Phosphorus, sediment, and water interactions in the Gallatin River of southwestern Montana
by Floyd James Adamsen

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
Montana State University

Abstract:
The predominant ions in the water of the Gallatin River and its tributaries were Ca^+2 and HCO3-. During May and June in the Gallatin River above the East Gallatin confluence, the concentration of dissolved solids was lower than other periods, while the concentrations of suspended solids and dissolved phosphorus and the phosphorus content of the sediments were highest. The higher phosphorus content of the sediments in May and June was probably due to increased amounts of surface soil being eroded. The East Gallatin River was supersaturated in phosphorus with respect to hydroxyapatite while sites on the Gallatin River above the East Gallatin confluence were below saturation.

Extraction of sediments with NaHCO3 sediments from the East Gallatin River and the Gallatin River below the East Gallatin were higher in extractable phosphorus than locations above the East Gallatin. Extraction of phosphorus from the sediments by fungus indicated that 20 to 70 percent of the phosphorus content of the sediments may be biologically available. This is 10 to 20 times more phosphorus extracted than by NaHCO3.

The differences found in the concentrations of phosphorus in the water and sediments of the Gallatin and East Gallatin Rivers were attributable to additions of phosphorus by sewage effluent and agricultural runoff to the East Gallatin River.

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Date August 7, 1974

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by

FLOYD JAMES ADAMSEN

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soils

Approved:

Murray G. Klages
Chairman, Examining Committee

K.C. Feltner
Head, Major Department

Henry L. Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

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ABSTRACT

The predominant ions in the water of the Gallatin River and its tributaries were Ca^{+2} and HCO_3^-. During May and June in the Gallatin River above the East Gallatin confluence, the concentration of dissolved solids was lower than other periods, while the concentrations of suspended solids and dissolved phosphorus and the phosphorus content of the sediments were highest. The higher phosphorus content of the sediments in May and June was probably due to increased amounts of surface soil being eroded. The East Gallatin River was supersaturated in phosphorus with respect to hydroxyapatite while sites on the Gallatin River above the East Gallatin confluence were below saturation.

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INTRODUCTION

Sediment exceeds in volume the combined total of all other substances carried by surface waters (60). Man has had a significant impact on the amount of sediment in surface waters. In the Potomac River, twenty-five percent of the sediment is attributable to construction sites in the metropolitan Washington, D. C. area (60). Some agricultural practices also increase the amount of sediment in surface water. Many polluting substances, such as pesticide residues and fertilizers, are associated with the sediments. The loss of fertilizer from agricultural lands increases the rate of eutrophication of lakes (33, 60).

Among the substances associated with sediment is phosphorus. This element is important in eutrophication because, in many cases, it is the element which limits the production of aquatic plants, and, indirectly, the production of fish (31, 57). While there have been many studies on the relationships of phosphorus in solution and lake sediments, there has been little work on the relationships of phosphorus and sediments in river systems, which are generally more oxygenated than lakes.

The purpose of this paper is 1) to investigate the relationships between the water, sediment and phosphorus in the Gallatin River and three of its tributaries, 2) determine whether the local sediments are a source or a sink for phosphorus, 3) identify the minerals that control the solubility of phosphorus and 4) to estimate the amount of phosphorus available from sediments for biological activity.

LITERATURE REVIEW

The surface and precipitation reactions of phosphorus as PO_4^{-3} with lake sediments have been studied by numerous workers (6, 8, 9, 10, 13, 16, 17, 18, 29, 31, 32, 45, 47). These same reactions have been studied in soils, and many similarities have been found (5, 18, 21, 38, 41, 42, 52, 53, 56, 59). The investigation of phosphorus and its relationships to river sediments has received little attention.

It has been found that iron and aluminum are the factors which contribute most to the sorption of orthophosphate by soils and sediments with calcium being of lesser importance (5, 9, 16, 17, 18, 21, 41, 42, 43, 44, 45, 52, 53, 56, 61). Frink, (9) in a study of the sediment of a eutrophic Connecticut lake, found that iron and aluminum phosphates are converted to calcium phosphates. Dunbar and Baker (5) found the forms of phosphate to be in the following order of activity: water soluble PO_4 > aluminum phosphate > iron phosphate > calcium phosphate. If this ranking is used for sediments it means that the phosphorus in the sediments becomes less available as the sediments age in calcareous systems. Harter (17) found two types of bonding of phosphorus in lake sediments. The first type was water soluble and loosely bound and the second tightly bound and related to the aluminum. In a later paper, Harter (18) associated the initial loosely bonded phosphorus with organic matter anion exchange sites. He found there was a subsequent conversion of this phosphorus to aluminum phosphates. Hsu (21) determined that iron and aluminum fixed in soils phosphorus in a form that was not tightly bound with a later conversion to a more tightly bonded form in soils. This finding may indicate an increase in the degree of organization of amorphous aluminum and iron oxides in the soil upon drying. This type of reaction would not be expected to occur in water-logged sediment.

Anaerobic conditions influence the solubility of phosphorus. According to Li, et al. (31), anaerobic conditions promoted the release of phosphate from bottom sediments. The remaining phosphorus was not as exchangeable as that in aerobic sediments. Similar results were reported by White and Beckett (59). They found that anaerobic conditions raised the equilibrium concentrations in solution of phosphate in their sorption isotherm studies. In anaerobic sediments, it was found by Li, et al. (32), that 19 to 43 percent of the phosphorus was exchangeable. These values are considerably higher than those for soils or aerobic sediments.

Syers, et al. (52), found two types of "non-exchangeable" inorganic phosphorus in soils, namely 1) that associated with the mineral lattice and 2) that bonded to sesquioxides. Ramula, Pratt and Page (41) found that the interlayer iron of vermiculite is not involved in phosphate fixation. This was attributed to the formation of large iron hydroxy polymers which prevented the entrance of phosphate into the interlayer spaces of vermiculite. Frink's study (7) of the mineralogy of lake sediments indicated that in a neutral lake environment there is a slow decrease in the amount of chlorite with a corresponding increase in vermiculite and illite. This indicates a transformation in the lake of chlorite to illite with vermiculite as an intermediate. Hall and Baker (13) made a study of the ability of montmorillonite and vermiculite to sorb phosphates under different conditions. They found that the amount of phosphate fixed by montmorillonite increased with increasing pH and the amount fixed by vermiculite decreased with increasing pH in the range from four to seven. They attributed the decrease in phosphate sorption by vermiculite with increasing pH to the formation of aluminum hydroxy polymers similar to those found for iron which block the penetration to the interlayer spaces of vermiculite and reduce the surface area available for reaction. Montmorillonite had a greater ability to fix phosphorus and the phosphorus sorbed by montmorillonite was more readily exchangeable than that fixed by vermiculite.

The organisms in an aquatic environment must compete with the sediment for phosphorus. Fitzgerald (6), in a study of aerobic lake sediments, found that sediments in dialysis tubing were able to sorb up to 85 percent of added phosphorus from an algal growth medium. Sorption of such large amounts of phosphorus by the sediments retarded the growth of the algae in this study. Frink's analysis of the nutrient budget of an eutrophic lake (8) shows that the sediments must provide phosphorus to support the amount of aquatic plant life found in the lake. Pomeroy, et al., (40) calculated zooplankton could supply only one-third to one-tenth of the needed phosphorus in an aquatic system through excretions and decay of dead organism. Harrison, et al., (16) were able to isolate a number of bacteria from aerobic lake sediments with the ability to solubilize inorganic phosphates. They were able to place the types of inorganic phosphates in the following order of ease of solubility for the bacteria:

$$CaHPO_4 > Ca_3(PO_4)_2 > FePO_4 > Mg_3(PO_4)_2 > Al_2(PO_4)_2$$

This is a complete reversal of the order of availability determined by Dunbar and Baker (5) in the absence of microbial activity. However, the importance of bacterial action in providing soluble phosphorus has not been evaluated nor have the presence of bacteria which can solubilize phosphorus been shown in streams.

The rate of reaction of phosphorus with sediments has been found to be quite rapid. Fitzgerald (6) found that most of the phosphorus sorbed by his aerobic sediments had been taken up in three hours. Iron-bonded phosphorus has been found to be more slowly exchanged than aluminum-bonded phosphorus. Tandon and Kurtz (53) reported that iron-bonded phosphorus was 1.11 to 2.80 times slower in exchange than that bonded to aluminum and that as much as one-half to two-thirds of the iron- and aluminum-bonded phosphorus was not exchangeable under aerobic conditions. Kuo and Lotse (28) demonstrated with both aerobic and anaerobic sediments that well over half of the phosphorus that can be sorbed by a sediment will be taken up within three hours and by 48 hours phosphorus sediment suspension will be very near equilibrium. The importance of rapid sorption of phosphorus was demonstrated by Taylor and Kunishi (55). They were able to show that high levels of phosphorus entering the river from a pig farm were sorbed within one mile of the source by stream banks and river bottom sediments. They also demonstrated that phosphate sorption by the streambanks and bottom sediments played an important role in reducing the dissolved phosphorus lost from agricultural areas. The importance of streambanks and bottom sediments in the removal of dissolved phosphorus from streams has not been demonstrated in other watersheds and may be important only in special situations.

Ryden, et al., (43, 44) have shown that the sediment in a stream can be an important source of phosphorus. It was found that sediments derived from the A and B horizons of the soils studied released significant amounts of phosphorus to the water while the sediments from calcareaous C horizon released very little phosphorus and, in fact, was able to reduce the amount dissolved in the water. A study of mixtures of the different horizons showed that calcium released from the C horizon sediments reduced the amount of phosphorus released by the A and B horizon sediments.

It has been shown that sediments can both provide dissolved phosphorus to, and remove it from, water. The sesquioxides and calcium have the greatest ability in sediments and solids to remove phosphorus from solution. The biotic community in a stream or lake must, in most cases, compete with the sediments for the phosphorus it needs. It is probable that saprophytic organisms such as bacteria are necessary in an aquatic environment to release phosphorus from sediments to achieve algal blooms in lakes and ponds. Phosphorus in many systems is the element which limits the production of an aquatic environment. Increasing development by man will, in many cases, increase the sediments carried by streams (2). The influence of sediments on phosphorus in solution will be of increasing importance.

DESCRIPTION OF THE STUDY AREA

Drainage and topography

The Gallatin River, located in Gallatin County, southwestern Montana, drains an area of about 1800 square miles (51). The Gallatin River is part of the geologic entity known as the Madison-Gallatin uplift (14). Originating in the northwestern part of Yellowstone Park, the river flows north through 40 miles of intermountain valleys between the Madison and Gallatin Ranges before entering the Gallatin Valley near the town of Gallatin Gateway. The river then flows northwest across a gently sloping valley floor for 28 miles before it leaves the valley through a small gorge near Logan. The elevation of the river varies from 6800 feet to 4100 feet with a variation of the surface gradient from 100 feet per mile at the southern end to less than 40 feet per mile in the valley (12).

Climate

The area drained by the Gallatin River experiences long cold winters with large fluctuations in daily and seasonal temperatures. The mean annual temperature is 35°F in the upper valley, and 42°F near Bozeman (14). The frost-free period is 40-60 days in the upper portion of the drainage and 90-100 days in the valley near Gallatin Gateway. The northwest section of the valley receives 12 to 14 inches of precipitation annually, while the southeastern area of the lower valley experiences 20-24 inches annually. The mountainous areas may receive in excess of 60 inches of precipitation mostly in the form of snowfall

(14). Snowmelt occurs in April, May, and June, which is the period with the greatest production of sediment. The water in the river is generally clear by the end of June, indicating that most of the snow has melted.

Geology

The whole Gallatin drainage can be divided into four geological units (20). The first unit, extending from Yellowstone Park to the mouth of West Fork, has been described in detail by Hall (14). In this unit, the Gallatin River flows through mostly Cretaceous age sedimentary rocks (65 million to 135 million years old). The upper part of this unit is late Cretaceous undifferentiated rocks. The rocks are soft, highly erodible shales, sandstones, and mudstones and are a likely source of sediments carried by the river in this area during periods of heavy rainfall and rapid snowmelt. Taylor Fork, which was determined by Hsieh (20) to be the major sediment contributor to the Gallatin River, drains part of this unit. The Taylor Fork drainage is subject to landslides with slope instability evident throughout the drainage. In addition to Cretaceous sediments, a few older sediments of late Paleozoic or early Mesozoic Age (200 million to 350 million years old) are in the Taylor Fork area.

The lower part of the first unit, from Buck Creek to West Fork, is dominated by the Kootenai Formation (early Cretaceous age). The upper and lower strata of the Kootenai formation consist of quartzitic sandstone while the middle is made up of erodible shale. Colorado shale and highly weathered sills also occur in this area. Both West Fork and Taylor Fork drainages show evidence of landslides and slope instability. Glacial deposits occur throughout this unit.

The second geological unit extends from West Fork to Spanish Creek. A detailed geological study was made of this area by Mifflin (35). Outcrops of Precambrian rocks are common in the area with some sedimentary rocks of Cambrian and Devonian ages (370 million to 600 million years old). The rocks in this area are hard and resistant to weathering and erosion. There are no major tributaries of the Gallatin River in this unit, but there are a number of small creeks. This unit is not an important source of sediment to the Gallatin River (20).

The third geological unit is an extensive area lying east of the Gallatin River. The rocks found in this unit are generally younger than those in units one and two. McMannis and Chadwick (34) found that volcanic rocks overlie Precambrian metamorphic rocks. Paleozoic-Mesozoic sedimentary rocks cap the higher ridges including the Gallatin Range.

The Gallatin Valley comprises the fourth geologic unit. The East Gallatin River and a number of smaller tributaries enter the Gallatin River in this unit. The unit is bounded on the north by the Horseshoe Hills and extends southward to the Gallatin Gateway area. Hackett, et al. (12), made a detailed study of the area. This unit consists of alluvium and fans with a tertiary outcrop in the Camp Hills, Dry Creek area. With the exception of the Dry Creek area, the alluvium and fans are of Quaternary age varying in thickness from 10 to 400 feet. Many of the hills are mantled with buff colored calcareous silt.

Soils

The soils of the Gallatin drainage can be divided into two groups, the upland soils of the Gallatin Canyon area, and the alluvial soils of the Gallatin Valley north of Gallatin Gateway (49).

