CHARACTERISTICS OF RUNOFF FROM THREE WATERSHEDS IN MONTGOMERY COUNTY, VIRGINIA

by

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I. INTRODUCTION

If the lives of rivers, lakes, and streams are to be preserved, man must deal with all forms of pollution. The major problems concerning runoff from agricultural and forest lands involve the collection and treatment of tremendous quantities of water containing, for the most part, low concentrations of nutrients and contaminants.

The detrimental effects of runoff from agricultural and forest lands on surface waters in the United States remain largely unknown. Research efforts during the past thirty years have been centered around evaluating the constituents of and the treatment methods associated with domestic and industrial wastes.

The reasons for concentrating pollution research and development on point sources are many. Rapid urbanization has led to degradation of lakes and other surface waters surrounding metropolitan areas. Concentrations of pollutants from point sources are usually very high compared to those of natural runoff, indicating, at least superficially, that they pose a much greater hazard to our environment. The areas affected by point source discharges are in most instances quite small, thus placing great stress on the assimilative capacity of receiving water.

Many ecologists, however, fail to realize the extremely large quantity of water associated with runoff from agricultural and forest lands. Wadleigh (1) states that an average of 1,380 million acre-ft of runoff reaches U. S. streams annually, transporting approximately 700 times as much sediment as produced by domestic sewage plants. The amount of runoff from these areas is dependent upon factors too numerous to mention here; however, it is important that pollution abatement experts recognize the danger of even low pollutant concentrations where large amounts of runoff are involved.

Modern farming methods in this country, while designed to produce the greatest amount of food from the land, contribute greatly to runoff hazards. More and more fertilizers high in nitrogen and phosphorus content are being used to maximize land yield. Even the most practical tillage methods cannot insure that most of the available nutrients are used by crops or remain on the land.

In conclusion, both man and nature have been and will continue to be polluters; however, it is man's responsibility to rectify the problem.

Research Objectives

The main objective of this project was to determine the amounts of nitrogen, phosphorus, organic matter, and sediment in runoff from three drainage areas along State Highway Route 657 (Merrimac Road) in Montgomery County, Virginia.

It was also an objective to study the relationships of various constituents and characteristics of land runoff.

Scope of the Project

Stations 1, 2, and 3, shown in Figure 1, served as sampling points for the respective drainage areas, described as follows:

Watershed number 1 includes approximately 80 acres of steeply sloping forest land which drains into a gently sloping stream. The stream empties into a 36-in. concrete pipe 470 ft from Stroubles Creek. The stream draining Section 1 also receives flow from the streams draining Sections 2 and 3, as illustrated in Figure 1.

Watershed number 2 encompasses approximately 50 acres of grazed pasture land and a small section of barren land.

Watershed number 3 encompasses approximately 20 acres of forest land and brush. The stream through Section 3 receives drainage from Highway Route 657, which runs through some steep, barren cuts.

The sampling period covered from March 15 to July 1, 1974. In the Blacksburg area, this time of the year is marked by intense rains of short duration.

No attempts were made to control field conditions, and manual sampling was conducted whenever runoff occurred.

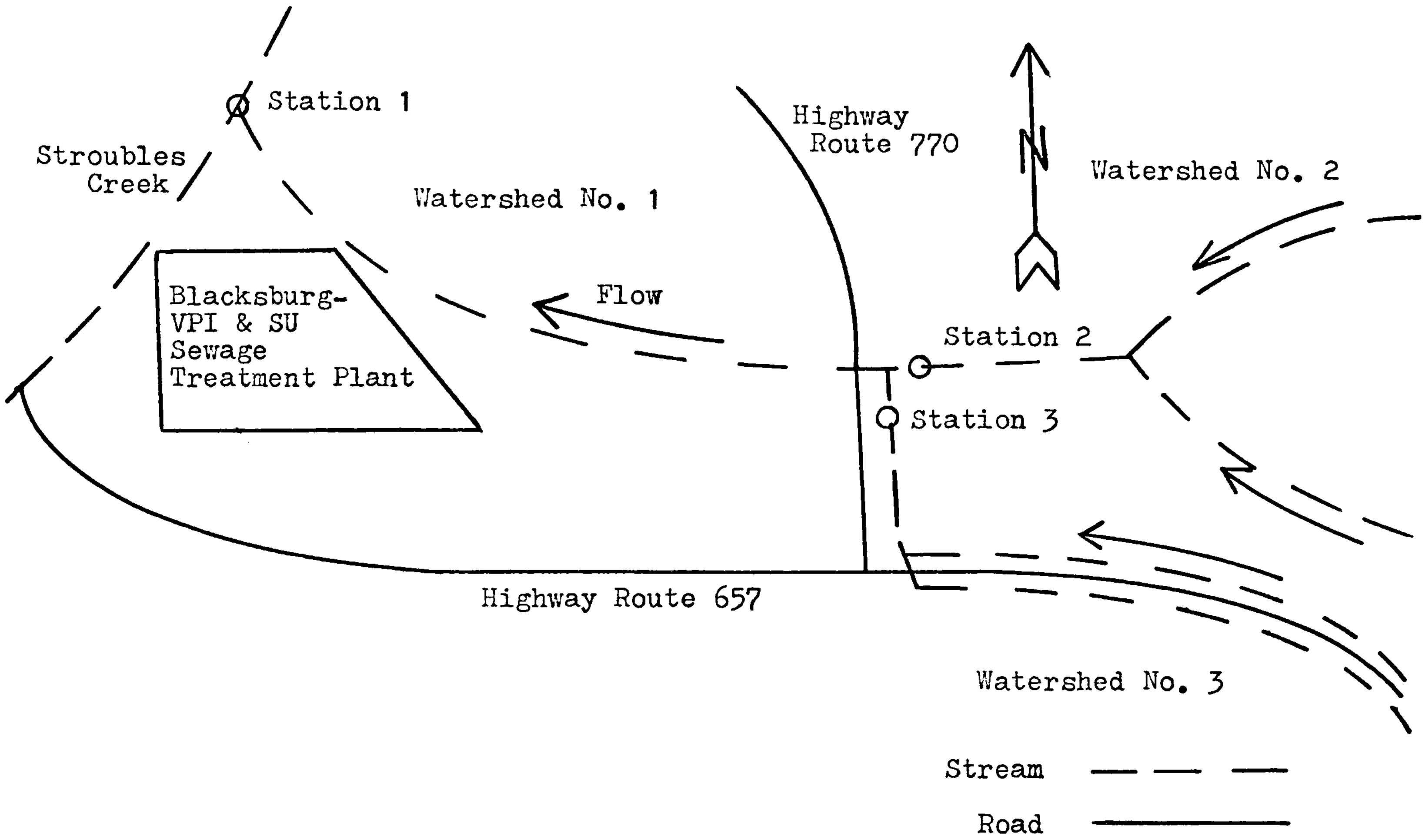


FIGURE 1.--Plan view of drainage basin.

II. LITERATURE REVIEW

Agricultural Runoff - Field and Pasture Drainage

Quantity of Soil-Loss. Soil losses due to the erosion of agricultural lands exceed the imaginations of most pollution abatement experts. The results of various studies indicate how damaging erosion can be to both agricultural lands and receiving bodies of water.

Fippin (2) compiled data taken from nine different locations within the Tennessee River System during 1939. Mean estimated silt loads of 1.58 tons/acre for open farm land, and 5.2 tons/acre for row crop and idle land were found.

Table I lists results of a survey by Weidner *et al.* (3), who studied losses from eight 1.5-acre agricultural research watersheds. The watersheds, located near Coshocton, Ohio, were subjected to crop rotation and were evaluated by the Agricultural Research Service. Eighty-five percent of the annual soil-loss from the research plots occurred between May and September, when the rainfall was of high intensity and short duration.

McGuinneas *et al.* (4) also conducted experiments on improved farming methods at the Coshocton research plots. They found that contour tillage in hilly land can reduce field erosion by 75 percent over straight row farming.

TABLE I.--Runoff by Crops in Four-Year Rotation 1945-1956 (3)

Crop	Average Monthly Runoff (in.)	Total Runoff (in.)	Time on Land	Soil-Loss (tons/acre)
Corn	0.43	2.31	May 1-Oct. 10	7.7
Wheat	0.21	1.95	Oct. 11-Apr. 30	0.88
Meadow	0.1	3.57	33 months	Trace

A survey similar to Weidner's was conducted by Rogers (5), who rotated crops on five experimental plots of differing slopes on Dunmore silt loam in Virginia. Soil losses over the 3-yr research period ranged from 4.4 tons/acre on land with a 5 percent slope, to 19.5 tons/acre on land with a 25 percent slope.

Erosion: Cause and Effect. The amount of soil-loss during a storm is dependent on a variety of factors. Walker (6) discusses the two most common types of erosion: gully and sheet. Gully erosion occurs at spots where the flow of water is concentrated, gouging out the soil. Sheet erosion occurs when a thin layer of soil is removed from an entire slope. Sheet erosion is usually considered more destructive than gully erosion because it is much more extensive.

Walker also states that slow-moving water has been found to do little damage in most areas. However, as the speed of flowing water increases, its ability to hold particles in suspension as well as to roll other particles is increased(6).

Several studies have been conducted to determine the mechanisms governing erosion rates. Ellison (7) found that, in addition to the soil moved downslope by flowing water, some soil is carried downhill by the splash of raindrops. His experiments showed that drops which fall vertically tend to strike glancing blows against soil particles and throw them downhill. Raindrop impact has been shown to move stones as large as 10 mm in diameter which were submerged in water. Ellison states that splash erosion is usually not apparent because of the high velocity of particle movement and unfavorable light and background conditions.

Epstein and Grant (8) studied the erosion rates of six different soils which had been placed in 30.5 cm square pans at a depth of 15 cm. Some of their results are listed in Table II. Splash soil losses were as high as three to four times the amounts moved in the runoff. Hartland soil, which had the least amount of clay and highest amount of sand, experienced the greatest amount of splash loss.

It is interesting to note that the rate of soil-loss in the experiments reached a maximum after 10 min of rainfall and then decreased sharply. Epstein and Grant's study also indicated that the soil-loss rate at the time of peak rainfall increased with increasing clay content of the original soil, suggesting that crust formation is one important factor in determining the maximum point of soil-loss (8).

Much work has been done in an attempt to predict the amount of soil which will be lost from a given plot of land. Rogers *et al.* (9) used a rain simulator, known as a rainulator, to generate rainfall on Cecil sandy loam and sandy clay loam soils. Results indicated that 70 percent of the

TABLE II.--Average Soil and Water Loss for Six Soils Following 90 Minutes of Simulated Rainfall (8)

Soil	Water Loss % of Rain	Soil-Loss, gm/pan (930 sq cm)		
		Runoff	Splash	Total
Dunkirk	44.8	1.24	2.89	4.13
Marshall	49.2	1.39	2.38	3.77
Hartland	24.8	0.66	3.10	3.76
Caribou	44.0	1.01	2.66	3.67
Nicholville	32.5	0.76	2.52	3.28
Winoski	23.1	0.58	2.09	2.67

variation in soil-loss data could be explained by a factor obtained by multiplying rainfall intensity by rainfall amount. Further investigations showed that 89 percent of the variation in total runoff was explained by the rainfall amount. The effects of rainfall intensity and land slope were not as important as the initial moisture content of the soil.

Results of the previous study do not correlate closely with investigations by Wischmeier (10). He found that the rainfall characteristic most indicative of the capacity of a soil to erode is the variable whose value is the product of rainfall energy and maximum 30-min rainfall intensity. In Wischmeier's experiments on tilled continuous fallow, the factor explained from 72 to 97 percent of the variation in individual storm erosion.

Development of an acceptable soil-loss prediction equation proved to be a long and arduous task. Wischmeier and Smith discuss the development of the "universal soil-loss equation" as cited by the Agricultural Research Service (11). The equation is:

$$A = RKLSCP$$

where
- A = Soil-loss per unit acre
- R = Rainfall factor
- K = Soil-erodibility factor
- L = Slope-length factor
- S = Slope-gradient factor
- C = Cropping-management factor

P = Erosion-control practice factor

They state that results of investigations conducted as far back as 1930 were used in formulating the equation. Research has supplied sufficient information from which at least approximate values for the various soil-loss factors can be derived for any location east of the Rocky Mountains.

Eutrophication. Eutrophication is the rapid aging of a body of water caused by an excess of nutrients. It is usually associated with the presence of algae and aquatic vegetation which flourish when vital nutrients are available. Eutrophication is mentioned in context with this thesis because it will be shown that surface runoff is a vital source of nutrients.

Factors affecting eutrophication are many and varied. A complete discussion of such factors is not presented; however, an attempt has been made to mention a portion of the vast amount of literature dealing with eutrophication.

The two nutrients generally cited as being responsible for eutrophication are nitrogen and phosphorus. Sawyer (12) cites phosphorus as the key element in determining the biological activity of a water body. After conducting experments on water from three Wisconsin lakes, he reported nuisance algal blooms occurring with organic phosphorus concentrations of .1 ppm PO_4-P and with inorganic phosphorus concentrations of .01 ppm PO_4-P. The same study revealed critical nitrogen levels of .3 ppm NO_3-N. Sawyer also states that blooms have been obtained in the laboratory with an abundance of phosphorus and a nitrogen deficit; however, when phosphorus was not available algae did not grow. These findings tend to indicate that the required nitrogen is supplied by fixation, either bacterial or algal, if it is not readily available.

Shapiro (13) investigated the possibility that there are factors in natural waters which are capable of inhibiting or facilitating the use of phosphorus by algae. From his experiments, Shapiro concluded that inorganic anions are capable of stimulating phosphate usage. Of the anions tested, nitrate was the most potent.

