughfall values collected at each plot within each zone.

Stormflow-Precipitation-Sediment Relationships

The three watersheds utilized for this study are vegetated with a pine-hardwood forest that has not been disturbed in 30 years. Relationships established among stormflow, sediment, and precipitation for the watersheds in natural conditions can be used for comparison in future studies when two of the watersheds will receive silvicultural treatments. These relationships were established for the winter and spring seasons because in southeastern Oklahoma, the greatest amount of precipitation and runoff occurs during these seasons within the water year. Relationships were tested using sediment concentrations and total sediment loads as test variables.

Sampling Method

Stormflow was monitored for a period beginning in January, 1983 and ending in June, 1983. This time period will be referred to as Winter-Spring, 1983 for the remainder of this discussion.

Stream discharge was determined on an individual storm basis, as described in the watershed instrumentation section, and then converted to stormflow using computer programs developed for each watershed.

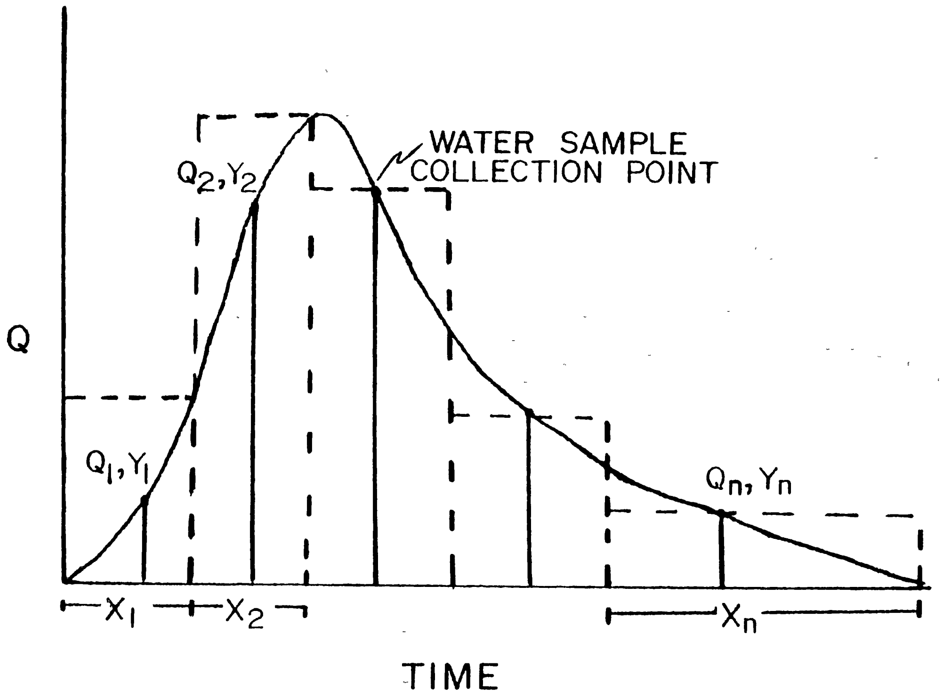
Stormflow was calculated in area-cm for each watershed based on watershed area.

Water samples collected at 3.05 cm stage intervals, as described in the watershed instrumentation section, were analyzed for total suspended solids concentrations by procedures described by EPA (1979). Total suspended solids concentrations were used as an estimate of the suspended sediment concentration. Suspended sediment was considered to be a combination of mineral soil and organic materials. Sediment concentrations were used to calculate sediment loads by integrating concentrations determined at known points on the hydrograph over time (Figure 12).

Precipitation data were collected for each precipitation event from the recording rain gage located on each watershed. Rain gage data were converted to total precipitation, precipitation intensity, and storm duration by the procedures described previously.

Data Analysis

Sediment Concentration. Average sediment concentrations were determined for three flow periods on each storm hydrograph. These flow periods were the rising limb, falling limb, and delayed recession (Figure 13). The rising limb represents the immediate runoff produced during a storm event. The falling limb was defined as the flow occurring between the peak discharge and 24 hours after the occurrence of peak discharge. Delayed recession is flow occurring after the falling limb and was due mainly to subsurface drainage and interflow. Delayed recession can last for several days. The basis of this separation technique was from the fixed interval method and direct hydrograph inspection (Dunne and Leopold, 1978). Hydrograph inspection indicated a distinct change in slope



$$\text{Total Sediment} = \sum_{i=1}^{n} \left[Q_i \cdot X_i \cdot Y_i \cdot C \right]$$

Q_i = Discharge at Sample Collection Point (cfs)

X_i = Time (s)

Y_i = Sediment Concentration for each Sample (mg/l)

C = 28.317 l/ft^3

Figure 12. Calculation of Total Sediment Production for a Runoff Event

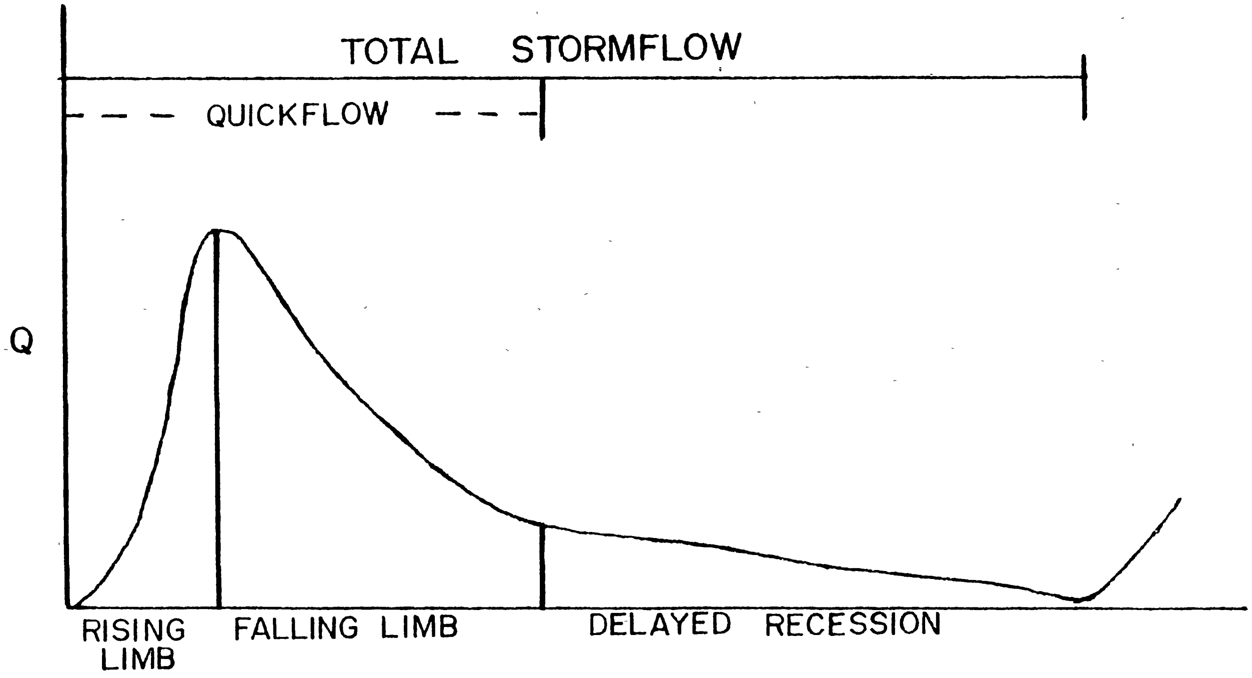


Figure 13. Sample Hydrograph Flow and Time Separation for Sediment Load and Concentration Comparisons

of the recession limb at an average of 24 hours after peak discharge (Figure 13). The slope difference indicated a difference in discharge rates within the total recession limb.

The average sediment concentration of each of the flow periods was determined by averaging the sediment concentrations obtained by analysis of water samples collected during each flow period by the automatic pump sampler (EPA, 1979). A randomized block analysis of variance was used to test for significant difference in average sediment concentration among the three watersheds for each flow period (SAS, 1982). Runoff events were blocks, with sediment concentration per flow period per watershed as treatments.

Each sediment concentration used in the determination of the average sediment concentration were presented as a function of the time of collection within each of the three defined flow periods, rising limb, falling limb, and delayed recession, for each watershed. As described in the watershed instrumentation section, the water samples were collected at discrete intervals based on stage change. The exact time each sample was recorded and the flow period the sample occurred was identified on the storm hydrograph. The time each flow period lasted was determined for each storm and the time elapsed from the start of each flow period until the time when each sample was taken was converted to a percentage of the total time a flow period lasted. Total time of each flow period varied with the magnitude of each storm event, so presenting sediment as a percent of the total time per flow period was used to normalize variations in storm time for the seasons. This normalization procedure allowed the data to be presented in a scatter diagram for each watershed by combining all the stormflow events monitored for the Winter-Spring, 1983, season. This scatter diagram provides a view of the variability of all of the sediment concentrations obtained for the entire season within each flow period.

During stormflow events monitored in Winter-Spring, 1983, season concentration variation as a function of time was examined using first flush analysis. This procedure looks at cumulative percentages of sediment load and stormflow versus the percent time elapsed during a stormflow event (Helsel et al., 1979). The occurrence of first flush indicates higher sediment concentrations during the early part of a stormflow event than in the latter parts of an event.

Total Sediment Loads-Stormflow Relationships. Pearson's correlation procedure was used to test for associations among sediment load, stormflow, and precipitation (Graybill, 1976). Sediment loadings for total stormflow and quickflow were used for the correlation tests. Total stormflow was defined as the total runoff due to a rainfall event. It is measured from the beginning of flow rise until the beginning of flow rise of the next storm event (Figure 13). For the ephemeral watersheds studied, the flow preceding the start of a stormflow event was zero or very small.

Specific comparisons made using Pearson's correlation procedure include: (1) total sediment load and total stormflow, and average precipitation; and (2) total stormflow and total precipitation, average precipitation intensity, and storm duration.

Quickflow was defined as the total runoff occurring from the start of a flow event until 24 hours after the peak discharge occurs. This is a combination of the rising limb and falling limb flow described earlier.

Quickflow was separated out of the total stormflow in an attempt to identify sediment loading differences with time in the stormflow event. Total sediment for the quickflow section was calculated by the same procedure described previously (Figure 12). Specific comparisons made using Pearson's correlation procedure were total sediment load for quickflow and total quickflow.

Total quickflow sediment as a percent of total stormflow sediment was determined on an individual storm basis for each watershed for each storm monitored in the Winter-Spring, 1983, season. This ratio was used to look at trends in the amount of transported sediment over time during a stormflow event.

The total sediment load for each of the three flow periods within a hydrograph was determined for every monitored event in each watershed. A randomized block analysis of variance was used to test for significant differences in sediment load among the three flow periods for each watershed (SAS, 1982). Each runoff event was a block with flow periods being the treatments. Also, the total sediment load for each total stormflow period was determined. A randomized block analysis of variance was used to test for significant differences in total sediment load among the three watersheds. Each runoff event was a block with watersheds being the treatments (SAS, 1982).

A mass diagram of average total sediment accumulation as a function of percent storm time was developed for each watershed. Sediment load was accumulated to the peak discharge, to the end of falling limb flow, and to the end of the total stormflow. Then an average total sediment accumulation of all the storms monitored in the Winter-Spring, 1983, season was determined and presented for each watershed.

Stormflow and Precipitation

Associations identified between stormflow and precipitation could aid in developing predictive models for estimating stormflow volumes from precipitation parameters. In an ephemeral watershed, flow in stream channels can be tied to individual precipitation events. The amount of flow is a function of the amount of precipitation and the time of occurrence in relation to previous precipitation events. Stormflow and precipitation data were collected for a four-year period and were used for determining relationships between these two parameters for each watershed.

Sampling Method

Total stormflow and peak discharge were determined on an individual storm basis for each watershed for a four-year period beginning in 1979 and ending in 1983. Total stormflow and peak discharge were calculated by procedures described previously.

Precipitation data were collected on an individual storm basis from weighing bucket recording rain gages and converted to total precipitation, precipitation intensity, and storm duration by procedures described in previous sections.

Data Analysis

Pearson's correlation procedure was used to test for relationships between (1) total stormflow and total precipitation, average precipitation intensity, and storm duration; and (2) peak discharge and total precipitation, and average precipitation intensity on a two-season year and a four-season year basis (Table IV) (Graybill, 1976). The seasons were delineated based on precipitation and runoff patterns observed for the four-year period (Figures 4 and 5). The seasons were designed to account for soil moisture differences which might be possible during different times of years.

Pearson's correlation procedure also was used to test for correlations between stormflow and total precipitation, average precipitation intensity, and storm duration for events producing greater than 2.54 cm of precipitation. These tests were conducted based on a four-year season year as defined in Table IV (Graybill, 1976).

