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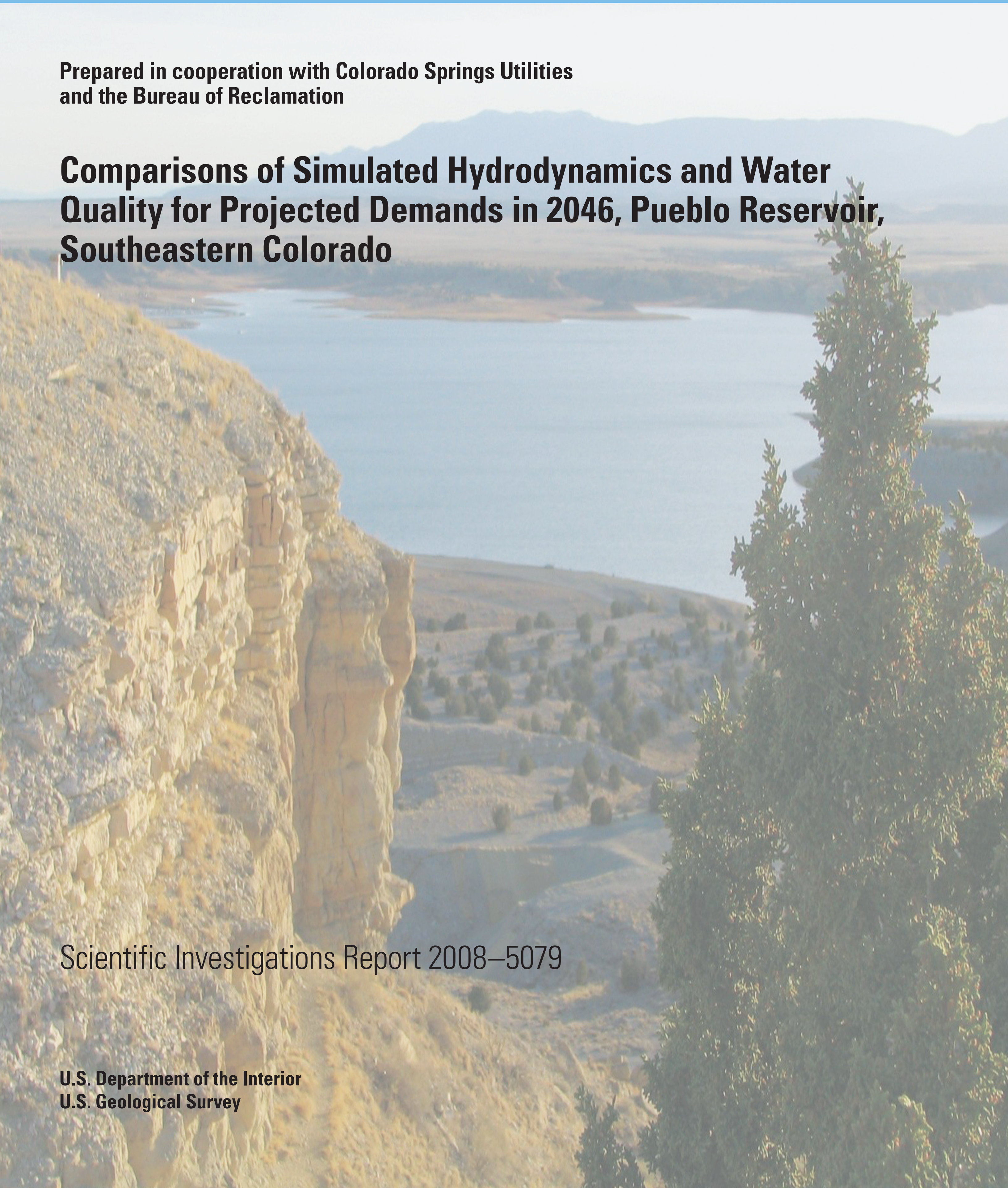
Comparisons of Simulated Hydrodynamics and Water Quality for Projected Demands in 2046, Pueblo Reservoir, Southeastern Colorado



Scientific Investigations Report 2008–5079

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

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By Roderick F. Ortiz, Joel M. Galloway, Lisa D. Miller, and David P. Mau

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Conversion Factors and Datums

Multiply	By	To obtain
inch	2.54	centimeter
foot	0.3048	meter
mile	1.609	kilometer
acre-foot	1,233	cubic meter
foot per second	0.3048	meter per second
cubic foot per second	0.02832	cubic meter per second
gallons per day	0.00378	cubic meter per day

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

°F=(1.8×°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.

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

Water Year (WY) is defined as beginning October 1 and continuing through September 30 of the following year.

Abbreviations and acronyms used in this report:

BOD	biological oxygen demand
Daily Model	Arkansas River Daily Simulation Model
DO	dissolved oxygen
DS	dissolved solids
EIS	Environmental Impact Statement
GIS	Geographical Information System
Reclamation	Bureau of Reclamation
SDS	Southern Delivery System
USGS	U.S. Geological Survey

Comparisons of Simulated Hydrodynamics and Water Quality for Projected Demands in 2046, Pueblo Reservoir, Southeastern Colorado

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Abstract

Pueblo Reservoir is one of southeastern Colorado's most valuable water resources. The reservoir provides irrigation, municipal, and industrial water to various entities throughout the region. The reservoir also provides flood control, recreational activities, sport fishing, and wildlife enhancement to the region. The Bureau of Reclamation is working to meet its goal to issue a Final Environmental Impact Statement (EIS) on the Southern Delivery System project (SDS). SDS is a regional water-delivery project that has been proposed to provide a safe, reliable, and sustainable water supply through the foreseeable future (2046) for Colorado Springs, Fountain, Security, and Pueblo West. Discussions with the Bureau of Reclamation and the U.S. Geological Survey led to a cooperative agreement to simulate the hydrodynamics and water quality of Pueblo Reservoir. This work has been completed and described in a previously published report, U.S. Geological Survey Scientific Investigations Report 2008–5056. Additionally, there was a need to make comparisons of simulated hydrodynamics and water quality for projected demands associated with the various EIS alternatives and plans by Pueblo West to discharge treated water into the reservoir. Plans by Pueblo West are fully independent of the SDS project.

This report compares simulated hydrodynamics and water quality for projected demands in Pueblo Reservoir resulting from changes in inflow and water quality entering the reservoir, and from changes to withdrawals from the reservoir as projected for the year 2046. Four of the seven EIS alternatives were selected for scenario simulations. The four U.S. Geological Survey simulation scenarios were the No Action scenario (EIS Alternative 1), the Downstream Diversion scenario (EIS Alternative 2), the Upstream Return-Flow scenario (EIS Alternative 4), and the Upstream Diversion scenario (EIS Alternative 7). Additionally, the results of an Existing Conditions scenario (water years 2000 through 2002) were compared to the No Action scenario (projected demands in 2046) to assess changes in water quality over time. All scenario modeling used an external nutrient-decay model to simulate degradation and assimilation of nutrients along the riverine reach upstream from Pueblo Reservoir.

Reservoir modeling was conducted using the U.S. Army Corps of Engineers CE–QUAL–W2 two-dimensional water-quality model. Lake hydrodynamics, water temperature, dissolved oxygen, dissolved solids, dissolved ammonia, dissolved nitrate, total phosphorus, algal biomass, and total iron were simulated. Two reservoir site locations were selected for comparison. Results of simulations at site 3B were characteristic of a riverine environment in the reservoir while results of at site 7B (near the dam) were characteristic of the main body of the reservoir. Simulation results for the epilimnion and hypolimnion at these two sites also were evaluated and compared. The simulation results in the hypolimnion at site 7B were indicative of the water quality leaving the reservoir.

Comparisons of the different scenario results were conducted to assess if substantial differences were observed between selected scenarios. Each of the scenarios was simulated for three contiguous years representing a wet, average, and dry annual hydrologic cycle (water years 2000 through 2002). Additionally, each selected simulation scenario was evaluated for differences in direct- and cumulative-effects on a particular scenario. Direct effects are intended to isolate the future effects of the scenarios. Cumulative effects are intended to evaluate the effects of the scenarios in conjunction with all reasonably foreseeable future activities in the study area.

Comparisons between the direct- and cumulative-effects analyses indicated that there were not large differences in the results between most of the simulation scenarios and, as such, the focus of this report was on results for the direct-effects analysis. Additionally, the differences between simulation results generally were small for the Existing Conditions scenario (water years 2000 through 2002) and the No Action scenario (projected demands in 2046). Finally, comparisons of the simulation results for the No Action scenario to the remaining simulation scenarios (Downstream Diversion, Upstream Return-Flow, and Upstream Diversion) indicated that, in general, the Upstream Diversion scenario was the most similar to the No Action scenario. Conversely, simulated concentrations associated with the Upstream Return-Flow scenario typically were substantially larger than the concentrations for the No Action scenario.

Introduction

Pueblo Reservoir is one of southeastern Colorado's most valuable water resources. Located approximately 6 miles west of Pueblo, Colorado (fig. 1), the reservoir has a total storage capacity of 357,678 acre-feet (U.S. Bureau of Reclamation, 1977). It provides irrigation, municipal, and industrial water to various entities throughout the region. Specifically, water is released from Pueblo Reservoir to the Arkansas River for downstream irrigation and municipal use, conveyed by pipeline for municipal use by Colorado Springs and other communities north of the reservoir, and diverted from the reservoir for irrigation east of Pueblo (Southeastern Colorado Water Conservancy District, 2007). Water also is conveyed to Pueblo and Pueblo West through the municipal outlet works in Pueblo Dam. A fish hatchery located immediately downstream from the reservoir relies on water from the reservoir to raise several cold- and warm-water species. The reservoir also provides flood control, recreational activities, sport fishing, and wildlife enhancement to the region.

The population in the region has increased rapidly in the past 10 years and it is expected to nearly double by the year 2040 (GEI Consultants Inc., 2000). As such, a regional water-delivery project has been proposed to provide a safe, reliable, and sustainable water supply through the foreseeable future (2046) for Colorado Springs, Fountain, Security, and Pueblo West (fig. 1). A substantial component of the proposed project, known as the Southern Delivery System (SDS), is a pipeline capable of conveying 78 million gallons of raw water per day (240 acre-feet) from Pueblo Reservoir (Bureau of Reclamation, 2007). The proposed project would divert untreated water from the municipal outlet at the Pueblo Dam and deliver it north to Colorado Springs Utilities, the city of Fountain, Security Water District, and Pueblo West Metropolitan Water District (the Participants). Return flows would be stored in a new reservoir on Williams Creek prior to exchange down Fountain Creek to the Arkansas River downstream from Pueblo Reservoir (fig. 1). A complete description of the proposed SDS project can be found on the world-wide web at http://www.csu.org/about/projects/sds/index.html.

As proposed, the SDS would require contracts with the Bureau of Reclamation (Reclamation) to store and convey water in the federally owned Pueblo Reservoir facility. Reclamation initiated an Environmental Impact Statement (EIS) in response to the proposed project. Seven reasonable alternatives, including the proposed SDS alternative, were selected for evaluation as part of the EIS (Bureau of Reclamation, 2007). The alternatives were selected based upon the purpose and need of the SDS project, the overall project cost, the environmental impact of the project, and the technical feasibility of the alternative. A generalized description of the seven alternatives as they relate to potential impacts to the water quality in Pueblo Reservoir can be found in figure 2. A more detailed discussion of the alternatives, as they relate to four subsequent water-quality simulation scenarios, will be provided later in this report. For a detailed description of the seven EIS alternatives, the reader is referred to the world-wide web at *http://www.sdseis.com/alternatives.html*. Operational changes as a result of implementation of these alternatives could change the hydrodynamics and water-quality conditions in the reservoir.

Pueblo West Utilities is proceeding with a design that will include a site application to the Colorado Department of Public Health and Environment for a proposed discharge point for treated water that will ultimately flow into Pueblo Reservoir on the north shore of the reservoir near the dam structure (Stephen Harris, Pueblo West Utilities, written commun., 2006). Pueblo West's plans are fully independent of the SDS project and also could have an impact on the hydrodynamics and water-quality conditions in the reservoir.

Reclamation is working with numerous federal, state, and local agencies to meet its goal to issue a Final EIS on the SDS project. Discussions with Reclamation, the U.S. Geological Survey (USGS), and Colorado Springs Utilities concerning the need to accurately simulate hydrodynamics and water quality in Pueblo Reservoir led to a cooperative agreement between the two federal agencies to simulate the hydrodynamics and water quality of Pueblo Reservoir, and to make comparisons of simulated hydrodynamics and water quality for projected demands associated with the selected EIS alternatives. Additionally, plans by Pueblo West to discharge treated water into the reservoir were incorporated into the simulation process. The hydrodynamics and water quality of Pueblo Reservoir were modeled previously and the results of the modeling were documented by Galloway and others (2008), referred to as the USGS Pueblo Reservoir model in this report.

Purpose and Scope

The purpose of this report is to compare simulated hydrodynamics and water quality for projected demands in Pueblo Reservoir resulting from changes in inflow and water quality entering the reservoir and from changes to withdrawals from the reservoir as projected for the year 2046. Four of the seven EIS alternatives were selected for scenario simulations (fig. 2) using the USGS Pueblo Reservoir model (Galloway and others, 2008) developed from the U.S. Army Corps of Engineers CE–QUAL–W2 model (version 3.2) (Cole and Wells, 2003). Comparisons of the simulated results were conducted to determine if substantial differences were observed between selected scenarios.

The four scenarios characterized the various projected changes in inflow, outflow, and water quality to Pueblo Reservoir as characterized in the original seven EIS alternatives. Specifically, the four simulation scenarios are the No Action scenario (EIS Alternative 1), the Downstream Diversion scenario (EIS Alternative 2), the Upstream Return-Flow scenario (EIS Alternative 4), and the Upstream Diversion scenario (EIS Alternative 7) (fig. 2). Each of the four scenarios was simulated for 3 contiguous water years representing a wet (WY 2000), average (WY 2001), and dry (WY2002) annual

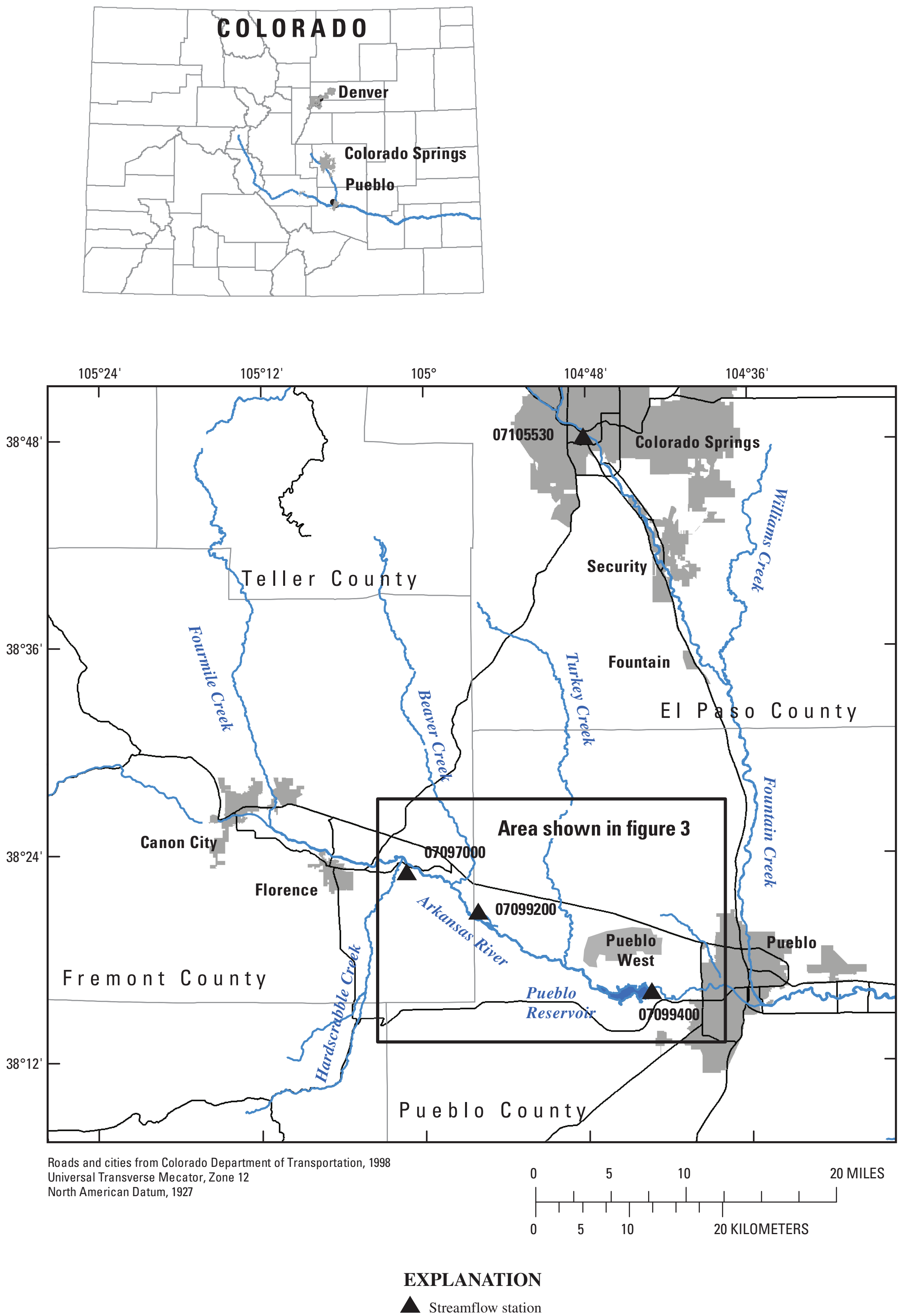

Figure 1. Location of the study area.

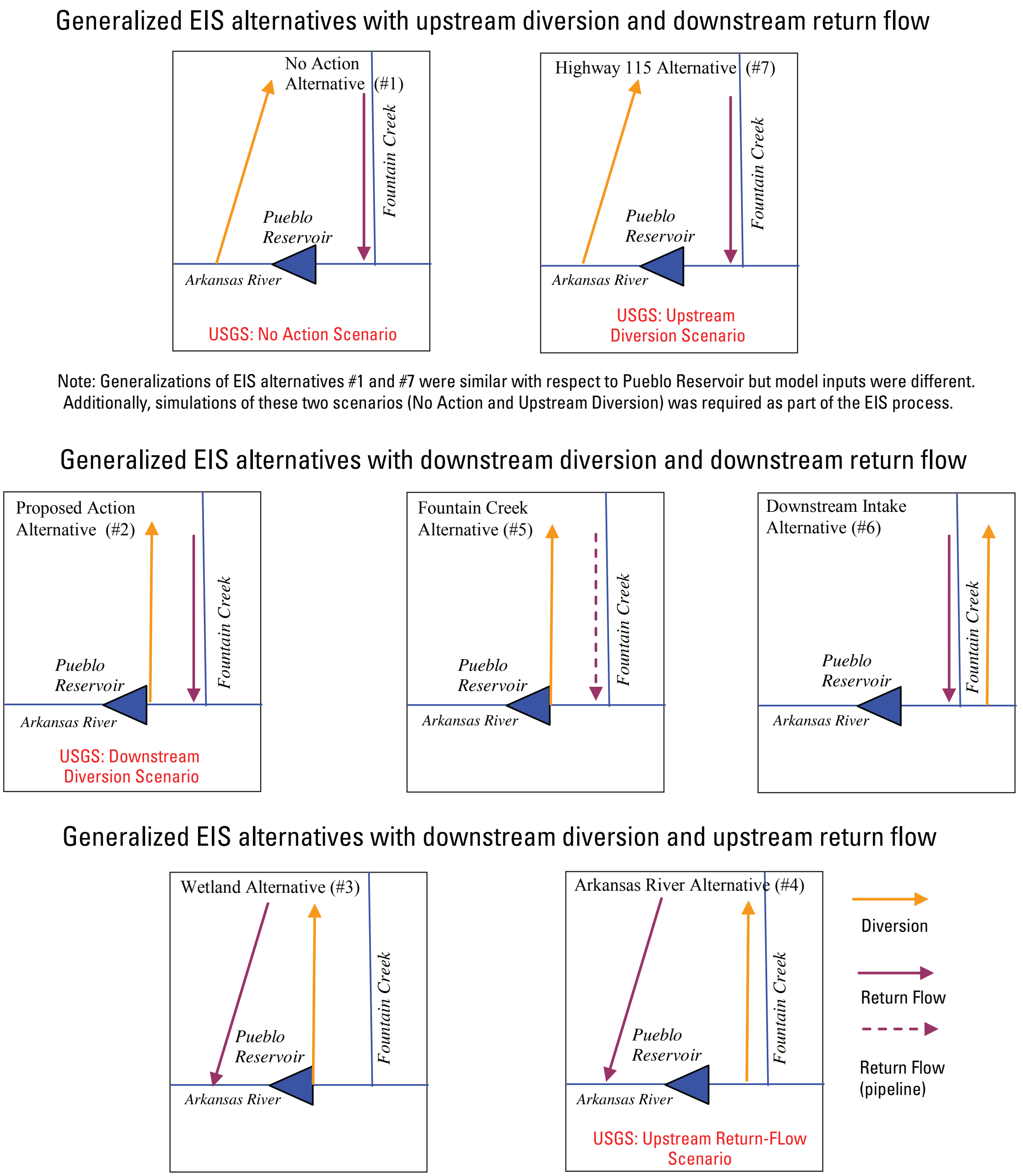

Figure 2. Generalized description of the seven Environmental Impact Statement (EIS) alternatives associated with the Southern Delivery System as they relate to potential impacts to the water quality in Pueblo Reservoir. (USGS scenario descriptors shown in red type)

hydrologic cycle. Streamflow, diversion, reservoir storage, and return-flow quantity and quality data for projected demands in 2046 were provided to the USGS by contractors for Reclamation (Tracy Kosloff, MWH Americas, Inc., written commun., 2006).

Additionally, each selected simulation scenario was evaluated for differences in direct/indirect effects and cumulative effects on a particular scenario. Direct/indirect effects (herein referred to as “direct effects”) are intended to isolate the future effects of the scenarios. Cumulative effects are intended to evaluate the effects of the scenarios in conjunction with all reasonably foreseeable future activities in the study area. Direct and cumulative effects generally represent operations and municipal water demands for the Participants as they are anticipated to be in 2046; this is the expected timeframe when hydrologic effects would be the greatest. The primary difference between the two sets of simulations was that the direct-effects simulations include existing levels of demand by nonparticipants in the SDS project, while the cumulative-effects simulations include projected demands in 2046 by the nonparticipants in the SDS project (MWH Americas, 2007).

Finally, scenario simulations were done that represented existing conditions in Pueblo Reservoir during water years 2000 through 2002. The results of the Existing Conditions scenario only were compared to the No Action scenario to assess changes in water quality from current demands (WY 2000–2002) to projected demands in 2046.

A summary of the simulation scenarios can be found in table 1. All simulations used an external nutrient-decay model to simulate degradation and assimilation of nutrients along the riverine reach upstream from Pueblo Reservoir.

Acknowledgments

The authors thank Tom Musgrove and his staff of the Bureau of Reclamation for their assistance providing data used in this study. The authors also would like to thank Bill Van Derveer and Tracy Kosloff of MWH Americas, Inc., for their support providing data and review comments of the draft report. Thanks to Reed Green (USGS Arkansas Water Science Center) and Annett Sullivan (USGS Oregon Water Science Center) for their technical assistance and advice in model development and calibration. Thanks also are extended to Brian Clark (USGS Arkansas Water Science Center) for his many hours developing a model postprocessor and simulation animations. Additionally, the authors also would like to thank Steve Char (USGS Colorado Water Science Center) for his Geographic Information System (GIS) expertise in developing the model computational grid.

Methods of Hydrodynamic and Water-Quality Simulation

Various modeling tools were used to simulate results for comparison between the different simulation scenarios. Reservoir simulations were conducted using a two-dimensional water-quality reservoir model. Input data to the reservoir model that represented the projected demands in 2046 were prepared by Reclamation’s consultant. Nutrient decay along the riverine reach upstream from Pueblo Reservoir was simulated to account for the degradation and assimilation of selected constituents in the Arkansas River. Each of these efforts is described in the following sections.

Reservoir Modeling Using CE–QUAL–W2

The construction, calibration, and testing of the USGS Pueblo Reservoir model was documented by Galloway and others (2008). In summary, the laterally averaged, two-dimensional model was calibrated at four locations in the reservoir (fig. 3) using data collected from October 1985 to October 1987 and verified with data from October 1999 to October 2002. The 3-year contiguous period from October 1999 through September 2002 had various hydrologic conditions that allowed for verification of the model during a relatively wet (WY 2000), average (WY 2001), and dry year (WY 2002). Lake hydrodynamics, water temperature, dissolved oxygen, dissolved solids, dissolved ammonia, dissolved nitrate (represented by dissolved nitrite-plus-nitrate concentrations), total phosphorus, algal biomass (measured as chlorophyll *a*), and total iron were simulated. The model accurately captured the most important seasonal and spatial influences on the reservoir water quality (Galloway and others, 2008).

CE–QUAL–W2 has been applied to many reservoir systems around the world, and the model will accurately simulate the heat budget and water temperature dynamics of a system when accurate bathymetric data, a balanced water budget, and good meteorological data are provided (Cole and Wells, 2003). Past performance and recent USGS applications of this model have demonstrated its success in simulating water temperature in reservoir systems (Bales and others, 2001; Green, 2001; Rounds and Wood, 2001; Sullivan and Rounds, 2004; Sullivan and Rounds, 2005). Similarly, the model’s water-quality predictions should be useful and relatively accurate as long as the water-quality algorithms in CE–QUAL–W2 capture the most important processes affecting water quality in the reservoir, and if the processes that control the water quality in the reservoir do not change substantially over time. In the

Table 1. Selection of simulation scenarios compared to Environmental Impact Statement alternatives including generalized characteristics of simulated scenarios, comparisons made between simulation scenarios, effects analyses simulated, and use of proposed Pueblo West treated water in simulation effort.

[EIS, Environmental Impact Statement; Y, yes; N, no; NA, not applicable]

USGS simulation scenario	EIS alternative name[1] (EIS numerical designation)	Generalized diversion or return-flow characteristics of EIS alternative				USGS scenario comparisons made in this report	Direct and cumulative effects analysis simulated	Pueblo West treated water included in simulation
		Upstream diversion	Down-stream diversion	Down-stream return flow	Upstream return flow			
No Action scenario	No Action Alternative (1)	Y	N	Y	N	All other scenarios	Y	Y
Downstream Diversion scenario	Proposed Action Alternative (2)	N	Y	Y	N	No Action	Y	Y
---[2]	Fountain Creek Alternative (5)	N	Y	Y	N	--	--	--
---[2]	Downstream Intake Alternative (6)	N	Y	Y	N	--	--	--
Upstream Return-Flow scenario	Arkansas River Alternative (4)	N	Y	N	Y	No Action	Y	Y
---[3]	Wetland Alternative (3)	N	Y	N	Y	--	--	--
Upstream Diversion scenario	Highway 115 Alternative (7)	Y	N	Y	N	No Action	Y	Y
Existing Conditions scenario	NA	---	---	---	---	No Action	NA	N

[1] For a detailed description of the seven EIS alternatives, the reader is referred to the world-wide web at *http://www.sdseis.com/alternatives.html*

[2] USGS Downstream Diversion Scenario was representative of EIS Fountain Creek Alternative (5) and EIS Downstream Intake Alternative (6)

[3] USGS Upstream Return-Flow scenario was representative of EIS Wetland Alternative (3)

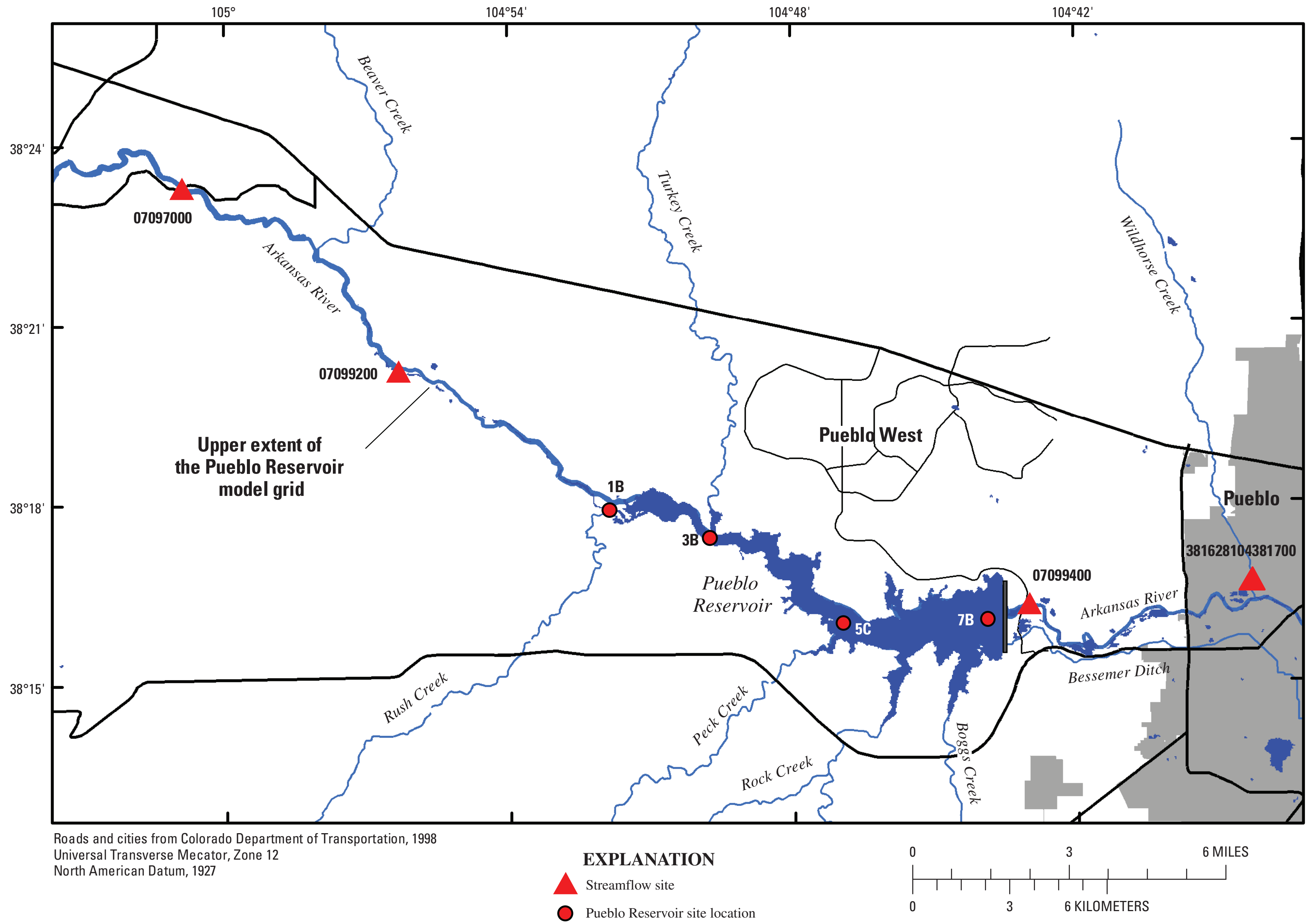

Figure 3. Location of selected sites on the Arkansas River and Pueblo Reservoir.

