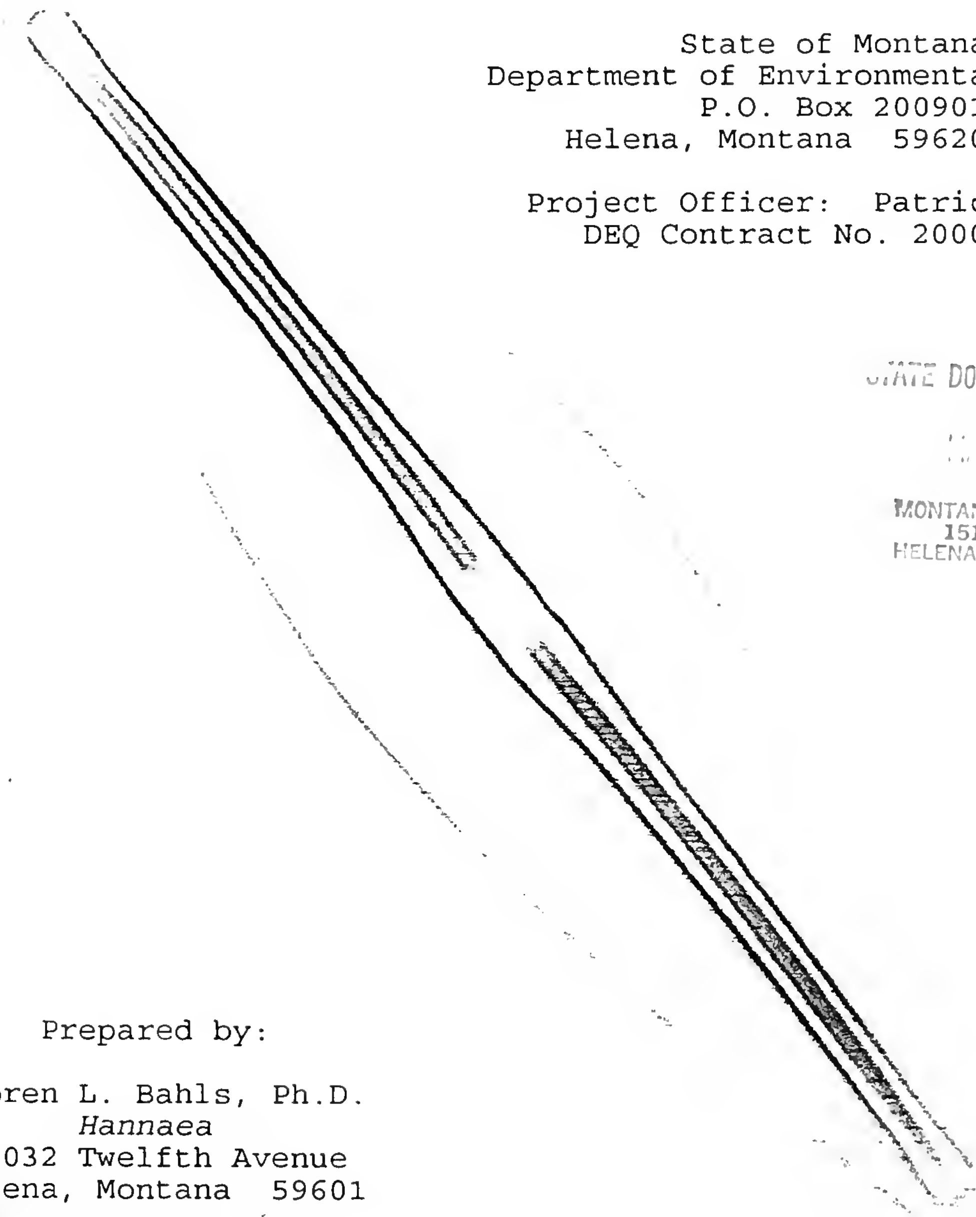
BIOLOGICAL INTEGRITY OF COTTONWOOD CREEK AND ROCK CREEK NEAR CLYDE PARK, MONTANA BASED ON THE COMPOSITION AND STRUCTURE OF THE BENTHIC ALGAE COMMUNITY

Prepared for:

State of Montana
Department of Environmental Quality
P.O. Box 200901
Helena, Montana 59620-0901

Project Officer: Patrick Newby
DEQ Contract No. 200012-2



Prepared by:

Loren L. Bahls, Ph.D.
Hannaea
1032 Twelfth Avenue
Helena, Montana 59601

October 21, 2000

Printed on 100% Recycled Post-Consumer Paper

SUMMARY

In late July and early August 2000, periphyton samples were collected at four stations on Cottonwood and Rock Creeks near Clyde Park, Montana for the purpose of assessing whether the creeks are water-quality limited and in need of TMDLs. The samples were collected following DEQ standard operating procedures, processed and analyzed using standard methods for periphyton, and evaluated following modified USEPA rapid bioassessment protocols for wadeable streams.

The non-diatom algae indicated cold, fast-flowing waters and low concentrations of dissolved nutrients. Algal standing crops were evidently very small, judging by the sparse contents of the samples. No algae were found in the sample collected at **Cottonwood Creek Station 1**.

