THE NUTRIENT COMPOSITION, DYNAMICS, AND ECOLOGICAL SIGNIFICANCE OF DRIFT MATERIAL IN THE RED CEDAR RIVER

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Niles Russell Kevern
1961

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ABSTRACT

THE NUTRIENT COMPOSITION, DYNAMICS, AND ECOLOGICAL SIGNIFICANCE OF DRIFT MATERIAL IN THE RED CEDAR RIVER

by Niles Russell Kevern

A quantitative and qualitative evaluation of drift material was undertaken on the Red Cedar River, a warm-water stream in south central Michigan.

Drift material, collected by a pump and filter system, varied at three stations primarily as a result of temperature effects on decomposition and bacterial action. The concentration of material was found to increase with increasing depth.

The organic component of drift material was highest in samples from the shallower strata due to the lower specific gravity of the organic material. A high organic component was also found in those samples taken during the winter as a result of reduced decomposition. A high coefficient of correlation was calculated for the relationship between the phosphorus content of drift material and the weight of the drift material being carried by the stream. Organic nitrogen of drift samples followed the same general fluctuations as did the phosphorus of drift samples. The total annual movement of drift material past a single sampling station was estimated at 265.7 metric tons; the total phosphorus movement was 12.6 metric tons, of which 2.5 percent was phorphorus from drift material.

Niles Russell Kevern

Discharge volume, as affected by rain, runoff, and frozen ground, was found to be the greatest single factor affecting the concentration and amount of drift material. Increases in flow volume produced a flushing action which resulted in the occurrence of peak drift volumes during rises in the river level.

Turbidity closely paralleled the discharge fluctuations and the specific conductivity was inversely related to the discharge.

The contribution of drift material to the food web was significant. Invertebrate organisms moved down the stream in the amount of 416 kilograms per year, while diatoms moved downstream past the sampling station in the amount of 634 metric tons per year. Diatom concentration reached a peak of 3549 per milliliter.

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By

Niles Russell Kevern

A THESIS

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INTRODUCTION

Drift material in a fresh-water stream is defined in this study as the living and non-living material suspended in the water and removable by filtration through No. 20 mesh bolting cloth. As such, the drift material is synonymous with seston, containing both inorganic and organic components. Diatoms pass through No. 20 bolting cloth and are thus not included in the drift as defined here, but because of the importance of diatoms they were sampled separately and included in the drift material.

Theoretically drift material is eventually exploited either as food or as elemental nutrients by various trophic levels in a stream. The extent to which this material serves as food for organisms and as potential plant nutrient has received little attention in studies of stream biodynamics.

A few reports have speculated upon the importance of some of the sestonic components. Jones (1949) points out the role of organic debris as food for aquatic insects, and Teal (1957) has demonstrated that organic debris imported into a small spring accounted for approximately three-fourths of the annual energy available to the organisms of the community. Odum (1959) has theorized an energy flow diagram based on studies of Florida springs in which the import of organic matter accounts for as much available energy as that produced in the community by photosynthesis.

Another aspect of the importance of organic debris is in the eutrophication process, which is largely a result of the production or presence of organic material beyond that which can be oxidized or consumed by respiration, predation, and bacterial decomposition. Lindeman (1942) included the importance of drift material in his statement that one cannot separate the living from the non-living in an ecosystem as the continual processes of physical-chemical-biological activities presents a merging of the two. Drift material, including both living and non-living components, is actively employed in this merging. As the non-living drift material moves downstream it is taken up by animals as organic detritus. As the non-living drift gradually decays it is the source of nutrients for plants. Living drift components are either utilized by animals as food or they die and revert back to nutrient levels through decay and bacterial decomposition.

Many studies of stream nutrients have been reported, but few have investigated the relationship of sestonic material to the nutrient levels and little is known of the energy relationships of drift materials within a stream. The role of drift material in nutrient levels is included by Ruttner (1953) who lists the three components of total phosphorus and total nitrogen as (1) the inorganic, (2) the dissolved colloidal organic, and (3) the particulate, or that fraction bound up in the suspended particles, i.e., the drift material. In a recent study of the nutrient relationships in the Red Cedar River, Brehmer (1958) theorized the transport of phosphorus to be through sloughed-off periphyton, which as such had become a component of the seston. High downstream soluble phosphorus concentrations were attributed to the decomposition of this senescent periphyton and the subsequent return of the nutrient to the stream.

In this study a quantitative and qualitative evaluation of drift material in the Red Cedar River was undertaken in July, 1958 and was continued until July, 1959. The drift weights and nutrient composition were related to the ecology of the stream and the effects of various physical factors on the drift values were determined.

DESCRIPTION OF THE STUDY AREA

The Red Cedar River watershed is located in rolling agricultural lands immediately east of Lansing, Michigan. The river itself, a typical southern Michigan warm-water stream, is a tributary of the Grand River system and originates as the outflow from Cedar Lake, located in Marion Township, Livingston County, in sections 28 and 29, Township 1 North, Range 3 East of the Michigan Meridian.

The Red Cedar River and the adjoining tributaries drain an area of approximately 472 square miles. The course of the river is initially northwestward for some 18 miles and then westward for 28 miles. It passes through or near the towns of Fowlerville, Webberville, Williamston, Okemos, and East Lansing and enters the Grand River in Lansing (Fig. 1). The river receives the treated sewage effluent from the above communities, untreated sewage from suburban residences along its course, and some small amounts of industrial wastes. Despite this there is no gross pollution as shown by sludge beds, obnoxious odors, or oxygen depletions. At the time of the study the stream cannot be classified as a polluted stream although it receives appreciable amounts of nutrients.

The main channel of the river is natural except for the upper portion where it has been dredged and straightned for drainage purposes. Many of the tributaries have been altered in this way. Three artificial impoundments are found on the

Figure 1. Drainage area of the Red Cedar River and its tributaries showing sampling stations I, II, and III.

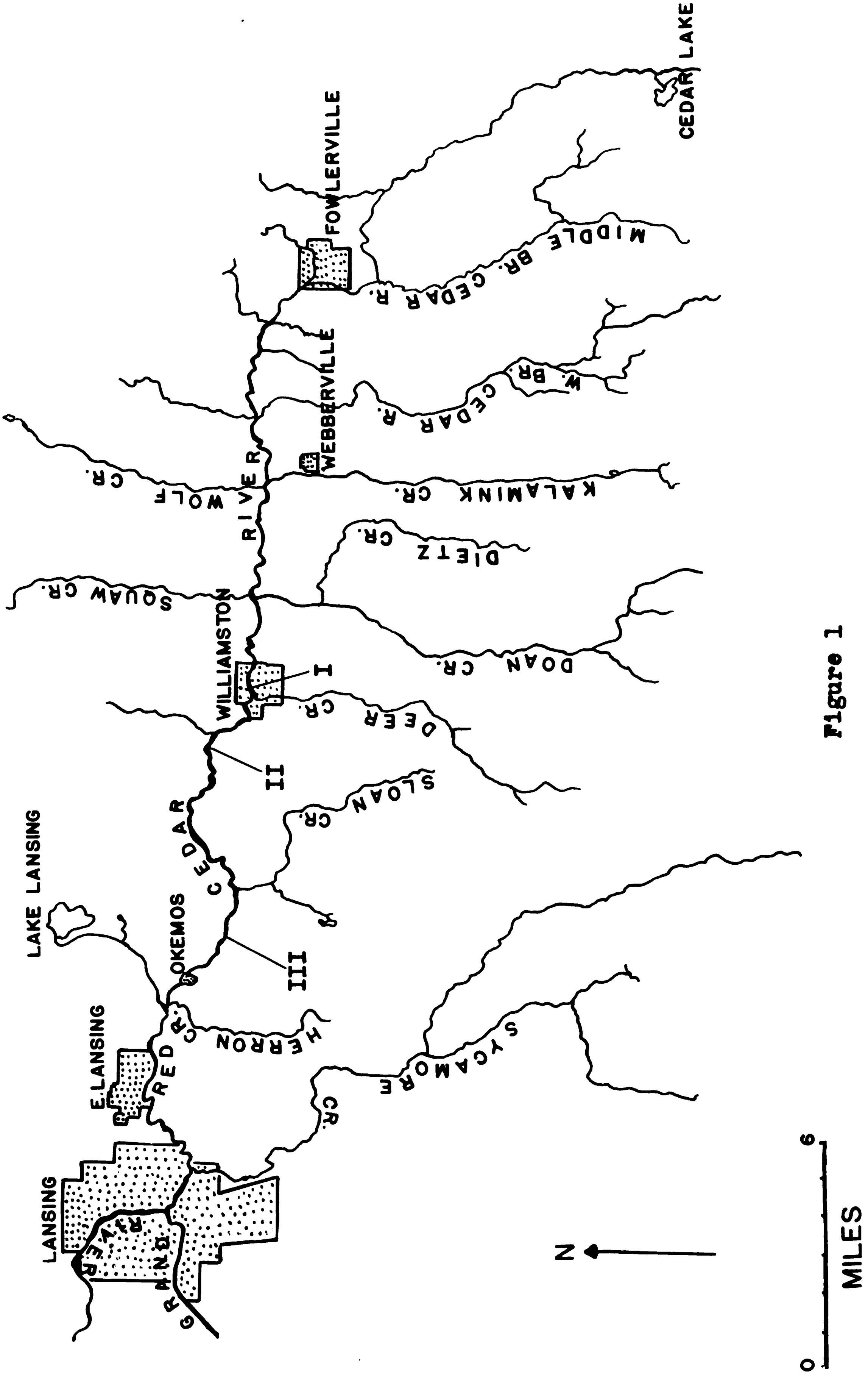

LANSING
GRAND RIVER
E. LANSING
RED CR.
LAKE LANSING
OKEMOS
HERRON CR.
SYCAMORE CR.
III
CEDAR
SLOAN CR.
II
WILLIAMSTON
I
DEER CR.
DOAN CR.
SQUAW CR.
DIETZ CR.
RIVER
WOLF CR.
KALAMINK CR.
WEBBERVILLE
W. BR. CEDAR R.
FOWLERVILLE
MIDDLE BR. CEDAR R.
CEDAR LAKE
N
0
6
MILES

Figure 1

river and are located at Williamston, Okemos, and East Lansing. The Williamston impoundment was originally created in 1870 to provide water power and is still used to some extent for that purpose. The other two impoundments are used primarily for recreational purposes. The stream bed of the Red Cedar River varies from mud and silt in the upper regions to rocks and gravel in the middle and lower portions. A few stretches of the lower part are chiefly sand. In general, the well vegetated river banks slope gradually, thus allowing only slight bank erosion. The gradient of the stream is relatively gradual. Brehmer (1956) gives the average drop of 2.5 feet per mile as the stream originates at 934 feet above sea level and travels a distance of about 49 miles to an elevation of 817 feet above sea level.

The stream discharge varies from a few cubic feet per second in some dry years to upwards of 5,000 cubic feet per second in the most serious floods. The minimum flow usually occurs in the fall, whereas the highest water levels occur in the spring and early summer. Spring floods are usually a result of excessive run-off of rain and melting snow from frozen ground.

Three sampling stations were established on the river (Fig. 1). The selection of the sampling areas was determined by the bottom type, relative current velocity, and the convenience of the location. The bottom types varied from sand to coarse gravel with silted areas, and the velocity varied from a relatively rapid riffle area to a long sluggish stretch. All stations were in close proximity to roads to make possible the use of the bulky sampling equipment.

Station I was located approximately 0.3 mile below the Williamston dam in Section 35, Township 4 North, Range 2 East of the Michigan Meridian. The river at this point is quite near U.S. Route 16. The stream width was approximately 50 feet and the average depth was 18 inches during normal flow. Occasional fluctuations in depth and velocity occurred at this station due to operations at the Williamston dam. The bottom material was composed of small rocks and gravel, and after midsummer dense beds of <u>Vallisneria americana</u> were present immediately upstream from the station. Station I was a riffle area and the current was relatively swift.

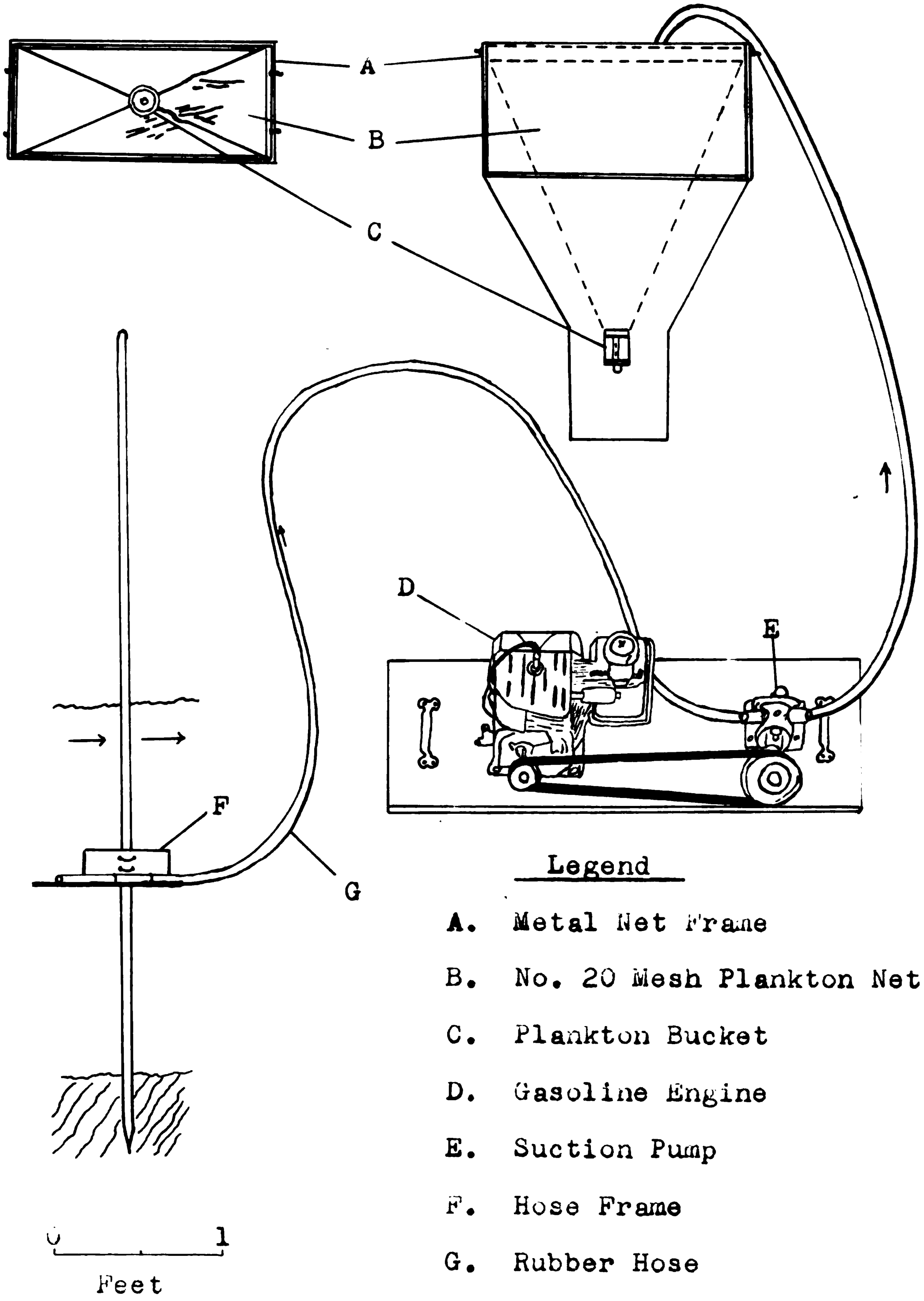
Station II, located in Section 27, Township 4 North, Range 1 East of the Michigan Meridian, was immediately above the Zimmer Road bridge and approximately 3.3 miles below Station I. The bottom material in this area consisted of large rocks and gravel with the intervening spaces filled with sand and silt. The stream was 60 feet wide and had an average depth of 36 inches. The sampling site was in the upstream part of a wide shallow pool. The river directly upstream was 50 feet wide and 20 inches deep; thus the water entering the sampling area was in the process of velocity reduction. Scattered beds of <u>V. americana</u> and <u>Sagittaria latifolia</u> were found at this station.

Station III, approximately 6.5 miles below Station II, was located in Section 27, Township 4 North, Range 1 West of the Michigan Meridian and was 0.4 mile below the Dobie Road bridge. In this area the stream was 70 feet wide and varied in depth from 18 inches on the south side to 48 inches on the north side. There was little change in the stream channel for some 300 yards upstream. The bottom material was primarily sand with very little benthic vegetation present. The stream velocity in this stretch was quite low. A few hundred feet below the sampling site is the permanent location of the Taylor thermograph used to record continuous water temperatures. The thermograph was installed by and is the property of the Department of Fisheries and Wildlife of Michigan State University.

METHODS AND TECHNIQUES

Sampling Procedures

The sampling procedures for the collection of drift material from the river were designed to satisfy specific requirements of this study. An efficient, unbiased filtration system was needed as well as a method to determine the amount of water filtered. The first attempt to accomplish this was by mounting a net, fashioned from No. 20 mesh nylon bolting cloth, in a metal flume which was designed to incorporate a current meter behind the net. The apparatus was then placed in the stream and held at the desired depth by an adjustable frame. The failure of this method, due to the eddy currents produced by the resistance of the fine mesh net, led to the development of the method that was ultimately used. This sampling system consisted of a Briggs and Stratton four-cycle gasoline engine (3/4 horsepower) which was used to operate a small self-priming Jabasco suction pump. The engine and pump were bolted to a short piece of 2" x 8" board. Handles were attached to the board to facilitate carrying (Fig. 2). This unit weighed approximately 50 pounds. Three-quarter-inch garden hose, 50 feet in length, was used to reach the sampling site from the pump. This hose was attached to a movable frame bolted to a stake and directed upstream at the desired depth and location in the stream (Fig. 2).



Legend

A. Metal Net Frame

B. No. 20 Mesh Plankton Net

C. Plankton Bucket

D. Gasoline Engine

E. Suction Pump

F. Hose Frame

G. Rubber Hose

Figure 2. Apparatus used in the collection of drift samples.

