CHEMICAL AND HYDROLOGICAL INVESTIGATIONS OF THE RED CEDAR RIVER WATERSHED

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ABSTRACT

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OF THE RED CEDAR RIVER WATERSHED

by Robin L. Vannote

An investigation was made to determine the source and level of phosphorus entering the Red Cedar River from the various tributaries in the watershed. The Red Cedar River is a warm water stream which drains the south central portion of Michigan. The physiography of the watershed is typical of many of the small rivers which drain agricultural areas in the state.

In addition to determining the contribution of phosphorus by the tributaries, eight stations on the Red Cedar River were studied to determine phosphorus transport within the main stream. Hydrological investigations were conducted on the tributaries and at the main stream stations in conjunction with the phosphorus studies.

A statistical design is presented which facilitated the chemical sampling of tributary streams on the basis of seasonal flow patterns and size.

The study revealed that the tributaries contributed, on an annual basis, slightly less than 50 percent of the total phosphorus passing through the terminal study station on the main stream. Additional phosphorus sources were: effluent from sewage disposal plants, septic tank overflows, and municipal drains. The largest source of phosphorus entered the stream through Wilmarth Drain, with the greatest

phosphorus accrual being in the lower one-third of the stream.

A significant positive correlation was found to exist between phosphorus transport and stream discharge for those tributaries draining agricultural and woodland and not enriched by domestic pollution. Tributaries which were enriched by domestic and light industrial pollution were found to have phosphorus transport rates independent of stream discharge patterns regardless of the season of the year.

A positive phosphorus gradient was observed in the river from the upstream areas to the downstream area, and was associated with increased watershed drainage area and increased urbanization of the downstream area.

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by

Robin Lewis Vannote

A THESIS

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INTRODUCTION

The role of nutrients in any ecosystem is of prime importance in the development and success of the biocoensis. In an aquatic biotope inorganic nutrients and solar energy are two components necessary for autotrophic production. Autotrophic organisms, unlike auxotrophic organisms, require no organic material during normal growth and reproduction. Auxotrophic or mixotrophic organisms have the ability to assimilate inorganic nutrients, but in addition depend upon organic substances for part of their nutrition (Ruttner 1953). Heterotrophic organisms, on the other hand, utilize through decomposition only those organic materials of the ecosystem previously formed by the producer organisms.

The metabolic role of chemosynthetic bacteria in contributing to the productivity and circulation of nutrients in waters is largely unknown and may be very important. The role of autotrophic bacterioplankton in contributing to the productivity of lakes was investigated by Rodina (1959), and led the author to believe that the primary production of waters could not be determined accurately without taking into consideration the extent of protein synthesis by autotrophic bacteria. Rodina (1959) calculated the bacterioplankton biomass in small ponds to vary between 5.04 and 27.44 mg/L in weed beds and between 0.065 and 9.02 mg/L in the open waters of the ponds.

Autotrophic populations are considered the basis of the food web; their activities are governed by many complex interactions. Although nutrients and solar energy are the fuel, speed and efficiency are governed by environmental conditions. In an open ecosystem such as the Red Cedar River, many catastrophies can cause the annihilation of the autotrophic community. Brehmer (1959) has described the biodynamics of the producer communities in the Williamston area of the Red Cedar River and has described the molar effects of stream-borne sediments on the periphyton community. Brehmer associated the destruction of the periphyton with high water levels accompanied by increased turbidity.

Autotrophic production is regulated by the supply of inorganic nutrients. The amounts of the various nutrient components in streams occasionally are not present in ratios which promote maximum organic synthesis, and one or more vital nutrients may limit stream productivity.

Hutchinson (1957) reports that of all the elements present in living organisms, phosphorus is most apt to be a limiting factor since the ratio of phosphorus to elements in organisms tends to exceed that ratio found in the biosphere. Phosphorus is a rare mineral in the earth's crust averaging less than 0.05 percent by weight (Curl 1959).

Whereas nitrogen and carbon are derived to an appreciable extent, either directly or indirectly, from a great reservoir, the atmosphere, phosphorus comes almost exclusively from the weathering of phosphate rock and from the soils. The entrance of phosphorus into an aquatic community may be direct through the action of watershed erosion or indirect by regeneration of the organic stream bottom sediments by microbial action. Large amounts of phosphorus are added directly to streams by sewage disposal plants and septic tank overflow.

Since the advent of household detergents, some of which are high in phosphorus compounds, the phosphorus load of sewage effluent has more than doubled (Neil 1958). Most modern treatment plants do not remove or reduce the concentration of phosphorus in the effluent but may change those complex phosphate compounds into forms readily available for plant utilization and therefore are of concern to the aquatic biologist.

Odum (1959) describes the phosphorus cycle as being imperfect in contrast to the perfect cycles of carbon and nitrogen. An imperfect cycle is one which tends to have some portion of the element lost from the system for a considerable period of time or in forms which are not readily available for plant production.

Nitrogen and carbon with vast reservoirs in the atmosphere have perfect cycles since the materials are returned to the biosphere as they are utilized, although local and sometimes critical shortages may exist temporarily.

Man's activities tend to accelerate these chemical cycles and may even cause them to be acyclic by deposition in the depths of the oceans. Since phosphorus is relatively earth-bound in its cycle (exceptions being atmospheric borne volcanic ash and industrial smokes), the primary mechanisms for recycling the element are erosion, sedimentation, and biological transport. Many biologists have reported the downhill tendency of the phosphorus cycle which produces a concentration of phosphorus in the low land areas at the expense of the upland areas. The local recycling mechanisms are important in limiting the downhill loss from exceeding uphill regeneration.

Marshland drainage, realignment of existing watercourses, and dredging have accelerated the sedimentary cycle of phosphorus and have tended to make it acyclic in that there is a more rapid movement of nutrients to the downstream areas, lakes, estuaries and oceans. By interfering with the "in-sight" regeneration, large amounts of phosphorus pass through the stream without being assimulated by the autotrophic community. The luxury concentration of nutrients in the lowlands is not necessarily beneficial to the primary producers since other limiting factors such as space, light, and/or competition may inhibit efficient utilization.

Clarke (1954) maintains that the majority of inorganic phosphorus available for primary production arises from the decomposition and regeneration of organic material already present in the environment. This concept is perhaps more applicable to lakes with a relatively closed system. Streams tend to be flushed of the organic matter during periods of high discharges and much of the phosphorus is lost from the system.

The data presented here are the result of a study to determine the source and level of phosphorus entering the Red Cedar River from the various tributaries in the watershed. The results of the intensive study of nutrient levels in the stream will be correlated with future studies of organic synthesis. By equating organic production to the chemical conditions of various sections, it is hoped that support may be given to the concept that biological productivity of streams depends in part upon the nutrient quality of the water. Furthermore the study will contribute insight into the complex interrelationships of essential substances and thus contribute to our knowledge of productivity.

METHODS

For those physical and chemical measurements not made in the field, water samples were collected in polyethylene bottles and refrigerated until analysis could be performed. The chemical analyses were completed usually within an hour upon returning to the laboratory. However, the water samples for total and dissolved phosphorus were acidified and stored for several days before being analyzed.

Sampling Schedule

The chemical sampling scheme employed to measure the level of chemical constituents entering the Red Cedar River from the tributaries was designed to take into account two naturally occurring characteristics associated with streams. These characteristics are:

1. Recurrent high water and low water stages. Inherently associated with the variations in river stages are the chemical levels. It was postulated that during the high water periods, the chemical properties of the tributaries would be dynamic, fluctuating to a greater extent than during the low water stages. During the low water stages the tributaries exhibit base flow conditions and the chemical levels approach a static condition.

During the period of high water, the chemical nutrient levels fluctuate and attain a seasonal maximum due to runoff and stream bed erosion. Seasonal erosion is attributed to increased water movement throughout the watershed and increased stream velocities during the wet season. Conversely, during the dry season base flow velocities are so reduced that stream sediments are deposited and built up rather than flushed from the system. Also contributing to the static chemical conditions of the dry season are reduced runoff (streams sustained at base flow by ground waters) during the summer months and frozen ground during the winter months.

2. Stream discharge directly proportional to drainage area size. It was theorized that chemical nutrient contributions of the tributaries would be in direct proportion to the magnitude of stream flow; that is, the major tributaries would constitute a greater source of nutrients than the minor tributaries. Therefore, it was necessary in designing the sampling scheme to include tributary flow patterns.

The flow characteristics of the Red Cedar River during the past ten years (Figure I) were determined from measurements made by the U. S. Geological Survey. From these data, a sampling schedule was constructed around both the river stages and drainage area of the tributaries. To include the differences between high and low water stages, the sampling schedule was divided into two seasonal phases.

It was observed that a period extending from the 15th of February to the 5th of June could be designated as the high water stage while the remainder of the year, June 6 to February 14 was chacteristically the low water stage.

Figure 1. Average monthly discharge of the Red Cedar River for 1947-1958 and average monthly discharge for February 1958 through January 1959. (Data from U. S. Geological Survey)

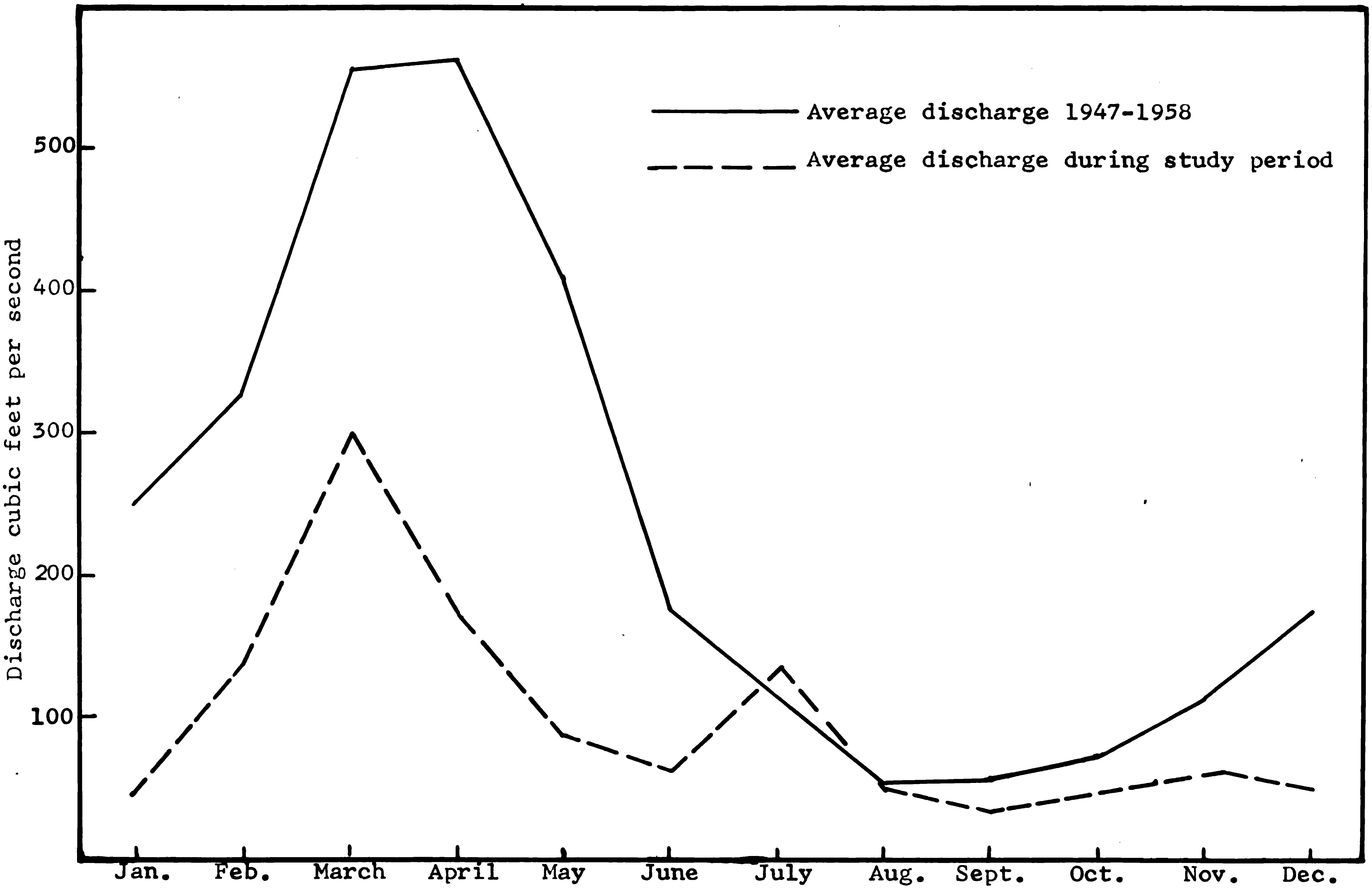

Average discharge 1947-1958
Average discharge during study period
Discharge cubic feet per second
500
400
300
200
100
Jan.
Feb.
March
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

Figure 1

To incorporate the tributaries, both major and minor, into the sampling scheme on a ranked basis relative to discharge, it was necessary to make an estimate of annual discharge rates for each tributary. Since flow data were available from the U.S.G.S. on only two tributaries, it was necessary to make a comparison of the annual discharge rates to drainage area for these two streams. Table 1 shows the existing flow records for these two drainages for the years 1955 and 1956 as well as those recorded at the Farm Lane station on the Red Cedar River.

The drainage area of each tributary was calculated from U.S.G.S. topographical maps. Deer Creek which has a drainage above the gauging station of 16.3 square miles, representing 4.59 percent of the Red Cedar River watershed, contributed 4.86 percent of the total annual discharge recorded at the Farm Lane station during the 1956 season and 4.59 percent during the 1955 season. Sloan Creek representing 2.63 percent of the watershed contributed 2.76 percent of the total annual flow.

Interpretation of these data indicated that it was possible to determine the relative discharge rates of each tributary by a direct comparison of drainage area. Table 2 shows the tributaries ranked according to drainage area and the sampling intensity for both the wet and dry seasons.

The sampling schedule was built around a stratified random block design. The wet season was subdivided into four 28-day quarters to facilitate statistical treatment; further-

Table 1. A comparison of annual discharge rates to watershed areas for two tributary streams and the Red Cedar River.

Ecosystem	Area Mi.^{2}	Discharge cfs Yr.$^{-1}$	Percent Total Area	Percent Total Discharge
1955				
Red Cedar River	355	65,935	100	100
Deer Creek	16.3	3,028	4.59	4.59
1956				
Red Cedar River	355	100,345	100	100
Deer Creek	16.3	4,880	4.59	4.86
Sloan Creek	9.34	2,774	2.63	2.76

Table 2. The tributaries of the Red Cedar River ranked according to drainage area and seasonal sampling intensities.

Tributary	Percent of Watershed	Relative Rank[1]	Seasonal Sampling Intensity Wet	Seasonal Sampling Intensity Low
Doan Creek	15.89	9.57	19	10
West Branch	12.34	7.43	15	6
East Branch	9.63	5.80	12	6
Deer Creek	7.72	4.65	9	5
Middle Branch	7.38	4.45	9	4
Kalamink Creek	5.92	3.57	7	4
Lake Lansing Drain	5.55	3.34	7	3
Sloan Creek	5.07	3.05	6	3
Wolf Creek	3.44	2.07	4	2
Squaw Creek	1.97	1.19	2	1
Coon Creek	1.72	1.04	2	1
Herron Creek	1.66	1.00	2	1
Misc. Tributaries	21.72	13.08	26	2
Totals	100.00		120	48

1. Herron Creek equals 1.00.

more each quarter was subsequently subdivided into seven 4-day blocks of which five blocks were each randomly assigned six tributaries to be sampled in pairs. The sampling schedule for the wet season, as shown in Appendix A, called for the assigning of three days from each 4-day block as sampling days during which time two randomly selected tributaries were to be sampled on each of the three days.

The dry season was subdivided into four 60-day quarters, each assigned six paired tributaries to be sampled on six randomly selected days. Appendix B shows the sampling schedule followed during the dry season. The sampling design required that two tributaries were to be visited on each of the six randomly selected sampling days in each quarter requiring 12 visits per quarter and a total of 48 visits during the dry season.

In order to determine the nutrient levels in the Red Cedar River, a sampling pattern was developed parallel to the tributary sampling schedule. When a tributary was sampled, an established station on the main stream below the confluence of the tributary was also sampled. In addition, the terminal downstream station located at Farm Lane bridge on the Michigan State University campus was sampled. Figure 2 shows the location of the sampling stations on the main stream and tributaries.

Water Temperature

At every water collection at each station, water temp-

Figure 2. Drainage map of the Red Cedar River and its principal tributaries showing sampling stations.

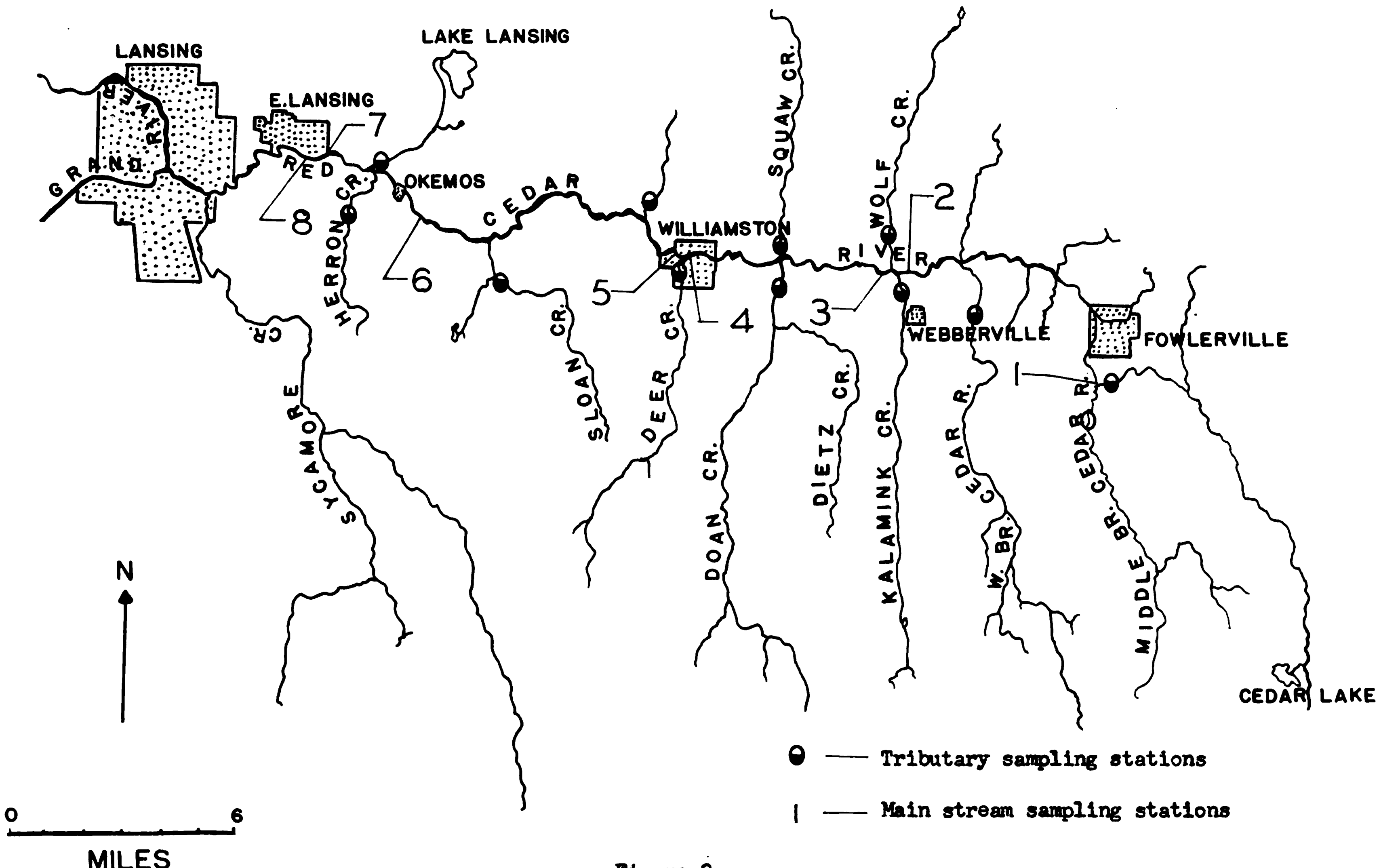

LANSING
GRAND RIVER
E. LANSING
LAKE LANSING
OKEMOS
RED CEDAR RIVER
HERRON CR.
SYCAMORE CR.
SLOAN CR.
DEER CR.
WILLIAMSTON
SQUAW CR.
DOAN CR.
DIETZ CR.
WOLF CR.
KALAMINK CR.
WEBBERVILLE
W. BR. CEDAR R.
FOWLERVILLE
MIDDLE BR. CEDAR R.
CEDAR LAKE
1
2
3
4
5
6
7
8
N
0
6
MILES
Tributary sampling stations
Main stream sampling stations

Figure 2

erature was recorded with a Taylor mercury column hand thermometer held in the current approximately one foot beneath the the water surface. Temperature data for the entire study period were also recorded on a Taylor continuous recording thermometer permanently located at the Michigan State University's river farm in Okemos, Michigan.

Hydrogen Ion Concentration

The pH was determined in the laboratory immediately upon return from the field. All pH values were measured on a Beckman, model H-2 glass electrode pH meter.

Conductivity

Conductivity, a reciprocal reading of resistance at a constant temperature, was determined with a Model RC-7 portable conductivity meter made by the Industrial Instrument Company. Conductivity readings are reported as ohm^{-1} cm^{-1} X 10^{-6} at 18 degrees centigrade.

Turbidity

Turbidity measurements were made on a Klett-Summerson photoelectric colorimeter equipped with a blue filter which transmits light in the range of 400-465 mu. All turbidity measurements were corrected for water color; the colorimeter was calibrated with a diatomaceous earth standard in the Jackson Candle Turbidimeter. One turbidity unit is equivalent to 1 mg SiO_2 per liter.

Stream Flow

Stream flow measurements were made utilizing gauging equipment manufactured by the W. and L. E. Gurley Company. The models used were the Price pattern, pygmy current meter, and a Type AA Price current meter. The latter was suspended by either the wading rod assembly or the cable assembly with a 15 pound lead torpedo-shaped weight. Gauge height scales were established at each station to determine river or stream stages during sampling visits.

Phosphorus

All phosphorus determinations were made utilizing a slight modification of the highly sensitive acidified ammonium molybdate test as described by Ellis, Westfall, and Ellis (1948). The modification was that the final digested 100 ml sample was divided and neutralized with saturated sodium hydroxide before the strong reducing agent, stannous chloride, was added to the fully oxidized phosphorus sample. The color intensity resulting from the reduction process was read on a Klett-Summerson colorimeter equipped with a red filter transmitting light in the range of 640 to 700 mu. Both the Total and dissolved phosphorus values reported are in the form of total elemental phosphorus (P).

Phosphorus may be present in the form of either organic or inorganic compounds, and both in particulate forms and in solution. Total phosphorus values reported here include all of the above mentioned forms, which upon acid digestion, are converted to a soluble form of phosphorus. Dissolved phosphorus values include only the soluble phosphorus forms which upon acid digestion yield the orthophosphate form. Colloidal phosphorus forms of a size less than 0.45 microns would be included in the dissolved phosphorus fraction.

Total Phosphorus

Total phosphorus determinations were made on 100-ml water samples collected in polyethylene bottles. The water samples were acidified with concentrated H_2SO_4 upon returning to the laboratory to prevent phosphorus loss to the walls of the bottles.

Dissolved Phosphorus

Dissolved phosphorus samples were collected and treated in the same manner as the total phosphorus samples except that the water samples were filtered through a HA-type Millipore filter before the addition of H_2SO_4. The HA-type Millipore filter removes all particles in excess of 0.45 microns.

RESULTS AND DISCUSSION

Hydrology

Hydrology, the science of water, encompasses the study of the physical and chemical properties of water and is especially concerned with its origin and distribution.

Hydrological studies of the Red Cedar River were conducted to determine the quantitative characteristics of stream flow on both the tributaries and main stream stations. The products of stream discharges and phosphorus concentrations were utilized to calculate the weight of phosphorus transported during each season at each station on the tributaries and main stream.

Discharge data for this investigation were obtained from hydrographic rating charts constructed for each tributary and station on the Red Cedar River. The hydrographs may be found in Appendix C.

Tributaries

The tributaries of the Red Cedar River accounted for approximately 90 percent of the estimated total annual discharge recorded at the Farm Lane bridge station. The unaccounted discharge resulted either from ground-water,drainage of areas immediately adjacent to the river, or a combination of both.

