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Characterization of Water Quality in Government Highline Canal at Camp 7 Diversion and Highline Lake, Mesa County, Colorado, July 2000 through September 2003

Scientific Investigations Report 2004–5281

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

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Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

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Conversion Factors and Datums

Mulitply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
meter (m)	3.281	foot (ft)
micrometer (µm)	0.0000394	inches (in)
	Area	
acre	4,047	square meter (m^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
cubic inch ($in.^3$)	16,387	cubic micrometer ($µm^3$)
liter (L)	0.2642	gallon (gal))
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8 \times °C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Additional abbreviations used in this report

col/100mL	Colonies per 100 milliliters
DOC	Dissolved organic carbon
LRL	Laboratory reporting level
LT-MDL	Long-term method detection level
NAVD88	North American Vertical Datum of 1988
N:P ratio	Nitrogen to phosphorus ratio
NWQL	National Water Quality Laboratory
NTU	Nephelometric turbidity units
TSI	Trophic status index
s.u.	Standard units
USGS	United States Geological Survey
<	Less than

Characterization of Water Quality in Government Highline Canal at Camp 7 Diversion and Highline Lake, Mesa County, Colorado, July 2000 through September 2003

By Roderick F. Ortiz

Abstract

The U.S. Geological Survey, in cooperation with the Colorado Division of Parks and Recreation, collected and analyzed water-quality data for the Government Highline Canal and Highline Lake from July 2000 through September 2003. Implementation of modernization strategies for the canal, which supplies most of the water to the lake, would decrease the amount of water spilled to Highline Lake from August through October. A reduction in spill water into Highline Lake could adversely affect the recreational uses of the lake. To address this concern and to characterize the water quality in the Government Highline Canal and Highline Lake, the U.S. Geological Survey conducted a study to evaluate limnological conditions prior to implementation of the modernization strategies.

This report characterizes the water quality of inflow from the Government Canal and in Highline Lake prior to implementation of modernization strategies in the Government Canal. Flow entering the lake from the Government Canal was characterized using field properties and available chemical, sediment, and bacteria concentrations. Data collected at Highline Lake were used to characterize the seasonal stratification patterns, water-quality chemistry, bacteria populations, and phytoplankton community structure in the lake. Data used for this report were collected at one inflow site to the lake and four sites in Highline Lake.

Highline Lake is a mesotrophic/eutrophic lake that has dimictic thermal stratification patterns. Samples collected in the photic zone indicated that there was little physical, chemical, or biological variability at this depth at any of the sampled sites in Highline Lake. Strong thermal and dissolved-oxygen stratification patterns were observed during summer. Dissolved-oxygen concentrations of less than 1 milligram per liter were observed during the summer. Ammonia likely was released from the bottom sediments of Highline Lake. The limiting nutrient in Highline Lake could be nitrogen or phosphorus.

In general, the seasonal succession of phytoplankton was similar to that of other lakes in the temperate zone. Several types of algae associated with taste and odor issues were identified in samples, but critical concentrations were not exceeded for any listed algal group with the exception of the diatom genus *Cyclotella* in one sample.

Bacteria concentrations were determined at the public swim beach at Highline Lake. *E. coli* samples were collected periodically by the USGS and weekly by the Colorado Division of Parks and Recreation. During the study period, no reported *E. coli* concentration exceeded the standard for natural swimming areas.

Inflow water quality was characterized by samples collected at the Camp 7 check structure on the Government Canal. Inflow water temperatures reflected the seasonal patterns of the source water in the Colorado River. The water was well oxygenated. Nitrogen and phosphorus concentrations were low, and concentrations did not differ substantially from year to year or seasonally within a year. All samples had reportable numbers of fecal streptococcus. The maximum reported concentration of *E. coli* was reported at 77 colonies per 100 milliliters of sample. Suspended-sediment concentrations were relatively low.

Introduction

Highline Lake is located about 20 mi northwest of Grand Junction, Colo., in an area known as the Grand Valley (fig. 1). The lake was built to address the need for more water-related recreational opportunities in the Grand Valley. Highline Lake offers quality fishing, swimming, boating, jet skiing, and water skiing to more than 250,000 visitors annually (Chris Foreman, Colorado Division of Parks and Recreation, oral commun., 2004). With a surface area of 153 acres, Highline Lake is the larger of two lakes that compose Highline Lake State Park. Maximum depths in the lake are about 50 ft, and the storage capacity is approximately 3,400 acre-ft. The smaller of the two lakes, Mack Mesa Lake, is designated for fishing and wakeless boating only. Highline Lake State Park has become one of the most popular destinations on the western slope of Colorado and the center for water sports in the Grand Valley.

The contents of Highline Lake consist almost entirely of water diverted through the Government Highline Canal (hereinafter referred to as the Government Canal) from the Colorado River near Cameo, Colo. (fig. 1). The 55-mi canal is used to convey water to irrigated farmlands northwest of Grand Junction, Colo. Excess water in the canal is siphoned directly into Highline Lake at the Camp 7 check structure just east of Highline Lake (fig. 2)

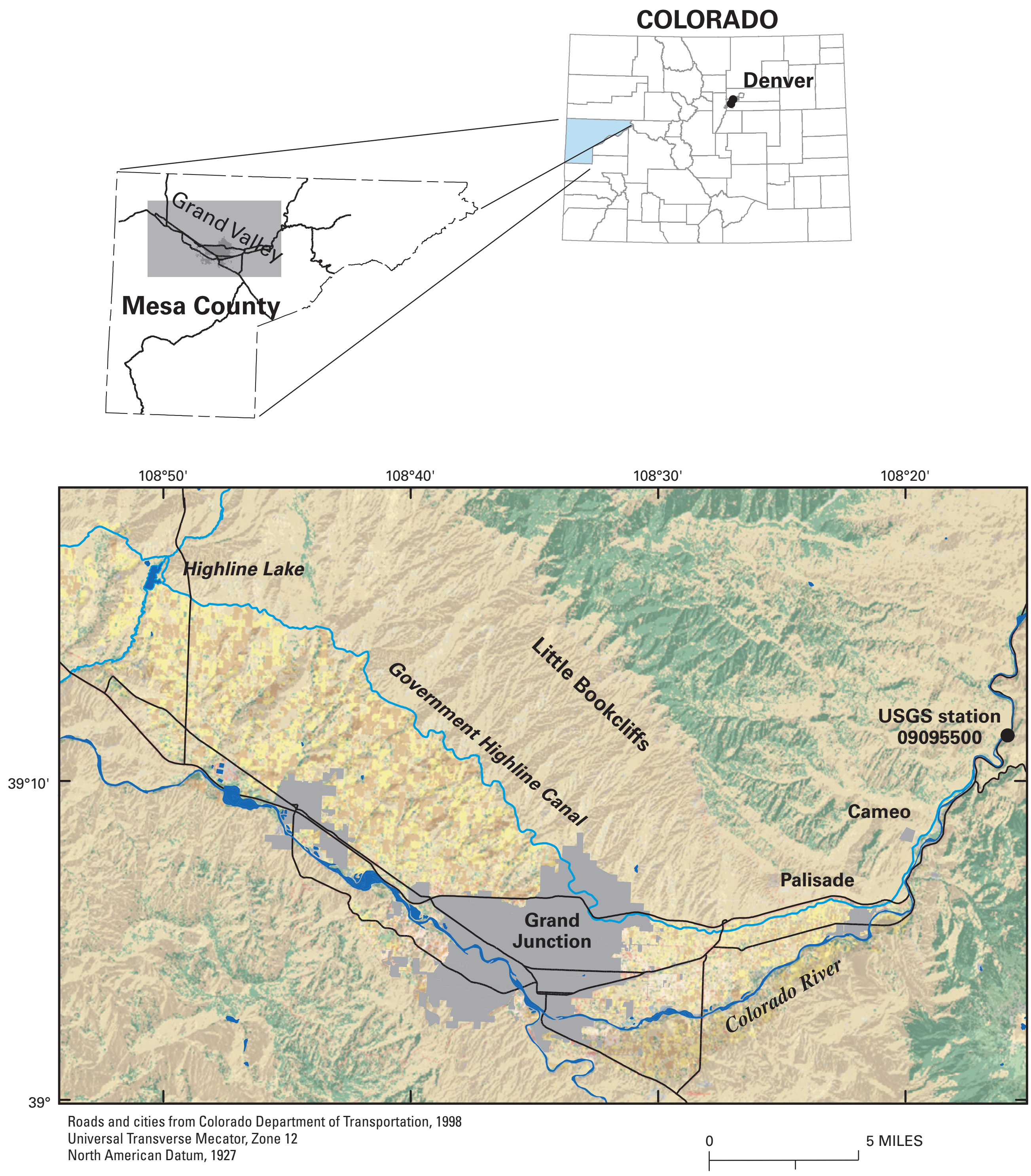
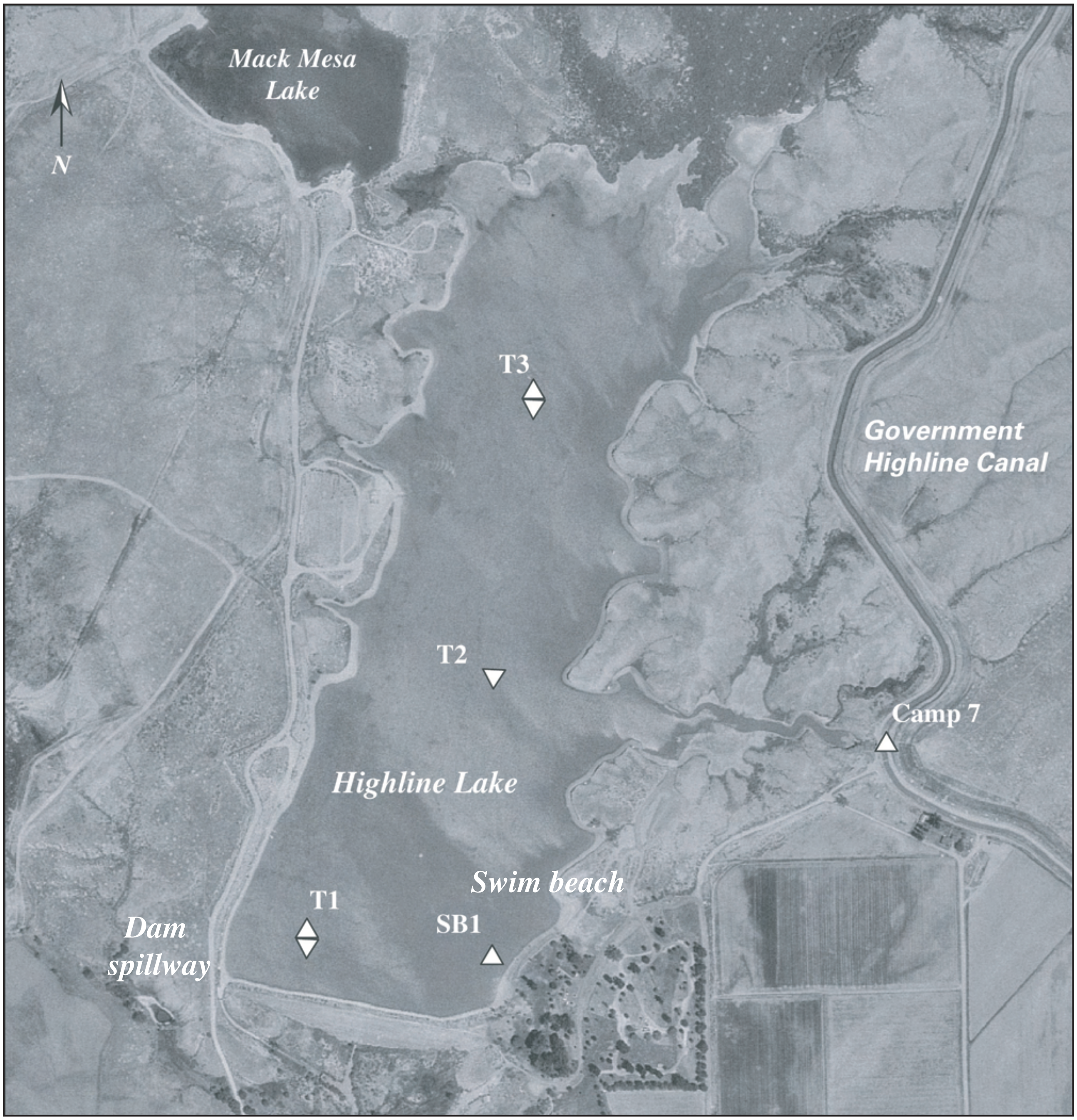


Figure 1. Location of study area.



Aerial photograph from U.S. Geological Survey, July 1, 1993

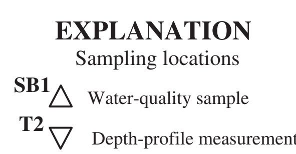


Figure 2. Highline Lake and Government Highline Canal with locations of water-quality sampling sites.

and about 35 mi from the diversion point on the Colorado River. Historically, more than 10,000 acre-ft of spill water from the Government Canal enters into Highline Lake from August through October. Depending on stratification patterns in the lake, the spill water results in short residence times of approximately 3 weeks or rapid flushing of the water in the upper stratum of the reservoir (epilimnion) above the thermocline; the thermocline refers to the plane of maximum rate of decrease of temperature with respect to depth (Wetzel, 2001). Estimates of residence time were made using daily streamflow data collected from 1995 through 1997 at Camp 7 (Rocky Dial, Bureau of Reclamation, written commun., 2003). Excess capacity in Highline Lake leaves the impoundment by spilling over the dam spillway at the south end of the lake (fig. 2) and flows downstream to the Colorado River. A fish screen was installed at the spillway of the dam to prevent nonnative species in the lake from entering the Colorado River where they pose a threat to several endangered species. Although a bottom outlet exists at the dam, it is reserved for emergency storage evacuation purposes.

The Government Canal is part of the Federal Grand Valley Project in the Colorado River Basin in west-central Colorado and is maintained and operated by the Grand Valley Water Users Association. The canal has a capacity of 1,675 ft^3/s at the diversion structure on the Colorado River. Approximately one-half of this flow is directed to the Orchard Mesa Power Canal for power generation. The remaining flow is used to irrigate about 23,300 acres of farmland along the 55-mi length of the canal (fig. 1). Typically, the canal is flushed in April or early May in preparation of the irrigation season. The canal is operated at full capacity from June until irrigation demands begin to decrease in late August. During September and October, the canal is operated at two-thirds capacity in order to keep the water surface (head) in the canal high enough to meet the irrigation demands of the higher altitude farmlands.

In 1987, the U.S. Fish and Wildlife Service identified a 15-mi reach of the Colorado River near Grand Junction, Colo. as an area needing additional water supplies during the late summer and fall months to maintain habitat conditions for the endangered Colorado squawfish (pikeminnow) and the razorback sucker (Pitts, 2000). In response, the Bureau of Reclamation evaluated potential improvements to its Grand Valley Project that might provide the needed additional flows. Specifically, a study was completed to evaluate options for reducing the flow-rate requirement of the Government Canal during the late summer and fall water-delivery months (Styles and others, 1999). The study incorporated several modernization strategies to optimize water delivery to irrigated lands. Results of the study identified 28,500 acre-ft of excess spill water that could be conserved by implementation of these strategies.

