THE VERTICAL AND HORIZONTAL REDISTRIBUTION OF NITROGEN, CHLORIDE, AND PHOSPHORUS BY PRECIPITATION AND SURFACE RUNOFF ON TWO SMALL WATERSHEDS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

ROBERT KINGSLEY HUBBARD

1975

ABSTRACT

THE VERTICAL AND HORIZONTAL REDISTRIBUTION OF NITROGEN, CHLORIDE, AND PHOSPHORUS BY PRECIPITATION AND SURFACE RUNOFF ON TWO SMALL WATERSHEDS

By

Robert Kingsley Hubbard

Causes of runoff over a one and one half year period were determined and changes in sediment and nutrient contents of surface runoff were related to time of year and field operations. Leaching of nutrients was traced during the summer and downslope movement of nutrients was related to surface runoff. Comparisons of phosphorus status were made between a watershed profile and a nearby virgin profile.

The magnitude of runoff during the summer months increased with rainfall intensity, duration of rainfall after the start of runoff, and compactness of the soil surface. During the winter months runoff depended on the amount of rain and accumulated snow on the watersheds and the rise in temperature above 32 F.

Analyses showed that sediment content of runoff samples during the summer was related to field operations. Highest sediment concentrations were found in the first

runoffs after plowing and planting. Winter runoff sediment concentrations depended on whether or not the soil was frozen.

Runoff samples were separated into water and sediment phases by filtration. It appeared that nitrogen and chloride amounts of both phases were related to time of year and fertilizer practices. During the summer the highest contents were found in runoff after fertilization, and decreased thereafter. Low amounts were found during the winter when the soil was frozen. Warming of the soil in early spring prior to fertilization appeared to cause increases in nitrogen and chloride content of the runoff as compared to winter data.

Phosphate concentrations in sediment and water phases of runoff were related to both fertilizer application and sediment content in grams per liter. Phosphate increased as sediment increased except for the runoffs of late spring prior to fertilization. Contents were highest in the first few summer runoffs after fertilizer application.

Soil core data showed downward movement of nitrate nitrogen and chloride through the profile. The 1974 data showed leaching after fertilization followed by an upward movement of nitrate nitrogen and chloride during the first month. This appeared to be a capillarity effect. Leaching occurred during the rest of the season.

There was horizontal movement of chloride, nitrate nitrogen, and phosphate from upper sloping areas of the watersheds to the flume approach areas. The amount of nutrient moved depended on how recently fertilizer had been applied and runoff magnitude. Kjeldahl data showed high nitrogen in the flat flume approach areas; clear evidence of movement of nitrogen downslope over time in surface runoff.

Mass balance calculations were made of percent applied nutrient lost in surface runoff. Nitrogen losses in runoff were equivalent to 1.5 to 3.0 percent of input fertilizer nitrogen. Losses of phosphorus were equivalent to 0.3 percent of applied fertilizer phosphorus on both watersheds. Nitrogen was lost mainly in organic forms and phosphorus was lost mainly in the sediment phase of surface runoff.

A comparison between a watershed profile and a virgin profile showed evener and deeper distribution of phosphorus in the virgin soil. Total phosphorus and phosphate were higher in the cultivated soil, but percent organic matter was lower.

THE VERTICAL AND HORIZONTAL REDISTRIBUTION OF NITROGEN, CHLORIDE, AND PHOSPHORUS BY PRECIPITATION AND SURFACE RUNOFF ON TWO SMALL WATERSHEDS

By

Robert Kingsley Hubbard

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

1975

To My Wife

ACKNOWLEDGMENTS

The author is grateful to Dr. A. E. Erickson for guidance and for patient help in preparation of this thesis.

Thanks are given to Drs. B. G. Ellis, E. H. Kidder, and A. R. Wolcott for correcting the thesis and serving on the guidance committee.

The author thanks Ms. Elizabeth Shields and staff of the Soil Chemistry Laboratory for assistance and analytical work. Assistance in laboratory analyses and encouragement by my wife Rae are greatly appreciated.

Finally, the author expresses appreciation to Michigan State University, and the Southeast Environmental Research Laboratory of the Environmental Protection Agency, Athens, Georgia, for financial assistance during the Master's program.

TABLE OF CONTENTS

Page

LIST OF TABLES

TABLE		Page

LIST OF FIGURES

INTRODUCTION

Within the past century, American life has changed from a predominantly agrarian society barely able to meet its food and fiber needs, to a society fed and clothed as no other has been. Production efficiency has so improved that now only about 10% of the population grows the food for the rest of the nation. Although non-agricultural developments have played essential roles in the tremendous increases in agricultural production, adaptive research by agronomists has been of equal or greater significance. One third to one half of our present agricultural production depends on fertilizers. Research on plant nutrients and their movements is of tremendous significance.

Historically, the main concern with nutrients has been to provide correct kinds and quantities for optimum plant growth. Much of the first agricultural research concerned quantities of naturally occurring nutrients in the soil and their availability to plants. As chemical fertilizers became increasingly available, research shifted into studies of application rates and studies on fertilizer movement within the soil as related to crop production. The 1954 study by Lawton and Vomicil on dissolution and migration of phosphorus from granular superphosphate is a good example of the concern with fertilizer movement in the soil. Recent concern with fertilizers has shifted greatly into the area of pollution. As nitrates are a suspected health hazard, there is concern with movement into ground or surface waters. Phosphate is the prime limiting growth factor for algae in open bodies of water, so there is concern with pollution from phosphate. Present research on movement of fertilizers in and over soils concerns both plant nutrition and agricultural pollution.

Experimental watersheds with flumes for capturing and measuring surface runoff are ideal for studying many natural plant and soil processes and their relationships. Many experimental watersheds were originally conceived and built to study soil erosion. They were used to establish long time records of naturally occurring hydrologic events and soil erosion. Since there is less concern with soil erosion studies in America today, many recent researchers have used watersheds to study movement of agricultural chemicals in surface water.

Recent watershed research on movement of agricultural chemicals has been primarily concerned with the movement of nitrates and phosphates in the surface runoff. Nitrogen and phosphorus losses in surface runoff were studied intensively by Schuman, Burwell, Piest, and Spomer (1973). They related different crops and fertilizer rates to amounts of fertilizer lost in surface runoff. Similarly, other investigators have compared the effects of tillage methods or different methods of soil management on surface runoff losses of nitrogen and phosphorus (Klausner, Zwerman, and Ellis, 1974; Römkens, Nelson, and Mannering, 1973).

Unique to this study is concern with both loss of nutrients in surface runoff and vertical and horizontal redistribution of the nutrients on the watershed. Also unique is the collection and analyses of winter runoff. The objectives are:

1. To determine loss of nitrates and phosphates in surface runoff throughout a one and one half year period with specific fertilizer practices in relation to hydrologic events.

2. To determine downward leaching of nitrates, ammonia, and phosphates in the profile and their relation with corresponding hydrologic events.

3. To determine lateral redistribution of nitrates and phosphates down the watershed after runoff events.

4. To compare levels of current phorphorus with virgin soil and relate them to past fertilizer practices.

This study should provide a clearer picture of movements of both residual and applied fertilizers through, over, and off natural watersheds with naturally occurring rain and snow. Comparisons of phosphorus levels between virgin and cultivated soils should give a clearer idea of the effects of fertilization and cropping over time.

LITERATURE REVIEW

Nitrogen

Nitrogen in the Soil

Nitrogen found in the soil can generally be classified as inorganic or organic. The inorganic forms include NH_4^+, NO_3^-, NO_2^-, N_2O, NO, and elemental nitrogen, which is inert except for its utilization by Rhizobia (Tisdale and Nelson, 1968). The organic forms of soil nitrogen occur as consolidated amino acids or proteins, free amino acids, amino sugars, and other complex compounds (Tisdale, *et al.*, 1968). Native soil N consists primarily of the organic forms. A recent nitrogen characterization of Brenton silt loam for example, showed an average of 1.3% N in available mineral forms (NO_3^- plus exchangeable NH_4^+), 5.0% fixed NH_4^+, and 93.8% organic forms with the largest single amount occurring as amino acid - N (33.7%) (Allen, Stevenson, and Kurtz, 1973).

Addition of Nitrogen to Soil

Nitrogen is added to the soil naturally or with the aid of man. Nitrogen compounds in the atmosphere are returned to earth in rainfall in the form of ammonia, nitrate, nitrite, nitrous oxide and in organic combinations.

The ammonia comes largely from industrial sites, whereas nitrate is thought to form during electrical discharges, from industrial waste gases, or from the soil. Total amount of fixed nitrogen brought down in rainfall has been variously estimated to range between 1.12 and 56.00 kg/ha annually, depending on location (Tisdale et al., 1968). The total amount of N appearing annually in rainfall can be greater than that removed in surface runoff (Klausner, et al., 1974).

For centuries man provided nitrogen to his crops by the use of legumes in crop rotations and the application of animal manures. Legumes add nitrogen to the soil due to Rhizobia and other microorganisms living symbiotically on their roots and fixing atmospheric N. Nitrogen added in animal manures is primarily in organic forms.

Over the past two decades, nitrogen fertilization practices have changed from addition of animal manures or use of legumes to addition of nitrogen in chemical form. Most of the chemical sources of nitrogen are ammonia derivatives. The following ammoniacal compounds are used as sources of fertilizer nitrogen: anhydrous ammonia, NH_3 (82% N); anhydrous ammonia-sulfur (74% N, 10% S); aqua ammonia and other nitrogen salts (24-49% N); ammonium nitrate with lime, ANL (20.5% N); ammonium nitrate-sulfate (30% N, 5% S); ammonium sulfate (20.5% N, 23.4% S);

monoammonium phosphate, MAP (11% N, 21% P); diammonium phosphate, DAP (16-21% N, 21-23% P); ammonium phosphate-sulfate (16% N, 9% P, 15% S); ammonium chloride (26% N); urea (45% N); urea-sulfur (40% N, 10% S); and urea phosphates (Tisdale et al., 1968).

The Nitrogen Cycle

The nitrogen released from organic reserves and the fate of applied nitrogen fertilizer is dependent on the balance existing between factors affecting nitrogen mineralization, immobilization, and losses from the soil. Nitrogen mineralization is the conversion of organic nitrogen to a mineral (NH_4^+, NO_2^-, NO_3^-) form. Nitrogen immobilization is the conversion of inorganic or mineral nitrogen to the organic form. Losses of nitrogen from soils include crop removal, denitrification, and leaching.

Nitrogen is needed by heterotrophic soil microorganisms for the decomposition of organic matter. When organic materials with a C:N ratio greater than 30 are added to soils, there is immobilization of soil nitrogen during the initial decomposition process (Tisdale et al., 1968).

The mineralization of organic compounds consists of three reactions: aminization, ammonification, and nitrification.

Aminization follows the formula:

$$\text{proteins} \longrightarrow R\text{-}NH_2 + CO_2 + \text{energy} + \text{other products}$$

Ammonification follows the formula:

$$R\text{-}NH_2 + HOH \longrightarrow NH_3 + R\text{-}OH + \text{energy}$$

Nitrification is a biological oxidation of ammonia to nitrate. It is a two step process following the formula:

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + H_2O + 4H^+$$

$$2NO_2^- + O_2 \longrightarrow 2NO_3^-$$

Conversion of ammonia to nitrite is brought about largely by the obligate autotrophic bacteria *Nitrosomonas*, and conversion from nitrite to nitrate is brought about by the obligate autotrophic bacteria *Nitrobacter* (Tisdale *et al.*, 1968). All nitrogen fertilizers, regardless of the form applied, will ultimately be changed to the nitrate form of nitrogen (Edwards, Fischbach, and Young, 1972).

Denitrification occurs in waterlogged soils where anaerobic decomposition takes place and oxygen is excluded. Species of the genera *Pseudomonas*, *Micrococcus*, *Achromobacter*, and *Bacillus* obtain their oxygen from nitrates and nitrites with the accompanying release of nitrogen and nitrous oxide.

Movement of Nitrate Nitrogen

Nitrate nitrogen is completely mobile in soils and within limits moves largely with the soil water. With rainfall or irrigation, nitrate is leached out of the upper into the lower horizons of the soil. During dry weather and when capillary movement of water is possible there is an upward movement of the ion, related to the upward movement of water.

There are two main concerns with nitrate leaching. One is the loss of nitrogen for crop use, and the second is concern with contamination of ground waters. The only suspected health hazard from fertilizer is nitrate (Kurtz, 1970).

There have been numerous studies on nitrate leaching. In most soils nitrates move at an equal rate with downward moving water (Kurtz and Melsted, 1973). Articles by Stewart (1970) and Pratt, Jones, and Hunsaker (1972) assume that NO_3^- moves at the same rate as water and that adsorption is not a major consideration. Shaw (1962) states that there is little difference in the amount of rain required to remove nitrate from surface layers of light or heavy soils, but heavy and continuous rain is required to remove nitrate completely from either type of soil. Wallace and Smith (1954) observed that when nitrate was added to the surface of a 61 cm column of loam soil at field capacity, approximately 25.4 cm of water was required to leach 50% of the added nitrogen from the column, and 40.6 cm to remove 98% of the nitrogen. Wetselaar (1961) states that during dry periods there may occur appreciable reverse movement of nitrate, but this upward movement is usually confined to the upper 30.5 to 45.7 cm of soil.

Sommerfeldt and Smith (1973) studied the downward movement of NO_3^--N in dryland soils under native grass and concluded that with good management, fertilizer N on grassland soils is not an important contributor to groundwater pollution. Downward movement of NO_3^--N in the soil under native grass fertilized in 1961 at rates up to 976 kg/ha reached a depth of 180 cm by 1969. Depth of penetration of NO_3^--N with natural rainfall varied with the kind of vegetation growing on the dryland, being greatest under native grass. Under irrigation, the differences in the amount of NO_3^--N leached were attributed to management and the kind of crop growing on the land.

Edwards et al. (1972) concluded from irrigation studies that nitrates move essentially with the wetting front when soil is initially air dry, but do not move at the same rate as the water when the soil is initially saturated. They found that with a properly designed and managed irrigation system, little or no movement of nitrates outside the root zone occurs. Cassel (1971) compared downward movement of chlorides and nitrates between a plot covered to prevent exchange of water at the soil surface and a bare plot subjected to prevailing environmental conditions. Nitrate and chloride ions leached to a greater soil depth per unit of applied irrigation water on the covered plots where there was no evaporation. Linville and Smith (1971) traced nitrate nitrogen movement on corn plots after repeated nitrogen fertilization. Nitrate accumulation and losses by leaching and/or denitrification were found to be related to soil texture.

The coarser the texture and the greater the large pore space, the greater the mean downward movement of nitrates under the influence of a given quantity of added water (Tisdale _et al_., 1968). Nitrates can thus move quickly through sandy soils. Figure 1, from data of Olsen, Hensler, Attoe, Witzel, and Peterson (1970) shows movement of NO_3-N in a fallowed Plainfield sand over an 8 month period following the application of N as NH_4NO_3. NO_3 is expected to leach in similar manner on the sandy soils in this study.

Nitrates can also be lost through movement in surface run-off. A discussion of this phenomenon is included in the Watersheds section of the literature review.

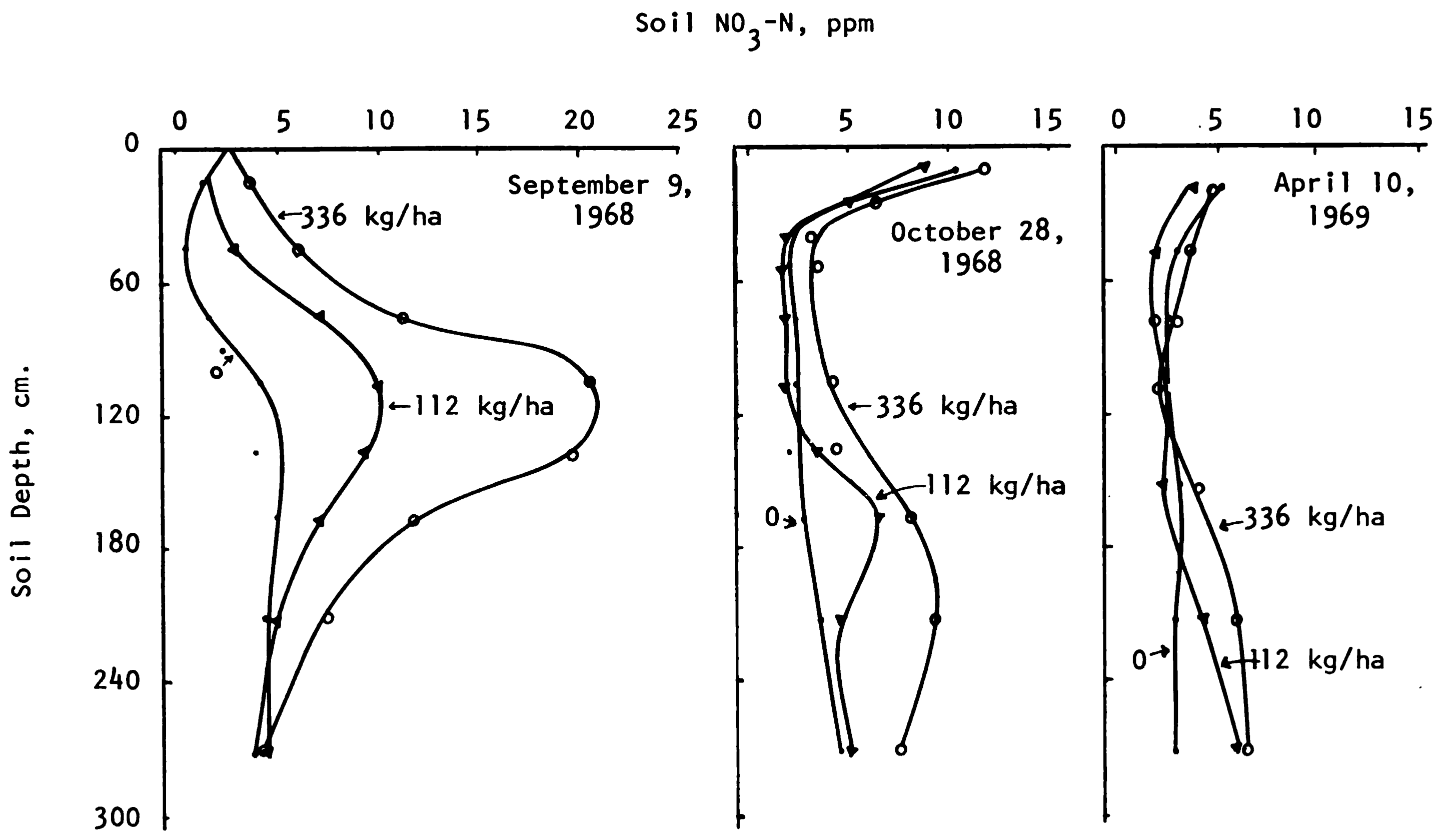


Figure 1.--Movement of NO_3-N in a fallowed Plainfield sand over an 8-month period following the application of N as NH_4NO_3 on August 1, 1968. The plot area received 30 cm of rain or irrigation between August 1 and September 9, 1968, 14 cm of rain between September 9 and October 28, 1968 and 16 cm of precipitation between October 28, 1968 and April 10, 1969. (Olsen et al., 1970).

Phosphorus

A variety of studies have been done on phosphorus diffusion in soils. In Michigan, Lawton et al. (1954) studied the dissolution and migration of phosphorus from granular superphosphate. At field capacity 50 to 80% of water soluble phosphorus moved out of the granules within 24 hours, and even in soils as low as 2 to 4% moisture, 20 to 50% moved from the granule into the soil in one day. Maximum movement was about 2.5 cm at soil moistures approximating field capacity and most of the movement occurred within one week.

Bouldin and Black (1954) investigated the validity of activity measurements as estimates of phosphorus diffusion from P^{32} tagged phosphate sources. Significant changes in the apparent specific activity of diffusing phosphorus were found, but could be accounted for by assuming exchange between diffusing P^{32} and native soil P^{31}. The overall picture of phosphorus diffusion obtained from activity measurements was not substantially different from that obtained by total phosphorus analysis.

A study by Phillips, Place, and Brown (1968) measured self-diffusion coefficients of P^{32} in kaolinite clay, montmorillonite clay, illite clay, Dundee silt loam soil, and Sharkey clay soil. Concentrated superphosphate was added to each clay or soil at the rates of 10,20,40,80,160 and 320 ppm. An interface between tagged and untagged clays and soils was created for each sample and the samples allowed to equilibrate. The experimental distributions obtained for the clays and soils were used to calculate self-diffusion coefficients. Self-diffusion coefficients and phosphorus rates of each clay and soil were found to be linearly and positively correlated.

Williams (1970) investigated the reaction of surface-applied superphosphate with soil. Phosphate moving into moist soil from particles of surface-applied superphosphate was found to penetrate a hemispherical zone beneath the particle. Size of the zone and distribution of phosphate through it were governed by the phosphate sorption capacity of the soil, size of the particle, and soil moisture. Leaching influenced the movement of phosphorus by distorting the hemispherical distribution of phosphate beneath superphosphate particles. The result was deeper penetration of phosphate below the particles and smaller horizontal movement away from them.

Vaidyanathan and Nye (1971) also worked with diffusion coefficients of phosphorus. By following the efflux of phosphate into a limited volume of well-stirred $CaCl_2$ solution, of the same ionic composition as the soil-pore solution except for lower initial phosphate concentration, the counter-diffusion of phosphate against chloride was measured. By varying this phosphate concentration, effective diffusion coefficients over a wide range of depletion were measured. Their experiment was designed to test the tentative conclusion that concentration-dependent diffusion coefficients of phosphate can most readily be calculated from the desorption isotherm of soil phosphate.