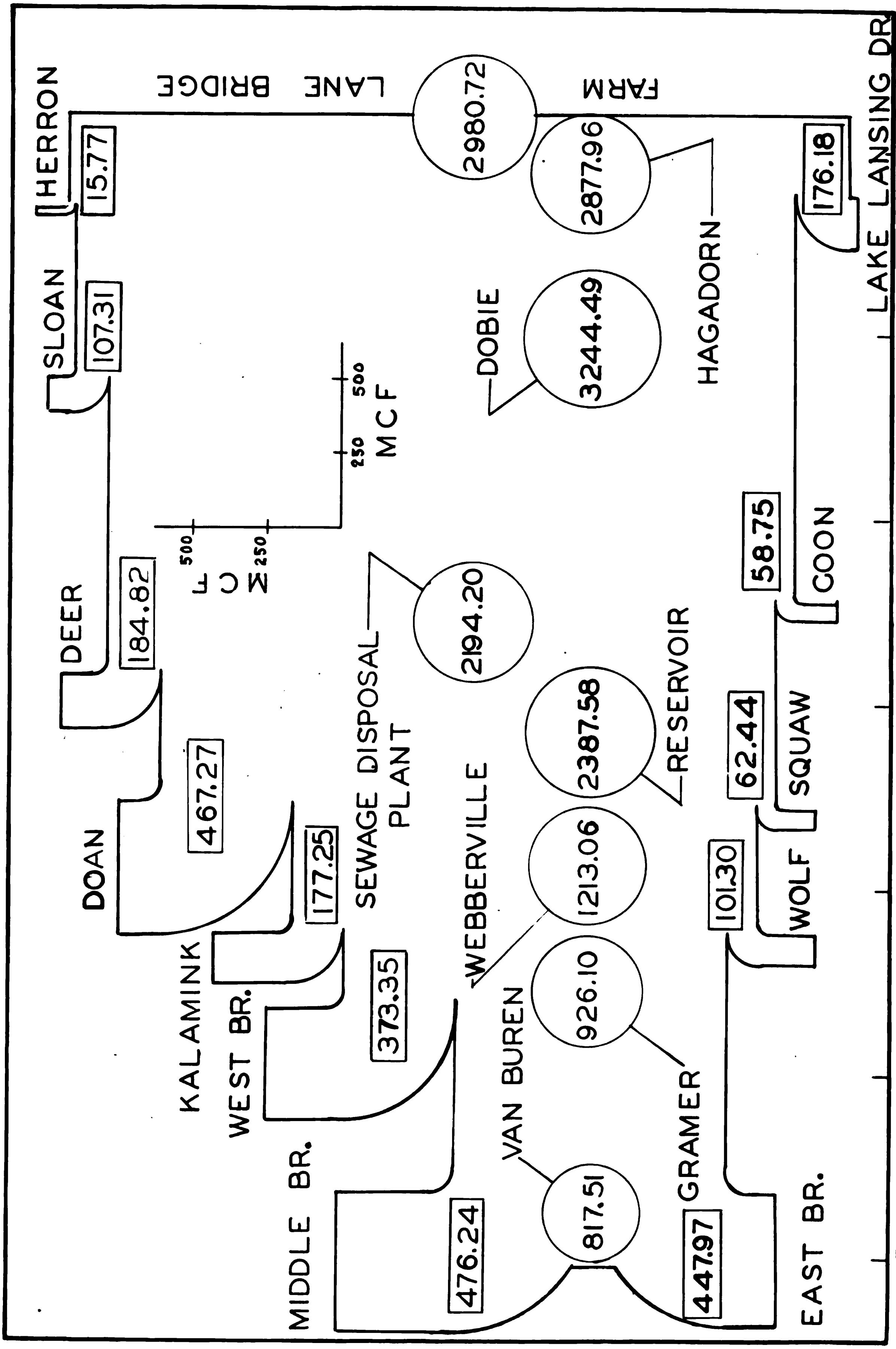
During the high water stage (February 15 to June 5) the data indicated that the tributaries contributed approximately 70 percent of the total discharge which was measured at the Farm Lane bridge station. This indicates that those areas not actually drained by a tributary (approximately 20 percent) have characteristically high runoff properties with a low storage capacity.

During the low water stage (June 6 to February 14) the tributary discharges were approximately 15 percent greater than those recorded at the Farm Lane station. The water loss shows that at base flow the stream is either recharging underground aquifers, suppling irrigation projects, or that the loss is due to evaporation and transpiration. It is probable that a combination of the above factors is in operation. It has been observed that considerable quantities of water are removed from the system during the summer months for golf course, nursery, and garden maintenance.

During September 1958, a minimum discharge of 17 cubic feet per second was recorded by the U. S. G. S. at the Farm Lane station. This would indicate that just one large-scale irrigation project during the periods of minimum discharge would reduce stream flow to a critical level in regard to stream life.

The total annual discharge of the tributaries is diagrammatically shown in Figure 3. The numerical figures in the rectangles are stream discharges in million cubic feet per year, and the encircled figures are the estimates of the

Figure 3. Annual volume of discharge for 12 tributaries and 8 main stream stations on the Red Cedar River. February 1958 to February 1959.



HERRON
15.77
SLOAN
107.31
DEER
184.82
DOAN
467.27
KALAMINK
177.25
WEST BR.
373.35
MIDDLE BR.
476.24
BRIDGE
LANE
FARM
2980.72
2877.96
HAGADORN
DOBIE
3244.49
LAKE LANSING DR.
176.18
COON
58.75
SQUAW
62.44
WOLF
101.30
EAST BR.
447.97
SEWAGE DISPOSAL PLANT
2194.20
RESERVOIR
2387.58
WEBBERVILLE
1213.06
VAN BUREN
926.10
GRAMER
817.51
CFM
250
500
MCF
RIVER MILES
5
10
15
20
25
30
35

annual discharge in million cubic feet at the eight stations located on the Red Cedar River.

In general, tributary discharges are in close agreement with the size of the drainage area. Table 3 compares the percent area with the percent discharge for each tributary. Only the relative rank of the Middle Branch and the East Branch, the confluence of which forms the Red Cedar River proper, depart significantly in the discharge-drainage area proportions.

The departure in relative rank can be attributed in part to the type of watershed these tributaries drain. The East Branch has its origin as the outfall of Cedar Lake, and the Middle Branch drains an area of extensive marsh lands. The discharge of these two streams was sustained during the summer months to a greater degree than that of other tributaries.

The average daily discharge for the East Branch during the wet and dry seasons was 1.09 and 1.29 million cubic feet per day respectively; the values for the Middle Branch were 1.42 and 1.25 million cubic feet per day. The average daily discharges for the other tributaries (Table 4) were all greatly reduced during the low water stage. Phosphorus values, as will be shown, followed the reduction in stream flow.

Red Cedar River

The Red Cedar River drainage basin is characteristic of many small Michigan watersheds in which a large proportion of the land area is under agriculture. The tributary drainage

Table 3. Comparison of drainage area with annual discharge for the tributaries of the Red Cedar River.

Tributary	Area: Square Miles	Area: Percent Total	Discharge: Million Cubic Feet	Discharge: Percent Total
Doan Creek	56.4	15.89	467.27	17.64
West Branch	43.8	12.34	373.35	14.10
East Branch	34.2	9.63	447.97	16.91
Deer Creek	27.4	7.72	184.82	6.97
Middle Branch	26.2	7.38	476.24	17.98
Kalamink Creek	21.0	5.92	177.25	6.69
Lake Lansing Dr.	19.7	5.55	176.18	6.65
Sloan Creek	18.0	5.07	107.31	4.05
Wolf Creek	12.2	3.44	101.30	3.82
Squaw Creek	7.0	1.97	62.44	2.36
Coon Creek	6.1	1.72	58.75	2.22
Herron Creek	5.9	1.66	15.77	0.60
Totals	278.9		2648.68	
Farm Lane	355.		2980.72	

Table 4. Average daily discharge for the tributaries during high and low stream stages.

Tributary	Discharge Million Cubic Feet Per Day High Water Season	Low Water Season
Doan Creek	2.06	0.93
West Branch	1.67	0.74
East Branch	1.09	1.29
Deer Creek	0.79	0.38
Middle Branch	1.42	1.25
Kalamink Creek	0.67	0.41
Lake Lansing Drain	1.29	0.13
Sloan Creek	0.70	0.11
Wolf Creek	0.56	0.13
Squaw Creek	0.46	0.04
Coon Creek	0.32	0.09
Herron Creek	0.04	0.04
Totals	11.07	5.44

system is underlain by glacial drift that has a low rate of water intake and a low water storage capacity. These soil characteristics result in the rapid runoff of precipitation. Flooding of the marginal lowlands is common following intense summer storms and following the spring thaw.

The common farm drainage practices of tiling fields, dredging tributaries, and establishing networks of random ditch surface drains all contribute to an increase in runoff rates. The recent increase in flood damage is not due entirely to the increase in runoff rates, but is more closely associated with the increased values of the flood plains. The marginal lands along the river's course have attracted housing developments either because of low land value or the aesthetic attractions of water. Further utilization of the flood plains are made by farmers who are attracted to the rich alluvial soil deposits.

Runoff and sediment rates have been studied and reported by the Michigan Water Resources Commission (1958) for the Deer Creek and Sloan Creek basins where the percentages of drainage area under cultivation was approximately 70 and 80 percent respectively. The study revealed that within eleven hours following a 3-hour storm, approximately 60 percent of the total precipitation resulted in direct runoff. This rapid runoff produces flooding and excessive siltation and turbid condition in the tributaries and main stream of the Red Cedar River. Deer Creek, following peak runoff of the three hour storm, attained a maximum sediment rate of 27.72

tons per hour.

Brehmer (1959) described the cataclysmic effects of Deer Creek on the producer communities in the Williamston area of the Red Cedar River following periods of high runoff. Tarzwell (1957) reported the investigation of the adverse effect of settleable solids and turbidity on benthic organisms in northern Michigan trout streams. His investigation showed that the addition of silt and sand to gravel or rubble stream bottoms greatly decreased the benthic productivity. The effect of reduced benthic fauna due to turbidity on fish production in Oklahoma ponds and reservoirs has been described by Buck (1956) who reported growth of fish in clear ponds to be 1.7 times greater than those in ponds of intermediate turbidity and 5.5 times greater than those in muddy waters.

On the Red Cedar River a maximum turbidity of 140 units (one unit of turbidity equals 1 mg SiO_2 per liter) was recorded during July of the study period. The high turbidity followed a period of heavy precipitation and accompanied flooding.

The discharge patterns of the stream during the study period (Figure 1) were far below the "normal" flow conditions and the usual spring flooding did not occur.

The U. S. Weather Bureau at East Lansing reported several new low precipitation records for the first five months of 1958. February precipitation was 1.25 inches below normal, only in three Februarys since 1900 was the level below that recorded for this month. During the month of March only 0.43 inches of precipitation fell establishing a new record low for this month. April and May precipitation accumulations were 1.30 and 2.18 inches below normal respectively; the departure from normal since the first of the year was a minus 7.6 inches.

Kevern (1961), Grzenda (1960), and Brehmer (1959) all reported that phosphorus movement in the Red Cedar River reached a maximum during the high water levels following the spring thaw and intense summer storms. The effects of the reduced discharge during the atypical year on nutrient transport in the ecosystem is made evident by the minimal phosphorus levels (Figures 4 and 5) encountered during the study period.

Chemical Characteristics

The Red Cedar River and its tributary network is a highly buffered system having little variation in pH levels. The waters are alkaline with seasonal pH values ranging from 7.5 to 8.4. Low pH values occur following periods of moderate to heavy precipitation and during the winter months when photosynthetic activities were suppressed.

Alkalinity determinations revealed that only the bicarbonate ions, $Ca(HCO_3)_2$, were contributing to the alkalinity of both the tributaries and main stream. Methyl orange alkalinity varied between 160 and 330 mg l^{-1}. Alkalinity varied inversely with stream discharge, i.e., low readings were attained during high water periods.

Conductivity measurements, like alkalinity, varied inversely with stream flow. Conductivity measurements corrected to 18° C ranged between 330 uohms cm^{-1} during high stream stages to 620 uohms cm^{-1} during base flow conditions. Welch (1948) states that waters rich in electrolytes generally have greater biological productivity than those of low specific conductance. It was observed that the electrolytic components (Table 6) increased towards downstream stations indicating that ionic enrichment occurred with increasing stream length. Perhaps this is directly related to drainage area. As will be shown, phosphorus levels as recorded on the main stream stations indicated a distinct increase towards downstream stations in a pattern similar to conductivity. The downstream concentration of electrolytes could not be correlated with alkalinity since all main stream stations exhibited similar readings, and no gradient was observed.

Tables 5 and 6 summarize the average seasonal values of the interrelated measurements of pH, alkalinity, and conductivity for the tributaries and eight main stream stations.

The physical and chemical data collected during the investigation are presented in tabular form in Appendix D.

Phosphorus

Phosphorus concentrations of the 12 tributaries and 8 main stream stations were measured in accordance with the sampling schedule. Elemental phosphorus concentrations were converted mathematically and reported on a seasonal weight basis. The conversion to a time-weight basis (kilograms of phosphorus per year or season) was made by multiplying the product of phosphorus concentration and stream discharge by the unit time.

The phosphorus levels during the wet season were reported both as seasonal and quarterly rates. Quarterly measurements during the wet season were utilized to demonstrate the fluctuation of phosphorus levels during the high water stage and the gradual trend toward stability as stream conditions approached base flow.

The difference between total and dissolved phosphorus measurements is attributed to sestonic phosphorus. Sestonic

Table 5. Average seasonal physical-chemical properties of the tributaries.

Tributary	pH		Turbidity ppm		Alkalinity ppm Methyl Orange		Conductivity $uohm^{-1}$ cm^{-1} 18° C.	
	Season							
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Doan Creek	8.0	8.0	17	13	237	252	559	508
West Branch	8.0	8.0	14	11	237	250	566	454
East Branch	8.0	7.9	16	15	245	263	572	502
Deer Creek	8.0	8.0	14	19	237	244	544	598
Middle Branch	7.8	7.8	18	28	243	244	507	407
Kalamink Cr.	8.0	8.1	22	10	262	268	625	484
Lk. Lansing D.	7.9	7.9	16	24	234	261	525	467
Sloan Creek	8.0	8.0	13	6	199	253	437	396
Wolf Creek	8.1	7.7	18	8	239	284	558	342
Squaw Creek	7.9	8.2	13	10	213	282	436	624
Coon Creek	7.9	8.1	12	19	258	284	486	468
Herron Creek	8.0	8.0	34	11	258	233	536	400

Figure 6. Average seasonal physical-chemical properties at eight stations on the Red Cedar River.

Station	pH		Turbidity ppm		Alkalinity ppm Methyl Orange		Conductivity $uohm^{-1}$ cm^{-1} 18° C	
	Season							
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Van Buren Rd.	7.9	7.9	18	21	247	264	515	472
Gramer Road	8.0	7.9	17	15	239	252	518	432
Webberville Rd.	8.0	7.9	20	11	243	268	532	473
Reservoir[1]	8.1	7.9	24	24	252	248	528	505
Disposal Plant[2]	8.0	7.9	16	24	248	244	515	613
Dobie Road	8.1	7.9	19	15	226	256	487	430
Hagadorn Road	8.1	8.0	16	13	241	235	534	414
Farm Lane	8.1	7.9	17	18	240	242	538	510

1. sampled below reservoir dam
2. sampled up-stream from outfall

phosphorus includes both organic and inorganic combined phosphorus in suspension. The ratios of dissolved phosphorus to total phosphorus are indices of sestonic phosphorus. This ratio for the tributaries of the Red Cedar River varied from 1:1.79 during the wet season to 1:1.59 during the dry season. These ratios indicate that greater amounts of phosphorus are in sestonic form during the wet season than during the dry season.

This increase of sestonic materials during the high water stage is attributed to the suspension of organic, detrital material from the stream bed rather than fixation by organic synthesis. In addition, sestonic materials are washed into the stream by runoff from adjacent land areas. Accordingly, it would be erroneous to assume that an increase in sestonic phosphorus is synonymous to phosphorus fixation (production).

Tributaries. On a yearly basis, the phosphorus contribution of the tributaries accounted for slightly less than 50 percent of the total amount of phosphorus passing through the Farm Lane station. The annual accrual of total and dissolved phosphorus from the tributaries was 4.27 and 2.77 metric tons respectively.

Brehmer (1959) calculated the total phosphorus accrual from the sewage disposal plant in Williamston to be 2.48 metric tons per year. As can be seen from the subtotals in Table 7, the allochthonous phosphorus values closely approximated the values recorded at Hagadorn Road, a station

Table 7. Comparison of the annual accrual of phosphorus from the tributaries and the sewage disposal plant with the level observed at Hagadorn Road

Nutrient Source	Nutrient Levels Total Phosphorus	Dissolved Phosphorus
Tributaries	4.27 Metric Tons	2.77 Metric Tons
Sewage Disposal Plant	2.48[1]	1.2[2]
Sub Total	6.75	3.97
Hagadorn Road	6.45	3.89

1. Brehmer (1959)
2. Estimated from total phosphorus

immediately down stream from the last tributary in the experimental section of the river.

The terminal study area, Farm Lane, is approximately 0.8 miles below Hagadorn Road. An estimate of phosphorus passing this station was 9.76 metric tons per year or an increase of 3.31 tons in a distance of less than a mile. The large increase is attributed to many septic tank over-flows and a large municipal (Wilmarth) drain which empties into the river midway between the two stations.

The tributaries may be divided into two groups depending upon the primary source of phosphorus. The groups are: (1) those receiving effluent from sanitary drains and septic tank outflows, and (2) those streams which drain agricultural and woodlands and receive little or no domestic pollutants.

Kalamink Creek and Lake Lansing Drain are two tributaries which fall in category one, and both receive considerable amounts of domestic pollution from suburban and urban areas. Kalamink Creek drains an extensive area of muck-land farms before passing through the community of Webberville and joining the Red Cedar River. The stream receives considerable amounts of domestic and light industrial pollution as it passes through the town. Lake Lansing Drain has as its source the outfall of cottage-lined Lake Lansing. In accordance with Whipple's classification as outlined by Welch (1952), the lake would be designated as a second order temperate lake. The lake is strongly eutrophic, and aquatic weed growth becomes excessive during the summer months. The drain is enriched as it flows near a housing development and trailer court before entering the main stream between the towns of Okemos and East Lansing.

The data tabulated in Table 8 for Lake Lansing Drain and Kalamink Creek show the average daily phosphorus transport and the average daily discharge during both the wet and dry seasons. Although the phosphorus concentrations varied with stream flow conditions during each sampling visit, the calculated daily phosphorus transport (product of phosphorus concentration and stream discharge) remained constant for both the wet and dry seasons. This indicated that the primary source of phosphorus entering these tributaries is constant irrespective of season or stream discharge. The primary source of phosphorus is considered to be domestic and light industrial pollution, and is of such magnitude that it completely masks the seasonal phosphorus response associated with the peak flow periods of the tributaries.

In summary, the phosphorus loads of Kalamink Creek and Lake Lansing Drain are independent of stream discharge and the season of the year. A ten fold increase in stream flow produced no detectible increase in the phosphorus load carried by Lake Lansing Drain during the wet season.

The influence of Kalamink and Wolf creeks on the nutrient level of the Red Cedar River during the high water stage (February 15 to June 5) is shown in Table 9. The tributaries enter the Red Cedar River at the same location; Wolf Creek drains agricultural lands to the north, and Kalamink Creek

Table 8. Estimates of the seasonal daily phosphorus levels and discharge for two tributaries of the Red Cedar River.

	Lake Lansing Drain	Kalamink Creek
Dissolved Phosphorus		
Wet Season	2.50 Kg. Day^{-1}	1.67 Kg. Day^{-1}
Dry Season	2.71	1.79
Total Phosphorus		
Wet Season	3.79 Kg. Day^{-1}	2.44 Kg. Day^{-1}
Dry Season	3.79	2.29
Discharge		
Wet Season	1.29 MCF* Day^{-1}	0.66 MCF Day^{-1}
Dry Season	0.13	0.41

* MCF equals million cubic feet

Table 9. Phosphorus content and discharge rates of two tributaries during the high water stage.

Station	Phosphorus in Kilograms				Discharge Rates	
	Total	$S_{\bar{x}}$	Dissolved	$S_{\bar{x}}$	C. F. x 10^6	$S_{\bar{x}}$
Kalamink Creek	273.56	8.74	186.57	8.87	74.51	3.41
Wolf Creek	58.25	2.54	25.35	1.32	62.42	3.41
Sub Total	331.81		211.92		136.93	
Red Cedar River at:						
Webberville Road	1187.73	15.04	472.42	6.55	775.83	13.03
Gramer Road	863.46	11.90	360.07	6.87	576.35	12.78
Increase	324.27		112.35		199.48	
Percent at Webberville Road Attributed to:						
Kalamink Creek	23.03		39.49		9.60	
Wolf Creek	4.90		5.37		8.04	
Combined	27.93		44.86		17.65	

drains agricultural lands to the south before passing through an urban community and joining the Red Cedar River. These tributaries enter the Red Cedar River (Figure 2) midway between the upstream station, Gramer Road, and the downstream station Webberville Road. Since the distance between the two main stream stations is approximately one mile, direct runoff to the river is minimal. Therefore the contributions of phosphorus and discharge by the two tributaries should closely approximate the phosphorus and discharge increment noted from the upstream station (Gramer Road) to the downstream station (Webberville Road). This comparison of tributary contribution to main stream increment shows the magnitude of the contributions and attests to the reliability and statistical soundness of the random sampling scheme employed throughout the investigation.

The contribution of total phosphorus by the two tributaries during the wet season amounted to 331.81 kilograms. The total phosphorus increment between the upstream station, Gramer Road, to the downstream station, Webberville Road, was 324.27 kilograms. Although the standard errors of the estimates reveal considerable variability, the close similarity of the total phosphorus estimates indicate that the sampling scheme was statistically sound.

Kalamink and Wolf creeks contributed 211.92 kilograms of dissolved phosphorus to the nutrient content of the main stream during the wet season. The dissolved phosphorus increment between the two main stream (Gramer-Webberville) stations amounted to 112.35 kilograms accounting for approximately 53 percent of the tributary contributions.

The apparent loss may be attributed to biological uptake once the high concentrations of dissolved phosphorus reaches the main stream. Brehmer (1959) reported that nearly all the dissolved phosphorus introduced by the effluent of the sewage disposal plant in Williamston was removed from solution within the first 0.6 mile below the outfall. Brehmer associated the loss with biological uptake after failing to demonstrate abiotic removal.

In summary, Kalamink Creek like Lake Lansing Drain increases the concentration of both total and dissolved phosphorus, while Wolf Creek and other tributaries which drain agricultural and woodlands tends to dilute the phosphorus concentration of the main stream.

The average daily phosphorus levels of the tributaries are presented in Table 10. Those tributaries not receiving domestic pollution showed reduced phosphorus loads during the dry season. The reduction was not entirely attributed to an increase in autotrophic production, but believed due primarily to reduced flow conditions. As previously explained in the section on Hydrology, the Middle and East Branch exhibited a sustained flow pattern during the summer months, and correspondingly there was no reduction in the phosphorus levels during the dry season. Since these two tributaries are free from domestic contamination and phosphorus levels were sustained during the summer months, it was concluded

Figure 10. Estimates of the seasonal daily phosphorus levels for the tributaries of the Red Cedar River.

Tributary	Dissolved Phosphorus Season Wet	Dissolved Phosphorus Season Dry	Total Phosphorus Season Wet	Total Phosphorus Season Dry
Doan Creek	0.92 Kg.	0.44 Kg.	1.80 Kg.	0.83 Kg.
West Branch	0.53	0.21	1.12	0.40
East Branch	0.40	0.53	0.84	1.04
Deer Creek	0.24	0.20	0.61	0.40
Middle Branch	0.45	0.61	1.04	1.62
Kalamink Creek	1.67	1.79	2.44	2.29
Lake Lansing Drain	2.47	2.71	3.79	2.79
Sloan Creek	0.37	0.07	0.79	0.11
Wolf Creek	0.23	0.07	0.79	0.10
Squaw Creek	0.24	0.08	0.47	0.08
Coon Creek	0.06	0.03	0.10	0.07
Herron Creek	0.05	0.03	0.14	0.05
Small Stream	t[1]	t	0.01	t
Totals	7.63	6.77	13.67	10.78

[1] t - trace amounts

that flow patterns rather than autotrophic production were the primary cause effecting phosphorus reduction during periods of minimal discharge.

Estimates of the total annual amount of phosphorus entering the Red Cedar River from the tributaries are presented diagrammatically in Figures 4 and 5. The numerical figures presented in the rectangles are phosphorus budget estimates for the tributaries measured in kilograms per year. The encircled figures are estimates of phosphorus movement in kilograms per year at eight stations located on the Red Cedar River. In comparing Figures 4 and 5 with the similarly constructed hydrographic diagram (Figure 3), it can be seen that the tributary phosphorus loads are in direct proportion to discharge; the exceptions being Lake Lansing Drain and Kalamink Creek which were described previously. For these two tributaries the comparison reveals a higher phosphorus-discharge ratio than found in the other tributaries and is attributed to artificial enrichment.

The tributaries of the Red Cedar River transported 4.27 metric tons of phosphorus to the main stream during the year. The contribution of Lake Lansing Drain was 1.38 metric tons or approximately 32 percent of the total accrual. The discharge of this tributary was estimated as 176.18 million cubic feet per year or approximately 6.65 percent of the estimated combined flow of the tributaries. The phosphorus accrual from Lake Lansing Drain represents the largest single source of phosphorus entering the main stream from a tributary.

Figure 4. Annual accrual of total phosphorus from the tributaries and at 8 stations of the Red Cedar River. February 1958 - February 1959.