A short piece of hose was used to direct the water from the pump to the previously described net, which was held perpendicularly by the metal flume. A removable plankton bucket such as the type used on Wisconsin plankton nets was used to concentrate the drift material.

Drift samples were pumped and filtered for a period of time suitable to produce a sample of convenient size for laboratory analysis. This time was measured with a stopwatch and varied from three to five minutes during flood periods to 10 - 12 minutes during low water. The pump rate was measured before and after each sampling period by recording the time required to fill a container of known volume. It was thus possible to calculate the volume of water pumped to obtain each sample.

The drift material collected in the plankton bucket was washed several times with distilled water to remove loosely attached phosphorus and was then rinsed with distilled water into a 130 milliliter, polyethylene bottle for transfer to the laboratory. Water samples were also collected in these bottles either from the hose or directly from the stream, depending upon the particular analysis intended. A diagrammatic summary of sample processing is shown in Figure 3.

Certain sediment sampling procedures were applied in this study on the assumption that drift material and suspended sediments are somewhat similarly distributed in streams. The distribution of suspended materials in a stream and the various methods used to select sampling stations are reviewed

DRIFT SAMPLES:

Collecting and Processing

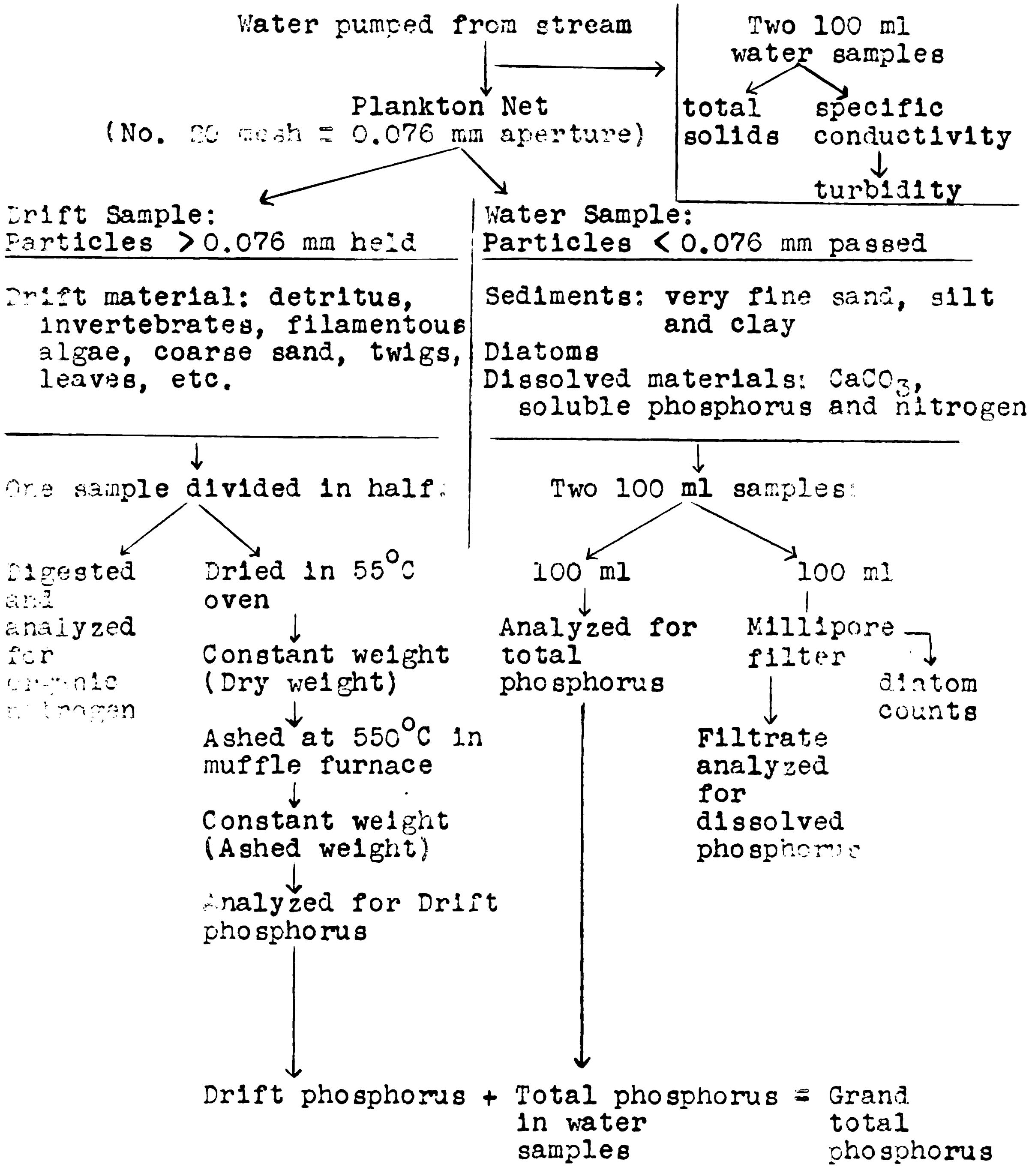


Figure 3. Flow diagram of the collection and processing of drift samples

and discussed in a series of U.S. Government reports.[1] Very little variation in cross sectional distribution is noted in theory; therefore when stream conditions would permit, samples were taken at the middle of each of two sections of equal discharge (Fig. 4). During high water periods or periods of thick ice cover, samples were taken at a single point at a reasonable distance from the bank.

The greatest variation in sediment distribution is in the vertical plane with the sediment load increasing in a curvilinear fashion from the surface to the bottom. For this reason more care was taken in selection of the vertical sampling points. U.S. Government reports give several methods of selecting vertical sampling points and of these, two were selected for use.[2] The most accurate method was used when time and conditions would permit. This, the Straub "two-point" method, employs mathematical derivations of the sediment distribution to supply coefficients for samples taken at 0.2 and 0.8 depth points (Fig. 4). The expression for the approximate sediment discharge per unit width of stream is: $S = (3/8s_{0.8d} - 5/8s_{0.2d})q$ where

S = the total sediment discharge per unit width,

$s_{0.8d}$ = the sediment concentration at 0.8 depth,

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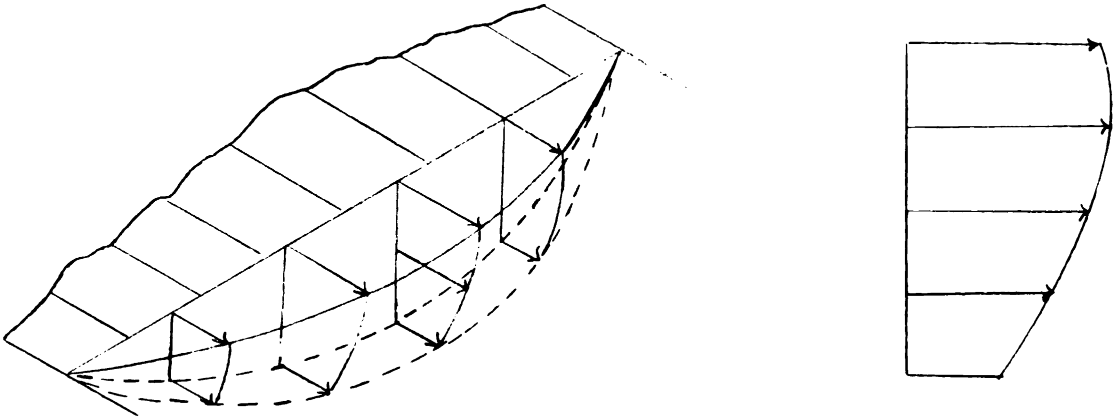
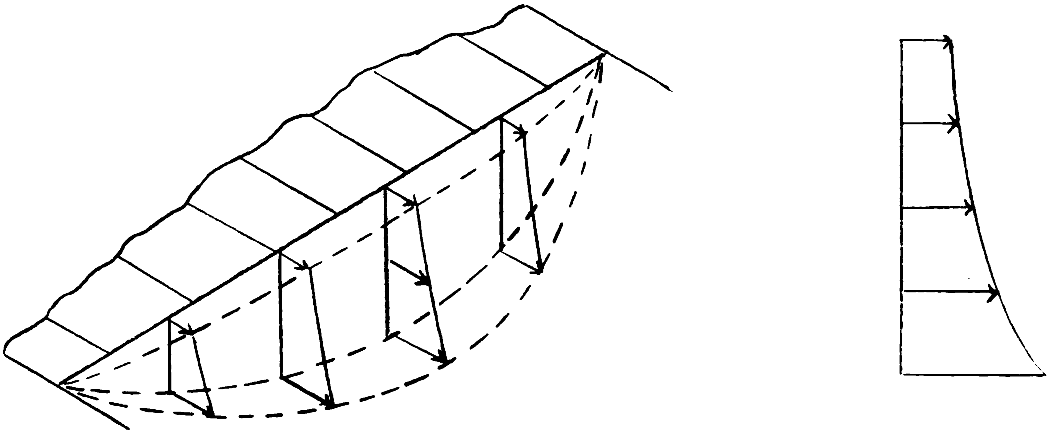
[1] "A study of methods used in measurement and analysis of sediment loads in streams, Report No. 1, Field practice and equipment used in sampling suspended sediment". 1940. T.V.A., Corps of Engineers, U.S.D.A., U.S.G.S., Bureau of Reclamation, Indian Service, and Ia. Institute of Hydraulic Research. St. Paul U.S. Engineer District Sub-Office Hydraulic Laboratory, University of Iowa, Iowa City. 175 pp.

[2] Ibid.

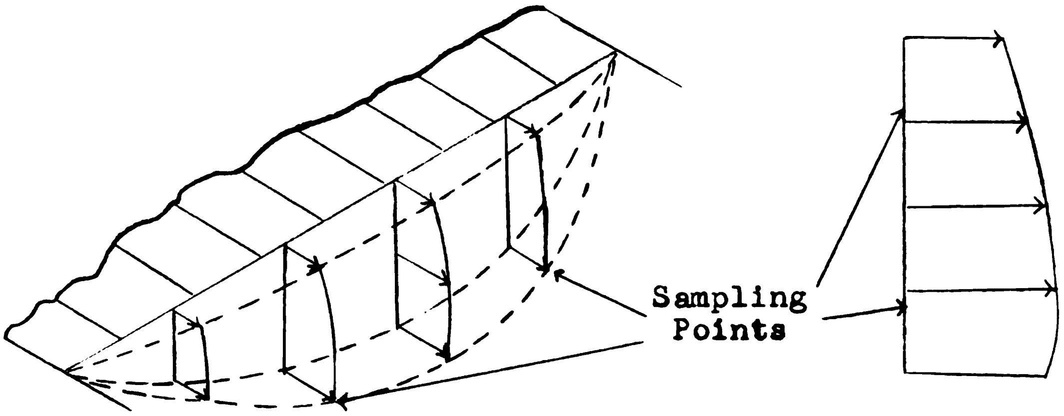
Figure 4. Velocity, sediment concentration, and sediment discharge in flowing streams. Taken from: "A study of methods used in measurement and analysis of sediment loads in streams, Report No. 8, Measurement of the sediment discharge of streams". 1948. T.V.A., Corps of Engineers, U.S.D.A., U.S. G.S., Bureau of Reclamation, Indian Service, and Ia. Institute of Hydraulic Research. St. Paul U.S. Engineer District Sub-Office Hydraulic Laboratory, University of Iowa, Iowa City. 92 pp.



VELOCITY



SEDIMENT CONCENTRATION



SEDIMENT DISCHARGE

Figure 4

$s_{0.2d}$ = the sediment concentration at 0.2 depth,

and q = the water discharge per unit width.

Since the pumping period was timed it was possible to weight the vertical point samples accordingly by a fraction of the pumping period (e.g., 3/8 of period and 5/8 of period).

The time required to set up the equipment and to take various samples was considerable. In addition, it was necessary to chop holes through the ice during part of the study period; thus it required approximately eight hours to sample three stations and to process the samples at the laboratory. It was decided to base results on single samples provided that these samples were representative. A set of four duplicate samples was taken during four varying discharge periods to test the differences between duplicate samples. Table 1. shows that, in view of the time element, the differences were small enough to warrent single samples. Statistical analysis, based on matched samples, confirmed the use of single samples. The two-tailed "t" test revealed the differences between the samples were not significantly different from zero at the 5% level. The statistical values used are as follows:

$n = 4,$ $\Sigma d^2 = 7,472.85,$

$df = 3,$ $(\Sigma d)^2 = 20,635.32,$

$\Sigma d = 143.65,$ $s_{\bar{d}} = 13.89,$ and

$\bar{d} = 35.91,$ $t = 2.585.$

$$D^{-}_{.975} = 35.91 - 13.89\ (-3.182) = 80.11$$

$$D^{+}_{.975} = 35.91 - 13.89\ (+3.182) = -8.29$$

Table 1. Duplicate drift samples collected at station II to determine the representativeness of single samples.

Sample	Drift weight mg m^{-3}	Percent ash free dry weight	Phosphorus ug m^{-3}	Discharge m^3 sec^{-1}
1	471.43	35.8	893.65	3.62
2	542.06	44.9	1074.60	3.62
1	1241.27	35.2	2261.90	7.02
2	1195.24	33.8	2071.43	7.02
1	231.75	27.0	166.67	1.42
2	219.05	28.9	134.92	1.42
1	199.21	29.0	283.33	1.19
2	184.92	30.0	277.78	1.19

Since the confidence interval includes zero the difference is not significant.

Samples were taken approximately every two weeks during periods of sustained low discharge as occurred during late fall and when ice covered the stream. Since any rise in water levels greatly affected the volume of sestonic material, samples were collected more often during these periods. Samples were taken daily during the water rise of floods and then every other day as the water receded. A total of 60 drift collections were taken over the annual period. All samples were collected during daylight hours and an average 275 liters were filtered for each drift sample.

Physical and Chemical Analyses

Weights

Processing of drift material samples was begun immediately upon return to the laboratory. The samples were rinsed from the polyethylene bottles with distilled water into constant-weight evaporating dishes and were placed in a 55°C. drying oven. Approximately 36 hours were required to reduce the samples to dryness, after which oven-dry weights were obtained. The dishes were removed from the oven and allowed to cool in a dessicator before weighing on an analytical balance. Constant weights were determined by obtaining two consecutive readings of of ± 0.5 mg after 24 hour intervals. Loss on ignition or ash-free dry weight, assumed to be the organic weight, was then determined by heating the dishes to

550^{o}C. for 30 minutes. Constant weights were then determined after cooling the dishes in a drying oven - dessicator series. The samples were then prepared for phosphorus analysis by dissolving the ash in concentrated sulfuric acid in the evaporating dish and then rinsing the contents into a flask for the digestion process. Drift weight concentrations are expressed as weight per cubic unit of water (i.e., mg m^{-3}).

Phosphorus

All phosphorus analyses were made after digestion of the samples to convert organic and polyphosphates to the orthophosphate form. The samples were treated with acidified ammonium molybdate and reduced with stannous chloride to produce a blue color. The procedure was slightly modified from that given by Ellis, Westfall, and Ellis (1948) in that the final 100 ml solution was divided in half and neutralized with saturated sodium hydroxide before the color-producing reagents were added as described by Taylor (1937). Care was taken during the digestion period to avoid boiling to dryness as Titus and Meloche (1931) recommended after reporting phosphorus loss from samples in which all SO_3 fumes had been lost at high temperatures.

A Klett-Summerson colorimeter was used to read the density of blue color produced. The readings were made using red filter with a spectral range of 640 - 700 millimicrons. Recommendations by Snell and Snell (1954) were followed in that readings were made after full development of the color, but before fading of the color had begun. A 10-minute wait after the color-producing reagents were added was found to be a suitable period. A graph prepared by analysis of solutions containing known phosphate concentrations was used to convert the colorimetric readings.

Water samples to be analyzed for phosphorus content were refrigerated until a number had accumulated so as to make processing efficient. According to Brehmer (1958) phosphorus is lost from water samples to the walls of polyethylene containers in which it is stored. To each water sample was added 0.2 ml of concentrated sulfuric acid to prevent the phosphorus loss as was suggested by Brehmer.

Three physical stages of phosphorus were determined during the study period: total phosphorus, dissolved or soluble phosphorus, and the phosphorus incorporated in the drift material. Total phosphorus was that obtained from 100 ml river water samples after digestion and treatment with the color-producing reagents. Dissolved phosphorus was determined by removing all particulate phosphorus by filtering a 100 ml water sample through a Millipore filter. The HA type filter having a pore size of 0.45 micron was used for all filtrations. The phosphorus content of drift material was determined on the ash residue after preliminary tests had shown this to be feasible. Drift phosphorus concentration is expressed as weight of phosphorus per cubic unit of water (i.e., ug m^{-3}).

Since the same drift sample was used for both weight and phosphorus determinations, it was necessary to utilize an ashing technique that would not alter the desired phosphorus content. Hayes and Anthony (1958), working with the phosphorus content of bottom muds, found that wet ashing with perchloric acid gave consistently higher values than did dry ashing. This was attributed to the breaking up of rock particles in the wet ashing method. Only the more readily available phosphorus was considered to be of importance in this study and thus the dry ashing method was used.

Some doubt existed as to whether some of the organic phosphorus would be volatile at ashing temperatures. A series of algal samples were analyzed to test this possibility. The algal samples consisted of homogeneous concentrations of <u>Anabena variabilis</u> taken from a pure laboratory culture. Six samples were prepared and divided into three pairs. All samples were oven-dried and weighed. One pair was placed in the furnace at room temperature and was heated to 550°C. for 30 minutes. Another pair was placed in the furnace at 550°C. and the third pair was excluded from the ashing process. The results of the tests did not indicate any loss of phosphorus on ignition (Table 2). The higher phosphorus values for the ashed samples may be the result of increased phosphorus availability due to ignition.

Total Kjeldahl Nitrogen

Drift samples to be analyzed for nitrogen were placed in a freezer immediately upon return to the laboratory. Nitrogen in the form of ammonia and organic nitrogen was determined by the distillation method as described in

Table 2. Weights and phosphorus values from algal samples to determine the possible loss of phosphorus on ignition.

