EAST CANYON RESERVOIR AND EAST CANYON CREEK

TOTAL MAXIMUM DAILY LOAD (TMDL)

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Utah Department of Environmental Quality
Division of Water Quality TMDL Section

East Canyon Reservoir TMDL

EPA Approval Date:

Waterbody ID	16020102
Location	Summit and Morgan counties, northern Utah
Pollutants of Concern	Low dissolved oxygen (DO) Excess total phosphorus (TP)
Designated Beneficial Uses	Domestic water use (1C) Primary contact recreation (2A) Secondary contact recreation (2B) Cold water game fish (3A) Agricultural water supply (4)
Impaired Beneficial Uses	Class 3A: Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
Current Load **Loading Capacity (TMDL)** **Margin of Safety (MOS)**	3,350 kgTP/year (9.2 kgTP/day) 2,619 kgTP/year (7.2 kgTP/day) 262 kgTP/year (0.7 kgTP/day)
Defined Targets/Endpoints	Trophic Status and Algae - In-reservoir mean seasonal chlorophyll *a* of 8 µg/L - Nuisance algal threshold of 30 µg/L not to be exceeded >10% of the season - Algal dominance other than blue-green species Dissolved Oxygen (DO) - Mixed reservoir periods: 4.0 mg/L DO throughout at least 50% of the water column - Stratified reservoir periods: 2-m layer throughout the reservoir in which DO is maintained above 4 mg/L and temperature below 20°C Phosphorus - Mean total phosphorus concentration of 0.031 mg/L - Mean dissolved phosphorus concentration of 0.021 mg/L
Wasteload Allocation **Load Allocation**	895 kgTP/year 1,462 kgTP/year - Nonpoint sources load allocation: 1,067 kgTP/year - Internal Reservoir load allocation: 395 kgTP/year
Regulated Point Sources	East Canyon Water Reclamation Facility
Watershed Nonpoint Sources	Spring melt runoff from ski resorts and urban areas Stormwater runoff from construction sites and Park City Streambank erosion Agricultural land uses Natural background sources including phosphatic shales

Utah Department of Environmental Quality
Division of Water Quality TMDL Section

East Canyon Creek TMDL

EPA Approval Date:

Waterbody ID	16020102
Location	Summit and Morgan counties, northern Utah
Pollutants of Concern	Low dissolved oxygen (DO) associated with physical stream characteristics causing light and temperature pollution
Designated Beneficial Uses	Domestic water use (1C) Primary contact recreation (2A) Secondary contact recreation (2B) Cold water game fish (3A) Agricultural water supply (4)
Impaired Beneficial Uses	Class 3A: Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
TMDL	Impairment in East Canyon Creek determined to be related to light and temperature pollution and low flow, associated with physical stream characteristics.
Defined Targets/Endpoints	Macrophyte biomass of 6.3 mg/cm^2 (Ash-free biomass) Minimum DO no less than 4.0 mg/L
Factors Contributing to Impairment	Lack of shade and riparian vegetation along stream Channel widening resulting in shallow reaches Low stream velocity and flow during summer months

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Foreword

This document represents the revised TMDL analysis for East Canyon Reservoir and East Canyon Creek in north-central Utah. The overall goal of the TMDL process is to restore and maintain water quality in East Canyon Reservoir to a level that protects and supports the designated beneficial uses (domestic water use, primary contact recreation, secondary contact recreation, cold water game fish, and agricultural water supply).

This study includes the following components: watershed characterization, beneficial use assessment, and the total maximum daily load analysis. The Watershed Characterization (Chapters 1 and 2) summarizes the physical, biological, and cultural characteristics of the East Canyon Reservoir watershed. The beneficial use assessment identifies in-reservoir water quality concerns, applicable water quality criteria and standards, available data and data sources, potential sources of pollutant loading, indicators of impairment, and an impairment assessment specific to the reservoir's designated uses (Chapter 3). Research related to the impairment in East Canyon Creek in addition to scenario modeling results are described in Chapter 4. The reservoir modeling component of the TMDL process describes the development and use of a reservoir model to describe reservoir dynamics and predict reservoir response under varying climatic and reservoir management conditions (Chapters 5). The source identification and Total Maximum Daily Load (TMDL) analysis quantifies current and projected load to the reservoir, identifies water quality objectives for the reservoir, and negotiated load allocations and reductions required to meet water quality standards (Chapters 6 and 7). Implementation and monitoring plans for East Canyon Creek (Chapter 8) and East Canyon Reservoir watershed (Chapter 9) describe recommended measures and priorities to attain the TMDL. It is important to note that even if water quality in East Canyon Reservoir is found to be impaired and steps are taken to improve it, correction of water quality problems will require successful implementation of a final water quality management plan that will require a coordinated effort of planning and implementation of best management practices between concerned government agencies and landowners in the watershed.

This TMDL was developed by SWCA Environmental Consultants under the direction of the Utah Department of Environmental Quality, Division of Water Quality, and is consistent with Utah Code Title 19, Chapter 5, Water Quality Act, 19-5-104 (powers and duties of board), which identifies the requirement for the development and implementation of TMDLs and/or equivalent processes.

Acknowledgments

The staff at SWCA gratefully acknowledges the time and effort that so many individuals and organizations have dedicated to assist with this project; their help has been indispensable to the success of this project. We would like to specifically acknowledge the efforts of the U.S. Bureau of Reclamation, Utah Division of Water Quality, Utah Division of Wildlife Resources, U.S. Geological Survey, U.S. Department of Agriculture, Natural Resources Conservation Service, Kamas Valley Conservation District, Mountainland Association of Governments, Bio West Consulting, Swaner Nature Preserve, and Snyderville Basin Water Reclamation District for contributions of important background information, data, and review.

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1. Introduction

This document represents the total maximum daily load (TMDL) analysis and implementation plan for the East Canyon Reservoir watershed as required by law.

The Federal Water Pollution Control Act (FWPCA) is the primary federal legislation that protects surface waters such as lakes and rivers. This legislation, originally enacted in 1948, was further expanded and enhanced in 1972 and became known as the Clean Water Act (CWA). This act has been and continues to be subject to change as new information and a more complete understanding of the natural system and our impacts (both positive and negative) are identified. A more thorough discussion of the CWA can be found in *The Clean Water Act: An Owner's Manual* (Elder et al. 1999).

The main purpose of the CWA is to improve and protect water quality through restoration and maintenance of the physical, chemical, and biological integrity of the nation's waterways. The CWA provides a mechanism to evaluate the status of the nation's waters, designate beneficial uses for specific waterbodies, and establish criteria for water quality to protect those uses.

In addition, Section 303(d) of the CWA requires that each state to submit a list of waters that fail state water quality standards. This list of impaired waters must be submitted to the U.S. Environmental Protection Agency (EPA) every two years. For each impaired segment, the CWA requires a TMDL study for each pollutant responsible for the impairment. Once the state has identified the pollutant load discharged from both point and nonpoint sources, controls can be implemented to reduce the daily load of pollutants until the waterbody is brought back into compliance with water quality standards. Once developed, TMDLs are submitted to the EPA for approval. The Utah Department of Environmental Quality (UDEQ) is directed by Utah Code Title 19, Chapter 5, Water Quality Act, 19-5-104 (powers and duties of board), to develop TMDLs.

1.1 THE TOTAL MAXIMUM DAILY LOAD PROCESS

A TMDL study describes the amount of an identified pollutant that a specific stream, lake, river, or other waterbody can contain while preserving its beneficial uses and maintaining state water quality standards.

Those TMDLs completed by the State of Utah include watershed-based plans for restoring beneficial uses of impaired waterbodies. These plans identify the causes of impairment and determine the reduction in pollutant loads necessary to meet standards and restore beneficial uses. Water quality criteria are specific to each use. Of particular importance to the beneficial uses in East Canyon Reservoir and East Canyon Creek are dissolved oxygen (DO), bacteria, temperature, pH, total dissolved solids (TDS), phosphorus, and nitrogen.

The TMDL process involves an evaluation of available data from listed waterbodies to determine the maximum allowable load from point and nonpoint sources of pollution. Pollutant load refers to the quantity of pollution contributed to a waterbody from a single point (e.g., a permitted industrial facility or a wastewater treatment plant (WWTT) or from a group of diffuse sources (e.g., an urban development, agricultural fields, and upland erosion).

A TMDL study outlines a watershed-wide or basin-wide pollution budget for a waterbody. The budget is determined by the amount of pollutants that can be added without causing exceedances of water quality standards; this amount is referred to as the waterbody's loading capacity. Calculations for pollutant loading capacity take into account seasonal variations, natural and background sources of loading, and a margin of safety (MOS) to allow for uncertainty in the analysis. Once the loading capacity is determined, sources of the pollutants are considered.

1.1.1 POINT SOURCES

Point sources of pollution such as WWTPs typically involve pipes that convey discharges directly into a waterbody. A point source is simply described as a discrete discharge of pollutants, as through a pipe or similar conveyance. A technical definition exists in federal regulation at 40 CFR 122.2. Point sources are grouped into a waste load allocation (WLA), which will become part of the TMDL equation.

1.1.2 NONPOINT SOURCES

Nonpoint sources such as roads, farmland, residential landscapes, and construction sites contribute pollution diffusely through runoff. Pollution may result from sources and activities such as livestock grazing, timber harvesting, leaking underground storage tanks, septic systems, fertilizers and pesticides applied to residential yards, construction sites, stream channel alteration, and other diffuse sources. Nonpoint sources are groups into a load allocation (LA) which will become part of the TMDL equation.

1.1.3 LOAD ALLOCATIONS (LA)

Once all point and nonpoint sources are accounted for, pollutants are then allocated among the sources in a manner that will describe the maximum amount of each pollutant (the total maximum load) that can be discharged into a waterbody over a specified amount of time while maintaining water quality standards. The LAs, distributed among the sources, indicate the maximum amount of a pollutant that can be discharged. Ultimately the responsibility for improving water quality belongs to everyone who lives, works, or recreates in the watershed. The TMDL study does not mandate how load reductions must be attained, but it provides recommendations, particularly for nonpoint sources.

Nonpoint sources, grouped as LAs, and point sources, grouped as WLAs, are combined with a MOS when designating the total pollutant load capacity or budget. The MOS accounts for uncertainty in the loading calculations. Combined, the loading capacity equation is:

Loading capacity: **TMDL = WLAs + LAs + MOS**

1.1.4 TMDL SCOPE

Once all point and nonpoint sources are accounted for, including the MOS, TMDLs are drafted to allocate the total pollutant loading among the various sources in a manner that meets water quality standards. The objective of TMDLs is to reduce loading from all point and nonpoint sources to restore the designated beneficial uses of a waterbody.

The TMDL does not specify how sources must attain their particular LA. The TMDL does not dictate best management practices (BMPs) for a source or otherwise tell the source how to meet the reduction goal.

1.2 WHY SHOULD TMDLS BE WRITTEN?

The primary purpose of TMDLs is to accurately estimate the contribution of point and nonpoint sources to total pollutant loads in a waterbody. In the State of Utah, as in many other states, the process of identifying waterbodies for TMDL plans, developing the proper methods to calculate loads from all pollutant sources, and implementing programs to reduce loads in order to meet water quality goals are all ongoing processes. Completing TMDLs for all waterbodies may take years; some will be completed more quickly than others depending on the cause of impairment and the degree to which it is impaired.

Over the past 25 years, pollution control efforts under the CWA have focused on controlling point sources of pollution through the National Pollutant Discharge Elimination System (NPDES) permitting process. Although water quality has improved in many instances, the goals of the CWA have not been met in a number of waterbodies. Data from the EPA suggest that nonpoint sources are now the largest source of pollution in streams and lakes (EPA 2000a).

The implementation of TMDLs should help identify specific links between various sources of pollutants and their aggregate load in waterbodies. The EPA expects that the data collected as part of this process will help local, state, and federal agencies focus and improve their efforts to restore impaired waters.

1.3 Who Is Responsible for Writing TMDLs?

The federal CWA grants individual states the first opportunity to establish TMDLs. In Utah, the bulk of the TMDL work is done by the UDEQ and submitted to the EPA for their approval. However, if the states do not set TMDLs to the EPA's satisfaction, then the EPA is required to do so (CWA §303[d]).

Federal and state statutes require the opportunity for public participation in the TMDL process. Participants may include permitted facilities, affected landowners, regulatory and other governmental agencies, local governments, public interest groups, and concerned citizens. Watershed associations and similar local organizations are encouraged to foster communication, planning, and consensus among those concerned individuals or groups.

1.4 Elements of a TMDL

Generally, TMDLs generally consist of three major sections:

- Waterbody and watershed assessment
- Loading analysis
- Implementation plan(s)

1.4.1 Waterbody and Watershed Assessment

Assessment of the waterbody and watershed describe the affected area, the water quality concerns and status of designated beneficial uses of individual waterbodies, nature and location of pollution sources, and a summary of past and ongoing management activities.

1.4.2 Loading Analysis

A loading analysis provides an estimate of a waterbody's pollutant load capacity and outlines TMDL allocations in accordance with EPA regulations (40 CFR 130.2). The sum of LAs and WLAs must meet the load capacity, with a portion of the load reserved for the MOS. Minor nonpoint sources may receive a lumped allocation.

Generally, a loading analysis is required for each pollutant of concern. However it is recognized that some listed pollutants are actually water quality problems that result from other pollutants. For example, habitat may be affected by sediment or by DO from nutrients that cause nuisance aquatic growths. In such cases, one listed stressor may be addressed by the loading analysis of another.

Although loading analyses are intended to provide a quantitative assessment of pollutant loads, federal regulations allow that "loads may be expressed as mass per unit time, toxicity, or other appropriate measures" (40 CFR 130.2[I]). In many cases, less data will be available than may be considered optimal for loading analysis. This cannot delay TMDL development. Federal regulations also acknowledge that "load allocations are best estimates of the loading, which may vary from reasonably accurate estimates to gross allotments" (40 CFR 130.2[g]).

A complete loading analysis lays out a general pollution control strategy and an expected time frame in which water quality standards will be met. For narrative criteria (criteria based on a qualitative description rather than quantifiable criteria), the measure of attainment of water quality standards is the full support of the waterbody's designated beneficial uses. Long recovery periods (greater than five years) are expected for TMDLs dealing with nonpoint sediment or temperature sources. Interim water quality targets are recommended in these instances. Along with the load reductions, these targets set the sideboards within which specific actions are scheduled in the subsequent implementation plan.

1.4.3 Implementation Plan(s)

Point source WLAs are implemented through an existing regulatory program under the federal CWA called the NPDES permit program (CWA Section 402). The EPA has delegated authority to the State of Utah to administer its own water quality regulatory permit program (UPDES permits). These permits set effluent quality limitations and require the implementation of best available technologies that may include specific BMPs already established by the EPA through existing regulation.

The LA covers nonpoint sources and therefore is not covered by any specific regulatory program. Rather, the LA is usually implemented through incentive-based programs, volunteer efforts, or government-funded projects. Provided that a viable trading framework is in place, pollutant trading is allowed between or within the LA and the WLA categories, but the MOS cannot be traded.

In most cases, pollution load data already exists for most permitted point sources through the NPDES permitting process. A similar level of data density is seldom available for nonpoint sources. Therefore, the TMDL process must develop load calculations for nonpoint sources of pollution and for natural sources of pollution. In many circumstances, nonpoint source contributions are broken down into additional categories such as agriculture, development, forestry, or mining.

Because identifying specific nonpoint sources of pollution for an entire watershed is practically impossible, data is rarely collected on individual nonpoint sources that contribute pollutant loading to a waterbody. Instead, most TMDLs focus on estimating the cumulative or combined contribution of all nonpoint sources.

2. CHARACTERIZATION OF WATERSHED

East Canyon Reservoir watershed is located in north-central Utah approximately 20 miles east of Salt Lake City, Utah and 15 miles north of Park City, Utah (Figure 2.1). The watershed drains 145 square miles that includes Park City, Utah and several major ski resorts at its headwaters and a portion of Snyderville Basin from the Morgan–Summit county line to the headwaters of East Canyon Creek (SBWRD 2005). The watershed covers an elevation range from 5,600 feet (1,707 m) at the reservoir to over 10,000 feet (3,049 m) near Park City. Its principal drainage, East Canyon Creek begins just north of I-80 at the confluence of Kimball Creek from the south and an unnamed creek from the north. From there if flows northeast and north to the reservoir (Judd 1999; SBWRD 2005).

The State of Utah has designated the beneficial uses of the reservoir and creek as domestic drinking water with prior treatment (1C), primary contact recreation (swimming) (2A), secondary contact recreation (2B), cold water game fish and the associated food chain (3A), and agricultural water supply (4). The cold water game fish designated use (3A) was identified as partially supported on the State of Utah 1998 303(d) list (UDEQ 2000a). The 1992–1997 average total phosphorus concentration in the reservoir water column exceeded the state pollution indicator (0.025 mg/L) at 0.117 mg/L (Judd 1999). This led to the development of a TMDL for East Canyon Reservoir in 2000. Since 2000 the largest point source in the watershed, the East Canyon Water Reclamation Facility, has reduced nutrient loads to East Canyon Creek significantly. In addition, BMPs have been implemented to reduce nutrient runoff from nonpoint sources throughout the watershed, and water quality in the reservoir has improved.

The lands in the watershed are almost entirely privately owned. The reservoir shoreline is owned by the State of Utah with unrestricted public access to East Canyon State Park on the eastern side of the reservoir, and restricted vehicle access to the west side of the reservoir. The historical agricultural irrigation use of water has decreased in recent years with a corresponding increase in culinary water use due to increasing population growth, recreation use, and development in the watershed. Population in the study area is projected to increase from approximately 24,000 in 2001 to approximately 64,000 in 2030 and to 86,000 by the year 2050. If per-capita use rates were to continue as at present, this increased population would result in a municipal and industrial demand of approximately 25,000 acre-feet (34.5 cfs) per year in 2030 and 32,000 acre-feet (44 cfs) per year by 2050. However, assuming current water conservation goals are met, the projected demands would be approximately 23,000 acre-feet (32 cfs) per year in 2030 and 27,000 acre-feet (37 cfs) per year by 2050 (Bureau of Reclamation [BOR] 2006). The resident and tourist populations of the area have greatly increased since 1980 (Brooks et al. 1998) with growth rates increasing prior to and following the 2002 Winter Olympics in Park City.

