HYDROLOGIC AND NUTRIENT RELATIONSHIPS ON A PINE - HARDWOOD FOREST IN SOUTHEAST OKLAHOMA

By

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Bachelor of Science in Agriculture

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Stillwater, Oklahoma

1978

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTERS OF SCIENCE
July, 1980

HYDROLOGIC AND NUTRIENT RELATIONSHIPS ON A PINE - HARDWOOD FOREST IN SOUTHEAST OKLAHOMA

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Acknowledgments

I would like to express my sincere gratitude and appreciation to Dr. Larry C. Tennyson, my major advisor, for his constant support and helpful criticism throughout this study. Thanks goes to Dr. Ron McNew for his personal interest and help with the statistical analysis. A thanks also goes to Dr. Greg Jones and Dr. Marcia Bates for their helpful review of my thesis.

A special note of thanks goes to a couple of foresters whose friendship and help made my study a pleasant task, Bob Bradford and Floyd Brown. Also thanks goes to Rich Wenneker and John Sherblom for their help with the computer. Finally and most importantly a note of thanks and love to Cathy, my wife, for her patience and hardwork.

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CHAPTER I

INTRODUCTION

Man and the environment he lives in are dependent on a constant supply of fresh water for industrial purposes to manufacture goods, agricultural uses to grow food, and personal needs. Since man's needs are so closely tied to water, a practical understanding of water and its movements in the hydrologic cycle is necessary. In the forest ecosystem, this cycle has inflows in the form of precipitation, streamflow, and groundwater and outflows in the form of runoff, evapotranspiration, and groundwater. The forest ecosystem can also have marked effects on water quality, quantity, and regimen. These effects can be influenced by forest management practices. Because of man's capability to influence water through forest management, he needs a complete understanding of the forest and its influence on water hydrology.

There have been many investigations on the quality and quantity of precipitation as it falls through the forest canopy to the forest floor. Many studies have been limited to measuring the quantity of water passing through the canopy, while others have incorporated investigations of water quality. However, little information exists on the effect of Oklahoma forests on these parameters.

Eastern Oklahoma has 1.74 million hectares of commercial forest land (Murphy, 1977), of which 20% is comprised of pine dominant timber with shortleaf pine (Pinus echinata) being the major species. Shortleaf pine accounts for over 26 million cubic meters of growing stock in southeast Oklahoma (Murphy, 1977). These forested watersheds are an important water supply. The management of these forested watersheds has the potential to change the quantity and quality of this water supply.

Objectives

A study of the influences of Oklahoma forests on water quantity and quality will have two purposes. One will be to provide baseline information for future studies and add to the basic knowledge of forest hydrology and, secondly, to assist forest and watershed managers in making proper management decisions. The study was conducted on a shortleaf pine-hardwood forested watershed in southeast Oklahoma. The objectives of this study are: (1) to characterize the relationship between throughfall and gross precipitation; (2) to characterize the relationship between surface runoff and gross precipitation, throughfall and slope; and (3) to define cation behavior in precipitation, throughfall, surface runoff, and stream runoff.

Definition of Terms

A full understanding of hydrology in the forest ecosystem requires a separation and definition of terms. Many hydrologists use interception terminology indiscriminately, making attempts to interpret results confusing.

Precipitation (gross precipitation) is moisture per storm measured in the open or above the forest canopy. Throughfall is that portion of precipitation that passes directly through the aerial vegetation or drips from leaves, twigs, and stems to the litter (Helvey and Patric, 1965). Another path precipitation can take to the forest floor is by stemflow which occurs when rain strikes the forest canopy and travels down the stem to the litter.

Interception according to Zink (1967), is the precipitation retained in the aerial portion of the vegetation and returned to the atmosphere by evaporation or is absorbed into the vegetation. Helvey and Patric (1965) separate interception into canopy interception and litter interception. Canopy interception is defined as rainfall which is retained in the standing vegetation, and litter interception is the moisture retained in the litter above the mineral soil. Both litter and canopy moisture are assumed to be evaporated without adding moisture to the mineral soil.

A further separation of terms is required when net precipitation (throughfall and stemflow) reaches the litter. The process of water passing through the litter into mineral soil is defined as infiltration, while the movement of water through the soil is percolation (Satterlund, 1972). When the infiltration rate is exceeded by rainfall intensity or infiltration and/or percolation is limited, a surplus of water can occur at the surface. The lateral movement of water at the surface over or through the litter is designated as overland flow or surface runoff (Pierce, 1967). Streamflow is the movement of water in channels.

CHAPTER II

LITERATURE REVIEW

Precipitation

Accurate measurement of precipitation is an important part of any watershed study. Some factors that can affect the accuracy of precipitation gages are evaporation, adhesion of water, inclination of the gage, splash, poor measurement technique, damaged gage, and exposure. Exposure of gages to wind produces the largest problem in accurate measurement of rain gages. Corbett (1967) compared various gages and wind shields and concluded that a pit gage, with the orifice level with the ground, is the best system to overcome exposure problems. However, pit gages were also the most difficult and expensive to install and maintain.

Steep inclines found in mountainous areas can also have an affect on rain gage accuracy. Storey and Wilm (1944) established that rain gages tilted parallel to the slope tend to collect more, therefore, produce a more representative measurement of the actual amount of precipitation incident upon an area. However, an adequate number of gages must be installed to get a representative sample of the various slopes and exposures.

Precipitation stations or throughfall gages that are to be compared to one another should be located on similar slopes and aspects. Also, trees and brush that intercept a 45 line from the raingage should be removed to prevent vegetation influence on measurement of gross precipitation (Helvey and Patric, 1965).

Helvey and Patric (1965) established that precipitation gages placed in conventional forest openings provided samples as cheaply and accurately as precipitation gages placed above the forest canopy level. A method of determining a precipitation gage's accuracy is to compare several gages in the vicinity (Corbett, 1967).

Throughfall

Numerous studies have been conducted on the phenomenon of throughfall, and investigators have suggested that adequate information exists to make the need for future studies unnecessary (eg. Patric, 1966). However, Helvey and Patric (1965), in a review of literature on throughfall in northern hardwoods, showed many of the earlier studies, while similar, were inadequate in sampling or measurement techniques. They found that many of the older papers expressed throughfall and interception as a percentage of gross precipitation. However, this is a useless expression unless the percentage is presented in a storm class distribution because the percent throughfall will vary with different size storms.

Sampling Throughfall

The number of throughfall gages used is important in determining the statistical validity of the data. Wood (1937) used four throughfall gages under four trees: a chestnut oak (Quercus montana); pitch pine (Pinus rigida); white oak (Quercus alba); and gum (Nyssa sylvatica); but found 18 gages were needed to explain throughfall variability within a 0.05 probability level. Helvey and Patric (1965) used the equation:

> Number of Throughfall Gages = [(Standard Deviation)/(Tolerable Error)] X (Mean of Storm)

to arrive at the number of gages needed to statistically sample a storm class at an acceptable probability level in northern hardwoods. They generalized a need of 30 gages to sample most storms. These researchers excluded storms less than 5.08 mm due to smaller storms having a greater variability in throughfall and the added expense in measuring this variability. Also, such storms accounted for only 4% of gross precipitation and produced little runoff. Lawson (1967), in a pine-hardwood forest, found that 36 gages were sufficient to maintain a 0.05 probability level for most storms greater than 6.35 mm. Helvey and Patric and Lawson both used a roving gage sampling technique suggested by Wilm (1946). Wilm stated that a roving gage system randomly moving in time and space would reduce the number of gages required to accurately sample at a given probability level.

Czarnowski and Olszewski (1970), in a mixed hardwood forest in Poland, indicated that the mean of 30 fixed throughfall gages varied little from the mean of a much larger number of gages. They also established that the distance between gages had no effect on variability around the mean. Kimmins (1973) in a study on western hemlock (Tsuga heterophylla) in British Columbia indicated in his comparison of throughfall sampling techniques that fixed collectors have a definite advantage over roving collectors. If a major interest of the study is concerned with a detailed storm analysis, or the study is of short duration or concerned with chemical parameters (cations) not consistently related to precipitation, the roving gage method is inappropriate. Kimmins also established that the measurement of chemical parameters had a much higher variability associated with it compared to throughfall, canopy density, or interception measurement, and would require hundreds of throughfall gages to sample with statistical significance; however, only a marginal improvement in reducing cation variability would be obtained by additional numbers of gages over the 30 fixed gages.

Kimmins (1973) also discovered that the relationship of roving throughfall collectors to a fixed precipitation gage was not always consistent. The relationship of fixed and roving collectors was assumed to be constant by many researchers. Helvey and Patric (1965) found the use of one fixed precipitation gage was adequate for most throughfall studies with roving throughfall gages; however, several precipitation gages would further reduce variability in measurement of gross precipitation.

Throughfall Predictability

Helvey and Patric (1965) in their extensive review of throughfall in northern hardwood forests discovered a similarity between most studies. They indicated gross precipitation expressed as a linear equation was the best single predictor of throughfall. They generated throughfall equations for growing and dormant seasons. Wilm and Neiderhof (1941) suggested no appreciable difference in percentages of net annual precipitation/gross annual precipitation.

Lawson (1967), in a 23 month study of shortleaf pine with a hardwood understory in the Ouachita Mountains in Arkansas, discovered throughfall averaged 84.9% of precipitation. Again, precipitation was the best single predictor, but the addition of a second variable, the long term mean temperature, increased the regression sum of squares significantly. Lawson discovered that, while the variation in throughfall between seasons was not statistically significant, the dormant season produced slightly more throughfall. This slight difference was attributed to changes in the hardwood foilage and possibly different storm types.

In Illinois, Boggess (1956) conducted a three year throughfall study on a 16 year old shortleaf pine plantation. Throughfall averaged 82.3% of precipitation during this period, and while the total annual rainfall ranged from 157 cm to 81 cm, throughfall as a percent of annual precipitation did not vary appreciably.

Swank et. al. (1972) compared interception measurements from four loblolly pine (Pinus taeda) plantations and a hardwood-shortleaf stand to mature hardwoods in South Carolina. They indicated that the loblolly pine plantations intercepted as much as 10 cm more precipitation than typical mature hardwoods.

Swank et. al. (1972) also discovered no statistically significant difference between seasons in a mature hardwood-shortleaf stand. They attributed this to the shortleaf pine which contributed 14% of the canopy cover. Yearly percentages of throughfall for their five, ten, twenty, and thirty year old loblolly plantations were 80, 73, 77, and 85% respectively. The hardwood-shortleaf stand showed 85% of precipitation to be throughfall. Swank et. al. also indicated that canopy interception increases with stand age unless some management activity reduces the stocking or tree canopy, and with typical management or natural mortality, interception would approximate 25.7 cm annually for the piedmont region. Since the South Carolina Piedmont region receives on the average 129.5 cm of rainfall annually, then annual interception would be approximately 19.6%.

Hoover (1953) conducted one of the first complete throughfall studies on a 10 year old plantation of loblolly pine. He established a linear relation between throughfall and precipitation with 75% of the annual precipitation occurring as throughfall.

Rogerson (1967), in a study on the effect of stand densities on throughfall, varied stand densities by thinning a 25 year old lobolly pine plot to specific basal areas. Rogerson sampled for two years on 405 m^2 rotating plots. Throughfall averaged 85.9% of precipitation with values ranging from 77.4 to 93.8% on individual plots. Precipitation was the only single variable significant explaining 98.5% of the throughfall variation. In an effort to reduce the variability, he included other variables. The best predictor was a combination of precipitation and basal area multiplied by precipitation (R^2 = 99.3%).

