Prepared in cooperation with the Bureau of Reclamation

Simulated Effects of Proposed Arkansas Valley Conduit on Hydrodynamics and Water Quality for Projected Demands through 2070, Pueblo Reservoir, Southeastern Colorado

Scientific Investigations Report 2013–5119

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

Cover: Pueblo Reservoir looking southwest towards Round Top Mountain, August 2008. Photograph by R.F. Ortiz, U.S. Geological Survey.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

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Conversion Factors and Datums

Inch/Pound to SI

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:

$$°F=(1.8\times°C)+32$$

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

$$°C=(°F-32)/1.8$$

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

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

Elevation, 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:

AVC	Arkansas Valley Conduit
Daily Model	Arkansas River Daily Simulation Model
DO	dissolved oxygen
DS	dissolved solids
EIS	Environmental Impact Statement
GIS	Geographical Information System
NEPA	National Environmental Policy Act
Project	Fryingpan-Arkansas Project
Reclamation	Bureau of Reclamation
SECWCD	Southeastern Colorado Water Conservancy District
USGS	U.S. Geological Survey
WY	Water Year

Simulated Effects of Proposed Arkansas Valley Conduit on Hydrodynamics and Water Quality for Projected Demands through 2070, Pueblo Reservoir, Southeastern Colorado

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Abstract

The purpose of the Arkansas Valley Conduit (AVC) is to deliver water for municipal and industrial use within the boundaries of the Southeastern Colorado Water Conservancy District. Water supplied through the AVC would serve two needs: (1) to supplement or replace existing poor-quality water to communities downstream from Pueblo Reservoir; and (2) to meet a portion of the AVC participants' projected water demands through 2070. The Bureau of Reclamation (Reclamation) initiated an Environmental Impact Statement (EIS) to address the potential environmental consequences associated with constructing and operating the proposed AVC, entering into a conveyance contract for the Pueblo Dam north-south outlet works interconnect (Interconnect), and entering into a long-term excess capacity master contract (Master Contract).

Operational changes, as a result of implementation of proposed EIS alternatives, could change the hydrodynamics and water-quality conditions in Pueblo Reservoir. An interagency agreement was initiated between Reclamation and the U.S. Geological Survey to accurately simulate hydrodynamics and water quality in Pueblo Reservoir for projected demands associated with four of the seven proposed EIS alternatives.

The four alternatives submitted to the USGS for scenario simulation included various combinations (action or no action) of the proposed Arkansas Valley Conduit, Master Contract, and Interconnect options. The four alternatives were the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only. Additionally, scenario simulations were done that represented existing conditions (Existing Conditions scenario) in Pueblo Reservoir. Water-surface elevations, water temperature, dissolved oxygen, dissolved solids, dissolved ammonia, dissolved nitrate, total phosphorus, total iron, and algal biomass (measured as chlorophyll-*a*) were simulated. Each of the scenarios was simulated for three contiguous water years representing a wet, average, and dry annual hydrologic cycle. Each selected simulation scenario also was evaluated for differences in direct/indirect effects and cumulative effects on a particular scenario. Analysis of the results for the direct/indirect- and cumulative-effects analyses indicated that, in general, the results were similar for most of the scenarios and comparisons in this report focused on results from the direct/indirect-effects analyses.

Scenario simulations that represented existing conditions in Pueblo Reservoir were compared to the No Action scenario to assess changes in water quality from current demands (2006) to projected demands in 2070. Overall, comparisons of the results between the Existing Conditions and the No Action scenarios for water-surface elevations, water temperature, and dissolved oxygen, dissolved solids, dissolved ammonia, dissolved nitrate, total phosphorus, and total iron concentrations indicated that the annual median values generally were similar for all three simulated years. Additionally, algal groups and chlorophyll-*a* concentrations (algal biomass) were similar for the Existing Conditions and the No Action scenarios at site 7B in the epilimnion for the simulated period (Water Year 2000 through 2002).

The No Action scenario also was compared individually to the Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios. These 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. Simulated water-surface elevations, water temperature, dissolved oxygen, dissolved solids, dissolved ammonia, dissolved nitrate, total phosphorus, total iron, algal groups, and chlorophyll-*a* concentrations in Pueblo Reservoir generally were similar between the No Action scenario and each of the other three simulation scenarios.

Introduction

The Fryingpan-Arkansas Project (Project) is a multipurpose transmountain, transbasin water diversion and delivery project in Colorado. Authorized for construction in 1962 under Public Law 87-590 (77 Stat. 393), the Project annually diverts an average of 69,200 acre-feet of surplus water from the western slope of the Rocky Mountains to the Arkansas River Basin on the eastern slope (Bureau of

Reclamation, 2011a). Together with available water supplies in the Arkansas River Basin, the Project provides an average annual water supply of 80,400 acre-feet for both municipal/domestic use and the supplemental irrigation of 280,600 acres in the Arkansas River valley (Bureau of Reclamation, 2011a).

As part of the original 1962 law, authorization was included to construct a municipal water-supply pipeline to provide communities downstream from Pueblo Reservoir with a source of high-quality water; initially, no action was taken on the authorization. In 2009, renewed local interest drove an initiative to construct such a pipeline and Congress amended the original legislation in Public Law 111-11, which authorized appropriations and cost-sharing language to proceed with project planning and implementation of the Arkansas Valley Conduit (AVC). The purpose of the AVC is to deliver water to 41 participants for municipal and industrial use within the boundaries of the Southeastern Colorado Water Conservancy District (Southeastern Colorado Water Conservancy District, 2013) (fig. 1). Water supplied through the AVC would serve two needs: (1) to supplement or replace existing poor-quality water to communities downstream from Pueblo Reservoir; and (2) to meet a portion of the AVC participants' projected water demands through 2070 (Bureau of Reclamation, 2011b).

The Bureau of Reclamation (Reclamation) initiated an Environmental Impact Statement (EIS) to address the potential environmental consequences associated with constructing and operating the proposed AVC, entering into a conveyance contract for the Pueblo Dam north-south outlet works interconnect (Interconnect), and entering into a long-term excess capacity master contract (Master Contract). Reclamation chose to evaluate the environmental effects of these three independent proposed actions in the same EIS because of overlap in area, timing, and participants. A complete description of the Arkansas Valley Conduit Draft Environmental Impact Statement can be found at *http://www.usbr.gov/avceis*. The Interconnect is a pipeline designed to convey water between the existing south outlet works and a future north outlet works at Pueblo Reservoir to provide a redundant means for release of municipal and environmental water from the reservoir (Bureau of Reclamation, 2011b). The purpose of the Master Contract is to use excess-capacity storage in Pueblo Reservoir to help provide a reliable water yield (through 2060) for 15 participants within the boundaries of the Southeastern Colorado Water Conservancy District (Bureau of Reclamation, 2011b).

A key element in the preparation of the AVC/Long-Term Excess Capacity Master Contract EIS (herein referred to as the AVC/Master Contract EIS) is the definition of the purpose, as well as, the analysis and documentation of the needs driving any proposed action that addresses the AVC and the Master Contract (Bureau of Reclamation, 2010). To that end, six action alternatives and one no action alternative were evaluated in the EIS to meet the purpose and needs of the AVC, Interconnect, and Master Contract. Reclamation understands that there may be water-based issues (surface-water hydrology, water quality, aquatic species, groundwater, wetlands, and recreation) associated with each of the proposed alternatives.

As the terminal storage facility for the Project, Pueblo Reservoir is the primary source of water for the AVC. Located approximately 6 miles west of Pueblo, Colo. (fig. 1), the 357,678 acre-feet reservoir is one of southeastern Colorado's most valuable water resources (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.

Operational changes, as a result of implementation of these alternatives, could change the hydrodynamics and water-quality conditions in Pueblo Reservoir. 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 an interagency 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 four of the seven proposed EIS alternatives. A hydrodynamic and water-quality model of Pueblo Reservoir was previously developed and calibrated, and the results of the modeling were documented by Galloway and others (2008). In this report, the modeling described in Galloway and others (2008) is referred to as the USGS Pueblo Reservoir model.

Purpose and Scope

The purpose of this report is to compare simulated effects on hydrodynamics and water quality for projected demands in Pueblo Reservoir resulting from changes in inflow entering the reservoir and from changes to withdrawals from the reservoir as projected for the year 2070 as described in the AVC/Master Contract EIS. Four of the seven EIS alternatives were selected for scenario simulations 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 among selected scenarios.

The four alternatives submitted to the USGS for scenario simulation included various combinations (action or no action) of the proposed AVC, Master Contract, and Interconnect options. Table 1 provides a schematic of how the four

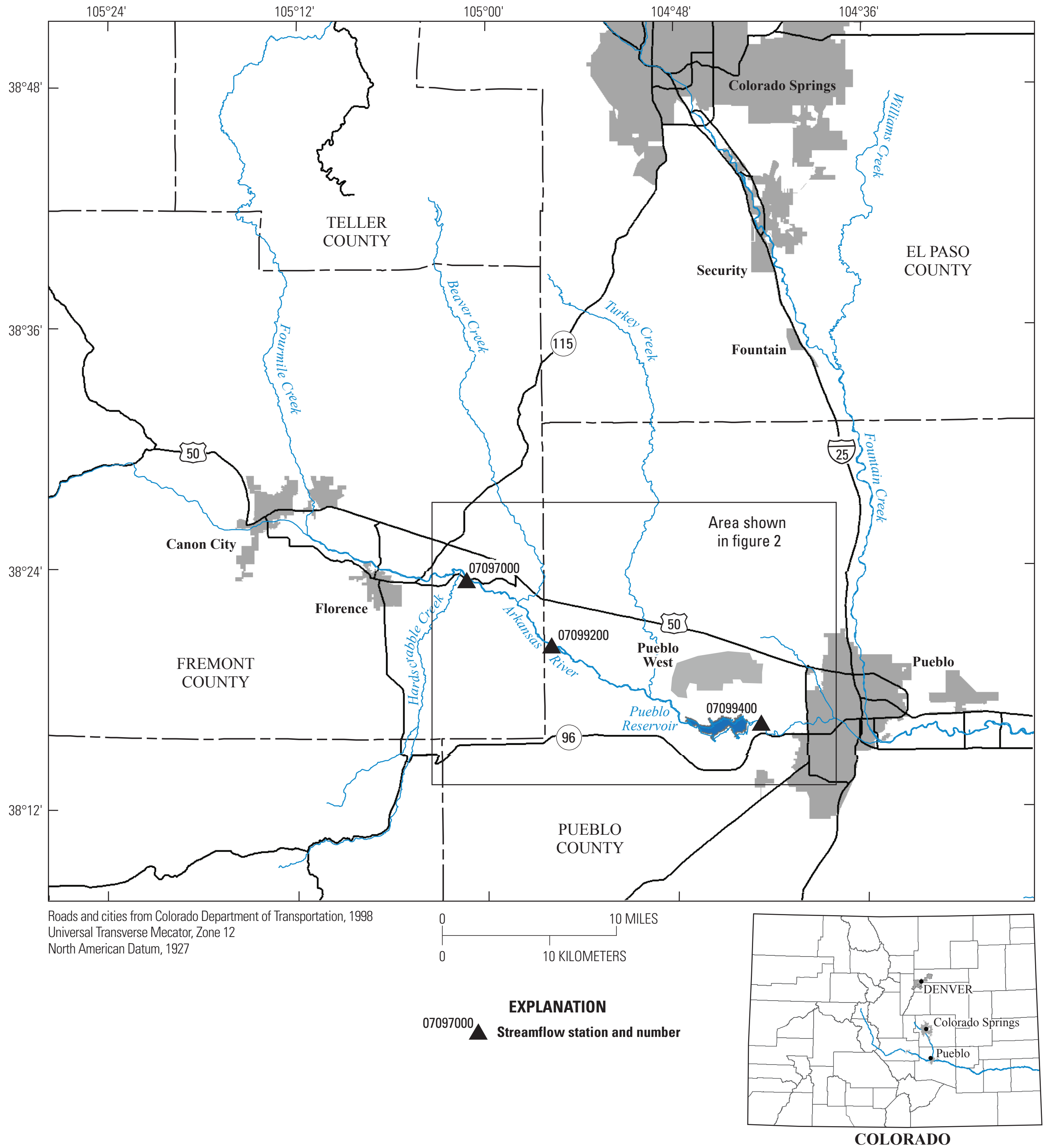

Figure 1. Location of the study area.

Table 1. Comparison of Environmental Impact Statement alternatives associated with the proposed Arkansas Valley Conduit and identification of four alternatives selected for scenario simulation.

[Selected alternatives are in bold type]

Environmental Impact Statement Alternative name	Alternative number	Proposed action		
		Arkansas Valley Conduit	Interconnect	Long-term Excess Capacity Master Contract
No Action Alternative	**1**	**no**	**no**	**no**
Comanche South Alternative	**2**	**yes**	**yes**	**yes**
Pueblo Dam South Alternative	3	yes	no	yes
Joint Use Pipeline North Alternative	**4**	**yes**	**yes**	**no**
Pueblo Dam North Alternative	5	yes	yes	yes
River South Alternative	6	yes	no	yes
Master Contract Only Alternative	**7**	**no**	**no**	**yes**

selected alternatives relate with regard to all the alternatives defined in the EIS. Specifically, the four alternatives identified for scenario simulation by the USGS were the No Action (EIS Alternative 1), the Comanche South (EIS Alternative 2), the Joint-Use Pipeline North (EIS Alternative 4), and the Master Contract Only (EIS Alternative 7). Each of the scenarios was simulated for three contiguous water years (WY) representing a wet (WY 2000), average (WY 2001), and dry (WY 2002) annual hydrologic cycle. Streamflow, diversion, reservoir storage, and return-flow quantity data for projected demands in 2070 were provided to the USGS by contractors for Reclamation (Lisa Fardal, MWH Americas, Inc., written commun., 2011). Water-quality data for this effort were originally provided to the USGS by contractors for Reclamation (Tracy Kosloff, MWH Americas, Inc., written commun., 2008) as described for the Existing Conditions simulation scenario in Ortiz and Miller (2009).

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. The primary difference between the two sets of simulations was that the direct-effects simulations include existing levels of demand by nonparticipants in the AVC/Master Contract project, whereas the cumulative-effects simulations include projected demands in 2070 by the nonparticipants in the AVC/Master Contract project (Lisa Fardal, MWH Americas, Inc., oral commun., 2011).

Finally, scenario simulations were modeled using existing conditions in Pueblo Reservoir during water years 2000 through 2002. The results of the Existing Conditions scenario were compared to the No Action scenario to assess changes in water quality from current demands (2006) to projected demands in 2070. All simulations used an external nutrient-decay model to simulate degradation and assimilation of selected nutrients along the riverine reach upstream from Pueblo Reservoir as described in Ortiz and Miller (2009).

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 2070 were prepared by Reclamation's consultant. Nutrient decay and assimilation along the riverine reach upstream from Pueblo Reservoir were simulated for selected constituents in the Arkansas River (Ortiz and Miller, 2009). A brief discussion of the reservoir model and development of the input data is described in the following sections.

Reservoir Modeling Using CE-QUAL-W2

The development, 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. 2) 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, total iron, algal groups, and chlorophyll-*a* (algal biomass) 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).

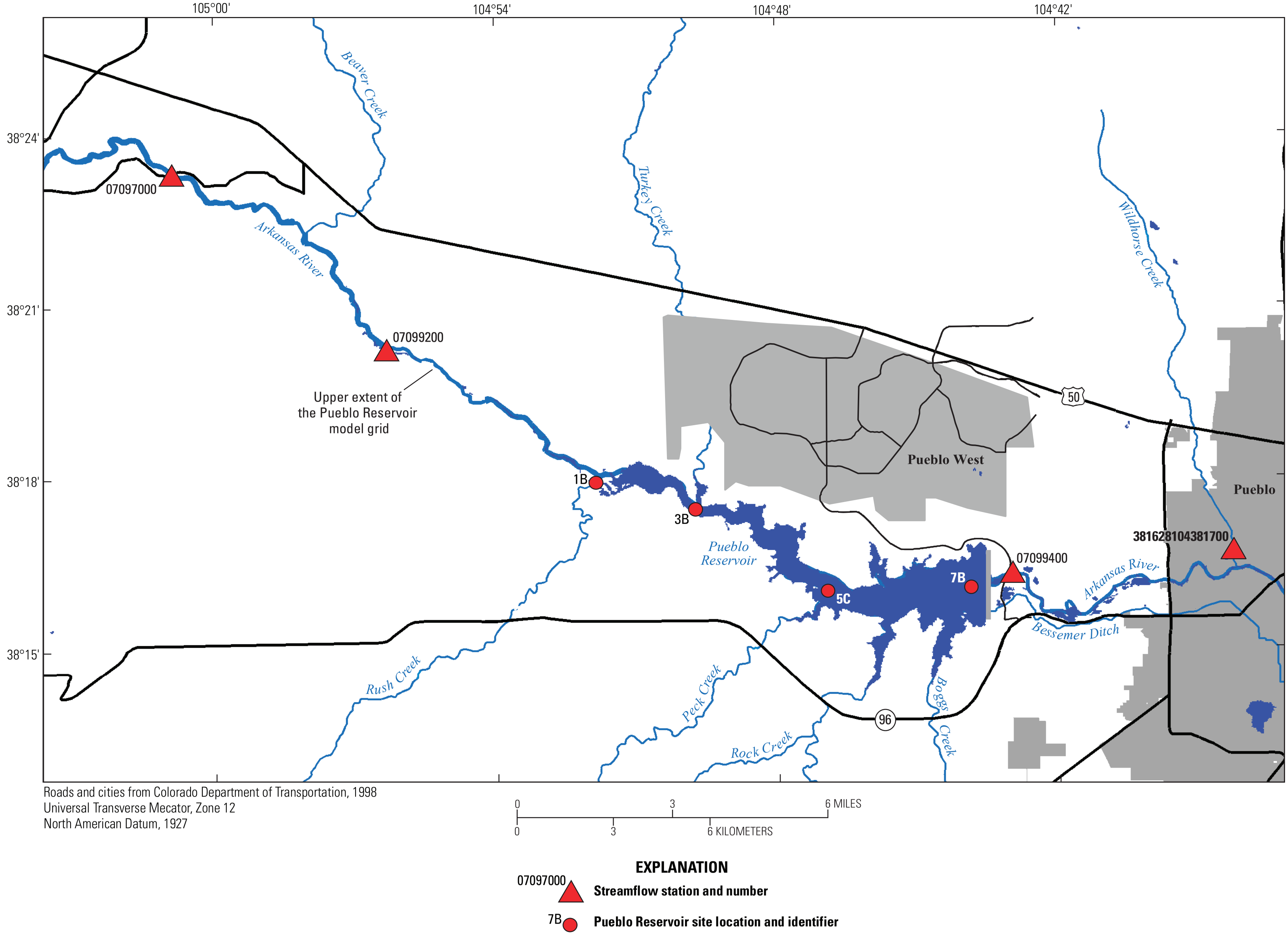

Figure 2. Location of selected sites on the Arkansas River and Pueblo Reservoir.

Past performance and recent USGS applications of this model have demonstrated its success in simulating water temperature in reservoir systems (Galloway and others, 2008; Sullivan and others, 2007; Sullivan and Rounds, 2004; Bales and others, 2001; Green, 2001; Rounds and Wood, 2001). 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. 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 more than a decade after the calibration period (Galloway and others, 2008). Several other USGS studies have demonstrated the application of the CE-QUAL-W2 model to water-quality constituents (Green, 2001; Sullivan and Rounds, 2005; and Galloway and Green, 2006).

Streamflow and Water-Quality Modeling for Projected Demands in 2070

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 AVC EIS was done on a daily time step for the study period of WY 1982 through WY 2009 (Lisa Fardal, MWH Americas, Inc., written commun., 2011).

The Daily Model superimposed existing 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., 2008). 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 (Lisa Fardal, MWH Americas, Inc., written commun., 2011).

Description of Simulation Scenarios

The simulation scenarios selected for modeling as part of this report were the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios. The four simulation scenarios are described in more detail below and a summary of how the four selected scenarios related to the seven EIS alternatives can be found in table 1. A detailed description of all the alternatives can be found in Chapter 2 of the Draft Environmental Impact Statement–Arkansas Valley Conduit and Long-term Excess Capacity Master Contract, Fryingpan-Arkansas Project (Bureau of Reclamation, 2012). Additionally, a simulation scenario that represented existing conditions (demand conditions for 2011) was run using water-quality input files that were similar to those used in the verification period of the Pueblo Reservoir model (Galloway and others, 2008) and streamflow and storage data based on Daily Model results (Lisa Fardal, MWH Americas, Inc., written commun., 2011). For the purposes of this report, this scenario is described as the Existing Conditions scenario.

Input data that represented the projected streamflow, diversion data, and reservoir storage (stage) for each of the simulation scenarios were provided to the USGS by Reclamation's consultant (Lisa Fardal, MWH Americas, Inc., written commun., 2011). Specifically, simulated streamflow data were provided for each scenario representing inflow to Pueblo Reservoir at Portland (USGS streamflow station 07097000) and outflow downstream from Pueblo Reservoir (USGS streamflow station 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.

The input water-quality data for all the simulation scenarios in this report were identical to those used in the Existing Conditions scenario as described in Ortiz and Miller (2009). The data 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 upstream from Pueblo Reservoir to Portland (fig. 1).

No Action Scenario

Required by the National Environmental Policy Act, this alternative represents future conditions without the AVC, Interconnect, and Master Contract. Water-supply and water-quality needs for this scenario are met using regional water treatment systems or local independent systems. Participants with existing water supplies and treatment systems that meet primary drinking standards would continue to use these supplies, whereas participants under water-quality enforcement actions would either upgrade water treatment facilities to meet primary drinking water standards, or regionalize with a larger entity. The No Action scenario states that the Master Contract would not be issued and the Interconnect would not be constructed (Bureau of Reclamation, 2011b).

Comanche South Scenario

The Comanche South scenario represents water diverted from the existing Pueblo Reservoir south outlet works. A new pipeline would be built along the existing Comanche Power Plant pipeline route south of Pueblo and generally along Highway 50 east of Pueblo for 235 miles. Excess capacity storage in Pueblo Reservoir (about 30,000 acre-feet annually) would be issued as part of the Master Contract. The Comanche South scenario also states that construction of the Interconnect would be completed (Bureau of Reclamation, 2011b).

Joint Use Pipeline North Scenario

The Joint Use Pipeline North scenario utilizes excess capacity available in the existing Joint Use Pipeline from Pueblo Dam downstream about 4 miles. A new pipeline would be built from that location to the existing water treatment plant in northwest Pueblo. A new pipeline would be built from the water treatment plant generally to the north side of Highway 50 east of Pueblo for about 233 miles. This scenario states that the Master Contract would not be issued but the Interconnect would be constructed (Bureau of Reclamation, 2011b).

Master Contract Only Scenario

As the Master Contract Only scenario implies, excess capacity storage in Pueblo Reservoir (about 30,000 acre-feet) would be issued as part of the Master Contract; the AVC and Interconnect are not constructed under this scenario. Participants would pursue actions similar to those for the No Action Alternative to meet their water-supply and water-quality needs (Bureau of Reclamation, 2011b).

Existing Conditions Scenario

This scenario represented the existing conditions in Pueblo Reservoir (demand conditions for 2006) 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 (Ortiz and Miller, 2009). Specifically, simulation results for the No Action scenario were compared to results for the Existing Conditions scenario.

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 (Lisa Fardal, MWH Americas, Inc., written commun., 2011). 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 AVC/Master Contract project, whereas the cumulative-effects-scenario simulations include projected demands in 2070 by the nonparticipants in the AVC/Master Contract 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 (Lisa Fardal, MWH Americas, Inc., written commun., 2011). 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 sites 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 were characteristic of a riverine environment in the reservoir (fig. 2). 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 were characteristic of the main body of the reservoir in the forebay near the dam wall (fig. 2). 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 (near surface) and the hypolimnion (near bottom) 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 is to describe the general patterns observed for 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- 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 to those from 7B but more variable because of the dynamic changes in water-surface elevations observed at this upstream location. Additionally, water quality at this site tended to be more reactive given the proximity of the site to river inputs. When appropriate, results from site 3B will be discussed.