Aasheim (1) estimated that 50 percent of the sediment carried by Porcupine Creek, which is located in the Gallatin Canyon, was attributable to landslides and earthflows into the stream channel with another 25 percent due to streambank erosion. A study of the same area by Sollid (47) indicated that the Garlet-Loberg soil association was predominant on the slide areas in the Porcupine drainage. A comparison of the surface geology maps prepared by Hall (14) and Goolsby, et al., (11) with the map of soil associations prepared by Olsen, et al., (36) shows the same trend throughout the areas drained by Taylor Fork and West Fork. In addition to the Garlet-Loberg association, the Loberg, Teton-Garlet, and to a lesser extent, the Leavitt-Loberg associations (for more detail, see Olsen, et al., 36) are found in the landslide areas. This indicates that patterns of sediment production similar to that found in the Porcupine drainage can be expected in Taylor Fork and West Fork. The Loberg soil series, which is found on many of the slopes in the area of over 30 percent, is the soil that is most common in unstable areas at elevations below 8100 feet.

Klages and McConnell (26) found that the locally named soil series, Carrot and Wapiti, were highly eroded and had sparse ground cover due to late snowmelt. Intense pocket gopher activity had aggravated the erosion problem in the Carrot Basin area where this study was conducted. The Carrot Basin ranges in elevation from 9100 to 9475 feet and is drained partly by Taylor Fork.

The Bigel-Hobacker association is found throughout the Gallatin Canyon adjacent to the Gallatin River and its tributaries (36). The gravelly alluvial soils of this association are the most common material making up the streambanks and therefore are the material most likely to be removed by streambank erosion. Bigel, Bearmouth, Hobacker and Michelson soils are found on stream terraces. These soils are subject to streambank erosion in areas where the streams have cut through the alluvial materials and are eroding stream terraces. Hsieh (20) determined that erosion of streambanks in the Gallatin River above Gallatin Gateway is not of major importance in the sediment load of the river.

The increase in the amount of suspended solids in the lower valley found by Hsieh (20) was determined to be from locally derived erosion.

When the topography of the lower valley is considered streambank erosion would appear to be of major importance in this area. Along the Gallatin River is found the material described as riverwash by DeYoung and Smith (4). In a few places, soils of the Havre series may also be found.

Along the East Gallatin River, soils of the Gallatin, Minatare, Beaverton and Bridger series are found in addition to the riverwash material. Hsieh's (20) study of the sediments in the East Gallatin River indicates that these sediments are eroded from soils developed on alluvial material originating in the Rocky Creek drainage and that local erosion is an important source of suspended solids in the East Gallatin River.

Hsieh (20) was not able to distinguish between sediments from streambank erosion, and erosion from agricultural and urban areas. At present, there are no data on the relative importance of sediments derived from these three areas in the Gallatin Valley.

MATERIALS AND METHODS

Nine sampling sites were located on the Gallatin River and its tributaries. The site farthest upstream was located at the first bridge north of the Yellowstone Park boundary on U. S. Highway 191 and will be referred to simply as the Park Boundary. Samples were taken from Taylor Fork and West Fork where they are crossed by U. S. Highway 191. The highway in this area runs adjacent to the Gallatin River so that the samples were taken within 1/4 mile above the mouths of the two streams. The Gallatin River was sampled approximately two miles below Taylor Fork from the access bridge of the 320 Ranch just off Highway 191, and from the highway bridge two miles below West Fork. A sampling site near the Gallatin National Forest Boundary seven miles south of Gallatin Gateway was used. This site was at a permanent Forest Service sampling station and will be referred to as the Forest Service site. Samples were taken from bridges over the East Gallatin and Gallatin Rivers where they are crossed by Montana Highway 346. These sites will be referred to as East Gallatin and Manhattan, respectively. The farthest downstream site sampled was located at the bridge where Montana Highway 286 crosses the Gallatin River, one mile below the town of Logan. This site will be referred to as the Logan site.

The four lower locations (i.e., Logan, East Gallatin, Manhattan, and Forest Service) were sampled twice each year during the early spring before there was any appreciable runoff from snowmelt in the higher elevations of the study area. In addition, all nine locations were sampled twice, one in May and once in June of each year, when runoff from snowmelt was contributing sediment to the stream, and twice during the late summer and fall in both years of the study during low flow.

Five gallon water samples were collected using a galvanized steel pail attached to a rope. The pail was lowered from a bridge located at the sampling site. A pole sampler was used at the Forest Service site because there is no bridge at this location. All samples were taken from just below the surface of the water.

The samples were placed in five gallon plastic bottles for transport. The sediment was removed from the water by filtration with ceramic filter candles rated at 10 to 16 pounds. One gallon of the clear water was retained for chemical analysis. The filtered water from some of the 1972 samples was checked for suspended solids with a nephelometer. Because all of these checks showed that there were no suspended solids in the filtered water, no checks were made on 1973 samples.

The sediments were collected by washing the filter candles with distilled water and the sand removed by use of a 44 μm sieve. The concentrated sediments were then diluted to 500 ml and a 25 ml aliquot of the suspension was oven-dried to determine the concentration.

A separate one liter sample was used to determine the amount of suspended solids. In 1972, a Jackson turbidity meter was used to estimate the suspended solids by means of a regression equation which had been calculated previously (25). In 1973, the suspended solids were determined by Jackson turbidity meter and gravimetrically. For the gravimetric determination the one liter sample was allowed to settle and the water was siphoned off. The solids were collected, oven-dried, and weighed.

Total dissolved solids were estimated by measurements of the specific conductivity of the filtered water. The concentration of specific ionic species in the filtered water were also determined. The cations Mg^{+2} and Ca^{+2} were determined using an atomic absorption spectrophotometer. Na^+ and K^+ were included in the analyses in 1973 only. All cation measurements were made with 0.5 percent Sr in the form of $SrCl_2$ in solution to reduce interference from other ions.

Titration with sulfuric acid was used to measure HCO_3^{-3} (39, p. 82-85). The determination of Cl^- was made by titration with $AgNO_3$ using K_2CrO_4 as the indicator (39, p. 85-87). Sulfate was measured in 1973 only, and the determination was made turbidimetrically (39, p. 291-292). Dissolved phosphorus in the form of PO_4^{-3} was determined at the wave length of 882 nm with a 10 cm path length using the color development presented by Watanabe and Olsen (58).

Total phosphorus and $NaHCO_3$ extractable phosphorus were determined for selected sediment samples. Samples were selected on the basis of the amount of sediment available. Some of the five gallon water samples yielded less than 100 mg of sediment.

A subsample of 0.1 g of sediment was used to determine total phosphorus. An aliquot was dried and weighed and then fused with Na_2CO_3 (22). The phosphorus was determine colorimetrically with a 2.5 cm path-length cell. The color development was the same as described above after adjustment to pH 5 with 1 N H_2SO_4 (58).

The sediment subsamples used for $NaHCO_3$ extraction were not dried. The sediment was flocculated using $CaCl_2$ and centrifuged. The supernatant liquid was decanted and the extracting solution added. The extracting method used was that of Olsen and Dean (37) and the color-development was the same as that used for Na_2CO_3 fusions (58).

Phosphate sorption isotherms were run on those samples from 1972, which had enough sediment for study. Initial concentrations of 2, 1, 0.5, 0.2, 0.1 and 0.05 mg/l of P as PO_4 were employed with a sediment concentration of 1000 mg/l. The sediment was separated from the suspension by flocculation as described above. All solutions had a final concentration of 0.01 N $CaCl_2$. The phosphate sediment suspensions were shaken for 48 hours and the concentration of phosphorus in solution determined in the same manner as the filtered water. This procedure was not repeated on 1973 samples.

To obtain an estimate of biologically available phosphorus

Rhizoctonia solani Kuhn, an imperfect mycelial fungus, was grown for fifteen days in phosphate deficient Czapec's solution (46) containing sediment. The potassium lost by the deletion of K_2HPO_4 from the solution was replaced by the addition of KCl. Sediment concentrations of 1000 and 2000 mg/l were used and the results evaluated against growth of the organism in solution of known phosphorus concentration. The fungal growth was washed, oven-dried, weighed, and ignited (15). Loss of weight on ignition was used as the measure of growth.

The measurement of particle size distribution by standard procedures proved to be highly unreliable. Therefore, a combination of x-ray diffraction and surface area was used to estimate the relative content of silt and clay in the sediments. The surface area was measured using 1, 10 phenanthroline in the procedure detailed by Lawrie (30). The sediments used for this procedure were not dried, but were separated by flocculation as before. To determine the concentration of 1, 10 phenanthroline in solution colorimetrically the aliquot used was reduced from 5 ml in 25 ml to 0.5 ml in 100 ml.

X-ray diffraction patterns were obtained with a General Electric XRD-5 X-ray diffractometer using a copper target tube. The separation of the silt and clay fractions was accomplished by centrifugation after dispersion with Na_2CO_3 and ultrasonic generator. Centrifuge times were determined from the nomographs of Tanner and Jackson (54). The clay fraction was saturated with Mg^{+2} (24), mounted on glass slides and air dried. The samples were then saturated with ethylene glycol by condensation (27). The silt fractions were mounted on glass slides and air dried. X-ray diffraction patterns were obtained from the silt and clay fractions of the selected 1973 samples.

RESULTS AND DISCUSSION

Weather

The weather conditions immediately prior to sampling are shown in Tables 1 and 2. The temperatures during March and April of both years were cooler in the canyon than those in the Gallatin Valley near Bozeman. Although there were temperatures above freezing during the period, the clarity of the Gallatin River at the Forest Service site shows that snowmelt in the Gallatin Canyon was not rapid enough to cause significant erosion. The readings from the Jackson turbidity meter, shown in Table 4 were less than 25 JCU* for samples taken during March and April of both years at the Forest Service site. During this period only the East Gallatin River and Logan, which is below the East Gallatin River, had readings above 25 JCU. During the period of May and June daily maximum temperatures were greater than 70°F in the Gallatin Canyon (Tables 1 and 2). The turbidity of the Gallatin River at the Forest Service site was between 40 and 111 JCU, which indicates that the snow in the Gallatin Canyon was melting at a rate sufficiently rapid to cause erosion. There was also a noticeable rise in the level of the river at the four downstream sampling sites as well as an increase in the turbidity as shown in Table 4. In the period from late August to mid-October daily maximum temperatures ranged from 56 to 78°F. The level of the river was well below the levels observed during May and June because

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* JCU = Jackson Candle Unit

Table 1. Precipitation (inches per day) and air temperatures (°F) prior to sampling in 1972.

	Days before sampling							
	0		1		2		3	
	*Sta 1	Sta 2	Sta 1	Sta 2	Sta 1	Sta 2	Sta 1	Sta 2
March 23, 1972								
Precip.	.35						.11	.19
Max. temp.	71	45	71	56	59	49	51	43
Min. temp.	33	31	28	23	27	20	32	26
April 13, 1972								
Precip.	.24	.25		.15	.07			
Max. temp.	50	38	53	47	52	46	50	42
Min. temp.	29	27	35	27	32	30	29	22
May 16, 1972								
Precip.	.02						.01	
Max. temp.	80	74	81	72	79	72	71	63
Min. temp.	48	30	42	25	44	40	37	36
June 6, 1972								
Precip.		.43			.06		.10	.03
Max. temp.	81	78	79	76	72	71	74	69
Min. temp.	49	32	44	35	47	35	50	37
September 6, 1972								
Precip.	.28	.48	.08	.12				
Max. temp.	61	53	70	70	75	76	74	78
Min. temp.	43	35	42	32	39	30	41	33
October 19, 1972								
Precip.								
Max. temp.	55	56	57	59	57	60	57	57
Min. temp.	28	24	28	24	34	26	31	29

* Station 1 -- Agr. Exp. Station 6 mi. West of Bozeman
Station 2 -- Beaver Creek 26 mi South-Southwest of Gallatin Gateway

Table 2. Precipitation (inches per day) and air temperatures (°F) prior to sampling in 1973.

	Days before sampling							
	0		1		2		3	
	*Sta 1	Sta 2	Sta 1	Sta 2	Sta 1	Sta 2	Sta 1	Sta 2
March 16, 1973								
Precip.					.05	1.30	.06	
Max. temp.	50	41	42	40	38	33	38	36
Min. temp.	26	29	20	8	21	19	15	7
April 18, 1973								
Precip.	.28		.39	.20	T	.03	T	
Max. temp.	44	36	49	42	49	45	43	44
Min. temp.	30	22	32	26	28	18	6	2
May 17, 1973								
Precip.								
Max. temp.	78	73	80	75	79	73	72	69
Min. temp.	48	30	47	29	43	26	40	23
June 11, 1973								
Precip.			.01		T			
Max. temp.	68	69	69	70	80	80	80	75
Min. temp.	37	30	39	36	49	39	46	39
August 29, 1973								
Precip.			.14	.14	T	.03		
Max. temp.	80	78	76	73	78	73	82	78
Min. temp.	40	31	40	34	41	35	38	40
October 6, 1973								
Precip.								
Max. temp.	69	61	73	66	63	61	51	57
Min. temp.	29	24	28	17	25	21	24	32

* Station 1 -- Agr. Exp. Station 6 mi. West of Bozeman
Station 2 -- Beaver Creek 26 mi South-Southwest of Gallatin Gateway

little snow remained in mountainous areas of the drainage. The suspended solids during this period decreased as seen in Table 4 and Figure 3. A rain storm prior to the collection of samples on September 6, 1972 caused a large increase in the suspended solids in the Taylor Fork sample taken on that date. This increase was still apparent at the location below West Fork where the turbidity measured 61 JCU. All other samples taken in the period from late August to mid-October read less than 25 JCU.

Water

The summary of analysis of the filtered water samples is shown in Table 3. The values shown are averages of the months specified for both years. The predominant ions in the water of the Gallatin River were Ca^{+2} and HCO_3^-. The concentration of Ca^{+2} exceeded the sum of all other cations measured and HCO_3^- exceed all other anions measured. The sum of cations agreed well with the sum of anions and indicates that the analyses are accurate.