Diatom association metrics indicated no stress or only minor stress and full support of aquatic life uses at the remaining three sites. Diatom indicator species confirmed these waters to be cold and nutrient poor; at least some of the observed stress was natural in origin. Phosphorus was likely the nutrient most limiting to algal growth.

The two Rock Creek stations had about half of their diatom assemblages in common, which is to be expected given the intervening tributaries between these sites. The diatom assemblage at Rock Creek Station 2 was slightly more similar to the assemblage at Cottonwood Creek Station 2 than it was to the assemblage at Rock Creek Station 1.

Using Rock Creek Station 1 as a local reference site under Protocol II, **Rock Creek Station 2** proved to have good to excellent biological integrity, little or no stress, and no impairment of aquatic life uses.

INTRODUCTION

This report evaluates the biological integrity, support of aquatic life uses, and probable causes of impairment to those uses, in Cottonwood Creek and Rock Creek near Clyde Park, Montana. The purpose of this report is to provide information that will help the State of Montana determine whether these streams are water-quality limited and in need of TMDLs.

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 use support in this report is based on the species composition and structure of the periphyton (benthic algae, phytobenthos) community at three sites that were sampled in late July and early August 2000. 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 Stevenson and Bahls (1999) list several advantages of using periphyton in biological assessments:

- Algae are universally present in large numbers in all streams and unimpaired periphyton assemblages typically support a large number (>30) of species;

- Algae have rapid reproduction rates and short life cycles, making them useful indicators of short-term impacts;

- As primary producers, algae are most directly affected by physical and chemical factors, such as temperature, nutrients, dissolved salts, and toxins;

- Sampling is quick, easy and inexpensive, and causes minimal damage to resident biota and their habitat;

- Standard methods and criteria exist for evaluating the composition, structure, and biomass of algal associations;

- Identification to species is straightforward for the diatoms, for which there is a large body of taxonomic and ecological literature;

- Excessive algae growth in streams is often correctly perceived as a problem by the public.

- Periphyton and other biological communities reflect the *biological integrity*[1] of waterbodies; restoring and maintaining the biological integrity of waterbodies is a goal of the federal Clean Water Act;

- Periphyton and other biological communities integrate the effects of different stressors and provide a measure of their aggregate impact; and

- Periphyton and other biological communities may be the only practical means of evaluating impacts from non-point sources of pollution where specific ambient criteria do not exist (e.g., impacts that degrade habitat or increase nutrients).

Periphyton is a diverse assortment of simple photosynthetic organisms called algae, and other microorganisms that live attached to or in close proximity of the stream bottom. Most algae, such as the diatoms, are microscopic. Diatoms are distinguished by having a cell wall composed of opaline glass--hydrated amorphous silica. Diatoms often carpet a stream bottom with a slippery brown film.

---

[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).

Some algae, such as the filamentous greens, are conspicuous and their excessive growth may be aesthetically displeasing, deplete dissolved oxygen, interfere with fishing and fish spawning, clog water filters and irrigation intakes, create tastes and odors in drinking water, and cause other problems.

PROJECT AREA AND SAMPLING SITES

The project area is located in northern Park County in southcentral Montana. Cottonwood Creek and Rock Creek head in the Crazy Mountains (maximum elevation 11,214 feet) and flow southwesterly for about 15 miles to where they enter the Shields River near the town of Clyde Park (pop. 302).

The headwaters of Cottonwood Creek and Rock Creek are in the Middle Rockies Ecoregion of North America; the lower reaches of these streams pass through the Montana Valley and Foothill Prairies Ecoregion (Woods et al. 1999). The surface geology of the watersheds consists of a matrix of Paleocene continental deposits with granitic intrusives of Tertiary age (Renfro and Feray 1972). Vegetation is alpine tundra at the highest elevations, mixed conifer forest at intermediate elevations, and mixed grassland at lower elevations (USDA 1976).

Periphyton samples were collected at two sites on Cottonwood Creek in late July and early August 2000 (Maps 1 and 2, Table 1). The sample collected at the upper site (Map 1, Station 1) contained no algae and could not be used for bioassessment. The lower site (Map 2, Station 2) was located at an elevation of 5,500 feet about 7 miles upstream from the mouth of Cottonwood Creek at Clyde Park.

Periphyton samples were collected at two sites on Rock Creek on July 28, 2000 (Map 2, Table 1). The upper site (Station 1)

was located at an elevation of 6,000 feet, just above the confluence of Little Rock Creek. The lower site (Station 2) was located at an elevation of 5,300 feet about 5 miles downstream of Station 1 at the county road crossing east of Clyde Park.

Both Cottonwood Creek and Rock Creek are classified B-1 in the Montana Surface Water Quality Standards.

METHODS

Periphyton samples were collected by Patrick Newby of the MDEQ Monitoring and Data Management Bureau following standard operating procedures of the MDEQ Planning, Prevention, and Assistance Division.

Using appropriate tools, microalgae were scraped, brushed, or sucked from natural substrates in proportion to the rank of those substrates at the study site. Macroalgae were picked by hand in proportion to their abundance at the site. All collections of microalgae and macroalgae were pooled into a common container and preserved with Lugol's solution.

