To the Graduate Council:

I am submitting herewith a thesis written by Mark Almon Johnson entitled "Sampling and Analysis of Selected Water Quality Constituents in Agricultural Runoff." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

Curtis H. Shelton

Curtis H. Shelton, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

SAMPLING AND ANALYSIS OF SELECTED WATER QUALITY CONSTITUENTS IN AGRICULTURAL RUNOFF

A Thesis

Presented for the

Master of Science

Degree

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ABSTRACT

Water pollution from point and nonpoint sources has resulted in the passage of two major laws to enforce high quality in effluents leaving these sources. Runoff leaving agricultural land could carry with it readily soluble materials, sediment, nutrients, and other chemicals. When land has been sewage sludge-amended, heavy metals could also be carried away in runoff waters. With sediment as the greatest water pollutant on a volume basis and with recent interest in applying sewage sludges to agricultural lands for renovation, a fuller understanding is needed of the fate of sediment and metals which leave agricultural lands.

This study was divided into two sections: sediment, and metals. The purposes of the sediment section were to determine the representativeness of some techniques used to sample sediment and to develop a method for predicting sediment yield. The purpose of the metals section was to determine metal discharge in the runoff from land amended with municipal sewage sludges. The study was conducted on two watersheds at the Middle Tennessee Agricultural Experiment Station near Spring Hill and two watersheds at the Milan Experiment Station.

One watershed was sewage sludge-amended. Runoff samples were collected from each watershed by an automatic pumping sampler and analyzed for sediment and selected metal concentrations.

Examination of the multiple determinations of sediment concentration in the runoff samples was done to establish justification for replacement with single determinations. Sampling of the entire stream cross-section was examined to establish validity of one point sampling. The runoff rate-weighted method for computation of sediment yield was done to establish justification for replacement with the arithmetic mean method. Data from generating watersheds were used to develop equations to predict sediment yield. Regional, local, and seasonal variations of sediment yield were investigated.

Results indicated that multiple determinations for sediment concentration of the runoff samples must be done. Network sampling of the stream should be employed. The runoff rate-weighted method needs to be utilized to calculate accurately sediment yield. Regional and local variations of sediment yield were significant with watershed differences accounting for these variations. Seasonal variations of sediment yield were significant with differences of cropping and tillage practices and rainfall characteristics accounting for these variations.

Metal concentrations in the sewage sludge were evaluated according to recommended standards. Metal discharges in runoff from one watershed were evaluated within runoff events, for runoff events during each year, and for runoff events throughout the study period. Occurrence of metals in groundwater, corn leaf, and soil from this watershed was investigated.

Concentrations of cadmium and nickel in the sludge frequently exceeded the recommended sludge standards. Cadmium and copper could pose potential threats to runoff and groundwater. There was no increased availability of metals in either corn leaf or the soil in time.

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BACKGROUND AND STATEMENT OF PROBLEM

Water pollution from point and nonpoint sources has resulted in the passage of two major laws dealing with the quality of effluents from these sources. These laws (Public Law 94-580 of 1976 and the Clean Water Act of 1977) require methods to monitor, inspect, and control point and nonpoint sources of pollution, particularly from waste-treated land. Runoff from agricultural land carries with it readily soluble materials, sediment, nutrients, and other chemicals. When land has been sewage sludge-amended, heavy metals could also be carried away in runoff waters. Excess quantities of these constituents could be detrimental to public water supplies, aquatic life, wildlife, and recreational uses. Proper control of runoff and its constituents from agricultural land is essential to the conservation of quality in surface water sources and for compliance with these laws.

Samples of water quality are frequently obtained for purposes of control, regulation, or development of prediction techniques. Regardless of the purpose, satisfactory results are predicated upon reliable data which, in turn, require correct sampling and analysis techniques.

For purposes of this study, the water quality constituents were limited to sediment and selected metals. For the convenience of the reader, this thesis has been divided into two sections: sediment, and selected metals, with emphasis given to the sediment section.

PART I

SEDIMENT

CHAPTER I

INTRODUCTION

On a volume basis, sediment is the greatest water pollutant. About half of all sediment originates on agricultural land; thus, control of sediment is a primary management problem on cropland in the United States (Holt, et al., 1973 and DeCoursey, 1973). The detachment, transport, and deposition of soil particles (sedimentation) is a complex process, and many programs are in progress to study its pollution effects. Despite these many studies, much remains to be understood about the sequential process of sedimentation. This need for understanding is basically due to the discontinuity of the erosion and transportation processes as sediment moves through the overland flow and channel systems (Wolman, 1977).

Since the Public Laws (94-580 of 1976 and the Clean Water Act of 1977) require an understanding of sediment pollution through methods that monitor, inspect, and control sources of pollution, the development of an equation to predict sediment yield leaving agricultural land would help fulfill the requirements of these public laws. Such a prediction equation could indicate the parameters which need to be monitored for inspection and control purposes.

The research objectives of this part of the study dealing with sediment were:

1. To determine the validity of some techniques used to sample sediment; and,

2. To develop a method of predicting sediment yield.

CHAPTER II

REVIEW OF LITERATURE

A. Sediment Sampling

1. Types of sediment

Sediment is transported either as bed-load or suspended-load. Bed-load sediment represents the heavier, coarser particles that settle quickly to the bottom of the stream and roll or slide along the stream bed. This type of sediment does not travel with the same velocity as the water and, therefore, cannot be estimated from the amount trapped in a unit volume of water (Nelson and Benedict, 1951).

Suspended-load is composed of the fine-grained sediment. In general, clay and silt particles are uniformly distributed in a stream cross-section (Nelson and Benedict, 1951). Present erosion-control methods might not control suspended sediment because any water leaving agricultural land would still contain this sediment (Robinson, 1971). This type of sediment can be a real problem since it is usually the bulk of the sediment load.

2. Representative Sampling

For data to be valid, the sample(s) must be representative of the total population. Quality constituents in runoff often vary with time and space; therefore, sampling techniques must be chosen with regard to time and space so that a sample will be representative of the population.

Sampling relative to time means that samples are taken periodically regardless of flow rate. Single samples might not be representative of the stream cross-section at any given sampling time. According to Drechsler and Nemetz (1978), there are three types of sampling - continuous, grab, and composite.

Continuous sampling. This type of sampling is usually preferable because it provides a complete effluent profile of the parameters being measured. However, only a relatively small number of parameters can be monitored continuously. The use of this method could result in an excess of information; whereas, a noncontinuous monitoring procedure might provide sufficient, relevant data at lower cost.

Grab sampling. This type of sampling is less expensive than continuous sampling and requires less time. In grab sampling the assumption is that the instantaneous sample is representative of the effluent both during and between samplings. However, there could be a loss of critical information between samplings. The concentrations between sampling periods could differ quite markedly from those obtained at a given time.

Composite sampling. This type of sampling involves combining a series of individual samples, thus allowing data accumulation over a long period of time. While labor and chemical costs might be reduced with this method, equipment costs might increase. The averaging associated with composite sampling might conceal the existence of a potentially hazardous discharge of short duration. Thus, sampling results might not be representative of the effluent concentration levels in the periods between samples.

Time-oriented sampling is less desirable than flow-oriented (space) sampling because it reduces the representational accuracy of the sample (Drechsler and Nemetz, 1978). Nelson and Benedict (1951) stated that water discharge and sediment concentration vary more rapidly on the rising stage of a hydrograph than on the falling stage. Therefore, it is important for sediment to be sampled more frequently on the rising limb than on the recession limb. Also, the silt-carrying capacity of runoff varies directly with the depth and velocity of runoff (Wischmeier, et al., 1958).

The distribution of sediment in a stream cross-section is an important factor to be considered in conducting a sampling program, especially in the selection of sampling points and in the analysis of the data. Accurate determination of the sediment carried by a stream requires measurement of both the suspended-load and bed-load. Usually, the suspended-load plays a more prominent role than does the bed-load (Nelson and Benedict, 1951). The distribution of sediment in a stream cross-section generally varies more vertically than horizontally. Consequently, greater emphasis should be given to sampling in the vertical direction than in the horizontal direction.

A more complete sampling of the cross-section (network) is more representative of the actual sediment discharge than single samplings if turbulent flow and eddies exist. Vertical network sampling has been variously spaced at the quarter points, at the centroids of equal area, and at the centroids of equal discharge. When sampling has been done on a complete network basis, or periodically checked by such, a single sample may suffice (Nelson and Benedict, 1951).

3. Sampling Equipment

Requirements of an ideal sediment sampler were summarized by Nelson and Benedict (1951) as follows:

1. The velocity within the cutting circle of the intake should be equal to the stream velocity;

2. The intake should be pointed into the approaching flow and should protrude upstream from the zone of disturbance caused by the presence of the sampler; and,

3. The sampler container should be removable and suitable for transportation to the laboratory without loss or spoilage of the contents.

Additional requirements for a sampler given by Nelson and Benedict are:

1. Fill the collector smoothly without sudden inrush or gulping;

2. Permit sampling close to the stream bed;

3. Be streamlined and of sufficient weight to avoid excessive drag;

4. Be rugged and simply constructed to minimize the need for repairs in the field; and,

5. Be as inexpensive as possible, consistent with good design and performance.

Nelson and Benedict (1951) recognized that a sample must be taken from a stream without modifying the velocity of that stream or disturbing adjacent flow lines. Modification of either of these could result in a sample with a concentration different than that of the stream. They stated that, to avoid any disturbing effects due to the presence of the sampler itself, the instrument should be as streamlined as practical. Also, the point of entry of the sampler should be in the form of a nozzle projecting upstream beyond the zone where there is any appreciable disturbance in the flow pattern.

Pumping samplers usually take samples from one point in the stream cross-section. The intake is usually parallel to the stream flow, and the pumping system is operated by a timing device that can be adjusted to take samples at a desired frequency. This type of sampler obtains a time-weighted sample that is accurate for concentrations of fine sands and coarse silts during periods of steady flow. But with sudden or short time changes in stream flow, the concentrations might not be accurate (Witzigman, 1963).

Harris and Keffer (1975) found in their evaluation of automatic wastewater compositors that the apparent characteristics of raw municipal wastewater were highly dependent upon the choice of sampling equipment and technique. They concluded from their study that:

1. Currently available sampling equipment cannot be relied upon to take representative samples;

2. High vacuum samplers produce more representative samples and should be used on raw municipal wastewater and other wastes with sufficient levels of large, heavy suspended material; and,

3. Current sampling equipment and methodologies need to be refined to improve data reproducibility and accuracy.

B. Predicting Sediment Yield

Present methods used to predict sediment yield include empirical equations, bed-load function equations, and simulated-watershed models (Piest, et al., 1975). However, much remains to be understood about the sedimentation process. The following is a review of factors affecting sedimentation.

1. Factors Affecting Sediment Yield

Detachment and movement of soil require energy. The primary forces that detach soil are rainfall impact energy and the shearing effects of water or wind (McGuiness, et al., 1971). Most of the energy for rainfall erosion comes from falling raindrops (Wischmeier, 1962). Wischmeier stated that the quantity of soil eroded from a field depends in large degree upon the kind of rainstorms as well as the extent to which the soil is protected at the time that an erosive storm occurs. The intensity of a rainstorm is more important to soil erosion than the storm's volume. Wischmeier explained that storms of high volume and low intensities cause little erosion, while storms of low volume and high intensities could cause serious erosion. Wischmeier, et al. (1958) found the relationship between rainstorm intensities and kinetic energy to be as follows:

$$Y = 916 + 331 \log (i)$$

where Y = rainfall kinetic energy in foot-tons per acre inch; and,

i = rainfall intensity in inches per hour.

Runoff also plays an important role in the process of sedimentation. The shearing action of running water can detach soil particles (McGuiness, et al., 1971). Runoff water also provides transportation for many of the detached soil particles that would not otherwise move off the land (Wischmeier, et al., 1958). They stated that the velocity attained by runoff water is, among other factors, a function of the water depth and vertical fall. The silt-carrying capacity of runoff increases exponentially with increasing velocity.

Striffler (1963) explained that sediment yield and stream discharge are related. As a stream rises and cuts into its bank, sediment becomes available for transport. As the stream recedes, the decreased energy in the stream is no longer sufficient to cause erosion of the bank or to carry heavy sediment. As a result, sedimentation decreases.

Soils, the primary material of sedimentation, vary in their resistance to erosion, and sediment discharge from watersheds is related to that lack of resistance (Anderson and Wallis, 1963). Wischmeier, et al. (1971) stated that erodibility of soil is a function of its percent silt plus very fine sand, percent sand larger than 0.10 millimeters, organic matter content, structure, and permeability.

According to Maner (1963), when sediment comes only from sheet erosion, the apparent link between channel density and sediment delivery is the distance which low-velocity runoff laden with sediment must travel before concentrating in permanent drainage channels. Channel density is defined as the ratio of the total length of the channel segments to the area drained. Any increase in channel density reduces the possibilities of the deposition of sediment between source and point of delivery. Channel density is, therefore, an efficiency index of sediment delivery.

Land use and condition are important in the sedimentation process. Disturbance of soil increases the erosion hazard tremendously (Schultz, 1972). Grant (1975) found that the losses of soil from tilled land were more than those losses from untilled land.

Land use is especially important because it largely controls the amount of water which runs off the land and that which infiltrates the soil. Land uses that provide continuous vegetative cover on the soil promote infiltration and discourage runoff and, therefore, erosion (Sartz, 1975). According to Guy (1963), the lack of vegetative cover reduces the infiltration rate and causes an increase in runoff. Sixty to 70 percent ground cover is needed effectively to control runoff and erosion due to torrential summer rainstorms (Noble, 1963). If ground cover is not present, runoff and soil losses increase at an extremely rapid rate. The USDA (1978) developed a method to compute ground cover effectiveness, better known as the cropping-management factor.

2. Methods of Predicting Sediment Yield

The universal soil loss equation (USLE) was developed to estimate average annual soil loss from agricultural land. The USLE is expressed:

$$A = RKLSCP$$

where A = average annual soil loss in tons per acre;

R = rainfall factor;

K = soil-erodibility factor;

LS = slope-length and gradient factor;

C = cropping-management factor; and

P = erosion-control practice factor.

Although this equation estimates average annual soil loss, it was not intended to predict sediment yield, which is influenced as well by the transport and deposition of sediment.

Researchers have attempted to develop equations to predict sediment yield on an individual storm basis or short-term basis. Williams (1975) explained that a delivery ratio can be used to modify the USLE to predict sediment yield on a short-term basis. However, he found that substituting a combination of runoff factors (volume of runoff and peak flow rate) for the rainfall factor eliminated the need for a delivery ratio. He found that for 16 small watersheds having montmorrillonite clay soils and two watersheds having silt loam soils, 92 percent of the variation was accounted for in predicting sediment yield. He explained that, although runoff is highly correlated to rainfall energy, it is also affected by antecedent soil moisture. If the soil moisture is low, large energy-producing rainstorms may produce little or no runoff. Without runoff there can be no sediment yield.

Shelton (1977) worked with the USLE variables and other variables that describe climatic and watershed factors. His study indicated that more satisfactory results for predicting sediment yield were obtained using the soil-erodibility and erosion-control factors of the USLE and two variables (runoff volume and drainage density) to account for the transport phase of sedimentation.

According to Simmons (1976), sediment yield was found to be highly related to erosion-index. However, to adapt regression equations to other watersheds, the cropping-management and soil-erodibility factors should be included.

Striffler (1963) found that, for the prediction of sediment yield, a large portion of the total variation was accounted for by stream discharge and whether the discharge rate was increasing or decreasing. Sediment yield was also found to be a function of the eroding banks of the stream.

Anderson and Wallis (1963), in explaining sediment discharge from watersheds, used variables based on two criteria:

1. The variables should be related to sediment discharge; and,

2. They should be expressed in terms applicable to individual land areas within watersheds.

They developed regression equations for the watersheds investigated. Variables used in the equations include percent roads and percent recent cover, as well as more conventional variables such as area, slope, and cover density.

CHAPTER III

PROCEDURE

A. Data Collection and Reduction

This study represents a segment of a watershed hydrology research project initiated in 1965 by the University of Tennessee Agricultural Experiment Station. The study involved collecting and analyzing selected rainfall, runoff, and watershed data from small agricultural watersheds. The nature of the watersheds and their treatments precluded the use of statistical designs involving replications. Consequently, the procedure consisted of determining relationships of sediment yield to selected watershed, rainfall, and runoff parameters. Data for this study were obtained during the period April, 1974 through October, 1979.

1. Watersheds

The study watersheds included two (watersheds 5 and 6) on the Middle Tennessee Agricultural Experiment Station near Spring Hill and two (watersheds 8 and 9) on the Milan Experiment Station in west Tennessee. These sites were chosen because instrumentation was already established for previous research. Also, they are representative of a large portion of agricultural land in middle and west Tennessee. Descriptions of the watersheds and their land use throughout the period of research are given in Tables 32-36 of Appendix A.

The soil-erodibility factor, erosion-control practice factor, and topographic factor were used to describe resistance of soil to erosion, cultivation with regard to slope, and topography conditions, respectively, of the watersheds. Computations for these values are outlined by Wischmeier, et al. (1971) and the USDA (1979). Relief ratios of the watersheds were computed as the difference between the highest elevation and outlet elevation divided by the longest horizontal measurement from the outlet.

The effectiveness of crop cover to control soil erosion has best been described by the cropping-management factor (USDA, 1979). Table 1 contains example data necessary to calculate values of the cropping-management factor for the 1974 growing season on watershed 8. The cropping-management factor (C) for the selected runoff event of May 15, 1974 would be 0.075. When multiple crops exist on the watershed, an area-weighted cropping-management factor should be calculated. For example,

TABLE 1. Data Necessary to Compute Cropping-Management Factors During the 1974 Growing Season Runoff Events on Watershed 8.

		Crop = Cotton (After corn)			
Date (1)	Cropstage* Period (2)	Accumulated Erosion-Index (EI) of Region for Date (3)	EI in Period (4)	Soil Loss Factor (5)	Cropstage** Cropping-Management Factor Values(C) (6)
4/15	F	27	0.06	0.42	0.025
5/1	SB	33	0.11	0.68	0.075
5/10	-	-	-	-	-
6/1	1	44	0.07	0.63	0.044
6/20	2	51	0.08	0.49	0.039
7/20	3	59	0.25	0.44	0.011
10/15	4	84	0.43	1.0	0.430

* F = fallow; and SB = seed bed.

** Column 6 = column 4 x column 5.

if cotton (after corn) with a C-value of 0.075 = 50 percent of watershed area, third year corn with a C-value of 0.074 = 10 percent, and pasture with a C-value of 0.003 = 40 percent; the calculation of the weighted cropping-management factor on May 15 would be as follows:

$$C_{WT} = (0.5 \times 0.075) + (0.1 \times 0.074) + (0.4 \times 0.003)$$

$$= 0.046$$

2. Water Samples

Water samples were obtained with automatic pumping samplers. The sampler intake for each of the watersheds 5, 6, and 8 was approximately 3 m upstream from the gage. Watershed 5 had a sharp crest 90 degree triangular weir. Watersheds 6 and 8 had 2:1 broad crest weirs. For watershed 9, the intake was located approximately 1.3 m upstream from a 1.4 m H-flume. In June, 1977, the flume was replaced by a 2:1 broad crest weir, and the sampler intake was located 3 m upstream from the weir. Each sampler intake was located approximately 1 m from the center of the channel and 6 cm above the elevation of the weir crest.

To facilitate year-round operation and prevent freezing of equipment, the pumping shelter on watershed 9 was heated during the winter months throughout the study period. Beginning in 1976, the sampler shelter on watershed 8 was also heated for winter operation. Operation of the other samplers was discontinued in the winter months.

Water samples were removed within a few hours of each runoff event and stored in a freezer located at the branch stations. At a convenient time, the samples were transported from the station to a laboratory at Knoxville for analysis.

3. Rainfall

Rainfall data were obtained with the use of continuous recording rain gages. These gages were located either on or within 0.4 km of each watershed. The data were read from the line charts and programmed into a digital computer which analyzed depth and time to produce rate of rainfall (inches per hour) and total volume (inches).