Pueblo Reservoir model, these influences are not likely to change greatly although streamflow and water-quality inputs and outputs differ between the selected scenarios. Although the Pueblo Reservoir model was constructed and calibrated for conditions observed in WY 1986 through WY 1987, it should be able to make useful predictions of future changes in the hydrodynamic, thermal, and water-quality conditions in the reservoir. This usefulness was demonstrated by the results of the model verification that used data collected over a decade after the calibration period.

Streamflow and Water-Quality Modeling for Projected Demands in 2046

Hydrologic operations of Pueblo Reservoir were simulated using the Arkansas River Daily Simulation Model (Daily Model) which used the MODSIM software developed by Colorado State University and Reclamation as the primary model engine (Labadie and others, 2000). The MODSIM software is driven by time-series inflow and demand data contained at nodes, water rights information contained in the links, and reservoir storage information contained at reservoir nodes. The Daily Model simulated basin operations on a daily time step by moving inflows and stored water to demands using the priority information contained in the links and other physical and operational constraints found in both links and nodes. Simulation for the SDS EIS was done on a daily time step for the study period of WY 1982 through WY 2004 (Tracy Kosloff, MWH Americas, Inc., written commun., 2006).

The Daily Model superimposed existing and future water rights, water development operations, and water demand conditions on historical hydrology. Data required for input into the model included historical streamflow data, historical and future diversion data, historical storage data, water-rights data, and other miscellaneous data. Ungaged gains and losses were calculated using the ArkExcel Microsoft Excel spreadsheet model, which is an adaptation of the previous ArkEx exchange model used by Colorado Springs Utilities for their Arkansas River Exchange Program (MWH Americas, Inc., 2005). Ungaged gains and losses then were entered in the Daily Model as constant values through the reaches for each day.

Streamflow and storage data pertinent to the modeling effort described in this report (reservoir inflows, outflows, and storage) were extracted from the Daily Model runs for selected simulation scenarios for October 1, 1999, to September 30, 2002 (MWH Americas, Inc., 2007).

Water-quality and streamflow data for proposed alternatives that returned treated wastewater effluent (through a pipeline) back to the Arkansas River upstream from Pueblo Reservoir were provided to the USGS by Reclamation's consultant (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). This return flow would convey a combination of water diverted from Fountain Creek and treated wastewater effluent from Colorado Springs. Water quality for the Fountain Creek diversion was set equal to historical concentrations (1997–2007) at Fountain Creek below Janitell Road (USGS 07105530) (U.S. Geological Survey, 1997–2007). Quality-assurance measures associated with these data were of acceptable quality to meet publication standards for the annual USGS water-resources data reports. Quality of the wastewater fraction of pipeline flows was set equal to historic wastewater quality (2000–2003) from the Colorado Springs Las Vegas Street Wastewater Treatment Facility or modeled simulation data from the Daily Model. The treatment facility is located just upstream from the USGS site 07105530. These fractions were mixed to determine discharge water quality according to the ratio of sources simulated in the Daily Model. Only data from 1997 or later were used to estimate pipeline water quality to account for the most recent upgrades to treatment facilities in Colorado Springs.

Riverine Nutrient-Decay Modeling

Riverine nutrient-decay modeling involved decaying concentrations of selected constituents along the 10 miles in the Arkansas River from the USGS site, Arkansas River at Portland (07097000) downstream to Pueblo Reservoir prior to input into the Pueblo Reservoir model. Specific data were not available to directly determine decay coefficients, however, procedures were used and assumptions were made to estimate the decay coefficients for selected constituents using literature research. This approach was deemed necessary because a substantial nutrient load to the reservoir was projected as part of the Upstream Return-Flow scenario. As such, nutrient-decay modeling provided a reasonable alternative to a "worst case" approach where the proposed nutrient loads would be input directly into the Pueblo Reservoir model. This approach was used for all the simulation scenarios even though only one scenario was projected to add nutrient loading beyond existing (WY 2000 through WY 2002) background concentrations.

Decay or attenuation of constituent concentrations in streams often is dependent on velocity, depth, time of travel, and water temperature. Relations were developed between streamflow and average velocity and between streamflow and average depth. Streamflow-measurement data collected by the State of Colorado from September 1999 through December 2006 at the Arkansas River at Portland stream gage (07097000), hereinafter referred to as the "Portland gage," were used to develop these relations (U.S. Geological Survey, 2000–2007). These relations were used to determine the average daily velocity and depth in the Arkansas River between the Portland gage and upstream segment of the reservoir model grid (segment 1) (Galloway and others, 2008) from October 1999 through September 2002. The distance between the two sites was determined using GIS analysis. Daily time-of-travel from the Portland gage was estimated for the verification period by multiplying the average daily velocity and the distance between the sites. Daily water-temperature data for the verification period (WY 2000–02) were recorded at the

Portland stream gage by the USGS (U.S. Geological Survey, 2000–2002).

Reaeration rates are necessary to calculate dissolved oxygen (DO) concentrations. Daily reaeration coefficients were computed using the equation given by Padden and Gloyna (1971) as referenced in Bowie and others (1985). This equation was recommended by Goddard (1980) as being the most applicable to the Arkansas River because the DO values calculated using this equation best fit the observed values. Water temperature is used to determine DO-saturation values and to adjust reaction rates. All coefficients were temperature corrected using the following equation:

$$K_T = K_{20} * \theta^{T-20} \quad (1)$$

where

K_T is the temperature corrected coefficient, base e (1/day),

K_{20} is the reaeration coefficient at 20° Celsius, base e (1/day),

θ is the temperature adjustment factor, and

T is the temperature, in degrees Celsius.

A temperature adjustment factor of 1.022 (Bowie and others, 1985) was used to adjust the reaeration coefficient, and a temperature adjustment factor of 1.047 was used to adjust the nitrate, orthophosphorus, and biological oxygen-demand (BOD) coefficients (Roesner and others, 1981).

A total nitrate nitrogen decay rate of 1.7 day^{-1} (log base 10 units) was used to compute nitrate concentrations entering the reservoir from the Arkansas River (Cain and others, 1980). This decay rate was determined by Cain and others (1980) for a 6-mile reach downstream from the Pueblo Reservoir on the Arkansas River which is similar to the Arkansas River upstream from the reservoir to the Portland gage. No data were available for orthophosphorus decay rates. The decay rate for nitrate was used to compute the change in orthophosphorus between the Portland gage and the upstream segment of the reservoir model. BOD settling and sorption rates were assumed to be negligible because stream velocities are relatively high, ranging from about 2 to 6 feet per second between the Portland gage and the upstream segment of the reservoir model. Therefore, the deoxygenation rate was assumed to be approximately equal to the overall BOD removal rate. The daily deoxygenation rate was calculated as a function of flow rate using an equation developed by Wright and McDonnell (1979). This equation is applicable for flow rates that ranged from 10 to 800 cubic feet per second. During the verification period, more than 80 percent of the daily flow values in the Arkansas River upstream from the reservoir ranged from 10 to 800 cubic feet per second. The integrated form of a first-order kinetics equation was used to determine the concentrations of nitrate, orthophosphorus, and BOD in the river near the upstream segment of the model. As an example, BOD was computed using the following equation:

$$L = L_o \exp(-K_R X/V) \quad (2)$$

where

L is the BOD concentration downstream from source, mass/volume,

L_o is the initial BOD concentration immediately downstream from source, at X=0, mass/volume,

K_R is the overall BOD removal rate, 1/day (base e)

X is the distance downstream from source, length, and

V is the average stream velocity, in length/time.

The previous discussion on nutrient decay only described the assumptions used to decay nutrient concentrations from the Portland gage downstream to the reservoir. In order to simulate the effects of the discharge from the return-flow pipeline associated with the Upstream Return-Flow scenario, nutrient concentrations in the pipeline and in the Arkansas River needed to be mixed before being routed to the Portland gage. The return-flow pipeline would be a mixture of Fountain Creek water and treated effluent (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). The pipeline would discharge into the Arkansas River approximately 2 miles upstream from the Portland gage. As such, concentrations in the pipeline and in the river were combined using their respective volumetric flow rates. Estimates of daily combined streamflow at the Portland gage and daily streamflow and concentration data in the pipeline were provided to the USGS by contractors to Reclamation (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). The combined concentrations of these constituents were calculated using the following equation:

$$Y_{mixed} = ((Y_w \times Q_w) + (Y_s \times Q_s)) \div (Q_w + Q_s) \quad (3)$$

where

Y_{mixed} is the combined concentration of selected constituent in the Arkansas River immediately downstream from the return flow pipeline, mass/volume,

Y_w is the concentration of selected constituents in the return flow pipeline discharge, mass/volume,

Q_w is the return flow pipeline discharge, volume/time,

Y_s is the concentration of selected constituent in the Arkansas River immediately upstream from return flow pipeline outfall, mass/volume, and

Q_s is the streamflow in the Arkansas River immediately upstream from the return flow pipeline outfall, volume/time.

Additionally, waste assimilation models on the South Platte River and the Arkansas River downstream from Pueblo Reservoir showed larger decay rates for ammonia than forward-reaction rates resulting in a model-computed removal of ammonia from the river systems (Paschal and Mueller, 1991 and Cain and others, 1980). For this reason, all ammonia entering the Arkansas River at the return-flow pipeline outfall was assumed to be oxidized to nitrate before nutrient-decay simulations were done.

Based on concurrent data collected at the Portland gage and at the Arkansas River near Portland stream gage (USGS 07099200) (fig. 3), dissolved-solids concentrations do not appear to decrease (decay) between the two gages. Concentrations of iron also were assumed to be conservative in the river for each scenario. Changes in dissolved-oxygen concentrations due to increased BOD loading were assumed to be negligible in the river because the computed reaeration coefficients were typically an order of magnitude greater than the computed deoxygenation coefficients.

Description of Simulation Scenarios

The selected simulation scenarios can be described as the No Action scenario, the Downstream Diversion scenario, the Upstream Return-Flow scenario, and the Upstream Diversion scenario. The four simulation scenarios are described in more detail below with emphasis given to potential impacts on Pueblo Reservoir. A summary of how the four selected scenarios related to the original seven EIS alternatives can be found in figure 2 and table 1. Additionally, a simulation scenario that represented existing conditions (WY 2000 through 2002) was run using input files that were similar to those used in the verification period of the Pueblo Reservoir model in Galloway and others (2008). For the purposes of this report this scenario is described as the Existing Conditions scenario.

Input data that represented the projected streamflow, diversion data, return-flow water quality, and reservoir storage (stage) for each of the simulation scenarios were provided to the USGS by Reclamation's consultant (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). Specifically, simulated streamflow data were provided for each scenario representing inflow to Pueblo Reservoir at the Portland gage (USGS 07097000) and outflow downstream from Pueblo Reservoir (USGS 07099400) as simulated by Reclamation's consultant. Diversion data also were provided representing projected removal of water from Pueblo Reservoir for delivery to various entities in the study area. Additionally, projected daily reservoir storage for each scenario was provided to the USGS. Finally, discharge and water-quality data for the return-flow pipeline associated with the Upstream Return-Flow scenario were provided for input into the simulation efforts described in this report.

The input water-quality data for all the simulation scenarios in this report reflect the results of an initial simulation effort to decay and assimilate nutrient concentrations. This approach to the scenario simulations was done to simulate changes in nutrient concentrations in the Arkansas River between a proposed return-flow location near Florence, Colorado, and the upstream boundary of the Pueblo Reservoir model (fig. 1). It was deemed necessary by Reclamation and the USGS to quantify degradation and assimilation of nutrients along this 10-mile reach given the increase in nutrient loading to the reservoir as projected by the Upstream Return-Flow scenario. For reasons of consistency, all the scenario simulations incorporated this approach prior to initiating the CE-QUAL-W2 simulation efforts for this report.

Additionally, proposed discharge of treated water from Pueblo West (Stephen Harrison, Pueblo West Metropolitan District, written commun., 2006) was added to the Pueblo Reservoir model as a tributary input along the north shore of the reservoir near the dam. Input streamflow and water-quality data for this discharge were provided to the USGS by Reclamation's consultant (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). Daily water temperatures were estimated from periodic data collected from Wildhorse Creek at the mouth (USGS 381628104381700) from WY 1976 to WY 2005 (fig. 3). These data were used as a surrogate to derive an estimate of daily water temperatures for input into the model. It should be noted that the input from Pueblo West was used only when simulating projected demands in 2046 and not when modeling existing conditions (WY 2000 through 2002) (table 1).

No Action Scenario

The No Action scenario represented the most likely future (2046) in the absence of a major Reclamation action, such as a storage contract. This scenario was based on the No Action Alternative (EIS alternative 1) (table 1) and was designed on the conveyance of raw water from the Arkansas River upstream from Pueblo Reservoir near Florence, Colorado, and limited conveyance of raw water from the Fountain Valley diversion outlet at the Pueblo Dam. The raw water would be conveyed by pipeline for use by the city of Colorado Springs. Return flows would be released to Fountain Creek and returned to the Arkansas River downstream from Pueblo Reservoir. Simulation results for the No Action scenario serve as the basis for all other comparisons described in this report (table 1).

Downstream Diversion Scenario

The Downstream Diversion scenario represented the Participant's proposed SDS action to divert untreated water from the outlet at Pueblo Dam for distribution to the Participant's customers. Reusable return flows would be stored in a new reservoir on Williams Creek prior to exchange down Fountain Creek. This scenario was based on the Proposed Action Alternative (EIS alternative 2) (table 1). EIS alternatives 5 and 6 also were similar enough in terms of probable effects to Pueblo Reservoir to be represented by this simulation effort. EIS alternative 5 represented the Participant's proposed action with specific modifications to minimize geomorphic and water-quality effects of return flows on Fountain Creek. Diversion of untreated water would remain the same but return flows would be piped to the Arkansas River at the mouth of Fountain Creek. EIS alternative 6 would use an untreated water intake from the Arkansas River downstream from Fountain Creek for the diversion, instead of diversion from Pueblo Dam. These components match the Downstream Diversion scenario with the exception of the location of the untreated water intake. Specifically, simulation results for the Downstream Diversion scenario were compared to results for the No Action scenario (table 1).

Upstream Return-Flow Scenario

The Upstream Return-Flow scenario represented proposed conditions where untreated water would be diverted from the Arkansas River downstream from the dam but upstream from Fountain Creek and reusable return flows would be piped from existing or future wastewater treatment plants in Colorado Springs to the Arkansas River near Florence, Colorado (fig. 1). This scenario was based on the Arkansas River Alternative (EIS alternative 4) (table 1) and was selected because it represented the highest volume of upstream return flow to Pueblo Reservoir. EIS alternative 3 also was similar enough in terms of probable effects to Pueblo Reservoir to be represented by this simulation effort; untreated water would be diverted directly from the Pueblo Dam. Specifically, simulation results for the Upstream Return-Flow scenario were compared to results for the No Action scenario (table 1).

Upstream Diversion Scenario

The Upstream Diversion scenario represented an upstream diversion condition which consisted of conveyance of raw water from the Arkansas River upstream from Pueblo Reservoir near Florence, Colorado, and limited conveyance of raw water from the Fountain Valley diversion outlet at the Pueblo Dam. Return flows would be released to Fountain Creek and returned to the Arkansas River east of Pueblo Reservoir. This scenario was based on the Highway 115 Alternative (EIS alternative 7) (table 1). This scenario was similar to the No Action scenario with respect to the overall configuration of inflows, outflows, and diversions from Pueblo Reservoir, however, differences in the input data to the Pueblo Reservoir model warranted the inclusion of this scenario. Mean monthly reservoir contents typically would be lower for the Upstream Diversion scenario than for the No Action scenario (MWH Americas, Inc., 2007). It is important to understand that the Upstream Diversion scenario represents one of the proposed alternatives as defined in the Environmental Impact Statement and, although similar, it is unrelated to the No Action scenario. As stated earlier in this report, Reclamation required that the results for all the simulation scenarios be compared to the results for the No Action scenario (table 1).

Existing Conditions Scenario

This scenario represented the existing conditions in Pueblo Reservoir (WY 2000 through 2002) as simulated during the verification period of the calibrated Pueblo Reservoir model (Galloway and others, 2008) with minor changes to the water quality that enters the reservoir resulting from simulated decay of nutrients in the riverine reach upstream from the reservoir. It should be noted that this scenario did not include a tributary input associated with the proposed discharge of treated water from Pueblo West because that discharge was not in place at that time. Specifically, simulation results for the Existing Conditions scenario were compared to results for the No Action scenario (table 1).

General Comparisons Between All Simulation Scenarios

Each of the four selected simulation scenarios was evaluated for the direct- and cumulative-effects analyses. As stated earlier in this report, direct effects are intended to isolate the future effects of the scenarios whereas cumulative effects are intended to evaluate the effects of all reasonably foreseeable future activities in the study area on a simulation scenario (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). The primary difference between the two sets of simulations was that the direct-effects scenario simulations include existing levels of demand by nonparticipants in the SDS project, whereas the cumulative-effects scenario simulations include projected demands in 2046 by the nonparticipants in the SDS project. Quantification of the differences between the two different effects analyses was modeled by Reclamation's consultant, and input data were provided to the USGS by the consultant (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). Additionally, the four scenarios were modeled and comparisons were made within the context of three (wet, average, and dry) hydrologic conditions.

Two of the four site locations in the previous Pueblo Reservoir simulation effort (Galloway and others, 2008) were selected for comparison in this report. Results of scenario simulations at site 3B (model segment 12) were characteristic of a riverine environment in the reservoir (fig. 3). The other upstream site, 1B, often was dry during the scenario simulations and was not chosen for comparisons in this report. Results of scenario simulations at site 7B (model segment 23) were characteristic of the main body of the reservoir in the forebay near the dam wall (fig. 3). The other "deep water" site, 5C, displayed similar results to 7B and, as such, was not chosen for comparisons in this report. Simulation results in the epilimnion and the hypolimnion at sites 7B and 3B were evaluated and compared. Located near the Pueblo Dam, the simulation results in the hypolimnion at site 7B were indicative of the quality of the water leaving the reservoir. Each of the sites also was compared with regard to depth in the water column.

The following discussion focuses on a general comparison between all simulation scenarios including the Existing Conditions scenario. The focus of the discussion describes general patterns observed from the simulated results, and discusses how the simulation scenarios compare to each other. Selected graphics are presented as a means to describe the results. Some discussion will involve the similarities and differences observed between the direct-effects and cumulative-effects analyses, as they pertain to individual scenarios. The following discussion primarily focuses on results from site 7B near the dam. Results from the upstream riverine site, 3B, were similar but more variable because of the dynamic changes in reservoir stage observed at this upstream location. When appropriate, discussion of results from site 3B will be discussed.

Simulated water-surface elevations in Pueblo Reservoir were variable between the simulation scenarios, between the different effects analyses, and between the simulated hydrologic conditions (fig. 4). Generally, there was a substantial temporal decrease in water-surface elevations between the wet, average, and dry years; severe drought conditions were observed in WY 2002. Water-surface elevations associated with the cumulative-effects analyses were less than the water-surface elevations for the corresponding direct-effects analyses, and the differences between the effects analyses, for any scenario, increased temporally from wet to dry year. The smallest water-surface elevations were associated with the cumulative-effects analysis associated with the No Action scenario. Simulated water-surface elevations for the direct-effects analysis of any simulation scenario were similar to the water-surface elevations for the Existing Conditions scenario. Water-surface elevations in Pueblo Reservoir related directly to the active storage in the reservoir (U.S. Bureau of Reclamation, 1977) and were one of the primary differentiators between scenarios in the simulations described in this report. It is important to understand that many of the differences in the model input files was not a change in water quality but a change in inflow and outflow in Pueblo Reservoir, which resulted in a change in water-surface elevations (storage).

Water temperature is an important component of the hydrodynamics in a reservoir. Life processes, chemical reactions, and the solubility of chemical constituents in water are all temperature dependent. Water temperature also is a major factor in controlling the density of freshwater that drives stratification in a reservoir and routing of inflows in a reservoir. Pueblo Reservoir has been shown to stratify during the summer prior to mixing in September (Edelmann, 1989). Results from the various simulation scenarios showed a similar pattern (fig. 5). In general, the reservoir was isothermal and water temperatures were coldest from December to April when thermal stratification began to occur. By May, a strong thermal stratification was apparent at site 3B (riverine site) and 7B (near-dam site). This condition persisted at 7B into August when maximum temperatures were observed. Because of the shallow depths at 3B, thermal stratification was no longer apparent in May. Pueblo Reservoir typically mixed in September at the deeper locations. In general, the water temperatures in Pueblo Reservoir were similar for all the simulation scenarios for the 3-year model period, and there were no substantial changes in the annual thermal pattern between the 3 simulated years (fig. 6).

Adequate concentrations of dissolved oxygen (DO) are critical to the health of a water body and its aquatic biota. Results of the scenario simulations showed the stratification that occurred in Pueblo Reservoir near the dam (fig. 7). With the exception of the Upstream Return-Flow scenario, DO concentrations in the epilimnion of the reservoir were similar to the Existing Conditions scenario for all the simulation scenarios (fig. 8*A*). DO concentrations associated with the Upstream Return-Flow scenario generally were larger than the other scenarios and were at a maximum in May or June prior to onset of anoxic conditions in the hypolimnion of the reservoir. Maximum concentrations increased between the three simulated years from the wet year (WY 2000) to the dry year (WY 2002). The increase in DO concentration in the Upstream Return-Flow scenario was most likely a result of decreased storage in the reservoir and increased nutrient loading associated with the Upstream Return-Flow scenario. DO concentrations in the hypolimnion generally were similar for all the simulation scenarios although the Upstream Return-Flow scenario generally had slightly larger concentrations during the third year, the dry year (fig. 8*B*). In Pueblo Reservoir, anoxic conditions typically were observed during the summer months before the reservoir turned over and mixed. It did not appear that the anoxic period was substantially longer for any particular simulation scenario. There appeared to be no substantial change in the general seasonal pattern in the epilimnion and hypolimnion between the wet, average, and dry years for the various simulation scenarios.

Simulated dissolved-solids (DS) concentrations in Pueblo Reservoir provided a good illustration of the general patterns observed between the various simulation scenarios and between the two different effects analyses (fig. 9*A*). Typically, the simulated concentrations of the Existing Conditions scenario were the smallest of the simulation scenarios. This scenario represented the conditions for WY 2000 through WY 2002 with no changes to water quality entering the reservoir and no input from a proposed discharge of treated water from Pueblo West. In comparison, concentrations for the No Action and Upstream Diversion scenarios were slightly larger than concentrations for the Existing Conditions scenario but similar among the two scenarios themselves. These two scenarios represented similar configurations for removal of water from the Arkansas River as part of Reclamation’s EIS alternatives; both scenarios would be categorized as upstream diversion alternatives (table 1, fig. 2). In general, there appeared to be only limited differences in the simulated results between the direct- and cumulative-effects analyses simulations for each of these two scenarios.

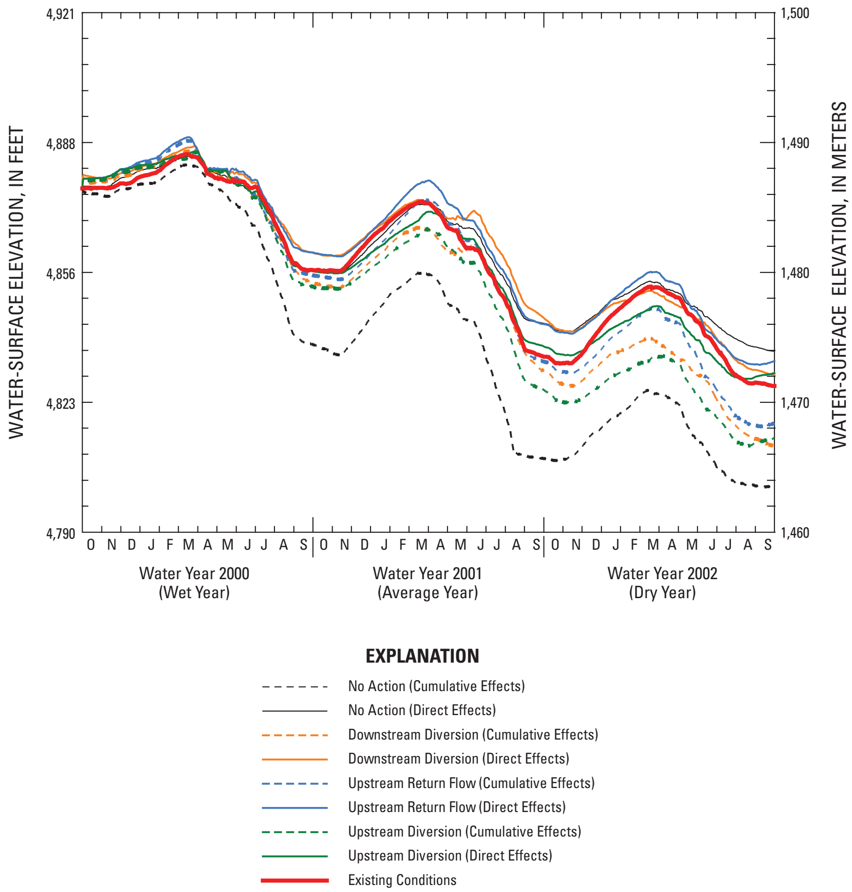

Figure 4. Comparison of water-surface elevations in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-effects analyses for selected simulation scenarios.

Slight differences between the two effects analyses were observed during the fall of 2001. Differences in the input DS data provided to the USGS for the tributary (Pueblo West return flow) resulted in the observed differences between the direct- and cumulative-effects analyses; the simulated DS concentrations during this short period ranged from 60 to 100 milligrams per liter (mg/L) greater for the cumulative-effects analysis than for the direct-effects analysis. Other input data for the two simulations were nearly identical.

Simulated results for the Downstream Diversion scenario were only slightly larger than results for the No Action and Upstream Diversion scenarios. In contrast, simulated results for the Upstream Return-Flow scenario were consistently larger than all the other simulation scenarios, and the difference between the results increased temporally. Simulated results for the third year (WY 2002) showed a gradual increase in the difference in concentrations from about 100 to 180 mg/L over the course of the water year relative to the Existing Conditions scenario. Modeled results for DS provided a good means of evaluating the effects of changes to the input data because DS modeling in the CE–QUAL–W2 model is independent of other constituents. As such, the increased concentrations in DS observed in the Arkansas River for the Upstream Return-Flow scenario can be directly related to increased concentrations of DS associated with the results for this scenario.