Hashimoto and Lehr (1973) surface applied ammonium ortho-, pyro-, tripoly-, tetrapoly-, and long-chain polyphosphates and cyclic ammonium tri- and tetrametaphosphates to soil columns. Measurements were made of the gross mobilities in soil in an attempt to determine the effect of chain length and structural configuration of mobility. General features of the distribution patterns were found to establish by the first week, after which soluble P moved much more slowly and the amount of immobilized P increased slowly. Total distance of movement and distribution patterns of water-soluble P were similar for all the phosphates tested, but the polyphosphates differed markedly in the degree of immobilization and differed significantly in the positions of maximum retention of P in the soil columns.

Phosphate is rarely moved more than a few centimeters from the point of application (Kurtz, 1970). Leaching of phosphate on soils of moderate textures is very small. However, for soils that are very sandy and contain little silt or clay, leaching of any element can be appreciable. The sand fraction is essentially inert and does not combine with even the "immobile" ions to prevent their movement in soil water. Downward movement of phosphate even on sandy soil is likely to stop in the lower soil horizons which tend to have more clay (Parker, 1972).

Humphreys and Pritchett (1971) investigated phosphorus adsorption and movement in some sandy forest soils. Soils were examined seven to eleven years after application of rock or superphosphate to locate the applied phosphates. Little or no residual P from superphosphate remained in the top 20 cm of soils with no P sorption or buffering capacity. Almost all of the superphosphate remained in an available form in the rooting zone in soils with a low P sorption and buffering capacity. In a soil with a high P sorption and buffering capacity most of the added P was retained in the surface horizon in a poorly available form.

Logan and McLean (1973a and 1973b) conducted column experiments on movement of P^{32} in three soils of varying chemical and physical properties. Two separate papers were written concerning their results; "Nature of Phosphorus Retention and Adsorption with Depth in Soil Columns" (1973a), and "Effects of Phosphorus Application Rate, Soil Properties, and Leaching Mode on P^{32} Movement in Soil Columns" (1973b). In the first paper, major effects on P movement were due to soil differences and P application rates. Leaching was greatest in the sandy loam soil. In the soils studied, the percentage of NH_4Cl-extractable P decreased rapidly in the initial 2 cm depth and then remained fairly constant. The percentage of NaOH-extractable P increased as that of NH_4F-extractable P decreased and that of H_2SO_4-extractable P increased gradually with depth. (In general, NH_4Cl and NH_4F-extractable P are forms more available to plants, and NaOH and H_2SO_4-extractable P are less available forms.)

The second article relates application rate, soil properties, and leaching mode to movement. Leaching of P increased with P application rate and intensity of leaching. Constant head leaching resulted in greater movement of P^{32} out of the surface layer and greater accumulation in the leachate than intermittent leaching. Significant amounts of P were recovered in the leachate only with sandy loam soil and at the highest P application rate. Figure 2 shows the effect of soil type on the distribution of P^{32} with leaching. Clearly phosphates can leach in sandy soils.

The primary method of loss of phosphorus from agricultural fields is soil erosion. Since nearly all phosphate is bound securely is the soil, erosion presents the greatest potential for loss of phosphate.

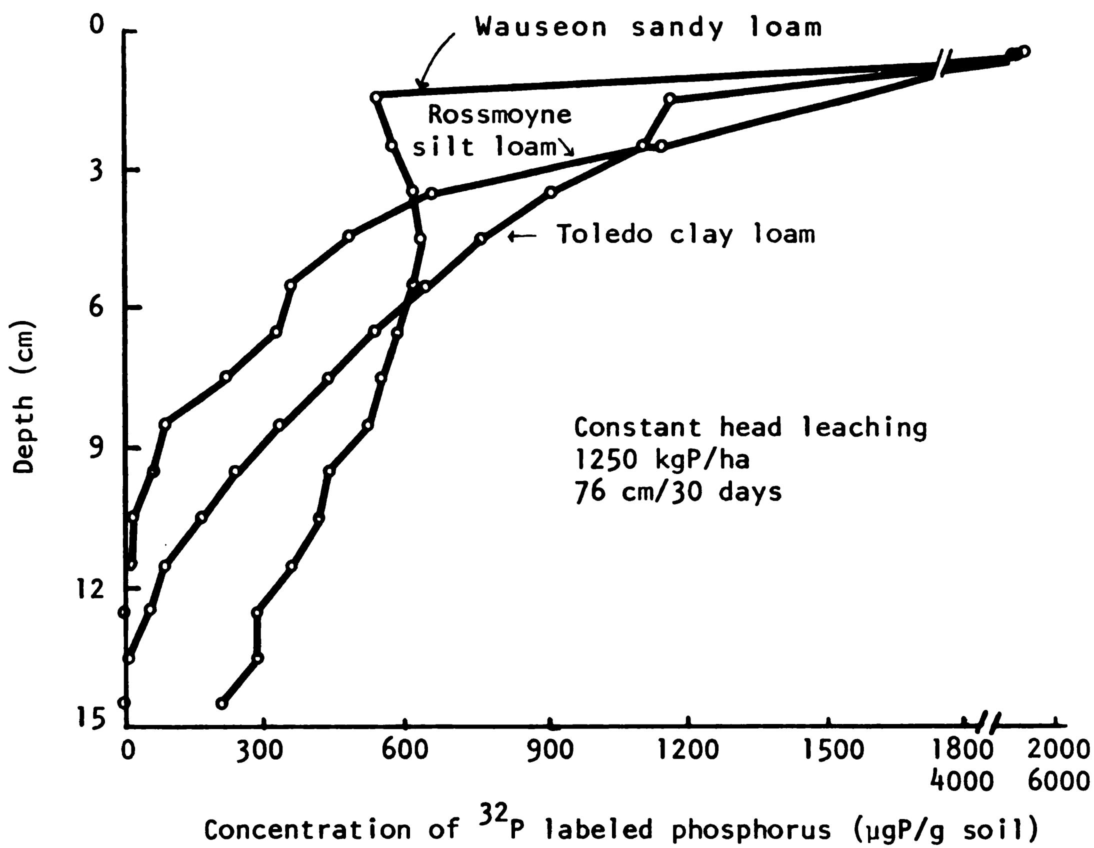


Figure 2.--The effect of soil type on the distribution of ^{32}P with leaching with high P application. (Logan et al., 1973b).

Chloride

The best way to trace the movement of soil water is to dissolve something in it that moves easily and can be easily traced. The chloride ion is usually considered as the most nearly ideal tracer, although negative or positive adsorption may be encountered to a limited extent in some soils (Kurtz et al., 1973). Comparisons of chloride with tritium as ground water tracers have shown that at high flow velocities (2.0 cm/hr) both move simultaneously through both glass beads and clay, but that at low flow velocities they move at different rates (Biggar and Nielsen, 1962). Corey and Fenimore (1968) compared chloride and tritium as groundwater tracers on acid kaolinitic soil and concluded that chloride and other negatively charged ions have limited usefulness as water tracers in acid soils. For most situations however, chloride is an excellent tracer of groundwater movement.

In addition to being useful for tracing groundwater movement, chloride is an excellent indicator of how nitrate should move. In most soils, they appear to move at an equal rate with each other and with the water. Fulcher and Tyner (1959) and Cassel (1971) have presented data indicating equivalent rates of movement of NO_3^- and Cl^-.

Simultaneous transport of chloride and water during infiltration was investigated by Kirda, Nielsen, and

Biggar (1973). It was determined that initial soil water content did not influence the depth of chloride displacement for a given quantity of water infiltrated; whereas keeping the water content at the soil surface below saturation resulted in a deeper and more complete displacement of chloride. A numerical method for predicting chloride distribution was outlined and was found to give satisfactory agreement with experimental data provided the predicted water content distributions were sufficiently accurate.

Chloride diffusivities in medium and fine-textured soils at moisture tensions from 1/3 to 15 atmospheres were measured by Porter, Kemper, Jackson, and Stewart (1960). Calcium and calcium-sodium soil systems were studied. Effective diffusivity of chloride was divided by the diffusivity of chloride in bulk water to obtain a transmission factor. In the Ca-saturated systems, the transmission factors of the different soil textures used were essentially straight-line functions of the moisture contents. Transmission coefficients in the sodium systems were similar.

Using chloride Smith (1972) investigated the phenomenon of anions moving through soil faster than the average velocity of the water molecules present. The theory behind such movement is that the greater average velocity of the anions is due to the fact that they are excluded from the immediate vicinity of negatively charged soil particles where the water is relatively immobile and from narrow pores where solution velocities are slow. Using 15 widely varying surface soils and 0.01N $CaCl_2$, he found that chloride moved through the soils 1.04 to 1.67 times faster than it would if it had been associated uniformly with all the soil water. Results of his study support the view that anion exclusion can be an important factor contributing to loss of anions from soil.

The ability of chloride to trace water movement and predict nitrate movement makes it quite important for watershed studies. Determination of chloride movements through soil and in surface runoff was thus essential in this study.

Watersheds

Watershed Models

In tracing movement of an agricultural chemical on a watershed eight compartments need to be considered. These are: the plant, surface water, surface soil, intermediate water, intermediate soil, groundwater, runoff, and erosion. These are shown in Figure 3. Adsorption, degradation, and volatilization are processes which affect agricultural chemicals while within these compartments, and may cause losses of the chemical separate from the effects of a hydrologic event.

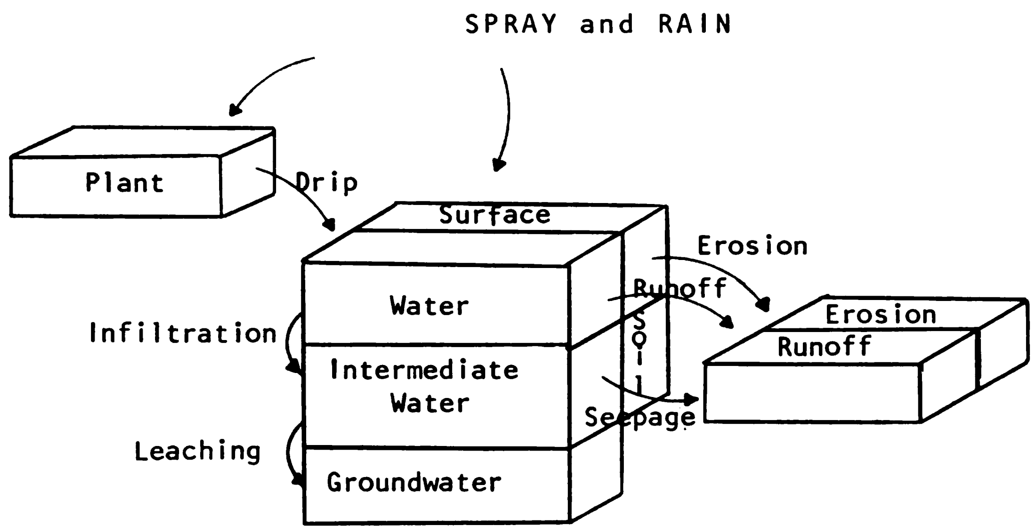


Figure 3.--Compartments of a model for chemical movement in watersheds. (Frere, 1973.)

During a storm chemicals in the surface water compartment and also chemicals in drip from the plant compartment are partitioned into infiltration to the intermediate water compartment, and into addition to the runoff compartment. In the runoff compartment the hydrology of the event and the physical condition of the watershed determine the amount of runoff and amount of sediment in the runoff. As a storm increases and runoff increases, amount of sediment moved increases but amount of adsorbed agricultural chemical moved may actually decrease, if it was initially all concentrated at the surface of the soil. The physical parameters of the watershed determine whether the infiltrating portion of water and chemical leach through the intermediate water compartment to the ground water or seep to the surface farther down the watershed into the runoff compartment. Time of travel, degradation rate, distance of travel, degree of adsorption, and rate of application determine the concentration of the chemical at the end of its path in either runoff or leaching (Frere, 1973).

Models to predict water yield from a watershed have always been of interest. Hamon (1966) developed a model for predicting water yield on a small grassed watershed utilizing a water balance concept. In his model the soil water available for evaporation was defined. Evaporation was computed equal to the potential evaporation rate, except for the last 30 mm which was lost at a reduced rate in proportion to the percentage of available water remaining in the soil. Recently, Richardson and Ritchie (1973) developed a model to predict soil water on a continuous basis for use in runoff prediction. In developing models such parameters as soil moisture, soil texture, soil structure, soil evaporation, soil drainage, plant cover, plant evaporation, amount of precipitation, and intensity of precipitation must be considered.

Movement of Agricultural Chemicals on Watersheds

Movement of nitrogen on watersheds has been examined by several authors. Sievers, Lentz, and Beasley (1970) found after applying fertilizer and rainfall to the Sarpy and Mexico soils, that most of the nitrogen was adsorbed by the soil rather than being removed by the runoff water.

Schuman *et al*. (1973) measured nitrogen losses in surface runoff from four field-size watersheds in 1969, 1970, and 1971. A watershed contour-planted to corn and a watershed in pasture were fertilized at the recommended N rate, (168 kg/ha). A level-terraced watershed and a watershed contour-planted to corn were fertilized at 2.5 times this rate. Nitrogen losses associated with sediment in the runoff accounted for 92% of the total loss for the 3-year period from the contour-planted corn watersheds.

The N loss for the terraced watershed was only one tenth that of the contour-planted watersheds, and a large portion of the N loss was also associated with the sediment. Sediment-N concentrations were similar for both watersheds receiving 168 kg/ha and those receiving 448 kg/ha annual N applications. Water-soluble-N and sediment-N losses in runoff usually were found to be highest at the beginning of the cropping season with progressive decreases throughout the year, reflecting a seasonal effect believed to be associated with nutrient removal by the crop, leaching, and N tie-up in organic matter.

Phosphorus losses were also measured from the same watersheds in 1969, 1970, and 1971 (Schuman, Spomer, and Piest, 1973). Two levels of fertilization were used. The heavily fertilized corn watershed lost approximately 1.8 times more P in solution and in the sediment than the normally fertilized watershed for the 3-year average. Therefore, greater P loss may be associated with higher application of P fertilizer. P concentrations in spring runoff from the pasture watershed were considerably higher than in runoff occurring later in the season. This was attributed to leaching of dead tissues of the forage crop. The P level of the runoff and sediment was much higher from all watersheds than from the uneroded loess material. The authors conclude that this was due to the sorting of soil particles which occurs during the erosion process with finer particles that have a greater adsorption capacity being most readily transported. A decrease in solution P in the runoff from the headcut to the weir was accompanied by an increase of P on the sediment transported. Decrease in solution P concentration was partially attributable to the adsorption of P by sediments from the gully.

Munn, McLean, Ramirez and Logan (1973) investigated effects of soil, cover, slope, and rainfall factors on soil and phosphorus movement using simulated rainfall. Quantity of runoff water, eroded solids, and P in the runoff was found to increase with degree of slope and rainfall intensity. A high correlation (r = 0.997) was found between total P in the runoff from bare plots and the quantity of soil eroded. Römkens and Nelson (1974) also used artificial rainstorms to study phosphorus movement. A linear relationship was found between rate of fertilization and soluble orthophosphate and sediment extractable phosphorus level in the runoff. A linear relationship was also found between soluble orthophosphate concentration in runoff water and extractable P content in sediment.

Surface runoff losses of nitrogen and phosphorus in relation to specific management practices are of concern in studying agricultural pollution. Klausner (1974) combined two rates of fertilization (high and moderate) and two soil management practices (good vs. poor) factorially to study annual losses of nitrogen and phosphorus as derived from natural rainfall. Ammoniacal N losses were found to be not significantly associated with crop, fertility level, or management practice. Values ranged from 0.14 to 1.30 kg/ha per year. Surface losses of nitrate N and inorganic P were directly influenced by crop, fertility level, and soil management. These losses ranged from 0.39-29.23 and 0.04-0.49 kg/ha per year, respectively. Except for heavy fall fertilization of N on poorly managed soils, the total yearly accumulative N discharge in surface runoff did not exceed the amount delivered in rainfall as measured during a 10-month period. Phosphorus losses exceeded the amount contained in rainfall.

The effect of agricultural management of wet sloping soil on nitrate and phosphorus in surface and subsurface water was studied by Benoit (1973). The results indicate that draining wet sloping land may decrease total soil nitrogen, that nitrate nitrogen may be lost from organic matter breakdown in cold but unfrozen soil, that nitrates but not phosphates will move both vertically and laterally through the soil to subsurface drains, that surface runoff contains few nitrates but significant concentrations of phosphates, and that more nitrates were lost from fertilized corn plots than from alfalfa plots or hay-pasture areas.

The effect of tillage methods on N and P composition in runoff water and sediment from corn (<u>Zea mays</u> L.) plots was investigated by Römkens _et al_. (1973) using simulated rainstorms. Coulter and chisel systems were found to control soil loss but runoff water contained high levels of soluble N and P from surface-applied fertilizer. Disk and till systems were less effective in controlling soil erosion, but had lower concentrations of soluble N and P in runoff water. Conventional tillage, in which fertilizers were plowed under, had the highest losses of soil and water but small losses of soluble N and P. High percentages of the total nutrients removed by runoff were components of the sediment from all treatments.

Experimental watersheds are versatile for studies of nutrient movement and agricultural pollution. They provide meaningful data which can be amplified according to models into data representing the whole of the earth's surface.

MATERIALS AND METHODS

Watersheds Site

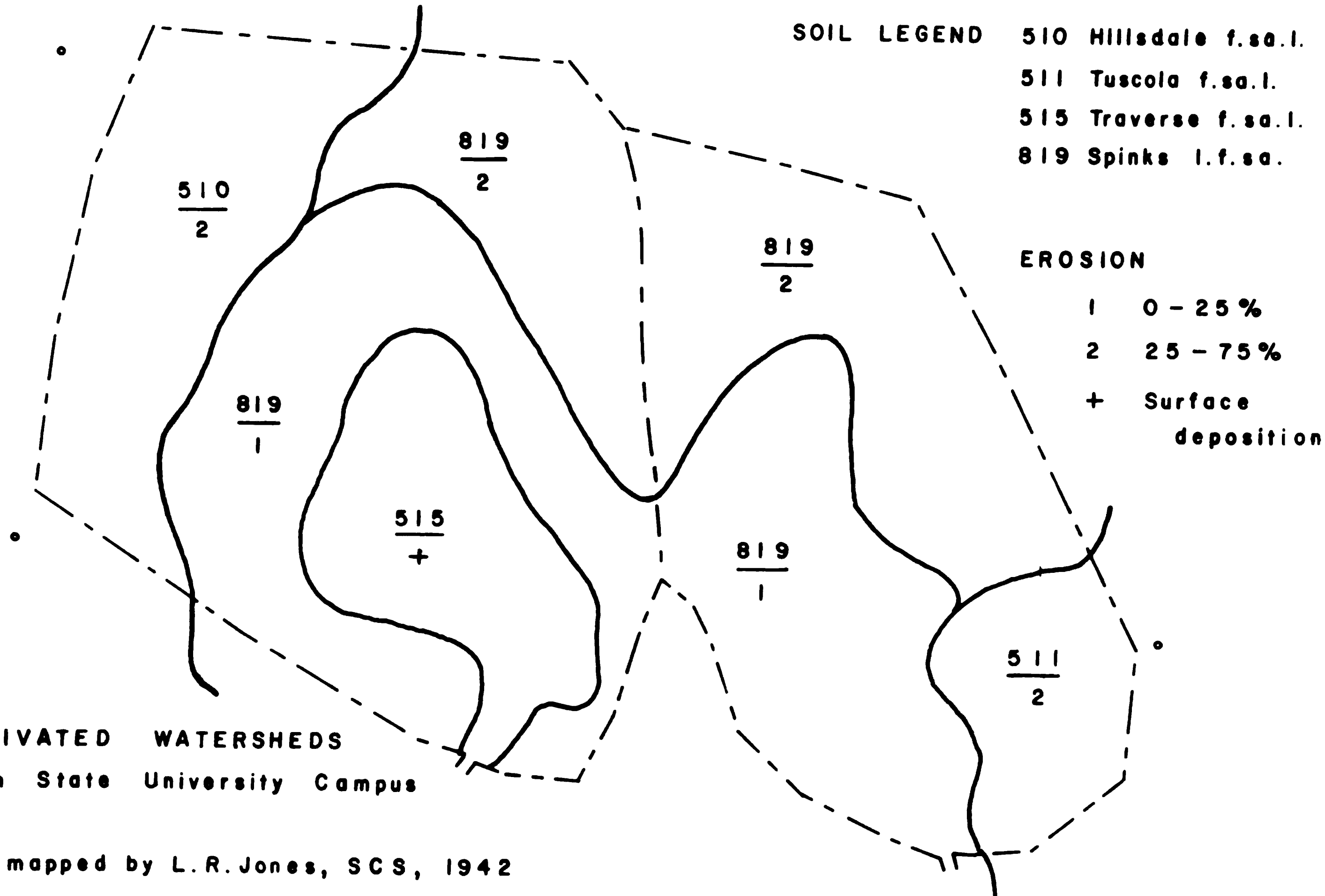
Two watersheds located on the Michigan State University Soils Farm were used for this study. The watersheds adjoin each other and drain from south to north. The east watershed is 0.80 hectares and the west one is 0.55 hectares.

Figure 4 is a soils map of the watersheds. Soil series description sheets may be found in the appendix. The soils found on the watersheds are sandy loams or loamy sands. Bands of finer textures may be found in the B horizons of several of these soil series and are prominent on the steeper slopes of the watersheds. Figure 5 is a contour map of the watersheds at 61 cm intervals.

Field Operations

The watershed study started in the spring of 1973 was primarily a study of pesticide movement. Nutrient analyses of soil and runoff in 1973 were made as background data for 1974. Consequently, the crops grown and fertilization practices on the watersheds differ between the two growing seasons.