Throughfall studies conducted in the western United States have also shown similar results. Orr (1972) compared throughfall in a thinned and unthinned stand of ponderosa-pine (Pinus ponderosa) in South Dakota. He incorporated the use of a canopy density index expressed as a percent. Using a stepwise regression, Orr indicated that precipitation was the only statistically significant variable for predicting throughfall measurements. Canopy density was not significant in separate treatments, but was when the thinned and unthinned data were combined, indicating the usefulness of a canopy index on a broad range. Throughfall was greater on the thinned plots. However, the unthinned plots produced greater variability in throughfall measurements.

Rothacher (1963) studied throughfall relationships in a Douglas-Fir (Pseudotsuga menziesii) forest in western Oregon. Due to the nature of rainfall and season he was unable to draw any conclusions about throughfall in the winter where there are several weeks of continuous rain, this in combination with inaccessibility of the area proved too difficult to sample. However, he established a linear relation for the summer where throughfall averaged 87.7% and up to 95.7% in a 20 cm. rain.

In the Juneau, Alaska, area, throughfall was measured in western hemlock (Tsuga heterophylla) and sitka spruce (Picea sitchensis) stands by Patric (1966). Annual throughfall was estimated to be 85.6% of precipitation. Patric also showed in his study that a higher basal area consistently produced less throughfall.

Rutter (1963) in a general study in England found interception in scotch pine (Pinus sylvestris) accounted for 32% of precipitation regardless of season. The method of the water reaching the litter did change, however, between throughfall and stemflow. Throughfall averaged 85% of net precipitation in the summer and 70% in the winter.

The majority of these studies agree that precipitation is the best single predictor of throughfall and that linear regression techniques produce a reliable method for modeling that relationship. Tables I and V presents some of the throughfall equations developed in these studies.

Interception

Grah and Wilson (1944) in a laboratory study found that monterey pine (Pinus radiata) and Baccharis pilularis (an evergreen bush) retained a certain amount of water in their canopies after exposure to 0.25 to 2.50 cm of simulated rain. Monterey pine held 0.025 to 0.102 cm and Baccharis held 0.051 to 0.152 cm of precipitation. While this may appear an insignificant amount compared to precipitation, it shows that a fixed amount of water is required to wet the canopy (Lawson, 1967).

Research has shown that a high degree of variability exists in the amount of interception for individual storms. Lawson (1967) found 100% of precipition was intercepted by the forest canopy for storms less than 0.254 cm and 10% interception for a 6.35 cm storm. Analysis of this data indicates Lawson's shortleaf pine sites in Arkansas have a canopy storage range of 0.254 to 0.636 cm. White and Carlisle (1968) recorded some unusual interception percentages in England. Ash and Oak (Fraxinus excelsior and Quereus petraea) interception averaged 12 to 13% of gross precipitation, while in a dense stand of Yew (Taxus baccata), they discovered 59% of the total amount of precipitation measured was captured in the forest canopy.

TABLE I

REGRESSION EQUATIONS FOR PREDICTING THROUGHFALL (TF) FROM GROSS PRECIPITATION (P) IN CENTIMETERS

Source	Forest Type	Equation
Swank, Goeble, and Helvey (1972)	5-year-old Loblolly Pine	TF = -0.076 + 0.83 (P)
	10-year-old Loblolly Pine	TF = 0.00 + 0.73 (P)
	20-year-old Loblolly Pine	TF = 0.254 + 0.76 (P)
	30-year-old Loblolly Pine	TF = 0.00 + 0.85 (P)
Hoover (1953)	10-year-old Loblolly Pine Plantation	TF = -0.041 + 0.732 (P)
Rogerson (1967)	25-year-old Loblolly Pine	TF = -0.0450 + 0.877 (P)
Helvey (1967)	10-year-old Eastern White Pine	TF = -0.127 + 0.85 (P)
	35-year-old Eastern White Pine	TF = -0.102 + 0.85 (P)
	60-year-old Eastern White Pine	TF = -0.127 + 0.83 (P)
Helvey and Patric (1965)	Summary Eastern Hardwoods	Growing (TF) = -0.079 + 0.90 (P) Dormant (TF) = -0.038 + 0.941 (P)
Orr (1972)	Ponderosa Pine - Unthinned	TF = -0.010 + 0.888 (P)
	Ponderosa Pine - Thinned	TF = -0.137 + 0.813 (P)
Rothhacher (1963)	Douglas Fir - Summer	TF = -0.1168 + 0.8311 (P)
Patric (1966)	Western Hemlock and Sitka Spruce	TF = -0.218 + 0.77 (P)

Helvey and Patric (1965) discovered a lack of consistent evidence that interception loss is affected by canopy density, although they indicated this might be due to past sampling techniques. Helvey (1967) indicated 0.15 cm of precipitation was required to satisfy the canopy storages in a 10 year and 60 year old untreated white pine (Pinus strobus) forest, and 0.10 cm of precipitation was required to saturate a 35 year old white pine forest that was thinned five years previously. Thorud (1963) took a different approach when he pruned 50% of the live crown of a red pine (Pinus resinosa) forest in Minnesota. He indicated the canopy storage did change but that the maximum difference in throughfall was in small storms. Once the canopy storage was satisfied, the throughfall behaved the same as an unpruned stand. Presently, there is general agreement that the amount of precipitation required to satisfy canopy storage or interception is directly related to stand age and canopy density (Skau, 1963; Helvey, 1967; Orr, 1972).

Stemflow

The importance of stemflow is open to debate by many hydrologists. Stemflow is much more variable than throughfall due to differences in bark texture, form class, branching of trees within a given species, therefore it is much more difficult to measure. Voigt (1960) showed that stemflow was beneficial to individual trees by concentrating moisture around the trunk. He also indicated stemflow might enhance runoff since the water from the trunk was concentrated around root channels. Swank et. al. (1972) indicated stemflow accounted for 9% of gross precipitation in young loblolly pine stands and 2% in hardwood pine forest. This value is comparable to the 2.4% of precipitation that Lawson (1967) discovered for stemflow in a shortleaf pine forest with a hardwood understory.

Skau (1963) in Arizona indicated stemflow values ranged from 1 to 2% of gross precipitation. He suggested this was due to the rough bark and droopy limbs of juniper (Juniperus pachyphloca). Patric (1966) established stemflow was always less than 1% in a western hemlock stand in Alaska. He indicated this was much less than the inherent error, up to 5%, in his rainfall sampling. He also stated that stemflow had negligible input and was the most difficult and expensive to measure.

Surface Runoff

Surface runoff is an undesirable process in the forest or any watershed because it tends to rapidly concentrate water into stream channels increasing runoff and erosion problems. Surface runoff can be influenced by many factors which include the type of precipitation, precipitation intensity, or a general climatic variable like air temperature. Surface runoff may also be influenced by the characteristics of the soil, such as type, texture, depth, or porosity. The slope and shape of the land, vegetative and litter cover, or the presence of rocks can also influence surface runoff (Pierce, 1967). Pierce generally concluded forest lands have optimum infiltration and negligible surface runoff. He attributed this to the soils having porous channels allowing rapid infiltration and percolation due to root and animal activity. Rowe (1955) credited the litter layer of the forest floor with reducing surface runoff and evaporation from the soil and increasing percolation rates.

Lowdermilk (1930) in a series of experiments showed that destruction of the forest litter greatly increased surface runoff. He also suggested the forest litter's ability to absorb was insignificant compared to it's abilityy to maintain maximum percolating capacity of the soil. When surface runoff did occur on bare soil, the suspended particles in the runoff sealed the soil further decreasing percolation and increasing surface runoff.

Duley (1939) contradicted the theory of suspended particles closing the soil pores by showing that the compaction of the rain drops on bare soil closed the surface to percolation. Chapman (1948) demonstrated that the forest canopy did not alter the impact of raindrops on the soil, further showing the importance of litter in reducing compaction and increasing infiltration.

While the importance of litter has been shown to reduce surface runoff by reducing compaction and maintaining infiltration into the soils, other factors may adversly influence surface runoff. Tackett and Pearson (1965) found that mineral soils with a high clay content expanded after initial wetting, sealing off the surface layer. The result in larger storms is that the percolation rate is exceeded by rainfall intensity resulting in surface runoff. Singh and Woolhiser (1976) suggested that the largest error in predicting surface runoff was the calculation of rainfall excess rate, which is the rainfall intensity minus the infiltration or the percolation rate. Pierce (1966) noted that a forest may have an infiltration rate as high as 50.8 cm per hour, but percolation rates may be much lower.

A problem in the chaparrel forests and woodlands of California are hydrophobic soils. Krammes and DeBano (1965) found an interaction of the soils with organic leachates from the chaparrel created a non-wettability of the surface soils. They found that wildfires with temperatures greater than 300° C tended to reduce the non-wettability of the soil in the first five centimeters, but that fires in the 200-300° C range actually increased the hydrophobia characteristic of the surface soil.

Trimble (1959) contends that surface runoff does not involve long distances. He indicated surface runoff was only to the nearest rill or channel. Pierce (1967) observed overland flow distances of three to nine meters over a hardwood litter of several inches with a porous mineral soil. The leaves, when wet and matted, acted like shingles on a roof allowing little infiltration. However, runoff was not common and was uninterrupted when the litter composition was broken by the terrain, stumps, logs, or rocks.

Rowe (1955), using a series of litter pans, lysimeters, and moisture sampling experiments, studied the effect of the forest floor compared to bare soil on surface runoff, percolation, and evaporation. He found the forest litter served two functions: 1) to absorb and hold precipitation for evaporation, and 2) to increase infiltration and reduce soil evaporation. On the northfork site southeast of Bass Lake, California, surface runoff was measured on bare soil and forest litter. The bare soil produced 33.8 cm of runoff annually or 36% of the annual precipitation, while the ponderosa pine forest floor at the same site produced only 0.8 cm of runoff annually or 0.9% of the gross precipitation. Rowe also separated a monterey pine forest floor into litter depths at Berkeley, California. Surface runoff comprised 25 and 10% of annual precipitation on bare soil and litter 0.6 cm deep, respectively. However, surface runoff from a litter depth of 1.2 cm averaged 0.1% of precipitation and did not change appreciably with greater litter depths.

Cations

The forest exerts a continuous need for nutrients for growth and reproduction. Precipitation, throughfall, and runoff provide inputs and outputs in the cycling of these nutrients in the forest ecosystem. Precipitation is a source of cation input for the forest. Particles suspended in the atmosphere may act as condensation nuclei for raindrop formation, or precipitation may wash these particles out of the atmosphere. The origin of such particles is largely oceanic and terrestrial, but may also include extraterrestrial or air pollution sources (Attinwell, 1966).

When precipitation reaches the forest, an increase in nutrient concentration in throughfall usually occurs. This increase is primarily due to foliar leaching and washing of particular matter from leaves and stems (Maddwick and Ovington, 1959; Attinwell, 1966; Winters, 1976).

Attinwell (1966) conducted a two year study on the variation of cations between precipitation and throughfall in a eucalyptus (Eucalyptus obliqua) stand. He indicated concentrations in throughfall were greater than gross precipitation, and the greatest increase of ionic concentrations, due to the canopy, was sodium (Na) followed by potassium (K), calcium (Ca) and magnesium (Mg). The high concentration of sodium was attributed to nearby oceanic sources. He also established that cation concentrations were generally higher for precipitation and throughfall in the summer than in the winter, and the greatest increase in cation concentration under the canopy occurred in the summer. Attinwell also indicated an inverse and exponential relationship between ion concentrations and rainfall intensity.