Figure 1 shows the change in conductivity on the Gallatin River from the Park Boundary to Logan. The points not on the lines are the values for the tributaries. The conductivity increased between the Forest Service site and Logan during all periods. During the periods May-June and August-October the conductivity decreased between the Below West Fork and Forest Service sites. This is probably due to dilution of the water in the Gallatin River by purer water entering the river from streams draining the Spanish Peaks area. The peak found in

Table 3. Summary of analysis of filtered water samples from the Gallatin River collected in 1972 and 1973.

	*Na	*K	+Ca	+Mg	+HCO_3	*Cl	*SO_4	†conductivity
				me/l				µmhos/cm
March-April								
Logan	0.50	0.09	2.14	0.79	3.35	0.13	0.74	383
East Gallatin	0.43	0.09	2.88	0.80	3.87	0.12	0.38	383
Manhattan	0.33	0.07	2.18	0.73	2.67	0.03	1.10	344
Forest Service	0.31	0.07	1.99	0.72	2.34	0.04	1.20	314
May-June								
Logan	0.12	0.06	1.69	0.40	2.08	0.03	0.32	214
East Gallatin	0.29	0.06	1.99	0.56	2.79	0.04	0.32	277
Manhattan	0.21	0.05	0.99	0.37	2.11	0.05	0.32	195
Forest Service	0.10	0.05	1.49	0.29	1.48	0.03	0.26	150
Below West Fork	0.13	0.05	1.29	0.40	2.29	0.03	0.38	199
West Fork	0.10	0.05	0.98	0.24	1.31	0.04	0.22	130
Below Taylor Fork	0.28	0.05	1.58	0.41	2.02	0.02	0.34	204
Taylor Fork	0.36	0.04	1.51	0.35	2.03	0.03	0.30	209
Park Boundary	0.10	0.06	1.53	0.43	1.89	0.03	0.40	202
August-October								
Logan	0.51	0.10	2.41	0.83	3.78	0.14	0.62	394
East Gallatin	0.47	0.08	3.03	0.84	4.02	0.14	0.40	399
Manhattan	0.35	0.07	2.40	0.67	2.65	0.05	0.76	319
Forest Service	0.30	0.05	1.94	0.63	2.07	0.05	0.82	275
Below West Fork	0.35	0.05	2.47	0.82	2.32	0.07	1.44	374
West Fork	0.35	0.04	2.33	0.48	2.53	0.04	0.38	248
Below Taylor Fork	0.32	0.05	1.90*	0.68*	2.53*	0.04	0.84	332*
Taylor Fork	0.55	0.05	2.16	0.55	2.88	0.06	0.76	319
Park Boundary	0.16	0.05	2.15	0.68	2.48	0.04	0.88	291

* Measured in 1973 only.
† Measured in 1972 and 1973.

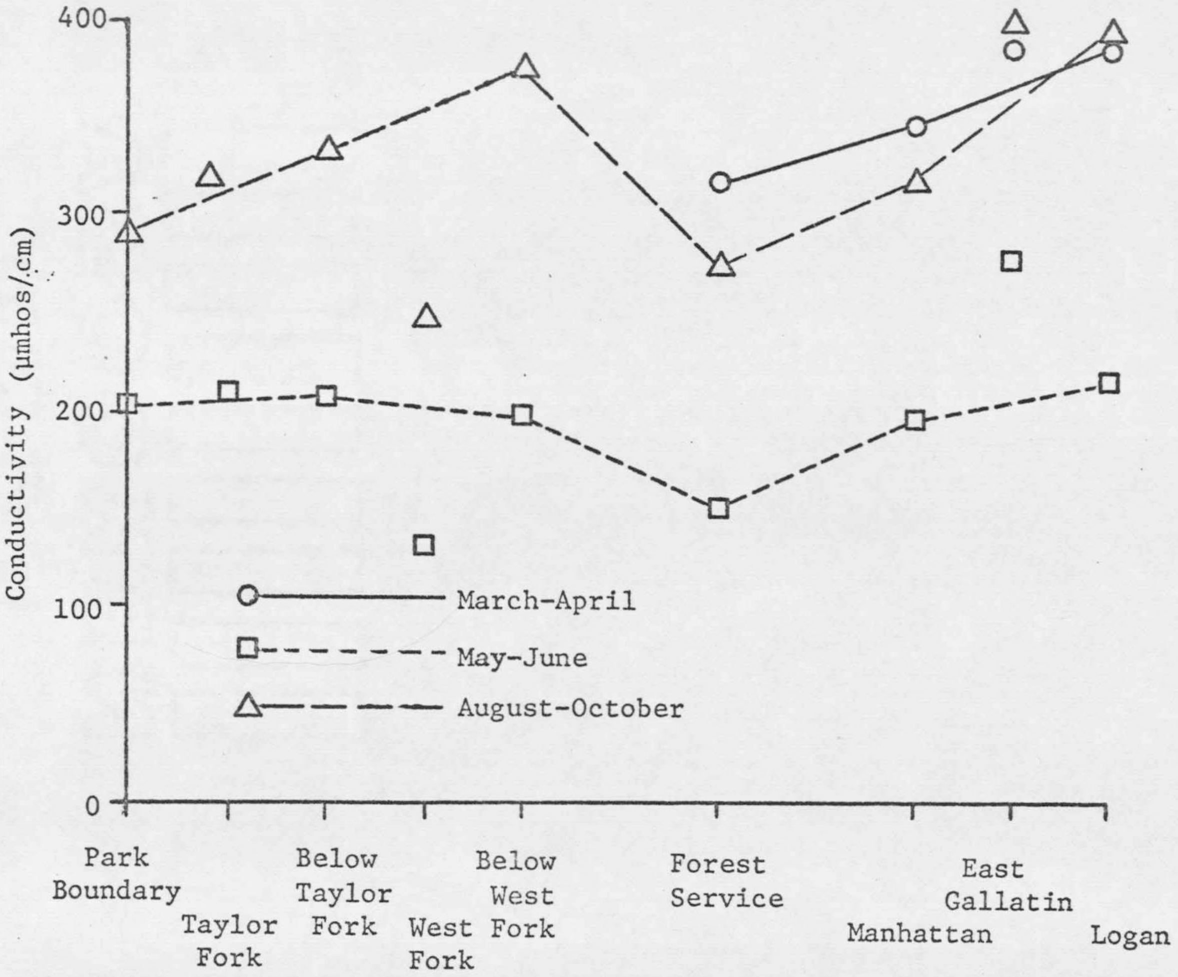

Figure 1. Conductivity vs. location on the Gallatin River.

the conductivity below West Fork during August-October may be the result of water entering the Gallatin River from springs in the area around the mouth of West Fork, which are higher in dissolved solids.

The East Gallatin site was higher in conductivity than the Gallatin River during all three periods, while West Fork samples were lower in conductivity. Taylor Fork had nearly the same conductivity as the Gallatin River. The higher conductivities shown in Figure 1 for the East Gallatin site may be due to the addition of salts by sewage effluent and runoff from agricultural areas.

The conductivity was lower during the May-June period than during periods of lower flow. The reduction in the concentration of dissolved solids during periods of high flow, as indicated by the conductivity, is similar to the findings of Hsieh (20). He attributed the decrease in dissolved solids to dilution of water derived from ground water sources by water from snowmelt and rainfall.

The concentrations of ionic species shown in Table 3 had trends similar to those of the conductivity with the exception of SO_4^{-2}. That is, a peak below West Fork and an increase between the Forest Service site and Logan. Concentrations were lower in May and June than during other periods.

Figure 2 shows the change of SO_4^{-2} concentration with location on the Gallatin River. Between the Forest Service and Logan sites, the SO_4^{-2} concentration decreased in contrast to the conductivity. There is

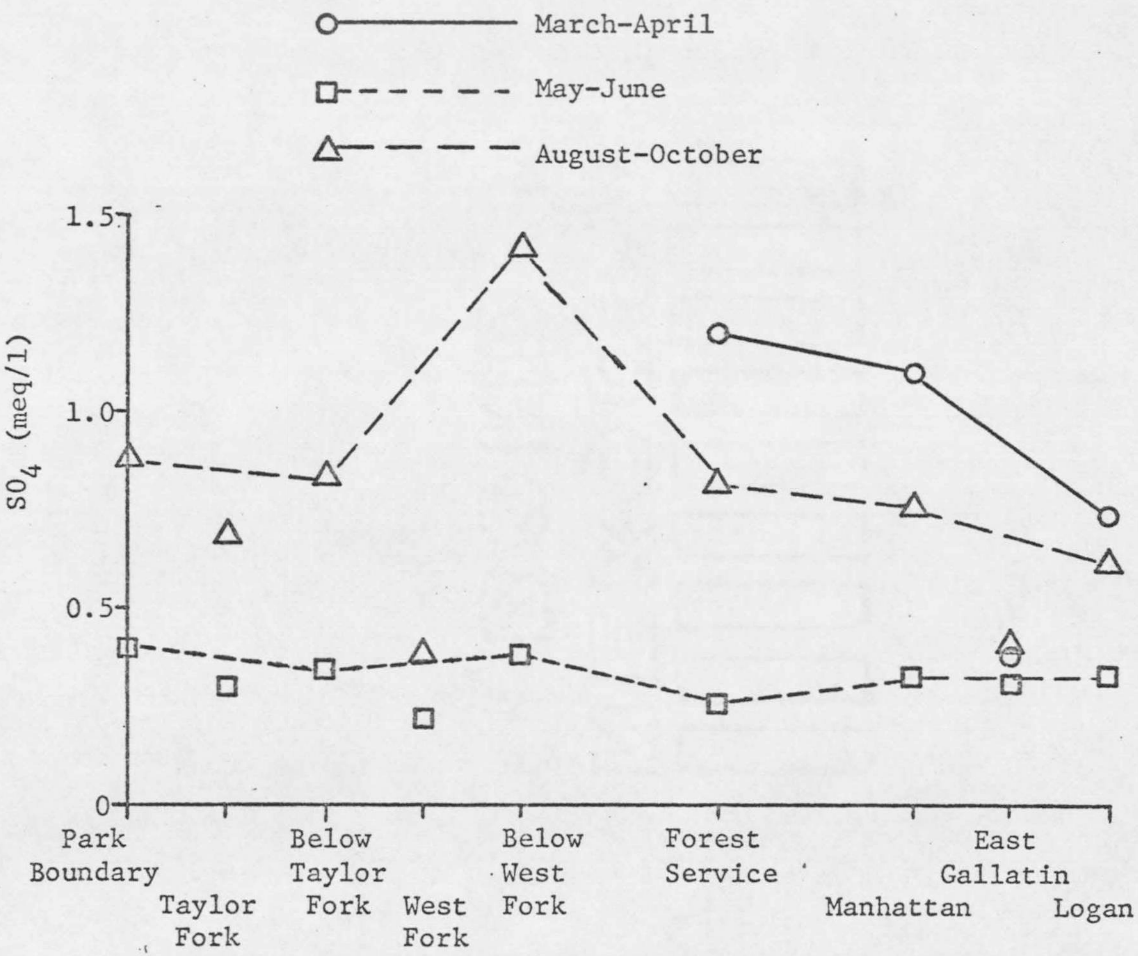

Figure 2. Sulfate concentration vs. location on the Gallatin River.

a peak in Figure 2 at the Below West Fork site during both May-June and August-October periods. The East Gallatin, West Fork and Taylor Fork samples were lower than the Gallatin River in SO_4^{-2} during all periods. The May-June line shows that the concentration of SO_4^{-2} was lower during this period and that there was little fluctuation in concentration. The lower concentration of SO_4^{-2} corresponds to the lower conductivity in the same period in Figure 1.

The pH of the filtered water samples was read after the samples had been allowed to stand for several days which allowed the samples to equilibrate with the CO_2 in the atmosphere. The pH's of the samples had an upper limit of 8.5, the upper limit of $Ca(HCO_3)_2$ solutions. The pH readings, for a set of samples taken in June of 1974, were made on the same day the samples were collected. These samples had a range of 6.4 to 7.0. The lower pH values in fresh samples is the result of supersaturation of the water with CO_2.

Table 4 shows the results of turbidity measurements as well as estimated and gravimetrically determined suspended solids. Figure 3 is a plot of the average values of suspended solids from Table 4, averaged for the months indicated and for both years of the study. As can be seen from Figure 3 the suspended solids increased between the Forest Service site and Logan during all three periods. The peak seen at the Below West Fork site in the August-October period is due to increased sediment from Taylor Fork caused by the rain storm preceding the

Table 4. Turbidity and suspended solids of water samples collected from the Gallatin River in 1972 and 1973.

Month and Location	Turbidity 1972 Total	Turbidity 1972 Silt and Clay	Turbidity 1973 Total	Turbidity 1973 Silt and Clay	Suspended Solids 1972 Total*	Suspended Solids 1972 Silt and Clay*	Suspended Solids 1973 Total*	Suspended Solids 1973 Silt and Clay*	Suspended Solids 1973 Gravimetric
	JCU				ppm				
March									
Logan	<25		<25		<64		<64		48
East Gallatin	40	52	36	33	93	76	85	52	62
Manhattan	– +	–	<25		–	–	<64		20
Forest Service	<25		<25		<64		<64		0
April									
Logan	<25		48	40	<64		109	61	100
East Gallatin	<25		75	72	<64		161	101	168
Manhattan	<25		<25		<64		<64		32
Forest Service	<25		<25		<64		<64		28
May									
Logan	175	205	280	272	355	269	559	353	552
East Gallatin	280	255	280	275	559	332	559	357	540
Manhattan	190	192	185	185	384	252	375	244	382
Forest Service	111	123	100	94	231	165	210	129	206
Below West Fork	100	107	90	88	210	145	191	121	192
West Fork	78	78	105	100	167	109	219	136	208
Below Taylor Fork	–	–	100	98	–	–	210	134	212
Taylor Fork	102	105	160	160	213	143	326	212	324
Park Boundary	27	26	40	36	68	43	93	56	92

Table 4. Continued.

