Ecology of the diatom communities of Soda Butte Creek, Montana and Iron Springs Creek, Wyoming by Frank James Pickett

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Botany
Montana State University
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Abstract:
Diatoms, collected from plexiglass plates, and water chemistry samples were taken and analyzed biweekly in 1972 from five stations on the upper portion of Soda Butte Creek, Montana, one above and four below the entry of seepage from a mine tailings dump.

Soda Butte Creek was found to be of the calcium-magnesium-bicarbonate type. Total iron increased markedly from a mean of .2 mg.l-1 above to 6.7 mg.l-1 below the seep, and pH was depressed slightly from a mean of 8.32 to 7.80.

A total of 33 genera and 171 species and varieties of diatoms were identified. Dominant diatoms were: Hannaea arcus, Achnanthes lanceolata, Gomphonema angustatum, and Diatoma hiemale var. mesodon.

The diatom flora was adversely affected in the area of the seep, where chlorophyll and diatom counts were nil. The next station, 1.5 miles downstream, showed few ill effects from the tailings drainage. The relatively high pH for the "acid" mine drainage allowed the ferric material to precipitate quickly. The addition of an approximately two times greater volume of dilution water from tributary streams also increased recovery.

The diatom flora of another stream of the area, Iron Springs Creek, Wyoming, was compared to that of Soda Butte Creek due to the contrasting nature of the two streams' water chemistry. Iron Springs Creek was of the sodium-potassium-bicarbonate type. Cocconeis placentula var. lineata was the dominant diatom found in Iron Springs Creek. The multivariate statistical techniques of principle components and cluster analysis suggested that unique diatom communities existed in the two streams and that the monovalent:divalent cation ratio was the best discriminator between the streams.

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Date May 22, 1978

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by

FRANK JAMES PICKETT

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

of

MASTER OF SCIENCE

in

Botany

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Bozeman, Montana

May, 1978

ACKNOWLEDGMENTS

The author thanks Dr. John C. Wright for his encouragement and assistance during the course of this study. Sincere thanks are also extended to Drs. James M. Pickett and Calvin Kaya, and to other members of the Graduate Faculty and colleagues of the author for their careful review of the manuscript and assistance in its preparation.

The assistance of Mr. James Chadwick in the collection of field data is gratefully acknowledged. Special thanks are also due to the author's parents and Mr. and Mrs. D. H. Fritts for their continued support and encouragement. Deep appreciation is expressed to the author's wife, Donna Jean, for typing and review of the manuscript. The use of the computer facilites of Duke Power Company is gratefully acknowledged.

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ABSTRACT

Diatoms, collected from plexiglass plates, and water chemistry samples were taken and analyzed biweekly in 1972 from five stations on the upper portion of Soda Butte Creek, Montana, one above and four below the entry of seepage from a mine tailings dump.

Soda Butte Creek was found to be of the calcium-magnesium-bicarbonate type. Total iron increased markedly from a mean of .2 $mg \cdot \ell^{-1}$ above to 6.7 $mg \cdot \ell^{-1}$ below the seep, and pH was depressed slightly from a mean of 8.32 to 7.80.

A total of 33 genera and 171 species and varieties of diatoms were identified. Dominant diatoms were: *Hannaea arcus, Achnanthes lanceolata, Gomphonema angustatum,* and *Diatoma hiemale* var. *mesodon.*

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The diatom flora of another stream of the area, Iron Springs Creek, Wyoming, was compared to that of Soda Butte Creek due to the contrasting nature of the two streams' water chemistry. Iron Springs Creek was of the sodium-potassium-bicarbonate type. *Cocconeis placentula* var. *lineata* was the dominant diatom found in Iron Springs Creek.

The multivariate statistical techniques of principle components and cluster analysis suggested that unique diatom communities existed in the two streams and that the monovalent:divalent cation ratio was the best discriminator between the streams.

INTRODUCTION

In 1972, the National Park Service awarded contract number 2-101-0387 to Dr. John C. Wright of Montana State University to undertake limnological investigations in Yellowstone and Glacier National Parks. This paper details a study of the benthic diatoms and water chemistry on Soda Butte Creek near Cooke City, Montana, and Iron Springs Creek near Old Faithful Geyser in the Yellowstone National Park area. These two streams were studied to determine the impact of mine tailings drainage on Soda Butte Creek and sewage lagoon percolation and run-off on Iron Springs Creek.

A survey of Soda Butte Creek was conducted in 1967 by Mills and Sharp (1968) to determine if the stream was receiving pollution from the old McClaren mill tailings located at Cooke City, Montana. They found smaller numbers of aquatic insects immediately below the mill tailings than in other sections of the stream and increasing numbers at locations progressively downstream from the tailings. In 1969 the Kennecott Copper Corp. leveled and shaped the mill tailings and covered them with two to four feet of topsoil (Hill 1970 and Duff 1972). Soda Butte Creek was also re-routed around the area of the reclaimed tailings. Hill (1970) sampled Soda Butte Creek about a year after the rehabilitation and found that the stream immediately below the tailings had about the same chemical qualities as before reclamation.

Iron Springs Creek is located adjacent to a series of sewage lagoons which receive all waste water from the Old Faithful area in Yellowstone National Park. No previous surveys of this stream have been conducted prior to this investigation. The purposes of this study were to determine whether the sewage lagoon percolation was polluting the stream and to compare Iron Springs Creek diatoms to those found in the chemically different waters of Soda Butte Creek.

Soda Butte Creek and Iron Springs Creek have little if any macrophyte and phytoplankton growth. The benthic algal community constitutes the major primary producer. Clear mountain streams often provide excellent habitat for diatom growth (Patrick and Reimer 1966), and this group of algae often dominates the benthic algae. This seems to be the case in both streams. The species composition and structure of benthic diatom communities have often been used to evaluate conditions in rivers receiving various kinds of pollution (Butcher 1974, Fjerdingstadt 1950, Patrick, Hohn, and Wallace 1954, Blum 1957, Hohn and Hellerman 1963, and Patrick 1963).

DESCRIPTION OF STUDY AREA

Soda Butte Creek is located in south central Montana and the northeast portion of Yellowstone National Park. U.S.G.S. maps and U.S. Forest Service aerial photographs indicate that Soda Butte Creek originates about one mile east of Cooke City, Montana, and flows in a southwest direction approximately 40.2 stream km (25 stream miles) before emptying into the Lamar River. The stream drains an area of approximately 259 km^2 (100 square miles). Major tributaries are Woody, Amphitheater, Pebble, and Sheep creeks. Soda Butte Creek originates at an elevation of about 2365 meters (7,760 feet) above mean sea level and has an average drop of 9.1 $m \cdot km^{-1}$ (48 $feet \cdot mile^{-1}$). Five sampling stations were established on the stream (Figure 1). Station 1 was located approximately 150 m (165 yards) above the area of the reclaimed tailings and was considered the control station. Station 2 was located about 21 m (23 yds) below the visual point of entry of seepage from the tailings area. Station 3 was situated approximately 2.4 km (1.5 mi) below the tailings area and immediately below the entrance of Woody creek. Station 4 was established approximately 15.1 km (9.4 mi) below the tailings area just inside the park boundary. Station 5 was located about 32.6 km (20.3 mi) below the tailings area and below the entrance of Pebble Creek. The substratum consisted of gravel in the riffle areas where the stations were located. Some boulders and rubble were present at the upper stations.

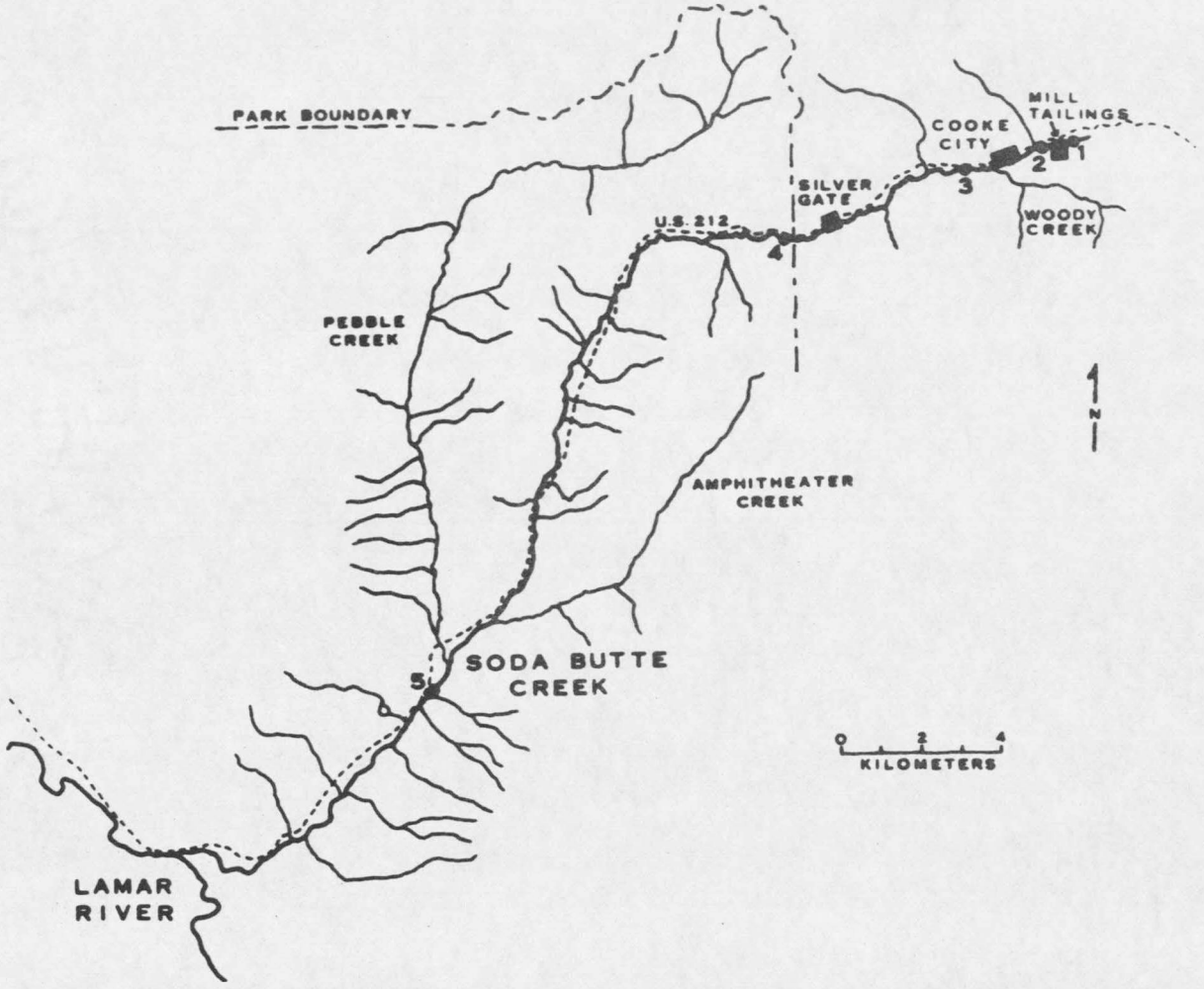


Figure 1. Map of Soda Butte Creek showing location of the sampling stations and the Yellowstone National Park boundary.

The substratum at Station 2 was covered by large deposits of ferric hydroxide giving the stream bottom a dark red color.

Iron Spring Creek is located in the southwest portion of Yellowstone National Park near Old Faithful Geyser. It originates at an elevation of about 2,380 m (7,800 ft) above mean sea level and flows north about 6.8 km (4 mi) before emptying into the Little Firehole River at an elevation of 2,220 m (7,280 ft). Two sampling stations were established on the stream. Station IS1 was located 56.7 m (62 yds) upstream from the Old Faithful sewage lagoons, and Station IS2 was about 293 m (320 yds) downstream from the ponds. Water entered the stream from several hot springs located along the 1,052 m (1,150 yds) of stream channel separating Stations IS1 and IS2. During September, volumes of .24 m^3 $sec.^{-1}$ (8.5 c.f.s.) were measured at Station IS1 and .30 m^3 $sec.^{-1}$ (10.7 c.f.s.) at Station IS2.

METHODS

Water samples and diatom collections from artificial substrates were made according to the schedule in Table 1.

Table 1. Sampling schedule of water chemistry and diatom collections from artificial substrates.

Date	Water Chemistry		Diatoms	
	Soda Butte	Iron Springs	Soda Butte	Iron Springs
5 May 72	X			
9 June 72	X			
24 June 72	X	X		
8 July 72	X	X		
21-22 July 72	X	X	X	X
4 August 72	X	X	X	X
18 August 72	X	X	X	X
31 August 72	X	X	X	X
18 September 72	X	X	X	X
29 September 72	X	X	X	X
17 October 72	X		X	
11 November 72	X			

Chemical and Physical Determinations

Dissolved oxygen concentration, temperature, and pH were determined in the field. The standard Winkler method was used for oxygen analysis (APHA 1965). Temperature was taken with a mercury thermometer. A Beckman Model G and an Orion Ion Analyzer Model 407 were used to determine pH.

Concentrations of nitrite, nitrate, ortho-phosphate, sulfate, calcium, magnesium, flouride, chloride, and total alkalinity were all determined as described by the American Public Health Association (1965). A Baush and Lomb Spectronic 20 was used in all colorimetric determinations.

Zinc and copper were determined by atomic absorption with a Beckman DU Flame Spectrophotometer. Sodium and potassium were determined by emission with the same spectrophotometer. Iron was determined using the Hach Ferrover® method (Phenanthroline), and manganese was analyzed by the Leuco Base Method (Strickland and Parsons 1972).

The monovalent:divalent cation ratio was calculated in the following manner:

$$M : D = \frac{Na^{+}\ meq.\ell^{-1} + K^{+}\ meq.\ell^{-1}}{Ca^{++}\ meq.\ell^{-1} + Mg^{++}\ meq.\ell^{-1}}$$

Estimates of stream discharge were computed from individual flowmeter and stream depth measurements made at uniform intervals across the stream. Stream discharge was the flow through the stream crossectional area.

Chlorophyll and Autotrophic Index

A plexiglass plate with a collecting surface area of 140 cm^2 was bolted vertically to a ½ inch concrete reinforcing rod which had been driven into the stream bed. The plate was oriented so that the top edge was approximately 10 cm below the water surface and the collecting surface was at an approximate angle of 150° to the current flow. After a period of four weeks, the plate was carefully removed from the water and inserted into its individual black plastic bag. The plates were frozen until chlorophyll analyses were conducted, usually the following day. The accumulated biomass was scraped with a single-edged razor blade from an area of 140 cm^2 on each plate. The upstream side was always scraped. The scrapings were dissolved in enough 90% acetone to result in an absorbance reading between 0.1 and 0.7 (80% and 20% transmittance respectively). The acetone mixture was shaken vigorously and placed in a light-proof test tube and refrigerated at 0°C for at least 20 hours. At the end of the extraction period, the entire acetone extract was spun in a clinical centrifuge at high speed for ten minutes. The

acetone-phytopigment supernate was then decanted and brought up to the original volume with 90% acetone. The remaining particulate fraction was transferred to preweighed Vycor® crucibles for the biomass analysis. The absorbance of the phytopigment extract was then measured on a Beckman DU Spectorphotometer Model 2400. The centrifuged particulate remainder from the chlorophyll extraction was oven dried at 105°C for 24 hours and weighed on a Mettler Type H16 Balance. Chlorophyll production per unit area was calculated from Parsons' and Strickland's (1972) equations.

Biomass was then determined by incineration of the material at 600°C for one hour and by calculation of the weight loss (ash-free dry weight). The autotrophic index is the ratio of grams ash-free dry weight to grams chlorophyll a.

Diatom Studies

Diatom material was scraped from outside the area delimited for chlorophyll determination on the plexiglass substrate. The diatoms were then cleaned using the boiling nitric acid potassium dichromate technique described by Hohn and Hellerman (1963). The cleaned material was then mounted in a medium of high refractive index, according to the method used by the Federal Water Pollution Control Administration (1966).