Foster (1974) conducted a similar study in Canada with jack pine (Pinus banksiana). Foster measured the circulation and input of nutrients to the forest floor in throughfall, stemflow, and litterfall. He concluded potassium in throughfall was derived largely from leaf wash, while sources of calcium and magnesium were derived from precipitation. The major source of calcium and magnesium for the forest floor was from tree litterfall. However, throughfall supplied 54% of the total potassium to the forest floor.

Miceli et. al. (1975) compared shortleaf and loblolly pine plantations in Illinois to determine nutrient transfer characteristics. He determined that shortleaf pine, due to less interception in the canopy and litter, would transfer more nutrients to the soil than loblolly pine.

As moisture passes through the litter, cation concentrations may vary due to season, temperature, or the status of the litter. Winters (1976) indicated potassium concentrations in Missouri hardwood leachate to be higher in winter because it was readily leached from freshly fallen litter, while higher concentration rates of calcium and magnesium were found in the summer due to higher decomposition rates of the litter. The average concentration of nutrients in precipitation, throughfall, litter leachate, and streamflow from Winters' study and others is shown in Table II.

TABLE II

AVERAGE CHEMICAL CONCENTRATIONS OF PRECIPITATION, THROUGHFALL, FOREST FLOOR LEACHATE, AND STREAM RUNOFF

Study	Forest Type	Years	Source	Ca	Mg	K
				mg/l		
Attinwell (1966)	Eucalyptus	60-62	Precipitation	0.28	0.54	0.20
			Throughfall	1.38	1.26	2.14
Micheli et. al. (1975)	Shortleaf Pine	70-71	Precipitation	<1.86	<1.40	<0.30
			Throughfall	2.90	3.06	0.61
			Litter Leachate	5.17	4.58	1.27
Micheli et. al. (1975)	Loblolly Pine	70-71	Precipitation	<1.86	<1.40	<0.30
			Throughfall	2.77	3.20	0.61
			Litter Leachate	5.43	3.66	1.46
Foster (1974)	Jack Pine	69-70	Precipitation	0.69	0.13	0.50
			Throughfall	1.07	0.22	1.86
Likens et. al. (1967)	Northern Hardwoods	63-64	Precipitation	0.26	0.06	0.21
			Streamflow	1.18	0.38	0.26
		64-65	Precipitation	0.30	0.12	0.19
			Streamflow	0.80	0.38	0.22
Winters (1976)	Oak Hickory	75-76	Precipitation	0.96	0.08	0.20
			Throughfall	2.13	0.41	2.11
			Litter Leachate	5.41	1.10	4.73
			Streamflow	2.82	1.17	0.86

CHAPTER III

THE STUDY AREA

The study was conducted on a forested watershed which drains into Clayton Lake Reservoir 12.9 km southeast of Clayton, Oklahoma (Figure 1). The 7.3 ha watershed is one of three small watersheds which are typical of small headwater catchments in this area. These watersheds are instrumented and maintained by the Foresty Department at Oklahoma State University to study the effects of forest management on forested watersheds. These watersheds are owned by Nekoosa Edwards Paper Company, Inc., and Weyerhauser Company.

Vegetation

The primary vegetation on watershed 1 (WS 1) is shortleaf pine with an oak-hickory understory. The basal area for pine is 14 m^2/ha compared to 3 m^2/ha for hardwoods. The average number of trees per hectare is 74 for pine and 30 for hardwoods. A breakdown of diameter classes is given in Table III. The forest shows evidence of extensive high grading 20 to 35 years previously with natural reseeding.

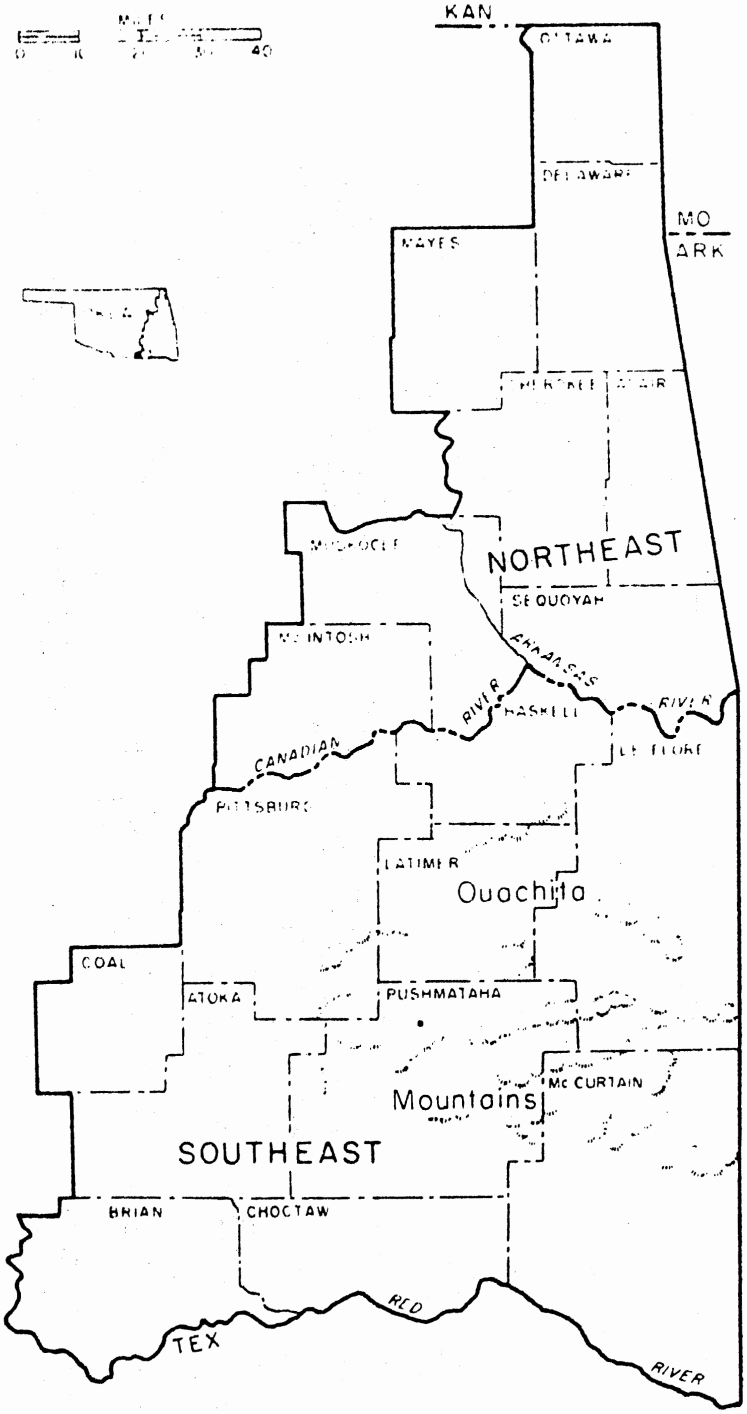

Figure 1. Southeast Oklahoma. (Reprinted from Murphy, P.A. 1977. East Oklahoma Forests: Trends and Outlooks. USDA For. Ex. Sta. Resource Bull. 50-63. 20 p.)

TABLE III

FOREST INVENTORY OF WATERSHED 1

Diameter Class (cm)	Trees/ha		Basal Area (m^2/ha)	
	Pine	Oak-Hickory	Pine	Oak-Hickory
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	74.03	29.90	13.73	3.01

Soils

The Carnasaw series which is formed from weathered sandstone and shale is the principle soil type. This strongly acidic soil is deep and well-drained with a slow permeability (0.15 to 0.45 cm/hr). The A horizon is 0 to 18 cm deep and is a fine stoney sandy loam. The B horizon is a red clay 18 to 89 cm deep (Bain and Waterson, 1979).

Climate

Mean annual precipitation from 1951 to 1974 at the Antlers, Oklahoma weather station was 119.5 cm (Bain and Watterson, 1979). Comparison of the average monthly precipitation from 1951 to 1974 from Antlers to the monthly precipitation from the study area is illustrated in Figure 2. Mean annual temperature from 1951 to 1974 at Antlers was 16.9° C.

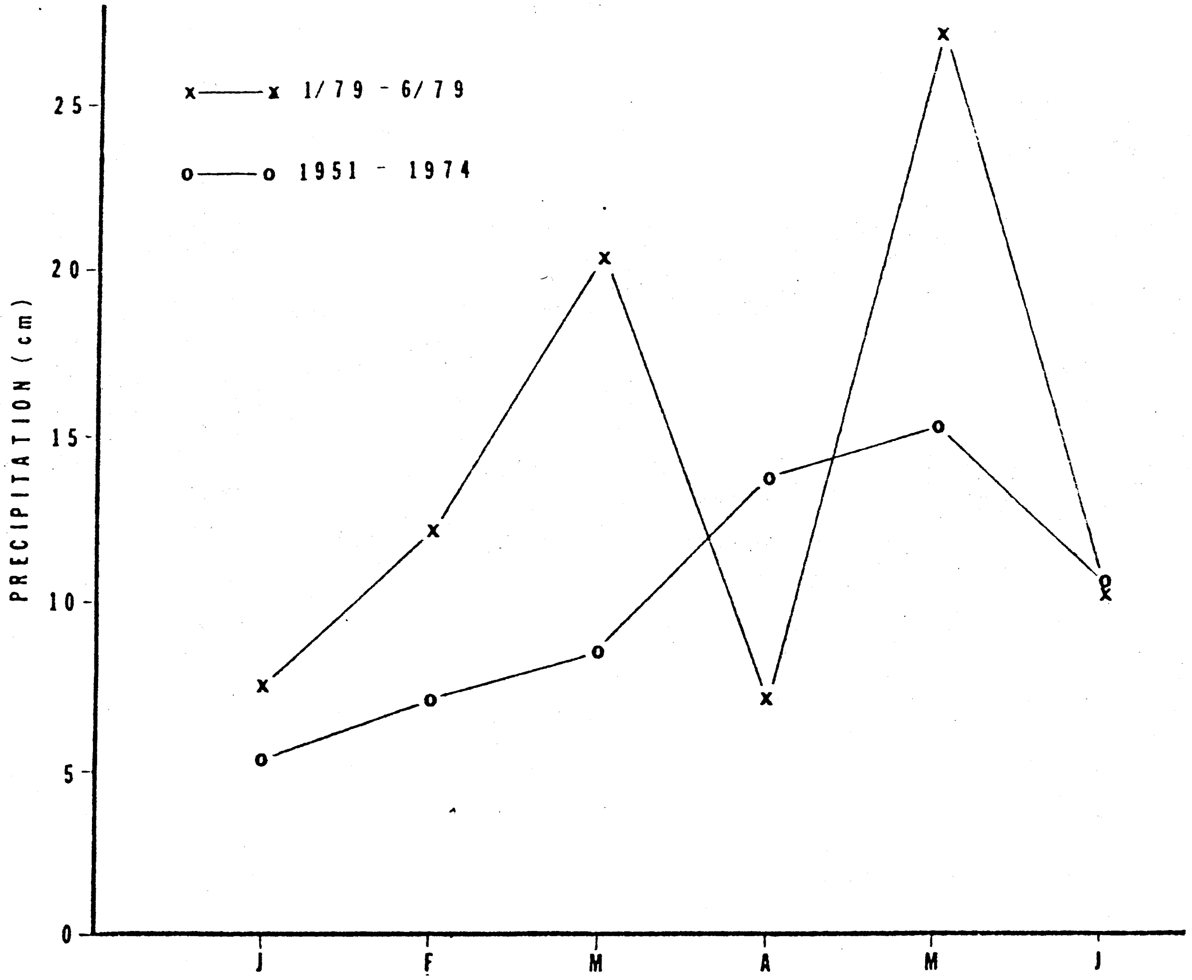

Figure 2. Mean Monthly Precipitation Values for Antlers and Watershed 1.

