RECLAMATION

*Managing Water in the West*

# Windy Gap Firming Project

# Lake and Reservoir Water Quality Technical Report

July 2008

**U.S. Department of the Interior**
**Bureau of Reclamation**
**Great Plains Region**

# Lake and Reservoir Water Quality Technical Report

## Windy Gap Firming Project

**prepared for:**

**U.S. Bureau of Reclamation**
**Eastern Area Office**
**Loveland, Colorado**

**prepared by:**

**AMEC Earth & Environmental**
**(formerly Hydrosphere Resource Consultants)**
**1002 Walnut Street, Suite 200**
**Boulder, Colorado 80302**
**(303) 443-7839**

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ac | acute |
| AF | Acre-Feet |
| BTWF | Big Thompson Watershed Forum |
| C-BT | Colorado-Big Thompson |
| CDPHE | Colorado Department of Public Health and Environment |
| CRWCD | Colorado River Water Conservation District |
| CWCB | Colorado Water Conservation Board |
| Chla | Chlorophyll *a* |
| DW | Denver Water |
| ch | chronic |
| cm | centimeter |
| dis | dissolved |
| DL | Detection Limit |
| DM | Daily Maximum |
| DO | Dissolved Oxygen |
| EIS | Environmental Impact Statement |
| elsp | early life stage present |
| EPA | Environmental Protection Agency |
| ft | feet |
| GCWIN | Grand County Water Information Network |
| HOD | hypolimnetic oxygen demand |
| l | liter |
| m | meter |
| M&E | Monitoring and Evaluation |
| mg | milligram |
| MOD | metalimnetic oxygen demand |
| MPWCD | Middle Park Water Conservancy District |
| MWAT | Maximum Weekly Average Temperature |
| N | Nitrogen |
| NCWCD | Northern Colorado Water Conservancy District |
| P | Phosphorus |
| SD | Secchi-disk Depth |
| sp | spawning |
| SU | Standard Unit |
| T & O | Taste and Odor |
| TDS | Total Dissolved Solids |
| TKN | Total Kjeldahl Nitrogen |
| TMDL | Total Maximum Daily Load |
| TOC | Total Organic Carbon |
| TP | Total Phosphorus |
| TRec | Total Recoverable |
| TSI | Trophic State Index |
| TSS | Total Suspended Solids |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |

| | |
|---|---|
| USBR | U.S. Bureau of Reclamation |
| WGFP | Windy Gap Firming Project |
| WHO | World Health Organization |
| WQCC | Water Quality Control Commission |
| WQCD | Water Quality Control Division |
| WY | Water Year (October 1 - September 30) |
| μg | micrograms |
| μS | microSiemens |

**WINDY GAP FIRMING PROJECT**
**LAKE AND RESERVOIR WATER QUALITY TECHNICAL REPORT**

# 1.0 INTRODUCTION

The Bureau of Reclamation (Reclamation) has received a proposal from the Municipal Subdistrict, Northern Colorado Water Conservancy District, acting by and through the Windy Gap Firming Project Water Activity Enterprise (Subdistrict) to improve the firm yield from the existing Windy Gap Project water supply by constructing the Windy Gap Firming Project (WGFP). The proposal includes a connection of WGFP facilities to the Colorado-Big Thompson Project. For more information on the background and purpose of the WGFP, see the Windy Gap Firming Project Purpose and Need Report (ERO, 2005a). This technical report was prepared to address the potential environmental effects on lake and reservoir water quality associated with the alternatives described below and will be used in the preparation of the EIS. Surface and ground water resources and ground water quality are addressed in the Water Resource Technical Report (ERO and Boyle 2007). Stream water quality is described in ERO and AMEC, 2008.

The Windy Gap Firming Project alternatives that are being evaluated in the EIS are described in Section 2. Section 3 provides a description of the reservoirs that may be affected by the Project alternatives. The objectives of this technical report are described in Section 4. Data obtained and used for the completion of this report are described in Section 5. Section 6 provides a discussion of federal, state, and local water-quality regulations. Concepts of trophic status and the eutrophication process are described in Section 7. Section 8 provides a description of the potentially affected environment, which summarizes the existing water quality of the west and east slope lakes and reservoirs that could be affected by the WGFP alternatives. A summary of regulatory water-quality issues is located in Section 9 and the methods used for analysis are described in Section 10. Section 11 provides an analysis of the direct effects of the WGFP alternatives on the lakes and reservoirs described in previous sections and Section 12 provides an analysis of cumulative effects on these reservoirs.

# 2.0 ALTERNATIVES

The Windy Gap Firming Project Alternatives Report (ERO, 2005b) identified four action alternatives in addition to the No Action alternative for evaluation in the EIS. All action alternatives include development of 90,000 AF of new storage in either a single reservoir on the East Slope or a combination of East and West Slope reservoirs. The Subdistrict's Proposed Action is the construction of a 90,000 AF Chimney Hollow Reservoir with prepositioning. The alternatives are:

- Alternative 1 (No Action) – Continuation of existing operations and agreements between Reclamation and the Subdistrict for conveyance of Windy Gap water through the Colorado-Big Thompson facilities, including the enlargement of Ralph Price Reservoir by the City of Longmont
- Alternative 2 (Proposed Action) – Chimney Hollow Reservoir (90,000 AF) with prepositioning

- Alternative 3 – Chimney Hollow Reservoir (70,000 AF) and Jasper East Reservoir (20,000 AF)
- Alternative 4 – Chimney Hollow Reservoir (70,000 AF) and Rockwell/Mueller Creek Reservoir (20,000 AF)
- Alternative 5 – Dry Creek Reservoir (60,000 AF) and Rockwell/Mueller Creek Reservoir (30,000 AF)

Prepositioning, under the Proposed Action, involves the storage of Colorado-Big Thompson (C-BT) water in Chimney Hollow Reservoir. Windy Gap water pumped into Lake Granby would then be exchanged for C-BT water stored in Chimney Hollow. Windy Gap water stored in Chimney Hollow would be delivered and allocated to the WGFP Participants. This arrangement ensures temporary space in Lake Granby to introduce and store Windy Gap water. Total allowable C-BT storage would not change and the existing C-BT water rights and diversions would not be expanded. To prevent the C-BT Project from expanding their diversions through prepositioning, total modeled C-BT storage in Lake Granby and Chimney Hollow was limited to the capacity of Lake Granby, which is 539,758 AF. If this capacity limitation is reached, the model forces the C-BT Project to bypass water at Lake Granby. This water is then available for diversion at Windy Gap. Therefore, under prepositioning, C-BT diversions would not be expanded with respect to their current water rights and capacity limitations.

In addition to the action alternatives, a No Action alternative was identified based on what is reasonably likely to occur if Reclamation does not approve the connection of the new WGFP facilities to C-BT facilities. Under this alternative, the existing contractual arrangements between Reclamation and the Subdistrict for storage and transport of Windy Gap water through the C-BT system would remain in place. All Project Participants in the near term would maximize delivery of Windy Gap water according to their demand, Windy Gap water rights, and C-BT facility capacity constraints including availability of storage space in Lake Granby, and the Adams Tunnel conveyance constraints. The City of Longmont would develop storage independently for firming Windy Gap water if the WGFP is not implemented. Most Participants indicate that in the long term, they would seek other storage options, individually or jointly, to firm Windy Gap water because of their need for reliable Windy Gap deliveries and the substantial investment in existing infrastructure.

Those Participants that do not have a currently defined storage option would take delivery of Windy Gap water whenever it is available within the capacity of their existing water systems and delivery points under the terms of the existing Carriage Contract with Reclamation and the Northern Colorado Water Conservancy District (NCWCD). Participants that would operate under this scenario include Broomfield, Central Weld County Water District, Erie, Evans, Fort Lupton, Greeley, Little Thompson Water District, Louisville, Loveland, Platte River Power Authority, and Superior. The City of Lafayette anticipates that it would withdraw from participating in the WGFP and dispose of existing Windy Gap units and not pursue acquisition of future units if the Firming Project is not constructed.

Longmont indicates that it would develop storage facilities for Windy Gap water independently if Reclamation does not approve a connection of WGFP facilities to C-BT facilities. The City would evaluate the enlargement of the existing Ralph Price Reservoir (Button Rock Dam) located on North St. Vrain Creek or Union Reservoir located east of the City. The enlargement of Ralph Price by 13,000 AF would be the City’s preferred option because Union Reservoir would not have sufficient capacity for Windy Gap water and conveyance and distribution would be more efficient from a higher elevation reservoir.

Middle Park Water Conservancy District (MPWCD), under No Action, would continue to use Windy Gap water to provide augmentation flows for other water diversions in a manner similar to current operations. MPWCD can store up to 3,000 AF of Windy Gap water in Lake Granby each year if Windy Gap water can be diverted and storage space is available.

Detailed descriptions of the components and operation of the alternatives is included in the Draft Windy Gap EIS Alternatives Descriptions report (Boyle and NCWCD, 2005).

# 3.0 STUDY AREA

This analysis is focused on in-lake or in-reservoir water quality. Therefore, the study area for the Lake and Reservoir Water Quality Technical Report includes 1) the existing lakes and reservoirs that may be impacted by one or more of the alternatives and 2) the proposed reservoirs. Stream water quality is described elsewhere (ERO and AMEC, 2008). The existing lakes and reservoirs considered in this analysis include:

- Grand Lake;
- Shadow Mountain Reservoir;
- Granby Reservoir;
- Horsetooth Reservoir;
- Carter Lake Reservoir; and
- Ralph Price Reservoir.

Proposed reservoirs considered in this analysis are:

- Jasper East Reservoir;
- Rockwell/Mueller Creek Reservoir;
- Chimney Hollow Reservoir; and
- Dry Creek Reservoir.

There are eight other reservoirs in the C-BT system that are not described in detail in this report because the effects are expected to be minor or the water quality would remain unchanged from existing conditions. They include:

- Mary's Lake;
- Lake Estes;
- Pinewood Reservoir;
- Flatiron Reservoir;
- Windy Gap Reservoir;
- Willow Creek Reservoir;
- Green Mountain Reservoir; and
- Boulder Reservoir.

Mary's Lake, Pinewood Reservoir, Flatiron Reservoir, and Windy Gap Reservoir are small, shallow reservoirs (mean depths of less than 8 meters) with very short residence times (on the order of 1 to 3 days). Hydraulic water residence times were computed as the average annual contents of the reservoir divided by the average annual water outflow. This is the average time required to refill a lake or reservoir with new water if it were to be emptied (Kalff, 2002). Note that the residence time for Windy Gap Reservoir was also computed on a monthly basis using the average monthly flow through the reservoir for existing conditions and a reservoir volume of 445 AF. This was done to differentiate between periods when Windy Gap is pumping and when it is not. The reservoir residence time in Windy Gap ranges from 0.2 to 3.4 days, when computed on a monthly basis. The minimum value occurs in June while the maximum value is for January. The range for the nonpumping period (August to March) is 1.3 days (August) to 3.4 days (January).

In-reservoir water-quality data for Mary's Lake, Pinewood Reservoir, Flatiron Reservoir, and Windy Gap Reservoir could not be located, with the exception of Mary's Lake, which was sampled on two days in July 1987. These reservoirs are assumed to be well-mixed reservoirs and it is anticipated that with short residence times, in-reservoir water quality approximates that of the major inflows.

Lake Estes is also shallow (mean depth of 5 meters) with a short residence time (average of 5 days in July / August). Summer temperature profiles for 1998 – 2005 are somewhat isothermal and do not show the formation of stratified layers (Figure 1). Specific conductivity profiles for the same period also show somewhat uniform conditions with depth (Figure 2). In addition, total phosphorus concentrations of the Adams Tunnel (the major source of inflow into Lake Estes), the Olympus Tunnel (the major outflow), and the surface of Lake Estes are similar (Figure 3). Note that values in Figure 3 for the period prior to August 2000 were found to be below the detection limits and are shown to be at the detection limit. The detection limit between December 1998 and August 2000 was 50 µg/l, thus forming a plateau. The outflow and in-reservoir concentrations are greater than the Adams Tunnel concentrations due to Big Thompson River inflows to the reservoir (the Adams Tunnel is the major source of inflow). Based on this information, it is assumed that the water quality of Lake Estes approximates the water quality of the inflows (a mixture of the Adams Tunnel and the Big Thompson River).

The other three reservoirs are not included because the alternatives would not impact in-reservoir water quality. The operations of Willow Creek Reservoir would be the same between alternatives and the inflow into the reservoir would not change. Thus, there would be no change in Willow Creek water quality for any of the alternatives. In addition, Green Mountain Reservoir would not be impacted by any of the alternatives. Boulder Reservoir receives water from Carter Lake. It is assumed that if the effects at Carter Lake are minimal, then the water quality of Boulder Reservoir would be minimally impacted.

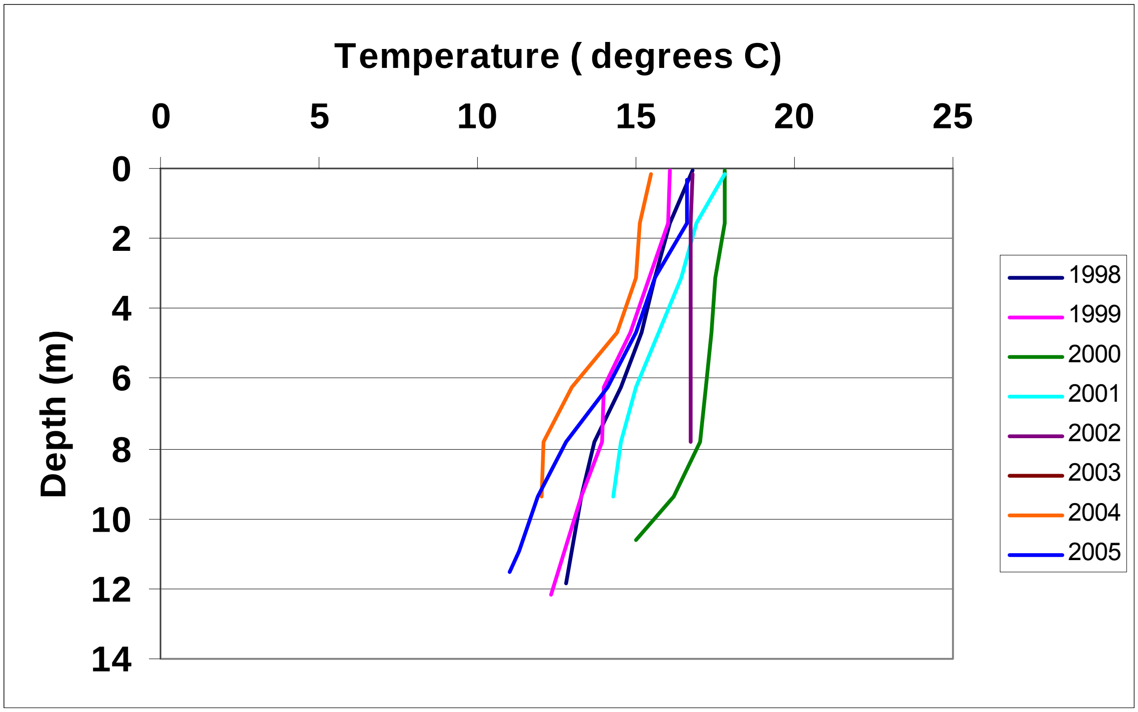


**Figure 1: August Temperature Profiles in Lake Estes - 1998 – 2005 (Data Source: USGS 2007 NWIS Database)**

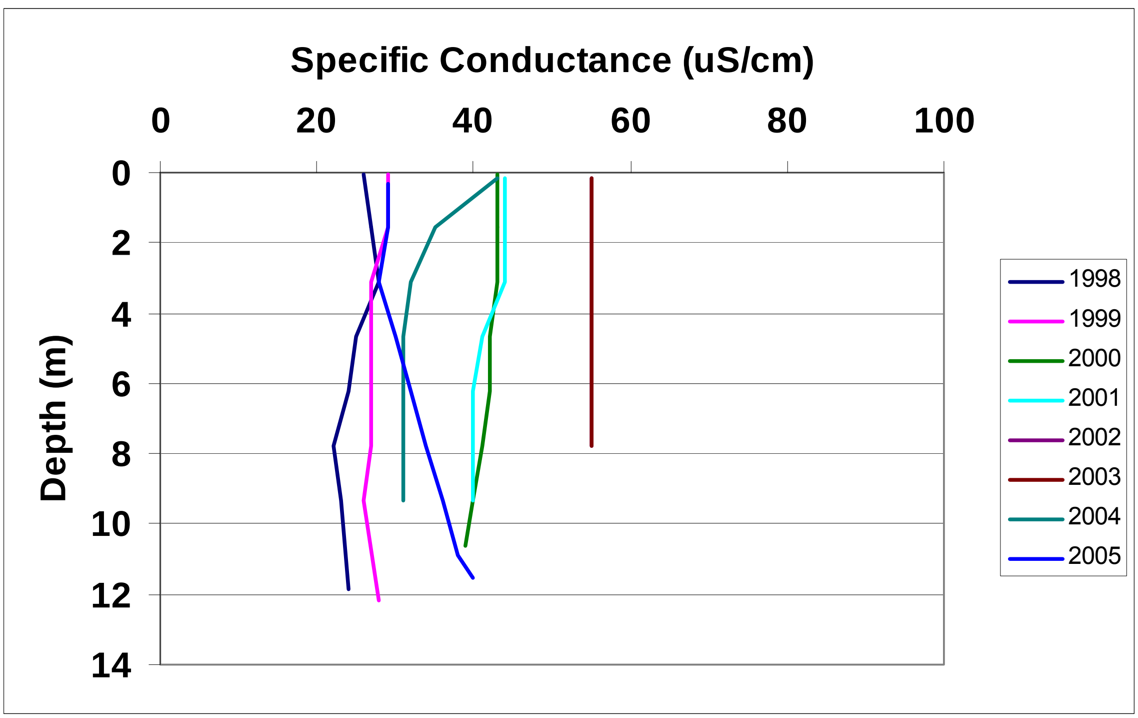


**Figure 2: Specific Conductance Profiles in Lake Estes (1998 – 2005) (Data Source: USGS 2007 NWIS Database)**

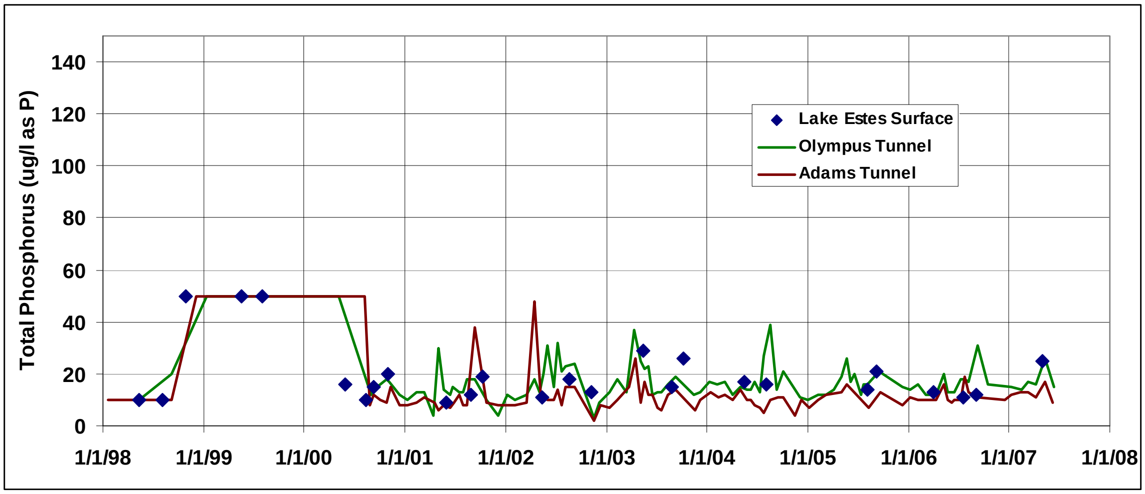


**Figure 3: Total Phosphorus Concentrations at the Adams Tunnel (E. Portal), Olympus Tunnel at Lake Estes, and the Surface of Lake Estes (Data Source: USGS 2007 NWIS Database)**

# 4.0 OBJECTIVES

The purpose of this technical report is to characterize the affected environment and potential environmental effects regarding lake and reservoir water quality for the proposed Windy Gap Firming Project.

# 5.0 DATA SOURCES

The best available information was used to describe the water quality in potentially affected lake and reservoirs and to assess the impacts of the Firming Project alternatives. The data sources and impact assessment used for the analysis are described in the following sections.

## 5.1. Existing Data Sources and Review

AMEC collected and reviewed existing data from a variety of sources for this effort (Table 1). In general, this table includes data for either in-reservoir samples or inflowing tributaries. In addition, several reports and studies were reviewed (Table 2). For purposes of the data analyses performed for this EIS, water-quality data reported as being below the detection or reporting limit were assumed to equal one-half of the detection or reporting limit.

## Table 1: Data Obtained for the Windy Gap Firming Project Water-Quality Analysis

| | | | Water-Quality Data | | |
|---|---|---|---|---|---|
| **Source of Data** | **Site Name** | **Site Identifier** | **Chemistry** | **Biology*** | **Period of Record** |
| **USGS[1]** | **Grand Lake at Grand Lake** | 09013900 | ● | | 8/73 - 6/75, 11/00 - 3/07 |
| | **Grand Lake Outlet at Grand Lake** | 09014000 | ● | | 11/00 - 8/04 |
| | Grand Lake | 401441105493100 | ● | | 7/87 - 10/87 |
| | **Grand Lake (South East) Near Grand Lake** | 401422105483100 | ● | | 11/00 - 9/01 |
| | **North Inlet at Grand Lake** | 09012500 | ● | | 11/00 - 9/04 |
| | **East Inlet at Grand Lake** | 09013500 | ● | | 11/00 - 9/04 |
| | **Shadow Mountain Lake near Grand Lake** | 09014500 | ● | | 8/73 - 6/75, 5/89 - 3/07 |
| | **Colorado River Near Grand Lake (N. Fork)** | 0910500 | ● | | 11/56 - 9/04 |
| | **Granby Pump Canal Near Grand Lake** | 09018300 | ● | | 3/78 - 7/04 |
| | **Lake Granby Near Granby** | 09018500 | ● | | 8/73 - 3/07 |
| | **Lake Granby (East) Near Granby** | 400806105474700 | ● | | 11/00 - 9/02 |
| | **Lake Granby (West) Near Granby** | 400844105530800 | ● | | 5/89 - 9/02 |
| | Lake Granby Inflow from Windy Gap Tunnel | 400833105532000 | ● | | 6/91 - 5/94 |
| | **Stillwater Creek Ab Lk Granby, Nr Grand Lake** | 09018000 | ● | | 10/55 - 9/04 |
| | Columbine Creek Above Lake Granby, Nr Grand Lake | 09015500 | ● | | 10/55 - 11/55 |
| | **Arapaho Creek at Monarch Lake Outlet** | 09016500 | ● | | 10/68 - 8/71, 11/00 - 9/04 |
| | Carter Reservoir at Middle Site | 402009105130700 | ● | | 8/83 - 8/88 |
| | Carter Reservoir at North Site | 402053105125800 | ● | | 8/83 - 7/88 |
| | **Carter Lake Near Berthoud** | 06742500 | ● | | 2/70 - 5/07 |
| | **Horsetooth Reservoir Near Fort Collins** | 06737500 | ● | | 9/69 - 8/04 |
| | **Horsetooth Reservoir Nr Spring Canyon Dam, Site C** | 403147105083800 | ● | | 8/83 - 4/07 |
| | Horsetooth Reservoir Nr Dixon Canyon Dam, Site B | 403317105090000 | ● | | 8/83 - 7/88 |
| | **Olympus Tunnel At Lake Estes, CO** | 6734900 | ● | | 9/70 - 6/07 |
| | **Big Thompson Rive Below Sanitation Outflow Above Lake Estes** | 402245105302300 | ● | | 8/00 - 6/07 |
| | **Big Thomson River Near Estes Park** | 6735500 | ● | | 5/72 - 6/07 |
| | **Mary's Lake** | 402032105314700 | ● | | Jul-87 |
| | **Alva B. Adams Tunnel at E. Portal, Nr Estes Park, CO** | 9013000 | ● | | 9/70 - 6/07 |
| | **Hansen Canal Above Tunnel No. 5 Nr Loveland, CO** | 403020105114700 | ● | | 8/00 - 6/07 |
| | | | | | |
| **EPA[2]** | Grand Lake, South-West bay | 121 | ● | | 8/69 - 9/69 |
| | Grand Lake, NW part of Lake, West of North Inlet | 120 | ● | | 8/69 - 9/69 |
| | **Grand Lake, East End** | 6 | ● | ● | 1969, 1990, 2000 - 2001 |
| | Shadow Mountain Res, near the NW shore | 116 | ● | | 8/29/69 |
| | Shadow Mountain Reservoir, in the north end near the Hilltop Ranger St | 115 | ● | | 8/69 - 9/69 |
| | Shadow Mountain Reservoir, EPA station, location unknown | 118 | ● | | 8/69 - 9/69 |
| | Shadow Mountain Reservoir, on Eastern shore | 114 | ● | | 9/2/69 |
| | Lake Granby, in Grand Bay north of ranger station | 124 | ● | | 8/29/69 |
| | Lake Granby, between Sunset Point and Harvey Island | 123 | ● | | 8/69 - 9/69 |
| | Lake Granby, just off the NW shore Campground | 122 | ● | | 8/69 - 9/69 |
| | **Lake Granby, eastern part of reservoir off Twin Pines Point** | 10 | ● | ● | 1969, 2000 - 2002 |
| | **Lake Granby, Just into Rainbow Bay** | 12 | ● | ● | 1969, 1990 - 2002 |
| | | | | | |
| **CDPHE[3]** | **Alligator Rock in SE Grand Lake** | 108 | ● | ● | 1990 - 2000 |
| | **Grand Lake West Central, BoykinNeuby** | 109 | ● | ● | 1990 - 2000 |
| | **Grand Lake, East end** | 6 | ● | ● | 1969, 1990, 2000 -2001 |
| | Mid-Channel between Grand Lake & Shadow Mountain | 111 | ● | | 8/92 - 6/94 (secchi disc only) |

**Table 1: Data Obtained for the Windy Gap Firming Project Water-Quality Analysis**

| | | | Water-Quality Data | | |
|---|---|---|---|---|---|
| Source of Data | Site Name | Site Identifier | Chemistry | Biology* | Period of Record |
| | | | | | |
| Univ of Colorado[4] | Grand Lake | | ● | ● | 5/84 - 11/84 |
| | Shadow Mountain | | ● | ● | 5/84 - 11/84 |
| | Lake Granby | | ● | ● | 5/84 - 11/84 |
| | | | | | |
| GCWIN[5] | Grand Lake | | ● | ● | 1990-1993, 1996-2000, 7/04 - 9/05 |
| | Shadow Mountain | | | ● | 7/04 - 9/05 |
| | Lake Granby | | | ● | 7/04 - 9/05 |
| | | | | | |
| BTWF[6] | Inlet Bay Narrows | R20 | ● | ● | 9/99 -8/05 |
| | Spring Canyon Dam | R21, R21-A, R21-B | ● | ● | 10/00 - 6/06 |
| | Dixon Canyon Dam | R30 | ● | ● | 10/00 - 9/05 |
| | Soldier Canyon Dam | R40, R40-A, R40-B | ● | ● | 1/00 - 6/06 |
| | South Bay | R-22 | ● | ● | 2000, 2004 |
| | | | | | |
| NCWCD[7] | Arapahoe Creek (USGS Station) (09016500) | AC-1 | ● | | 2004 |
| | Colorado River DS discharge chute of Granby Dam[9] | CR-1 | ● | | 1991 - 1999 |
| | Colorado River US of confluence w/Fraser, north side Hwy 40 | CR-WGU | ● | | 1991 - 2005 |
| | East Inlet near USGS station near Grand Lake | EI-GLU | ● | | 1997 - 2004 |
| | Fraser River upstream of Winter Park by USGS station | FR-1 | ● | | 1991 - 2004 |
| | Fraser River upstream of Colorado River by NCWCD station | FR-WQU | ● | | 1991 - 2005 |
| | Grand Lake Outlet (USGS Station) (09014000) | GLO | ● | | 2004 |
| | Granby Pump Canal | GR-Pump | ● | | 1991 - 2004 |
| | Hansen Canal @ Inlet to Horsetooth | HFC-HT | ● | | 1996 - 2005 |
| | North Fork Colorado @ USGS on Hwy 34 near Shadow Mt Reservoir | NF-1 | ● | | 1996 - 2004 |
| | North Inlet @ NCWCD station in Grand Lake | NI-1 | ● | | 1996 - 2004 |
| | Stillwater Creek (USGS Station) (09018000) | SW-1 | ● | | 2004 |
| | Willow Ck 0.5 mile upstream of Colorado River | WC-3 | ● | | 1991 - 2004 |
| | Willow Creek discharge chute to Lake Granby | WC-Pump | ● | | 1991 - 2005 |
| | | | | | |

**Table 1: Data Obtained for the Windy Gap Firming Project Water-Quality Analysis**

| | | | Water-Quality Data | | |
|---|---|---|---|---|---|
| **Source of Data** | **Site Name** | **Site Identifier** | **Chemistry** | **Biology*** | **Period of Record** |
| | | | | | |
| | **Windy Gap discharge chute to Lake Granby** | WG-Pump | ● | | 1991 - 2005 |
| **USBR[8]** | **Grand Lake at Grand Lake** | | | ● | |
| | **Grand Mid** | GL-MID | ● | ● | 5/05 - 7/07 |
| | **Grand Portal** | | | ● | |
| | **West Portal Adams Tunnel** | | | ● | |
| | **Shadow Mountain Lake near Grand Lake** | SM-DAM | ● | ● | 5/05 - 7/07 |
| | **Lake Granby Near Granby** | GR-DAM | ● | ● | 5/05 - 7/07 |
| | **Carter Lake** | CL-DAM1 | ● | | 5/05 - 10/06 |
| | **Horsetooth Reservoir Hansen Inlet** | | ● | | 8/03 - 9/04 |
| | **Horsetooth Reservoir Dixon Canyon** | | ● | | 8/03 - 9/04 |
| | **Horsetooth Reservoir Spring Canyon** | HT-SPR | ● | | 8/03 - 10/06 |
| | **Horsetooth Reservoir Soldier Canyon** | HT-SOL | ● | | 8/03 - 10/06 |

[1] USGS NWIS Database (www.usgs.gov)
[2] Retrieved from Legacy STORET Database
[3] Provided by Joni Nuttle, WQCD
[4] Morris and Lewis, 1988
[5] Provided by S. Clements, GCWIN
[6] www.btwatershed.org
[7] Provided by Esther Vincent, NCWCD
[8] Provided by C. Holdren and D. Liebermann, USBR
[9] Data from Three Lakes Database which identified NCWCD as source of this data though it was not present in the NCWCD database.
**BOLD** Sites with Recent Data (since 2000)
* Chlorophyll a, cell counts, and/or algal toxins

**Table 2: Reports and Studies Reviewed**

| Title | Author / Organization | Year |
|---|---|---|
| Nutrient Project Priority Descriptions, Known Information Summaries, and Data Gap Analysis (Technical Report 3B) | NCWCD | 2005a |
| Three Lakes Clean Lakes Watershed Assessment | Hydrosphere | 2003 |
| Water Quality Study, Grand Lake, Shadow Mountain Lake, and Lake Granby, Colorado | EPA | 1977 |
| Water Quality Conditions in Grand Lake, Shadow Mountain Lake, Lake Granby | EPA | 1970 |
| Analysis of Water Quality Effects on Three Lakes Windy Gap Project | Dames & Moore | 1977 |
| Potential Impact of Windy Gap Diversions on the Productivity of the Three Lakes System | Yahnke, USBR | 1978 |
| Water Quality of the Upper Big Thompson Watershed | Jassby and Goldman | 2003 |
| Horsetooth and Carter Lake Reservoirs - Water Quality Comparisons | Jassby and Goldman | 1999 |
| Water Quality and Trend Analysis of Colorado-Big Thompson System Reservoir and Related Conveyances, 1996-2000 | Stevens, USGS | 2003 |
| Physical, Chemical, and Biological Characteristics of Horsetooth Reservoir, Fort Collins, Colorado (2003-2004) | Lieberman, USBR | 2005 |
| Preliminary Assessment of Nutrients and Nutrient-Related Concerns in the C-BT Watershed | Alexander, Big Thompson Watershed Forum | 2004 |
| Physical Attributes of Five Reservoirs on the Colorado – Big Thompson Project, 2005 to 2006: Lake Granby, Grand Lake, Shadow Mountain Reservoir, Horsetooth Reservoir, and Carter Lake (Draft) | Lieberman, USBR | 2007a |
| Nutrients, Chlorophyll a, and Secchi-Disk Transparency of Five Reservoirs on the Colorado – Big Thompson Project, 2005 to 2006: Lake Granby, Grand Lake, Shadow Mountain Reservoir, Horsetooth Reservoir, and Carter Lake (Draft) | Lieberman, USBR | 2007b |
| Horsetooth Reservoir: 1996 Water Quality Conditions | Ecological Research Associates | 1998 |

# 6.0 FEDERAL, STATE, AND LOCAL WATER-QUALITY REGULATIONS

The Federal Clean Water Act (33 U.S.C. 1251, et. seq.) is a set of laws that govern and regulate surface and groundwater quality and improve watersheds nationwide. This Act requires states to adopt water quality criteria for the waters and develop a plan to implement and enforce the criteria (Colorado Water Quality Management and Drinking Water Protection Handbook, 2002). The Colorado Water Quality Control Commission (the administrative agency) and the Water Quality Control Division (the implementing and enforcing agency) govern water quality in Colorado. This includes 1) assigning use classifications to state water segments, 2) establishing water-quality standards for each water segment, and 3) reporting on attainment of water-quality standards.

The non-attainment of water-quality standards is reported every two years via the State's 303(d) List. Segments on the 303(d) List are considered to be impaired for one or more water-quality parameters and a TMDL (Total Maximum Daily Load) effort will need to occur to resolve the impairment. If an impairment is suspected and there are not sufficient data to draw a conclusion, the water segment is placed on the Monitoring and Evaluation (M&E) List.

Thus, the 303(d) List and the M&E List can be used to identify potential water quality issues in the study area from a regulatory perspective. The regulatory status of each reservoir considered in this report is described in Section 9.

# 7.0 EUTROPHICATION PROCESS AND TROPHIC STATUS

The process of eutrophication is used to describe the increase in a lake's level of biological production. The cause of cultural eutrophication (versus natural eutrophication which can take thousands of years) is often attributed to increases in nutrient loadings from the watershed.

Lakes and reservoirs are commonly evaluated with respect to their trophic state or their position on the continuum (Figure 4) between oligotrophy (low production) and eutrophy (high production).

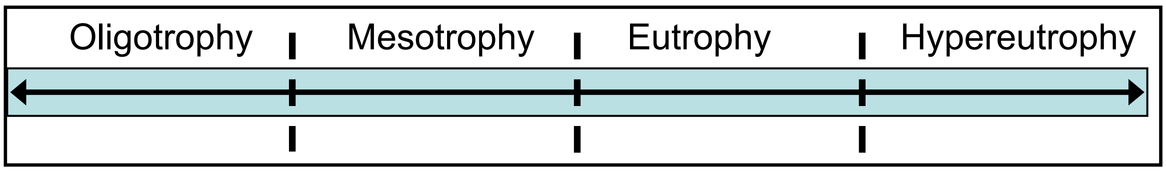


**Figure 4: The Continuum of Trophic States (Data Source: EPA, 2000)**

There are a number of potential deleterious effects associated with eutrophic or hypereutrophic lakes. These effects are listed in the left-hand column of Table 3. These effects can impact classified uses in a lake or reservoir and are also shown in this table.

**Table 3: Potential Impacts from Advanced Eutrophication**

| | Potential Negative Impact on Uses | | | | |
|---|---|---|---|---|---|
| Potential Result of Eutrophication | Aquatic Life | Recreation / Aesthetics | Water Supply / Treatment | Agriculture | System Operations |
| High Organic Carbon | | | X | | |
| Excessive Algae | | X | X | | |
| Blue Green Algae | X | X | X | X | |
| High Manganese | | | X | | |
| High Iron | | | X | | |
| Low Dissolved Oxygen | X | | | | |
| High Nutrients | X* | | X** | | |
| Excessive Aquatic Vegetation | | X | | | X |
| Smell | | X | X | | |
| Green Color | | X | | | |
| Decreased Clarity / More Turbidity | | X | X | | |

*ammonia, ** nitrate

Common values of chlorophyll *a* (Chla) associated with various levels of trophic state are listed in Table 4. In cases where chlorophyll *a* data are not available, other data such as Secchi-disk

(SD) depth or total phosphorus (TP) can be used instead of chlorophyll *a* data, if the lake is a phosphorus-limited North American temperate lake (Carlson and Simpson, 1996).

**Table 4: Common Values Expected by Trophic Status**

(Phosphorus-Limited North American Temperate Lakes) (www.nalms.org, reproduced with permission from NALMS)

| Condition | Chla (µg/l) | Surrogate Metrics | |
|---|---|---|---|
| | | SD (m) | TP (µg/l) |
| Oligotrophic | < 0.95 | >8 | < 6 |
| Oligotrophic-Mesotrophic | 0.95-2.6 | 8-4 | 6-12 |
| Mesotrophic | 2.6-7.3 | 4-2 | 12-24 |
| Eutrophic | 7.3-20 | 2-1 | 24-48 |
| Eutrophic-Hypereutrophic | 20-56 | 0.5-1 | 48-96 |
| Hypereutrophic | 56-155 | 0.25-0.5 | 96-192 |
| Extremely Hypereutrophic | >155 | <0.25 | 192-384 |

Values based on average summer values (June 15-Sept 1)

# 8.0 AFFECTED ENVIRONMENT

This section describes the current state of the potentially affected lakes and reservoirs based on recent water-quality data. In most cases, data from the period 2000 to 2007 are used in the data summary tables. An exception to this is the analysis for Horsetooth Reservoir, which used data from 2004 to 2007 due to the reservoir drawdown in 2000-2003. The specific sites considered in this section are listed in Table 5. For standards evaluation, data from the previous five years (September, 2002 on) were used according to Water Quality Control Division's Guidance on Data Requirements (CDPHE, 2005). Note that lake and reservoir data are often listed according to layer. The epilimnion refers to the surface layer, metalimnion refers to a middle layer, and hypolimnion refers to the lower layer.

**Table 5: List of Data Sites and Sources Evaluated for the Data Summary Tables**

| EIS Site Identifier | Data Sources | Source's Site Name | Start Date | End Date |
|---|---|---|---|---|
| Carter Lake Near Berthoud | USBR Nutrient Project | CL-DAM1 | 5/17/05 | 10/12/06 |
| | USGS | 06742500 Carter Lake Near Berthoud | 5/4/00 | 5/1/07 |
| Grand Lake At Grand Lake | USGS | #09013900 Grand Lake at Grand Lake | 11/21/00 | 3/13/07 |
| Grand Lake Middle | USBR Nutrient Project | GL-MID | 5/18/05 | 7/24/07 |
| Horsetooth Reservoir Soldier Canyon Dam | BTWF | R40 | 4/12/04 | 6/19/06 |
| | USBR Nutrient Project | HT-SOL | 5/16/05 | 10/11/06 |
| Horsetooth Reservoir Spring Canyon Dam | BTWF | R21 | 4/12/04 | 6/19/06 |
| | USBR Nutrient Project | HT-SPR | 5/16/05 | 10/11/06 |
| | USGS | 403147105083800 Horsetooth Reservoir Near Spring Canyon Dam Site C | 5/4/00 | 4/30/07 |
| Lake Granby Near Granby | USBR Nutrient Project | GR-DAM | 5/18/05 | 7/24/07 |
| | USGS | 09018500 Lake Granby Near Granby | 5/25/00 | 3/13/07 |
| Shadow Mountain Lake Near Grand Lake | USBR Nutrient Project | SM-DAM | 5/19/05 | 7/24/07 |
| | USGS | 09014500 Shadow Mountain Lake Near Grand Lake | 5/25/00 | 3/12/07 |

## 8.1. Description of the Overall System

With the exception of Ralph Price Reservoir, the existing lake/reservoirs considered in this report are part of the Colorado - Big Thompson (C-BT) Project. The configuration and general operation of the C-BT system is described elsewhere (ERO and Boyle, 2007).

A portion of the overall C-BT system, however, operates as its own sub-system. Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir are often referred to as the Three Lakes System (Figure 5). These three water bodies are located on the West Slope and are operated together as part of the Colorado - Big Thompson (C-BT) project.

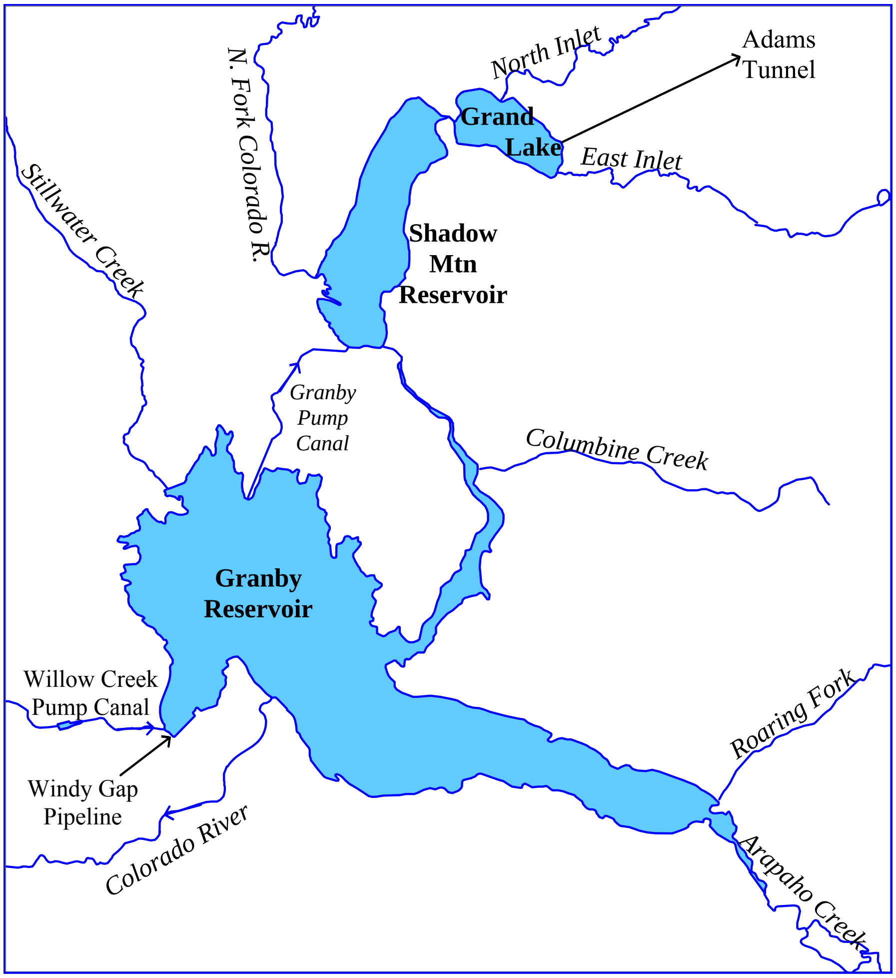


**Figure 5: Three Lakes System (Data Source: Hydrosphere, 2003a)**

During the runoff season, water flows from Grand Lake, through Shadow Mountain Reservoir, and is stored in Granby Reservoir. When water is needed on the East Slope, water is pumped up from Granby Reservoir through Shadow Mountain Reservoir to Grand Lake and then flows east through the Adams Tunnel. Since water can flow either direction, the entire watershed (Figure 6) has an impact on each of the three water bodies. Additional input to the Three Lakes system comes via pumping from Windy Gap Reservoir on the Colorado River below the confluence with the Frasier River and from Willow Creek Reservoir via the Willow Creek Pump Canal. Thus, water input from the Windy Gap Basin and Willow Creek Basin also influence water quality in the Three Lakes.

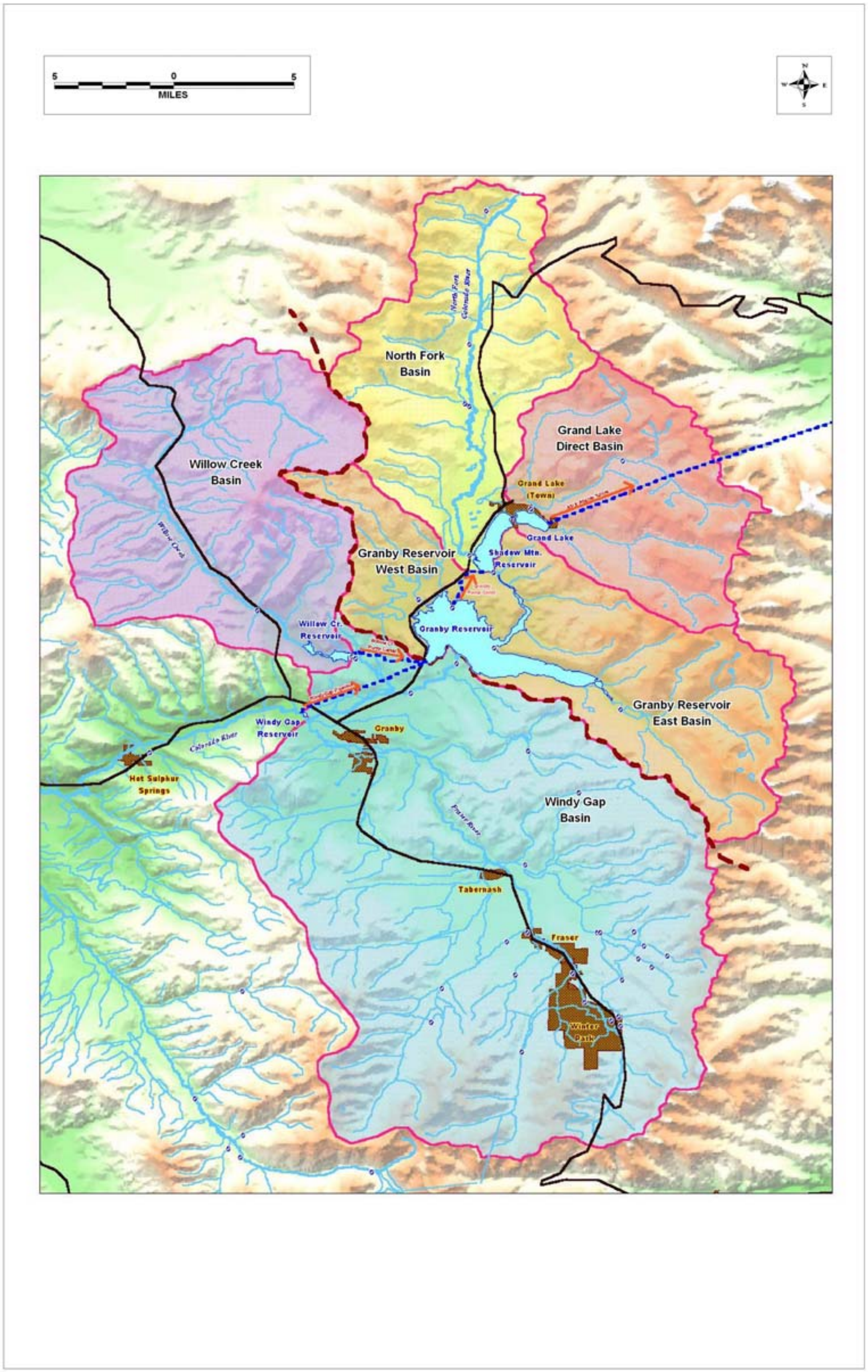


**Figure 6: Three Lakes System Watersheds**

Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir are separately described in the following section along with the other existing reservoirs, which are located on the east slope. Water-quality monitoring stations used for this report for the Three Lakes are shown in Figure 7.

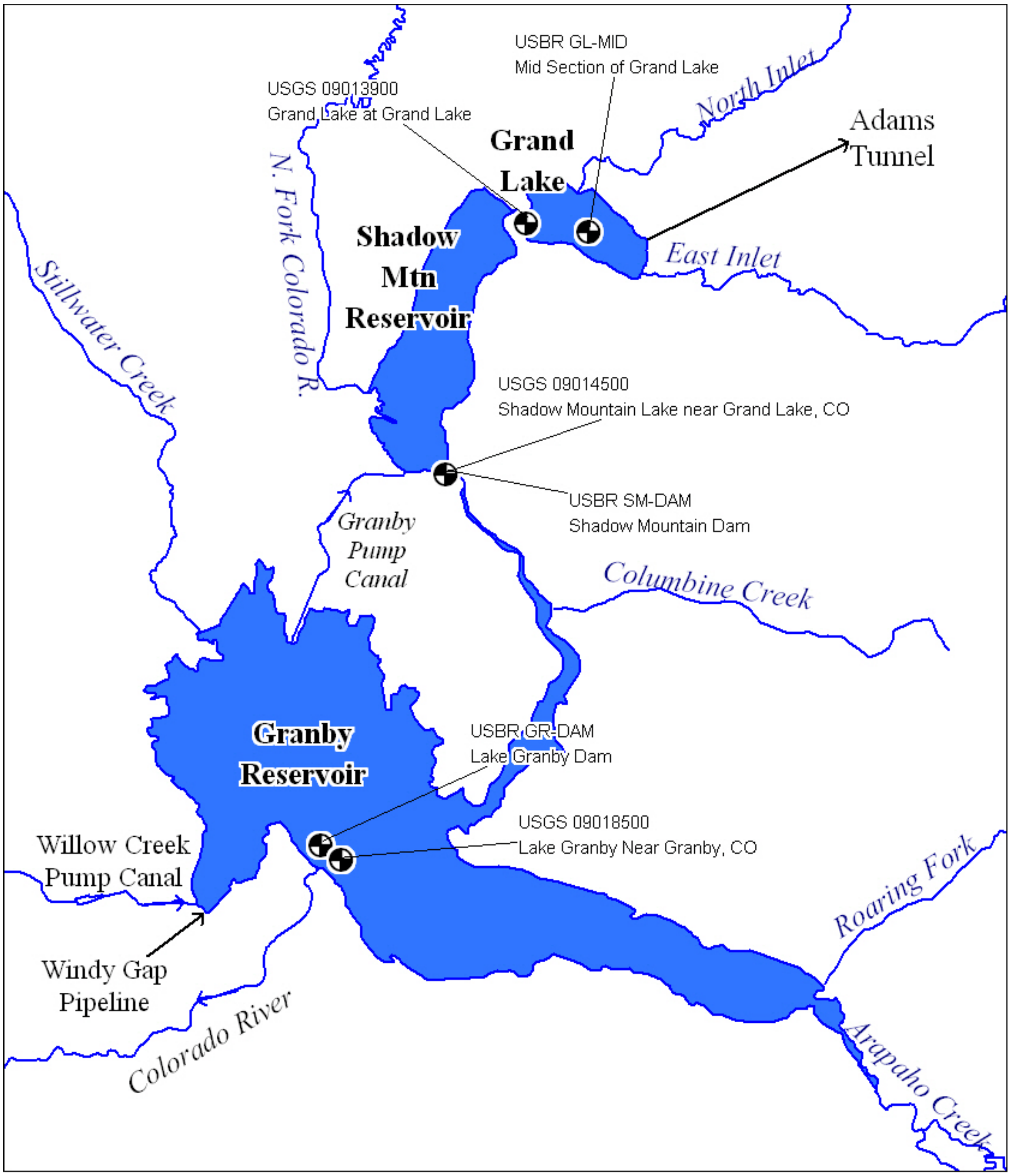


**Figure 7: Three Lakes Water-Quality Monitoring Stations**

## 8.2. Existing Reservoir Water Quality

### 8.2.1. Granby Reservoir

Granby Reservoir is the 2nd largest reservoir in Colorado and serves as the primary storage reservoir in the C-BT system. The reservoir also supports high-quality fishing for kokanee and trophy lake trout. Its surface water elevation can vary considerably depending on hydrology and operations. These variations can affect in-reservoir water quality. The reservoir has four use classifications which are used by CDPHE to set appropriate water-quality standards.

- Aquatic Life Cold 1;
- Recreation 1a;
- Water Supply; and
- Agriculture.

These use classifications are defined in Table 6.

**Table 6: Definitions of Use Classifications Applicable to the Lakes and Reservoirs Described in this Report (CDPHE, 2007)**

| Use Classification | Description |
|---|---|
| Aquatic Life Class 1 – Cold Water | These are waters that (1) currently are capable of sustaining a wide variety of cold water biota, including sensitive species, or (2) could sustain such biota but for correctable water quality conditions. Water shall be considered capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of species. |
| Agriculture | These surface waters are suitable or intended to become suitable for irrigation of crops usually grown in Colorado and which are not hazardous as drinking water for livestock. |
| Recreation 1a (also referred to as class E – Existing Primary Contact Use) | These surface waters are used for primary contact recreation or have been used for such activities since November 28, 1975. |
| Domestic Water Supply | These surface waters are suitable or intended to become suitable for potable water supplies. After receiving standard treatment (defined as coagulation, flocculation, sedimentation, filtration, and disinfection with chlorine or its equivalent) these waters will meet Colorado drinking water regulations and any revision, amendments, or supplements thereto. |

Major tributaries include Arapaho Creek, Stillwater Creek, Columbine Creek, and the Roaring Fork. Water is also pumped to the reservoir from Willow Creek Reservoir and Windy Gap Reservoir. Outflow is to the Colorado River and to Shadow Mountain (via the Farr Pumping Plant). Granby Reservoir's physical characteristics and hydrology are described in Table 7. The estimated residence time is based on average annual reservoir contents and total annual outflow.

**Table 7: Physical Characteristics and Hydrology of Granby Reservoir**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume** | 539,758 AF | 665.8 x $10^6$ $m^3$ |
| Surface Area** | 7,256 acres | 2,940 hectares |
| Mean Depth** | 74 ft | 22.5 m |
| Maximum Depth*, ** | 221 ft | 67.4 m |
| Shoreline* | 40 miles | 64.4 km |
| Hydraulic Residence Time | 0.9-1.8 years | |

Source: Hydrosphere, 2003a, * NCWCD, 2007a; ** at maximum capacity

Concentrations of key water-quality constituents in Granby Reservoir are summarized in Table 8. More detailed information can be found in Appendix A. Only recent data (2000-2007) are considered in these tables because a more comprehensive monitoring program was put into place for the reservoir in 2000. Data from the USGS sampling site 'Lake Granby Near Granby' and the USBR Nutrient Project sampling site GR-DAM, which are located in close proximity to each other, were used (Figure 7). Note that composite samples and grab samples are listed separately.

A detailed evaluation of the water quality in Granby Reservoir, focused on data from 2005 to 2006 can be found in Lieberman, 2007a and Lieberman, 2007b.

## Table 8: Summary of Key Water-Quality Parameters for Lake Granby Near Granby Site (see Table 5 for Data Sources)

***Epilimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | 1.57 | 3.66 | 3.90 | 7.95 |
| Chlorophyll a, ug/l | 1.00 | 4.40 | 6.02 | 29.80 |
| DO, mg/l | 6.10 | 7.20 | 8.66 | 14.10 |
| Conductivity, uS/cm | 43.00 | 61.00 | 65.28 | 117.00 |
| pH, field | 7.00 | 7.70 | 7.83 | 9.20 |
| Temperature, deg C | 0.20 | 11.20 | 10.38 | 19.40 |
| Ammonia, dis, ug/l as N | 1.50 | 7.00 | 10.67 | 78.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 8.00 | 13.77 | 70.00 |
| TKN, ug/l as N | 23.00 | 215.00 | 225.35 | 480.00 |
| TP, ug/l as P | 1.50 | 11.00 | 11.46 | 31.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 3.00 | 2.30 | 7.00 |
| Silica, dis, mg/l | 4.39 | 5.21 | 5.73 | 8.17 |
| TOC, mg/l | 1.30 | 3.70 | 3.48 | 6.30 |
| DOC, mg/l | 3.20 | 3.55 | 3.59 | 4.10 |
| Calcium, dis, mg/l | 6.60 | 7.96 | 8.12 | 9.63 |
| Magnesium, dis, mg/l | 1.17 | 1.48 | 1.48 | 1.75 |
| Sulfate, dis, mg/l | 2.00 | 3.94 | 3.64 | 4.70 |
| Chloride, dis, mg/l | 0.36 | 0.78 | 0.70 | 0.95 |
| Alkalinity, dis, mg/l as CaCO3 | 27.10 | 27.10 | 27.10 | 27.10 |
| Iron, dis, ug/l | 5.00 | 9.00 | 16.18 | 70.00 |
| Manganese, dis, ug/l | 0.20 | 0.50 | 1.04 | 5.00 |
| Potassium, dis, mg/l | 0.62 | 0.79 | 0.79 | 1.07 |
| Sodium, dis, mg/l | 1.81 | 2.61 | 2.56 | 3.26 |
| TSS, mg/l | 0.50 | 2.00 | 2.51 | 4.70 |
| Copper, dis, ug/l | 0.50 | 1.10 | 2.12 | 5.00 |
| Cadmium, dis, ug/l | 0.02 | 0.03 | 0.08 | 0.50 |
| Lead, dis, ug/l | 0.04 | 0.13 | 5.83 | 50.00 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.09 | 0.10 |
| Zinc, dis, ug/l | 0.50 | 5.00 | 4.67 | 10.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Epilimnion Composite Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Chlorophyll a, ug/l | 1.00 | 4.20 | 5.44 | 15.50 |
| DO, mg/l | 6.20 | 7.25 | 7.71 | 11.90 |
| Conductivity, uS/cm | 37.00 | 54.00 | 55.44 | 96.00 |
| pH, field | 6.50 | 7.30 | 7.38 | 8.20 |
| Temperature, deg C | 0.40 | 11.85 | 11.04 | 19.20 |
| Ammonia, dis, ug/l as N | 3.50 | 3.50 | 5.63 | 24.00 |
| Nitrate + Nitrite, dis, ug/l as N | 11.00 | 22.50 | 29.38 | 68.00 |
| Nitrate, dis, ug/l | 5.00 | 5.00 | 5.43 | 10.00 |
| TKN, ug/l as N | 80.00 | 185.00 | 193.67 | 270.00 |
| TP, ug/l as P | 3.00 | 11.00 | 11.18 | 22.00 |
| Orthophosphate, dis, ug/l as P | 3.00 | 3.50 | 3.60 | 7.00 |
| Silica, dis, mg/l | 4.27 | 5.10 | 5.01 | 5.41 |
| TOC, mg/l | 2.60 | 4.50 | 4.25 | 5.10 |
| DOC, mg/l | 2.50 | 3.30 | 3.38 | 4.80 |
| Calcium, dis, mg/l | 6.62 | 7.00 | 7.13 | 7.68 |
| Magnesium, dis, mg/l | 1.16 | 1.24 | 1.24 | 1.31 |
| Sulfate, dis, mg/l | 2.89 | 3.17 | 3.15 | 3.48 |
| Chloride, dis, mg/l | 0.38 | 0.45 | 0.44 | 0.50 |
| Alkalinity, dis, mg/l as CaCO3 | 21.00 | 23.00 | 23.14 | 25.00 |
| Iron, dis, ug/l | 21.00 | 21.00 | 21.00 | 21.00 |
| Manganese, dis, ug/l | 0.20 | 0.20 | 0.20 | 0.20 |
| Potassium, dis, mg/l | 0.61 | 0.69 | 0.67 | 0.70 |
| Sodium, dis, mg/l | 1.76 | 1.99 | 1.97 | 2.15 |
| TSS, mg/l | 2.00 | 2.00 | 2.33 | 3.00 |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | 0.07 | 0.07 | 0.07 | 0.07 |
| Lead, dis, ug/l | --- | --- | --- | --- |
| Silver, dis, ug/l | --- | --- | --- | --- |
| Zinc, dis, ug/l | --- | --- | --- | --- |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 0.20 | 3.45 | 4.20 | 8.60 |
| Conductivity, uS/cm | 43.00 | 53.00 | 55.05 | 81.00 |
| pH, field | 6.20 | 6.90 | 7.01 | 7.80 |
| Temperature, deg C | 2.90 | 7.20 | 6.98 | 13.50 |
| Ammonia, dis, ug/l as N | 1.00 | 9.00 | 12.90 | 97.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 97.00 | 90.87 | 273.00 |
| Nitrate, dis, ug/l | 5.00 | 5.00 | 28.75 | 100.00 |
| TKN, ug/l as N | 89.00 | 165.00 | 171.58 | 280.00 |
| TP, ug/l as P | 3.00 | 18.00 | 19.69 | 38.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 6.00 | 6.12 | 13.00 |
| Silica, dis, mg/l | 4.64 | 6.24 | 6.75 | 9.29 |
| TOC, mg/l | 1.00 | 3.20 | 2.97 | 4.50 |
| DOC, mg/l | 2.70 | 3.10 | 3.12 | 3.50 |
| Calcium, dis, mg/l | 6.68 | 7.67 | 7.66 | 8.59 |
| Magnesium, dis, mg/l | 1.18 | 1.46 | 1.39 | 1.60 |
| Sulfate, dis, mg/l | 2.20 | 3.48 | 3.37 | 4.70 |
| Chloride, dis, mg/l | 0.38 | 0.54 | 0.59 | 0.92 |
| Alkalinity, dis, mg/l as CaCO3 | 21.00 | 23.50 | 23.78 | 27.10 |
| Iron, dis, ug/l | 5.00 | 30.00 | 33.32 | 100.00 |
| Manganese, dis, ug/l | 0.50 | 5.00 | 24.86 | 160.00 |
| Potassium, dis, mg/l | 0.64 | 0.75 | 0.75 | 0.94 |
| Sodium, dis, mg/l | 1.77 | 2.60 | 2.32 | 2.81 |
| TSS, mg/l | 2.00 | 2.00 | 2.00 | 2.00 |
| Copper, dis, ug/l | 0.50 | 1.00 | 1.76 | 5.00 |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.07 | 0.50 |
| Lead, dis, ug/l | 0.04 | 0.16 | 5.82 | 50.00 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.09 | 0.10 |
| Zinc, dis, ug/l | 0.50 | 2.15 | 3.28 | 10.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Composite Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 1.10 | 5.40 | 4.98 | 8.80 |
| Conductivity, uS/cm | 39.00 | 51.00 | 50.97 | 65.00 |
| pH, field | 6.00 | 6.70 | 6.72 | 7.80 |
| Temperature, deg C | 2.40 | 7.45 | 6.79 | 9.60 |
| Ammonia, dis, ug/l as N | 3.50 | 3.50 | 6.34 | 21.00 |
| Nitrate + Nitrite, dis, ug/l as N | 17.00 | 111.00 | 99.25 | 160.00 |
| Nitrate, dis, ug/l | 5.00 | 30.00 | 35.50 | 90.00 |
| TKN, ug/l as N | 70.00 | 170.00 | 167.31 | 270.00 |
| TP, ug/l as P | 3.00 | 12.00 | 13.03 | 25.00 |
| Orthophosphate, dis, ug/l as P | 3.00 | 3.50 | 4.96 | 16.00 |
| Silica, dis, mg/l | 4.97 | 5.49 | 5.44 | 5.80 |
| TOC, mg/l | 2.80 | 4.10 | 4.05 | 5.10 |
| DOC, mg/l | 2.30 | 3.20 | 3.22 | 4.00 |
| Calcium, dis, mg/l | 6.63 | 7.03 | 6.98 | 7.21 |
| Magnesium, dis, mg/l | 1.16 | 1.23 | 1.22 | 1.27 |
| Sulfate, dis, mg/l | 2.88 | 3.16 | 3.15 | 3.27 |
| Chloride, dis, mg/l | 0.37 | 0.47 | 0.46 | 0.56 |
| Alkalinity, dis, mg/l as CaCO3 | 22.00 | 22.50 | 22.75 | 24.00 |
| Iron, dis, ug/l | 42.00 | 42.00 | 42.00 | 42.00 |
| Manganese, dis, ug/l | 95.70 | 95.70 | 95.70 | 95.70 |
| Potassium, dis, mg/l | 0.62 | 0.67 | 0.66 | 0.70 |
| Sodium, dis, mg/l | 1.75 | 1.94 | 1.92 | 2.04 |
| TSS, mg/l | 3.00 | 3.00 | 3.00 | 3.00 |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | 0.07 | 0.07 | 0.07 | 0.07 |
| Lead, dis, ug/l | --- | --- | --- | --- |
| Silver, dis, ug/l | --- | --- | --- | --- |
| Zinc, dis, ug/l | --- | --- | --- | --- |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

### *Major Ions and Trace Elements*

The median concentrations of major ions (calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate [as indicated by alkalinity]) are typical of non-polluted watersheds.

Together, they make up most of the total dissolved solids concentration (TDS), which is closely approximated by specific conductance. Specific conductance is a measure of the ability of water to conduct an electrical current. Total dissolved solids concentrations in mg/l are typically between 55% and 75% of the specific conductance in µS/cm (Hem, 1985). Since the concentrations of these ions are relatively uninfluenced by biological activities within the reservoir (Jassby and Goldman, 1999), they can serve as a signature for source waters.

Trace metals occur in natural and industrial water. They can also be present as a result of management alternatives, such as the use of copper as an algicide. Copper is of concern for aquatic life and the standard is hardness dependent. Although there are not sufficient data to evaluate whether or not chronic copper standards are being met for Granby Reservoir (Table 9), the data that do exist indicate an exceedance of the acute standard on one day. Elevated dissolved iron and dissolved manganese concentrations can be a problem for water providers. Dissolved iron and dissolved manganese concentrations listed in Table 8 show higher values in the hypolimnion versus the epilimnion. This is common in lakes and reservoirs which experience low dissolved oxygen concentrations in the hypolimnion.

*Algae and Trophic State*

A time series of chlorophyll *a* data measured since 1984 is displayed in Figure 8. Since 2000, the average chlorophyll a concentration was about 5.5 to 6.0 µg/l, with a maximum of 15.5 µg/l. There is not a clear seasonal pattern for chlorophyll *a*, although most often the highest concentrations occur in the early part of the year (January - May). Chlorophyll *a* concentrations (2000-2007) are indicative of a mesotrophic trophic state (Table 4).

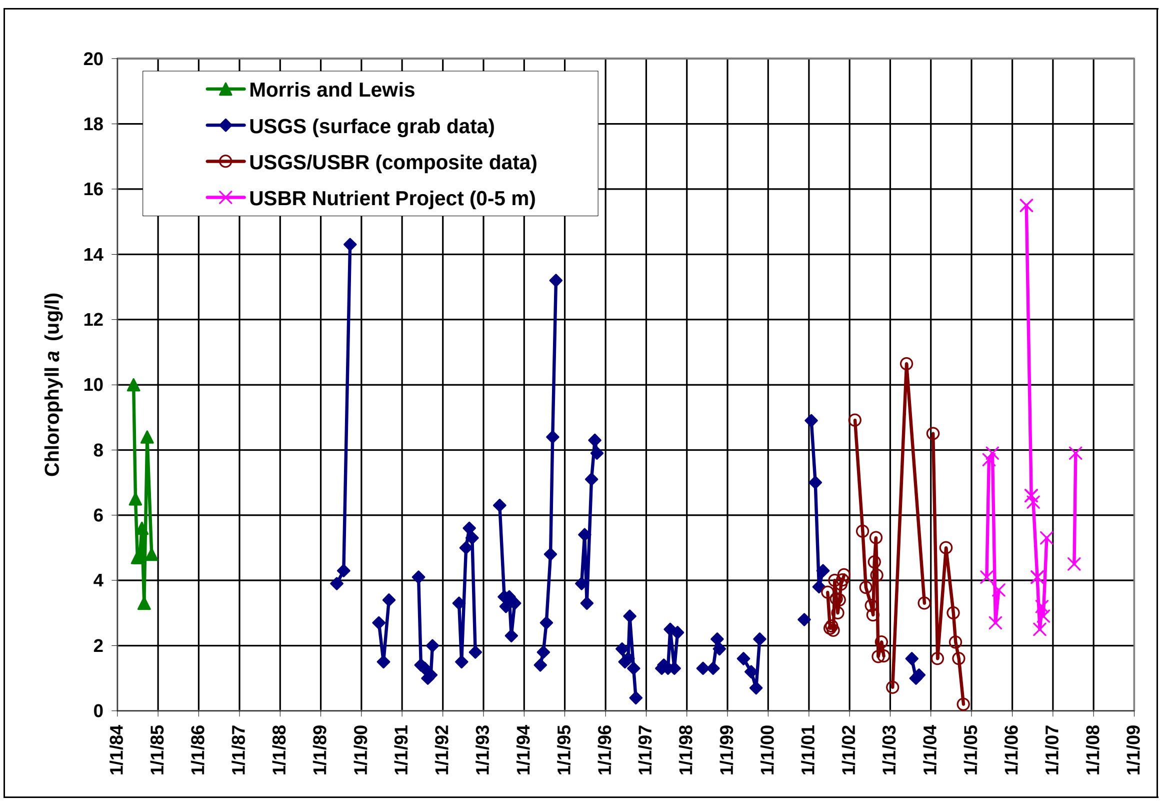


**Figure 8: Chlorophyll *a* Concentrations in Granby Reservoir**
**(Data Sources: Morris & Lewis, 1988; USGS, 2007; USBR, 2005, NCWCD, 2007b)**

Recent monitoring in Granby Reservoir includes microcystin toxicity testing along with cell counts of dominant cyanobacteria (blue-green algae) (GCWIN, 2007). Microcystin is a hepatotoxin which targets the liver and can be produced by some cyanobacteria. The presence or excessive abundance of toxin-producing algae does not translate into the presence of toxins in the water column. All microcystin results received through July 24, 2007 for Granby Reservoir have been below the detection limit (0.1 to 0.4 μg/l) (Clements, 2007). Microcystin toxin levels of over 1 μg/l are of concern for drinking-water purposes (WHO, 1998).

Cyanobacteria cell counts generally peak between July and September. The peak in 2004 of 246 cells/ml of *Anabaena* occurred on September 8th. The peak in 2005 of 2,210 cells/ml of *Anabaena* occurred on July 7th. In 2006, the peak *Anabaena* cell count was 2,358 cells/ml (July 10, 2006). The American Water Works Association Research Foundation suggests testing for toxins when toxin-producing alga cell counts reach 2,000 cells/ml (Yoo, 1995). The relationships between the abundance of toxin-producing algae and levels of microcystin are unclear and the subject of research efforts. Current research indicates that microcystin production is not only controlled by environmental factors (such as light, nutrients, and grazing pressure) but also by genetic composition (Zurawell, et al. 2005). There are toxic and nontoxic strains of microcystin-producing cyanobacteria. Although cell counts are sometimes used to assess the magnitude of a bloom or when to start testing for toxins, they are not an accurate measure of bloom toxicity. This is because cell counts do not differentiate between the different strains. According to Dyble (2006), "the underlying genetic structure of the population will profoundly affect the toxicity of individual blooms" and "predicting bloom toxicity requires an understanding of the genetic variation within the bloom and cannot be predicted based on cell counts alone."

Thus, a water body could have optimum environmental conditions for microcystin production (which are not well understood) and a high microcystin-producing cyanobacteria cell count, and no microcystin production. High cell counts do not necessarily translate into high levels of microcystin production and the relationships are not well-understood. Of course, if there is a complete absence of microcystin-producing species, then one can conclude that microcystin should not be present. Relationships between environmental factors, cell counts, distributions of toxic versus nontoxic strains, and microcystin production are all being actively researched.

*Nutrients*

Phosphorus concentrations are lower in the epilimnion and higher in the hypolimnion. Grab samples taken near the bottom of the reservoir have higher concentrations than hypolimnetic composite samples. Total nitrogen concentrations (TKN + nitrate + nitrite) are also elevated in the hypolimnion. Inorganic nitrogen concentrations (ammonia, nitrate, and nitrite -- the forms bioavailable for phytoplankton growth) are low and typical of an oligotrophic system (Wetzel, 2001). Orthophosphate concentrations are also low. Organic carbon concentrations are in the range of what one would expect given the setting and chlorophyll *a* concentrations.

Lake analyses often include an investigation to determine which nutrient is limiting the growth of algae. Increases in the limiting nutrient often cause increases in algal growth. Increases of the non-limiting nutrient will not cause increases in algal growth because its concentration is already in excess (there is more available that the algae can take up, given the concentration of the limiting nutrient). Previous bioassays have shown nitrogen limitation (EPA, 1970; EPA 1977) or primarily N limitation (there were a few periods of P limitation and / or the need to increase both

P and N) (Morris and Lewis, 1988). There have not been any recent bioassays to determine if this situation has changed. Lieberman (2007b) concluded that the reservoir is mainly phosphorus limited with periods of co-limitation based on nutrient concentrations.

*Water Clarity*

The mean Secchi-disk depth value since 2000 is 3.9 meters and the range is 1.6 to 8.0 meters. Figure 9 shows Secchi-disk depths since 1989. For many years, there is a steady increase in clarity between May until September – October. A seasonal Mann Kendall test for trends was conducted using Secchi-disk depth values for Granby Reservoir (1989 – 2006, N = 111). The test shows a statistically significant increasing trend from May to October at a 95% confidence level.

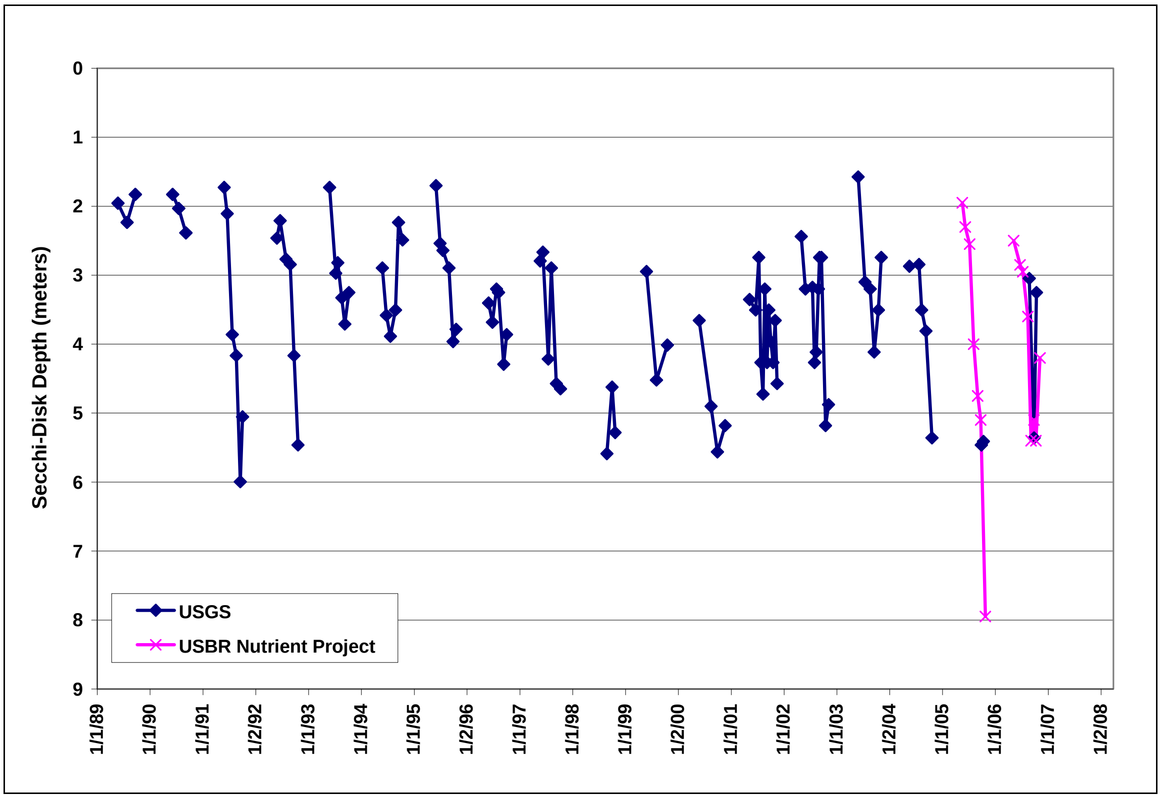


**Figure 9: Secchi-Disk Depth in Granby Reservoir**
**(Data Sources: USGS, 2007; NCWCD, 2007b)**

*Dissolved Oxygen*

Dissolved oxygen concentrations are lower in the hypolimnion versus the epilimnion (Table 8). This is expected because the hypolimnion is essentially cut off from oxygen additions at the lake's air-water interface. Also, there can be significant demands of oxygen at the bottom of a lake due to decomposition of organic matter and other reactions. Recent (2006) profile data are displayed in Figure 10. Dissolved oxygen was low (<= 3 mg/l) at the reservoir bottom in March and October of 2006. There was also the development of low dissolved oxygen concentrations at the elevation of the metalimnion in the summer. This is called a negative heterograde curve. Possible causes for this drop in dissolved oxygen at the metalimnion include 1) decomposition of oxidizable material in the metalimnion, 2) significant concentrations of zooplankton in the metalimnion which respire and drop the DO concentration, and 3) reservoir morphometry or the shape of the reservoir basin (Wetzel, 2001). Inflowing water could be entering the reservoir at the metalimnion and supplying organic matter (Lieberman, 2007a).

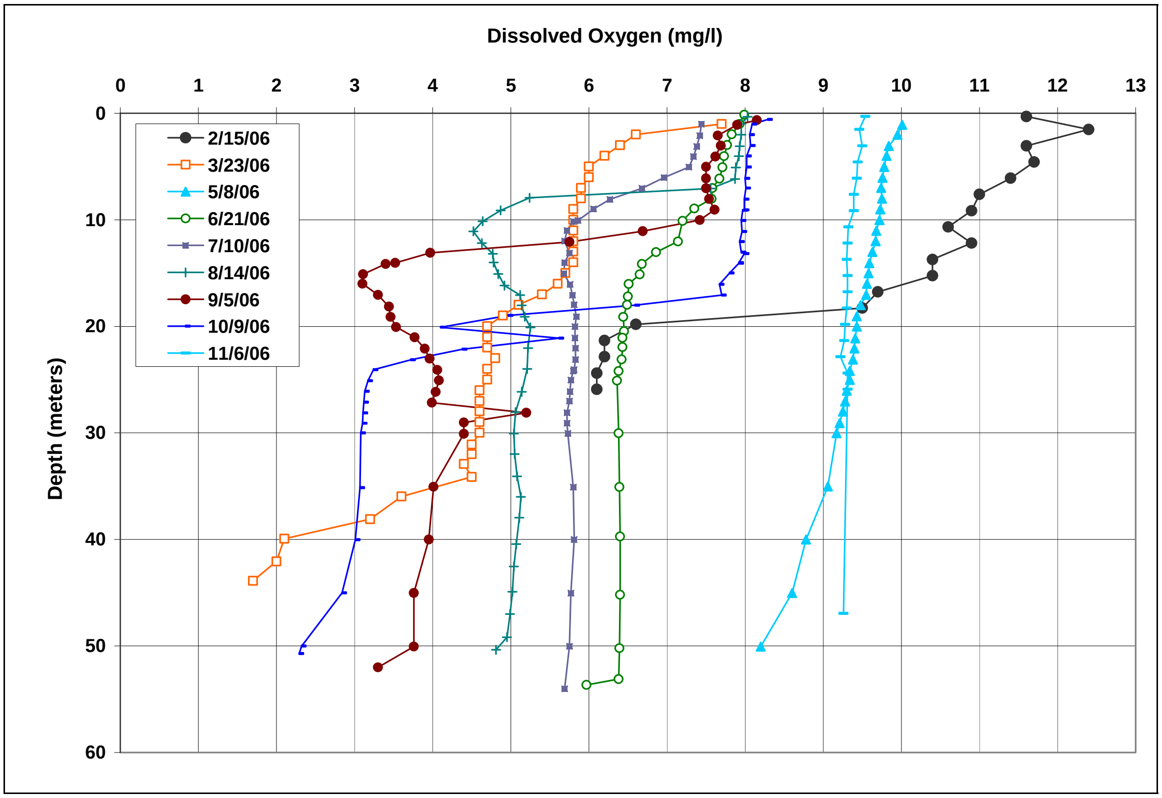


**Figure 10: Dissolved Oxygen Profiles for Granby Reservoir in 2006 (Data Sources: USGS, 2007; NCWCD, 2007b)**

### *Water-Quality Standards*

Comparisons between the data and key applicable water-quality standards were made for Granby Reservoir using data for the period 2000 - 2007. The results are shown in Table 9. All of the key applicable water-quality standards are met with the exception of dissolved oxygen, dissolved manganese (for water quality), and temperature, using the anticipated (December, 2008) temperature standards. The interim temperature standards (which are currently in place) are met.

## Table 9: Comparison Between Key Applicable Water-Quality Standards and Existing Conditions, Granby Reservoir

| Use Classification | Parameter Category | Parameter | Unit | Applicable Standard | In-Lake Value | Standard Met? |
|---|---|---|---|---|---|---|
| Aquatic Life | Physical | Dissolved Oxygen (elsp) | mg/l | 6.0 | 5.6 (42) | No |
| | | pH (epilimnion) | SU | 6.5 - 9.0 | 7.1 - 8.2 | Yes |
| | | pH (hypoliminon) | SU | 6.5 - 9.0 | 6.6 - 7.8 | Yes |
| | | Temperature (effective December 31, 2008) | °C | 9 (ch winter) | 1.7 - 2.1 | Yes |
| | | | | 13 (ac winter) | 2.1 - 2.8 | Yes |
| | | | | 18.2 (ch summer) | 16.5 - 19.3 | No |
| | | | | 23.8 (ac summer) | 16.9 - 19.9 | Yes |
| | | Temperature (interim) | °C | 20.0 (ch) | 1.7 - 19.3 | Yes |
| | Inorganic | Ammonia | mg/l as N | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | Metals | Cadmium, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (tr) (varies) | varies | Yes |
| | | Copper, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes (1 exceedance in 3 yrs of data) |
| | | Iron, Trec | µg/l | 1000 (ch) | no data | |
| | | Lead, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Manganese, dis | µg/l | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | | Silver, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| Water Supply | Physical | Dissolved Oxygen | mg/l | 3.0 | 5.6 (42) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.1 - 8.2 | Yes |
| | Inorganic | Nitrate | mg/l | 10 (1-day) | max = 0.3 (80) | Yes |
| | Metals | Cadmium, dis | µg/l | 5.0 (1-day) | not enough data | |
| | | Iron, dis | µg/l | 300 (30-day) | 0 - 80 | Yes |
| | | Lead, Trec | µg/l | 50 (1-day) | no data | |
| | | Manganese, dis | µg/l | 50 (30-day) | 0 - 160 | No |
| | | Silver, Trec | µg/l | 100 (1-day) | no data | |
| Recreation | Physical | Dissolved Oxygen | mg/l | 3.0 | 5.6 (42) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.1 - 8.2 | Yes |
| Agriculture | Physical | Dissolved Oxygen | mg/l | 3.0 | 5.6 (42) | Yes |
| | Inorganic | Nitrate | mg/l as N | 100 | max = 0.3 (80) | Yes |
| | Metals | Cadmium, Trec | µg/l | 10 (30-day) | no data | |
| | | Lead, Trec | µg/l | 100 (30-day) | no data | |
| | | Manganese, Trec | µg/l | 200 (30-day) | no data | |

- Available water quality data for past five years (9/02 on) was evaluated against standards applicable to the reservoir according to Colorado water quality regulations.
- Values in parenthesis in "In-Lake Value" column are the number of samples or daily average values evaluated for the paramet
- D.O. "In-Lake Values" are 15th percentile of daily average epilimnion and metalimnion profile results (elsp = early life stage present). In addition, per the WQCD, if all measurements in the epiliminion and metalimnion on any one day were below the standard the reservoir was found to be out of attainment.
- pH range is 15th percentile - 85th percentile value of daily average profile sample results.
- "Large Lake" temperature criteria applied. Temperature "In-Lake Values" are for epilimnion layer min - max of MWAT (ch) (lake equivalent of maximum weekly average temperature) and DM (ac) (daily maximum).
- In 2007 new temperature standards were adopted as defined in Colorado's Regulation No. 31 (5 CCR 1002-31). Interim standards were established to be applicable until the next Triennial Review process for each basin, at which point it is anticipated the new temperature standards will be adopted.
- Nitrate "In-Lake Value" is the maximum of all discrete Nitrate + Nitrite results.
- Water Supply "In-Lake Value" is min - max range of 30-day averages of hypolimnion samples (did not have enough data points to evaluate epilimnion layer).
- Metals 1 acute exceedance in 3 years is allowable to satisfy standard
- For acute computations, evaluated all data. For all other computations, evaluated only if at least 12 data points (per WQCD guidelines)
- 'no data' includes instances where there are no hardness data available to evaluate the standard

### 8.2.2. Shadow Mountain Reservoir

Shadow Mountain Reservoir serves to maintain a constant water surface elevation in Grand Lake. Thus, its contents are relatively stable. In addition, it is a conduit for flow between Granby Reservoir and Grand Lake (NCWCD, 2007c). The lake has the following use classifications which are used by the CDPHE to set appropriate water-quality standards:

- Aquatic Life Cold 1;
- Recreation 1a;
- Water Supply; and
- Agriculture.

These standards are defined in Table 6.

The North Fork of the Colorado River is the major tributary flowing into Shadow Mountain Reservoir. The reservoir also receives and discharges water to both Grand Lake and Granby Reservoir depending on C-BT operations. Shadow Mountain Reservoir's physical characteristics and hydrology are described in Table 10. The estimated residence time is based on annual average reservoir contents and annual outflow. The reservoir does not strongly stratify during the summer months due to a high level of mixing (from wind and flow) in this shallow reservoir.

**Table 10: Physical Characteristics and Hydrology of Shadow Mountain Reservoir**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume | 17,354 AF | 21.4 x 106 $m^3$ |
| Surface Area | 1,852 acres | 750 hectares |
| Mean Depth | 9.4 ft | 2.9 m |
| Shoreline* | 8 miles | 12.9 km |
| Hydraulic Residence Time | 2.7 - 3.3 weeks | |

Source: Hydrosphere, 2003a, *NCWCD, 2007d

Concentrations of key water-quality constituents in Shadow Mountain Reservoir are summarized in Table 11. More detailed information can be found in Appendix A. Only recent data (2000-2007) are considered in these tables since a more comprehensive monitoring program was put into place for the lake in 2000. A detailed evaluation of the water quality in Shadow Mountain Reservoir, focused on data from 2005 to 2006 can be found in Lieberman, 2007a and Lieberman, 2007b.

There are two areas of concern among users of Shadow Mountain Reservoir that do not become evident by analyzing the concentrations of water-quality constituents. Excessive growth of aquatic vegetation in the reservoir has been a problem since the reservoir was filled (Sisneros, 2007). Reservoir drawdowns occurred in 1990 and again in 2006 to help mitigate the problem. In addition, sediment has been accumulating where the North Fork enters the reservoir, forming a 15-acre delta. This delta interferes with recreation in that area of the reservoir. Studies have been conducted to assess the delta, identify potential restoration alternatives, and identify strategies for sediment management (e.g., HDR, 2003; Barclay, 2000).

**Table 11: Summary of Key Water-Quality Parameters for Shadow Mountain Reservoir (see Table 5 for Data Sources)**

***Epilimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | 0.97 | 2.44 | 2.40 | 3.95 |
| Chlorophyll a, ug/l | 0.50 | 3.40 | 5.13 | 35.40 |
| DO, mg/l | 6.10 | 8.00 | 7.92 | 9.60 |
| Conductivity, uS/cm | 40.00 | 65.50 | 62.58 | 94.00 |
| pH, field | 7.10 | 7.50 | 7.66 | 8.40 |
| Temperature, deg C | 1.20 | 8.50 | 7.78 | 16.00 |
| Ammonia, dis, ug/l as N | 1.00 | 5.00 | 8.18 | 24.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 17.00 | 25.02 | 114.00 |
| TKN, ug/l as N | 76.00 | 258.00 | 243.47 | 393.00 |
| TP, ug/l as P | 4.00 | 15.00 | 15.50 | 27.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 2.00 | 2.15 | 5.00 |
| Silica, dis, mg/l | 5.37 | 6.55 | 6.45 | 7.76 |
| TOC, mg/l | 1.40 | 2.85 | 2.93 | 5.90 |
| DOC, mg/l | 3.10 | 3.25 | 3.52 | 4.90 |
| Calcium, dis, mg/l | 5.82 | 8.00 | 7.69 | 8.80 |
| Magnesium, dis, mg/l | 1.23 | 1.50 | 1.44 | 1.56 |
| Sulfate, dis, mg/l | 2.20 | 3.79 | 3.42 | 4.12 |
| Chloride, dis, mg/l | 0.35 | 0.78 | 0.68 | 0.92 |
| Alkalinity, dis, mg/l as CaCO3 | --- | --- | --- | --- |
| Iron, dis, ug/l | 12.00 | 17.00 | 27.00 | 102.00 |
| Manganese, dis, ug/l | 0.50 | 2.20 | 2.88 | 6.90 |
| Potassium, dis, mg/l | 0.70 | 0.80 | 0.81 | 0.96 |
| Sodium, dis, mg/l | 1.67 | 2.67 | 2.42 | 2.86 |
| TSS, mg/l | 2.00 | 3.78 | 4.28 | 12.50 |
| Copper, dis, ug/l | 0.50 | 1.00 | 2.10 | 5.10 |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.03 | 0.05 |
| Lead, dis, ug/l | 0.04 | 0.16 | 6.43 | 50.00 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.09 | 0.10 |
| Zinc, dis, ug/l | 0.50 | 1.25 | 4.10 | 12.90 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 3.90 | 7.40 | 7.01 | 9.50 |
| Conductivity, uS/cm | 34.00 | 65.00 | 59.31 | 79.00 |
| pH, field | 6.80 | 7.40 | 7.46 | 8.20 |
| Temperature, deg C | 1.80 | 8.30 | 6.98 | 12.30 |
| Ammonia, dis, ug/l as N | 1.50 | 6.00 | 8.38 | 28.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 20.00 | 22.52 | 56.00 |
| TKN, ug/l as N | 170.00 | 230.00 | 240.15 | 367.00 |
| TP, ug/l as P | 8.00 | 17.00 | 16.72 | 28.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 3.00 | 2.52 | 5.00 |
| Silica, dis, mg/l | 2.12 | 5.62 | 5.96 | 7.84 |
| TOC, mg/l | 1.60 | 2.80 | 2.95 | 6.80 |
| DOC, mg/l | 3.20 | 3.30 | 3.37 | 3.80 |
| Calcium, dis, mg/l | 5.38 | 8.03 | 7.63 | 8.50 |
| Magnesium, dis, mg/l | 1.19 | 1.50 | 1.42 | 1.53 |
| Sulfate, dis, mg/l | 2.20 | 3.81 | 3.41 | 4.13 |
| Chloride, dis, mg/l | 0.28 | 0.78 | 0.68 | 0.92 |
| Alkalinity, dis, mg/l as CaCO3 | --- | --- | --- | --- |
| Iron, dis, ug/l | 12.00 | 40.00 | 57.39 | 220.00 |
| Manganese, dis, ug/l | 0.50 | 7.00 | 18.42 | 210.00 |
| Potassium, dis, mg/l | 0.64 | 0.79 | 0.80 | 0.95 |
| Sodium, dis, mg/l | 1.47 | 2.71 | 2.41 | 2.86 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | 0.50 | 0.96 | 1.82 | 5.00 |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.03 | 0.05 |
| Lead, dis, ug/l | 0.04 | 0.32 | 6.49 | 50.00 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.09 | 0.10 |
| Zinc, dis, ug/l | 0.50 | 2.20 | 3.70 | 10.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Full Composite***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 4.70 | 7.60 | 7.53 | 9.60 |
| Conductivity, uS/cm | 23.00 | 54.00 | 53.36 | 83.00 |
| pH, field | 6.50 | 7.10 | 7.24 | 8.50 |
| Temperature, deg C | 1.40 | 10.00 | 10.07 | 19.70 |
| Ammonia, dis, ug/l as N | 3.50 | 3.50 | 5.04 | 12.00 |
| Nitrate + Nitrite, dis, ug/l as N | 6.00 | 11.00 | 26.93 | 133.00 |
| Nitrate, dis, ug/l | 5.00 | 5.00 | 6.82 | 20.00 |
| TKN, ug/l as N | 120.00 | 210.00 | 212.81 | 310.00 |
| TP, ug/l as P | 8.00 | 15.00 | 15.70 | 29.00 |
| Orthophosphate, dis, ug/l as P | 1.00 | 3.50 | 3.40 | 6.00 |
| Silica, dis, mg/l | 4.26 | 5.21 | 5.23 | 6.41 |
| TOC, mg/l | 3.20 | 4.40 | 4.90 | 8.70 |
| DOC, mg/l | 2.50 | 3.50 | 3.50 | 5.00 |
| Calcium, dis, mg/l | 6.82 | 7.24 | 7.28 | 7.70 |
| Magnesium, dis, mg/l | 1.20 | 1.31 | 1.30 | 1.39 |
| Sulfate, dis, mg/l | 3.05 | 3.20 | 3.23 | 3.39 |
| Chloride, dis, mg/l | 0.35 | 0.44 | 0.44 | 0.52 |
| Alkalinity, dis, mg/l as CaCO3 | 22.00 | 23.50 | 23.67 | 27.00 |
| Iron, dis, ug/l | 28.00 | 28.00 | 28.00 | 28.00 |
| Manganese, dis, ug/l | 1.50 | 1.50 | 1.50 | 1.50 |
| Potassium, dis, mg/l | 0.63 | 0.69 | 0.72 | 0.89 |
| Sodium, dis, mg/l | 1.85 | 1.99 | 2.01 | 2.19 |
| TSS, mg/l | 3.00 | 3.50 | 3.50 | 4.00 |
| Cadmium, dis, ug/l | 0.07 | 0.07 | 0.07 | 0.07 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

### *Major Ions and Trace Elements*

The median concentrations of major ions (calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate [as indicated by alkalinity]) are typical of non-polluted watersheds. Together, they make up most of the total dissolved solids concentration (TDS), which is closely approximated by specific conductance. Specific conductance is a measure of the ability of water to conduct an electrical current. Total dissolved solids concentrations in mg/l are typically between 55% and 75% of the specific conductance in µS/cm (Hem, 1985). Because the concentrations of these ions are relatively uninfluenced by biological activities within the reservoir (Jassby and Goldman, 1999), they can serve as a signature for source waters.

Trace metals occur in natural and industrial water. They can also be present as a result of management alternatives such as the use of copper as an algicide. Copper is of concern for aquatic life and the standard is hardness dependent. Although there are not sufficient data to evaluate whether or not copper standards are being met for Shadow Mountain Reservoir (Table 12), the data that do exist indicate an exceedance of the acute standard on two days.

Elevated dissolved iron and dissolved manganese concentrations can be a problem for water providers. Dissolved iron and dissolved manganese concentrations listed in Table 11 show higher values in the hypolimnion versus the epilimnion. This is common in lakes and reservoirs which experience low dissolved oxygen concentrations in the hypolimnion.

*Algae and Trophic State*

A time series of chlorophyll *a* data measured since 1984 is displayed in Figure 11. Since 2000, chlorophyll *a* concentrations have averaged 5.1 µg/l and peak chlorophyll *a* concentrations have reached 32.7 µg/l. There is not a clear seasonal pattern for chlorophyll *a*, although most often the highest concentrations occur in September. Average summer values of chlorophyll *a* concentrations (2000-2007) are indicative of a mesotrophic trophic state (Table 4), with higher summer peak concentrations.

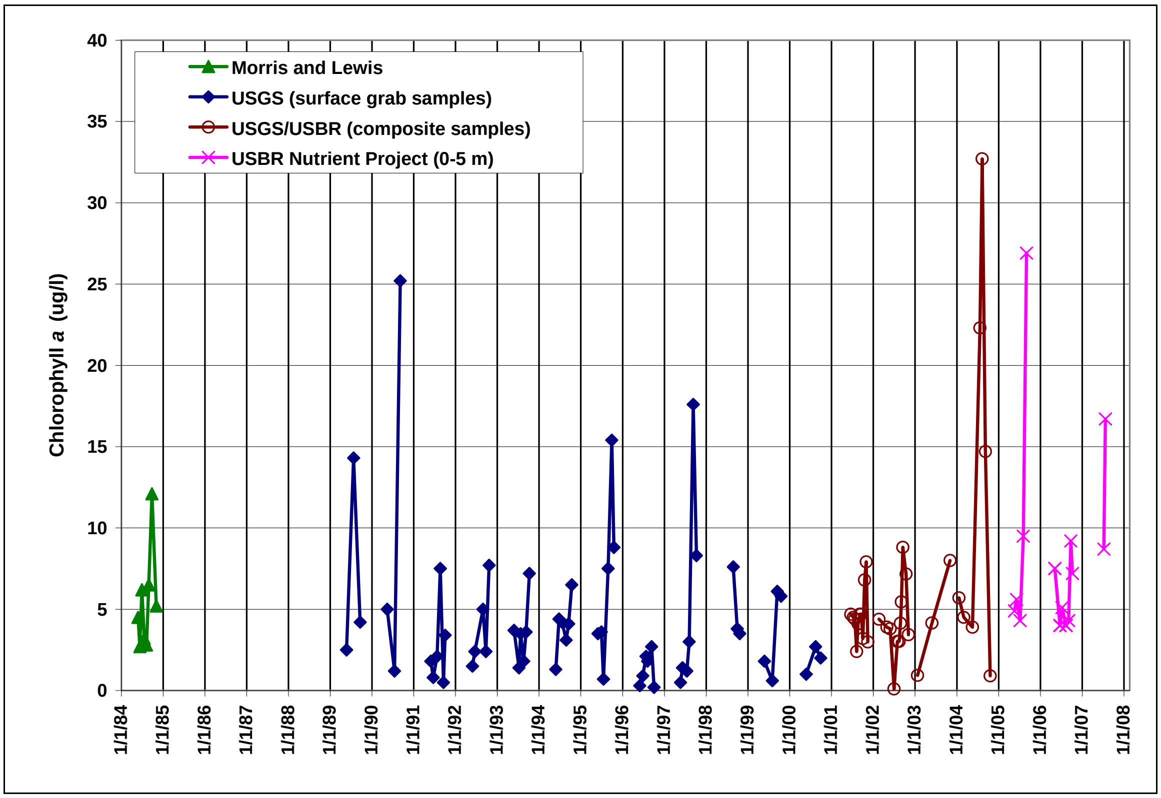


**Figure 11: Chlorophyll a Concentrations in Shadow Mountain Reservoir (Data Sources: Morris & Lewis, 1988; USGS, 2007; USBR, 2005; NCWCD, 2007b)**

Recent monitoring in Shadow Mountain Reservoir includes microcystin toxicity testing along with cell counts of dominant cyanobacteria (blue-green algae) (GCWIN, 2007). Microcystin is a hepatotoxin which targets the liver and can be produced by some cyanobacteria. The presence or excessive abundance of toxin-producing algae does not translate into the presence of toxins in the water column. All microcystin results received through July 24, 2007 for Shadow Mountain Reservoir have been below the detection limit (0.1 to 0.4 µg/l) (Clements, 2007). Microcystin toxin levels of over 1 µg/l are of concern for drinking-water purposes (WHO, 1998).

Cyanobacteria cell counts generally peak in August and September. The peak in 2004 of 57,000 cells/ml of *Anabaena* occurred on August 23rd. The peak in 2005 of 32,436 cells/ml of *Anabaena* occurred on September 8th. The peaks in 2006 and 2007 were 5,635 (August 14) and 16,077 cells/ml (July 31), respectively. The American Water Works Association Research Foundation suggests testing for toxins when toxin-producing alga cell counts reach 2,000 cells/ml (Yoo, 1995). The relationships between the abundance of toxin-producing algae and levels of microcystin are unclear and the subject of research efforts.

*Nutrients*

Total phosphorus concentrations are similar near the bottom of the reservoir and at the surface. The same can be said for total nitrogen (TKN + nitrate + nitrite). Inorganic nitrogen concentrations (ammonia, nitrate, and nitrite -- the forms bioavailable for phytoplankton growth) are low and typical of an oligotrophic system (Wetzel, 2001). Orthophosphate concentrations are also low. Organic carbon concentrations are in the range of what one would expect given the setting and chlorophyll *a* concentrations.

Lake analyses often include an investigation to determine which nutrient is limiting the growth of algae. Increases in the limiting nutrient often cause increases in algal growth. Increases of the non-limiting nutrient will not cause increases in algal growth because its concentration is already in excess (there is more available that the algae can take up, given the concentration of the limiting nutrient). Previous bioassays have shown nitrogen limitation (EPA, 1970; EPA, 1977) or primarily N limitation (there were a few periods of P limitation and / or the need to increase both P and N) (Morris and Lewis, 1988). There have not been any recent bioassays to determine if this situation has changed.

*Water Clarity*

The mean Secchi-disk depth is 2.4 meters with a range between 1 and 4 meters. Figure 12 shows Secchi-disk depth since 2000. The highest clarity occurs in the months of July and August. Using a t-test for means and assuming unequal variances, the mean Secchi-disk depth during July and August are significantly different at the 95% confidence level and are higher than values observed during other months.

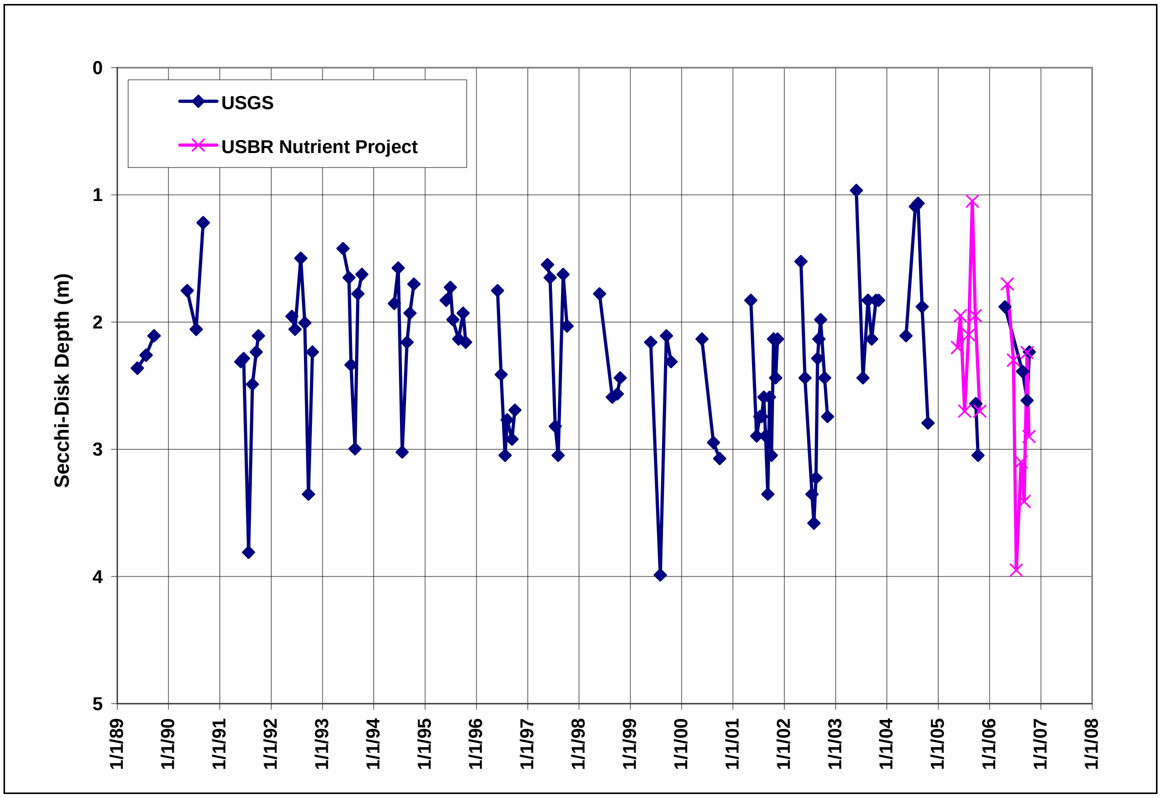


**Figure 12: Shadow Mountain Reservoir Secchi-Disk Depth**

*Dissolved Oxygen*

Recent dissolved oxygen profile data are displayed in Figure 13. Although the reservoir is considered to be relatively well mixed, there have been occurrences of low dissolved oxygen concentrations near the bottom of the reservoir. Shadow Mountain Reservoir is included on the 2008 M&E list for low dissolved oxygen. Low dissolved oxygen concentrations at the bottom are of concern because of the potential for the release of orthophosphate, ammonia, iron, and manganese from the sediments under anoxic conditions.

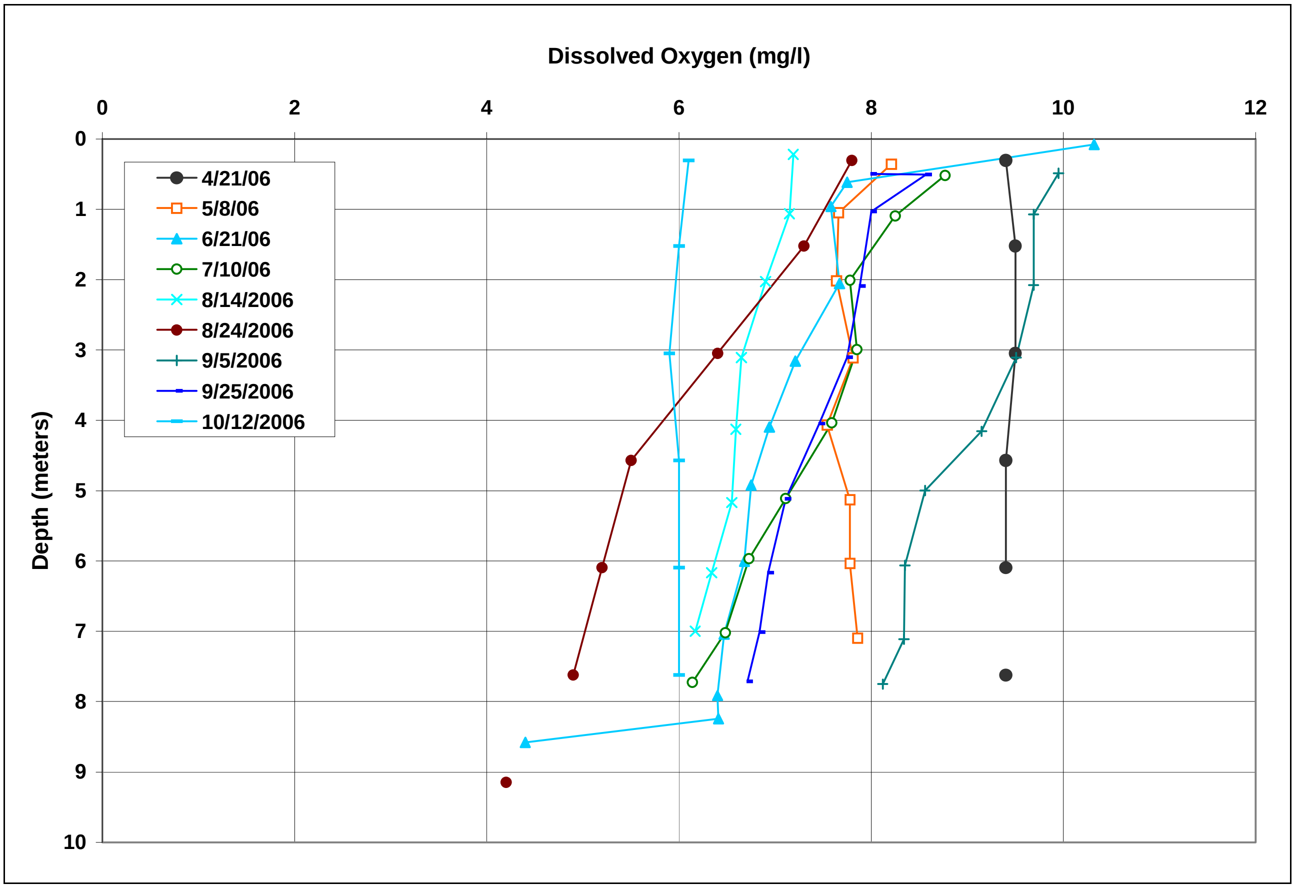


**Figure 13: Dissolved Oxygen Profiles for Shadow Mountain Reservoir in 2006 (Data Sources: USGS, 2007; NCWCD, 2007b)**

### *Water-Quality Standards*

Comparisons between the data and key applicable water-quality standards were made for Shadow Mountain Reservoir using data from the period 2000 - 2007. The results are shown in Table 12. All of the standards listed in this table are met for all four classified uses, with the exception of dissolved manganese (for water quality).

## Table 12: Comparison between Key Applicable Water-Quality Standards and Existing Conditions, Shadow Mountain Reservoir

| Use Classification | Parameter Category | Parameter | Unit | Applicable Standard | In-Lake Value | Standard Met? |
|---|---|---|---|---|---|---|
| Aquatic Life | Physical | Dissolved Oxygen (elsp) | mg/l | 6.0 | 6.7 (40) | Yes |
| | | pH (epilimnion) | SU | 6.5 - 9.0 | 7.0 - 8.3 | Yes |
| | | pH (hypoliminon) | SU | 6.5 - 9.0 | 6.9 - 8.2 | Yes |
| | | Temperature (effective December 31, 2008) | °C | 9 (ch winter) | 1.7 - 2.2 | Yes |
| | | | | 13 (ac winter) | 2.1 - 2.4 | Yes |
| | | | | 18.2 (ch summer) | 14.6 - 19.3 | Yes |
| | | | | 23.8 (ac summer) | 15.5 - 19.7 | Yes |
| | | Temperature (interim) | °C | 20.0 (ch) | 1.7 - 19.3 | Yes |
| | Inorganic | Ammonia | mg/l as N | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | Metals | Cadmium, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (tr) (varies) | varies | Yes |
| | | Copper, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes (1 exceedance in 3 yrs of data) |
| | | Iron, Trec | µg/l | 1000 (ch) | no data | |
| | | Lead, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Manganese, dis | µg/l | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | | Silver, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| Water Supply | Physical | Dissolved Oxygen | mg/l | 3.0 | 6.7 (40) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.0 - 8.3 | Yes |
| | Inorganic | Nitrate | mg/l | 10 (1-day) | max = 0.1 (61) | Yes |
| | Metals | Cadmium, dis | µg/l | 5.0 (1-day) | not enough data | |
| | | Iron, dis | µg/l | 300 (30-day) | 13 - 220 | Yes |
| | | Lead, Trec | µg/l | 50 (1-day) | no data | |
| | | Manganese, dis | µg/l | 50 (30-day) | 0 - 210 | No |
| | | Silver, Trec | µg/l | 100 (1-day) | no data | |
| Recreation | Physical | Dissolved Oxygen | mg/l | 3.0 | 6.7 (40) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.0 - 8.3 | Yes |
| Agriculture | Physical | Dissolved Oxygen | mg/l | 3.0 | 6.7 (40) | Yes |
| | Inorganic | Nitrate | mg/l as N | 100 | max = 0.1 (61) | Yes |
| | Metals | Cadmium, Trec | µg/l | 10 (30-day) | no data | |
| | | Lead, Trec | µg/l | 100 (30-day) | no data | |
| | | Manganese, Trec | µg/l | 200 (30-day) | no data | |

- Available water quality data for past five years (9/02 on) was evaluated against standards applicable to the reservoir according to Colorado water quality regulations.
- Values in parenthesis in "In-Lake Value" column are the number of samples or daily average values evaluated for the parame
- D.O. "In-Lake Values" are 15th percentile of daily average epilimnion and metalimnion profile results (elsp = early life stage present). In addition, per the WQCD, if all measurements in the epilimինion and metalimnion on any one day were below the standard the reservoir was found to be out of attainment.
- pH range is 15th percentile - 85th percentile value of daily average profile sample results.
- "Large Lake" temperature criteria applied. Temperature "In-Lake Values" are for epilimnion layer min - max of MWAT (ch) (lake equivalent of maximum weekly average temperature) and DM (ac) (daily maximum).
- In 2007 new temperature standards were adopted as defined in Colorado's Regulation No. 31 (5 CCR 1002-31). Interim standards were established to be applicable until the next Triennial Review process for each basin, at which point it is anticipated the new temperature standards will be adopted.
- Nitrate "In-Lake Value" is the maximum of all discrete Nitrate + Nitrite results.
- Water Supply "In-Lake Value" is min - max range of 30-day averages of hypolimnion samples (did not have enough data points to evaluate epilimnion layer).
- Metals 1 acute exceedance in 3 years is allowable to satisfy standard
- For acute computations, evaluated all data. For all other computations, evaluated only if at least 12 data points (per WQCD guidelines)
- 'no data' includes instances where there are no hardness data available to evaluate the standard

#### 8.2.3. Grand Lake

Grand Lake is the largest natural lake in Colorado. The lake is a very popular recreation area with numerous seasonal homes and cottages along the shoreline. The lake has the following use classifications which are used by the CDPHE to set appropriate water-quality standards:

- Aquatic Life Cold 1;
- Recreation 1a;
- Water Supply; and
- Agriculture.