The implementation of these modernization strategies would result in a decrease in water in the Government Canal and a decrease in the quantity of water spilled to Highline Lake from August through October. As a result, longer residence times could be expected in the lake that could increase water temperature, increase productivity/algal biomass, shift the taxonomic structure of algae in the lake, and decrease already deplenished dissolved-oxygen concentrations in the lower stratum (hypolimnion) of the lake. Increased water temperatures could increase decay rates (die-off) resulting in increased decomposition of algal biomass, which could further deplete oxygen concentrations in the deeper parts of the lake. It also is plausible that longer residence times (less flushing and dilution) could adversely affect bacterial populations at the public swim beach on the south end of Highline Lake.

The Colorado Division of Parks and Recreation was concerned that a reduction in spill water into Highline Lake could adversely affect the recreational uses of the lake. To address this concern and to characterize water quality in the Government Highline Canal and Highline Lake, the U.S. Geological Survey (USGS), in cooperation with the Colorado Division of Parks and Recreation, conducted a study to evaluate limnological conditions prior to implementation of the management strategies.

Purpose and Scope

The purpose of this report is to characterize the water quality of inflow from the Government Canal and in Highline Lake prior to proposed implementation of modernization strategies in the Government Canal. Flow entering the lake from the Government Canal is characterized using field properties and available chemical, sediment, and bacteria concentration data. Data collected at Highline Lake are used to characterize the seasonal mixing and stratification patterns, water-quality, bacteria populations, and phytoplankton community structure in the lake. Data described in this report include (1) depth-profile measurements of water temperature, dissolved oxygen, pH, and specific conductance, (2) measurements of water transparency and turbidity, (3) chemical analyses for suspended solids, nitrogen, phosphorus, dissolved organic carbon, bacteria, and chlorophyll-*a* concentrations, and (4) the phytoplankton community structure. Data used for this report were collected from July 2000 through September 2003 at one inflow site to the lake and four sites in Highline Lake (table 1 and fig. 2).

Description of the Study Area

Highline Lake is located in western Colorado in an area known as the Grand Valley (fig. 1). The mild winter climate in the area is well suited for farming, and the area has developed a thriving fruit industry. In 1912, the Government Canal was constructed to help supply irrigation water to farmlands northwest of Grand Junction, Colo. In 1969, Highline Lake was constructed to provide a sizeable recreational lake in the area. Excess irrigation flow from the Government Canal

Table 1. List of sampling sites with location coordinates and associated data-collection activities at each site.

[USGS, U.S. Geological Survey; WQ, water quality; Q, instantaneous streamflow; DP, depth profiles]

Site name used in this report	Site identifier	USGS site number	Latitude/longitude coordinates (degrees/minutes/seconds)	Data collection activities
Camp 7	Camp No. 7 spillway near Mack, Colo.	09095529	39°16′22″ 108°49′56″	WQ and Q
T1	Highline Lake site T1	391611108503200	39°16′11″ 108°50′32″	WQ and DP
T2	Highline Lake site T2	391623108501900	39°16′23″ 108°50′19″	DP
T3	Highline Lake site T3	391645108501500	39°16′45″ 108°50′15″	WQ and DP
SB1	Highline Lake site SB1	391610108502100	39°16′10″ 108°50′21″	WQ

supplies inflow to the lake. Located near Grand Junction, the population center in Mesa County, the importance of Highline Lake as the centerpiece of water recreation in the area cannot be overstated.

The study area receives abundant sunshine; the annual percentage of possible sunshine is 71 percent (Western Regional Climate Center, 2004). Although winter temperatures can drop below freezing, the winter climate is relatively mild and extreme cold is rare. The average annual air temperature is 53°F, but summer temperatures can exceed 100°F. The mean annual precipitation in the area is 8.7 in. (Western Regional Climate Center, 2004). For most of western Colorado, the greatest monthly precipitation occurs in the early spring and late summer; June is the driest month. Even though precipitation averages about 9 in., heavy localized storms can result in flooding.

Highline Lake is south of the Little Bookcliffs at an altitude of approximately 4,700 ft above NAVD88 (fig. 1). The Grand Valley is an erosional depression carved into Mancos Shale, which is composed of silt and clay deposited during the Late Cretaceous Period (Colorado State Parks, 2004). The Mancos Shale is exposed throughout most of the Highline Lake State Park, and soils in the area are rich in salts.

The terrain around Highline Lake is dominated by mat saltbush shrublands and saline bottomland shrublands (Colorado State Parks, 2004). Mat saltbush shrubland is dominated by several low growing or prostrate saltbush species, including mat and Gardner saltbush, shadscale, and horsebrush. These shrubs tolerate the high concentrations of sodium and sulfate contained in shale-derived soils. Saline bottomland shrublands are dominated by greasewood, rabbitbrush, four-wing saltbush, shadscale, salt cedar, western wheatgrass, Indian rice grass, and needle-and-thread grass (Colorado State Parks, 2004). Diverse wetland, riparian, and aquatic plant communities have become established around Highline and Mack Mesa Lakes and downstream from both dams.

Acknowledgments

The author thanks the many individuals who assisted in the collection of data analyzed in this report. Thanks are extended to Chris Foreman of the Colorado Division of Parks and Recreation for his timely response to numerous requests for data and support and to Joe Sullivan, Ken Butcher, Mike Whiteman, and Patricia Solberg of the USGS for their sampling efforts. The author also thanks Robert Stogner, Sr., for his help with graphics preparation.

Methods of Investigation

This section of the report describes the various methods of data collection including sample collection, sample processing, and laboratory analytical methods. Data-collection activities associated with depth-profiling measurements on Highline Lake and streamflow measurements from the Government Canal into Highline Lake also are described. This section of the report also describes the quality-assurance measures and data-analysis methods used in this report.

Sample Collection and Processing

Water-quality samples were collected during July 2000 through September 2003 from an inflow site from the Government Canal and three sites in Highline Lake (table 1 and fig. 2); sample collection at site T3 did not begin until April 2002. Generally, samples were collected monthly from April through September when the Government Canal was operating. The site on the Government Canal was located immediately upstream from the Camp 7 check structure (Camp 7) where excess water in the canal is siphoned directly

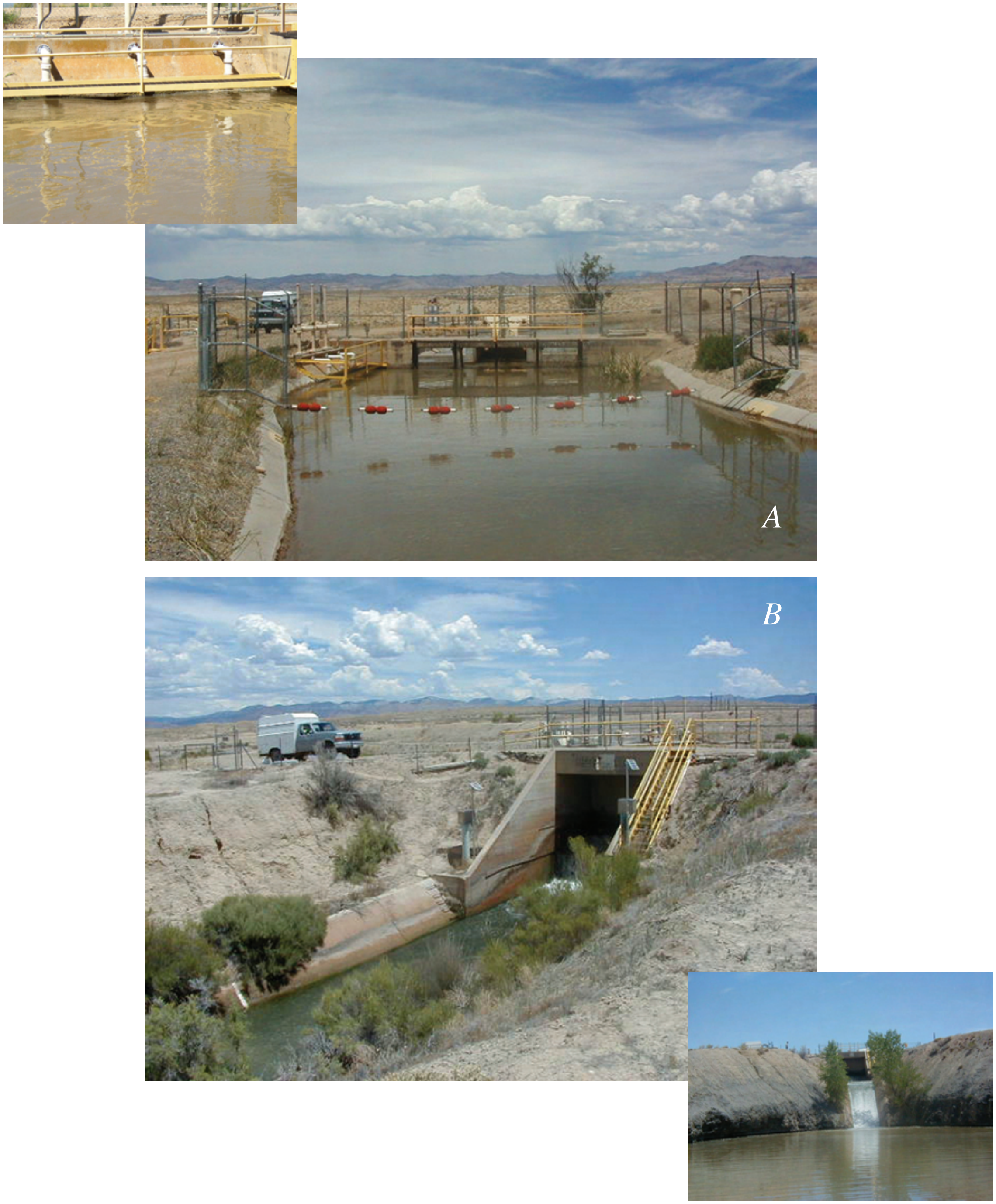


Figure 3. (*A*) Camp 7 sampling location just upstream from check structure on the Government Highline Canal with inset of siphon works to spillway, and (*B*) view of Camp 7 spillway with inset of inflow to Highline Lake.

into the lake through the Camp 7 spillway (fig. 3). The sites in Highline Lake included a deep-water site near the dam (T1), a shallow-water site at the upper end of the lake (T3), and a site at the public swim beach (SB1). In 2002, samples were collected once in December at sites T1 and T3 to help characterize conditions in the lake during the winter when no spill water was entering the lake.

Two depth-specific samples were collected at site T1 when depth-profile measurements at this site indicated that the water column was well mixed. One sample was collected near the water surface at a depth corresponding to the Secchi-disk depth in the photic zone, and the other sample was collected in the hypolimnion within 3 ft of the lake bottom. An additional sample was collected in the metalimnion along the thermocline when the lake was stratified and the presence of a strong thermocline was observed. Only two samples (one from the photic zone and one from near the lake bottom) were collected at site T3 for each sampling date because of the relatively shallow depths (about 12 ft) at this site. Samples collected at sites T1 and T3 for taxonomic classification of phytoplankton were collected from a single depth in the photic zone.

Sample-collection techniques varied by site. Water-quality and suspended-sediment samples were collected from the Government Canal at Camp 7 using equal-width increment procedures (Edwards and Glysson, 1998). Samples collected at T1 and T3 were collected from a boat using an open-tube sampling device that was lowered to a specified depth and remotely triggered to collect a water sample. Specific sample depths were selected after stratification patterns at the site were evaluated using depth-profile measurements. Water-quality samples were collected at the swim beach using a grab-sample technique at wading depths. At this site, a member of the sampling team waded out to a depth of about 3 ft, similar to what would be expected by the average swimmer/wader. A sample rod was used to lower and raise a 3-L nozzled sample bottle through the water column to collect the sample. After sample collection was completed at a site, the sampled water was composited in a 3-L plastic bottle that had been field rinsed with lake water. The sample was immediately placed on ice, and all sample containers were transported to the USGS laboratory in Grand Junction, Colo., for processing after the last sample was collected. Typically, sample processing was completed within 2 to 4 hours of the sample collection. In all cases, field measurements of water temperature, dissolved oxygen, pH, and specific conductance were recorded for each sample collected.

Samples were not collected directly from the Camp 7 spillway because of safety concerns (fig. 3). Samples collected from the canal, however, were representative of the water entering the lake because the samples were collected at the point where water was diverted into the lake.

Instantaneous streamflow from the Government Canal into Highline Lake was estimated at sample-collection time using stage-streamflow ratings for this site. Continuous streamflow data were not available for this site because data-collection activities were discontinued in 1999 (Rocky Dial, Bureau of Reclamation, written commun., 2003).

Depth-profile measurements of water temperature, pH, dissolved oxygen, and specific conductance were made at sites T1, T2, and T3 prior to any sample-collection activities. Depth-profile measurements were recorded at increments of 3 ft from the water surface to the lake bottom using a multiparameter field meter. In addition, measurements of light penetration using a Secchi disk were made at each site. A Secchi-disk measurement corresponds to the depth at which 10 percent of the surface light penetrates the water (Wetzel, 2001). In comparison, the photic zone extends from the lake surface down to where light dims to 1 percent of that at the surface (Goldman and Horne, 1983, p. 15).

Water-quality samples collected as part of this study were processed using techniques described in the USGS field-methods manual (U.S. Geological Survey, variously dated). Briefly, water collected for turbidity and total suspended-solids analyses was not filtered, and no preservation techniques were used. Water collected for the analysis of dissolved nutrients was filtered through 0.45-µm membrane capsule filters, and no preservative was added to the filtrate. Water collected for the determination of total phosphorus was not filtered but was preserved with sulfuric acid. Water collected for the analysis of dissolved organic carbon was filtered through glass-filter membranes, and the filtrate was preserved with sulfuric acid. Water collected for analysis of chlorophyll-*a* was filtered through glass-filter membranes, and the filters were placed in a glass vial, wrapped in foil, and frozen. All samples were stored on ice at 4°C prior to delivery to the designated laboratory. Chlorophyll-*a* samples were transported on dry ice as recommended in the USGS field-methods manual (U.S. Geological Survey, variously dated).

Water collected for analysis of fecal streptococcus and *Escherichia coli* (*E. coli*) bacteria was filtered through sterile 0.45-µm filters. The filters then were placed on the appropriate agar media and incubated as required (Myers and Wilde, 2003). Bacteria counts were recorded at the appropriate time. Samples collected for analysis of phytoplankton taxonomy were collected in appropriate containers and placed on ice as requested by the laboratory (Anne St. Amand, PhycoTech Inc., St. Joseph, Michigan, oral commun., 2002).

Samples collected for chemical analysis were delivered to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado. Samples collected for analysis of phytoplankton taxonomy were shipped to PhycoTech Inc. in St. Joseph, Michigan. Samples collected for analysis of suspended sediments were shipped to the USGS Sediment Laboratory in Iowa City, Iowa.