Shapiro also cited separate works by MacKereth and Rhode, who confirmed the presence of a phosphate stimulating factor. MacKereth's findings, however, indicate that the factor might possibly be of an organic nature (13).

Sylvester (14) lists some factors affecting algal productivity, such as:

1. water temperature.
2. light penetration into the water.
3. rate at which nutrients can be supplied once growth commences.

He states that when algal productivity exceeds the amount needed for fish food, the eutrophication rate greatly increases.

Another source of information on nutrients, algae, and the problems they cause is an American Water Works Association Task Group Report (15). The report lists 79 references on related subjects.

Nitrogen, Phosphorus, and Organic Matter in Agricultural Runoff. The detrimental effects of agricultural runoff on a receiving body of water depend on its physical, chemical, and organic constituents. Factors such as soil type, fertilizing practices, crop cover, and farming methods determine constituents of agricultural runoff.

Phosphorus may find its way to agricultural lands by numerous routes. Studies, such as that by Holt *et al.* (16), have shown that phosphorus has a high affinity for soil particles, and when applied to the land as fertilizer, is sorbed onto these particles. Holt states that once sorbed, the phosphorus is prevented from moving downward and therefore is not a factor in groundwater pollution. The sorbed phosphorus is highly susceptible to transportation by erosion, and it is in this manner that most phosphorus reaches receiving streams.

Holt also infers that phosphorus in surface waters is either in the form of soluble phosphorus, including inorganic orthophosphate, hydrolyzable polyphosphates, and organic phosphates; or suspended insoluble phosphorus, including insoluble inorganic phosphorus, sorbed phosphorus, and phosphorus in microorganisms (16).

An interesting article by Silvey (17) relates the effect of pH on soil phosphorus. He found that clays act as ion exchange compounds, and that certain phosphates in calcium-bearing soils are converted to calcium phosphate and remain in the humus or subsoil until the pH approaches 7, at which time the soluble phosphorus would be eluded.

Silvey also implies that crops utilize about 60 percent of the available phosphorus, most of which terminates in the plant leaf structure. In some agricultural practices, leaves return to the ground as organic matter, carrying with them organic phosphorus (17).

In attempting to determine the fate of organic phosphorus, Neess (18) found that organic phosphorus is not soluble in water as long as it remains part of the leaf. If vegetable remains are decayed, organic phosphorus is oxidized first to insoluble and later to soluble phosphate.

Nitrogen, on the other hand, usually follows a different route in reaching surface waters. Power (19) discusses the various forms of nitrogen present in most soils. He states that the fate of fertilizer nitrogen cannot be accurately predicted because of the many pathways, indicated by Figure 2, that soluble nitrogen travels. Power infers that regardless of the nitrogen source, nitrogen fertilizers must enter the soluble nitrogen pool as ammonia or nitrate nitrogen before they can be of any

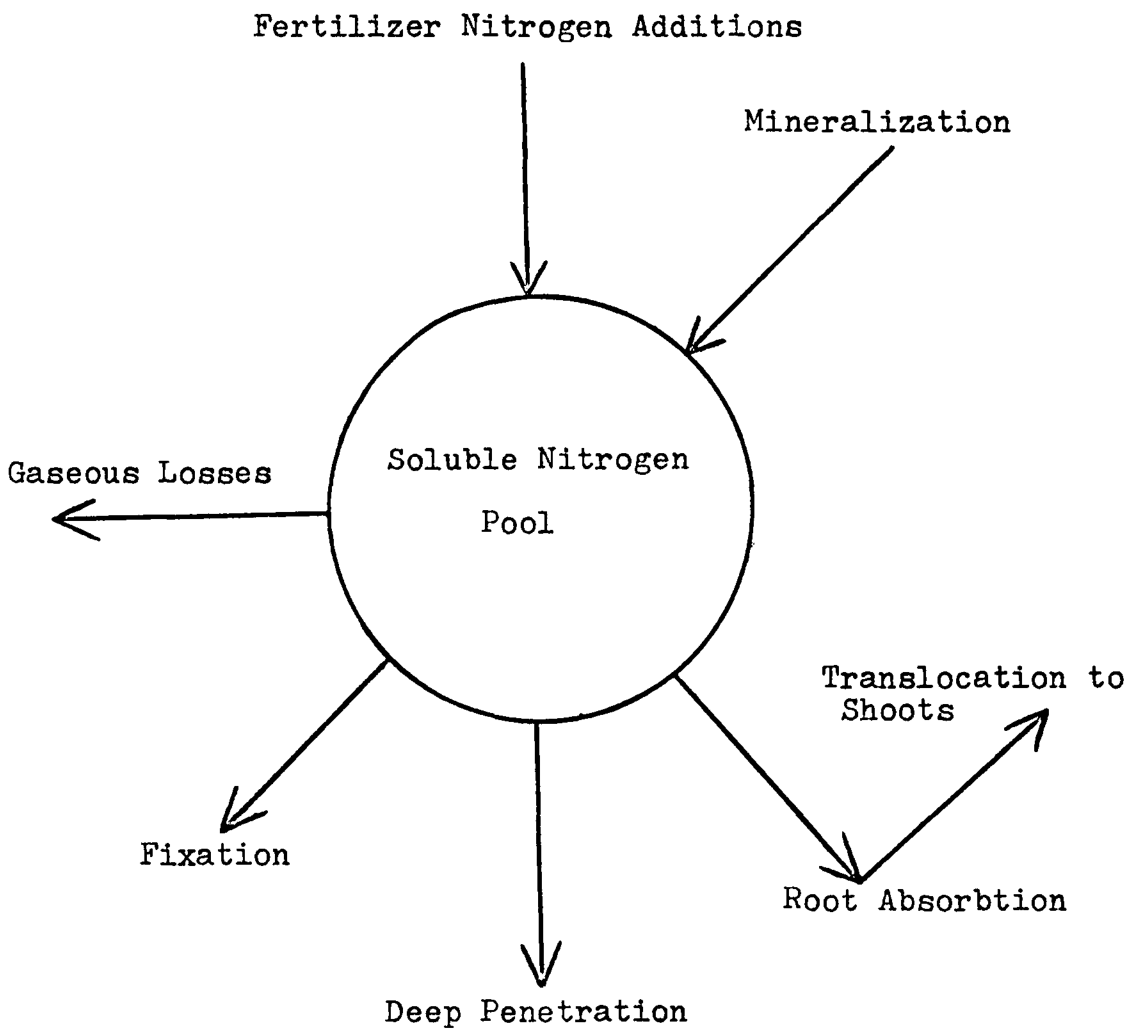


FIGURE 2.--Pathways of soluble nitrogen in soil (19).

benefit to a crop. Any ammonia ions in the soil are converted to NO_3 or are sorbed onto clay and organic matter surfaces. The organic matter is eventually degraded, and the NH_3 released is usually oxidized to NO_2 and NO_3.

The interaction of nitrates from agricultural waste disposal and other sources with soil particles was studied by Stephenson and Rodrique (20). They equalized 200 solutions of nitrates with coarse-sized sodium and potassium montmorillonite particles. Their investigations revealed that at temperatures between 6°C and 35°C, with either sodium or potassium present, nitrate anions were repelled from the surfaces of coarse montmorillonite particles whenever the pH was between 4.5 and 10.2 and the equilibrium NO_3 concentration was less than 20 mg/l.

Experiments such as those by Stephenson and Rodrique tend to support conclusions that little of the available nitrates which are not used by vegetation or crops adheres to soil particles. Stewart et al. (21) state that unless additions of nitrogen to a basin or watershed are balanced by withdrawals or denitrification losses, soluble nitrogen will accumulate in surface and underground waters.

Numerous investigations have been conducted to determine the concentrations of nitrogen, phosphorus, and organic matter in agricultural runoff. Table III lists results of a study by Weidner et al. (3) who examined runoff from two 7.5-acre experimental plots at Coshocton,

TABLE III.--Calculated Average Annual Loads

From Watersheds at Coshocton, Ohio (3)

Watershed No.	Cover	TS lb/acre	BOD lb/acre	COD lb/acre	PO_4 lb/acre	Total N lb/acre
113	Corn	3,660	27.5	480	8.4	88
118	Corn	13,200	120.0	1,300	27.7	237
113	Wheat	480	3.7	64	1.1	11
118	Wheat	1,730	15.5	170	3.6	31
113	Meadow	Trace	----	----	----	----
118	Meadow	Trace	----	----	----	----

Ohio. Prevailing farming methods were used on watershed number 118, whereas improved methods were tested on watershed number 113. As can be seen, extremely large amounts of nitrogen and phosphorus were lost from the fertilized corn field, which had the least amount of crop cover.

Witzel _et al._ (22) sampled runoff from three small watersheds near Fennimore, Wisconsin. The watersheds had areas of 22.8, 52.5, and 171 acres. Cover for the natural watersheds consisted of 30 percent hay, 30 percent pasture, 30 percent cultivated crops, and 10 percent roads, buildings, and idle lands. Approximately 22.1 lb of nitrogen, 4.82 lb of phosphorus, and 18.3 lb of potassium fertilizer were applied to the moderately permeable silt loam soil between January and September of 1967. Nutrient losses over the period were 3.62 lb/acre of nitrogen, 1.14 lb/acre of phosphorus, and 7.7 lb/acre of potassium. Witzel states that these values are about double what could be expected during a normal growing season, because rainfall in 1967 was unusually heavy.

Phosphorus determinations were conducted on six cultivated drainage areas in the Kaskaskia River Basin in Illinois by Engelbrecht and Morgan (23). The drainage areas ranged in size from 12 to 5,220 sq miles, and farm lands contained from 40 to 50 lb of available P_2O_5 per acre. Values of orthophosphate plus hydrolyzable P_2O_5 ranged from 0-15 lb/acre/yr as P. The authors estimate that the total phosphorus values would have been 20 to 30 percent higher than the figures given, because only a portion of the organic phosphate was measured by the method of analysis used.

Pratt et al. (24) were interested in the ability of phosphorus to penetrate through sandy loam soil. The site examined was the Citrus Experimental Station at Riverside, California. The irrigated citrus orchard had received 56 lb/acre of phosphate fertilizer for the previous 28 yr. Findings of the investigation revealed a 150 percent increase in the total phosphate concentration of upper soil layers over the 28-yr period; however, phosphate concentrations below the 3-ft deep level had not increased.

Runoff from plots with different slopes was examined by Rogers (5). Crops of corn, wheat, and clover were rotated over a 3-yr experimental period. His findings showed total phosphorus losses of from 8 lb/acre/yr from a plot sloped 5 percent to 26 lb/acre/yr from a plot sloped 25 percent.

In 1939, Fippin (2) analyzed runoff from nine drainage areas within the Tennessee River Basin. The large drainage areas consisted mostly of large farms and forests. Total phosphorus values for open farm land ranged from 1.6 to 50.2 lb/acre/yr, and from 9.86 to 135 lb/acre/yr for new crops and idle land. Total nitrogen values ranged from 3.4 to 31.1 lb/acre/yr for open farm land, and from 16.4

to 71 lb/acre/yr for row crops and idle land.

Tile drainage effluent from systems on irrigated land in the San Joaquin Valley of California was analyzed for nitrogen and phosphorus by Johnston et al. (25). One of the four fields had an area of 90 acres and was not fertilized; however, its irrigation drainage contained 3.1 lb/acre/yr of nitrogen and 0.067 lb/acre/yr of phosphorus. The authors state that most of the fertilizer nitrogen lost was in the form of NO_3, but NH_3 was also found immediately after application.

Sawyer (12) investigated the fertilization of several Wisconsin lakes by agricultural and urban drainage. Results of his tests are given in Tables IV and V, contrasting nutrient loads from domestic sewage plants in the area and agricultural drainage. He states that it requires about 750 persons to supply an amount of nitrogen equivalent to that released by one sq mile of agricultural land, and only about 212 people to supply the phosphorus equivalent.

Harms (26) determined nutrient concentrations of runoff from seven single crop farm plots, with areas ranging from 7 to 19 acres, in eastern South Dakota. The sampling period took place over a 2-yr period, covering 91 snowmelt and 32 rainfall events. Nitrogen losses ranged from 0.03 to 3.0 lb/acre/yr, and phosphorus losses from 0.01 to 0.72 lb/acre/yr. Harms states that most of the nutrient load

TABLE IV.--Contributions of Fertilizing Elements In Drainage from Agricultural Lands (12)

Drainage area tributary to	Contributed lb/sq mile/yr			
	Inorganic nitrogen	Organic nitrogen	Inorganic phosphorus	Organic phosphorus
Lake Monona	2,800	1,035	35	---
Lake Waubesa	3,130	1,180	62	186
Lake Kegonsa	4,100	1,150	62	200

TABLE V.--Comparison of Fertilizing Elements Supplied By Agricultural Drainage and by Biologically Treated Sewage Tributary to the Madison Lakes (12)

Fertilizing element	lb/sq mile/yr	lb/capita/yr	Population equivalent/ sq mile
Nitrogen (total)	4,500	6.0	750
Phosphorus (total)	255	1.2	212

was in soluble form and a large percentage was lost in snowmelt runoff.

Forest Runoff

<u>Quantity of Runoff and Soil-Loss</u>. Over the years the importance of forest litter in the prevention of excessive runoff and soil-loss has become increasingly apparent. Wadleigh (1) states that reductions in forest cover result in increased total stream flow due to reduced transpiration and increased interception of rainfall at the ground level. He states that studies in the Rocky Mountains of Colorado have shown that cutting half the pine-spruce-fir forest produced a 25 percent increase in annual streamflow. Wadleigh reports that experiments at the Cowecta Hydrologic Laboratory in North Carolina showed an increased water yield of 17 acre-in./acre during the first year after all trees and shrubs had been cut.