TABLE IV

SEASONAL DELINEATION USED FOR STATISTICAL TESTING OF STORMFLOW AND PRECIPITATION

Two-Season Year	Four-Season Year
January-June	October-December
July-December	January-March
	April-June
	July-September

Multiple linear regression was used to develop models of total stormflow as a function of total precipitation and antecedent precipitation (Graybill, 1976). Antecedent precipitation was the total amount of precipitation occurring in a set time period before a runoff event. Antece-precipitation was designed to serve as an estimate of antecedent soil moisture conditions. For the above regression, precipitation was accumulated for 0 to 2.5, 0 to 5, and 0 to 10 days preceding a precipitation event.

Watershed Pairing

Paired watersheds are useful tools in hydrologic studies, where one watershed can serve as a control as the other watershed is subjected to some treatment. If reliable predictive models can be developed, the control watershed can be used to estimate treatment effects on certain hydrologic parameters.

In anticipation of future treatments occurring on two of the three watersheds, WS-3 has been established as a control watershed. Multiple linear regression was used to develop models between WS-1 and WS-3, and WS-2 and WS-3 for storm runoff (Graybill, 1976). Models were developed on a monthly stormflow basis and an individual storm basis. The stormflow utilized for model development was collected between 1979 and 1983. The water year was divided into four seasons as defined in Table III and a model was developed for each season.

Multiple linear regression also was used to model sediment load between WS-1 and WS-3, and WS-2 and WS-3 (Graybill, 1976). The sediment collection procedures have been described in previous sections.

CHAPTER IV

RESULTS AND DISCUSSION

Large Plot Surface Runoff and Erosion

Surface runoff was observed on all of the plots with a variation in volumes within watersheds, among watersheds, and among storms (Tables XXVIII, XXIX, and XXX, Appendix B). However, the results of a randomized block analysis of variance indicated no significant differences in total runoff among the six plots (Table XLVI, Appendix C). Ground cover within the large plots was similar to the ground cover of the watersheds, indicating the plots were representative of the watersheds in this respect (Tables II and V).

In almost all cases, total surface runoff was correlated with total precipitation, but was not correlated with average precipitation intensity and maximum precipitation intensity (Table VI). These findings support past work which indicates that in a forested watershed, surface runoff is more closely dependent on total precipitation than on precipitation intensity (Hewlett and Forsten, 1977). Infiltration capacity usually exceeds rainfall intensities in an undisturbed forest (Linsley and Franzini, 1979). However, high volumes of rainfall can lead to saturation of the upper layers of soil, resulting in surface runoff.

Most of the surface runoff values ranged between 0.1 to 5.0 percent of total stormflow with some extreme values greater than 5.0 percent (Table VII). Most of the percentages were less than 1.0 percent of the

TABLE V

LARGE PLOT GROUND COVER CHARACTERISTICS

Groundcover Type	Percent Cover					
	Watershed 1		Watershed 2		Watershed 3	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
Litter	66.8	82.6	78.8	86.7	82.9	79.8
Branch, Limb Debris	6.0	8.0	0.8	1.0	4.0	6.0
Rock	27.0	9.0	19.8	12.0	9.0	11.0
Mineral Soil	0.0	0.0	0.0	0.0	4.0	3.0
Tree	0.3	0.5	0.5	0.3	0.1	0.2

TABLE VI

CORRELATIONS AMONG SEDIMENT, SURFACE RUNOFF, AND PRECIPITATION FOR THE LARGE PLOT STUDY

Variable	Total Precipitation	Average Precipitation Intensity	Maximum Precipitation Intensity	Surface Runoff
Watershed One				
Plot One				
Sediment	0.90*	-0.14	0.28	0.99*
Surface Runoff	0.97*	-0.06		
Plot Two				
Sediment	-0.20	0.48	0.50	0.73*
Surface Runoff	0.10	0.47		
Watershed Two				
Plot One				
Sediment	0.69**	0.43	-0.35	0.92*
Surface Runoff	0.76*	0.47		
Plot Two				
Sediment	0.17	0.99†	0.06	0.10
Surface Runoff	-0.34	0.14		
Watershed Three				
Plot One				
Sediment	0.70**	-0.10	0.48	0.81*
Surface Runoff	0.79*	0.06		
Plot Two				
Sediment	0.68**	0.06	0.47	0.96*
Surface Runoff	0.79*	0.06		

*P-value < 0.005.

**P-value 0.01-0.005.

†Data clustered about zero except for single outlying point.

TABLE VII

SURFACE RUNOFF AS A PERCENTAGE OF TOTAL STORMFLOW FOR LARGE PLOT STUDY

Date (1983)	Watershed 1 Plot 1	Watershed 1 Plot 2	Watershed 2 Plot 1	Watershed 2 Plot 2	Watershed 3 Plot 1	Watershed 3 Plot 2
4/24	0.1	---*	0.4	0.4	0.1	---
5/3	---	---	0.04	0.1	0.1	0.1
5/12	0.2	0.3	5.6	6.0	8.1	--
5/17	1.7	0.2	0.4	1.6	0.2	0.3
5/19	0.1	0.6	0.3	0.7	0.2	0.3
5/22	0.1	0.3	0.2	0.3	0.4	0.2
5/27	0.4	0.7	1.0	11.0	6.6	3.2
6/1	0.6	1.3	1.7	5.6	---	---
6/9	0.7	2.4	---	---	---	---
6/29	0.4	2.4	8.6	4.2	1.4	5.0

*Data missing.

total stormflow. The wide range in percentages may have been due to spatial variability of soil moisture conditions or differences in storm magnitude. In addition, some seepage may have occurred around the collection troughs, resulting in lower estimates of total surface runoff in some cases.

Plot 1 of WS-1 had the smallest range of surface runoff to stormflow percentages, ranging between 0.1 to 1.7 percent (Table VII). In addition, Plot 1 of WS-1 had the highest correlation coefficient between precipitation and surface runoff. Other plots such as Plot 2 of WS-2 had percentages ranging from 0.1 to 11.0 percent (Table VII). Plots with wide ranges tended to have lower correlation coefficients between precipitation and surface runoff (Table VI). Correlations appeared to be better where surface runoff occurrence was less variable in response to precipitation.

Total sediment production correlated well with total surface runoff and with total precipitation (Table VI). Sediment production increased with the amount of surface runoff due to higher volumes of water and increased velocities associated with increased runoff (EPA, 1973; Meyer, 1975). Sediment production and surface runoff directly correlated with total precipitation, indicating a possible relationship between the three variables.

Sediment production did not show any relationship with precipitation intensity (Table VI). Previous work has indicated that erosion and sediment production can be a function of the increased erosive forces of high rainfall intensities (Wischmeier and Smith, 1958; Satterlund, 1972). However, other investigators have indicated that the forest floor serves as protection against the erosive force caused by rainfall intensity (Pritchett, 1979). Additionally, sediment measurements may have been biased due to the combining of rainfall events, resulting in unreliable sediment estimates used for correlations. The individual storms used for the sediment-precipitation intensity analyses often were a combination of several storm events. The convective nature of spring rainfall and the distance to the sampling sites made it difficult to determine the occurrence of each storm event. Possible bias could have resulted because it was impossible to know which event may have produced sediment. In some instances, precipitation intensities from several separate events had to be combined and a weighted average intensity of the events was used.

Sediment loading did not significantly differ among the six plots within the watersheds (Table XLVII, Appendix C). However, one trend was that Plot 2 of WS-1 and Plot 2 of WS-2 produced larger sediment loads per unit area for the study period. These two plots were the smallest of the six plots (Table VIII). These trends may indicate that plot size is important when attempting to characterize total watershed variables. These trends would also be due to specific characteristics of the two plots.

Variable Source Study

Surface Runoff

There was no significant difference of surface runoff production among the three hypothesized runoff producing zones (Table XLVIII, Appendix C). Significance was determined by testing for differences among the hypothesized zones with the surface runoff plots established within

TABLE VIII

TOTAL SEDIMENT LOAD PER PLOT FOR LARGE PLOT STUDY

Date (1983)	Watershed 1		Watershed 2		Watershed 3	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
4/24	0.57[1]	---[2]	---	0.76	0.30	2.95
5/3	---	---	0.28	2.28	1.47	3.04
5/12	0.58	---	0.33	0.76	3.61	0.29
5/17	0.55	3.05	1.68	4.90	1.66	0.16
5/19	0.60	1.52	0.58	1.39	0.96	0.18
5/22	0.30	---	0.54	0.36	0.54	0.02
5/27	0.15	1.24	1.05	9.29	0.27	---
6/1	0.11	1.51	0.17	0.52	0.65	0.43
6/9	0.06	1.87	0.30	0.24	0.46	0.33
6/28	---	---	1.21	2.53	---	---
6/29	1.91	5.80	1.05	---	---	---

[1] Mg/m^2.

[2] --- indicates no available data.

each zone in a split-plot design analysis of variance. The median surface runoff volumes for Zone III, however, tended to be higher than for the other two zones (Figure 14).

Several factors could have affected the measurements of the variability of surface runoff production between the three zones. The zone delineation may have been too broad to accurately define potential runoff producing zones for the watershed. The three zones were delineated on a rough topographic map and from field observation. There may have been microtopographic characteristics that determined surface runoff producing areas. These microtopographic areas may not be adjacent to each other and could be isolated areas within the watershed. A detailed soils map and intensive soils moisture monitoring would have aided in identifying potential surface runoff producing areas. Dunne et al. (1975) indicated that soil moisture, vegetation, and soil type were all important in determining potential runoff producing zones.

The streamside areas of Zone I were the steepest slopes in the watershed (Figure 7). According to Dunne et al. (1975), the areas adjacent to stream channels were the most likely to produce surface runoff. The steep topography may have prevented the development of saturation areas adjacent to the stream channel due to rapid drainage. Also, the lower slopes were composed of Carnasaw and Octavia soils. The B horizons of these soils are clayey or fine loamy and the A horizons are sandy loam. These relatively impermeable lower horizons overtopped with permeable horizons and coupled with steep slopes may have facilitated increased subsurface stormflow. This could have limited the formation of saturated areas. Without the development of saturation areas, surface runoff potential would have been greatly reduced.

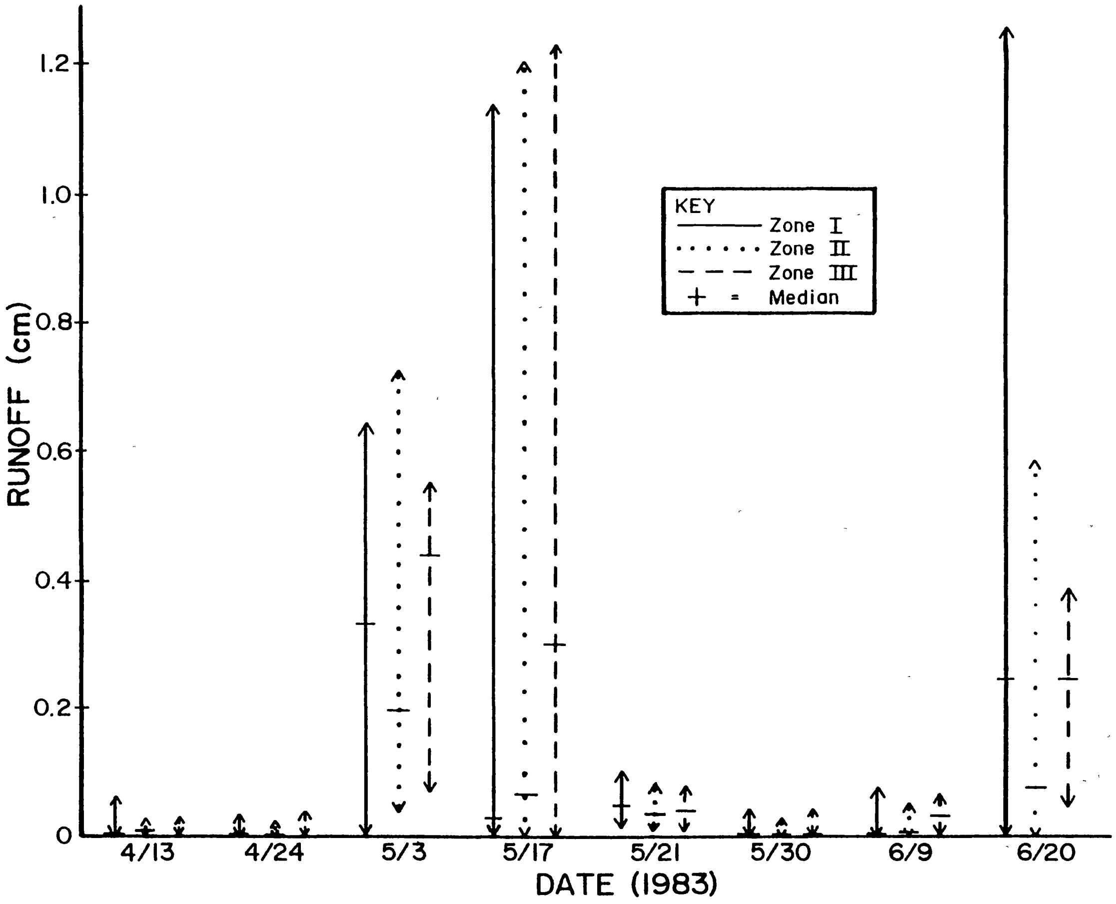


Figure 14. Range and Median Value of Surface Runoff Per Zone for the Variable Source Study

There was a high degree of variability, ranging from 0.0 to 1.3 cm, in surface runoff between the plots within a zone from any given storm (Figure 14). The variability indicates that there is an areal variability in surface runoff within the watershed. The zones as delineated, however, did not reflect the pattern of variability in surface runoff production.