The original TMDL was developed with a limited dataset and therefore was not able to attribute an internal load from reservoir sediments. A revised TMDL is currently under development for East Canyon Creek, incorporating a more detailed modeling of the nutrient spiraling in this tributary to East Canyon Reservoir. The original East Canyon Reservoir TMDL did not designate any additional implementation measures beyond those recommended in the East Canyon Creek TMDL. Therefore, the revised TMDL for East Canyon Reservoir is critical to determine if revised LAs in the East Canyon Creek TMDL are still protective of beneficial uses in East Canyon Reservoir. The incorporation of internal reservoir dynamics that govern phosphorus sedimentation and sediment nutrient release is critical to this reassessment. This requires the development of a reservoir model that accounts for internal processes and incorporates the more comprehensive dataset now available to the TMDL process.

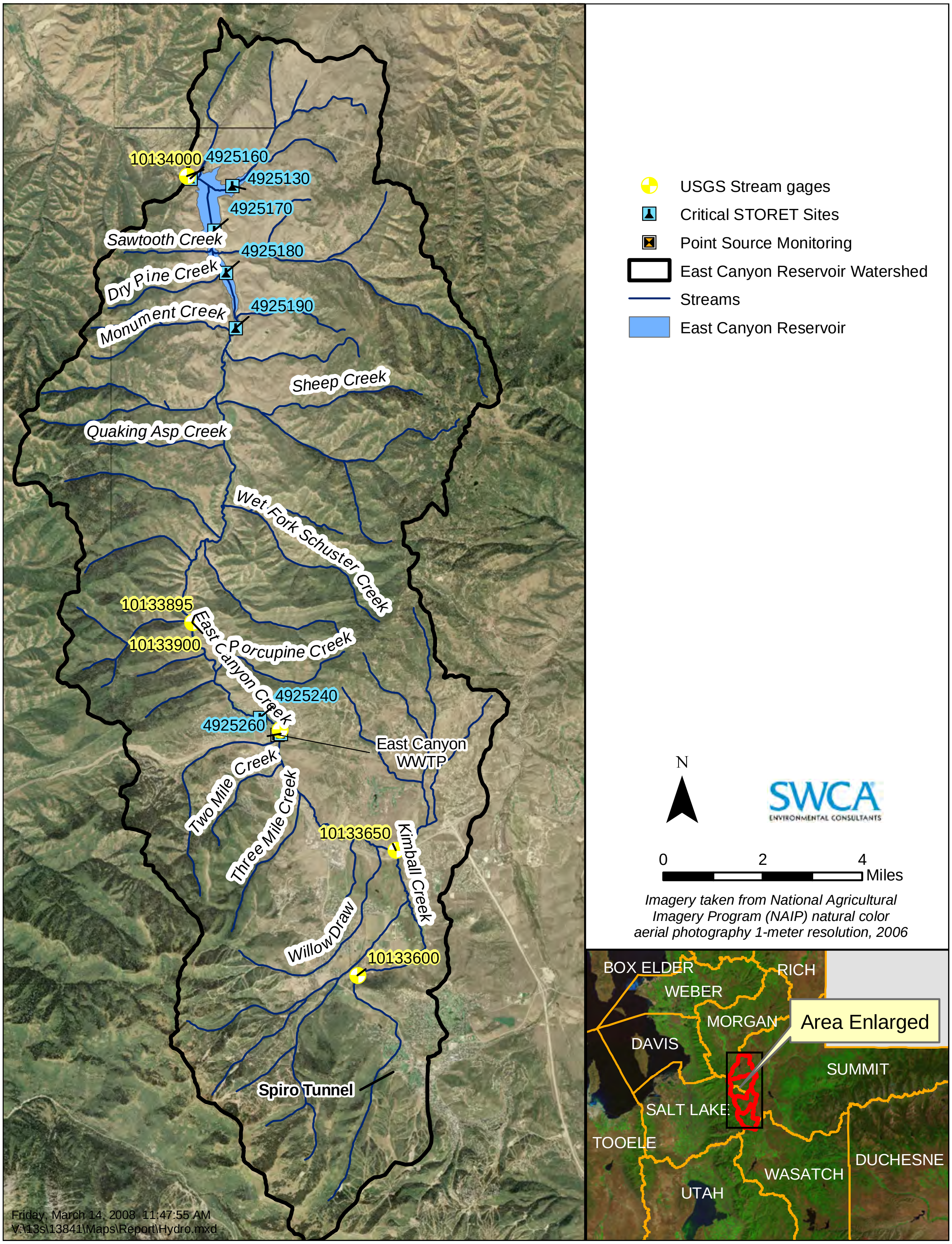


Figure 2.1. East Canyon Reservoir watershed boundary and hydrologic features map.

The only regulated point source in the watershed is Snyderville Basin's East Canyon Water Reclamation Facility (ECWRF). Nonpoint sources of pollutants include urban runoff, streambank erosion, agricultural land use, residential and commercial development, and stormwater. Additional phosphorus sources in the watershed consist of naturally occurring soil phosphate derived from the Phosphoria geologic formation in the southeastern and southwestern portions of the watershed, and phosphorus loading from reservoir sediments due to anoxic conditions.

2.1 Physical and Biological Characteristics

East Canyon Reservoir is an impoundment of East Canyon Creek, the latter of which drains 120 square miles of the eastern side of the Wasatch Range, including Park City and Snyderville Basin. East Canyon Reservoir is approximately 35 miles northeast of Salt Lake City and is one of six reservoirs in the Weber River Basin, which eventually drains to the Great Salt Lake. East Canyon Reservoir is approximately 3 miles (4.8 km) long and 2,000 feet (610 m) wide with a surface area of 681 acres (275 ha) at its full maximum depth of 195 feet (60 m) (BOR 2003). The minimum elevation of the reservoir is 5,577 feet (1,700 m).

The original dam was constructed in 1896, modified to increase storage capacity in 1900 and 1902, and then reconstructed in 1917 and 1966 to further increase the reservoir's water storage capacity to 28,800 acre-feet and 51,200 acre-feet, respectively (Judd 1999; BOR 2003). The reservoir's current active capacity is 48,100 acre-feet, with an additional 1,400 acre-feet of inactive storage and 1,690 acre-feet of dead storage (BOR 2003). The reservoir's drawdown volume is 23,268 acre-feet, with an average depth of 75 feet (23 m) and a maximum depth of 195 feet (59 m) (Judd 1999). The highest elevation in the watershed is at the southern end, with an average slope of 9% from 9,034 feet (2,753 m) near Park City to 5,690 feet (1,734 m) at the reservoir, and an average stream gradient of 4.2% (220 feet per mile) (Judd 1999). Slopes in the watershed range from 0 to greater than 100% (76.8 degrees; Figure 2.2). Most of the inflow to East Canyon Reservoir comes from East Canyon Creek (see Figure 2.1).

There has been a steady increase in residential, recreational, and commercial development in the upper portion of the East Canyon Reservoir watershed from Park City to Jeremy Ranch (BOR 2003). Runoff associated with construction sites and the associated increase in pollutant runoff from developed areas has contributed to water quality impairments identified in East Canyon Reservoir. The 1,210-acre (490-ha) Swaner Nature Preserve occurs in close proximity to most concentrated areas of development in the watershed north of Park City. The preserve contains portions of East Canyon Creek immediately north and south of I-80, and has likely reduced urban and agricultural impacts to water quality along this reach by capturing nutrients and sediments in riparian and wetland areas.

2.1.1 Climate

The climate of the East Canyon Reservoir watershed study area is typical of semiarid central and northern mountainous regions of Utah. The majority of the land is at an elevation of 5,000 feet (1,525 m) or higher, where approximately 65% to 75% of the annual precipitation occurs in the winter months predominantly in the form of snow (Stonely 2004). Much of the water in the reservoir is derived from snowmelt runoff from high elevations and upstream reaches of tributaries.

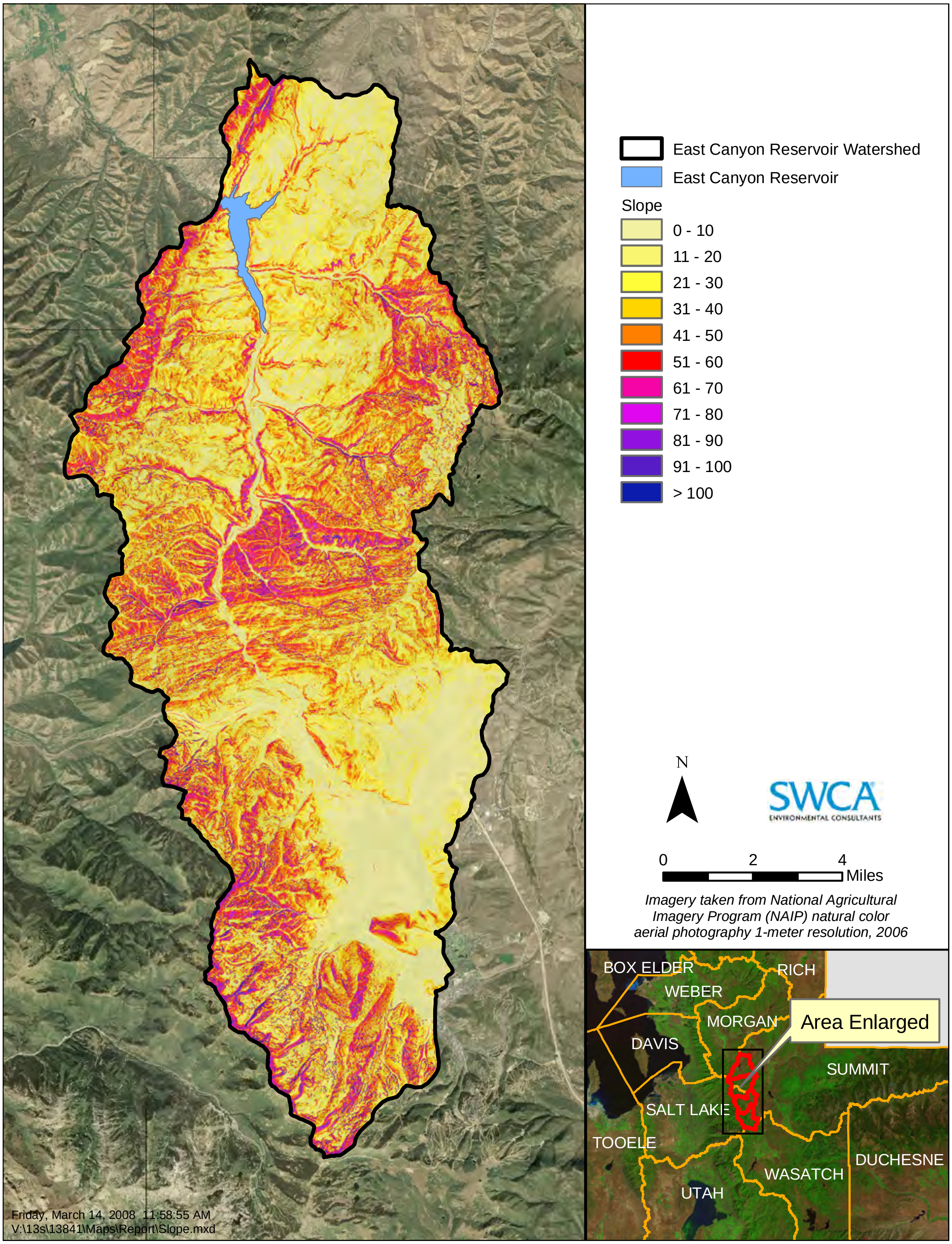


Figure 2.2. East Canyon Reservoir watershed slope map.

Climate data are not available from the reservoir directly. However, three climate sites maintained by the Western Regional Climate Center (WRCC) are available in or near the watershed boundaries: the Mountain Dell Dam Site, the Wanship Dam Site, and the Park City Fire Station 31 site.

The Mountain Dell Dam WRCC site is located at an elevation of 5,420 feet (1,652 m), approximately 8 linear miles southwest of the reservoir. Reported conditions at the site are assumed to accurately represent conditions at East Canyon Reservoir. The site has been in operation since July 1948 to the present, and data are available through June of 2007 (WRCC 2008). Average and extreme minimum and maximum temperatures recorded over the period of record for the Mountain Dell WRCC site are displayed in Table 2.1 and Figure 2.3. Average total monthly precipitation for this site is displayed in Table 2.2 and Figure 2.4.

Table 2.1. Mountain Dell Dam: Average Monthly Air Temperature Data Summary (1948–2007)

	Monthly Average			Extreme High (ºF)		Extreme Low (ºF)	
	Max (ºF)	Min (ºF)	Average (ºF)				
Annual	61.5	32.3	46.9	102	July 1960	-30	Jan 1963
Winter	39.6	15.9	27.7	68	Feb 1963	-30	Jan 1963
Spring	59.1	30.8	44.9	92	May 2003	-14	Mar 1966
Summer	84.4	49.1	66.8	102	July 1960	21	Jun 1966
Fall	62.9	33.4	48.2	95	Sept 1959	-16	Nov 1955

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August;
Fall = September, October, and November.
Source: WRCC 2008.

Table 2.2. Mountain Dell Dam: Average Monthly Precipitation Data Summary (1948–2007)

	Average (inches)	High (inches)		Low (inches)	
Annual	23.81	38.51	1983	14.86	1976
Winter	6.58	14.42	1965	2.50	1990
Spring	7.59	13.14	1957	3.67	1969
Summer	3.50	9.10	1984	0.64	1972
Fall	6.13	13.75	1982	1.22	1952

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August; Fall = September, October, and November.
Source: WRCC 2008.

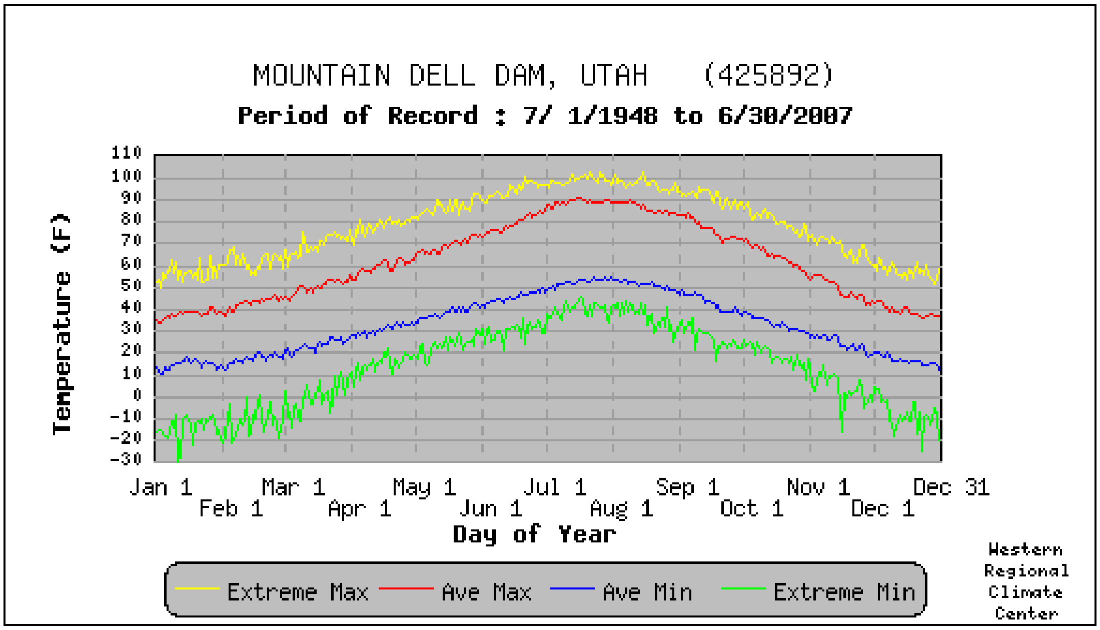


Figure 2.3. Average monthly air temperature conditions at the Mountain Dell Dam meteorological site, Utah (Source: WRCC 2008).

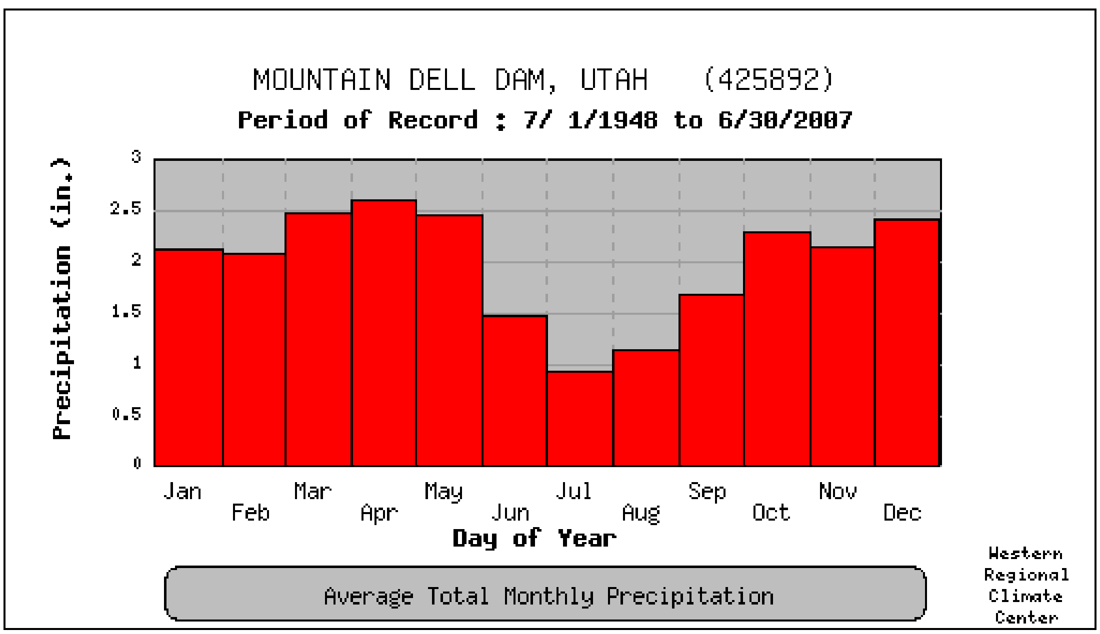


Figure 2.4. Average monthly total precipitation at the Mountain Dell Dam meteorological site, Utah (Source: WRCC 2008).