These classifications are defined in Table 6.

Its major tributaries are the East Inlet and North Inlet, which emanate from Rocky Mountain National Park. As part of the C-BT project, Grand Lake also receives flow from Shadow Mountain Reservoir. The majority of the lake's outflow is via the Adams Tunnel although some water also flows back to Shadow Mountain Reservoir, depending on project operations. By law, the water surface elevation of the lake is maintained within a 1-vertical foot range as part of the C-BT system operations, when there is flow through the Adams Tunnel. Therefore, the lake's surface water elevation is relatively stable.

Grand Lake's physical characteristics and hydrology are described in Table 13. The lake has a small surface area compared to its depth. The residence time (the average amount of time water spends in the reservoir) is short due to the operation of the C-BT system and varies according to operations. The estimated residence time is based on reservoir contents and annual flow. The lake strongly stratifies during the summer, forming an epilimnion, a metalimnion and a hypolimnion.

**Table 13: Physical Characteristics and Hydrology of Grand Lake**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume | 68,621 AF | 84.6 x $10^6$ $m^3$ |
| Surface Area | 507 acres | 205 hectares |
| Mean Depth | 135 ft | 41.1 m |
| Maximum Depth | 265 ft | 81 m |
| Hydraulic Residence Time | 2-3 months | |

Concentrations of key water-quality constituents in Grand Lake are summarized in Table 14. More detailed information can be found in Appendix A. Only recent data (2000-2007) are considered in these tables since a more comprehensive monitoring program was put into place for the lake in 2000. Data for the epilimnion and hypolimnion are listed separately where applicable.

A detailed evaluation of the water quality in Grand Lake, focused on data from 2005 to 2006 can be found in Lieberman, 2007a and Lieberman, 2007b.

# Table 14: Summary of Key Water-Quality Parameters for Grand Lake at Grand Lake (see Table 5 for Data Sources)

***Epilimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | 1.98 | 3.43 | 3.48 | 5.74 |
| Chlorophyll a, ug/l | 1.60 | 2.70 | 3.05 | 5.80 |
| DO, mg/l | 7.30 | 7.90 | 8.42 | 10.90 |
| Conductivity, uS/cm | 16.00 | 49.00 | 46.53 | 63.00 |
| pH, field | 6.40 | 7.30 | 7.42 | 8.70 |
| Temperature, deg C | 0.10 | 8.10 | 7.33 | 16.90 |
| Ammonia, dis, ug/l as N | 3.50 | 7.25 | 7.75 | 15.00 |
| Nitrate + Nitrite, dis, ug/l as N | 8.00 | 15.00 | 45.67 | 139.00 |
| Nitrate, dis, ug/l | 40.00 | 40.00 | 40.00 | 40.00 |
| TKN, ug/l as N | 180.00 | 200.00 | 200.00 | 220.00 |
| TP, ug/l as P | 5.00 | 9.50 | 9.44 | 15.00 |
| Orthophosphate, dis, ug/l as P | 3.00 | 3.00 | 3.25 | 4.00 |
| Silica, dis, mg/l | 4.10 | 6.48 | 6.11 | 7.78 |
| TOC, mg/l | 3.30 | 3.90 | 3.85 | 4.30 |
| DOC, mg/l | 2.40 | 3.00 | 2.94 | 3.60 |
| Calcium, dis, mg/l | 4.39 | 5.57 | 5.95 | 8.03 |
| Magnesium, dis, mg/l | 0.82 | 1.06 | 1.11 | 1.44 |
| Sulfate, dis, mg/l | 2.37 | 2.85 | 3.03 | 3.82 |
| Chloride, dis, mg/l | 0.32 | 0.55 | 0.53 | 0.71 |
| Alkalinity, dis, mg/l as CaCO3 | --- | --- | --- | --- |
| Iron, dis, ug/l | 12.00 | 29.50 | 31.67 | 57.00 |
| Manganese, dis, ug/l | 0.50 | 1.30 | 2.58 | 9.60 |
| Potassium, dis, mg/l | 0.45 | 0.54 | 0.61 | 0.85 |
| Sodium, dis, mg/l | 1.36 | 2.27 | 2.18 | 2.62 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | 0.60 | 2.10 | 1.67 | 2.50 |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.02 | 0.03 |
| Lead, dis, ug/l | 0.04 | 0.04 | 0.08 | 0.18 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.08 | 0.10 |
| Zinc, dis, ug/l | 1.20 | 3.30 | 3.82 | 8.20 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Epilimnion Layered Composites***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Chlorophyll a, ug/l | 0.70 | 3.40 | 3.38 | 7.10 |
| DO, mg/l | 7.10 | 7.70 | 7.74 | 8.70 |
| Conductivity, uS/cm | 16.00 | 44.00 | 44.46 | 86.00 |
| pH, field | 6.50 | 7.10 | 7.27 | 8.90 |
| Temperature, deg C | 1.40 | 11.40 | 10.01 | 18.50 |
| Ammonia, dis, ug/l as N | 3.50 | 3.50 | 5.14 | 24.00 |
| Nitrate + Nitrite, dis, ug/l as N | 11.00 | 32.00 | 37.00 | 81.00 |
| Nitrate, dis, ug/l | 5.00 | 5.00 | 12.61 | 50.00 |
| TKN, ug/l as N | 60.00 | 190.00 | 198.33 | 350.00 |
| TP, ug/l as P | 6.00 | 9.00 | 9.39 | 14.00 |
| Orthophosphate, dis, ug/l as P | 2.00 | 3.50 | 3.32 | 3.50 |
| Silica, dis, mg/l | 3.61 | 4.75 | 4.84 | 6.05 |
| TOC, mg/l | 2.80 | 3.80 | 3.88 | 5.40 |
| DOC, mg/l | 2.30 | 3.30 | 3.26 | 4.10 |
| Calcium, dis, mg/l | 4.80 | 5.88 | 5.83 | 7.23 |
| Magnesium, dis, mg/l | 0.88 | 1.05 | 1.06 | 1.32 |
| Sulfate, dis, mg/l | 2.38 | 2.76 | 2.78 | 3.20 |
| Chloride, dis, mg/l | 0.24 | 0.37 | 0.36 | 0.41 |
| Alkalinity, dis, mg/l as CaCO3 | 15.00 | 18.00 | 18.29 | 22.00 |
| Iron, dis, ug/l | 43.00 | 43.00 | 43.00 | 43.00 |
| Manganese, dis, ug/l | 0.90 | 0.90 | 0.90 | 0.90 |
| Potassium, dis, mg/l | 0.50 | 0.52 | 0.57 | 0.75 |
| Sodium, dis, mg/l | 1.36 | 1.70 | 1.69 | 2.05 |
| TSS, mg/l | 2.00 | 3.00 | 3.00 | 4.00 |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.02 | 0.02 |
| Lead, dis, ug/l | --- | --- | --- | --- |
| Silver, dis, ug/l | --- | --- | --- | --- |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 1.20 | 3.20 | 3.39 | 6.50 |
| Conductivity, uS/cm | 34.00 | 49.00 | 51.19 | 75.00 |
| pH, field | 6.20 | 6.70 | 6.74 | 7.60 |
| Temperature, deg C | 3.40 | 4.00 | 3.95 | 4.10 |
| Ammonia, dis, ug/l as N | 3.50 | 5.00 | 6.32 | 14.00 |
| Nitrate + Nitrite, dis, ug/l as N | 8.00 | 126.50 | 119.69 | 161.00 |
| Nitrate, dis, ug/l | 40.00 | 80.00 | 73.33 | 100.00 |
| TKN, ug/l as N | 120.00 | 170.00 | 180.00 | 240.00 |
| TP, ug/l as P | 5.00 | 9.00 | 12.16 | 32.00 |
| Orthophosphate, dis, ug/l as P | 3.00 | 3.00 | 3.53 | 5.00 |
| Silica, dis, mg/l | 5.62 | 6.56 | 6.53 | 7.24 |
| TOC, mg/l | 3.30 | 3.70 | 3.92 | 4.90 |
| DOC, mg/l | 2.80 | 3.10 | 3.11 | 3.50 |
| Calcium, dis, mg/l | 5.30 | 6.91 | 6.72 | 7.42 |
| Magnesium, dis, mg/l | 0.97 | 1.31 | 1.25 | 1.33 |
| Sulfate, dis, mg/l | 2.50 | 3.46 | 3.26 | 3.69 |
| Chloride, dis, mg/l | 0.34 | 0.68 | 0.59 | 0.75 |
| Alkalinity, dis, mg/l as CaCO3 | 17.00 | 17.50 | 17.50 | 18.00 |
| Iron, dis, ug/l | 7.00 | 13.00 | 21.00 | 47.00 |
| Manganese, dis, ug/l | 1.70 | 17.30 | 28.33 | 90.10 |
| Potassium, dis, mg/l | 0.56 | 0.76 | 0.75 | 0.89 |
| Sodium, dis, mg/l | 1.45 | 2.27 | 2.15 | 2.40 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | 0.66 | 1.50 | 1.43 | 2.40 |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.03 | 0.07 |
| Lead, dis, ug/l | 0.04 | 0.08 | 0.08 | 0.12 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.08 | 0.10 |
| Zinc, dis, ug/l | 0.70 | 3.00 | 4.05 | 10.30 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Layered Composites***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 3.50 | 5.75 | 5.74 | 7.40 |
| Conductivity, uS/cm | 25.00 | 41.00 | 41.31 | 52.00 |
| pH, field | 6.20 | 6.50 | 6.54 | 7.10 |
| Temperature, deg C | 3.10 | 4.25 | 4.24 | 6.10 |
| Ammonia, dis, ug/l as N | 3.50 | 3.50 | 4.40 | 7.50 |
| Nitrate + Nitrite, dis, ug/l as N | 80.00 | 87.00 | 88.78 | 101.00 |
| Nitrate, dis, ug/l | 30.00 | 70.00 | 67.14 | 80.00 |
| TKN, ug/l as N | 25.00 | 140.00 | 136.61 | 180.00 |
| TP, ug/l as P | 4.00 | 6.00 | 7.07 | 13.00 |
| Orthophosphate, dis, ug/l as P | 2.00 | 3.50 | 3.33 | 3.50 |
| Silica, dis, mg/l | 4.80 | 5.17 | 5.24 | 5.97 |
| TOC, mg/l | 2.60 | 3.70 | 3.59 | 4.20 |
| DOC, mg/l | 2.30 | 3.30 | 3.22 | 3.70 |
| Calcium, dis, mg/l | 4.77 | 5.64 | 5.66 | 6.63 |
| Magnesium, dis, mg/l | 0.84 | 1.03 | 1.03 | 1.20 |
| Sulfate, dis, mg/l | 2.37 | 2.88 | 2.76 | 3.03 |
| Chloride, dis, mg/l | 0.27 | 0.39 | 0.38 | 0.45 |
| Alkalinity, dis, mg/l as CaCO3 | 15.00 | 18.00 | 17.80 | 22.00 |
| Iron, dis, ug/l | 21.00 | 21.00 | 21.00 | 21.00 |
| Manganese, dis, ug/l | 0.60 | 0.60 | 0.60 | 0.60 |
| Potassium, dis, mg/l | 0.49 | 0.60 | 0.60 | 0.69 |
| Sodium, dis, mg/l | 1.34 | 1.68 | 1.67 | 1.94 |
| TSS, mg/l | 3.00 | 3.00 | 3.00 | 3.00 |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.02 | 0.02 |
| Lead, dis, ug/l | --- | --- | --- | --- |
| Silver, dis, ug/l | --- | --- | --- | --- |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

# Table 15: Summary of Key Water-Quality Parameters for Grand Lake Middle (see Table 5 for Data Sources)

***Epilimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | 1.75 | 3.60 | 3.49 | 5.65 |
| Chlorophyll a, ug/l | 3.60 | 5.70 | 7.28 | 16.30 |
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | --- | --- | --- | --- |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 1.50 | 7.00 | 10.43 | 37.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 14.00 | 26.17 | 100.00 |
| TKN, ug/l as N | 81.00 | 240.00 | 253.27 | 448.00 |
| TP, ug/l as P | 1.50 | 8.00 | 9.53 | 33.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 0.50 | 0.63 | 2.00 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 1.20 | 2.30 | 2.58 | 4.00 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | 5.90 | 5.90 | 5.90 | 5.90 |
| Magnesium, dis, mg/l | 1.10 | 1.10 | 1.10 | 1.10 |
| Sulfate, dis, mg/l | 4.00 | 4.00 | 4.00 | 4.00 |
| Chloride, dis, mg/l | 0.40 | 0.40 | 0.40 | 0.40 |
| Alkalinity, dis, mg/l as CaCO3 | 18.90 | 18.90 | 18.90 | 18.90 |
| Iron, dis, ug/l | 10.00 | 20.00 | 20.00 | 30.00 |
| Manganese, dis, ug/l | 5.00 | 5.00 | 5.00 | 5.00 |
| Potassium, dis, mg/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Sodium, dis, mg/l | 1.90 | 1.90 | 1.90 | 1.90 |
| TSS, mg/l | 1.00 | 2.00 | 2.51 | 7.07 |
| Copper, dis, ug/l | 1.00 | 1.00 | 1.00 | 1.00 |
| Cadmium, dis, ug/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Lead, dis, ug/l | 1.00 | 1.00 | 1.00 | 1.00 |
| Silver, dis, ug/l | --- | --- | --- | --- |
| Zinc, dis, ug/l | 2.50 | 2.50 | 2.50 | 2.50 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | --- | --- | --- | --- |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 1.50 | 8.00 | 12.30 | 68.00 |
| Nitrate + Nitrite, dis, ug/l as N | 16.00 | 146.00 | 135.20 | 350.00 |
| TKN, ug/l as N | 95.00 | 160.00 | 188.33 | 418.00 |
| TP, ug/l as P | 1.50 | 10.00 | 8.27 | 16.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 1.00 | 1.53 | 8.00 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 1.00 | 2.20 | 2.49 | 6.20 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | 7.50 | 7.50 | 7.50 | 7.50 |
| Magnesium, dis, mg/l | 1.40 | 1.40 | 1.40 | 1.40 |
| Sulfate, dis, mg/l | 4.50 | 4.50 | 4.50 | 4.50 |
| Chloride, dis, mg/l | 0.60 | 0.60 | 0.60 | 0.60 |
| Alkalinity, dis, mg/l as CaCO3 | 24.60 | 24.60 | 24.60 | 24.60 |
| Iron, dis, ug/l | 10.00 | 15.00 | 23.75 | 60.00 |
| Manganese, dis, ug/l | 5.00 | 56.00 | 157.73 | 1100.00 |
| Potassium, dis, mg/l | 0.70 | 0.70 | 0.70 | 0.70 |
| Sodium, dis, mg/l | 2.30 | 2.30 | 2.30 | 2.30 |
| TSS, mg/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Copper, dis, ug/l | 1.00 | 1.00 | 1.00 | 1.00 |
| Cadmium, dis, ug/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Lead, dis, ug/l | 1.00 | 1.00 | 1.00 | 1.00 |
| Silver, dis, ug/l | --- | --- | --- | --- |
| Zinc, dis, ug/l | 5.00 | 6.50 | 6.50 | 8.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

### *Major Ions and Trace Elements*

The median concentrations of major ions (calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate [as indicated by alkalinity]) are typical of non-polluted watersheds. Together, they make up most of the total dissolved solids concentration (TDS), which is closely approximated by specific conductance. Specific conductance is a measure of the ability of water to conduct an electrical current. Total dissolved solids concentrations in mg/l are typically between 55% and 75% of the specific conductance in µS/cm (Hem, 1985). Since the concentrations of these ions are relatively uninfluenced by biological activities within the reservoir (Jassby and Goldman, 1999), they can serve as a signature for source waters.

Trace metals occur in natural and industrial water. They can also be present as a result of management alternatives such as the use of copper as an algicide. Copper is of concern for aquatic life and the standard is hardness dependent. Although there are not sufficient data to evaluate whether or not copper standards are being met for Grand Lake (Table 16), the data that do exist indicate no exceedances.

Elevated dissolved iron and dissolved manganese concentrations can be a problem for water providers. Dissolved iron and dissolved manganese concentrations listed in Table 14 and Table 15 show higher values in the hypolimnion versus the epilimnion. This is common in lakes and reservoirs which experience low dissolved oxygen concentrations in the hypolimnion. Although there are not sufficient data to evaluate whether or not dissolved manganese standards are being met for Grand Lake (Table 16), the data that do exist show values in the hypolimnion that are above the water supply standard of 50 µg/l.

### *Algae and Trophic State*

A time series of chlorophyll *a* data for Grand Lake measured since 1984 is displayed in Figure 14. The data show greater variability during the period 1990-1999 when volunteers sampled the lake and analysis was done by CDPHE. Since 2000, chlorophyll *a* has averaged 7.3 µg/ while peak chlorophyll *a* concentrations have risen to 16.0 µg/l. There is not a clear seasonal pattern for chlorophyll *a* although most often, the highest concentrations occur in September. Average chlorophyll *a* concentrations (2000-2005) are indicative of a mesotrophic trophic state (Table 4).

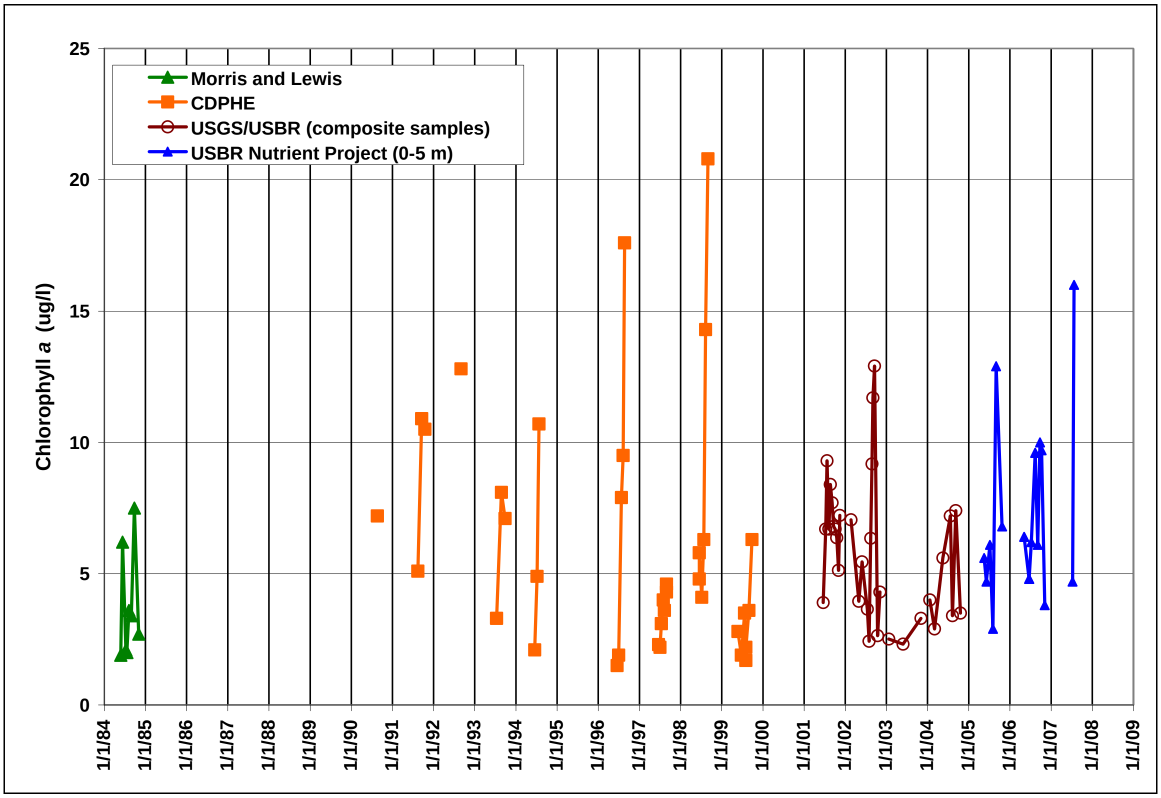


**Figure 14: Grand Lake Chlorophyll *a (*Data from Grand Lake at Grand Lake Site except for USBR Nutrient Data, which is at the Grand Lake Mid Site) (Data Sources: Morris & Lewis, 1988; USGS, 2007; USBR, 2005; NCWCD, 2007b)**

Recent monitoring in Grand Lake includes microcystin toxicity testing along with cell counts of dominant cyanobacteria (blue-green algae) (GCWIN, 2007). Microcystin is a hepatotoxin which targets the liver and can be produced by some cyanobacteria. The presence or excessive abundance of toxin-producing algae does not translate into the presence of toxins in the water column. All microcystin results received through July 24, 2007 for Grand Lake have been below the detection limit (0.1 to 0.4 µg/l) (Clements, 2007). Microcystin toxin levels of over 1 µg/l are of concern for drinking-water purposes (WHO, 1998).

Cyanobacteria cell counts peak the end of August through the end of September. The peak in 2004 of 5,763 cells/ml of *Anabaena* occurred on August 31st. The peak in 2005 of 21,471 cells/ml of *Anabaena* occurred on September 16th. Peaks for 2006 and 2007 were 27,871 (August 10) and 18,882 (August 14) cells/ml, respectively. The American Water Works Association Research Foundation suggests testing for toxins when toxin-producing alga cell counts reach 2,000 cells/ml (Yoo, 1995). The relationships between the abundance of toxin-producing algae and levels of microcystin are unclear and the subject of research efforts.

*Nutrients*

Phosphorus and nitrogen are considered major nutrients. Orthophosphate concentrations (the form available to algae) are low. Inorganic nitrogen concentrations (ammonia, nitrate, and nitrite -- the forms bioavailable for phytoplankton growth) are also low and typical of an oligotrophic system (Wetzel, 2001). Organic carbon concentrations are in the range of what one would expect given the setting and chlorophyll *a* concentrations.

Lake analyses often include an investigation to determine which nutrient is limiting the growth of algae. Increases in the limiting nutrient often cause increases in algal growth. Increases of the non-limiting nutrient will not cause increases in algal growth because its concentration is already in excess (there is more available that the algae can take up, given the concentration of the limiting nutrient). Previous bioassays have shown nitrogen limitation (EPA, 1970; EPA, 1977) or primarily N limitation (there were a few periods of P limitation and / or the need to increase both P and N) (Morris and Lewis, 1988). There have not been any recent bioassays to determine if this situation has changed.

*Water Clarity*

Figure 15 shows Secchi-disk depth since 2000. The values range from 1.8 to 5.6 meters with a mean of 3.5 meters. Water clarity in Grand Lake is a concern among stakeholders in Grand County. Northwest Colorado Council of Governments (NWCCOG), Grand County, and the Greater Grand Lake Shoreline Association recently proposed a Secchi-disk depth standard for the lake of 4 meters (CWQCC, 2008). In June 2008, the Colorado Water Quality Control Commission established a narrative clarity standard for Grand Lake effective December 31, 2008. This narrative standard is “the highest level of clarity attainable, consistent with the exercise of established water rights and the protection of aquatic life”. The Colorado Water Quality Control Commission also established a numeric clarity standard of 4 meter Secchi-disk depth for the months of July through September, with an effective date of January 1, 2014. Local communities and other water utilities plan to evaluate ways to improve water clarity. Reclamation and the Northern Colorado Water Conservancy District will experiment with reoperation of the C-BT by altering pumping from Granby Reservoir to Grand Lake during critical periods to determine impacts on Grand Lake clarity.

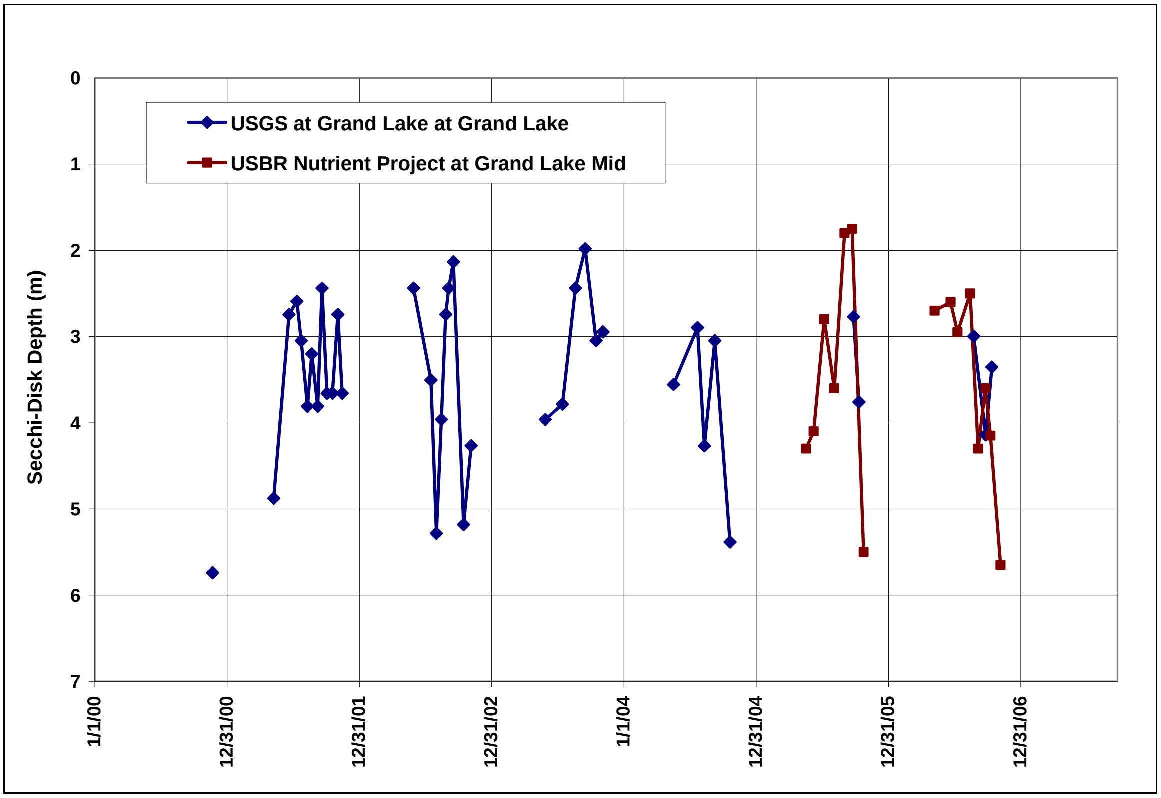


**Figure 15: Grand Lake Secchi-Disk Depth (Data Sources: USGS, 2007; NCWCD, 2007b)**

*Dissolved Oxygen*

Dissolved oxygen concentrations (Table 14) are lower in the hypolimnion versus the epilimnion. This is expected because the hypolimnion is essentially cut off from oxygen additions at the lake's air-water interface. Also, there can be significant demands of oxygen at the bottom of a lake due to decomposition of organic matter and other reactions. Recent dissolved oxygen profile data are displayed in Figure 16 and Figure 17 for two locations (Figure 7). Dissolved oxygen is lowest at the bottom just before fall turnover. Low dissolved oxygen concentrations at the bottom are of concern because of the potential for the release of orthophosphate, ammonia, iron, and manganese from the sediments under anoxic conditions. Note the development of a negative heterograde curve, similar to that of Granby Reservoir at an approximate depth of 10 meters. In August and September, a positive heterograde is evident at about 5 meters deep at the mid section site. Positive heterograde curves have also occurred at the Grand Lake at Grand Lake site in other years (e.g., 2002).

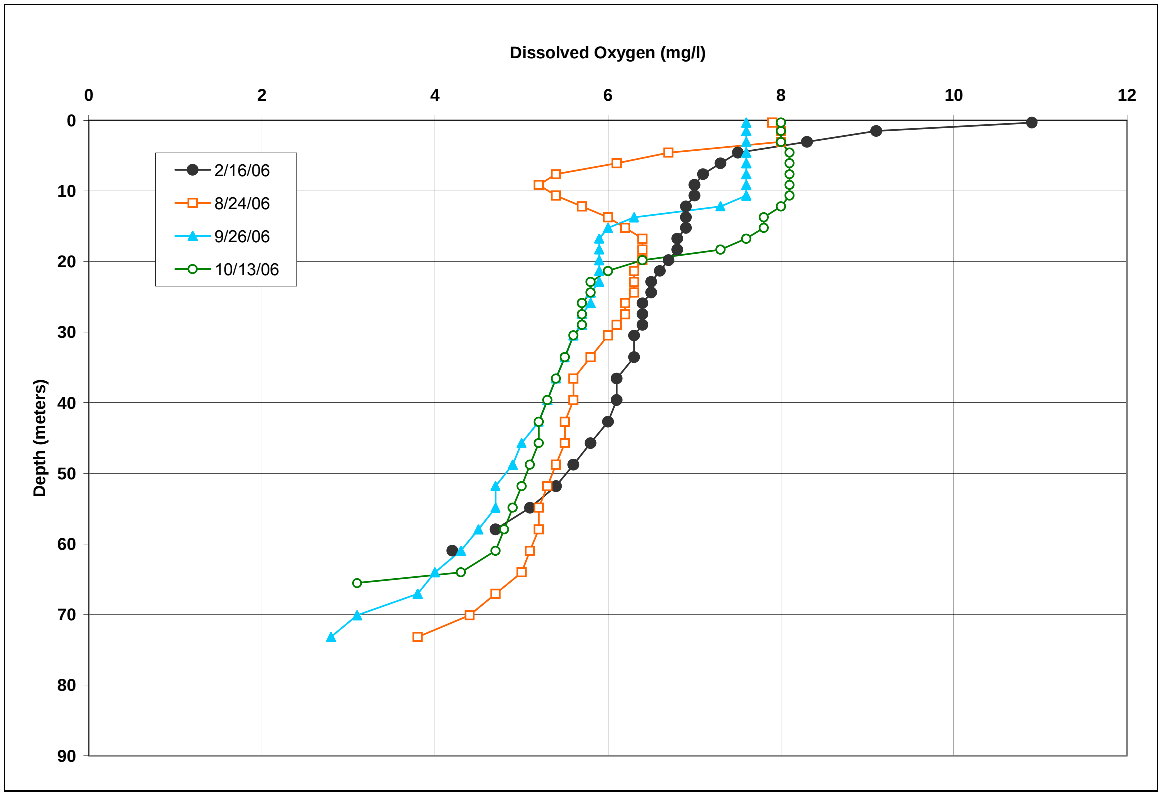


**Figure 16: Dissolved Oxygen Profiles for Grand Lake in 2006 (Site: Grand Lake at Grand Lake) (Data Source: USGS, 2007)**

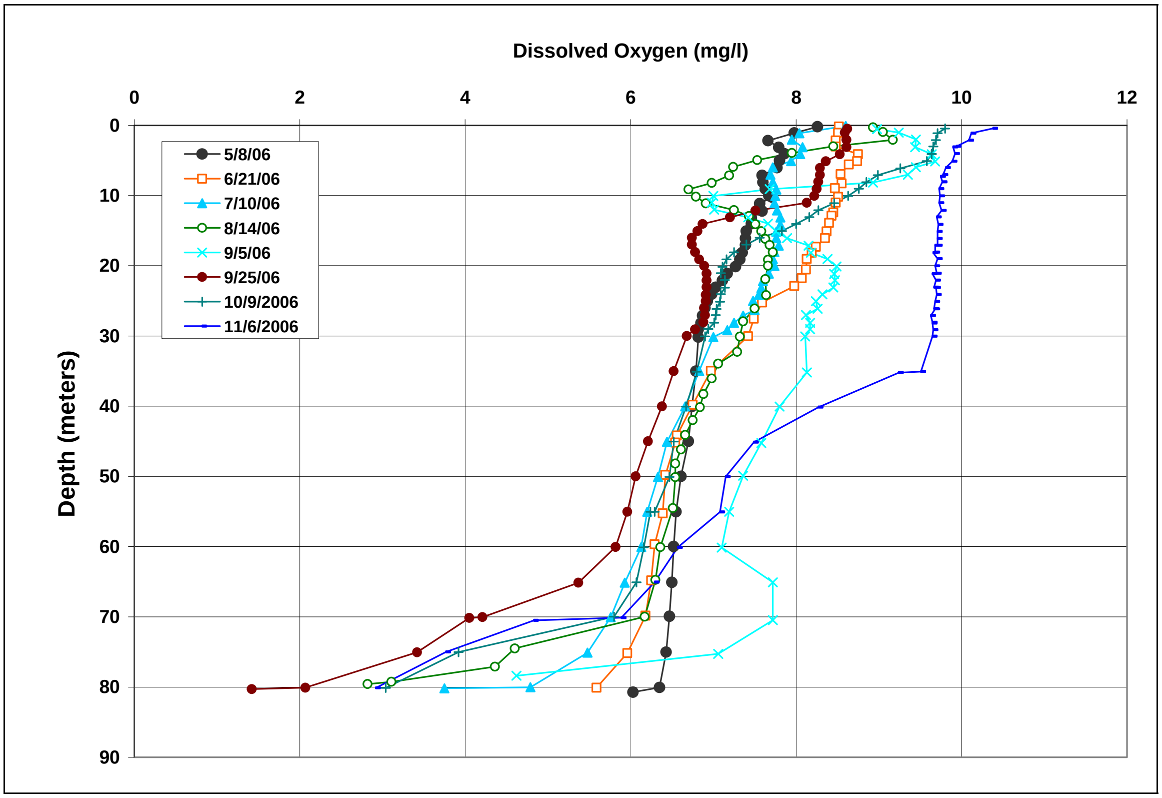


**Figure 17: Dissolved Oxygen Profiles Grand Lake in 2006 (Site: Mid Section of Grand Lake) (Data Source: NCWCD, 2007b)**

### *Water-Quality Standards*

Comparisons between the data and key applicable water-quality standards were made for Grand Lake using data from the period 2000 – 2007 at two different sites. The results are shown in Table 16 and Table 17. All standards listed are met with the exception of pH for aquatic life and manganese for water supply.

## Table 16: Comparison between Key Applicable Water-Quality Standards and Existing Conditions, Grand Lake (Site: Grand Lake at Grand Lake)

| Use Classification | Parameter Category | Parameter | Unit | Applicable Standard | In-Lake Value | Standard Met? |
|---|---|---|---|---|---|---|
| Aquatic Life | Physical | Dissolved Oxygen (elsp) | mg/l | 6.0 | 6.7 (25) | Yes |
| | | pH (epilimnion) | SU | 6.5 - 9.0 | 6.8 - 8.4 | Yes |
| | | pH (hypoliminon) | SU | 6.5 - 9.0 | 6.4 - 7.1 | No |
| | | Temperature (effective December 31, 2008) | °C | 9 (ch winter) | 1.5 - 2.2 | Yes |
| | | | | 13 (ac winter) | 2 - 2.3 | Yes |
| | | | | 18.2 (ch summer) | 15.5 - 16.2 | Yes |
| | | | | 23.8 (ac summer) | 16.2 - 16.9 | Yes |
| | | Temperature (interim) | °C | 20.0 (ch) | 1.5 - 16.2 | Yes |
| | Inorganic | Ammonia | mg/l as N | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | Metals | Cadmium, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (tr) (varies) | varies | Yes |
| | | Copper, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Iron, Trec | µg/l | 1000 (ch) | no data | |
| | | Lead, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Manganese, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Silver, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| Water Supply | Physical | Dissolved Oxygen | mg/l | 3.0 | 6.7 (25) | Yes |
| | | pH | SU | 6.5 - 9.0 | 6.8 - 8.4 | Yes |
| | Inorganic | Nitrate | mg/l | 10 (1-day) | max = 0.2 (50) | Yes |
| | Metals | Cadmium, dis | µg/l | 5.0 (1-day) | not enough data | |
| | | Iron, dis | µg/l | 300 (30-day) | not enough data | |
| | | Lead, Trec | µg/l | 50 (1-day) | no data | |
| | | Manganese, dis | µg/l | 50 (30-day) | not enough data | |
| | | Silver, Trec | µg/l | 100 (1-day) | no data | |
| Recreation | Physical | Dissolved Oxygen | mg/l | 3.0 | 6.7 (25) | Yes |
| | | pH | SU | 6.5 - 9.0 | 6.8 - 8.4 | Yes |
| Agriculture | Physical | Dissolved Oxygen | mg/l | 3.0 | 6.7 (25) | Yes |
| | Inorganic | Nitrate | mg/l as N | 100 | max = 0.2 (50) | Yes |
| | Metals | Cadmium, Trec | µg/l | 10 (30-day) | no data | |
| | | Lead, Trec | µg/l | 100 (30-day) | no data | |
| | | Manganese, Trec | µg/l | 200 (30-day) | no data | |

- Available water quality data for past five years (9/02 on) was evaluated against standards applicable to the reservoir according to Colorado water quality regulations.
- Values in parenthesis in "In-Lake Value" column are the number of samples or daily average values evaluated for the param
- D.O. "In-Lake Values" are 15th percentile of daily average epilimnion and metalimnion profile results (elsp = early life stage present). In addition, per the WQCD, if all measurements in the epiliminion and metalimnion on any one day were below the standard the reservoir was found to be out of attainment.
- pH range is 15th percentile - 85th percentile value of daily average profile sample results.
- "Large Lake" temperature criteria applied. Temperature "In-Lake Values" are for epilimnion layer min - max of MWAT (ch) (lake equivalent of maximum weekly average temperature) and DM (ac) (daily maximum).
- In 2007 new temperature standards were adopted as defined in Colorado's Regulation No. 31 (5 CCR 1002-31). Interim standards were established to be applicable until the next Triennial Review process for each basin, at which point it is anticipated the new temperature standards will be adopted.
- Nitrate "In-Lake Value" is the maximum of all discrete Nitrate + Nitrite results.
- For acute computations, evaluated all data. For all other computations, evaluated only if at least 12 data points (per WQCD guidelines)
- 'no data' includes instances where there are no hardness data available to evaluate the standard

**Table 17: Comparison between Key Applicable Water-Quality Standards and Existing Conditions, Grand Lake (Site: Mid Section of Grand Lake)**

| Use Classification | Parameter Category | Parameter | Unit | Applicable Standard | In-Lake Value | Standard Met? |
|---|---|---|---|---|---|---|
| Aquatic Life | Physical | Dissolved Oxygen (elsp) | mg/l | 6.0 | 7.6 (15) | Yes |
| | | pH (epilimnion) | SU | 6.5 - 9.0 | 7.6 - 8.4 | Yes |
| | | pH (hypoliminon) | SU | 6.5 - 9.0 | 7.2 - 8.1 | Yes |
| | | Temperature (effective December 31, 2008) | °C | 9 (ch winter) | no data | |
| | | | | 13 (ac winter) | no data | |
| | | | | 18.2 (ch summer) | not enough data | |
| | | | | 23.8 (ac summer) | 17.3 - 17.8 | Yes |
| | | Temperature (interim) | °C | 20.0 (ch) | not enough data | |
| | Inorganic | Ammonia | mg/l as N | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | Metals | Cadmium, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (tr) = 0.41 | 0.5 | only 1 data point |
| | | Copper, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Iron, Trec | µg/l | 1000 (ch) | no data | |
| | | Lead, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Manganese, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Silver, dis | µg/l | ch (varies) | no data | |
| | | | | ac (varies) | no data | |
| Water Supply | Physical | Dissolved Oxygen | mg/l | 3.0 | 7.6 (15) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.6 - 8.4 | Yes |
| | Inorganic | Nitrate | mg/l | 10 (1-day) | max = 0.4 (30) | Yes |
| | Metals | Cadmium, dis | µg/l | 5.0 (1-day) | not enough data | |
| | | Iron, dis | µg/l | 300 (30-day) | 0 - 60 | Yes |
| | | Lead, Trec | µg/l | 50 (1-day) | no data | |
| | | Manganese, dis | µg/l | 50 (30-day) | 0 - 1100 | No |
| | | Silver, Trec | µg/l | 100 (1-day) | no data | |
| Recreation | Physical | Dissolved Oxygen | mg/l | 3.0 | 7.6 (15) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.6 - 8.4 | Yes |
| Agriculture | Physical | Dissolved Oxygen | mg/l | 3.0 | 7.6 (15) | Yes |
| | Inorganic | Nitrate | mg/l as N | 100 | max = 0.4 (30) | Yes |
| | Metals | Cadmium, Trec | µg/l | 10 (30-day) | no data | |
| | | Lead, Trec | µg/l | 100 (30-day) | no data | |
| | | Manganese, Trec | µg/l | 200 (30-day) | no data | |

- Available water quality data for past five years (9/02 on) was evaluated against standards applicable to the reservoir according to Colorado water quality regulations.
- Values in parenthesis in "In-Lake Value" column are the number of samples or daily average values evaluated for the parameter.
- D.O. "In-Lake Values" are 15th percentile of daily average epilimnion and metalimnion profile results (elsp = early life stage present). In addition, per the WQCD, if all measurements in the epiliminion and metalimnion on any one day were below the standard the reservoir was found to be out of attainment.
- pH range is 15th percentile - 85th percentile value of daily average profile sample results.
- "Large Lake" temperature criteria applied. Temperature "In-Lake Values" are for epilimnion layer min - max of MWAT (ch) (lake equivalent of maximum weekly average temperature) and DM (ac) (daily maximum).
- In 2007 new temperature standards were adopted as defined in Colorado's Regulation No. 31 (5 CCR 1002-31). Interim standards were established to be applicable until the next Triennial Review process for each basin, at which point it is anticipated the new temperature standards will be adopted.
- Nitrate "In-Lake Value" is the maximum of all discrete Nitrate + Nitrite results.
- For acute computations, evaluated all data. For all other computations, evaluated only if at least 12 data points (per WQCD guidelines)
- 'no data' includes instances where there are no hardness data available to evaluate the standard

### 8.2.4. Carter Lake

Carter Lake is a C-BT project reservoir on the East Slope. The reservoir supplies water to various front range and eastern plains cities and the agricultural community in Boulder and Weld counties. The reservoir is also used for recreational activities including sailing, boating, swimming, waterskiing, and fishing. Carter Lake has the following use classifications which are used by the CDPHE to set appropriate water-quality standards:

- Aquatic Life Cold 1;
- Recreation 1a;
- Water Supply; and
- Agriculture.

These classifications are defined in Table 6.

There are three dams which enclose the reservoir (Figure 18). Water for the reservoir is derived from the Upper Colorado River and the Big Thompson River. Carter Lake is supplied by water pumped up from Flatiron Reservoir through a submerged tunnel which opens into the main reservoir body. Reservoir releases supply the St. Vrain Supply Canal and the Southern Water Supply Project.

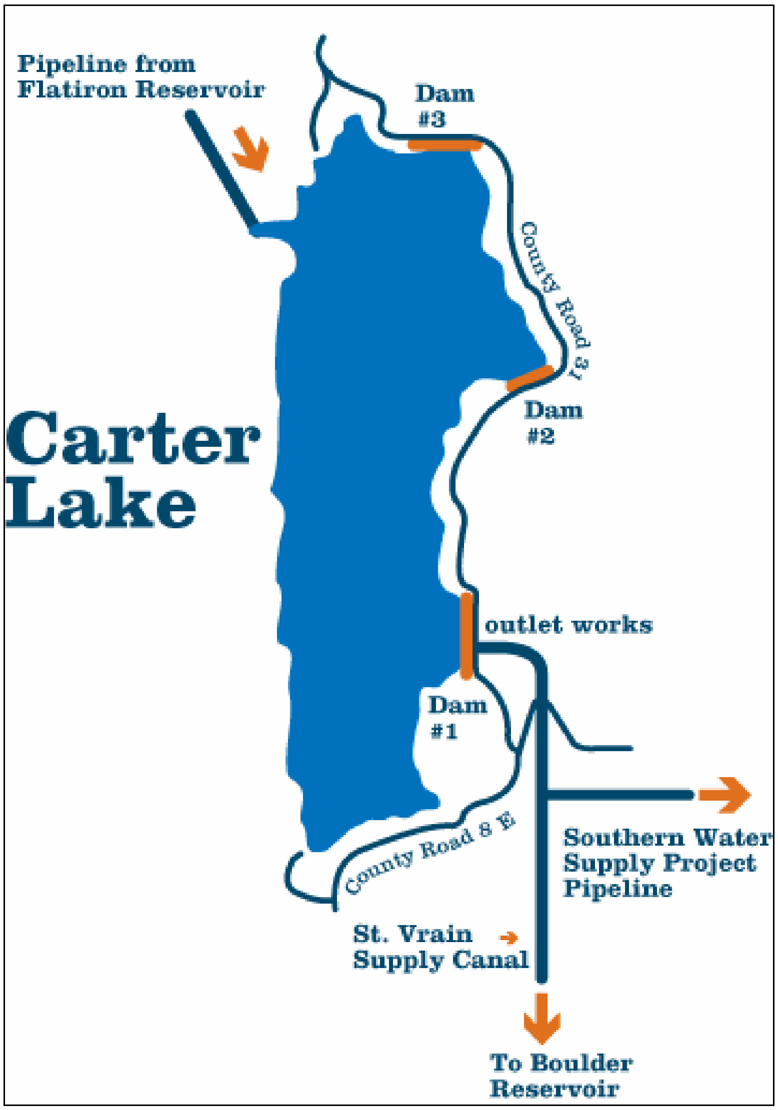


**Figure 18: Carter Lake (Data Source: NCWCD, 2007e)**

Carter Lake's physical characteristics and hydrology are described in Table 18. The estimated residence time is based on reservoir contents and annual flow. The lake stratifies in the summer, forming an epilimnion and a hypolimnion.

**Table 18: Physical Characteristics and Hydrology of Carter Lake**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume* | 112,230 AF | 138.4 x $10^6$ $m^3$ |
| Surface Area*, + | 1,110 acres | 449 hectares |
| Mean Depth | 101 ft | 30.8 m |
| Maximum Depth*, **, + | 180 ft | 55 m |
| Shoreline* | 12 miles | 19.3 km |
| Maximum Width+ | 1.0 miles | 1.6 km |
| Length*, + | 2.8 miles | 4.5 km |
| Maximum Surface Water Elevation+ | 5,759 ft | 1,755 m |
| Hydraulic Residence Time+ | One Year | |

Source: * NCWCD, 2007f, + Jassby and Goldman, 1999; ** at maximum capacity

Concentrations of key water-quality constituents in Carter Lake are summarized in Table 19. More detailed information can be found in Appendix A. The sampling sites are shown in Figure 19. Only recent data (2000-2007) are considered in Table 19. Note that nutrient concentrations in Carter Lake are lower than in Horsetooth Reservoir. Although Flatiron Reservoir supplies both Horsetooth Reservoir and Carter Lake, the Dille Tunnel is an additional source for Horsetooth Reservoir. It has been surmised that the Dille Tunnel water could be a cause of the differences in water quality between the two reservoirs (Jassby and Goldman, 1999).

A detailed evaluation of the water quality in Carter Lake, focused on data from 2005 to 2006 can be found in Lieberman, 2007a and Lieberman, 2007b.

## Table 19: Summary of Key Water-Quality Parameters for Carter Lake (see Table 5 for Data Sources)

***Epilimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | 1.60 | 2.77 | 2.92 | 5.05 |
| Chlorophyll a, ug/l | 0.50 | 1.60 | 1.86 | 5.80 |
| DO, mg/l | 6.60 | 7.75 | 8.10 | 11.20 |
| Conductivity, uS/cm | 55.00 | 65.50 | 68.95 | 101.00 |
| pH, field | 7.00 | 7.80 | 7.73 | 8.50 |
| Temperature, deg C | 4.80 | 14.55 | 15.60 | 22.20 |
| Ammonia, dis, ug/l as N | 1.00 | 9.00 | 17.04 | 129.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 9.50 | 29.54 | 212.00 |
| TKN, ug/l as N | 111.00 | 194.00 | 189.92 | 260.00 |
| TP, ug/l as P | 1.50 | 9.50 | 9.19 | 16.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 3.00 | 2.40 | 5.00 |
| Silica, dis, mg/l | 0.93 | 2.54 | 2.51 | 4.68 |
| TOC, mg/l | 1.00 | 3.20 | 2.92 | 4.80 |
| DOC, mg/l | 3.10 | 3.25 | 3.25 | 3.40 |
| Calcium, dis, mg/l | 7.68 | 9.18 | 9.36 | 10.70 |
| Magnesium, dis, mg/l | 1.18 | 1.32 | 1.32 | 1.53 |
| Sulfate, dis, mg/l | 2.20 | 2.80 | 2.89 | 3.99 |
| Chloride, dis, mg/l | 0.33 | 0.75 | 0.80 | 1.23 |
| Alkalinity, dis, mg/l as CaCO3 | 33.00 | 33.00 | 33.00 | 33.00 |
| Iron, dis, ug/l | 3.00 | 5.00 | 5.13 | 9.00 |
| Manganese, dis, ug/l | 0.10 | 0.50 | 0.50 | 1.10 |
| Potassium, dis, mg/l | 0.58 | 0.67 | 0.69 | 0.94 |
| Sodium, dis, mg/l | 1.83 | 2.07 | 2.14 | 2.63 |
| TSS, mg/l | 0.47 | 1.00 | 3.24 | 26.60 |
| Copper, dis, ug/l | 1.00 | 1.80 | 2.03 | 5.00 |
| Cadmium, dis, ug/l | 0.02 | 0.05 | 0.05 | 0.10 |
| Lead, dis, ug/l | 0.04 | 0.04 | 3.41 | 50.00 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.10 | 0.15 |
| Zinc, dis, ug/l | 0.30 | 0.50 | 1.54 | 10.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 3.60 | 6.65 | 6.84 | 10.70 |
| Conductivity, uS/cm | 43.00 | 57.00 | 59.00 | 86.00 |
| pH, field | 6.30 | 7.20 | 7.18 | 8.40 |
| Temperature, deg C | 4.00 | 8.10 | 8.22 | 13.60 |
| Ammonia, dis, ug/l as N | 2.00 | 9.50 | 20.94 | 118.00 |
| Nitrate + Nitrite, dis, ug/l as N | 6.50 | 50.00 | 68.81 | 256.00 |
| TKN, ug/l as N | 80.00 | 190.00 | 186.04 | 415.00 |
| TP, ug/l as P | 1.50 | 11.50 | 13.31 | 77.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 3.25 | 3.57 | 14.00 |
| Silica, dis, mg/l | 2.49 | 3.71 | 3.80 | 5.25 |
| TOC, mg/l | 0.80 | 3.00 | 2.65 | 4.00 |
| DOC, mg/l | 2.90 | 3.00 | 3.00 | 3.10 |
| Calcium, dis, mg/l | 6.36 | 7.90 | 7.99 | 9.89 |
| Magnesium, dis, mg/l | 1.01 | 1.20 | 1.23 | 1.46 |
| Sulfate, dis, mg/l | 1.90 | 2.80 | 2.74 | 3.71 |
| Chloride, dis, mg/l | 0.29 | 0.74 | 0.77 | 1.25 |
| Alkalinity, dis, mg/l as CaCO3 | 25.00 | 25.00 | 25.00 | 25.00 |
| Iron, dis, ug/l | 3.00 | 10.00 | 15.68 | 40.00 |
| Manganese, dis, ug/l | 0.50 | 5.00 | 7.28 | 60.00 |
| Potassium, dis, mg/l | 0.57 | 0.63 | 0.65 | 0.87 |
| Sodium, dis, mg/l | 1.59 | 2.03 | 2.03 | 2.47 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | 1.30 | 1.90 | 2.37 | 5.00 |
| Cadmium, dis, ug/l | 0.02 | 0.05 | 0.05 | 0.10 |
| Lead, dis, ug/l | 0.04 | 0.04 | 3.42 | 50.00 |
| Silver, dis, ug/l | 0.05 | 0.10 | 0.10 | 0.15 |
| Zinc, dis, ug/l | 0.30 | 0.75 | 2.54 | 14.30 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

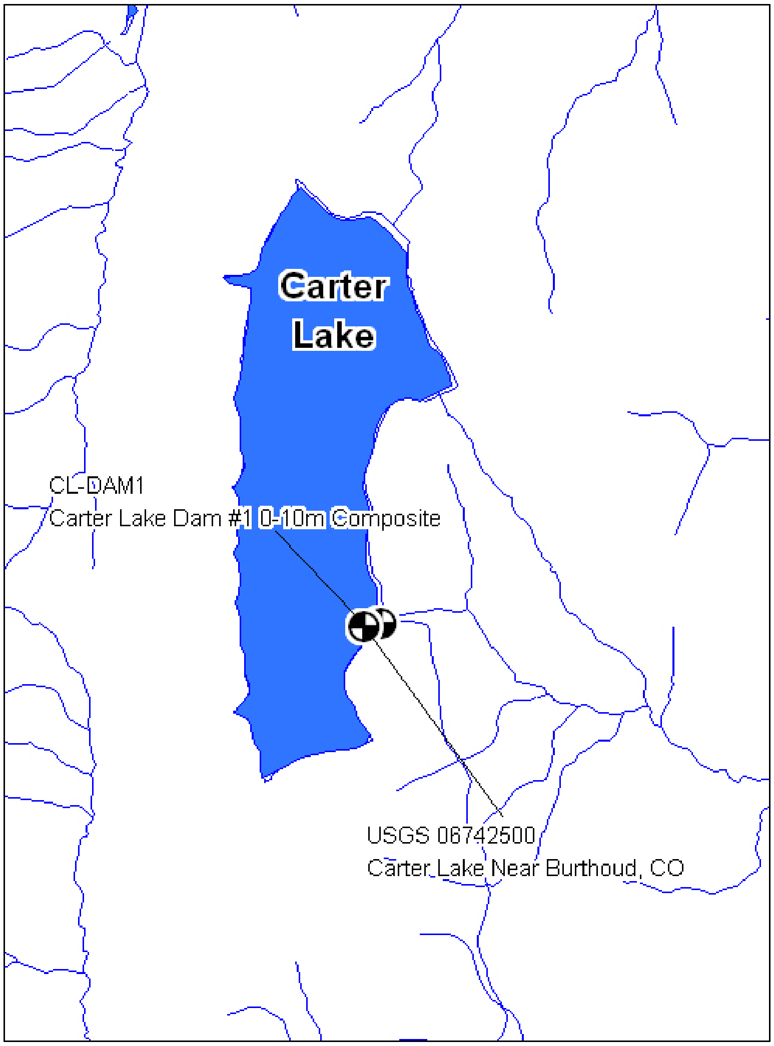


**Figure 19: Water-Quality Monitoring Stations for Carter Lake**

*Major Ions and Trace Elements*

The median concentrations of major ions (calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate [as indicated by alkalinity]) are typical of non-polluted watersheds. Together, they make up most of the total dissolved solids concentration (TDS) which is closely approximated by specific conductance. Specific conductance is a measure of the ability of water to conduct an electrical current. Total dissolved solids concentrations in mg/l are typically between 55% and 75% of the specific conductance in µS/cm (Hem, 1985). Since the concentrations of these ions are relatively uninfluenced by biological activities within the reservoir (Jassby and Goldman, 1999), they can serve as a signature for source waters.

Trace metals occur in natural and industrial water. They can also be present as a result of management alternatives such as the use of copper as an algicide. Copper is of concern for aquatic life and the standard is hardness dependent. Although there are not sufficient data to evaluate whether or not copper standards are being met for Carter Lake (Table 20), the data that do exist indicate an exceedance of the standard on one day.

Elevated dissolved iron and dissolved manganese concentrations can be a problem for water providers. Dissolved iron and dissolved manganese concentrations listed in Table 19 show higher values in the hypolimnion versus the epilimnion. This is common in lakes and reservoirs which experience low dissolved oxygen concentrations in the hypolimnion. Dissolved manganese concentrations are also relatively low with the exception of a spike in the hypolimnion which occurred in September 2006.

*Algae and Trophic State*

A time series of chlorophyll *a* data measured since 1989 is displayed in Figure 20. Since 2000, the peak concentration was 4.7 µg/l. Peak concentrations tend to occur in the spring and/or fall. The average chlorophyll *a* concentrations translate to a mesotrophic trophic state.

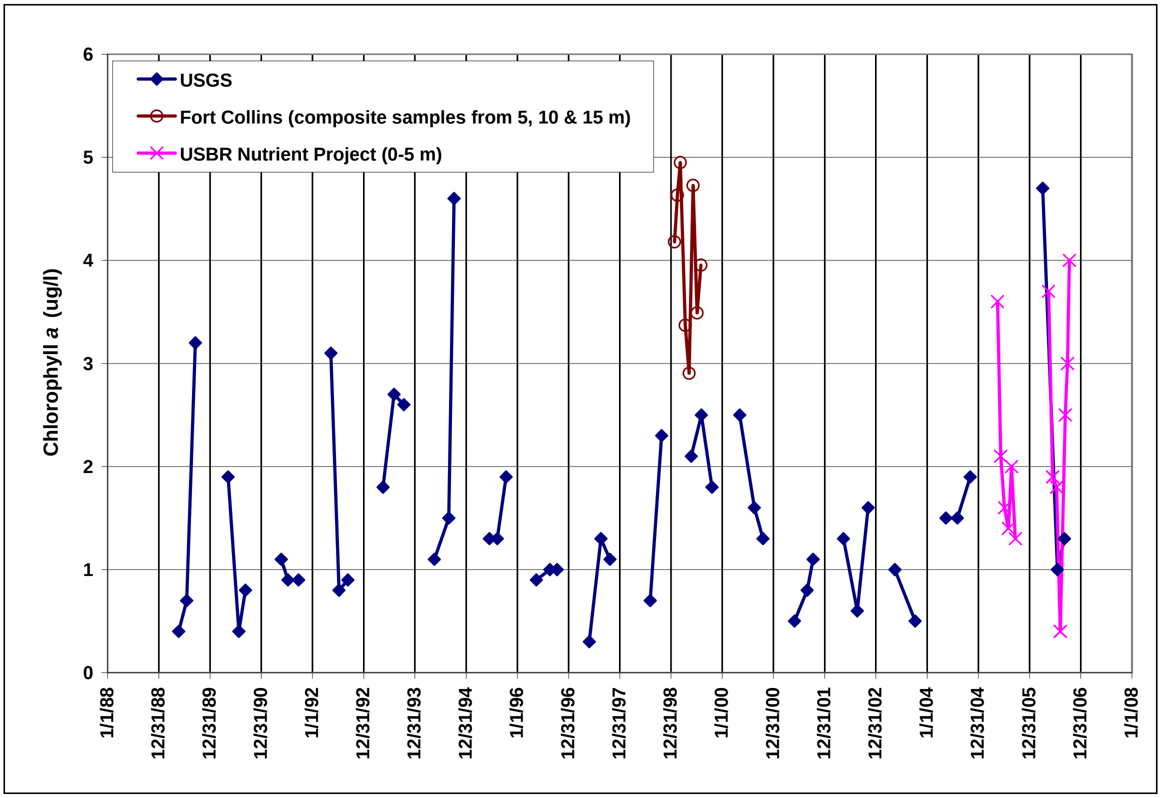


**Figure 20: Carter Lake Chlorophyll *a* Concentrations (Data Sources: USGS, 2007; NCWCD, 2007b; Ft. Collins, 2007)**

*Nutrients*

Orthophosphate concentrations (the form available to algae) are low. Inorganic nitrogen concentrations (ammonia, nitrate, and nitrite -- the forms bioavailable for phytoplankton growth) are low and typical of an oligotrophic system (Wetzel, 2001). Organic carbon concentrations are in the range of what one would expect given the setting and chlorophyll *a* concentrations.

Lake analyses often include an investigation to determine which nutrient is limiting the growth of algae. Increases in the limiting nutrient often cause increases in algal growth. Increases of the non-limiting nutrient will not cause increases in algal growth because its concentration is already in excess (there is more available that the algae can take up, given the concentration of the limiting nutrient). Bioassays, which are more informative than estimates based on nutrient concentrations, have not been completed on Carter Lake. Estimates based on inorganic nutrient concentrations are uninformative due to the high number of results below the detection limits. Jassby and Goldman (1999) concluded that the reservoir was co-limited by nitrogen and phosphorus.

*Water Clarity*

Figure 21 shows Secchi-disk depths since 1978. Since 2000, the range is 1.6 to 5.1 meters with a mean value of 2.9 meters.

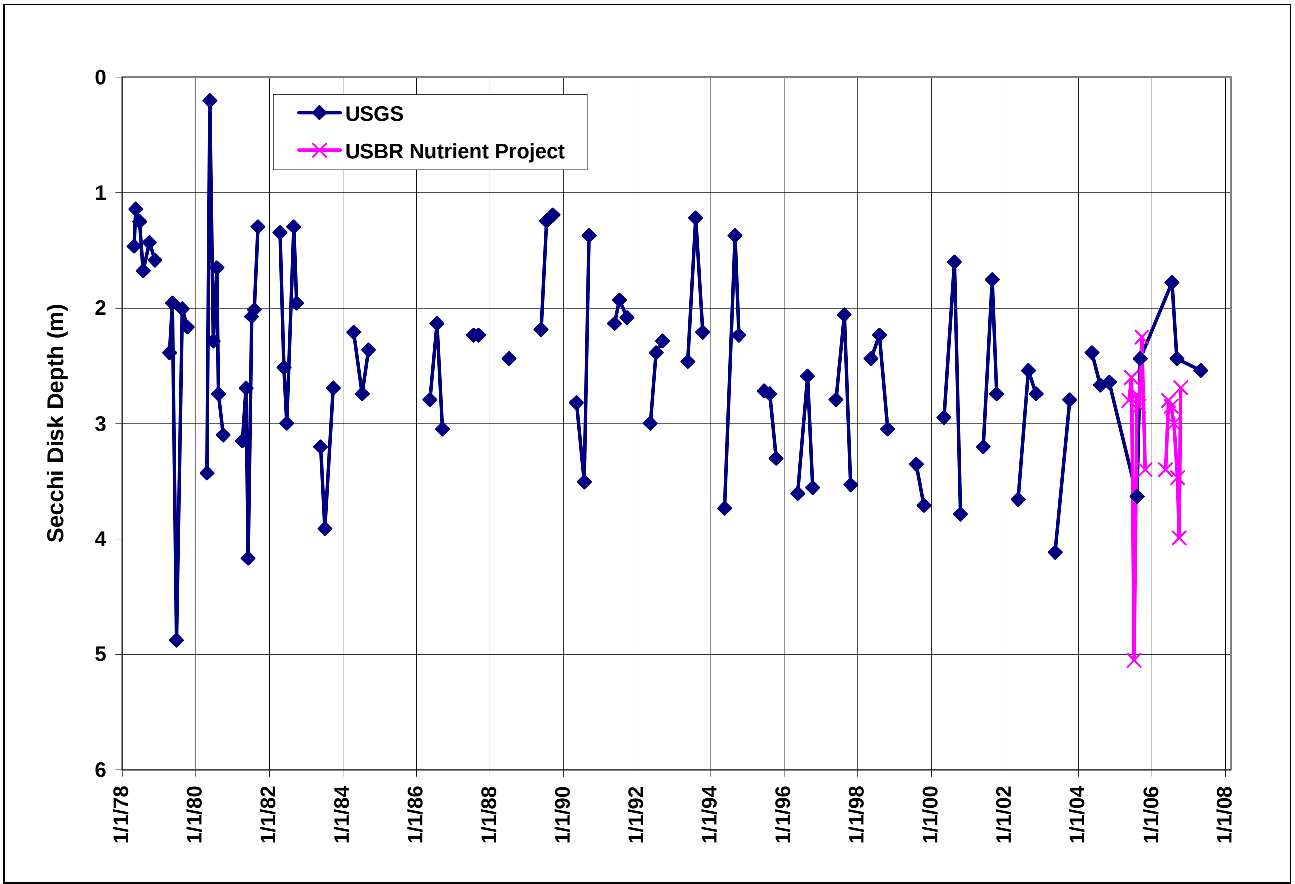


**Figure 21: Carter Lake Secchi-Disk Depth (Data Sources: USGS, 2007; NCWCD, 2007b)**

*Dissolved Oxygen*

Dissolved oxygen concentrations are lower in the hypolimnion versus the epilimnion (Table 19). This is expected because the hypolimnion is essentially cut off from oxygen additions at the lake's air-water interface. Also, there can be significant demands of oxygen at the bottom of a lake due to decomposition of organic matter and other reactions. Recent profile data are displayed in Figure 22. Dissolved oxygen fell to below 4 mg/l at the bottom. Low dissolved oxygen concentrations (< 2 mg/l) at the bottom are of concern because of the potential for the release of orthophosphate, ammonia, iron, and manganese from the sediments under anoxic conditions.

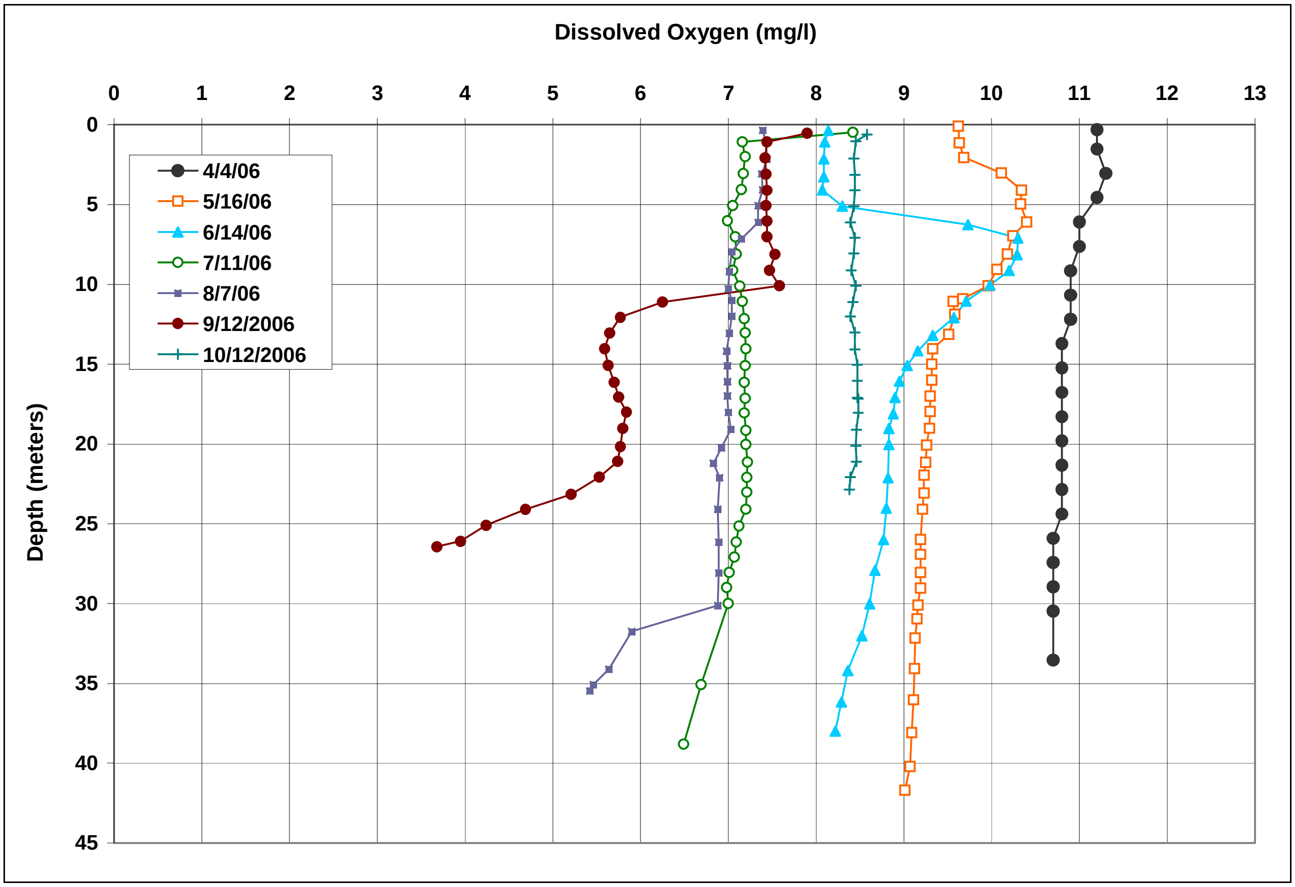


**Figure 22: Dissolved Oxygen Profiles Carter Lake in 2006 (Data Sources: USGS, 2007; NCWCD, 2007b)**

Note also the increase in dissolved oxygen for the spring – early summer time profiles at a depth of about 5-10 meters (metalimnetic oxygen maxima). This phenomenon nearly always occurs due to large algal populations that develop more rapidly than they sink out of this strata (Wetzel, 2001). This is opposite of what occurs in Granby Reservoir and Grand Lake.

### *Water-Quality Standards*

Comparisons between the data and key applicable water-quality standards were made for Carter Lake using data from the period 2000 - 2005. The results are shown in Table 20. All of the standards listed for all four classified uses were met with the exception of temperature in the summer. This conclusion is reached for both the interim standard and the anticipated December 2008 standard.

## Table 20: Comparison between Key Applicable Water-Quality Standards and Existing Conditions, Carter Lake

| Use Classification | Parameter Category | Parameter | Unit | Applicable Standard | In-Lake Value | Standard Met? |
|---|---|---|---|---|---|---|
| Aquatic Life | Physical | Dissolved Oxygen (elsp) | mg/l | 6.0 | 7.2 (26) | Yes |
| | | pH (epiliminion) | SU | 6.5 - 9.0 | 7.6 - 8.5 | Yes |
| | | pH (hypoliminon) | SU | 6.5 - 9.0 | 7.0 - 8.4 | Yes |
| | | Temperature (effective December 31, 2009) | °C | 9 (ch winter) | no data | |
| | | | | 13 (ac winter) | no data | |
| | | | | 18.2 (ch summer) | 20.8 - 22.7 | No |
| | | | | 23.8 (ac summer) | 21.3 - 22.9 | Yes |
| | | Temperature (interim) | °C | 20.0 (ch) | 20.8 - 22.7 | No |
| | Inorganic | Ammonia | mg/l as N | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | Metals | Cadmium, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (tr) (varies) | varies | Yes |
| | | Copper, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes (1 exceedance in 5 yrs of data) |
| | | Iron, Trec | µg/l | 1000 (ch) | no data | |
| | | Lead, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Manganese, dis | µg/l | ch (varies) | varies | Yes |
| | | | | ac (varies) | varies | Yes |
| | | Silver, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| Water Supply | Physical | Dissolved Oxygen | mg/l | 3.0 | 7.2 (26) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.6 - 8.5 | Yes |
| | Inorganic | Nitrate | mg/l | 10 (1-day) | max = 0.3 (53) | Yes |
| | Metals | Cadmium, dis | µg/l | 5.0 (1-day) | not enough data | |
| | | Iron, dis | µg/l | 300 (30-day) | 0 - 40 | Yes |
| | | Lead, Trec | µg/l | 50 (1-day) | no data | |
| | | Manganese, dis | µg/l | 50 (30-day) | 0 - 37.8 | Yes |
| | | Silver, Trec | µg/l | 100 (1-day) | no data | |
| Recreation | Physical | Dissolved Oxygen | mg/l | 3.0 | 7.2 (26) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.6 - 8.5 | Yes |
| Agriculture | Physical | Dissolved Oxygen | mg/l | 3.0 | 7.2 (26) | Yes |
| | Inorganic | Nitrate | mg/l as N | 100 | max = 0.3 (53) | Yes |
| | Metals | Cadmium, Trec | µg/l | 10 (30-day) | no data | |
| | | Lead, Trec | µg/l | 100 (30-day) | no data | |
| | | Manganese, Trec | µg/l | 200 (30-day) | no data | |

- Available water quality data for past five years (9/02 on) was evaluated against standards applicable to the reservoir according to Colorado water quality regulations.
- Values in parenthesis in "In-Lake Value" column are the number of samples or daily average values evaluated for the param
- D.O. "In-Lake Values" are 15th percentile of daily average epilimnion and metalimnion profile results (elsp = early life stage present). In addition, per the WQCD, if all measurements in the epiliminion and metalimnion on any one day were below the standard the reservoir was found to be out of attainment.
- pH range is 15th percentile - 85th percentile value of daily average profile sample results.
- "Large Lake" temperature criteria applied. Temperature "In-Lake Values" are for epilimnion layer min - max of MWAT (ch) (lake equivalent of maximum weekly average temperature) and DM (ac) (daily maximum).
- In 2007 new temperature standards were adopted as defined in Colorado's Regulation No. 31 (5 CCR 1002-31). Interim standards were established to be applicable until the next Triennial Review process for each basin, at which point it is anticipated the new temperature standards will be adopted.
- Nitrate "In-Lake Value" is the maximum of all discrete Nitrate + Nitrite results.
- Water Supply "In-Lake Value" is min - max range of 30-day averages of hypolimnion samples (did not have enough data points to evaluate epilimnion layer).
- Metals 1 acute exceedance within 3 years is allowable to satisfy standard
- For acute computations, evaluated all data. For all other computations, evaluated only if at least 12 data points (per WQCD guidelines)
- 'no data' includes instances where there are no hardness data available to evaluate the standard

#### 8.2.5. Horsetooth Reservoir

Horsetooth Reservoir is located in Larimer County on the East Slope and supplies water to the City of Fort Collins as well as several rural domestic suppliers, industries, and the agricultural community in the Poudre River Basin. The reservoir is an important recreation area serving more than 500,000 visitors per year who use the area to fish, boat, camp, picnic, and hike. Horsetooth Reservoir is owned by the U.S. Bureau of Reclamation and operated and maintained by the Northern Colorado Water Conservancy District. It has the following use classifications which are used by the CDPHE to set appropriate water-quality standards:

- Aquatic Life Cold 1;
- Recreation 1a;
- Water Supply; and
- Agriculture.

These classifications are defined in Table 6.

Four dams enclose this narrow reservoir (Figure 23). The main outlet is through Horsetooth Dam to the Poudre River via the Hansen Supply Canal. Water is supplied from Flatiron Reservoir and the Dille Tunnel via the Hansen Feeder Canal. Horsetooth Reservoir's physical characteristics and hydrology are described in Table 21. The estimated residence time is based on reservoir contents and annual flow.

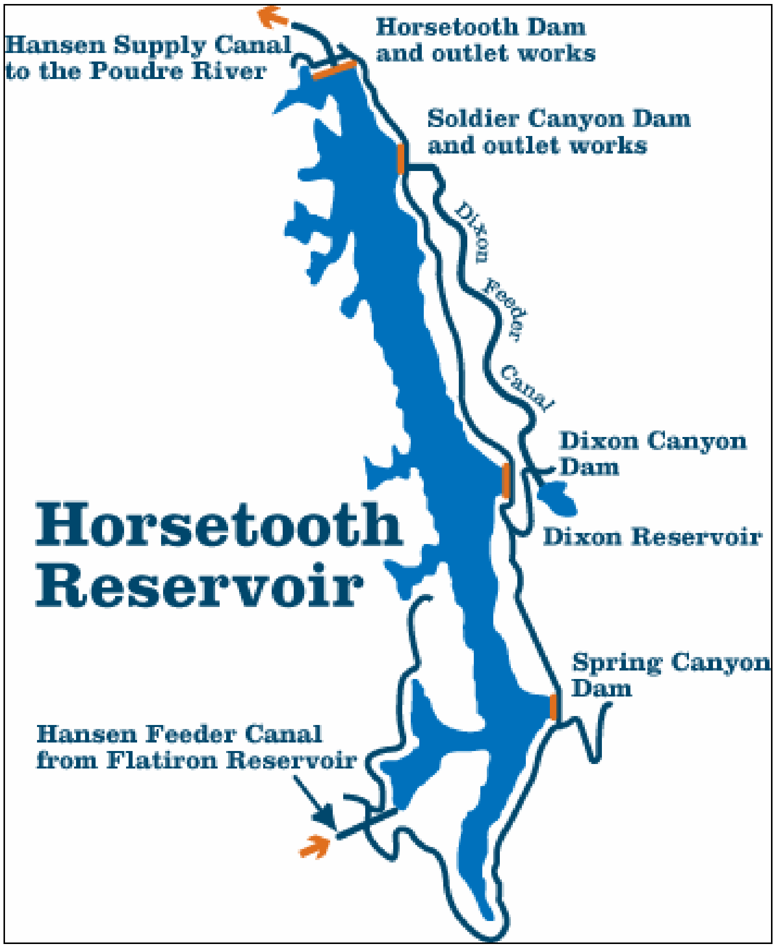


**Figure 23: Horsetooth Reservoir (Data Source: NCWCD, 2007g)**

**Table 21: Physical Characteristics and Hydrology of Horsetooth Reservoir**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume* | 156,735 AF | $193.3 \times 10^6$ $m^3$ |
| Surface Area**, + | 2,143 acres | 868 hectares |
| Mean Depth | 73.1 ft | 22.3 m |
| Maximum Depth*, ** | 188 ft | 57.3 m |
| Shoreline* | 25 miles | 40 km |
| Maximum Length+ | 6.7 miles | 10.6 km (+) |
| Maximum Width+ | 0.9 miles | 1.5 km (+) |
| Maximum Surface Water Elevation | 5,436 ft | 1,657 m (+) |
| Hydraulic Residence Time | One Year (+) | |

Data Sources: * NCWCD, 2007h, + Jassby and Goldman, 1999; ** at maximum capacity,

Concentrations of key water-quality constituents in Horsetooth Reservoir are summarized in Table 22 and Table 23. More detailed information can be found in Appendix A. There are two sampling sites represented -- one near Spring Canyon Dam and the other near Soldier Canyon Dam. These sites are shown in Figure 24. Only recent data (2004-2007) are considered in these tables this is the period after the reservoir drawdown. The reservoir was drawn down in late 2000 for dam maintenance and it began to refill in early 2004.

### Table 22: Summary of Key Water-Quality Parameters for Horsetooth Reservoir Soldier Canyon Dam (see Table 5 for Data Sources)

***Epilimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | 1.45 | 2.80 | 2.90 | 4.83 |
| Chlorophyll a, ug/l | 0.30 | 2.70 | 3.02 | 6.80 |
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | 82.00 | 106.00 | 106.00 | 130.00 |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 1.50 | 10.00 | 19.46 | 108.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 20.00 | 25.89 | 64.00 |
| Nitrate, dis, ug/l | 10.00 | 50.00 | 43.85 | 50.00 |
| TKN, ug/l as N | 50.00 | 210.00 | 217.58 | 550.00 |
| TP, ug/l as P | 1.50 | 10.00 | 8.98 | 20.00 |
| Orthophosphate, dis, ug/l as P | 0.00 | 2.00 | 1.69 | 5.00 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 1.20 | 3.20 | 2.92 | 3.94 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | 7.70 | 8.40 | 8.43 | 9.30 |
| Magnesium, dis, mg/l | 1.40 | 1.50 | 1.50 | 1.60 |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.05 | 5.30 |
| Chloride, dis, mg/l | --- | --- | --- | --- |
| Alkalinity, dis, mg/l as CaCO3 | 26.00 | 29.60 | 28.92 | 32.20 |
| Iron, dis, ug/l | 52.00 | 158.00 | 178.80 | 355.00 |
| Manganese, dis, ug/l | --- | --- | --- | --- |
| Potassium, dis, mg/l | 0.82 | 0.87 | 0.87 | 0.94 |
| Sodium, dis, mg/l | 2.40 | 2.50 | 2.50 | 2.70 |
| TSS, mg/l | 1.69 | 2.33 | 2.65 | 4.37 |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | --- | --- | --- | --- |
| Lead, dis, ug/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Silver, dis, ug/l | 0.25 | 0.25 | 0.25 | 0.25 |
| Iron, TR, ug/l | 163.00 | 164.00 | 171.00 | 186.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Epilimnion Composite Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Chlorophyll a, ug/l | 1.30 | 3.30 | 3.47 | 6.40 |
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | --- | --- | --- | --- |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 10.00 | 10.00 | 13.46 | 29.00 |
| Nitrate + Nitrite, dis, ug/l as N | --- | --- | --- | --- |
| Nitrate, dis, ug/l | 20.00 | 50.00 | 48.46 | 100.00 |
| TKN, ug/l as N | 70.00 | 220.00 | 230.83 | 400.00 |
| TP, ug/l as P | 5.00 | 10.00 | 8.08 | 10.00 |
| Orthophosphate, dis, ug/l as P | 0.00 | 2.50 | 2.00 | 2.50 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 2.75 | 3.35 | 3.25 | 3.61 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | 7.70 | 8.00 | 8.07 | 8.80 |
| Magnesium, dis, mg/l | 1.40 | 1.45 | 1.45 | 1.50 |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.07 | 5.30 |
| Chloride, dis, mg/l | --- | --- | --- | --- |
| Alkalinity, dis, mg/l as CaCO3 | 25.40 | 28.80 | 28.62 | 31.00 |
| Iron, dis, ug/l | 87.00 | 177.50 | 175.40 | 287.00 |
| Manganese, dis, ug/l | --- | --- | --- | --- |
| Potassium, dis, mg/l | 0.78 | 0.86 | 0.85 | 0.90 |
| Sodium, dis, mg/l | 2.40 | 2.40 | 2.45 | 2.60 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | --- | --- | --- | --- |
| Lead, dis, ug/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Silver, dis, ug/l | 0.25 | 0.25 | 0.25 | 0.25 |
| Iron, TR, ug/l | 146.00 | 168.00 | 166.33 | 185.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Hypolimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | --- | --- | --- | --- |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 1.50 | 11.00 | 31.46 | 197.00 |
| Nitrate + Nitrite, dis, ug/l as N | 22.00 | 79.50 | 97.14 | 309.00 |
| Nitrate, dis, ug/l | 30.00 | 100.00 | 131.54 | 200.00 |
| TKN, ug/l as N | 50.00 | 210.00 | 220.00 | 530.00 |
| TP, ug/l as P | 1.50 | 11.00 | 16.26 | 83.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 5.00 | 5.78 | 20.00 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 0.90 | 2.90 | 2.56 | 3.50 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | 7.30 | 7.90 | 8.01 | 9.00 |
| Magnesium, dis, mg/l | 1.40 | 1.50 | 1.46 | 1.50 |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.08 | 5.40 |
| Chloride, dis, mg/l | --- | --- | --- | --- |
| Alkalinity, dis, mg/l as CaCO3 | 24.60 | 27.80 | 27.85 | 31.00 |
| Iron, dis, ug/l | 20.00 | 60.00 | 117.67 | 270.00 |
| Manganese, dis, ug/l | 5.00 | 5.00 | 31.43 | 140.00 |
| Potassium, dis, mg/l | 0.79 | 0.84 | 0.84 | 0.87 |
| Sodium, dis, mg/l | 2.40 | 2.40 | 2.47 | 2.70 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | --- | --- | --- | --- |
| Lead, dis, ug/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Silver, dis, ug/l | 0.25 | 0.25 | 0.25 | 0.25 |
| Iron, TR, ug/l | 141.00 | 175.00 | 184.67 | 238.00 |
| Zinc, dis, ug/l | 2.50 | 2.50 | 2.50 | 2.50 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Hypolimnion Composite Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | --- | --- | --- | --- |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 5.00 | 10.00 | 16.54 | 48.00 |
| Nitrate + Nitrite, dis, ug/l as N | --- | --- | --- | --- |
| Nitrate, dis, ug/l | 30.00 | 100.00 | 127.69 | 400.00 |
| TKN, ug/l as N | 40.00 | 200.00 | 197.50 | 400.00 |
| TP, ug/l as P | 5.00 | 10.00 | 12.69 | 20.00 |
| Orthophosphate, dis, ug/l as P | 2.00 | 7.00 | 5.58 | 9.00 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 2.60 | 3.26 | 3.13 | 3.54 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | 7.70 | 8.00 | 8.07 | 8.40 |
| Magnesium, dis, mg/l | 1.40 | 1.50 | 1.47 | 1.50 |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.08 | 5.30 |
| Chloride, dis, mg/l | --- | --- | --- | --- |
| Alkalinity, dis, mg/l as CaCO3 | 24.10 | 27.40 | 27.79 | 30.80 |
| Iron, dis, ug/l | 132.00 | 197.50 | 194.10 | 235.00 |
| Manganese, dis, ug/l | --- | --- | --- | --- |
| Potassium, dis, mg/l | 0.78 | 0.83 | 0.84 | 0.93 |
| Sodium, dis, mg/l | 2.40 | 2.40 | 2.47 | 2.70 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | --- | --- | --- | --- |
| Lead, dis, ug/l | 0.50 | 0.50 | 0.50 | 0.50 |
| Silver, dis, ug/l | 0.25 | 0.25 | 0.25 | 0.25 |
| Iron, TR, ug/l | 143.00 | 177.00 | 165.67 | 177.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

# Table 23: Summary of Key Water-Quality Parameters for Horsetooth Reservoir Spring Canyon Dam (see Table 5 for Data Sources)

***Epilimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | 1.06 | 2.45 | 2.55 | 4.40 |
| Chlorophyll a, ug/l | 0.30 | 3.10 | 3.52 | 15.80 |
| DO, mg/l | 7.20 | 7.50 | 8.20 | 11.40 |
| Conductivity, uS/cm | 47.00 | 71.00 | 73.89 | 95.00 |
| pH, field | 7.20 | 7.80 | 7.72 | 8.20 |
| Temperature, deg C | 6.30 | 19.60 | 16.27 | 22.90 |
| Ammonia, dis, ug/l as N | 2.00 | 10.00 | 26.43 | 231.00 |
| Nitrate + Nitrite, dis, ug/l as N | 1.50 | 16.00 | 44.70 | 260.00 |
| Nitrate, dis, ug/l | 20.00 | 50.00 | 55.38 | 200.00 |
| TKN, ug/l as N | 100.00 | 230.00 | 226.50 | 450.00 |
| TP, ug/l as P | 1.50 | 10.00 | 10.29 | 20.00 |
| Orthophosphate, dis, ug/l as P | 0.00 | 2.50 | 2.14 | 14.00 |
| Silica, dis, mg/l | 0.57 | 1.52 | 2.00 | 4.39 |
| TOC, mg/l | 1.30 | 3.20 | 2.98 | 3.90 |
| DOC, mg/l | 3.00 | 3.25 | 3.25 | 3.50 |
| Calcium, dis, mg/l | 8.06 | 8.61 | 8.59 | 9.09 |
| Magnesium, dis, mg/l | 1.38 | 1.40 | 1.42 | 1.48 |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.17 | 5.40 |
| Chloride, dis, mg/l | 1.18 | 1.25 | 1.38 | 1.85 |
| Alkalinity, dis, mg/l as CaCO3 | 25.00 | 29.40 | 29.07 | 32.40 |
| Iron, dis, ug/l | 7.00 | 138.00 | 144.07 | 439.00 |
| Manganese, dis, ug/l | 0.20 | 0.60 | 1.46 | 5.40 |
| Potassium, dis, mg/l | 0.70 | 0.82 | 0.81 | 0.93 |
| Sodium, dis, mg/l | 2.37 | 2.43 | 2.53 | 2.89 |
| TSS, mg/l | 1.00 | 2.35 | 2.99 | 6.42 |
| Copper, dis, ug/l | 2.70 | 3.20 | 3.38 | 4.40 |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.02 | 0.02 |
| Lead, dis, ug/l | 0.04 | 0.04 | 0.09 | 0.25 |
| Silver, dis, ug/l | 0.10 | 0.10 | 0.10 | 0.10 |
| Iron, TR, ug/l | 159.00 | 208.00 | 192.33 | 210.00 |
| Zinc, dis, ug/l | 0.30 | 1.00 | 2.90 | 9.60 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Epilimnion Composite Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| Secchi Disk Depth, m | --- | --- | --- | --- |
| Chlorophyll a, ug/l | 1.30 | 3.60 | 3.95 | 7.20 |
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | --- | --- | --- | --- |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 5.00 | 10.00 | 15.25 | 34.00 |
| Nitrate + Nitrite, dis, ug/l as N | --- | --- | --- | --- |
| Nitrate, dis, ug/l | 30.00 | 50.00 | 54.62 | 100.00 |
| TKN, ug/l as N | 120.00 | 220.00 | 224.17 | 300.00 |
| TP, ug/l as P | 5.00 | 10.00 | 10.38 | 20.00 |
| Orthophosphate, dis, ug/l as P | 0.00 | 2.50 | 2.50 | 5.00 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 2.83 | 3.48 | 3.31 | 3.72 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | --- | --- | --- | --- |
| Magnesium, dis, mg/l | --- | --- | --- | --- |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.01 | 5.30 |
| Chloride, dis, mg/l | --- | --- | --- | --- |
| Alkalinity, dis, mg/l as CaCO3 | 25.60 | 27.40 | 27.62 | 31.20 |
| Iron, dis, ug/l | 90.00 | 167.00 | 171.40 | 267.00 |
| Manganese, dis, ug/l | --- | --- | --- | --- |
| Potassium, dis, mg/l | --- | --- | --- | --- |
| Sodium, dis, mg/l | --- | --- | --- | --- |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | --- | --- | --- | --- |
| Lead, dis, ug/l | --- | --- | --- | --- |
| Silver, dis, ug/l | --- | --- | --- | --- |
| Iron, TR, ug/l | 142.00 | 182.00 | 170.67 | 188.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Hypolimnion Grab Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | 0.10 | 5.00 | 5.21 | 10.90 |
| Conductivity, uS/cm | 42.00 | 71.00 | 73.11 | 95.00 |
| pH, field | 6.80 | 7.05 | 7.21 | 7.90 |
| Temperature, deg C | 4.20 | 7.60 | 6.94 | 7.80 |
| Ammonia, dis, ug/l as N | 2.00 | 11.00 | 42.30 | 240.00 |
| Nitrate + Nitrite, dis, ug/l as N | 25.00 | 160.00 | 153.57 | 444.00 |
| Nitrate, dis, ug/l | 40.00 | 200.00 | 136.15 | 200.00 |
| TKN, ug/l as N | 50.00 | 220.00 | 235.35 | 470.00 |
| TP, ug/l as P | 4.00 | 24.00 | 26.64 | 74.00 |
| Orthophosphate, dis, ug/l as P | 0.50 | 9.00 | 12.22 | 51.00 |
| Silica, dis, mg/l | 3.13 | 4.56 | 4.28 | 4.89 |
| TOC, mg/l | 1.20 | 2.90 | 2.68 | 3.80 |
| DOC, mg/l | 2.80 | 2.95 | 2.95 | 3.10 |
| Calcium, dis, mg/l | 7.75 | 9.27 | 9.22 | 10.60 |
| Magnesium, dis, mg/l | 1.33 | 1.50 | 1.52 | 1.73 |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.20 | 5.40 |
| Chloride, dis, mg/l | 1.14 | 1.33 | 1.33 | 1.51 |
| Alkalinity, dis, mg/l as CaCO3 | 24.00 | 28.10 | 29.03 | 36.00 |
| Iron, dis, ug/l | 8.00 | 40.00 | 95.28 | 295.00 |
| Manganese, dis, ug/l | 0.70 | 20.00 | 172.25 | 1380.00 |
| Potassium, dis, mg/l | 0.70 | 0.80 | 0.82 | 0.96 |
| Sodium, dis, mg/l | 2.38 | 2.49 | 2.51 | 2.67 |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | 3.10 | 3.70 | 3.75 | 4.50 |
| Cadmium, dis, ug/l | 0.02 | 0.02 | 0.02 | 0.03 |
| Lead, dis, ug/l | 0.04 | 0.05 | 0.07 | 0.13 |
| Silver, dis, ug/l | 0.10 | 0.10 | 0.10 | 0.10 |
| Iron, TR, ug/l | 194.00 | 212.00 | 225.33 | 270.00 |
| Zinc, dis, ug/l | 0.50 | 2.20 | 2.04 | 4.60 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Hypolimnion Composite Samples***

| Parameter | Min | Med | Mean | Max |
|---|---|---|---|---|
| DO, mg/l | --- | --- | --- | --- |
| Conductivity, uS/cm | --- | --- | --- | --- |
| pH, field | --- | --- | --- | --- |
| Temperature, deg C | --- | --- | --- | --- |
| Ammonia, dis, ug/l as N | 10.00 | 10.00 | 22.39 | 61.00 |
| Nitrate + Nitrite, dis, ug/l as N | --- | --- | --- | --- |
| Nitrate, dis, ug/l | 30.00 | 100.00 | 127.69 | 200.00 |
| TKN, ug/l as N | 50.00 | 200.00 | 206.67 | 400.00 |
| TP, ug/l as P | 10.00 | 20.00 | 16.15 | 30.00 |
| Orthophosphate, dis, ug/l as P | 2.50 | 9.00 | 8.54 | 15.00 |
| Silica, dis, mg/l | --- | --- | --- | --- |
| TOC, mg/l | 2.65 | 3.30 | 3.16 | 3.60 |
| DOC, mg/l | --- | --- | --- | --- |
| Calcium, dis, mg/l | --- | --- | --- | --- |
| Magnesium, dis, mg/l | --- | --- | --- | --- |
| Sulfate, dis, mg/l | 2.50 | 2.50 | 3.08 | 5.40 |
| Chloride, dis, mg/l | --- | --- | --- | --- |
| Alkalinity, dis, mg/l as CaCO3 | 24.60 | 27.60 | 27.80 | 30.80 |
| Iron, dis, ug/l | 139.00 | 195.00 | 199.40 | 249.00 |
| Manganese, dis, ug/l | --- | --- | --- | --- |
| Potassium, dis, mg/l | --- | --- | --- | --- |
| Sodium, dis, mg/l | --- | --- | --- | --- |
| TSS, mg/l | --- | --- | --- | --- |
| Copper, dis, ug/l | --- | --- | --- | --- |
| Cadmium, dis, ug/l | --- | --- | --- | --- |
| Lead, dis, ug/l | --- | --- | --- | --- |
| Silver, dis, ug/l | --- | --- | --- | --- |
| Iron, TR, ug/l | 173.00 | 191.00 | 187.00 | 197.00 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*
*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

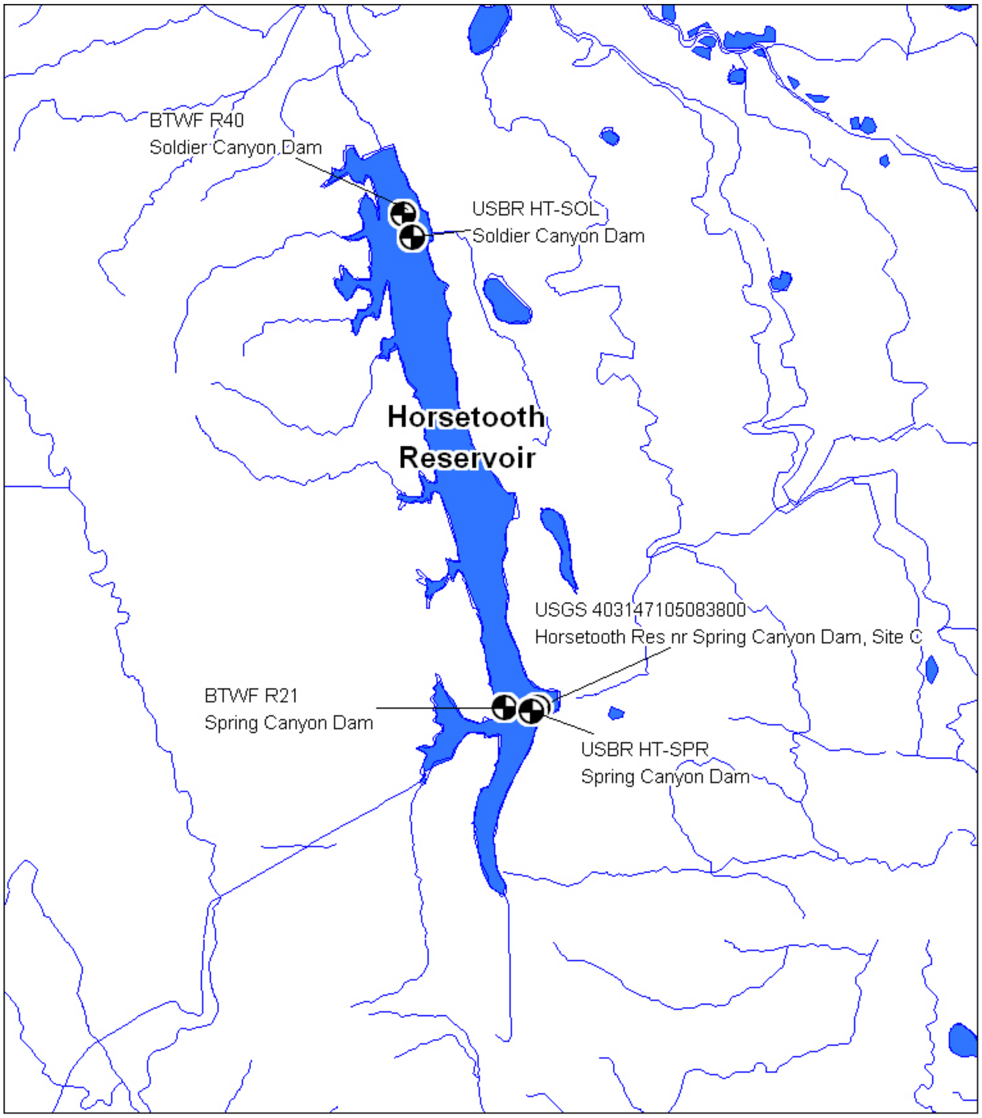


**Figure 24: Water-Quality Sampling Sites for Horsetooth Reservoir**

*Major Ions and Trace Elements*

The median concentrations of major ions (calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate [as indicated by alkalinity]) are typical of non-polluted watersheds. Together, they make up most of the total dissolved solids concentration (TDS), which is closely approximated by specific conductance. Specific conductance is a measure of the ability of water to conduct an electrical current. Total dissolved solids concentrations in mg/l are typically between 55% and 75% of the specific conductance in μS/cm (Hem, 1985). Because the concentrations of these ions are relatively uninfluenced by biological activities within the reservoir (Jassby and Goldman, 1999), they can serve as a signature for source waters.

Trace metals occur in natural and industrial water. They can also be present as a result of management alternatives such as the use of copper as an algicide. Copper is of concern for aquatic life and the standard is hardness dependent. Although there are not sufficient data to evaluate whether or not copper standards are being met for Horsetooth Reservoir (Table 24), the data that do exist indicate an exceedance of the acute standard on one day at Spring Canyon.

Elevated dissolved iron and dissolved manganese concentrations can be a problem for water providers. Dissolved iron and dissolved manganese concentrations listed in Table 22 and Table 23 show higher values in the hypolimnion versus the epilimnion. This is common in lakes and reservoirs which experience low dissolved oxygen concentrations in the hypolimnion.

*Algae and Trophic State*

A time series of chlorophyll *a* data at the Soldier Canyon monitoring site is displayed in Figure 25. Since 2004, peak chlorophyll *a* concentrations have been as high as 6.8 µg/l. There is not a clear seasonal pattern for chlorophyll *a,* although most often the highest concentrations occur during the summer months. Average chlorophyll *a* concentrations (2004-2006) are indicative of a mesotrophic trophic state (Table 4).

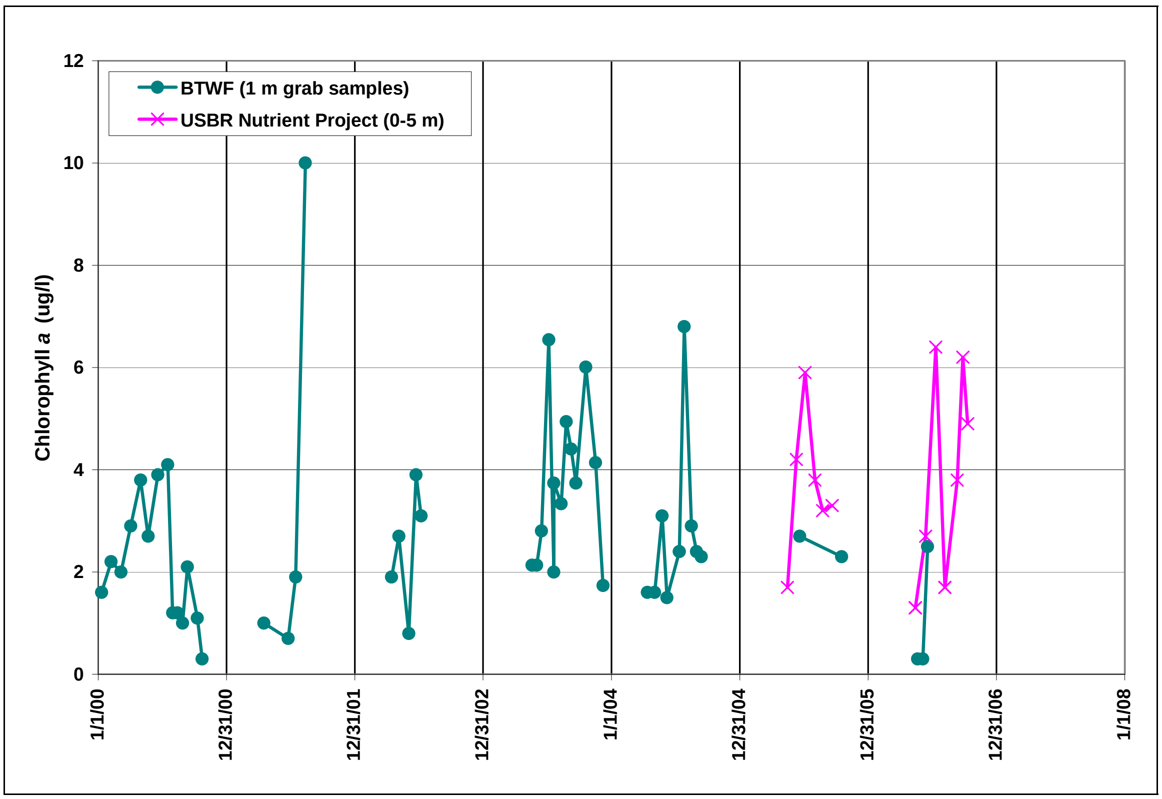


**Figure 25: Chlorophyll a, Concentrations in Horsetooth Reservoir (Site: Soldier Canyon Dam) (Data Sources: USGS, 2007; NCWCD, 2007b)**

*Nutrients*

Phosphorus and nitrogen are considered major nutrients. Over 70% of the orthophosphate concentrations (the form available to algae) are below the detection limit. Inorganic nitrogen concentrations (ammonia, nitrate, and nitrite -- the forms bioavailable for phytoplankton growth) are low and typical of an oligotrophic system (Wetzel, 2001). Organic carbon concentrations are in the range of what one would expect given the setting and chlorophyll *a* concentrations.

Lake analyses often include an investigation to determine which nutrient is limiting the growth of algae. Increases in the limiting nutrient often cause increases in algal growth. Increases of the non-limiting nutrient will not cause increases in algal growth because its concentration is already in excess (there is more available that the algae can take up, given the concentration of the limiting nutrient). Due to the high nutrient detection limits, it is difficult to draw conclusions on the limiting nutrient. Jassby and Goldman (1999) concluded that the reservoir was co-limited by nitrogen and phosphorus.

*Water Clarity*

Figure 26 shows Secchi-disk depth at Soldier Canyon Dam since 1999. Since 2004, the mean Secchi-disk depth is 2.9 meters and the range is 1.5 to 4.8 meters.

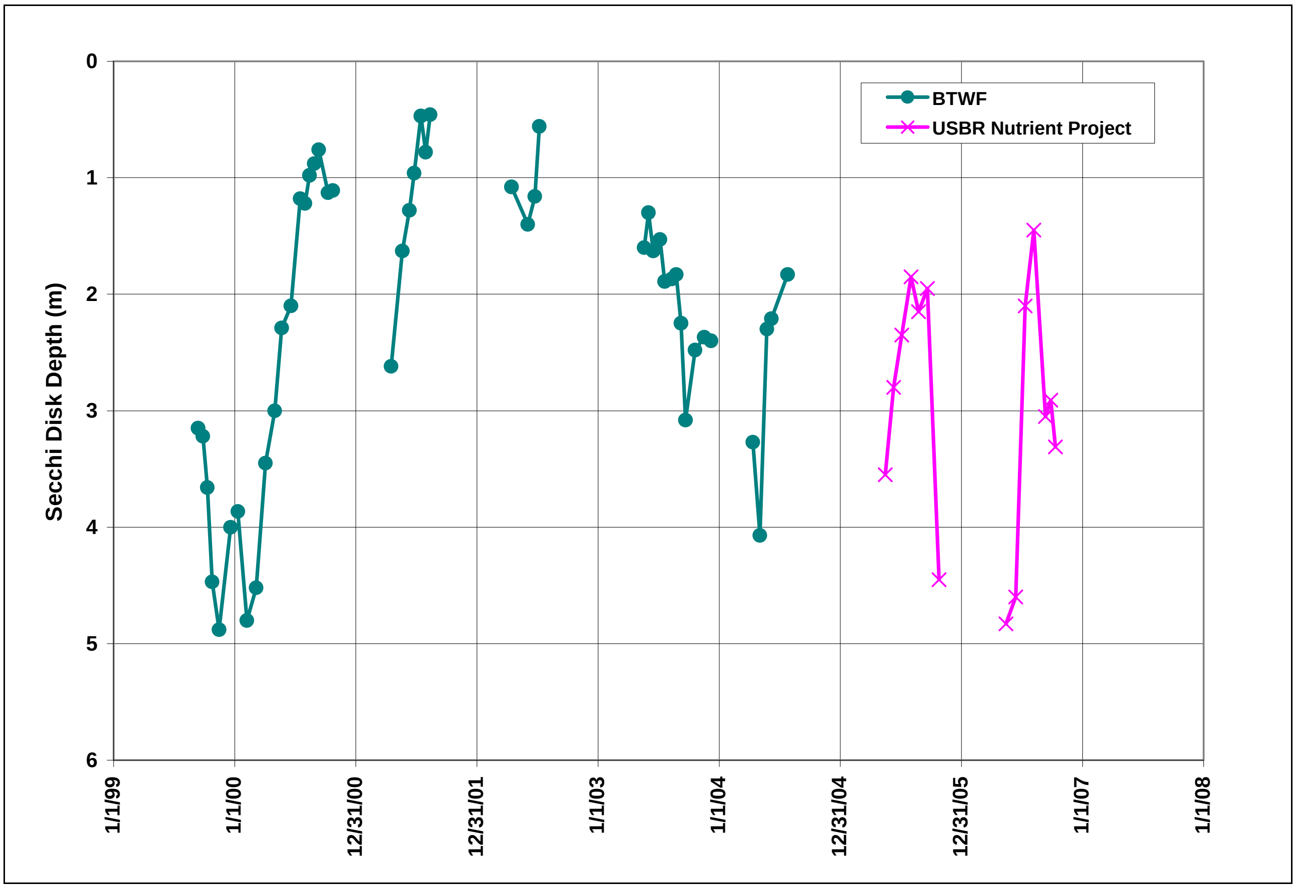


**Figure 26: Secchi-Disk Depth in Horsetooth Reservoir (Site: Soldier Canyon Dam) (Data Sources: USGS, 2007; NCWCD, 2007b)**

*Dissolved Oxygen*

Recent dissolved oxygen profile data are displayed in Figure 27. Note the low concentrations at about 10 meters deep during the summer months, similar to Granby Reservoir. This is called a negative heterograde curve and is less frequently observed than positive heterograde curves, which are found in Carter Lake and the surface of Grand Lake. Possible causes for this drop in dissolved oxygen at the metalimnion include 1) decomposition of oxidizable material in the metalimnion, 2) significant concentrations of zooplankton in the metalimnion which respire and drop the DO concentration, and 3) reservoir morphometry or the shape of the reservoir basin (Wetzel, 2001). Lieberman (2007b) identified the possibility of an interflow into the reservoir at the elevation of the metalimnion from the Hansen Feeder Canal, based on specific conductance profiles. It is possible that an interflow from this source results in an increased loading of organic material, causing a reduction in dissolved oxygen concentrations in the metalimnion.

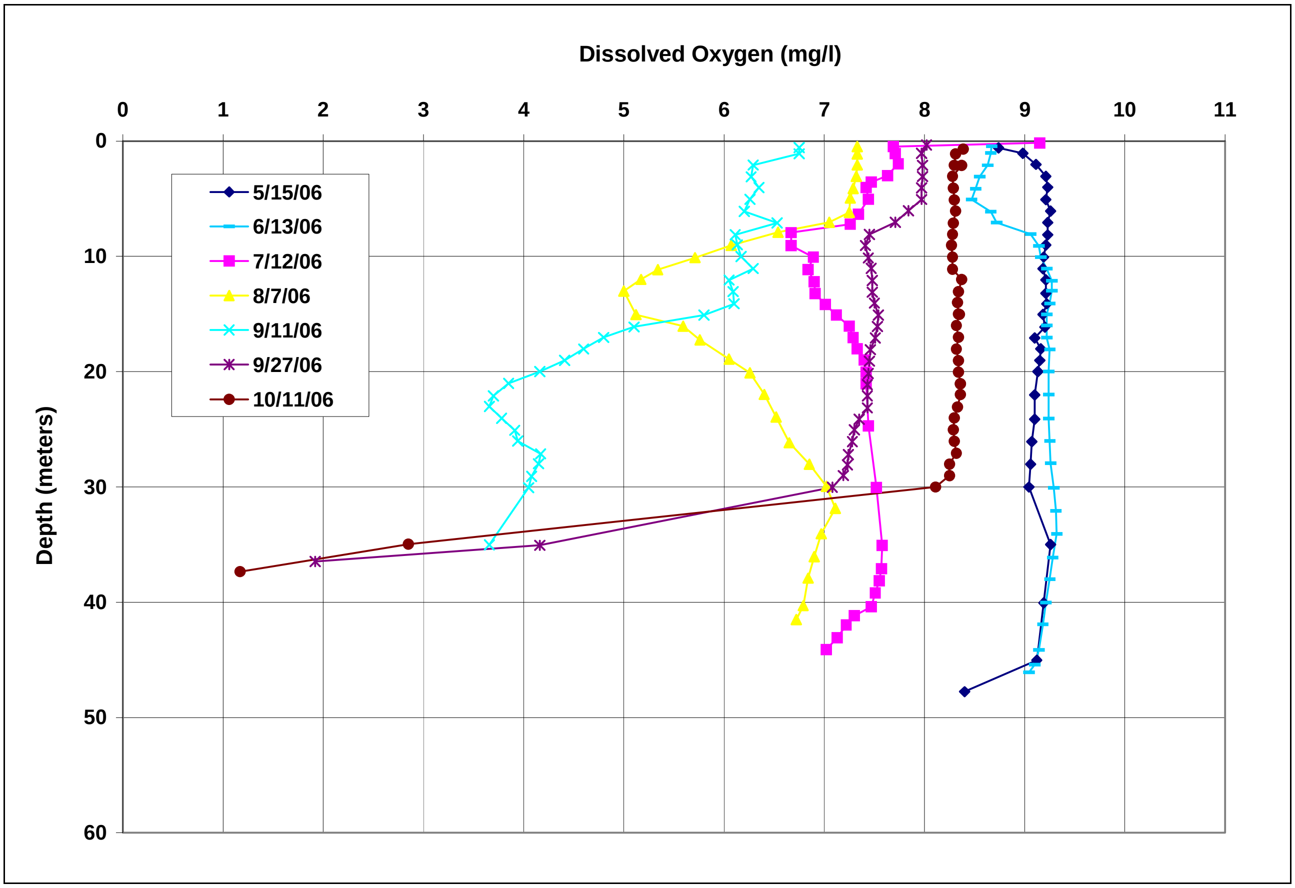


**Figure 27: Dissolved Oxygen Profiles for Horsetooth Reservoir in 2006 (Site: Soldier Canyon Dam) (Data Sources: USGS, 2007: NCWCD, 2007b)**

### *Water-Quality Standards*

Comparisons between the data and key applicable water-quality standards were made for Horsetooth Reservoir at the Soldier Canyon site using data for the period 2004 - 2006. The results are shown in Table 24. From this analysis, all of the listed standards are met, with the exception of temperature in the summer and dissolved manganese for water supply. The temperature standard is exceeded using either the interim standard or the anticipated December 2008 standard. Horsetooth Reservoir is currently on the 2006 303(d) List for dissolved oxygen.