The 18 plots used in the study may not have been sufficient to adequately measure surface runoff within the delineated zones. A greater number of plots may have been useful in redefining the zones since trends would have been more easily traced with more intense coverage. However, some indication of natural variability in surface runoff production within the watershed was demonstrated using the 18 plots.

Soil Moisture

Soil moisture was significantly different among the three zones, as identified by using a split-plot design analysis of variance, testing differences between zones with plots nested within zones ($p < 0.01$) (Table XLIX, Appendix C). A Duncan multiple comparison test indicated that Zone III had significantly higher soil moisture than Zones I and II (Table L, Appendix C). Zone III was composed of very gentle slopes. Subsurface drainage was probably lower in Zone III than in Zones I and II, which were composed of steeper slopes. Soil differences among the zones also may have been a factor in soil moisture differences. The soil found on the ridge tops, where Zone III was located, usually has a stony fine sandy loam A horizon over a loamy B horizon with very gentle slopes. Water movement may have been slower through the fine textured A horizon material of Zone III than for the fine sandy loam A horizons of Zones I and II with steeper slopes. The decreased downward movement due to decreased permeability and the reduced drainage due to decreased slopes may have been factors in higher soil moisture conditions throughout the study period (Figure 15). Water movement would have been dependent completely on pore interconnectedness in the vertical direction in the upper zone due to shallow slopes. On the steep slopes water movement was probably horizontal in addition to vertical, allowing for increased drainage movement. The higher soil moisture in Zone III may have been a factor in the production of greater volumes of surface runoff than Zones I and II.

Some of the differences in soil moisture measurements within the zones may have been due to differences in upper horizon soil depths (Figure 16). The soils were composed of the Carnasaw, Pirum, and Octavia soil series, which have a wide range in the possible depths of the upper horizons due to natural variability in the soils (Bain and Abernathy, 1984). Differences in soil depths may have affected the relative moisture holding capacity of the soils. More sampling sites within the zones may have more specifically identified trends in horizon depth and soil moisture within each zone. Additional soil moisture measurements would also aid in the redefining of potential surface runoff producing areas.

Sediment-Surface Runoff-Precipitation

Average surface runoff per zone correlated well with total rainfall with coefficients of correlation in the range of 0.91 to 0.98, but not with average precipitation intensity (Table IX). Total sediment correlated highly with total surface runoff and total precipitation with

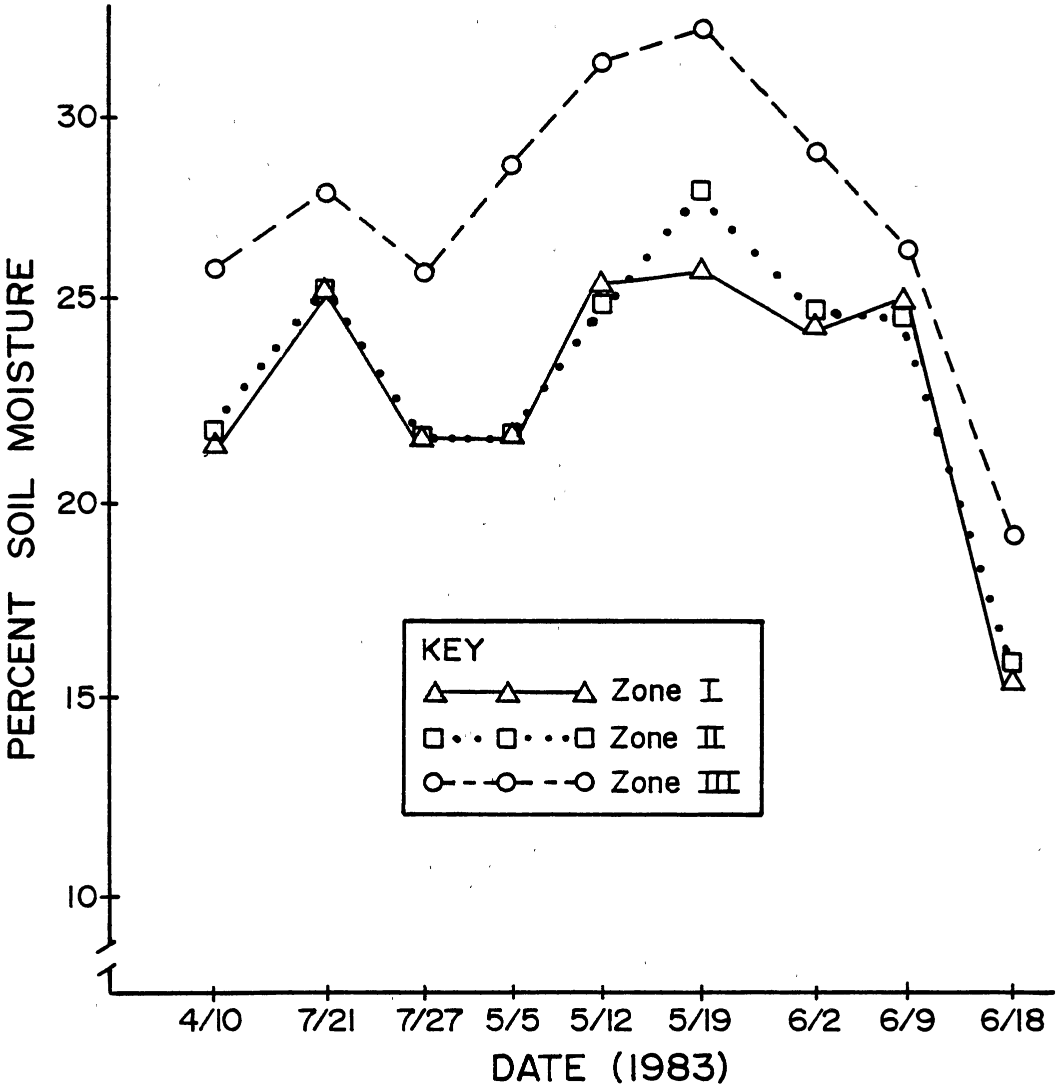


Figure 15. Average Soil Moisture by Weight
Per Zone by Date

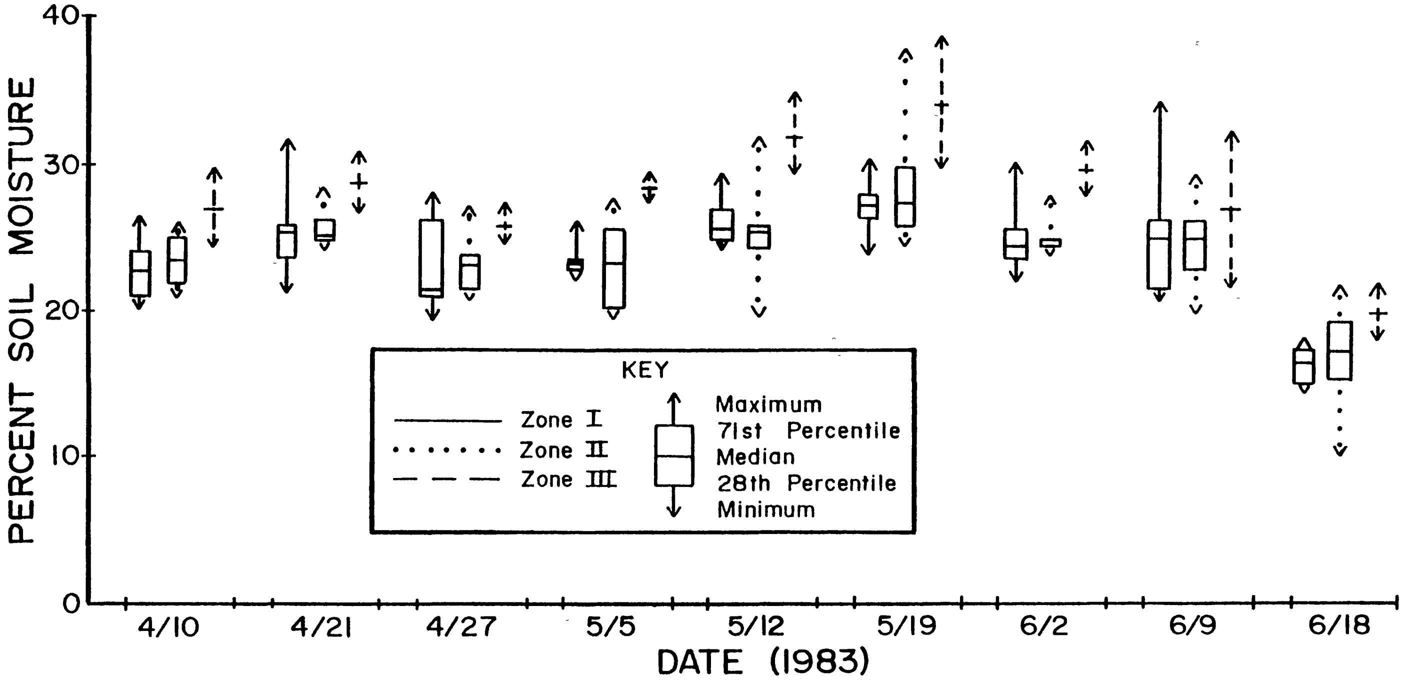


Figure 16. Box and Whisker Plot of Percent Soil Moisture Per Zone

TABLE IX

CORRELATION RESULTS FOR SURFACE RUNOFF, TOTAL PRECIPITATION, AND AVERAGE INTENSITY PER ZONE

Parameter	Surface Runoff by Zone		
	I	II	III
Total Precipitation	0.98 *	0.99 *	0.91 *
Average Intensity	0.22	0.22	0.22

*P-value < 0.005.

TABLE X

CORRELATION RESULTS FOR TOTAL SEDIMENT, TOTAL PRECIPITATION, AND TOTAL SURFACE RUNOFF PER ZONE

Parameter	Total Sediment by Zone		
	I	II	III
Total Precipitation	0.94 *	0.97 *	0.86 **
Total Surface Runoff	0.88 *	0.95 *	0.55

*P-value 0.01-0.005.

**P-value < 0.005.

coefficients in the range of 0.55 to 0.97 (Table X, p. 64). These correlations suggest possible relationships between total precipitation, total surface runoff, and total sediment, and support the correlations presented in the large plot surface runoff study discussed previously. The correlations for the small plots tended to be somewhat better than those for the large plots. One factor may have been the larger number of small plots used for the study. More plots may have accounted for some of the natural variability of the watersheds. Also, the small plot size may have reduced some of the variation in possible factors affecting surface runoff such as slope and ground cover differences.

The average total sediment load produced for the small surface runoff plots for the study period was approximately 266 mg per m^2 per plot. For the large plots the total sediment load for the same period was approximately 9.91 mg per m^2. The large plots produced much less sediment per m^2 than the small plots. The difference may be due to the transport distance in the large plots. The longer distance in the large plots could have allowed more opportunities for obstructions to increase flow resistance. Increased flow resistance can reduce sediment carrying power. However, both produced less than the total sediment transported by stormflow for the same period of approximately 4762 mg per m^2. Previous research has indicated that sediment produced by surface erosion in a forested watershed is a small portion of the total amount of sediment produced from a watershed (Lull and Reinhart, 1972; EPA, 1973). The findings of this study agree with the findings of previous research.