Each slide was examined using oil immersion. Successive fields were observed, from the edge of the coverslip inward, until approximately 400 diatom cells were identified and tabulated. The slide was then scanned at 430X for additional species that were not found during the initial count. The percentage or abundance of each taxon was computed for each slide. Taxa which were observed during the scan count but not during the initial count were tabulated with a t (trace). This counting method was used by Thomasson (1925) as well as Roeder (1966) and Cholnoky (1960, 1968).

Diatom community diversity (d) was calculated for each sample using the equation (Margalef 1951): $d = \frac{m - 1}{\ln N}$ where m equals the number of species and N equals the number of diatom cells counted.

Taxonomic keys used for diatom identification were Hustedt (1930), Cleve Euller (1951), FWPCA (1966), and Patrick and Reimer (1966), (1975).

RESULTS: SODA BUTTE CREEK

Chemical and Physical Determinations

The range and mean values for chemical and physical analyses are presented in Table 2. The complete results of the determinations are given in the Appendix (Tables 25 through 45).

Iron, manganese, and sulfate exhibited a sharp increase in concentration at Station 2, followed by a gradual decrease downstream. The values found at Station 5 were similar to those found at Station 1 (control station). Average increases at Station 2 over Station 1 were as follows: manganese--57 times, iron--39 times, sulfate--10 times. Recovery of the stream to control levels was essentially complete for manganese and sulfate by Station 4. Iron concentrations generally decreased at successive downstream stations during most of the year, but during the spring runoff period this pattern was reversed with increasing iron levels at successive downstream stations. The reversed pattern probably resulted from the scouring effect upon the stream bed, produced by high current velocity and silt load.

Total hardness, calcium, and magnesium levels rose sharply below the tailing seepage. At Station 3, the concentrations fell below Station 1 levels. The decrease at Station 3 was due to dilution by Woody Creek. Levels then gradually rose to pre-seep concentrations at Station 5.

Table 2. Ranges and mean values for chemical and physical analyses of Soda Butte Creek

Variable	Station 1	2	3	4	5
Zinc ($mg \cdot \ell^{-1}$)	0.0 - .035 T	0.0 - 0.035 T	0.0 - .035 T	0.0 - .025 T	0.0 - .04 T
Temperature (C°)	0.5 - 6.0 3.2	0.5 - 6.7 4.0	0.0 - 9.0 4.4	0.0 - 11.3 5.9	1.0 - 13.7 8.0
Turbidity (JTU)	0.3	75.0	15.0	4.0	1.5
Dissolved Oxygen ($mg \cdot \ell^{-1}$)	8.3 - 10.8 10.0	8.4 - 10.0 8.9	8.6 - 11.0 10.0	8.6 - 11.2 9.9	8.3 - 11.2 9.6
Potassium ($mg \cdot \ell^{-1}$)	0.39 - 0.70 0.60	0.39 - 2.19 1.03	0.20 - 1.33 0.60	0.27 - 0.82 0.52	0.59 - 1.29 1.02
Nitrate No_2-N ($mg \cdot \ell^{-1} NO_3N$)	0.002 - 0.038 0.018	0.001 - 0.047 0.019	0.0 - 0.052 0.014	0.0 - 0.034 0.017	0.0 - 0.042 0.008
Chlorophyll "a" accrual ($mg \cdot m^{-2}$)	0.11 - .04 3.12	0.0 - 0.0 0.0	0.72 - 12.34 4.08	.83 - 18.86 7.24	0.65 - 15.99 7.41
Total Iron ($mg \cdot \ell^{-1}$)	0.07 - 0.28 0.17	0.68 - 21.45 6.70	0.50 - 5.05 1.76	0.16 - 3.18 1.18	0.05 - 4.88 .93
Manganese ($mg \cdot \ell^{-1}$)	0.001 - 0.012 0.004	0.001 - 0.880 0.227	0.001 - 0.102 0.061	0.001 - 0.030 0.008	0.001 - 0.029 0.006
Sulfate ($mg \cdot \ell^{-1}$)	5.0 - 8.4 6.4	11.4 - 191.0 64.4	2.0 - 15.5 8.6	2.0 - 12.2 7.9	2.5 - 11.8 6.2

Table 2. Continued

Variable	Station 1	2	3	4	5
Total Hardness ($mg \cdot \ell^{-1} CaCO_3$)	62.0 - 117.0 99.1	60.0 - 170.0 135.9	26.0 - 73.8 49.9	41.0 - 86.4 59.4	53.0 - 105.8 80.43
Calcium ($mg \cdot \ell^{-1} Ca^{++}$)	20.0 - 37.5 32.4	18.8 - 65.7 40.7	10.4 - 28.5 16.3	8.4 - 36.7 18.9	14.4 - 33.5 21.9
Magnesium ($mg \cdot \ell^{-1} Mg^{++}$)	2.9 - 7.3 5.6	3.2 - 21.3 9.5	.7 - 4.3 3.1	2.2 - 5.6 3.9	1.3 - 10.9 6.4
Alkalinity ($mg \cdot \ell^{-1} CaCO_3$)	56.5 - 115.5 98.0	52.0 - 128.0 92.0	36.0 - 77.5 51.6	38.8 - 104.5 62.6	47.4 - 120.0 81.8
pH	7.87 - 8.84 8.32	6.95 - 8.20 7.80	7.58 - 8.47 8.08	7.95 - 8.66 8.29	7.93 - 8.85 8.39
Sodium ($mg \cdot \ell^{-1}$)	0.23 - 3.04 1.13	0.12 - 3.47 1.21	1.50 - 6.21 3.64	1.84 - 4.78 3.49	1.50 - 3.50 2.86
Phosphate ($mg \cdot \ell^{-1} PO_4$-P)	0.0 - .013 0.003	0.0 - .008 0.002	.02 - .061 0.035	.024 - .058 0.033	.018 - .044 0.033
Copper ($mg \cdot \ell^{-1}$)	0.0 - 0.10 T	0.0 - 0.07 T	0.0 - 0.04 T	0.0 - 0.05 T	0.0 - 0.05 T
Discharge ($m^3 \cdot sec^{-1}$)	.065 - 1.325 .430	.079 - 1.994 .610	.295 - 7.556 2.452	.481 - 6.553 2.343	1.526 - 2.393 1.908

The total alkalinity of Soda Butte Creek was not changed by seep entry from the mine tailings, but decreased at Station 3 due to dilution by Woody Creek. Downstream from Station 3, alkalinity values gradually increased to near control levels by Station 5. The pH fell at Station 2 and then gradually recovered to control levels at Station 4. The pH values ranged from 7.61 to 8.85, which is within the limits of most natural fresh waters (Hutchinson 1957).

Sodium and phosphate levels at Stations 1 and 2 were unchanged, but increased at Station 3. Sodium rose threefold and phosphate increased tenfold at Station 3 over the upstream levels. These higher levels remained essentially unchanged at the downstream stations.

Potassium levels ranged from 0.2 to 2.19 $mg \cdot \ell^{-1}$. A slight increase was noticed at Stations 2 and 5. Nitrate levels were low, ranging from 0.008 to 0.019 $mg \cdot \ell^{-1}$. Copper and zinc were usually found in undetectable amounts, but with slightly higher concentrations during periods of high water. Temperature increased gradually downstream, and ranged from 0°C at all stations to a maximum of 6°C at Station 1 and 13.7°C at Station 5.

The water at Station 2 was always observed to be much more "turbid" than the clear water upstream. Turbidity measurements were made in November when the diluting and scouring effects of

heavy run-off were minimized. Station 2 had a turbidity of 75 JTU, which was a 250 fold increase over the turbidity of Station 1. Maximum dissolved oxygen concentrations were approximately 10 $mg \cdot \ell^{-1}$ during the entire study period.

Stream discharge values followed a pattern of maximum values in the spring gradually subsiding to minimum values in the fall. Run-off from melting snow swelled the discharge in Soda Butte Creek up to 20 times over fall discharge values (Table 3). The rampaging water carried high silt loads that continually scoured the stream bottom. The sandpaper texture of the stream bottom, noticed while wading the stream, indicated that the scouring action prevented successful algal growth.

Table 3. Discharge ($m^3 \cdot sec^{-1}$) of Soda Butte Creek by station and sampling date

Dates	Stations				
	1	2	3	4	5
24 June 72	1.325	1.994	7.556		
22 July 72	.402	.368	1.801	2.620	
18 Aug 72	.136	.119	.487	1.000	1.526
18 Sept 72	.105	.079	.620	1.059	2.393
11 Nov 72	.065	.093	.295	.481	1.804
2 June 73	.544	1.008	3.951	6.553	

Monovalent:Divalent Cation Ratio

M:D ratio varied from a mean of .03 at Station 1 to a mean of .18 at Station 3. Ratio values are presented in Table 4.

Table 4. Monovalent:divalent cation ratios for Soda Butte and Iron Springs Creeks from sample dates for which diatom data is available

	Soda Butte Creek Stations				Iron Springs Creek Stations	
Date	1	3	4	5	IS1	IS2
21 July 72	.037		.160		2.53	3.89
4 August 72	.034		.147		2.45	3.80
18 August 72	.026	.177	.117	.087	2.06	3.79
31 August 72	.026	.163	.110	.076	2.04	3.71
18 September 72	.026	.215	.154	.083	1.55	3.86
29 September 72	.027	.178		.084	2.52	4.19
17 October 72	.026	.167	.164	.100		
Mean	.03	.18	.14	.09	2.13	3.81

Chlorophyll, Biomass, and Autotrophic Index

Primary productivity was approximated by measuring the amount of chlorophyll "a" accrual on plexiglass substrata over a four-week growth period. Table 5 lists the chlorophyll accrual for each sampling period and the mean chlorophyll accrual for each station.

Table 5. Soda Butte Creek chlorophyll "a" accrual ($mg \cdot m^{-2}$) for all stations and sampling dates for a four-week growth period

Date	Station				
	1	2	3	4	5
8 July 72	0.28	0.0			
21 July 72	0.58	0.0		3.58	15.99
4 August 72	2.09	0.0		6.21	2.95
18 August 72	5.66	0.0	4.01	12.17	0.65
31 August 72	7.04	0.0	0.86	18.86	10.80
18 September 72	5.67	0.0	12.34	6.32	9.11
29 September 72	2.13	0.0	3.25	2.73	8.56
17 October 72	0.73	0.0	0.72	0.83	3.81
Mean	3.12	0.0	4.08	7.24	7.41

Generally the chlorophyll production was much higher at the warmer downstream stations than at the cooler upstream stations. Chlorophyll values ranged from 0.0 at Station 2 to 18.86 $mg \cdot m^{-2}$ at Station 4. With

the exception of the area of Soda Butte Creek affected by the tailings (Station 2), chlorophyll production was similar to that found for mountain streams by Todd (1967) and Klarich and Wright (1974). The tailings exerted a drastic effect at Station 2 reducing chlorophyll production to an average of 0.0 $mg \cdot m^{-2}$. The detrimental effects of the flocculent ferric hydroxide mat, produced by the tailings, was probably caused by the physical barrier to algal growth it presented rather than a chemical toxic effect produced by the dissolved and colloidal iron in the water.

Biomass (ash-free dry weight) accrual measurements are presented in Table 6.

Table 6. Soda Butte Creek biomass values ($mg \cdot m^{-2}$) for all stations and all sampling dates

	Station				
Date	1	2	3	4	5
21 July 72	171	308		834	3152
4 August 72	15	5121		1698	199
18 August 72	1017	2656	1625	4689	150
31 August 72	529	333	5176	2756	2634
18 September 72	764	1187	3104	1860	6219
29 September 72	322	3026	1131	915	2099
17 October 72	139		434	391	1397
Mean	422	2016	2294	1878	2264
Median	322	1484	1625	1698	2099

Accumulation of stream sediment on the plexiglass plates contributed to erratic and extreme biomass measurements, especially at Station 2. This problem was acute during periods of high sediment load and periods of fluctuating water levels.

It is important to note that the biomass estimates at the stations below the mine tailings were not accurate measurements of biomass because the weight loss upon ignition was not only attributable to biomass but also to water loss from the precipitated ferric hydroxide, $Fe(OH)_3 \cdot (H_2O)_n$, found at these three stations. Ferric hydroxide is highly hydrated and remains hydrated even when heated to 105°C; it does not lose all of the water of hydration until heated to 300-400°C. Upon further heating, the ferric hydroxide loses more weight in the conversion to ferroferric oxide ($FeO + Fe_2O_3$) (Latimer and Hydebrand 1951). The balanced equations follow:

$$Fe(OH)_3 \cdot (H_2O)_n \xrightarrow{105°C} Fe(OH)_3 \cdot (H_2O)_a + (H_2O)_b \text{ where } a + b = n$$

$$Fe(OH)_3 \cdot (H_2O)_a \xrightarrow{300\text{-}400°C} Fe(OH)_3 + (H_2O)_a$$

$$6Fe(OH)_3 \xrightarrow{500\text{-}600°C} 2(FeO + Fe_2O_3) + \tfrac{1}{2}O_2 + 9H_2O$$

Therefore, the ash-free dry weight attributed to biomass at Station 2 was probably weight loss due to dehydration of ferric hydroxide. The influence of ferric hydroxide at Stations 3, 4, and 5 was

much less drastic as only a small amount of the total ash-free dry weight was due to ferric precipitate dehydration.

The autotrophic index is the ratio of biomass (ash-free dry weight) to chlorophyll a that accumulates on each plate during the incubation period. The index measures the relative amount of heterotrophs versus autotrophs and thus the consumptive versus the photo-productive nature of the periphyton community. Increased growth of heterotrophs, such as protozoa, fungi, bacteria and sedimented organic matter, tends to raise the index value proportionately.

Autotrophic index values for Soda Butte Creek are given in Table 7.

Table 7. Soda Butte Creek autotrophic index values for all stations and all sampling dates

			Station		
Date	IS1	IS2	3	4	5
21 July 72	295	∞		233	197
4 August 72	7	∞		273	674
18 August 72	180	∞	406	385	236
31 August 72	75	∞	6016	146	244
18 September 72	135	∞	253	211	440
29 September 72	151	∞	348	335	245
17 October 72	190	∞	602	470	365
Median	135	∞	406	335	245

The median autotrophic index values for the period of 18 August to 17 October 1972, from Station 1 downstream, were 135, ∞, 406, 335, 245. The value for Station 1 represented a periphyton community with a high degree of autotrophic production and relatively little heterotrophic growth (Weber and McFarland 1969). Station 2 had index values approaching infinity due to zero chlorophyll production. The autotrophic index values at the remaining downstream stations indicated the gradual recovery toward but not reaching the proportions of autotrophic and heterotrophic organisms found at Station 1.

Interrelationships Between Chlorophyll "a" and Chemical and Physical Parameters

Water chemistry and chlorophyll values from sampling dates 8/18/72--10/17/72 inclusive were used to determine simple, partial, and multiple correlation coefficients between chlorophyll "a" production and stream variables. The statistical analyses are performed on two groups of stations: all stations (1, 2, 3, 4, and 5), and all stations excluding station 2 (1, 3, 4, and 5). This approach is necessary because correlations could not be computed for the zero chlorophyll data at station 2. Calculations are based on the five sampling dates in order to evaluate the correlations over the same time span for each station.