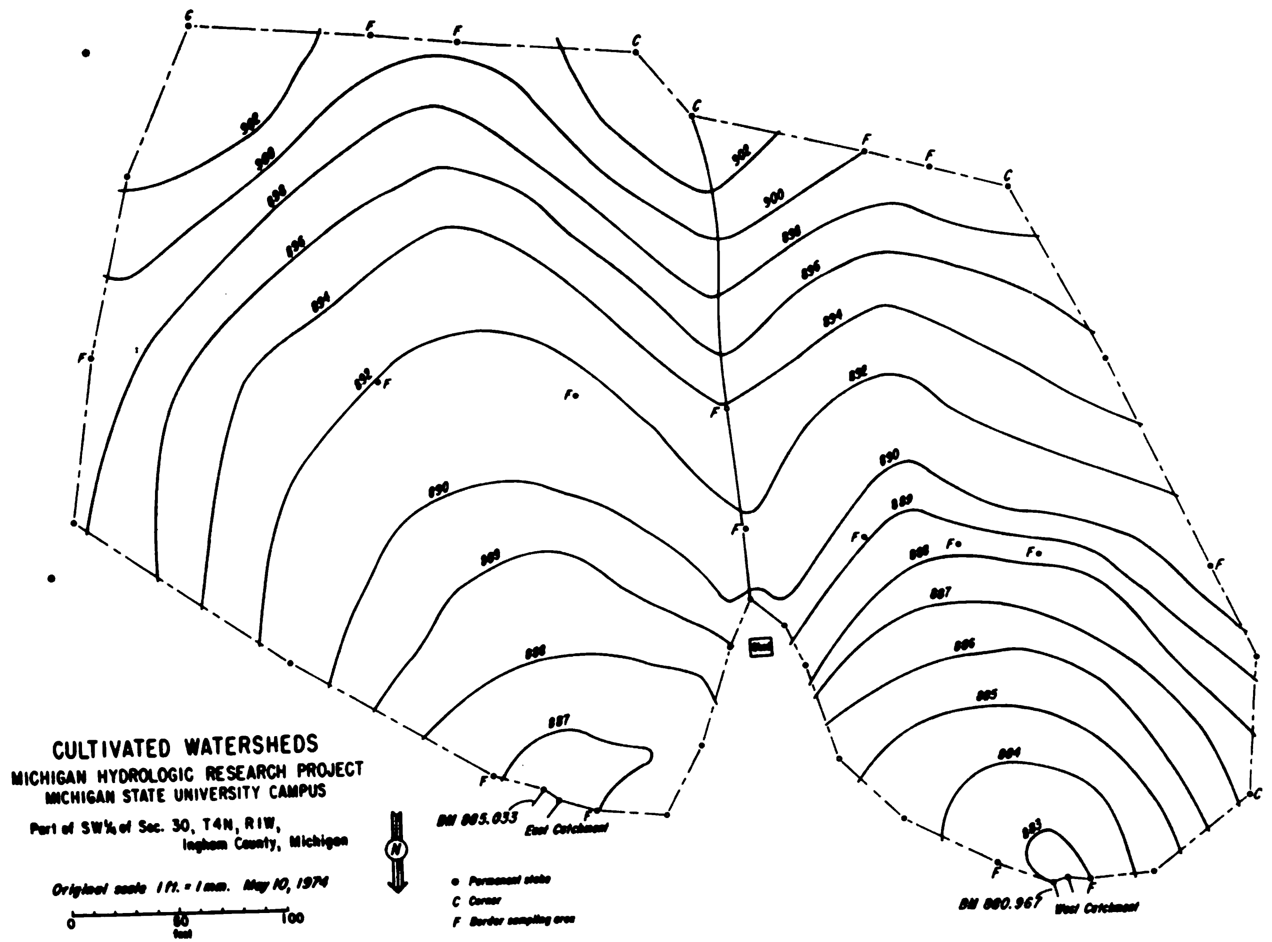
Figure 4.--Soil map of the watersheds.



CULTIVATED WATERSHEDS
Michigan State University Campus

Soils mapped by L.R. Jones, SCS, 1942
Profile descriptions, E.P. Whiteside, MSU, 1952

Figure 5.--Contour map of the watersheds.


CULTIVATED WATERSHEDS
MICHIGAN HYDROLOGIC RESEARCH PROJECT
MICHIGAN STATE UNIVERSITY CAMPUS
Part of SW¼ of Sec. 30, T4N, R1W,
Ingham County, Michigan
Original scale 1 ft. = 1 mm. May 10, 1974
0
50
feet
100
N
• Permanent stake
C Corner
F Border sampling area
BM 885.033
East Catchment
BM 880.967
West Catchment
902
900
898
896
894
892
890
889
888
887
886
885
884
883

In 1973 soybeans (*Glycine max*, var. Hark) were grown on both east and west watersheds. Fertilization consisted of broadcasting KCl and sidedressing basic fertilizer. One hundred twelve kg/ha of 60% KCl was broadcast through a grain drill with hoses removed. Two hundred twenty-four kg/ha of 12-12-12 was placed 3.8 cm to the side and 3.8 cm below the soybean seed.

Corn (*Zea mays*, var. Pioneer 3780) was grown on the east watershed in 1974, and soybeans (var. Hark) on the west. One hundred seven cm rows were used and the planter was set to deliver 54 to 59 thousand seeds per hectare for each crop. Basic fertilizer was broadcast on both watersheds and tilled in to a 7.6 cm depth, using a horizontal tool bar agitator. Calculated applications of the broadcast fertilizer based on actual deliveries over the estimated area were 68.4 kg/ha N, 93.0 kg/ha P, and 172.6 kg/ha K. An additional 130.0 kg/ha N was sidedressed on the corn only.

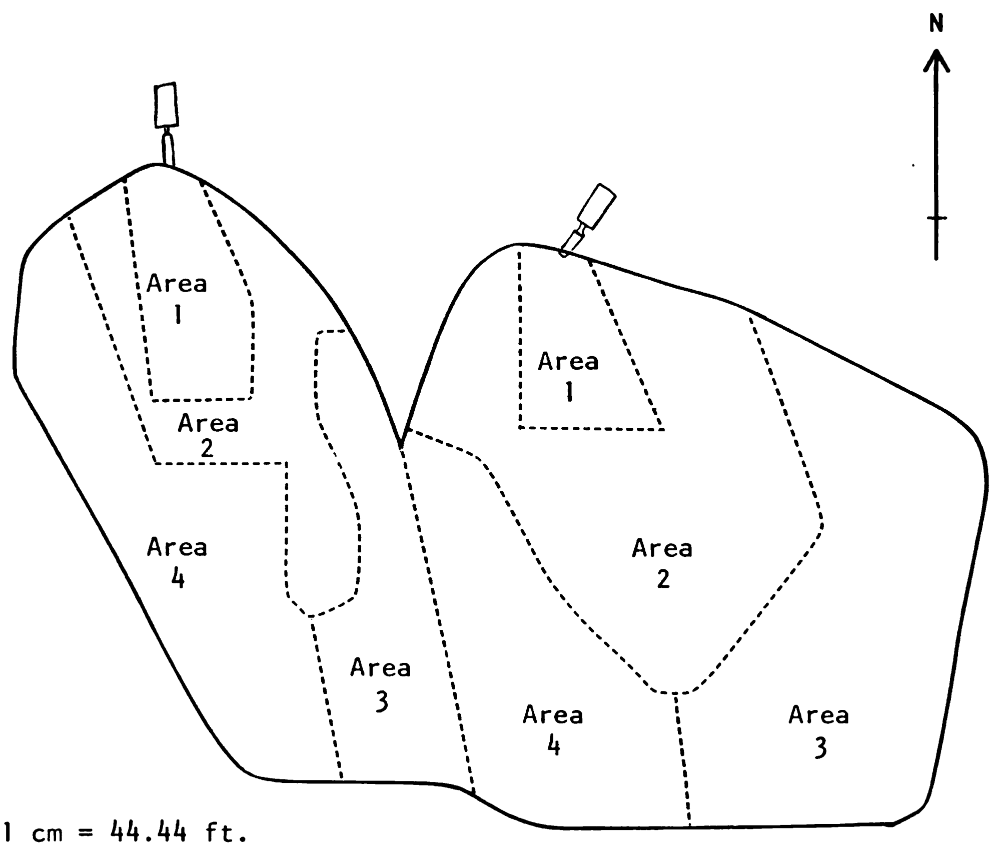
Soil Sampling Sites

Figures 6 and 7 respectively show the soil sampling areas for 1973 and 1974. Four sampling areas per watershed were used the summer and fall of 1973. The four areas on each watershed were:

1. flume approach (0 to 2%);
2. lower slopes (2 to 4%);

West Watershed (007)

Segment	Hectares
1	.07
2	.14
3	.11
4	.22
Total	.54



East Watershed (006)

Segment	Hectares
1	.05
2	.28
3	.25
4	.22
Total	.80

MSU WATERSHEDS

Sampling Segments 1973-74

Figure 6.--1973 Soil Sampling Areas.

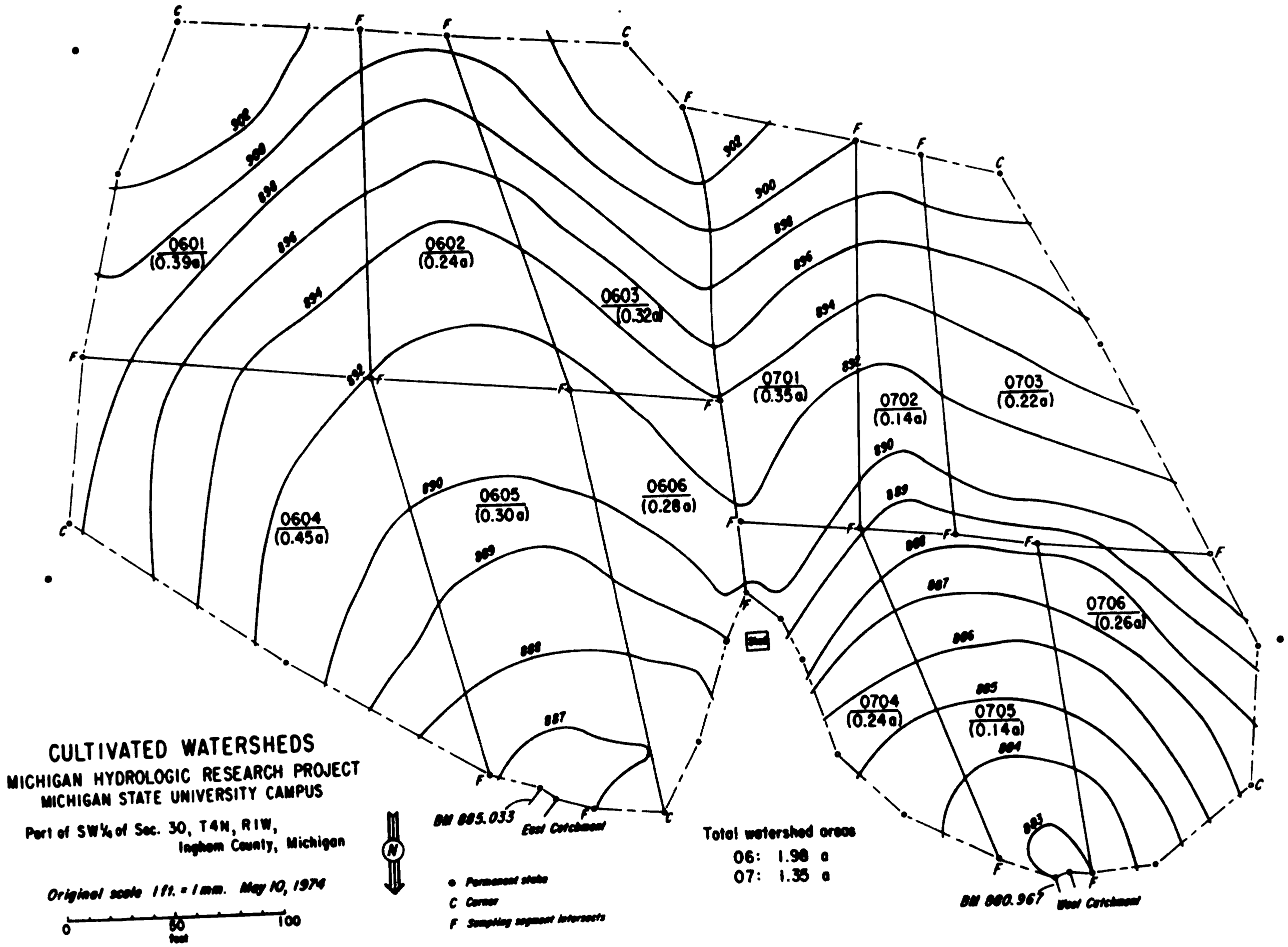


Figure 7.--1974 Soil Sampling Areas.

3. upper slopes (4 to 12%) east side of the watershed;

4. upper slopes (4 to 12%) west side of the watershed.

For 1974 the number of sampling areas per watershed was increased to six. This was done to better distinguish separate topographic features of the watershed. The areas were:

1. upper slopes (6 to 12%) east side of watershed;

2. concave upper part of the natural drainage-way;

3. upper slopes (6 to 12%) west side of watershed;

4. lower slopes (2 to 6%) east side of watershed;

5. flume approach (0 to 2%);

6. lower slopes (2 to 6%) west side of watershed.

Soil Sampling Methods

The incremental depths sampled in this study are:

1.	0 - 1.0 cm.	(0- 0.4 in.)
2.	1.0- 2.5 cm.	(0.4- 1 in.)
3.	2.5- 5.0 cm.	(1- 2 in.)
4.	5.0- 7.5 cm.	(2- 3 in.)
5.	7.5-15.0 cm.	(3- 6 in.)
6.	15.0-22.5 cm.	(6- 9 in.)
7.	22.5-30.0 cm.	(9-12 in.)
8.	30.0-38.0 cm.	(12-15 in.)
9.	38.0-46.0 cm.	(15-18 in.)
10.	46.0-61.0 cm	(18-24 in.)
11.	61.0-76.0 cm.	(24-30 in.)
12.	76.0-91.0 cm.	(30-36 in.)

Samplings were to four depths for the first three samplings in the spring and early summer of 1973. Samplings were to seven depths thereafter, except when the soil was too dry to reach increment seven. Samplings were taken to twelve depths in November, 1973, and again in May, 1974.

Soil samplings were made before and after fertilization and application of pesticides in the spring, and after each significant runoff event in both 1973 and 1974. Additional samplings were made when time between significant runoff events was quite long. Soil samples were also taken from a wooded area directly south of the watersheds in late fall 1973 to get a virgin soil similar to the watershed soils. Samples from the wooded area were taken to twelve depths and were composites of ten cores for the first nine increments and three cores for the last three. The virgin samples were used for comparison of nitrate, phosphate and chloride levels with the cropped soils of the watersheds. The soil series taken from the wooded area was judged to be Spinks sandy loam.

A sampling was taken in August, 1974, as a measure of variability of compositing. One hundred cores were taken from the east watershed. Fifty cores were taken from each of two areas. Five composited samples for each of two different increments on areas 1 and 3 of the 1973 system were collected. Depth increments one and five on each area were tested for variability. Total number of samples was twenty, or four replicates representing two depth increments each in two areas.

Most soil samples were collected from the watershed areas using a specially designed probe. One side of the probe was removable for measuring incremental depths, and the other side had an opening through which each increment could be removed without disturbing the rest of the core. For sampling loose surface soil in the spring, large spatulas were used in 1973, and specially designed tools similar to "cookie cutters" were used in 1974. The "cookie cutters" were made for the correct depths for increments one through four. The soil was cut with the "cookie cutter," and a spatula was slid under the cutter to support the sample as it was lifted from the ground. A conventional probe was used for increments between 30 and 46 cm, and a bucket auger for samples below 46 cm.

Soil samples were composited from each area to get one sample per area per increment. Ten separate cores were taken from each area and composited into one sample for depth increments three through nine. For the first two surface increments fifteen to twenty cores were taken to get sufficient samples for analysis. Three cores were taken per area and composited for depths below 46 cm.

In 1973, compositing of the ten or more samples into one was accomplished by hand mixing in glass jars or stainless steel cups. Improvement in compositing was made in 1974 by sieving the samples through an 8 mesh stainless steel screen into a stainless steel pot. Samples were then hand-mixed in the pots. The final field procedure with soil samples was to split the mixed composited samples in half. One part went into glass jars for the pesticide study, and the second part into seal-tite plastic bags for the nutrient study.

Collection of Runoff Samples

Runoff waters were collected from all runoff events. Splitting devices were located below the weir, and in the pipeline to the catchment house. A motorized Coshocton wheel in front of the weir gave a 100:1 split when running or a 5:1 split when the slot was stationary below the lip of the weir. A sample splitter in the line to the catchment house gave an additional 10:1 split when in use. In 1973, the 100:1 splitter was automatically turned on after 0.025 cm rain had fallen.

Samples collected in 1973 were either 1/100 or 1/1000 of runoff from the plots, except for several occasions when the motors on the Coshocton wheel failed. The sp

mo

or

Mo

ru

re

or

or

un

co

ti

ru

re

th

pe

an

ra

to

Th

de

tak

split during mechanical failure was 50:1. The system was modified in 1974 so that the Coshocton wheel was not turned on until after one pot of water had been collected. Since May of 1974, the first pot collected is always 1/50 of the runoff, and pots thereafter are 1/1000 of the runoff.

Event and Weather Monitoring Equipment

Runoff for each event was recorded on water stage recorders. These records were used to calculate total runoff in hectare-centimeters and to note duration and patterns of runoff intensity. In the few cases of mechanical failure of the water stage recorders, total volume of water collected was used to back calculate total runoff. The time at which each sample pot completed filling during a runoff event was recorded on a ten pen chart recorder.

Standard gravimetric and tipping bucket rain gauges recorded precipitation. Each .025 cm of rain falling in the tipping bucket gauge was recorded as one mark by one pen on a chart record. An electrical counter tied to another pen on the chart recorder counted every .30 cm of rain.

Tipping bucket and gravimetric records were used to calculate rainfall intensities and note rainfall patterns. The standard rain gauge was used for total rainfall. Snow depths were taken after each snowfall, and snow cores were taken periodically for equivalent moisture content during the winter. Additional weather information, including maximum and minimum air temperature, maximum and minimum water temperature, anemometer readings, and evaporation, was available from a weather station located at the watersheds.

Storage and Preparation of Samples

Soil and water samples from the field were kept in a refrigerated room at 35 F until analysis. Soil samples were stored in plastic seal-tite bags, and water samples in one gallon plastic milk jugs or glass bottles. Soil samples removed from the cooler for weighing analytical amounts were returned for future use.

Moist soil samples were mixed by stirring with a spatula when weighing samples for analysis. After completion of tests requiring moist samples, the sample was air dried on brown paper. The air dry soil was crushed with a rolling pin and sieved through a 10 mesh sieve where necessary.

Runoff was collected in 11.4 liter pots in the field. The 11.4 liter samples were split three ways before transferring from field to laboratory. A double funnel system accomplished the three way split. Sample poured into the upper funnel filled the lower funnel with maximum turbulence and mixing. The lower funnel had a three way splitter and three separate outlets. After splitting, 3.8 liters each were used for pesticide analyses, nutrient analyses, and sediment content determination. The 3.8 liter sample used for sediment content determination was split in half (using the three way splitter and tying off one outlet) again to get duplicate results.

Runoff samples for nutrient analyses were separated into water and sediment phases. Separation of sediment from water was accomplished using number 50 Whatman filter paper, Buchner funnels, and vacuum suction flasks. Approximately 250 ml of the separated water was run through 0.45 micron millipore filters to get the water phase completely free of sediment.

Determination of Sediment Content

Sediment content of runoff samples was determined by measuring one liter samples in a graduated cylinder. The sediment was precipitated with saturated $AlCl_3$, the water decanted, and the sediment oven-dried. Sediment content was expressed in grams per liter. Sediment content was also determined by personnel doing pesticide analyses. In their analyses, all sediment was precipitated with $CaCl_2$, and total volume of runoff sample was used in the calculations.

Chemical Analyses

Chloride, nitrate, and phosphate were determined on all soil samples from 1973. Total phosphorus and total carbon were determined on one watershed profile and the virgin profile from 1973. Kjeldahl nitrogen and ammonia in addition to chlorides, nitrates, and phosphates were determined for all 1974 soil samples.

Nitrates, ammonia, Kjeldahl nitrogen, chlorides, phosphates, and total phosphorus were run on the water phase of the runoff in both 1973 and 1974. Nitrates, Kjeldahl nitrogen, ammonia, and phosphates were run on the sediment phase in both years.

Nitrate

Twenty grams of moist soil were used for the soil nitrate analyses. Nitrates were extracted from the soil in a saturated $CaSO_4$ solution. The first one hundred fifty samples in 1973 were extracted with 50 ml saturated $CaSO_4$, a 2.5:1 dilution. Thereafter nitrates were extracted with 20 ml of saturated $CaSO_4$, a 1:1 dilution factor. Soil nitrates were determined using an Orion, Model 801, digital pH meter and the Orion selective-ion nitrate electrode (Dahnke, 1971). The calibration curve technique was used for calibrating the electrode. Standard solutions of 100, 50, 10, 5, 2.5, and 1 ppm NO_3 in saturated $CaSO_4$ were prepared. Millivolt readings were plotted on semilogarithmic paper with potentials on the linear axis and nitrate concentrations of the standard solutions on the log axis.

Nitrate ion concentrations of the unknown solutions were determined from the calibration curve.