Nitrogen is essential for primary production in a reservoir. Ammonia is one of the more commonly used and measured aqueous nitrogen species. In the CE–QUAL–W2 model, ammonia concentrations are inherently linked to other modeled constituents such as water temperature, DO concentrations, and algal concentrations. Simulated dissolved-ammonia concentrations provided another illustration of the general patterns observed between the various simulation

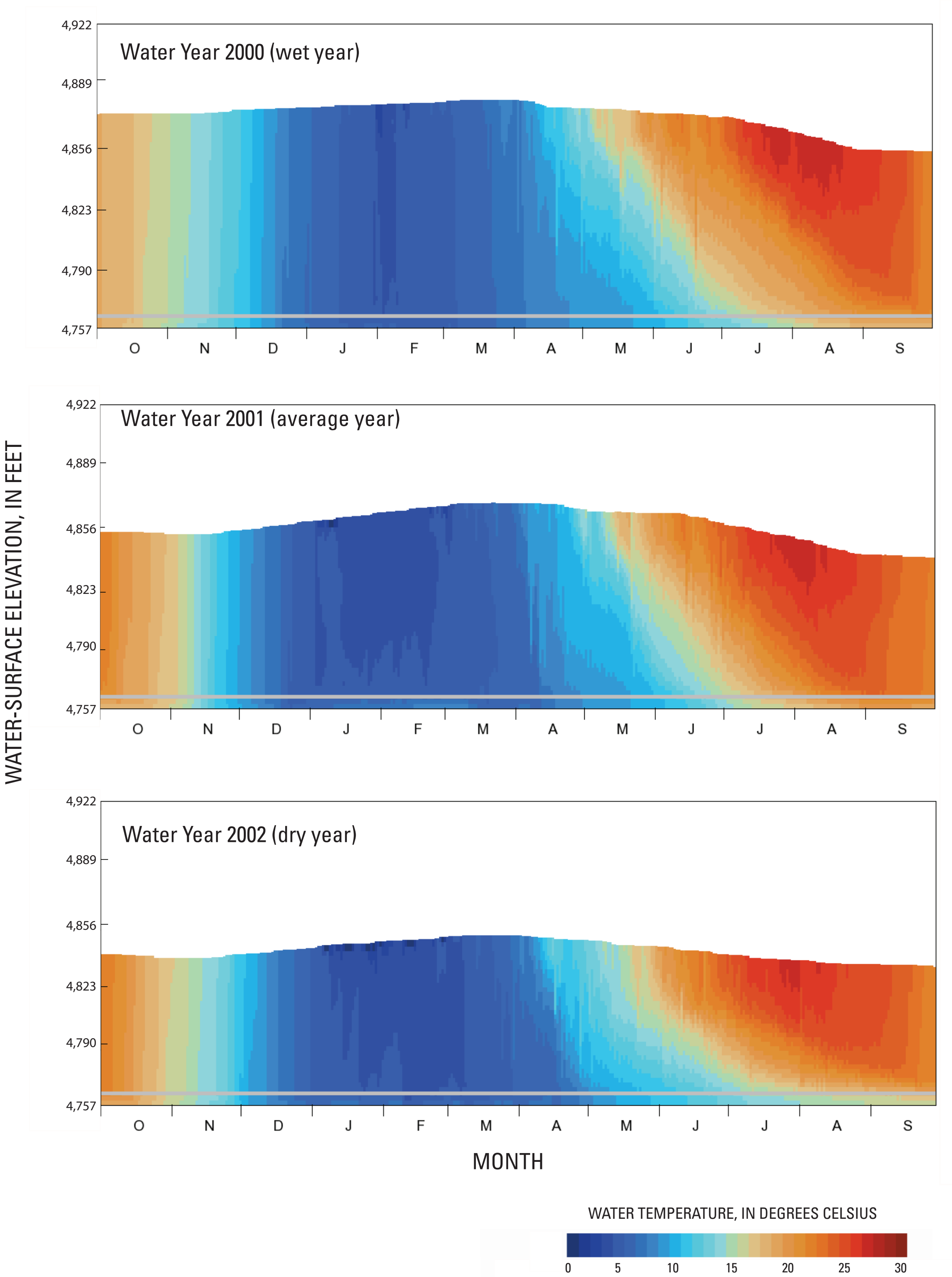

Figure 5. Simulated water temperature at site 7B near the dam for the No Action scenario, water years 2000 through 2002. (Gray line represents approximate elevation of Arkansas River outlet.)

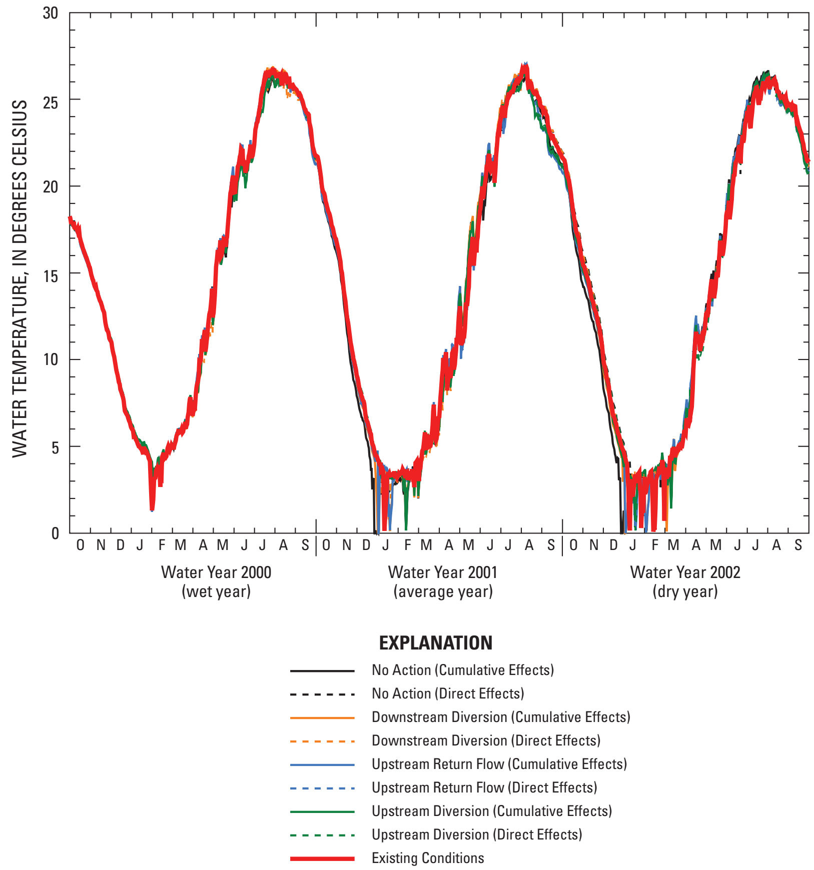

Figure 6. Comparison of water temperatures at site 7B in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-analyses for selected simulation scenarios.

scenarios and between the direct- and cumulative-effects analyses (fig. 9*B*). In general, the simulated concentrations of the Existing Conditions scenario were the smallest of the simulation scenarios. In comparison, ammonia concentrations for the No Action and Upstream Diversion scenarios were only slightly larger than concentrations for the Existing Conditions scenario, and the simulated results for the Downstream Diversion scenario were only slightly larger than results for No Action and Upstream Diversion scenarios. In contrast, simulated ammonia concentrations for the Upstream Return-Flow scenario were consistently larger than for all the simulation scenarios particularly during the summer months (June through August). The overall differences from the Upstream Return-Flow concentrations during the summer months relative to the Existing Conditions scenario increased temporally from about 0.05 mg/L in WY 2000, to about 0.08 mg/L in WY 2001, and to a difference of about 0.15 mg/L in WY 2002. The increased concentrations in ammonia observed for the Upstream Return-Flow scenario can be related to increased concentrations of dissolved ammonia associated with the return-flow pipeline upstream from Pueblo Reservoir. In general, there appeared to be little difference between the two effects analyses for any of the simulation scenarios with the possible exception of differences observed for the No Action scenario.

Comparison of Results for Selected Simulation Scenarios

The previous discussion compared the results of the simulation scenarios in the context of general similarities or differences in the simulated results. However, quantitative comparisons between specific scenarios were done to support Reclamation's decisions as part of the EIS process. These comparisons will be discussed in the following sections of this report. Specifically, comparisons were made between the

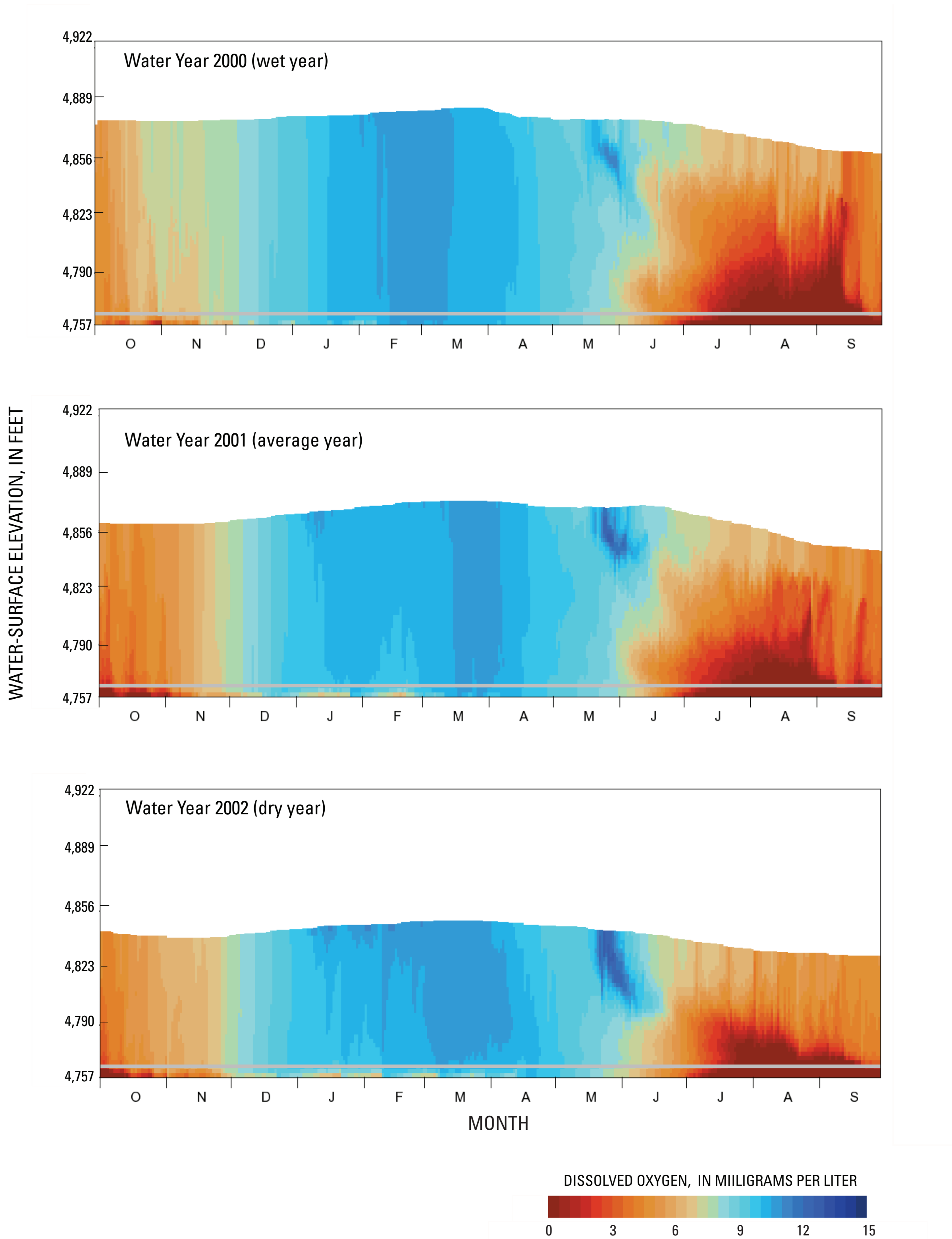

Figure 7. Simulated dissolved-oxygen concentrations at site 7B near the dam for the No Action (direct-effects analysis) scenario. (Gray line represents approximate elevation of Arkansas River outlet.)

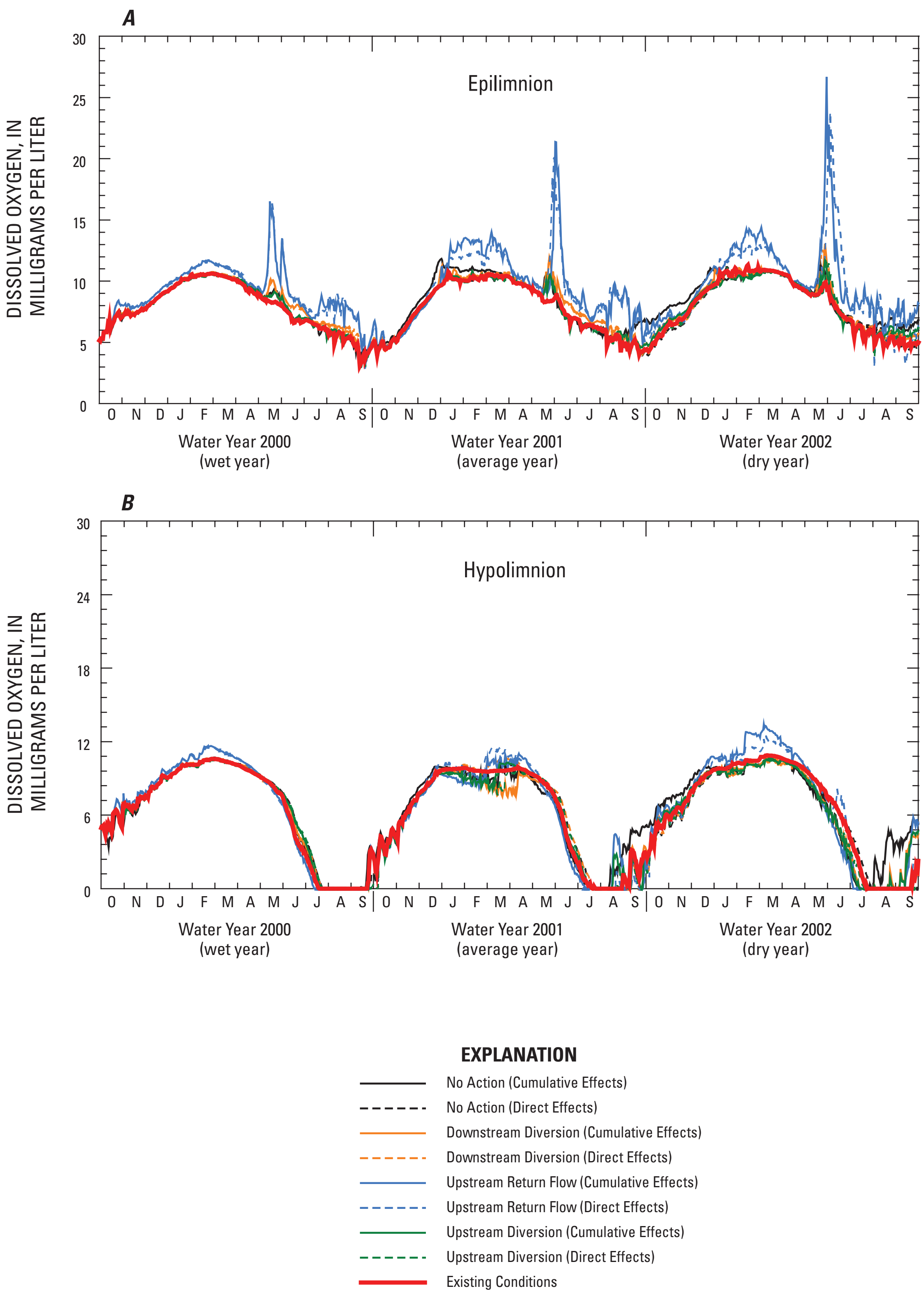

Figure 8. Comparison of dissolved-oxygen concentrations at site 7B in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-effects analyses for selected simulation scenarios.

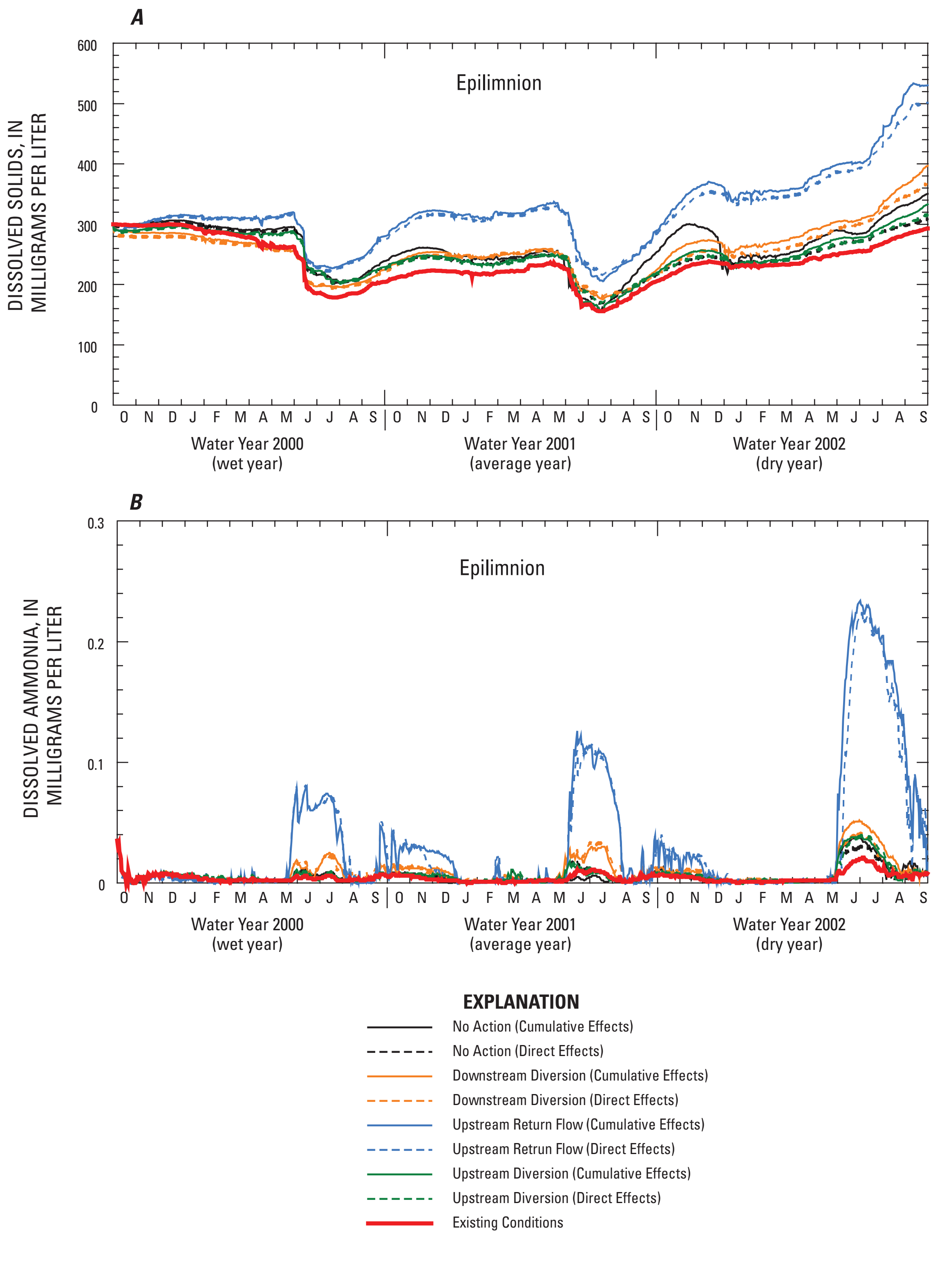

Figure 9. Comparison of dissolved-solids and dissolved-ammonia concentrations at site 7B in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-effects analyses for selected simulation scenarios.

Existing Conditions scenario and the No Action scenario to determine what differences, if any, were observed between existing conditions in Pueblo Reservoir (WY 2000 through 2002) and the most likely conditions in 2046 assuming the absence of a major Reclamation action, such as a storage contract. Additionally, comparisons were made between the No Action scenario and each of the other scenarios; that is, the Downstream Diversion scenario, the Upstream Return-Flow scenario, and the Upstream Diversion scenario. These comparisons provided information that allowed for a comparison of each scenario to a common simulated result, the No Action scenario.

Comparison of Existing Conditions Scenario and No Action Scenario

For the purposes of this report, comparisons between scenarios were conducted for site 3B in the upstream riverine section of the reservoir and 7B in the main body in Pueblo Reservoir near the dam structure (fig. 3). Analysis of the results for the direct- and cumulative-effects analyses indicated that, in general, the results were similar for most of the scenarios. As such, comparisons in this report will focus on the results from the direct-effects analysis for each modeled scenario. Results from the cumulative-effects analyses were tabulated and are presented in the Appendixes at the back of the report. Annual median concentrations were calculated for each constituent for each of the simulated water years in the epilimnion and hypolimnion for each of the reservoir sites. The annual 85th percentile concentrations also were compared as they related to possible water-quality standards. For DO, the 15th percentile was used because anoxic conditions were important in Pueblo Reservoir. It should be noted that simulation results and any comparisons to water-quality standards should not be interpreted as definitive values but as an estimate given the uncertainties of the modeling processes. Water-surface elevations at site 3B were insufficient to compute results for some of the simulation scenarios during the later period of WY 2001 (August and September) and much of WY 2002. As such, annual summary statistics only were calculated when 70 percent or more of the simulated daily values were available for computation. Caution should be used when comparing summary statistics for WY 2001 and WY 2002 at site 3B because the resultant value may be skewed due to the lack of seasonal values in the computation. Comparisons were made using the differences in the calculated summary statistic (median, 85th or 15th percentile) and by calculating the percent change in concentrations between the Existing Conditions and the No Action scenario and between the No Action scenario and each of three other simulation scenarios (table 1).

Water-Surface Elevations

Simulated water-surface elevations in Pueblo Reservoir generally were similar between the Existing Conditions and No Action scenarios (fig. 10). There was a substantial temporal decrease in water-surface elevations from the wet year (WY 2000) to the dry year (WY 2002). Annual maximum water-surface elevations for the simulated period were similar for each scenario and ranged from about 4,888 feet (1,490 meters) in WY 2000 to about 4,855 feet (1,480 meters) in WY 2002; the annual maximum elevation decreased about 16 feet per year. Typically, maximum storage occurred in late March of each year as winter storage was nearly complete and releases of water to downstream irrigators had not yet started.

Water Temperature

Comparisons of the results between the Existing Conditions and the No Action scenarios for water temperature indicated that the two simulation scenarios generally provided similar results (fig. 11). At site 7B near the dam, the percent change from the Existing Conditions scenario was within 10 percent for all simulated years and within 3 percent for WY 2000 and 2002 (table 2); the largest difference was associated with results for WY 2001. Water temperatures in the hypolimnion were about 4 degrees cooler than those in the epilimnion but relatively similar between scenarios. At site 3B, the annual median water temperatures in WY 2000 were similar between the two scenarios (table 3). In WY 2001, a 24 percent change in water temperature in the epilimnion at 3B was due to 36 days of missing output values (summer maximum values) that skewed the Existing Conditions result lower than would be expected.

Dissolved Oxygen

Comparisons of the DO simulation results between the Existing Conditions and No Action scenarios indicated that the annual median values for the two scenarios generally provided similar results (fig. 12). At site 7B, the percent change from the Existing Conditions scenario was within 4 percent for all simulated years in either the epilimnion or the hypolimnion (table 2). The median values were smaller in the hypolimnion than in the epilimnion. At site 3B, median DO concentrations were similar between scenarios with the largest differences observed in the epilimnion during WY 2001 (table 3).

The minimum DO concentration suitable to meet the DO water-quality standard in Pueblo Reservoir was 6.0 mg/L as measured in the epilimnion of the water body (Colorado Department of Public Health and Environment, 2006). The standard is compared to the 15th percentile values. For the Existing Conditions and No Action scenarios, the standard value was not always attained when compared to the simulated annual 15th percentile value in the epilimnion at sites 7B and 3B (tables 4 and 5). Caution should be used when comparing these results to the water-quality standard because the absolute mean error of the DO calibration for the Pueblo Reservoir model (Galloway and others, 2008) was 1.42 mg/L at site 7B

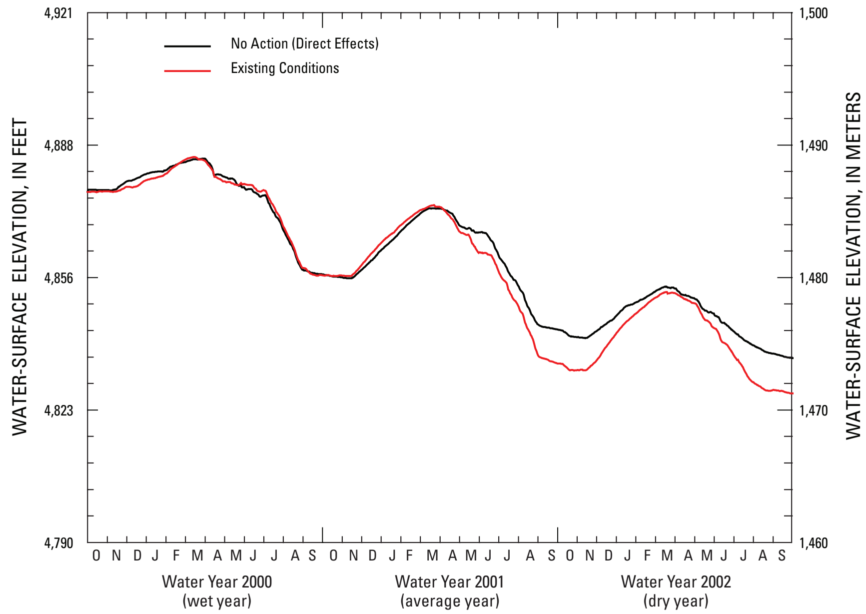

Figure 10. Comparison of water-surface elevations in Pueblo Reservoir for the Existing Conditions (water years 2000 through 2002) and No Action scenarios.

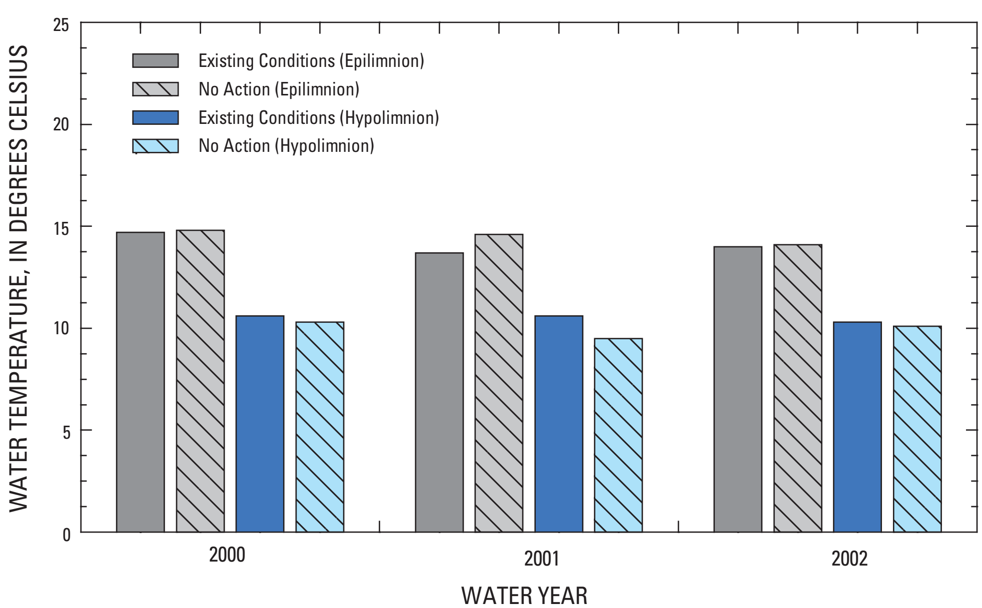

Figure 11. Annual median water temperature in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

Table 2. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (direct-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	Existing Conditions	100	14.7	7.8	278	0.003	0.006	0.014	<0.001	0.5
	No Action	100	14.8	8.0	290	.004	.006	.018	<.001	.6
	Percent change		.7%	2.6%	4.3%	33%	0%	29%	NA	20%
2001	Existing Conditions	100	13.7	8.2	218	.002	.008	.015	.001	.3
	No Action	100	14.6	8.1	238	.004	.008	.021	<.001	.4
	Percent change		6.6%	-1.2%	9.2%	100%	0%	40%	NA	33%
2002	Existing Conditions	100	14.0	8.4	236	.003	.007	.018	<.001	.4
	No Action	100	14.1	8.3	246	.004	.009	.026	<.001	.4
	Percent change		.7%	-1.2%	4.2%	33%	29%	44%	NA	0%
					Hypolimnion					
2000	Existing Conditions	100	10.6	7.5	280	.009	.005	.015	.004	.1
	No Action	100	10.3	7.6	290	.013	.009	.020	.004	.2
	Percent change		-2.8%	1.3%	3.6%	44%	80%	33%	0%	100%
2001	Existing Conditions	100	10.6	7.6	222	.007	.010	.016	.003	.1
	No Action	100	9.5	7.8	247	.017	.013	.033	.002	.1
	Percent change		-10%	2.6%	11%	143%	30%	106%	-33%	0%
2002	Existing Conditions	100	10.3	7.8	236	.006	.005	.018	.003	.1
	No Action	100	10.1	7.5	254	.015	.015	.042	.003	.1
	Percent change		-1.9%	-3.8%	7.6%	150%	200%	133%	0%	0%

Table 3. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (direct-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	Existing Conditions	100	14.0	7.9	285	0.001	0.008	0.016	0.013	0.9
	No Action	100	14.1	8.0	293	.001	.006	.018	.011	1.0
	Percent change		.7%	1.3%	2.8%	0%	-25%	12%	-15%	11%
2001	Existing Conditions	90	10.0	8.9	238	.005	.065	.019	.022	.3
	No Action	100	12.4	8.5	246	.007	.057	.022	.026	.5
	Percent change		24%	-4.5%	3.4%	40%	-12%	18%	18%	67%
2002	Existing Conditions	51	--	--	--	--	--	--	--	--
	No Action	85	10.0	8.1	279	.019	.079	.026	.391	.2
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
2000	Existing Conditions	100	12.1	7.8	282	.002	.015	.016	.028	.6
	No Action	100	12.2	7.8	292	.002	.009	.018	.024	.7
	Percent change		.8%	0%	3.5%	0%	-40%	12%	-14%	17%
2001	Existing Conditions	85	8.3	9.4	240	.005	.059	.019	.043	.3
	No Action	90	8.9	9.1	244	.005	.051	.022	.046	.4
	Percent change		7.2%	-3.2%	1.7%	0%	-14%	16%	7%	33%
2002	Existing Conditions	28	--	--	--	--	--	--	--	--
	No Action	42	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

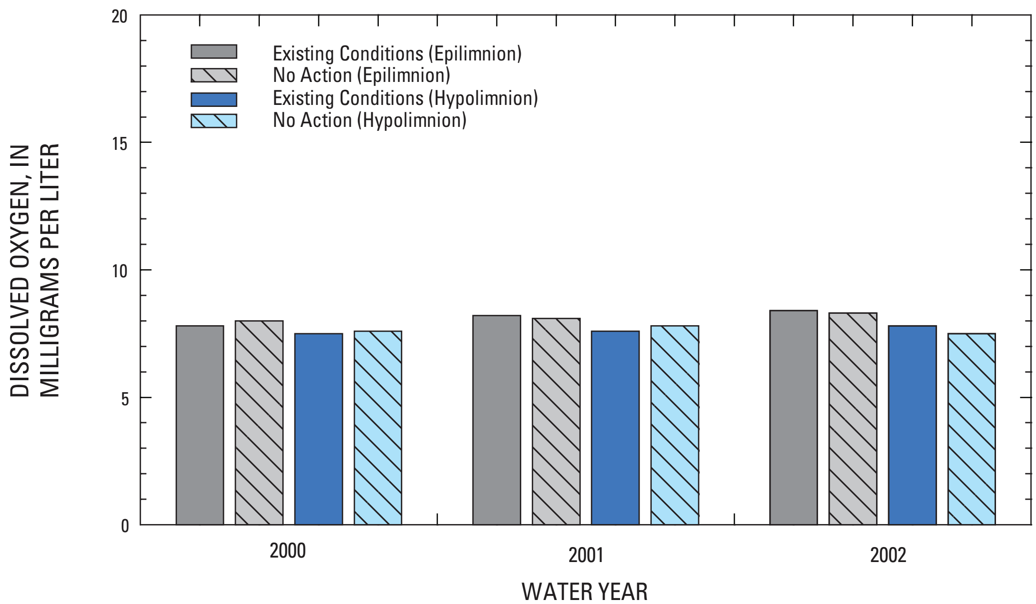

Figure 12. Annual median dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

indicating that the standard value of 6.0 mg/L was within the error of the smallest simulation results in the epilimnion.