# Table 24: Comparison between Key Applicable Water-Quality Standards and Existing Condition, Horsetooth Reservoir (Site: Soldier Canyon Dam)

| Use Classification | Parameter Category | Parameter | Unit | Applicable Standard | In-Lake Value | Standard Met? |
|---|---|---|---|---|---|---|
| Aquatic Life | Physical | Dissolved Oxygen (elsp) | mg/l | 6.0 | 5.5 (28) | No |
| | | pH (epilimnion) | SU | 6.5 - 9.0 | 7.0 - 8.1 | Yes |
| | | pH (hypoliminon) | SU | 6.5 - 9.0 | 6.7 - 7.6 | Yes |
| | | Temperature (effective December 31, 2009) | °C | 9 (ch winter) | no data | |
| | | | | 13 (ac winter) | no data | |
| | | | | 18.2 (ch summer) | 21.4 - 22.8 | No |
| | | | | 23.8 (ac summer) | 22.3 - 23.7 | Yes |
| | | Temperature (interim) | °C | 20.0 (ch) | 21.4 - 22.8 | No |
| | Inorganic | Ammonia | mg/l a N | ch (varies) | not enough data | |
| | | | | ac (varies) | not enough data | |
| | Metals | Cadmium, dis | µg/l | ch (varies) | no data | |
| | | | | ac (tr) (varies) | no data | |
| | | Copper, dis | µg/l | ch (varies) | no data | |
| | | | | ac (varies) | no data | |
| | | Iron, Trec | µg/l | 1000 (ch) | not enough data | |
| | | Lead, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| | | Manganese, dis | µg/l | ch (varies) | no data | |
| | | | | ac (varies) | no data | |
| | | Silver, dis | µg/l | ch (varies) | not enough data | |
| | | | | ac (varies) | varies | Yes |
| Water Supply | Physical | Dissolved Oxygen | mg/l | 3.0 | 5.5 (28) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.0 - 8.1 | Yes |
| | Inorganic | Nitrate | mg/l | 10 (1-day) | max = 0.3 (28) | Yes |
| | Metals | Cadmium, dis | µg/l | 5.0 (1-day) | no data | |
| | | Iron, dis | µg/l | 300 (30-day) | 20 - 237.5 | Yes |
| | | Lead, Trec | µg/l | 50 (1-day) | no data | |
| | | Manganese, dis | µg/l | 50 (30-day) | 0 - 140 | No |
| | | Silver, Trec | µg/l | 100 (1-day) | no data | |
| Recreation | Physical | Dissolved Oxygen | mg/l | 3.0 | 5.5 (28) | Yes |
| | | pH | SU | 6.5 - 9.0 | 7.0 - 8.1 | Yes |
| Agriculture | Physical | Dissolved Oxygen | mg/l | 3.0 | 5.5 (28) | Yes |
| | Inorganic | Nitrate | mg/l as N | 100 | max = 0.3 (28) | Yes |
| | Metals | Cadmium, Trec | µg/l | 10 (30-day) | no data | |
| | | Lead, Trec | µg/l | 100 (30-day) | no data | |
| | | Manganese, Trec | µg/l | 200 (30-day) | no data | |

- Available water quality data for past five years (9/02 on) was evaluated against standards applicable to the reservoir according to Colorado water quality regulations.
- Values in parenthesis in "In-Lake Value" column are the number of samples or daily average values evaluated for the param
- D.O. "In-Lake Values" are 15th percentile of daily average epilimnion and metalimnion profile results (elsp = early life stage present). In addition, per the WQCD, if all measurements in the epiliminion and metalimnion on any one day were below the standard the reservoir was found to be out of attainment.
- pH range is 15th percentile - 85th percentile value of daily average profile sample results.
- "Large Lake" temperature criteria applied. Temperature "In-Lake Values" are for epilimnion layer min - max of MWAT (ch) (lake equivalent of maximum weekly average temperature) and DM (ac) (daily maximum).
- In 2007 new temperature standards were adopted as defined in Colorado's Regulation No. 31 (5 CCR 1002-31). Interim standards were established to be applicable until the next Triennial Review process for each basin, at which point it is anticipated the new temperature standards will be adopted.
- Nitrate "In-Lake Value" is the maximum of all discrete Nitrate + Nitrite results.
- Water Supply "In-Lake Value" is min - max range of 30-day averages of hypolimnion samples (did not have enough data points to evaluate epilimnion layer).
- For acute computations, evaluated all data. For all other computations, evaluated only if at least 12 data points (per WQCD guidelines)
- 'no data' includes instances where there are no hardness data available to evaluate the standard

### 8.2.6. Ralph Price Reservoir

Ralph Price Reservoir (also known as Button Rock Reservoir) is located within the Button Rock Preserve and is the primary water supply for the City of Longmont. Limited fishing is allowed at the reservoir and access to the preserve and reservoir is walk-in only. The reservoir has the following use classifications which are used by the CDPHE to set appropriate water-quality standards:

- Aquatic Life Cold 1;
- Recreation 1a;
- Water Supply; and
- Agriculture.

These classifications are defined in Table 6.

Ralph Price Reservoir stores water from North St. Vrain Creek, which emanates from the Wild Basin Area of Rocky Mountain National Park. The watershed upstream of the reservoir is predominantly wilderness.

Ralph Price Reservoir's physical characteristics and hydrology are described in Table 25. The reservoir is operated such that it is full from June until October. The surface water elevation then drops to about 75% capacity in March. The reservoir is refilled during spring runoff. The estimated residence time is based on reservoir contents and annual flow.

**Table 25: Physical Characteristics and Hydrology of Ralph Price Reservoir**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume* | 16,197 AF | $20.0 \times 10^6$ $m^3$ |
| Surface Area* | 227 acres | 91.9 hectares |
| Mean Depth | 71.3 ft | 21.7 m |
| Average Annual Outflow* | 48,600 AF/year | $60 \times 10^6$ $m^3$/year |
| Hydraulic Residence Time | 1.1 years | |

(Data Source: Boyle, 2006)

No water quality data are available to describe in-lake conditions, although some water-quality data were collected downstream of Ralph Price Reservoir (below Longmont Dam) in the 1970s (USGS, 2006). These data indicate relatively pristine conditions, which are expected given the nature of the upstream watershed. Ralph Price is not impaired nor is it a concern from a water quality standpoint. A summary of findings for Ralph Price Reservoir are displayed in Table 26.

**Table 26: Summary of Water-Quality Findings for Ralph Price Reservoir**

| Reservoir | Standards Met? | Impairments* | Other Concerns |
|---|---|---|---|
| Ralph Price Reservoir | No Data | None | None |

*Actual or Suspected as noted from the 303(d) List and M&E List

## 9.0 SUMMARY OF REGULATORY WATER-QUALITY ISSUES

Regulatory water-quality concerns for all of the lakes and reservoirs described above are summarized in Table 27.

**Table 27: 303(d) List and M&E List Status by Reservoir**

| Reservoir | Segment | On 2008 303(d) List? | On 2008 M&E List? | Met Standards (using data from this analysis)? |
|---|---|---|---|---|
| Granby Reservoir | Upper Colorado River Sediment 2 COUCUC02 | No | No | No [Dissolved Oxygen, Temperature*, Dissolved Manganese] |
| Shadow Mountain Reservoir | Upper Colorado River Segment 2 COUCUC02 | No | Yes for Dissolved Oxygen | No [Dissolved Manganese] |
| Grand Lake | Upper Colorado River Segment 2 COUCUC02 | No | No | No [pH, Dissolved Manganese] |
| Carter Lake Reservoir | COSPBT11 | No | No | No [Temperature**] |
| Horsetooth Reservoir | COSPCP14 | Yes for Dissolved Oxygen | No | No [Temperature**,, Dissolved Manganese] |
| Ralph Price Reservoir | COSPSV02 | No | No | - |

- *- according to the anticipated December 2008 standard
- ** - according to both the anticipated December 2009 standard and the current interim standard

# 10.0 METHODS USED FOR THE IMPACT ANALYSIS

The direct and indirect effects to lake and reservoir water quality were evaluated for each of the alternatives. The impact assessment is based on the probable changes to water quality that would result from implementation of the alternatives. These changes are identified through reservoir modeling and data analysis. The impact assessment also identifies any possible conflicts between the alternatives and federal, state, and local water-quality regulations for the study area. The cumulative effects assessment evaluated the potential water-quality impacts of the project alternatives in relation to reasonably foreseeable activities within the study area. The modeling techniques used to determine the direct and indirect effects to the potentially affected lakes and reservoirs are described in this section.

## 10.1. Three Lakes Water Quality

The method used for the prediction of water-quality for Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir is based on the Three Lakes Water-Quality Model (Hydrosphere, 2003a). The original model was significantly enhanced and updated for this effort and is documented in a separate report (AMEC, 2008). The model was used to evaluate both direct effects and cumulative effects. An overview is provided below.

The Three Lakes Water-Quality Model is a dynamic, process-based model. It is dynamic in that it simulates results over time (versus a steady-state condition). It is process-based in that the impacts of inflows, outflows, settling, and constituent transformations are described using differential equations based on an understanding of the processes which occur in lakes and reservoirs. Since the model is process-based, versus empirically-based, it can be used to predict water-quality conditions under a variety of situations that are different from what has happened historically. The Three Lakes Model has been developed to simulate flow and water-quality of Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir in an integrated fashion. This is important due to the interdependencies between the three water bodies due to C-BT operations.

The Three Lakes Model characterizes Grand Lake and Granby Reservoir as three-layer lakes. Thus, both have an epilimnion, a metalimnion, and a hypolimnion during the stratified period and the water quality of each layer is assumed to be uniform throughout the layer. The model mixes the three layers during other portions of the year. Epilimnion and metalimnion layer thicknesses are listed in Table 28. These values were determined based on water-quality data collected by USBR during 2005 and 2006 (NCWCD, 2007b). The thickness of Granby Reservoir's hypolimnion varies over time as the total contents changes. Note that since the surface water elevation of Grand Lake is fixed at 8,366.5 feet through each simulation, the thickness of the hypolimnion is also unchanging.

**Table 28: Reservoir Layer Thicknesses Used in the Three Lakes Water-Quality Model**

| | Granby Reservoir | Grand Lake |
|---|---|---|
| Epilimnion | 7 m | 4.6 m |
| Metalimnion | 10 m | 25.9 m |

Although Grand Lake and Granby Reservoir are deep and strongly stratify in the summer, Shadow Mountain Reservoir is shallow and does not strongly stratify due to a high level of mixing (from wind and flow). Thus, Shadow Mountain Reservoir is characterized as a single, well-mixed layer in the model.

The Three Lakes Model considers tributaries flowing into the system, water pumped into the system, miscellaneous gains, precipitation, releases and losses (groundwater and evaporation) from the system, and interflows between the three water bodies. The inflows and outflows into and out of the Three Lakes System are listed in Table 29. Note that this list does not include the inter-reservoir flows between the three reservoirs.

**Table 29: Inflows into and Outflows from the Three Lakes System for the Three Lakes Water-Quality Model**

| | Granby Reservoir | Shadow Mountain Reservoir | Grand Lake |
|---|---|---|---|
| **Inflows** | Arapaho Creek<br>Stillwater Creek<br>Roaring Fork<br>Columbine Creek<br>Windy Gap Pump Canal<br>Willow Crk Pump Canal<br>Precipitation<br>Miscellaneous Gains | N. Fork of the Colorado River<br>Precipitation<br>Miscellaneous Gains | N. Inlet<br>E. Inlet<br>Precipitation<br>Miscellaneous Gains |
| **Outflows** | Releases to the CO River<br>Evaporation<br>Miscellaneous Losses | Evaporation<br>Miscellaneous Losses | Outflows to the Adams Tunnel Evaporations<br>Miscellaneous Losses |

The flows listed in Table 29, along with flows through the Farr pumping plant are model variables, entered as input on a daily basis. Model input also includes the lake layer in which an inflow is entering into or an outflow is releasing from. The hydrologic portion of the model then performs a mass balance for each reservoir and each layer on a daily basis, accounting for the quantity and direction of flow. The model uses the elevation-area-capacity relationship for Granby Reservoir layer contents. Thus, although the epilimnion thickness is fixed, the contents of the epilimnion change over time as the surface water elevation varies. The contents of each reservoir and layer are computed on a daily basis. Model segmentation, inflows, and outflows are displayed in Figure 28.

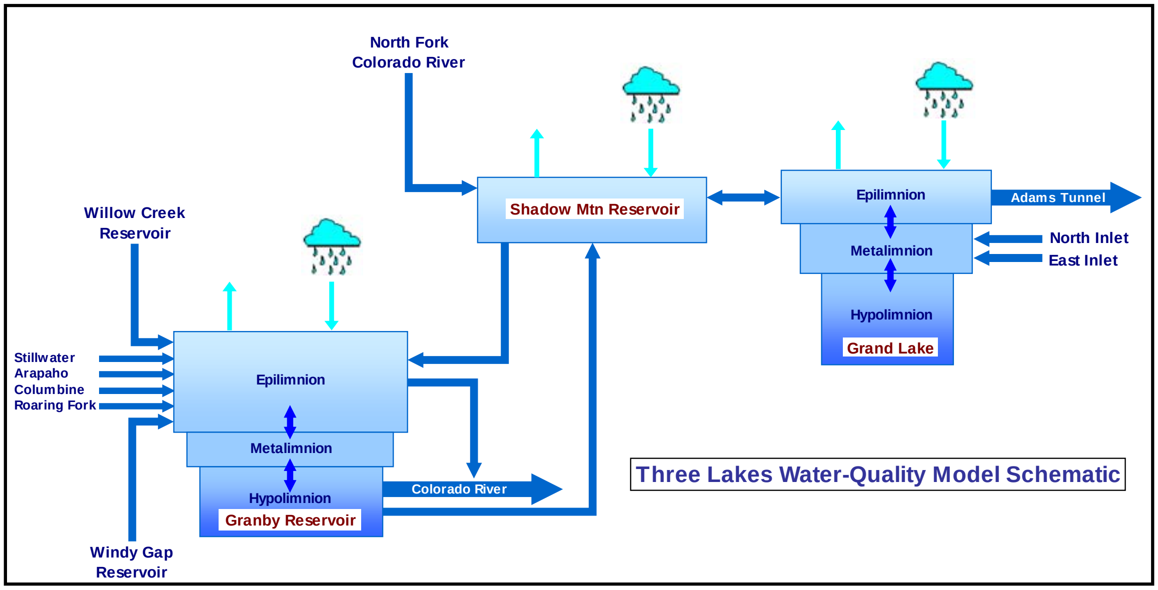


**Figure 28: Three Lakes Water-Quality Model Schematic Showing Model Segmentation, Inflows, and Outflows**

The Three Lakes Water-Quality Model simulates the water quality of each layer over time on a daily basis. Constituents simulated are listed in Table 30. The bulk of the algorithms used in the model are described in Chapra, 1997. The details of the algorithms used can be found in AMEC, 2008. Flow and water-quality results are computed on a daily basis.

**Table 30: Constituents Simulated in the Three Lakes Water-Quality Model**

| Constituent |
|---|
| Orthophosphate |
| Organic Phosphorus |
| Total Phosphorus |
| Ammonia |
| Nitrate |
| Organic Nitrogen |
| Total Nitrogen |
| Total Organic Carbon |
| Chlorophyll a |
| Secchi-Disk Depth |
| Dissolved Oxygen |
| Total Suspended Solids |

The assumptions and limitations of the Three Lakes Water-Quality Model include:

1. The model assumes that Granby Reservoir and Grand Lake can be represented by three homogeneous layers and that Shadow Mountain Reservoir can be represented by one homogeneous layer. Thus, it is assumed that there is little variation longitudinally and laterally and vertical and lateral variations in water-quality constituents within a layer cannot be predicted. In addition, all inflows of water and associated water-quality constituents entering a layer are instantaneously dispersed throughout that layer.
2. The model assumes that the physical, chemical, and biological dynamics in a lake or reservoir can be described using the principle of conservation of mass. The model considers 1) mass added by inflows, 2) mass removed via outflows, 3) the diffusion of mass, and 4) changes in concentrations due to processes such as settling, transformations due to reactions, growth, respiration, grazing, etc.
3. The model assumes that complex chemical and biological processes can be represented by equations incorporating simplified kinetic formulations.
4. The model simulates based on average daily conditions. Thus, changes that occur within a day (e.g. turning a pump on mid-day) can not be captured.

The model was calibrated using measured data from the period of October 1, 2005 to September 30, 2006. This period was chosen to take advantage of the data collected by USBR for the C-BT Nutrient Study. The calibration process involved determining appropriate parameters such as reaction rates and diffusion coefficients for the Three Lakes. Results from the calibration process can be found in AMEC, 2008.

The calibrated model was used to predict future water-quality conditions for each alternative, using anticipated flows (described in ERO and Boyle, 2007) and inflow concentrations for various water quality parameters. Since the water-resources model used for the hydrologic analysis provided monthly flows, these data needed to be disaggregated to daily flows for the water-quality model based on gage data. Gage data were limited during some portions of the 47-year simulation period used in the water resource model (ERO and Boyle, 2007). Thus, a representative shorter simulation period for the water-quality model (being statistically consistent with the 47-year period and coinciding with available gage data making the disaggregation process more accurate) was desirable. An analysis was conducted by Boyle Engineering (Thompson, 2005) which concluded that the 15 years from WY75 through WY89 met the criteria listed above. Thus, the direct effect and cumulative effect alternative model runs were based on hydrology from a 15-year period (WY75-WY89) that is representative of the full 47-year period used in the water resource model.

For the alternative model runs, inflow concentrations for Stillwater Creek, North Inlet, East Inlet, the North Fork of the Colorado River, Arapaho Creek, and the Willow Creek Pipeline were estimated using historical median concentrations for the month under consideration. For the alternatives, concentrations in the Windy Gap Pipeline were based on historical flow and concentration data in the Windy Gap Pipeline, when these data were available. For periods when no data existed, concentrations were estimated based on a mass balance above Windy Gap Reservoir, which considered flows and concentrations from Granby Reservoir, Willow Creek, and the Fraser River. These concentrations are listed in Table 31. The concentrations were subsequently adjusted due to predicted changes in Granby Reservoir release concentrations for each alternative.

For the cumulative effects analysis, concentrations in the Windy Gap Pipeline were estimated based on assumed future conditions in the Fraser River Basin. These changes are described in the Stream Water-Quality Technical Report (ERO and AMEC, 2008). Concentrations for the Roaring Fork and Columbine Creek were assumed to be the same as Arapaho Creek because there were no data available for these tributaries and the three tributaries each have less-developed watersheds.

**Table 31: Estimated Nutrient Concentrations at Windy Gap Reservoir (Existing Conditions)**

| Month | Total Phosphorus (μg/l) | Total Nitrogen (μg/l) |
|---|---|---|
| January | 47 | 362 |
| February | 47 | 365 |
| March | 52 | 380 |
| April | 77 | 710 |
| May | 57 | 448 |
| June | 39 | 253 |
| July | 40 | 178 |
| August | 44 | 226 |
| September | 48 | 358 |
| October | 52 | 366 |
| November | 52 | 384 |
| December | 47 | 364 |

Differences between anticipated manganese concentrations and existing conditions are based on relative hypolimnetic dissolved concentration. Low dissolved oxygen concentrations in the hypolimnion can result in the conversion of manganese in the reservoir sediments to a soluble form.

The Three Lakes Water-Quality Model does not currently predict water temperatures. To estimate anticipated changes in temperature for each alternative, a separate model was used. The approach involved using the LAKE2K model (Chapra and Martin, 2004) to simulate temperature in Granby Reservoir. If there were no discernable differences from the existing conditions model run, then it could be assumed that the alternative would not have a temperature impact on the rest of the lakes in the system. Model calibration and use of the model are described in Appendix C.

## 10.2. Prediction of Water Quality for Horsetooth Reservoir, Carter Lake, Ralph Price Reservoir, and the Proposed Reservoirs

Carter Lake, Horsetooth Reservoir, Ralph Price Reservoir, and the four proposed reservoirs were evaluated using a Corps of Engineers Water-Quality Model called BATHTUB. This model contains several empirical relationships to translate nutrient loading into in-reservoir conditions based on data from Corps of Engineers' reservoirs. A description of the model and how it was used is provided in Appendix B. Results from the Three Lakes Water-Quality Model were used to develop input files for the BATHTUB model runs. Output from BATHTUB includes nutrients, chlorophyll *a*, Secchi-disk depth, hypolimnetic oxygen demand (HOD), metalimnetic oxygen demand (MOD), and trophic state.

The BATHTUB model is limited to steady-state evaluations of relationships between nutrient loading, hydrology, transparency, and eutrophication-related responses. Short-term responses, responses to variables other than nutrients, and effects related to structural modifications cannot be explicitly evaluated (Old Dominion University, 2007).

The alternatives were evaluated by comparing annual predicted in-reservoir changes in 1) trophic state, 2) nutrients, 3) algae (chlorophyll *a*), 4) metalimnetic and hypolimnetic oxygen demand, and 4) clarity (Secchi-disk depth) relative to existing conditions and to the No Action alternative. Thus, incremental changes due to the alternatives were evaluated in this analysis.

The metalimnetic oxygen demand (MOD) and hypolimnetic oxygen demand (HOD) were predicted using empirical relationships. The HOD is a linear function of the chlorophyll *a* concentration in the reservoir and an inverse function of the hypolimnion thickness. Hypolimnetic thickness is entered into the model by the user. Increases in chlorophyll *a* or decreases in the hypolimnion thickness increase the HOD, which is expressed in $mg/m^3$-day. Water quality in the metalimnion is not specifically modeled in BATHTUB, but the oxygen demand in this layer is predicted using an empirical, linear function of the HOD and a constant fraction of the hypolimnion thickness. The predicted MOD is a function of the HOD for a given reservoir alternative, using an empirical relationship. For this application, a 10 meter epilimnion was assumed for Horsetooth Reservoir, Carter Lake, Ralph Price Reservoir, and Chimney Hollow Reservoir. Jasper East Reservoir, Rockwell Creek Reservoir, and Dry Creek Reservoir are more shallow and were assumed to be well-mixed. The hypolimnion depth was computed as the reservoir mean depth less the epilimnion depth.

The BATHTUB model does not provide a direct prediction of dissolved oxygen concentration or quantification of oxygen sources from algae photosynthesis, diffusion and inflows. Therefore, a prediction of dissolved oxygen concentration can not be calculated from the BATHTUB model results for the alternatives. However, the relative magnitudes of HOD and MOD predictions can be compared between existing conditions and the action alternatives to provide insight to an alternatives' relative potential impact on the dissolved oxygen concentration in the metalimnion or hypolimnion. Larger HOD or MOD values as compared to existing conditions indicate a potential for lower dissolved oxygen in the reservoir for that alternative. Quantification of the likelihood of the dissolved oxygen concentration to be below the current water-quality standards for an alternative is not possible based on the BATHTUB model predictions. The HOD and MOD comparisons from existing conditions can only provide some guidance as to the direction for dissolved oxygen for the alternatives.

Differences between anticipated manganese concentrations and existing conditions are based on relative hypolimnetic oxygen demand. Low dissolved oxygen concentrations in the hypolimnion can result in the conversion of manganese in the reservoir sediments to a soluble form.

The BATHTUB model also does not simulate water temperature. Therefore, direct prediction of water temperatures in the reservoirs modeled using this model cannot be done using the model output.

## 10.3. Comparison of Alternatives

Model results for each action alternative were compared to predictions made for existing conditions. In addition, the Proposed Action alternative and Alternatives 3, 4, and 5 were compared to the No Action alternative. These evaluations were made to understand the anticipated incremental changes due to the alternatives.

Comparisons between alternatives were made for:

- Trophic State;
- Total Phosphorus;
- Total Nitrogen;
- Chlorophyll *a* (a measure of algae); and
- Clarity.

For Granby Reservoir, Shadow Mountain Reservoir, and Grand Lake, comparisons were also made for peak chlorophyll *a*, minimum hypolimnetic dissolved oxygen, minimum Secchi-disk depth, and total suspended solids. For Horsetooth Reservoir, Carter Lake, Ralph Price Reservoir, Jasper East Reservoir, Rockwell Creek Reservoir, Chimney Hollow Reservoir and Dry Creek Reservoir, comparisons were also made for hypolimnetic oxygen demand and metalimnetic oxygen demand. The discussion also includes the results of the analyses to compare manganese and temperature.

The water-quality variables listed above are displayed on an average annual basis in graphs. The exceptions to this are 1) minimum dissolved oxygen where the minimum value for each year is displayed, 2) minimum Secchi-disk depth where the minimum value for each year is displayed, and 3) peak chlorophyll *a* concentration where the maximum value for the year is displayed.

The trophic state index is computed using the Carlson Trophic State Index (TSI) (see Table 4). This is a widely-used index which was developed to better communicate to the public "both the current nature or status of lakes and their future condition after restoration" (Carlson, 1977) or some other change. Since chlorophyll *a* values are predicted for this analysis, they serve as the basis for the TSI computation instead of using total phosphorus or Secchi-disk depth values, which are to be used when chlorophyll *a* values are not available (Carlson, 1983). The reported TSI is based on the average value for the period May 1 to November 15 for the Three Lakes and on the average annual value for the reservoirs modeled with BATHTUB, per the model documentation. Trophic state indices are also computed on a monthly basis for the reservoirs modeled using the Three Lakes Water-Quality Model.

Trophic state indices are based on an average chlorophyll *a* value rather than peak values because there can be significant variations within the averaging period. The predicted average and peak chlorophyll *a* concentration by year were graphed for the reservoirs modeled using the Three Lakes Water-Quality Model. In addition, the entire daily chlorophyll *a* time-series was graphed for Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir to show the differences between alternatives on a finer time scale.

# 11.0 ENVIRONMENTAL CONSEQUENCES – DIRECT AND INDIRECT EFFECTS

The purpose of this section is to evaluate the environmental consequences of the action alternatives described in Section 2 and compare them to both existing conditions and to the No Action alternative. It is organized first by an evaluation of the existing reservoirs followed by proposed reservoirs and then by geographic area -- the west slope reservoirs and Grand Lake followed by the east slope reservoirs.

## 11.1. Direct and Indirect Effects - Existing West Slope Reservoirs and Grand Lake

To illustrate the overall differences between the alternatives from a Three Lakes water-quality perspective, some of the variables driving in-reservoir water quality are displayed in Figure 29 through Figure 35.

Changes in Granby Reservoir contents are displayed in Figure 29. This graph shows the variation in reservoir contents over time and the differences between alternatives. In general, contents are greatest for existing conditions, but the No Action alternative is very similar. Contents are lowest for the Proposed Action. The other three alternatives (Alternatives 3, 4, and 5) result in essentially the same contents, but values fall between the Proposed Action alternative and the No Action alternative. Contents are lowest in 1977, 1979, and 1981 and are consistently higher in 1983-1987. As the contents of the reservoir decrease, the volume of the hypolimnion relative to the epilimnion changes, which can impact water quality, particularly dissolved oxygen. The contents of Grand Lake and Shadow Mountain Reservoir are considered to be constant over time for each alternative.

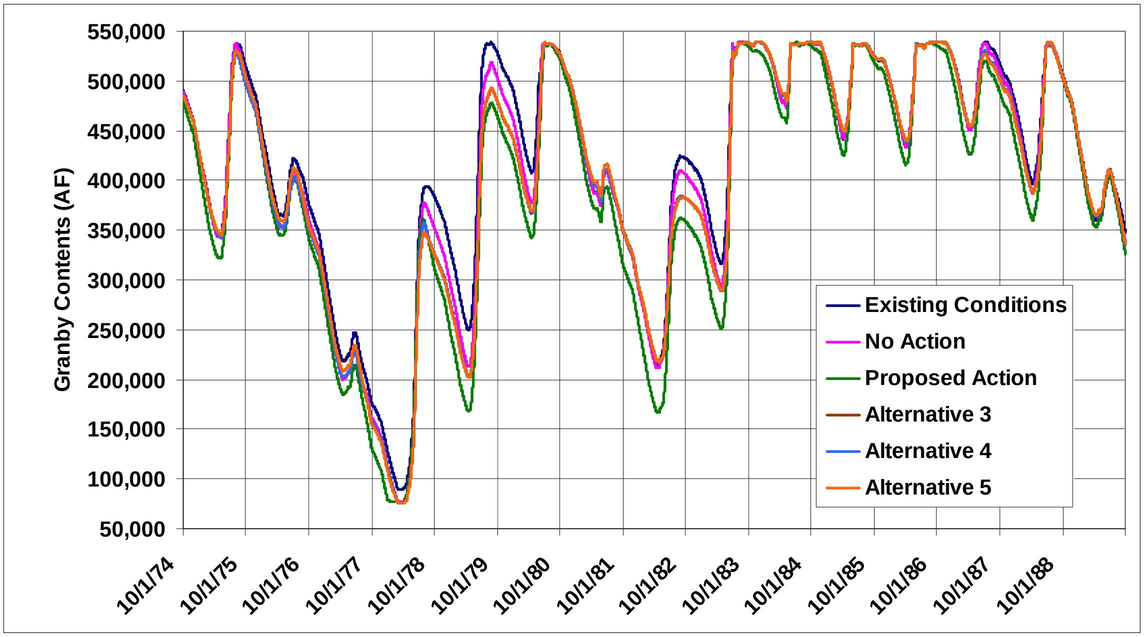


**Figure 29: Estimated Granby Reservoir Contents, WY75-WY89 in Acre-Feet (Data Source: Boyle, 2006)**

Figure 30 and Figure 31 illustrate the differences in the timing and quantity of total pumping from downstream reservoirs (Windy Gap and proposed Jasper East or Rockwell Creek) back up to Granby Reservoir. The water source for the proposed reservoirs would be Granby Reservoir, Willow Creek, and the Colorado River below the Fraser River confluence. For the existing conditions, No Action, and the Proposed Action alternative, pumping only occurs from April through August. The other alternatives involve pumping year round from proposed West Slope storage reservoirs. The greatest quantity of water pumped into Granby per year (excluding water from Willow Creek Reservoir), would occur with the Proposed Action (Table 32). Higher amounts are pumped in 1978-1980 and 1983.

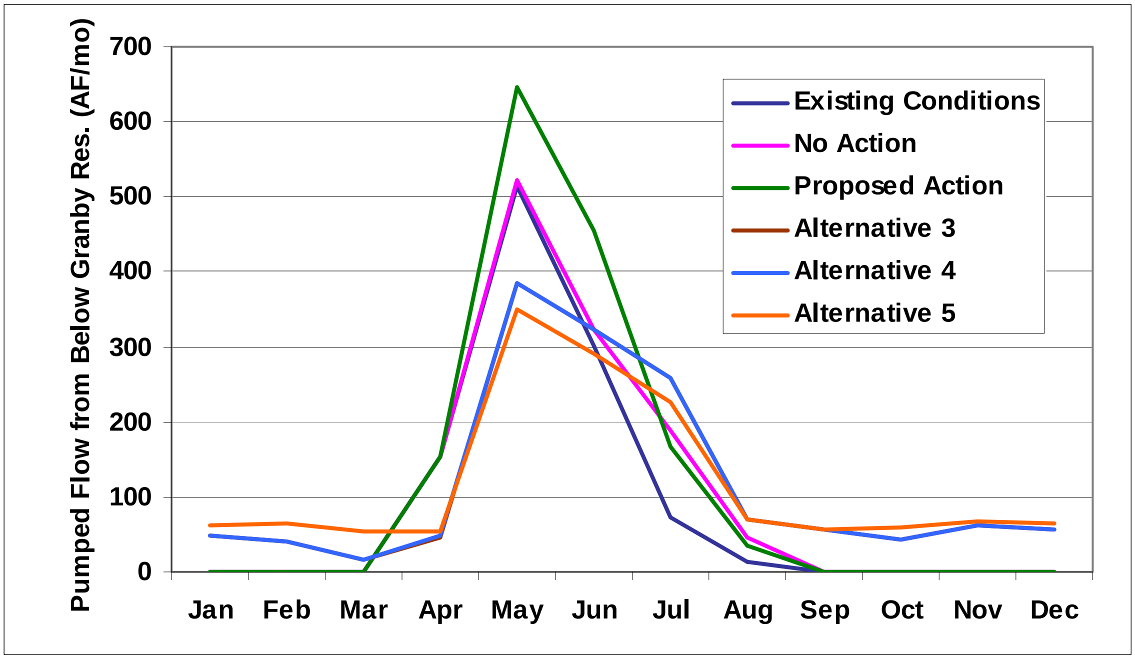


**Figure 30: Estimated Total Pumping from Windy Gap Reservoir, Proposed Jasper East Reservoir (Alternative 3), and Proposed Rockwell Creek Reservoir (Alternatives 4 and 5) into Granby Reservoir, Average by Month for WY75-WY89 in Acre-Feet Per Month (Data Source: Boyle, 2006)**

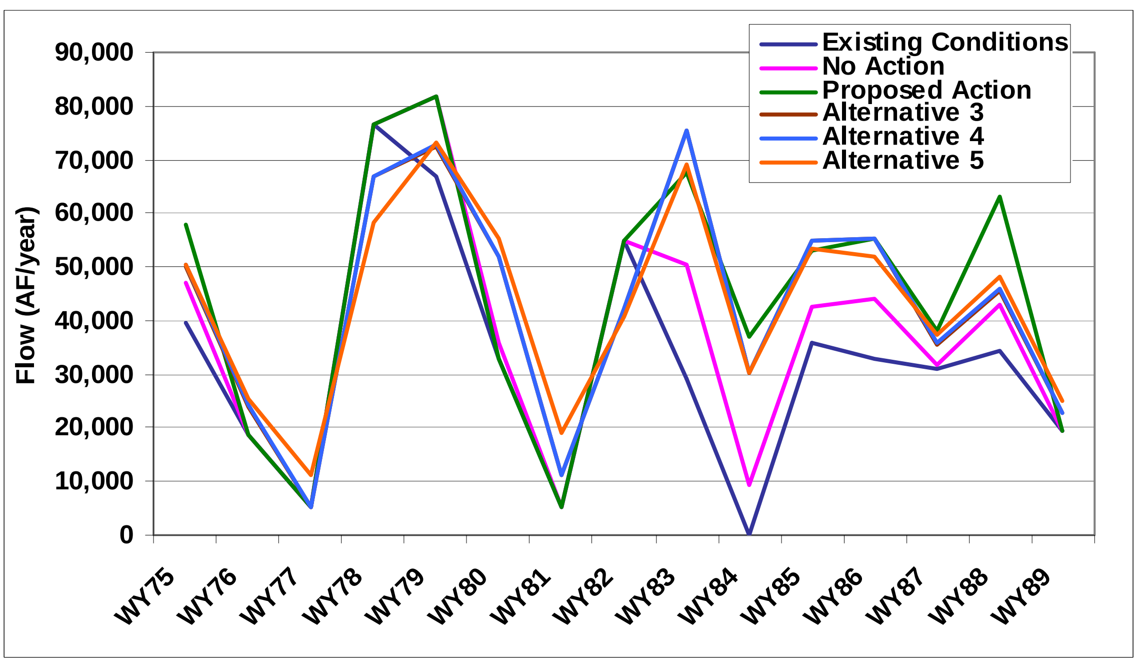


**Figure 31: Estimated Pumping from Windy Gap Reservoir, Proposed Jasper East Reservoir (Alternative 3), and Proposed Rockwell Creek Reservoir (Alternatives 4 and 5) into Granby Reservoir by Water Year (Data Source: Boyle, 2006)**

**Table 32: Estimated Average Amount of Water Pumped into Granby Reservoir from Windy Gap Reservoir, Proposed Jasper East Reservoir (Alternative 3), and Proposed Rockwell Creek Reservoir (Alternatives 4 and 5)-WY75-WY89 (Data Source: Boyle, 2006)**

| Alternative | Average Amount Pumped (AF/Yr) |
|---|---|
| Existing Conditions | 32,201 |
| No Action | 37,718 |
| Proposed Action: Chimney Hollow with Pre-Positioning | 44,457 |
| Alternative 3: Chimney Hollow with Jasper East | 42,910 |
| Alternative 4: Chimney Hollow with Rockwell Creek | 42,968 |
| Alternative 5: Dry Creek with Rockwell Creek | 43,229 |

The timing and amount of water pumped from Granby Reservoir into Shadow Mountain Reservoir via the Farr Pumping Plant is shown in Figure 32 and Figure 33 for existing conditions and the alternatives. The largest inter-annual differences between the alternatives occur in August and September. The Proposed Action alternative involves the most pumping from Granby Reservoir to Shadow Mountain Reservoir (Table 33).

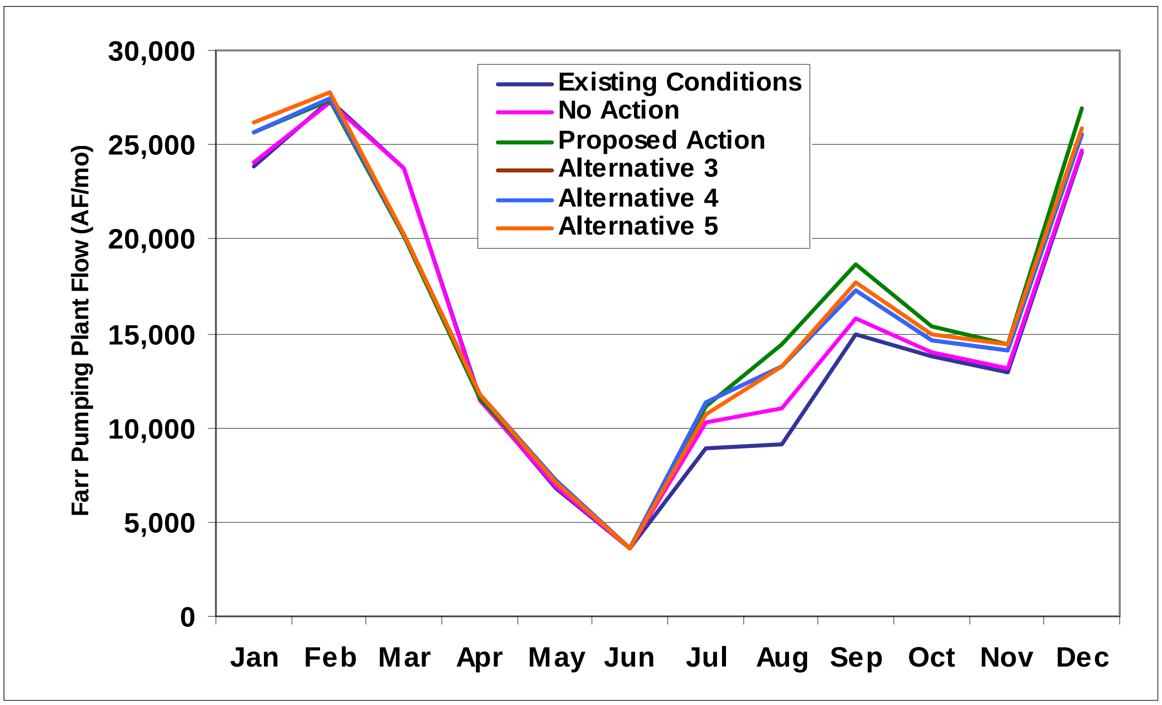


**Figure 32: Estimated Pumping at the Farr Pumping Plant (from Granby Reservoir to Shadow Mountain Reservoir), Average by Month for WY75-WY89 in Acre-Feet Per Month (Data Source: Boyle, 2006)**

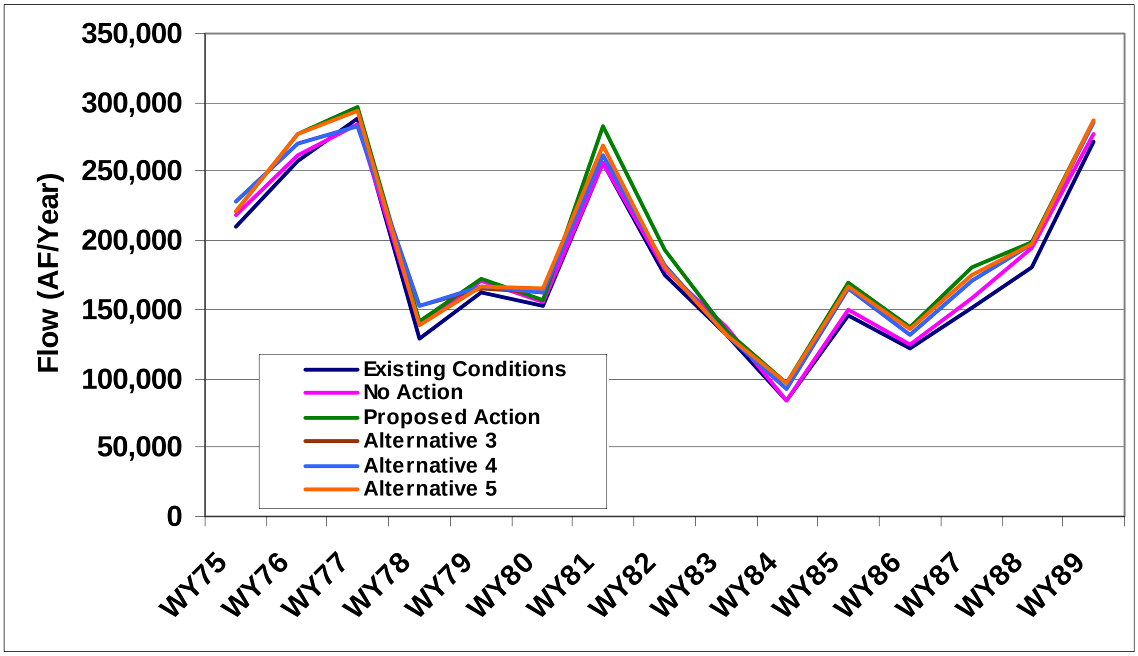


**Figure 33: Estimated Pumping by Water Year at the Farr Pumping Plant (from Granby Reservoir to Shadow Mountain Reservoir) in Acre-Feet Per Year (Data Source: Boyle, 2006)**

**Table 33: Estimated Average Amount of Water Pumped into Shadow Mountain Reservoir via the Farr Pumping Plant (WY75-WY89) (Data Source: Boyle: 2006)**

| Alternative | Average Amount Pumped (AF/Yr) |
|---|---|
| Existing Conditions | 181,103 |
| No Action | 186,060 |
| Proposed Action: Chimney Hollow with Pre-Positioning | 196,402 |
| Alternative 3: Chimney Hollow with Jasper East | 191,938 |
| Alternative 4: Chimney Hollow with Rockwell Creek | 191,969 |
| Alternative 5: Dry Creek with Rockwell Creek | 193,559 |

The timing (Figure 34) and amount of water flowing through the Adams Tunnel (Figure 35) follows similar patterns as Farr Pumping, although the months where the largest differences occur are July and August versus August and September. Alternative 5 would have the greatest Adams Tunnel delivery followed closely by the Proposed Action and other alternatives (Table 34). These patterns also illustrate how water would be delivered to the east slope reservoirs for each alternative.

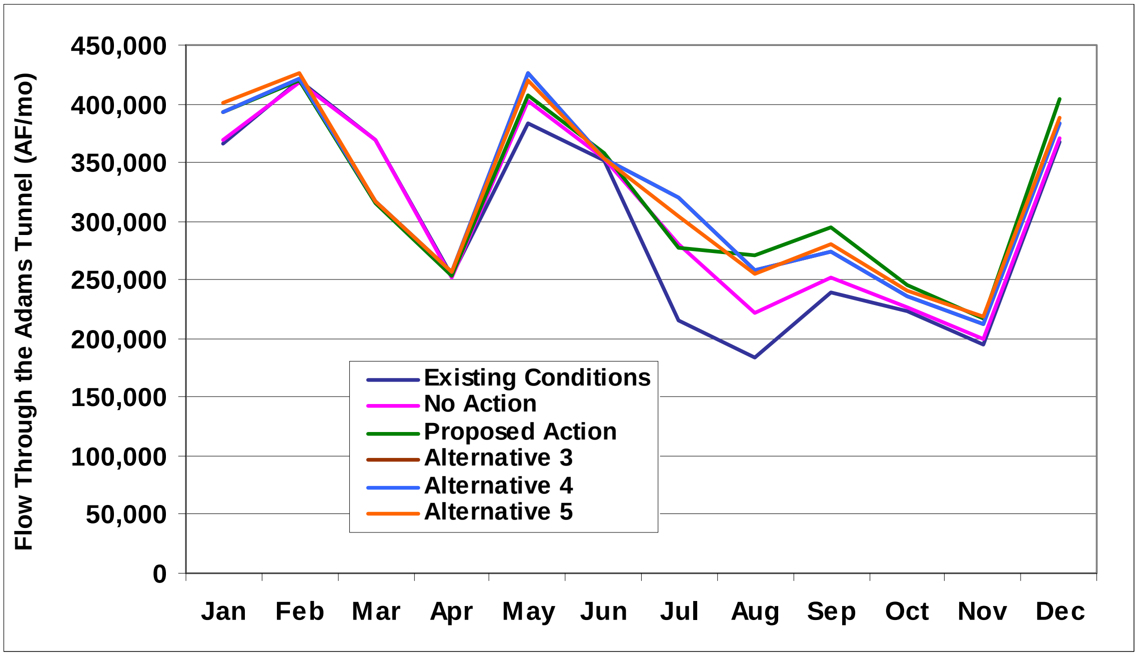


**Figure 34: Estimated Flow through the Adams Tunnel, Average by Month for WY75-WY89 in Acre-Feet Per Month (Data Source: Boyle, 2006)**

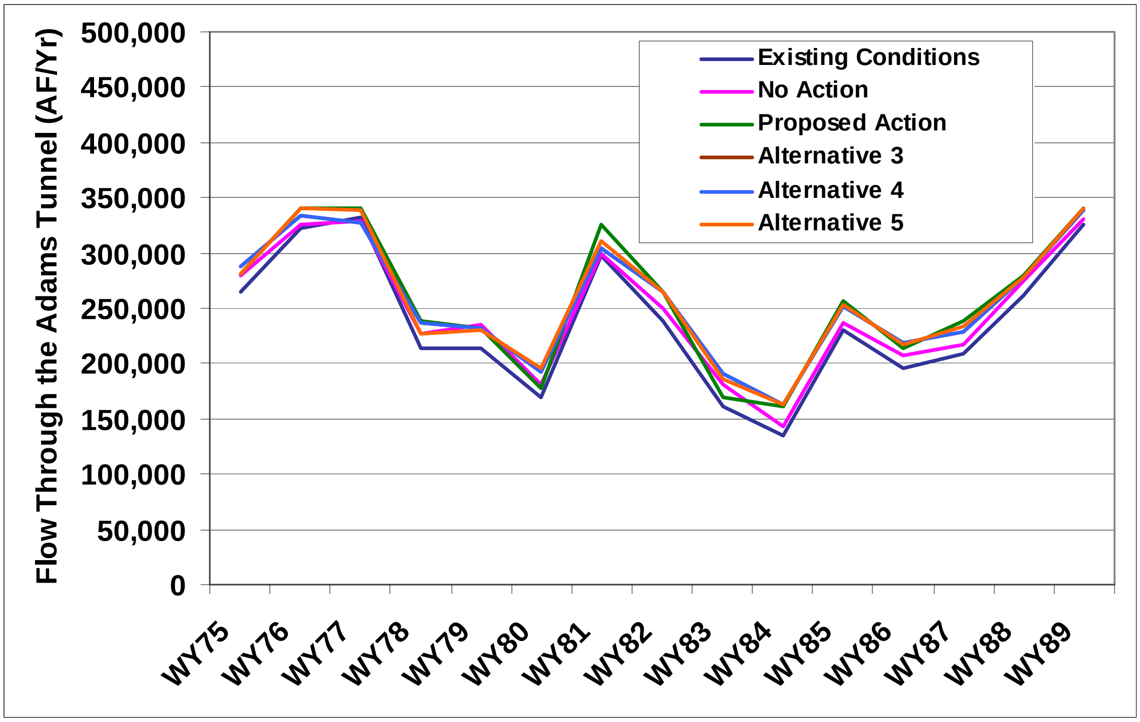


**Figure 35: Estimated Flow through the Adams Tunnel by Water Year in Acre-Feet Per Year (Data Source: Boyle, 2006)**

**Table 34: Estimated Average Amount of Water Diverted through the Adams Tunnel. (WY75-WY89) (Data Source: Boyle, 2006)**

| Alternative | Average Amount Pumped (AF/Yr) |
|---|---|
| Existing Conditions | 237,953 |
| No Action | 247,696 |
| Proposed Action: Chimney Hollow with Pre-Positioning | 257,175 |
| Alternative 3: Chimney Hollow with Jasper East | 256,725 |
| Alternative 4: Chimney Hollow with Rockwell Creek | 256,750 |
| Alternative 5: Dry Creek with Rockwell Creek | 257,254 |

Spills from Granby Reservoir to the Colorado River would vary somewhat between alternatives. The average amount discharged over the period WY75 through WY89 is displayed in Table 35. The alternatives with new west slope reservoirs (Alternatives 3, 4, and 5) result in lower releases to the Colorado River. Granby Reservoir releases under all alternatives would be lower because more storage would be available in Granby for Windy Gap water.

**Table 35: Estimated Average Amount of Water Released from Granby Reservoir to the Colorado River. (WY75-WY89) (Data Source: Boyle, 2006)**

| Alternative | Average Amount Released (AF/Yr) |
|---|---|
| Existing Conditions | 72,321 |
| No Action | 71,128 |
| Proposed Action: Chimney Hollow with Pre-Positioning | 68,926 |
| Alternative 3: Chimney Hollow with Jasper East | 67,588 |
| Alternative 4: Chimney Hollow with Rockwell Creek | 67,617 |
| Alternative 5: Dry Creek with Rockwell Creek | 67,322 |

Nutrient loading also varies between the different alternatives. The estimated amount of nutrient loading coming from various sources into the Three Lakes system for existing conditions is displayed in Table 36. The changes in loading for each alternative relative to existing conditions are shown in Table 37 and Table 38. Note that loadings from Willow Creek increase over existing conditions due to increased flows through the Willow Creek Pipeline during some years. Contributions from Jasper East Reservoir and Rockwell Creek Reservoir were determined as described in Sections 11.3.1 and 11.3.2.

The Proposed Action alternative has the highest additional phosphorus and nitrogen loadings. The alternatives that include a new west slope reservoir (Alternatives 3, 4, and 5) retain a portion of the nutrients in the new reservoir, which serves to reduce contributions to the Three Lakes System. Alternative 5 results in less nitrogen loading to the Three Lakes System than Existing Conditions. This is due to the retention of nitrogen in Rockwell Creek Reservoir coupled with less pumping during the runoff season when concentrations at Windy Gap Reservoir are higher (Figure 30).

Nutrients are often retained in lakes and reservoirs, which results in a reduction of nitrogen and phosphorus from the water column. For nitrogen, retention processes include volatilization and settling of particulate nitrogen. For phosphorus, the processes include settling of externally delivered particulate phosphorus and settling of phytoplankton biomass, which has incorporated dissolved phosphorus. A portion of the deposited phosphorus and nitrogen will return back to the water column.

Kronvang, et al. (2004) developed a database of lakes and reservoir from around the world for purposes of computing nutrient retention as varying with residence time. The amount of nitrogen and phosphorus retained was found to vary with hydraulic residence time, where nutrient retention increases as hydraulic residence time increases. Phosphorus retention ranged from 17-70% while nitrogen retention ranged from 16-60%. Kronvang, et al. (2004) also noted that phosphorus retention was consistently higher in reservoirs than lakes.

The next sections of this report focus on the impacts to the individual reservoirs within the Three Lakes System.

**Table 36: Estimated Average Annual Nutrient Loads Into the Three Lakes System for Existing Conditions (WY75-WY89)**

| | Average Total Phosphorus Load (kg/yr) | % of Total Phosphorus Load | Average Total Nitrogen Load (kg/yr) | % of Total Nitrogen Load |
|---|---|---|---|---|
| **Willow Creek Pumping** | 1,465 | 19.3% | 15,948 | 13.8% |
| **Windy Gap Pumping** | 2,143 | 28.2% | 16,391 | 14.2% |
| **Arapaho Creek** | 503 | 6.6% | 20,578 | 17.9% |
| **Stillwater Creek** | 1,566 | 20.6% | 7,023 | 6.1% |
| **North Fork of the Colorado** | 596 | 7.8% | 7,962 | 6.9% |
| **North Inlet** | 355 | 4.7% | 10,717 | 9.3% |
| **East Inlet** | 225 | 3.0% | 6,819 | 5.9% |
| **Roaring Fork** | 92 | 1.2% | 3,784 | 3.3% |
| **Columbine Creek** | 62 | 0.8% | 2,523 | 2.2% |
| **Precipitation** | 377 | 5.0% | 13,671 | 11.9% |
| **Miscellaneous Gains** | 218 | 2.9% | 9,755 | 8.5% |
| **Total** | 7,602 | 100% | 114,049 | 100% |

**Table 37: Estimated Additional Total Phosphorus Load into the Three Lakes System for Alternatives over Existing Conditions (WY75-WY89)**

| Alternative | TP Load From Willow Creek Reservoir (kg/yr) | TP Load From Windy Gap Reservoir (kg/yr) | TP Load From Jasper East Reservoir (kg/yr) | TP Load From Rockwell Creek Reservoir (kg/yr) | Total (kg/yr) |
|---|---|---|---|---|---|
| No Action | +123 | +299 | | | +422 |
| Proposed Action | +143 | +730 | | | +873 |
| Alternative 3 | +142 | -436 | +557 | | +263 |
| Alternative 4 | +142 | -435 | | +525 | +232 |
| Alternative 5 | +143 | -654 | | +613 | +102 |

**Table 38: Estimated Additional Total Nitrogen Load into the Three Lakes System for Alternatives over Existing Conditions (WY75-WY89)**

| Alternative | TN Load From Willow Creek Reservoir (kg/yr) | TN Load From Windy Gap Reservoir (kg/yr) | TN Load From Jasper East Reservoir (kg/yr) | TN Load From Rockwell Creek Reservoir (kg/yr) | Total (kg/yr) |
|---|---|---|---|---|---|
| No Action | +765 | +1,455 | | | +2,220 |
| Proposed Action | +888 | +4,625 | | | +5,513 |
| Alternative 3 | +882 | -4,892 | +4,560 | | +550 |
| Alternative 4 | +882 | -4,886 | | +4,238 | +234 |
| Alternative 5 | +895 | -6,287 | | +5,036 | -356 |

### 11.1.1. Granby Reservoir

Predictions for existing conditions and the five alternatives are summarized in and displayed in Table 39 and Figure 36 to Figure 52. Annual average and daily output are presented. Trophic state was estimated using average predicted chlorophyll a concentrations (May 1 to November 15) and the Carlson Trophic State Index (Carlson and Simpson, 1977). Changes in water-quality as compared to existing conditions are shown in Table 40. Changes as compared to the No Action alternative are displayed in Table 41. There is no change from existing conditions for any of the alternatives with respect to trophic state (mesotrophic) and Secchi-disk depth. Phosphorus concentrations would increase under all of the alternatives (Figure 36). This is due to an increase in the amount of water pumped up from downstream reservoirs (see Figure 31). There is little or no change in the predicted annual average chlorophyll *a* concentration. The annual average and daily time series of chlorophyll *a* predictions and peak chlorophyll *a* concentrations are shown in Figure 40 through Figure 42. In addition, dissolved oxygen in the hypolimnion would be the lowest during the years when reservoir contents are lowest (see Figure 29 and Figure 48). Under these conditions, the volume of the hypolimnion decreases and does not hold as much oxygen to meet hypolimnetic oxygen demands.

For Granby Reservoir, there is a decrease in residence time between existing conditions and the alternatives. Not only would more water be flowing through the reservoir, but also the reservoir contents would be less for the alternatives. Thus, more flushing of Granby Reservoir would occur. This impacts the resulting nutrient concentrations shown in Table 39. Nitrogen concentrations would be lower than existing conditions for Alternatives 3, 4, and 5. These three alternatives would have the lowest additional nitrogen loadings (Table 38) and although loading increases for Alternatives 3 and 4, the impact of a decreased residence time counteracts this increase in loading (which is less than 0.5%). Phosphorus concentrations increase with each of the alternatives. The increase in phosphorus loading (1-3% for Alternatives 3, 4, and 5) is greater than that of the nitrogen loading and the decrease in residence time is not enough to counteract the increased phosphorus loading. Predicted chlorophyll a is also slightly higher for the Proposed Action, with minimal or no change for other alternatives. Overall, the reservoir is predominantly in a mesotrophic state (Figure 46 and Figure 47). Note that the model predictions for peak chlorophyll a are lower than the observed data for existing conditions. Although the peaks are captured, it is very difficult to simulate the full magnitude of the maximum concentrations. As described in the model documentation (AMEC, 2008), the model was determined to be capable of adequately predicting changes between the alternatives.

Minimum hypolimnetic dissolved oxygen concentrations would remain unchanged for Alternatives 3, 4, and 5 but would decrease slightly for the No Action and Proposed Action alternatives. Total suspended solids concentrations would increase slightly for the Proposed Action alternative and Alternatives 3, 4, and 5.

Predicted epilimnetic temperatures are displayed in Figure 52. There is no discernable difference in temperature between the alternatives and existing conditions. Therefore, it is anticipated that there would not be a negative impact on Granby Reservoir or any of the other reservoirs due to the alternatives.

### Table 39: Average Predicted Conditions for Granby Reservoir (Existing Conditions and All Alternatives)

| Average Annual Values Over the 15-Year Model Period | | | | | | |
|---|---|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
| Total Phosphorus (µg/l) | 12.6 (4.5 – 25.2) | 13.4 (4.5 – 26.3) | 14.2 (4.5 – 26.5) | 13.1 (4.8 – 22.2) | 13.0 (4.8 – 22.1) | 12.8 (4.9 – 21.7) |
| Total Nitrogen (µg/l) | 289 (228 – 375) | 290 (229 – 380) | 291 (229 – 379) | 282 (229 – 360) | 281 (229 – 359) | 279 (229 – 358) |
| Chlorophyll a (µg/l) | 4.2 (2.0 – 7.3) | 4.2 (2.0 – 7.2) | 4.3 (2.0 – 7.2) | 4.2 (2.0 – 7.4) | 4.2 (2.0 – 7.4) | 4.2 (2.0 – 7.3) |
| Peak Chlorophyll *a* (µg/l) | 6.6 | 6.6 | 6.5 | 6.6 | 6.6 | 6.6 |
| Secchi-Disk Depth (m) | 3.6 (2.1 – 5.3) | 3.6 (2.0 – 5.3) | 3.6 (2.0 – 5.3) | 3.6 (2.1 – 5.2) | 3.6 (2.1 – 5.2) | 3.6 (2.1 – 5.1) |
| Trophic State (Index) | Mesotrophic (46) | Mesotrophic (46) | Mesotrophic (46) | Mesotrophic (46) | Mesotrophic (46) | Mesotrophic (46) |
| Minimum DO (mg/l) | 4.5 | 4.4 | 4.3 | 4.5 | 4.5 | 4.5 |
| TSS (mg/l) | 2.3 (1.1 – 5.9) | 2.3 (1.1 – 6.2) | 2.4 (1.1 – 6.3) | 2.4 (1.2 – 5.7) | 2.4 (1.2 – 5.7) | 2.4 (1.1 – 5.7) |

Range of data (min – max) included. All concentrations are for the epilimnion with the exception of minimum dissolved oxygen, which is for the hypolimnion.

### Table 40: Predicted Changes by Alternative for Granby Reservoir Relative to Existing Conditions

| | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|---|
| Total Phosphorus (µg/l) | +6.3% | +12.7% | +4.0% | +3.2% | +1.6% |
| Total Nitrogen (µg/l) | +0.3% | +0.7% | -2.1% | -2.8% | -3.5% |
| Chlorophyll *a* (µg/l) | No Change | +2.4% | No Change | No Change | No Change |
| Peak Chlorophyll a (µg/l) | No Change | -1.5% | No Change | No Change | No Change |
| Secchi-Disk Depth (m) | No Change | No Change | No Change | No Change | No Change |
| Trophic State | No Change | No Change | No Change | No Change | No Change |
| Minimum DO (mg/l) | -2.2% | -4.4% | No Change | No Change | No Change |
| TSS (mg/l) | No Change | +4.3% | +4.3% | +4.3% | +4.3% |

**Table 41: Predicted Changes for Granby Reservoir by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|
| Total Phosphorus (µg/l) | +6.0% | -2.2% | -3.0% | -4.5% |
| Total Nitrogen (µg/l) | +0.3% | -2.8% | -3.1% | -3.8% |
| Chlorophyll *a* (µg/l) | +2.4% | No Change | No Change | No Change |
| Peak Chlorophyll *a* (µg/l) | -1.5% | No Change | No Change | No Change |
| Secchi-Disk Depth (m) | No Change | No Change | No Change | No Change |
| Trophic State | No Change | No Change | No Change | No Change |
| Minimum DO (mg/l) | -2.3% | +2.3% | +2.3% | +2.3% |
| TSS (mg/l) | +4.3% | +4.3% | +4.3% | +4.3% |

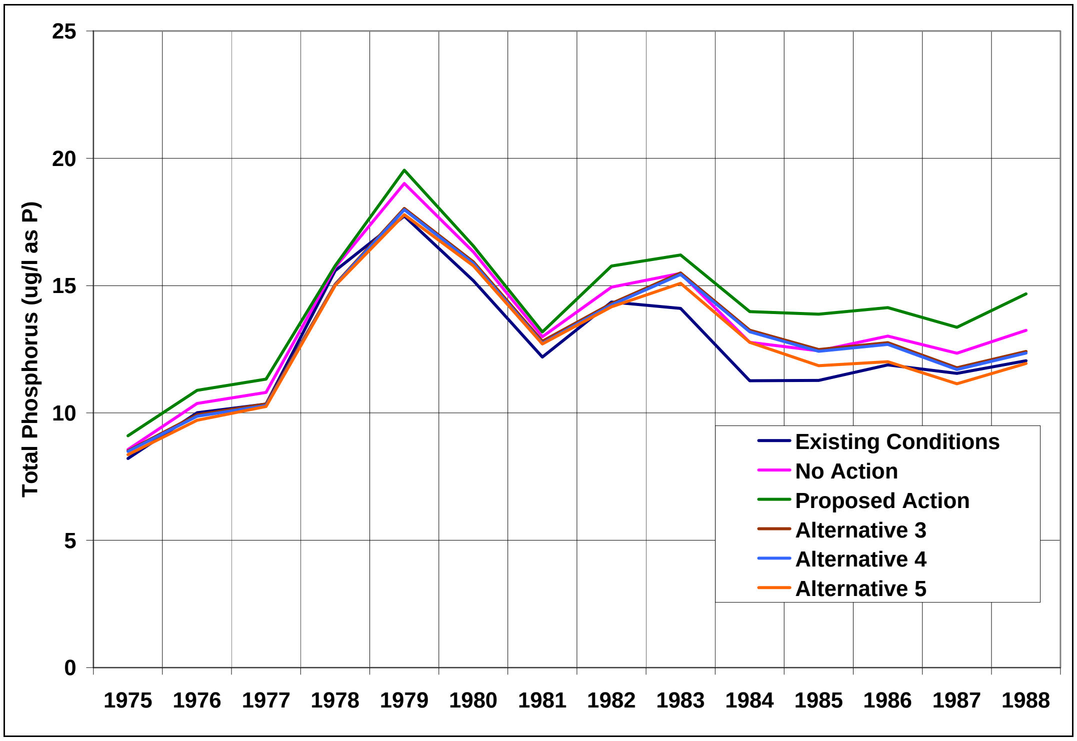


**Figure 36: Predicted Annual Average Total Phosphorus Concentrations in Granby Reservoir Epilimnion (Existing Conditions and All Alternatives)**

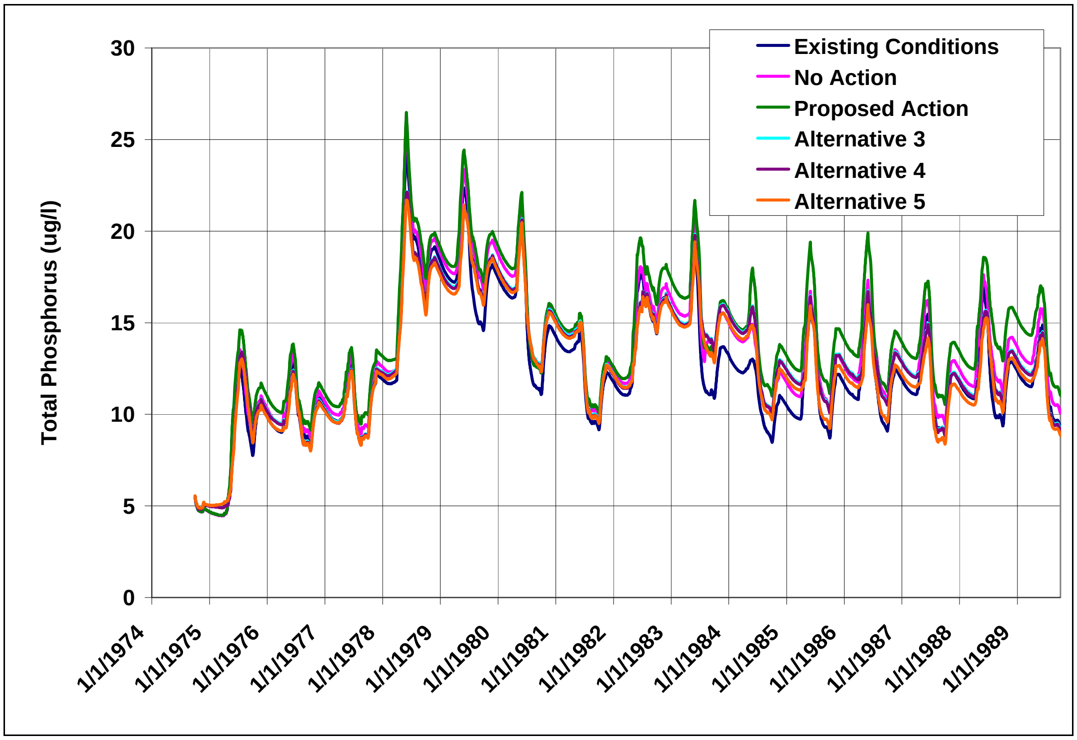


**Figure 37: Predicted Daily Total Phosphorus Concentrations in Granby Reservoir Epilimnion (Existing Conditions and All Alternatives)**

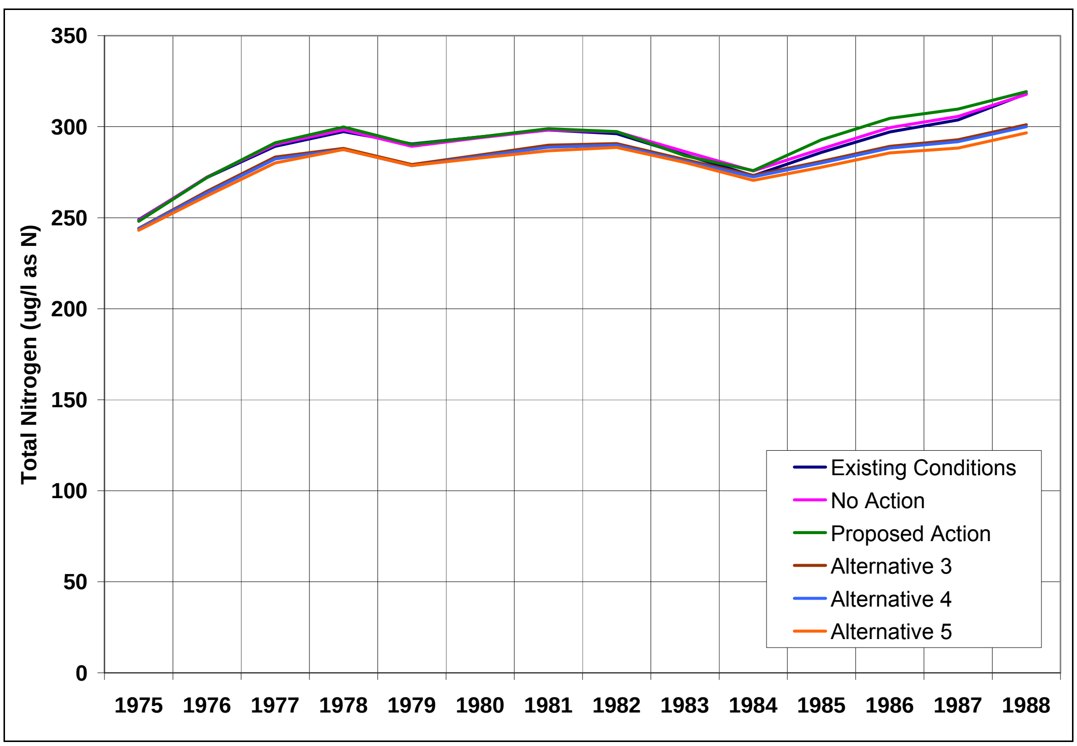


**Figure 38: Predicted Annual Average Total Nitrogen Concentrations in Granby Reservoir Epilimnion (Existing Conditions and All Alternatives)**

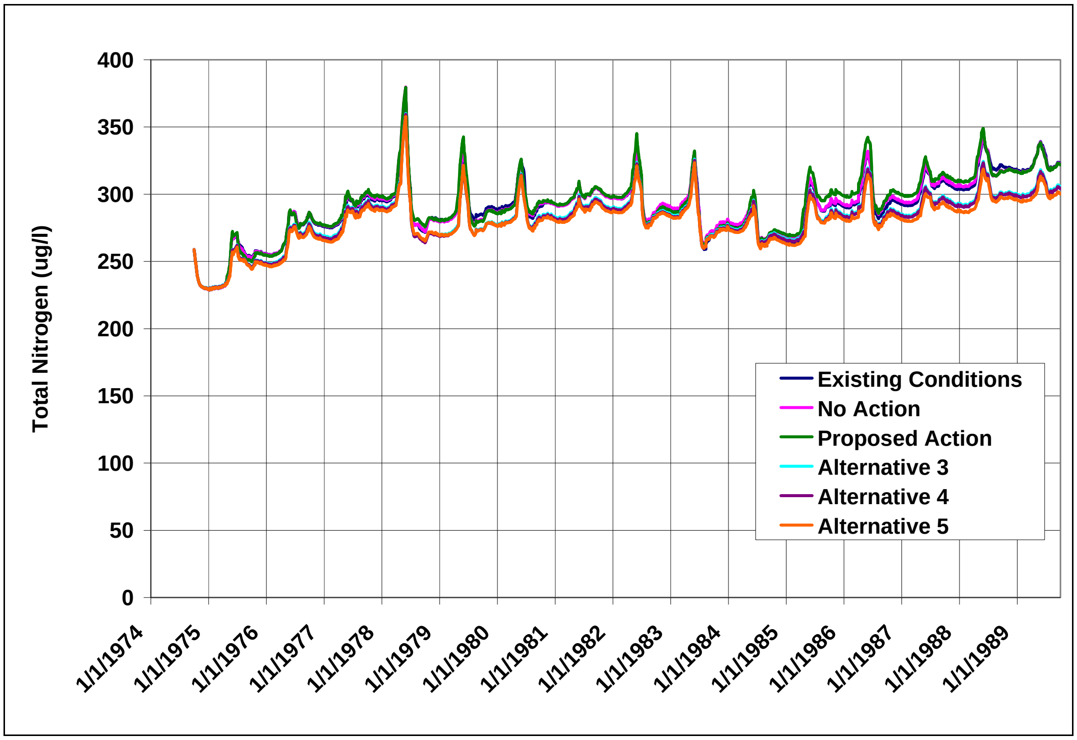


**Figure 39: Predicted Daily Total Nitrogen Concentrations in Granby Reservoir Epilimnion (Existing Conditions and All Alternatives)**

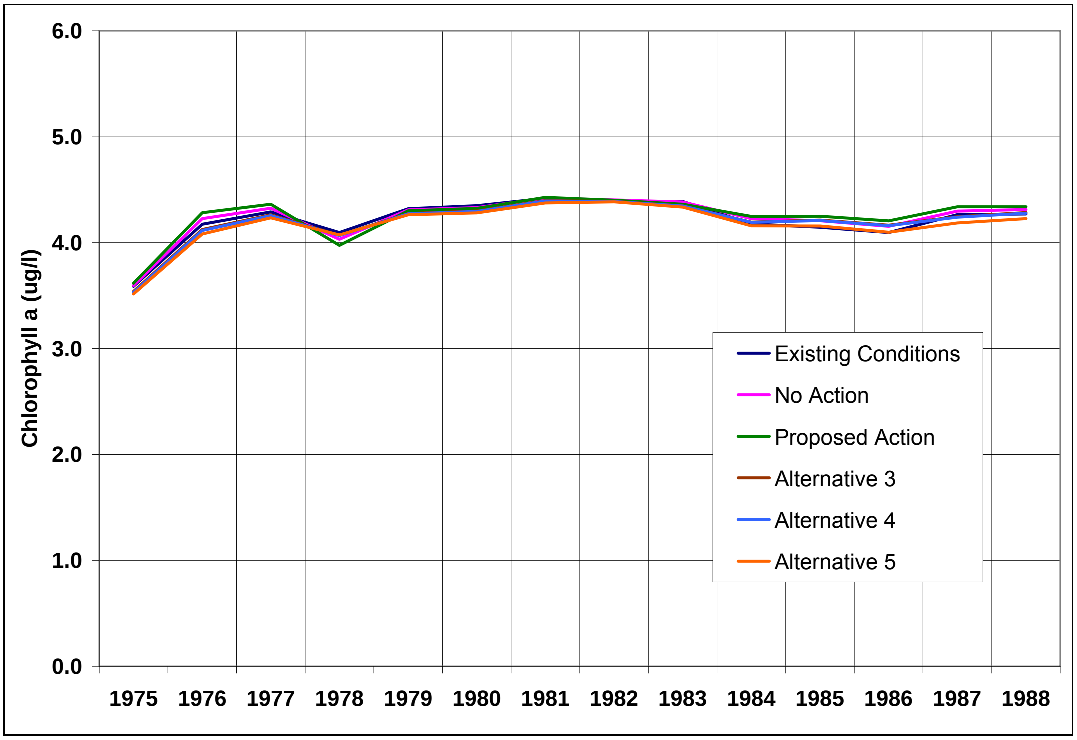


**Figure 40: Predicted Annual Average Chlorophyll *a* Concentrations in Granby Reservoir (Existing Conditions and All Alternatives)**

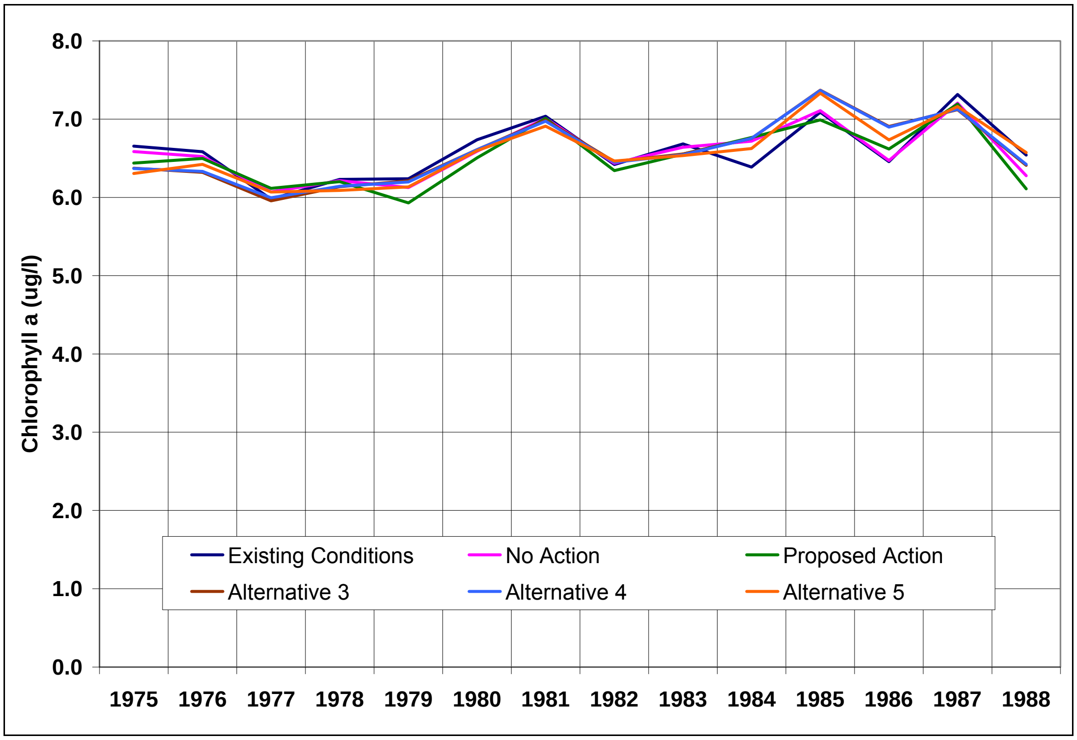


**Figure 41: Simulated Annual Average Peak Chlorophyll *a* Concentrations in Granby Reservoir by Year for Existing Conditions and the Alternatives**

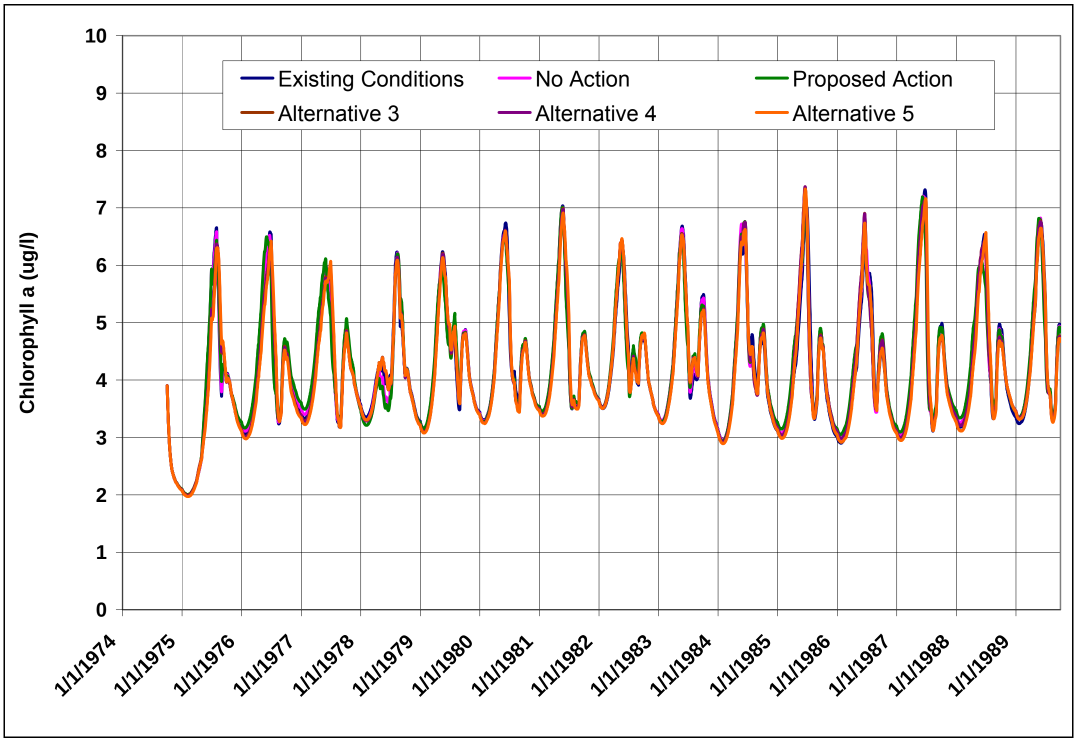


**Figure 42: Simulated Daily Chlorophyll *a* Concentrations in Granby Reservoir (Existing Conditions and All Alternatives)**

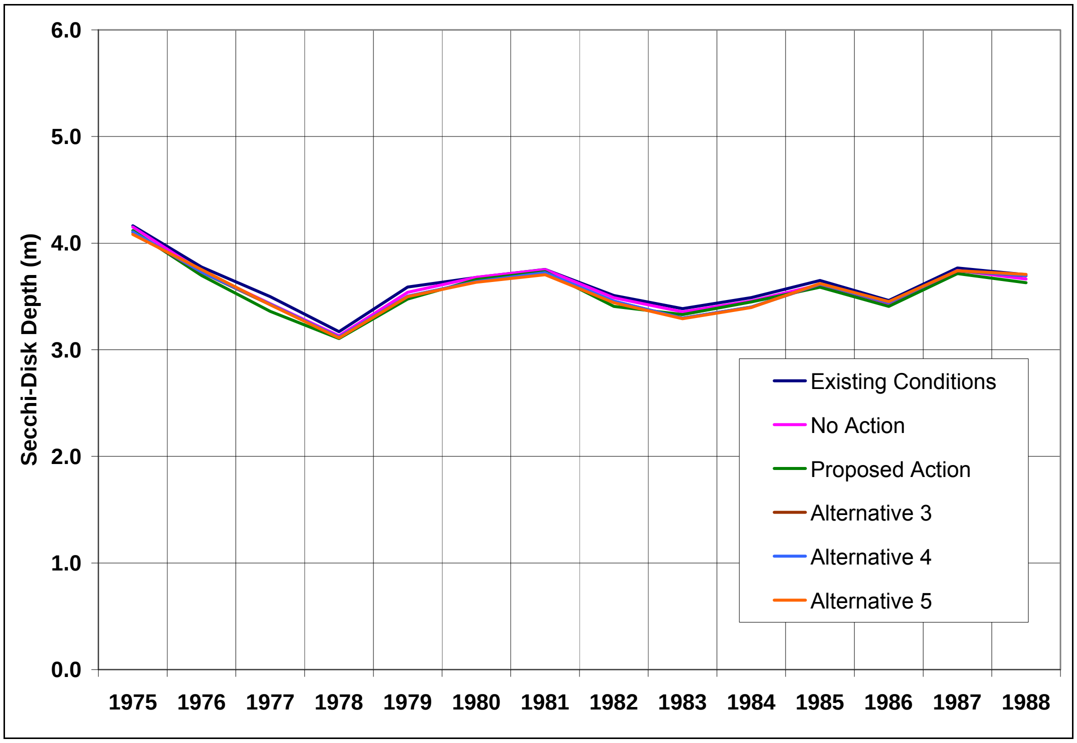


**Figure 43: Predicted Annual Average Secchi-Disk Depth in Granby Reservoir (Existing Conditions and All Alternatives)**

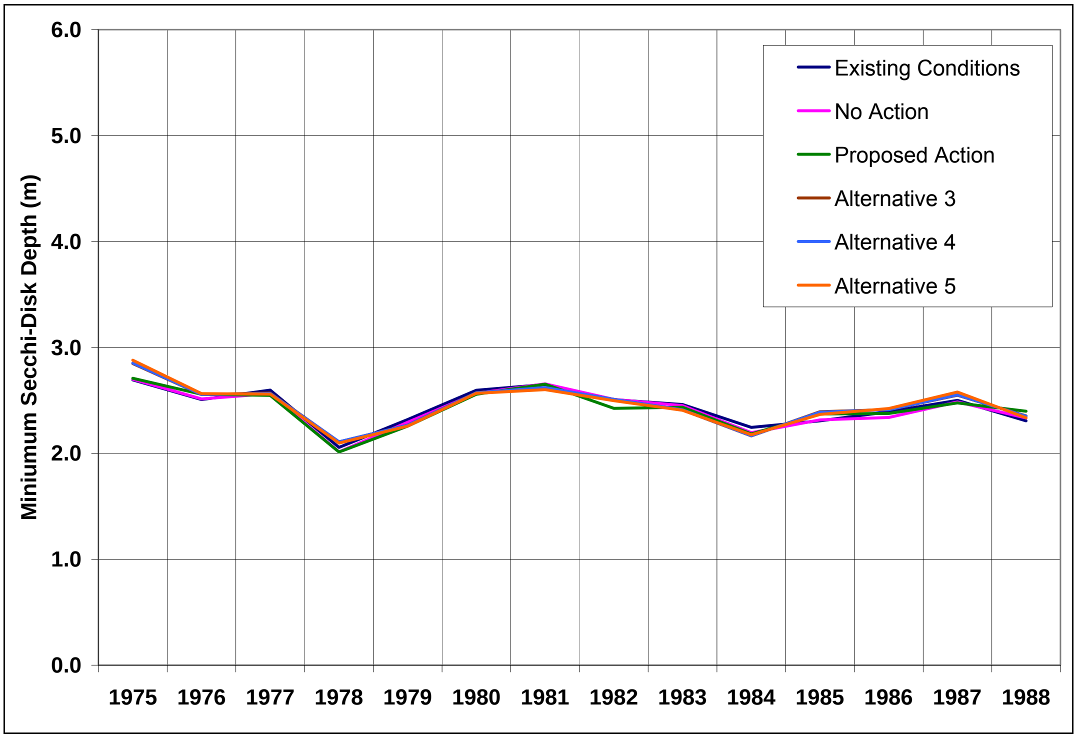


**Figure 44: Predicted Minimum Secchi-Disk Depth in Granby Reservoir (Existing Conditions and All Alternatives)**

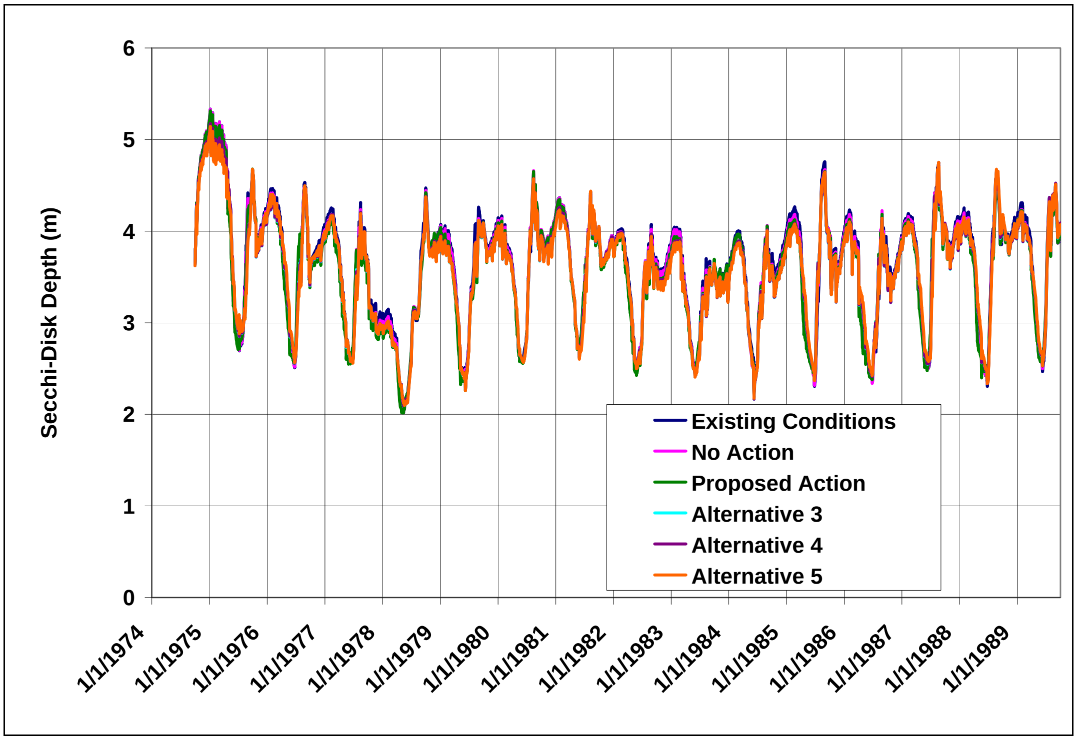


**Figure 45: Predicted Daily Secchi-Disk Depth in Granby Reservoir (Existing Conditions and All Alternatives)**

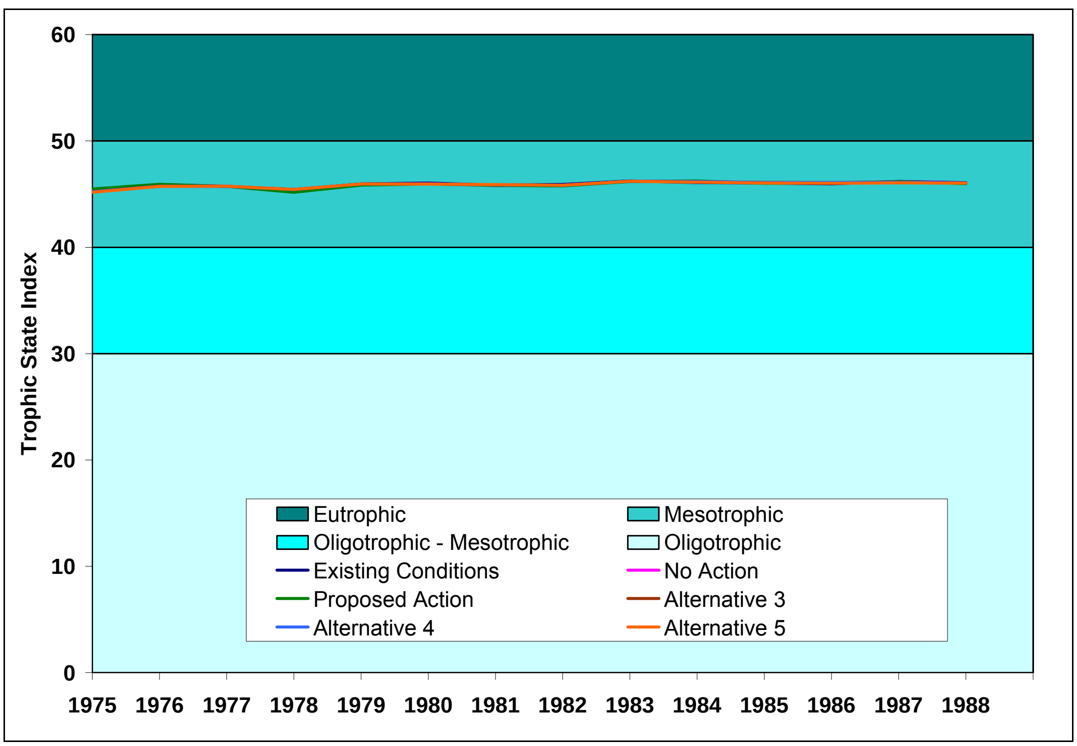


**Figure 46: Predicted Trophic State Indices in Granby Reservoir (Existing Conditions and All Alternatives)**

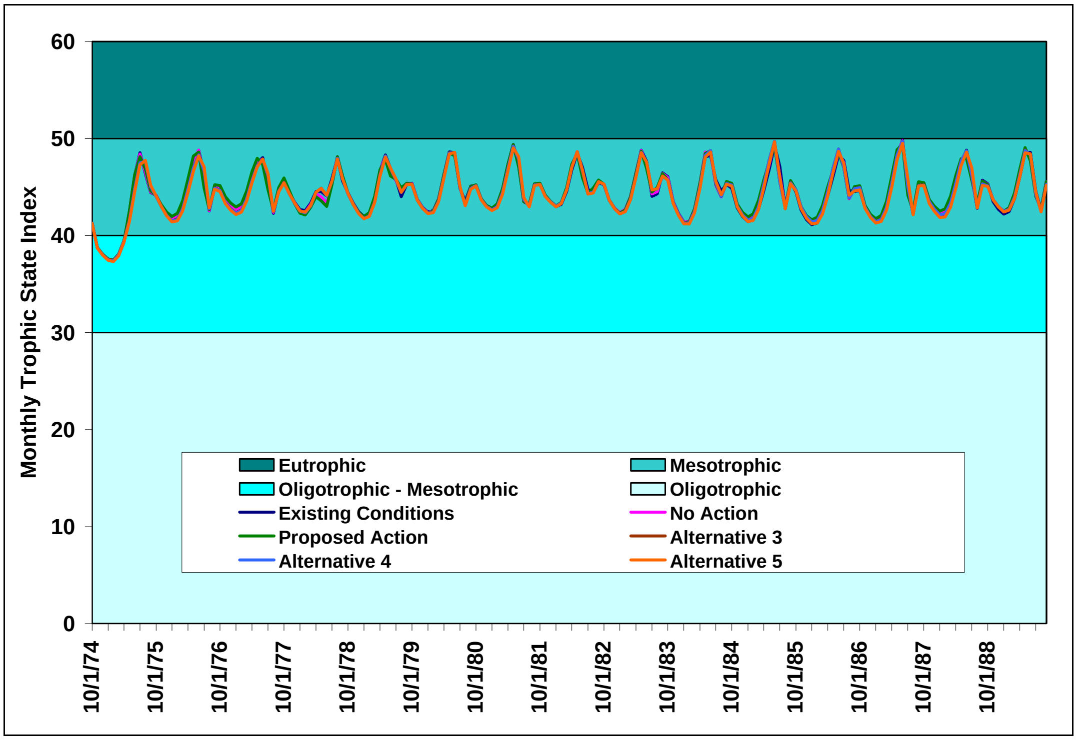


**Figure 47: Predicted Monthly Trophic State Index for Granby Reservoir**

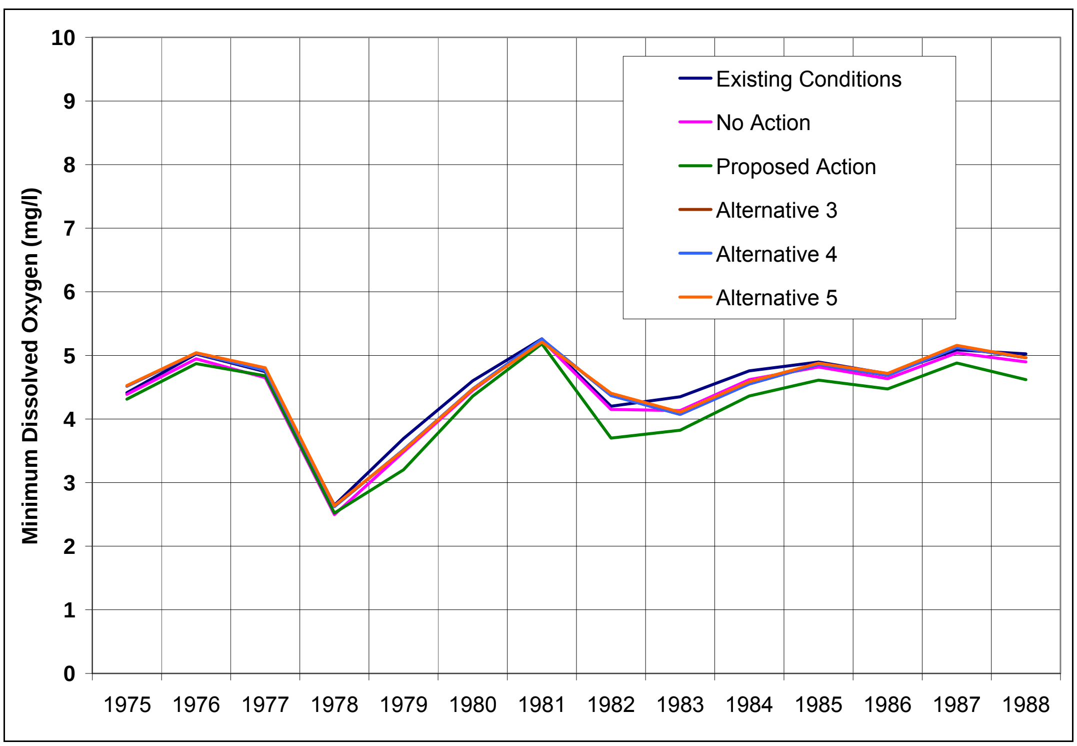


**Figure 48: Predicted Minimum Dissolved Oxygen Concentration in Granby Reservoir Hypolimnion (Existing Conditions and All Alternatives)**

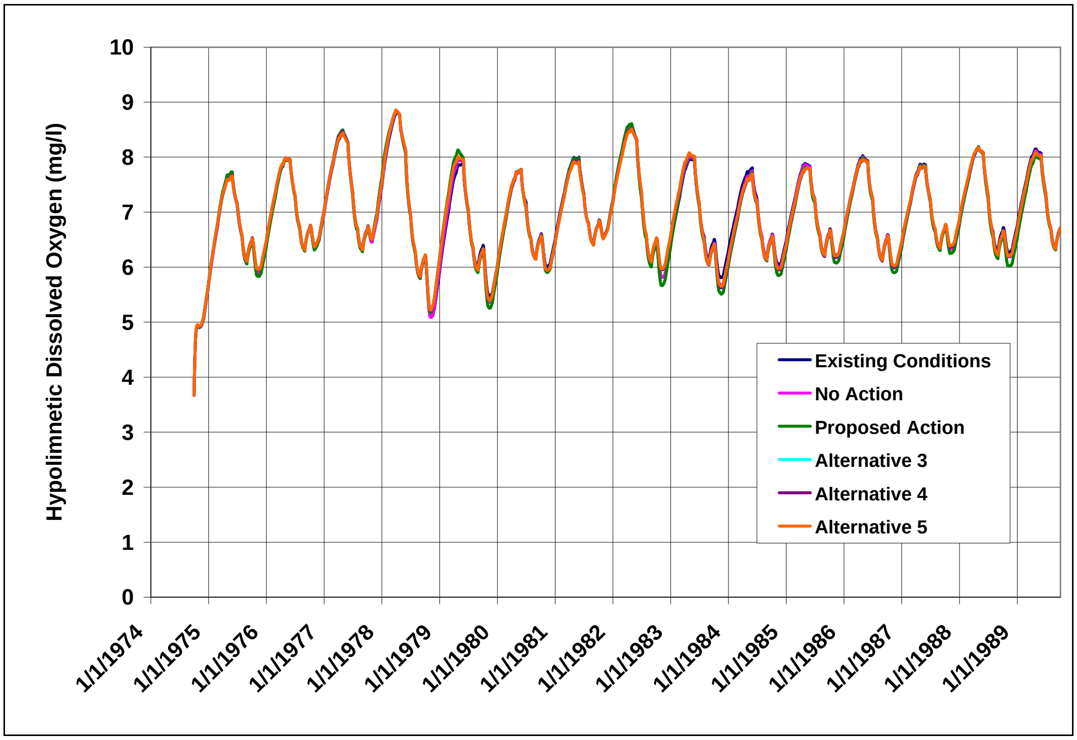


**Figure 49: Predicted Daily Dissolved Oxygen Concentration in Granby Reservoir Hypolimnion (Existing Conditions and All Alternatives)**

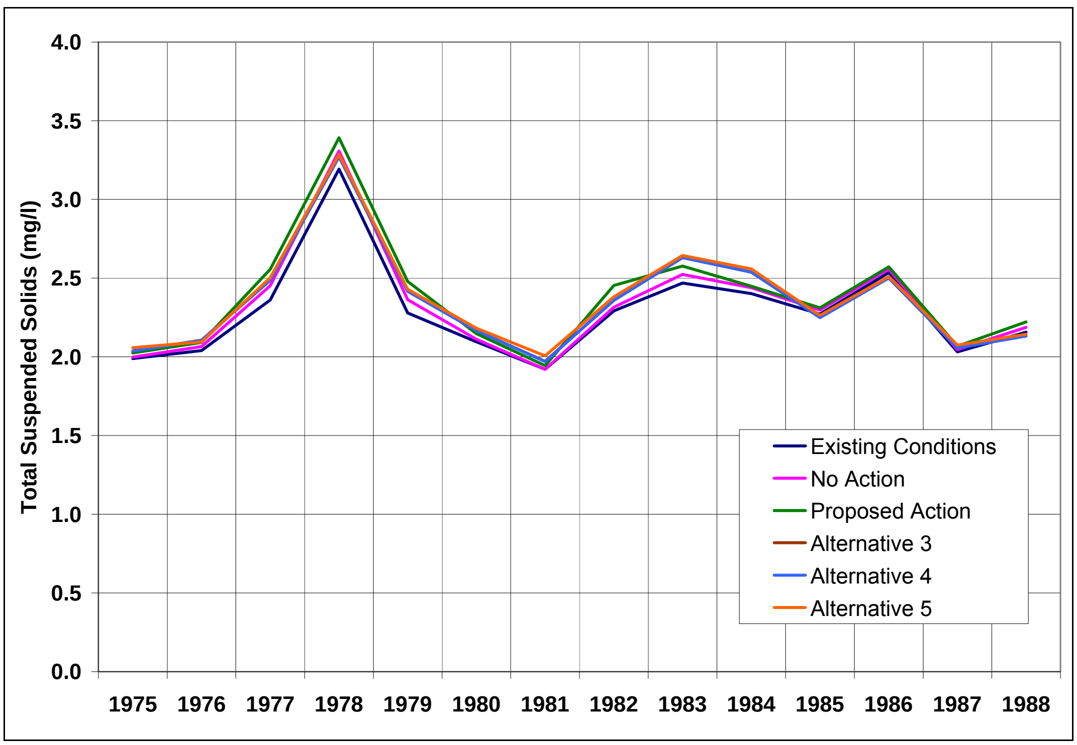


**Figure 50: Predicted Annual Average Total Suspended Sediment Concentration in Granby Reservoir Epilimnion (Existing Conditions and All Alternatives)**

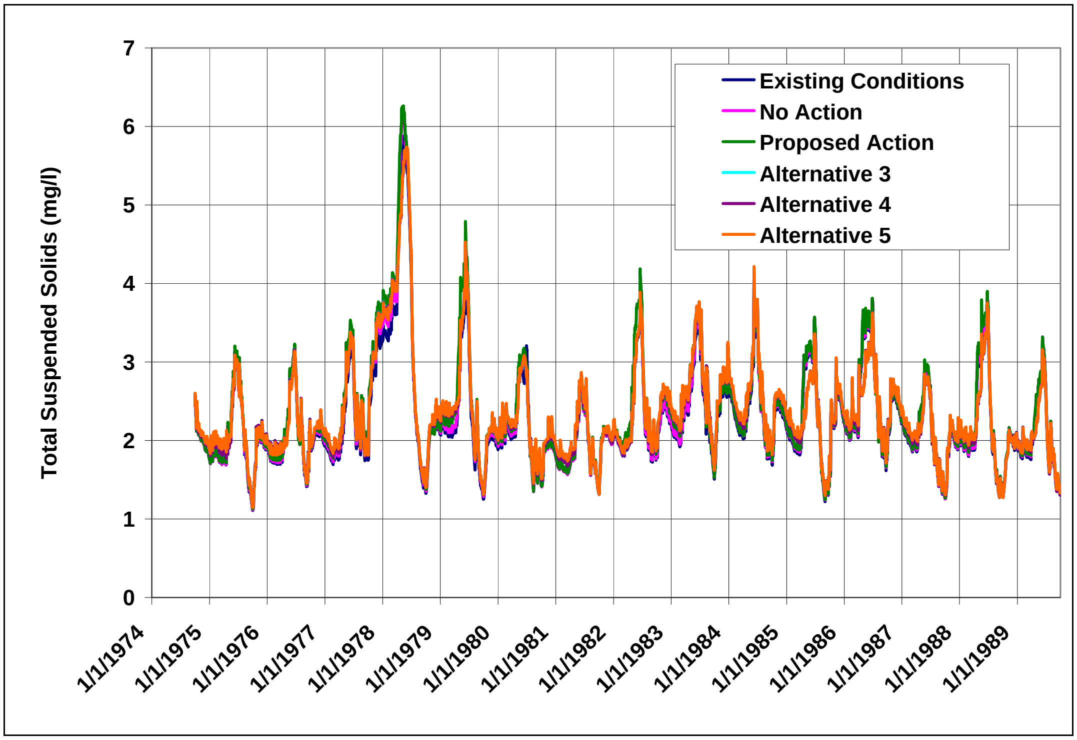


**Figure 51: Predicted Daily Total Suspended Sediment Concentration in Granby Reservoir Epilimnion (Existing Conditions and All Alternatives)**

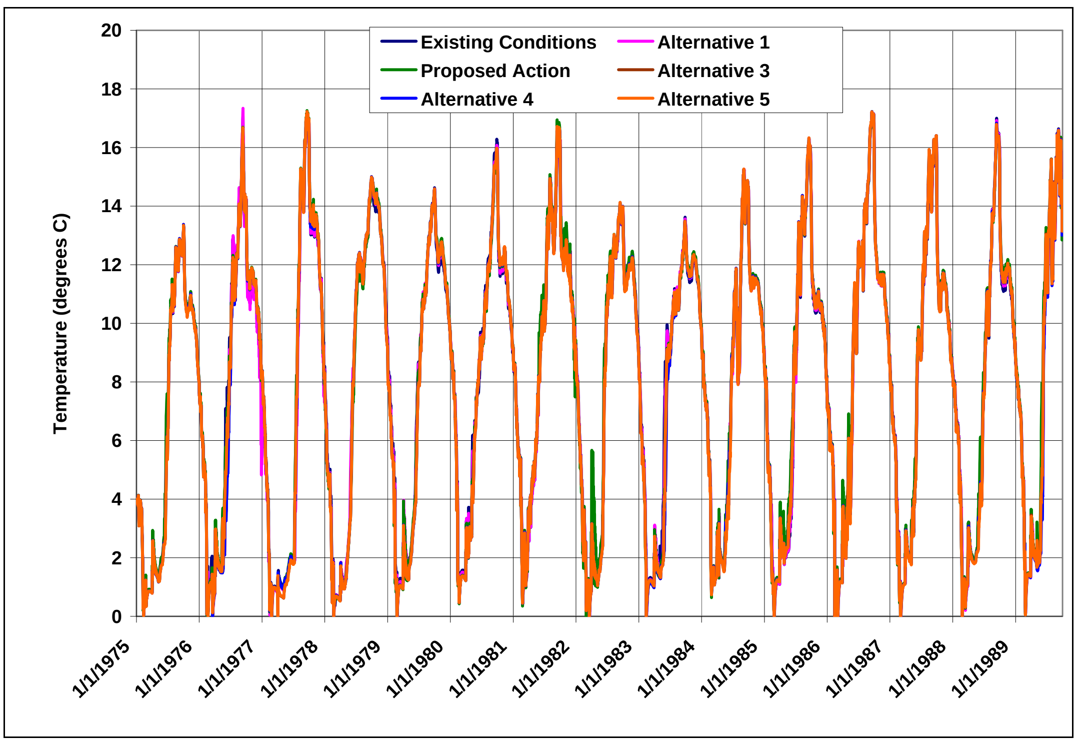


**Figure 52: Simulated Epilimnetic Temperature in Granby Reservoir for Existing Conditions and the Alternatives**

The alternatives were evaluated to determine if standards would be met using model predictions. Granby Reservoir would continue to meet ammonia and nitrate standards. It is anticipated that manganese concentrations would increase over existing conditions for the No Action and Proposed Action alternatives due to lower dissolved oxygen concentrations in the hypolimnion. Thus, the manganese standard for water supply may continue to be exceeded for all of the alternatives. Dissolved oxygen concentrations would continue to exceed the spawning standard under the action alternatives since there are no improvements in dissolved oxygen. No change in hypolimnetic dissolved oxygen is predicted for each of the alternatives, with the exception of the Proposed Action. The Proposed Action results in a 1.6% decrease in the 15$^{th}$ percentile of the predicted epilimnion dissolved oxygen concentrations. Based on the temperature modeling, it is predicted that the temperature standard will continue to be exceeded under the alternatives, in the same manner as it occurs under existing conditions.

#### 11.1.2. Shadow Mountain Reservoir

Predictions for existing conditions and the five alternatives are summarized in Table 42 and displayed in Figure 54 through Figure 69. Annual average and daily output are presented. Trophic state was predicted using average predicted chlorophyll a concentrations (May 1 to November 15) and the Carlson Trophic State Index (Carlson and Simpson, 1977). Changes in water-quality as compared to existing conditions are shown in Table 43. Changes as compared to the No Action alternative are displayed in Table 42. Based on annual averages, the reservoir remains in a mesotrophic state for all alternatives (Figure 64), although on a monthly basis, the trophic state can range between oligotrophic-mesotrophic and eutrophic conditions (Figure 65). Seasonal variations in trophic state for Existing Conditions and the alternatives show that Shadow Mountain borders on eutrophic conditions during the summer.

The increases in total phosphorus and total nitrogen concentrations follow a similar pattern as the increased nutrient loadings into the Three Lakes System, where the Proposed Action and No Action alternatives would have greater loading than Alternatives 3 to 5 (Table 37 and Table 38). Chlorophyll *a* concentrations are predicted to be the same or slightly higher for the alternatives. Clarity would not be expected to change. The daily time series of simulated chlorophyll *a* concentrations is displayed in Figure 60. The general patterns for each alternative are similar, but the peak concentrations differ. This is illustrated in Figure 59 where the peak simulated chlorophyll *a* concentration by year is displayed. The difference between the amount of water pumped from Windy Gap Reservoir to Granby Reservoir for existing conditions and the proposed action is greatest for the later. Thus, predicted peak chlorophyll a concentrations are higher. For each year, either the No Action alternative or the Proposed Action alternative results in the highest peak value.

Note that the model predictions for peak chlorophyll *a* are lower than the observed data for existing conditions. Although the peaks are captured, it is very difficult to simulate the full magnitude of the maximum concentrations. As described in the model documentation (AMEC, 2008), the model was determined to be capable of adequately predicting changes between the alternatives. The model is successful at computing average chlorophyll *a* concentrations and changes in the averages with changes in hydrology. With respect to the alternatives, peak annual chlorophyll *a* concentrations may be underestimated if unanticipated nutrient loads occur.

Total suspended solids concentrations are predicted to increase the same amount for each of the alternatives. Average minimum dissolved oxygen concentrations in the entire reservoir are predicted the same, with the exception of the Proposed Action. Overall, there are no changes in trophic state anticipated with any of the alternatives.

It is anticipated that maximum summertime temperature of Shadow Mountain Reservoir would not increase with any of the action alternatives and may be cooler. This would not occur because of changes in the temperatures of the inflowing water, but instead, it would be due to changes in the amount of flow through Shadow Mountain Reservoir. This conclusion is based on historical data which show that Shadow Mountain Reservoir temperatures vary with flow at the Farr Pumping Plant during August (Figure 53). August is the month of highest temperatures when temperature exceedances are more likely to occur. Higher flows through the Farr Pumping Plant translate into cooler surface temperatures in Shadow Mountain Reservoir. Flows through the Farr Pumping Plant would increase for each action alternative as compared to existing conditions (Figure 32). The largest decrease would occur with the Proposed Action alternative because this alternative results in the largest pumping through the Farr Pumping Plant in August.

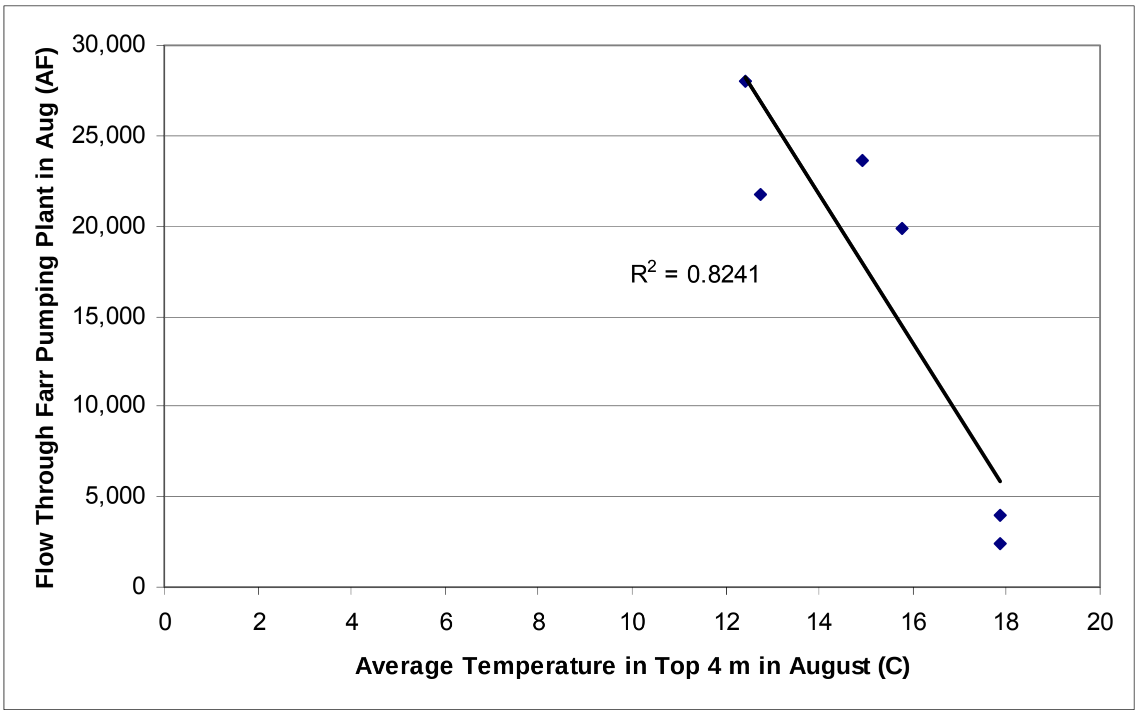


**Figure 53: Relationship between Flow at the Farr Pumping Plant and Surface Temperature in Shadow Mountain Reservoir in August (2001-2006) (Data Sources: USGS, 2007; NCWCD, 2007; USBR, 2007)**

Significant levels of aquatic vegetation or macrophytes in Shadow Mountain Reservoir have been a concern since the reservoir was built (Sisneros, 2007). In general, there are four conditions that can lead to high levels of macrophyte growth in lakes: 1) shallow water, 2) high water transparency, 3) a stable water surface, and 4) the presence of suitable substrate (Lewis, 1992). Shadow Mountain Reservoir has met these conditions since its construction and the all of the action alternatives are not anticipated to result in changes to the four conditions listed above.