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 Dillard (1999), Prescott (1978), Smith (1950), and Whitford and Schumacher (1984). These books also served as references on the ecology of the soft algae, along with Palmer (1977).

After the identification of soft algae, the raw periphyton samples were cleaned of organic matter using sulfuric acid, and 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). Between 400 and 406 diatom cells (800 to 812 valves) were counted at random and identified to species. The following were used as the main taxonomic and autecological references for the diatoms: Krammer and Lange-Bertalot 1986, 1988, 1991a, 1991b; Patrick and Reimer 1966, 1975. Lowe (1974) was also used as an ecological reference for the diatoms.

The diatom proportional counts were used to generate an array of diatom association metrics (Table 2). A metric is a characteristic of the biota that changes in some predictable way with increased human influence (Barbour et al. 1999).

Metric values from Cottonwood Creek and Rock Creek were compared to numeric biocriteria or threshold values developed for streams in the Rocky Mountain Ecoregions of Montana (Table 3). These criteria are based on metric values measured in least-impaired reference streams (Bahls et al. 1992) and on metric values measured in streams that are known to be impaired by various sources and causes of pollution (Bahls 1993).

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

Besides the ecoregional biocriteria listed in Table 3, lower Rock Creek metrics were compared to metrics generated from an upstream control site (Rock Creek Station 1) using Protocol II in Bahls (1993). Protocol II may be used on relatively short segments of stream where an upstream control site fully supports its aquatic life uses, that is, if it has a rating of "good" or "excellent" biological integrity using Protocol I. Protocol II

is based on the percentage of change in metric values at study sites from values measured at the upstream control site. Criteria for evaluating biological integrity using Protocol II are given in Table 12 in Bahls (1993).

Quality Assurance. Several steps were taken to assure that the study results are accurate and reproducible.

Upon receipt of the samples, station and sample information were recorded in a laboratory notebook and the samples were assigned a unique number compatible with the Montana Diatom Database, e.g., 1989-01. The first part of this number (1989) designates the sampling site (Cottonwood Creek Station 2); the second part of this number (01) designates the number of periphyton samples that have been collected at this site to date for which data have been entered into the Montana Diatom Database.

Sample observations and analyses of soft (non-diatom) algae were recorded in a lab notebook along with station and sample information provided by MDEQ. A portion of the raw sample was used to make duplicate diatom slides. After completing the diatom proportional count, the slide used for the count will be deposited in the University of Montana Herbarium in Missoula. The other slide will be retained by *Hannaea* in Helena.

On completion of the project, station information, sample information, and diatom proportional count data will be 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 Literature Cited section. Spreadsheets containing completed diatom proportional counts, with species' pollution tolerance classes (PTC) and percent abundances, are attached as Appendix A.

SAMPLE NOTES

Cottonwood Creek Station 1. No algae were observed in the

sample collected at this site during a 15-minute scan under low power (100X). A diatom slide was not prepared. This site is evidently pristine with very little algal growth.

Cottonwood Creek Station 2. The *Schizothrix* in this sample appeared as rubbery and pustular macroscopic colonies up to 1 cm across. *Phormidium* and *Protoderma* were epiphytes on *Tetraspora*.

Rock Creek Station 1. This sample contained one small rock, which I brushed with a toothbrush into the sample container. *Hydrurus* occurred in this sample as scattered cells.

Rock Creek Station 2. This sample was very sparse and consisted mostly of roots from terrestrial plants.

NON-DIATOM ALGAE

The periphyton sample from **Cottonwood Creek Station 2** contained a healthy mix of diatoms, cyanobacteria, and green algae (Table 4). *Tetraspora*, a green alga that is characteristic of cold, fast-flowing mountain streams, was dominant. Diatoms ranked second in biovolume and various genera of cyanobacteria ranked third through fifth. *Ulothrix*, another green alga typical of cold waters, was common and ranked sixth.

The sample from **Rock Creek Station 1** also contained a mix of chrysophytes (including diatoms), cyanobacteria, and green algae. The most abundant alga at this site was *Hydrurus foetidus*, a common chrysophyte in mountain streams. Diatoms ranked second in biovolume, followed by green algae and cyanobacteria (Table 4).

The sample from **Rock Creek Station 2** was very sparse. Only one cell of *Closterium* (a green alga) and several diatoms were observed during a 15-minute scan. This site probably supported

cyanobacteria, although none were found in the sample.

The non-diatom algae from these sites indicated cold, fast-flowing waters and low concentrations of dissolved nutrients. Algal standing crops were evidently very small, especially at **Cottonwood Creek Station 1**.

DIATOMS

Diatom association metrics indicated good to excellent biological integrity at all of the sampling sites (Table 5).

Most of the major diatom species in Cottonwood Creek and Rock Creek were sensitive to or only somewhat tolerant of pollution (Table 5). *Nitzschia palea*, a nitrogen indicator and a diatom that is quite tolerant of pollution, was a major species only at **Cottonwood Creek Station 2**, where it accounted for 5.25% of the cells. The pollution index at this site was borderline and indicated minor impairment from organic loading but full support of aquatic life uses. The siltation index was also borderline at this site, but well within the range of good biological integrity.