CHAPTER IV

METHODS AND MATERIALS

Watershed 1 has several instruments which continually monitor hydrologic activities. A 1.22 m "H" type flume and a Belfort water level recorder provide a continuous record of depth and volume of streamflow. Streamflow samples for water quality analysis were collected by a 0.91 m Coshocton wheel located below the flume and a single stage sampler stationed immediately in front of the approach pad of the flume. Whenever possible, grab samples were collected at a station approximately 30 m upstream from the flume. Daily temperature data from the Antlers, Oklahoma weather station were used in this study.

Precipitation Sampling

A Belfort Universal recording raingage provided data for analysis of storm intensity and duration. Three 10 cm standard precipitation gages located around WS 1 (Figure 3) provided gross precipitation data and samples for quality analysis. Three throughfall containers were located at each standard raingage station. The purpose for including throughfall containers with the precipitation gages was to

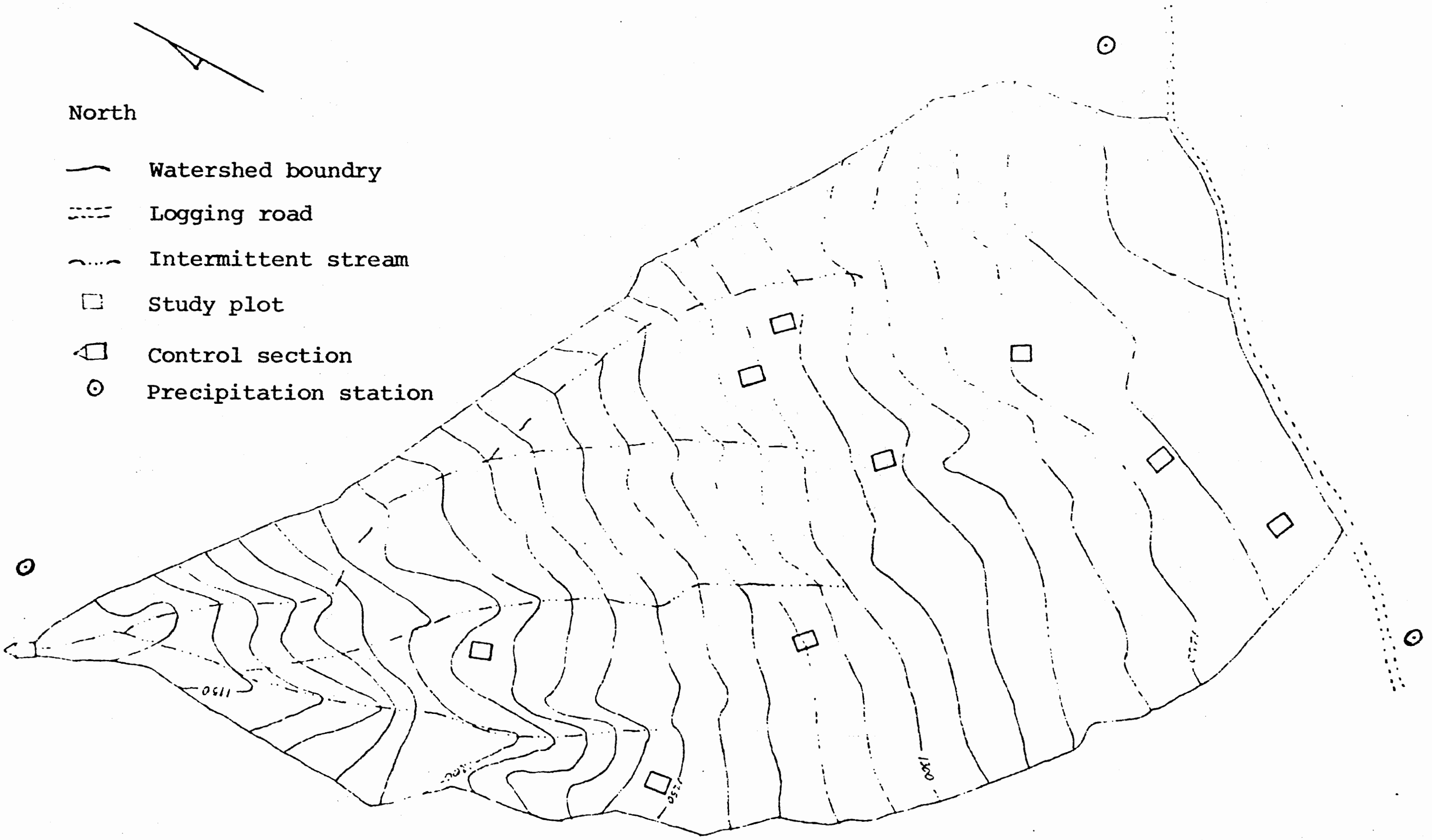

Figure 3. Clayton Lake Watershed 1.

compare the similarity between the collection characteristics of two different types of gages. When a rainfall event greater than 0.508 cm occurred, precipitation and throughfall gages in the open at each station were measured, using a calibrated measuring tube. A water sample was obtained from each standard precipitation gage and placed in an acid washed bottle. If the storm rainfall was less than 0.508 cm, the precipitation and throughfall gages were emptied. After each rainfall event, the emptied precipitation gage was rinsed with de-ionized water.

Surface Runoff Sampling Methods

Surface runoff was collected from 4×10^{-4} ha plots, 1.3 m wide and 3.05 m long. The plot was partitioned with 2.5 cm by 1.5 cm yellow pine lumber placed into the "A" horizon on three sides. The downhill boundary contained a modified rain gutter. The lip of the gutter was placed between the litter layer and "A" horizon. A galvanized wire screen was placed around the lip to prevent soil and litter from falling into the trough, and a 2.5 cm by 1.5 cm board was placed on the lip to hold the trough and screen in place. The trough, covered with plastic to keep precipitation out, drained into a 19 liter plastic container.

Each surface runoff plot location was randomly obtained from a grid placed over a contour map of WS 1. The topography and locations of the nine research plots are shown in

Figure 3. Three plot locations were selected for each of the three slope classes (<10%, 10 to 20%, and >20%). In the field each plot was located and placed in the area of maximum ground cover and without the influence of vegetative stems within the plot.

After each precipitation event, total surface runoff was measured in a 2,000 ml graduated cylinder, and a water quality sample was placed into an acid-washed bottle.

Throughfall

Throughfall was collected in a one liter plastic bottle with a 10 cm funnel secured by a nut and sealed with silicon to the lid of the bottle. Galvanized screen was placed in the funnel to prevent twigs and needles from entering the bottle. The entire assembly was supported by a wooden box.

A cluster of five throughfall gages was placed around each surface runoff plot. One gage was placed at the top of the surface runoff plot, and the remaining four were placed 35.9 m from that gage in each of the cardinal directions.

If a rainfall event greater than 0.508 cm occurred, the throughfall containers were measured with the calibrated measurement tube. If precipitation was less than 0.508 cm, the storm was not sampled. Storms with snow and sleet were also discarded due to inherent differences in throughfall-interception behavior between rain and snow.

Two randomly selected throughfall locations from each cluster were chosen to sample for cations. If a water quality sample was required from a throughfall station, the plastic container was replaced with an acid-washed container, and the sample was returned to the lab for analysis.

Water Quality Analysis

Samples for cation analysis were taken from precipitation, throughfall, surface runoff, and streamflow grab samples. The samples were filtered through a Gelman 0.45 u membrane filter and stored in acid-washed 10 ml plastic vials. The samples were refrigerated with no fixing agents being used. The Oklahoma State University Soils and Water Testing Laboratory performed analysis for calcium, magnesium, and potassium using a Perkin-Elmer 373 atomic emission flame spectrophotometer.

Compiling Data and Statistical Analysis

Samples were collected and labeled according to date, watershed, type of sample, and location. This coding allowed grouping by types, dates, or individual observations. Several statistical analyses were employed using Statistical Analysis System Programming Language (Barr and Goodnight, 1979). Analysis of variance was used to examine variation among samples by date and slope class. Simple and stepwise regressions were generated to explain the variation in funnel collectors and standard raingages, and variation in throughfall, surface runoff and nutrient concentrations. Additional variables used in statistical analysis were mean storm precipitation, mean and maximum daily temperature, storm class, storm duration, maximum storm intensity, average storm intensity, and an indicator of the number of days since a previous rain, anticedent rainfall. Independent variables used for the stepwise regressions to explain surface runoff and cation activity were; precipitation, maximum and average storm intensity, maximum and mean daily temperature, storm duration, season, storm class, a thorughfall precipitation ratio and when applicable previously defined mean nutrient concentrations.

CHAPTER V

RESULTS AND DISCUSSION

Precipitation

Sixteen storms, ranging from 0.48 cm to 8.97 cm, were sampled from March 1 to May 30, 1979, Monthly precipitation values were compared to average monthly precipitation values from 1951 to 1974 from the Antlers, Oklahoma station (Figure 2).

Since two types of raingages, a standard raingage and a funnel collector for throughfall, were used to sample amounts, a comparison of the collection behavior of these gages was made for precipitation. Table XVII, Appendix A shows the average values of standard raingages and funnel collectors. An analysis of variance showed the values between standard raingages and funnel collector amounts to be significantly different (Table XXIV, Appendix B). A simple linear regression equation:

$$S = -0.2487 + 0.94412\ F$$
$$r^2 = 0.99$$

where S = standard raingage (cm) and F = funnel collector (cm), was generated to adjust funnel collection amounts to standard raingage amounts. Corrected funnel values were used in the remaining analysis.

Throughfall

Throughfall for the study period averaged approximately 87.6% of total precipitation (41.11 cm). Throughfall percentages ranged from 78.8% in a 1.03 cm storm to 93.0% in a 1.73 cm storm. A comparison of mean precipitation and throughfall values is shown in Table XVIII, Appendix A.

A two way classification analysis of variance using date, slope, the interaction of date and slope, the value of station nested in slope, and the individual locations nested in station and slope as independent variables was made to classify the variation in throughfall (Table XXV, Appendix B). The variable date explained 96.3% of the variation in throughfall amount, indicating that some combination of the variables that change with date such as precipitation, storm intensity, and others are responsible for the majority of the variation of throughfall. Slope classes, stations within slope classes, and individual locations within stations and slope classes were also significantly different. The remaining variation is unexplained variation within sample locations.

Multiple regression analysis (Table IV), indicated that precipitation was the only significant variable in predicting throughfall. Other variables considered were storm intensities, storm duration, maximum daily temperature, and season.

TABLE IV

ANALYSIS OF VARIANCE FOR MULTIPLE LINEAR REGRESSION FOR THROUGHFALL

Source	DF	Sum of Squares	Mean Squares	F Value	P.Value
P	1	435.0424	435.0424	18594.74	0.0001
SM	1	0.0514	0.0514	2.14	0.1436
SA	1	0.0291	0.0291	1.24	0.2655
SD	1	0.0029	0.0029	0.12	0.7253
TM	1	0.0000	0.0000	0.00	0.9862
S	1	0.0315	0.0315	1.35	0.2461
Error	708	16.5644	0.0234		
Total	714	451.7204			

P = Storm Precipitation
SM - Maximum Rainfall Intensity in Half-Hour Intervals
SA = Average Rainfall Intensity in Half-Hour Intervals
SD = Storm Duration in Hours
TM = Maximum Temperature the Day of the Storm
S = Indicator Variable for Season (Equals 1 if Hardwoods are Leafed out on April 24, Otherwise, Equals 0)

The regression equation was:

$$TF = -0.06995 + 0.91348\ P$$
$$r^2 = 0.96$$

where TF = throughfall (cm) and P = precipitation (cm) (Figure 4). This equation indicates 0.08 cm of precipitation is required before measurable throughfall occurs.