Conditions		Dry weight of algae (mg)	Organic weight (mg)	Phosphorus content (ug/mg algal wt.)
Ashed at 550°C for 30 minutes	Placed in cold furnace	4.1	3.2	27.1
		4.5	3.4	25.0
	Placed in hot furnace	5.3	4.3	23.8
		4.2	3.3	28.0
Not ashed		4.6	-	21.8
		4.5	-	21.8

"Standard Methods" (APHA, AWWA, FSIWA, 1955) under Kjeldahl Nitrogen. The selenium and sulfate catalyst recommended for hard-to-destroy organic matter was utilized.

Turbidity

Turbidity readings were made directly upon returning to the laboratory on a Klett-Summerson photoelectric colorimeter using a blue filter having a spectral range of 400 - 465 millimicrons. Corrections for intrinsic color were made by filtering the sample through a Millipore membrane and subtracting the reading of the filtrate from the reading of the unfiltered sample. The colorimeter had been calibrated with the Jackson Candle Turbidimeter. All turbidity readings are given in turbidity units as used in "Standard Methods" (APHA, AWWA, FSIWA, 1955).

Specific Conductivity

The specific conductance of the water samples was ascertained by reading the electrical resistance on an

Industrial Instrument Company Model RC-7 conductivity meter. The resistance readings were corrected to 18°C. and converted to micromhos cm^{-1} according to the formulas given in the "Operating Manual" (Industrial Instruments Incorporated). All measurements were made as soon as possible after returning to the laboratory.

Total Solids

Total solids determinations were made gravimetrically on an analytical balance after evaporation of a 100 ml water sample in a 55°C drying oven, as described under Total Residue in "Standard Methods" (APHA, AWWA, FSIWA, 1955). Constant dry weights were recorded after obtaining two consecutive readings of ± 0.5 mg over a 24-hour interval.

Water Temperature

Water temperatures were taken at the time and place of sampling with a pocket thermometer held approximately four inches under the water surface. Temperatures reported in Appendix A were recorded on a Taylor thermograph located a few hundred yards below station III.

Discharge

The discharge or volume of flow of the river was determined on the same date as the drift samples were taken except during extreme flood conditions and when ice cover existed. The volume of flow for the river at any one time was determined by measuring the velocity of flow and the dimensions of sub-sections of the stream cross-section. The total discharge was then the sum of the sub-section volumes. Sub-sectional discharge, in cfs, was the product of the velocity in feet per second, as measured with a Gurly current meter, and the area in square feet. Usual sub-section widths varied from two to eight feet, with the widest sections occurring in areas of uniform depth and velocity. The section dimensions were measured with a calibrated cable and with the calibrated current meter stand.

To facilitate the calculation of the total phosphorus and drift movement in the stream it was necessary to know the daily discharge rates at the sampling stations. Estimates of the rates were obtained by solving regressions of the measured discharges on those recorded at a gaging station at the Michigan State University campus (Appendices B and C). This permanent station is maintained by the Lansing Office, Surface Water Branch, U.S. Geological Survey.

Biological Analyses

Zooplankton and Bottom Fauna

Examination of all drift samples for the abundance and types of zooplankton and bottom fauna was undertaken at the time of transfer of the sample from the polyethylene bottle to the evaporating dish, just prior to the placement of the sample in the drying oven.

Phytoplankton

Drift samples were examined for macro-phytoplankton in the same manner and at the same time as for zooplankton.

In addition, 100 ml river water samples were filtered through a Millipore filter to collect and concentrate diatoms. The pore diameter of the HA type filter is 0.45 ± 0.02 microns and thus is very efficient for the retention of microscopic organisms. Creitz and Richards (1955) found Millipore filters more efficient for the concentration and retention of plankton than the Foerst plankton centrifuge.

After filtration the filter membrane was allowed to dry and was then made to adhere to a glass slide by the addition of two or three drops of immersion oil in the manner described by Peters (1959). The filters have a porosity of 80 percent thus allowing a large absorption of immersion oil and since both the type A oil and the filter have a refractory index of 1.49 - 1.51 the result is that the filter pad becomes transparent when treated with the oil (Millipore Filter Corporation, 1955).

The slides were analyzed quantitatively and qualitatively with a compound microscope using 10X eye pieces and a 97X immersion oil objective. Identification of the dominant diatoms to genus was accomplished with the aid of keys in "The Fresh-water Algae of the United States" (Smith, 1933). Quantitative determinations were preceded by statistical tests to ascertain the distribution of the diatoms on the slides. These tests suggested a tendency for the diatoms to aggregate as was found by Ballentine (1953) when comparing methods of estimating nannoplankton. Peters (1959) found little deviation from randomness in his studies of diatom distribution on Millipore pads; however, this may have been the result of his mixing of the organisms with a "Mag Mix" prior to filtration.

The total number of diatoms in the filtered 100 ml sample was determined by counting 50 randomly chosen microscope fields and substituting this figure in the following formula: $m = N\overline{X}$, where m is an estimate of the total number of individuals on the area; N is the total number of microscope fields on the filter pad; and $\overline{X}$ is the mean number of individuals counted per field. The relative frequency of abundance of the dominant genera for each sample was determined by dividing the count for each genus by the total count for all genera.

RESULTS AND CONCLUSIONS

Quantitative Drift Relationships

Quantitative studies included an evaluation of sampling techniques regarding particle size and particle distribution. This evaluation was designed to determine the size material to be included as drift and the size to be included in the water samples.

Other quantitative studies compared the weight of drift and the phosphorus content of drift between different stations up and down the river and between different vertical strata at one of the stations. On the basis of the above studies the primary quantitative study was planned to measure the annual movement of drift material, and its nutrient composition at a representative station.

Comparison of Sampling Techniques

The assumption by Brehmer (1958) that certain low phosphorus values in his study were caused by the exclusion of drift material led to a study of sampling methods. Water samples were collected by immersing a polyethylene bottle into the stream as done by Brehmer (1958) and by filling a similar bottle with water after it had passed through a No. 20 mesh plankton net. Phosphorus values in ug 1^{-1} were obtained for 45 paired samples from Station II during the period from October, 1958 to May, 1959 (Appendix D). These values were analyzed statistically to test whether the unfiltered samples were significantly greater than the filtered phosphorus values. A one-tailed "t" test was applied to the sum of the differences of matched samples. The values used in the statistics are as follows:

$n = 45,$

$df = 44,$

$\Sigma d = 20,$

$\bar{d} = 0.444$

$\Sigma d^2 = 712$

$(\Sigma d)^2 = 400,$

$$s_{\bar{d}} = \left(\frac{\Sigma d^2 - \frac{(\Sigma d)^2}{n}}{n\,(n-1)} \right)^{\frac{1}{2}},$$

$$= 0.5966,$$

$$t = \frac{\bar{d} - 0}{s_{\bar{d}}},$$

and $t = 0.7442$.

n = total number of matched samples.

df = degrees of freedom.

Σd = the sum of the differences between the matched samples.

$s_{\bar{d}}$ = the standard error.

$$t_{.80} = 0.850 > 0.7442.$$

$$t_{.90} = 1.300 > 0.7442.$$

The statistical results show the values of the unfiltered samples were not significantly greater than the filtered samples at the 20 percent level of significance. This result can be interpreted in two ways. It might be said that nothing had been removed from the filtered samples; thus they contained as much phosphorus as the unfiltered samples. However, when the size of the individual samples is considered (100 ml) it might also be concluded that the unfiltered samples were too small to adequately include the drift material. In other words, immersing a bottle to collect water samples is adequate to take a representative sample of the silt, clay, diatoms, and other microscopic particles that are densely and homogeneously distributed in the stream; however, a larger sample is needed to take a representative collection of larger particles that are distributed in a more diffuse, heterogeneous fashion. As previously stated under sampling procedures, it was necessary to pump and filter water for several minutes to obtain sufficient drift material for laboratory analysis.

Welch (1948) lists the average aperture size of No. 20 bolting cloth as 0.076 mm and the materials below that size include some very fine sand, silt, and clay. These materials were not collected in the drift samples and were considered as belonging to that group of material adequately represented in water samples collected by the bottle method.

Although drift material and sediments are similar in many respects (e.g., distribution and response to stream velocity), they differ greatly in quantity. Lane and Koelzer (1943) list particles smaller than 0.076 mm as composing as much as 97 percent of the sediments in some cases. Since particles of this size were not collected as drift material, no quantitative comparisons were made between drift material and sediment studies.

Variations between Stations and Depths

Stations. An investigation to determine differences in drift movement at three stations was undertaken. Drift material was sampled at stations I and II from September 16, 1958 to February 24, 1959. Station II was incorporated in the comparative study on November 4, 1958.

The drift values were consistently higher at Station I than at Station III until well into the winter period (Fig. 5). The higher values were probably due to the station being located a few hundred yards below the Williamston dam. It is assumed that the reservoir was a source of planktonic material, and floating vegetation such as *Lemna minor* which, after coming over the dam, was available as drift material at Station I. Station II, in addition to being below the dam (3.5 miles), was also three miles below the Deer Creek confluence and about 2.5 miles below the sewage plant outfall at Williamston. It is doubtful that much of the drift material supplied by these sources remained in suspension long enough under normal discharge to greatly affect the values at Station II. The sharp rise in drift values during mid-November coincided with a rise in the discharge (Figs. 5 and 9). During such increases in the volume of flow, the effects of Deer Creek and the sewage outfall are most likely more prominent at Station II.

A reduction in the amount of drift material carried by the stream after December (Fig. 5) can be attributed to reductions in stream velocity, rainfall, runoff, and

Figure 5. Comparison of drift weights and the phosphorus content of drift material collected at three sampling stations from September, 1958 througn February, 1959.

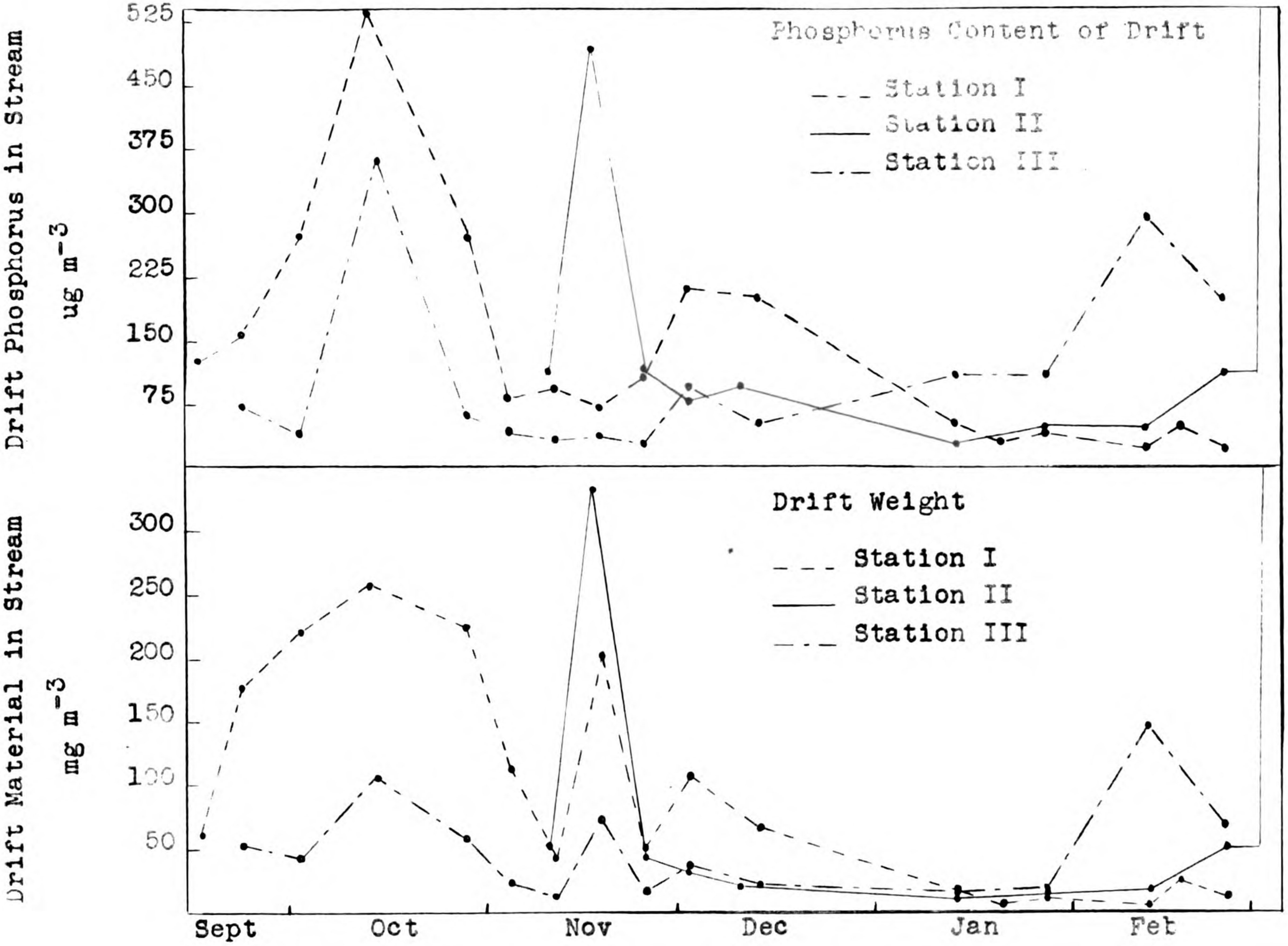

Drift Phosphorus in Stream
ug m^-3
525
450
375
300
225
150
75
Phosphorus Content of Drift
Station I
Station II
Station III
Drift Material in Stream
mg m^-3
300
250
200
150
100
50
Drift Weight
Station I
Station II
Station III
Sept
Oct
Nov
Dec
Jan
Feb

Figure 5

production rate of aquatic vegetation. The water temperature had reached 0°C. by December 2, 1958.

Brehmer (1958), investigating the effects of the Williamston sewage outfall, discusses the downstream shift of the phosphorus regeneration zone and relates this to the periphyton decay rate being reduced by decreasing water temperatures. This slowing in the rate of decomposition of materials is reflected in the drift samples of the three stations during the onset of colder temperatures. Although the drift weights are greatly reduced after December as previously stated, the materials that are present remain in suspension as drift particles for a longer period because of the reduction in decay processes. Thus the greater drift concentrations tend to shift further downstream and result in Station III being highest in January (Fig. 5). Since bacterial action is at a minimum and decomposition is very slow during cold water periods, the phosphorus component of the drift material remains high as little is released by decomposition. When the greatest drift weight concentrations of the three stations shifted downstream to Station III in January, the highest phosphorus content of the three stations also shifted downstream to Station III (Fig. 5).

The high value at Station III on February 12 (Fig.5) is misleading as this was due to the unusual collection of a large clump of plant material in the sample. Near the end of the station-comparison-period the drift values at all stations had risen because of an increase in the discharge.

Depth. It was decided to investigate quantitatively the assumption that drift material would be increasingly concentrated toward the stream bottom. Station II was selected for the study site as this station would best show the depth differences. The current at this station is in the process of deceleration as it enters pool conditions. Samples were collected at 0.5 depth and on the stream bed from April 8, 1959 to July 2, 1959. Samples at 0.2 depth and at 0.8 depth were also taken from April 8, 1959 to May 8, 1959. Sampling times were determined by the stage of the river so as to compare a range of discharge effects. In general the concentration of drift material was found to increase with the depth, and at all sampling dates the concentration of drift material was greatest in the bed load samples (Table 3).

The largest differences in drift concentrations between the various vertical sampling strata occurred during mid-April and early May when the stream was under flood conditions. During these periods large amounts of inorganic matter were moved downstream. Since this inorganic material was silt and sand it settled out quickly and ensuing movement was by saltation thus accounting for the large concentration of drift material in the bed load samples.

Samples taken on April 8 and April 15 (Table 3) show the drift weight at the 0.2 level to be higher than that at the deeper 0.5 level. This was contrary to expectations; however, these samples were taken during flood periods when water turbulence was very evident. A great amount of

Table 3. Comparison of vertical differences in phosphorus and weight values from drift analyses.

Date	Depth fraction from surface	Drift weight mg m^{-3}	Percent ash free dry weight	Drift phosphorus ug m^{-3}	Discharge m^3 sec^{-1}
1959 April 8	0.2	1176.1	15.6	718.3	23.79
	0.5	1077.5	17.1	676.1	
	0.8	1545.1	12.8	845.1	
	B.L.*	2695.8	11.8	1577.5	
April 12	0.2	483.1	22.1	309.9	13.17
	0.5	700.0	21.5	640.9	
	0.8	636.6	11.9	493.0	
	B.L.	1522.5	13.8	887.3	
April 15	0.2	907.9	17.1	565.8	8.27
	0.5	528.9	29.8	578.9	
	0.8	710.5	31.2	723.7	
	B.L.	1002.6	34.5	1315.8	
April 22	0.2	239.5	28.5	197.4	4.76
	0.5	311.8	21.9	217.1	
	0.8	289.5	30.4	246.1	
	B.L.	392.1	27.1	236.8	
May 2	0.2	618.4	28.5	605.3	11.13
	0.5	785.5	24.6	723.7	
	0.8	948.7	25.3	763.2	
	B.L.	1204.0	29.8	1171.1	
May 8	0.2	348.7	35.8	500.0	3.71
	0.5	357.9	31.2	518.4	
	0.8	465.8	29.6	596.1	
	B.L.	598.7	51.8	973.6	
May 22	0.5	270.5	43.5	751.9	4.36
	B.L.	531.8	36.5	1116.3	
May 30	0.5	506.8	40.7	984.1	3.62
	B.L.	630.2	36.3	1222.2	
June 16	0.5	225.4	27.9	150.8	1.42
	B.L.	277.8	23.7	198.4	
July 2	0.5	192.1	29.5	280.6	1.19
	B.L.	345.2	18.1	341.3	

*Denotes bed load.

turbulence would cause the suspended materials to be violently mixed and at any one time during the flood period the concentration might be greater nearer the surface of the water.

Samples taken after May 8, 1959, when the floods had receded, revealed the bed load materials to contain a lower percentage of organic material than did the upper strata samples. This holds true since the lighter organic material would remain suspended longer than would silt and sand when the turbulent effects of high water were removed.