A simple correlation coefficient matrix for all stations and variables, 1) chlorophyll "a", 2) total iron, 3) temperature,

Table 8. Simple correlation coefficients for chlorophyll and chemical and physical variables for all stations on Soda Butte Creek and for dates 8/18-10/17/72 inclusive

	Chla	Fe	Temp	PO_4	Hard	pH
1. Chlorophyll a	1.000					
2. Total Iron	-.399*	1.000				
3. Temperature	.508**	-.259	1.000			
4. Orthophosphate	.379	-.410*	.591**	1.000		
5. Total Hardness	-.417*	.628**	-.325	-.849**	1.000	
6. pH	.483*	-.764**	.276	.202	-.388	1.000

*Significant at the .05 level

**Significant at the .01 level

4) orthophosphate, 5) total hardness, and 6) pH is presented in Table 8. The results indicate significant correlations exist between chlorophyll and the indicated variables. Table 9 gives the simple correlation coefficients for chlorophyll and the four significantly correlated variables and orthophosphate for each station and for stations 1, 3, 4, and 5. The coefficients for the separate stations require higher values for significance because of the smaller number of observations, n = 5. This data indicates that temperature is significantly correlated (r = .501*) to chlorophyll production at stations other than station 2. A second matrix of simple correlation

Table 9. Simple correlation coefficients for chlorophyll vs total iron, temperature, orthophosphate, hardness and pH for individual stations 1, 3, 4, and 5 as well as a combined value. Data represents five sampling dates 8/18--10/17/72 inclusive on Soda Butte Creek.

	Fe	Temp.	$PO_4^{\equiv}$	Hard.	pH
Station 1	.074	.894*	.471	-.656	.357
Station 3	.852*	.129	.532	.282	.523
Station 4	.030	.932**	-.315	-.273	-.416
Station 5	.731	.265	-.013	.478	-.648
1,3,4,5	.222	.501*	.169	-.072	.142

*Significant at the .05 level
**Significant at the .01 level

coefficients for stations 1, 3, 4, and 5 and variables chlorophyll, total iron, temperature and orthophosphate is presented in Table 10. Comparison of this matrix with the matrix for all stations demonstrates the effect of station 2 upon the correlation coefficients.

Table 10. Simple correlation coefficient matrix for chlorophyll and iron, temperature, and orthophosphate for the aggregate of stations 1, 3, 4, 5, on Soda Butte Creek for dates 8/18--10/17/72 inclusive

	Chla	Fe	Temp.	$PO_4^{\equiv}$
1. Chlorophyll *a*	1.000			
2. Total iron	.222	1.000		
3. Temperature	.501*	.064	1.000	
4. Orthophosphate	.169	.609**	.431	1.000

*Significant at the .05 level
**Significant at the .01 level

The best multiple correlations indicate that iron and temperature, taken together, account for approximately one-third of the total variation in chlorophyll *a*.

all stations $R_{1.23} = .579$, $R^2 = .34$

stations 1, 3, 4, 5 $R_{1.23} = .536$, $R^2 = .29$

The best simple correlation coefficient r^2 values for chlorophyll *a* and temperature are:

all stations	$r_{13} = .508,$	$r^2 = .26$
stations 1, 3, 4, 5	$r_{13} = .501$	$r^2 = .25$

A dependent relationship most likely exists between solar radiation and water temperature. Incident radiation was not measured so the relative amount of dependence of the two variables is not known. However, since solar radiation is considered to be constant at all stations for each sample date, then the general increase in chlorophyll production downstream can be more probably related to temperature.

It is apparent that the significant degrading effect of the mine tailings seepage on chlorophyll production is limited to Station 2 when the simple correlation coefficients for total iron and chlorophyll at each station (Table 9) are compared to the all stations coefficient (Table 8) for the same variables. The individual station correlations are all positive but the all stations correlation is significantly negative ($r_{12} = -.399*$). This data indicates the drastic influence of the mine tailings seepage at Station 2 and the rapid recovery at downstream stations. A graphical illustration of the interrelationship of chlorophyll a, temperature and total iron is shown in Figure 2. The effect of iron at station 2 suggests that iron controls chlorophyll production at that station. The statistical analyses suggest that temperature controls chlorophyll production at the remaining stations.

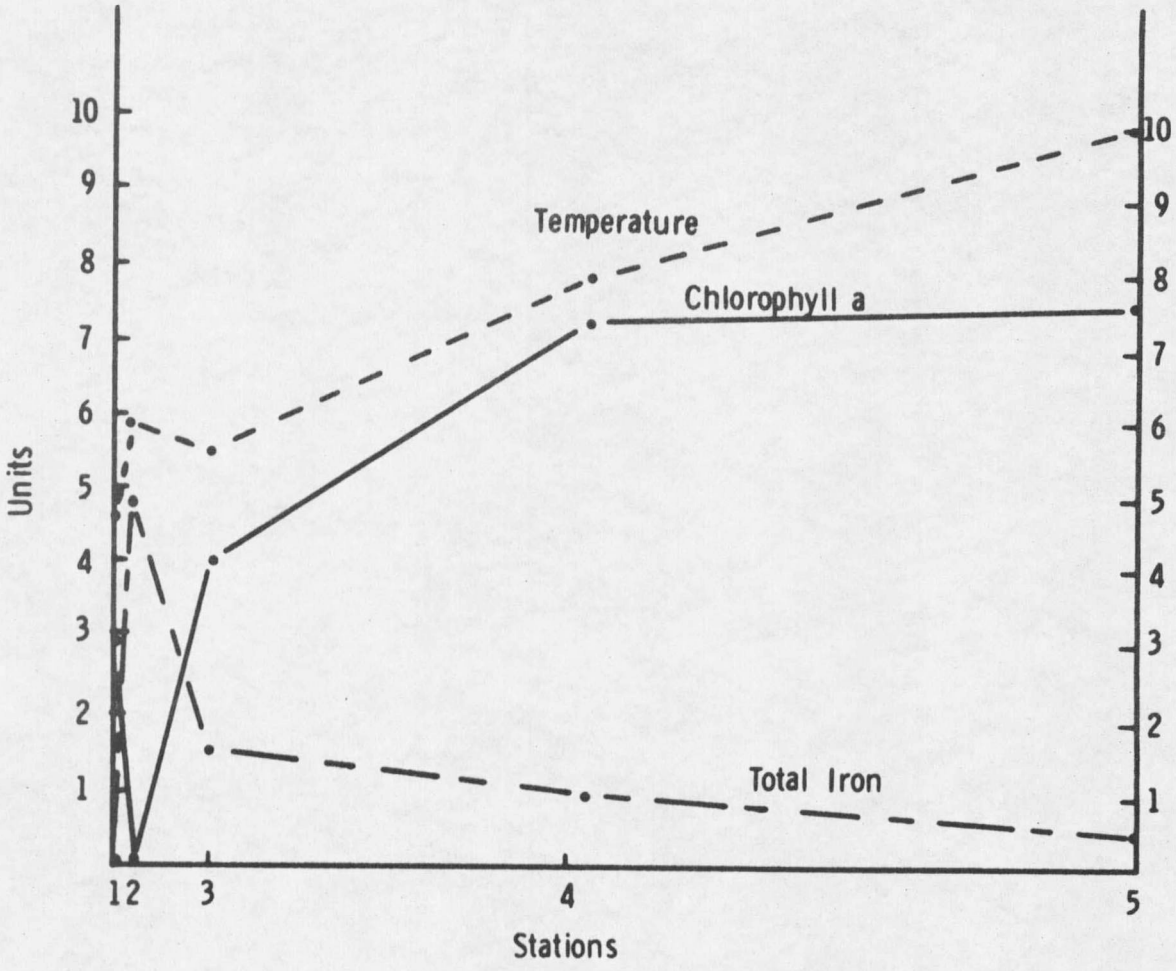


Figure 2. Downstream changes in mean temperature (°C), mean chlorophyll a ($mg \cdot m^{-2}$), and mean total iron ($mg \cdot \ell^{-1}$) at each station on Soda Butte Creek.

Diatom Flora of Soda Butte Creek

Genera and Species Enumeration

A total of 33 genera and 171 species and varieties were found in Soda Butte Creek from an enumeration of 9,606 diatom cells. An average of 380 cells were counted for each of 32 slides. The six slides from Station 2 were examined for presence of taxa only, due to the insignificant numbers of cells. Table 11 shows the numbers of genera and species of diatoms at each station.

Table 11. Number of genera and species found at each station on Soda Butte Creek over the entire study period

Stations	1	2	3	4	5
Genera	24	17	21	22	20
Species and varieties	89	49	72	83	95

Table 12. Alphabetical list of the diatom taxa found in Soda Butte Creek for all five stations

Genera	Species	Station
Achnanthes	*conspicua* A. Mayer	1,5
	exigua Grun.	1
	exigua var *heterovalva* Krasske	5
	flexella (Kütz.) Brun	1
	groenlanica (Cl.) Grun.	5
	inflata (Kütz.) Grun.	5
	lanceolata (Breb.) Grun.	All
	lanceolata var *dubia* Grun.	1,2,3,4
	lanceolata var *haynaldii* (Istv.-Schaarsch) Cl.	3,4
	microcephala (Kütz.) Grun.	1,2,5
	minutissima Kütz.	All
	spp.	3,4,5
Amphipleura	*pellucida* Kütz.	1
Amphora	*delicatissima* Krasske	1
	ovalis Kütz.	1,2,5
	ovalis var *pediculus* Kütz.	1,2,5
	sp.	4
Anomeoneis	*sp.*	1
Caloneis	*bacillum* (Grun.) Mereschkowsky	1,2,4
	ventricosa var *truncatula* (Grun.) Meist.	5
Cocconeis	*diminuta* Pant.	2,3,5
	fluviatilis Wallace	1
	klamathensis Sov.	1
	pediculus Ehr.	1
	placentula var *euglypta* (Ehr.) Cl.	1
	placentula var *lineata* (Ehr.) Cl.	All
	rugosa Sov.	1
	scutellum Ehr.	3,5
Cyclotella	*sp.*	4
Cymatopleura	*solea* (Breb.) W. Smith	1

Table 12. Continued

Genera	Species	Station
Cymbella	*affinis* Kütz.	1,2,5
	cistula (Ehr.) Kirchn.	1,4,5
	gracilis (Rabr.) Cl.	1,4
	herbridica (Greg.) Grun.	4
	laevis Naegel	1
	minuta Hilse ex. Rabh.	All
	parva (W. Smith) Cl.	1,3
	prostrata (Berk.) Cl.	1
	sinuata Greg	1,4,5
	turgida (Greg.) Cl.	1,2,5
Diatoma	*anceps* (Ehr.) Kirchn.	3
	hiemale (Roth.) Heib.	All
	hiemale var *mesodon* (Ehr.) Grun.	All
	tenue var *elongatum* Lyngb.	4
	vulgare Bory	1,5
Diatomella	*balfouriana* Grev.	2,3,4,5
Diploneis	*elliptica* (Kütz.) Cl.	3
	oblongella (Naeg.ex Kütz.) Ross	2
	sp.	1,3
Epithemia	*sorex* Kütz.	1
	turgida (Ehr.) Kütz.	1
	sp.	1
Fragilaria	*brevistriata* Grun.	1,4,5
	capucina Desm.	1,4
	construens (Ehr.) Grun.	1,2,4,5
	construens var *venter* (Ehr.) Grun.	3,4
	leptostauron (Ehr.) Hust.	1,4,5
	leptosauron var *dubia* (Grun.) Hust.	1,5
	nitzschioides Grun.	5
	pinnata Ehr.	2,4,5
	vaucheriae (Kütz.) Peters.	All
	vaucheriae var *capitellata* (Grun.) Patr.	1,3,5
	spp.	2,5

Table 12. Continued

Genera	Species	Station
Frustulia	*rhomboides* (Ehr.) DeT.	3,4
Gomphoneis	*herculeana* (Ehr.) Cl.	3,4,5
Gomphonema	*abbreviatum* Ag.	4
	angustatum (Kütz.) Rabh.	All
	angustatum var *producta* Grun.	1,2,3,5
	bohemicum Reich. and Fricke	1,2,3,4
	cumrhis Hohn and Hellerm.	3,5
	dichotomum Kütz.	3,4
	hedinii Hust.	All
	helveticum var *tenuis* (Fricke) Hust.	4,5
	instabilis Hohn and Hellerm.	1,3,5
	intricatum var *pumulia* (Grun.) Kütz.	4
	longiceps Ehr.	3,4
	longiceps var *subclava* Grun.	1,3,5
	olivaceum (Lyn.) Kütz.	All
	olivaceum var *calcarea* Cleve	5
	olivaceum var *minutissima* Hust.	4,5
	parvulum Kütz.	1,3,4,5
	quadripunctatum (Ostr.) Wisl.	1,5
	staurophorum Pant.	3
	tergestinum (Grun.) Fricke	3,4
	spp.	3,4,5
Hannaea	*arcus* (Ehr.) Patr.	All
	arcus var *amphioxys* (Rabh.) Patr.	3
Hantzschia	*amphioxys* (Ehr.) Grun.	1,3,4,5
Melosira	*distans* (Ehr.) Kütz.	3,4
	granulata (Ehr.) Ralfs.	4
	islandica O.Müll.	3,4
	sp.	4
Meridion	*circulare* (Grev.) Ag.	All
	circulare var *constrictum* (Ralfs.) V.H.	1

Table 12. Continued

Genera	Species	Station
Navicula	*arvensis* Hust.	A11
	bacillum Ehr.	2,3,4
	contenta fo. *parallela* Petersen	1,2,3,5
	cincta (Ehr.) Ralfs.	3,4,5
	crucicula (W.Smith) Donk.	3
	cryptocephala Kütz.	A11
	cryptocephala var *veneta* (Kütz.) Rabh.	1,4,5
	exigua Greg. ex Grun.	5
	graciloides A. Mayer	3,4
	gysingensis Foged	4
	halophila (Grun.) Cl.	3
	heufleri Grun.	4,5
	lanceolata (Ag.) Kütz.	1,3,5
	minima Grun.	2,4,5
	mutica Kütz.	2,3,4,5
	notha Wallace	3,5
	paucivistriata Patr.	5
	pelliculosa (Breb.ex Kütz.) Hilse	2,4,5
	peregrina (Ehr.) Kütz.	1
	pseudoreinhardtii Patr.	3
	pseudoscutiformis Hust.	5
	pupula Kütz.	4
	pupula var *elliptica* Hust.	2
	radiosa Kütz.	2,3,4
	rhynchocephala Kütz.	3,5
	salinarum var *intermedia* (Grun.) Cl.	5
	scutum Schum.	4
	subhalophila Hust.	5
	tripunctata (O. Müll.) Bory	1,2,4,5
	variostriata Krasske	1
	viridula var *avenacea* (Breb.ex Grun.) V.H.	1,5
	spp.	A11

Table 12. Continued

Genera	Species	Station
Nitzschia	*acicularis* W. Smith	5
	amphibia Grun.	3,4,5
	capitellata Hust.	2
	dissipata (Kütz.) Grun.	All
	epiphytica O. Müll.	4
	filliformis (W.Smith) Hust.	1
	fonticola Grun.	2,3,5
	frustulum Kütz.	1,4
	kutzingiana Hilse	5
	linearis W.Smith	All
	microcephala Grun.	1,2,4,5
	palea (Kütz.) W. Smith	All
	parvula Levis	4
	sublinearis Hust.	5
	subtilis Kütz.	5
	thermalis Kütz.	2,5
	spp.	All
Pinnularia	*biceps* Greg.	3
	borealis Ehr.	1,3,5
	microstauron (Ehr.) Cl.	3
	obscura Krasske	3
	subcapitata var *paucistriata* (Grun.) Cl.	4
	sp.	5
Rhoicosphenia	*curvata* (Kütz.) Grun. ex Rabh.	1,3,4,5
Rhopalodia	*gibba* (Ehr.) O.Müll.	1
Stauroneis	*sp.*	1
Stephanodiscus	*sp.*	2

Table 12. Continued

Genera	Species	Station
Surirella	*augusta* Kütz.	1,4,5
	linearis W. Smith	5
	linearis var *constricta* (Ehr.) Grun.	1
	ovata Kütz.	1,3,4,5
	ovata var *salina* W. Smith	5
	sp.	1,3,5
Synedra	*actinastroides* Lemm	1
	amphicephala Kütz.	1
	cyclopum Brutschy	1,4,5
	minscula Grun.	1,4
	rumpens Kütz.	1,4
	socia Wallace	4
	tabulata (Ag.) Kütz.	1,4
	ulna (Nitz) Ehr.	All
	ulna var *contracta* Østr.	3,5
	ulna var *oxyrhynchus* Kütz.	1,2,3,5
	ulna var *spathulifera* (Grun.) V.H.	1
	sp.	1,4,5

A complete list of all taxa is found in Table 12. Twenty species and varieties were found at all stations. There were four taxa found at every station except Station 2. These were *Gomphonema parvulum, Hantzchia amphioxys, Rhoicosphenia curvata,* and *Surirella ovata.* A total of 73 species were found at only one of any of the five stations.

