SUPPORT OF AQUATIC LIFE USES IN THE SHIELDS RIVER BASED ON THE STRUCTURE AND COMPOSITION OF THE BENTHIC ALGAE COMMUNITY

Prepared for:

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DEQ Contract No. 200012-10**

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March 16, 2004

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Summary

During the 2003 field season, six periphyton samples were collected from four sites on the Shields River for the purpose of assessing whether this river is water-quality limited and in need of TMDLs. Four of the samples were grab samples of conspicuous macroalgae and were collected for identification only. Two samples from two sites (Johnstone's and Near Mouth) were composite samples collected following MDEQ standard operating procedures, processed and analyzed using standard methods for periphyton, and evaluated following modified USEPA rapid bioassessment protocols for wadeable streams.

Since the Shields River begins in a mountain ecoregion and flows for most of its length through a prairie ecoregion, diatom metrics generated from the two standard TMDL samples were compared to criteria developed for both mountain streams and plains streams.

Diatom metrics indicate good biological integrity, minor impairment, and full support of aquatic life uses at both sites where composite samples were collected in 2003. An assessment of minor impairment resulted from a comparison of metrics to biocriteria for both mountain and plains streams. Diatoms dominated the periphyton at both sites in September. *Cladophora* was a co-dominant near the mouth but was missing at Johnstone's.

The only apparent deviation from excellent biological integrity at Johnstone's and near the mouth was a few abnormal diatom valves at each station and slightly elevated percentages of *Achnanthes minutissimum*, which indicates chemical, physical, or biological disturbance. The stress causing this disturbance and the abnormal diatom valves may be natural in origin. The two sites were virtually identical in terms of diatom floristics and ecological conditions.

The majority of diatoms at Johnstone's and near the mouth were non-motile nitrogen autotrophs that exert a continuously high demand for dissolved oxygen. The majority of diatoms at both sites also indicate fresh, alkaline waters with only a small amount of BOD loading. Most diatoms at Johnstone's indicate eutrophic waters that are rich in inorganic nutrients. The modal category for trophic state near the mouth was "variable". Diatoms in this category can prosper under a wide range of nutrient regimes from oligotrophic to hypereutrophic.

Grab samples of macro-algae indicate cool, nutrient-rich waters at Coal Camp Road in September and Elk Creek Road in August. The filamentous green alga *Cladophora* was abundant at the lowermost bridge in July and August, as well as in September.

Introduction

This report evaluates the biological integrity¹, support of aquatic life uses, and probable causes of stress or impairment to aquatic communities in the Shields River near Livingston, Montana. The purpose of this report is to provide information that will help the State of Montana determine whether the Shields River is water-quality limited and in need of TMDLs. Previous periphyton reports have examined biological integrity in the upper reaches of the Shields River (Bahls 2001b) and in tributaries to the Shields River (Bahls 2000, 2001a).

The federal Clean Water Act directs states to develop water pollution control plans (Total Maximum Daily Loads or TMDLs) that set limits on pollution loading to water-quality limited waters. Water-quality limited waters are lakes and stream segments that do not meet water-quality standards, that is, that do not fully support their beneficial uses. The Clean Water Act and USEPA regulations require each state to (1) identify waters that are water-quality limited, (2) prioritize and target waters for TMDLs, and (3) develop TMDL plans to attain and maintain water-quality standards for all water-quality limited waters.

Evaluation of aquatic life use support in this report is based on the species composition and structure of periphyton (benthic algae, phytobenthos) communities at sites that were sampled in 2003. Periphyton is a diverse assortment of simple photosynthetic organisms called algae that live attached to or in close proximity of the stream bottom. Some algae form long filaments or large colonies that are conspicuous to the unaided eye. But most algae, including the ubiquitous diatoms, can be seen and identified only with the aid of a microscope. The periphyton community is a basic biological component of all aquatic ecosystems. Periphyton accounts for much of the primary production and biological diversity in Montana streams (Bahls et al. 1992). Plafkin et al. (1989) and Barbour et al. (1999) list several advantages of using periphyton in biological assessments.

¹ *Biological integrity* is defined as “the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region” (Karr and Dudley 1981).

