

Prepared in cooperation with the Montana Department of Environmental Quality

Algal and Water-Quality Data for the Yellowstone River and Tributaries, Montana and Wyoming, 1999–2000



Data Series 484

Cover. Upper right: View looking downstream in the Yellowstone River at Corwin Springs (site Y1). Photograph by Gregory K. Boughton, U.S. Geological Survey.
Lower left: Quiet water on the Yellowstone River below the mouth of the Bighorn River. Photograph by Stephen D. Porter, U.S. Geological Survey.

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By David A. Peterson

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Data Series 484

**U.S. Department of the Interior
U.S. Geological Survey**

U.S. Department of the Interior
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U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
square meter (m ²)	10.76	square foot (ft ²)
cubic meter (m ³)	264.2	gallon (gal)
liter (L)	61.02	cubic inch (in ³)
cubic meter (m ³)	35.31	cubic foot (ft ³)
gram (g)	0.03527	ounce, avoirdupois (oz)

Abbreviations

cm	centimeter
g/m ²	gram per square meter
g/m ³ /hr	gram per cubic meter per hour
m	meter
P _{max}	maximum rate of dissolved-oxygen production
R ²	coefficient of determination
R _{max}	maximum rate of dissolved-oxygen respiration
µg/L	microgram per liter
mg/m ²	milligram per square meter
AFDM	ash-free dry mass
NAWQA	National Water-Quality Assessment
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
PAR	photosynthetically available radiation
USGS	U.S. Geological Survey
WWSC	Wyoming Water Science Center
YELL	Yellowstone River Basin study unit of the NAWQA Program

Algal and Water-Quality Data for the Yellowstone River and Tributaries, Montana and Wyoming, 1999–2000

By David A. Peterson

Abstract

Streams of the Yellowstone River Basin in Montana and Wyoming were sampled as part of the U.S. Geological Survey's National Water-Quality Assessment Program. Algal communities were sampled in 1999 in conjunction with other ecological sampling and in 2000 during synoptic sampling. Water-quality measurements related to the algal sampling included light attenuation and dissolved-oxygen concentrations. Sites were sampled on the main-stem Yellowstone River, major tributaries such as the Clarks Fork Yellowstone River and the Bighorn River, and selected minor tributaries. Some of the data collected, such as the phytoplankton chlorophyll-*a* data, were referenced or summarized in previous U.S. Geological Survey reports but were not previously published in tabular form, and therefore are presented in this report, prepared in cooperation with the Montana Department of Environmental Quality. Data presented in this report include chlorophyll-*a* concentrations in phytoplankton and periphyton samples, as well as light attenuation and dissolved-oxygen production data from 1999–2000.

Introduction

At low to moderate concentrations, algae are an integral part of a healthy stream ecosystem (Peterson and others, 2001). 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.

An ecological and water-quality investigation of streams in the Yellowstone River Basin in Montana and Wyoming was conducted as part of the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program (<http://water.usgs.gov/nawqa/>). This investigation was conducted to provide insight into ecological variability over time, the role that water quality plays in community structure and stability, and differences with respect to various environmental settings (Miller and Quinn, 1997). Sampling in the basin (named study unit YELL) was designed to be more frequent and included more sites during 1999–2001 (the high-intensity phase) than from 2002 to present (2009; Miller and Quinn, 1997). The results of the high-intensity phase indicated that the water quality of streams in the YELL was influenced largely by natural factors, although some anthropogenic effects were noted (Peterson and others, 2004). Several topical reports were published on the YELL, including a description of water quality at 10 fixed stations, or high-intensity water-quality sites (Miller and others, 2005), and a summary of biological and chemical indicators of nutrient enrichment in the main-stem Yellowstone River (Peterson and others, 2001; Peterson and Porter, 2002).

Most of the ecological sampling in the YELL investigation occurred during 1998–2000. The ecological sampling focused on fish-tissue and bed-sediment chemistry in 1998; algal, macroinvertebrate, and fish communities, and aquatic habitat in 1999; and algal and macroinvertebrate communities in 2000. During 1999, the ecological sampling included collection of periphyton (algae attached to substrates such as rocks) at 10 fixed stations. During 2000, the ecological sampling included collection of periphyton and phytoplankton (algae suspended in the water column) at fixed stations and at nine other sites on the main-stem Yellowstone River and tributaries during a synoptic sampling event (Peterson and others, 2001). Water-quality measurements related to the algal sampling during 1999–2000 included light attenuation and dissolved-oxygen concentrations. Samples for additional water-quality constituents were collected and analyzed during 1999 to present (2009). Ecological sampling was reduced to one or two sites per year starting in 2001 and continuing to the present (2009).