Water-surface elevations in Pueblo Reservoir were directly related to the active storage in the reservoir (Bureau of Reclamation, 1977) and were inherently driven by changes in inflow/outflow data. As such, storage in the reservoir was the primary differentiator between simulation scenarios described in this report. Water-quality inputs to the modeling were identical for all simulation scenarios as submitted by consultants for Reclamation (Lisa Fardal, MWH Americas, Inc., written commun., 2011).

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. 3). Generally, there was a substantial temporal decrease in water-surface elevations between the wet, average, and dry years. Water-surface elevations associated with the direct-effects analyses were higher than the water-surface elevations for the corresponding cumulative-effects analyses, and the differences between the effects analyses, for any scenario, increased temporally from wet to dry year. During the dry year (WY 2002), the lowest water-surface elevations for either the direct-effects or cumulative-effects analysis were associated with the No Action and Joint Use Pipeline North

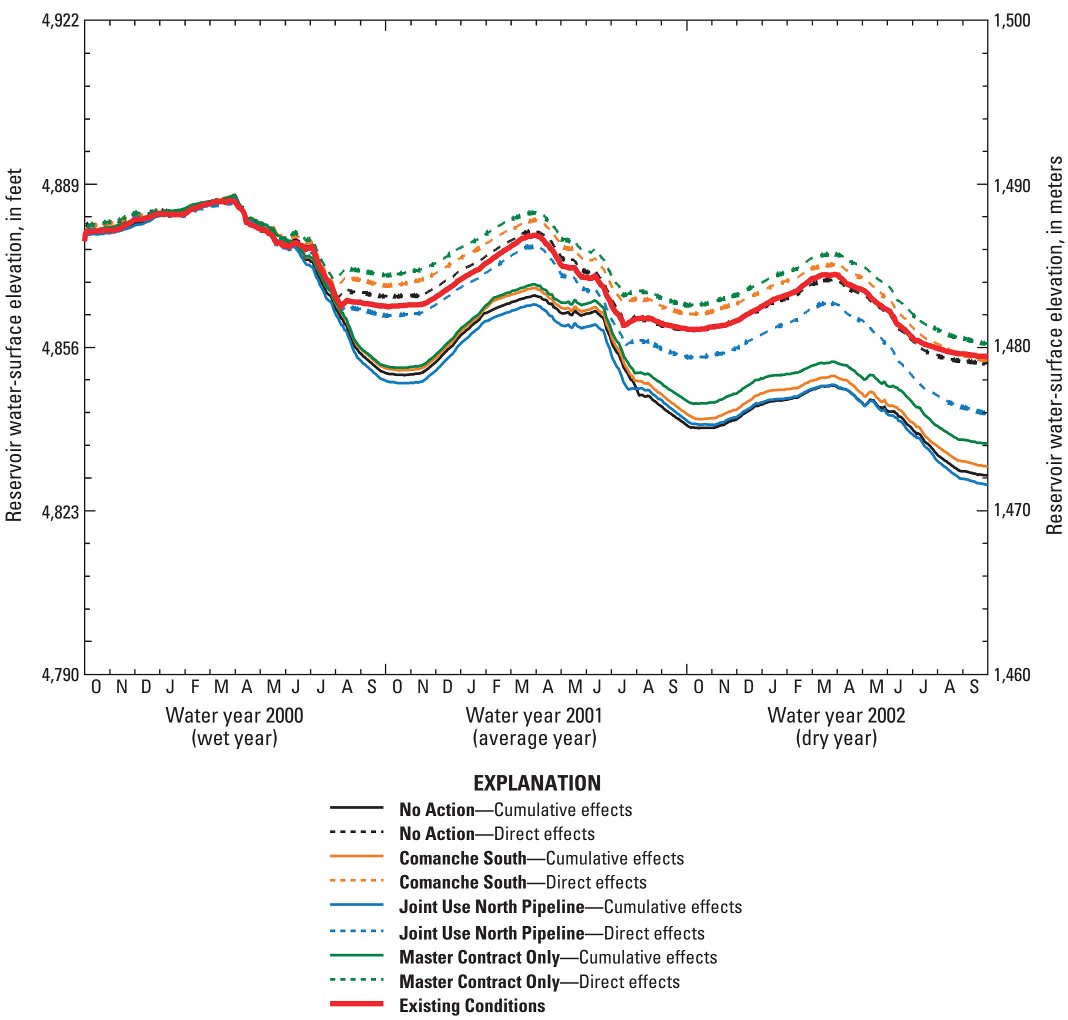

Figure 3. Comparison of water-surface elevations in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-effects analyses for selected simulation scenarios. Datum is North American Vertical Datum of 1988 (NAVD 88).

scenarios; these two scenarios do not include an excess capacity storage component as part of the proposed EIS alternative. Simulated water-surface elevations for the direct-effects analysis of any simulation scenario during WY 2000 (wet year) and WY 2001 (average year) were similar to the water-surface elevations for the Existing Conditions scenario. Water-surface elevations during WY 2002 (dry year) remained similar to those of the Existing Conditions scenario with the exception of the Joint Use Pipeline North scenario.

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 (June-August) prior to mixing in September (Edelmann, 1989). Results from the various simulation scenarios showed a similar pattern (fig. 4), which also was consistent with previous simulations by Ortiz and Miller (2009). In general, the reservoir has been shown to be isothermal during the winter with the coldest water temperatures occurring from December to April. Typically, thermal stratification is apparent by May at site 3B (riverine site) and 7B (near-dam site). Maximum water temperatures were observed in August prior to when 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 simulation period regardless of the effects analysis (fig. 5). There were no substantial changes in the annual thermal pattern between the three simulated years (fig. 5).

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 typical stratification patterns that occur in Pueblo Reservoir (Edelmann, 1989) including anoxic conditions observed near the bottom of the reservoir during the summer before the reservoir turned over and mixed (fig. 6). DO concentrations in the epilimnion and hypolimnion of the reservoir near the dam were similar to the Existing Conditions scenario for all the simulation scenarios regardless of the effects analysis (fig. 7). At either depth, maximum DO concentrations occurred in the early spring when water temperatures also were at minimum; colder water has the capacity for higher DO concentrations (Hem, 1985). DO concentrations of less than 6 milligrams per liter (mg/L) were simulated in the epilimnion during September and October for all selected simulation scenarios. These lower concentrations lagged about a month behind the anoxic conditions simulated in the hypolimnion. It did not appear that the anoxic period was substantially longer for any particular simulation scenario and there appeared to be no substantial change in the general seasonal pattern in the epilimnion and hypolimnion between the wet, average, and dry years.

Typically, the simulated dissolved solids (DS) concentrations for the Existing Conditions scenario were similar to concentrations for all the direct-effects simulation scenarios (fig. 8*A*). Concentrations for the cumulative-effects simulation scenarios were slightly larger than concentrations for the Existing Conditions scenario; typically less than 5 percent different but could be as much as 10 percent different during the winter months. Concentrations for the cumulative-effects simulation scenarios were similar among themselves. These results would be expected given that the reservoir storage for the cumulative-effects analyses was less, due to an increase water demand in the future, than that for the direct-effect analyses (fig. 3) and water-quality inputs were identical.

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, dissolved ammonia concentrations are inherently linked to other simulated 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 scenarios and between the direct- and cumulative-effects analyses. In general, the simulated dissolved ammonia concentrations for the Existing Conditions scenario were similar to the concentrations for all the other simulation scenarios whether for direct-effects or cumulative-effects analyses (fig. 8*B*).

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 Existing Conditions scenario and the No Action scenario to determine what differences, if any, were observed between existing conditions in Pueblo Reservoir (demand conditions for 2006) and the most likely conditions in 2070 assuming the absence of a major Reclamation action, such as the AVC or a storage contract. Additionally, comparisons were made between the No Action scenario and each of the other scenarios—the Comanche South scenario, the Joint Use Pipeline North scenario, and the Master Contract Only scenario. These comparisons provided information that allowed for a correlation of the effectiveness of each scenario relative to a common simulated result, the No Action scenario.

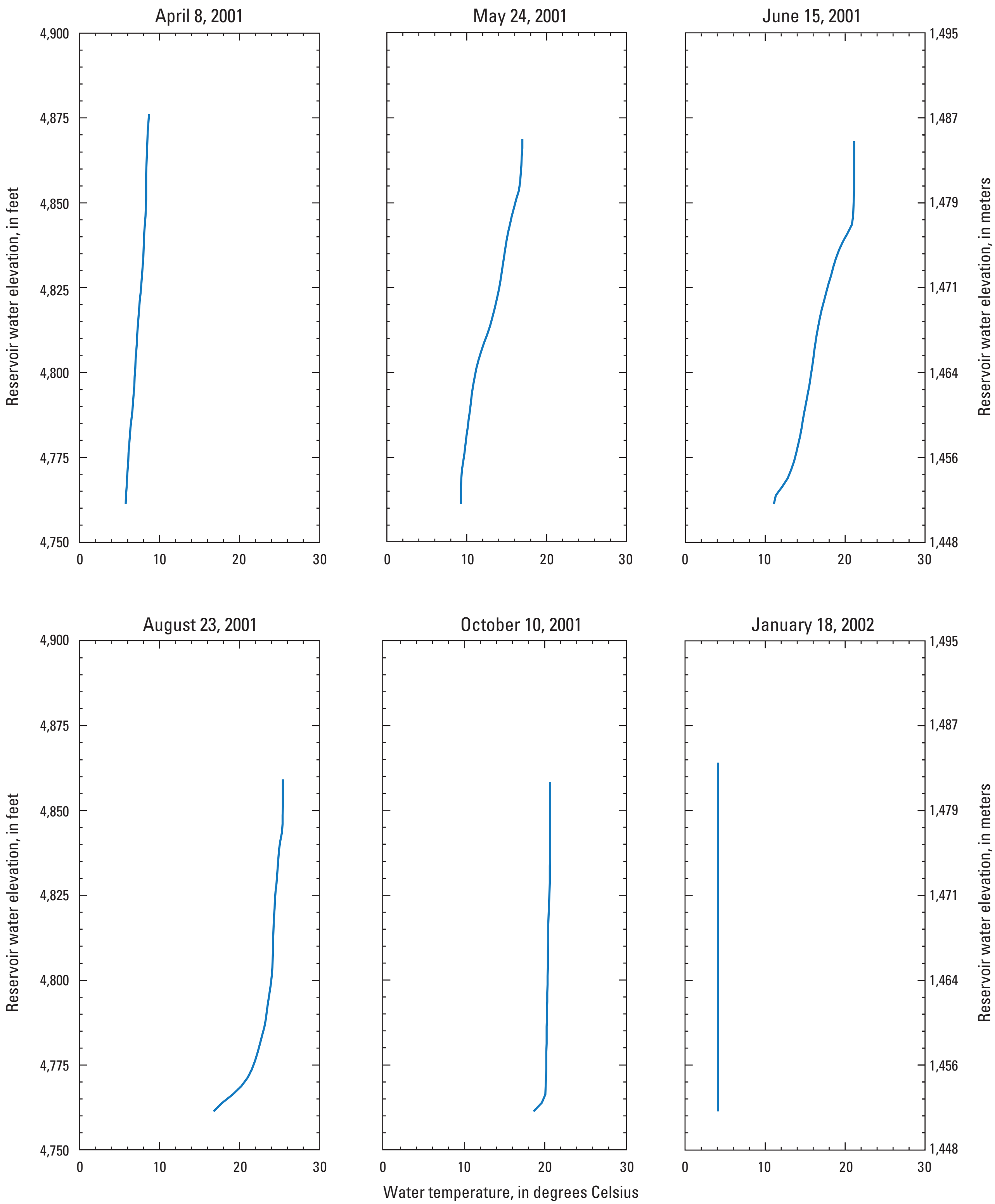

Figure 4. Simulated water temperature profiles for Pueblo Reservoir, Colorado, at site 7B, April 2001 through January 2002. Datum is North American Vertical Datum of 1988 (NAVD 88).

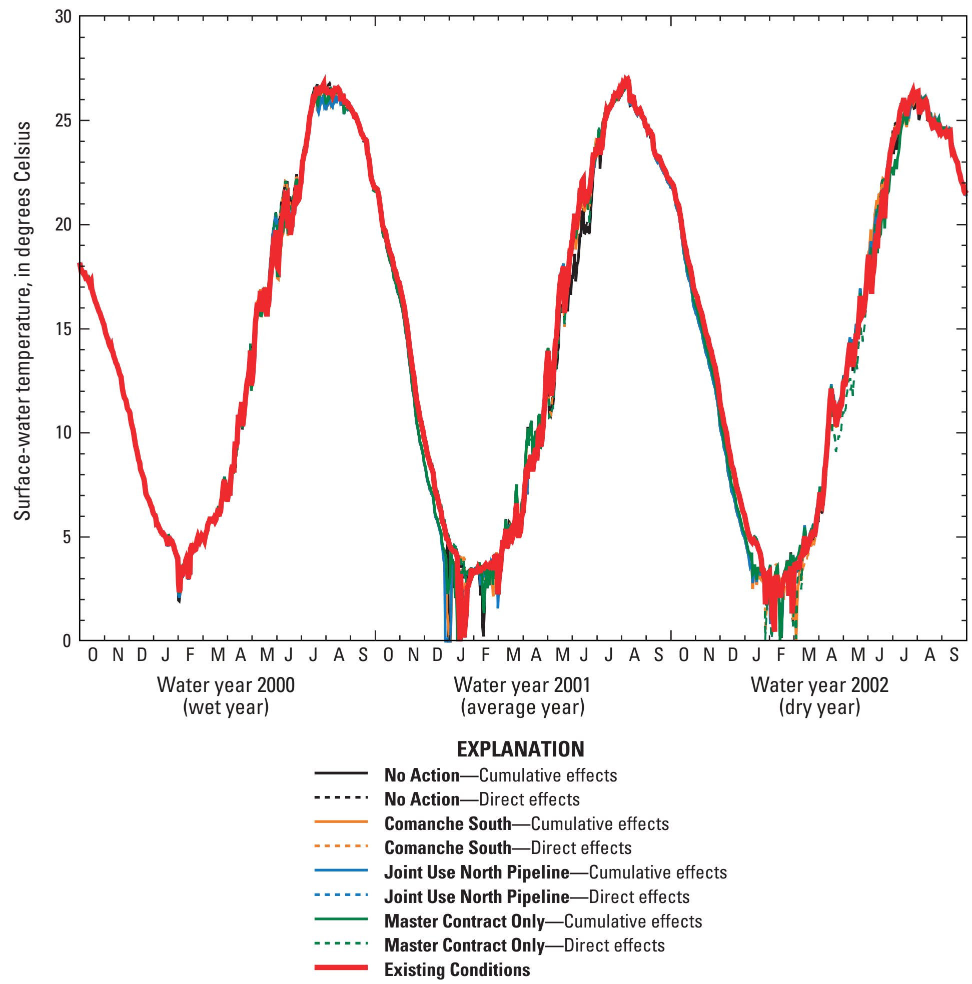

Figure 5. Comparison of water temperatures in the epilimnion at site 7B in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-analyses for selected simulation scenarios.

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 site 7B in the main body in Pueblo Reservoir near the dam structure (fig. 2). Analysis of the results for the direct- and cumulative-effects analyses indicated that, in general, the results were similar for most of the scenarios. Additionally, simulated results for cumulative-effects analyses scenarios were more likely to be reported as uncomputed at the more shallow upstream riverine site (3B) as reservoir water-surface elevations decreased in WY 2001 and WY 2002 and the site "dried up." As such, comparisons in this section and throughout 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 two reservoir sites. The annual 85th percentile concentrations also were compared as they relate to possible water-quality standards; for DO, the 15th percentile was used because anoxic conditions are 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

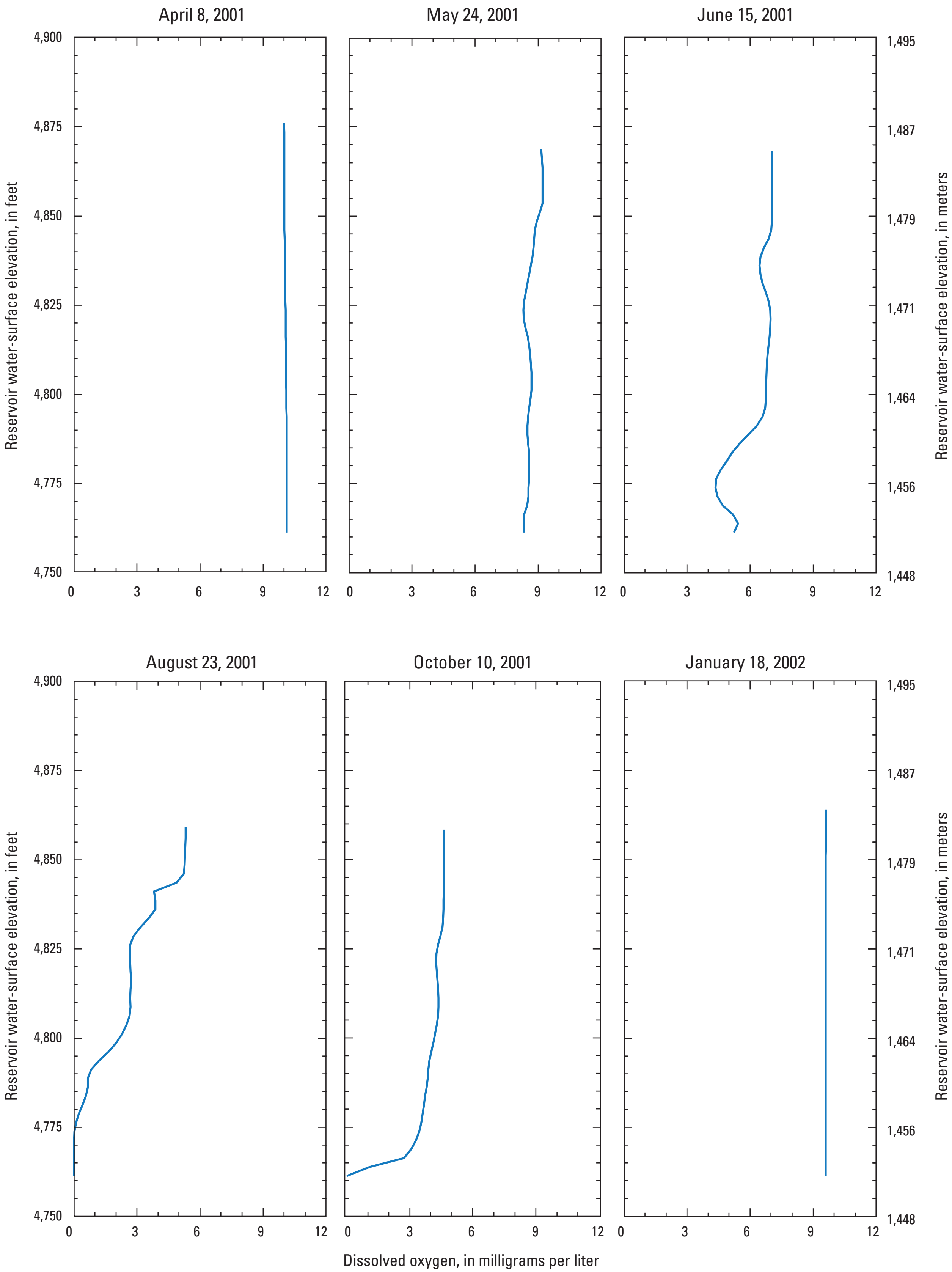

Figure 6. Simulated dissolved oxygen profiles for Pueblo Reservoir, Colorado, at site 7B, April 2001 through January 2002. Datum is North American Vertical Datum of 1988 (NAVD 88).

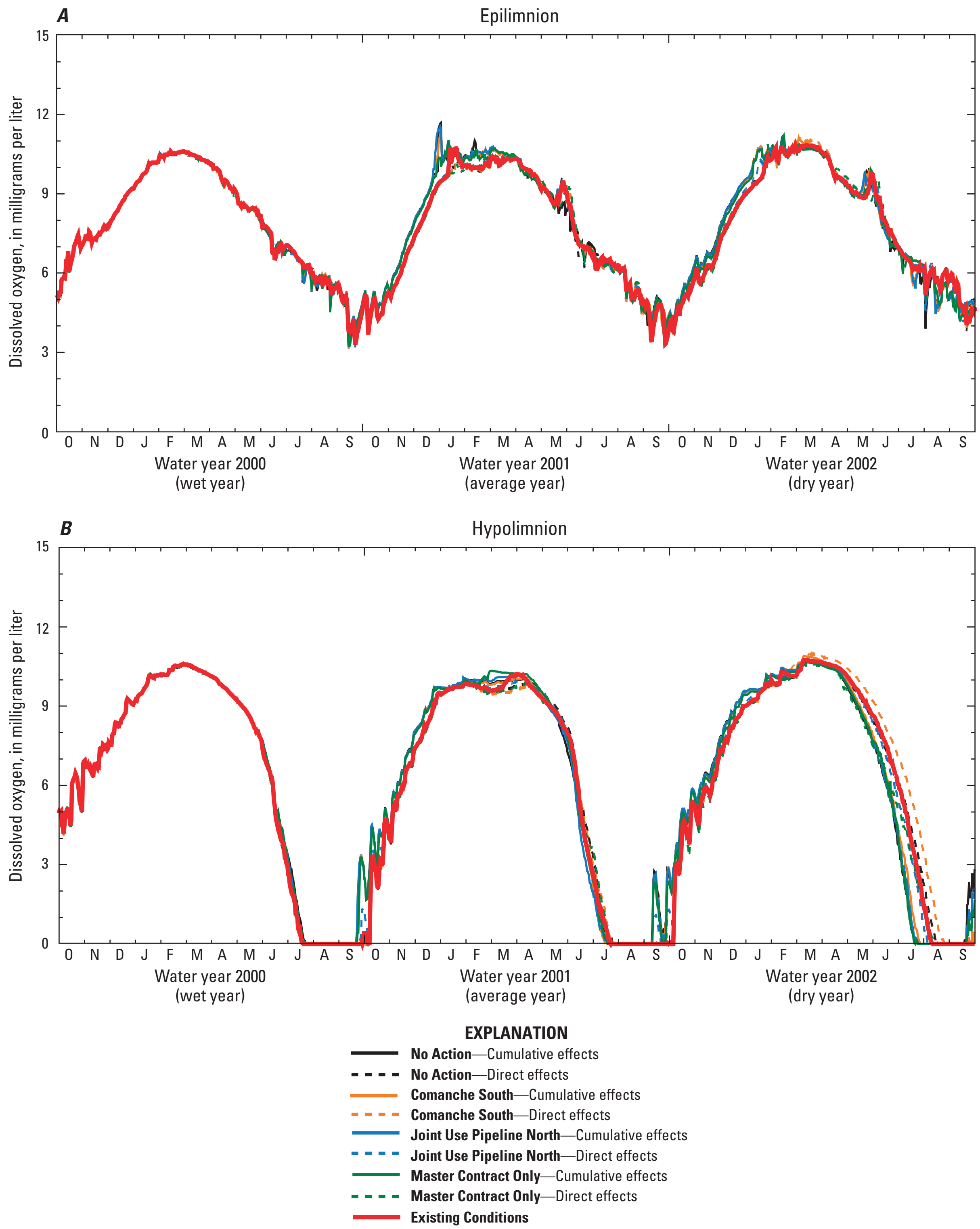

Figure 7. Comparison of dissolved oxygen concentrations at site 7B in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-effects analyses for selected simulation scenarios.