Rock Creek Station 1 had somewhat depressed species richness and species diversity values, indicating minor stress (Table 5). This stress was likely natural in origin and due to the cold and nutrient-poor water at this site. The pollution index at this site was on the threshold of minor impairment due to the large percentage of cells in the species *Gomphonema angustatum*. This taxon prefers small, cold-water streams (Krammer & Lange-Bertalot 1986) and oligotrophic to somewhat mesotrophic water (Patrick and Reimer 1975). Although it is somewhat tolerant of pollution (Lange-Bertalot 1979), it is also found in nutrient-poor waters.

The dominant diatom at **Rock Creek Station 2** was *Achnanthes minutissima* (Table 5). This pioneer species is among the first to colonize bare substrates after they have been disturbed; it has a broad ecological amplitude, but is sensitive to low concentrations of dissolved oxygen. The large percentage of this taxon (42.10%) resulted in minor impairment due to the elevated disturbance index and percent dominant species. The disturbance at this site may have been natural in origin, e.g., grazing by macroinvertebrates.

All three sites had at least one teratological cell, but not enough to suggest chemical toxicity or more than minor impairment (Table 5). Diatoms in the family Epithemiaceae were absent or scarce at all three sites, suggesting that phosphorus, and not nitrogen, was limiting to algal growth.

The two Rock Creek stations had about half of their diatom assemblages in common (Table 5), which is to be expected given the intervening tributaries between these sites. The diatom assemblage at Rock Creek Station 2 was actually more similar to the assemblage at Cottonwood Creek Station 2 than it was to the assemblage at Rock Creek Station 1.

Using Rock Creek Station 1 as a local reference site under Protocol II (Table 6), **Rock Creek Station 2** proved to have good to excellent biological integrity and no impairment of aquatic life uses.

LITERATURE CITED

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. Proc. Mont. Acad. Sci. 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., 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. EPA, Office of Water, Washington, D.C.

Dillard, G.E. 1999. Common Freshwater Algae of the United States. J. Cramer, Berlin.

Johansen, J.R. 1999. Diatoms of Aerial Habitats. Chapter 12 *in* Stoermer, E.F., and J.P. Smol (eds.), The Diatoms, Cambridge University Press, New York.

Karr, J.R., and D.R. Dudley. 1981. Ecological perspectives on water quality goals. Environmental Management 5:55-69.

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.

Lowe, R.L. 1974. Environmental Requirements and Pollution Tolerance of Freshwater Diatoms. EPA-670/4-74-005.

McFarland, B.H., B.H. Hill, and W.T. Willingham. 1997. Abnormal *Fragilaria* spp. (Bacillariophyceae) in streams impacted by mine drainage. Jour. of Freshwater Ecology 12(1):141-149.

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.

Patrick, Ruth, and C.W. Reimer. 1966. The Diatoms of The United States Exclusive of Alaska and Hawaii. Volume 1: Fragilariaceae, Eunotiaceae, Achnanthaceae, Naviculaceae. Monograph Number 13, The Academy of Natural Sciences, Philadelphia.

Patrick, Ruth, and C.W. Reimer. 1975. The Diatoms of The United States Exclusive of Alaska and Hawaii. Volume 2, Part 1: Entomoneidaceae, Cymbellaceae, Gomphonemaceae, Epithemiaceae. Nonograph Number 13, The Academy of Natural Sciences, Philadelphia.

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. 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.