Several researchers have expressed throughfall and precipitation amounts for shortleaf pine in similar regressions. These regressions are presented and compared in Table V.

While all of these equations are similar, consideration of the location, forest type, and study period may explain the differences which do occur. Boggess's (1956) study at Dixon Springs Experimental Station, Illinois, took place from 1951 through 1954 and was based on 157 storms. Boggess's study took place in a pine plantation where the influence of any understory was removed. Basal area values for his plantation were higher than WS 1 ranging from 25.3 to 31.0 m^2/ha.

Lawson (1967) based his regression on 53 storms collected from November, 1962 through September, 1964. Lawson's Arkansas study area had higher basal areas (22.0 m^2/ha for pine and 3.9 m^2/ha for hardwoods) compared to WS 1 (14.0 m^2/ha for pine and 3.0 m^2/ha for hardwoods). The fact that Lawson's equation estimated less throughfall than WS 1 supports Rogerson's supposition (1967) that less throughfall occurs on forests with higher basal area values.

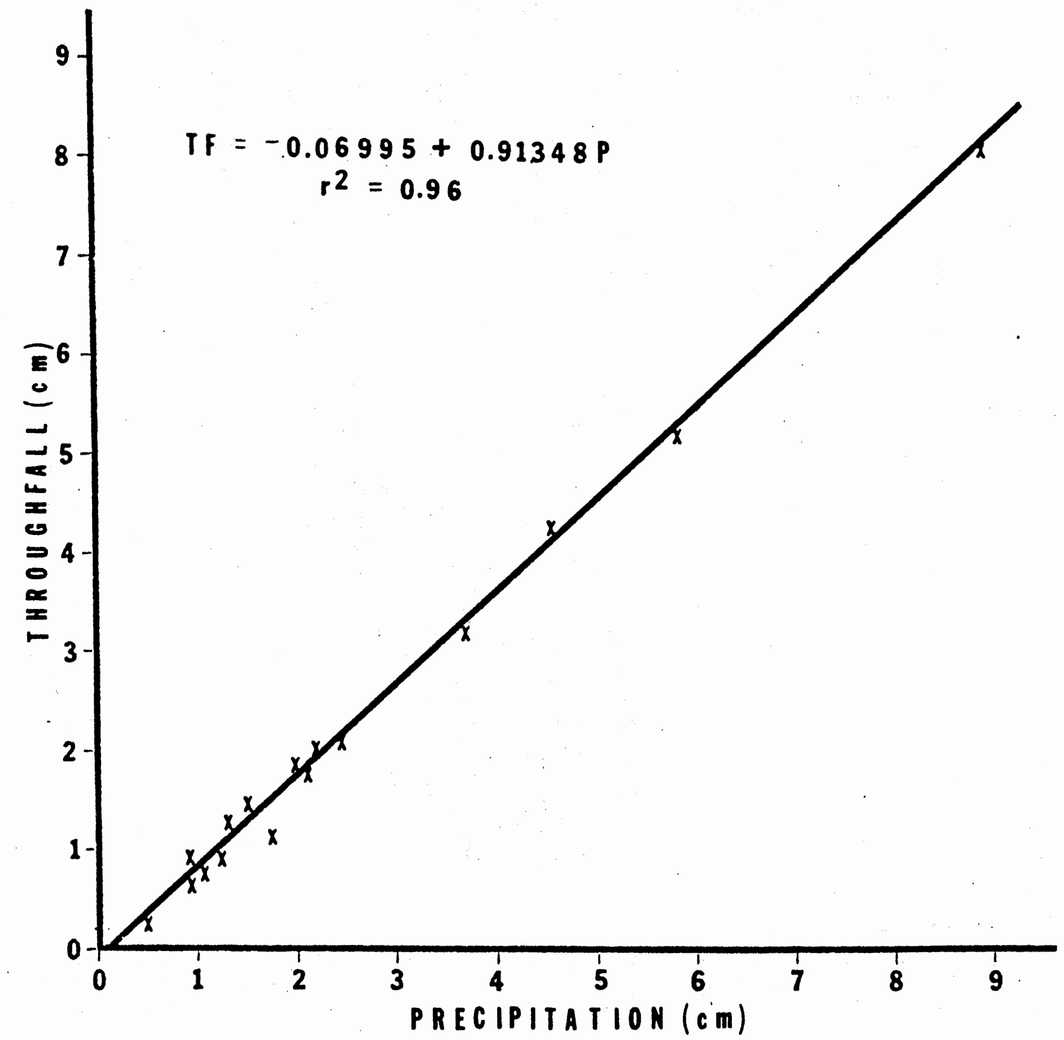

Figure 4. The Gross Precipitation and Throughfall Relationship for March 1 - May 30, 1979.

TABLE V

REGRESSION EQUATIONS FOR PREDICTING THROUGHFALL (TF) AND PRECIPITATION (P) IN SHORTLEAF PINE FORESTS

Source	Location	Forest Type	Equation
Lawson (1967)	Arkansas	Shortleaf pine with a Hardwood Understory	$TF\ (cm) = -0.2387 + 0.937\ P\ (cm)$
Boggess (1956)	Illinois	Shortleaf Pine Plantation	$TF\ (cm) = -0.1427 + 0.8957\ P\ (cm)$
Swank, et. al. (1972)	South Carolina	Hardwood and Shortleaf Pine	$TF\ (cm) = -0.051 + 0.87\ P\ (cm)$
Watershed 1 (1979)	Oklahoma	Shortleaf Pine with a Hardwood Understory	$TF\ (cm) = -0.06995 + 0.91348\ P\ (cm)$

Swank's et. al. (1972) study used a mature hardwood forest in South Carolina that had a codominant shortleaf pine overstory. The basal area estimate for hardwoods was 30.0 m^2/ha and 4.9 m^2/ha for pine. Although these studies occurred over a time period of 16 to 36 months, and the study period for WS 1 was over a three month time span, the regression equations are very similar.

Surface Runoff

Surface runoff averaged 0.028 cm for the 16 storms sampled. Mean storm surface runoff values ranged from 0.0027 cm in a 0.48 cm storm to 0.1661 cm in a 8.89 cm storm. A comparison of precipitation and surface runoff is made in Table XIX, Appendix A.

A two way classification analysis of variance was made to determine sources of variation in surface runoff quantities. The independent variables were date, slope class, the interaction of date and slope class, and the nested values of station within slope class. As in throughfall, date was the major source of variation in surface runoff. The classification date indicates variables that change with the date such as precipitation, storm intensity, temperature, and others are the source of variation in surface runoff volume. The values between stations within slope class were also significantly different. A table of the analysis of variance is presented in Table XXVI, Appendix B.

A stepwise regression was generated to find the best predictor of surface runoff quantities. Precipitation was the best single variable and subsequent steps entered variables closely related to precipitation. A simple linear regression model for prediction of the average amount of surface runoff gave this equation:

$$SRO = -0.01864 + 0.01790\ P$$
$$r^2 = 0.921$$

where SRO = mean surface runoff (cm) and P = gross precipitation (cm). The regression line and data are plotted in Figure 5.

Rowe (1955) found surface runoff amounts to be 0.9% gross precipitation in a ponderosa pine forest floor and 0.1% of gross precipitation in a monterey pine forest floor with a litter depth greater than 1.2 cm. Surface runoff averaged 1.07% of gross precipitation on WS 1. This percentage is similar to Rowe's percentages.

Nutrient Concentrations in Precipitation

Mean concentrations for precipitation were: calcium, 0.62 mg/l; magnesium, 0.15 mg/l; and potassium, 1.24 mg/l. Mean nutrient concentrations for each storm are listed in Table XX, Appendix A. A two way classification analysis of variance was performed on each nutrient to determine the source of sample variation. Samples were classified by date and station. The variable date was significant in each instance explaining 84% of the variation in calcium, 60% in

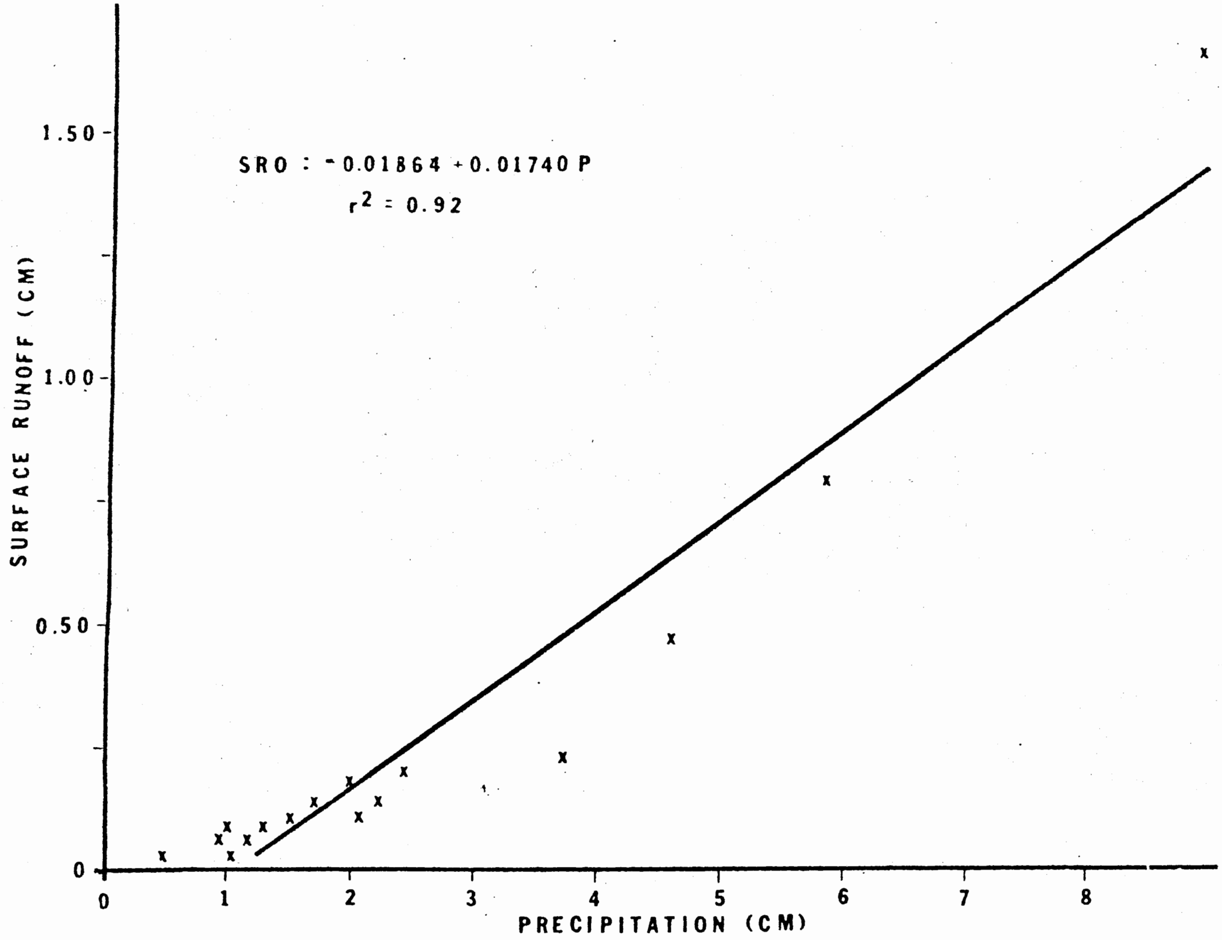

Figure 5. The Gross Precipitation and Surface Runoff Relationship for March 1 - May 30, 1979

magnesium, and 59% in potassium. The significance of date indicates variables that change with date such as precipitation and seasonal variables may be significant in explaining variation within date. The classification analysis of variance for calcium, magnesium, and potassium values for precipitation are presented in Tables XXVII through XXIX, Appendix B.