Note that rooted macrophytes generally meet their nutrient needs directly from the sediments (Barko, et al., 1986). Thus, they can thrive even in oligotrophic systems (Cooke, et al., 2005). Therefore, changes in nutrient concentrations cannot be expected to result in changes in macrophyte growth and biomass (Cooke, et al., 2005) and, although there are anticipated changes in nutrient concentrations associated with the alternatives, it is not anticipated that these changes will impact the macrophyte problem.

**Table 42: Average Predicted Conditions for Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

| Average Annual Values Over the 15-Year Model Period | | | | | | |
|---|---|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
| Total Phosphorus (µg/l) | 12.4 (4.9 – 20.3) | 13.1 (4.9 – 22.5) | 13.8 (4.9 – 23.8) | 13.4 (5.2 – 21.7) | 13.0 (5.2 – 21.7) | 12.8 (5.3 – 20.9) |
| Total Nitrogen (µg/l) | 275 (190 – 330) | 278 (198 – 332) | 280 (197 – 333) | 276 (197 – 316) | 273 (197 – 315) | 272 (197 – 314) |
| Chlorophyll *a* (µg/l) | 5.7 (1.8 – 10.5) | 5.8 (1.7 – 11.2) | 5.8 (1.7 – 11.2) | 5.8 (1.6 – 11.1) | 5.7 (1.6 – 11.0) | 5.7 (1.6 – 11.4) |
| Peak Chlorophyll *a* (µg/l) | 8.8 | 9.1 | 9.4 | 8.9 | 8.8 | 8.7 |
| Secchi-Disk Depth (m) | 2.0 (1.4 – 3.0) | 2.0 (1.3 – 3.0) | 2.0 (1.3 – 3.1) | 2.0 (1.3 – 3.2) | 2.0 (1.3 – 3.2) | 2.0 (1.3 – 3.2) |
| Trophic State (Index) | Mesotrophic (48) | Mesotrophic (48) | Mesotrophic (48) | Mesotrophic (48) | Mesotrophic (48) | Mesotrophic (48) |
| Minimum DO (mg/l) | 7.1 | 7.1 | 7.0 | 7.1 | 7.1 | 7.1 |
| TSS (mg/l) | 2.0 (1.1 – 5.3) | 2.1 (1.1 – 5.5) | 2.1 (1.1 – 5.5) | 2.1 (1.1 – 5.5) | 2.1 (1.1 – 5.5) | 2.1 (1.1 – 5.4) |

Range of data (min – max) included. All concentrations are for the epilimnion with the exception of minimum dissolved oxygen, which is for the hypolimnion.

**Table 43: Predicted Changes by Alternative for Shadow Mountain Reservoir Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|---|
| Total Phosphorus (µg/l) | +5.6% | +11.3% | +8.1% | +4.8% | +3.2% |
| Total Nitrogen (µg/l) | +1.1% | +1.8% | +0.4% | -0.7% | -1.1% |
| Chlorophyll a (µg/l) | +1.8% | +1.8% | +1.8% | No Change | No Change |
| Peak Chlorophyll a (µg/l) | +3.4% | +6.8% | +1.1% | No Change | -1.1% |
| Secchi-Disk Depth (m) | No Change | No Change | No Change | No Change | No Change |
| Trophic State | No Change | No Change | No Change | No Change | No Change |
| Minimum DO (mg/l) | No Change | -1.4% | No Change | No Change | No Change |
| TSS (mg/l) | +5.0% | +5.0% | +5.0% | +5.0% | +5.0% |

**Table 44: Predicted Changes for Shadow Mountain Reservoir by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|
| Total Phosphorus (µg/l) | +5.3% | +2.3% | -0.8% | -2.3% |
| Total Nitrogen (µg/l) | +0.7% | -0.7% | -1.8% | -2.2% |
| Chlorophyll a (µg/l) | No Change | No Change | -1.7% | -1.7% |
| Peak Chlorophyll a (µg/l) | +3.3% | -2.2% | -3.3% | -4.4% |
| Secchi-Disk Depth (m) | No Change | No Change | No Change | No Change |
| Trophic State | No Change | No Change | No Change | No Change |
| Minimum DO (mg/l) | -1.4% | No Change | No Change | No Change |
| TSS (mg/l) | No Change | No Change | No Change | No Change |

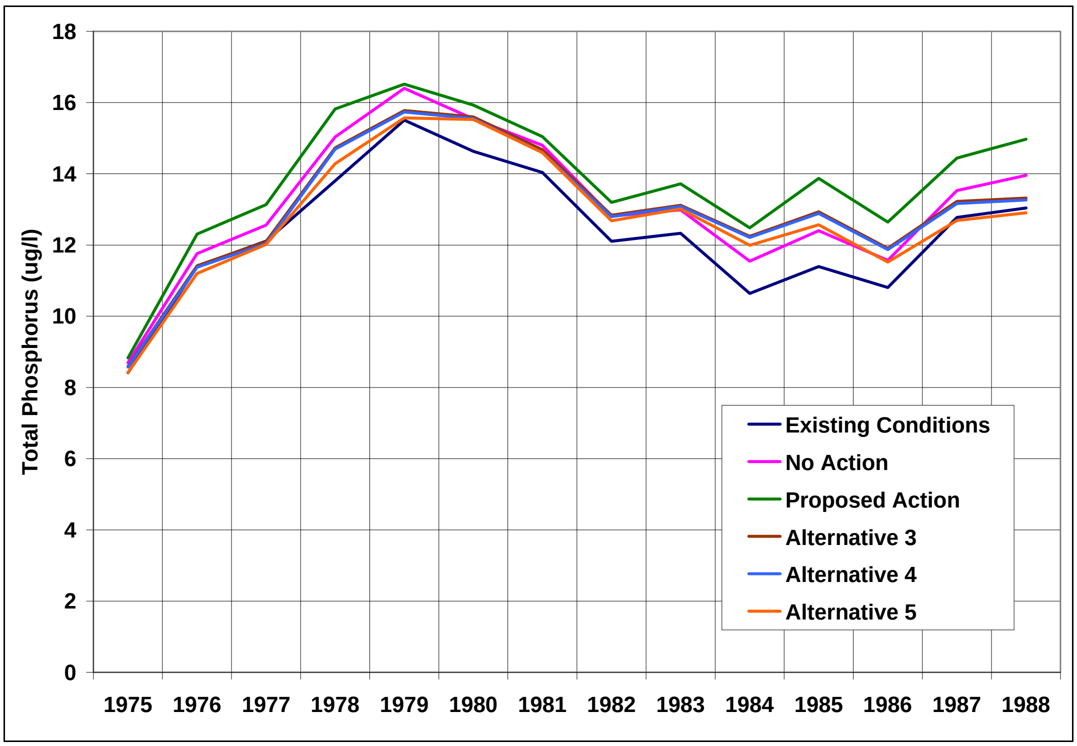


**Figure 54: Predicted Annual Average Total Phosphorus Concentrations in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

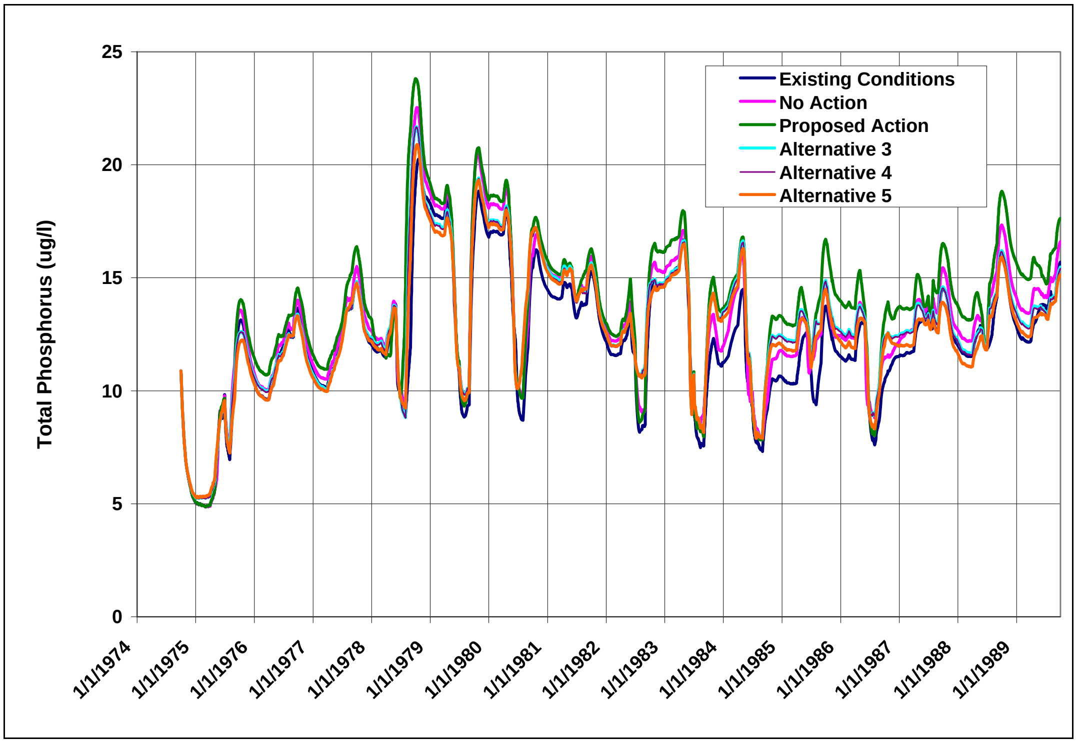


**Figure 55: Predicted Daily Total Phosphorus Concentrations in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

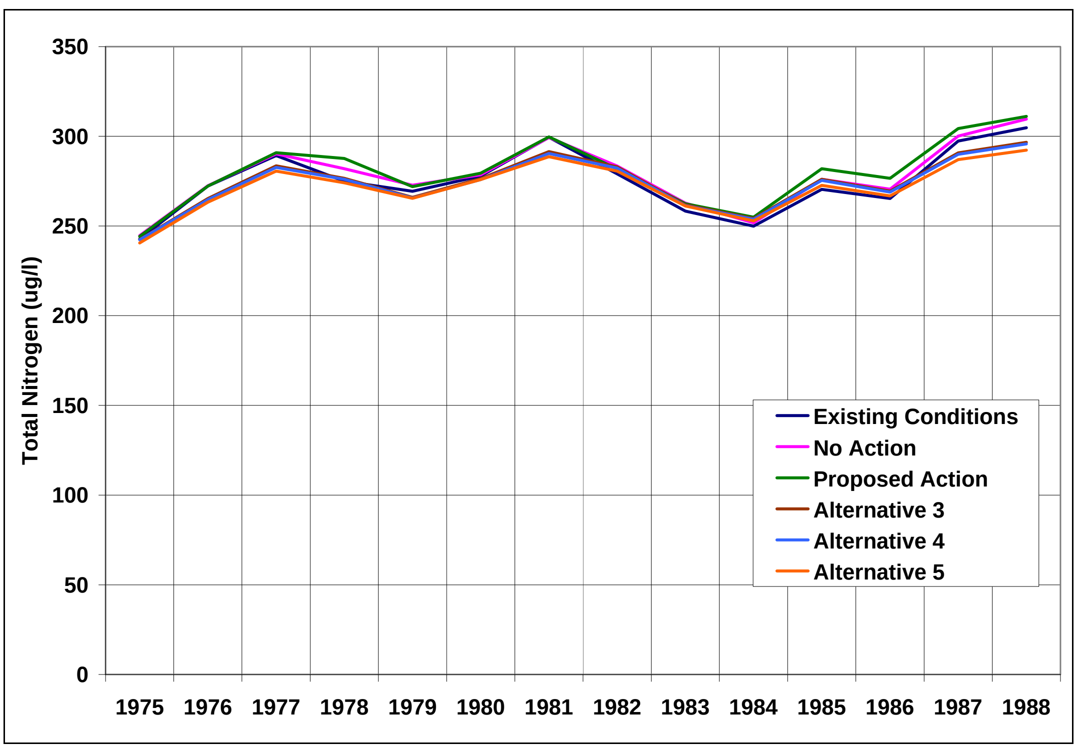


**Figure 56: Predicted Annual Average Total Nitrogen Concentrations in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

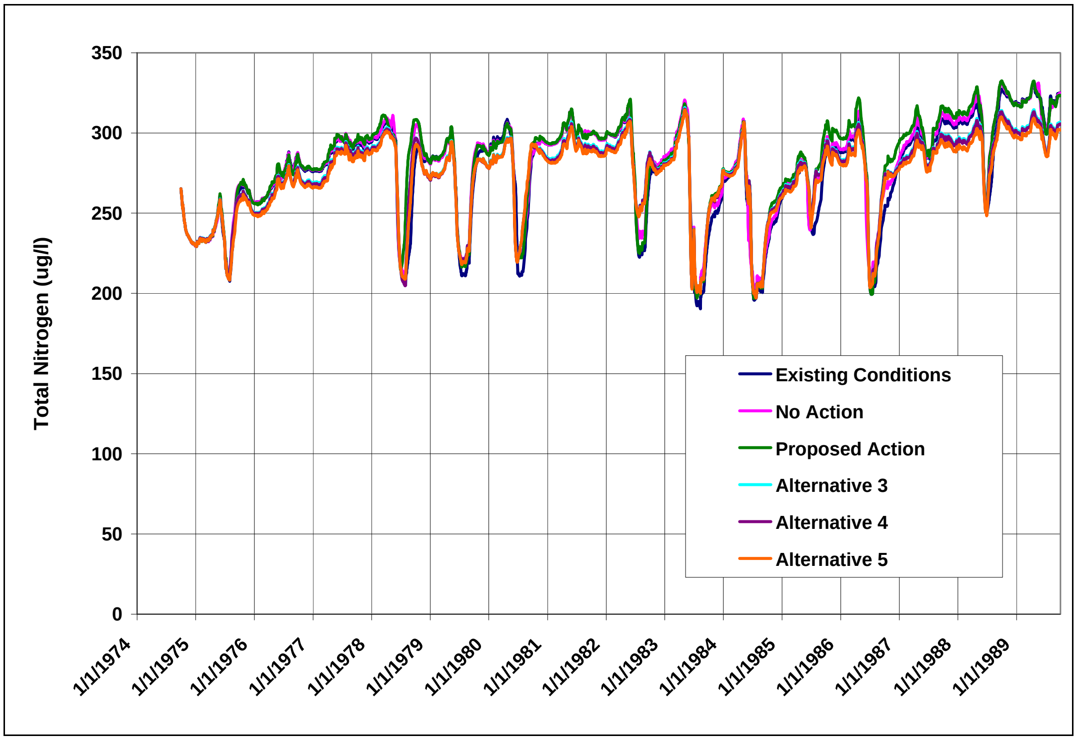


**Figure 57: Predicted Daily Total Nitrogen Concentrations in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

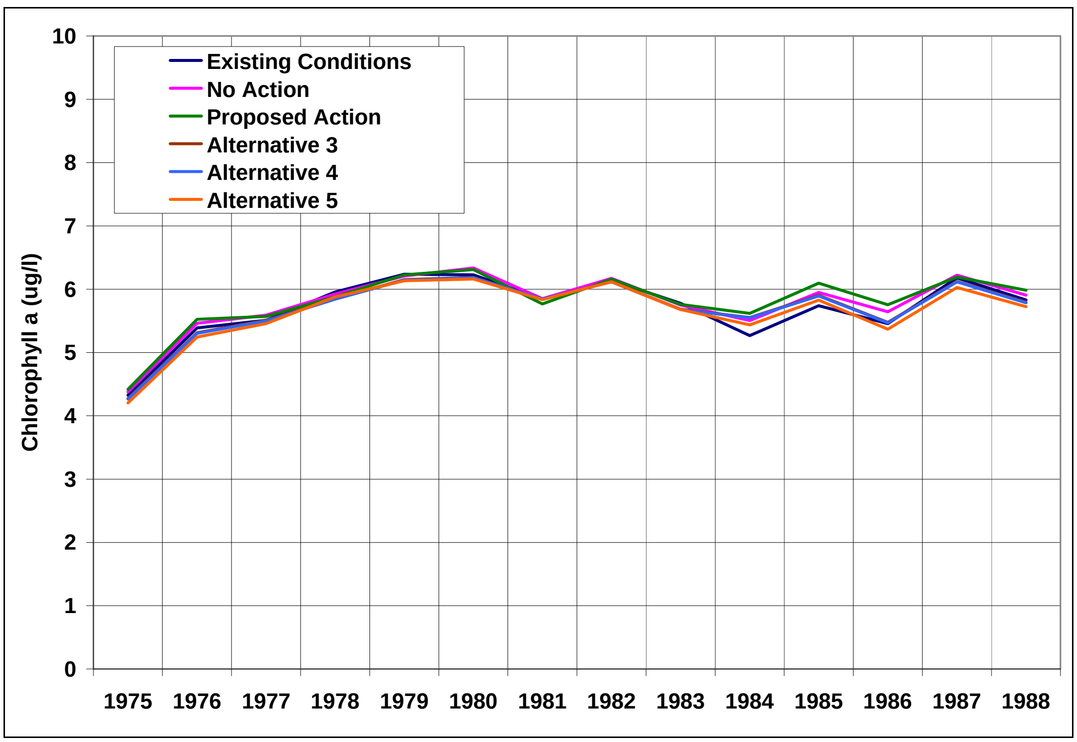


**Figure 58: Predicted Annual Average Chlorophyll *a* Concentrations in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

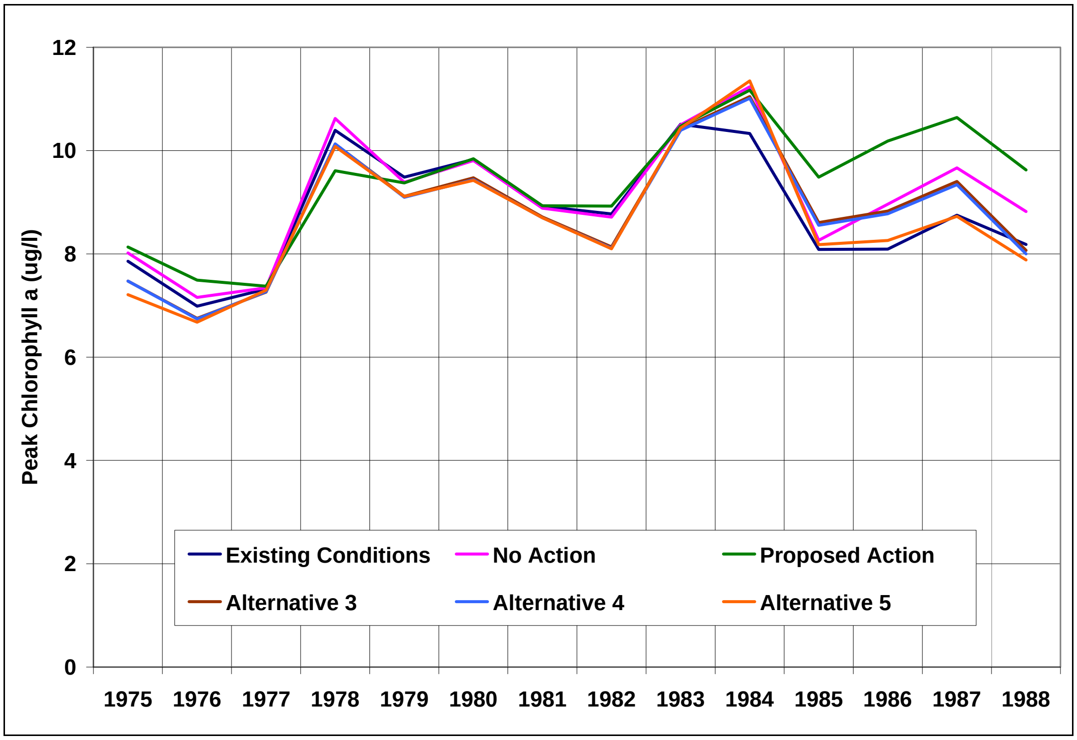


**Figure 59: Simulated Peak Chlorophyll *a* Concentrations in Shadow Mountain Reservoir by Year for Existing Conditions and All Alternatives**

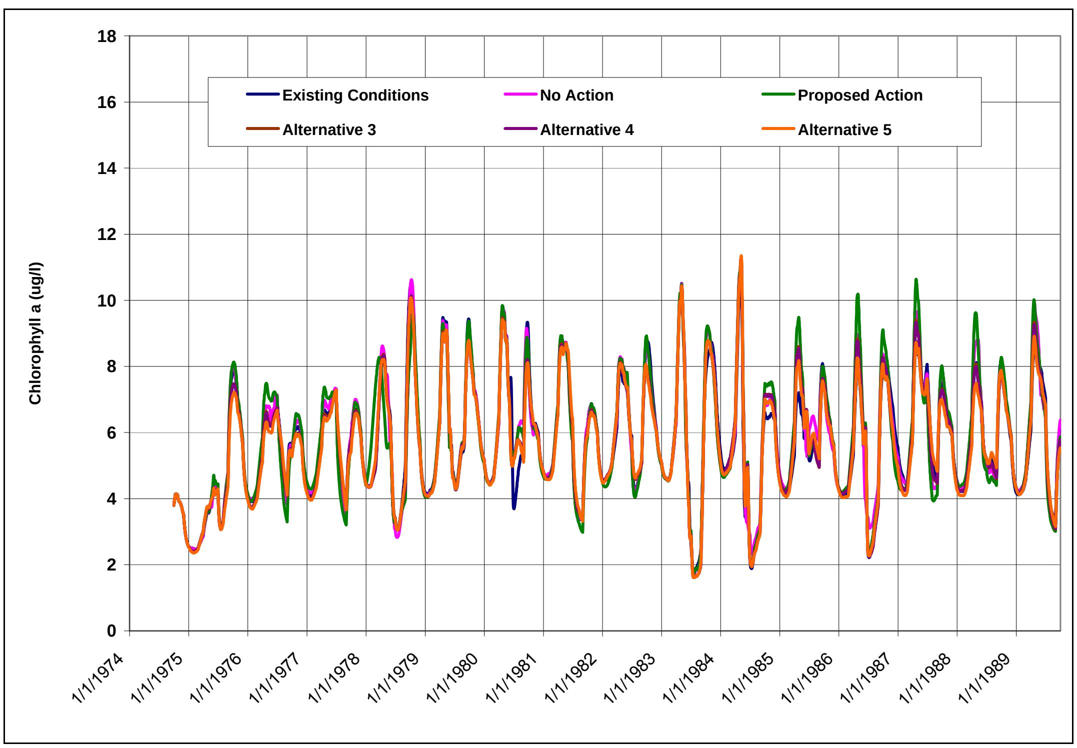


**Figure 60: Simulated Daily Chlorophyll *a* Concentrations in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

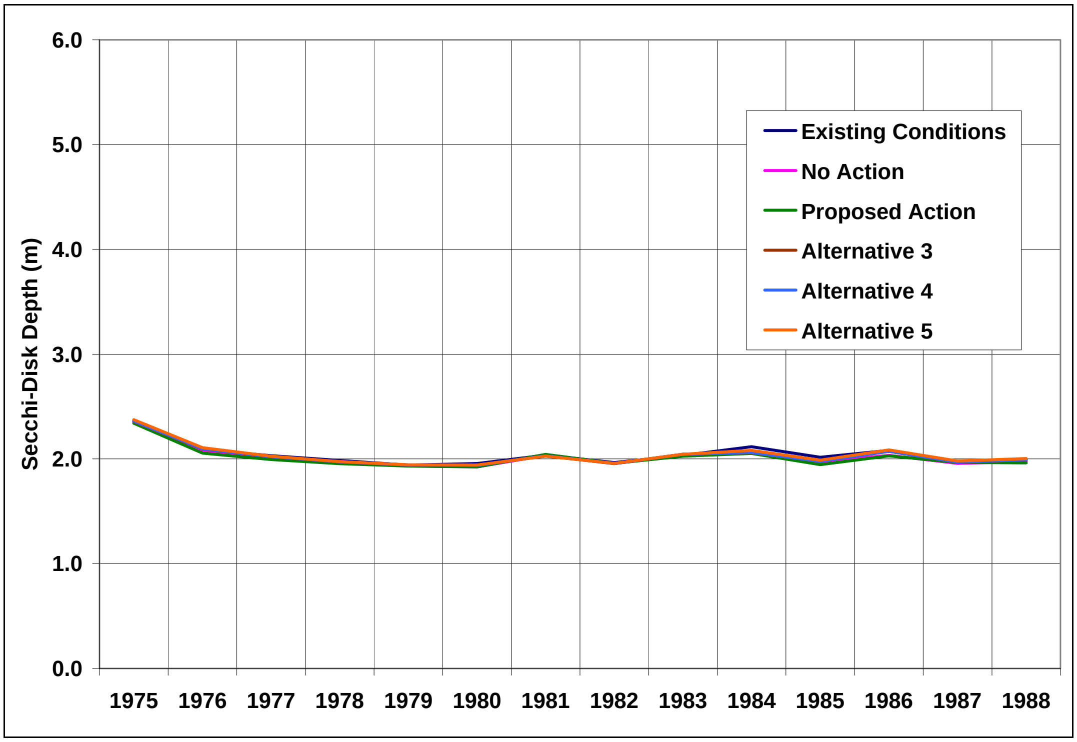


**Figure 61: Predicted Annual Average Secchi-Disk Depths in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

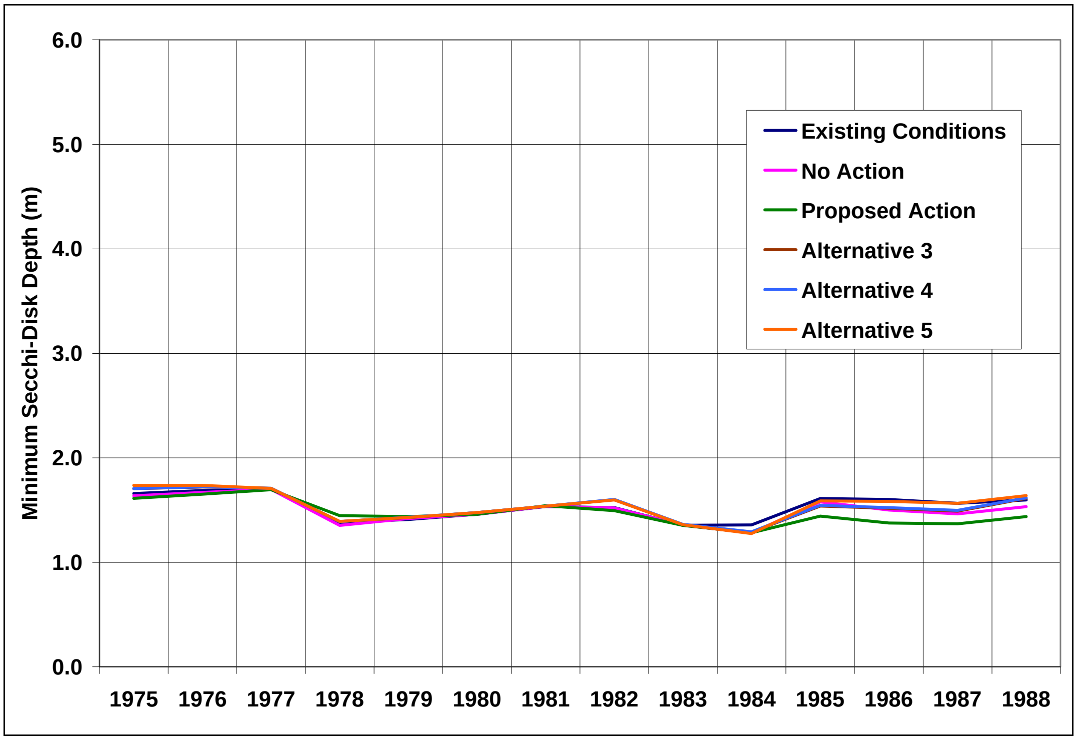


**Figure 62: Predicted Minimum Secchi-Disk Depths in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

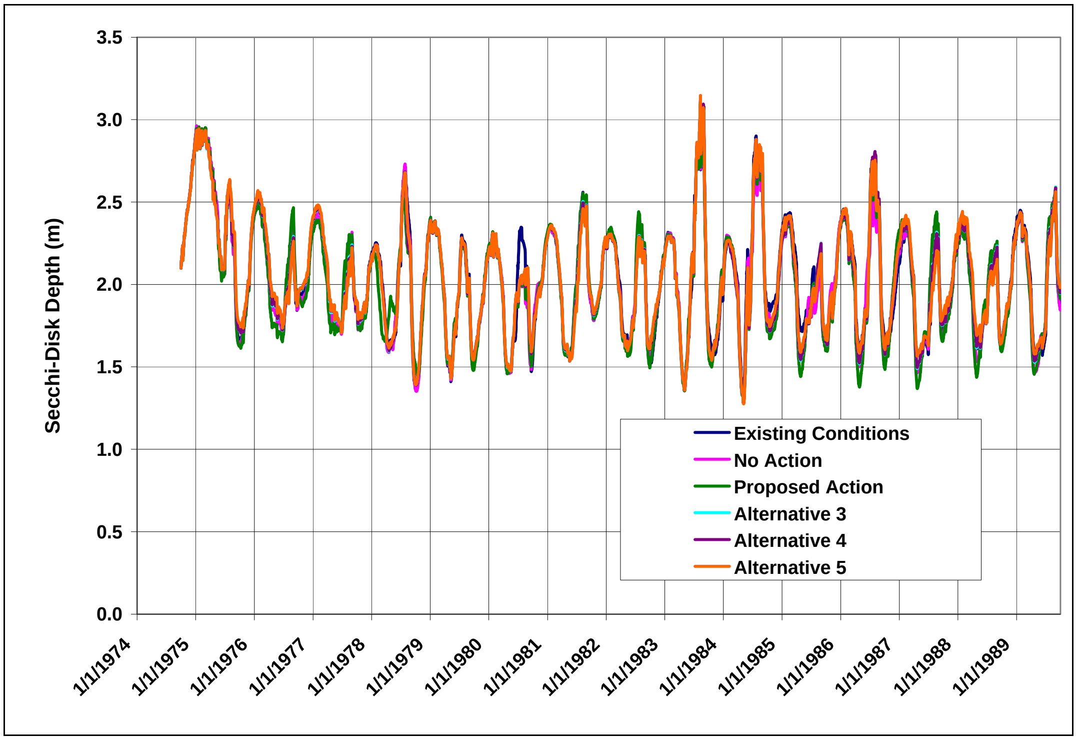


**Figure 63: Predicted Daily Secchi-Disk Depths in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

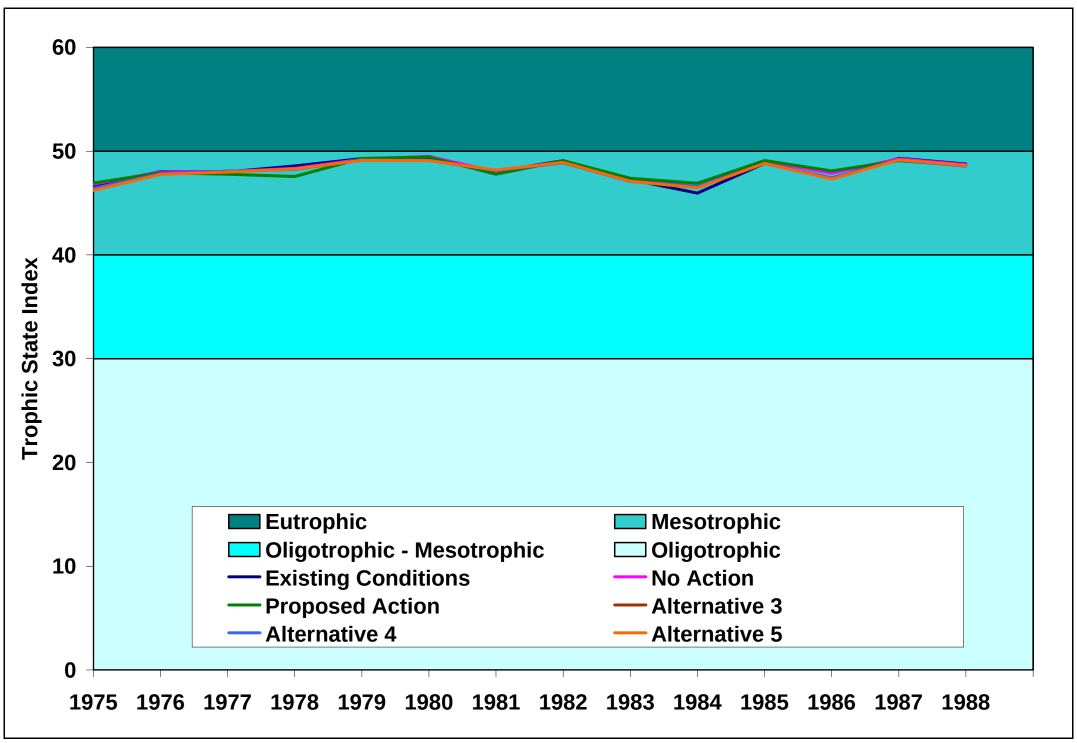


**Figure 64: Predicted Trophic State Indices in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

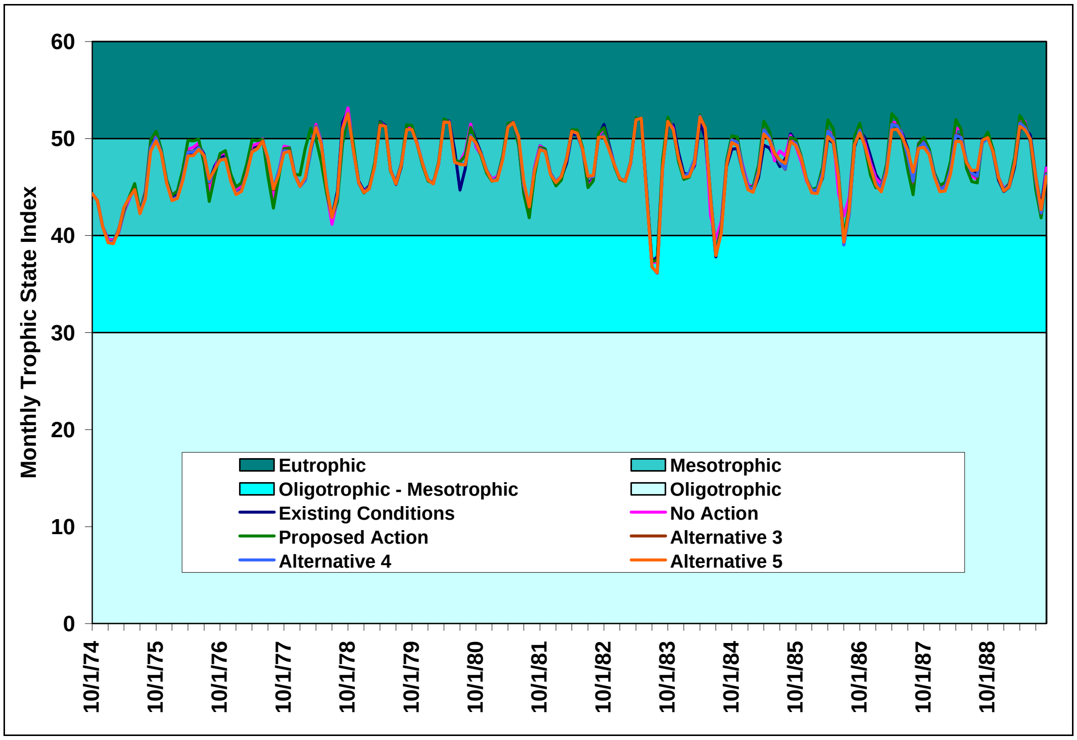


**Figure 65: Predicted Monthly Trophic State Index for Shadow Mountain Reservoir**

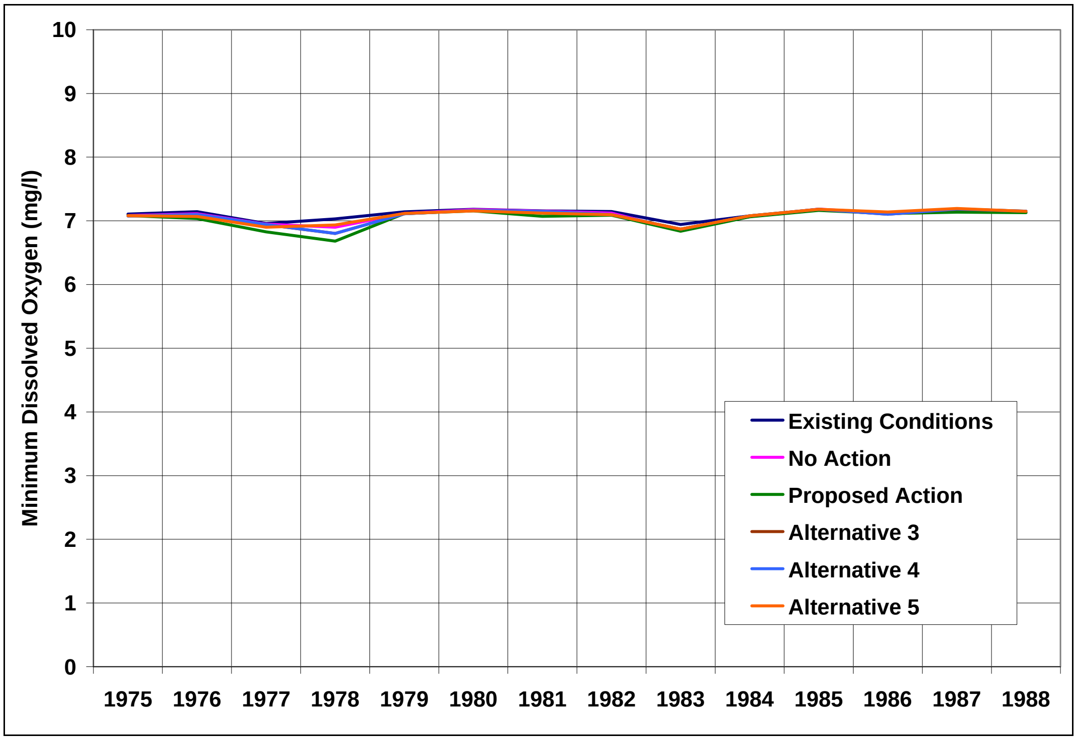


**Figure 66: Predicted Minimum Dissolved Oxygen in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

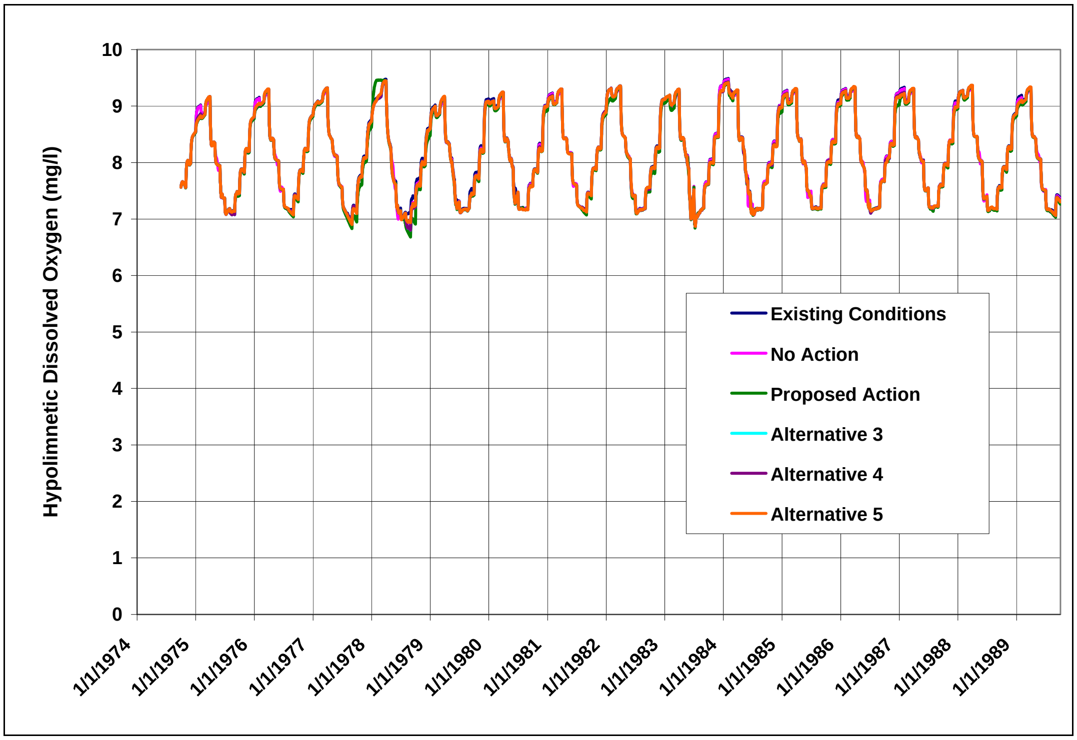


**Figure 67: Predicted Daily Dissolved Oxygen in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

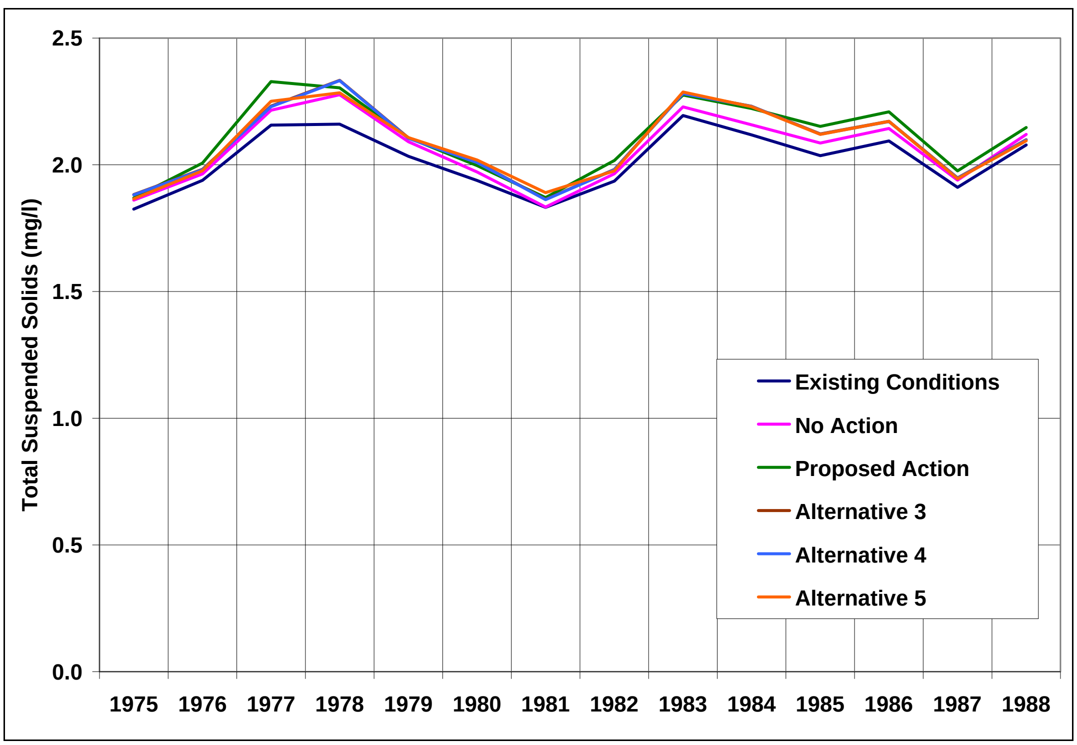


**Figure 68: Predicted Annual Average Total Suspended Sediment Concentration in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

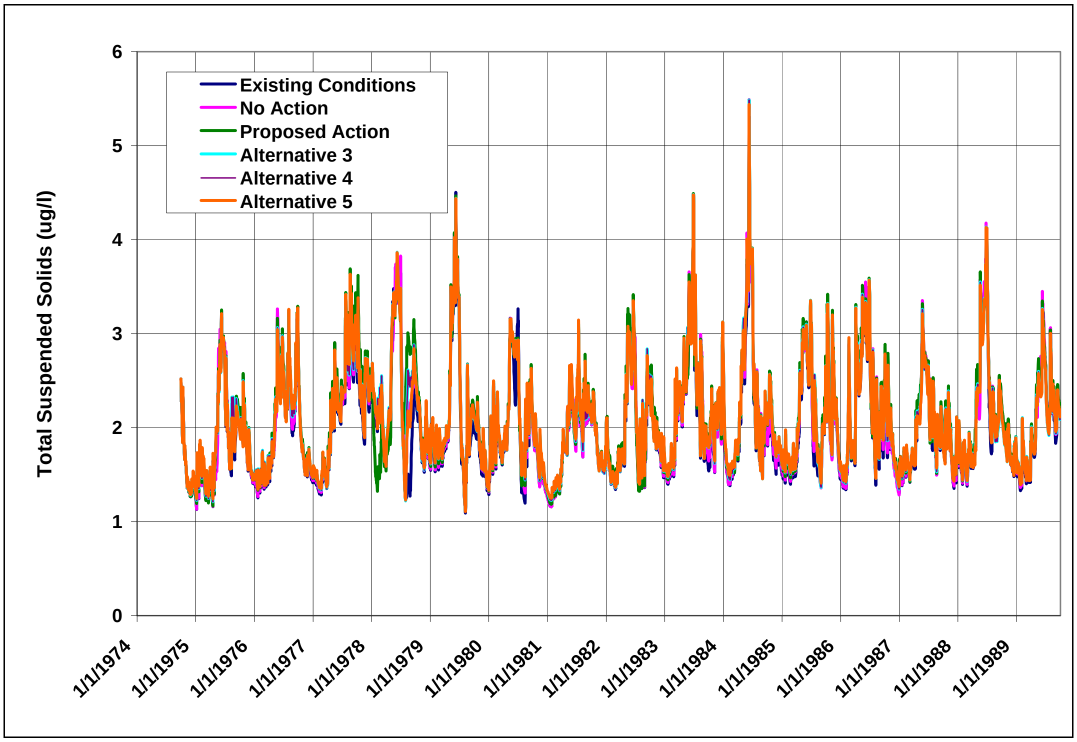


**Figure 69: Predicted Daily Total Suspended Sediment Concentration in Shadow Mountain Reservoir (Existing Conditions and All Alternatives)**

The alternatives were evaluated to determine if standards would be met or exceeded using model predictions. Shadow Mountain Reservoir would continue to meet dissolved oxygen, ammonia, and nitrate standards. It is anticipated that manganese concentrations would stay about the same for each alternative with the exception of the Proposed Action, which is predicted to result in slightly increased manganese concentrations based on the minimum dissolved oxygen concentrations in the hypolimnion. Thus, the manganese standard for water supply may not be met under any of the alternatives, similar to existing conditions. Temperature standards would continue to be met under any of the alternatives.

### 11.1.3. Grand Lake

Average annual predictions for existing conditions and the five alternatives are displayed over the simulation period in Figure 70 - Figure 85 and summarized in Table 45. Annual average and daily output are presented. Trophic state was predicted using average predicted chlorophyll *a* concentrations (May 1 to November 15) and the Carlson Trophic State Index (Carlson and Simpson, 1977). Predicted changes in water quality relative to existing conditions are shown in Table 46. Predicted changes relative to the No Action alternative are displayed in Table 47. The following observations are made based on model results.

1. All alternatives result in increases in phosphorus concentrations relative to existing conditions. The largest increase in in-reservoir phosphorus concentrations (12%) is for the Proposed Action alternative.
2. Changes in total nitrogen concentrations relative to existing conditions are small (< 2%).
3. There is no change in estimated average annual chlorophyll *a*, clarity, and trophic state between alternatives.
4. There is little change in total suspended sediment concentrations.
5. Dissolved oxygen concentrations in the hypolimnion are slightly lower for the alternatives.

The magnitude of the chlorophyll *a* change can be checked with the following analysis. Grand Lake has been found to be co-limited, therefore one should consider both phosphorus and nitrogen. Looking at nitrogen, the predicted change in total nitrogen from existing conditions to the No Action alternative is about 4 µg/l. The concentration increase of total inorganic nitrogen, the form that is bioavailable to algae, would be lower than the total nitrogen concentration. Algae are about 7.2% nitrogen and 1% chlorophyll *a* (Chapra, 1997). Assuming 100% efficiency, the theoretical increase in chlorophyll *a* due to the increase in total nitrogen is about 0.5 µg/l chlorophyll *a*. The actual value would be lower than the theoretical value because algae are not 100% efficient in the conversion. In addition, other processes such as settling, grazing by zooplankton, death, and flushing cause reductions in chlorophyll *a*. Assuming that the actual value is 1/8th of the theoretical value (A. Horne, personal communication 2006), one could expect an increase in chlorophyll *a* on the order of 0.1 µg/l.

Similarly, the predicted change in total phosphorus concentration from existing conditions under the Proposed Action is about 1 µg/l. Algae are about 1% phosphorus (Chapra, 1997). The theoretical increase in chlorophyll *a* from a 1 µg/l increase in bioavailable phosphorus is about 1 µg/l chlorophyll *a*. Assuming that the actual value is 1/10th that of the theoretical value (A. Horne, personal communication 2006), one would expect an increase in chlorophyll *a* on the order of 0.1 µg/l. Thus, one would anticipate a small change in chlorophyll *a* due to the increased nutrient loads predicted by this study. This is consistent with the results reported in Table 45. The results for clarity and trophic state are also consistent with the chlorophyll *a* results.

The daily time series of simulated chlorophyll *a* concentrations is displayed in Figure 76. The general patterns for each alternative are similar, but the peak concentrations differ. This is illustrated in Figure 75 where the peak simulated chlorophyll *a* concentration by year is displayed. For each year, either the No Action alternative or the Proposed Action alternative results in the highest peak value.

Note that the model predictions for peak chlorophyll *a* are lower than the observed data for existing conditions. Although the peaks are captured, it is very difficult to simulate the full magnitude of the maximum concentrations. As described in the model documentation (AMEC, 2008), the model was determined to be capable of adequately predicting changes between the alternatives.

The increases in total phosphorus concentrations follow the same general patterns as the increased phosphorus loadings into the Three Lakes System (Table 37). Total nitrogen concentrations do not follow the same patterns as shown in Table 38. Although there is a slight increase in nitrogen loading (with the exception of Alternative 5), there is also an increase in the flushing rate of Grand Lake with the alternative scenarios (as indicated by Table 34). Given the same amount of loading, a higher flushing rate can serve to improve water quality, while higher loadings tend to worsen water quality. Since the additional nitrogen loading is a small percentage of the total nitrogen loading, the increased flushing rate can have a greater impact and the nitrogen concentrations can decrease. This happens for Alternatives 3, 4, and 5 where the increased nitrogen load is <1%.

Predicted annual average hypolimnetic dissolved oxygen concentrations would decrease for all of the alternatives. The highest change would occur with the No Action alternative.

Based on average chlorophyll a results, no changes in trophic state would be anticipated for any of the alternatives. No increases in lake temperature are predicted for any of the alternatives based on the simulated temperatures in Granby Reservoir and the relationship between Farr pumping and Shadow Mountain Reservoir temperatures.

**Table 45: Average Predicted Conditions for Grand Lake (Existing Conditions and All Alternatives)**

| Average Annual Values Over the 15-Year Model Period | | | | | | |
|---|---|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
| Total Phosphorus (µg/l) | 8.3 (4.3 – 13.7) | 8.8 (4.1 – 17.0) | 9.3 (4.2 – 19.9) | 8.8 (4.2 – 16.7) | 8.8 (4.2 – 16.7) | 8.7 (4.2 – 15.6) |
| Total Nitrogen (µg/l) | 247 (174 – 330) | 248 (157 – 384) | 251 (156 – 329) | 246 (164 – 334) | 246 (163 – 334) | 245 (163 – 333) |
| Chlorophyll *a* (µg/l) | 4.9 (2.1 – 10.2) | 5.1 (2.2 – 10.5) | 5.2 (2.2 – 9.7) | 5.1 (2.2 – 10.2) | 5.0 (2.1 – 10.2) | 5.0 (2.1 – 10.2) |
| Peak Chlorophyll *a* (µg/l) | 7.4 | 7.7 | 7.8 | 7.5 | 7.5 | 7.4 |
| Secchi-Disk Depth (m) | 2.6 (1.3 – 4.3) | 2.5 (1.3 – 3.9) | 2.5 (1.4 – 4.3) | 2.5 (1.3 – 4.2) | 2.5 (1.3 – 4.2) | 2.6 (1.3 – 4.2) |
| Trophic State (Index) | Mesotrophic (47) | Mesotrophic (47) | Mesotrophic (47) | Mesotrophic (47) | Mesotrophic (47) | Mesotrophic (47) |
| Hypolimnetic Minimum DO (mg/l) | 5.4 | 4.8 | 5.0 | 5.1 | 5.1 | 5.1 |
| TSS (mg/l) | 1.8 (1.0 – 4.1) | 1.8 (1.1 – 4.3) | 1.9 (1.1 – 4.2) | 1.9 (1.2 – 4.2) | 1.9 (1.2 – 4.2) | 1.8 (1.2 – 4.2) |

Range of data (min – max) included. All concentrations are for the epilimnion with the exception of minimum dissolved oxygen, which is for the hypolimnion.

**Table 46: Predicted Changes by Alternative for Grand Lake Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|---|
| Total Phosphorus (µg/l) | +6.0% | +12.0% | +6.0% | +6.0% | +4.8% |
| Total Nitrogen (µg/l) | +0.4% | +1.6% | -0.4% | -0.4% | -0.8% |
| Chlorophyll *a* (µg/l) | +4.2% | +6.1% | +4.2% | +2.0% | +2.0% |
| Peak Chlorophyll *a* (µg/l) | +4.1% | +5.4% | +1.4% | +1.4% | No Change |
| Secchi-Disk Depth (m) | -3.8% | -3.8% | -3.8% | -3.8% | No Change |
| Trophic State | No Change | No Change | No Change | No Change | No Change |
| Hypolimnetic Minimum DO (mg/l) | -11.1% | -7.4% | -5.6% | -5.6% | -5.6% |
| TSS (mg/l) | No Change | +5.6% | +5.6% | +5.6% | No Change |

**Table 47: Predicted Changes for Grand Lake by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|
| Total Phosphorus (µg/l) | +5.7% | No Change | No Change | -1.1% |
| Total Nitrogen (µg/l) | +1.2% | -0.8% | -0.8% | -1.2% |
| Chlorophyll *a* (µg/l) | +1.9% | No Change | -1.9% | -1.9% |
| Peak Chlorophyll *a* (µg/l) | +1.3% | -2.6% | -2.6% | -3.9% |
| Secchi-Disk Depth (m) | No Change | No Change | No Change | +4.0% |
| Trophic State | No Change | No Change | No Change | No Change |
| Minimum DO (mg/l) | +4.2% | +6.3% | +6.3% | +6.3% |
| TSS (mg/l) | +5.6% | +5.6% | +5.6% | No Change |

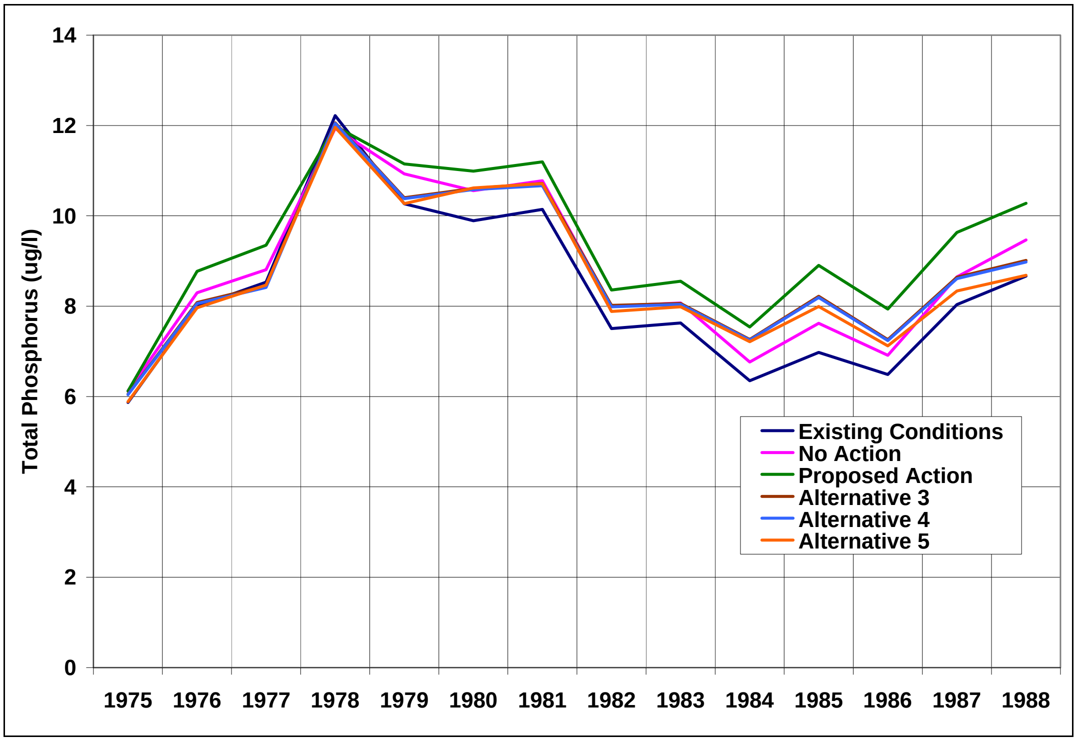


**Figure 70: Predicted Annual Average Total Phosphorus Concentrations in Grand Lake Epilimnion (Existing Conditions and All Alternatives)**

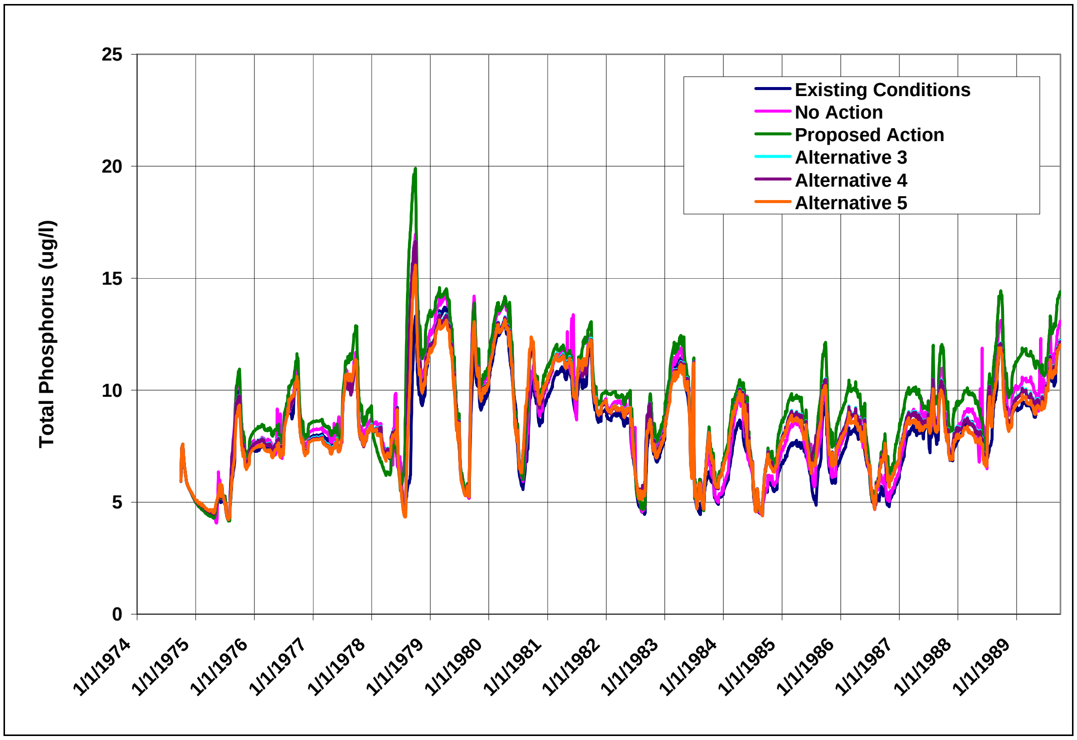


**Figure 71: Predicted Daily Total Phosphorus Concentrations in Grand Lake Epilimnion (Existing Conditions and All Alternatives)**

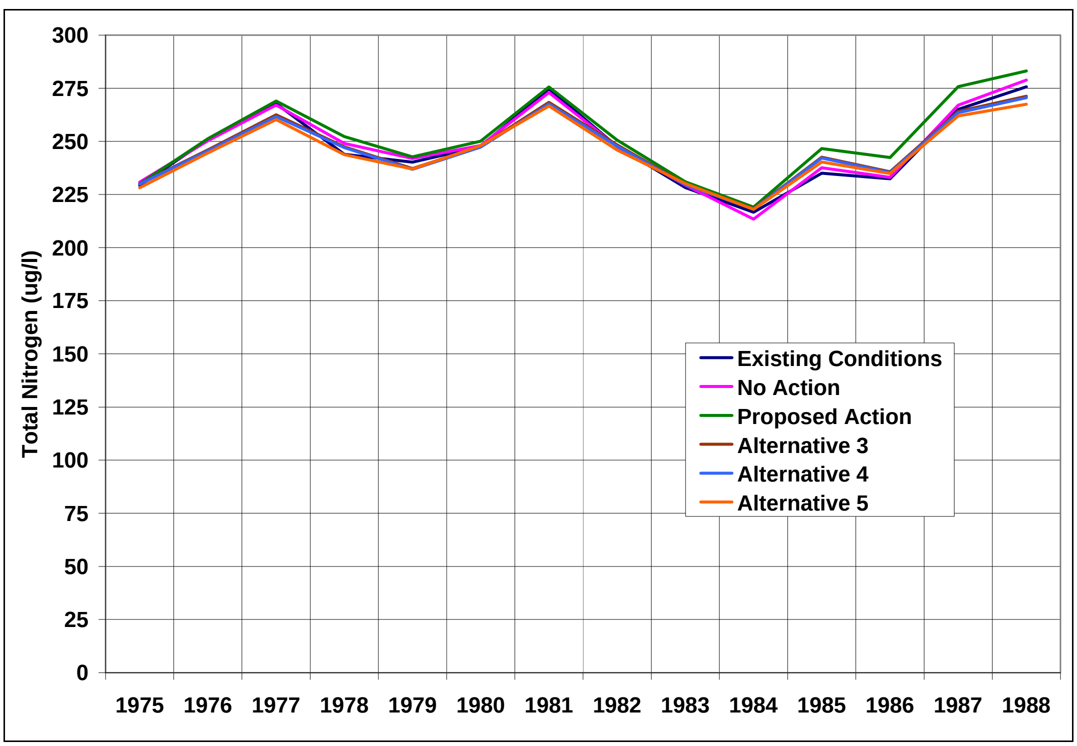


**Figure 72: Predicted Annual Average Total Nitrogen Concentrations in Grand Lake Epilimnion (Existing Conditions and All Alternatives)**

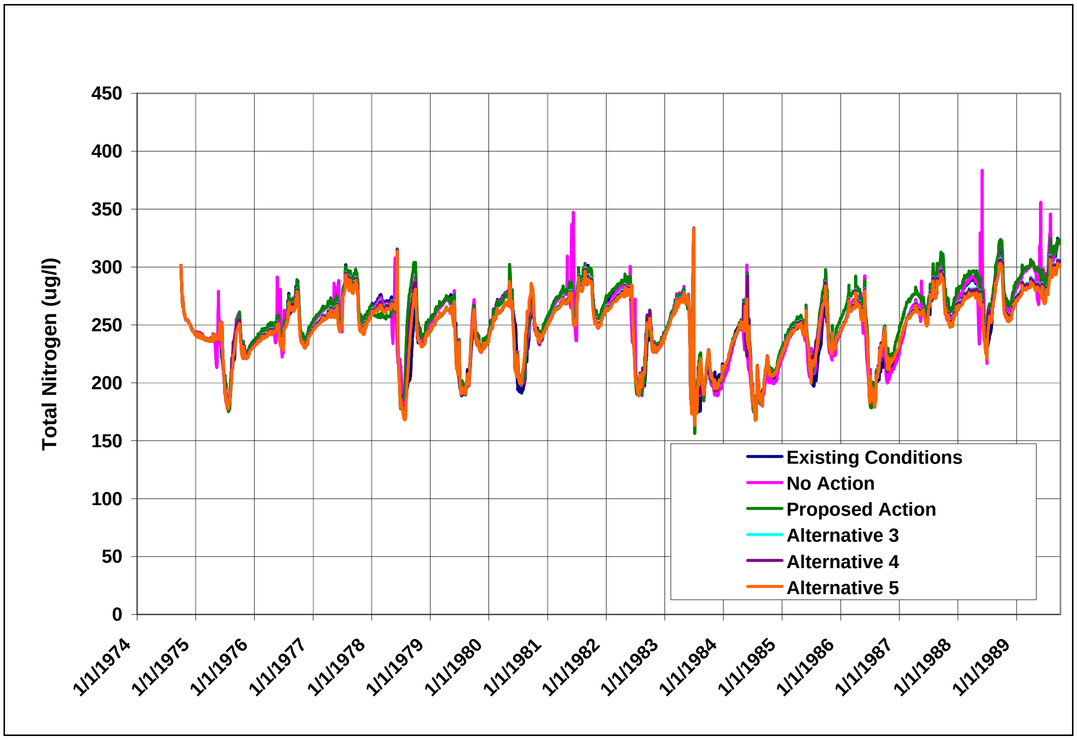


**Figure 73: Predicted Daily Total Nitrogen Concentrations in Grand Lake Epilimnion (Existing Conditions and All Alternatives)**

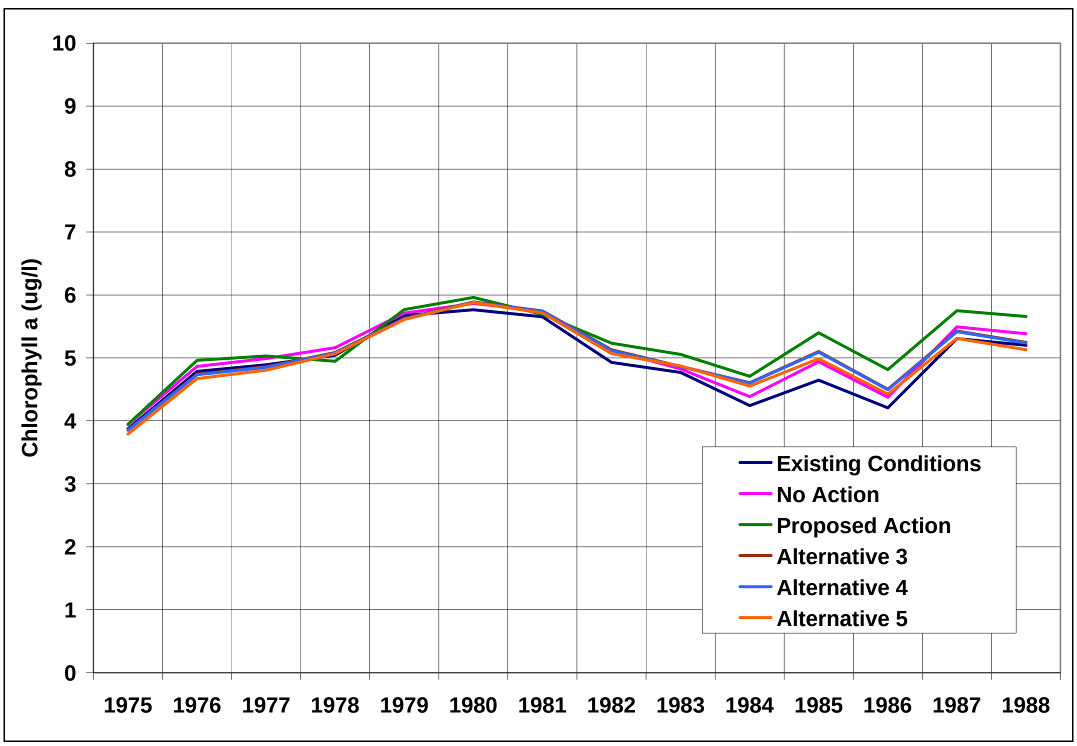


**Figure 74: Predicted Annual Average Chlorophyll *a* Concentrations in Grand Lake (Existing Conditions and All Alternatives)**

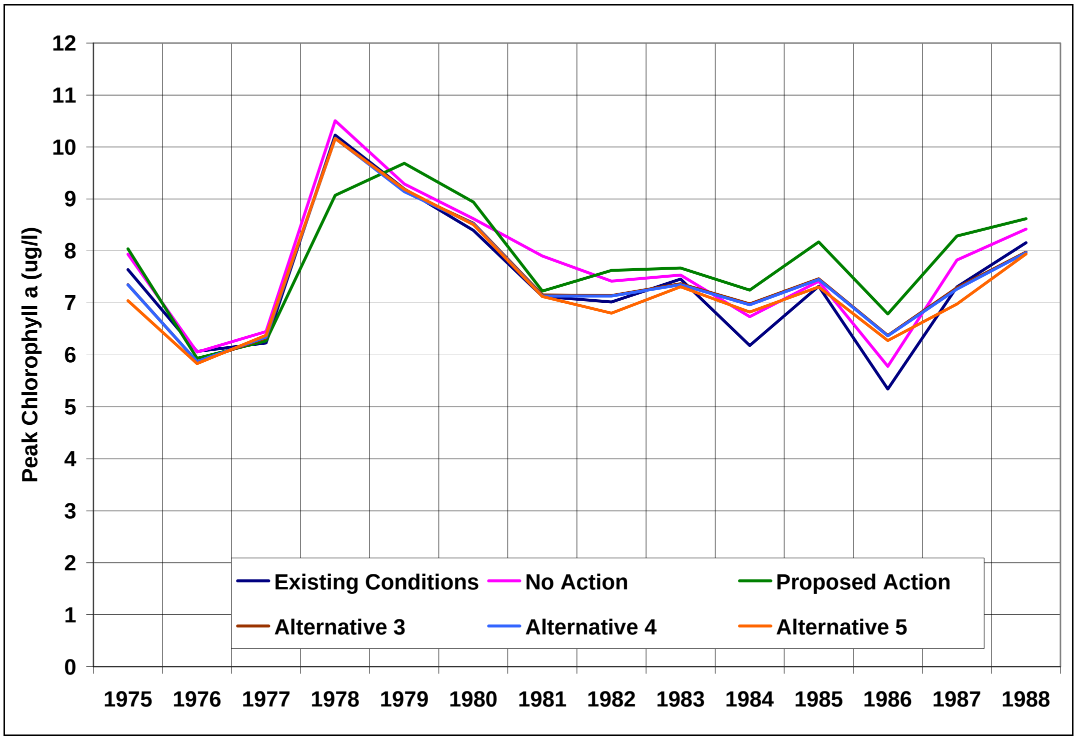


**Figure 75: Predicted Peak Chlorophyll *a* Concentrations in Grand Lake by Year (Existing Conditions and the Alternatives)**

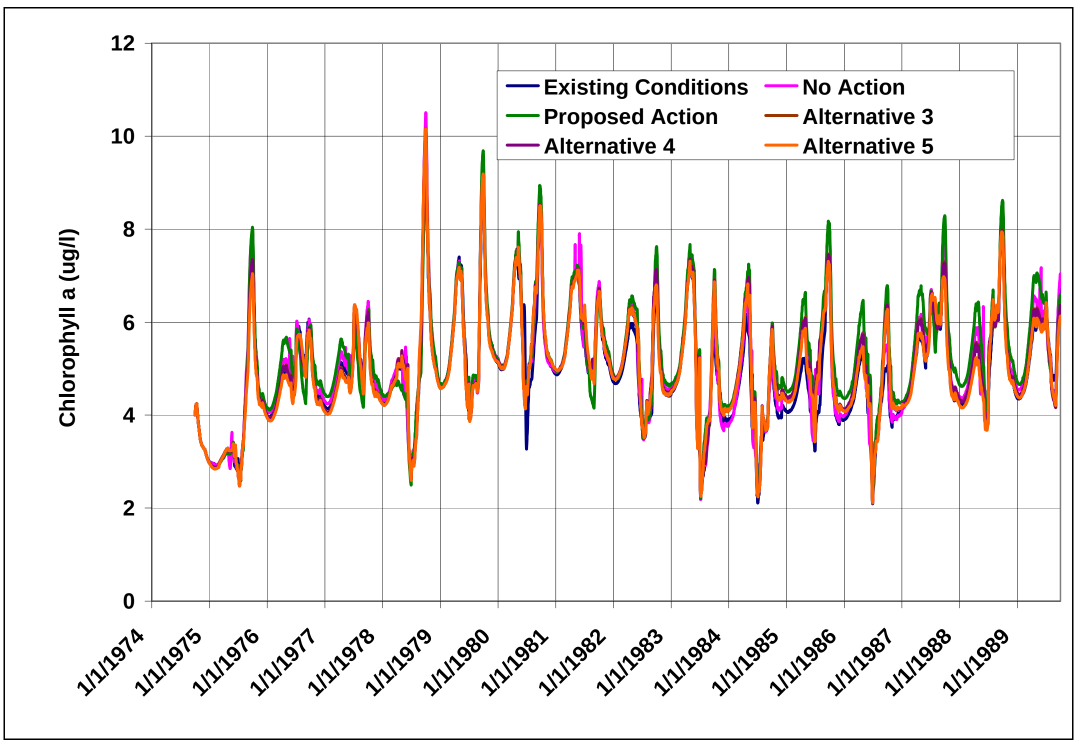


**Figure 76: Predicted Daily Chlorophyll *a* Concentrations in Grand Lake (Existing Conditions and the Alternatives)**

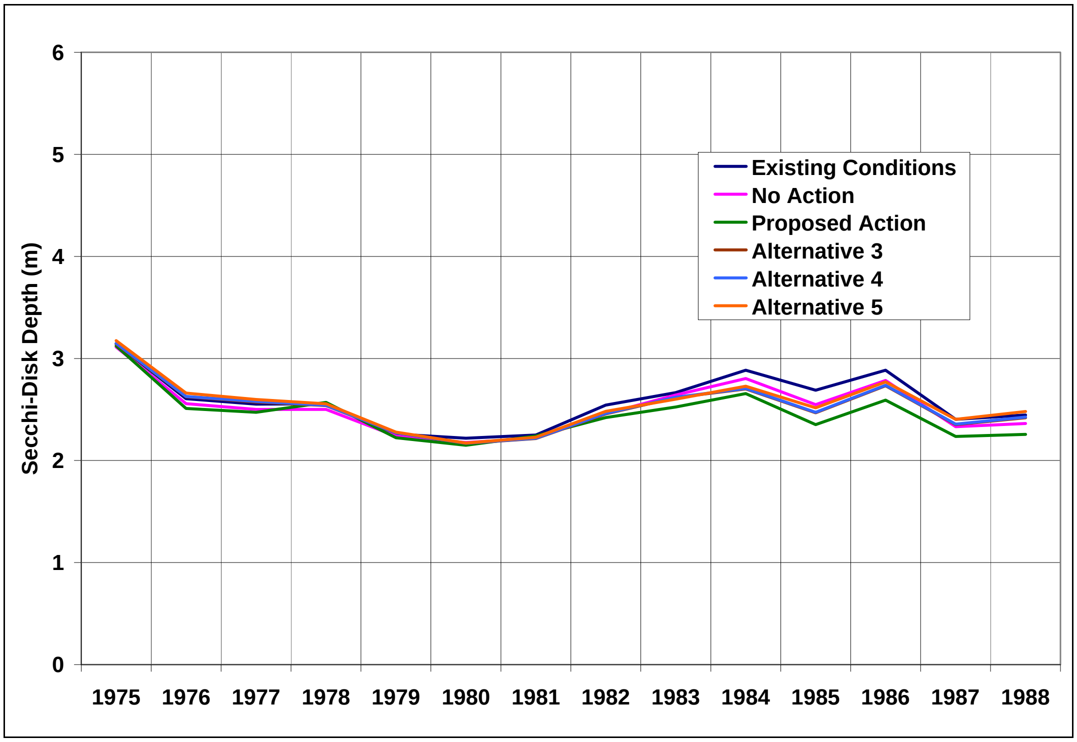


**Figure 77: Predicted Annual Average Secchi-Disk Depths in Grand Lake (Existing Conditions and All Alternatives)**

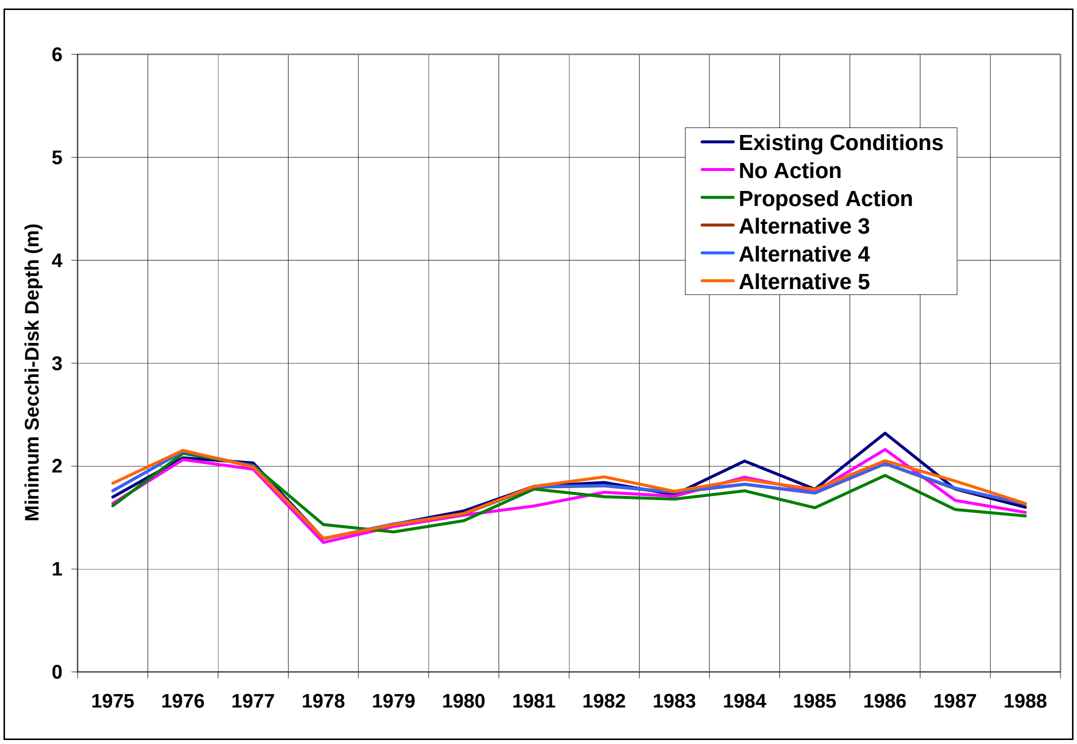


**Figure 78: Predicted Minimum Secchi-Disk Depths in Grand Lake (Existing Conditions and All Alternatives)**

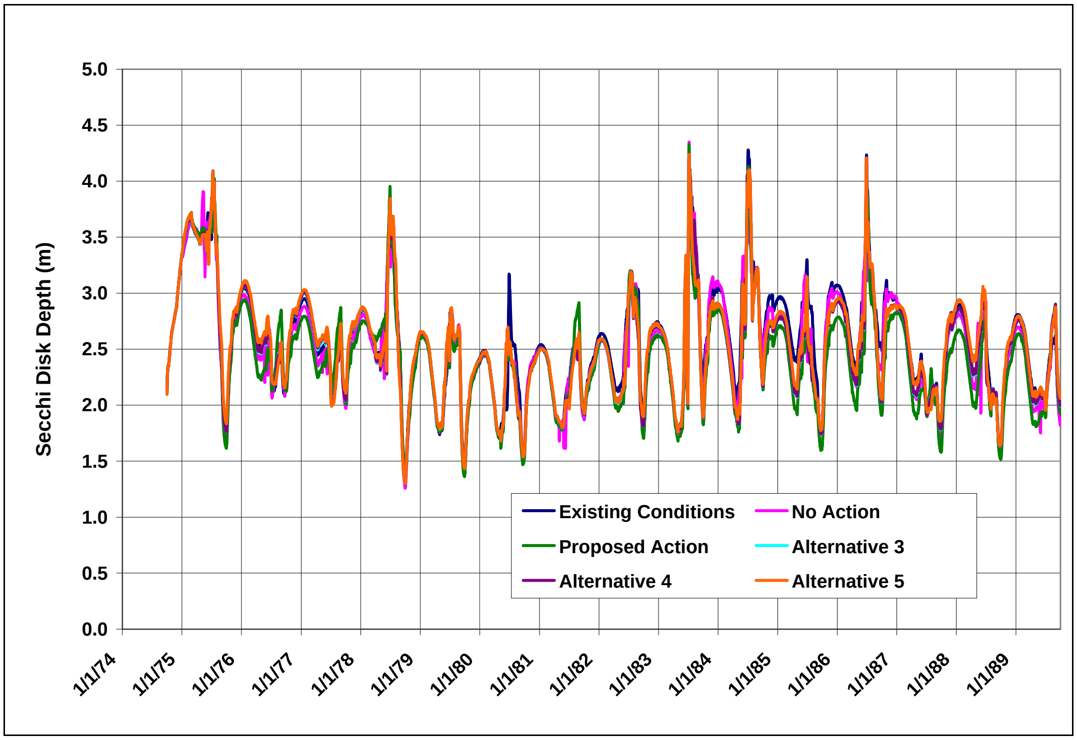


**Figure 79: Predicted Daily Secchi-Disk Depths in Grand Lake (Existing Conditions and All Alternatives)**

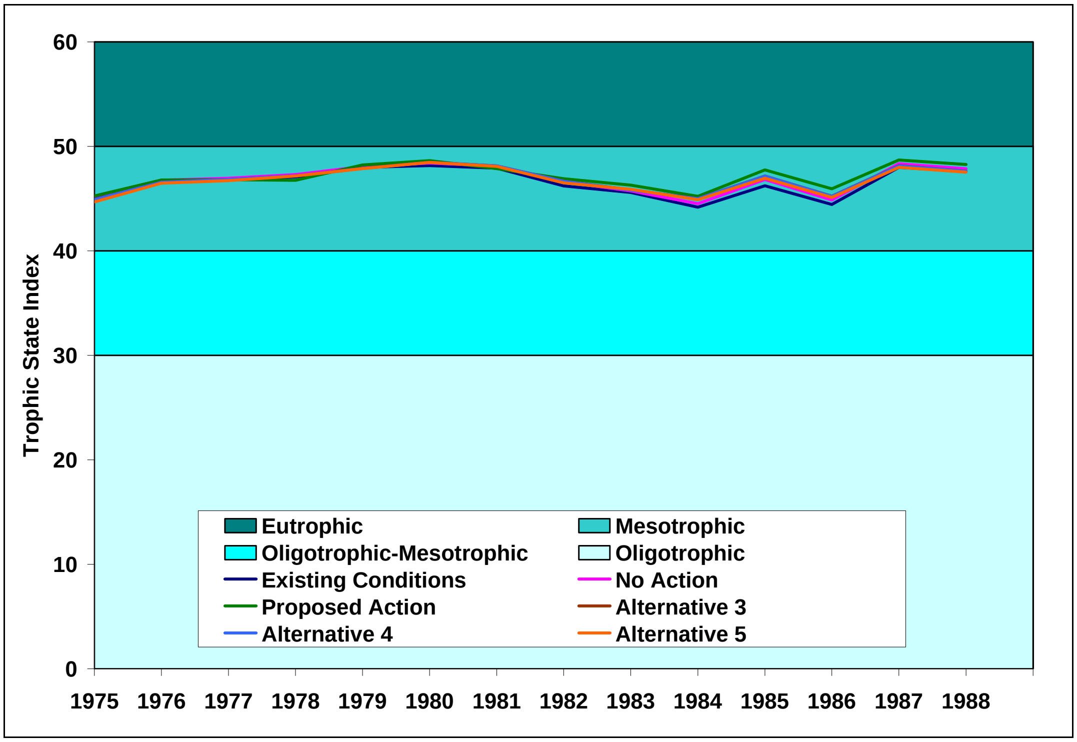


**Figure 80: Predicted Trophic State Indices in Grand Lake (Existing Conditions and All Alternatives)**

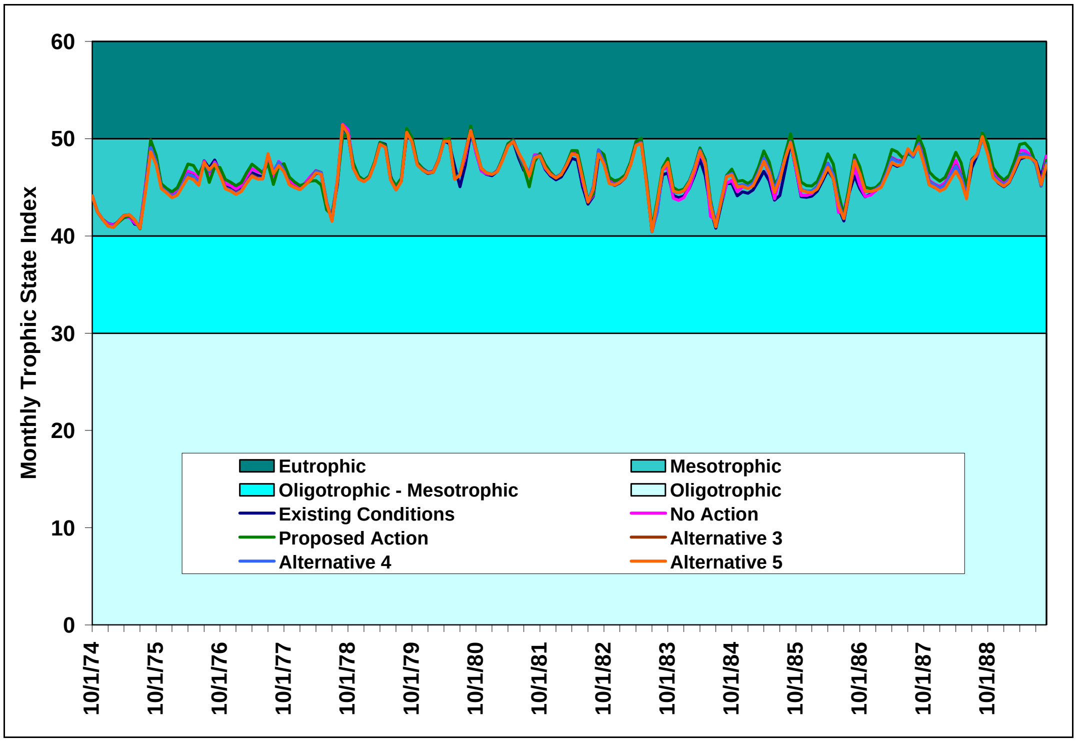


**Figure 81: Predicted Monthly Trophic State Index for Grand Lake**

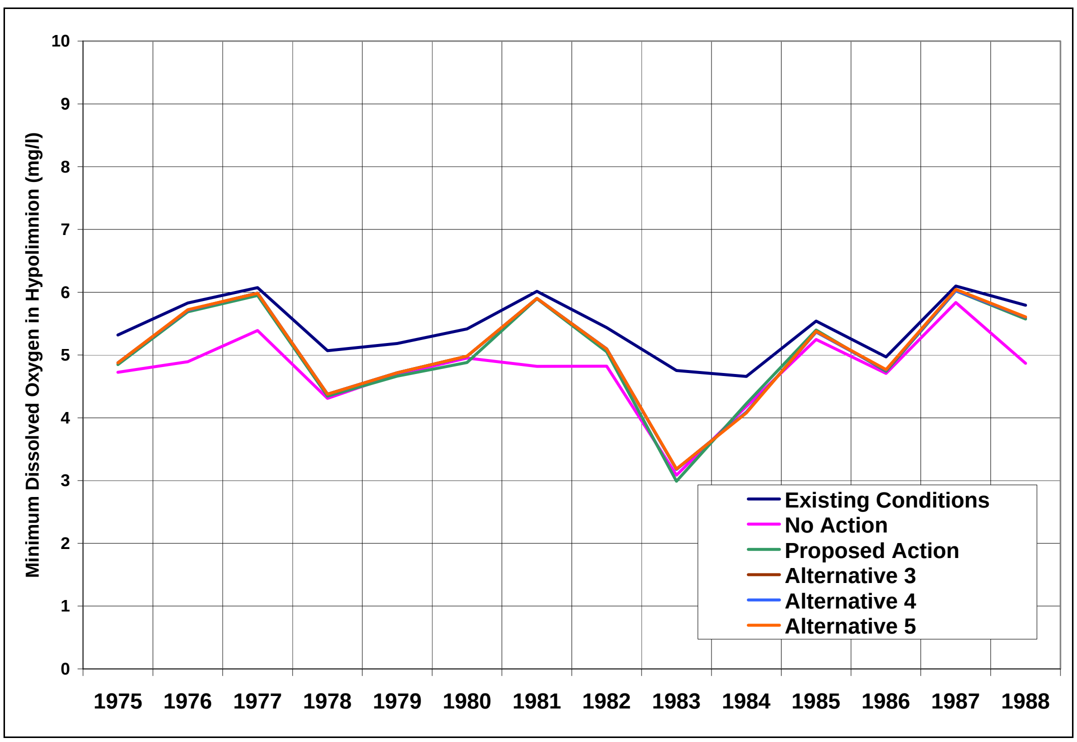


**Figure 82: Predicted Minimum Dissolved Oxygen Concentration in Grand Lake (Existing Conditions and All Alternatives)**

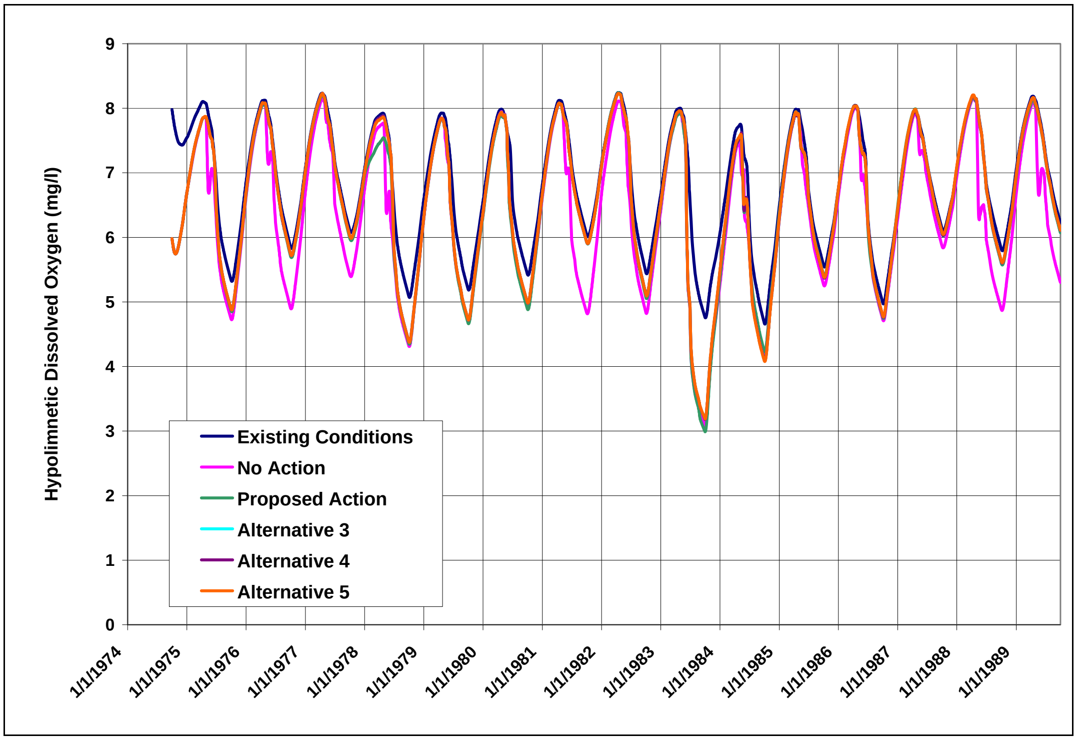


**Figure 83: Predicted Daily Dissolved Oxygen Concentration in Grand Lake (Existing Conditions and All Alternatives)**

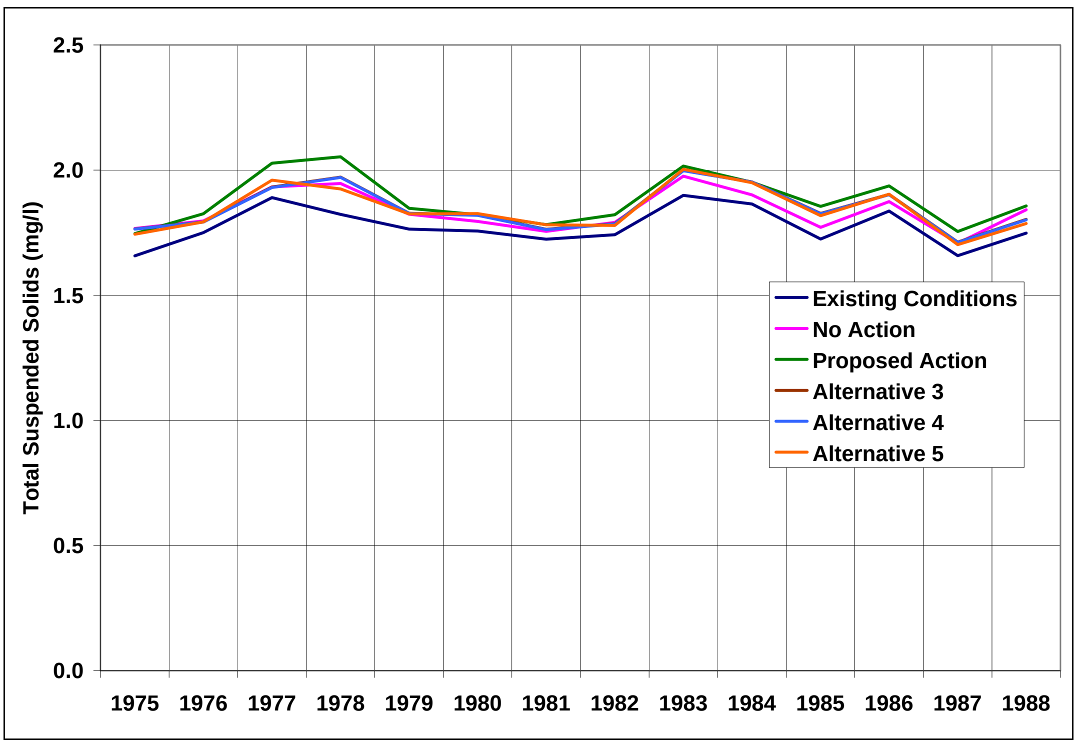


**Figure 84: Predicted Annual Average Total Suspended Sediment Concentration in Grand Lake (Existing Conditions and All Alternatives)**

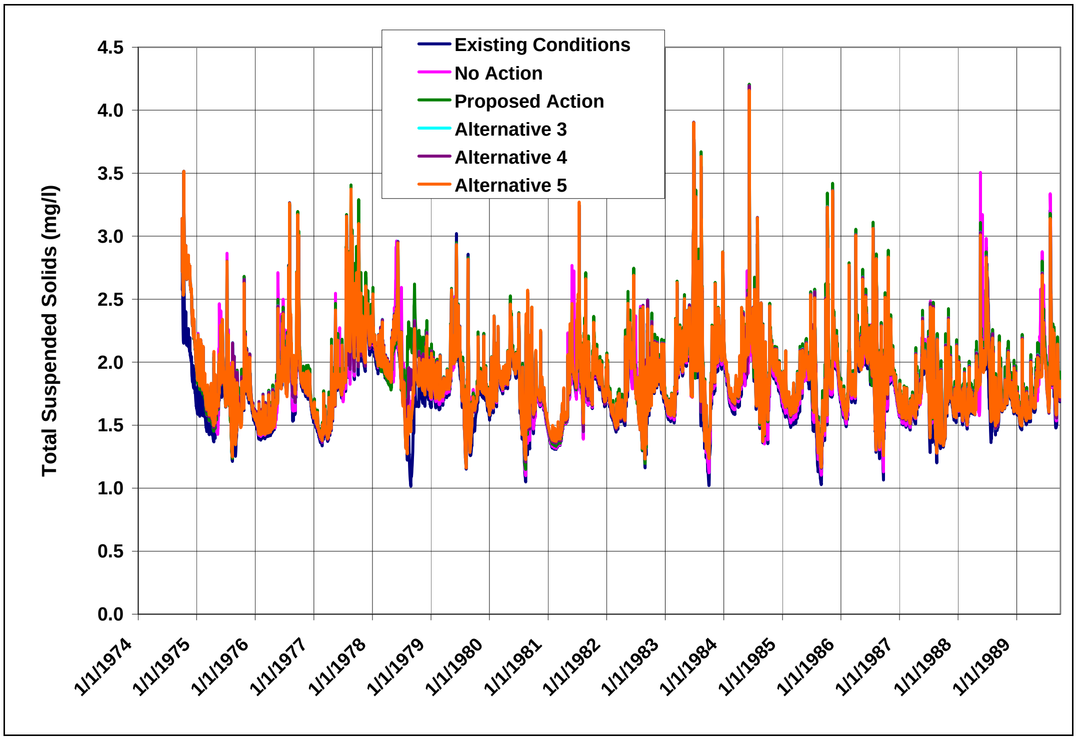


**Figure 85: Predicted Daily Total Suspended Sediment Concentration in Grand Lake (Existing Conditions and All Alternatives)**

The alternatives were evaluated to determine if standards would be met or exceeded using model predictions. Grand Lake would continue to meet dissolved oxygen, ammonia, and nitrate standards. It is anticipated that manganese concentrations would increase over existing conditions due to lower dissolved oxygen concentrations in the hypolimnion. Thus, the manganese standard for water supply may not be met, as is the case for existing conditions. It is predicted that the No Action alternative would result in the highest manganese concentrations and the Proposed Action alternative would result in the second highest concentrations. There is no indication that temperature standards would be exceeded because no increases in temperature are predicted. In addition, there is no evidence to suggest that pH would decrease more under any of the alternatives, thus the pH standard is predicted to be exceeded under any of the alternatives, similar to existing conditions.

## 11.2. Direct and Indirect Effects - Existing East Slope Reservoirs

Environmental impacts to Horsetooth Reservoir, Carter Lake, and Ralph Price Reservoir are described in this section. The BATHTUB model was used to describe predicted changes in total phosphorus, total nitrogen, chlorophyll *a*, Secchi-disk depth and trophic status. The model does not predict dissolved oxygen or total suspended solids. Use of the BATHTUB model for this effort is described in Appendix B.

Changes in Horsetooth Reservoir and Carter Lake are driven not only by changes in hydrology, but also by changes in loading to the east slope at the east portal of the Adams Tunnel. To help interpret the results by individual reservoir, the average annual nutrient loads delivered through the Adams Tunnel as predicted by the Three Lakes Model (WY1975-WY1989) are listed in

Table 48. The highest loading occurs for the Proposed Action followed by Alternatives 3, 4, and 5, which are very similar. The No Action alternative is next followed by existing conditions, which has the lowest loading. This pattern is the same for both phosphorus and nitrogen.

**Table 48: Average Nutrient Load through the Adams Tunnel (WY75-WY89)**

| Alternative | Average Phosphorus Load (kg/yr) | Average Nitrogen Load (kg/yr) |
|---|---|---|
| Existing Conditions | 2,480 | 75,484 |
| No Action | 2,738 | 78,303 |
| Proposed Action | 3,058 | 82,328 |
| Alternative 3 | 2,782 | 79,894 |
| Alternative 4 | 2,773 | 79,739 |
| Alternative 5 | 2,744 | 79,627 |

### 11.2.1. Carter Lake

Model results for Carter Lake for existing conditions and the five alternatives are displayed in Figure 86 to Figure 90. Average annual concentrations are listed in Table 49. Comparisons against existing conditions and the No Action alternative are listed in Table 50 and Table 51. No changes are predicted for trophic state for any of the alternatives. Phosphorus and nitrogen concentrations would increase for each of the alternatives with the Proposed Action having the largest increase. Chlorophyll *a* would increase for the No Action and Proposed Action alternatives. Clarity would decrease with all of the alternatives.

Relative results for metalimnetic oxygen demand (MOD) and hypolimnetic oxygen demand (HOD) for Carter Lake are listed in Table 52 and Table 53. Model predictions for the action alternatives indicate that all alternatives may slightly reduce oxygen concentrations in both the metalimnion and hypolimnion of Carter Lake. The oxygen demand predictions indicate that the Proposed Action alternative would likely result in the lowest dissolved oxygen concentrations among the alternatives for both the metalimnion and hypolimnion. In addition, no negative change in temperature is anticipated for any of the alternatives.

The alternatives were evaluated to determine if standards would be met or exceeded using model predictions. Carter Lake would continue to meet dissolved oxygen, ammonia, and nitrate standards. Temperature standards are not predicted to be exceeded more than what is occurring for existing conditions. Dissolved manganese concentrations may increase due to decreased hypolimnetic dissolved oxygen concentrations, but is in unlikely that standards would be exceeded for the action alternatives.

**Table 49: Average Predicted Conditions for Carter Lake (Existing Conditions and All Alternatives)**

| | Average Annual Values Over the 15-Year Model Period | | | | | |
|---|---|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
| Total Phosphorus (µg/l) | 9.9 | 10.4 | 10.8 | 10.2 | 10.2 | 10.2 |
| Total Nitrogen (µg/l) | 226 | 230 | 235 | 229 | 229 | 230 |
| Chlorophyll a (µg/l) | 1.8 | 1.9 | 2.0 | 1.8 | 1.8 | 1.9 |
| Secchi-Disk Depth (m) | 2.9 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| MOD (mg/[m3-day]) | 24 | 25 | 26 | 25 | 25 | 25 |
| HOD (mg/[m3-day]) | 22 | 23 | 24 | 23 | 23 | 23 |
| Trophic State (Index) | Oligotrophic-Mesotrophic (36) | Oligotrophic-Mesotrophic (37) | Oligotrophic-Mesotrophic (37) | Oligotrophic-Mesotrophic (37) | Oligotrophic-Mesotrophic (37) | Oligotrophic-Mesotrophic (37) |

**Table 50: Predicted Changes by Alternative for Carter Lake Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|---|
| Total Phosphorus (µg/l) | +5.1% | +9.1% | +3.0% | +3.0% | +3.0% |
| Total Nitrogen (µg/l) | +1.8% | 4.0% | +1.3% | +1.3% | +1.8% |
| Chlorophyll a (µg/l) | +5.6% | +11.1% | No Change | No Change | +5.6% |
| Secchi-Disk Depth (m) | -3.6% | -3.6% | -3.6% | -3.6% | -3.6% |
| Trophic State Index | No Change | No Change | No Change | No Change | No Change |

**Table 51: Predicted Changes for Carter Lake by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|
| Total Phosphorus (µg/l) | +3.8% | -1.9% | -1.9% | -1.9% |
| Total Nitrogen (µg/l) | +2.2% | -0.4% | -0.4% | No Change |
| Chlorophyll a (µg/l) | +5.3% | -5.3% | -5.3% | No Change |
| Secchi-Disk Depth (m) | No Change | No Change | No Change | No Change |
| Trophic State Index | No Change | No Change | No Change | No Change |

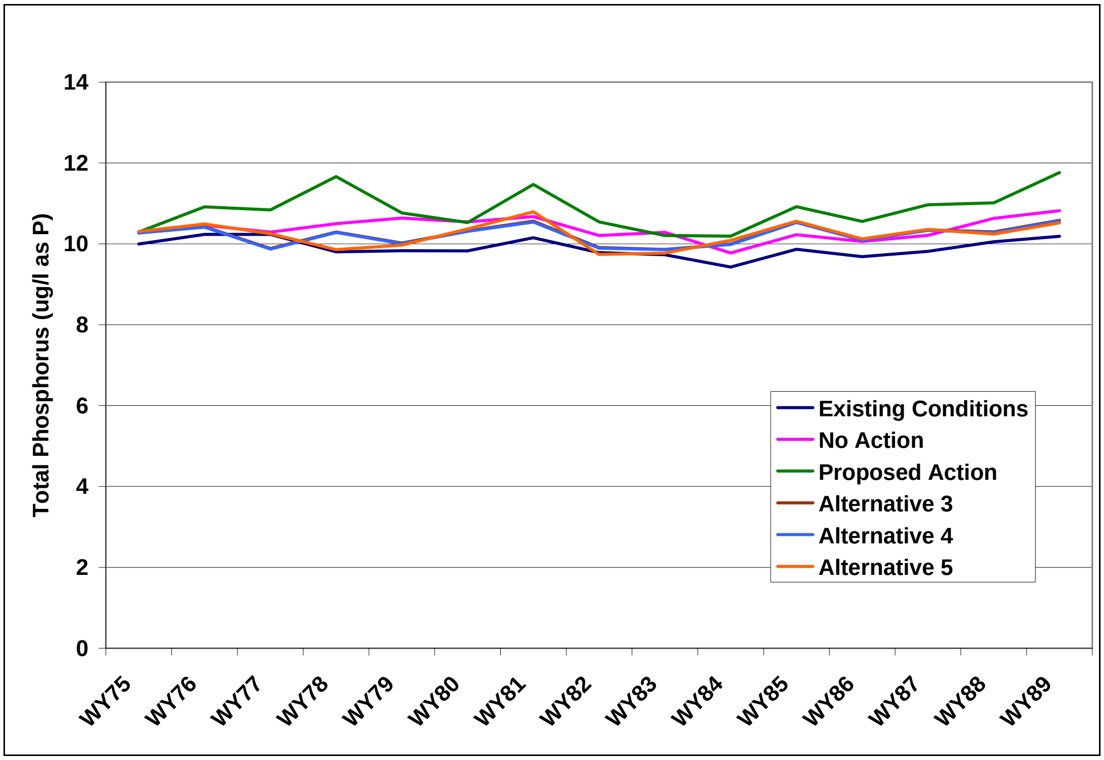


**Figure 86: Predicted Annual Average Total Phosphorus Concentrations in Carter Lake (Existing Conditions and All Alternatives)**

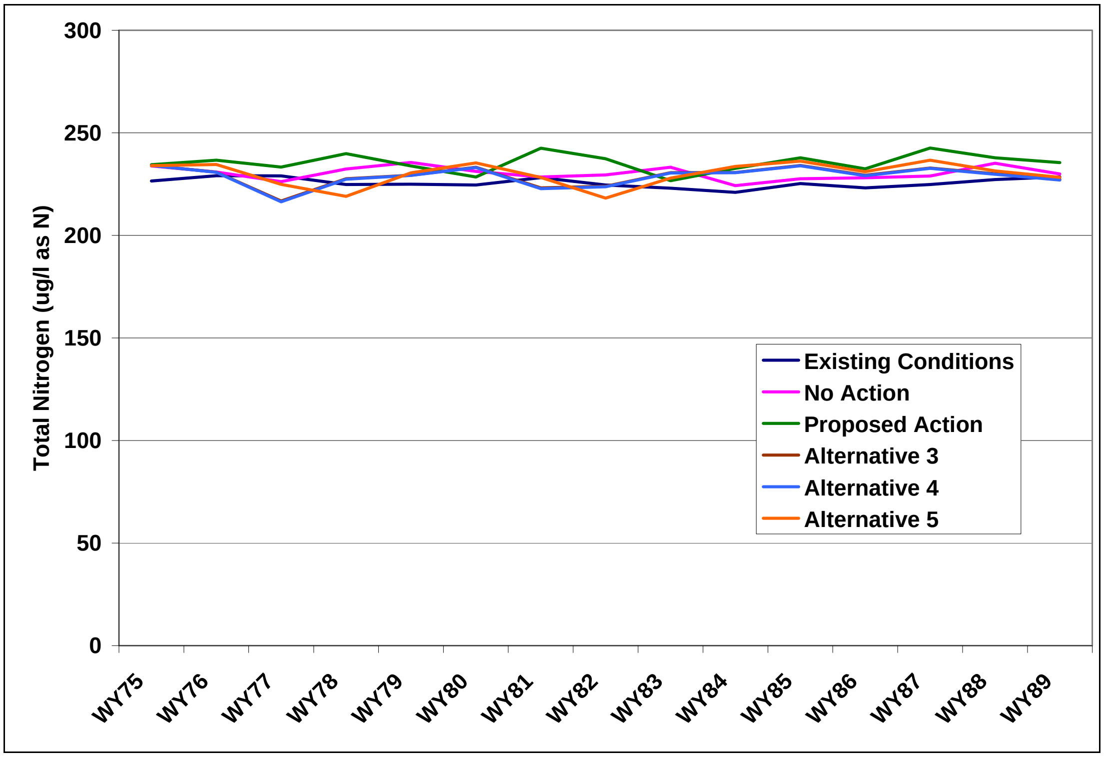


**Figure 87: Predicted Annual Average Total Nitrogen Concentrations in Carter Lake (Existing Conditions and All Alternatives)**

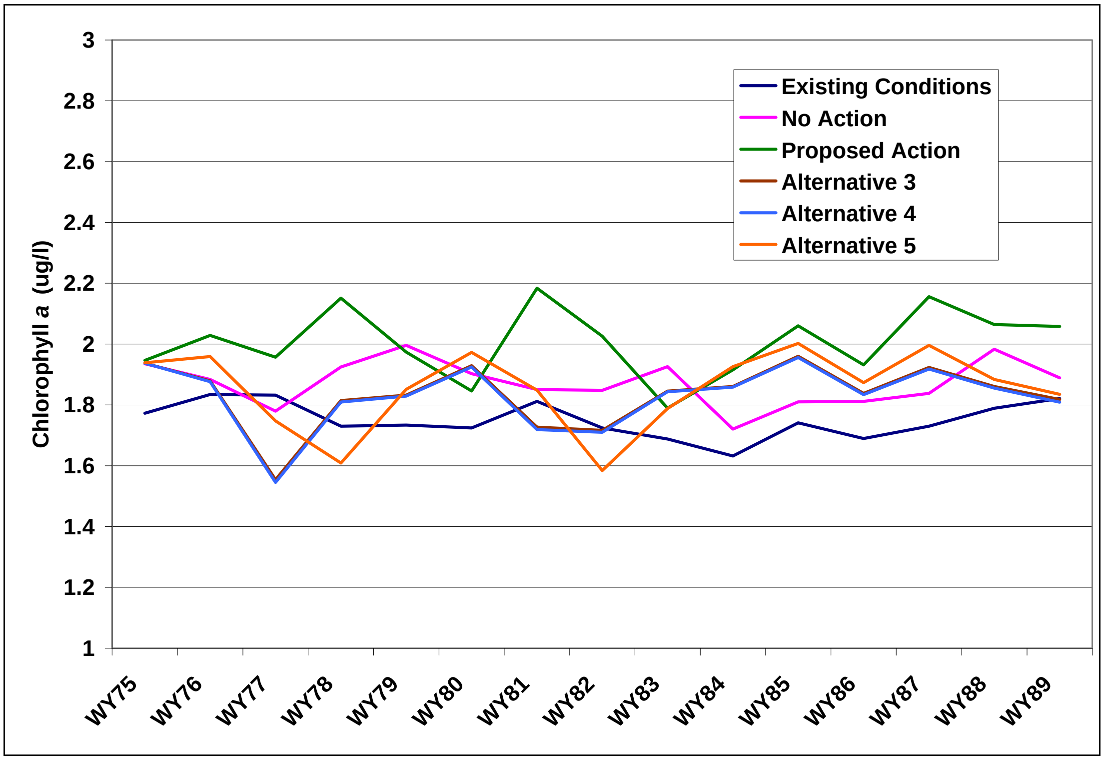


**Figure 88: Predicted Annual Average Chlorophyll *a* Concentrations in Carter Lake (Existing Conditions and All Alternatives)**

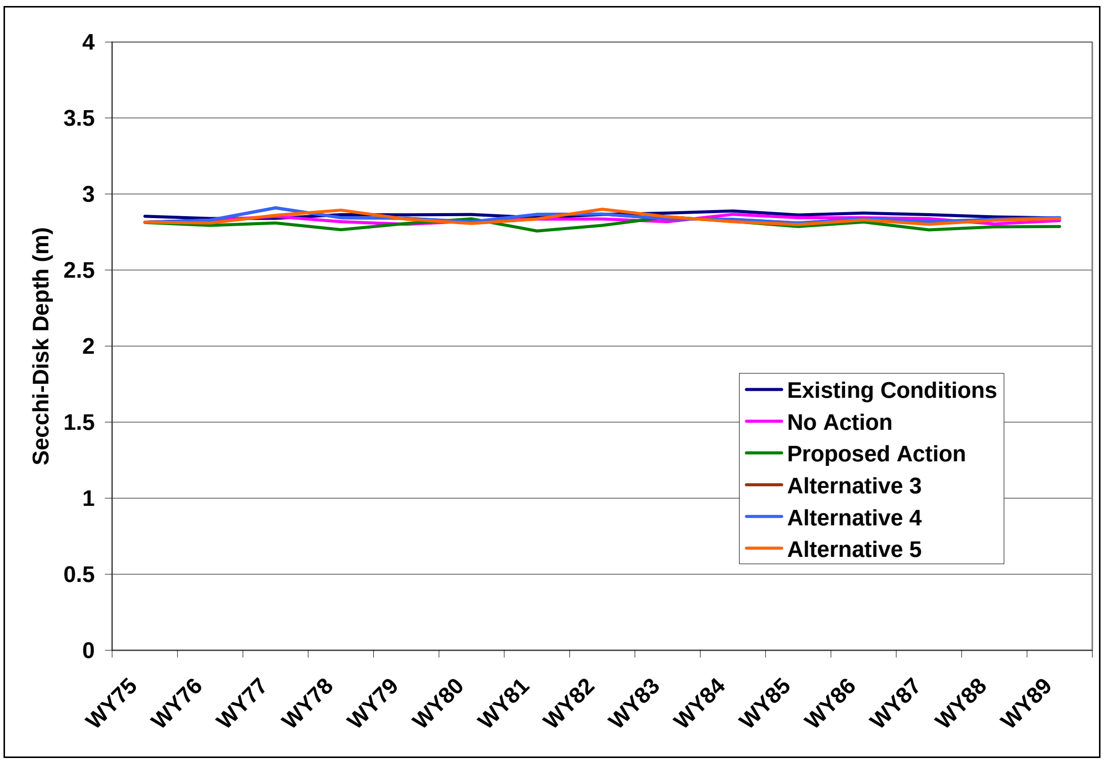


**Figure 89: Predicted Annual Average Secchi-Disk Depths in Carter Lake (Existing Conditions and All Alternatives)**

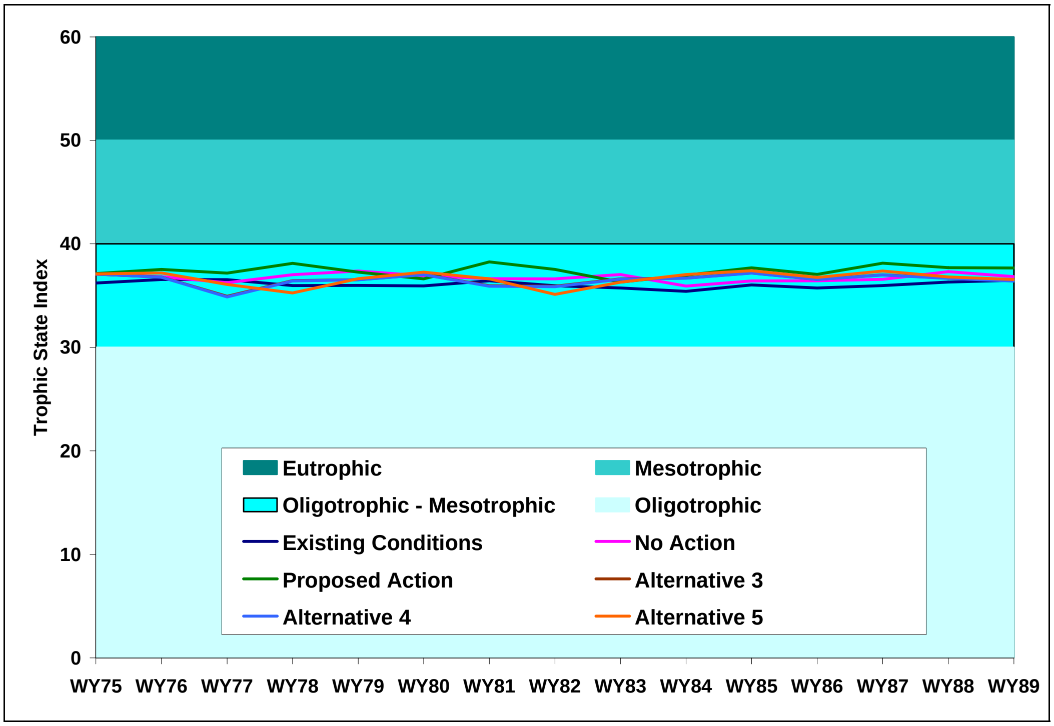


**Figure 90: Predicted Trophic State Indices in Carter Lake (Existing Conditions and All Alternatives)**

**Table 52: Predicted Changes in Oxygen Demand by Alternative for Carter Lake Relative to Existing Conditions**

| *Oxygen Demand* | *No Action* | *Proposed Action* | *Alternative 3* | *Alternative 4* | *Alternative 5* |
|---|---|---|---|---|---|
| *MOD (mg/(m³ day))* | *+4.2%* | *+8.3%* | *+4.2%* | *+4.2%* | *+4.2%* |
| *HOD (mg/(m³ day))* | *+4.3%* | *+9.1%* | *+4.3%* | *+4.3%* | *+4.3%* |

**Table 53: Predicted Changes in Oxygen Demand by Alternative for Carter Lake Relative to the No Action Alternative**

| *Oxygen Demand* | *Proposed Action* | *Alternative 3* | *Alternative 4* | *Alternative 5* |
|---|---|---|---|---|
| *MOD (mg/(m³ day))* | *+4.0%* | *No Change* | *No Change* | *No Change* |
| *HOD (mg/(m³ day))* | *+4.3%* | *No Change* | *No Change* | *No Change* |

### 11.2.2. Horsetooth Reservoir

Model predictions for Horsetooth Reservoir for existing conditions and the five alternatives are displayed in Figure 91 to Figure 95 and summarized in Table 54. Comparisons with existing conditions and the No Action alternative are made in Table 55 and Table 56. Trophic state and Secchi-disk depth would remain unchanged from existing conditions for all alternatives, except for a slight decrease in clarity for the Proposed Action. The Proposed Action also has the highest nutrient loading from the Adams Tunnel and results in the highest in-reservoir nutrient and chlorophyll *a* concentrations.