The drift concentration for the various depths was plotted and is similar to the theoretical distribution pattern for sediments (Fig. 6).[3] The high drift concentration near the surface can be attributed to unusual water turbulence, since many of the samples were taken during flood periods.

Nutrient Relations

Phosphorus. The study was initiated primarily to investigate the movement of phosphorus in the form of drift material; thus emphasis was placed on that phase of the research. The phosphorus content of the drift was found to closely follow the fluctuations in drift weight (Table 4). The decline in drift weight during late fall and early winter can be attributed in a large part to the low discharge rates. The productivity at this time is reduced due to shortening daily

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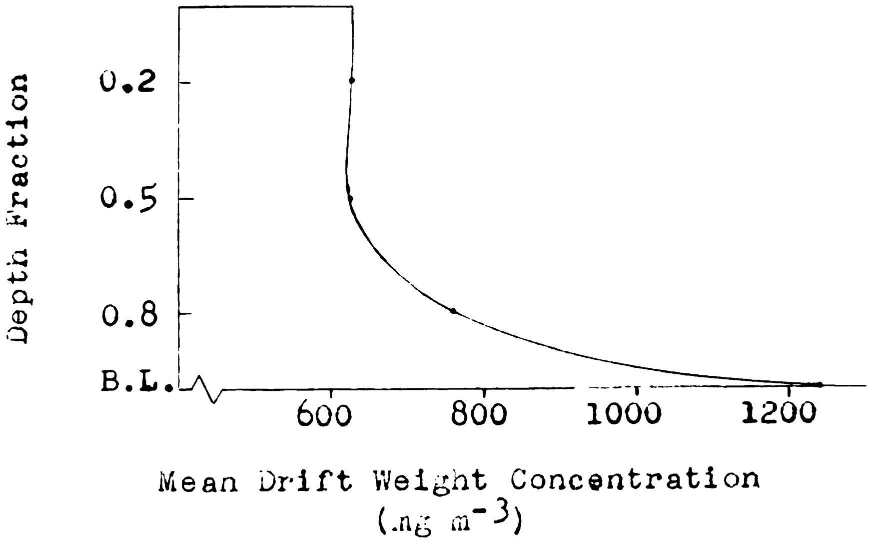
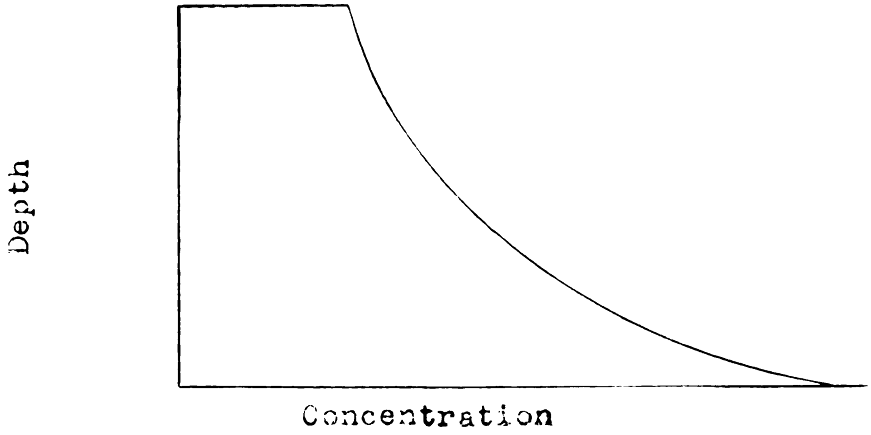
[3] "A study of methods used in measurement and analysis of sediment loads in streams, Report No. 8, Measurements of the sediment discharge of streams". 1948. T.V.A., Corps of Engineers, U.S.D.A., U.S.G.S., Bureau of Reclamation, Indian Service, and Ia. Institute of Hydraulic Research. St. Paul U.S. Engineer District Sub-Office Hydraulic Laboratory, University of Iowa, Iowa City. 92 pp.





Typical Vertical Sediment Distribution

Figure 6. Comparison of the distribution of drift weight concentrations with vertical sediment distribution.

Table 4. Mean drift values and mean discharge per month from September, 1958 to July, 1959.

Month	Drift weight mg m^{-3}	Percent ash-free dry weight	Drift phosphorus ug m^{-3}	Discharge m^3 sec^{-1}*
September	98.05	32.80	141.28	0.683
October	152.77	34.38	369.81	1.114
November	87.45	44.85	199.83	1.531
December	48.07	60.98	173.33	1.539
January	13.82	63.20	34.17	0.924
February	46.56	54.87	66.31	2.897
March	2085.41	19.40	2078.83	26.420
April	2645.14	16.80	2458.48	15.178
May	489.37	32.60	769.28	5.748
June	721.83	31.20	1158.73	2.760
July	192.06	29.50	280.56	1.189

* m^3 = cubic meter of water.

light periods and lowering water temperatures. Ice covered the stream during all of January and most of February and production was probably at a minimum. The percent of ash-free dry weight of the drift material increased during the late fall and early winter (Table 4, Fig. 7). This increase of the percent of organic weight is a result of the reduced decomposition in the cold water. The action of bacteria on the organic material causing dephosphorulation (Harvey, 1940) is also reduced by the low temperatures thus helping to maintain the high organic phosphorus levels of the drift material (Fig. 7). Although the rate of organic production decreases, the amount that is still being sloughed off into the current decomposes at a much slower rate.

The discharge rates increased greatly during the flood periods in March and April. At the same time, the drift weight and drift phosphorus concentrations increased even more than the volume of flow. Large quantities of material were washed into the stream from the land during the spring runoff. Organic and inorganic materials that had previously settled out in the quiet areas of the stream were lifted into the current by the turbulent flood waters, and algal growth was removed from the bottom by the abrasive action of sand and silt. Although the mean discharge in April was less than in March, the drift weight and phosphorus concentrations were greater in April. The soil during March was still frozen during the heaviest periods of runoff and the removal of materials was not as great as during April when the ground

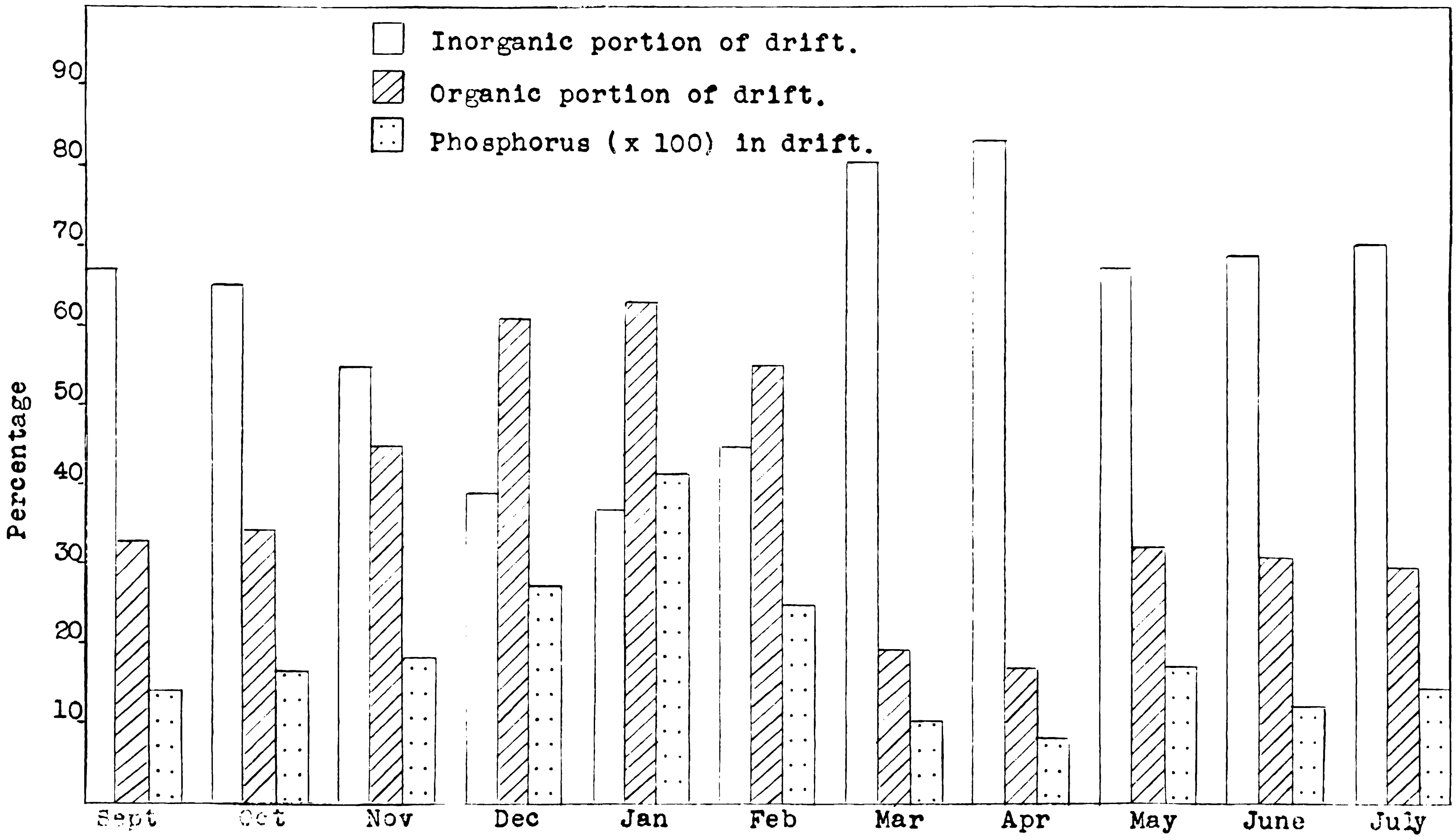


Figure 7. The relationships of the organic and inorganic portions of drift material compared with the total phosphorus in drift material.

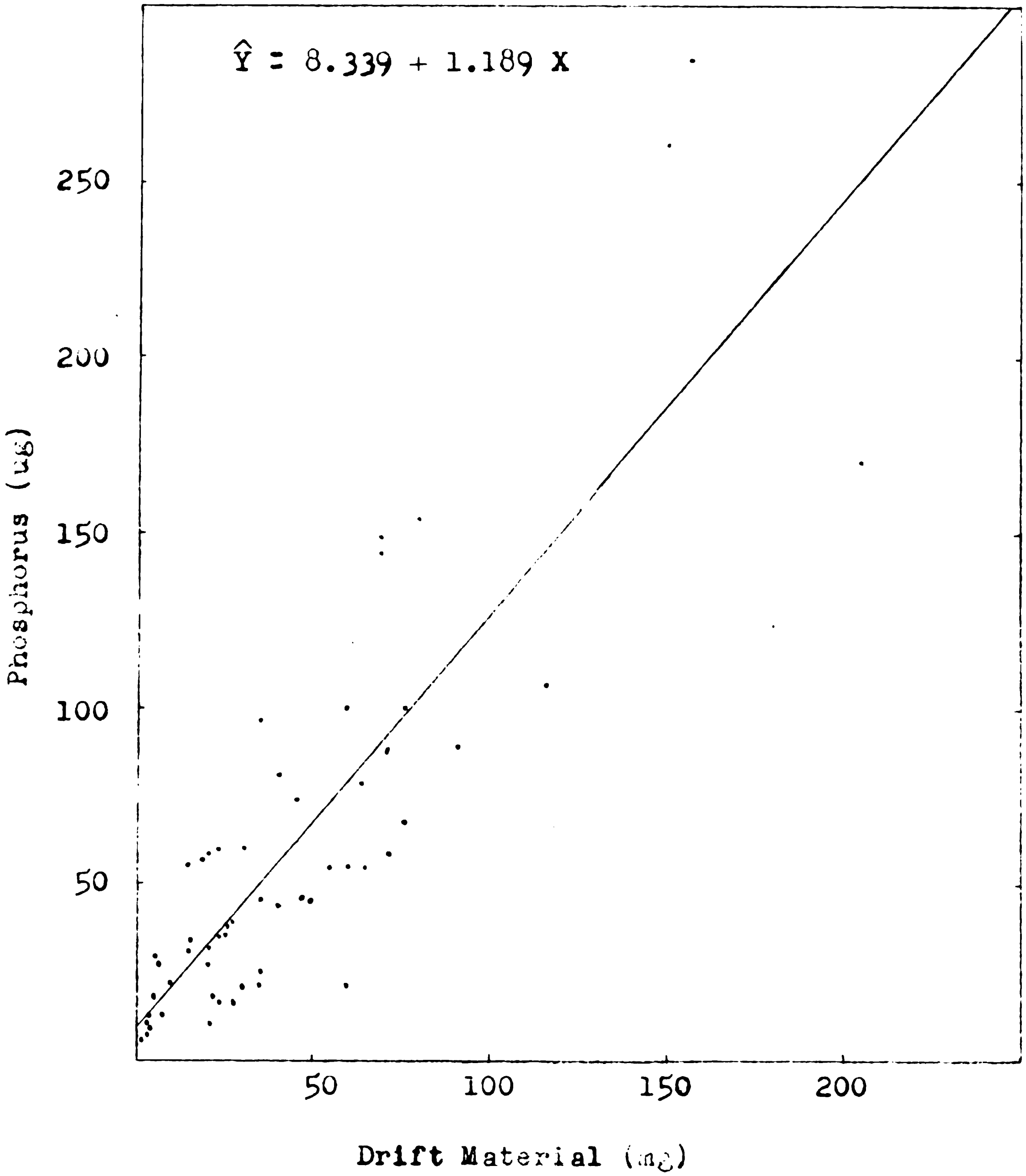
had thawed.

The drift phosphorus concentration showed a decline from March and April values in May, June, and July (Table 4). This decline was probably a result of a decrease in runoff, as shown by the discharge, which brought less drift material into the stream. The steady decline of the ash-free dry weight in the spring as shown in Table 4 reflects the increase in decomposition rate as the water temperature increased. The high drift weight and phosphorus concentration, in Table 4, for June are influenced by one extremely high sample obtained directly after a rain when the water was rising and this excessively weighted the mean values.

The relationship between the weight and phosphorus content of drift material was determined by solving the regression of phosphorus content as a function of drift weight (Fig. 8) and by calculating the coefficient of correlation (Snedecor, 1956). Figures obtained for the coefficient of correlation are as follows:

$$r_{xy} = 0.85 \text{ and } r^2_{xy} = 0.72$$

where r_{xy} is the coefficient of correlation and r^2_{xy} is the percent of variation in Y due to variations in X. The high correlation coefficient, 0.85, indicates that the phosphorus content of drift material is in a large part directly dependent on the total drift weight. Since the phosphorus is a component of the drift this high correlation is expected, but an absolute dependence would give a correlation of 1.0, so there must be some influence on the phosphorus content of



$n = 56$

$\Sigma X = 2402$

$\Sigma X^2 = 194,603$

$\Sigma Y = 3,322$

$\Sigma Y^2 = 377,280$

$\Sigma XY = 251,338$

Figure 8. Relationship of phosphorus content of drift material to weight of drift material.

the drift other than the total drift weight thus reducing the correlation to 0.85. A credible explanation is the effect produced by the organic content of the drift material. Figure 7 shows the phosphorus content to closely follow the pattern of the organic component.

The organic component of drift material has a greater phosphorus content than does the inorganic component. It was shown in Table 4 that the organic content was inversely related to the total drift weight. Thus the samples low in drift weight, but with a high organic component, would have a higher percent of phosphorus than would samples high in drift material, but with a low percent of organic matter. The effect would be to reduce the correlation between phosphorus content and total drift weight; however, the reduction would be small because the organic component was always much less than the inorganic (Fig. 7). To have an absolute dependence of phosphorus content on the total drift weight, it would be necessary to have a constant percent of organic matter in the drift material.

The movement of drift material and phosphorus past the sampling point at Station II was determined at approximately weekly intervals for a full year from July 3, 1958 through July 2, 1959 (Table 5). Since water samples used for total phosphorus determinations had been filtered through the drift collecting net they did not contain the phosphorus in the drift material. The total phosphorus weights (Table 5) were represented by the sum of the total water phosphorus plus

Table 5. Kilograms of drift material and phosphorus moving past station II per month.

Month	Total drift weight	Phosphorus				Mean * discharge m^3 sec^{-1}
		Water		+ Drift	= Grand total	
		Dissolved	Total			
1958						
July 3-31	4,340	590.4	1,095.9	5.2	1,101.1	3.787
August	468	125.9	255.0	1.7	256.7	1.325
September	174	89.1	161.3	0.3	161.6	0.893
October	441	149.1	213.2	1.4	214.6	1.239
November	347	95.6	263.7	0.9	264.6	1.668
December	192	96.1	220.0	0.3	220.3	1.332
1959						
January	33	70.3	164.3	0.1	164.4	1.275
February	349	381.1	730.9	2.0	732.9	3.227
March	142,819	2,372.3	5,162.1	173.2	5,335.3	25.204
April	104,069	743.8	2,149.9	78.8	2,228.7	14.475
May	7,286	401.0	964.4	9.8	974.2	5.489
June	5,155	234.2	944.7	8.4	953.1	2.626
July 1-2	30	13.4	24.2	0.1	24.3	1.269
Totals	265,703	5,358.3	12,349.7	282.2	12,631.8	

*Corrected for station II from U.S.G.S. station at Farm Lane bridge on M.S.U. campus.

the phosphorus incorporated as drift.

Monthly phosphorus weights (Table 5) were obtained by expanding the phosphorus concentrations of those samples taken during each month. Each sample was allowed to represent the middle half of the time period between the previous and the following samples. Thus if samples were collected on the 5th day, the 10th day, and the 15th day, that sample collected on the 10th day represented the period from the 8th through the 12th day as follows:

(5)- 6 - 7 { 8 - 9 -(10)- 11 - 12 } 13 - 14 -(15)

The weight of phosphorus for each period was calculated from the discharge and the length of the time period:

(weight P/water vol.) x (water vol./time) x (time) = weight P.

The monthly totals then represent the sum of the phosphorus weights for each of the sample periods within that month. The yearly figures (Table 5) were based on 60 sampling dates. Periods of high water were sampled more frequently than periods of low, constant flow.