The genera represented by the greatest number of species were *Navicula* (32), *Gomphonema* (20), *Nitzschia* (18), *Achnanthes* (12), *Synedra* (12), *Fragilaria* (11), and *Cymbella* (10).

Variations in Relative Abundance

The ranges and mean abundance values for major diatoms at each of four stations for all collections are given in Table 13. The rank of the 14 major diatom taxa ordered by mean abundance at each station is given in Table 14. All other taxa had a mean abundance of less than 2%.

The variation in mean abundance of the 14 major taxa at stations 1, 3, 4, and 5 was divided into four groups of longitudinal distribution (Figure 3). The mean abundance at Station 2 for each major taxon was zero on the basis of zero chlorophyll measurements at that station. Group 1, *Achnanthes minutissima, Diatoma hiemale* var *mesodon,* and *Gomphonema angustatum* were highest in mean abundance at Station 1. There was a significant decrease in abundance of these taxa at Station 3 and this trend was generally continued at each station thereafter. It should be noted that the sharp decline in these three diatom species between Stations 1 and 3 may be associated with the sharp increase in total iron at Station 2.

Table 13. Range and mean abundance values (%) for the major diatom taxa found on artificial substates at four stations for all sampling dates on Soda Butte Creek. t<1% abundance

Taxon	1	3	4	5
Achnanthes lanceolata	0.0-15.9 3.2	2.7-22.6 12.1	6.1-51.9 18.3	1.9-24.3 7.4
Achnanthes minutissima	1.2-46.7 13.7	t-3.0 1.3	0.0-1.6 t	0.0-2.6 t
Cocconeis placentula var *lineata*	2.1-3.5 3.0	t-t t	t-1.1 t	t-27.9 6.7
Cymbella sinuata	0.0-t t	0.0-14.3 2.9	0.0-3.0 1.1	t-58.3 11.9
Diatoma hiemale var *mesodon*	2.0-41.1 17.7	1.2-6.1 4.0	t-8.8 3.4	0.0-1.4 t
Fragilaria vaucheriae	t-17.4 4.5	6.3-20.2 12.2	9.2-23.1 15.4	t-14.4 5.1
Gomphonema angustatum	11.9-74.1 27.4	2.3-14.0 7.5	1.7-8.0 5.5	5-6.3 2.0
Gomphonema hedinii	0.0-t t	0.0-26.0 15.6	0.0-3.3 2.3	1.8-7.5 4.6
Gomphonema olivaceum	0.0-t t	0.0-10.8 3.6	t-6.4 1.7	3.0-39.0 18.9
Hannaea arcus	0.0-13.2 2.0	8.5-60.7 25.6	7.6-58.1 30.1	1.0-3.5 1.6
Navicula cryptocephala	0.0-t t	0.0-t t	0.0-4.0 2.1	1.8-9.2 6.4
Nitzschia dissipata	t-t t	t-1.2 t	0.0-5.7 1.8	0.0-10.8 4.8
Surirella ovata	0.0-t t	0.0-t t	0.0-19.1 5.6	0.0-10.9 3.8
Synedra ulna	0.0-19.3 4.3	0.0-t t	0.0-t t	0.0-17.2 7.9

Table 14. Rank of major diatoms of Soda Butte Creek according to mean abundance (%) based on all collections at Stations 1, 3, 4, and 5.

Rank	Diatom	Mean Abundance
1	*Hannaea arcus*	14.8
2	*Gomphonema angustatum*	10.6
3	*Achnanthes lanceolata*	10.2
4	*Fragilaria vaucheriae*	9.3
5	*Diatoma hiemale* var *mesodon*	6.4
6	*Gomphonema olivaceum*	6.2
7	*Gomphonema hedinii*	5.8
8	*Achnanthes minutissima*	4.1
9	*Cymbella sinuata*	4.0
10	*Synedra ulna*	3.1
11	*Cocconeis placentula* var *lineata*	2.7
12	*Surirella ovata*	2.6
13	*Navicula cryptocephala*	2.3
14	*Nitzschia dissipata*	2.0

Group 2 consists of diatoms that were found to be high in mean abundance at Stations 3 and 4 and low in abundance at Stations 1 and 5. The taxa *Achnanthes lanceolata, Fragilaria vaucheria, Hannaea arcus,* and *Gomphonema hedinii* all exhibited this tendency. The

increase in these diatom species may be associated with the increase in orthophosphate at Station 3 or to a change in competitive relationships. *Hannaea arcus* of group 2 was the most abundant diatom found during the study of Soda Butte Creek. One sample at Station 3 contained a 60% abundance of this diatom.

Group 3 consists of diatoms that had relatively higher abundance at Stations 1 and 5 and lower abundance at Stations 3 and 4. *Cocconeis placentula* var *lineata* and *Synedra ulna* exhibited this pattern.

Group 4 includes those diatom species that were highest in mean abundance at Station 5 and were lowest in abundance at Stations 1, 3, and 4. *Cymbella sinuata, Gomphonema olivaceum, Navicula cryptocephala* var *veneta, Nitzschia dissipata,* and *Surirella ovata* were classified in this group.

Station Similarity

Station similarity was determined by pairwise comparisons of the diatom communities using two methods. The first uses species presence in the form of Jaccard's coefficient (Sokal and Sneath 1963):

$$J = \frac{a}{a+b+c}$$

where a is the number of taxa found at both stations, b is the number found at the first station but not at the second, and c is the number found at the second station but not at the first.

This index was calculated for all stations except for Station 2 and all taxa (Table 15). The two most similar stations were 1 and 5. The least similar were 1 and 3 stations above and below the tailings seepage.

Table 15. Jaccard's coefficient and rank for all station pairs based on species present, Soda Butte Creek

Station Pairs	Total Species	Shared Species	$100\% \times \frac{\text{shared}}{\text{total}}$	Rank
1,3	124	37	29.8	6
1,4	129	43	33.3	5
1,5	130	54	41.5	1
3,4	111	44	39.6	2
3,5	120	47	39.2	3
4,5	130	48	36.9	4

The second method, based upon species relative abundance, uses the following formula (Whittaker and Fairbanks 1958):

$$PS_c = 100 - .5\sum|a-b|$$

where PS_c is the percentage similarity of community samples; a and b are the mean abundance (%) of a given species at two stations.

This index was calculated for all stations except Station 2, and all major taxa (Table 16). According to this index, the most similar stations were stations 3 and 4 and the least similar were stations 1 and 4. These results suggest that the diatom communities

at stations 1 and 5 may be composed of similar diatom communities but the relative abundance may be altered due to differences in environmental and competitive factors.

Table 16. Percentage similarities (PS_c) of diatom communities based on mean abundance values for all stations and collection dates, Soda Butte Creek (Whittaker and Fairbanks 1958)

Station Pairs	PS_c	Rank
1,3	41.7	4
1,4	38.7	6
1,5	40.8	5
3,4	77.7	1
3,5	46.9	2
4,5	44.7	3

Diatom Diversity

Diatom diversity d = (m-1)/lnN, (Margalef, 1951), for five dates is given in Table 17. Station averages indicate a gradual downstream increase in diversity. Analysis of variance and Neuman-Keuls comparison demonstrated that the only real difference in mean diversity between stations existed at Station 5. The mean diatom diversity between stations 1, 3, and 4 was not significantly different. Diversity calculations were not computed for Station 2 because of the scarcity of diatoms.

Table 17. Diatom diversity values [d = (m-1)/lnN] for Soda Butte Creek stations 1, 3, 4, and 5

Date	Station 1	3	4	5
18 August 72	3.05	4.33	3.05	7.50
31 August 72	6.33	5.19	4.51	6.62
18 September 72	4.69	4.14	7.03	6.36
29 September 72	4.70	4.93	5.09	6.31
17 October 72	4.92	5.43	5.78	6.50
Mean	4.74	4.80	5.05	6.66

Diversity was not significantly correlated to any of the variables, chlorophyll a production, temperature, orthophosphate, or total iron when compared with data from stations 1, 3, 4, and 5 (Table 18).

Table 18. Simple correlation coefficients for diversity against chlorophyll a, temperature, orthophosphate, and total iron for aggregate stations 1, 3, 4, 5 and dates 8/18--10/17/72 inclusive

	Diversity
Chlorophyll a	-.222
Temperature	.277
Orphophosphate	.235
Total Iron	-.106

DISCUSSION: SODA BUTTE CREEK

Streams such as Soda Butte Creek, located at high elevations, are subject to unusual environmental factors which largely control their biological processes. Two important factors that were found in Soda Butte Creek were high spring run-off and extended periods of very cold temperature. These factors combined to form a short time, July and August, for favorable growth conditions for algae.

The seepage from the mill tailings entirely eliminated the algae at Station 2. The macroinvertebrates were considerably reduced in both numbers and diversity and on several occasions were entirely absent (Pickett and Chadwick, 1974). Fish were not present at this station and bioassays showed the stream to be highly toxic to fingerling trout (Pickett and Chadwick, 1974).

Chemical analysis showed a sharp increase in manganese, sulfate, and total iron concentration over the levels found above the tailings. Other chemical and physical parameters showed only negligible changes and therefore probably do not contribute to the observed degradation of the aquatic environment at Station 2. Manganese levels did not exceed the lower limit of the tolerance range (1.5 $mg \cdot \ell^{-1}$) for fresh-water aquatic life and sulfate ion is not considered a toxic substance (EPA, 1976). However, iron did exceed the recommended criterion (1 $mg \cdot \ell^{-1}$) for

fresh-water aquatic life and is considered to be the primary pollutant acting as a physical barrier to algal growth.

Environmental Requirements of the Major Taxa

The mean downstream abundance of the major diatom taxa naturally divided into four groups as shown in Figure 3 (see Variations in Relative Abundance of Major Taxa). A review of the diatom literature was conducted to determine whether the members of each group exhibited similar environmental requirements.

In general, it was found that all the major taxa in this study were reported to be alkaliphilous (occurring around pH 7 with best development at pH's over 7) and fresh-water forms that tolerate small amounts of salt, Lowe (1974). All of the major taxa except four, *Gomphonema angustatum, Diatoma hiemale* var *mesodon, Gomphonema hedinii,* and *Surirella ovata* were identified as being cosmopolitan (Lowe, 1974). Cosmopolitan species are abundant in a wide variety of habitats and ecological conditions and have broad tolerance ranges. On the other hand, endemic species are native to a certain region and are restricted to specific habitats, and have limited tolerance ranges. Therefore, the four endemic species identified above are more valuable as indicators of specific habitats than the cosmopolitan types. Since the first two diatom species, *Gomphonema angustatum* and *Diatoma hiemale* var *mesodon* were found

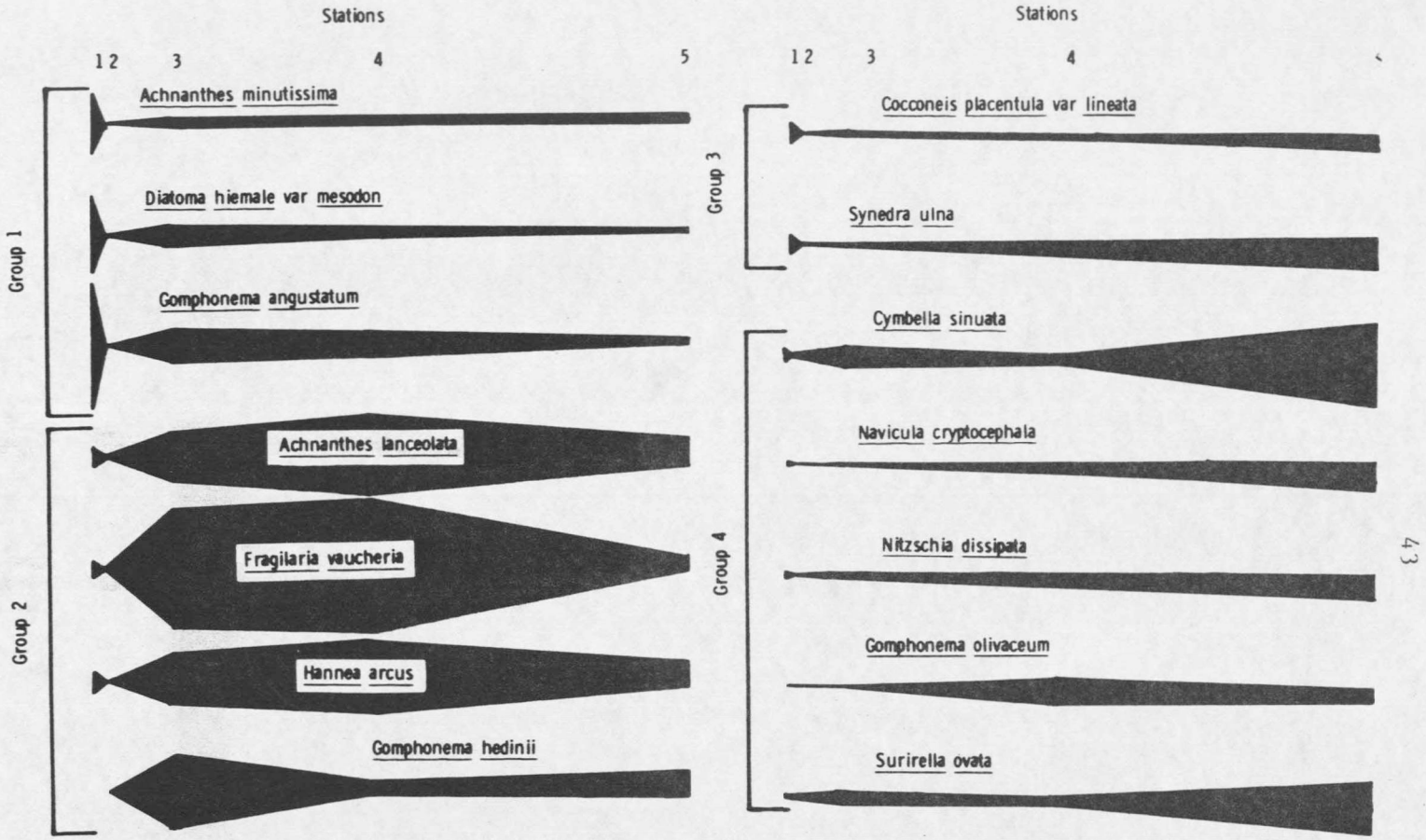


Figure 3. A graphical representation of the relative abundance (%) of major species at all stations on Soda Butte Creek.

most abundantly at Station 1, *Gomphonema hedinii* at Station 3, and *Surirella ovata* at Station 4, knowledge of their specific habitats may indicate the downstream changes in habitat for Soda Butte Creek.

Gomphonema angustatum and *Diatoma hiemal* var *mesodon* were both found to be fairly abundant by Roeder (1966) in the study of four rivers in Yellowstone National Park, and by Lawson (1975) in the upper Provo River, Utah. Kolkwitz (1908) termed *G. angustatum* an oligiosaprobe, characteristic of waters where oxidation of degradable compounds is complete and concentration of inorganic nutrients may be high. He described *D. hiemale* var *mesodon* as katharobic, occurring in mountain regions most characteristic of waters unexposed to pollutants. Patrick and Reimer (1975) describe *G. angustatum* as preferring oligotrophic to mesotrophic water and *D. hiemale* var *mesodon* as preferring flowing water with a fairly high nutrient content.