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Although most of the data from the Yellowstone River Basin investigation have been published and are available online from USGS databases, some of the algal and water-quality data collected in 1999–2000 were not previously published in tabular form and therefore, are included in this report, prepared in cooperation with the Montana Department of Environmental Quality. Chlorophyll-*a* and ash-free dry mass (AFDM) concentrations in algae from 1999–2000 are included in this report; chlorophyll-*a* and AFDM concentrations from 2001 to present (2009) are available from two online USGS databases: the NAWQA data warehouse at <http://water.usgs.gov/nawqa/data> and the National Water Information System (NWIS) at <http://waterdata.usgs.gov/wy/nwis/qw>. Water-quality data associated with the YELL sampling, such as bacteria, trace element, nutrient, major ion, volatile organic compound, and pesticide analyses from the USGS National Water Quality Laboratory (NWQL), are available from the NAWQA data warehouse and NWIS. Taxonomic data for algae, macroinvertebrates, and fish communities sampled in the YELL from 1999 to present are available from the NAWQA data warehouse. Additional information about the YELL investigation and associated publications are available at <http://wy.water.usgs.gov/YELL/index.htm>.

Purpose and Scope

The purpose of this report is to present algal and water-quality data collected from the Yellowstone River and tributaries during 1999–2000 that were referenced or summarized in previous USGS reports but were not otherwise available. Most of the data presented are for chlorophyll-*a* concentrations in either phytoplanktonic algae or periphytic algae. Other data presented include AFDM in periphyton, dry mass in macroalgae samples, light attenuation, and dissolved-oxygen production.

Methods of Sampling and Analysis

Algal and water-quality samples were collected from 11 sites on the main-stem Yellowstone River and from 5 selected tributaries (fig. 1). Sampling sites and corresponding data types included in this report are listed in table 1.

Samples of phytoplankton were collected at the same time as water-quality samples by using width- and depth-integrated techniques described by Shelton (1994). Aliquots of the samples were filtered, preserved on dry ice, and shipped to the USGS Wyoming Water Science Center (WWSC) for analysis of chlorophyll-*a* by using the fluorometric method described by Arar and Collins (1992). For quality-assurance purposes, a subset of replicate phytoplankton samples were split and sent to the NWQL for similar analysis by the fluorometric method.

Samples of periphyton were collected by scraping the top surface of representative rocks in riffle areas, using techniques described by Porter and others (1993). Aliquots

of the periphyton samples were processed and analyzed for chlorophyll-*a* by the WWSC following the same techniques as for the phytoplankton samples. In addition, the periphyton samples were analyzed for AFDM by the WWSC following methods described by the American Public Health Association (1980).

Samples of *Cladophora glomerata*, a filamentous green algae hereafter referred to as macroalgae, generally were collected from five or more representative locations at selected stream reaches by using a 0.25-square-meter (m²) standard sampling area. Macroalgae samples were preserved on ice and shipped to the WWSC for determination of dry mass by using techniques described by the American Public Health Association (1980).

Light attenuation was measured in the field by using a quantum-light sensor to measure photosynthetically available radiation. At each site, vertical profiles of light readings at 10-centimeter intervals were recorded to estimate the depth of the photic zone, or the zone where sufficient light existed for photosynthesis.

Dissolved-oxygen production was estimated by using the techniques described by Sorenson and others (1999). Dissolved-oxygen concentrations were measured in the stream at 15-minute intervals for a minimum of 48 hours. The linear portion of the dissolved-oxygen curve during the daytime hours was used to estimate P_{\max} , the maximum rate of dissolved-oxygen production. Similarly, the linear portion of the dissolved-oxygen curve during the nighttime hours was used to estimate R_{\max} , the maximum rate of dissolved-oxygen respiration. Although P_{\max} and R_{\max} are used according to the convention of Sorenson and others (1999), this technique does not remove the effect of reaeration arising from differences in oxygen saturation between the stream and the atmosphere (Odum, 1956). Thus, these values represent relative rather than actual measures of stream metabolism.

Algal Data

Concentrations of chlorophyll-*a* in phytoplankton samples analyzed at the WWSC laboratory are listed in table 2. Phytoplankton samples were collected at fixed sites approximately monthly during February to December 2000; data from a synoptic sampling event in August 2000 also are listed in table 2. Concentrations of chlorophyll-*a* in phytoplankton samples ranged from 0.2 to 38.6 micrograms per liter, with the largest concentration measured at the Yellowstone River near Livingston, Montana (site Y2, station 06192500).