Nitrate ion concentrations of runoff waters were determined using the Orion 801 digital pH meter and the Orion selective-ion nitrate electrode prior to May, 1974. Concentrations were read directly on the water samples. Starting in May, 1974, nitrate concentrations of runoff waters were determined using the Technicon Autoanalyzer II. In the Technicon Autoanalyzer II the initial step is to reduce the nitrates to nitrites using a cadmium-copper catalyst. The nitrites are then reacted with sulfanilamide to form the diazo compound which is then coupled in an acid solution (pH 2.0-2.5) with N-1 naphthyl-ethylenediamine hydrochloride to form the azo dye. The azo dye intensity, which is proportional to the nitrate concentration is then measured (U. S. Environmental Protection Agency, 1974).

Nitrate content of runoff sediment was determined by steam distillation with MgO and Devarda's alloy. One half gram sediment was used for the analyses. The steam distillation with MgO and Devarda's alloy for nitrate was done after removal of ammonia by steam distillation with MgO. In the nitrate analyses, the ammonia liberated by steam distillation was collected in boric acid-indicator solution and determined by titration with standard (0.009 $\underline{N}$) H_2SO_4.

Ammonia

Ammonia concentration of soil samples was also determined by steam distillation. Five grams of moist soil sample were shaken for one hour in 50 ml of 2N KCL and then filtered through number 42 Whatman filter paper. The filtered extract was steam distilled with .1N NaOH and the liberated ammonia was collected in boric acid-indicator solution and determined by titration with standard (0.009 N) H_2SO_4. Ammonia concentrations of runoff waters and sediments were both determined by steam distillation with MgO. Ten ml of runoff water or one half gram of sediment was used for the analyses.

Total Nitrogen

Total nitrogen in soil samples was determined by a semimicro-Kjeldahl method (Bremner, 1965). A one gram soil sample was digested with 1.1 g of K_2SO_4-catalyst mixture and 2 ml of H_2SO_4. The digest was neutralyzed with 20 ml of 10N NaOH and steam distilled into a H_3BO_3-indicator solution. The ammonium-N in the distillate was determined by titration with .01N H_2SO_4. The same method was used for the runoff waters and sediments except that 5 ml of H_2SO_4 instead of 2 ml was used for the runoff waters. Five ml of runoff water or one half gram of sediment was used for the analyses.

Chloride

All chloride analyses were done using the Orion selective-ion chloride electrode. The Orion 801 digital pH meter or a Sargent pH meter was used with the chloride electrode. Chlorides were generally done on the same extract or water sample and at the same time as nitrate determinations. For soil samples the $CaSO_4$ extract of 20 grams moist soil was used for both nitrate and chloride analyses. Chloride concentrations in runoff waters were read directly with chloride electrode and pH meter.

Phosphate

Available phosphates were extracted from air dry soil samples with Bray's solution (4 ml concentrated HCl and 2.22 grams NH_4F made to a volume of 2 liters). Five grams soil were extracted with 20 ml of Bray's solution. Charcoal was added to the samples to decolorize the solution in 1973 but not in 1974. The samples were shaken for five minutes and then filtered through number 42 Whatman filter paper.

Extracted soil phosphate concentrations were determined manually until May, 1974, and then were determined using the Technicon Autoanalyzer II. With both manual and Technicon phosphate determinations the chemical method used was a 1,2,4-aminonaphtholsulfonic-reduced molybdophosphoric blue color method in a hydrochloric acid system.

An Evelyn Photoelectric Colorimeter or a Bausch and Lomb Spectronic 20 was used to measure transmittance with the samples run manually.

Phosphate concentrations in runoff sediments were determined with the same methods as the soil samples. Two grams of sediment were used for the analyses.

Runoff waters were also analyzed for phosphates manually prior to May, 1974, and automatically thereafter with the Technicon Autoanalyzer II. Both methods of analyses involve ammonium molybdate and potassium antimonyl-tartrate reacting in an acid medium with dilute solutions of phosphorus to form an antimony-phosphomolybdate complex. This complex is reduced to an intensely blue-colored complex by ascorbic acid, and the color is proportional to the phosphorus concentration (U. S. Environmental Protection Agency, 1974).

Total Phosphorus and Carbon

Total phosphorus in runoff waters was determined by persulfate digestion followed by the same methods used in orthophosphate determination. Total phosphorus in soil samples was determined by perchloric acid digestion and the orthophosphate methods.

Total carbon was determined using a .100 gram sample which had been ground in a ball-mill shaker, and a Leco induction furnace.

RESULTS AND DISCUSSION

Hydrologic Events

Tables 1, 2, and 3 give weather and runoff information from June, 1973, through August, 1974. Table 1 shows total monthly precipitation. Table 2 shows runoff events and their magnitude (ha-cm), rainfall on the event date (cm), and the maximum 2 minute, 5 minute, and 10 minute rainfall intensities (cm/hr). Table 3 shows the four summer runoffs of highest magnitude, total rainfall prior to the start of runoff on the event date, duration of continuous rain after the start of runoff, and rainfall in the seven days prior to the runoff event.

Maximum total monthly precipitation occurred in November, 1973, (11-18 cm). Minimum precipitation was in July, 1974, (3.56 cm). Thirty five years of rainfall records for this location show that low monthly precipitation generally occurs in the summer months of June, July, and August.

The summer runoffs of 1973 were all of quite low magnitude. Winter runoffs of 1973-1974 were associated with snowmelt or rain on wet or frozen soil. Measurable summer runoffs occurred in July and August, 1974. The largest summer runoff occurred on August 13, 1974.

TABLE 1.--Total Monthly Precipitation from June, 1973, through August, 1974.

Year	Month	Precipitation in cm
1973	June	7.98
	July	3.68
	August	4.67
	September	7.95
	October	6.53
	November	11.18
	December	7.70
1974	January	7.90
	February	4.78
	March	10.92
	April	4.17
	May	10.49
	June	3.61
	July	3.56
	August	8.94

TABLE 2.--Runoff Events with Rainfall Data from June, 1973, through August, 1974.

Date	Watershed	Runoff Magnitude ha-cm	Total Rain cm	Maximum Rainfall Intensity by Time Intervals (cm/hr) 2 min	5 min	10 min
6-16-73	East	Trace	2.49	7.62	6.10	6.10
	West	Trace				
7- 2-73	East	Trace	1.14	5.33	4.32	3.05
	West	Trace				
8- 9-73	East	Trace	2.03	3.81	3.35	2.59
	West	Trace				
8-17-73	East	Trace	0.53	3.05	1.83	1.07
	West	Trace				
9-18-73	East	Trace	2.74	1.52	1.22	0.91
9-25-73	East	Trace	1.24	5.33	3.66	2.44
	West	Trace				
11-24-73	East	0.02	2.92	4.57	3.35	2.44
1-21-74	East	0.13	3.48	2.29	1.52	1.07
	West	0.01				
1-23-74	East	Trace	1.32	0.76	0.61	0.03
1-25-74	East	Trace		Snowmelt on east watershed		
1-26-74	East	0.16	1.12	3.81	2.13	1.83
	West	0.03				
2-22-74	East	0.74	2.08	0.76	0.61	0.61
	West	0.21		Snowmelt on both watersheds		
2-28-74	East	0.31				
	West	Trace		Snowmelt on both watersheds		
3- 2-74	East	0.06	0.43	1.52	1.22	0.91
	West	0.03				
3- 4-74	East	Trace	2.46	2.29	1.52	1.22
3- 8-74	East	Trace	2.54	3.05	1.83	1.07
3-30-74	East	Trace	1.62	1.52	0.91	0.76
4- 1-74	East	Trace	1.12	2.29	1.83	1.07
	West	Trace				
4- 3-74	East	0.02	1.27	4.56	3.66	2.90
	West	Trace				
5-11-74	East	Trace	1.68	6.10	4.88	3.05
	West	Trace				
5-16-74	East	0.01	3.51	6.10	4.57	3.66
	West	Trace				
5-17-74	East	Trace	1.17	3.05	2.74	1.52
	West	Trace				
5-29-74	West	Trace	1.09	4.57	3.66	3.20
7- 2-74	East	0.12	1.35	6.10	3.96	3.20
	West	0.05				
7- 9-74	East	0.01	0.89	7.32	7.32	7.32
	West	0.02				
8-13-74	East	0.72	3.23	9.14	7.32	6.10
	West	0.43				
8-27-74	East	0.54	3.18	6.10	4.88	4.72
	West	0.34				

TABLE 3.--Maximum Summer Runoffs and Related Factors.

Date	Watershed	Runoff Magnitude	Maximum Rainfall Intensity			Total Rain	Rain Prior to Start of Runoff	Duration of Continuous Rain after Start of Runoff	Total Rain in Previous Seven Days
			2 min	5 min	10 min				
		cm		cm/hr		cm	cm	Minutes	cm
5-16-74	East	0.01	6.10	4.57	3.66	3.51	0.43	120	0.33[a]
									0.71[b]
									0.08[c]
									1.68[e]
7-2-74	East	0.12	6.10	3.96	3.20	1.35	0.41	25	0.91[b]
	West	0.05							
7-9-74	East	0.01	7.32	7.32	7.32	0.89		15	0.71[e]
	West	0.02							1.35[g]
8-13-74	East	0.72	9.14	7.32	6.10	3.23	0.15	55	0.30[b]
	West	0.43							0.30[e]
8-27-74	East	0.54	6.10	4.88	4.72	3.18	0.76	30	0.08[d]
	West	0.34							

[a]Rain one day previous

[b]Rain two days previous

[c]Rain three days previous

[d]Rain four days previous

[e]Rain five days previous

[f]Rain seven days previous

Factors Influencing Runoff Magnitude

Table 3 shows information relating to the causes of summer runoff on the watersheds. Since all runoffs in summer, 1973, were of trace magnitude, only runoff events in July and August, 1974, are shown. From Table 3 the most important factors causing runoff were rainfall intensity and duration of continuous rain after the start of runoff. The maximum two minute rainfall intensity occurred on 8-13-74, the date of maximum runoff. On this date the longest continuous rainfall occurred after the start of runoff, excluding 5-16-74. The watersheds were plowed on 5-14-74 so loose soil structure was an important consideration in relation to runoff magnitude on 5-16-74.

Total rainfall on the event date was related to runoff magnitude. Total precipitation of 3.23 cm on 8-13-74 and 3.18 cm on 8-27-74 led to much greater runoffs on those dates than total rains of 1.35 cm on 7-2-74 and 0.89 on 7-9-74. Rain prior to the start of runoff on the event date might be related to runoff magnitude in 1974. Comparison between the events of 7-2-74 and 8-27-74 showed much greater runoff on 8-27-74. These dates have identical two minute rainfall intensities, and similar duration of rainfall after the start of runoff, but more rainfall prior to the start of runoff on 8-27-74. The five and ten minute rainfall intensities on 8-27-74, however, were larger than those of 7-2-74 so greater runoff cannot be attributed only to greater rainfall prior to runoff.

The total rainfall in the previous seven days, and thus the moisture content of the watersheds prior to runoff, clearly did not have the same importance in runoff magnitude that rainfall intensity and duration had in 1974. Maximum rainfalls prior to the event date occurred on 7-2-74 and 7-9-74, the dates with minimum runoffs in Table 3.

One factor which must be considered in analyzing runoff magnitude is the infiltration rate as influenced by the structure and bulk density of the soil surface. The data for 5-16-74 in Table 3 indicate that larger magnitudes of runoff should have occurred on that date. Rainfall intensity was high, total rainfall was high, rainfall in the previous week and thus soil moisture was high, and the duration of rain after the start of runoff was 120 minutes. The plow layer on 5-16-74 was loose and porous due to plowing on 5-14-74. Consequently, runoff was small. It was observed in both 1973 and 1974 that a compact surface structure conducive to runoff forms only after considerable time and rainfall, usually including several events that have the intensity to cause runoff but do not. This structure has usually formed by late July or August. The high runoff magnitudes of August, 1974, reflect that the surface soil had become hard and compact.

Runoff magnitudes during the winter depended primarily on amount of precipitation. The soil generally was frozen, or if thawed, quite saturated. Much lower intensity rains caused runoff during the winter period. The majority of winter runoffs were caused by snowmelt, and magnitude depended on amount of snow on the watershed and the rise in temperatures above 32 F.

Runoff Samples

Sediment Content

Table 4 includes the average sediment content (g/l) of runoff samples for the period 6-16-73 through 8-27-74. The data show relatively low sediment contents for the summer of 1973 with the exception of one high sediment sample on 7-2-73. Winter runoff was quite low in sediment except for the runoff of 1-26-74. This runoff was caused by rainfall on thawed ground in contrast to snowmelt over frozen ground on the other winter dates. The runoffs of 4-1-74 and 4-3-74 show increased sediment due to partially thawed and thawed soil respectively. Runoffs of summer 1974 were considerably higher in sediment than summer 1973 due to greater rainfall and runoff intensities. The higher sediment contents on 5-16-74, 7-2-74, and 7-9-74, as compared to 8-13-74 and 8-27-74, were due to the loose surface soil structure from plowing on 5-14-74.

Nutrient Content of Water Phase

Table 4 also shows the average nutrient content (ppm) of the water phase of the runoff samples. Nitrate nitrogen ranged from 0.3 to 6.4 ppm, NH_4/N from not detectable to 3.8 ppm, KjN/N from 0.8 to 4.9 ppm, Cl from 2.4 to 25.8 ppm, PO_4/P from 0.02 to 1.28 ppm, and total P from 0.05 to 1.32 ppm.

The only NO_3/N data of the summer water phase for 1973 show relatively high amounts of NO_3/N. These values are from 8-9-73, the largest runoff from a summer with very little runoff. High NO_3/N content of runoff on this date reflects little removal of NO_3/N in the previous runoffs of the summer of 1973.

Nitrate nitrogen content of the runoff water phase is quite low during winter 1973-1974. An increase on the east watershed on 5-11-74 (1.8 ppm) reflects the warmer soil and the release of nitrate as part of the nitrogen cycle. The high NO_3/N of the runoff water phases on 5-29-74 (2.1 ppm), 7-2-74 (4.0, 4.8 ppm), and 7-9-74 (8.8, 6.4 ppm) are directly attributable to nitrogen fertilization on 5-20-74. The increase in NO_3/N between 5-29-74 (2.1 ppm) and 7-9-74 (8.8, 6.4 ppm) represents the conversion of NH_4/N to NO_3/N, and the mineralization of organic nitrogen.

TABLE 4.--Average Nutrient Content (ppm) and Sediment Content (g/l) of Runoff Water on East and West Watersheds.

	NO_3/N		NH_4/N		KjN/N		Cl		PO_4/P		Total P		Sediment	
	E	W	E	W	E	W	E	W	E	W	E	W	E	W
	ppm		ppm		ppm		ppm		ppm		ppm		g/l	
6-16-73	---	---	---	---	---	---	---	---	---	---	---	---	0.06*	0.02*
7- 2-73	---	---	---	---	---	---	---	---	---	---	---	---	7.04*	0.06*
8- 9-73	1.4*	2.9	1.5*	0.03	3.4*	1.7	12.7*	12.2	0.26*	0.20	0.26*	0.20	0.91	1.07
9-18-73	---		---		---		---		---		---		0.05*	
11-24-73	0.5	0.4*	0.2	ND *	1.6	1.4*	6.9	8.2*	0.13	0.08*	0.05	0.08*	1.64	1.70
1-21-74	---	---	---	---	---	---	---	---	---	---	---	---	0.10	0.20
1-26-74	0.6	0.4	0.3	0.4	1.5	1.6	6.0	7.5	0.24	0.13	0.25	0.14	6.60	2.20
2-22-74	0.7	0.7	0.4	0.6	1.2	1.6	9.3	8.0	0.06	0.08	0.11	0.15	0.12	0.25
2-28-74	0.5	0.6	0.9	0.4	3.1	2.0	8.3	6.1	0.30	0.14	0.40	0.17	0.44	0.22
3- 2-74	0.7	0.8	0.4	0.6	1.8	1.8	5.3	5.2	0.08	0.08	0.14	0.15	0.34	0.12
3- 4-74	---	---	---	---	---	---	---	---	---	---	---	---	0.26	0.19
4- 1-74	0.5	0.8	0.2	0.7	0.8	1.7	10.2	12.4	0.05	0.02	0.08	0.07	1.96	2.01
4- 3-74	0.3*	---	0.1*	---	1.4*	---	7.5*	---	0.24*	---	0.05*	---	6.52	3.11
5-11-74	1.8*	0.7*	1.2*	1.2*	3.7*	2.9*	2.4*	2.9*	0.02*	0.06*	0.09*	0.07*	1.68*	5.18
5-16-74	0.8	1.2*	0.4	0.1*	1.8	1.6*	2.4	2.4*	0.07	0.08*	0.07	0.10*	5.60	6.64*
5-29-74		2.1*		3.8*		4.9*		9.6*		0.10*		0.88*		6.66*
7- 2-74	4.0	4.8*	0.7	1.2*	3.3	3.6*	18.0	13.8*	0.93	1.21*	0.64	1.32*	8.63	11.00
7- 9-74	8.8	6.4	1.6	1.6	3.1	4.6	22.1	25.8	0.94	1.28	0.86	0.73	3.20*	13.20*
8-13-74	0.9	1.0	0.5	0.4	2.0	2.0	4.4	4.0	0.46	0.63	0.48	0.56	3.04	5.10
8-27-74	0.5	0.5	0.6	0.3	1.6	1.4			0.49	0.38			3.42	2.80

*Only one sample available for analyses.
---Insufficient sample for analyses.
ND Not detectable.

The NH_4/N of the runoff water phase followed much the same pattern as the NO_3/N. The east watershed shows high NH_4/N (1.5 ppm) on 8-9-73, and both watersheds were low during winter 1973-1974. High NH_4/N on 5-11-74 (1.2, 1.2 ppm) represents an active nitrogen cycle in the spring plus any residue from the fall. The highest NH_4/N in the water phase was found on 5-29-74 (3.8 ppm), 9 days after fertilization. Ammonium nitrogen of runoff water phase decreased thereafter.

Kjeldahl nitrogen of the water phase shows a pattern similar to NO_3/N and NH_4/N. A high content of KjN/N was found on the east watershed on 8-9-73 (3.4 ppm). Winter 1973-1974 has low KjN/N content except for the east watershed on 2-28-74 (3.1 ppm). This particular runoff was the final melting of an extended snowmelt over partially thawed soil. Fine organic matter may have been differentially removed in this runoff. High PO_4/P content of the runoff from the east watershed on this date supports that conclusion.

Water phase KjN/N was high on 5-11-74 (2.9, 2.4 ppm). This was similar to the NO_3/N and NH_4/N data and reflected the status of the soil in early spring. The highest KjN/N was found on 5-29-74 (4.9 ppm), 9 days after fertilization. Kjeldahl nitrogen in the water phase of runoff samples decreased thereafter.

Chloride content of the water phase of runoff was similar to that of nitrogen. High Cl contents were found on 8-9-73 (12.7, 12.2 ppm), 4-1-74 (10.2, 12.4 ppm), 5-29-74 (9.6 ppm), 7-2-74 (18.0, 13.8 ppm), and 7-9-74 (22.1, 25.8 ppm). High Cl on 8-9-73 shows what was present after a summer with very little runoff. Low Cl contents during the winter reflect snowmelt. The high Cl content in the samples from both watersheds on 4-1-74 reflect rain on thawed soil in the spring. Soils data discussed later show higher Cl at the soil surface in spring 1974 than in fall 1973. This may account for higher removal of Cl by rain on thawed soil on 4-1-74 than on 1-26-74.

Chloride content of the water phase of runoff increased by 5-29-74 (9.6 ppm) after added fertilizer of 5-20-74. It continued to increase to a maximum on 7-9-74 (22.1, 25.8 ppm). Increasing Cl reflects the more even distribution of fertilizer over the watershed after initial application of the fertilizer granules. More even distribution of the fertilizer over the watershed (caused by dissolution and migration in soil solution) leads to greater chance for removal in runoff.

Phosphate phosphorus and total P content of the water phase of runoff follow both sediment content of the water and fertilization practices. Phosphate phosphorus and total P in parts per million are higher with higher sediment in grams per liter. Large increases were also noted after fertilization in spring, 1974. Phosphate phosphorus and total P contents were high on 8-9-73 (0.26, 0.20; 0.26, 0.20 ppm). This reflects what was present after a summer of little runoff. Phosphate phosphorus and total P were high again on the east watershed on 1-26-74 (0.24; 0.25 ppm). This was a runoff with high sediment removal in grams per liter. High PO_4/P and total P on the east watershed on 2-28-74 (0.30; 0.40 ppm) may reflect differential removal of lighter weight organic materials in a runoff over partially thawed to frozen soil as discussed under the Kjeldahl nitrogen section. Low PO_4/P and total P with high sediment removal on 4-1-74 (0.05, 0.02; 0.08, 0.07 ppm), 4-3-74 (0.24; 0.05 ppm), 5-11-74 (0.02, 0.06; 0.09, 0.07 ppm), and 5-16-74 (0.07, 0.08; 0.07, 0.10 ppm) reflect that most of the movable PO_4/P and total P were removed in previous runoffs. The high increases on 5-29-74 (0.10; 0.88 ppm), 7-2-74 (0.93, 1.21; 0.64, 1.32 ppm), and 7-9-74 (0.94, 1.28; 0.86, 0.73 ppm) reflect higher sediment removal in grams per liter but also reflect the application of phosphorus fertilizer on 5-20-74. Almost all phosphorus found in the water phase of runoff was found as orthophosphate.

Nutrient Content of Sediment Phase

Table 5 shows the average nutrient content in parts per million of the sediment phase of runoff for both watersheds. It also repeats specific sediment contents in grams per liter from Table 4. Nitrate nitrogen contents range from 7 to 34 ppm, NH_4/N from 10 to 112 ppm, KjN/N from 2751 to 5487 ppm, and PO_4/P from 92 to 378 ppm.