Wischmeier, et al. (1958) have shown that rainfall energy and sediment yield are highly correlated to the maximum 30-minute intensity rainfall (I) of a rainstorm. A rainfall-erosion index (R), associated with a rainstorm, was derived by using maximum 30-minute intensity rainfall and total kinetic energy of the storm (Ke). Calculations for the storm indicated in Table 2 are as follows:

TABLE 2.* Sample Data Used for Calculation of Maximum 30-minute Intensity Rainfall and Rainfall-Erosion Index for May 15, 1974 Rainstorm on Watershed 8.

Military Time (hr)	Time Interval (hr)	Rainfall Intensity(i) (in/hr)	Interval Accumulation (in)	Kinetic Energy Associated with the Intensity (ft·ton/ac·in)**	Kinetic Energy times Interval Accumulation (ft·ton/ac)
0.1667	77.4165	0	----	---	---
2.0833	1.9167	0.1565	0.30	650	195
3.2500	1.1667	0	----	---	---
3.4167	0.1665	0.3003	0.05	740	37
4.0000	0.5835	0.2571	0.15	720	108
4.5000	0.5000	0.0600	0.03	500	13
5.3333	0.8333	0	----	---	---
5.4167	0.0833	1.4414	0.12	967	116
5.6667	0.2500	0.6000	0.15	840	126
7.0000	1.3335	0.0750	0.10	540	54
				Σ (Ke) =	651

* Expressed in English units to correspond with equation of Wischmeier, et al. (1958).

** Computed from: kinetic energy = 916 + 331 log i.

1. Maximum depth for a 30-minute duration = (0.12 + 0.15 + (10 min/30 min x 0.1)) in = 0.303 in = 0.770 cm.

2. Maximum 30-minute intensity rainfall (I) = 0.770 cm x 60 min/hr ÷ 30 min = 1.540 cm/hr.

3. The rainfall-erosion index (R = KeI ÷ 100) = 651 ft·ton/ac x 1.540 cm/hr x 0.01 x 0.685 m·t·ac·/ft·ton·ha = 6.867 m·t·cm/ha·hr.

4. Runoff

Runoff was recorded by an automatic continuous water level recorder located at the stream gage of each watershed. Since each watershed was equipped with a precalibrated stream gage, the runoff rate was determined from the stage of water over the gage.

As a sample was extracted, an event marker was activated to mark the time of sampling on the line chart of the water level recorder. The samplers were set to start when the depth of flow reached 6 cm and to take one sample every half-hour as long as the flow equaled or exceeded this depth. Runoff data from the line charts were programmed into a digital computer to analyze stage-time relationships and produce rates (inches per hour) and volume (inches).

5. Sediment yield

Sediment type. Sediment considered in this study was almost entirely the suspended type, since field observations showed that very little bed-load remained in the stream gage approach channels after a runoff event. The soils on the watersheds were basically silt-loams or loamy clays consisting of fine-grained particle sizes.

Sediment laboratory analysis. Sediment concentration was determined in the research laboratory of the Agricultural Engineering Department by gravimetric analysis as outlined by the American Public Health Association (1976). The samples were thawed and continually stirred in order to keep the sediment in suspension. During the stirring operation, 25 milliliters of the sample were pipetted into an evaporation dish and dried at 105 degrees Celsius for 24 hours. The temperature of 105 degrees was chosen to assure drying of the sample without combustion of the organic matter. The difference in weight between the empty dish and the dish-plus-residue was the weight of sediment. Sediment concentration was expressed in milligrams per liter which is approximately equivalent to parts per million.

Three replications of each sample were performed to obtain an average sediment concentration.

Sediment yield analysis. Whenever flow equaled or exceeded 6 cm in depth, a pumping sampler removed a sample from the stream on a half-hour basis. As the samples were drawn, an event marker placed a mark on the runoff hydrograph chart to indicate the time of sampling (Figure 1). The hydrograph was divided into time segments dependent upon the number of sampling events and the complexity of the hydrograph. Whenever the depth of flow fell below 6 cm, as happened between samples 1 and 2, sampling did not take place again until the flow equaled or exceeded this depth.

To compute sediment yield, an integration procedure was followed which utilized the trapezoidal technique, with the runoff rate at the time of sampling assumed to be the average rate. Integral sediment yield was computed through multiplying the average runoff rate by the time segment and by the sediment concentration of the sample. Summation of the integral sediment yields gave the total sediment yield for the runoff event. If either the rising limb or the recession limb had a prolonged segment below the level of activation when no sampling took place, as for sample 6 (Figure 1), sediment yield was still calculated for the entire segment. It

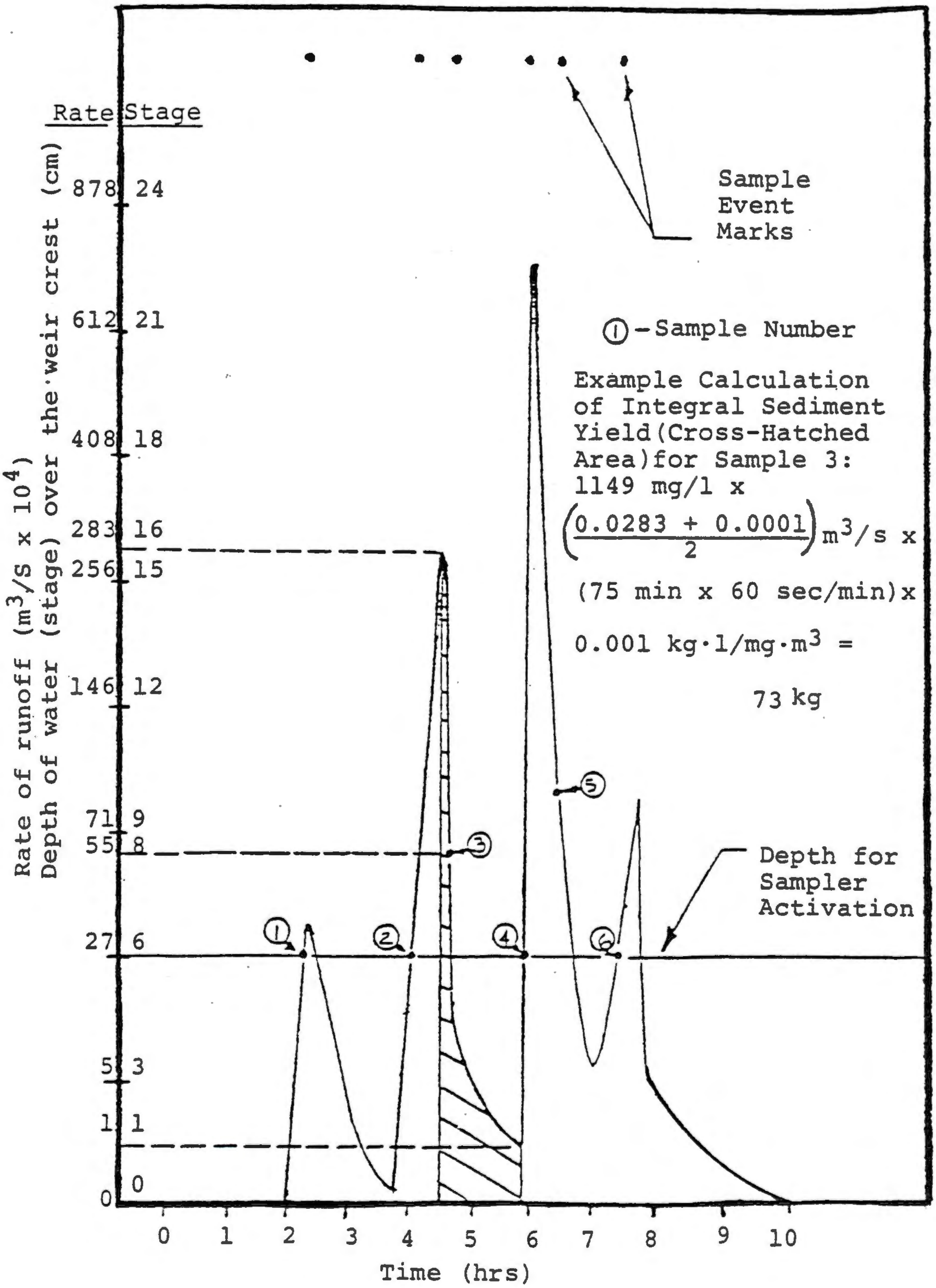

Figure 1. Runoff Hydrograph and Example of Sediment Yield Calculation for the Storm of May 15, 1974 on Watershed 8.

should be noted that for sampling situations similar to that of sample 3 the runoff rate at the time of sampling was not assumed to be the average rate. The figure explains the methodology used to arrive at an average runoff rate. This integration procedure is defined as the runoff rate-weighted method. Data for calculation of sediment yield for the May 15, 1974 runoff event on watershed 8 (Figure 1) are given in Table 3.

B. Single- and Multiple Determinations of Sediment Concentrations

In laboratory analysis, the practice of making multiple determinations of concentrations of a given constituent is sometimes employed. The mean value is taken to be the correct value. This process is time-consuming and expensive. To evaluate the necessity of multiple determinations, the first of three determinations was compared to the mean of the last two determinations by using paired t-tests and procedures outlined in Statistical Analysis Systems (SAS) developed by Barr, et al. (1979). A total of 1193 observations from all the watersheds was compared. An example list of sediment concentrations for the sub-samples can be found in Table 37 of Appendix B.

TABLE 3. Data Used to Calculate Sediment Yield for May 15, 1974 Runoff Event on Watershed 8.

Sample	Sediment Concentration (mg/l)	Average Runoff Rate (m^3/s)	Time Interval (Sec)	Runoff Volume (m^3)	Sediment Yield (kg)*
1	325	0.0014	5400	7.6	2.5
2	661	0.0142	2400	34.1	22.4
3	1149	0.0142	3600	51.1	73.4
4	5004	0.0368	900	33.1	165.7
5	1807	0.0345	3300	122.4	206.0
6	1237	0.0026	10500	27.3	33.3
				Sediment Yield =	503.3 kg

* Sediment yield = sediment concentration x runoff rate x time interval ÷ 1000.

C. Single-Point and Network Sampling for Sediment

Representative and practical sampling requires an adequate number of samples at minimum cost. If a single sampling point could be established as representative of the cross-section, costs could be significantly lowered.

To determine if the single-point sampling used in this study can be considered representative for the stream, a network of sampling points was established in the cross-section of the stream on watershed 9. Figure 2 shows the layout of the network in the cross-section. Grab samples were taken at the indicated points to correspond to the time a sample was drawn automatically (automatic sample). Mean concentrations from the grab samples were compared to the concentrations of the corresponding automatic samples for sediment and orthophosphate-P by using paired t-tests and procedures outlined in SAS. Values for sediment and orthophosphate-P concentrations for grab and automatic samples are given in Tables 38 and 39 of Appendix B.

D. Computations of Sediment Yield Using Arithmetic Mean and Runoff Rate-Weighted Methods

Sediment concentration usually varies throughout a given hydrograph. Thus, depending upon the complexity

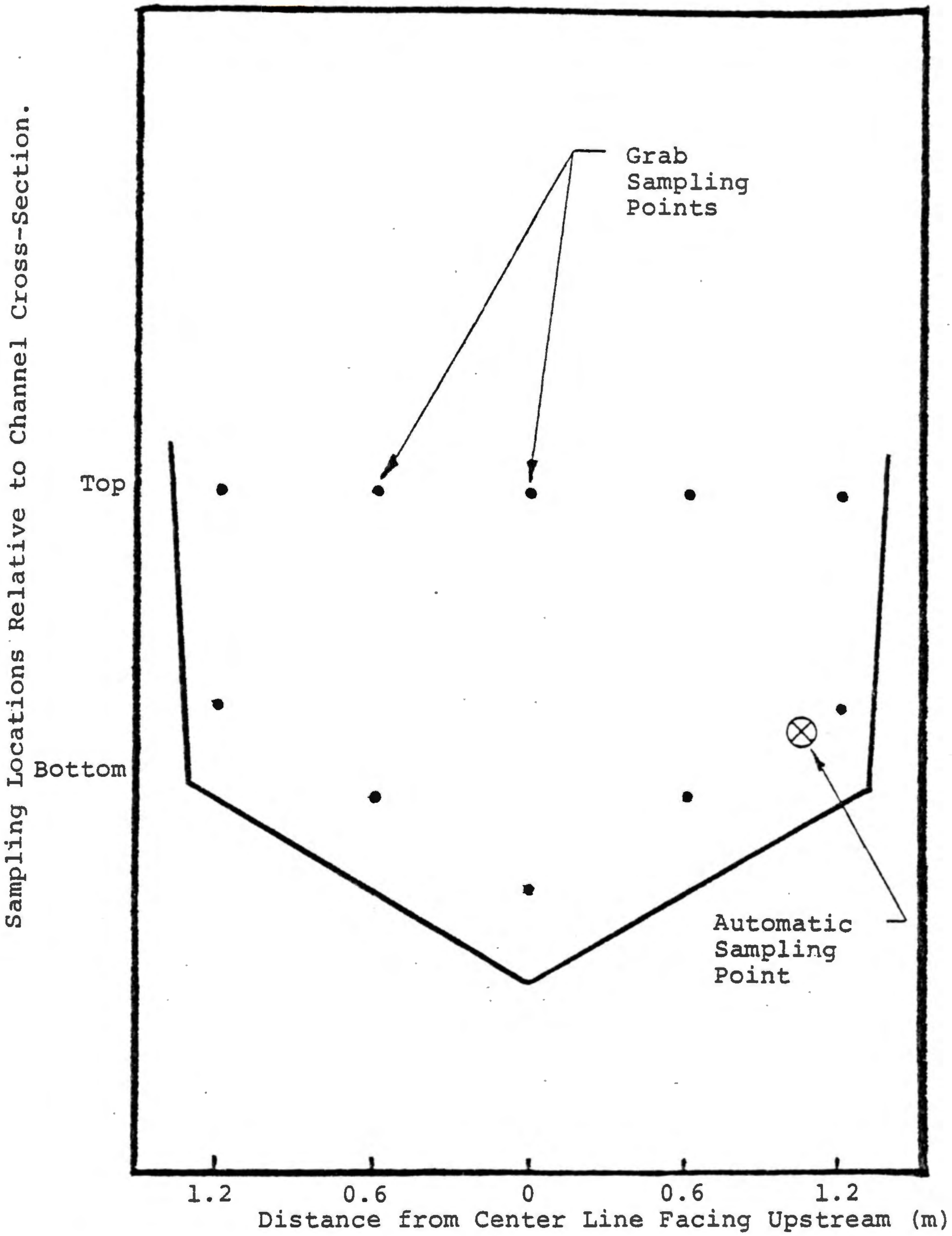

Figure 2. Cross-Section (Network) Sampling Locations on Watershed 9.

of the hydrograph and the variation in sediment concentration, integration of the area under the hydrograph could be expensive and time-consuming. Substantial savings could be realized if the sediment yield for the runoff event could be computed with sufficient accuracy by using the arithmetic mean computation of sediment concentrations instead of the runoff rate-weighted method. To compute sediment yield by the arithmetic mean method, the arithmetic mean of all sediment concentrations associated with a hydrograph is multiplied by the total volume of runoff. Eight events from watershed 5, 19 from watershed 6, 34 from watershed 8, and 25 from watershed 9 were analyzed for sediment yield as computed by both methods. To compare the methods, paired t-tests and procedures outlined in SAS were used. The methods were compared for each of the watersheds. Values computed by the arithmetic mean and runoff rate-weighted methods are listed in Tables 40-43 of Appendix B.

E. Predicting Sediment Yield

As discussed in the literature review, the sedimentation process involves interaction among many complex variables. Regression analysis was used to evaluate the effect of several independent variables acting simultaneously on the dependent variable, sediment. Thus, regression equations could be used to predict relationships between sediment yield and the independent variables on test watersheds.

A complete list of variables used for multiple regression analysis of sediment yield is given in Table 4. Rainfall erosion index (R), soil-erodibility factor (K), topography factor (T), cropping-management factor (C), and the erosion-control practice factor (P) were selected because they constitute the USLE. Maximum 30-minute intensity rainfall (I), H, W, N, and B were used as measures of rainfall characteristics or antecedent moisture conditions. The maximum 5-, 10-, and 25-minute intensity rainfalls (variables E, F, and J, respectively) were selected because the values correspond to time of concentration for the watersheds. Volume (V) and peak flow rate (Q) were chosen because of their close association to sediment yield. Measures of watershed characteristics were represented by variables Z, G, and U. Values for all the variables are given in Tables 44-47 of Appendix B.

Table 5 shows the models used in the regression analyses. Model number 1 is the USLE. Models 2 through

TABLE 4. Variables Used in Analysis of Sediment Yield.

Symbol	Variable Definition	Units
Y	Sediment yield for a single runoff event	kg
R	Rainfall-erosion index for individual storm	m·t·cm/ha·hr
K	Soil-erodibility factor	---
T	Topographic (LS) factor	---
C	Cropping-management factor for runoff event analyzed	---
P	Erosion-control practice factor for runoff event analyzed	---
H	Number of rainstorms in month $\geq$ 1.27 cm	---
W	Rainfall for antecedent month in which runoff occurred	cm
N	Maximum rainfall for the month in the period of record	cm
I	Maximum 30-minute intensity rainfall for runoff event analyzed	cm/hr
E	Maximum 5-minute intensity rainfall for runoff event analyzed	cm/hr
F	Maximum 10-minute intensity rainfall for runoff event analyzed	cm/hr
J	Maximum 25-minute intensity rainfall for runoff event analyzed	cm/hr
V	Volume of runoff for event analyzed	m^3
Q	Peak flow rate during event analyzed	cm/hr
Z	Area of watershed	ha
G	Watershed relief ratio	m/m
U	Total length of channels	m
B	Maximum permeability of the A horizon	cm/hr

TABLE 5. Models Used in Generation of Regression Equations.

Model No.	Model
1	Y = R K T C P
2	Y = R K T C P Q B Z G U
3	Y = R K T C P V B Z G U
4	Y = R K T C P E B Z G U
5	Y = R K T C P F B Z G U
6	Y = R K T C P I B Z G U
7	Y = R K T C P J B Z G U
8	Y = R K T C P H B Z G U
9	Y = R K T C P W B Z G U
10	Y = R K T C P N B Z G U
11	Y = H B Z C P G
12	Y = N B Z C P G
13	Y = W B Z C P G
14	Y = I B Z C P G
15	Y = J B Z C P G
16	Y = E B Z C P G
17	Y = F B Z C P G
18	Y = R B G C P I E G
19	Y = R B G C P J F L
20	Y = H B G C P W N
21	Y = H K T C P
22	Y = N K T C P
23	Y = W T T C P
24	Y = F K Z C B H W N
25	Y = E K G C U H W N
26	Y = T R G N W
27	Y = T E G N W
28	Y = Z R G N W
29	Y = Z E G N W
30	Y = U R G N W
31	Y = U E G N W
32	Y = R K T C P V H N W / Include = 5*
33	Y = R K T C P Q H N W / Include = 5*
34	Y = R K T C P E H N W / Include = 5*
35	Y = R K T C P F H N W / Include = 5*
36	Y = R K T C P I H N W / Include = 5*
37	Y = R K T C P J H N W / Include = 5*
38	Y = R K T C P B H N W / Include = 5*
39	Y = R K T C P U H N W / Include = 5*
40	Y = R K T C P G H N W / Include = 5*
41	Y = R K T C P Z H N W / Include = 5*
42	Y = R K T C P V H W N / Include = 5*

* Forces the first five variables into the equation (not used in the multiplicative regressions).

10 contain the USLE variables to describe detachment and deposition of sediment to the bottom of slope segments, as well as other variables to describe the transport and final deposition of sediment. Models 11 through 31 represent attempts to replace the USLE variables with variables that also describe detachment, transport, and deposition of sediment. Models 32 through 42 forced the USLE variables into these regressions and used other variables to describe the transport and deposition of sediment.