Some of the phytoplankton samples were split and analyzed for chlorophyll-*a* at both the WWSC laboratory and the NWQL as part of quality-assurance procedures. Concentrations of chlorophyll-*a* measured in the split samples are listed in table 3. The correlation of concentrations of chlorophyll-*a*

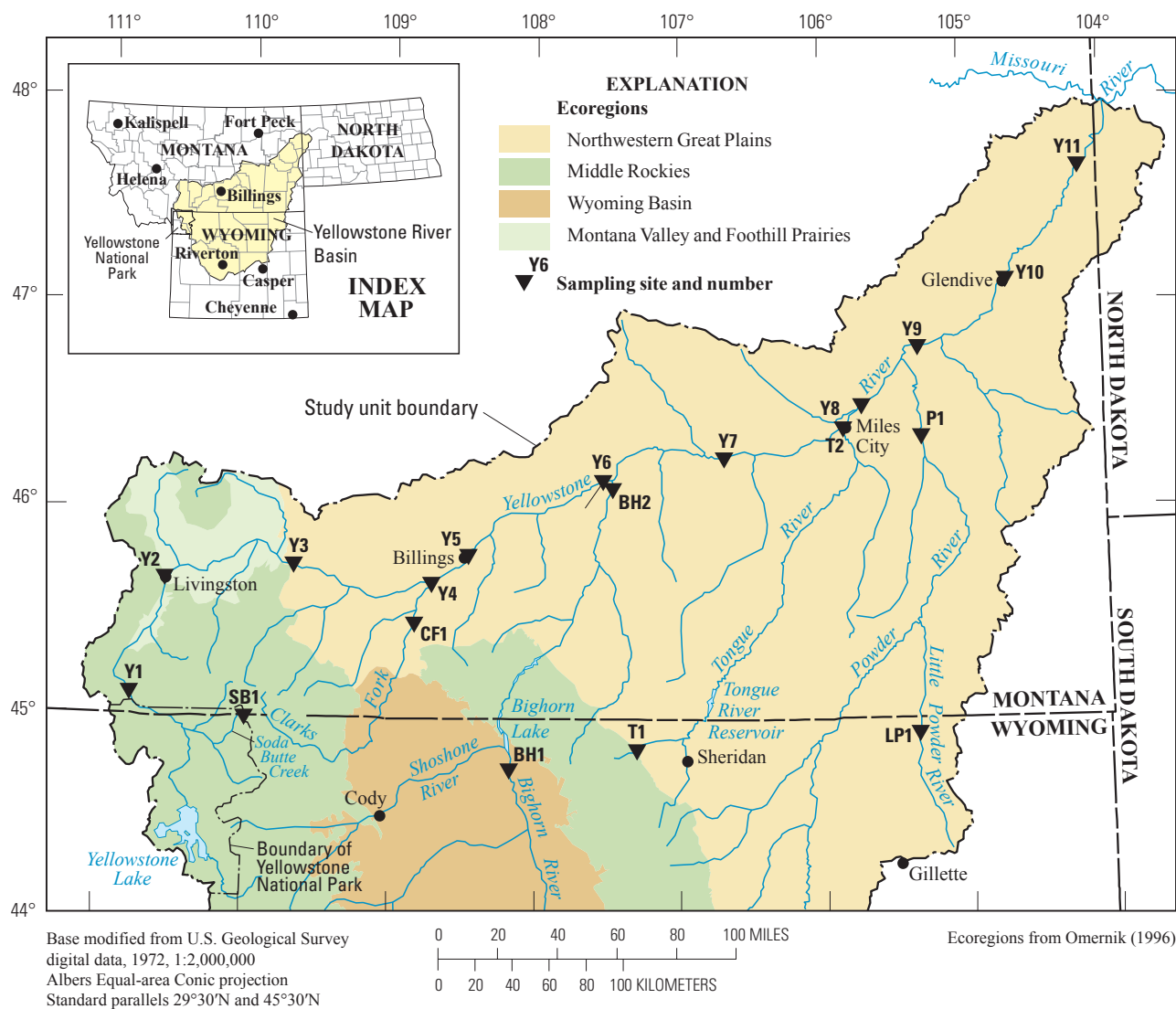


Figure 1. Locations of sampling sites for algae and water quality, Yellowstone River and tributaries, Montana and Wyoming, 1999–2000.

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Table 1. Sampling sites and data types listed in this report, Yellowstone River and tributaries, Montana and Wyoming, 1999–2000.

[Shaded cells indicate fixed sites; X, sample or measurement was made; NS, sample not collected or measurement not made]