Nitrogen contents of the sediment phase of runoff do not show trends as clearly as the water phase. A decrease occurs in NO_3/N between summer and fall, 1973, and spring, 1974. This is followed by an increase in NO_3/N after fertilization on 5-20-74. Ammonium nitrogen seems quite high on 4-1-74 (92, 112 ppm), but this may represent ammonification in the very early spring. Ammonium nitrogen decreased in May, 1974, but increased after fertilization on 5-20-74. It continued to remain high during the summer. Kjeldahl nitrogen of the sediment phase shows only the trend of being high in April and May, 1974, prior to plowing.

Phosphate phorphorus in the sediment phase increased as sediment content of runoff increased. It also increased after fertilization in the spring of 1974. High sediment contents on 5-11-74 (5.18 g/l) and 5-16-74 (5.60 g/l)

TABLE 5.--Average Nutrient Content (ppm) of Runoff Sediment and Sediment Content (g/l) of Runoff Water on East and West Watersheds.

	NO_3/N		NH_4/N		KjN/N		PO_4/P		Sediment	
	E	W	E	W	E	W	E	W	E	W
	ppm		ppm		ppm		ppm		g/l	
8- 9-73	21*	23*	33*	31*	3432*	3207*	103*	112*	0.91	1.07
11-24-73	33		58		3820		119		1.64	
1-26-74	15	28	47	64	2751	4081	215	264	6.60	2.20
4- 1-74	16	19	92	112	4413	5487	140	170	1.96	2.01
4- 3-74	19*		44*		3881*		210*		6.52*	
5-11-74		7*		44*		4301*		92*		5.18
5-16-74	11		10		3344		102		5.60	
5-29-74		22*		95*		3938*		151*		6.66*
7- 2-74	23	34*	44	24*	3146	3051*	339	301*	8.63	11.00
7- 9-74	17	28	78	34	3420	3328	338	378	3.20*	13.20*
8-13-74	19	16	85	40	3054	3097	284	313	3.04	5.10
8-27-74	13	10	71	38	2865	3347	313	256	3.42	2.80

*only one sample available for analyses.

did not produce high phosphate contents, but after the fertilization of 5-20-74 both sediment contents in grams per liter and phosphate content of the sediment were high.

Soil Samples

Tables 6 through 21 give nutrient content in parts per million of soil cores from east and west watersheds by area and with depth for 1973 and 1974. The tables provide information regarding both downward and lateral movement of nutrients on the watersheds.

Sampling Variability

Table 22 shows data collected to determine soil sampling variability in the field. Five composite samples, comprised of ten cores each, were collected for four different increments from two different areas of the east watershed. The 1973 area scheme was used. The samples were collected on 9-12-74, a time when both NO_3/N and Cl content was low. Consequently, only PO_4/P was considered in calculating an s value. (The s value is the standard deviation, or root mean squared deviation of the numbers in a sample of size n. It is the square root of the variance.) Pooling data from all four PO_4/P area-increments gave an s value of 11.32 ppm. Pooling just the surface depths, area 1, 0-1 cm, and area 3, 0-1 cm, gave an s value of 14.34 ppm. Pooling the subsurface depths, area 1, 7.5-15 cm, and area

TABLE 6.--Soil Cores, East Watershed, 6-73 to 5-74 (ppm NO_3-N).

	6-9-73	6-18-73	7-4-73	8-11-73	9-30-73	11-5-73	5-2-74
Area 1							
Depth 1	13	20	21	16	22	7	19
2	15	15	22	13	17	4	5
3	15	16	23	20	14	3	4
4	15	21	30	40	18	5	4
5				37	19	9	5
6				24	21	15	5
7				14	19	11	5
8						8	3
9						10	2
10						18	2
11						8	2
12						4	2
Area 2							
Depth 1	12	17	23	20	22	25	14
2	12	14	12	10	13	4	5
3	8	15	14	17	10	4	4
4	9	17	13	18	15	3	4
5				61	16	6	6
6				20	26	7	6
7				9	12	9	5
8						9	2
9						6	2
10						9	2
11						4	2
12						2	2
Area 3							
Depth 1	10	16	17	35	18	6	15
2	10	15	15	23	16	5	5
3	10	14	16	23	10	3	3
4	9	18	28	24	27	3	4
5				18	21	5	5
6				10	16	8	5
7				2	16	8	4
8						8	2
9						8	3
10						4	3
11						4	2
12						3	2
Area 4							
Depth 1	9	13	25	8	21	4	13
2	12	11	19	9	13	4	4
3	8	13	15	9	17	2	3
4	9	16	17	17	17	5	4
5				20	15	5	4
6				15	11	5	6
7				5	14	7	4
8						9	3
9						7	2
10						6	2
11						5	2
12						2	2

TABLE 7.--Soil Cores, West Watershed, 6-73 to 5-74 (ppm NO_3-N).

	6-9-73	6-18-73	7-4-73	8-11-73	9-30-73	11-5-73	5-2-74
Area 1							
Depth 1	14	25	26	19	19	11	40
2	18	15	19	12	13	6	4
3	19	16	20	21	15	6	6
4	17	20	32	39	11	4	5
5				33	20	6	5
6				27	15	11	6
7				7	15	12	6
8						12	3
9						9	2
10						5	5
11						5	3
12						3	3
Area 2							
Depth 1	13	25	24	13	14	9	24
2	18	14	20	9	13	7	5
3	17	15	17	15	12	4	4
4	17	21	21	31	14	4	5
5				24	23	4	5
6				21	13	9	5
7					8	8	5
8						9	3
9						11	3
10						6	2
11						3	2
12						2	2
Area 3							
Depth 1	9	19	22	8	19	7	14
2	11	12	10	7	8	3	3
3	13	17	12	9	16	3	3
4	9	15	17	15	14	4	3
5				14	15	4	4
6				8	17	8	3
7					10	6	4
8						7	3
9						5	2
10						6	3
11						3	2
12						2	3
Area 4							
Depth 1	10	18	23	9	24	7	21
2	11	12	11	7	12	4	4
3	9	11	9	8	12	3	3
4	8	18	13	15	18	5	4
5				14	20	5	4
6				8	19	7	5
7					10	8	4
8						4	2
9						7	2
10						4	2
11						6	3
12						2	3

TABLE 8.--Soil Cores, East Watershed, 6-73 to 5-74 (ppm Cl).

	6-9-73	6-18-73	7-4-73	8-11-73	9-30-73	11-5-73	5-2-74
Area 1							
Depth 1	162	65	33	18	6	2	7
2	122	62	34	29	3	2	5
3	140	107	55	54	9	2	5
4	202	147	69	121	3	2	5
5				70	11	5	6
6				12	24	3	6
7				10	40	4	4
8						9	9
9						24	9
10						46	7
11						27	6
12						15	5
Area 2							
Depth 1	300	64	17	14	5	3	8
2	216	50	4	15	6	1	4
3	163	80	16	16	5	4	3
4	61	117	35	56	9	1	2
5				74	14	1	4
6				23	26	2	6
7				5	25	2	5
8						10	5
9						21	9
10						37	8
11						20	5
12						10	13
Area 3							
Depth 1	233	80	24	97	5	9	8
2	171	87	30	55	5	2	5
3	77	95	34	95	16	6	10
4	36	105	64	77	21	6	7
5				43	17	1	6
6				6	17	2	7
7				8	21	3	9
8						21	11
9						24	6
10						18	6
11						12	6
12						12	6
Area 4							
Depth 1	179	136	22	24	4	7	8
2	215	92	19	14	5	1	5
3	186	120	33	17	5	2	8
4	177	196	52	24	7	2	6
5				48	10	1	4
6				32	17	7	5
7				8	20	4	4
8						17	6
9						19	8
10						37	8
11						43	9
12						12	13

TABLE 9.--Soil Cores, West Watershed, 6-73 to 5-74 (ppm Cl).

	6-9-73	6-18-73	7-4-73	8-11-73	9-30-73	11-5-73	5-2-74
Area 1							
Depth 1	246	63	71	24	6	8	5
2	285	58	54	18	9	8	3
3	302	106	65	48	7	2	5
4	44	141	116	100	13	7	7
5				89	17	12	6
6				23	31	9	4
7				3	36	16	5
8						27	6
9						33	6
10						14	11
11						20	10
12						18	14
Area 2							
Depth 1	271	95	28	18	5	9	10
2	273	64	24	10	7	1	4
3	248	147	37	33	8	7	5
4	101	155	51	82	11	14	4
5				69	17	5	3
6				19	22	6	5
7					43	10	5
8						7	6
9						22	6
10						42	6
11						11	5
12						4	5
Area 3							
Depth 1	141	89	8	7	8	9	6
2	238	61	8	9	6	7	6
3	316	93	8	18	8	5	9
4	181	122	22	30	8	7	7
5				43	10	4	7
6				25	18	2	6
7					15	7	7
8						11	6
9						13	8
10						40	13
11						21	13
12						7	18
Area 4							
Depth 1	229	84	16	23	10	10	9
2	127	78	5	12	11	5	6
3	136	86	15	32	8	6	6
4	122	139	23	54	13	2	5
5				55	11	8	8
6				24	22	10	7
7					40	4	8
8						7	5
9						20	8
10						19	7
11						21	10
12						8	12

TABLE 10.--Soil Cores, East Watershed, 6-73 to 5-74 (ppm PO_4-P).

	6-9-73	6-18-73	7-4-73	8-11-73	9-30-73	11-5-73	5-2-74
Area 1							
Depth 1	96	96	89	96	94	76	86
2	93	95	93	102	106	92	96
3	95	90	94	112	102	91	97
4	101	92	89	112	106	89	94
5				118	108	88	99
6				106	99	93	96
7				107	81	70	46
8						32	24
9						7	12
10						8	6
11						4	7
12						6	8
Area 2							
Depth 1	94	94	94	92	90	79	92
2	100	91	103	98	98	88	96
3	95	93	94	93	91	94	98
4	87	95	104	90	94	85	96
5				90	94	86	102
6				90	89	86	105
7				69	70	68	100
8						23	26
9						6	10
10						3	6
11						4	6
12						6	7
Area 3							
Depth 1	66	72	90	65	76	82	70
2	75	79	80	72	84	87	94
3	80	80	84	88	90	90	105
4	77	82	92	82	80	88	104
5				92	90	91	101
6				98	68	74	102
7				36	43	47	62
8						16	10
9						14	6
10						6	5
11						12	9
12						10	11
Area 4							
Depth 1	82	92	87	90	90	76	78
2	80	92	92	100	94	92	96
3	82	94	93	97	91	88	94
4	83	92	84	96	80	97	98
5				97	88	104	107
6				98	72	106	102
7				55	39	104	83
8						18	22
9						9	18
10						4	5
11						5	8
12						6	6

TABLE 11.--Soil Cores, West Watershed, 6-73 to 5-74 (ppm PO_4-P).

	6-9-73	6-18-73	7-4-73	8-11-73	9-30-73	11-5-73	5-2-74
Area 1							
Depth 1	46	51	56	50	54	43	45
2	42	52	52	51	58	46	50
3	48	52	52	48	60	54	51
4	51	54	54	52	53	46	58
5				60	54	49	54
6				65	31	57	60
7				42	22	35	40
8						4	5
9						3	4
10						10	4
11						11	3
12						4	6
Area 2							
Depth 1	62	57	56	62	56	56	46
2	57	58	56	76	64	63	57
3	60	56	57	76	62	54	56
4	60	54	52	74	67	61	56
5				80	62	54	67
6				85	13	55	63
7					14	44	26
8						5	4
9						5	4
10						4	3
11						4	6
12						6	6
Area 3							
Depth 1	46	65	64	66	69	58	50
2	52	50	68	60	71	59	63
3	46	60	62	59	74	58	66
4	45	60	62	64	76	76	56
5				67	73	56	54
6				62	65	68	69
7					32	46	25
8						13	5
9						10	6
10						8	10
11						8	9
12						9	7
Area 4							
Depth 1	56	56	56	54	53	52	48
2	64	54	56	50	60	59	59
3	56	53	67	58	56	42	67
4	54	50	78	51	54	56	62
5				66	52	54	61
6				68	25	52	72
7					22	21	52
8						11	10
9						8	7
10						8	5
11						9	4
12						8	5

TABLE 12.--Soil Cores, E. Watershed, 5-74 to 9-74 (ppm NO_3-N).

		5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area	1						
Depth	1	88	21	114	10	6	1
	2	34	12	82	13	5	2
	3	25	25	103	50	14	4
	4	15	36	63	77	32	11
	5	4	15	20		60	18
	6	3	6	10		14	33
	7	2	6	7		3	4
Area	2						
Depth	1	29	22	55	4	4	1
	2	38	12	56	5	1	1
	3	39	16	14	5	2	3
	4	31	28	64	11	5	3
	5	0.5	10	24		22	13
	6	4	6	15		21	25
	7	5	10	11		14	6
Area	3						
Depth	1	50	8	40	4	1	1
	2	65	8	32	4	1	1
	3	65	14	47	11	1	2
	4	25	18	66	8	2	2
	5	5	16	26		4	4
	6	8	5	13		10	4
	7	7	3	10		1	21
Area	4						
Depth	1	52	14	98	10	5	1
	2	90	10	92	8	5	2
	3	51	16	93	17	18	4
	4	4	26	51	45	39	6
	5	6	15	14		40	11
	6	4	6	10		8	24
	7	5	6	7		1	2
Area	5						
Depth	1	61	18	235	5	2	1
	2	51	12	135	7	2	1
	3	35	19	113	14	4	2
	4	8	46	68	24	11	3
	5	4	29	20		22	13
	6	5	7	15		12	13
	7	6	7	10		3	10
Area	6						
Depth	1	33	16	182	5	1	1
	2	48	7	112	4	2	1
	3	35	14	142	13	2	1
	4	9	32	82	32	2	1
	5	5	36	18		8	2
	6	4	7	11		9	17
	7	5	6	8		2	10

TABLE 13.--Soil Cores, W. Watershed, 5-74 to 9-74 (ppm NO_3-N).

	5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area 1						
Depth 1	48	14	38	8	2	1
2	60	8	38	9	5	1
3	40	14	70	12	8	1
4	23	35	72	30	9	1
5	4	30	23		29	5
6	3	7	14		38	18
7	4	6	9		5	10
Area 2						
Depth 1	40	8	40	8	4	1
2	40	8	49	8	4	1
3	48	22	77	6	7	1
4	37	30	68	13	17	1
5	3	22	29		29	4
6	2	6	16		25	4
7	6	6	9		13	19
Area 3						
Depth 1	80	12	55	14	4	1
2	66	9	57	12	5	1
3	33	20	78	26	11	1
4	20	26	58	67	16	3
5	5	24	24		26	11
6	4	6	13		17	22
7	6	3	8		6	19
Area 4						
Depth 1	56	15	41	10	5	1
2	95	10	59	8	5	1
3	62	17	99	22	5	2
4	7	19	76	52	10	4
5	6	12	25		35	19
6	4	7	14		14	31
7	6	7	9		5	10
Area 5						
Depth 1	63	8	70	6	4	1
2	60	9	75	8	4	2
3	36	14	94	24	6	1
4	8	24	69	70	16	3
5	4	29	23		20	13
6	5	10	14		27	30
7	7	7	9		19	26
Area 6						
Depth 1	30	12	16	4	4	1
2	44	10	52	10	4	1
3	35	20	69	24	10	1
4	10	34	54	55	21	2
5	4	18	24		60	6
6	4	6	13		33	11
7	5	6	11		7	12

TABLE 14.--Soil Cores, E. Watershed, 5-74 to 9-74 (ppm NH_4-N).

		5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area	1						
Depth	1	42	26	14	11	5	9
	2	31	22	1	11	2	4
	3	25	25	6	9	1	0.5
	4	18	15	0.5	4	1	0.5
	5	2	0.5	1		0.5	1
	6	2	0.5	5		0.5	0.5
	7	3	0.5	14		0.5	0.5
Area	2						
Depth	1	30	23	2	5	4	9
	2	41	31	9	2	2	6
	3	52	20	7	1	0.5	2
	4	33	0.5	2	1	0.5	0.5
	5	2	0.5	1		0.5	0.5
	6	1	1	1		0.5	1
	7	2	1	1		0.5	1
Area	3						
Depth	1	46	23	112	3	3	8
	2	61	10	3	2	0.5	6
	3	80	14	2	1	0.5	1
	4	30	0.5	2	1	0.5	1
	5	4	1	2		0.5	1
	6	7	1	1		0.5	1
	7	3	1	2		0.5	2
Area	4						
Depth	1	40	14	34	12	6	12
	2	83	6	19	10	4	6
	3	57	2	4	6	2	0.5
	4	5	4	1	5	1	0.5
	5	3	0.5	1		1	4
	6	2	2	2		1	2
	7	2	0.5	2		0.5	0.5
Area	5						
Depth	1	48	21	7	13	4	12
	2	60	18	38	10	1	11
	3	37	15	14	2	1	0.5
	4	4	18	5	1	0.5	1
	5	2	3	2		0.5	0.5
	6	1	1	2		1	1
	7	1	1	1		1	0.5
Area	6						
Depth	1	28	20	20	10	5	8
	2	47	11	4	6	2	3
	3	40	38	3	4	1	0.5
	4	9	15	1	3	0.5	0.5
	5	1	2	1		1	1
	6	2	0.5	1		0.5	1
	7	3	0.5	1		0.5	0.5

TABLE 15.--Soil Cores, W. Watershed, 5-74 to 9-74 (ppm NH_4-N).

		5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area	1						
Depth	1	37	14	15	9	9	2
	2	48	7	6	6	4	0.5
	3	46	2	3	1	0.5	0.5
	4	20	8	2	1	1	<0.5
	5	<0.5	0.5	2		0.5	<0.5
	6	0.5	<0.5	2		0.5	<0.5
	7	0.5	<0.5	2		0.5	<0.5
Area	2						
Depth	1	53	16	12	12	5	1
	2	98	29	4	4	1	1
	3	101	20	3	1	1	<0.5
	4	36	14	2	2	0.5	<0.5
	5	0.5	1	3		1	<0.5
	6	0.5	0.5	1		0.5	0.5
	7	0.5	<0.5	2		0.5	0.5
Area	3						
Depth	1	59	22	14	12	8	2
	2	63	24	3	8	1	1
	3	33	26	2	6	0.5	0.5
	4	16	13	1	3	0.5	<0.5
	5	1	2	1		0.5	<0.5
	6	<0.5	1	3		0.5	<0.5
	7	0.5	0.5	2		0.5	<0.5
Area	4						
Depth	1	36	17	14	13	7	2
	2	33	14	10	11	6	2
	3	57	8	4	6	1	<0.5
	4	31	0.5	4	4	0.5	<0.5
	5	<0.5	<0.5	2		1	<0.5
	6	1	0.5	1		0.5	0.5
	7	0.5	0.5	2		0.5	0.5
Area	5						
Depth	1	54	20	20		12	4
	2	77	15	13	20	3	2
	3	47	12	12	7	0.5	0.5
	4	1	13	1	2	1	0.5
	5	1	4	2		1	0.5
	6	0.5	0.5	1		0.5	0.5
	7	<0.5	<0.5	1		0.5	<0.5
Area	6						
Depth	1	72	59	14	6	15	2
	2	54	37	4	6	9	1
	3	28	29	1	2	1	<0.5
	4	0.5	18	2	1	0.5	<0.5
	5	0.5	2	3		1	0.5
	6	0.5	0.5	3		1	0.5
	7	0.5	<0.5	2		0.5	<0.5

TABLE 16.--Soil Cores, E. Watershed, 5-74 to 9-74 (ppm KjN).

	5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area 1						
Depth 1	656	602	700	740	556	549
2	665	581	721	649	611	609
3	642	456	739	680	661	631
4	646	586	737	713	729	634
5	618	621	635		720	632
6	554	582	641		665	668
7	516	436	589		449	473
Area 2						
Depth 1	818	631	706	840	616	614
2	710	670	737	834	639	656
3	774	646	772	899	658	735
4	758	740	777	805	614	694
5	688	637	696		642	695
6	661	704	696		673	757
7	651	699	701		665	694
Area 3						
Depth 1	738	544	559	434	466	459
2	661	588	509	490	542	387
3	646	577	560	545	569	564
4	587	522	626	515	548	558
5	563	846	646		549	534
6	595	614	409		502	528
7	455	390	534		464	531
Area 4						
Depth 1	810	812	702	679	703	583
2	780	796	803	754	734	719
3	789	761	706	728	752	711
4	732	760	724	740	793	828
5	740	807	620		737	784
6	710	734	724		757	781
7	653	555	689		787	773
Area 5						
Depth 1	1022	788	1037	792	843	924
2	1033	916	972	855	799	926
3	1007	896	910	919	806	953
4	857	890	816	924	807	803
5	865	884	856		820	978
6	907	927	846		730	640
7	841	818	774		782	842
Area 6						
Depth 1	872	820	1007	877	862	758
2	884	874	1057	831	870	800
3	848	835	974	870	862	842
4	892	833	841	855	817	889
5	832	672	825		876	721
6	811	901	788		843	791
7	823	566	652		832	811

TABLE 17.--Soil Cores, W. Watershed, 5-74 to 9-74 (ppm KjN).