Relative results for metalimnetic oxygen demand (MOD) and hypolimnetic oxygen demand (HOD) for Horsetooth Reservoir are listed in Table 57 and Table 58. Model predictions for the action alternatives indicate that all alternatives may slightly reduce oxygen concentrations in both the metalimnion and hypolimnion of Horsetooth Reservoir. The oxygen demand predictions indicate that the Proposed Action alternative would likely result in the lowest dissolved oxygen concentrations among the alternatives for both the metalimnion and hypolimnion. In addition, no negative change in temperature is anticipated for any of the alternatives.

The alternatives were evaluated to determine if standards would be met or exceeded. Horsetooth Reservoir would continue to exceed dissolved oxygen standards. The reservoir would continue to meet ammonia and nitrate standards. Temperature standards are not predicted to be exceeded more than what is occurring for existing conditions. Dissolved manganese concentrations may increase due to decreased hypolimnetic dissolved oxygen concentrations, and the water supply standard may not be met for the action alternatives, as is the case for existing conditions.

**Table 54: Average Predicted Conditions for Horsetooth Reservoir (Existing Conditions and All Alternatives)**

| Average Annual Values Over the 15-Year Model Period | | | | | | |
|---|---|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
| Total Phosphorus (µg/l) | 9.9 | 10.4 | 11.0 | 10.3 | 10.3 | 10.2 |
| Total Nitrogen (µg/l) | 274 | 281 | 290 | 285 | 284 | 284 |
| Chlorophyll a (µg/l) | 3.5 | 3.7 | 3.9 | 3.7 | 3.7 | 3.7 |
| Secchi-Disk Depth (m) | 2.6 | 2.6 | 2.5 | 2.6 | 2.6 | 2.6 |
| Trophic State (Index) | Mesotrophic (43) | Mesotrophic (43) | Mesotrophic (44) | Mesotrophic (43) | Mesotrophic (43) | Mesotrophic (43) |

**Table 55: Predicted Changes by Alternative for Horsetooth Reservoir Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|---|
| Total Phosphorus (µg/l) | +5.1% | +11.1% | +4.0% | +4.0% | +3.0% |
| Total Nitrogen (µg/l) | +2.6% | +5.8% | +4.0% | +3.6% | +3.6% |
| Chlorophyll a (µg/l) | +5.7% | +11.4% | +5.7% | +5.7% | +5.7% |
| Secchi-disk Depth (m) | No Change | -3.8% | No Change | No Change | No Change |
| Trophic State | No Change | No Change | No Change | No Change | No Change |

**Table 56: Predicted Changes for Horsetooth Reservoir by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|
| Total Phosphorus (µg/l) | +5.8% | -1.0% | -1.0% | -1.9% |
| Total Nitrogen (µg/l) | +3.2% | +1.4% | +1.1% | +1.1% |
| Chlorophyll *a* (µg/l) | +5.4% | No Change | No Change | No Change |
| Secchi-disk Depth (m) | -3.8% | No Change | No Change | No Change |
| Trophic State Index | No Change | No Change | No Change | No Change |

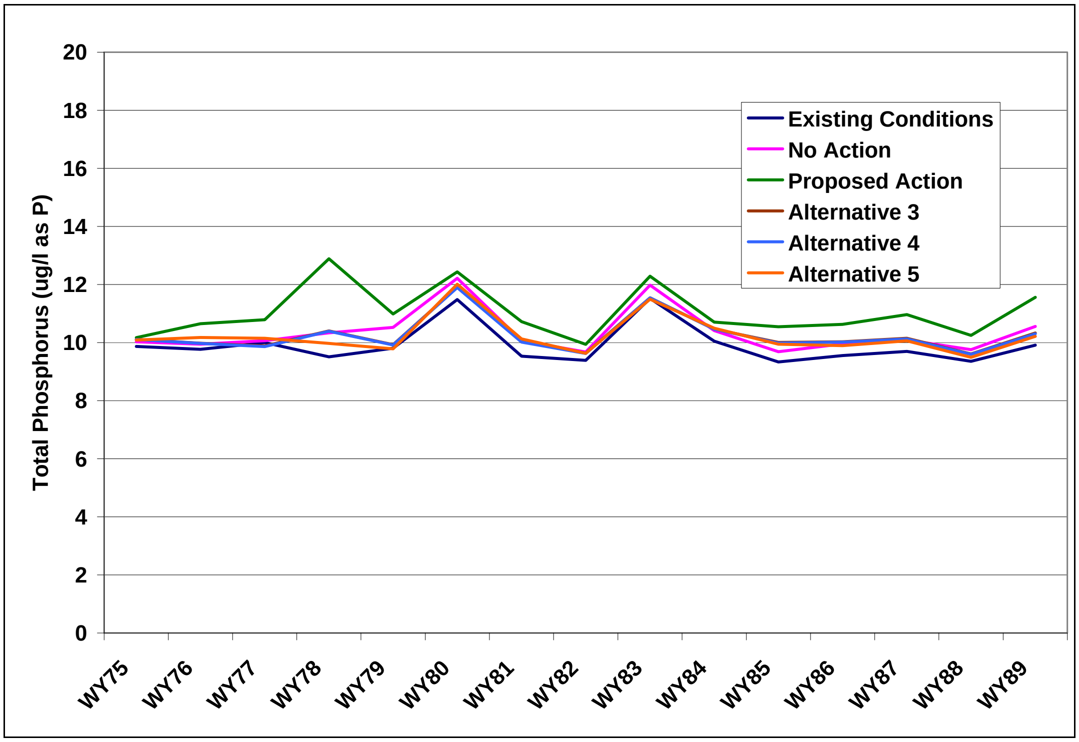


**Figure 91: Predicted Annual Average Total Phosphorus Concentrations in Horsetooth Reservoir (Existing Conditions and All Alternatives)**

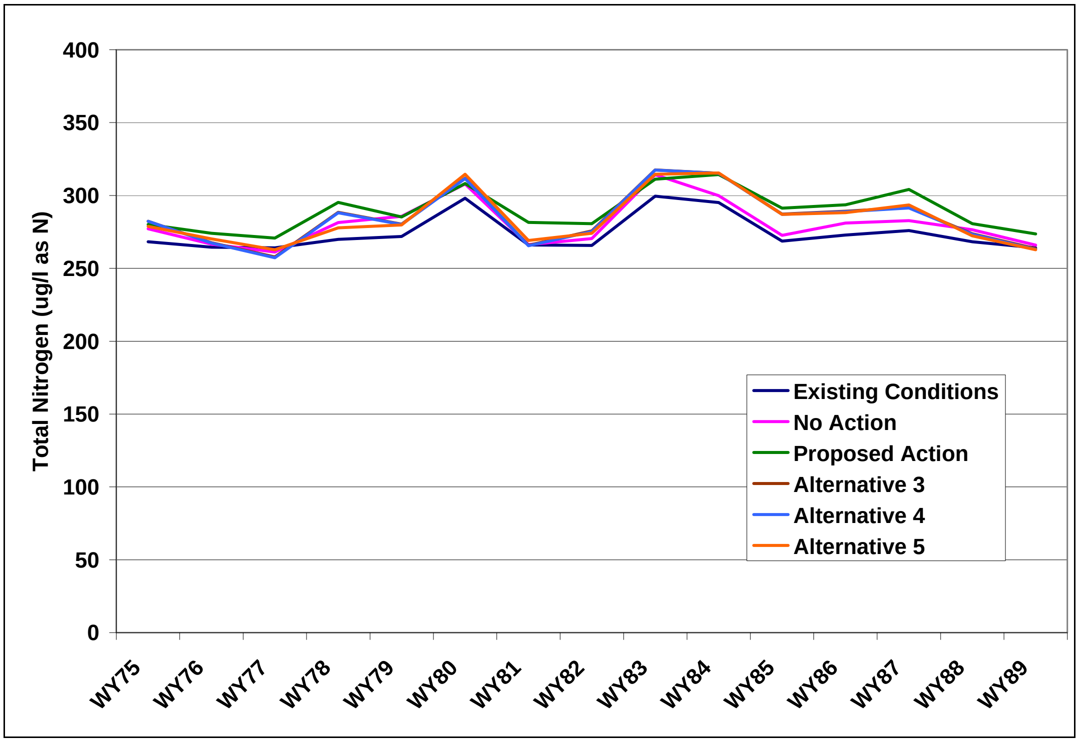


**Figure 92: Predicted Annual Average Total Nitrogen Concentrations in Horsetooth Reservoir (Existing Conditions and All Alternatives)**

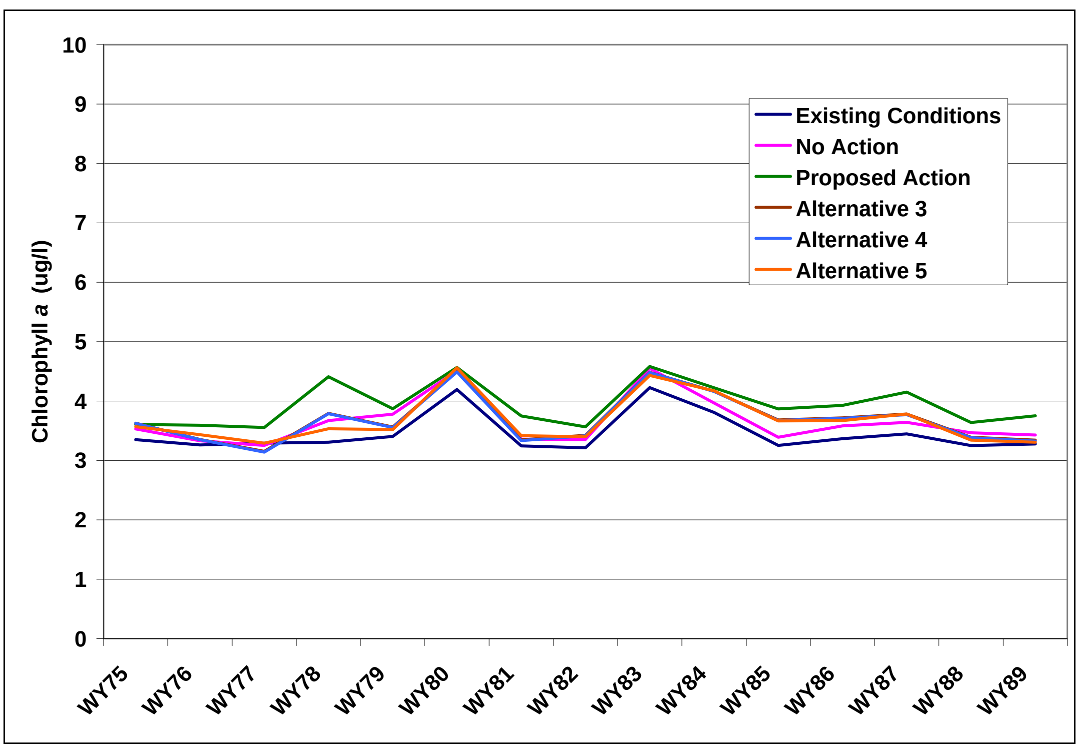


**Figure 93: Predicted Annual Average Chlorophyll *a* Concentrations in Horsetooth Reservoir (Existing Conditions and All Alternatives)**

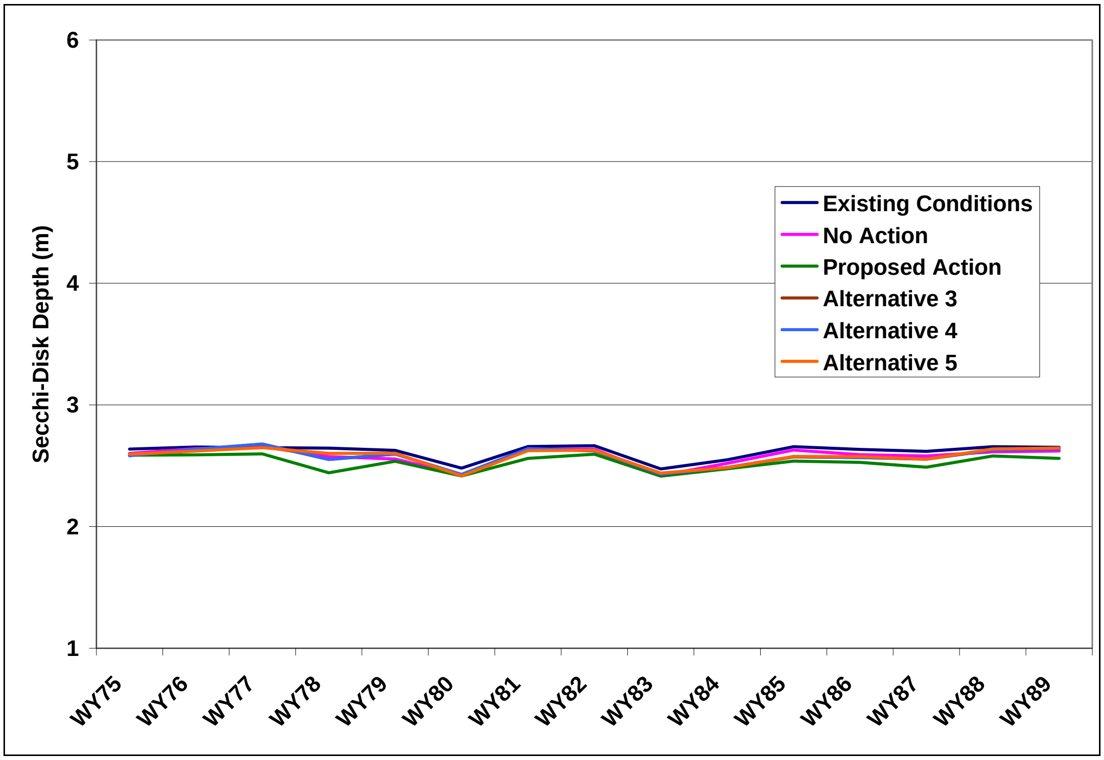


**Figure 94: Predicted Annual Average Secchi-Disk Depths in Horsetooth Reservoir (Existing Conditions and All Alternatives)**

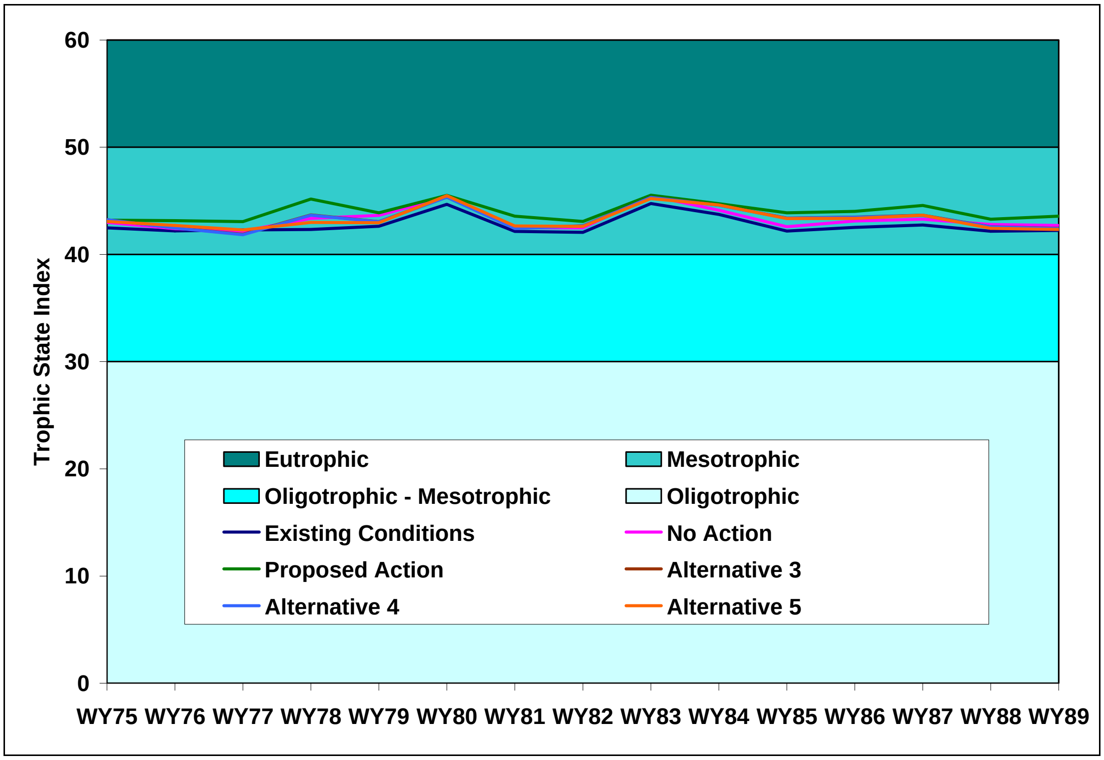


**Figure 95: Predicted Trophic State Indices in Horsetooth Reservoir (Existing Conditions and All Alternatives)**

**Table 57: Predicted Changes in Oxygen Demand by Alternative for Horsetooth Reservoir Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|---|
| MOD (mg/($m^3$ day)) | +2.3% | +11% | +4.5% | +2.3% | +4.5% |
| HOD (mg/($m^3$ day)) | +2.2% | +17% | +4.3% | +4.3% | +6.5% |

**Table 58: Predicted Changes in Oxygen Demand by Alternative for Horsetooth Reservoir Relative to the No Action Alternative**

| | Proposed Action | Alternative 3 | Alternative 4 | Alternative 5 |
|---|---|---|---|---|
| MOD (mg/($m^3$ day)) | +8.9% | +2.2% | No Change | +2.2% |
| HOD (mg/($m^3$ day)) | +15% | +2.1% | +2.1% | +4.2% |

### 11.2.3. Ralph Price Reservoir

Ralph Price Reservoir is only included in the No Action alternative. Therefore, the BATHTUB model was run for two conditions - existing conditions and the No Action alternative.

Anticipated in-reservoir water quality, as predicted using the BATHTUB model, are reported in Figure 96 - Figure 100. Average predicted conditions are listed in Table 59. Comparisons are made in Table 60. Relative results for metalimnetic oxygen demand (MOD) and hypolimnetic oxygen demand (HOD) in Ralph Price Reservoir are listed in Table 61. The oxygen demand predictions indicate that the No Action alternative would likely result in higher dissolved oxygen concentrations. Overall, the No Action alternative shows improvements in water quality compared with existing conditions. Changes occur due to the increase in reservoir volume and mean depth.

An estimate of alternative influence on Ralph Price Reservoir water temperatures can be made based solely on the influence of the change in reservoir volume. The No Action alternative involves increasing storage in Ralph Price Reservoir. The water inflow temperatures and inflow volume to this reservoir are assumed the same as existing conditions. A reservoir with a larger volume has a larger thermal mass, a deeper water column and increased thermal stratification. These characteristics result in a reservoir that has a greater tendency to resist heating influences at the air – water interface. The reservoir outlet structure for No Action would be deeper than existing conditions. Therefore, the water temperature in Ralph Price Reservoir for the No Action alternative is likely to be cooler than existing conditions.

The alternatives were evaluated to determine if standards would be met or exceeded. Ralph Price Reservoir would continue to meet dissolved oxygen, ammonia, nitrate, dissolved manganese, and temperature standards.

**Table 59: Average Predicted Conditions for Ralph Price Reservoir (Existing Conditions and No Action Alternative)**

| Average Annual Values Over the 15-Year Model Period | | |
|---|---|---|
| | Existing Conditions | No Action |
| Total Phosphorus (µg/l) | 5.1 | 4.9 |
| Total Nitrogen (µg/l) | 188 | 177 |
| Chlorophyll *a* (µg/l) | 0.6 | 0.4 |
| Secchi-Disk Depth (m) | 3.8 | 3.8 |
| Trophic State (Index) | Oligotrophic (26) | Oligotrophic (22) |

**Table 60: Predicted Changes by Alternative for Ralph Price Reservoir Relative to Existing Conditions**

| | No Action |
|---|---|
| Total Phosphorus (µg/l) | -3.9% |
| Total Nitrogen (µg/l) | -5.9% |
| Chlorophyll *a* (µg/l) | -33% |
| Secchi-Disk Depth (m) | No Change |
| Trophic State | No Change |

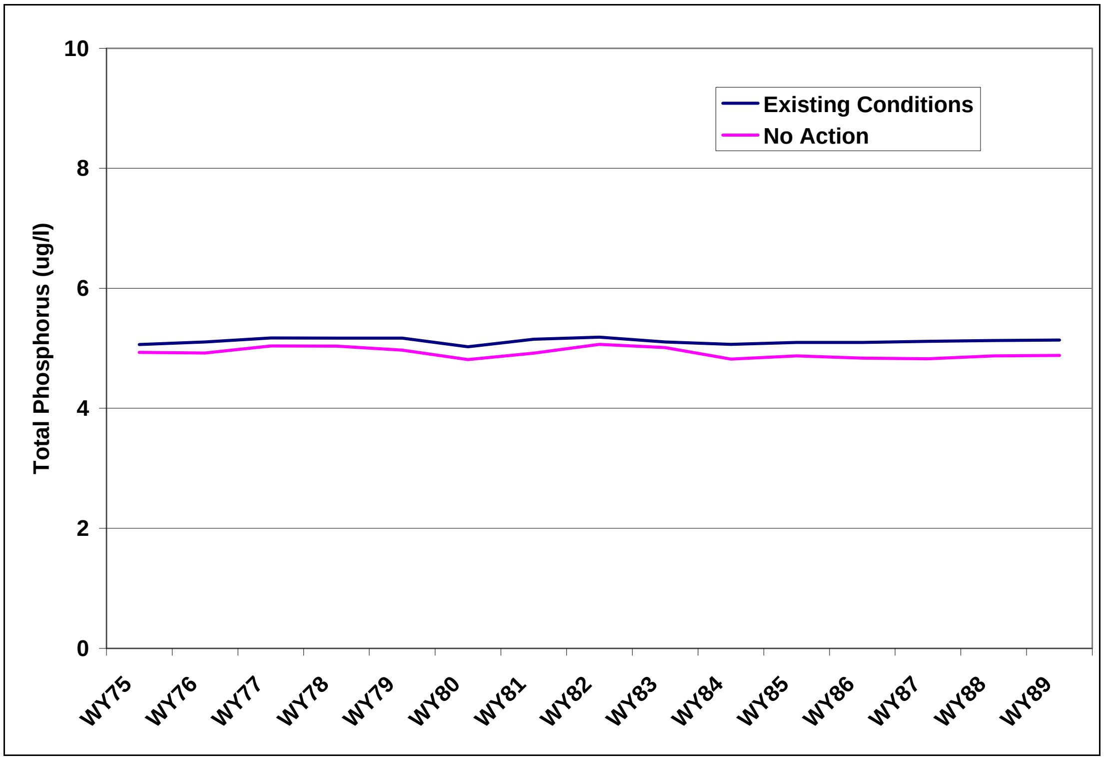


**Figure 96: Predicted Annual Average Total Phosphorus Concentrations in Ralph Price Reservoir (Existing Conditions and No Action Alternative)**

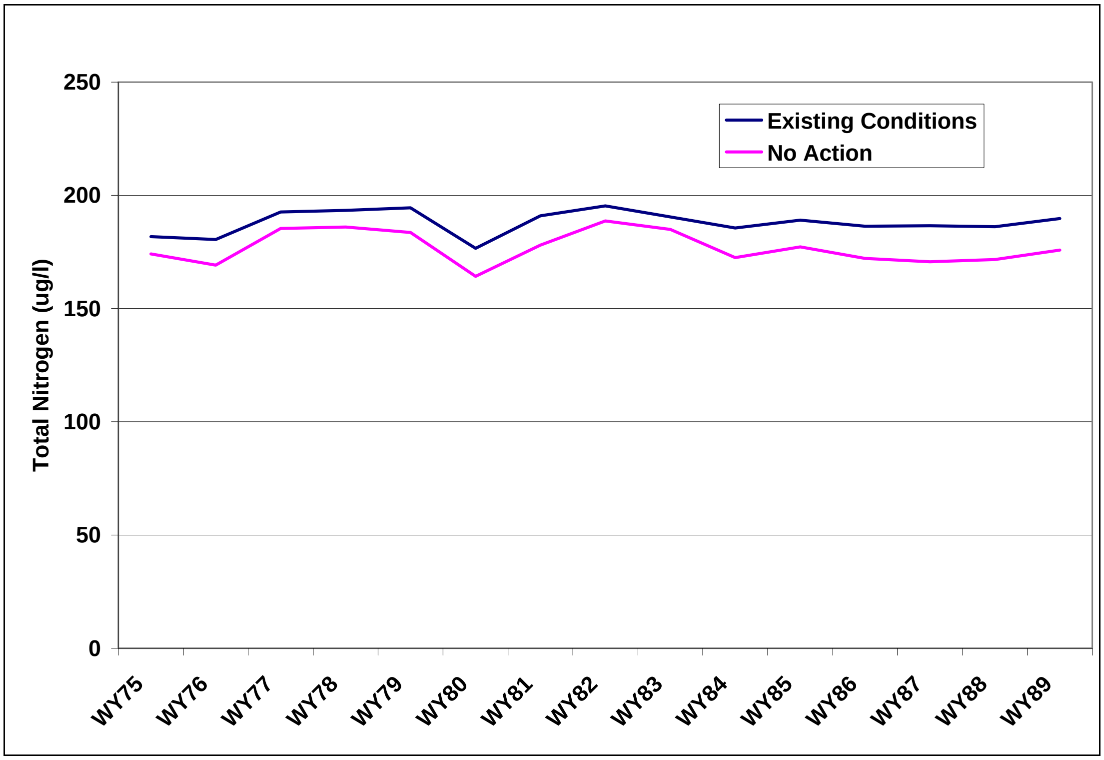


**Figure 97: Predicted Annual Average Total Nitrogen Concentrations in Ralph Price Reservoir (Existing Conditions and No Action Alternative)**

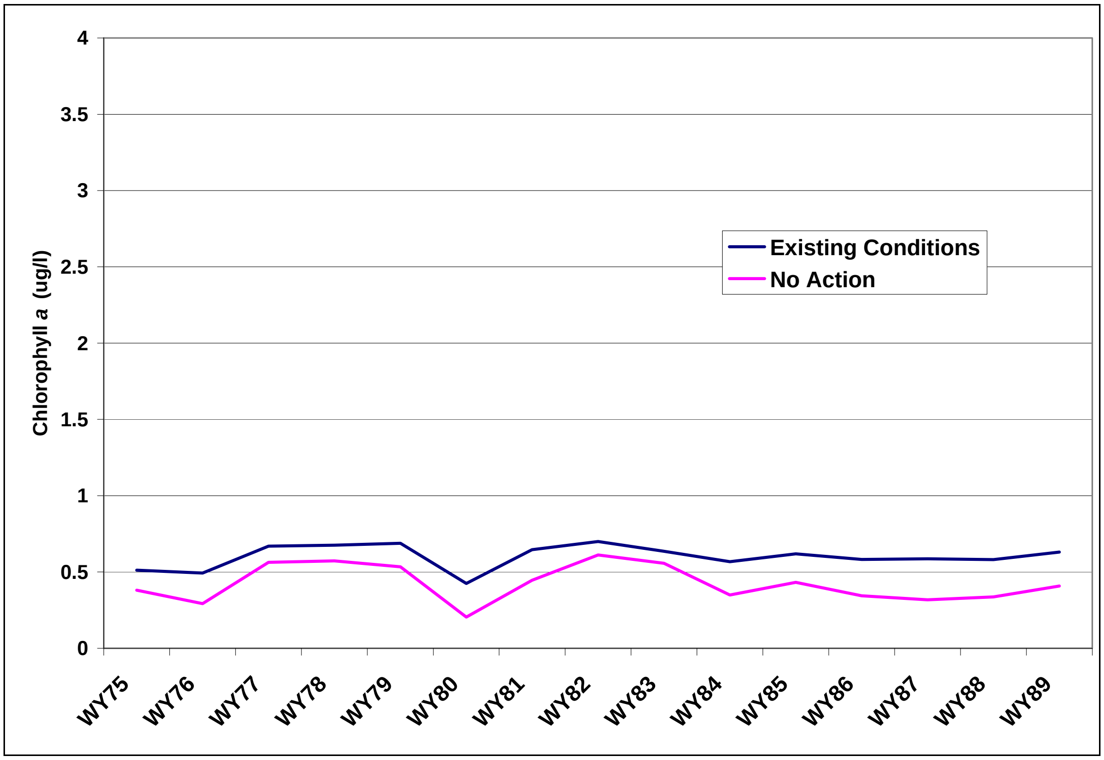


**Figure 98: Predicted Annual Average Chlorophyll *a* Concentrations in Ralph Price Reservoir (Existing Conditions and No Action Alternative)**

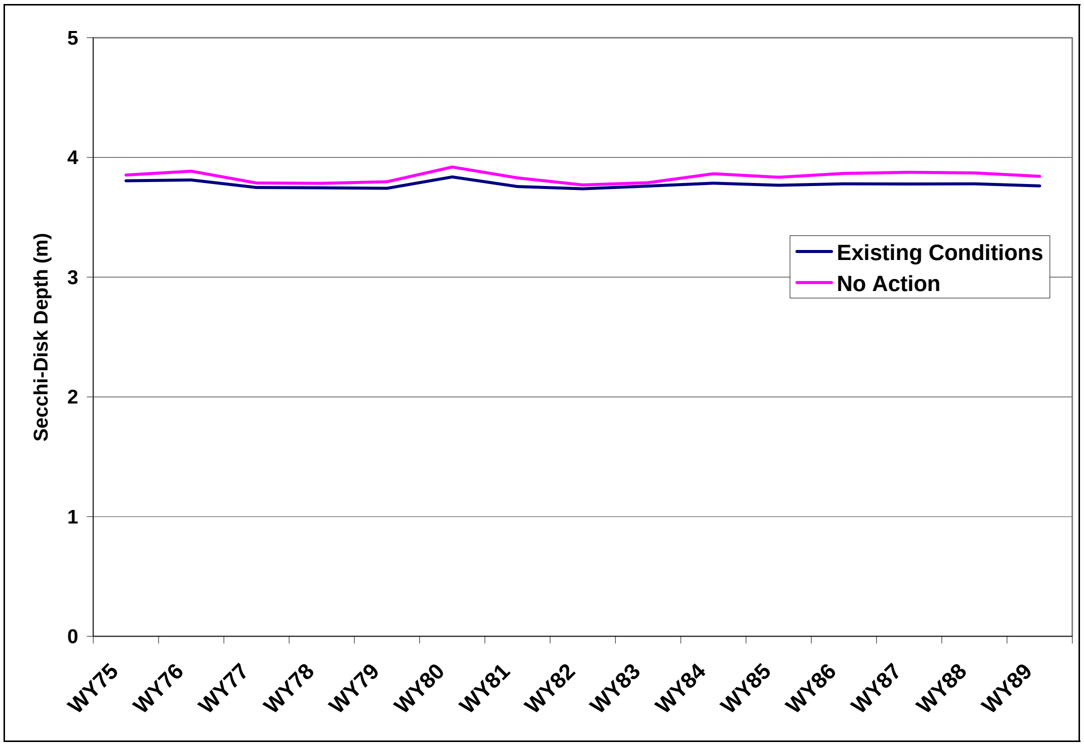


**Figure 99: Predicted Annual Average Secchi-Disk Depths in Ralph Price Reservoir (Existing Conditions and No Action Alternative)**

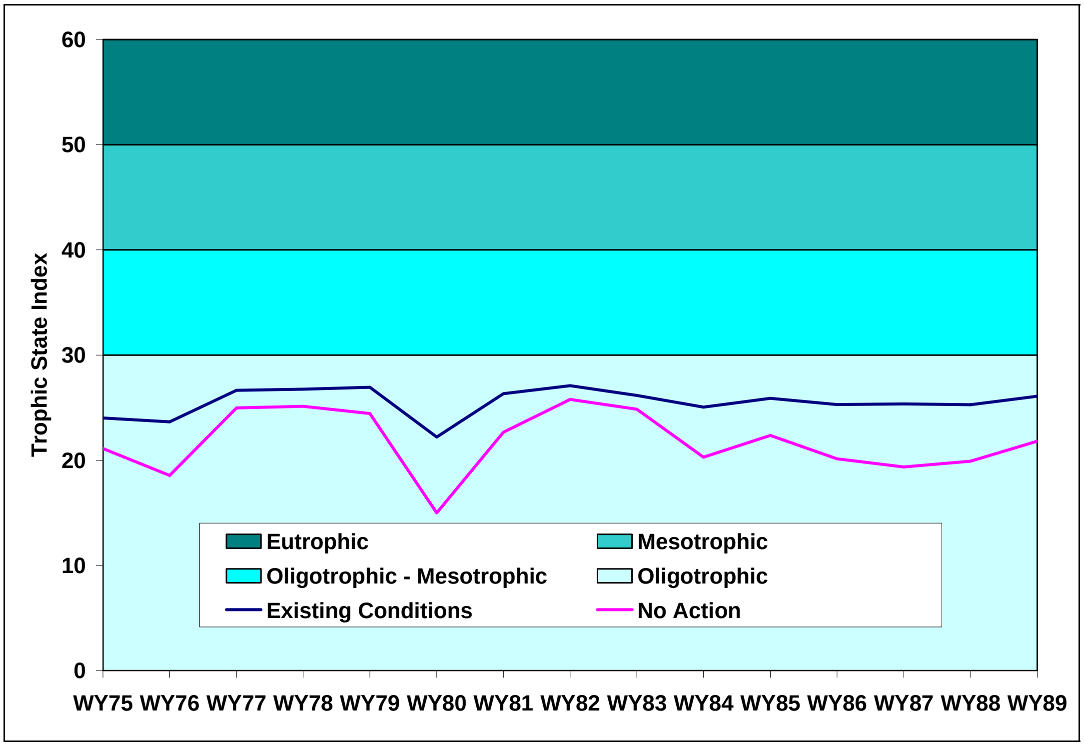


**Figure 100: Predicted Trophic State Indices in Ralph Price Reservoir (Existing Conditions and No Action Alternative)**

**Table 61: Predicted Changes in Oxygen Demand by Alternative for Ralph Price Reservoir Relative to Existing Conditions**

| Oxygen Demand | No Action |
|---|---|
| MOD (mg/(m$^3$ day)) | -29% |
| HOD (mg/(m$^3$ day)) | -39% |

## 11.3. Direct and Indirect Effects - Proposed West Slope Reservoirs

### 11.3.1. Jasper East Reservoir

Jasper East Reservoir is included in Alternative 3. Inflow into this proposed 20,000 AF reservoir would be provided via a pipeline from Windy Gap Reservoir. Anticipated reservoir characteristics are listed in Table 62. Since this is a proposed reservoir, there are no results to report for existing conditions or the No Action alternative for comparison purposes. Therefore, the anticipated in-reservoir water quality, as predicted using the BATHTUB model, are reported in Figure 101 - Figure 105. Average predicted conditions are listed in Table 63. The differences over time are predominantly due to changes in hydraulic residence time during the 15-year model period. Note that the reservoir is predicted to be in an oligotrophic - mesotrophic state. As described previously in Table 37 and Table 38, Jasper Reservoir would retain some nitrogen and phosphorus, thus reducing nutrient deliveries to Lake Granby.

The planned operations for Jasper East Reservoir involve rapid drawdowns and fillings of the reservoir. This type of operation is not accounted for in the BATHTUB model and could lead to an increase in reservoir erosion, turbidity, and suspended sediment delivery to Granby Reservoir.

**Table 62: Physical Characteristics of Jasper East Reservoir**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume | 20,000 AF | 24.7 x $10^6$ m$^3$ |
| Surface Area | 294 acres | 119 hectares |
| Mean Depth | 68 ft | 20.7 m |

**Table 63: Average Predicted Conditions for Jasper East Reservoir (Alternative 3)**

| Average Annual Values Over the 15-Year Model Period | |
|---|---|
| Total Phosphorus (µg/l) | 30 |
| Total Nitrogen (µg/l) | 246 |
| Chlorophyll *a* (µg/l) | 2.3 |
| Secchi-disk Depth (m) | 3.3 |
| Trophic State Index | Oligotrophic - Mesotrophic (39) |

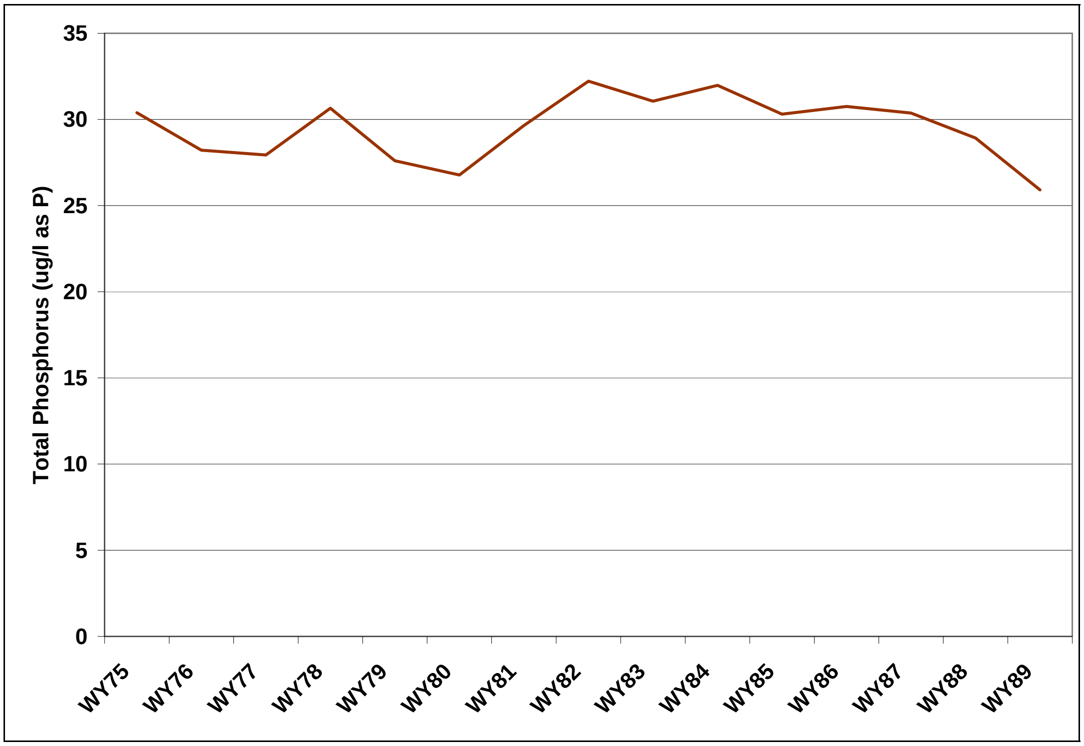


**Figure 101: Predicted Annual Average Total Phosphorus Concentrations in Jasper East Reservoir (Alternative 3)**

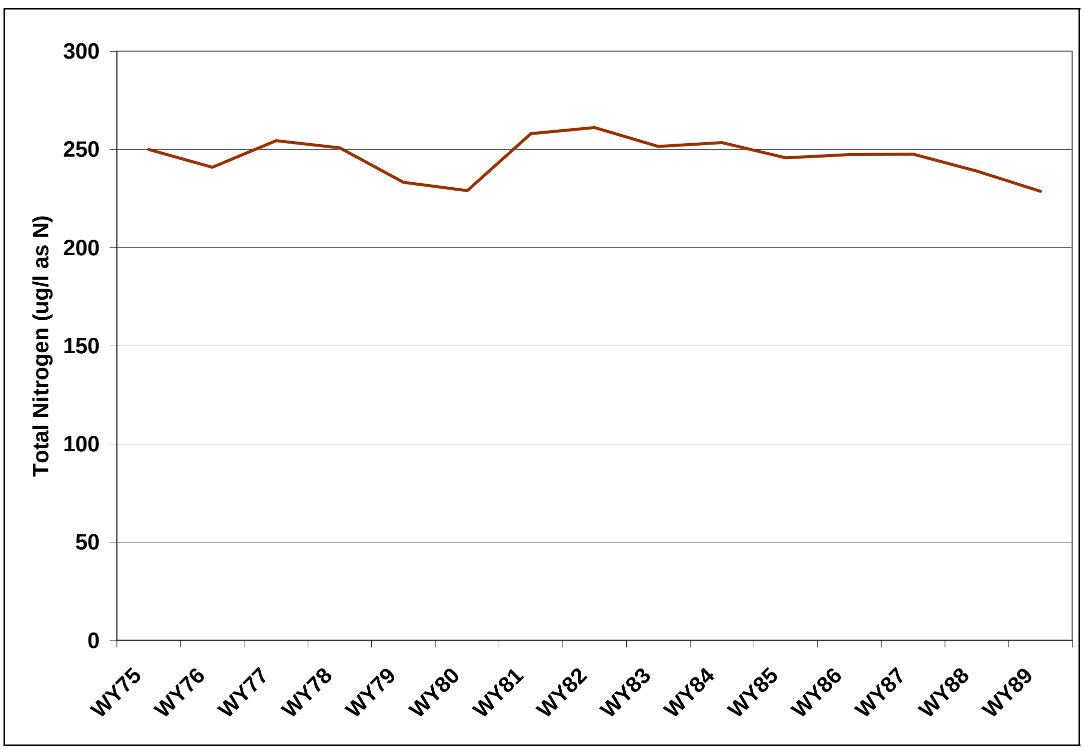


**Figure 102: Predicted Annual Average Total Nitrogen Concentrations in Jasper East Reservoir (Alternative 3)**

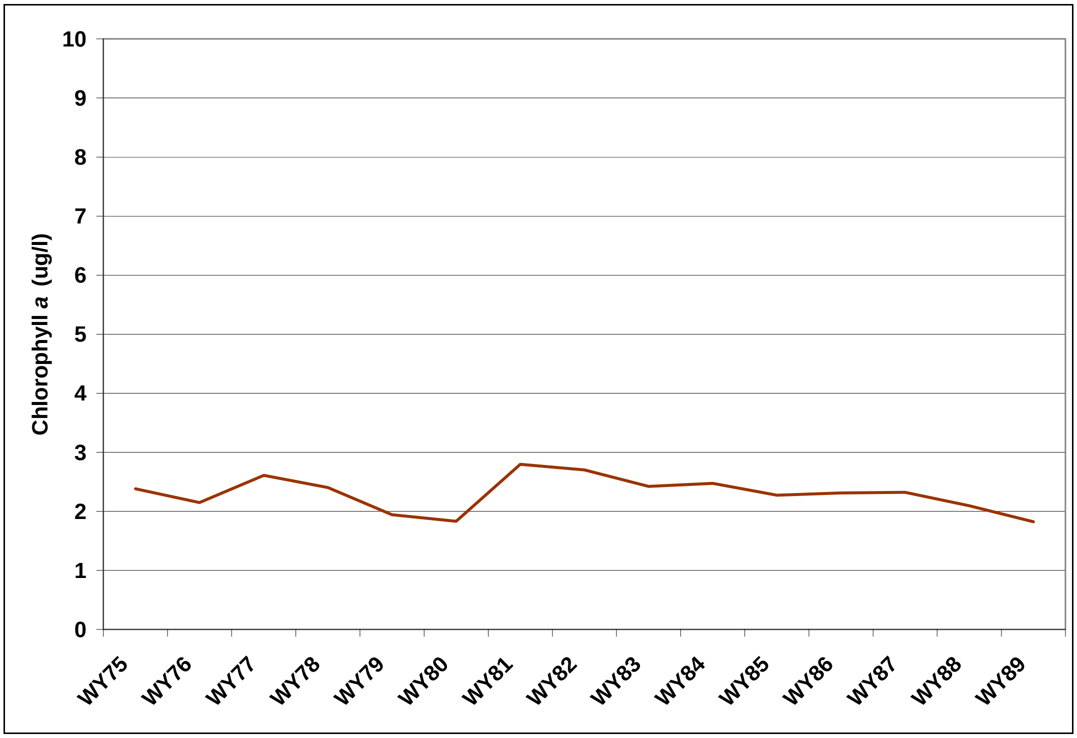


**Figure 103: Predicted Annual Average Chlorophyll *a* Concentrations in Jasper East Reservoir (Alternative 3)**

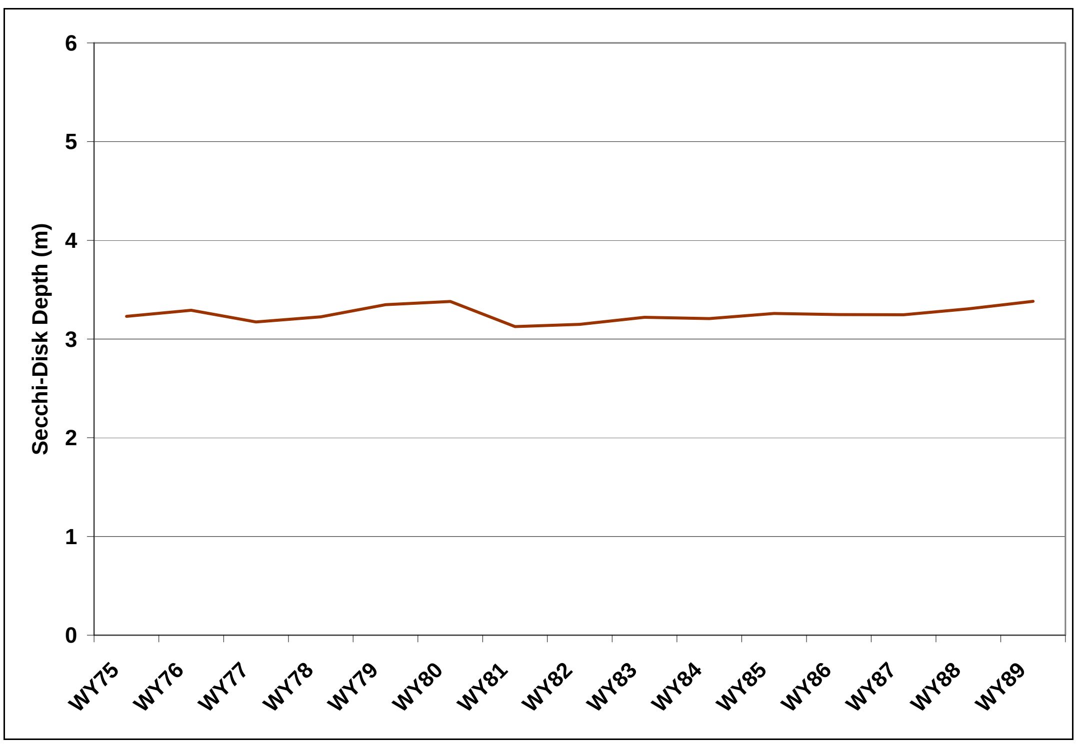


**Figure 104: Predicted Annual Average Secchi-Disk Depths in Jasper East Reservoir (Alternative 3)**

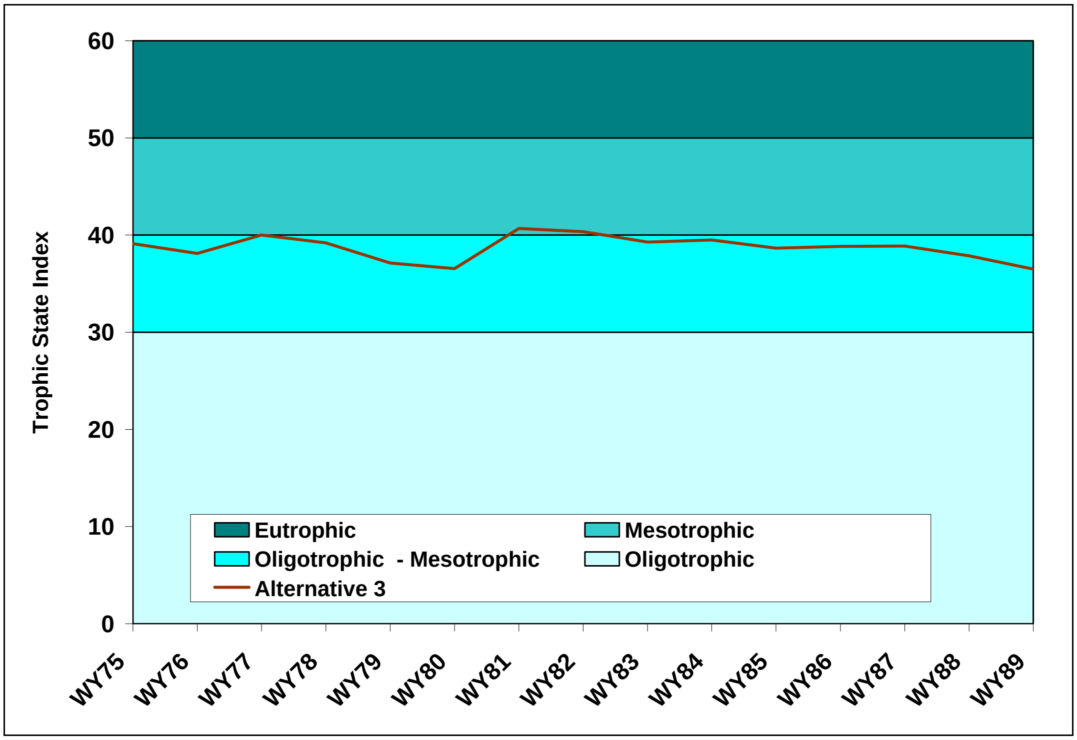


**Figure 105: Predicted Trophic State Indices in Jasper East Reservoir (Alternative 3)**

### 11.3.2. Rockwell Creek Reservoir

Rockwell Creek Reservoir is included in two alternatives - Alternative 4 (Chimney Hollow with Rockwell Creek) and Alternative 5 (Dry Creek with Rockwell Creek). For Alternative 4, the reservoir would have a maximum capacity of 20,000 AF. For Alternative 5, the maximum capacity would be 30,000 AF. Anticipated reservoir characteristics are listed in Table 64. Inflow into this reservoir would be provided via a pipeline from the Windy Gap Reservoir. Since this reservoir is proposed, there are no results to report for existing conditions or the No Action alternative for comparison purposes.

Anticipated in-reservoir water quality, as predicted using the BATHTUB model, is provided in Figure 106 - Figure 110. Average predicted conditions are listed in Table 65. Nutrient and chlorophyll *a* concentrations would be slightly lower for Alternative 5 than for Alternative 4, primarily due to a higher flushing rate for Alternative 5. As described previously in Table 37 and Table 38, Rockwell Reservoir would retain some nitrogen and phosphorus, thus reducing nutrient deliveries to Granby Reservoir.

The planned operations for Rockwell Creek Reservoir involve rapid drawdowns and fillings of the reservoir. This type of operation is not accounted for in the BATHTUB model and could lead to an increase in reservoir erosion turbidity, and suspended sediment delivery to Granby Reservoir.

**Table 64: Physical Characteristics of Rockwell Creek Reservoir**

| Alternative | Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|---|
| 4 | Volume | 20,000 AF | 24.7 x $10^6$ $m^3$ |
| | Surface Area | 294 acres | 119 hectares |
| | Mean Depth | 68 ft | 20.7 m |
| 5 | Volume | 30,000 AF | 37.0 x $10^6$ $m^3$ |
| | Surface Area | 348 acres | 141 hectares |
| | Mean Depth | 86 ft | 26.2 m |

**Table 65: Average Annual Predicted Conditions for Rockwell Creek Reservoir (Alternatives 4 and 5)**

| Average Annual Values Over the 15-Year Model Period | | |
|---|---|---|
| | Alternative 4 | Alternative 5 |
| Total Phosphorus (µg/l) | 28 | 26 |
| Total Nitrogen (µg/l) | 229 | 214 |
| Chlorophyll *a* (µg/l) | 1.8 | 1.4 |
| Secchi-disk Depth (m) | 3.4 | 3.5 |
| Trophic State (Index) | Oligotrophic-Mesotrophic (36) | Oligotrophic-Mesotrophic (34) |

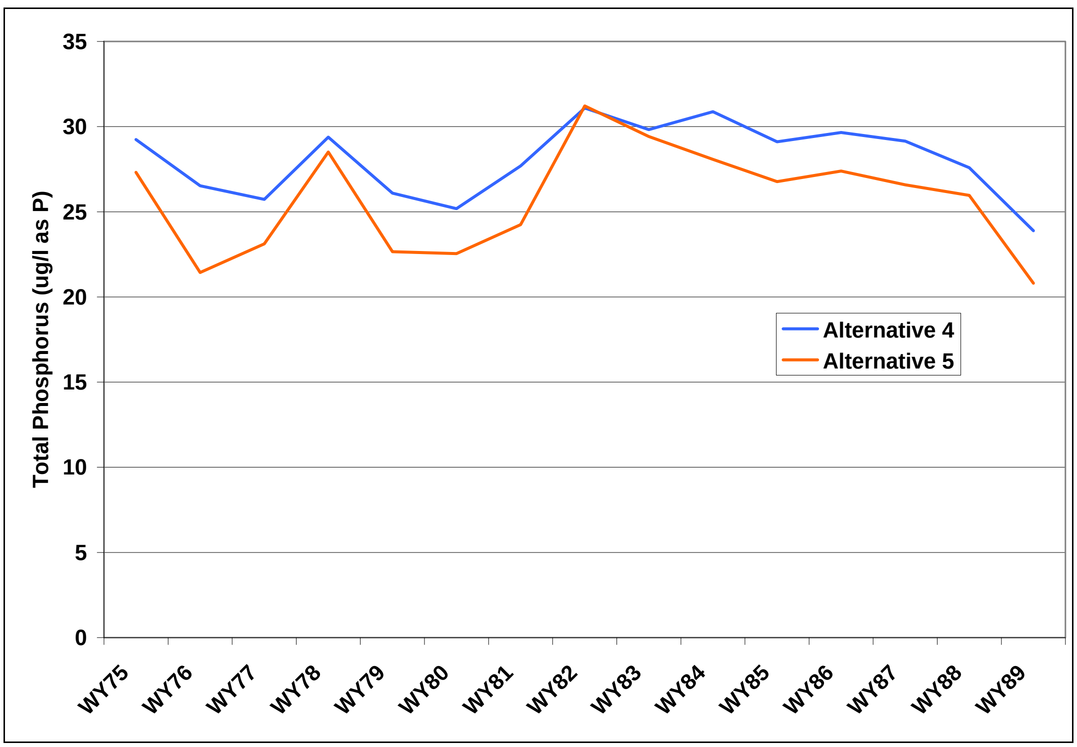


**Figure 106: Predicted Annual Average Total Phosphorus Concentrations in Rockwell Creek Reservoir (Alternatives 4 and 5)**

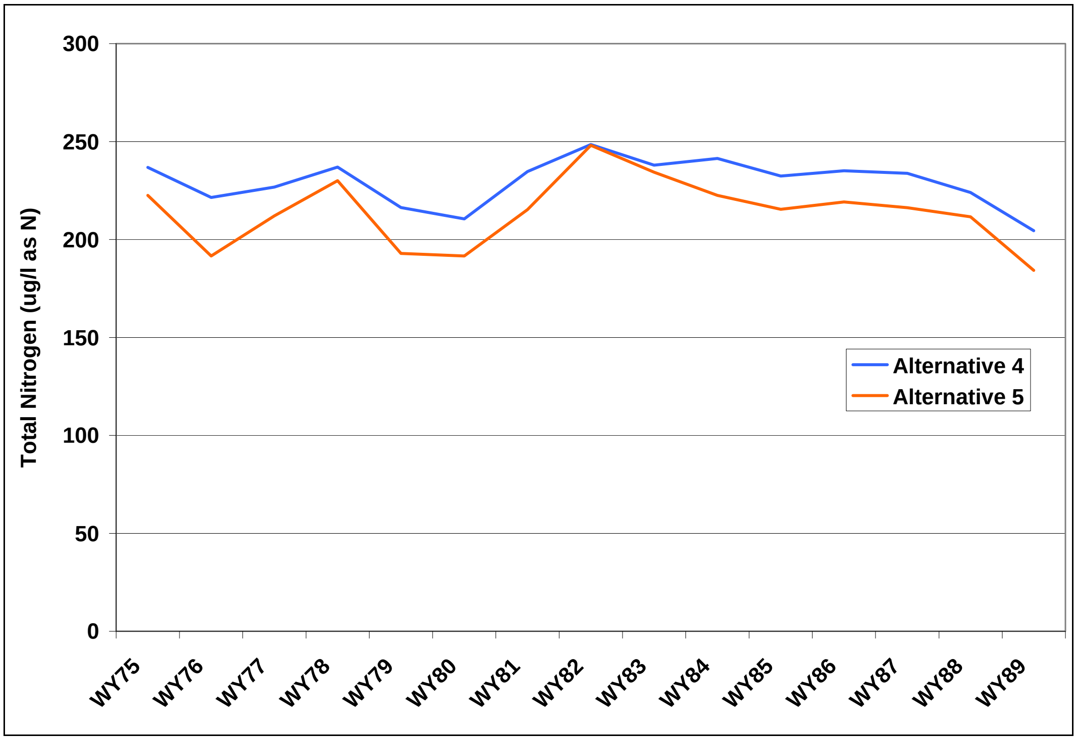


**Figure 107: Predicted Annual Average Total Nitrogen Concentrations in Rockwell Creek Reservoir (Alternatives 4 and 5)**

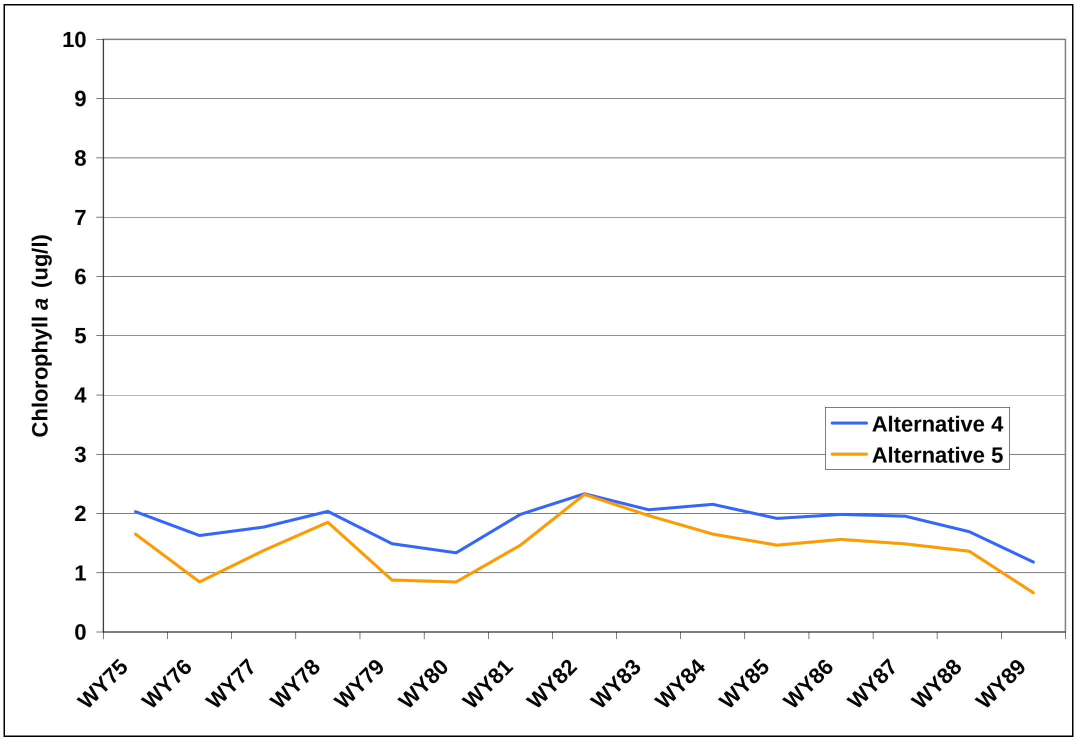


**Figure 108: Predicted Annual Average Chlorophyll *a* Concentrations in Rockwell Creek Reservoir (Alternatives 4 and 5)**

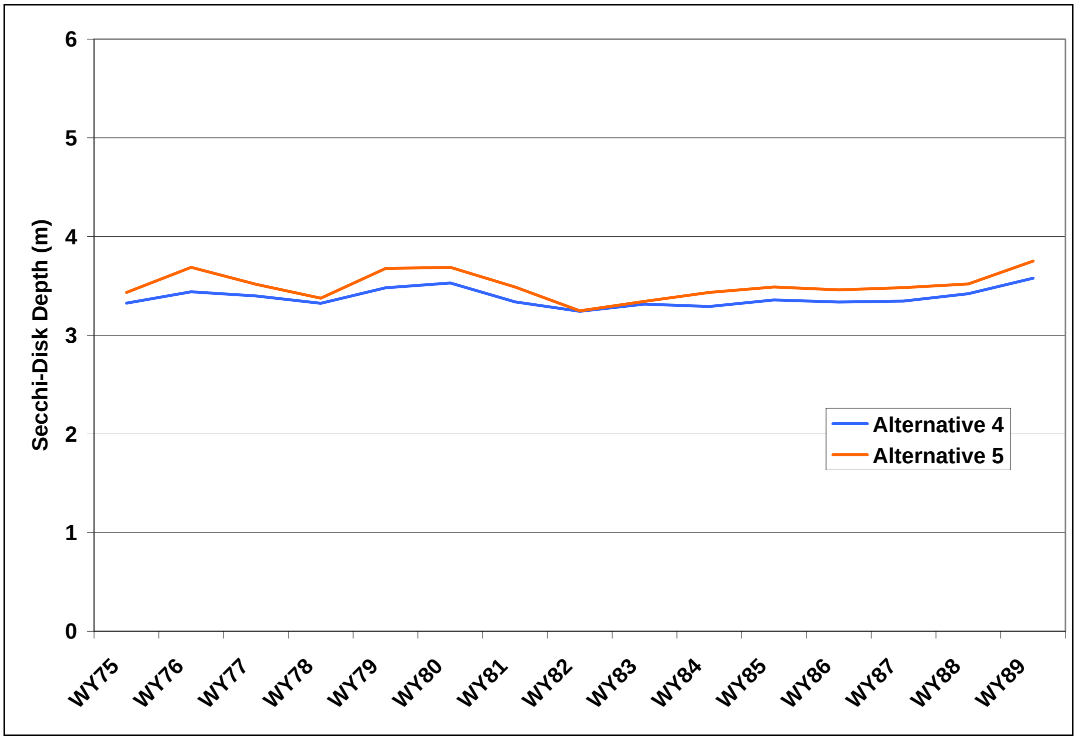


**Figure 109: Predicted Annual Average Secchi-Disk Depths in Rockwell Creek Reservoir (Alternatives 4 and 5)**

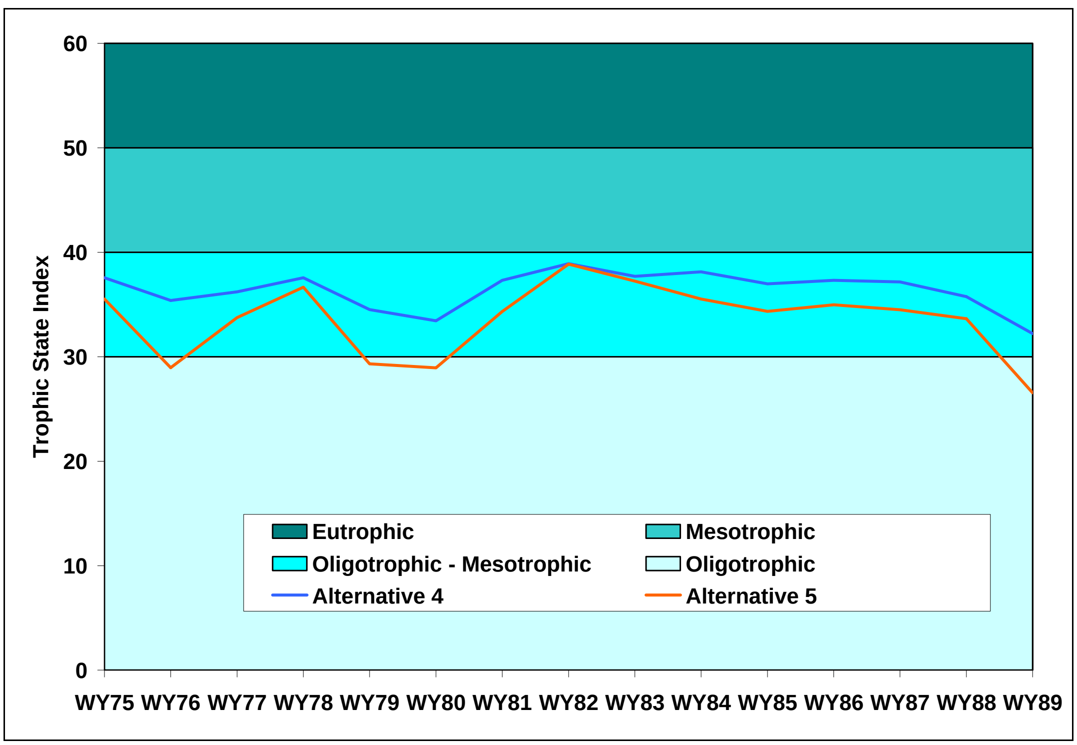


**Figure 110: Predicted Trophic State Indices in Rockwell Creek Reservoir (Alternatives 4 and 5)**

## 11.4. Direct and Indirect Effects - Proposed East Slope Reservoirs

### 11.4.1. Chimney Hollow Reservoir

Chimney Hollow Reservoir is included in three alternatives – the Proposed Action, Alternative 3, and Alternative 4. The reservoir has a maximum capacity of 90,000 AF for the Proposed Action and a capacity of 70,000 AF for Alternatives 4 and 5. Anticipated reservoir characteristics are listed in Table 66. Inflow into this reservoir would be provided via the Olympus Tunnel. Since this is a proposed reservoir, there are no results to report for existing conditions or the No Action alternative for comparison purposes.

The anticipated in-reservoir water quality, as predicted using the BATHTUB model, is provided in Figure 111 - Figure 115. Average annual predicted conditions are listed in Table 67. The reservoir is predicted to be in an oligotrophic state. The results for Alternatives 3 and 4 are almost identical. The Proposed Action shows higher nutrient and chlorophyll *a* concentrations due to a higher residence time (lower flushing)

It appears that the results from the Proposed Action are more variable than those for Alternatives 3 and 4. Note that the inflows into Chimney Hollow Reservoir are zero for four years of the 15-year simulation. The BATHTUB model does not compute reasonable concentrations under these conditions. Under conditions of no inflow, the reservoir water quality is expected to improve since there is no loading. To be conservative for this analysis however, values for these years were filled in with the average of the other years instead of choosing some lower concentration. This results in smoothing out the results for Alternatives 3 and 4.

**Table 66: Physical Characteristics of Chimney Hollow Reservoir**

| Alternative | Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|---|
| 2 | Volume | 90,000 AF | 111 x $10^6$ $m^3$ |
| | Surface Area | 742 acres | 300 hectares |
| | Mean Depth | 121 ft | 36.9 m |
| 3, 4 | Volume | 70,000 AF | 86.3 x $10^6$ $m^3$ |
| | Surface Area | 627 acres | 254 hectares |
| | Mean Depth | 112 ft | 34.1 m |

**Table 67: Average Annual Predicted Conditions for Chimney Hollow Reservoir (Proposed Action and Alternatives 3 and 4)**

| Average Annual Values Over the 15-Year Model Period | | | |
|---|---|---|---|
| | Proposed Action | Alternative 3 | Alternative 4 |
| Total Phosphorus (µg/l) | 8.7 | 7.2 | 7.3 |
| Total Nitrogen (µg/l) | 183 | 158 | 158 |
| Chlorophyll a (µg/l) | 0.7 | 0.2 | 0.2 |
| Secchi-disk Depth (m) | 3.8 | 3.9 | 3.9 |
| Trophic State (Index) | Oligotrophic (24) | Oligotrophic (13) | Oligotrophic (13) |

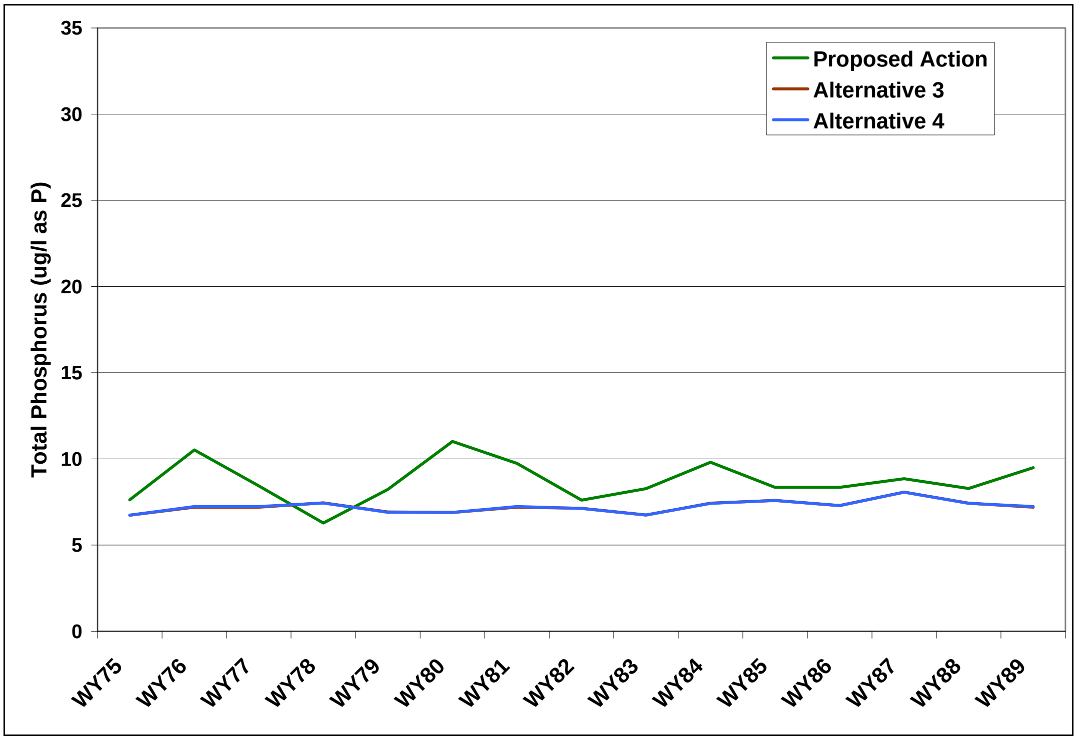


**Figure 111: Predicted Annual Average Total Phosphorus Concentrations in Chimney Hollow Reservoir (Proposed Action and Alternatives 3 and 4)**

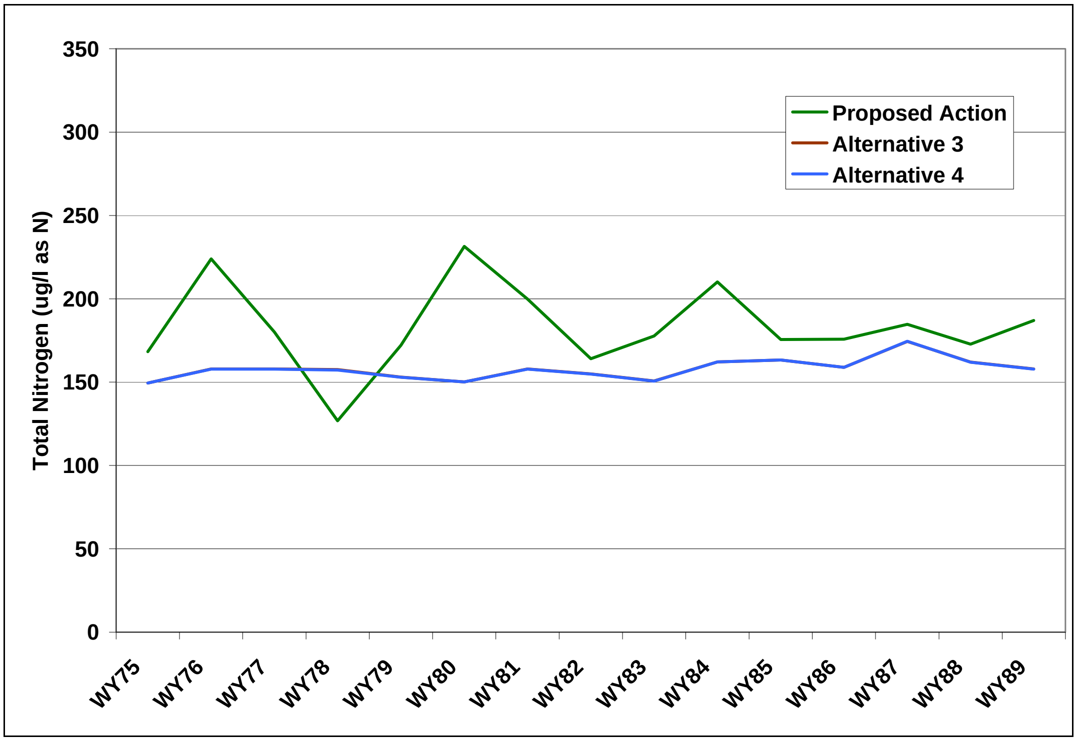


**Figure 112: Predicted Annual Average Total Nitrogen Concentrations in Chimney Hollow Reservoir (Proposed Action and Alternatives 3 and 4)**

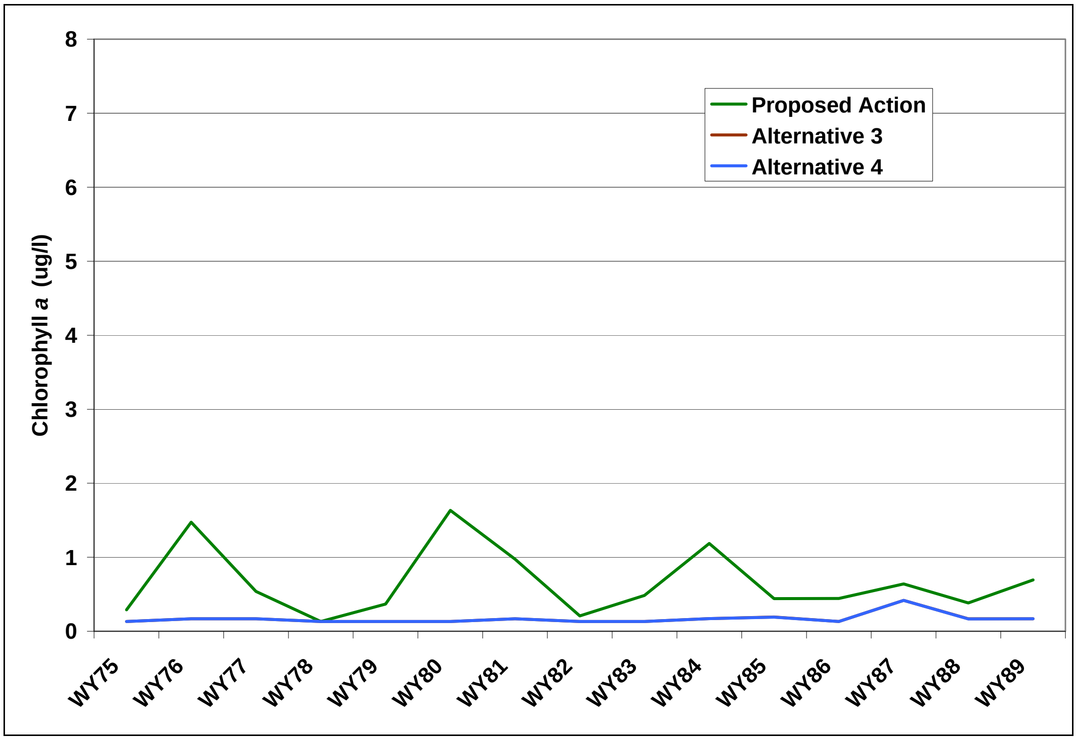


**Figure 113: Predicted Annual Average Chlorophyll *a* Concentrations in Chimney Hollow Reservoir (Proposed Action and Alternatives 3 and 4)**

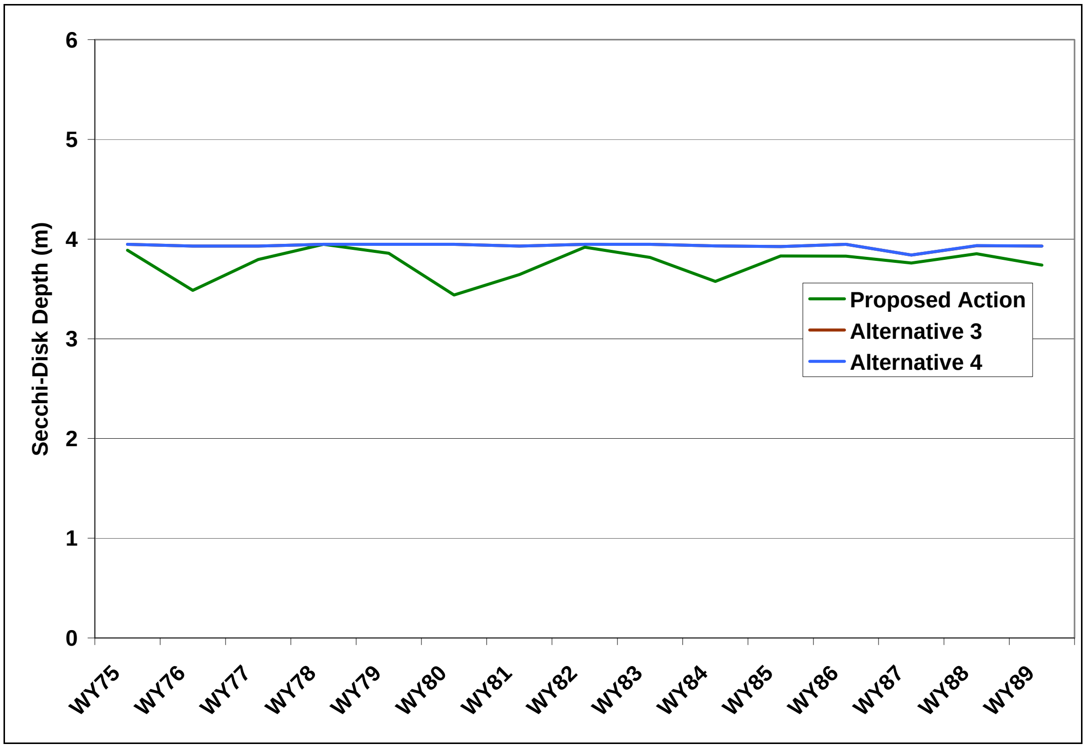


**Figure 114: Predicted Annual Average Secchi-Disk Depths in Chimney Hollow Reservoir (Proposed Action and Alternatives 3 and 4)**

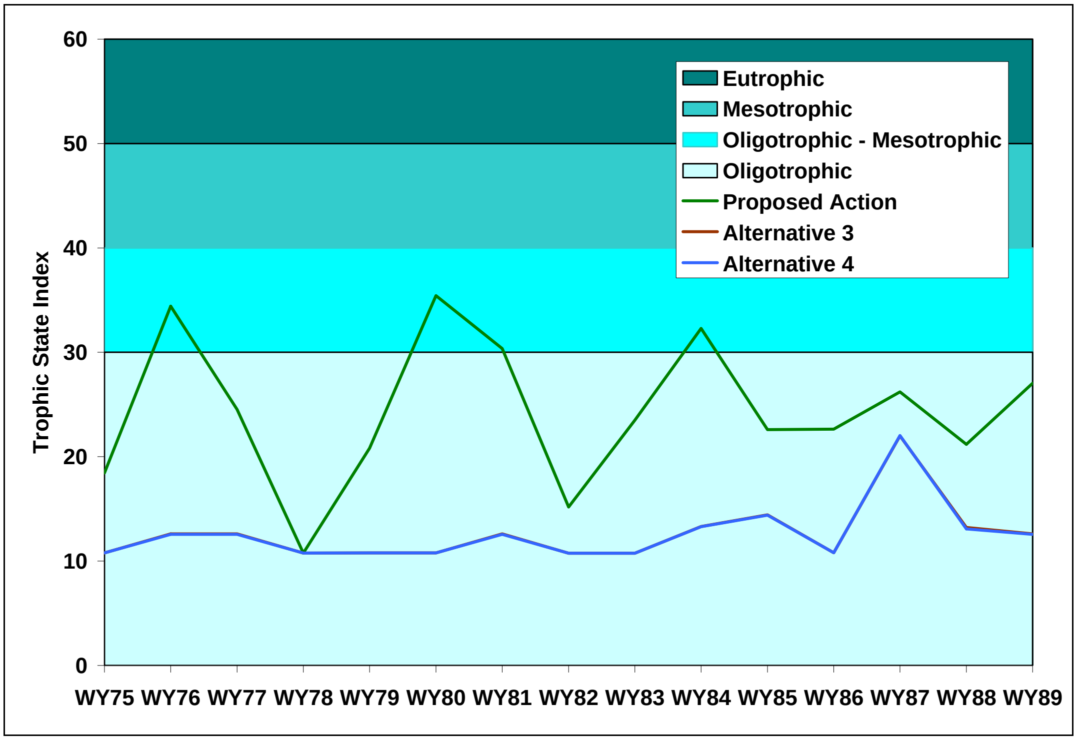


**Figure 115: Predicted Trophic State Indices in Chimney Hollow Reservoir (Proposed Action and Alternatives 3 and 4)**

### 11.4.2. Dry Creek Reservoir

Dry Creek Reservoir is included in Alternative 5 (Dry Creek with Rockwell Creek). Anticipated reservoir characteristics are listed in Table 68. Inflow into this reservoir would be provided via the Olympus Tunnel. Since this is a proposed reservoir, there are no results to report for existing conditions or the No Action alternative for comparison purposes. The anticipated in-reservoir water quality, as predicted using the BATHTUB model is provided in Figure 116 - Figure 120. Average predicted conditions are listed in Table 69. The reservoir is predicted to be in an oligotrophic state. The changes in water quality during the 15-year period are related to changes in inflow patterns into the reservoir.

**Table 68: Physical Characteristics of Dry Creek Reservoir**

| Metric | Value (English Units) | Value (Metric Units) |
|---|---|---|
| Volume | 60,000 AF | 74.0 x $10^6$ $m^3$ |
| Surface Area | 589 acres | 238 hectares |
| Mean Depth | 102 ft | 31.1 m |

**Table 69: Average Predicted Conditions for Dry Creek Reservoir (Alternative 5)**

| Average Annual Values Over the 15-Year Model Period | |
|---|---|
| Total Phosphorus (µg/l) | 9.3 |
| Total Nitrogen (µg/l) | 204 |
| Chlorophyll *a* (µg/l) | 1.1 |
| Secchi-disk Depth (m) | 3.6 |
| Trophic State (Index) | Oligotrophic (26) |

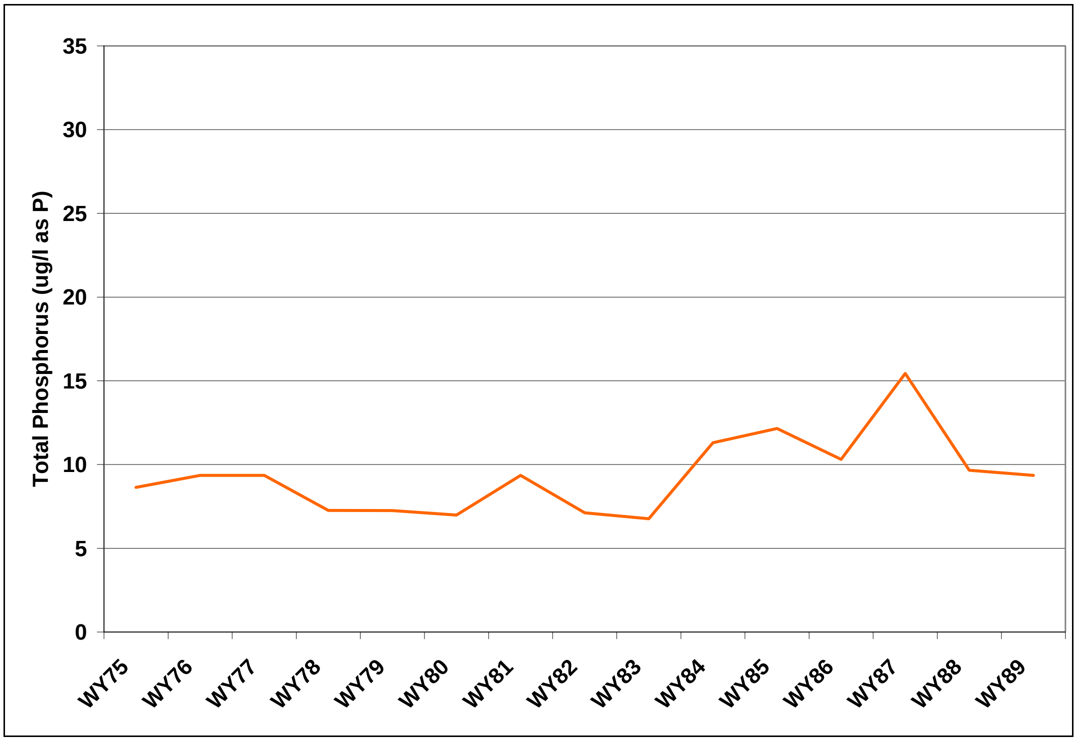


**Figure 116: Predicted Annual Average Total Phosphorus Concentrations in Dry Creek Reservoir (Alternative 5)**

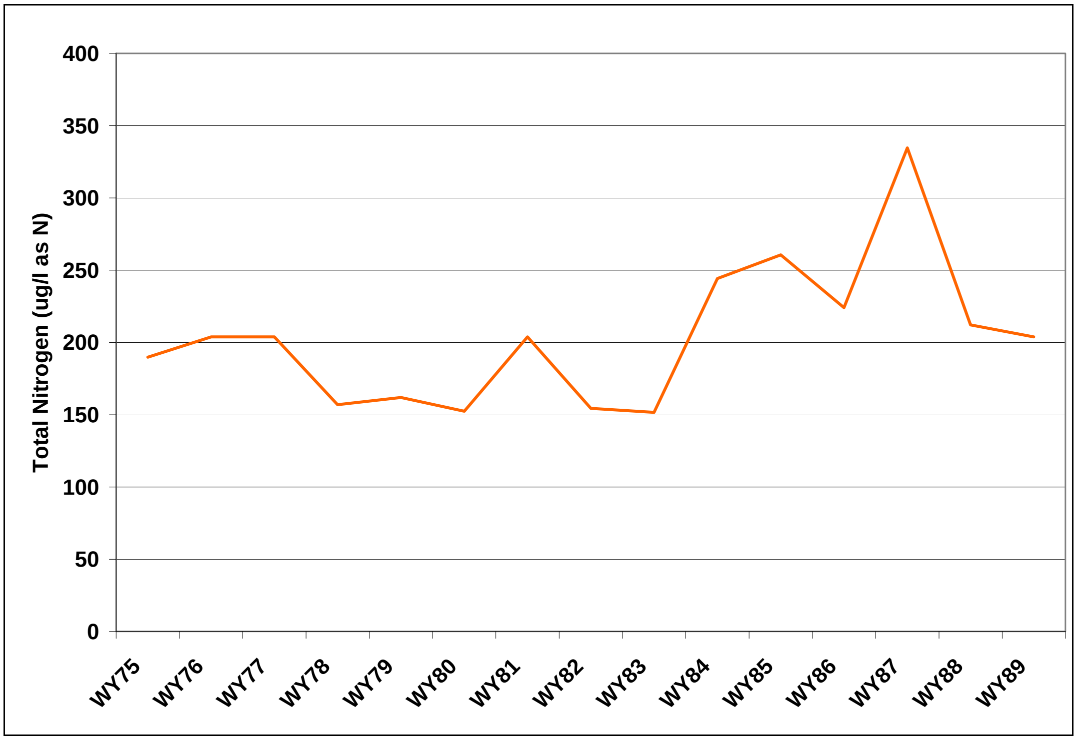


**Figure 117: Predicted Annual Average Total Nitrogen Concentrations in Dry Creek Reservoir (Alternative 5)**

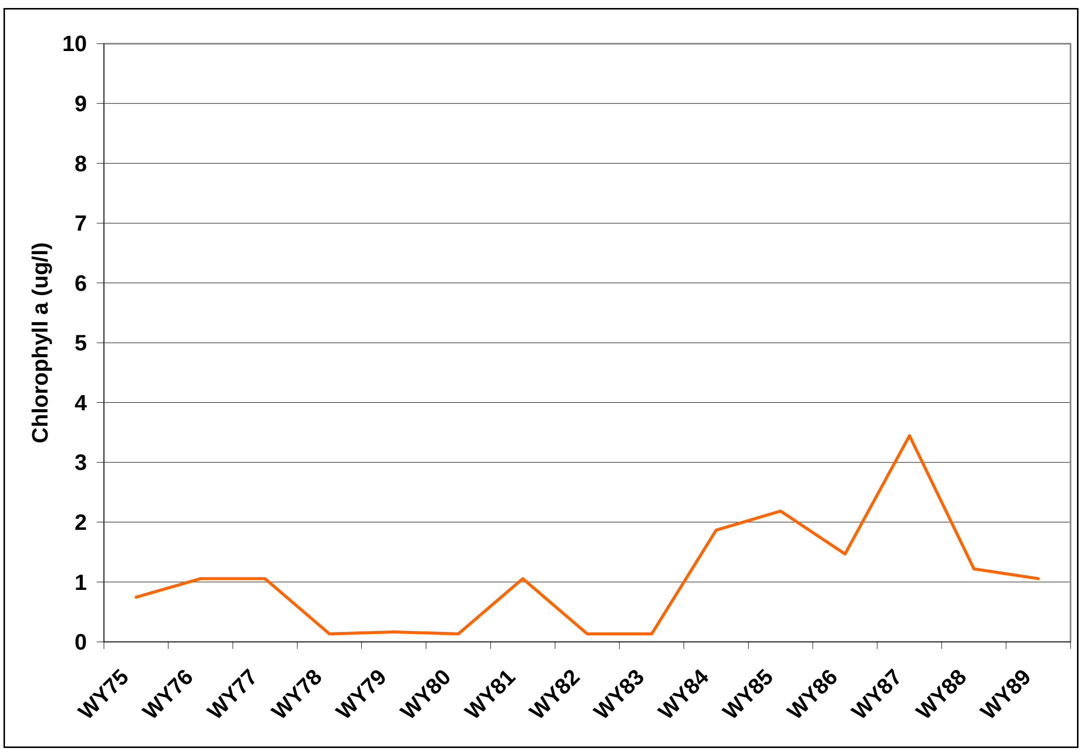


**Figure 118: Predicted Annual Average Chlorophyll *a* Concentrations in Dry Creek Reservoir (Alternative 5)**

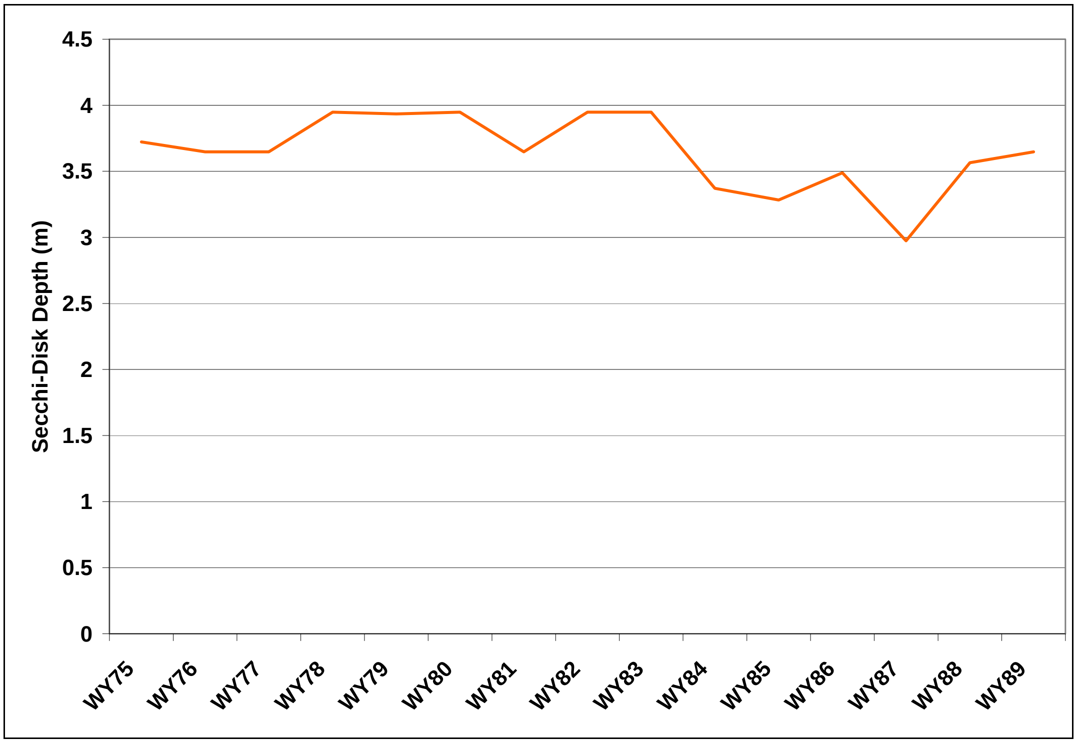


**Figure 119: Predicted Annual Average Secchi-Disk Depths in Dry Creek Reservoir (Alternative 5)**

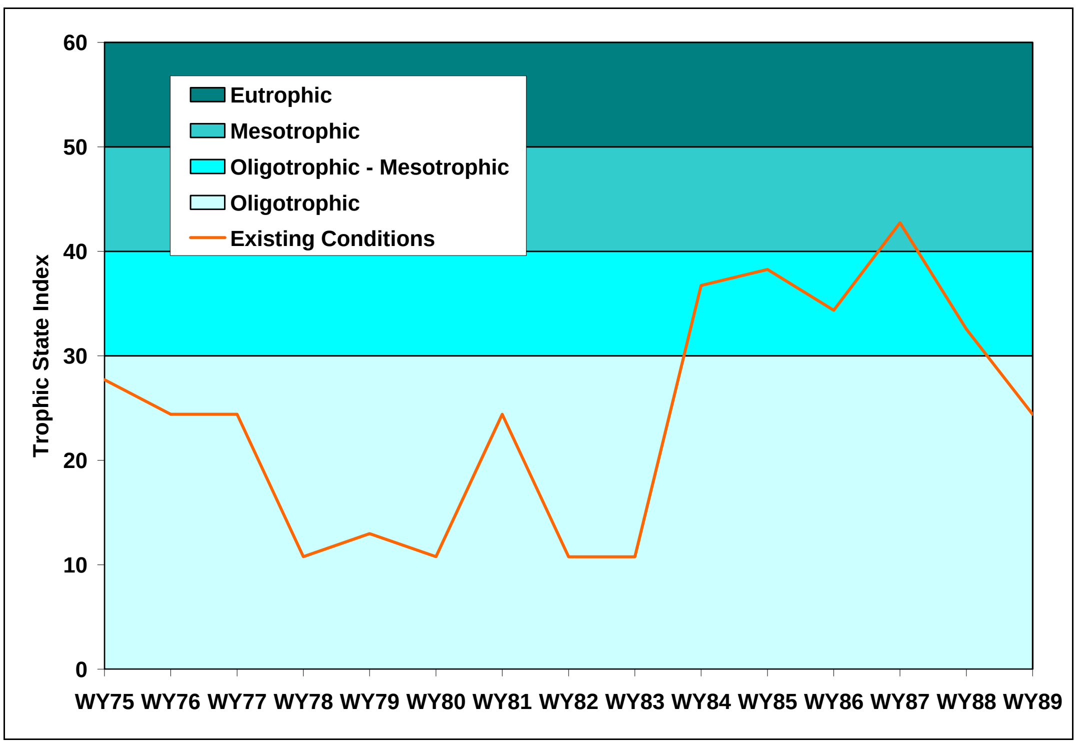


**Figure 120: Predicted Trophic State Indices in Dry Creek Reservoir (Alternative 5)**

# 12.0 ENVIRONMENTAL CONSEQUENCES - CUMULATIVE EFFECTS

## 12.1. Introduction

Cumulative effects result from the incremental effect of an alternative action when added to other past, present, and reasonably foreseeable future actions. Cumulative effects can result from individually minor, but collectively significant actions taking place over a time period. This section of the report evaluates the potential cumulative effects to reservoir water quality associated with alternative actions in addition to identified reasonably foreseeable actions that are expected to occur in the future. Changes in water quality are discussed for the alternatives in a similar format and sequence as the direct environmental effects.

## 12.2. Reasonably Foreseeable Actions

Several reasonably foreseeable actions are anticipated to occur in the future regardless of the implementation of any of the WGFP action alternatives or the No Action alternative. Reasonably foreseeable actions were divided into water-based actions that would affect portions of the Colorado River where Windy Gap diversions would occur, and land-based actions that include ground disturbances or other activities near potential WGFP facilities. Water- and land-based reasonably foreseeable actions are defined below.

*Water-Based Reasonably Foreseeable Actions*

**DW Moffat Collection System Project.** The Moffat Collection System Project is currently proposed by DW to develop 18,000 AF/year of new, annual yield to the Moffat Treatment Plant to meet future raw water demands on the East Slope. This project is anticipated to result in additional diversions, primarily from the upper Fraser River and Williams Fork River basins. DW's proposed additional Fraser River diversions would be located upstream of the Windy Gap Project diversion site on the Colorado River and would directly affect the availability of water for the WGFP. Because a Proposed Action has not been identified for the Moffat Collection System Project, a scenario for hydrologic modeling was considered that maximizes DW's future diversions from the Fraser River basin. DW provided output from its Platte and Colorado Simulations Model (PACSM) run that includes DW's total system demand at approximately 393,000 AF/year, which would be full use of its existing system, plus 18,000 AF of new firm yield generated by the Moffat Collection System Project. DW's current demand is 285,000 AF/year; therefore, an increase in demand of 108,000 AF/year was considered for the cumulative effects analysis.

**Urban Growth in Grand and Summit Counties.** The population in Grand and Summit Counties is expected to more than double over the next 25 years, from a year-round population of about 39,000 in 2005 to about 79,000 in 2030 (ERO 2005a). Most growth in Grand County is likely to occur in the Fraser River basin upstream of the Windy Gap Project diversion site on the Colorado River. Future increases in water use in Summit County would occur primarily in the Blue River basin, a tributary to the Colorado River downstream of Windy Gap's point of diversion. Increased water use and wastewater discharges are expected to result in changes in streamflow and water quality and contribute to cumulative effects. Urban growth in Grand and Summit Counties was based on build-out municipal and industrial demands of 16,168 AF for Grand County and 17,940 AF for Summit County as identified in the *Upper Colorado River Basin Study* (Hydrosphere, 2003b). Year 2000 water demand in Grand County was about 3,100 AF and in Summit County was about 7,700 AF.

**Reduction of Excel Energy's Shoshone Power Plant Call**. DW and Excel Energy have negotiated an agreement to periodically invoke a relaxation of the junior Shoshone call for hydropower generation on the Colorado River.[1] The agreement to relax the call could result in a one-turbine call of 704 cfs, which would be managed in such a way to avoid a Cameo Call by the Grand Valley Water users[2]. The Shoshone call could be increased above 704 cfs as needed to keep the Cameo water rights satisfied. The Shoshone call relaxation could be invoked if, in March, DW predicts its total system storage to be at or below 80 percent on July 1 that year, and the March 1 Natural Resources Conservation Service (NRCS) forecast for Colorado River flows at Kremmling or Dotsero are at or below 85 percent of average. The Shoshone call relaxation could be invoked between March 14 and May 20. DW would make available 15 percent of the "net water" stored or diverted by DW by virtue of the call relaxation for Excel Energy. Net water is water stored less water subsequently spilled after filling. In addition, DW would make available 10 percent of the net water stored or diverted by DW by virtue of the call relaxation to West Slope entities. The West Slope beneficiaries and the timing and amount of deliveries are not specified, but would be determined by DW and the CRWCD. The term of this agreement is from January 1, 2007 through February 28, 2032.

**Changes in Releases from Williams Fork and Wolford Mountain Reservoirs to Meet USFWS Flow Recommendations for Endangered Fish in the 15-Mile Reach.** An agreement which extends through July 1, 2009 between the City and County of Denver, the Colorado Water Conservation Board (CWCB) and the U.S. Fish and Wildlife Service (USFWS) exists for the interim provision of water to the 15-Mile Reach of the Colorado River near Grand Junction as part of the Recovery Program to benefit endangered fish. A similar agreement exists between the CRWCD, CWCB, and the USFWS. These agreements provide for the total release of 10,825 AF of water annually from both Williams Fork and Wolford Mountain Reservoirs (5,412.5 AF from each reservoir) to meet USFWS flow recommendations for the 15-Mile Reach. These contracts expire in 2009 and 2010, respectively, and both DW and the CRWCD have said they do not plan to continue making these releases from Williams Fork and Wolford Mountain Reservoirs in the future. The source and location of future water releases of 10,825 AF/year has not been determined. For the purposes of this analysis, it was assumed that the releases would be made from a reservoir located downstream of Kremmling and outside the study area considered for the cumulative effects analysis.

**Wolford Mountain Reservoir Contract Demand.** The CRWCD projects that the demand for contract water out of Wolford Mountain Reservoir will increase in the future. Currently there is about 8,750 AF/year of available contract water in Wolford Mountain Reservoir (Colorado Springs has a lease for contract water from Wolford Mountain Reservoir which reduces the firm yield of the contract pool from 10,000 AF/year to 8,750 AF/year). The CRWCD indicates that the full 8,750 AF/year would likely be contracted for by 2030. In

[1] The Shoshone Hydro Plant owned by Excel Energy, is a large senior water right on the Colorado River 8 miles east of Glenwood Springs. At flows less than 1,408 cfs, it is the most senior water right on the River and can "call" water downstream from junior water rights upstream, including the Moffat Tunnel, C-BT Project, Windy Gap, and other water rights.

[2] The Cameo Call is a senior water right owned by five entities near Grand Junction. The water is used primarily for irrigation and power.

addition, MPWCD has 3,000 AF/year of water from Wolford Mountain Reservoir, of which 613 AF/year is owed to DW under the Clinton Reservoir Agreement. The CRWCD indicated that the remaining 2,387 AF/year would likely be contracted for by 2030. Therefore, the total additional future demand for contract water from Wolford Mountain Reservoir is assumed to be 11,137 AF/year by 2030.

**Expiration of DW's Contract with Big Lake Ditch in 2013.** The Big Lake Ditch is a senior irrigation right in the Williams Fork basin that diverts below DW's Williams Fork collection system and above Williams Fork Reservoir. Big Lake Ditch diversions are currently delivered for irrigation above Williams Fork Reservoir and for use in the Reeder Creek drainage, which is a tributary of the Colorado River. Return flows associated with irrigation in the Reeder Creek drainage return to the Colorado River between the confluence with the Williams Fork River and the confluence with the Blue River.

In 1963, DW entered into a contract with Bethel Hereford Ranch Inc., which owned and operated the Big Lake Ditch, whereby DW purchased the Ranch's water rights. Bethel Hereford was granted a 40-year lease to continue its operation under the condition that the Big Lake Ditch water rights are not called if needed by DW. The 1963 agreement was superseded by a 1998 agreement, which extended the operation of the Big Lake Ditch through 2013, and provided more detail on the conditions under which DW would need the water. The 1998 agreement expires November 1, 2013 and DW does not plan to extend the existing contract. After the contract expires in 2013, the Big Lake Ditch can no longer divert water under the enlargement decree for 111 cfs for irrigation in the Reeder Creek drainage. As a result, future Big Lake Ditch water right diversions to the Reeder Creek basin would be abandoned, which would allow DW to capture additional water from the Williams Fork and store the water in Williams Fork Reservoir during all years that its Williams Fork Reservoir water rights are in priority.

#### *Land-Based Reasonably Foreseeable Actions*

**Land Development.** A variety of new land developments are expected to occur in the vicinity of the potential reservoir sites in Larimer, Grand, and Boulder Counties. This includes residential and commercial developments on the West Slope; on the East Slope, this includes residential development, a quarry, and a new reservoir.

**Larimer County Open Space.** Larimer County Parks and Open Lands acquired about 1,850 acres of land adjacent to the proposed Chimney Hollow Reservoir site. The County intends to manage this property for recreation use regardless of whether Chimney Hollow Reservoir is constructed.

**Urban Growth in the Northern Front Range**. Continued population growth and development is expected to occur in the Northern Front Range, Colorado communities served by many of the Firming Project Participants.

## 12.3. Alternatives Evaluated for Cumulative Effects

Alternatives 3, 4, and 5 each have a new east slope reservoir and a new west slope reservoir. For the evaluation of cumulative water-quality effects, it was assumed that these three alternatives would have similar results and that Alternative 5 could be used to represent Alternatives 3 and 4. Therefore, the discussion below focuses on Alternatives 1, 2, and 5.

## 12.4. Cumulative Effects - Existing West Slope Reservoirs and Grand Lake

To evaluate the cumulative water quality effects of the alternatives, assumptions were made about future conditions. Flow information developed by Boyle (Boyle, 2006) was used in the analysis. In addition, future water-quality conditions of each of the inflows into the Three Lakes system were needed. It was assumed that the water quality of East Inlet, North Inlet, Arapaho Creek, Stillwater Creek, Roaring Fork, the North Fork of the Colorado, and the quality of water pumped from Willow Creek Reservoir would remain unchanged from existing conditions. For pumping from Windy Gap and Rockwell Creek reservoirs, assumptions were made about future conditions in the Fraser River Basin due to anticipated growth. The assumptions made are described in the Stream Water Quality Technical Report (ERO and AMEC, 2008) and include the wastewater treatment plant upgrades including nutrient removal. The upgrades would result in lower total phosphorus concentrations than existing conditions for the alternatives considered, but higher total nitrogen concentrations. The resulting anticipated loads from Windy Gap Reservoir and Rockwell Creek Reservoir are summarized in Table 70 and Table 71. Loads from Willow Creek pumping are also included.

**Table 70: Total Phosphorus Load Delivered to Granby Reservoir from Willow Creek Reservoir, Windy Gap Reservoir, and Rockwell Creek Reservoir by Alternative - Cumulative Effects (WY75-WY89)**

| Alternative | TP Load From Willow Creek Reservoir (kg/yr) | TP Load From Windy Gap Reservoir (kg/yr) | TP Load From Rockwell Creek Reservoir (kg/yr) | Total (kg/yr) |
|---|---|---|---|---|
| Existing Conditions | 1,465 | 2,143 | | 3,608 |
| No Action | 1,591 | 1,645 | | 3,236 |
| Proposed Action | 1,633 | 1,944 | | 3,577 |
| Alternative 5 | 1,608 | 1,007 | 387 | 3,002 |

**Table 71: Total Nitrogen Load Delivered to Granby Reservoir from Willow Creek Reservoir, Windy Gap Reservoir, and Rockwell Creek Reservoir by Alternative - Cumulative Effects (WY75-WY89)**

| Alternative | TN Load From Willow Creek Reservoir (kg/yr) | TN Load From Windy Gap Reservoir (kg/yr) | TN Load From Rockwell Creek Reservoir (kg/yr) | Total (kg/yr) |
|---|---|---|---|---|
| Existing Conditions | 15,948 | 16,391 | | 32,339 |
| No Action | 16,731 | 19,911 | | 36,642 |
| Proposed Action | 16,986 | 22,798 | | 39,784 |
| Alternative 5 | 16,840 | 10,546 | 6,533 | 33,919 |

### 12.4.1. Granby Reservoir

Predictions for existing conditions and the three cumulative effects alternatives are summarized in Table 72 and displayed in Figure 121 - Figure 137. Annual average and daily output are presented. Trophic state was predicted using average predicted chlorophyll *a* concentrations (May 1 to November 15) and the Carlson Trophic State Index (Carlson and Simpson, 1977).