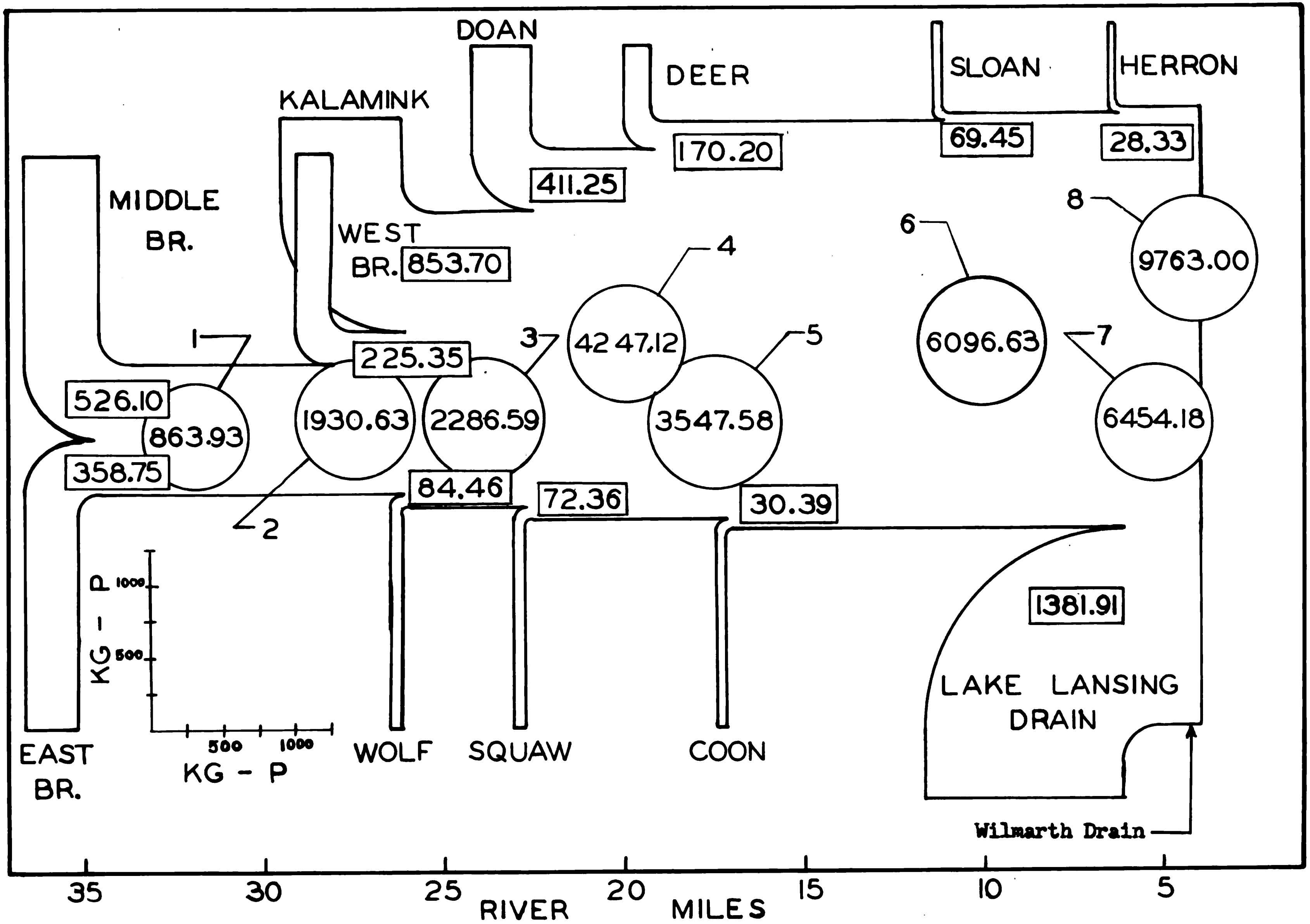
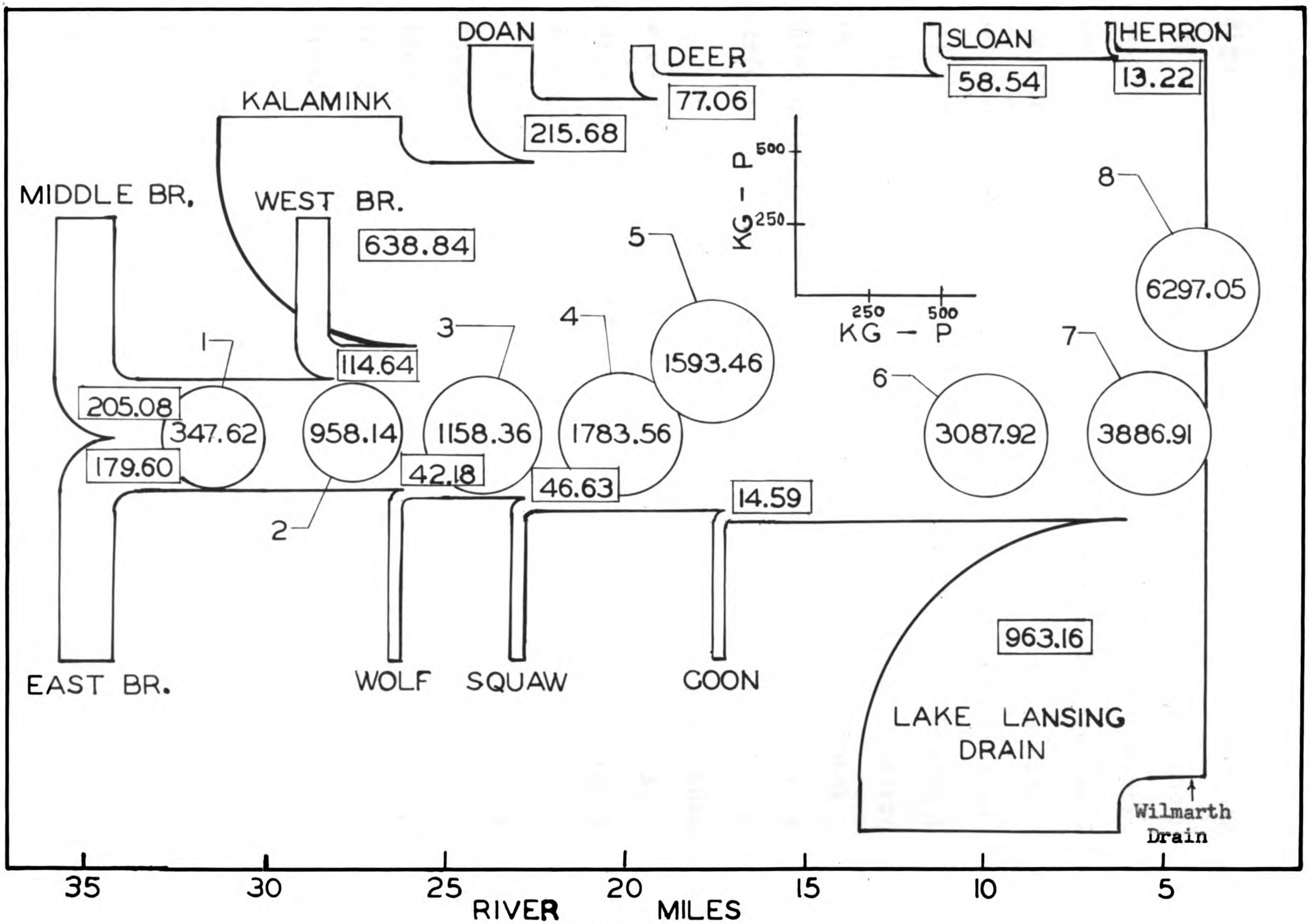

DOAN
KALAMINK
DEER
SLOAN
HERRON
MIDDLE BR.
WEST BR.
853.70
411.25
170.20
69.45
28.33
1
2
3
4
5
6
7
8
526.10
863.93
358.75
1930.63
225.35
2286.59
84.46
42 47.12
3547.58
72.36
30.39
6096.63
6454.18
9763.00
1381.91
LAKE LANSING DRAIN
Wilmarth Drain
EAST BR.
KG - P
500
1000
WOLF
SQUAW
COON
35
30
25
20
15
10
5
RIVER MILES

Figure 4

Figure 5. Annual accrual of dissolved phosphorus from the tributaries and at 8 stations of the Red Cedar River. February 1958 - February 1959.



DOAN
DEER
SLOAN
HERRON
KALAMINK
MIDDLE BR.
WEST BR.
EAST BR.
WOLF
SQUAW
COON
LAKE LANSING DRAIN
Wilmarth Drain
205.08
179.60
347.62
114.64
958.14
638.84
42.18
1158.36
215.68
46.63
1783.56
1593.46
77.06
14.59
58.54
13.22
3087.92
3886.91
6297.05
963.16
1
2
3
4
5
6
7
8
KG - P
250
500
35
30
25
20
15
10
5
RIVER MILES

Figure 5

Wilmarth Drain, a tiled township interceptor drain, (Figure 4 and 5) enters the main stream midway between Station 7 (Hagadorn Road) and Station 8 (Farm Lane). Although the phosphorus contribution by this drain was not measured directly, its magnitude may be estimated by the increase in phosphorus transport between stations 7 and 8. Assuming that the increase in phosphorus transport between the two main stream stations was due entirely to Wilmarth Drain, then the annual contribution by this drain would be 3.31 metric tons. This amount is 33 percent greater than the annual contribution by the Williamston sewage disposal plant (2.48 metric tons).

The effluent from the Williamston disposal plant enters the main stream approximately 1000 feet below Station 5. The phosphorus accrual from the disposal plant was reflected in the measurements made at Station 6 (Dobie Road).

The phosphorus transport at stations 5 and 6 was estimated as 3.55 and 6.10 metric tons per year respectively. The increase between the two stations (2.55 metric tons) approximates the phosphorus yield of 2.48 metric tons from the disposal plant effluent. Two small tributaries, Coon Creek and Sloan Creek, enter the main stream between stations 5 and 6. The combined phosphorus contribution of these tributaries was approximately 0.10 metric tons per year.

In describing the total and dissolved phosphorus content of Ellersile Brook, a Prince Edward Island trout stream, Smith (1959) reported that the rise and fall in phosphorus was directly associated with changes in water level (discharge) of the stream. A similar correlation was found to exist for the Red Cedar River watershed.

A significant positive correlation (Table 11) was found to exist between the rate of phosphorus movement (weight per unit time) and discharge of those tributaries not enriched by domestic pollution. Furthermore, the correlation between phosphorus transport and stream discharge revealed that it was possible to predict, on an annual or seasonal level, both the total and dissolved phosphorus contribution from the discharge data.

On the strength of the significant correlation, the phosphorus transport rates (Y) in kilograms per season or year were plotted against stream discharge (X) in million cubic feet for all the tributaries except Kalamink Creek and Lake Lansing Drain. The regression equation describing the the relationship between phosphorus transport (Y) and stream discharge (X) was calculated on the principle of least squares as outlined by Snedecor (1956) and reported as

$$\hat{y} = bx,$$

where y is the estimated deviation of Y corresponding to any x-deviation.

The regression equations showing the relationship between kilograms of phosphorus transported per unit time and stream discharge were computed for the following stream stages: (1) high water stage, (2) low water stage, and (3) on a combined basis. In addition to a correlation significant at the one percent level, the slopes (b) of the phosphorus-

Table 11. Correlation values and "t" test values for the regression of phosphorus against discharge for the tributaries of the Red Cedar River.

River Stage	Correlation Value[1] Phosphorus Total	Correlation Value[1] Phosphorus Dissolved	"T" Value[1] Phosphorus Total	"T" Value[1] Phosphorus Dissolved
High	0.96	0.95	9.86	5.27
Low	0.94	0.97	7.53	12.05
Combined	0.93	0.97	8.95	12.01

1. all values significant at the one percent level

	Total Phosphorus		Dissolved Phosphorus	
	Wet Season	Dry Season	Wet Season	Dry Season
ΣX =	1,020.63	1,269.59	1,020.63	1,269.59
ΣX^2 =	150,385.18	309,403.32	150,385.18	309,403.32
ΣY =	831.31	1,192.84	392.78	574.44
ΣY^2 =	97,441.22	305,141.24	22,898.81	61,037.91
ΣXY =	119,629.51	296,872.74	57,531.69	135.691.42
n =	10	10	10	10

discharge regression equations were found to be significantly different from zero at the one percent level by the "t" test (Table 11). The regression coefficients (slope and intercept) were calculated from the data presented in Table 11. The accompanying Figures 6-8 show the original data with the estimated regression lines.

Figure 6 shows the relationships between both total and dissolved phosphorus transport and stream discharge during the high water stage (February 15 to June 6). The regression formulae are:

1. Total Phosphorus $Y = 6.32 + 0.75X$
2. Dissolved Phosphorus $Y = 0.32 + 0.38X$

Figure 7 shows the relationship between total and dissolved phosphorus and stream discharge during the low water stage (June 6 to February 14). The regression formulae are:

1. Total Phosphorus $Y = -5.29 + 0.98X$
2. Dissolved Phosphorus $Y = 3.69 + 0.42X$

The phosphorus and stream discharge parameters for the wet and dry seasons were combined and tested for heterogenity by the analysis of covariance. The analysis revealed that neither the slopes nor the elevations of the regression lines were significantly different. Failing to demonstrate a significant difference between the seasonal, phosphorus transport-discharge regressions, a grand regression equation was calculated.

Figure 8 shows the relationship between both total and dissolved phosphorus transport and stream discharge following

Figure 6. Relationship between phosphorus transport and stream discharge for the high water stage on ten tributaries of the Red Cedar River.

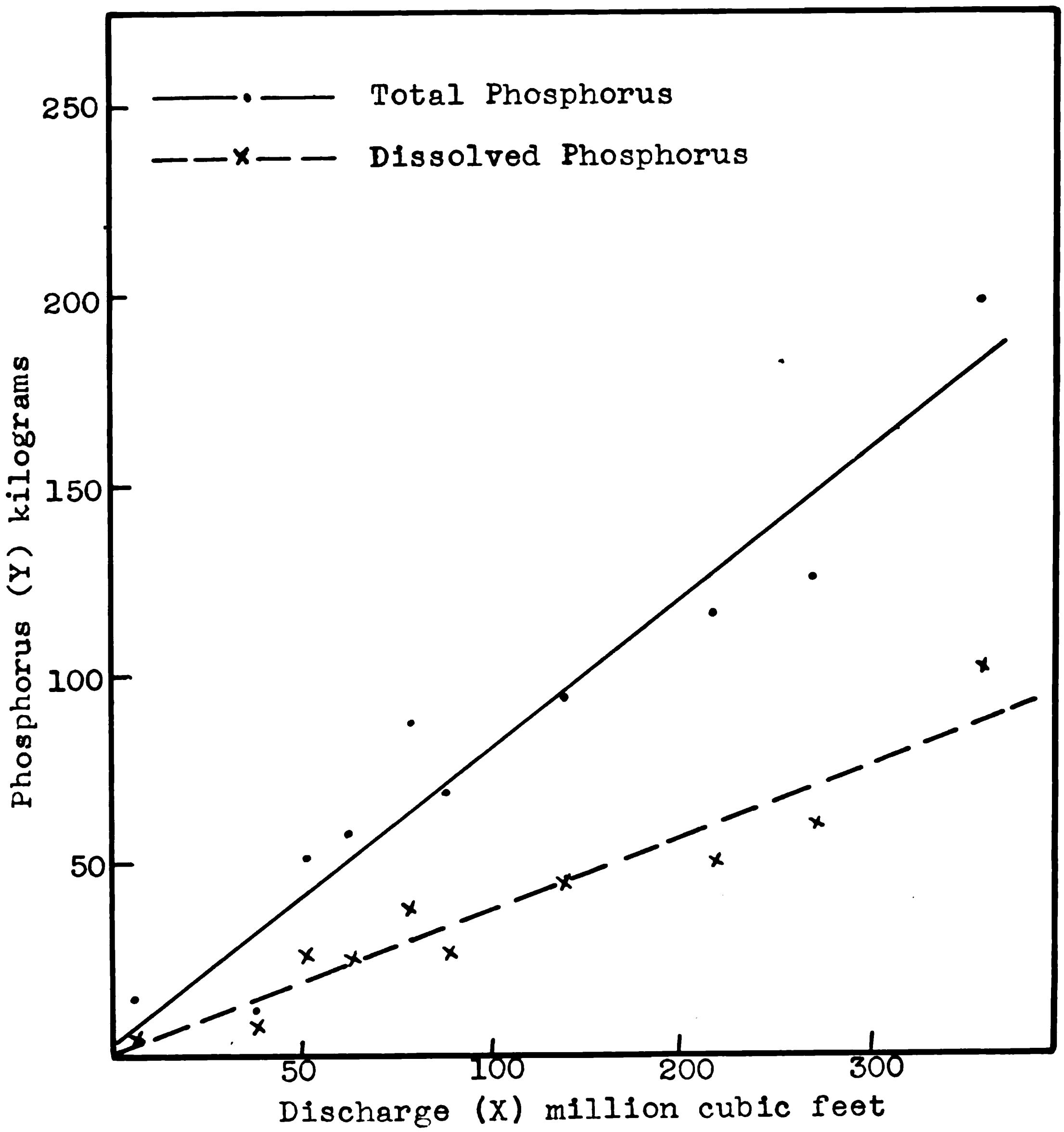
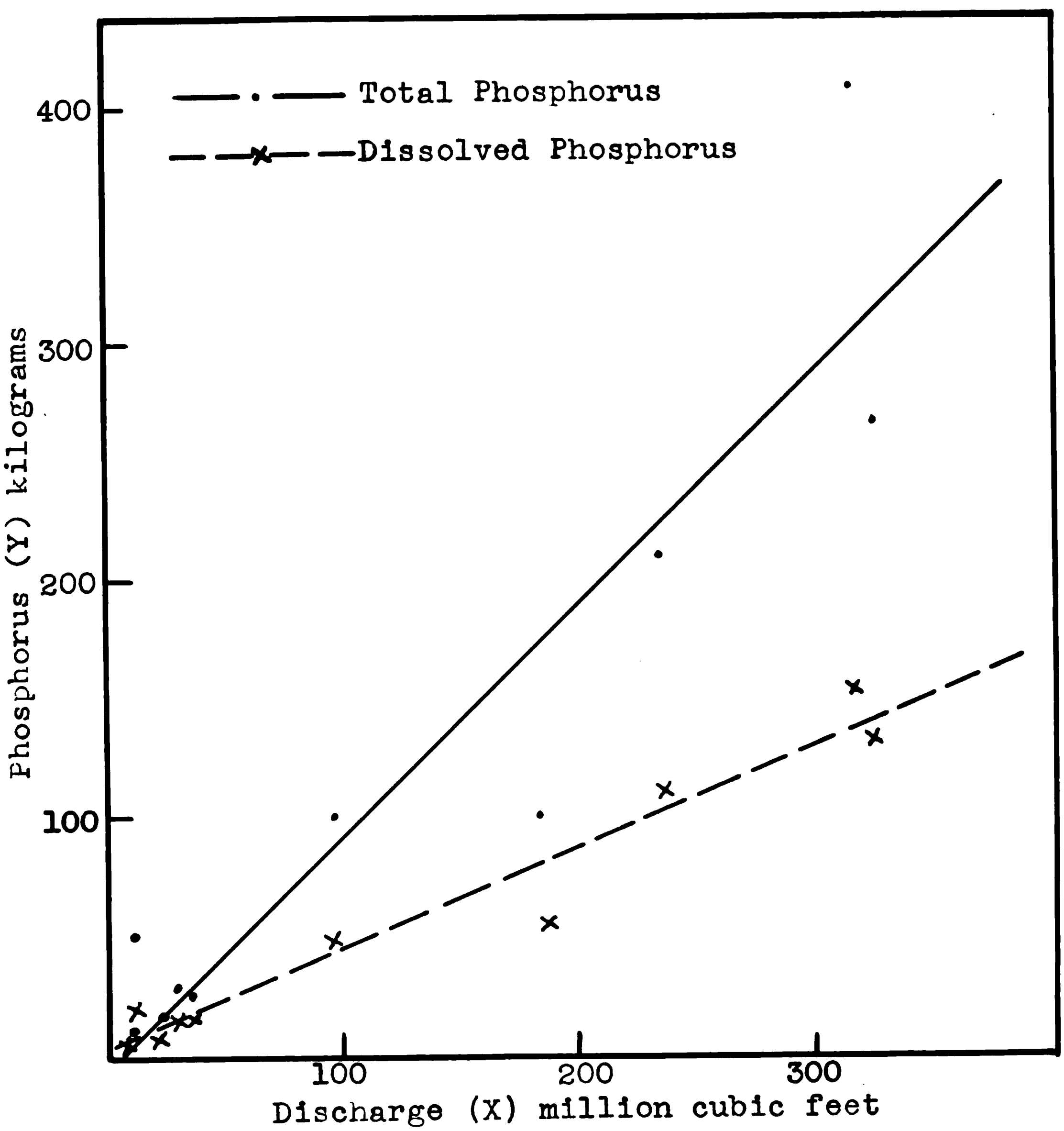

Total Phosphorus
Dissolved Phosphorus
250
200
150
100
50
Phosphorus (Y) kilograms
50
100
200
300
Discharge (X) million cubic feet

Figure 6

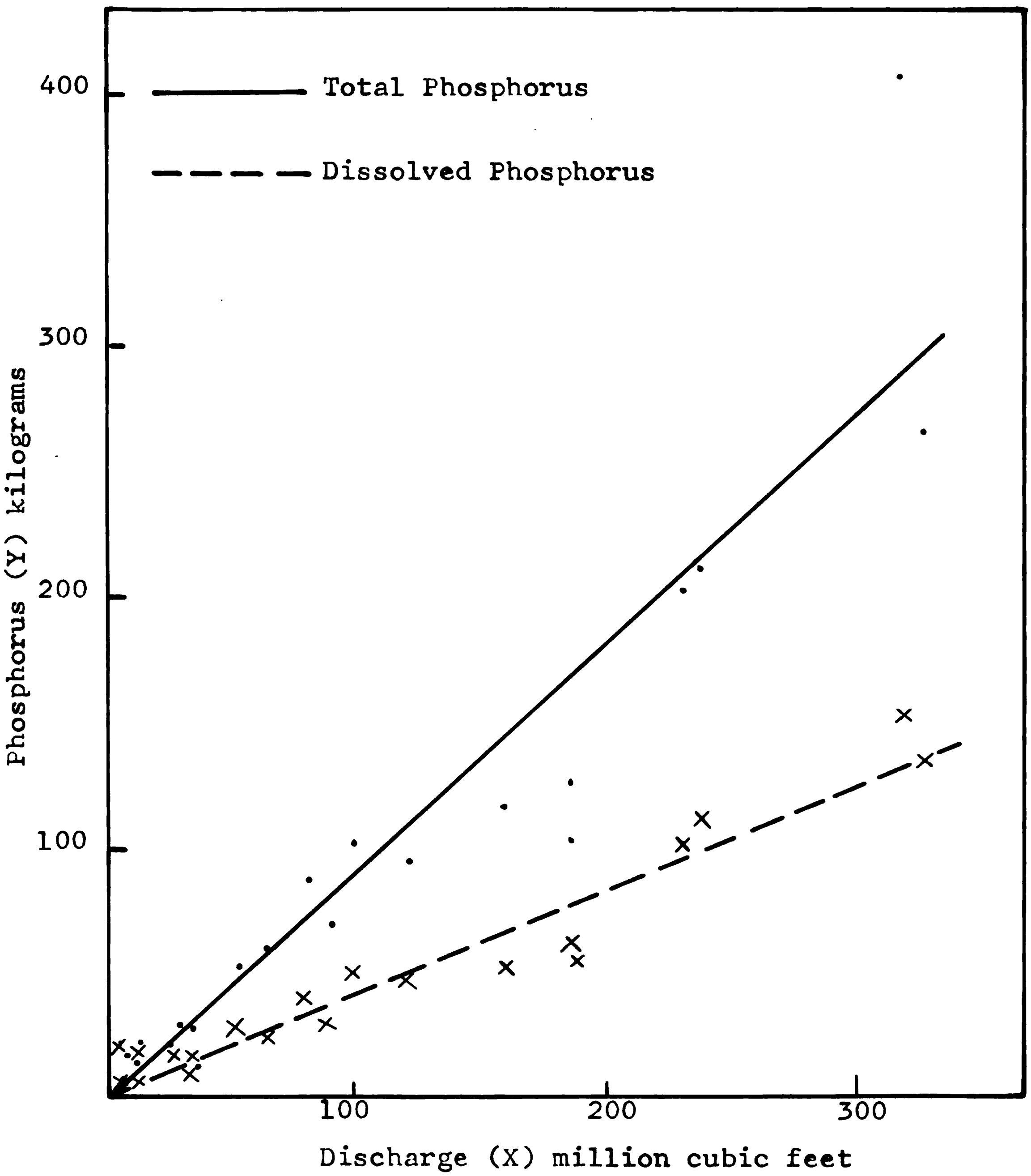
Figure 7. Relationship between phosphorus transport and stream discharge for the low water stage on ten tributaries of the Red Cedar River.



Total Phosphorus
Dissolved Phosphorus
400
300
200
100
Phosphorus (Y) kilograms
100
200
300
Discharge (X) million cubic feet

Figure 7

Figure 8. Relationship between phosphorus transport and stream discharge irrespective of the season of the year.



Total Phosphorus
Dissolved Phosphorus
400
300
200
100
Phosphorus (Y) kilograms
100
200
300
Discharge (X) million cubic feet

Figure 8

the combination of the seasonal rates. Accepting the assumption that the seasonal rates are homogeneous, then the regression formulae are:

1. Total Phosphorus $Y = -4.93 + 0.93\ X$

2. Dissolved Phosphorus $Y = 0.62 + 0.41\ X$

The combined regression formulae may be used to predict phosphorus transport (Y) from the stream discharge (X) regardless of the season of the year.

The investigation of phosphorus transport by tributary streams should not be limited entirely to the quality of the water within the stream. Phosphorus enters the streams by many processes; however the primary sources for natural streams are associated with the surface erosional processes occurring over the entire watershed and accretion through ground water. The phosphorus contributed by the ground water supply to the Red Cedar River is quite low (approximately 20 ug/L) and occurs only when the stream is lower than the water table.

Summer flow is supplied largely by ground water; excepttions being surface runoff following intense summer storms which often produce considerable runoff.

The erosional forces of surface runoff produce the large periodic pulses of phosphorus in streams. The amount of phosphorus eroded from the watershed depends upon the dominant land use, topography, hydrological properties of the soil, and duration and intensity of precipitation.

The movement of phosphorus within the watershed may be determined by computing the phosphorus transport of the stream on an annual-area basis. In this way area is reduced to a common denominator ($mi.^2$) and the erosional characteristics of each watershed are comparable.

Table 12 shows the annual phosphorus contribution as well as runoff to each tributary on an area basis. The average watershed contribution of total and dissolved phosphorus to the tributaries was 11.99 and 7.24 kilograms per square mile per year. Excluding those tributaries enriched by domestic pollution (Kalamink Creek and Lake Lansing Drain) and intermittent streams, the total and dissolved phosphorus contributions from the agricultural watersheds were 8.23 and 3.93 kilograms per square mile per year respectively.

In general, streams with the largest runoff transported the greatest amount of phosphorus. Tributaries such as Coon and Herron creeks whose watersheds are devoted primarily to dairy production yielded less phosphorus than those tributaries such as the Middle and East Branch where large areas are devoted to corn and wheat production.

<u>Red Cedar River</u>. Phosphorus levels as recorded at the eight main stream stations indicated an enrichment gradient towards downstream stations. The enrichment is a contribution of upland erosion and increased urbanization of downstream watershed areas. The greatest inflow of phosphorus occurs in the lower one-third of the river system and is associated with domestic pollution.

Table 12. Kilograms of phosphorus per square mile per year and discharge in million cubic feet per square mile per year for the tributaries of the Red Cedar River.

Tributary	Area $Mi.^2$	Phosphorus $Kg. Mi.^{-2} Yr.^{-1}$ Total	Dissolved	Discharge M. C. F. $Mi.^{-2} Yr.^{-1}$
Doan Creek	56.4	7.29	2.82	8.28
West Branch	43.8	5.14	2.68	8.52
East Branch	34.2	10.49	5.25	13.10
Deer Creek	27.4	6.21	2.81	6.75
Middle Branch	26.2	20.08	7.83	18.18
Kalamink Creek	21.0	40.65	30.42	8.44
Lake Lansing Drain	19.7	70.14	48.89	8.94
Sloan Creek	18.0	6.50	3.25	5.98
Wolf Creek	12.2	6.92	3.46	8.30
Squaw Creek	7.0	10.34	6.66	8.92
Coon Creek	6.1	4.98	2.39	9.63
Herron Creek	5.9	4.37	2.12	2.67
Small Streams	77.1	0.01	t[1]	

[1] t - trace amounts

Many workers have observed an enrichment gradient towards downstream areas (Dietz and Harmeson 1957, Slack 1955, and Curl 1959). Since phosphorus is earth bound in its cycle, the mechanisms for transporting the element are erosion, sedimentation, and biological transport. The local recycling mechanisms present in the stream are very important in limiting the down stream loss of phosphorus from excceding the upstream contributions.