	5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area 1						
Depth 1	756	771	598	693	606	588
2	840	800	571	643	648	641
3	722	706	676	672	648	673
4	661	742	629	697	654	655
5	692	707	653		754	583
6	764	853	626		770	702
7	625	604	540		619	570
Area 2						
Depth 1	786	702	673	712	700	610
2	791	638	730	741	788	807
3	789	570	637	808	798	839
4	804	721	799	628	833	812
5	727	583	812		783	801
6	783	853	758		817	768
7	552	604	674		782	866
Area 3						
Depth 1	843	702	695	667	608	663
2	755	638	734	649	716	655
3	666	570	307	690	718	689
4	757	721	672	737	765	679
5	700	583	691		718	706
6	625	657	559		679	726
7	624	363	485		617	775
Area 4						
Depth 1	841	800	744	786	842	559
2	812	773	824	830	817	797
3	806	787	785	867	879	800
4	845	582	813	793	849	739
5	771	676	792		814	751
6	823	668	582		838	746
7	692	534	630		752	753
Area 5						
Depth 1	1006	874	913	871	855	937
2	998	894	1002	901	847	903
3	885	896	988	969	879	1002
4	924	864	964	1007	891	916
5	915	836	977		911	930
6	970	884	939		891	954
7	761	729	744		861	975
Area 6						
Depth 1	835	710	485	745	716	545
2	678	773	645	714	757	537
3	825	798	764	711	743	615
4	717	678	754	760	748	612
5	751	678	648		731	587
6	749	749	712		716	549
7	638	640	694		737	539

TABLE 18.--Soil Cores, E. Watershed, 5-74 to 9-74 (ppm Cl).

		5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area	1						
Depth	1	155	95	232	6	4	3
	2	189	58	175	8	3	5
	3	210	90	220	23	14	8
	4	230	219	132	54	38	11
	5	14	141	30		96	20
	6	5	9	4		17	35
	7	4	6	8		4	10
Area	2						
Depth	1	225	59	95	3	7	3
	2	215	41	65	3	3	2
	3	170	50	122	3	4	3
	4	100	119	108	11	11	5
	5	9	110	44		14	27
	6	4	25	12		28	66
	7	3	12	6		18	20
Area	3						
Depth	1	185	31	69	5	4	3
	2	175	34	59	3	3	2
	3	130	52	103	5	4	4
	4	165	99	165	8	4	6
	5	22	95	63		11	10
	6	7	22	10		21	17
	7	4	4	6		3	66
Area	4						
Depth	1	185	119	158	7	4	3
	2	165	110	122	6	8	3
	3	54	205	182	10	12	4
	4	24	325	108	27	45	7
	5	26	196	14		72	24
	6	7	25	6		22	44
	7	7	11	5		3	5
Area	5						
Depth	1	240	50	300	4	2	2
	2	220	39	182	5	2	2
	3	150	73	170	10	5	2
	4	37	172	125	28	12	6
	5	16	129	30		27	34
	6	7	132	14		18	40
	7	6	9	9		3	26
Area	6						
Depth	1	165	31	380	4	4	2
	2	145	27	232	3	2	2
	3	150	42	265	5	3	3
	4	60	130	150	14	4	3
	5	7	134	38		13	10
	6	5	14	10		17	66
	7	7	2	15		6	36

TABLE 19.--Soil Cores, W. Watershed, 5-74 to 9-74 (ppm Cl).

	5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area 1						
Depth 1	170	26	82	3	3	2
2	140	26	80	5	4	2
3	100	48	135	6	5	3
4	45	172	160	16	7	2
5	35	180	54		21	11
6	16	23	11		26	50
7	14	12	6		4	42
Area 2						
Depth 1	220	27	90	4	3	2
2	205	46	100	3	2	2
3	155	73	170	4	6	2
4	84	114	150	6	14	3
5	15	109	50		29	8
6	8	23	10		26	52
7	12	11	8		23	96
Area 3						
Depth 1	170	43	86	8	3	2
2	120	41	90	7	3	2
3	60	66	185	20	7	3
4	72	120	142	47	15	3
5	21	62	54		23	12
6	15	6	12		20	40
7	11	5	5		6	66
Area 4						
Depth 1	270	105	65	6	5	2
2	210	41	115	5	4	3
3	76	95	200	17	3	2
4	21	130	153	42	8	6
5	26	40	33		29	70
6	6	5	5		12	26
7	7	9	8		2	22
Area 5						
Depth 1	460	28	125	4	2	2
2	370	28	105	6	2	2
3	185	44	160	14	4	2
4	35	110	107	36	6	4
5	14	70	29		24	14
6	8	13	8		38	59
7	6	5	9		23	60
Area 6						
Depth 1	230	42	105	8	2	2
2	170	38	120	6	2	2
3	220	100	225	29	6	2
4	62	130	175	18	18	3
5	8	75	60		37	10
6	5	8	7		47	20
7	7	5	5		5	28

TABLE 20.--Soil Cores, E. Watershed, 5-74 to 9-74 (ppm PO_4-P).

		5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area	1						
Depth	1	118	125	132	126	133	137
	2	134	178	135	145	139	148
	3	152	163	119	197	156	126
	4	152	122	126	222	150	104
	5	92	113	96		99	91
	6	73	108	110		103	100
	7	52	58	62		95	49
Area	2						
Depth	1	144	127	137	148	126	134
	2	144	176	151	195	140	153
	3	175	166	212	256	242	203
	4	146	136	175	136	175	192
	5	99	104	122		111	115
	6	98	113	109		109	104
	7	87	99	103		115	111
Area	3						
Depth	1	157	113	136	110	133	113
	2	206	132	153	158	144	144
	3	203	154	136	186	175	207
	4	212	152	122	169	124	191
	5	123	99	110		109	120
	6	99	102	112		107	99
	7	62	72	85		89	90
Area	4						
Depth	1	138	125	110	125	110	108
	2	131	161	161	169	141	125
	3	159	142	155	159	167	141
	4	94	106	114	129	144	86
	5	94	87	87		99	76
	6	89	88	98		86	80
	7	65	66	52		77	77
Area	5						
Depth	1	118	122	169	171	183	154
	2	140	144	212	159	222	190
	3	157	168	150	135	185	292
	4	113	122	148	112	129	148
	5	117	99	104		104	95
	6	92	101	100		110	105
	7	84	85	74		101	89
Area	6						
Depth	1	102	136	137	152	164	155
	2	150	144	157	186	200	196
	3	237	150	191	199	191	183
	4	168	123	152	148	135	121
	5	84	88	84		103	104
	6	80	93	82		94	98
	7	67	53	59		98	107

TABLE 21.--Soil Cores, W. Watershed, 5-74 to 9-74 (ppm PO_4-P).

		5-22-74	5-30-74	7-3-74	8-5-74	8-14-74	9-3-74
Area	1						
Depth	1	97	97	130	141	111	119
	2	175	126	134	177	160	138
	3	154	130	131	132	161	132
	4	98	122	100	89	115	95
	5	84	77	78		72	74
	6	69	66	67		73	70
	7	44	41	42		48	47
Area	2						
Depth	1	106	115	132	128	157	152
	2	154	163	136	139	177	160
	3	142	193	135	154	182	185
	4	115	122	84	122	185	122
	5	73	83	80		101	95
	6	62	72	77		83	90
	7	53	40	61		85	83
Area	3						
Depth	1	118	120	122	132	109	119
	2	107	190	197	141	95	161
	3	166	128	172	165	97	146
	4	113	95	106	129	93	81
	5	66	64	68		81	66
	6	60	58	66		70	63
	7	50	34	26		92	57
Area	4						
Depth	1	92	119	105	107	56	101
	2	197	124	148	117	79	106
	3	152	83	111	133	100	87
	4	80	61	64	126	61	68
	5	53	69	55		69	54
	6	69	48	50		67	57
	7	36	25	40		55	50
Area	5						
Depth	1	108	75	134	91	121	122
	2	144	122	158	157	145	142
	3	125	134	165	183	78	154
	4	49	88	114	139	88	122
	5	53	62	60		77	64
	6	49	50	55		66	57
	7	36	39	35		128	57
Area	6						
Depth	1	69	84	102	105	54	90
	2	142	140	136	131	126	304
	3	87	224	145	171	122	126
	4	57	103	82	108	55	86
	5	45	48	49		113	70
	6	40	47	50		61	57
	7	40	20	30		52	68

TABLE 22.--Nitrate Nitrogen, Chloride, and Phosphate Phosphorus Content in Parts per Million of Five Composited Soil Samples per Depth for Variability Studies.

Watershed	Area	Depth cm	NO_3/N ppm	Cl ppm	PO_4/P ppm
East	1	0-1	5	3	138
East	1	0-1	5	3	130
East	1	0-1	5	2	154
East	1	0-1	4	3	148
East	1	0-1	5	3	164
East	1	7.5-15	7	10	102
East	1	7.5-15	8	10	100
East	1	7.5-15	5	13	88
East	1	7.5-15	5	12	99
East	1	7.5-15	5	6	96
East	3	0-1	8	7	118
East	3	0-1	10	8	114
East	3	0-1	18	14	138
East	3	0-1	7	6	124
East	3	0-1	9	9	96
East	3	7.5-15	15	21	102
East	3	7.5-15	19	21	103
East	3	7.5-15	13	11	83
East	3	7.5-15	28	19	92
East	3	7.5-15	21	17	90

3, 7.5-15 cm, gave an s value of 7.12 ppm. These values can be used as a very rough guide for determining significant differences in PO_4/P content between dates and between areas of the watershed.

In 1973 112 kg/ha of 60% KCl was broadcast, and 224 kg/ha of 12-12-12 was sidedressed on both watersheds. Because of this relatively low fertilizer application the soils data in 1973 do not show a great deal of nutrient movement and redistribution. The high application of KCl makes chloride easily traceable. The 1973 data primarily show types of movements on lightly fertilized watersheds and serve as background data for 1974.

Nutrient Content in 1973

The NO_3/N data in 1973 show increases in NO_3/N content of the fourth increment on area 1 of both watersheds by 8-11-73. The fifth increment of areas 1 and 2 on the east watershed, and area 1 on the west watershed, are at their highest point during summer 1973 on this date. After 8-11-73 NO_3/N decreases to a minimum level on 11-5-73. The high NO_3/N levels in the fourth and fifth increments of areas 1 and 2 of both watersheds indicate leaching of NO_3/N to that depth. These NO_3/N levels were significantly higher than NO_3/N levels at the same depths on areas 3 and 4. They indicate higher nitrogen content of the flat flume approach areas and thus past movement of nitrogenous materials downslope both in previous years and in the most recent runoff.

Chloride content of soil samples on the watersheds follows a logical leaching pattern. Chlorides were highest on 6-9-73 after fertilizer application and decreased and moved downwards through the profile with time. By 9-30-73 the maximum Cl content was found 15 to 30 cm deep, and by 11-5-73 the maximum was 38 to 61 cm deep. High Cl was found in the 0-1 cm depth on 5-2-74, indicating a return of Cl to the surface soil over the winter.

Evidence of redistribution of Cl down the watershed is clearly seen on 7-4-73 and 8-11-73. On the west watershed area 1 was significantly higher in Cl than the other three areas. Rain, runoff, and leaching by 8-11-73 caused a much higher Cl content 5-7.5 cm deep on area 1 than in any of the other areas. A high 5-7.5 cm Cl content was also found on the east watershed on 8-11-73. Higher Cl contents on 7-4-73 were not as significant on the east watershed as on the west watershed.

Phosphate phosphorus contents of watershed soils in 1973 do not clearly show redistribution patterns related to runoff or leaching. The highest PO_4/P on the east watershed was found 2.5-15 cm deep on area 1 on 8-11-73. These values are significantly higher than the determinations on samples from 7-4-73, and higher than the other areas on 8-11-73. On the west watershed 1-30 cm on area 2 were significantly higher on 8-11-73 than on 7-4-73. They also were higher than the other areas on 8-11-73. Although these PO_4/P increases may indicate a movement of phosphorus materials downslope onto areas 1 and 2 and a leaching through the sandy soil, mineralization of organic matter might account for these results.

Nutrient Content in 1974

In 1974 basic fertilizer was applied to both watersheds at the rate of 68.4 kg/ha N, 93.0 kg/ha P, and 172.6 kg/ha K. An additional 130.0 kg/ha N was sidedressed on the corn on the east watershed. This application of fertilizer provided source material for studying the movement and redistribution of nutrients on the watersheds.

The soil NO_3/N data in 1974 show high contents 0-7.5 cm deep on 5-22-74. By 5-30-74 the NO_3/N contents in all areas had dropped considerably and the highest values were 5-7.5 cm deep. The immediate reduction in NO_3/N resulted from the immobilization of the ammonium nitrate fertilizer by soil microorganisms. On 7-3-74 tremendous increases in NO_3/N levels, often above the levels of 5-22-74, were seen on all areas of both watersheds. These increases result from the mineralization of the nitrogen fertilizer previously immobilized. They also show conversion of NH_4/N to NO_3/N and upward movement of NO_3/N by water evaporating at the soil surface.

The highest NO_3/N levels on the east watershed were in the 0-1 cm depths of areas 5 and 6 on 7-3-74. Area 5 is the flume approach area and area 6 is an area which quite often ponds during runoff. Clearly NO_3/N was moved by runoff from the other areas onto areas 5 and 6. On the west watershed the highest surface NO_3/N on 7-3-74 occurs on area 5, also indicating movement of nitrate in the runoff of 7-2-74. Runoff water and sediment samples on 7-2-74 were high in NO_3/N.

The NO_3/N data shows leaching movement through the profile after 7-3-74. On 8-14-74 the maximum NO_3/N was at 7.5-22.5 cm. By 9-3-74 little NO_3/N remained in the 0-30 cm profile. The runoffs of 8-13-74 and 8-27-74 plus monthly rainfall in August provided the driving energy for leaching NO_3/N out of the profile.

The NH_4/N content of 1974 soil samples was highest on 5-22-74, after the fertilization of 5-20-74. On many of these areas the NH_4/N in 0-1 cm is lower than that in 1-2.5 cm. This may indicate volatilization of NH_4/N from the surface increment. There is some increase in NH_4/N in the 0-2.5 cm depths of area 4 and the 1-2.5 cm depth of area 5, and a large increase in the 0-1 cm depth of area 3 on the east watershed on 7-3-74. These may be related to the mineralization of nitrogen as shown by NO_3/N on that date. Ammonium nitrogen on both watersheds was quite low by 9-3-74.

Figure 8 shows parts per million KjN/N versus date for 0-1 cm on both watersheds. Figure 9 shows parts per million KjN/N versus date for 1-2.5 cm on both watersheds. The trends seen in these figures are true for the entire profile on both watersheds. Kjeldahl nitrogen was highest on both watersheds throughout summer 1974 in area 5. Areas 1 and 3, the upper side slopes of the watersheds, tended to decrease in KjN/N during the summer. On the east watershed areas 4 and 6, the lower slopes, generally were higher in KjN/N than the upper slopes, areas 1 and 3, directly above them. On the west watershed area 4 is significantly higher than area 1, but the same trend is not seen between areas 3 and 6. Area 6 on the east watershed was much higher in KjN/N than area 4 on the east watershed. Area 6 on the east watershed often ponded with water during a runoff, whereas area 6 on the west watershed did not.

The differences in KjN/N of the 0-2.5 cm depths between areas on both watersheds clearly show that nitrogen moves in surface runoff. Evidence of nitrogen movement directly related with the 1974 runoffs is clear only with NO_3/N. However, the high initial and final KjN/N of area 5 on both watersheds and area 6 on the east watershed show that over time nitrogen moved from the upper slopes to the flatter areas in front of the catchment.

The 1974 Cl data from both watersheds showed the downward leaching of Cl with time. Chlorides were high in

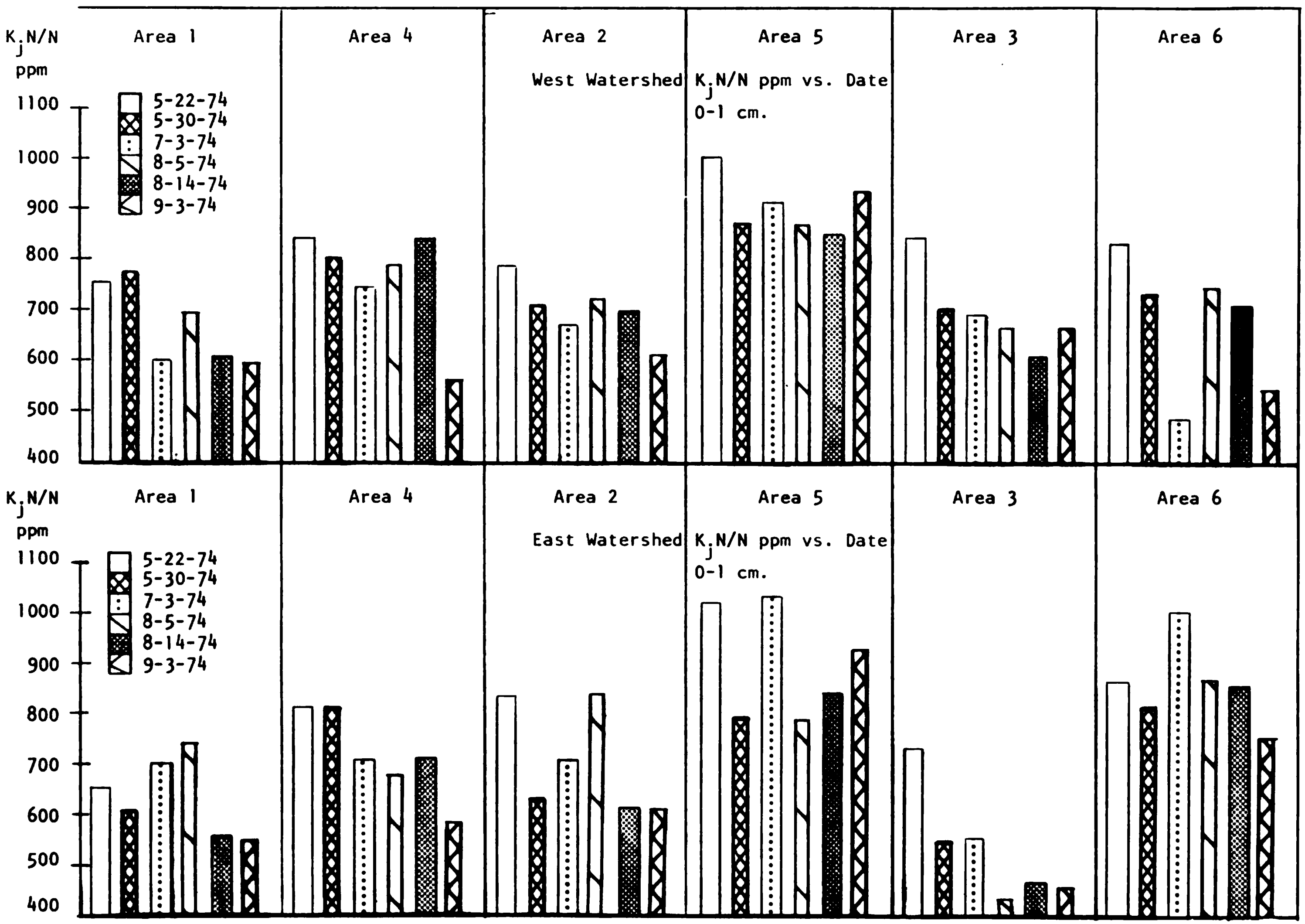


Figure 8.--Kjeldahl nitrogen content of the 0-1 cm. depths of east and west watersheds by date.

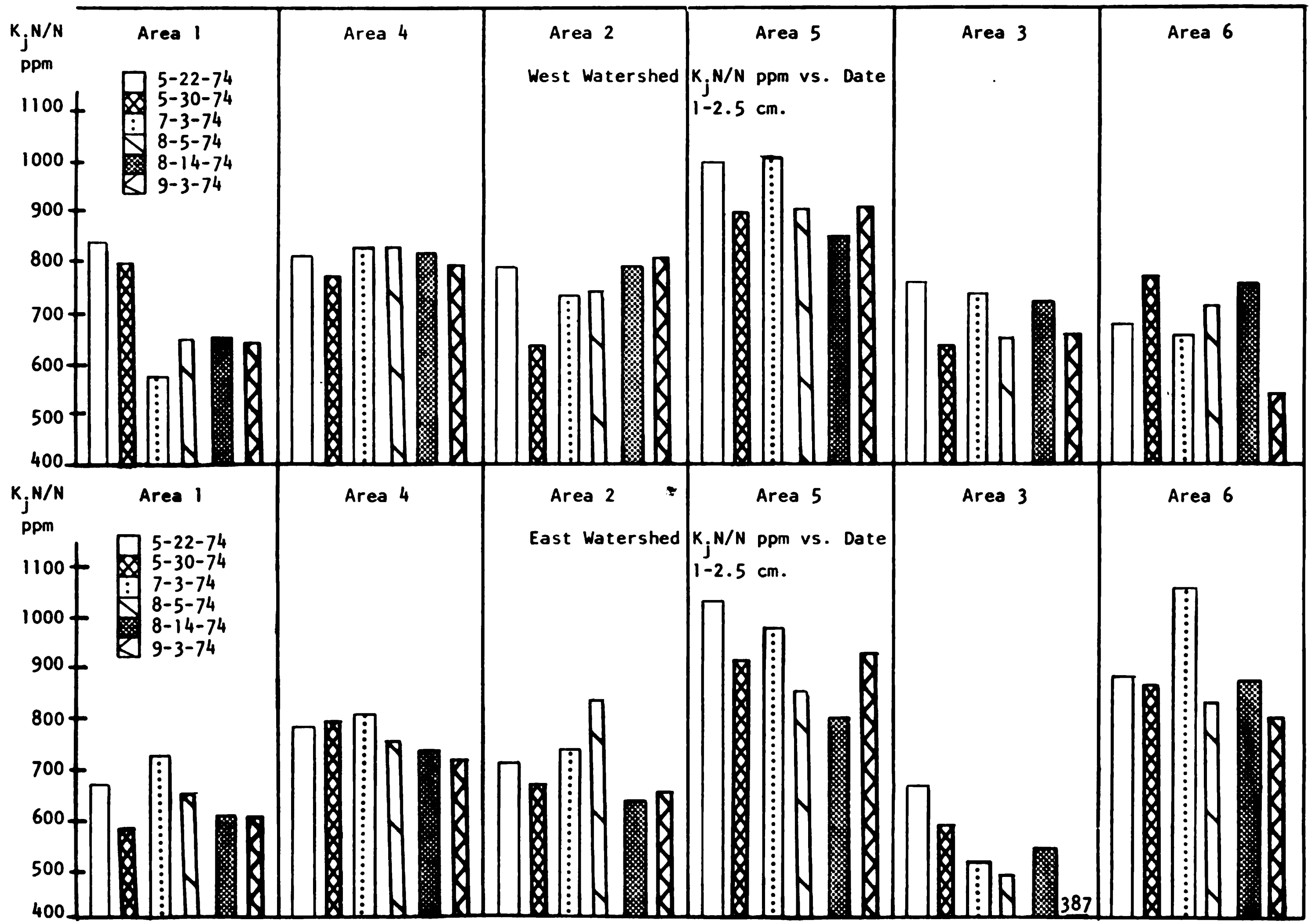


Figure 9.--Kjeldahl nitrogen content of the 1-2.5 cm. depths of east and west watersheds by date.

the 0-7.5 cm depths on 5-22-74 after the fertilization of 5-20-74. By 5-30-74 there was a large decrease in the Cl content in the 0-5 cm depths, and the highest content was found 5-7.5 cm deep. By 7-3-74 Cl increased back to or higher than the levels of 5-22-74 in the 0-5 cm depths. This is explained by a salinity effect or the upward movement of salts in soil solution as water is evaporated from the soil surface. After 7-3-74 chlorides leached downward, and on 9-3-74 the peak was seen in the 7.5-30 cm depths.