Analytical Methods

Generally, all the samples were analyzed for selected dissolved-nitrogen and dissolved-phosphorus compounds, total phosphorus, dissolved organic carbon, total-suspended solids, and turbidity (table 2). These samples were extracted and analyzed at the NWQL using methods described by Fishman (1993) and Fishman and others (1994). Low-level detection limits were requested for analyses of dissolved ammonia, nitrite, and nitrite plus nitrate (all reported as nitrogen), and dissolved orthophosphorus and dissolved phosphorus (all reported as phosphorus).

Concentrations were reported in terms of laboratory reporting levels (LRLs), which the NWQL defines as equal to twice the yearly determined long-term method detection level (LT-MDL). The LT-MDL is a detection level derived by determining the standard deviation of 20 or more spike-sample measurements conducted over an extended time. In September 2001, the USGS analytical laboratory began to calculate the LT-MDL using nonparametric statistics as described in Childress and others (1999). Yearly changes to the LT-MDL and, subsequently, the LRL were made if the values were different from the previous year. As a result, multiple LRLs could be reported for any particular constituent over the course of several years of sampling. Multiple LRLs were particularly evident when analyzing the results of low-level nitrogen and phosphorus analyses as part of this study. Additional information pertaining to the application of LT-MDL to data analyzed at the NWQL can be found in Childress and others (1999).

Table 2. List of field measurements and analyses done at each sampling site in inflow to Highline Lake and in Highline Lake including reporting levels and units.

[°C, degrees Ce
-
y; USGS,
U.S. Geological Survey]

Water-quality parameter	Site name				Range of laboratory reporting levels[1]	Reporting units	Analytical methodology
	Camp7	T1	T3	SB1			
Water temperature	✓	✓	✓	✓	0.5	°C	Multiprobe
Dissolved oxygen	✓	✓	✓	✓	0.1	mg/L	Multiprobe
pH	✓	✓	✓	✓	0.1	s.u.	Multiprobe
Specific conductance	✓	✓	✓	✓	1.0	µS/cm	Multiprobe
Turbidity	✓	✓	✓	✓	0.1 to 1.0	NTU	Nephelometry
Total-suspended solids	--	✓	✓	✓	10	mg/L	Gravimetric
Dissolved ammonia	✓	✓	✓	✓	0.002 to 0.015	mg/L	Colorimetric
Dissolved nitrite plus nitrate	✓	✓	✓	✓	0.005 to 0.022	mg/L	Colorimetric
Dissolved nitrite	✓	✓	✓	✓	0.001 to 0.0023	mg/L	Colorimetric
Dissolved orthophosphorus	✓	✓	✓	✓	0.001 to 0.007	mg/L	Colorimetric
Dissolved phosphorus	✓	✓	✓	✓	0.0044 to 0.006	mg/L	Colorimetric
Total phosphorus	✓	✓	✓	✓	0.0037 to 0.008	mg/L	Colorimetric
Dissolved organic carbon	✓	✓	✓	✓	0.15 to 0.33	mg/L	Infrared spectrometry
Fecal streptococcus[2]	✓	✓	✓	✓	--	col/100mL	Agar
Escherichia coli[2]	✓	✓	✓	✓	--	col/100mL	Agar
Chlorophyll-*a*[2]	--	✓	✓	✓	0.1	µg/L	HPLC
Suspended sediment	✓	--	--	--	1	mg/L	Gravimetric
Phytoplankton[2]	--	✓	✓	--	--	--	--

[1]See Childress and others (1999) for
at the USGS National Water Quality Laboratory.

[2]Analysis only done on sample collected in the photic zone.

A concentration also can be reported as an estimated value or as a less-than value depending on certain laboratory criteria (Pritt, 1994). A numerical value is reported for measurements less than the LRL if a response signal (a peak) is observed at the correct retention time and the qualifying information from the spectra conclusively identifies the analyte. In this case, the value is reported as a quantifiable value less than the LRL with a remark code that indicates that the result is an estimated value. If no signal is observed at the characteristic retention time or a small signal (corresponding to a value less than the LRL) is observed at the characteristic retention time but the analyte is not conclusively identified from the spectrum, the result is reported as a nondetection with a less-than sign (<) and the LRL. For the purposes of statistical calculations in this report, concentrations reported as less than the LRL were assigned a value equal to one-half of the LRL established at that time. Values that were reported as estimated values were assigned as that value; that is to say, a value estimated at 0.002 mg/L was assigned a value of 0.002 mg/L.

All samples collected in the photic zone, including samples collected at Camp 7, were analyzed for fecal streptococcus and *E. coli* bacteria by USGS personnel in Grand Junction, Colo., using methods described in Myers and Wilde (2003). Colorado Division of Parks and Recreation (Parks) personnel also collected *E. coli* samples from the swim area on a weekly basis from May to September of each year (Chris Foreman, Colorado State Parks, written commun., 2003). These samples were collected as part of required compliance monitoring for *E. coli* in natural swim areas. The Colorado State Board of Health has adopted an *E. coli* standard of 235 col/100mL for natural swimming areas to ensure the suitability of the beach area for public use (Colorado Department of Public Health and Environment, 1998). Samples collected by the Parks were analyzed by laboratories for the Ute Water Conservancy District in 2000 and 2001 and the Colorado Department of Public Health and Environment in 2002 and 2003. All samples collected in the photic zone, excluding Camp 7, also were analyzed for chlorophyll-*a* concentrations. Samples collected at Camp 7 were analyzed for suspended-sediment concentration.

All field measurements and water-quality data, with the exception of the phytoplankton taxonomy, were entered into the USGS National Water Information System data base. Water-quality data analyzed as part of this report can be obtained on the Web at *URL http://waterdata.usgs.gov/co/nwis/qwdata* (search for the USGS site number(s) listed in table 1 and a specific date range between July 2000 and October 2003). Phytoplankton data are presented in Appendix 1, available on CD-ROM at the back of this report.

Quality Assurance

Quality-assurance samples are collected to assess the variability and bias of water-quality data that may be introduced by sample collection, processing, storage, and analysis. As part of this study, 19 field blanks were collected to evaluate the potential for cross contamination (carry over) between sampling sites due to the reuse of sampling equipment following cleaning and decontamination procedures. The field blanks were collected at various study sites. A field blank consisted of a collection of organic-free rinse water from laboratory-cleaned or field-decontaminated surfaces of the sampling equipment. Care was taken to collect the rinse water only from surfaces that would normally be in contact with the environmental sample. This water then was processed in a manner consistent with procedures at the site where the field blank was collected. Table 3 summarizes the results of these samples. In general, more than 92 percent of the analyte concentrations were reported at concentrations less than the highest laboratory reporting level for that constituent during the study period. In the small number of samples where concentrations in the field blanks were higher than might be expected, the values were compared to the environmental data to assess the effect on the data interpretation. In most cases, the concentration in the environmental sample was higher than the field blank and within the range of expected values. This indicated that there was little likelihood that the environmental data were compromised. Coupled with the fact that the sampling equipment was rinsed numerous times with native water prior to sample collection, no adjustments were made to the original data to account for field-blank results.

Process blanks for bacteria analyses were done throughout the study. About 95 percent of the bacteria samples processed also included a blank analysis. None of the blanks contained reportable numbers of either fecal streptococcus or *E. coli*.

One replicate sample was collected during the study. Comparisons between the two samples indicated that concentrations in the replicate sample were essentially the same as those in environmental sample. These data provide information on the precision of the concentration values and the consistency in identifying the constituent of interest.

A multiprobe field meter that measures water temperature, pH, dissolved oxygen, and specific conductance was calibrated at the first site prior to depth profiling. Calibration procedures were documented on field forms, and routine maintenance was done by the sampling team as needed (Wilde and Radtke, 1998). Following the collection of the last sample, a calibration check was done to determine if the meter was still operating within calibration limits.

Data Analysis Methods

Hydrologic data were analyzed by using time-series plots to characterize seasonal patterns of inflow to Highline Lake. Additionally, time-series plots were used to characterize the seasonal water-quality patterns in Highline Lake itself. Vertical mixing and stratification patterns within the water column of Highline Lake were characterized by using depth-profile

Table 3. Summary of analytical data reported from 19 field blanks collected from July 2000 through September 2003.

[NTU, nephelometric units; mg/L, milligrams per liter; N, nitrogen; P, phosphorus]

Constituent (reporting units)	Highest laboratory reporting level	Concentration of blank[1]			Percentage of results less than the highest reporting level
		Minimum	Median	Maximum	
Turbidity (NTU)	1	0.2	0.7	5.2	68
Total-suspended solids (mg/L)	10	5	5	[2]61	95
Dissolved ammonia as N (mg/L)	.015	.001	.008	.008	100
Dissolved nitrite plus nitrate, as N (mg/L)	.022	.003	.007	.011	100
Dissolved nitrite, as N (mg/L)	.002	.001	.001	.001	100
Dissolved orthophosphorus, as P (mg/L)	.007	.001	.004	.004	100
Dissolved phosphorus (mg/L)	.006	.002	.002	.003	100
Total phosphorus (mg/L)	.008	.002	.002	.004	100
Dissolved organic carbon (mg/L)	.3	.15	.30	2.1	63

[1] Less-than values were set to one-half of the laboratory reporting level for that specific laboratory analysis.

[2] Maximum concentration was the only concentration that exceeded reporting level.

measurements of water temperature, dissolved oxygen, pH, and specific conductance that were measured from July 2000 through September 2003. Linear regression techniques were used to estimate dissolved-solids concentrations from specific conductance data at Camp 7 and to estimate suspended-sediment concentrations from turbidity data. The coefficient of determination, R^2, of the equations is the proportion of the variation in the estimated variable that is explained by the sample regression curve (Iman and Conover, 1983).

This report also uses the numeric trophic-state index (TSI) developed by Carlson (1977) to define the degree of eutrophication in Highline Lake using total-phosphorus and chlorophyll-*a* concentrations, and Secchi-disk measurements. Total-phosphorus concentrations also were used to characterize trophic state using techniques described by Vollenweider (1968). Mass ratios of nitrogen to phosphorus were computed for Highline Lake to characterize the limiting nutrient for algal growth present in the lake (Britton and Gaggiani, 1987; Woods, 1992). Bacteria concentrations at the public swim beach were evaluated and compared to existing Colorado standards for natural swimming areas to determine the general suitability of the swim area for public use (Colorado Department of Public Health and Environment, 1998). When applicable, comparisons were made to Federal or State water-quality standards.

Analysis of phytoplankton data was done to establish the taxonomic structure of the algal community in Highline Lake. These data were analyzed using reported concentration data to determine the relative abundance of taxa for each sampling event. These data were graphically displayed using boxplots. A boxplot shows the entire distribution of the data including the median value, the interquartile range (25^{th} to 75^{th} percentiles), and data outliers. A limited analysis of seasonal biomass also is presented to determine seasonal succession of phytoplankton in the lake.

Water Quality

The following sections of this report describe the inflow water quality to Highline Lake from the Government Canal and the water quality of Highline Lake at several locations on the lake. Specifically, field measurements, selected chemical concentrations, sediment concentrations, and biological measurements are discussed, where applicable. Annual and seasonal stratification patterns in Highline Lake also are described.

Government Canal at Camp 7

Water temperatures in the Government Canal at Camp 7, the inflow site, ranged from 12.5 to 24.5°C with a median temperature of 18°C; the canal is operated from about late-March through early-November of each year. The highest temperatures generally occurred in July and August and seasonal temperature variations reflected the source water in the Colorado River. The water was well oxygenated; the median dissolved-oxygen concentration was 7.7 mg/L. Although not directly applicable, all periodic measurements of dissolved oxygen at Camp 7 would have met the instream standard for aquatic life (6.0 mg/L) in the Upper Colorado River Basin (Colorado Department of Public Health and Environment, 2004). Dissolved-oxygen concentrations indicated a seasonal trend that was inversely related to water temperature. The median pH value was 8.4 standard units. Although not directly applicable, all pH values would have been within the acceptable range of instream standards for aquatic life (6.5 to 9.0 s.u.) in the Upper Colorado River Basin (Colorado Department of Public Health and Environment, 2004). Specific conductance values ranged from 379 to 1,260 μS/cm with a median value of 865 μS/cm. Dissolved-solids concentrations at Camp 7 were estimated using a linear regression equation developed from paired specific-conductance and dissolved-solids data collected at the USGS streamflow-gaging station 09095500, Colorado River near Cameo (fig. 1). The equation was:

$$DS = (0.59 \times SC) - 2.15 \qquad (1)$$

where

DS is total the estimated dissolved-solids concentration, in milligrams per liter; and

SC is the measured specific conductance, in microsiemens per centimeter.

The coefficient of determination, R^2, of the equation was 0.99, which indicates that nearly all of the uncertainty in estimating dissolved solids was attributable to specific conductance. As such, dissolved-solids concentrations estimated using this equation ranged from 221 to 741 mg/L with a median concentration of 508 mg/L. Generally, the smallest concentrations were measured in June when snowmelt and higher streamflow conditions were observed in the Colorado River. Likewise, the highest concentrations at Camp 7 were observed in early spring and in late summer when low streamflow conditions occurred in the Colorado River. Time-series graphs of periodic measurements of water temperature, dissolved oxygen, pH, and specific conductance at Camp 7 are shown in figure 4.

Hem (1985) reported that the average concentration of dissolved organic carbon (DOC) in rivers located in arid or semiarid regions was 3 mg/L. DOC concentrations at Camp 7 ranged from 2.1 to 3.6 mg/L with a median value of 2.5 mg/L. Concentrations during the sampling period showed little annual variability, and the monthly variability did not indicate a pronounced seasonal pattern.

Nitrogen and phosphorus compounds are needed for plant growth. Chronic nutrient enrichment of a water body can lead to low dissolved-oxygen concentrations, fish kills, algal blooms, overabundance of macrophytes, and species shifts of flora and fauna. Sources of nutrients include natural processes such as atmospheric deposition, precipitation, erosion, and biochemical mechanisms in the basin. Manmade sources of nutrients include urban runoff, domestic and septic-system effluent, livestock waste, and erosion caused by development.

Generally, nitrogen concentrations in samples collected at Camp 7 were low, and concentrations did not differ substantially from year to year or seasonally within a year (fig. 5). The median ammonia concentration was less than 0.01 mg/L. The un-ionized form of ammonia (NH_3) is toxic but is not the predominant ammonia species in unpolluted natural water systems where pH is typically less than 9 (Hem, 1985). Concentrations of un-ionized ammonia can be estimated from reported concentrations of ammonia, pH, water temperature, and an equilibrium constant for solvated ammonia and ammonium ions (U.S. Geological Survey Memorandum No. 93.12, accessed on December 1, 2004 at URL http://water.usgs.gov/admin/memo/QW/qw93.12.html). The estimated median un-ionized ammonia concentration at Camp 7 was more than 10 times lower than the chronic instream standard for ammonia (0.02 mg/L) in the Colorado River at the Government Canal diversion (Colorado Department of Public Health and Environment, 2004). The median nitrite concentration was 0.001 mg/L, which was substantially lower than the 0.05 mg/L standard for most main-stem and tributary waters in the Upper Colorado River Basin (Colorado Department of Public Health and Environment, 2004). The maximum nitrite concentration was 0.012 mg/L. The median nitrite plus nitrate concentration was less than 0.02 mg/L of which more than 90 percent of that value would be nitrate. By comparison, the Colorado instream standard for nitrate is 10 mg/L (Colorado Department of Public Health and Environment, 2004).

