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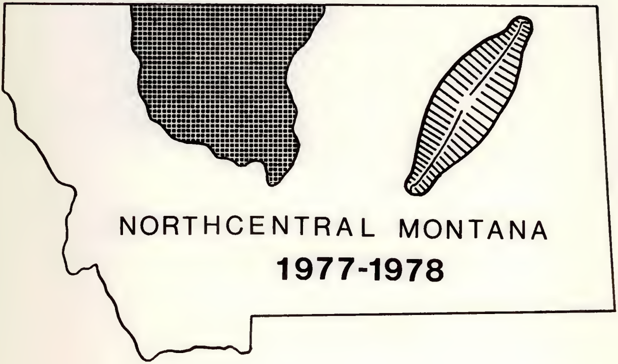
BIOLOGICAL WATER QUALITY MONITORING



NORTHCENTRAL MONTANA

1977-1978

STATE OF MONTANA
WATER QUALITY BUREAU
ENVIRONMENTAL SCIENCES DIVISION
DEPARTMENT OF HEALTH AND ENVIRONMENTAL SCIENCES
HELENA, MONTANA 59601

BIOLOGICAL WATER QUALITY MONITORING

NORTHCENTRAL MONTANA

1977-1978

by

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March 1979

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DISCLAIMER

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This report has been reviewed by the Montana Operations Office, U.S. Environmental Protection Agency, and approved for publication.

ABSTRACT

Values for 31 biologically-related water quality parameters were measured seasonally at 16 stations on 11 streams in northcentral Montana from September 1977 to April 1978. Mean values for 15 key indicators were used to develop a composite water quality rating based on biological conditions. Three stations had poor water quality from the standpoint of stream biology: Big Sandy, Muddy, and Pondera Creeks. All three suffered from heavy silt loads resulting from accelerated stream bank erosion, poor irrigation practices, and natural causes. Also, nutrient levels were seasonally very high at these stations due to agricultural runoff. Big Sandy and Pondera Creeks were affected to a lesser extent by municipal discharges. Eleven other stations were ranked as fair and were affected to varying degrees by non-point source pollution. Two of these 11 stations--Milk River at Chinook and Teton River near Dutton--also receive municipal discharges in need of upgrading. Only two streams were rated as good: the Dearborn River and the Missouri River at Cascade. On this basis, it was concluded that non-point source pollution is the most serious, biologically debilitating water quality problem at stations on the Northcentral Loop. Survey results probably can be considered representative of overall water quality in the lowland portions of northcentral Montana because of similar water and land use practices.

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PREFACE

> The importance of long term monitors is evident when one considers the ecology of our biosphere, because it is being increasingly manipulated and polluted by the civilization of man. This is due to the increased population which results in an increased demand for materials for life and for habitation......(Patrick, 1977).

The national goal of fishable and swimmable water by 1983 is supported by the fact that water quality that permits these uses is also suitable for most other beneficial uses. This goal presumes that basic biological communities and processes that permit these uses are maintained in a healthy balance. For example, it presumes that the small aquatic animals that fish eat will be present in variety and abundance, and it presumes that algae will not become a nuisance to boating, swimming, and fishing. Until recently, basic biological processes such as photosynthesis and aquatic life forms lower than fish had been given little consideration in water quality planning and management, yet these processes and life forms are basic to the integrity of the entire aquatic ecosystem. Any effects here on the "ground floor" likely will have repercussions on up the food chain.

Chemical and physical properties of water affect living organisms in ways we are just beginning to understand. Aquatic organisms are capable of integrating the many and diverse factors of their environment and of expressing their combined effect in terms of growth, reproductive success, and diversity. Aquatic organisms vary in their sensitivity to pollutants, hence some of the more sensitive and tolerant taxa have become useful as water quality indicators. Lower life forms are particularly useful as indicators because they are almost always present in statistically significant numbers.

To maintain water quality for fish and aquatic life is public policy of the State of Montana (Sec. 69-4801(1), R.C.M. 1947). Pollution is defined in part as "contamination, or other alteration of the physical, chemical, or biological properties of any state waters . . ." (Sec. 69-4802(5), R.C.M. 1947). To measure our success at protecting aquatic life and controlling pollution, we need a good yardstick. What is a better yardstick than the biological organisms and processes themselves? Yet there has been no comprehensive, systematic, and continuing biological monitoring to date in Montana.

The Montana Biological Monitoring Program is designed to help fill this need. The program consists of a network of stations, a battery of parameters, and a sampling strategy.

The network includes 79 stations on 60 streams statewide, selected from completed water quality inventories and management plans (Water Quality Bureau, 1976) on the basis of likely improvement or degradation of water quality. Stations are grouped geographically into five loops, each with about 16 stations. Streams and stations in the network are listed in Appendix A. Sites monitored for biological parameters by the U.S. Geological Survey were considered in station selection in order to complement state and federal programs.

Data are gathered in seven biologically-related areas: streamflow, common ions (including specific conductance and total alkalinity), algal nutrients, algal growth response to nutrient additions (algal assay), periphyton production, periphyton community structure, and macroinvertebrate community structure.

Stations are monitored seasonally, once in summer, once in fall, and once in spring. Ice has proven to be a serious impediment to sampling. Consequently, winter sampling will not be pursued, even though it is a season of stress for aquatic organisms.

Realistically, with available manpower, only one or two loops can be monitored each year, hence each loop will be resampled every fourth or fifth year. Subsequent reports will evaluate changes in water quality over the intervening periods. Obviously, the program is not designed for rapid detection of acute problems but rather for evaluation of chronic, long-term trends.

Comments are welcome, especially now when the program is new. All stations, parameters, and procedures are on trial and subject to continuing evaluation. If we have overlooked a stream of particular interest to you, please let us know and give us your reasons why it should be included in the network. We would also like your comments on the overall usefulness of the program to you. It is hoped that these reports will be more than just internal planning and management documents, and that they will aid resource managers, municipalities, industries, and laymen in assessing water quality conditions and trends in their area.

INTRODUCTION

This is the second in a continuing series of reports on biological conditions in Montana rivers and streams.

Streams included in the Northcentral Loop of the Water Qualtiy Bureau's Biological Monitoring Program are of many types. They range from clear, nutrient poor, cold water trout streams to silt-laden, nutrient rich, lowland streams. Most of the streams more closely approximate the latter category. In these streams, gradients and velocities have been greatly reduced, sediment loads have accumulated, and temperatures have increased over the miles traversed from their upland origins. These are natural processes. However, agriculture, the economic base of northcentral Montana, has in many cases increased the rate of these processes. Degradation of streams in northcentral Montana results from sediment, dewatering, high temperature, nutrients, salinity, coliforms, solid waste, and to a lesser extent, acid mine drainage and oil spills (Water Quality Bureau, 1974, 1975).

The sixteen stream stations comprising this loop are listed in Table 1, along with station locations and abbreviations used in subsequent tables. Nine stations occur in the Missouri-Sun-Marias basin, four are located in the Milk River basin, and the remaining three fall within the Missouri-Smith basin.

Parameters covered in this report are listed in Table 2. An attempt was made to collect all parameters seasonally, except common ions, which were restricted to the summer run (September 1977). Late fall sampling (December 1977) was greatly hindered by a winter storm, and heavy ice formation on most of the streams resulted in much missing data. Also, abnormally high flows during the spring (March 1978), including some near record flows, caused additional problems and more missing data. All future loops will be sampled earlier in the fall and spring to minimize these problems, even though weather and stream discharge patterns are never totally predictable.

The Northcentral Loop is scheduled to be sampled again in 1981-1982 or sooner, depending on available manpower and funds. At that time, changes in values of the different parameters can be compared and evaluation of long-term trends in water quality can begin. Also, missing data points will be filled in and techniques refined to provide a more complete and reliable information baseline. Meanwhile, the Water Quality Bureau will strive to develop a comprehensive biological water quality index to simplify the rating of streams and the evaluation of trends.

Table 1. Stream stations covered in this report

Code	Description	Location
Big Sandy Creek	Big Sandy Creek near mouth	T32N R15E 5DCC
Dearborn River	Dearborn River near mouth	T16N R03W 13ACC
Lodge Creek	Lodge Creek near Chinook	T33N R19E 26BCA
Marias River/Loma	Marias River near Loma	T25N R09E 2DDB
Marias River/Shelby	Marias River south of Shelby	T31N R02W 20DBD
Milk River/Chinook	Milk River near Chinook	T33N R19E 34ACA
Milk River/Havre	Milk River near Havre	T32N R16E 6DAD
Missouri River/Cascade	Missouri River near Cascade	T17N R01W 35ACC
Missouri River/Ft. Benton	Missouri River at Fort Benton	T24N R08E 26ACB
Muddy Creek	Muddy Creek near Vaughn	T21N R01E 24DAC
Pondera Creek	Pondera Creek near mouth	T29N R05E 15DAD
Smith River	Smith River near Ulm	T19N R02E 14CCD
Sun River/Ft. Shaw	Sun River near Fort Shaw	T20N R02W 2DDA
Sun River/Vaughn	Sun River below Vaughn	T21N R02E 30BCA
Teton River/Dutton	Teton River north of Dutton	T25N R01W 15BBA
Teton River/Ft. Benton	Teton River near Fort Benton	T24N R08E 9DCC

Table 2. Parameters covered in this report

Instantaneous Streamflow (m^3/sec)

Common Ions
- -Cation Ratio: Ca:Mg:Na
- -Anion Ratio: HCO_3:SO_4:Cl
- -Specific Conductance (micromhos @ 25 C)
- -Total Alkalinity (mg/l $CaCO_3$)

Algal Nutrients
- -NO_2+NO_3-N; NH_3-N; Kjeldahl-N; PO_4-P; Total P (all in mg/l)
- -Total Soluble Inorganic Nitrogen (NO_2+NO_3-N plus NH_3-N): PO_4-P Ratio
- -TSIN and Total P as % of recommended maximum instream levels (0.35 mg/l TSIN and 0.05 mg/l Total P)

Algal Assay
- -Control
  - Mean Maximum Standing Crop (MMSC) (mg/l)
  - Statistical significance of MMSC
  - Limiting Nutrient
- -Nutrient Spike
  - Mean Maximum Standing Crop (MMSC) (mg/l)
  - Statistical significance of MMSC
  - Limiting Nutrient

Periphyton Production
- -Chlorophyll *a* Accrual (mg/m^2/day)
- -Biomass Accrual (mg/m^2/day)
- -Autotrophic Index
- -Chlorophyll *a*/Pheophytin *a* Ratio ($OD663_b/OD663_a$)
- -Carotene/Chlorophyll Ratio (OD430/OD663)

Periphyton Community Structure
- -Rank of diatoms relative to other algae
- -Percent Relative Abundance (PRA) of Major Diatom Species
- -PRA *Achnanthes* species and *Nitzschia* species
- -Number of Diatom Species
- -Diatom Species Diversity ($\bar{d}$)

Macroinvertebrate Community Structure
- -Mean PRA Major Macroinvertebrate Orders
- -Mean PRA Tolerant, Facultative and Intolerant Macroinvertebrates
- -Number of Macroinvertebrate Genera
- -Macroinvertebrate Genus Diversity ($\bar{d}$)
- -Number of Macroinvertebrates collected per unit effort sample time

RATIONALE, METHODS, RESULTS, AND INTERPRETATIONS

STREAMFLOW

Rationale

Accurate measurements of streamflow are essential for calculating loads of dissolved constituents, particularly nutrients. Many aquatic organisms have specific instream flow requirements for various activities. Exceptionally high and low flows--overbank flooding and complete dewatering in the extremes--are rather traumatic events for a river and its aquatic life. Periodic streamflow measurements also circumscribe a stream's size, which in turn dictates the nature of the aquatic community it can support.