Project Area and Sampling Sites

The project area is located in northern Park County in south central Montana. The Shields River is a tributary of the Yellowstone River. It heads in the Bridger and Crazy Mountains (maximum elevation 11,214 feet) and flows west and south for about 40 miles to where it enters the Yellowstone River a few miles downstream from the city of Livingston. The headwaters of the Shields River are in the Middle Rockies Ecoregion, while some tributaries and the mainstem of the Shields River flow mostly through the Northwestern Great Plains Ecoregion (USEPA 2000). All of the sampling sites are in the Northwestern Great Plains Ecoregion.

Periphyton samples were collected at 4 sites (Table 1). Elevations at the sampling sites range from about 5,400 feet above mean sea level at the upper site (Coal Camp Road) to about 4,400 feet at the lower site near the mouth. The surface geology of the watershed consists of a matrix of Paleocene continental deposits with granitic intrusives of Tertiary age (Renfro and Feray 1972). Vegetation in the study area is alpine tundra at the highest elevations, mixed conifer forest at intermediate elevations, and mixed grassland along the lower Shields River (USDA 1976). Land use is primarily livestock grazing and hay production, with logging and recreation in the headwaters. The Shields River is classified B-1 in the Montana Surface Water Quality Standards.

Methods

Two of the periphyton samples were collected following standard operating procedures of the MDEQ Planning, Prevention, and Assistance Division. Using appropriate tools, micro-algae were scraped, brushed, or sucked from natural substrates in proportion to the importance of those substrates at each study site. Macro-algae were then picked by hand in proportion to their abundance at the site. All collections of micro-algae and macro-algae were pooled into a common container and preserved with Lugol's (IKI) solution. Four of the samples were grab samples of conspicuous macro-algae and were collected for the purpose of identification only.

The samples were examined to estimate the relative abundance and rank by biovolume of diatoms and genera of soft (non-diatom) algae according to the method described in Bahls (1993). Soft algae were identified using Smith (1950), Prescott (1962, 1978), John et al. (2002), and Wehr and Sheath (2003). These books also served as references on the ecology of the soft algae, along with Palmer (1969, 1977).

After the identification of soft algae, the two composite samples were cleaned of organic matter using sulfuric acid, potassium dichromate, and 3% hydrogen peroxide. Then, permanent diatom slides were prepared using Naphrax™, a high refractive index mounting medium, following *Standard Methods for the Examination of Water and Wastewater* (APHA 1998). Approximately 450 diatom cells (900 valves) were counted at random and identified to species. The following were the main taxonomic references for the diatoms: Krammer and Lange-Bertalot 1986, 1988, 1991a, 1991b; Lange-Bertalot 2001; Krammer 2002. Conventions for diatom nomenclature followed those adopted by the Integrated Taxonomic Information System (<http://www.itis.usda.gov>). For taxa not included in ITIS, naming conventions followed those adopted by the Academy of Natural Sciences for USGS NAWQA samples (Morales and Potapova 2000). Van Dam et al. (1994) was the main ecological reference for the diatoms.

The diatom proportional counts were used to generate an array of diatom association metrics. A metric is a characteristic of the biota that changes in some predictable way with increased human influence (Barbour et al. 1999). Diatoms are particularly useful in generating metrics because there is a wealth of information available in the literature regarding the pollution tolerances and water quality preferences of common diatom species (e.g., Lowe 1974, Beaver 1981, Lange-Bertalot 1996, Van Dam et al. 1994).

Values for selected metrics were compared to biocriteria (numeric thresholds) developed for streams in the Rocky Mountains and Great Plains ecoregions of Montana (Tables 2 and 3). These criteria are based on the distribution of metric values measured in least-impaired reference streams (Bahls et al. 1992) and metric values measured in streams that are known to be impaired

by various sources and causes of pollution (Bahls 1993). The biocriteria in Tables 2 and 3 are valid only for samples collected during the summer field season (June 21-September 21).

The biocriteria in Tables 2 and 3 distinguish among four levels of stress or impairment and three levels of aquatic life use support: (1) no impairment or only minor impairment (full support); (2) moderate impairment (partial support); and (3) severe impairment (nonsupport). These impairment levels correspond to excellent, good, fair, and poor biological integrity, respectively.

Quality Assurance

Several steps were taken to assure that the study results are accurate and reproducible. Upon receipt of the samples, station and sample attribute data were recorded in the Montana Diatom Database and the samples were assigned a unique number. One of the sites that was sampled in 2003 (Johnstone's) was also sampled in 2000 (Bahls 2001b).