Further investigations at the Coshocton Hydrologic Field Station in Ohio revealed that establishing a farm woodlot on a 44-acre watershed significantly reduced runoff. Wadleigh (1) states that water yield was reduced by 5.32 in. by the 19th year after the trees were planted.

Lowdermilk (27) used artificial rainfall to contrast runoff from forested and burned lands on three different types of soils. Results of his investigations are given in Table VI. As can be seen, forest litter served to

TABLE VI.--Summary of Artificial Rain and Comparative Surficial Runoff (27)

Tanks		Series A*	F	B	G	C	D	E
		Depth of rain and runoff (in.)						
I	Rain	5.68	6.56	12.05	14.28	15.05	39.87	52.01
	Runoff	0.17	2.02	1.73	3.40	4.41	13.13	18.95
II	Rain	5.68	7.13	14.69	18.14	19.18	45.48	67.07
	Runoff	0.07	0.07	0.48	0.49	0.59	1.80	3.09
III	Rain	5.68	8.19	15.27	20.77	21.13	44.03	75.24
	Runoff	0.11	3.37	9.12	4.05	8.05	12.38	17.75
IV	Rain	5.68	8.36	15.95	22.47	22.59	46.24	80.00
	Runoff	0.08	1.34	3.61	0.94	2.70	6.15	8.53
V	Rain	5.68	8.12	17.23	23.49	23.01	45.61	83.91
	Runoff	0.95	2.25	7.17	14.44	14.44	19.33	47.70
VI	Rain	5.68	8.43	17.92	24.96	23.44	44.84	88.89
	Runoff	0.06	0.09	0.31	0.63	0.88	2.38	3.12
		Percentages of runoff						
I		3.0	30.8	14.3	23.8	27.4	32.9	36.2
II		1.2	0.9	3.2	2.7	3.0	3.9	4.6
III		1.9	41.1	59.7	19.5	38.0	28.1	23.5
IV		1.4	16.0	22.6	4.1	11.9	13.3	10.6
V		16.7	27.7	41.6	61.5	62.7	42.4	56.8
VI		1.0	1.0	1.7	2.5	3.7	5.3	3.5

Soil Series: Tanks I & II - Aiken, III & IV - Holland, V & VI - Altamont.

Tanks I, III, & V - Burned land.
Tanks II, IV, & VI - Forested land.

*Natural rain totaled from March 8 through April and May.

maintain the soils under them in a state of greater absorbency than the burned soils. Lowdermilk states that runoff from plots covered with litter remained clear regardless of the rain intensity, whereas water from the burned area carried heavy sediment loads.

Nutrients from Forest Runoff. Little work has been done in the way of measuring nutrient concentrations in forest runoff alone. Most of the investigations have been conducted on areas containing agricultural ground covers in addition to forests, making no differentiation between the two.

Table VII lists results of a survey by Sylvester (14), who measured the nitrogen and phosphorus content of three streams draining forests. Values were considerably less than totals for nitrogen and phosphorus from most farmlands.

Edwards and Harrold (28), after studying results of tests at the Coshocton North Appalachian Experimental Watershed, concluded that forest runoff must contain sufficient nutrients to promote the growth of aquatic life. Herb algal growths were found in pools of water along stream systems draining wooded areas which have not been farmed for over 35 yr.

As previously mentioned, the majority of surveys reviewed dealt with forest runoff in conjunction with agricultural lands. Fippin's study of nine drainage basins within the Tennessee River System is one such survey (2).

TABLE VII.--Nutrients in Streams from Forested Areas* (14)

Characteristics	Yakima R. at Easton (12 months)	Tiston R. (7 months)	Cedar R.** at Landsberg (12 months)
Mean annual flow, cfs	587	559	690
Mean flow, cfs	630	520	587
Drainage area, sq miles	182	239	125
Phosphorus as P, ppb			
Total			
Range of values	19-140	32-200	15-85
Weighted average	70	115	22
Soluble			
Range of values	0-23	0-23	2-7
Weighted average	9	8	4
Nitrates as N, mg/l			
Range of values	0.05-0.50	0.03-0.18	0.018-0.154
Weighted average	0.20	0.126	0.065
Total kjeldahl N, mg/l			
Range of values	0-0.22	0-0.13	---
Weighted average	0.08	0.068	---
Total nitrogen as N, mg/l	0.28	0.194	---
Total phosphorus, lb/acre/yr	0.74	0.77	0.32
Total nitrogen, lb/acre/yr	2.96	1.30	---
Ratio $\frac{\text{Total N}}{\text{Total P}}$	4	1.7	---

*Areas subject only to logging and road construction--large reservoirs present on all headwaters.

**Seattle Engineering Department data.

He found total P_2O_5 values ranging from 0.87 to 19.8 lb/acre/yr, and total nitrogen values ranging from 1.72 to 11.4 lb/acre/yr.

Investigations of forest and pasture land near Roanoke, Virginia were conducted by Grizzard and Jennelle (29). By projecting 2 months' sampling data, they predicted that 0.9 lb/acre/yr of nitrogen and 0.33 lb/acre/yr of phosphorus would be lost in runoff.

Summary

The various investigations cited indicated that the quantity of runoff from most agricultural and forest lands is dependent on factors such as rainfall intensity and crop cover.

Most runoff contains a small amount of organic matter; however, the sediment, or SS, content varies significantly. Runoff from lands supporting crops such as corn contained large amounts of sediment, whereas meadows and forests produced little. Predictions of soil-loss east of the Rocky Mountains can be made using the "universal soil-loss equation" developed by the Agricultural Research Service.

Many studies have shown the important role of nutrients produced by runoff from agricultural and forest lands. The literature reviewed showed that a wide variety of nitrogen and phosphorus values have been found in storm runoff. Average annual quantities of nitrogen lost ranged from 2 to 200 lb/acre with values seldom exceeding 30 lb/acre, whereas phosphorus losses were between 0.1 and 30 lb/acre.

III. METHODS AND MATERIALS

Site Selection

In keeping with the objectives of this research, three watersheds were chosen for examination. Drainage area number 1, 80 acres, is owned by Henry Heth and only includes runoff from densely forested land. The western side of the property adjoins land owned by the Blacksburg-VPI & SU Sanitation Authority.

Drainage area number 2 consists primarily of 50 acres of pasture land, but includes less than 0.1 acre of barren ground near the sampling station. A small portion of the pasture is owned by Roscoe Quesenberry. The remainder is owned by L. D. Helms. The Quesenberry property, located near station number 2, has not been fertilized for the past two years. The Helms property did not receive fertilizer this year; however, the pasture was fertilized in the spring of 1973 with 400 lb/acre of fertilizer containing 5 percent nitrogen, 10 percent phosphoric acid, and 10 percent potash. About ten cattle graze on the Helms pasture.

Drainage area number 3, 20 acres, includes sparsely wooded brush land and Highway Route 657. The private property within watershed number 3 is owned by L. D. Helms.

Runoff Quantity Determinations

To determine the quantities of runoff constituents, it was necessary to determine not only pollutant concentrations, but also the quantities of runoff during storms. The amounts of runoff from drainage areas 2 and 3 were determined by constructing hydrographs, shown in Figures 3 and B1-B4, and calculating areas under the curves. By subtracting the total runoff at stations 2 and 3 from that at station 1, runoff values from watershed number 1 were compiled. (See Table VIII.)

Streamflows at stations 2 and 3 were determined from Figure A1. The graphs were formulated by plotting theoretical flow versus channel depth for the two stations. By simply measuring the water depths in each stream, flow values could be obtained.

Theoretical flows at stations 2 and 3 were found by the formula:

$$Q = VA \qquad \text{Eqn. 2}$$

where Q = Streamflow

V = Velocity of flow

A = Channel cross-sectional areas, shown in Figure 4

Stream velocity was calculated from Manning's formula for open channel flow (30):

$$V = \frac{1.49}{n} R_h^{2/3} S^{1/2} \qquad \text{Eqn. 3}$$

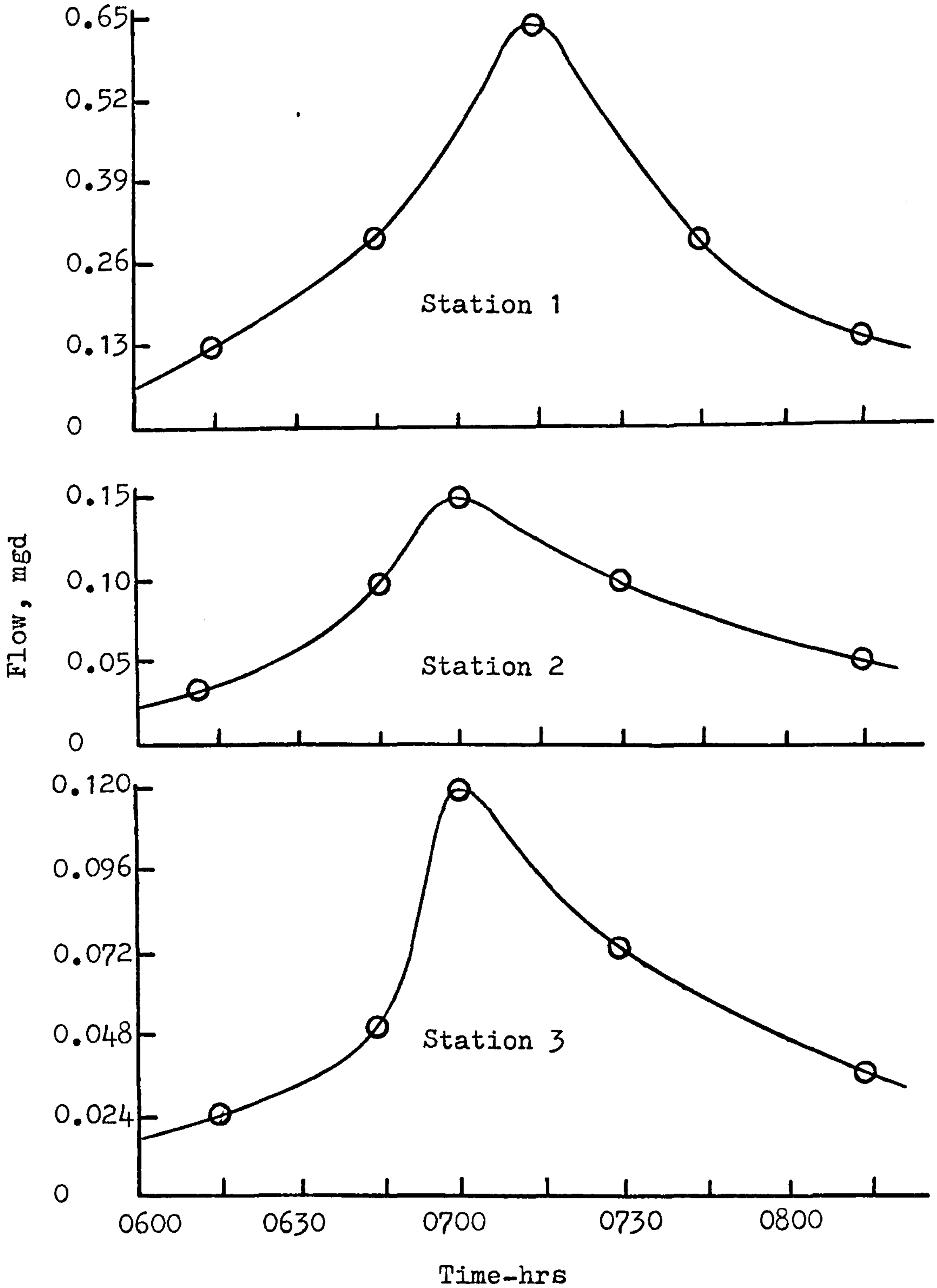


FIGURE 3.--Hydrographs of storm on June 16, 1974.