Dissolved Solids

Comparisons of dissolved-solids concentrations for the Existing Conditions and No Action scenarios indicated that the annual median concentrations generally were similar for all three simulated years at either depth (fig. 13). Results for the No Action scenario, however, were consistently larger than those for the Existing Conditions scenario at sites 7B (near-dam site) and 3B (riverine site); the percent change between the two scenarios ranged from 1.7 to 11 percent (tables 2 and 3). A possible explanation for the slightly larger median concentration associated with the No Action scenario at these two sites was a decrease in inflow to Pueblo Reservoir as part of this simulation; the No Action scenario diverted water from the Arkansas River upstream from the reservoir which would provide less dilution in the reservoir. Additionally, slightly larger median concentrations at T7 associated with the No Action scenario could have been effected by a treated-water input from Pueblo West.

No water-quality standard for dissolved solids exists for Pueblo Reservoir. However, a guideline for aesthetic considerations, such as taste, color and odor in public water systems is set at 500 mg/L (U.S. Environmental Protection Agency, 1992). The annual median and 85th percentile values did not exceed this threshold in the epilimnion and hypolimnion at sites 7B and 3B for either of two simulation scenarios (tables 4 and 5).

Major Nutrients

Compounds of nitrogen and phosphorus are referred to as “major nutrients” because they are needed for plant growth. In excess concentrations, nutrients can promote nuisance algal growth in streams and reservoirs (causing eutrophication). Natural sources of nutrients include precipitation and biogeochemical processes in the watershed. Anthropogenic sources of nutrients include urban runoff, domestic effluent, livestock waste, and erosion caused by development.

Dissolved Ammonia

Generally, the annual median dissolved-ammonia concentrations (as nitrogen) in the epilimnion of Pueblo Reservoir were similar for the Existing Conditions and the No Action scenarios although the No Action results were slightly larger in each of the simulated years (fig. 14). The difference in concentrations between the two scenarios for any simulated year was no more than 0.002 mg/L (tables 2 and 3).

Substantial differences, however, were observed between the median annual concentrations in the hypolimnion at site 7B for all three simulated years (fig. 14). At this site, the percent change from the Existing Conditions scenario ranged from 44 to 150 percent for all simulated years which indicated that results from the No Action scenario were consistently

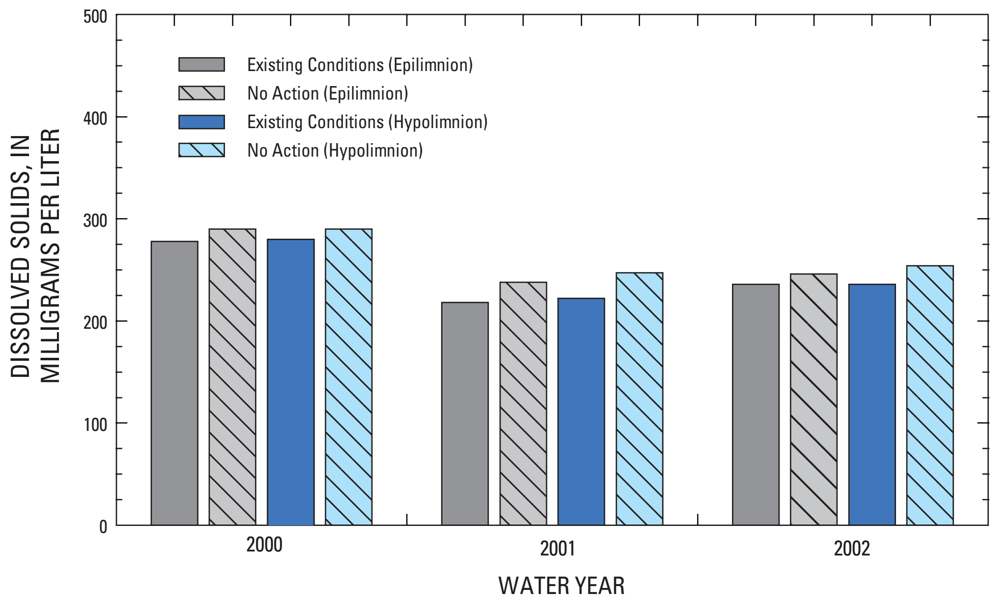

Figure 13. Annual median dissolved-solids concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

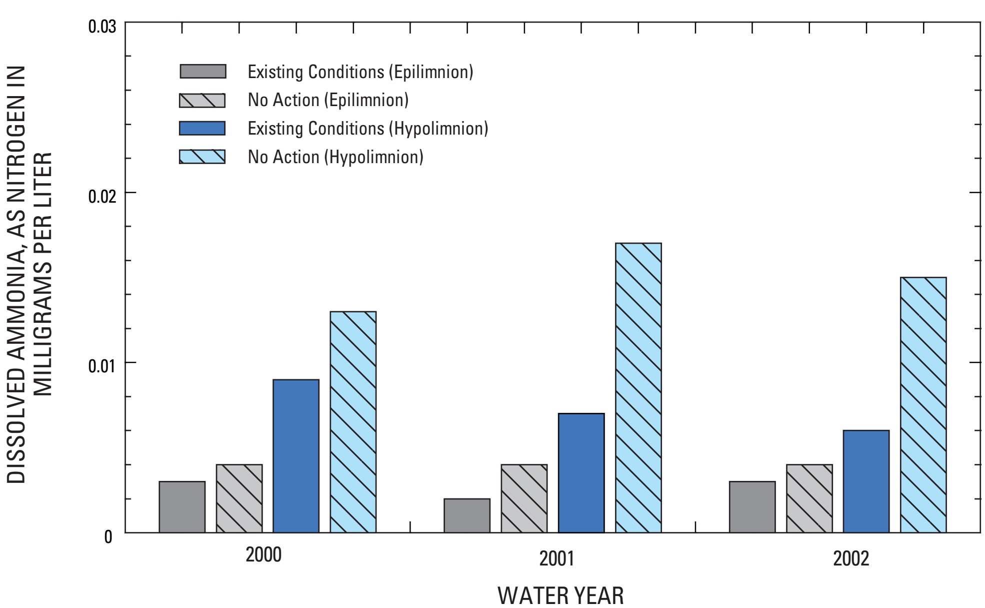

Figure 14. Annual median dissolved-ammonia concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

Table 4. Percent change between annual 85th percentile values for selected constituents and the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (direct-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	Existing Conditions	100	25.3	5.7	299	0.006	0.017	0.017	0.007	1.1
	No Action	100	25.2	5.7	301	.008	.020	.019	.005	1.5
	Percent change		-.4%	0%	.7%	33%	18%	12%	-29%	36%
2001	Existing Conditions	100	24.5	5.0	225	.007	.022	.016	.005	.9
	No Action	100	24.6	5.0	247	.008	.020	.024	.004	1.0
	Percent change		.4%	0%	10%	14%	-9.1%	50%	-20%	11%
2002	Existing Conditions	100	24.7	5.1	271	.010	.023	.019	.002	1.0
	No Action	100	24.5	5.4	289	.020	.040	.028	.002	1.5
	Percent change		-.8%	5.9%	6.6%	100%	74%	47%	0%	50%
					Hypolimnion					
2000	Existing Conditions	100	18.5	<.1	300	.014	.010	.019	5.48	.8
	No Action	100	17.8	<.1	302	.027	.023	.042	5.10	1.0
	Percent change		-3.8%	NA	.7%	93%	130%	121%	-6.9%	11%
2001	Existing Conditions	100	20.9	<.1	230	.011	.015	.018	.473	.2
	No Action	100	20.1	<.1	252	.030	.028	.051	.090	.2
	Percent change		-3.8%	NA	10%	173%	87%	183%	-81%	0%
2002	Existing Conditions	100	19.3	<.1	253	.021	.009	.025	1.42	.3
	No Action	100	16.7	<.1	291	.040	.024	.075	4.08	.2
	Percent change		-13%	NA	15%	90%	167%	200%	188%	-33%

Table 5. Percent change between annual 85th percentile values for selected constituents and the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (direct-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	Existing Conditions	100	23.5	6.1	298	0.002	0.034	0.017	0.06	1.8
	No Action	100	23.5	6.0	301	.003	.028	.019	.06	1.9
	Percent change		0%	-1.6%	1.0%	50%	-18%	8.0%	0%	5.6%
2001	Existing Conditions	90	21.3	5.6	256	.015	.096	.022	1.40	1.1
	No Action	100	21.3	5.5	275	.018	.089	.024	.58	1.2
	Percent change		0%	-1.8%	7.4%	20%	-7.3%	9.1%	-59%	9.1%
2002	Existing Conditions	51	--	--	--	--	--	--	--	--
	No Action	85	21.6	5.5	357	.020	.098	.032	.65	1.0
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
2000	Existing Conditions	100	22.8	4.8	304	.005	.036	.018	.50	1.4
	No Action	100	23.0	4.8	303	.006	.026	.019	.36	1.5
	Percent change		.9%	0%	-.3%	20%	-28%	5.6%	-28%	7.1%
2001	Existing Conditions	85	20.0	5.4	252	.014	.090	.022	1.41	.9
	No Action	90	21.2	5.2	271	.013	.084	.023	1.14	1.0
	Percent change		6.0%	-3.7%	7.5%	-7.1%	-6.7%	4.5%	-19%	11%
2002	Existing Conditions	28	--	--	--	--	--	--	--	--
	No Action	42	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

larger than the results for the Existing Conditions scenario (table 2). Median values increased from 0.004 to 0.01 mg/L in the hypolimnion at site 7B. Additional ammonia concentrations from the simulated Pueblo West treated water input may provide one possible explanation for the increase in concentrations at the downstream site in Pueblo Reservoir; the Existing Conditions scenario did not contain an input for this anticipated inflow to the reservoir. At the upstream site in the reservoir (3B), there did not appear to be any differences in the annual dissolved-ammonia concentrations in the hypolimnion between the Existing Conditions and No Action scenarios (table 3).

The Colorado Department of Public Health and Environment (2006) defines the chronic and acute water-quality standards for dissolved ammonia by algorithms that use water temperature and pH to calculate the standard. Under historical conditions, the chronic standard ranged from 1.1 to 5.7 mg/L and the acute standard ranged from 2.1 to 21.9 mg/L (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). Compared to these historical values, the standards were not exceeded by any of the annual median or 85th percentile values simulated as part of the Existing Conditions or No Action scenarios (tables 2-5).

Dissolved Nitrate

The annual median dissolved-nitrate concentrations (as nitrogen) in the epilimnion at site 7B near the dam generally were similar for the Existing Conditions and the No Action scenarios (fig. 15). The difference in concentrations between the two scenarios for any simulated year was no more than 0.002 mg/L (table 2). It should be noted that dissolved nitrite plus nitrate concentrations were input as a surrogate for nitrate; nitrate is the predominant fraction of the nitrite plus nitrate analysis in Pueblo Reservoir.

Differences between the two simulation scenarios were observed in the hypolimnion at site 7B for all three simulated years (table 2). The percent change from the Existing Conditions scenario ranged from 30 to 200 percent for all simulated years which indicated that the results for the No Action scenario were larger than the results for the Existing Conditions scenario. Because of the relatively small concentrations involved, the largest percent increase (WY 2002) equated to only a 0.01 mg/L increase in dissolved nitrate. A possible explanation for the observed increase in the median dissolved-nitrate concentration from the Existing Conditions scenario could be the input of nitrate associated with the modeled tributary (Pueblo West treated water) as part of the No Action scenario.

At the upstream site (3B), the percent change from the Existing Conditions scenario in the epilimnion and hypolimnion ranged from –12 to –40 percent for all simulated years (table 3); negative values indicated that the No Action results were consistently smaller than the Existing Conditions results. Overall, the simulated concentrations at the upstream site (3B) were several times larger than those observed at the downstream site (7B).

The water-quality standard for dissolved nitrate is 10 mg/L (Colorado Department of Public Health and Environment, 2006). The standard was not exceeded by any of the annual median or annual 85th percentile values for either simulation scenario for any simulated year at either the epilimnion or hypolimnion (tables 2-5).

Total Phosphorus

Annual median total-phosphorus concentrations in the epilimnion of Pueblo Reservoir generally were similar between the two simulation scenarios, although the median total-phosphorus concentrations for the No Action scenario were consistently larger than concentrations for the Existing Conditions scenario (fig. 16). At site 7B and 3B, the percent change in the epilimnion from the Existing Conditions scenario ranged from 12 to 44 percent for all simulated years; the differences in concentration ranged from 0.002 to 0.008 mg/L in these cases (tables 2 and 3).

More substantial differences were observed in the hypolimnion at site 7B near the dam, particularly for simulated concentrations for WY 2001 and WY 2002 (fig. 16). The percent change from the Existing Conditions scenario at this site ranged from 33 to 133 percent for all simulated years; the differences in concentration ranged from 0.005 to 0.024 mg/L in these cases (table 2). At site 7B, the annual median concentrations for the Existing Conditions scenario in the hypolimnion and epilimnion were nearly the same.

Total Iron

The annual median total-iron concentrations for the Existing Conditions and No Action scenarios in the epilimnion at site 7B were typically less than the minimum calculation threshold (0.001 mg/L; Galloway and others, 2008) for the Pueblo Reservoir model (fig. 17); little or no total iron was simulated in the upper strata of the reservoir at this site. Only slightly larger annual median concentrations of total iron were simulated in the hypolimnion at this downstream site and there were little differences in the results between the two simulation scenarios for any of the three simulated years (table 2). The largest simulated annual median total-iron concentration in the hypolimnion was 0.004 mg/L. Temporally, larger concentrations of total iron were simulated in the hypolimnion during the summer months at 7B (fig. 18). Total-iron concentrations increased in the hypolimnion during the same relative time when anoxic conditions were simulated at depth at site 7B near the dam.

Overall, the concentrations of total iron at site 3B were larger than those simulated at the downstream site (tables 2 and 3); suspension of particulate material at this more riverine site would result in larger concentrations. Comparisons between the Existing Conditions and No Action scenarios in the epilimnion and hypolimnion at site 3B indicated that there

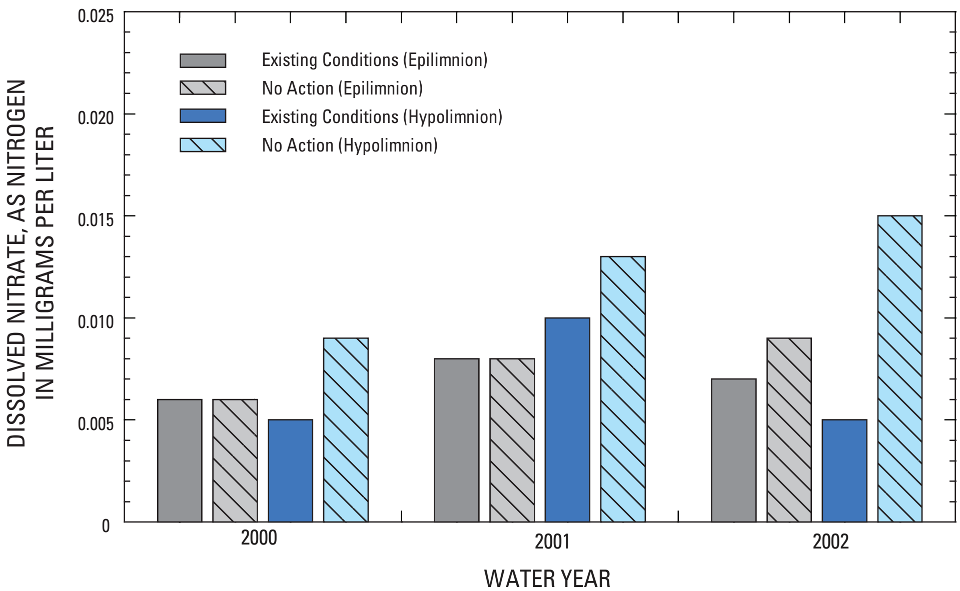

Figure 15. Annual median dissolved-nitrate concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

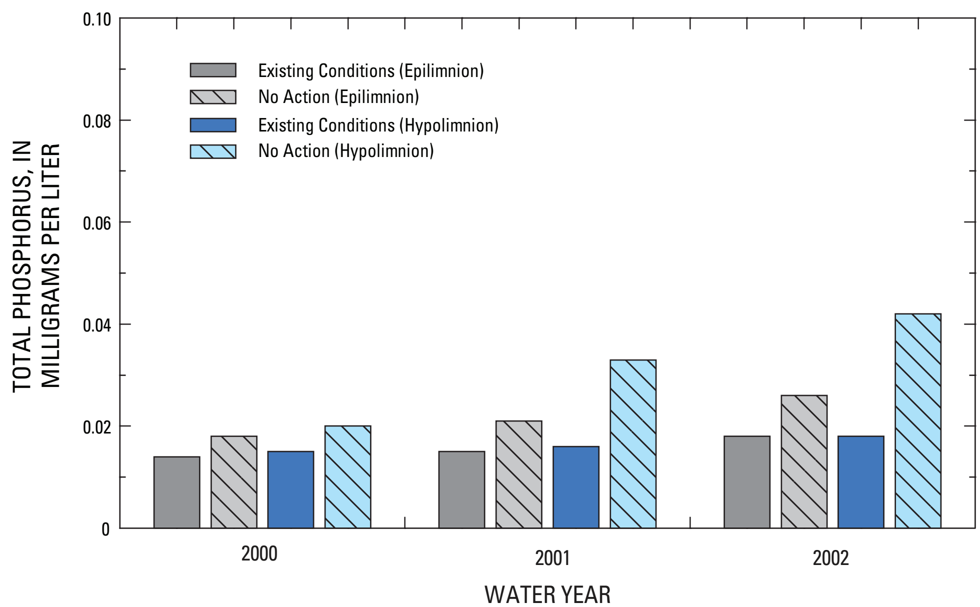

Figure 16. Annual median total-phosphorus concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

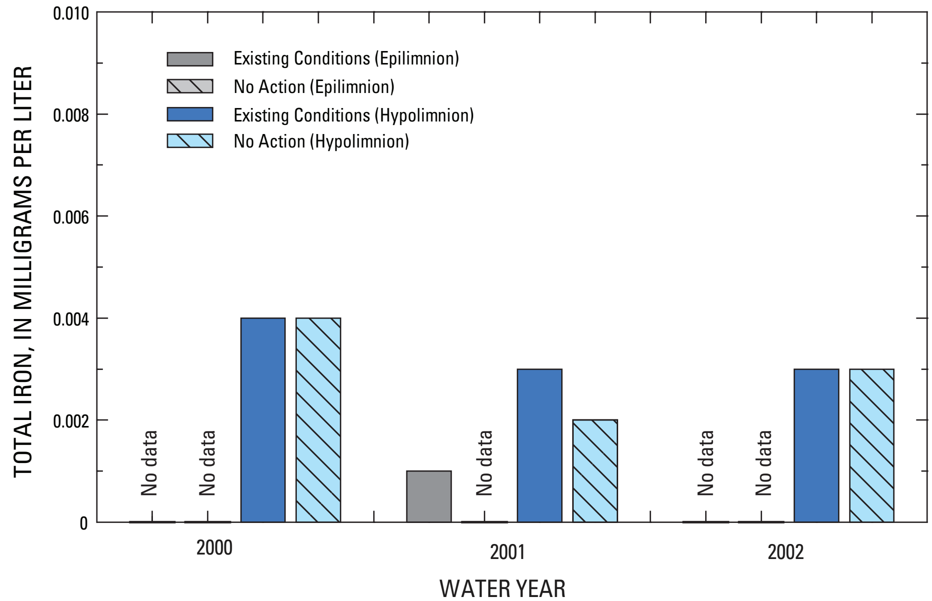

Figure 17. Annual median total-iron concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

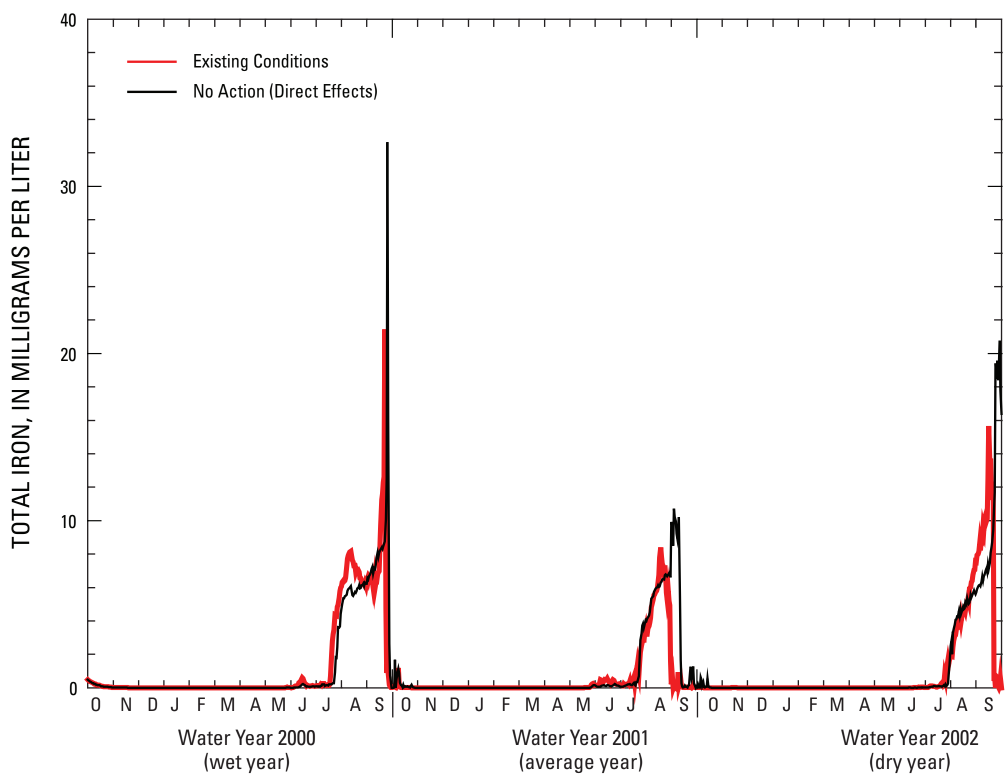

Figure 18. Comparison of total-iron concentrations in the hypolimnion at site 7B in Pueblo Reservoir for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

was little difference between the results for the simulations. Generally, the results only differed by 0.002 to 0.004 mg/L.

Chronic surface-water water-quality standards for total iron in Pueblo Reservoir are set at 1 mg/L as compared to the mean value (Colorado Department of Public Health and Environment, 2006). No calculated annual median value in the epilimnion or in the hypolimnion at sites 7B or 3B exceeded this standard for either modeled scenario (tables 2 and 3). If simulated results were compared to the annual 85th percentile values, the chronic standard was exceeded in the epilimnion (surface water) at site 3B in WY 2001 for the Existing Conditions scenario (table 5). If compared to the simulated results in the hypolimnion, the chronic standard was exceeded in WY 2000 and WY 2002 at site 7B for both simulated scenarios (table 4) and in WY 2001 at site 3B for both simulated scenarios (table 5). Caution should be used when applying the simulated total-iron concentrations to water-quality standards since the absolute mean error reported for the calibrated Pueblo Reservoir model was 1.48 mg/L (Galloway and others, 2008).

Algal Groups and Chlorophyll *a*

The composition and dynamics of the algal community in a reservoir can be highly complex, and modeling is a simplification of what actually occurs in a reservoir. In the Pueblo Reservoir model, diverse-species composition was generalized into four main groups to reduce the complexity of the modeling effort. The four algal groups simulated as part of this report include blue-green algae (cyanobacteria), green algae, diatoms, and flagellates. Algal growth in the Pueblo Reservoir model was affected by temperature, light, and the availability of nutrients. Decreases in algal population in the model generally are due to mortality, respiration, and settling to the bottom sediments (Cole and Wells, 2003).

The simulated distribution of algal populations was highly variable in Pueblo Reservoir from WY 2000 through WY 2002 (figs. 19 and 20). The largest algal biomass in Pueblo Reservoir generally occurred from May through September when blue-green and green algae were the dominant algal groups in the reservoir. The smallest algal biomass generally occurred from November through March when diatoms and flagellates were the dominant groups. Seasonal differences in algal communities were the result of nutrient availability and differences in water temperature. Generally, simulated algae concentrations were less than 0.5 mg/L as carbon in the epilimnion and hypolimnion at sites 7B and 3B for either of the two simulation scenarios (Existing Conditions and No Action). The exception was the increase in blue-green algae concentration in the epilimnion at 7B, particularly for the No Action scenario.

Generally, algae concentrations were similar for the Existing Conditions and the No Action scenarios at site 7B for the simulated period (WY 2000 through WY 2002) (fig. 19). The similarities were observed in the epilimnion and in the hypolimnion. The only marked difference appeared to be the increased blue-green algae concentrations in each of the simulated years in the epilimnion at 7B associated with the No Action scenario. Maximum concentrations of blue-green algae were about two times larger for the No Action scenario when compared to concentrations for the Existing Conditions (fig. 19). The increase in blue-green algae concentrations occurred each year during May and June when water temperature, light, and nutrient availability were conducive for increased growth in surface waters. At site 3B, concentrations of blue-green algae, green algae, diatoms, and flagellates generally were similar between scenarios at any depth (fig. 20). With the exception of blue-green algae, algae concentrations were similar to concentrations simulated in the epilimnion at site 7B.

Harmful algal blooms in freshwater, particularly from blue-green algae, can occur anytime water use is impaired due to excessive accumulations of nutrients. This occurrence is affected by a complex set of physical, chemical, biological, hydrological, and meteorological conditions making it difficult to isolate specific causative environmental factors (Graham, 2006). Potential impairments include reduction in water quality, accumulation of malodorous scum in beach areas, algal production of toxins potent enough to poison both aquatic and terrestrial organisms, and algal production of taste-and-odor compounds that cause unpalatable drinking water and fish. Modeled algae concentrations associated with Existing Conditions and No Action scenarios would not be expected to pose any health issues or produce any taste-and-odor problems in Pueblo Reservoir (Graham, 2006).