Stormflow-Precipitation-Sediment Relationships

Sediment Concentrations

Sediment concentrations varied directly with stormflow hydrograph fluctuations (Figures 17, 18, 19, 20, and Table XI). For each watershed, sediment concentrations tended to be higher during the early stages of the storm, as depicted by the rising limb of the hydrograph, than during the later stages, as depicted by the falling limb and delayed recession portions of the hydrograph (Figures 17, 18, 19, and 20). This supports findings by Paustrian and Beschta (1979), which indicated higher sediment concentrations occurred early in a stormflow event. The higher sediment concentrations early in the storm could have been due to a first flush effect. This effect is caused by fine material being picked up and transported early during a storm event (Helsel et al., 1979). This phenomenon was observed in all three watersheds for a majority of the stormflows monitored during the study period (Table XI). This first flush effect may be attributed to high transport capacity due to velocity and flow increases early in a storm. Hewlett and Nutter (1969) determined that carrying power of streams was higher with increased velocity such as is associated with the rising limb of the storm hydrograph. The early high velocities flush fine particles from the stream channel and are capable of carrying large particles, therefore resulting in an increased sediment concentration early in a storm. This effect could explain why sediment concentrations peak before peak discharge. As the fine particles were removed, then the concentrations would start to decrease even before peak flow. As flow decreases after peak, the

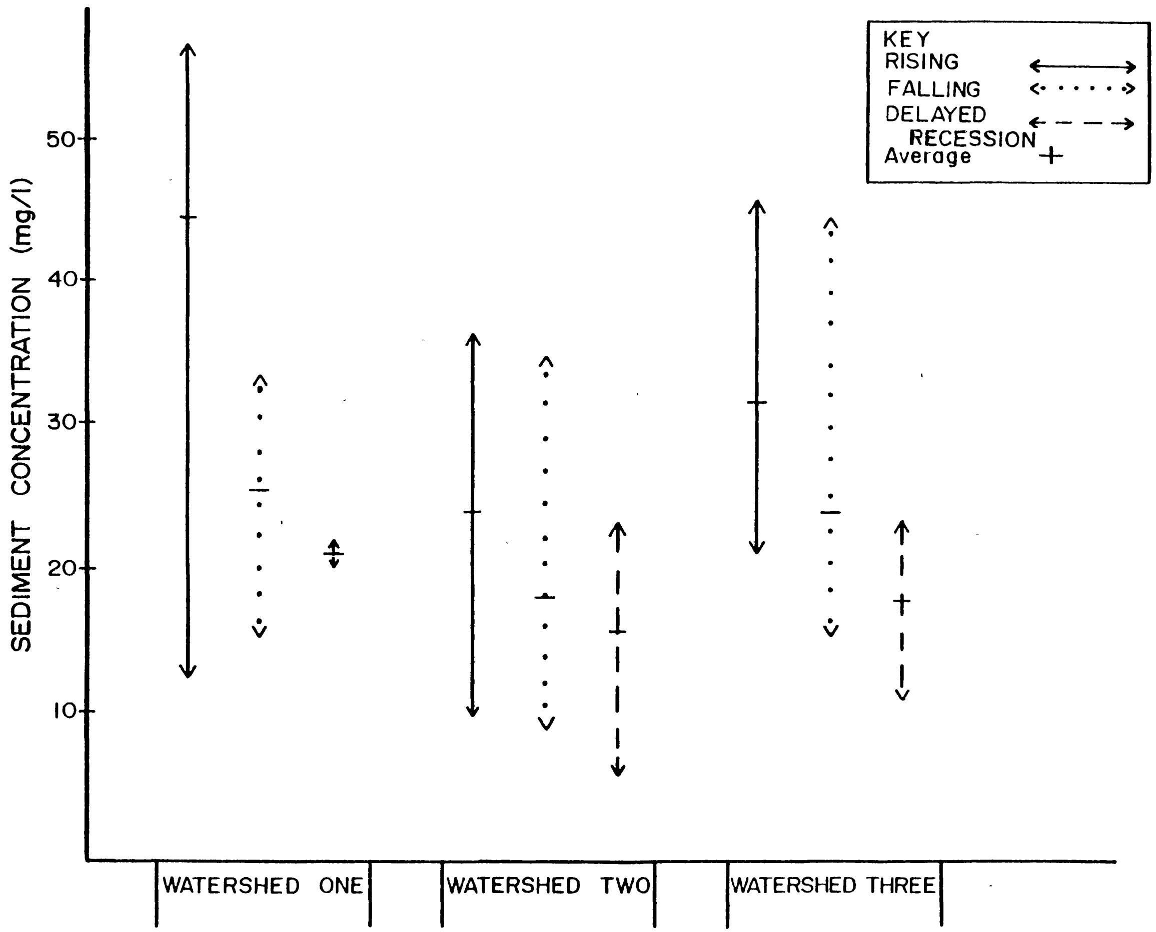


Figure 17. Maximum, Minimum, and Average Sediment Concentration Per Hydrograph Segment by Watershed for Winter-Spring, 1983

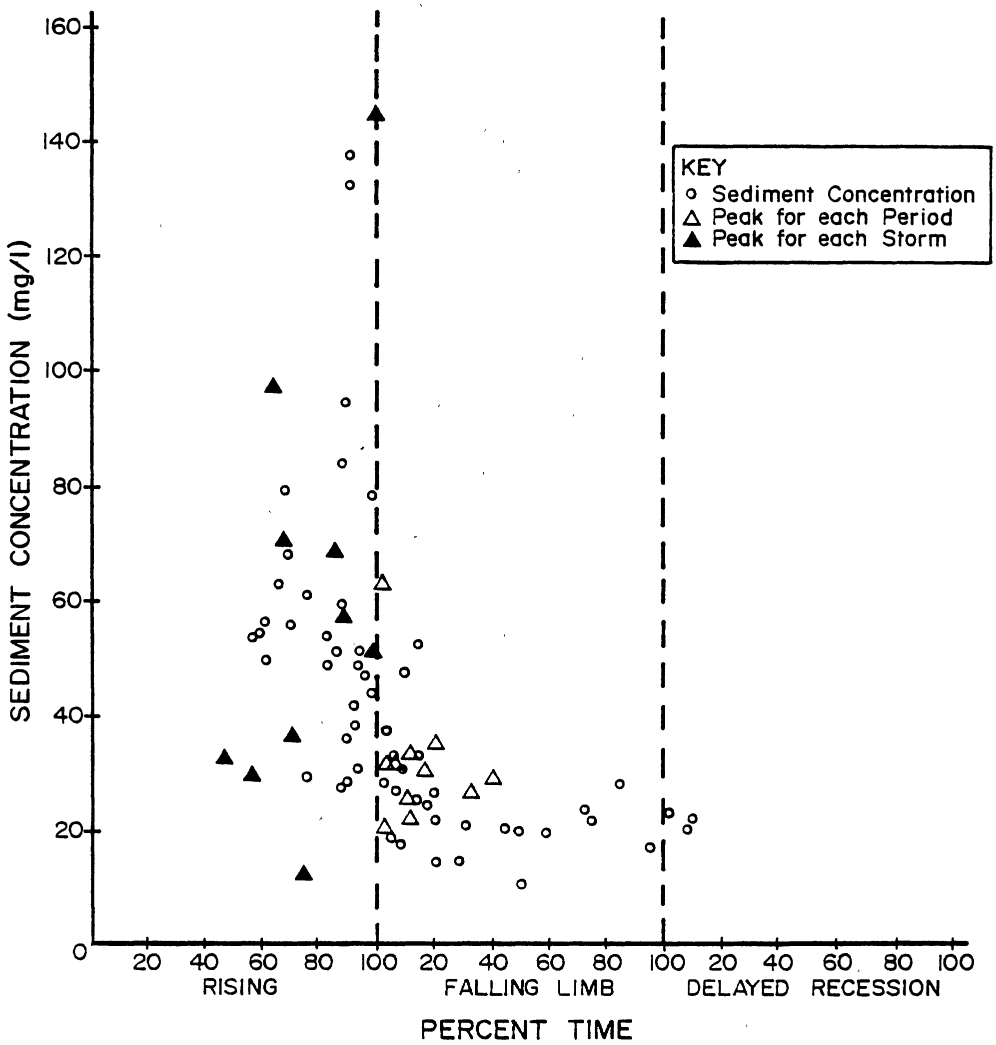


Figure 18. Sediment Concentration as a Function of Percent Total Time of Rising Limb, Falling Limb, and Delayed Recession for Watershed One

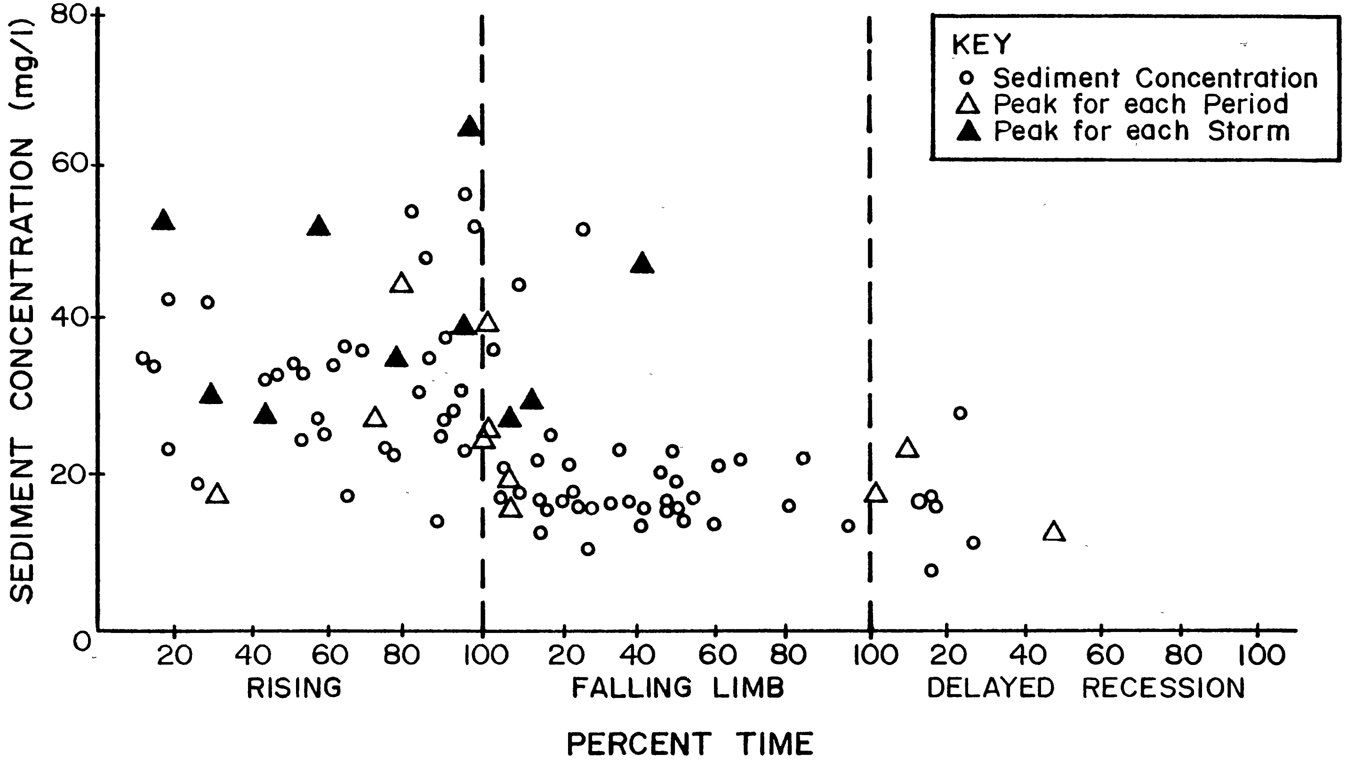


Figure 19. Sediment Concentration as a Function of Percent Total Time of Rising Limb, Falling Limb, and Delayed Recession for Watershed Two

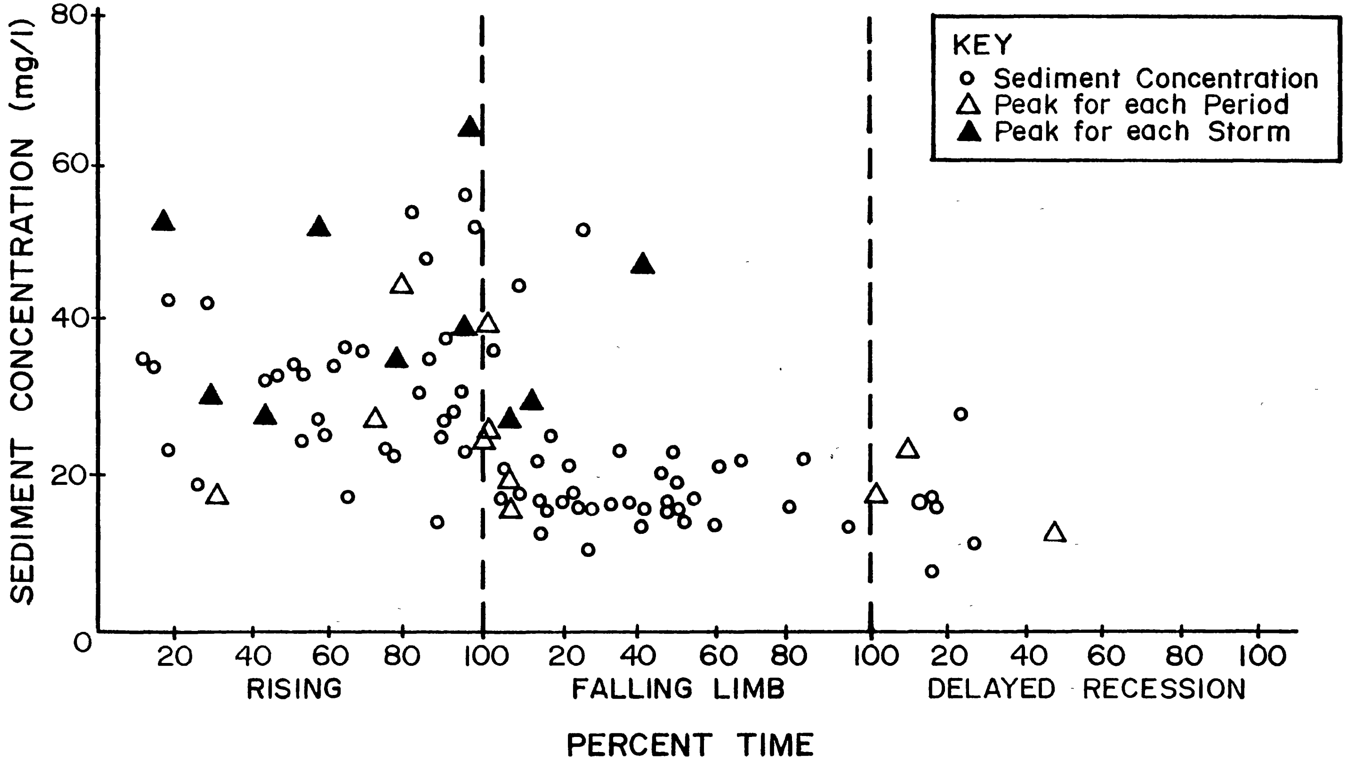


Figure 20. Sediment Concentration as a Function of Percent Total Time of Rising Limb, Falling Limb, and Delayed Recession for Watershed Three