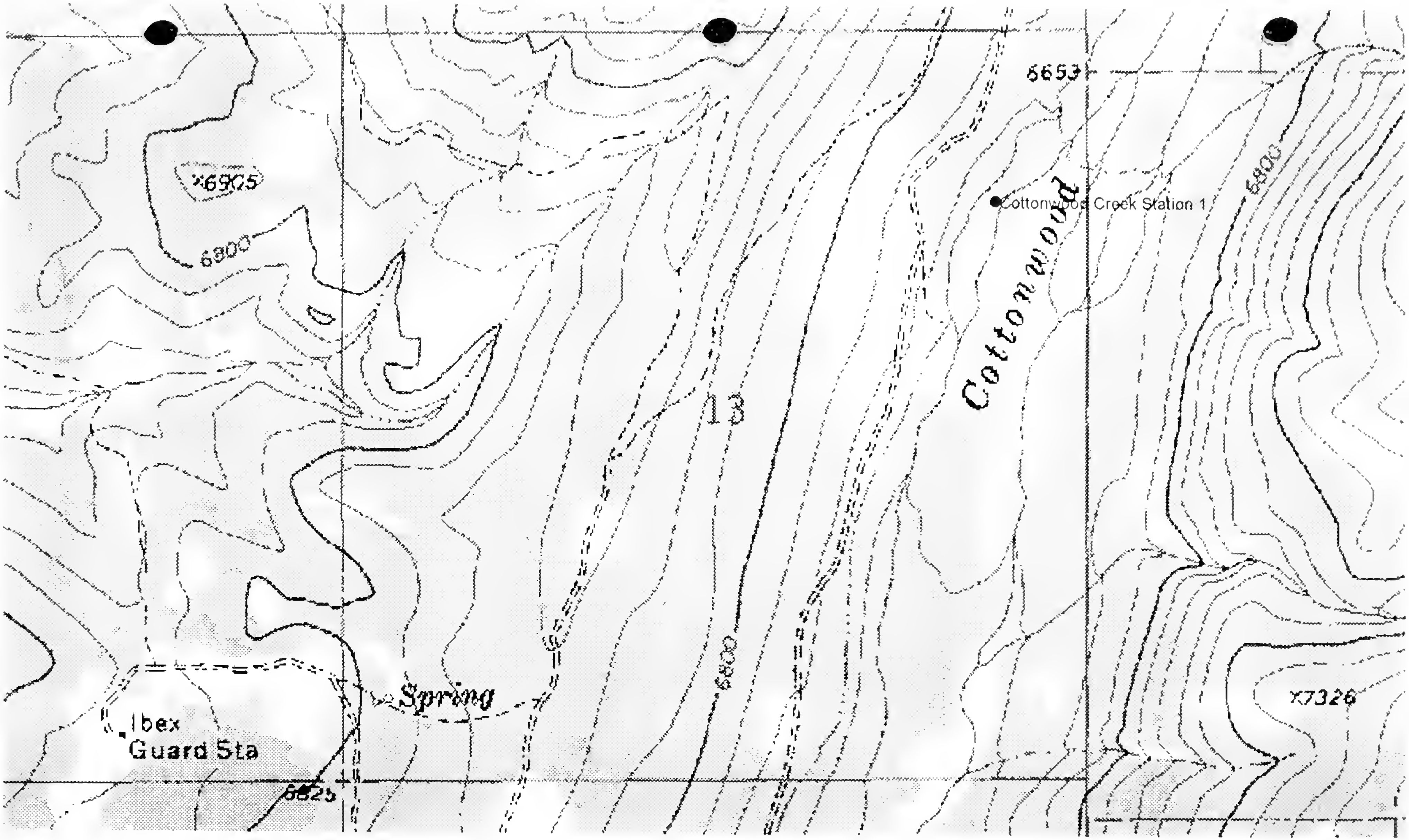
Stevenson, R.J., and L.L. Bahls. 1999. Periphyton Protocols. Chapter 6 *in* Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish. Second Edition. EPA/841-B-99-002. U.S. EPA, Office of Water, Washington, D.C.

USDA. 1976. Climax Vegetation of Montana (map). U. S. Department of Agriculture, Soil Conservation Service, Cartographic Unit, Portland.

Whitford, L.A., and G.J. Schumacher. 1984. A Manual of Fresh-Water Algae (Revised). Sparks Press, Raleigh, North Carolina.

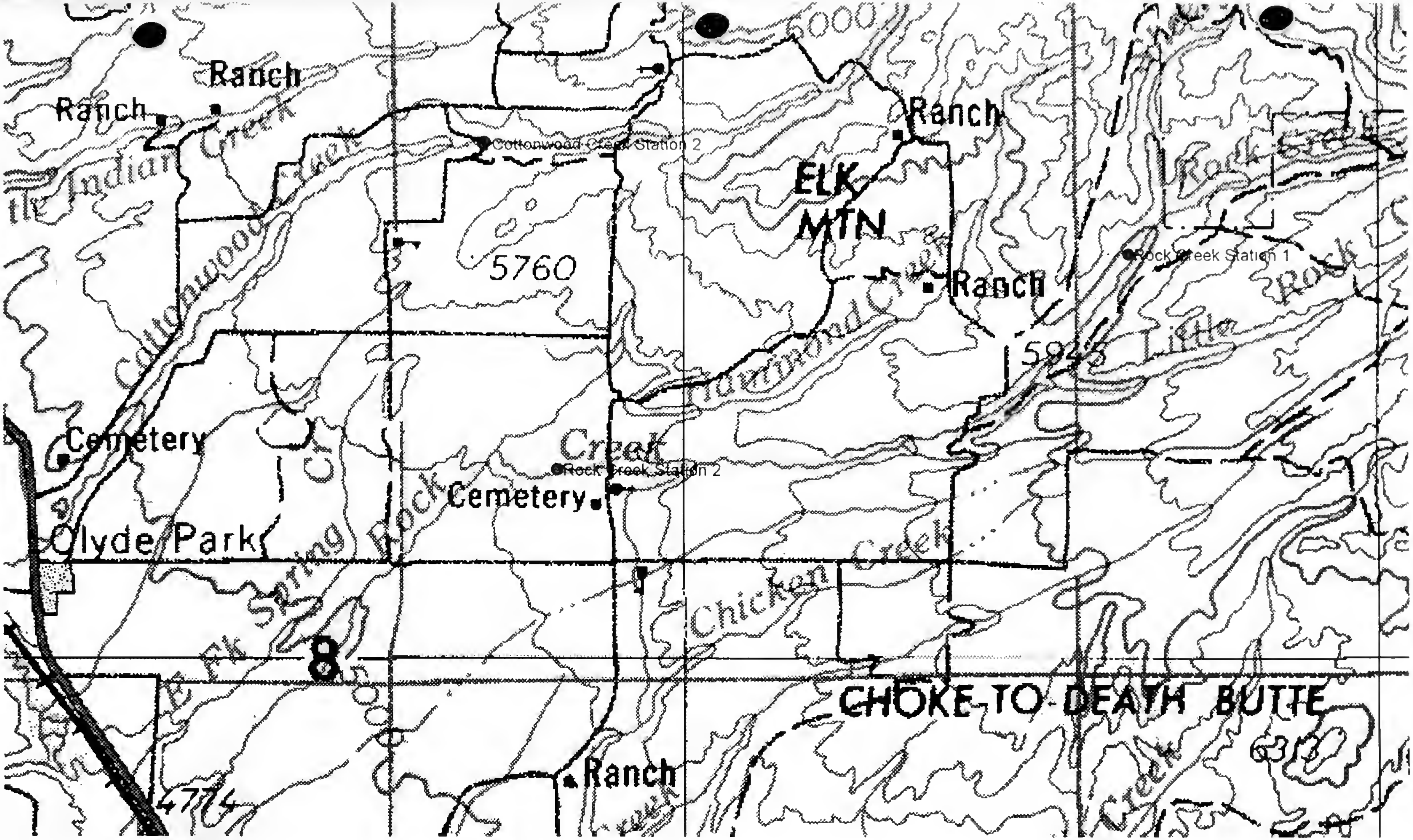
Whittaker, R.H. 1952. A study of summer foliage insect communities in the Great Smoky Mountains. Ecological Monographs 22:1-44.