Sediment yield was calculated from a total of 145 runoff-producing rainstorms on the four watersheds during the six-year period, 1974-1979. The number was determined by the availability of runoff hydrographs having complete information relative to time and number of samples. Data obtained from watershed 6 (43 events) and watershed 8 (42 events) were used for the generation of prediction equations, while data from watershed 5 (22 events) and watershed 9 (38 events) were reserved to test the equations. The data from watersheds 8 and 9 were also used to study the variations of sediment yield between dormant and growing seasons.

SAS procedures and the IBM 360/65 computer were used to generate regression equations of the dependent variable on the independent variables. The forms of the equations investigated included:

1. $Y = a + bX + cY + dZ + \ldots$ (Linear)

2. $Y = a + eX^bY^cZ^d \ldots$ (Logarithmic transformation)

3. $Y = m* (XYZ \ldots)$ (Multiplicative)

Selection of the best prediction equations from the regressions was based upon the following:

1. Coefficient of determination (R^2) which indicates that part of the variation about the mean which is explained by the regression equation;

2. Test for significance (5 percent level) of partial regression coefficients after adjusting for joint relationship with variables previously entered into the equation;

3. Rationality and utility; and,

4. Goodness-of-prediction (graphically) on test watershed data.

CHAPTER IV

RESULTS AND DISCUSSION

A. Single- Versus Multiple Determinations of Sediment Concentration

The comparison of single determinations and multiple determinations of sediment concentrations has an R^2 of 0.97, which indicated that the variation about the mean as explained by the regression was good (Table 6). With this good fit of data to the regression line, the line was evaluated to determine if it passed through the origin and had a slope of one. Such an equation would yield a one-to-one (equal value) relationship between predicted and observed values. The equation line did not statistically pass through the origin, nor did the slope statistically equal one. Therefore, single determinations of sediment concentration could not be substituted for the mean of the multiple determinations. Inadequate stirring of samples in the laboratory, however, could have caused the variability in concentrations of sub-samples.

B. Single-Point Versus Network Sampling for Sediment

For the May 3, 1979 runoff event on watershed 9, an R^2 of 0.18 indicated a poor fit of the data to the

TABLE 6. Analysis of Variance Summaries for First Sediment Sub-Sample Versus Mean of the Second and Third Sub-Samples for all Watersheds.

Source	df	Mean Square	F	R^2
Model	1	4,261,922,743	35,265**	0.97
Residual	1191	120,853		

$a = 23.91 \pm 11.11$

$b = 0.93 \pm 0.00$

Ho: $a = 0$; $t_{1,1192} = 2.15$*

Ho: $b = 1$; $t_{1,1192} = 187.79$**

* Significant at the 5 percent level.

** Significant at the 1 percent level.

regression line (Table 7). However, there exists a one-to-one relationship between single sampling and network sampling. Since the data are limited, and there is a poor fit of the data to the regression line, perhaps more data need to be analyzed before utilizing a single sampling of the network.

As a further check of network sampling, the grab and automatic samples were analyzed for orthophosphate-P concentrations. Mean concentrations of the grab samples were compared to corresponding concentrations of the automatic samples (Table 8). The R^2 of only 0.24 indicated a poor fit of the data to the regression line. A one-to-one relationship was found between these methods of sampling. Again, more data need to be analyzed before concluding that single sampling of the cross-section is representative of the network.

Figure 3 shows variations in sediment and orthophosphate-P concentrations throughout the stream cross-section. Note that variations in discharge of the two constituents present different patterns. Therefore, while a single sampling of the cross-section for one constituent might be satisfactory, more samples might be required to represent adequately another constituent.

TABLE 7. Analysis of Variance Summaries for Sediment Concentrations Obtained by Automatic- and Grab Sampling from Watershed 9.

Source	df	Mean Square	F	R^2
Model	1	7,119,670.92	1.13 NS	0.18
Residual	5	31,593,720.80		

a = 491.76 ± 2,357.01

b = 1.61 ± 1.52

Ho: a = 0; $t_{1,6}$=0.21 NS

Ho: b = 1; $t_{1,6}$=1.06 NS

NS Not Significant at the 5 percent level.

TABLE 8. Analysis of Variance Summaries for Orthophosphate-P Concentrations Obtained by Automatic- and Grab Sampling from Watershed 9.

Source	df	Mean Square	F	R^2
Model	1	0.0007	1.28 NS	0.24
Residual	4	0.0006		

$a = 0.05 \pm 0.04$

$b = 0.63 \pm 0.56$

Ho: $a = 0$; $t_{1,5} = 1.23$ NS

Ho: $b = 1$; $t_{1,5} = 0.66$ NS

NS Not Significant at the 5 percent level.

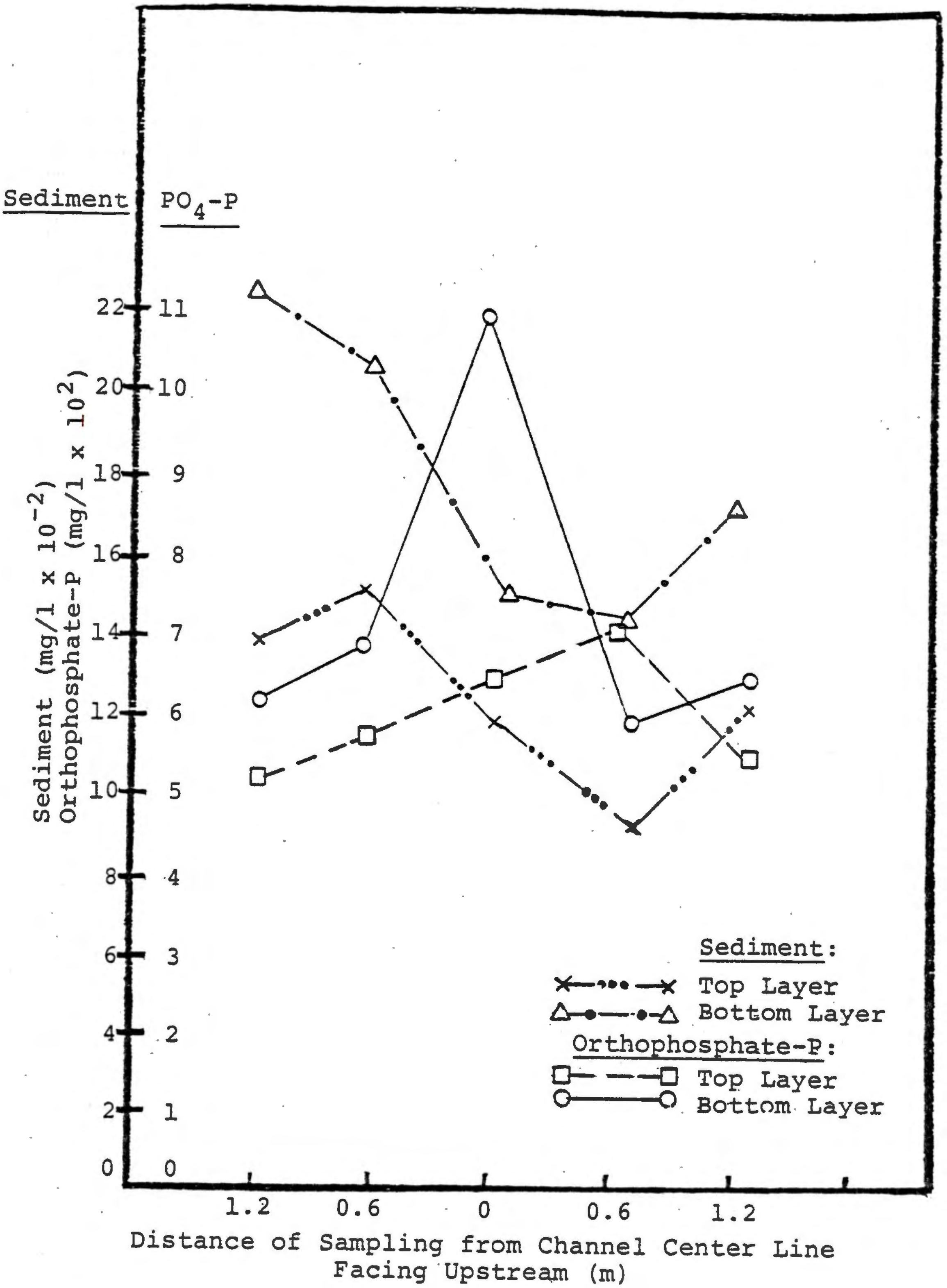

Figure 3. Variation of Mean Concentration of Sediment and Orthophosphate-P at Grab Sampling Points in the Network on Watershed 9.

C. Arithmetic Mean Versus Runoff Rate-Weighted Method Computations of Sediment Yield

The analysis of variance of arithmetic mean and runoff rate-weighted methods of sediment yield computation for watershed 5 (Table 9) indicated a good fit of the data to the regression line. Although this line statistically passed through the origin, the slope differed significantly from one. Thus, the more tedious and costly runoff rate-weighted method should be used to compute sediment yield. Similar results, as for watershed 5, were found for watersheds 6, 8, and 9 (Tables 10, 11, and 12, respectively). Again, the runoff rate-weighted method should be used to compute sediment yield.

D. Predicting Sediment Yield

The combined data from watersheds 6 and 8 were used to develop regression equations to predict sediment yield. From the forms of equations investigated, the best equation developed was:

1) $$\log Y = -1.52 - 0.22 \log R - 3.45 \log K - 0.28 \log C + 1.39 \log P + 1.03 \log V - 0.52 \log H.$$

Although the coefficient of determination is only 0.75, the equation was selected because it included

TABLE 9. Analysis of Variance Summaries: Arithmetic Mean Versus Runoff Rate-Weighted Method of Sediment Yield Calculation for Watershed 5.

Source	df	Mean Square	F	R^2
Model	1	288,228.76	614.75 *	0.99
Residual	6	468.85		

$a = 3.32 \pm 8.54$

$b = 0.88 \pm 0.04$

Ho: $a = 0$; $t_{1,7} = 0.39$ NS

Ho: $b = 0$; $t_{1,7} = 24.79$ *

* Significant at the 1 percent level.

NS Not Significant at the 5 percent level.

TABLE 10. Analysis of Variance Summaries: Arithmetic Mean Versus Runoff Rate-Weighted Method of Sediment Yield Calculation for Watershed 6.

Source	df	Mean Square	F	R^2
Model	1	1,496,266.18	12.25 **	0.41
Residual	17	122,135.15		

a = 222.28 ± 102.05

b = 0.32 ± 0.09

Ho: a = 0; $t_{1,17}$ = 2.18 NS

Ho: b = 1; $t_{1,17}$ = 3.50 *

* Significant at the 5 percent level.

** Significant at the 1 percent level.

NS Not Significant at the 5 percent level.

TABLE 11. Analysis of Variance Summaries: Arithmetic Mean Versus Runoff Rate-Weighted Method of Sediment Yield Calculation for Watershed 8.

Source	df	Mean Square	F	R^2
Model	1	12,621,587.56	90.76 *	0.74
Residual	32	139,072.12		

a = -17.49 ± 73.98

b = 0.82 ± 0.09

Ho: $a = 0$; $t_{1,33} = -0.24$ NS

Ho: $b = 1$; $t_{1,33} = 9.53$ *

* Significant at the 1 percent level.

NS Not Significant at the 5 percent level.

TABLE 12. Analysis of Variance Summaries: Arithmetic Mean Versus Runoff Rate-Weighted Method of Sediment Yield Calculation for Watershed 9.

Source	df	Mean Square	F	R^2
Model	1	31,830,907.09	71.96 *	0.76
Residual	23	442,346.76		

a = 145.34 ± 151.03

b = 0.69 ± 0.008

Ho: a = 0; $t_{1,24}$ = 0.96 NS

Ho: b = 1; $t_{1,24}$ = 8.48 *

* Significant at the 1 percent level.

NS Not significant at the 5 percent level.

four of the five USLE variables. The other two variables (V and H) are reasonable with regard to sediment yield. Soils for the two regions which these watersheds represent differ significantly in their resistance to erosion. Therefore, the high dependence of sediment yield on the soil-erodibility factor as indicated in this equation is logical. The logarithmic relationship among variables is reasonable because, for example, doubling the runoff volume would not normally double the sediment yield if other variables remained constant.

Hydrologic reason would refute the implication that sediment yield would decrease as the rainfall-erosion index (R) or the number of storms per month equal to or greater than 1.27 cm (H) increase. However, for regression equations, the entire equation must be considered in evaluating its performance. Although volume of runoff is not truly independent of the rainfall-erosion index, variable V should be included to help explain the discontinuous nature of sedimentation.

The regression equation developed from data of watersheds 6 and 8 was tested with data of watersheds 5 and 9. Figure 4 shows that the equation generally underpredicted sediment yield for both watersheds. A decision was then made to develop separate equations

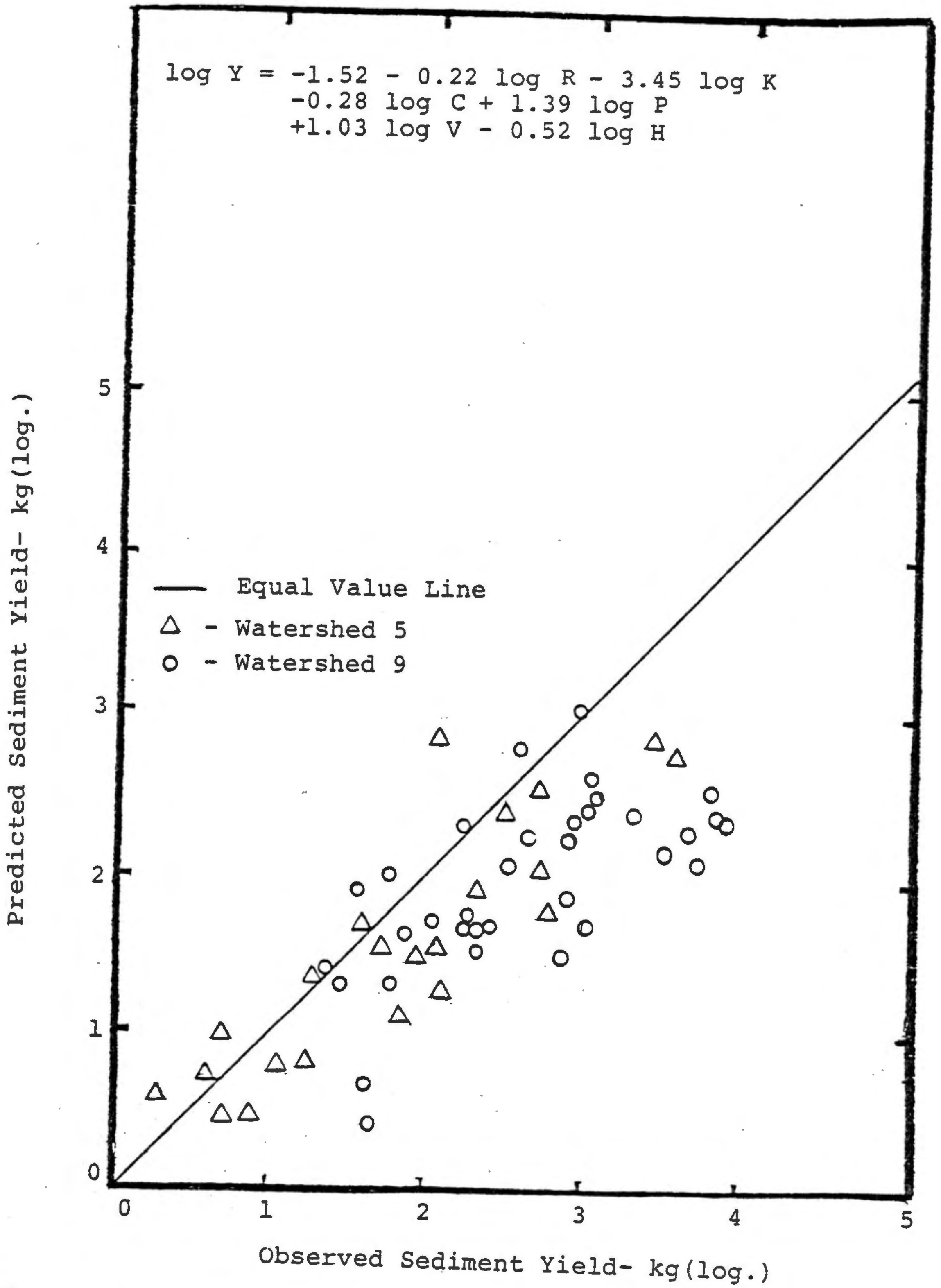

Figure 4. Comparison of Predicted- to Observed Sediment Yield for Watersheds 5 and 9.

for watersheds 6 and 8 because each represented vastly different regions.

The equation selected for watershed 6 was:

2) $Y = 826.17 - 240.30\ J + 6663.65\ Q$

while that selected for watershed 8 was:

3) $\log Y = -0.59 - 0.26 \log C + 0.96 \log V.$

Coefficients of determination for equations 2 and 3 are 0.66 and 0.73, respectively. The negative coefficient of variable J in equation 2 indicated that sediment delivery decreased with increasing intensity of rainfall, which is not hydrologically reasonable. However, the entire equation must be considered to evaluate its performance as a predictor of sediment yield. Equation 3 for watershed 8 is hydrologically reasonable.

Data of watershed 5 were used to test the performance of equation 2 which was developed from data of watershed 6. Figure 5 indicates overprediction of sediment yield; therefore, this equation was considered to be unique to watershed 6. This overprediction of sediment yield was probably due to the differences in land uses for these two watersheds (Tables 33 and 34 of Appendix A), although watershed 5 is a subwatershed of watershed 6. For much of the study period, all of watershed 5 was in hay and pasture, while watershed 6 contained approximately 40 percent pasture with the rest in fallow, row crops, or wheat.

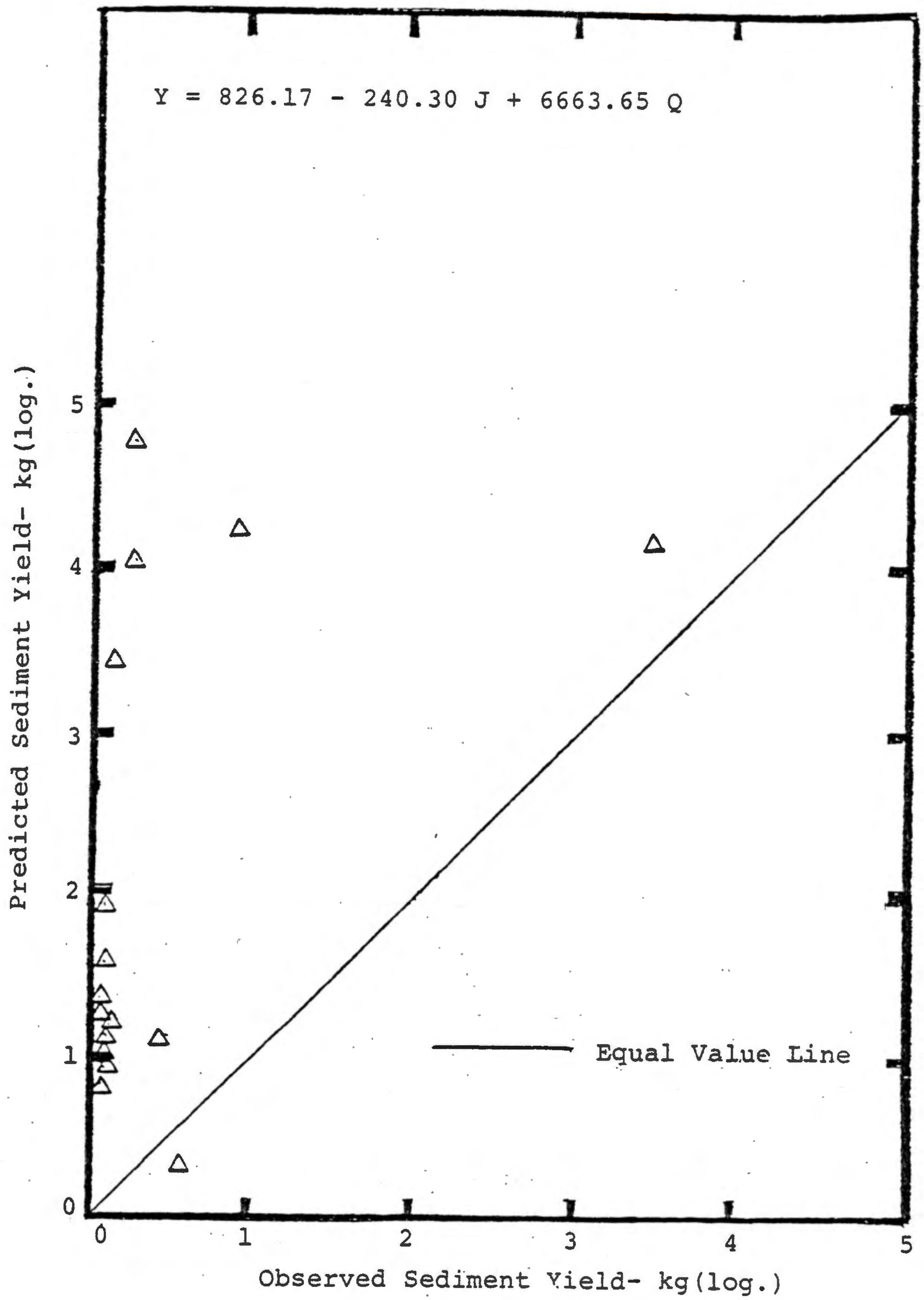

Figure 5. Comparison of Predicted- to Observed Sediment Yield for Watershed 5.