Gomphonema hedinii was very common in the lower Provo River, Lawson (1975). Kolkwitz (1908) described this species as β-mesosaprobic (weakly polluted waters with nitrogen occurring in the form of ammonia compounds). Patrick (1975) states that this species seems to grow best when the nitrate concentration is fairly high.

As stated above, the abundance of the major taxa seemed to divide into four natural groups. The differences in the literature

between groups was most evidently exhibited with respect to tolerance for organic pollution and temperature. The first group composed of *Achnanthes minutissima, Diatoma hiemale* var *mesodon,* and *Gomphonema angustatum* was classified as oligosaprobic or katharobic. They also occur in oligothermal waters (cold water forms, usually occurring between 0° and 15°C) (Lowe, 1974).

Group two, composed of *Hannaea arcus, Fragilaria vaucheria,* and *Gomphonema hedinii*, had greater tolerance for organic compounds, being categorized by Lowe (1974) as oligothermal and mesosaprobic (characteristic where oxidation of organic compounds is proceeding).

The third group of diatoms, *Cocconeis placentula* and *Synedra ulna*, was listed as being slightly less tolerant of organics (oligosaprobic), but *Synedra ulna* was described as occurring in eutrophic waters (characteristic of water with high nutrient concentrations) by Lowe (1974).

The fourth group, *Gomphonema olivaceum, Nitzschia dissipata, Navicula cryptocephala, Cymbella sinuata* and *Surirella ovata*, was generally classed as mesosaprobic with three species also being listed as eutrophic types. This group was slightly more tolerant of higher temperature, oligothermal to mesothermal (temperate water forms usually occurring between 15° and 30°C) (Lowe, 1975).

The published literature on these taxa did not completely agree with the aquatic habitat observed. Rather than being organically

polluted, Soda Butte Creek was only slightly enriched by inorganic nutrients. Thus the presence of these taxa does not necessarily indicate an organically polluted stream, but the reported tolerance of these species for organic pollutants may indicate tolerance to other types of pollution such as the tailings seepage in Soda Butte Creek.

It seems reasonable to generalize that diatoms which are reported to be somewhat tolerant to organic pollution but which are found in a stream that does not appear to be organically polluted are indicating tolerance to some other sort of pollutional stress. Evidently the diatoms found downstream of Station 2 are reacting to the combination of iron, orthophosphate, and other factors in Soda Butte Creek in this manner.

Autotrophic Index and Diatom Diversity

Autotrophic index values for cultured algae vary from approximately 40 to 100 (Cobb and Myers, 1964, Weber and McFarland, 1969). Typical index values from relatively clean waters range between 125 and 180. The mean value for polluted waters of the Ohio River was 1019 (Weber and McFarland, 1969). Bahls (1971) used autotrophic index to measure the trophic nature of the aufwuchs in the Gallatin River above and below a secondary treated sewage outflow. He found

mean values of 121 above, 428 2.2 km below, 388 5.3 km below, and 177 23.5 km below the point of entry.

Increases in autotrophic index cited in the literature are related to increased heterotrophic growth below sources of organic pollution. This is also true of this study where a high autotrophic index could result from heterotrophic iron and sulfur bacteria originating in the tailings dump.

The autotrophic index values found downstream of Station 2 did not return to the low levels which occurred at Station 1 (135 median) indicating incomplete recovery of the stream at Station 5 (245 median). However, the amount of biomass error caused by iron complex hydration cannot be determined. Therefore, autotrophic index is not a suitable indicator in this study.

The diversity values from this study were similar to those which Roeder (1966) reported for the upper station of the Gardner River. Diversities from other stations of his study showed values much higher than those found in Soda Butte Creek. Soda Butte diversities were slightly higher than those found in Bahls' (1971) study of the East Gallatin River.

Diversities were generally much more stable in Soda Butte than from either of the two studies by Roeder and Bahls. An important

finding of this study was that diversities gradually increased downstream from Station 3. Associated downstream trends were increases in chlorophyll a production and temperature. The statement that diversity increased with increased production is contrary to Roeder's findings that diversity decreased with increases in productivity. The relationship of chlorophyll a production and diatom diversity as plotted in Figure 4 suggests that no consistent relationship exists between the two variables.

Diversity and chlorophyll a production may be more generally related to the potential for growth and production arising from the basic environmental requirements of light, temperature, and nutrients. The gradual downstream increase in diversity, chlorophyll a, and temperature would seem to support this. An environmental index was calculated to estimate the biotic potential in the following manner; variables were ranked by station from a low of 1 to a high of 5. Spearman's rank correlation was run on each variable with chlorophyll a and diversity. All rankings with significant positive correlation with both chlorophyll and diversity were given a positive sign, and all rankings with a significant negative correlation were given a negative sign. The rankings were then summed to give a scaler index of environmental variables. The larger the value of the index the greater was the potential for growth and production. The values of the environmental index with the incorporated variables of temperature,

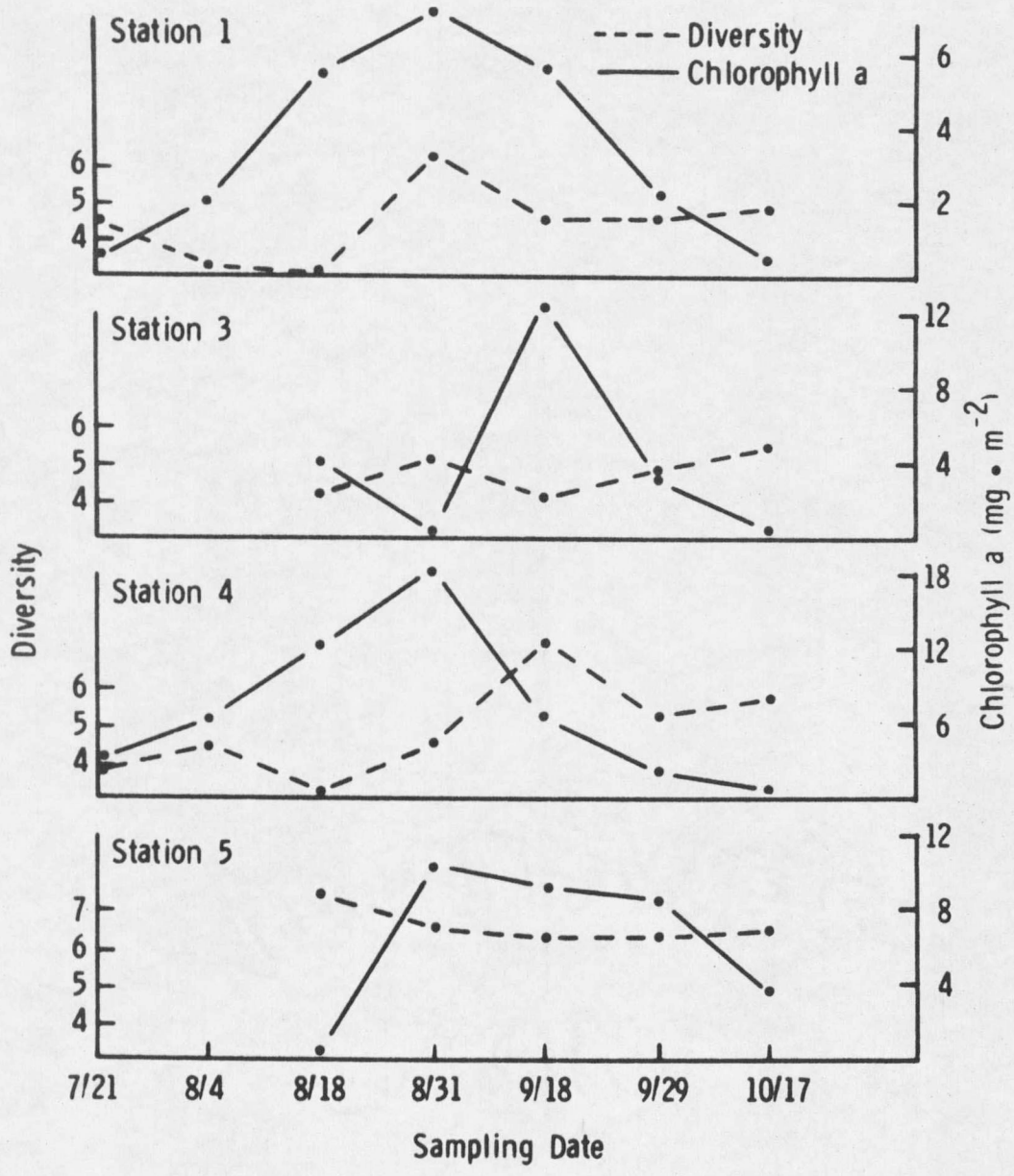


Figure 4. Graphical comparison of the diatom community diversity vs chlorophyll a ($mg \cdot m^{-2}$) production of Soda Butte Creek.

orthophosphate, total iron, nitrate, and nitrogen:phosphorus ratio are given in Table 19. The index values indicate increasing potential for production downstream.

Table 19. Signed ranks of variables, summed for environmental index values for each station of Soda Butte Creek

	Station				
Variable	1	2	3	4	5
Chlorophyll *a*	2	1	3	4	5
Diversity	2	1	3	4	5
Temperature	1	2	3	4	5
Orthophosphate	2	1	5	4	3
Iron	-1	-5	-4	-3	-2
Nitrate	-4	-5	-2	-3	-1
N/P	-4	-5	-2	-3	-1
Environmental Index	-2	-10	6	7	14

Indications of Stream Recovery

The measures of chlorophyll *a* and diatom diversity indicated that recovery was accomplished by Station 3. This conclusion conflicts with the major diatom environmental requirements which suggest that the downstream diatoms were more tolerant to pollution compared

to those at Station 1, indicating that recovery of the diatom community was not complete by Station 5. However, it is most likely that the change in diatom community was not reversible because of the changing environmental conditions resulting from the entry of Woody Creek and other tributaries.

RESULTS: IRON SPRINGS CREEK

Chemical and Physical Determinations

The ranges and mean values for water chemical and physical analyses are presented in Table 20. The complete results of the determinations are given in the Appendix Tables 25 through 45.

Iron Springs Creek was found to be a sodium-bicarbonate system. Hot springs drainage into the stream accounted for the higher than normal levels of temperature, sodium, potassium flouride, and chloride as demonstrated by a sample taken from the largest thermal body feeding the stream. The thermal discharge sample contained 115 $mg \cdot \ell^{-1}$ sodium, 9 $mg \cdot \ell^{-1}$ potassium, and 82 $mg \cdot \ell^{-1}$ chloride (data not reported in Appendix).

Stream temperature averaged 16°C during the study, and flouride concentrations were high, averaging 3.82 $mg \cdot \ell^{-1}$. Orthophosphate and nitrate levels were somewhat elevated over that expected for a clear mountain stream. Orthophosphate averaged .034 $mg \cdot \ell^{-1}$ and nitrate averaged .024 $mg \cdot \ell^{-1}$. The probable cause of elevated nitrate concentrations was run-off from a livestock corral located on a sidehill bordering the stream rather than sewage lagoon percolation. The elevated orthophosphate level may be related to this cause too; however, it may also be a result of thermal water input. Vincent (1967), in his work on the Gibbon River, found that phosphate was

among several chemical variables that showed significant increases below the entrance of thermal water.

Chlorophyll a production in Iron Springs Creek was very high with an average rate of .71 $mg \cdot m^{-2} \cdot day^{-1}$ (Table 20). The predominately autotrophic nature of the community was indicated by a mean autotrophic index of 141.

Table 20. Ranges and mean values for chemical and physical analyses of Iron Springs Creek

Variable	Station IS1	Station IS2
Temperature (°C)	11.2 - 17.1 15.0	13.0 - 19.2 17.1
pH	7.95 - 8.10 8.01	7.68 - 8.39 7.88
Alkalinity ($mg \cdot \ell^{-1} CaCO_3$)	27.0 - 37.0 32.7	34.5 - 44.5 39.0
Dissolved Oxygen ($mg \cdot \ell^{-1} O_2$)	7.2 - 8.6 7.8	7.2 - 10.1 8.1
Total Iron ($mg \cdot \ell^{-1}$)	0.07 - 0.21 0.15	0.01 - 0.77 0.19
Chloride ($mg \cdot \ell^{-1}$)	6.20 - 7.15 6.66	12.50 - 13.75 13.10
Manganese ($mg \cdot \ell^{-1}$)	<0.001 - 0.020 0.003	<0.001 - 0.018 0.005
Total Hardness ($mg \cdot \ell^{-1} CaCO_3$)	13.4 - 16.0 14.7	13.0 - 15.0 13.6

Table 20. Continued

Variable	Station IS1	Station IS2
Sodium ($mg \cdot \ell^{-1}$)	10.58 - 16.62 13.23	19.50 - 22.08 21.21
Potassium ($mg \cdot \ell^{-1}$)	3.13 - 3.79 3.48	3.71 - 4.18 4.26
Flouride ($mg \cdot \ell^{-1}$)	3.60 - 4.20 3.80	3.60 - 3.70 3.84
Calcium ($mg \cdot \ell^{-1}$)	4.4 - 6.6 5.0	3.6 - 4.4 4.1
Magnesium ($mg \cdot \ell^{-1}$)	0.4 - 1.0 0.7	0.5 - 1.1 0.8
Orthophosphate ($mg \cdot \ell^{-1} PO_4$-P)	0.006 - 0.025 0.014	0.008 - 0.097 0.053
Nitrate ($m \cdot g^{-1} NO_3$-N)	0.0 - 0.009 0.003	0.001 - 0.150 0.045
Sulfate ($m \cdot g^{-1} SO_4$)	2.0 - 5.8 4.0	2.8 - 7.6 4.7
Chlorophyll *a* ($mg \cdot m^{-2}$)	7.56 - 15.51 16.01	4.91 - 45.60 23.81
Biomass ($mg \cdot m^2$)	312 - 4016 2147	484 - 3222 2040
Autotrophic Index	25 - 351 154	25 - 335 127

Diatoms of Iron Springs Creek

A total of 24 genera and 76 species and varieties of diatoms was identifed from plexiglass substrates at two sampling locations in Iron Springs Creek. Table 21 lists the taxa found. A total of 2562 cells was enumerated from 12 samples.

Cocconeis placentula var *lineata* (Ehr.) Cl. was by far the most frequently occurring diatom with a mean relative abundance of 40.5%. This taxon was dominant on 9 out of 12 samples. The other eight major taxa are listed by mean relative abundance in Table 22. Roeder (1966) reported *C. placentula* to be one of the most common diatoms in his study of the sodium bicarbonate type waters of the Madison River system.