Most phosphorus entering aquatic systems is readily adsorbed onto soil particles or incorporated into organic compounds, and any unbound phosphate ions are taken up by aquatic plants and microorganisms. The rapid biological uptake and ease in chemical bonding helps explain why phosphate concentrations in natural waters are low (U.S. Environmental Protection Agency, 1991). Overall, dissolved-phosphorus concentrations at the Camp 7 site were low (fig. 6). The median dissolved-phosphorus concentration was 0.008 mg/L, and the dissolved-orthophosphorus concentrations typically were reported at concentrations less than 0.007 mg/L. In addition to the dissolved-phosphorus constituents, total phosphorus (dissolved and particulate) concentrations were measured at Camp 7. The median total-phosphorus concentration for 20 samples collected during the study period was 0.1 mg/L, which is two times the concentration recommended by the U.S. Environmental Protection Agency (1986) for rivers or streams that drain into lakes or reservoirs. The maximum measured total-phosphorus concentration was 0.29 mg/L; the highest concentrations generally were observed in April or May.

Bacterial analyses at Camp 7 included the determination of fecal streptococcus and *E. coli* concentrations. Because large numbers of streptococcal bacteria are in the feces of warm-blooded animals, including humans, their presence is one indicator of fecal contamination. All of the samples

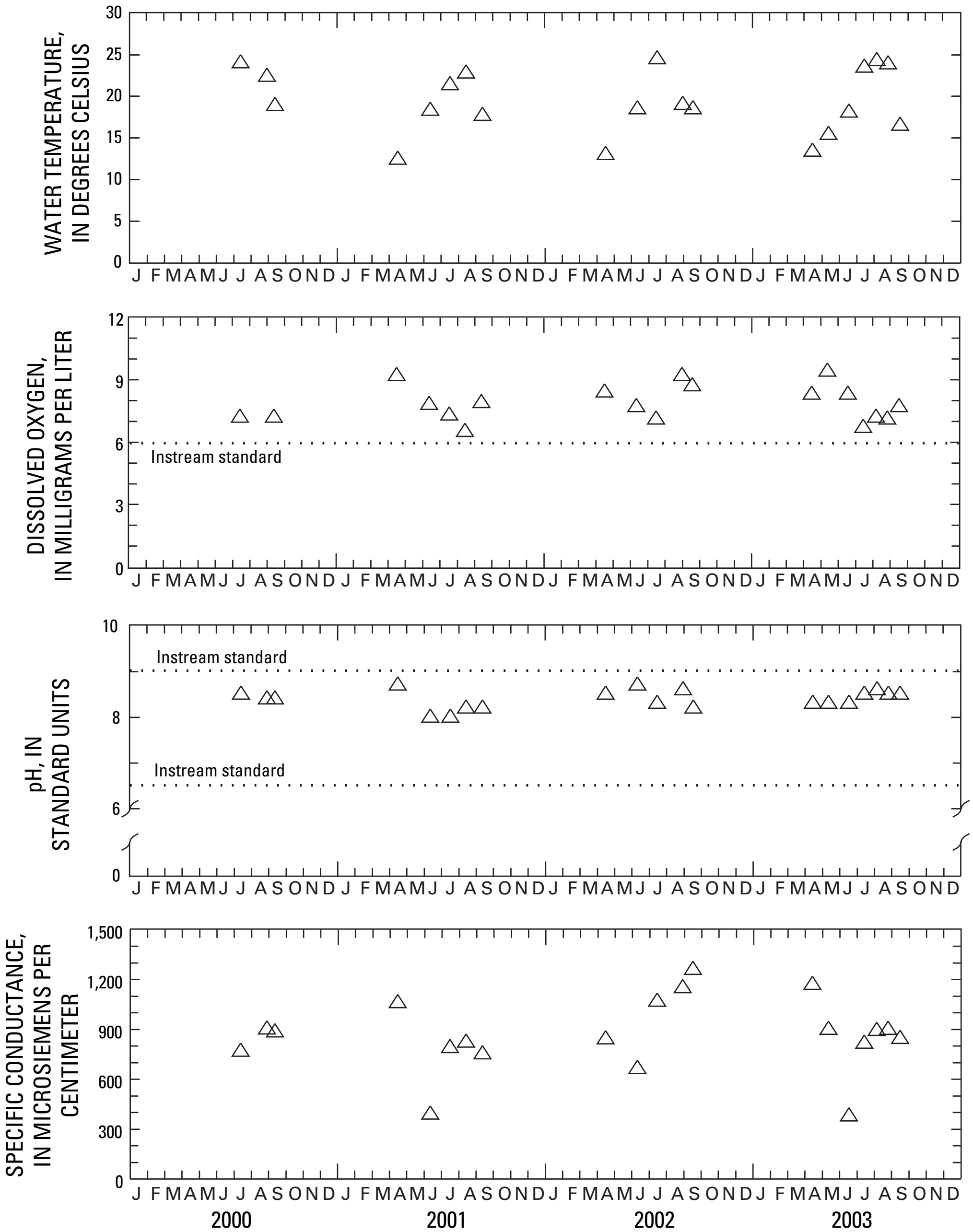


Figure 4. Time-series plots of water temperature, dissolved oxygen, pH, and specific conductance at Camp 7 near Highline Lake, Grand Junction, Colorado, July 2000 through September 2003.

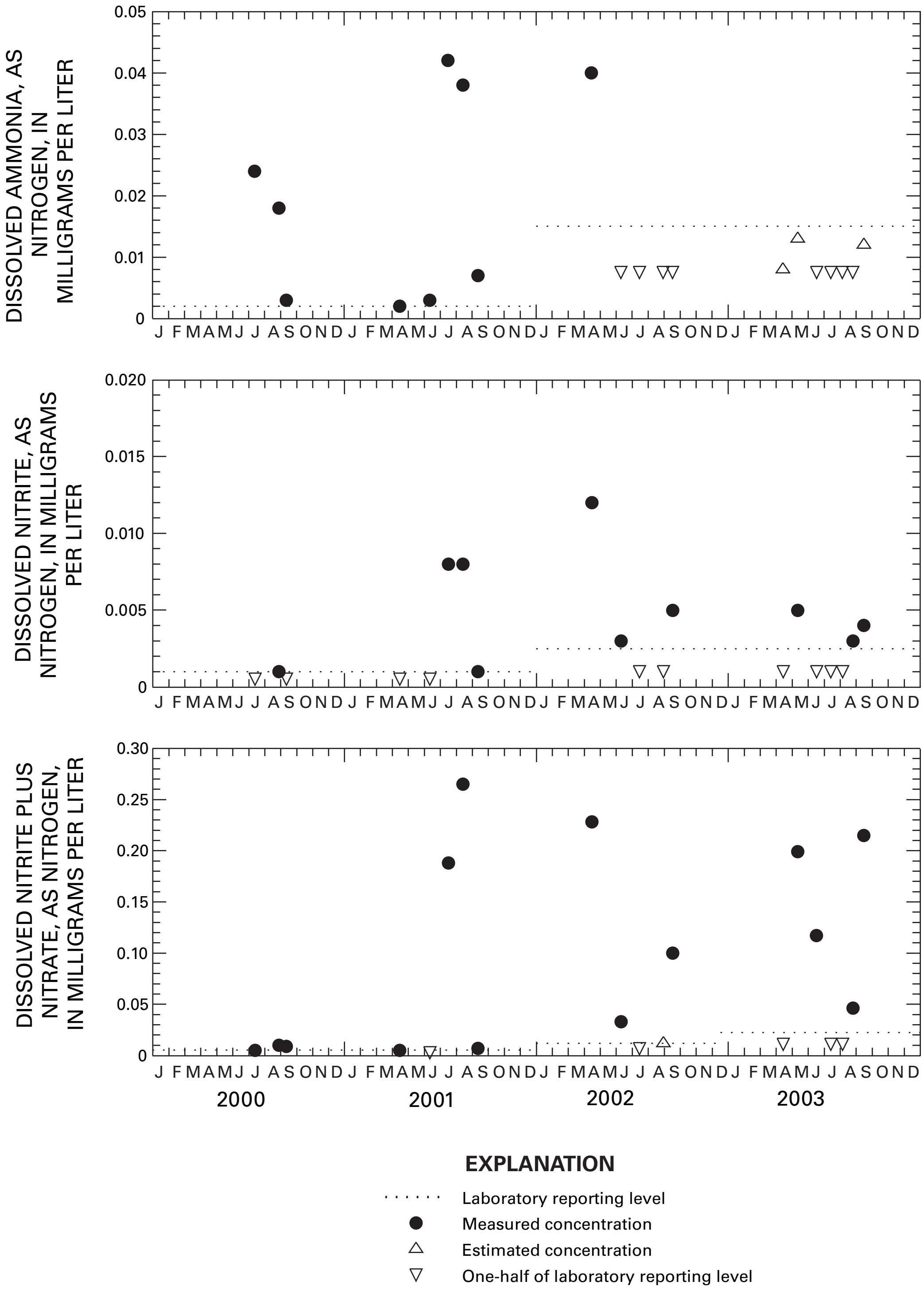


Figure 5. Time-series plots of nitrogen-compound concentrations at Camp 7 near Highline Lake, Grand Junction, Colorado, July 2000 through September 2003.

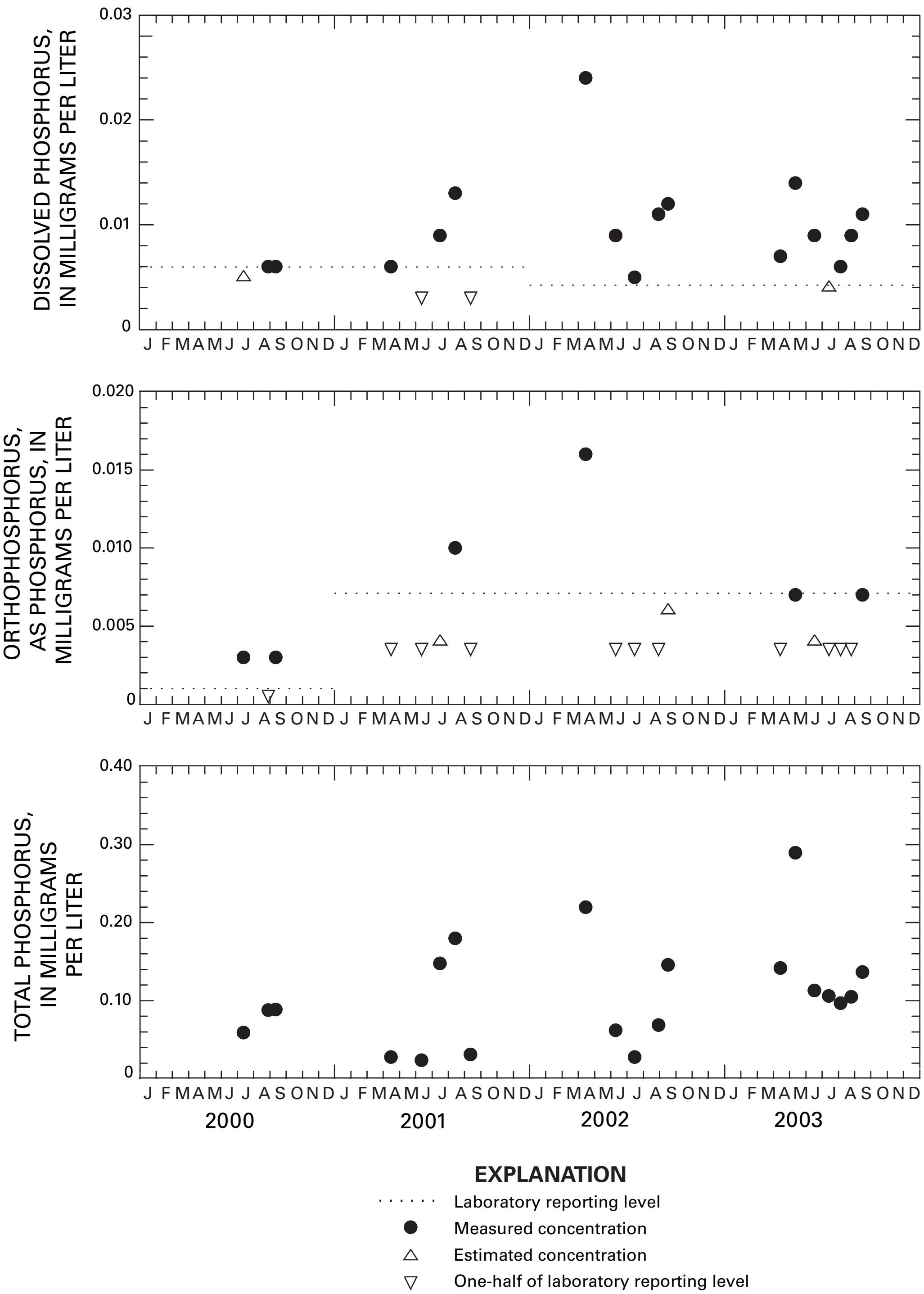


Figure 6. Time-series plots of phosphorus-compound concentrations at Camp 7 near Highline Lake, Grand Junction, Colorado, July 2000 through September 2003.

analyzed at Camp 7 had reportable numbers of fecal streptococcus colonies; the median value was 69 col/100mL. About 72 percent of the samples had concentrations less than 100 col/100mL. The maximum concentration was estimated as 480 col/100mL. Generally, the largest concentrations were associated with samples collected soon after the Government Canal was operational for the year (April) or later in the irrigation season (August and September). However, this was not necessarily observed in each year of sampling.

Fecal-coliform bacteria are in the intestinal tract of warm-blooded mammals, including humans. One type of fecal-coliform bacteria is *E. coli*. Although most strains of these bacteria are harmless, the strain O157:H7 produces a powerful toxin that can cause severe illness and death in humans. Infection from *E. coli* can occur after swimming in or drinking contaminated water. The instream standard for primary contact recreation, such as swimming, is typically 126 col/100mL (Colorado Department of Public Health and Environment, 2004). During the study period, the largest concentration reported in any sample collected at Camp 7 was 77 col/100mL. All other concentrations of *E. coli* were reported as estimated values or less-than values; the median concentration was 14 col/100mL. Although the site at Camp 7 would not be considered a recreational site, the bacteria concentrations entering Highline Lake from the Government Canal and their potential effect on the public swim beach is important to quantify.