The Wanship Dam WRCC site is located at an elevation of 5,940 feet (1,810 m), approximately 10 linear miles southeast of the reservoir; it is representative of the topography and elevation of much of the watershed. The site has been in operation since August 1955 to the present, and data are available through June 2007 (WRCC 2008). Average and extreme minimum and maximum temperatures recorded over the period of record for the Wanship Dam WRCC site are displayed in Table 2.3 and Figure 2.5. Average total monthly precipitation for the Wanship Dam Site is displayed in Table 2.4 and Figure 2.6.

Table 2.3. Wanship Dam: Average Monthly Air Temperature Data Summary (1957–2007)

	Monthly Average			Extreme High (°F)		Extreme Low (°F)	
	Max (°F)	Min (°F)	Average (°F)				
Annual	60.3	28.7	44.5	101	Jul 2002	-37	Feb 1982
Winter	38.0	13.2	25.6	66	Feb 1963	-37	Feb 1982
Spring	58.0	28.5	43.2	94	May 2003	-25	Mar 1964
Summer	83.2	44.4	63.8	101	Jul 2002	21	Jun 1966
Fall	62.1	28.8	45.4	93	Sep 1990	-21	Nov 1984

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August;
Fall = September, October, and November.
Source: WRCC 2008.

Table 2.4. Wanship Dam: Average Monthly Precipitation Data Summary (1957–2007)

	Average (inches)	High (inches)		Low (inches)	
Annual	16.15	23.29	1982	9.61	1976
Winter	3.53	8.23	1965	1.29	1961
Spring	4.97	8.80	1995	1.61	1969
Summer	3.15	7.06	1983	0.80	1988
Fall	4.50	9.65	1982	1.14	1999

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August;
Fall = September, October, and November.
Source: WRCC 2008.

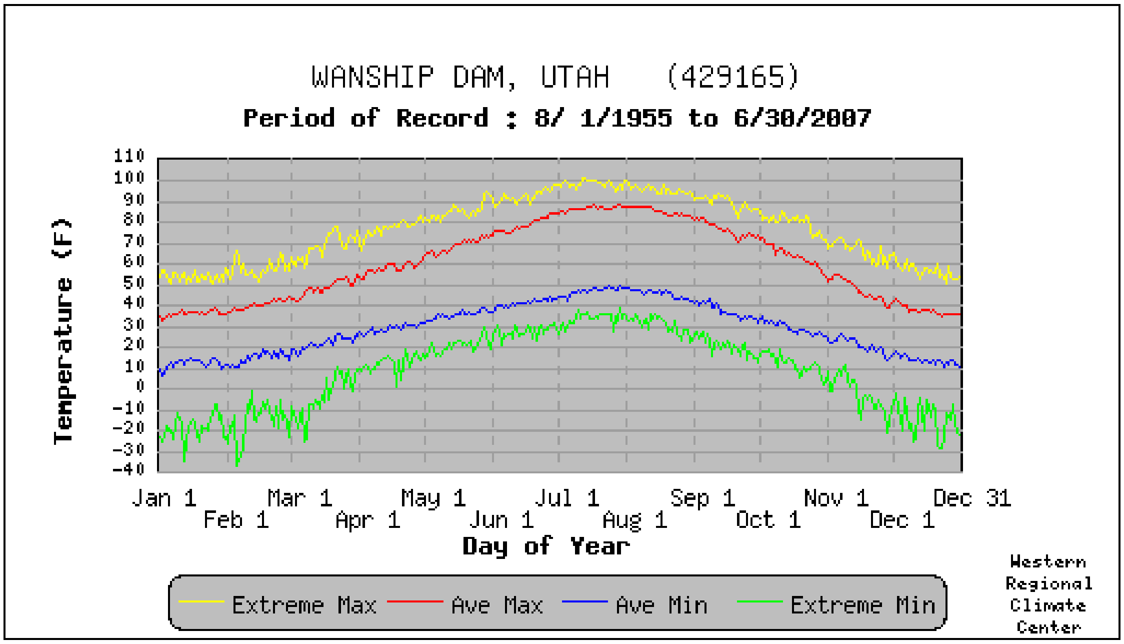


Figure 2.5. Average monthly air temperature conditions at the Wanship Dam meteorological site, Utah (Source: WRCC 2008).

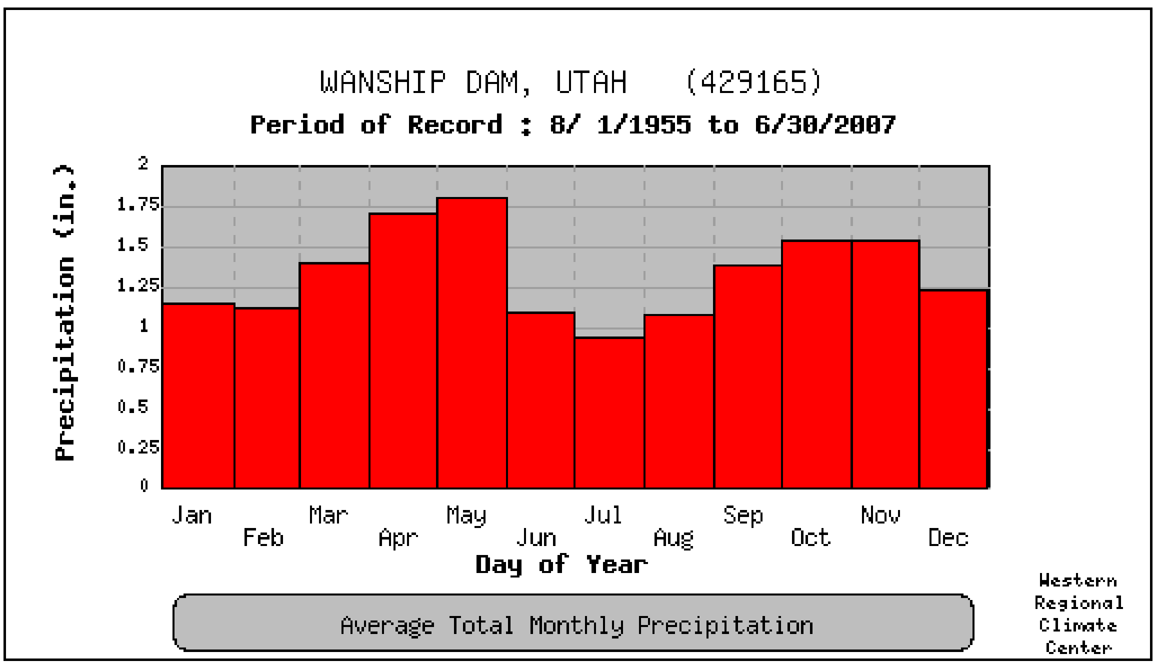


Figure 2.6. Average monthly total precipitation at the Wanship Dam meteorological site, Utah (Source: WRCC 2008).

The Park City Fire Station 31 WRCC site is located at an elevation of approximately 7,000 feet (2,133 m), approximately 15 linear miles south-southeast of the reservoir; it is representative of higher elevation areas in the southern portion of the watershed. The site has been in operation since September 1992 to the present, and data are available through June 2007 (WRCC 2008). Average and extreme minimum and maximum temperatures recorded over the period of record for the Park City Fire Station 31 WRCC site are displayed in Table 2.5 and Figure 2.7. Average total monthly precipitation for the Park City Fire Station 31 WRCC site is displayed in Table 2.6 and Figure 2.8.

Table 2.5. Park City Fire Station 31: Average Monthly Air Temperature Data Summary (1992–2007)

	Monthly Average			Extreme High (°F)		Extreme Low (°F)	
	Max (°F)	Min (°F)	Average (°F)				
Annual	57.0	29.2	43.0	99	Jul 2001	-19	Jan 2007
Winter	35.5	13.6	24.5	57	Dec 1995	-19	Jan 2007
Spring	55.2	28.2	41.6	89	May 2002	-13	Mar 2007
Summer	79.5	45.5	62.5	99	Jul 2001	21	Jun 2002
Fall	57.7	29.5	43.6	87	Sep 2000	-13	Nov 2006

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August; Fall = September, October, and November.

Source: WRCC 2008.

Table 2.6. Park City Fire Station 31:Average Monthly Precipitation Data Summary (1992–2007)

	Average (inches)	High (inches)		Low (inches)	
Annual	20.69	24.41	2005	18.03	2001
Winter	5.59	9.00	1993	3.18	2003
Spring	5.74	7.79	1995	3.08	2007
Summer	3.61	6.85	1998	2.31	2000
Fall	5.74	9.79	2004	1.55	1999

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August;
Fall = September, October, and November.

Source: WRCC 2008.

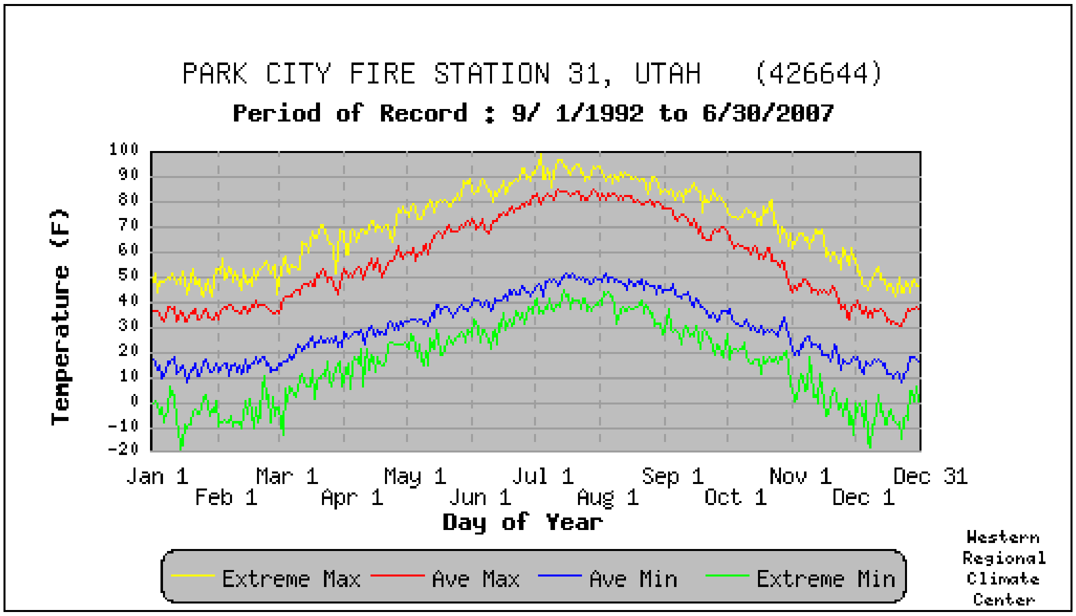


Figure 2.7. Average monthly air temperature conditions at the Park City Fire Station 31 meteorological site, Utah (Source: WRCC 2008).

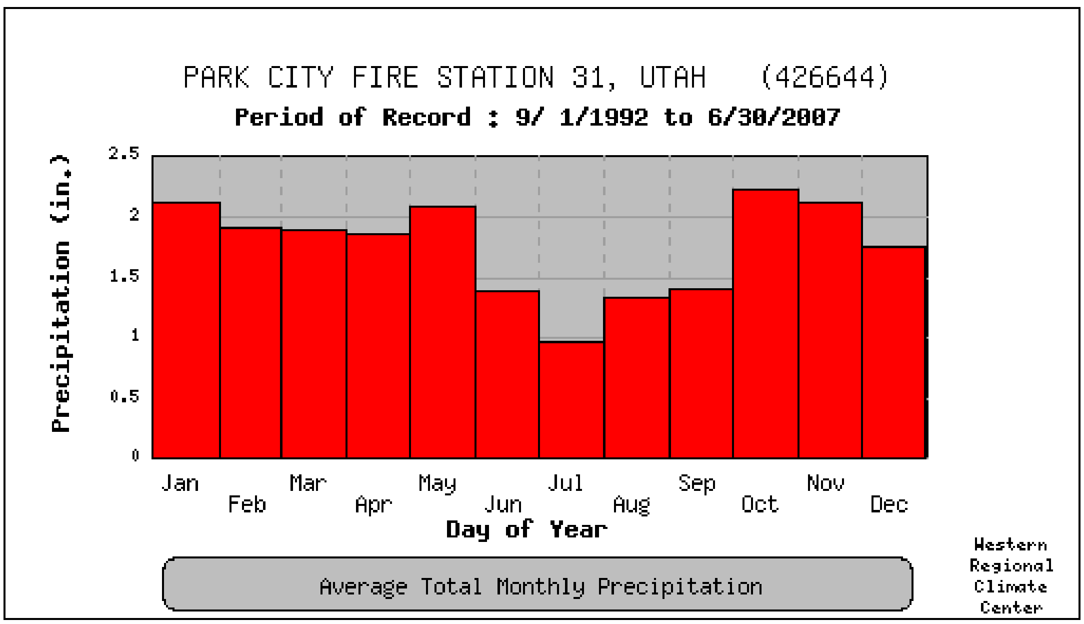


Figure 2.8. Average monthly total precipitation at the Park City Fire Station 31 meteorological site, Utah (Source: WRCC 2008).

Despite their difference in elevation, the observed temperatures and precipitation for the Mountain Dell Dam, Wanship Dam, and Park City Fire Station 31 WRCC sites are relatively similar (Table 2.7). Average precipitation ranges from 16.2 to 23.8 inches across the watershed and average annual temperature ranges from 43^{o}F to 46.9^{o}F.

Table 2.7. Climate Summaries for the East Canyon Reservoir Watershed

Climate Station	Average Annual Precipitation (inches)	Record High (inches)	Record Low (inches)	Average Annual Temperature (ºF)	Extreme High (ºF)	Extreme Low (ºF)
Mountain Dell Dam	23.8	38.5	14.9	46.9	102	-30
Wanship Dam	16.2	23.3	9.6	44.5	101	-37
Park City Fire Station 31	20.7	24.4	18.0	43.0	99	-19

Source: WRCC 2008.

High-elevation meteorological data are available from the Parley's Summit SNOTEL (snow telemetry) site located on the extreme eastern edge of the watershed, about 8.6 linear miles from the reservoir. The SNOTEL site elevation is approximately 7,500 feet (2,286 m) and is assumed to be characteristic of climate conditions in the higher elevations in the watershed. Station data indicate that in the past 20 years, the average annual precipitation is 31.5 inches (80 cm) with a minimum of 22.2 inches (56.4 cm) recorded in 1988 and maximum of 45.3 inches (115 cm) falling in 1995 (National Resources Conservation Service 2008). Mean monthly high temperatures at the SNOTEL station from 1987–2007 ranged from 24.9 ºF (-4 ºC) in December to 64º F (17.8 ºC) in July.

2.1.2 HYDROLOGY

Watershed hydrology includes both surface water and groundwater characterization in relationship to natural precipitation patterns and management. The hydrology of the East Canyon Reservoir watershed has been modified due to historic diversion of streams for mining activities, more recent diversion for irrigation and culinary use, and the impoundment of water in the reservoir itself (Brooks et al. 1998, Judd 1999). There are three other large reservoirs in the area: Echo Reservoir, Rockport Reservoir, and the Jordanelle Reservoir, but there are no impoundments in the Snyderville Basin (SBWRD 2005). In the East Canyon Reservoir watershed, there are several small lakes at high elevation and numerous ponds in the Park City area (see Figure 2.1).

2.1.2.1 Surface Water Hydrology

Most of the inflow to East Canyon Reservoir comes from East Canyon Creek, which drains 80% of the 145 square mile watershed (Judd 1999; SBWRD 2005). High elevation snow and spring runoff from snowmelt provide most of the water in East Canyon Creek, with the highest flows occurring in April and May (BOR 2003). Mean annual precipitation in the East Canyon drainage is 26 to 37 inches (66–94 cm) per year, 73% of which occurs as snow from October to April, with East Canyon Creek flows increasing from approximately 10,859 acre-feet per year (15 cfs) to 253,387 acre-feet per year (350 cfs) during spring runoff between March and May (Judd 1999). East Canyon Creek's headwaters are McLeod Creek near Thaynes Canyon, which receives a major portion of its perennial flow from the Spiro Tunnel and Sullivan Springs near Park City (SBWRD 2005). Groundwater discharge near Park Meadows and Snyderville and small perennial and ephemeral streams contribute to McLeod Creek before it becomes

Kimball Creek, just south of I-80. Kimball Creek joins an unnamed creek from the North to become East Canyon Creek. East Canyon Creek flows west and north from the confluence and receives additional water from Kimball Junction, Threemile Creek, Twomile Creek, Porcupine Creek, the Snyderville Basin WWTP (Judd 1999; SBWRD 2005), and numerous other small drainages along the creek. East Canyon Creek then flows through the Jeremy Ranch Golf Course and residential development before it travels approximately 12 miles (19 km) (ECRFC 2002) through rangelands confined within a narrow canyon before entering East Canyon Reservoir (BOR 2003).