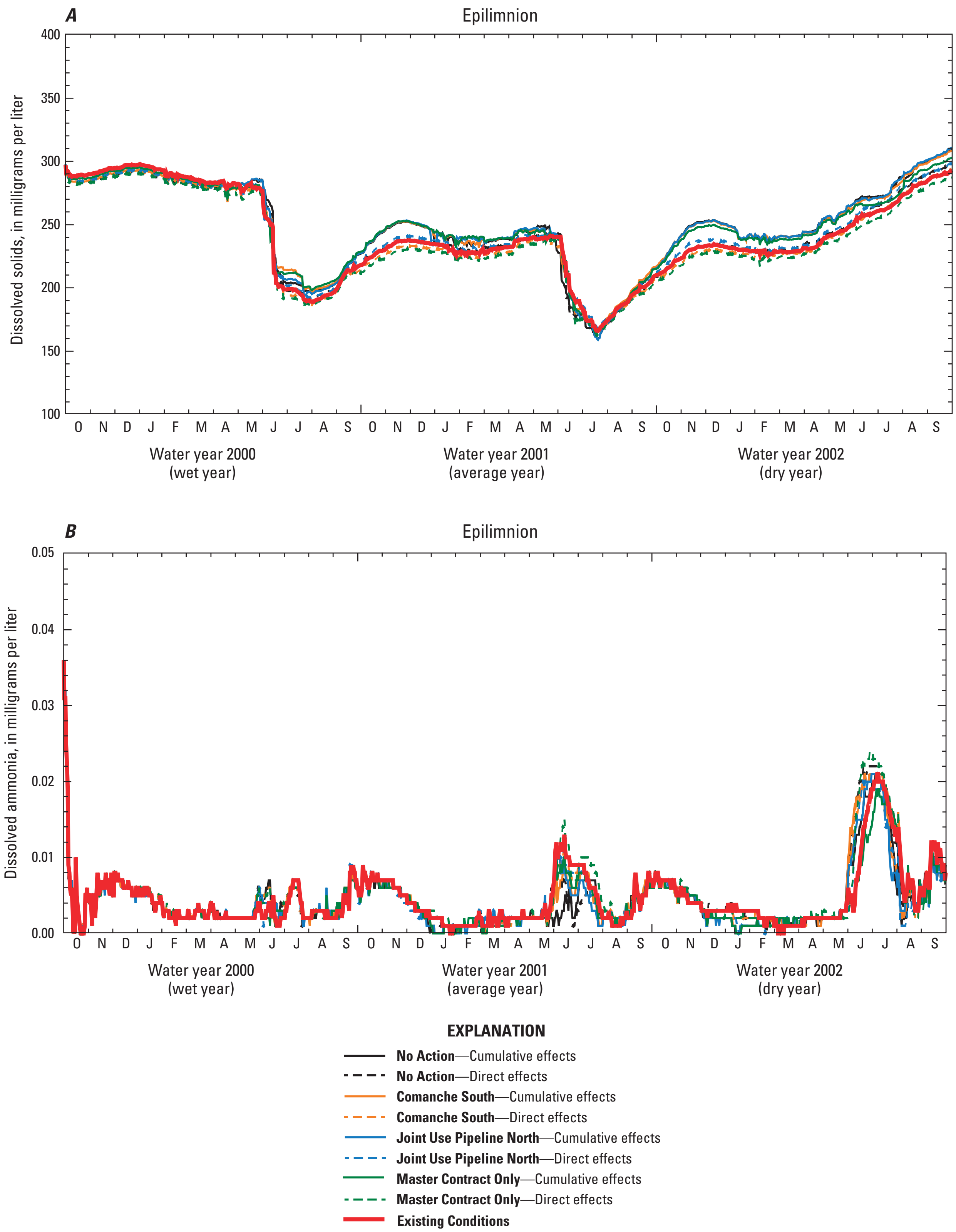

Figure 8. Comparison of (*A*) dissolved solids and (*B*) dissolved ammonia concentrations at site 7B in Pueblo Reservoir for the Existing Conditions scenario (water years 2000 through 2002) and cumulative- and direct-effects analyses for selected simulation scenarios.

differences in the calculated summary statistic (median, 85th or 15th percentiles) and by calculating the percent change in concentrations between the Existing Conditions and the No Action scenarios and between the No Action scenario and each of three other simulation scenarios.

Water-Surface Elevations

In general, simulated water-surface elevations in Pueblo Reservoir were similar between the Existing Conditions and No Action scenarios (fig. 9). Overall, there was a temporal decrease in water-surface elevations from the wet year (WY 2000) to the dry year (WY 2002). Over the three-year simulation period, maximum water-surface elevations decreased from about 4,890 feet (ft) to about 4,870 ft (1,489 meters (m) to 1,484 m, respectively); the annual maximum elevation decreased about 6 ft 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 indicated similar patterns in water temperature over the simulation period (fig. 10). At site 7B near the dam, the percent change from the Existing Conditions scenario was within 4 percent for all simulated years and was nearly identical for all comparisons in the epilimnion (table 2). Water temperatures in the hypolimnion were about 4 degrees Celsius (°C) cooler than those in the epilimnion but relatively similar between scenarios at site 7B. At site 3B, the annual median water temperatures in the epilimnion and hypolimnion were similar (less than or equal to a 3 percent change) between the two scenarios (table 3). At site 3B, water temperatures in the hypolimnion were about 2 °C cooler than those in the epilimnion but relatively similar between scenarios (table 3).

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 were similar (fig. 11). At site 7B, the percent change from the Existing Conditions scenario was within 3 percent of the No Action scenario for all simulated years in both the epilimnion or the hypolimnion (table 2). The median values in the hypolimnion generally were about 0.5 mg/L lower than concentrations in the epilimnion. At site 3B, median DO concentrations were similar between scenarios and reservoir depths (table 3); the largest observed difference was 0.2 mg/L during WY 2001.

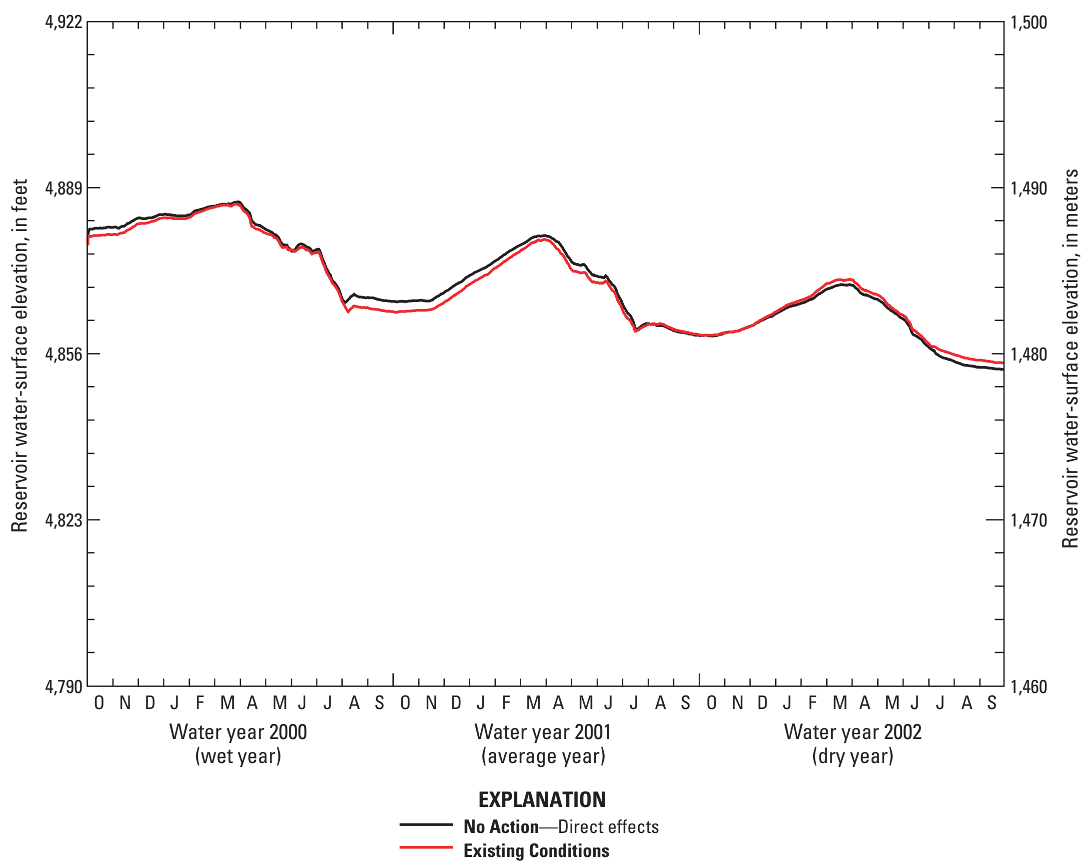

Figure 9. Comparison of water-surface elevations in Pueblo Reservoir for the Existing Conditions (water years 2000 through 2002) and No Action scenarios. Datum is North American Vertical Datum of 1988 (NAVD 88).

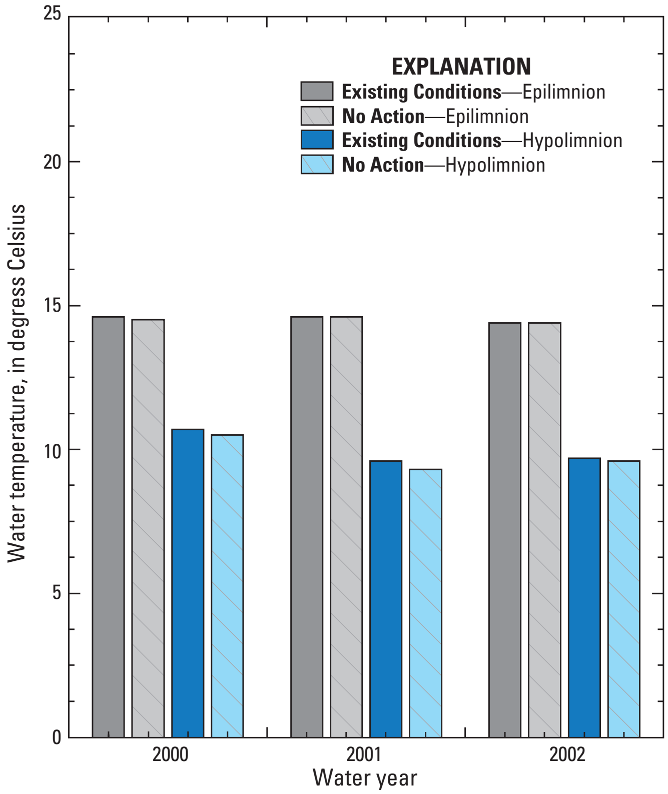

Figure 10. Annual median water temperature in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

The minimum DO concentration suitable to meet the DO water-quality standard in Pueblo Reservoir as defined by the State of Colorado is 6.0 mg/L as measured in the epilimnion of the water body (Colorado Department of Public Health and Environment, 2007). The standard is compared to the 15th percentile of the annual data values. For the Existing Conditions and No Action scenarios, the simulated 15th percentile value in the epilimnion at sites 7B and 3B was typically at or slightly below the standard value (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 was 1.42 mg/L at site 7B for the Pueblo Reservoir model (Galloway and others, 2008). Simulated DO concentrations (daily) were suppressed below 6.0 mg/L during much of August through November for each of the simulated water years (fig. 7).

Dissolved Solids

Dissolved solids concentrations for the Existing Conditions and No Action scenarios were similar between the two scenarios and at both of the simulated depths for any particular water year (fig. 12). Typically, the percent change between the annual median DS concentration for either of the scenarios was less than 2 percent (tables 2 and 3).

No water-quality standard for DS exists for Pueblo Reservoir. However, a guideline for aesthetic considerations, such as taste, color, and odor in public water systems, the secondary maximum contaminant level, is set at 500 mg/L by the

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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	Existing Conditions	100	14.6	7.8	283	0.003	0.006	0.014	<0.001	0.55
	No Action	100	14.5	7.9	281	.003	.006	.014	<.001	.53
	Percent change		–0.7%	1.3%	–0.7%	0%	0%	0%	NA	–3.6%
2001	Existing Conditions	100	14.6	7.8	229	.003	.009	.016	<.001	.26
	No Action	100	14.6	7.8	231	.003	.009	.017	<.001	.25
	Percent change		0%	0%	0.9%	0%	0%	6.2%	NA	–3.8%
2002	Existing Conditions	100	14.4	8.0	233	.003	.007	.017	<.001	.30
	No Action	100	14.4	8.0	235	.004	.007	.017	<.001	.30
	Percent change		0%	0%	0.9%	33%	0%	0%	NA	0%
					Hypolimnion					
2000	Existing Conditions	100	10.7	7.5	284	.010	.006	.015	.005	.12
	No Action	100	10.5	7.6	281	.009	.005	.015	.005	.12
	Percent change		–1.9%	1.3%	–1.1%	–10%	–17%	0%	0%	0%
2001	Existing Conditions	100	9.6	7.6	233	.007	.008	.017	.003	.07
	No Action	100	9.3	7.7	234	.007	.009	.018	.003	.05
	Percent change		–3.1%	1.3%	.4%	0%	12%	5.9%	0%	–29%
2002	Existing Conditions	100	9.7	8.0	233	.006	.005	.017	<.001	.06
	No Action	100	9.6	7.8	235	.006	.005	.018	<.001	.07
	Percent change		–1.0%	–2.5%	0.9%	0%	0%	5.9%	NA	17%

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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	Existing Conditions	100	14.1	7.9	287	0.001	0.005	0.015	0.010	0.98
	No Action	100	14.0	7.9	282	.001	.005	.015	.010	.91
	Percent change		–.7%	0%	–1.7%	0%	0%	0%	0%	–7.1%
2001	Existing Conditions	100	13.5	8.0	235	.002	.019	.018	.010	.74
	No Action	100	13.9	7.8	235	.002	.017	.018	.009	.75
	Percent change		3.0%	–2.5%	0%	0%	–11%	0%	–10%	1.4%
2002	Existing Conditions	100	13.4	7.9	260	.003	.008	.023	.013	1.41
	No Action	100	13.4	7.9	260	.003	.008	.023	.014	1.29
	Percent change		0%	0%	0%	0%	0%	0%	7.7%	–8.5%
					Hypolimnion					
2000	Existing Conditions	100	12.1	7.8	286	.002	.013	.016	.029	.68
	No Action	100	12.0	7.8	282	.002	.012	.016	.031	.70
	Percent change		–8%	0%	–1.4%	0%	–7.7%	0%	6.9%	2.9%
2001	Existing Conditions	100	11.1	7.8	239	.003	.036	.019	.027	.51
	No Action	100	11.2	7.6	239	.003	.033	.019	.027	.51
	Percent change		.9%	–2.6%	0%	0%	–8.3%	0%	0%	0%
2002	Existing Conditions	100	12.2	7.8	260	.003	.009	.022	.020	1.40
	No Action	100	12.3	7.8	260	.003	.009	.022	.022	1.31
	Percent change		.8%	0%	0%	0%	0%	0%	10%	–6.4%

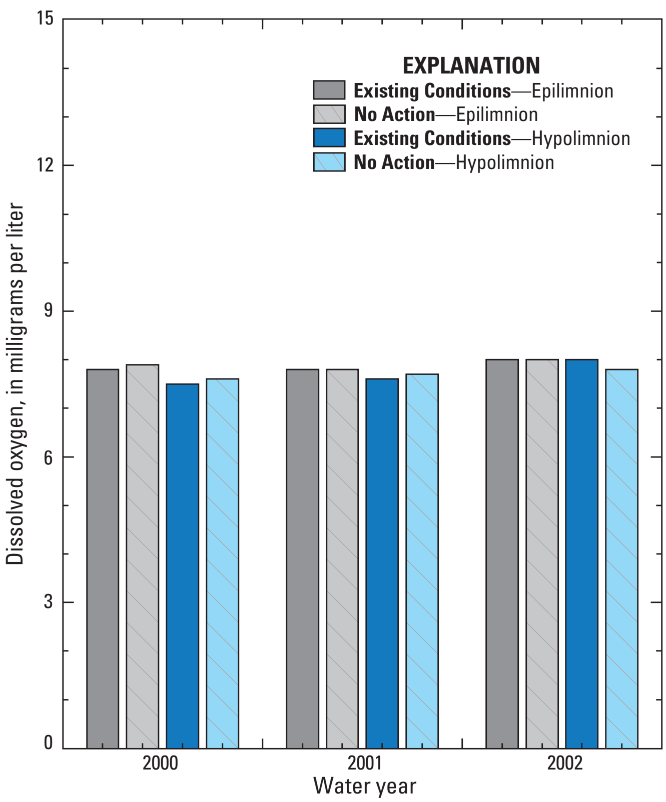

Figure 11. Annual median dissolved oxygen concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1992). Neither the annual median nor the 85th percentile values exceeded 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 (N) and phosphorus (P) are referred to as "major nutrients" because they are needed for plant growth. In excess concentrations, nutrients can promote nuisance algal growth in streams, reservoirs, and other water bodies (eutrophication). Natural sources of nutrients include precipitation and biogeochemical processes in the watershed. Anthropogenic sources of nutrients include but are not limited to urban runoff, domestic effluent, livestock waste, and erosion caused by development (Graffy and others, 1996).

Dissolved Ammonia

Generally, the annual median dissolved ammonia concentrations (as nitrogen (N)) in the epilimnion of Pueblo Reservoir at site 7B were similar for the Existing Conditions and the No Action scenarios. Concentrations in the epilimnion were slightly larger in WY 2002 for the No Action scenario but the difference was only 0.001 mg/L as N (fig. 13 and table 2). Concentrations in the hypolimnion were slightly larger in WY 2000 for the Existing Conditions scenario but, again, the difference was only 0.001 mg/L as N. Concentrations in the hypolimnion generally were about

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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	Existing Conditions	100	25.2	5.8	294	0.006	0.012	0.017	0.017	1.17
	No Action	100	25.2	5.7	289	.006	.017	.016	.005	1.11
	Percent change		0%	–1.7%	–.1.7%	0%	42%	–.5.9%	–71%	–5.1%
2001	Existing Conditions	100	24.5	5.0	237	.007	.016	.017	.005	.94
	No Action	100	24.6	5.0	238	.006	.016	.017	.006	.97
	Percent change		.4%	0%	.4%	–14%	0%	0%	20%	3.2%
2002	Existing Conditions	100	24.5	5.5	275	.011	.028	.018	<.001	1.08
	No Action	100	24.6	5.5	280	.013	.030	.019	<.001	.97
	Percent change		.4%	0%	1.8%	18%	7.1%	5.6%	NA	–.10%
					Hypolimnion					
2000	Existing Conditions	100	18.3	<.1	296	.016	.009	.020	6.49	.82
	No Action	100	17.7	<.1	290	.015	.009	.019	5.87	.80
	Percent change		–3.3%	NA	–2.0%	–.6.3%	0%	–.5.0%	–.9.6%	–.2.4%
2001	Existing Conditions	100	18.9	<.1	238	.016	.014	.022	5.65	.14
	No Action	100	18.9	<.1	238	.015	.014	.022	6.98	.13
	Percent change		0%	NA	0%	–.6.3%	0%	0%	24%	–.7.1%
2002	Existing Conditions	100	15.5	<.1	249	.013	.007	.022	2.18	.25
	No Action	100	14.8	.6	247	.010	.007	.022	.60	.25
	Percent change		–4.5%	NA	–.8%	–.23%	0%	0%	–.72%	0%

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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	Existing Conditions	100	23.8	6.1	296	0.002	0.034	0.017	0.098	1.89
	No Action	100	24.0	6.1	291	.003	.030	.016	.070	1.87
	Percent change		.8%	0%	–1.7%	50%	–12%	–5.9%	–29%	–1.1%
2001	Existing Conditions	100	23.3	5.9	243	.008	.063	.021	.181	1.21
	No Action	100	23.2	5.9	247	.006	.064	.021	.187	1.34
	Percent change		–.4%	0%	1.6%	–25%	1.6%	0%	3.3%	11%
2002	Existing Conditions	100	23.2	6.1	326	.010	.059	.027	.041	5.27
	No Action	100	23.1	5.8	329	.009	.060	.027	.047	4.43
	Percent change		–.4%	–4.9%	.9%	–10%	1.7%	0%	15%	–16%
					Hypolimnion					
2000	Existing Conditions	100	23.1	4.8	299	.004	.032	.018	.498	1.50
	No Action	100	23.3	4.7	294	.004	.031	.017	.445	1.40
	Percent change		.9%	–2.1%	–1.7%	0%	–3.1%	–5.6%	–11%	–6.7%
2001	Existing Conditions	100	23.3	5.9	243	.008	.063	.021	.181	1.21
	No Action	100	22.4	5.0	252	.006	.058	.020	.733	1.16
	Percent change		–3.9%	–15%	3.7%	–25%	–7.9%	–4.8%	305%	–4.1%
2002	Existing Conditions	100	23.0	5.9	326	.009	.047	.027	.047	4.92
	No Action	100	22.8	5.6	330	.008	.047	.028	.054	3.85
	Percent change		–.9%	–5.1%	1.2%	–11%	0%	3.7%	15%	–22%

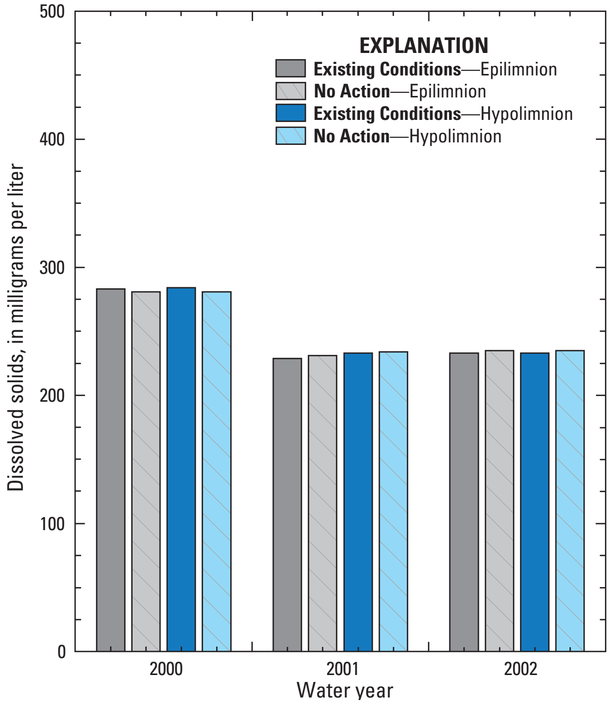

Figure 12. Annual median dissolved solids concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

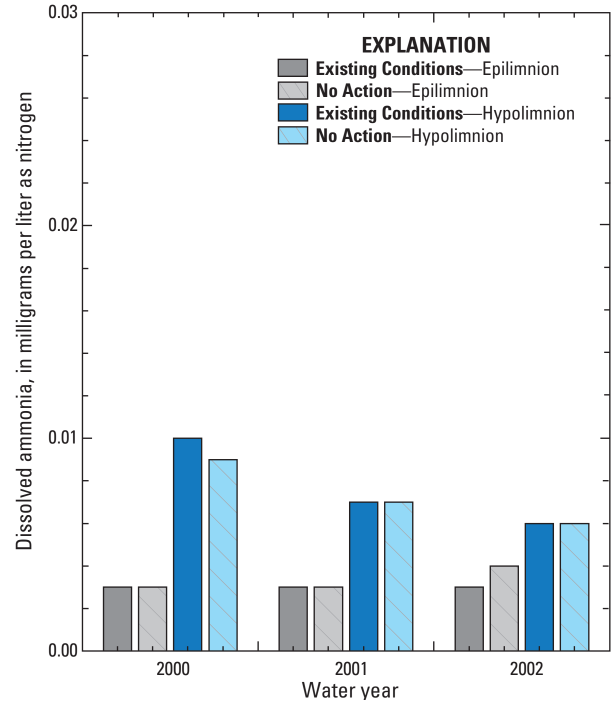

Figure 13. Annual median dissolved ammonia concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

two to three times higher than what were observed in the epilimnion at site 7B. At the upstream site in the reservoir (3B), similar annual dissolved ammonia concentrations were observed between the two scenarios and between the epilimnion and the hypolimnion (table 2).