Data of watershed 9 were substituted into equation 3 which was developed from data of watershed 8, and results are shown graphically in Figure 6. The general underprediction of sediment yield could be attributed to the fact that no-till practices were utilized to a greater extent on watershed 8 than on watershed 9.

Since neither equation 2 nor equation 3 adequately predicted sediment yield, and since the coefficients of determination for both equations are low, separate equations were developed for watersheds 5 and 9 (Table 13). Equation 4 of Table 13 shows that sediment yield was a function of R, C, and N on watershed 5. However, the positive coefficient of C is illogical. The dependence of sediment yield on variables R and N, in equation 4, rather than on variable Q as in equation 2, would account for the overprediction of sediment yield using equation 2. The relationship of sediment yield to rainfall-erosion index (R), and its strong relationship to the maximum rainfall for the month in the period of record (N) in equation 4 of watershed 5, are reasonable. Rainstorms of large magnitude and kinetic energy would be necessary to deliver sediment from a watershed which was in hay and pasture for much of the study period. Thus, for a small watershed where significant crop cover

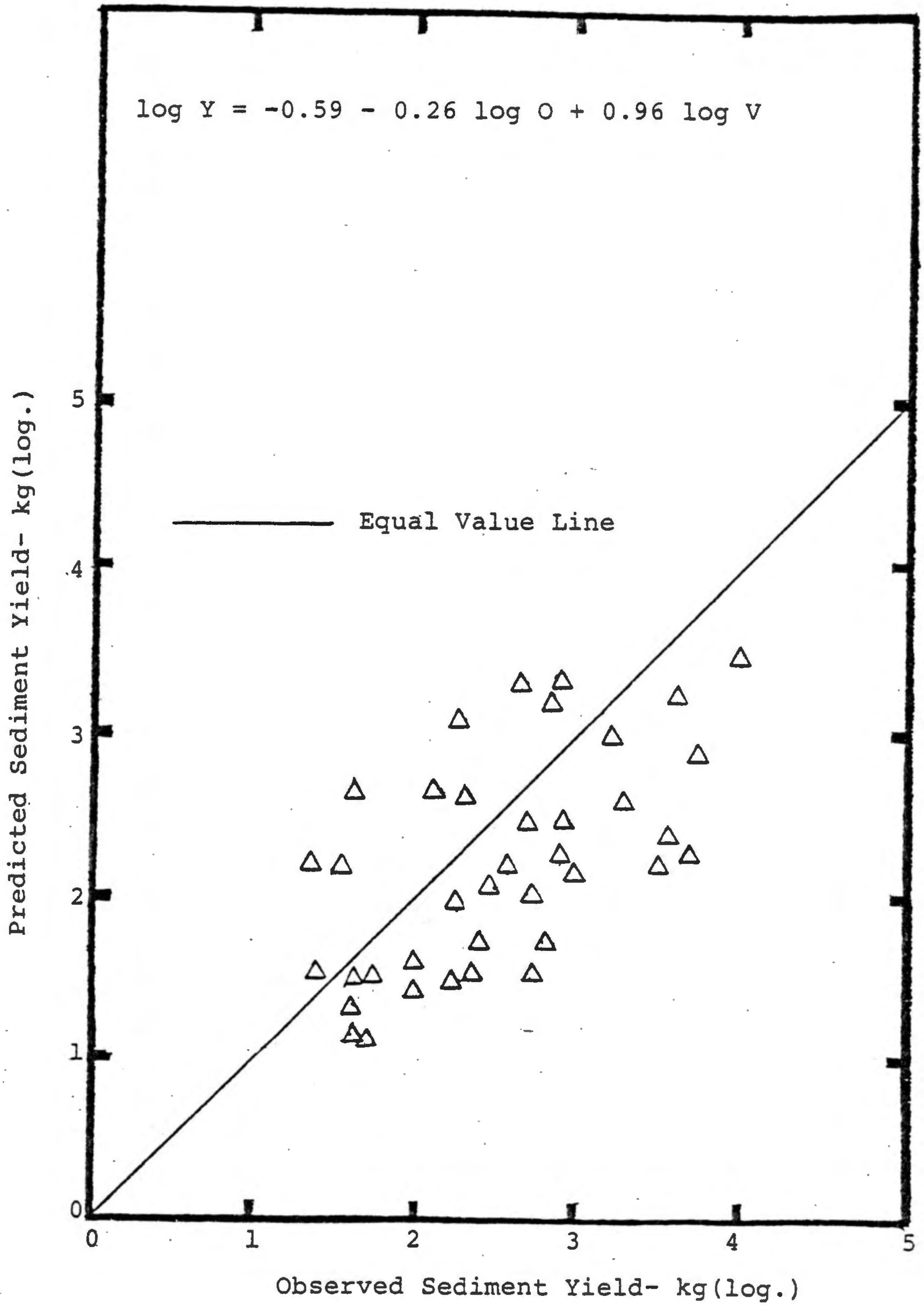

Figure 6. Comparison of Predicted- to Observed Sediment Yield for Watershed 9.

TABLE 13. Equations for Predicting Sediment Yield from Individual Watersheds.

Equation Number	Watershed	Equation
2	6	$Y = 826.17 - 240.30\ J + 6663.65\ Q$
3	8	$\log Y = -0.59 - 0.26 \log C + 0.96 \log V$
4	5	$\log Y = -2.71 + 0.93 \log R + 1.11 \log C + 4.41 \log N$
5	9	$\log Y = 0.11 + 0.21 \log R + 0.24 \log T + 1.62 \log P + 0.82 \log V + 0.72 \log H + 0.49 \log W$

exists, sediment yield would not be expected to be a function of peak flow rate (Q).

Equation 5 of Table 13 shows that, for watershed 9, sediment yield is a function of R, T, P, V, H, and W, and this equation is hydrologically reasonable. Sediment yield in this equation had a somewhat stronger relationship to the erosion-control practice factor (P) than to the other factors. This is logical because conservation practices that were used on the watershed varied with tillage methods.

The fact that the erosion-control practice coefficient is high for watershed 9 is consistent with the dependence of sediment yield on the number of storms equal to or greater than 1.27 cm (H), rainfall for antecedent month in period of record (W), and volume of runoff (V). Thus, before sediment could be effectively delivered from a watershed that contains erosion-control practices, rainstorms of large magnitude, high antecedent moisture conditions, or large volumes of runoff would have to occur. This same reasoning would explain sediment yield as a function of the rainfall-erosion index (R) and topographic factor (T).

Equations 3 and 5 have similarities. While equation 5 for watershed 9 does not present sediment yield as a function of C, topography and erosion-control practices have a strong bearing on selection of crops and cultivation practices which, in turn, influence the cropping-management factor (C). However, the similarities of these equations do not explain the underprediction of sediment yield obtained when the data from watershed 9 were used to test equation 3. Again, differences in tillage practices account for the variations in sediment yield.

A seasonal variation of sediment yield was suspected since cropping and tillage practices, as well as rainfall characteristics, varied between dormant and growing seasons. Growing season data from watershed 8 were subjected to regression analysis, and the best (R^2 = 0.69) equation developed was:

$$6) \quad \log Y = -0.47 - 0.20 \log C + 0.96 \log V.$$

The best (R^2 = 0.76) equation developed with growing season data from watershed 9 was:

$$7) \quad \log Y = -1.01 + 0.44 \log R - 0.32 \log T + 1.92 \log P + 0.74 \log V + 1.61 \log H + 0.87 \log W.$$

Both equations are hydrologically reasonable, since the variables and coefficients are reasonable and logical with regard to sediment yield.

In equations (6) and (7), the dependency of sediment yield on the variables C, V, R, P, H, and W is logical because these variables represent conditions that would vary widely from season to season. However, test data showed that equation 6 slightly overpredicted sediment yield (Figure 7), while equation 7 underpredicted sediment yield (Figure 8) for the dormant seasons on the two watersheds. Equation 6 predicted equally well throughout the range of values. Cropping and tillage practices (Tables 35 and 36, Appendix B), as well as rainfall characteristics, varied significantly for the two seasons on both watersheds and probably accounted for the seasonal variations of sediment yield.

A practical equation to predict sediment yield requires that the variables be hydrologically reasonable and readily obtained. However, if an equation utilizes even one variable which is not easily obtained, use of the entire equation would be questionable. Since measurements of peak flow rate and volume of runoff are not available for ungaged watersheds, some method must be used to estimate them. The literature contains many methods to predict these variables, and Shelton (1975) discussed several such methods. One method used to predict peak flow rate was:

$$q = CiA$$

where q = peak flow rate (cfs);

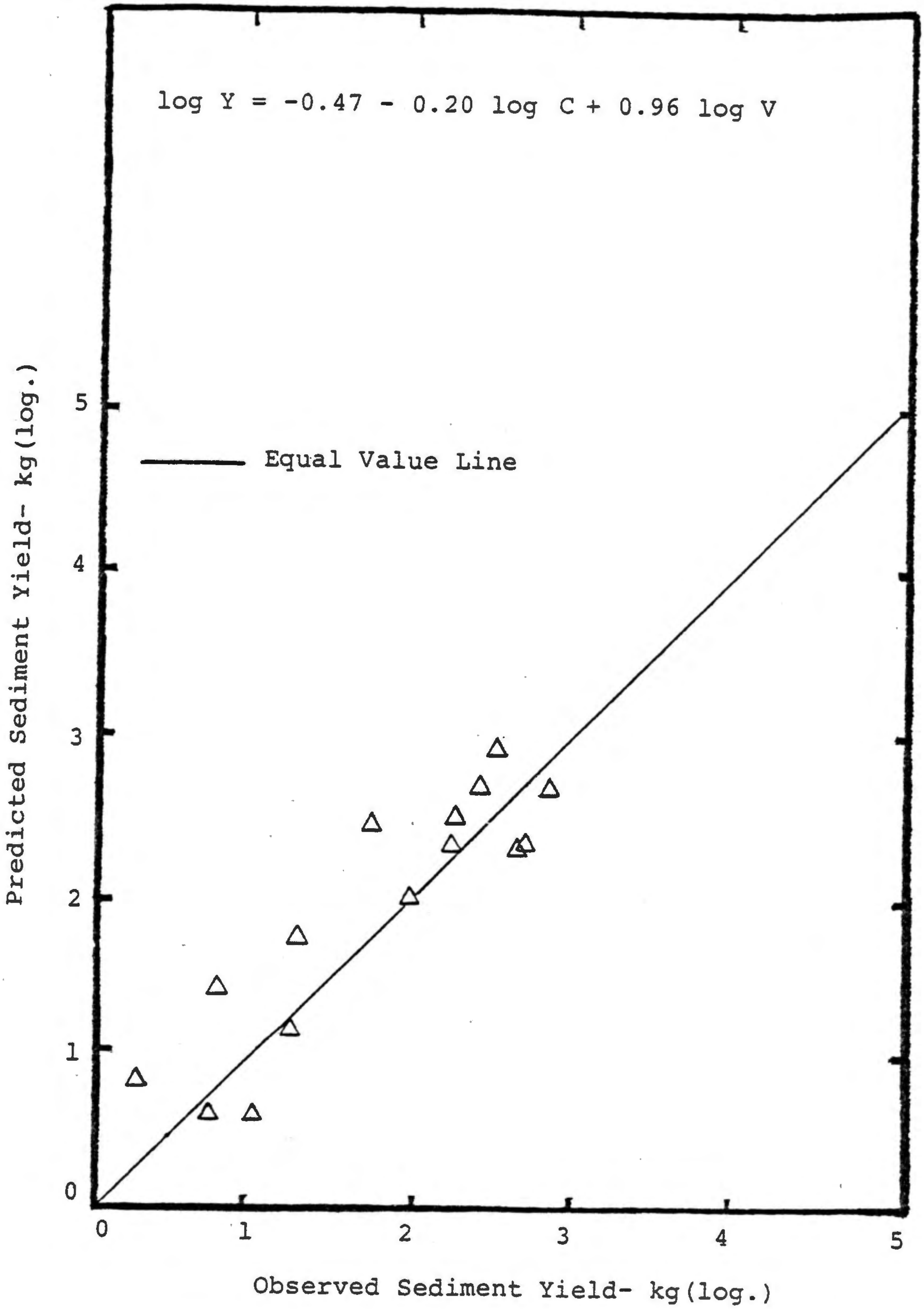

Figure 7. Comparison of Predicted- to Observed Sediment Yield for Dormant Season on Watershed 8.

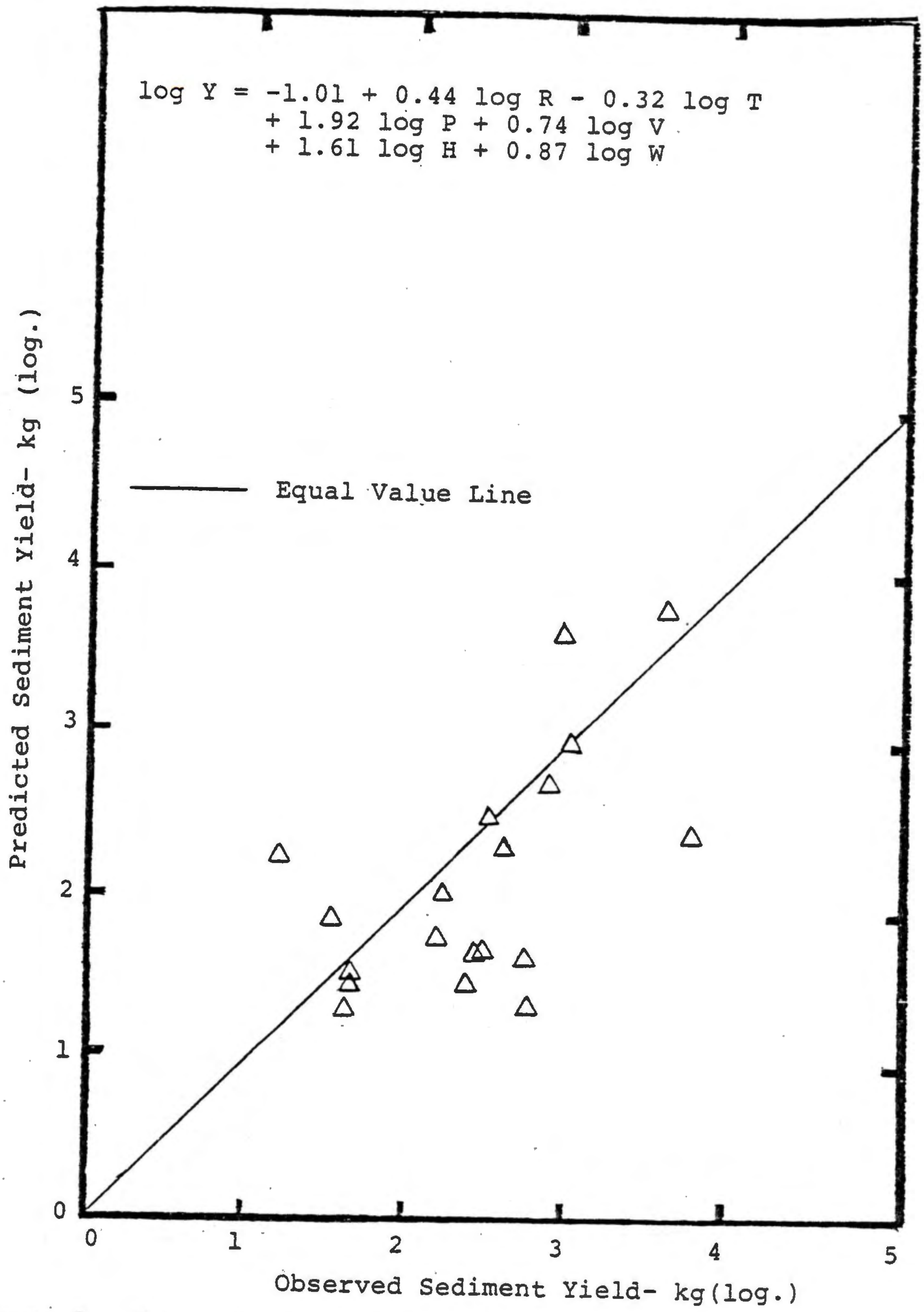

Figure 8. Comparison of Predicted- to Observed Sediment Yield for Dormant Season on Watershed 9.

C = runoff coefficient depending upon infiltration rate, surface cover, storage, and rainfall intensity;

i = rainfall intensity of a design storm with duration equal to time of concentration of the watershed (iph); and,

A = area of watershed (acres).

Explanations of this equation are given by Schwab, et al. (1966). To apply the equation in this study, rainfall intensity (i) was determined for return periods of 3-, 6-, and 12-months. Knowing the area (A), and obtaining C from tables, peak flow rates were computed. Table 48 of Appendix B lists the computed and observed values. Comparison of the computed with the observed values from watershed 6 was done using paired t-tests and procedures outlined in SAS.

Table 14 contains the results of comparing the predicted peak flow rate for a 3-month return period to the observed peak flow rate for watershed 6. The intercept was found to be significantly different from zero, and the slope did not differ significantly from one. The same results were found for the 6- and 12-month periods as shown in Tables 15 and 16, respectively. In every case, there was a poor fit of the data to the regression line.

TABLE 14. Analysis of Variance Summaries for Observed-Versus Calculated Peak Flow Rates for 3-Months Return Period on Watershed 6.

Source	df	Mean Square	F	R^2
Model	1	1.13	3.74 NS	.09
Residual	40	0.30		

A = 3.55

b = 0.40

Ho: a = O; $t_{1,41}$ = 36.91 *

Ho: b = 1; $t_{1,41}$ = 1.93 NS

* Significant at the 5 percent level.

NS Not significant at the 5 percent level.

TABLE 15. Analysis of Variance Summaries for Observed-Versus Calculated Peak Flow Rates for 6-Months Return Period on Watershed 6.

Source	df	Mean Square	F	R^2
Model	1	2.21	3.74 NS	.09
Residual	40	0.59		

A = 4.96

b = 0.56

Ho: a = O; $t_{1,41}$ = 36.90 *

Ho: b = 1; $t_{1,41}$ = 1.93 NS

* Significant at the 5 percent level.

NS Not significant at the 5 percent level.

TABLE 16. Analysis of Variance Summaries for Observed-Versus Calculated Peak Flow Rates for 12-Months Return Period on Watershed 6.

Source	df	Mean Square	F	R^2
Model	1	3.17	3.74 NS	.09
Residual	40	0.85		

a = 5.93

b = 0.67

Ho: a = 0; $t_{1,41}$ = 36.90 *

Ho: b = 1; $t_{1,41}$ = 1.93 NS

* Significant at the 5 percent level.

NS Not significant at the 5 percent level.

Therefore, the calculated peak flow rates could not be used to predict adequately the observed peak flow rates. Thus, equations that utilize peak flow rate as an independent variable would be questionable.