Many of the original stream channels in the watershed have been altered by mining, agriculture and development. Red Pine Creek and Willow Draw no longer flow into McLeod Creek, having been diverted into channels or into the valley. Additionally, a large portion of McLeod Creek is diverted to the West Grade Canal and water is discharged at several other pumping points along McLeod Creek, Kimball Creek and East Canyon Creek (SBWRD 2005). Treated municipal wastewater from the ECWRF averages 3,478 acre-feet (4.8 cfs), which represents a significant portion of discharge into East Canyon Creek, particularly during the summer (SBWRD 2005). From 1939 to 2006, the average annual flow into East Canyon Reservoir from East Canyon Creek was 41,377 acre-feet per year (57.1 cfs) according to U.S. Geological Survey (USGS) flow records for 10134500 (Table 2.8).

Table 2.8. East Canyon Watershed Average Flow and Drainage Area

Gaging Station	Name	Period of Record	Average flow (cfs)	Elevation (feet)	Drainage Area (square miles)
10133600	McLeod Creek near Park City	1994–2006	14.4	6,590	8.8
10133650	East Canyon Creek below the I-80 Rest Stop	2004–2006	23.6	6,360	41.1
10133800	East Canyon Creek near Jeremy Ranch	2002–2006	32.9	6,240	57.2
10133900	East Canyon Creek near Park City, Utah	1982–1985	77.4	6,120	68.9
10133895	East Canyon Creek above Big Bear Hollow	1990–1996 1998–2001	36.0	6,120	75.0
10134500	East Canyon Creek near Morgan, Utah	1939–2006	57.1	5,460	145.0

Source: USGS NWISWeb 2008.

Recent East Canyon Reservoir water retention times vary between wet to dry years from 8 months to approximately 1.5 years, respectively. The average retention time from 2002 to 2007 was one year (Table 2.9). Retention times vary seasonally, with the lowest retention times in April during spring runoff and highest retention times in late summer and early fall. Outflow rates are determined by irrigation use and the associated water rights downstream of the reservoir.

Table 2.9. East Canyon Reservoir Inflow and Retention Times from 2001 to 2007

Water Year	Total cfs	Acre-feet per year	Average Storage Capacity (acre-feet)	Retention Time (years)
2001	23.4	16,987	*	*
2002	34.2	24,803	30,306	1.2
2003	25.0	18,091	29,475	1.6
2004	36.3	26,264	32,825	1.3
2005	65.9	47,751	38,969	0.8
2006	82.8	60,013	39,427	0.7
2007	35.7	25,848	37,175	1.4
Total Average Inflow	**45.7**	**33,114**	**34,390**	**1.0**

*2001 was not included because due to the 2001 water year starting October 1, 2000 for which data was not available.

Source: Reservoir daily storage record obtained from Beau Urionoa, BOR, by Greg Larson, SWCA, in February 2008.

2.1.2.2 Groundwater Hydrology

Groundwater in the upper East Canyon watershed collects in shallow unconsolidated deposits and consolidated fractured rock, and generally flows from high elevations in the southwestern portion of the watershed toward lower elevations in the northeast (Ashland et al. 2001; BOR 2003). The unconsolidated deposits are primarily alluvium, glacial till and glacial outwash, which are thin in most upland areas, generally in excess of 40 feet (12 m) thick in lowland areas and up to as much as 275 feet (220 m) thick in Parley's Park (Ashland et al. 2001). The unconsolidated material is heterogeneous with variable hydraulic conductivity values from 0.1 feet to 60 feet per day and is less productive than consolidated rock, where all public groundwater wells in the watershed are located (BOR 2003). Withdrawals from wells are greatest in late summer when water is needed for lawn and garden irrigation, but this represents a small portion of total groundwater discharge (BOR 2003). Groundwater seepage from wetlands or from excess irrigation may flow back to streams or aquifers; however base flow to streams during spring runoff is the largest component of groundwater discharge in the East Canyon watershed (Brooks et al. 1998; SBWRD 2005). Due to the limited storage capacity of the aquifer, there is a rapid decrease in groundwater baseflow following spring runoff (SBWRD 2005).

There are numerous springs in the East Canyon Reservoir watershed, with four large springs in the upper portion of the watershed discharging more than 200 acre-feet per year (0.276 cfs): Thiriot Springs, Sullivan Springs, Spring Creek Springs, and Twomile Springs (SBWRD 2005). Flows from these springs vary seasonally from 72 to 13,755 acre-feet (0.1–19 cfs) and a portion of these waters are diverted for public water supply and irrigation with excess flowing into the East Canyon Creek watershed (SBWRD 2005).

Spiro Tunnel, located in Thaynes Canyon, extends several miles into the mountains above Park City to intersect a spring that would otherwise flow to the Big Cottonwood Canyon drainage. Spiro Tunnel currently provides 3,791 acre-feet of water to Park City (BOR 2006). A portion of water that flows through the Spiro Tunnel is diverted for municipal water supply, with the remainder diverted to the East Canyon Creek and Silver Creek watersheds. In 2004, discharge from the Spiro Tunnel into McLeod Creek ranged from 723 to 2,895 acre-feet per year (1.0 to 4.0 cfs), but varied with diversions to Silver

Creek (SBWRD 2005). A large portion of McLeod and Kimball Creeks, as well as White Pine Creek, Red Pine Creek and Willow Creek are seasonally diverted into the West Grade Canal west of Quarry Mountain for irrigation purposes (SBWRD 2005). The canal flows north then east to rejoin McLeod Creek, but there is generally no surface water remaining to flow back into the creek in the summer and during dry years (SBWRD 2005).

2.1.3 GEOLOGY AND SOILS

2.1.3.1 Geology

The East Canyon Reservoir watershed is located in north-central Utah in the topographically rugged area to the east of the Wasatch Range knows as the Wasatch Hinterlands section of the Middle Rocky Mountains physiographic province (Stokes 1986). Rainfall in this area has contributed to the development of deep soil and dense vegetation cover with limited outcroppings of bedrock (Stokes 1986). An elongate crustal block bounded by faults, the East Canyon Graben, forms the valley where the reservoir is located. This valley is geologically complex, containing bedrock of varying composition (BOR 2003, Figure 2.9). The remainder of the East Canyon watershed is primarily composed of sedimentary rock and fine-grained alluvial deposits and glacial outwash (Olsen and Stamp 2000a) which produce high sediment loads in East Canyon Creek (Olsen and Stamp 2000a). Permian phosphatic shales (Park City Phosphoric Limestone Formation) occur in two distinct locations: the Threemile and Upper Spring Creek subbasins along the southern side of Threemile Canyon, and the Treasure Hollow and Willow Draw subbasins in the extreme southeastern corner of the watershed in Park City. A large proportion of these subbasins have been recently developed or are in active development, which has likely increased the erosion of phosphatic parent material and phosphorus loading in East Canyon Creek and East Canyon Reservoir (Olsen and Stamp 2000a).

2.1.3.2 Soils

Impacts to water quality from soils are due to streambank erosion and excess nutrients associated with runoff and sediments washed into the stream. As noted by the East Canyon Riparian and Fisheries Committee (ECRFC) (2002), erosion along East Canyon Creek occurs where riparian vegetation is sparse and there is direct disturbance to the streambank from livestock, recreation, or roadways. The soil groups that affect water quality in East Canyon Reservoir are generally the farmland soils near the streams, which are mostly of the Broadhead and Henefer groups characterized by deep topsoil, moderate permeability, and low erosion hazard (Judd 1999) (Figure 2.10). The surface soils in the watershed are not naturally high in phosphorus, with the exception of soils derived from the Park City Phosphoric Limestone Formation, as described in Section 2.1.3.1 above (Figure 2.9). As noted above, there has been recent development in the subbasins where the Phosphoria formation occurs in the watershed, which has likely caused the erosion of phosphatic soils and increased phosphorus loading in East Canyon Creek (Olsen and Stamp 2000a).

Soil data for the East Canyon Reservoir watershed were collected from the U.S. Department of Agriculture (USDA) Soil Conservation Service (NRCS 2007). The dominant soil types in the East Canyon Reservoir watershed are detailed in Table 2.10. The soils vary greatly in texture throughout the watershed (Table 2.11 and Figure 2.11) but generally have low erodibility factors ranging from 0.10 to 0.37 (NRCS 2007).

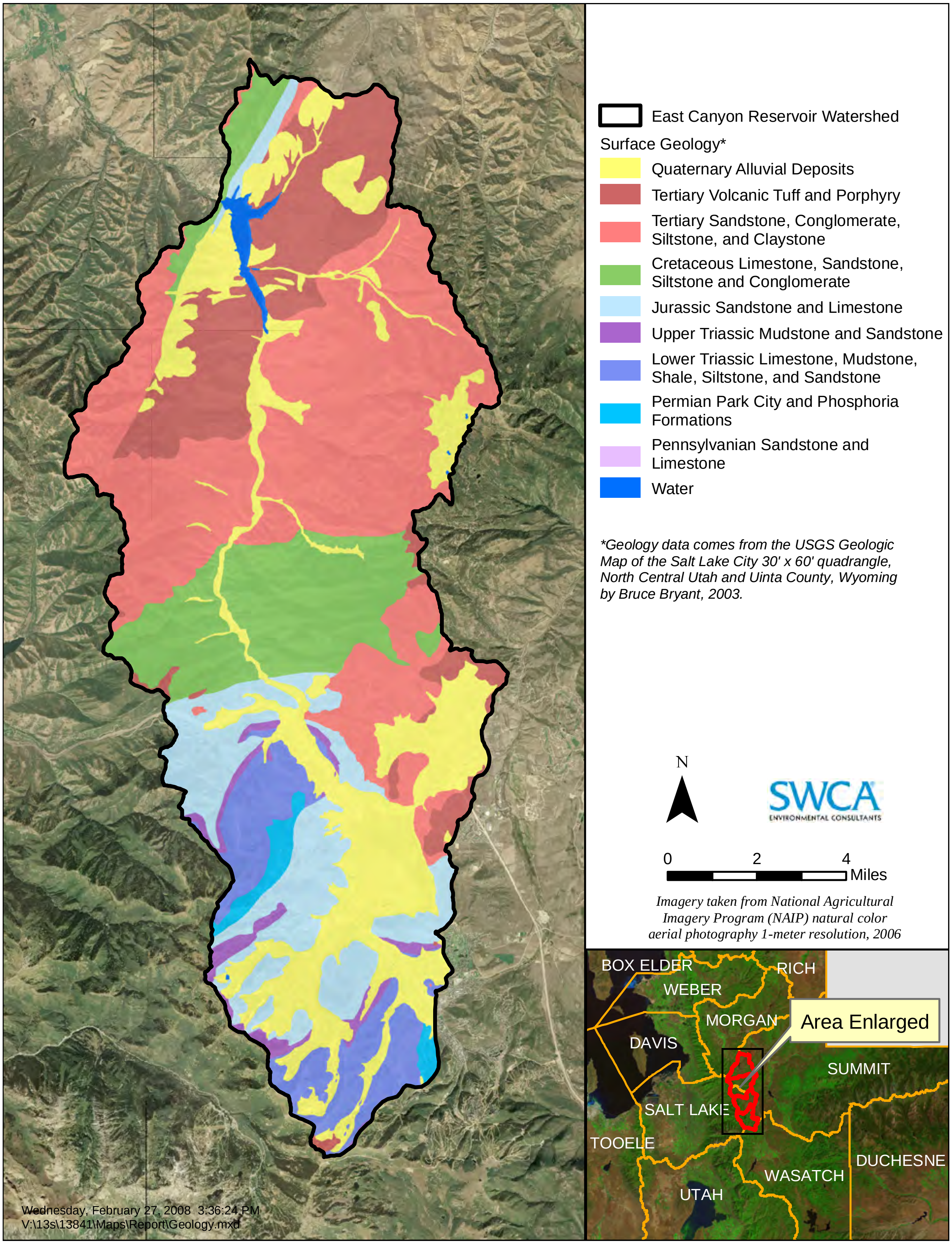


Figure 2.9. East Canyon Reservoir watershed geology map.

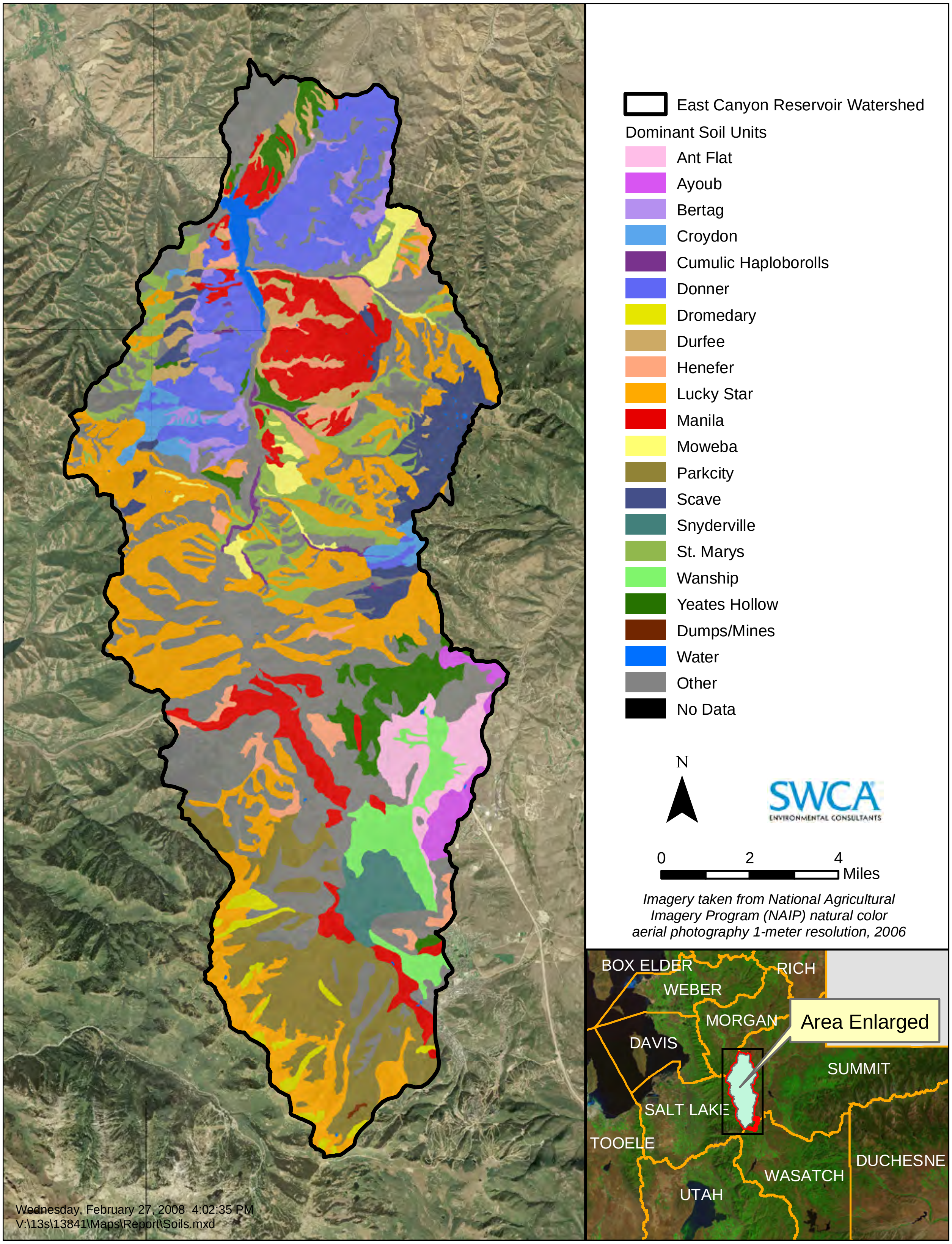


Figure 2.10. East Canyon Reservoir watershed soil classifications.

Table 2.10. Soil Types and Characteristics in the East Canyon Reservoir Watershed

Soil Name	Soil Texture	Estimated Soil Erodibility (K Factor)	Percent of East Canyon Reservoir Watershed
Lucky Star	Gravelly loam/silt loam	0.15/0.28	18.4%
Agassiz	Very cobbly loam	0.10	9.7%
Park City	Gravelly loam	0.10	8.2%
Donner	Cobbly loam	0.15	8.1%
Manila	Loam	0.24	7.5%
St. Mary's	Cobbly loam	0.15	4.8%
Scave	Loam	0.24	3.6%
Yeates Hollow	Cobbly loam/very stony loam	0.05/0.15	3.4%
Schuster	Loam	0.24	3.3%
Wanship	Loam	0.17	2.8%
Henefer	Loam	0.32	2.8%
Ant Flat	Loam	0.28	2.4%
Durfee	Stony loam	0.10	2.3%
Hades	Loam	0.24	1.9%
Fewkes	Gravelly loam	0.15	1.8%
Snyderville	Gravelly loam	0.15	1.6%
Bertag	Cobbly loam	0.20	1.5%
Moweba	Gravelly loam	0.10	1.4%
Croydon	Loam	0.24	1.3%
Ayoub	Cobbly loam	0.15	1.2%
Dromedary	Gravelly loam	0.17	1.1%
Hoskin	Cobbly loam	0.17	1.0%
Other Soils	NA	NA	10.0%

Source. NRCS 2007.

Table 2.11. Soil Texture in the East Canyon Reservoir Watershed

Texture	Acres	Percent
Gravelly loam	25,795.0	28.1%
Loam	24,043.2	26.2%
Cobbly loam	16,122.9	17.5%
Very cobbly loam	10,192.4	11.1%
Silt loam	5,974.6	6.5%
Gravelly fine sandy loam	3,054.5	3.3%
Very stony loam	2,415.8	2.6%
Stony loam	2,149.9	2.3%
Silty clay	1,039.5	1.1%
Water	714.3	0.8%
Variable	221.4	0.2%
Cobbly clay loam	76.4	0.1%
Other	56.1	0.1%
Extremely stony loam	42.5	<0.1%
Rock	37.5	<0.1%
Total	91,936	100%

Source: NRCS 2007.