Station identification number	Station name	Site number (fig. 1)	Phytoplankton chlorophyll- <i>a</i>	Periphyton chlorophyll- <i>a</i> and ash-free dry mass	Macroalgae dry weight	Light extinction	Dissolved-oxygen production
06187915	Soda Butte Creek at park boundary, at Silver Gate, Mont.	SB1	X	X	NS	X	NS
06191500	Yellowstone River at Corwin Springs, Mont.	Y1	X	X	NS	X	X
06192500	Yellowstone River near Livingston, Mont.	Y2	X	X	X	X	X
454634109463401	Yellowstone River at Greycliff, Mont.	Y3	NS	X	X	X	NS
06205200	Yellowstone River at Laurel, Mont.	Y4	NS	X	X	X	NS
06208500	Clarks Fork Yellowstone River at Edgar, Mont.	CF1	X	X	NS	X	X
06214500	Yellowstone River at Billings, Mont.	Y5	X	X	X	X	X
06218000	Yellowstone River at Custer, Mont.	Y6	NS	X	X	X	X
06279500	Bighorn River at Kane, Wyo.	BH1	X	X	NS	X	NS
06294500	Bighorn River above Tullock Creek, near Bighorn, Mont.	BH2	NS	X	NS	X	X
06295000	Yellowstone River at Forsyth, Mont.	Y7	X	X	X	X	X
06298000	Tongue River near Dayton, Wyo.	T1	X	X	NS	X	NS
06308500	Tongue River at Miles City, Mont.	T2	X	X	NS	X	NS
06309000	Yellowstone River at Miles City, Mont.	Y8	X	X	X	X	X
06324970	Little Powder River above Dry Creek, near Weston, Wyo.	LP1	X	X	NS	X	NS
06326500	Powder River at Locate, Mont.	P1	X	X	NS	X	NS
06326530	Yellowstone River near Terry, Mont.	Y9	X	X	NS	X	X
06327500	Yellowstone River at Glendive, Mont.	Y10	X	X	NS	X	NS
06329500	Yellowstone River near Sidney, Mont.	Y11	X	X	NS	X	X

Table 2. Concentrations of chlorophyll-*a* in phytoplankton samples analyzed at the U.S. Geological Survey Wyoming Water Science Center laboratory, Yellowstone River and tributaries, Montana and Wyoming, 2000.[$\mu\text{g/L}$, micrograms per liter]

Station identification number	Site number (fig. 1)	Sample date	Chlorophyll- <i>a</i> , ($\mu\text{g/L}$)	Station identification number	Site number (fig. 1)	Sample date	Chlorophyll- <i>a</i> , ($\mu\text{g/L}$)
06187915	SB1	2/08/2000	0.4	06208500	CF1	2/09/2000	3.2
		3/14/2000	.9			3/14/2000	7.1
		4/10/2000	1.7			4/12/2000	4.0
		5/16/2000	1.2			6/23/2000	1.2
		5/25/2000	1.3			7/10/2000	4.2
		6/07/2000	1.0			8/14/2000	3.0
		6/27/2000	.5			9/26/2000	6.8
		7/11/2000	.8			10/03/2000	32.2
		8/15/2000	.5			10/31/2000	7.2
		9/27/2000	1.9			11/17/2000	1.8
		10/23/2000	.5			12/13/2000	3.6
		11/29/2000	.5				
12/18/2000	.2						
06191500	Y1	2/09/2000	1.7	06214500	Y5	2/07/2000	3.7
		3/15/2000	.9			3/13/2000	2.1
		4/11/2000	2.0			4/05/2000	2.5
		5/15/2000	1.3			6/09/2000	1.7
		5/25/2000	2.2			6/23/2000	1.2
		6/08/2000	1.1			7/10/2000	2.6
		6/27/2000	1.0			8/14/2000	2.8
		7/11/2000	1.2			9/26/2000	5.5
		8/15/2000	.9			10/30/2000	5.6
		8/23/2000	1.4			11/16/2000	3.3
		09/27/2000	1.3			12/13/2000	4.7
		10/23/2000	2.3				
		11/29/2000	3.6				
12/19/2000	2.5						
06192500	Y2	8/22/2000	38.6	06279500	BH1	3/21/2000	1.2
						4/20/2000	7.9
						5/09/2000	6.6
						6/20/2000	6.6
						7/18/2000	28.9
						8/07/2000	12.4
						8/15/2000	18.3
						9/11/2000	8.0
						10/12/2000	2.0
						11/29/2000	.6
		12/28/2000	1.0				

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Table 2. Concentrations of chlorophyll-*a* in phytoplankton samples analyzed at the U.S. Geological Survey Wyoming Water Science Center laboratory, Yellowstone River and tributaries, Montana and Wyoming, 2000.—Continued

[$\mu\text{g/L}$, micrograms per liter]