Turbidity measurements are a common way to obtain water-clarity data and can be used to evaluate the general condition and productivity of the system. Considered a bulk optical property of water, turbidity represents an integration of the suspended and dissolved matter in the water that cause light to be absorbed or scattered. Typically, the presence of clay, silt, finely divided organic matter, plankton, other microscopic organisms, organic acids, and dyes contributes to the turbidity of the water. Turbidity measurements also may be useful in studies of sediment transport (where they can be used to infer suspended-sediment concentrations), ecological processes, and environmental regulation and control. The median turbidity value in the Government Canal at Camp 7 was 60 NTU; turbidity generally becomes visible to the unaided eye at about 5 NTU. The conditions at Camp 7 on August 26, 2003, when the measured turbidity was 66 NTU are shown in figure 7. The minimum and maximum turbidity measured at this site was 12 and 390 NTU, respectively.

The U.S. Environmental Protection Agency (1998) identified sediment as the single most widespread pollutant affecting the beneficial uses of the Nation's rivers and streams. Accelerated sedimentation can affect fisheries by reducing water clarity, spawning areas and rearing ponds, food sources, and habitat complexity. In recreational waters, high levels of suspended sediment reduce aesthetics, and impair swimming, fishing, and boating. In addition to affecting aquatic life, accelerated sedimentation can result in a substantial loss of storage capacity in reservoirs because of deposition of large amounts of sediment.

Figure 7. Government Highline Canal at Camp 7 near Highline Lake, Grand Junction, Colorado, August 23, 2003, when the measured turbidity was 66 nephelometric turbidity units.

Suspended-sediment concentrations were relatively low at Camp 7. Concentrations ranged from 21 to 490 mg/L. The median concentration was 118 mg/L. Turbidity measurements provided a reasonable estimator for suspended-sediment concentrations at this site. A least-squares regression equation was developed from paired turbidity and suspended-sediment data. The equation was:

$$SED = (1.07 \text{ x } TURB) + 60.05 \tag{2}$$

where

SED is the estimated suspended-sediment concentration, in milligrams per liter; and

TURB is the measured turbidity, in nephelometric turbidity units.

The coefficient of determination, R^2, of the equation was 0.673, which indicates that more than two-thirds of the variance in estimating suspended-sediment concentrations could be explained using measurements of turbidity.

No strong seasonal pattern in suspended-sediment concentrations was apparent other than a tendency for higher concentrations to occur early in the irrigation season (April 2002 and May 2003). Suspended-sediment data collected in the Colorado River upstream from the canal diversion point (near Cameo) were analyzed and compared to data collected at Camp 7. In general, concentrations in the interquartile range (25^{th} to 75^{th} percentiles) were similar for both sites. However, maximum suspended-sediment concentrations in the canal were much smaller than what was observed in the river (500 mg/L compared to 2,000–10,500 mg/L). Additionally, the percentage of silt in samples collected at the Camp 7 was considerably higher than what was seen in the river; silt is the fraction of the sediment that measures less than 0.063 mm in diameter (Hem, 1985). At Camp 7, nearly all of the suspended sediment would be categorized as silt, whereas only about two-thirds of the suspended sediments in the Colorado River would be silt. The amount and size of sediments determine the mass of suspended sediment entering Highline Lake; additional streamflow data are needed to quantify the rate of sedimentation. Proposed operational changes along the canal would reduce the amount of water spilled into Highline Lake. The resulting increase in residence times could result in more sediments settling from the water column and an associated increase in water clarity (Michael Lewis, U.S. Geological Survey, written commun., 2004).

Highline Lake

The following sections of this report describe the water quality of Highline Lake. Vertical mixing and stratification patterns are presented to define the annual and seasonal mixing and stratification characteristics of the lake with regard to water temperature, dissolved oxygen, pH, and specific conductance. Discussion of other measured physical and chemical characteristics, including biological measurements, are presented to provide a basis for assessing water-quality conditions in Highline Lake from July 2000 through September 2003. Additionally, the trophic state of the lake and a determination of the limiting nutrient(s) in the lake are presented. These data provide a basis from which to compare future water-quality assessments of Highline Lake as they may pertain to anticipated changes in operation of the Government Canal.

Spatial distribution using depth-profile measurements

Three sites on Highline Lake were selected for routine collection of depth-profile data (fig. 2 and table 2). Site T1 was located near the dam at the deepest location in the lake (approximately 45 ft). Site T2 was a midlake site near where inflow from the Camp 7 site entered the lake; average depths at this site were about 25 ft. Site T3 was located near the upper end of the lake with a depth of about 10 ft. Minimum, median, and maximum values for water temperature, dissolved oxygen, pH, specific conductance, and water clarity were calculated at selected depth ranges for each site (table 4).

Analysis of the data presented in table 4 shows that water temperature, pH, and specific conductance values were similar at each site for a given depth. These data indicate that the spatial variability along the horizontal plane of the lake was relatively small and longitudinal mixing was complete. Comparisons of field measurements recorded in the photic zone at the swim beach area (site SB1) also support this conclusion. The dissolved-oxygen data have a similar longitudinal pattern, but there is more variation (at equal depths) as the lake depth increases; dissolved oxygen can be completely depleted near the lake bottom depending on the stratification patterns in the lake at the time.

Water transparency is an important measurement that is directly related to key ecological variables and human perceptions of water quality in a water body. It is the capability of water to transmit light and is useful to determine the depth where sufficient light is available for photosynthesis. Typically, water transparency is measured using a Secchi disk. Secchi-disk measurements also provide one measurement of the trophic state of a lake that indicates the general health of a lake. Summary statistics indicate that the water clarity at sites T1 and T2 was similar at the two sites (table 4). Median Secchi-disk measurements at these two sites were 36 in. with maximum depths of 60 to 66 in. Maximum clarity was observed in December 2002 when the Government Canal was no longer spilling water to the lake. This was the only measurement taken when the Government Canal was not operational. Typically, water transparency at site T3 was about 12 in. less than at sites T1 and T2. Wind action at this shallow location likely resuspended bottom sediments resulting in diminished water clarity.

Annual stratification patterns

Depth profiles of water temperature, dissolved oxygen, pH, and specific conductance were used to characterize stratification patterns in Highline Lake. No seasonal stratification was observed for any of the field measurements at site T3 because of the shallow depths at this site. Differences in spatial stratification between the midlake site (T2) and the deeper site (T1) were relatively minor as both sites had similar patterns for most profile measurements. Additionally, seasonal stratification patterns did not differ substantially from year to year. As such, the following discussion will focus primarily on depth-profile data collected at the deep-water site (T1). For the purposes of illustration, the annual stratification patterns for water temperature, dissolved oxygen, pH, and specific conductance will focus on data collected from December 2002 through September 2003 (fig. 8); this period included measurements in December and May that were not collected during previous sampling periods.

Highline Lake is presumed to be dimictic. Dimictic lakes are very common in temperate lakes of moderate size that are subject to ice-cover conditions during winter. Typically, a dimictic lake undergoes complete circulation in spring and fall separated by thermal summer stratification and inverse winter stratification under ice cover (Cole, 1994). Although no profiling was done on Highline Lake during ice cover, it is likely that thermal stratification occurred during the winter months as is typical for northern temperate lakes of this latitude and altitude (Wetzel, 2001). Ice cover on Highline Lake generally is present from early January through the middle of March of

Table 4. Summary statistics for water temperature, dissolved oxygen, pH, specific conductance, and water clarity at selected depths in Highline Lake, July 2000 through September 2003.

[±, plus or minus; --, not applicable]

Range in measurement depth from water surface, in feet	Number of values	Minimum values			Median values			Maximum values		
		Site T1	Site T2	Site T3	Site T1	Site T2	Site T3	Site T1	Site T2	Site T3
Water temperature, in degrees Celsius										
1 to 5	21	4.8	4.7	4.6	20.4	20.4	20.1	24.8	24.9	24.6
7 to 13	21	4.8	4.7	4.6	20.2	19.9	20.0	24.6	24.5	24.3
19 to 25	21	4.7	4.6	--	16.9	17.6	--	20.9	22.3	--
[1]43 to 47	21	4.7	--	--	12.8	--	--	17.6	--	--
Dissolved oxygen, in milligrams per liter										
1 to 5	21	6.3	6.3	6.2	7.1	7.2	6.9	10.4	10.4	10.6
7 to 13	21	6.0	5.5	5.4	6.9	7.1	6.5	10.4	10.3	10.3
19 to 25	21	.3	0.2	--	3.4	4.1	--	10.3	10.3	--
[1]43 to 47	21	.0	--	--	.2	--	--	10.2	--	--
pH, in standard units										
1 to 5	21	8.0	8.0	7.9	8.2	8.3	8.2	8.4	8.6	8.6
7 to 13	21	8.0	8.0	7.9	8.2	8.3	8.2	8.4	8.5	8.4
19 to 25	21	7.2	7.2	--	7.8	8.1	--	8.2	8.5	--
[1]43 to 47	21	7.1	--	--	7.5	--	--	8.2	--	--
Specific conductance, in microsiemens per centimeter										
1 to 5	21	495	492	497	867	871	866	1,300	1,300	1,300
7 to 13	21	495	491	497	867	870	866	1,300	1,290	1,300
19 to 25	21	564	567	--	864	874	--	1,300	1,300	--
[1]43 to 47	21	672	--	--		--	--	1,390	--	--
Water clarity, Secchi-disk measurement, in inches										
--	21	12	12	12	36	36	24	60	66	48

[1]Measurement taken near the bottom of the lake on July 17, 2001 was at a depth of 39 feet.

each year (Chris Foreman, Colorado State Parks, oral commun., 2004). In April, minor thermal stratification was evident, and the epilimnion extended down to about 10 ft (fig. 8). Thermal stratification intensified through the summer as water temperatures at the surface of the lake increased. Water temperatures during the summer months ranged from 20 to 25°C in the epilimnion and from 10 to 14°C in the hypolimnion. The epilimnion extended down to about 10 ft and the thermocline extended to about 30 ft. Thermal stratification in August was similar to what was observed in July. In September, the lake fully mixed as the surface cooled, and overturn of the lake occurred. Following overturn, temperatures in Highline Lake were about 16 to 18°C. Water temperatures continued to decrease in the lake during the months of October and November as cooler air temperatures prevailed. In December prior to ice cover on Highline Lake, thermal stratification was not apparent in Highline Lake. At this time, fall turnover had fully mixed the lake, and water temperatures were at a

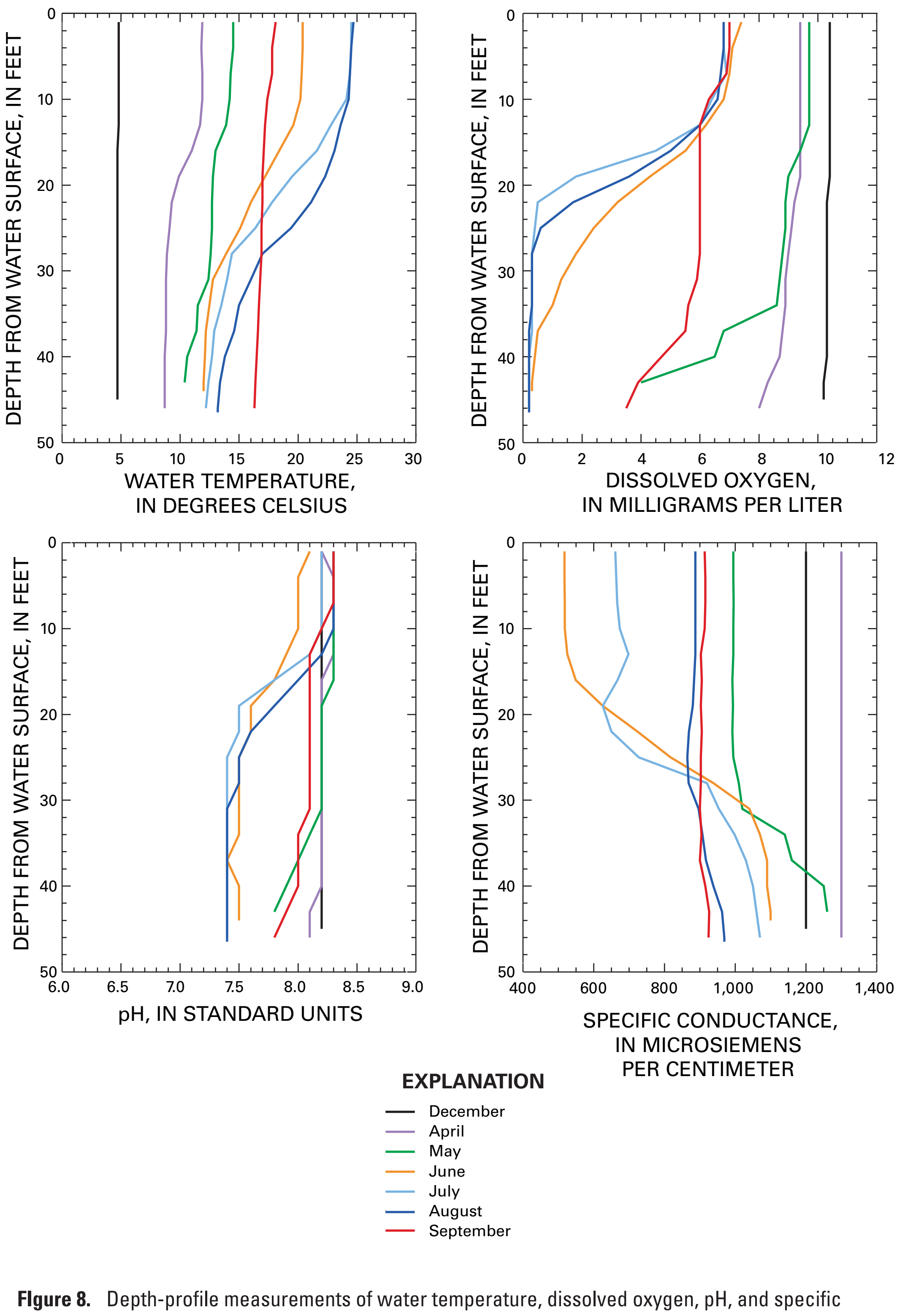


Figure 8. Depth-profile measurements of water temperature, dissolved oxygen, pH, and specific conductance at site T1 in Highline Lake, December 2002 through September 2003.

measured minimum of about 5°C. Overall, the thermal-stratification patterns observed in Highline Lake are similar to Wetzel's (2001) description of lakes of the temperate zone that were strongly contrasted during seasonal conditions.

Thermal-induced stratification (as density) influences many of the physical and chemical properties of lakes, including Highline Lake. As an example, water entering the lake from the Government Canal likely stayed near the surface of the lake because inflow water temperatures (densities) were similar to those observed in the epilimnion of the lake. As a result, oxygen-rich water from the Government Canal does not mix with the colder oxygen-depleted water near the base of the dam. It is important to restate that water from Highline Lake is released over the dam spillway, thus further hindering the mixing of water in the lake.