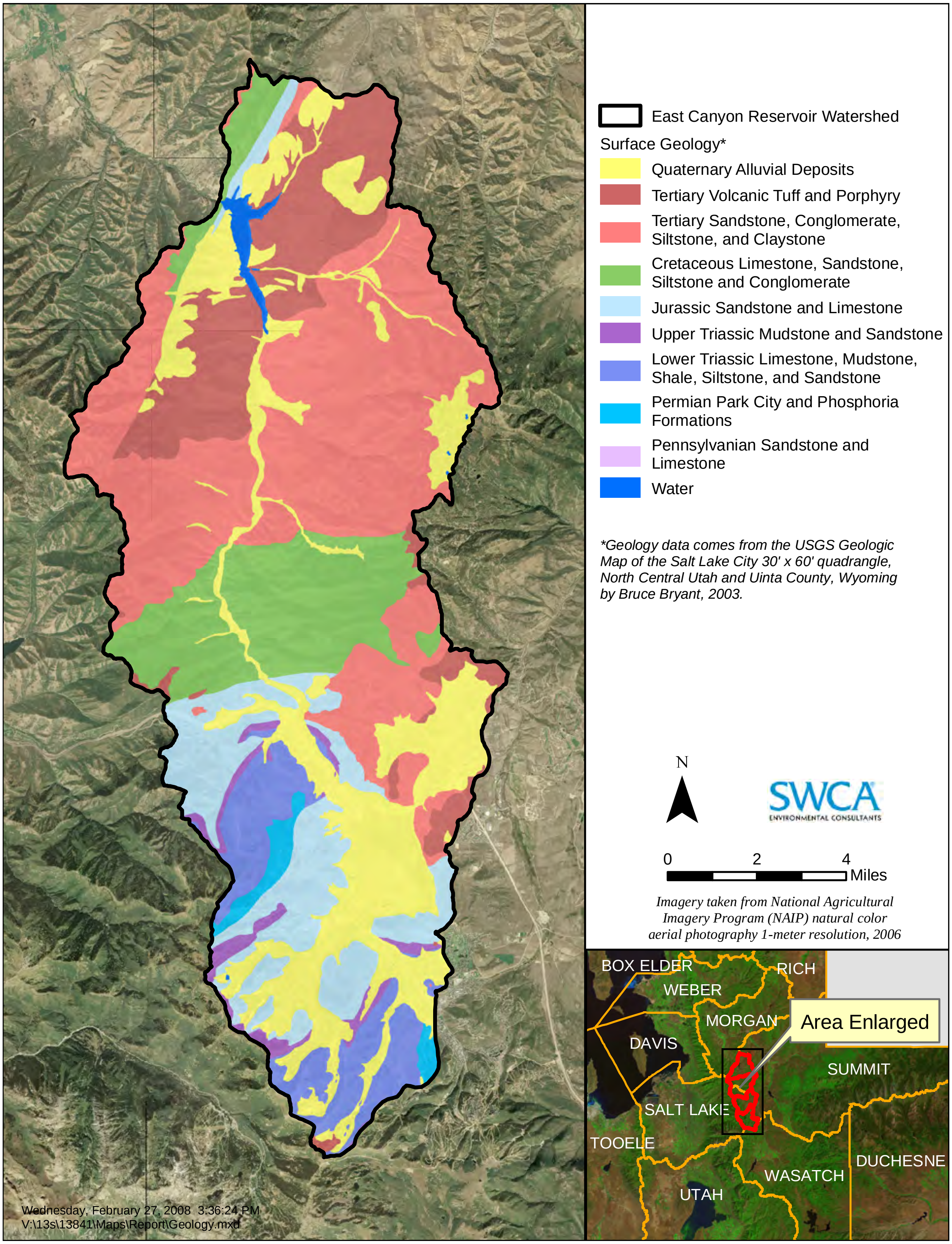


Figure 2.11. East Canyon Reservoir watershed soil textures.

2.1.3.3 Stream Geomorphology

In August 2001, the ECRFC (2002) conducted an inventory of the East Canyon Creek stream channel and riparian corridor using the Stream Visual Assessment Protocol (SVAP) developed by the USDA NRCS National Water and Climate Center (1998). A Stream Erosion Condition Inventory (SECI) developed by the Idaho NRCS was conducted simultaneously with the SVAP. The SECI rated the following criteria in each reach: bank erosion evidence, bank stability condition, bank cover/vegetation, lateral channel stability, channel bottom stability, and in-channel deposition in each reach. The survey included 40 miles (64 km) of East Canyon Creek from Park City to the creek's confluence with the Weber River downstream from East Canyon Reservoir. The stream was divided into 26 reaches based on geographic location, types and amounts of vegetation, impacts, and stream type. Approximately 24 miles (39 km), or 13 reaches of East Canyon Creek from East Canyon Reservoir to Old Ranch Road in Park City are included in the East Canyon Reservoir watershed.

The SVAP rates the overall condition of each stream reach based on average ranking of 14 categories; these rankings are poor (0–6.0), fair (6.1–7.4), good (7.5–8.9), and excellent (9.0–10.4) (NRCS 1998a). The 14 resource categories were combined to assess four general resource conditions for each reach: riparian habitat, fisheries habitat, excess nutrients, and channel function. Combined average ratings for the 13 reaches of East Canyon Creek within the watershed are presented here. The combined average rating for riparian habitat of 5.8 (poor) was based on SVAP rankings of the riparian zone, which averaged 6.9 (fair) in stream reaches in agricultural and grazing land from the mouth of East Canyon Creek above the reservoir to the ECWRF, and 4.7 (poor) in the upper part of the watershed below Old Ranch Road in Park City. The combined average rating for fisheries habitat of 5.1 (poor) was based on SVAP rankings of canopy cover, invertebrate habitat, macroinvertebrates, fish cover, fish barriers, pools, and bank stability. Fisheries habitat rankings averaged 5.27 (poor) in stream reaches through agricultural and grazing land from the reservoir to the ECWRF, and 4.9 (poor) in the upper part of the watershed. The combined average rating for excess nutrients of 5.3 (poor) was based on SVAP rankings for nutrient enrichment, animal waste, and water appearance. Excess nutrient rankings averaged 4.4 (poor) in stream reaches in agricultural and grazing land from the reservoir to the ECWRF, probably due to sewage effluent combined with other factors, and 6.3 (fair) from the ECWRF to Old Ranch Road. The combined average rating for channel function of 6.7 (fair) was based on SVAP rankings for channel condition, hydrologic alteration, and bank stability. Channel function rankings averaged 6.1 (fair) for stream reaches from the reservoir to the ECWRF, and 7.5 (good) from the ECWRF to Old Ranch Road (ECRFC 2002).

According to the SVAP, the most common impairments to channel stability were low riparian vegetation cover, road banks, recreation and livestock access to the stream, excess nutrients from the ECWRF prior to treatment upgrades to remove nutrients, or local development. The condition of East Canyon Creek was variable, with areas of low erosion and good riparian habitat immediately above the reservoir and in one of the uppermost reaches of the creek south of I-80 (Swaner Nature Preserve). The reaches through Jeremy Ranch golf course and the uppermost reach near Old Ranch Road in Park City also had low levels of erosion but riparian habitat was poor due to livestock access in small ranchettes and groomed turf up to the waterway. Several reaches just above the reservoir and below the ECWRF exhibited high rates of bank erosion, but had good riparian habitat with large amounts of woody vegetation. Within these reaches, erosion was noted to be largely due to road banks and livestock access. Reaches with high rates of erosion and poor riparian habitat occur above the reservoir, with areas near the State Park impacted by a primitive camping area, and by land clearing and continuous grazing activities further upstream. More than half of the stream reaches surveyed had excessive nutrient inputs, most occurring downstream from the ECWRF with additional nonpoint sources from sediment and animal waste. The reach just above the reservoir was significantly impacted, potentially due to camping in close proximity to or in the riparian area. One reach in the uppermost portion of the watershed was impacted by excess nutrient inputs from nonpoint sources in Park City (ECRFC 2002). Stream reaches north and parallel to I-80 are mostly in

Swaner Nature Preserve, but are also bordered by residential developments to the north, which may affect water quality and streambank stability.

2.1.4 PLANTS, ANIMALS, AND FISHERIES

The health, diversity, and distribution of vegetation, wildlife, and fish in a watershed can be both an influence on and an indicator of habitat and water quality status. The characteristics of these three categories are often a reflection of the level of use, management, and short-term climate conditions.

2.1.4.1 Riparian Plant Community

The riparian community of the East Canyon watershed is mostly comprised of willow species (*Salix* spp.), currant (*Ribes*), hawthorn (*Crataegus*), and river birch (*Betula nigra*). Herbaceous species include meadow foxtail (*Alopecurus arundinaceus*) (ECRFC 2002), sedges (*Carex* spp.), rushes (*Juncus* spp.), spike rush (*Eleocharis* spp.), and other graminoids (BOR 2003). Riparian areas constitute less than 3% of the watershed, but are ecologically important for maintaining plant diversity and wildlife habitats, bank stabilization, and capture and uptake of nonpoint source pollutants along waterways (Figure 2.12). Riparian areas in the upper portion of the watershed along private ranchettes, the Jeremy Ranch golf course, and I-80 are narrow and do not contain a lot of woody vegetation (ECRFC 2002). Throughout the watershed, the riparian vegetation is limited or absent with actively eroding banks where livestock have access to the riparian zone (ECRFC 2002). Approximately 45 acres of riparian vegetation occur along the shoreline of the reservoir, but the habitat is limited due to seasonal water level fluctuations (BOR 2003). Riparian vegetation may also be limited by seasonal variability in water flow in East Canyon Creek.

2.1.4.2 Dominant Upland Plant Community

East Canyon Reservoir lies on the eastern edge of the Intermountain Semi-Desert and Desert Province and the western edge of the Southern Rocky Mountain Steppe Province (BOR 2003). The climate is relatively dry in the watershed compared to higher elevation areas at the headwaters of East Canyon Creek closer to the Wasatch Front (Judd 1999). Gambel oak (*Quercus gambelii*) and bigtooth maple (*Acer grandidentatum*) associations dominate hillsides across 26.3% of the watershed (see Figure 2.12). Sagebrush (*Artemisia tridentata*) steppe occupies 29.4% of the watershed and is common around the reservoir and at lower elevations. Coniferous trees such as white fir (*Abies concolor*), subalpine fir (*A. lasiocarpa*), Douglas fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), blue spruce (*P. pungens*), and limber pine (*Pinus flexilis*) are dominant on 27.9% of the watershed on north-facing slopes at elevations above approximately 6,000 feet (1,829 m). Alpine tundra zones occur on less than 4% of the watershed and are found above the tree line (Judd 1999). Invasive weeds, specifically cheatgrass, are known to occur in the project area.

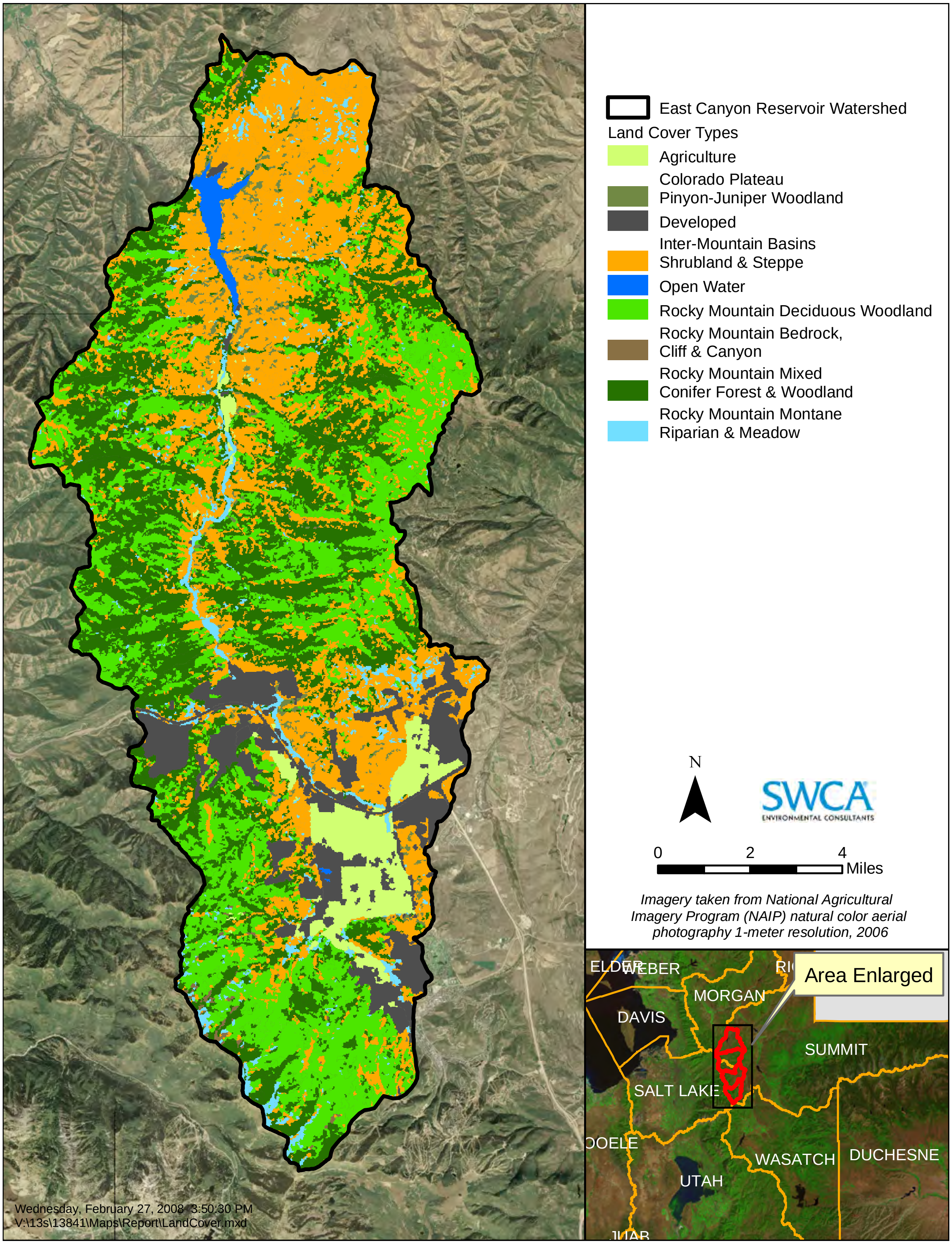


Figure 2.12. East Canyon Reservoir watershed vegetation and land cover.

2.1.4.3 Wildlife

Wildlife in and around East Canyon Reservoir are generally adversely affected by habitat degradation due to recreational activities, trespassing livestock, and water management (BOR 2003). However, some species, such as shorebirds, benefit during seasonal low water levels by increased habitat and prey availability. Overall shoreline habitat is limited by seasonal fluctuations in water levels and scouring of the shoreline that limits the development of riparian vegetation (BOR 2003).

Big game species in the watershed include mule deer, elk and moose. Mountain lions and bobcats are also known to occur in the area (BOR 2003). Beaver activity and dams have been noted along riparian areas in the watershed (ECRFC 2002). Common mammals in the area include yellow-bellied marmot, gophers, coyotes, porcupines, striped skunks, and raccoons. Common waterfowl and shorebird species in and around the reservoir likely include mallard, gadwall, northern pintail, teal, redhead, Canada goose, sandhill crane, killdeer, great blue heron, Clark's grebe, western grebe, gulls, and plovers (BOR 2003). It is likely that some of these species use riparian habitats along East Canyon Creek as well, and bald eagles are known to use riparian areas along the creek as wintering range (Stonely 2004). The upland areas surrounding the reservoir provide abundant small prey for raptors such as red-tailed hawks, Swainson's hawks, golden eagles, and American kestrels (BOR 2003).

2.1.4.4 Fisheries

Historically, East Canyon Reservoir and East Canyon Creek were high-quality trout fisheries and popular angling destinations in northern Utah. Until fairly recently, East Canyon Reservoir provided over 50,000 angling hours and 92 pounds per acre of rainbow trout, but water quality and habitat conditions have continuously degraded over the past 25 years (BOR 2003). The upstream portion of East Canyon Creek historically supported a reproducing population of kokanee salmon, which is no longer present due to degraded water quality (BOR 2003). The reservoir is managed as a cold water fishery, and the DWR stocks East Canyon Reservoir with approximately 300,000 fingerling rainbow trout annually. The reservoir has not been chemically treated to eliminate rough fish competition and so sustains both stocked and self-sustaining fish populations (Judd 1999). Fish species known to occur in the reservoir include black crappie, brown trout, Bonneville and Colorado River cutthroat trout, kokanee salmon, rainbow trout, tiger trout, Utah chub, speckled dace, fathead minnow, redside shiner, smallmouth bass, and cutbows (cutthroat trout × rainbow trout hybrids) (BOR 2003; Nadolski and Schaugaard 2008). East Canyon Creek is currently managed as a wild brown trout fishery with limited numbers of cutthroat and rainbow trout from upstream and the reservoir, respectively (BOR 2003). The Bonneville cutthroat trout, a Utah Sensitive Species, historically occurred in East Canyon Creek but is no longer believed to be present due to decreased flows, increased nutrient input, and degradation to water and habitat quality (BOR 2003).