Methods

Flow rates were measured with a Pygmy current meter in small streams and with a Price Type AA current meter in the larger streams. A straight section of stream with a uniform cross-section and a smooth bottom was chosen whenever available. A measuring tape was stretched across the channel and depths and velocities were recorded at selected points such that no more than 10 percent of the total discharge fell between two consecutive points. Total instantaneous discharge was then estimated by summing flows for each of the measured subsections. Streamflow measurements were provided by the U.S. Geological Survey for the following streams: Big Sandy Creek, Marias River/Shelby, Milk River/Havre, Missouri River/Fort Benton, Pondera Creek, Sun River/Vaughn, and Teton River/Dutton.

Results

Instantaneous streamflows are presented in Table 3.

Table 3. Instantaneous Streamflow (m^3/sec)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	0.00	FNM(ICE)	141.50	70.75
Dearborn River	0.57	FNM(ICE)	6.99	3.78
Lodge Creek	0.03(E)	FNM(ICE)	FNM	0.03
Marias River/Loma	FNM	FNM(ICE)	FNM	FNM
Marias River/Shelby	4.22	5.09	52.07	20.46
Milk River/Chinook	0.68	FNM(ICE)	FNM	0.68
Milk River/Havre	0.74	0.42	155.65	52.27
Missouri River/Cascade	85.19(E)	169.00(E)	200.00(E)	151.40
Missouri River/Ft. Benton	108.39	169.23	261.78	179.80
Muddy Creek	3.65	1.42(E)	2.21	2.43
Pondera Creek	0.00	0.01	50.94	16.98
Smith River	2.63	6.46(E)	FNM	4.54
Sun River/Ft. Shaw	1.36	2.26(E)	7.75	3.79
Sun River/Vaughn	5.52	4.24(E)	11.52	7.09
Teton River/Dutton	0.62	1.73	6.03	2.79
Teton River/Ft. Benton	0.57	FNM(ICE)	FNM	0.57
Mean	14.28	35.99	81.49	40.85

FNM: Flow not measured

(E): Estimate

Interpretation

Streamflow measurements are spotty for the fall sampling run in particular because of problems with ice. Most data for this period are based on U.S. Geological Survey records. Some flows are recorded as estimates because of poor gaging conditions or because U.S. Geological Survey measurement sites varied somewhat from our stations. Missing data for the spring run are the result of extremely high water or the lack of U.S. Geological Survey gages near our stations.

On the average, spring flows were highest, followed by fall and then summer flows. Many of the streams within the Northcentral Loop are subject to extremely large seasonal discharge fluctuations. This results from heavy spring runoff into upland tributaries and/or flow regulation by flood control and irrigation structures such as Fresno dam on the Milk River. For example, Big Sandy Creek varied from a stagnant condition in summer to 141.5 m^3/sec in spring. At this time, Big Sandy Creek was contributing roughly 90 percent of the Milk River's flow at Havre.

COMMON IONS

Rationale

Common ions are the basic ingredients of the chemical "soup" in which aquatic organisms live. Their relative proportions often dictate the nature of plant and animal communities inhabiting surface waters. Specific conductance is a measure of osmotic stress on organisms--both aquatic and terrestrial--that live in, drink of, or are irrigated by the water in question. Total alkalinity measures the acid-neutralizing capacity of water. It is, thus, an indicator of a water's resiliency to acid and heavy metals pollution. It is also roughly proportional to a water's basic fertility or productivity.

Methods

Unpreserved and unfiltered grab samples were collected in one liter plastic bottles and transported under ice back to the laboratory. Analytical procedures followed the American Public Health Association (1971; 1975) or the U.S. Environmental Protection Agency (1974). Specific conductance was measured with a Wheatstone Bridge. Calcium and magnesium were measured by EDTA titration. Sodium was measured by atomic absorption. Bicarbonate and total alkalinity were measured by the automated methyl orange method or by titration with 0.02 N H_2SO_4 to a pH 4.5 endpoint. Sulfate was determined by the automated turbidimetric method. Chloride was measured by the automated mercuric thiocyanate method or by mercuric nitrate titration.

Results

Common ion ratios and conductance and alkalinity values for the summer 1977 sampling run are presented in Table 4.

Interpretation

Streams of the Northcentral Loop, as determined from summer samples at the sixteen stations, can be divided into five major chemical types: calcium bicarbonate, magnesium sulfate, sodium sulfate, sodium bicarbonate, and calcium sulfate, in descending order of frequency. Lodge Creek had a mixed type of water containing sodium, calcium, and magnesium, and bicarbonate and sulfate in roughly the same proportions.

Only two streams, Big Sandy and Pondera Creeks, had unusually high specific conductance values. Both were in excess of 3,000 micromhos. As such, these waters would be questionable for irrigation of crops (E.P.A., 1973), but probably would not be responsible for a reduction in the diversity of stream organisms. In both cases, the conductivities were associated with disproportionately high sulfate ion concentrations. It should be noted that both streams were sampled during stagnant periods when water was restricted to small isolated pools. This is common on both streams much of the year, resulting in high specific conductance values through concentration of dissolved substances. However, such values are not of much consequence since irrigation is unlikely along these streams due to their low flows. The remaining streams had specific conductance values suitable for irrigation and most other beneficial uses (E.P.A., 1973). However, other factors such as sediment, substrate, temperature, and flow are much more crucial for instream biological uses.

Table 4. Specific Conductance (umhos @ 25°C), Total Alkalinity (mg/l $CaCO_3$), and common ion ratios (as meq/l)

Station	Specific Conductance	Total Alkalinity	Ca:Mg:Na	HCO_3:SO_4:Cl
Big Sandy Creek	3431	496	1:1:4	1:3:1
Dearborn River	371	164	3:2:1	38:10:1
Lodge Creek	1145	328	1:1:1	19:18:1
Marias River/Loma	669	144	1:1:1	16:26:1
Marias River/Shelby	533	140	2:1:1	19:18:1
Milk River/Chinook	625	201	1:1:2	7:4:1
Milk River/Havre	474	150	2:1:2	9:6:1
Missouri River/Cascade	396	147	3:1:1	10:3:1
Missouri River/Ft. Benton	480	201	3:2:1	11:6:1
Muddy Creek	909	251	1:2:1	26:28:1
Pondera Creek	3130	233	1:1:1	5:41:1
Smith River	384	159	4:3:1	22:6:1
Sun River/Ft. Shaw	728	244	2:2:1	41:30:1
Sun River/Vaughn	918	244	1:2:1	25:31:1
Teton River/Dutton	767	193	1:2:1	20:25:1
Teton River/Ft. Benton	1119	205	1:1:1	8:28:1
Mean	1005	219		

ALGAL NUTRIENTS

Rationale

Nitrogen and phosphorus are the two elements most commonly limiting algal growth in lakes and streams. Phosphorus is usually limiting in lakes because many common lake algae can use atmospheric nitrogen. Nitrogen-fixers are not common in streams, therefore, this element is more often a limiting nutrient in flowing water. Only the soluble inorganic forms of these two nutrients--nitrate, nitrite and ammonia nitrogen and ortho-phosphate--are readily available for plant uptake. The sum of the soluble inorganic nitrogen fractions is called total soluble inorganic nitrogen or TSIN.

Some indication of whether nitrogen or phosphorus is growth limiting may be obtained by determining the weight ratio of the appropriate forms of nitrogen and phosphorus found in a river, and comparing that with the stoichiometric ratio required for growth (Zison et al., 1977). Specifically, let

$$R = \frac{(\mathrm{TSIN})}{(\mathrm{PO_4\text{-}P})}$$

where (TSIN) equals the concentration of total soluble inorganic nitrogen as N in mg/l and (PO_4-P) equals the concentration of phosphate as P in mg/l. If R is greater than 10, phosphorus is more likely limiting than nitrogen. If R is less than 5, nitrogen is more likely limiting than phosphorus. If R is less than 10 but greater than 5, it's a tossup as to which one is limiting. (See Table 5)

Nuisance growths of aquatic plants in streams usually can be avoided if total phosphorus is kept below 0.05 mg/l as P (Mackenthun, 1969) and if TSIN remains less than 0.35 mg/l as N (Muller, 1953). The phosphorus criterion is particularly applicable if the stream enters a standing body of water, which is eventually true of all streams in the Northcentral Loop. If instream phosphorus and TSIN values are computed as a percentage of these critical levels, as they are in Tables 6 and 7, the algae growth potential of these waters can be assessed. Nuisance growths can be expected where both P and TSIN are significantly greater than 100 percent of the critical levels, other factors being amenable to algae growth.

Methods

Unfiltered grab samples were collected in separate one liter plastic bottles, each preserved with 4 ml of $HgCl_2$ and transported under ice back to the laboratory. Analytical procedures followed the American Public Health Association (1971; 1975) or the U.S. Environmental Protection Agency (1974). Orthophosphate was measured by automated ascorbic acid reduction. Total phosphorus was determined by persulfate digestion followed by automated ascorbic acid reduction. Nitrate plus nitrite nitrogen was measured by the hydrazine reduction method. (Future analyses will be done by the automated cadmium reduction method.) Ammonia was measured by the automated phenolate method. Total Kjeldahl nitrogen was determined by manual digestion followed by the automated phenolate procedure.

Results

Measured algal nutrient levels for the 1977-1978 sampling season are listed in Appendixes B through F. TSIN-phosphate phosphorus ratios are presented in Table 5. Tables 6 and 7 give instream TSIN and total phosphorus values as percentages of maximum recommended instream concentrations.

Interpretation

From the nutrient ratios in Table 5, it appears that northcentral Montana streams are generally nitrogen limited in summer. Nutrient limitations in spring are variable or not determinable because of intermediate ratios, i.e., $10>R>5$. The few data points for the fall run are not sufficient to draw any general conclusions, although they suggest phosphorus limitation at this time of year. Based on pooled data, seven streams are phosphorus limited: Marias River/Loma, Missouri River/Fort Benton, Muddy Creek, both Sun River stations, and both Teton River stations. On the other hand, Big Sandy Creek, Lodge Creek, Pondera Creek, the Smith River, and both Milk River stations appear to be nitrogen limited. The remaining three streams have intermediate ratios and must await confirmation from the algal assay tests. These interpretations are based on averages which do not express the evident seasonal variability. All but four streams--the Dearborn River, Missouri River at Cascade, the Sun River near Fort Shaw, and the Teton River near Dutton--had nitrogen and phosphorus levels significantly in excess of recommended instream concentrations during the spring sample run (Tables 6 and 7). This enrichment results from agricultural runoff.

These twelve streams would be capable of producing nuisance algal growths at this time of year assuming other growth factors were favorable. However, high turbidities and scouring effectively inhibit such blooms in spring. On the other hand, when growth conditions are more favorable, such as in summer, none of the stream sites examined had both nitrogen and phosphorus values exceeding recommended levels. Muddy Creek and the Sun River below Muddy Creek border on the capacity to produce algal blooms in summer given slightly greater concentrations of phosphorus. But again, the tremendous sediment load and resultant turbidity contributed by Muddy Creek to the Sun River would probably restrict algal growth at both sites.

Table 5. Ratio of total soluble inorganic nitrogen (NO_2+NO_3-N plus NH_3-N) to phosphate phosphorus (PO_4 as mg/l P)

Station	Summer	Fall	Spring	Mean (Pooled)
Big Sandy Creek	1:1	ICE	2:1	2:1
Dearborn River	<1:1	20:1	8:1	9:1
Lodge Creek	<1:1	ICE	7:1	3:1
Marias River/Loma	<1:1	ICE	10:1	10:1
Marias River/Shelby	1:1	ICE	7:1	7:1
Milk River/Chinook	<1:1	ICE	2:1	2:1
Milk River/Havre	110:1	ICE	2:1	3:1
Missouri River/Cascade	<1:1	9:1	7:1	7:1
Missouri River/Ft. Benton	<1:1	ICE	8:1	10:1
Muddy Creek	>500:1*	ICE	56:1	>64:1
Pondera Creek	40:1	ICE	4:1	4:1
Smith River	<1:1	ICE	2:1	2:1
Sun River/Ft. Shaw	520:1	1070:1	25:1	200:1
Sun River/Vaughn	172:1	ICE	20:1	39:1
Teton River/Dutton	<1:1	240:1	6:1	19:1
Teton River/Ft. Benton	<1:1	375:1	8:1	16:1
Mean* (Pooled)	>9:1	83:1	8:1	>9:1

*Insufficient sample. Actual value not determined.