Sample observations and analyses of soft (non-diatom) algae were recorded in a lab notebook along with information on the sample label. Portions of the two composite samples were used to make duplicate diatom slides. The slide used for the diatom proportional count will be deposited in the Montana Diatom Collection at the University of Montana Herbarium in Missoula. The duplicate slide will be retained in the offices of *Hannaea* in Helena. Diatom proportional counts have been entered into the Montana Diatom Database.

Results and Discussion

Results are presented in Tables 4, 5 and 6, which are located near the end of this report following the references section. Appendix A consists of two diatom reports, one for each composite sample. Each diatom report contains an alphabetical list of diatom species and their percent abundances, and values for 65 diatom metrics and ecological attributes (Table 7).

Sample Notes

Coal Camp Road (9/30/03). This sample consisted of semi-consolidated olive-green masses of what appeared to be filamentous algae. Upon closer inspection under the microscope, these masses proved to be composed primarily of:

1. *Melosira varians*. This centric diatom forms long chains and indicates eutrophic conditions, i.e., waters rich in inorganic nutrients (nitrogen and phosphorus).
2. *Oscillatoria* sp. This cyanobacterium (blue-green alga) grows in short filaments and certain species may also indicate elevated nutrient concentrations.
3. *Vaucheria* sp. This yellow-green alga forms felt-like mats in springs and spring brooks and indicates steady flows of cool water.
4. *Mougeotia* sp. This green alga forms un-branched filaments and also prefers cool water.

Besides *Melosira varians*, other diatoms were also very abundant in this sample. Diatoms dominated the sample, overall.

Elk Creek Road (8/13/03). This sample consisted of a large dark brown mass of very fine filamentous algae, which proved to be *Tribonema*, a yellow-green alga. *Tribonema* grows in long, un-branched filaments composed of cylindrical cells attached end-to-end. *Tribonema* generally prefers cool waters.

Near Mouth (7/10/03 and 8/1/03). Macroscopically, the sample collected here on July 10 appeared as a large gray-brown mass of filamentous algae. Microscopically, the mass proved to be a senescent colony of *Cladophora*, a common green alga that often becomes a nuisance in nutrient-rich lakes and streams of temperate regions around the world. The gray-brown color indicates older filaments that have been colonized by epiphytic diatoms, in this case a species of *Diatoma* (*Diatoma tenuis*).

The sample collected here on the first of August also consisted of a large clump of old, coarse, senescent filaments of *Cladophora*, also covered with epiphytic diatoms, but this time a species of *Cocconeis* (*Cocconeis pediculus*). *Cladophora* is an attached alga with branched filaments that may grow to several feet in length. *Cladophora* typically indicates elevated concentrations of bio-available phosphorus.

Non-Diatom Algae (Table 4)

Both of the standard composite samples that were collected in September 2003 were dominated by diatoms and contained healthy numbers of non-diatom genera. *Cladophora* was also a dominant near the mouth, but it was missing from the sample collected at Johnstone's (Table 4). The *Cladophora* collected near the mouth in September was senescent, as it was here in July and August (see above). Next to diatoms, green algae accounted for the most diversity and the most biomass at both stations. An occasional cyanobacterium was present at both sites. The non-diatom algal assemblages at Johnstone's and near the mouth were very similar.

Diatoms (Table 5)

Five of the major diatom species in the Shields River are sensitive to organic pollution (pollution tolerance class 3). One of these (*Cymbella excisa*) was most abundant at Johnstone's and two (*Encyonopsis* spp.) were most abundant near the mouth. Two of the sensitive species (*Achnanthes minutissimum* and *Denticula kuetzingii*) were about equally abundant at both sites (Table 5). Two of the major diatom species are somewhat tolerant of organic pollution (pollution tolerance class 2). One of these was most abundant at Johnstone's and the other was most abundant near the mouth. None of the major diatom species in the 2003 samples from the Shields River are most tolerant of organic pollution (pollution tolerance class 1).