Dissolved Nitrate

The annual median dissolved nitrate concentrations (as N) in the epilimnion and the hypolimnion at site 7B near the dam generally were similar between the Existing Conditions and the No Action scenarios (fig. 14). The difference in concentrations between the two scenarios for any simulated year was no more than 0.001 mg/L at site 7B (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 (Edelmann, 1989). At the upstream site (3B), the percent change from the Existing Conditions scenario in the epilimnion and hypolimnion was within 11 percent for all simulated years but did not exceed 0.003 mg/L (table 3).

The water-quality standard for dissolved nitrate is 10 mg/L as N, as set by the Colorado Department of Public Health and Environment (Colorado Department of Public Health and Environment, 2007). The standard was not exceeded by any of the annual median or annual 85th percentile values for either simulation scenario for any simulated year in either the epilimnion or hypolimnion (tables 2–5).

Total Phosphorus

Annual median total phosphorus concentrations in the epilimnion and hypolimnion of Pueblo Reservoir generally were similar between the two simulation scenarios (fig. 15). At site 7B and site 3B, the change in concentration between the epilimnion and hypolimnion from the Existing Conditions scenario was only 0.001 mg/L for all of the water years (tables 2 and 3). No specific water-quality standards were applicable for comparison to the simulated results.

Total Iron

The annual median total iron concentrations for the Existing Conditions and No Action scenarios in the epilimnion at site 7B were typically at the minimum calculation threshold (0.001 mg/L; Galloway and others, 2008) for the Pueblo Reservoir model (fig. 16); little or no total iron was simulated in the epilimnion of the reservoir at this site. Only slightly larger annual median concentrations of total iron were simulated in the hypolimnion at site 7B, 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 0.005 mg/L. Temporally, larger total iron concentrations were simulated in the hypolimnion during the summer months at 7B (fig. 17). 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.

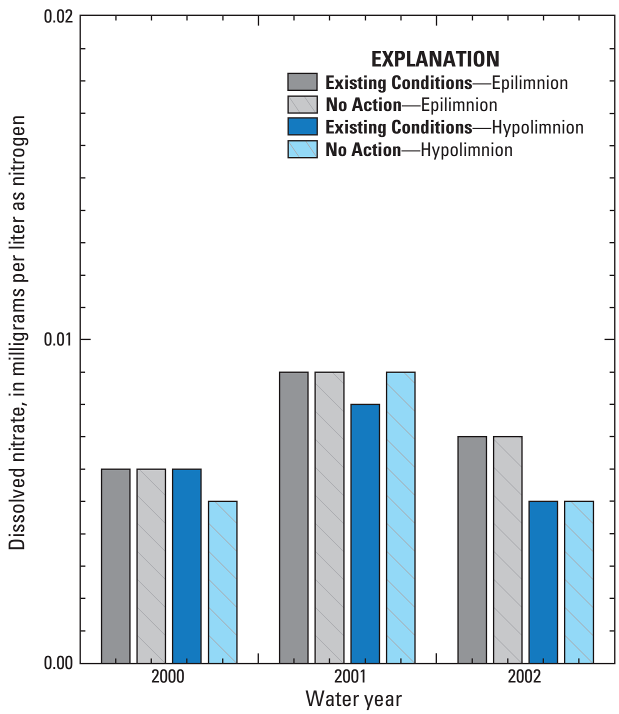

Figure 14. Annual median dissolved nitrate concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

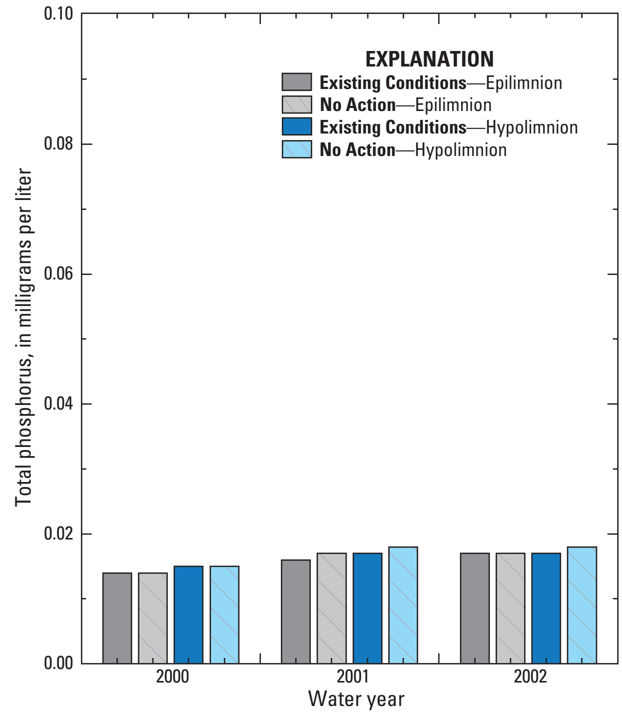

Figure 15. Annual median total phosphorus concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

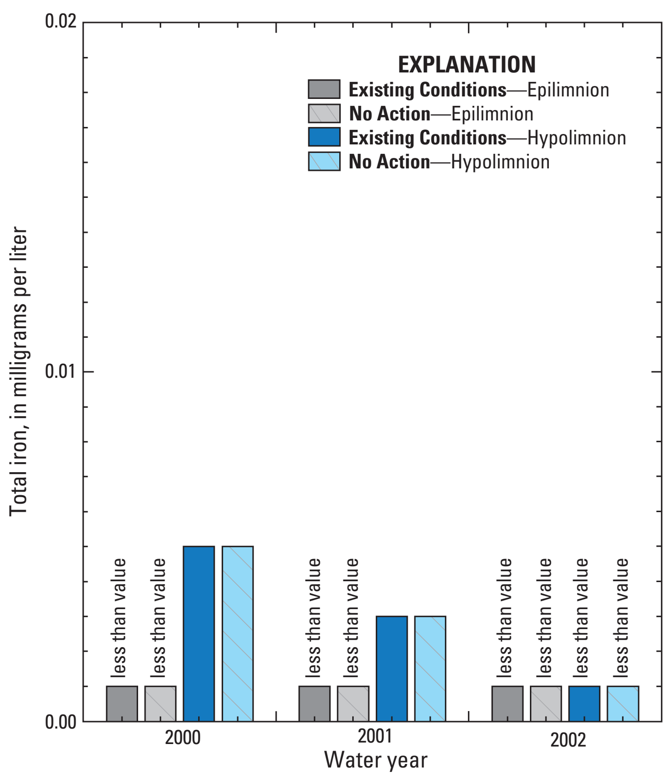

Figure 16. Annual median total iron concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

Overall, the concentrations of total iron at site 3B were substantially larger than those simulated at the downstream site (tables 2 and 3) likely from suspension of particulate material at this more riverine site. Comparisons between the Existing Conditions and No Action scenarios in the epilimnion and hypolimnion at site 3B indicated that there was little difference between the results for the simulations during any water year. Similar to site 7B, larger concentrations were observed in the hypolimnion than in the epilimnion at site 3B.

The State chronic surface-water water-quality standard for total iron in Pueblo Reservoir is set at 1 mg/L (Colorado Department of Public Health and Environment, 2007). No calculated annual median concentration in the epilimnion or in the hypolimnion at sites 7B or 3B exceeded the standard for either simulated scenario (tables 2 and 3). Caution should be used when applying the simulated total iron concentrations to water-quality standards because 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

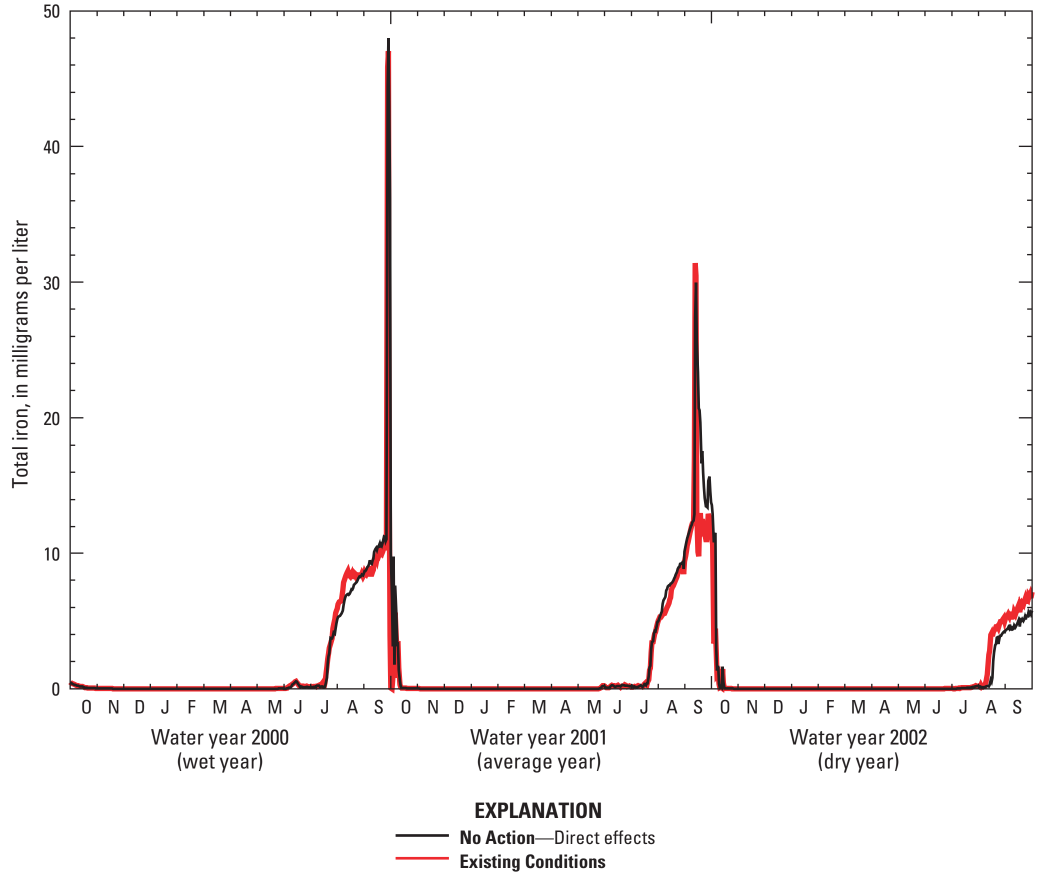

Figure 17. Comparison of total iron concenrations in the hypolimnion at site 7B in Pueblo Reservoir for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

this report included 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. 18 and 19). The largest algal biomass in Pueblo Reservoir generally occurred from May through September when blue-green and green algae were the dominant algal groups at site 7B near the dam of 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 and light availability, and differences in water temperature. Generally, simulated biomass concentrations of green algae, diatoms, and flagellates were less than 0.5 mg/L in the epilimnion and hypolimnion at sites 7B and 3B for either of the two simulation scenarios (Existing Conditions and No Action). Blue-green algae biomass concentrations in the epilimnion at 7B and 3B and in the hypolimnion at 3B could be about 2 to 3 times these concentrations.

Generally, algae biomass concentrations were similar for the Existing Conditions and the No Action scenarios at site 7B in the epilimnion for the simulated period (WY 2000 through WY 2002) (fig. 18). The increase in blue-green algae biomass concentrations occurred each year during May and June when water temperature, light, and nutrient availability were conducive for increased growth in surface waters. Maximum biomass concentrations of blue-green algae in the epilimnion were less than 1 mg/L for the two scenarios at site 7B. In the hypolimnion, there was no marked difference between the two simulation scenarios (fig. 18). Overall, biomass concentrations were less than 0.4 mg/L for any of the algal types at this site.

At site 3B, concentrations of blue-green algae, green algae, diatoms, and flagellates generally were similar between scenarios at any depth (fig. 19). Diatoms were the predominant algal type at this upstream site on Pueblo Reservoir in WY 2000 but transitioned to blue-green algae in WY 2002.

Harmful algal blooms in freshwater, particularly from blue-green algae, can occur when 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

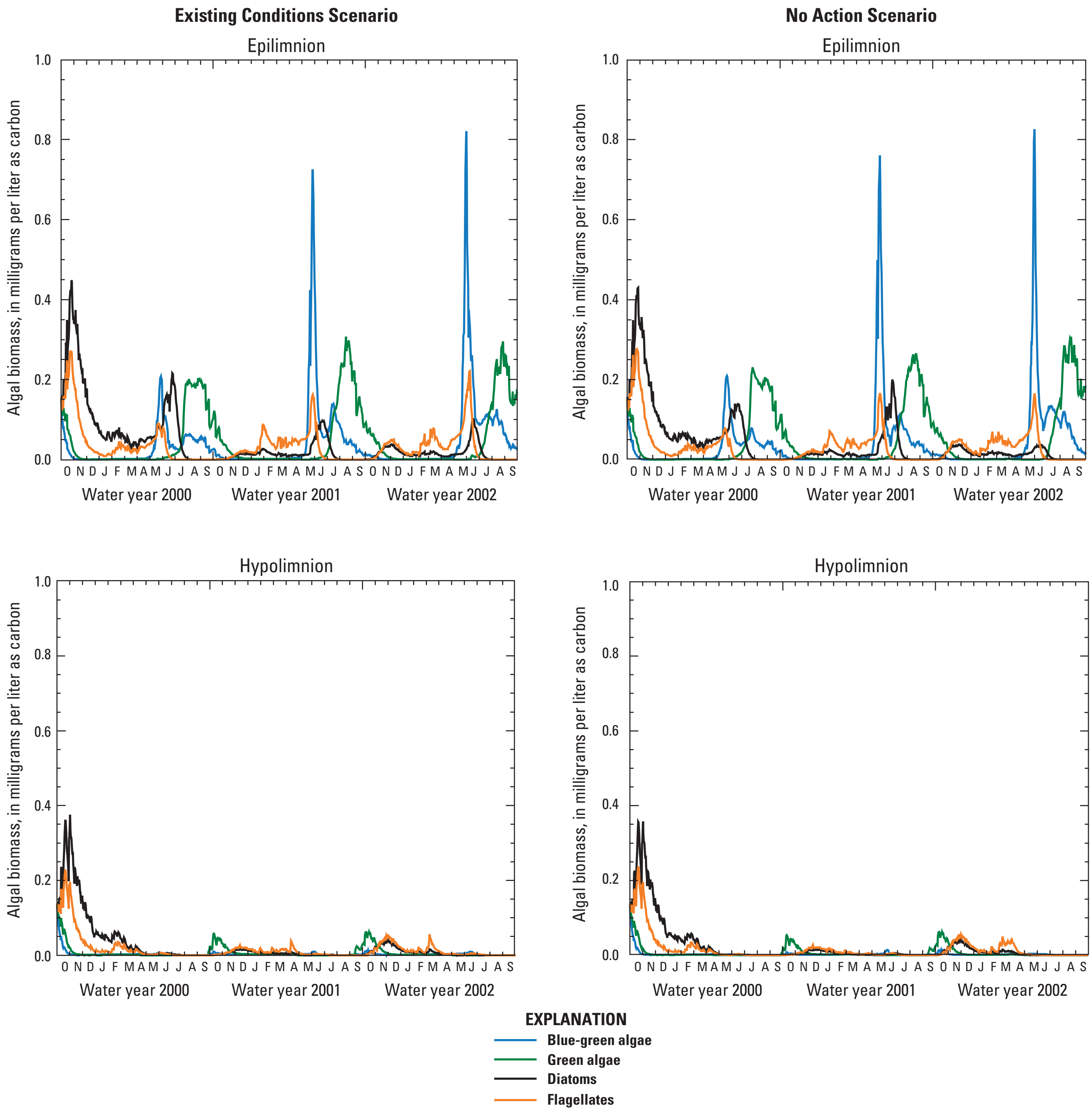

Figure 18. Relation between various algal groups in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

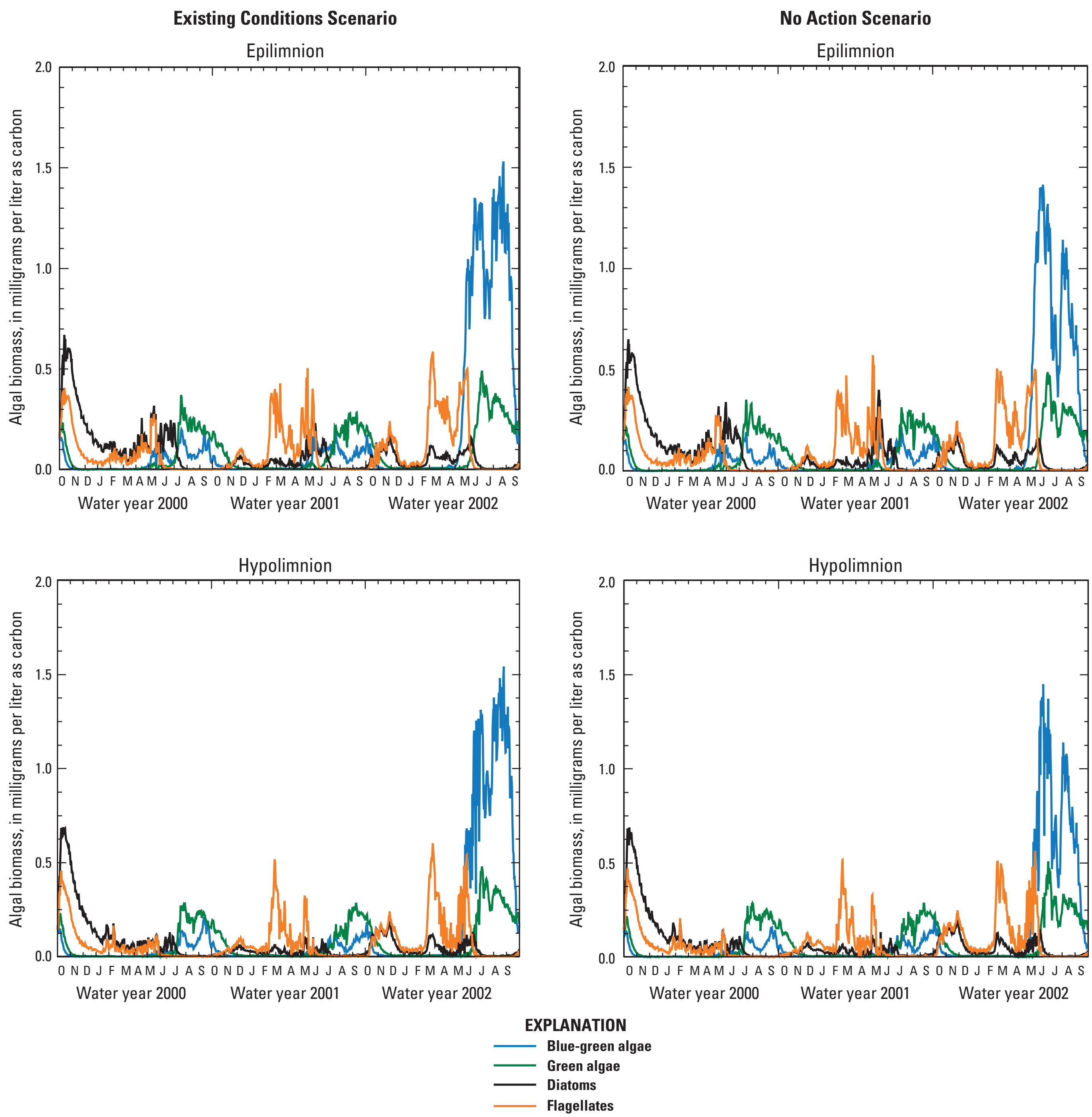

Figure 19. Relation between various algal groups in the epilimnion and hypolimnion at site 3B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

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. Simulated algae biomass 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 ft (Chorus and Bartram, 1999). Secchi depth is a measurement of the clarity of a reservoir defined as the depth at which an 8-inch diameter black and white disk is no longer visible in the water column.

Annual median chlorophyll-*a* concentrations in the epilimnion and hypolimnion near the dam (site 7B) were similar for the No Action scenario and the Existing Conditions scenario (fig. 20, table 2). In the epilimnion, the differences in median concentrations between the two scenarios differed by no more than 0.02 µg/L over the three simulated years; the percent change from the Existing Conditions scenario was less than 4 percent for all simulated years (table 2). In the hypolimnion, annual median concentrations differed by no more than 0.02 µg/L over the three years. Concentrations were consistently larger in the epilimnion where photosynthesis was greater than in the hypolimnion.

Annual median chlorophyll-*a* concentrations in the epilimnion and hypolimnion at site 3B were similar between the No Action and Existing Conditions scenarios (table 3). Generally, concentrations differed by no more than 0.1 µg/L at any depth.

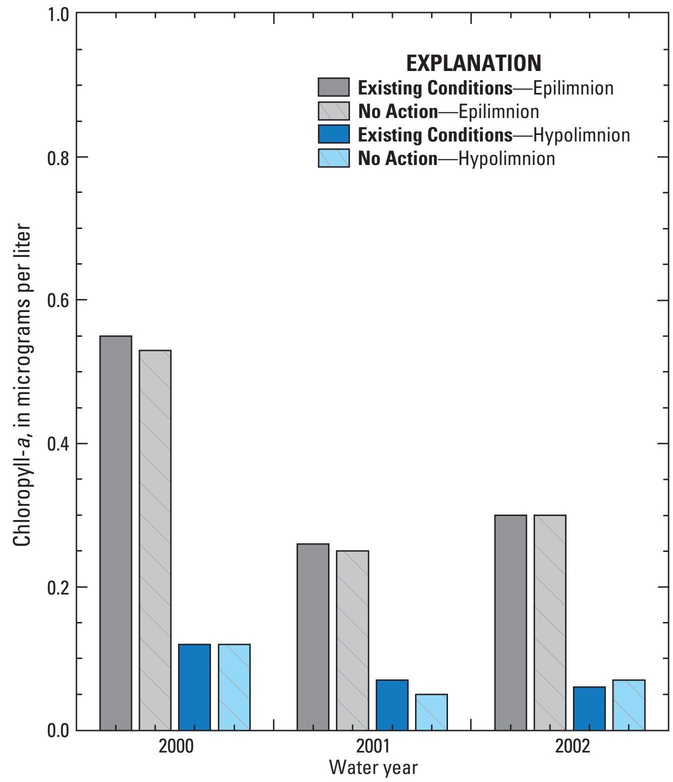

Figure 20. Annual median chlorophyll-*a* concentrations in the epilimnion and hypolimnion at site 7B for the Existing Conditions (water years 2000 through 2002) and No Action (direct-effects analysis) scenarios.