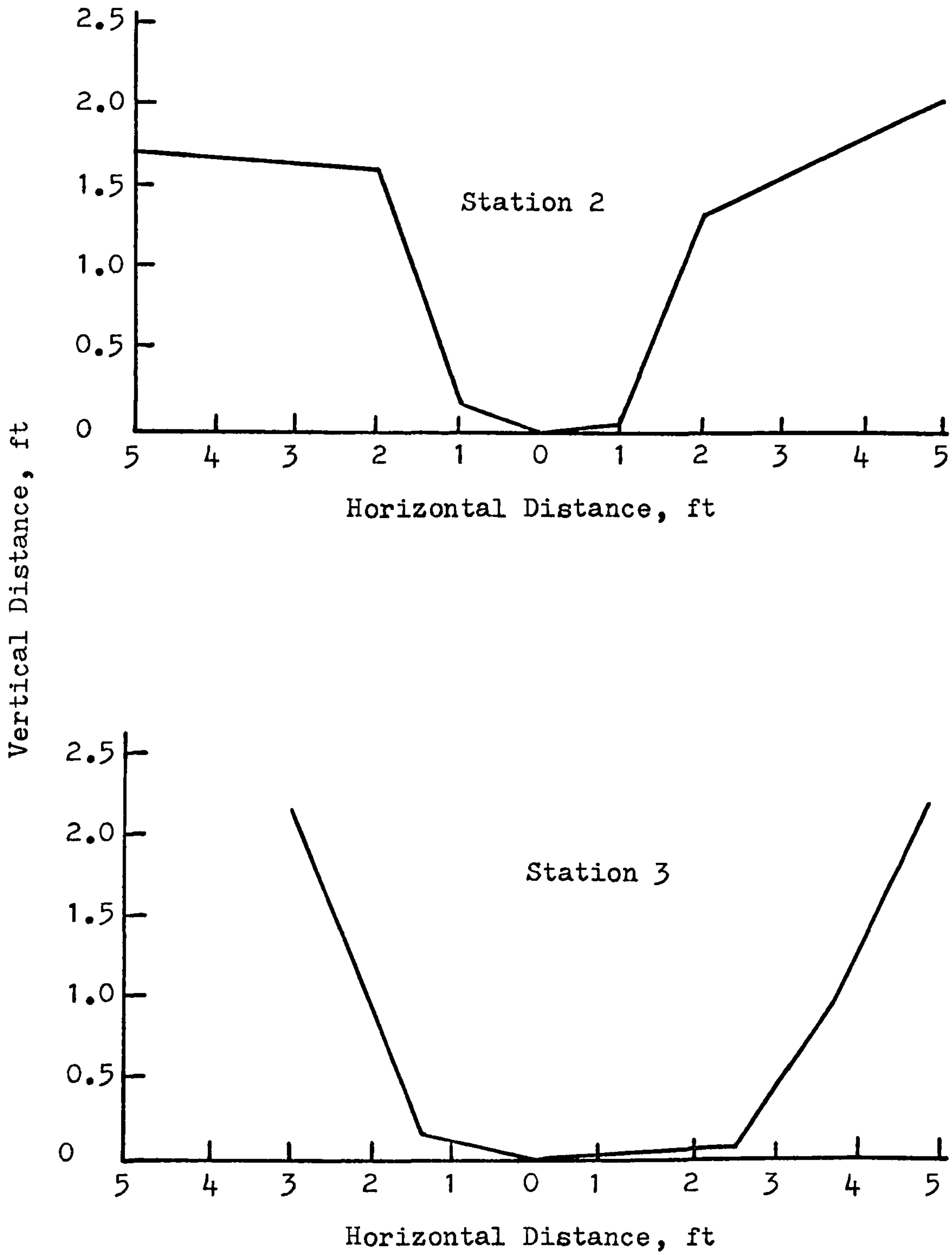


FIGURE 4.--Cross-sections for stations 2 and 3.

where V = Stream velocity

R_h = Hydraulic radius, $\frac{\text{x-sectional area}}{\text{wetted perimeter}}$

S = Channel slope

n = Manning's roughness coefficient

A roughness coefficient of 0.08 was used to simulate natural conditions as closely as possible (31). Slopes of channels 2 and 3 were determined by dividing the differences in elevations 50 ft upstream and downstream from the sampling points by 100.

Flow through the 36-in. concrete storm sewer draining all three watersheds was approximated from relative velocity and flow curves in the "Concrete Pipe Design Manual" (32). A portion of the curve relating flow and velocity is illustrated in Figure A2. A roughness coefficient of 0.01 was assumed.

Samples were also collected from the streams during dry weather for comparison with those taken during storms. When calculating the constituent poundage during dry weather, it was assumed that the streamflow was constant over a 24-hr period.

Sample Collection and Preservation

Neither automatic sampling devices nor flow recorders were available for use on this project. Samples and stream level measurements were taken manually whenever sufficient runoff was present.

Following storms, samples were composited into a single sample from each station according to flow information obtained from hydrographs. Samples taken during dry weather for comparative analysis were not composited. Since 24-hr streamflow during dry weather was assumed constant, grab samples were used.

In all cases, samples were refrigerated at $4^{\circ}C$ as soon after collection as possible. Testing was completed within 1 wk after collection.

Testing Methods

The following tests were conducted on samples taken during both wet and dry periods:

Total phosphorus, PO_4-P

Chemical oxygen demand, COD

pH

Total suspended matter, SS

Total kjeldhal nitrogen, TKN

Nitrate nitrogen, NO_3-N

Tests for total phosphorus, COD, pH, and SS were carried out according to procedures outlined in "Standard Methods" (33). All analyses were conducted in the VPI & SU sanitary engineering laboratories, and duplicate tests were conducted for SS, PO_4-P, and COD.

The persulfate digestion method was used in preparing total phosphorus samples for examination. Colorimetric analyses were conducted by the ascorbic acid method, using spectrophotometer number 0380 at a wavelength of 880 nanometers.

Total suspended matter was measured by passing a recorded amount of sample through a preweighed glass fiber filter placed on a membrane filtering apparatus. The filter plus residue was dried at 103°C for 1 hr and cooled in a desiccator before weighing. Suspended matter was computed from the weight difference.

Chemical oxygen demand was measured by the dichromate reflux method. When low concentrations were expected, normalities of the dichromate and the titrant were reduced for accuracy.

Total Kjeldhal nitrogen values were determined using an autoanalyzer system as manufactured by the Technicon Corporation. The laboratory method used was number 30-69A, obtained from the Technicon Corporation (34).

Nitrate nitrogen measurements were taken using a specific ion electrode, model 92-07, manufactured by the Orion Research Corporation. The analytical methods followed were those listed in the Orion instruction manual (35).

IV. RESULTS AND DISCUSSION

Surface runoff samples were collected during five storms which occurred in May and June of 1974. Samples of groundwater drainage, sometimes called dry weather run-off, were taken from each station on four separate occasions during the spring of 1974. Dry weather sampling was dis-continued after May 5 because little drainage was present.

In applicable places through this discussion, the term runoff refers to both surface runoff and groundwater drainage. Appropriate designation is made between the two whenever necessary.

Determining the Characteristics of Forest Runoff

A major objective of this research was to compare the quantity and quality of runoff from three different water-sheds. Watershed number 2, consisting of pasture and barren land, and watershed number 3, consisting of brush land and a paved highway surface, drain directly into shallow ditches. Runoff from the two watersheds could be sampled and measured directly from respective ditches. Direct measurements of runoff from forest land could not be taken because it drains into the stream containing runoff from watersheds numbers 2 and 3, as illustrated by Figure 1. It was possible, however, to collect samples and obtain flow measurements of runoff from the entire drainage area, watersheds numbers 1, 2, and 3, at station 1.

The physical and chemical characteristics of forest drainage, listed in Tables VIII and IX, were obtained by adding values of flow times concentration from the watersheds 2 and 3, and subtracting the total from the value of flow times concentration at station 1. The following example illustrates the method used in determining a NO_3-N concentration of 1.90 mg/l in forest runoff on May 12:

Total drainage area - watershed 2 - watershed 3 = watershed 1

(2.8 mil gal)(1.38 mg/l) - (1.38 mil gal)(1.2 mg/l) - (0.61 mil gal)(1.1 mg/l) = (0.81 mil gal)(conc.)

conc. = 1.9 mg/l

Factors Affecting Runoff

Rainfall and storm runoff information is summarized in Tables VIII and X. The quantities of rainfall which appeared as runoff, expressed as percentages in the tables, seem much higher than expected. The inflated values probably resulted from the error involved in taking manual flow measurements. Although most of the figures seem high, the same degree of inaccuracy is believed to be present in each of the values, since each was obtained in the same manner.

Throughout this discussion, numerous references are made to rainfall intensity. Since continuous rainfall

TABLE VIII.--Calculated Characteristics of Storm Runoff From 80-acre Forest Land (Watershed No. 1)

Parameter	Date 5-12	5-23	5-31	6-16	6-27
Rainfall, in.	1.24	0.41	0.80	0.32	0.80
Rainfall intensity, in./hr	0.38	0.12	0.64	0.18	0.07
Runoff, acre-in.	30.1	15.8	47.0	14.3	9.2
Runoff, mil gal	0.81	0.44	1.28	0.39	0.25
Runoff intensity, mil gal/acre/hr	0.003	0.002	0.013	0.003	0.001
Storm duration, hr	3.25	3.50	1.25	1.75	12.00
Runoff/rainfall, %	30.3	48.2	73.4	56.0	14.4
NO_3-N, mg/l	1.90	1.37	2.41	1.65	
lb/acre	0.16	0.06	0.32	0.07	
TKN, mg/l	1.41	0.90	1.36	0.26	1.75
lb/acre	0.12	0.04	0.18	0.01	0.05
PO_4-P, mg/l	0	0	0.21	0.15	0.1
lb/acre			0.030	0.006	0.003
SS, mg/l	0	0	0	0	0
COD, mg/l	0	11	0	0	0
lb/acre		0			

TABLE IX.--Calculated Characteristics of Drainage Water From 80-acre Forest Land During Dry Weather (Watershed No. 1)

Characteristic	Date 4-18	4-23	5-2	5-5
Drainage, mgd	0.030	0.015	0.040	0.040
NO_3-N, mg/l	2.43	1.93	2.25	2.17
lb/acre	0.008	0.003	0.009	0.009
TKN, mg/l	1.29	1.30	1.24	0.85
lb/acre	0.004	0.002	0.005	0.004
PO_4-P, mg/l	0.05	0.04	0.02	0.05
lb/acre	0.0002	0	0	0.0002
SS, mg/l	0	0	0	0
COD, mg/l	28	40	29	44
lb/acre	0.09	0.06	0.12	0.18

TABLE X.--Quantities of Rainfall and Runoff

	Date				
Station 1	5-12	5-23	5-31	6-16	6-27
Rainfall, in.	1.24	0.41	0.80	0.32	0.80
Rainfall intensity, in./hr	0.38	0.12	0.64	0.18	0.07
Runoff, acre-in.	102.9	35.2	82.0	27.8	33.5
Runoff, mil gal	2.80	0.96	2.23	0.76	0.91
Storm duration, hr	3.25	3.50	1.25	1.75	12.00
Runoff intensity, mil gal/acre/hr	0.006	0.002	0.013	0.003	0.001
Runoff/rainfall, %	59.3	61.3	73.2	62.1	29.9
Station 2					
Rainfall, in.	1.24	0.41	0.80	0.32	0.80
Rainfall intensity, in./hr	0.38	0.12	0.64	0.18	0.07
Runoff, acre-in.	50.6	11.8	19.9	7.9	13.8
Runoff, mil gal	1.38	0.32	0.54	0.21	0.38
Storm duration, hr	3.25	3.50	1.25	1.75	12.00
Runoff intensity, mil gal/acre/hr	0.009	0.002	0.009	0.002	0.001
Runoff/rainfall, %	81.6	57.6	49.8	49.4	34.5
Station 3					
Rainfall, in.	1.24	0.41	0.80	0.32	0.80
Rainfall intensity, in./hr	0.38	0.12	0.64	0.18	0.07
Runoff, acre-in.	22.2	7.6	15.1	5.6	10.5
Runoff, mil gal	0.61	0.21	0.41	0.15	0.28
Storm duration, hr	3.25	3.50	1.25	1.75	12.00
Runoff intensity, mil gal/acre/hr	0.009	0.003	0.016	0.004	0.001
Runoff/rainfall, %	89.5	92.7	94.4	87.5	65.6

indicators and recorders were not used, the intensities given in Tables VIII and X are assumed to be constant over the duration of the storm.

While in the process of collecting field data for this research, it was noted that many factors have roles in determining whether or not surface runoff occurs. Ground cover, storm intensity, frequency, and duration all affected surface runoff.

Rainfall intensity and frequency were usually found to be related in connection with surface runoff from forest land. Generally, a higher rainfall intensity was required to produce runoff during periods of infrequent precipitation than during periods of plentiful rainfall. A complete rainfall frequency analysis for the period under examination is not given; however, 4.41 in. of rain fell during May, and 2.40 in. were received during June, mostly in the form of short showers which did not produce runoff. In Table VIII it can be seen that approximately 50 percent of the rain that fell during low intensity storms on May 23 and June 16 accumulated as runoff, indicating that the frequent showers had rendered the watershed unsuitable to receive large amounts of infiltration.

Several conclusions can be drawn from the storm on June 27. Data from this storm indicate the importance of total amount and duration of rainfall in determining runoff flow. Since only 0.8 in. of rain fell in 12 hr, this was the smallest intensity storm measured; however, significant quantities of runoff occurred from all three watersheds. The percentage of rainfall which appeared as runoff was less on the 27th than on the other dates; however, the figures show that even a light storm can produce runoff if it proceeds long enough to saturate the ground.

Ground cover seemed to have more of an effect on runoff quantities from pasture land than from the other watersheds studied. Table X shows that, regardless of storm intensity, percentages of rainfall appearing as runoff decreased as spring progressed and the grass cover thickened. Only 49.8 percent of the rainfall drained from watershed number 2 during the very intense storm on May 31, whereas 57.6 percent escaped during the small storm on May 23.

Ground cover could be cited as retaining precipitation on forest land only once, on May 12, when 30.2 percent of the rainfall was present as runoff. It is quite possible that the frequent showers which occurred in May and early June kept the heavy leaf cover moist, and thus lessened its ability to retain water from storms which took place during this period. Another possible explanation for the seemingly high percentage runoff figures is the estimated 45-50 percent slope of land within watershed number 1. The steep slope increases the velocity of flowing water and does not permit much time for infiltration. The runoff figures in Table VIII do not support those of Lowdermilk (27), who found that land covered by forest litter yielded very little runoff. The negligible SS concentrations found in all samples indicate that forest litter does hold soil in place and prevents its erosion even during intense rainfall.

Physical and Chemical Characteristics of Runoff

Results of the physical and chemical analyses conducted on all samples are listed in Tables CI-CIII, with lb/acre values in Tables DI-DIII. A summary of the average concentration and poundage values is given in Table XI.

Characteristics of Forest Runoff. Nitrogen was identified as the major nutrient contributed by forest runoff. Nitrate concentrations as high as 2.41 mg/l during storms and 2.43 mg/l from groundwater drainage were found. Maximum TKN values of 1.75 mg/l and 1.30 mg/l were found during wet and dry weather respectively. The values are somewhat higher than those found by Sylvester (14)(see Table VII), who conducted a similar analysis on forest runoff. If using the figure of 0.3 mg/l inorganic nitrogen, quoted by Sawyer (12), as that concentration causing nuisance algal problems in lakes, then forest land could be a significant contributor to eutrophication.