Station identification number	Site number (fig. 1)	Sample date	Chlorophyll- <i>a</i> , ($\mu\text{g/L}$)	Station identification number	Site number (fig. 1)	Sample date	Chlorophyll- <i>a</i> , ($\mu\text{g/L}$)
06295000	Y7	2/23/2000	3.1	06324970	LP1	3/06/2000	3.4
		3/22/2000	1.6			4/05/2000	1.6
		4/06/2000	3.1			5/17/2000	11.3
		5/24/2000	7.6			6/08/2000	9.7
		6/10/2000	2.4			7/13/2000	4.6
		6/26/2000	3.4			8/01/2000	3.6
		7/07/2000	6.8			8/16/2000	3.6
		8/16/2000	6.9			9/12/2000	8.0
		9/25/2000	3.1			10/16/2000	4.4
		10/26/2000	7.0			10/25/2000	1.8
		11/27/2000	4.0			11/15/2000	2.1
12/12/2000	2.8	12/12/2000	1.1				
06298000	T1	3/07/2000	1.3	06326500	P1	2/03/2000	3.3
		4/04/2000	1.5			4/06/2000	4.3
		5/05/2000	1.1			6/12/2000	13.2
		6/09/2000	1.0			7/06/2000	15.5
		7/12/2000	1.0			8/16/2000	.8
		8/02/2000	.7			9/25/2000	6.3
		9/12/2000	1.0			10/25/2000	6.5
		10/23/2000	.6			11/28/2000	1.1
		11/28/2000	.5			12/14/2000	.7
06308500	T2	8/26/2000	2.5	06326530	Y9	8/26/2000	5.3
06309000	Y8	8/26/2000	6.0	06327500	Y10	8/25/2000	5.7
06329500	Y11	2/02/2000	1.1	06329500	Y11	2/02/2000	1.1
		3/21/2000	8.1			3/21/2000	8.1
		6/05/2000	5.0			6/05/2000	5.0
		8/07/2000	12.0			8/07/2000	12.0
		8/22/2000	7.3			8/22/2000	7.3
		8/24/2000	7.5			8/24/2000	7.5
		9/06/2000	6.1			9/06/2000	6.1
10/25/2000	10.3	10/25/2000	10.3				
12/07/2000	.4	12/07/2000	.4				

between the two laboratories was high, as indicated by the coefficient of determination (R^2) value of 0.99 (fig. 2).

Concentrations of chlorophyll-*a* and AFDM in periphyton samples are listed in table 4. Periphyton samples generally were collected at fixed stations during three time periods: August–September 1999, March–May 2000, and August–September 2000. Periphyton samples also were collected at several additional sites on the main-stem Yellowstone River and sites on the Bighorn River and Tongue River near the confluences of these rivers with the Yellowstone River during the synoptic sampling in August 2000 (table 4). Concentrations of chlorophyll-*a* in periphyton ranged from 1.4 to

797 milligrams per square meter (mg/m^2), with the largest concentration measured at the Yellowstone River at Billings, Montana (site Y5, station 06214500).

Macroalgae (mainly *Cladophora*) were sampled at several sites on the main-stem Yellowstone River during the synoptic sampling event in August 2000 (table 5). The dry weight of macroalgae was greatest (490 grams per square meter) in the Yellowstone River at Billings, Montana (site Y5, station 06214500), which also is the site where the maximum concentration of periphytic chlorophyll-*a* was measured in August 2000.

Table 3. Concentrations of chlorophyll-*a* in phytoplankton samples split between the U.S. Geological Survey Wyoming Water Science Center laboratory and the U.S. Geological Survey National Water Quality Laboratory, Yellowstone River and tributaries, Montana and Wyoming, 2000.

[WWSC, Wyoming Water Science Center laboratory; NWQL, National Water Quality Laboratory; $\mu\text{g}/\text{L}$, micrograms per liter]

Station identification number	Site number (fig. 1)	Sample date	Chlorophyll- <i>a</i> , WWSC ($\mu\text{g}/\text{L}$)	Chlorophyll- <i>a</i> , NWQL ($\mu\text{g}/\text{L}$)
06187915	SB1	10/23/2000	0.5	0.5
06191500	Y1	10/23/2000	2.3	2.3
06208500	CF1	10/3/2000	32.2	24.0
06208500	CF1	10/31/2000	7.2	5.8
06208500	CF1	11/17/2000	1.8	1.8
06214500	Y5	10/30/2000	5.6	5.4
06214500	Y5	11/16/2000	3.3	2.7
06295000	Y7	11/27/2000	4.0	3.2
06326500	P1	10/25/2000	6.5	7.7
06326500	P1	11/28/2000	1.1	1.2