Table 21. Alphabetical list of the diatom taxa found in Iron Springs Creek for both stations

Genera	Species	Station
Achnanthes	*affinis* Grun.	2
	clevei Grun.	1
	exigua Grun.	1,2
	hungarica (Grun.) Grun.	1
	lanceolata (Breb.) Grun.	1,2
	lanceolata var *dubia* Grun.	2
	linearis (W. Smith) Grun.	2
	minutissima Kütz.	1,2
	sp.	1

Table 21. Continued

Genera	Species	Station
Amphora	*delicatissima* Krasske	2
	ovalis var *pediculus* Kütz.	1,2
	veneta Kütz.	1
	sp.	2
Anomoenoneis	*serians* var *brachysira* (Breb.ex Kütz) Hust.	2
Cocconeis	*placentula* var *lineata* Ehr.	1,2
	placentula var *euglypta* (Ehr.) Cl.	1,2
	sp.	1
Cymbella	*affinis* Kütz.	1
	gracilis (Rabh.) Cl.	1,2
	herbridica (Greg.) Grun.	1
	mexicana (Ehr.) Cl.	1
	minuta Hilse ex Rabh.	1,2
	sinuata Greg	1
	sp.	1,2
Denticula	*elegans* Kütz.	1,2
Diatoma	*hiemale* (Roth) Heib.	1
	hiemale var *mesodon* (Ehr.) Grun.	1,2
Diatomella	*balfouriana* Grev.	1,2
Diploneis	*sp.*	1
Epithemia	*turgida* (Ehr.) Kütz	1,2
Eunotia	*curvata* (Kütz.) Lagerst	1,2
	praerupta var *bidens* (Ehr.) Grun.	2
	sp.	1,2

Table 21. Continued

Genera	Species	Station
Fragilaria	*bicapitata* A.Mayer	2
	construens (Ehr.) Grun.	1,2
	construens var *venter* (Ehr.) Grun.	2
	pinnata Ehr.	1,2
	vaucheriae (Kütz.) Peters.	1,2
	vaucheriae var *capitellata* (Grun.) Patr.	1
Frustulia	*sp.*	2
Gomphoneis	*herculeana* (Ehr.) Cl.	2
Gomphonema	*angustatum* (Kütz.) Rabh.	1,2
	angustatum var *producta* Grun.	1,2
	hedinii Hust.	2
	intricatum Kütz.	2
	lanceolata Ehr.	1,2
	parvulum Kütz.	1,2
Hannaea	*arcus* (Ehr.) Patr.	1,2
Melosira	*distans* (Ehr.) Kütz.	1,2
	distans var *alpigena* Grun.	1
	italica (Ehr.) Kütz.	2
	varians Ag.	1,2
	sp.	2
Meridion	*circulare* var *constrictum* (Ralfs) V.H.	1,2
Navicula	*cryptocephala* Kütz.	2
	cryptocephala var *veneta* (Kütz.) Rabh.	1,2
	minima Grun.	1
	seminulum var *hustedtii* Patr.	1,2
	tripunctata (O.Müll.) Bory	1
	sp.	1,2

Table 21. Continued

Genera	Species	Station
Nitzschia	*acicularis* W. Smith	2
	amphibia Grun.	1,2
	denticula Grun.	1,2
	denticula var *curta* Grun.	1
	dissipata (Kütz.) Grun.	1,2
	frustulum Kütz.	1,2
	holsatica sp. Hust.	1,2
	kutzingiana Hilse	1,2
	linearis W. Smith	1,2
	obtusa W. Smith	2
	palea (Kütz.) W. Smith	1,2
	paleacea Grun.	2
Pinnularia	*borealis* Ehr.	1,2
	latevittata Cl.	1
	subcapitata var *paucistriata* (Grun.) Cl.	1
Rhoicosphenia	*curvata* (Kütz.) Grun. ex Rabh.	1,2
Rhopalodia	*gibba* (Ehr.) O.Müll.	1
	gibberula (Ehr.) O.Müll	1,2
Synedra	*acus* Kütz.	1
	rumpens Kütz.	1,2
	rumpens familiaris (Kütz.) Hust.	1,2
	rumpens fragiliaroides Grun.	1
	socia Wallace	1,2
	ulna (Nitz.) Ehr.	1,2
	ulna var *oxyrhynchus* Kütz.	1,2

Table 22. Rank of the major diatom taxa from plexiglass substrate of Iron Springs Creek by mean relative abundance

	Station IS1	Station IS2	Mean Relative Abundance
Cocconeis placentula var *lineata*	40.3	40.7	40.5
Achnanthes lanceolata	13.8	20.6	17.2
Gomphonema augustatum	17.5	5.2	11.4
Nitzschia holsatica	3.9	8.8	6.4
Achnanthes minutissima	5.6	3.8	4.7
Gomphonema parvulum	1.6	2.0	1.8
Cocconeis placentula var *euglypta*	1.6	1.9	1.3
Synedra ulna	1.9	.4	1.2
Fragilaria vaucheriae	.9	1.1	1.0

DISCUSSION: IRON SPRINGS CREEK

Comparison of Diatom Communities from Soda Butte Creek and Iron Springs Creek

A comparison of diatoms found in both streams reveals that 50 common taxa or 30% of the diatom taxa found in Soda Butte Creek were also found in Iron Springs Creek. The Jaccard coefficient for Soda Butte vs. Iron Springs (Jaccard coefficient .25) shows the greatest difference between the stations in Soda Butte was less than the difference between the two streams.

The relative abundance of the major diatom taxa from each stream differed considerably. Abundant diatoms found in Soda Butte Creek, such as *Hannaea arcus, Diatoma hiemale* var *mesodon, Gomphonema olivaceum, Gomphonema hedinii,* and *Cymbella sinuata* were found infrequently in Iron Springs Creek. On the other hand, the diatom taxa *Gomphonema angustatum, Achnanthes lanceolata, Synedra ulna,* and *Achnanthes minutissima* were found in both streams with similar frequency. Another large difference between the two streams was the domination of *Cocconeis placentula* var *lineata* in Iron Springs Creek.

It appears that Soda Butte Creek and Iron Springs Creek support two different diatom communities. In order to support this hypothesis, the relative abundance values of the major diatom taxa and physical-chemical variables from all samples of both streams were analyzed by the Statistical Analysis System (SAS) program of principle components

and cluster analysis. This analysis is similar to that used by Sprules (1977) in the classification of Canadian lakes using zooplankton abundance data.

Principle components analysis is a multivariant statistical technique that summarizes the variation of species abundance into a set of component vectors. The two components which account for the greatest portion of cumulative variability are selected as axes for a plot diagram. Samples that have similar diatom association will form a cluster on the plot. Chemical-physical data added to the analysis will characterize the axes. Each variable has a coefficient on each component which gives the weighting of that variable. The variables having high positive and negative coefficients on a particular component characterize that component.

The complement to principle components analysis is cluster analysis. Cluster analysis groups the samples by measuring Euclidean distance between each sample and clustering those which are closest. Because the two analyses are distinctly different methods, the comparison of clusters formed by each analysis will reveal any distortion in sample association resulting from the data reduction of the principle component analysis.

The plot resulting from principle component analysis of relative abundance data of 17 major diatom taxa and 9 physical-chemical variables from Soda Butte and Iron Springs Creeks is presented in

Figure 5. The two components which form the axes accounted for 39% of the cumulative variance in the data. The sample points fell into four distinct clusters: Soda Butte Station 1, Soda Butte Stations 3 and 4, Soda Butte Station 5, and Iron Springs Stations 1 and 2. The variable coefficients for each component are listed in Table 23.

The coefficients with the highest positive and negative values indicate that the variables *Fragilaria vaucheriae,* total iron, *Nitzschia dissipata, Nitzschia holsatica*, chlorophyll a production, temperature, and M:D ratio are most important in the first component. Samples with high values for the first three variables and low values for the last four variables will have high scores on the first component. As principle component one accounts for the single largest portion of the variance in the data, 24%, the major difference between the two streams is related to variation in these seven variables. Similarly, since M:D ratio had the highest absolute coefficient value, -.91144, it was the major discriminator between the two streams.

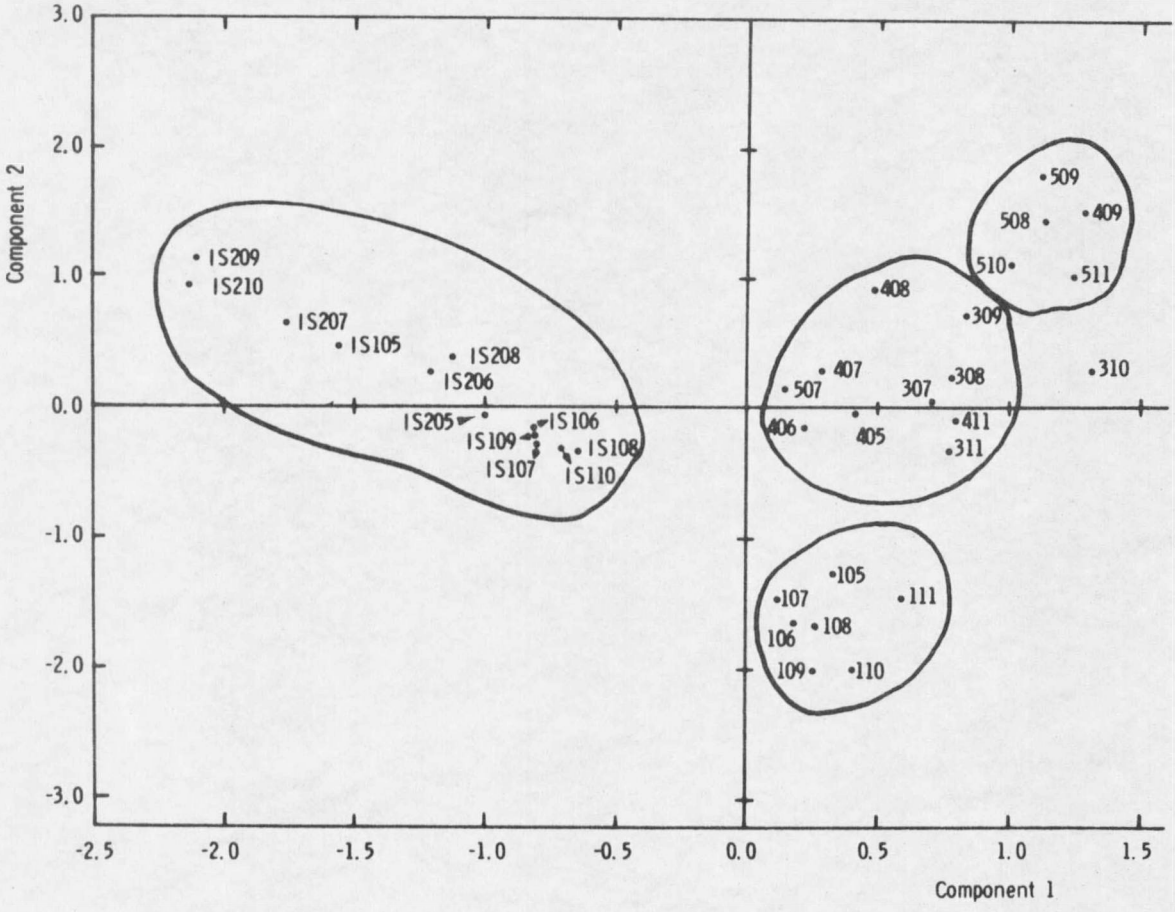


Figure 5. Principle component ordination of Soda Butte Creek and Iron Springs Creek samples. Large circles represent clusters formed by principle component ordination. The station number is the first digit of the sample code. Iron Springs Creek stations are denoted by "IS."

Table 23. Variable coefficients of relative abundance and physical-chemical variables with components 1 and 2 for Soda Butte Creek and Iron Springs Creek.

	Principle Component	
	1 Variable Coefficient	2 Variable Coefficient
Fragilaria vaucheriae	.58195	.13752
Total Iron	.55038	.39333
Nitzschia dissipata	.53292	.55727
Gomphonema hedinii	.49831	.30974
Navicula cryptocephala	.49710	.53991
Surirella ovata	.44960	.46312
Gomphonema olivaceum	.43638	.48354
Synedra ulna	.39656	.04472
Cymbella sinuata	.39524	.26799
Hannaea arcus	.38029	.02813
Achnanthes lanceolata	.31193	.20465
Diatoma hiemale var *mesodon*	.23598	-.71417
Gomphonema angustatum	.21037	-.58710
Achnanthes minutissima	.12394	-.57190
Cocconeis placentula var *lineata*	-.18014	-.00953
Orthophosphate (PO_4)	-.26652	.68826
Gomphonema parvulum	-.33931	.14502
Cocconeis placentula var *euglypta*	-.45107	.10039
Nitrate (NO_3)	-.49546	.13457
Nitzschia holsatica	-.57760	.19840
Chlorophyll a	-.73145	.41059
Temperature	-.79878	.37509
M:D	-.91144	.23402

The second component is characterized by the variation in the variables orthophosphate, *Nitzschia dissipata, Navicula cryptocephala, Diatoma hiemale* var *mesodon,* and *Gomphonema angustatum.*

The results of the cluster analysis are listed by cluster members in Table 24. A comparison of the cluster analysis and groups of sample points from the principle components analysis demonstrate agreement and thus minimal distortion of the data by the principle components analysis. The formation of these clusters supports the hypothesis for two distinctly different diatom communities in the two streams, as well as the three unique diatom communities in Soda Butte Creek.

Monovalent:Divalent Comparisons

Chemically speaking, Soda Butte Creek and Iron Springs Creek differed most noticeably in monovalent and divalent cation concentrations. Soda Butte was calcium dominated and Iron Springs was sodium dominated. This difference expressed as the ratio of monovalent to divalent cations (M:D ratio) showed that Iron Springs (2.97) had a mean M:D approximately 27 times higher than Soda Butte (.11). The effect of this characteristic on diatom growth is not clear. Pearsall (1932) stated that a low monovalent to divalent cation ratio was necessary for abundant growth of diatoms. However, Droop (1958) and Lund (1965) concluded that many species were

Table 24. Cluster listing from cluster analysis of relative abundance and physical-chemical variables for Soda Butte Creek and Iron Springs Creek. The station number is the first digit of the sample code. Iron Springs Creek stations are denoted by "IS."

Cluster	Sample	Cluster	Sample
1	105	3	508
1	106	3	509
1	107	3	510
1	108	3	511
1	109		
1	110	4	IS 105
1	110	4	IS 106
1	507	4	IS 107
		4	IS 108
2	307	4	IS 109
2	308	4	IS 110
2	309	4	IS 205
2	310	4	IS 206
2	311	4	IS 207
2	405	4	IS 208
2	406	4	IS 209
2	407	4	IS 210
2	408		
2	409		
2	411		

indifferent to M:D ratios and could flourish over a wide range of ratio values. Roeder (1966) found no indication of diatom growth inhibition by M:D ratios ranging from 2.89 to 27.60 in the Madison River system.

The results of this study indicated much more chlorophyll a production in Iron Springs Creek than Soda Butte Creek. However, the water temperature of Iron Springs was noticeably higher than Soda Butte and is probably more of a controlling factor regarding chlorophyll production than the M:D ratios.

Stumm and Morgan (1970), in describing the double layer theory of interaction at solid-solution interfaces, state that the affinity of a negatively charged surface, such as an algal cell, for bivalent ions is much larger than that for monovalent ions. The selectivity for higher valent ions is significant in solutions of ionic strength similar to natural waters, approximately .01. The extent of the hydration of solution ions is much less for divalent cations than for monovalent ions. Because only half as many divalent ions are needed as monovalent ions to neutralize the surface charge, the osmotic pressure difference between solution and surface is smaller with divalent ions. Thus, osmotic pressure and hence cell permeability to water is less with calcium ions than sodium ions at the cell-solution interface. Mean station calcium to sodium ratios

in this study range from 18.4 at Soda Butte Station 1 to .1 at Iron Springs Station 2 on a moles/liter basis. It may be that this 180 fold range of relative concentrations of cations affected cell permeability enough to cause species differences in the two streams.

SUMMARY

The findings of this study demonstrated that Soda Butte Creek differed from Iron Springs Creek in the same way that the Madison River system was found to differ from the Gardner River by Roeder (1966). In both water chemistry and relative composition of diatom communities, similarities were found between Soda Butte Creek and the Gardner River and between Iron Springs Creek and the Madison River system.

Roeder found that the diatom distributions at eleven sampling locations could be grouped into categories depending upon whether calcium or sodium was the dominant cation. The dominant cation-diatom taxa relationship is reinforced by the principle components analysis completed in this study, which indicated that the main discriminator between major diatom taxa was the monvalent:divalent cation ratio.

