CHEMICAL AND BIOLOGICAL INDICATORS OF NUTRIENT ENRICHMENT IN THE YELLOWSTONE RIVER BASIN, MONTANA AND WYOMING, AUGUST 2000: STUDY DESIGN AND PRELIMINARY RESULTS

OVERVIEW

A water-quality investigation of the Yellowstone River was conducted during low-flow conditions in August 2000, under the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program. Samples for analysis of water chemistry (nutrients, field measurements, and other constituents) and biological communities (periphyton, phytoplankton, and macroinvertebrates) were collected at 11 sites on the main stem of the Yellowstone River between Corwin Springs and Sidney, Montana, as well as from tributaries including the Clarks Fork of the Yellowstone River, the Bighorn River, and the Tongue River.

Preliminary results of the investigation indicate concentrations of total nitrogen varied little throughout the length of the main stem of the Yellowstone River; total phosphorus concentrations increased slightly in the downstream direction. In contrast, periphyton chlorophyll a and ash-free dry mass concentrations, and algal productivity rates, were highest in the middle sections of the Yellowstone River.

Background

At low to moderate concentrations, algae are an integral part of a healthy stream ecosystem. Algae are single-celled plants that contain chlorophyll and carry out photosynthesis. The periphyton (algae attached to rocks, logs and submerged objects) and phytoplankton (suspended or floating algae) are primary producers in the aquatic food chain, and provide food and habitat for invertebrates and other organisms. During daylight, algae produce oxygen that is essential for aquatic life, sometimes causing the water to be supersaturated with oxygen. During the night, excessive algal growths can deplete dissolved-oxygen concentrations to levels lethal to fish, particularly trout, due to algal respiration and consumption of oxygen through decay of dead algal cells and other organic matter in the water. Respiration and decay of organic matter consume oxygen throughout the day and night, but are offset by photosynthesis during the daylight hours. Excessive growths of algae also can be aesthetically displeasing, as well as a nuisance for anglers, irrigators, and other water users.

View looking downstream in the Yellowstone River at Corwin Springs (site Y1) *(photo by Greg Boughton)*.

In response to nuisance growths of the green algae *Cladophora glomerata* and dissolved-oxygen concentrations less than State of Montana standards, voluntary nutrient criteria were adopted in the Clark Fork basin of western Montana (tributary to the Columbia River) (Watson and others, 2000). The nutrient criteria from the Clarks Fork are presented in this paper as a point of reference, as are the ambient water-quality recommendations issued by the U.S. Environmental Protection Agency (2000a) to help the states establish nutrient criteria for control of nuisance algal conditions. The EPA recommendations for concentrations of two causal variables, total

nitrogen and total phosphorus, and two response variables, chlorophyll a and turbidity, are based on ecoregions (Omernik, 1996) to account for natural variations in water quality; ecoregions for the Yellowstone River Basin in Montana are shown in figure 1. Nitrogen and phosphorus are considered causal variables because limited supply of either phosphorus or nitrogen, or both, can hinder algal growth, and excess supply of either nutrient, or both, can result in excessive algal growth. The response variables chlorophyll a and turbidity are considered potential indicators of excessive algal growth. Chlorophyll a is a measure of algal biomass or standing crop. Turbidity is a measurement of light penetration through a water sample, and is influenced by phytoplankton, inorganic particles such as clay and silt, and other materials such as dissolved organic matter.

Purpose and Scope

The U.S. Geological Survey is conducting various studies in the Yellowstone River basin under the NAWQA program (Miller and Quinn, 1997, and http://wy.water.usgs.gov/YELL/index.htm. The purpose of this report is to describe the design of one of the studies and present preliminary results. Eleven sampling sites were located on the main stem of the Yellowstone River, spanning almost 1,000 kilometers and bracketing major tributaries (fig. 1). Sampling sites also were located on the major tributaries near their confluence with the Yellowstone River and at selected NAWQA sites (SB1, BH1, and LP1) (fig. 1). Table 1 lists the samples and measurements at each site; only the preliminary results are described here. Additional data presentation and interpretation are planned to meet the objectives of this study, which are:

- Evaluate the trophic condition of the Yellowstone River using chemical and biological indicators of eutrophication,
- Understand sources of nutrient enrichment and biological responses associated with tributary inflows and land-use practices, and