TABLE XI

OCCURRENCE OF FIRST FLUSH FOR EACH WATERSHED ON AN INDIVIDUAL STORM BASIS

Date (1983)	Watershed 1	Watershed 2	Watershed 3
1/31		+	+
2/9	-*	+	+
2/20			+
3/4	+	+	+
4/13	+		+
5/2	+	+	+
5/10	+		
5/14	+	+	+
5/17	+	+	+
5/20	+		-
5/25		+	
5/28	+	+	
6/25	+		
6/28	+	-	-

*(+) first flush effect occurred.
(-) no first flush.
( ) no measurement available.

carrying power is reduced also, resulting in further decreased sediment concentrations.

There was a large amount of variability in sediment concentration within each stormflow segment: rising limb, falling limb, and delayed recession (Figures 18, 19, 20). This variation was probably due to differences in magnitude and intensity within the measured storms. The magnitude and intensity of storm events have been determined to affect sediment movement within a stream (Doty, 1980). However, there was an overall trend of higher sediment concentrations during the rising limb and peak of each stormflow hydrograph and lower sediment concentrations during the recession flows of each stormflow event.

Two trends should be noted from Figures 18, 19, and 20. In almost every case the overall peak sediment concentration per storm occurred during the rising limb of the hydrograph. However, the peak sediment concentration did not occur at the same time as the peak discharge. In a few storm events the peak concentration did not occur in the rising limb, but the peak did occur very soon after the peak discharge. This supports work by Paustrian and Beschta (1979) which indicated that the peak sediment concentrations of a runoff event occur before or near the peak discharge point of a hydrograph.

The second trend was the varied distribution of peak sediment concentrations for each flow period. Peak sediment concentrations measured in the rising limb for the storm events were found to be scattered at different points within the flow period. However, for the falling limb flow period, the peak concentration usually occurred very soon after the peak discharge. Additionally, the variation in sediment concentrations tended to decrease after the midway point of the falling limb period.

Hewlett and Nutter (1969) indicated that the carrying power of stormflow or channel flow is greatest with increased velocities. The trends identified from Figures 18, 19, and 20 indicate that the velocities were greatest before or at the peak discharge. After peak discharge the carrying power was reduced as flow velocity decreased. The slighter variation in sediment concentration toward the latter stages of stormflow indicate a fairly even carrying power. The uniform carrying power may have resulted from uniform velocities in the later stages of flow.

Sediment concentrations for the rising limb and falling limb of WS-1 tended to be higher than those for the rising limbs and falling limbs of WS-2 and WS-3. The results of a randomized block analysis of variance testing for significant differences in sediment concentrations among the three watersheds by flow period indicated there were significant differences in the sediment concentrations for the watersheds ($p = 0.120$-0.003) (Tables LVIII, LIX, and LX, Appendix C).

Sediment Loading

Total sediment load per storm was positively correlated to total precipitation and total runoff with correlation coefficients ranging between 0.77 and 0.99 (Table XII). The results indicate that increased flows cause increased sediment transport. High flows are more capable of detaching and moving soil particles due to the increased force and velocity (EPA, 1973).

Total stormflow correlated well with total precipitation for the Winter-Spring, 1983, season storms utilized in the sediment loading study (Table XII). Past research has indicated that stormflow is a function of the amount of precipitation with increased flows resulting from increased precipitation (Hewlett and Forsten, 1977). Sediment load correlated well with stormflow and precipitation, suggesting a correlation between all three variables. This is supported by previous work which suggested that large stormflows increase the erosive potential of the flow by increasing the carrying power, the detachment capabilities, and the surface area exposed to the flow (Hewlett and Nutter, 1969; Satterlund, 1972).

TABLE XII

CORRELATIONS AMONG TOTAL SEDIMENT LOAD, STORMFLOW, AND PRECIPITATION BY WATERSHED

Watershed and Variable	Total Precipitation	Average Precipitation Intensity	Duration	Total Stormflow
Watershed One				
Total Sediment	0.95*	0.91*	-0.28	0.77*
Total Stormflow	0.85*	-0.22	0.59**	
Watershed Two				
Total Sediment	0.82*	---†	0.34	0.99*
Total Stormflow	0.85*	-0.04	0.37	
Watershed Three				
Total Sediment	0.92*	0.28	0.66*	0.97*
Total Stormflow	0.89*	0.17	0.71*	

*P-value < 0.005.

**P-value 0.01 to 0.005.

†Missing data.

Total sediment loads produced during quickflow correlated well with total quickflow, with correlation coefficients ranging from 0.94 to 0.99 (Table XIII). The separation of quickflow sediment load and total sediment load gives some indication of sediment transport trends during a runoff event. On average, the rate of sediment loading was greatest for the quickflow portion of a stormflow event (Figure 21). On an individual storm basis, quickflow often accounted for more than 50 percent of the total sediment produced in a stormflow event (Table XIV). As discussed earlier, the rising limb and initial section of the falling limb, or that portion of the hydrograph defined as quickflow, have high flow velocities and discharge. These sections of the stormflow hydrograph are the most capable of transporting sediment.

The results of a randomized block analysis of variance indicate that there was significant difference in the total sediment loading among the three flow periods for all three watersheds ($p = 0.09$-0.0005) (Tables LI, LII, and LIII, Appendix C). However, a randomized block analysis of variance testing for differences in sediment loading within flow periods among watersheds indicated that the rising and falling limbs of all three watersheds were not significantly different in sediment loading ($p = 0.12$ and 0.22) but the delayed recession did differ ($p = 0.02$) (Tables LV, LVI, and LVII, Appendix C). WS-1 tended to have higher loading rates for the delayed recession (Figure 21). On WS-1, sediment loading rates appeared to be more similar throughout the hydrograph (Figure 21). Also, a randomized block analysis of variance indicated there were significant differences in the total sediment loads among the three watersheds for the storms measured ($p = 0.03$) (Table LIV, Appendix C). WS-1 had the highest sediment loads on the average.

TABLE XIII

CORRELATIONS AMONG QUICKFLOW SEDIMENT LOADS, QUICKFLOW, AND PRECIPITATION FOR EACH WATERSHED

Watershed and Variable	Quickflow	Quickflow Sediment
Watershed One		
Average Precipitation Intensity	0.03	-0.22
Quickflow		0.99*
Watershed Two		
Average Precipitation Intensity	-0.10	-0.22
Quickflow		0.94*
Watershed Three		
Average Precipitation Intensity	0.14	0.28
Quickflow		0.97*

*P-value < 0.005.

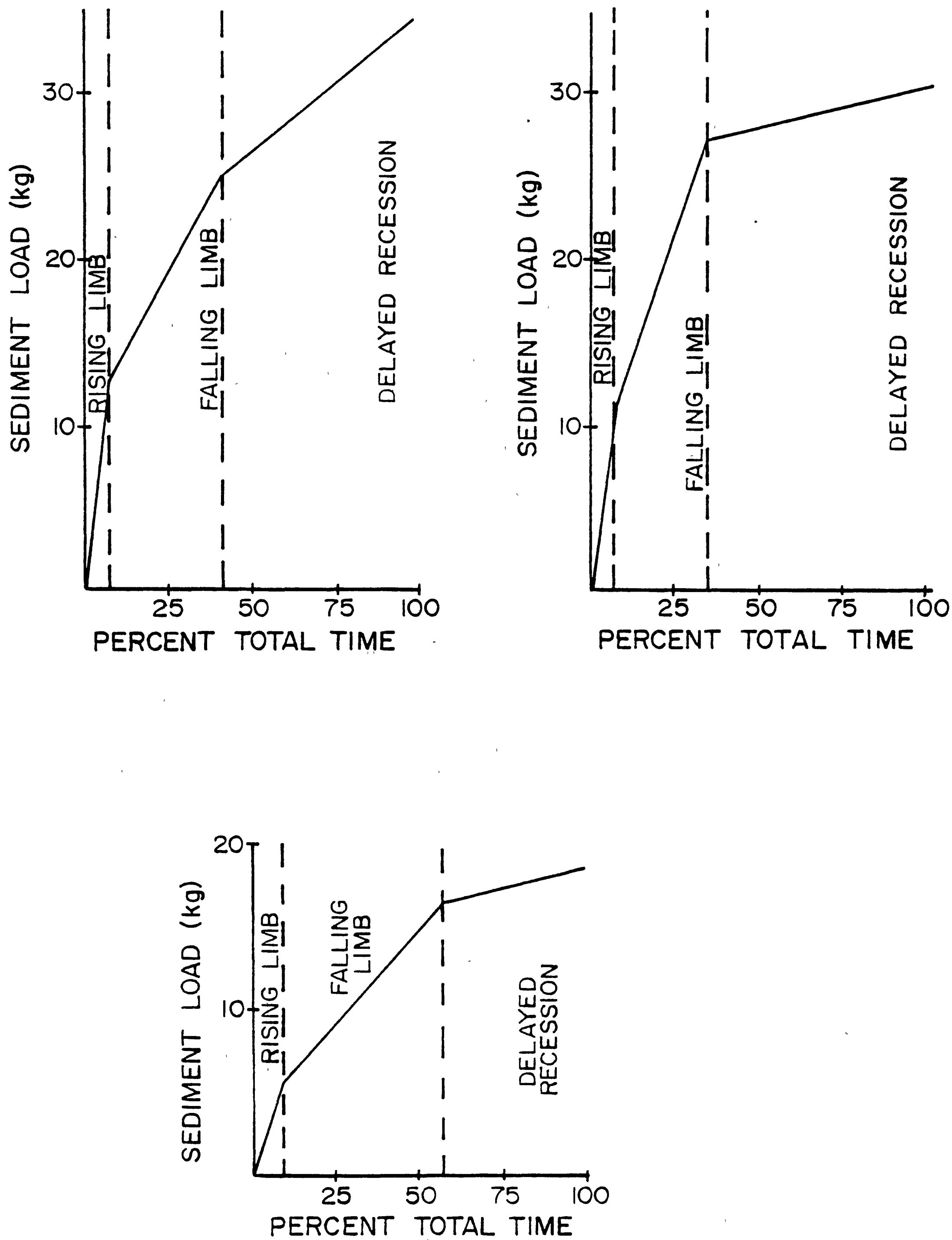


Figure 21. Average Accumulated Sediment Load Versus Time for the Three Study Watershed, Based on Winter-Spring, 1983

TABLE XIV

PERCENTAGE OF TOTAL SEDIMENT LOAD CONTAINED IN QUICKFLOW

Date (1983)	Watershed 1	Watershed 2	Watershed 3
1/31	---*	100	89
2/3	---	92	---
2/9	55	77	47
2/22	---	---	88
3/4	41	76	91
4/13	66	---	100
5/2	85	89	90
5/10	75	---	---
5/14	82	89	90
5/17	73	93	98
5/21	47	---	100
5/26	93	98	---
5/28	66	97	---
6/26	100	---	---
6/28	100	100	100
6/29	74	---	---

*Data unavailable for these dates.

WS-1 had higher sediment concentrations in the rising limb, the sediment loading rate per flow period did not vary as much for WS-1 as for WS-2 and WS-3, and overall sediment loading tended to be higher for WS-1 (Figure 21). One possible explanation for these findings could be that WS-1 had a higher drainage density than WS-2 and WS-3 (Table I). Anderson (1957) indicated that sediment production was a function of factors such as channel density. The greater numbers of channels and length of channel provide a larger area for channel and bank erosion to occur. Channel and bank erosion have been identified as the primary sources of erosion in a forested watershed (EPA, 1973).

A second possible factor was the length of time that stormflow lasted. Field observations indicated that WS-1 consistently flowed longer after a precipitation event than WS-2 and WS-3. The longer flow period may account for the lower variability of sediment loading among the flow periods on WS-1. Also, the longer flow time may have allowed more sediment to be transported overall, causing WS-1 to have higher sediment loads.