The method used to predict volume of runoff was:

$$V = (P - Ia)^2 / (P - Ia + S)$$

where V = volume (inches);

P = design storm rainfall (inches);

S = maximum potential difference (infiltration) between P and V at the beginning of the storm (inches); and,

Ia = initial abstraction due to interception, surface storage, and infiltration before runoff (inches). Based upon data from small watersheds in various parts of the country, an empirical relationship, Ia = 0.2 S, has been established.

An explanation of this equation is given by Schwab, et al. (1966). Design storm rainfall (P) was based on a return period of one year and a duration of 10-, 30-, and 60-minutes. Upon determining S and utilizing the Ia and S relationship, runoff volumes were computed (Tables 49 and 50, Appendix B). Comparison of the calculated to the observed values from watersheds 8 and 9 was done using paired t-tests and procedures outlined in SAS.

For watershed 8, the comparisons of predicted volumes with observed volumes for durations of 10-, 30-, and 60-minutes are found in Tables 17, 18, and 19, respectively. In each case, the intercept differed significantly from zero, the slope did not differ significantly from one, and a low R^2 indicated a poor fit of the data to the regression line. Therefore, the calculated volumes of runoff could not be used in the prediction equations. Similar results were obtained for watershed 9 (Tables 20, 21, and 22). Thus, equations that utilized volume of runoff as an independent variable would be questionable.

TABLE 17. Analysis of Variance Summaries for Observed-Versus Calculated Volumes of Runoff Values for Storms of 10-Minute Duration on Watershed 8.

Source	df	Mean Square	F	R^2
Model	1	251.52	1.15 NS	.03
Residual	40			

a = 18.14

b = 0.00

Ho: a = 0; $t_{1,41}$ = 6.23 *

Ho: b = 1; $t_{1,41}$ = 1.07 NS

* Significant at the 5 percent level.

NS Not significant at the 5 percent level.

TABLE 18. Analysis of Variance Summaries for Observed-Versus Calculated Volumes of Runoff Values for Storms of 30-Minute Duration on Watershed 8.

Source	df	Mean Square	F	R^2
Model	1	3,250.15	1.91 NS	.05
Residual	40	1,699.19		

a = 123.37

b = 0.02

Ho: a = 0; $t_{1,41}$ = 15.18 *

Ho: b = 1; $t_{1,41}$ = -1.38 NS

* Significant at the 5 percent level.

NS Not significant at the 5 percent level.

TABLE 19. Analysis of Variance Summaries for Observed-Versus Calculated Volumes of Runoff Values for Storms of 60-Minute Duration on Watershed 8.

Source	df	Mean Square	F	R^2
Model	1	40,193.94	1.95 NS	.05
Residual	40	20,564.13		

a = 870.25

b = -0.06

Ho: a = 0; $t_{1,41}$ = 30.79 *

Ho: b = 1; $t_{1,41}$ = -1.40 NS

* Significant at the 5 percent level.

NS Not significant at the 5 percent level.

TABLE 20. Analysis of Variance Summaries for Observed-Versus Calculated Volumes of Runoff Values for Storms of 10-Minute Duration on Watershed 9.

Source	df	Mean Square	F	R^2
Model	1	536.23	0.33 NS	.01
Residual	36	1,605.92		

a = 48.92

b = 0.00

Ho: a = O; $t_{1,37}$ = 6.22 *

Ho: b = 1; $t_{1,37}$ = 0.58 NS

* Significant at the 5 percent level.

NS Not significant at the 5 percent level.

TABLE 21. Analysis of Variance Summaries for Observed-Versus Calculated Volumes of Runoff Values for Storms of 30-Minute Duration on Watershed 9.

Source	df	Mean Square	F	R^2
Model	1	260,543.08	7.54 *	.17
Residual	36	34,537.89		

a = 309.32

b = -0.05

Ho: a = 0; $t_{1,37}$ = 8.48 *

Ho: b = 1; $t_{1,37}$ = -2.75 *

* Significant at the 5 percent level.

TABLE 22. Analysis of Variance Summaries for Observed-Versus Calculated Volumes of Runoff Values for Storms of 60-Minute Duration on Watershed 9.

Source	df	Mean Square	F	R^2
Model	1	5,915,091.28	9.05 *	.20
Residual	36	655,935.18		

a = 2,697.17

b = -0.26

Ho: a = 0; $t_{1,37}$ = 16.98 *

Ho: b = 1; $t_{1,37}$ = -3.00 *

* Significant at the 5 percent level.

CHAPTER V

SUMMARY AND CONCLUSIONS

A. Summary

Concern for water pollution from nonpoint sources has resulted in laws requiring the monitoring and controlling of pollution from these sources. Since sediment in runoff leaving agricultural lands can adversely affect surface water quality, and since the processes of sedimentation are not fully understood, there is a need to monitor sediment discharge. A method that could adequately predict sediment yield would help to fulfill the requirements of these laws.

A runoff-water quality study was conducted to evaluate sampling techniques and to develop an equation to predict sediment yield. Sampling techniques were evaluated for single- versus multiple determinations of water sub-samples for sediment concentration. Single-point sampling of a channel cross-section was compared to a network of sampling points. Arithmetic mean versus runoff rate-weighted method of calculating sediment yield was evaluated.

Runoff samples and measurements of climatic and watershed parameters were collected from four watersheds located in middle and west Tennessee. The samples were analyzed to determine sediment concentrations, and sediment yields were determined. Using data from a total of 145 rainfall-runoff events, regression analyses were performed using sediment yield as the dependent variable and various combinations of climatic and watershed parameters as independent variables.

B. Conclusions

1. Multiple determinations of sediment concentrations and multiple sampling of the stream cross-section should be employed for representative sampling.

2. Sediment yield should be computed by the more tedious runoff rate-weighted method rather than by the arithmetic mean method.

3. Regression equations that were developed to predict sediment yield for both regions of the state and within those regions were unique for each watershed. Watershed differences accounted for variations in sediment yield.

4. Seasonal variations in sediment yield were significant, with cropping and tillage practices and rainfall characteristics accounting for the variations.

5. Attempts to predict peak flow rate and volume of runoff for return periods of a year or less were unsuccessful.

C. Recommendations for Further Study

Sediment yield is computed as a function of volume of runoff and peak flow rate. Therefore, prediction equations presenting sediment yield as a function of volume of runoff or peak flow rate would be biased. Also, equations that have interrelated independent variables would be biased. Thus, independent variables should be selected that have more differences among themselves and with the dependent variable. The study of more watersheds over longer periods of time would help reduce bias in prediction equations.

PART II

METALS

CHAPTER I

INTRODUCTION

Recently, there has been increasing interest in applying municipal sewage sludge to agricultural land as an attractive financial alternative to its disposal by incineration, landfill, or dumpage into waterways (Walker, 1975). Benefits derived from land application of sewage sludges include renovation of the sludge by the soil, and utilization of nutrients, metals, and other chemicals from the sludge. However, increased pollution can occur when sewage sludges are added to land. Anderson (1976) stated that water pollution easily occurs if wastes such as municipal sewage sludges are continuously deposited on agricultural land.

Presently, only guidelines are available for metal concentrations in water discharge. Better information is needed about the occurrence of metals in runoff from land under given management practices. Therefore, the objective of this segment of the study was to determine the discharge of selected metals in the runoff from land amended with municipal sewage sludges.

CHAPTER II

REVIEW OF LITERATURE

Since sediment in runoff water may carry metals absorbed on the sediment particles, factors affecting sedimentation can affect discharge of metals in the runoff (Robinson, 1971). He also explained that, depending on the chemical environment, sediment may absorb or release metal ions into solution. Reactions between chemicals, including metals and colloidal sediment, determine relative concentrations of pollutants in solution and in suspension. However, sediment-free runoff can carry dissolved metals.

Frere (1973) stated that sediment with absorbed chemicals, including metals, will act as a buffer to maintain the concentration of the chemicals in the runoff. He further stated that, as microgullies form from sheet erosion during a storm, chemicals that are spread on the surface are washed away. As the storm continues, an increasingly large fraction of sediment comes from the bottom and sides of the microgullies which have no absorbed chemicals. The result is that the amount of chemical per unit weight of sediment decreases through time. The chemical interactions control the chemical availability, while the behavior of the water controls the timing and amount of chemical movement.

According to Dean (1973), heavy metals applied in sludge are bound in the soil where they are available for plant use but might reach toxic levels. Insoluble minerals are covered by the soil and eventually raise the salt level.

Since the capacity of soils to retain metals is limited, the metals might eventually break through to the groundwater when the metal complexing agents in the sludge decompose (Kirkham, 1975). In general, heavy metals move very little with percolating water and usually remain at the point of application. They might, however, be transported away with eroded sediment, except perhaps in coarse, sandy-textured soils. Therefore, surface water pollution by soil erosion or flooding of the disposal site might occur. Holt, et al. (1973) stated that the risk of surface water pollution from metals is especially high when sludges are applied on lands where no-till practices are used.

Heavy metals usually occur as oxides that are relatively insoluble. If the oxygen supply is low, these oxides lose part of their oxygen and change to more soluble forms. Good drainage and aeration, therefore, are important to keep the solubility low and minimize the danger of heavy-metal toxicity (Holmgren, 1974).

Anderson (1976a), studying the release of metals into solution, found that length of extraction time affected release of metal ions to solution. He stated that the metal ions increase in solubility when reaction time is increased. He found that, at ph 7.0, small differences exist between the relative amounts of metals dissolved in successive extractions, indicating that no definite fraction of the metals can be considered as exchangeable or easily soluble. Anderson also stated that, with the exception of manganese (Mn), metals seem to be gradually extracted due to dissolution of difficult soluble compounds.

Davies, et al. (1969) stated that the extractability of a metal decreases as more of the metal comes into solution. To demonstrate this, they used the equilibrium equation of copper (Cu) and its solubility product equation given, respectively, as:

A) Cu^{++} (solid) + xH^{+} (solution) = Cu^{++} (solution) + xH^{+} (solid)

B) $K = (Cu^{++}\ (\text{solution}))\ ((H^{+})^{x}\ (\text{solid}))/(Cu^{++}\ (\text{solid}))\ ((H^{+})^{x}\ (\text{solution}))$

The equilibrium equation (A) makes no assumptions about the mechanism of binding. In the solubility product equation (B), as total Cu decreases for any value of x, the solubility product decreases. The authors stated that, although calculations from the solubility product equation involve many assumptions, the results strongly suggested that the strength of binding increases as total Cu decreases. The same would be true for any metal substituted for Cu.

Warman and Thomas (1976) suggested that disposal of high rates of organic matter in soil can modify the capacity of a soil to react with metals, as well as the status quo of natural trace elements in the soil. Larson, et al. (1973) explained that organic matter in sludge contains natural chelating agents that might prevent metals from becoming toxic. Therefore, if organic matter is not applied periodically, the chelates might decompose, and metal toxicities might arise.

Results of a study by Warman and Thomas (1976) showed that stage of decomposition of organic matter seems to be important in relation to metal extractability. They found that, as manure decomposed, complexing properties of the organic matter present increased, and cadmium (Cd) was held more strongly. Thus, they concluded that Cd was bound more strongly in the soil which had the most organic matter addition than in those soils of lower or of no organic matter addition.

Mill and Zwarich (1975), investigating soils in Manitoba, compared cultivated-fertilized soils to uncultivated soils. They found no significant differences between the metal contents of the matched cultivated-fertilized and uncultivated fields. These results are attributed to the minimal use of metal-containing agricultural chemicals on cereal crops in Manitoba.

In a study of some soils which had been treated with sludge for 35 years and others saturated with supernatant from sludge-holding lagoons for three years, Kirkham (1975) found that total concentration of the elements in the soils indicated a significant build-up of metals over the years. The build-up of metals for sludge-treated soil was greater than that for supernatant-treated soil, except for aluminum (Al), iron (Fe), and nickel (Ni) in the surface layer. Anderson (1976a) stated that solubility of metals increased when soils were polluted with heavy metals during a 15 year period, indicating that applied amounts were more soluble than native fractions.

Meister, et al. (1979) stated that mercury (Hg) is generally not found in the solute form but rather is strongly attached to a substrate such as soil. They found the source of Hg for an impoundment to be in the soil but could not totally preclude water as a source. They discovered Hg in the soil to be introduced into the food chain through direct uptake by microorganisms rather than by a dissolution process.

Studying wastewater treatment by overland flow, Carlson, et al. (1974) found that the effects of treatment increased with distance from the point of application. Overland flow was thus found to be effective in removing heavy metals. Zinc (Zn) was the most mobile heavy metal in the wastewater. As much as 22.3 percent of the applied Zn remained in the runoff. Lead (Pb) was also more mobile than the other heavy metals, with 8 percent of the applied Pb appearing in the runoff. They found that the largest portions of heavy metals applied in wastewater were fixed within 3 m of the point of application.

Anderson (1976b) stated that the annual input of Cd for agricultural purposes should be kept at or below 1-4 g per ha. He also recommended that phosphorous (P) fertilizers should have no more than 8 mg Cd per gram in order to keep annual input below 4 g per ha. Bodman and Baker (1973) stated that soil and plant monitoring for Cd at three-year intervals or less is required to protect animal and human health when sewage sludge is applied to cropland. They recommended that, for sludges applied at no more than an annual rate of 22.4 t/ha, soil monitoring be conducted at least every three years when the maximum metal concentrations do not exceed those concentrations listed in Table 23. One should be confident that, in addition to the elements listed, industrial sources of Hg or other trace metals are not present in the sludge.

Table 24 shows maximum allowable metal concentrations in sludge which, according to Menzies (1973), can safely be applied to land. This table differs from Bodman and Baker's (Table 23) because the maximum allowable concentration of Cd is presented as a function of Zn concentration. Also, maximum allowable concentrations for Zn, Cu, and Pb are higher while that for Ni is lower.

Limitations relative to the metals listed in Table 24 for effluent discharges to streams have been established by the Tennessee Division of Water Quality Control (1979) and are given in Table 25.

Table 23. Maximum Allowable Metal Concentrations in Municipal Sewage Sludges Applied to Cropland (after Bodman and Baker, 1973).

Metal	Concentration (mg/l)
Zinc	1500
Copper	750
Nickel	150
Cadmium	50
Lead	550
Chromium	550

Table 24. Maximum Allowable Metal Concentrations for a Good Sludge for Land Application (after Menzies, 1973).

Metal	Concentration (mg/l)
Zinc	2000
Copper	800
Nickel	100
Cadmium	0.5% of Zn
Lead	1000
Mercury	15

Table 25. Recommended Daily Maximum Effluent Concentrations of Metals in Discharge to Streams (after Tennessee Division of Water Quality Control, 1979).

Metal	Daily Maximum Concentration (mg/l)
Zinc	2.00
Copper	1.00
Nickel	3.00
Cadmium	0.01
Lead	0.10
Mercury	0.05

CHAPTER III

PROCEDURE

A. Data Collection and Reduction

This segment of the study involved collecting and analyzing selected rainfall, watershed, and other water quality data from a watershed located in west Tennessee. The nature of the watershed and its treatment precluded the use of statistical designs involving replications.

1. Watershed

The study watershed (watershed 8) was located on the Milan Experiment Station in west Tennessee. This site was chosen because instrumentation was already established for previous research. Also, this watershed is representative of a large portion of agricultural land in west Tennessee. Descriptions of the watershed are given in Tables 32-36 of Appendix A.

Starting in the winter of 1976, municipal sewage sludge from Milan, Tennessee, was applied to watershed 8 for three consecutive winters. An average of 24 t/ha/yr (dry wt) sludge with primary sedimentation treatment was applied over the entire watershed, generally from December to April. The sludge was approximately 25 percent solids and was spread in strips which extended across the width of the watershed, beginning at the most remote location from the stream gage. It was immediately disk harrowed and plowed into the soil. When the ground was wet or frozen, the sludge was stockpiled until it could be spread and incorporated into the soil. Although no sludge was applied in the winter of 1979, this period was considered pertinent to evaluation of residual effects of the metals. At the beginning of this study, the soil was slightly acidic with a pH of 6.2. The soil was limed each year during the study period.

2. Water Samples

Water samples were obtained with an automatic pumping sampler. The sampler intake was approximately 3 m upstream from the stream gage which was a 2:1 broad crest weir. The intake was 1 m from the channel center line and 6 cm above the elevation of the weir crest. To facilitate year-round operation and to prevent freezing of equipment, the pumping sampler shelter was heated during the winter months throughout the study period.

Water samples were removed within a few hours of each runoff event and stored in a freezer located at the branch station. At a convenient time, the samples were transported from the station to a laboratory at Knoxville for analysis.

3. Rainfall

Rainfall data were obtained with the use of a continuous recording rain gage located on the watershed. Data were read from the line charts and programmed into a digital computer which analyzed depth and time to produce rate of rainfall (inches per hour) and total volume (inches).

4. Runoff

Runoff was recorded with an automatic continuous water level recorder located at the stream gage. The watershed was equipped with a precalibrated stream gage, and runoff rate was determined from stage of water over the gage.

An event marker was activated to mark the time of sampling on the line chart of the water level recorder whenever a sample was extracted. The pumping sampler was set to start when the depth of flow reached 6 cm and to take a sample every half hour as long as flow exceeded this depth.

Runoff data from line charts were programmed into a digital computer to analyze stage-time relationships and produce rates (inches per hour) and volume (inches).

5. Metals

Menzies's recommendations (Table 24) were used as a basis for selection of metals to be included in the study. These metals are Cd, Cu, Hg, Ni, Pb, and Zn. Concentrations of these selected metals were determined by commercial laboratories utilizing the graphite furnace technique of the atomic adsorption method. Runoff, groundwater, plant, and soil samples were examined for total concentrations of the six metals.

B. Occurrence of Metals in Runoff, Groundwater, Plants, and Soil

Due to the random nature of the data for the metal concentrations, only trends could be evaluated. The composition of sludge was evaluated according to the standards established by Menzies (1973). Trends for metal concentrations within runoff events (extraction periods), runoff events during each year, and runoff events throughout the study period were investigated. Occurrence of metals in groundwater and corn leaf was also investigated. Soil sampled at the 0-30 cm depth was also analyzed for occurrence of metals.

CHAPTER IV

RESULTS AND DISCUSSION

Concentrations of metals in the sludges by month and yearly mean are given in Table 26. The elements Ni and Cd frequently violated the standard established by Menzies (1973). However, the excess of Ni seemed to be tempered in time.

Cadmium is important, because of its interaction effect with Zn. If the Zn concentration in the sludge is low, the Cd concentration of the sludge should fall within 0.5 percent of the Zn concentration. The sludges applied to watershed 8 frequently violated this standard. However, according to values given by Bodman and Baker (Table 23), this sludge could be applied for three years without soil monitoring.

Metal concentrations in runoff within the time of extraction for the runoff events (Table 27) were evaluated to determine trends of extraction. Cadmium, Cu, and Zn generally followed a rising-falling pattern. The low, but initially extractable concentrations indicated a readily available portion. As extraction time continued, the metal concentrations increased, indicating the probability of an easily extractable portion. However,

TABLE 26. Concentrations of Selected Metals in Milan Sewage Sludge after Primary Treatment.

Date	Cd	Cu	Hg	Ni	Pb	Zn
			Metals (mg/l)			
1976						
Jan.	1	40	0.24	90	370	440
Feb.	1	50	0.16	180	280	320
Mar.	2	70	0.14	80	300	350
Apr.	2	60	0.11	100	240	300
$\bar{x}$	1.5	55	0.16	112	298	353
1977						
Dec./76	9	84	0.32	76	1020	266
Feb.	3	57	0.26	19	710	303
Mar.	7	112	0.20	58	759	192
Apr.	3	84	0.28	51	606	198
$\bar{x}$	6	84	0.27	51	774	366
1978						
Jan.	1	48	0.35	93	199	399
Feb.	1	81	0.61	90	105	228
Mar.	2	104	0.68	108	441	673
Apr.	2	105	1.54	103	413	724
$\bar{x}$	1.5	84	0.79	99	290	506

TABLE 27. Metal Concentrations Within Selected Runoff Events (Extraction Periods) from Watershed 8.