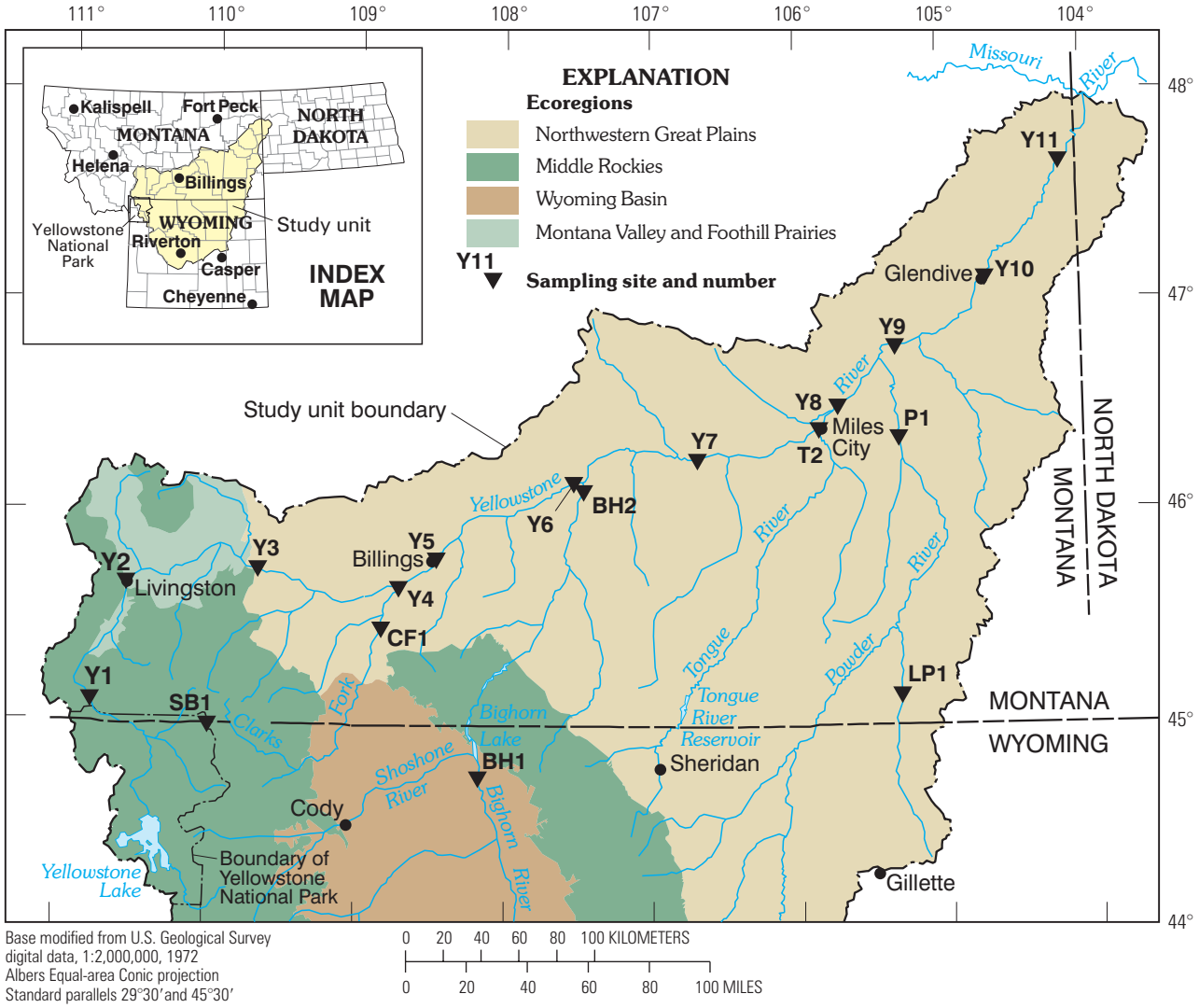

Figure 1. Location of sampling sites for Yellowstone River study, August 2000. Ecoregions are based on patterns of land use, land surface form, potential natural vegetation, and soils (modified from Omernik, 1996).

- Compare biological indicators of river quality in 2000 with those representing water-quality conditions present in the mid-1970s to determine whether any changes have occurred in the trophic condition of the Yellowstone River during the past few decades.

