



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

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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.

Extraction of sediments with NaHCO_3 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 NaHCO_3 .

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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August 7, 1974

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

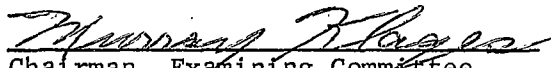
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ABSTRACT

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.

Extraction of sediments with NaHCO_3 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 NaHCO_3 .

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.

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.

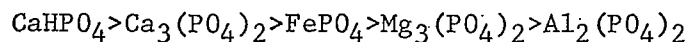
Anaerobic conditions influence the solubility of phosphorus. According to Li, et al. (31), anaerobic conditions promoted the release of phosphate from bottom sediments. The remaining phosphorus was not as exchangeable as that in aerobic sediments. Similar results were reported by White and Beckett (59). 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:



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 calcareous 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 determined 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/1 of P as PO_4 were employed with a sediment concentration of 1000 mg/1. 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 Czapek'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

* 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.