Reservoir water quality has been impacted by agricultural and recreational land-use practices, and by upland development and highway construction in the area. In the 1990s the cold water fishery was impacted by blue-green algal blooms and depleted DO levels in the hypolimnion during the winters and summers of some years (Judd 1999; BOR 2003). Oxygen levels on the bottom of the reservoir are still depleted during summer months. This represents a dramatic change from the information presented in the "East Canyon Reservoir-Water Quality Assessment" (Merritt et al. 1980) where DO at the bottom of the reservoir was shown to rarely drop below 4 mg/L even in summer months. Sport fish species are seasonally stressed by high water temperatures and low oxygen conditions in the reservoir, and may become more susceptible to parasites, such as the rainbow trout parasitic anchorworm (*Lernaea)*. These conditions compromise the overall health and survival of affected fish. Fingerling rainbow trout stocked in the spring have not survived recent summers and the UDWiR is evaluating the feasibility of establishing a warm water fishery in the reservoir (BOR 2003).

Today East Canyon Reservoir is managed as a basic-yield trout fishery and is maintained by stocking sub-catchable rainbow trout and catchable tiger trout. Recent monitoring of the fishery indicates that the abundance and diversity of fish species netted is low throughout East Canyon Reservoir. Rainbow trout compose 94% of the total fish biomass, and tiger trout compose the remaining 6%. A diversity of age and size classes was not present in 2007 for rainbow trout in East Canyon Reservoir, with a noticeable absence of smaller fish. This is most likely due to poor survival over the winter of 2006–2007 (Nadolski and Schaugaard 2008). Compared to 2005 data, size structure of rainbow trout in East Canyon Reservoir has become unbalanced and is now dominated by fish greater than 280 mm in length (Nadolski and Schaugaard 2008). Survival of tiger trout in the reservoir is generally poor and may be attributable to water quality and the presence of the anchorworm (Nadolski and Schaugaard 2008).

2.1.4.5 Special Designations

Federally listed wildlife species known to occur in the watershed include experimental population of the endangered black-footed ferret, the threatened Canada lynx, and a candidate for listing, the yellow-billed cuckoo (UDWiR 2008). Other species on the *Utah Sensitive Species List* include the bobolink, bald eagle, ferruginous hawk, greater sage-grouse, sharp-tailed grouse, Lewis's woodpecker, long-billed curlew, northern goshawk, three-toed woodpecker, grasshopper sparrow, Columbia spotted frog, western toad, and smooth greensnake (Table 2.12). Utah sensitive fish species known to occur in the watershed include the Bonneville cutthroat trout, Colorado River cutthroat trout, bluehead sucker, and leatherside chub. No threatened, endangered or sensitive plants are located in the project area.

Table 2.12. Utah Sensitive Species in Morgan and Summit Counties

Morgan County		
Common Name	**Scientific Name**	**State Status***
Bald Eagle	*Haliaeetus leucocephalus*	S-ESA
Bluehead Sucker	*Catostomus discobolus*	CS
Bobolink	*Dolichonyx oryzivorus*	SPC
Bonneville Cutthroat Trout	*Oncorhynchus clarkii utah*	CS
Deseret Mountainsnail	*Oreohelix peripherica*	SPC
Ferruginous Hawk	*Buteo regalis*	SPC
Grasshopper Sparrow	*Ammodramus savannarum*	SPC
Gray Wolf	*Canis lupus*	S-ESA
Greater Sage-Grouse	*Centrocercus urophasianus*	SPC
Lewis's Woodpecker	*Melanerpes lewis*	SPC
Lyrate Mountainsnail	*Oreohelix haydeni*	SPC
Northern Goshawk	*Accipiter gentilis*	CS
Sharp-tailed Grouse	*Tympanuchus phasianellus*	SPC
Western Pearlshell	*Margaritifera falcata*	SPC
Western Toad	*Bufo boreas*	SPC
Yellow-billed Cuckoo	*Coccyzus americanus*	S-ESA

Table 2.12. Utah Sensitive Species in Morgan and Summit Counties

Summit County		
Common Name	**Scientific Name**	**State Status***
Bald Eagle	*Haliaeetus leucocephalus*	S-ESA
Bluehead Sucker	*Catostomus discobolus*	CS
Bobolink	*Dolichonyx oryzivorus*	SPC
Bonneville Cutthroat Trout	*Oncorhynchus clarkii utah*	CS
Brown (Grizzly) Bear	*Ursus arctos*	S-ESA
Canada Lynx	*Lynx canadensis*	S-ESA
Colorado River Cutthroat Trout	*Oncorhynchus clarkii pleuriticus*	CS
Columbia Spotted Frog	*Rana luteiventris*	CS
Deseret Mountainsnail	*Oreohelix peripherica*	SPC
Ferruginous Hawk	*Buteo regalis*	SPC
Greater Sage-Grouse	*Centrocercus urophasianus*	SPC
Leatherside Chub	*Gila copei*	SPC
Lewis's Woodpecker	*Melanerpes lewis*	SPC
Long-billed Curlew	*Numenius americanus*	SPC
Northern Goshawk	*Accipiter gentilis*	CS
Smooth Greensnake	*Opheodrys vernalis*	SPC
Three-toed Woodpecker	*Picoides tridactylus*	SPC
Western Pearlshell	*Margaritifera falcata*	SPC
Western Toad	*Bufo boreas*	SPC

Source: UDWiR 2007. Utah Conservation Data Center

Disclaimer: This list was compiled using known species occurrences and species observations from the Utah Natural Heritage Program's Biodiversity Tracking and Conservation System (BIOTICS); other species of special concern likely occur in counties in Utah. This list includes both current and historic records.

S-ESA = Federally listed or candidate species under the Endangered Species Act.

CS = Species receiving special management under a Conservation Agreement in order to preclude need for federal listing.

SPC = Wildlife species of concern.

2.2 CULTURAL CHARACTERISTICS

2.2.1 LAND USE AND OWNERSHIP

The watershed is predominantly forest (62%) and shrub/scrub (31%) habitat, the majority of which is privately owned (96%) (Table 2.13 and Figure 2.13). The second largest landowner is the United States Forest Service with jurisdiction over 2% of the land (Table 2.14). The privately owned land is used for residential and commercial development, ski resorts, and agricultural purposes. Agricultural operations include croplands and grazing for cattle and sheep. However, only 6% of the land in the watershed boundary is considered developed or agricultural (see Table 2.13 and Figure 2.14). The steep mountain slopes and forested land cover limit the amount of private development that can occur in the area.

Development is concentrated along Interstate 80 which connects the Snyderville Basin to Salt Lake City to the west and Evanston, Wyoming to the north.

Table 2.13. Land Use in the East Canyon Creek Watershed

	Area (acres)	Percentage of Total Land
Deciduous Forest	44,258.1	48%
Shrub/Scrub	28,121.1	31%
Evergreen Forest	12,628.1	14%
Developed Uses	4,228.8	
Pasture/Hay	993.6	1%
Open Water	599.4	1%
Mixed Forest	464.7	1%
Cultivated Crops	368.5	<1%
Woody Wetlands	228.6	<1%
Barren Land (Rock/Sand/Clay)	36.8	<1%
Grassland/Herbaceous	8.4	<1%
Total	**91,936**	**100%**

Source: USGS 2007

Table 2.14. Land Ownership in the East Canyon Creek Watershed

	Area (acres)	Percentage of Total Land
Private	88,130	96%
U.S. Forest Service	1,761	2%
State Parks and Recreation	747	1%
Water	650	1%
State Trust Lands	549	1%
State Wildlife Resources	99	<1%
TOTAL	**91,936**	**100%**

Source: 1995 Utah GAP Analysis project, Remote Sensing and GIS Laboratories, Department of Geography and Earth Resources, Utah State University, Logan.

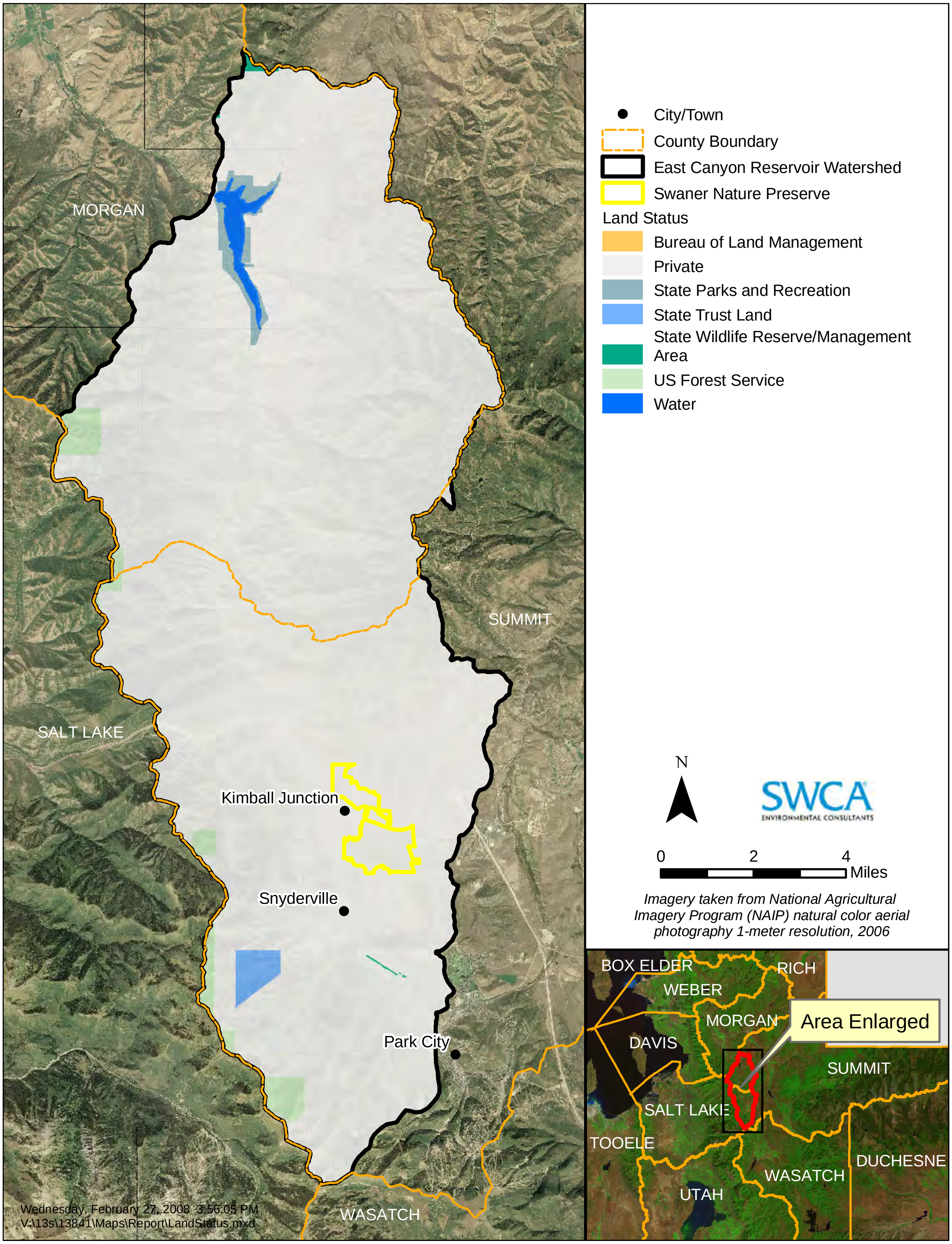


Figure 2.13. East Canyon Reservoir watershed land ownership.

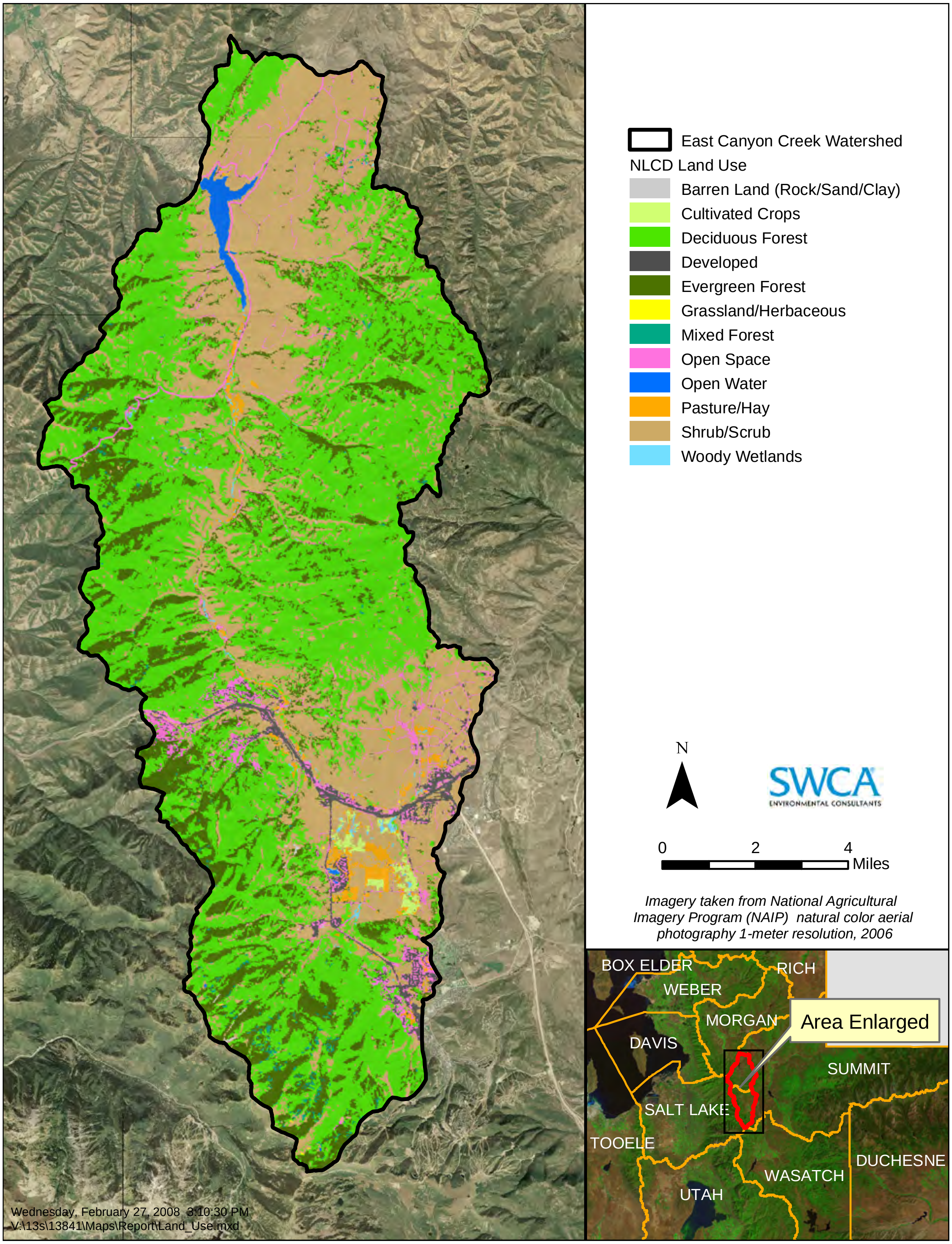


Figure 2.14. East Canyon Reservoir watershed land use.

2.2.2 POPULATION

The East Canyon Reservoir watershed lies in Summit and Morgan counties. Both of these counties have experienced considerable growth in the past decade; however, population growth in Summit County has been remarkable. Although the statewide population growth average from 1990 to 2000 was 29.6%, Summit County's population grew 91.6%. Park City has nearly doubled since 1990 from 4,468 residents to 7,497 in 2005. According to the Utah Governor's Office of Planning and Budget (GOPB), Morgan County's population increase was more consistent with the state average at a 29.0% increase (GOPB 2000). Populations in both counties are anticipated to increase exponentially in the coming decades. See Table 2.15 for population projections through 2050. The population center of the East Canyon Reservoir watershed lies in the Snyderville Basin. The Snyderville Basin includes the Park City and the unincorporated areas outside of the city limits. The population projections for Snyderville Basin are represented as the "Balance of Summit County" in Table 2.15. This number includes area residents living outside of incorporated cities and towns in Summit County.

Table 2.15. Population in East Canyon Reservoir Watershed

County/City	Population 2005	Estimated Population 2030	Estimated Population 2050
Summit County	36,417	85,660	132,681
Park City	7,497	16,312	n/a
Balance of Summit County	15,734	31,887	n/a
Morgan County	8,525	24,595	46,596
Total	**68,173**	**158,454**	**179,277**

Source: GOPB 2005; GOPB 2000a.

2.2.3 HISTORY AND ECONOMICS

Land use in the East Canyon Reservoir watershed has historical ties to the agricultural and mining industries. In the 1850s, European settlers began to colonize what is now considered Morgan and Summit counties (Hampshire 1998; Smith 1999). The high mountain valleys were ideal for agricultural practices. Numerous cattle, sheep, mink, and poultry farms were established by the turn of the century. Field crops produced in the area included barley, oats, alfalfa, and vegetables. Mining practices began in the 1870s upon the discovery of silver, coal, lead, and zinc in the Wasatch Mountains. Concentrated primarily in Summit County, the mining boom continued until the 1950s. Once the price of silver and other minerals began to drop and extraction was no longer deemed profitable, miners deserted the Park City area.

Although agricultural practices continued to be a way of life for residents in Morgan County in the mid-1900s, mining companies began to construct ski areas and golf courses on the previously mined lands in Summit County. In the 1960s the Park City area was reborn as a recreation destination. The development of three ski resorts, numerous golf courses, shopping, and luxury homes in the Snyderville Basin suggests that recreation and tourism has become a way of life for western Summit County. Today, recreation and tourism are undoubtedly the economic drivers in western Summit County. Eastern Summit County and Morgan County continue to maintain their agricultural roots but there are few residents in these counties who earn their living solely from agricultural production. Many residents are employed in the retail and trade sectors outside of the high mountain valleys. Because current economic conditions make farming and ranching a difficult way to earn a living, many landowners have begun to sell their land to residential developers (Smith 2007).