Diatom metrics indicate good biological integrity, minor impairment, and full support of aquatic life uses at both sites where composite samples were collected in 2003 (Table 5). The only apparent deviation from excellent biological integrity was a few abnormal diatom valves at each station and slightly elevated percentages of *Achnanthes minutissimum*, which indicates chemical, physical, or biological disturbance. The stress causing this disturbance and the abnormal diatom valves may be natural in origin. An assessment of minor impairment resulted from a comparison of metrics to criteria for mountain streams and criteria for plains streams. The two sites were virtually identical in terms of diatom floristics and ecological conditions.

Modal Categories (Table 6)

Several ecological attributes were selected from Table 7 and modal categories of these attributes were extracted from the appendix to characterize water quality tendencies at the two sites (Table 6). Modal categories for the selected attributes were nearly identical for the two sites. The majority of diatoms at both sites were non-motile nitrogen autotrophs that exert a continuously high demand for dissolved oxygen. Nitrogen autotrophs require inorganic nitrogen (nitrates and ammonia) as nutrients. The majority of diatoms at both sites also indicate fresh, alkaline waters with only a small amount of BOD loading. Most diatoms at Johnstone's indicate eutrophic waters that are rich in inorganic nutrients. The modal category for trophic state near the mouth was "variable". Diatoms in this category can prosper under a wide range of nutrient regimes from oligotrophic to hypereutrophic.

References

- APHA. 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition. American Public Health Association, Washington, D.C.
- Bahls, L.L. 1979. Benthic diatom diversity as a measure of water quality. *Proceedings of the Montana Academy of Sciences* 38:1-6.
- Bahls, L.L. 1993. *Periphyton Bioassessment Methods for Montana Streams (revised)*. Montana Department of Health and Environmental Sciences, Helena.
- Bahls, L.L. 2000. Biological Integrity of Cottonwood Creek and Rock Creek near Clyde Park, Montana Based on the Composition and Structure of the Benthic Algae Community. Prepared for the Montana Department of Environmental Quality, Helena.
- Bahls, L.L. 2001a. Biological Integrity of Antelope Creek and Potter Creek Based on the Composition and Structure of the Benthic Algae Community. Prepared for the Montana Department of Environmental Quality, Helena.
- Bahls, L.L. 2001b. Biological Integrity of the Shields River near Wilsall, Montana Based on the Composition and Structure of the Benthic Algae Community. Prepared for the Montana Department of Environmental Quality, Helena.
- Bahls, L.L., Bob Bukantis, and Steve Tralles. 1992. *Benchmark Biology of Montana Reference Streams*. Montana Department of Health and Environmental Sciences, Helena.
- Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use In Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*. Second Edition. EPA/841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