Table 6. Total soluble inorganic nitrogen (NO_2+NO_3-N plus NH_3-N) as a percentage of the recommended maximum instream level (0.35 mg/l)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	3	ICE	146	74
Dearborn River	<3	6	20	9
Lodge Creek	17	ICE	246	132
Marias River/Loma	<3	ICE	186	93
Marias River/Shelby	3	ICE	263	133
Milk River/Chinook	<3	ICE	163	82
Milk River/Havre	31	ICE	143	87
Missouri River/Cascade	<3	74	46	40
Missouri River/Ft. Benton	<3	ICE	126	63
Muddy Creek	>286*	ICE	1651	>968
Pondera Creek	11	ICE	234	122
Smith River	<3	ICE	60	30
Sun River/Ft. Shaw	146	265	43	151
Sun River/Vaughn	246	ICE	220	233
Teton River/Dutton	<3	274	103	126
Teton River/Ft. Benton	<3	214	189	134
Mean*	>29	167	240	>139

*Insufficient sample. Actual value not determined.

Table 7. Total phosphorus as a percentage of the recommended maximum instream level (0.05 mg/l)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	78	ICE	1180	629
Dearborn River	6	10	30	15
Lodge Creek	440	ICE	670	555
Marias River/Loma	24	ICE	1918	971
Marias River/Shelby	78	ICE	806	442
Milk River/Chinook	220	ICE	3340	1780
Milk River/Havre	28	ICE	1776	902
Missouri River/Cascade	36	80	86	67
Missouri River/Ft. Benton	118	ICE	466	292
Muddy Creek	74	ICE	1052	563
Pondera Creek	38	ICE	6760	3399
Smith River	48	ICE	872	460
Sun River/Ft. Shaw	36	16	44	32
Sun River/Vaughn	90	ICE	246	168
Teton River/Dutton	46	40	732	273
Teton River/Ft. Benton	26	40	1700	589
Mean	87	37	1355	628

ALGAL ASSAY

Rationale

The algal assay is based on Liebig's law of the minimum, which states that "growth is limited by the substance that is present in minimal quantity with respect to the needs of the organism" (U.S. E.P.A., 1971). Algal assays are used: 1) to confirm or refute conclusions regarding limiting nutrients based on N/P ratios; 2) to determine biologically the availability of algal growth-limiting nutrients; 3) to quantify biological response to change in concentrations of algal growth-limiting nutrients; and 4) to determine whether various compounds or water samples are toxic or inhibitory to algae. The basic reasons for including algal assays in this monitoring program are to determine each stream's algal growth potential and sensitivity to additions of algal nutrients.

Methods

Algal assays were conducted following "bottle test" procedures published by the U.S. Environmental Protection Agency (1971). The unicellular green alga Selenastrum capricornutum Printz was used as the test alga. Combined nutrient spikes consisted of 0.10 mg/l P plus 1.00 mg/l N. (Spikes with a chelating agent, i.e., EDTA, to test for algal growth inhibition by heavy metals, were not applied in this instance, but will be applied in all future assays.) Three replicates were run on each treatment, i.e., control and combined nutrient spike. Maximum standing crop was measured and reported in terms of mg/l dry weight, averaged over the three replicates. Theoretical maximum standing crop (TMSC) was determined by multiplying measured ortho-P and TSIN values by the appropriate production coefficient (430 and 38, respectively) and by taking the lesser of the two resulting values. Statistical reliability of mean maximum standing crop (MMSC) results as compared to theoretical maximum standing crop (TMSC) was determined from coefficient of variance criteria presented by Miller *et al*. (1978):

$\pm$ 50% for TMSC $<$1.00 mg/l

$\pm$ 30% for TMSC $>$1.00 but $<$3.00 mg/l

$\pm$ 20% for TMSC $>$3.00 but $<$10.00 mg/l

$\pm$ 10% for TMSC $>$10.00 mg/l

Low MMSC values that are significantly different could be due to: 1) micronutrients limiting; 2) something toxic or inhibitory in the water sample; and/or 3) nutrients incorrectly overestimated in analysis. High values that are significantly different could be the result of incorrectly underestimating nutrients in analysis.

Results

Algal assay results for summer and fall 1977 and spring 1978 are presented in Tables 8, 9, and 10, respectively.

Interpretation

The algal assay data substantiate or clarify the nutrient limitation predictions based on nitrogen to phosphorus ratios. Of these two nutrients, nitrogen was in short supply (limiting) in the assay water relative to the needs of the test alga (*Selenastrum capricornutum*) for the following streams: Marias, Missouri, and Smith rivers, Lodge and Big Sandy creeks, and the Milk River at Chinook. Phosphorus was limiting in the Sun River and Muddy Creek. In the remaining five streams, nitrogen and phosphorus exchange the role of limiting nutrient from season to season or they are co-limiting. More complete data for the fall period would help to clarify seasonal nutrient availability trends.

Table 8. Algal assay results, Summer 1977

Station	CONTROL Mean Maximum Standing Crop (mg/l)	CONTROL Significantly Different from TMSC?	CONTROL Limiting Nutrient	NUTRIENT SPIKE Mean Maximum Standing Crop (mg/l)	NUTRIENT SPIKE Significantly Different from TMSC?	NUTRIENT SPIKE Limiting Nutrient
Big Sandy Creek	0.27	NO	N	39.36	NO	N
Dearborn River	1.35	YES-High	N or P	50.82	YES-High	N
Lodge Creek	0.83	YES-Low	N	45.60	YES-High	N
Marias River/Loma	0.44	NO	N	45.22	YES-High	N
Marias River/Shelby	0.37	NO	N	37.66	NO	N
Milk River/Chinook	3.49	YES-High	N	41.09	NO	N
Milk River/Havre	0.35	NO	P	41.54	NO	N
Missouri River/Cascade	0.56	NO	N	39.86	NO	N
Missouri River/Ft. Benton	0.43	NO	N	40.13	NO	N
Muddy Creek	4.34	YES-High	P	55.33	YES-High	P
Pondera Creek	0.26	NO	P	4.00	YES-Low	N
Smith River	0.38	NO	N	38.48	NO	N
Sun River/Ft. Shaw	0.48	NO	P	54.18	YES-High	P
Sun River/Vaughn	0.49	YES-Low	P	48.05	NO	P
Teton River/Dutton	0.38	NO	N	36.67	NO	N
Teton River/Ft. Benton	0.30	NO	N	33.41	YES-Low	N

Table 9. Algal assay results, Fall 1977

	CONTROL			NUTRIENT SPIKE		
Station	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient
Big Sandy Creek		ICE			ICE	
Dearborn River	0.38	NO	P	42.67	NO	N
Lodge Creek		ICE			ICE	
Marias River/Loma		ICE			ICE	
Marias River/Shelby		ICE			ICE	
Milk River/Chinook		ICE			ICE	
Milk River/Havre		ICE			ICE	
Missouri River/Cascade	7.18	YES-Low	N	63.36	YES-High	N
Missouri River/Ft. Benton		ICE			ICE	
Muddy Creek		ICE			ICE	
Pondera Creek		ICE			ICE	
Smith River		ICE			ICE	
Sun River/Ft. Shaw	0.30	NO	P	65.66	YES	P
Sun River/Vaughn		ICE			ICE	
Teton River/Dutton	0.36	YES-Low	P	62.1	YES-High	P
Teton River/Ft. Benton	0.32	YES-Low	P	67.32	YES-Low	P

Table 10. Algal assay results, Spring 1978

	CONTROL			NUTRIENT SPIKE		
Station	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient
Big Sandy Creek	16.92	YES-Low	N	70.87	YES-High	N
Dearborn River	0.49	NO	N	79.92	YES-High	N
Lodge Creek	11.13	YES-Low	N	71.88	YES-High	N
Marias River/Loma	12.42	YES-Low	N	73.56	YES-High	N
Marias River/Shelby	24.69	NO	N	87.61	YES-High	N
Milk River/Chinook	12.55	YES-Low	N	81.85	YES-High	N
Milk River/Havre	--------SAMPLE LOST----------			--------SAMPLE LOST------------		
Missouri River/Cascade	4.52	YES-Low	N	60.03	YES-High	N
Missouri River/Ft. Benton	3.65	YES-Low	N	71.60	YES-High	N
Muddy Creek	65.56	YES-High	P	65.70	YES-Low	P
Pondera Creek	33.74	NO	N	103.60	YES-High	N
Smith River	22.46	YES-High	N	76.20	YES-High	N
Sun River/Ft. Shaw	0.66	YES-Low	P	83.66	YES-High	N
Sun River/Vaughn	2.55	YES-Low	P	8.06	YES-Low	P
Teton River/Dutton	--------SAMPLE LOST-----------			-------SAMPLE LOST------------		
Teton River/Ft. Benton	14.04	NO	N	81.59	NO	N

PERIPHYTON PRODUCTION

Rationale

Periphyton is the community of plants and animals, most of them microscopic, living attached to or in close proximity of the stream bottom. In terms of primary production--converting solar energy to plant biomass--it is the most important community in the majority of Montana streams.

Measuring the growth of periphyton organisms on artificial substrates placed in a stream is one method of estimating the productive potential of the stream. The two parameters most commonly measured are chlorophyll a (the most significant photosynthetic pigment) and ash-free weight or biomass. Measurements of these parameters have been made on a great variety of surface waters worldwide and in Montana. Chlorophyll accrual rates in Montana streams have been summarized by Klarich (1976). An assessment of a streams' trophic status can be made by comparing its rate of accrual to rates in other waters known to be oligotrophic, mesotrophic or eutrophic.

The autotrophic index (AI) is the mass ratio of biomass to chlorophyll a. Chlorophyll a usually contributes from 1 to 2 percent of algal dry weight, resulting in AI values of 50 to 100 in pure algal cultures. As a stream is enriched with organic compounds, the proportion of consuming, non-chlorophyll bearing organisms increases and the fraction of autotrophic, chlorophyll bearing organisms (algae) decreases. Unpolluted stream AI values normally range from 50 to 200. Larger AI values indicate poor water quality (A.P.H.A., 1975).

The amount of pheophytin a in a periphyton sample relative to the amount of chlorophyll a is an indicator of the physiological condition of the algae. Pheophytin a is derived from chlorophyll a upon breakdown and loss of magnesium ion. Acidification in the laboratory has the same effect. Acidification of a solution of pure chlorophyll a results in a 40 percent reduction in optical density, yielding a before/after acidification ratio of about 1.7. Field samples with a ratio of 1.7 are considered to contain little if any pheophytin a and to be in excellent physiological condition. Solutions of pure pheophytin show no reduction in optical density upon acidification and have a before/after ratio of 1.0. Thus, mixtures of chlorophyll a and pheophytin a have optical density ratios ranging between 1.0 and 1.7 (A.P.H.A., 1975).

The ratio of yellow pigment (carotene) to green pigment (chlorophyll) in a sample of mixed algae can be used as an index of community stability and productivity (Margalef, 1969). In young, vigorously growing algal communities, the green photosynthetic pigment chlorophyll a predominates and the yellow to green optical density ratio is low, usually about 2. As the community ages and becomes more diversified, yellow pigments predominate and the yellow to green ratio increases to 3 or greater (Odum, 1963).