For nearly a decade the Snyderville Basin has been subject to tremendous growth pressure. Since the 2002 Winter Olympics the area has seen outstanding residential, commercial, and industrial development. The attractions of a year-round recreation destination have placed considerable strain on Snyderville Basin's infrastructure, water quality, and quantity. As illustrated in the land ownership map (Figure 2.13), the large amount of privately owned land (96%) in Morgan and Summit counties suggests that the area will be susceptible to development pressures for years to come.

2.2.4 RECREATIONAL USES OF EAST CANYON RESERVOIR

The recreational amenities of East Canyon Reservoir gained recognition in 1967 after the BOR completed the modern-day dam. Recreational facilities, managed by Utah Division of State Parks and Recreation, include a wide concrete boat ramp, modern restrooms with showers, sewage disposal, a 31-unit campground with a large overflow area, and fish cleaning stations. A concessionaire provides snacks and boat rentals. The fishery is stocked by the Utah Division of Wildlife Resources (Smith 1999). The reservoir is located approximately 35 miles northeast of Salt Lake City and accessible to motorists via Highway 65 and 66 which have connections to I-80 and I-84.

Recreational activities in the watershed area include cross-country skiing, fishing, boating, swimming, camping, picnicking, ice fishing, and water skiing. State park records indicate that the majority of recreational users are residents of nearby Salt Lake, Weber, Davis, Cache, Morgan, Tooele, and Summit counties.

Visitation to the East Canyon Reservoir State Park has fluctuated in recent years as indicated in Table 2.16. The average annual number of visitors is 85,423. Currently, visitation is measured by using a car counter and a visitor per car multiplier. It has been difficult for park managers to discern the specific type of usage per visitor. For example, although one user may come for a picnic in the day use area and go boating as well, another visitor may go boating and fishing. Park managers report the three most popular uses are boating, picnicking, and camping (personal communication between John Sullivan, East Canyon Reservoir State Park Manager, and Laura Vernon, SWCA, on February 14, 2008). Park visitation peaks during June, July, and August.

Table 2.16. East Canyon Reservoir State Park Visitation

Year	Number of Visitors
2002	105,737
2003	71,101
2004	57,371
2005	Unavailable
2006	94,807
2007	98,101

Source: personal communication between John Sullivan, East Canyon Reservoir State Park Manager, and Laura Vernon, SWCA, on February 14, 2008

East Canyon Resort is a privately owned 9,600-acre recreation-based resort that has been in operation since 1982. The property contains 32 town homes and an RV park that includes 84 hook-ups, restaurants, tennis courts, a mini-golf course, and hunting opportunities. East Canyon Resort is located southeast of the reservoir. It is generally assumed that patrons to East Canyon Resort also visit the reservoir.

2.2.4.1 Boating and Related Activities

Although previous reports suggest that fishing was once the most popular pastime at the reservoir, park managers today are suggesting that boating and water-sport activities are the most popular activities followed by picnicking and camping. On weekends the reservoir is crowded with boats, jet skis and other motor-powered watercraft. Boaters will often use the day-use areas for picnicking and camping areas for overnight stays. Swimming is also popular on the lake during the summer months. As noted above, peak months for swimming and boating are June, July, and August. In recent years park managers have reported that weekend park closures, during peak months, have been necessary as the parking lots have been at full capacity. In 2007 the East Canyon State Park was closed approximately 25 to 33 summer weekend days due to lack of parking. The number of closures in 2006 was considerably less at 6 to 10 days. The increase in closures from 2006 to 2007 could be a result of the closure of boat ramps at nearby lakes (Willard Bay and Deer Creek) (personal communication between John Sullivan, East Canyon Reservoir State Park Manager, and Laura Vernon, SWCA, on February 14, 2008). Weekdays are reported to be far less crowded with a larger percentage of the population fishing in comparison to other activities on the weekends.

As noted above, fishing was once a very popular pastime on the reservoir but has declined in previous decades. The decline could be attributed to the rise in popularity of motorized water sports, which undoubtedly makes fishing a challenge. Declining water quality and subsequent reduction in fish populations may also be attributed to the decrease in anglers. In previous years the reservoir was stocked with 300,000 rainbow trout for recreational fishing. East Canon Reservoir also had an annual run of kokanee salmon and healthy populations of cutthroat and brown trout. Today kokanee salmon no longer exist in East Canyon Reservoir, trout populations have been significantly reduced, and fish are stocked in the reservoir during the fall because of summer die-off (Nadolski and Schaugaard 2008)

There are no reports of park closures due to *Escherichia coli* or other potentially harmful bacteria. In warm summer months algal blooms may appear in the reservoir, and although visitors have commented on the presence of these blooms, they do not appear to deter swimmers and other users from their activities.

2.2.4.2 Hunting and Wildlife Observation

East Canyon Wildlife Management Area is located in the watershed, north of the reservoir, and was acquired in 1985 as an important big-game winter range. The area is managed by the Utah Division of Wildlife Resources and is used primarily for deer hunting. Neotropical migratory birds can be observed along riparian corridors. Hikers visiting the area also enjoy the scenery of Red Rock Canyon (UDWiR 2002).

The East Canyon Resort offers deer hunting on their nearby property. In 2005, 352 deer hunting applications were received by the resort. An annual harvest of approximately 50 buck occurs on the private property (Austin 2006).

2.2.4.3 Camping

The state park offers 15 tent sites and 31 recreational vehicle sites. Other than the recreational vehicle campsites offered at East Canyon Resort, there are no other campgrounds in the area and little public land is available for dispersed camping.

2.2.5 Public Involvement

Throughout the TMDL process, local experience and participation were invaluable in identifying water quality issues and developing reduction strategies at the local scale. Because of the potential influence of the TMDL process on the local community and the dependence of any implementation plan on local participation, public involvement is viewed as critical to the entire TMDL process.

The East Canyon Watershed Committee attends quarterly meetings to discuss water resource issues in the basin. Feedback is welcomed from members of the committee and the public at large. Numerous members of the committee have contributed data, documents, and valuable input to the TMDL process. The watershed advisory group comprises local representatives from all major sectors of the local community as follows:

- Utah Department of Agriculture and Food
- Snyderville Basin Water Reclamation District
- Morgan County Health Department
- Weber Basin Water Conservancy District
- UDEQ/Division of Water Quality
- Utah Department of Natural Resources/Division of Wildlife Resources
- Kamas Valley Conservation District
- BOR
- Mountainland Association of Governments
- BIO-WEST Consulting
- Stantec Consulting
- Swaner Nature Preserve
- Citizens at large
- Environmental interests
- Sporting or recreational interests
- Agricultural interests
- Timber interests

Committee members are encouraged to work directly with their respective interest groups to provide direction to UDEQ in developing and implementing a watershed management plan. They may also help identify funding needs and sources of support for specific projects that may be implemented. The watershed advisory group is encouraged to assist in setting priorities for spending restoration funds and in periodically reviewing progress toward water quality improvement goals.

SWCA, in cooperation with the UDWQ and the East Canyon Watershed Committee, presented the findings of the TMDL at a public meeting on July 9, 2008 at the Sheldon Richins Building in Park City. A 30-day public comment period from October 15 to December 1, 2008 was advertised in local newspapers (*The Salt Lake Tribune, Deseret News,* and *Park Record*) and on the UDWQ website. No written comments were received during the 30-day comment period.

3. WATER QUALITY CONCERNS AND STATUS

This section defines impaired waters, outlines designated beneficial uses for surface waters, and summarizes the water quality standards that are necessary to support those uses. In addition, this section summarizes current water quality data available for East Canyon Reservoir and provides an assessment of the support status of beneficial uses.

3.1 BENEFICIAL USES AND IMPAIRED WATERS

The main purpose of the CWA is the improvement and protection of water quality through the restoration and maintenance of the physical, chemical, and biological integrity of the nation's waters. Protection of waters under the CWA consists of three main components: designating beneficial uses, establishing water quality criteria to protect those uses, and antidegradation policies and procedures.

Under section 303(d) of the CWA, each state must submit a list to the EPA identifying waters throughout the state that are not achieving water quality standards in spite of the application of technology-based controls in NPDES permits. The waters identified on the 303(d) list are known as impaired waters.

The State of Utah designates beneficial uses to all of the surface waters in the state according to the classes outlined in Table 3.1. Recreational classifications are for waterbodies that are suitable or are intended to be made suitable for primary and secondary contact recreation.

Table 3.1. Summary of Use Designations for Waters of the State of Utah (Rule Code R317-2)

Class	Designated Beneficial Use
1	Protected for use as a raw water source for domestic water systems.
1C	Protected for domestic purposes with prior treatment by treatment processes as required by the Utah Division of Drinking Water.
2	Protected for recreational use and aesthetics.
2A	Protected for primary contact recreation such as swimming.
2B	Protected for secondary contact recreation such as boating, wading, or similar uses.
3	Protected for use by aquatic wildlife.
3A	Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
3B	Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain.
3C	Protected for nongame fish and other aquatic life, including the necessary aquatic organisms in their food chain.
3D	Protected for waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain.
3E	Severely habitat-limited waters. Narrative standards will be applied to protect these waters for aquatic wildlife.
4	Protected for agricultural uses including irrigation of crops and stock watering.
5	The Great Salt Lake. Protected for primary and secondary contact recreation, waterfowl, shore birds and other water-oriented wildlife including their necessary aquatic organisms in their food chain, and mineral extraction.

Secondary contact recreation (2B) refers to uses where full immersion does not occur, such as boating and wading. Waters designated for secondary contact recreation are required to maintain low bacteria counts in order to maintain healthy conditions for recreational users. Waters designated for warm water game fish and associated food chains (3B) are required to exhibit appropriate levels of DO, temperature, pH, and other parameters for warm water aquatic life support. Waters designated for use by waterfowl, shorebirds, and other water-oriented wildlife (3D) not included in classes 3A or 3B (including the necessary aquatic organisms in their food chain) are required to exhibit physical, chemical, and biological characteristics supportive of all levels of the food chain. Waters designated as agricultural water supply (4) (including irrigation and livestock watering) are required to be suitable for the irrigation of crops or as water for livestock. They are also required to meet general surface water quality criteria for TDS (salinity) and various metals such as lead and cadmium.

The State of Utah has designated the beneficial uses for East Canyon Reservoir to be domestic water use (1C), primary contact recreation (2A), secondary contact recreation (2B), cold water game fish and the associated food chain (3A), and agricultural water supply (4). The cold water game fish designated use was identified on the State of Utah's 1998 303(d) list as impaired due to low DO and excess phosphorus loading to the reservoir, whereas domestic water use with prior treatment, primary and secondary contact recreation, and agricultural water supply uses were listed as fully supported. Assessment of these uses and the level of support of conditions appropriate for cold water game fish will be discussed here.

3.2 WATER QUALITY STANDARDS APPLICABLE TO EAST CANYON RESERVOIR

Water quality criteria, specific to designated beneficial uses, consist of both numeric limits for individual pollutants and conditions and narrative descriptions of desired conditions. Water quality standards applicable to the uses designated for East Canyon Reservoir are summarized in Table 3.2.

The State of Utah has not identified numeric water quality criteria for chlorophyll *a*, although a narrative criteria relating to nuisance algae has been established. It reads as follows:

It shall be unlawful, and a violation of these regulations, for any person to discharge or place any waste or other substance in such a way as will be or may become offensive such as unnatural deposits, floating debris, oil, scum or other nuisances such as color, odor or taste; or cause conditions which produce undesirable aquatic life or which produce objectionable tastes in edible aquatic organisms; or result in concentrations or combinations of substances which produce undesirable physiological responses in desirable resident fish, or other desirable aquatic life, or undesirable human health effects, as determined by bioassay or other tests performed in accordance with standard procedures. (Utah State Code R317-2).

Table 3.2. Selected Water Quality Criteria for Designated Uses in East Canyon Reservoir

Parameter	1C	2A	2B	3A	4
Physical					
pH (range)	6.5–9.0	6.5–9.0	6.5–9.0	6.5–9.0	6.5–9.0
Turbidity Increase (NTU)		10	10	10	N/A
Temperature (ºC)				20[1]	
Max Temperature Change (ºC)				2[1]	
DO[2]					
30-day average				6.5	
7-day average				9.5/5.0	
1-day minimum				8.0/4.0	

Table 3.2. Selected Water Quality Criteria for Designated Uses in East Canyon Reservoir

Parameter	1C	2A	2B	3A	4
Total Dissolved Gases				<110%	
Metals (Dissolved, Maximum mg/L)[3]					
Arsenic	0.01				0.10
Barium	1.00				
Beryllium	<0.004				
Cadmium	0.01				0.01
Chromium	0.05				0.10
Copper					0.2
Lead	0.015				0.1
Mercury	0.002				
Selenium	0.050				0.5
Silver	0.050				
Metals (Dissolved, Maximum µg/L)[3,4]					
Aluminum[5]				87/750	
Arsenic (trivalent)				150/340	
Cadmium				0.25/2	
Chromium (hexavalent)				11/16	
Chromium (trivalent)[6]				74/570	
Copper[6]				9/13	
Cyanide (Free)				5.2/22	
Iron (maximum)				1,000	
Lead[6]				2.5/65	
Mercury				0.012/2.4	
Nickel				52/468	
Selenium				4.6/18.4	
Silver				NA/1.6	
Zinc[6]				120/120	
Inorganics (Maximum mg/L)					
Bromate	0.01	N/A	N/A	N/A	N/A
Boron	N/A	N/A	N/A	N/A	0.75
Chlorine (Total Residual) [4]				0.011/0.019	
Chlorite	<1.0	N/A	N/A	N/A	N/A
Fluoride[7]	1.4–2.4	N/A	N/A	N/A	N/A
Hydrogen Sulfide (Undissociated, Max. *µg*/L)				2	
Nitrates as N	10	N/A	N/A	N/A	N/A
Total Ammonia as N[8]				See footnote 8	
TDS[9] for Irrigation	N/A	N/A	N/A	N/A	1,200
TDS[9] for Stock Watering	N/A	N/A	N/A	N/A	2,000

Table 3.2. Selected Water Quality Criteria for Designated Uses in East Canyon Reservoir

Parameter	1C	2A	2B	3A	4
Pollution Indicators[10]					
BOD (mg/L)	N/A	5	5	5	5
Total Phosphorus as P (mg/L)	N/A	0.025	0.025	0.025	N/A
Nitrate as N (mg/L)	N/A	4	4	4	N/A
Bacteriological					
E. coli (30-day geometric mean (No.)/100 ml)[11]	206	126	206	N/A	N/A
E. coli (maximum (No.)/100 ml)[11]	940	576	940	N/A	N/A
Total coliform (30-day geometric mean (No.)/100 ml) (old standard)	5,000	1,000	1,000	N/A	5,000
Fecal coliform (30-day geometric mean (No.)/100 ml) (old standard)	2,000	200	200	N/A	200

[1] The temperature standard shall be at background where it can be shown that natural or un-alterable conditions prevent its attainment. In such cases rulemaking will be undertaken to modify the standard accordingly.

[2] These limits are not applicable to lower water levels in deep impoundments. First number in column details when early life stages are present, second number details when all other life stages present.

[3] The dissolved metals method involves filtration of the sample in the field, acidification of the sample in the field, no digestion process in the laboratory, and analysis by atomic absorption or inductively coupled plasma (ICP) spectrophotometry.

[4] First number in column is a 4-day average and the second number is a 1-hour average. Where criteria are listed as 4-day average and 1-hour average concentrations, these concentrations should not be exceeded more often than once, every three years on the average.

[5] The criterion for aluminum will be implemented as follows: Where the pH is equal to or greater than 7.0 and the hardness is equal to or greater than 50 ppm (as CaC03 in the receiving water after mixing), the 87 µg/1 chronic criterion (expressed as total recoverable) will not apply, and aluminum will be regulated based on compliance with the 750 µg/1 acute aluminum criterion (expressed as total recoverable).

[6] Hardness dependent criteria. 100 mg/L used. Conversion factors for ratio of total recoverable metals to dissolved metals must also be applied. In waters with hardness greater than 400 mg/L (as CaC03), calculations will assume a hardness of 400 mg/L (as CaC03).

[7] Maximum concentration varies according to the daily maximum mean air temperature (12ºC = 2.4 mg/L; 12.1–14.6ºC = 2.2 mg/L; 14.7–17.6ºC = 2.0 mg/L; 17.7–21.4ºC = 1.8 mg/L; 21.5–26.2ºC = 1.6 mg/L; and 26.3–32.5ºC = 1.4 mg/L).

[8] The following equations are used to calculate Ammonia criteria concentrations:

The 30-day average concentration of total ammonia nitrogen (in mg/L as N) does not exceed more than once every three years on the average, the chronic criterion calculated using the following equations:

Fish Early Life Stages are Present: mg/L as N (Chronic) = ((0.0577/1+107.688-pH)+ (2.487/1+10PH-7.688)) * MIN (2.85, 1.45*100.028*(25-T)).

Fish Early Life Stages are Absent: mg/1 as N (Chronic) = ((0.0577/1+107.688-pH) + (2.487/1+10pH-7.688)) * 1.45*100.028* (25-MAX(T,7))).

The one-hour average concentration of total ammonia nitrogen (in mg/L as N) does not exceed, more than once every three years on the average the acute criterion calculated using the following equations. Class 3A: mg/L as N (Acute) = (0.275/ (1+107.204-pH)) + (39.0/1+10pH-7.204)).

[9] TDS limits may be adjusted if such adjustment does not impair the designated beneficial use of the receiving water. The TDS standards shall be at background where it can be shown that natural or un-alterable conditions prevent its attainment. In such cases rulemaking will be undertaken to modify the standard accordingly.

[10] Investigations should be conducted to develop more information where these pollution indicator levels are exceeded.