Nutrients

Total nitrogen (TN) concentrations in the main stem of the Yellowstone River were relatively unchanged throughout the length of the river during August 2000 (fig. 2), while total phosphorus (TP) concentrations increased slightly in the downstream direction. Most of the nutrient concentrations shown in figure 2 exceeded voluntary criteria of 0.300 milligrams per liter (mg/L) TN and 0.020 mg/L TP set by the Tri-State Council to control nuisance algal growths of *Cladophora* in the Clark Fork River, Montana (tributary to the Columbia River) (Watson and others, 2000). Some of the nutrient concentrations in the Yellowstone River also exceeded the ecoregion specific criteria recommended by the U.S. Environmental Protection Agency (2000a). For example, the TP concentration from the Yellowstone River at site Y1 (table 2) exceeded the proposed TP criterion of 0.015 mg/L for the Middle Rockies ecoregion, and the TP concentration from the Yellowstone River at site Y2 exceeded the proposed TP criterion of 0.010 mg/L for the Montana Valley and Foothill Prairies ecoregion. The concentrations of TN at sites Y1 and Y2 were less than the proposed criteria for their respective ecoregions. Other than sites Y1 and Y2, the sites on the main stem of the Yellowstone River are located in the Northwestern Great Plains ecoregion, where EPA recommendations are unavailable at this time (November 2001).

Table 1. Sampling sites and measurements for ecological synoptic, Yellowstone River Basin, August 2000
[chl a, chlorophyll a; AFDM, ash-free dry mass; NS, not sampled (no flow)]

Station name	USGS station number	Site code	Turbidity	Light extinction	Diel measure-ments	Suspended sediment	Nutrients	Periphyton taxonomy	Periphyton chl a and AFDM	Invertebrate taxonomy
Soda Butte Creek at Park boundary	06187915	SB1		X				X	X	X
Yellowstone River at Corwin Springs	06191500	Y1	X	X	X	X	X	X	X	X
Yellowstone River near Livingston	06192500	Y2	X	X	X	X	X	X	X	X
Yellowstone River at Greycliff	454634109463401	Y3		X				X	X	X
Yellowstone River at Laurel	06205200	Y4	X	X			X	X	X	X
Clarks Fork Yellowstone River	06208500	CF1	X	X	X	X	X	X	X	X
Yellowstone River at Billings	06214500	Y5	X	X	X	X	X	X	X	X
Yellowstone River at Custer	06218000	Y6	X	X	X		X	X	X	X
Bighorn River at Kane	06279500	BH1		X				X	X	X
Bighorn River at mouth	06294500	BH2	X	X	X	X	X	X	X	
Yellowstone River at Forsyth	06295000	Y7	X	X	X	X	X	X	X	X
Tongue River at mouth	06308500	T2	X	X		X	X	X	X	
Yellowstone River at Miles City	06309000	Y8	X	X	X	X	X	X	X	X
Little Powder River above Dry Creek	06324970	LP1	NS	NS		NS		NS	NS	
Powder River at Locate	06326500	P1	NS	NS		NS	NS	NS	NS	
Yellowstone River near Terry	06326530	Y9	X	X	X		X	X	X	X
Yellowstone River at Glendive	06327500	Y10	X	X			X	X	X	X
Yellowstone River near Sidney	06329500	Y11	X	X	X	X	X	X	X	X