A stepwise regression model was generated to define independent variables that account for significant variation in nutrient concentrations for precipitation. Variation in magnesium and potassium concentrations in precipitation were not significantly explained by any independent or group of independent variables. Stepwise regression analysis suggested the following equation for predicting calcium concentrations:

$$\mathrm{Ca} = -162.4646 - 1.0135\ I - 9.7344\ \mathrm{Log}\ (T)$$
$$R^2 = 0.53$$

where Ca = calcium concentration in precipitation (mg/l), I = maximum storm intensities (cm/hr), and T = the mean temperature the day of the storm (C^{o}). Calcium concentrations decrease as maximum storm intensities and mean daily temperatures increase. The analysis of variance for the regression is presented in Table VI.

Nutrient Concentrations in Throughfall

Average nutrient concentrations for throughfall were:

TABLE VI

ANALYSIS OF VARIANCE FOR A STEPWISE MULTIPLE REGRESSION EXPLAINING MEAN CALCIUM CONCENTRATIONS IN PRECIPITATION

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
I	1	0.7258	1.3965	9.13	0.0098
Log (T)	1	1.5092	1.5092	9.87	0.0078
Error	13	1.4988			
Total	15	4.2236			

I = Maximum Storm Intensity (cm/hr)
T = Mean Temperature the day of the storm (C^o)

calcium, 0.60 mg/l; magnesium, 0.16 mg/l; and potassium, 1.55 mg/l. Mean concentrations for storm throughfall are presented in Table XXI, Appendix A. Two way classification analysis of variance tests were completed for each nutrient using the sample nutrient concentration as the dependent variable. Samples were classified by date, slope class, the nested value of station within slope class, and the individual sample locations nested within station and slope class. The remaining variation is a measure of sampling variability within individual sample locations.

The analysis of variance results are given in Tables XXX through XXXII in the Appendix B. Date was highly significant in each case explaining 81% of the variation in calcium, 68% of the variation in magnesium, and 36% of the variation in potassium. The signifiance of the date is probably due to time related factors including precipitation characteristics and seasonal variation in the forest. The variable slope class was also significant for all three nutrients indicating differences between slope classes. An interaction between slope class and date was also significant for calcium, magnesium, and potassium values. The variation between stations within slope classes and between locations within stations and slope class was also significant for all three nutrients.

Calcium in Throughfall

Mean calcium concentrations in throughfall ranged from

0.14 mg/l in a 2.02 cm storm on April 3, 1979, to 1.30 mg/l in a 8.97 cm storm on March 27, 1979 (Table XXI, Appendix A). The regression equation was:

$$\mathrm{Ca} = 0.1899 + 0.0422\ \mathrm{A} + 0.4290\ \mathrm{PCA}$$
$$R^2 = 0.56$$

where Ca = calcium concentration (mg/l), A = number of days since a previous rainfall event, and PCA = mean calcium concentration (mg/l) in precipitation. The analysis of variance information is presented in Table VII.

In this model the concentration of calcium increases as the number of days since a previous rainfall increases, and the concentration of calcium in precipitation increases. However, the concentration of calcium in precipitation accounted for more variation than antecedent rainfall. Since the concentration of calcium in precipitation is significant in explaining variation in throughfall concentrations, indications are the forest canopy does not greatly affect calcium concentrations.

Magnesium in Throughfall

Magnesium concentrations ranged from 0.007 mg/l in a 2.23 cm storm on April 11, 1979, to 0.382 mg/l in a 2.43 cm storm on May 11, 1979 (Table XXI, Appendix A). The analysis of the stepwise regression suggested the equation:

$$\mathrm{Mg} = 0.9031 + 0.0162\ \mathrm{A} + 0.1230\ \mathrm{S} - 0.9823\ \mathrm{R}$$
$$R^2 = 0.66$$

TABLE VII

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION EXPLAINING MEAN CALCIUM CONCENTRATIONS IN THROUGHFALL

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
A	1	0.4121	0.3618	5.04	0.0428
PCAM	1	0.7757	0.7757	10.80	0.0059
Error	13	0.933			
Total	15	2.1214			

A = Antecedent rainfall (Days)
PCAM = Mean Calcium Concentration in Precipitation (mg/l)

where Mg = magnesium concentration in throughfall (mg/l), A = number of days since a previous rainfall event, S = season indicator (1 if leaves are on trees, 0 if otherwise), R = percentage of throughfall divided by precipitation volumes. The analysis of variance for the stepwise regression is presented in Table VIII.

In this model, increasing throughfall percentages yield decreasing magnesium concentrations. However, the variables season and antecedent rainfall account for more variation than throughfall. As the number of days since a previous rainfall event increases, magnesium increases indicating possible leaf wash or leaching as a source of magnesium. Magnesium concentration also increases in the early growing season. Winters (1976) indicated that magnesium may be more available for leaching during the initial leafing out in the spring.

Potassium in Throughfall

Potassium concentration for throughfall ranged from 0.63 mg/l in a 2.11 cm storm on March 3, 1979, to 2.97 mg/l in a 1.03 cm storm on April 19, 1979 (Table XXI, Appendix A). Stepwise regression analysis suggested the equation:

$$\begin{aligned} K = 22.6865 + 0.0440\ T + 1.3687\ \mathrm{Log}\ (A) \\ - 1.3429\ \mathrm{Log}\ (C) \\ R^2 = 0.71 \end{aligned}$$

where K = potassium concentration (mg/l), T = maximum temperature the day of the storm (C^o), A = antecedent rainfall

TABLE VIII

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN MAGNESIUM CONCENTRATIONS IN THROUGHFALL

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
A	1	0.0268	0.0455	8.11	0.0147
S	1	0.0726	0.0498	8.81	0.0117
R	1	0.0324	0.0324	5.76	0.0335
Error	12	0.0674			
Total	15	0.1991			

A = Antecedent Rainfall (Days)
S = Season Indicator (= 1 if Trees are Leafed Out, 0 if Otherwise)
R = Mean Throughfall Volume/Mean Precipitation Volume

(days), and C = precipitation storm class (1 equals storms $<$ 1.5 cm, 2 equals storms between 1.5 and 2.5 cm, and 3 equals storms $>$ 2.5 cm). The analysis of variance for the stepwise regression equation is shown in Table IX.

The concentration of potassium is directly related to antecedent rainfall indicating a curvilinear increase in potassium availability with the time interval between precipitation events. This supports Abee and Lavender's (1972) theory that a limited fraction of nutrients is available for leaching and that frequent rains reduce the available fraction. Potassium concentrations in throughfall decrease as precipitation storm class values increase indicating larger storms leach or wash less potassium from the canopy than smaller storms. This is also in agreement with Abee and Lavender (1972). However, maximum daily temperature accounted for more variation in potassium concentrations than storm class or antecedent rainfall. This positive relation is possibly an indication of greater potassium availability for leaching due to the growing season or stomatal activity.

Nutrient Concentrations in Surface Runoff

Mean concentrations for surface runoff were: calcium, 2.03 mg/l; magnesium, 0.83 mg/l; and potassium, 5.58 mg/l. Mean nutrient concentrations are shown in Table XXII, Appendix A. Two way classification analysis of variance tests

TABLE IX

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN POTASSIUM CONCENTRATIONS IN THROUGHFALL

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
T	1	3.2899	2.0815	12.29	0.0043
Log (A)	1	0.6593	0.9224	5.45	0.0378
Log (S)	1	1.0414	1.0414	6.15	0.0290
Error	12	2.0322			
Total	15	7.0228			

T = Maximum Temperature the Day of the Storm (C^{o})
A = Antecedent Rainfall (Days)
S = Storm Class Distribution (Equals 1 if Precipitation Volume is less than 1.5 cm, Equals 2 if Volume (cm) is greater than 1.5 and less than 2.5, and Equals 3 if Volume (cm) is greater than 2.5)

were completed for each nutrient to identify the source of the variation. As in throughfall and precipitation, Date was a major source of variation in nutrient concentration. Slope class was a significant variable in explaining variation of potassium concentrations in surface runoff. The variation between stations within slope classes was also significantly different for all three nutrients. Two way classification analysis of variance for nutrient samples are presented in Tables XXXIII through XXXV, Appendix B.

Calcium in Surface Runoff

Calcium concentrations ranged from 0.53 mg/l in a 1.17 cm storm on May 27, 1979, to 6.52 mg/l in a 0.99 cm storm, March 1, 1979. Mean calcium concentrations for each storm are presented in Table XXII, Appendix A. The stepwise regression analysis suggested a single variable as the best predictor of calcium concentrations in surface runoff:

$$\mathrm{Ca} = 0.6342 + 2.1468\ \mathrm{PCA}$$
$$r^2 = 0.49$$

where Ca = calcium concentrations in surface runoff (mg/l) and PCA = calcium concentrations in precipitation (mg/l). The analysis of variance for the stepwise regression is presented in Table X.

The positive relationship between precipitation calcium and surface runoff calcium indicates the variation in surface runoff for this cation is dependent on the calcium variation in precipitation. A similar result was indicated for

TABLE X

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN CALCIUM CONCENTRATIONS IN SURFACE RUNOFF

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
PCAM	1	19.4662	19.4662	13.55	0.0025
Error	14	20.1175			
Total	15	39.5837			

PCAM = Mean Calcium Concentration in Precipitation (mg/l) this ion for throughfall. However, average surface runoff calcium concentrations are approximately two times greater than average precipitation calcium concentrations indicating additional calcium sources from the system.

Magnesium in Surface Runoff

Magnesium concentrations for surface runoff ranged from 0.20 mg/l in a 4.60 cm storm, May 30, 1979, to 1.91 mg/l in a 0.99 cm storm, March 1, 1979. The average concentrations for storms are presented Table XXII, Appendix A. The stepwise regression analysis identified the following equation as the best predictor of magnesium concentration in surface runoff:

$$\begin{gathered} Mg = 185.9063 + 0.0772\ A - 9.8698\ \mathrm{Log}\ (T) \\ - 2.1773\ \mathrm{Log}\ (I) \\ R^2 = 0.80 \end{gathered}$$

where Mg = magnesium concentration for surface runoff (mg/l), A = number of days since a previous rainfall event, T = maximum temperature the day of storm (C^o), and I = maximum storm intensity (cm/hr). The analysis of variance for the stepwise regression is presented in Table XI.

Magnesium concentrations increased with antecedent rainfall and decreased exponentially with an increase in temperature or storm intensity.

Potassium in Surface Runoff

Potassium values for surface runoff ranged from 1.82

TABLE XI

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN MAGNESIUM CONCENTRATIONS IN SURFACE RUNOFF

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
A	1		1.1074	16.39	0.0016
Log (T)	1		1.2058	17.85	0.0012
Log (I)	1	2.4910	2.4910	36.87	0.0001
Error	12	0.8108			
Total	15	4.1131			

A = Antecedent Rainfall (Days)
T = Maximum Temperature the Day of the Storm (C^{o})
I = Maximum Storm Intensity (cm/hr)

mg/l in a 0.99 cm storm, May 30, 1979, to 10.13 mg/l in a 4.60 cm storm, March 1, 1979 (Table XXII, Appendix A). The stepwise regression analysis generated:

$$K = 865.8068 + 3.5049 \text{ Log } (A) - 45.9500 \text{ Log } (T) - 6.9416 \text{ Log } (I)$$
$$R^2 = 0.78$$

where K = potassium concentration in surface runoff (mg/l), A = antecedent rainfall (days), T = mean temperature the day of the storm (C^o), and I = maximum storm intensity (cm/hr). The analysis of variance for this stepwise regression equation is presented in Table XII.