The entry of Woody Creek above Station 3 accounted for the recovery of Soda Butte Creek chlorophyll production from the mine tailings seepage and seemed to be an important factor in explaining the tolerant type of diatom communities which existed downstream from Station 2. Woody Creek greatly influenced Soda Butte water chemistry by virtue of accounting for a mean 79% of Soda Butte Creek discharge. The cluster of diatom communities formed by Stations 3 and 4 in the principle components analysis indicated that these two

stations were indistinguishable. Because no significant taxa change occurred between these two stations, it is assumed that the recovery of the stream with respect to species relative abundance was accomplished by Station 3. The two chemical parameters which were most noticeably linked to Woody Creek are orthophosphate and sodium. Both of these parameters exhibited sharp increase at Station 3, and these levels were maintained downstream to Station 5. The tolerant nature (generalized from the specific reference to organic enrichment) of the diatom taxa also extended from Station 3 to Station 5. The existence of these diatom communities was probably a result of their tolerance to large amounts of iron from Soda Butte and orthophosphate from Woody Creek.

APPENDIX

APPENDIX

Table 25. Soda Butte Creek alkalinity values (as $mg \cdot \ell^{-1}$ $CaCO_3$)

Date	Station 1	2	3	4	5
5/27/72	82.5	67.5	52.5	55.0	65.0
6/9	56.5	52.0	37.0	40.5	53.5
6/24	69.5	58.5	36.0	41.0	58.0
7/8	97.5	72.0	40.0	49.5	56.0
7/21	99.0	88.0	49.5	55.0	75.0
8/4	106.5	99.0	50.5	57.5	82.5
8/18	113.5	105.5	50.0	65.0	99.0
8/31	115.5	114.5	55.5	75.0	105.5
9/18	112.0	110.5	47.0	60.0	93.5
9/29	105.0	104.5	51.0	69.0	90.5
10/17	113.5	105.5	61.0	68.0	95.0
11/11	111.0	108.5	68.5	82.5	104.5
1/20/73	113.5	108.0	----	----	----
3/22	113.0	121.5	77.5	104.5	120.0
5/5	111.5	128.0	70.1	95.1	107.8
5/20	76.5	62.5	36.5	38.8	47.4
6/2	68.8	58.1	42.5	45.6	55.3
Mean	98.0	92.0	51.6	62.6	81.8

Table 26. Soda Butte Creek calcium values ($mg \cdot \ell^{-1}$ Ca^{++})

Date	Station 1	2	3	4	5
5/27/72	30.5	34.5	18.4	19.2	18.4
6/9	20.0	18.8	15.6	8.4	14.4
6/24	24.9	21.6	10.4	12.4	16.0
7/8	31.3	28.5	11.6	12.4	15.2
7/21	32.1	33.1	12.8	15.6	19.6
8/4	35.3	41.7	15.2	16.8	21.6
8/18	36.9	47.3	14.8	18.4	24.5
8/31	36.1	46.5	16.8	21.0	26.9
9/18	35.3	46.7	13.0	16.6	24.1
9/29	36.5	47.7	16.4	21.6	26.5
10/17	35.3	44.5	16.4	18.8	24.9
11/11	34.9	46.9	28.5	25.1	28.5
1/20/73	37.5	56.7	----	----	----
3/22	37.3	65.7	24.1	34.1	33.5
5/5	37.1	61.3	21.6	36.7	27.7
5/20	26.9	25.7	11.6	11.6	13.4
6/2	23.5	24.9	13.6	13.2	15.6
Mean	32.4	40.7	16.3	18.9	21.9

Table 27. Soda Butte Creek copper values ($mg \cdot \ell^{-1}$)

Date	Station 1	2	3	4	5
5/27/72	T	T	T	0.0	0.0
6/9	T	0.04	0.04	0.05	0.05
6/24	0.04	T	T	T	0.04
7/8	0.0	0.04	0.0	0.0	T
7/21	0.0	T	0.0	0.05	0.0
8/4	0.0	0.04	T	0.0	T
8/18	0.0	T	0.0	0.0	0.0
8/31	0.0	0.0	T	0.04	T
9/18	0.0	0.0	0.0	0.0	0.0
9/29	0.04	0.07	0.0	0.0	0.0
10/17	0.10	T	0.0	0.0	0.0
11/11	0.05	0.04	0.0	0.0	0.04
1/20/73	0.0	0.0	---	---	---
3/22	0.0	0.0	0.0	0.0	0.0
5/5	0.0	0.05	0.0	0.0	0.0
5/20	0.0	0.0	T	0.0	0.0
6/2	0.04	0.0	0.04	0.0	0.0

T = <.04

Table 28. Soda Butte Creek total hardness values (as $mg \cdot \ell^{-1}$ $CaCO_3$)

Date	Station 1	2	3	4	5
5/27/72	92.0	105.0	59.0	60.0	63.0
6/9	62.0	60.0	39.0	41.0	71.0
6/24	79.0	80.0	26.0	41.0	54.0
7/8	99.0	87.0	39.0	42.0	53.0
7/21	44.4	170.0	49.0	54.6	72.0
8/4	114.0	140.0	49.0	57.6	79.4
8/18	117.0	163.0	49.0	66.0	90.0
8/31	115.6	165.6	55.2	73.8	96.8
9/18	116.0	166.6	44.2	57.8	91.8
9/29	121.4	169.2	56.8	74.6	98.4
10/17	114.4	155.8	58.2	58.0	90.0
11/11	114.8	169.0	73.8	86.4	105.8
1/20/73	116.4	204.4	----	----	----
3/22	----	----	----	----	----
5/5	120.4	119.6	71.8	104.2	114.0
5/20	87.8	80.0	38.0	38.4	48.6
6/2	76.4	81.0	47.0	47.0	57.0
Mean	99.4	132.3	43.7	57.5	80.3

Table 29. Soda Butte Creek total iron values ($mg \cdot \ell^{-1}$)

Date	Station 1	2	3	4	5
5/27/72	0.24	3.03	2.12	2.02	1.37
6/9	0.70	0.80	1.16	2.44	4.88
6/24	0.23	0.68	0.60	1.00	1.26
7/8	0.16	0.90	0.50	0.45	0.78
7/21	0.08	2.32	0.79	0.59	0.49
8/4	0.07	3.30	1.24	0.60	0.40
8/18	0.07	4.22	1.24	0.85	0.05
8/31	0.11	5.86	1.30	1.09	1.28
9/18	0.16	8.64	2.21	1.70	0.37
9/29	0.03	7.10	1.69	0.96	0.33
10/17	0.15	6.36	1.49	0.86	0.32
11/11	0.08	8.54	2.06	0.83	0.81
1/20/73	0.12	13.8	----	----	----
3/22	0.12	21.45	2.52	0.16	0.12
5/5	0.08	21.45	2.24	0.85	0.22
5/20	0.27	2.40	5.05	3.18	1.55
6/2	0.28	3.04	2.00	1.34	0.71
Mean	0.17	6.70	1.76	1.18	0.93

Table 30. Soda Butte Creek magnesium values ($mg \cdot \ell^{-1}$ Mg^{++})

Date	Station 1	2	3	4	5
5/27/72	3.9	4.6	3.2	2.9	4.1
6/9	2.9	3.2	---	4.9	8.5
6/24	4.1	6.3	---	2.4	7.5
7/8	5.1	3.9	2.4	2.7	3.7
7/21	5.7	21.3	4.1	3.9	1.3
8/4	6.3	8.8	2.7	3.8	6.2
8/18	6.1	10.9	2.9	4.9	7.1
8/31	6.3	12.0	3.2	5.1	7.3
9/18	6.7	12.2	2.8	3.9	7.8
9/29	7.3	12.2	3.9	5.0	7.8
10/17	6.4	10.9	4.1	5.1	6.8
11/11	6.8	12.7	0.7	5.6	8.5
1/20/73	5.2	15.3	---	---	---
3/22	---	---	---	---	---
5/5	6.8	---	4.3	3.2	10.9
5/20	5.1	3.9	2.2	2.2	3.7
6/2	4.4	4.6	3.2	3.4	4.6
Mean	5.6	9.5	3.1	3.9	6.4

Table 31. Soda Butte Creek manganese values ($mg \cdot \ell^{-1}$)

Date	Station 1	2	3	4	5
5/21/72					
6/9	0.012	0.013	0.015	0.030	0.029
6/24	0.010	0.017	0.012	0.016	0.020
7/8	T	0.013	0.002	T	0.006
7/21	T	0.021	0.003	T	T
8/4	T	0.014	0.005	T	T
8/18	T	0.275	0.039	0.004	T
8/31	T	0.250	0.014	0.007	0.003
9/18	0.005	0.263	0.040	0.011	0.003
9/29	T	0.250	0.048	0.008	0.002
10/17	0.015	0.250	0.102	0.005	0.001
11/11	0.004	0.288	0.078	0.008	0.017
1/20/73	0.004	0.200	---	---	---
3/22	0.001	0.880	0.530	0.002	0.001
5/5	0.001	0.880	0.011	0.008	0.002
5/20	0.005	0.011	0.011	0.011	0.009
6/2	T	0.001	0.001	0.007	0.002
Mean	0.004	0.227	0.061	0.008	0.006

T = <.001

Table 32. Soda Butte Creek nitrate values (as $mg \cdot \ell^{-1}$ NO_3-N)

Date	Station 1	2	3	4	5
5/27/72	---	---	---	---	---
6/9	0.011	0.019	0.027	0.031	0.024
6/24	---	---	---	---	---
7/8	0.022	0.017	0.007	0.010	0.003
7/21	0.018	0.011	0.006	0.006	0.005
8/4	0.013	0.013	0.002	0.007	0.002
8/18	0.009	0.012	0.001	0.007	0.002
8/31	0.002	0.009	0.001	0.001	0.001
9/18	0.004	0.007	0.003	0.009	0.003
9/29	0.009	0.007	0.003	0.007	0.004
10/17	0.024	0.001	0.000	0.000	0.000
11/11	0.015	0.010	0.000	0.000	0.000
1/20/73	0.035	0.030	---	---	---
3/22	0.038	0.047	0.027	0.031	0.010
5/5	0.034	0.036	0.015	0.021	0.009
5/20	0.028	0.046	0.052	0.070	0.042
6/2	0.014	0.020	0.052	0.034	0.013
Mean	0.018	0.019	0.014	0.017	0.008

Table 33. Soda Butte Creek orthophosphate values (as $mg \cdot \ell^{-1}$ soluble inorganic PO_4-P)

Date	Station 1	2	3	4	5
5/27/72	---	---	---	---	---
6/9	0.001	0.004	0.026	0.028	0.033
6/24	---	---	---	---	---
7/8	0.004	0.002	0.038	0.037	0.038
7/21	0.000	0.000	0.035	0.035	0.035
8/4	0.005	0.005	0.042	0.040	0.040
8/18	0.003	0.003	0.038	0.038	0.038
8/31	0.002	0.004	0.044	0.024	0.023
9/18	0.008	0.008	0.045	0.058	0.044
9/29	0.003	0.001	0.027	0.038	0.033
10/17	0.000	0.000	0.020	0.029	0.018
11/11	0.000	0.000	0.020	0.027	0.035
1/20/73	0.004	0.005	---	---	---
3/22	0.001	0.001	0.034	0.030	0.035
5/5	0.013	0.000	0.036	0.025	0.032
5/20	0.003	0.001	0.022	0.032	0.032
6/2	0.000	0.000	0.061	0.024	0.025
Mean	0.003	0.002	0.035	0.033	0.033

Table 34. Soda Butte Creek oxygen values ($mg \cdot \ell^{-1}$)

Date	Station 1	2	3	4	5
5/27/72	10.0	10.0	10.3	10.2	10.4
6/9	9.3	9.1	9.1	9.1	9.2
6/24	---	---	---	---	---
7/8	8.3	8.4	8.6	8.6	8.3
7/21	9.9	9.2	9.0	9.0	8.8
8/4	9.7	8.8	9.2	9.0	8.4
8/18	9.6	8.7	9.4	9.2	9.0
8/31	9.6	8.7	9.8	9.5	9.2
9/18	10.2	8.8	10.0	10.1	9.9
9/29	10.5	9.4	10.9	10.3	10.0
10/17	10.2	9.0	10.8	10.4	9.8
11/11	10.5	9.0	10.8	11.0	10.8
1/20/73	---	---	---	---	---
3/22	10.8	6.8	11.0	11.2	11.2
5/5	10.6	6.8	10.8	10.2	9.2
5/20	10.6	10.3	10.8	10.4	10.0
6/2	10.2	9.8	10.2	10.2	10.2
Mean	10.9	8.9	10.0	9.9	9.6

Table 35. Soda Butte Creek pH

Date	Station 1	2	3	4	5
5/27/72	8.84	8.08	8.28	8.60	8.85
6/9	8.30	8.09	8.22	8.19	8.44
6/24	8.17	8.20	8.27	8.18	8.48
7/8	8.34	7.98	8.07	8.13	8.39
7/21	8.40	7.86	8.22	8.39	8.45
8/4	8.64	8.05	8.24	8.66	8.49
8/18	8.47	7.61	7.61	8.17	8.29
8/31	8.40	7.71	8.18	8.37	8.43
9/18	8.24	7.69	8.08	---	---
9/29	8.49	7.76	8.05	8.47	8.35
10/17	8.06	7.78	7.98	8.09	8.13
11/11	8.42	7.92	8.08	8.44	8.45
1/20/73	7.88	6.95	---	---	---
3/22	8.09	7.62	---	---	---
5/5	8.53	7.88	8.47	8.48	8.56
5/20	7.87	7.55	7.58	7.95	7.93
6/2	8.23	7.85	7.90	7.95	8.16
Mean	8.32	7.80	8.08	8.29	8.39

Table 36. Soda Butte Creek potassium values ($mg \cdot \ell^{-1}$)

Date	Station 1	2	3	4	5
5/27/72	0.59	0.74	0.55	0.59	1.09
6/9	0.66	0.66	0.55	0.55	1.02
6/24	0.39	0.39	0.20	0.27	0.59
7/8	0.59	0.74	0.59	0.27	0.74
7/21	0.66	0.86	0.51	0.59	1.02
8/4	0.70	1.02	0.51	0.55	1.06
8/18	0.66	1.06	0.51	0.55	0.70
8/31	0.70	1.29	0.78	0.82	1.29
9/18	0.66	1.29	0.66	0.66	1.13
9/29	0.70	1.17	0.59	0.63	1.13
10/17	0.66	1.17	0.51	0.59	1.13
11/11	0.63	1.25	0.59	0.59	1.13
1/20/73	0.43	1.14	---	---	---
3/22	0.55	2.19	1.33	0.55	1.17
5/5	0.55	1.33	0.55	0.66	1.25
5/20	0.63	0.66	0.74	0.55	1.02
6/2	0.51	0.59	0.47	0.47	0.86
Mean	0.60	1.03	0.60	0.52	1.02

Table 37. Soda Butte Creek sodium values ($mg \cdot \ell^{-1}$)

Date	Station 1	2	3	4	5
5/27/72	0.35	0.23	2.30	2.76	1.61
6/9	0.23	0.12	1.50	1.84	1.50
6/24	1.04	0.92	2.65	2.99	2.76
7/8	1.17	0.97	2.99	3.01	2.78
7/21	1.38	3.47	3.68	3.70	3.22
8/4	1.38	1.38	3.68	3.59	3.36
8/18	1.01	1.10	3.68	3.22	3.22
8/31	0.97	1.10	3.68	3.22	2.62
9/18	0.97	1.01	3.96	3.68	2.85
9/29	1.10	1.13	4.32	3.96	3.13
10/17	0.97	1.10	4.14	4.78	3.50
11/11	1.10	1.10	3.68	3.50	2.76
1/20/73	3.04	1.84	---	---	---
3/22	1.29	1.61	6.21	4.19	3.15
5/5	1.29	1.61	5.47	4.28	3.04
5/20	0.97	0.87	3.22	3.73	3.54
6/2	0.97	0.94	3.04	3.36	2.76
Mean	1.13	1.21	3.64	3.49	2.86

Table 38. Soda Butte Creek sulfate values ($mg \cdot \ell^{-1}$ as $SO_4^{=}$)