Estimates of phosphorus transport were made at eight main stream stations on a seasonal, river-stage basis. The average daily phosphorus levels recorded on the Red Cedar River during the wet season are present in Figures 9 and 10 for total and dissolved phosphorus respectively. Phosphorus transport during the wet season is shown quarterly to demonstrate the diversity of phosphorus levels recorded during the high water stage. As the season progressed and discharge rates approached base flow, the composite picture of phosphorus levels became less variable as shown in the data for the final quarter of the wet season.

A general enrichment gradient (Figures 9 and 10) was observed between Station 1 (Van Buren Road) and Station 4 (0.3 miles below Williamston Dam), however, between stations 4 and 5, a distance of 0.2 miles, a negative gradient occurred during three of the four sampling quarters of the wet season. This decrease in the estimated phosphorus transport occurred even though a tributary, Deer Creek, joined the main stream midway between the two stations.

Figure 9. Average daily total phosphorus level at 8 stations on the Red Cedar River during the high water stage. Station numbers are given on the median abscissa.

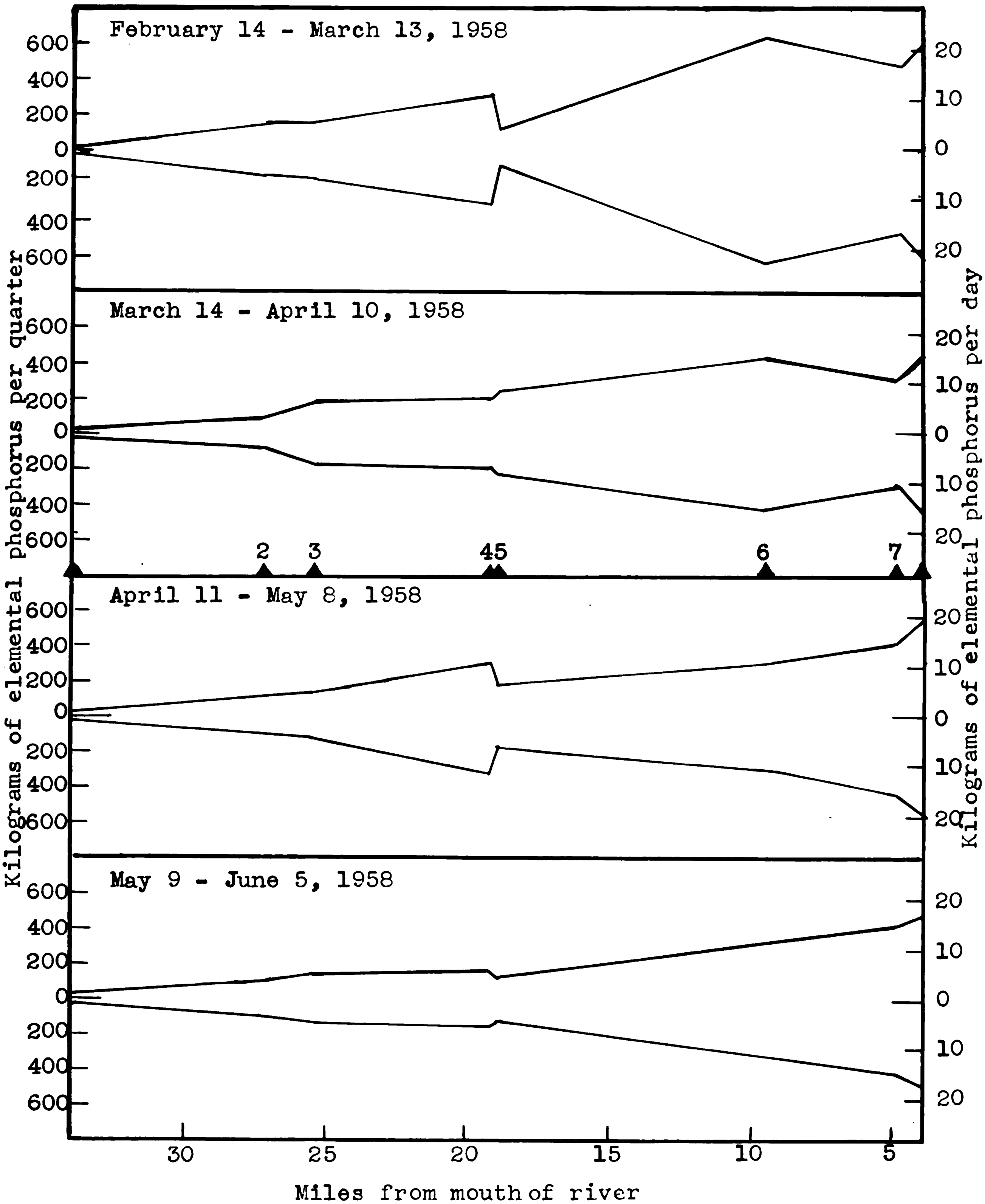
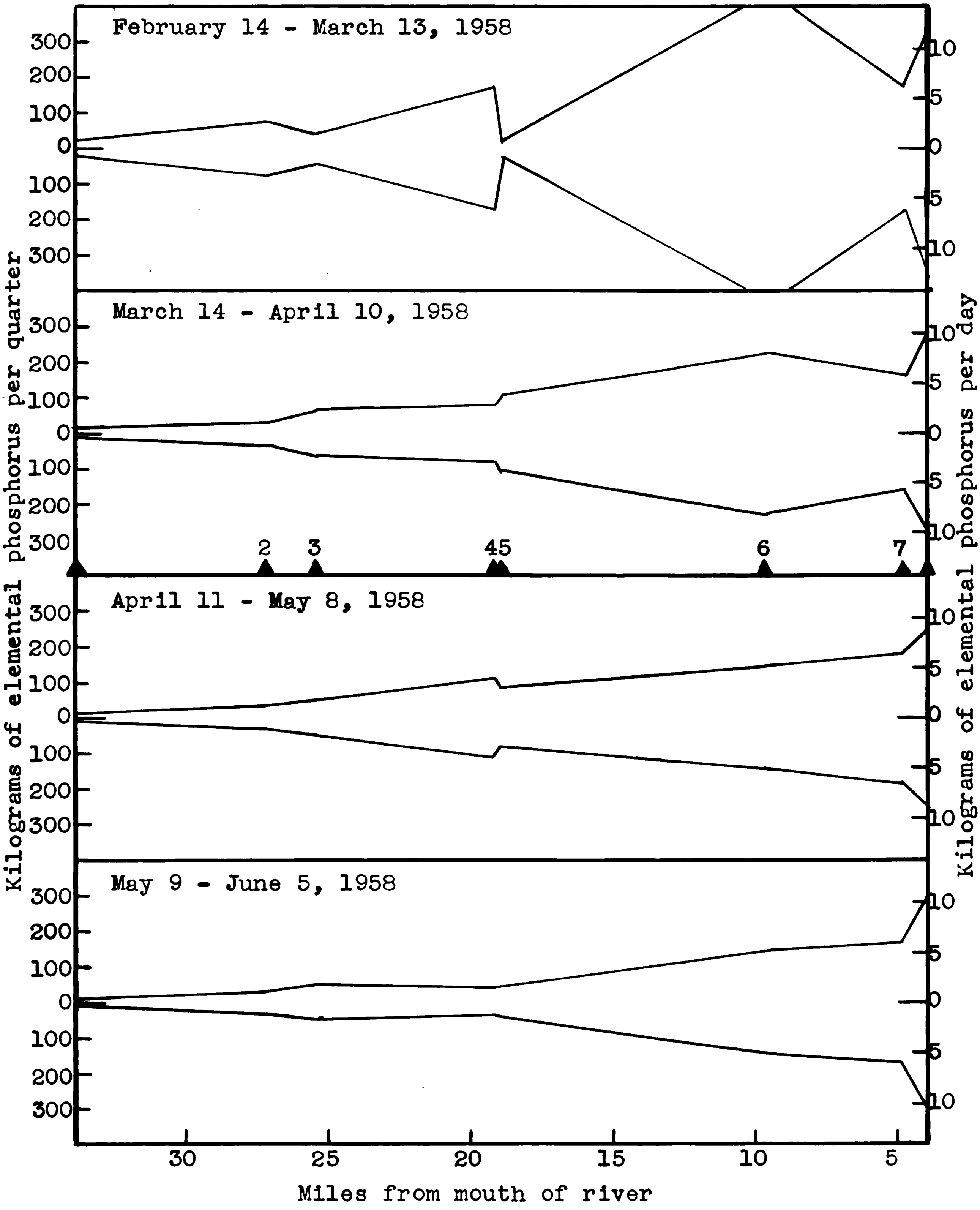

February 14 - March 13, 1958
March 14 - April 10, 1958
April 11 - May 8, 1958
May 9 - June 5, 1958
Kilograms of elemental phosphorus per quarter
Kilograms of elemental phosphorus per day
600
400
200
0
200
400
600
20
10
0
10
20
2
3
45
6
7
30
25
20
15
10
5
Miles from mouth of river

Figure 9.

Figure 10. Average daily dissolved phosphorus level at 8 stations on the Red Cedar River during the high water stage. Station numbers are given on the median abscissa.



February 14 - March 13, 1958
March 14 - April 10, 1958
April 11 - May 8, 1958
May 9 - June 5, 1958
300
200
100
0
10
5
2
3
45
6
7
Kilograms of elemental phosphorus per quarter
Kilograms of elemental phosphorus per day
30
25
20
15
10
5
Miles from mouth of river

Figure 10.

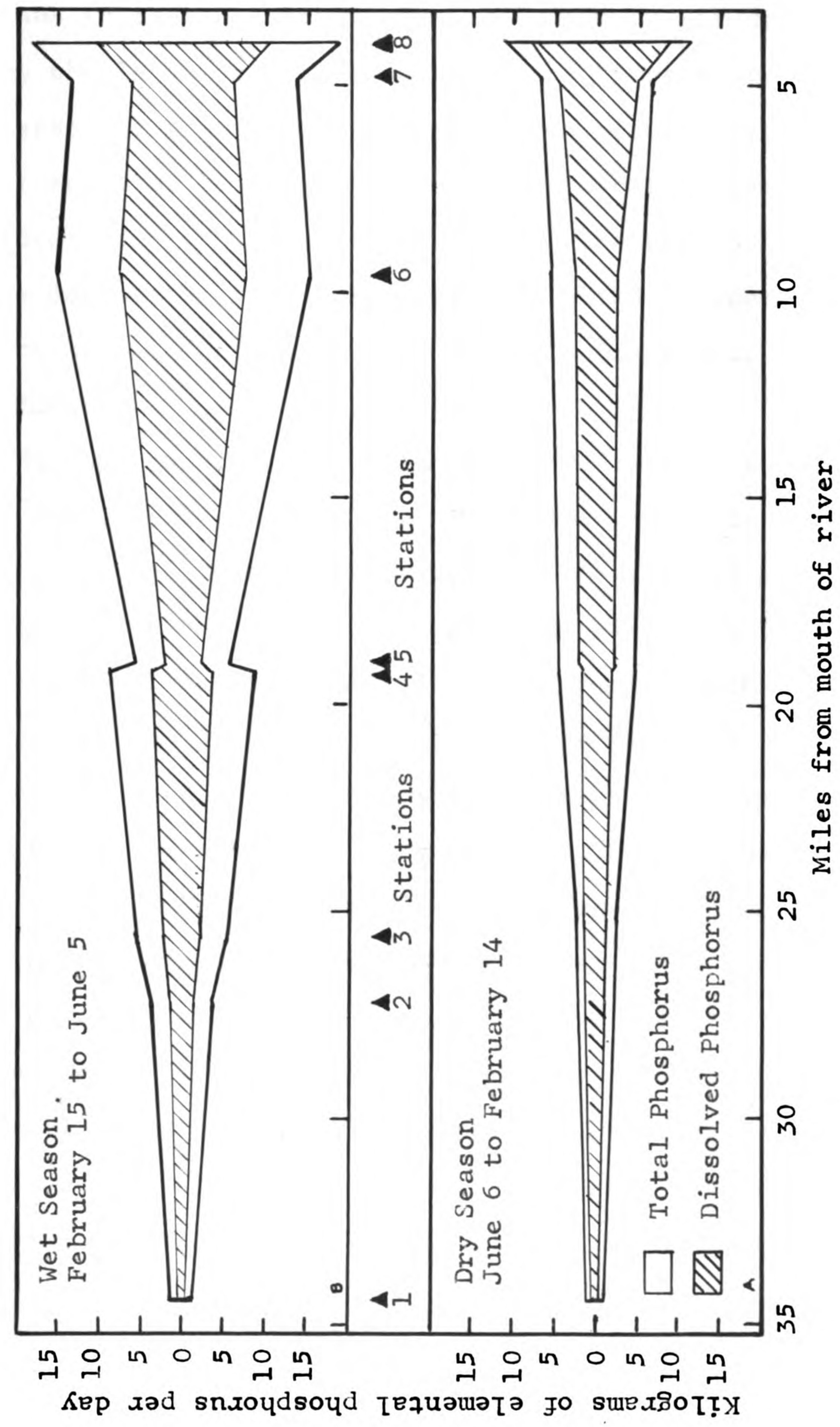
The cause of the upstream station having a phosphorus transport value greater than the downstream station was attributed to localized water turbulence as the stream passed over the Williamston dam. It was theorized that the overflow from the 13 foot dam effected a suspension of stream bottom sediments in the vicinity of the upstream station causing an increase in phosphorus. The effects of this would not be registered at the downstream station due to settling of the disturbed sediments.

The larger dissolved phosphorus values obtained at Station 4 can not be attributed to suspended solids. However, an increase in dissolved phosphorus may occur following the destruction of euplankton and other organic material with the subsequent release of phosphorus due to the hydro-mechanical forces associated with the overflow.

Approximately 300 yards downstream from Station 5, the phosphorus-rich effluent from the Williamston disposal plant enters the Red Cedar River. Its effect on the nutrient budget of the stream was recorded at Station 6 located at Dobie Road. The effluent from the disposal plant represents a major source of nutrients entering the Red Cedar River.

A composite of the average daily phosphorus transport as recorded on the main stream during the wet season is summarized and diagrammatically shown in Figure 11 and compared to the level recorded during the dry season. Maximum phosphorus movement is attained in the stream during the high water stage of the wet season. During the dry season a

Figure 11. Average daily phosphorus levels at 8 stations for the wet and dry seasons on the Red Cedar River.



Wet Season,
February 15 to June 5
Dry Season
June 6 to February 14
Stations
Stations
1
2
3
4 5
6
7
8
Total Phosphorus
Dissolved Phosphorus
Kilograms of elemental phosphorus per day
Miles from mouth of river
35
30
25
20
15
10
5

Figure 11

phosphorus gradient can be demonstrated from the upstream stations to the downstream station. However, it does not attain the level associated with the high water stage of the wet season. The increase of phosphorus between successive downstream stations is by gradual increases, unlike that recorded during the high water stage. The reduced phosphorus levels during the dry season are attributed to increased autotrophic production and perhaps more important, the reduced land runoff.

Maximum phosphorus movement occurred at the terminal study area, Farm Lane bridge. The annual estimate of 9763 kilograms of elemental phosphorus passing by this station and out of the section of stream above this point is equivalent to 130 tons of 18 percent P_2O_5 - superphosphate. This amount would be sufficient to cover approximately 3000 acres of agricultural land at a rate of 100 pounds per acre.

It is also useful to compute phosphorus accrual rates on an annual-area basis to facilitate comparison of data with that of other authors. Table 13 shows the Red Cedar River data compared with those of other midwestern streams. The Red Cedar River figure of 27.5 Kg. was calculated from the level observed at the terminal study station.

Sawyer (1947) reported that the Yahara River immediately below the outfall of Lake Mendota contained between 40 and 160 ug l^{-1} total phosphorus. Further downstream, after passing through Lake Kegonsa, the phosphorus concentration in the river ranged between 300 and 780 ug l^{-1}. On an annual-

Table 13. Comparison of phosphorus levels reported from several midwestern drainage systems.

River System	Kilograms Mile^{-2} Year^{-1} Total P	Total Dissolved P	Ortho-Phosphate PO_4-P
Red Cedar River Michigan	27.5	17.7	
Madison, Wisconsin[1] Drainage and Seepage from Agricultural and Urban Lands	72.0		
Drainage to Lake[2] Mendota, Wisconsin 1947	12.6		
1949	7.4		
Huron River[3] Michigan			6.3
Portage River[3] Ohio			13.9
Maumee River[3] Ohio			19.0
Raisin River[3] Michigan			8.8
Kaskaskia River[4] Agricultural Drainage Illinois	3.8		
Little Miami River[5] Ohio			4.9
Todd Fork[5] Ohio			4.8
Massie Creek[5] Ohio			23.3

1. Sawyer (1947) 2. Wis. Comm. on Water Pollution (1949)
3. Curl (1959) 4. Dietz and Harmeson (1958)
5. Brown (1960)

area basis the increase in the amount of phosphorus transported by Yahara River is approximately 72 Kg. per square mile per year. Sawyer (1947) concluded that the large increase was due to domestic and agricultural drainage from the Madison area.

On an annual-area basis the contribution of phosphorus from the Red Cedar River watershed is considerably below that of the Yahara River. This is attributed to the greater population density in the Madison area, and to the fact that that the data obtained for phosphorus transport in the Red Cedar River were taken during a year when stream discharges were far below the normal flow rates.

SUMMARY

1. The Red Cedar River, a warm-water stream in south central Michigan, was investigated to determine the source and level of phosphorus entering the stream from its tributaries. In addition, phosphorus transport was studied at eight stations in the 30-mile experimental section of the main stream.

2. Flow measurements were made at each tributary and main stream station in order to study phosphorus transport.

3. The stream discharge data indicated that the tributary network accounted for approximately 90 percent of the total annual volume discharge of the Red Cedar River.

4. On a seasonal basis, the tributaries supplied approximately 70 percent of the volume of discharge recorded at the terminal study area, Farm Lane, during the wet season. During the dry season, tributary volume of flow exceeded the flow at the terminal study station by approximately 15 percent.

5. Tributary discharge rates were found to be directly proportional to the size of the drainage area, and the latter parameter could be utilized to predict tributary stream flow throughout the watershed.

6. The chemical data revealed the stream to be highly buffered. Methyl orange alkalinity varied between 160 and 330 mg l^{-1}, pH values ranged between 7.5 and 8.5. Conductivity measurements ranged between 330 and 610 $uohm^{-1}$ cm^{-1}.

7. The tributaries of the Red Cedar River accounted for slightly less than 50 percent of the total amount of phosphorus passing through the Farm Lane bridge station. The annual accrual of total and dissolved phosphorus from the tributaries was 4.27 and 2.77 metric tons respectively. An estimated 9.76 metric tons of phosphorus passed through the terminal study station of the Red Cedar River during the 12 month period of February 1958 to February 1959.

8. The phosphorus accruals of Kalamink Creek and Lake Lansing Drain, both of which received considerable amounts of domestic pollution, were independent of their discharge.

9. A significant positive correlation was found between phosphorus accrual and discharge for those tributaries which drained agricultural and woodlands and were free from domestic pollution.

10. Regression equations were presented to predict tributary phosphorus accruals from discharge data.

11. Phosphorus levels were significantly reduced during the dry seasons. The summer phosphorus reduction appeared to be more closely associated with reduction in stream flow and surface runoff than with increased autotrophic production.

12. A distinct phosphorus enrichment gradient was observed from the upstream to the downstream stations. The greatest increment was observed in the lower third of the stream and was associated with domestic pollution

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APPENDIX A

Wet season sampling schedule.

Tributary Sampling Schedule

First Quarter - Wet Season

February 14 to March 13

Blocks	Days 1	2	3	4
I	Kalamink Ck. East Branch	Doan Creek Kalamink Ck.	Mile 5 Mile 2	Fourth day reserved for chemical analysis
II	Doan Creek Mile 17	Mile 19 West Branch	Mile 6 East Branch	
III	Lake Lansing Middle Branch	Middle Branch Deer Creek	West Branch Deer Creek	
IV				
V	West Branch Sloan Creek	East Branch West Branch	Squaw Creek Doan Creek	
VI	Lake Lansing Doan Creek	Wolf Creek Sloan Creek	Mile 8 Doan Creek	
VII				

Appendix A-1

Tributary Sampling Schedule

Second Quarter - Wet Season

March 14 to April 10

Blocks	Days 1	2	3	4
I	Mile 4 Kalamink Creek	Deer Creek Doan Creek	Coon Creek East Branch	Fourth day reserved for chemical analysis
II	Doan Creek West Branch	Deer Creek Mile 26	Lake Lansing Mile 15	
III	West Branch Mile 14	Sloan Creek East Branch	Doan Creek West Branch	
IV	Mile 21 Doan Creek	East Branch Doan Creek	West Branch Lake Lansing	
V				
VI				
VII	Mile 20 Kalamink Creek	Middle Branch Wolf Creek	Middle Branch Sloan Creek	

Appendix A-2

Tributary Sampling Schedule

Third Quarter - Wet Season

April 11 to May 5

Blocks	Days 1	2	3	4
I	Deer Creek West Branch	East Branch Middle Branch	Deer Creek Mile 18	Fourth day reserved for chemical analysis
II	Squaw Creek Lake Lansing	West Branch Wolf Creek	Lake Lansing Doan Creek	
III	West Branch East Branch	Doan Creek East Branch	Doan Creek West Branch	
IV	Mile 16 Doan Creek	Kalamink Ck. Mile 11	Mile 7 Herron Creek	
V				
VI	Mile 3 Sloan Creek	Doan Creek Kalamink Creek	Mile 10 Middle Branch	
VII				

Appendix A-3

Tributary Sampling Schedule

Fourth Quarter - Wet Season

May 6 to June 5

Blocks	Days 1	2	3	4
I	Deer Creek Lake Lansing	East Branch Mile 22	Doan Creek East Branch	Fourth day reserved for chemical analysis
II	Sloan Creek Doan Creek	Mile 23 Deer Creek	West Branch East Branch	
III	Doan Creek West Branch	Middle Branch Deer Creek	Doan Creek Middle Branch	
IV	Wolf Creek Kalamink Ck.	Mile 25 Mile 13	West Branch Mile 9	
V	Mile 24 Herron Creek	Mile 1 Coon Creek	Middle Branch Mile 12	
VI				
VII				

Appendix A-4

APPENDIX B

Dry season sampling schedule.