Figures taken from Table 5 show that 69 percent of the final annual phosphorus figure moved past Station II in 25 percent of the year, and that 90 percent went past in 50 percent of the year. Drift phosphorus was even more concentrated as 89 percent moved past the sampling point in 16 percent of the time. This is demonstrative of the discharge effect. Annual phosphorus figures for the Red Cedar River for different periods are quite similar when the discharge and sampling sites are considered (Table 6).

Table 6. Comparison of estimations from three sources of annual phosphorus movement in the Red Cedar River.

Period	Kilograms of phosphorus	Mean discharge m^3 sec^{-1}	Sampling * site
July, 1957- July, 1958	16,048.4 **	5.064	Station III
Feb., 1958- Feb., 1959	9,763.0 ***	2.786	Farm Lane on M.S.U. campus
July, 1958- July, 1959	12,631.8	4.907	Station II

*Station numbers refer to those used in this study.
**Grzenda, 1960.
***Vannote, 1961.

Viewing the annual phosphorus load in terms of a phosphate fertilizer tends to make the figures of Tables 5 and 6 more meaningful. The total of 12.6 metric tons of elemental phosphorus would be equivalent to 159 metric tons of super phosphate fertilizer (18 percent by weight = P_2O_5). This amount of fertilizer, distributed over the 359 square miles of farm land in the Red Cedar River watershed, would have a value of 1.5 pounds per acre or spread at a rate of 250 pounds per acre, this amount of fertilizer would cover 1400 acres.

The significance of this drift and phosphorus movement is that this food and nutrient are lost to the area at and above the sampling point, but at the same time becomes available to downstream areas. As long as the supply of phosphorus and organic material maintains the concentrations that it has over the years, the amount lost from an area in a stream is not important as it is replenished constantly. However, the supply must certainly be exhaustable. Perhaps the availability of the drift and phosphorus to downstream areas is of more apparent and prevailing importance than the loss from the upstream areas. Curl (1959) has shown the value of phosphorus movement in streams in maintaining the nutrient levels in western Lake Erie, thus providing for growth and production there. Many immature aquatic insects such as net-spinning Trichoptera and many Diptera which spin nets or have bristle-like mouth parts obtain their food by filtering actions and thus depend on the movement of food particles for survival. The great importance of organic debris as food for aquatic insects has been reported by Jones (1949, 1950). It is also possible for some algae to utilize phosphorus in organic form (Chu, 1946).

The movement of drift material might also be viewed in relation to the energy flow diagram of Odum (1959). The import of organic material into a community can be represented by detritus removed from the drift material either by filtration by insects or by settling out and utilization by the herbivores and thus passed on through the community either in the form of an animal or as a metabolite. The export of dead organic matter from the community, represented here by the sloughing off of senescent algae, is added to the drift material. Thus the drift material is continually supplying communities and is continually being added to by the communities.

Nitrogen. Drift samples for organic nitrogen content were taken during ice cover, floods, and periods of warmer temperatures and as such the samples represented the extremes of conditions that occurred in the river. The concentration of organic nitrogen was generally higher than the drift phosphorus, but both were found to be affected by the same factors and both varied the same with the stream discharge (Table 7).

High nitrogen concentrations were maintained for a longer period during floods than were phosphorus concentrations which fell off more rapidly as is shown for March 5 and 7 in Table 7. It is unlikely that drift material maintained a higher nitrogen than phosphorus content during floods. Probably the reason for the slower decline of organic nitrogen is that organic material would remain suspended longer than would heavier materials such as sand. The sand, when present in drift samples, would yield more to the rigorous phosphorus digestion process than to the nitrogen digestion and upon settling would result in drift samples with reduced phosphorus concentrations; however, the nitrogen concentration being entirely a result of the organic material would decline more slowly.

The relationship between drift phosphorus and the organic nitrogen content of drift material was determined using the values in Table 7. The regression formula, based on 16 samples, revealed the following relationship:

mg organic N = 1.53 x mg drift phosphorus + 0.18; $r_{xy} = 0.88$, and at a significance of .05, $2.131/\sqrt{15} < 0.88 < -2.131/\sqrt{15}$.

Table 7. Comparison of the phosphorus content of drift and organic nitrogen concentrations with discharge at station II.

Sampling date	Phosphorus mg m^{-3} *	Organic nitrogen mg m^{-3} *	Discharge m^3 sec^{-1}
1959			
February 12	0.04	0.05	1.161
February 17	0.05	0.34	5.663
February 24	0.11	0.01	3.822
March 2	1.66	2.65	10.760
March 3	3.08	4.28	16.990
March 4	2.64	4.57	25.060
March 5	0.90	2.06	29.874
March 7	0.57	1.47	44.741
March 10	0.46	0.44	27.892
March 12	0.39	0.78	17.216
April 15	0.63	0.52	8.268
April 22	0.22	0.27	4.757
May 2	0.70	0.81	11.128
May 8	0.54	0.31	3.709
May 22	0.75	3.73	4.360
July 2	0.28	0.49	1.189

*Nutrient concentrations are per cubic unit of stream water while discharge is unit of stream water per time unit.

The cellular N/P ratio for drift material was 1.60. Grzenda (1960) reported a N/P ratio of 1.04 for periphyton in the Red Cedar River. Since these ratios extend up to 5.0 or 10.0 when phosphorus is limiting the drift ratio is very similar to the periphyton ratio. This may be a reflection of comparable nutrient conditions between the stream and the watershed which contributed a large portion of the drift material.

The monthly movement of nitrogen is given in Table 8. The available nitrogen values were calculated using data collected by fellow graduate students, Messrs. John Carr and Robin Vannote, for a concurrent nutrient study of the Red Cedar River. The organic nitrogen values of drift were calculated from concentrations in Table 7 for those months when samples were collected; for other months estimations of the organic nitrogen were made from the drift phosphorus concentrations using the regression formula. Discharge was a major factor in the quantity of nitrogen that moved downstream. About 80 percent of the total movement occurred during the flood months of March and April (Table 8). The ratio of available nitrogen to dissolved phosphorus and to total phosphorus for normal flow periods was approximately 20:1 and 10:1 respectively. Similar ratios were calculated from data given by Grzenda (1960) for the Red Cedar River.

Effects of Discharge

Drift material and drift phosphorus. The factor most affecting the concentration and total amount of drift material, and thus drift phosphorus, was discharge. Assuming

Table 8. Kilograms of available nitrogen and of the organic nitrogen of drift moving past station II per month.

Month	Available nitrogen (NH_3 - NO_2 - NO_3)	Organic nitrogen of drift	Mean * discharge m^3 sec^{-1}
1958			
July	5,600	8.1	3.787
August	2,446	2.8	1.325
September	530	0.6	0.893
October	916	2.3	1.239
November	1,669	1.6	1.668
December	2,438	0.6	1.332
1959			
January	4,647	0.3	1.275
February	6,314	3.2	3.227
March	147,433	264.9	25.204
April	49,033	120.7	14.475
May	11,003	15.2	5.489
June	9,271	13.0	2.626
Totals	241,300	433.3	

*Corrected for station II from U.S.G.S. station at Farm Lane bridge on M.S.U. campus.

that the concentration of drift would remain the same, it follows that an increase in flow volume, resulting from increases in rain and runoff, would cause a proportional increase in the total amount of drift material transported. However, in general, an increase in discharge also produced an increase in the concentration of drift material (Table 9) thus having a multiplying effect on the total amount. The low concentration of drift material shown in Table 9 for March 12 was a result of the discharge falling from a peak on March 8 (Appendix B) which had flushed the stream.

The increase in drift concentration in October and November (Fig. 10) during periods of fall rains can be attributed in large part to the abundance of fallen leaves and other organic debis that were washed into the stream. The first significant increase in volume of flow in February did not affect the drift levels other than to maintain the concentration against dilution (Fig. 10). The discharge increase at that time was due to thawing conditions which supplied water from the melting snow and ice. This water carried very small amounts of extraneous materials. Much of the increased flow was carried on top of the existing ice cover; thus agitation of bottom materials was minimized. The great increase in flow volume during late February and through the spring are a result of thawing and rainfall. The effects of increased discharge on the concentration of drift material became more pronounced as the ice cover disappeared from the stream and as the ground thawed and

Table 9. Concentration of drift material compared with discharge levels at station II.

Sampling date	Drift material (mg m^{-3})	Discharge (m^3 sec^{-1})
1958		
November 10	52.04	1.305
November 17	333.33	1.950
December 10 *	23.16	1.601
1959		
January 20 *	5.43	0.962
February 12 *	16.67	1.161
February 24	50.68	3.822
March 2	1076.99	10.760
March 3	4764.71	16.990
March 12	326.89	17.216
March 16	4782.35	36.812
March 19	3587.41	26.618
April 2	8697.48	25.768
April 15	718.94	8.268
May 8	392.51	3.709
June 16	225.40	1.415
July 2	192.06	1.189

*Stream frozen over.

Figure 9. Drift material from Station II compared with the stream discharge for the period of September, 1958 through February, 1959.

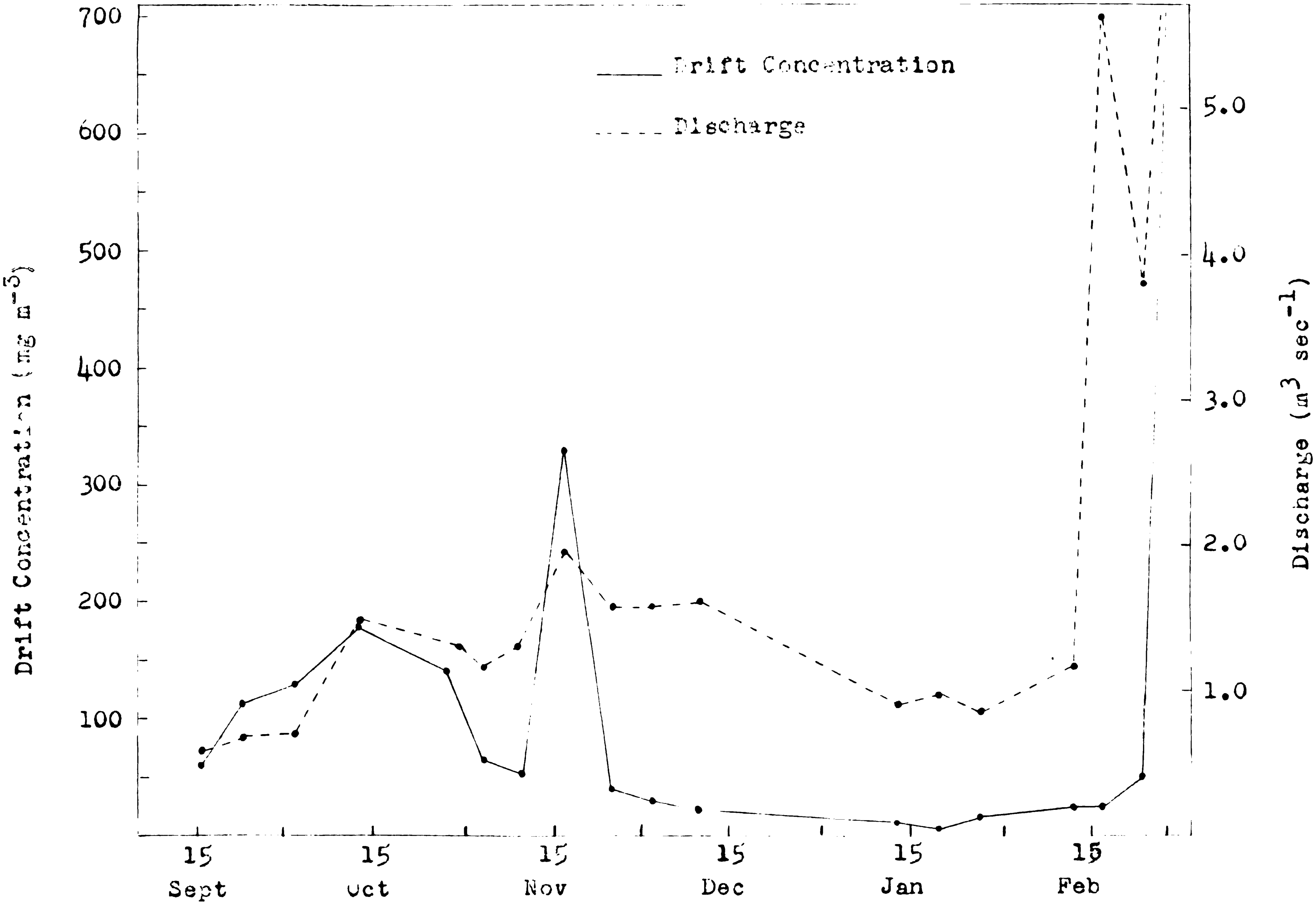

Drift Concentration
Discharge
700
600
500
400
300
200
100
Drift Concentration (mg m^{-3})
5.0
4.0
3.0
2.0
1.0
Discharge (m^3 sec^{-1})
15
Sept
15
Oct
15
Nov
15
Dec
15
Jan
15
Feb

Figure 9

Figure 10. Drift material from Station II compared with the stream discharge for the period of March, 1959 to July, 1959.

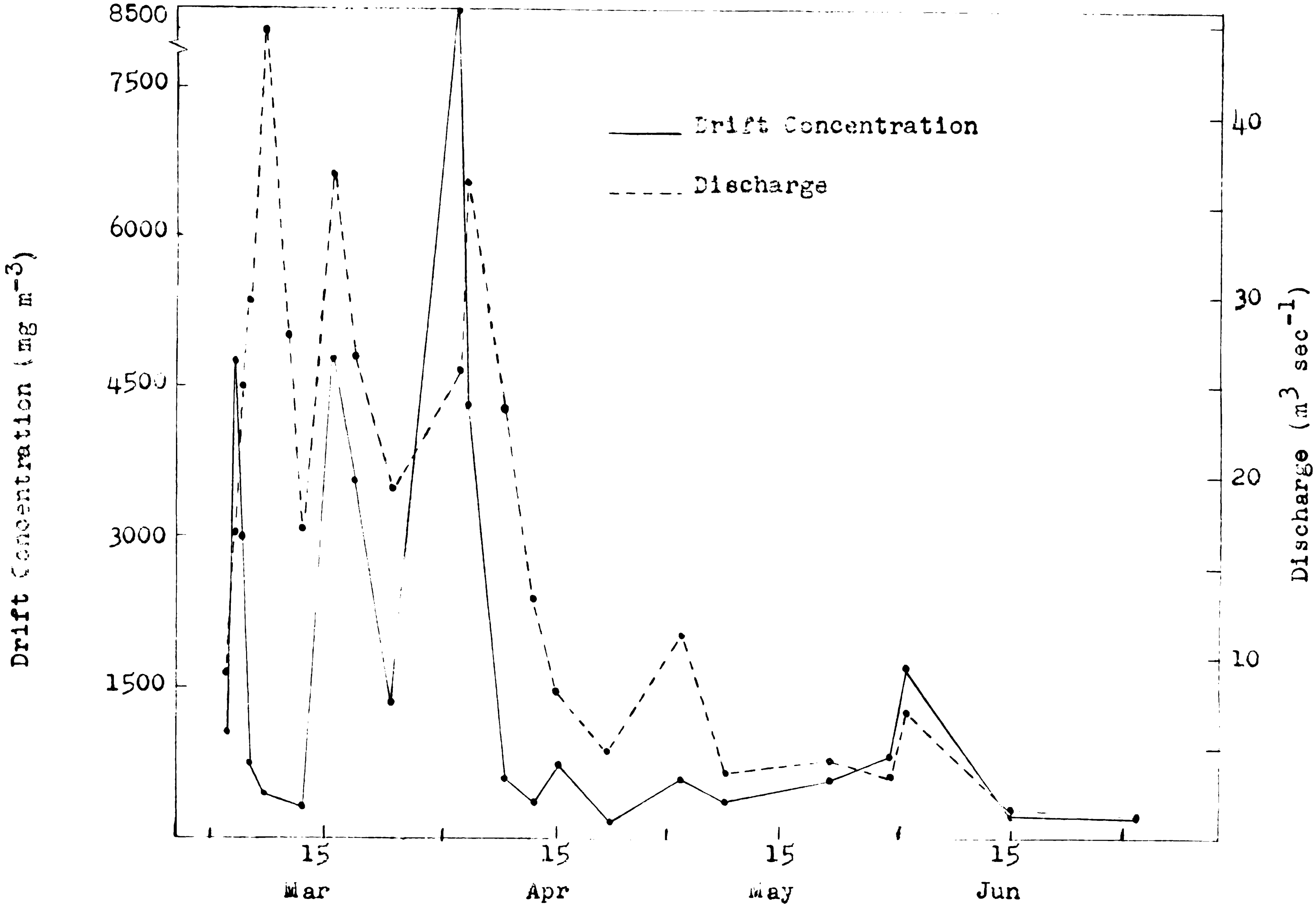

Drift Concentration (mg m-3)
8500
7500
6000
4500
3000
1500
Discharge (m3 sec-1)
40
30
20
10
Drift Concentration
Discharge
15
Mar
15
Apr
15
May
15
Jun

Figure 10

yielded more materials to the runoff.

The importance of frequent sediment sampling during periods of increasing discharge is stressed in studies of sediment measurements, and in general the peak of sediment movement occurs during the rise in stream stage.[4] This was found to be true for the drift material. During early March and early April, when discharge increases occurred, it was found that the drift peak was reached during the discharge increase (Fig. 10). After reaching a peak, the drift values declined, although the volume of flow continued to increase. Thus the initial discharge increase has a flushing action which quickly stirs up the settled drift and transports this material downstream. The stream bed is more or less swept clean of previously accumulated materials by the initial rise in stage. The knowledge of this flushing action should be used to establish the sampling frequency in order to obtain representative samples during flood periods. A sample taken at the peak of the discharge would often miss the peak of the phosphorus and drift concentrations. Likewise a sample taken at the peak of the drift concentration during high water cannot be used to calculate the drift weight or drift phosphorus for a long time period, because the concentrations decline rapidly following the peak concentration.