As the number of days since the previous storm increases, potassium concentrations also increase. A similar relation was found for potassium in throughfall. Maximum storm intensity was expressed as a negative curvilinear relationship with potassium concentrations. The temperature relationship with potassium values was also described in a negative curvilinear manner, possibly a result of cation exchange in the soil or as an indication of increased vegetative uptake. The regression equation for magnesium in surface runoff is similar to the regression equation for potassium in surface runoff indicating similar paths.

Nutrient Concentrations in Streamflow

Mean concentrations in streamflow were: calcium, 0.73 mg/l; magnesium, 0.65 mg/l; and potassium, 1.85 mg/l. Mean nutrient concentrations for each storm are presented in

TABLE XII

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN POTASSIUM CONCENTRATIONS IN SURFACE RUNOFF

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
Log (A)	1		20.1868	14.87	0.0023
Log (T)	1		33.4219	24.62	0.0003
Log (I)	1	26.2182	26.2182	19.32	0.0009
Error	12	16.2874			
Total	15	71.5206			

A = Antecedent Rainfall (Days)
T = Mean Temperature the Day of the Storm (C^o)
I = Maximum Storm Intensity (cm/hr)

Table XXIII, Appendix A. For each nutrient sample, a two way classification analysis of variance was generated to determine the source of variation. Date was significant in explaining a large portion of variation in all nutrient samples. Sample location was also significant in explaining variation in magnesium samples. The analysis of variance tables for nutrient samples are presented in Tables XXXVI through XXXVIII, Appendix B.

Calcium in Streamflow

Mean calcium values ranged from 0.42 mg/l in a 1.17 cm storm, May 10, 1979, to 1.89 mg/l in a 3.72 cm storm, March 20, 1979 (Table XXIII, Appendix A). The stepwise regression analysis generated this equation:

$$\mathrm{Ca} = 0.3170 + 0.0664\ \mathrm{A} + 0.0870\ \mathrm{OCAM}$$
$$R^2 = 0.79$$

where Ca = calcium concentration in streamflow (mg/l), A = antecedent rainfall (days), and OCAM = calcium concentration in surface runoff (mg/l). The analysis of variance for the stepwise regression equation is presented in Table XIII.

Calcium concentrations in surface runoff were significant in explaining calcium variation in streamflow. This is similar to calcium values in precipitation being significant in explaining variation of calcium concentration in throughfall and surface runoff. However, antecedent rainfall explained more variation in calcium streamflow values than calcium concentration in surface runoff. The significance

TABLE XIII

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN CALCIUM CONCENTRATIONS IN STREAMFLOW

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
A	1	1.1936	0.7068	18.48	0.0016
OCAM	1	0.2294	0.2294	6.00	0.0343
Error	10	0.3824			
Total	12	1.8054			

A = Antecedent Rainfall (Days)
OCAM = Mean Calcium Concentration in Surface Runoff (mg/l)

of antecedent rainfall indicates calcium builds ups over time and flushing of concentrations occurs with storm runoff.

Magnesium in Streamflow

Magnesium concentrations in streamflow ranged from 0.34 mg/l in a 4.6 cm storm on May 30, 1979, to 1.18 mg/l in a 3.72 cm storm, March 20, 1979 (Table XXIII, Appendix A). The stepwise regression analysis generated the equation:

$$Mg = 0.3419 + 0.3792\ OMGM$$
$$r^2 = 0.46$$

where Mg = magnesium concentration in streamflow (mg/l) and OMGM = mean magnesium concentration in surface runoff (mg/l). The analysis of variance for the stepwise regression is presented in Table XIV.

The magnesium concentration in surface runoff was the only variable significant in explaining variation in magnesium values in streamflow. This is an indication that streamflow concentrations are directly related to mangesium concentrations in surface runoff.

Potassium in Streamflow

In streamflow mean potassium ranged from 0.81 mg/l in a 0.93 cm storm, May 3, 1979, to 3.18 mg/l in a 3.72 cm storm, March 20, 1979 (Table XXIII, Appendix A). The stepwise regression analysis produced the equation:

$$K = 11.9030 - 1.0920\ S_2 - 10.5935\ R - 2.8297\ \text{Log}\ (I)$$
$$R^2 = 0.87$$

TABLE XIV

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN MAGNESIUM CONCENTRATIONS IN STREAMFLOW

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
OMGM	1	0.5284	0.5284	9.36	0.0109
Error	11	0.6211			
Total	12	1.1495			

OMGM = Mean Magnesium Concentration in Surface Runoff (mg/l) where K = potassium concentration in streamflow (mg/l), S = season indicator (equals 1 if trees are leafed our, 0 if otherwise), R = mean throughfall (cm)/mean precipitation (cm), and I = maximum storm intensity (cm/hr). The analysis of variance for the stepwise regression is presented in Table XV.

The ratio of throughfall and precipitation is inversely related with potassium concentrations in streamflow. Maximum storm intensity produced a negative curvilinear relationship with potassium values in streamflow. Season was the best variable in explaining variation in potassium values. This negative relationship is probably a result of vegetative uptake, thus, reducing potassium availability in the spring.

Average Nutrient Concentrations

The average nutrient concentrations and variations for precipitation, throughfall, surface runoff, and streamflow are presented in Table XVI. From this table, values whose ranges intersect are not significantly different.

Calcium concentrations in precipitation were not significantly different from calcium concentration in throughfall and streamflow. However, streamflow calcium values were significantly higher than throughfall calcium values. Calcium values in surface runoff were significantly higher than other areas where calcium was measured.

TABLE XV

ANALYSIS OF VARIANCE FOR STEPWISE REGRESSION EQUATION TO EXPLAIN MEAN POTASSIUM CONCENTRATIONS IN STREAMFLOW

Source	DF	Sequential Sum of Squares	Partial Sum of Squares	F Value	P Value
S	1	4.8147	3.5605	29.41	0.0004
R	1	0.6233	1.8968	15.67	0.0033
Log (I)	1	1.9299	1.9299	15.94	0.0031
Error	9	1.089			
Total	12	8.4573			

S = Season Indicator (Equals 1 if Trees are Leafed Out, 0 if Otherwise)
R = Ratio of Mean Throughfall Volume/Mean Precipitation Volume
I = Maximum Storm Intensity (cm/hr)

TABLE XVI

AVERAGE NUTRIENT CONCENTRATIONS AND VARIATION FOR PRECIPITATION, THROUGHFALL, SURFACE RUNOFF, AND STREAMFLOW

Source	Ca	Mg	K
	mg/l		
Precipitation	0.618 ± 0.141	0.149 ± 0.054	1.238 ± 0.646
Throughfall	0.595 ± 0.060	0.161 ± 0.023	1.547 ± 0.292
Surface Runoff	2.032 ± 0.113	0.827 ± 0.307	5.578 ± 1.599
Streamflow	0.730 ± 0.001	0.654 ± 0.073	1.847 ± 0.392

Using Variation among Stations as an Error Term

Precipitation and throughfall magnesium concentrations were not significantly different. However, magnesium values for surface runoff and streamflow were significantly higher than precipitation and throughfall values. While not significantly different, surface runoff magnesium values tended to be higher than streamflow magnesium values.

Potassium values for precipitation, throughfall, and streamflow were statistically similar. Surface runoff values were significantly higher than potassium values in other areas.

Generally more variation occurs in precipitation and surface runoff than in throughfall and streamflow. The large variation in precipitation may be an indication of sample contamination due to dust or pollen or inherent variability in precipitation water chemistry.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The objective of this study was to characterize the behavior of throughfall and surface runoff quantities to precipitation and time related variables and to define cation behavior in precipitation, throughfall, surface runoff, and streamflow. Nine research stations were established and 16 storms were sampled from March 1, 1979 through May 30, 1979.

Precipitation, throughfall, and surface runoff amounts and samples were collected through a series of gages and runoff plots. Calcium, magnesium, and potassium concentrations were determined using flame emission spectrophotometry.

The initial statistical analysis was to determine sources of variation in throughfall and surface runoff and nutrient concentrations in precipitation, throughfall, surface runoff, and streamflow. Subsequent multiple and stepwise regressions were designed to identify significant independent variables in explaining variation of time related factors.

Throughfall

The classification analysis of variance showed date to be significant in explaining variation in throughfall. A multiple regression indicated the variable precipitation to be the only significant variable in predicting mean throughfall. Similar results have been found by other researchers.

On WS 1, throughfall was approximately 87.6% of gross precipitation, and 0.08 cm of precipitation occurred before measurable throughfall. Although this study was conducted over a three month period, the regression results are similar to other studies.

Surface Runoff

The classification analysis of variance explaining variation of surface runoff indicated date to be the most significant. The stepwise regression analysis established precipitation to be significant in explaining mean surface runoff. Surface runoff averaged 1.07% of gross precipitation for the study period.

Although one percent of gross precipitation is a small value, the documentation of surface runoff in a undisturbed forest floor is important. A measure of water carrying sediment and nutrients is moving through the litter layer and may have a significant influence on stream runoff.

Nutrient Concentrations

The classification of analysis of variance indicated date to be significant in explaining nutrient sample variation for precipitation, throughfall, surface runoff, and streamflow. Subsequent stepwise regressions produced various independent variable significant in explaining variation of mean nutrient concentrations.

Variation in mean magnesium and potassium concentrations in precipitation were not significantly explained by any single or group of independent variables. This is possibly a result of sample contamination by dust or pollen. Calcium concentrations in precipitation were inversely related to maximum storm intensity and temperature.

Antecedent rainfall, the number of days since a previous rainfall event, was significant in explaining variation for mean nutrient concentrations in throughfall for all three nutrients. This is probably due to the available fraction of nutrients being limited and the washing and leaching of leaves during a rain, thus, reducing that fraction.

In addition to the positive relationship of antecedent rainfall, surface runoff concentrations for magnesium and potassium were inversely related to temperature and maximum storm intensity. An increase in temperature is possibly an indication of increased nutrient uptake by vegetation. The inverse relationship of storm intensity is an indication of reduced nutrient leaching during high intensity rainfall.

Variation in calcium and magnesium values in streamflow were directly related to nutrient concentrations in surface runoff. This indicates that other factors investigated had little influence in streamflow concentrations.

The nutrient relationships had several inherent problems. They exhibited high variability and possible contamination of precipitation values. However, more importantly, the sampling period was inadequate by not covering large changes in season.

Interpretation of results

This study has provided important information concerning throughfall and surface runoff. It has also helped to define cation activity in precipitation, throughfall, surface runoff, and streamflow, and to determine certain time related factors affecting nutrient concentrations. The throughfall and surface runoff quantity relationships and cation concentration relationships can provide useful information for future studies.