Tributary Sampling Schedule

Dry Season

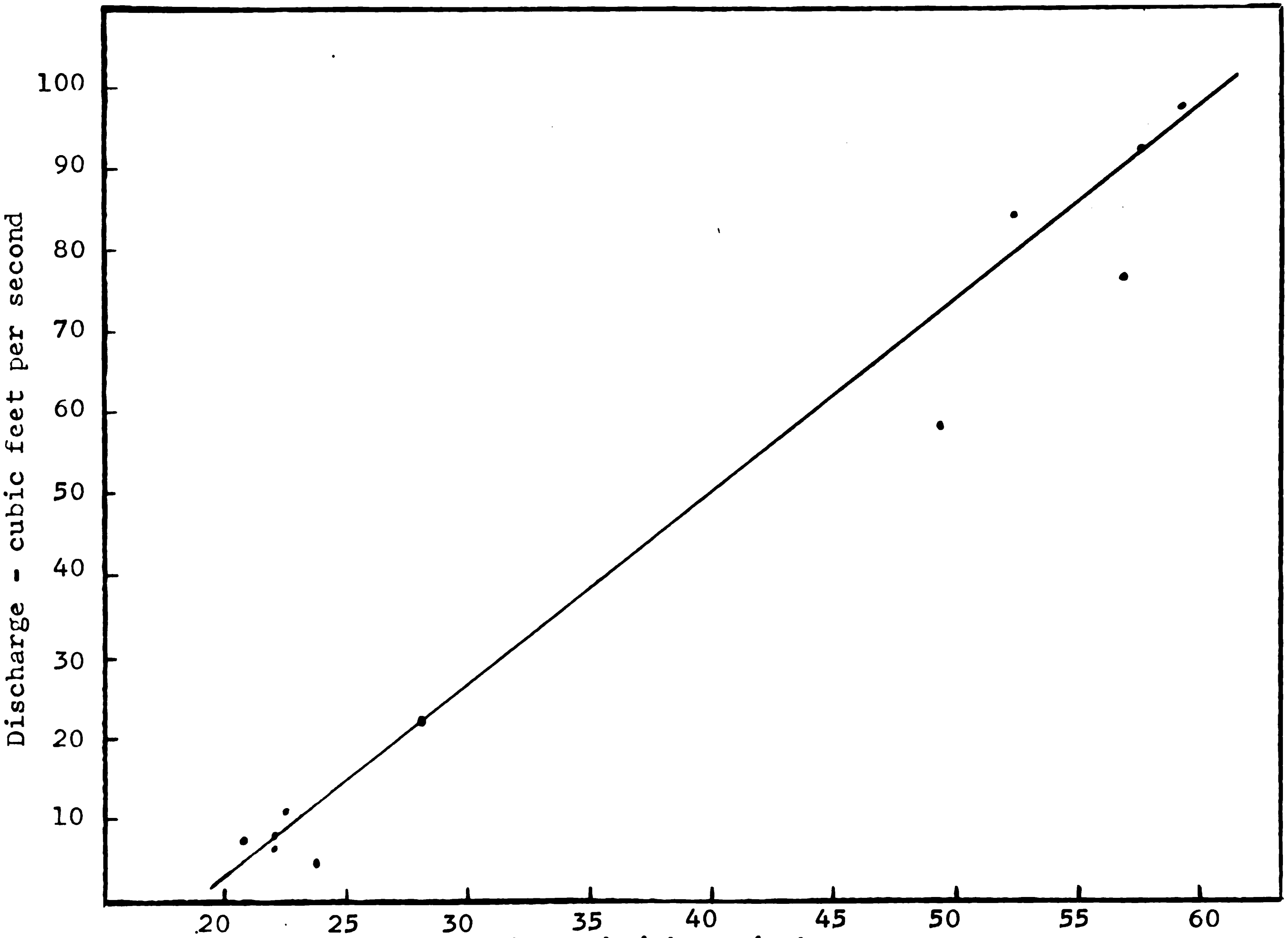
June 6 to February 13

Days	Quarters I	II	III	IV
1	Doan Creek Middle Branch	Doan Creek Kalamink Ck.	West Branch Deer Creek	Doan Creek West Branch
2	Mile 21 East Branch	Middle Branch Deer Creek	Doan Creek Kalamink Ck.	Middle Branch East Branch
3	Doan Creek Deer Creek	East Branch Doan Creek	West Branch Herron Creek	Kalamink Ck. Doan Creek
4	Sloan Creek West Branch	West Branch Lake Lansing	East Branch Doan Creek	Sloan Creek Wolf Creek
5	Deer Creek Kalamink Ck.	East Branch Doan Creek	Lake Lansing Sloan Creek	Lake Lansing East Branch
6	West Branch Coon Creek	Wolf Creek Squaw Creek	Middle Branch Mile 23	Doan Creek Deer Creek

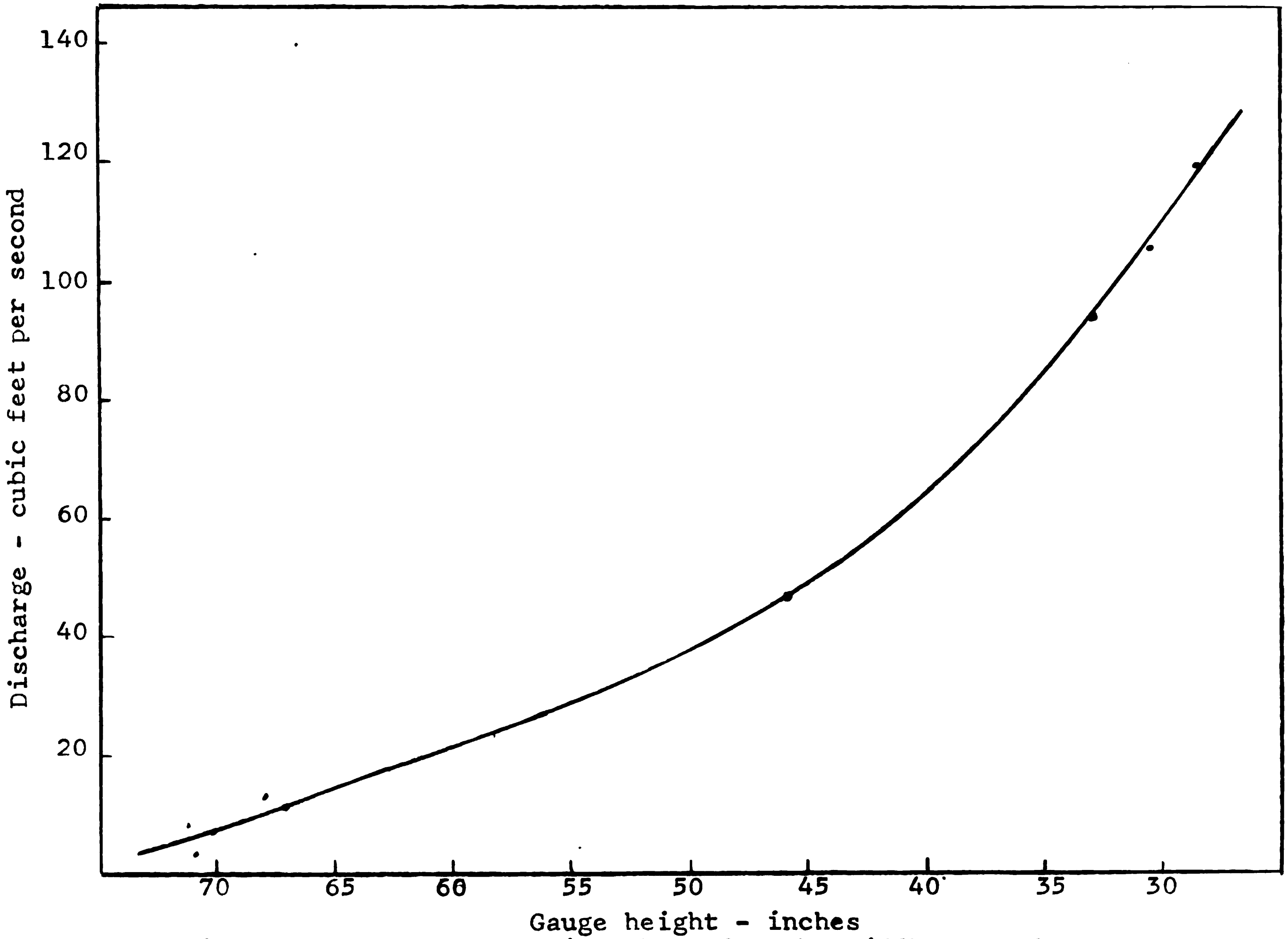
Appendix B-1

APPENDIX C

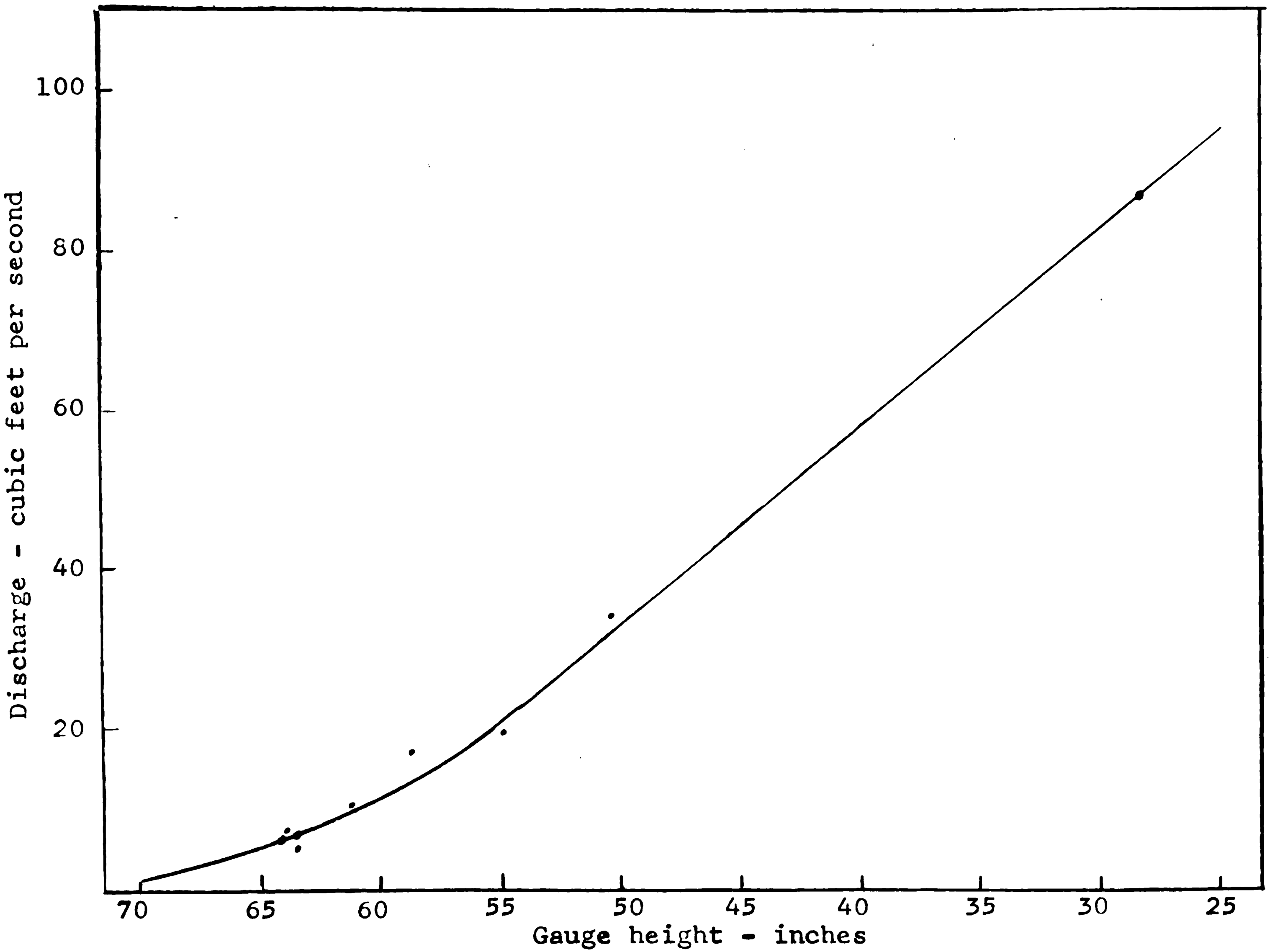
Hydrographs for the stations on the tributaries and the Red Cedar River.



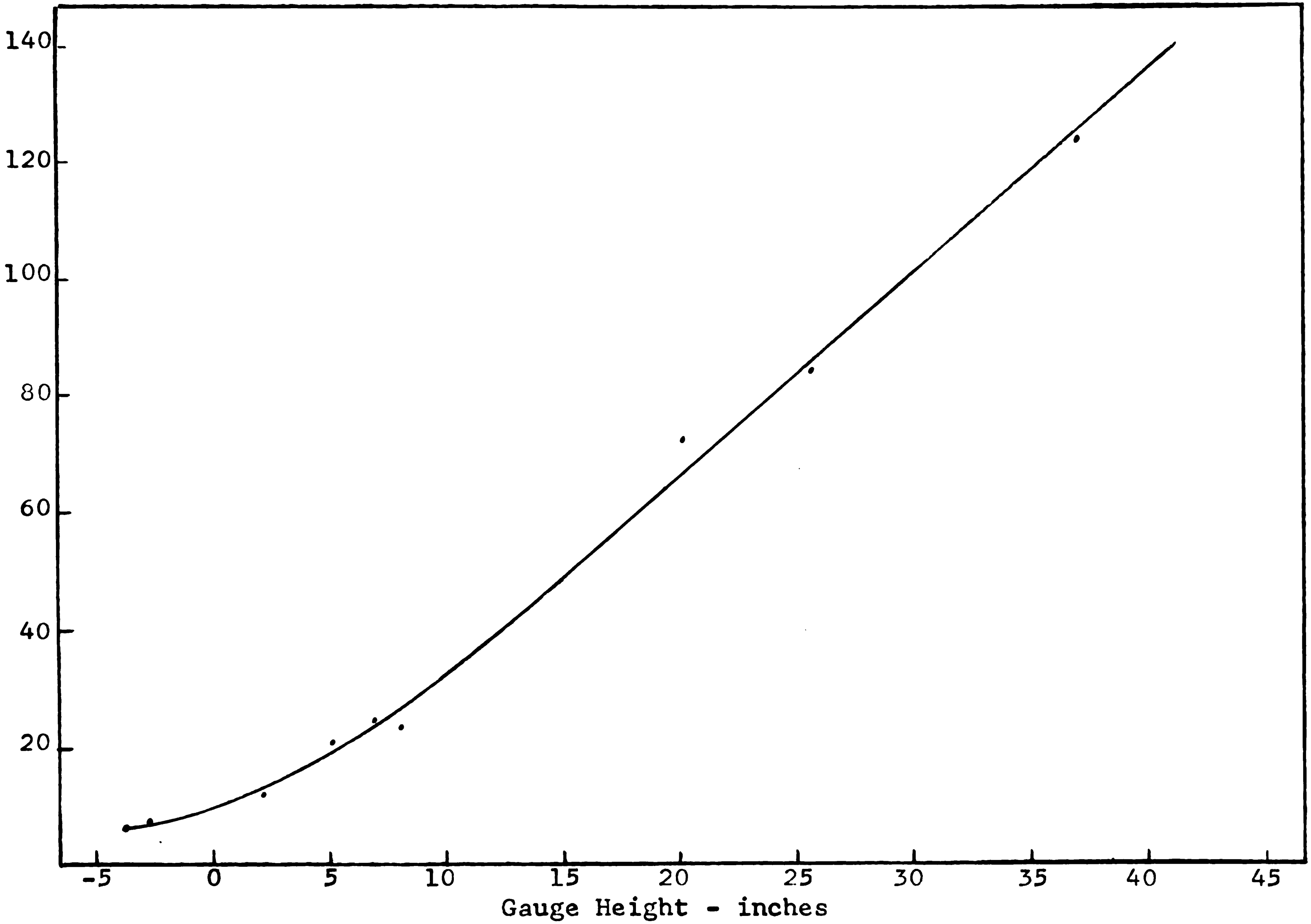
Appendix C-1. Hydrograph rating chart for the East Branch.



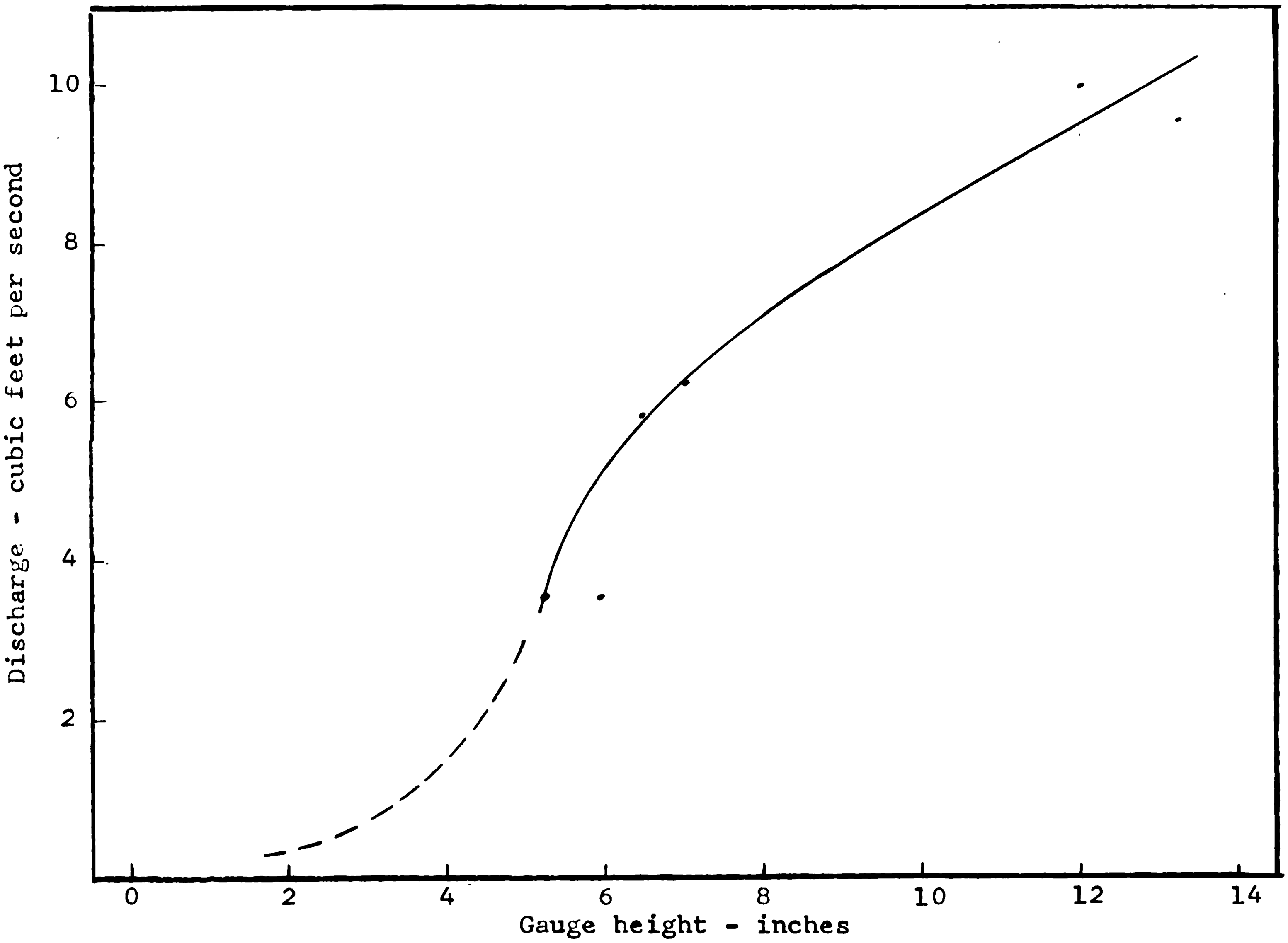
Appendix C-2. Hydrograph rating chart for the Middle Branch



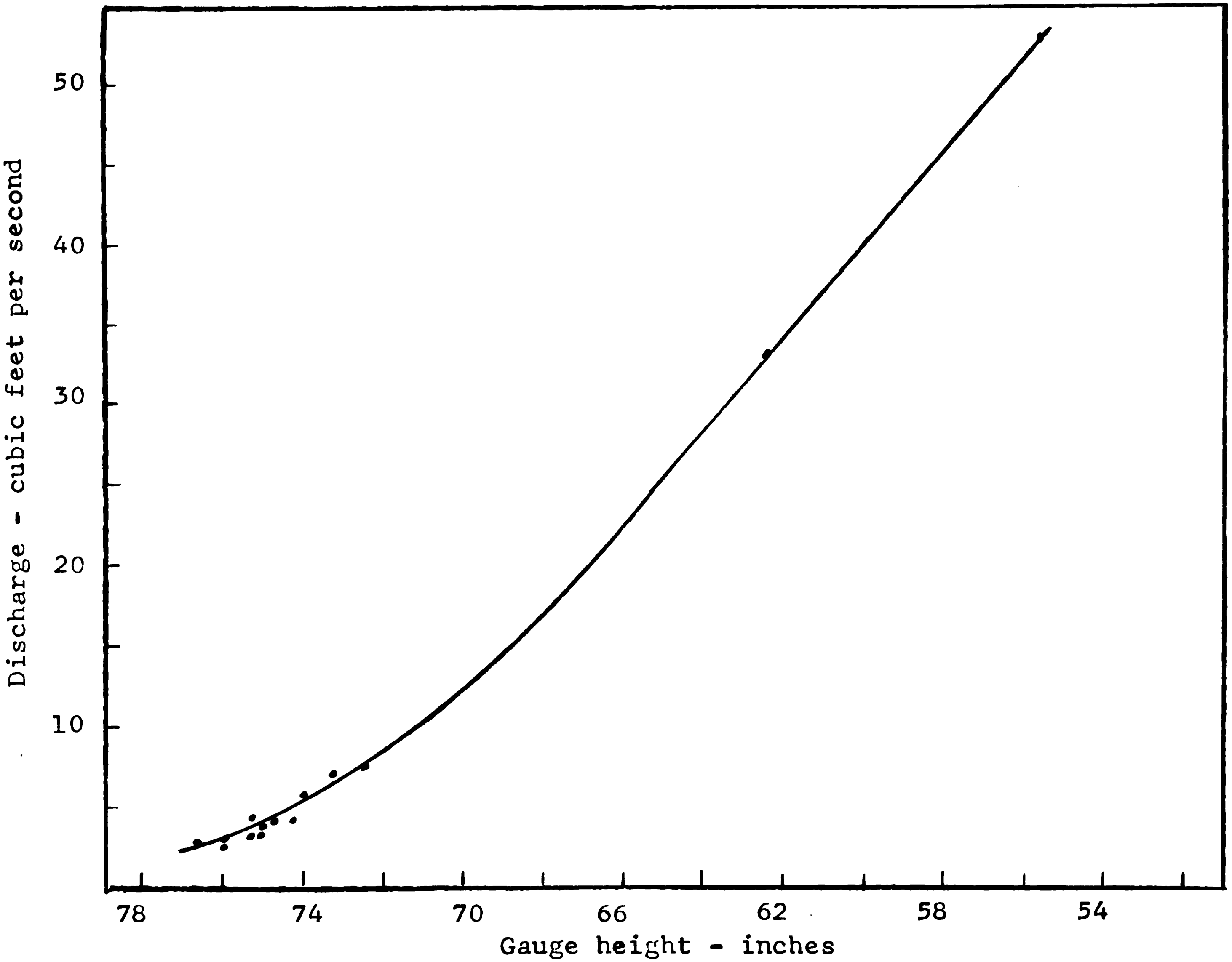
Appendix C-3. Hydrograph rating chart for the West Branch.



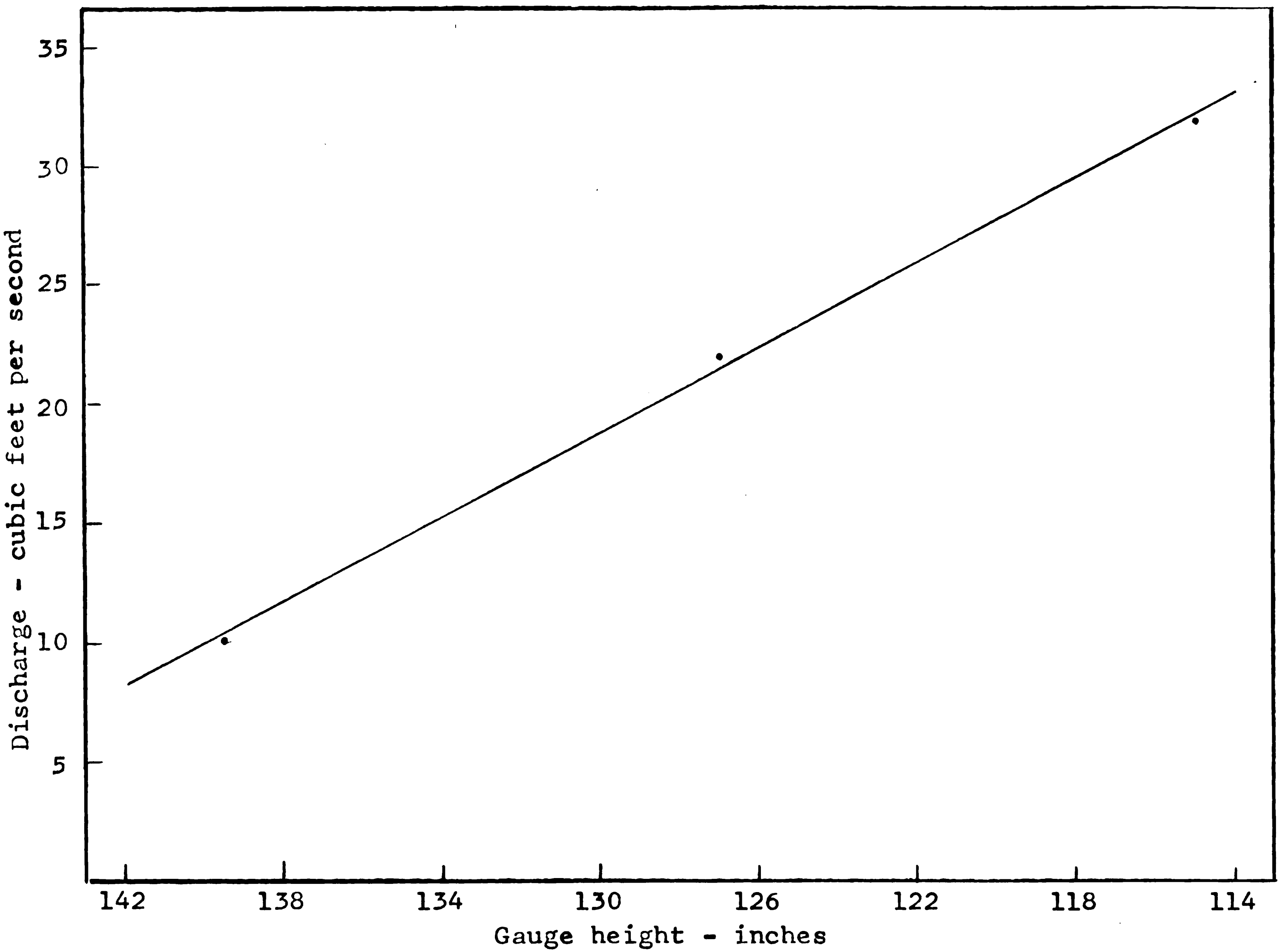
Appendix C-4. Hydrograph rating chart for Doan Creek.