Approximately two-thirds of the nitrogen in forest

TABLE XI.--Comparison of Average Wet Weather and Dry Weather Runoff Characteristics

Characteristic		Watershed 1	Watershed 2	Watershed 3	Watershed 1	Watershed 2	Watershed 3
		Mean concentration, mg/l			Mean value, lb/acre		
NO_3-N	wet	1.83	1.61	1.54	0.153	0.150	0.203
	dry	2.20	0.91	1.22	0.007	0.008	0.023
TKN	wet	1.14	2.76	2.07	0.081	0.278	0.290
	dry	1.17	0.95	0.95	0.004	0.009	0.020
PO_4-P	wet	0.09	0.65	0.43	0.008	0.084	0.064
	dry	0.04	0.12	0.13	0	0.001	0.003
SS	wet	0	1401	868	0	167	137
	dry	0	0	0	0	0	0
COD	wet	2	98	123	0.1	12.0	19.2
	dry	35	33	31	0.1	0.3	0.6

runoff appeared as NO_3-N. Assuming that all of the nitrogen in a forest watershed is originally present as organic nitrogen in dead leaves, etc., the findings indicate that an appreciable amount of biological activity is taking place as the organic nitrogen is converted to NO_3-N. The NO_3-N delivered to receiving water bodies is more readily available for use by aquatic plants than is organic nitrogen or ammonia.

The negligible SS and COD values shown in Table VIII raise questions as to the validity of the method used in determining forest runoff parameters when dealing with characteristics involving suspended particles. The zero values were reported because negative concentrations were calculated, reflecting the suspended matter which settled to the stream bottom before reaching Stroubles Creek. (See Figure 1.) Although it is doubtful that the SS and COD content of forest runoff is zero, the figures indicate that the concentrations are probably too low to be of significance.

The phosphorus concentrations given in Table VIII are questionable, considering the widespread belief that phosphorus adheres strongly to soil particles and is eroded with them. The figures do indicate, however, that more phosphorus is present in forest runoff than in groundwater drainage. No relationship could be found between total phosphorus content, shown in Table VIII, and rainfall intensity, except that the largest concentration, 0.21 mg/l, was found in a sample taken during the storm of highest intensity.

Characteristics of Agricultural and Barren Land. Most of the nitrogen in surface runoff from unfertilized pasture land was in the form of organic nitrogen or ammonia with average TKN values of 2.76 mg/l (0.278 lb/acre) found. Average NO_3-N values of 1.61 mg/l (0.15 lb/acre) were about one-half as large as the TKN figures.

By examining data in Table CII, it was determined that much higher TKN and NO_3-N concentrations can be expected in surface runoff than in dry weather groundwater drainage. Furthermore, the magnitude of TKN concentrations generally seemed to vary in proportion to rainfall intensity. Except for the storm on June 16, higher COD values were also accompanied by increased TKN concentrations.

The plot of agricultural and barren land studied during this research produced significant amounts of phosphorus during storms. Table CII lists PO_4-P concentrations as high as 1.16 mg/l, with an average figure of 0.65 mg/l given in Table XI. If concentrations of 0.1 mg/l organic phosphorus and 0.01 mg/l inorganic phosphorus, quoted by Sawyer (12), are assumed necessary to cause nuisance algal blooms, watershed number 2 could be responsible for maintaining a significant amount of undesirable aquatic plant life.

It is a widespread opinion throughout the literature reviewed that phosphorus adheres to soil particles and reaches its ultimate destination through the transportation of these particles. An examination of total phosphorus and suspended solids data from agricultural and barren land supports this opinion. A graph of SS versus PO_4-P has been prepared in Figure 5, showing the corresponding increases in each constituent. The representative line was drawn using the least squares method described by Steel and Torrie (36). By observing the graph, one can also speculate that about 0.2 mg/l of soluble PO_4-P was present in the samples tested.

A conclusion concerning phosphorus concentrations can also be drawn by examining the PO_4-P and rainfall intensity data in Tables X and CII. Although there was not as strict a relationship between these data and the SS and PO_4-P values, the PO_4-P concentrations tended to be higher during more intense rains. This was somewhat expected, since SS concentrations generally increased with higher rainfall intensities.

By extrapolating the experimental data found during the 2-month sampling period covered by this research, it is felt that approximate yearly nutrient values can be obtained. Using this procedure, totals of 2.57 lb/acre/yr of nitrogen and 0.15 lb/acre/yr of phosphorus are attributed to surface runoff from the watershed under consideration.

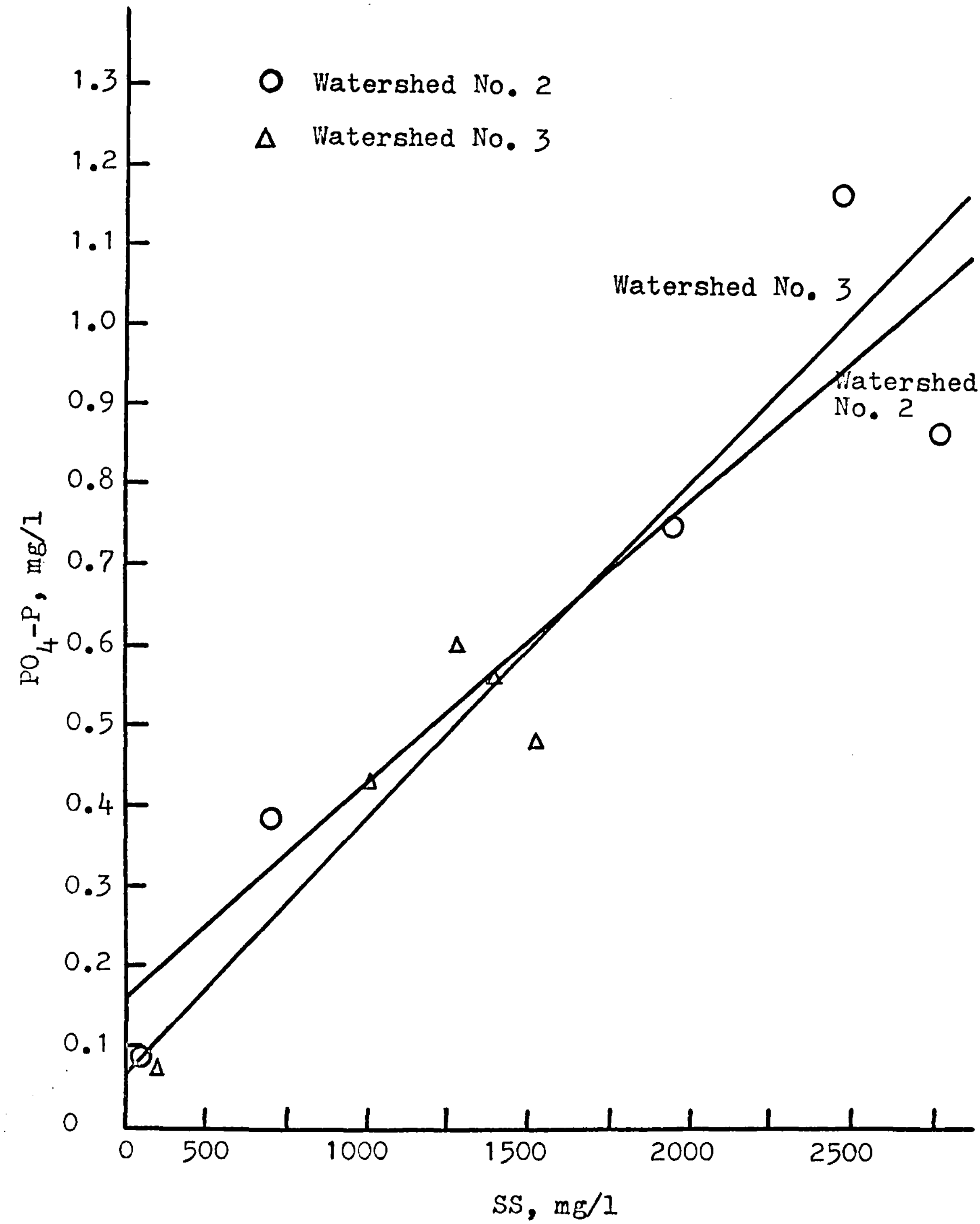


FIGURE 5.--Total phosphorus concentration, PO_4-P vs. SS content for watersheds 2 and 3.

The literature reviewed reports a wide range of nutrient values in agricultural runoff; however, most of the variation can be traced to different fertilizing practices or crop cover. The extrapolated figures mentioned in the preceding paragraph correlate with those reported in several studies. Johnson (25) examined tile drainage effluent from irrigated lands in California's San Joaquin Valley which had not received fertilizer, and found 3.1 lb/acre/yr of nitrogen and 0.067 lb/acre/yr of phosphorus. Harms (26) found nitrogen values ranging from 0.03 to 3.0 lb/acre/yr and phosphorus contents ranging from 0.01 to 0.72 lb/acre/yr in runoff from South Dakota farmland.

It is interesting to note the high SS content of surface runoff from watershed number 2, despite the fact that only about 0.1 acre is barren land. Since the amounts of SS in agricultural and barren land were not determined separately and factors such as land slope were not determined, a detailed discussion of the data is not presented. Assuming that only a small percentage of the suspended matter comes from agricultural land, it can be seen that the soil-loss from barren land can be extremely heavy.

A direct relationship, shown in Figure 6, was found between SS and COD concentrations. It seems, from examining the graph, that most of the organic matter in runoff from watershed number 2 was associated with suspended particles, and that only a small fraction was in soluble

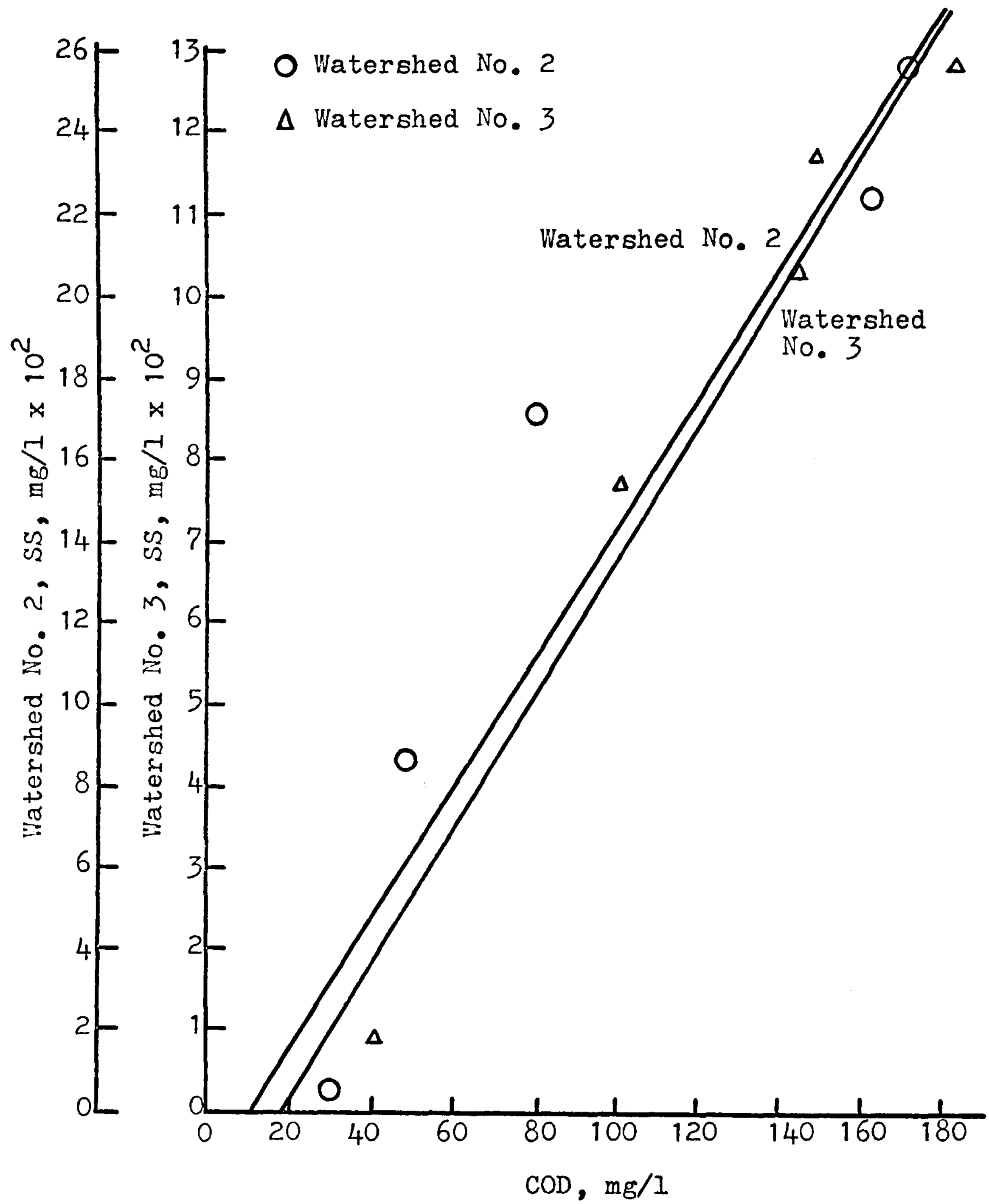


FIGURE 6.--COD vs. SS for watersheds 2 and 3.

form. A direct conclusion cannot be drawn because some organic matter was found in dry weather groundwater drainage, which did not contain SS. It may be that both COD and SS from watershed number 2 increase at corresponding rates as the rainfall intensity increases.