A third possible factor could be due to some cutting and fire disturbance on WS-1. Approximately 1.21 ha of WS-1 were thinned and burned in 1981-1982. The disturbance associated with this treatment may have led to higher sediment loads for WS-1. Other possibilities which could be considered are channel slope, bank slope, and bank protection. Measurements would be needed to determine the possible effects of these channel characteristics on loading.

As stated previously, Patric (1976) and Yoho (1980) determined that sediment loading for most undisturbed forested watersheds ranged between 122 to 224 kg per ha per year. The average sediment load from the three study watersheds was approximately 33 kg per ha for the Winter-Spring, 1983, season. This period lasted for approximately one-half of a year and accounted for much of the expected rainfall and runoff. Even if the 33 kg per ha figure was tripled for the remaining six months, the average sediment production for the three study watersheds would still be below the range for most forested watersheds in the nation.

Stormflow and Precipitation

Total stormflow and peak discharge correlated well with total precipitation tested on a two-season year, four-season year, and precipitation events having greater than 2.54 cm of rainfall (Tables XV, XVI, XVII, and XVIII). A multiple linear regression was used to determine if a relationship could be established for total stormflow as a function of total precipitation and antecedent precipitation on a four-season year basis (Table XIX). Total stormflow and peak discharge did not correlate with average intensity and did not consistently correlate with storm duration (Tables XV, XVI, and XVII).

Average storm intensity does not necessarily reflect the intensities which may have occurred during a precipitation event. A long period of drizzle or light rain may shadow a short period of very intense rainfall. The short period of high intensity may have been the most important period during a precipitation event for the production of stormflow. A relationship between peak rainfall intensity and stormflow on ephemeral watersheds in southeastern Oklahoma has already been demonstrated by Vowell (1980).

When looking at relationships between stormflow and precipitation, it is important to consider other factors such as antecedent soil

TABLE XV

CORRELATIONS BETWEEN STORMFLOW AND PRECIPITATION ON A TWO-SEASON BASIS FOR EACH WATERSHED

Watershed and Variable	Stormflow by Season January-June	Stormflow by Season July-December
Watershed One		
Total Precipitation	0.88*	0.59*
Average Precipitation Intensity	-0.06	-0.06
Duration	0.51*	0.20**
Watershed Two		
Total Precipitation	0.51*	---†
Average Precipitation Intensity	0.10	---
Duration	0.35*	0.03
Watershed Three		
Total Precipitation	0.84*	0.51*
Average Precipitation Intensity	-0.08	-0.06
Duration	0.50*	0.22**

*P value < 0.005.

**P value < 0.01 to 0.005.

†No runoff for period.

TABLE XVI

CORRELATIONS BETWEEN STORMFLOW AND PRECIPITATION ON A FOUR-SEASON BASIS FOR EACH WATERSHED

Watershed and Variable	Stormflow by Season			
	October-December	January-March	April-June	July-September
Watershed One				
Total Precipitation	0.69*	0.91*	0.86*	0.65*
Average Precipitation Intensity	0.10	0.07	-0.10	0.20
Duration	0.17	0.20	0.63*	-0.04
Watershed Two				
Total Precipitation	0.45**	0.88*	0.82*	---†
Average Precipitation Intensity	0.77*	0.17	0.06	-0.10
Duration	-0.14	0.33**	0.55*	0.49**
Watershed Three				
Total Precipitation	0.61*	0.91*	0.82*	0.88*
Average Precipitation Intensity	0.14	0.10	-0.10	-0.08
Duration	0.10	0.37	0.52**	0.63*

*P value < 0.005.

**P value 0.01 to 0.005.

†No data for period.

TABLE XVII

CORRELATION BETWEEN STORMFLOW AND EVENTS PRODUCING GREATER THAN 2.54 CM OF PRECIPITATION ON A FOUR-SEASON BASIS FOR EACH WATERSHED

Watershed and Variable	Stormflow by Season			
	October-December	January-March	April-June	July-September
Watershed One				
Total Precipitation	0.50	0.96*	0.90*	0.66*
Watershed Two				
Total Precipitation	0.17	0.68**	0.81*	---†
Watershed Three				
Total Precipitation	0.10	0.90*	0.90*	0.90*

*P value < 0.005.

**P value 0.01 to 0.005.

†No data for period.

TABLE XVIII

CORRELATIONS BETWEEN PEAK DISCHARGE AND PRECIPITATION ON A FOUR-SEASON BASIS FOR EACH WATERSHED

Watershed and Variable	Peak Discharge by Season October-December	January-March	April-June	July-September
Watershed One				
Total Precipitation	0.57*	0.82*	0.82*	-0.03
Average Precipitation Intensity	0.26	0.09	-0.08	-0.04
Duration	0.01	0.10	0.59*	-0.04
Watershed Two				
Total Precipitation	0.41**	0.81*	0.78*	---†
Average Precipitation Intensity	0.80*	0.14	-0.03	---
Duration	0.14	0.26	0.46*	---
Watershed Three				
Total Precipitation	0.49*	0.82*	0.74*	0.04
Average Precipitation Intensity	0.17	0.10	0.09	0.10
Duration	0.03	0.28**	0.36*	0.05

*P value < 0.005.

**P value 0.01 to 0.005.

†No data for period.

moisture and evapotranspiration (Linsley and Ackerman, 1942; Kohler and Linsley, 1951; Linsley et al., 1982). Testing for correlations between precipitation and stormflow on a seasonal basis was one attempt to account for soil moisture differences. Winter and spring are the periods of highest rainfall and stormflow for the three study watersheds (Figures 4 and 5). The summers are hot and dry. Rainfall that does occur in the summer is convective, usually in isolated and short lived showers which have little effect on easing soil moisture deficits. The fall rains initiate the start of basin recharge and begin to alleviate soil moisture deficits. By dividing the water year into two or four seasons, it was possible to obtain correlations for the wetter winter and spring seasons. Correlations were not as good for the summer and fall due to the measurements of zero stormflow obtained for the majority of the few storm events occurring during these seasons. Reduced stormflow was probably due to the utilization of rainfall by vegetation, evaporation, or infiltration into the soil. Measurable stormflow was possible during these seasons after several storm events occurred within a short time period or an exceptionally large event occurred.

The multiple regression utilizing antecedent precipitation was a second attempt to account for soil moisture conditions. The addition of antecedent precipitation as an independent variable to a multiple regression model with total stormflow as the dependent variable did not appear to improve the model (Table XIX). Linsley and Franzini (1979) stressed the importance of antecedent moisture conditions to stormflow production. They suggested adding the variable antecedent precipitation or another estimate of antecedent soil moisture conditions when developing precipitation-stormflow models for a watershed. The antecedent moisture

TABLE XIX

MULTIPLE REGRESSION RESULTS FOR STORMFLOW AS A FUNCTION OF PRECIPITATION AND ANTECEDENT PRECIPITATION

Watershed and Season	R^2 Total Precipitation[1]	R^2 Precipitation Accumulation Period[2] 0-25 Days	0-50 Days	0-100 Days
Watershed One				
October-December	0.47	0.47	0.47	0.49
January-March	0.83	0.84	0.83	0.83
April-June	0.67	0.68	0.68	0.69
July-September	0.40	0.40	0.40	0.50
Watershed Two				
October-December	0.20	0.21	0.21	0.21
January-March	0.77	0.78	0.78	0.79
April-June	0.67	0.69	0.69	0.69
July-September	---[3]	---	---	---
Watershed Three				
October-December	0.37	0.42	0.37	0.38
January-March	0.82	0.82	0.82	0.82
April-June	0.67	0.68	0.69	0.70
July-September	0.77	0.80	0.78	0.78

[1]$\hat{Y} = b_o + b_1x_1$, where b_o = total precipitation.

[2]$\hat{Y} = b_o = b_1x_1 + b_2x_2$, where b_1 = total precipitation and b_2 = accumulated precipitation.

[3]No runoff occurred during the July-September period.

conditions can reflect the amount of precipitation needed to bring a soil to saturation before runoff can occur. In the case of ephemeral watersheds such as the ones in this study, soil moisture may be the most important factor to consider when looking at storm runoff and total stormflow. However, antecedent precipitation as used in this study does not adequately account for soil moisture.

Watershed Pairing

Linear regression models were successfully established between WS-1 and WS-3, the control watershed, and WS-2 and WS-3 for total stormflow on an individual storm basis and monthly basis. Regression equations are included in Tables XX, XXI, and XXII. Using these results, it will be possible to pair these watersheds in future studies when WS-1 and WS-2 undergo silvicultural treatments.

Sediment production correlated well within these pairings, WS-1 and WS-3, and WS-2 and WS-3 (Table XXIII). The models developed may be used to compare sediment loads with WS-3 as a control; however, more data may aid in developing a more reliable model. The small number of storms in the Winter-Spring, 1983, season used for these tests may not be adequate to develop an accurate model.

TABLE XX

PREDICTION EQUATIONS FOR WATERSHED ONE STORMFLOW AS A FUNCTION OF WATERSHED THREE STORMFLOW DEVELOPED ON AN INDIVIDUAL STORM BASIS USING MULTIPLE LINEAR REGRESSION BY SEASON

Season	R^2	Degree Freedom	Mean Square Error	Equations
January-March[1,2]	0.96	20	0.0740	$\hat{Y} = 0.08124 + 0.83\ (X)$
April-June	0.89	41	0.3050	$\hat{Y} = 0.24780 + 0.78\ (X)$
July-September	0.86	16	0.0008	$\hat{Y} = 0.00370 + 12.99\ (X)$
October-December	0.86	13	0.0730	$\hat{Y} = 0.04160 + 0.56\ (X)$

[1]Units of data = cm.

[2]Data collected for 1979-1983.

TABLE XXI

PREDICTION EQUATIONS FOR WATERSHED TWO STORMFLOW AS A FUNCTION OF WATERSHED THREE STORMFLOW DEVELOPED ON AN INDIVIDUAL STORM BASIS USING MULTIPLE LINEAR REGRESSION BY SEASON

Season	R^2	Degree Freedom	Mean Square Error	Equations
January-March[1,2]	0.96	22	0.132	$\hat{Y} = -0.113 + 0.90\ (X)$
April-June	0.94	42	0.193	$\hat{Y} = -0.042 + 0.90\ (X)$
July-September	---[3]	---	---	---
October-December	0.85	12	0.124	$\hat{Y} = -0.092 + 0.87\ (X)$

[1]Units of data = cm.

[2]Data collected for 1979-1983.

[3]Data not available due to no runoff for period.

TABLE XXII

PREDICTION EQUATIONS FOR WATERSHED ONE AND WATERSHED TWO AS A FUNCTION OF WATERSHED THREE STORMFLOW ON A MONTHLY BASIS USING MULTIPLE LINEAR REGRESSION

Watersheds	R^2	Degree Freedom	Mean Square Error	Equations
WS-1 and WS-3[1,2]	0.89	37	0.214	$\hat{Y} = 0.078 + 0.85\ (X)$
WS-2 and WS-3	0.95	41	0.072	$\hat{Y} = 0.008 + 0.84\ (X)$

[1]Units for data = cm.

[2]Data collected for 1979-1983.

TABLE XXIII

PREDICTION EQUATIONS FOR SEDIMENT LOADING DEVELOPED USING MULTIPLE LINEAR REGRESSION ON AN INDIVIDUAL STORM BASIS

Watersheds	R^2	Degree Freedom	Mean Square Error	Equations
WS-1 and WS-3[1,2]	0.89	6	231.28	$\hat{Y} = -4.34 + 1.66\ (X)$
WS-2 and WS-3	0.93	5	44.13	$\hat{Y} = -4.47 + 0.86\ (X)$

[1]Units for data = kg.

[2]Data collected for January-June, 1983.

CHAPTER V

SUMMARY AND CONCLUSIONS

The project was a combination of two studies, a surface runoff and sediment study and a total stormflow and sediment study. The surface runoff study was conducted during the spring of 1983. It examined surface runoff and associated sediment production on three forested ephemeral watersheds in southeastern Oklahoma using two large runoff plots on each watershed. In addition, the variability of surface runoff within one of the ephemeral forested watersheds was examined by intensively monitoring soil moisture and surface runoff within hypothesized runoff-producing zones. Relationships among surface runoff, precipitation, and total sediment were examined. In addition, surface runoff as a percent of total stormflow was determined, and sediment production of the surface runoff was compared to total sediment yield of the basin for the study period.

Relationships between total stormflow, sediment production, and precipitation for the study watersheds were examined using data collected for the period January through July, 1983. In addition, variations and trends in sediment concentrations and sediment loading within stormflow hydrographs were determined for the three watersheds. Also, relationships between total stormflow and precipitation were examined for the three watersheds using data collected between 1979 and 1983. An additional part of the stormflow study was development of predictive models for stormflow and sediment loading among the three watersheds.