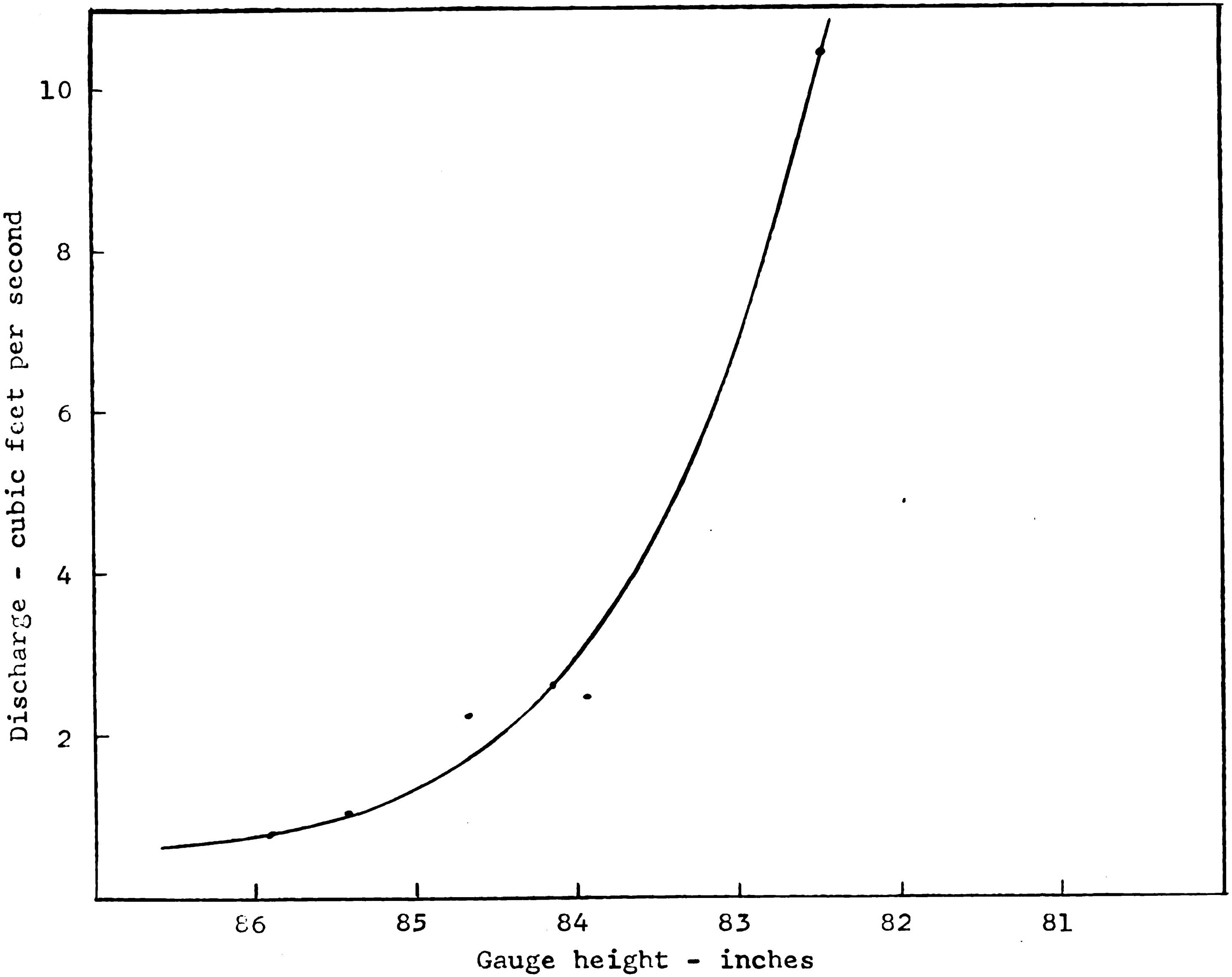
Appendix C-5. Hydrograph rating chart for Deer Creek



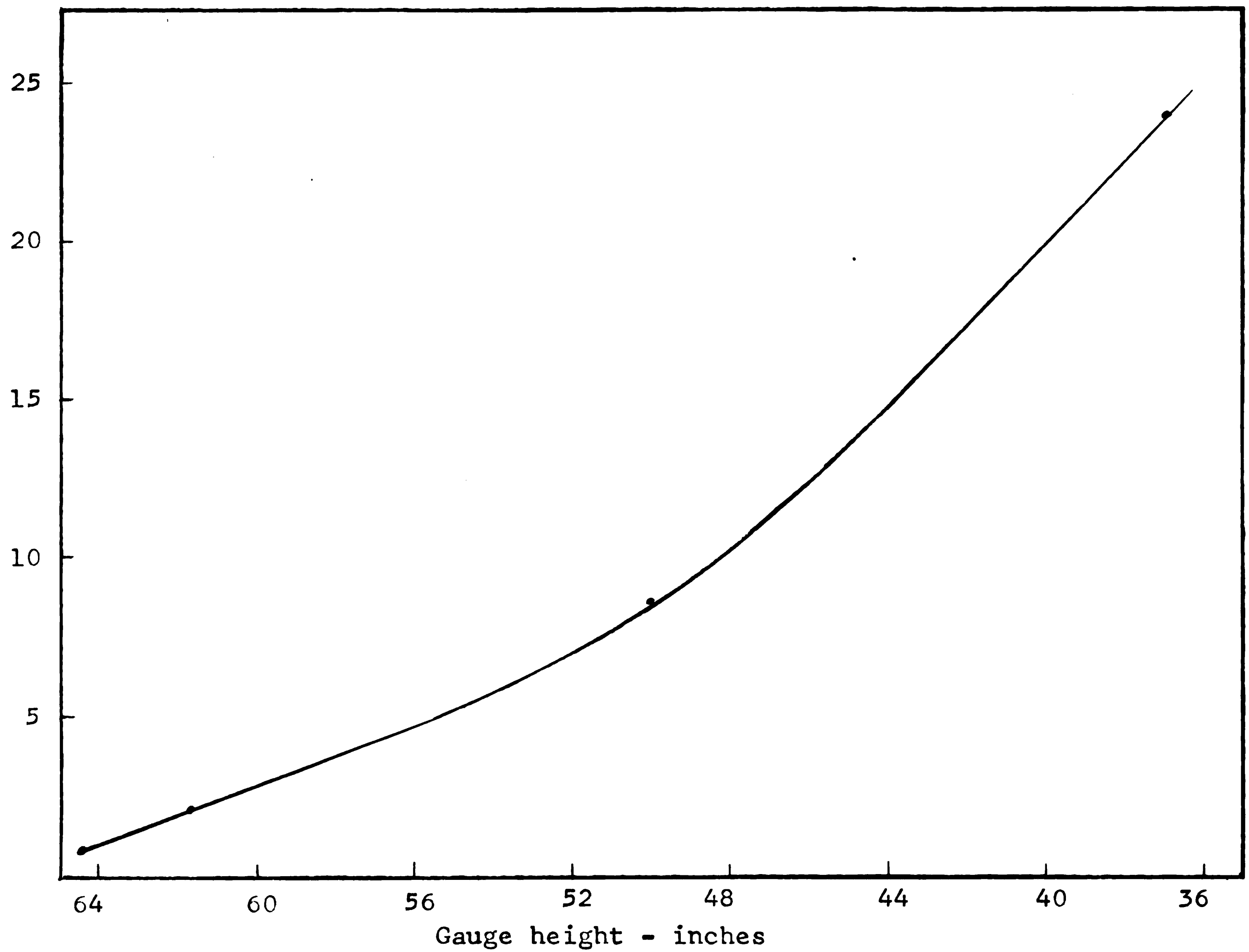
Appendix C-6. Hydrograph rating chart for Kalamink Creek.



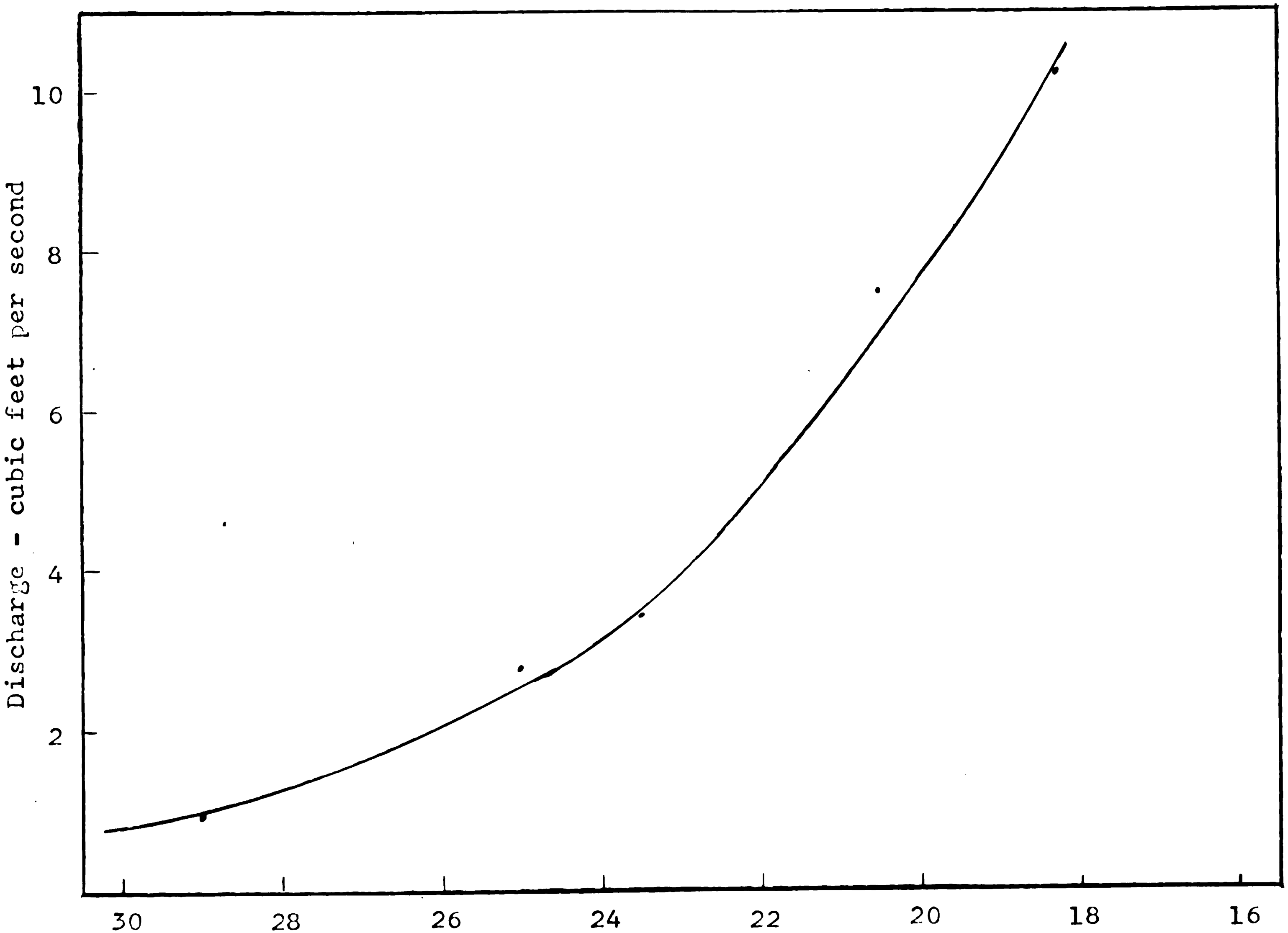
Appendix C-7. Hydrograph rating chart for Lake Lansing Drain.



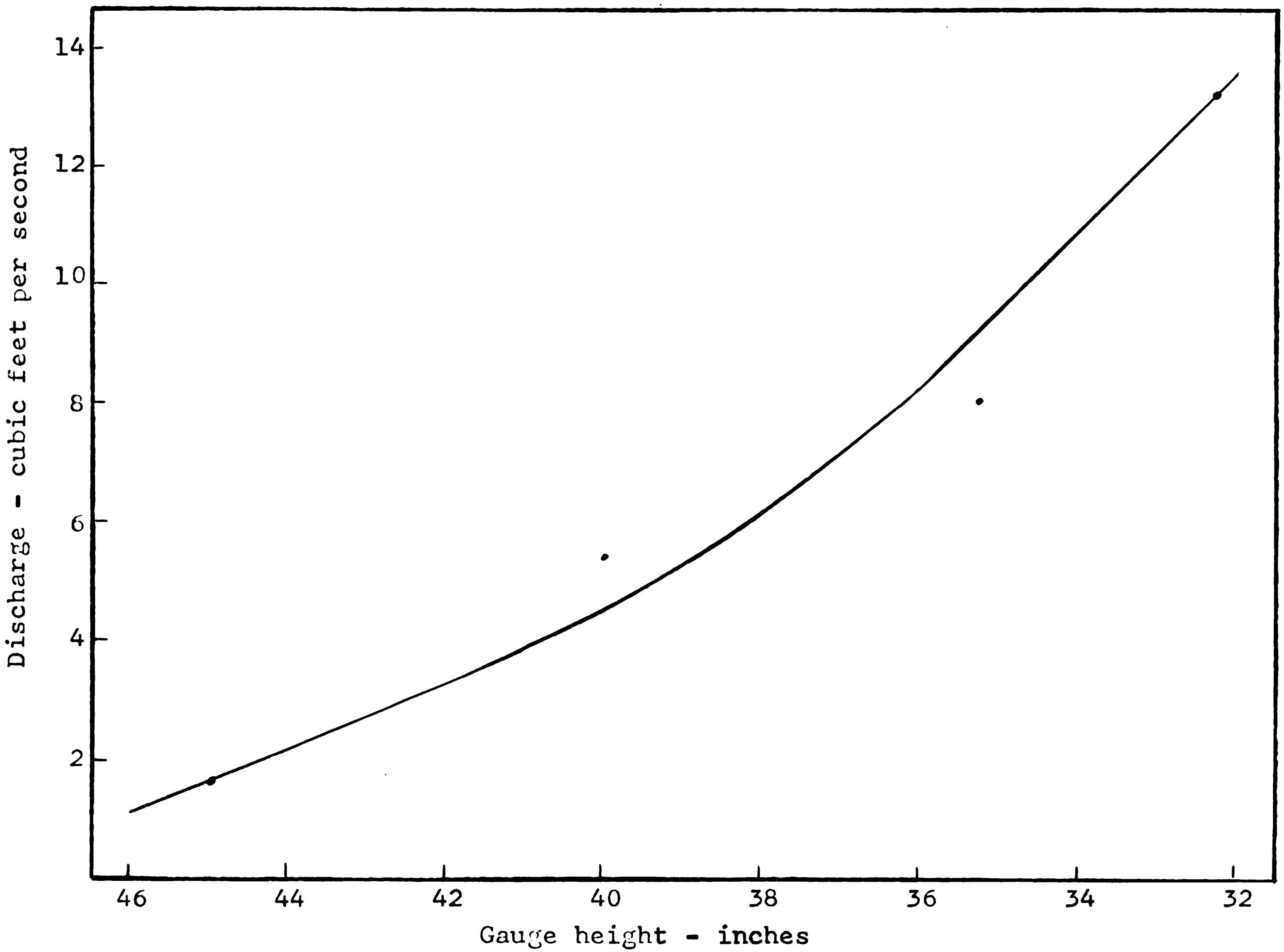
Appendix C-8. Hydrograph rating chart for Sloan Creek.



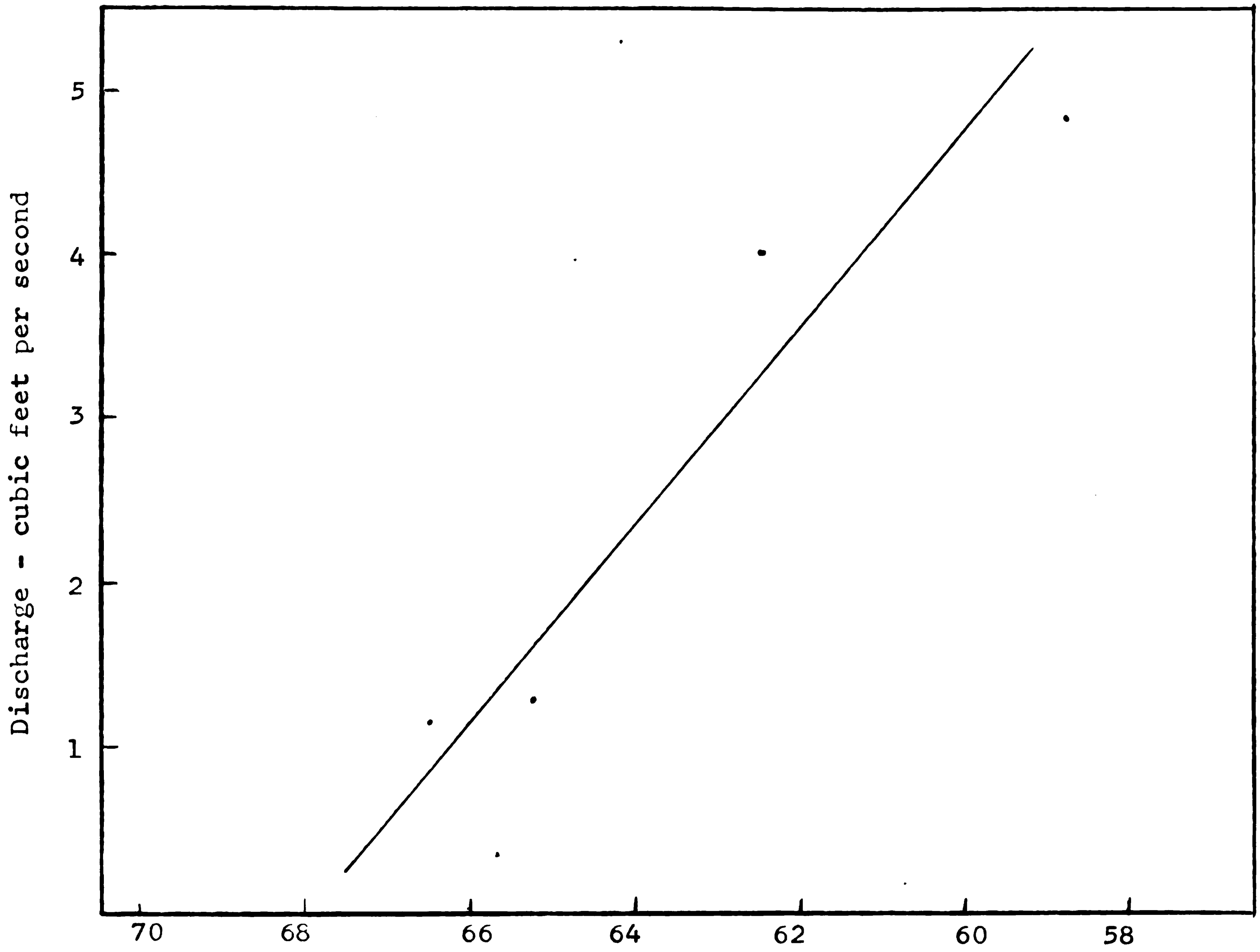
Appendix C-9. Hydrograph rating chart for Squaw Creek.



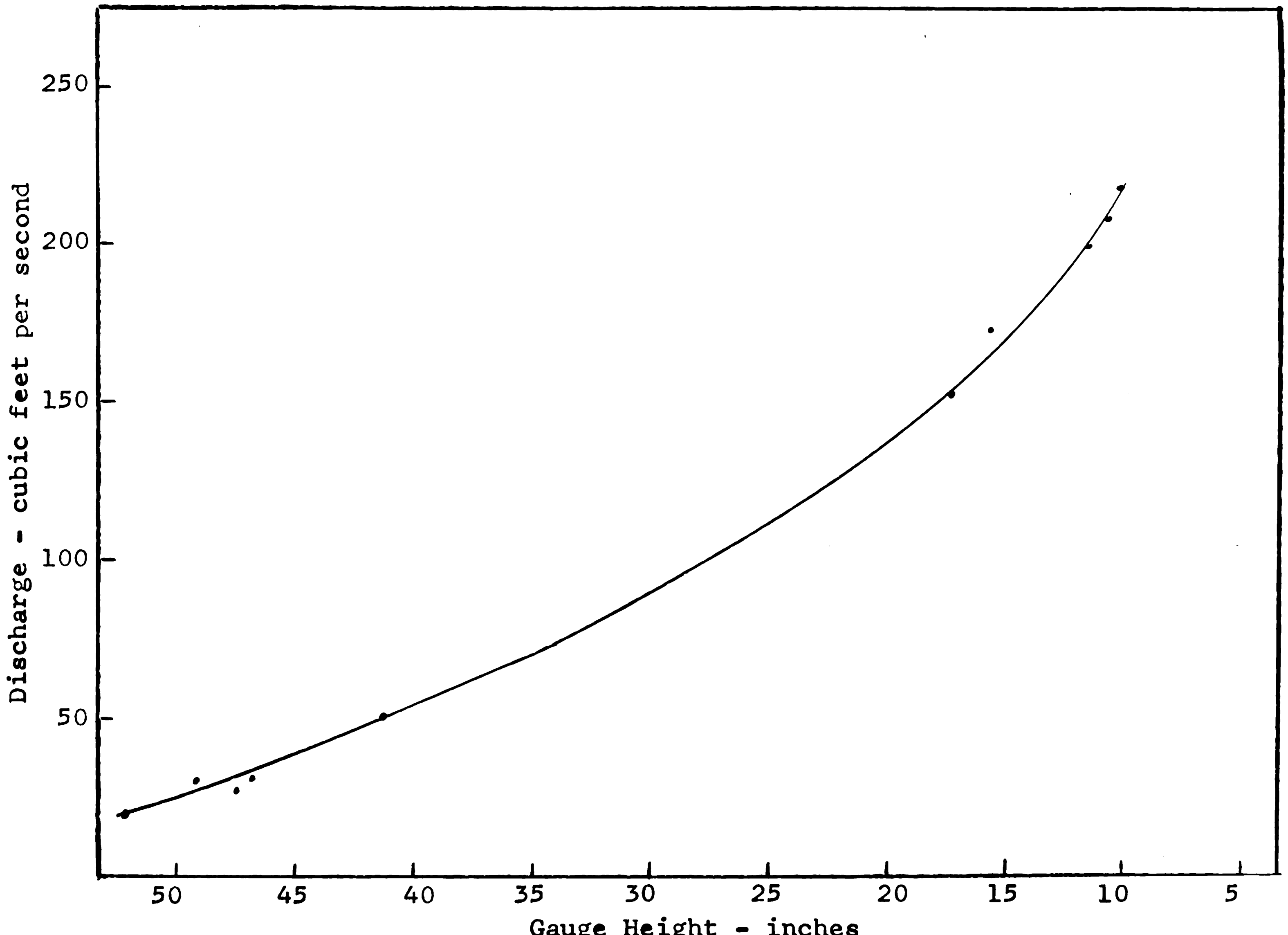
Appendix C-10. Hydrograph rating chart for Herron Creek.



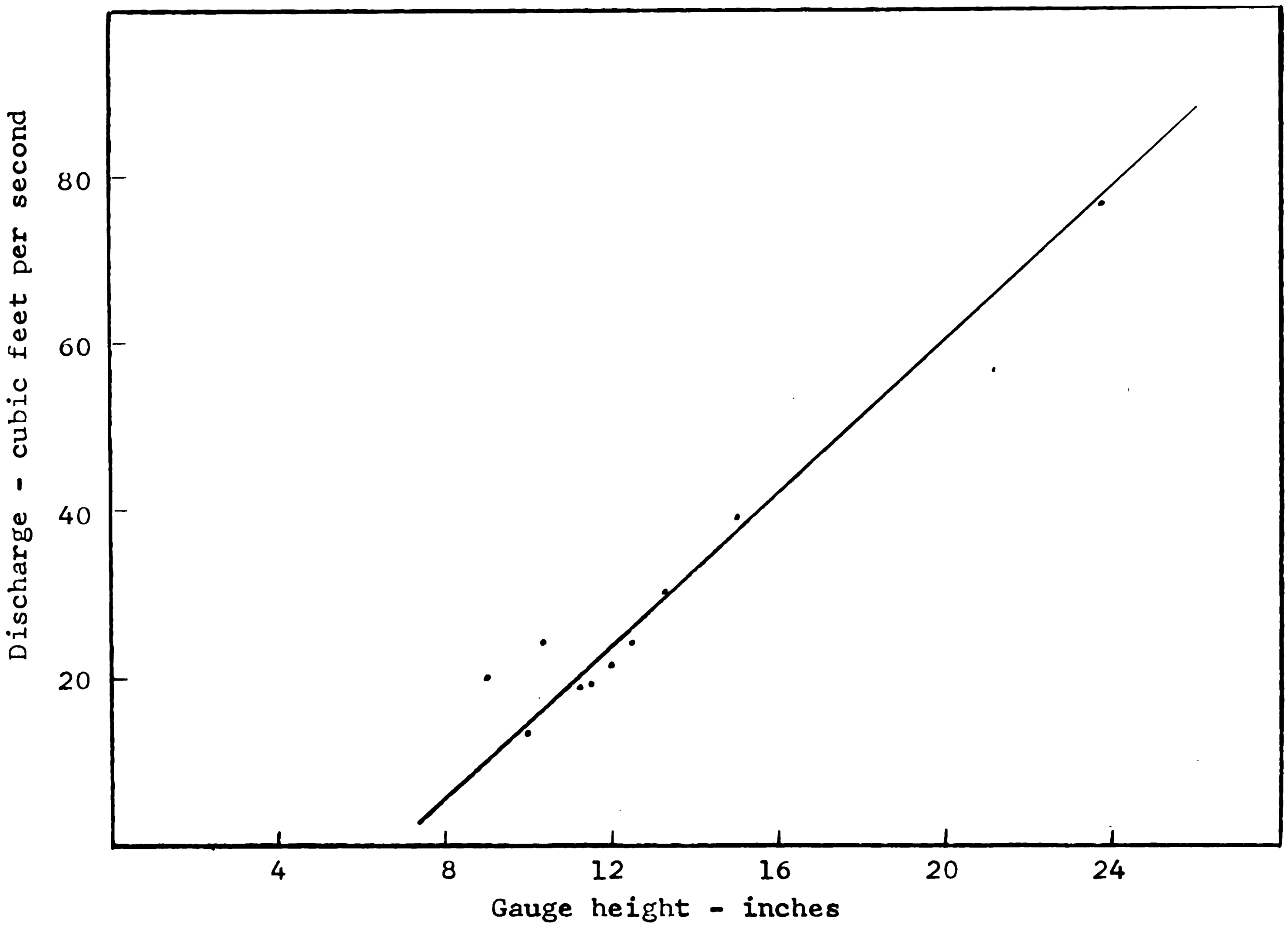
Appendix C-11. Hydrograph rating chart for Coon Creek.



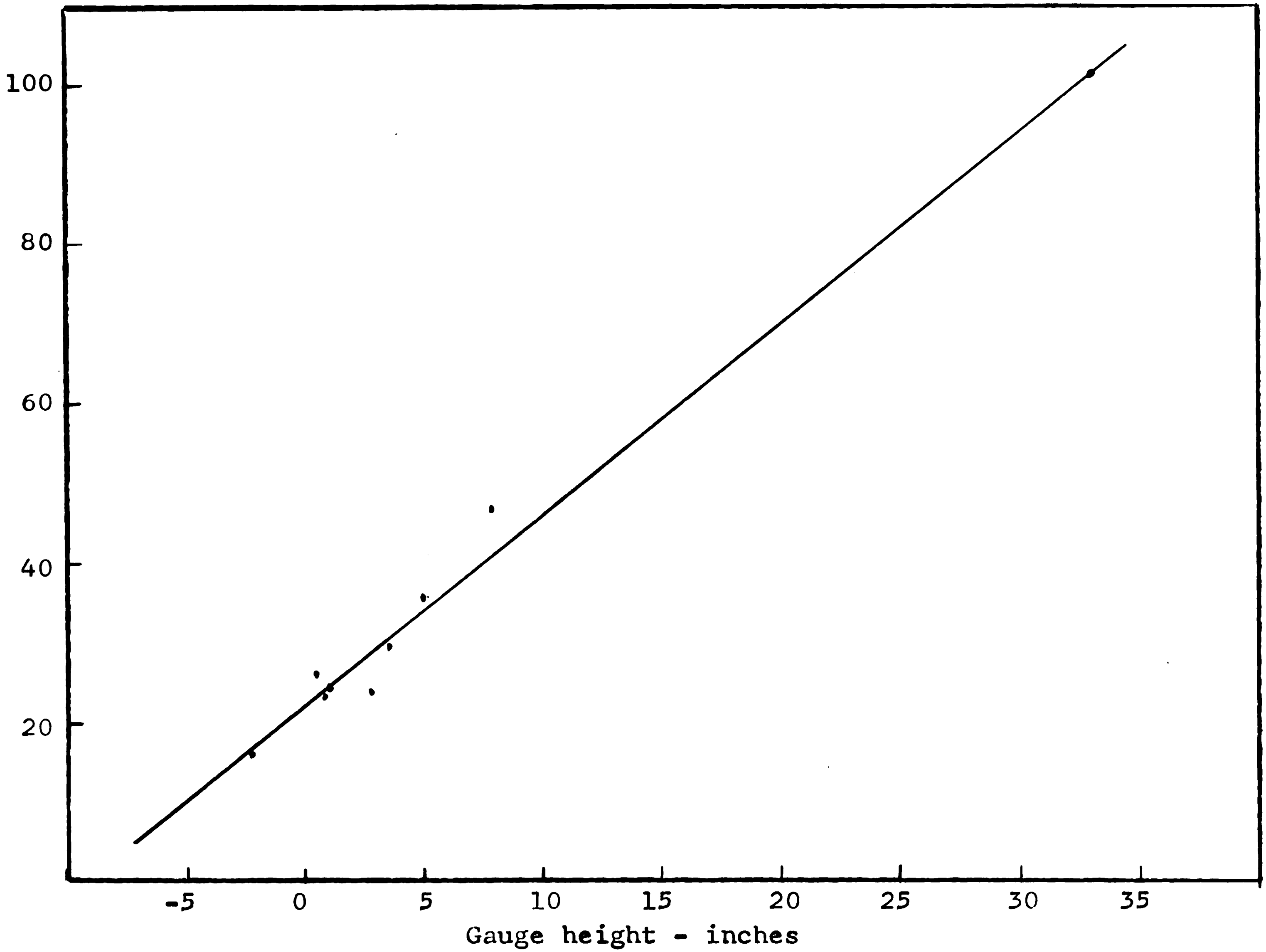
Appendix C-12. Hydrograph rating chart for Wolf Creek.