Figure 10 shows the PO_4/P content in parts per million in the 0-2.5 cm depths of all areas of the east watershed. Graphing of the remaining five increments of the profile would show similar results. Figure 10 shows that on areas 1 through 4 PO_4/P either stayed about the same over the summer or decreased. On areas 5 and 6 PO_4/P increased over the summer. Clearly PO_4/P materials were deposited on area 5 by the runoff of 7-2-74. Area 6 also showed an increase in PO_4/P which must result from deposition on 7-9-74, 8-13-74, or 8-27-74.

The data from the west watershed does not show the increase in PO_4/P on areas 5 and 6. However, the west watershed is shaped differently from the east one. Water tends to run quickly over and off areas 5 and 6 of the west watershed. On the east watershed it ponds for a much longer

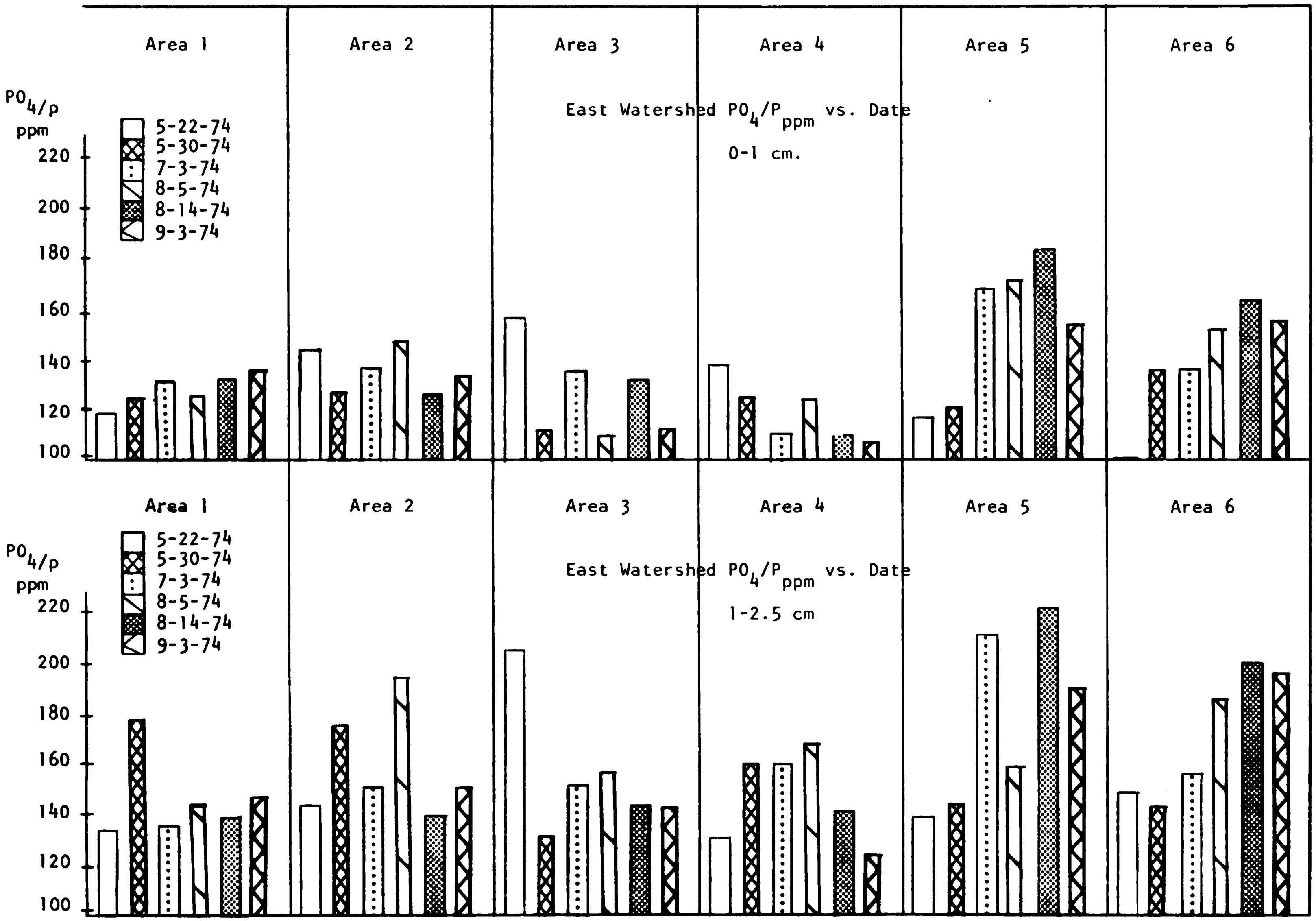


Figure 10.--Phosphate phosphorus content of the 0-2.5 cm depths of the east watershed by date.

time with corresponding increased chances for deposition of organic matter and eroded soil.

The PO_4/P content of runoff waters and sediment from the runoffs of 7-2-74, 7-9-74, 8-13-74, and 8-27-74 further support evidence of phosphate movement from the upper slopes onto the lower slopes or off the watershed. The dramatic increase in PO_4/P on area 5 of the east watershed on 7-3-74 shows that the runoff water picked up the available phosphorus from the fertilization of 5-20-74. Increases in PO_4/P on area 5 after 7-3-74 were not as great because the most readily movable PO_4/P was moved by the runoff of 7-2-74.

Mass Balance

Table 23 shows the total sediment (kg/ha) lost from 6-73 to 8-74 by event date. The data was calculated

TABLE 23.--Total Sediment Lost from the Watersheds in Runoff (6-73 to 8-74).

Date	East Watershed kg/ha	West Watershed kg/ha
11-24-73	4.1	
1-26-74	132.0	12.0
4- 3-74	16.3	
5-16-74	7.0	
7- 2-74	129.0	100.0
7- 9-74	4.0	48.0
8-13-74	274.0	399.0
8-27-74	231.0	173.0
TOTAL	797.4	732.0

from average sediment content (g/l) in each runoff event and runoff magnitude. Table 24 shows total NO_3-N, NH_4-N, KjN, and PO_4/P (kg/ha) lost from the watersheds in water and sediment phases of runoff from 6-73 to 8-74.

Magnitude of sediment lost per event depended on sediment content (g/l) of the runoff and runoff magnitude. Table 23 shows high losses from both watersheds on 7-2-74, 8-13-74, and 8-27-74. The totals lost for the period 6-73 to 8-74 are quite similar for the two watersheds: 797.4 kg/ha on the east watershed, and 732.0 kg/ha on the west watershed.

The data in Table 24 show that NO_3-N and NH_4-N were mainly lost in the water phase of surface runoff. On the east watershed 95% of the NO_3-N and 77% of the NH_4-N were in the water phase. On the west watershed 94% of the NO_3-N and 78% of the NH_4-N were in the water phase.

KjN was lost mainly in the sediment phase of surface runoff. On the east watershed 79% of the KjN was in the sediment phase, and on the west watershed 86% was in the sediment phase.

Total N from the watersheds was lost mainly as KjN. On the east watershed 91% of total N was lost as KjN, and on the west watershed 92% was lost as KjN.

About twice as much PO_4-P was lost in the sediment phase as in the water phase of surface runoff. On the east

TABLE 24.--Total NO_3-N, NH_4-N, KjN, and PO_4-P Lost from the Watersheds in Water and Sediment Phases of Runoff (6-73 to 8-74).

	11-24-73	1-26-74	2-22-74	2-28-74	3-2-74	4-3-74	5-16-74	7-2-74	7-9-74	8-13-74	8-27-74	Total
						g/ha						
NO_3-N												
Water	1.25	12.00	64.75	19.38	5.25	0.75	1.00	60.00	11.00	81.00	33.75	290.13
Sediment	0.14	1.98				0.31	0.08	2.98	0.07	5.20	3.00	13.76
NH_4-N												
Water	0.50	6.00	37.00	34.88	3.00	0.25	0.50	10.50	2.00	45.00	40.50	180.13
Sediment	0.24	6.20				0.72	0.07	5.70	0.31	23.26	16.39	52.89
KjN												
Water	4.00	30.00	111.00	120.12	13.50	3.50	2.25	49.50	3.88	180.00	108.00	625.75
Sediment	15.66	363.13				63.26	23.41	407.25	13.68	835.57	661.38	2383.34
PO_4-P												
Water	0.32	4.80	5.50	11.62	0.60	0.60	0.09	13.95	1.18	41.40	33.08	113.14
Sediment	0.49	28.38				3.42	0.71	43.88	1.35	77.70	72.26	228.19
			Total N added (1973 to 1974)			225 kg/ha		Total N removed		3.31 kg/ha		
			Total P added (1973 to 1974)			105 kg/ha		Total PO_4-P removed		0.34 kg/ha		
NO_3-N												
Water		2.18	26.73		4.36			43.64	23.27	78.18	30.91	209.27
Sediment								3.40	1.34	6.38	1.73	12.85
NH_4-N												
Water		2.18	22.91		3.27			10.91	5.82	31.27	18.54	94.90
Sediment								2.40	1.63	15.95	6.58	26.56
KjN												
Water		8.73	61.10		9.82			32.73	16.73	156.36	86.55	372.02
Sediment								305.10	159.75	1234.86	579.34	2279.05
PO_4-P												
Water		0.71	3.10		0.44			11.00	4.65	49.27	23.49	92.66
Sediment								30.10	18.14	124.80	44.31	217.35
			Total N added (1973 to 1974)			95 kg/ha		Total N removed		2.87 kg/ha		
			Total P added (1973 to 1974)			105 kg/ha		Total PO_4-P removed		0.31 kg/ha		

watershed 67% of the PO_4-P was lost in the sediment phase. On the west watershed 70% of the PO_4-P was lost in the sediment phase.

Total N added to the east watershed from 6-73 to 8-74 was 225 kg/ha. Total P added was 105 kg/ha. On the west watershed 95 kg/ha N and 105 kg/ha P were added from 6-73 to 8-74.

Total losses of N and PO_4-P were quite similar for the two watersheds. The east watershed lost 3.31 kg/ha N and 0.34 kg/ha PO_4-P. The west watershed lost 2.87 kg/ha and 0.31 kg/ha PO_4-P.

Nitrogen losses in runoff were equivalent to 1.5% of input fertilizer N on the east watershed and 3.0% of input on the west. Losses of P were equivalent to 0.3% of applied fertilizer P on both watersheds.

Soil Phosphorus: Comparison Between Virgin and Cultivated Watershed Soils

Table 25 shows total P (ppm), PO_4/P (ppm), and organic matter (5) for a profile from area 1 of the east watershed, and a profile of virgin soil from a forest near the watersheds. The data show high total phosphorus from 0.22.5 cm, high PO_4/P from 0-30 cm, and high percent organic matter from 0-30 cm on the cultivated watershed soil. On the virgin soil total P is high from 0-46 cm, PO_4/P high from 0-61 cm, and percent organic matter stayed

TABLE 25.--Comparison of Total Phosphorus (ppm), Phosphate Phosphorus (ppm) and Percent Organic Matter between Cultivated Watershed Soil and Virgin Soil.

Depth cm	East Watershed 11-5-73 Area 1			Virgin Soil 12-29-73		
	Total P ppm	PO_4/P ppm	O.M. %	Total P ppm	PO_4/P ppm	O.M. %
0 - 1	719	76	1.76	512	29	10.07
1 - 2.5	812	92	2.21	275	34	7.50
2.5- 5	762	91	2.21	212	34	6.00
5 - 7.5	844	89	1.98	419	38	5.43
7.5-15	781	88	2.12	369	32	2.86
15 -22.5	856	93	2.12	312	32	1.71
22.5-30	562	70	2.14	306	25	1.28
30 -38	500	32	1.14	294	26	1.28
38 -46	219	7	0.71	331	25	1.60
46 -61	312	8	0.90	250	34	1.10
61 -76	344	4	0.60	206	18	1.12
76 -91	406	6	0.43	250	15	1.14

in the same range from 22.5-91 cm. Total phosphorus and PO_4/P were higher on the cultivated soil than the virgin soil 0-30 cm deep. Percent organic matter is much higher in the 0-7.5 cm depths of the virgin soil than that cultivated.

Study of fertilizer records show that 990 kg/ha phosphorus have been added to the east watershed since 1956. Consequently we find the total P and PO_4/P at higher levels on the cultivated soil. The PO_4/P data from the cultivated watershed show that orthophosphates have moved deeper in the profile than the zone of maximum total phosphorus. Depth 22.5-38 cm on the cultivated watershed has not yet reached maximum P adsorption. Total phosphorus and PO_4/P contents on the cultivated watershed were closely related to percent organic matter.

On the virgin soil total P and PO_4/P maintain the same levels deeper in the profile than on the cultivated soil. Except for high total P 0-1 cm deep, total P and percent organic matter appear unrelated. Phosphate phosphorus also appears independent of percent organic matter on the virgin soil.

Comparisons of the virgin and cultivated soils show that cultivation and cropping decreased organic matter and fertilization increased total P and PO_4/P. Cropping also depleted the lower depths of total P and PO_4/P whereas the virgin soil had a more equal distribution of total P and PO_4/P with depth.

CONCLUSIONS

Summer runoff magnitudes on the experimental watersheds depended on rainfall intensity, duration of rainfall after the start of runoff, and soil structure on the event date. Runoff magnitude increased with increasing rainfall intensity, increasing duration of rainfall after the start of runoff, and increasing bulk density or compactness of the soil surface. Winter runoffs depended on the amount of rain and accumulated snow on the watersheds and the rise in temperatures above 23 F.

Sediment content of runoff samples in grams per liter depended on the structure of watersheds on the runoff event date. During the summer seasons the highest contents were found in early summer after tillage operations. During the winter season contents were quite low when the soil was frozen and higher when the soil was thawed or partially thawed.

The NO_3/N, NH_4/N, and KjN/N contents of runoff waters and sediment during the winter season were generally quite low. Winter runoffs with higher NO_3/N occurred when the water moved over thawed or partially thawed soil. Lighter weight organic matter may have been differentially removed in such runoffs.

The NO_3/N, NH_4/N, and KjN/N contents of runoff waters and sediment increased in the spring above the values of the winter runoffs. These increases reflected the warming of the soil and the nitrogen cycle in the spring. Contents of NO_3/N, NH_4/N, and KjN/N in runoff waters were highest in the runoffs following spring fertilization. Sediment contents of NO_3/N and NH_4/N but not KjN/N were also high following spring fertilization. Sediment and water phase runoff concentrations of NO_3/N, NH_4/N, and KjN/N decreased in successive runoffs after the initial high values in the first runoffs after fertilization.

Chloride contents of the runoff sediment and water were low during the winter season. Increases in the spring reflected the thawed soil and an upward movement of chloride to the surface soil as seen in soil sample data. Chloride contents of runoff sediment and water phases were highest in early summer and decreased thereafter.

The PO_4/P and total P contents of runoff waters, and the PO_4/P content of runoff sediments reflected both sediment content of the runoff samples in grams per liter and the spring fertilization. The PO_4/P and total P contents increased as sediment content increased except for the spring runoffs prior to fertilization. The runoffs of spring 1974 prior to fertilization had higher sediment contents than many of the winter runoffs but were low in PO_4/P

and total P because prior runoffs during fall and winter had removed most of the easily movable PO_4/P and total P. High PO_4/P and total P were found in runoffs following fertilization, with successive decreases thereafter. Most of the phosphorus moved in runoff was in the orthophosphate form.

Soil cores taken in the summers of 1973 and 1974 show both downward and lateral movement of nutrients. Chlorides and NO_3/N leached through the soil during the summer after the high initial application of fertilizer in the spring. Movement of Cl, NO_3/N, and PO_4/P from upper watershed areas to the lower flume approach areas clearly occurred.

Nitrate nitrogen in 1974 moved to the flume approach areas in runoff. In 1973 there was some indication of NO_3/N movement in runoff although the evidence was not as clear. High KjN/N in the flume approach areas throughout summer 1974 was evidence of past movements of nitrogen in surface runoff down the watersheds.

Phosphate phosphorus data in 1974 showed movement of PO_4/P onto the flume approach areas on the east watershed. The west watershed did not show the same movement, but it was shaped differently than the east watershed and did not get as much ponding of runoff water.

Mass balance calculations showed that nitrogen losses in runoff were equivalent to 1.5% of input fertilizer N on the east watershed and 3.0% of input on the west. Total P lost from the watersheds as PO_4/P in surface runoff was equal to 0.3% of that added to both watersheds over the same time period. Nitrogen lost in surface runoff was mainly in organic forms. Nitrate nitrogen and NH_4/N were mainly in the water phase of runoff. Organic N was mainly in the sediment phase of runoff. Of the PO_4/P lost, two thirds was in the sediment phase.

Comparisons between a cultivated soil and a virgin soil showed higher organic matter in the virgin soil. Higher PO_4/P and total P were found in the cropped soil, but PO_4/P and total P had more equal distribution to a greater depth in the virgin soil.

REFERENCES

REFERENCES

Allen, A. L., F. J. Stevenson, and L. T. Kurtz. 1973. Chemical distribution of residual fertilizer nitrogen in soil as revealed by nitrogen--15 studies. J. Environ. Qual. 2:120-124.

Benoit, G. R. 1973. Effect of agricultural management of wet sloping soil on nitrate and phosphorus in surface and subsurface water. Water Resour. Res. 9: 1296-1303.

Biggar, J. W., and D. R. Nielsen. 1962. Miscible displacement: II.Behavior of tracers. Soil Sci. Soc. Am. Proc. 26:125-128.

Bouldin, D. R., and C. A. Black. 1954. Phosphorus diffusion in soils. Soil Sci. Soc. Am. Proc. 18:255-259.

Bremner, J. M. 1965. Inorganic forms of nitrogen. Chapter 85 in C. A. Black, ed. Methods of soil analysis, part 2. Agronomy series 9. Amer. Soc. Agron. Madison, Wisconsin.

Cassell, D. K. 1971. Water and solute movement in Svea loam for two water management regimes. Soil Sci. Soc. Am. Proc. 35:859.

Corey, J. C., and J. W. Fenimore. 1968. Tracing groundwater with chloride ions and tritium through acid kaolinitic soil. Int. J. Appl. Radiat. Isotop. 19: 741-746.

Dahnke, W. C. 1971. Use of the nitrate specific ion electrode in soil testing. Comm. in Soil Sci. and Plant Ana. 2:73-84.

Edwards, D. M., P. E. Fischbach, and L. L. Young. 1972. Movement of nitrates under irrigated agriculture. Am. Soc. Agric. Engin. Trans. 15:73-75.

Frere, M. H. 1973. Adsorption and transport of agricultural chemicals in watersheds. Am. Soc. Agric. Engin. Trans. 16:569-572.

Fulcher, C. E., and E. H. Tyner. 1959. Movement of chloride ions through unsaturated and saturated cores. Annual report, project 00-15-15-317. Agronomy Department, University of Illinois, Urbana, Ill.

Hamon, R. W. 1966. Evapotranspiration and water yield predictions. Conference Proceedings; Evapotranspiration and its role in water resources mangement. American Society of Agricultural Engineers. St. Joseph, Mich. 49085 pp. 8-9, 13.

Hashimoto, I., and J. R. Lehr. 1973. Mobility of polyphosphates in soil. Soil Sci. Soc. Am. Proc. 37:36-41.

Humphreys, F. R., and W. L. Pritchett. 1971. Phosphorus adsorption and movement in some sandy forest soils. Soil Sci. Soc. Am. Proc. 35:495-500.

Kirda, C., D. R. Nielsen, and J. W. Biggar. 1973. Simultaneous transport of chloride and water during infiltration. Soil Sci. Soc. Am. Proc. 37:339-45.

Klausner, S. D., P. J. Zwerman, and D. F. Ellis. 1974. Surface runoff losses of soluble nitrogen and phosphorus under two systems of soil management. J. Environ. Qual. 3:42-6.

Kurtz, L. T. 1970. The fate of applied nutrients in soils. J. Agr. Food Chem. 18:773-80.