Surface runoff production was highly variable within the study watershed; however, the variability could not be explained through the use of runoff producing zones as delineated for the study. Total surface runoff was a small percentage of the total stormflow for all three watersheds with most percentages less than 2 percent. Soil moisture for the upper soil horizon was consistently higher for the upper ridge part of the watershed for the entire study period. To accurately identify the surface runoff pattens and soil mositure trends for the watershed would require more intensive sampling than was utilized in the study.

Surface runoff and sediment loads in the surface runoff correlated well with total precipitation but not with average precipitation intensity. There were indications of a relationship between the three variables, surface runoff, total precipitation, and sediment, for the three watersheds. A comparison of sediment transport by surface runoff to total stormflow sediment transport indicated that surface erosion is a minor contributor to total sediment transport from the forested watershed used in the study.

Sediment concentrations tended to be higher for the rising limb for the stormflow hydrograph than for the recession limb for all three watersheds, with one watershed having significantly higher concentrations for the watershed than the other two watersheds in the study. Total sediment loading rates were generally higher for the rising limb and the initial sections of the falling limb of the total stormflow hydrograph. Total sediment loads correlated very well with total stormflow and total precipitation, but not with storm duration or average precipitation intensity. This indicates that there were positive relationships between total precipitation, total stormflow, and sediment loading. More work is needed to develop workable models for predicting the true relationships between the three variables. There were indications that sediment loading rates were lower than many of the rates observed in the eastern United States with ranges of 27 kg/hr to 58 kg/hr for this study period.

Total stormflow and peak stormflow correlated well with total precipitation. However, total stormflow did not correlate with average precipitation tensity and storm duration.

Stormflow models using two watersheds as a function of a third control watershed were developed on an individual storm basis and a monthly basis with R^2 between 0.85 and 0.96. These models will be useful when silvicultural treatments are applied to the two watersheds for estimating treatment effects. Sediment loads correlated well between the control watershed and the other two watersheds which are to be silvicultural treated. Model development is possible for these watersheds based on sediment loading with the collection of more data.

Future studies using the surface runoff data should include testing the applicability of the Universal Soil Loss Equation and current stormflow models on ephemeral watersheds in southeastern Oklahoma. Other work is needed to develop a precipitation-stormflow model. This work should include estimates of antecedent moisture, evapotranspiration, and maximum rainfall intensity. Total sediment loading information determined in this study will be useful in evaluating future studies which might involve silvicultural treatment of the watersheds.

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APPENDIX A

PRECIPITATION MODELS

TABLE XXIV

PREDICTION EQUATIONS FOR WATERSHED TWO AS A FUNCTION OF WATERSHED ONE AND WATERSHED THREE ON AN INDIVIDUAL STORM BASIS USING MULTIPLE LINEAR REGRESSION

Watersheds[1, 2]	R^2	Degree Freedom	Mean Square Error	Equations
WS-2 and WS-1	.97	112	0.019	$\hat{Y} = 0.012 + 0.97(X)$
WS-2 and WS-3	.85	63	0.038	$\hat{Y} = 0.014 + 0.84(X)$

[1]Data collected from 1979-1983.

[2]Units equal cm.

APPENDIX B

TABULATED DATA

TABLE XXV

TIMBER INVENTORY OF WATERSHED ONE[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 from Vonell, 1980.

TABLE XXVI

TIMBER INVENTORY OF WATERSHED TWO[1]

Diameter Class (cm)	Trees/ha		Basal Area (M^2/ha)	
	Pine	Hardwood	Pine	Hardwood
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 was collected from sample points at 20 meter intervals on a random grid from Vonell, 1980.

TABLE XXVII

TIMBER INVENTORY OF WATERSHED THREE[1]

Diameter Class (cm)	Trees/ha		Basal Area (M^2/ha)	
	Pine	Hardwood	Pine	Hardwood
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 from Vonell, 1980.

TABLE XXVIII

SURFACE RUNOFF, THROUGHFALL, AND TOTAL SEDIMENT CONCENTRATIONS PER PLOT FOR LARGE PLOT SURFACE RUNOFF STUDY, WATERSHED ONE

	Plot 1			Plot 2		
Date (1983)	Surface Runoff (ml)	Throughfall (cm)	Total Sediment (mg/l)	Surface Runoff (ml)	Throughfall (cm)	Total Sediment (mg/l)
4/24	1200	1.95	86.8	----[1]	----	----
5/12	2900	2.59	36.5	450	2.83	----
5/17	139605	4.64	7.2	1290	5.49	59.05
5/19	2020	1.79	54.8	1600	1.77	23.75
5/22	2600	1.67	20.8	770	1.73	----
5/27	2810	2.76	9.9	720	2.99	44.3
6/1	4900	2.30	4.2	1590	2.27	23.8
6/9	5100	2.39	2.2	2440	2.34	19.8
6/29	13500	11.38	25.7	10500	11.45	13.8

[1]Data unavailable for date.

TABLE XXIX

SURFACE RUNOFF, THROUGHFALL, AND TOTAL SEDIMENT CONCENTRATIONS PER PLOT FOR LARGE PLOT SURFACE RUNOFF STUDY, WATERSHED TWO

Date (1983)	Plot 1 Surface Runoff (ml)	Plot 1 Throughfall (cm)	Plot 1 Total Sediment (mg/l)	Plot 2 Surface Runoff (ml)	Plot 2 Throughfall (cm)	Plot 2 Total Sediment (mg/l)
4/24	680	1.99	----[1]	580	2.04	68.2
5/3	1400	4.16	16.0	2100	5.51	56.6
5/11	2000	1.38	13.5	1600	1.55	24.9
5/17	14020	4.86	9.8	48500	5.09	5.2
5/19	3830	2.45	12.2	7300	2.40	9.9
5/22	1740	1.52	25.2	1690	1.34	11.2
5/27	3790	2.53	22.4	32050	2.79	15.1
6/1	2430	1.77	5.7	6100	1.53	4.4
6/9	1600	0.75	15.0	380	0.65	33.2
6/28	9740	6.05	10.1	3660	5.59	11.6
6/29	4300	2.33	19.8	17040	2.41	7.8

[1]Data unavailable for date.

TABLE XXX

SURFACE RUNOFF, THROUGHFALL, AND TOTAL SEDIMENT CONCENTRATIONS PER PLOT FOR LARGE PLOT SURFACE RUNOFF STUDY, WATERSHED THREE

	Plot 1			Plot 2		
Date (1983)	Surface Runoff (ml)	Throughfall (cm)	Total Sediment (mg/l)	Surface Runoff (ml)	Throughfall (cm)	Total Sediment (mg/l)
4/24	580	2.02	62.5	0	1.35	----
5/3	5030	3.31	34.9	49820	5.82	14.8
5/11	800	0.88	----[1]	0	0.78	----
5/16	7220	6.91	59.7	72200	6.46	10.5
5/20	3860	2.59	51.3	9360	2.79	7.6
5/22	2390	2.01	47.8	3020	2.00	13.0
5/27	920	0.52	----	970	0.67	47.4
6/1	2500	1.69	26.0	2720	1.61	2.0
6/9	1730	0.97	18.4	3200	0.78	----
6/28	6020	6.95	12.9	21080	7.82	5.2
6/29	2820	2.27	19.8	4940	2.08	16.7

[1]Data unavailable for date.

TABLE XXXI

RUNOFF PER PLOT IN ZONE I BY COLLECTION DATE

Plot	Date (1983)										
	4/13	4/22	5/3	5/10	5/17	5/19	5/21	5/27	6/1	6/9	6/29
2	0[1]	150	19431	0	34000	0	0	65	0	0	37854
4	0	0	19438	0	0	0	0	1560	0	0	23207
5	0	0	1416	0	500	0	0	156	0	0	0
8	0	1100	200	0	0	0	0	212	0	0	280
10	790	1140	12818	0	4000	0	0	3020	1020	2170	15540
10	1000	336	9911	0	13500	0	0	1150	440	840	3020
13	172	0	1266	0	1000	0	0	1160	490	990	7100

[1] Ml.

TABLE XXXII

RUNOFF PER PLOT IN ZONE II BY COLLECTION DATE

Plot	Date (1983)										
	4/13	4/22	5/3	5/10	5/17	5/19	5/21	5/27	6/1	6/9	6/29
1	500[1]	420	1088	0	1750	0	0	750	600	0	2220
3	0	0	5907	0	0	0	0	0	0	0	0
6	113	170	19430	0	36000	0	0	47	0	0	17320
7	88	160	1312	0	1000	0	0	1220	0	0	2170
9	0	0	6900	0	4500	0	0	0	0	0	0
12	0	0	21682	0	0	0	0	0	0	0	2500
15	620	680	2176	0	2000	0	0	2320	680	1240	---

[1]Ml.

TABLE XXXIII

RUNOFF PER PLOT IN ZONE III BY COLLECTION DATE

Plot	Date (1983)										
	4/13	4/22	5/3	5/10	5/17	5/19	5/21	5/27	6/1	6/9	6/29
14	218[1]	0	16551	0	36500	0	0	1600	0	820	1220
16	810	1200	13900	0	---	0	0	0	0	800	11300
17	382	600	2055	0	3000	0	0	2300	980	1820	3840
18	---	700	12184	0	14250	0	0	0	0	0	10500

[1]Ml.

TABLE XXXIV

THROUGHFALL PER PLOT IN ZONE I BY DATE

Plot	Date (1983)										
	4/13	4/24	5/3	5/12	5/17	5/19	5/22	5/27	6/1	6/9	6/29
2	1.69[1]	2.47	4.29	2.99	4.68	1.95	1.67	2.86	1.75	2.01	11.56
4	1.82	2.39	4.55	2.21	4.03	1.82	2.01	2.86	1.62	2.27	11.69
5	1.69	2.34	6.75	2.40	5.91	1.30	1.40	4.03	1.62	2.34	7.79
8	2.08	2.08	5.00	2.27	4.94	1.56	1.56	2.47	2.21	2.27	9.61
10	1.92	1.74	6.37	2.60	4.81	1.82	1.47	2.60	1.43	1.43	8.44
11	2.40	2.21	6.94	2.47	5.20	1.43	1.53	2.21	1.43	1.82	10.13
13	1.69	1.47	5.33	2.47	5.20	1.56	1.43	2.47	1.88	1.62	8.77

[1]Cm.

TABLE XXXV

THROUGHFALL PER PLOT IN ZONE II BY DATE

	Date (1983)										
Plot	4/13	4/24	5/3	5/12	5/17	5/19	5/22	5/27	6/1	6/9	6/29
1	1.88[1]	2.10	7.40	2.66	5.52	1.82	1.56	2.66	2.47	2.34	10.50
3	2.14	2.28	7.08	2.73	5.85	1.69	1.33	2.86	2.08	2.14	11.69
6	2.21	2.38	7.53	2.60	5.20	1.69	1.30	2.21	1.75	1.95	10.39
7	1.69	2.08	4.94	2.73	4.94	1.62	1.66	3.38	1.62	2.27	10.91
9	1.98	2.31	5.33	2.92	5.26	2.60	1.83	2.73	2.73	2.40	12.99
12	1.95	2.86	6.69	3.12	7.27	2.01	2.91	1.95	2.73	3.57	13.77
15	1.88	2.32	5.33	3.31	5.91	2.01	1.51	2.86	2.86	2.27	---

[1] Cm.

TABLE XXXVI

THROUGHFALL PER PLOT IN ZONE III BY DATE

Plot	Date (1983)										
	4/13	4/24	5/3	5/12	5/17	5/19	5/22	5/27	6/1	6/9	6/29
14	1.95[1]	1.84	7.27	2.08	5.52	1.36	1.73	3.51	1.69	2.73	---
16	2.37	1.95	2.44	2.79	4.81	1.88	1.58	2.79	1.62	2.40	9.81
17	1.69	1.75	5.72	1.88	4.94	1.30	1.30	---	1.62	1.95	8.83
18	---	1.09	6.88	2.60	5.85	1.62	1.51	2.86	2.40	2.40	10.52

[1]Cm.