Date	Sample	Cd	Cu	Hg**	Ni	Pb	Zn
				(mg/l)			
3/14/78							
	A	0.004	0.1	1	0.1	0.2	0.26
	B	0.007	3.4	1	<0.1	0.1	0.66
	C	0.003	0.2	1	0.1	<0.1	0.27
5/12/78							
	A	<0.001	<0.1	1	0.1	0.3	0.10
	B	0.012	0.2	1	<0.1	0.1	0.56
	C	0.002	<0.1	1	<0.1	0.1	0.20
7/13/78							
	A	<2*	0.2	<10	0.3	<0.2	0.40
	B	<2*	0.2	<10	<0.1	<0.2	0.18
	C	7*	0.4	<10	0.1	<0.2	0.69
	D	<2*	0.2	<10	0.3	<0.2	0.22
	E	<2*	0.1	<10	0.1	<0.2	0.33
	F	6*	0.1	<10	<0.1	<0.2	0.30
	G	2*	0.2	<10	<0.1	<0.2	0.27

* = ug/l.

** Minimum values vary according to sensitivity of laboratory equipment.

the concentrations declined after continued extraction, and a period of gradual extraction occurred. This indicated that, after the readily available and easily extractable portions were washed away, there was a more complexed portion that was gradually extracted. The readily available portions that were initially washed away were probably available from previous extraction periods, had not recomplexed, and were not washed away during the prior event. Also, availability of these portions could have been due to breakdowns of the complexed portions between extraction periods.

Lead became decreasingly available throughout the extraction period. This indicated that the metal had either no readily available or easily extractable portions and was somewhat complexed. Thus, as it was extracted, the remaining portions were less readily available. The sensitivity of measurements for Hg and Ni concentrations was not sufficiently low to permit determination of the trends for these elements within extraction periods.

Due to the expense of determining metal concentrations in runoff water samples, only a limited number of samples were collected and analyzed. To relate the metal extraction periods to such parameters as length of extraction, volume of runoff, or rainfall-runoff ratio would be beyond the scope of the limited data.

Concentrations of the selected metals in runoff within a yearly period are shown in Table 28. The metal concentrations during the colder months of the year were generally lower. Due to limited sensitivity of measurements used by the laboratories, nothing could be concluded about the occurrence of Hg, Ni, or Pb concentrations within any one of the four years.

The metal concentrations were somewhat higher during the period of land preparation when the soil was more vulnerable to erosion. The relatively high concentrations for the March 5 and March 29 events of 1976 would be attributed to the runoff events occurring shortly after an application of sludge to the watershed when it was fallow. This was particularly true for the March 29 event when runoff rate was high. After applications of sewage sludge were terminated each year, concentrations of metals in runoff tended to decrease throughout the year.

Metal concentrations throughout the study period (Table 28) indicate need for concern about metal discharge to the water resource. Cadmium concentrations frequently violated effluent limitations of 0.01 mg/l established by the Tennessee Division of Water Quality

TABLE 28. Metal Concentrations in Runoff from Watershed 8 on Selected Dates.

Date	Cd	Cu	Hg	Ni	Pb*	Zn
			(mg/l)			
1976						
2/ 17	0.005	<0.1	<0.5	<0.2	<1	0.16
2/ 21	0.008	<0.1	<0.5	<0.2	36	0.18
3/ 5	0.031	0.2	<0.5	<0.2	<1	0.46
3/ 8	0.003	<0.1	<0.5	<0.2	<1	0.14
8/ 9	0.005	<0.1	<0.5	<0.2	<1	0.62
3/ 26	0.005	<0.1	<0.5	<0.2	<1	0.24
3/ 29	0.015	<0.1	<0.5	<0.2	<1	0.78
4/ 24	0.003	<0.1	<3.5	<0.2	3	0.48
5/ 14	0.030	<0.1	<0.5	<0.2	<1	0.19
5/ 15	0.002	<0.1	<0.5	<0.2	<1	0.19
5/ 18	0.002	<0.1	<0.5	<0.2	<1	0.17
5/ 28	0.008	<0.1	<0.5	<0.2	<1	0.14
6/ 2	0.002	<0.1	<0.5	<0.2	<1	0.19
1977						
9/ 24	< 2*	0.3	<10	0.2	<0.2	0.22
9/ 25	< 2*	0.1	<10	0.1	<0.2	0.08
11/30	< 2*	0.1	<10	0.1	<0.2	0.15
12/ 5	< 2*	0.2	<10	0.1	<0.2	0.15
1978						
12/ 9/ 77	0.003	<0.1	1	<0.1	14	0.23
1/ 9	0.072	0.1	1	<0.1	<0.1	0.20
3/ 14	0.004	1.0	1	0.1	0.1	0.36
5/ 8	0.019	0.3	1	2.5	0.3	1.65
5/ 12	0.004	0.1	1	<0.1	0.1	0.62
6/ 21	< 2*	0.5	<10	0.6	<0.2	0.75
6/ 22	< 2*	0.3	<10	0.6	<0.2	0.52
7/ 13	< 2*	0.2	<10	0.1	<0.2	0.30
1979						
12/ 4/ 78	0.002	3.3	<1	<0.1	0.0	0.08
4/ 2	0.002	3.3	<1	<0.1	0.0	0.08

* = ug/l.

** Minimum values vary according to sensitivity of laboratory equipment.

Control (Table 25). This could be a threat to surface water sources. However, the availability of Cd to runoff did not increase during the study period.

Copper seemed to become increasingly available during the years of sludge application. However, the concentrations of Cu in the sludges for the second and third year were higher than the first year and could account for much of the increased availability.

The importance of Cu as a pollutant to surface waters occurred during the residue year of the study (1979) when no sludge was applied. The availability of Cu to runoff during this period increased significantly, indicating that, as time continued, agents complexing Cu must break down, and the element became more readily available for extraction. This increased availability could not be attributed to the land preparation period because this increased availability was evident in December of 1978, when there was no land preparation. These high concentrations of Cu violated the effluent limitation of 1.00 mg/l set by the Tennessee Division of Water Quality Control (Table 25) and could have adversely affected the stream into which the runoff flowed.

Although the Zn concentration in runoff was higher in the third year than in the first year, the input during the third year was much higher than that of the first year. Due to the sensitivity of measurement limitations, nothing could be concluded for the occurrence of Hg, Ni, and Pb throughout the study period.

Concentrations of metals found in the groundwater (Table 29) indicate that Cd and Cu increased significantly during the residual year over the last year of sludge application. These metals posed a potential threat to groundwater because their concentrations violated the effluent limitations set by the Tennessee Division of Water Quality Control. Neither Hg, Ni, Pb, nor Zn showed increased availability to the groundwater.

Corn leaf data (Table 30) indicated no increased availability to the leaf for the third year of sludge application over that for the first year. Although Zn concentration was higher for the third year than the first, input of Zn was also higher for the third year than for the first year. Therefore, no conclusion could be made as to whether the higher Zn concentration in the corn leaf was from the accumulative effects of Zn in the soil or from the applied amounts in the sludge for the third year. Metal concentrations in the 0-30 cm depth of soil (Table 31) did not increase in time.

TABLE 29. Concentrations of Selected Metals in Groundwater of Watershed 8.

Date	Cd*	Cu	Hg*	Ni	Pb	Zn
			(mg/l)			
1978	<2	0.31	<10	0.16	<0.2	0.72
1979	12	3.4	< 1	<0.10	0.2	0.89

* = ug/l.

TABLE 30. Metal Concentrations in Corn Leaf from Watershed 8.

Date	Cd	Cu	Hg	Ni	Pb	Zn
			(mg/l)			
1976	<1	15	0.11	2	9	74
1978	<1	9	<0.05	2	<2	136

TABLE 31. Metal Concentrations in the Soil of Watershed 8.

Date	Cd	Cu	Hg	Ni	Pb	Zn
			(mg/l)			
1976	<1	17	0.13	8	15	-
1977	<4	19	<0.10	30	<20	54
1978	<4	18	<0.10	20	<20	75

CHAPTER V

SUMMARY AND CONCLUSIONS

A. Summary

Concern for water pollution from nonpoint sources has resulted in laws requiring methods to monitor and control pollution from these sources, particularly from lands treated with wastes. With the recent interest in applying sewage sludges to agricultural land, better information is needed about occurrence of metals in runoff under given land management practices.

A water quality study of a watershed amended with sewage sludge was conducted to determine occurrence of selected metal concentrations in runoff waters, groundwaters, plants, and soil. The runoff data were evaluated for pattern of discharge within a runoff event (extraction period), within a year, and throughout the study period. The metal concentrations were also evaluated for increased availability to groundwaters, in plants, and in the soil.

B. Conclusions

1. Cadmium and Ni concentrations frequently exceeded Menzies's (1973) standards for metal

concentrations in sewage sludges renovated by land treatment.

2. Cadmium in runoff frequently exceeded effluent limitations and posed a potential threat to both runoff and groundwater.

3. Copper increased in availability to runoff and groundwater during the residual year and posed potential threats to these water sources.

4. There was no increase of metal concentrations in corn leaf or soil in time.

C. Recommendations for Further Study

Since the data pertaining to metals were limited in this study, perhaps a more complete monitoring could lead to a mass balance analysis involving the use of rate-time relationships of metal concentrations (metal yield). Such a mass balance could significantly enhance a study of the fate of metals applied to agricultural lands.

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APPENDICES

APPENDIX A

Watershed Description

TABLE 32. Description of Watersheds.

Watershed	Location	Physiographic Province	Area (ha)	Average Slope (%)	Predominant Soils	Primary Soils Texture
5	Spring Hill	Central Basin	4.9	5	Armour	silt loam
					Captina	silt loam
					Maury	silt loam
6	Spring Hill	Central Basin	80.4	6	Armour	silt loam
					Huntington	silt loam
					Maury	silt loam
8	Milan	Gulf Coastal Plain	3.7	3	Calloway	silt loam
					Henry	silt loam
					Loring	silt loam
9	Milan	Gulf Coastal Plain	14.5*	2.5**	Collins	silt loam
					Loring	silt loam
					Memphis	silt loam

* 11.5 ha after land forming in July, 1975.

** 2.0 after land forming in July, 1975.

TABLE 33. Land Use, Practice, and Tillage by Year for Watershed 5.

Season	Year	Land Use % Area	Land Use Crop	Practice	Tillage
	1974	100	Hay	Disregard Slope	-
	1975	100	Hay	Disregard Slope	-
	1976	100	Hay	Disregard Slope	-
Growing	1977	36	Fescue	Disregard Slope	-
		64	Corn	Disregard Slope	Conventional*
Dormant	1977-1978	36	Fescue	Disregard Slope	-
		64	Fallow	-	-
Growing	1978	100	Corn	Disregard Slope	Conventional*
Dormant	1978-1979	100	Fallow	-	-
Growing	1979	85	Corn	Disregard Slope	Conventional*
		15	Wheat	Disregard Slope	Conventional*

* Conventional = plow, disk, cultivate.

TABLE 34. Land Use, Practice, and Tillage by Year for Watershed 6.

Season	Year	Land Use % Area	Land Use Crop	Practice	Tillage
Growing	1974	60	Pasture	Disregard Slope	-
		20	Wheat	Disregard Slope	Conventional*
		10	Hay	Disregard Slope	-
		10	Corn	Disregard Slope	Conventional*
Dormant	1974-1975	70	Pasture	Disregard Slope	-
		30	Fallow	-	-
Growing	1975 and 1976	60	Pasture	Disregard Slope	-
		30	Wheat	Disregard Slope	Conventional*
		5	Hay	Disregard Slope	-
		5	Corn	Disregard Slope	-
Dormant	1975-1976; and	65	Pasture	Disregard Slope	-
	1976-1977	35	Fallow	-	-

TABLE 34. (Continued).

Season	Year	Land Use % Area	 Crop	Practice	Tillage
Growing	1977 and 1978	51	Pasture	Disregard Slope	-
		33	Corn	Disregard Slope	Conventional*
		16	Hay	Disregard Slope	-
Dormant	1977-1978	67	Pasture	Disregard Slope	-
		33	Fallow	-	-
Dormant	1978-1979	40	Wheat	Disregard Slope	Conventional*
		60	Fallow	-	-
Growing	1979	26	Soybeans	Disregard Slope	Conventional*
		13	Soybeans	Disregard Slope	No Till
		47	Corn	Disregard Slope	Conventional*
		14	Hay	Disregard Slope	-

* Conventional = plow, disk, cultivate.

TABLE 35. Land Use, Practice, and Tillage by Year for Watershed 8.

Season	Year	Land Use % Area	Land Use Crop	Practice	Tillage
Growing	1974	100	Cotton	Disregard Slope	-
Dormant	1974-1975	100	Wheat	Disregard Slope	Conventional*
Growing	1975	100	Soybeans	Disregard Slope	No Till
Dormant	1975-1976	100	Wheat	Disregard Slope	Conventional*
Growing	1976	100	Corn	Disregard Slope	Conventional*
Dormant	1976-1977	100	Fallow	-	-
Growing	1977	100	Corn	Disregard Slope	Conventional*
Dormant	1977-1978	100	Fallow	-	-
Growing	1978	100	Corn	Disregard Slope	Conventional*
Dormant	1978-1979	100	Wheat	Disregard Slope	Conventional*
Growing	1979	100	Soybeans	Disregard Slope	No Till

* Conventional = plow, disk, cultivate.

TABLE 36. Land Use, Practice, and Tillage by Year for Watershed 9.

Season	Year	Land Use % Area	Crop	Practice	Tillage
Growing	1974	90 10	Cotton Corn	Disregard Slope Disregard Slope	- Conventional*
Dormant	1974-1975	100	Wheat	Disregard Slope	Conventional*
Growing	1975	100	Land Forming	-	-
Dormant	1975-1976	100	Wheat	Contour	Conventional*
Growing	1976	100	Soybeans	Contour	Conventional*
Dormant	1976-1977	100	Wheat	Contour	Conventional*
Growing	1977	70 30	Soybeans Soybeans	Contour Contour	No Till Conventional*
Dormant	1977-1978	100	Wheat	Contour	Conventional*
Growing	1978	30 70	Soybeans Soybeans	Contour Contour	No Till Conventional*

TABLE 36 (Continued).

Season	Year	Land Use % Area	Land Use Crop	Practice	Tillage
Dormant	1978-1979	100	Wheat	Contour	Conventional*
Growing	1979	78	Soybeans	Contour	No Till
		22	Cotton	Contour	Conventional*

* Conventional = plow, disk, cultivate.

APPENDIX B

Sediment Data

TABLE 37. First, Second, and Third Laboratory Determinations of Sediment Concentration for the Sub-Samples from Watershed 6.

Observation	(mg/l) 1st	2nd	3rd	Observation	(mg/l) 1st	2nd	3rd
1	1064	1164	904	41	124	120	132
2	1124	1612	1102	42	228	228	256
3	1248	1328	1256	43	228	244	200
4	716	700	740	44	208	204	208
5	540	556	528	45	204	200	204
6	476	528	420	46	188	184	196
7	408	448	400	47	188	192	152
8	468	572	632	48	188	204	196
9	332	432	380	49	208	212	204
10	384	384	340	50	216	216	228
11	3200	3324	3120	51	232	216	220
12	1968	1980	1956	52	252	220	212
13	184	1016	396	53	92	284	112
14	116	740	772	54	480	492	476
15	548	352	520	55	268	308	316
16	416	420	440	56	344	352	320
17	396	376	384	57	296	324	328
18	360	396	504	58	268	284	284
19	356	452	432	59	272	340	260
20	356	368	336	60	252	252	52
21	280	256	236	61	228	240	232
22	220	268	232	62	8	4	8
23	248	340	340	63	8	8	---
24	300	300	308	64	80	76	96
25	480	564	468	65	44	72	76
26	508	520	512	66	48	56	48
27	500	472	464	67	48	56	48
28	192	224	224	68	48	44	44
29	264	308	240	69	36	44	52
30	224	228	232	70	44	32	36
31	88	108	112	71	40	40	44
32	300	96	100	72	48	76	108
33	92	104	144	73	56	72	72
34	84	100	124	74	104	112	160
35	144	144	144	75	176	152	148
36	108	116	80	76	176	164	172
37	72	64	48	77	24	12	16
38	56	60	88	78	60	72	76
39	92	116	100	79	100	112	304
40	100	100	108	80	52	52	60

TABLE 37. (Continued).

Observation	(mg/l) 1st	2nd	3rd	Observation	(mg/l) 1st	2nd	3rd
81	92	92	96	123	148	144	140
82	104	104	116	124	148	168	148
83	108	104	112	125	200	192	176
84	124	104	116	126	108	92	100
85	112	84	112	127	172	144	136
86	92	108	104	128	96	28	32
87	100	100	104	129	24	12	16
88	88	80	100	130	20	12	20
89	80	104	96	131	28	36	44
90	80	104	104	132	164	164	228
91	52	44	124	133	72	80	72
92	1320	1160	780	134	92	92	104
93	724	864	1012	135	584	576	568
94	816	56	64	136	408	408	384
95	64	72	64	137	212	404	540
96	56	60	72	138	620	628	620
97	88	684	160	139	512	548	556
98	156	112	140	140	492	448	464
99	160	136	540	141	132	452	400
100	412	108	100	142	112	96	140
101	64	60	192	143	132	104	116
102	32	80	20	144	124	116	104
103	60	64	40	145	100	104	112
104	44	92	64	146	452	512	460
105	88	64	68	147	212	224	216
106	84	48	80	148	156	176	168
107	80	60	100	149	160	156	160
108	92	132	64	150	260	280	268
109	88	96	108	151	228	228	228
110	108	132	112	152	188	188	168
111	52	32	48	153	304	316	332
112	40	104	76	154	124	136	128
113	128	84	124	155	140	532	580
114	100	112	132	156	104	152	92
115	148	120	104	157	116	96	88
116	140	128	160	158	92	100	88
117	152	136	340	159	196	88	100
118	216	168	184	160	132	140	156
119	192	176	168	161	328	208	188
120	156	164	172	162	124	328	124
121	152	144	156	163	80	84	84
122	144	152	148	164	44	48	72

TABLE 37. (Continued).

Observation	(mg/l) 1st	2nd	3rd	Observation	(mg/l) 1st	2nd	3rd
165	96	68	72	207	172	156	164
166	84	84	88	208	360	336	336
167	68	64	72	209	236	252	256
168	24	16	12	210	308	348	276
169	8	32	100	211	344	396	384
170	16	24	16	212	216	240	240
171	36	28	32	213	300	216	208
172	32	32	52	214	216	228	220
173	100	116	116	215	212	216	212
174	120	88	92	216	208	204	208
175	100	80	88	217	200	196	204
176	68	64	72	218	196	132	136
177	820	840	804	219	144	140	128
178	608	688	580	220	136	144	156
179	2584	2360	2228	221	172	156	140
180	184	180	184	222	200	176	168
181	208	372	220	223	184	188	184
182	780	844	884	224	176	180	180
183	800	740	924	225	264	276	284
184	712	984	808	226	240	224	224
185	804	792	772	227	112	96	76
186	688	720	732	228	120	160	144
187	840	820	812	229	140	132	144
188	112	92	88	230	168	180	176
189	564	520	536	231	268	264	268
190	144	124	112	232	196	184	232
191	116	116	116	233	44	72	80
192	436	436	472	234	36	36	36
193	340	352	348	235	36	36	36
194	536	540	548	236	164	164	172
195	776	772	688	237	1168	1660	1912
196	544	560	608	238	1748	1868	1964
197	220	204	200	239	1104	1124	1216
198	60	96	56	240	1460	1472	1412
199	76	76	116	241	876	568	636
200	108	108	132	242	764	616	768
201	128	132	132	243	780	584	640
202	144	148	136	244	692	644	696
203	152	240	220	245	232	232	248
204	156	156	152	246	260	264	256
205	164	160	156	247	160	144	160
206	166	160	160	248	120	124	128

TABLE 37. (Continued).