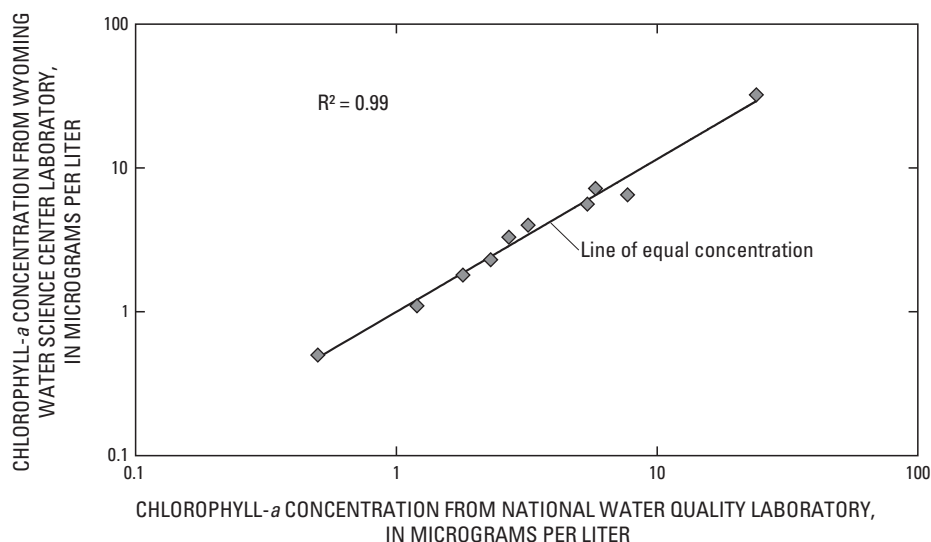


Figure 2. Correlation of chlorophyll-*a* concentrations in phytoplankton samples split between the U.S. Geological Survey Wyoming Water Science Center laboratory and the U.S. Geological Survey National Water Quality Laboratory, Yellowstone River and tributaries, 2000.

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Table 4. Concentrations of chlorophyll-*a* and ash-free dry mass in periphyton samples, Yellowstone River and tributaries, Montana and Wyoming, 1999–2000.

[mg/m²; milligrams per square meter; g/m², grams per square meter]

Station identification number	Site number (fig. 1)	Sample date	Chlorophyll- <i>a</i> (mg/m ²)	Ash-free dry mass (g/m ²)
06187915	SB1	9/12/1999	22.9	22.6
06187915	SB1	5/16/2000	84.9	25.1
06187915	SB1	8/23/2000	20.6	16.3
06191500	Y1	9/14/1999	19.2	13.5
06191500	Y1	4/11/2000	139	23.9
06191500	Y1	8/23/2000	25.0	8.2
06192500	Y2	8/22/2000	18.9	11.9
454634109463401	Y3	8/22/2000	22.8	12.7
06205200	Y4	8/23/2000	39.2	20.3
06208500	CF1	9/8/1999	28.4	19.5
06208500	CF1	3/30/2000	44.5	15.8
06208500	CF1	8/23/2000	114	29.4
06214500	Y5	9/10/1999	52.0	35.2
06214500	Y5	3/27/2000	78.7	39.7
06214500	Y5	8/21/2000	797	234
06218000	Y6	8/24/2000	6.7	16.0
06279500	BH1	9/1/1999	89.0	58.7
06279500	BH1	3/30/2000	26.0	15.8
06279500	BH1	8/27/2000	50.9	28.6
06294500	BH2	8/24/2000	164	87.8
06295000	Y7	9/23/1999	158	51.5
06295000	Y7	3/29/2000	36.4	14.6
06295000	Y7	8/25/2000	84.9	51.8
06298000	T1	8/30/1999	13.1	25.4
06298000	T1	3/28/2000	31.7	14.7
06298000	T1	9/26/2000	6.9	9.2
06308500	T2	8/26/2000	33.0	21.9
06309000	Y8	8/25/2000	3.9	13.1
06324970	LP1	9/29/1999	39.6	46.1
06324970	LP1	3/28/2000	6.1	15.0
06326500	P1	9/26/1999	3.7	8.8
06326500	P1	3/29/2000	31.1	10.0
06326530	Y9	8/26/2000	5.8	9.1
06327500	Y10	8/25/2000	1.4	3.7
06329500	Y11	9/27/1999	1.4	4.7
06329500	Y11	3/29/2000	76.0	22.7
06329500	Y11	8/24/2000	4.4	9.7

Table 5. Biomass of macroalgae, main-stem Yellowstone River, Montana, August 2000.[m², square meters; g/m², grams per square meter of substrate]

Station identification number	Site number (fig. 1)	Sample date	Area sampled (m ²)	Wet weight (g/m ²)	Dry weight (g/m ²)
06192500	Y2	8/25/2000	1.50	174	43
454634109463401	Y3	8/24/2000	1.25	358	111
06205200	Y4	8/25/2000	1.25	201	24
06214500	Y5	8/23/2000	1.50	1,910	490
06218000	Y6	8/30/2000	1.25	186	22
06295000	Y7	8/31/2000	1.25	146	40
06309000	Y8	8/31/2000	1.25	258	58

Water-Quality Data

Vertical profiles of light attenuation, measured as photosynthetically available radiation (PAR), were collected in conjunction with collection of periphyton samples. The light-attenuation data are presented in table 6 as percentages of surface light remaining at 10-centimeter intervals in the water column. A regression equation between the percentage of surface light remaining (light attenuation) and the logarithm of water depth (fig. 3) was developed for each site and sampling date (table 7). The regression equation was then used to calculate the depth of the photic zone (table 7), the zone where sufficient light is available for photosynthesis, which is traditionally defined as 1 percent of the surface light (Stevenson and others, 1996).

Diel fluctuation in dissolved-oxygen concentrations in water was recorded as a relative indicator of gross production (P_{\max}) and respiration (R_{\max}). The linear portions of the dissolved oxygen curve were used to estimate P_{\max} during daytime hours and R_{\max} during nighttime hours (fig. 4). Table 8 lists values of P_{\max} and R_{\max} from the synoptic sampling in August 2000 and from miscellaneous sampling in September and October 2000.