Month and Location	Turbidity				Suspended Solids				
	1972		1973		1972		1973		
	Total	Silt and Clay	Total	Silt and Clay	Total*	Silt and Clay*	Total*	Silt and Clay*	Gravi-metric
	JCU				ppm				
June									
Logan	175	160	135	131	355	212	278	175	270
East Gallatin	84	85	65	65	179	117	148	92	150
Manhattan	170	158	120	115	345	209	248	155	230
Forest Service	93	95	40	37	196	130	93	57	92
Below West Fork	95	93	41	40	200	128	95	61	114
West Fork	59	53	<25		130	79	<64		64
Below Taylor Fork	94	98	40	38	198	134	93	58	118
Taylor Fork	195	190	85	80	394	250	169	111	180
Park Boundary	38	40	<25		89	61	<64		56
August-September									
Logan	<25		<25		<64		<64		18
East Gallatin	<25		<25		<64		<64		22
Manhattan	<25		<25		<64		<64		4
Forest Service	<25		<25		<64		<64		8
Below West Fork	61	58	<25		<64	58	<64		4
West Fork	<25		<25		<64		<64		8
Below Taylor Fork	-		<25		-	-	<64		2
Taylor Fork	142	150	<25		291	150	<64		8
Park Boundary	<25		<25		<64		<64		8

Table 4. Continued.

Month and Location	Turbidity 1972 Total	Turbidity 1972 Silt and Clay	Turbidity 1973 Total	Turbidity 1973 Silt and Clay	Suspended Solids 1972 Total*	Suspended Solids 1972 Silt and Clay*	Suspended Solids 1973 Total*	Suspended Solids 1973 Silt and Clay*	Suspended Solids 1973 Gravimetric
	JCU				ppm				
October									
Logan	<25		<25		<64		<64		25
East Gallatin	-		<25		-	-	<64		33
Manhattan	<25		<25		<64		<64		6
Forest Service	<25		<25		<64		<64		4
Below West Fork	<25		<25		<64		<64		5
West Fork	<25		<25		<64		<64		6
Below Taylor Fork	-		<25		-	-	<64		5
Taylor Fork	<25		<25		<64		<64		7
Park Boundary	<25		<25		<64		<64		2

* Calculated from equation developed by Klages et. al. (25).

\+ Sample not collected.

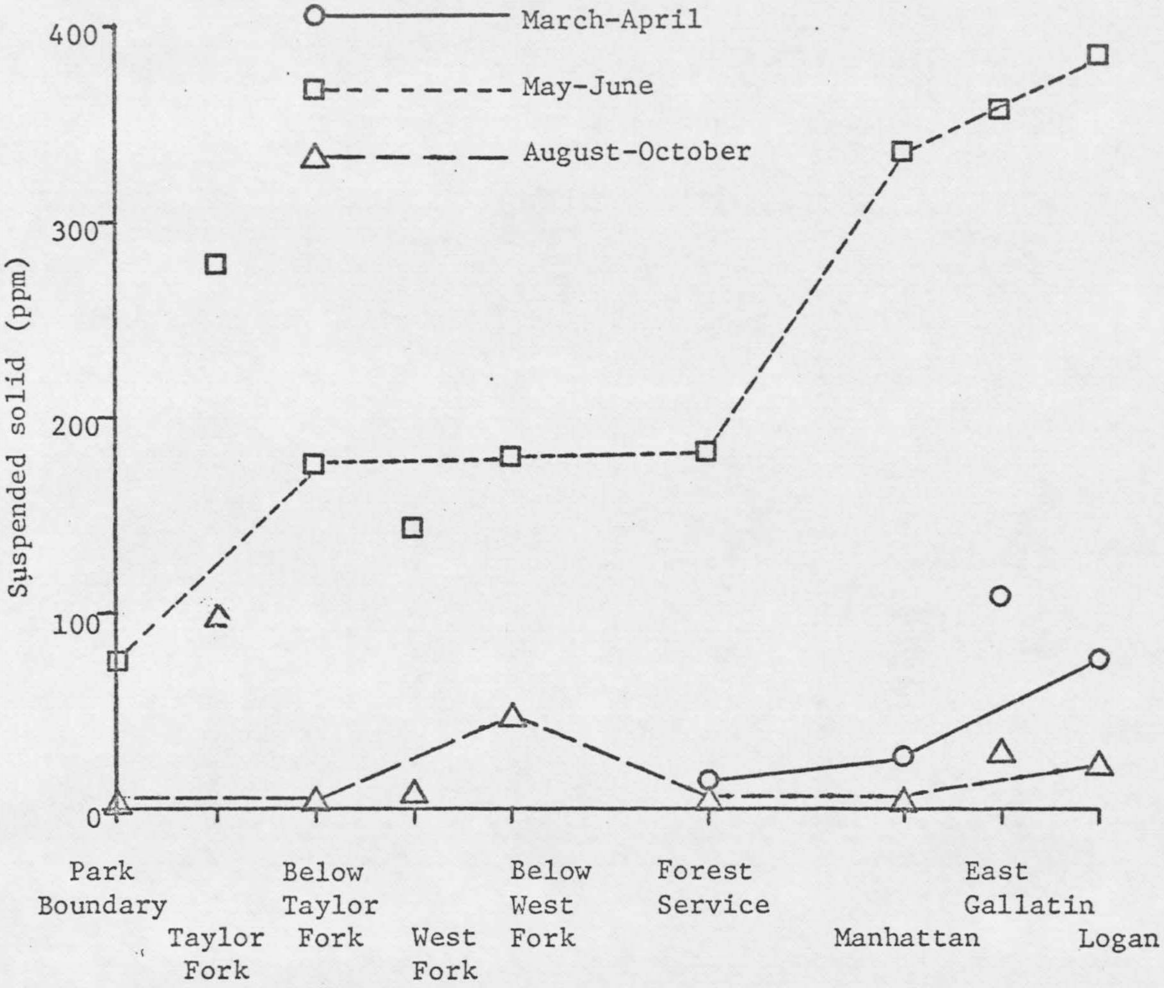

Figure 3. Suspended solids vs. location on the Gallatin River.

September 6, 1972 sampling date. This peak shows at the Below West Fork site and not at the Below Taylor Fork site because the site below Taylor Fork was not sampled on September 6, 1972. The East Gallatin site was higher in suspended solids than the Gallatin River both in the March-April and August-October periods. The rise in the suspended solids between Manhattan and Logan (Figure 3) is caused by the addition of suspended solids by the East Gallatin River. During the May-June period the East Gallatin site was near the concentration Gallatin River in suspended solids. The rapid rise in the concentration of suspended solids in the Gallatin Valley during the May-June period occurred between the Forest Service and Manhattan sites. This is probably due to channel cutting in this area during high flow.

In the Gallatin Canyon Taylor Fork was the major contributor of sediments to the Gallatin River. The rapid increase in the suspended solids between the Park Boundary and Below Taylor Fork in May-June line in Figure 3 is a result of the addition of sediments by Taylor Fork. There is only a slight increase in the sediment load of the Gallatin River during the May-June period from below Taylor Fork to the Forest Service. This small increase in the suspended solids indicates that bank erosion is not of major importance in the Gallatin Canyon. These findings are similar to those of Hsieh (20).

The pattern shown in Figure 3 for suspended solids in the Gallatin River is similar to that found by Klages et al. (25). That is, the highest sediment loads are found in the spring with Taylor Fork being the stream highest in the suspended solids in the Gallatin Canyon.

A comparison of Figures 1 and 3 shows that dissolved solids decreased when suspended solids increased. This is similar to the results found by Hsieh (20). The decrease in the concentration of dissolved solids associated with rapid snowmelt and rainfall also increases the erosion and therefore the concentration suspended solids.

Phosphorus in the water

Concentrations of dissolved phosphorus, phosphorus in sediments and $NaHCO_3$ extractable phosphorus are shown in Table 5. The average values of dissolved phosphorus for both years are plotted against the location on the Gallatin River in Figure 4. The East Gallatin River as shown by Figure 4 was higher in dissolved phosphorus than the Gallatin River during all periods while Taylor Fork was lower. The higher levels of phosphorus in the East Gallatin River may be due to additions of phosphorus by the Bozeman sewage treatment plant and runoff from agricultural land.

The May-June line in Figure 4 is above the August-October line and slightly above part of the March-April line. This is similar to the pattern followed by the suspended solids. The East Gallatin however, was higher in March-April and August-October than in May-June. This shows in the following regression equations relating dissolved phosphorus (DP) and total suspended solids (TSS) calculated

Table 5. Dissolved phosphorus and total and $NaHCO_3$ extractable phosphorus in sediments from samples collected from the Gallatin River in 1972 and 1973.

	1972		1973		
	Dissolved P	Content of P in sediments	Dissolved P	Content of P in sediments	$NaHCO_3$ Extracted P in sediments
	ppb	ppm	ppb	ppm	ppm
March					
Logan	54	1143	42	1134	
East Gallatin	114	1188	55	1031	
Manhattan			8	1031	
Forest Service	27		17		
April					
Logan	44	1109	63	1007	18.8
East Gallatin	140	1310	87	1093	37.6
Manhattan	12	859	24	2343	
Forest Service	18		24	692	
May					
Logan	51	866	6	889	20.2
East Gallatin	41	1033	29	1010	34.7
Manhattan	8	1119	28	880	18.3
Forest Service	31	880	26	793	15.6
Below West Fork	30	845	15	824	18.3
West Fork	5	1020	35	1023	1.8
Below Taylor Fork	20		16	727	11.5
Taylor Fork	19	687	6	671	19.2
Park Boundary	10	1076	23	963	16.0

Table 5. Continued.

	1972		1973		
	Dissolved P	Content of P in sediments	Dissolved P	Content of P in sediments	$NaHCO_3$ Extracted P in sediments
	ppb	ppm	ppb	ppm	ppm
June					
Logan	23	918	9	936	7.7
East Gallatin	67	1058	27	1145	21.4
Manhattan	17	868	14	1053	4.3
Forest Service	29	1194	15	869	8.8
Below West Fork	10	869	12	783	2.2
West Fork	29	1000	14	760	20.0
Below Taylor Fork	13	720	15	764	4.0
Taylor Fork	19	655	6	658	12.9
Park Boundary	19	1065	26	844	
August-September					
Logan	68		27	938	
East Gallatin	47	2422	69	915	
Manhattan	3		6		
Forest Service	20		10		
Below West Fork			8		
West Fork	11	1086	6	416	
Below Taylor Fork		530	9		
Taylor Fork	6		6		
Park Boundary	21		19		

Table 5. Continued.

	1972		1973		
	Dissolved P	Content of P in sediments	Dissolved P	Content of P in sediments	$NaHCO_3$ Extracted P in sediments
	ppb	ppm	ppb	ppm	ppm
October					
Logan	17		13	515	
East Gallatin	38	1240	34	1195	
Manhattan	3		6		
Forest Service	10		10		
Below West Fork	2		6		
West Fork	3		6		
Below Taylor Fork			9		
Taylor Fork	13	749	6	557	
Park Boundary	14		14		

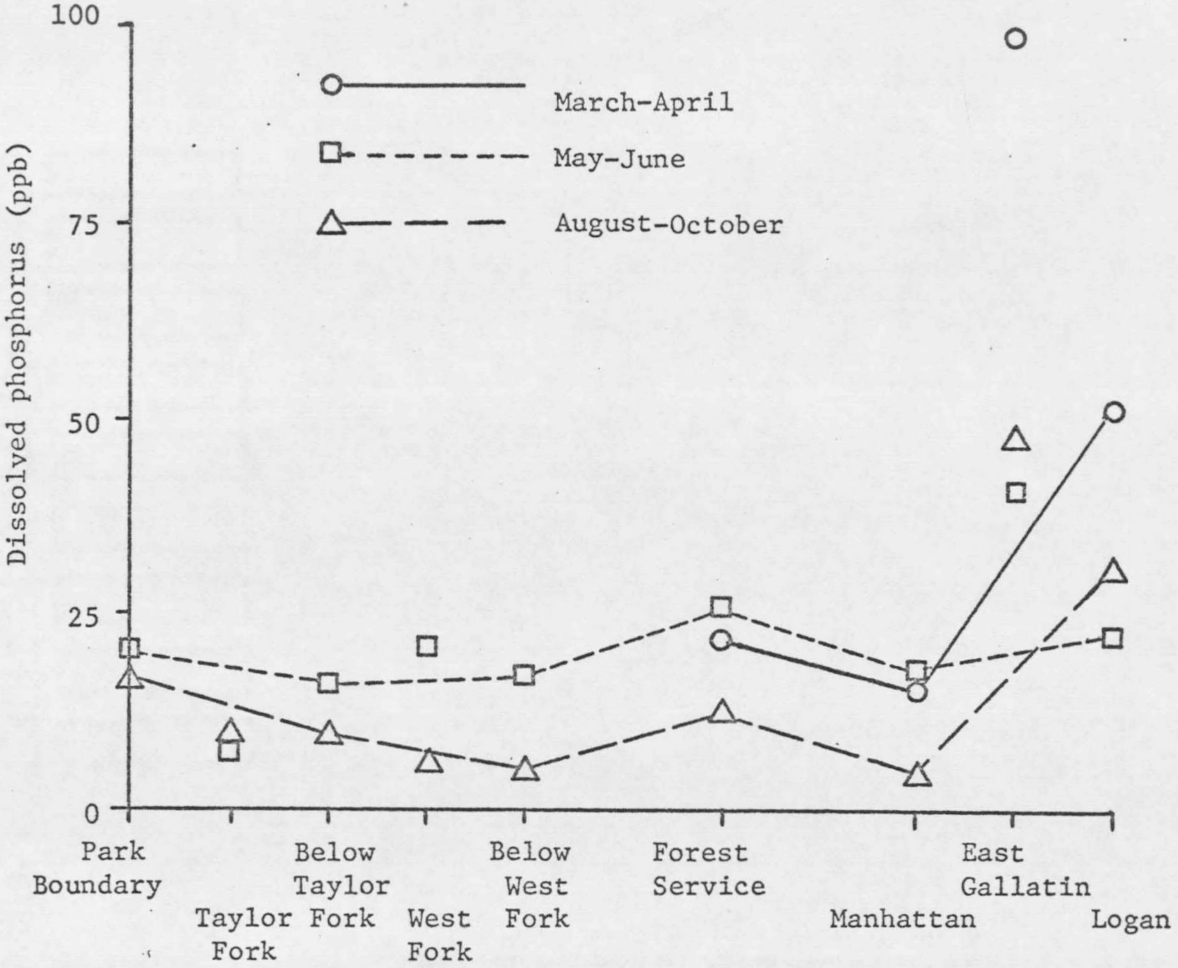

Figure 4. Dissolved phosphorus vs. location on the Gallatin River.

for the Forest Service and East Gallatin sites.