Changes in water-quality as compared to existing conditions are shown in Table 73. Changes as compared to the No Action alternative are displayed in Table 74. No change in trophic state would be expected with any of the alternatives. The reservoir would remain in a mesotrophic state for all alternatives. Nitrogen concentrations would be higher than existing conditions for all alternatives and phosphorus concentrations would be lower under No Action and Alternative 5 and slightly higher under the Proposed Action. Phosphorus concentrations would be lower than in the direct effects analysis due to anticipated advanced wastewater treatment in the Fraser Basin in the future. No changes in average chlorophyll *a* are predicted. The predicted annual average and daily chlorophyll *a* concentrations are shown in Figure 125 and Figure 127. The peak chlorophyll *a* concentrations by year are shown in Figure 126.

Predicted epilimnetic temperatures are displayed in Figure 137. There is no discernable difference in temperature between the alternatives and existing conditions. Therefore, it is anticipated that there would not be a negative impact on Granby Reservoir or any of the other reservoirs due to the alternatives.

**Table 72: Average Predicted Conditions for Granby Reservoir (Existing Conditions and Cumulative Effects No Action, Proposed Action, and Alternative 5)**

| Average Annual Value Over the 15-Year Model Period | | | | |
|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 5 |
| Total Phosphorus (µg/l) | 12.6<br>(4.5 – 25.0) | 12.2<br>(4.5 – 22.1) | 12.9<br>(4.5 – 22.4) | 10.9<br>(4.8 – 17.7) |
| Total Nitrogen (µg/l) | 289<br>(228 – 375) | 298<br>(229 – 396) | 300<br>(229 – 395) | 303<br>(230 – 360) |
| Chlorophyll *a* (µg/l) | 4.2<br>(2.0 – 7.3) | 4.2<br>(2.0 – 7.3) | 4.2<br>(2.0 – 7.1) | 4.1<br>(2.0 – 6.9) |
| Peak Chlorophyll *a* (µg/l) | 6.6 | 6.5 | 6.5 | 6.3 |
| Secchi-Disk Depth (m) | 3.6<br>(2.1 – 5.3) | 3.6<br>(2.0 – 5.3) | 3.6<br>(2.0 – 5.3) | 3.6<br>(2.1 – 5.1) |
| Trophic State (Index) | Mesotrophic<br>(46) | Mesotrophic<br>(46) | Mesotrophic<br>(46) | Mesotrophic<br>(46) |
| Minimum DO (mg/l) | 4.5 | 4.5 | 4.3 | 4.5 |
| TSS (mg/l) | 2.3<br>(1.1 – 5.9) | 2.3<br>(1.1 – 6.1) | 2.4<br>(1.1 – 6.2) | 2.4<br>(1.1 – 5.1) |

Range of data (min – max) included. All concentrations are for the epilimnion with the exception of minimum dissolved oxygen, which is for the hypolimnion.

**Table 73: Predicted Changes by Alternative for Granby Reservoir Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 5 |
|---|---|---|---|
| Total Phosphorus (µg/l) | -3.2% | +2.4% | -13.5% |
| Total Nitrogen (µg/l) | +3.1% | +3.8% | +4.8% |
| Chlorophyll *a* (µg/l) | No Change | No Change | -2.4% |
| Peak Chlorophyll *a* (µg/l) | -1.5% | -1.5% | -4.5% |
| Secchi-Disk Depth (m) | No Change | No Change | No Change |
| Trophic State | No Change | No Change | No Change |
| Minimum DO (mg/l) | No Change | -4.4% | No Change |
| TSS (mg/l) | No Change | +4.3% | +4.3% |

**Table 74: Predicted Changes for Granby Reservoir by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 5 |
|---|---|---|
| Total Phosphorus (µg/l) | +5.7% | -10.7% |
| Total Nitrogen (µg/l) | +0.7% | +1.7% |
| Chlorophyll *a* (µg/l) | No Change | -2.4% |
| Peak Chlorophyll *a* (µg/l) | No Change | -3.1% |
| Secchi-Disk Depth (m) | No Change | No Change |
| Trophic State | No Change | No Change |
| Minimum DO (mg/l) | -4.4% | No Change |
| TSS (mg/l) | +4.3% | +4.3% |

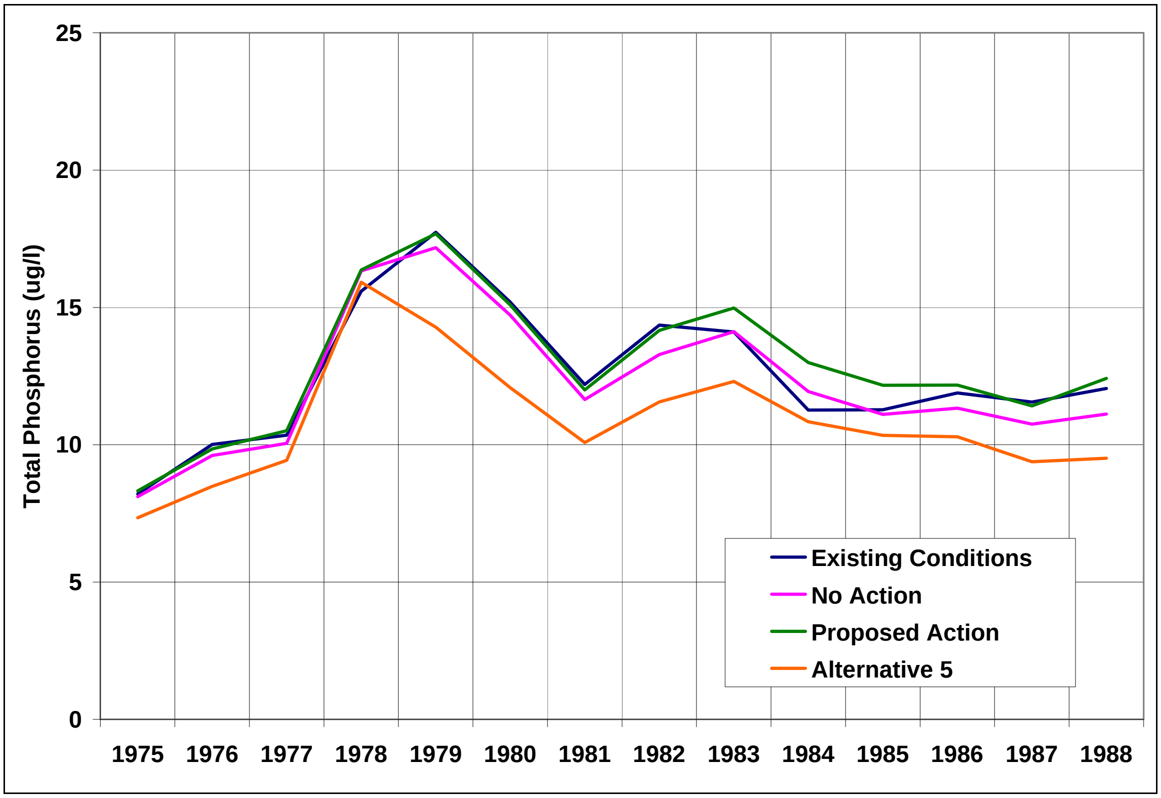


**Figure 121: Predicted Average Annual Total Phosphorus Concentrations in Granby Reservoir --Cumulative Effects**

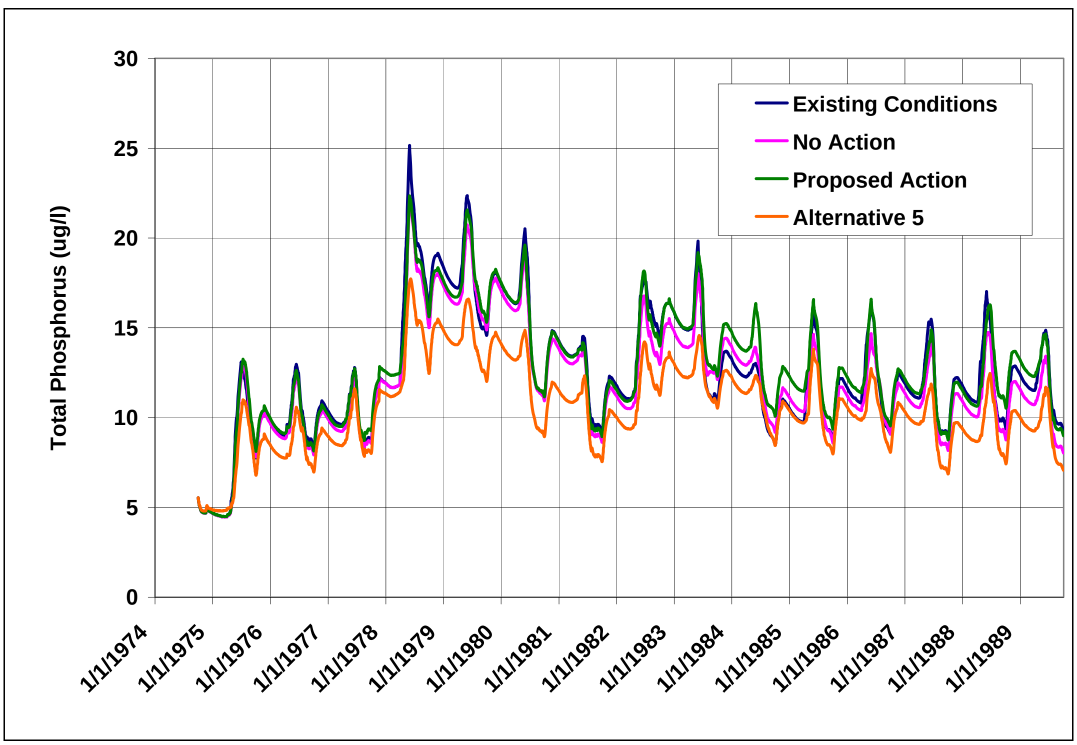


**Figure 122: Predicted Daily Total Phosphorus Concentrations in Granby Reservoir --Cumulative Effects**

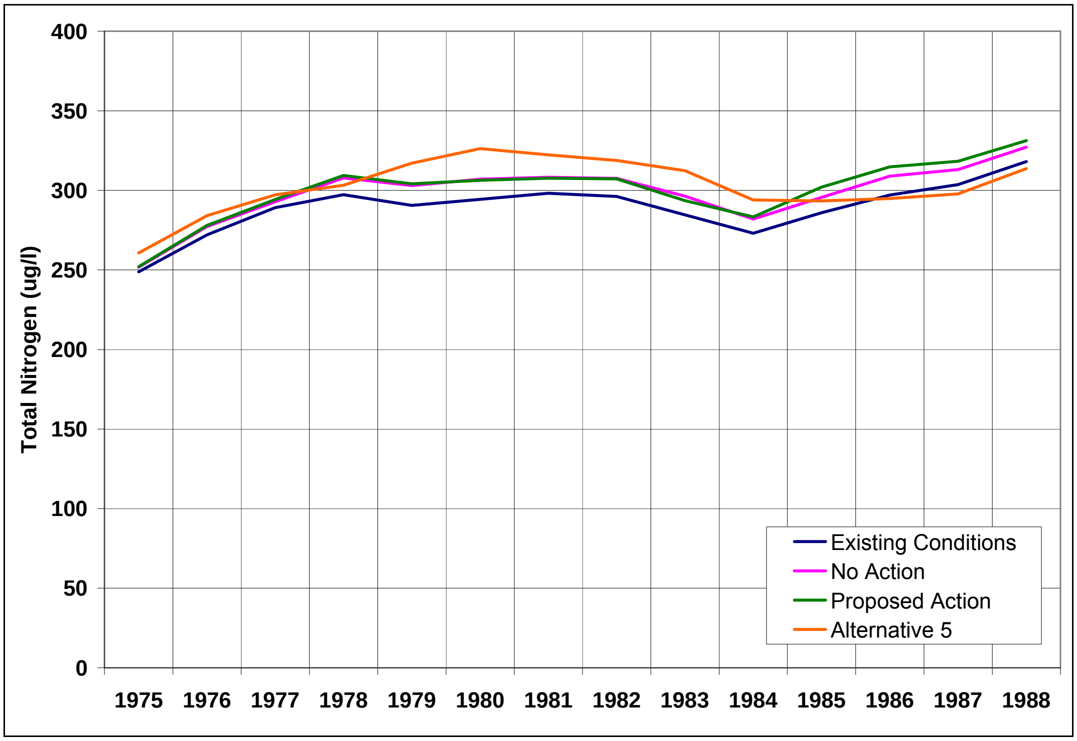


**Figure 123: Predicted Average Annual Total Nitrogen Concentrations in Granby Reservoir --Cumulative Effects**

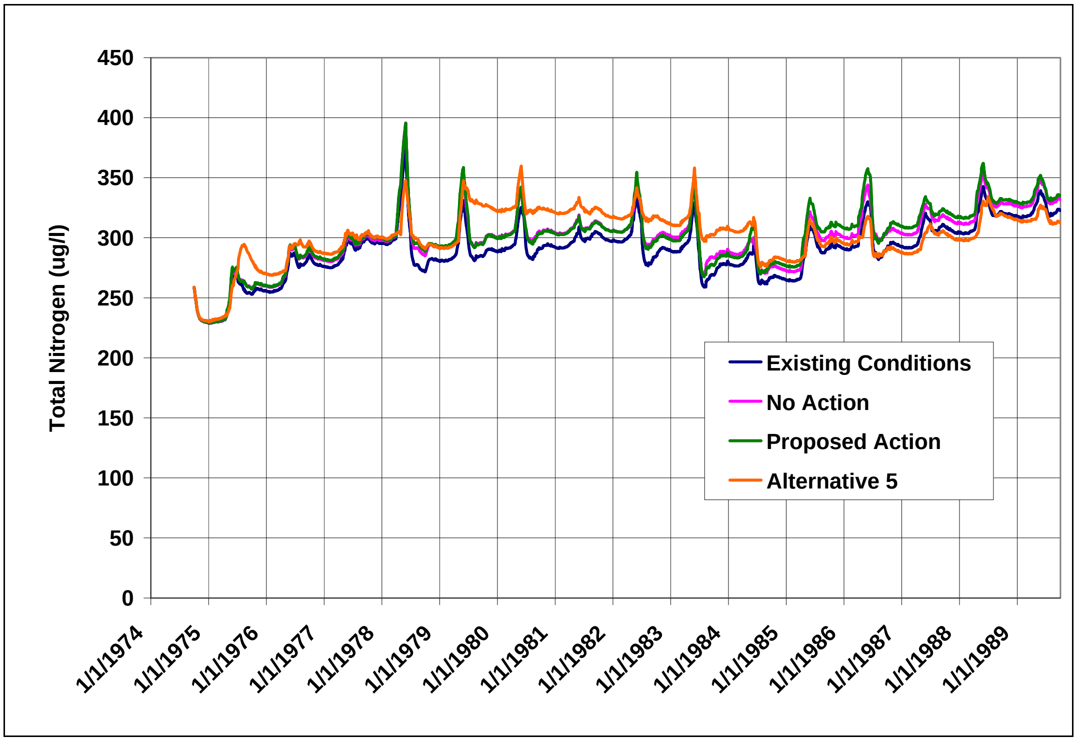


**Figure 124: Predicted Daily Total Nitrogen Concentrations in Granby Reservoir --Cumulative Effects**

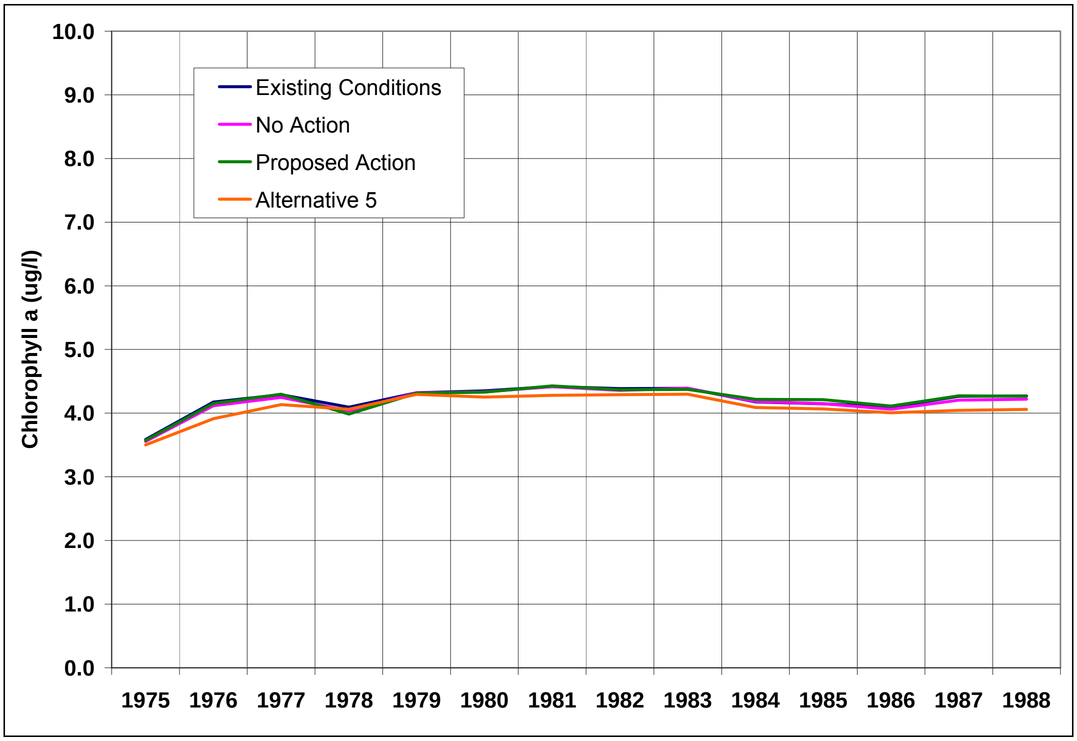


**Figure 125: Predicted Average Annual Chlorophyll *a* Concentrations in Granby Reservoir --Cumulative Effects**

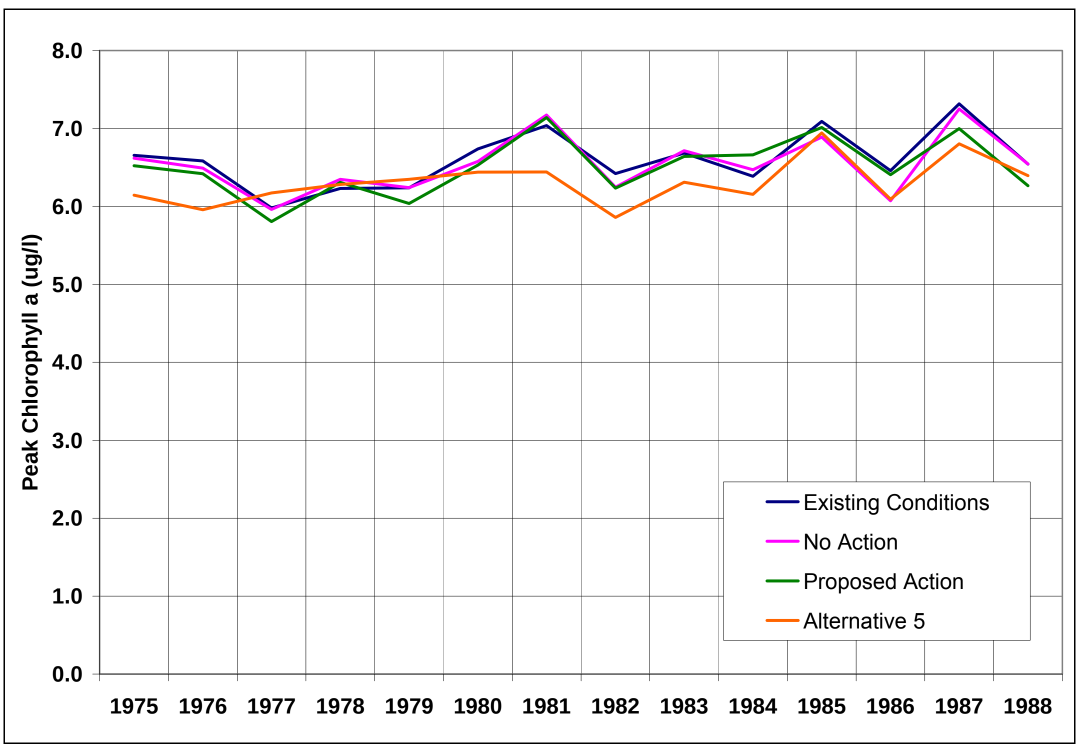


**Figure 126: Predicted Annual Peak Chlorophyll *a* Concentrations in Granby Reservoir--Cumulative Effects**

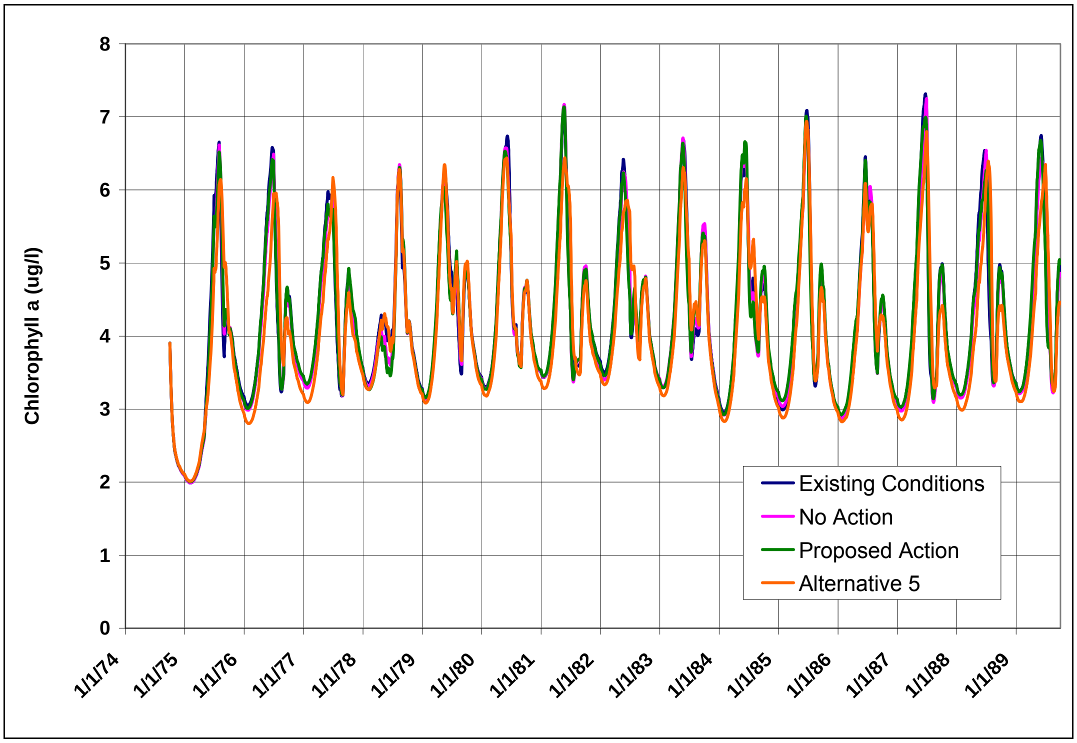


**Figure 127: Predicted Daily Chlorophyll *a* Concentrations in Granby Reservoir--Cumulative Effects**

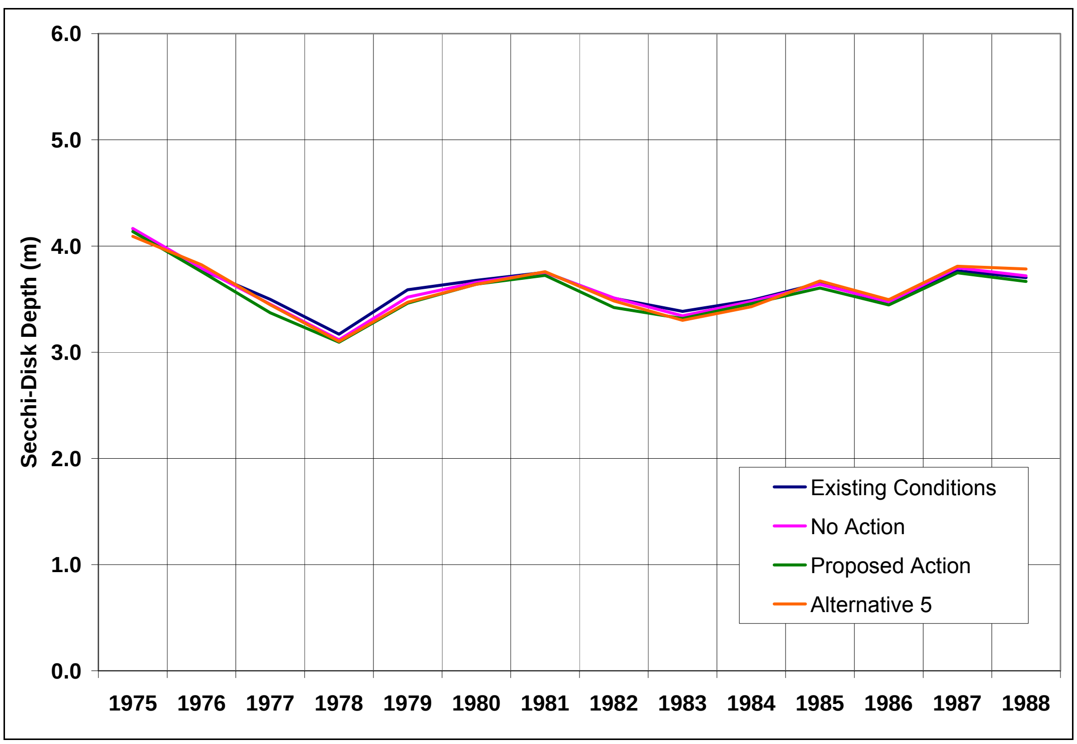


**Figure 128: Predicted Average Annual Secchi-Disk Depths in Granby Reservoir--Cumulative Effects**

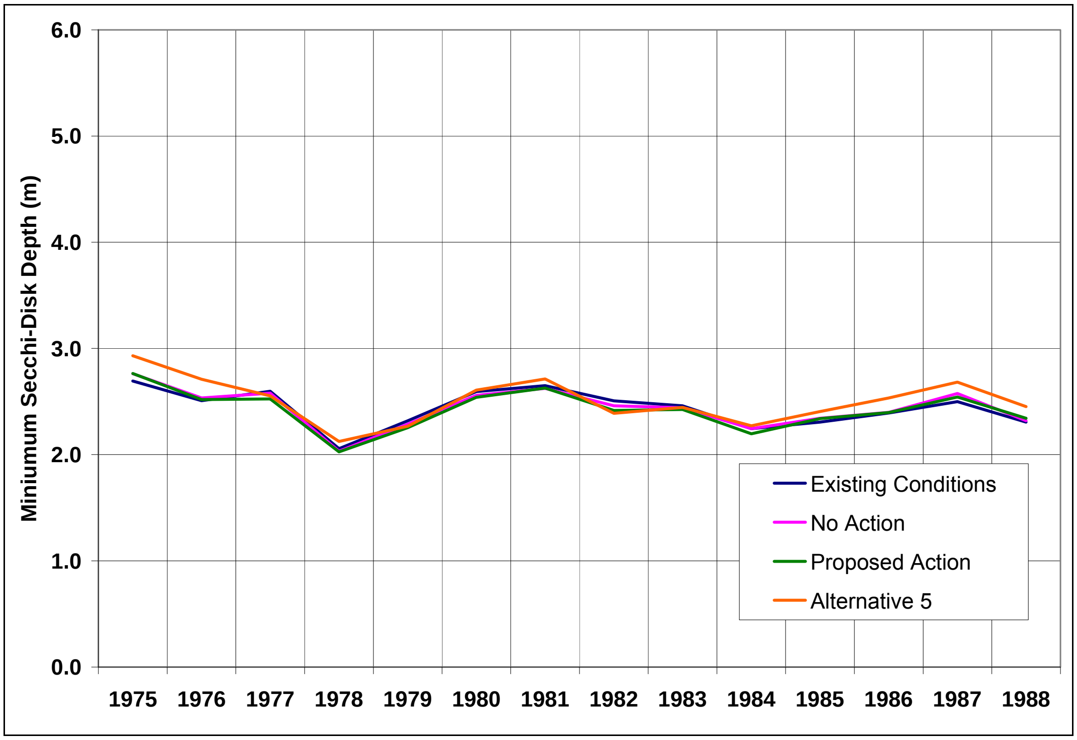


**Figure 129: Predicted Minimum Secchi-Disk Depths in Granby Reservoir--Cumulative Effects**

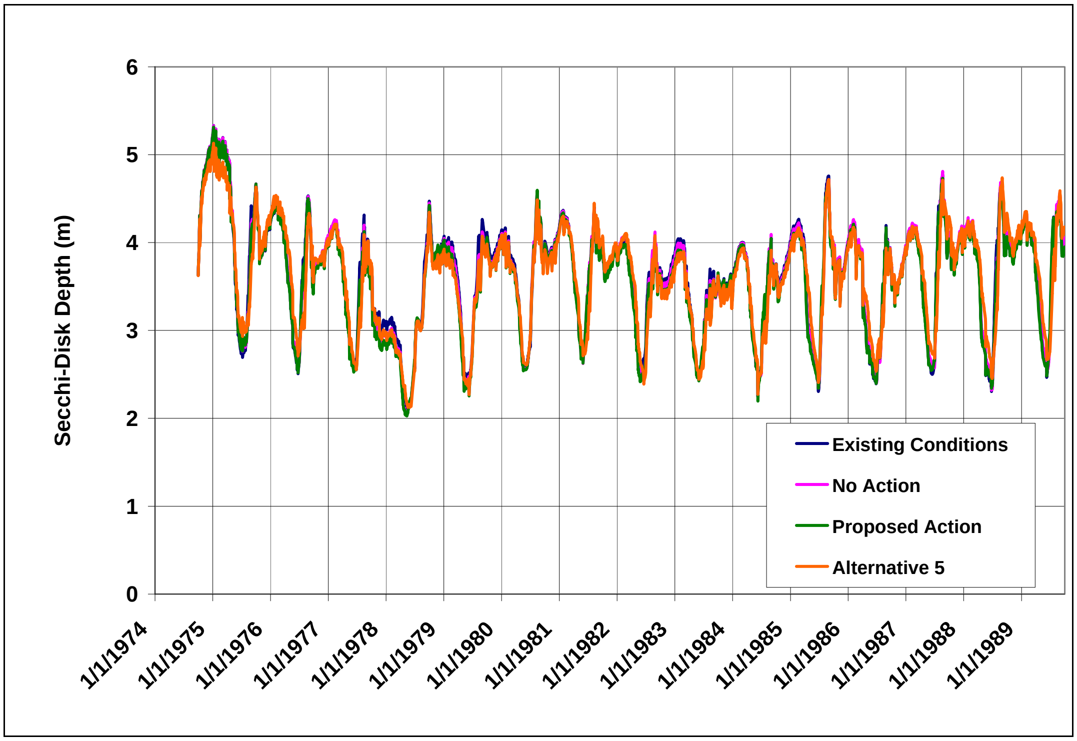


**Figure 130: Predicted Daily Secchi-Disk Depths in Granby Reservoir--Cumulative Effects**

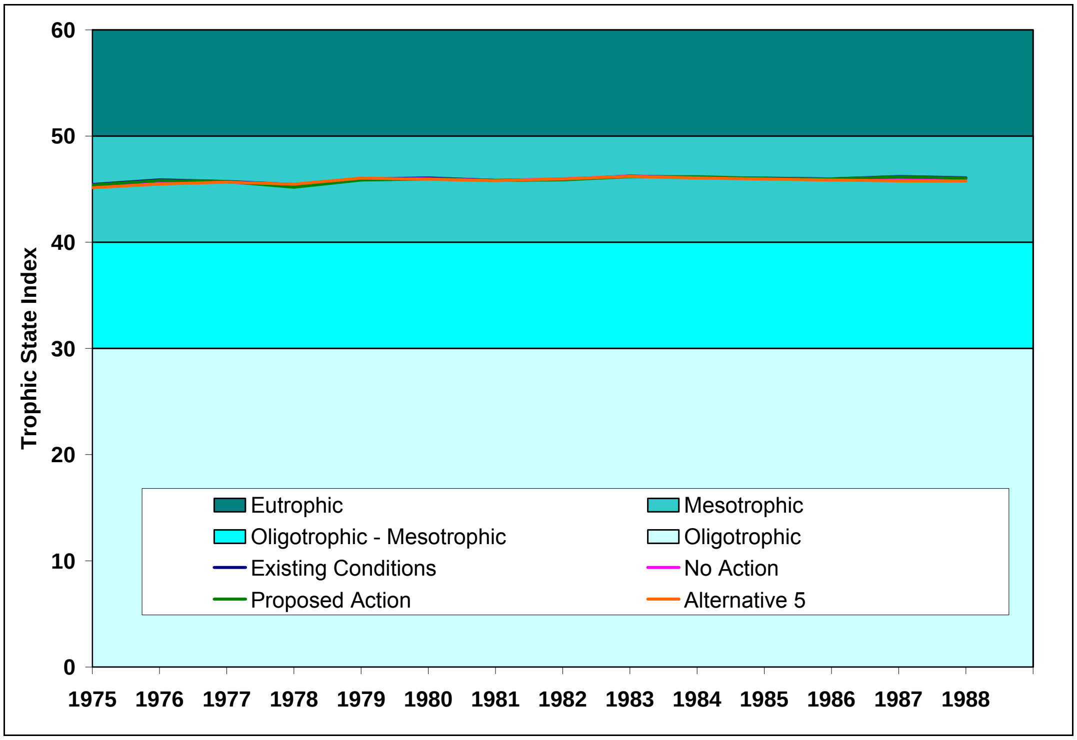


**Figure 131: Predicted Annual Trophic State Indices in Granby Reservoir--Cumulative Effects**

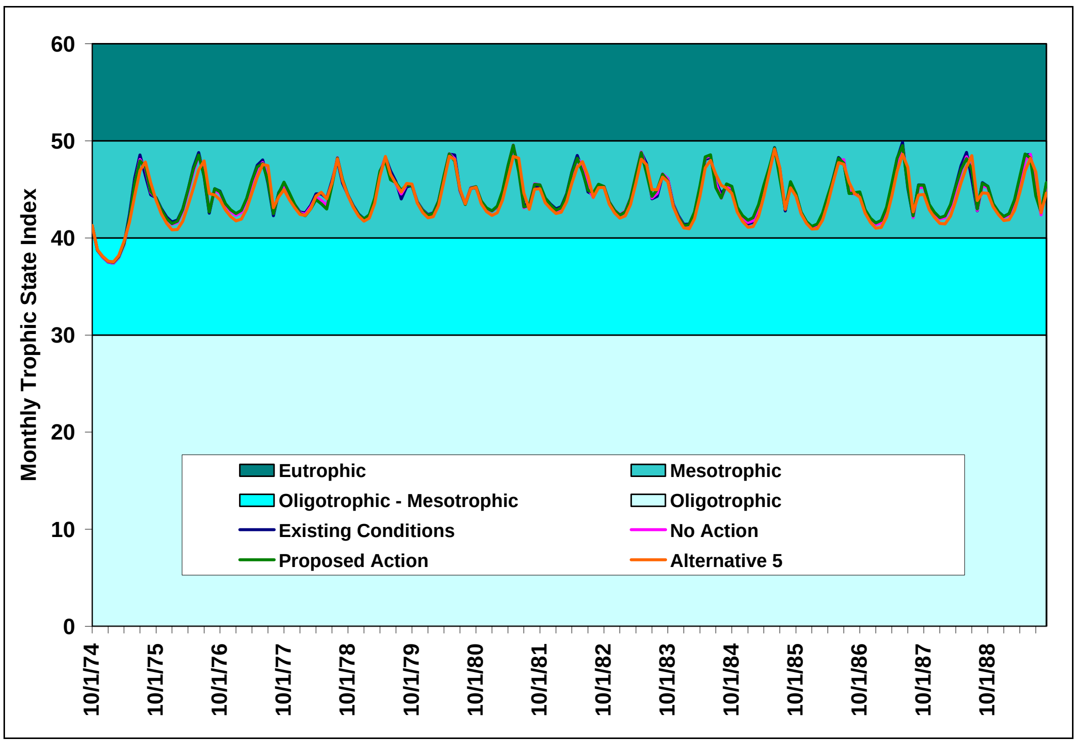


**Figure 132: Predicted Monthly Trophic State Index for Granby Reservoir--Cumulative Effects**

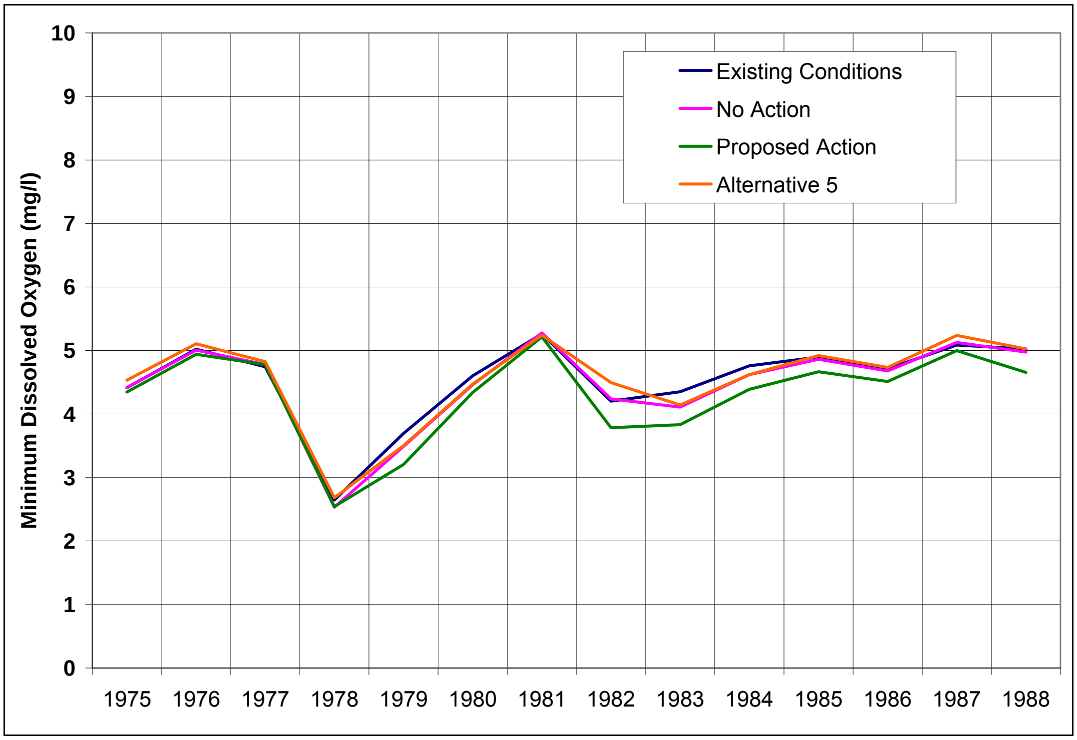


**Figure 133: Predicted Minimum Dissolved Oxygen Concentrations in Granby Reservoir Hypolimnion--Cumulative Effects**

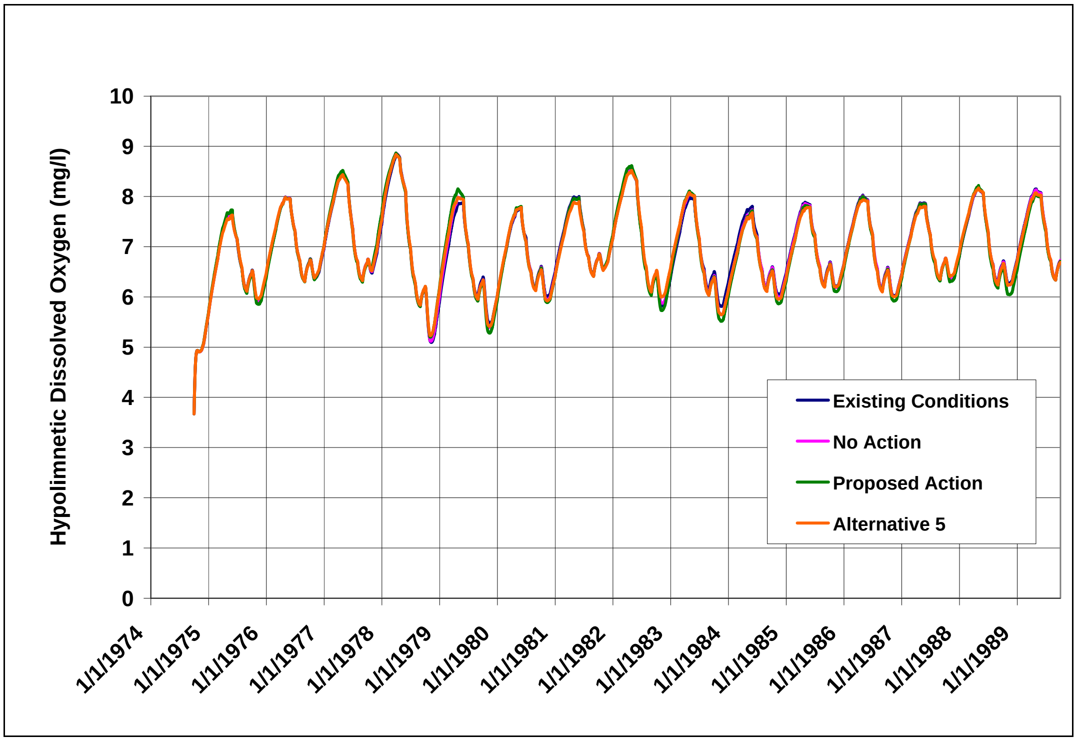


**Figure 134: Predicted Daily Dissolved Oxygen Concentrations in Granby Reservoir Hypolimnion--Cumulative Effects**

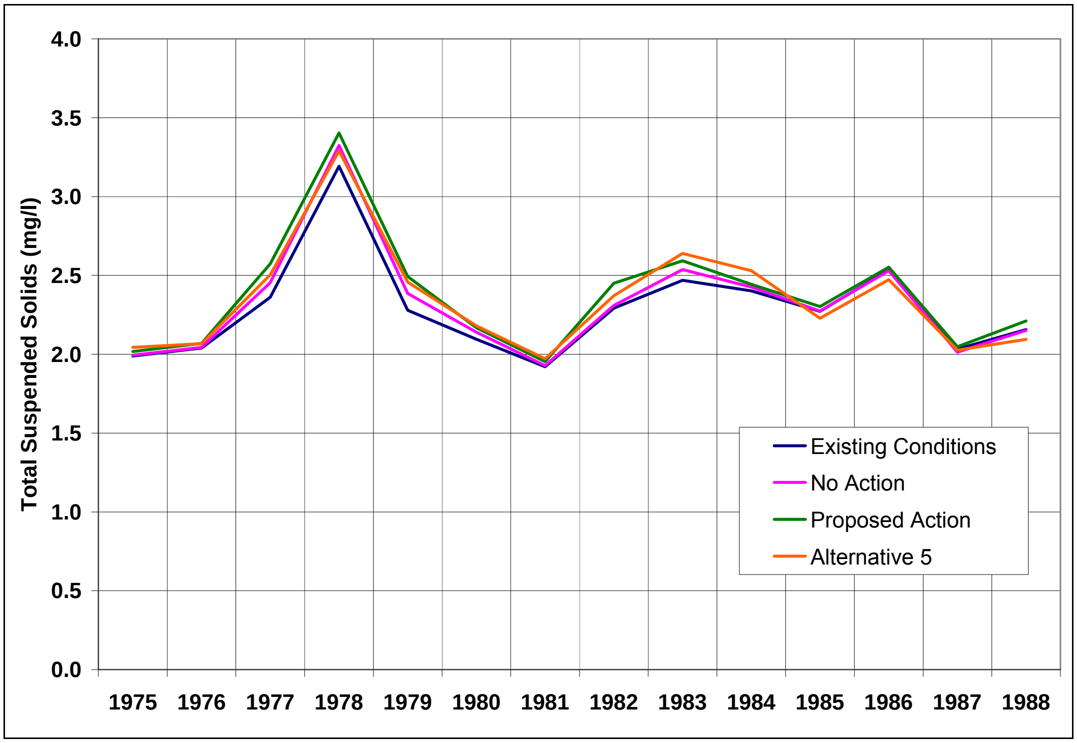


**Figure 135: Predicted Average Annual Total Suspended Sediment Concentrations in Granby Reservoir--Cumulative Effects**

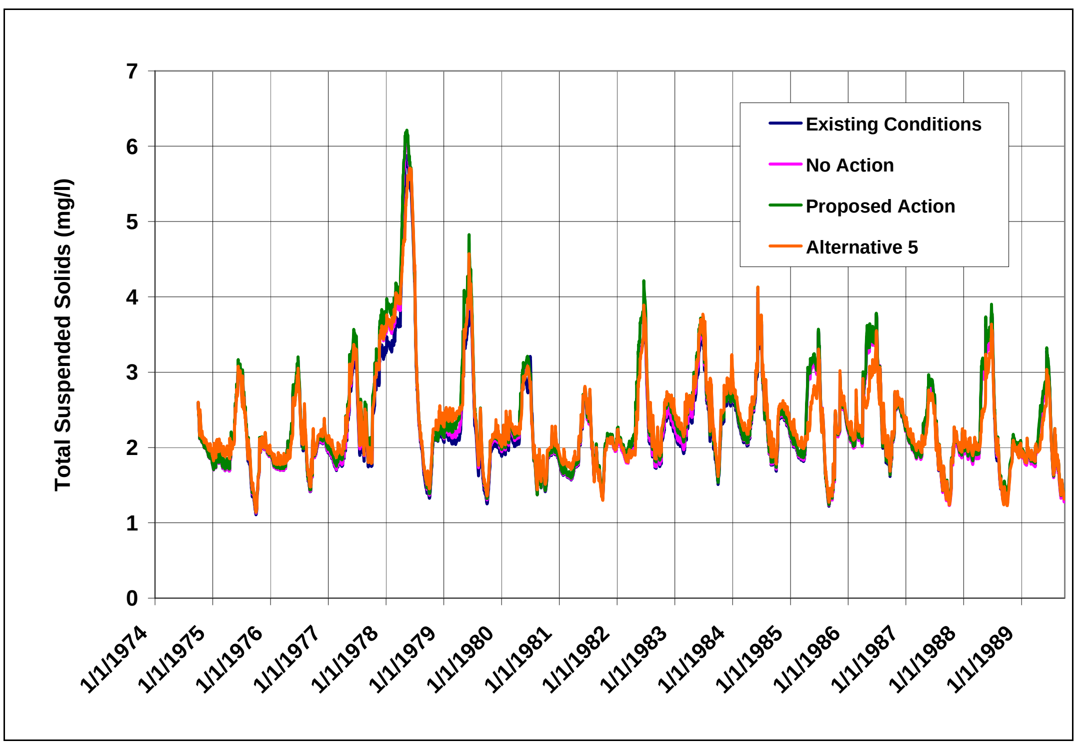


**Figure 136: Predicted Daily Total Suspended Sediment Concentrations in Granby Reservoir--Cumulative Effects**

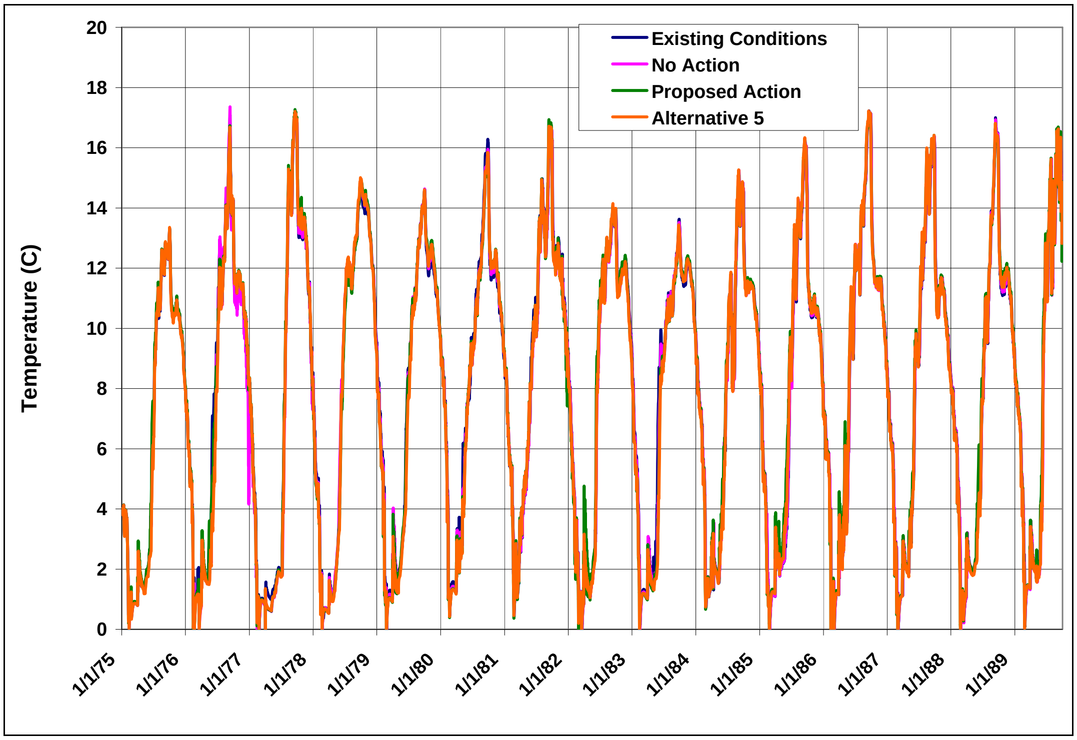


**Figure 137: Simulated Epilimnetic Temperature in Granby Reservoir--Cumulative Effects**

The alternatives were evaluated to determine if standards would be met or exceeded using model predictions. Granby Reservoir would continue to meet ammonia and nitrate standards. It is anticipated that manganese concentrations would increase over existing conditions for the Proposed Action alternative due to lower dissolved oxygen concentrations in the hypolimnion. Thus, manganese standards may continue to be exceeded for all alternatives. Dissolved oxygen concentrations would continue to be below the spawning standard under all alternatives. Minimum dissolved oxygen standards would not change under No Action or Alternative 5 and would decrease by 0.2 mg/l under the Proposed Action. Based on the temperature modeling, it is predicted that the temperature standard will continue to be exceeded under the alternatives, in the same manner as it occurs under existing conditions.

### 12.4.2. Shadow Mountain Reservoir

Predictions for existing conditions and the three cumulative effects alternatives are summarized in Table 75 and displayed in Figure 138-Figure 153. Annual average and daily output are presented. Trophic state was predicted using average predicted chlorophyll *a* concentrations (May 1 to November 15) and the Carlson Trophic State Index (Carlson and Simpson, 1977). Changes in water-quality as compared to existing conditions are shown in Table 76. Changes as compared to the No Action alternative are displayed in Table 77. Overall, there would be no changes in trophic state anticipated with any of the alternatives. The reservoir would remain in a mesotrophic state for all alternatives. Nitrogen concentrations would be higher than existing conditions for all alternatives and phosphorus concentrations would be lower for Alternatives 1 and 5 and about 3 percent higher for the Proposed Action. Chlorophyll *a* would not change under No Action or the Proposed Action, but would decrease slightly under Alternative 5. The predicted annual average and daily chlorophyll *a* concentrations are displayed in Figure 142 and Figure 144. The peak chlorophyll *a* concentrations by year are shown in Figure 143. Because the nutrient concentration changes would be very low for all of the alternatives, changes in the amount and type of aquatic vegetation in Shadow Mountain Reservoir would not be anticipated to occur. Rooted macrophytes generally meet their nutrient needs directly from the sediments (Barko, et al., 1986). Thus, they can thrive even in oligotrophic systems (Cooke, et al., 2005). Therefore, changes in nutrient concentrations cannot be expected to result in changes in macrophyte growth and biomass (Cooke, et al., 2005) and although there are anticipated changes in nutrient concentrations associated with the alternatives, we predict that these changes will not impact the macrophyte problem. It is expected that the temperature of Shadow Mountain Reservoir would not increase under any of the action alternatives and may be cooler (see discussion for Shadow Mountain Reservoir in Section 11).

**Table 75: Average Predicted Conditions for Shadow Mountain Reservoir (Existing Conditions and Cumulative Effects No Action, Proposed Action, and Alternative 5)**

| Average Annual Value Over the 15-Year Model Period | | | | |
|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 5 |
| Total Phosphorus (µg/l) | 12.4<br>(4.9 – 20.3) | 12.2<br>(4.9 – 21.3) | 12.8<br>(4.9 – 22.3) | 11.2<br>(5.1 – 18.7) |
| Total Nitrogen (µg/l) | 275<br>(190 – 330) | 283<br>(198 – 338) | 285<br>(196 – 344) | 286<br>(265 – 341) |
| Chlorophyll a (µg/l) | 5.7<br>(1.8 – 10.5) | 5.7<br>(1.6 – 10.9) | 5.7<br>(1.7 – 11.6) | 5.4<br>(1.5 – 10.6) |
| Peak Chlorophyll a (µg/l) | 8.8 | 8.8 | 9.1 | 8.3 |
| Secchi-Disk Depth (m) | 2.0<br>(1.4 – 3.1) | 2.0<br>(1.3 – 3.0) | 2.0<br>(1.3 – 3.1) | 2.1<br>(1.3 – 3.2) |
| Trophic State Index | Mesotrophic (48) | Mesotrophic (48) | Mesotrophic (48) | Mesotrophic (48) |
| Minimum DO (mg/l) | 7.1 | 7.1 | 7.1 | 7.1 |
| TSS (mg/l) | 2.0<br>(1.1 – 5.3) | 2.0<br>(1.1 – 5.5) | 2.1<br>(1.1 – 5.4) | 2.2<br>(1.1 – 5.4) |

Range of data (min – max) included.

**Table 76: Predicted Changes by Alternative for Shadow Mountain Reservoir Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 5 |
|---|---|---|---|
| Total Phosphorus (µg/l) | -1.6% | +3.2% | -9.7% |
| Total Nitrogen (µg/l) | +2.9% | +3.6% | +4.0% |
| Chlorophyll *a* (µg/l) | No Change | No Change | -5.3% |
| Peak Chlorophyll *a* (µg/l) | No Change | +3.7% | -5.7% |
| Secchi-Disk Depth (m) | No Change | No Change | +5.0% |
| *Trophic State* | *No Change* | *No Change* | *No Change* |
| Minimum DO (mg/l) | No Change | -1.4% | No Change |
| TSS (mg/l) | No Change | +5.0% | +10% |

**Table 77: Predicted Changes for Shadow Mountain Reservoir by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 5 |
|---|---|---|
| Total Phosphorus (µg/l) | +4.9% | -8.2% |
| Total Nitrogen (µg/l) | +0.7% | +1.1% |
| Chlorophyll *a* (µg/l) | No Change | -5.3% |
| Peak Chlorophyll *a* (µg/l) | +3.7% | -5.7% |
| Secchi-Disk Depth (m) | No Change | +5.0% |
| Trophic State | No Change | No Change |
| Minimum DO (mg/l) | -1.4% | No Change |
| TSS (mg/l) | +5.0% | +10% |

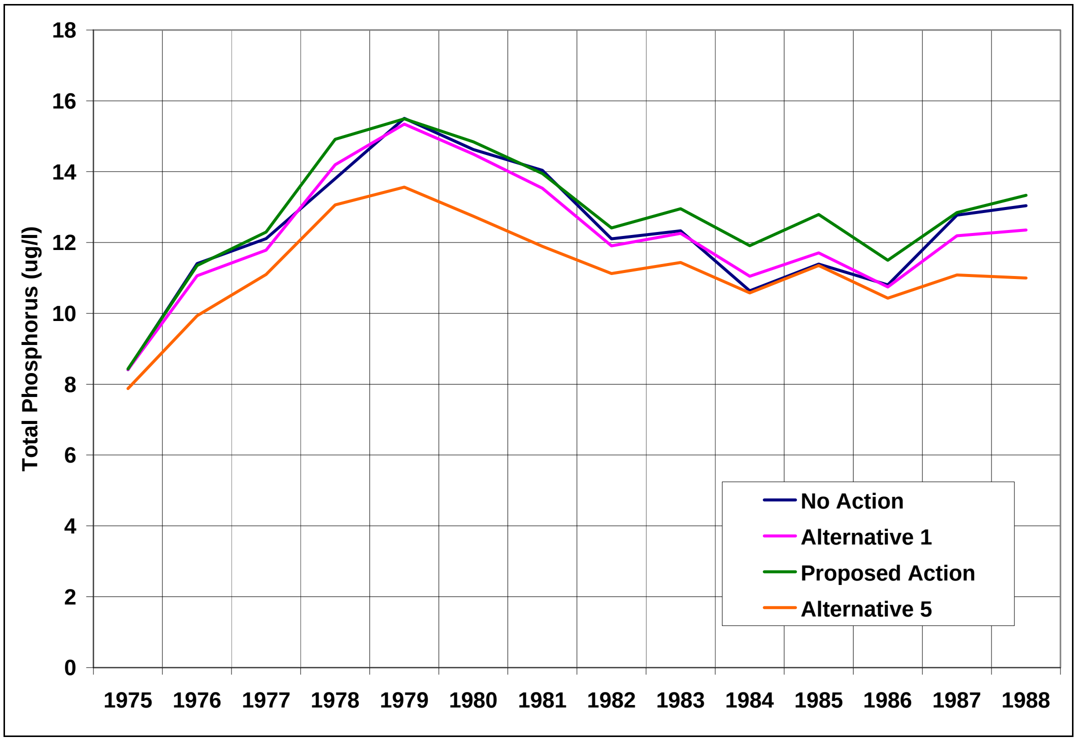


**Figure 138: Predicted Average Annual Total Phosphorus Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

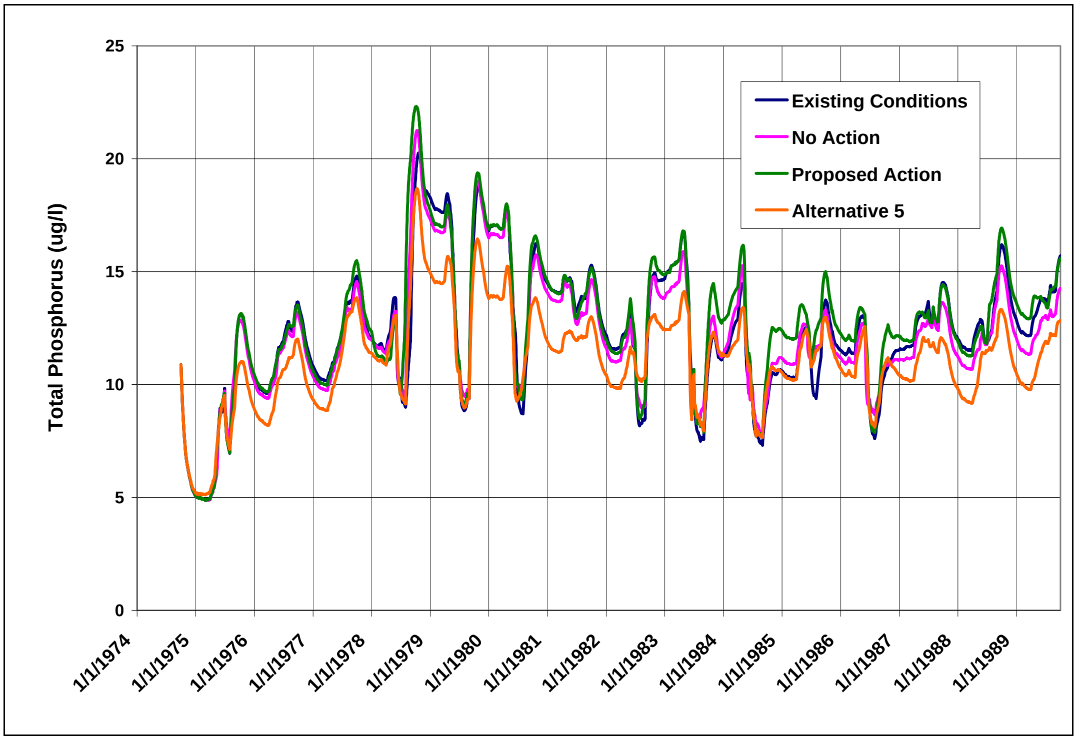


**Figure 139: Predicted Daily Total Phosphorus Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

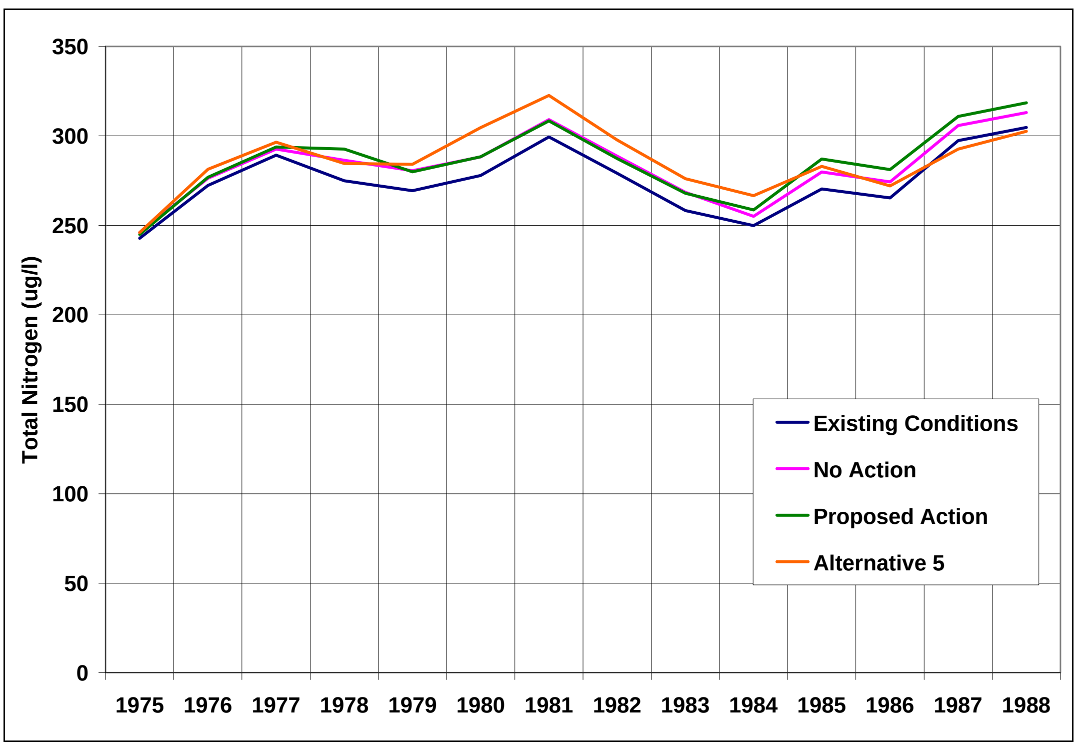


**Figure 140: Predicted Average Annual Total Nitrogen Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

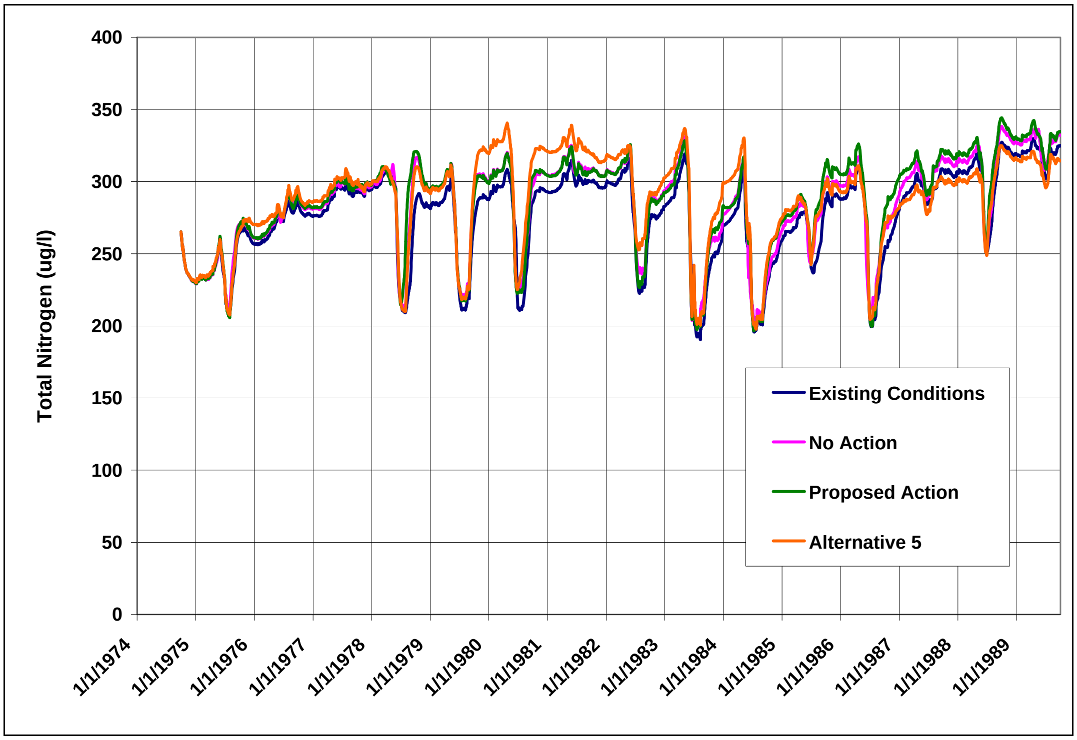


**Figure 141: Predicted Daily Total Nitrogen Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

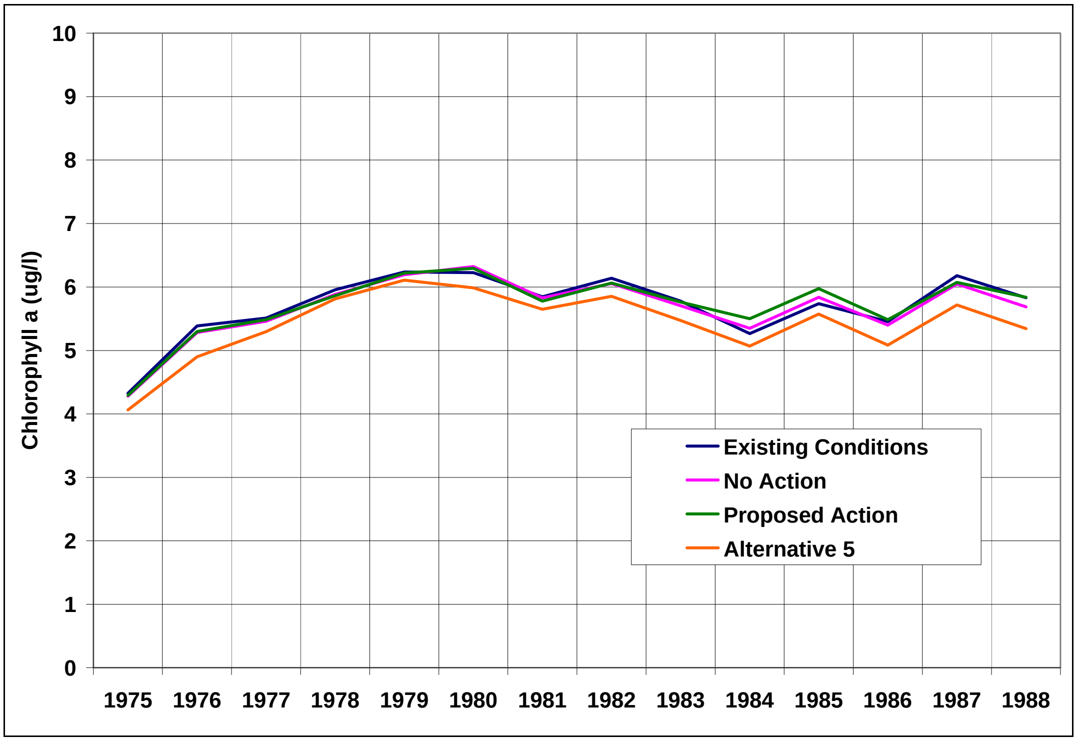


**Figure 142: Predicted Average Annual Chlorophyll *a* Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

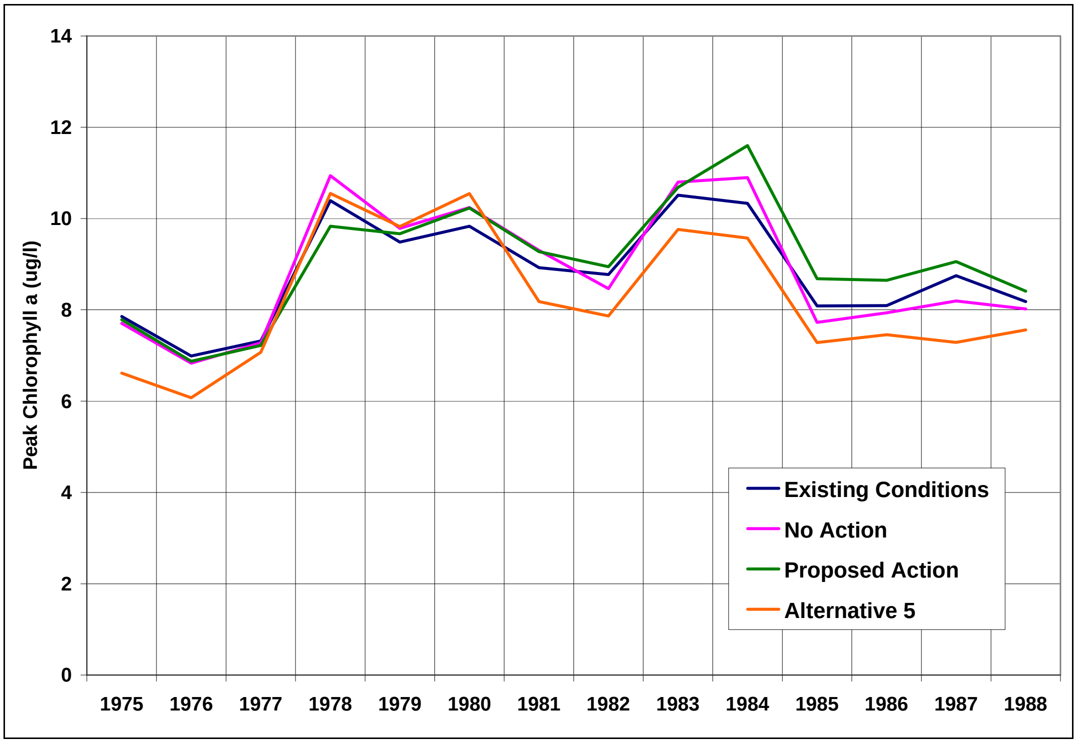


**Figure 143: Predicted Annual Peak Chlorophyll *a* Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

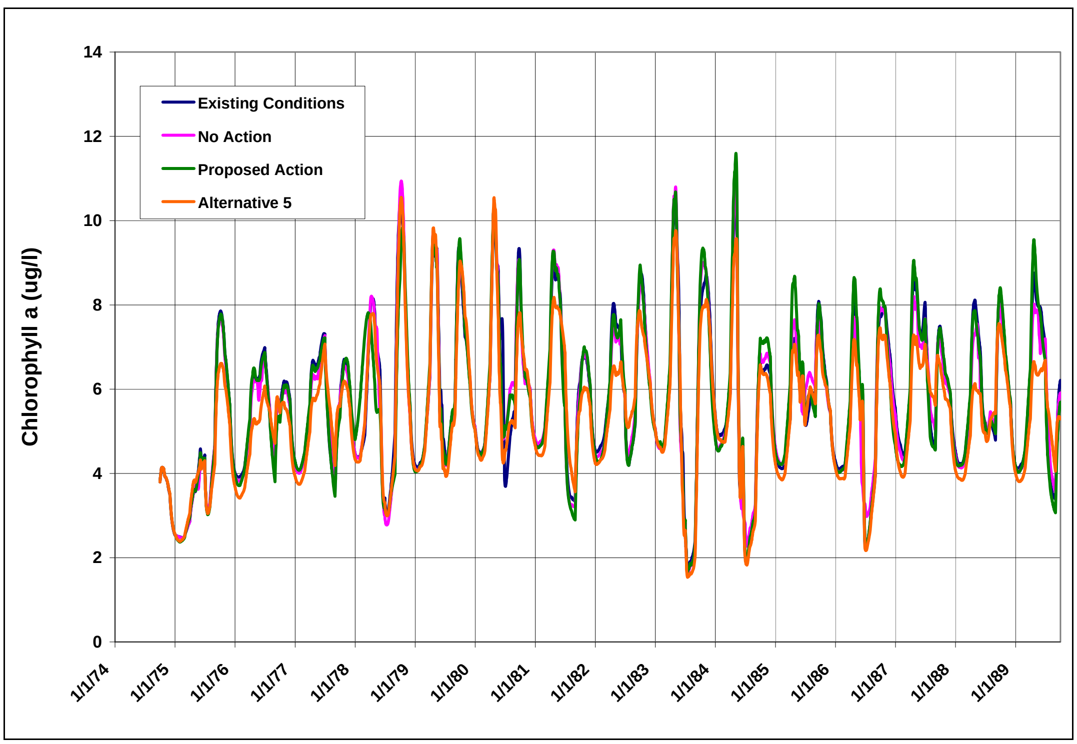


**Figure 144: Predicted Daily Chlorophyll *a* Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

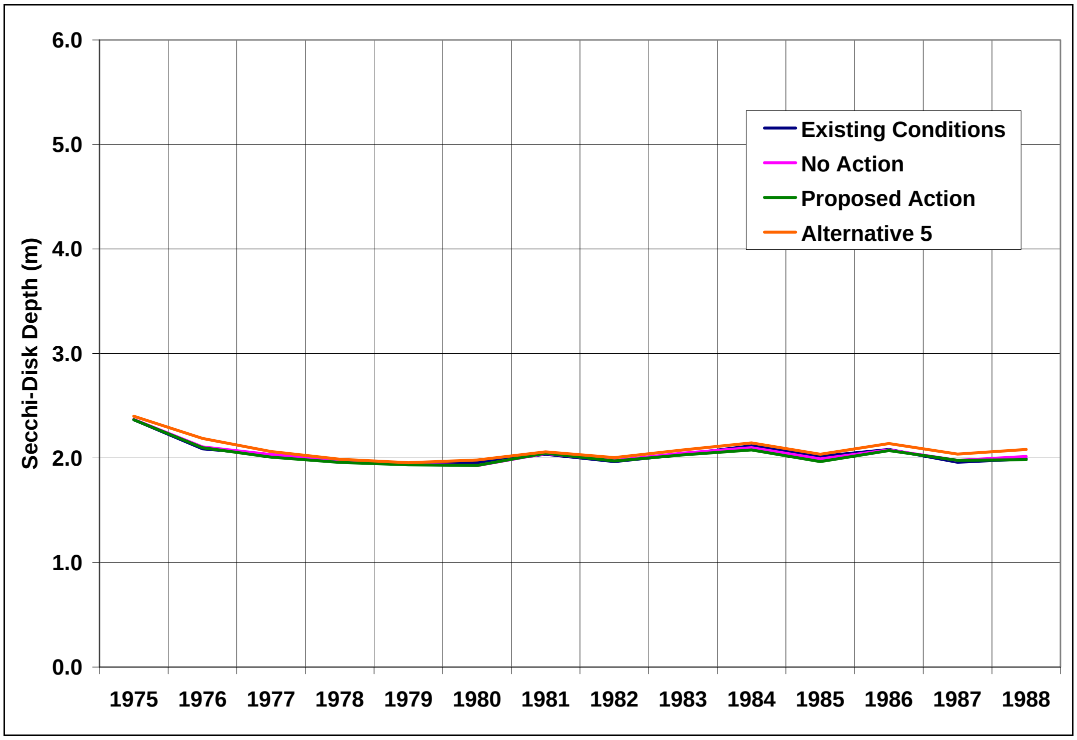


**Figure 145: Predicted Average Annual Secchi-Disk Depth in Shadow Mountain Reservoir--Cumulative Effects**

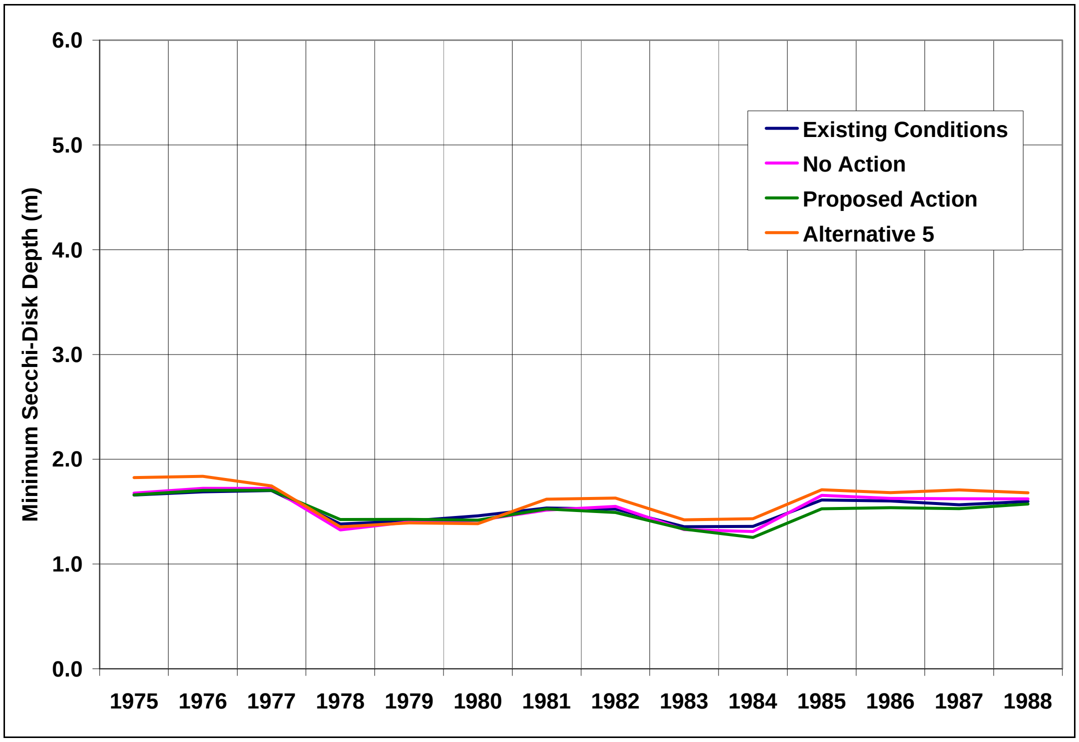


**Figure 146: Predicted Minimum Secchi-Disk Depth in Shadow Mountain Reservoir--Cumulative Effects**

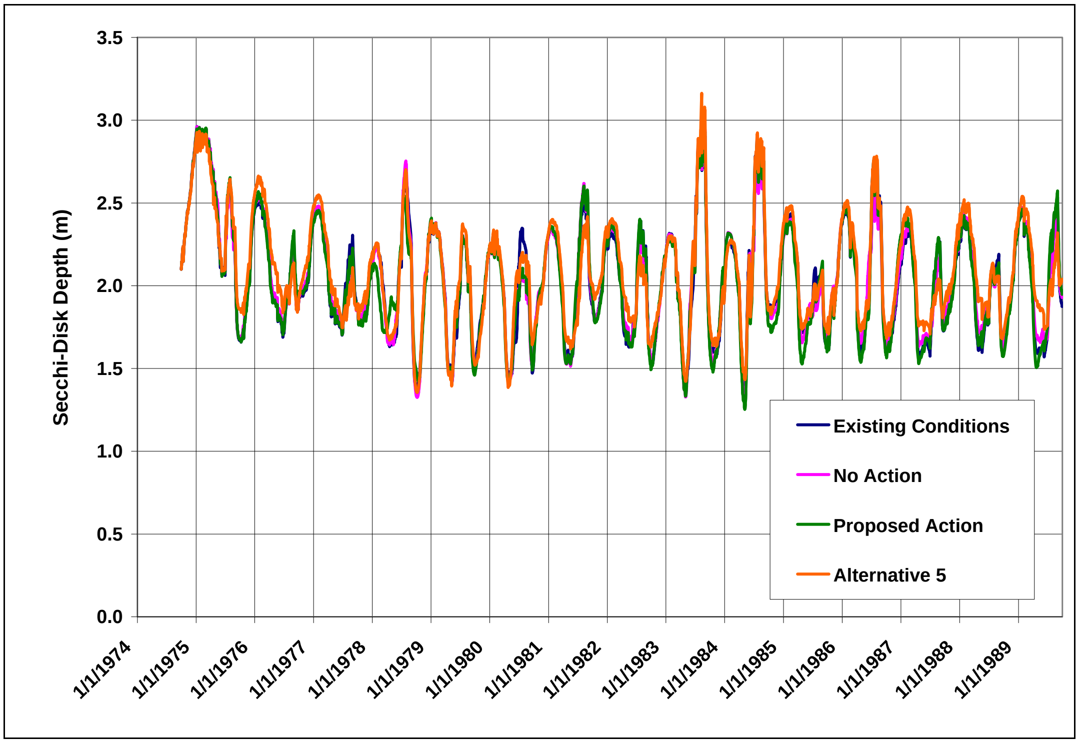


**Figure 147: Predicted Daily Secchi-Disk Depth in Shadow Mountain Reservoir--Cumulative Effects**

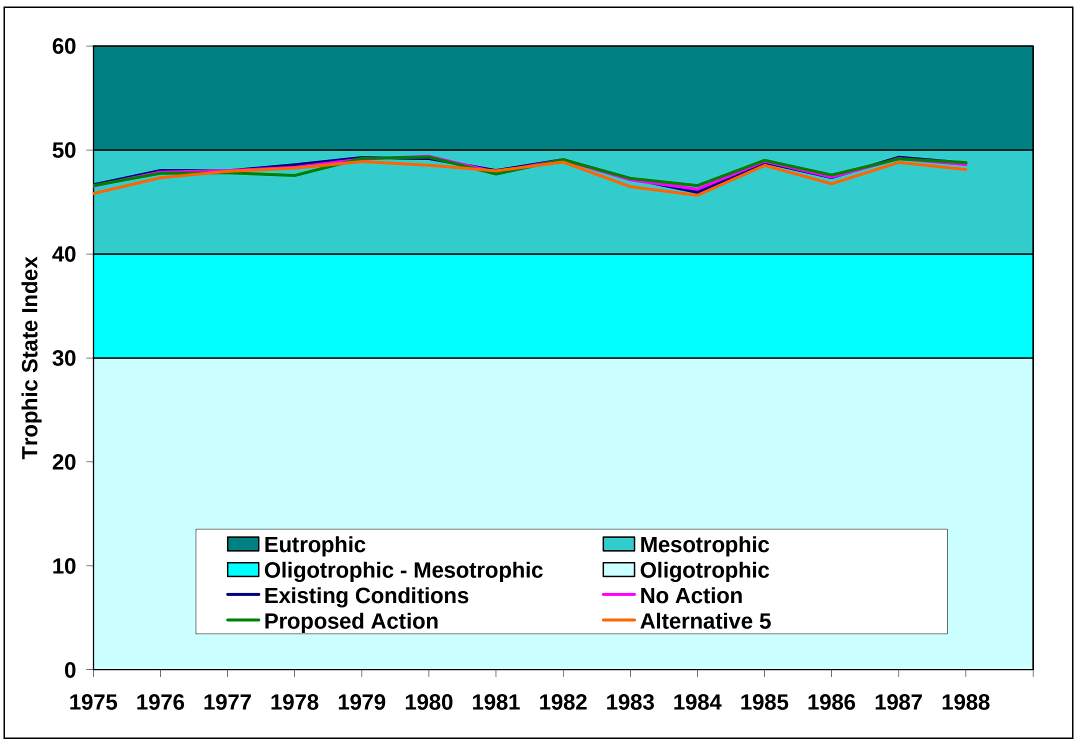


**Figure 148: Predicted Annual Trophic State Indices in Shadow Mountain Reservoir--Cumulative Effects**

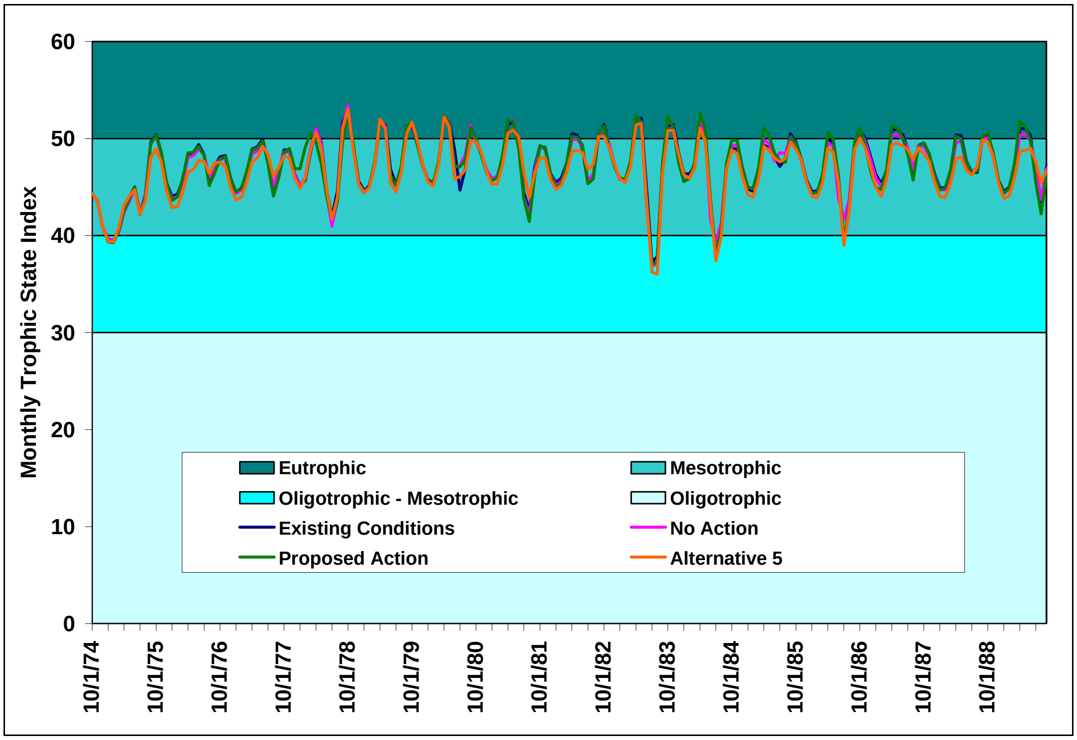


**Figure 149: Predicted Monthly Trophic State Index for Shadow Mountain Reservoir--Cumulative Effects**

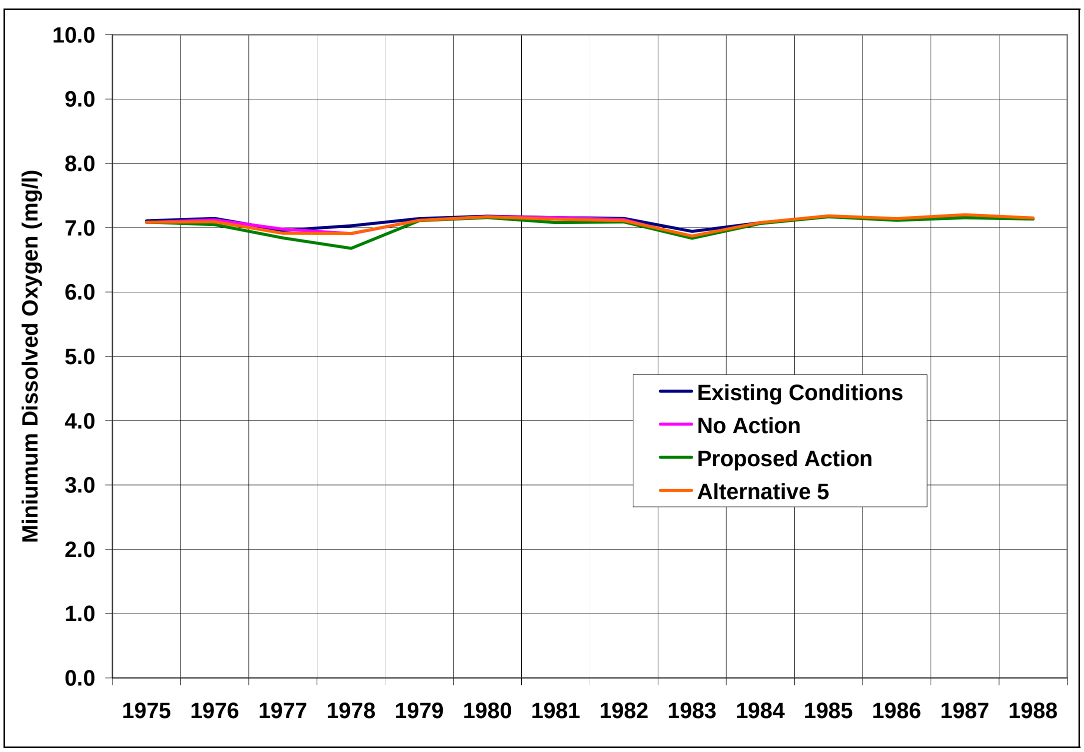


**Figure 150: Predicted Minimum Dissolved Oxygen in Shadow Mountain Reservoir--Cumulative Effects**

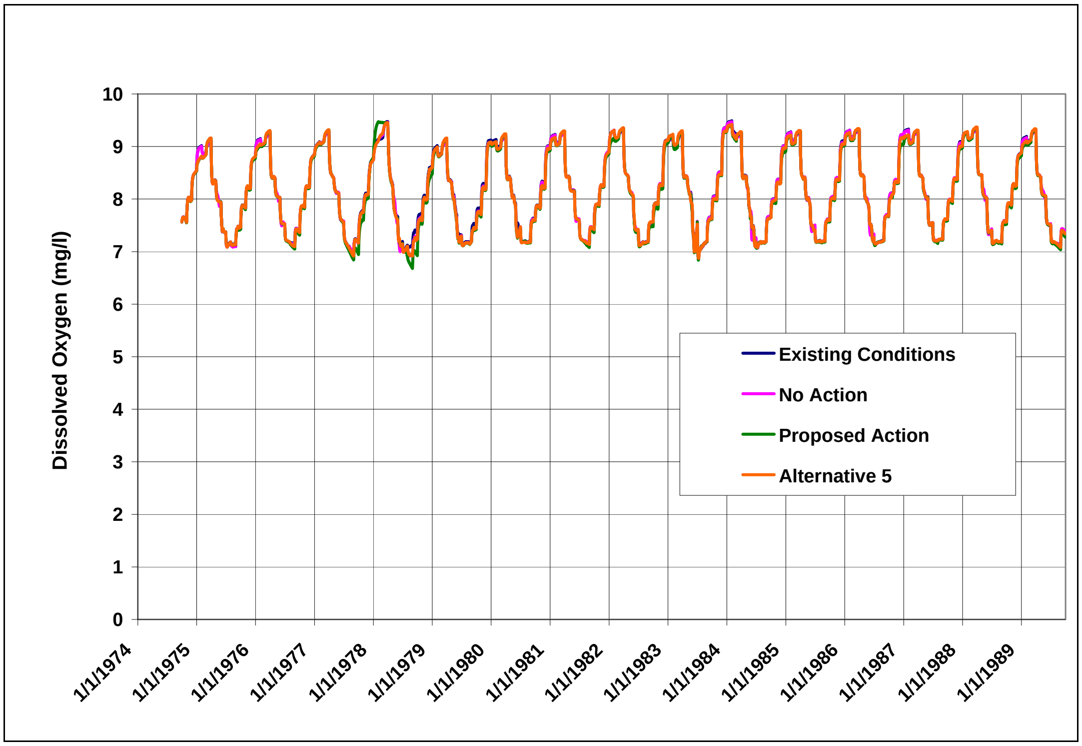


**Figure 151: Predicted Daily Dissolved Oxygen in Shadow Mountain Reservoir--Cumulative Effects**

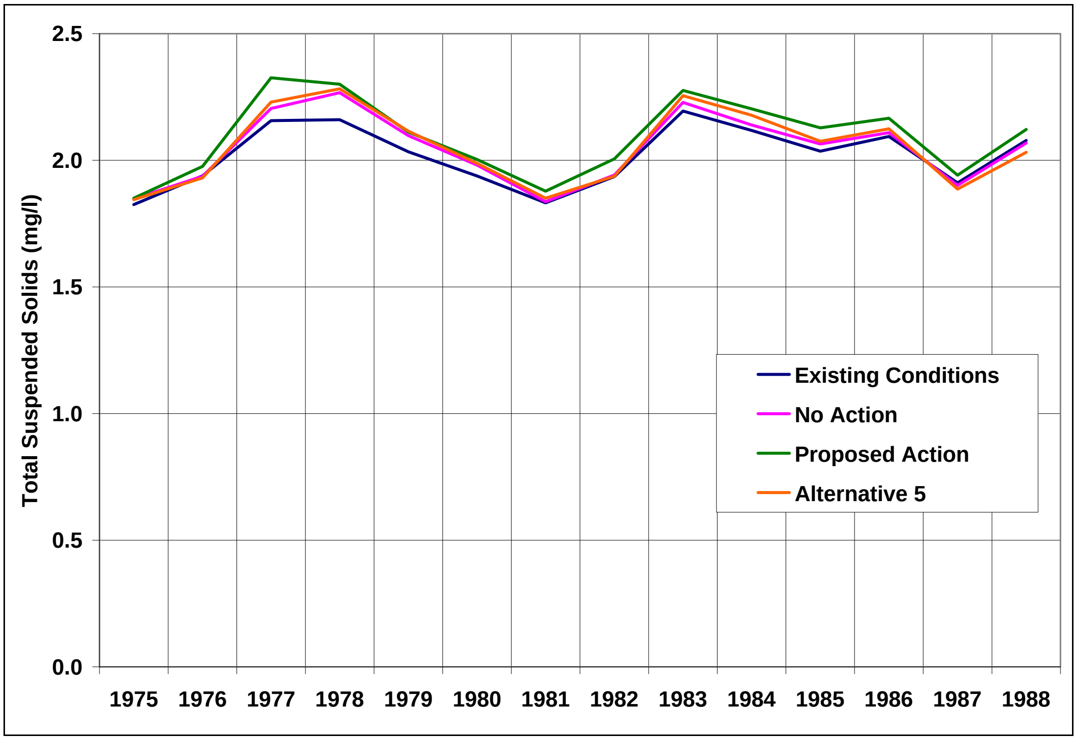


**Figure 152: Predicted Average Annual Total Suspended Sediment Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

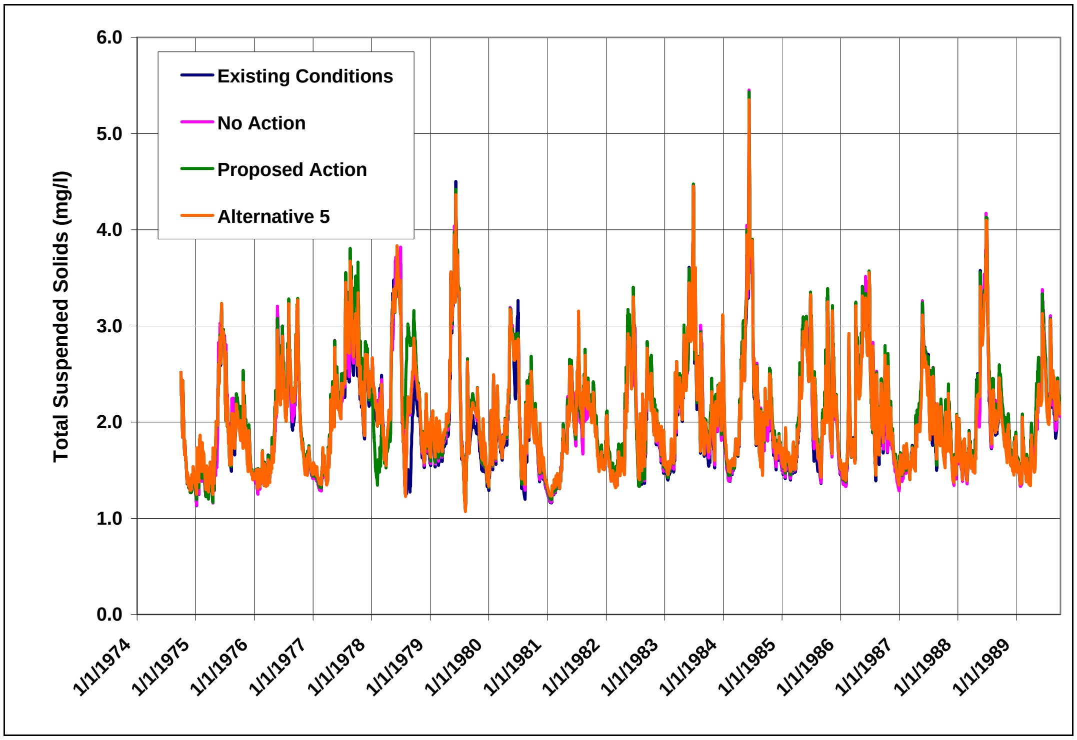


**Figure 153: Predicted Daily Total Suspended Sediment Concentrations in Shadow Mountain Reservoir--Cumulative Effects**

The alternatives were evaluated to determine if standards would be met using model predictions. Shadow Mountain Reservoir would continue to meet dissolved oxygen, ammonia, and nitrate standards. It is anticipated that manganese concentrations would stay about the same for each alternative based on the minimum dissolved oxygen concentrations in the hypolimnion. Thus, manganese standards may continue to be exceeded for all alternatives.

### 12.4.3. Grand Lake

Predictions for existing conditions and the three cumulative effects alternatives are summarized in Table 78 and displayed in Figure 154 - Figure 168. Annual average and daily output are presented. Trophic state was predicted using average predicted chlorophyll *a* concentrations (May 1 to November 15) and the Carlson Trophic State Index (Carlson and Simpson, 1977). Changes in water-quality as compared to existing conditions are shown in Table 79. Changes as compared to the No Action alternative are displayed in Table 80. As for the direct effects analysis, the reservoir remains in a mesotrophic state for all alternatives. Nitrogen concentrations are slightly higher than existing conditions for all alternatives and phosphorus concentrations are lower than existing conditions for Alternatives 1 and 5. A small increase in chlorophyll *a* is predicted for the Proposed Action and small decrease for Alternative 5. The predicted annual average and daily chlorophyll a concentrations over time are displayed in Figure 158 and Figure 160. The peak chlorophyll *a* concentrations by year are shown in Figure 159. Overall, there are no changes in trophic state anticipated with any of the alternatives. It is anticipated that the temperature of Grand Lake would not increase with any of the action alternatives.

**Table 78: Average Predicted Conditions for Grand Lake (Existing Conditions and Cumulative Effects No Action, Proposed Action, and Alternative 5)**

| Average Annual Value Over the 15-Year Model Period | | | | |
|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 5 |
| Total Phosphorus (µg/l) | 8.3<br>(4.3 – 13.7) | 8.2<br>(4.1 – 16.0) | 8.7<br>(4.2 – 18.6) | 7.7<br>(4.2 – 13.9) |
| Total Nitrogen (µg/l) | 247<br>(174 – 330) | 251<br>(158 – 386) | 255<br>(157 – 336) | 256<br>(165 – 339) |
| Chlorophyll a (µg/l) | 4.9<br>(2.1 – 10.2) | 4.9<br>(2.1 – 10.7) | 5.0<br>(2.1 – 9.7) | 4.6<br>(2.0 – 10.2) |
| Peak Chlorophyll a (µg/l) | 7.4 | 7.4 | 7.6 | 6.9 |
| Secchi-Disk Depth (m) | 2.6<br>(1.3 – 4.3) | 2.6<br>(1.2 – 4.5) | 2.5<br>(1.4 – 4.4) | 2.7<br>(1.3 – 4.4) |
| Trophic State (Index) | Mesotrophic (47) | Mesotrophic (46) | Mesotrophic (47) | Mesotrophic (46) |
| Minimum DO (mg/l) | 5.4 | 4.8 | 5.0 | 5.1 |
| TSS (mg/l) | 1.8<br>(1.0 – 4.1) | 1.8<br>(1.1 – 3.8) | 1.9<br>(1.1 – 4.2) | 1.8<br>(1.1 – 4.1) |

Range of data (min – max) included. All concentrations are for the epilimnion with the exception of minimum dissolved oxygen, which is for the hypolimnion.