Summary

An ecological and water-quality investigation of streams in the Yellowstone River Basin was conducted by the U.S. Geological Survey's National Water-Quality Assessment Program. Although most of the data from the investigation have been published and are available online from USGS databases, some of the algal and water-quality data collected in 1999–2000 were not previously published in tabular form. This report, prepared in cooperation with the Montana Department of Environmental Quality, presents previously unpublished data, including chlorophyll-*a* concentrations in phytoplankton and periphyton, ash-free dry mass in periphyton, light attenuation, and dissolved-oxygen production. Related data, such as dry mass of macroalgae samples and chlorophyll-*a* concentrations from interlaboratory split samples also are presented.

Concentrations of chlorophyll-*a* in phytoplankton samples ranged from 0.2 to 38.6 micrograms per liter, with the largest concentration measured at the Yellowstone River near Livingston, Montana. Concentrations of chlorophyll-*a* in periphyton ranged from 1.4 to 797 milligrams per square meter (mg/m²), with the largest concentration measured at the Yellowstone River at Billings, Montana. The dry weight of macroalgae was greatest (490 grams per square meter) in the Yellowstone River at Billings, Montana.

Figure 3. Example of regression used to determine depth of photic zone from measurements of light attenuation with depth in water column, Yellowstone River near Sidney, Montana (station 06329500), September 27, 1999.

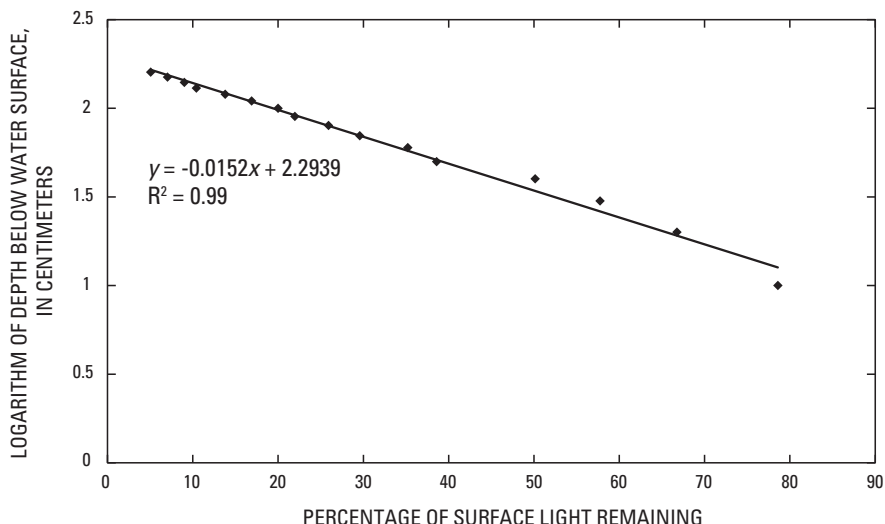


Table 7. Regression equations for relation between light attenuation and water depth used to estimate depth of photic zone, Yellowstone River and tributaries, Montana and Wyoming, 1999–2000.

[Depth, water depth in centimeters; LR, percentage of surface light remaining; R², coefficient of determination; m, meters; >, greater than]