Forest Service DP (ppb) = 7.1 TSS (ppm) + 13, $r^2 = 0.71$ (1)

East Gallatin DP (ppb) = − 5.6 TSS (ppm) + 70, $r^2 = 0.16$ (2)

The negative regression coefficient for the East Gallatin site indicates that dilution of dissolved phosphorus may be taking place during periods of high flow. The reverse was found for the Forest Service site. The positive regression coefficient in Equation 1 shows that the concentration of dissolved phosphorus increased as the concentration of suspended solids increased. The square of the correlation coefficient, r^2, had a value of 0.71 for the Forest Service site and indicates that the concentration of dissolved phosphorus is closely related to the concentration of suspended solids.

Assuming hydroxyapatite ($Ca_5OH(PO_4)_3$) as the solid phase, pK_{sp}* values were calculated from the Ca^{+2} concentrations in Appendix Table 12 and phosphorus concentrations in Table 5. A pH of 8 and pK values for phosphoric acid of 2.12, 7.21, and 12.67 were used to calculate the pK_{sp}. The pK_{sp} of hydroxyapatite was taken to be 55.56. The East Gallatin samples had pK_{sp} values of 54.98, 56.94, and 54.56 for March 16, 1973, May 17, 1973, and August 29, 1973, respectively, while the Forest Service samples had pK_{sp} values of 57.11, 58.24, and 58.15 for the same dates.

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* $pK_{sp} = -\log K_{sp}$ where K_{sp} is the solubility product.

East Gallatin samples were supersaturated in phosphorus and calcium with respect to hydroxyapatite during March and April and August thru October and below saturation in May and June. The Forest Service site on the other hand was below saturation with respect to hydroxyapatite during all three periods as shown by pK_{sp} values larger than 55.56.

The concentration below saturation at the Forest Service site may be the result of a limited amount of phosphorus, or a less soluble form of calcium phosphate such as fluorapatite ($Ca_5F(PO_4)_3$) may be controlling the solubility of PO_4^{-3}. In the May-June period it is unlikely that a limited amount of phosphorus is the reason the concentration of dissolved phosphorus is below saturation with respect to hydroxyapatite since the sediment in suspension during that period contains four to five times as much phosphorus as the water. During periods of low flow such as August-October the amount of phosphorus carried by the sediments is less than that in solution. However,even at low flow, phosphorus should be available from the banks and bottom sediments which would indicate that some mineral other than hydroxyapatite is controlling the solubility of phosphorus at the Forest Service site.

The supersaturation of the East Gallatin samples might be accounted for by the formation of metastable solid phases of calcium phosphate such as octacalcium phosphate ($Ca_8H_2(PO_4)_6 \cdot 5H_2O$). Brown (3) reports that thin coatings of more soluble forms of calcium phosphate can coat hydroxyapatite resulting in higher concentrations of phosphorus than would occur if hydroxyapatite were not so coated. The growth of hydroxyapatite crystals is slow in relation to the growth of other less stable crystals (3). When phosphorus is added to a system such as the East Gallatin River, precipitation of less stable forms of calcium phosphate may result with a slow conversion to hydroxyapatite. In a system where no phosphorus has been added, such as the Gallatin River above the East Gallatin River the sediments should have only limited amounts of less stable solid phases of calcium phosphate before they are eroded. After solution of the metastable solid phase in the dilute river system only the most stable solid phase would remain. Supersaturation of the system with respect to that mineral would not occur under normal conditions.

Phosphorus in the sediments

The phosphorus content of the sediments is shown in Table 5. The phosphorus in the sediments varied from 2422 ppm for East Gallatin, September 1972 to 416 ppm in the Below West Fork, August 1973 sample. The sediments from the East Gallatin were higher in phosphorus than other locations varying from 915 ppm to 2422 ppm as compared to Taylor Fork which ranged from 450 ppm to 744 ppm of phosphorus. The phosphorus content of the sediments (TP) tended to increase as the concentration of suspended solids increased (TSS) at sites above the East Gallatin River. Equations 3 and 4 were developed by regression and compare the phosphorus content of the sediments and the concentration of suspended solids.

Taylor Fork TP (ppm) = 0.37 TSS (ppm) + 527, $r^2 = 0.38$ (3)

East Gallatin TP (ppm) = - 0.11 TSS (ppm) + 1097, $r^2 = 0.07$ (4)

Equation 3 shows that 38 percent of the variation in phosphorus content in Taylor Fork sediments could be attributed to variation in the suspended solids. An increase in phosphorus with an increase in suspended solids suggests that during periods of rapid snowmelt increased amounts of phosphorus-rich surface material are being carried by the streams. Taylor Fork sediments were generally lower in phosphorus than those from the Gallatin River. This may indicate that erosion of subsurface materials is important in the Taylor Fork drainage.

The high levels of phosphorus in the East Gallatin sediments shown in Table 5 did not correlate well with the amount of suspended solids as shown by Equation 4. This probably reflects adsorption by the sediments of phosphorus added to the East Gallatin River by effluent from the Bozeman sewage treatment plant. The results at Logan are similar to those in the East Gallatin River.

Phosphate sorption isotherms were run on sediments collected in 1972 and the results are presented in Appendix Table 9. The data were plotted in two forms. The first form was similar to a Langmuir plot which allows the prediction of a phosphate sorption maximum. The plots referred to as Langmuir phosphate sorption isotherms differed from a usual Langmuir isotherm in that the phosphate already on the sediments was not added to the amount adsorbed from solution. This difference in the plotting of the isotherms made only a small difference in sorption maxima calculated by Olsen and Watanabe (38). The second form of the isotherm plotted was a semi-log form which allows the determination of a zero adsorption point (7).

The plots of the data fell into three types. The first type which is shown by Figures 5 and 6, approximated a straight line in both the Langmuir and semi-log plot of the data. Phosphate sorption maxima were calculated for this type. The inverse of the slope of the Langmuir plot was taken as the phosphate sorption maximum (38). Plots of data in Appendix Table 9 for East Gallatin, Forest Service and Taylor Fork May 16, 1972, Logan, West Fork, Below Taylor Fork, and Park Boundary June 6, 1972, and Taylor Fork September 6, 1972 were similar to Figures 5 and 6. The sorption maxima ranged from 0.21 to 0.53 mg of P sorbed per g of sediment with an average of 0.33 mg of P sorbed/g of sediment. This is slightly higher than the value of 0.25 mg of P sorbed per gram of soil for the clay soils studied by Olsen and Watanabe (38). Eight samples were of this type. Six had zero adsorption points below 0.01 ppm of P in solution, with Logan and West Fork June 6, 1972 falling between 0.01 and 0.02 ppm of P in solution. The expected zero adsorption point for a system with 0.01 M Ca^{+2} and hydroxyapatite controlling the phosphorus concentration, is 0.005 ppm of P in solution.

The second type of isotherm showed phosphorus desorption. They approximated a straight line on the semi-log plot and had a Langmuir

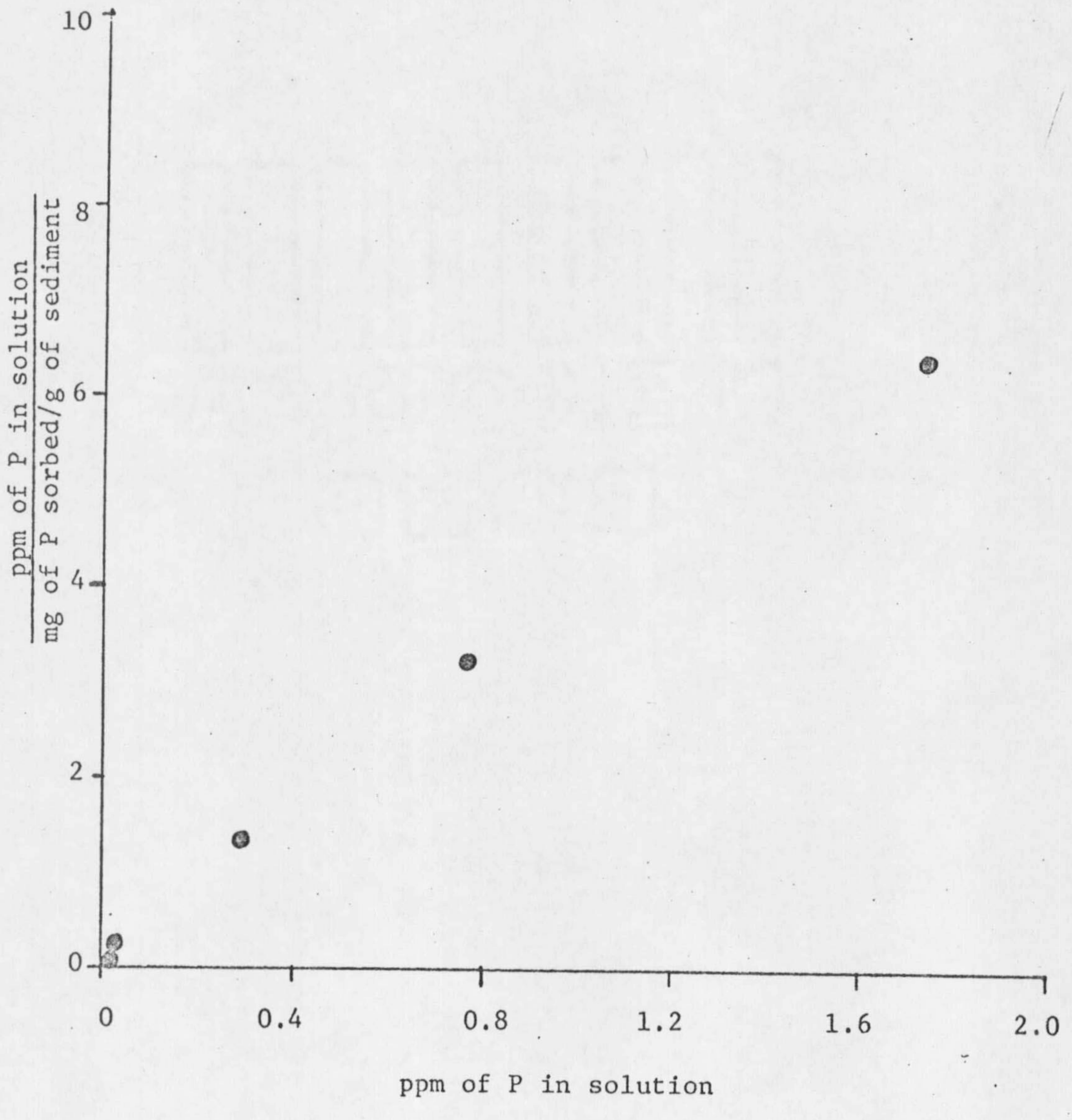

Figure 5. Langmuir phosphate sorption isotherm of sediments from the Forest Service site May 16, 1972.

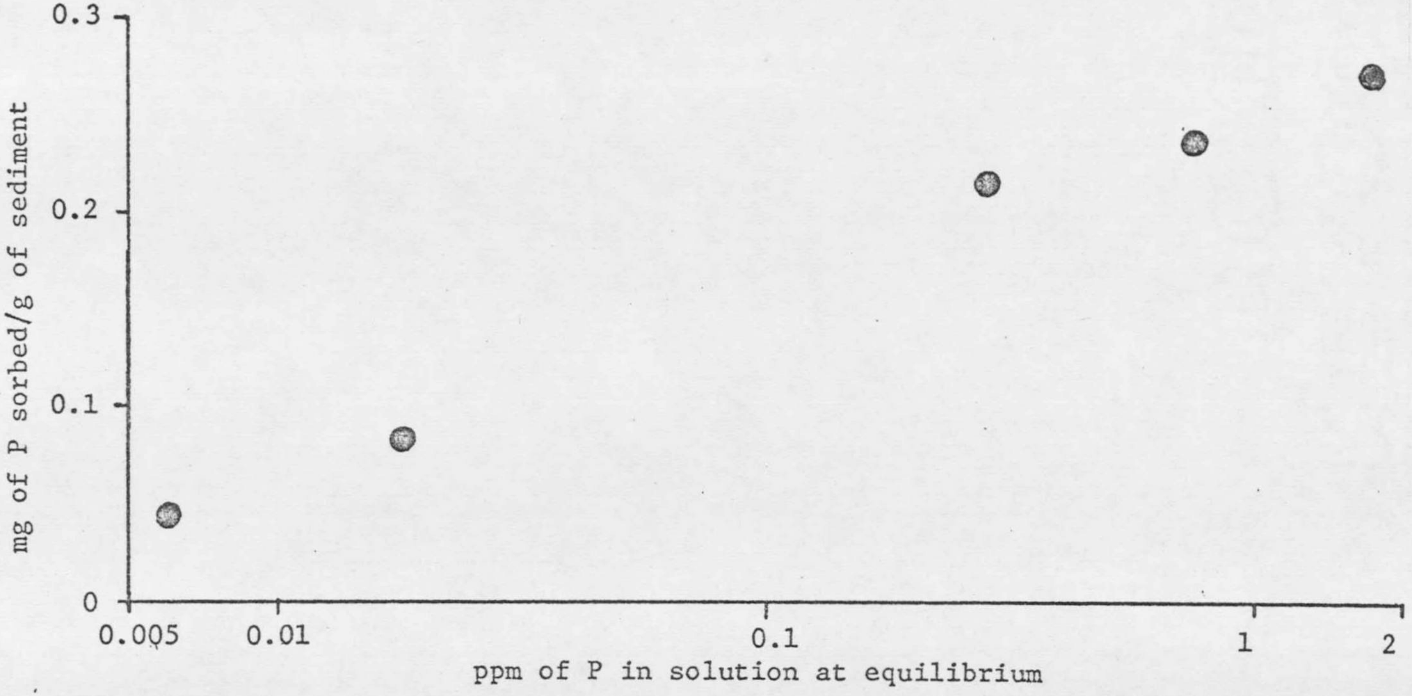

Figure 6. Semi-log phosphate sorption isotherm of sediments from the Forest Service site May 16, 1972.

plot with a discontinuity at zero mg of P sorbed (see Figure 7 and 8). Sorption maxima were not calculated for these samples due to the discontinuity in the Langmuir isotherms. Manhattan and Below West Fork May 16, 1972 were the only samples of this type and had zero sorption points between 0.06 and 0.09 ppm of P in solution.