Characteristics of Brush Land and Steep Highway Embankments. Significant amounts of nitrage nitrogen and total kjeldhal nitrogen were present in surface runoff from watershed number 3 with average concentrations reaching 1.54 mg/l and 2.07 mg/l respectively. Tables CIII and XI reveal that considerably higher TKN values were found in storm runoff than could be detected in dry weather drainage, which averaged 0.95 mg/l. Dry weather NO_3-N concentrations, averaging 1.22 mg/l, were slightly lower than those present in surface runoff. It is believed that a major portion of the TKN which was present in surface runoff was in the form of organic nitrogen. On all storm dates except June 27, higher TKN values accompanied increased COD concentrations.

Results of tests conducted on groundwater drainage support the conclusion that a high percentage of organic nitrogen on brush and barren land is converted to NO_3-N as it penetrates through the soil. Rainfall intensity seemed to have little effect on the NO_3-N concentrations, because higher values were found in samples taken during less intense storms.

As was the case with watershed number 2, only small amounts of total phosphorus were present in groundwater drainage; however, the concentrations rose considerably during storms. A graph of SS versus PO_4-P content is shown in Figure 5. The curve, drawn using the least squares method, indicates that total phosphorus concentrations have a strong tendency to increase as SS values rise. These data support the opinion that a large portion of the phosphorus on land adheres to soil particles and is eroded with them. Figure 5 suggests a PO_4-P value of 0.08 when the SS content is 0. The predicted value compares favorably with the average dry weather value of 0.13 mg/l in Table XI.

Using the projection method discussed in the previous section, a calculated nitrogen value of 2.96 lb/acre/yr and phosphorus value of 0.12 lb/acre/yr was determined. These are similar to those predicted for unfertilized agricultural land despite a great deal of difference in ground cover.

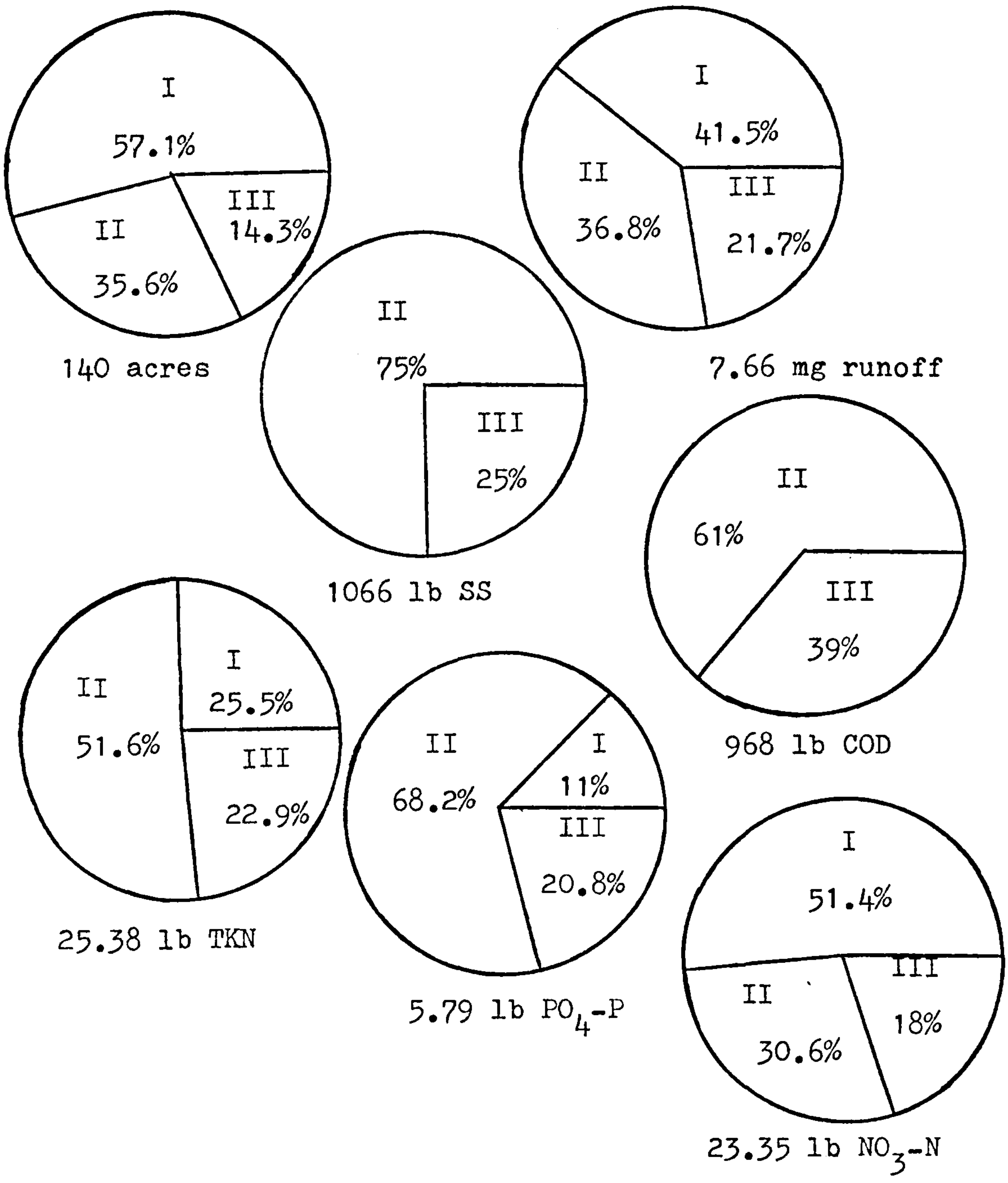
The curve in Figure 6, drawn using the least squares method, illustrates the strong relationship between organic matter content and SS concentrations. The graph indicates that most of the organic matter found in runoff from watershed number 3 is accompanied by suspended particles. Furthermore, since the amount of suspended matter in surface runoff can be expected to remain high with increasing rainfall intensities, the total phosphorus content will probably do likewise.

The extremely high suspended solids concentrations given in Table CIII illustrate the quantity of soil-loss which can result from surface runoff. By projecting the SS data over a period of 1 yr, it is predicted that 0.411 tons/acre of soil will be eroded from steeply cut highway embankments adjoined by brush land.

Comparisons of Physical and Chemical Characteristics

By examining Figure 7, showing a breakdown of storm runoff characteristics, Appendices C and D, and Tables VIII and XI, comparisons of watershed contributions can be made.

Although 57.1 percent of the entire drainage area surveyed was in forest, only 41.5 percent of the total surface runoff during May and June of 1974 could be attributed to this section. Steep highway embankments and brush land, on the other hand, were responsible for 21.7 percent of the storm runoff, even though it covered only 14.3 percent of the watershed. By averaging the ratios of runoff to rainfall, in Tables VIII and X, it can be seen that 44.5 percent of the heavy rainfall from forest land, 55.3 percent of that from agricultural land, and 85.5 percent of that from highways appeared as runoff. When interpreting these figures, one should keep in mind that they omit frequent spring showers which did not produce



I - Forest land

II - Agricultural and barren land

III - Brush land and highway

FIGURE 7.--Breakdown of storm runoff contributions.

runoff. By assuming that each storm that produced runoff was measured, and comparing the runoff figures to total rainfall values, it was found that 23, 29, and 45 percent of the 2-month rainfall appeared as runoff from watersheds numbers 1, 2, and 3 respectively.

At first glance, the SS information in Figure 6 is somewhat misleading. The value of 75 percent attributed to watershed number 2 and 25 percent to number 3 reflects the differences in acreage more so than those in surface runoff concentrations. Average SS values from the two watersheds were similar as can be seen in Table XI. One hundred sixty-seven lb/acre were received from pasture and barren land, whereas 137 lb/acre were attributed to highway embankments adjoining brush land. No measurable amount of SS could be found in forest runoff.

Watershed number 3 contributed the highest unit quantity of organic matter, 19.2 lb/acre. Runoff from watershed number 2 contained an average of 12 lb/acre of COD. Very little organic matter was present in runoff from watershed number 1. When the flow quantities were taken into consideration, 61 percent of organic matter was traced to watershed number 2 and 39 percent to number 3.

Table XI illustrates the effect that runoff quantities can have on poundage values. Runoff from highway embankments and brush land contributed the largest unit poundages of both TKN and NO_3-N; however, agricultural runoff had the highest average TKN and forest runoff the highest average NO_3-N concentration.

As was expected, runoff from agricultural and barren land usually contained the largest PO_4-P concentrations and contributed the highest average lb/acre quantity.

V. SUMMARY AND CONCLUSIONS

The project included surface runoff and ground-water drainage measurements and determinations of physical and chemical characteristics from three watersheds located within the same drainage basin in Montgomery County, Virginia. Comparisons were made of the results obtained for watershed number 1, forest land; watershed number 2, agricultural and barren land; and watershed number 3, a paved highway bordered by steep embankments and brush land. The research period covered from March through June of 1974.

The following conclusions were reached:

1. Generally, a higher rainfall intensity is required to produce surface runoff during periods of infrequent precipitation than during periods of plentiful rainfall.

2. Many factors, such as ground cover and slope, rainfall intensity and frequency, and storm duration affect the amount of surface runoff occurring from a particular watershed.

3. A higher percentage of rainfall will appear as runoff from highways and their adjoining territory than from pasture or forest land. Pasture land can be expected to yield slightly more runoff per acre than forests.

4. Nitrogen was identified as the major nutrient contributed by forest runoff. Average TKN and NO_3-N concentrations in surface runoff were 1.14 and 1.83 mg/l

respectively. Surface runoff from forests can be expected to contain more total phosphorus than groundwater drainage.

5. Dry weather groundwater drainage from forests contained relatively high amounts of nitrogen, with average TKN values of 1.17 mg/l and NO_3-N values of 2.20 mg/l.

6. Most of the nitrogen in surface runoff from unfertilized pasture and barren land is in the form of organic nitrogen or ammonia, with concentrations averaging 2.76 mg/l. Average NO_3-N concentrations were about one-half as large.

7. Higher TKN and NO_3-N concentrations can be expected in surface runoff from pasture land than in groundwater drainage. The magnitude of TKN and NO_3-N values generally vary in proportion to rainfall intensity.

8. Significant amounts of phosphorus are removed from pasture and barren land by surface runoff. Total PO_4-P concentrations averaged 0.65 mg/l and tended to vary with rainfall intensity.

9. Dry weather groundwater drainage from agricultural land contains significant concentrations of nitrogen and phosphorus. Average values found during the sampling period were 0.91 mg/l NO_3-N, 0.95 mg/l TKN, and 0.12 mg/l PO_4-P.

10. Fairly high concentrations of nitrogen and phosphorus are present in surface runoff from brush land and

steep highway embankments. The average concentrations found were 0.43 mg/l PO_4-P, 1.54 mg/l NO_3-N, and 2.07 mg/l TKN.

11. Although not as large as those present in surface runoff, nutrient contributions of groundwater drainage originating from brush land and highway slopes are sufficient to stimulate some aquatic plant life. The average concentrations found were 1.22 mg/l NO_3-N, 0.95 mg/l TKN, and 0.13 mg/l PO_4-P.

12. As was the case with pasture land values, phosphorus concentrations from highway embankments and brush land tend to vary with rainfall intensity.

13. Watersheds consisting of agricultural and barren land and highway embankments and brush land experience large soil losses during periods of heavy runoff. Over the 2-month sampling period, an average of 167 lb/acre of SS was lost from watershed number 2 and 137 lb/acre from watershed number 3.

14. An average of over 54 percent of the nitrogen found in groundwater drainage and over 47 percent found in surface runoff from the three watersheds was in the form of NO_3-N. Assuming that all of the nitrogen was originally present as organic nitrogen, much of the organic nitrogen underwent biological decomposition and conversion to soluble NO_3-N.

15. Phosphorus has a tendency to adhere to soil particles and be transported with them in surface runoff,

as illustrated by Figure 5.

16. A strong relationship exists between the concentrations of organic matter and suspended solids in runoff from both watersheds numbers 2 and 3, as shown by Figure 6.

17. Generally, much more TKN per acre and total phosphorus per acre can be expected in runoff from pasture land and highway slopes and brush land than from forests.