Station identification number	Site number (fig. 1)	Sample date	Equation	R ²	Depth of photic zone (m)
06187915	SB1	9/12/1999	$\log(\text{Depth}) = -0.0247(LR) + 3.0742$	0.73	11.2
06187915	SB1	8/23/2000	$\log(\text{Depth}) = -0.0493(LR) + 5.5354$	.97	>20.0
06191500	Y1	9/14/1999	$\log(\text{Depth}) = -0.0222(LR) + 2.8271$	.96	6.4
06191500	Y1	8/23/2000	$\log(\text{Depth}) = -0.0387(LR) + 4.8140$	.96	>20.0
06192500	Y2	8/22/2000	$\log(\text{Depth}) = -0.0395(LR) + 4.3670$	.93	16.7
454634109463401	Y3	8/22/2000	$\log(\text{Depth}) = -0.0131(LR) + 2.8256$	.97	>20.0
06205200	Y4	8/23/2000	$\log(\text{Depth}) = -0.0228(LR) + 2.9994$	.99	9.5
06208500	CF1	9/8/1999	$\log(\text{Depth}) = -0.0163(LR) + 2.1046$	.96	1.2
06208500	CF1	8/23/2000	$\log(\text{Depth}) = -0.1109(LR) + 9.8038$	.68	>20.0
06214500	Y5	9/10/1999	$\log(\text{Depth}) = -0.0156(LR) + 2.4773$	.98	2.9
06214500	Y5	8/21/2000	$\log(\text{Depth}) = -0.0195(LR) + 2.7701$	.96	5.6
06218000	Y6	8/24/2000	$\log(\text{Depth}) = -0.1522(LR) + 15.000$	.97	>20.0
06279500	BH1	9/10/1999	$\log(\text{Depth}) = -0.0159(LR) + 1.6849$	.91	.5
06279500	BH1	8/27/2000	$\log(\text{Depth}) = -0.0144(LR) + 2.5290$	.84	3.3
06294500	BH2	8/24/2000	$\log(\text{Depth}) = -0.0157(LR) + 2.6312$	.98	4.1
06295000	Y7	9/23/1999	$\log(\text{Depth}) = -0.0203(LR) + 2.6191$	.98	4.0
06295000	Y7	8/25/2000	$\log(\text{Depth}) = -0.0212(LR) + 2.5490$	.98	3.4
06298000	T1	8/30/1999	$\log(\text{Depth}) = -0.0181(LR) + 2.9679$	.85	8.9
06308500	T2	8/26/2000	$\log(\text{Depth}) = -0.0198(LR) + 2.7382$	.93	5.2
06309000	Y8	8/25/2000	$\log(\text{Depth}) = -0.0153(LR) + 2.5081$	.95	3.1
06324970	LP1	9/29/1999	$\log(\text{Depth}) = -0.0129(LR) + 2.2052$	.82	1.6
06326500	P1	9/26/1999	$\log(\text{Depth}) = -0.0162(LR) + 1.7747$	.98	.6
06326530	Y9	8/26/2000	$\log(\text{Depth}) = -0.0174(LR) + 2.2651$	.91	1.8
06327500	Y10	8/25/2000	$\log(\text{Depth}) = -0.0171(LR) + 2.4216$	.99	2.5
06329500	Y11	9/27/1999	$\log(\text{Depth}) = -0.0152(LR) + 2.2939$	.99	1.9
06329500	Y11	8/24/2000	$\log(\text{Depth}) = -0.0136(LR) + 2.0994$	.99	1.2

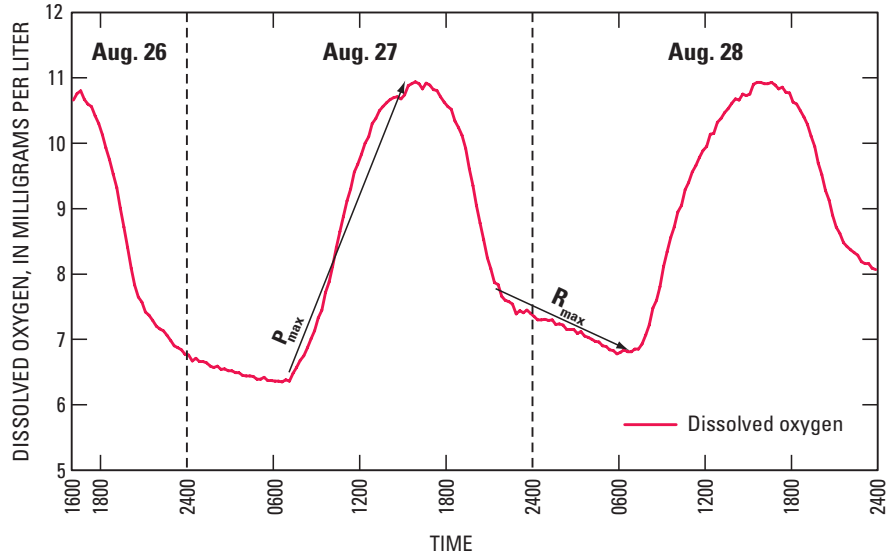


Figure 4. Example of diel fluctuations in dissolved-oxygen concentration, Yellowstone River at Custer, Montana (station 06218000), August 26–28, 2000.

Table 8. Relative rates of dissolved-oxygen production and respiration, Yellowstone River and tributaries, Montana and Wyoming, 2000.

[P_{max} , dissolved-oxygen production; g/m³/hr, grams per cubic meter per hour; R_{max} , dissolved-oxygen respiration]

Station identification number	Site number (fig. 1)	Sample date	P_{max} (g/m ³ /hr)	R_{max} (g/m ³ /hr)
06191500	Y1	Aug. 23–25, 2000	0.350	0.000
06192500	Y2	Aug. 22–24, 2000	.295	.000
06208500	CF1	Sep. 25–27, 2000	.317	.031
06208500	CF1	Oct. 18–20, 2000	.232	.033
06214500	Y5	Aug. 23–25, 2000	.610	.290
06214500	Y5	Oct. 17–20, 2000	.392	.129
06218000	Y6	Aug. 26–28, 2000	.523	.092
06294500	BH2	Aug. 26–28, 2000	.369	.243
06295000	Y7	Aug. 26–28, 2000	.175	.104
06309000	Y8	Aug. 29–30, 2000	.216	.008
06326530	Y9	Sep. 13–14, 2000	.079	.044
06329500	Y11	Aug. 28–30, 2000	.152	.050

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