- Beaver, Janet. 1981. Apparent Ecological Characteristics of Some Common Freshwater Diatoms. Ontario Ministry of The Environment, Technical Support Section, Don Mills, Ontario.
- Johansen, J.R. 1999. Diatoms of Aerial Habitats. Chapter 12 in Stoermer, E.F., and J.P. Smol (eds.), *The Diatoms: Applications For the Environmental and Earth Sciences*, Cambridge University Press, New York.
- John, D.M., B.A. Whitton, and A.J. Brook (eds.). 2002. *The Freshwater Algal Flora of the British Isles: An Identification Guide to Freshwater and Terrestrial Algae*. Cambridge University
- Karr, J.R., and D.R. Dudley. 1981. Ecological perspectives on water quality goals. *Environmental Management* 5:55-69.
- Krammer, Kurt. 2002. *Cymbella*. Volume 3 in *Diatoms of Europe*, Horst Lange-Bertalot, ed. A.R.G. Gantner Verlag K.G., Germany.
- Krammer, K., and H. Lange-Bertalot. 1986. Bacillariophyceae, Part 2, Volume 1: Naviculaceae. In Ettl, H., J Gerloff, H. Heynig, and D. Mollenhauer (eds.), *Freshwater Flora of Middle Europe*. Gustav Fischer Publisher, New York.
- Krammer, K., and H. Lange-Bertalot. 1988. Bacillariophyceae, Part 2, Volume 2: Bacillariaceae, Epithemiaceae, Surirellaceae. In Ettl, H., J. Gerloff, H. Heynig, and D. Mollenhauer (eds.), *Freshwater Flora of Middle Europe*. Gustav Fischer Publisher, New York.
- Krammer, K., and H. Lange-Bertalot. 1991a. Bacillariophyceae, Part 2, Volume 3: Centrales, Fragilariaceae, Eunotiaceae. In Ettl, H., J. Gerloff, H. Heynig, and D. Mollenhauer (eds.), *Freshwater Flora of Middle Europe*. Gustav Fischer Publisher, Stuttgart.
- Krammer, K., and H. Lange-Bertalot. 1991b. Bacillariophyceae, Part 2, Volume 4: Achnanthaceae, Critical Supplement to *Navicula* (Lineolatae) and *Gomphonema*, Complete List of Literature for Volumes 1-4. In Ettl, H., G. Gartner, J. Gerloff, H. Heynig, and D. Mollenhauer (eds.), *Freshwater Flora of Middle Europe*. Gustav Fischer Publisher, Stuttgart.
- Lange-Bertalot, Horst. 1979. Pollution tolerance of diatoms as a criterion for water quality estimation. *Nova Hedwigia* 64:285-304.
- Lange-Bertalot, Horst. 1996. Rote Liste der limnischen Kieselalgen (Bacillariophyceae) Deutschlands. *Schr.-R. f. Vegetationskde.*, H. 28, pp. 633-677. BfN, Bonn-Bad Godesberg.
- Lange-Bertalot, Horst. 2001. *Navicula sensu stricto*: 10 Genera Separated from *Navicula sensu lato*; *Frustulia*. Volume 2 in *Diatoms of Europe*, Horst Lange-Bertalot, ed. A.R.G. Gantner Verlag K.G., Germany.
- Lowe, R.L. 1974. Environmental Requirements and Pollution Tolerance of Freshwater Diatoms. EPA-670/4-74-005. U.S. Environmental Protection Agency, National Environmental Research Center, Office of Research and Development, Cincinnati, Ohio.
- McFarland, B.H., B.H. Hill, and W.T. Willingham. 1997. Abnormal *Fragilaria* spp. (Bacillariophyceae) In streams impacted by mine drainage. *Journal of Freshwater Ecology* 12(1):141-149.
- Morales, E.A., and Marina Potapova. 2000. Third NAWQA Workshop on Harmonization of Algal Taxonomy, May 2000. Patrick Center for Environmental Research, The Academy of Natural Sciences, Philadelphia.
- Palmer, C.M. 1969. A composite rating of algae tolerating organic pollution. *Journal of Phycology* 5:78-82.

- Palmer, C.M. 1977. *Algae and Water Pollution: An Illustrated Manual on the Identification, Significance, and Control of Algae in Water Supplies and in Polluted Water*. EPA-600/9-77-036.
- Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. *Rapid Bioassessment Protocols for Use in Rivers and Streams: Benthic Macroinvertebrates and Fish*. EPA 440-4-89-001.
- Prescott, G.W. 1962. *Algae of the Western Great Lakes Area*. Wm. C. Brown Company, Dubuque, Iowa.
- Prescott, G.W. 1978. *How to Know the Freshwater Algae*. Third Edition. Wm. C. Brown Company Publishers, Dubuque, Iowa.
- Renfro, H.B., and D.E. Feray. 1972. *Geological Highway Map of the Northern Rocky Mountain Region*. American Association of Petroleum Geologists, Tulsa, Oklahoma.
- Smith, G.M. 1950. *The Fresh-Water Algae of The United States*. McGraw-Hill Book Company, New York.
- Stevenson, R.J., and Y. Pan. 1999. Assessing Environmental Conditions in Rivers and Streams with Diatoms. Chapter 2 in Stoermer, E.F., and J.P. Smol (eds.), *The Diatoms: Applications For the Environmental and Earth Sciences*, Cambridge University Press, New York.
- Stewart, W.D.P., P. Rowell, and A.N. Rai. 1980. Symbiotic Nitrogen-Fixing Cyanobacteria. Pp. 239-277 in Stewart, W.D.P., and J. Gallo (eds.), *Nitrogen Fixation*, Academic Press, New York.
- USDA. 1976. *Climax Vegetation of Montana (map)*. U.S. Department of Agriculture, Soil Conservation Service, Cartographic Unit, Portland.
- USEPA. 2000. *Level III Ecoregions of the Continental United States (map)*. U.S. Environmental Protection Agency, Corvallis, Oregon.
- Van Dam, Herman, Adrienne Mertens, and Jos Sinkeldam. 1994. A coded checklist and ecological Indicator values of freshwater diatoms from The Netherlands. *Netherlands Journal of Aquatic Ecology* 28(1):117-133.
- Weber, C.I. (ed.). 1973. *Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents*. EPA-670/4-73-001. U.S. Environmental Protection Agency, National Environmental Research Center, Office of Research and Development, Cincinnati, Ohio.
- Wehr, J.D., and R.G. Sheath. 2003. *Freshwater Algae of North America: Ecology and Classification*. Academic Press, New York.
- Whittaker, R.H. 1952. A study of summer foliage insect communities in the Great Smoky Mountains. *Ecological Monographs* 22:1-44.
- Woods, A.J., Omernik, J.M., Nesser, J.A., Sheldon, J., and S.H. Azevedo. 1999. *Ecoregions of Montana (color poster with map)*, U.S. Geological Survey, Reston, Virginia.