The third type of isotherm illustrated by Figures 9 and 10 gave a concave semi-log plot and a Langmuir plot with a maximum. West Fork May 16, 1972, East Gallatin and Below West Fork June 6, 1972 and Logan September 6, 1972 gave plots of this type (see Appendix Table 9). Sorption maxima were not calculated for these samples. Estimation of a zero adsorption point was difficult for these plots.

The purpose of running phosphate soprtion isotherms was to estimate the amount of phosphorus available from the sediments. Since only two of the samples had any significant desorption of phosphorus, this method was not as successful as anticipated. Furthermore the phosphate sorption maxima did not correlate well with the phosphorus content of the sediment or the dissolved phosphorus. Deviation of the isotherms from a straight in both types of isotherms may have been due to errors in the sediment concentration of 15 percent or large, or to other errors.

Extractable and Available Phosphorus in Sediments

Phosphorus extractable with $NaHCO_3$ was determined for 1973 sediments. These data, seen in Table 5, show that sediments from the East

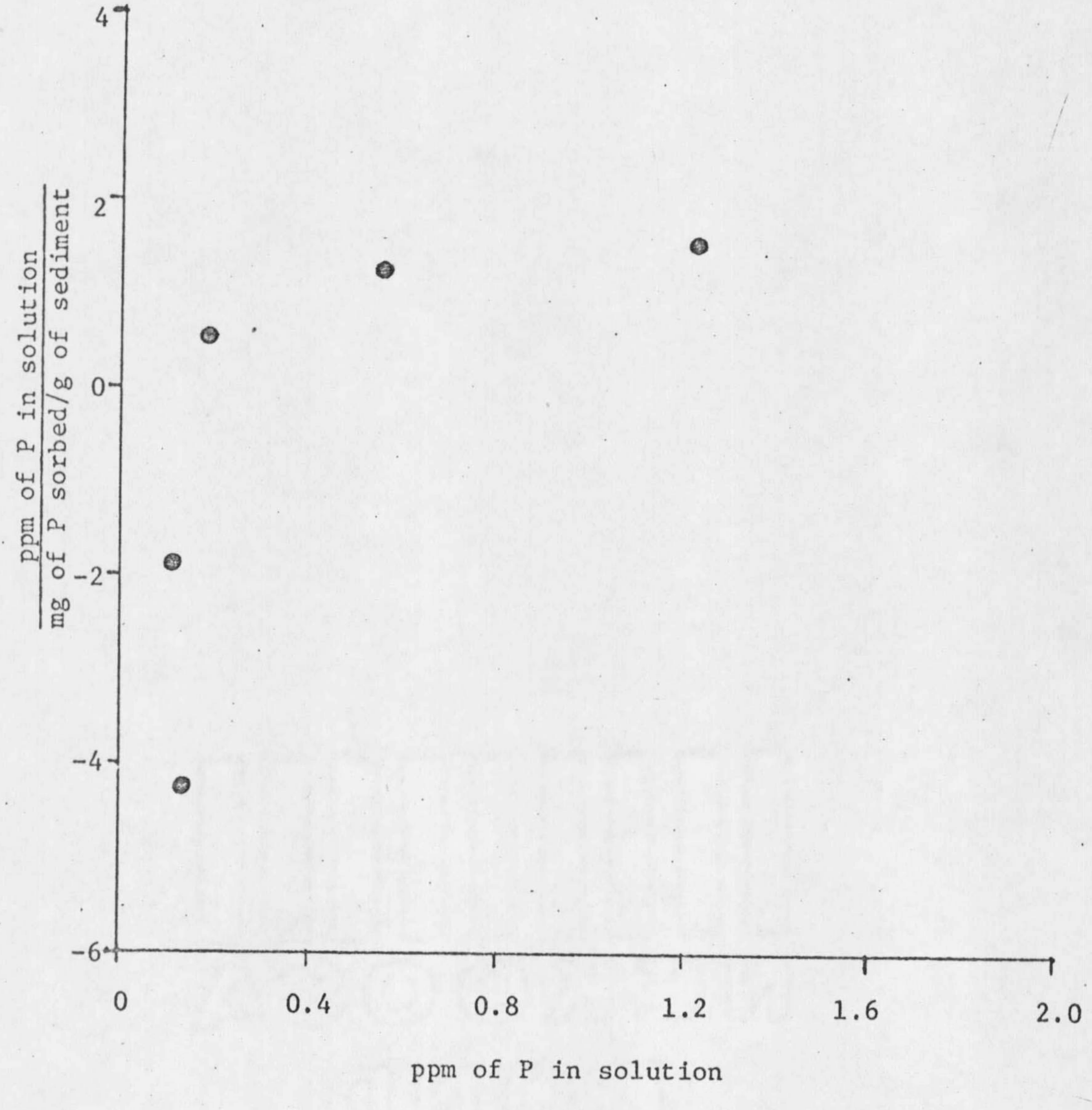

Figure 7. Langmuir phosphate sorption isotherm of sediment from Manhattan site May 16, 1972.

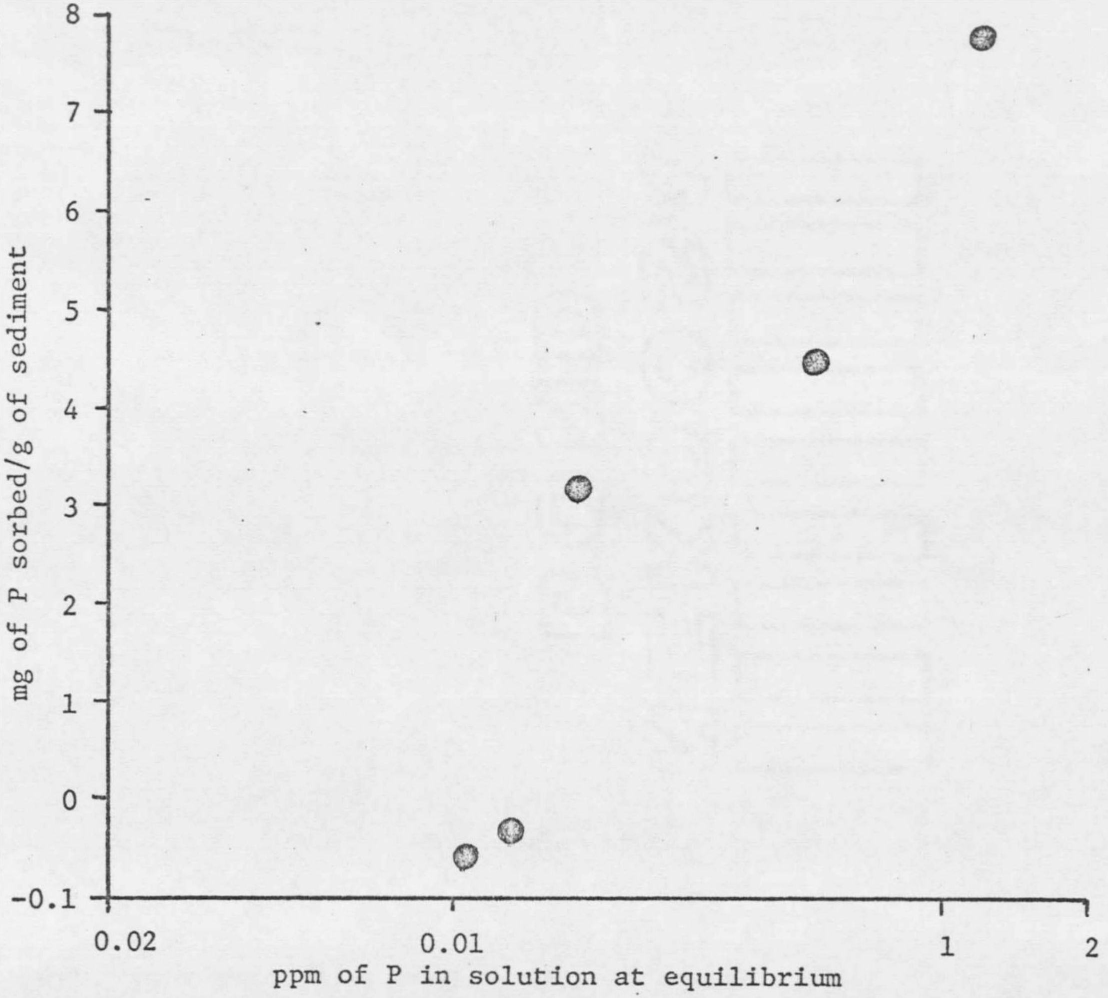

Figure 8. Semi-log phosphate sorption isotherm of sediments from the Manhattan site May 16, 1972.

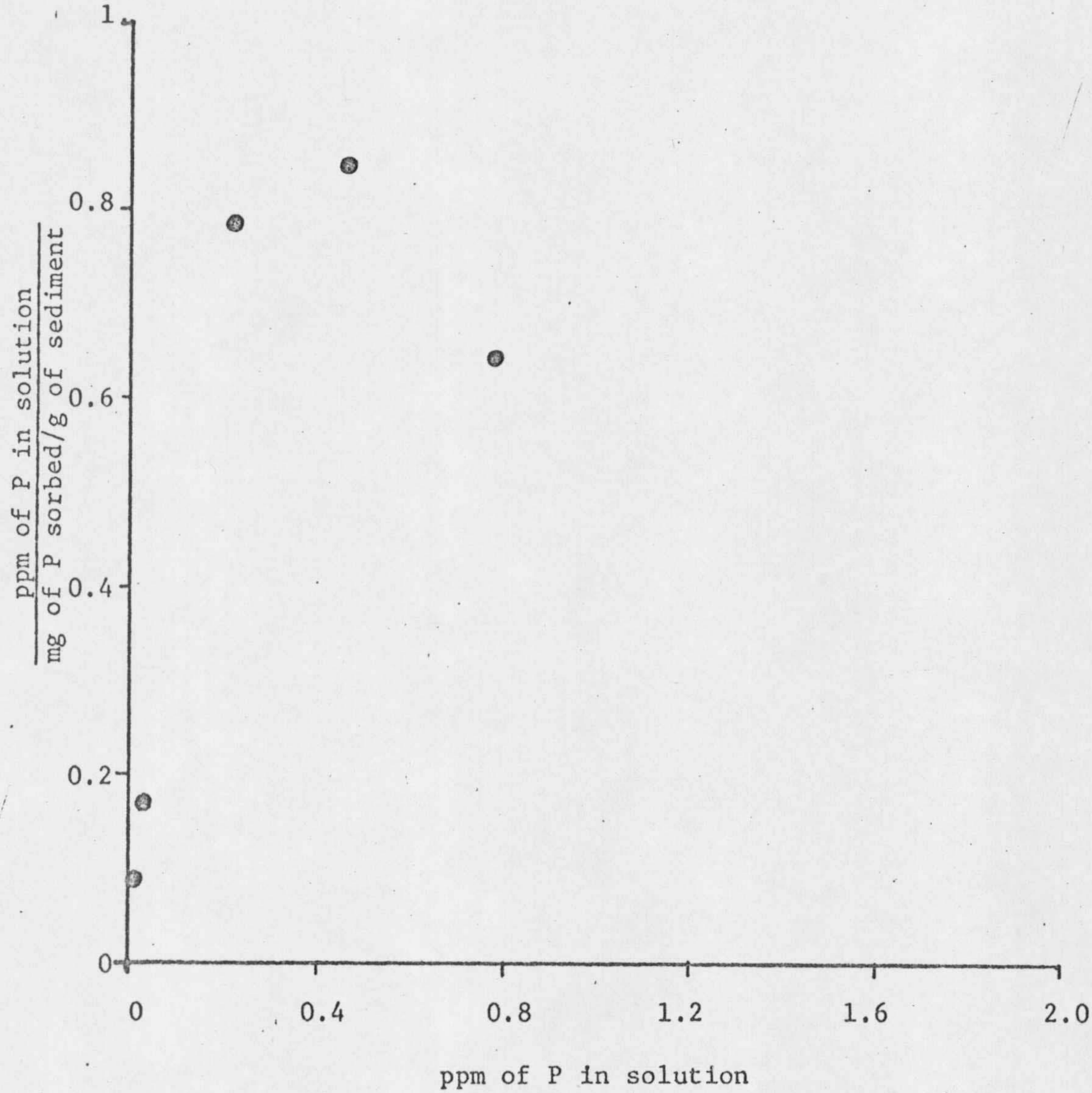

Figure 9. Langmuir phosphate sorption isotherm of sediment from the Below West Fork site June 6, 1972.