Observation	(mg/l) 1st	2nd	3rd	Observation	(mg/l) 1st	2nd	3rd
249	184	168	176	291	160	236	316
250	140	212	176	292	164	276	196
251	188	196	208	293	124	276	196
252	200	212	12	294	2260	1212	2060
253	256	248	244	295	1252	2016	1088
254	272	272	276	296	1132	1132	1052
255	1096	1088	1016	297	2832	2828	2624
256	1476	1492	1484	298	3028	3272	3396
257	280	240	160	299	3192	3032	2868
258	284	324	244	300	1820	1492	2060
259	120	192	192	301	1332	1576	892
260	120	404	200	302	1376	1292	1332
261	124	160	200	303	1456	1532	1492
262	280	364	324	304	1132	1132	1212
263	244	284	280	305	1416	1416	1452
264	280	324	---	306	1212	1332	1292
265	160	284	244	307	1252	1248	1088
266	2744	---	2828	308	2668	3996	3672
267	1980	2300	2584	309	1896	2100	2260
268	1656	2140	2300	310	1776	1808	1860
269	3476	6384	10624	311	1776	1980	2060
270	2100	2584	3432	312	1372	1456	1660
271	1820	2260	2064	313	2548	7392	7476
272	1172	1052	1376	314	2584	2788	2728
273	808	404	648	315	1616	1696	2100
274	600	320	240	316	2876	3552	3552
275	204	276	272	317	1776	2180	2140
276	124	232	236	318	1612	2060	2264
277	120	232	236	319	1900	2464	2380
278	164	72	232	320	1376	1256	1332
279	200	276	236	321	888	888	848
280	200	196	196	322	2064	2104	2344
281	204	196	196	323	200	200	160
282	204	152	192	324	244	244	280
283	204	196	192	325	972	728	888
284	640	196	192	326	440	368	324
285	204	232	196	327	1980	2624	2548
286	160	316	236	328	1128	1332	1332
287	160	236	152	329	2020	2464	2664
288	164	320	276	330	1820	1856	1816
289	164	276	236	331	4892	2580	1660
290	164	192	236	332	1616	1132	2180

TABLE 37. (Continued).

Obser- vation	1st	(mg/l) 2nd	3rd	Obser- vation	1st	(mg/l) 2nd	3rd
333	1252	1017	1980	358	3352	2872	2424
334	1172	1412	1940	359	1896	1696	1776
335	1132	1492	1208	360	1856	136	1780
336	3640	5040	4760	361	1412	932	1132
337	3920	4040	4112	362	1412	1252	2868
338	3112	3672	3476	363	588	1092	1532
339	2180	2660	2988	364	1896	2424	2020
340	2784	2704	2500	365	1248	928	968
341	3108	2460	2500	366	2128	1576	1412
342	2380	2136	2256	367	40	524	568
343	6584	9172	10220	368	884	484	484
344	2020	3592	4040	369	524	360	360
345	1680	1532	1576	370	684	376	400
346	2148	1816	2260	371	524	276	360
347	1704	1212	1376	372	480	340	276
348	1500	1492	1616	373	444	196	316
349	4528	3192	3832	374	444	444	240
350	4004	3632	3836	375	524	240	200
351	5176	5008	5612	376	284	160	160
352	2548	2180	2176	377	364	200	244
353	2104	1532	1492	378	564	324	240
354	1376	1292	1128	379	444	160	160
355	1460	1132	884	380	796	892	776
356	4364	2296	2500	381	2680	3132	2608
357	1248	888	728	382	372	228	280

TABLE 38. Sediment Concentrations in Samples Obtained by Grab- and Automatic Sampling for Watershed 9. Event of May 3, 1979.

(mg/l)
Channel Surface

Sample	Layer Average	Channel Location Transverse to Flow Direction L4*	L2*	C*	R2*	R4*	Automatic Sample
A	2143	2991	3240	2137	1101	1245	6175
B	604	565	627	488	660	680	828
C	1191	1476	655	1128	1216	1480	2284
D	619	564	---	617	675	---	2596

(mg/l)
Channel Bottom

Sample	Layer Average	Channel Location Transverse to Flow Direction L4*	L2*	C*	R2*	R4*	Automatic Sample
A	2325	2820	2614	1395	2026	2768	7664
B	1611	2427	2168	1371	811	1279	998
C	1444	1460	1584	1541	1300	1334	4485

* L = left of center, R = right of center, C = center line of channel, 2 = 0.6 m, and 4 = 1.2 m.

TABLE 39. Orthophosphate-P Concentrations in Samples Obtained by Grab- and Automatic Sampling for Watershed 9. Event of May 3, 1979.

(mg/l)
Channel Surface

Sample	Layer Average	Channel Location Transverse to Flow Direction L4*	L2*	C*	R2*	R4*	Automatic Sample
A	0.08	.04	0.04	0.05	0.06	0.05	0.05
B	0.06	.04	0.07	0.06	0.06	0.05	0.06
C	0.06	.08	0.06	0.08	0.07	0.06	0.07
D	0.06	.04	----	0.06	0.07	----	0.06

(mg/l)
Channel Bottom

Sample	Layer Average	Channel Location Transverse to Flow Direction L4*	L2*	C*	R2*	R4*	Automatic Sample
A	0.08	0.06	0.05	0.04	0.04	0.05	0.05
B	0.11	0.06	0.09	0.19	0.07	0.08	0.10

* L = left of center, R = right of center, C = center line of channel, 2 = 0.6 m, and 4 = 1.2 m.

TABLE 40. Sediment Yield Determined by Arithmetic Mean and Runoff Rate-Weighted Method for Watershed 5.

Observation	Arithmetic (Kg)	Rate-Weighted (Kg)
1	30	19
2	30	13
3	89	130
4	10	9
5	2	4
6	8	2
7	13	8
8	671	591
9	262	104
10	7	5

TABLE 41. Sediment Yield Determined by Arithmetic Mean and Runoff Rate-Weighted Method for Watershed 6.

Observation	Arithmetic (Kg)	Rate-Weighted (Kg)
1	2475	1790
2	60	112
3	300	267
4	157	156
5	549	603
6	751	510
7	601	785
8	270	246
9	318	265
10	6	5
11	32	29
12	663	526
13	3522	489
14	45	33
15	590	651
16	903	258
17	4	10
18	1572	1153
19	495	534

TABLE 42. Sediment Yield Determined by Arithmetic Mean and Runoff Rate-Weighted Method for Watershed 8.

Observation	Arithmetic Kg	Rate-Weighted
1	489	503
2	419	193
3	1225	754
4	3130	1941
5	1471	673
6	347	146
7	68	54
8	9	8
9	9	21
10	3	2
11	484	462
12	71	60
13	405	88
14	1005	2555
15	11	14
16	3	4
17	2842	2920
18	66	16
19	17	11

TABLE 42 (Continued).

Observation	Arithmetic Kg	Rate-Weighted
20	605	102
21	3	5
22	142	33
23	2	16
24	60	18
25	1	2
26	22	20
27	1	1
28	332	130
29	3	19
30	47	28
31	177	47
32	25	27
33	3	5
34	1111	859
35	129	90

TABLE 43. Sediment Yield Determined by Arithmetic Mean and Runoff Rate-Weighted Method for Watershed 9.

Observation	Arithmetic (Kg)	Rate-Weighted (Kg)
1	7712	4883
2	218	189
3	212	700
4	3024	5095
5	122	67
6	500	758
7	117	173
8	40	55
9	332	414
10	240	629
11	463	494
12	110	245
13	24	58
14	29	24
15	2276	903
16	38	36
17	95	216
18	28	39
19	92	155

TABLE 43 (Continued).

Observation	Kg Arithmetic	Kg Rate-Weighted
20	31	26
21	134	141
22	634	460
23	1524	963
24	1620	885
25	2382	1270

TABLE 44. Sediment Yield-, Climatic-, and Watershed Data for Selected Runoff Events on Watershed 5.

Observation	Date	Y*	R*	K*	T*	C*	P*	B*	V*	Q*	I*	J*	F*	E*	H*	W*	N*	X*	G*	U*
1	05/10/74	10	2.31	0.35	1.1	0.003	0.1	5.08	43	0.047	0.645	0.645	0.645	0.645	4	13.16	19.61	4.9	0.035	96
2	05/15/74	5	4.79	0.35	1.1	0.003	0.1	5.08	32	0.038	1.165	1.165	1.165	1.165	4	13.16	19.61	4.9	0.035	96
3	06/01/74	19	23.67	0.35	1.1	0.003	0.1	5.08	354	0.255	2.163	2.163	3.085	3.085	6	13.36	19.69	4.9	0.035	96
4	06/05/74	13	15.89	0.35	1.1	0.003	0.1	5.08	115	0.170	2.835	3.316	4.039	4.039	6	13.36	19.69	4.9	0.035	96
5	06/07/74	130	35.90	0.35	1.1	0.003	0.1	5.08	361	0.791	4.460	5.304	8.128	8.128	6	13.36	19.69	4.9	0.035	96
6	06/08/74	38	13.39	0.35	1.1	0.003	0.1	5.08	727	0.478	2.032	2.347	4.113	4.113	6	13.36	19.69	4.9	0.035	96
7	05/14/76	9	19.22	0.35	1.1	0.003	0.1	5.08	96	0.127	1.742	1.742	1.742	1.742	5	4.44	19.69	4.9	0.035	96
8	06/02/76	4	3.85	0.35	1.1	0.003	0.1	5.08	43	0.041	0.762	0.762	0.762	0.762	2	14.91	19.69	4.9	0.035	96
9	07/05/76	2	8.87	0.35	1.1	0.003	0.1	5.08	61	0.075	2.032	2.286	3.629	3.629	5	8.33	12.85	4.9	0.035	96
10	10/25/76	8	16.61	0.35	1.1	0.003	0.1	5.08	47	0.047	1.310	1.310	1.310	1.310	4	4.98	16.05	4.9	0.035	96
11	09/25/77	591	51.20	0.35	1.1	0.015	0.5	5.08	167	0.373	3.416	1.719	5.639	5.639	3	4.06	25.65	4.9	0.035	96
12	05/08/78	104	24.00	0.35	1.1	0.040	0.4	5.08	226	0.170	2.752	2.752	2.752	7.320	5	6.25	19.61	4.9	0.035	96
13	05/12/78	5	0.54	0.35	1.1	0.040	0.4	5.08	24	0.017	0.457	0.457	0.457	0.457	5	6.25	19.61	4.9	0.035	96
14	07/02/78	66	12.82	0.35	1.1	0.027	0.4	5.08	43	0.160	1.081	2.109	3.353	6.193	3	7.29	12.85	4.9	0.035	96
15	08/03/78	527	27.37	0.35	1.1	0.045	0.4	5.08	393	2.373	4.679	5.767	6.960	9.289	2	7.47	13.82	4.9	0.035	96
16	05/02/79	228	4.61	0.35	1.1	0.065	0.6	5.08	210	0.693	4.653	5.486	8.382	15.250	5	22.30	19.61	4.9	0.035	96
17	05/03/79	3778	39.05	0.35	1.1	0.065	0.6	5.08	2157	0.617	2.659	2.713	4.382	7.627	5	22.30	19.61	4.9	0.035	96
18	06/21/79	426	31.78	0.35	1.1	0.044	0.6	5.08	711	0.838	3.217	3.217	3.217	3.217	2	16.51	19.69	4.9	0.035	96
19	08/26/79	103	60.35	0.35	1.1	0.049	0.6	5.08	1645	1.063	8.509	9.815	9.815	9.815	2	8.92	13.82	4.9	0.035	96
20	09/13/79	2563	18.54	0.35	1.1	0.049	0.6	5.08	1629	1.922	4.149	4.623	5.355	5.355	4	10.90	25.65	4.9	0.035	96
21	09/20/79	3722	8.87	0.35	1.1	0.049	0.6	5.08	1277	2.222	0.579	0.579	1.219	2.477	4	10.90	25.65	4.9	0.035	96
22	10/02/79	82	10.17	0.35	1.1	0.049	0.6	5.08	64	0.239	3.050	3.414	4.115	4.115	3	24.97	16.05	4.9	0.035	96

* See Table 4 for definitions of variables.

TABLE 45. Sediment Yield-, Climatic-, and Watershed Data for Selected Runoff Events on Watershed 6.

Observation	Date	Y*	R*	K*	T*	C*	P*	B*	V*	Q*	I*	J*	F*	E*	H*	W*	N*	X*	G*	D*
1	04/08/74	1790	21.82	0.33	1.4	0.131	0.3	5.72	3510	0.101	2.721	2.721	2.721	2.721	4	7.79	22.17	80.4	0.014	916
2	04/12/74	112	2.00	0.33	1.4	0.131	0.3	5.72	122	0.005	1.080	1.269	2.965	5.797	4	7.79	22.17	80.4	0.014	916
3	06/01/74	267	33.50	0.33	1.4	0.009	0.3	5.72	1701	0.063	1.942	2.146	4.953	8.518	6	13.36	19.69	80.4	0.014	916
4	06/05/74	156	15.88	0.33	1.4	0.009	0.3	5.72	752	0.030	2.835	3.316	4.039	4.039	6	13.36	19.69	80.4	0.014	916
5	06/07/74A	603	35.90	0.33	1.4	0.009	0.3	5.72	3634	0.127	4.460	5.304	8.128	8.128	6	13.36	19.69	80.4	0.014	916
6	06/07/74B	510	13.90	0.33	1.4	0.009	0.3	5.72	5146	0.124	2.032	2.347	4.113	4.113	6	13.36	19.69	80.4	0.014	916
7	03/24/75	785	8.40	0.33	1.4	0.071	0.5	5.72	1877	0.074	2.154	2.438	2.896	2.896	7	7.87	35.31	80.4	0.014	916
8	03/29/75	246	22.75	0.33	1.4	0.071	0.5	5.72	2252	0.095	2.080	2.423	6.782	10.678	7	7.87	35.31	80.4	0.014	916
9	04/02/75	265	1.22	0.33	1.4	0.071	0.3	5.72	1247	0.034	0.457	0.467	0.467	0.467	2	35.30	22.17	80.4	0.014	916
10	07/19/75	5	26.72	0.33	1.4	0.007	0.3	5.72	64	0.015	4.267	4.816	9.908	9.908	3	7.28	12.85	80.4	0.014	916
11	07/24/75	29	21.58	0.33	1.4	0.007	0.3	5.72	63	0.008	3.861	4.550	7.315	7.315	3	7.28	12.85	80.4	0.014	916
12	10/17/75	526	21.55	0.33	1.4	0.062	0.3	5.72	7207	0.127	1.067	1.250	2.896	4.434	2	13.23	16.05	80.4	0.014	916
13	03/20/76	489	16.18	0.33	1.4	0.062	0.5	5.72	5353	0.003	2.297	2.743	4.623	8.238	5	7.87	35:31	80.4	0.014	916
14	03/29/76A	33	4.14	0.33	1.4	0.062	0.5	5.72	84	0.006	1.651	1.905	2.287	2.287	5	7.87	35.31	80.4	0.014	916
15	03/29/76B	651	18.94	0.33	1.4	0.062	0.5	5.72	2359	0.079	2.353	2.621	4.101	4.101	5	7.87	35.31	80.4	0.014	916
16	03/30/76	258	3.86	0.33	1.4	0.062	0.5	5.72	4364	0.027	0.820	0.967	2.321	4.572	5	7.87	35.31	80.4	0.014	916
17	05/14/76	10	19.22	0.33	1.4	0.011	0.3	5.72	92	0.008	1.742	1.742	1.742	1.742	5	4.44	19.61	80.4	0.014	916
18	05/15/76	1153	9.66	0.33	1.4	0.011	0.3	5.72	1580	0.037	2.149	2.530	8.706	8.706	5	4.44	19.61	80.4	0.014	916
19	06/07/76	12	3.85	0.33	1.4	0.007	0.3	5.72	86	0.001	0.762	0.762	0.762	0.762	2	14.90	19.69	80.4	0.014	916
20	07/04/76	125	10.52	0.33	1.4	0.007	0.3	5.72	709	0.042	1.549	1.768	2.743	4.954	5	8.33	12.85	80.4	0.014	916
21	09/05/76	238	8.87	0.33	1.4	0.007	0.3	5.72	1177	0.071	2.032	2.210	3.629	3.629	2	6.27	25.65	80.4	0.014	916
22	10/25/76	69	16.61	0.33	1.4	0.062	0.3	5.72	290	0.015	1.310	1.310	1.310	1.310	5	4.97	16.05	80.4	0.014	916
23	04/03/77	1346	4.81	0.33	1.4	0.062	0.5	5.72	754	0.042	0.711	0.671	0.813	1.217	3	18.05	22.17	80.4	0.014	916
24	04/04/77	4522	3.54	0.33	1.4	0.062	0.4	5.72	1725	0.062	0.849	0.932	1.676	1.831	3	18.05	22.17	80.4	0.014	916
25	04/23/77	179	3.82	0.33	1.4	0.006	0.5	5.72	174	0.013	1.727	1.768	2.235	2.439	3	18.05	22.17	80.4	0.014	916
26	04/24/77	194	2.17	0.33	1.4	0.006	0.4	5.72	215	0.013	1.016	1.118	1.524	1.526	3	18.05	22.17	80.4	0.014	916
27	05/07/77	885	25.81	0.33	1.4	0.010	0.4	5.72	689	0.065	4.267	4.682	8.412	14.645	1	13.97	19.61	80.4	0.014	916
28	06/12/77	534	37.87	0.33	1.4	0.008	0.4	5.72	316	0.075	5.100	6.096	9.144	9.144	4	4.19	19.69	80.4	0.014	916
29	06/20/77	762	4.91	0.33	1.4	0.007	0.4	5.72	173	0.037	1.900	2.134	5.105	10.039	4	4.19	19.69	80.4	0.014	916
30	06/22/77	672	9.80	0.33	1.4	0.007	0.4	5.72	363	0.067	2.896	2.560	3.932	3.932	4	4.19	19.69	80.4	0.014	916
31	06/25/77	1223	25.31	0.33	1.4	0.007	0.4	5.72	2298	0.317	3.505	3.993	8.317	8.317	4	4.19	19.69	80.4	0.014	916
32	09/27/77	225	0.96	0.33	1.4	0.009	0.4	5.72	74	0.009	0.768	0.874	1.815	1.815	3	4.06	25.65	80.4	0.014	916
33	10/08/77A	3870	12.19	0.33	1.4	0.009	0.4	5.72	1874	0.113	1.016	1.016	1.016	1.016	2	16.23	16.05	80.4	0.014	916
34	10/08/77B	468	0.97	0.33	1.4	0.009	0.4	5.72	243	0.051	0.894	1.060	1.727	1.727	2	16.23	16.05	80.4	0.014	916
35	10/25/77	316	7.03	0.33	1.4	0.046	0.4	5.72	791	0.033	0.813	0.874	1.118	1.118	2	16.23	16.05	80.4	0.014	916
36	07/27/78	466	8.46	0.33	1.4	0.009	0.5	5.72	340	0.051	2.133	2.194	3.048	3.048	3	7.29	12.85	80.4	0.014	916
37	08/03/78	991	27.37	0.33	1.4	0.009	0.5	5.72	1043	0.147	4.679	5.267	6.960	9.289	2	7.47	13.82	80.4	0.014	916
38	08/05/78	343	8.36	0.33	1.4	0.009	0.5	5.72	611	0.061	1.829	1.951	3.024	3.024	2	7.47	13.82	80.4	0.014	916
39	05/03/79	7974	39.05	0.33	1.4	0.041	0.5	5.72	10718	1.120	2.659	2.713	4.382	7.627	5	22.30	19.61	80.4	0.014	916
40	06/03/79	859	3.00	0.33	1.4	0.028	0.5	5.72	1119	0.052	0.914	0.914	0.914	0.914	2	16.51	19.69	80.4	0.014	916
41	07/25/79	33	19.31	0.33	1.4	0.038	0.5	5.72	127	0.015	3.533	4.233	4.233	4.233	2	9.63	12.85	80.4	0.014	916
42	08/25/79	1235	56.93	0.33	1.4	0.038	0.5	5.72	4586	0.576	8.890	10.360	12.622	12.622	2	8.92	13.82	80.4	0.014	916
43	08/31/79	792	34.79	0.33	1.4	0.038	0.5	5.72	969	0.148	4.572	5.283	8.128	8.128	2	8.92	13.82	80.4	0.014	916

* See Table 4 for definitions of variables.