Depth-profile measurements of dissolved oxygen in Highline Lake were similar to the thermal profiles; however, the magnitude and depths at which anoxic conditions occurred were more pronounced (fig. 8). In December, dissolved-oxygen stratification was not apparent, and with water temperatures at a minimum, dissolved-oxygen concentrations were at a maximum. Minor stratification was evident in April but concentrations only decreased by slightly more than 1 mg/L throughout the water column. In May, stratification was readily evident as dissolved-oxygen concentrations decreased by as much as 6 mg/L from top to bottom; concentrations decreased more than 4 mg/L within the bottom 10 ft of the lake. The typical pattern of dissolved-oxygen depletion in Highline Lake was apparent throughout the months of June, July, and August. During this time, concentrations in the epilimnion ranged from 6 to 7 mg/L. The transition through the metalimnion to near anoxic concentrations occurred very quickly, particularly in July, culminating in dissolved-oxygen concentrations of less than 1 mg/L at depths from about 20 ft from the lake surface to the bottom of the lake. Mixing between the overlying oxygenated layers and the hypolimnion did not appear to occur. Warmer water probably entered the lake from the Government Canal and was routed over the metalimnion and then was released from the lake without mixing with the oxygen-depleted water near the dam. Low dissolved-oxygen concentrations can result in death of aquatic organisms including insects and fish (Hem, 1985). Additionally, anoxic conditions at the sediment-water interface in a lake can result in the release of nitrogen and phosphorus from the sediments, which can compound water-quality issues in a lake (Elder and others, 2000). In September, the dissolved-oxygen concentrations became uniform as fall turnover mixed the lake. Dissolved-oxygen concentrations continued to increase in the lake during the fall months as the water became increasingly colder.

Stratification patterns for pH in Highline Lake were similar to those observed for dissolved oxygen (fig. 8). Measurements recorded in December and April showed no stratification with respect to pH; the pH was about 8.2 s.u. during this period. In May, a slight decrease in pH of about one-half s.u. was observed in the lower 12 ft of the lake. By June, a well-defined stratification pattern was established in the lake. Overall, the pH in the hypolimnion was about 1 s.u. less than what was observed in the epilimnion; a pH of 7.4 s.u. was the minimum observed value. The decrease in pH probably resulted from biomass decay and a lack of circulation during stratification (Kuhn and others, 2003). This pattern was evident until the lake turned over in September (fig. 8).

From December 2002 through September 2003, epilimnetic pH values in Highline Lake ranged from 8.0 to 8.3 s.u. During this same period, the pH at Camp 7 ranged from 8.3 to 8.6 s.u. (fig. 4). It appeared that the primary productivity of the lake was not substantially large enough to increase the pH above the ambient pH of the inflow. Overall, the pH values observed in Highline Lake were within the acceptable range (6.5 to 9.0 s.u.) for aquatic life in lakes contributing to the Colorado River (Colorado Department of Public Health and Environment, 2004).

Specific-conductance profiles at site T1 from December 2002 through September 2003 illustrated the flow-through (routing) patterns of inflow from the Government Canal. In April, the lake was uniformly mixed at all depths with a specific conductance of about 1,300 µS/cm (fig. 8); the specific conductance at Camp 7 was 1,170 µS/cm (fig. 4). At that time, diversions to the Government Canal from the Colorado River had started but only a relatively small amount of water had been spilled into the lake. In May, thermal stratification at site T1 became more pronounced as low specific-conductance water from the Colorado River was spilled into the lake. In the epilimnion and metalimnion, continued mixing resulted in specific-conductance values that were similar to those observed at Camp 7. However, mixing did not occur in the colder and denser hypolimnion where the specific conductance remained about 1,200 µS/cm. A strong thermal gradient (density) was apparent by mid-June as mixing in the epilimnion and metalimnion responded to seasonally low specific-conductance water from the Colorado River. Specific conductance in the upper 20 ft of the lake was 520 µS/cm while Camp 7 was at a minimum of 379 µS/cm. The specific conductance in the colder hypolimnion was still about 1,100 µS/cm. Stratification remained through August, but eventually mixing occurred and the profile was no longer stratified.

Dissolved-solids values are used widely in evaluating water quality and in comparing water. Freshwater has dissolved-solids concentrations less than 1,000 mg/L, whereas slightly saline water ranges from 1,000 to 3,000 mg/L (Winslow and Kister, 1956). High concentrations of dissolved solids also are associated with taste and odor issues. The U.S. Environmental Protection Agency (1986) has established a nonenforceable secondary drinking-water regulation of 500 mg/L for dissolved solids. Estimated dissolved-solids concentrations in Highline Lake ranged from about 300 to 800 mg/L using regression equation 1. Although the standard is not applicable to water in Highline Lake, it does provide a reference point for the quality of the water in the lake.

Selected physical and chemical properties

Physical and chemical characteristics of Highline Lake were determined by collecting water-quality samples at three sites in the lake (table 2). Samples collected in the photic zone at all three sites showed similar water-quality characteristics, which indicated that there was no spatial variability at this depth in Highline Lake. In addition, the water-quality characteristics at site T3 (shallow-depth site) did not differ substantially from the photic zone to the bottom of the lake. As such, the following discussion of the water quality of Highline Lake primarily will focus on data collected at site T1, the deep-water site. Discussions or conclusions made concerning the water quality within the photic zone at T1 generally were relevant to the other two sites. A specific discussion of the bacteria concentrations at SB1 will be made as it applies to current (2004) health standards for a natural swim area.

Turbidity

Turbidity was substantially less at site T1 than what was measured at Camp 7 particularly in samples collected near the surface. The median value in the photic zone at T1 was 7.5 NTU compared to 60 NTU at Camp 7. The turbidity increased at deeper depths; the median turbidity was 20 NTU at the bottom of the lake. Although turbidity in Highline Lake is relatively low, elevated levels can cause increased temperatures as suspended particles absorb radiant heat. Additionally, a reduction in light penetrating the water column can decrease the rate of primary productivity, which can decrease the amount of dissolved oxygen in the water. Habitat required for fish spawning and for aquatic macroinvertebrates also can be impaired as suspended particles settle. However, increased turbidity can reduce algal activity that could ultimately reduce taste and odor issues associated with algal blooms.

Nutrients

Nitrogen concentrations in samples collected near the surface at site T1 were similar in concentration to samples collected at Camp 7. The median ammonia, nitrite, and nitrite plus nitrate concentrations in samples collected in the epilimnion at T1 were 0.02 mg/L, 0.004 mg/L, and 0.03 mg/L, respectively (fig. 9). In comparison, the median ammonia, nitrite, and nitrite plus nitrate concentrations in samples collected at Camp 7 were 0.01 mg/L, 0.001 mg/L, and <0.02 mg/L, respectively (fig. 5). Generally, nitrite concentrations did not increase with depth; the median nitrite concentrations in the epilimnion and hypolimnion were 0.004 and 0.005 mg/L, respectively. Concentrations of nitrate (as nitrite plus nitrate) in the hypolimnion were about two times those measured in the epilimnion. The median nitrite plus nitrate concentrations in the epilimnion and hypolimnion at site T1 were 0.031 and 0.063 mg/L, respectively. Ammonia concentrations also were much higher in the hypolimnion than in the epilimnion. This was particularly evident in samples collected in late summer when anoxic conditions were measured in the hypolimnion (fig. 9). Ammonia concentrations in samples collected near the bottom of the lake could be as much as 10 to 100 times more than the concentrations measured in the near-surface samples. The median dissolved ammonia concentrations in the epilimnion and hypolimnion at site T1 were 0.018 and 0.318 mg/L, respectively. The maximum ammonia concentration in a sample collected near the bottom at T1 was 0.59 mg/L. However, only a small percentage of this concentration typically would be in the un-ionized form that is toxic to fish (Hem, 1985). A calculation of the un-ionized ammonia concentration in this sample resulted in a value of about 0.01 mg/L which is lower than the chronic instream standard (0.02 mg/L) for un-ionized ammonia in the Upper Colorado River Basin (Colorado Department of Public Health and Environment, 2004). Concentrations of un-ionized ammonia can be estimated from reported concentrations of ammonia, pH, water temperature, and an equilibrium constant for solvated ammonia and ammonium ions (U.S. Geological Survey Memorandum No. 93.12, accessed on December 1, 2004 at URL http://water.usgs.gov/admin/memo/QW/qw93.12.html).

Ammonia likely was released from the bottom sediments of Highline Lake. This is typical of stratified lakes that become anoxic or anaerobic in the bottom waters. Ammonia tends to adsorb to sediment particles. When the sediment-water interface in a lake bottom becomes anoxic, the adsorptive capacity of the sediments is reduced and a release of ammonia from the sediments occurs (Wetzel, 2001). Contributions of nitrogen and phosphorus compounds to water bodies can lead to excessive algal growth, which may produce taste and odor issues in drinking water, stress aquatic organisms, and decrease the aesthetic and recreational value of the water body (Wetzel, 2001).

Concentrations of phosphorus nutrient species were low in Highline Lake. Total-phosphorus concentrations in samples collected at T1 in the epilimnion (photic zone) ranged from 0.008 to 0.037 mg/L (fig. 10) with a median concentration of 0.017 mg/L. Total-phosphorus concentrations generally increased with depth at site T1; the median concentration increased to 0.031 mg/L at the bottom of the lake. The maximum total-phosphorus concentration of 0.085 mg/L was measured in September 2003. In comparison, the median total-phosphorus concentration in the inflow from Camp 7 was 0.100 mg/L. Similarly, the dissolved-phosphorus concentrations in the epilimnion ranged from 0.003 to 0.006 mg/L (fig. 10) with a median concentration of 0.003 mg/L. Dissolved-phosphorus concentrations also increased with depth at site T1; the median concentration increased to 0.005 mg/L at the bottom of the lake. The maximum dissolved-phosphorus concentration of 0.015 mg/L

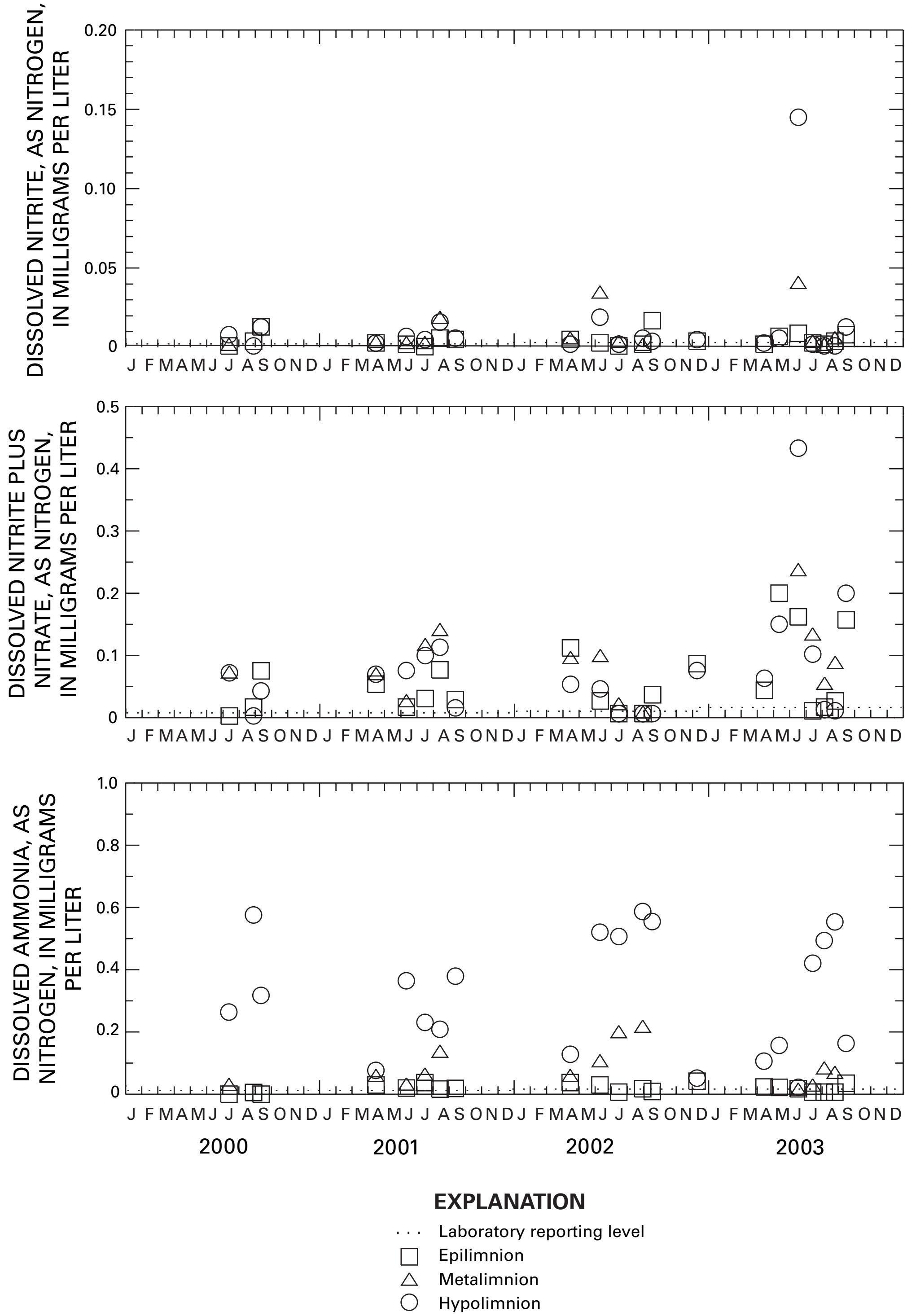


Figure 9. Time-series plots of nitrogen-compound concentrations at site T1 in Highline Lake, July 2000 through September 2003.