Date	Station 1	2	3	4	5
5/27/72	----	----	----	----	----
6/9	6.0	11.4	2.0	2.0	4.0
6/24	6.5	14.0	4.0	3.8	3.5
7/8	6.0	18.8	4.8	3.8	3.5
7/21	5.5	35.0	7.3	6.3	4.8
8/4	5.4	57.6	9.0	7.0	5.5
8/18	6.8	60.0	10.0	9.0	11.8
8/31	5.9	70.0	10.0	10.6	7.9
9/18	8.4	68.0	13.4	12.2	10.5
9/29	7.0	58.0	11.0	11.2	8.3
10/17	7.0	59.0	11.0	9.6	6.8
11/11	6.8	66.2	15.5	12.2	8.0
1/20/73	6.0	112.0	----	----	----
3/22	8.0	191.0	12.5	11.0	6.5
5/5	5.0	182.0	8.0	10.0	7.0
5/20	6.0	12.0	4.5	4.5	2.5
6/2	6.0	16.0	6.0	4.5	2.5
Mean	6.39	64.4	8.6	7.85	6.2

Table 39. Soda Butte Creek temperature values (°C)

Date	Station 1	2	3	4	5
5/27/72	3.1	3.5	2.8	5.9	7.3
6/9	2.0	2.2	2.3	3.4	6.2
6/24	3.4	3.9	5.1	5.0	6.6
7/8	5.2	6.5	8.7	9.5	10.1
7/21	4.5	6.7	8.8	9.1	10.0
8/4	4.8	6.7	9.0	11.3	13.7
8/18	6.0	6.0	7.9	8.6	10.5
8/31	5.0	6.7	7.1	9.0	13.0
9/18	5.0	5.9	5.9	6.8	8.6
9/29	3.5	5.0	3.0	6.0	7.5
10/17	2.8	4.0	4.0	4.1	6.1
11/11	1.3	1.3	0.0	0.0	1.0
1/20/73	.5	.5	---	---	---
3/22	1.3	1.2	0.0	0.0	2.0
5/5	2.0	3.0	1.3	3.9	8.0
5/20	1.6	1.8	1.1	3.1	5.0
6/2	2.7	3.0	3.5	4.3	5.7
Mean	3.22	3.99	4.41	5.9	7.95

Table 40. Soda Butte Creek zinc values ($mg \cdot \ell^{-1}$)

Date	Station 1	2	3	4	5
5/27/72	0.03	0.03	0.03	0.0	0.0
6/9	0.035	0.0	0.025	T	0.04
6/24	T	T	0.0	T	0.0
7/8	T	T	T	T	0.0
7/21	T	T	T	T	T
8/4	0.0	0.0	0.0	0.0	0.0
8/18	T	0.035	0.035	0.0	0.0
8/31	0.0	T	0.0	0.0	0.0
9/18	T	T	0.03	T	0.0
9/29	0.0	T	0.0	0.0	0.0
10/17	0.0	T	T	T	0.0
11/11	0.0	0.0	T	0.0	0.0
1/20/73	T	0.03	---	---	---
3/22	T	T	0.0	0.0	0.0
5/5	0.0	0.035	T	0.0	0.0
5/20	0.0	T	0.0	0.0	0.0
6/2	0.0	0.0	0.0	0.0	0.0

T = <.025

Table 41. Iron Springs Creek temperature, pH, alkalinity, and dissolved oxygen values

Date	Temperature (°C)		pH		Alkalinity ($mg \cdot \ell^{-1}$ $CaCO_3$)		Dissolved Oxygen ($mg \cdot \ell^{-1}$ O_2)	
	IS1	IS2	IS1	IS2	IS1	IS2	IS1	IS2
6/24	13.9	15.5	8.00	7.88	37.0	38.5	8.0	10.1
7/8	16.2	19.1	8.00	7.75	35.0	40.0	7.6	7.7
7/21	15.3	17.0	8.08	7.73	30.5	44.5	7.5	7.7
8/4	17.1	19.2	8.10	8.39	31.5	36.0	7.4	7.6
8/18	16.8	19.2	7.91	7.94	31.0	38.5	7.2	8.2
8/31	14.2	16.1	7.96	7.68	34.5	40.0	8.2	7.2
9/18	15.6	18.0	7.95	7.88	35.0	40/0	8.0	8.0
9/29	11.2	13.0	8.07	7.77	27.0	34.5	8.6	8.4
Mean	15.0	17.1	8.01	7.88	32.7	39.0	7.8	8.1

Table 42. Iron Springs Creek total iron, chloride, manganese, and total hardness values

Date	Total Iron ($mg \cdot \ell^{-1}$)		Chloride ($mg \cdot \ell^{-1}$)		Manganese ($mg \cdot \ell^{-1}$)		Total Hardness (ppm $CaCO_3$)	
	IS1	IS2	IS1	IS2	IS1	IS2	IS1	IS2
6/24	0.17	0.12	----	----	0.001	0.007	----	----
7/8	0.21	0.77	----	----	0.020	0.018	16.0	15.0
7/21	0.21	0.36	----	----	<0.001	<0.001	14.4	14.0
8/4	0.10	0.11	----	----	<0.001	<0.001	14.2	14.0
8/18	0.07	0.07	7.05	13.75	<0.001	0.001	15.0	13.0
8/31	0.21	0.01	6.20	12.50	<0.001	0.005	13.4	13.0
9/18	0.07	0.08	7.15	13.05	<0.001	0.005	14.4	13.8
Mean	0.15	0.19	6.66	13.10	0.003	0.005	14.7	13.6

Table 43. Iron Springs Creek sodium, potassium, fluoride, calcium and magnesium values

Date	Sodium ($mg \cdot \ell^{-1}$)		Potassium ($mg \cdot \ell^{-1}$)		Flouride ($mg \cdot \ell^{-1}$)		Calcium ($mg \cdot \ell^{-1}$)		Magnesium ($mg \cdot \ell^{-1}$)	
	IS1	IS2	IS1	IS2	IS1	IS2	IS1	IS1	IS1	IS2
6/24	13.23	20.93	3.13	3.71	3.60	3.70	---	---	---	---
7/8	13.34	23.00	3.40	4.61	3.60	3.60	5.2	4.4	0.7	1.0
7/21	14.08	21.80	3.56	4.38	3.70	3.75	4.4	4.0	0.7	1.0
8/4	14.08	22.08	3.71	4.38	3.80	3.90	4.6	4.0	0.7	1.0
8/18	12.14	20.01	3.40	4.18	---	---	4.8	4.0	0.7	0.7
8/31	10.58	19.50	3.79	4.42	---	---	4.8	4.2	0.4	0.6
9/18	11.78	21.16	3.48	3.99	---	---	6.6	3.6	---	1.1
9/29	16.62	21.16	3.40	4.38	4.20	4.25	4.8	4.2	1.0	0.5
Mean	13.23	21.21	3.48	4.26	3.80	3.84	5.0	4.1	0.7	0.8

Table 44. Iron Springs Creek orthophosphate, nitrate, and sulfate values

Date	Orthophospate ($mg \cdot \ell^{-1}$ PO_4P)		Nitrate ($mg \cdot \ell^{-1}$ NO_3N)		Sulfate ($mg \cdot \ell^{-1}$ SO_4)	
	IS1	IS2	IS1	IS2	IS1	IS2
6/24	---	---	---	---	2.3	2.3
7/8	0.021	0.047	0.004	0.028	2.0	2.8
7/21	0.025	0.008	0.009	0.073	2.9	2.9
8/4	0.012	0.035	0.001	0.018	2.0	2.9
8/18	0.010	0.055	0.001	0.017	5.6	7.6
8/31	0.006	0.070	0.0	0.001	5.8	5.9
9/18	0.014	0.097	0.0	0.150	5.5	6.6
9/29	0.010	0.062	0.007	0.030	5.9	6.0
Mean	0.014	0.053	0.003	0.045	4.0	4.7

Table 45. Iron Springs Creek chlorophyll, biomass, and autotrophic index concentrations for the summer of 1972

	7/8	7/21	8/4	8/18	8/31	9/18	Mean
Station IS1							
Chlorophyll $mg \cdot m^{-2}$	36.79	12.30	9.56	12.31	9.59	15.51	16.01
Biomass $mg \cdot m^{-2}$	4016	312	3351	1546	1867	1792	2147
Autotrophic Index	109	25	351	126	195	116	154
Station IS1							
Chlorophyll $mg \cdot m^{-2}$	4.91	19.29	15.26	16.55	41.27	45.60	23.81
Biomass $mg \cdot m^{-2}$	1644	484	2275	1986	2529	3322	2040
Autotrophic Index	335	25	149	120	61	73	127

Chlorophyll "a", biomass, and autotrophic index measurements are corrected for midpoint of incubation period.

LITERATURE CITED

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American Public Health Association, Inc. 1971. Standard Methods for the Examination of Water and Wastewater. 13th Ed. Amer. Pub. Health Assoc., New York, N.Y. 874 p.

Bahls, L. L. 1971. Ecology of the Diatom Community of the Upper East Gallatin River, Montana, with In Situ Experiments on the Effect of Current Velocity on Features of the Aufwuchs. Ph.D. Thesis, Montana State University, Bozeman. 145 p.

Blum, J. L. 1957. An ecological study of the algae of the Saline River, Michigan. Hydrobiol., 9(4):361-408.

Butcher, R. W. 1947. Studies in the ecology of rivers. VII. The algae of organically enriched waters. Jour. Ecol., 35:186-191.

Cholnoky, B. J. 1960. In Harrison, A. D., P. Keller and D. Dimovic. Ecological studies on Olifantsvlei, near Johannesburg: with notes on the diatoms by B. J. Cholnoky. Hydrobiol., 15:89-134.

Cholnoky, B. J. 1968. Die Ökologie der Diatomeen in Binnengewässern. J. Cramer, Lehre. 699 pp.

Cleve-Euler, A., 1951. Die Diatomeen von Schweden und Finnland. K. Sv. Vet. Akad.. Fjarde seriens 1-5:961 pp.

Cobb, H. D. and J. Myers. 1964. Comparative studies of nitrogen fixation and photosynthesis in Anabaena cylindrica. Amer. Jour. Bot., 51(7):753-762.

Droop, M. R., 1958. Optimum relative and actual ionic concentrations for growth of some euryhaline algae. Verhandl. Intern. Ver. Limnol., 13:722-730.

Duff, D. A. 1972. Reconnaissance Survey of Aquatic Habit Conditions Affected by Acid Mine Pollution in the Cooke City Area, Custer and Gallatin National Forests, Montana, and Shoshone National Forest, Wyoming. U.S. Forest Service, Unpublished Report. 16 p.

Federal Water Pollution Control Administration. 1966. A guide to the common diatoms at water pollution surveillance system stations. F.W.P.C.A., U.S.D.I., Cincinnati. 101 pp.

Fjerdingstad, E. 1950. The microflora of the River Molleaa with special reference to the relation of the benthal algae to pollution. Folia Limnol. Scand. No. 5. 123 pp.

Hill, R. D. 1970. McLaren Mine Tailings Mine Drainage. Federal Water Quality Administration, Unpublished Report. 11 p.

Hohn, M. H. and J. Hellerman. 1963. The taxonomy and structure of diatom populations from three eastern North American rivers using three sampling methods. Trans. Amer. Microscop. Soc., 82:250-329.

Hustedt, F. and Sven Hedin. 1922. in Sovereign, H.E. 1963, New and Rare Diatoms from Oregon and Washington. Proceedings of the California Academy of Sciences. 31(14):349-368.

Hustedt, F., 1930. Baccillariophyta (Diatomeae). In Pascher, A. Die Susswasser-Flora Mitteleuropas. Heft 10:1-466.

Hutchinson, G. E. 1957. A treatise on limnology. I. Geography, physics, and chemistry. John Wiley & Sons, New York. 1015 pp.

Kolkwitz, R. and M. Marsson. 1908. Ökaologie de pflanzlichen Saprobein. (Saprobein ecology of plants.) Ber. Deut. Bot. Ges. Stuttgart. 26:505-519.

Latimer, W. M. and Hildebrand, J. H. 1951. Refernce Book of Inorganic Chemistry, 3rd Ed. The Macmillan Co., New York. pp 401-420.

Lawson, L. L., and Samuel R. Rushforth. 1975. The Diatom Flora of the Provo River Utah, USA. J. Coamer, Germany. 149pp.

Lowe, Rex L. 1974. Environmental Requirements and Pollution Tolerance of Freshwater Diatoms. United States Environmental Protection Agency. 333 pp.

Lund, J. W. G., 1965. The ecology of the freshwater phytoplankton. Biol. Rev. Camb. Phil. Soc. 40(2):231-293.

Margalef, R. 1951. Diversidad de especies en las communidades naturales. P. Inst. Biol., Apl. 9:5-27.

Mills, L. E., and F. P. Sharpe. 1968. Pollution Study on Soda Butte Creek, Yellowstone National Park, Wyoming. Bureau of Sport Fisheries and Wildlife, Unpublished Report. 14 p.

Patrick, R., Hohn, M. H. and Wallace, J. H., 1954. A new method for determining the pattern of the diatom flora. Not. Nat. Acad. Nat. Sci. No. 259:1-12.

Patrick, R. 1963. The structure of diatom communities under varying ecological conditions. Ann. N.Y. Acad. Sci., 108(2):359-365.

Patrick, R. and C. W. Reimer. 1966. The diatoms of the United States exclusive of Alaska and Hawaii. Vol. I. Fragilariaceae, Eunotiaceae, Achnanthaceae, Naviculaceae. Acad. Nat. Sci. Phila. Monogr. No. 13. 688 pp.

Patrick, R. and C. W. Reimer. 1975. The Diatoms of the United States. Vol. II. Acad. Nat. Sci. Phila. Monogr. No. 13.

Pearsall, W. H., 1932. Phytoplankton in the English Lakes II. The composition of the phytoplankton in relation to dissolved substances. Journ. Ecol. 20:241-262.

Pickett, Frank J. and James W. Chadwick. 1974. Studies on Soda Butte, Slough, and Iron Springs Creeks, Yellowstone National Park. Unpublished report. 53 pp.

Roeder, T. S. 1966. Ecology of the diatom communities of the upper Madison River system, Yellowstone National Park. Ph.D. Thesis. Montana State University, Bozeman. 85 pp.

Sokal, R. A. and Peter H. A. Sneath. 1963. Principles of Numerical Taxonomy, W. H. Freeman and Co., San Francisco. pp 125-207.

Sovereign, H. F. 1963. New and Rare Diatoms from Oregon and Washington. Proceedings of the California Academy of Sciences. Vol. 31(14):349-368.

Sprules, G. W. 1977. Crustacean Zooplankton Communities as Indicators of Limnological Conditions: An Approach Using Principle Component Analysis. J. Fish. Res. Board Can., 34:962-975.

Strickland, J. D. H. and T. R. Parsons. 1972. A Practical Handbook of Seawater Analysis, 2nd Edition. Fisheries Research Board of Canada, Ottawa. 310 p.

Stumm, Werner and James J. Morgan. 1970. Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters. John Wiley and Sons, Inc., New York. 583 pp.

Thomasson, K. 1925. Methoden zur Untersuchung der Mikrophyten der limnischen Litoral- und Profundalzone. Abderhalden's Handbuch der biologischen Arbeitsmethoden, Abt. IX, Teil 2, 1. Berlin.

U.S. Environmental Protection Agency. 1976. Quality criteria for water. No. EPA-440/9-76-023. USEPA. 501 pp.

Vincent, E. R. 1967. A Comparison of Riffle Insect Populations in the Gibbon River Above and Below the Geyser Basins, Yellowstone National Park. Linmology and Oceanography. 12(1):18-26.

Weber, C. I. and B. H. McFarland. 1969. Periphyton biomass-chlorophyll ratio as an index of water quality. Unpublished Report. Anal. Qual. Cont. Lab., F.W.P.C.A., U.S.D.I., Cincinnati, Ohio. 19 pp.

Whittaker, R. H. and C. W. Fairbanks. 1958. A study of plankton copepod communities in the Columbia Basin, southeastern Washington. Ecol., 39:46-65.

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