Table 46: Sediment Yield-, Climatic-, and Watershed Data for Selected Runoff Events on Watershed 8.*

Observation	Date	Y*	R*	K*	T*	C*	P*	B*	V*	Q*	I*	J*	F*	E*	H*	W*	N*	Z*	G*	U*
1	05/15/74	503	6.87	0.40	0.4	0.075	0.8	4.32	238	0.731	1.540	1.748	2.591	3.662	7	17.83	26.01	3.7	0.018	79
2	06/10/74	193	1.62	0.40	0.4	0.044	0.8	4.32	177	0.615	1.143	1.219	1.524	1.524	3	19.79	14.78	3.7	0.018	79
3	06/15/74A	754	14.34	0.40	0.4	0.044	0.8	4.32	233	0.921	2.880	3.251	3.811	3.811	3	19.79	14.78	3.7	0.018	79
4	06/15/74B	1941	2.16	0.40	0.4	0.044	0.8	4.32	320	2.492	1.053	1.168	4.770	4.577	3	19.79	14.78	3.7	0.018	79
5	07/04/74	673	24.63	0.40	0.4	0.039	0.8	4.32	239	1.246	3.846	4.572	9.073	9.073	2	13.54	16.10	3.7	0.018	79
6	03/22/75	146	14.24	0.40	0.4	0.178	0.8	4.32	643	1.138	2.794	2.804	3.810	6.712	8	16.54	31.04	3.7	0.018	79
7	04/30/75	54	34.49	0.40	0.4	0.020	0.8	4.32	622	1.436	3.912	4.145	5.080	5.080	2	31.04	24.36	3.7	0.018	79
8	12/15/75	8	5.02	0.40	0.4	0.178	0.8	4.32	66	0.115	1.585	1.646	2.032	2.032	2	12.24	32.39	3.7	0.018	79
9	03/08/76	21	0.75	0.40	0.4	0.178	0.8	4.32	42	0.040	0.207	0.473	0.711	0.711	7	9.42	31.04	3.7	0.018	79
10	03/09/76	2	1.19	0.40	0.4	0.178	0.8	4.32	18	0.017	0.914	0.914	0.914	0.914	7	9.42	31.04	3.7	0.018	79
11	03/29/76	462	33.97	0.40	0.4	0.178	0.8	4.32	539	0.479	2.252	2.621	3.696	5.492	7	9.42	31.04	3.7	0.018	79
12	04/24/76A	60	12.55	0.40	0.4	0.020	0.8	4.32	30	0.209	2.489	2.804	3.962	6.102	1	18.05	24.36	3.7	0.018	79
13	04/24/76B	88	7.19	0.40	0.4	0.020	0.8	4.32	185	1.111	0.920	2.377	3.759	3.759	1	18.05	24.36	3.7	0.018	79
14	05/13/76	2555	11.91	0.40	0.4	0.020	0.8	4.32	726	1.138	0.899	0.985	2.696	3.051	3	5.21	26.01	3.7	0.018	79
15	05/15/76	48	1.88	0.40	0.4	0.020	0.8	4.32	61	0.209	0.982	1.158	2.210	3.051	3	5.21	26.01	3.7	0.018	79
16	05/17/76	14	0.36	0.40	0.4	0.020	0.8	4.32	19	0.040	0.279	0.279	0.279	0.279	3	5.21	26.01	3.7	0.018	79
17	05/28/76	4	1.01	0.40	0.4	0.020	0.8	4.32	6	0.028	0.356	0.396	0.609	0.609	3	5.21	26.01	3.7	0.018	79
18	06/02/76	2920	49.08	0.40	0.4	0.003	0.8	4.32	1508	2.925	3.251	3.719	4.268	4.268	4	5.21	14.78	3.7	0.018	79
19	06/18/76	16	5.27	0.40	0.4	0.003	0.8	4.32	51	0.341	1.659	1.910	4.064	7.627	4	14.50	14.78	3.7	0.018	79
20	06/23/76	11	5.72	0.40	0.4	0.003	0.8	4.32	39	0.148	1.676	1.849	2.722	2.722	4	14.50	14.78	3.7	0.018	79
21	06/29/76	102	10.34	0.40	0.4	0.003	0.8	4.32	267	1.408	2.709	3.366	7.259	7.259	4	14.50	14.78	3.7	0.018	79
22	07/03/76	5	0.25	0.40	0.4	0.003	0.8	4.32	4	0.053	0.399	0.466	1.058	1.058	6	14.78	16.10	3.7	0.018	79
23	07/04/76A	33	5.33	0.40	0.4	0.003	0.8	4.32	162	0.840	1.981	2.276	4.536	4.536	6	14.78	16.10	3.7	0.018	79
24	07/04/76B	16	1.83	0.40	0.4	0.003	0.8	4.32	3	0.187	1.016	1.057	1.219	1.219	6	14.78	16.10	3.7	0.018	79
25	07/14/76	18	8.63	0.40	0.4	0.029	0.8	4.32	120	0.731	2.413	2.743	4.064	4.064	6	14.78	16.10	3.7	0.018	79
26	07/31/76	2	2.90	0.40	0.4	0.029	0.8	4.32	11	0.017	0.982	1.077	1.210	1.210	6	14.78	16.10	3.7	0.018	79
27	08/14/77	20	9.13	0.40	0.4	0.029	0.8	4.32	118	0.198	2.032	2.134	2.295	2.295	4	9.93	26.59	3.7	0.018	79
28	09/15/77	1	5.97	0.40	0.4	0.430	0.8	4.32	5	0.020	1.250	1.353	2.322	2.322	4	8.79	20.27	3.7	0.018	79
29	09/25/77	130	81.02	0.40	0.4	0.430	0.8	4.32	1732	2.086	4.978	5.165	5.165	5.165	4	8.79	20.27	3.7	0.018	79
30	09/27/77	19	2.94	0.40	0.4	0.430	0.8	4.32	23	0.025	1.016	1.158	2.167	2.167	4	8.79	20.27	3.7	0.018	79
31	09/30/77	47	2.52	0.40	0.4	0.430	0.8	4.32	196	0.390	1.060	1.234	1.930	1.930	4	8.79	20.27	3.7	0.018	79
32	11/21/77	27	52.63	0.40	0.4	0.430	0.8	4.32	827	1.138	4.826	5.715	13.934	13.934	4	3.89	16.71	3.7	0.018	79
33	11/29/77	5	4.89	0.40	0.4	0.430	0.8	4.32	128	0.093	1.016	1.113	1.981	2.477	4	3.89	16.71	3.7	0.018	79
34	12/08/77	859	2.11	0.40	0.4	0.430	0.8	4.32	10	0.015	0.943	1.052	2.029	3.547	1	16.71	32.39	3.7	0.018	79
35	01/08/78	90	38.64	0.40	0.4	0.178	0.8	4.32	1380	1.897	5.791	5.791	5.791	5.791	4	16.08	23.19	3.7	0.018	79
36	03/13/78	191	23.07	0.40	0.4	0.178	0.8	4.32	227	0.615	3.214	3.730	8.382	12.204	2	2.16	31.04	3.7	0.018	79
37	12/04/78	141	16.56	0.40	0.4	0.178	0.8	4.32	925	0.372	0.982	1.158	1.219	1.219	5	16.71	32.39	3.7	0.018	79
38	12/07/78	423	11.00	0.40	0.4	0.178	0.8	4.32	393	0.265	2.286	2.286	3.406	3.406	5	16.71	32.39	3.7	0.018	79
39	03/23/79	326	12.37	0.40	0.4	0.178	0.8	4.32	731	0.546	1.597	1.873	5.080	5.475	3	12.27	31.04	3.7	0.018	79
40	04/08/79	520	14.04	0.40	0.4	0.178	0.8	4.32	2003	0.928	2.032	2.032	2.032	2.032	3	12.60	24.36	3.7	0.018	79
41	07/12/79	882	17.15	0.40	0.4	0.003	0.5	4.32	520	0.672	2.358	2.358	2.358	2.358	3	4.27	16.10	3.7	0.018	79
42	03/13/79	4883	29.72	0.40	0.4	0.003	0.5	4.32	882	0.693	1.903	1.903	1.903	1.903	9	9.14	20.27	3.7	0.018	79

* See Table 4 for definitions of variables.

TABLE 47. Sediment Yield-, Climatic-, and Watershed Data for Selected Runoff Events on Watershed 9.

Observation	Date	Y*	R*	K*	T*	C*	P*	S*	V*	Q*	I*	J*	F*	E*	H*	W*	N*	Z*	G*	U*
1	05/02/74	4883	2.78	0.40	0.5	0.074	0.8	4.70	331	0.050	1.041	1.204	1.448	1.448	7	17.83	26.01	14.0	0.017	846
2	05/03/74	189	0.15	0.40	0.5	0.074	0.8	4.70	49	0.036	0.406	0.411	0.458	0.458	7	17.83	26.01	14.0	0.017	846
3	05/04/74	700	0.73	0.40	0.5	0.074	0.8	4.70	330	0.309	0.474	0.481	0.534	0.534	7	17.83	26.01	14.0	0.017	846
4	05/20/74	4156	3.56	0.40	0.5	0.074	0.8	4.70	490	6.074	1.626	1.890	4.271	4.271	7	17.83	26.01	14.0	0.017	846
5	05/22/74	5095	1.81	0.40	0.5	0.074	0.5	4.70	540	0.623	0.745	0.745	0.745	0.745	7	17.83	26.01	14.5	0.017	846
6	10/15/74	74	8.20	0.40	0.5	0.430	0.5	4.70	232	0.090	2.205	2.546	5.728	5.728	2	7.37	12.93	14.5	0.017	846
7	11/04/74	67	9.96	0.40	0.5	0.430	0.5	4.70	270	0.164	2.786	2.621	3.962	3.962	2	3.94	16.71	14.5	0.017	846
8	12/24/74	758	1.98	0.40	0.5	0.178	0.5	4.70	248	0.090	0.931	1.050	1.524	1.524	2	9.32	32.39	14.5	0.017	846
9	12/29/74	173	3.67	0.40	0.5	0.178	0.5	4.70	199	0.055	2.642	2.642	2.642	2.642	2	9.32	32.39	14.5	0.017	846
10	12/31/74	55	1.28	0.40	0.5	0.178	0.5	4.70	109	0.024	0.396	0.549	0.549	0.549	2	9.32	32.39	14.5	0.017	846
11	01/03/75	414	0.76	0.40	0.5	0.178	0.5	4.70	410	0.073	0.440	0.488	0.508	0.508	2	7.11	23.19	14.5	0.017	846
12	01/09/75	629	1.35	0.40	0.5	0.178	0.5	4.70	105	0.099	1.118	1.134	1.280	1.524	2	7.11	23.19	14.5	0.017	846
13	02/04/75	494	0.35	0.40	0.5	0.178	0.5	4.70	1146	0.188	0.231	0.231	0.231	0.231	3	11.68	14.05	14.5	0.017	846
14	02/11/75	245	0.18	0.40	0.5	0.178	0.5	4.70	111	0.101	0.395	0.440	0.847	1.526	3	11.68	14.05	14.5	0.017	846
15	02/16/75	58	0.51	0.40	0.5	0.178	0.5	4.70	61	0.040	0.572	0.572	0.572	0.572	3	11.68	14.05	14.5	0.017	846
16	03/18/75	74	0.24	0.40	0.5	0.178	0.5	4.70	97	0.036	0.093	0.264	0.508	0.915	8	14.05	31.04	14.5	0.017	846
17	04/18/75	903	9.95	0.40	0.5	0.020	0.5	4.70	555	0.009	2.860	4.340	6.452	12.204	2	31.04	24.36	14.5	0.017	846
18	04/25/75	36	6.50	0.40	0.5	0.020	0.5	4.70	209	0.192	1.964	2.344	4.577	4.577	2	31.04	24.36	14.5	0.012	846
19	06/09/75	216	10.22	0.40	0.5	0.900	0.9	4.70	448	0.568	2.083	2.377	3.099	3.661	1	20.78	14.78	11.0	0.012	355
20	04/24/76	103	12.55	0.40	0.5	0.020	0.2	4.70	324	0.215	2.489	2.804	3.962	6.102	1	18.05	24.36	11.0	0.012	355
21	07/14/76	39	8.63	0.40	0.5	0.003	0.2	4.70	22	0.053	2.413	2.413	2.413	4.060	6	14.78	16.10	11.0	0.012	355
22	07/11/77	155	16.90	0.40	0.5	0.003	0.2	4.70	387	0.297	3.471	4.064	6.858	10.837	3	10.52	16.10	11.0	0.012	355
23	08/14/77	26	9.13	0.40	0.5	0.011	0.2	4.70	212	0.062	2.032	2.134	2.295	2.295	4	9.93	26.59	11.0	0.012	355
24	09/24/77	141	17.11	0.40	0.5	0.007	0.2	4.70	784	0.159	1.846	2.113	3.404	5.264	4	8.79	20.27	11.0	0.012	355
25	09/25/77	460	81.02	0.40	0.5	0.007	0.2	4.70	4064	0.918	4.978	5.165	5.165	5.165	4	8.79	20.27	11.0	0.012	355
26	09/27/77	56	2.94	0.40	0.5	0.007	0.2	4.70	773	0.108	1.016	1.158	2.167	2.167	4	8.79	20.27	11.0	0.012	355
27	11/21/77	963	52.36	0.40	0.5	0.003	0.3	4.70	2445	0.441	4.826	5.715	13.934	13.934	4	3.89	16.71	11.0	0.012	355
28	11/29/77	270	3.79	0.40	0.5	0.003	0.3	4.70	1872	0.194	0.787	0.914	1.486	2.477	4	3.89	16.71	11.0	0.012	355
29	01/08/78	885	38.64	0.40	0.5	0.178	0.3	4.70	5008	1.197	5.791	5.791	5.791	5.791	4	16.08	23.19	11.0	0.012	355
30	05/07/78	189	9.42	0.40	0.5	0.020	0.4	4.70	716	0.140	1.101	1.219	2.285	2.285	4	2.54	26.01	11.0	0.012	355
31	05/08/78	1270	37.00	0.40	0.5	0.020	0.4	4.70	1438	0.747	4.928	5.793	5.793	5.793	4	2.54	26.01	11.0	0.012	355
32	06/21/78	1574	28.23	0.40	0.5	0.020	0.4	4.70	623	1.044	4.877	5.486	8.771	8.771	2	17.42	14.78	11.0	0.012	355
33	03/23/79	40	12.37	0.40	0.5	0.178	0.4	4.70	40	0.140	1.597	1.873	5.080	5.475	3	12.27	31.04	11.0	0.012	355
34	03/31/79	918	8.72	0.40	0.5	0.178	0.4	4.70	499	0.630	2.540	3.048	3.048	3.048	3	12.27	31.04	11.0	0.012	355
35	04/01/79	4223	56.73	0.40	0.5	0.178	0.4	4.70	4093	0.487	2.549	2.549	3.814	7.017	3	12.60	24.36	11.0	0.012	355
36	04/04/79	132	1.08	0.40	0.5	0.178	0.4	4.70	184	0.089	0.627	0.643	0.813	0.813	3	12.60	24.36	11.0	0.012	355
37	04/11/79	7614	33.33	0.40	0.5	0.178	0.4	4.70	2818	1.863	3.556	3.861	5.080	5.080	3	12.60	24.36	11.0	0.012	355
38	05/03/79	8707	65.75	0.40	0.5	0.020	0.2	4.70	6020	2.187	2.187	5.994	5.994	5.994	5	26.01	26.01	11.0	0.012	355

* See Table 4 for definitions of variables.

TABLE 48. Observed- and Predicted Peak Flow Rates for Watershed 6.

Observation	Observed	m^3/sec Predicted for Return Periods of 3-months	6-months	12-months
1	0.218	3.050	4.265	5.100
2	0.011	3.050	4.265	5.100
3	0.014	3.050	4.265	5.100
4	0.067	3.050	4.265	5.100
5	0.280	3.050	4.265	5.100
6	0.274	3.050	4.265	5.100
7	0.162	3.135	4.384	5.241
8	0.207	3.135	4.384	5.241
9	0.073	3.135	4.384	5.241
10	0.034	3.135	4.384	5.241
11	0.017	3.135	4.384	5.241
12	0.028	3.135	4.384	5.241
13	0.067	3.135	4.384	5.241
14	0.011	3.135	4.384	5.241
15	0.174	3.135	4.384	5.241
16	0.062	3.135	4.384	5.241
17	0.017	3.135	4.384	5.241
18	0.067	3.135	4.384	5.241
19	0.003	3.135	4.384	5.241
20	0.090	3.135	4.384	5.241
21	0.157	3.135	4.384	5.241
22	0.034	3.135	4.384	5.241
23	0.092	4.236	5.924	7.083
24	0.134	4.236	5.924	7.083
25	0.028	4.236	5.924	7.083
26	0.028	4.236	5.924	7.083
27	0.140	4.236	5.924	7.083
28	0.146	4.236	5.924	7.083
29	0.078	4.236	5.924	7.083
30	0.146	4.236	5.924	7.083
31	0.700	4.236	5.924	7.083
32	0.022	4.236	5.924	7.083
33	0.246	4.236	5.924	7.083
34	0.112	4.236	5.924	7.083
35	0.073	4.236	5.924	7.083
36	0.112	4.236	5.924	7.083
37	0.322	4.236	5.924	7.083
38	0.133	4.236	5.924	7.083
39	2.450	4.236	5.924	7.083
40	0.115	4.236	5.924	7.083
41	0.034	4.236	5.924	7.083
42	1.260	4.236	5.924	7.083
43	0.325	4.236	5.924	7.083

TABLE 49. Observed- and Predicted Volumes of Runoff for Watershed 8.

Observation	Observed	m^3 Predicted for Durations of 10-minutes	30-minutes	60-minutes
1	298	32	159	980
2	177	32	159	980
3	233	32	159	980
4	320	32	159	980
5	239	32	159	980
6	643	2	87	766
7	622	2	87	766
8	66	2	87	766
9	42	2	87	766
10	18	2	87	766
11	539	2	87	766
12	30	2	87	766
13	185	2	87	766
14	726	2	87	766
15	61	2	87	766
16	19	2	87	766
17	6	2	87	766
18	1508	32	159	980
19	51	32	159	980
20	29	32	159	980
21	267	32	159	980
22	4	32	159	980
23	162	32	159	980
24	3	32	159	980
25	120	32	159	980
26	11	32	159	980
27	118	32	159	980
28	5	32	159	980
29	1732	32	159	980
30	23	32	159	980
31	196	32	159	980
32	827	2	87	766
33	128	2	87	766
34	10	2	87	766
35	1380	2	87	766
36	227	2	87	766
37	925	2	87	766
38	393	2	87	766
39	731	2	87	766
40	2003	2	87	766
41	520	15	10	406
42	882	15	20	406

TABLE 50. Observed and Predicted Volumes of Runoff for Watershed 9.

Observation	Observed	Predicted for Durations of (m³) 10-minutes	30-minutes	60-minutes
1	331	124	622	3842
2	49	124	622	3842
3	330	124	622	3842
4	490	124	622	3842
5	540	124	622	3842
6	232	124	622	3842
7	270	7	340	3000
8	248	7	340	3000
9	199	7	340	3000
10	109	7	340	3000
11	410	7	340	3000
12	105	7	340	3000
13	1146	7	340	3000
14	111	7	340	3000
15	61	7	340	3000
16	97	7	340	3000
17	555	7	340	3000
18	209	7	340	3000
19	448	7	340	3000
20	324	59	77	1592
21	22	59	77	1592
22	387	59	77	1592
23	212	59	77	1592
24	784	59	77	1592
25	4064	59	77	1592
26	773	59	77	1592
27	2445	59	77	1592
28	1872	59	77	1592
29	5008	59	77	1592
30	716	59	77	1592
31	1438	59	77	1592
32	623	59	77	1592
33	40	59	77	1592
34	499	59	77	1592
35	4893	59	77	1592
36	184	59	77	1592
37	2818	59	77	1592
38	6020	59	77	1592

VITA

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