Table 1. Location of MDEQ periphyton sampling stations on the Shields River near Livingston, Montana in 2003.

Station	Montana DEQ Station Code	Latitude	Longitude	Elevation (feet)	Sample Dates	Analysis Type
Shields River at Coal Camp Road	Y02SHLDR15	46 06 39	110 36 46	5,400	9/30/03	Soft Algae ID
Shields River at Elk Creek Road	Y02SHLDR26	46 01 07	110 38 21	5,080	8/13/03	Soft Algae ID
Shields River at Johnstone's	Y02SHLDR02	45 57 21	110 38 01	4,900	9/16/03	Complete
Shields River near mouth above lowermost bridge	Y02SHLDR50	45 43 35	110 27 46	4,400	7/10/03 8/1/03 9/16/03	Soft Algae ID Soft Algae ID Complete

Table 2. Diatom association metrics used by the State of Montana to evaluate biological integrity in **mountain** streams: references, range of values, expected response to increasing impairment or natural stress, and criteria for rating levels of biological integrity. The lowest rating for any one metric is the rating for that site.

Biological Integrity/ Impairment or Stress/ Use Support	No. of Species Counted ¹	Diversity Index ² (Shannon)	Pollution Index ³	Siltation Index ⁴	Disturbance Index ⁵	% Dominant Species ⁶	% Abnormal Cells ⁷
Excellent/None Full Support	>29	>2.99	>2.50	<20.0	<25.0	<25.0	0
Good/Minor Full Support	20-29	2.00-2.99	2.01-2.50	20.0-39.9	25.0-49.9	25.0-49.9	>0.0, <3.0
Fair/Moderate Partial Support	19-10	1.00-1.99	1.50-2.00	40.0-59.9	50.0-74.9	50.0-74.9	3.0-9.9
Poor/Severe Nonsupport	<10	<1.00	<1.50	>59.9	>74.9	>74.9	>9.9
References	Bahls 1979 Bahls 1993	Bahls 1979	Bahls 1993	Bahls 1993	Barbour et al. 1999	Barbour et al. 1999	McFarland et al. 1997
Range of Values	0-100+	0.00-5.00+	1.00-3.00	0.0-90.0+	0.0-100.0	~5.0-100.0	0.0-30.0+
Expected Response	Decrease ⁸	Decrease ⁸	Decrease	Increase	Increase	Increase	Increase

¹Based on a proportional count of 400 cells (800 valves)

²Base 2 [bits] (Weber 1973)

³Composite numeric expression of the pollution tolerances assigned by Lange-Bertalot (1979) to the common diatom species

⁴Sum of the percent abundances of all species in the genera *Navicula*, *Nitzschia* and *Surirella*

⁵Percent abundance of *Achnantheidium minutissimum* (synonym: *Achnanthes minutissima*)

⁶Percent abundance of the species with the largest number of cells in the proportional count

⁷Cells with an irregular outline or with abnormal ornamentation, or both

⁸Species richness and diversity may increase somewhat in mountain streams in response to slight to moderate increases in nutrients or sediment

Table 3. Diatom association metrics used by the State of Montana to evaluate biological integrity in **prairie** streams: references, range of values, expected response to increasing impairment or natural stress, and criteria for rating levels of biological integrity. The lowest rating for any one metric is the rating for that site.