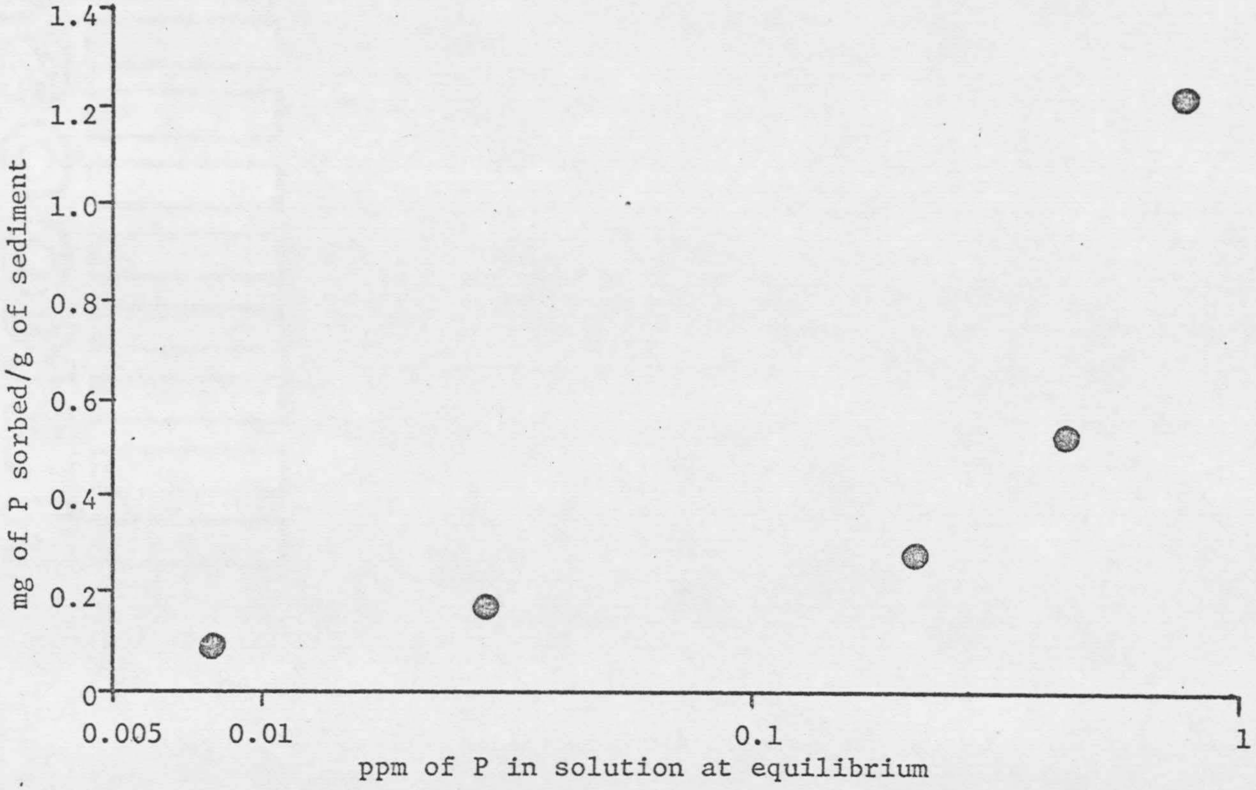

Figure 10. Semi-log phosphate sorption isotherm of sediments from the Below West Fork site June 6, 1972.

Gallatin and Logan sites had the highest extractable phosphorus content. Only 4 of the 19 samples were below 5 ppm of extractable P which is the level reported to be deficient in phosphorus for agricultural soils (37). Two samples had between 5 and 10 ppm of extractable phosphorus, which is the level at which a crop response to phosphorus fertilizer is probable. All other values were above 10 ppm of extractable phosphorus. These figures show that sediments from the Gallatin River are richer in extractable phosphorus than most soils.

The fungus Rhizoctonia solani Kuhn was grown with the sediments to obtain an estimate of the biologically available phosphorus. The results of the fungal growth (Table 6) on 1973 sediments showed that between 20 and 70 percent of the total phosphorus in the sediments was available to the fungus. The amounts of phosphorus extracted by the fungus ranged from 175 to 600 ppm of P from the sediments as compared to a maximum of 37.6 ppm of $NaHCO_3$ extractable phosphorus (Table 5). The $NaHCO_3$ extractable phosphorus did not correlate well with fungal extracted phosphorus, but this may be due to erratic results in the fungal growth. Table 7 gives the results of fungal growth in solutions of known phosphorus concentration. The concentration of phosphorus in the water did not correlate well with the fungal growth. This may have been due to lack of adequate control of growth conditions. Even though the results were erratic, the results shown in Table 6 and those of Harrison et. al. (16) indicate that larger amounts of phosphorus are available

Table 6. Results of fungal growth on 1973 sediments from the Gallatin River.

	1000 ppm of sediment	2000 ppm of sediment	1000 ppm of sediment	2000 ppm of sediment
	ppm of P extracted		% of total P	% of total P
March 16, 1973				
Logan	320		28.2	
East Gallatin	390	250	37.8	24.2
April 18, 1973				
Logan	530	275	52.6	27.3
East Gallatin	530	355	48.5	32.5
Manhattan	400	325	17.1	13.9
May 17, 1973				
Logan	350	270	39.4	30.4
East Gallatin	560	420	55.4	41.6
Manhattan	530	200	60.2	22.8
Forest Service	540	270	68.1	34.0
Below West Fork	480	345	58.3	41.9
West Fork	600	320	58.7	31.3
Below Taylor Fork	410	270	56.4	37.1
Taylor Fork	340	225	50.7	33.5
Park Boundary	670	295	69.6	30.6
June 11, 1973				
Logan	490	345	52.4	30.5
East Gallatin	520	365	45.4	31.9
Manhattan	470	235	44.6	22.3
Forest Service	270	285	31.1	22.8
Below West Fork	210	275	29.9	35.1
West Fork	450	325	57.5	42.8
Below Taylor Fork	230	175	30.1	17.3
Taylor Fork	380	240	57.8	36.5
Park Boundary	330	305	39.1	36.1
August 29, 1973				
Logan	260		27.7	

Table 7. Results of fungal growth on samples collected from the Gallatin River June 4, 1974.

Location	Dissolved P	Water only	Water and sediment
	ppb	mg of fungal growth	
Logan	36	4.1	6.7
East Gallatin	53	4.7	8.9
Manhattan	9	4.8	6.6
Forest	55	4.4	5.9
Below West Fork	26	5.2	6.2
West Fork	65	4.1	7.3
Below Taylor Fork	22	5.5	5.9
Taylor Fork	21	4.2	5.6
Park Boundary	25	5.6	6.2
Wapite Creek	8	4.3	6.6
Beaver Creek	53	4.3	5.6
Squaw Creek	28	4.8	6.2
Porcupine Creek	21	4.6	5.2

to saprophytic organisms than is indicated by chemical measurements such as $NaHCO_3$ extractions.

X-ray analysis and surface area of the sediments

The results of x-ray analysis, shown in Appendix Tables 10 and 11, show the sediments to have smectite, vermiculite, illite, kaolinite and quartz as well as illite-vermiculite intergrade material (14Å intergrade) in the clay fraction and vermiculite, mica, crystabolite, quartz and feldspar as the chief minerals in the silt fraction. Smaller amounts of pyrophyllite, amphibole, kaolinite, dolomite and apatite were also present in the silt fraction of some samples.

The clay mineral percentages shown in Appendix Table 10 were calculated by the following method*.

1. The area of the 17Å smectite peak was divided by four times the area of the 10Å illite peak.
2. The 14Å vermiculite peak was divided by two times the illite peak.
3. The sum of the areas of all the peaks between 14Å and 10Å was divided by two times the area of the illite peak to determine the 14Å intergrade material.
4. The area of 10Å illite peak was divided by itself.
5. The area of 7Å kaolinite peak was divided by four times the illite peak.
6. The area of the 3.3Å quartz peak minus 3/4 the area of the illite peak divided by four times the area of the illite peak.

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* After an unpublished method by L. P. Willing, Ohio State University, modified from the procedure by John et al.

7. The percent of minerals shown in Table 10 is the percentage of the ratios described above for each peak.

The percent smectite shown in Appendix Table 10 was used to calculate the percent clay in the sediments which appears in Table 8.

The following assumptions were used to compute the percent clay from the surface area in Table 8 and the smectite from Appendix Table 10.

1. Only smectite expands sufficiently to adsorb 1, 10 phenanthroline on internal surfaces (30).
2. The internal surface area of smectite is 800 m^2/g (30).
3. The surface area of minerals other than smectite is 40 m^2/g.

Assumption 3 is based upon data presented by Lawrie (30) for minerals other than smectite. He found that the surface area of clay minerals ranged from 50 to 80 m^2/g. The surface area of silt particles would be lower than 50 m^2/g. The value of 40 m^2/g may be an underestimation of surface area of all other minerals but the error should not be large. The clay estimated by this method was in excess of 100 percent for sediments from the East Gallatin and West Fork sites. This is probably due to an underestimation of smectite caused by the presence of interstratified smectite and vermiculite.

Statistical analysis revealed no relationships between the mineralogy, amount of clay, or surface area and the dissolved phosphorus, extractable phosphorus, or phosphorus content of the sediments. This may be due to the relative uniformity of the samples.

Table 8. Surface area and estimated percent clay in 1973 sediments from the Gallatin River.

	Surface area	Estimated clay
	m^2/g	%
March 16, 1973		
Logan	292	69
East Gallatin	304	62
Manhattan	195	
Forest Service	196	
April 18, 1973		
Logan	280	66
East Gallatin	316	83
Manhattan	268	84
May 17, 1973		
Logan	280	87
East Gallatin	292	124
Manhattan	169	31
Forest Service	280	73
Below West Fork	280	62
West Fork	244	94
Below Taylor Fork	340	75
Taylor Fork	304	66
Park Boundary	268	57
June 11, 1973		
Logan	268	62
East Gallatin	316	113
Manhattan	292	67
Forest Service	244	62
Below West Fork	244	58
West Fork	207	148
Below Taylor Fork	268	58
Taylor Fork	268	53
Park Boundary	268	67
August 29, 1973		
Logan	219	43
East Gallatin	268	64
West Fork	244	100

The mineralogy of the sediments, shown in Appendix Tables 10 and 11, appear to be similar to the results reported by Hsieh (20), but detailed comparison was difficult because he reported peak intensities and not peak areas.

SUMMARY AND CONCLUSIONS

Samples were collected from the Gallatin River and three of its tributaries in 1972 and 1973. The sediments were separated from the water by filtration.

The predominant ions in the water of the Gallatin River were Ca^{+2} and HCO_3^-. The concentration of dissolved solids decreased during periods of high runoff in May and June and increased during late summer and early fall. The peak in the concentration of dissolved solids in the Gallatin Canyon at the Below West Fork sampling site was probably due to addition of more saline water to the Gallatin River from springs in the area around the mouth of West Fork. The concentration of dissolved solids increased in the Gallatin River between the Forest Service site and Logan.

Sulfate concentration peaked at the Below West Fork site and decreased between the Forest Service and Logan sampling sites. All of the tributaries to the Gallatin River had sulfate concentrations lower than those found in the Gallatin River.

The dissolved phosphate concentration increased between the Forest Service and Logan sampling sites. The concentration of dissolved phosphorus increased in May and June in contrast to the concentration of dissolved solids. This increase in concentration appeared to be related to concentration of suspended solids.

The concentration of dissolved phosphorus in the Gallatin River above the East Gallatin River was below saturation with respect to hydroxyapatite during all sampling periods. This may indicate that some mineral other than hydroxyapatite is controlling the solubility of phosphorus, or may be due to lack of equilibration of the water with prevalent phosphate minerals.

The East Gallatin River was supersaturated with respect to hydroxyapatite during March and April and August thru October. This may be the result of precipitation of metastable solid phases of calcium phosphate.

The phosphorus content of the sediments from sites above the East Gallatin River tended to increase as the total suspended solids increased indicating an increase in the amount of surface material being eroded.

Sediments from the East Gallatin and Logan sites remained fairly constant in phosphorus content. This may reflect the adsorption of added phosphorus by these sediments while in the river.

Phosphate sorption isotherms were able to predict the zero adsorption point for the test conditions and the phosphate sorption maximum for some samples.

Extraction of phosphorus with $NaHCO_3$ showed the Gallatin River sediments to be high in extractable phosphorus when compared to soils. The East Gallatin and Logan sediments were higher in extractable phosphorus than were other sediments. This is most likely due to adsorption of added phosphorus by the sediments from these locations.

Extraction of phosphorus from sediment samples by the fungus Rhizoctonia solani Kuhn showed that large amounts of phosphorus were available to this organism. Between 20 and 70 percent of the phosphorus in the sediments was found to be available to the fungus while values of only one to two percent of the phosphorus was extractable with $NaHCO_3$. The results of the fungal growth were erratic which was probably due to lack of adequate control of growth conditions.

The result of mineralogical analysis, surface area and estimated clay content of the sediments showed no relationships with phosphorus content of the sediments. This may have been due in part to the uniformity of the samples with regard to these properties.

APPENDIX

Appendix Table 9. Phosphate sorption data for 1972 sediments.

Location	P sorbed per g of sediment	P in solution at equilibrium	Location	P sorbed per g of sediment	P in solution at equilibrium
	mg	ppm		mg	ppm
			May 16, 1972		
Logan	0.370	1.630	East Gallatin	0.210	1.790
	0.150	0.850		0.160	0.840
	-	-		0.198	0.302
	-	-		-	-
	-	-		0.072	0.028
	-	-		0.029	0.021
Manhattan	0.780	1.220	Forest Service	0.270	1.730
	0.450	0.550		0.235	0.765
	0.320	0.180		0.215	0.285
	-	-		-	-
	-0.031	0.131		0.082	0.018
	-0.056	0.106		0.044	0.006
Below West Fork	0.490	1.510	West Fork	0.950	1.050
	0.350	0.650		0.440	0.560
	0.248	0.252		0.223	0.277
	-	-		-	-
	-0.006	0.106		0.039	0.061
	-0.006	0.056		0.028	0.022
Below Taylor Fork	0.090	1.910	Taylor Fork	0.400	1.600
	0.025	0.975		0.340	0.660
	-	-		0.223	0.277
	-	-		-	-
	-	-		0.082	0.018
	-	-		0.035	0.015
Park Boundary	0.590	1.410			
	0.300	0.700			
	-	-			
	-	-			
	-	-			
	0.045	0.005			

Appendix Table 9. Continued.

Location	P sorbed per g of sediment	P in solution at equilibrium	Location	P sorbed per g of sediment	P in solution at equilibrium
	mg	ppm		mg	ppm
			June 6, 1972		
Logan	0.190	1.810	East Gallatin	0.080	1.920
	0.135	0.865		0.025	0.975
	0.097	0.403		-	-
	0.072	0.128		-	-
	0.033	0.066		0.003	0.097
	0.020	0.030		-0.038	0.088
Manhattan	0.760	1.240	Below West Fork	1.220	0.780
	0.735	0.265		0.540	0.460
	0.412	0.088		0.280	0.220
	-	-		0.171	0.029
	-	-		0.092	0.008
	-	-		-	-
West Fork	0.740	1.260	Below Taylor Fork	0.450	1.550
	0.455	0.545		0.335	0.665
	0.325	0.175		-	-
	-	-		0.185	0.015
	-	-		0.094	0.006
	0.035	0.015		0.046	0.004
Park Boundary	0.240	1.760			
	0.171	0.829			
	0.172	0.328			
	-	-			
	0.078	0.022			
	0.035	0.015			

Appendix Table 9. Continued.