Methods

Artificial substrates (glass microscope slides) were used to measure the accrual of periphyton pigments and biomass. The slides were placed in a plastic carriage (Periphytometer II) produced by Design Alliance, Inc. of Cincinnati, Ohio. The carriage and slides ensemble was tied to a cement cinder block, which served as an anchor. The sampling device was placed in water of moderate current velocity (0.1 to 0.5 m/sec) and moderate depth (0.3 to 1.0 m) such that the slides were oriented vertically with their surfaces perpendicular to the direction of flow. The slides were exposed from 13 to 28 days depending on season, water temperature, and inherent productivity.

Upon retrieval, the slides were removed from the carriage and immediately placed into light-proof slide boxes. The boxes were labeled and transferred to the laboratory on ice. On arrival at the lab, the boxes were placed in a freezer for at least 24 hours to enhance cell lysis.

Pigment extraction and measurement were then performed according to the American Public Health Association (1975) with the following procedural exceptions. Periphyton was scraped into 50 ml, foil-wrapped centrifuge tubes. For each slide scraped, 10 ml of 90 percent acetone-10 percent saturated $MgCO_3$ solution was added to the tube. Usually, one sample consisted of scrapings from 4 slides, consequently, the total acetone volume equalled 40 ml. The tubes were placed in a sonic bath for at least 20 minutes to aid pigment extraction and then allowed to steep for at least 24 hours in the dark under refrigeration at 4^0C. Pigment optical density readings were made with a Perkin-Elmer Model 200 Spectrophotometer at a resolution setting of 1.0 nanometer.

Biomass determinations were also made according to the A.P.H.A. (1975) with the following variations. Biomass and chlorophyll were measured on separate slides for the summer 1977 run but the same material was used for both measurements during the spring 1978 run. Inconel alloy metal crucibles were used. Prior to placing the samples in the drying oven, the acetone was evaporated under a bank of sun lamps.

Results

Tables 11 through 15 contain chlorophyll _a_ accrual rates, biomass accrual rates, autotrophic index values, chlorophyll _a_/pheophytin _a_ ratios, and carotene/chlorophyll ratios, respectively. Analysis for the last parameter was begun only in spring and results are incomplete.

Interpretation

Chlorophyll a accrual rates in streams of northcentral Montana averaged from 0.11 to 2.59 mg/m^2/day (Table 11). Klarich (1976) reported mean accrual values ranging from 0.7 at Laurel to 12.2 at Huntley for a stretch of the Yellowstone River he describes as "mesotrophic". Ingman (1978) found accrual rates averaging 3.1 for a moderately enriched section of Prickly Pear Creek below the Helena sewage treatment plant discharge. At the other extreme, Bahls (1978) found two very oligotrophic streams in northwestern Montana to have mean chlorophyll a accrual rates of 0.13 and 0.14 mg/m^2/day. Streams of the Northcentral Loop thus might be rated oligotrophic to mesotrophic, with the Marias River near Shelby least productive in terms of chlorophyll a accrual. However, realistic comparisons between streams cannot be drawn because of the many missing data points.

Mean biomass accrual rates in streams of the Northcentral Loop ranged from a low of 134 mg/m^2/day in the Marias River near Shelby to a high of 431 mg/m^2/day in Muddy Creek (Table 12). Klarich (1976) reported extreme values of 50 and 730 mg/m^2/day in the Yellowstone River above and below Billings, respectively. Ingman (1978) reported a mean biomass accrual rate of 338 mg/m^2/day for Prickly Pear Creek. Bahls (1978) found mean biomass accrual rates of 115 and 102 mg/m^2/day for the two oligotrophic northwestern Montana streams. Normal biomass production rates for streams range from 300 to 4,100 mg/m^2/day according to Whittaker (1970). Consequently, biomass accrual in northcentral Montana streams falls toward the low end of the stream productivity spectrum, substantiating the oligotrophic to mesotrophic classifications applied on the basis of chlorophyll a accrual. Again, caution should be used because of missing data and because existing stream vegetation may compete with colonizing algae for available nutrients.

Mean autotrophic index values ranged from 400 (Sun River/Vaughn) to 1,247 (Marias River/Shelby). Mean values for all 16 stations indicate poor water quality. However, the summer figures are suspected to be unnaturally high due to faulty procedures. With the few remaining data points, very little can be said with confidence in the interpretation of these results.

Mean chlorophyll a/pheophytin a ratios ranged from 1.58 (Missouri River/Cascade) to 1.74 (Smith River) with an overall mean of 1.68 (Table 14). This indicates that the physiological condition of algae colonizing artificial substrates in northcentral Montana streams is good.

"Yellow/green" or carotene/chlorophyll ratios were between 6.85 and 10.41 (Table 15). All the values signify stable, mature floras. However, figures are available only for the spring run of five streams. Therefore, seasonal and station-to-station comparisons cannot be made.

Table 11. Chlorophyll a accrual (mg/m^2/day)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	DNA	DNA	DNA	DNA
Dearborn River	.25	DNA	.08	.16
Lodge Creek	.34	DNA	DNA	.34
Marias River/Loma	DNA	DNA	DNA	DNA
Marias River/Shelby	.11	DNA	DNA	.11
Milk River/Chinook	.35	DNA	DNA	.35
Milk River/Havre	DNA	DNA	DNA	DNA
Missouri River/Cascade	DNA	DNA	2.59	2.59
Missouri River/Ft. Benton	DNA	DNA	DNA	DNA
Muddy Creek	.64	DNA	DNA	.64
Pondera Creek	DNA	DNA	DNA	DNA
Smith River	.52	DNA	DNA	.52
Sun River/Ft. Shaw	.44	DNA	.15	.30
Sun River/Vaughn	.40	DNA	.99	.65
Teton River/Dutton	.94	DNA	.10	.52
Teton River/Ft. Benton	DNA	DNA	DNA	DNA
Mean	.44	DNA	.78	.56

DNA: Data not available

Table 12. Biomass accrual (mg/m^2/day)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	DNA	DNA	DNA	DNA
Dearborn River	213	DNA	65	139
Lodge Creek	148	DNA	DNA	148
Marias River/Loma	DNA	DNA	DNA	DNA
Marias River/Shelby	134	DNA	DNA	134
Milk River/Chinook	414	DNA	DNA	414
Milk River/Havre	DNA	DNA	DNA	DNA
Missouri River/Cascade	DNA	DNA	198	198
Missouri River/Ft. Benton	DNA	DNA	DNA	DNA
Muddy Creek	431	DNA	DNA	431
Pondera Creek	DNA	DNA	DNA	DNA
Smith River	398	DNA	DNA	398
Sun River/Ft. Shaw	371	DNA	49	210
Sun River/Vaughn	231	DNA	212	195
Teton River/Dutton	611	DNA	30	320
Teton River/Ft. Benton	DNA	DNA	DNA	DNA
Mean	328	DNA	111	250

DNA: Data not available

Table 13. Autotrophic Index

Station	Summer*	Fall	Spring**	Mean
Big Sandy Creek	DNA	DNA	DNA	DNA
Dearborn River	847	DNA	782	814
Lodge Creek	430	DNA	DNA	430
Marias River/Loma	DNA	DNA	DNA	DNA
Marias River/Shelby	1247	DNA	DNA	1247
Milk River/Chinook	1245	DNA	DNA	1245
Milk River/Havre	DNA	DNA	DNA	DNA
Missouri River/Cascade	1048	DNA	77	562
Missouri River/Ft. Benton	DNA	DNA	DNA	DNA
Muddy Creek	679	DNA	DNA	679
Pondera Creek	DNA	DNA	DNA	DNA
Smith River	646	DNA	DNA	646
Sun River/Ft. Shaw	841	DNA	329	585
Sun River/Vaughn	577	DNA	224	400
Teton River/Dutton	652	DNA	308	480
Teton River/Ft. Benton	DNA	DNA	DNA	DNA
Mean	821	DNA	344	662

DNA: Data not available

*Biomass and chlorophyll measurements on separate slides

**Biomass and chlorophyll measurements on same slide(s)

Table 14. Chlorophyll a/Pheophytin a ratio (OD 663_b/OD 663_a)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	DNA	DNA	DNA	DNA
Dearborn River	1.72	DNA	1.58	1.65
Lodge Creek	1.90	DNA	DNA	1.90
Marias River/Loma	DNA	DNA	DNA	DNA
Marias River/Shelby	1.73	DNA	DNA	1.73
Milk River/Chinook	1.65	DNA	DNA	1.65
Milk River/Havre	DNA	DNA	DNA	DNA
Missouri River/Cascade	1.43	DNA	1.72	1.58
Missouri River/Ft. Benton	DNA	DNA	DNA	DNA
Muddy Creek	1.65	DNA	DNA	1.65
Pondera Creek	DNA	DNA	DNA	DNA
Smith River	1.74	DNA	DNA	1.74
Sun River/Ft. Shaw	1.64	DNA	1.58	1.61
Sun River/Vaughn	1.73	DNA	1.70	1.72
Teton River/Dutton	1.61	DNA	1.63	1.62
Teton River/Ft. Benton	DNA	DNA	DNA	DNA
Mean	1.68	DNA	1.64	1.67

DNA: Data not available

Table 15. Carotene/Chlorophyll ratio (OD 430/OD 663)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	DNA	DNA	DNA	DNA
Dearborn River	DNA	DNA	10.05	10.05
Lodge Creek	DNA	DNA	DNA	DNA
Marias River/Loma	DNA	DNA	DNA	DNA
Marias River/Shelby	DNA	DNA	DNA	DNA
Milk River/Chinook	DNA	DNA	DNA	DNA
Milk River/Havre	DNA	DNA	DNA	DNA
Missouri River/Cascade	DNA	DNA	10.41	10.41
Missouri River/Ft. Benton	DNA	DNA	DNA	DNA
Muddy Creek	DNA	DNA	DNA	DNA
Pondera Creek	DNA	DNA	DNA	DNA
Smith River	DNA	DNA	DNA	DNA
Sun River/Ft. Shaw	DNA	DNA	10.16	10.16
Sun River/Vaughn	DNA	DNA	10.24	10.24
Teton River/Dutton	DNA	DNA	6.84	6.84
Teton River/Ft. Benton	DNA	DNA	DNA	DNA
Mean	DNA	DNA	9.54	9.54

DNA: Data not available

PERIPHYTON COMMUNITY STRUCTURE

Rationale

Except in the lower reaches of our largest rivers--the Kootenai, Clark Fork, Missouri and Yellowstone--the stream periphyton (bottom) community is more important than the stream plankton (open water) community in terms of plant diversity and plant production. The periphyton community may have more than 300 different kinds of plants (mostly single-celled algae) on one square inch of river bottom.

In unpolluted waters, the dominant algae are diatoms. Diatoms are microscopic, golden-brown plants encased in silica. They are often attached to the river bottom by a short gelatinous stalk. Millions of these creatures underfoot can make a river bottom treacherous, yet they are a sign of good river health. Moreover, they are the preferred food of many aquatic invertebrates.

When a river is polluted and its chemical and biological equilibria are disturbed, diatoms are often displaced by coarser, less palatable green and blue-green algae (Patrick, 1978). In Montana streams and elsewhere, this takeover is often accomplished by the long, filamentous green alga _Cladophora_, which often becomes a nuisance. For this reason, we have ranked diatoms relative to other significant algae as a rough index of stream well-being. Theoretically, the lower diatoms are ranked, the more polluted and unbalanced is the river. It should be noted that some non-diatom algae may be seasonally very abundant in nearly pristine streams, for example, the blue-green alga _Nostoc_.

Each one of the many thousand different species of stream diatoms is unique in the conditions it requires for growth. Many of the more common species have been classified as to their general environmental requirements and pollution tolerances (Lowe, 1974). They run the gamut from tolerant to intolerant. Consequently, diatoms are valuable pollution indicators and subtle shifts within the diatom association on a river bottom can signal environmental disturbances long before a stream becomes totally "unglued" and nuisance growths appear.