Woods, A.J., Omernik, J.M., Nesser, J.A., Shelden, J., and Azevedo, S.H. 1999. Ecoregions of Montana (color poster with map), U.S. Geological Survey, Reston, Virginia.



Map 1

'Campfire Lake; MT'; Scale: 1" = 0.179Mi 288Mt 943Ft, 1 Mi = 5.596" , 1 cm = 113Mt



Map 2

'Bozeman; MT,WY'; Scale: 1" = 1.191Mi 1,917Mt 6,290Ft, 1 Mi = 0.839" , 1 cm = 755Mt

Table 1. Location of periphyton stations on Cottonwood Creek and Rock Creek near Clyde Park, Montana: Station codes, sample numbers in the Montana Diatom Database, latitudes and longitudes, and sample dates. Stations are listed in order from upstream to downstream.

Location	Station Code	Sample Number	Latitude/ Longitude	Sample Date
Cottonwood Creek (upper)	Station 1	1988-01	46 00 49 110 25 14	07/27/00
Cottonwood Creek (lower)	Station 2	1989-01	45 56 27 110 31 14	08/01/00
Rock Creek (upper)	Station 1	1990-01	45 55 32 110 24 04	07/28/00
Rock Creek (lower)	Station 2	1991-01	45 53 55 110 30 26	07/28/00

Table 2. Diatom association metrics used to evaluate biological integrity in Montana streams: reference, range of values in Montana streams, and expected direction of metric response to increasing anthropogenic perturbation or natural stress.

Metric	Reference	Range of Values	Expected Response
Shannon Species Diversity	Bahls 1979	0.00-5.00+	Decrease[1]
Pollution Index[2]	Bahls 1993	1.00-3.00	Decrease
Siltation Index[3]	Bahls 1993	0.00-90.0+	Increase
Disturbance Index[4]	Barbour *et al.* 1999	0.00-100.0	Increase
No. Species Counted	Bahls 1979, 1993	0-100+	Decrease[1]
Percent Dominant Species	Barbour *et al.* 1999	5.0-100.0	Increase
Percent Abnormal Cells	McFarland *et al.* 1997	0.0-20.0+	Increase
Similarity Index	Whittaker 1952	0.0-80.0+	Decrease
Percent Epithemiaceae	Stevenson & Pan 1999	0.0-80.0+	Decrease
Percent Aerophiles	Johansen 1999	0.0-100	Increase

1 Shannon diversity and species richness may increase somewhat in naturally nutrient-poor mountain streams in response to slight to moderate increases in nutrients or sediment.

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

3 Sum of the percent abundances of all species in the genera *Navicula*, *Nitzschia*, and *Surirella*, plus the species *Cymbella sinuata*.

4 Percent abundance of *Achnanthes minutissima*.

Table 3. Criteria for rating levels of biological integrity, environmental impairment or natural stress, and aquatic life use support in wadeable **mountain** streams of Montana using selected metrics for benthic diatom associations. The lowest rating for any one metric is the overall rating for the study site.

Biological Integrity/ Impairment or Natural Stress/Use Support	Diversity Index (Shannon)	Pollution Index	Siltation Index	Disturbance Index	Number of Species Counted	Percent Dominant Species	Percent Abnormal Cells	Similarity Index[1]
Excellent None/Full Support	>2.99	>2.50	<20.0	<25.0	>29	<25.0	0.0	>59.9
Good/Minor Full Support	2.00-2.99	2.01-2.50	20.0-39.9	25.0-49.9	20-29	25.0-49.9	>0.0-<1.0	40.0-59.9
Fair/Moderate Partial Support	1.00-1.99	1.50-2.00	40.0-59.9	50.0-74.9	10-19	50.0-74.9	1.0-9.9	20.0-39.9
Poor/Severe Nonsupport	<1.00	<1.50	>59.9	>74.9	<10	>74.9	>9.9	<20.0