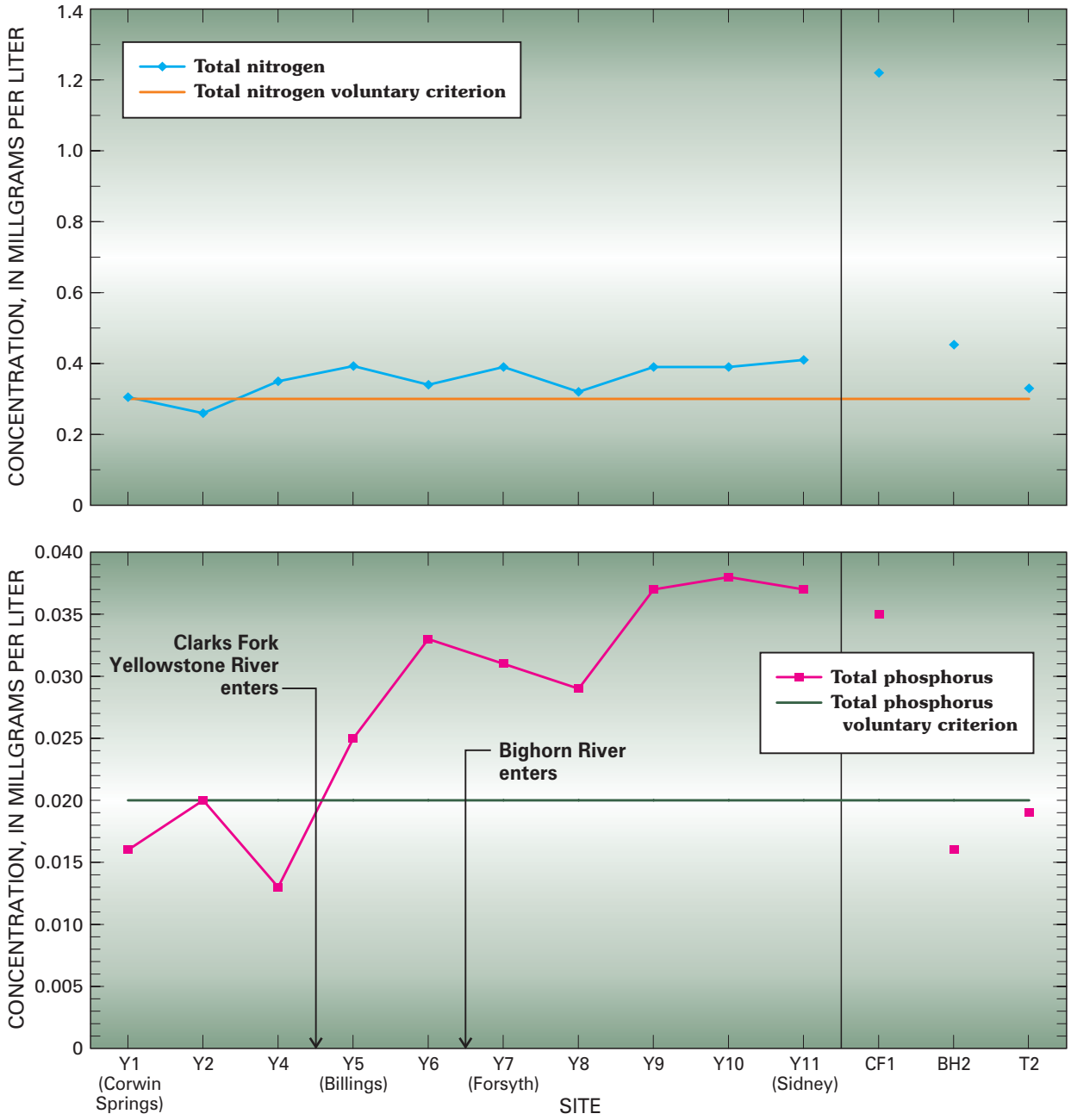

Figure 2. Nutrient concentrations in the Yellowstone River and selected tributaries, August 2000. Voluntary criteria for control of nuisance algal growths in the Clark Fork River, Montana (Watson and others, 2000) are shown for reference.

Table 2. Proposed algal-nutrient criteria for selected ecoregions in the Yellowstone River Basin

[mg/L, milligrams per liter; NTU, Nephelometric Turbidity Units; μg/L, micrograms per liter; mg/m^2, milligrams per square meter; MR, Middle Rockies; MVFP, Montana Valley and Foothill Prairies; WB, Wyoming Basin]

Site	Ecoregion	Total nitrogen (mg/L)		Total phosphorus (mg/L)		Turbidity (NTU)		Plankton chlorophyll a (μg/L)		Periphyton chlorophyll a (mg/m^2)	
		Aug. 2000	[1]Proposed criterion	Aug. 2000	[1]Proposed criterion	Aug. 2000	[1]Proposed criterion	Aug. 2000	[1]Proposed criterion	Aug. 2000	[1]Proposed criterion
Y1	MR	0.305	0.34	0.016	0.015	1.5	0.5	1.4	1.42	25.0	[2]33
Y2	MVFP	0.260	0.30	0.020	0.010	2.8	1.0	38.6	[2]1.08	18.9	[2]33
BH1	WB	1.23	0.368	0.095	0.022	66	4.2	18.3	[2]1.78	50.9	[2]43.9

[1]Proposed criteria from U.S. Environmental Protection Agency (2000a)
[2]Criterion for aggregate ecoregion is shown because specific criterion is not available.