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APPENDIX A

Stage Discharge Relationships

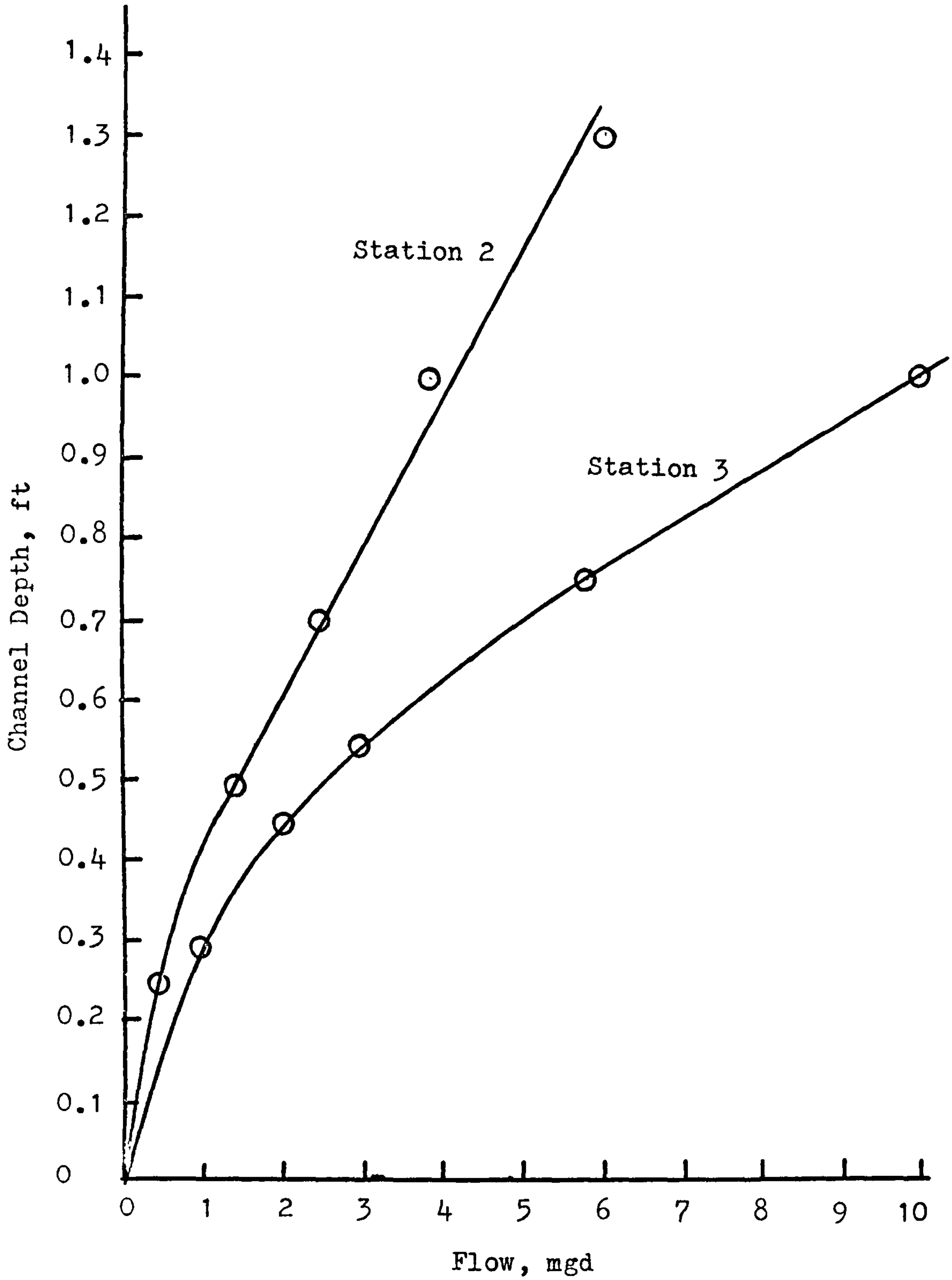

FIGURE A1.--Channel depth vs. flow for stations 2 and 3.

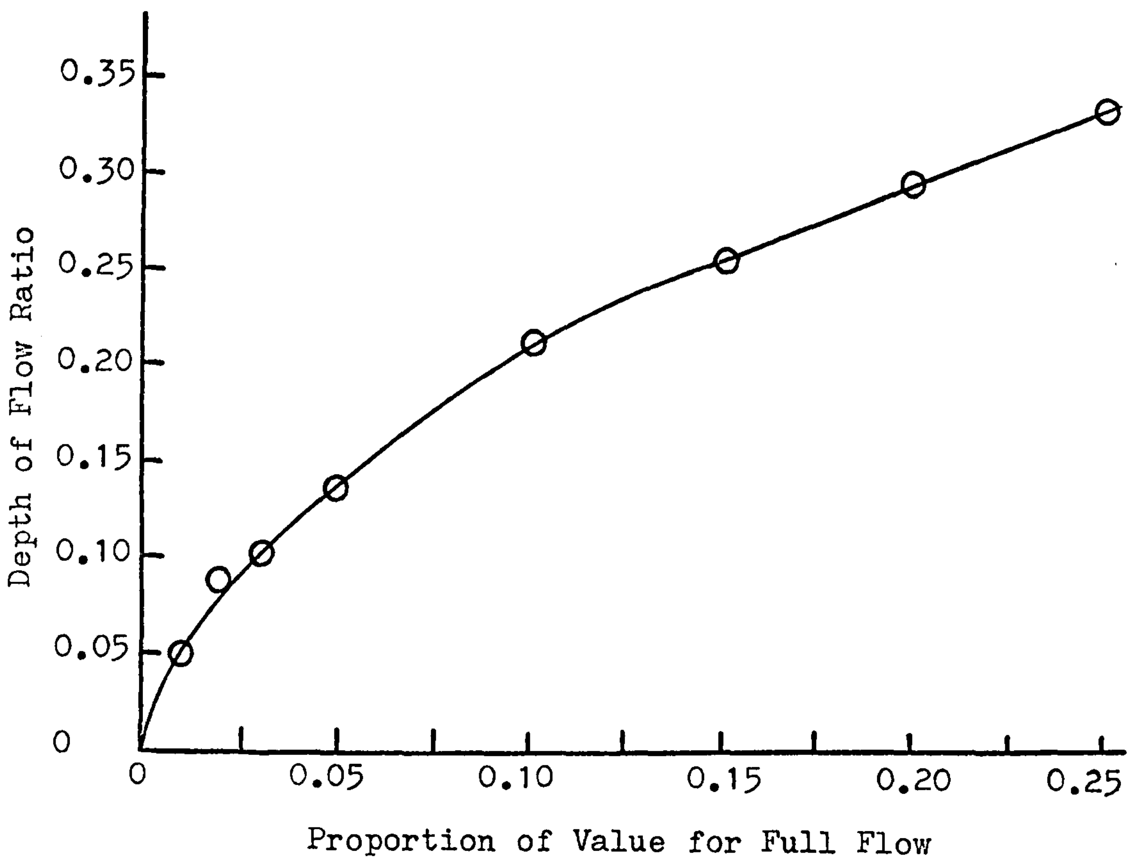

FIGURE A2.--Relative flow in circular pipe for any depth of flow.

APPENDIX B

Storm Hydrographs

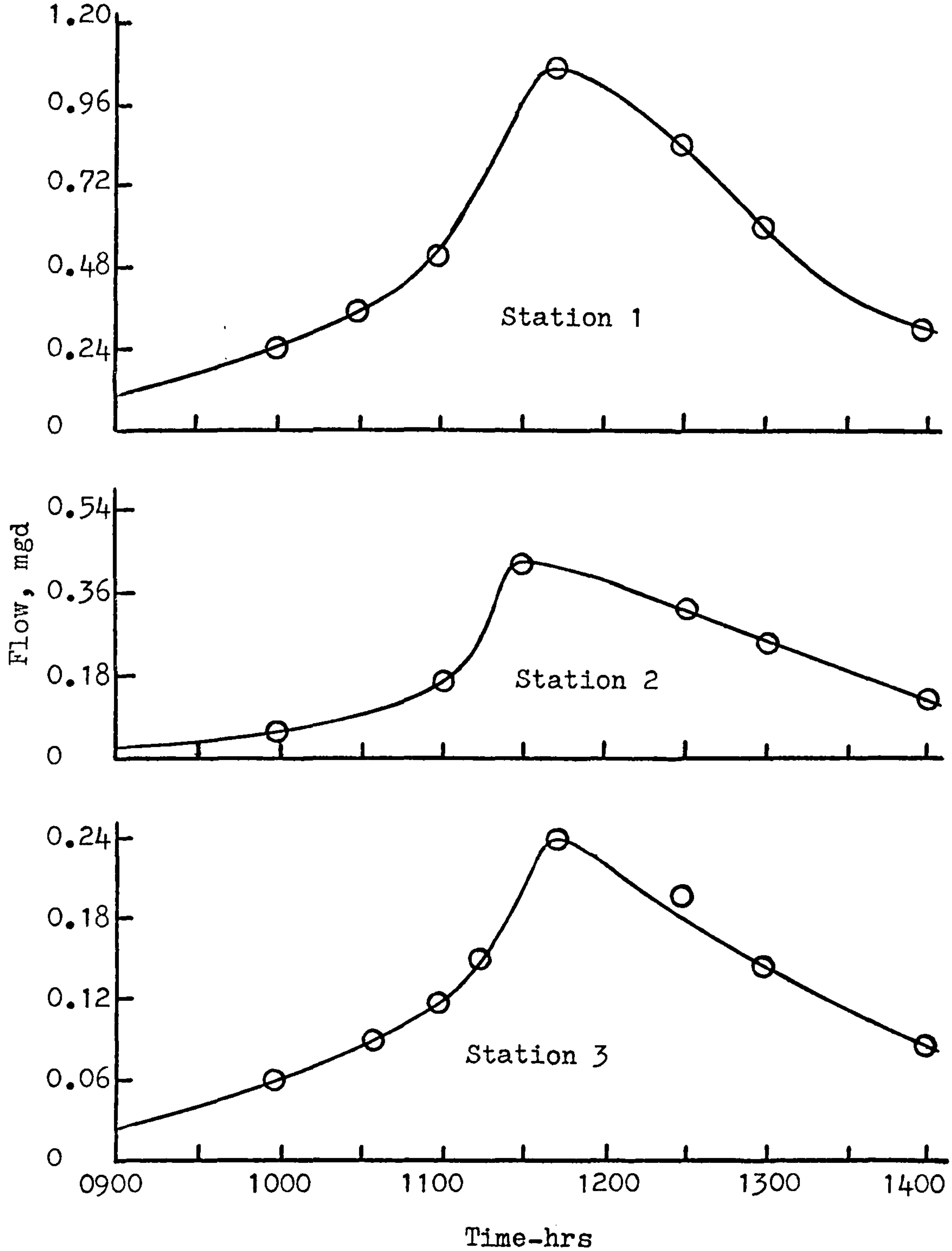

FIGURE B1.--Hydrographs for storm on May 12, 1974.

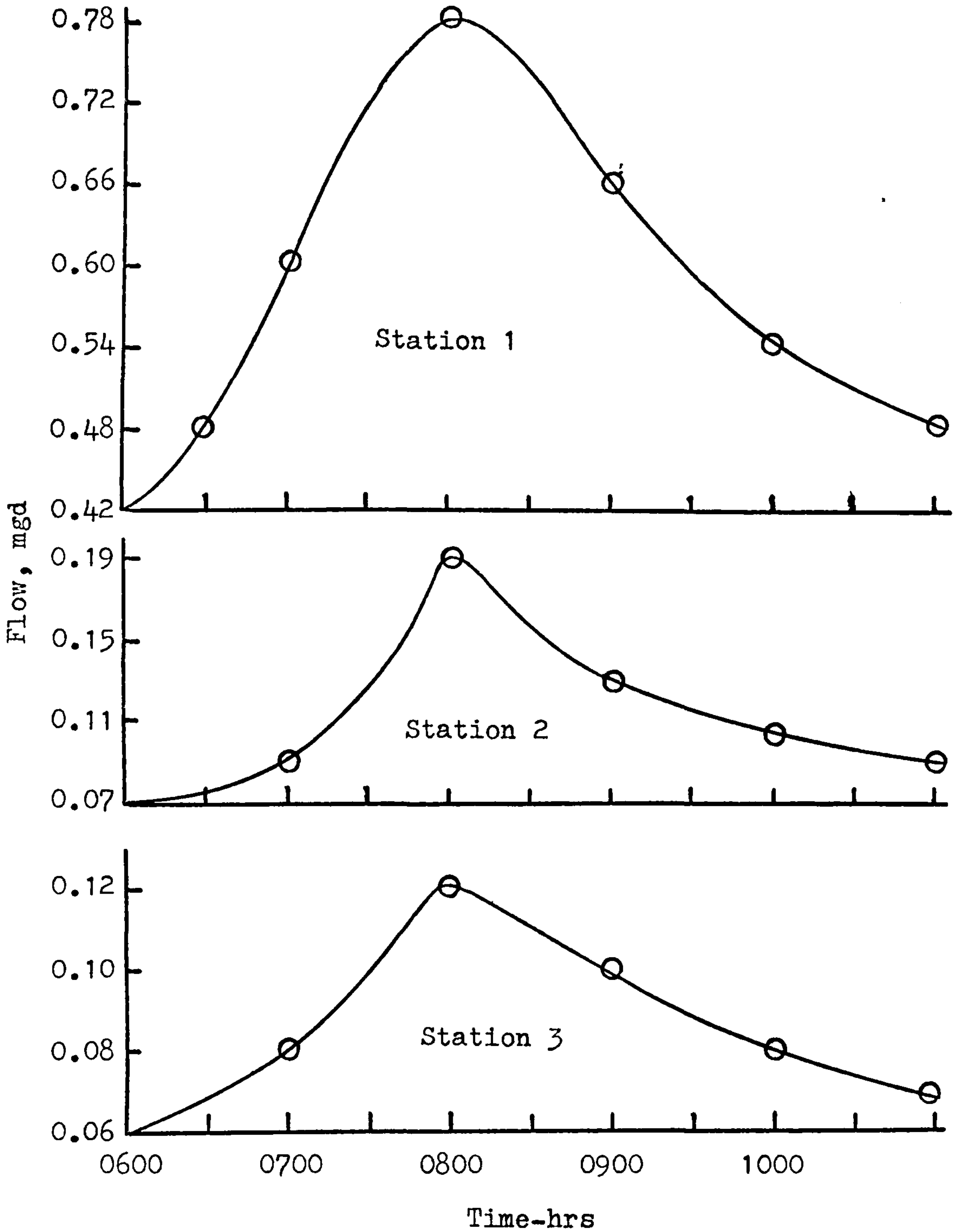

FIGURE B2.--Hydrographs of storm on May 23, 1974.