Achnanthes and _Nitzschia_ are two particularly useful diatom indicators. _Achnanthes_ is almost always found in significant numbers, but only in water having a high concentration of dissolved oxygen, approaching saturation. _Nitzschia_, on the other hand, is usually associated with waters high in nitrogen. The relative abundance of _Nitzschia_ is often directly proportional to the amount of nitrogen contained in the water. Some species of _Nitzschia_, such as _N. palea_, require organic nitrogen for their growth (Cholnoky, 1968).

Clean waters usually have many different species with some fairly common but with none really dominant. Polluted waters have fewer species, often with one or two species very abundant. Clean water is said to have high diversity and polluted water is said to have low diversity. Diversity can be measured simply by counting the number of species in a sample or by calculating a rather involved formula called a diversity index. The most widely accepted diversity index is the Shannon-Weaver Index or $\bar{d}$. Bahls (In Press) found that benthic diatom associations in unpolluted Montana streams average between 25 and 40 species with $\bar{d}$ values greater than 3. Species numbers significantly below 25 and diversity values significantly below 3 are indications of pollution.

Methods

Periphytic algae were collected from natural substrates on the stream bottom. Quantities of larger, macroscopic species were picked in proportion to their abundance relative one to one another and to the attached diatom (slime) community as a whole. Accordingly, an appropriate amount of the diatom community was collected by scraping rocks and other submerged substrates with a razor blade, pocket knife, or scalpel. Different substrates in turn were scraped in proportion to their areal coverage. An effort also was made to collect algae from both pools and riffles, again in proportion to the extent these stream features prevail at a given site. The ultimate objective is to obtain a sample of algae that is a miniature replicate of the stream's periphyton community. Samples were preserved with Lugol's (IKI) solution and returned to the lab for analyses.

Conspicuous non-diatom algae were removed, examined microscopically, and identified to genus. The relative abundance and rank of each significant non-diatom genus and the diatom community as a whole were then recorded. A portion of the diatom community was used to prepare a permanent, randomly strewn mount using sulfuric acid and potassium dichromate as the oxidizing agents and Cargille's "Carmount-165" as the mounting medium (A.P.H.A., 1975). A diatom species proportional count was performed on each slide following the technique outlined by Weber (1973), except that in excess of 300 rather than 250 cells were tallied. The results were used to compute percent relative abundance of indicator taxa and diatom species diversity using the Shannon-Weaver formula recommended by Weber (1973):

$$\bar{d} = \frac{C}{N} (N \log_{10} N - \Sigma n_i \log_{10} n_i)$$

where $C = 3.321928$; N = total number of individuals; and n_i = number of individuals in the i^{th} species.

Results

Parameters depicting periphyton community structure are presented in Tables 16 through 21.

Interpretation

Diatoms dominated the periphyton of most streams in the Northcentral Loop (Table 16). However, diatoms were substantially outranked by other algae in Lodge and Big Sandy Creeks, indicating serious perturbations in these streams. Schizomeris, a green alga, dominated the algal flora at the Sun River station below Vaughn in September (summer 1977). Prescott (1968) describes this alga as being favored by water enriched with nitrogen wastes, and elsewhere (Prescott, 1964) he reports that it is often found near the entrance of drains or sewage treatment plant discharges. The Muddy Creek station at Vaughn was dominated at this time by Cladophora, another green alga that is responsive to nutrient enrichment (Whitton, 1970). Cladophora was easily the most abundant and most frequently occurring non-diatom alga at Northcentral Loop stations.

Water quality requirements of major diatom species from the Northcentral Loop are summarized in Appendix G. Most of these species (Table 17) indicate alkaline, somewhat salty water approaching eutrophic conditions. Particularly eutrophic conditions were indicated by the dominance of Navicula perparva in the spring collection from Muddy Creek, Navicula minima in the summer collection from Lodge Creek, and Nitzschia palea in the spring collection from the Teton River near Dutton.

A large number of collections had low relative abundance values for oxygen-indicating Achnanthes species (Table 18). In all cases where two stations were sampled on one river (Marias, Milk, Missouri, Sun, Teton), the downstream station had the lower mean relative abundance. However, this difference was not significant between Cascade and Fort Benton on the Missouri. Other streams with low relative abundance values for Achnanthes were Big Sandy and Lodge Creeks and the Smith River. Consequently, these streams are the ones most likely to suffer from depressed dissolved oxygen concentrations.

Most of the streams in the Northcentral Loop had substantial populations of Nitzschia species (Table 19). One notable exception was the Sun River at Fort Shaw which had consistently low populations of this nitrogen indicator diatom. Particularly high values were recorded for Big Sandy Creek, the Marias River near Shelby, and the Teton River near Dutton. These stations may be more affected than others by nitrogenous wastes.

Diatom diversities and numbers of diatom species were significantly lower in spring than in summer or fall. Three particularly stressed stations at this time were Pondera Creek, the Marias River at Loma, and the Teton River at Fort Benton. All three had fewer than 25 species and diversity values less than 3. Although only 22 species were recorded for Muddy Creek, diatom diversity was satisfactory in this stream.

Table 16. Estimated rank of diatoms and other significant algae, by volume

Station	Summer	Fall	Spring
Big Sandy Creek	1. *Chara*	Ice	Flood
	2. *Spirogyra*		
	3. Diatoms		
	4. *Mougeotia*		
Dearborn River	1. Diatoms	1. *Rivularia*	1. Diatoms
	2. *Chara*	2. Diatoms	2. *Ulothrix*
	3. *Zygnema*		3. *Phormidium*
	4. *Mougeotia*		
	5. *Spirogyra*		
	6. *Rhizoclonium*		
Lodge Creek	1. *Spirogyra*	Ice	Flood
	2. *Oedogonium*		
	3. *Audouinella*		
	4. *Mougeotia*		
	5. Diatoms		
Marias River/Loma	1. Diatoms	Ice	1. Diatoms
	2. *Chara*		
	3. *Cladophora*		
Marias River/Shelby	1. Diatoms	Ice	1. *Lyngbya*
	2. *Cladophora*		2. Diatoms
	3. *Cosmarium*		
Milk River/Chinook	1. Diatoms	Ice	1. *Phormidium*
	2. *Phormidium*		2. Diatoms
	3. *Scenedesmus*		3. *Oscillatoria*
Milk River/Havre	1. Diatoms	Ice	1. Diatoms
	2. *Spirogyra*		2. *Phormidium*
	3. *Cladophora*		3. *Rivularia*
Missouri River/Cascade	1. *Cladophora*	1. *Cladophora*	1. Diatoms
	2. Diatoms	2. Diatoms	2. *Cladophora*
	3. *Enteromorpha*		3. *Hormidium*
			4. *Ulothrix*
Missouri River/Fort Benton	1. Diatoms	Ice	1. Diatoms
			2. *Cladophora*
Muddy Creek	1. *Cladophora*	Ice	1. Diatoms
	2. Diatoms		

Table 16. (Continued)

Station	Summer	Fall	Spring
Pondera Creek	1. Diatoms 2. *Cladophora* 3. *Oedogonium* 4. *Spirogyra* 5. *Pediastrum*	Ice	1. Diatoms
Smith River	1. Diatoms	Ice	1. Diatoms
Sun River/Fort Shaw	1. Diatoms 2. *Cladophora*	1. Diatoms 2. *Cladophora*	1. Diatoms 2. *Ulothrix*
Sun River/Vaughn	1. *Schizomeris* 2. Diatoms	Ice	1. Diatoms 2. *Ulothrix*
Teton River/Dutton	1. Diatoms 2. *Spirogyra* 3. *Cosmarium* 4. *Scenedesmus*	Ice	1. Diatoms
Teton River/Fort Benton	1. Diatoms	1. Diatoms	1. Diatoms

Table 17. Percent relative abundance of major diatom species (Appendix G)

Station	Summer	Fall	Spring
Big Sandy Creek	NIFR: 17.6 DPPU: 11.9 ENOR: 10.4	Ice	Flood
Dearborn River	ACMI: 26.3 CMMC: 12.5	DITE: 36.8 ACMI: 20.4 CMMC: 14.2	ACMI: 25.1 GOOL: 13.2 NIDI: 12.1
Lodge Creek	NAMI: 21.9	Ice	Flood
Marias River/Loma	CMMC: 23.1 ACMI: 12.2 SYDE: 10.3	Ice	DITE: 69.6 FRVA: 14.5
Marias River/Shelby	FRVA: 28.3 ACMI: 22.0	Ice	AMPE: 45.4 RHCU: 16.8
Milk River/Chinook	STSU: 28.8 AMPE: 13.9 CYME: 11.5	Ice	GOTE: 25.6 RHCU: 15.4
Milk River/Havre	ACMI: 54.0 CMMC: 10.8	Ice	ACMI: 30.3 CMMC: 21.6 FRVA: 14.3
Missouri River/Cascade	EPSO: 51.1 NIFR: 11.9	DIVU: 22.0 NIFR: 16.4	NATR: 27.7 GOOL: 19.6 DIVU: 18.2
Missouri River/Fort Benton	NIFR: 11.3 NAMI: 10.7	Ice	AMPE: 18.6 NAMI: 18.3 NARA: 17.8 COPL: 11.4
Muddy Creek	ACMI: 31.7 CMAF: 15.6	Ice	NAPE: 19.6 ACMI: 19.0 NIFR: 15.8 AMPE: 14.9
Pondera Creek	SYPU: 12.6 NIFR: 11.5 ACMO: 11.0	Ice	STHA: 77.3 NIAC: 14.7

Table 17. (Continued)

Station	Summer	Fall	Spring
Smith River	AMPE: 15.9	Ice	GOOL: 43.9 DIVU: 13.5 SYUL: 11.0
Sun River/Fort Shaw	ACMI: 19.8 FRVA: 18.9	DITE: 25.4 ACMI: 18.5 ACMO: 10.3	ACMI: 16.5 DITE: 15.3 SYRU: 14.8 FRVA: 10.8 GOOL: 10.5
Sun River/Vaughn	DIVU: 12.3 ACMI: 11.4	Ice	SYRU: 19.3 DITE: 15.2
Teton River/Dutton	CMMN: 28.0 FRVA: 12.6 ACMI: 11.7 DITE: 11.1	Ice	NIPA: 19.9 DITE: 10.5
Teton River/Fort Benton	CMMC: 16.6 APPE: 13.4 ACMI: 10.9 NIMI: 10.9	CMMC: 22.1 CMAF: 20.4 ACMI: 11.2 DITE: 10.3	GOOL: 40.7 DITE: 35.6

Table 18. Percent relative abundance of Achnanthes species

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	5.4	Ice	Flood	5.4
Dearborn River	27.1	20.1	27.8	25.0
Lodge Creek	3.8	Ice	Flood	3.8
Marias River/Loma	13.6	Ice	1.2	7.4
Marias River/Shelby	22.0	Ice	25.4	23.7
Milk River/Chinook	1.5	Ice	6.8	4.2
Milk River/Havre	52.9	Ice	30.3	41.6
Missouri River/Cascade	3.1	1.8	0.8	1.9
Missouri River/Fort Benton	2.6	Ice	1.0	1.8
Muddy Creek	31.7	Ice	65.0	46.4
Pondera Creek	21.0	Ice	0.0	10.5
Smith River	3.5	Ice	0.5	2.0
Sun River/Ft. Shaw	29.6	29.3	20.5	26.5
Sun River/Vaughn	11.7	Ice	13.4	12.6
Teton River/Dutton	12.0	Ice	3.8	7.9
Teton River/Fort Benton	2.6	11.2	1.0	4.9
Mean	15.3	15.6	14.1	14.8