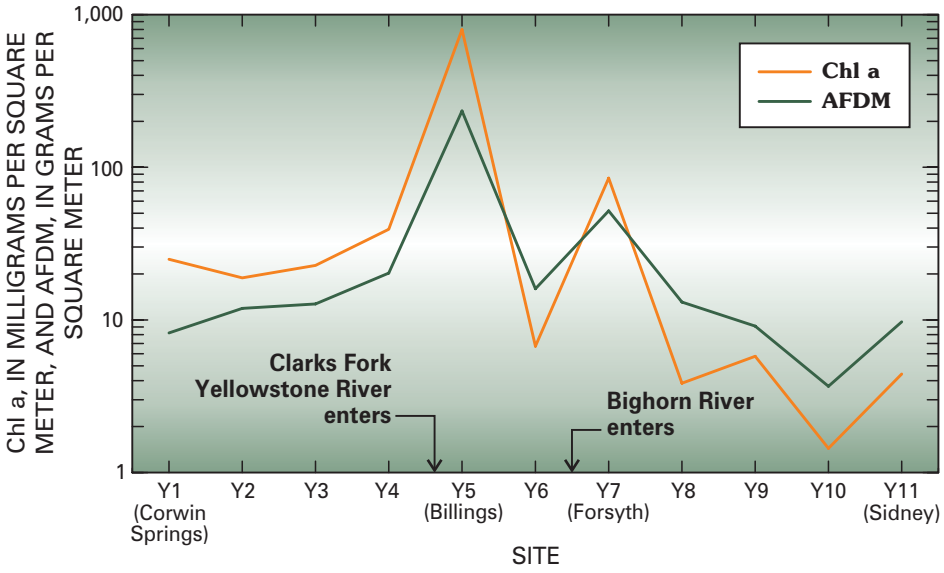

Figure 3. Periphyton chlorophyll a (chl a) and ash-free dry mass (AFDM), August 2000.

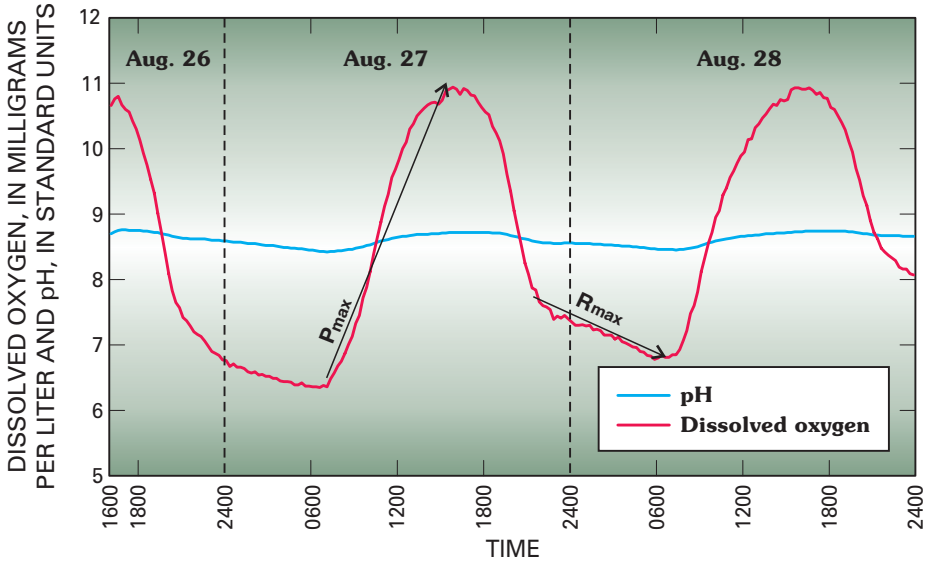

Figure 4. Diel fluctuations in dissolved oxygen concentration and pH in the Yellowstone River at Custer, site Y6, August 26-28, 2000 (P_{max}, dissolved oxygen production, R_{max}, respiration).