Chlorophyll *a* is the primary pigment in plants responsible for photosynthesis and can be used as a general indicator of primary production and the quantity of algae present in a water body. Because chlorophyll *a* concentrations can be affected by various environmental and nutritional factors without affecting algal biomass (Britton and Greeson, 1989), chlorophyll *a* measurements are considered to provide only an approximation of primary production and algal biomass. Nevertheless, a widely used measure of algal and blue-green algal biomass is the chlorophyll *a* concentration. Peak values of chlorophyll *a* for an oligotrophic lake are about 1 to 10 micrograms per liter (µg/L). Concentrations in a eutrophic lake can reach 300 µg/L (Chorus and Bartram, 1999). For protection from health outcomes not due to cyanotoxins, but due to the irritative or allergenic effects of other cyanobacterial compounds, a guideline level of 10 µg/L of chlorophyll *a* (under conditions of cyanobacterial dominance) can be derived from the prospective epidemiological study by Pilotto and others (1997). In temperate regions of the United States, the occurrence of cyanobacteria and the potential presence of microcystin are most common during late summer and early autumn and may last 2 to 4 months. Blooms of microcystis (a toxin forming cyanobacteria) typically are found in lakes with average summer chlorophyll *a* concentrations of 20 to 50 µg/L and a secchi depth of 3 to 6 feet (Chorus and Bartram, 1999). Secchi depth is a measurement of the clarity of a reservoir

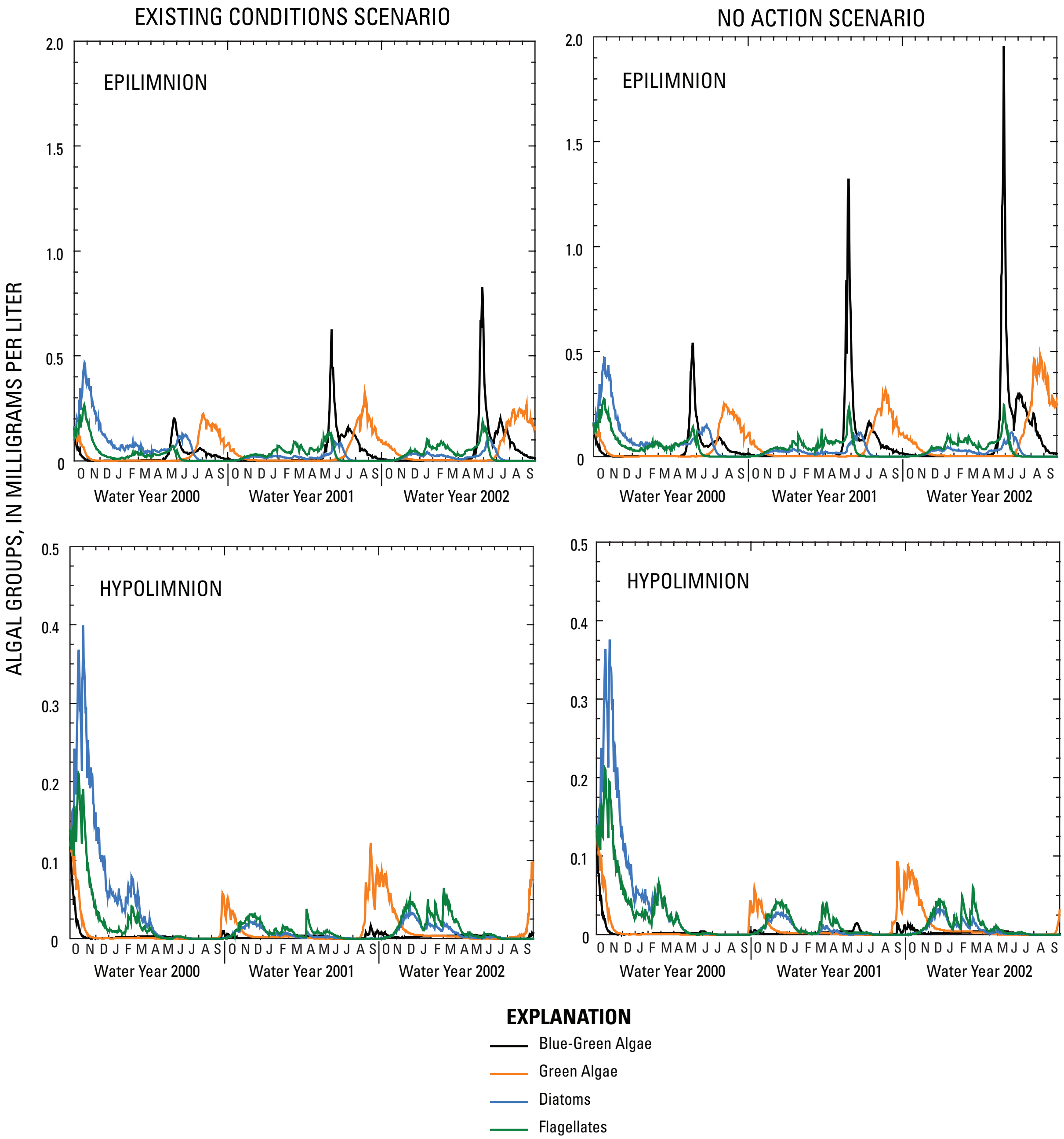

Figure 19. Relation between various algal groups in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

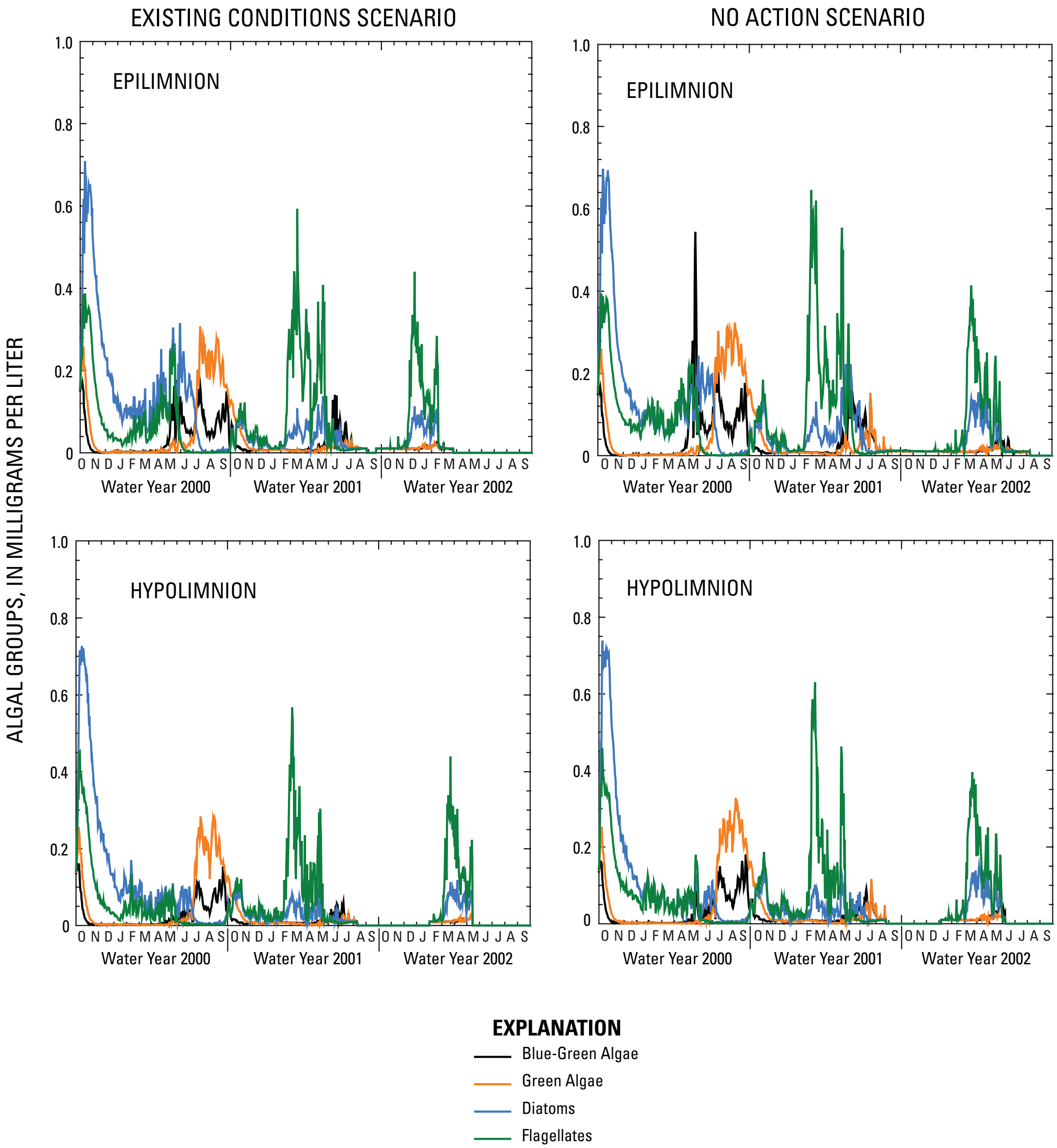

Figure 20. Relation between various algal groups in the epilimnion and hypolimnion at site 3B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

measured by lowering an 8-inch white disk through the water column until it is no longer visible.

Annual median chlorophyll *a* concentrations in the epilimnion at the site near the dam (7B) generally were similar for the Existing Conditions and No Action scenarios during the 3 simulated years (fig. 21). At site 7B and 3B, the differences in concentration were less than 0.2 µg/L; the percent change from the Existing Conditions scenario ranged from 0 to 67 percent for all simulated years (tables 2 and 3). Generally, substantial differences also were not observed in the annual 85th percentile concentrations in the epilimnion and hypolimnion between the two simulation scenarios (tables 4 and 5). Percent change from the Existing Conditions scenario ranged from –33 to 50 percent (maximum difference between the Existing Conditions and the No Action scenarios was 0.5 µg/L). Concentrations in the hypolimnion at either site were consistently smaller than concentrations in the epilimnion where photosynthesis was at a maximum.

Comparison of No Action Scenario and Other Simulation Scenarios

The following comparisons were made between the No Action scenario and each of the other scenarios as described in the previous section entitled "Description of Simulation Scenarios." Specifically, the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios were compared to the No Action scenario. Comparisons were made to describe changes in the annual median, 85th percentile, or 15th percentile concentration between the No Action scenario and each of the other three simulation scenarios. The reader is directed back to figure 2 and table 1 for a reference to the simulation scenarios as they relate to the original Reclamation EIS alternatives. Comparisons between scenario results in this section of the report will be similar to those described in the section "Comparison of Existing Conditions Scenario and No Action Scenario."

Water-Surface Elevations

Simulated water-surface elevations in Pueblo Reservoir generally were similar between the No Action scenario and each of the other three simulation scenarios (fig. 22). There was a substantial temporal decrease in water-surface elevations from WY 2000 through WY 2002. Annual maximum water-surface elevations for the simulated period were similar for each scenario and ranged from about 4,888 feet (1,490 meters) in WY 2000 to about 4,855 feet (1,480 meters) in WY 2002. The difference in the maximum or minimum elevations for any specific date for the simulated scenarios generally was about 6.6 feet (2 meters). Typically, maximum storage occurred in late March of each year as winter storage was nearly complete and releases of water to downstream irrigators had not yet started.

Water Temperature

Comparisons of the results between the No Action scenario and each of the other three simulation scenarios for water temperature indicated that the modeled scenarios generally provided similar results (fig. 23). At site 7B, the percent change from the No Action scenario was within 4 percent for all simulated years with the exception of results in the hypolimnion during WY 2002 for the Upstream Return-Flow scenario (14 percent) and the Upstream Diversion scenario (18 percent) (table 6). Simulation results for WY 2002 were representative of a drought year and decreased reservoir storage and, as such, increased inflow water temperatures (Upstream Return-Flow scenario) or decreased inflow to the reservoir (Upstream Diversion scenario) could help explain the differences in the median water temperatures in WY 2002. Water temperatures in the hypolimnion were relatively similar between the simulation scenarios, and generally were 4 to 5 degrees smaller than those in the epilimnion. Annual median water temperatures in the epilimnion and the hypolimnion at site 3B between scenarios were more varied (table 7). The differences ranged from –21 to 18 percent when compared to the No Action scenario.

Dissolved Oxygen

Comparisons of simulated DO concentrations between the No Action scenario and the three other scenarios indicated that the annual median values in the epilimnion at site 7B generally were similar to results for the No Action scenario (fig. 24). Typically, the percent change from the No Action scenario was within 3 percent for the Downstream Diversion and Upstream Diversion scenarios for any simulated year. However, DO concentrations in the epilimnion at site 7B were consistently larger for the Upstream Return-Flow scenario than the No Action scenario; the percent difference ranged from 11 to 15 percent (table 6). The increase can be attributed to an increase in algal photosynthesis resulting from increased nutrient loading associated with the Upstream Return-Flow scenario. Seasonal spikes in DO concentration can be observed at site 7B during the summer months for the Upstream Return-Flow scenario (fig. 8). Comparisons of DO concentrations in the epilimnion at site 3B showed similar increases for WY 2000 and WY 2001 (table 7).

In general, annual median DO concentrations in the hypolimnion at site 7B near the dam were similar for all the simulation scenarios. The annual median value for any simulated year ranged from 7.0 to 7.8 mg/L in the hypolimnion (table 6).

Differences between the annual 15th percentile DO concentrations in the epilimnion at site 7B were similar to the differences observed for the annual median values at this depth. The Downstream Diversion scenario differed by ±7 percent from the No Action scenario while the Upstream Diversion scenario differed by ±4 percent (table 8). Larger percent differences were observed between the No Action and

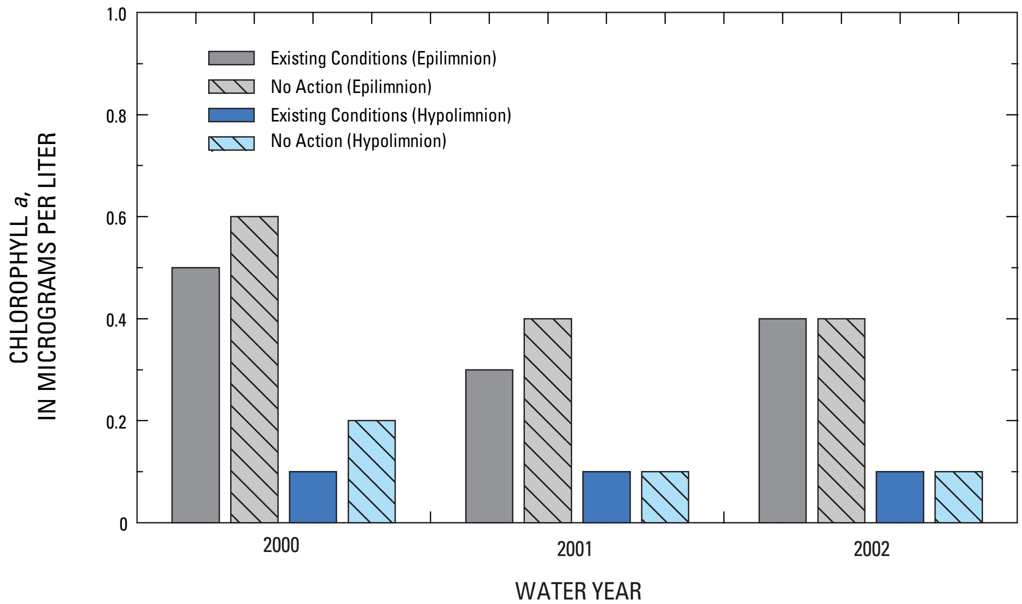

Figure 21. Annual median chlorophyll *a* concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

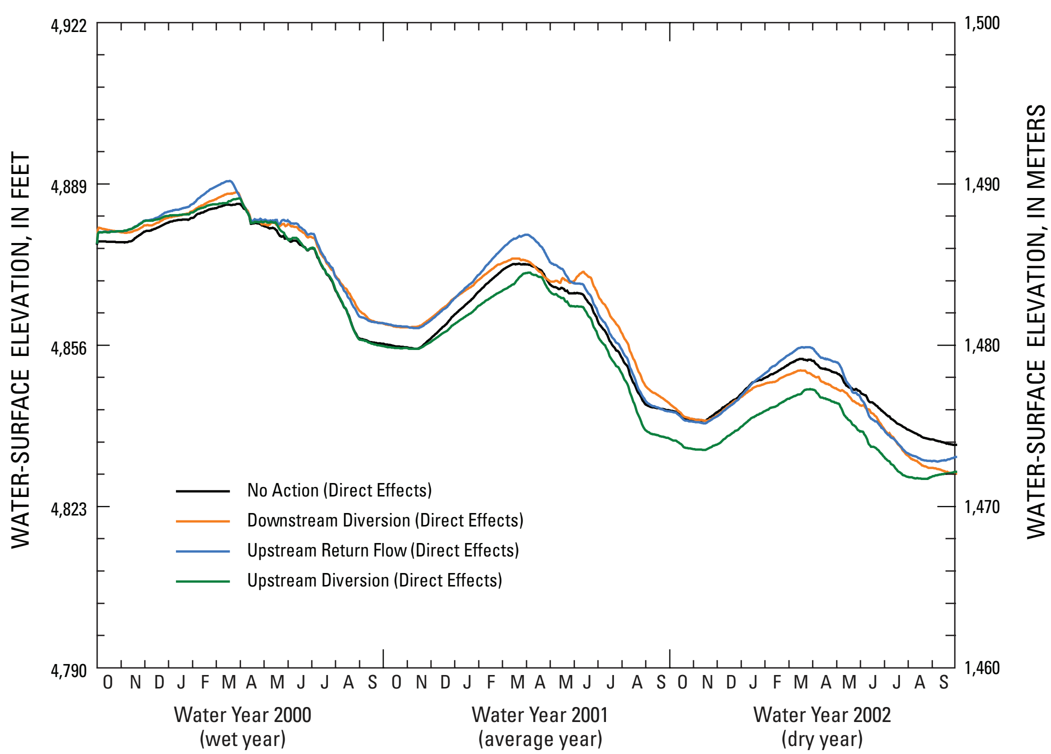

Figure 22. Comparison of water-surface elevations in Pueblo Reservoir for the No Action, Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios (direct-effects analyses).

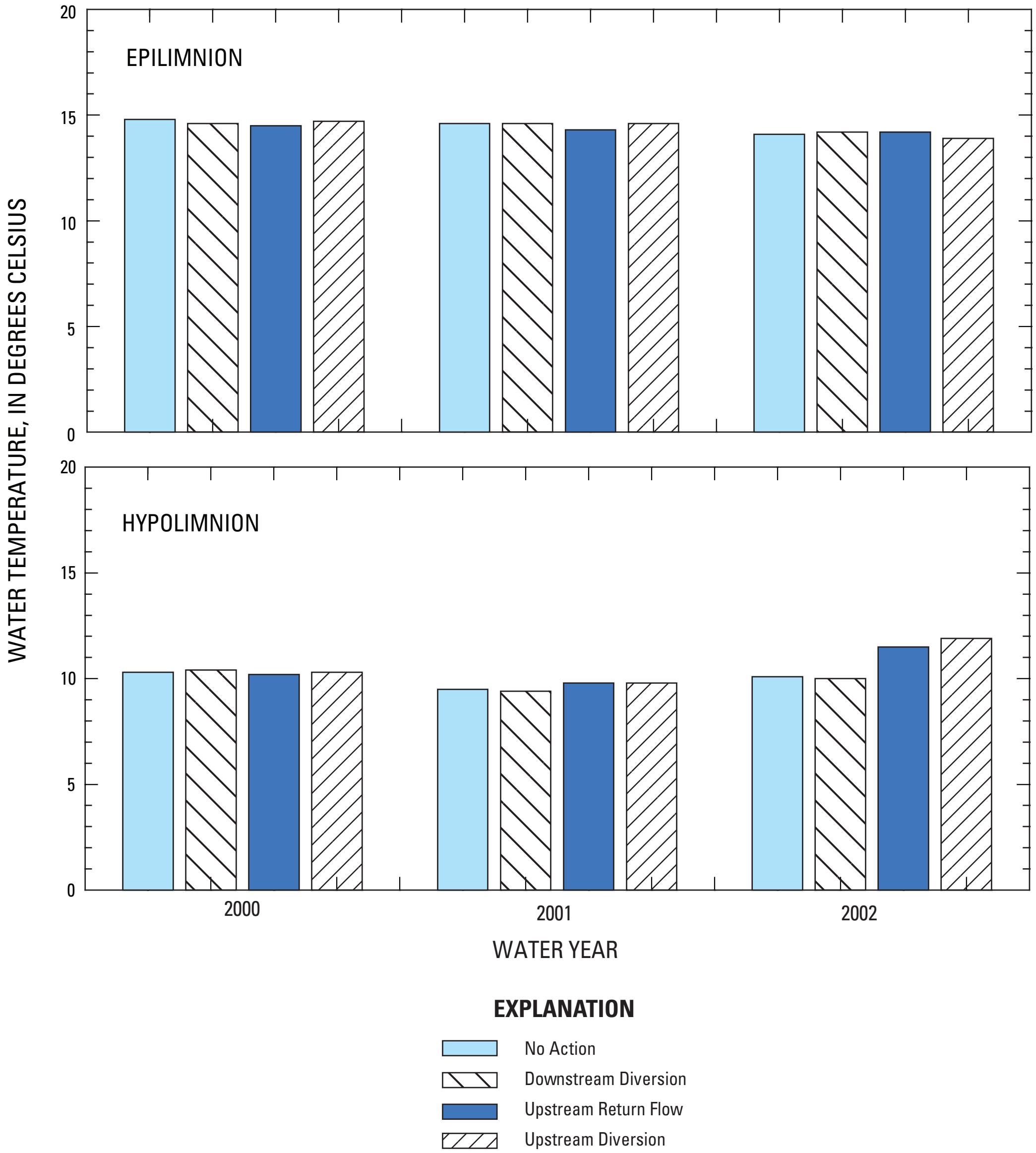

Figure 23. Annual median water temperature in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

Table 6. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	14.8	8.0	290	0.004	0.006	0.018	<0.001	0.6
	Downstream Diversion	100	14.6	8.2	265	.005	.009	.022	.001	1.1
	Percent change		-1.4%	2.5%	-8.6%	25%	17%	22%	NA	83%
	No Action	100	14.8	8.0	290	.004	.006	.018	<.001	.6
2000	Upstream Return Flow	100	14.5	8.9	307	.003	.016	.060	<.001	2.3
	Percent change		-2.0%	11%	5.9%	-25%	167%	233%	NA	283%
	No Action	100	14.8	8.0	290	.004	.006	.018	<.001	.6
	Upstream Diversion	100	14.7	7.9	285	.004	.006	.018	<.001	.6
	Percent change		-.7%	-1.3%	-1.7%	0%	0%	0%	NA	0%
					Hypolimnion					
	No Action	100	10.3	7.6	290	.013	.009	.020	.004	.2
	Downstream Diversion	100	10.4	7.5	267	.013	.009	.024	.004	.2
	Percent change		1.0%	-1.3%	-7.9%	0%	0%	20%	0%	0%
	No Action	100	10.3	7.6	290	.013	.009	.020	.004	.2
2000	Upstream Return Flow	100	10.2	7.7	311	.034	.022	.074	.005	.6
	Percent change		-1.0%	1.3%	7.2%	161%	144%	270%	25%	200%
	No Action	100	10.3	7.6	290	.013	.009	.020	.004	.2
	Upstream Diversion	100	10.3	7.5	285	.013	.008	.020	.003	.1
	Percent change		0%	-1.3%	-1.7%	0%	-11%	0%	-25%	-50%

Table 6. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	14.6	8.1	238	.004	.008	.021	<.001	.4
	Downstream Diversion	100	14.6	8.3	245	.006	.015	.030	<.001	.6
	Percent change		0%	2.5%	2.9%	50%	88%	43%	NA	50%
	No Action	100	14.6	8.1	238	.004	.008	.021	<.001	.4
2001	Upstream Return Flow	100	14.3	9.3	308	.005	.056	.090	<.001	2.4
	Percent change		-2.1%	15%	29%	25%	600%	329%	NA	500%
	No Action	100	14.6	8.1	238	.004	.008	.021	<.001	.4
	Upstream Diversion	100	14.6	8.1	235	.004	.008	.020	<.001	.3
	Percent change		0%	0%	-1.3%	0%	0%	-4.8%	NA	-25%
					Hypolimnion					
	No Action	100	9.5	7.8	247	.017	.013	.033	.002	.1
	Downstream Diversion	100	9.4	7.8	249	.017	.018	.040	.002	.2
	Percent change		-1.1%	0%	.8%	0%	38%	21%	0%	100%
	No Action	100	9.5	7.8	247	.017	.013	.033	.002	.1
2001	Upstream Return Flow	100	9.8	7.3	317	.052	.056	.110	.002	.3
	Percent change		3.2%	-6.4%	28%	206%	331%	233%	0%	200%
	No Action	100	9.5	7.8	247	.017	.013	.033	.002	.1
	Upstream Diversion	100	9.8	7.7	245	.019	.013	.036	.001	.1
	Percent change		3.2%	-1.3%	-.8%	12%	0%	9.1%	-50%	0%

Table 6. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	14.1	8.3	246	.004	.009	.026	<.001	.4
	Downstream Diversion	100	14.2	8.4	265	.006	.011	.032	<.001	.5
	Percent change		.7%	1.2%	7.7%	50%	22%	23%	NA	25%
	No Action	100	14.1	8.3	246	.004	.009	.026	<.001	.4
2002	Upstream Return Flow	100	14.2	9.4	352	.012	.050	.123	<.001	3.1
	Percent change		.7%	13%	43%	200%	456%	373%	NA	675%
	No Action	100	14.1	8.3	246	.004	.009	.026	<.001	.4
	Upstream Diversion	100	13.9	8.5	246	.005	.008	.026	<.001	.4
	Percent change		-1.4%	2.4%	0%	25%	-11%	0%	NA	0%
					Hypolimnion					
	No Action	100	10.1	7.5	254	.015	.015	.042	.003	.1
	Downstream Diversion	100	10.0	7.7	273	.018	.017	.048	.004	.1
	Percent change		-1.0%	2.7%	7.5%	20%	13%	14%	33%	0%
	No Action	100	10.1	7.5	254	.015	.015	.042	.003	.1
2002	Upstream Return Flow	100	11.5	7.6	359	.047	.041	.139	.004	.8
	Percent change		14%	1.3%	41%	213%	173%	231%	33%	700%
	No Action	100	10.1	7.5	254	.015	.015	.042	.003	.1
	Upstream Diversion	100	11.9	7.0	254	.017	.013	.044	.003	.1
	Percent change		18%	-6.7%	0%	13%	-13%	4.8%	0%	0%

Table 7. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	No Action	100	14.1	8.0	293	0.001	0.006	0.018	0.011	1.0
	Downstream Diversion	100	14.1	8.1	263	.002	.005	.024	.012	1.7
	Percent change		0%	1.3%	-10%	100%	-17%	33%	9.1%	70%
	No Action	100	14.1	8.0	293	.001	.006	.018	.011	1.0
	Upstream Return Flow	100	14.0	9.0	305	.001	.017	.066	.008	5.6
	Percent change		-.7%	12%	4.1%	0%	183%	267%	-27%	460%
	No Action	100	14.1	8.0	293	.001	.006	.018	.011	1.0
	Upstream Diversion	100	14.1	7.9	287	.002	.004	.017	.009	1.0
	Percent change		0%	-1.3%	-2.0%	100%	-33%	-5.6%	-18%	0%
					Hypolimnion					
2000	No Action	100	12.2	7.8	292	.002	.009	.018	.024	.7
	Downstream Diversion	100	12.1	7.9	265	.005	.008	.024	.032	1.0
	Percent change		-.8%	1.3%	-9.2%	150%	-11%	33%	33%	43%
	No Action	100	12.2	7.8	292	.002	.009	.018	.024	.7
	Upstream Return Flow	100	12.0	8.5	314	.005	.079	.078	.040	3.3
	Percent change		-1.6%	9.0%	7.5%	150%	778%	333%	67%	371%
	No Action	100	12.2	7.8	292	.002	.009	.018	.024	.7
	Upstream Diversion	100	12.2	7.8	287	.002	.006	.018	.022	.8
	Percent change		0%	0%	-1.7%	0%	-33%	0%	-8.3%	14%

Table 7. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2001	No Action	100	12.4	8.5	246	.007	.057	.022	.026	.5
	Downstream Diversion	100	12.9	8.4	259	.012	.023	.032	.025	.9
	Percent change		4.0%	-1.2%	5.3%	71%	-60%	45%	-3.8%	80%
	No Action	100	12.4	8.5	246	.007	.057	.022	.026	.5
	Upstream Return Flow	100	11.7	9.8	325	.001	.251	.125	.024	5.3
	Percent change		-5.6%	15%	32%	-86%	340%	468%	-7.7%	1,060%
	No Action	100	12.4	8.5	246	.007	.057	.022	.026	.5
	Upstream Diversion	91	9.8	9.0	243	.002	.049	.020	.022	.8
	Percent change		-21%	5.9%	-1.2%	-71%	-14%	-9.1%	-15%	60%
					Hypolimnion					
2001	No Action	90	8.9	9.1	244	.005	.051	.022	.046	.4
	Downstream Diversion	96	10.5	8.2	262	.020	.025	.033	.054	.6
	Percent change		18%	-10%	7.4%	300%	-51%	50%	17%	50%
	No Action	90	8.9	9.1	244	.005	.051	.022	.046	.4
	Upstream Return Flow	90	8.4	9.0	327	.010	.243	.124	.045	3.0
	Percent change		-5.6%	-1.1%	34%	100%	376%	464 %	-2.2%	650%
	No Action	90	8.9	9.1	44	.005	.051	.022	.046	.4
	Upstream Diversion	86	8.7	9.3	244	.002	.052	.021	.035	.5
	Percent change		-2.2%	2.2%	0%	-60%	2.0%	-4.5%	-24%	25%

Table 7. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2002	No Action	85	10.0	8.1	279	.019	.079	.026	.391	.2
	Downstream Diversion	76	8.5	8.3	304	.044	.034	.033	.403	.2
	Percent change		-15%	2.5%	9.0%	132%	-57%	27%	3.1%	0%
	No Action	85	10.0	8.1	279	.019	.079	.026	.391	.2
	Upstream Return Flow	75	9.3	8.2	386	.020	.723	.172	.298	.2
	Percent change		-7.0%	1.2%	38%	5.3%	815%	562%	-24%	0%
	No Action	85	10.0	8.1	279	.019	.079	.026	.391	.2
	Upstream Diversion	43	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
2002	No Action	42	--	--	--	--	--	--	--	--
	Downstream Diversion	35	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	42	--	--	--	--	--	--	--	--
	Upstream Return Flow	40	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	42	--	--	--	--	--	--	--	--
	Upstream Diversion	5	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

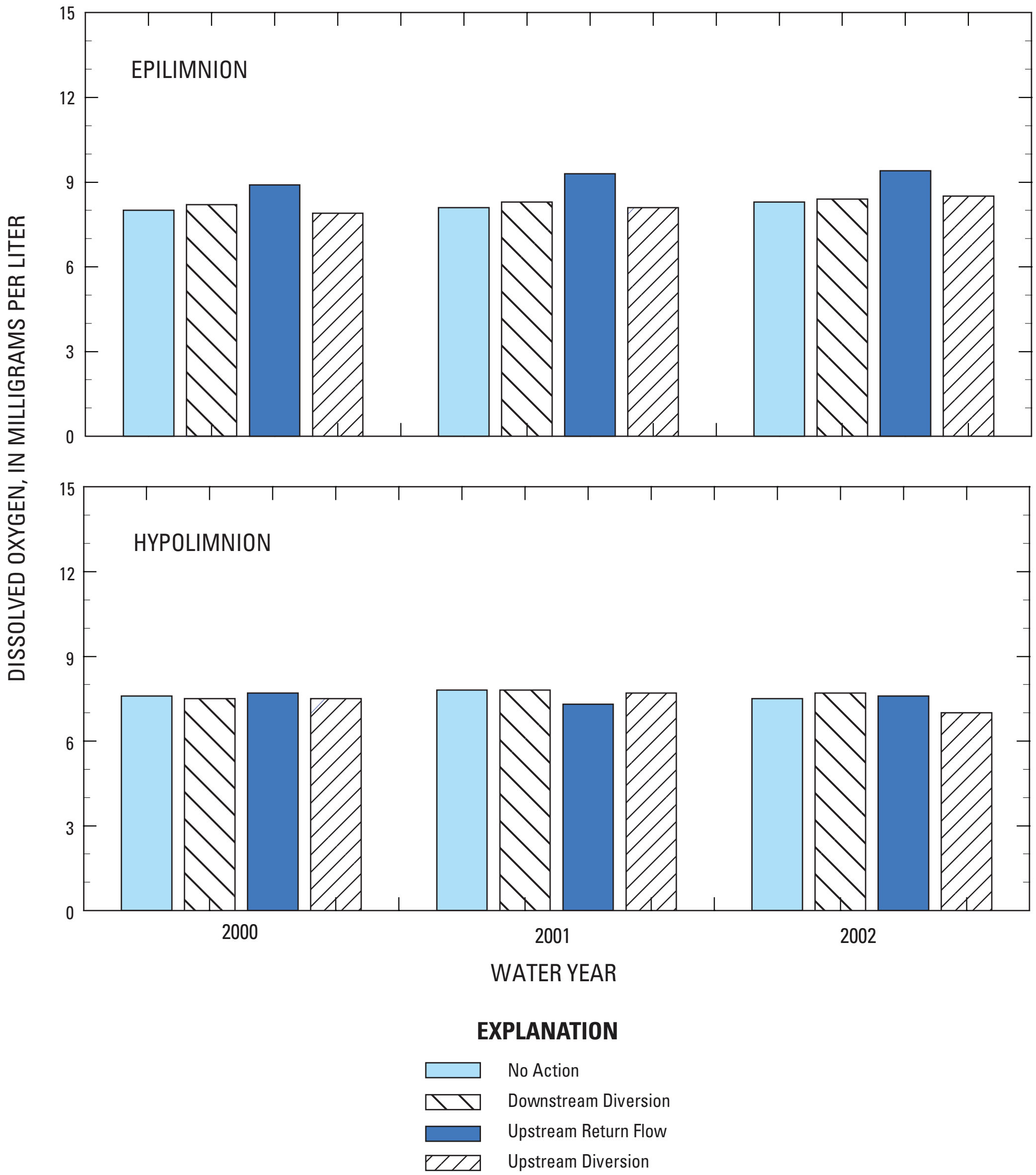

Figure 24. Annual median dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

Upstream Return-Flow scenarios (15–28 percent) (table 8). Overall, the annual 15th percentile values in the epilimnion at site 7B ranged from 5.0 to 7.3 mg/L for any of the simulation scenarios.