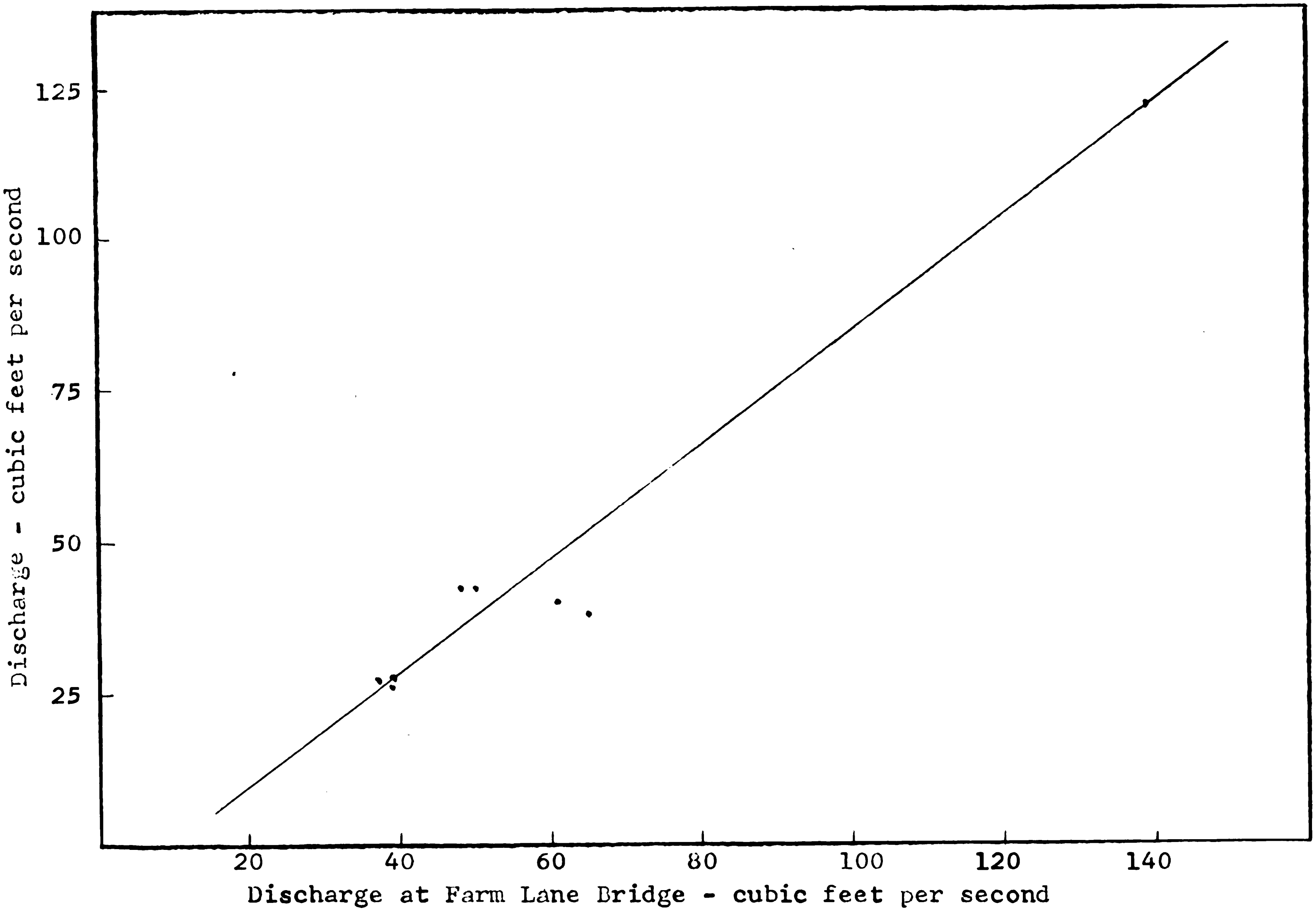
Appendix C-13. Hydrograph rating chart for Van Buren Road station.



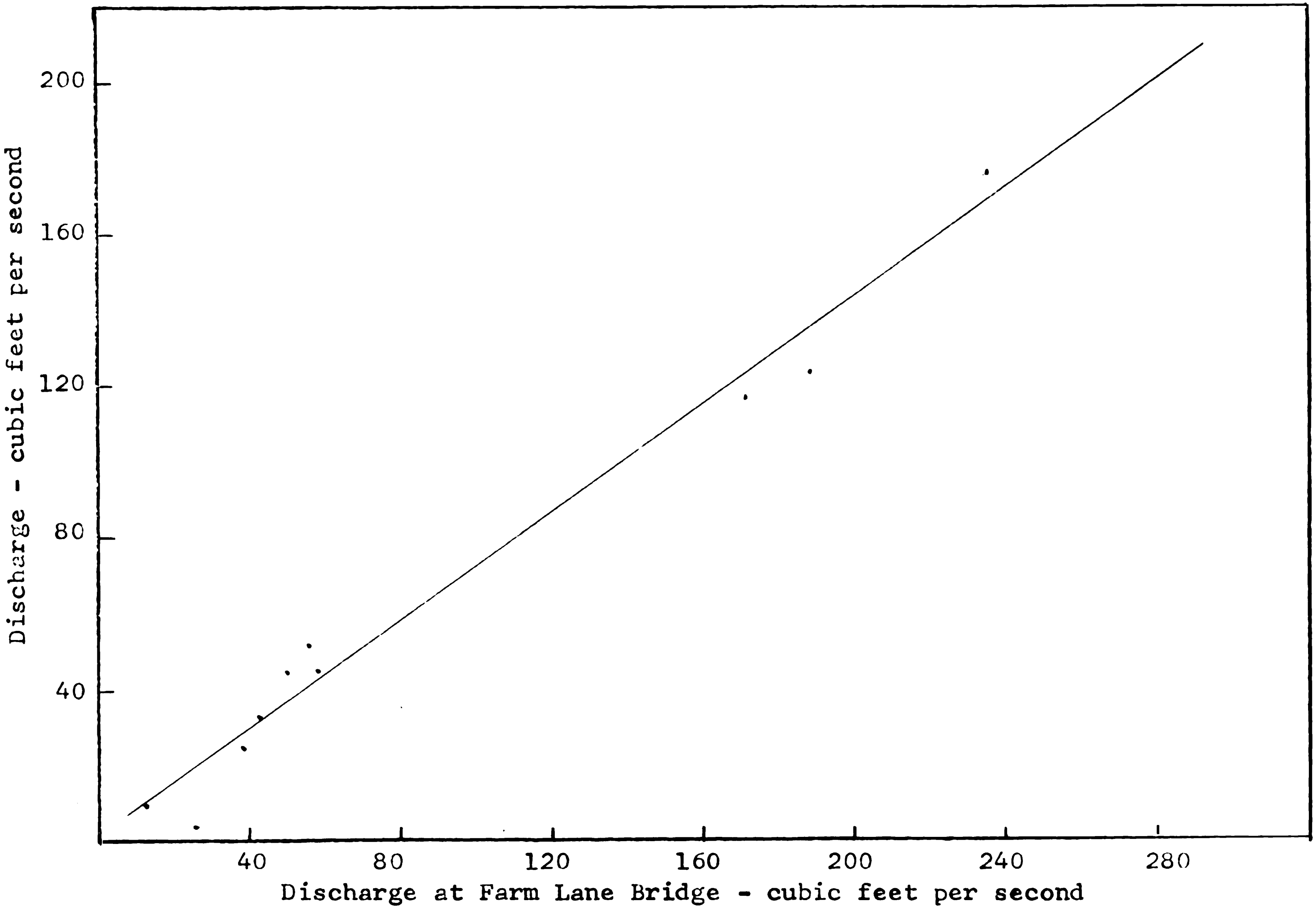
Appendix C-14. Hydrograph rating chart for Gramer Road station.



Appendix C-15. Hydrograph rating chart for Webberville Road Station.



Appendix C-16. Hydrograph rating chart for the Dobie Road Station.



Appendix C-17. Hydrograph rating chart for Williamston Reservoir Station.

APPENDIX D

The chemical and physical data collected on the tributaries and the Red Cedar River during the study period.

Phosphorus concentrations for the tributaries of the Red Cedar River. February 1958 to February 1959.

Wet Season			Dry Season		
	Phosphorus (ug/l)			Phosphorus (ug/l)	
Date	Dissolved	Total	Date	Dissolved	Total
Doan Creek:					
2-15-58	12	23	6-9-58	21	72
2-18-58	8	19	7-2-58	19	46
3-4-58	17	44	8-15-58	28	43
3-6-58	38[1]	39	8-28-58	13	21
3-8-58	14	39	9-22-58	12	19
3-15-58	6	27	10-27-58	9	14
3-18-58	9	24	11-7-58	11	19
3-24-58	12	21	12-16-58	6	12
3-26-58	8	19	1-6-59	21	34
3-27-58	7	20	1-19-59	13	24
4-17-58	10	25			
4-20-58	17	26			
4-21-58	12	25			
4-23-58	18	26			
5-2-58	17	22			
5-11-58	10	24			
5-13-58	9	29			
5-15-58	15	38			
5-19-58	10	37			
West Branch					
2-19-58	8	15	7-15-58	19	34
2-24-58	10	14	8-1-58	14	31
3-2-58	13	25	9-9-58	15	29
3-3-58	14	33	10-24-58	10	17
3-18-58	10	14	10-31-58	6	14
3-22-58	10	17	12-16-58	5	9
3-24-58	10	20			
3-28-58	8	17			
4-11-58	12	19			
4-16-58	10	27			
4-19-58	9	26			
4-21-58	18	26			
5-15-58	8	41			
5-17-58	11	43			
5-23-58	14	28			

1- water sample probably not filtered

Wet Season			Dry Season		
	Phosphorus (ug/l)			Phoaphorus (ug/l)	
Date	Dissolved	Total	Date	Dissolved	Total
East Branch:					
2-14-58	9	21	6-11-58	25	51
2-20-58	9	19	8-28-58	14	27
3-3-58	16	31	9-22-58	12	23
3-16-58	7	21	11-7-58	14	31
3-23-58	9	22	12-26-58	8	17
3-27-58	13	24	1-13-59	14	25
4-12-58	16	23			
4-19-58	11	32			
4-20-58	24	48			
5-10-58	17	37			
5-11-58	15	42			
5-15-58	12	40			
Deer Creek:					
2-23-58	5	19	7-2-58	26	52
2-24-58	10	29	7-23-58	18	38
3-15-58	9	31	8-23-58	22	38
3-19-58	8	23	10-24-58	10	39
4-11-58	11	-	1-19-59	18	28
4-13-58	16	30			
5-9-58	13	24			
5-14-58	11	32			
5-18-58	16	46			
Middle Branch:					
2-22-58	3	14	6-9-58	17	98
2-23-58	5	14	8-23-58	27	46
4-8-58	13	28	11-26-58	16	43
4-9-58	14	25	12-26-58	9	25
4-12-58	14	23			
5-3-58	21	31			
5-18-58	18	84			
5-19-58	22	74			
5-27-58	19	66			
Kalamink Creek:					
2-14-58	48	81	7-23-58	173	211
2-15-58	254	279	8-15-58	147	175
3-14-58	53	78	10-27-58	239	250
4-7-58	64	121	1-6-59	105	175
4-24-58	23	79			
5-2-58	25	91			
5-21-58	100	141			

Wet Season			Dry Season		
	Phosphorus (ug/l)			Phosphorus (ug/l)	
Date	Dissolved	Total	Date	Dissolved	Total
Lake Lansing Drain:					
2-22-58	229	261	9-9-58	914	1129
3-6-58	41	46	11-19-58	636	758
3-20-58	98	143	1-13-59	757	929
3-28-58	179	143			
4-15-58	147	240			
4-17-58	144	255			
5-9-58	227	425			
Sloan Creek:					
3-2-58	19	43	7-15-58	21	37
3-7-58	21	42	11-19-58	15	26
3-23-58	13	24	1-9-59	18	22
4-9-58	16	35			
5-1-58	16	30			
5-13-58	13	35			
Wolf Creek:					
3-7-58	14	28	9-26-58	15	35
4-8-58	14	34	1-9-59	17	24
4-16-58	18	39			
5-21-58	18	73			
Squaw Creek:					
3-4-58	17	36	9-26-58	38	64
4-15-58	21	36			
Coon Creek:					
3-16-58	6	9	8-1-58	8	20
5-26-58	11	21			
Herron Creek:					
4-25-58	27	67	10-31-58	26	40
5-25-58	53	190			

Appendix D-3

Date	River Mile	Phosphorus (ug/l) Dissolved	Total
Small Streams:			
2-16-58	2	25	61
2-16-58	5	14	33
2-20-58	6	9	9
3-19-58	26	8	8
3-20-58	15	14	38
4-7-58	20	4	11
4-13-58	18	8	26
4-23-58	16	42	72
4-24-58	11	47	141
5-3-58	10	20	51
5-10-58	22	35	140
5-22-58	13	21	70
5-22-58	25	25	77
5-23-58	9	24	75
5-25-58	24	51	142
5-27-58	12	19	166

Phosphorus concentrations for eight main stream stations of the Red Cedar River. February 1958 to February 1959.

Wet Season			Dry Season		
	Phosphorus (ug/l)			Phosphorus (ug/l)	
Date	Dissolved	Total	Date	Dissolved	Total
Van Buren Road:					
2-14-58	9	21	6-9-58	18	86
2-20-58	12	17	6-11-58	22	52
2-22-58	4	15	8-23-58	24	35
2-23-58	8	21	8-28-58	18	31
3-3-58	16	33	9-22-58	15	33
3-16-58	11	22	11-7-58	12	34
3-23-58	12	21	11-26-58	15	44
3-27-58	11	21	12-26-58	8	22
4-8-58	13	29	1-13-59	15	30
4-9-58	13	21			
4-12-58	16	25			
4-19-58	11	31			
4-20-58	21	46			
5-3-58	14	32			
5-10-58	15	41			
5-11-58	14	42			
5-15-58	-	52			
5-18-58	18	78			
5-19-58	21	68			
5-27-58	15	53			
Gramer Road:					
2-19-58	32	66	7-15-58	73	123
2-24-58	35	86	8-1-58	55	107
3-2-58	19	38	9-9-58	68	119
3-3-58	22	40	10-24-58	80	134
3-18-58	22	44	10-31-58	44	76
3-22-58	13	32	12-16-58	44	93
3-24-58	21	41			
3-28-58	13	34			
4-11-58	16	40			
4-16-58	17	50			
4-19-58	21	72			
4-21-58	33	91			
5-10-58	28	92			
5-15-58	39	120			
5-17-58	42	125			
5-23-58	36	116			

Appendix D-5

Wet Season			Dry Season		
	Phosphorus (ug/l)			Phosphorus (ug/l)	
Date	Dissolved	Total	Date	Dissolved	Total
Webberville Road:					
2-14-58	17	54	7-23-58	49	70
2-15-58	23	67	8-15-58	72	107
3-7-58	19	44	9-26-58	68	112
3-14-58	25	44	10-27-58	49	72
3-26-58	17	41	1-6-59	52	98
4-7-58	19	57	1-9-59	37	74
4-8-58	17	47			
4-16-58	22	56			
4-24-58	29	72			
5-2-58	28	70			
5-21-58-	35	94			
Williamston (1000 yards below dam):					
2-15-58	18	47	6-9-58	28	93
2-18-58	17	47	7-2-58	42	119
3-4-58	22	36	8-15-58	53	125
3-6-58	15	28	8-28-58	42	105
3-8-58	26	44	9-22-58	30	74
3-15-58	12	31	9-26-58	34	73
3-18-58	16	31	10-27-58	51	86
3-20-58	14	32	11-7-58	36	72
3-24-58	14	39	12-16-58	16	73
3-26-58	16	35	1-6-59	51	89
3-27-58	12	32	1-19-59	36	77
4-15-58	30	94			
4-17-58	17	51			
4-20-58	28	72			
4-21-58	33	86			
4-23-58	24	69			
5-2-58	22	.049 mg/l			
5-11-58	14	.054			
5-13-58	15	.054			
5-17-58	17	.061			
5-19-58	22	.082			
Sewage Disposal Plant (1000 yards upstream from outfall):					
2-23-58	9	43	7-2-58	42	113
2-24-58	14	44	7-23-58	34	78
3-15-58	16	35	8-23-58	44	63
3-19-58	16	34	10-24-58	42	70
4-11-58	17	32	1-19-59	36	81
4-13-58	10	28			
5-9-58	19	57			
5-14-58	11	32			
5-18-58	15	56			

Wet Season			Dry Season		
	Phosphorus (ug/l)			Phosphorus (ug/l)	
Date	Dissolved	Total	Date	Dissolved	Total
Dobie Road:					
2-20-58	-	57	7-15-58	22	69
3-2-58	24	64	11-19-58	11	69
3-7-58	25	59	1-9-59	52	85
3-23-58	41	44			
4-9-58	23	45			
4-25-58	27	67			
5-1-58	44	88			
5-13-58	62	104			
Hagadorn Road:					
2-22-58	36	81	9-9-58	116	154
3-6-58	17	47	10-31-58	68	95
3-20-58	26	46	11-19-58	72	101
3-28-58	24	46	1-13-59	76	97
4-15-58	34	64			
4-17-58	24	72			
5-9-58	42	83			
5-25-58	76	152			
Farm Lane Bridge:					
2-14-58	79	117	6-9-58	106	179
2-15-58	78	101	6-11-58	120	185
2-16-58	75	117	7-2-58	134	187
2-18-58	-	105	7-15-58	116	163
2-19-58	-	116	7-23-58	114	138
2-20-58	-	109	8-1-58	112	182
2-22-58	47	91	8-23-58	112	162
2-23-58	74	111	8-28-58	128	178
2-24-58	74	116	9-9-58	260	332
3-2-58	29	77	9-22-58	133	166
3-3-58	32	64	10-24-58	122	173
3-4-58	38	64	10-27-58	108	152
3-6-58	27	65	10-31-58	127	166
3-7-58	31	61	11-7-58	88	123
3-8-58	36	61	11-19-58	120	148
3-14-58	59	79	11-26-58	140	236
3-15-58	38	69	12-16-58	84	105
3-16-58	31	61	12-26-58	105	136
3-18-58	31	56	1-6-59	120	161
3-19-58	32	57	1-9-59	97	146
3-20-58	34	66	1-13-59	92	131
3-22-58	44	70	1-19-59	142	154
3-23-58	31	51			
3-24-58	35	63			

Wet Season			Dry Season		
	Phosporus (ug/l)			Phosphorus (ug/l)	
Date	Dissolved	Total	Date	Dissolved	Total
Farm Lane Bridge:					
3-26-58	34	57	4-24-58	42	97
3-27-58	41	65	4-25-58	40	101
3-28-58	28	-	5-1-58	48	103
4-7-58	26	64	5-2-58	84	202
4-8-58	34	79	5-3-58	49	118
4-9-58	48	72	5-9-58	80	134
4-11-58	44	77	5-10-58	62	112
4-12-58	36	69	5-13-58	74	138
4-13-58	26	57	5-14-58	69	160
4-15-58	38	72	5-17-58	104	186
4-16-58	51	108	5-18-58	123	186
4-17-58	39	96	5-19-58	118	180
4-19-58	68	129	5-21-58	114	180
4-20-58	61	139	5-22-58	141	230
4-21-58	43	110	5-25-58	94	172
4-23-58	40	140	5-26-58	128	201

Miscellaneous Main Stream Stations

		Phosphorus (ug/l)	
Station	Date	Dissolved	Total
Okemos Road	2-16-58	36	63
Zimmer Road	3-16-58	15	36
Gregory Road	3-19-58	23	47
Dietz Road	4-13-58	17	35
Meridian Road	4-24-58	27	75
Meridian Road	5-3-58	32	64
Nickelson Road	5-22-58	62	187
Zimmer Road	5-22-58	50	92
Meridian Road	5-23-58	24	75
Stow Road	5-25-58	43	142
Zimmer Road	5-26-58	45	98
Zimmer Road	11-10-58	41	84
Zimmer Road	11-17-58	35	100
Zimmer Road	12-2-58	42	103
Zimmer Road	12-9-58	37	73

Physical and chemical characteristics of the tributaries of the Red Cedar River. February 1958 to Febuaray 1959.

Date	Temp. Air	°F. Water	Gauge Height inches	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett units
Doan Creek:								
2-15-58	20	32	3	614	262	7.8	13	7
2-18-58	8	32	3	675	292	7.8	10	17
3-4-58	33	35	21.5	510	186	7.9	26	28
3-6-58	35	36	22.5	506	180	7.9	28	31
3-8-58	30	36	17.75	534	198	7.8	16	30
3-15-58	32	35	11.25	583	222	8.0	16	26
3-18-58	33	38	9.25	591	228	8.1	16	22
3-24-58	37	40	8	575	232	8.1	16	20
3-26-58	40	39	7	595	232	7.9	15	23
3-27-58	37	40	7	581	236	8.1	15	23
4-17-58	55	52	6	534	242	8.1	18	25
4-20-58	60	58	5	511	242	8.0	17	22
4-21-58	55	52	5.25	463	244	8.0	24	20
4-23-58	46	47	5.5	457	244	8.2	21	25
5-2-58	56	63	2.0	545	233	8.2	23	15
5-11-58	76	60	-0.25	529	250	8.1	15	23
5-13-58	62	64	-0.75	537	249	8.0	14	23
5-17-58	65	59	-2.75	649	274	8.0	16	24
5-19-58	63	60	-2.75	638	263	8.0	17	23
6-9-58	56	61	0.00	449	233	8.0	30	25
7-2-58	82	80	-6.5	842	250	8.2	14	22
8-15-58	73	73	7	246	262	8.1	6	25
8-28-58	82	74	5.75	786	250	8.2	9	13
9-22-58	70	65	-7	642	252	8.2	11	15
10-27-58	51	50	0.00	354	215	8.4	7	37
11-7-58	45	42	-3.75	391	212	8.3	13	16
12-16-58	16	32	-1.5	380	270	7.5	10	17
1-6-59	10	32	1.5	478	298	7.7	14	18
1-19-59	-	32	0.75	-	281	7.6	15	10
West Branch:								
2-19-58	19	32	58.5	658	278	7.7	5	18
2-24-58	32	32	59	611	254	7.8	11	16
3-2-58	35	35	40	505	180	7.8	15	54
3-3-58	30	34	43.25	516	180	7.8	15	52
3-18-58	33	38	54.5	586	230	8.1	12	30
3-22-58	41	43	57.5	585	228	8.1	10	47
3-24-58	37	42	58	598	230	8.1	12	43

Date	Temp. Air	°F. Water	Gauge Height inches	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett units
West Branch:								
3-28-58	42	41	57.75	595	239	7.8	13	42
4-11-58	36	40	56.75	331	234	7.8	10	50
4-16-58	80	62	57	609	234	8.0	18	55
4-19-58	76	63	59	662	240	8.2	16	52
4-21-58	55	54	58	441	244	8.1	24	44
5-15-58	72	69	64.25	-	-	8.0	22	37
5-17-58	65	60	64.5	628	278	8.0	23	33
5-23-58	62	66	64.25	591	272	8.2	20	26
7-15-68	82	76	62.5	430	278	8.2	15	45
8-1-58	-	-	-	502	268	8.3	15	25
9-9-58	59	58	66.5	498	268	8.0	9	24
10-24-58	50	52	62.75	472	224	8.1	11	33
10-31-58	61	51	62.25	410	224	8.1	11	43
East Branch:								
2-20-58	20	32	23.75	540	264	7.8	15	9
2-14-58	15	32	23.75	-	262	-	16	8
3-3-58	30	34	33	474	192	7.8	14	47
3-16-58	33	37	25	474	228	7.9	13	32
3-23-58	41	44	24	512	236	8.0	11	37
3-27-58	37	40	23.5	524	234	8.1	11	37
4-12-58	43	42	27.75	386	234	7.9	13	53
4-19-58	76	62	22	617	244	8.2	14	39
4-20-58	60	57	22.25	464	250	8.1	27	35
5-10-58	68	64	20.25	567	267	8.0	17	28
5-11-58	76	59	20	567	274	8.0	19	28
5-15-58	72	66	19.75	559	272	8.0	24	25
6-11-58	67	67	25.25	331	264	8.0	20	44
8-28-58	82	68	26.5	756	274	8.1	11	11
9-22-58	70	60	24	624	272	8.0	18	11
11-7-58	45	43	21.25	460	228	8.0	15	16
12-26-58	29	32	25.5	339	270	7.7	13	9
1-13-59	24	32	26.5	-	274	7.7	12	7
Deer Creek:								
2-23-58	34	32	12	564	244	7.8	10	8
2-24-58	32	32	12.25	549	242	7.8	13	13
3-15-58	32	35	14.5	529	222	8.1	17	22
3-19-58	35	38	13	552	228	8.1	16	22
4-11-58	36	40	13.25	305	224	7.9	13	25
4-13-58	45	43	18	414	216	7.8	10	32
5-9-58	50	52	6.5	512	246	8.2	17	19