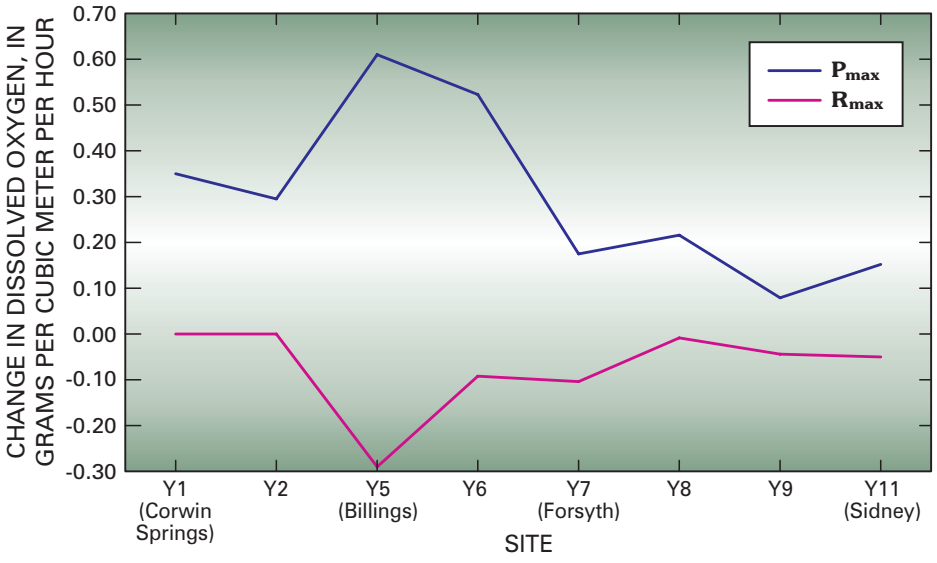

Figure 5. Rates of dissolved oxygen production (P_{max}) and respiration (R_{max}), August 2000.

Algal Standing Crop

The standing crop of periphyton in the Yellowstone River, as indicated by chlorophyll a and ash-free dry mass (AFDM) concentrations (fig. 3), was highest in the middle segments of the river near Billings (site Y5) and Forsyth (site Y7). The peaks in standing crop might be a reflection of inflows from the Clarks Fork Yellowstone River (site CF1), which joins the main stem between sites Y4 and Y5, and the Bighorn River, which joins the main stem between sites Y6 and Y7. The filamentous green algae *Cladophora glomerata* was noted during the sampling at many of the sites and was particularly abundant at sites Y5, Y7, and CF1. The chlorophyll concentration of 797 mg/m^2 (milligrams per square meter) in the Yellowstone River at Billings (site Y5), 114 mg/m^2 in the Clarks Fork Yellowstone River (site CF1), and 164 mg/m^2 in the Bighorn River (site BH2) were in the range of or exceeded the 100 to 200 mg/m^2 chlorophyll a concentration suggested as an indicator of nuisance algal conditions (U.S. Environmental Protection Agency, 2000b). Periphyton chlorophyll a concentrations from sites Y1 and Y2 were less than the Aggregate Nutrient Ecoregion II proposed criterion of 33 mg/m^2 (U.S. Environmental Protection Agency, 2000a). Aggregate Nutrient Ecoregion II, the Western Forested Mountains, contains the Middle Rockies, the Montana Valley and Foothill Prairies, and other level III ecoregions in the western United States.

Algal Productivity

Algal productivity and respiration were highest in the middle segments of the main stem Yellowstone River. Data sondes were deployed for about 48 hours at selected sites to record dissolved oxygen and pH at 15-minute intervals. The linear portions of the diel curves (for example,

fig. 4) were used to estimate P_{max} (the maximum rate of production) and R_{max} (the maximum rate of respiration). The highest value for P_{max} in the Yellowstone River was 0.61 grams O_2/cubic meter/hour at site Y5 in Billings (fig. 5). The R_{max} also was highest at site Y5 (fig. 5), consistent with the highest standing crop of periphyton.

Where Do We Go From Here?

Preliminary results indicate relatively high algal standing crop and productivity in the middle segments of the Yellowstone River during August 2000. Those algal factors appear to be uncorrelated to the total nitrogen and total phosphorus concentrations, indicating that the algal factors provide a more sensitive measure of nutrient influx to the system than instantaneous sampling of total nutrient concentrations in the water column, at least for the snapshot provided by the August 2000 data. Additional analyses that may help to understand the trophic status and functioning of the river include evaluation of seasonal nutrient data, examination of algal and invertebrate community structure and autecology, and study of interrelationships of those factors with other physical and chemical factors such as turbidity and suspended sediment.

Quiet water on the Yellowstone River below the mouth of the Bighorn River.

- *By David A. Peterson, Stephen D. Porter, and S.M. Kinsey*
  Layout and final illustrations by Suzanne C. Roberts

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