[1] The Similarity Index or Percent Community Similarity (Whittaker 1952) may be used to compare a study site to an unimpaired upstream control site on the same stream. This metric measures the degree of floristic similarity between diatom associations at the two sites and is the sum of the smaller of the two percent abundance values for each species that is common to both sites. Adjacent riffles on the same stream, without intervening tributaries or environmental perturbations, will generally have at least 60% of their diatom floras in common (Bahls 1993). PCS may also be used to guage the relative amount of impairment or recovery that occurs between adjacent study sites: >59.9% = very similar floras, no change; 40.0-59.9% = somewhat similar floras, minor change; 20.0-39.9% = somewhat dissimilar floras, moderate change; <20.0% = very dissimilar floras, major change.

Table 4. Relative abundance of cells and rank by biovolume of diatoms and genera of non-diatom algae in periphyton samples collected from Cottonwood Creek and Rock Creek near Clyde Park, Montana in the summer of 2000.

Taxa	Relative Abundance and (Rank)		
	Cottonwood Creek	Rock Creek	
	Station 2	Station 1	Station 2
Chlorophyta (green algae)			
Cladophora	occasional (8)		
Closterium	occasional (9)		rare (2)
Cosmarium	occasional (10)		
Oedogonium		occasional (4)	
Protoderma	common (7)		
Scenedesmus	occasional (11)		
Spirogyra		occasional (5)	
Tetraspora	dominant (1)		
Ulothrix	common (6)	occasional (6)	
Zygnema		common (3)	
Chrysophyta (golden algae)			
Diatoms	abundant (2)	frequent (2)	occasional (1)
Hydrurus foetidus		abundant (1)	
Cyanophyta (cyanobacteria)[1]			
Oscillatoria	frequent (5)		
Phormidium	abundant (4)	occasional (7)	
Schizothrix	frequent (3)		

[1] Formerly known as blue-green algae.

Table 5. Percent abundance of major diatom species[1] and values of selected diatom association metrics for periphyton samples collected from Cottonwood Creek and Rock Creek near Clyde Park, Montana in the summer of 2000.

Species/Metric (Pollution Tolerance Class)[3]	Percent Abundance/Metric Values[2]		
	Cottonwood Creek	Rock Creek	
	Station 2	Sta. 1	Sta. 2
Achnanthes minutissima (3)	29.25	26.85	42.10
Cymbella affinis (3)	11.13	0.62	2.59
Cymbella minuta (2)	16.88	1.11	3.58
Cymbella silesiaca (2)	9.25	0.62	17.65
Gomphonema angustatum (2)	0.50	44.33	8.15
Gomphonema minutiforme (3)		5.91	1.11
Nitzschia palea (1)	5.25		0.62
Reimeria sinuata (2)	0.50	5.05	5.80
Cells Counted	400	406	405
Total Species	40	31	37
Species Counted	39	28	37
Species Diversity	3.58	2.66	3.12
Percent Dominant Species	29.25	44.33	42.10
Disturbance Index	29.25	26.85	42.10
Pollution Index	2.48	2.50	2.64
Siltation Index	21.27	6.29	10.11
Percent Abnormal Cells	0.13	0.49	0.25
Percent Epithemiaceae	0.13	0.00	0.00
Similarity Index[4]		36.93	52.64

[1] A major diatom species is here considered to be one that accounts for 5% or more of the cells in one or more samples of a sample set.

[2] Underlined values indicate good biological integrity, minor impairment, and full support of aquatic life uses; all other values indicate excellent biological integrity, no impairment, and full support of aquatic life uses when compared to criteria for mountain streams in Table 3.

[3] 3 = sensitive to pollution; 2 = tolerant of pollution; 1 = most tolerant of pollution.

[4] The percent community similarity between Cottonwood Creek Station 2 and Rock Creek Station 2 was 53.88%.

Table 6. Metric scores and impairment ratings for Rock Creek based on a comparison of diatom metrics at the downstream study site to metrics at the upstream control site (#1) using Protocol II and Table 12 in Bahls (1993). Underlined values indicate full support of aquatic life uses, minor impairment, and good biological integrity; all other values indicate full support of aquatic life uses, no impairment, and excellent biological integrity.

Metric	Rock Creek Station	
	1	2
Shannon Diversity Index	100	117
Pollution Index	100	106
Siltation Index	100	62
Similarity Index	100	53