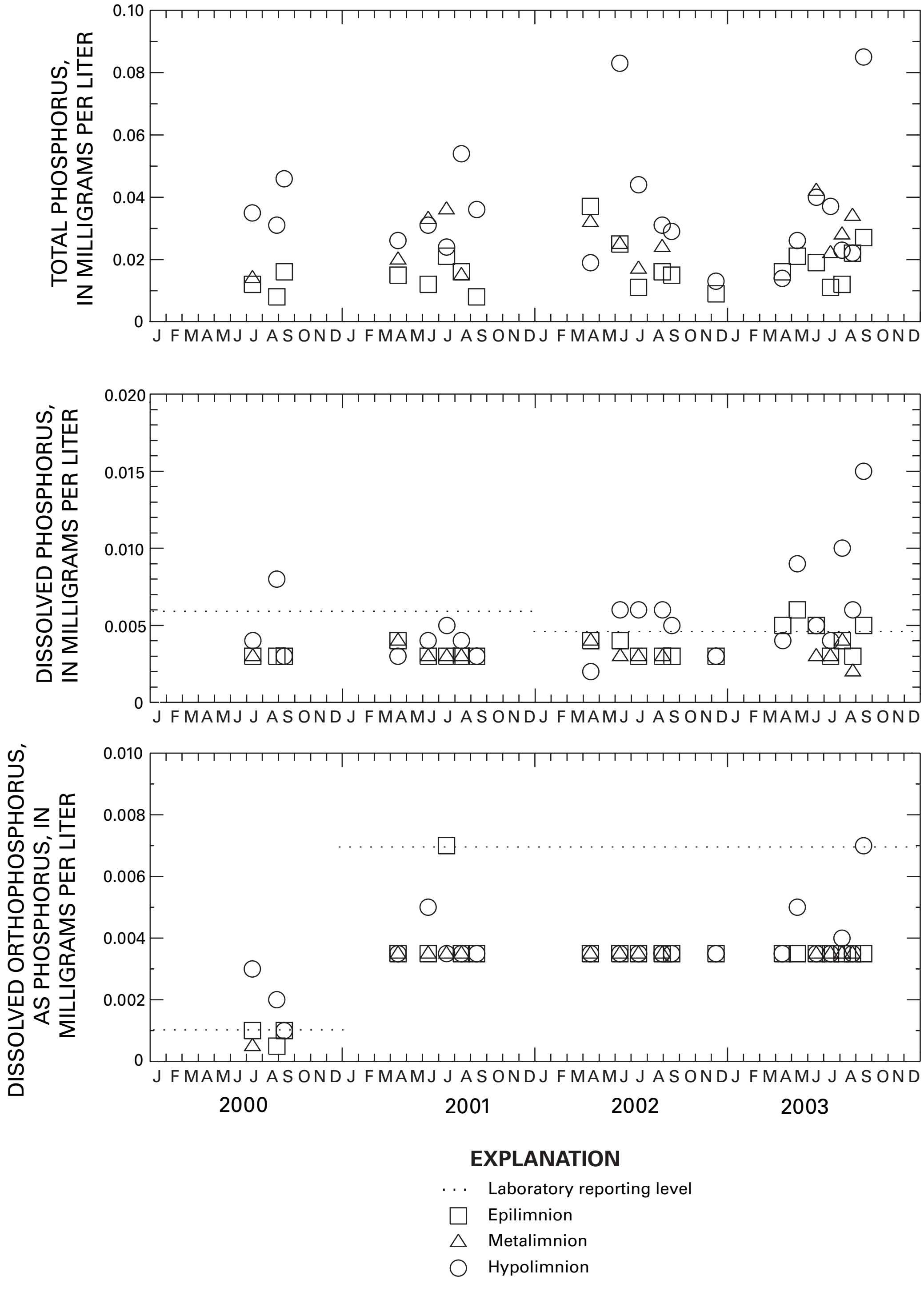


Figure 10. Time-series plots of phosphorus-compound concentrations at site T1 in Highline Lake, July 2000 through September 2003.

was measured in September 2003. The median dissolved-phosphorus concentration at Camp 7 was 0.008 mg/L. An increase in phosphorus concentrations in the lower hypolimnion, particularly during the later phases of thermal stratification, is commonly observed in lakes with anaerobic conditions in the hypolimnion (Wetzel, 2001).

Dissolved orthophosphorus usually was reported at concentrations less than the laboratory reporting levels. Maximum concentrations of orthophosphorus did not exceed 0.007 mg/L (fig. 10). Orthophosphorus is an inorganic form of phosphorus and is the only form readily available for uptake by phytoplankton.

Dissolved organic carbon

In freshwater ecosystems, DOC can affect many ecological processes (Schindler and Curtis, 1997; Gergel and others, 1999). These effects include altering sedimentation rates, providing a source of energy and nutrients to the microbial food chain, protecting aquatic organisms from the effects of ultraviolet radiation, restricting the depth of the euphotic zone, stabilizing the depth of the thermocline, and depressing primary productivity in lakes. Additionally, DOC is important in influencing the cycling of metals through changes in acid-base chemistry and influencing the availability of some forms of phosphorous and nitrogen (for example, ammonium) (Bushaw and others, 1996). The main sources of DOC are from precipitation, leaching, and decomposition primarily in the form of dissolved fulvic and humic acids.

The median DOC concentration in the epilimnion was 2.4 mg/L. This concentration was similar to concentrations measured at Camp 7 and was similar to concentrations in rivers of temperate and arid or semiarid zones (Hem, 1985). Generally, DOC concentrations increased with depth but, overall, the median DOC concentration at the bottom of the lake only was about 0.3 mg/L higher than what was observed in the epilimnion. However, the maximum DOC concentration (5.2 mg/L) was measured in the hypolimnion in July 2001, and two other samples collected in the hypolimnion had DOC concentrations greater than 4 mg/L. These higher concentration DOC samples were associated with higher ammonia concentrations in the hypolimnion (fig. 9).

Bacteria

Bacteria analyses at site T1 included the determination of fecal streptococcus and *E. coli* concentrations from samples collected near the surface of the water in the photic zone (fig. 11). All but one of the fecal streptococcus samples analyzed at site T1 were reported as being an estimated value or reported as a less than value. The median value would have been 4 col/100mL if the data qualifier was disregarded for each estimated sample. This median concentration was substantially less than the median concentration of 69 col/100mL at Camp 7. The maximum reported concentration at T1 was 28 col/100mL. In general, the concentration of fecal streptococcus at T1 was similar to that observed at site T3.

Fecal coliform bacteria have been used as an indicator organism for the sanitary quality of water for drinking or body-contact recreation. The presence of fecal coliform bacteria in water indicates the possible presence of various pathogens that may cause human diseases (Dufour, 1977; Pepper and others, 1996). Fecal coliform bacteria are found in the feces of all warm-blooded animals, but some members of the group also can originate in soil and water (Holt and others, 1993). The fecal coliform bacteria group can include any combination of *E. coli* and species of the Klebsiella, Enterobacter, and Citrobacter genera (Gleeson and Gray, 1997). Of the fecal group, *E. coli* is the only member that is exclusively fecal in origin and, therefore, is definitive evidence of fecal contamination from warm-blooded animals. Measuring *E. coli* has been shown to be a good indicator of possible contamination by organisms associated with swimming illnesses (Cabelli, 1977; Dufour and Cabelli, 1984).

The Colorado instream standard for primary contact recreation typically is 126 col/100mL for *E. coli* (Colorado Department of Public Health and Environment, 2004). Site T1 would be representative of a recreational site in the sense that primary contact, in the form of water skiing, does occur on Highline Lake. During the study period, all *E. coli* concentrations at T1 were reported as estimated values or as less than values. The median value would have been 3 col/100mL if the data qualifier was disregarded for each estimated sample. This median concentration was substantially less than the median concentration of 14 col/100mL at Camp 7. The maximum reported concentration at T1 was estimated at 8 col/100mL. In general, the concentrations of *E. coli* at site T1 were similar to those observed at site T3.

Bacteria concentrations also were determined at the public swim beach (site SB1) at Highline Lake (fig. 11). The swim beach is a popular destination for many people in the Grand Valley; more than 34,000 swimmers used the swim beach in 2003 (Colorado State Parks, 2003). During the study period, 17 fecal streptococci and 18 *E. coli* samples were collected by the USGS at SB1. In addition, weekly analyses of *E. coli* were conducted by the Colorado State Parks during the summer of each year. Results from 94 analyses were provided by the Parks to supplement the USGS data (Chris Foreman, Colorado State Parks, written commun., 2004). Overall, the median *E. coli* concentration for both sets of data was 4 col/100mL. The maximum concentration reported from a sample collected by the USGS was estimated at 18 col/100mL; all samples were reported as estimated values or as less than values. The maximum concentration reported by the Parks was 70 col/100mL. During the study period, no reported *E. coli* concentration exceeded the standard for natural swimming areas. The median fecal-streptococcus concentration from samples collected by the USGS at SB1 was 16 col/100mL.

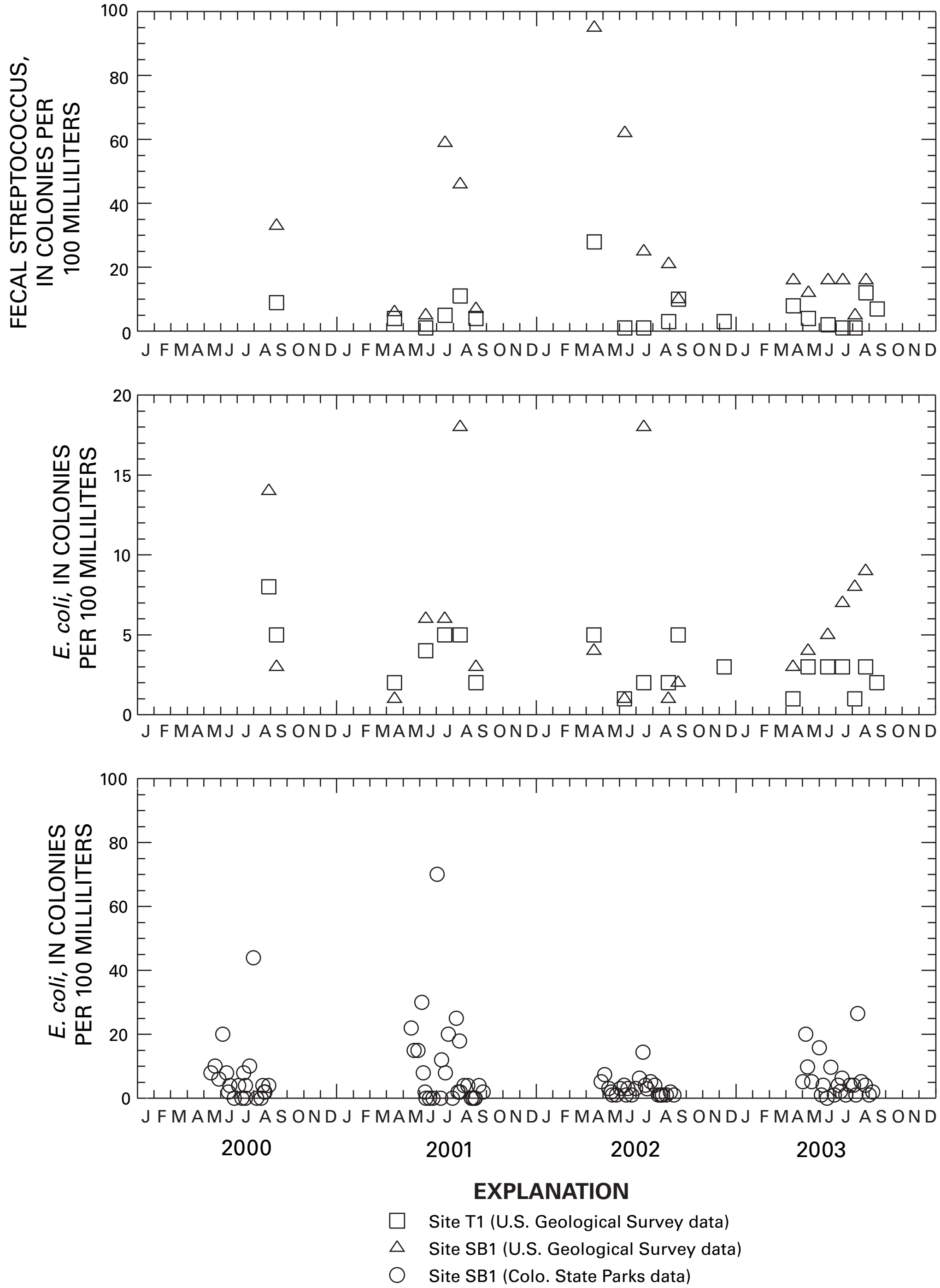


Figure 11. Time-series plots of fecal streptococcus and *E. coli* at sites T1 and SB1 in Highline Lake, July 2000 through September 2003.

Chlorophyll

Chlorophyll is the pigment that enables plants (including algae) to convert sunlight into organic compounds by the process of photosynthesis. Chlorophyll-*a* is the predominant type of chlorophyll in algae. Measurements of chlorophyll-*a* concentrations in water often are used to approximate the primary productivity and algal biomass. Wetzel (1983) indicated that lakes with chlorophyll-*a* concentrations ranging from 0.3 to 3 µg/L generally have small nutrient concentrations and a small algal biomass; exceedingly higher concentrations are associated with larger nutrient concentrations and biomass. At site T1 in Highline Lake, the median chlorophyll-*a* concentration was 1.0 µg/L, which indicates that the lake has low nutrient concentrations and biomass. The maximum chlorophyll-*a* concentration was 2.6 µg/L. Chlorophyll-*a* concentrations at site T1 from July 2000 through September 2003 were similar to concentrations at site T3 and SB1.

Phytoplankton

General patterns in the composition of phytoplankton communities can be observed in lakes and reservoirs of different trophic categories (Wetzel, 2001). In oligotrophic and mesotrophic lakes, the characteristic phytoplankton would be comprised of golden algae (Chrysophyta), cryptomonads (Cryptophyta), and diatoms (Bacillariophyta). In the more nutrient-rich lakes, blue-green algae (Cyanophyta) and diatoms would be expected to be the dominant phytoplankton groups. In Highline Lake, the phytoplankton community was dominated by the blue-green algae. The community structure at T1 and T3 was nearly the same for all samples. Concentra-

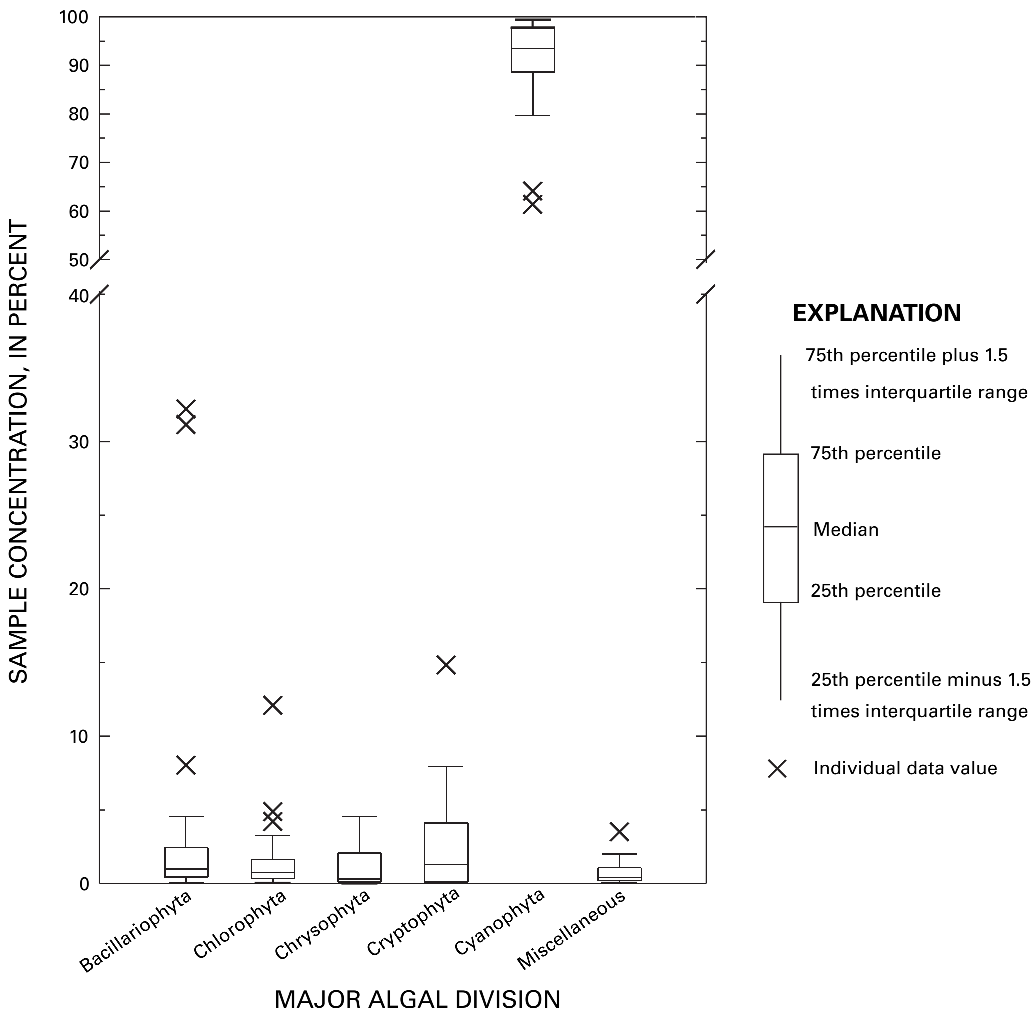


Figure 12. Boxplot showing major algal concentrations as a percentage of sample concentrations in Highline Lake, August 2001 through September 2003.

tions of blue-green algae (Cyanophyta) accounted for about 95 percent of the phytoplankton community during most of the sampling events (fig. 12). The major family group was *Chroococcaceae* of which *Synechococcus* was a dominant genus (phytoplankton data are included on a CD-ROM at the back of this report). Other phytoplankton types present at smaller concentrations were the diatoms (Bacillariophyta), the green algae (Chlorophyta), the golden algae (Chrysophyta), and the cryptomonads (Cryptophyta). Generally, none of these phytoplankton types accounted for more than 5 percent of the sample concentration in Highline Lake. The one noteable exception was observed in April 2003 when the concentration of diatoms exceeded 30 percent at sites T1 and T3; the dominant diatom in these samples was *Cyclotella ocellata*.