Biological Integrity/ Impairment or Stress/ Use Support	No. of Species Counted ¹	Diversity Index ² (Shannon)	Pollution Index ³	Siltation Index ⁴	Disturbance Index ⁵	% Dominant Species ⁶	Similarity Index ⁷
Excellent/None Full Support	>39	>3.99	>2.25	<50.0	<25.0	<25.0	>59.9
Good/Minor Full Support	30-39	3.00-3.99	1.76-2.25	50.0-69.9	25.0-49.9	25.0-49.9	40.0-59.9
Fair/Moderate Partial Support	20-29	2.00-2.99	1.25-1.75	70.0-89.9	50.0-74.9	50.0-74.9	20.0-39.9
Poor/Severe Nonsupport	<20	<2.00	<1.25	>89.9	>74.9	>74.9	<20.0
References	Bahls 1979 Bahls 1993	Bahls 1979	Bahls 1993	Bahls 1993	Barbour et al. 1999	Barbour et al. 1999	Whittaker 1952
Range of Values	0-100+	0.00-5.00+	1.00-3.00	0.0-90.0+	0.0-100.0	~5.0-100.0	0.0-100.0
Expected Response	Decrease	Decrease	Decrease	Increase	Increase	Increase	Decrease

¹Based on a proportional count of 400 cells (800 valves)

²Base 2 [bits] (Weber 1973)

³Composite numeric expression of the pollution tolerances assigned by Lange-Bertalot (1979) to the common diatom species

⁴Sum of the percent abundances of all species in the genera *Navicula*, *Nitzschia*, and *Surirella*

⁵Percent abundance of *Achnanthes minutissimum* (synonym: *Achnanthes minutissima*)

⁶Percent abundance of the species with the largest number of cells in the proportional count

⁷Percent Community Similarity (Whittaker 1952)

Table 4. Relative abundance of cells and ordinal rank by biovolume of diatoms (Division Bacillariophyta) and genera of non-diatom algae in periphyton samples collected from the Shields River in 2003.

Taxa	Coal Camp Rd. 9/30/03	Elk Creek Rd. 8/13/03	Johnstone's 9/16/03	7/10/03	Near Mouth 8/1/03	9/16/03
Cyanophyta (cyanobacteria)						
<i>Merismopedia</i>			occasional/9th			occasional/9th
<i>Oscillatoria</i>	abundant/2nd		occasional/6th			
Chlorophyta (green algae)						
<i>Ankistrodesmus</i>			common/5th	dominant/1st	dominant/1st	occasional/10th
<i>Cladophora</i>			rare/10th			dominant/2nd
<i>Closterium</i>			occasional/8th			occasional/7th
<i>Coelastrum</i>			occasional/7th			
<i>Cosmarium</i>						occasional/8th
<i>Mougeotia</i>			common/3rd			
<i>Oedogonium</i>	common/4th		common/4th			occasional/5th
<i>Pediastrum</i>			frequent/2nd			frequent/4th
<i>Scenedesmus</i>			rare/11th			frequent/3rd
<i>Staurastrum</i>						occasional/6th
Chrysophyta (yellow-green algae)						
<i>Tribonema</i>		dominant/1st				
<i>Vaucheria</i>	common/3rd					
Bacillariophyta (diatoms)	dominant/1st	common/2nd	dominant/1st	abundant/2nd	abundant/2nd	dominant/1st
Number of Non-Diatom Genera	3	1	10	1	1	9

Table 5. Percent abundance of major diatom species¹ and values of selected diatom association metrics for periphyton samples collected from the Shields River on 9/16/03. Underlined values indicate minor stress; **bold values** indicate moderate stress; **underlined and bold** values indicate severe stress; all other values indicate no stress and full support of aquatic life uses when compared to criteria for mountain streams in Table 2 and plains streams in Table 3. Stress may be natural or anthropogenic.