Table 19. Percent relative abundance of Nitzschia species

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	34.2	Ice	Flood	34.2
Dearborn River	13.0	7.6	16.5	12.4
Lodge Creek	26.3	Ice	Flood	26.3
Marias River/Loma	11.6	Ice	0.6	6.1
Marias River/Shelby	36.9	Ice	7.5	22.2
Milk River/Chinook	16.7	Ice	19.7	18.2
Milk River/Havre	14.2	Ice	9.0	11.6
Missouri River/Cascade	15.8	21.7	10.3	15.9
Missouri River/Fort Benton	26.5	Ice	14.6	20.6
Muddy Creek	10.9	Ice	16.7	13.8
Pondera Creek	23.7	Ice	18.1	20.9
Smith River	22.8	Ice	2.2	12.5
Sun River/Ft. Shaw	4.1	1.7	2.0	2.6
Sun River/Vaughn	24.0	Ice	17.7	20.8
Teton River/Dutton	10.6	Ice	33.5	22.0
Teton River/Fort Benton	24.7	9.4	10.7	14.9
Mean	19.8	10.1	12.8	15.8

Table 20. Number of diatom species

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	44	Ice	Flood	44
Dearborn River	56	32	38	42
Lodge Creek	50	Ice	Flood	50
Marias River/Loma	47	Ice	17	32
Marias River/Shelby	33	Ice	31	32
Milk River/Chinook	44	Ice	28	36
Milk River/Havre	46	Ice	35	40
Missouri River/Cascade	32	39	31	34
Missouri River/Fort Benton	58	Ice	28	43
Muddy Creek	28	Ice	22	25
Pondera Creek	42	Ice	13	28
Smith River	61	Ice	32	46
Sun River/Fort Shaw	37	41	38	39
Sun River/Vaughn	56	Ice	45	50
Teton River/Dutton	36	Ice	49	42
Teton River/Fort Benton	44	35	23	34
Mean	45	37	31	38

Table 21. Diatom species diversity ($\bar{d}$)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	4.42	Ice	Flood	4.42
Dearborn River	4.42	3.05	3.79	3.75
Lodge Creek	4.53	Ice	Flood	4.53
Marias River/Loma	4.33	Ice	1.64	2.99
Marias River/Shelby	3.55	Ice	3.02	3.28
Milk River/Chinook	3.97	Ice	3.86	3.92
Milk River/Havre	3.28	Ice	3.37	3.33
Missouri River/Cascade	3.01	4.01	3.24	3.42
Missouri River/Fort Benton	4.84	Ice	3.51	4.18
Muddy Creek	3.56	Ice	3.34	3.45
Pondera Creek	4.33	Ice	1.24	2.79
Smith River	5.00	Ice	3.04	4.02
Sun River/Fort Shaw	4.00	3.82	3.80	3.87
Sun River/Vaughn	4.84	Ice	4.27	4.56
Teton River/Dutton	3.67	Ice	4.49	4.08
Teton River/Fort Benton	4.24	3.69	2.56	3.50
Mean	4.12	3.64	3.23	3.70

MACROINVERTEBRATE COMMUNITY STRUCTURE

Rationale

Macroinvertebrates comprise the energy link between periphyton and fish in Montana streams. Most organisms in this community of bottom dwellers are immature insects. As with the periphyton, macroinvertebrates are differentially tolerant to pollution, thereby allowing certain groups to be used as indicators. Another characteristic in common with the periphyton is their ability to integrate the effects of a variety of water quality constituents over time. Macroinvertebrate life cycles are considerably longer than those of periphyton organisms: up to three years as compared to just a day or two for diatoms. Consequently, they reflect water conditions over a much longer period of time than do the diatoms.

Of the common aquatic insects in Montana steams, three groups are generally indicators of waters with little organic pollution and ample dissolved oxygen. These are the stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera). Another group, the order of true flies (Diptera), has species that are either tolerant or intolerant of pollution. Two remaining orders, the bugs (Hemiptera) and beetles (Coleoptera), are generally considered tolerant of pollution.

On closer examination, a number of invertebrates are actually facultative or able to get along in both clean and polluted water (Weber, 1973). For a large number of Montana stream insects, water quality preferences simply are not known. Nevertheless, the relative abundance of organisms in various sensitivity groups is still a valid approximator of water quality conditions.

The number of macroinvertebrate genera and macroinvertebrate genus diversity are more concise and perhaps more valid estimators of macroinvertebrate community health. Wilhm (1970) reported clean waters to have from 11 to 54 species and Shannon-Weaver diversity values from 2.6 to over 4. Polluted streams, on the other hand, had diversity values less than 2 and frequently less than 1. From our experience, unpolluted streams with favorable dissolved oxygen levels, temperatures, and substrates generally produce a minimum of 10 genera. The number of macroinvertebrates collected per unit effort of sampling time is an indicator of productivity and habitat availability. It should be noted that genus diversities computed from samples of less than 100 organisms should be interpreted with caution (E.P.A., 1973).

Methods

The technique used for macroinvertebrate collection is a modification of the "unit-effort-traveling-kick" method described by Kinney *et al*. (In Press).

The objective is to sample each type of habitat at the designated site in a random fashion, and to apply a similar amount of effort at each station, except where bugs are scarce. Equipped with a long-handled D-frame aquatic net (Ward's 10W0620)*, the sampler works all the major habitat types--riffles, pools, submerged vegetation, etc.--by dislodging organisms with his feet and capturing them as they drift downstream. Research has shown this method to have better statistical reproducibility than artificial substrate and Surber samplers in semi-arid regions where the fauna tends to be patchy and sparse (Kinney, et al., In Press).

When an adequate number of insects has been collected, the sampler randomly selects 100 or more specimens from the net and places them in a small jar one-third full of water. Care is taken not to be biased by size of the organism. The jar is then filled with 95 percent ethanol, labeled, and returned to the lab for analysis. (A few drops of glycerine are added if extended storage is required.) Organisms were identified to genus wherever possible. Enumeration results were used to compute the percent relative abundance of major insect orders and pollution sensitivity groups (Weber, 1973). Shannon-Weaver diversity was calculated in the same fashion as it was for the diatoms (See "Periphyton Community Structure - Methods").

Results

Macroinvertebrate sampling of Northcentral Loop streams was difficult, owing to ice cover in the fall and high water in the spring. Some drainages experienced early spring floods and severe scouring. At such times, it was impossible to reach the main stream channel because the water was over the banks. A thorough sample never was collected from the Missouri River at Fort Benton because of naturally deep water. The only sample obtained from Lodge Creek was lost in transit. Macroinvertebrate community parameters are presented in Tables 22 through 26.

Interpretation

Streams in the Northwest Loop yielded diverse types of macroinvertebrate associations. For most, the aquatic fauna was dominated by four orders: Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddisflies), and Diptera (true flies). However, in the Dearborn, Smith, and Marias rivers, beetles (Order Coleoptera), dragonflies (Order Odonata), and true bugs (Order Hemiptera) were also important. Macroinvertebrates found in Pondera Creek were limited to beetles (Families Hydrophilidae and Elmidae), amphipod crustaceans (Genus Gammarus), and dragonflies (Genus Ishnura). Big Sandy Creek contained primarily amphipod crustaceans (Genus Hyalella).

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*Approximately 21.5 meshes per inch with 1 mm openings

With few exceptions, pollution tolerant taxa were never plentiful in streams of the Northwest Loop (Table 23). Facultative or uncategorized forms averaged 34 percent and pollution intolerant taxa dominated, averaging 60 percent of all organisms. However, mostly tolerant and facultative organisms were collected at four stations. These were Big Sandy and Pondera creeks, plus the Sun River below Vaughn and the Milk River at Havre.

Numbers of macroinvertebrate genera varied greatly from stream to stream and from season to season, the latter due in part to sampling conditions. Seven streams failed to produce at least 10 genera on any one visit. Five of these seven streams (Big Sandy, Milk River/Chinook, Milk River/Havre, Pondera, Sun River/Vaughn) had poor substrates and suffered from heavy silt loads. Two of these five streams, Big Sandy and Pondera creeks, commonly go dry in summer. The Teton River near Fort Benton had a favorable substrate but failed to produce a variety of taxa for unknown reasons. (The final stream, the Missouri River at Fort Benton, produced only a few taxa, possibly because of the difficulty in sampling.)

Macroinvertebrate genus diversity values (Table 25) ranged from a low of 0.54 in Big Sandy Creek to a high of 3.52 in the Dearborn River. Five stations had mean diversities greater than 2.6, indicating relatively clean water and an unstressed invertebrate association. These are, in descending order: Dearborn River, Sun River/Fort Shaw, Marias River/Loma, Muddy Creek, and Marias River/Shelby. Diversities between 2.0 and 2.6 were tallied for Missouri River/Cascade, Milk River/Havre, Smith River, Teton River/Dutton, and Milk River/Chinook. On the basis of this parameter, invertebrates in these streams are under some stress, perhaps resulting from silt, lack of a suitably diverse habitat, pollution, or a combination of these factors. The remaining five streams--Pondera Creek, Sun River/Vaughn, Teton River/Fort Benton, Missouri River/Fort Benton, and Big Sandy Creek--had values less than 2.0, indicating more severe stress. However, caution should be used because values for some of the streams were derived from only one sample. Also, some mean values were depressed owing to the scarcity of macroinvertebrates in spring. Table 26 best expresses the seasonal availability of macroinvertebrates in these streams.

Table 22. Mean percent relative abundance of major macroinvertebrate orders

Station	Plecoptera (Stoneflies)	Ephemeroptera (mayflies)	Trichoptera (caddisflies)	Diptera (true flies)	Coleoptera (beetles)	Hemiptera (true bugs)	Miscellaneous
Big Sandy	0	0	0	12.5	0	0	87.5
Dearborn River	31.1	13.9	29.2	13.1	11.8	.7	.2
Lodge Creek	DNA	DNA	DNA	DNA	DNA	DNA	DNA
Marias River/Loma	31.2	14.8	17.5	11.6	0	5.0	19.9
Marias River/Shelby	14.1	13.8	66.4	3.9	1.1	0	.7
Milk River/Chinook	0	31.7	63.5	0	1.9	0	2.9
Milk River/Havre	0	89.4	0	0	0	5.3	5.3
Missouri River/Cascade	2.3	34.5	26.0	34.4	2.8	0	0
Missouri River/Ft. Benton	4.4	84.4	4.4	6.8	0	0	0
Muddy Creek	23.6	17.9	26.8	19.4	0	1.2	11.7
Pondera Creek	0	0	0	0	60.0	0	40.0
Smith River	27.2	47.6	4.9	2.2	0	17.0	1.1
Sun River/Ft. Shaw	28.5	10.4	28.0	29.0	1.6	2.5	0
Sun River/Vaughn	5.0	58.2	18.4	0	0	0	18.4
Teton River/Dutton	2.3	14.7	73.9	8.0	0	0	1.1
Teton River/Ft. Benton	0	5.5	57.0	33.3	1.4	0	2.8
Mean	11.3	29.1	27.7	11.6	5.4	2.1	12.8

Table 23. Mean percent relative abundance of tolerant, facultative and intolerant macroinvertebrates

Station	Tolerant	Facultative or Unknown	Intolerant
Big Sandy Creek	0	100.0	0
Dearborn River	12.5	27.7	59.8
Lodge Creek	DNA	DNA	DNA
Marias River/Loma	0	41.1	58.9
Marias River/Shelby	1.2	13.9	84.9
Milk River/Chinook	1.9	4.8	93.3
Milk River/Havre	5.3	52.6	42.1
Missouri River/Cascade	2.8	40.7	56.5
Missouri River/Ft. Benton	0	6.7	93.3
Muddy Creek	.6	29.9	69.5
Pondera Creek	60.0	40.0	0
Smith River	.5	36.1	63.4
Sun River/Ft. Shaw	1.6	33.9	64.5
Sun River/Vaughn	2.6	63.4	34.0
Teton River/Dutton	0	4.6	95.4
Teton River/Ft. Benton	1.4	19.4	79.2
Mean	6.0	34.3	59.7