Seasonal periods of anoxic conditions in Pueblo Reservoir have been documented by Edelmann (1989). Simulated results for the No Action scenario show depleted concentrations of DO during the summer in the hypolimnion at site 7B (fig. 7). Simulated results for the Downstream Diversion, Upstream Return Flow, and Upstream Diversion scenarios also show similar results (table 8). The 15th percentile concentration for all of these scenarios was 0.2 mg/L or less in the hypolimnion.

The minimum DO concentration suitable to meet the DO water-quality standard in Pueblo Reservoir was 6.0 mg/L as measured in the epilimnion of the water body (Colorado Department of Public Health and Environment, 2006). The standard is compared to the 15th percentile of the data. For the No Action scenario, the standard value was not always attained when compared to the simulated annual 15th percentile value in the epilimnion at sites 7B and 3B (tables 8 and 9). Additionally, the standard value was not always attained for the Downstream Diversion, Upstream Return Flow, and Upstream Diversion scenarios (tables 8 and 9). Caution should be used when comparing these results to the water-quality standard because the absolute mean error of the DO calibration for the Pueblo Reservoir model (Galloway and others, 2008) was 1.42 mg/L at site 7B indicating that the standard value of 6.0 mg/L was within the error of the simulated results.

Dissolved Solids

Comparisons of simulated dissolved-solids concentrations indicated that the annual medians were relatively similar between the No Action and Downstream Diversion scenarios, and the No Action and Upstream Diversion scenarios in the epilimnion and hypolimnion at site 7B (near-dam site) (fig. 25). Simulated results for the Upstream Return-Flow scenario were consistently larger than the No Action scenario particularly during WY 2001 and WY 2002 as drier conditions prevailed in the simulations. These results were observed in the epilimnion and in the hypolimnion. Specifically, differences between the No Action scenario and the Downstream Diversion and Upstream Diversion scenarios were less than ±10 percent over the 3 years (table 6), whereas the percent differences between the No Action and Upstream Return-Flow scenarios increased annually from 5.9 percent (WY 2000) to 43 percent (WY 2002) (table 8). Similar results were observed in the epilimnion and hypolimnion at site 3B (table 7).

No water-quality standard for dissolved solids exists for Pueblo Reservoir. However, a guideline does exist to assist managers of public water systems in managing their drinking water for aesthetic considerations, such as taste, color, and odor. The guideline is set at 500 mg/L (U.S. Environmental Protection Agency, 1992). The largest annual median dissolved-solids concentration at site 7B or site 3B was 386 mg/L annual in WY 2002 (tables 6 and 7). No annual 85th percentile value exceeded the recommended guideline for any of the modeled scenarios at sites 7B and 3B (tables 8 and 9).

Major Nutrients

Compounds of nitrogen and phosphorus are referred to as “major nutrients” because they are needed for plant growth. In excess quantities, nutrients can promote nuisance algae growth in streams and reservoirs (causing eutrophication). Natural sources of nutrients include precipitation and biochemical processes in the watershed. Anthropogenic sources of nutrients include urban and agricultural runoff, domestic effluent, livestock waste, and erosion caused by development.

Dissolved Ammonia

The annual median dissolved-ammonia (as nitrogen) concentrations in the epilimnion of Pueblo Reservoir at site 7B generally were similar between the No Action scenario and either the Downstream Diversion, Upstream Return Flow, or Upstream Diversion scenarios (fig. 26). The only substantial difference was observed in WY 2002 when the percent increase in ammonia associated with the Upstream Return-Flow scenario was 3 times greater than the corresponding median value for the No Action scenario; concentrations increased 200 percent from 0.004 to 0.012 mg/L (table 6). Similar results were observed in the epilimnion at site 3B in the upstream riverine section of the reservoir (table 7). Annual median ammonia concentrations in the epilimnion at site 7B were less than the simulated concentrations in the hypolimnion. Algal utilization in the epilimnion produced lower concentrations near the reservoir surface while nutrients in the hypolimnion resulted from density gradients.

In the hypolimnion at site 7B, concentrations generally were similar between the No Action scenario and either the Downstream Diversion or Upstream Diversion scenarios. Percent differences from the No Action scenario did not exceed 20 percent for these comparisons. Substantial differences in concentration, however, were observed between the No Action scenario and the Upstream Return-Flow scenario for all 3 simulated years at this location (fig. 26). Specifically, the percent differences between these two scenarios ranged from 161 percent (WY 2000) to 213 percent (WY 2002). The largest percent increase equated to an increase from 0.015 to 0.047 mg/L in WY 2002. Increased nutrient loading associated with the return-flow pipeline upstream from Pueblo Reservoir likely resulted in the observed increases in ammonia. Additionally, releases of ammonia also may have occurred from the reservoir bottom at site 7B during anoxic conditions.

The Colorado Department of Public Health and Environment (2006) defines the chronic and acute water-quality standards for dissolved ammonia by algorithms that use water temperature and pH to calculate the standard. Under historical conditions, the chronic standard ranged from 1.1 to 5.7 mg/L

Table 8. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	No Action	100	25.2	5.7	301	0.008	0.020	0.019	0.005	1.5
	Downstream Diversion	100	25.0	6.1	279	.013	.033	.026	.014	2.2
	Percent change		-.8%	7.0%	-7.3%	62%	65%	37%	180%	47%
	No Action	100	25.2	5.7	301	.008	.020	.019	.005	1.5
	Upstream Return Flow	100	25.1	7.3	312	.059	.163	.073	.006	6.6
	Percent change		-.4%	28%	3.6%	637%	715%	284%	20%	340%
	No Action	100	25.2	5.7	301	.008	.020	.019	.005	1.5
	Upstream Diversion	100	25.2	5.8	293	.008	.017	.018	.006	1.5
	Percent change		0%	1.7%	-2.7%	0%	-15%	-5.3%	20%	0%
					Hypolimnion					
2000	No Action	100	17.8	<.1	302	.027	.023	.042	5.10	.8
	Downstream Diversion	100	17.7	<.1	280	.031	.024	.053	3.31	.8
	Percent change		-.6%	NA	-7.3%	15%	4.3%	26%	-35%	0%
	No Action	100	17.8	<.1	302	.027	.023	.042	5.10	.8
	Upstream Return Flow	100	17.5	<.1	314	.063	.048	.093	2.76	1.6
	Percent change		-1.7%	NA	4.0%	133%	109%	121%	-46%	100%
	No Action	100	17.8	<.1	302	.027	.023	.042	5.10	.8
	Upstream Diversion	100	17.8	<.1	295	.027	.023	.043	5.21	.8
	Percent change		0%	NA	-2.3%	0%	0%	2.4%	-2.1%	0%

Table 8. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2001	No Action	100	24.6	5.0	247	.008	.020	.024	.004	1.0
	Downstream Diversion	100	24.8	5.2	252	.022	.041	.033	.002	2.4
	Percent change		.8%	4.0%	2.0%	175%	105%	37%	-50%	140%
	No Action	100	24.6	5.0	247	.008	.020	.024	.004	1.0
	Upstream Return Flow	100	24.4	6.2	318	.075	.194	.107	.003	6.6
	Percent change		-.8%	24%	29%	838%	870%	346%	-25%	560%
	No Action	100	24.6	5.0	247	.008	.020	.024	.004	1.0
	Upstream Diversion	100	24.1	5.1	245	.008	.019	.023	.004	1.1
	Percent change		-2.0%	2.0%	-.8%	0%	-5.0%	-4.2%	0%	10%
					Hypolimnion					
2001	No Action	100	20.1	.1	252	.030	.028	.051	.904	.2
	Downstream Diversion	100	19.7	.1	258	.034	.031	.059	.467	.4
	Percent change		-2.0%	0%	2.4%	13%	11%	16%	-48%	100%
	No Action	100	20.1	.1	252	.030	.028	.051	.904	.2
	Upstream Return Flow	100	19.8	<.1	331	.079	.146	.127	1.54	1.4
	Percent change		-1.5%	NA	31%	163%	421%	149%	71%	600%
	No Action	100	20.1	.1	252	.030	.028	.051	.904	.2
	Upstream Diversion	100	19.9	.2	256	.038	.027	.052	.591	.2
	Percent change		-1.0%	100%	1.6%	27%	-3.6%	2.0%	-35%	0%

Table 8. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2002	No Action	100	24.5	5.4	289	.020	.040	.028	.002	1.5
	Downstream Diversion	100	24.6	5.2	329	.024	.056	.034	.003	1.8
	Percent change		0.4%	-3.7%	14%	20%	40%	21%	50%	20%
	No Action	100	24.5	5.4	289	.020	.040	.028	.002	1.5
	Upstream Return Flow	100	24.4	6.2	442	.157	.450	.133	.003	9.4
	Percent change		-.4%	15%	53%	685%	1,025%	375%	50%	527%
	No Action	100	24.5	5.4	289	.020	.040	.028	.002	1.5
	Upstream Diversion	100	24.5	5.2	291	.024	.056	.029	.002	1.6
	Percent change		0%	-3.7%	.7%	20%	40%	3.6%	0%	6.7%
					Hypolimnion					
2002	No Action	100	16.7	<.1	291	.040	.024	.075	4.08	.2
	Downstream Diversion	100	18.4	<.1	326	.058	.027	.094	2.25	.4
	Percent change		10%	NA	12%	45%	12%	25%	-45%	100%
	No Action	100	16.7	<.1	291	.040	.024	.075	4.08	.2
	Upstream Return Flow	100	19.3	<.1	411	.183	.108	.186	2.22	1.8
	Percent change		16%	NA	41%	357%	350%	148%	-46%	800%
	No Action	100	16.7	<.1	291	.040	.024	.075	4.08	.2
	Upstream Diversion	100	17.5	<.1	316	.068	.027	.111	3.52	.3
	Percent change		4.8%	NA	8.6%	70%	12%	48%	-14%	50%

Table 9. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	23.5	6.0	301	0.003	0.028	0.019	0.063	1.9
	Downstream Diversion	100	24.0	6.4	279	.006	.025	.028	.056	4.0
	Percent change		2.1%	6.7%	-7.3%	100%	-11%	47%	-11%	110%
	No Action	100	23.5	6.0	301	.003	.028	.019	.063	1.9
2000	Upstream Return Flow	100	23.9	7.8	321	.029	.192	.089	.048	9.3
	Percent change		1.7%	30%	6.6%	867%	586%	368%	-24%	389%
	No Action	100	23.5	6.0	301	.003	.028	.019	.063	1.9
	Upstream Diversion	100	23.3	6.1	294	.003	.022	.018	.055	1.9
	Percent change		-.9%	1.7%	-2.3%	0%	-21%	-5.3%	-13%	0%
					Hypolimnion					
	No Action	100	23.0	4.8	303	.006	.026	.019	.358	1.5
	Downstream Diversion	100	22.7	5.0	278	.014	.018	.032	.426	2.8
	Percent change		-1.3%	4.2%	-8.3%	133%	-31%	68%	19%	87%
	No Action	100	23.0	4.8	303	.006	.026	.019	.358	1.5
2000	Upstream Return Flow	100	22.1	5.6	327	.019	.190	.094	.415	7.8
	Percent change		-3.9%	17%	7.9%	217%	631%	395%	16%	420%
	No Action	100	23.0	4.8	303	.006	.026	.019	.358	1.5
	Upstream Diversion	100	22.3	4.9	296	.006	.029	.019	.376	1.5
	Percent change		-3.0%	2.1%	-2.3%	0%	11%	0 %	5.0%	0%

Table 9. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	21.3	5.5	275	.018	.089	.024	.577	1.2
	Downstream Diversion	100	21.6	6.0	274	.036	.046	.034	.317	3.4
	Percent change		1.4%	9.1%	-.4%	100%	-48%	42%	-45%	183%
	No Action	100	21.3	5.5	275	.018	.089	.024	.577	1.2
2001	Upstream Return Flow	100	20.7	5.9	349	.020	.692	.144	.506	12.4
	Percent change		-2.8%	7.3%	27%	11%	644%	500%	-12%	933%
	No Action	100	21.3	5.5	275	.018	.089	.024	.577	1.2
	Upstream Diversion	91	20.8	5.8	273	.009	.078	.023	.806	1.7
	Percent change		-2.3%	5.5%	-.7%	-50%	-12%	-4.2%	38%	42%
					Hypolimnion					
	No Action	90	21.2	5.2	271	.013	.084	.023	1.14	1.0
	Downstream Diversion	96	21.3	5.4	274	.033	.045	.035	.86	1.6
	Percent change		.5%	3.8%	1.1%	154%	-46%	52%	-25%	60%
	No Action	90	21.2	5.2	271	.013	.084	.023	1.14	1.0
2001	Upstream Return Flow	90	19.9	5.5	348	.026	.724	.146	1.09	7.9
	Percent change		-6.1%	5.8%	28%	100%	762%	535%	-4.4%	690%
	No Action	90	21.2	5.2	271	.013	.084	.023	1.14	1.0
	Upstream Diversion	86	20.1	5.3	270	.009	.079	.022	1.38	1.3
	Percent change		-5.2%	1.9%	-.4%	-31%	-6.0%	-4.3%	21%	30%

Table 9. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for direct-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	85	21.6	5.5	357	.020	.098	.032	.647	1.0
	Downstream Diversion	76	17.0	6.3	354	.045	.055	.035	.791	.5
	Percent change		-21%	14%	-.8%	125%	-44%	9.4%	22%	-50%
	No Action	85	21.6	5.5	357	.020	.098	.032	.647	1.0
2002	Upstream Return Flow	75	16.7	5.7	486	.021	.958	.183	.582	7.5
	Percent change		-23%	3.6%	36%	5.0%	878%	472%	-10%	650%
	No Action	85	21.6	5.5	357	.020	.098	.032	.647	1.0
	Upstream Diversion	43	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
	No Action	42	--	--	--	--	--	--	--	--
	Downstream Diversion	35	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	42	--	--	--	--	--	--	--	--
2002	Upstream Return Flow	40	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	42	--	--	--	--	--	--	--	--
	Upstream Diversion	5	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

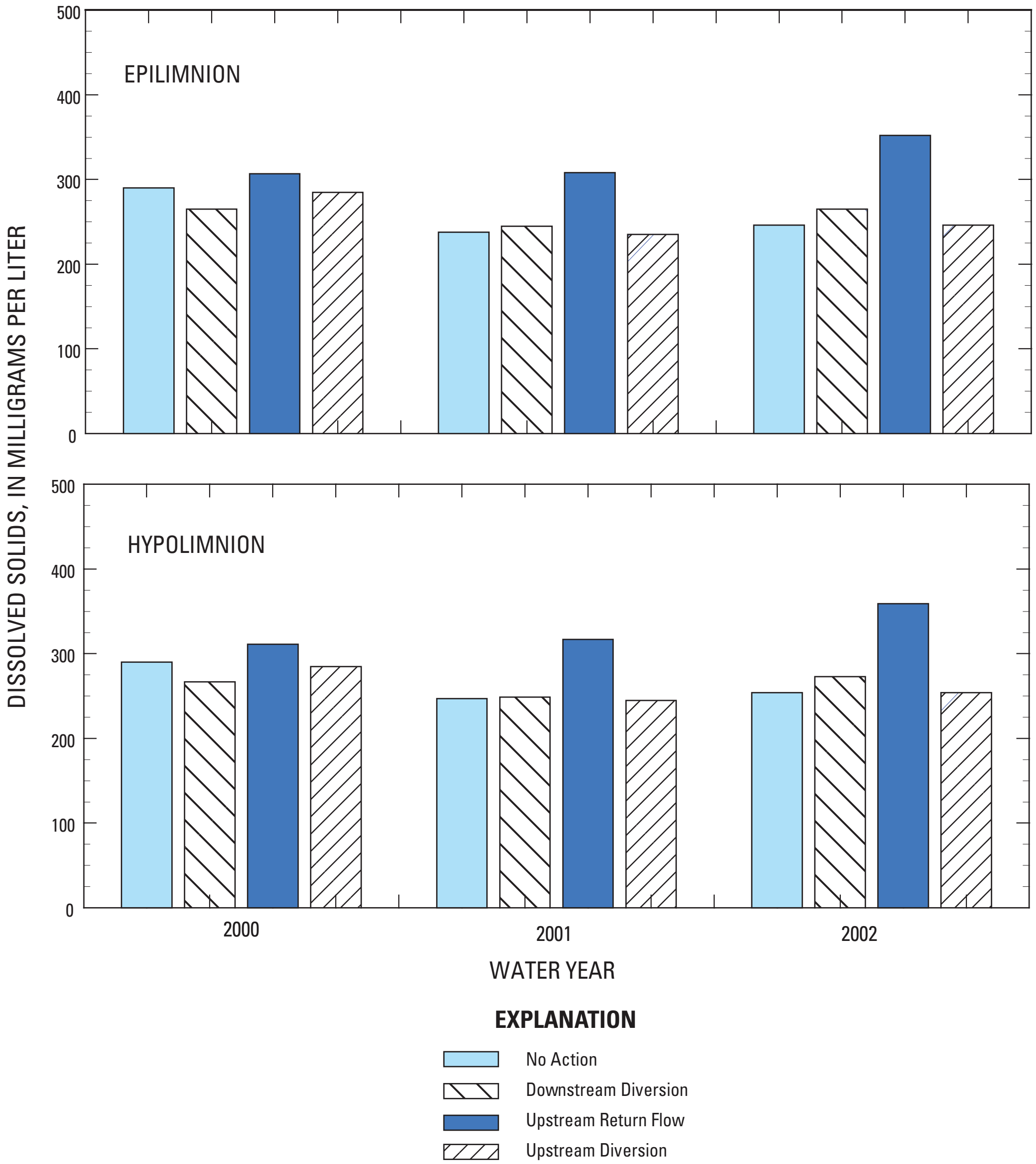

Figure 25. Annual median dissolved-solids concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

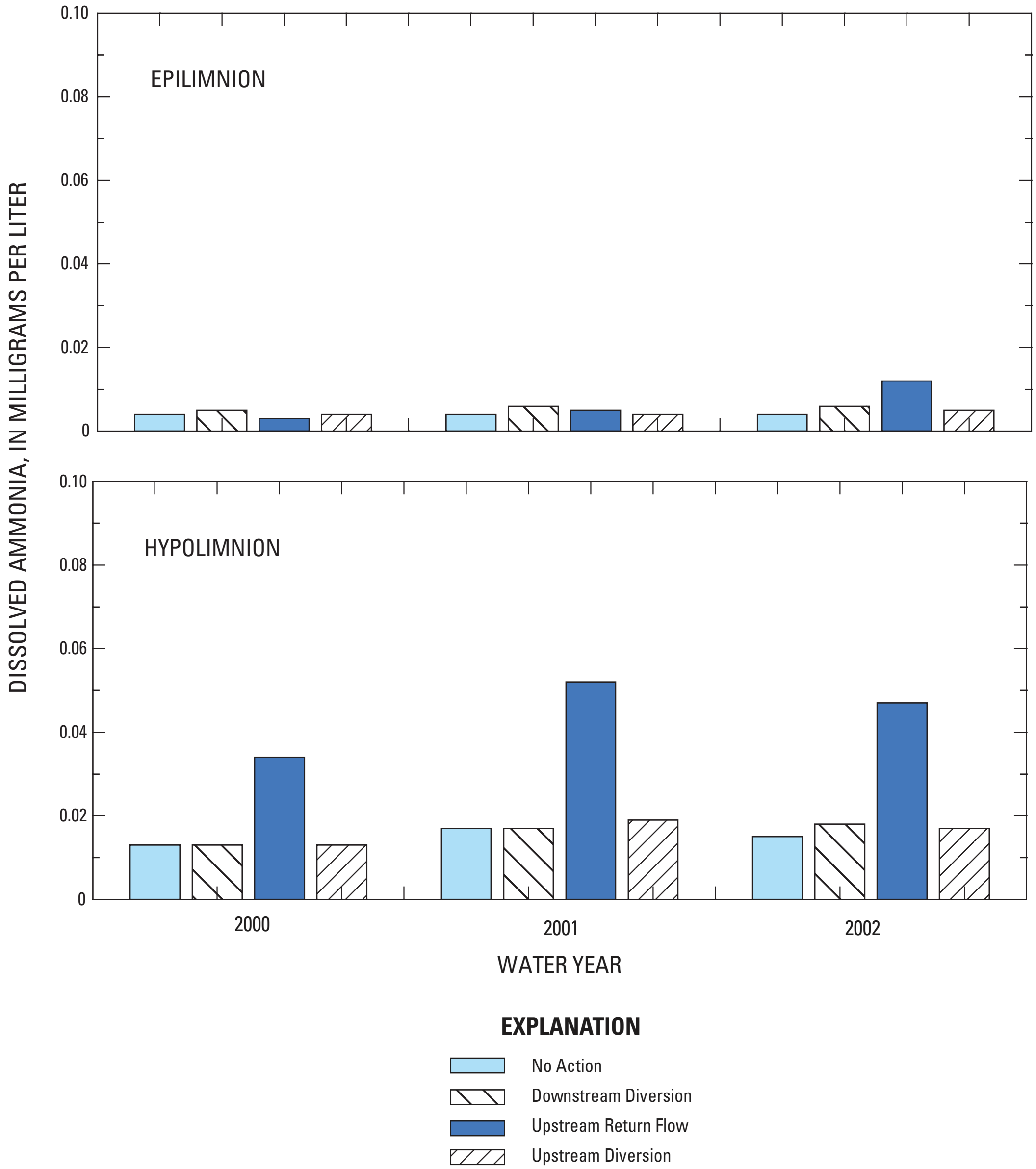

Figure 26. Annual median dissolved-ammonia concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

and the acute standard ranged from 2.1 to 21.9 mg/L (Tracy Kosloff, MWH Americas, Inc., written commun., 2006). Compared to these historical values, the standards were not exceeded by any of the annual median or 85th percentile values simulated as part of the No Action, Downstream Diversion, Upstream Return Flow, or Upstream Diversion scenarios (tables 8 and 9).

Dissolved Nitrate

The annual median dissolved-nitrate concentrations in the epilimnion of Pueblo Reservoir at site 7B generally were similar between the No Action scenario and either the Downstream Diversion or Upstream Diversion scenarios (fig. 27). Percent differences from the No Action scenario generally did not exceed 25 percent for these comparisons although an 88 percent increase was observed in one instance (table 6). Because of the relatively small concentrations of nitrate in Pueblo Reservoir, an increase of this magnitude equated to an increase of only 0.07 mg/L. Similar results were observed in the hypolimnion at site 7B (table 6).

In the epilimnion and hypolimnion, substantial differences were observed between the No Action and Upstream Return-Flow scenarios at site 7B for all 3 modeled years. Simulated results for the Upstream Return-Flow scenario were consistently larger than the No Action scenario. Specifically, the percent differences from the No Action scenario ranged from 144 to 600 percent. Because of the relatively small nitrate concentrations, the largest percent increase equates to a maximum increase of 0.048 mg/L. Similar results also were observed when comparisons were made to the 85th percentile concentrations (tables 8 and 9).

Similar results were observed in the epilimnion and hypolimnion at site 3B with regard to the percent change in concentrations when compared to the No Action scenario (table 7). However, median nitrate concentrations at this upstream site were larger than concentrations observed at site 7B near the dam. Denitrification processes likely resulted in this spatial decrease in concentration. Increased concentrations resulting from additional nutrient loading from the return-flow pipeline upstream from Pueblo Reservoir also were observed at this site. The maximum annual median nitrate concentration associated with the Upstream Return-Flow scenario was observed in WY 2002 at 0.723 mg/L (table 7). This concentration still was small in terms of nitrate concentrations with public health implications. The water-quality standard for dissolved nitrate is 10 mg/L (Colorado Department of Public Health and Environment, 2006). The standard was not exceeded by any of the annual 85th percentile values for any simulated scenario for any simulated year at either site (tables 8 and 9).

Total Phosphorus

Annual total-phosphorus concentrations at site 7B exhibited similar characteristics as described in the previous section on dissolved-nitrate concentrations. The annual median concentrations in the epilimnion at site 7B generally were similar between the No Action scenario and either the Downstream Diversion or Upstream Diversion scenarios (fig. 28). Percent differences from the No Action scenario generally did not exceed 25 percent for these comparisons although a 43 percent increase was observed in WY 2001 (table 6). Because of the relatively small concentrations of total phosphorus in Pueblo Reservoir, an increase of this magnitude equated to an increase of only 0.009 mg/L. Similar results were observed in the hypolimnion at site 7B (table 6).

In the epilimnion and hypolimnion, substantial differences were observed between the No Action and Upstream Return-Flow scenarios at site 7B for all 3 simulated years. Simulated results for the Upstream Return-Flow scenario were consistently larger than the No Action scenario. Specifically, the percent differences from the No Action scenario ranged from 231 to 373 percent. Because of the relatively small total-phosphorus concentrations, the largest percent increase equates to a maximum increase of 0.097 mg/L. Similar results also were observed when comparisons were made to the 85th percentile concentrations (tables 8 and 9).

Annual median total-phosphorus concentrations at site 3B were similar in magnitude to concentrations observed at site 7B in the epilimnion and hypolimnion. Similar comparisons between the No Action scenario and the other simulation scenarios can be made (tables 6 and 7). No specific water-quality standards were applicable for comparison to the simulated results.

Total Iron

The annual median total-iron concentrations were small in the epilimnion at site 7B for the No Action scenario and the three other simulation scenarios (fig. 29). Simulation results for these various scenarios typically indicated that concentrations were equal to or less than 0.001 mg/L during much of the year. Larger concentrations of total iron were observed at site 3B near the upstream end of Pueblo Reservoir. Typically, the annual median concentrations in the epilimnion at site 3B were many times larger than those near the surface at site 7B. Total-iron concentrations in the epilimnion at site 3B did show a temporal increase over the 3 years of simulation from about 0.01 mg/L (WY 2000) to about 0.4 mg/L (WY 2002) (table 7). Total-iron concentrations would be expected to be larger in response to suspension of particulate matter at the upstream site.