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 No Action scenario was compared individually to the Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios. 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. 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. 21). However, differences in reservoir water-surface elevation (storage) among the four scenarios did increase each year. Reservoir storage for the Master Contract Only and Comanche South scenarios was greater than the No Action scenario, whereas,

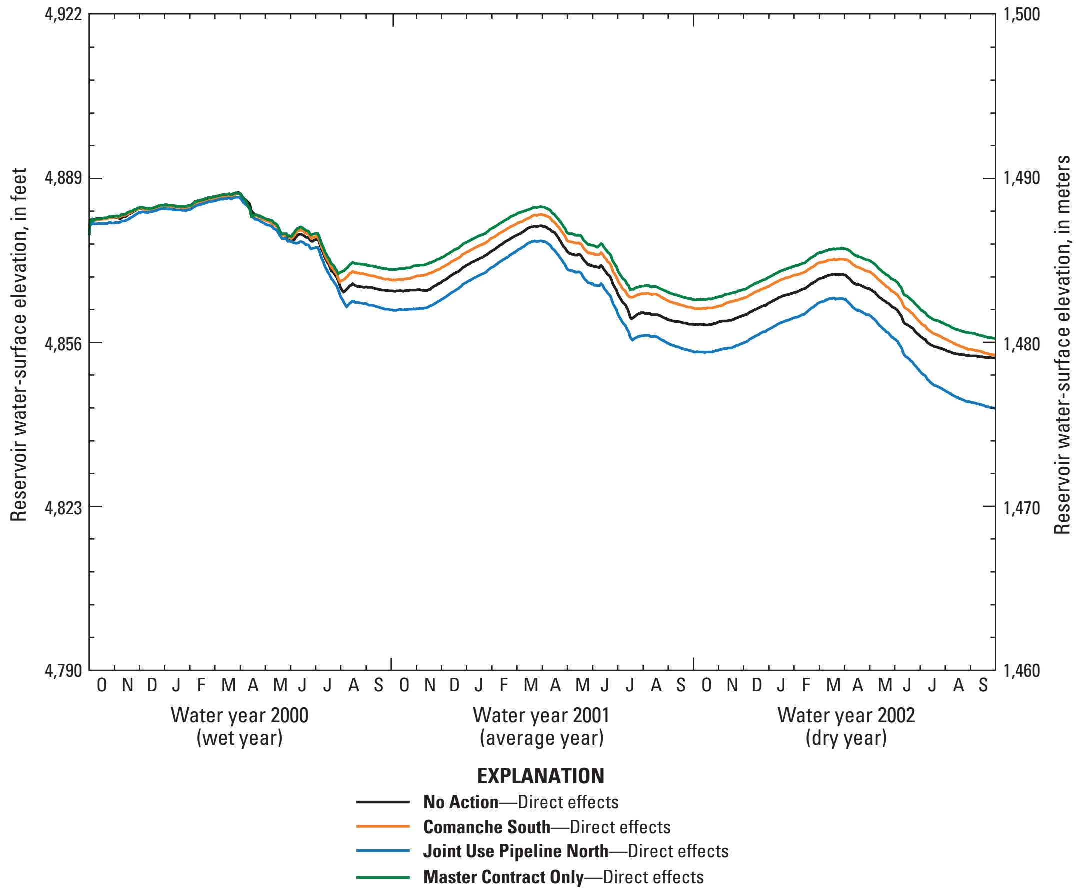

Figure 21. Comparison of water-surface elevations in Pueblo Reservoir for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses). Datum is North American Vertical Datum of 1988 (NAVD 88).

storage for the Joint Use Pipeline North was less. Overall, there was a temporal decrease in water-surface elevations from WY 2000 through WY 2002 for all the simulated scenarios. At the peak annual storage, the difference between the surface-water elevation for the No Action scenario and any other comparable simulated elevation was no more than 1 ft in WY 2000, 3 ft in WY 2001, and 6 ft in WY 2002. Typically, maximum storage occurred in late March of each year as winter storage was nearly complete and releases of water to downstream irrigators had yet to start.

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 simulated scenarios generally provided similar results (fig. 22). At site 7B, the percent change from the No Action scenario in the epilimnion was less than 5 percent for all simulated years (table 6). Water temperatures in the hypolimnion were similar but more variable between the simulation scenarios. In WY 2000, there were no differences in the simulated annual hypolimnetic water temperature between the No Action scenario and the other three modeled simulations. In WY 2001, the difference in annual median water temperature between the No Action and the Master Contract Only scenarios was 1 °C (11 percent) increasing to 1.7 °C (18 percent) in WY 2002. The water temperature associated with the Master Contract Only scenario was higher during both years. Generally, temperatures in the hypolimnion were 4 °C to 5 °C lower than those in the epilimnion. Annual median water temperatures in the epilimnion and the hypolimnion at site 3B between scenarios also were similar; the differences were within 10 percent when compared to the No Action scenario (table 7).

Dissolved Oxygen

Comparisons between the No Action scenario and the three other scenarios indicated that the annual median values of simulated DO concentrations in the epilimnion at site 7B generally were similar (fig. 23). Typically, the percent change from the No Action scenario was within 2 percent in the epilimnion for the simulated scenarios for any simulated year at site 7B (table 6). The percent change from the No Action scenario in the hypolimnion was less than 6 percent for the simulated scenarios for any simulated year (table 6).

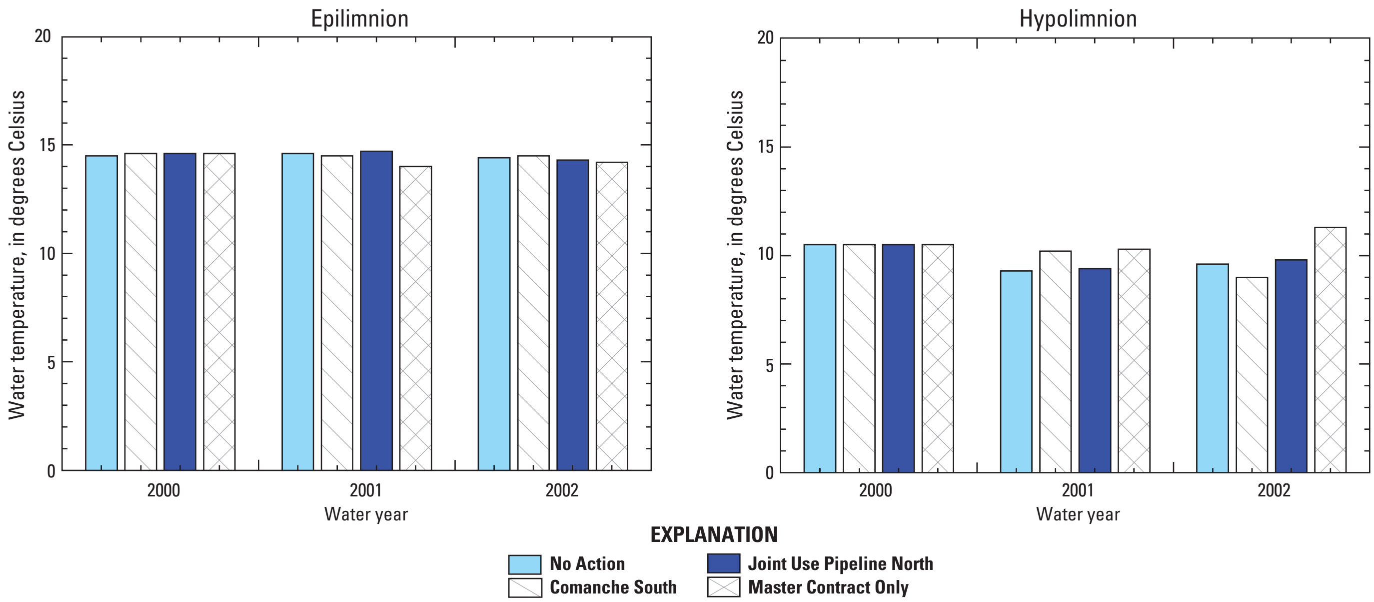

Figure 22. Annual median water temperature in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

Comparisons of DO concentrations in the epilimnion and hypolimnion at site 3B generally showed similar results for WY 2000 through WY 2002 (table 7). The Joint Use Pipeline North scenario had a median concentration in 2002 that was substantially higher than the No Action (18 percent), however, only 83 percent of data were available to compute this statistic; the Joint Use Pipeline North scenario was the only scenario that "dried up" during model simulations.

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 results from the No Action scenario differed by no more than 2 percent (0.1 mg/L) from any of the other three compared scenarios (table 8). Overall, the annual 15th percentile values in the epilimnion at site 7B were at least 4.9 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 months in the hypolimnion at site 7B (fig. 6). Simulated results for the Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios also show similar results (fig. 7). The 15th percentile concentration was 1.6 mg/L or less in the hypolimnion for all of these scenarios (table 8).

The minimum DO concentration suitable to meet the DO water-quality standard in Pueblo Reservoir (measured in the epilimnion) was 6.0 mg/L (Colorado Department of Public Health and Environment, 2007). The standard is compared to the 15th percentile of the data. 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). 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 was 1.42 mg/L at site 7B (Galloway and others, 2008).

Dissolved Solids

Comparisons of simulated dissolved solids concentrations indicated that the annual medians were relatively similar between the No Action and the Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios in the epilimnion and hypolimnion at site 7B (near-dam site) (fig. 24). Simulated results for the No Action scenario were no more than 3 percent larger than the annual medians for the other three scenarios during WY 2000 through WY 2002 (table 6). The results were similar for both the epilimnion and the hypolimnion. For the most part, similar results also 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 secondary maximum contaminant level is set at 500 mg/L (U.S. Environmental Protection Agency, 1992). The largest annual median dissolved solids concentration was reported at site 3B (284 mg/L) in WY 2000 (tables 6 and 7). No annual 85th percentile value exceeded the recommended guideline for any of the simulated scenarios at sites 7B and 3B (tables 8 and 9).

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 Comanche South, Joint-Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	No Action	100	14.5	7.9	281	0.003	0.006	0.014	<0.001	0.53
	Comanche South	100	14.6	7.9	280	.003	.006	.014	<.001	.54
	Percent change		.7%	0%	–.4%	0%	0%	0%	NA	1.9%
	No Action	100	14.5	7.9	281	.003	.006	.014	<.001	.53
	Joint Use Pipeline North	100	14.6	7.8	281	.003	.006	.014	<.001	.53
	Percent change		.7%	–1.3%	0%	0%	0%	0%	NA	0%
	No Action	100	14.5	7.9	281	.003	.006	.014	<.001	.53
	Master Contract Only	100	14.6	7.8	278	.003	.006	.014	<.001	.52
	Percent change		.7%	–1.3%	–1.1%	0%	0%	0%	NA	–1.9%
					Hypolimnion					
2000	No Action	100	10.5	7.6	281	.009	.005	.015	.005	.12
	Comanche South	100	10.5	7.6	281	.009	.005	.015	.005	.12
	Percent change		0%	0%	0%	0%	0%	0%	0%	0%
	No Action	100	10.5	7.6	281	.009	.005	.015	.005	.12
	Joint Use Pipeline North	100	10.5	7.6	281	.010	.006	.015	.005	.12
	Percent change		0%	0%	0%	11%	20%	0%	0%	0%
	No Action	100	10.5	7.6	281	.009	.005	.015	.005	.12
	Master Contract Only	100	10.5	7.6	279	.009	.005	.015	.005	.12
	Percent change		0%	0%	–.7%	0%	0%	0%	0%	0%
					Epilimnion					
2001	No Action	100	14.6	7.8	231	.003	.009	.017	<.001	.25
	Comanche South	100	14.5	7.9	227	.002	.009	.016	<.001	.25
	Percent change		–.7%	1.3%	–1.7%	–33%	0%	–5.9%	NA	0%
	No Action	100	14.6	7.8	231	.003	.009	.017	<.001	.25
	Joint Use Pipeline North	100	14.7	7.9	233	.002	.008	.016	<.001	.26
	Percent change		.7%	1.3%	.9%	–33%	–11%	–5.9%	NA	4.0%
	No Action	100	14.6	7.8	231	.003	.009	.017	<.001	.25
	Master Contract Only	100	14.0	7.8	224	.003	.012	.017	<.001	.26
	Percent change		–4.1%	0%	–3.0%	0%	33%	0%	NA	4.0%
					Hypolimnion					
2001	No Action	100	9.3	7.7	234	.007	.009	.018	.003	.05
	Comanche South	100	10.2	7.5	231	.006	.009	.017	.003	.05
	Percent change		9.7%	–2.6%	–1.3%	–14%	0%	–5.6%	0%	0%
	No Action	100	9.3	7.7	234	.007	.009	.018	.003	.05
	Joint Use Pipeline North	100	9.4	7.7	235	.007	.007	.017	.003	.06
	Percent change		1.1%	0%	.4%	0%	–22%	–5.6%	0%	20%
	No Action	100	9.3	7.7	234	.007	.009	.018	.003	.05
	Master Contract Only	100	10.3	7.5	228	.006	.008	.018	.003	.04
	Percent change		11%	–2.6%	–2.6%	–14%	–11%	0%	0%	–20%
					Epilimnion					
2002	No Action	100	14.4	8.0	235	.004	.007	.017	<.001	.30
	Comanche South	100	14.5	8.0	230	.003	.009	.017	<.001	.26
	Percent change		.7%	0%	–2.1%	–25%	29%	0%	NA	–13%
	No Action	100	14.4	8.0	235	.004	.007	.017	<.001	.30
	Joint Use Pipeline North	100	14.3	8.1	238	.003	.008	.018	<.001	.26
	Percent change		–.7%	1.3%	1.3%	–25%	14%	5.9%	NA	–13%
	No Action	100	14.4	8.0	235	.004	.007	.017	<.001	.30
	Master Contract Only	100	14.2	8.1	228	.003	.009	.017	<.001	.22
	Percent change		–1.4%	1.3%	–3.0%	–25%	29%	0%	NA	–27%
					Hypolimnion					
2002	No Action	100	9.6	7.8	235	.006	.005	.018	<.001	.07
	Comanche South	100	9.0	8.1	230	.006	.005	.017	<.001	.07
	Percent change		–6.3%	3.8%	–2.1%	0%	0%	–5.6%	NA	0%
	No Action	100	9.6	7.8	235	.006	.005	.018	<.001	.07
	Joint Use Pipeline North	100	9.8	7.9	237	.006	.006	.018	<.001	.06
	Percent change		2.1%	1.3%	.9%	0%	20%	0%	NA	–14%
	No Action	100	9.6	7.8	235	.006	.005	.018	<.001	.07
	Master Contract Only	100	11.3	7.4	228	.006	.005	.018	<.001	.07
	Percent change		18%	–5.1%	–3.0%	0%	0%	0%	NA	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 Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-a (µg/L)
	Epilimnion									
	No Action	100	14.0	7.9	282	<0.001	0.005	0.015	0.010	0.91
	Comanche South	100	14.0	7.9	284	<.001	.004	.015	.009	.90
	Percent change		0%	0%	.7%	0%	–20%	0%	–10%	–1.1%
	No Action	100	14.0	7.9	282	<.001	.005	.015	.010	.91
2000	Joint Use Pipeline North	100	14.0	7.9	284	<.001	.005	.015	.011	1.02
	Percent change		0%	0%	.7%	NA	0%	0%	10%	12%
	No Action	100	14.0	7.9	282	<.001	.005	.015	.010	.91
	Master Contract Only	100	14.0	7.8	282	<.001	.004	.015	.007	.87
	Percent change		0%	–1.3%	0%	NA	–20%	0%	–30%	–4.4%
	Hypolimnion									
	No Action	100	12.0	7.8	282	.002	.012	.016	.031	.70
	Comanche South	100	12.1	7.8	283	.002	.012	.016	.031	.69
	Percent change		.8%	0%	.4%	0%	0%	0%	0%	–1.4%
	No Action	100	12.0	7.8	282	.002	.012	.016	.031	.70
2000	Joint Use Pipeline North	100	12.0	7.8	283	.002	.012	.016	.034	.72
	Percent change		0%	0%	.4%	0%	0%	0%	9.7%	2.9%
	No Action	100	12.0	7.8	282	.002	.012	.016	.031	.70
	Master Contract Only	100	12.1	7.8	281	.002	.011	.016	.030	.71
	Percent change		.8%	0%	–.4%	0%	–8.3%	0%	–3.2%	1.4%
	Epilimnion									
	No Action	100	13.9	7.8	235	.002	.017	.018	.009	.75
	Comanche South	100	13.8	7.7	230	.002	.014	.017	.006	.71
	Percent change		–.7%	–1.3%	–2.1%	0%	–18%	–5.6%	–33%	–5.3%
	No Action	100	13.9	7.8	235	.002	.017	.018		.75
2001	Joint Use Pipeline North	100	13.4	8.0	239	.003	.026	.019	.014	.64
	Percent change		–3.6%	2.6%	1.7%	50%	53%	5.6%	56%	–15%
	No Action	100	13.9	7.8	235	.002	.017	.018	.009	.75
	Master Contract Only	100	13.9	7.7	227	.002	.016	.017	.006	.73
	Percent change		0%	–1.3%	–3.4%	0%	–5.9%	–5.6%	–33%	–2.7%
	Hypolimnion									
	No Action	100	11.2	7.6	239	.003	.033	.019	.027	.51
	Comanche South	100	10.9	7.7	235	.003	.027	.018	.027	.53
	Percent change		–2.7%	1.3%	–1.7%	0%	–18%	–5.3%	0%	3.9%
	No Action	100	11.2	7.6	239	.003	.033	.019	.027	.51
2001	Joint Use Pipeline North	100	11.1	7.9	242	.004	.035	.019	.035	.52
	Percent change		–.9%	3.9%	1.3%	33%	6.1%	0%	30%	2%
	No Action	100	11.2	7.6	239	.003	.033	.019	.027	.51
	Master Contract Only	100	11.0	7.6	233	.003	.029	.018	.024	.50
	Percent change		–1.8%	0%	–2.5%	0%	–12%	–5.3%	–11%	–2.0%
	Epilimnion									
	No Action	100	13.4	7.9	260	.003	.008	.023	.014	1.29
	Comanche South	100	14.3	7.9	258	.003	.009	.022	.010	1.19
	Percent change		6.7%	0%	-.8%	0%	12%	–4.3%	–29%	–7.8%
	No Action	100	13.4	7.9	260	.003	.008	.023	.014	1.29
2002	Joint Use Pipeline North	100	12.2	8.1	282	.009	.037	.024	.032	.64
	Percent change		–9.0%	2.5%	8.5%	200%	362%	4.3%	129%	–50%
	No Action	100	13.4	7.9	260	.003	.008	.023	.014	1.29
	Master Contract Only	100	14.5	8.0	255	.003	.010	.022	.008	1.14
	Percent change		8.2%	1.3%	-1.9%	0%	25%	–4.3%	–43%	–12%
	Hypolimnion									
	No Action	100	12.3	7.8	260	.003	.009	.022	.022	1.31
	Comanche South	100	12.4	7.7	254	.003	.010	.021	.017	1.12
	Percent change		.8%	–1.3%	–2.3%	0%	11%	–4.5%	–23%	–15%
	No Action	100	12.3	7.8	260	.003	.009	.022	.022	1.31
2002	Joint Use Pipeline North	83[1]	11.4	9.2	261	.006	.034	.024	.033	.62
	Percent change		–7.3%	18%	.4%	100%	278%	9.1%	50%	–53%
	No Action	100	12.3	7.8	260	.003	.009	.022	.022	1.31
	Master Contract Only	100	12.1	7.6	249	.003	.010	.021	.015	.91
	Percent change		–1.6%	–2.6%	–4.2%	0%	11%	–4.5%	–32%	–31%

[1]Computational cells in the model "dry up" for this scenario due to drought conditions observed in 2002. Percent change calculated on less than 100 percent of the daily values for this water year.

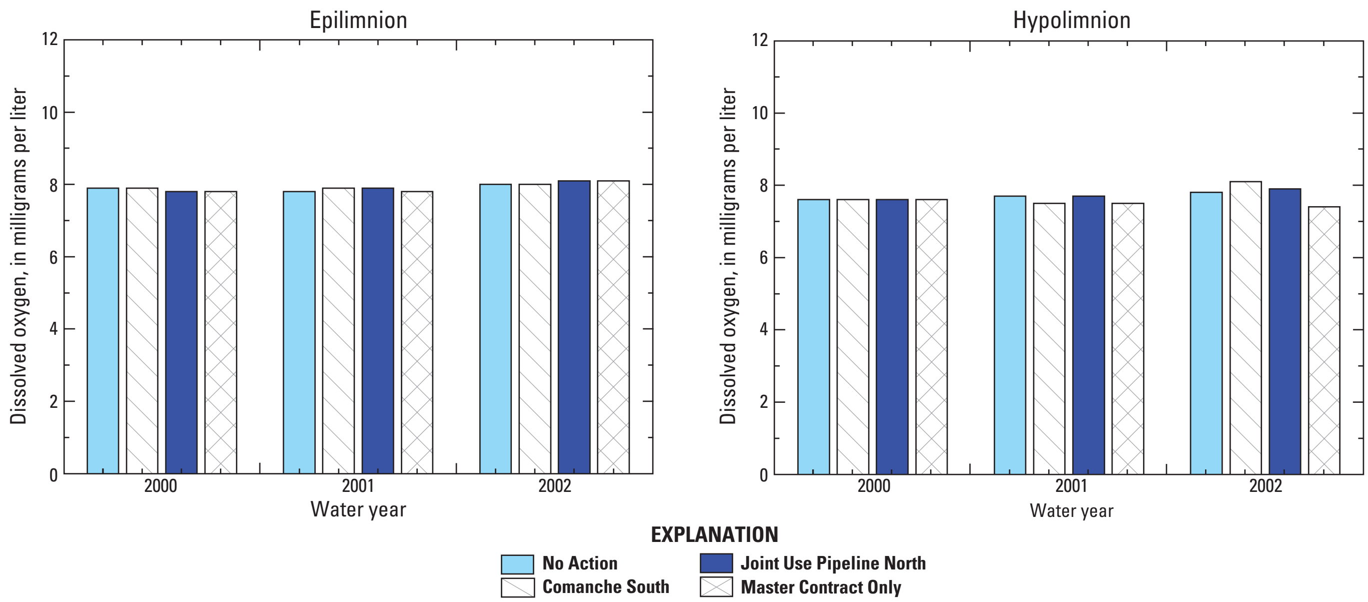

Figure 23. Annual median dissolved oxygen concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

Major Nutrients

Nutrients are essential for plant growth. The main nutrients of concern in lakes and streams are nitrogen and phosphorus, which can be found in various forms. Factors such as water temperature, pH, dissolved oxygen concentrations, and biological activity influence the concentrations of nitrogen and phosphorus forms found in lakes and streams. Natural sources of nitrogen and phosphorus include precipitation and biogeochemical processes in the watershed. Anthropogenic sources of nutrients include but are not limited to urban runoff, domestic effluent, livestock waste, and erosion caused by development (Gaffey and others, 1996).

Dissolved Ammonia

The annual median dissolved ammonia (as nitrogen (N)) concentrations in the epilimnion and hypolimnion of Pueblo Reservoir at site 7B were similar between the No Action scenario and either the Comanche South, Joint Use Pipeline North, or Master Contract Only scenarios (fig. 25). Annual median simulated ammonia concentrations at either depth for the No Action scenario were within 0.001 mg/L of any of the other simulated scenarios (table 6). Annual median simulated ammonia concentrations in the epilimnion at site 7B were less than annual median simulated concentrations in the hypolimnion.

Similar results were observed in the epilimnion and hypolimnion at site 3B in the upstream riverine section of the reservoir with the exception of comparisons to the Joint Use Pipeline North scenario in WY 2002 (table 7). Typically, differences from the No Action scenario did not exceed more than 0.001 mg/L for these comparisons. Larger differences in concentration, however, were observed between the No Action scenario and the Joint Use Pipeline North scenario at either of the two simulated depths; the differences were as large as 0.006 mg/L.

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 any of the three simulated scenarios (fig. 26). Percent differences from the No Action scenario compared to the three simulated scenarios did not exceed 33 percent for these comparisons (table 6). Because of the relatively small concentrations of nitrate in Pueblo Reservoir, a change of 33 percent equated to an overall difference of only 0.003 mg/L as N between the annual median concentrations. Similar results were observed in the hypolimnion at site 7B (table 6).