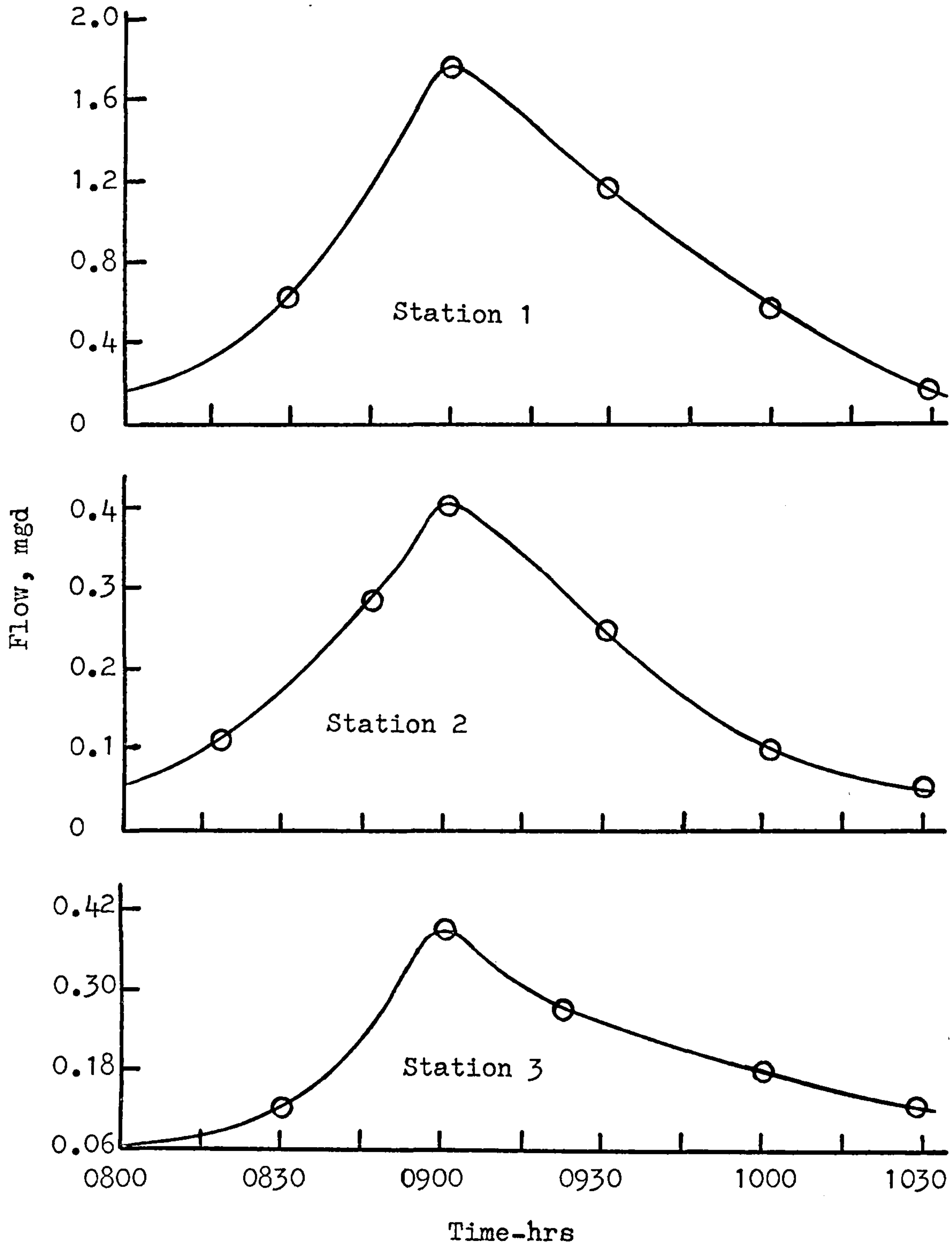

FIGURE B3.--Hydrographs for storm on May 31, 1974.

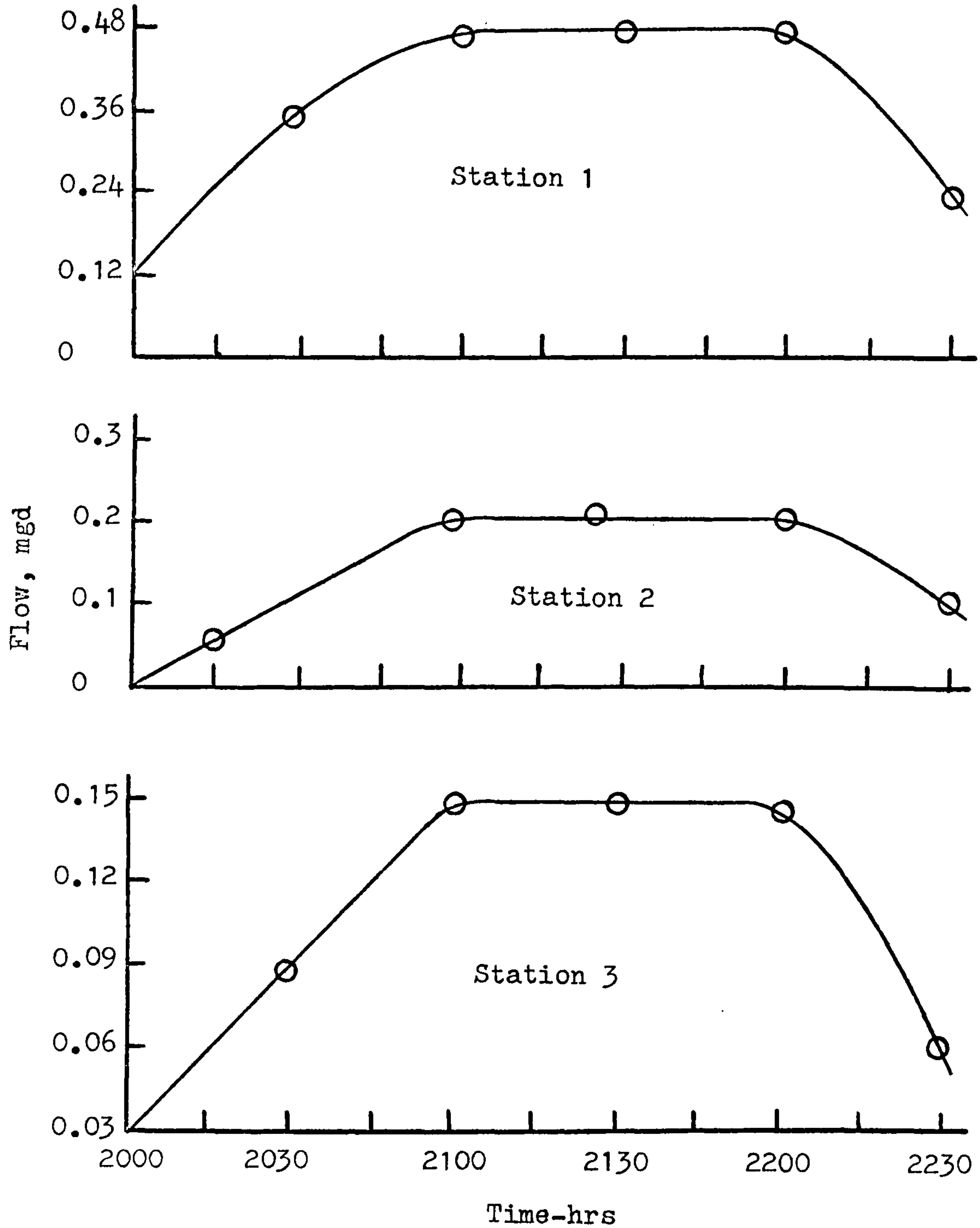

FIGURE B4.--Hydrographs of storm on June 27, 1974.

APPENDIX C

Physical and Chemical Quality Data

Station 1

Area: 140 acres

TABLE CI.--Physical and Chemical Quality of Runoff from Total Drainage Area

	Storm Runoff Samples					Dry Weather Samples			
Characteristic	5-12	5-23	5-31	6-16	6-27	4-18	4-23	5-2	5-5
pH	7.5	7.2	7.3	7.0	7.2	7.5	7.0	7.5	7.4
NO_3-N, mg/l	1.38	1.38	2.38	1.68		1.75	1.68	1.23	1.30
TKN, mg/l	2.5	1.35	2.06	1.5	2.0	0.87	0.73	1.20	1.08
PO_4-P, mg/l	0.65	0.03	0.45	0.44	0.33	0.055	0.035	0.137	0.183
SS, mg/l	248	24	330	300	125	0	0	0	0
COD, mg/l	57	23	80	50	35	27	30	36	37

Station 2

Area: 50 acres

TABLE CII.--Physical and Chemical Quality of Runoff from Watershed No. 2

	Storm Runoff Samples					Dry Weather Samples			
Characteristic	5-12	5-23	5-31	6-16	6-27	4-18	4-23	5-2	5-5
pH	7.1	7.2	7.2	6.9	7.3	7.4	7.1	7.6	7.5
NO_3-N, mg/l	1.20	1.16	2.38	1.68		0.91	0.92	0.95	0.87
TKN, mg/l	3.25	1.66	3.35	3.60	1.92	0.54	0.55	1.28	1.44
PO_4-P, mg/l	1.16	0.094	0.86	0.75	0.40	0.033	0.046	0.188	0.224
SS, mg/l	2238	54	2547	1712	458	0	0	0	0
COD, mg/l	162	29	171	80	48	29	28	35	38

Station 3

Area: 20 acres

TABLE CIII.--Physical and Chemical Quality of Runoff from Watershed No. 3

	Storm Runoff Samples					Dry Weather Samples			
Characteristic	5-12	5-23	5-31	6-16	6-27	4-18	4-23	5-2	5-5
pH	7.9	7.1	7.0	6.9	7.1	7.0	6.9	7.3	7.4
NO_3-N, mg/l	1.10	1.68	1.52	1.87		1.87	0.91	0.79	1.30
TKN, mg/l	2.25	1.75	2.13	1.90	2.33	0.80	0.69	1.11	1.21
PO_4-P, mg/l	0.48	0.07	0.57	0.60	0.43	0.08	0.02	0.17	0.23
SS, mg/l	1280	105	1166	1025	764	0	0	0	0
COD, mg/l	182	37	148	144	105	25	28	41	30

APPENDIX D

Physical and Chemical Quality Data

Expressed as Pounds per Acre

Station 1

Area: 140 acres

TABLE DI.--Physical and Chemical Quality of Runoff from Total Drainage Area

	Storm Runoff Samples*					Dry Weather Samples**			
Characteristic	5-12	5-23	5-31	6-16	6-27	4-18	4-23	5-2	5-5
NO_3-N, lb/acre	0.23	0.08	0.32	0.08		0.013	0.009	0.011	0.013
TKN, lb/acre	0.42	0.08	0.27	0.07	0.11	0.005	0.004	0.011	0.011
PO_4-P, lb/acre	0.11	0.002	0.06	0.02	0.02	0.0003	0.0002	0.0012	0.002
SS, lb/acre	41.5	1.4	43.8	13.6	6.8	0	0	0	0
COD, lb/acre	9.5	1.3	10.6	2.3	1.9	0.16	0.26	0.32	0.37

*Values indicate poundage over storm duration.

**Values indicate poundage per day.

Station 2

Area: 50 acres

TABLE DII.--Physical and Chemical Quality of Runoff from Watershed No. 2

	Storm Runoff Samples*					Dry Weather Samples**			
Characteristic	5-12	5-23	5-31	6-16	6-27	4-18	4-23	5-2	5-5
NO_3-N, lb/acre	0.27	0.06	0.21	0.06		0.005	0.006	0.008	0.012
TKN, lb/acre	0.75	0.09	0.30	0.13	0.12	0.003	0.004	0.011	0.019
PO_4-P, lb/acre	0.27	0.01	0.08	0.03	0.03	0.0002	0.0003	0.0016	0.0030
SS, lb/acre	515.2	2.9	229.4	60.0	29.0	0	0	0	0
COD, lb/acre	37.3	1.5	15.4	2.8	3.0	0.15	0.19	0.29	0.51

*Values indicate poundage over storm duration.

**Values indicate poundage per day.

Station 3

Area: 20 acres

TABLE DIII.--Physical and Chemical Quality of Runoff from Watershed No. 3

	Storm Runoff Samples*					Dry Weather Samples**			
Characteristic	5-12	5-23	5-31	6-16	6-27	4-18	4-23	5-2	5-5
NO_3-N, lb/acre	0.28	0.15	0.26	0.12		0.031	0.013	0.029	0.027
TKN, lb/acre	0.57	0.15	0.36	0.12	0.27	0.013	0.010	0.028	0.025
PO_4-P, lb/acre	0.12	0.01	0.10	0.04	0.05	0.0013	0.0003	0.0045	0.0047
SS, lb/acre	325.5	9.2	199.4	64.1	89.2	0	0	0	0
COD, lb/acre	46.2	3.2	25.3	9.0	12.3	0.42	0.41	1.03	0.63

*Values indicate poundage over storm duration.

**Values indicate poundage per day.

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CHARACTERISTICS OF RUNOFF FROM THREE WATERSHEDS IN MONTGOMERY COUNTY, VIRGINIA

by

Eugene Decker Millar, Jr.

(ABSTRACT)

The project included surface runoff and groundwater drainage measurements in addition to determinations of physical and chemical characteristics from three watersheds located within the same drainage basin in Montgomery County, Virginia.

Watershed number 1 included 80 acres of heavily forested land; number 2 consisted of 50 acres of pasture land and approximately 0.1 acre of barren land; and number 3 included 20 acres of brush land and steep embankments adjoining a paved highway.

The research period covered from March 15 to July 1, 1974. Dry weather groundwater drainage was sampled on four separate occasions. Surface runoff was sampled during five storms. A single composite sample was made from individual samples taken periodically from each watershed.

The amount of rainfall which was present as runoff from watershed number 3 averaged over 85 percent and was much greater than that from the other two watersheds.

Significant concentrations of TKN and NO_3-N were found in both groundwater drainage and surface runoff from all

three watersheds. Steep embankments contributed the largest amount of TKN, NO_3-N, and COD, averaging 0.290, 0.203, and 19.2 lb/acre respectively in surface runoff.

Pasture and barren land contributed the most total phosphorus and suspended matter, with values averaging 0.084 lb/acre PO_4-P and 167 lb/acre SS.