**Table 79: Predicted Changes by Alternative for Grand Lake Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 5 |
|---|---|---|---|
| Total Phosphorus (µg/l) | -1.2% | +4.8% | -7.2% |
| Total Nitrogen (µg/l) | +1.6% | +3.2% | +3.6% |
| Chlorophyll *a* (µg/l) | No Change | +2.0% | -6.1% |
| Peak Chlorophyll *a* (µg/l) | No Change | +2.7% | -6.8% |
| Secchi-Disk Depth (m) | No Change | -3.8% | +3.8% |
| Trophic State | No Change | No Change | No Change |
| Minimum DO (mg/l) | -11.1% | -7.4% | -5.6% |
| TSS (mg/l) | No Change | +5.6% | No Change |

**Table 80: Predicted Changes for Grand Lake by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 5 |
|---|---|---|
| Total Phosphorus (µg/l) | +6.1% | -6.1% |
| Total Nitrogen (µg/l) | +1.6% | +2.0% |
| Chlorophyll *a* (µg/l) | +2.0% | -6.1% |
| Peak Chlorophyll *a* (µg/l) | +2.7% | -6.8% |
| Secchi-Disk Depth (m) | -3.8% | +3.8% |
| Trophic State | No Change | No Change |
| Minimum DO (mg/l) | +4.2% | +6.3% |
| TSS (mg/l) | +5.6% | No Change |

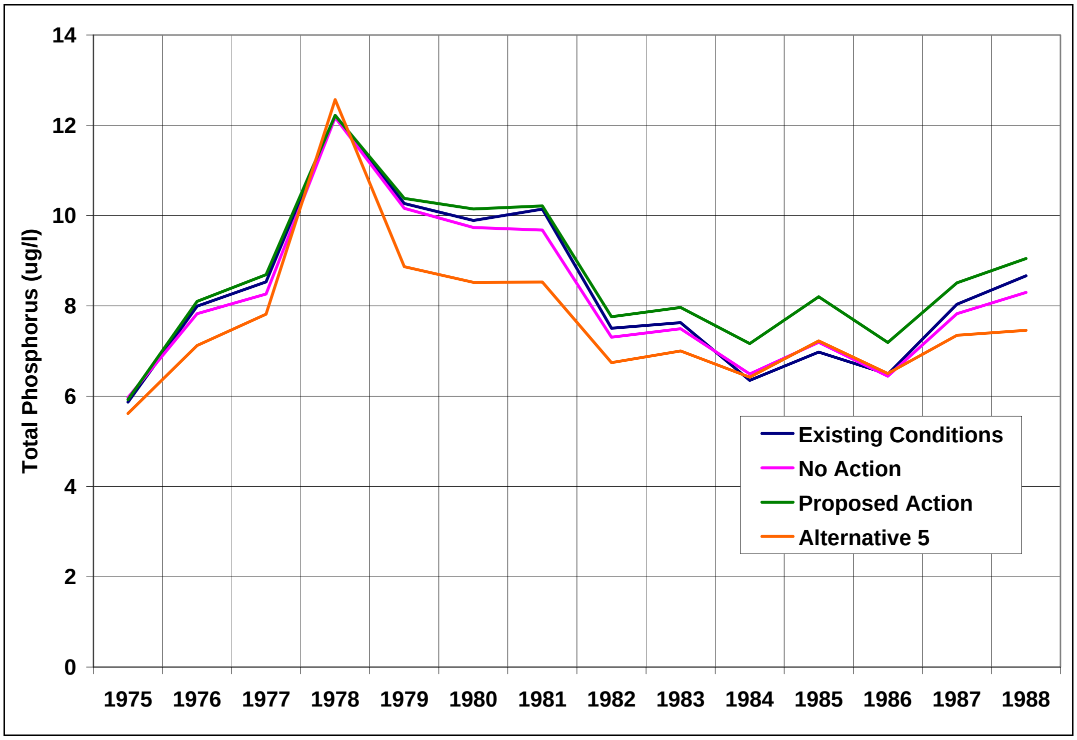


**Figure 154: Predicted Average Annual Total Phosphorus Concentrations in Grand Lake--Cumulative Effects**

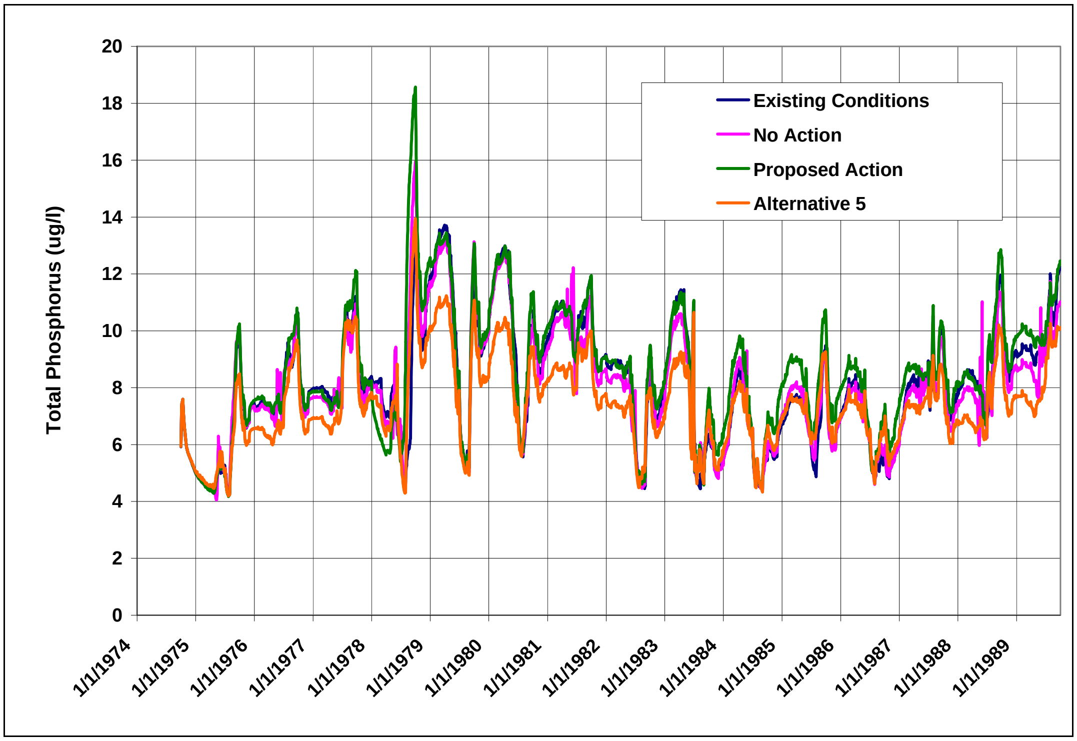


**Figure 155: Predicted Daily Total Phosphorus Concentrations in Grand Lake--Cumulative Effects**

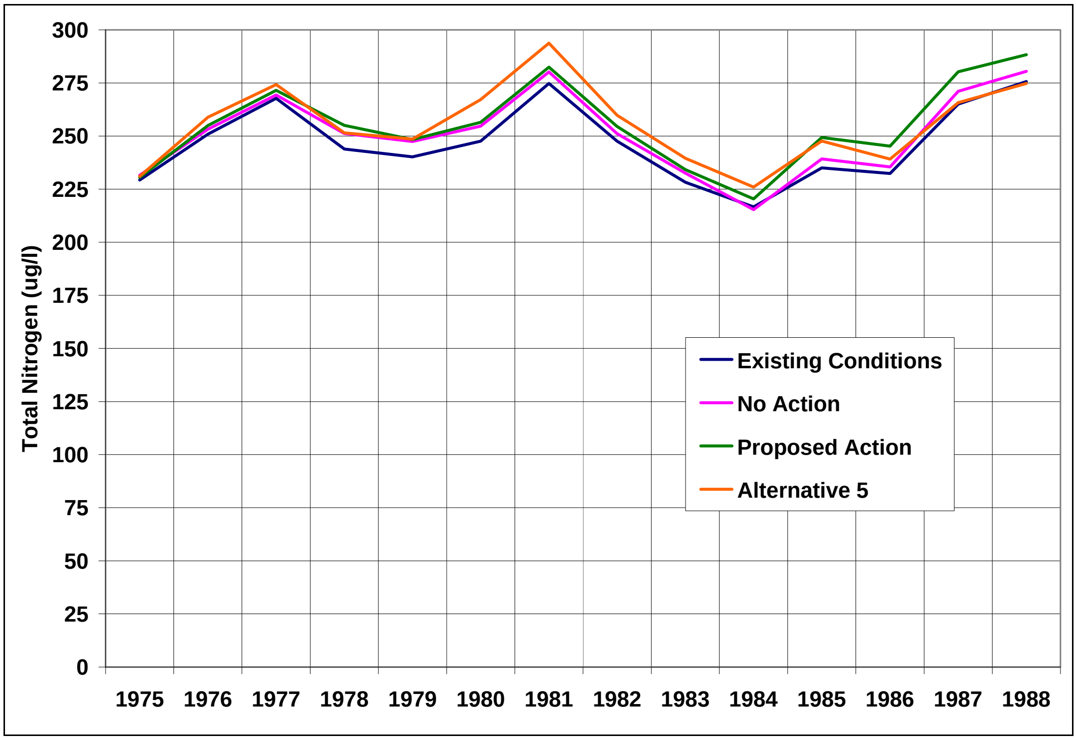


**Figure 156: Predicted Average Annual Total Nitrogen Concentrations in Grand Lake--Cumulative Effects**

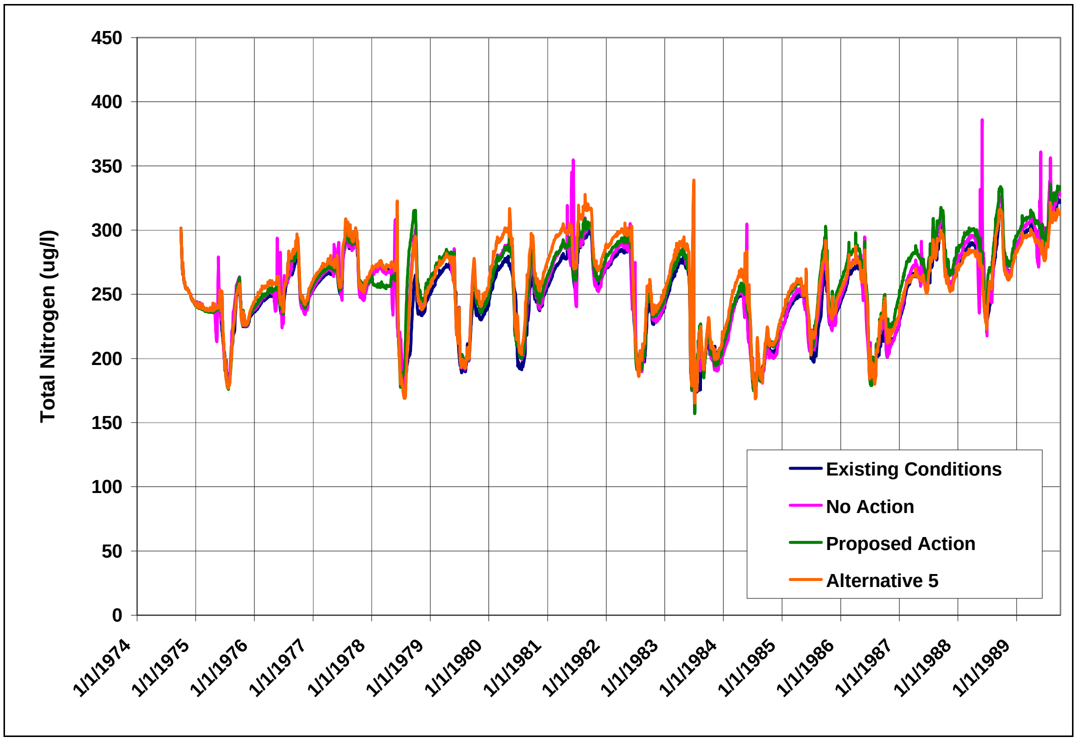


**Figure 157: Predicted Daily Total Nitrogen Concentrations in Grand Lake--Cumulative Effects**

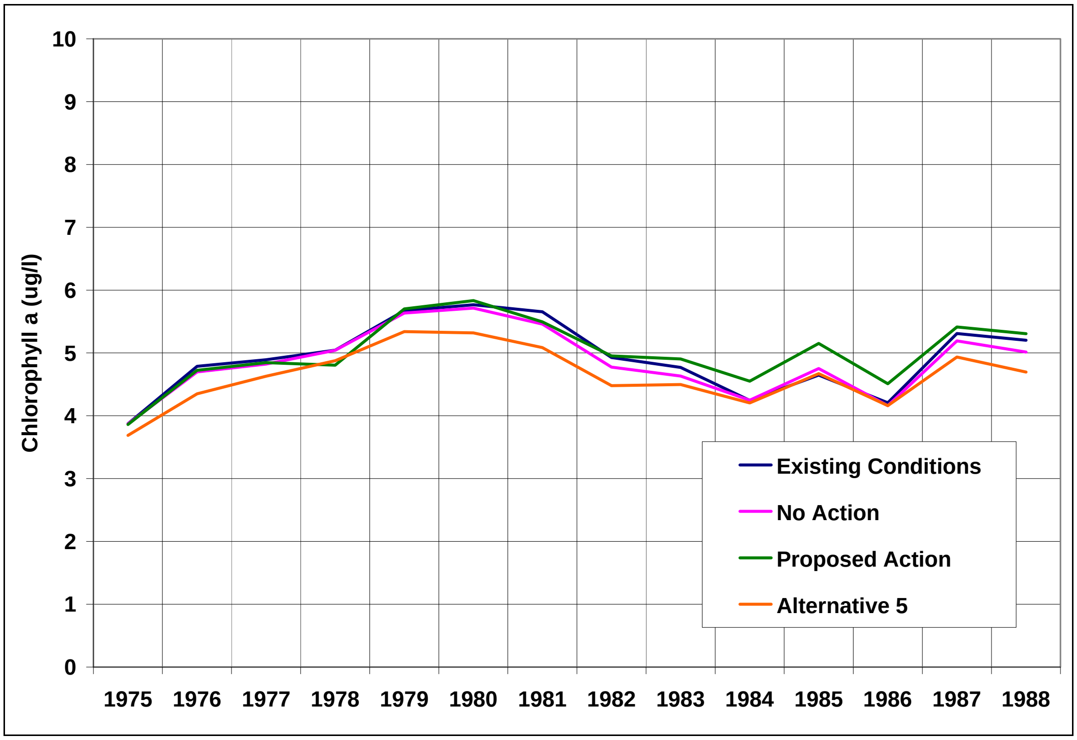


**Figure 158: Predicted Average Annual Chlorophyll *a* Concentrations in Grand Lake--Cumulative Effects**

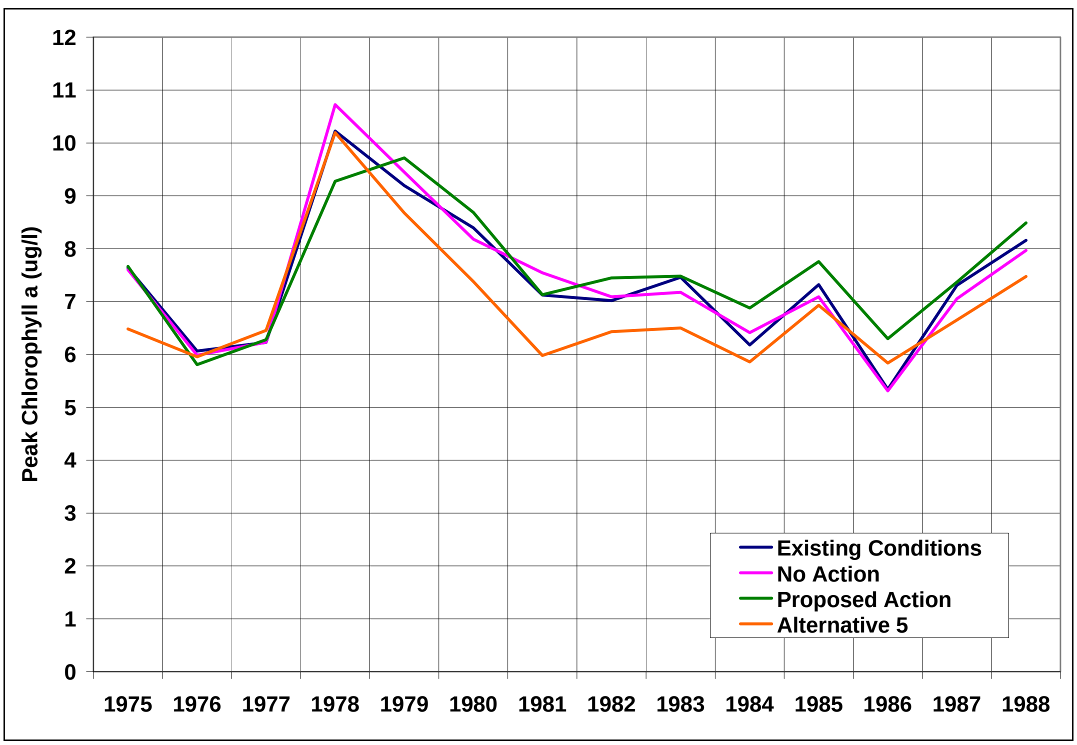


**Figure 159: Predicted Annual Peak Chlorophyll *a* Concentrations in Grand Lake--Cumulative Effects**

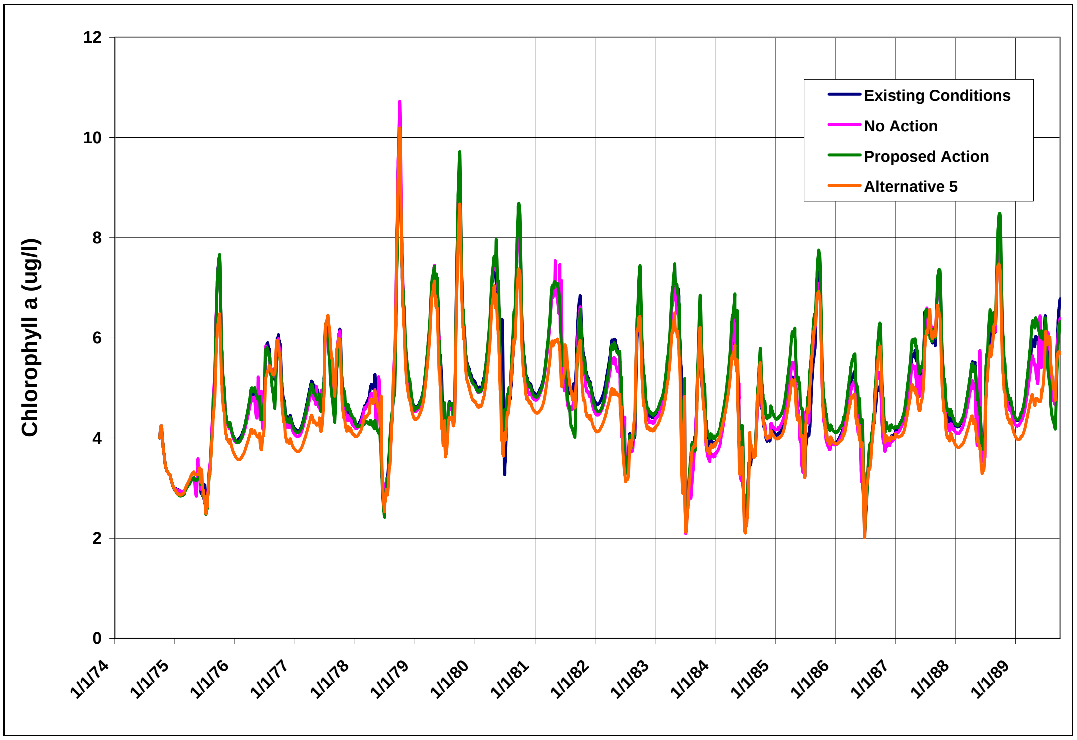


**Figure 160: Predicted Daily Chlorophyll *a* Concentrations in Grand Lake--Cumulative Effects**

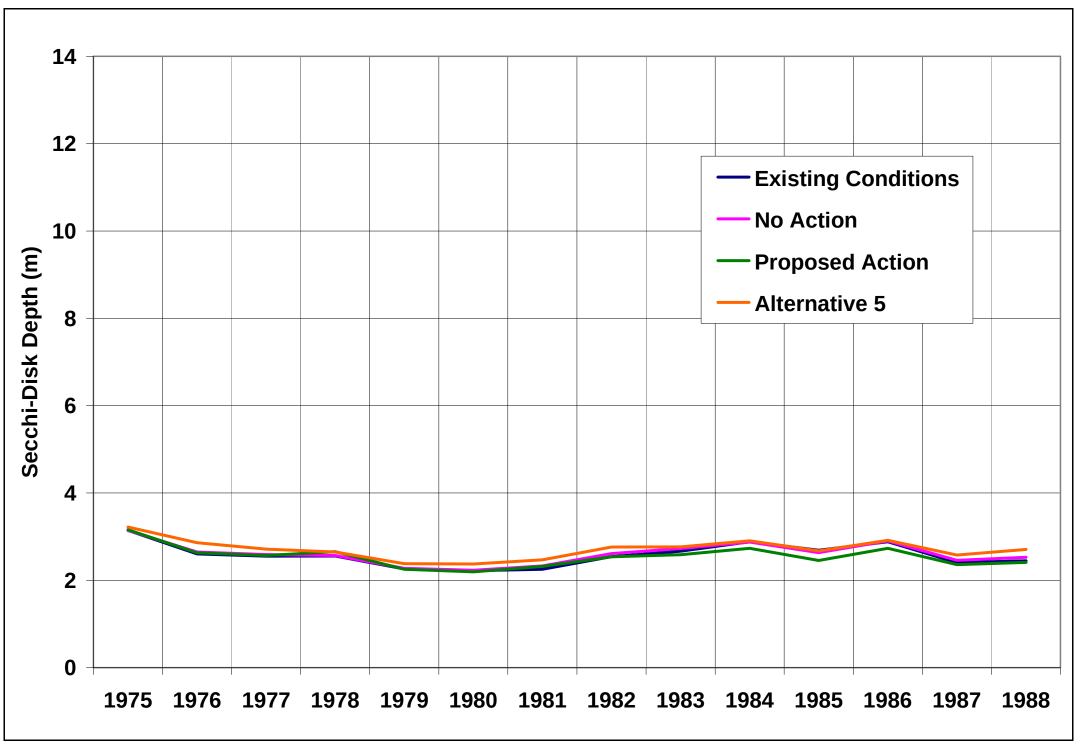


**Figure 161: Predicted Average Annual Secchi-Disk Depth in Grand Lake--Cumulative Effects**

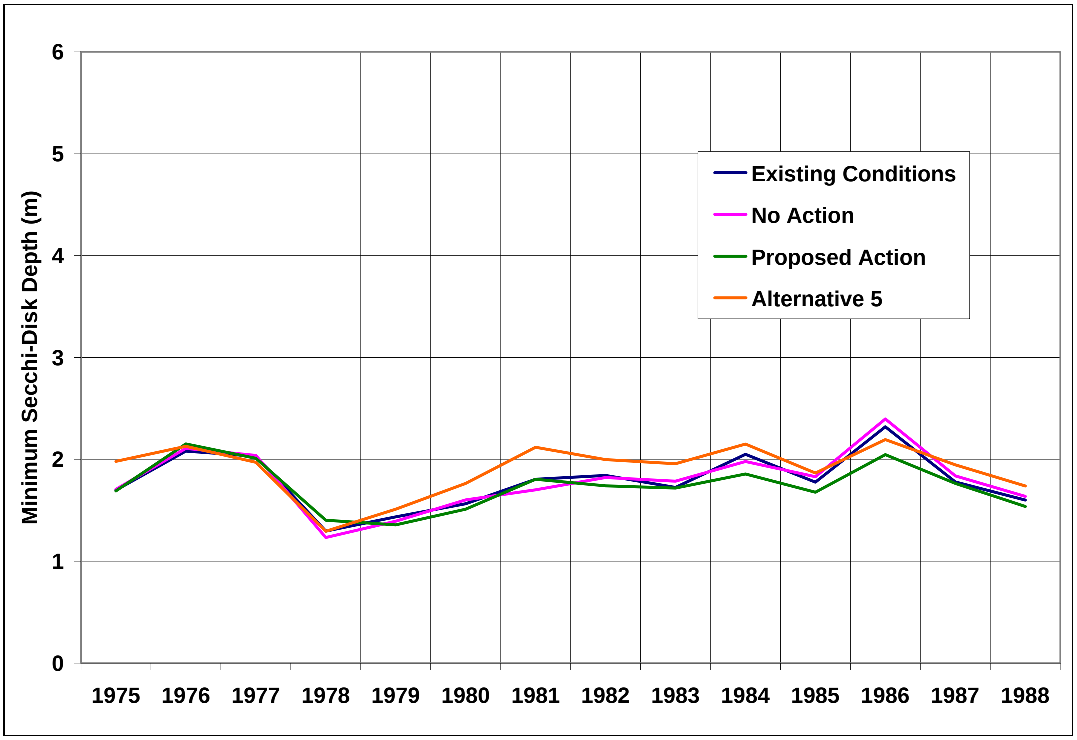


**Figure 162: Predicted Minimum Secchi-Disk Depth in Grand Lake--Cumulative Effects**

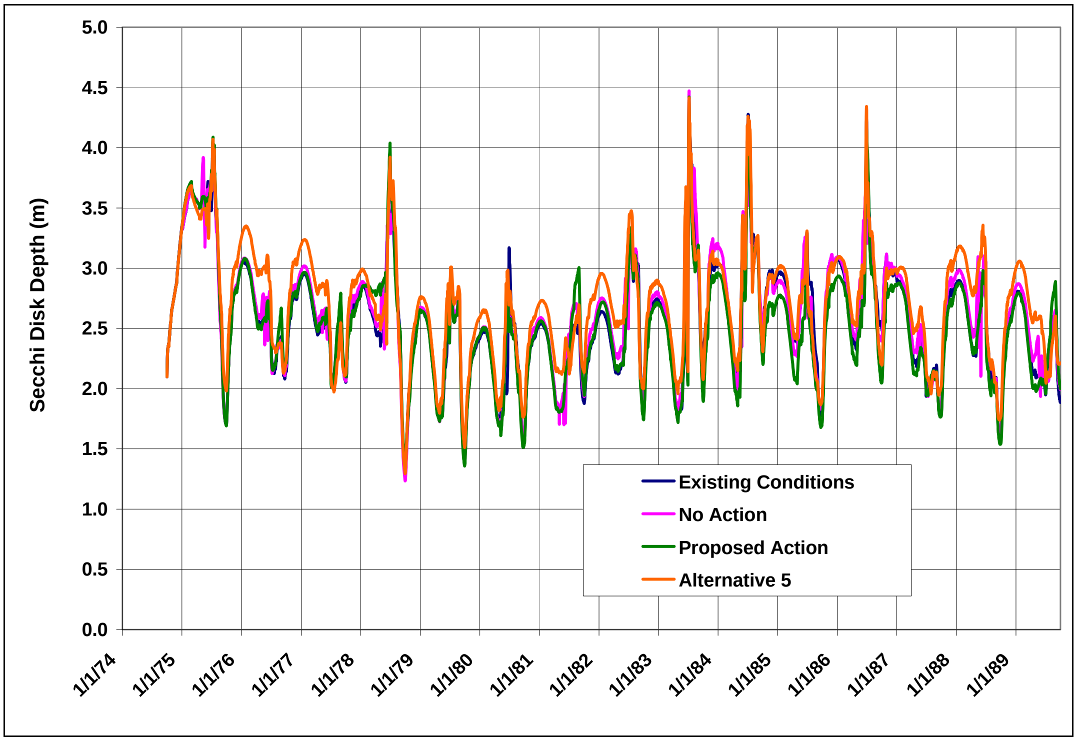


**Figure 163: Predicted Daily Secchi-Disk Depth in Grand Lake--Cumulative Effects**

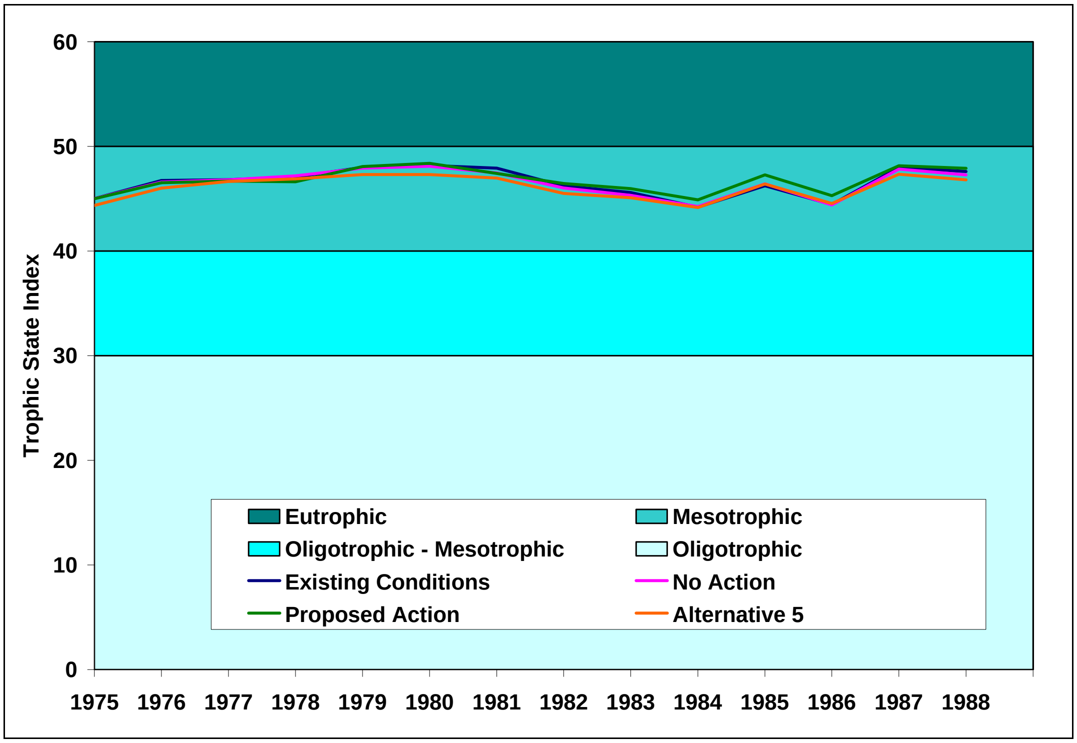


**Figure 164: Predicted Annual Trophic State Indices in Grand Lake--Cumulative Effects**

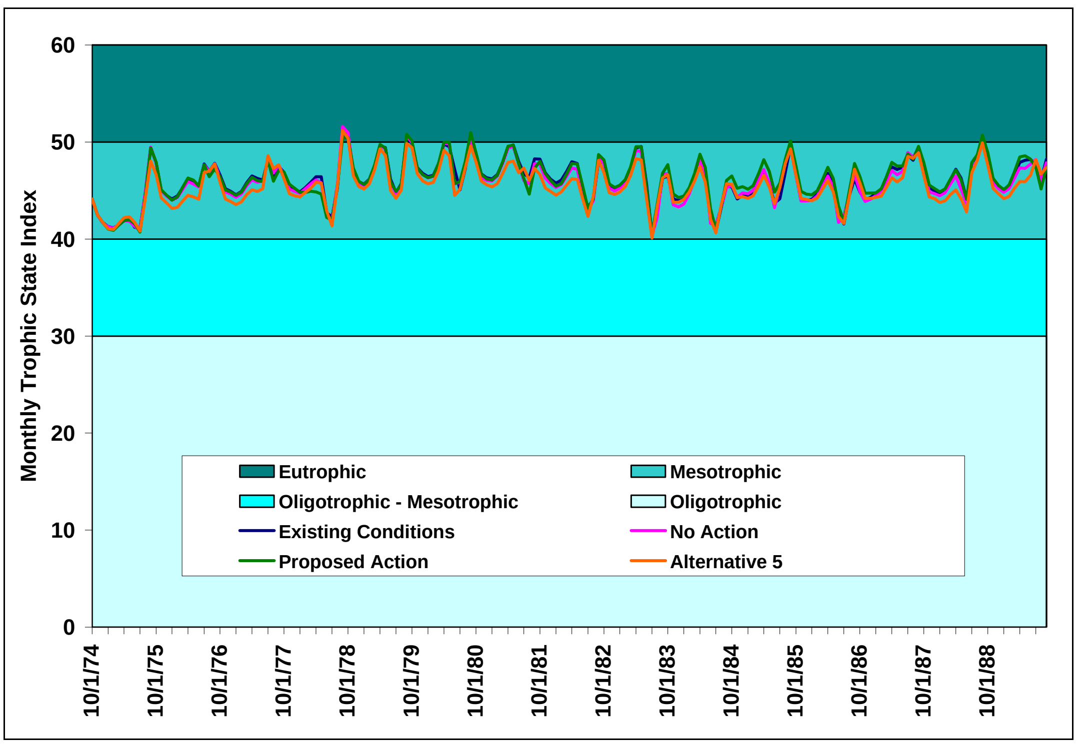


**Figure 165: Predicted Monthly Trophic State Index for Grand Lake--Cumulative Effects**

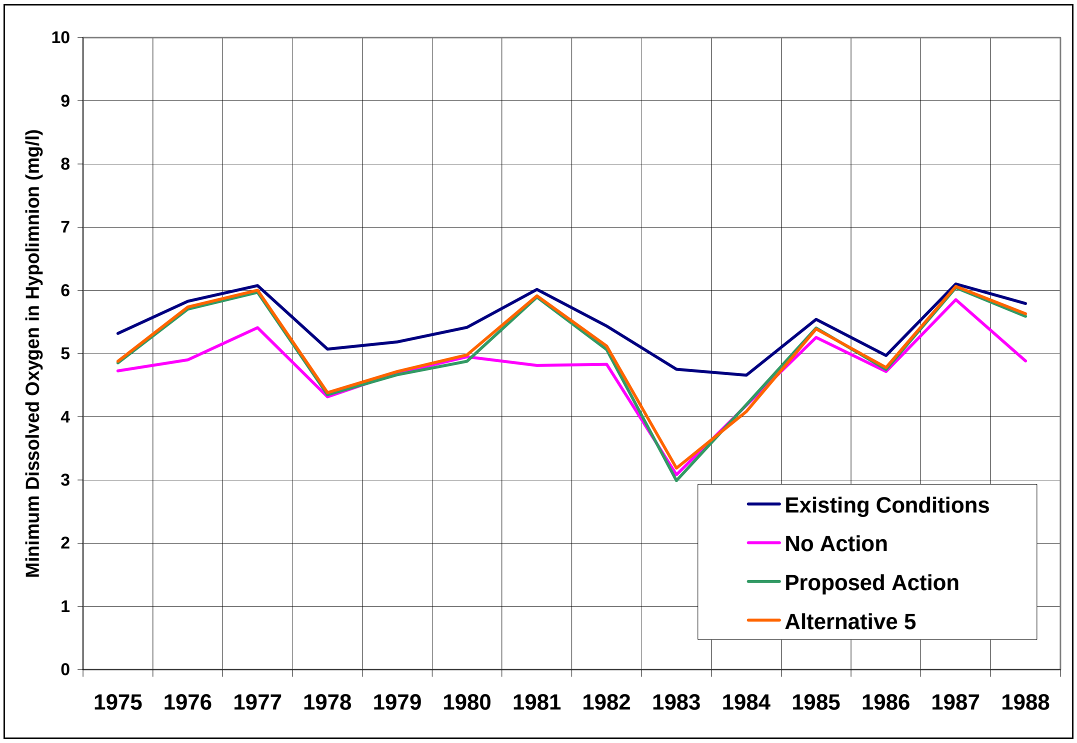


**Figure 166: Predicted Minimum Dissolved Oxygen Concentrations in Grand Lake--Cumulative Effects**

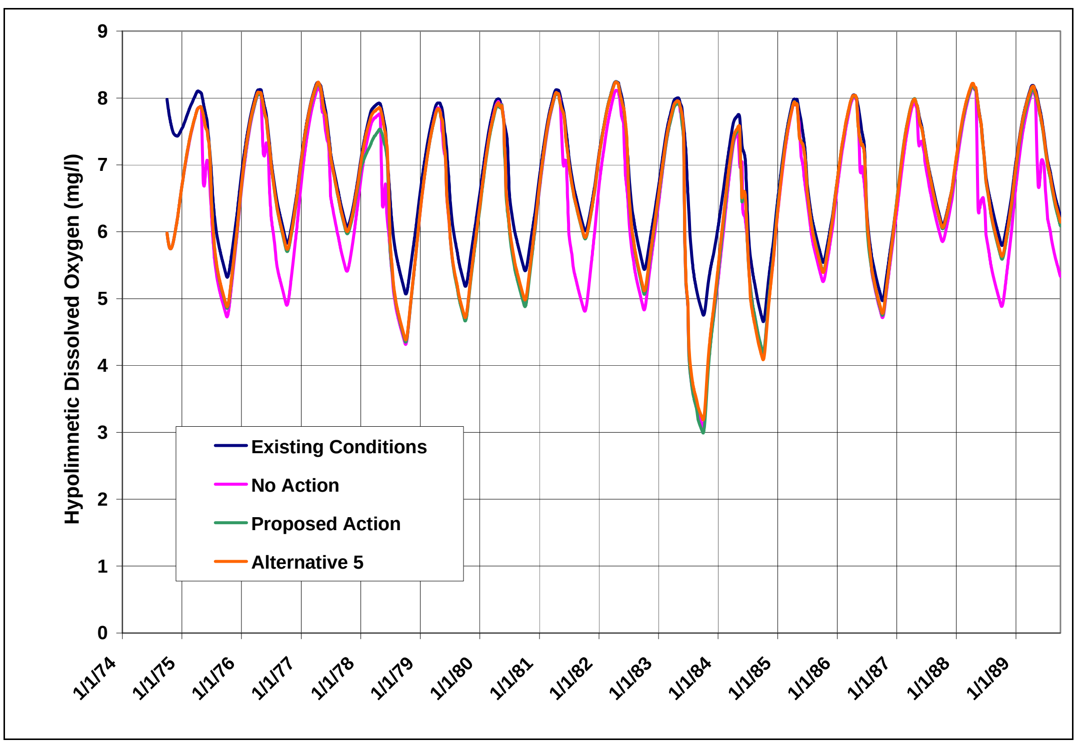


**Figure 167: Predicted Daily Dissolved Oxygen Concentrations in Grand Lake--Cumulative Effects**

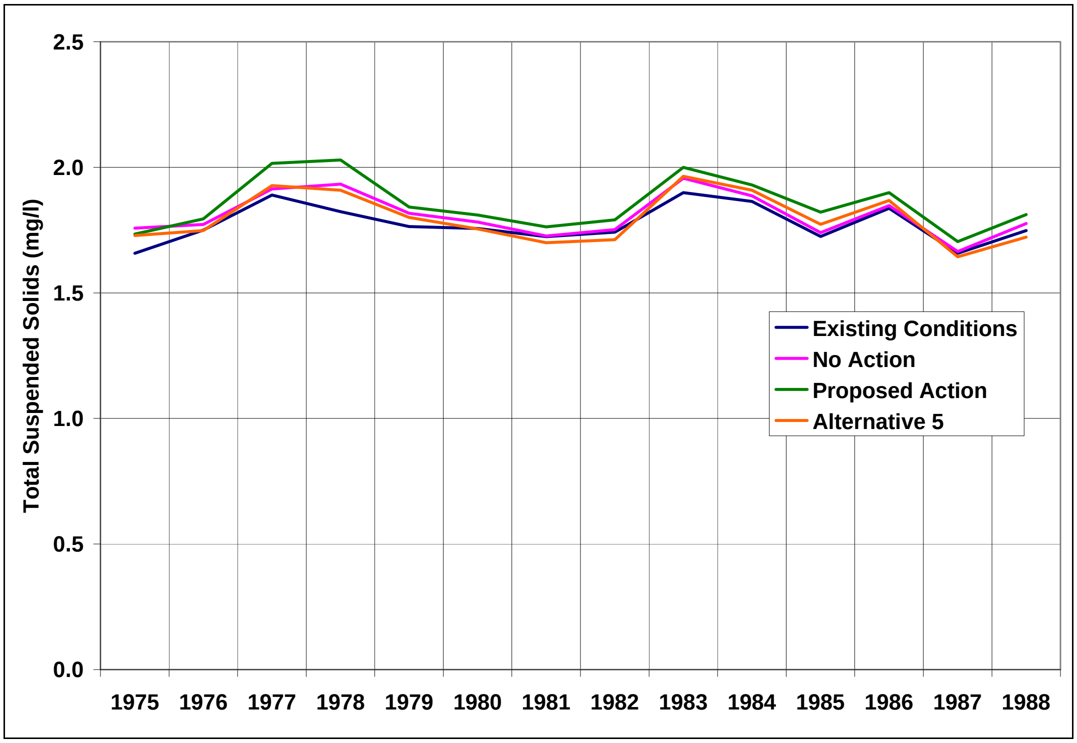


**Figure 168: Predicted Average Annual Total Suspended Sediment Concentrations in Grand Lake--Cumulative Effects**

The cumulative effects of the alternatives were evaluated to determine if standards would be met using model predictions. Grand Lake would continue to meet dissolved oxygen, ammonia, and nitrate standards. It is anticipated that manganese concentrations would increase over existing conditions due to lower dissolved oxygen concentrations in the hypolimnion. It is predicted that the No Action alternative would result in the highest manganese concentrations and the Proposed Action alternative would result in the second highest concentration. There is no indication that temperature standards would be exceeded because no increases in temperature are predicted. In addition, there is no evidence to suggest that pH would decrease more under any of the alternatives, thus the pH standard is predicted to be exceeded under any of the alternatives, similar to existing conditions.

## 12.5. Cumulative Effects - Existing East Slope Reservoirs

Cumulative environmental impacts for Horsetooth Reservoir, Carter Lake, and Ralph Price Reservoir are described in this section. The methodology used is the same as the one used for direct effects.

Changes in Horsetooth Reservoir and Carter Lake are driven not only by changes in hydrology, but also by changes in loading to the east slope at the east portal of the Adams Tunnel. To help interpret the results by individual reservoir, the average annual nutrient loads as predicted by the Three Lakes Model (WY1975-WY1989) are listed in Table 81. The highest nitrogen loading occurs for Alternative 2 followed by Alternative 5. The No Action alternative is next, followed by existing conditions, which has the lowest nitrogen loading. Phosphorus loadings are lower for Alternative 5 relative to existing conditions.

**Table 81: Average Nutrient Load through the Adams Tunnel--Cumulative Effects (WY75-WY89)**

| Alternative | Average Phosphorus Load (kg/yr) | Average Nitrogen Load (kg/yr) |
|---|---|---|
| Existing Conditions | 2,480 | 75,484 |
| No Action | 2,501 | 78,942 |
| Proposed Action | 2,774 | 82,947 |
| Alternative 5 | 2,369 | 82,516 |

### 12.5.1. Carter Lake

Model predictions for Carter Lake for existing conditions and the three cumulative effects alternatives are displayed in Figure 169 to Figure 173 and summarized in Table 82. Comparisons with existing conditions and the No Action alternative are made in Table 83 and Table 84. Trophic state and Secchi-disk depth remain unchanged between the different scenarios.

Alternative 2 would have the highest nutrient loading from the Adams Tunnel and would result in the highest in-reservoir nutrient and chlorophyll *a* concentrations. Under Alternative 5, Dry Creek Reservoir would serve to retain phosphorus, thus reducing the phosphorus load directly into Carter Lake and the resulting in-reservoir concentrations.

Relative results for metalimnetic oxygen demand (MOD) and hypolimnetic oxygen demand (HOD) for Carter Lake are listed in Table 85 and Table 86. Model predictions for the action alternatives indicate that all alternatives may slightly reduce oxygen concentrations in both the metalimnion and hypolimnion of Carter Lake. The oxygen demand predictions indicate that the Proposed Action alternative would likely result in the lowest dissolved oxygen concentrations among the alternatives for both the metalimnion and hypolimnion.

The alternatives were evaluated to determine if standards would be met or exceeded using model predictions. Carter Lake would continue to meet dissolved oxygen, ammonia, and nitrate standards. Temperature standards are not predicted to be exceeded more than what is occurring for existing conditions. Dissolved manganese concentrations may increase due to decreased hypolimnetic dissolved oxygen concentrations, but is in unlikely that standards would be exceeded for the action alternatives.

**Table 82: Average Predicted Conditions for Carter Lake (Existing Conditions and Cumulative Effects No Action, Proposed Action, and Alternative 5)**

| Average Annual Values Over the 15-Year Model Period | | | | |
|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 5 |
| Total Phosphorus (µg/l) | 9.9 | 9.9 | 10.4 | 9.7 |
| Total Nitrogen (µg/l) | 226 | 231 | 237 | 236 |
| Chlorophyll a (µg/l) | 1.8 | 1.8 | 2.0 | 1.9 |
| Secchi-Disk Depth (m) | 2.8 | 2.8 | 2.8 | 2.8 |
| Trophic State (Index) | Oligotrophic - Mesotrophic (36) | Oligotrophic - Mesotrophic (37) | Oligotrophic - Mesotrophic (37) | Oligotrophic - Mesotrophic (37) |

**Table 83: Predicted Changes by Alternative for Carter Lake Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 5 |
|---|---|---|---|
| Total Phosphorus (µg/l) | No Change | +5.1% | -2.0% |
| Total Nitrogen (µg/l) | +2.2% | +4.9% | +4.4% |
| Chlorophyll *a* (µg/l) | No Change | +11.1% | +5.6% |
| Secchi-Disk Depth (m) | No Change | No Change | No Change |
| Trophic State | No Change | No Change | No Change |

**Table 84: Predicted Changes for Carter Lake by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 5 |
|---|---|---|
| Total Phosphorus (µg/l) | +5.1% | -2.0% |
| Total Nitrogen (µg/l) | +2.6% | +2.2% |
| Chlorophyll *a* (µg/l) | +11.1% | +5.6% |
| Secchi-Disk Depth (m) | No Change | No Change |
| Trophic State Index | No Change | No Change |

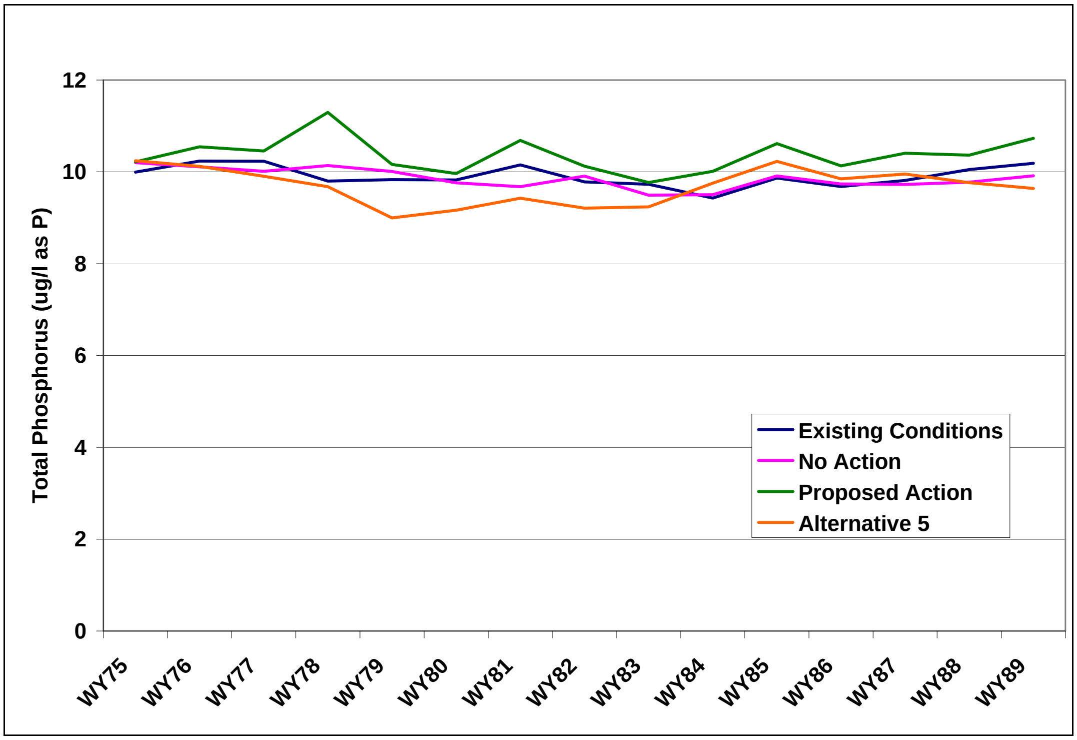


**Figure 169: Predicted Total Phosphorus Concentrations in Carter Lake--Cumulative Effects**

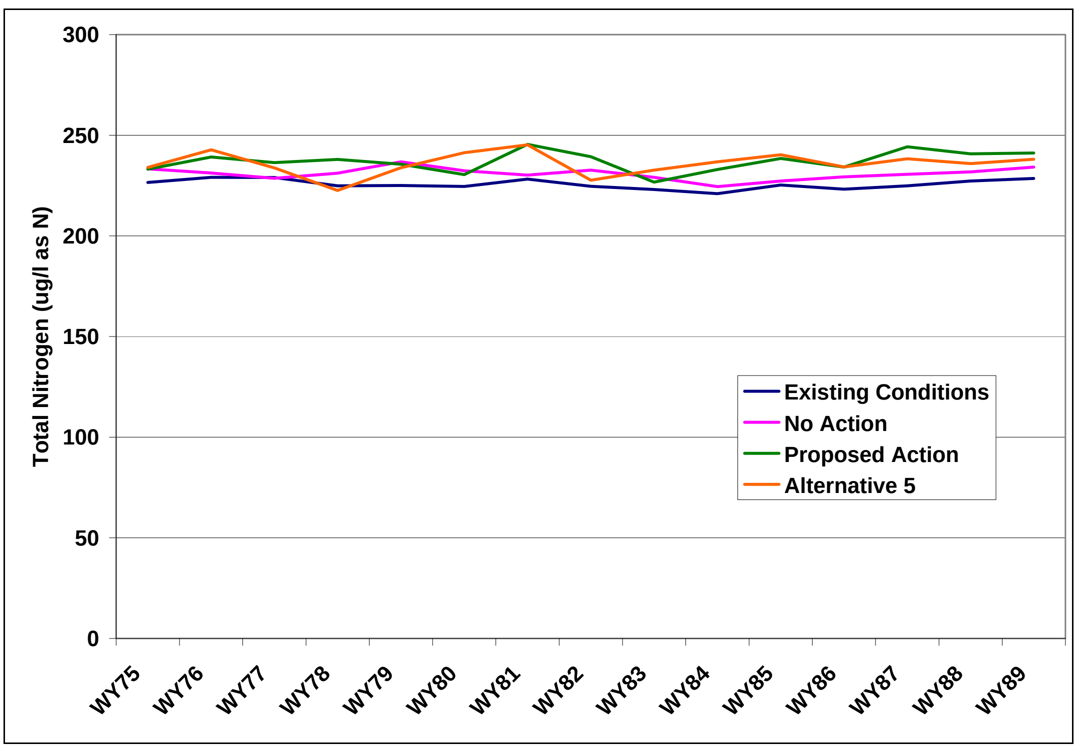


**Figure 170: Predicted Total Nitrogen Concentrations in Carter Lake--Cumulative Effects**

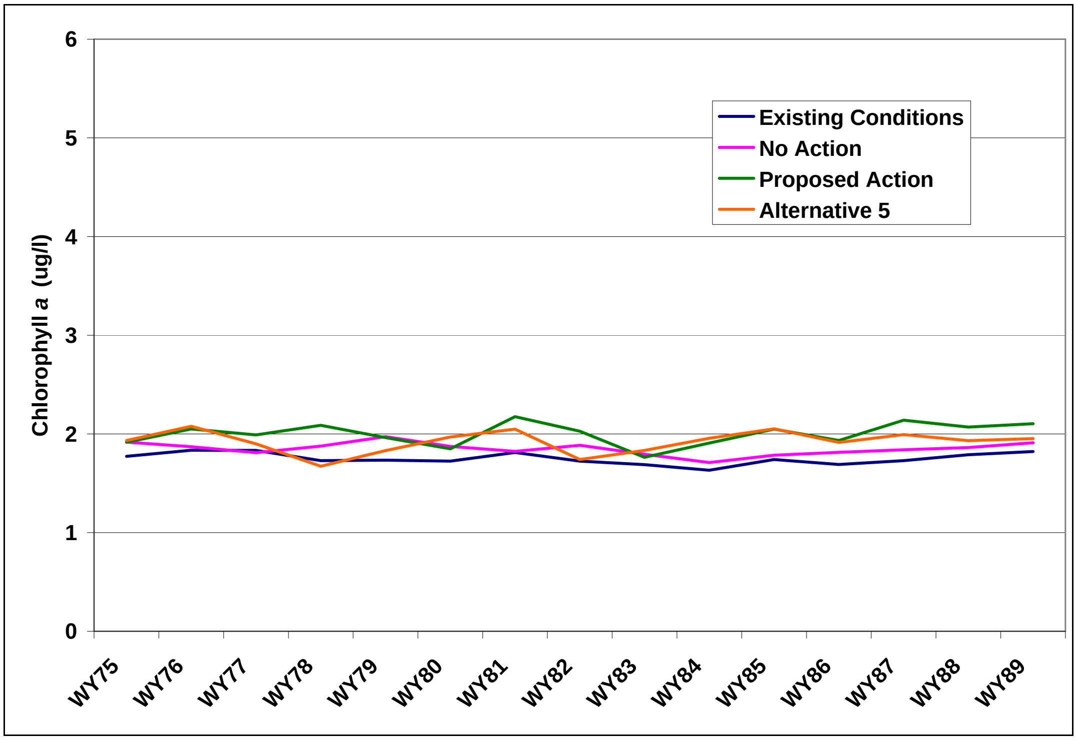


**Figure 171: Predicted Chlorophyll *a* Concentrations in Carter Lake--Cumulative Effects**

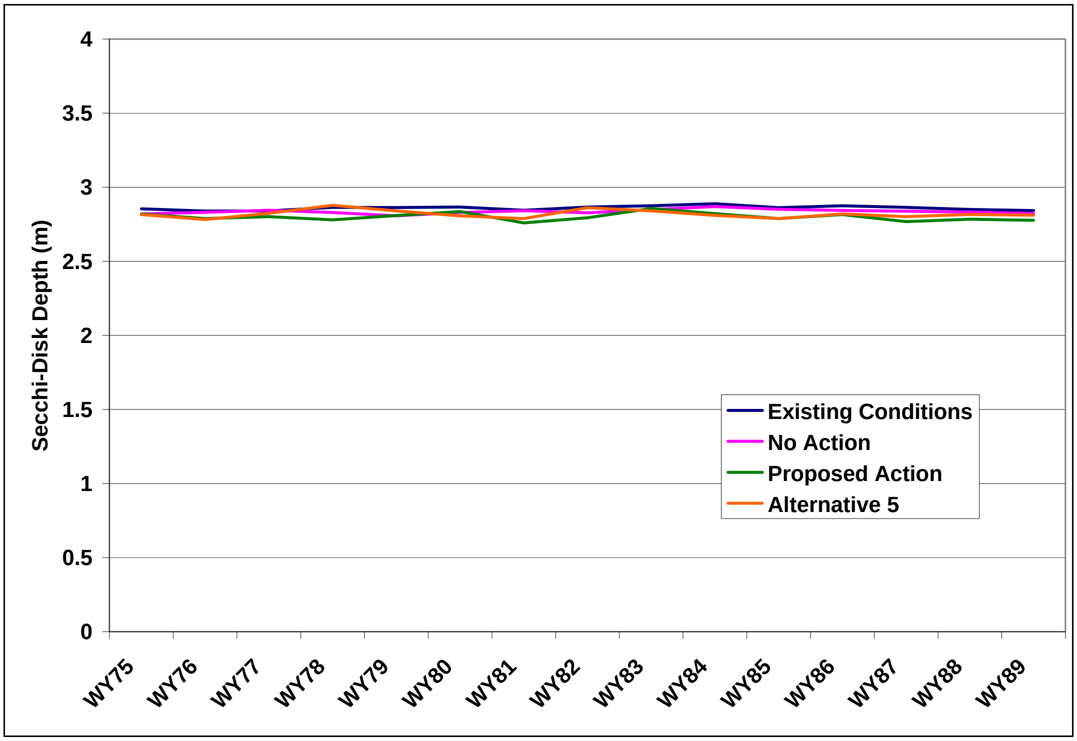


**Figure 172: Predicted Secchi-Disk Depths in Carter Lake--Cumulative Effects**

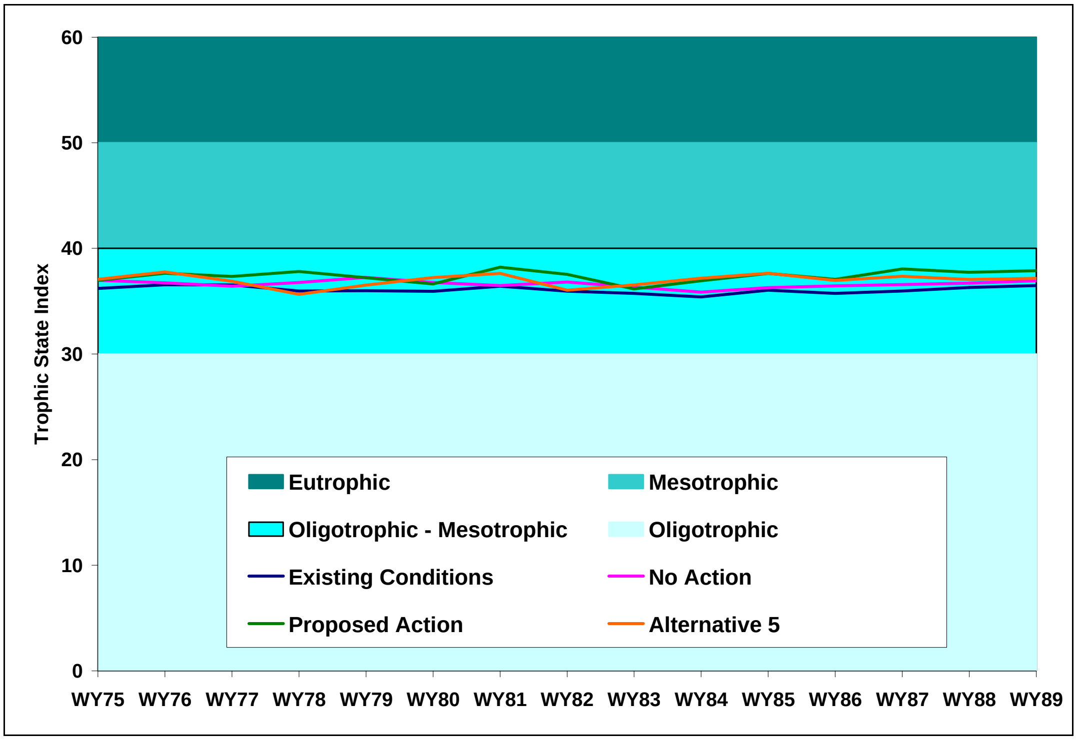


**Figure 173: Predicted Trophic State Indices in Carter Lake--Cumulative Effects**

**Table 85: Predicted Changes in Oxygen Demand by Alternative for Carter Lake Relative to Existing Conditions--Cumulative Effects**

| Oxygen demand | No Action | Proposed Action | Alternative 5 |
|---|---|---|---|
| MOD (mg/(m$^3$ day)) | +4.2% | +8.3% | +8.3% |
| HOD (mg/(m$^3$ day)) | +4.5% | +9.1% | +4.5% |

**Table 86: Predicted Changes in Oxygen Demand by Alternative for Carter Lake Relative to the No Action Alternative--Cumulative Effects**

| Oxygen demand | Proposed Action | Alternative 5 |
|---|---|---|
| MOD (mg/(m$^3$ day)) | +4.0% | +4.0% |
| HOD (mg/(m$^3$ day)) | +4.3% | No Change |

### 12.5.2. Horsetooth Reservoir

Model predictions for Horsetooth Reservoir for existing conditions and the three cumulative effects alternatives are displayed in Figure 174 to Figure 178 and summarized in Table 87. Comparisons with existing conditions and the No Action alternative are made in Table 88 and Table 89. Trophic state would remain unchanged from existing conditions for all alternatives. Secchi-Disk depth would decrease by 0.1 m for the Proposed Action, but would be unchanged for the other alternatives.

The Proposed Action would have the highest nutrient loading from the Adams Tunnel and would result in the highest in-reservoir nutrient and chlorophyll *a* concentrations. Under Alternative 5

Dry Creek Reservoir would serve to retain phosphorus, thus reducing the phosphorus load directly into Horsetooth Reservoir and the resulting in-reservoir concentrations.

Relative results for metalimnetic oxygen demand (MOD) and hypolimnetic oxygen demand (HOD) for Horsetooth Reservoir are listed in Table 57 and Table 58. Model predictions for the action alternatives indicate that all alternatives may slightly reduce oxygen concentrations in both the metalimnion and hypolimnion of Horsetooth Reservoir. The oxygen demand predictions indicate that the Proposed Action alternative would likely result in the lowest dissolved oxygen concentrations among the alternatives for both the metalimnion and hypolimnion. In addition, no negative change in temperature is anticipated for any of the alternatives.

The alternatives were evaluated to determine if standards would be met or exceeded. Horsetooth Reservoir would continue to exceed dissolved oxygen standards. The reservoir would continue to meet ammonia and nitrate standards. Temperature standards are not predicted to be exceeded more than what is occurring for existing conditions. Dissolved manganese concentrations may increase due to decreased hypolimnetic dissolved oxygen concentrations, but is in unlikely that standards would be exceeded for the action alternatives.

**Table 87: Average Predicted Conditions for Horsetooth Reservoir (Existing Conditions and Cumulative Effects No Action, Proposed Action, and Alternative 5)**

| Average Annual Values Over the 15-Year Model Period | | | | |
|---|---|---|---|---|
| | Existing Conditions | No Action | Proposed Action | Alternative 5 |
| Total Phosphorus (µg/l) | 9.9 | 9.9 | 10.5 | 9.6 |
| Total Nitrogen (µg/l) | 274 | 283 | 292 | 291 |
| Chlorophyll a (µg/l) | 3.5 | 3.6 | 3.8 | 3.6 |
| Secchi-Disk Depth (m) | 2.6 | 2.6 | 2.5 | 2.6 |
| Trophic State (Index) | Mesotrophic (43) | Mesotrophic (43) | Mesotrophic (44) | Mesotrophic (43) |

**Table 88: Predicted Changes by Alternative for Horsetooth Reservoir Relative to Existing Conditions**

| | No Action | Proposed Action | Alternative 5 |
|---|---|---|---|
| Total Phosphorus (µg/l) | No Change | +6.1% | -3.0% |
| Total Nitrogen (µg/l) | +3.3% | +6.6% | +6.2% |
| Chlorophyll a (µg/l) | +2.9% | +8.6% | +2.9% |
| Secchi-Disk Depth (m) | No Change | -3.8% | No Change |
| Trophic State | No Change | No Change | No Change |

**Table 89: Predicted Changes for Horsetooth Reservoir by Alternative Relative to the No Action Alternative**

| | Proposed Action | Alternative 5 |
|---|---|---|
| Total Phosphorus (µg/l) | +6.1% | -3.0% |
| Total Nitrogen (µg/l) | +3.2% | No Change |
| Chlorophyll a (µg/l) | +5.6% | No Change |
| Secchi-Disk Depth (m) | -3.8% | No Change |
| Trophic State | No Change | No Change |

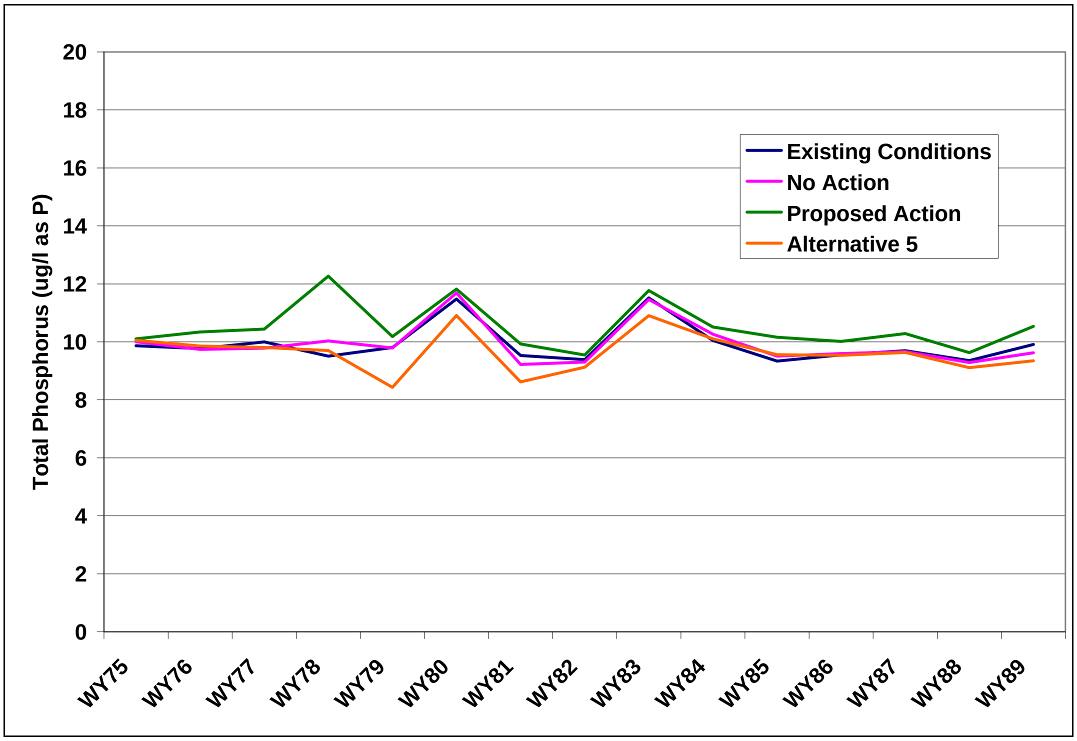


**Figure 174: Predicted Total Phosphorus Concentrations in Horsetooth Reservoir--Cumulative Effects**

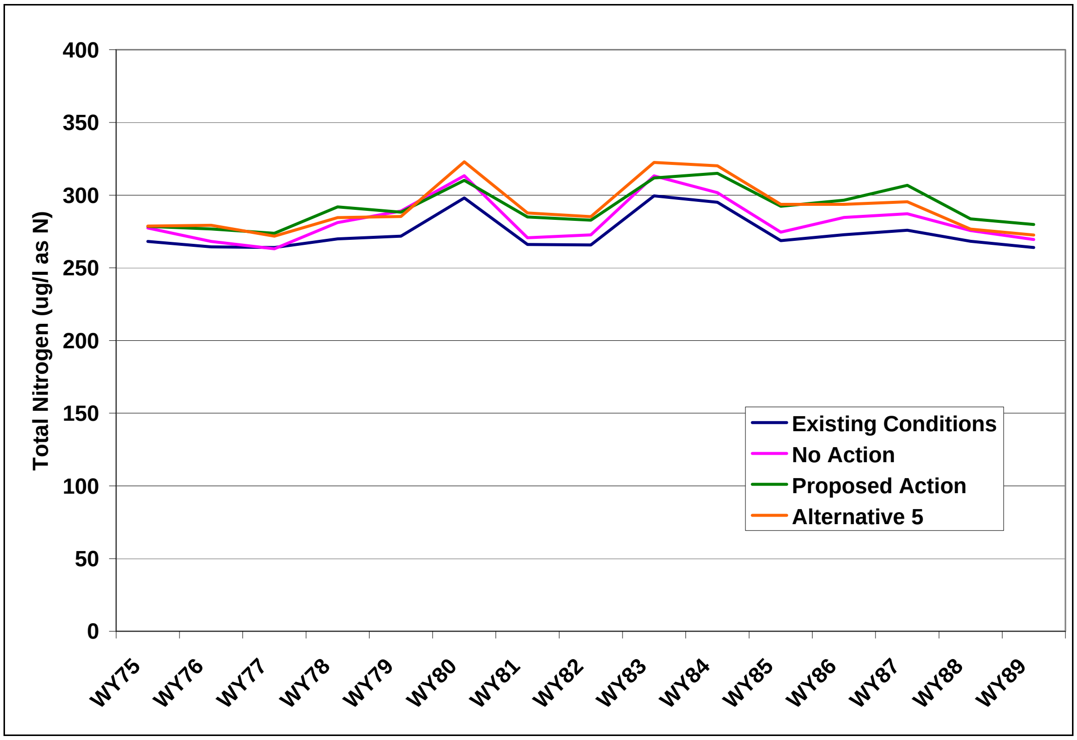


**Figure 175: Predicted Total Nitrogen Concentrations in Horsetooth Reservoir--Cumulative Effects**

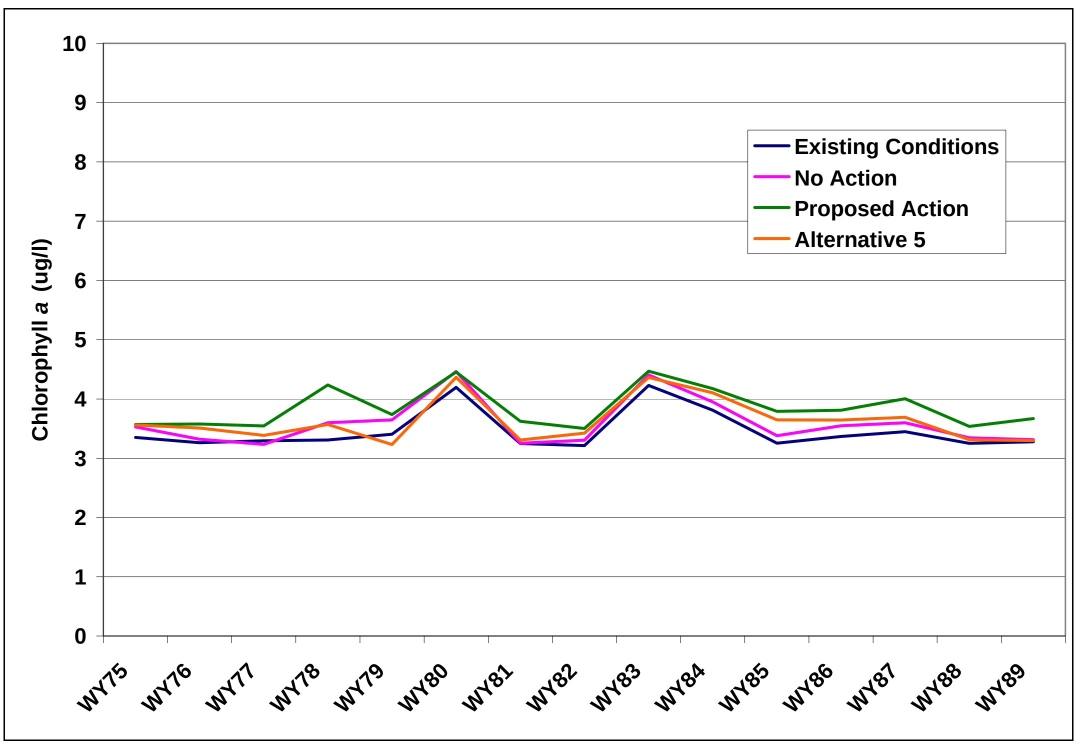


**Figure 176: Predicted Chlorophyll *a* Concentrations in Horsetooth Reservoir--Cumulative Effects**

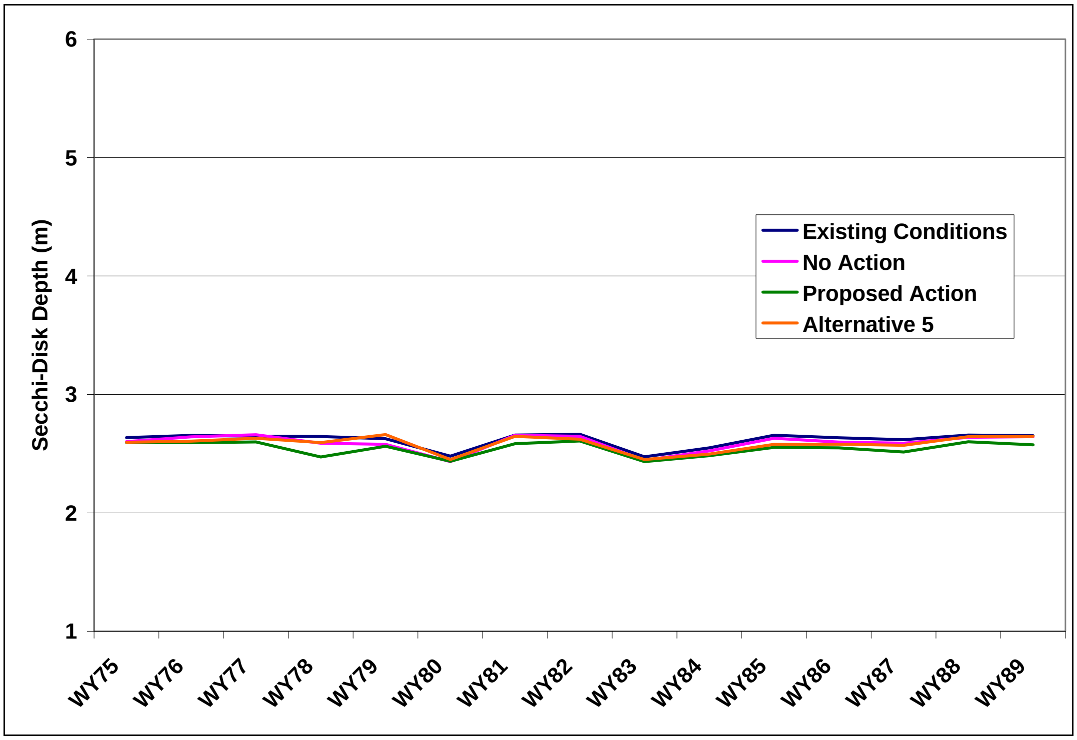


**Figure 177: Predicted Secchi-Disk Depths in Horsetooth Reservoir--Cumulative Effects**

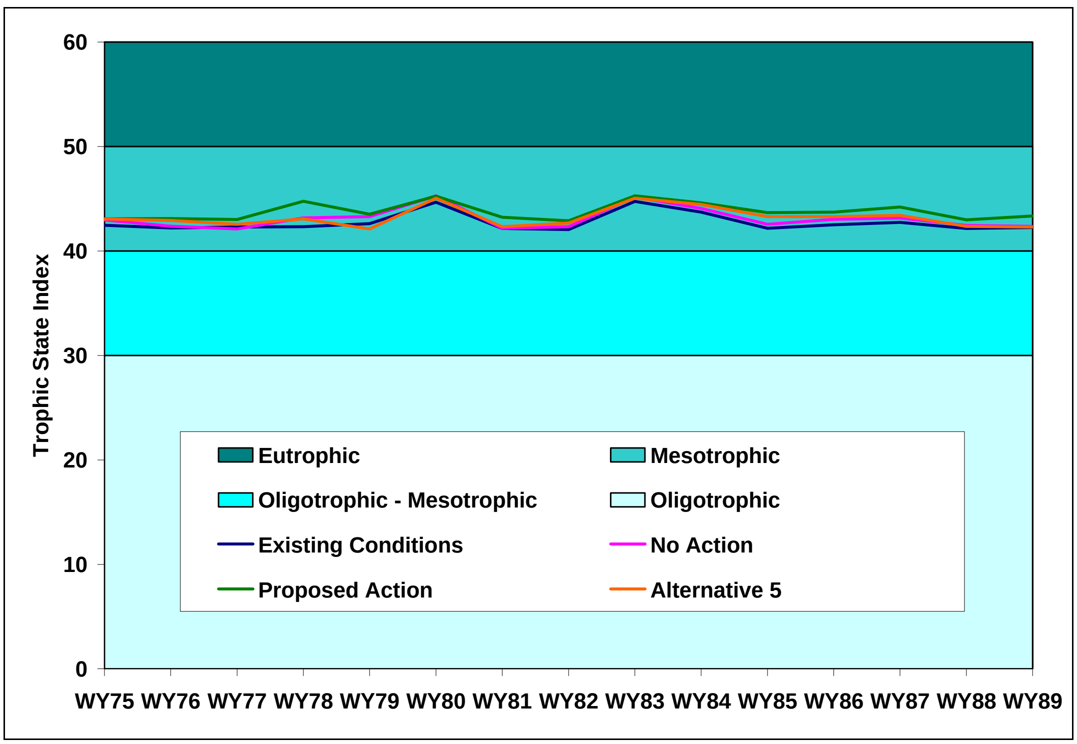


**Figure 178: Predicted Trophic State Indices in Horsetooth Reservoir--Cumulative Effects**

**Table 90: Predicted Changes in Oxygen Demand by Alternative for Horsetooth Reservoir Relative to Existing Conditions--Cumulative Effects**

| Oxygen demand | No Action | Proposed Action | Alternative 5 |
|---|---|---|---|
| MOD ($mg/(m^3$ day)) | +2.2% | +15% | +6.5% |
| HOD ($mg/(m^3$ day)) | No Change | +11% | +4.5% |

**Table 91: Predicted Changes in Oxygen Demand by Alternative for Horsetooth Reservoir Relative to the No Action Alternative--Cumulative Effects**

| Oxygen demand | Proposed Action | Alternative 5 |
|---|---|---|
| MOD ($mg/(m^3$ day)) | +13% | +4.3% |
| HOD ($mg/(m^3$ day)) | +11% | +4.5% |

### 12.5.3. Ralph Price Reservoir

Ralph Price Reservoir is only included in the No Action alternative. Anticipated in-reservoir water quality concentrations are reported in Figure 179 - Figure 183. Average predicted conditions are listed in Table 92. Comparisons are made in Table 93. Alternative 1 shows improvements in water quality compared with existing conditions.

Relative results for metalimnetic oxygen demand (MOD) and hypolimnetic oxygen demand (HOD) Ralph Price Reservoir are listed in Table 61. The oxygen demand predictions indicate that the No Action alternative would likely result in higher dissolved oxygen concentrations. Overall, the No Action alternative shows improvements in water quality compared with existing conditions. Changes occur due to the increase in reservoir volume and mean depth.

An estimate of alternative influence on Ralph Price Reservoir water temperatures can be made based solely on the influence of the change in reservoir volume. The No Action alternative involves increasing storage in Ralph Price Reservoir. The water inflow temperatures and inflow volume to this reservoir are assumed the same as existing conditions. A reservoir with a larger volume has a larger thermal mass, a deeper water column and increased thermal stratification. These characteristics result in a reservoir that has a greater tendency to resist heating influences at the air – water interface. The reservoir outlet structure for No Action would be deeper than existing conditions. Therefore, the water temperature in Ralph Price Reservoir for the No Action is likely to be cooler than existing conditions.

The alternatives were evaluated to determine if standards would be met or exceeded. Ralph Price Reservoir would continue to meet dissolved oxygen, ammonia, nitrate, dissolved manganese, and temperature standards.

**Table 92: Average Predicted Conditions for Ralph Price (Existing Conditions and Cumulative Effects No Action)**

| Average Annual Values Over the 15-Year Model Period | | |
|---|---|---|
| | Existing Conditions | No Action |
| Total Phosphorus (µg/l) | 5.1 | 4.9 |
| Total Nitrogen (µg/l) | 188 | 177 |
| Chlorophyll a (µg/l) | 0.6 | 0.4 |
| Secchi-Disk Depth (m) | 3.8 | 3.8 |
| Trophic State (Index) | Oligotrophic (26) | Oligotrophic (22) |

**Table 93: Predicted Changes by Alternative for Ralph Price Reservoir Relative to Existing Conditions**

| | No Action |
|---|---|
| Total Phosphorus (µg/l) | -3.9% |
| Total Nitrogen (µg/l) | -5.9% |
| Chlorophyll a (µg/l) | -33% |
| Secchi-Disk Depth (m) | No Change |
| Trophic State | No Change |

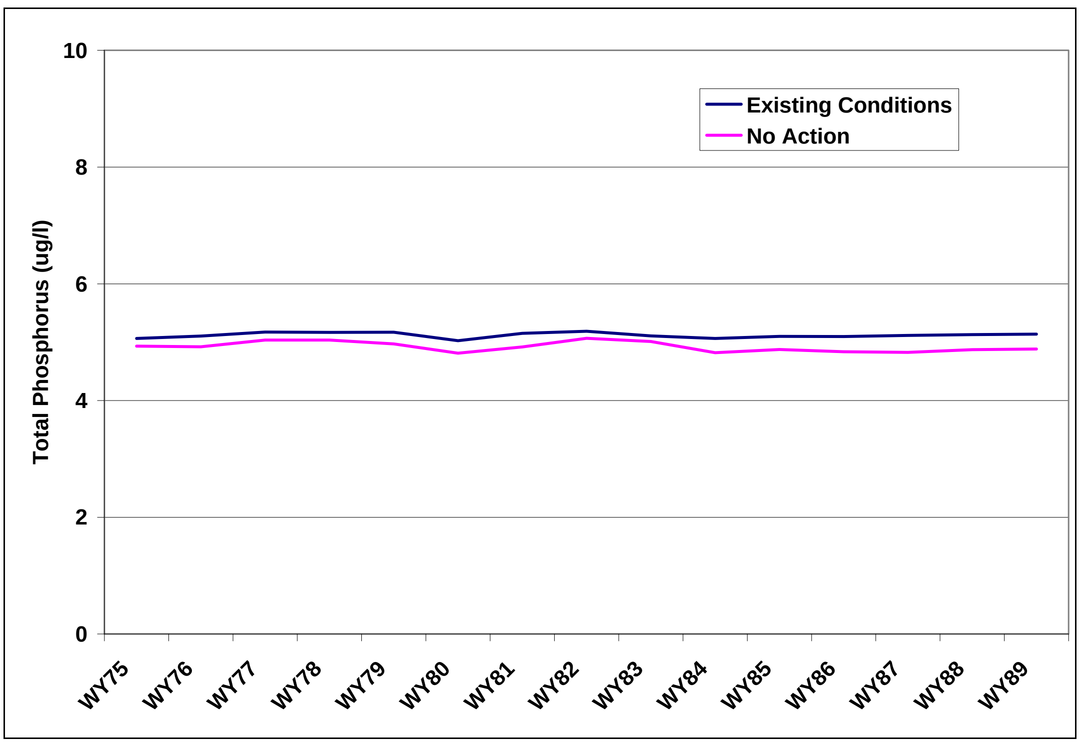


**Figure 179: Predicted Total Phosphorus Concentrations in Ralph Price Reservoir--Cumulative Effects**

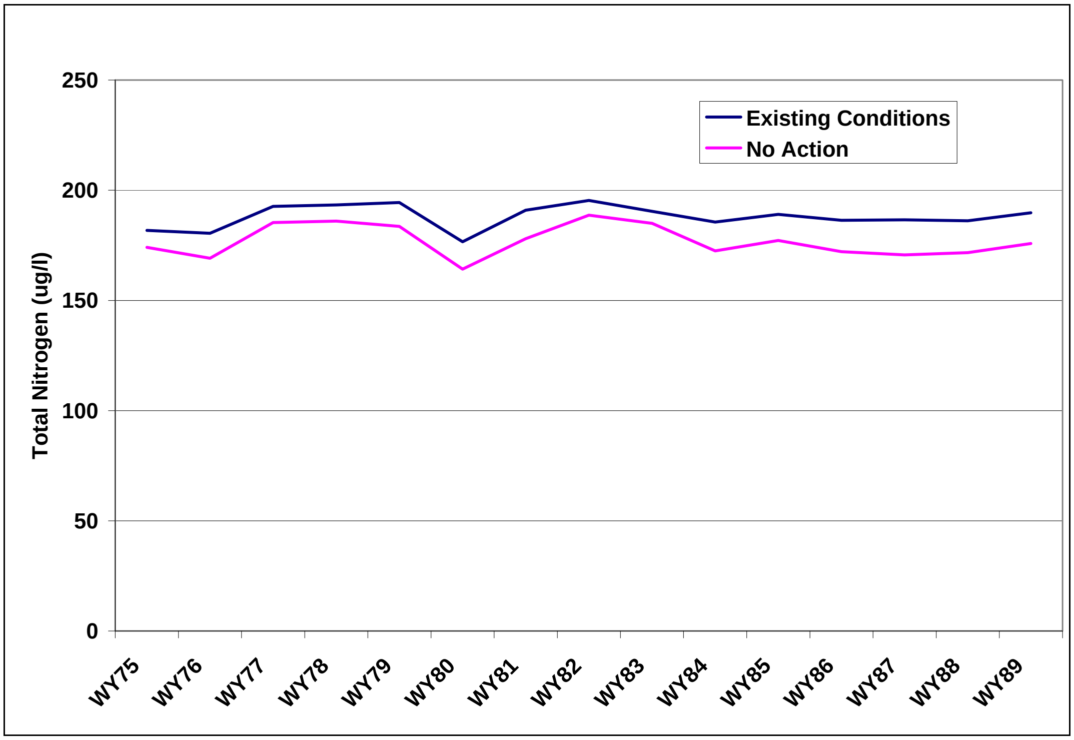


**Figure 180: Predicted Total Nitrogen Concentrations in Ralph Price Reservoir--Cumulative Effects**

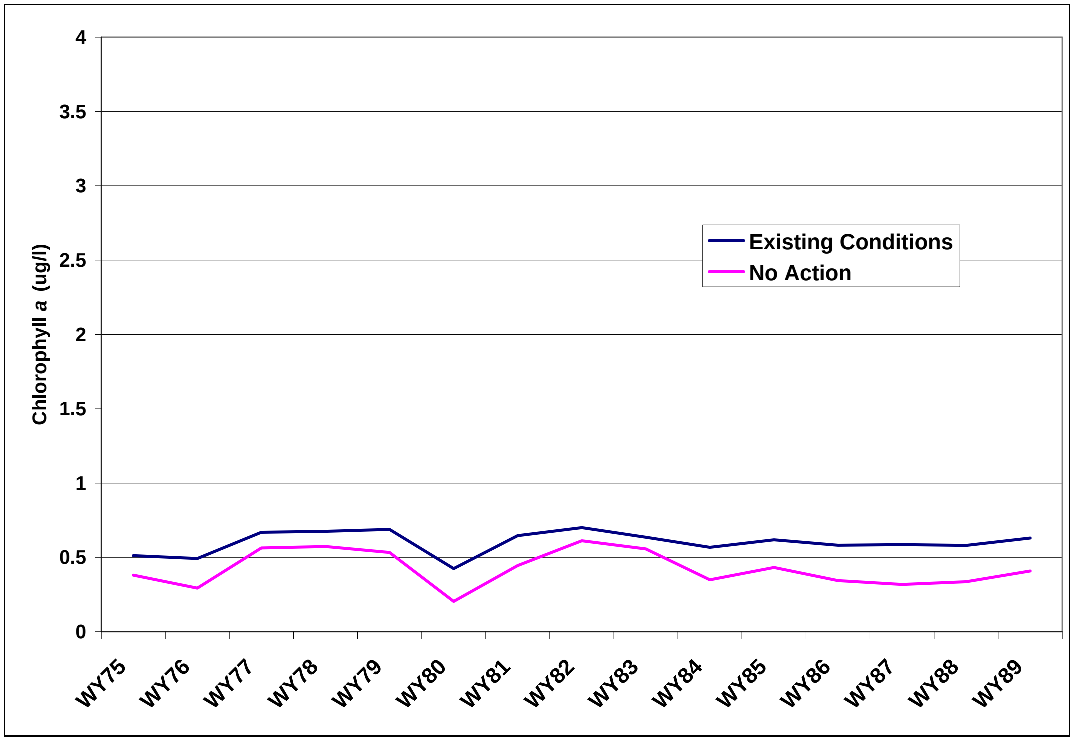


**Figure 181: Predicted Chlorophyll *a* Concentrations in Ralph Price Reservoir--Cumulative Effects**

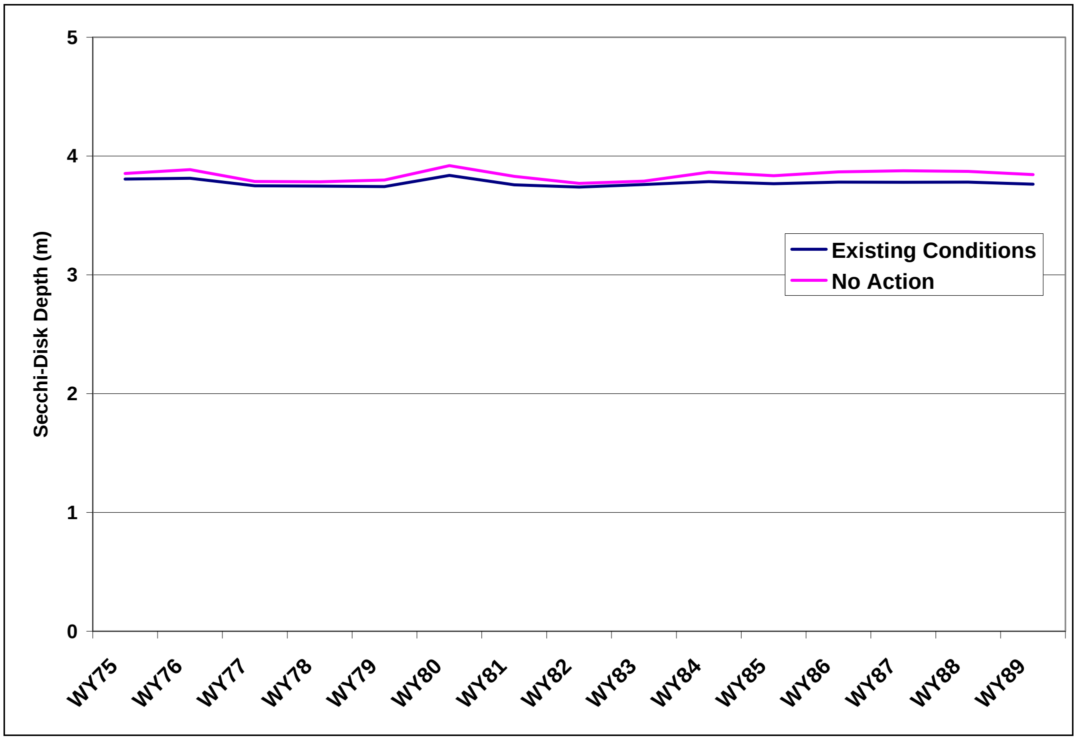


**Figure 182: Predicted Secchi-Disk Depths in Ralph Price Reservoir--Cumulative Effects**

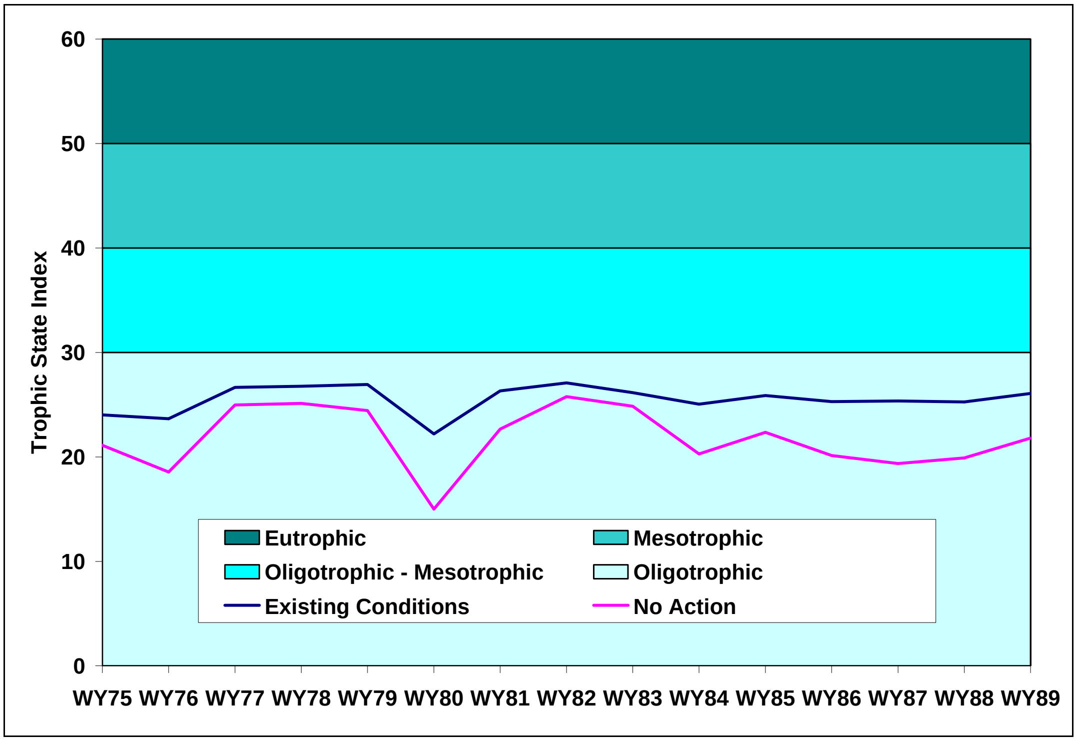


**Figure 183: Predicted Annual Trophic State Indices in Ralph Price Reservoir--Cumulative Effects**

## 12.6. Cumulative Effects - Proposed West Slope Reservoirs

### 12.6.1. Jasper East Reservoir

Jasper East Reservoir is included in Alternative 3. This alternative was not evaluated for cumulative effect impacts, but predicted water quality would be similar to that described for Rockwell Creek Reservoir described below.

### 12.6.2. Rockwell Creek Reservoir

Rockwell Creek Reservoir is included in two alternatives - Alternative 4 (Chimney Hollow with Rockwell Creek) and Alternative 5 (Dry Creek with Rockwell Creek). Anticipated in-reservoir water quality is reported in Figure 106 - Figure 110 for Alternative 5. Average predicted conditions are listed in Figure 184 - Figure 188. The reservoir is predicted to be in a mesotrophic state.

**Table 94: Average Predicted Conditions for Rockwell Creek Reservoir (Cumulative Effects Alternative 5)**

| Average Annual Values Over the 15-Year Model Period | |
|---|---|
| | Alternative 5 |
| Total Phosphorus (µg/l) | 15.1 |
| Total Nitrogen (µg/l) | 286 |
| Chlorophyll a (µg/l) | 3.0 |
| Secchi-disk Depth (m) | 3.1 |
| Trophic State (Index) | Mesotrophic (41) |

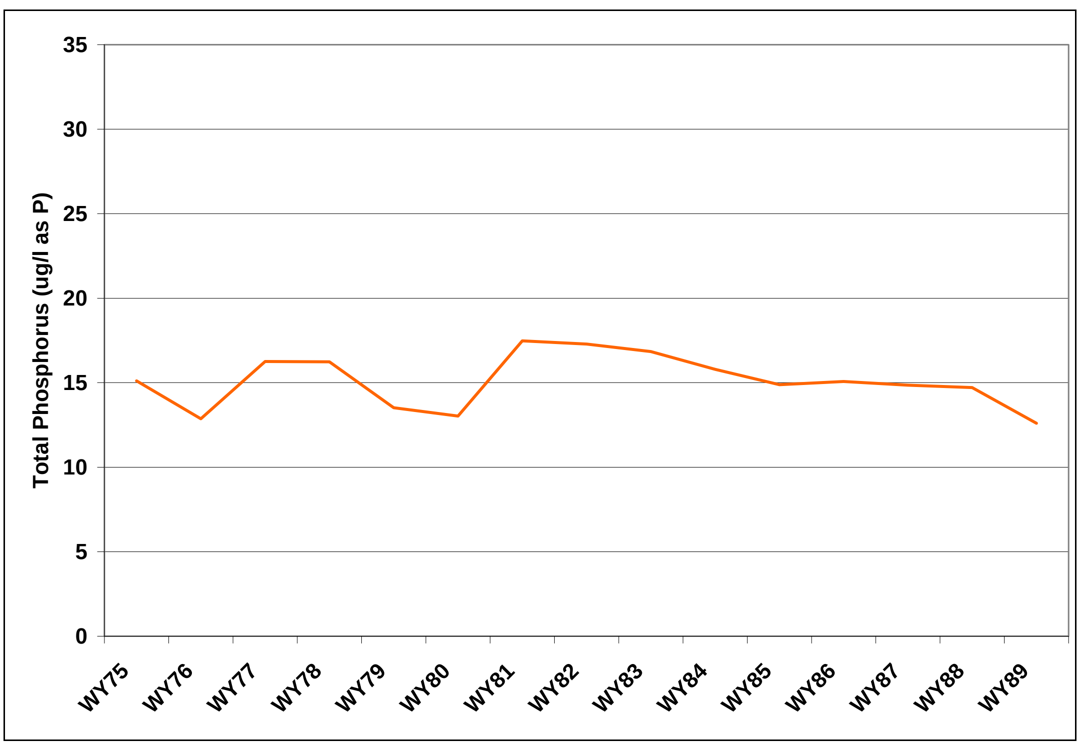


**Figure 184: Predicted Total Phosphorus Concentrations in Rockwell Creek Reservoir--Cumulative Effects**

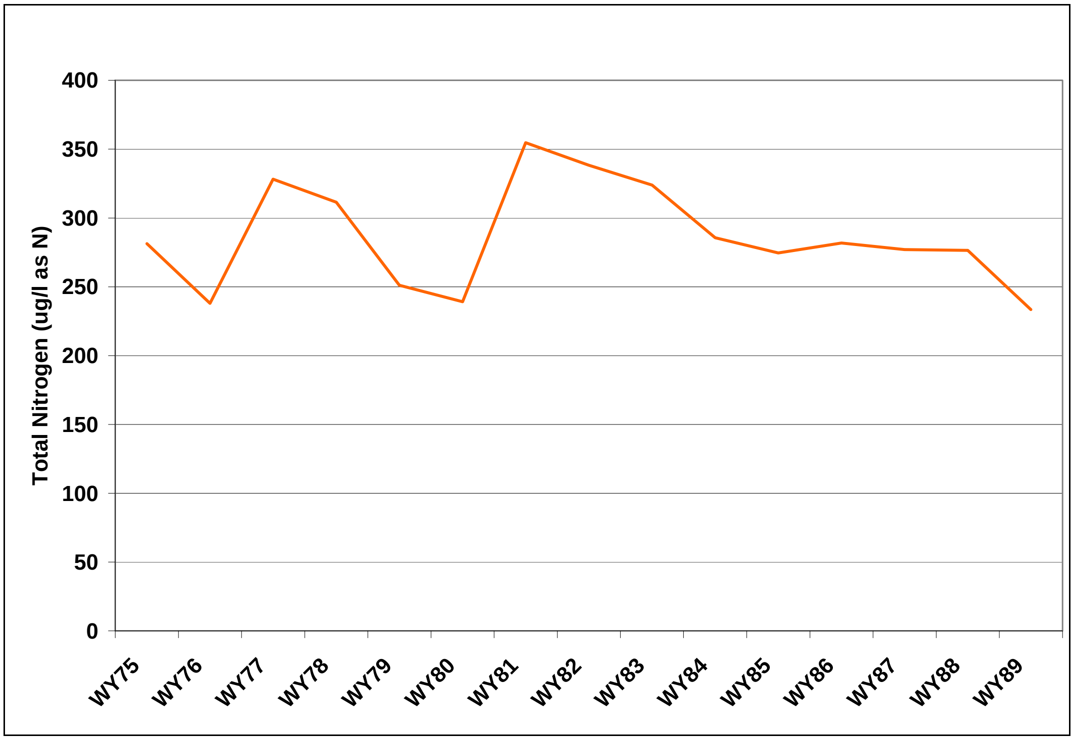


**Figure 185: Predicted Total Nitrogen Concentrations in Rockwell Creek Reservoir--Cumulative Effects**

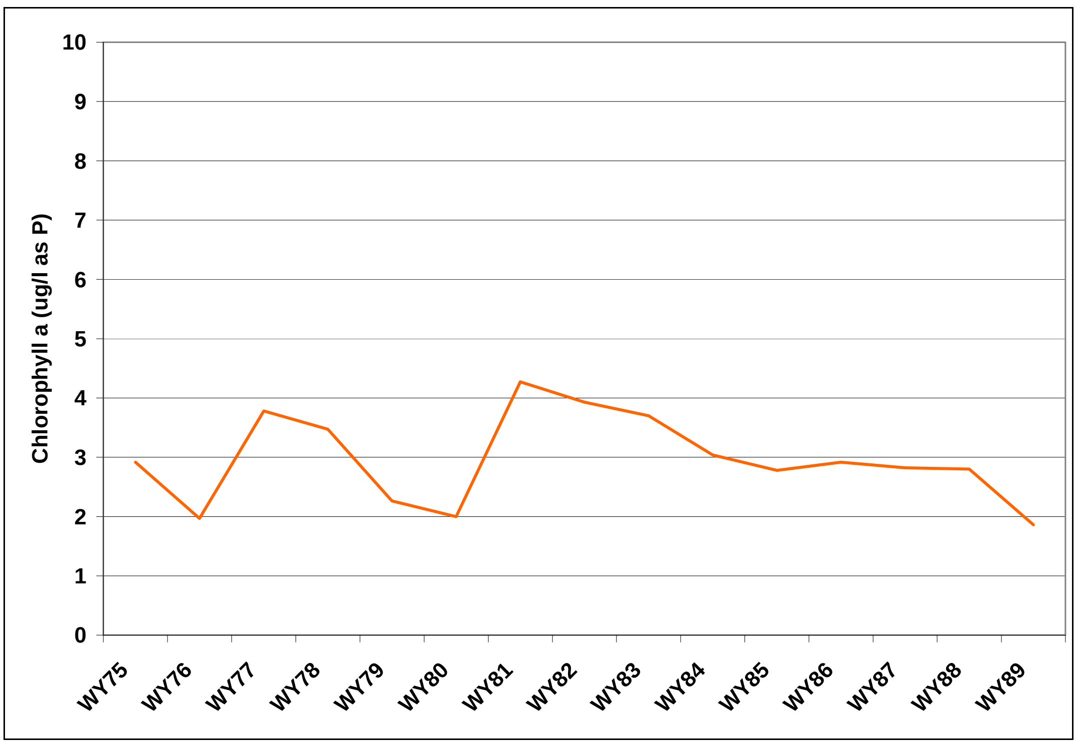


**Figure 186: Predicted Chlorophyll *a* Concentrations in Rockwell Creek Reservoir--Cumulative Effects**

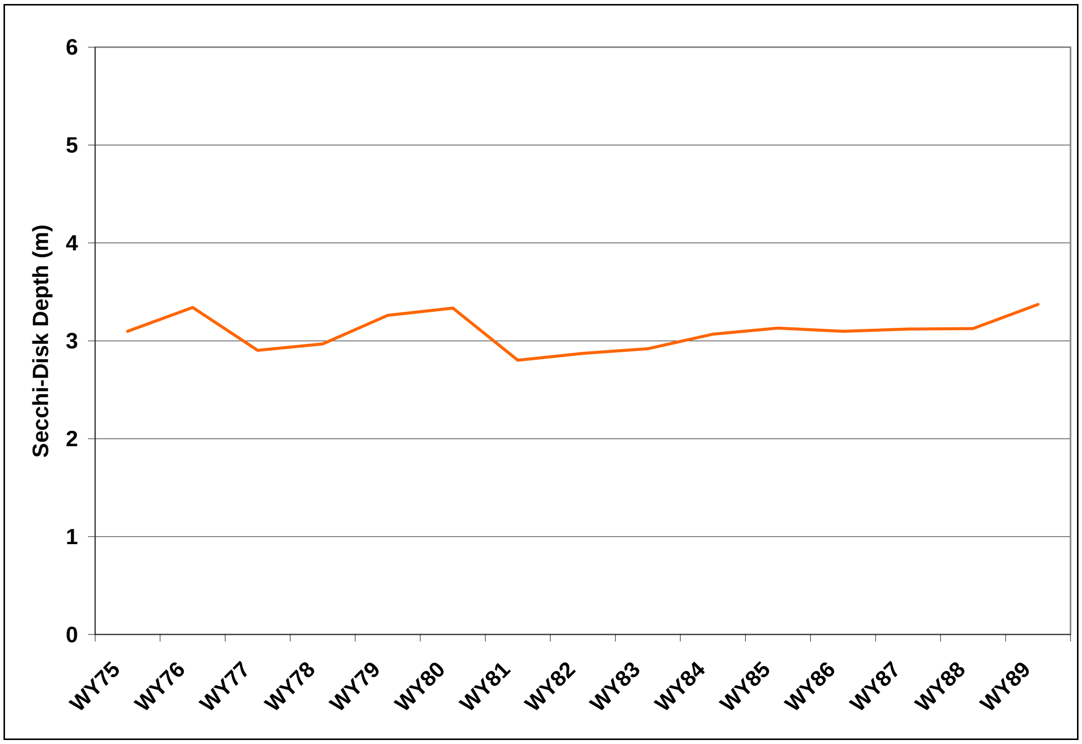


**Figure 187: Predicted Secchi-Disk Depth in Rockwell Creek Reservoir--Cumulative Effects**

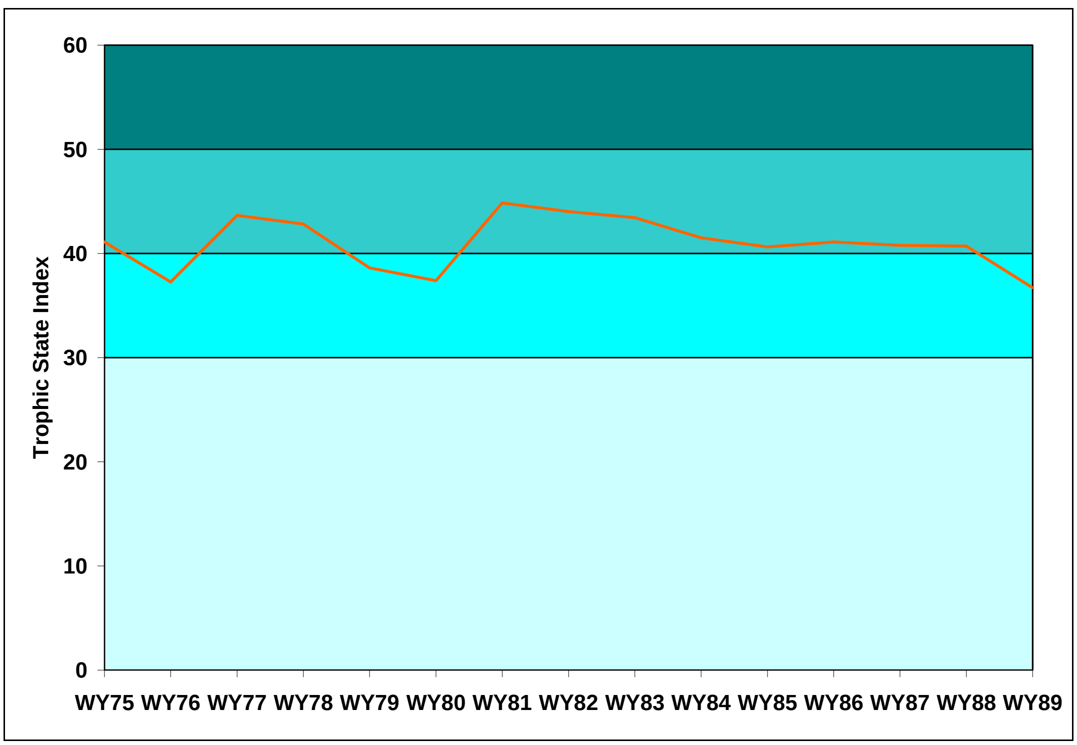


**Figure 188: Predicted Annual Trophic State Indices in Rockwell Creek Reservoir--Cumulative Effects**

**Table 95: Predicted Changes in Oxygen Demand by Alternative for Ralph Price Reservoir Relative to Existing Conditions--Cumulative Effects**

| | No Action |
|---|---|
| MOD (mg/(m³ day)) | -29% |
| HOD (mg/(m³ day)) | -39% |

# 12.7. Cumulative Effects--Proposed East Slope Reservoirs

## 12.7.1. Chimney Hollow Reservoir

Cumulative effect water-quality predictions for Chimney Hollow Reservoir under the Proposed Action alternative are summarized in Table 96. Changes over time are shown in Figure 189 - Figure 193. The reservoir is predicted to be in an oligotrophic state with low nutrient and chlorophyll *a* concentrations.

**Table 96: Average Predicted Conditions for Chimney Hollow Reservoir (Cumulative Effect Proposed Action)**

| Average Annual Values Over the 15-Year Model Period | |
|---|---|
| | Proposed Action |
| Total Phosphorus (µg/l) | 8.5 |
| Total Nitrogen (µg/l) | 185 |
| Chlorophyll *a* (µg/l) | 0.7 |
| Secchi-Disk Depth (m) | 3.7 |
| Trophic State (Index) | Oligotrophic (25) |

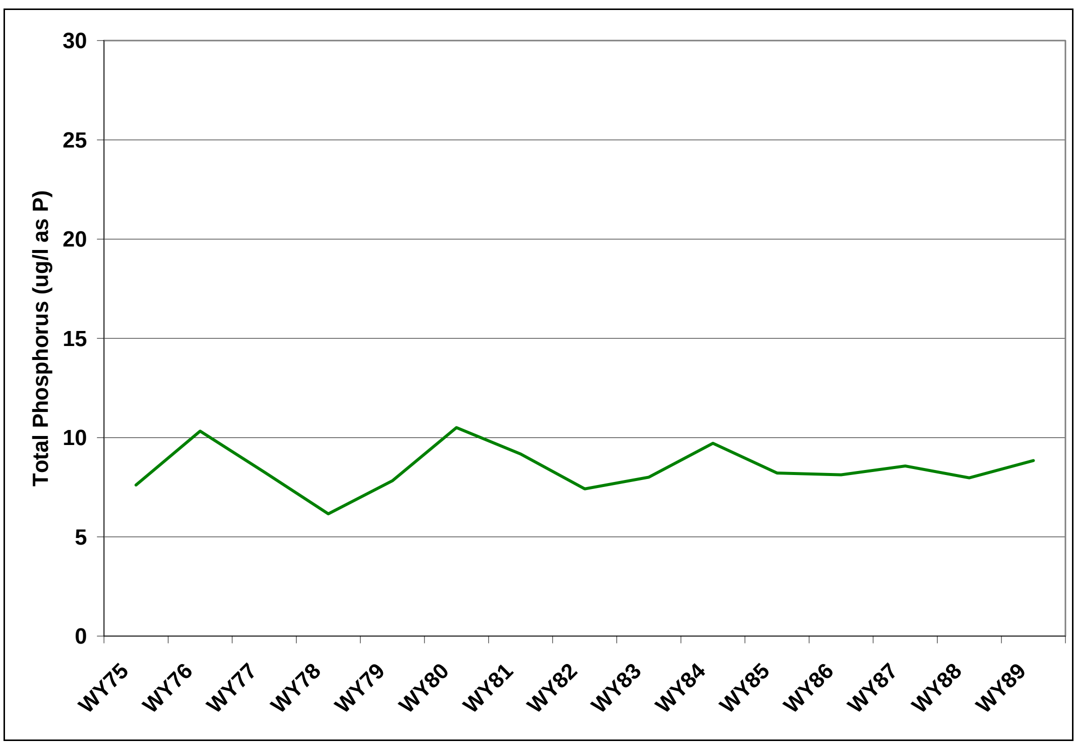


**Figure 189: Predicted Total Phosphorus Concentrations in Chimney Hollow Reservoir (Cumulative Effects Proposed Action)**

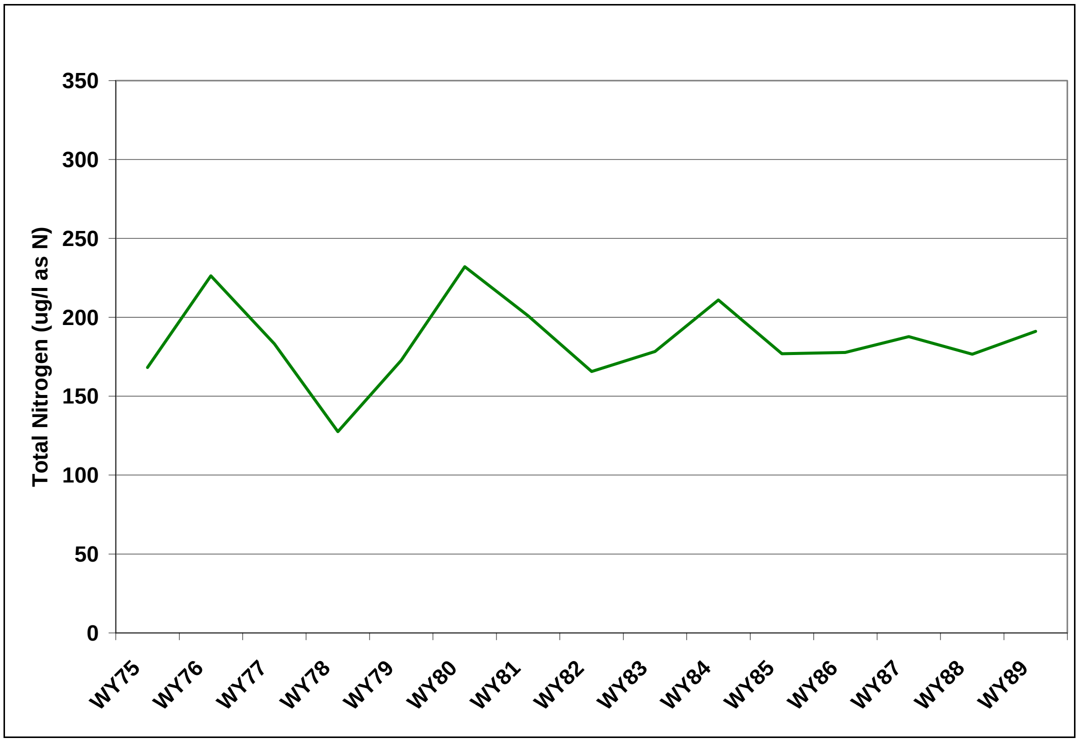


**Figure 190: Predicted Total Nitrogen Concentrations in Chimney Hollow Reservoir (Cumulative Effects Proposed Action)**

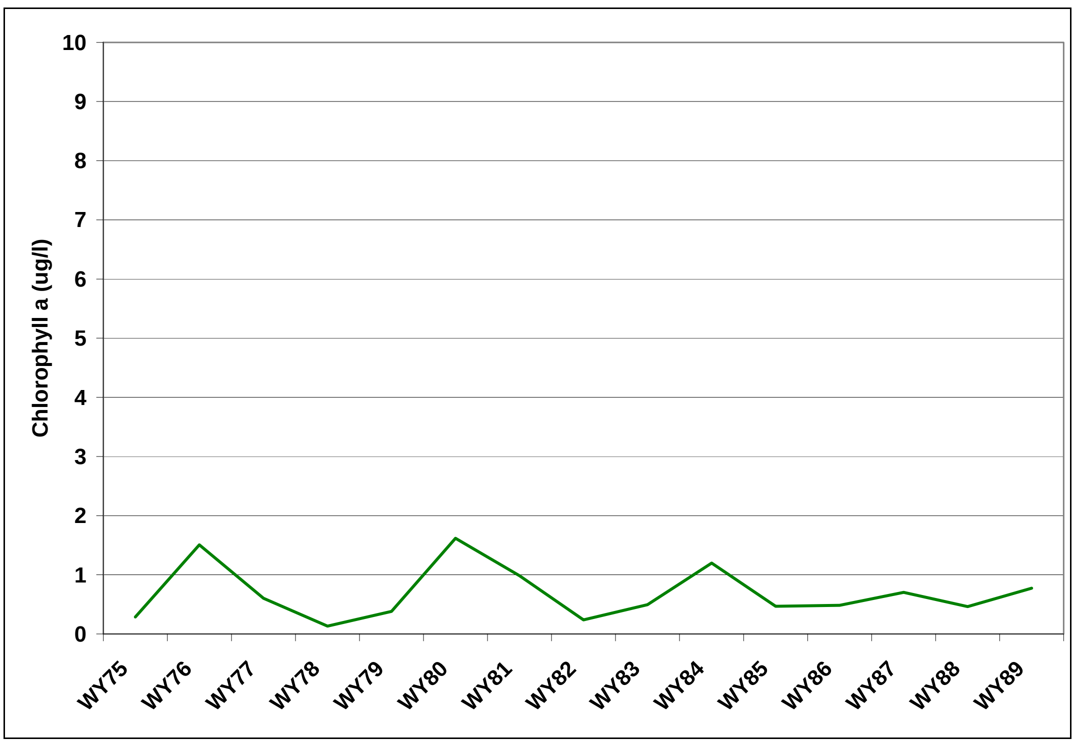


**Figure 191: Predicted Chlorophyll *a* Concentrations in Chimney Hollow Reservoir (Cumulative Effects Proposed Action)**

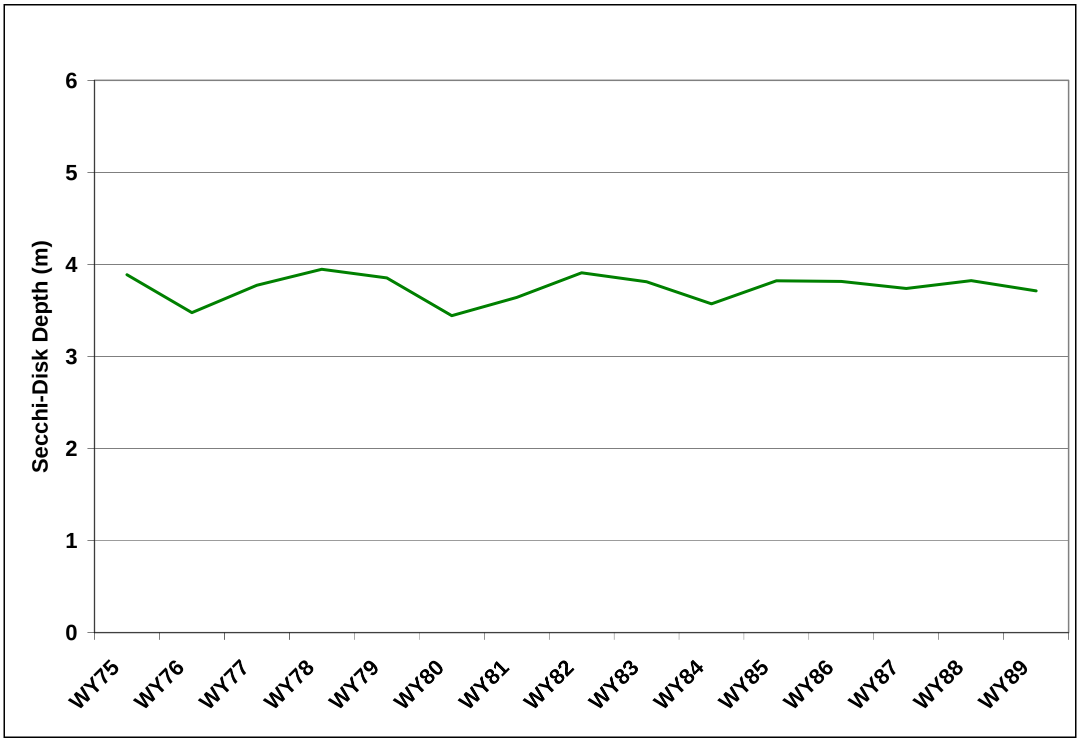


**Figure 192: Predicted Secchi-Disk Depths in Chimney Hollow Reservoir (Cumulative Effects Proposed Action)**

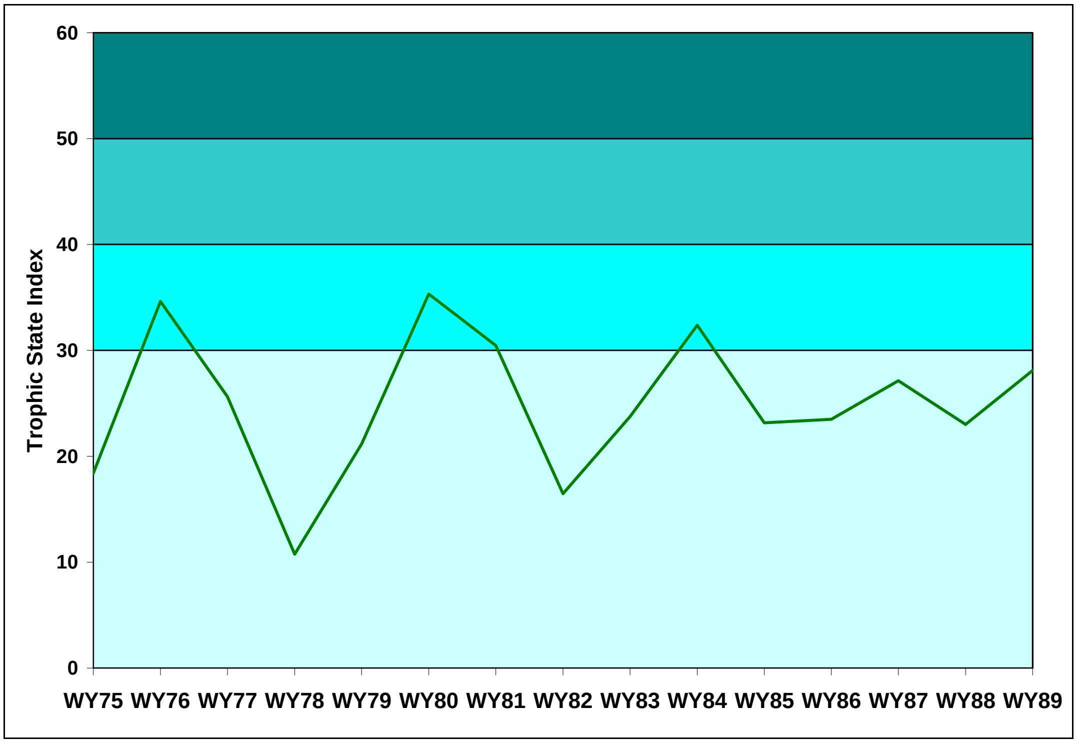


**Figure 193: Predicted Annual Trophic State Indices in Chimney Hollow Reservoir (Cumulative Effects Proposed Action)**

### 12.7.2. Dry Creek Reservoir

Dry Creek Reservoir is included in Alternative 5 (Dry Creek with Rockwell Creek). Average predicted conditions are listed in Table 97. The anticipated in-reservoir water quality conditions are reported over time in Figure 194 - Figure 198. The reservoir is predicted to be in an oligotrophic state.