Overall, observed results in the epilimnion and hypolimnion at site 3B were more variable with regard to the percent change in concentrations when compared to the No Action scenario (table 7). Whereas, concentrations varied by only 0.003 mg/L as N at site 7B, concentrations at site 3B varied from the No Action results by as much as 0.029 mg/L as N (Joint Use Pipeline North in WY 2002). Annual median nitrate concentrations at this upstream site also were larger than concentrations observed at site 7B near the dam. Denitrification processes and consumption from algal growth likely resulted in the decrease in concentration in the lower portion of the reservoir. A maximum annual median concentration of 0.037 (Joint Use Pipeline North in WY 2002) was still small in terms of nitrate concentrations with public health implications. The water-quality standard for dissolved nitrate is 10 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 Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-a (µg/L)
					Epilimnion					
2000	No Action	100	25.2	5.7	289	0.006	0.017	0.016	0.005	1.11
	Comanche South	100	25.2	5.7	290	.006	.017	.016	.005	1.08
	Percent change		0%	0%	0.3%	0%	0%	0%	0%	–2.7%
	No Action	100	25.2	5.7	289	.006	.017	.016	.005	1.11
	Joint Use Pipeline North	100	25.2	5.7	290	.006	.011	.016	.008	1.13
	Percent change		0%	0%	.3%	0%	–35%	0%	60%	1.8%
	No Action	100	25.2	5.7	289	.006	.017	.016	.005	1.11
	Master Contract Only	100	25.2	5.7	288	.006	.017	.016	.005	1.07
	Percent change		0%	0%	–.3%	0%	0%	0%	0%	–3.6%
					Hypolimnion					
2000	No Action	100	17.7	<.1	290	.015	.009	.019	5.87	.80
	Comanche South	100	17.6	<.1	291	.015	.009	.019	6.71	.80
	Percent change		–.6%	NA	.3%	0%	0%	0%	14%	0%
	No Action	100	17.7	<.1	290	.015	.009	.019	5.87	.80
	Joint Use Pipeline North	100	18.3	<.1	292	.015	.009	.020	6.86	80
	Percent change		3.4%	NA	.7%	0%	0%	5.3%	17%	0%
	No Action	100	17.7	<.1	290	.015	.009	.019	5.87	.80
	Master Contract Only	100	17.3	<.1	289	.015	.009	.019	6.40	.79
	Percent change		–2.3%	NA	–.3%	0%	0%	0%	9.0%	–1.3%
					Epilimnion					
2001	No Action	100	24.6	5.0	238	.006	.016	.017	.006	.97
	Comanche South	100	24.7	4.9	233	.007	.016	.017	.006	.90
	Percent change		.4%	–2.0%	–2.1%	17%	0%	0%	0%	–7.2%
	No Action	100	24.6	5.0	238	.006	.016	.017	.006	.97
	Joint Use Pipeline North	100	24.8	5.0	241	.007	.015	.017	.003	.93
	Percent change		.8%	0%	1.3%	17%	–6.3%	0%	–50%	–4.1%
	No Action	100	24.6	5.0	238	.006	.016	.017	.006	.97
	Master Contract Only	100	24.7	5.0	231	.007	.020	.017	.006	.89
	Percent change		.4%	0%	–2.9%	17%	25%	0%	0%	–8.2%
					Hypolimnion					
2001	No Action	100	18.9	<.1	238	.015	.014	.022	6.98	.13
	Comanche South	100	18.7	<.1	234	.014	.014	.022	6.10	.13
	Percent change		–1.1%	NA	–1.7%	–6.7%	0%	0%	–13%	0%
	No Action	100	18.9	<.1	238	.015	.014	.022	6.98	.13
	Joint Use Pipeline North	100	19.3	<.1	240	.014	.012	.021	2.76	.17
	Percent change		2.1%	NA	.8%	–6.7%	–14%	–4.5%	–60%	31%
	No Action	100	18.9	<.1	238	.015	.014	.022	6.98	.13
	Master Contract Only	100	18.5	<.1	233	.014	.016	.022	6.35	.10
	Percent change		–2.1%	NA	–2.1%	–6.7%	14%	0%	–9.0%	–23%
					Epilimnion					
2002	No Action	100	24.6	5.5	280	.013	.030	.019	<.001	.97
	Comanche South	100	24.5	5.5	277	.014	.034	.018	.002	.90
	Percent change		–.4%	0%	–1.1%	7.7%	13%	–5.3%	NA	–7.2%
	No Action	100	24.6	5.5	280	.013	.030	.019	<.001	.97
	Joint Use Pipeline North	100	24.6	5.5	282	.010	.013	.020	<.001	1.11
	Percent change		0%	0%	.7%	–23%	–57%	5.3%	NA	14%
	No Action	100	24.6	5.5	280	.013	.030	.019	<.001	.97
	Master Contract Only	100	24.5	5.5	271	.013	.034	.018	<.001	.92
	Percent change		–.4%	0%	–3.2%	0%	13%	–5.3%	NA	–5.2%
					Hypolimnion					
2002	No Action	100	14.8	.6	247	.010	.007	.022	.605	.25
	Comanche South	100	14.5	1.6	243	.009	.008	.021	.209	.23
	Percent change		–2.0%	167%	–1.6%	–10%	14%	–4.5%	–66%	–8%
	No Action	100	14.8	.6	247	.010	.007	.022	.605	.25
	Joint Use Pipeline North	100	17.0	<.1	255	.014	.009	.024	2.38	.18
	Percent change		15%	NA	3.2%	40%	29%	9.1%	293%	–28%
	No Action	100	14.8	.6	247	.010	.007	.022	.605	.25
	Master Contract Only	100	15.0	.2	242	.010	.008	.022	1.48	.18
	Percent change		1.4%	–67%	–2.0%	0%	14%	0%	144%	–28%

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 Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
				Epilimnion						
2000	No action	100	24.0	6.1	291	0.003	0.030	0.016	0.070	1.87
	Comanche South	100	24.3	6.1	292	.003	.029	.016	.062	1.79
	Percent change		1.3%	0%	.3%	0%	–3.3%	0%	–11%	–4.3%
	No action	100	24.0	6.1	291	.003	.030	.016	.070	1.87
	Joint Use Pipeline North	100	23.8	6.1	292	.002	.030	.017	.083	1.82
	Percent change		–.8%	0%	.3%	–33%	0%	6.2%	19%	–2.7%
	No action	100	24.0	6.1	291	.003	.030	.016	.070	1.87
	Master Contract only	100	24.4	6.1	289	.003	.030	.016	.061	1.84
	Percent change		1.7%	0%	–.7%	0%	0%	0%	–13%	–1.6%
				Hypolimnion						
2000	No action	100	23.3	4.7	294	.004	.031	.017	.445	1.40
	Comanche South	100	23.2	4.7	295	.004	.030	.017	.493	1.36
	Percent change		–.4%	0%	.3%	0%	–3.2%	0%	11%	–2.9%
	No action	100	23.3	4.7	294	.004	.031	.017	.445	1.40
	Joint Use Pipeline North	100	22.7	4.8	296	.005	.035	.018	.541	1.60
	Percent change		–2.6%	2.1%	.7%	25%	13%	5.9%	22%	14%
	No action	100	23.3	4.7	294	.004	.031	.017	.445	1.40
	Master Contract only	100	23.2	4.6	294	.004	.029	.017	.469	1.38
	Percent change		–.4%	–2.1%	0%	0%	–6.5%	0%	5.4%	–1.4%
				Epilimnion						
2001	No action	100	23.2	5.9	247	.006	.064	.021	.187	1.34
	Comanche South	100	23.6	6.0	242	.005	.056	.020	.092	1.21
	Percent change		1.7%	1.7%	–2.0%	–17%	–12%	–4.8%	–51%	–9.7%
	No action	100	23.2	5.9	247	.006	.064	.021	.187	1.34
	Joint Use Pipeline North	100	22.4	5.5	258	.009	.073	.022	.373	1.15
	Percent change		–3.4%	–6.8%	4.5%	50%	14%	4.8%	99%	–14%
	No action	100	23.2	5.9	247	.006	.064	.021	.187	1.34
	Master Contract only	100	23.7	6.0	239	.006	.049	.020	.069	1.18
	Percent change		2.2 %	1.7%	–3.2%	0%	–23%	–4.8%	–63%	–12%
				Hypolimnion						
2001	No action	100	22.4	5.0	252	.006	.058	.020	.733	1.16
	Comanche South	100	22.8	4.8	247	.005	.051	.020	.462	1.09
	Percent change		1.8%	–4.0%	–2.0%	–17%	–12%	0%	–37%	–6.0%
	No action	100	22.4	5.0	252	.006	.058	.020	.733	1.16
	Joint Use Pipeline North	100	22.0	5.1	263	.008	.068	.021	.791	.80
	Percent change		–1.8%	2.0%	4.4%	33%	17%	5.0%	7.9%	–31%
	No Action	100	22.4	5.0	252	.006	.058	.020	.733	1.16
	Master Contract only	100	22.8	4.8	244	.005	.051	.020	.498	1.03
	Percent change		1.8%	–4.0%	–3.2%	–17%	–12%	0%	–32%	–11%
				Epilimnion						
2002	No Action	100	23.1	5.8	329	.009	.060	.027	.047	4.43
	Comanche South	100	23.2	6.1	324	.009	.048	.026	.042	5.46
	Percent change		.4%	5.2%	–1.5%	0%	–20%	–3.7%	–11%	23%
	No Action	100	23.1	5.8	329	.009	.060	.027	.047	4.43
	Joint Use Pipeline North	100	22.5	5.4	336	.016	.073	.032	.175	1.94
	Percent change		–2.6%	–6.9%	2.1%	78%	22%	18%	272%	–56%
	No Action	100	23.1	5.8	329	.009	.060	.027	.047	4.43
	Master Contract Only	100	23.3	6.1	313	.009	.041	.024	.034	4.14
	Percent change		.9 %	5.2%	–4.9%	0%	–32%	–11%	–28%	–6.5%
				Hypolimnion						
2002	No Action	100	22.8	5.6	330	.008	.047	.028	.054	3.85
	Comanche South	100	23.0	5.9	324	.008	.033	.026	.054	5.24
	Percent change		.9%	5.4%	–1.8%	0%	–30%	–7.1%	0%	36%
	No Action	100	22.8	5.6	330	.008	.047	.028	.054	3.85
	Joint Use Pipeline North	83	22.1	5.6	313	.014	.067	.027	.139	2.04
	Percent change		–3.1%	0%	–5.2%	75%	43%	–3.6%	157%	–47%
	No action	100	22.8	5.6	330	.008	.047	.028	.054	3.85
	Master Contract only	100	23.1	5.6	315	.008	.035	.024	.035	4.02
	Percent change		1.3%	0%	–4.5%	0%	–26%	–14%	–35%	4.4%

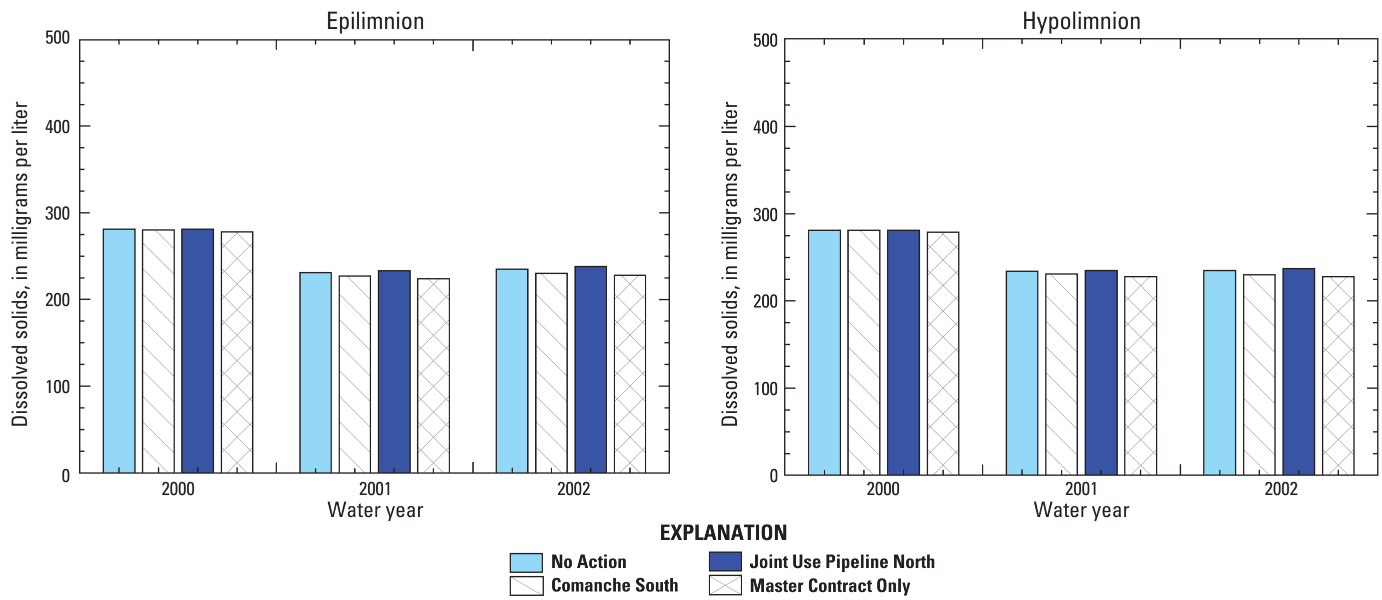

Figure 24. Annual median dissolved solids concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

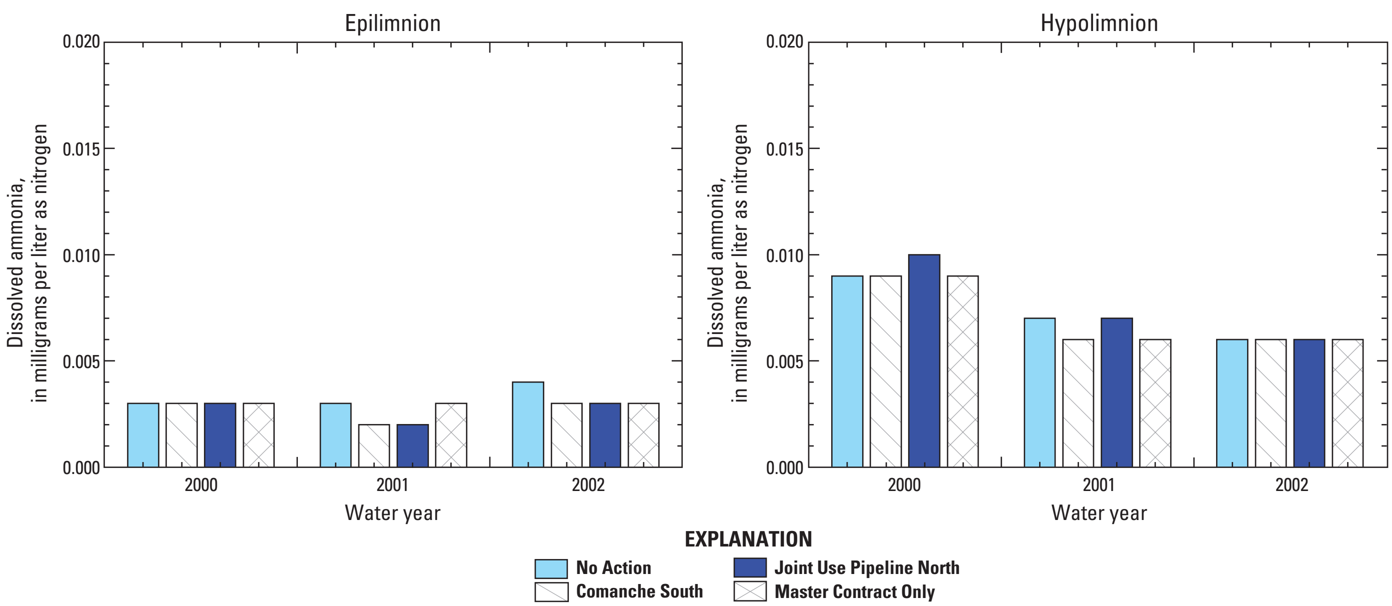

Figure 25. Annual median dissolved ammonia concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

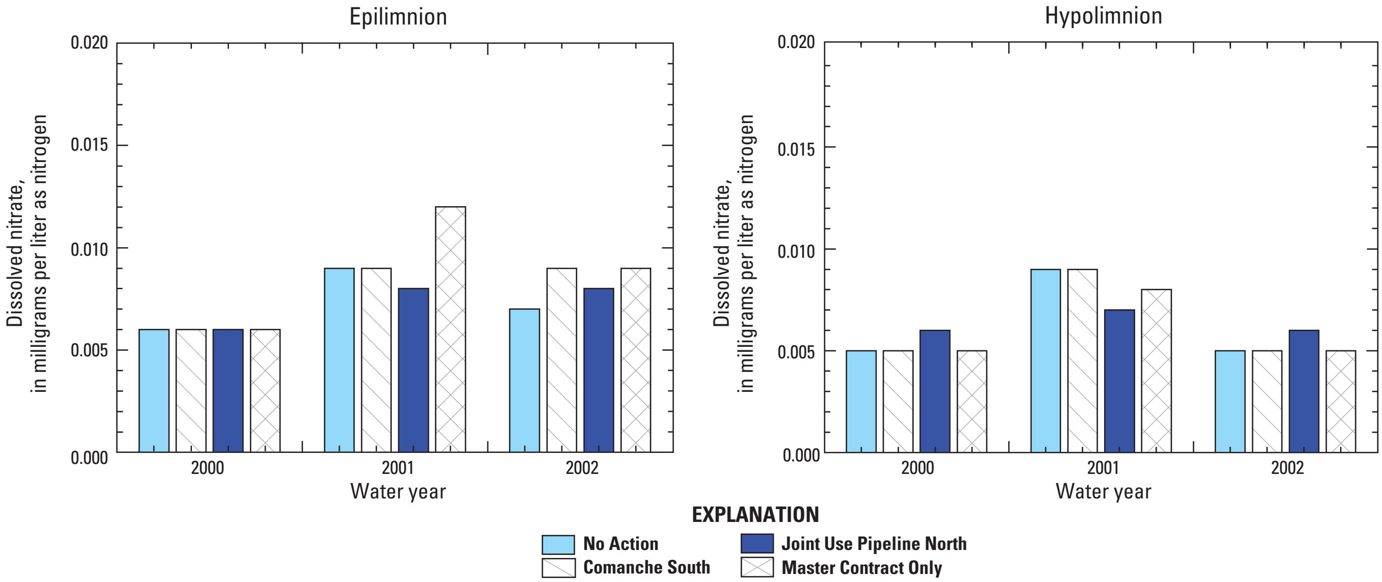

Figure 26. Annual median dissolved nitrate concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

(Colorado Department of Public Health and Environment, 2007). 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

Comparisons among scenarios for annual median total phosphorus concentrations at site 7B were similar to the comparisons of dissolved nitrate concentrations. The annual median concentrations in the epilimnion at site 7B generally were the same between the No Action scenario and either the Comanche South, Joint Use Pipeline North, or Master Contract Only scenarios (fig. 27). The largest percent difference from the No Action scenario did not exceed 6 percent; an increase of this magnitude equated to a difference of only 0.001 mg/L. Similar results were observed in the hypolimnion at site 7B (table 6).

Similar comparisons were made between the No Action scenario and the other simulation scenarios at site 3B (table 7). Annual median total phosphorus concentrations at site 3B were similar in magnitude to concentrations observed in the epilimnion and hypolimnion at site 7B. 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. 28). Simulation results for these various scenarios indicated that concentrations were less than or equal to 0.001 mg/L during much of the year. Annual median total iron concentrations in the hypolimnion at site 7B were larger than in the epilimnion but still were relatively small. However, a seasonal analysis of total iron concentrations in the hypolimnion at this site showed periods of increased concentrations (fig. 29). The seasonal periods occurred at similar times when anoxic conditions in the reservoir were observed (fig. 6). It is likely that iron was released from the reservoir bottom during these times. These relatively short episodes of high iron concentrations were reflected in the annual 85th percentile concentrations shown in table 8.

Concentrations generally were similar between the No Action scenario and each of the three other simulation scenarios at site 3B. Differences in concentration from the No Action scenario were no more than 0.01 mg/L for any comparison to the Comanche South or Master Contract Only scenarios (table 7). Comparisons of simulated iron concentrations between the No Action scenario and the Joint Use Pipeline North scenario were more variable, particularly in WY 2002 when the difference in the epilimnion was 0.018 mg/L. Larger annual median total iron concentrations were observed near the upstream end of Pueblo Reservoir (site 3B) than those near the surface at site 7B (tables 6 and 7). Total iron concentrations would be expected to be larger in response to suspension of particulate matter at the upstream site.

The chronic surface-water water-quality standard for total iron in Pueblo Reservoir is 1 mg/L (Colorado Department of Public Health and Environment, 2007). The impacts of iron on aquatic life 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). Caution should be used when applying the

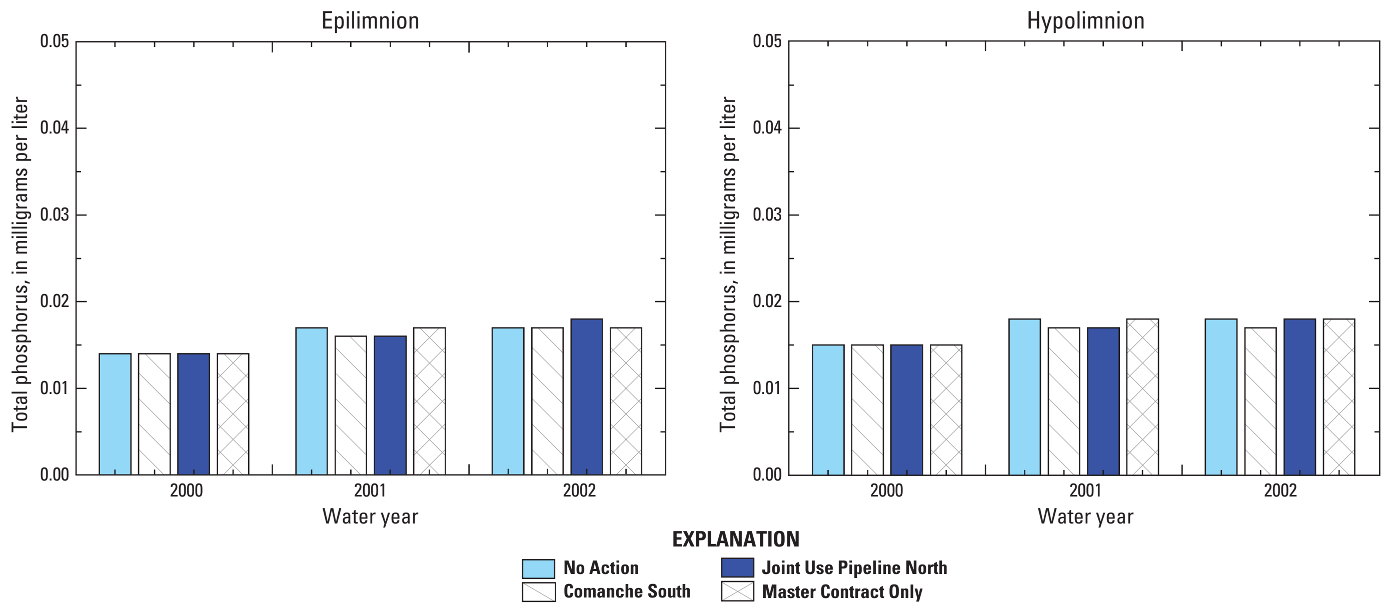

Figure 27. Annual median total phosphorus concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