Many types of algae are associated with taste and odor issues in water bodies, and critical concentrations that produce odorous metabolites have been quantified for selected algae (Mallevialle and Suffet, 1987). Although identified at relatively small concentrations, several algae genera associated with taste and odor issues were routinely identified in samples collected at sites T1 and T3. These genera included: *Cyclotella* (diatoms); *Dinobryon* (golden algae); *Cryptomonas* (cryptomonad); and *Ankistrodesmus, Chlamydomonas, Closterium,* and *Scenedesmus* (green algae). In general, the critical concentrations were not exceeded for any listed algal genera with the exception of the diatom *Cyclotella* in a sample collected in April 2003 at sites T1 and T3.

Water residence time has been shown to strongly influence phytoplankton abundance; algal abundance generally increases with residence time (Soballe and Kimmel, 1987). The short residence times in Highline Lake could limit the time phytoplankton had to reproduce, thus limiting the population size.

The general seasonal succession of major phytoplankton groups (as biomass) in dimictic lakes in the temperature zone has been described by Wetzel (2001). Although few biomass data were available, a comparison of the biomass of the major diatom species (*Cyclotella ocellata*) and the major blue-green algae group (*Chroococcaceae*) was done as part of this study to determine if the seasonal succession in Highline Lake was similar to that described by Wetzel (2001). The biovolume of *Cyclotella ocellata* was reported in a list of 545 biovolumes of algal taxa from samples collected by the USGS National Water Quality Assessment Program (Academy of Natural Sciences, 2004). The biovolume of *Chroococcaceae* was calculated from morphological data provided by the analyzing laboratory (Anne St. Amand, PhycoTech Inc., St. Joseph, Michigan, written commun., 2004). In general, the seasonal succession of phytoplankton was similar to that described by Wetzel (2001), that is, the biomass in the spring was dominated by one diatom species (*Cyclotella ocellata*), and algal populations declined as summer stratification patterns developed. Furthermore, blue-green algae such as *Chroococcaceae* become more profuse during late summer until thermal stratification was disrupted and diatoms again became the dominant algal group.

Trophic state

Carlson (1977) developed the numeric trophic-state index (TSI) to define the degree of eutrophication in water bodies and to enable comparisons to other water bodies. The index is based on changes in nutrient concentrations that may cause changes in algal biomass, resulting in changes in lake clarity. The TSI is calculated from total-phosphorus concentrations, chlorophyll-*a* concentrations (biomass), or Secchi-disk transparency measurements (clarity) using a distinct formula for each parameter. The TSI scale ranges from 0 to 110, and ranges of values often are grouped into classifications associated with the productivity of a water body. Values less than 40 are associated with low productivity (oligotrophic) lakes. Values from 40 to 50 usually are associated with moderately productive (mesotrophic) lakes. Index values greater than 50 are associated with highly productive (eutrophic) lakes. The TSI equations presented here are algebraically simplified versions of the equations in Carlson (1977) and provide a normalized value for each constituent (U.S. Environmental Protection Agency, 2003). Each of the three TSI's can be used independently to describe the trophic state of a water body. The derived equations to compute TSI values based on total-phosphorus concentrations, chlorophyll-*a* concentrations, and Secchi-disk depths are as follows:

$$TSI_{TP} = 14.42(1n\ TP) + 4.15 \quad (3)$$

$$TSI_{CHLA} = 9.81(1n\ CHLA) + 30.6 \quad (4)$$

$$TSI_{SD} = 60 - 14.41(1n\ SD) \quad (5)$$

where

TP is total-phosphorus concentration, in micrograms per liter;

1n is the natural logarithm function;

CHLA is chlorophyll-*a* concentration, in micrograms per liter; and

SD is Secchi-disk depth, in meters.

TSI values were computed for each lake site using available total-phosphorus concentrations (photic zone only), chlorophyll-*a* concentrations, and Secchi-disk depths. In general, there was little spatial variation in the TSI, so the results were averaged to determine an annual TSI value for the lake based on each of the three indicator parameters (table 5). Based on data collected from July 2000 through September 2003, the trophic state for Highline Lake ranged from oligotrophic (low productivity) to eutrophic (high productivity) with each of the indicator parameters indicating a different trophic state. TSI's based on chlorophyll-*a* concentrations were lower than those calculated using Secchi-disk depths and total-phosphorus concentrations. Bauch and Malick (2003) state that lower index values for chlorophyll-*a* can be expected when differences in analytical methods are considered. The Carlson (1977) method assumes that fluorometric analysis was used to determine chlorophyll-*a* concentrations; current (2004) USGS methods use spectrophotometry-analysis techniques

Table 5. Summary of trophic status indices for total phosphorus and chlorophyll-*a* concentrations, and Secchi-disk measurements at selected sites in Highline Lake from July 2000 through September 2003.

[TSI, trophic status index; --, not applicable]

Site	Number of results	Total phosphorus		Chlorophyll-*a*		Secchi disk	
		TSI	Classification	TSI	Classification	TSI	Classification
T1	21	44	Mesotrophic	30	Oligotrophic	63	Eutrophic
T2	21	--	--	--	--	64	Eutrophic
T3	13	49	Mesotrophic	32	Oligotrophic	68	Eutrophic
SB1	19	50	Mesotrophic/ Eutrophic	30	Oligotrophic	--	--
Average	--	48	Mesotrophic	31	Oligotrophic	65	Eutrophic

(Britton and Greeson, 1987). Additionally, this difference could be a result of turbid conditions caused by suspended sediment and turbidity from Camp 7 that increase total-phosphorus and Secchi-depth TSI’s but do not affect the chlorophyll-*a* index due to decreased light penetration (Kuhn and others, 2003). Given the relatively small biomass in the lake, primary production is most likely driven by light limitation as opposed to phosphorus limitation. Use of TSI’s can give a qualitative indication of relative trophic status of water bodies, but should not be considered as a definition of trophic status.

Phosphorus most often is considered to be the nutrient that regulates the production in lakes and often is the variable of concern in regards to lake eutrophication. Vollenweider (1968) categorized trophic status according to total-phosphorus concentrations. Lakes with total-phosphorus concentrations less than 0.01 mg/L were classified as oligotrophic; concentrations from 0.01 to 0.02 mg/L were indicative of mesotrophic lakes; and concentrations exceeding 0.02 mg/L were classified as eutrophic. The median total-phosphorus concentration for all samples collected in the photic zone at sites T1, T3, and SB1 was 0.021 mg/L. Using this method, Highline Lake would be classified as a mesotrophic/eutrophic lake.

Nutrient limitations

Phytoplankton (algae) can assimilate inorganic nitrogen and phosphorus for growth (Horne and Goldman, 1994). Inorganic nitrogen compounds available for growth include nitrite, nitrate, and ammonia; the only inorganic phosphorus compound readily available for growth is orthophosphorus. Nitrogen to phosphorus (N:P) ratios can be used to identify which of the two nutrients may be growth limiting for phytoplankton; a mass ratio of 7N:1P is the theoretical boundary between nitrogen and phosphorus limitation (Redfield, 1958). Nutrient-limitation information is important because it indicates which nutrient controls algal growth. If a nutrient is limiting, the addition of that nutrient could cause an increase in algal production (Britton and Gaggiani, 1987; Woods, 1992). In practice, N:P ratios smaller than 5 are thought to represent nitrogen-limiting situations, whereas N:P ratios larger than 10 represent phosphorus-limiting conditions. Nitrogen to phosphorus ratios from 5 to 10 could indicate nitrogen or phosphorus limitation (Britton and Gaggiani, 1987; Woods, 1992).

Ratios of inorganic nitrogen mass to inorganic phosphorus mass were computed at sites T1, T3, and SB1. Only samples collected near the surface of the water (the photic zone) were used to calculate the N:P ratios. The inorganic nitrogen mass was defined as the sum of the nitrite plus nitrate and ammonia concentration. The inorganic phosphorus mass was defined as the orthophosphorus concentrations. Data values reported as less than the laboratory reporting levels were assigned concentrations equal to the reporting level at the time the sample was analyzed. This technique provided for a more conservative estimate of nutrient limitations. At all three sites, the median N:P ratios ranged from 7 to 10, which indicate that the limiting nutrient in Highline Lake could be nitrogen or phosphorus. However, phosphorus-limiting conditions (N:P ratios ranging from 20 to 77) were observed during some periods in early spring, late fall, and winter.

Summary

Highline Lake is located about 20 mi northwest of Grand Junction, Colorado. The lake consists almost entirely of irrigation water diverted from the Colorado River along the Government Highline Canal. Excess irrigation water is siphoned from the canal into the lake at the Camp 7 check structure. Typically, the canal is operated at full capacity from June until late August. The Colorado Division of Parks and Recreation was concerned that a reduction in spill water into Highline Lake could adversely affect the recreational uses of the lake. To address this concern and to characterize the water quality in the Government Highline Canal and Highline Lake, the U.S. Geological Survey, in cooperation with the Colorado Division of Parks and Recreation, conducted a study to evaluate limnological conditions prior to implementation of the management strategies.

This report characterizes the water quality of flow from the Government Canal and in Highline Lake during July 2000 through September 2003. Flow entering the lake from the Government Canal was characterized using field properties and available chemical, sediment, and bacteria concentrations. Data collected at Highline Lake were used to characterize the seasonal stratification patterns, water-quality chemistry, bacteria populations, and phytoplankton community structure in the lake. Data used for this report were collected from one inflow site (Camp 7) to the lake and four sites in Highline Lake (T1,T2, T3, SB1).

Water temperatures at Camp 7 reflected the source water in the Colorado River. The water was well oxygenated, and dissolved oxygen and pH were within acceptable stream standards for aquatic life. Nitrogen and phosphorus concentrations at Camp 7 generally were low, and concentrations did not differ substantially from year to year or seasonally within a year.

All samples from Camp 7 had reportable numbers of fecal streptococcus. The median fecal streptococcus concentration was 69 colonies per 100 milliliters of sample, and the maximum concentration was estimated at 480 colonies per 100 milliliters of sample. The median *E. coli* concentration at Camp 7 was 14 colonies per 100 milliliters of sample, and the maximum reported concentration was 77 colonies per 100 milliliters of sample. All other concentrations of *E. coli* were reported as estimated values or less-than values. The median turbidity value at Camp 7 was 60 nephelometric turbidity units; the maximum turbidity measured at this site was 390 nephelometric turbidity units. Suspended-sediment concentrations were relatively low.

Three sites in Highline Lake were selected for routine collection of depth-profile data. Analysis of these data indicated that the spatial variability in the lake was relatively small and longitudinal mixing was complete. Depth profiles of water temperature, dissolved oxygen, pH, and specific conductance were used to characterize stratification patterns in Highline Lake. No seasonal stratification patterns were observed for any of the field measurements at site T3 because of the shallow depths at this site. Differences in spatial stratification between the midlake site (T2) and the deeper site (T1) were relatively minor because both sites had similar patterns for most profile measurements.

Highline Lake is presumed to be dimictic, and strong thermal stratification occurred during summer. In September, the lake fully mixed as the surface cooled, and overturn of the lake occurred. Stratification of dissolved oxygen was similar to the thermal profiles; however, the magnitude and depths at which anoxic conditions occurred were more pronounced. During summer, dissolved-oxygen concentrations of less than 1 milligram per liter were measured at the bottom of the lake. Mixing of water in the hypolimnion did not appear to occur. Stratification patterns for specific conductance were caused by inflow from the Government Canal.

Physical and chemical characteristics of Highline Lake were determined by collecting water-quality samples at three sites in the lake. Samples collected near the water surface in the photic zone at all three sites showed similar water-quality characteristics. Turbidity in Highline Lake was relatively low but increased at deeper depths. Nitrogen concentrations in samples collected near the surface at site T1 were similar in concentration to those samples collected at Camp 7. Ammonia concentrations, however, were much higher in the near-bottom samples collected in late summer when anoxic conditions were evident. It appeared that ammonia was released from the bottom sediments of Highline Lake. Concentrations of phosphorus compounds were low in Highline Lake.

Bacteria concentrations were determined at the public swim beach at Highline Lake. During the study period, no reported *E. coli* concentration exceeded the standard for natural swimming areas. The maximum *E. coli* concentration reported by the U.S. Geological Survey was estimated at 18 colonies per 100 milliliters. The maximum concentration reported by the Colorado Division of Parks and Recreation was 70 colonies per 100 milliliters.

Phytoplankton in Highline Lake was dominated by the blue-green algae (cyanobacteria), which accounted for about 95 percent of the phytoplankton community during most of the sampling events. Although identified at relatively small concentrations, several genera associated with taste and odor issues were routinely identified in samples collected at sites T1 and T3. These genera included- *Cyclotella* (diatoms); *Dinobryon* (golden algae); *Cryptomonas* (cryptomonad); and *Ankistrodesmus, Chlamydomonas, Closterium,* and *Scenedesmus* (green algae). In general, the critical concentrations were not exceeded for any listed algal genera with the exception of the diatom *Cyclotella* in one sample.

The trophic status of Highline Lake can range from oligotrophic to eutrophic depending on the indicator parameter used to calculate the trophic-state index value. The lake would be classified as a mesotrophic/eutrophic lake using total phosphorus concentrations as an indicator. The limiting nutrient in Highline Lake could be nitrogen or phosphorus.

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