Kurtz, L. T., and S. W. Melsted. 1973. Movement of chemicals in soils by water. Soil Sci. 115:231-9.

Lawton, K., and J. A. Vomocil. 1954. The dissolution and migration of phosphorus from granular superphosphate in some Michigan soils. Soil Sci. Soc. Am. Proc. 18:26-32.

Linville, K. W., and G. E. Smith. 1971. Nitrate content of soil cores from corn plots after repreated nitrogen fertilization. Soil Sci. 112:249-55.

Logan, T. J., and E. O. McLean. 1973a. Nature of phosphorus retention and adsorption with depth in soil columns. Soil Sci. Soc. Am. Proc. 37:351-5.

Logan, T. J., and E. O. McLean. 1973b. Effects of phosphorus application rate, soil properties, and leaching mode on ^{32}P movement in soil columns. Soil Sci. Soc. Am. Proc. 37:371-4.

Munn, D. A., E. O. McLean, A. Ramirez, and T. J. Logan. 1973. Effect of soil, cover, slope, and rainfall factors on soil and phosphorus movement under simulated rainfall conditions. Soil Sci. Soc. Am. Proc. 37:428-31.

Olsen, R. J., R. F. Hensler, O. J. Attoe, S. A. Witzel, and L. A. Peterson. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. Soil Sci. Soc. Am. Proc. 34:448-452.

Parker, J. H. 1972. How fertilizer moves and reacts in the soil. Crops and Soils 25:7-11.

Phillips, R. E., G. A. Place, and D. A. Brown. 1968. Self-diffusion of phosphorus in clays and soils: I. The effect of phosphorus rate. Soil Sci. Soc. Am. Proc. 32:41-44.

Porter, L. K., W. D. Kemper, R. D. Jackson, and B. A. Stewart. 1960. Chloride diffusion in soils as influenced by moisture content. Soil Sci. Soc. Am. Proc. 24:460-463.

Pratt, P. F., W. W. Jones, and V. E. Hunsaker. 1972. Nitrate in deep soil profiles in relation to fertilizer rates and leaching volume. J. Environ. Qual. 1: 97-102.

Richardson, C. W., and J. T. Ritchie. 1973. Soil water balance for small watersheds. American Society of Agricultural Engineers Trans. 16:72-7.

Römkens, M. J. M., and D. W. Nelson. 1974. Phosphorus relationships in runoff from fertilized soils. J. Environ. Qual. 3:10-13.

Römkens, M. J. M., D. W. Nelson, and J. V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. J. Environ. Qual. 2:292-5.

Schuman, G. E., R. E. Burwell, R. F. Piest, and R. G. Spomer. 1973. Nitrogen losses in surface runoff from agricultural watersheds on Missouri valley loess. J. Environ. Qual. 2:299-302.

Schuman, G. E., R. G. Spomer, and R. F. Piest. 1973. Phosphorus losses from four agricultural watersheds on Missouri valley loess. Soil Sci. Soc. Am. Proc. 37: 424-7.

Shaw, K. 1962. Loss of mineral nitrogen from soil. J. Agr. Sci. 58:145-51.

Sievers, D. M., G. L. Lentz, and R. P. Beasley. 1970. Movement of agricultural fertilizers and organic insecticides in surface runoff. Trans. Amer. Soc. Agr. Engin. 13:323-325.

Smith, S. J. 1972. Relative rate of chloride movement in leaching of surface soils. Soil Sci. 114:259-263.

Sommerfeldt, T. G., and A. D. Smith. 1973. Movement of nitrate nitrogen in some grassland soils of southern Alberta. J. Environ. Qual. 2:112-115.

Stewart, B. A. 1970. A look at agricultural practices in relation to nitrate accumulation. (Pp. 47-60 in O. P. Engelstad (ed.), Nutrient mobility in soils: Accumulation and losses, Soil Sci. Soc. Am. Special Publ. No. 4, Soil Sci. Soc. Am., Madison, Wis.).

Tisdale, S. L., and W. L. Nelson. 1968. Soil fertility and fertilizers. The Macmillan Company, New York.

U. S. Environmental Protection Agency. Methods Development and Quality Assurance Research Laboratory. 1974. p. 207. Methods for chemical analyses of water and wastes.

Vaidyanathan, L. V., and P. H. Nye. 1971. The measurement and mechanism of ion diffusion in soils. VII. Counter diffusion of phosphate against chloride in a moisture-saturated soil. J. Soil Sci. 22:94-100.

Wallace, A., and R. L. Smith. 1954. Nitrogen interchange during decomposition of orange and avocado tree residues in soil. Soil Sci. 78:231-242.

Wetselaar, R. 1961. Nitrate distribution in tropical soils. II. Extent of capillary accumulation of nitrate during a long dry period. Plant Soil 15:121-133.

Williams, C. H. 1971. Reactions of surface-applied superphosphate with soil. II. Movement of the phosphorus and sulphur into the soil. Aust. J. Soil Res. 9:95-106.

APPENDIX

APPENDIX

Draft
Subject to Review

Established Series

Hillsdale Series

Hillsdale series comprises well-drained soils developed in calcareous sandy loam till with the thickness of the sola ranging from 40 to 60 inches or more. Hillsdale soils are the well-drained member of the drainage sequence which includes the moderately well-drained Elmdale soils, the somewhat poorly drained Teasdale soils and the poorly drained Barry soils. Lapeer soils are also developed in sandy loam till but have a less acid sola which ranges in thickness from 18 to 40 inches. Miami soils which have finer-textured and thinner B2t horizons than Hillsdale soils and are underlain by neutral to calcareous sand and gravel at depths greater than 42 inches. Hillsdale soils are finer-textured throughout the profile than the Coloma and Spinks soils which were developed on loamy sand parent materials. Kalamazoo soils have neutral to calcareous, stratified sand and gravel at 42 to 66 inches while Hillsdale soils have calcareous sandy laom till at 42 to 66 inches or more. The moderately well-drained Hodunk soils also developed on sandy loam till but have a weak to moderate fragipans which are absent in the Hillsdale Soils.

Soil Profile: Hillsdale sandy loam

Ap	0-9"	Sandy Loam: dark grayish brown (10YR 4/2), very dark gray (10YR 3/1) or very dark grayish brown (10YR 3/2), weak, fine, granular structure; very friable or friable low to medium in organic matter content slightly to medium acid abrupt smooth boundary. 6 to 11 inches thick.
A2	15-24"	Loamy Sand or Sandy Loam: yellowish brown (10YR 5/4-5/6 very weak, thick, platy to weak, fine, granular structure; very friable or friable; medium to strongly acid; gradual wavy boundary. 6 to 14 inches thick.
B1	15-24"	Sandy Loam: dark brown (10YR 4/3 - 7.5 4/4) or brown (10YR 5/3); weak, medium, subangular blocky structure; friable, medium to strongly acid; clear wavy boundary. 6 to 18 inches thick.
B21t	24-35"	Sandy Clay Loam or Loam: dark yellowish brown (10YR 4/4) or dark brown (7.5YR 4/4); weak to moderate, medium, subangular block structure; friable; medium to strongly acid; gradual wavy boundary. 5 to 20 inches thick.

B22t 35-46" Sandy Loam with sandy lenses or layers or variable thickness; the finer textures are brown or dark brown (7.5YR 4/4-5/4) while the coarser-textured lenses or layers are brown (10YR-5/3); weak, coarse, subangular blocky structure; very friable; slightly to medium acid; gradual wavy boundary. 5 to 15 inches thick.

B3 46-58" Sandy loam with discontinuous layers, lenses, or pockets, of loamy sand and sand from 2 to over 12 inches in thickness; sandy loam is brown or dark yellowish brown (7.5YR 4/4-10YR 4/4) and the sands are yellowish brown or pale brown (10YR 5/3 - 6/3); sandy loam is friable and loamy sand is very friable; medium to slightly acid; abrupt irregular boundary. 5 to 40 inches thick.

C 58" Sandy Loam: brown or yellowish brown (10YR 5/3 - 5/4); massive to very weak, coarse, subangular blocky structure friable; neutral to calcareous.

Range in Characteristics: Sandy loam , fine sandy loam, loam and loamy sand types have been mapped. The depth to calcareous materials ranges from 40 to 80 or more inches. The texture of the B2t horizons varies from sandy loam to sandy clay loam within a short distance. In places, the B3 horizon is mainly sand with loamy sand and sandy loam lenses and layers similar to the lower sola of Spinks and Coloma soils. The C1 horizon is a loamy sand in some places and ranges in reaction from slightly acid to calcareous. Colors refer to moist conditions.

Topography: Nearly level to strongly sloping areas on till plains, moraines and drumlins.

Drainage and Permeability: Well-drained. Runoff is moderate on the smoother slopes and rapid on the steeper slopes. Permeability is moderate.

Natural Vegetation: Oak, hickory, sugar maple and beech.

Use: The level to moderately sloping soils are cleared and used for corn, oats, wheat, and legume-grass mixtures. The steeper areas are used for permanent pasture or farm woodlots.

Soil Management Group: 3a

Distribution: Southern Michigan and northern Indiana. Widely distributed in large and small bodies.

Type Location: Ionia County, Michigan

Series Established: Hillsdale County, Michgan 1923.

Source of Name: County in Michigan National Cooperative Soil Survey - U.S.A.

Reviewed for class use.
Not an official series description.
Classification is tentative.

ORDER: Alfisol

SUBORDER: Udalf

GREAT GROUP: Hapludalf

SUBGROUP: Typic Hapludalf

FAMILY: Coarse-loamy, mixed, mesic

Draft
Subject to Review

Spinks Series

Established Series

Spinks series comprises well-drained soils developed in calcareous or neutral loamy sands, sands, or fine sands. Spinks soils have a pH above 5.6 in the sola instead of medium to strongly acid sola of the Coloma soils, thus Spinks soils are similar to Coloma soils except for reaction. Oakville soils have the same pH range in the sola as Spinks, but lack the thin textural B2t horizons (bands) of the Spinks soils. Stroh soils are the Mollisol intergrade to Alfisols. Oshtemo soils have a finer-textured sola and are underlain at depths of more than 42 inches by neutral or calcareous, stratified sands and fine gravel. Plainfield soils lack the textural B2t horizons (bands) within 60 inches found in Spinks but are medium to strongly acid in the sola. In Chelsea soils, the bands are below 40 inches.

Soil Profile: Spinks loamy sand

Ap	0-7:	Loamy Sand: brown (10YR 5/3) very dark grayish brown (10YR 3/2), or dark grayish brown (10YR 4/2); very weak, medium, granular structure; very friable, neutral to medium acid; abrupt smooth boundary. 6 to 12 inches thick.
A2	7-20"	Loamy Sand or Sand: brown (10YR 5/3) or yellowish brown (10YR 5/4); very weak, medium, granular to single grain structure; very friable to loose; neutral to medium acid; abrupt wavy boundary. 8 to 30 inches thick.
B2t	20-23"	Sandy Loam or Fine, Loamy Sand: brown (7.5YR 4/4), strong brown (7.5YR 5/6) or dark yellowish brown (10YR 4/4); weak, fine to medium, subangular blocky structure; very friable; slightly acid to neutral; abrupt wavy boundary. 1/2 to 8 inches thick.
Series of A'2 and B'2t horizons	23-50"	The A'2 parts of the horizon are Pale brown (10YR 6/3) or light yellowish brown (10YR 6/4) sand, while the B'2t parts of the horizon are strong brown (7.5YR 5/6), or dark yellowish brown (10YR 4/4) sandy loam or fine, loamy sand B'2t horizon; the B'2t horizons which occur as thin (1/4 to 4 inches thick) bands or lenses are often wavy and discontinuous; A'2 horizons have single grain structure; while the B'2t horizons have weak, fine to medium, subangular blocky structure; mildly alkaline to slightly acid; 20 to 40 inches thick.
C1	50"+	Sand, Loamy Sand, or Fine Sand: pale brown (10YR 6/3); single grain structure; loose; neutral to calcareous.

Range in Characteristics: Loamy fine sand, loamy sand, and sand types have been mapped. The depth to the first B2t horizon ranges from 15 to 42 inches. The thickness, number, and continuity of the B'2t horizons varies considerably in short horizontal distances. The thickness of the B'2t horizons, separated by A'2 horizons in the A'2 and B2t horizon varies from 1/4 to 8 inches in thickness, with the cumulative thickness greater than six inches. Where Spinks soils grade toward Oshtemo soils the thickness of the individual B2t horizons, and the combined thickness of the B2t bands approaches 10 inches. Where Spinks soils grade toward Coloma soils the pH of the sola is medium acid and the C1 horizon is neutral to mildly alkaline but not calcareous. Colors refer to moist conditions.

Topography: Gently sloping to steep areas on moraines and outwash plains.

Drainage and Permeability: Well-drained. Surface runoff is slow to very slow. Permeability is rapid to very rapid.

Native Vegetation: Oaks and Hickory

Use: Forage crops and pasture, with variable acreage in corn, wheat, oats, and soybeans. Some areas are in orchards, especially in southwestern Michigan near Lake Michigan. Many areas are still in second-growth forest.

Distribution: Southern Michigan and Northern Indiana.

Type Location: NE 1/4 of SE 1/4 Sec. 24, T6N, R7W, Ionia County, Michigan.

Series Established: Lenawee County, Michigan, 1955.

Source of Name: Community in Berrien County, Michigan.

Remarks: Spinks soils were formerly mapped as Coloma or Hillsdale soils in Michigan and as Coloma or Plainfield soils in Indiana.

National Cooperative Soil Survey--USA

Reviewed for class use.
Not an official soil series description.
Placement is tentative.

ORDER: Alfisol

SUBORDER: Udalf

GREAT GROUP: Hapludalf

SUBGROUP: Psammetic Hapludalf

FAMILY: Sandy, mixed, mesic.

Draft
Subject to Review | Traverse Series | Established Series

The Traverse series are well to moderately well drained soils developed in medium acid to neutral sandy loams to loam materials. Traverse soils occupy depressions and old abandoned drainageways that are largely of glacial origin. Traverse soils are associated with McBride and Montcalm soils. Echo soils have profiles similar to Traverse, but are developed in sands to loamy sand materials. Pennock soils are Alluvial soils developed in sandy loam, loam, or silt loam materials and are subject to flooding and deposition of additional alluvium.

Soil Profile: Traverse sandy loam

Ap	0-7"	Sandy Loam: very dark brown (10YR 2/2); weak, fine, granular structure; very friable; medium acid; abrupt smooth boundary. 6 to 10 inches thick.
A1	7-20"	Sandy Loam: very dark grayish brown (10YR 3/2); weak, fine, subangular blocky structure; very friable; medium acid; abrupt wavy boundary. 6 to 15 inches thick.
A'1b	20-29"	Sandy Loam: black (10YR 2/1); weak, fine, granular structure; very friable; medium acid; abrupt wavy boundary. 3 to 10 inches thick.
B'2	29-42"	Loamy Sand: dark yellowish brown (10YR 3/4); very weak, fine, subangular blocky structure; very friable; medium acid; abrupt irregular boundary. 10 to 16 inches thick.
A'2	42-44"	Loamy Sand: brown (10YR 5/3); massive; very friable; medium acid; abrupt irregular boundary. 1 to 3 inches thick.
A'2 and B'2t	44-66"	Brown (10YR 5/3) loamy sand; single grained; loose which represents the A'2 horizon; dark brown (7.5YR 4/4) sandy loam; massive to weak fine subangular blocky structure; friable which represents the B2t horizons, the B'2 horizons occur as thin and often discontinuous bands, separated by A'2 horizons; medium acid; clear to abrupt wavy boundary. 10 to 30 inches thick.
C	66"+	Loamy Sand to Sandy Loam: pale brown (10YR 6/3), with many, common, faint brownish yellow (10YR 6/6) and yellowish brown (10YR 5/6) mottles; massive; very friable; mildly alkaline.

Range in Characteristics: Sandy loam, loam, and loamy sand types have been recognized. The surface soil is dark yellowish brown (10YR 4/4) in some areas, especially where there has been relatively recent deposition. Depth to mottling is as little as 20 inches in some areas. Colors of the B horizons grade to the 7.5YR hue. The total thickness of the textural bands in the A'2 and B'2 horizon ranges from about 1/3 of the horizon to only an occasional thin band. Colors refer to moist conditions.

Topography: Depressions and old glacial drainageways.

Drainage and Permeability: Well to moderately well drained. Runoff is very slow. Permeability is moderately rapid.

Vegetation: Chiefly northern hardwoods.

Use: A considerable proportion is in permanent pasture.

Soil Management Group: L-3b

Distribution: Central and northern Michigan.

Type Location: NE 1/4 of SE 1/4, Section 8, T20N, R8W, Osceola County, Michigan. See Osceola soil survey reports.

Series Established: Grand Traverse Project Area, Grand Traverse County, Michigan, 1940.

National Cooperative Soil Survey--USA

Placement is tentative

ORDER: Mollisol

SUBORDER: Udoll

GREAT GROUP: Hapludoll

SUBGROUP: Cumulic hapludoll

FAMILY: Coarse-loamy, mixed, frigid

Draft
Subject to Review

Tuscola Series

Established Series

The Tuscola series comprises moderatly well drained soils which developed in stratified silts, very fine sands, and fine sands in southern Michigan. Tuscola series is the moderately well drained member of the drainage sequence that includes the well-drained Sisson, somewhat poorly drained Kibbie, and the poorly to very poorly drained Colwood soils. The moderately well drained Celina soils are developed from loam or silt loam till with finer-textured Bt horizons, stronger grade of structure and usually a more acid sola than Tuscola soils. The well to moderately well drained Gagetown soils which developed in materials similar to those of the Tuscola soils, are calcareous at or near the surface and have a much thinner sola than the Tuscola soils. The well to moderately well drained Shinrock soils developed from stratified, lacustrine fine silts and silty clay loams and are finer textured throughout the profile than the Tuscola soils. The moderately well drained Arkport soils developed from stratified lacustrine loamy find sands and fine sandy loams and are coarser textured throughout the profile than Tuscola soils. Bohemian soils are the northern analog of the Tuscola soils.

Soil Profile:

Ap 0-9" Fine Sandy Loam: dark grayish brown (10YR 4/2) or very dark grayish brown (10YR 3/2); weak, coarse, granular structure; friable; slightly acid; abrupt smooth boundary. 7 to 10 inches thick.

A2 9-13" Fine Sandy Loam: yellowish brown (10YR 5/4) or brown (10YR 5/3) with grayish brown (10YR 3/2) organic coatings on some ped faces and in worm casts; weak, fine, subangular blocky to weak, thin, platy structure; friable; slightly acid to neutral; clear smooth boundary. 3 to 6 inches thick.

B21t 13-24" Fine Sandy Loam or Loam: dark yellowish brown (10YR 4/4) with a few peds coated with dark grayish brown (10YR 4/2); weak to moderate, medium, subangular blocky structure; friable; very thin discontinuous clay flows; slightly acid to neutral; gradual smooth boundary. 8 to 17 inches thick.

B22t 24-34" Very Fine Sandy Loam or Silt Loam: brown (10YR 5/3) with common, medium, faint yellowish brown (10YR 5/8) and gray (10YR 5/1) mottles; weak, medium, subangular blocky structure; firm; very thin discontinuous or patchy clay flows; slightly acid to neutral; clear smooth boundary. 6 to 14 inches thick.

B23tg 34-40" Silt Loam or Silts: grayish brown (10YR 5/2) with common, medium, distinct yellowish brown (10YR 5/4-5/8) mottles; weak; medium, subangular blocky to weak, thin, platy structure; firm; very thin patchy clay flows; neutral; clear wavy boundary. 6 to 12 inches thick.

B3g 40-44" Very Fine Sandy Loam: grayish brown (10YR 5/2) mottled with yellowish brown (10YR 5/6-5/8) and gray (10YR 5/1) mottles are common, medium, and distinct; massive (stratified) to very weak, coarse, subangular blocky structure; friable; mildly alkaline; abrupt wavy boundary. 1 to 10 inches thick.

44-55" Silts and Very Fine Sands: gray (10 YR 5/1) mottled with grayish brown (10YR 5/2), and dark brown (7.5YR 4/4) mottles are common, medium, and distinct, massive (stratified); friable; calcareous.

Range in Characteristics: Fine sandy loam, loam, and silt loam types have been mapped. The texture of the B horizons is variable commonly within short distances. The range includes fine sandy loam, clay loam, silty clay loam, or silt loam. Depth to mottling ranges from 16 to 30 inches. The C horizon occurs at 24 to 46 inches or more in depth. Texture of the C horizon ranges from stratified silts and very fine sands to dominantly silts or dominantly very fine sands. Thin strata of loam and silty clay occur in the profile in some areas. Colors refer to moist conditions.

Topography: Nearly level to gently sloping areas on lake plains and deltas.

Drainage and Permeability: Moderately well drained. Runoff is slow on nearly level areas, medium on sloping areas. Permeability is moderate.

Natural Vegetation: Sugar maple, oaks, beech, elm, and basswood.

Use: Largely under cultivation to corn, soybeans, wheat, oats, and legume-grass mixtures.

Soil Management Group: 2.5a

Distribution: Southern Michigan, northwestern Ohio, and probably southeastern Wisconsin and northern Indiana.

Type Location: Lenawee County, Michigan, NW 1/4 of NW 1/4 of NW 1/4 of Sec. 14, T7C, R5E.

Series Established: Tuscola County, Michigan, 1926.

Source of Name: County in Michigan.

National Cooperative Soil Survey--USA

Reviewed for temporary use in series file.
Not an official soil series.
Classification is tentative.

ORDER: Alfisol

SUBORDER: Udalf

GREAT GROUP: Hapludalf

SUBGROUP: Hapludalf

FAMILY: Fine loamy, mixed, mesic.