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[4] "A study of methods used in measurement and analysis of sediment loads in streams, Report No. 1, Field practice and equipment used in sampling suspended sediment". 1940. T.V.A., Corps of Engineers, U.S.D.A., U.S.G.S., Bureau of Reclamation, Indian Service, and Ia. Institute of Hydraulic Research. St. Paul U.S. Engineer District Sub-Office Hydraulic Laboratory, University of Iowa, Iowa City. 175 pp.

Samples taken shortly thereafter would give much lower and more representative drift and drift phosphorus values if used to calculate the drift and/or phosphorus weights for an extended period.

Turbidity. Turbidity values were found to be affected by the stream discharge in the same manner as was the drift material; however, a comparison of Figures 10 and 11 shows that some differences in magnitude and fluctuation of responses do exist. Turbidity values (Fig. 11) were generally more sensitive to changes in flow rates than was drift material as shown in Figure 10 for early March. A slight reduction in the rate of increase of the discharge from March 4 to March 5 was accompanied by a drop in both turbidity values and drift concentration. The discharge increased more rapidly again from March 5 to March 7, but only the turbidity increased (Fig. 11), while the drift continued a steady decline (Fig. 10). Since the turbidity is primarily a function of the smaller particles such as silt and clay, it is assumed that these smaller particles were more easily swept into suspension by slight turbulence increases than were the larger particles which made up the drift material.

The pronounced increase of turbidity accompanying the discharge increase on June 1 (Fig. 11) demonstrates the difference in the components contributing to turbidity and drift material (Fig. 10). The drift materials on the stream bottom and banks had previously been flushed out and removed by earlier floods and thus a relatively smaller increase in

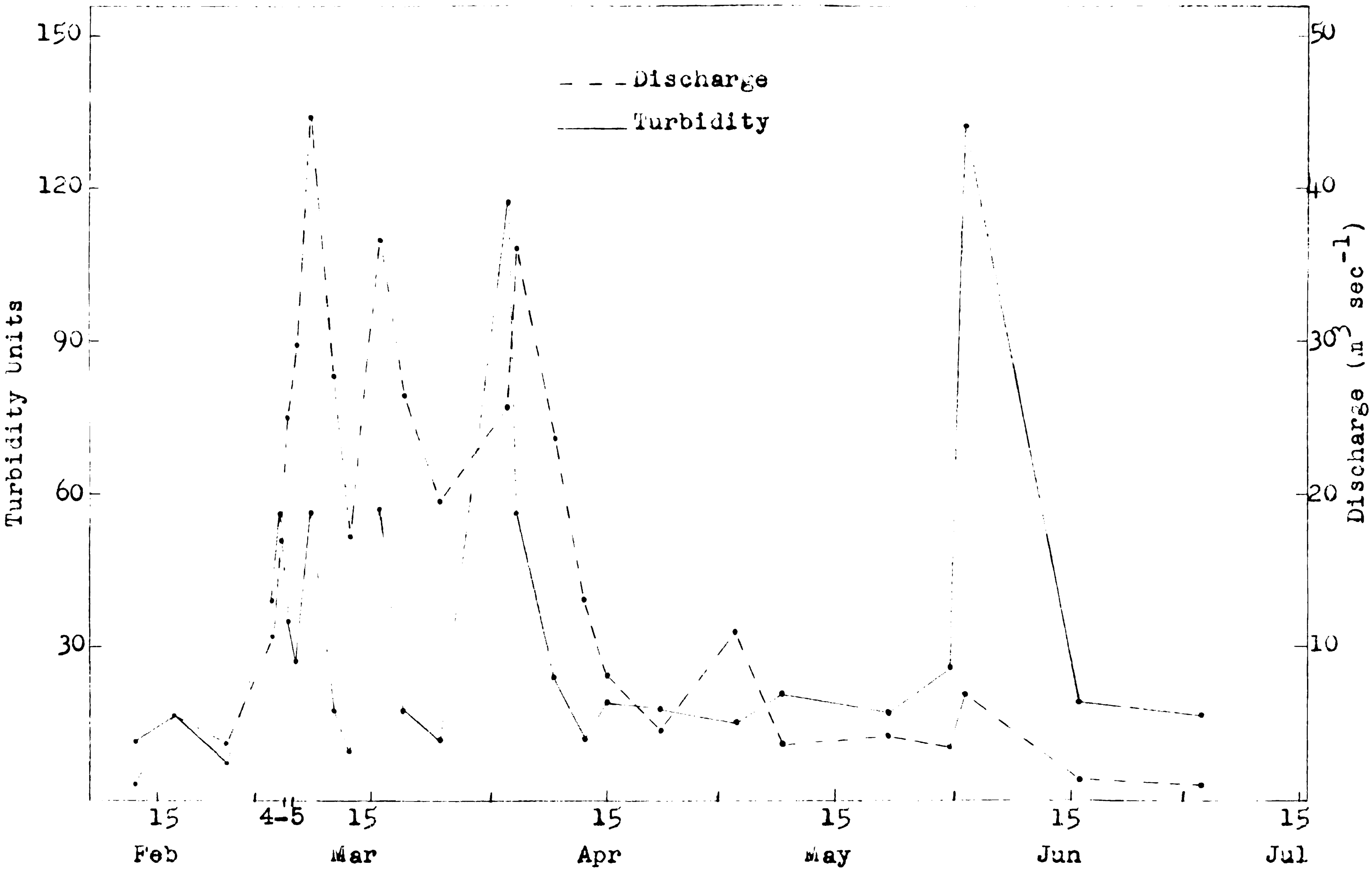
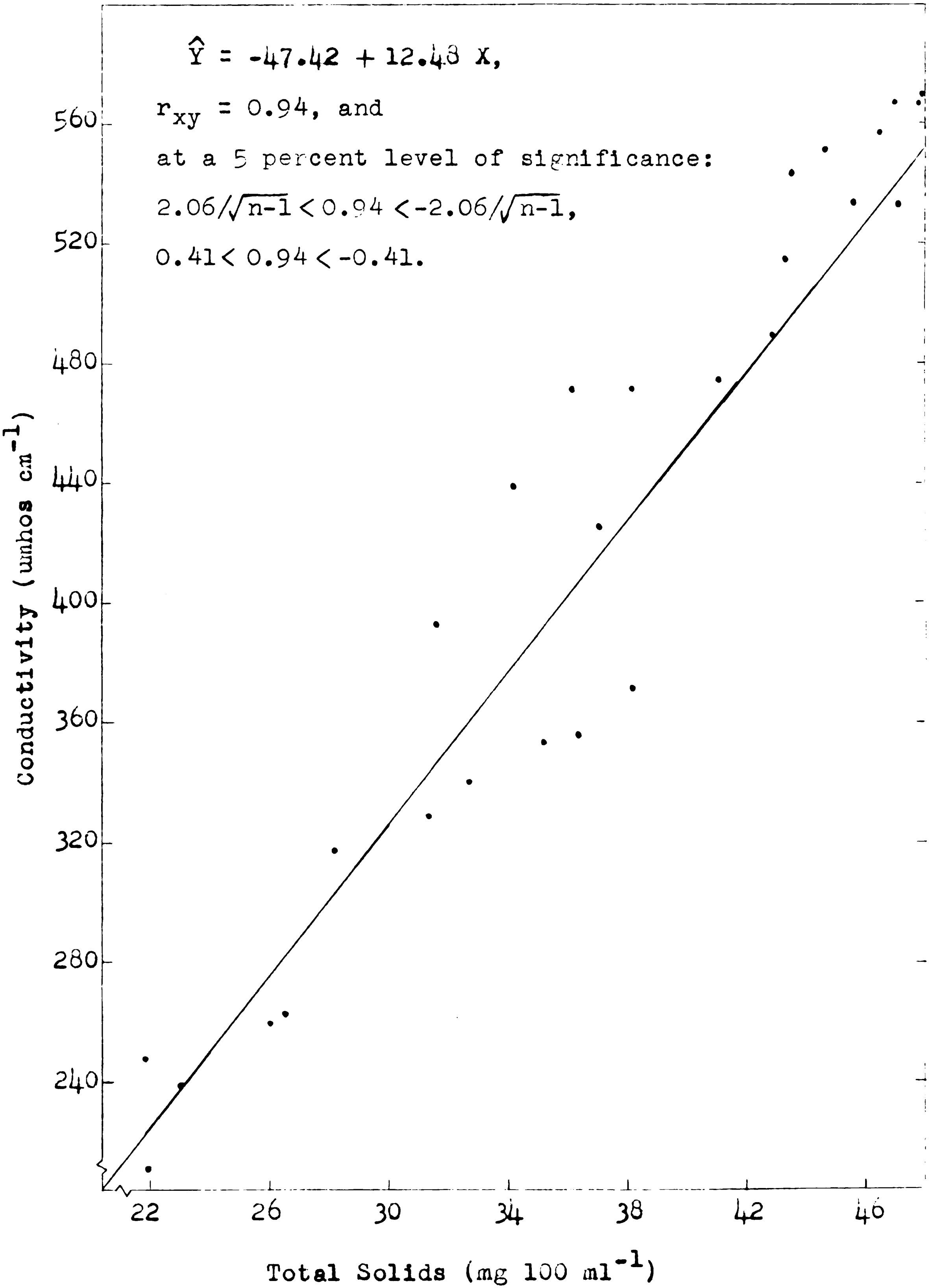


Figure 11. Turbidity units compared with stream discharge for the period of February, 1959 to July, 1959.

the drift volume was produced (Fig. 10). The clays and silts, largely responsible for the turbidity, are not as completely removed by an initial runoff and discharge increase and were washed into the stream in large quantities on June 1.

Total solids and specific conductivity. In this study total solids were considered as the entire weight of material, expressed as mg l^{-1}, remaining after a 100 ml river water sample had been evaporated to dryness. It was found by comparing the dry material from millipore filtered samples with that of non-filtered samples that the weight of total solids was primarily a function of dissolved materials. The specific conductivity of water, or the capacity of a standard volume of water to transmit an electrical current, is a function of the amount of electrolytes dissolved in the water. The high electrolyte content of the total solids was shown by a correlation coefficient of 0.94 for the relationship between total solids and specific conductivity (Fig. 12). The deviation that does exist can be accounted for by consideration of the minor amounts of non-electrolytes included in the total solids.

The effect of increased discharge on conductivity was that of dilution of the soluble substances, since relatively small amounts of dissolved materials were incorporated in the runoff from rains and melting snow which produced the discharge increases. Because of the high correlation between total solids and conductivity it follows that total solids would parallel the conductivity of Figure 13. Comparing



$\hat{Y} = -47.42 + 12.48\,X$,

$r_{xy} = 0.94$, and

at a 5 percent level of significance:

$2.06/\sqrt{n-1} < 0.94 < -2.06/\sqrt{n-1}$,

$0.41 < 0.94 < -0.41$.

$n = 26$ $\Sigma X^2 = 37{,}391$ $\Sigma Y^2 = 4{,}785{,}882$

$\Sigma X = 960.9$ $\Sigma Y = 10{,}761$ $\Sigma XY = 421{,}133$

Figure 12

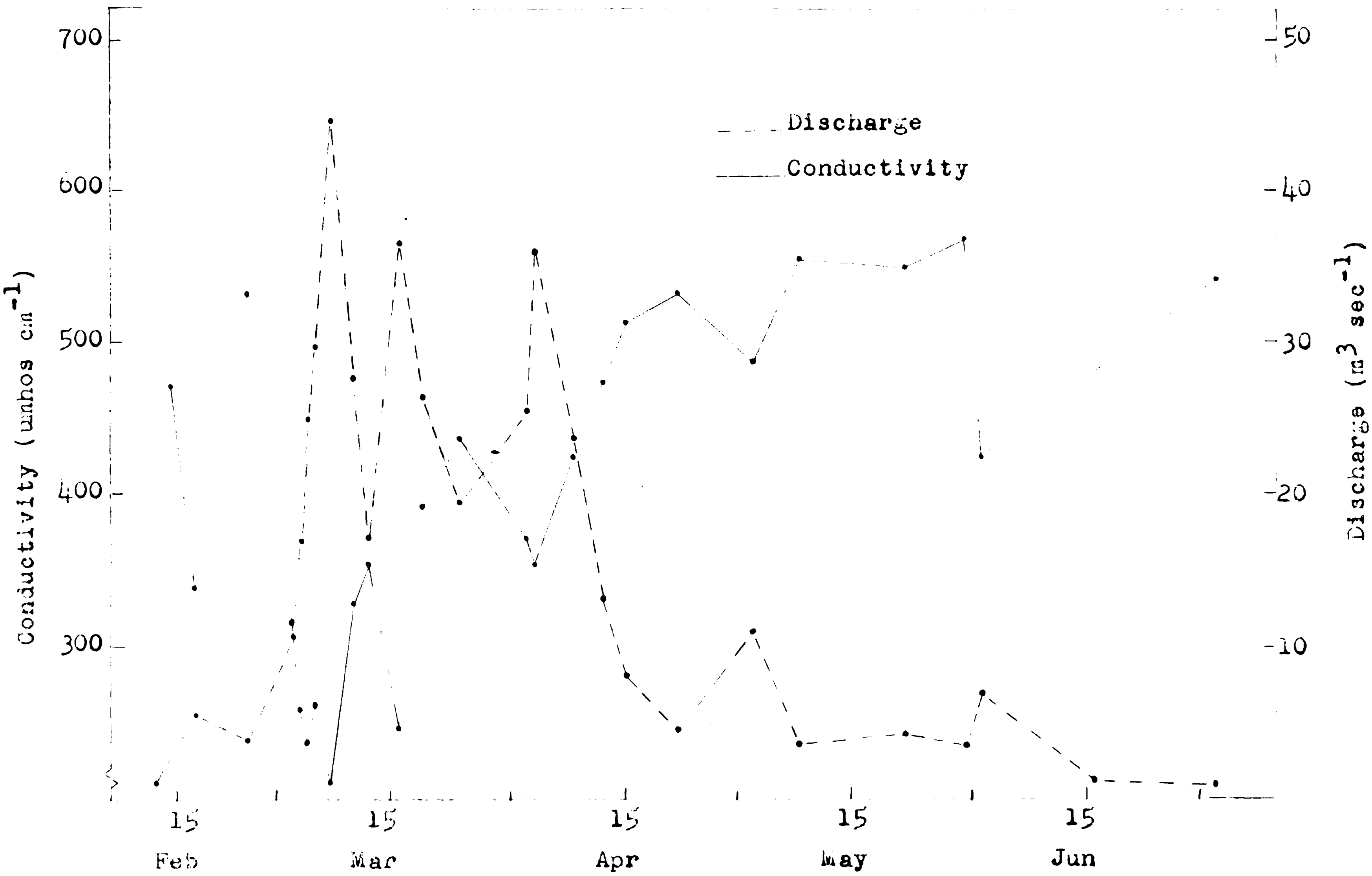


Figure 13. Specific conductivity values from station II compared with stream discharge for the period of February, 1959 to July, 1959.

Figure 11 and Figure 13, it can be seen that no positive relationship existed between drift material and conductivity or between drift material and total solids.

Qualitative Studies

Gross identification of the drift material was undertaken on a macroscopic basis since particles of microscopic size were not retained by the mesh size of the plankton netting. Water samples were passed through Millipore filters and the filter membranes were examined microscopically for the smaller organisms. The drift matter was divided into three categories: the tripton or the suspended dead organic and inorganic matter, the zooplankton and bottom fauna, and the phytoplankton.

Tripton. The vast majority of the drift material was placed in this category. Tripton consisted of such materials as sand granules and other particles of inorganic nature, bits of leaves, roots, bark, seeds, and other plant material, as well as clumps of senescent algal mat that had broken away from the stream bottom, and other organic matter. The sources of the material varied, some being derived from terrestrial plants, some from aquatic sources, some from the soils of the watershed, and some from industrial and sewage disposal outfalls of the stream.

Zooplankton and bottom fauna. The numbers of zooplankton present in smaller streams are usually quite small. Eddy (1932) reported no plankton at all in the upper 50 miles of the Sangumon River in Illinois, and Pennak (1943) reported only negligible numbers of copepods, cladocerans, and rotifers in a Colorado mountain stream. Hornuff (1957) found no plankton in four small Oklahoma streams. The zooplankton in the Red Cedar River drift samples was also negligible. Samples collected at stations I and II contained more zooplankton than those collected at Station III. This was due to the proximity of the first two stations to the Williamston reservoir, which was assumed to be a major source of the plankton. Copepods were found in nearly all samples, but only in numbers less than 10 per sample. Considering that as much as 300 liters of water were filtered per sample the number of copepods present was very small. Copepods were identified from several different samples as Cyclops spp. Rarely, samples included a small back-swimmer of the family Notonectidae.

The Red Cedar River is fairly rich in bottom fauna and thus it was expected that samples, especially bed load samples, would contain significant numbers of these organisms; this was partly substantiated by the data. Fewer than half of the samples contained any bottom fauna; those organisms that were found in samples were generally midges, oligochaetes, and rarely, mayfly nymphs.

The mean number of organisms per sample was estimated to be 3.5 with copepods accounting for 3.0 per sample. The mean value was expanded by the discharge and the number and weight of organisms per month was tabulated (Table 10).

Table 10. Numbers and weights of drift organisms moving past station II.

Month	Number ($x 10^3$) per month with copepods	Number ($x 10^3$) per month without copepods	Weight/month (Kg.) without copepods
1958			
September	19,569.0	2,798.4	2.2
October	29,192.7	4,174.6	3.3
November	46,137.0	6,597.6	5.3
December	52,228.8	7,468.7	6.0
1959			
January	30,801.6	4,404.6	3.5
February	109,992.4	15,728.9	12.6
March	1,759,680.9	251,634.4	201.3
April	908,538.0	129,920.9	103.9
May	235,045.1	33,611.4	26.9
June	303,000.0	43,329.0	34.7
July	88,387.2	12,639.4	10.1
August	53,978.1	7,718.9	6.2
Totals:	3,636,550.9	520,026.8	416.0

The weight of drifting bottom fauna was calculated using an average of 0.8 mg per organism estimated from weights and numbers of similar bottom fauna given by Müller (1954). Numerically, faunal drift values were of the same magnitude, hundreds of thousands per month, as those found in north Sweden by Müller (1954) where the average current velocity was 1.6 to 2.3 feet per second compared with 1.0 to 2.0 feet per second in the Red Cedar River.