Table 24. Number of macroinvertebrate genera

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	2	--	--	2
Dearborn River	15	20	12	16
Lodge Creek	--	--	--	--
Marias River/Loma	11	--	7	9
Marias River/Shelby	18	--	12	15
Milk River/Chinook	9	--	--	9
Milk River/Havre	8	--	--	8
Missouri River/Cascade	13	--	10	12
Missouri River/Ft. Benton	7	--	--	7
Muddy Creek	12	--	8	10
Pondera Creek	4	--	--	4
Smith River	14	--	7	12
Sun River/Ft. Shaw	12	11	13	12
Sun River/Vaughn	7	--	3	5
Teton River/Dutton	11	--	--	11
Teton River/Ft. Benton	6	--	3	4
Mean	10	16	8	10

Table 25. Macroinvertebrate genus diversity ($\bar{d}$)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	0.54	--	--	0.54
Dearborn River	3.08	3.52	3.00	3.20
Lodge Creek	--	--	--	--
Marias River/Loma	2.96	--	2.72	2.84
Marias River/Shelby	2.63	--	2.60	2.62
Milk River/Chinook	2.02	--	--	2.02
Milk River/Havre	2.46	--	--	2.46
Missouri River/Cascade	2.63	--	2.40	2.52
Missouri River/Ft. Benton	1.22	--	--	1.22
Muddy Creek	3.02	--	2.49	2.75
Pondera Creek	1.92	--	--	1.92
Smith River	2.19	--	2.50	2.34
Sun River/Ft. Shaw	2.83	2.65	3.03	2.84
Sun River/Vaughn	2.36	--	.92	1.64
Teton River/Dutton	2.18	--	--	2.18
Teton River/Ft. Benton	1.54	--	1.58	1.56
Mean	2.24	3.08	2.36	2.34

Table 26. Number of macroinvertebrates collected per unit effort sample time

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	8	-	-	8
Dearborn River	134	140	72	115
Lodge Creek	Sample lost	-	-	-
Marias River/Loma	64	-	10	37
Marias River/Shelby	137	-	62	100
Milk River/Chinook	104	-	-	104
Milk River/Havre	19	-	-	19
Missouri River/Cascade	152	-	99	126
Missouri River/Ft. Benton	45	-		45
Muddy Creek	84	-	52	68
Pondera Creek	5	-	-	5
Smith River	93	-	15	54
Sun River/Ft. Shaw	133	39	67	80
Sun River/Vaughn	19	-	10	14
Teton River/Dutton	88	-	-	88
Teton River/Ft. Benton	36	-	3	20
Mean	75	90	43	65

SUMMARY AND CONCLUSIONS

This report presents data for 31 biologically-related water quality parameters at 16 stations over three seasons. There is clearly a need for consolidating this information so that stations in the Northcentral Loop can be compared at a glance and prioritized from the standpoint of management urgency. Two such consolidation schemes are presented. Both schemes incorporate mean values for 15 key indicators. The many missing data points for some stations necessitated selective utilization of only relatively complete sets of results. Use of the incomplete data (all fall data and spring data for certain parameters) would have inaccurately shifted overall averages for most stations and resulted in misleading comparisons. The 15 indicator parameters used in the two schemes are listed below, together with the seasons for which their means were determined.

	Parameter	Seasons
1.	Specific conductance (micromhos @ 25C)	Summer
2.	Total soluble inorganic nitrogen (mg/l)	Summer, Spring
3.	Total phosphorus (mg/l)	Summer, Spring
4.	Algal assay control maximum standing crop (mg/l)	Summer, Spring
5.	Chlorophyll *a* accrual (mg/m^2/day)	Summer
6.	Biomass accrual (mg/m^2/day)	Summer
7.	Autotrophic Index (Biomass accrual/Chlorophyll *a* accrual)	Summer
8.	Percent relative abundance *Achnanthes* species	Summer, Spring
9.	Percent relative abundance *Nitzschia* species	Summer, Spring
10.	Number of diatom species	Summer, Spring
11.	Diatom species diversity ($\bar{d}$)	Summer, Spring
12.	Percent relative abundance intolerant macroinvertebrates	Summer
13.	Number of macroinvertebrate genera	Summer
14.	Macroinvertebrate genus diversity ($\bar{d}$)	Summer
15.	Number of macroinvertebrates collected per unit effort sample time	Summer

In Scheme A, the assumption is made that the least amount of nutrients and production, whatever the cause, is the most desirable case. All mean values are listed in order from lowest to highest for each indicator. Indicators where the highest value is presumed to reflect the best water quality are numbers 8 and 10-15 in the preceding list. Indicators where the lowest value is presumed to reflect the best water quality are numbers 1-7 and 9. The station with the extreme (highest or lowest) value indicating the poorest water quality is given a ranking of one for that indicator. The station with the second highest or lowest value indicating the second poorest water quality is then given a rank of two, and so on until all 16 stations are ranked for that indicator. When all 16 stations have been ranked for each of the 15 indicators, ranks for each station are totalled and divided by the number of indicators measured at that station. The resulting composite rank may be used to assess relative biological health among the 16 stations of the Northcentral Loop.

Scheme B presumes that moderate amounts of nutrient enrichment are desirable and that too much (eutrophication) or too little (natural sterility or man-caused toxicity) production is not good. Scheme B differs from Scheme A in that production-related indicators (numbers 2-6) are ranked according to their divergence from the median value, which is considered representative of a moderately enriched stream in northcentral Montana. In other words, the station with the median value is given a ranking of 16 and the value most distant from the median is given a ranking of 1. The remaining indicators, which are principally indicators of water quality (#1, 7, 8, 9, and 12) and community stability and diversity (#10, 11, 13, 14, and 15) are ranked as they were under System A.

Composite rankings under the two schemes, arranged in order from highest (best quality) to lowest (worst quality), are presented in Table 26.

Table 26. Composite ranking of stations in the Northcentral Loop
Best possible rank = 15; Worst possible rank = 1

	SCHEME A		SCHEME B	
Water Quality	Station	Rank	Station	Rank
Good	Dearborn River	11.2	Marias River/Loma	8.7
	Missouri River/Cascade	10.8	Smith River	8.5
	Missouri River/Ft. Benton	9.2	Sun River/Vaughn	8.5
	Smith River	9.1	Dearborn River	8.4
	Sun River/Ft. Shaw	8.8	Lodge Creek	8.4
	Teton River/Dutton	7.7	Missouri River/Cascade	8.2
	Marias River/Shelby	7.5	Missouri River/Ft. Benton	7.9
Fair	Marias River/Loma	7.4	Teton River/Ft. Benton	7.8
	Sun River/Vaughn	7.4	Marias River/Shelby	7.7
	Milk River/Chinook	7.1	Milk River/Chinook	7.7
	Lodge Creek	6.9	Milk River/Havre	7.6
	Milk River/Havre	6.8	Sun River/Vaughn	7.0
	Teton River/Ft. Benton	6.4	Teton River/Dutton	6.9
	Muddy Creek	5.3	Muddy Creek	6.0
Poor	Big Sandy Creek	3.6	Big Sandy Creek	5.5
	Pondera Creek	2.7	Pondera Creek	3.4

Under Scheme A, only two streams had good water quality relative to other northcentral Montana streams on the basis of biological conditions. These were the Dearborn River and the Missouri River at Cascade. Streams rated as poor were Muddy, Big Sandy, and Pondera creeks. The other eleven streams were arbitrarily categorized as fair, with many of these having nearly equal scores.

The three poorest streams all suffer from excessive silt loads due to accelerated stream bank erosion and poor irrigation practices (Water Quality Bureau, 1974, 1975). Nutrient enrichment is also very great, primarily as a result of agricultural runoff. It is suspected that municipal discharges may contribute some nutrients to Pondera and Big Sandy creeks. Nearly all of the "fair" streams suffer from some degree of non-point source pollution and many receive municipal discharges as well.

Scheme B resulted in some major shifts from the arrangement in Scheme A. Only the three poorest streams remained in the same relative position. The remaining thirteen stations had a very narrow range of scores and, as a result, it was impossible to clearly distinguish "good" streams from "fair" ones. Thus, under Scheme B, most of the northcentral Montana streams sampled can be considered to be at least moderately enriched and productive.

On the basis of these composite rating systems, it may be concluded that nearly all of the Northcentral Loop streams are affected by some degree of biologically debilitating water quality degradation. Many streams of the loop receive municipal discharges at one point or another. Only three discharges are in need of upgrading. These affect the upper Marias River (Valier), the Milk River (Chinook), and Big Sandy Creek (Big Sandy), but probably have no more than minimal impact for a short distance (R. Braico, personal communication). Therefore, the authors conclude that most of the serious water quality problems in streams of the Northcentral Loop result from non-point pollution. Some of this is due to the natural hyrdologic characteristics of lowland streams: large silt and nutrient accumulations caused by natural erosion, sedimentation, and runoff. Howver, it is known that natural pollution has been aggravated by man's activities in this area. Practices contributing to water quality degradation in northcentral Montana streams include overgrazing, dewatering, irrigation returns, channel disturbances, and less commonly, oil spills, solid waste disposal and acid mine drainage. Consequently, achievement of a reasonable level of biological improvement will require better land use practices.

Conditions at these 16 stations probably can be considered fairly representative of overall water quality in the lowland portions of northcentral Montana. This assumption is based on the fact that land and water uses in this region are overwhelmingly agricultural and very uniform. It is thus expected that water quality elsewhere in the region would fall within the range of that encountered during this study.

The quality of upland tributaries in northcentral Montana, particularly those originating in the Rocky Mountains, was not documented in this study. However, it is probably safe to assume that generally they have healthier biological conditions than those at the monitoring stations of the Northcentral Loop.

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APPENDICES

Appendix A. Streams and stations in the Montana biological monitoring network

SOUTHWEST LOOP

Completion Year: 1978

Beaverhead River at Twin Bridges
Big Hole River near Twin Bridges
Boulder River below Boulder
Clark Fork River at Deer Lodge
East Gallatin River at Thompson Creek
Grasshopper Creek near mouth
Jefferson River near Three Forks
Madison River near Three Forks
Muddy Creek at mouth near Dell
Prickly Pear Creek above Lake Helena
Prickly Pear Creek at East Helena
Red Rock River above Lima Reservoir
Ruby River near Twin Bridges
Sheep Creek above Muddy Creek
Silver Bow Creek below Warm Springs Ponds
West Fork Madison River near mouth
West Gallatin River at Central Park

NORTHCENTRAL LOOP

Completion Year: 1978

Big Sandy Creek near mouth
Dearborn River near mouth
Lodge Creek near Chinook
Marias River at Loma
Marias River at Shelby WTP intake
Milk River above Chinook
Milk River at Havre WTP intake
Missouri River at Fort Benton WTP intake
Missouri River at Cascade
Muddy Creek near mouth at Vaughn
Pondera Creek near mouth
Smith River near Ulm
Sun River below Vaughn
Sun River near Fort Shaw
Teton River at Loma
Teton River north of Dutton

NORTHWEST LOOP

Completion Year: 1979

Bitterroot River at Maclay Bridge
Clark Fork River at Huson RR Bridge
Clark Fork River below Bonner Dam
Clearwater River at mouth
Fisher River at mouth
Flathead River at mouth

Appendix A. (Continued)

NORTHWEST LOOP (Continued)

- Flathead River above Flathead Lake
- Lake Creek at mouth
- Little Blackfoot River at Avon
- Middle Fork Flathead River near mouth
- North Fork Flathead River at mouth
- Swift Current Creek near Babb
- Stillwater River near Kalispell
- Swan River near mouth
- Whitefish River near Kalispell
- Yaak River at mouth

NORTHEAST LOOP Completion Year: 1980

- Beaver Creek near Saco
- Box Elder Creek near Winnett
- Big Muddy Creek near Culbertson
- Big Spring Creek below Lewistown
- Judith River near Danvers
- Judith River near Utica
- Milk River at Nashua
- Missouri River at Culbertson
- Musselshell River at Mosby
- Poplar River at mouth
- Redwater River near mouth
- Redwater River at Circle
- Wolf Creek at Denton