Location	P sorbed per g of sediment	P in solution at equilibrium	Location	P sorbed per g of sediment	P in solution at equilibrium
	mg	ppm		mg	ppm
	September 6, 1972				
Logan	0.250	1.750	Below West Fork	0.606	1.394
	0.116	0.884		0.319	0.681
	0.137	0.363		0.259	0.241
	0.186	0.014		-	-
	0.087	0.013		-	-
	0.040	0.010		-	-
Taylor Fork	0.320	1.680			
	0.250	0.750			
	0.187	0.313			
	0.127	0.073			
	0.039	0.061			
	0.044	0.006			

Appendix Table 10. Estimated mineralogical composition in the clay fraction of 1973 sediments in percent.

March 16, 1973

	Logan	East Gallatin
Smectite	45.6	53.6
Vermiculite	6.3	6.4
14Å intergrade	18.6	13.2
Illite	21.1	18.3
Kaolinite	6.3	4.6
Quartz	2.1	3.9

April 18, 1973

	Logan	East Gallatin	Manhattan
Smectite	45.5	41.8	33.9
Vermiculite	12.3	11.6	11.5
14Å intergrade	6.2	12.2	15.7
Illite	30.8	30.5	31.9
Kaolinite	5.2	4.0	5.8
Quartz	0	0	1.3

May 17, 1973

	Logan	East Gallatin	Manhattan	Forest Service	Below West Fork
Smectite	34.3	25.5	52.4	41.2	48.3
Vermiculite	5.9	13.4	6.7	9.3	3.4
14Å intergrade	19.9	30.9	8.8	23.3	10.8
Illite	32.7	22.7	23.2	19.9	31.0
Kaolinite	6.5	5.9	4.9	4.0	5.3
Quartz	0.7	1.6	3.9	2.4	1.2

	West Fork	Below Taylor Fork	Taylor Fork	Park Boundary
Smectite	27.1	49.9	50.3	50.0
Vermiculite	12.2	5.8	6.0	9.3
14Å intergrade	12.2	14.1	14.9	22.2
Illite	39.2	24.3	22.3	15.5
Kaolinite	8.2	4.1	3.6	2.8
Quartz	1.2	1.7	2.9	0.1

Appendix Table 10. Continued.

	June 11, 1973				
	Logan	East Gallatin	Manhattan	Forest Service	Below West Fork
Smectite	46.1	30.5	47.2	41.3	43.8
Vermiculite	9.4	7.7	6.2	8.5	11.0
14Å intergrade	18.9	29.6	13.8	22.2	20.6
Illite	18.4	28.5	28.2	20.7	18.7
Kaolinite	4.8	3.7	4.5	4.8	5.4
Quartz	2.4	0	0	2.5	0.6
	West Fork	Below Taylor Fork	Taylor Fork	Park Boundary	
Smectite	14.1	49.1	54.1	42.4	
Vermiculite	8.0	4.4	2.0	5.2	
14Å intergrade	14.6	14.6	15.2	17.0	
Illite	46.9	19.0	16.5	24.9	
Kaolinite	14.6	6.6	6.9	6.2	
Quartz	1.9	6.3	5.3	4.2	

	August 29, 1973		
	Logan	East Gallatin	West Fork
Smectite	51.5	44.3	25.5
Vermiculite	12.9	5.9	7.8
14Å intergrade	13.2	20.4	19.8
Illite	16.2	23.7	26.8
Kaolinite	6.0	3.1	11.0
Quartz	0.2	2.6	9.1

Appendix Table 11. Minerals in 1973 Gallatin River silt fractions*.

	March 16, 1973	
	Logan	East Gallatin
Vermiculite	12.4	9.2
Mica	12.9	10.5
Pyrophyllite	0	0
Amphibole	5.3	2.4
Kaolinite	5.0	3.6
Crystobalite	18.3	6.7
Quartz	14.7	17.6
Feldspar	31.4	45.9
Dolomite	0	4.0

	April 18, 1973		
	Logan	East Gallatin	Manhattan
Vermiculite	11.8	11.8	11.1
Mica	13.0	18.0	14.6
Pyrophyllite	0	0	0
Amphibole	3.5	8.2	4.6
Kaolinite	5.6	6.5	3.8
Crystobalite	4.9	5.5	6.7
Quartz	14.9	25.1	18.4
Feldspar	36.7	22.7	40.9
Dolomite	4.6	2.3	0

	May 17, 1973				
	Logan	East Gallatin	Manhattan	Forest Service	Below West Fork
Vermiculite	12.3	9.5	25.9	7.3	10.8
Mica	8.9	9.8	11.1	14.5	9.7
Pyrophyllite	4.8	9.9	0	7.1	3.0
Amphibole	5.4	4.3	6.4	6.5	5.4
Kaolinite	3.3	6.4	4.2	8.0	5.4
Crystobalite	4.7	1.7	3.4	3.8	6.6
Quartz	23.1	17.1	30.8	26.8	24.1
Feldspar	31.9	33.5	16.8	26.2	26.2
Dolomite	5.5	7.7	1.4	0	7.6
Apatite	0	0	0	0	1.2

Table 11. Continued.

May 17, 1973

	West Fork	Below Taylor Fork	Taylor Fork	Park Boundary
Vermiculite	22.7	13.1	16.0	10.8
Mica	12.7	12.0	10.0	11.0
Pyrophyllite	2.2	4.1	0	0
Amphibole	5.4	2.5	7.9	3.7
Kaolinite	6.3	5.5	6.2	5.1
Crystobalite	3.1	4.6	12.7	6.1
Quartz	23.2	22.6	39.1	19.4
Feldspar	22.9	28.4	0	43.8
Dolomite	0	7.1	8.2	0
Apatite	1.3	0	0	0

June 11, 1973

	Logan	East Gallatin	Manhattan	Forest Service	Below West Fork
Vermiculite	14.0	13.0	19.2	22.0	17.1
Mica	11.5	10.6	10.8	16.3	9.8
Pyrophyllite	0	0	0	0	0
Amphibale	6.1	5.0	7.1	0	1.6
Kaolinite	8.3	7.3	6.9	9.2	10.9
Crystobalite	6.0	5.0	7.3	4.1	0
Quartz	14.6	17.0	24.6	20.2	24.1
Feldspar	37.9	39.2	22.9	28.2	22.4
Dolomite	1.6	2.9	1.1	0	14.2

	West Fork	Below Taylor Fork	Taylor Fork	Park Boundary
Vermiculite	20.6	12.9	14.6	8.2
Mica	10.4	5.9	6.0	7.7
Pyrophyllite	0	0	0	0
Amphibole	0	0	0	3.4
Kaolinite	9.7	5.6	2.3	4.0
Crystobalite	0	0	1.9	6.9
Quartz	44.4	27.5	29.1	30.4
Feldspar	14.9	28.1	17.9	33.8
Dolomite	0	19.9	28.3	5.6

Table 11. Continued.

	August 29, 1973		
	Logan	East Gallatin	West Fork
Vermiculite	14.4	21.0	12.4
Mica	2.7	11.7	6.6
Pyrophyllite	0	0	0
Amphibole	1.7	4.5	1.2
Kaolinite	3.3	4.5	5.5
Crystobalite	27.4	0	7.2
Quartz	34.3	19.4	23.8
Feldspar	14.7	38.9	43.4
Dolomite	1.5	0	0

* Values given are the diagnostic x-ray diffraction peak areas as percent of all measured peaks.

Appendix Table 12. Analysis of water samples collected from the Gallatin River 1972 and 1973: Cations.

Month and Location	Na	K	Ca		Mg	
	1973	1973	1972	1973	1972	1973
	meq/1					
March						
Logan	0.50	0.09	2.55	2.45	0.76	0.87
East Gallatin	0.44	0.09	3.45	2.55	0.69	0.90
Manhattan	0.37	0.07	-	2.15	-	0.76
Forest Service	0.37	0.06	2.20	1.95	0.76	0.73
April						
Logan	0.49	0.10	1.15	2.40	0.78	0.83
East Gallatin	0.41	0.09	3.10	2.40	0.78	0.83
Manhattan	0.30	0.07	2.35	2.05	0.71	0.73
Forest Service	0.26	0.07	2.20	1.60	0.68	0.71
May						
Logan	0.21	0.06	2.50	1.40	0.52	0.43
East Gallatin	0.21	0.07	2.20	1.50	0.63	0.48
Manhattan	0.21	0.04	1.40	1.20	0.46	0.37
Forest Service	0.16	0.06	1.80	0.90	0.38	0.28
Below West Fork	0.16	0.06	1.80	1.25	0.47	0.42
West Fork	0.16	0.05	1.30	0.80	0.28	0.23
Below Taylor Fork	0.30	0.06	2.05	1.35	0.48	0.42
Taylor Fork	0.41	0.04	2.20	1.25	0.43	0.35
Park Boundary	0.10	0.06	1.95	1.45	0.46	0.49
June						
Logan	0.03	0.05	1.90	0.95	0.38	0.27
East Gallatin	0.37	0.05	2.40	1.85	0.58	0.57
Manhattan	0.21	0.06	1.60	1.20	0.32	0.35
Forest Service	0.03	0.04	2.45	0.80	0.29	0.22
Below West Fork	0.10	0.04	1.00	1.10	0.36	0.34
West Fork	0.03	0.04	1.00	0.80	0.23	0.23
Below Taylor Fork	0.26	0.04	1.65	1.25	0.38	0.35
Taylor Fork	0.30	0.04	1.40	1.20	0.33	0.29
Park Boundary	0.10	0.05	1.50	1.20	0.38	0.38

Appendix Table 12. Continued.

Month and Location	Na	K	Ca		Mg	
	1973	1973	1972	1973	1972	1973
	meq/l					
August-September						
Logan	0.53	0.11	1.35	2.60	0.80	0.92
East Gallatin	0.48	0.08	3.25	2.65	0.83	0.92
Manhattan	0.37	0.07	2.55	2.25	0.66	0.73
Forest Service	0.30	0.05	2.20	1.70	0.67	0.63
Below West Fork	0.37	0.05	-	2.25	-	0.83
West Fork	0.33	0.04	3.45	1.80	0.44	0.55
Below Taylor Fork	0.30	0.04	-	1.90	-	0.69
Taylor Fork	0.55	0.04	2.10	1.95	0.56	0.53
Park Boundary	0.21	0.04	2.30	1.90	0.58	0.76
October						
Logan	0.49	0.09	3.30	2.40	0.80	0.81
East Gallatin	0.45	0.08	3.65	2.55	0.78	0.83
Manhattan	0.33	0.06	2.85	1.95	0.63	0.64
Forest Service	0.30	0.05	2.30	1.55	0.66	0.57
Below West Fork	0.33	0.05	2.85	2.30	0.75	0.87
West Fork	0.37	0.04	2.40	1.65	0.43	0.50
Below Taylor Fork	0.33	0.05	-	1.90	-	0.66
Taylor Fork	0.55	0.06	2.65	1.95	0.57	0.55
Park Boundary	0.10	0.05	2.55	1.85	0.68	0.71

Appendix Table 13. Analysis of water samples collected from the Gallatin river 1972 and 1973: Anions.

Month and Location	HCO_3 1972	HCO_3 1973	Cl 1973	SO_4 1973
	meq/1			
March				
Logan	3.41	3.57	0.12	0.82
East Gallatin	3.67	4.15	0.13	0.40
Manhattan	-	2.79	0.04	1.16
Forest Service	2.15	2.45	0.03	1.23
April				
Logan	3.57	2.86	0.13	0.65
East Gallatin	3.76	3.90	0.10	0.36
Manhattan	2.67	2.57	0.02	1.03
Forest Service	2.32	2.45	0.04	1.19
May				
Logan	2.69	2.15	0.02	0.40
East Gallatin	2.87	2.45	0.03	0.40
Manhattan	2.19	1.77	0.01	0.37
Forest Service	1.73	1.51	0.02	0.29
Below West Fork	3.19	1.84	0.01	0.44
West Fork	1.47	1.24	0.02	0.25
Below Taylor Fork	2.10	1.99	0.01	0.40
Taylor Fork	2.44	2.08	0.04	0.33
Park Boundary	2.00	2.06	0.02	0.49
June				
Logan	1.99	1.50	0.03	0.25
East Gallatin	2.99	2.85	0.05	0.26
Manhattan	2.57	1.89	0.09	0.28
Forest Service	1.43	1.25	0.04	0.23
Below West Fork	1.67	2.44	0.05	0.31
West Fork	1.28	1.25	0.05	0.20
Below Taylor Fork	2.21	1.77	0.03	0.29
Taylor Fork	1.88	1.73	0.01	0.27
Park Boundary	1.74	1.76	0.04	0.32

Appendix Table 13. Continued.

Month and Location	HCO_3 1972	HCO_3 1973	Cl 1973	SO_4 1973
	- - - - - -	- - - - meq/l	- - - -	- - - - -
August-September				
Logan	3.86	4.05	0.15	0.62
East Gallatin	4.23	4.10	0.17	0.42
Manhattan	2.87	3.01	0.07	0.76
Forest Service	2.23	2.31	0.06	0.84
Below West Fork	-	2.70	0.10	1.38
West Fork	2.28	2.56	0.03	0.38
Below Taylor Fork	-	2.49	0.05	0.80
Taylor Fork	2.59	3.00	0.10	0.68
Park Boundary	2.40	2.37	0.05	0.89
October				
Logan	3.58	3.61	0.13	0.62
East Gallatin	3.71	4.02	0.11	0.39
Manhattan	2.06	2.66	0.04	0.78
Forest Service	1.90	1.84	0.04	0.80
Below West Fork	1.59	2.68	0.05	1.49
West Fork	2.76	2.51	0.04	0.39
Below Taylor Fork	-	2.56	0.02	0.87
Taylor Fork	2.82	3.09	0.02	0.67
Park Boundary	2.73	2.41	0.02	0.89

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