Drifting organisms are readily available as food for the carnivorous forms of the higher trophic levels. Thus in the Red Cedar River, during the period between September of 1958 and September of 1959, drifting bottom fauna contributed approximately 416 kilograms of material to the food web, but at the same time probably removed a much greater weight of material considering that food conversion efficiencies are usually low. In addition, this movement of benthic fauna is probably very important in the distribution of organisms allowing for optimal utilization of space and food (Müller, 1954).

Since a sum total of 12,600 kilograms of phosphorus moved downstream during the study period (Table 6), it is not likely that 416 kilograms of benthic fauna (Table 10) would contribute significantly to the phosphorus transport as was suspected by Brehmer (1958) in his nutrient study of the Red Cedar River.

Phytoplankton. The algae collected in water samples were primarily diatoms, although fragments of bluegreen algae were present occasionally. The diatoms were identified to genus and those genera found agreed closely with those in the periphyton collected on substrates by Peters (1959) from the Red Cedar River. All of the diatoms reported in Table 11, except *Cyclotella sp.*, are known to have some method of attachment; thus the source of the planktonic forms was assumed to be the benthos. Butcher (1932) and Blum (1957) also reported a benthic origin for the same diatom genera found in streams. Apparently the diatoms found in the Red Cedar River are typical stream forms as they are listed as stream phytoplankton by many other authors including Pennak (1943), Robeck, et al. (1954), and Lackey (1956).

The evidence that different genera become dominant at different periods is shown in Table 11. Figure 14 reflects the change in periphyton composition due to changes in ecological conditions which favor first one genus and then another throughout the year. The abrasive action of the silt load carried by floods on the periphyton communities, as discussed by Brehmer (1958), was strikingly evident in the phytoplankton concentrations of the early March samples (Table 11). The greater concentrations in the water samples taken during the spring can be attributed to the warming temperature effect on production and to the increased water velocity removing more of the sessile forms (Pennak, 1943). Lund (1950), studying a diatom species in lakes in England, claims that a spring maxima is related to an increase in the silica content of the water rather than to increases in light

Table 11. Percent frequency of abundance of dominant diatoms.

Date	Navicula	Synedra	Gomphonema	Cyclotella	Cymbella	Melosira	Cocconeis	Diatoms per ml.
Jan. 13	56.5	-	13.0	-	-	4.3	4.3	192
Jan. 27	66.7	6.7	6.7	-	6.7	-	3.3	251
Feb. 12	53.6	14.6	9.7	-	4.8	2.4	4.8	343
Feb. 24	47.2	22.2	13.8	2.7	-	-	2.7	301
Mar. 2	51.2	11.2	10.0	3.7	7.5	1.2	1.2	1340
Mar. 3	46.2	15.0	8.4	1.8	3.7	0.9	8.4	1775
Mar. 4	47.3	7.0	14.0	7.0	1.7	1.7	1.7	818
Mar. 5	60.4	8.3	6.2	4.1	6.2	-	4.1	689
Mar. 7	41.9	16.1	6.4	3.2	12.9	-	6.4	445
Mar. 10	53.5	7.1	21.4	-	3.5	3.5	-	402
Mar. 12	51.6	3.2	12.9	3.2	12.9	-	6.4	346
Mar. 16	58.3	11.1	5.5	2.7	-	-	5.5	402
Mar. 19	41.3	3.4	13.7	-	10.3	3.4	6.8	291
Mar. 24	41.8	11.8	20.9	2.3	4.6	-	9.3	432
Apr. 2	17.3	5.7	48.0	5.7	7.6	-	1.9	653
Apr. 15	47.8	15.2	14.1	7.6	3.2	-	3.2	1540
Apr. 22	21.8	31.2	10.9	15.6	3.1	3.1	3.1	918
May 2	37.3	23.5	16.2	8.9	0.8	0.8	0.8	2059
May 8	16.0	56.0	4.0	14.0	1.0	1.0	1.5	3349
May 22	25.0	24.1	3.2	31.4	3.2	1.6	1.6	2076
May 30	33.6	21.1	14.4	16.3	2.8	0.9	2.8	1741
June 1	38.6	21.2	11.3	4.5	5.3	1.5	4.5	2210
June 16	8.2	5.1	2.5	75.6	0.5	2.0	1.5	3231
July 2	4.2	3.2	2.8	86.7	-	-	0.9	3549

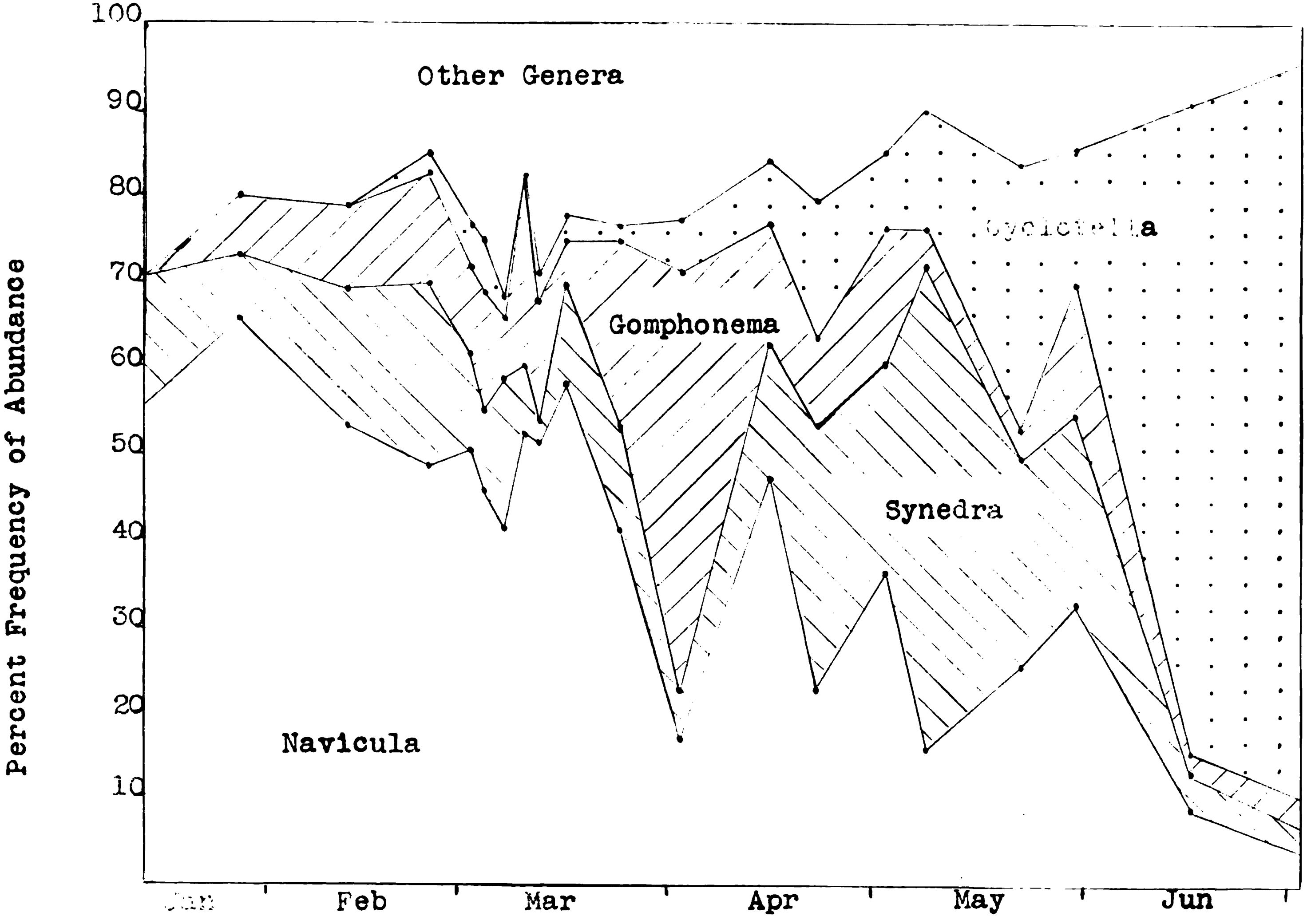


Figure 14. Fluctuations in dominant diatom abundance at station II.

or temperature. It is doubtful that silica is ever a limiting factor in the Red Cedar River.

The abundance and dominance of *Navicula*, *Synedra*, and *Gomphonema* in the late winter and early spring is in agreement with Butcher (1932) who reported the period of February to April as the time of abundance for the same genera and May to July as the peak for *Cyclotella*. Robeck, et al. (1954), found high concentrations of *Cyclotella* throughout the summer and fall in the Columbia River. The total diatom concentration ranged from 192 per milliliter in February to 3,549 per milliliter in July. Pennak (1943) found a range from 9 to 2,575 per milliliter in a Colorado mountain stream and figures of 50 to 67,000 diatoms per milliliter were given for the Columbia River (Robeck, et al., 1954).

Data in Table 12 were obtained by expanding the diatom concentration per milliliter by the discharge at the sampling time and place. Diatoms can be considered as the basic food form in the Red Cedar River, to which the nourishment for the higher trophic levels can be ultimately traced. Many insects and other organisms rely upon the drifting diatoms as their source of food and this fauna is in turn consumed by higher forms such as fish.

Numbers of diatoms found in water samples have little meaning as there is a great variation in size among the different diatom genera. Verduin (1959) commented on this subject, saying that a rough approximation of volume is vastly superior to a highly accurate enumeration because of

Table 12. High and low discharge, diatom concentration, and total diatom number per stream cross-section at Station II.

Date	Discharge m^3 sec^{-1}	Diatoms per milliliter	Diatoms x 10^8 per stream cross-section per second
January 13	0.91	192	1.74
March 3	16.99	1775	301.49
March 7	44.74	445	198.87
July 2	1.19	3549	42.20

the great size difference. Considering this, and because primary production values are probably best understood when presented on a gravimetric basis, the diatom numbers for the Red Cedar River were converted to weights. To do this, mean diatom dimensions were calculated using a Whipple micrometer disc and 970 X oil immersion magnification to obtain measurements. Diatom volumes were then calculated (Table 13). Since the diatoms were all in a suspended state when sampled, the specific gravity was assumed to be very near 1.0. On this basis volumes were converted to weights which were expanded with regard to time and the stream discharge to arrive at the figures given in Table 14. Since the specific gravity of diatoms is probably slightly greater than 1.0, the figures presented are conservative. Although a considerable portion of diatom weight is silica shell, a yearly figure of 634 metric tons must still be considered as an important component of primary production in the Red Cedar River.

Table 13. Calculated volumes of dominant diatoms.

Diatom genera	Volume in cubic microns	Standard units * Measured	Standard units * from literature**
Synedra spp.	8298	1.0	2.0
Melosira sp.	4185	0.5	0.5
Navicula spp.	3494	0.4	1.0
Cocconeis spp.	3421	0.4	0.5
Gomphonema spp.	2754	0.3	-
Cyclotella sp.	1019	0.1	-
Cymbella spp.	756	0.1	1.0

*1 cubic standard unit = 8000 u^3.

**Whipple, Fair, and Whipple, 1927.

Table 14. Metric tons of diatoms drifting past station II.

	Diatom weights			Caloric value
Month	Live wt.	Dry wt.*	Organic wt.**	(x 10^6)***
1958				
July	100.3	39.1	19.6	100.4
August	42.3	16.5	8.3	42.5
September	28.2	11.0	5.5	28.2
October	1.5	0.6	0.3	1.5
November	1.5	0.6	0.3	1.5
December	1.5	0.6	0.3	1.5
1959				
January	1.5	0.6	0.3	1.5
February	7.3	2.8	1.4	7.2
March	130.5	50.9	25.5	130.6
April	90.4	35.3	17.7	90.6
May	144.3	56.3	28.2	144.4
June	84.6	33.0	16.5	84.5
Totals:	633.9	247.3	123.9	634.4

*Estimated by conversion values from Riley, 1941.

**Estimated by conversion values from Strickland, 1960.

***Based on 5.12 Calories per gram organic weight.

Annual Drift Budget

The annual movement of materials past Station II is given in Table 15. Those materials listed entirely under particulate can be considered as the drift although some portions of the phosphorus and nitrogen were from particles smaller than that originally defined as drift. The figure for the total mass of all material, some 60,000 metric tons, can be considered only as an order of magnitude; however, it is calculated as a conservative figure. The drift is about 0.1 percent of this total amount. This should not detract from the significance of the drift material, but should serve as an indication of the vast amounts of silt, clay, and dissolved material that is transported by streams.

The significance of the drift material is best viewed in terms of energy conversion in which the drift can be considered as the producer or lowest trophic level, that is, the food available for higher levels. The majority of the drift in Table 15 can be considered as food material for herbivores. Using a conversion efficiency of 10 percent for herbivores, as estimated from Odum (1959), the biomass of herbivores consuming the drift could be as much as 52 metric tons. If the carnivores were considered to be smallmouth bass feeding directly on the herbivores, at a conversion efficiency of 5 percent, as estimated from Odum (1959) for large carnivores, then the fish represented by the drift material could constitute as much as 2.6 metric tons. These conversion values serve to show the drift material from a

Table 15. Total annual movement of materials in metric tons of dry weight past station II from July, 1958 to July, 1959.

Material	Particulate	Dissolved
Drift [1]	265.0	-
Diatoms	247.3	-
Bottom fauna [2]	0.4	-
Phosphorus	7.3	5.4
Nitrogen [3]	11.3	241.7
$CaCO_3$ [4]	-	37,200.0
Silt, clay, zooplankton, and dissolved materials other than N and P [5]	23,121.6	
Total solids	61,100.0	

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[1] Drift here excludes the portion listed as diatoms, bottom fauna, phosphorus, and nitrogen.

[2] Bottom fauna is expressed as live weight.

[3] Particulate nitrogen value calculated from N:P relationship.

[4] $CaCO_3$ calculated from the mean total alkalinity of 253 mg/L as $CaCO_3$ estimated from values given by Brehmer (1958), Grzenda (1960), and Vannote and Carr (unpublished) for the Red Cedar River.

[5] Estimated by difference from the total solids value.

different viewpoint. Although the drift material is not fully utilized as hypothesized here it contributes a considerable amount to the dynamic energy of the Red Cedar River.

SUMMARY

1. Drift material, collected by pumping known volumes of river water through plankton netting, included those particles and organisms larger than 0.076 mm. Particles smaller than 0.076 mm such as diatoms, silt, clay, and dissolved materials were included in and analyzed from unfiltered water samples. Diatoms were then included as drift.

2. The weight of drift varied at three sampling stations with the greater weights during warm-water periods being at the upstream stations. The concentration of drift was greater at the downstream station during the winter months. This was attributed to decomposition rates being reduced by declining water temperatures.

3. The concentration of drift material increased with increasing depth, with bed load samples having the greatest concentrations. Coarse sand particles, moving by saltation, caused high concentrations in bed load samples collected during flood periods. The relative organic composition of drift material decreased toward the stream bottom.

4. An increase in stream discharge was the greatest single factor causing increases in the concentration and amount of drift material. Peak values of drift weight and phosphorus were measured during the rise in water level rather than coinciding with the peak flow rate thus

demonstrating a flushing action by the initial discharge increase. The effects of discharge and runoff were less pronounced during early spring when the ground was still frozen.

5. Lowest drift concentrations occurred during winter months and were a result of low discharge and reduced primary productivity. The organic component of drift material was high during winter months as a result of reduced decay rates caused by the low water temperatures.

6. The phosphorus content of drift material was largely a function of the drift weight. The organic nitrogen content of drift was generally much greater than the phosphorus content.

7. The total annual flow of phosphorus past Station II was estimated at 12.6 metric tons with drift material contributing 2.5 percent.

8. Tripton comprised the vast majority of the 265.7 metric tons of annual drift movement. Drift of bottom fauna contributed 416 kilograms to the food web of the stream.

9. Diatoms in water samples were estimated in concentrations ranging from 192 to 3,549 per milliliter and amounted to an estimated movement of 634 metric tons.

10. The drift material constituted only a small fraction of the annual movement of total solids in the stream, being much less than the dissolved components. When represented as an integral part of the biological system, the drift material represents a major contribution to the energy flow in the Red Cedar River.

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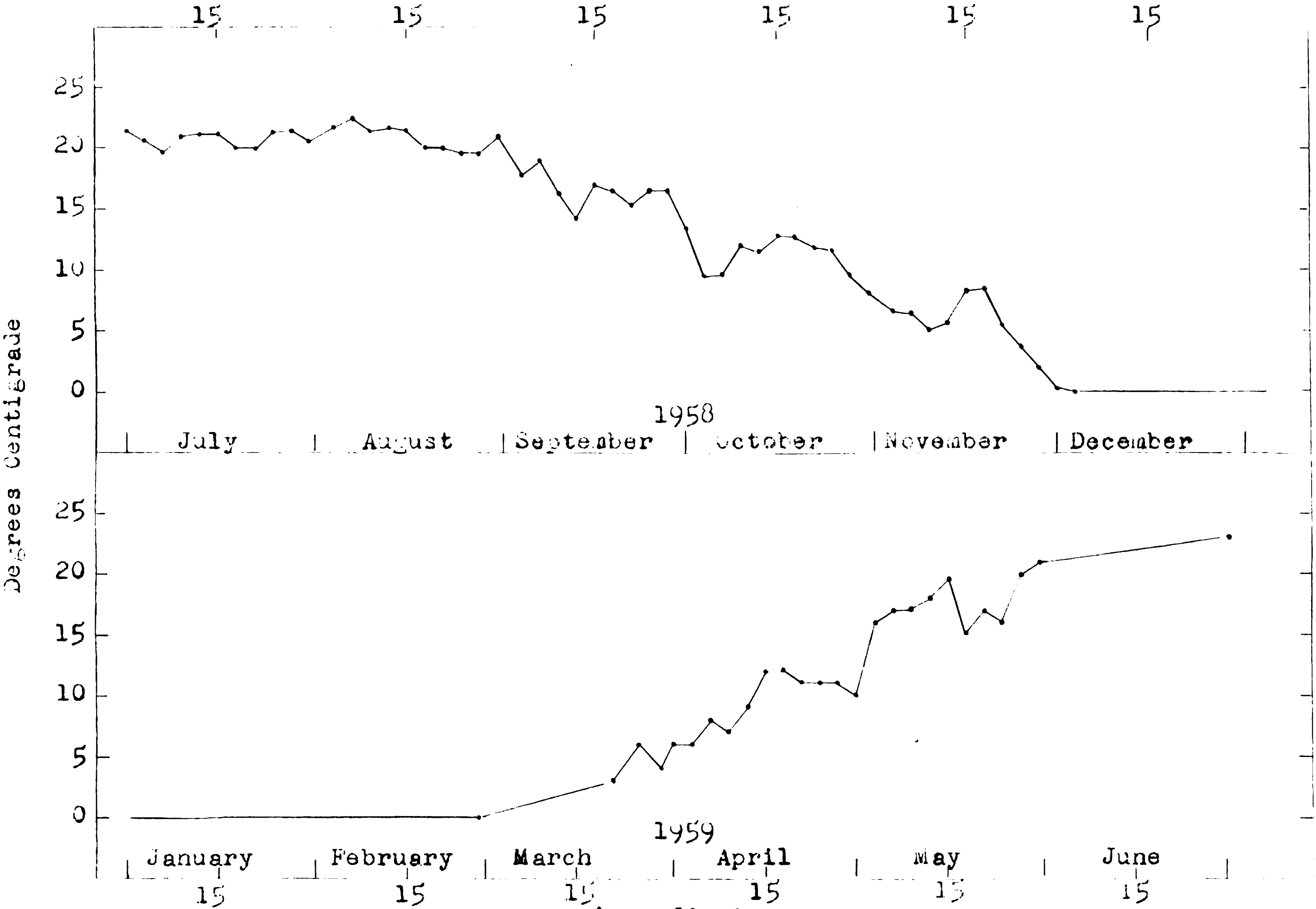
APPENDIX A

Mean water temperatures recorded at a station 10 miles upstream from the mouth of the Red Cedar River.