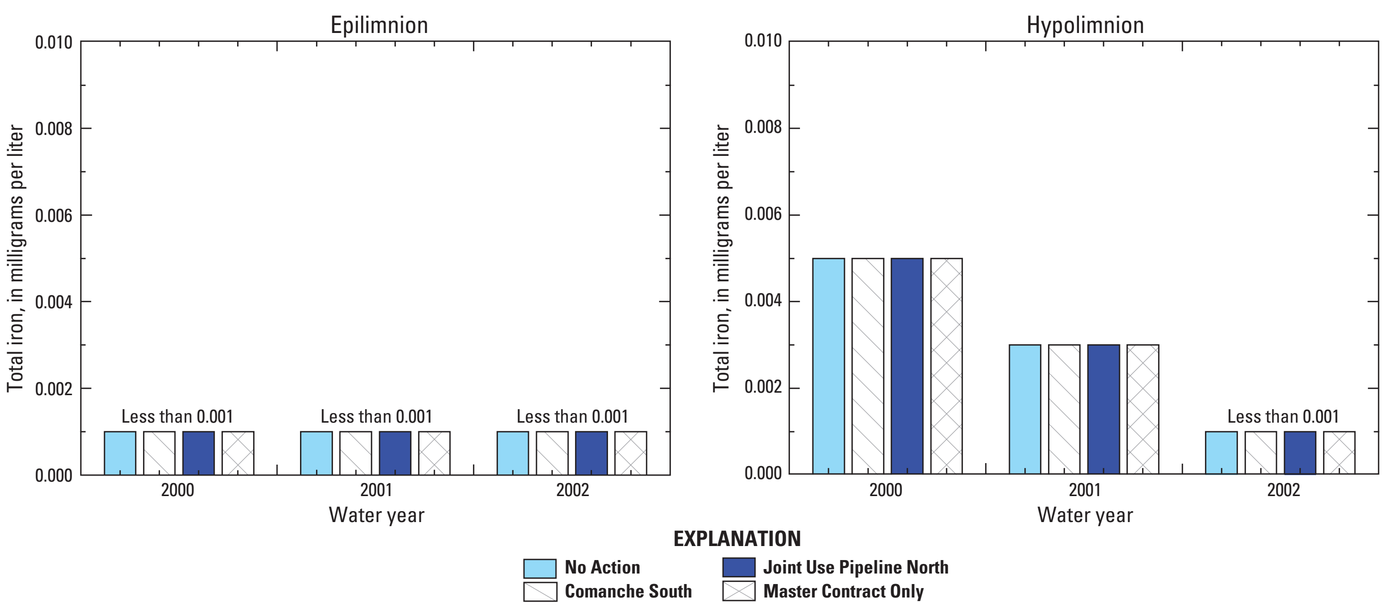

Figure 28. Annual median total iron concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

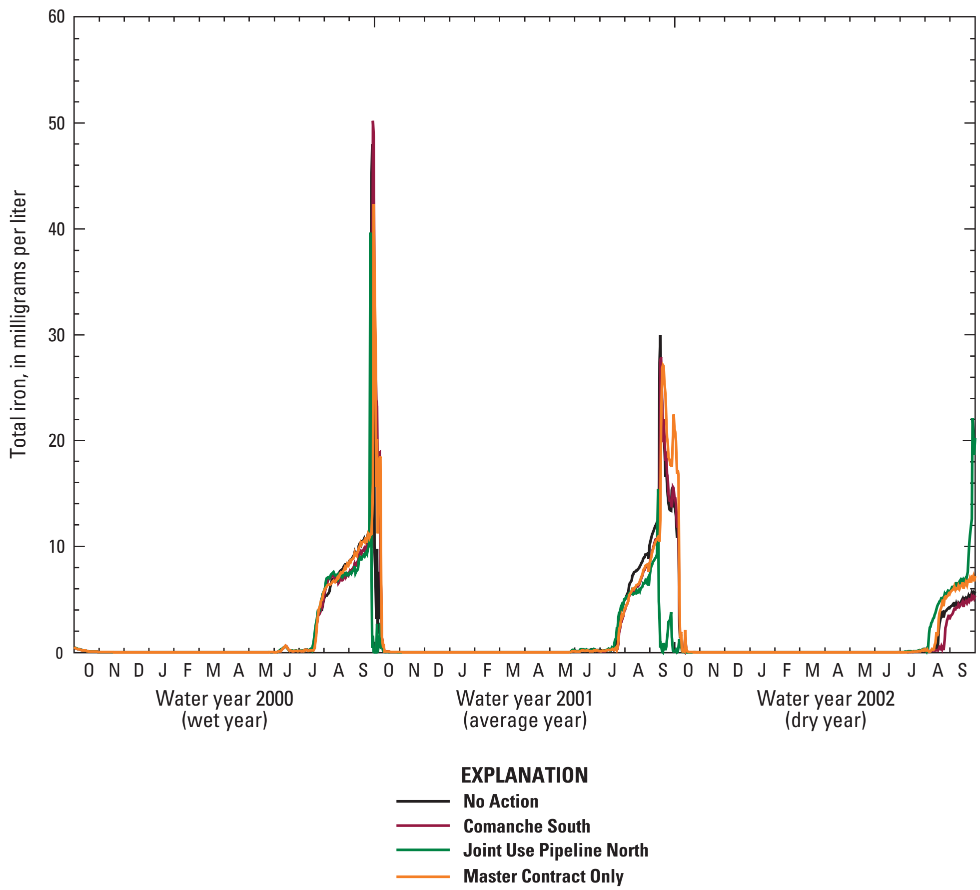

Figure 29. Comparison of total iron concentrations in the hypolimnion at site 7B in Pueblo Reservoir for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

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. 30). The largest algal biomass at site 7B generally occurred from May through September when blue-green and green algae were the dominant algal groups; blue-green algae increased sharply during the summer months. Generally, simulated algae biomass concentrations in the epilimnion at site 7B were similar for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios and typically were less than 1 mg/L for any group (fig. 30).

Algae biomass concentrations in the epilimnion at site 3B were more variable than in the epilimnion at site 7B, but the general relation between the biomass concentrations for the simulated scenarios remained similar to those observed at site 7B (fig. 30). The diatoms and flagellates were the dominant algal group at this upstream site in the reservoir in WY 2000 and WY 2001; biomass concentrations for the scenarios were less than 1 mg/L for all the algal groups. The blue-green algae were the dominant algal group in WY 2002 and biomass concentrations were less than 2 mg/L.

Harmful algal blooms in freshwater, particularly from blue-green algae, can occur when water use is impaired due to excessive accumulations of nutrients. Simulated algae biomass concentrations associated with No Action, Comanche South, Joint Use Pipeline North, or Master Contract Only scenarios would not be expected to pose a health issue or produce taste-and-odor problems in Pueblo Reservoir (Graham, 2006).

Annual median chlorophyll-*a* concentrations in the epilimnion at site 7B generally were similar between the No Action scenario and the Comanche South, Joint Use Pipeline North, and the Master Contract Only scenario (fig. 31). Specifically, the difference between the median chlorophyll-*a* concentrations and each of these scenarios did not exceed 0.08 µg/L in the epilimnion (table 6). Similar relations were observed in the hypolimnion, but concentrations were consistently smaller than concentrations in the epilimnion and the difference between the median chlorophyll-*a* did not exceed 0.01 µg/L.

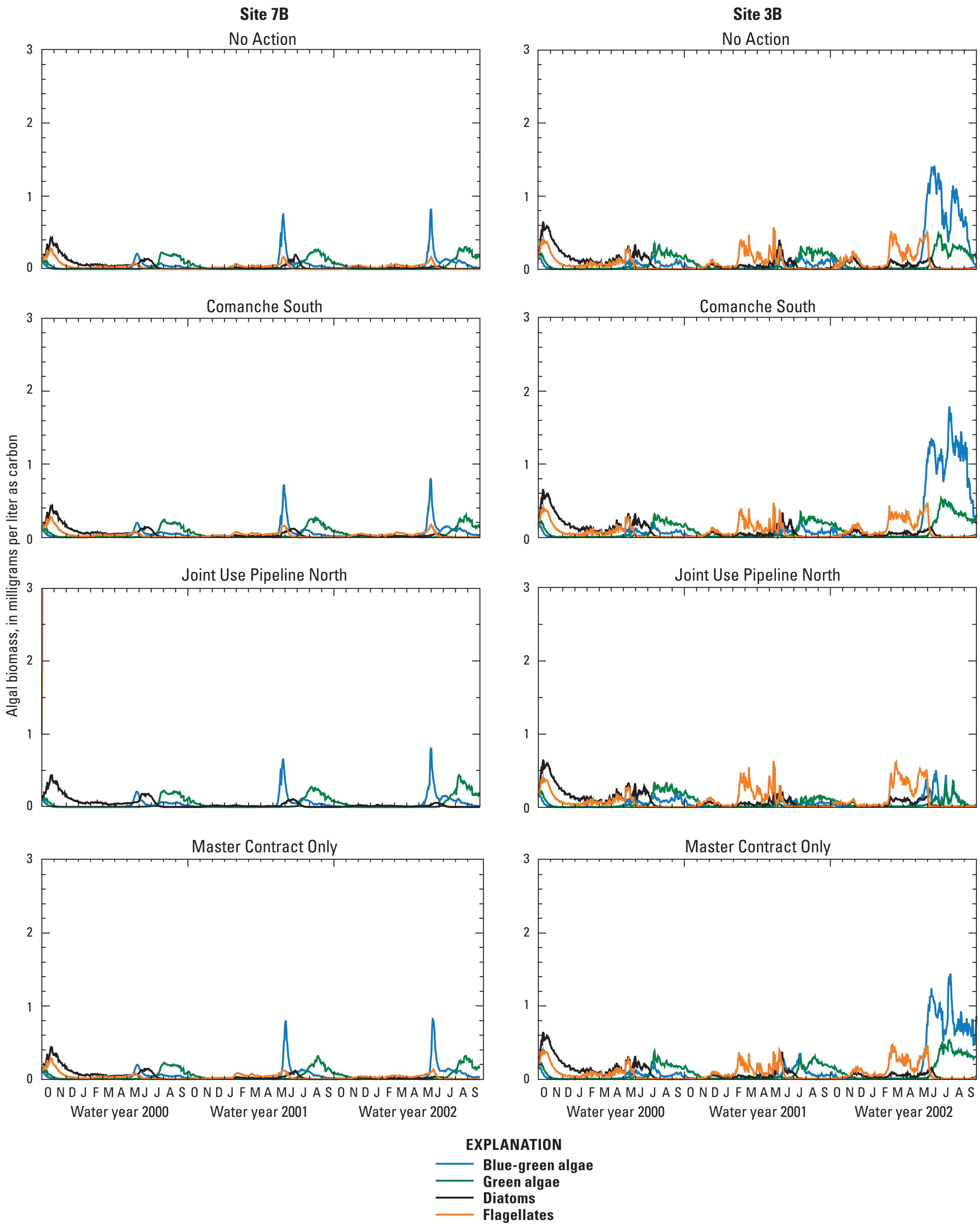

Figure 30. Relation between various algal groups in the epilimnion at sites 7B and 3B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

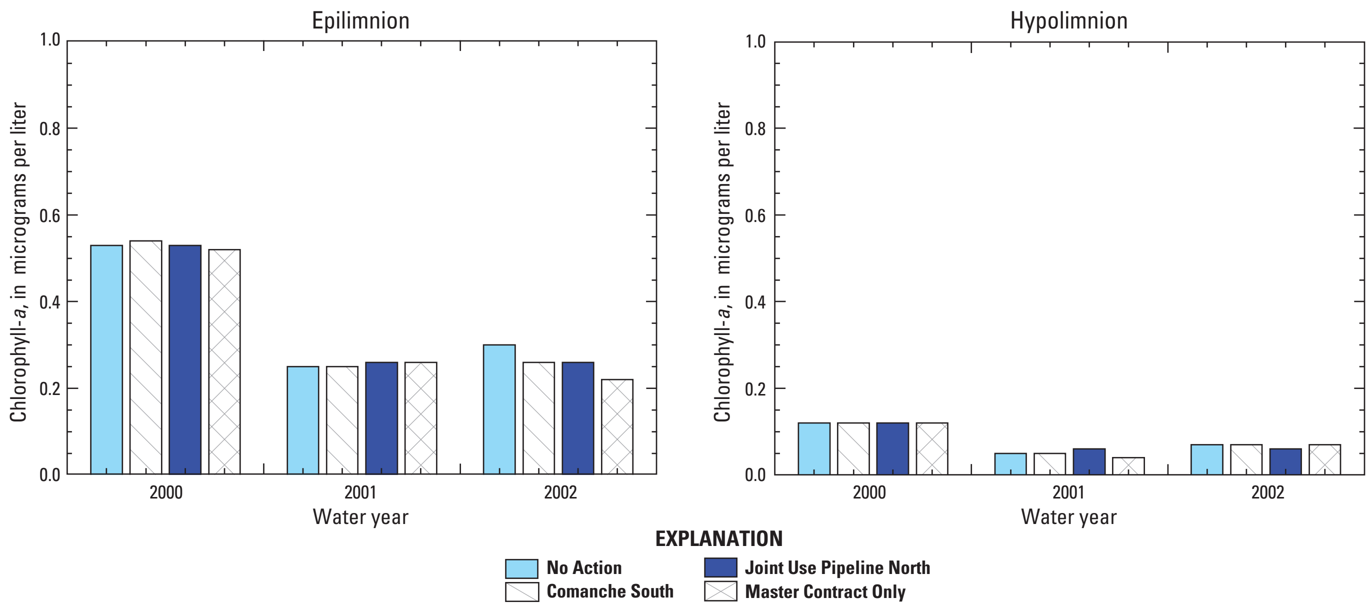

Figure 31. Annual median chlorophyll–*a* concentrations in the epilimnion and hypolimnion at site 7B for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios (direct-effects analyses).

Summary and Conclusions

The Fryingpan-Arkansas Project (Project) is a multipurpose transmountain, transbasin water diversion and delivery project that annually diverts surplus water from the western slope of the Rocky Mountains to the Arkansas River Basin. As part of the Public Law 87-590 which authorized the Project, authorization was included to construct a municipal water-supply pipeline to provide communities downstream from Pueblo Reservoir with a source of high-quality water. In 2009, Congress authorized appropriations and cost-sharing language to proceed with project planning and implementation of the Arkansas Valley Conduit (AVC). The purpose of the AVC is to deliver water for municipal and industrial use within the boundaries of the Southeastern Colorado Water Conservancy District. Water supplied through the AVC would serve two needs: (1) to supplement or replace existing poor-quality water to communities downstream from Pueblo Reservoir; and (2) to meet a portion of the AVC participants' projected water demands through 2070. The Bureau of Reclamation (Reclamation) initiated an Environmental Impact Statement (EIS) to address the potential environmental consequences associated with constructing and operating the proposed AVC, entering into a conveyance contract for the Pueblo Dam north-south outlet works interconnect (Interconnect), and entering into a long-term excess capacity master contract (Master Contract). Reclamation chose to evaluate the environmental effects of these three independent proposed actions in the same EIS because of overlap in area, timing, and participants. A complete description of the Arkansas Valley Conduit Draft Environmental Impact Statement can be found at *http://www.usbr.gov/avceis*. To that end, six action alternatives and one no action alternative were evaluated in the EIS to meet the purpose and needs of the AVC, Interconnect, and Master Contract. Reclamation understands that there may be water-based issues (surface-water hydrology, water quality, aquatic species, groundwater, wetlands, and recreation) associated with each of the proposed alternatives.

Operational changes, as a result of implementation of these alternatives, could change the hydrodynamics and water-quality conditions in Pueblo Reservoir. The reservoir, located west of Pueblo, Colo., is the primary source of water for the conduit and is one of southeastern Colorado's most valuable water resources. It provides irrigation, municipal, and industrial water to various entities throughout the region as well as providing flood control, recreational activities, sport fishing, and wildlife enhancements to the region. The hydrodynamics and water quality of Pueblo Reservoir were modeled previously (2008), and the results of the modeling were documented by the USGS.

Discussions with Reclamation and the U.S. Geological Survey (USGS) led to an interagency 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 four of the seven proposed EIS alternatives. Scenario simulations were done using the documented USGS Pueblo Reservoir model developed from the U.S. Army Corps of Engineers CE-QUAL-W2 model (version 3.2). Comparisons of the simulated results were conducted to determine if substantial differences were observed between selected scenarios.

The four alternatives submitted to the USGS for scenario simulation included various combinations (action or no action) of the proposed AVC, Master Contract, and Interconnect options. The four scenario simulations were the No Action (AVC and Interconnect, no action; Master Contract, no action), the Comanche South (AVC and Interconnect, proposed action; Master Contract, proposed action), the Joint Use Pipeline North (AVC and Interconnect, proposed action; Master Contract, no action), and the Master Contract Only (AVC and Interconnect, no action; Master Contract, proposed action). Each of the scenarios was simulated for three contiguous water years (WY) representing a wet, average, and dry annual hydrologic cycle. Streamflow, diversion, reservoir storage, and return-flow quantity data for projected demands in 2070 were provided to the USGS by contractors for Reclamation. Water-quality data for this effort was originally provided to the USGS (2009) by contractors for Reclamation as described for the Existing Conditions simulation scenario documented by the USGS in a previous report.

Additionally, each selected simulation scenario was evaluated for differences in direct/indirect effects (herein referred to as “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 include existing levels of demand by nonparticipants in the AVC/Master Contract project, whereas the cumulative-effects simulations include projected demands in 2070 by the nonparticipants in the AVC/Master Contract project.

Finally, scenario simulations were done that represented existing conditions in Pueblo Reservoir. The results of the Existing Conditions scenario were compared to the No Action scenario to assess changes in water quality from current demands (2006) to projected demands in 2070. All simulations used an external nutrient-decay model to simulate degradation and assimilation of selected nutrients along the riverine reach upstream from Pueblo Reservoir as described in previous USGS simulation reports on Pueblo Reservoir.

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, total iron, algal groups, and algae biomass (measured as chlorophyll-*a*) 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 2070 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 sites were selected for comparison in this report. Results of scenario simulations at site 3B were characteristic of a riverine environment in the reservoir, whereas 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 for water-surface elevations, water temperatures, dissolved oxygen, dissolved solids, and ammonia concentrations. Similarities and differences between the direct- and cumulative-effects analyses also were compared.

Simulated water-surface elevations in Pueblo Reservoir were variable between the simulation scenarios, between the different effects analyses, and between the simulated hydrologic conditions. Generally, there was a substantial temporal decrease in water-surface elevations between the wet, average, and dry years. Water-surface elevations associated with the direct-effects analyses were larger than the water-surface elevations for the corresponding cumulative-effects analyses, and the differences between the effects analyses, for any scenario, increased temporally from wet to dry year. During the dry year (WY 2002), the lowest water-surface elevations for either the direct-effects or cumulative-effects analysis were associated with the No Action and Joint Use Pipeline North scenarios; these two scenarios do not include an excess capacity storage component as part of the proposed EIS alternative. Simulated water-surface elevations for the direct-effects analysis of any simulation scenario during WY 2000 (wet year) and WY 2001 (average year) were similar to the water-surface elevations for the Existing Conditions scenario. Water-surface elevations during WY 2002 (dry year) remained similar to those of the Existing Conditions scenario with the exception of the Joint Use Pipeline North scenario.

Water temperatures in Pueblo Reservoir have been shown to stratify during the summer (June-August) prior to mixing in September. Results from the various simulation scenarios showed a similar pattern. In general, the reservoir has been shown to be isothermal during the winter and water temperatures were coldest from December to April. Thermal stratification is apparent by May. Maximum water temperatures were observed in August prior to when 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 simulation period regardless of the effects analysis.

Results of the scenario simulations for dissolved oxygen showed the typical stratification patterns that occur in Pueblo Reservoir. This included anoxic conditions near the bottom of the reservoir during the summer before the reservoir turned over and mixed. Dissolved oxygen concentrations in the epilimnion and hypolimnion of the reservoir near the dam were similar to the Existing Conditions scenario for all the simulation scenarios regardless of the effects analysis.

Typically, simulated dissolved solids concentrations for the Existing Conditions scenario were similar to concentrations for all the direct-effects simulation scenarios. Concentrations for the cumulative-effects simulation scenarios were slightly larger than concentrations for the Existing Conditions scenario. Typically, the percent differences were less than 5 percent but could be as much as 10 percent during the winter months. Concentrations for the cumulative-effects simulation scenarios were similar among themselves. These results would be expected given that the reservoir storage for the cumulative-effects analyses was less than that for the direct-effect analyses and water-quality inputs were identical.

Comparisons were made between the Existing Conditions scenario and the No Action scenario to determine what differences, if any, were observed between existing conditions in Pueblo Reservoir (demand conditions for 2006) and the most likely conditions in 2070 assuming the absence of a major Reclamation action, such as the AVC or a storage contract. 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 between the Existing Conditions and No Action scenarios focused on the results from the direct-effects analysis for each modeled scenario. Overall, comparisons of the results between the Existing Conditions and the No Action scenarios for water-surface elevations, water temperature, dissolved oxygen, dissolved solids, dissolved ammonia, dissolved nitrate, total phosphorus, and total iron concentrations indicated that the annual median values generally were similar for all three simulated years. Additionally, algal groups and chlorophyll-*a* concentrations (algal biomass) were similar for the Existing Conditions and the No Action scenarios at site 7B in the epilimnion for the simulated period (WY 2000 through WY 2002).

The No Action scenario also was compared individually to the Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios. 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.

Simulated water-surface elevations in Pueblo Reservoir generally were similar between the No Action scenario and each of the other three simulation scenarios. Overall, differences in reservoir water-surface elevation increased each year and there was a temporal decrease in water-surface elevations from WY 2000 through WY 2002 for all the simulated scenarios.

Comparisons of the results between the No Action scenario and each of the other three simulation scenarios for water temperature indicated that the simulated scenarios generally provided similar results. At site 7B, the percent change from the No Action scenario in the epilimnion was less than 5 percent for all simulated years.

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. Typically, the percent change from the No Action scenario was within 2 percent for the simulated scenarios for any simulated year. The percent change from the No Action scenario in the hypolimnion was less than 6 percent for the simulated scenarios for any simulated year.

Comparisons of simulated dissolved solids concentrations indicated that the annual medians were relatively similar between the No Action and the Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios in the epilimnion and hypolimnion at site 7B. Simulated results for the No Action scenario were 3 percent or less of the annual medians for the other three scenarios during WY 2000 through WY 2002. The results were similar for both the epilimnion and the hypolimnion. For the most part, similar results also were observed in the epilimnion and hypolimnion at site 3B.

The annual median dissolved ammonia (as nitrogen) and dissolved nitrate concentrations in the epilimnion and hypolimnion of Pueblo Reservoir at site 7B were similar between the No Action scenario and either the Comanche South, Joint Use Pipeline North, or Master Contract Only scenarios.

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. Simulation results for these various scenarios indicated that concentrations were less than or equal to 0.001 mg/L during much of the year. Iron concentrations at site 3B generally were similar between the No Action scenario and the each of the three other simulation scenarios. Differences in concentration from the No Action scenario were no more than 0.01 mg/L for any comparison to the Comanche South or Master Contract Only scenarios. Comparisons of simulated iron concentrations between the No Action scenario and the Joint Use Pipeline North scenario were more variable, particularly in WY 2002.

Generally, simulated algae biomass concentrations in the epilimnion at site 7B were similar for the No Action, Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios and concentrations typically were less than 1 mg/L. Annual median chlorophyll-*a* concentrations in the epilimnion at site 7B generally were similar between the No Action scenario and the Comanche South, Joint Use Pipeline North, and the Master Contract Only scenario. Specifically, the difference between the median chlorophyll-*a* concentrations and each of these scenarios did not exceed 0.08 µg/L.