In the hypolimnion at site 7B, annual median total-iron concentrations also were relatively small and concentrations generally were similar between the No Action scenario and the each of the three other simulation scenarios (fig. 29). Overall, the differences in concentration from the No Action scenario were no more than 0.001 mg/L for any comparison (table 6). However, a seasonal analysis of total-iron concentrations in the hypolimnion at this site showed periods of increased concentrations (fig. 30). The seasonal periods occurred at similar times when anoxic conditions in the reservoir were observed

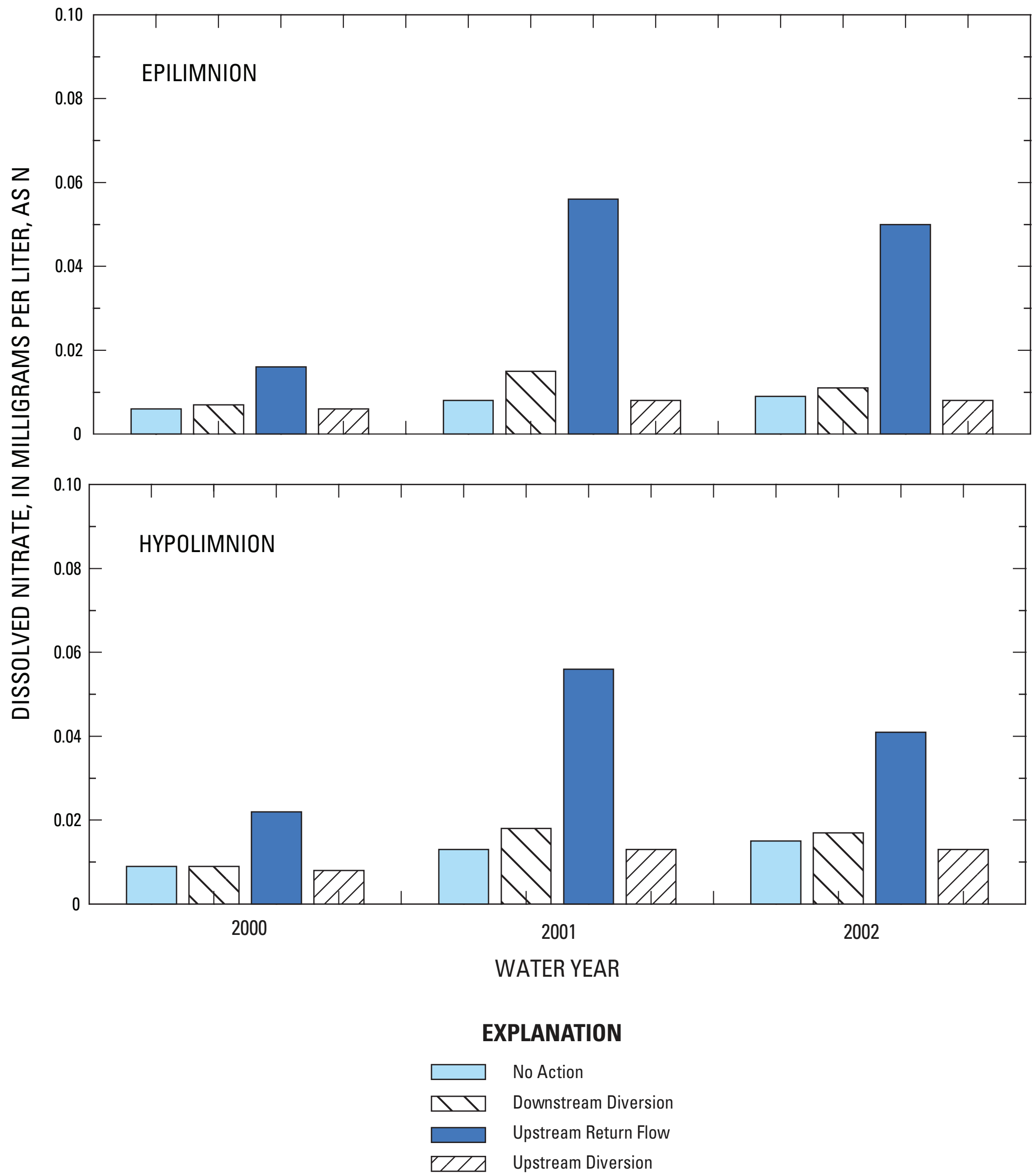

Figure 27. Annual median dissolved-nitrate concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

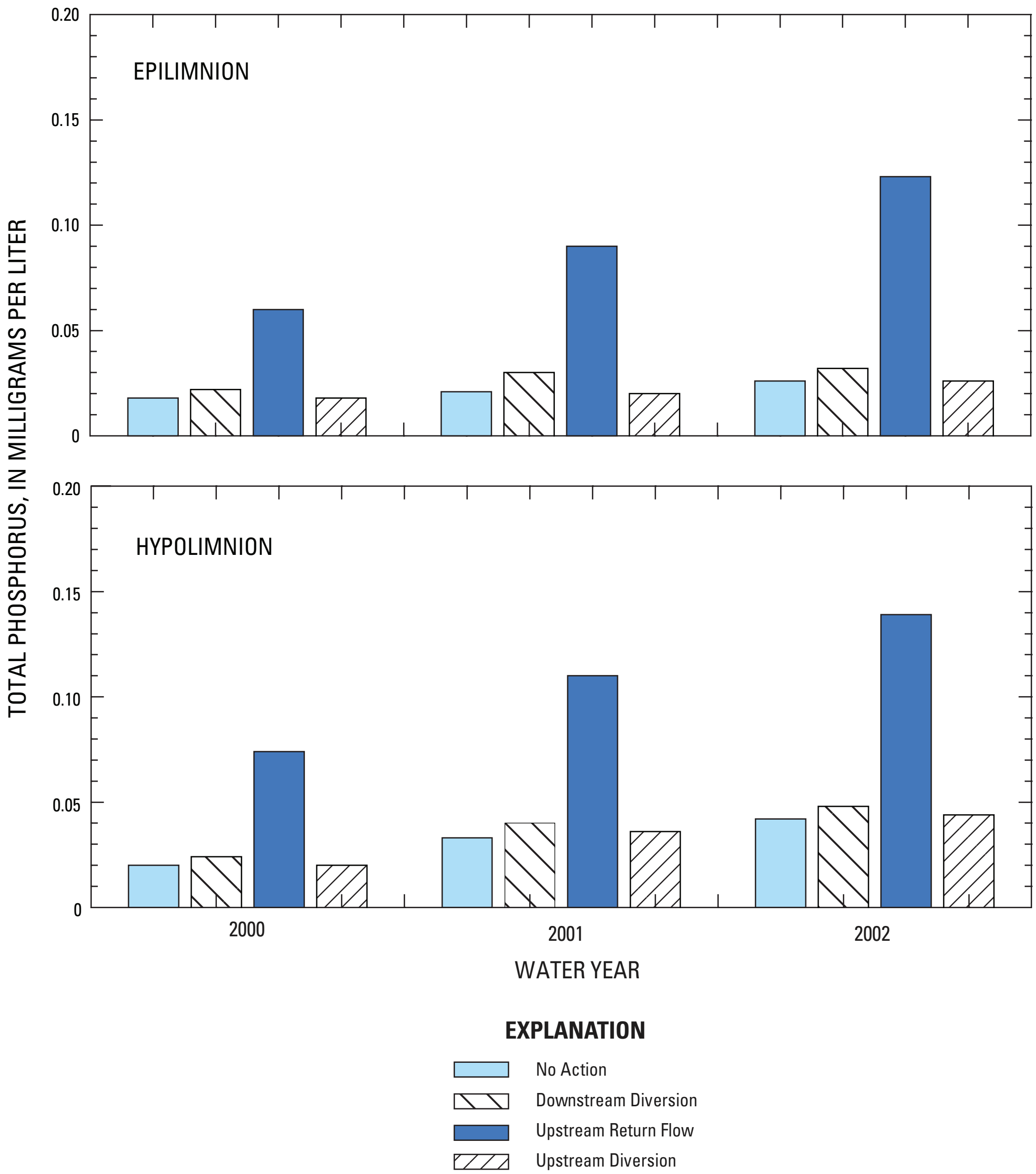

Figure 28. Annual median total-phosphorus concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

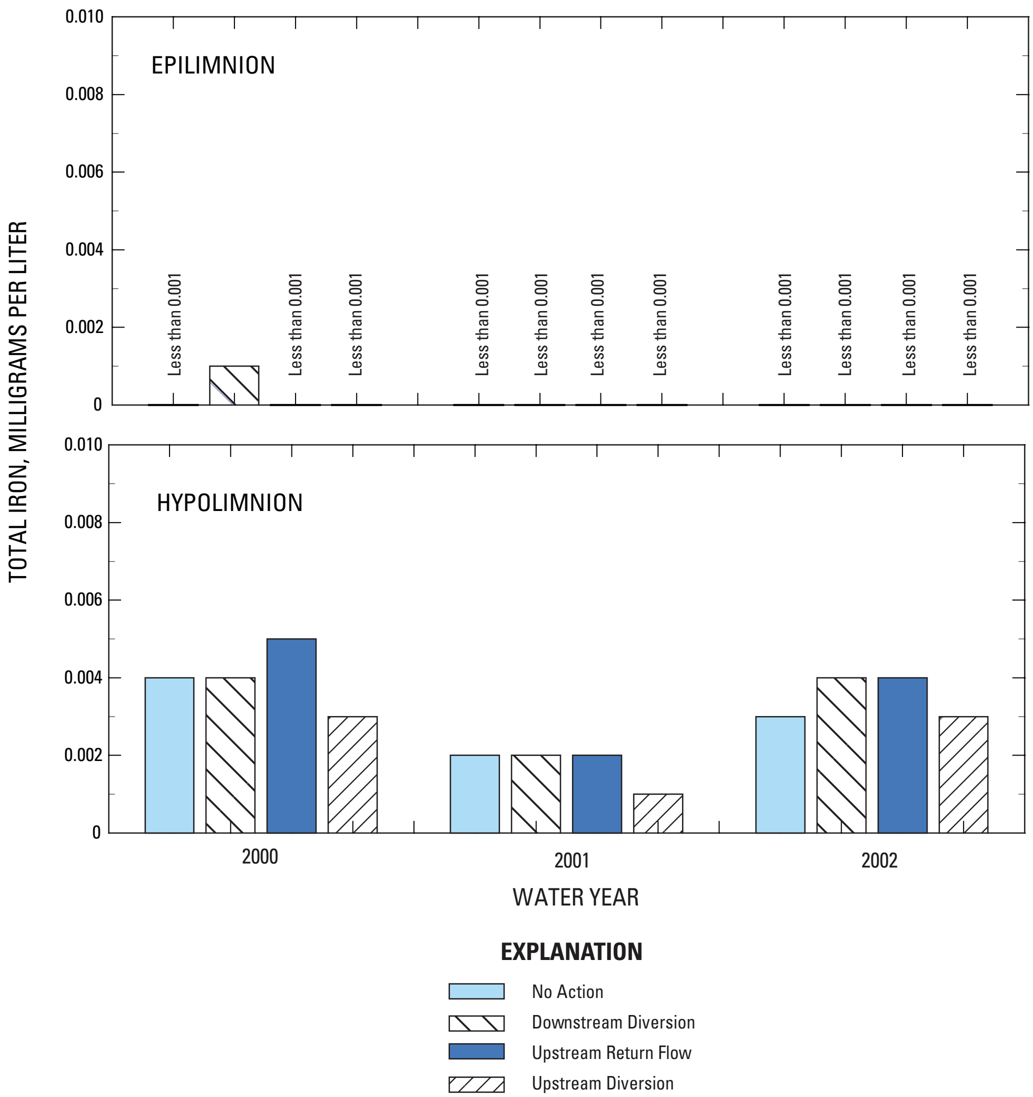

Figure 29. Annual median total-iron concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

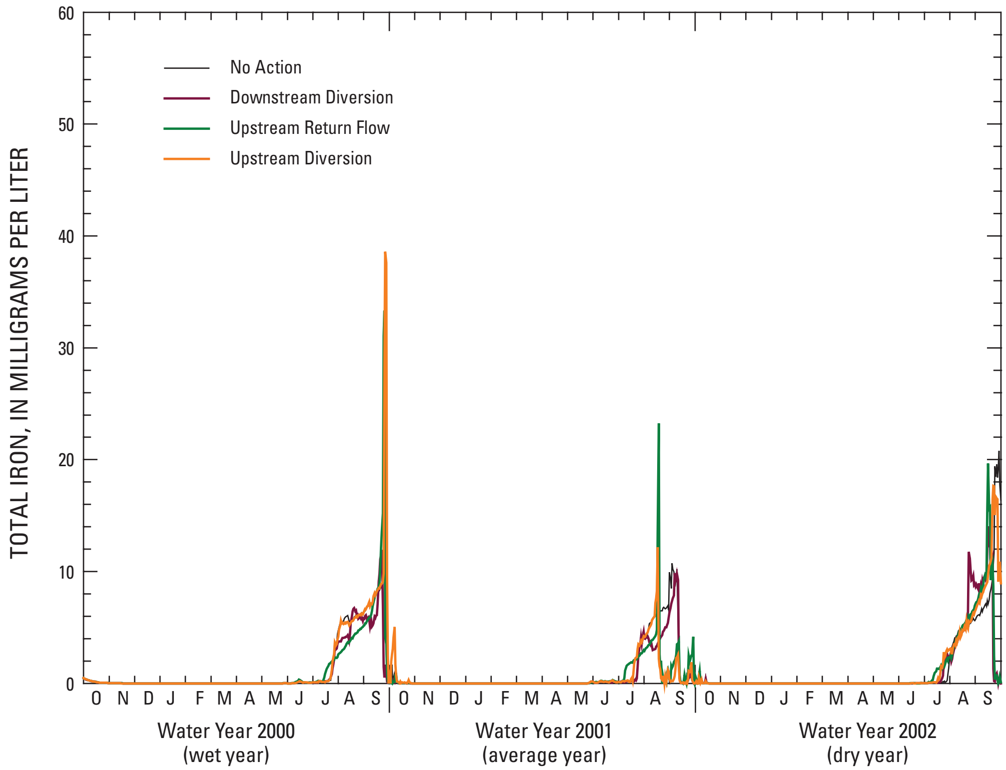

Figure 30. Comparison of total-iron concentrations in the hypolimnion at site 7B in Pueblo Reservoir for the No Action, Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios (direct-effects analyses).

(fig. 8). It is likely that iron was released from the reservoir bottom during these times. These relatively short episodes of large iron concentrations were reflected in the annual 85th percentile concentrations shown in table 8.

Chronic surface-water water-quality standards for total iron in Pueblo Reservoir are set at 1 mg/L when compared to the mean value (Colorado Department of Public Health and Environment, 2006). The impacts of iron on aquatic life uses are uncertain, and the benefit of iron as a water-quality standard is more an indicator of sediment loading (Colorado Department of Public Health and Environment, 2005). No calculated annual median value at sites 7B or 3B exceeded this standard value at any reservoir depth for any of the four simulation scenarios (tables 6 and 7). If simulated results were compared to the annual 85th percentile values, the chronic standard was not exceeded in the epilimnion (surface water) at sites 7B or 3B in any year. If compared to the simulated results in the hypolimnion, the chronic standard was exceeded for various scenarios (tables 8 and 9). Caution should be used when applying the simulated total-iron concentrations to water-quality standards since the absolute mean error reported for the calibrated Pueblo Reservoir model was 1.48 mg/L (Galloway and others, 2008).

Algal Groups and Chlorophyll *a*

The simulated distribution of algal populations was highly variable in Pueblo Reservoir from WY 2000 through WY 2002 (fig. 31). The largest algal biomass in Pueblo Reservoir generally occurred from May through September when blue-green and green algae were the dominant algal groups in the reservoir; blue-green algae increased sharply during the summer months. Diatoms and flagellates generally were the dominant groups from November through March. Generally, simulated algae concentrations in the epilimnion at sites 7B and 3B were similar for the No Action, Downstream Diversion, and Upstream Diversion scenarios and concentrations typically were less than 2 mg/L (fig. 31). Algae concentrations associated with the Upstream Return-Flow scenario were larger and could be 2 to 3 times larger than the other three scenarios.

Algae concentrations in the epilimnion at site 3B were more variable than in the epilimnion at site 7B but the general relation between the concentrations for the simulated scenarios remained similar (fig. 31). A slight shift in community structure from the No Action scenario appeared to occur in the

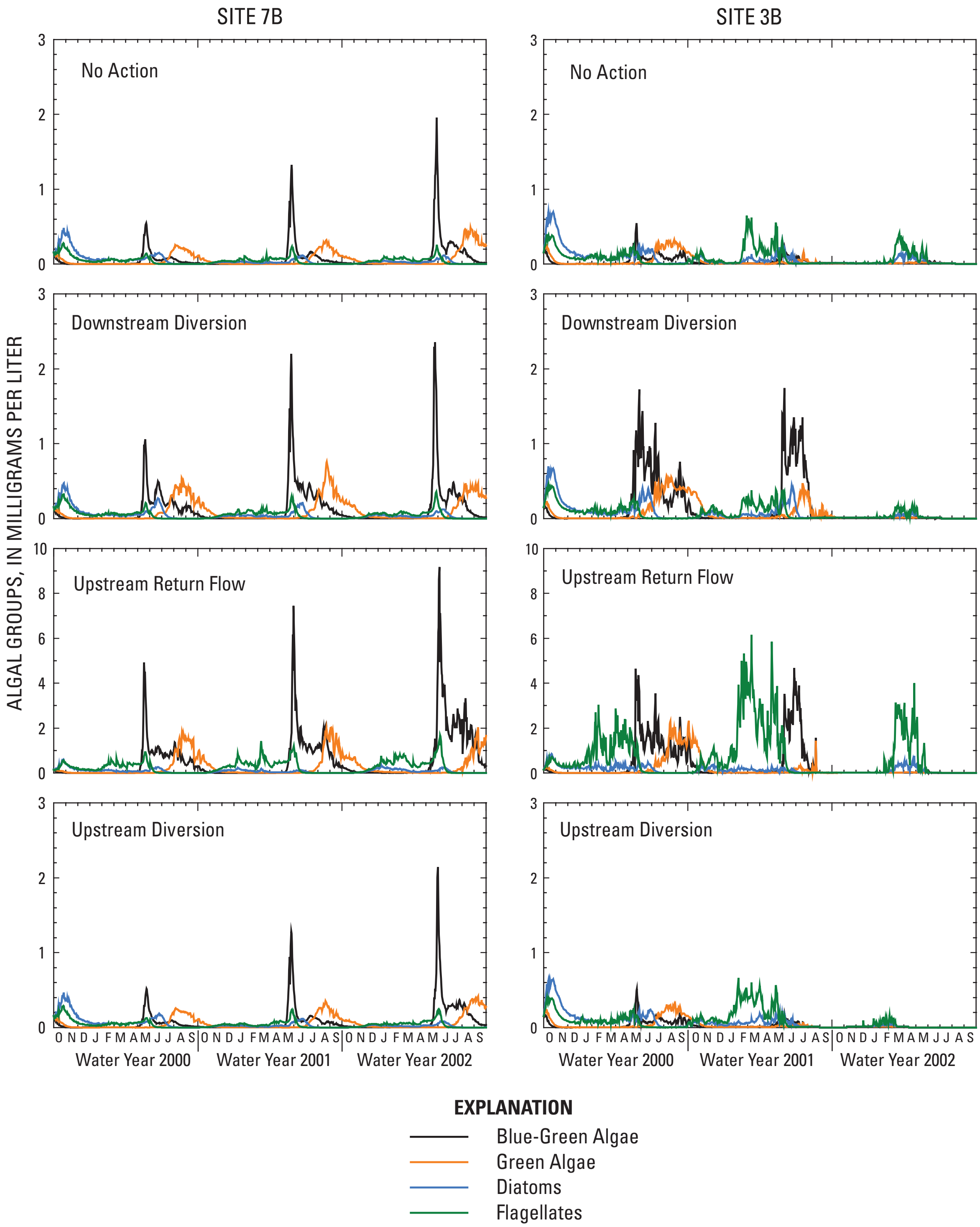

Figure 31. Relation between various algal groups in the epilimnion at sites 7B and 3B for the No Action, Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios (direct-effects analyses). (Note scales for y-axis of Upstream Return-Flow scenario are different from the other scenarios.)

Downstream Diversion scenario which showed an increase in blue-green algae growth similar to that observed at site 7B.

Harmful algal blooms in freshwater, particularly from blue-green algae, can occur anytime water use is impaired due to excessive accumulations of nutrients. Simulated algae concentrations associated with No Action, Downstream Diversion, Upstream Return-Flow, or Upstream Diversion scenarios would not be expected to pose a health issue or produce taste-and-odor problems in Pueblo Reservoir (Graham, 2006).

Chlorophyll *a* is the primary pigment in plants responsible for photosynthesis and can be used as a general indicator of primary productivity and the quantity of algae present in a water body. A discussion concerning the health effects of elevated chlorophyll *a* concentrations was presented earlier in this report in the 'Comparison of Existing Conditions and No Action scenario' section. Annual median chlorophyll *a* concentrations in the epilimnion at site 7B generally were similar between the No Action scenario and the Downstream Diversion scenario, and the No Action Scenario and the Upstream Diversion scenario (fig. 32). Specifically, the difference between the median chlorophyll *a* values for the No Action and Downstream Diversion scenarios ranged from 0.1 to 0.5 μg/L while the difference in median values for the No Action and Upstream Diversion scenarios ranged from 0 to 0.1 μg/L (table 6). Similar relations were observed in the hypolimnion but concentrations were consistently smaller than concentrations in the epilimnion.

Substantial differences in the annual median concentrations were observed between the No Action and Upstream Return-Flow scenarios in the epilimnion for all 3 simulated years. Specifically, the difference between the median values for the No Action and Upstream Return-Flow scenarios ranged from 1.7 to 2.7 μg/L; the percent differences ranged from 283 to 675 percent. Similar results also were observed when comparisons were made to the 85th percentile concentrations (tables 8 and 9).

Similar relations were observed in the epilimnion at site 3B (table 7). The maximum difference in the annual median concentrations (4.8 μg/L) occurred between the No Action and Upstream Return-Flow scenarios for WY 2001.

Summary and Conclusions

Pueblo Reservoir is one of southeastern Colorado's most valuable water resources. The 357,678 acre-feet reservoir provides irrigation, municipal, and industrial water to various entities throughout the region. The reservoir also provides flood control, recreational activities, sport fishing, and wildlife enhancement to the region. The population in the region has increased rapidly in the past 10 years and, as such, a regional water-delivery project has been proposed to provide a safe, reliable, and sustainable water supply through the foreseeable future (2046) for Colorado Springs, Fountain, Security, and Pueblo West. A substantial component of the proposed project, known as the Southern Delivery System (SDS), is a pipeline capable of conveying 78 million gallons of raw water per day (240 acre-feet) from Pueblo Reservoir. As proposed, the SDS would require contracts with the Bureau of Reclamation (Reclamation) to store and convey water in the federally owned Pueblo Reservoir facility. Reclamation initiated an Environmental Impact Statement (EIS) in response to the proposed project. Seven reasonable alternatives were selected for evaluation as part of the EIS. Additionally, Pueblo West Utilities is proceeding with a design to discharge treated water into Pueblo Reservoir near the dam; these plans are fully independent of the SDS project.

Reclamation is working to meet its goal to issue a Final EIS on the SDS project. Discussions with Reclamation and the U.S. Geological Survey (USGS) concerning the need to accurately simulate hydrodynamics and water quality in Pueblo Reservoir led to a cooperative agreement to simulate the hydrodynamics and water quality of Pueblo Reservoir. This work has been completed. Additionally, there was a need to make comparisons of simulated hydrodynamics and water quality for projected demands associated with the various EIS alternatives and plans by Pueblo West to discharge treated water into the reservoir.

This report compares simulated hydrodynamic and water quality for projected demands in Pueblo Reservoir resulting from changes in inflow and water quality entering the reservoir, and from changes to withdrawals from the reservoir as projected for the year 2046. Four of the seven EIS alternatives were selected for scenario modeling using the U.S. Army Corps of Engineers CE–QUAL–W2 model. Specifically, the four simulation scenarios are the No Action scenario (EIS Alternative 1), the Downstream Diversion scenario (EIS Alternative 2), the Upstream Return-Flow scenario (EIS Alternative 4) and the Upstream Diversion scenario (EIS Alternative 7). Comparisons of the simulation results were done to assess if substantial differences were observed between selected scenarios. Each of the scenarios was simulated for three contiguous years representing a wet (water year 2000), average (water year 2001), and dry (water year 2002) annual hydrologic cycle. Streamflow, diversion, reservoir storage, and return-flow quantity and quality data for projected demands in 2046 were provided to the USGS. Additionally, each of the selected model scenarios was evaluated for differences in direct effects and cumulative effects on a particular scenario. Direct effects are intended to isolate the future effects of the scenarios. Cumulative effects are intended to evaluate the effects of the scenarios in conjunction with all reasonably foreseeable future activities in the study area. The primary difference between the two sets of simulations was that the direct-effects simulations includes existing levels of demand by nonparticipants in the SDS project, while the cumulative-effects simulations include projected demands in 2046 by the nonparticipants in the SDS project. Finally, scenario simulations were done that represented existing conditions in Pueblo Reservoir during water years (WY) 2000 through 2002. The results of this simulation effort (Existing Conditions scenario) were compared to the

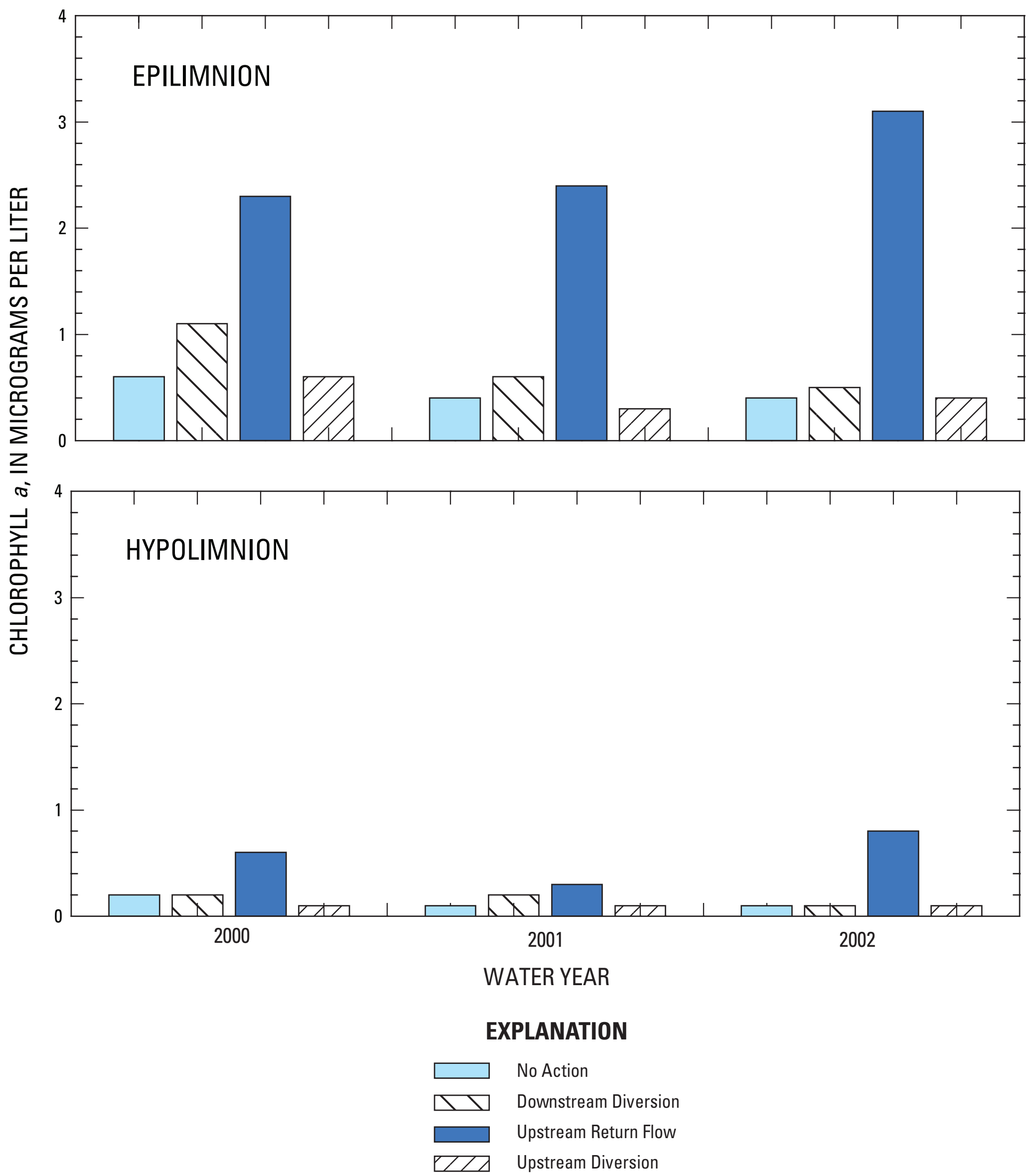

Figure 32. Annual median chlorophyll *a* concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Downstream Diversion, Upstream Return-Flow and Upstream Diversion scenarios (direct-effects analyses).

No Action scenario to assess changes in water quality from current demands (WY 2000 through WY 2002) to projected demands in 2046.

Various tools were used to simulate results for comparison between the different simulation scenarios. Reservoir simulations were done using a two-dimensional water-quality model. Lake hydrodynamics, water temperature, dissolved oxygen, dissolved solids, dissolved ammonia, dissolved nitrate, total phosphorus, algal biomass (chlorophyll *a*), and total iron were simulated. The model accurately captured the most important seasonal and spatial influences on the reservoir water quality. Input data to the reservoir model that represented the projected demands in 2046 were modeled externally and provided to the USGS by Reclamation's consultant. Nutrient decay along the riverine reach upstream from Pueblo Reservoir was simulated to account for the degradation and assimilation of selected constituents in the Arkansas River.

Two site locations were selected for comparison in this report. Results of scenario simulations at site 3B were characteristic of a riverine environment in the reservoir while results at site 7B (near the dam) were characteristic of the main body of the reservoir. Simulated results for the epilimnion and hypolimnion at these two sites were evaluated and compared. The results in the hypolimnion at site 7B were indicative of the quality of the water leaving the reservoir.

A general comparison of results for site 7B (near the dam) between all simulation scenarios was conducted. Similarities and differences between the direct-effects and cumulative-effects analyses also were described. Simulated water-surface elevations were variable between simulation scenarios, between the different effects analyses, and between the simulated hydrologic conditions. Generally, there was a substantial temporal decrease in water-surface elevations. Water-surface elevations associated with the cumulative-effects analyses were less than the water-surface elevations for the corresponding direct-effects analyses, and the differences between the effects analyses, for any scenario, increased temporally from wet to dry year. Simulated water-surface elevations for the direct-effects analysis of any simulation scenario were similar to the water-surface elevations for the Existing Conditions scenario. One of the primary differentiators between scenario results was reservoir storage.