Species/Metric	PTC ²	Johnstone's		Near Mouth	
		Mountain Criteria	Prairie Criteria	Mountain Criteria	Prairie Criteria
<i>Achnantheidium minutissimum</i>	3	31.36	31.36	24.89	24.89
<i>Cymbella excisa</i>	3	18.23	18.23	5.45	5.45
<i>Denticula kuetzingii</i>	3	2.67	2.67	3.10	3.10
<i>Diatoma moniliformis</i>	2	17.07	17.07	11.97	11.97
<i>Encyonopsis microcephala</i>	3	6.39	6.39	23.82	23.82
<i>Encyonopsis subminuta</i>	3	0.23	0.23	9.19	9.19
<i>Navicula stroemii</i>	2	0.36	0.36	3.53	3.53
Number of Species Counted		44	44	33	33
Shannon Species Diversity		3.42	3.42	3.40	3.40
Pollution Index		2.70	2.70	2.73	2.73
Siltation Index		9.99	9.99	9.29	9.29
Disturbance Index		31.36	31.36	24.89	24.89
Percent Dominant Species		31.36	31.36	24.89	24.89
Percent Abnormal Cells		0.35	0.35	0.21	0.21
Similarity Index ³		62.41	62.41	62.41	62.41

¹A major diatom species accounts for 3.0% or more of the cells at one or more stations in a sample set.

²(Organic) Pollution Tolerance Class (Lange-Bertalot 1979): 1 = most tolerant; 2 = tolerant; 3 = sensitive.

³Percent Community Similarity (Whittaker 1952) when compared to the diatom assemblage at the adjacent station.

Table 6. Modal categories for selected ecological attributes of diatom species in the Shields River on 9/16/03.

Ecological Attribute	Johnstone's 9/16/03	Near Mouth 9/16/03
Motility ¹	Not Motile	Not Motile
pH ²	Alkaliphilous	Alkaliphilous
Salinity ²	Fresh	Fresh
Nitrogen Uptake ²	Autotrophs (tolerate high organics)	Autotrophs (tolerate high organics)
Oxygen Demand ²	Continuously High	Continuously High
Saprobity ²	beta-Mesosaprobous	beta-Mesosaprobous
Trophic State ²	Eutraphentic	Variable

¹Dr. R. Jan Stevenson, Michigan State University, digital communication.

²Van Dam et al. 1994

Table 7. Metrics and ecological attributes that are calculated from diatom proportional counts. Source: Van Dam et al. 1994, unless otherwise indicated.

Metric	Category or Reference	Metric	Category or Reference
Valves Counted	Barbour et al. 1999	Nitrogen Uptake (% by Category)	Not Classified
Cells Counted	Barbour et al. 1999		Nitrogen Autotroph (low organics)
Total Number of Species	Barbour et al. 1999		Nitrogen Autotroph (high organics)
Total Number of Species Counted	Barbour et al. 1999		Facultative Nitrogen Heterotroph
Percent Dominant Species	Barbour et al. 1999		Obligate Nitrogen Heterotroph
Shannon's Diversity Index	Barbour et al. 1999	Oxygen Demand (% by Category)	Not Classified
Pollution Index	Lange-Bertalot 1979		Continuously High
Pollution Tolerance (% by Category)	Most Tolerant		Fairly High
(Lange-Bertalot 1979)	Tolerant		Moderate
	Sensitive		Low
Siltation Index	Bahls 1993		Very Low
Disturbance Index	Bahls 1993	Saprobity (% by Category)	alpha-Mesosaprobous/Polysaprobous
Stability Index	Bahls (unpublished)		Polysaprobous
Percent Rhopalodiales	Stevenson & Pan 1999		alpha-Mesosaprobous
Percent Aerophiles	Johansen 1999		Oligosaprobous
Percent Centrics			Not Classified
Heavy Metals Index	Bahls (unpublished)		beta-Mesosaprobous
Motility (% by Category)	Moderately Motile	Trophic State (% by Category)	Eutraphentic
(Stevenson, R.J., pers. com.)	Not Motile		Dystrophic
	Variable Motility		Not Classified
	Highly Motile		Hypereutraphentic
pH (% by Category)	Acidophilous		Meso-eutraphentic
	Indifferent		Mesotraphentic
	Alkalibiontic		Oligo-mesotraphentic
	Circumneutral		Oligotraphentic
	Acidobiontic		Variable
	Not Classified	Moisture (% by Category)	Not Classified
	Alkaliphilous		Rarely Outside Waterbodies
Salinity (% by Category)	Marine		Mainly in Waterbodies; Sometimes Wet
	Not Classified		Mainly in Waterbodies; Regularly Wet
	Very Fresh		Mainly Wet Places; Sometimes in Water
	Fresh		Exclusively Outside Waterbodies
Brackish-fresh		Similarity Index	Compared to Reference Sample No. XXXXXX
Brackish		(Whitaker 1952)	