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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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-a (µg/L)
					Epilimnion					
2000	Existing Conditions	100	14.6	7.8	283	0.003	0.006	0.014	<0.001	0.55
	No Action	100	14.6	7.9	284	.003	.006	.014	<.001	.52
	Percent change		0%	1.3%	.4%	0%	0%	0%	NA	–5.5%
2001	Existing Conditions	100	14.6	7.8	229	.003	.009	.016	<.001	.26
	No Action	100	13.4	8.2	237	.002	.007	.017	<.001	.44
	Percent change		–8.2%	5.1%	3.5%	–33%	–22%	6.2%	NA	69%
2002	Existing Conditions	100	14.4	8.0	233	.003	.007	.017	<.001	.30
	No Action	100	14.2	8.4	252	.003	.006	.019	<.001	.38
	Percent change		–1.4%	5.0%	8.2%	0%	–14%	12%	NA	27%
					Hypolimnion					
2000	Existing Conditions	100	10.7	7.5	284	.010	.006	.015	.005	12
	No Action	100	10.4	7.6	284	.009	.006	.015	.005	14
	Percent change		–2.8%	1.3%	0%	–10%	0%	0%	0%	17%
2001	Existing Conditions	100	9.6	7.6	233	.007	.008	.017	.003	.07
	No Action	100	10.4	7.6	242	.007	.010	.018	.003	.08
	Percent change		8.3%	0%	3.9%	0%	25%	5.9%	0%	14%
2002	Existing Conditions	100	9.7	8.0	233	.006	.005	.017	<.001	.06
	No Action	100	10.4	7.8	250	.006	.004	.019	.004	.10
	Percent change		7.2%	–2.5%	7.3%	0%	–20%	12%	NA	67%

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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	Existing Conditions	100	14.1	7.9	287	0.001	0.005	0.015	0.010	0.98
	No Action	100	14.0	7.9	289	.001	.010	.016	.018	.84
	Percent change		–.7%	0%	.7%	0%	100%	6.7%	80%	–14%
2001	Existing Conditions	100	13.5	8.0	235	.002	.019	.018	.010	.74
	No Action	100	11.3	8.3	246	.010	.083	.022	.122	.20
	Percent change		–16%	3.8%	4.7%	400%	337%	22%	1,120%	–73%
2002	Existing Conditions	100	13.4	7.9	260	.003	.008	.023	.013	1.41
	No Action	100	9.0	8.1	271	.020	.092	.026	.466	.15
	Percent change		–33%	2.5%	4.2%	567%	1,050%	13%	3,480%	–89%
					Hypolimnion					
2000	Existing Conditions	100	12.1	7.8	286	.002	.013	.016	.029	.68
	No Action	100	12.0	7.8	289	.002	.015	.016	.038	.60
	Percent change		–.8%	0%	1.0%	0%	15%	0%	31%	–12%
2001	Existing Conditions	100	11.0	7.8	239	.003	.036	.019	.027	.51
	No Action	88	8.4	9.3	245	.010	.081	.022	.133	.20
	Percent change		–24%	19%	2.5%	233%	125%	16%	393%	–61%
2002	Existing Conditions	100	12.2	7.8	260	.003	.009	.022	.020	1.40
	No Action	15	--	--	--	--	--	--	--	--
	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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	Existing Conditions	100	25.2	5.8	294	0.006	0.012	0.017	0.017	1.17
	No Action	100	25.2	5.6	294	.006	.016	.016	.006	1.11
	Percent change		0%	–3.4%	0%	0%	33%	–5.9%	–65%	–5.1%
2001	Existing Conditions	100	24.5	5.0	237	.007	.016	.017	.005	.94
	No Action	100	24.5	5.1	248	.006	.019	.018	.008	1.10
	Percent change		0%	2.0%	4.6%	–14%	19%	5.9%	60%	17%
2002	Existing Conditions	100	24.5	5.5	275	.011	.028	.018	<.001	1.08
	No Action	100	24.6	5.1	288	.010	.016	.021	.003	1.27
	Percent change		.4%	–7.3%	4.7%	–9.1%	–43%	17%	NA	18%
					Hypolimnion					
2000	Existing Conditions	100	18.3	<.1	296	.016	.009	.020	6.49	.82
	No Action	100	18.4	<.1	295	.014	.009	.018	4.97	.82
	Percent change		.5%	NA	–.3%	–12%	0%	–10%	–23%	0%
2001	Existing Conditions	100	18.9	<.1	238	.016	.014	.022	5.65	.14
	No Action	100	20.6	.4	248	.012	.018	.018	.432	.15
	Percent change		9.0%	NA	4.2%	–25%	29%	–18%	–92%	7.1%
2002	Existing Conditions	100	15.5	<.1	249	.013	.007	.022	2.18	.25
	No Action	100	19.2	<.1	269	.021	.009	.027	3.07	.29
	Percent change		24%	NA	8.0%	62%	29%	23%	41%	16%

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.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	Existing Conditions	100	23.8	6.1	296	0.002	0.034	0.017	0.098	1.89
	No Action	100	23.0	6.0	299	.003	.033	.018	.094	1.80
	Percent change		–3.4%	–1.6%	1.0%	50%	–2.9%	5.9%	–4.1%	–4.8%
2001	Existing Conditions	100	23.3	5.9	243	.008	.063	.021	.181	1.21
	No Action	100	20.9	5.6	303	.020	.103	.025	1.30	1.51
	Percent change		–10%	–5.1%	25%	150%	63%	19%	618%	25%
2002	Existing Conditions	100	23.2	6.1	326	.010	.059	.027	.041	5.27
	No Action	100	17.2	6.2	360	.020	.099	.029	.880	.40
	Percent change		–26%	1.6%	10%	100%	68%	7.4%	2,050%	–92%
					Hypolimnion					
2000	Existing Conditions	100	23.1	4.8	299	.004	.032	.018	.498	1.50
	No Action	100	22.4	4.9	304	.007	.037	.018	.450	1.52
	Percent change		–3.0%	2.1%	1.7%	75%	16%	0%	–9.6%	1.3%
2001	Existing Conditions	100	23.3	5.9	243	.008	.063	.021	.181	1.21
	No Action	88	20.6	5.4	282	.019	.103	.024	1.81	1.34
	Percent change		–12%	–8.5%	16%	138%	63%	14%	900%	11%
2002	Existing Conditions	100	23.0	5.9	326	.009	.047	.027	.047	4.92
	No Action	15	--	--	--	--	--	--	--	--
	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 Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
	No Action	100	14.6	7.9	284	0.003	0.006	0.014	<0.001	0.52
	Comanche South	100	14.7	7.8	281	.003	.005	.014	<.001	.53
	Percent change		.7%	–1.3%	–1.1%	0%	–17%	0%	NA	1.9%
	No Action	100	14.6	7.9	284	.003	.006	.014	<.001	.52
2000	Joint Use Pipeline North	100	14.6	7.9	285	.003	.006	.014	<.001	.54
	Percent change		0%	0%	.4%	0%	0%	0%	NA	3.8%
	No Action	100	14.6	7.9	284	.003	.006	.014	<.001	.52
	Master Contract Only	100	14.7	7.8	282	.003	.005	.014	<.001	.52
	Percent change		.7%	–1.3%	–.7%	0%	–17%	0%	NA	0%
					Hypolimnion					
	No Action	100	10.4	7.6	284	.009	.006	.015	.005	.14
	Comanche South	100	10.6	7.6	281	.010	.006	.015	.005	.14
	Percent change		1.9%	0%	–1.1%	11%	0%	0%	0%	0%
	No Action	100	10.4	7.6	284	.009	.006	.015	.005	.14
2000	Joint Use Pipeline North	100	10.5	7.6	284	.010	.006	.015	.005	.13
	Percent change		1.0%	0%	0%	11%	0%	0%	0%	–7.1%
	No Action	100	10.4	7.6	284	.009	.006	.015	.005	.14
	Master Contract Only	100	10.6	7.6	282	.010	.006	.015	.005	.13
	Percent change		1.9%	0%	–.7%	11%	0%	0%	0%	–7.1%
					Epilimnion					
	No Action	100	13.4	8.2	237	.002	.007	.017	<.001	.44
	Comanche South	100	14.4	8.2	238	.002	.007	.017	<.001	.45
	Percent change		7.5%	0%	.4%	0%	0%	0%	NA	2.3%
	No Action	100	13.4	8.2	237	.002	.007	.017	<.001	.44
2001	Joint Use Pipeline North	100	14.4	8.2	239	.002	.007	.017	<.001	.48
	Percent change		7.5%	0%	.8%	0%	0%	0%	NA	9.1%
	No Action	100	13.4	8.2	237	.002	.007	.017	<.001	.44
	Master Contract Only	100	14.4	8.2	239	.002	.008	.017	<.001	.42
	Percent change		7.5%	0%	.8%	0%	14%	0%	NA	–4.5%
					Hypolimnion					
	No Action	100	10.4	7.6	242	.007	.010	.018	.003	.08
	Comanche South	100	9.4	7.9	242	.007	.009	.018	.004	.08
	Percent change		–9.6%	3.9%	0%	0%	–10%	0%	33%	0%
	No Action	100	10.4	7.6	242	.007	.010	.018	.003	.08
2001	Joint Use Pipeline North	100	9.6	7.8	242	.007	.009	.018	.004	.09
	Percent change		–7.7%	2.6%	0%	0%	–10%	0%	33%	12%
	No Action	100	10.4	7.6	242	.007	.010	.018	.003	.08
	Master Contract Only	100	9.3	8.0	241	.007	.008	.018	.003	.07
	Percent change		–11%	5.3%	–.4%	0%	–20%	0%	0%	–12%
					Epilimnion					
	No Action	100	14.2	8.4	252	.003	.006	.019	<.001	.38
	Comanche South	100	14.2	8.3	251	.003	.006	.018	<.001	.37
	Percent change		0%	–1.2%	–.4%	0%	0%	–5.3%	NA	–2.6%
	No Action	100	14.2	8.4	252	.003	.006	.019	<.001	.38
2002	Joint Use Pipeline North	100	14.2	8.4	252	.003	.005	.019	<.001	.37
	Percent change		0%	0%	0%	0%	–17%	0%	NA	–2.6%
	No Action	100	14.2	8.4	252	.003	.006	.019	<.001	.38
	Master Contract Only	100	14.1	8.3	248	.003	.008	.018	<.001	.35
	Percent change		–.7%	–1.2%	–1.6%	0%	33%	–5.3%	NA	–7.9%
					Hypolimnion					
	No Action	100	10.4	7.8	250	.006	.004	.019	.004	.10
	Comanche South	100	10.1	7.8	249	.006	.005	.019	.004	.11
	Percent change		–2.9%	0%	–.4%	0%	25%	0%	0%	10%
	No Action	100	10.4	7.8	250	.006	.004	.019	.004	.10
2002	Joint Use Pipeline North	100	10.6	7.7	250	.006	.004	.019	.004	.11
	Percent change		1.9%	–1.3%	.0%	0%	0%	0%	0%	10%
	No Action	100	10.4	7.8	250	.006	.004	.019	.004	.10
	Master Contract Only	100	10.3	7.7	247	.006	.005	.019	.004	.13
	Percent change		–1.0%	–1.3%	–1.2%	0%	25%	0%	0%	30%

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 Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, summary statistic not calculated; 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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
2000	No Action	100	14.0	7.9	289	<0.001	0.010	0.016	0.018	0.84
	Comanche South	100	14.0	7.9	285	<.001	.008	.016	.018	.89
	Percent change		0%	0%	–1.4%	NA	–20%	0%	0%	6.0%
	No Action	100	14.0	7.9	289	<.001	.010	.016	.018	.84
	Joint Use Pipeline North	100	14.0	7.9	289	<.001	.011	.016	.019	.81
	Percent change		0%	0%	0%	NA	10%	0%	5.6%	–3.6%
	No Action	100	14.0	7.9	289	<.001	.010	.016	.018	.84
	Master Contract Only	100	14.0	7.9	286	<.001	.008	.015	.016	.85
	Percent change		0%	0%	–1.0%	NA	–20%	–6.3%	–11%	1.2%
					Hypolimnion					
2000	No Action	100	12.0	7.8	289	.002	.015	.016	.038	.60
	Comanche South	100	12.0	7.8	285	.002	.014	.016	.035	.66
	Percent change		0%	0%	–1.4%	0%	–6.7%	0%	–7.9%	10%
	No Action	100	12.0	7.8	289	.002	.015	.016	.038	.60
	Joint Use Pipeline North	100	12.0	7.8	290	.003	.016	.016	.041	.55
	Percent change		0%	0%	.3%	50%	6.7%	0%	7.9%	–8.3%
	No Action	100	12.0	7.8	289	.002	.015	.016	.038	.60
	Master Contract Only	100	12.0	7.8	286	.003	.014	.016	.034	.64
	Percent change		0%	0%	–1.0%	50%	–6.7%	0%	–11%	6.7%
					Epilimnion					
2001	No Action	100	11.3	8.3	246	.010	.083	.022	.122	.20
	Comanche South	100	11.5	8.4	246	.010	.074	.022	.100	.24
	Percent change		1.8%	1.2%	0%	0%	–11%	0%	–18%	20%
	No Action	100	11.3	8.3	246	.010	.083	.022	.122	.20
	Joint Use Pipeline North	100	11.2	8.1	248	.011	.084	.022	.187	.18
	Percent change		–.9%	–2.4%	.8%	10%	1.2%	0%	53%	–10%
	No Action	100	11.3	8.3	246	.010	.083	.022	.122	.20
	Master Contract Only	100	11.7	8.5	246	.010	.066	.022	.093	.33
	Percent change		3.5%	2.4%	0%	0%	–20%	0%	–24%	65%
					Hypolimnion					
2001	No Action	100	8.4	9.3	245	.010	.081	.022	.133	.20
	Comanche South	92	9.3	8.8	245	.010	.076	.022	.138	.22
	Percent change		11%	–5.4%	0%	0%	–6.2%	0%	3.8%	10%
	No Action	100	8.4	9.3	245	.010	.081	.022	.133	.20
	Joint Use Pipeline North	90	9.3	9.1	246	.010	.083	.022	.186	.18
	Percent change		11%	–2.2%	.4%	0%	2.5%	0%	40%	–10%
	No Action	100	8.4	9.3	245	.010	.081	.022	.133	.20
	Master Contract Only	98	10.5	8.4	245	.010	.069	.022	.130	.24
	Percent change		25%	–9.7%	0%	0%	–15%	0%	–2.3%	20%
					Epilimnion					
2002	No Action	100	9.0	8.1	271	.020	.092	.026	.466	.15
	Comanche South	79	8.8	8.2	273	.020	.090	.026	.420	.15
	Percent change		–2.2%	1.2%	.7%	0%	–2.2%	0%	–9.9%	0%
	No Action	100	9.0	8.1	271	.020	.092	.026	.466	.15
	Joint Use Pipeline North	74	8.6	8.3	267	.020	.093	.026	.455	.15
	Percent change		–4.4%	2.5%	–1.5%	0%	1.1%	0%	–2.4%	0%
	No Action	100	9.0	8.1	271	.020	.092	.026	.466	.15
	Master Contract Only	86	9.6	8.0	283	.019	.080	.026	.326	.17
	Percent change		6.7%	–1.2%	4.4%	–5.0%	–13%	0%	–30%	13%
					Hypolimnion					
2002	No Action	100	--	--	--	--	--	--	--	--
	Comanche South	36	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	100	--	--	--	--	--	--	--	--
	Joint Use Pipeline North	16	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	100	--	--	--	--	--	--	--	--
	Master Contract Only	56	--	--	--	--	--	--	--	--
	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 Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
	No Action	100	25.2	5.6	294	0.006	0.016	0.016	0.006	1.11
	Comanche South	100	25.2	5.7	290	.006	.010	.016	.022	1.10
	Percent change		0%	1.8%	–1.4%	0%	–38%	0%	267%	–.9%
	No Action	100	25.2	5.6	294	.006	.016	.016	.006	1.11
2000	Joint Use Pipeline North	100	25.2	5.7	294	.006	.014	.017	.010	1.10
	Percent change		0%	1.8%	0%	0%	–12%	6.3%	67%	–.9%
	No Action	100	25.2	5.6	294	.006	.016	.016	.006	1.11
	Master Contract Only	100	25.2	5.7	290	.006	.011	.016	.008	1.13
	Percent change		0%	1.8%	–1.4%	0%	–31%	0%	33%	1.8%
					Hypolimnion					
	No Action	100	18.4	<.1	295	.014	.009	.018	4.97	.82
	Comanche South	100	18.9	<.1	291	.013	.009	.018	4.38	.81
	Percent change		2.7%	NA	–1.4%	–7.1%	0%	0%	–12%	–1.2%
	No Action	100	18.4	<.1	295	.014	.009	.018	4.97	.82
2000	Joint Use Pipeline North	100	19.2	<.1	295	.014	.010	.018	4.54	.82
	Percent change		4.3%	NA	0%	0%	11%	0%	–8.7%	0%
	No Action	100	18.4	<.1	295	.014	.009	.018	4.97	.82
	Master Contract Only	100	18.6	<.1	293	.014	.009	.019	5.35	.81
	Percent change		1.1%	NA	–.7%	0%	0%	5.6%	7.6%	–1.2%
					Epilimnion					
	No Action	100	24.5	5.1	248	.006	.019	.018	.008	1.10
	Comanche South	100	24.6	5.0	246	.007	.021	.018	.003	1.03
	Percent change		.4%	–2.0%	–.8%	17%	11%	0%	–63%	–6.4%
	No Action	100	24.5	5.1	248	.006	.019	.018	.008	1.10
2001	Joint Use Pipeline North	100	24.6	5.1	247	.006	.021	.018	.003	1.04
	Percent change		.4%	0%	–.4%	0%	11%	0%	–63%	–5.5%
	No Action	100	24.5	5.1	248	.006	.019	.018	.008	1.10
	Master Contract Only	100	24.8	5.0	241	.007	.015	.017	.003	.93
	Percent change		1.2%	–2.0%	–2.8%	17%	–21%	–5.6%	–63%	–15%
					Hypolimnion					
	No Action	100	20.6	.4	248	.012	.018	.018	.432	.15
	Comanche South	100	20.3	<.1	249	.013	.019	.019	1.44	.15
	Percent change		–1.5%	NA	.4%	8.3%	5.6%	5.6%	233%	0%
	No Action	100	20.6	.4	248	.012	.018	.018	.432	.15
2001	Joint Use Pipeline North	100	20.3	.1	249	.013	.019	.019	1.16	.16
	Percent change		–1.5%	–75%	.4%	8.3%	5.6%	5.6%	168%	6.7%
	No Action	100	20.6	.4	248	.012	.018	.018	.432	.15
	Master Contract Only	100	20.1	<.1	248	.013	.018	.029	1.16	.16
	Percent change		–2.4%	NA	0%	8.3%	0%	61%	169%	6.7%
					Epilimnion					
	No Action	100	24.6	5.1	288	.010	.016	.021	.003	1.27
	Comanche South	100	24.7	5.2	290	.010	.020	.021	.003	1.24
	Percent change		.4%	2.0%	.7%	0%	25%	0%	0%	–2.4%
	No Action	100	24.6	5.1	288	.010	.016	.021	.003	1.27
2002	Joint Use Pipeline North	100	24.7	5.2	291	.009	.016	.021	.003	1.32
	Percent change		.4%	2.0%	1.0%	–10%	0%	0%	0%	3.9%
	No Action	100	24.6	5.1	288	.010	.016	.021	.003	1.27
	Master Contract Only	100	24.6	5.5	282	.010	.013	.020	.001	1.11
	Percent change		0%	7.8%	–2.1%	0%	–19%	–4.8%	–67%	–13%
					Hypolimnion					
	No Action	100	19.2	<.001	269	.021	.009	.027	3.07	.29
	Comanche South	100	17.6	<.001	265	.020	.009	.027	2.13	.27
	Percent change		–8.3%	NA	–1.5%	–4.8%	0%	0%	–31%	–6.9%
	No Action	100	19.2	<.001	269	.021	.009	.027	3.07	.29
2002	Joint Use Pipeline North	100	18.4	<.001	267	.022	.010	.027	2.41	.27
	Percent change		–4.2%	NA	–.7%	4.8%	11%	0%	–21%	–6.9%
	No Action	100	19.2	<.001	269	.021	.009	.027	3.07	.29
	Master Contract Only	100	19.7	<.001	265	.025	.011	.025	3.96	.25
	Percent change		2.6%	NA	–1.5%	19%	22%	–5.6%	29%	–14%

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 Comanche South, Joint Use Pipeline North, and Master Contract Only scenarios as compared to the No Action scenario.

[N, nitrogen; P, phosphorus; °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 as N (mg/L)	Dissolved nitrate as N (mg/L)	Total phosphorus as P (mg/L)	Total iron (mg/L)	Chlorophyll-*a* (µg/L)
					Epilimnion					
	No Action	100	23.0	6.0	299	.003	.033	.018	.094	1.80
	Comanche South	100	23.0	6.0	295	.003	.032	.017	.108	1.74
	Percent change		0%	0%	–1.3%	0%	–3.0%	–5.6%	15%	–3.3%
	No Action	100	23.0	6.0	299	.003	.033	.018	.094	1.80
2000	Joint Use Pipeline North	100	22.7	5.9	301	.004	.037	.018	.126	1.83
	Percent change		–1.3%	–1.7%	.7%	33%	12%	0%	34%	1.7%
	No Action	100	23.0	6.0	299	.003	.033	.018	.094	1.80
	Master Contract Only	100	23.0	6.0	295	.003	.030	.017	.106	1.78
	Percent change		0%	0%	–1.3%	0%	–9.1%	–5.6%	13%	–1.1%
					Hypolimnion					
	No Action	100	22.4	4.9	304	.007	.037	.018	.450	1.52
	Comanche South	100	22.5	4.9	300	.006	.033	.018	.449	1.43
	Percent change		.4%	0%	–1.3%	–14%	–11%	0%	–.2%	–5.9%
	No Action	100	22.4	4.9	304	.007	.037	.018	.450	1.52
2000	Joint Use Pipeline North	100	22.3	4.9	304	.007	.038	.018	.466	1.48
	Percent change		–.4%	0%	0%	0%	2.7%	0%	3.6%	–2.6%
	No Action	100	22.4	4.9	304	.007	.037	.018	.450	1.52
	Master Contract Only	100	22.5	4.9	301	.006	.032	.018	.434	1.42
	Percent change		–4%	0%	–1.0%	–14%	–14%	0%	–3.6%	–6.6%
					Epilimnion					
	No Action	100	20.9	5.6	303	.020	.103	.025	.131	1.51
	Comanche South	100	21.2	5.6	301	.019	.099	.025	.780	1.47
	Percent change		1.4%	0%	–.7%	–5.0%	–3.9%	0%	495%	–2.6%
	No Action	100	20.9	5.6	303	.020	.103	.025	.131	1.51
2001	Joint Use Pipeline North	100	20.7	5.5	305	.020	.104	.025	.147	1.67
	Percent change		–1.0%	–1.8%	.7%	0%	1.0%	0%	12%	11%
	No Action	100	20.9	5.6	303	.020	.103	.025	.131	1.51
	Master Contract Only	100	21.3	5.5	295	.019	.098	.024	.683	1.41
	Percent change		1.9%	–1.8%	–2.6%	–5.0%	–4.9%	–4.0%	421%	–6.6%
					Hypolimnion					
	No Action	100	20.6	5.4	282	.019	.103	.024	1.82	1.34
	Comanche South	92	21.1	5.3	283	.019	.098	.024	1.52	.96
	Percent change		2.4%	–1.9%	.4%	0%	–4.9%	0%	–16%	–28%
	No Action	100	20.6	5.4	282	.019	.103	.024	1.82	1.34
2001	Joint Use Pipeline North	90	20.8	5.4	285	.019	.104	.024	1.70	1.40
	Percent change		1%	0%	1.1%	0%	1.0%	0%	–6.6%	4.5%
	No Action	100	20.6	5.4	282	.019	.103	.024	1.82	1.34
	Master Contract Only	98	20.9	5.2	290	.019	.094	.024	.890	.89
	Percent change		1.5%	–3.7%	2.8%	0%	–8.7%	0%	–51%	–34%
					Epilimnion					
	No Action	100	17.2	6.2	360	.020	.099	.029	.880	.40
	Comanche South	79	19.0	5.9	360	.020	.099	.029	.814	.37
	Percent change		10%	–4.8%	0%	0%	0%	0%	–7.5%	–7.5%
	No Action	100	17.2	6.2	360	.020	.099	.029	.880	.40
2002	Joint Use Pipeline North	74	16.3	6.4	360	.020	.099	.029	.827	.45
	Percent change		–5.2%	3.2%	0%	0%	0%	0%	-6.0%	12%
	No Action	100	17.2	6.2	360	.020	.099	.029	.880	.40
	Master Contract Only	86	21.9	5.5	359	.020	.097	.030	.551	.62
	Percent change		27%	–11%	–.3%	0%	–2.0%	3.4%	–37%	55%
					Hypolimnion					
	No Action	100	--	--	--	--	--	--	--	--
	Comanche South	36	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	100	--	--	--	--	--	--	--	--
2002	Joint Use Pipeline North	16	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA
	No Action	100	--	--	--	--	--	--	--	--
	Master Contract Only	56	--	--	--	--	--	--	--	--
	Percent change		NA	NA	NA	NA	NA	NA	NA	NA

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