TABLE XXXVII

PERCENT SOIL WATER BY WEIGHT PER PLOT IN ZONE I BY DATE

Plot	Date (1983)								
	4/10	4/21	4/27	5/5	5/12	5/19	6/2	6/9	6/18
2	23.91	31.92	26.28	25.97	24.20	30.25	30.00	27.19	18.19
4	22.02	27.61	21.40	26.18	29.22	30.02	25.18	24.92	16.14
5	20.37	24.65	19.33	22.38	25.08	26.16	21.98	21.64	17.98
8	22.84	21.18	21.13	23.15	24.81	23.65	23.15	23.16	15.60
10	21.95	23.56	20.88	22.47	28.88	27.06	23.38	21.83	14.26
11	24.78	25.13	28.08	23.39	24.54	27.65	24.03	25.98	14.84
13	26.41	25.93	26.15	22.95	26.81	26.47	26.01	34.00	17.18

TABLE XXXVIII

PERCENT SOIL WATER BY WEIGHT PER PLOT IN ZONE II BY DATE

Plot	Date (1983)								
	4/10	4/21	4/27	5/5	5/12	5/19	6/2	6/9	6/18
1	20.69	24.63	23.69	19.82	24.22	24.09	23.98	19.97	10.00
3	25.00	25.08	20.61	25.47	24.16	32.64	23.85	27.71	21.78
6	26.19	26.37	23.49	25.56	25.47	29.73	24.20	29.21	19.16
7	23.95	26.04	27.29	22.01	19.58	27.41	27.93	25.89	17.16
9	21.65	24.35	21.63	19.47	31.77	25.49	23.58	23.16	16.53
12	22.36	24.81	21.25	23.61	25.58	26.14	23.93	22.61	15.03
15	25.02	28.42	24.84	27.82	27.39	31.38	27.70	25.33	19.40

TABLE XXXIX

PERCENT SOIL WATER BY WEIGHT PER PLOT IN ZONE III BY DATE

Plot	Date (1983)								
	4/10	4/21	4/27	5/5	5/12	5/19	6/2	6/9	6/18
14	29.90	26.95	25.09	28.99	29.05	33.63	27.95	21.65	17.99
16	27.02	30.96	26.89	29.61	34.82	33.60	31.30	26.84	19.19
17	24.35	27.29	24.50	27.22	31.26	29.53	29.87	26.57	18.98
18	---	27.09	27.26	28.77	29.72	32.37	28.33	32.20	21.63

TABLE XL

TOTAL SUSPENDED SOLID CONCENTRATIONS PER PLOT WITHIN ZONE I BY DATE

Plot	Date (1983)									
	4/22	5/3	5/10	5/17	5/19	5/21	5/27	6/1	6/9	6/29
2	---[1]	18.6[2]	---	9.1	---	---	---	---	---	---
4	---	9.3	---	---	---	---	13.9	---	---	11.3
5	---	29.4	---	13.9	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---	---	5.7
10	11.9	23.1	---	25.2	---	---	12.5	42.9	10.6	---
11	---	17.5	---	11.4	---	---	10.7	---	25.3	12.7
13	---	114.2	---	80.8	---	---	---	---	---	27.2

[1]Data unavailable for date.

[2]Mg/l.

TABLE XLI

TOTAL SUSPENDED SOLID CONCENTRATION PER PLOT WITHIN ZONE II BY DATE

Plot	Date (1983)									
	4/24	5/3	5/11	5/17	5/19	5/21	5/27	6/1	6/9	6/29
1	65.5[1]	75.7	---[2]	3.6	---	---	82.5	23.8	---	18.7
3	---	20.9	---	---	---	---	---	---	---	---
6	---	5.9	---	11.1	---	---	---	---	---	8.8
7	---	8.5	---	26.4	---	---	8.7	---	---	13.6
9	---	16.7	---	13.7	---	---	---	---	---	---
12	---	11.8	---	---	---	---	---	---	---	17.0
15	54.1	16.2	---	16.9	---	---	8.2	9.2	36.3	---

[1]Mg/l.

[2]Data unavailable for date.

TABLE XLII

TOTAL SUSPENDED SOLID CONCENTRATION PER PLOT WITHIN ZONE III BY DATE

Plot	Date (1983)									
	4/24	5/3	5/11	5/17	5/19	5/21	5/27	6/1	6/9	6/29
14	---[1]	5.5[2]	---	136.9	---	---	32.0	---	43.6	29.9
16	18.3	12.8	---	---	---	---	---	---	26.1	32.2
17	59.9	11.2	---	10.4	---	---	11.2	23.6	50.0	11.3
18	---	21.3	---	13.1	---	---	---	---	---	6.7

[1]Data unavailable for date.

[2]Mg/l.

TABLE XLIII

STORMFLOW, PRECIPITATION, AND SEDIMENT DATA FOR WINTER-SPRING, 1983 SEASON, WATERSHED ONE

Date (1983)	Total Storm Runoff (cm)	Quick Flow (cm)	Total Ppt (cm)	Average Intensity cm/hr	Duration (hr)	Total Sediment Quick Flow (kg)	Total Sediment (kg)
2/9	.923	.367	.91	.63	2	6.07	11.06
3/4	2.6556	1.0714	4.32	.3	15.6	20.26	48.94
4/13	.5275	.2283	2.31	.56	4.2	14.22	21.37
5/2	3.8588	2.7145	6.81	.1	60.7	98.17	114.98
5/10	.6426	.3914	2.84	1.9	5.2	9.35	12.44
5/14	4.4153	3.3774	5.74	1.22	5.6	74.49	90.53
5/17	.9794	.6802	2.21	.44	5.3	14.0	19.21
5/21	1.0134	.5359	1.88	.58	4.3	8.65	18.44
5/26	.3884	.3445	2.84	2.31	1.2	12.12	13.06
5/28	.7734	.5395	2.79	1.60	8.2	7.06	10.69
6/26	.1097	.1097	1.19	.45	2.7	3.24	3.24
6/28	.3172	.3172	3.71	.38	9.5	12.43	12.43
6/29	1.4247	.9944	3.38	1.14	2.8	22.43	30.36

TABLE XLIV

STORMFLOW, PRECIPITATION, AND SEDIMENT DATA FOR WINTER-SPRING, 1983 SEASON, WATERSHED TWO

Date (1983)	Total Storm Runoff (cm)	Quick Flow (cm)	Total Ppt (cm)	Average Intensity cm/hr	Duration (hr)	Total Sediment Quick Flow (kg)	Total Sediment (kg)
1/31	0.085	0.085	1.93	0.76	2.83	0.68	0.68
2/3	0.890	0.840	0.81	0.08	11.67	10.43	11.30
2/10	0.490	0.300	0.76	0.11	2.16	3.16	4.11
3/4	1.360	1.200	3.86	0.43	11.67	9.53	12.56
5/2	3.650	3.000	5.94	0.56	10.50	35.10	39.47
5/14	4.720	4.060	5.84	1.47	6.20	52.64	58.97
5/18	1.780	1.630	2.95	0.66	4.80	22.45	24.12
5/26	0.470	0.460	2.90	4.44	0.67	7.46	7.57
5/28	0.580	0.550	1.68	1.40	1.42	6.64	6.85
6/28	0.140	0.140	2.84	0.48	6.57	2.55	2.55

TABLE XLV

STORMFLOW, PRECIPITATION, AND SEDIMENT DATA FOR WINTER-SPRING, 1983 SEASON, WATERSHED THREE

Date (1983)	Total Storm Runoff (cm)	Quick Flow (cm)	Total Ppt (cm)	Average Intensity cm/hr	Duration (hr)	Total Sediment Quick Flow (kg)	Total Sediment (kg)
1/31	1.18	1.13	0.96	0.08	12.23	17.39	15.50
2/9	0.53	0.15	0.81	0.56	2.50	4.00	8.47
2/22	4.73	4.03	6.96	0.53	24.10	60.75	68.71
3/4	1.96	1.76	4.08	0.42	12.00	25.45	27.88
4/13	0.48	0.48	2.87	0.74	3.80	13.97	13.97
5/2	3.05	2.69	6.95	0.35	18.70	53.45	59.37
5/14	3.34	2.98	5.74	1.22	5.59	58.63	65.94
5/18	1.38	1.33	2.21	0.44	5.33	26.22	26.87
5/21	0.48	0.48	1.88	0.58	4.31	13.12	13.12
6/28	0.17	0.17	2.54	0.61	6.00	8.02	8.02

APPENDIX C

SUMMARY STATISTICS

TABLE XLVI

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR TOTAL SURFACE RUNOFF DIFFERENCES AMONG LARGE SURFACE RUNOFF PLOTS

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	15	0.00045	2.51	0.0089
Error	45	0.00018	----	----
Total	60	----	----	----
Date	10	0.00056	3.11	0.0043
Runoff per Plot	5	0.00023	1.29	0.2837

TABLE XLVII

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOAD DIFFERENCES AMONG LARGE SURFACE RUNOFF PLOTS

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	13	27209.95	1.00	0.47
Error	35	27161.31	----	----
Total	48	----	----	----
Date	8	26109.62	0.96	0.48
Sediment per Plot	5	28970.49	1.07	0.40

TABLE XLVIII

SPLIT-PLOT DESIGN ANALYSIS OF VARIANCE TABLE FOR RANKED SURFACE RUNOFF DATA FOR RUNOFF PRODUCING ZONE STUDY

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	38	3986.98	5.36	0.0001
Error	103	744.39	----	----
Total	141	----	----	----
Zones	2	4032.07	1.38	.10<
Plots with in Zones	15	2911.17	3.91	.0001
Dates	7	13010.0	17.48	.0001
Zone by Date	14	621.68	0.84	.630

TABLE XLIX

SPLIT-PLOT DESIGN ANALYSIS OF VARIANCE TABLE FOR RANKED SOIL MOISTURE DATA FOR RUNOFF PRODUCING ZONE STUDY

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	40	5447.87	8.09	0.0001
Error	111	673.12	----	----
Total	151	----	----	----
Zones	2	23184.60	8.08	<.005
Plots with in Zones	14	2871.35	4.26	0.0001
Dates	8	1529.63	22.36	0.0001
Zones by Dates	16	644.36	0.96	0.5078

TABLE L

RANKED SOIL MOISTURE MEANS AND RESULTS OF DUNCAN MULTIPLE COMPARISON BY ZONE FOR DATA COLLECTED APRIL-JUNE, 1983

Zone	Mean	Comparison
I	68.94	A
II	64.74	A
III	108.26	B

TABLE LI

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOADING DIFFERENCES AMONG FLOW PERIODS FOR WATERSHED ONE

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	13	353.63	5.32	----
Error	21	66.50	----	----
Total	34	----	----	----
Date	11	385.95	5.80	0.0003
Flow Periods	2	175.90	2.65	0.0945

TABLE LII

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOADING DIFFERENCES AMONG FLOW PERIODS FOR WATERSHED TWO

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	10	131.28	5.22	0.0022
Error	15	25.13	----	----
Total	25	----	----	----
Date	8	116.51	4.63	0.0052
Flow Periods	2	190.37	7.57	0.0053

TABLE LIII

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOADING DIFFERENCES AMONG FLOW PERIODS FOR WATERSHED THREE

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	11	215.48	6.51	0.0006
Error	15	33.12	----	----
Total	26	----	----	----
Date	9	164.64	4.97	0.0032
Flow Period	2	444.22	13.41	0.0005

TABLE LIV

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOADING DIFFERENCES AMONG WATERSHEDS FOR TOTAL STORMFLOW

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	10	1700.54	8.66	0.0003
Error	13	196.32	----	----
Total	23	----	----	----
Date	8	1890.5	9.63	0.0002
Watersheds	2	940.72	4.79	0.0276

TABLE LV

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOADING DIFFERENCES AMONG WATERSHEDS FOR THE RISING LIMB FLOW PERIOD

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	11	232.60	4.72	0.004
Error	14	49.28	----	----
Total	25	----	----	----
Date	9	265.93	5.40	0.0027
Watershed	2	82.62	1.68	0.2225

TABLE LVI

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOADING DIFFERENCES AMONG WATERSHEDS FOR THE FALLING LIMB FLOW PERIOD

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	4	65.73	14.52	0.0264
Error	3	4.53	----	----
Total	7	----	----	----
Date	2	128.75	28.43	0.0112
Watershed	2	2.70	0.60	0.6049

TABLE LVII

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT LOADING DIFFERENCES AMONG WATERSHEDS FOR THE DELAYED RECESSION FLOW PERIOD

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	9	74.83	2.74	0.0590
Error	11	27.29	----	----
Total	20	----	----	----
Date	7	49.64	1.82	0.1801
Watershed	2	162.99	5.97	0.0175

TABLE LVIII

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT CONCENTRATION DIFFERENCES AMONG WATERSHEDS FOR THE RISING LIMB FLOW PERIOD

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	12	446.76	4.87	0.0025
Error	15	91.80	----	----
Total	27	----	----	----
Date	10	377.56	4.11	0.0070
Watershed	2	792.74	8.64	0.0032

TABLE LIX

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT CONCENTRATION DIFFERENCE AMONG WATERSHEDS FOR THE FALLING LIMB FLOW PERIOD

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	12	132.84	10.47	0.0001
Error	15	12.69	----	----
Total	27	----	----	----
Date	10	150.47	11.86	0.0001
Watersheds	2	44.67	3.52	0.0558

TABLE LX

COMPLETE RANDOMIZED BLOCK ANALYSIS OF VARIANCE TABLE FOR SEDIMENT CONCENTRATION DIFFERENCES AMONG WATERSHEDS FOR THE DELAYED RECESSION FLOW PERIOD

Source	Degrees of Freedom	Mean Square	F - ratio	P - value
Model	12	352.64	9.94	0.0001
Error	1r	35.46	----	----
Total	26	----	----	----
Date	10	405.89	11.45	0.0001
Watersheds	2	70.79	2.44	0.1237

VITA

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