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APPENDIX A

DATA TABLES

TABLE XVII

COMPARISON OF STANDARD RAINGAGES AND PRECIPITATION FUNNEL COLLECTORS

Date Sampled	Average Standard Raingage Collection (cm)	Average Funnel Raingage Collection (cm)
March 1, 1979	0.99	1.09
March 3, 1979	2.11	2.25
March 20, 1979	3.72	4.00
March 24, 1979	1.32	1.40
March 27, 1979	2.02	2.17
March 31, 1979	5.84	6.27
April 3, 1979	8.97	9.49
April 11, 1979	2.23	2.42
April 19, 1979	1.03	1.13
April 29, 1979	0.48	0.52
April 30, 1979	0.93	0.98
May 4, 1979	1.53	1.64
May 11, 1979	2.43	2.62
May 12, 1979	1.17	1.27
May 27, 1979	1.74	1.86
May 30, 1979	4.60	4.87
TOTAL	41.11	43.98

TABLE XVIII

COMPARISON OF PRECIPITATION AND THROUGHFALL

Date Sampled	Mean Precipitation (cm)	Mean Throughfall (cm)
March 1, 1979	0.99	0.88
March 3, 1979	2.11	1.81
March 20, 1979	3.72	3.18
March 24, 1979	1.32	1.18
March 27, 1979	2.02	1.84
March 31, 1979	5.84	5.27
April 3, 1979	8.97	8.14
April 11, 1979	2.23	1.99
April 19, 1979	1.03	0.82
April 29, 1979	0.48	0.38
May 3, 1979	0.93	0.74
May 4, 1979	1.53	1.39
May 11, 1979	2.43	2.12
May 12, 1979	1.17	0.93
May 27, 1979	1.74	1.16
May 30, 1979	4.60	4.19
TOTAL	41.11	36.02

TABLE XIX

AVERAGE PRECIPITATION AND SURFACE RUNOFF

Date	Precipitation (cm)	Surface Runoff (cm)
March 1, 1979	0.99	0.009
March 3, 1979	2.11	0.011
March 20, 1979	3.72	0.023
March 24, 1979	1.32	0.009
March 27, 1979	2.02	0.018
March 31, 1979	5.84	0.078
April 3, 1979	8.87	0.166
April 11, 1979	2.23	0.014
April 19, 1979	1.03	0.003
April 29, 1979	0.48	0.003
May 3, 1979	0.93	0.007
May 4, 1979	1.53	0.010
May 11, 1979	2.43	0.020
May 12, 1979	1.17	0.006
May 27, 1979	1.74	0.013
May 30, 1979	4.60	0.047
TOTAL	41.11	0.437

TABLE XX

AVERAGE CHEMICAL CONCENTRATIONS IN PRECIPITATION SAMPLES

Date Sampled	Ca	Mg	K
	mg/l		
March 1, 1979	2.18	0.21	0.99
March 3, 1979	0.83	0.03	0.49
March 20, 1979	0.60	0.20	0.89
March 24, 1979	0.47	0.09	0.59
March 27, 1979	1.49	0.23	1.97
March 31, 1979	0.35	0.09	0.50
April 3, 1979	0.03	0.00	0.57
April 11, 1979	0.51	0.45	1.86
April 19, 1979	0.38	0.07	3.33
April 29, 1979	0.75	0.14	1.14
May 3, 1979	0.56	0.11	0.90
May 4, 1979	0.42	0.08	1.24
May 11, 1979	0.43	0.10	1.06
May 12, 1979	0.09	0.39	1.30
May 27, 1979	0.44	0.12	1.60
May 30, 1979	0.38	0.08	1.38

TABLE XXI

AVERAGE CHEMICAL CONCENTRATIONS IN THROUGHFALL SAMPLES

Date Sampled	Ca	Mg	K
	-------	mg/l	-------
March 1, 1979	0.92	0.09	0.95
March 3, 1979	0.81	0.07	0.63
March 20, 1979	1.09	0.33	1.81
March 24, 1979	0.38	0.11	1.59
March 27, 1979	1.30	0.14	1.49
March 31, 1979	0.33	0.08	1.35
April 3, 1979	0.14	0.02	0.80
April 11, 1979	0.21	0.01	1.78
April 19, 1979	1.15	0.22	2.97
April 29, 1979	0.81	0.21	1.85
May 3, 1979	0.68	0.21	1.96
May 4, 1979	0.46	0.13	1.20
May 11, 1979	0.31	0.38	2.93
May 12, 1979	0.14	0.35	1.27
May 27, 1979	0.56	0.14	1.54
May 30, 1979	0.31	0.08	0.72

TABLE XXII

AVERAGE CHEMICAL CONCENTRATIONS IN SURFACE RUNOFF SAMPLES

Date Sampled	Ca	Mg	K
	mg/l		
March 1, 1979	6.52	1.91	10.13
March 3, 1979	2.30	1.02	8.02
March 20, 1979	4.09	1.60	7.42
March 24, 1979	2.11	0.86	3.84
March 27, 1979	1.62	0.57	7.35
March 31, 1979	1.11	0.41	5.81
April 3, 1979	1.35	0.43	4.35
April 11, 1979	1.02	0.26	4.60
April 19, 1979	3.19	1.25	7.60
Arpil 29, 1979	3.23	1.37	6.74
May 3, 1979	0.31	0.57	3.59
May 4, 1979	1.23	0.60	4.64
May 11, 1979	1.04	0.45	4.15
May 12, 1979	0.53	1.27	5.20
May 27, 1979	1.06	0.32	3.08
May 30, 1979	0.63	0.20	1.82

TABLE XXIII

AVERAGE CHEMICAL CONCENTRATIONS IN STREAMFLOW SAMPLES

Date Sampled	Ca	Mg	K
	mg/l		
March 1, 1979	1.01	0.88	1.23
March 3, 1979	*	*	*
March 20, 1979	1.89	1.18	3.02
March 24, 1979	0.88	0.97	1.44
March 27, 1979	0.77	0.82	2.39
March 31, 1979	0.68	0.75	2.32
April 3, 1979	0.62	0.70	2.54
April 11, 1979	0.56	0.00	2.93
April 19, 1979	0.53	0.75	2.98
April 29, 1979	*	*	*
May 3, 1979	*	*	*
May 4, 1979	0.55	0.45	0.81
May 11, 1979	0.57	0.48	0.81
May 12, 1979	0.42	0.60	1.49
May 27, 1979	0.49	0.37	1.17
May 30, 1979	0.47	0.34	1.24

*Not Determined

APPENDIX B

AOV TABLES

TABLE XXIV

ANALYSIS OF VARIANCE FOR FUNNEL COLLECTORS

Source	DF	Sum of Squares	Mean Square	F Value	P Value
P	1	11.6210	11.6210	99999.99	0.0000
Error	14	0.0014	0.0001		
Total	15	11.6224			

P = Standard Precipitation Gage Volume (cm)

TABLE XXV

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR THROUGHFALL

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	435.9356	29.0624	1504.83	0.0001
Slope	2	0.1880	0.0940	4.87	0.0080
Date*Slope	30	0.7874	0.0262	1.36	0.0978
Station (Slope)	6	1.0987	0.1831	9.48	0.0001
Location (Station*Slope)	36	2.5233	0.0701	3.63	0.0001
Error	625	12.0704	0.0193		
Total	714	452.6035			

TABLE XXVI

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR SURFACE RUNOFF

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	0.03614	0.00241	6.70	0.0001
Slope	2	0.00010	0.00005	0.14	0.8691
Slope*Date	30	0.01374	0.00046	1.27	0.1951
Station (Slope)	6	0.00484	0.00081	2.24	0.0471
Error	83	0.02985	0.00036		
Total	136				

TABLE XXVII

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR CALCIUM IN PRECIPITATION

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	12.6707	0.8447	11.24	0.0000
Station	2	0.1007	0.0504	0.67	0.5189
Date*Station[1]	30	2.2548	0.0752		
Total	47	15.0263			

[1] Date*Station Used as Error Term

TABLE XXVIII

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR MAGNESIUM IN PRECIPITATION

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	0.6778	0.0452	3.16	0.0035
Station	2	0.0147	0.0074	0.51	0.6037
Date*Station[1]	30	0.4291	0.0143		
Total	47	1.1216			

[1] Date*Station Used as Error Term

TABLE XXIX

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR POTASSIUM IN PRECIPITATION

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	23.2882	1.5525	3.48	0.0024
Station	2	2.1219	1.0610	2.37	0.1202
Date*Station[1]	30	13.9919	0.4467		
Total	47	39.4020			

[1] Date*Station Used as Error Term

TABLE XXX

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR CALCIUM IN THROUGHFALL

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	37.0532	2.4702	105.88	0.0001
Slope	2	0.7629	0.3814	16.53	0.0001
Date*Slope	30	1.1869	0.0396	1.70	0.0175
Station (Slope)	6	0.7291	0.1215	5.21	0.0001
Location (Station*Slope)	11	0.9798	0.0891	3.82	0.0001
Error	215	5.0161	0.0233		
Total	279	45.7280			

TABLE XXXI

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR MAGNESIUM IN THROUGHFALL

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	3.4869	0.2325	67.61	0.0001
Slope	2	0.0751	0.0376	10.93	0.0001
Date*Slope	30	0.5339	0.0178	5.18	0.0001
Station (Slope)	6	0.1420	0.0237	6.88	0.0001
Location (Station*Slope)	11	0.1472	0.0134	3.89	0.0001
Error	215	0.7391	0.0034		
Total	279				

TABLE XXXII

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR POTASSIUM IN THROUGHFALL

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	123.7371	8.2491	15.97	0.0001
Slope	2	13.8946	6.9473	13.45	0.0001
Date*Slope	30	37.8329	1.2611	2.44	0.0001
Station (Slope)	6	21.9840	3.6641	7.09	0.0001
Location (Station*Slope)	11	30.0620	3.0056	5.82	0.0001
Error	215	111.0642	0.5166		
Total	279				

TABLE XXXIII

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR CALCIUM IN SURFACE RUNOFF

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	329.0664	21.9378	2.70	2.70
Slope	2	32.6501	16.3251	2.01	2.01
Date*Slope	30	205.2185	6.8406	0.84	0.84
Station (Slope)	6	181.4005	30.2334	3.72	3.72
Error	68	552.6933	8.1278		
Total	121				

TABLE XXXIV

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR MAGNESIUM IN SURFACE RUNOFF

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	33.5311	2.2354	4.10	0.0001
Slope	2	2.1281	1.06405	1.95	0.1496
Date*Slope	30	12.1224	0.4041	0.74	0.8154
Station (Slope)	6	14.9855	2.4976	4.59	0.0006
Error	68	37.0354	0.5446		
Total	121				

TABLE XXXV

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR POTASSIUM IN SURFACE RUNOFF

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	15	597.2956	39.8197	2.92	0.0013
Slope	2	165.7949	82.8975	6.09	0.0037
Date*Slope	30	316.7750	10.5592	0.78	0.7772
Station (Slope)	6	299.5951	49.9325	3.67	0.0033
Error	68	926.2226	13.6209		
Total	121				

TABLE XXXVI

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR CALCIUM IN STREAMFLOW

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	12	5.3898	0.4492	3.75	0.0031
Station	2	0.3281	0.1640	1.37	0.2742
Date*Station[1]	23	2.7556	0.1198		
Total	37	8.4735			

[1] Date*Station Used as Error Term

TABLE XXXVII

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR MAGNESIUM IN STREAMFLOW

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	12	3.0310	0.2526	112.59	0.0000
Station	2	0.0215	0.0108	4.79	0.0182
Date*Station[1]	23	0.0516	0.0022		
Total	37	3.1041			

[1] Date*Station Used as Error Term

TABLE XXXVIII

TWO WAY CLASSIFICATION ANALYSIS OF VARIANCE FOR POTASSIUM IN STREAMFLOW

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Date	12	24.2299	2.0192	5.20	0.0003
Station	2	0.6145	0.3072	0.79	0.4654
Date*Station[1]	23	8.9359	0.3885		
Total	37	33.7803			

[1] Date*Station Used as Error Term

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VITA

James Alan Clingenpeel

Candidate for the Degree of

Masters of Science

Thesis: HYDROLOGIC AND NUTRIENT RELATIONSHIPS ON A PINE - HARDWOOD FOREST IN SOUTHEAST OKLAHOMA

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