Date	Temp. Air	°F. Water	Gauge Height inches	Conduc-tivity mho cm X 10^{-6}	Alka-linity ppm	pH	Turbid-ity as ppm SiO_2	Color as Klett Units
Deer Creek:								
5-14-58	74	61	5.75	630	253	8.0	15	26
5-18-58	65	66	5.5	606	256	7.9	17	30
7-2-58	82	80	4.75	774	244	8.2	18	24
7-23-58	80	77	5.25	654	248	8.0	20	19
8-23-58	67	67	5.5	566	254	8.1	21	30
10-24-58	50	52	5.5	400	208	8.0	21	21
1-19-59	-	32	6.5	-	265	7.7	14	12
Middle Branch:								
2-22-58	22	32	71	510	250	7.6	8	20
2-23-58	34	32	71	492	244	7.6	13	21
4-8-58	35	43	61.5	494	223	7.6	7	66
4-9-58	34	47	63	495	220	7.9	10	58
4-12-58	43	42	60	351	218	7.8	12	65
5-3-58	64	58	70	482	244	7.9	-	-
5-18-58	65	67	71	547	254	7.9	27	86
5-19-58	63	63	72	554	266	7.9	29	63
5-27-58	58	62	73.5	484	270	8.1	29	41
6-9-58	56	64	69	310	238	7.8	59	47
8-23-58	67	68	65	578	274	7.9	20	51
11-26-58	26	36	67	386	228	7.9	13	60
12-26-58	29	32	64.5	355	236	7.5	19	29
Kalamink Creek:								
2-14-58	15	32	70.5	-	300	7.9	16	10
2-15-58	20	32	70.5	629	288	7.9	15	9
3-14-58	32	38	72	638	244	8.0	15	32
4-7-58	36	45	70.5	606	220	8.0	24	52
4-24-58	54	52	73	557	264	7.8	42	33
5-2-58	56	68	75.25	659	276	8.1	18	29
5-21-58	64	64	75.5	659	283	8.5	19	23
7-23-58	80	88	76	722	254	8.3	13	26
8-15-58	73	75	77	342	275	8.3	10	30
10-27-58	51	52	75.5	346	219	8.3	6	25
1-6-59	10	32	72.25	525	324	7.6	13	16
Lake Lansing Drain:								
2-22-58	22	32	150	597	250	7.6	14	22
3-6-58	35	35	112	518	198	7.7	16	51
3-20-58	32	37	130	554	228	7.8	9	46

Appendix D-11

Date	Temp. Air	°F. Water	Gauge Height inches	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett Units
Lake Lansing Drain:								
3-28-58	42	40	137	490	208	7.9	12	38
4-15-58	50	44	144.5	424	230	7.8	14	45
4-17-58	55	49	144.5	515	230	7.9	20	37
5-9-58	50	50	147.5	494	260	7.9	24	40
9-9-58	59	57	150	448	270	7.8	44	24
11-19-58	48	41	149.75	486	230	8.0	18	24
1-13-59	24	32	148.75	-	283	-	9	13
Sloan Creek:								
3-2-58	35	35	20cfs	386	154	7.8	19	25
3-7-58	30	34	17cfs	366	166	8.0	16	23
3-23-58	41	45	83.75	476	210	8.2	4	15
4-9-58	34	42	83.25	473	190	8.1	14	13
5-1-58	55	48	84.5	483	228	8.0	11	9
5-13-58	62	51	85.75	482	246	8.0	16	7
7-15-58	82	71	84	378	250	8.1	6	21
11-19-58	48	44	86	415	228	8.0	7	6
1-9-59	9	32	87	-	282	7.8	5	6
Wolf Creek:								
3-7-58	30	34	41.5	528	204	7.9	14	28
4-8-58	35	45	54.25	597	243	8.1	14	38
4-16-58	80	64	67	630	238	8.4	22	37
5-21-58	64	60	65.5	565	276	7.8	31	21
9-26-58	66	67	66.75	684	284	7.8	8	20
1-9-59	9	32	64.25	-	284	7.5	7	8
Squaw Creek:								
3-4-58	33	34	50.75	483	192	7.8	15	37
4-15-58	50	44	60	390	244	8.0	11	45
9-26-58	66	70	65	642	282	8.2	10	28
Coon Creek:								
3-16-58	33	36	39.5	486	234	7.9	7	15
5-26-58	58	61	45	486	283	7.9	17	13
8-1-58	-	-	45.25	468	284	8.1	19	14

Appendix D-12

Date	Temp. °F. Air	Temp. °F. Water	Gauge Height inches	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO2	Color as Klett Units
Herron Creek:								
4-25-58	40	42	32	536	262	7.9	29	30
5-25-58	58	74	32.25	-	254	8.2	40	29
10-31-58	61	53		400	233	8.0	11	24

Date	Temp. °F. Air	Temp. °F. Water	River Mile	Flow gpm	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO2	Color as Klett Units
Small Streams:									
2-16-58	4	34	2	1	727	288	7.9	10	6
2-16-58	4	33	5	9	583	294	7.9	8	7
2-20-58	20	39	6	1	427	216	8.1	1	5
3-19-58	35	42	26	12	587	214	8.0	2	46
3-20-58	32	39	15	8	451	206	7.8	9	35
4-7-58	36	41	20	7	494	179	7.7	0	3
4-13-58	45	48	18	50	475	244	8.0	23	13
4-23-58	46	56	16	8	368	238	8.1	22	52
4-24-58	54	50	11	80	504	240	7.9	8	21
5-3-58	64	61	10	12	370	204	8.0	22	14
5-10-58	68	55	22	20	552	312	7.9	57	97
5-22-58	58	53	25	60	518	282	7.6	29	61
5-22-58	58	55	13	2	490	256	7.8	22	16
5-23-58	62	61	9	12	445	230	7.9	10	16
5-25-58	58	66	24	17	-	274	8.2	21	42
5-27-58	58	50	2	12	417	233	7.9	73	3

Physical and chemical characteristics for eight main stream stations of the Red Cedar River. February 1958 to Feburary 1959.

Date	Temp. °F. Air	Water	Gauge Height inches	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett Units
Van Buren Road:								
2-14-58	15	32	49.5	-	268	-	14	11
2-20-58	20	32	49.5	582	280	7.8	15	14
2-22-58	22	32	48.75	523	256	7.7	8	16
2-23-58	34	32	48.75	505	252	7.7	18	12
3-3-58	30	34	34.25	458	186	7.7	12	51
3-16-58	33	35	34.75	516	224	7.9	11	40
3-23-58	41	48	45.5	508	236	8.0	13	45
3-27-58	37	41	46.25	505	228	8.0	13	45
4-8-58	35	43	41.25	528	232	7.9	8	59
4-9-58	34	46	44.6	523	228	8.0	13	45
4-12-58	43	43	40.25	361	228	7.8	13	56
4-19-58	76	65	49	521	238	8.3	21	48
4-20-58	60	59	48.75	459	242	8.0	27	48
5-3-58	64	57	51.75	503	258	7.9	-	-
5-10-58	68	54	52.25	509	260	7.9	20	37
5-11-58	76	59	52.75	544	269	8.0	20	41
5-15-58	72	65	53.75	537	268	8.0	-	-
5-18-58	65	64	52.25	562	260	7.9	31	49
5-19-58	63	59	53	544	272	7.9	34	43
5-27-58	58	55	54.25	492	275	8.0	29	24
6-9-58	56	61	50	370	236	7.8	36	36
6-11-58	67	68	49.75	282	268	8.0	27	50
8-28-58	82	73	54.5	750	284	8.1	13	19
9-22-58	70	65	54	636	278	8.0	18	21
11-7-58	45	41	50	429	238	8.0	20	31
11-26-58	26	35	47.5	391	231	7.8	20	42
12-26-58	29	32	49	339	269	7.6	18	14
8-23-58	67	65	54.5	578	274	7.9	18	37
1-13-58	-	32	47.25	-	299	7.7	15	12
Gramer Road:								
2-19-58	19	32	12	607	274	7.7	8	16
2-24-58	32	32	13	572	250	7.8	18	16
3-2-58	35	33	45	435	166	7.9	15	52
3-3-58	30	34	41	465	182	7.8	11	51
3-18-58	33	38	21	555	214	8.0	14	46

Date	Temp. °F. Air	Water	Gauge Height inches	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett Units
Gramer Road:								
3-22-58	41	42	22	543	234	8.2	11	43
3-24-58	37	42	20	541	236	8.1	13	38
3-28-58	42	42	18.5	546	243	8.0	16	38
4-11-58	36	41	20	317	232	7.8	11	48
4-16-58	80	60	18	548	240	8.4	19	54
4-19-58	76	62	16.5	594	244	8.3	19	54
4-21-58	55	55	16	391	250	8.0	29	40
5-10-58	68	53	10.25	534	263	8.1	22	35
5-15-58	72	64	8.5	-	-	8.0	30	33
5-17-58	65	60	6	571	284	8.0	-	-
5-23-58	62	58	8	545	280	8.1	17	35
7-15-58	82	71	12	440	282	8.0	17	50
8-1-58	-	-	-	492	264	7.8	18	22
9-9-58	59	60	8.75	482	262	8.1	11	21
10-24-58	50	52	5.5	440	224	7.8	22	33
10-31-58	61	48	16.75	363	233	7.8	12	39
12-16-58	16	32	10.5	376	252	7.5	9	20
Webberville Road:								
2-14-58	15	32	10	-	298	7.6	13	11
2-15-58	20	32	10	585	268	7.6	15	12
3-7-58	30	35	37	500	108	7.8	15	44
3-14-58	32	38	23	567	228	7.9	12	41
3-26-58	40	40	17.5	567	240	8.0	13	39
4-7-58	36	44	25.75	534	230	8.0	18	54
4-8-58	35	45	25	553	232	8.0	12	57
4-16-58	80	59	-	589	238	8.2	18	49
4-24-58	54	52	17	484	252	7.9	31	47
5-2-58	56	59	9.25	518	256	8.0	32	26
5-21-58	64	60	4	518	270	8.3	28	33
7-23-58	80	84	1.25	664	268	8.2	13	26
8-15-58	73	72	-1.5	332	270	8.1	8	31
9-26-58	66	69	0.0	602	270	8.2	13	22
10-27-58	51	50	9	346	217	7.9	9	56
1-6-59	10	32	8	421	286	7.5	15	20
1-9-59	9	32	7.5	-	296	7.5	10	16
Williamston (1000 yards below dam):								
2-15-58	20	32	56cfs	621	246	7.7	14	12
2-18-58	8	32	56cfs	626	-	7.8	13	15

Date	Temp. °F. Air	Water	Stream flow cfs	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO2	Color as Klett Units
Williamston (1000 yards below dam):								
3-4-58	33	33	384	486	180	7.8	12	39
3-6-58	35	36	360	512	198	7.9	11	41
3-8-58	30	36	360	500	190	7.8	33	21
3-15-58	32	37	190	516	224	8.0	12	36
3-18-58	33	38	174	563	234	7.9	12	38
3-20-58	32	38	170	541	236	8.0	16	32
3-24-58	37	42	160	581	228	8.2	15	30
3-26-58	40	42	150	546	236	7.9	12	33
3-27-58	37	41	144	558	230	8.3	12	33
4-15-58	50	52	160	466	238	8.2	22	47
4-17-58	55	59	133	522	240	8.2	26	43
4-20-58	60	62	114	494	245	8.1	45	38
4-21-58	55	60	121	420	252	8.2	50	33
4-23-58	46	57	130	494	254	8.0	44	30
5-2-58	56	58	95	494	250	8.1	34	24
5-11-58	76	60	79	571	254	8.3	27	30
5-13-58	62	63	66	545	256	8.3	26	24
5-17-58	65	68	66	523	274	8.2	26	28
5-19-58	63	69	60	562	272	8.2	24	33
6-9-58	56	66	55	508	261	8.0	25	32
7-2-58	82	76	40	774	256	7.9	31	24
8-15-58	73	-	53	342	264	7.9	33	29
8-28-58	82	68	32	748	262	7.9	32	20
9-22-58	70	64	38	594	240	7.9	20	18
9-26-58	66	69	32	614	254	8.0	22	19
10-27-58	51	51	38	326	214	7.8	22	31
11-7-58	44	45	47	410	224	8.1	23	23
12-16-58	16	32	46	363	294	7.4	18	17
1-6-59	10	32	36	373	215	7.7	18	26
1-19-59	-	32	36	-	296	7.6	32	19
Sewage Disposal Plant (1000 yards upstream from outfall):								
2-23-58	34	32	66	569	264	7.7	12	9
2-24-58	32	32	76	584	258	7.7	12	13
3-15-58	32	37	204	548	224	8.1	13	32
3-19-58	35	38	182	505	230	8.1	13	30
4-11-58	36	43	166	317	238	8.1	15	38
4-13-58	45	44	206	424	230	8.1	15	38
5-9-58	50	56	72	442	252	8.3	27	29
5-14-58	74	66	73	621	264	8.2	20	33
5-18-58	65	67	89	630	271	8.1	19	30

Date	Temp. °F. Air	Water	Stream flow cfs	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett Units
Sewage Disposal Plant (1000 yards upstream from outfall):								
7-2-58	82	76	52	774	252	7.9	23	27
7-23-58	80	73	44	676	260	7.9	17	26
8-23-58	50	54	47	570	242	8.0	24	29
10-24-58	50	54	39	432	220	7.9	34	20
1-19-58	-	32	41	-	268	7.6	32	12
Dobie Road:								
2-20-58	20	32	56	535	263	7.7	10	11
3-2-58	35	33	535	425	150	7.9	29	34
3-7-58	30	35	400	485	190	8.1	19	34
3-23-58	41	42	168	542	232	8.2	14	29
4-9-58	34	44	123	540	223	8.2	14	35
4-25-58	40	50	150	466	244	8.1	28	25
5-1-58	55	53	99	470	252	8.2	22	25
5-13-58	62	60	67	431	251	8.3	16	27
7-15-58	82	74	69	414	262	7.9	22	46
11-19-58	48	46	69	445	227	8.1	11	25
Hagadorn Road:								
2-22-58	22	32	66	638	276	7.6	8	19
3-6-58	35	36	440	495	196	8.0	18	36
3-20-58	32	39	209	567	232	8.2	17	28
3-28-58	42	42	171	548	234	8.3	11	28
4-15-58	50	50	196	443	236	8.2	13	42
4-17-58	55	56	162	540	240	8.3	27	28
5-9-58	50	56	114	505	252	8.2	15	27
5-25-58	58	65	68	-	259	7.9	19	25
9-9-58	59	62	24	482	258	8.1	15	18
10-31-58	61	48	60	354	221	7.8	11	30
11-19-58	48	47	84	405	226	8.0	13	23
1-13-59	24	32	43	-	299	7.6	4	5
Farm Lane Bridge:								
2-14-58	15	32	66	-	288	7.7	11	15
2-15-58	20	32	68	646	294	7.7	11	13
2-16-58	4	32	71	643	286	7.7	12	13
2-18-58	8	32	68	628	280	7.8	10	18
2-19-58	19	32	68	605	274	7.8	8	13

Date	Temp. °F. Air	Water	Stream flow cfs	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett Units
Farm Lane Bridge:								
2-20-58	20	32	68	618	274	7.8	10	11
2-21-58	22	32	66	638	282	7.7	8	12
2-23-58	34	32	68	611	278	7.7	9	8
2-24-58	32	32	81	612	266	7.7	13	12
3-2-58	35	32	666	423	154	7.9	28	36
3-3-58	30	33	540	448	163	7.9	18	37
3-4-58	33	34	468	486	178	7.9	16	35
3-6-58	35	36	440	490	194	8.0	18	35
3-7-58	30	35	482	495	192	8.0	16	34
3-8-58	30	35	440	494	190	8.0	12	34
3-14-58	32	38	245	567	224	8.1	14	30
3-15-58	32	38	235	568	224	8.1	12	31
3-16-58	33	37	228	548	224	8.2	13	29
3-18-58	33	37	212	595	230	8.2	13	24
3-19-58	35	37	209	560	230	8.2	14	24
3-20-58	32	39	209	541	234	8.1	11	33
3-22-58	41	40	212	556	232	8.2	10	33
3-23-58	41	40	202	541	232	8.2	10	33
3-24-58	37	40	196	554	230	8.2	14	25
3-26-58	40	41	184	567	232	8.2	14	28
3-27-58	37	41	177	544	226	8.3	14	28
3-28-58	42	41	171	540	234	8.3	15	28
4-7-58	36	46	269	534	235	8.2	18	30
4-8-58	35	45	298	555	223	8.1	22	29
4-9-58	34	44	245	550	224	8.1	23	30
4-11-58	36	44	190	354?	234	8.1	12	37
4-12-58	43	43	215	391?	234	8.1	14	35
4-13-58	45	44	238	449	228	8.2	15	32
4-15-58	50	51	196	476	234	8.2	14	40
4-16-58	80	54	174	618	232	8.2	18	39
4-17-58	55	57	162	567	234	8.3	20	39
4-19-58	76	62	142	545	240	8.1	21	35
4-20-58	60	61	139	512	240	8.1	26	35
4-21-58	55	58	148	445	244	8.1	27	32
4-23-58	46	54	159	476	243	8.1	30	24
4-24-58	54	54	168	476	246	8.0	41	25
4-25-58	40	50	180	420	242	8.1	13	48
5-1-58	55	51	119	540	253	8.2	24	26
5-2-58	56	58	116	497	248	8.2	25	21
5-3-58	64	58	111	482	246	8.2	-	-
5-9-58	50	56	114	505	256	8.2	20	25
5-10-58	68	58	105	494	254	8.2	15	26
5-13-58	62	63	81	548	255	8.1	19	31

Date	Temp. °F. Air	Temp. °F. Water	Stream flow cfs	Conductivity mho cm, X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett Units
Farm Lane Bridge:								
5-14-58	74	65	78	574	258	8.1	17	32
5-17-58	65	66	81	533	268	8.0	16	30
5-18-58	65	66	84	618	264	7.9	17	35
5-19-58	63	68	78	661	270	8.0	17	28
5-21-58	64	63	74	560	270	7.9	29	27
5-22-58	58	63	74	515	262	8.0	26	34
5-25-58	58	66	68	-	259	8.1	19	26
5-26-58	58	65	56	604	259	8.1	23	24
6-9-58	56	66	68	540	259	8.0	26	29
6-11-58	67	69	92	338	258	7.9	21	25
7-2-58	82	78	48	828	252	7.9	15	23
7-15-58	82	75	89	441	266	7.9	21	50
7-23-58	80	74	50	720	270	8.0	19	24
8-1-58	-	-	46	492	246	8.0	25	22
8-23-58	67	-	52	570	238	7.9	-	-
8-28-58	82	-	39	774	252	-	17	23
9-9-58	59	63	24	508	228	8.0	34	20
9-22-58	70	64	46	582	248	7.9	19	14
10-24-58	50	55	43	452	221	7.8	22	32
10-27-58	51	51	46	354	213	7.6	14	31
10-31-58	61	47	60	381	220	7.8	11	31
11-7-58	44	-	58	540	224	-	13	24
11-19-58	48	47	84	420	223	8.0	13	22
11-26-58	26	36	64	425	210	8.0	13	31
12-16-58	16	32	56	410	229	7.5	7	18
12-26-58	29	32	41	395	278	7.6	6	13
1-6-59	10	32	61	405	230	7.7	15	20
1-9-59	9	32	56	-	260	7.6	12	19
1-13-59	24	32	43	-	301	7.6	5	13
1-19-59	-	32	43		262	7.5	9	11

Appendix D-19

Station	Date	Temp. °F. Air	Water	Conductivity mho cm X 10^{-6}	Alkalinity ppm	pH	Turbidity as ppm SiO_2	Color as Klett Units
Miscellaneous Main Stream Stations:								
Okemos Road	2-16-58	4	32	628	288	7.8	10	12
Zimmer Road	3-16-58	33	36	554	226	8.1	12	29
Gregory Road	3-19-58	35	39	534	234	7.9	14	38
Dietz Road	4-13-58	45	45	429	232	8.0	11	51
Meridian Rd.	4-24-58	54	54	435	248	8.0	28	32
Meridian Rd.	5-3-58	64	57	488	244	8.2	20	29
Nickelson Rd.	5-22-58	58	56	505	272	7.7	34	47
Zimmer Road	5-22-58	58	60	494	258	8.1	19	34
Meridian Rd.	5-23-58	62	65	537	260	8.4	14	26
Stow Road	5-25-58	58	59	-	276	7.8	26	29
Zimmer Rd.	5-26-58	58	61	512	259	8.2	17	25
Zimmer Rd.	11-10-58	43	43	410	230	8.0	11	30
Zimmer Rd.	11-17-58	61	51	523	186	7.9	32	25
Zimmer Rd.	12-2-58	34	32	313	236	7.9	12	30
Zimmer Rd.	12-9-58	10	32	327	225	7.8	13	24

Stream flow measurements
February 1958 to September 1959

Date	Gauge Height inches	Stream Discharge cubic feet per second
Doan Creek:		
4-1-58	5.00	21.24
5-2-58	2.00	12.09
6-17-58	-2.75	7.58
7-9-58	8.00	23.39
11-6-58	-3.75	6.80
3-9-59	36.75	123.62
3-23-59	25.50	84.48
4-1-59	20.00	72.38
4-22-59	6.75	24.31
West Branch:		
4-1-58	58.50	17.84
5-2-58	61.25	10.84
5-23-58	64.25	6.77
6-17-58	64.00	7.46
7-9-58	55.00	19.72
7-17-58	63.50	7.17
11-6-58	63.50	5.06
3-23-59	28.25	86.82
4-17-59	50.50	34.48
East Branch:		
4-1-58	22.50	11.48
4-19-58	22.00	8.68
5-3-58	20.75	8.21
6-17-58	23.75	5.25
7-9-58	32.50	14.85
11-26-58	22.00	6.96
3-4-59	59.50	97.80
3-5-59	57.75	92.82
3-9-59	57.00	76.24
3-19-59	52.50	84.52
3-23-59	49.50	58.28
4-17-59	28.00	22.43
Deer Creek:		
4-3-58	9.00	7.78
5-2-58	7.00	6.26
5-9-58	6.50	5.82

Date	Gauge Height inches	Stream Discharge cubic feet per second
Deer Creek:		
6-17-58	6.00	3.52
7-10-58	12.00	10.00
3-9-59		57.66
4-22-59	13.25	9.54
Middle Branch:		
4-19-58	68.00	12.84
5-3-58	70.00	6.97
6-17-58	70.75	3.16
7-9-58	57.50	12.95
11-26-58	67.00	11.48
3-4-59	30.50	105.56
3-5-59	29.50	119.27
3-9-59	33.00	93.95
3-12-59	44.00	44.14
3-19-59	42.00	-
3-23-59	46.00	64.49
Kalamink Creek:		
2-1-58	72.00	7.16 (float)
5-2-58	75.25	4.50
5-23-58	75.00	3.13
6-17-58	76.75	3.08
7-9-58	73.25	7.27
3-2-59	55.50	53.12
4-15-59	70.00	14.46
Lake Lansing Drain:		
4-19-58	143.	7.16
4-3-58	139.50	10.16
5-2-58	145.5	4.46
5-9-58	145.75	3.28
6-17-58	145.25	1.08
11-19-58	sampling day	1.27
4-1-59	115.00	31.67
4-15-59	127.00	21.92
4-17-59		19.51
Sloan Creek:		
4-3-58	84.00	2.35
5-2-58	84.75	2.16
7-17-58	85.50	0.93
11-19-58	86.00	0.76
4-1-59	82.50	10.30

Date	Gauge Height inches	Stream Discharge cubic feet per second
Wolf Creek:		
2-1-58	64.00	6.07 (float)
4-1-58	62.50	4.08
5-23-58	65.25	1.30
6-17-58	66.50	1.16
7-10-58	58.75	4.83
4-18-58	55.00	6.47
Squaw Creek:		
4-3-58	61.75	2.17
5-23-58	64.50	0.79
3-19-59	37.00	24.11
7-24-59	50.50	8.45
Coon Creek:		
5-2-58	45.00	1.66
2-19-59	32.50	13.29
7-24-59	35.25	8.03
-	40.00	5.43
Herron Creek:		
4-3-58	29.00	0.98
3-19-59	18.25	10.20
3-31-59	23.00	3.89
3-23-59	20.50	7.49
4-1-59	23.50	3.43
4-15-59	25.00	2.79

Flow measurements of the main stream stations of the Red Cedar River February 1958 to September 1959

Date	Gauge Height inches	Stream Discharge cubic feet per second
Van Buren Road:		
3-5-59	10.75	228.51
3-23-59	17.25	153.67
5-15-59	46.50	27.06
Gramer Road:		
4-4-58	15.50	56.81 (float)
6-17-58	9.00	20.47
7-8-58	-	103.80
7-9-58	23.75	77.02
7-17-58	11.25	24.70
6-12-59	15.00	39.32
6-16-59	13.25	30.33
6-23-59	12.50	24.38
7-1-59	12.00	21.06
7-3-59	11.50	19.63
7-12-59	10.00	13.56
7-27-59	11.25	19.09
Webberville Road:		
4-4-58	13.25	54.35 (float)
6-17-58	2.75	23.75
6-12-59	7.75	46.98
6-16-59	5.00	35.95
6-23-59	3.50	29.29
7-1-59	1.00	24.37
7-3-59	0.75	23.63
7-12-59	-2.25	16.02
7-27-59	0.50	26.15
Williamston (1000 yards below dam):		
9-15-58		10.10
9-16-58		3.46
9-23-58		24.16
10-2-58		24.40
10-13-58		52.42
10-25-59		46.02
4-25-59		117.65
4-18-59		176.86
4-22-58		123.87

Date	Gauge Height inches	Stream Discharge cubic feet per second
Williamston (1000 yards below dam):		
1-7-59		45.74
1-13-59		32.61
Zimmer Road:		
3-26-59	65.00	556.57
3-2-59	56.00	392.79
3-8-59	43.00	131.26
4-22-59	44.00	150.21
4-25-59	-	141.52
5-15-59	-	131.03
5-22-59	44.50	153.89
Meridian Road (US 16):		
7-21-59		79.98
7-24-59		168.17
8-12-59		83.42
9-3-59		192.13
Dobie Road:		
8-15-58	-	37.37
8-22-58	8.00	39.93
8-30-58	6.00	27.53
9-23-58	-	27.24
10-2-58	10.00	26.51
10-14-58	12.00	43.29
10-28-58	14.00	43.56
5-15-59	-	121.89