Water temperatures in the reservoir stratify during the summer prior to mixing in September. Results from the various simulation scenarios showed a similar pattern. In general, the reservoir was isothermal from December to April. Thermal stratification was apparent by May and persisted into August when maximum temperatures were observed. In general, water temperatures were similar for all the simulation scenarios for the 3-year simulation period, and there were no substantial changes in the annual thermal pattern between the 3 simulated years.

Stratification of dissolved-oxygen occurred in Pueblo Reservoir near the dam and anoxic conditions typically were observed during the summer months before the reservoir turned over and mixed. It did not appear that the anoxic period was substantially longer for any particular simulation scenario. There appeared to be no substantial change in the general seasonal pattern in the epilimnion and hypolimnion between the wet, average, and dry years for the various simulation scenarios. Dissolved-oxygen concentrations in the epilimnion for all the simulation scenarios, with the exception of the Upstream Return-Flow scenario, were similar to the Existing Conditions scenario. Dissolved-oxygen concentrations in the hypolimnion generally were similar for all the simulation scenarios.

Simulated dissolved-solids concentrations in Pueblo Reservoir provided a good illustration of the general patterns observed between the various simulation scenarios and between the two effects analyses. Typically, the simulated concentrations of the Existing Conditions scenario were the smallest of the simulation scenarios. This scenario represented the conditions for WY 2000 through WY 2002 with no changes to water quality entering the reservoir and no input from a proposed discharge of treated water from Pueblo West. Concentrations for the No Action and Upstream Diversion scenarios were slightly larger than concentrations for the Existing Conditions scenario but similar among the two scenarios themselves; the two scenarios would be categorized as upstream diversion alternatives. In general, there appeared to be only limited differences between the direct- and cumulative-effects analyses simulations for each of these two scenarios. In contrast, simulated results for the Upstream Return-Flow scenario were consistently larger than all the other simulation scenarios, and the difference between the simulated results increased temporally.

Ammonia concentrations are inherently linked to other simulated constituents such as water temperature, dissolved-oxygen concentrations, and algae concentrations. Simulated dissolved-ammonia concentrations provided another illustration of the general patterns observed between the various simulation scenarios and between the direct- and cumulative-effects analyses. In general, the simulated concentrations of the Existing Conditions scenario were the smallest of the simulation scenarios. The No Action and Upstream Diversion scenarios were only slightly larger and the results for the Downstream Diversion scenario were only slightly larger still. In contrast, simulated ammonia concentrations were consistently larger for the Upstream Return-Flow scenario than for all the other simulation scenarios particularly during the summer months (June through August). The overall differences in the summer months increased temporally from about 0.05 to 0.15 milligrams per liter from WY 2000 through WY 2002. The increased concentrations in ammonia observed for the Upstream Return-Flow scenario can be related to increased concentrations of dissolved ammonia associated with the return-flow pipeline upstream from Pueblo Reservoir.

In general, results for the direct- and cumulative-effects analyses indicated that the results were similar for most of the scenarios. As such, comparisons between the Existing Conditions and the No Action scenarios focused on the results from the direct-effects analysis. Comparisons of the results between the Existing Conditions and the No Action scenarios for water-surface elevations, water temperature, dissolved-oxygen, dissolved-solids, total-iron, and chlorophyll *a* concentrations indicated that the annual median values generally were similar for all 3 simulated years. Additionally, the annual median dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations in the epilimnion of Pueblo Reservoir were similar for the Existing Conditions and the No Action scenarios. However, substantial differences in concentration for these three nutrients were observed in the hypolimnion at site 7B for all 3 simulated years.

The simulated distribution of algal populations was highly variable in Pueblo Reservoir. The largest algal biomass generally occurred from May through September when blue-green and green algae were the dominant algal groups. Seasonal differences in algal communities were the result of nutrient availability and differences in water temperature. Generally, algae concentrations were similar for the Existing Conditions and the No Action scenarios at site 7B for the simulated period; concentrations were less than 0.5 milligrams per liter in the epilimnion and hypolimnion.

Comparisons between the No Action scenario and each of the other simulation scenarios (Downstream Diversion, Upstream Return-Flow, and Upstream Diversion) also focused on the results from the direct-effects analysis. Comparisons were made to describe changes in the annual median, 85th percentile, or 15th percentile concentration between the No Action scenario and each of these three simulation scenarios.

Simulated water-surface elevations in Pueblo Reservoir generally were similar between the simulation scenarios. There was a substantial temporal decrease in water-surface elevations from WY 2000 through WY 2002. Comparisons of the results for water temperature between the No Action scenario and each of the other three simulation scenarios indicated that the simulated scenarios generally provided similar results. Seasonal periods of anoxic conditions in Pueblo Reservoir have been documented. The 15th percentile dissolved-oxygen concentration was 0.2 milligrams per liter or less for all of the simulation scenarios in the hypolimnion at site 7B. Comparisons of simulated dissolved-oxygen concentrations between the No Action scenario and the three other scenarios indicated that the annual median values in the epilimnion and hypolimnion at site 7B generally were similar to results for the No Action scenario. Comparisons of simulated dissolved-solids concentrations indicated that the annual medians were relatively similar between the No Action scenario and the Downstream Diversion and Upstream Diversion scenarios in the epilimnion and hypolimnion at site 7B. Simulated results for the Upstream Return-Flow scenario were consistently larger than the No Action scenario particularly during WY 2001 and WY 2002 as drier conditions prevailed in the simulations. The annual median dissolved-ammonia concentrations in the epilimnion of Pueblo Reservoir at site 7B generally were similar between the No Action scenario and either the Downstream Diversion, Upstream Return-Flow, or Upstream Diversion scenarios. In the hypolimnion at site 7B, concentrations generally were similar between the No Action scenario and either the Downstream Diversion or Upstream Diversion scenarios. Percent differences from the No Action scenario did not exceed 20 percent for these comparisons. Substantial differences in concentration, however, were observed between the No Action scenario and the Upstream Return-Flow scenario for all 3 simulated years at this location. The annual median dissolved-nitrate and total-phosphorus concentrations in the epilimnion of Pueblo Reservoir at site 7B generally were similar between the No Action scenario and either the Downstream Diversion or Upstream Diversion scenarios. In the epilimnion and hypolimnion, substantial differences were observed between the No Action and Upstream Return-Flow scenarios at site 7B for all 3 simulated years. Simulated results for the Upstream Return-Flow scenario were consistently larger than the No Action scenario. The annual median total-iron concentrations were small in the epilimnion at site 7B for the No Action scenario and the three other simulation scenarios. Larger concentrations of total iron were observed at site 3B than at site 7B in response to suspension of particulate matter at the upstream site. In the hypolimnion at site 7B, annual median total-iron concentrations also were relatively small and concentrations generally were similar between the No Action scenario and the each of the three other simulation scenarios. A seasonal analysis of total-iron in the hypolimnion at site 7B showed periods of increased concentration at similar times when anoxic conditions in the reservoir were observed. It is likely that iron was released from the reservoir bottom during these times. Generally, simulated algae concentrations in the epilimnion at sites 7B and 3B were similar for the No Action, Downstream Diversion, and Upstream Diversion scenarios and concentrations typically were less than 2 milligrams per liter. Algae concentrations associated with the Upstream Return-Flow scenario could be 2 to 3 times larger than the other three scenarios. Additionally, substantial differences in the annual median chlorophyll *a* concentrations were observed between the No Action and Upstream Return-Flow scenarios in the epilimnion for all 3 simulated years.

In conclusion, the four simulation scenarios represented the seven EIS Alternatives as defined by the Bureau of Reclamation. Comparisons between the direct- and cumulative-effects analyses indicated that there were not large differences in the results between most of the simulation scenarios and, as such, the focus of this report was on results for the direct-effects analysis. Additionally, the differences between simulation results generally were small for the Existing Conditions scenario (WY 2000 through WY 2002) and the No Action scenario (projected demands in 2046). Finally, comparisons of the simulation results for the No Action scenario to the remaining simulation scenarios (Downstream Diversion, Upstream Return-Flow, and Upstream Diversion) indicated that, in general, the Upstream Diversion scenario was the most similar to the No Action scenario. Conversely, simulated concentrations associated with the Upstream Return-Flow scenario typically were substantially larger than the concentrations for the No Action scenario.

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Appendixes

Appendix 1. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (cumulative-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	Existing Conditions	100	14.7	7.8	278	0.003	0.006	0.014	<0.001	0.5
	No Action	100	14.8	7.9	292	.004	.006	.019	.001	.6
	Percent change		0.7%	1.3%	5.0%	33%	0%	36%	NA	20%
2001	Existing Conditions	100	13.7	8.2	218	.002	.008	.015	.001	.3
	No Action	100	14.0	8.5	244	.002	.003	.023	.001	.6
	Percent change		2.2%	3.7%	12%	0%	-62%	53%	0%	100%
2002	Existing Conditions	100	14.0	8.4	236	.003	.007	.018	<.001	.4
	No Action	100	13.8	9.0	284	.004	.002	.031	.001	1.3
	Percent change		-1.4%	7.1%	20%	33%	-71%	72%	NA	225%
					Hypolimnion					
2000	Existing Conditions	100	10.6	7.5	280	.009	.005	.015	.004	.1
	No Action	100	10.6	7.5	293	.013	.008	.022	.004	.2
	Percent change		0%	0%	4.6%	44%	60%	47%	0%	100%
2001	Existing Conditions	100	10.6	7.6	222	.007	.010	.016	.003	.1
	No Action	100	9.9	7.6	258	.017	.018	.033	.005	.1
	Percent change		-6.6%	0%	16%	143%	80%	106%	67%	0%
2002	Existing Conditions	100	10.3	7.8	236	.006	.005	.018	.003	.1
	No Action	100	12.4	7.7	291	.016	.012	.045	.003	.5
	Percent change		20%	-1.3%	23%	167%	140%	150%	0%	400%

Appendix 2. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (cumulative-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	Existing Conditions	100	14.0	7.9	285	0.001	0.008	0.016	0.013	0.9
2000	No Action	100	12.7	8.0	297	.002	.015	.018	.015	.8
	Percent change		-9.3%	1.3%	4.2%	100%	87%	12%	15%	-11%
	Existing Conditions	90	10.0	8.9	238	.005	.065	.019	.022	.3
2001	No Action	67	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	Existing Conditions	51	--	--	--	--	--	--	--	--
2002	No Action	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
	Existing Conditions	100	12.1	7.8	282	.002	.015	.016	.028	.6
2000	No Action	88	10.7	8.3	296	.002	.015	.019	.026	.6
	Percent change		-12%	6.4%	5.0%	0%	0%	19%	-7.1%	0%
	Existing Conditions	85	8.3	9.4	240	.005	.059	.019	.043	.3
2001	No Action	34	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	Existing Conditions	28	--	--	--	--	--	--	--	--
2002	No Action	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

Appendix 3. Percent change between annual 85th percentile values for selected constituents and the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (cumulative-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	Existing Conditions	100	25.3	5.7	299	0.006	0.017	0.017	0.007	1.1
2000	No Action	100	25.2	5.7	303	.008	.026	.019	.005	1.7
	Percent change		-.4%	0%	1.3%	33%	53%	12%	-29%	54%
	Existing Conditions	100	24.5	5.0	225	.007	.022	.016	.005	.9
2001	No Action	100	24.2	5.6	256	.007	.018	.025	.010	1.5
	Percent change		-1.2%	12%	14%	0%	-18%	56%	100%	67%
	Existing Conditions	100	24.7	5.1	271	.010	.023	.019	.002	1.0
2002	No Action	100	24.9	6.4	316	.021	.040	.035	.002	2.8
	Percent change		.8%	25%	17%	110%	74%	84%	0%	180%
					Hypolimnion					
	Existing Conditions	100	18.5	<.1	300	.014	.010	.019	5.48	.8
2000	No Action	100	18.9	<.1	306	.028	.027	.045	3.88	.8
	Percent change		2.2%	NA	2.0%	100%	170%	137%	-29%	0%
	Existing Conditions	100	20.9	.7	230	.011	.015	.018	.473	.2
2001	No Action	100	21.4	1.8	272	.048	.032	.058	.336	.4
	Percent change		2.4%	157%	18%	336%	113%	222%	-29%	100%
	Existing Conditions	100	19.3	<.1	253	.021	.009	.025	1.42	.3
2002	No Action	100	22.4	3.0	334	.040	.022	.066	.015	1.7
	Percent change		16%	NA	32%	90%	144%	164%	-99%	467%

Appendix 4. Percent change between annual 85th percentile values for selected constituents and the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for the Existing Conditions scenario (water years 2000 through 2002) as compared to the No Action (cumulative-effects analysis) scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	Existing Conditions	100	23.5	6.1	298	0.002	0.034	0.017	0.064	1.8
2000	No Action	100	21.4	5.6	306	.005	.068	.020	.328	2.0
	Percent change		-8.9%	-8.2%	2.7%	150%	100%	12%	412%	11%
	Existing Conditions	90	21.3	5.6	256	.015	.096	.022	1.40	1.1
2001	No Action	67	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	Existing Conditions	51	--	--	--	--	--	--	--	--
2002	No Action	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
	Existing Conditions	100	22.8	4.8	304	.005	.036	.018	.502	1.4
2000	No Action	88	20.8	5.0	308	.007	.047	.020	.652	1.6
	Percent change		-8.8%	4.2%	1.3%	40%	31%	11%	30%	14%
	Existing Conditions	85	20.0	5.4	252	.014	.090	.022	1.41	.9
2001	No Action	34	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	Existing Conditions	28	--	--	--	--	--	--	--	--
2002	No Action	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

Appendix 5. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	14.8	7.9	292	0.004	0.006	0.019	0.001	0.6
	Downstream Diversion	100	14.7	8.2	269	.005	.007	.022	.001	1.0
	Percent change		-.7%	3.8%	-7.9%	25%	17%	16%	0%	67%
	No Action	100	14.8	7.9	292	.004	.006	.019	.001	.6
2000	Upstream Return Flow	100	14.6	8.8	308	.003	.014	.060	<.001	2.3
	Percent change		-1.4%	11%	5.5%	-25%	133%	216%	NA	283%
	No Action	100	14.8	7.9	292	.004	.006	.019	.001	.6
	Upstream Diversion	100	14.7	8.0	286	.004	.006	.018	<.001	.6
	Percent change		-.7%	1.3%	-2.1%	0%	0%	-5.3%	NA	0%
					Hypolimnion					
	No Action	100	10.6	7.5	293	.013	.008	.022	.004	.2
	Downstream Diversion	100	10.3	7.6	270	.013	.009	.024	.004	.2
	Percent change		-2.8%	1.3%	-7.8%	0%	12%	9.1%	0%	0%
	No Action	100	10.6	7.5	293	.013	.008	.022	.004	.2
2000	Upstream Return Flow	100	10.3	7.7	311	.036	.022	.074	.005	.6
	Percent change		-2.8%	2.7%	6.1%	177%	175%	236%	25%	200%
	No Action	100	10.6	7.5	293	.013	.008	.022	.004	.2
	Upstream Diversion	100	10.5	7.5	287	.013	.008	.020	.004	.2
	Percent change		-.9%	0%	-2.0%	0%	0%	-9.1%	0%	0%

Appendix 5. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	14.0	8.5	244	0.002	0.003	0.023	0.001	0.6
	Downstream Diversion	100	14.5	8.5	246	.006	.010	.030	<.001	.6
	Percent change		3.6%	0%	.8%	200%	233%	30%	NA	0%
	No Action	100	14.0	8.5	244	.002	.003	.023	.001	.6
2001	Upstream Return Flow	100	13.8	9.2	312	.010	.052	.098	<.001	3.2
	Percent change		-1.4%	8.2%	28%	400%	1,633%	326%	NA	433%
	No Action	100	14.0	8.5	244	.002	.003	.023	.001	.6
	Upstream Diversion	100	14.5	8.0	237	.005	.008	.021	<.001	.4
	Percent change		3.6%	-5.9%	-2.9%	150%	167%	-8.7%	NA	-33%
					Hypolimnion					
	No Action	100	9.9	7.6	258	.017	.018	.033	.005	.1
	Downstream Diversion	100	9.5	7.6	255	.024	.023	.045	.003	.1
	Percent change		-4.0%	0%	-1.2%	41%	28%	36%	-40%	0%
	No Action	100	9.9	7.6	258	.017	.018	.033	.005	.1
2001	Upstream Return Flow	100	10.4	7.1	323	.050	.064	.109	.003	.4
	Percent change		5.1%	-6.6%	25%	194%	256%	230%	-40%	300%
	No Action	100	9.9	7.6	258	.017	.018	.033	.005	.1
	Upstream Diversion	100	9.9	7.6	247	.017	.015	.032	.001	.1
	Percent change		0%	0%	-4.3%	0%	-17%	-3.0%	-80%	0%

Appendix 5. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 7B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	13.8	9.0	284	0.004	0.002	0.031	0.001	1.3
	Downstream Diversion	100	14.1	8.9	278	.006	.008	.034	.001	.7
	Percent change		2.2%	-1.1%	-2.1%	50%	300%	9.7%	0%	-46%
	No Action	100	13.8	9.0	284	.004	.002	.031	.001	1.3
2002	Upstream Return Flow	100	13.9	9.5	366	.010	.040	.127	<.001	3.7
	Percent change		.7%	5.6%	29%	150%	1,900%	310%	NA	185%
	No Action	100	13.8	9.0	284	.004	.002	.031	.001	1.3
	Upstream Diversion	100	14.1	8.7	255	.004	.003	.028	.001	.5
	Percent change		2.2%	-3.3%	-10%	0%	50%	-9.7%	0%	-62%
					Hypolimnion					
	No Action	100	12.4	7.7	291	.016	.012	.045	.003	.5
	Downstream Diversion	100	11.6	7.3	282	.020	.015	.050	.005	.3
	Percent change		-6.5%	-5.2%	-3.1%	25%	25%	11%	67%	-40%
	No Action	100	12.4	7.7	291	.016	.012	.045	.003	.5
2002	Upstream Return Flow	100	11.1	7.3	373	.052	.046	.149	.003	1.0
	Percent change		10%	-5.2%	28%	225%	283%	231%	0%	100%
	No Action	100	12.4	7.7	291	.016	.012	.045	.003	.5
	Upstream Diversion	100	11.9	7.3	258	.018	.010	.044	.002	.2
	Percent change		-4.0%	-5.2%	-11%	13%	-17%	-2.2%	-33%	-60%

Appendix 6. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2000	No Action	100	12.7	8.0	297	0.002	0.015	0.018	0.015	.8
	Downstream Diversion	100	14.1	8.1	271	.003	.006	.025	.015	1.3
	Percent change		11%	1.3%	-8.8%	50%	-60%	39%	0%	62%
	No Action	100	12.7	8.0	297	.002	.015	.018	.015	.8
	Upstream Return Flow	100	14.0	9.0	311	<.001	.037	.069	.011	5.7
	Percent change		10%	12%	4.7%	NA	147%	283%	-27%	612%
	No Action	100	12.7	8.0	297	.002	.015	.018	.015	.8
	Upstream Diversion	100	14.1	7.9	289	.002	.006	.018	.013	.9
	Percent change		11%	-1.3%	-2.7%	0%	-60%	0%	-13%	12%
					Hypolimnion					
2000	No Action	88	10.7	8.3	296	.002	.015	.019	.026	.6
	Downstream Diversion	100	12.1	7.9	272	.006	.009	.024	.031	1.0
	Percent change		13%	-4.8%	-8.1%	200%	-40%	26%	19%	67%
	No Action	88	10.7	8.3	296	.002	.015	.019	.026	.6
	Upstream Return Flow	100	12.1	7.9	265	.005	.008	.024	.032	1.0
	Percent change		13%	-4.8%	-10%	150%	-47%	26%	23%	67%
	No Action	88	10.7	8.3	296	.002	.015	.019	.026	.6
	Upstream Diversion	100	12.2	7.8	289	.003	.008	.018	.027	.7
	Percent change		14%	-6.0%	-2.4%	50%	-47%	-5.2%	3.8%	17%

Appendix 6. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2001	No Action	67	--	--	--	--	--	--	--	--
	Downstream Diversion	89	9.3	9.1	266	0.028	0.031	0.034	0.068	0.5
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	67	--	--	--	--	--	--	--	--
	Upstream Return Flow	90	9.0	9.3	329	.010	.317	.138	.038	2.4
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	67	--	--	--	--	--	--	--	--
	Upstream Diversion	86	9.4	9.3	244	.007	.072	.022	.042	.4
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
2001	No Action	34	--	--	--	--	--	--	--	--
	Downstream Diversion	85	8.0	9.3	268	.031	.029	.034	.094	.4
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	34	--	--	--	--	--	--	--	--
	Upstream Return Flow	85	10.5	8.2	262	.020	.025	.033	.054	.6
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	34	--	--	--	--	--	--	--	--
	Upstream Diversion	80	7.9	9.5	245	.006	.071	.022	.054	.3
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

Appendix 6. Percent change between annual median values for selected constituents in the epilimnion and hypolimnion at site 3B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2002	No Action	0	--	--	--	--	--	--	--	--
	Downstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Return Flow	32	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
2002	No Action	0	--	--	--	--	--	--	--	--
	Downstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Return Flow	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

Appendix 7. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	25.2	5.7	303	0.008	0.026	0.019	0.005	1.7
	Downstream Diversion	100	25.3	6.2	286	.013	.031	.026	.008	2.2
	Percent change		0.4%	8.8%	-5.6%	62%	19%	37%	60%	29%
	No Action	100	25.2	5.7	303	.008	.026	.019	.005	1.7
2000	Upstream Return Flow	100	25.3	7.2	313	.052	.156	.073	.006	6.6
	Percent change		.4%	26%	3.3%	550%	500%	284%	60%	288%
	No Action	100	25.2	5.7	303	.008	.026	.019	.005	1.7
	Upstream Diversion	100	25.0	5.7	294	.007	.018	.018	.006	1.5
	Percent change		-0.8%	0%	-3.0%	-12%	-31%	-5.3%	20%	-12%
					Hypolimnion					
	No Action	100	18.9	<.1	306	.028	.027	.045	3.88	.8
	Downstream Diversion	100	18.0	<.1	286	.036	.024	.063	4.98	.8
	Percent change		-4.8%	NA	-6.5%	29%	-11%	18%	28%	0%
	No Action	100	18.9	<.1	306	.028	.027	.045	3.88	.8
2000	Upstream Return Flow	100	18.0	<.1	315	.068	.049	.098	3.14	1.6
	Percent change		-4.8%	NA	2.9%	143%	82%	118%	-19%	100%
	No Action	100	18.9	<.1	306	.028	.027	.045	3.88	.8
	Upstream Diversion	100	18.5	<.1	296	.027	.025	.046	3.76	.8
	Percent change		-2.1%	NA	-3.3%	-3.6%	-7.4%	2.2%	-3.0%	0%

Appendix 7. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	24.2	5.6	256	0.007	0.018	0.025	0.010	1.5
	Downstream Diversion	100	24.7	5.3	254	.019	.034	.031	.003	2.5
	Percent change		2.1%	-5.4%	-.8%	171%	89%	24%	-70%	67%
	No Action	100	24.2	5.6	256	.007	.018	.025	.010	1.5
2001	Upstream Return Flow	100	23.8	6.3	322	.077	.197	.113	.002	6.8
	Percent change		-1.7%	12%	26%	1,000%	994%	328%	-80%	353%
	No Action	100	24.2	5.6	256	.007	.018	.025	.010	1.5
	Upstream Diversion	100	24.0	5.1	247	.008	.021	.025	.003	1.1
	Percent change		-.8%	-8.9%	-3.5%	14%	17%	0%	-70%	-27%
					Hypolimnion					
	No Action	100	21.4	1.8	272	.048	.032	.058	.336	.4
	Downstream Diversion	100	20.5	.7	277	.054	.040	.069	.290	.3
	Percent change		-4.2%	-61%	1.8%	12%	25%	19%	-14%	-25%
	No Action	100	21.4	1.8	272	.048	.032	.058	.336	.4
2001	Upstream Return Flow	100	20.3	.6	342	.082	.197	.149	.366	1.2
	Percent change		-5.1%	-67	26%	71%	516%	157%	8.9%	200%
	No Action	100	21.4	1.8	272	.048	.032	.058	.336	.4
	Upstream Diversion	100	20.7	1.0	252	.027	.028	.046	.250	.2
	Percent change		-3.3%	-44%	-7.4%	-44%	-12%	-21%	-26%	-50%

Appendix 7. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 7B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NA, not applicable; <, less than]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2002	No Action	100	24.9	6.4	316	0.021	0.040	0.035	0.002	2.8
	Downstream Diversion	100	24.8	5.6	340	.034	.067	.037	.003	1.7
	Percent change		-.4%	-12%	7.6%	62%	68%	5.7%	50%	-39%
	No Action	100	24.9	6.4	316	.021	.040	.035	.002	2.8
	Upstream Return Flow	100	24.5	7.1	463	.184	.422	.138	.002	9.7
	Percent change		-1.6%	11%	46%	776%	955%	294%	0%	246%
	No Action	100	24.9	6.4	316	.021	.040	.035	.002	2.8
	Upstream Diversion	100	24.5	5.8	298	.024	.048	.031	.002	1.8
	Percent change		-1.6%	-9.4%	-5.7%	14%	20%	-11%	0%	-36%
					Hypolimnion					
2002	No Action	100	22.4	3.0	334	.040	.022	.066	.015	1.7
	Downstream Diversion	100	21.2	.6	333	.047	.031	.074	.123	.6
	Percent change		-5.4%	-80%	-.3%	17%	41%	12%	720%	-65%
	No Action	100	22.4	3.0	334	.040	.022	.066	.015	1.7
	Upstream Return Flow	100	20.2	<.1	422	.172	.104	.183	1.51	2.5
	Percent change		-9.8%	NA	26%	330%	373%	177%	9,980%	47%
	No Action	100	22.4	3.0	334	.040	.022	.066	.015	1.7
	Upstream Diversion	100	20.6	.3	309	.046	.022	.078	.308	.5
	Percent change		-8.0%	-90%	-7.5%	15%	0%	18%	1,953%	-71%

Appendix 8. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
	No Action	100	21.4	5.6	306	0.005	0.068	0.020	0.328	2.0
	Downstream Diversion	100	23.3	6.4	286	.010	.025	.029	.063	3.9
	Percent change		8.9%	14%	-6.5%	100%	-63%	45%	-81%	95%
	No Action	100	21.4	5.6	306	.005	.068	.020	.328	2.0
2000	Upstream Return Flow	100	24.0	7.7	329	.017	.179	.099	.069	9.6
	Percent change		7.0%	38%	7.5%	240%	163%	395%	-79%	380%
	No Action	100	21.4	5.6	306	.005	.068	.020	.328	2.0
	Upstream Diversion	100	22.6	6.0	296	.004	.026	.019	.068	1.9
	Percent change		5.6%	7.1%	-3.3%	-20%	-62%	-50%	-79%	-5.0%
					Hypolimnion					
	No Action	88	20.8	5.0	308	.007	.047	.020	.652	1.6
	Downstream Diversion	100	22.7	5.1	284	.017	.019	.032	.449	2.6
	Percent change		9.1%	2.0%	-7.8%	143%	-60%	60%	-31%	62%
	No Action	88	20.8	5.0	308	.007	.047	.020	.652	1.6
2000	Upstream Return Flow	100	21.8	6.1	331	.017	.187	.100	.465	7.4
	Percent change		4.8%	22%	7.5%	143%	298%	400%	-28%	362%
	No Action	88	20.8	5.0	308	.007	.047	.020	.652	1.6
	Upstream Diversion	100	22.1	4.9	300	.007	.030	.019	.397	1.5
	Percent change		6.3%	-2.0%	-2.6%	0%	-36%	-50%	-39%	-6.3%

Appendix 8. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulated scenario	Percent of annual results available	Water temperature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2001	No Action	67	--	--	--	--	--	--	--	--
	Downstream Diversion	89	21.5	5.9	286	0.041	0.060	0.035	0.967	1.6
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	67	--	--	--	--	--	--	--	--
	Upstream Return Flow	90	20.6	5.7	369	.025	.813	.153	1.13	12.6
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	67	--	--	--	--	--	--	--	--
	Upstream Diversion	86	20.2	5.7	283	.015	.094	.023	1.82	1.8
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
2001	No Action	34	--	--	--	--	--	--	--	--
	Downstream Diversion	85	18.9	5.3	285	.041	.059	.035	1.43	1.1
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	34	--	--	--	--	--	--	--	--
	Upstream Return Flow	85	19.6	5.4	367	.027	.845	.155	1.51	7.0
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	34	--	--	--	--	--	--	--	--
	Upstream Diversion	80	17.1	5.8	281	.015	.088	.023	1.74	1.2
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

Appendix 8. Percent change between annual 85th percentile values for selected constituents and comparisons of the annual 15th percentile values for dissolved-oxygen concentrations in the epilimnion and hypolimnion at site 3B for cumulative-effects analyses for the Downstream Diversion, Upstream Return-Flow, and Upstream Diversion scenarios as compared to the No Action scenario.—Continued

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; NA, not applicable]

Water year	Simulation scenario	Percent of annual results available	Water temp-erature, (°C)	Dissolved oxygen, (mg/L)	Dissolved solids, (mg/L)	Dissolved ammonia, (mg/L)	Dissolved nitrate, (mg/L)	Total phosphorus, (mg/L)	Total iron, (mg/L)	Chlorophyll *a*, (µg/L)
					Epilimnion					
2002	No Action	0	--	--	--	--	--	--	--	--
	Downstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Return Flow	32	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
					Hypolimnion					
2002	No Action	0	--	--	--	--	--	--	--	--
	Downstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Return Flow	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	0	--	--	--	--	--	--	--	--
	Upstream Diversion	0	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

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