APPENDIX A: DIATOM PROPORTIONAL COUNTS

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
198901	Achnanthes biasolettiana	3	9	1.13
198901	Achnanthes lanceolata	2	3	0.38
198901	Achnanthes minutissima	3	234	29.25
198901	Amphora pediculus	3	2	0.25
198901	Cocconeis placentula	3	4	0.50
198901	Cymbella affinis	3	89	11.13
198901	Cymbella hebridica	3	4	0.50
198901	Cymbella microcephala	2	2	0.25
198901	Cymbella minuta	2	135	16.88
198901	Cymbella silesiaca	2	74	9.25
198901	Denticula tenuis	3	1	0.13
198901	Diatoma vulgaris	3	36	4.50
198901	Fragilaria leptostauron	3	2	0.25
198901	Fragilaria vaucheriae	2	4	0.50
198901	Gomphonema angustatum	2	4	0.50
198901	Gomphonema clavatum	2	1	0.13
198901	Gomphonema minutum	3	9	1.13
198901	Gomphonema parvulum	1	5	0.63
198901	Gomphonema pumilum	3	4	0.50
198901	Hannaea arcus	3	5	0.63
198901	Navicula capitatoradiata	2	12	1.50
198901	Navicula cryptocephala	3	2	0.25
198901	Navicula cryptotenella	2	15	1.88
198901	Navicula menisculus	2	2	0.25
198901	Navicula microcari	2	4	0.50
198901	Navicula minima	1	6	0.75
198901	Navicula minuscula	1	4	0.50
198901	Navicula reichardtiana	2	24	3.00
198901	Navicula tripunctata	3	36	4.50
198901	Nitzschia dissipata	3	2	0.25
198901	Nitzschia frustulum	2	1	0.13
198901	Nitzschia gracilis	2	4	0.50
198901	Nitzschia heufleriana	3	1	0.13
198901	Nitzschia inconspicua	2	4	0.50
198901	Nitzschia linearis	2	4	0.50
198901	Nitzschia palea	1	42	5.25
198901	Reimeria sinuata	3	4	0.50
198901	Rhoicosphenia curvata	3	0	0.00
198901	Surirella minuta	2	3	0.38
198901	Synedra ulna	2	3	0.38

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
199001	Achnanthes biasolettiana	3	8	0.99
199001	Achnanthes laevis	3	3	0.37
199001	Achnanthes minutissima	3	218	26.85
199001	Cocconeis placentula	3	4	0.49
199001	Cyclotella stelligera	3	1	0.12
199001	Cymbella affinis	3	5	0.62
199001	Cymbella hebridica	3	4	0.49
199001	Cymbella minuta	2	9	1.11
199001	Cymbella silesiaca	2	5	0.62
199001	Diatoma mesodon	3	3	0.37
199001	Fragilaria construens	3	2	0.25
199001	Fragilaria leptostauron	3	2	0.25
199001	Fragilaria pinnata	3	3	0.37
199001	Fragilaria vaucheriae	2	0	0.00
199001	Gomphonema angustatum	2	360	44.33
199001	Gomphonema angustum	3	0	0.00
199001	Gomphonema minutiforme	3	48	5.91
199001	Gomphonema minutum	3	26	3.20
199001	Gomphonema olivaceoides	3	15	1.85
199001	Gomphonema parvulum	1	9	1.11
199001	Gomphonema pumilum	3	8	0.99
199001	Hannaea arcus	3	19	2.34
199001	Meridion circulare	3	4	0.49
199001	Navicula cryptotenella	2	4	0.49
199001	Navicula microcari	2	2	0.25
199001	Navicula reichardtiana	2	2	0.25
199001	Nitzschia dissipata	3	2	0.25
199001	Reimeria sinuata	3	41	5.05
199001	Rhoicosphenia curvata	3	0	0.00
199001	Synedra rumpens	2	1	0.12
199001	Synedra ulna	2	4	0.49

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
199101	Achnanthes biasolettiana	3	19	2.35
199101	Achnanthes lanceolata	2	6	0.74
199101	Achnanthes minutissima	3	341	42.10
199101	Cocconeis placentula	3	27	3.33
199101	Cymbella affinis	3	21	2.59
199101	Cymbella hebridica	3	2	0.25
199101	Cymbella minuta	2	29	3.58
199101	Cymbella silesiaca	2	143	17.65
199101	Diatoma mesodon	3	1	0.12
199101	Fragilaria construens	3	3	0.37
199101	Fragilaria pinnata	3	2	0.25
199101	Fragilaria vaucheriae	2	3	0.37
199101	Gomphonema angustatum	2	66	8.15
199101	Gomphonema minutiforme	3	9	1.11
199101	Gomphonema minutum	3	14	1.73
199101	Gomphonema olivaceoides	3	4	0.49
199101	Gomphonema pumilum	3	11	1.36
199101	Hannaea arcus	3	19	2.35
199101	Meridion circulare	3	1	0.12
199101	Navicula capitatoradiata	2	1	0.12
199101	Navicula cryptocephala	3	1	0.12
199101	Navicula cryptotenella	2	2	0.25
199101	Navicula gregaria	2	2	0.25
199101	Navicula lanceolata (Ag.) E.	2	6	0.74
199101	Navicula microcari	2	1	0.12
199101	Navicula minima	1	3	0.37
199101	Navicula pupula	2	2	0.25
199101	Navicula reichardtiana	2	4	0.49
199101	Navicula tripunctata	3	5	0.62
199101	Nitzschia frustulum	2	1	0.12
199101	Nitzschia inconspicua	2	1	0.12
199101	Nitzschia microcephala	1	1	0.12
199101	Nitzschia palea	1	5	0.62
199101	Reimeria sinuata	3	47	5.80
199101	Rhoicosphenia curvata	3	3	0.37
199101	Synedra rumpens	2	1	0.12
199101	Synedra ulna	2	3	0.37