**Table 97: Average Predicted Conditions for Dry Creek Reservoir (Cumulative Effects Alternative 5)**

| | Average Annual Values Over the 15-Year Model Period |
|---|---|
| Total Phosphorus (µg/l) | 9.7 |
| Total Nitrogen (µg/l) | 222 |
| Chlorophyll *a* (µg/l) | 1.3 |
| Secchi-Disk Depth (m) | 3.6 |
| Trophic State (Index) | Oligotrophic (28) |

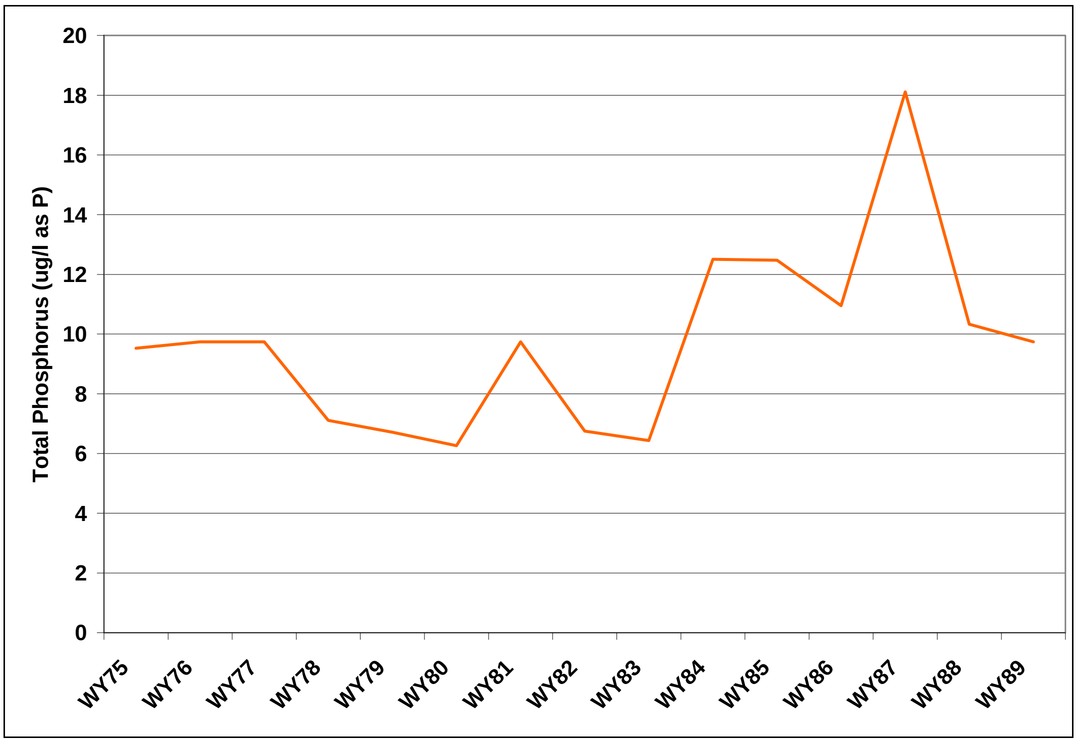


**Figure 194: Predicted Total Phosphorus Concentrations in Dry Creek Reservoir (Cumulative Effects Alternative 5)**

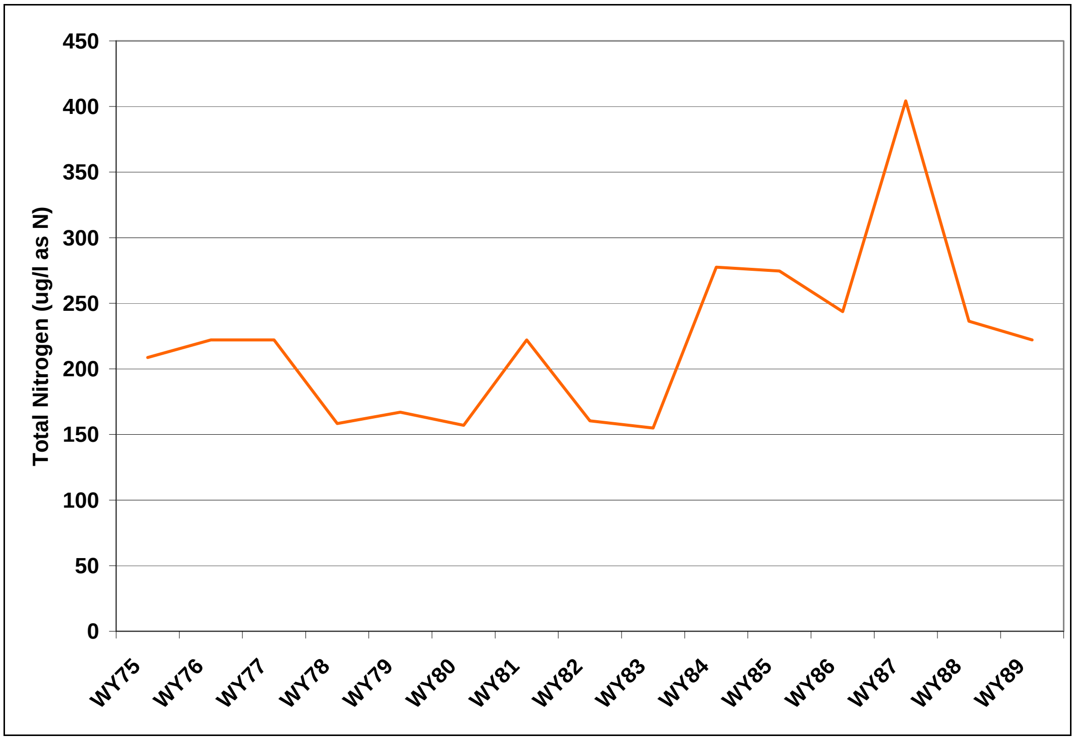


**Figure 195: Predicted Total Nitrogen Concentrations in Dry Creek Reservoir (Cumulative Effects Alternative 5)**

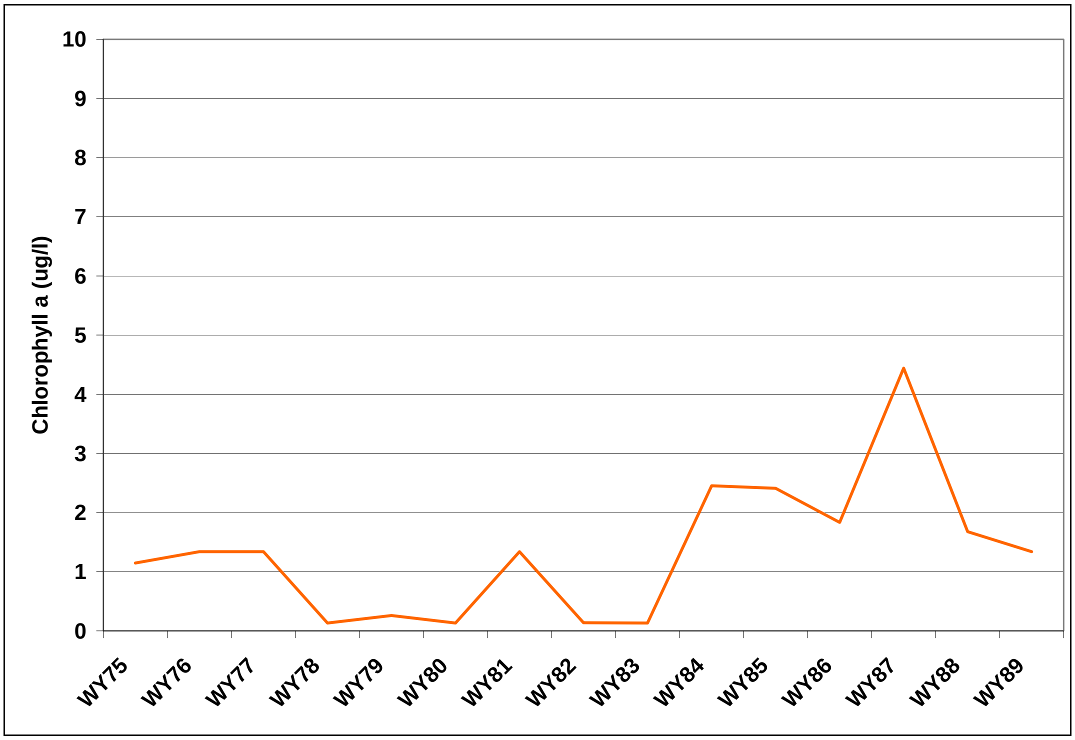


**Figure 196: Predicted Chlorophyll *a* Concentrations in Dry Creek Reservoir (Cumulative Effects Alternative 5)**

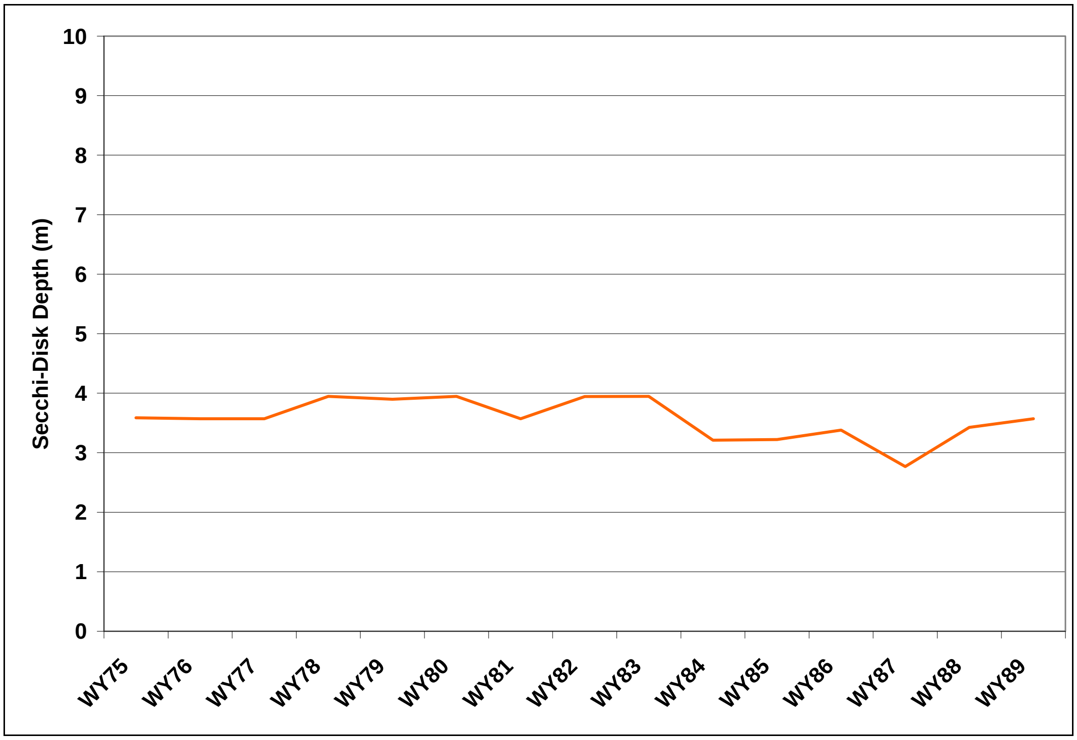


**Figure 197: Predicted Secchi-Disk Depth in Dry Creek Reservoir (Cumulative Effects Alternative 5)**

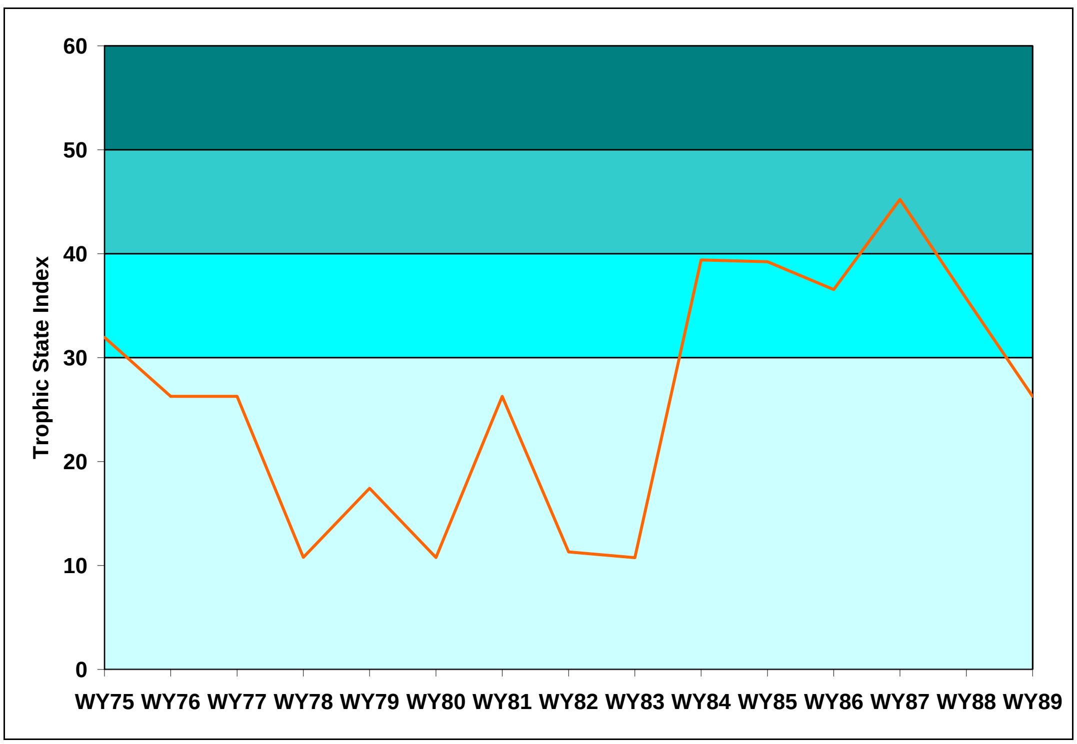


**Figure 198: Predicted Annual Trophic State Indices in Dry Creek Reservoir (Cumulative Effects Alternative 5)**

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# Appendix A: Detailed Data Summaries

## Appendix A–1: Summary of Key Water Quality Parameters for Grand Lake (Site: USGS 09013900 Grand Lake at Grand Lake, USBR Nutrient Project GL-MID)

***Epilimnion Composite Sample Data (2000 - 2004)***

| Variable | Recent Data Start | Recent Data End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | # < Reporting/ Detect Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll a, ug/l | 11/21/00 | 09/16/03 | 2.8 | 8 | 0.70 | 1.63 | 3.40 | 3.38 | 4.68 | 7.10 | 0 |
| DO, mg/l | 11/21/00 | 07/22/04 | 3.7 | 35 | 7.10 | 7.40 | 7.70 | 7.74 | 8.00 | 8.70 | 0 |
| Conductivity, uS/cm | 11/21/00 | 07/22/04 | 3.7 | 35 | 16.00 | 40.50 | 44.00 | 44.46 | 48.00 | 86.00 | 0 |
| pH, field | 11/21/00 | 07/22/04 | 3.7 | 34 | 6.50 | 6.83 | 7.10 | 7.27 | 7.48 | 8.90 | 0 |
| Temperature, deg C | 11/21/00 | 07/22/04 | 3.7 | 35 | 1.40 | 4.85 | 11.40 | 10.01 | 15.20 | 18.50 | 0 |
| Ammonia, dis, ug/l as N | 11/21/00 | 07/22/04 | 3.7 | 33 | 3.50 | 3.50 | 3.50 | 5.14 | 5.00 | 24.00 | 27 |
| Nitrate + Nitrite, dis, ug/l as N | 10/15/02 | 07/22/04 | 1.8 | 10 | 11.00 | 15.25 | 32.00 | 37.00 | 48.75 | 81.00 | 2 |
| Nitrate, dis, ug/l | 11/21/00 | 09/17/02 | 1.8 | 23 | 5.00 | 5.00 | 5.00 | 12.61 | 10.00 | 50.00 | 12 |
| TKN, ug/l as N | 11/21/00 | 11/04/03 | 3.0 | 30 | 60.00 | 160.00 | 190.00 | 198.33 | 217.50 | 350.00 | 0 |
| TP, ug/l as P | 11/21/00 | 07/22/04 | 3.7 | 33 | 6.00 | 8.00 | 9.00 | 9.39 | 11.00 | 14.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/09/01 | 07/22/04 | 3.2 | 30 | 2.00 | 3.50 | 3.50 | 3.32 | 3.50 | 3.50 | 28 |
| Silica, dis, mg/l | 11/21/00 | 07/17/02 | 1.7 | 7 | 3.61 | 4.43 | 4.75 | 4.84 | 5.32 | 6.05 | 0 |
| TOC, mg/l | 11/05/02 | 07/22/04 | 1.7 | 10 | 2.80 | 3.08 | 3.80 | 3.88 | 4.65 | 5.40 | 0 |
| DOC, mg/l | 11/21/00 | 07/22/04 | 3.7 | 25 | 2.30 | 2.90 | 3.30 | 3.26 | 3.60 | 4.10 | 0 |
| Calcium, dis, mg/l | 11/21/00 | 07/17/02 | 1.7 | 7 | 4.80 | 5.33 | 5.88 | 5.83 | 6.13 | 7.23 | 0 |
| Magnesium, dis, mg/l | 11/21/00 | 07/17/02 | 1.7 | 7 | 0.88 | 0.98 | 1.05 | 1.06 | 1.11 | 1.32 | 0 |
| Sulfate, dis, mg/l | 11/21/00 | 09/17/02 | 1.8 | 17 | 2.38 | 2.65 | 2.76 | 2.78 | 2.95 | 3.20 | 0 |
| Chloride, dis, mg/l | 11/21/00 | 09/17/02 | 1.8 | 17 | 0.24 | 0.35 | 0.37 | 0.36 | 0.39 | 0.41 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 11/21/00 | 07/17/02 | 1.7 | 7 | 15.00 | 16.00 | 18.00 | 18.29 | 20.50 | 22.00 | 0 |
| Iron, dis, ug/l | 03/03/04 | 03/03/04 | 0.0 | 1 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 0 |
| Manganese, dis, ug/l | 03/03/04 | 03/03/04 | 0.0 | 1 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0 |
| Potassium, dis, mg/l | 11/21/00 | 07/17/02 | 1.7 | 7 | 0.50 | 0.52 | 0.52 | 0.57 | 0.61 | 0.75 | 0 |
| Sodium, dis, mg/l | 11/21/00 | 07/17/02 | 1.7 | 7 | 1.36 | 1.59 | 1.70 | 1.69 | 1.79 | 2.05 | 0 |
| TSS, mg/l | 11/21/00 | 05/09/01 | 0.5 | 3 | 2.00 | 2.50 | 3.00 | 3.00 | 3.50 | 4.00 | 0 |
| Cadmium, dis, ug/l | 03/03/04 | 03/03/04 | 0.0 | 1 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 1 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Epilimnion Grab Sample Data (2000 - 2007)***

| Variable | Recent Data Start | Recent Data End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | # < Reporting/ Detect Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Secchi Disk Depth, m | 11/21/00 | 10/13/06 | 5.9 | 38 | 1.98 | 2.75 | 3.43 | 3.48 | 3.92 | 5.74 | 0 |
| Chlorophyll a, ug/l | 10/16/03 | 03/13/07 | 3.4 | 6 | 1.60 | 1.73 | 2.70 | 3.05 | 3.75 | 5.80 | 0 |
| DO, mg/l | 05/29/03 | 03/13/07 | 3.8 | 14 | 7.30 | 7.63 | 7.90 | 8.42 | 8.70 | 10.90 | 0 |
| Conductivity, uS/cm | 05/01/02 | 03/13/07 | 4.9 | 15 | 16.00 | 44.00 | 49.00 | 46.53 | 52.00 | 63.00 | 0 |
| pH, field | 05/01/02 | 03/13/07 | 4.9 | 14 | 6.40 | 6.88 | 7.30 | 7.42 | 7.80 | 8.70 | 0 |
| Temperature, deg C | 05/01/02 | 03/13/07 | 4.9 | 15 | 0.10 | 1.05 | 8.10 | 7.33 | 11.30 | 16.90 | 0 |
| Ammonia, dis, ug/l as N | 05/01/02 | 03/13/07 | 4.9 | 16 | 3.50 | 5.00 | 7.25 | 7.75 | 10.00 | 15.00 | 7 |
| Nitrate + Nitrite, dis, ug/l as N | 05/29/03 | 03/13/07 | 3.8 | 15 | 8.00 | 8.00 | 15.00 | 45.67 | 69.00 | 139.00 | 5 |
| Nitrate, dis, ug/l | 05/01/02 | 05/01/02 | 0.0 | 1 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 0 |
| TKN, ug/l as N | 05/01/02 | 10/16/03 | 1.5 | 3 | 180.00 | 190.00 | 200.00 | 200.00 | 210.00 | 220.00 | 0 |
| TP, ug/l as P | 05/01/02 | 03/13/07 | 4.9 | 16 | 5.00 | 8.00 | 9.50 | 9.44 | 10.00 | 15.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/01/02 | 03/13/07 | 4.9 | 16 | 3.00 | 3.00 | 3.00 | 3.25 | 3.50 | 4.00 | 13 |
| Silica, dis, mg/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 4.10 | 4.99 | 6.48 | 6.11 | 7.11 | 7.78 | 0 |
| TOC, mg/l | 05/29/03 | 09/08/04 | 1.3 | 4 | 3.30 | 3.60 | 3.90 | 3.85 | 4.15 | 4.30 | 0 |
| DOC, mg/l | 05/01/02 | 03/13/07 | 4.9 | 11 | 2.40 | 2.65 | 3.00 | 2.94 | 3.20 | 3.60 | 0 |
| Calcium, dis, mg/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 4.39 | 4.87 | 5.57 | 5.95 | 7.01 | 8.03 | 0 |
| Magnesium, dis, mg/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 0.82 | 0.95 | 1.06 | 1.11 | 1.29 | 1.44 | 0 |
| Sulfate, dis, mg/l | 05/01/02 | 03/13/07 | 4.9 | 7 | 2.37 | 2.74 | 2.85 | 3.03 | 3.36 | 3.82 | 0 |
| Chloride, dis, mg/l | 05/01/02 | 03/13/07 | 4.9 | 7 | 0.32 | 0.40 | 0.55 | 0.53 | 0.66 | 0.71 | 0 |
| Iron, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 12.00 | 20.75 | 29.50 | 31.67 | 40.50 | 57.00 | 0 |
| Manganese, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 0.50 | 0.55 | 1.30 | 2.58 | 2.20 | 9.60 | 0 |
| Potassium, dis, mg/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 0.45 | 0.48 | 0.54 | 0.61 | 0.75 | 0.85 | 0 |
| Sodium, dis, mg/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 1.36 | 2.08 | 2.27 | 2.18 | 2.47 | 2.62 | 0 |
| Copper, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 0.60 | 0.85 | 2.10 | 1.67 | 2.30 | 2.50 | 0 |
| Cadmium, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 4 |
| Lead, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 0.04 | 0.04 | 0.04 | 0.08 | 0.11 | 0.18 | 2 |
| Silver, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 0.05 | 0.05 | 0.10 | 0.08 | 0.10 | 0.10 | 5 |
| Zinc, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 1.20 | 2.40 | 3.30 | 3.82 | 4.00 | 8.20 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

# Appendix A–2: Summary of Key Water Quality Parameters for Grand Lake (Site: USGS 09013900 Grand Lake at Grand Lake, USBR Nutrient Project GL-MID)

***Hypolimnion Composite Sample Data (2001 - 2004)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect Limit |
| DO, mg/l | 01/23/01 | 07/22/04 | 3.5 | 32 | 3.50 | 5.43 | 5.75 | 5.74 | 6.13 | 7.40 | 0 |
| Conductivity, uS/cm | 01/23/01 | 07/22/04 | 3.5 | 32 | 25.00 | 36.00 | 41.00 | 41.31 | 48.00 | 52.00 | 0 |
| pH, field | 01/23/01 | 07/22/04 | 3.5 | 32 | 6.20 | 6.40 | 6.50 | 6.54 | 6.60 | 7.10 | 0 |
| Temperature, deg C | 01/23/01 | 07/22/04 | 3.5 | 32 | 3.10 | 3.80 | 4.25 | 4.24 | 4.55 | 6.10 | 0 |
| Ammonia, dis, ug/l as N | 01/23/01 | 07/22/04 | 3.5 | 29 | 3.50 | 3.50 | 3.50 | 4.40 | 5.00 | 7.50 | 26 |
| Nitrate + Nitrite, dis, ug/l as N | 10/15/02 | 07/22/04 | 1.8 | 9 | 80.00 | 82.00 | 87.00 | 88.78 | 95.00 | 101.00 | 0 |
| Nitrate, dis, ug/l | 01/23/01 | 09/17/02 | 1.7 | 21 | 30.00 | 60.00 | 70.00 | 67.14 | 80.00 | 80.00 | 0 |
| TKN, ug/l as N | 01/23/01 | 11/04/03 | 2.8 | 28 | 25.00 | 127.50 | 140.00 | 136.61 | 160.00 | 180.00 | 1 |
| TP, ug/l as P | 01/23/01 | 07/22/04 | 3.5 | 30 | 4.00 | 6.00 | 6.00 | 7.07 | 8.00 | 13.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/09/01 | 07/22/04 | 3.2 | 29 | 2.00 | 3.50 | 3.50 | 3.33 | 3.50 | 3.50 | 27 |
| Silica, dis, mg/l | 05/09/01 | 07/17/02 | 1.2 | 5 | 4.80 | 4.82 | 5.17 | 5.24 | 5.42 | 5.97 | 0 |
| TOC, mg/l | 11/05/02 | 07/22/04 | 1.7 | 9 | 2.60 | 3.30 | 3.70 | 3.59 | 4.00 | 4.20 | 0 |
| DOC, mg/l | 05/09/01 | 07/22/04 | 3.2 | 22 | 2.30 | 2.90 | 3.30 | 3.22 | 3.50 | 3.70 | 0 |
| Calcium, dis, mg/l | 05/09/01 | 07/17/02 | 1.2 | 5 | 4.77 | 5.05 | 5.64 | 5.66 | 6.19 | 6.63 | 0 |
| Magnesium, dis, mg/l | 05/09/01 | 07/17/02 | 1.2 | 5 | 0.84 | 0.92 | 1.03 | 1.03 | 1.17 | 1.20 | 0 |
| Sulfate, dis, mg/l | 05/09/01 | 09/17/02 | 1.4 | 15 | 2.37 | 2.67 | 2.88 | 2.76 | 2.92 | 3.03 | 0 |
| Chloride, dis, mg/l | 05/09/01 | 09/17/02 | 1.4 | 15 | 0.27 | 0.34 | 0.39 | 0.38 | 0.42 | 0.45 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 05/09/01 | 07/17/02 | 1.2 | 5 | 15.00 | 16.00 | 18.00 | 17.80 | 18.00 | 22.00 | 0 |
| Iron, dis, ug/l | 03/03/04 | 03/03/04 | 0.0 | 1 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 0 |
| Manganese, dis, ug/l | 03/03/04 | 03/03/04 | 0.0 | 1 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0 |
| Potassium, dis, mg/l | 05/09/01 | 07/17/02 | 1.2 | 5 | 0.49 | 0.55 | 0.60 | 0.60 | 0.69 | 0.69 | 0 |
| Sodium, dis, mg/l | 05/09/01 | 07/17/02 | 1.2 | 5 | 1.34 | 1.51 | 1.68 | 1.67 | 1.89 | 1.94 | 0 |
| TSS, mg/l | 01/23/01 | 01/23/01 | 0.0 | 1 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 0 |
| Cadmium, dis, ug/l | 03/03/04 | 03/03/04 | 0.0 | 1 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 1 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Sample Data (2000 - 2007)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect Limit |
| DO, mg/l | 11/21/00 | 03/13/07 | 6.3 | 16 | 1.20 | 2.45 | 3.20 | 3.39 | 4.55 | 6.50 | 0 |
| Conductivity, uS/cm | 11/21/00 | 03/13/07 | 6.3 | 16 | 34.00 | 43.00 | 49.00 | 51.19 | 60.25 | 75.00 | 0 |
| pH, field | 11/21/00 | 03/13/07 | 6.3 | 14 | 6.20 | 6.50 | 6.70 | 6.74 | 6.90 | 7.60 | 0 |
| Temperature, deg C | 11/21/00 | 03/13/07 | 6.3 | 16 | 3.40 | 4.00 | 4.00 | 3.95 | 4.00 | 4.10 | 0 |
| Ammonia, dis, ug/l as N | 11/21/00 | 03/13/07 | 6.3 | 19 | 3.50 | 5.00 | 5.00 | 6.32 | 7.75 | 14.00 | 16 |
| Nitrate + Nitrite, dis, ug/l as N | 05/29/03 | 03/13/07 | 3.8 | 16 | 8.00 | 109.25 | 126.50 | 119.69 | 144.50 | 161.00 | 1 |
| Nitrate, dis, ug/l | 11/21/00 | 05/01/02 | 1.4 | 3 | 40.00 | 60.00 | 80.00 | 73.33 | 90.00 | 100.00 | 0 |
| TKN, ug/l as N | 11/21/00 | 10/16/03 | 2.9 | 5 | 120.00 | 160.00 | 170.00 | 180.00 | 210.00 | 240.00 | 0 |
| TP, ug/l as P | 11/21/00 | 03/13/07 | 6.3 | 19 | 5.00 | 7.00 | 9.00 | 12.16 | 15.50 | 32.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/01/02 | 03/13/07 | 4.9 | 17 | 3.00 | 3.00 | 3.00 | 3.53 | 4.00 | 5.00 | 11 |
| Silica, dis, mg/l | 11/21/00 | 03/13/07 | 6.3 | 8 | 5.62 | 6.34 | 6.56 | 6.53 | 6.75 | 7.24 | 0 |
| TOC, mg/l | 05/29/03 | 09/08/04 | 1.3 | 5 | 3.30 | 3.50 | 3.70 | 3.92 | 4.20 | 4.90 | 0 |
| DOC, mg/l | 11/21/00 | 03/13/07 | 6.3 | 14 | 2.80 | 3.00 | 3.10 | 3.11 | 3.20 | 3.50 | 0 |
| Calcium, dis, mg/l | 11/21/00 | 03/13/07 | 6.3 | 8 | 5.30 | 6.41 | 6.91 | 6.72 | 7.18 | 7.42 | 0 |
| Magnesium, dis, mg/l | 11/21/00 | 03/13/07 | 6.3 | 8 | 0.97 | 1.21 | 1.31 | 1.25 | 1.32 | 1.33 | 0 |
| Sulfate, dis, mg/l | 11/21/00 | 03/13/07 | 6.3 | 9 | 2.50 | 2.98 | 3.46 | 3.26 | 3.50 | 3.69 | 0 |
| Chloride, dis, mg/l | 11/21/00 | 03/13/07 | 6.3 | 9 | 0.34 | 0.39 | 0.68 | 0.59 | 0.74 | 0.75 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 11/21/00 | 03/01/01 | 0.3 | 2 | 17.00 | 17.25 | 17.50 | 17.50 | 17.75 | 18.00 | 0 |
| Iron, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 6 | 7.00 | 9.50 | 13.00 | 21.00 | 31.50 | 47.00 | 0 |
| Manganese, dis, ug/l | 09/08/04 | 03/13/07 | 2.5 | 7 | 1.70 | 5.25 | 17.30 | 28.33 | 39.35 | 90.10 | 0 |
| Potassium, dis, mg/l | 11/21/00 | 03/13/07 | 6.3 | 8 | 0.56 | 0.71 | 0.76 | 0.75 | 0.80 | 0.89 | 0 |
| Sodium, dis, mg/l | 11/21/00 | 03/13/07 | 6.3 | 8 | 1.45 | 2.11 | 2.27 | 2.15 | 2.33 | 2.40 | 0 |
| Copper, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 0.66 | 0.70 | 1.50 | 1.43 | 1.90 | 2.40 | 0 |
| Cadmium, dis, ug/l | 09/08/04 | 03/13/07 | 2.5 | 7 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.07 | 5 |
| Lead, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 0.04 | 0.06 | 0.08 | 0.08 | 0.08 | 0.12 | 1 |
| Silver, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 0.05 | 0.05 | 0.10 | 0.08 | 0.10 | 0.10 | 5 |
| Zinc, dis, ug/l | 01/12/05 | 03/13/07 | 2.2 | 5 | 0.70 | 0.93 | 3.00 | 4.05 | 5.30 | 10.30 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

# Appendix A–3: Summary of Key Water Quality Parameters for Shadow Mountain Lake (USGS 09014500 Shadow Mountain Lake near Grand Lake, USBR Nutrient Project SM-DAM)

***Epilimnion Grab Sample Data (2000 - 2007)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th | Med | Mean | 75th | Max | Reporting/ |
| Secchi Disk Depth, m | 05/25/00 | 10/12/06 | 6.4 | 57 | 0.97 | 1.98 | 2.44 | 2.40 | 2.79 | 3.95 | 0 |
| Chlorophyll a, ug/l | 05/25/00 | 07/24/07 | 7.2 | 54 | 0.50 | 2.18 | 3.40 | 5.13 | 5.70 | 35.40 | 0 |
| DO, mg/l | 05/25/00 | 03/12/07 | 6.8 | 13 | 6.10 | 7.10 | 8.00 | 7.92 | 8.70 | 9.60 | 0 |
| Conductivity, uS/cm | 05/25/00 | 03/12/07 | 6.8 | 12 | 40.00 | 48.75 | 65.50 | 62.58 | 67.25 | 94.00 | 0 |
| pH, field | 05/25/00 | 03/12/07 | 6.8 | 13 | 7.10 | 7.40 | 7.50 | 7.66 | 8.00 | 8.40 | 0 |
| Temperature, deg C | 05/25/00 | 03/12/07 | 6.8 | 13 | 1.20 | 2.30 | 8.50 | 7.78 | 10.70 | 16.00 | 0 |
| Ammonia, dis, ug/l as N | 05/25/00 | 03/12/07 | 6.8 | 28 | 1.00 | 2.75 | 5.00 | 8.18 | 10.50 | 24.00 | 10 |
| Nitrate + Nitrite, dis, ug/l as N | 05/25/00 | 03/12/07 | 6.8 | 28 | 1.50 | 8.00 | 17.00 | 25.02 | 32.50 | 114.00 | 6 |
| TKN, ug/l as N | 05/25/00 | 10/09/06 | 6.4 | 17 | 76.00 | 216.00 | 258.00 | 243.47 | 280.00 | 393.00 | 0 |
| TP, ug/l as P | 05/25/00 | 03/12/07 | 6.8 | 28 | 4.00 | 11.75 | 15.00 | 15.50 | 18.25 | 27.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/25/00 | 03/12/07 | 6.8 | 27 | 0.50 | 0.50 | 2.00 | 2.15 | 3.00 | 5.00 | 7 |
| Silica, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 5.37 | 5.60 | 6.55 | 6.45 | 7.06 | 7.76 | 0 |
| TOC, mg/l | 05/25/00 | 10/09/06 | 6.4 | 14 | 1.40 | 2.10 | 2.85 | 2.93 | 3.40 | 5.90 | 0 |
| DOC, mg/l | 01/11/05 | 03/12/07 | 2.2 | 6 | 3.10 | 3.20 | 3.25 | 3.52 | 3.38 | 4.90 | 0 |
| Calcium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 5.82 | 6.79 | 8.00 | 7.69 | 8.42 | 8.80 | 0 |
| Magnesium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 1.23 | 1.28 | 1.50 | 1.44 | 1.53 | 1.56 | 0 |
| Sulfate, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 2.20 | 2.70 | 3.79 | 3.42 | 3.86 | 4.12 | 0 |
| Chloride, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 0.35 | 0.46 | 0.78 | 0.68 | 0.83 | 0.92 | 0 |
| Iron, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 12.00 | 15.00 | 17.00 | 27.00 | 23.00 | 102.00 | 0 |
| Manganese, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 0.50 | 1.10 | 2.20 | 2.88 | 5.10 | 6.90 | 1 |
| Potassium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 0.70 | 0.73 | 0.80 | 0.81 | 0.84 | 0.96 | 0 |
| Sodium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 1.67 | 1.89 | 2.67 | 2.42 | 2.79 | 2.86 | 0 |
| TSS, mg/l | 05/19/05 | 10/09/06 | 1.4 | 14 | 2.00 | 2.25 | 3.78 | 4.28 | 4.33 | 12.50 | 0 |
| Copper, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 7 | 0.50 | 0.74 | 1.00 | 2.10 | 3.30 | 5.10 | 2 |
| Cadmium, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 0.02 | 0.02 | 0.02 | 0.03 | 0.05 | 0.05 | 8 |
| Lead, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 8 | 0.04 | 0.06 | 0.16 | 6.43 | 0.50 | 50.00 | 5 |
| Silver, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 8 | 0.05 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 | 8 |
| Zinc, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 8 | 0.50 | 0.95 | 1.25 | 4.10 | 6.48 | 12.90 | 3 |
| Nitrite, dis, mg/l | 05/25/00 | 09/28/00 | 0.3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 3 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Sample Data (2000 - 2007)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect |
| DO, mg/l | 05/25/00 | 03/12/07 | 6.8 | 14 | 3.90 | 5.78 | 7.40 | 7.01 | 8.55 | 9.50 | 0 |
| Conductivity, uS/cm | 05/25/00 | 03/12/07 | 6.8 | 13 | 34.00 | 47.00 | 65.00 | 59.31 | 67.00 | 79.00 | 0 |
| pH, field | 05/25/00 | 03/12/07 | 6.8 | 14 | 6.80 | 7.23 | 7.40 | 7.46 | 7.68 | 8.20 | 0 |
| Temperature, deg C | 05/25/00 | 03/12/07 | 6.8 | 14 | 1.80 | 3.13 | 8.30 | 6.98 | 9.28 | 12.30 | 0 |
| Ammonia, dis, ug/l as N | 05/25/00 | 03/12/07 | 6.8 | 25 | 1.50 | 5.00 | 6.00 | 8.38 | 11.00 | 28.00 | 8 |
| Nitrate + Nitrite, dis, ug/l as N | 05/25/00 | 03/12/07 | 6.8 | 25 | 1.50 | 8.00 | 20.00 | 22.52 | 33.00 | 56.00 | 4 |
| TKN, ug/l as N | 05/25/00 | 10/09/06 | 6.4 | 13 | 170.00 | 220.00 | 230.00 | 240.15 | 260.00 | 367.00 | 0 |
| TP, ug/l as P | 05/25/00 | 03/12/07 | 6.8 | 25 | 8.00 | 13.00 | 17.00 | 16.72 | 20.00 | 28.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/25/00 | 03/12/07 | 6.8 | 24 | 0.50 | 1.00 | 3.00 | 2.52 | 3.00 | 5.00 | 9 |
| Silica, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 2.12 | 5.56 | 5.62 | 5.96 | 7.04 | 7.84 | 0 |
| TOC, mg/l | 05/25/00 | 10/09/06 | 6.4 | 14 | 1.60 | 2.03 | 2.80 | 2.95 | 3.40 | 6.80 | 0 |
| DOC, mg/l | 01/11/05 | 03/12/07 | 2.2 | 6 | 3.20 | 3.23 | 3.30 | 3.37 | 3.38 | 3.80 | 0 |
| Calcium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 5.38 | 6.84 | 8.03 | 7.63 | 8.43 | 8.50 | 0 |
| Magnesium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 1.19 | 1.28 | 1.50 | 1.42 | 1.52 | 1.53 | 0 |
| Sulfate, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 2.20 | 2.60 | 3.81 | 3.41 | 3.87 | 4.13 | 0 |
| Chloride, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 0.28 | 0.46 | 0.78 | 0.68 | 0.83 | 0.92 | 0 |
| Iron, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 23 | 12.00 | 20.00 | 40.00 | 57.39 | 65.00 | 220.00 | 0 |
| Manganese, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 24 | 0.50 | 5.00 | 7.00 | 18.42 | 10.58 | 210.00 | 4 |
| Potassium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 0.64 | 0.79 | 0.79 | 0.80 | 0.84 | 0.95 | 0 |
| Sodium, dis, mg/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 1.47 | 1.87 | 2.71 | 2.41 | 2.78 | 2.86 | 0 |
| Copper, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 8 | 0.50 | 0.58 | 0.96 | 1.82 | 2.40 | 5.00 | 3 |
| Cadmium, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 10 | 0.02 | 0.02 | 0.02 | 0.03 | 0.05 | 0.05 | 9 |
| Lead, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 8 | 0.04 | 0.08 | 0.32 | 6.49 | 0.52 | 50.00 | 5 |
| Silver, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 8 | 0.05 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 | 8 |
| Zinc, dis, ug/l | 05/25/00 | 03/12/07 | 6.8 | 9 | 0.50 | 1.10 | 2.20 | 3.70 | 5.00 | 10.00 | 3 |
| Nitrite, dis, mg/l | 05/25/00 | 09/28/00 | 0.3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 3 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Full Composite Data (2001 - 2004)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th | Med | Mean | 75th | Max | Reporting/ |
| DO, mg/l | 01/22/01 | 09/08/04 | 3.6 | 39 | 4.70 | 6.90 | 7.60 | 7.53 | 8.20 | 9.60 | 0 |
| Conductivity, uS/cm | 01/22/01 | 09/08/04 | 3.6 | 39 | 23.00 | 48.00 | 54.00 | 53.36 | 58.50 | 83.00 | 0 |
| pH, field | 01/22/01 | 09/08/04 | 3.6 | 37 | 6.50 | 7.00 | 7.10 | 7.24 | 7.40 | 8.50 | 0 |
| Temperature, deg C | 01/22/01 | 09/08/04 | 3.6 | 39 | 1.40 | 6.85 | 10.00 | 10.07 | 14.85 | 19.70 | 0 |
| Ammonia, dis, ug/l as N | 01/22/01 | 09/08/04 | 3.6 | 35 | 3.50 | 3.50 | 3.50 | 5.04 | 5.00 | 12.00 | 31 |
| Nitrate + Nitrite, dis, ug/l as N | 10/15/02 | 09/08/04 | 1.9 | 14 | 6.00 | 8.00 | 11.00 | 26.93 | 17.25 | 133.00 | 7 |
| Nitrate, dis, ug/l | 01/22/01 | 09/17/02 | 1.7 | 22 | 5.00 | 5.00 | 5.00 | 6.82 | 5.00 | 20.00 | 18 |
| TKN, ug/l as N | 01/22/01 | 11/04/03 | 2.8 | 32 | 120.00 | 180.00 | 210.00 | 212.81 | 242.50 | 310.00 | 0 |
| TP, ug/l as P | 01/22/01 | 09/08/04 | 3.6 | 37 | 8.00 | 13.00 | 15.00 | 15.70 | 19.00 | 29.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/08/01 | 09/08/04 | 3.3 | 35 | 1.00 | 3.25 | 3.50 | 3.40 | 3.50 | 6.00 | 32 |
| Silica, dis, mg/l | 02/28/01 | 07/17/02 | 1.4 | 6 | 4.26 | 4.90 | 5.21 | 5.23 | 5.43 | 6.41 | 0 |
| TOC, mg/l | 11/05/02 | 09/08/04 | 1.8 | 14 | 3.20 | 4.20 | 4.40 | 4.90 | 5.13 | 8.70 | 0 |
| DOC, mg/l | 02/28/01 | 09/08/04 | 3.5 | 29 | 2.50 | 3.10 | 3.50 | 3.50 | 3.70 | 5.00 | 0 |
| Calcium, dis, mg/l | 02/28/01 | 07/17/02 | 1.4 | 6 | 6.82 | 7.04 | 7.24 | 7.28 | 7.57 | 7.70 | 0 |
| Magnesium, dis, mg/l | 02/28/01 | 07/17/02 | 1.4 | 6 | 1.20 | 1.24 | 1.31 | 1.30 | 1.36 | 1.39 | 0 |
| Sulfate, dis, mg/l | 02/28/01 | 09/17/02 | 1.6 | 17 | 3.05 | 3.17 | 3.20 | 3.23 | 3.31 | 3.39 | 0 |
| Chloride, dis, mg/l | 02/28/01 | 09/17/02 | 1.6 | 17 | 0.35 | 0.43 | 0.44 | 0.44 | 0.45 | 0.52 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 02/28/01 | 07/17/02 | 1.4 | 6 | 22.00 | 22.25 | 23.50 | 23.67 | 24.00 | 27.00 | 0 |
| Iron, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 28.00 | 0 |
| Manganese, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 0 |
| Potassium, dis, mg/l | 02/28/01 | 07/17/02 | 1.4 | 6 | 0.63 | 0.65 | 0.69 | 0.72 | 0.74 | 0.89 | 0 |
| Sodium, dis, mg/l | 02/28/01 | 07/17/02 | 1.4 | 6 | 1.85 | 1.89 | 1.99 | 2.01 | 2.13 | 2.19 | 0 |
| TSS, mg/l | 01/22/01 | 05/08/01 | 0.3 | 2 | 3.00 | 3.25 | 3.50 | 3.50 | 3.75 | 4.00 | 0 |
| Cadmium, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

# Appendix A–4: Summary of Key Water Quality Parameters for Granby Reservoir (Site: USGS 09018500 Lake Granby Near Granby, USBR Nutrient Project GR-DAM)

***Epilimnion Composite Sample Data (2000 - 2007)***

| | Recent Data | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | # < Reporting/ Detect Limit |
| Chlorophyll a, ug/l | 11/20/00 | 07/24/07 | 6.7 | 28 | 1.00 | 3.13 | 4.20 | 5.44 | 6.70 | 15.50 | 0 |
| DO, mg/l | 11/20/00 | 03/02/04 | 3.3 | 34 | 6.20 | 6.83 | 7.25 | 7.71 | 8.18 | 11.90 | 0 |
| Conductivity, uS/cm | 11/20/00 | 03/02/04 | 3.3 | 34 | 37.00 | 50.25 | 54.00 | 55.44 | 57.75 | 96.00 | 0 |
| pH, field | 11/20/00 | 03/02/04 | 3.3 | 34 | 6.50 | 7.10 | 7.30 | 7.38 | 7.58 | 8.20 | 0 |
| Temperature, deg C | 11/20/00 | 03/02/04 | 3.3 | 34 | 0.40 | 5.20 | 11.85 | 11.04 | 17.20 | 19.20 | 0 |
| Ammonia, dis, ug/l as N | 11/20/00 | 03/02/04 | 3.3 | 31 | 3.50 | 3.50 | 3.50 | 5.63 | 5.00 | 24.00 | 25 |
| Nitrate + Nitrite, dis, ug/l as N | 10/15/02 | 03/02/04 | 1.4 | 8 | 11.00 | 11.00 | 22.50 | 29.38 | 40.75 | 68.00 | 3 |
| Nitrate, dis, ug/l | 11/20/00 | 09/04/02 | 1.8 | 23 | 5.00 | 5.00 | 5.00 | 5.43 | 5.00 | 10.00 | 21 |
| TKN, ug/l as N | 11/20/00 | 11/04/03 | 3.0 | 30 | 80.00 | 170.00 | 185.00 | 193.67 | 217.50 | 270.00 | 0 |
| TP, ug/l as P | 11/20/00 | 03/02/04 | 3.3 | 33 | 3.00 | 8.00 | 11.00 | 11.18 | 14.00 | 22.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/08/01 | 03/02/04 | 2.8 | 29 | 3.00 | 3.50 | 3.50 | 3.60 | 3.50 | 7.00 | 26 |
| Silica, dis, mg/l | 11/20/00 | 07/16/02 | 1.7 | 7 | 4.27 | 4.88 | 5.10 | 5.01 | 5.27 | 5.41 | 0 |
| TOC, mg/l | 11/05/02 | 03/02/04 | 1.3 | 8 | 2.60 | 3.98 | 4.50 | 4.25 | 4.85 | 5.10 | 0 |
| DOC, mg/l | 11/20/00 | 03/02/04 | 3.3 | 24 | 2.50 | 2.90 | 3.30 | 3.38 | 3.75 | 4.80 | 0 |
| Calcium, dis, mg/l | 11/20/00 | 07/16/02 | 1.7 | 7 | 6.62 | 6.86 | 7.00 | 7.13 | 7.46 | 7.68 | 0 |
| Magnesium, dis, mg/l | 11/20/00 | 07/16/02 | 1.7 | 7 | 1.16 | 1.20 | 1.24 | 1.24 | 1.28 | 1.31 | 0 |
| Sulfate, dis, mg/l | 11/20/00 | 09/04/02 | 1.8 | 17 | 2.89 | 3.13 | 3.17 | 3.15 | 3.20 | 3.48 | 0 |
| Chloride, dis, mg/l | 11/20/00 | 09/04/02 | 1.8 | 17 | 0.38 | 0.42 | 0.45 | 0.44 | 0.46 | 0.50 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 11/20/00 | 07/16/02 | 1.7 | 7 | 21.00 | 22.50 | 23.00 | 23.14 | 24.00 | 25.00 | 0 |
| Iron, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 0 |
| Manganese, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0 |
| Potassium, dis, mg/l | 11/20/00 | 07/16/02 | 1.7 | 7 | 0.61 | 0.65 | 0.69 | 0.67 | 0.69 | 0.70 | 0 |
| Sodium, dis, mg/l | 11/20/00 | 07/16/02 | 1.7 | 7 | 1.76 | 1.85 | 1.99 | 1.97 | 2.08 | 2.15 | 0 |
| TSS, mg/l | 11/20/00 | 05/08/01 | 0.5 | 3 | 2.00 | 2.00 | 2.00 | 2.33 | 2.50 | 3.00 | 0 |
| Cadmium, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Epilimnion Grab Sample Data (2000 - 2007)***

| | Recent Data | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | # < Reporting/ Detect Limit |
| Secchi Disk Depth, m | 05/25/00 | 11/06/06 | 6.5 | 58 | 1.57 | 3.06 | 3.66 | 3.90 | 4.85 | 7.95 | 0 |
| Chlorophyll a, ug/l | 05/25/00 | 07/24/07 | 7.2 | 31 | 1.00 | 2.35 | 4.40 | 6.02 | 6.40 | 29.80 | 0 |
| DO, mg/l | 05/25/00 | 03/13/07 | 6.8 | 19 | 6.10 | 7.00 | 7.20 | 8.66 | 10.10 | 14.10 | 0 |
| Conductivity, uS/cm | 05/25/00 | 03/13/07 | 6.8 | 18 | 43.00 | 48.50 | 61.00 | 65.28 | 72.50 | 117.00 | 0 |
| pH, field | 05/25/00 | 03/13/07 | 6.8 | 18 | 7.00 | 7.53 | 7.70 | 7.83 | 8.08 | 9.20 | 0 |
| Temperature, deg C | 05/25/00 | 03/13/07 | 6.8 | 19 | 0.20 | 4.65 | 11.20 | 10.38 | 15.10 | 19.40 | 0 |
| Ammonia, dis, ug/l as N | 05/25/00 | 03/13/07 | 6.8 | 35 | 1.50 | 5.00 | 7.00 | 10.67 | 10.50 | 78.00 | 13 |
| Nitrate + Nitrite, dis, ug/l as N | 05/25/00 | 03/13/07 | 6.8 | 35 | 1.50 | 8.00 | 8.00 | 13.77 | 20.00 | 70.00 | 16 |
| TKN, ug/l as N | 05/25/00 | 11/06/06 | 6.5 | 20 | 23.00 | 157.50 | 215.00 | 225.35 | 272.00 | 480.00 | 0 |
| TP, ug/l as P | 05/25/00 | 03/13/07 | 6.8 | 35 | 1.50 | 9.00 | 11.00 | 11.46 | 13.50 | 31.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/25/00 | 03/13/07 | 6.8 | 35 | 0.50 | 1.00 | 3.00 | 2.30 | 3.00 | 7.00 | 17 |
| Silica, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 9 | 4.39 | 5.05 | 5.21 | 5.73 | 5.70 | 8.17 | 0 |
| TOC, mg/l | 05/25/00 | 11/06/06 | 6.5 | 21 | 1.30 | 2.40 | 3.70 | 3.48 | 4.20 | 6.30 | 0 |
| DOC, mg/l | 05/29/03 | 03/13/07 | 3.8 | 12 | 3.20 | 3.28 | 3.55 | 3.59 | 3.83 | 4.10 | 0 |
| Calcium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 6.60 | 7.06 | 7.96 | 8.12 | 9.18 | 9.63 | 0 |
| Magnesium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 1.17 | 1.27 | 1.48 | 1.48 | 1.68 | 1.75 | 0 |
| Sulfate, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 2.00 | 2.71 | 3.94 | 3.64 | 4.48 | 4.70 | 0 |
| Chloride, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 0.36 | 0.50 | 0.78 | 0.70 | 0.90 | 0.95 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 11/06/06 | 11/06/06 | 0.0 | 1 | 27.10 | 27.10 | 27.10 | 27.10 | 27.10 | 27.10 | 0 |
| Iron, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 11 | 5.00 | 6.50 | 9.00 | 16.18 | 11.50 | 70.00 | 2 |
| Manganese, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 0.20 | 0.20 | 0.50 | 1.04 | 1.08 | 5.00 | 3 |
| Potassium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 0.62 | 0.66 | 0.79 | 0.79 | 0.88 | 1.07 | 0 |
| Sodium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 1.81 | 2.01 | 2.61 | 2.56 | 3.06 | 3.26 | 0 |
| TSS, mg/l | 05/18/05 | 11/06/06 | 1.5 | 15 | 0.50 | 1.76 | 2.00 | 2.51 | 3.79 | 4.70 | 1 |
| Copper, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 9 | 0.50 | 1.00 | 1.10 | 2.12 | 3.10 | 5.00 | 3 |
| Cadmium, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 0.02 | 0.02 | 0.03 | 0.08 | 0.05 | 0.50 | 6 |
| Lead, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 9 | 0.04 | 0.12 | 0.13 | 5.83 | 0.50 | 50.00 | 4 |
| Silver, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 8 | 0.05 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 | 8 |
| Zinc, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 9 | 0.50 | 1.60 | 5.00 | 4.67 | 7.40 | 10.00 | 2 |
| Nitrite, dis, mg/l | 05/25/00 | 09/28/00 | 0.3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 3 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Composite Sample Data (2001 - 2004)***

| Variable | Recent Data | | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | # < Reporting/ Detect Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Start | End | | | | | | | | | |
| DO, mg/l | 01/22/01 | 03/02/04 | 3.1 | 30 | 1.10 | 3.55 | 5.40 | 4.98 | 6.43 | 8.80 | 0 |
| Conductivity, uS/cm | 01/22/01 | 03/02/04 | 3.1 | 30 | 39.00 | 47.25 | 51.00 | 50.97 | 54.00 | 65.00 | 0 |
| pH, field | 01/22/01 | 03/02/04 | 3.1 | 30 | 6.00 | 6.50 | 6.70 | 6.72 | 6.90 | 7.80 | 0 |
| Temperature, deg C | 01/22/01 | 03/02/04 | 3.1 | 30 | 2.40 | 5.05 | 7.45 | 6.79 | 8.58 | 9.60 | 0 |
| Ammonia, dis, ug/l as N | 01/22/01 | 03/02/04 | 3.1 | 28 | 3.50 | 3.50 | 3.50 | 6.34 | 7.50 | 21.00 | 21 |
| Nitrate + Nitrite, dis, ug/l as N | 10/15/02 | 03/02/04 | 1.4 | 8 | 17.00 | 69.75 | 111.00 | 99.25 | 131.00 | 160.00 | 0 |
| Nitrate, dis, ug/l | 01/22/01 | 09/17/02 | 1.7 | 20 | 5.00 | 10.00 | 30.00 | 35.50 | 60.00 | 90.00 | 4 |
| TKN, ug/l as N | 01/22/01 | 11/04/03 | 2.8 | 26 | 70.00 | 152.50 | 170.00 | 167.31 | 180.00 | 270.00 | 0 |
| TP, ug/l as P | 01/22/01 | 03/02/04 | 3.1 | 29 | 3.00 | 11.00 | 12.00 | 13.03 | 15.00 | 25.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/08/01 | 03/02/04 | 2.8 | 27 | 3.00 | 3.50 | 3.50 | 4.96 | 5.00 | 16.00 | 14 |
| Silica, dis, mg/l | 05/08/01 | 10/17/01 | 0.4 | 4 | 4.97 | 5.15 | 5.49 | 5.44 | 5.78 | 5.80 | 0 |
| TOC, mg/l | 11/05/02 | 03/02/04 | 1.3 | 8 | 2.80 | 3.78 | 4.10 | 4.05 | 4.45 | 5.10 | 0 |
| DOC, mg/l | 05/08/01 | 03/02/04 | 2.8 | 20 | 2.30 | 2.80 | 3.20 | 3.22 | 3.70 | 4.00 | 0 |
| Calcium, dis, mg/l | 05/08/01 | 10/17/01 | 0.4 | 4 | 6.63 | 6.83 | 7.03 | 6.98 | 7.17 | 7.21 | 0 |
| Magnesium, dis, mg/l | 05/08/01 | 10/17/01 | 0.4 | 4 | 1.16 | 1.19 | 1.23 | 1.22 | 1.26 | 1.27 | 0 |
| Sulfate, dis, mg/l | 05/08/01 | 09/17/02 | 1.4 | 14 | 2.88 | 3.14 | 3.16 | 3.15 | 3.21 | 3.27 | 0 |
| Chloride, dis, mg/l | 05/08/01 | 09/17/02 | 1.4 | 14 | 0.37 | 0.42 | 0.47 | 0.46 | 0.48 | 0.56 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 05/08/01 | 10/17/01 | 0.4 | 4 | 22.00 | 22.00 | 22.50 | 22.75 | 23.25 | 24.00 | 0 |
| Iron, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 0 |
| Manganese, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 95.70 | 95.70 | 95.70 | 95.70 | 95.70 | 95.70 | 0 |
| Potassium, dis, mg/l | 05/08/01 | 10/17/01 | 0.4 | 4 | 0.62 | 0.64 | 0.67 | 0.66 | 0.69 | 0.70 | 0 |
| Sodium, dis, mg/l | 05/08/01 | 10/17/01 | 0.4 | 4 | 1.75 | 1.84 | 1.94 | 1.92 | 2.02 | 2.04 | 0 |
| TSS, mg/l | 01/22/01 | 01/22/01 | 0.0 | 1 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 0 |
| Cadmium, dis, ug/l | 03/02/04 | 03/02/04 | 0.0 | 1 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Sample Data (2000 - 2007)***

| Variable | Recent Data | | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | # < Reporting/ Detect Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Start | End | | | | | | | | | |
| DO, mg/l | 05/25/00 | 03/13/07 | 6.8 | 22 | 0.20 | 2.53 | 3.45 | 4.20 | 6.18 | 8.60 | 0 |
| Conductivity, uS/cm | 05/25/00 | 03/13/07 | 6.8 | 21 | 43.00 | 48.00 | 53.00 | 55.05 | 62.00 | 81.00 | 0 |
| pH, field | 05/25/00 | 03/13/07 | 6.8 | 21 | 6.20 | 6.60 | 6.90 | 7.01 | 7.30 | 7.80 | 0 |
| Temperature, deg C | 05/25/00 | 03/13/07 | 6.8 | 23 | 2.90 | 4.45 | 7.20 | 6.98 | 8.40 | 13.50 | 0 |
| Ammonia, dis, ug/l as N | 05/25/00 | 03/13/07 | 6.8 | 39 | 1.00 | 4.50 | 9.00 | 12.90 | 14.50 | 97.00 | 13 |
| Nitrate + Nitrite, dis, ug/l as N | 05/25/00 | 03/13/07 | 6.8 | 35 | 1.50 | 48.00 | 97.00 | 90.87 | 118.00 | 273.00 | 1 |
| Nitrate, dis, ug/l | 11/20/00 | 07/16/02 | 1.7 | 4 | 5.00 | 5.00 | 5.00 | 28.75 | 28.75 | 100.00 | 3 |
| TKN, ug/l as N | 05/25/00 | 11/06/06 | 6.5 | 24 | 89.00 | 146.00 | 165.00 | 171.58 | 190.75 | 280.00 | 0 |
| TP, ug/l as P | 05/25/00 | 03/13/07 | 6.8 | 39 | 3.00 | 12.00 | 18.00 | 19.69 | 27.00 | 38.00 | 0 |
| Orthophosphate, dis, ug/l as P | 05/25/00 | 03/13/07 | 6.8 | 37 | 0.50 | 3.00 | 6.00 | 6.12 | 9.00 | 13.00 | 5 |
| Silica, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 12 | 4.64 | 5.43 | 6.24 | 6.75 | 8.21 | 9.29 | 0 |
| TOC, mg/l | 05/25/00 | 11/06/06 | 6.5 | 23 | 1.00 | 2.00 | 3.20 | 2.97 | 3.80 | 4.50 | 0 |
| DOC, mg/l | 11/20/00 | 03/13/07 | 6.3 | 16 | 2.70 | 2.98 | 3.10 | 3.12 | 3.40 | 3.50 | 0 |
| Calcium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 13 | 6.68 | 6.85 | 7.67 | 7.66 | 8.30 | 8.59 | 0 |
| Magnesium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 13 | 1.18 | 1.22 | 1.46 | 1.39 | 1.52 | 1.60 | 0 |
| Sulfate, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 14 | 2.20 | 2.94 | 3.48 | 3.37 | 3.78 | 4.70 | 0 |
| Chloride, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 14 | 0.38 | 0.38 | 0.54 | 0.59 | 0.78 | 0.92 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 11/20/00 | 11/06/06 | 6.0 | 4 | 21.00 | 21.75 | 23.50 | 23.78 | 25.53 | 27.10 | 0 |
| Iron, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 25 | 5.00 | 12.00 | 30.00 | 33.32 | 40.00 | 100.00 | 2 |
| Manganese, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 25 | 0.50 | 5.00 | 5.00 | 24.86 | 20.00 | 160.00 | 5 |
| Potassium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 13 | 0.64 | 0.67 | 0.75 | 0.75 | 0.80 | 0.94 | 0 |
| Sodium, dis, mg/l | 05/25/00 | 03/13/07 | 6.8 | 13 | 1.77 | 1.84 | 2.60 | 2.32 | 2.70 | 2.81 | 0 |
| TSS, mg/l | 11/06/06 | 11/06/06 | 0.0 | 1 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 0 |
| Copper, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 9 | 0.50 | 0.80 | 1.00 | 1.76 | 2.60 | 5.00 | 3 |
| Cadmium, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 11 | 0.02 | 0.02 | 0.02 | 0.07 | 0.05 | 0.50 | 9 |
| Lead, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 9 | 0.04 | 0.06 | 0.16 | 5.82 | 0.50 | 50.00 | 5 |
| Silver, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 8 | 0.05 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 | 8 |
| Zinc, dis, ug/l | 05/25/00 | 03/13/07 | 6.8 | 10 | 0.50 | 1.48 | 2.15 | 3.28 | 4.48 | 10.00 | 2 |
| Nitrite, dis, mg/l | 05/25/00 | 09/28/00 | 0.3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 3 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

# Appendix A–5: Summary of Key Water Quality Parameters for Horsetooth Reservoir (Site: BTWF Soldier Canyon Dam, USBR Nutrient Project HT-SOL)

***Epilimnion Composite Sample Data (2004 - 2006)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect Limit |
| Chlorophyll a, ug/l | 05/16/05 | 10/11/06 | 1.4 | 15 | 1.30 | 1.70 | 3.30 | 3.47 | 4.55 | 6.40 | 0 |
| Ammonia, dis, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 13 | 10.00 | 10.00 | 10.00 | 13.46 | 10.00 | 29.00 | 9 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 20.00 | 50.00 | 50.00 | 48.46 | 50.00 | 100.00 | 9 |
| TKN, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 12 | 70.00 | 155.00 | 220.00 | 230.83 | 302.50 | 400.00 | 0 |
| TP, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 5.00 | 5.00 | 10.00 | 8.08 | 10.00 | 10.00 | 5 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 0.00 | 2.50 | 2.50 | 2.00 | 2.50 | 2.50 | 10 |
| TOC, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.75 | 3.07 | 3.35 | 3.25 | 3.46 | 3.61 | 0 |
| Calcium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 7.70 | 7.90 | 8.00 | 8.07 | 8.10 | 8.80 | 0 |
| Magnesium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 1.40 | 1.40 | 1.45 | 1.45 | 1.50 | 1.50 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.50 | 2.50 | 2.50 | 3.07 | 4.00 | 5.30 | 9 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 06/19/06 | 2.2 | 13 | 25.40 | 27.60 | 28.80 | 28.62 | 30.00 | 31.00 | 0 |
| Iron, dis, ug/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 87.00 | 133.75 | 177.50 | 175.40 | 203.25 | 287.00 | 0 |
| Potassium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 0.78 | 0.85 | 0.86 | 0.85 | 0.87 | 0.90 | 0 |
| Sodium, dis, mg/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 2.40 | 2.40 | 2.40 | 2.45 | 2.50 | 2.60 | 0 |
| Lead, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 1 |
| Silver, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 146.00 | 157.00 | 168.00 | 166.33 | 176.50 | 185.00 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Epilimnion Grab Sample Data (2004 - 2006)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect |
| Secchi Disk Depth, m | 04/12/04 | 10/11/06 | 2.5 | 19 | 1.45 | 2.12 | 2.80 | 2.90 | 3.43 | 4.83 | 0 |
| Chlorophyll a, ug/l | 04/12/04 | 10/11/06 | 2.5 | 29 | 0.30 | 1.70 | 2.70 | 3.02 | 4.10 | 6.80 | 2 |
| Conductivity, uS/cm | 08/30/04 | 06/20/05 | 0.8 | 2 | 82.00 | 94.00 | 106.00 | 106.00 | 118.00 | 130.00 | 0 |
| Ammonia, dis, ug/l as N | 04/12/04 | 10/11/06 | 2.5 | 27 | 1.50 | 8.00 | 10.00 | 19.46 | 20.50 | 108.00 | 10 |
| Nitrate + Nitrite, dis, ug/l as N | 05/16/05 | 10/11/06 | 1.4 | 14 | 1.50 | 9.50 | 20.00 | 25.89 | 34.25 | 64.00 | 0 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 10.00 | 50.00 | 50.00 | 43.85 | 50.00 | 50.00 | 11 |
| TKN, ug/l as N | 04/12/04 | 10/11/06 | 2.5 | 26 | 50.00 | 166.50 | 210.00 | 217.58 | 238.50 | 550.00 | 1 |
| TP, ug/l as P | 04/12/04 | 10/11/06 | 2.5 | 27 | 1.50 | 5.00 | 10.00 | 8.98 | 10.00 | 20.00 | 4 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 10/11/06 | 2.5 | 27 | 0.00 | 0.50 | 2.00 | 1.69 | 2.50 | 5.00 | 10 |
| TOC, mg/l | 04/12/04 | 10/11/06 | 2.5 | 23 | 1.20 | 2.70 | 3.20 | 2.92 | 3.48 | 3.94 | 0 |
| Calcium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 7.70 | 8.00 | 8.40 | 8.43 | 8.70 | 9.30 | 0 |
| Magnesium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 1.40 | 1.50 | 1.50 | 1.50 | 1.50 | 1.60 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.50 | 2.50 | 2.50 | 3.05 | 3.80 | 5.30 | 9 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 06/19/06 | 2.2 | 13 | 26.00 | 27.00 | 29.60 | 28.92 | 30.40 | 32.20 | 0 |
| Iron, dis, ug/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 52.00 | 126.25 | 158.00 | 178.80 | 237.00 | 355.00 | 0 |
| Potassium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 0.82 | 0.85 | 0.87 | 0.87 | 0.90 | 0.94 | 0 |
| Sodium, dis, mg/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 2.40 | 2.43 | 2.50 | 2.50 | 2.50 | 2.70 | 0 |
| TSS, mg/l | 05/16/05 | 10/11/06 | 1.4 | 14 | 1.69 | 2.00 | 2.33 | 2.65 | 3.00 | 4.37 | 0 |
| Lead, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 1 |
| Silver, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 163.00 | 163.50 | 164.00 | 171.00 | 175.00 | 186.00 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Hypolimnion Composite Sample Data (2004 - 2006)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect Limit |
| Ammonia, dis, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 13 | 5.00 | 10.00 | 10.00 | 16.54 | 10.00 | 48.00 | 10 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 30.00 | 50.00 | 100.00 | 127.69 | 200.00 | 400.00 | 1 |
| TKN, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 12 | 40.00 | 157.50 | 200.00 | 197.50 | 235.00 | 400.00 | 1 |
| TP, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 5.00 | 10.00 | 10.00 | 12.69 | 20.00 | 20.00 | 3 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.00 | 2.50 | 7.00 | 5.58 | 8.00 | 9.00 | 3 |
| TOC, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.60 | 2.80 | 3.26 | 3.13 | 3.35 | 3.54 | 0 |
| Calcium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 7.70 | 7.90 | 8.00 | 8.07 | 8.40 | 8.40 | 0 |
| Magnesium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 1.40 | 1.45 | 1.50 | 1.47 | 1.50 | 1.50 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.50 | 2.50 | 2.50 | 3.08 | 4.00 | 5.30 | 9 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 06/19/06 | 2.2 | 13 | 24.10 | 26.20 | 27.40 | 27.79 | 29.80 | 30.80 | 0 |
| Iron, dis, ug/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 132.00 | 189.00 | 197.50 | 194.10 | 206.50 | 235.00 | 0 |
| Potassium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 0.78 | 0.83 | 0.83 | 0.84 | 0.85 | 0.93 | 0 |
| Sodium, dis, mg/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 2.40 | 2.40 | 2.40 | 2.47 | 2.50 | 2.70 | 0 |
| Lead, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 1 |
| Silver, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 143.00 | 160.00 | 177.00 | 165.67 | 177.00 | 177.00 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

*Reservoir was low 2000 - 2003 for dam repairs. Data during this period is not considered representative so is not included.*

***Hypolimnion Grab Sample Data (2004 - 2006)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect |
| Ammonia, dis, ug/l as N | 04/12/04 | 10/11/06 | 2.5 | 27 | 1.50 | 10.00 | 11.00 | 31.46 | 33.50 | 197.00 | 10 |
| Nitrate + Nitrite, dis, ug/l as N | 05/16/05 | 10/11/06 | 1.4 | 14 | 22.00 | 32.25 | 79.50 | 97.14 | 109.00 | 309.00 | 0 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 30.00 | 100.00 | 100.00 | 131.54 | 200.00 | 200.00 | 0 |
| TKN, ug/l as N | 04/12/04 | 10/11/06 | 2.5 | 26 | 50.00 | 152.50 | 210.00 | 220.00 | 240.00 | 530.00 | 1 |
| TP, ug/l as P | 04/12/04 | 10/11/06 | 2.5 | 27 | 1.50 | 8.50 | 11.00 | 16.26 | 20.00 | 83.00 | 1 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 10/11/06 | 2.5 | 27 | 0.50 | 3.00 | 5.00 | 5.78 | 8.00 | 20.00 | 0 |
| TOC, mg/l | 04/12/04 | 10/11/06 | 2.5 | 27 | 0.90 | 1.65 | 2.90 | 2.56 | 3.21 | 3.50 | 0 |
| Calcium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 7.30 | 7.80 | 7.90 | 8.01 | 8.10 | 9.00 | 0 |
| Magnesium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 1.40 | 1.40 | 1.50 | 1.46 | 1.50 | 1.50 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.50 | 2.50 | 2.50 | 3.08 | 3.90 | 5.40 | 9 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 06/19/06 | 2.2 | 13 | 24.60 | 26.40 | 27.80 | 27.85 | 29.00 | 31.00 | 0 |
| Iron, dis, ug/l | 04/12/04 | 10/11/06 | 2.5 | 24 | 20.00 | 40.00 | 60.00 | 117.67 | 208.50 | 270.00 | 0 |
| Manganese, dis, ug/l | 05/16/05 | 10/11/06 | 1.4 | 14 | 5.00 | 5.00 | 5.00 | 31.43 | 37.50 | 140.00 | 4 |
| Potassium, dis, mg/l | 04/12/04 | 09/13/04 | 0.4 | 9 | 0.79 | 0.83 | 0.84 | 0.84 | 0.86 | 0.87 | 0 |
| Sodium, dis, mg/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 2.40 | 2.40 | 2.40 | 2.47 | 2.48 | 2.70 | 0 |
| Lead, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 1 |
| Silver, dis, ug/l | 10/17/05 | 10/17/05 | 0.0 | 1 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 141.00 | 158.00 | 175.00 | 184.67 | 206.50 | 238.00 | 0 |
| Zinc, dis, ug/l | 05/16/05 | 05/16/05 | 0.0 | 1 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 0 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

# Appendix A–6: Summary of Key Water Quality Parameters for Horsetooth Reservoir (Site: BTWF Spring Canyon Dam, USBR Nutrient Project HT-SPR)

***Epilimnion Composite Sample Data (2004 - 2006)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect Limit |
| Chlorophyll a, ug/l | 05/16/05 | 10/11/06 | 1.4 | 15 | 1.30 | 1.70 | 3.60 | 3.95 | 6.00 | 7.20 | 0 |
| Ammonia, dis, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 13 | 5.00 | 10.00 | 10.00 | 15.25 | 24.30 | 34.00 | 9 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 30.00 | 50.00 | 50.00 | 54.62 | 50.00 | 100.00 | 8 |
| TKN, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 12 | 120.00 | 187.50 | 220.00 | 224.17 | 300.00 | 300.00 | 0 |
| TP, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 5.00 | 10.00 | 10.00 | 10.38 | 10.00 | 20.00 | 3 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 0.00 | 2.50 | 2.50 | 2.50 | 2.50 | 5.00 | 9 |
| TOC, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.83 | 2.96 | 3.48 | 3.31 | 3.58 | 3.72 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.50 | 2.50 | 2.50 | 3.01 | 3.70 | 5.30 | 9 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 06/19/06 | 2.2 | 13 | 25.60 | 26.60 | 27.40 | 27.62 | 28.60 | 31.20 | 0 |
| Iron, dis, ug/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 90.00 | 133.50 | 167.00 | 171.40 | 217.00 | 267.00 | 0 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 142.00 | 162.00 | 182.00 | 170.67 | 185.00 | 188.00 | 0 |
| Nitrite, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 0.01 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 | 13 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Epilimnion Grab Sample Data (2004 - 2007)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect |
| Secchi Disk Depth, m | 04/12/04 | 04/30/07 | 3.1 | 28 | 1.06 | 1.74 | 2.45 | 2.55 | 3.34 | 4.40 | 0 |
| Chlorophyll a, ug/l | 04/12/04 | 10/11/06 | 2.5 | 33 | 0.30 | 1.70 | 3.10 | 3.52 | 4.50 | 15.80 | 2 |
| DO, mg/l | 05/13/04 | 04/30/07 | 3.0 | 9 | 7.20 | 7.40 | 7.50 | 8.20 | 8.00 | 11.40 | 0 |
| Conductivity, uS/cm | 05/13/04 | 04/30/07 | 3.0 | 9 | 47.00 | 66.00 | 71.00 | 73.89 | 81.00 | 95.00 | 0 |
| pH, field | 05/04/00 | 04/30/07 | 7.0 | 9 | 7.20 | 7.60 | 7.80 | 7.72 | 7.90 | 8.20 | 0 |
| Temperature, deg C | 05/13/04 | 04/30/07 | 3.0 | 9 | 6.30 | 12.10 | 19.60 | 16.27 | 21.30 | 22.90 | 0 |
| Ammonia, dis, ug/l as N | 04/12/04 | 04/30/07 | 3.1 | 36 | 2.00 | 8.00 | 10.00 | 26.43 | 20.75 | 231.00 | 12 |
| Nitrate + Nitrite, dis, ug/l as N | 05/13/04 | 04/30/07 | 3.0 | 23 | 1.50 | 8.00 | 16.00 | 44.70 | 51.50 | 260.00 | 4 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 20.00 | 50.00 | 50.00 | 55.38 | 50.00 | 200.00 | 9 |
| TKN, ug/l as N | 04/12/04 | 10/11/06 | 2.5 | 26 | 100.00 | 169.00 | 230.00 | 226.50 | 265.00 | 450.00 | 0 |
| TP, ug/l as P | 04/12/04 | 04/30/07 | 3.1 | 36 | 1.50 | 6.00 | 10.00 | 10.29 | 12.25 | 20.00 | 3 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 04/30/07 | 3.1 | 36 | 0.00 | 0.88 | 2.50 | 2.14 | 3.00 | 14.00 | 17 |
| Silica, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.57 | 0.88 | 1.52 | 2.00 | 2.64 | 4.39 | 0 |
| TOC, mg/l | 04/12/04 | 10/11/06 | 2.5 | 26 | 1.30 | 2.97 | 3.20 | 2.98 | 3.56 | 3.90 | 0 |
| DOC, mg/l | 08/17/05 | 09/07/06 | 1.1 | 2 | 3.00 | 3.13 | 3.25 | 3.25 | 3.38 | 3.50 | 0 |
| Calcium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 8.06 | 8.26 | 8.61 | 8.59 | 8.94 | 9.09 | 0 |
| Magnesium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 1.38 | 1.40 | 1.40 | 1.42 | 1.42 | 1.48 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 09/07/06 | 2.4 | 17 | 2.50 | 2.50 | 2.50 | 3.17 | 3.70 | 5.40 | 9 |
| Chloride, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 1.18 | 1.20 | 1.25 | 1.38 | 1.44 | 1.85 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 09/07/06 | 2.4 | 14 | 25.00 | 27.50 | 29.40 | 29.07 | 30.30 | 32.40 | 0 |
| Iron, dis, ug/l | 04/12/04 | 09/07/06 | 2.4 | 15 | 7.00 | 19.00 | 138.00 | 144.07 | 223.50 | 439.00 | 0 |
| Manganese, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 5 | 0.20 | 0.40 | 0.60 | 1.46 | 0.70 | 5.40 | 0 |
| Potassium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.70 | 0.78 | 0.82 | 0.81 | 0.85 | 0.93 | 0 |
| Sodium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 2.37 | 2.39 | 2.43 | 2.53 | 2.58 | 2.89 | 0 |
| TSS, mg/l | 05/16/05 | 10/11/06 | 1.4 | 14 | 1.00 | 2.00 | 2.35 | 2.99 | 4.00 | 6.42 | 0 |
| Copper, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 2.70 | 2.85 | 3.20 | 3.38 | 3.73 | 4.40 | 0 |
| Cadmium, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 5 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 5 |
| Lead, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.04 | 0.04 | 0.04 | 0.09 | 0.09 | 0.25 | 3 |
| Silver, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 4 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 159.00 | 183.50 | 208.00 | 192.33 | 209.00 | 210.00 | 0 |
| Zinc, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.30 | 0.70 | 1.00 | 2.90 | 9.60 | 9.60 | 0 |
| Nitrite, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 15 | 0.00 | 0.01 | 0.05 | 0.04 | 0.05 | 0.05 | 14 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Hypolimnion Composite Sample Data (2004 - 2006)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect Limit |
| Ammonia, dis, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 13 | 10.00 | 10.00 | 10.00 | 22.39 | 21.10 | 61.00 | 8 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 30.00 | 50.00 | 100.00 | 127.69 | 200.00 | 200.00 | 1 |
| TKN, ug/l as N | 04/12/04 | 06/19/06 | 2.2 | 12 | 50.00 | 192.50 | 200.00 | 206.67 | 220.00 | 400.00 | 1 |
| TP, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 10.00 | 10.00 | 20.00 | 16.15 | 20.00 | 30.00 | 0 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.50 | 6.00 | 9.00 | 8.54 | 11.00 | 15.00 | 2 |
| TOC, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.65 | 2.89 | 3.30 | 3.16 | 3.38 | 3.60 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 2.50 | 2.50 | 2.50 | 3.08 | 4.00 | 5.40 | 9 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 06/19/06 | 2.2 | 13 | 24.60 | 26.60 | 27.60 | 27.80 | 29.80 | 30.80 | 0 |
| Iron, dis, ug/l | 04/12/04 | 10/17/05 | 1.5 | 10 | 139.00 | 184.75 | 195.00 | 199.40 | 228.50 | 249.00 | 0 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 173.00 | 182.00 | 191.00 | 187.00 | 194.00 | 197.00 | 0 |
| Nitrite, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 0.01 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 | 13 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

***Hypolimnion Grab Sample Data (2004 - 2007)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect |
| DO, mg/l | 05/13/04 | 04/30/07 | 3.0 | 9 | 0.10 | 2.80 | 5.00 | 5.21 | 8.00 | 10.90 | 0 |
| Conductivity, uS/cm | 05/13/04 | 04/30/07 | 3.0 | 9 | 42.00 | 62.00 | 71.00 | 73.11 | 85.00 | 95.00 | 0 |
| pH, field | 08/06/04 | 04/30/07 | 2.7 | 8 | 6.80 | 6.90 | 7.05 | 7.21 | 7.38 | 7.90 | 0 |
| Temperature, deg C | 05/13/04 | 04/30/07 | 3.0 | 9 | 4.20 | 6.40 | 7.60 | 6.94 | 7.60 | 7.80 | 0 |
| Ammonia, dis, ug/l as N | 04/12/04 | 04/30/07 | 3.1 | 36 | 2.00 | 9.75 | 11.00 | 42.30 | 70.25 | 240.00 | 12 |
| Nitrate + Nitrite, dis, ug/l as N | 05/13/04 | 04/30/07 | 3.0 | 23 | 25.00 | 67.50 | 160.00 | 153.57 | 186.50 | 444.00 | 0 |
| Nitrate, dis, ug/l | 04/12/04 | 06/19/06 | 2.2 | 13 | 40.00 | 50.00 | 200.00 | 136.15 | 200.00 | 200.00 | 1 |
| TKN, ug/l as N | 04/12/04 | 10/11/06 | 2.5 | 26 | 50.00 | 171.50 | 220.00 | 235.35 | 290.00 | 470.00 | 1 |
| TP, ug/l as P | 04/12/04 | 04/30/07 | 3.1 | 36 | 4.00 | 14.50 | 24.00 | 26.64 | 38.50 | 74.00 | 1 |
| Orthophosphate, dis, ug/l as P | 04/12/04 | 04/30/07 | 3.1 | 36 | 0.50 | 4.75 | 9.00 | 12.22 | 14.25 | 51.00 | 2 |
| Silica, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 3.13 | 4.12 | 4.56 | 4.28 | 4.72 | 4.89 | 0 |
| TOC, mg/l | 04/12/04 | 10/11/06 | 2.5 | 29 | 1.20 | 2.00 | 2.90 | 2.68 | 3.40 | 3.80 | 0 |
| DOC, mg/l | 08/17/05 | 09/07/06 | 1.1 | 2 | 2.80 | 2.88 | 2.95 | 2.95 | 3.03 | 3.10 | 0 |
| Calcium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 7.75 | 8.04 | 9.27 | 9.22 | 10.45 | 10.60 | 0 |
| Magnesium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 1.33 | 1.38 | 1.50 | 1.52 | 1.63 | 1.73 | 0 |
| Sulfate, dis, mg/l | 04/12/04 | 09/07/06 | 2.4 | 17 | 2.50 | 2.50 | 2.50 | 3.20 | 3.80 | 5.40 | 9 |
| Chloride, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 1.14 | 1.22 | 1.33 | 1.33 | 1.44 | 1.51 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 04/12/04 | 09/07/06 | 2.4 | 14 | 24.00 | 26.85 | 28.10 | 29.03 | 30.45 | 36.00 | 0 |
| Iron, dis, ug/l | 04/12/04 | 10/11/06 | 2.5 | 29 | 8.00 | 20.00 | 40.00 | 95.28 | 169.00 | 295.00 | 0 |
| Manganese, dis, ug/l | 05/13/04 | 10/11/06 | 2.4 | 19 | 0.70 | 5.00 | 20.00 | 172.25 | 156.00 | 1380.00 | 3 |
| Potassium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.70 | 0.74 | 0.80 | 0.82 | 0.88 | 0.96 | 0 |
| Sodium, dis, mg/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 2.38 | 2.41 | 2.49 | 2.51 | 2.59 | 2.67 | 0 |
| Copper, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 3.10 | 3.48 | 3.70 | 3.75 | 3.98 | 4.50 | 0 |
| Cadmium, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 5 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 4 |
| Lead, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.04 | 0.04 | 0.05 | 0.07 | 0.08 | 0.13 | 2 |
| Silver, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 4 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 4 |
| Iron, TR, ug/l | 05/22/06 | 06/19/06 | 0.1 | 3 | 194.00 | 203.00 | 212.00 | 225.33 | 241.00 | 270.00 | 0 |
| Zinc, dis, ug/l | 05/13/04 | 09/07/06 | 2.3 | 5 | 0.50 | 1.00 | 2.20 | 2.04 | 4.08 | 4.60 | 0 |
| Nitrite, dis, mg/l | 04/12/04 | 06/19/06 | 2.2 | 15 | 0.00 | 0.01 | 0.05 | 0.04 | 0.05 | 0.05 | 14 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

*Reservoir drawn down 2000 - 2003. No data used from this unrepresentative period.*

# Appendix A–7: Summary of Key Water Quality Parameters for Carter Lake (Site: USGS 06742500 Carter Lake near Berthoud, CO, USBR Nutrient Project CL-DAM1)

***Epilimnion Grab Sample Data (2000 - 2007)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect |
| Secchi Disk Depth, m | 05/04/00 | 05/01/07 | 7.0 | 36 | 1.60 | 2.54 | 2.77 | 2.92 | 3.40 | 5.05 | 0 |
| Chlorophyll a, ug/l | 05/04/00 | 10/12/06 | 6.4 | 33 | 0.50 | 1.30 | 1.60 | 1.86 | 1.90 | 5.80 | 0 |
| DO, mg/l | 05/04/00 | 05/01/07 | 7.0 | 20 | 6.60 | 7.25 | 7.75 | 8.10 | 8.63 | 11.20 | 0 |
| Conductivity, uS/cm | 05/04/00 | 05/01/07 | 7.0 | 20 | 55.00 | 60.00 | 65.50 | 68.95 | 71.50 | 101.00 | 0 |
| pH, field | 05/04/00 | 05/01/07 | 7.0 | 19 | 7.00 | 7.35 | 7.80 | 7.73 | 8.00 | 8.50 | 0 |
| Temperature, deg C | 05/04/00 | 05/01/07 | 7.0 | 20 | 4.80 | 12.68 | 14.55 | 15.60 | 20.70 | 22.20 | 0 |
| Ammonia, dis, ug/l as N | 05/04/00 | 05/01/07 | 7.0 | 34 | 1.00 | 5.00 | 9.00 | 17.04 | 14.00 | 129.00 | 13 |
| Nitrate + Nitrite, dis, ug/l as N | 05/04/00 | 05/01/07 | 7.0 | 34 | 1.50 | 7.25 | 9.50 | 29.54 | 26.50 | 212.00 | 13 |
| TKN, ug/l as N | 05/04/00 | 10/12/06 | 6.4 | 25 | 111.00 | 168.00 | 194.00 | 189.92 | 220.00 | 260.00 | 0 |
| TP, ug/l as P | 05/04/00 | 05/01/07 | 7.0 | 34 | 1.50 | 6.25 | 9.50 | 9.19 | 11.00 | 16.00 | 1 |
| Orthophosphate, dis, ug/l as P | 05/04/00 | 05/01/07 | 7.0 | 34 | 0.50 | 0.63 | 3.00 | 2.40 | 3.50 | 5.00 | 18 |
| Silica, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.93 | 1.40 | 2.54 | 2.51 | 3.49 | 4.68 | 0 |
| TOC, mg/l | 05/04/00 | 10/11/06 | 6.4 | 25 | 1.00 | 2.50 | 3.20 | 2.92 | 3.40 | 4.80 | 0 |
| DOC, mg/l | 08/05/05 | 09/06/06 | 1.1 | 2 | 3.10 | 3.18 | 3.25 | 3.25 | 3.33 | 3.40 | 0 |
| Calcium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 7.68 | 8.74 | 9.18 | 9.36 | 10.15 | 10.70 | 0 |
| Magnesium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 1.18 | 1.23 | 1.32 | 1.32 | 1.39 | 1.53 | 0 |
| Sulfate, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 2.20 | 2.50 | 2.80 | 2.89 | 3.30 | 3.99 | 0 |
| Chloride, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.33 | 0.64 | 0.75 | 0.80 | 1.04 | 1.23 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 09/06/06 | 09/06/06 | 0.0 | 1 | 33.00 | 33.00 | 33.00 | 33.00 | 33.00 | 33.00 | 0 |
| Iron, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 16 | 3.00 | 5.00 | 5.00 | 5.13 | 5.00 | 9.00 | 10 |
| Manganese, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 16 | 0.10 | 0.30 | 0.50 | 0.50 | 0.63 | 1.10 | 1 |
| Potassium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.58 | 0.62 | 0.67 | 0.69 | 0.76 | 0.94 | 0 |
| Sodium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 1.83 | 1.96 | 2.07 | 2.14 | 2.36 | 2.63 | 0 |
| TSS, mg/l | 05/17/05 | 10/11/06 | 1.4 | 15 | 0.47 | 1.00 | 1.00 | 3.24 | 2.04 | 26.60 | 0 |
| Copper, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 1.00 | 1.60 | 1.80 | 2.03 | 2.25 | 5.00 | 1 |
| Cadmium, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 16 | 0.02 | 0.02 | 0.05 | 0.05 | 0.06 | 0.10 | 14 |
| Lead, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.04 | 0.04 | 0.04 | 3.41 | 0.05 | 50.00 | 12 |
| Silver, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.05 | 0.10 | 0.10 | 0.10 | 0.10 | 0.15 | 15 |
| Zinc, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.30 | 0.50 | 0.50 | 1.54 | 1.15 | 10.00 | 10 |
| Nitrite, dis, mg/l | 05/04/00 | 08/04/04 | 4.3 | 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 13 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

***Hypolimnion Grab Sample Data (2000 - 2007)***

| | Recent Data | | | | | | | | | | # < |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Start | End | # Yrs | N | Min | 25th %tile | Med | Mean | 75th %tile | Max | Reporting/ Detect |
| DO, mg/l | 05/04/00 | 05/01/07 | 7.0 | 20 | 3.60 | 5.18 | 6.65 | 6.84 | 8.55 | 10.70 | 0 |
| Conductivity, uS/cm | 05/04/00 | 05/01/07 | 7.0 | 20 | 43.00 | 52.50 | 57.00 | 59.00 | 65.25 | 86.00 | 0 |
| pH, field | 05/04/00 | 05/01/07 | 7.0 | 19 | 6.30 | 6.85 | 7.20 | 7.18 | 7.60 | 8.40 | 0 |
| Temperature, deg C | 05/04/00 | 05/01/07 | 7.0 | 20 | 4.00 | 6.45 | 8.10 | 8.22 | 9.75 | 13.60 | 0 |
| Ammonia, dis, ug/l as N | 05/04/00 | 05/01/07 | 7.0 | 34 | 2.00 | 5.25 | 9.50 | 20.94 | 21.50 | 118.00 | 5 |
| Nitrate + Nitrite, dis, ug/l as N | 05/04/00 | 05/01/07 | 7.0 | 34 | 6.50 | 20.50 | 50.00 | 68.81 | 106.75 | 256.00 | 2 |
| TKN, ug/l as N | 05/04/00 | 10/12/06 | 6.4 | 25 | 80.00 | 154.00 | 190.00 | 186.04 | 200.00 | 415.00 | 0 |
| TP, ug/l as P | 05/04/00 | 05/01/07 | 7.0 | 34 | 1.50 | 7.25 | 11.50 | 13.31 | 16.00 | 77.00 | 1 |
| Orthophosphate, dis, ug/l as P | 05/04/00 | 05/01/07 | 7.0 | 34 | 0.50 | 2.00 | 3.25 | 3.57 | 4.75 | 14.00 | 12 |
| Silica, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 2.49 | 3.25 | 3.71 | 3.80 | 4.12 | 5.25 | 0 |
| TOC, mg/l | 05/04/00 | 10/11/06 | 6.4 | 28 | 0.80 | 1.60 | 3.00 | 2.65 | 3.33 | 4.00 | 0 |
| DOC, mg/l | 08/05/05 | 09/06/06 | 1.1 | 2 | 2.90 | 2.95 | 3.00 | 3.00 | 3.05 | 3.10 | 0 |
| Calcium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 6.36 | 7.09 | 7.90 | 7.99 | 8.87 | 9.89 | 0 |
| Magnesium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 1.01 | 1.16 | 1.20 | 1.23 | 1.36 | 1.46 | 0 |
| Sulfate, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 1.90 | 2.40 | 2.80 | 2.74 | 3.05 | 3.71 | 0 |
| Chloride, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.29 | 0.61 | 0.74 | 0.77 | 0.92 | 1.25 | 0 |
| Alkalinity, dis, mg/l as CaCO3 | 09/06/06 | 09/06/06 | 0.0 | 1 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 0 |
| Iron, dis, ug/l | 05/04/00 | 10/11/06 | 6.4 | 31 | 3.00 | 7.00 | 10.00 | 15.68 | 20.00 | 40.00 | 8 |
| Manganese, dis, ug/l | 05/04/00 | 10/11/06 | 6.4 | 30 | 0.50 | 1.00 | 5.00 | 7.28 | 5.00 | 60.00 | 5 |
| Potassium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.57 | 0.59 | 0.63 | 0.65 | 0.69 | 0.87 | 0 |
| Sodium, dis, mg/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 1.59 | 1.83 | 2.03 | 2.03 | 2.19 | 2.47 | 0 |
| Copper, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 1.30 | 1.65 | 1.90 | 2.37 | 2.90 | 5.00 | 1 |
| Cadmium, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 16 | 0.02 | 0.04 | 0.05 | 0.05 | 0.06 | 0.10 | 14 |
| Lead, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.04 | 0.04 | 0.04 | 3.42 | 0.08 | 50.00 | 11 |
| Silver, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 15 | 0.05 | 0.10 | 0.10 | 0.10 | 0.10 | 0.15 | 15 |
| Zinc, dis, ug/l | 05/04/00 | 09/06/06 | 6.3 | 16 | 0.30 | 0.50 | 0.75 | 2.54 | 1.73 | 14.30 | 7 |
| Nitrite, dis, mg/l | 05/04/00 | 08/04/04 | 4.3 | 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 12 |

*Data below reporting/detection limits treated as 1/2 of the reporting/detection limit*

# Appendix B. BATHTUB Model Description and Application

## Introduction

The BATHTUB Model is a reservoir water-quality model that uses a series of empirical equations to predict eutrophication-related water-quality conditions. Predicted water-quality constituents include growing season phosphorus, nitrogen, chlorophyll *a*, metalimnetic oxygen demand, hypolimnetic oxygen demand, and transparency in the form of Secchi-disk depth. The suite of empirical equations embedded in the model were developed based on data from 300 reservoirs managed by the Corps of Engineers (Ernst, 1994). The algorithms assume steady-state conditions.

The model has been used in several applications and can be used for “proposed” reservoirs where observed water-quality data are lacking (Walker, internal model documentation) and has been used in several settings (e.g., Ashby and Kennedy, 1999; Woodbury and Padmanabhan, 1993). However, model results for proposed reservoirs do not capture the “reservoir aging” period where additional internal nutrient loadings may occur due to recently inundated soils and vegetation. Thus, for the potential new reservoirs, it assumed that the reservoirs have achieved an equilibrium several years following construction.

BATHTUB has been recommended as a valuable tool for evaluating reservoir water quality, particularly for initial and internal screenings and where data are limited (Ernst et al., 1994). The model is documented within the model and in several papers (Walker, 1985; Walker, 1986; and Walker, 1996). It is distributed by the Army Corps of Engineers at http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual.

## Application for the Windy Gap Firming Project EIS

The BATHTUB model was used to describe water quality for Horsetooth Reservoir, Carter Lake, Ralph Price Reservoir, Jasper East Reservoir, Rockwell Creek Reservoir, Chimney Hollow Reservoir, and Dry Creek Reservoir. The model assumes a steady state condition, which may not be the case for these reservoirs. However, since the BATHTUB model is based on numerous Corps of Engineers’ reservoirs, which can be considered to be non-steady state, it was decided that the BATHTUB model would provide a reasonable representation of potential changes in water quality for comparing alternatives for this EIS and a reasonable estimate of the likely water quality in new reservoirs. The model was also chosen to characterize Carter Lake, Horsetooth Reservoir, and Ralph Price Reservoir. This approach allowed us to investigate the differences between alternatives using a reasonable well-accepted approach. Although this approach is less detailed than the one taken for the Three Lakes analysis, it provides expected annual averages for most of the parameters of interest.

The BATHTUB model allows the user to choose specific algorithms for each application. The algorithms chosen for the WGFP EIS include those listed in Table B-1. The model was run on a water-year basis for the fifteen-year period WY75-WY89 for each reservoir / alternative combination. The BATHTUB model was run to calculate annual average water quality for 15 years in sequence, providing water quality conditions for each year in the time series. A description of the input data can be found in Table B-2. Note that precipitation and evaporation were set to zero because they were considered in the water balance completed by Boyle to determine reservoir contents. The loading from precipitation is considered as part of the atmospheric deposition, as described later in this section.

**Table B–1: Algorithms Used within BATHTUB to Simulate Water Quality in Carter Lake, Horsetooth Reservoir, Ralph Price Reservoir, and the Four Proposed Reservoirs Considered in the Windy Gap Firming Project EIS**

| Model | Algorithm Number | Algorithm Description |
|---|---|---|
| Phosphorus Model | 1 | Second Order, Available Phosphorus |
| Nitrogen Model | 2 | Second Order Decay Rate Function |
| Chlorophyll *a* Model | 1 | Function of Phosphorus, Nitrogen, Light, and Temperature |
| Secchi-Disk Depth Model | 1 | Function of Chlorophyll *a* and Turbidity |

**Table B–2: Description of Input Data for the BATHTUB Model**

| Input Parameter | Description of Input Data |
|---|---|
| Surface Area ($km^2$) | Average Surface Area |
| Mean Depth (m) | Reservoir Contents Divided by Surface Area |
| Mixed Layer Depth (m) | If mean depth > 10 meters, mixed layer depth equals 10 meters. Otherwise mixed layer depth equals mean depth |
| Length (km) | Estimated based on ERO maps |
| Hypolimnetic Depth (m) | Mean depth minus mixed layer depth |
| Flow Rate ($hm^3$/yr) | Annual Inflow (see discussion below) |
| Inflow Chemistry | See discussion below |
| Atmospheric Deposition - Chemistry ($mg/m^2$-yr) | See discussion below |
| Non-Algal Turbidity (1/m) | Default Value (0.025 1/m) |
| Calibration Coefficients | See discussion below |

Annual inflow rates, as provided by Boyle, were used to characterize the quantity of inflow. There were four years during the 15-year period under consideration where the annual inflow was equal to zero. This occurs in 1976, 1977, 1981, and 1989 for Chimney Hollow Reservoir (Alternatives 3 and 4) and Dry Creek Reservoir (Alternative 5). The BATHTUB model does not compute reasonable concentrations under these conditions. Under conditions of no inflow, the reservoir water quality is expected to improve since there is no loading. To be conservative for this analysis however, values for these years were filled in with the average of the other years instead of choosing some lower concentration.

Inflow chemistry_was determined differently for the different reservoirs. The inflow concentrations for Jasper East and Rockwell Creek were assumed to equal the concentrations at the Windy Gap Reservoir. Concentrations at the Windy Gap Reservoir were determined as a function of the releases from Granby Reservoir and flow and quality in the Fraser River. First, available existing water-quality data at Windy Gap Reservoir, Willow Creek, Fraser River, and the Colorado River below Granby Reservoir were analyzed, combined in a mass-balance model and a monthly distribution of concentrations at Windy Gap reservoir were developed. These concentrations (Table B-3) were assumed for Windy Gap Reservoir, Existing Conditions. For the alternatives, since increases in concentrations coming from Granby Reservoir can impact concentrations at Windy Gap and vice versa, the Three Lakes Model and the BATHTUB models were run twice and the results from the second pass were compared to those from the first pass to see if there were large differences, which there were not (<1.5%). The reason for running the models twice with equivalent water management for a given alternative was to test the confidence in the model prediction given the hydraulic feedback between Granby and Windy Gap pumping. Note that it was assumed that the flows and water quality at the mouth of the Fraser River did not change between the direct effects alternatives. For the cumulative effects runs, the Fraser Basin was characterized as described in the River Technical Report (Hydrosphere, 2007) and the Windy Gap mass-balance model was adjusted accordingly. The resulting total phosphorus and total nitrogen concentrations, used in the BATHTUB models are listed in Table B-4 . Orthophosphorus and total inorganic nitrogen were computed in a similar fashion.

**Table B–3: Estimated Nutrient Concentrations at Windy Gap Reservoir (Existing Conditions)**

| | Total Phosphorus (µg/l) | Total Nitrogen (µg/l) |
|---|---|---|
| January | 47 | 362 |
| February | 47 | 365 |
| March | 52 | 380 |
| April | 77 | 710 |
| May | 57 | 448 |
| June | 39 | 253 |
| July | 40 | 178 |
| August | 44 | 226 |
| September | 48 | 358 |
| October | 52 | 366 |
| November | 52 | 384 |
| December | 47 | 364 |

**Table B–4: Average Estimated Annual Inflow Nutrient Concentrations (WY75-WY89) for the Proposed West Slope Reservoirs**

| | Jasper East | | Rockwell Creek | |
|---|---|---|---|---|
| | Total Phosphorus (µg/l) | Total Nitrogen (µg/l) | Total Phosphorus (µg/l) | Total Nitrogen (µg/l) |
| **Direct Effects** | | | | |
| Alternative 3 | 50 | 361 | ----- | ----- |
| Alternative 4 | ----- | ----- | 50 | 361 |
| Alternative 5 | ----- | ----- | 50 | 360 |
| **Cumulative Effects** | | | | |
| Alternative 5 | ----- | ----- | 22 | 543 |

Inflow concentrations into the east slope reservoirs (Carter Lake, Horsetooth Reservoir, Chimney Hollow Reservoir, and Dry Creek Reservoir) were determined using the following methodology. For the Existing Conditions scenario, water-quality data from the Big Thompson Watershed Forum's (BTWF's) site C20 (Olympus Tunnel) was used to characterize the water-quality entering Carter Lake for Existing Conditions. Site C50 was used to characterize the inflow water quality into Horsetooth Reservoir. For the alternatives, the following assumptions were made:

1. There is negligible retention of nutrients in Mary's Lake, Lake Estes, Pinewood Reservoir and Flatirons Reservoir. This assumption is based on the very short residence time for these reservoirs and is also supported by data presented by Jassby and Goldman (2003).
2. The only change in nutrient loading on the east slope for each alternative is the change in nutrient loading which occurs at the east portal of the Adams Tunnel.
3. There is no change in nutrient concentrations between Grand Lake and the east portal of the Adams Tunnel.
4. The additional load at the Adams Tunnel is completely mixed with Big Thompson River flow at Lake Estes and the additional loading can be distributed between the Olympus Tunnel and the Big Thompson River according to flow.

For each alternative, the additional loading (as compared to existing conditions) was determined for each water year. Prorating this load between the Olympus Tunnel and the Big Thompson River, the existing water quality concentrations at site C20 were adjusted. The adjusted concentrations at C20 were used in the BATHTUB model to describe the water quality entering Carter Lake for No Action, Chimney Hollow for the Proposed Action, Alternative 3, and Alternative 4, and Dry Creek Reservoir for Alternative 5. The results from the BATHTUB model for Chimney Hollow (the Proposed Action and Alternatives 3 and 4) and Dry Creek (Alternative 5) Reservoirs were then combined with the flow into Carter Lake from the new reservoir, the flow into Carter Lake from Flatiron Reservoir, and the concentrations at Flatiron Reservoir to compute the inflow concentrations into Carter Lake for the Proposed Action and Alternatives 3, 4, and 5.

Similarly, concentrations at site C50 were modified for each alternative to account for the impacts of additional loading on Horsetooth Reservoir. The additional loading to the Big

Thompson River below Lake Estes and the additional loading at Flatirons Reservoir (via the Olympus Tunnel) were accounted for using mass balance to compute a net additional loading at Horsetooth Reservoir. Although the inflow concentrations vary on an annual basis, average water-year concentrations over the 15-year period are shown in Tables B-5 and B-6 for total phosphorus and total nitrogen.

**Table B–5: Average Estimated Annual Inflow Phosphorus Concentrations (WY75-WY89) for the East Slope Reservoirs**

| | Additional Load at the Adams Tunnel (kg/yr) | Concentration Into New Reservoir (µg/l) | Concentration Into Carter Lake (µg/l) | Concentration Into Horsetooth Reservoir (µg/l) |
|---|---|---|---|---|
| **Direct Effects** | | | | |
| Existing Conditions | 0 | ----- | 14.0 | 18.0 |
| No Action | 258 | ----- | 14.6 | 18.9 |
| Proposed Action | 578 | 15.3 | 15.3 | 19.9 |
| Alternative 3 | 302 | 14.7 | 14.4 | 19.0 |
| Alternative 4 | 293 | 14.7 | 14.4 | 19.0 |
| Alternative 5 | 264 | 14.6 | 14.4 | 18.9 |
| **Cumulative Effects** | | | | |
| No Action | 21 | ----- | 14.1 | 18.2 |
| Proposed Action | 294 | 14.7 | 14.7 | 19.1 |
| Alternative 5 | -111 | 13.8 | 13.6 | 17.8 |

**Table B–6: Average Estimated Annual Inflow Nitrogen Concentrations (WY75-WY89) for the East Slope Reservoirs**

| | Additional Load at the Adams Tunnel (kg/yr) | Concentration Into New Reservoir (µg/l) | Concentration Into Carter Lake (µg/l) | Concentration Into Horsetooth Reservoir (µg/l) |
|---|---|---|---|---|
| **Direct Effects** | | | | |
| Existing Conditions | 0 | ----- | 265 | 271 |
| No Action | 2,819 | ----- | 272 | 281 |
| Proposed Action | 6,845 | 281 | 281 | 293 |
| Alternative 3 | 4,411 | 280 | 275 | 286 |
| Alternative 4 | 4.255 | 276 | 271 | 286 |
| Alternative 5 | 4,144 | 278 | 274 | 285 |
| **Cumulative Effects** | | | | |
| No Action | 3,459 | ----- | 274 | 282 |
| Proposed Action | 7,464 | 283 | 282 | 294 |
| Alternative 5 | 7,032 | 282 | 278 | 293 |

Inflow concentrations into Ralph Price Reservoir were estimated based on an analysis of the available data on the North St. Vrain River (North St. Vrain Near Allenspark, USGS gage

06721500). Inflow concentrations were assumed to be the same in this pristine watershed for existing conditions, No Action - direct effects, and No Action - cumulative effects.

Atmospheric deposition chemistry for the west slope reservoirs was estimated using data from two USGS stations 1) the Green Ridge Precipitation station located between Granby Reservoir and Shadow Mountain Reservoir and 2) the East Inlet Near Grand Lake station. For the east slope reservoirs, atmospheric deposition chemistry data obtained near Cherry Creek Reservoir (2001-2005) was used to estimate the values. Concentrations from these sites were combined with precipitation values to compute the loadings listed in Table B-7.

**Table B–7: Atmospheric Deposition Chemistry**

| | West Slope Reservoirs | East Slope Reservoirs |
|---|---|---|
| Total Phosphorus (mg/m$^2$-yr) | 16 | 58 |
| Orthophosphorus (mg/m$^2$-yr) | 2.0 | 27 |
| Total Nitrogen (mg/m$^2$-yr) | 588 | 822 |
| Inorganic Nitrogen (mg/m$^2$-yr) | 316 | 517 |

Calibration coefficients were used in the modeling are listed below in Table B-8.

**Table B–8: Calibration coefficients used in BATHTUB simulations**

| Reservoir | Total Phosphorus | Total Nitrogen | Chlorophyll *a* | Secchi-Disk Depth |
|---|---|---|---|---|
| Ralph Price | 1.0 | 1.0 | 1.0 | 1.0 |
| Carter Lake | 0.5 | 0.31 | 1.2 | 0.84 |
| Horsetooth Reservoir | 0.64 | 0.13 | 1.65 | 0.88 |
| Jasper East Reservoir | 1.0 | 1.0 | 1.0 | 1.0 |
| Rockwell Creek Reservoir | 1.0 | 1.0 | 1.0 | 1.0 |
| Chimney Hollow Reservoir | 1.0 | 1.0 | 1.0 | 1.0 |
| Dry Creek Reservoir | 1.0 | 1.0 | 1.0 | 1.0 |

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# Appendix C.  LAKE2K Model Description and Application

## Introduction

To predict potential changes in temperature due to the action alternatives, the LAKE2K model was chosen to simulate temperature in Granby Reservoir.  If it was determined that there were no discernable differences in temperature between the existing conditions model run and the action alternatives model runs, then it would be assumed that there would not be increases in temperature for the other reservoirs in the system.  The development and application of the LAKE2K model to Granby Reservoir is described in this appendix.

LAKE2K is a mechanistic water-quality for a single stratified lake or reservoir (Chapra and Martin, 2004).  Although the model has been developed to simulate a variety of water-quality constituents, it was used to simulate temperature only for this application.  In LAKE2K, a lake is characterized as a three-layer system – an epilimnion, a metalimnion, and a hypolimnion.  The epilimnion layer thickness changes with changes in total reservoir contents.  Temperature is simulated using a heat balance for each reservoir layer.  The model accounts for solar radiation, convection, evaporation, long-wave radiation, and conduction, as well as vertical mixing, diffusion, and impacts of inflowing and outflowing water from the reservoir on reservoir water temperature.

## Data

The LAKE2K model requires inflow, outflow, inflow temperature, meteorological (air temperature, dew point temperature, cloud cover, wind speed, and precipitation), and elevation-area-volume data for the simulation.  All flows used in the LAKE2K simulations were consistent with the flows used for the Three Lakes Water-Quality Model (described in the main body of this report).  Inflow temperatures from the Willow Creek Pipeline and Windy Gap Pipeline were obtained from NCWCD (Vincent, 2007).  Windy Gap Pipeline data were supplemented for months having no data using temperature data at the 'Colorado River at Windy Gap' station (USGS, 2007).  These data were adjusted for temperature gains between the reservoir and the gauge.  Arapaho Creek temperature data were obtained from USGS, 2007.  Due to the small number of data points available for Stillwater Creek, a sine curve was developed to fit the temperature data.  There were no data available for the Roaring Fork and Columbine Creek.  It was assumed that the temperature of these two inflows was the same as that of Arapaho Creek.

It was also assumed that the temperature of water flowing from Shadow Mountain Reservoir to Granby Reservoir would not change as a result of an alternative.  This is a conservative assumption because there is evidence that the temperature of Shadow Mountain Reservoir decreases if the flow through the Farr Pumping Plant increases (see Section 11 in the main body of this report).  Flow through the Farr Pumping Plant is higher for each of the action alternatives relative to existing conditions.

Weather data were obtained from the National Climatic Data Center (NOAA, 2007) for the station Grand Lake SSW.  Data obtained included air temperature and precipitation.  Dew point temperatures were estimated using relative humidity observations at Kremmling (Weather Underground, 2007) and air temperature data at Grand Lake.  Cloud cover was estimated as a function of precipitation. Wind speed was assumed to be the same as that at Kremmling (Weather Underground, 2007). The elevation-area-contents relationship used in the Three Lakes Water-Quality Model for Granby Reservoir was also used for the LAKE2K simulations.

## Calibration

The LAKE2K model was calibrated using data for 2005, taking advantage of recent data collected by USBR as part of the Nutrient Study. Observed temperatures for each reservoir layer were computed as volume-weighted average temperatures. The model was run using the default model parameters. The results are shown below in Figure C-1.

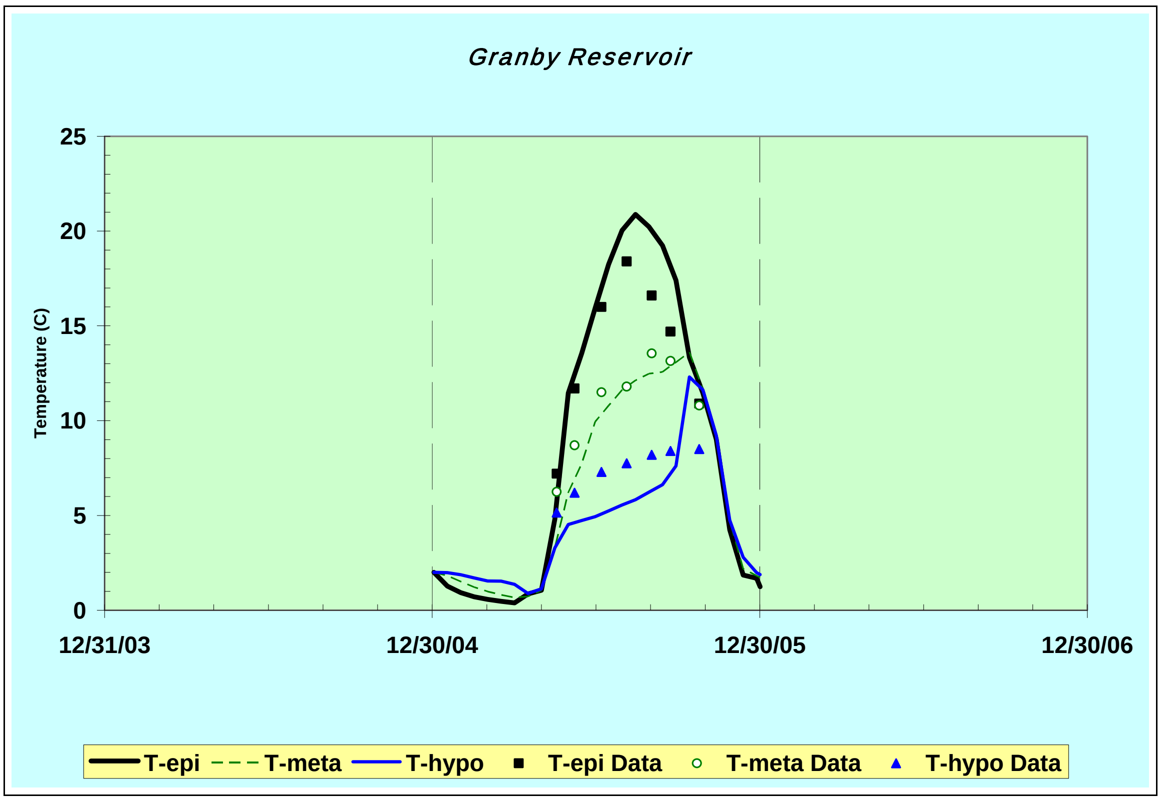


**Figure C-1: LAKE2K Calibration Results**

The simulated results match the observations relatively well, especially for the epilimnion during the first half of the year and the metalimnion. The epilimnetic temperatures are overpredicted in August and September. The model characterizes reservoir temperature well enough to be able to predict changes due to action alternatives relative to existing conditions.

## Evaluation of Alternatives

The model was used to simulate Granby Reservoir temperatures over the period 1975 through 1989. This is the same model period used by the Three Lakes Water-Quality Model. Model runs were made for existing conditions, the direct effects action alternatives (No Action, the Proposed Action, Alternatives 3, 4, and 5), and the cumulative effects action alternatives (No

Action, the Proposed Action, and Alternative 5). Each run used the corresponding flows, consistent with the Three Lakes Water-Quality Model. Meteorological data for 1975-1989 was also used. The results are reported in the main body of this report. It was determined that there were no discernable changes between the alternatives and existing conditions. It was also determined that there would not be any negative impacts on temperature to any of the reservoirs studied in this report, due to the action alternatives.

## References

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