Degrees Centigrade
25
20
15
10
5
0
1958
July
August
September
October
November
December
15
1959
January
February
March
April
May
June
15

Appendix A

APPENDIX B

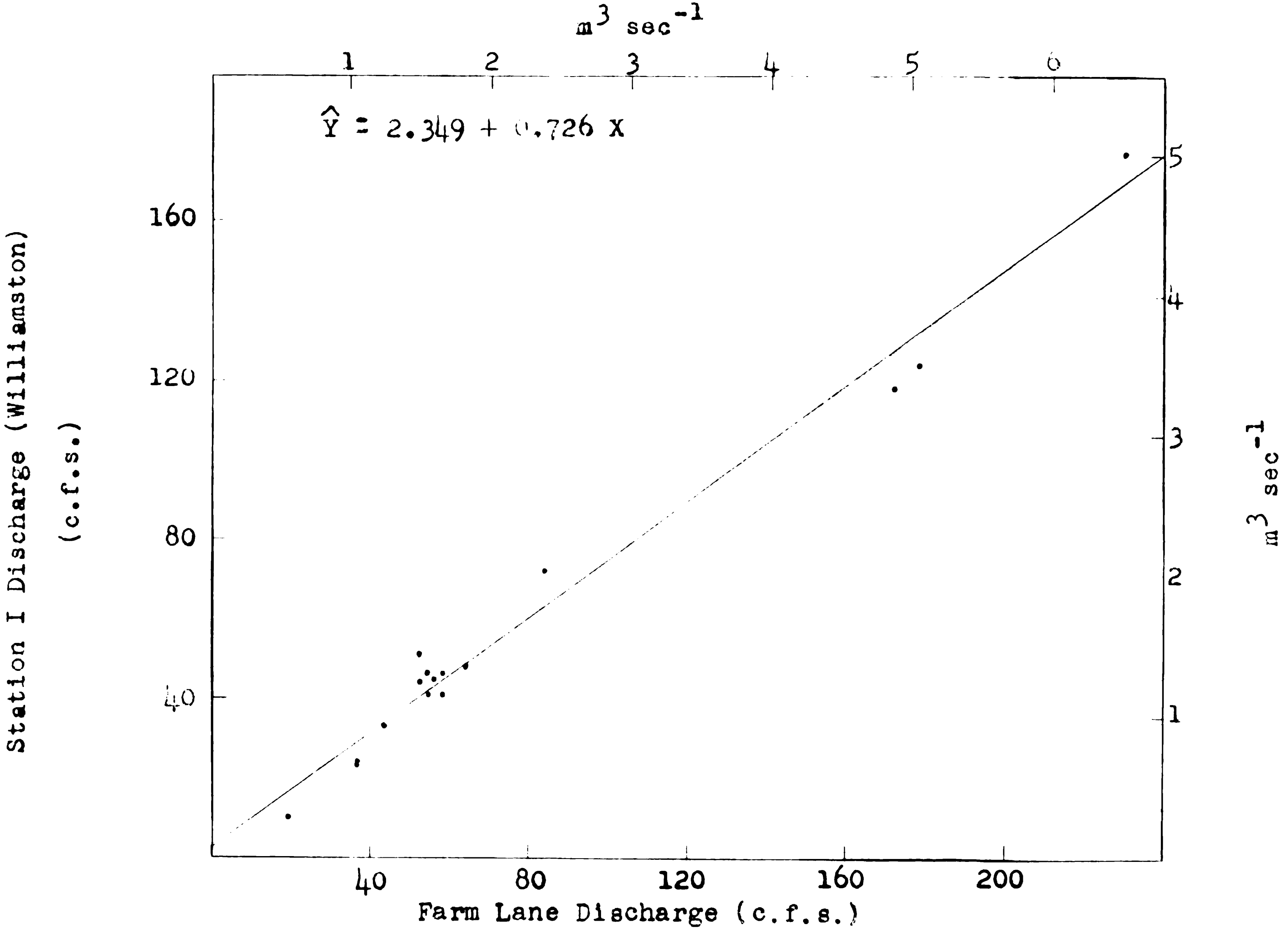
Red Cedar River discharge at Farm Lane bridge taken from records of the Surface Water Division, U. S. Geological Survey, Lansing Office.

Appendix B

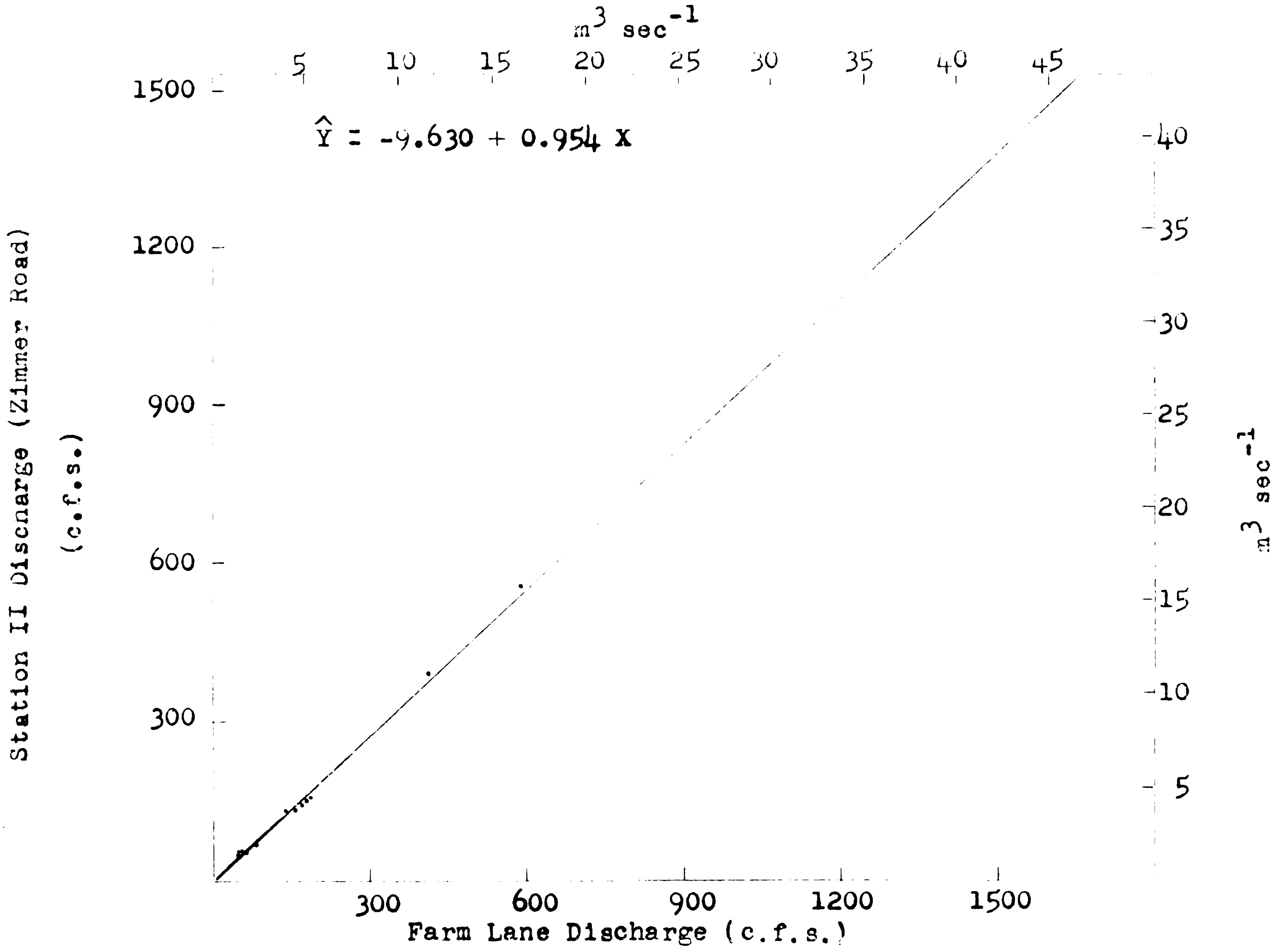
	Daily discharge in cfs											
	1958						1959					
Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
1	46	46	31	39	58	64	46	47	270	493	488	207
2	48	31	30	39	58	56	50	49	410	590	414	338
3	78	28	30	37	54	56	54	49	660	1000	342	288
4	222	37	26	39	56	56	58	49	970	1400	278	227
5	560	31	17	37	54	56	56	47	1150	1540	230	185
6	506	41	30	39	54	46	61	49	1240	1350	201	151
7	391	50	37	37	58	64	58	56	1720	1060	176	121
8	345	74	35	41	56	52	58	54	1810	890	157	107
9	259	76	24	58	58	58	56	47	1390	890	145	91
10	187	68	15	52	54	56	61	51	1070	800	136	81
11	148	61	13	66	56	58	61	49	845	690	154	73
12	125	61	33	71	58	54	50	54	670	585	179	78
13	108	64	41	56	61	54	43	56	541	507	179	76
14	92	54	31	48	64	54	43	83	483	432	157	68
15	89	65	12	43	64	52	43	127	700	376	139	63
16	84	66	26	41	66	56	43	230	1410	318	130	66
17	78	56	37	41	66	52	43	278	1540	281	119	59
18	76	48	43	43	86	46	43	267	1190	253	113	51
19	71	33	50	43	84	43	43	233	1030	236	121	56
20	66	30	48	35	76	43	43	198	1390	227	130	49
21	54	76	46	35	71	41	41	172	1470	210	136	45
22	54	61	46	37	66	41	41	163	1180	198	148	45
23	50	52	39	39	64	41	41	154	884	188	221	45
24	50	48	37	43	64	46	41	151	754	172	371	45
25	50	43	37	54	64	43	41	154	671	169	330	47
26	50	41	39	52	64	41	41	157	585	172	270	51
27	54	39	37	46	64	41	41	160	590	172	220	51
28	61	39	37	50	56	41	41	170	640	169	176	51
29	58	37	37	52	54	41	43	-	605	250	145	54
30	54	37	37	58	54	43	43	-	545	507	136	56
31	54	37	-	60	-	43	46	-	511	-	166	-
Total	4168	1530	1001	1431	1862	1538	1473	3354/	28924/	16080/	6307/	2925
Mean	134	49.4	33.4	46.2	62.1	49.6	47.5	62.1	933	536	203	97.5

APPENDIX C

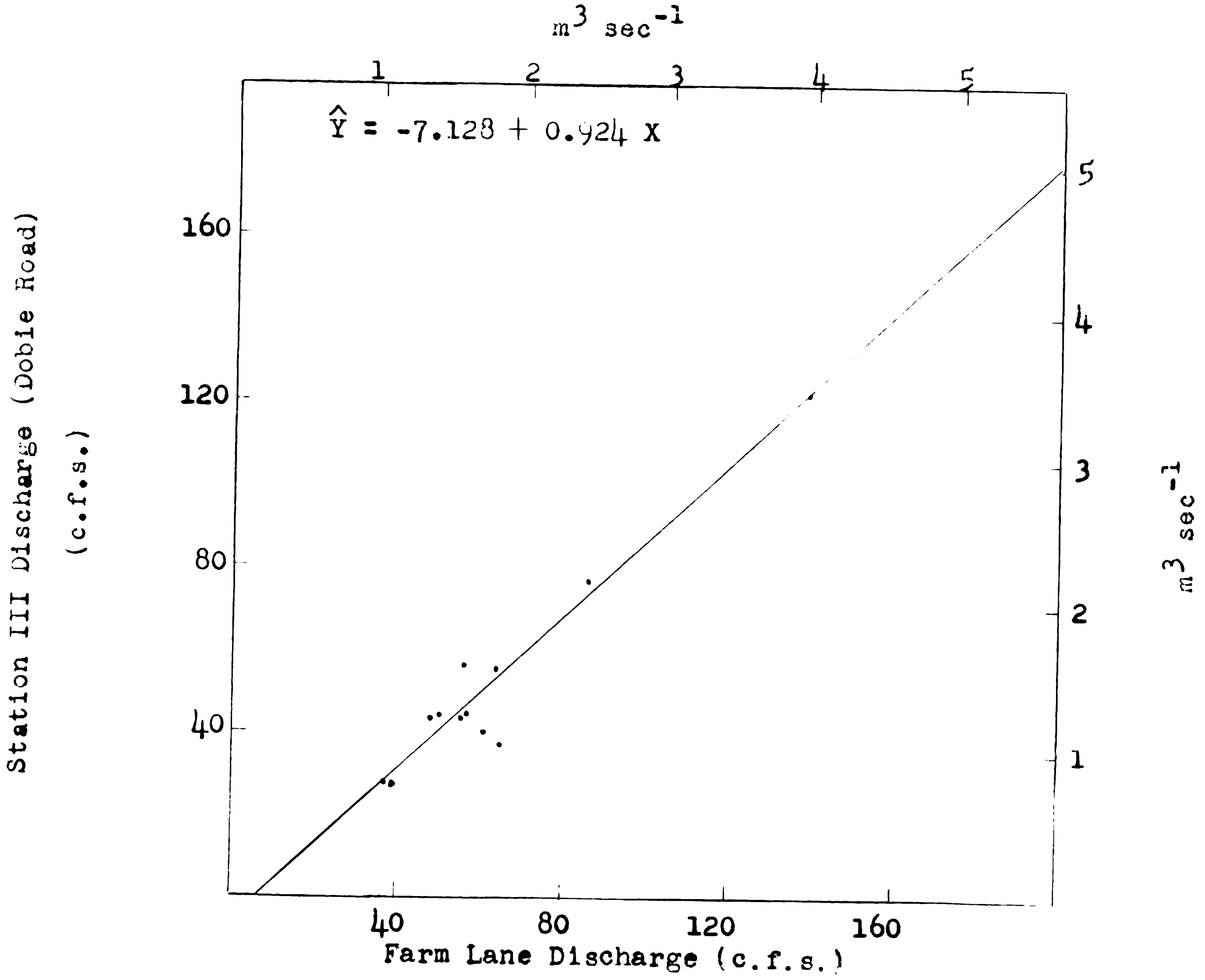
Flow correlations for discharge at Farm Lane bridge to sampling stations.


m³ sec⁻¹
1
2
3
4
5
6
Ŷ = 2.349 + 0.726 X
Station I Discharge (Williamston)
(c.f.s.)
160
120
80
40
5
4
3
2
1
m³ sec⁻¹
40
80
120
160
200
Farm Lane Discharge (c.f.s.)

Appendix C-1


$m^3\ sec^{-1}$
5
10
15
20
25
30
35
40
45
$\hat{Y} = -9.630 + 0.954\ X$
Station II Discharge (Zimmer Road)
(c.f.s.)
1500
1200
900
600
300
$m^3\ sec^{-1}$
40
35
30
25
20
15
10
5
300
600
900
1200
1500
Farm Lane Discharge (c.f.s.)

Appendix C-2


$m^3\ sec^{-1}$
1
2
3
4
5
$\hat{Y} = -7.128 + 0.924\ X$
Station III Discharge (Doble Road)
(c.f.s.)
160
120
80
40
5
4
3
2
1
$m^3\ sec^{-1}$
40
80
120
160
Farm Lane Discharge (c.f.s.)

Appendix C-3

APPENDIX D

Phosphorus concentrations in unfiltered water samples and in samples filtered through No. 20 mesh plankton net.

Appendix D

Date	Micrograms P per liter in water samples Filtered	 Non-filtered
1959		
January 13	73	67
January 13	71	70
January 13	73	83
January 20	60	63
January 27	62	59
February 7	115	118
February 12	76	78
February 12	92	89
February 12	84	84
February 14	104	109
February 17	106	107
February 24	60	63
February 24	76	81
March 2	133	129
March 4	116	119
March 5	94	92
March 7	107	105
March 10	52	52
March 12	44	42
March 16	100	103
March 19	46	44
March 24	60	59
March 24	40	42
April 2	122	119
April 3	74	82
April 3	80	75
April 3	73	73
April 8	42	35
April 8	32	34
April 8	38	43
April 12	42	35
April 12	36	37
April 12	36	42
April 15	52	52
April 15	44	50
April 15	55	54
April 22	52	50
April 22	57	54
April 22	53	53
May 2	50	54
May 2	48	53
May 2	54	53
May 8	66	67
May 8	60	64
May 8	69	62