SOUTHEAST LOOP Completion Year: 1981

- Armell's Creek near Colstrip
- Beaver Creek at Wibaux
- Bighorn River at Bighorn
- Clark's Fork River at Laurel
- Little Missouri River at Capitol
- Musselshell River at Delphia
- Musselshell River at Bundy
- Powder River near mouth
- Powder River at Broadus
- Rosebud Creek near Colstrip
- Shields River near mouth
- Tongue River at Miles City
- Tongue River at Ashland
- Yellowstone River at Glendive
- Yellowstone River at Huntley Dam
- Yellowstone River at U.S.G.S. Station in Billings
- Yellowstone River at Livingston

Appendix B. Phosphate (PO_4 as P in mg/l)

Station	Summer	Fall	Spring	Mean*
Big Sandy Creek	0.008	ICE	0.263	0.136
Dearborn River	$<$0.001	0.001	0.009	0.003
Lodge Creek	0.170	ICE	0.130	0.150
Marias River/Loma	0.001	ICE	0.062	0.032
Marias River/Shelby	0.007	ICE	0.127	0.067
Milk River/Chinook	0.073	ICE	0.252	0.162
Milk River/Havre	0.001	ICE	0.238	0.120
Missouri River/Cascade	0.006	0.029	0.022	0.019
Missouri River/Fort Benton	0.009	ICE	0.054	0.032
Muddy Creek	0.002	ICE	0.104	0.053
Pondera Creek	0.001	ICE	0.203	0.102
Smith River	0.002	ICE	0.113	0.058
Sun River/Ft. Shaw	0.001	0.001	0.006	0.004
Sun River/Vaughn	0.005	ICE	0.037	0.021
Teton River/Dutton	0.003	0.004	0.063	0.023
Teton River/Fort Benton	0.001	0.002	0.085	0.029
Mean	0.018	0.007	0.110	0.057

*Assumes concentrations less than 0.001 equal zero

Appendix C. Total phosphorus (P in mg/l)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	0.039	ICE	0.590	0.314
Dearborn River	0.003	0.005	0.015	0.008
Lodge Creek	0.220	ICE	0.335	0.278
Marias River/Loma	0.012	ICE	0.959	0.486
Marias River/Shelby	0.039	ICE	0.403	0.221
Milk River/Chinook	0.110	ICE	1.670	0.890
Milk River/Havre	0.014	ICE	0.888	0.451
Missouri River/Cascade	0.018	0.040	0.043	0.034
Missouri River/Fort Benton	0.059	ICE	0.233	0.146
Muddy Creek	0.037	ICE	0.526	0.282
Pondera Creek	0.019	ICE	3.380	1.700
Smith River	0.024	ICE	0.436	0.230
Sun River/Fort Shaw	0.018	0.008	0.022	0.016
Sun River/Vaughn	0.045	ICE	0.123	0.084
Teton River/Dutton	0.023	0.020	0.366	0.136
Teton River/Fort Benton	0.013	0.020	0.850	0.294
Mean	0.043	0.019	0.677	0.314

Appendix D. Nitrate plus nitrite ($NO_3 + NO_2$ as N in mg/l)

Station	Summer	Fall	Spring	Mean*
Big Sandy Creek	<0.01	ICE	0.30	0.15
Dearborn River	<0.01	<0.01	0.06	0.02
Lodge Creek	<0.01	ICE	0.70	0.35
Marias River/Loma	<0.01	ICE	0.60	0.30
Marias River/Shelby	<0.01	ICE	0.80	0.40
Milk River/Chinook	<0.01	ICE	0.30	0.15
Milk River/Havre	0.10	ICE	0.30	0.20
Missouri River/Cascade	<0.01	0.24	0.15	0.13
Missouri River/Fort Benton	<0.01	ICE	0.40	0.20
Muddy Creek	>1.00**	ICE	5.70	>3.35
Pondera Creek	<0.01	ICE	0.70	0.35
Smith River	<0.01	ICE	0.16	0.08
Sun River/Fort Shaw	0.51	0.91	0.14	0.52
Sun River/Vaughn	0.84	ICE	0.73	0.78
Teton River/Dutton	<0.01	0.90	0.30	0.40
Teton River/Fort Benton	<0.01	0.70	0.60	0.43
Mean*	>0.15	0.55	0.75	>.46

*Assumes concentrations less than 0.01 equal zero.

**Insufficient sample. Actual value not determined.

Appendix E. Ammonia (NH_3 as N in mg/l)

Station	Summer	Fall	Spring	Mean*
Big Sandy Creek	0.01	ICE	0.21	0.11
Dearborn River	<0.01	0.02	0.01	0.01
Lodge Creek	0.06	ICE	0.16	0.11
Marias River/Loma	<0.01	ICE	0.05	0.02
Marias River/Shelby	0.01	ICE	0.12	0.06
Milk River/Chinook	<0.01	ICE	0.27	0.14
Milk River/Havre	0.01	ICE	0.20	0.11
Missouri River/Cascade	<0.01	0.02	0.01	0.02
Missouri River/Fort Benton	<0.01	ICE	0.04	0.02
Muddy Creek	<0.01	ICE	0.08	0.04
Pondera Creek	0.04	ICE	0.12	0.08
Smith River	<0.01	ICE	0.05	0.02
Sun River/Fort Shaw	0.01	0.16	0.01	0.06
Sun River/Vaughn	0.02	ICE	0.04	0.03
Teton River/Dutton	<0.01	0.06	0.06	0.04
Teton River/Fort Benton	<0.01	0.05	0.06	0.04
Mean*	0.01	0.06	0.09	0.05

*Assumes concentrations less than 0.01 equal zero

Appendix F. Kjeldahl nitrogen (N in mg/l)

Station	Summer	Fall	Spring	Mean
Big Sandy Creek	0.76	ICE	2.80	1.78
Dearborn River	0.17	0.08	0.20	0.15
Lodge Creek	0.64	ICE	1.50	1.07
Marias River/Loma	0.26	ICE	3.45	1.86
Marias River/Shelby	0.38	ICE	1.68	1.03
Milk River/Chinook	0.50	ICE	4.00	2.25
Milk River/Havre	0.35	ICE	1.06	0.70
Missouri River/Cascade	0.30	0.23	0.25	0.26
Missouri River/Fort Benton	0.63	ICE	0.51	0.57
Muddy Creek	0.33	ICE	2.5	1.42
Pondera Creek	0.67	ICE	5.95	3.31
Smith River	0.31	ICE	1.73	1.02
Sun River/Fort Shaw	0.30	0.17	0.21	0.26
Sun River/Vaughn	0.54	ICE	1.15	0.84
Teton River/Dutton	0.33	0.32	1.45	0.70
Teton River/Fort Benton	0.30	0.30	2.90	1.17
Mean	0.42	0.22	1.96	1.06

Appendix G. Water quality requirements of major diatom species

CODE	SPECIES	WATER QUALITY REQUIREMENTS	REFERENCE(S)
ACMI	*Achnanthes minutissima* Kutz.	Optimum pH 7.5-7.8; "high oxygen concentrations"	Lowe, 1974
ACMO	*Achnanthes microcephala* (Kutz.) Grun.	Optimum pH 6.4-6.6; tolerates some salt	Lowe, 1974
AMPE	*Amphora perpusilla* (Grun.) Grun.	Alkaliphil (pH>7); epilithic (fixed, solid surfaces)	Patrick and Reimer, 1975
APPE	*Amphipleura pellucida* Kutz.	Optimum pH 7.3; eutrophic; hard to slightly brackish water	Lowe, 1974, Patrick and Reimer, 1966
CMAF	*Cymbella affinis* Kutz.	Optimum pH 7.8-8.5; summer form; tolerates some salt	Lowe, 1974
CMMC	*Cymbella microcephala* Grun.	Optimum pH 7.2; well aerated habitats; tolerates some salt	Lowe, 1974, Patrick and Reimer, 1975
CMMN	*Cymbella minuta* Hilse ex Rabh.	Optimum pH 7.7-7.8; widespread; tolerates some salt	Lowe, 1974, Patrick and Reimer, 1975
COPL	*Cocconeis placentula* Ehr.	Optimum pH 8; epiphytic; tolerates some salt	Lowe, 1974
CYME	*Cyclotella meneghiniana* Kutz.	Optimum pH 8.0-8.5; halophilous; fall maximum	Lowe, 1974
DITE	*Diatoma tenue* Ag.	Optimum pH 7.4-7.8; halophilous; slightly salty water	Lowe, 1974 Patrick and Reimer, 1966
DIVU	*Diatoma vulgare* Bory	Optimum pH 8.2; eutrophic; winter dominant; cool, flowing water	Lowe, 1974, Patrick and Reimer, 1966
DPPU	*Diploneis puella* (Schum.) Cl.	Hard to slightly salty water	Patrick and Reimer, 1966

Appendix G. (Continued)

CODE	SPECIES	WATER QUALITY REQUIREMENTS	REFERENCE(
ENOR	*Entomoneis ornata* (J.W. Bail.) Reim.	Freshwater (<500 mg/l Cl); mud bottoms	Patrick an Reimer, 1
EPSO	*Epithemia sorex* Kutz.	Optimum pH 8.3-8.5; eutrophic; tolerates some salt	Lowe, 1974
FRVA	*Fragilaria vaucheriae* (Kutz.) Peters	Optimum pH 6.5-6.9; eutrophic; o-15°C	Lowe, 1974
GOOL	*Gomphonema olivaceum* (Lyngb.) Kutz.	pH range 6.4-9.0; eutrophic; winter or spring form	Lowe, 1974
GOTE	*Gomphonema tenellum* Kutz.	Unknown	
NAMI	*Navicula minima* Grun.	Optimum pH 7.5-8.0; eutrophic; tolerates some salt	Lowe, 1974
NAPE	*Navicula perparva* Hust.	Optimum pH 8.2-8.4; obligate nitrogen heterotroph	Schoeman,
NARA	*Navicula radiosa* Kutz.	Optimum pH 6.5-7.0; water of low mineral content	Lowe, 1974. Patrick a Reimer, 1
NATR	*Navicula tripunctata* (O.F. Mull.) Bory	Optimum pH 8.3; eutrophic; tolerates some salt	Lowe, 1974
NIAC	*Nitzschia acicularis* W. Sm.	Optimum pH 8.3-8.5; eutrophic; tolerates some salt	Lowe, 1974
NIDI	*Nitzschia dissipata* (Kutz.) Grun.	Optimum pH 8.0; eutrophic; tolerates some salt	Lowe, 1974
NIFR	*Nitzschia frustulum* Kutz.	pH range 6.2-8.6; eutrophic; tolerates broad range of salt	Lowe, 1974
NIMI	*Nitzschia microcephala* Grun.	Optimum pH 8.3-8.5; stimulated by small amounts of salt	Lowe, 1974
NIPA	*Nitzschia palea* (Kutz.) W. Sm.	Optimum pH 8.4; eutrophic; 0-30°C	Lowe, 1974
RHCU	*Rhoicosphenia curvata* (Kutz.) Grun. ex Rabh.	Optimum pH > 8.0; eutrophic; epiphytic; flowing water	Lowe, 1974

endix G. (Continued)

E	SPECIES	WATER QUALITY REQUIREMENTS	REFERENCE(S)
A	*Stephanodiscus hantzschii* Grun.	Optimum pH 8.2; eutrophic; euplanktonic; spring form	Lowe, 1974
U	*Stephanodiscus subtilis* Van Goor	Unknown	
E	*Synedra demerarae* Grun.	Unknown	
U	*Synedra pulchella* Ralfs ex Kutz.	Water of high conductivity and mineral content	Patrick and Reimer, 1966
U	*Synedra rumpens* Kutz.	pH range 6.0-9.0; tolerates some salt; widely distributed	Lowe, 1974, Patrick and Reimer, 1966
L	*Synedra ulna* (Nitz.) Ehr.	pH range 5.7-9.0; eutrophic; tolerates some salt	Lowe, 1974