[11] Where the criteria are exceeded and there is a reasonable basis for concluding that the indicator bacteria are primarily from natural sources (wildlife), e.g., in National Wildlife Refuges and State Waterfowl Management Areas, the criteria may be considered attained. Exceedances of bacteriological numeric criteria from nonhuman nonpoint sources will generally be addressed through appropriate Federal, State, and local nonpoint source programs.

3.2.1 Pollutants of Concern

Pollutants of concern include nutrients, sediment, organic matter, dissolved solids, and bacteria. These are described in the following paragraphs.

3.2.1.1 Nutrients

Elevated nutrient concentrations can contribute to eutrophication or excessive growth of algae and periphyton in surface waters. General concerns associated with excessive algal growth include both direct and indirect effects. Direct effects are associated with nuisance algae and periphyton growth. Indirect effects include low DO, elevated pH, and cyanotoxins from cyanobacteria (blue-green algae) production. Measurements of phosphorus and nitrogen represent both particulate or suspended and dissolved nutrients within the system and are good indicators of the total loading that will be available over time for plant growth and production. Nutrients bound to organic particles and sediments compose the largest source of enrichment in reservoir systems, although particulate forms are generally considered kinetically less available for algal uptake. Mineralization and microbial activity can convert substantial portions of these nutrient-bound particles and sediments to more soluble forms over time, further enhancing the pool of nutrients available for algal uptake and growth.

Phosphorus can be present in a waterbody in a variety of forms. The most common forms of phosphorus monitored in the East Canyon Reservoir watershed are total phosphorus (TP), which includes all phosphorus (dissolved and particulate-bound) in a sample, and dissolved phosphorus (primarily present as orthophosphate) which includes highly soluble, oxidized phosphorus. Because of its solubility, orthophosphate or dissolved phosphorus are commonly more available for biological uptake and more likely to lead to increased algal growth than TP (Sonzongi et al. 1982). The relative amount of each form measured can provide information on the potential for algal growth within the system; however, the STORET (EPA water quality database) data for the reservoir included dissolved phosphorus not orthophosphate. If a high percentage of TP is present as dissolved phosphorus (a surrogate for soluble orthophosphate), it is more likely that rapid algal growth will occur than if the majority of the TP was mineral phosphorus incorporated in sediment, provided other conditions such as light and temperature are adequate. Due to phosphorus cycling (conversion between forms) it is important to consider TP concentrations in the evaluation of nutrient loading. In East Canyon Reservoir, it appears that TP concentrations have been mostly static, with declining chlorophyll *a* concentrations, which suggests that particulate-bound phosphorus has increased relative to bio-available dissolved phosphorus (see Section 3.5.3.1).

Total nitrogen measurements represent both particulate and dissolved nitrogen within the system and are a good indicator of the total loading that will be available over time for plant growth. Nitrogen bound to organic particles and sediments generally compose the largest source of enrichment in reservoir and wetland systems. Although particulate forms are generally less available for algal uptake, mineralization and microbial activity can convert substantial portions to more soluble forms over time, further enhancing the pool of nutrients available for algal uptake and growth. Dissolved nitrate + nitrite measurements represent the fraction of the nitrogen loading that is readily available for immediate algal uptake and has the greatest short-term potential to stimulate growth. Excessive dissolved nitrogen concentrations can contribute to eutrophication or nuisance growth (algae and periphyton) in surface waters.

Both nitrogen and phosphorus can contribute to eutrophication. Either nutrient may be the limiting factor for algal growth, depending on algal species. Which nutrient limits the growth of phytoplankton is not necessarily specific to the element in least abundance. Aquatic organisms require nutrients to be present in certain relative quantities. For phytoplankton, the appropriate ratio for healthy growth is 16:1 nitrogen-to-phosphorus (N:P) ratio. This appropriate ratio of 16:1 for healthy growth of phytoplankton is called the Redfield Ratio, named after the researcher who first published it. This means that for phytoplankton to grow, 16 nitrogen atoms must be present in the water for every phosphorus atom. With fewer than 16 nitrogen atoms, the algae cannot utilize all of the available phosphorus. In this case, nitrogen would be the limiting nutrient and would act to reduce or curtail growth.

Generally, a phosphate concentration of 0.01 mg/L will support plankton, whereas concentrations of 0.03 to 0.1 mg/L phosphate or higher will likely trigger blooms (EPA 1986; Dunne and Leopold 1978). A high availability of phosphorus does not always indicate a continued production of algae because the system may become nitrogen limited. Estuarine systems tend to be nitrogen limited and fresh waters are phosphorus limited. However, there is recent evidence that many freshwater systems are co-limited, including Utah reservoirs (Oldham 2001; personal communication between Erica Gaddis, SWCA, and Wayne Wurtsbaugh, Utah State University, October 12, 2007).

Freshwater systems are usually phosphorus limited, however there is a large body of literature concerning the impact of the N:P ratio in freshwater systems. Typically N:P ratios less than 10:1 suggest a nitrogen-limited system, whereas higher ratios suggest that nitrogen and phosphorus are either co-limiting or that the system is phosphorus limited. However, the cutoff for an N:P ratio below which nitrogen is likely the limiting agent ranges from 7:1 to 15:1 (EPA 2000). Above a 10:1 to 16:1 N:P ratio, surface water systems will likely experience an algal bloom, the severity of which is most commonly in direct relation to the excess phosphorus available (Schindler 1977). In systems where cyanobacteria (blue-green algae) are the dominant population, nitrogen is not a limiting agent based on the blue-green algae's ability to fix nitrogen. Therefore, blue-green algae can grow where low nitrogen concentrations may inhibit the growth of other algal species (Sharpley et al. 1984, 1995; Tiessen 1995). These systems are therefore phosphorus limited.

Many sources and conditions contribute to levels of phosphorus and nitrogen in the environment. Phosphorus can be present as a constituent of certain rock types and is found in the mineral apatite. The environment itself can also be a factor in the phosphorus and nitrogen levels occurring in a region because the climate, pH of natural waters, and presence of other substances that may adsorb or release phosphorus can all potentially affect phosphorus levels (Hedley et al. 1995). Wildlife and waterfowl that utilize the watershed often mobilize nutrients from stable to dissolved forms. Although these populations are relatively stable throughout much of the year, substantial increases in some populations are observed with spring and fall wildlife and waterfowl migration patterns. In the case of East Canyon Reservoir, N:P ratios have consistently been below 14:1 (Judd 1999) and the current average N:P ratio of less than 4:1 indicates that nitrogen is the limiting nutrient for algal growth, except for blue-green algae that can fix atmospheric nitrogen (see Section 3.4.2.3).

3.2.1.2 Sediment

Sediment is the most visible pollutant in freshwaters, leading to increased turbidity in water. It is usually reflected in measurements of total suspended solids (TSS) (mg/L). Erosion of upland soils and streambanks are the primary causes of elevated sediment levels in rivers and reservoirs, both of which reflect land management practices in the watershed. Excessive sediment loading in receiving waters can lead to the alteration of aquatic habitat, reduced reservoir storage capacity due to sedimentation, and reduced aesthetic value of waters. Accumulation of sediments can directly harm fish and aquatic wildlife, or indirectly impact the functioning of aquatic systems by contributing to nutrient loading and eutrophication (algal overgrowth) (Novotny and Olem 1994). Sediments also readily adsorb other pollutants such as persistent organochlorine compounds and polychlorinated biphenyls (PCB), particularly from surface runoff, air pollution, and litter accumulation in urban areas (Novotny and Olem 1994).

3.2.1.3 Organic Matter

Low DO often results from high nutrient, organic, or algal loading to a surface water system. Nutrients promote algal growth, which in turn consumes oxygen from the water column during periods when respiration is the dominant process (generally at night). In addition, dying algae in lakes and reservoirs settle to the bottom of the waterbody and decompose; aerobic decomposition of the dead algae and other detritus (nonliving organic material) depletes the oxygen supply in the overlying water and sediment. In systems where suspended solids are primarily organic in origin, low DO levels may be correlated with sediment inputs as well.

Concentrations of DO are also reduced by pollutants that require oxygen for decomposition of organic matter. Biochemical oxygen demand (BOD) is a measure of the DO required to oxidize material (usually organic), whether the material is naturally occurring, the result of increased natural material, or contained in municipal, agricultural, or industrial wastes. Some of the delivered organic material is algae and some is detritus. Both of these organic matter components produce a certain amount of BOD. A substantial organic load may be delivered to the reservoir during high volume and high velocity spring flow events.

3.2.1.4 Dissolved Solids

Total dissolved solids (TDS) is a term used to define the amount of dissolved minerals in water. In surface waters, water picks up TDS as it passes over or through the earth. Various rocks that line the course of travel are continuously eroded and their minerals are slowly dissolved by the water. Excessive concentrations of dissolved solids can result in scale buildup in pipes, valves, and filters, reducing performance and adding to system maintenance costs in drinking water systems. In agricultural applications, high dissolved solids can lead to lower crop yields and lack of weight gain in livestock.

3.2.1.5 Bacteria

Escherichia coli is a bacterium that is commonly found in the lower intestine of humans and animals. There are many strains of *E. coli*, most of which are harmless, but the common serotype O157:H7 is known to produce toxins that can cause enterohemorrhagic illness in humans. The presence of *E. coli* in waterbodies is an indicator of fecal contamination, and gastrointestinal illness can occur from swimming in or swallowing contaminated water.

Violations of the numeric criteria for bacteria in surface waters can result in health risks to individuals using the water for recreation or other activities. Such activities carry the risk of ingestion of small quantities of water. High bacteria counts can be indicators of improper animal or human waste disposal, grazing, or livestock management practices.

3.2.2 INDICATORS OF BENEFICIAL USE IMPAIRMENT

Indicators of degradation to designated beneficial uses (DBUs) consist of algal and cyanobacterial blooms, low concentrations of DO, oxygen supersaturation, turbidity, extreme swings of pH, and temperature increases.

3.2.2.1 Nuisance Algal Growth

Nuisance aquatic growth consisting of both algae (phytoplankton or water column algae and periphyton or attached algae) and rooted plants (macrophytes) can adversely affect aquatic life and recreational water uses. Algal blooms occur where nutrient concentrations (nitrogen and phosphorus) are sufficient to support growth. Levels necessary to support growth may occur at concentrations well below the identified water quality thresholds and criteria. Available nutrient concentrations, flow rates, velocities, water temperatures, and penetration of sunlight in the water column are all factors that influence algae (and macrophyte) growth. When conditions are appropriate and nutrient concentrations exceed the quantities needed to support algal growth, excessive blooms may develop. Commonly, these blooms appear as extensive layers or algal mats on the surface of the water. Reservoir systems that experience low flow-through rates during the growing season, such as the East Arm of East Canyon Reservoir, can experience conditions that are optimal to algae growth and decomposition.

Excessive suspended algae or periphyton growth is a good indicator of eutrophication or elevated nutrient loading to a surface water system. Increased algal density and growth rates are often episodic, with algal blooms occurring in response to nutrient influx and favorable climatic conditions. Both the explosive growth and subsequent collapse of an algal bloom contribute to low DO concentrations. Although some growth is natural and beneficial to river and reservoir systems, excessive growth can decrease DO through respiration and decomposition processes and is therefore often directly linked to the support status of aquatic life. Excessive algal growth can also shade the water below, which prevents photosynthesis and can contribute to the decline of submerged aquatic vegetation (Dennison et al. 1993). Algal growth is also commonly linked to the public's aesthetic perception of degraded water quality.

In addition to the direct effects of excessive algal growth, when algae die they sink slowly through the water column, eventually collecting on the bottom sediments. The biochemical processes that occur as the algae decompose remove oxygen from the surrounding water. Because most of the decomposition occurs in the lower levels of the water column, DO concentrations near the bottom of lakes and reservoirs can be substantially depleted by a large algal bloom. Low DO in these areas can lead to decreased fish habitat and even fish kills if the fish can find no safe area in which to take refuge.

Algae is not always damaging to water quality. The extent of the effect is dependent on both the type(s) of algae present and the size, extent, and timing of the bloom. In many systems algae provides a critical food source for several aquatic insects, which in turn serves as food for fish. Furthermore, submerged aquatic vegetation (macrophytes) provides food for waterfowl and aquatic life and essential habitat for fish and other aquatic life.

Chlorophyll *a* concentrations are a common surrogate measure of algal growth and density. Chlorophyll *a* is the green pigment in plants associated with photosynthesis (the process whereby plants combine light energy, nutrients, and carbon to grow). A measure of chlorophyll is representative of the amount of photosynthesizing algae that are in the water column. On average, chlorophyll *a* makes up approximately 1.5% of algal organic matter (Raschke 1993) and if chlorophyll *a* concentrations are known, the phytoplankton biomass in a waterbody can be estimated.

A separate consideration is the difference between algal concentrations and the rate of algal growth. Algal concentrations are a function of the availability of nutrients on a continuing basis, the availability of adequate light, and the presence of flows (velocities) that will permit continued growth without losses due to flushing of phytoplankton, sloughing of attached algae or periphyton, or mechanical breakage and scouring of rooted macrophytes. In quiescent systems algal concentrations are dependent on nutrient availability. Only if nutrient concentrations have been depleted by algal uptake does the growth rate approach zero and phytoplankton begin to die. In fast moving systems, the opportunity for periodic flushing can keep algal concentrations down, whereas slow moving systems provide for more algal growth and accumulation.

3.2.2.2 Cyanobacteria (Blue-green Algae)

The relative densities of algal species and diversity of the algal community both serve as surrogate measures of water quality by identifying overall species diversity, excessive algal growth or eutrophication, and the presence and relative abundance of toxic blue-green algae.

Cyanobacteria (blue-green algae) can dominate in nitrogen-limited systems as they are able to fix nitrogen from the atmosphere (at the air/water interface) and from the water column. Based on this ability to fix nitrogen, nitrogen is not a limiting agent in systems where cyanobacteria are the dominant population. As a result, cyanobacteria can increase where low nitrogen limits the growth of other algal species (Sharpley et al. 1984, 1995; Tiessen 1995). High phosphorus concentrations can increase the density of blue-green algae, and increased growth and reproduction of the blue-green algae Genus *Anabaena* has been demonstrated to occur with increased phosphorus (personal communication between Wayne Wurtsbaugh, Utah State University, and Erica Gaddis, SWCA, on October 15, 2007).

Nutrient effects on water quality could eventually impair the quality, safety, and frequency of recreational use. Nutrient loading causes algal overgrowth which can reduce water clarity (turbidity) and color and increase the growth of algal mats (periphyton) and potentially harmful blue-green algae. Overgrowth of cyanobacteria has been associated in other systems with the occurrence of toxins and mortality to resident animal populations (Sabater and Admiraal 2005). Although cyanobacteria may be of low toxicity, cyanotoxins can become highly concentrated in the environment or through bioaccumulation where cyanobacterial overgrowth occurs. The introduction and overgrowth of cyanobacterial species is a potential hazard to the water quality and the aquatic ecosystem of East Canyon Reservoir.

In East Canyon Reservoir, the diatom species *Melosira granulata*, *Stephanodiscus niagarae*, *Fragilaria crotonensis* and *Tabellaria fenestrata* dominate throughout the algal growth season. Three species of blue-green algae, *Aphanizomenon flos-aquae*, *Microcystis incerta*, and *Anabaena* species, occasionally co-dominate with diatoms during late summer and fall blooms. Phytoplankton abundance data were not available for East Canyon Creek or other tributaries. The planktonic genera *Anabaena*, *Aphanizomenon*, and *Microcystis* form unsightly surface scum and can potentially concentrate toxins. Although no reports of toxic cyanobacteria blooms are known for East Canyon Reservoir, the potential for such blooms is demonstrated by the dominance of blue-green algae species in the reservoir. High volume blue-green algae and diatom blooms may also be contributing to nocturnal and seasonal DO depletions.

3.2.2.3 Dissolved Oxygen (DO)

High concentrations of DO (6–8 mg/L or greater) are necessary for the health and viability of fish and other aquatic life. Low concentrations of DO (below 4 mg/L) can result in stress to aquatic species, lowered resistance to environmental stressors, and even death at very low levels (less than 2 mg/L). Dissolved oxygen is generally highest in the early afternoon when sunlight is at its peak and when photosynthesis is occurring at maximum levels. This is followed by a decline in oxygen concentrations over time as light levels and photosynthesis decrease. Although photosynthesis is the dominant oxygen-exchange process during the day, respiration (where plants take in oxygen and give off carbon dioxide) is constantly occurring and during low- and no-light hours, respiration is the dominant oxygen-exchange process, resulting in a nightly sag in water column DO (generally shortly before dawn) when oxygen uptake by aquatic plants reaches its peak.

East Canyon Reservoir and upstream and downstream portions of East Canyon Creek contain a diverse fish community of black crappie, brown trout, Bonneville and Colorado River cutthroat trout, kokanee salmon, rainbow trout, tiger trout, Utah chub, speckled dace, fathead minnow, redside shiner, smallmouth bass, and cutbows (cutthroat-rainbow trout hybrids) (BOR 2003, Nadolski and Schaugaard 2008). Thresholds of DO for fish vary by species and are also affected by environmental conditions such as water temperature and hardness. Generally fish are more tolerant of low oxygen levels at cold temperatures. Nighttime oxygen sags followed by daytime oxygen supersaturation generally occur in summer and can affect fish at both extremes. Nighttime oxygen sags generally last a few hours but short exposure to DO concentrations of 3.1 mg/L or less in summer and 1.4 mg/L or less in winter are regarded as hazardous or lethal to most fish (McKee and Wolf 1963). Low DO caused by algal blooms was implicated in two-thirds of all fish kills where the cause was known in canals and tidal creeks and rivers of the Atlantic Coastal Bays Region (Luckett and Poukish 2004). Lowest observed concentrations at which certain fish groups died or survived after 24 hours in summer varied considerably by species (Table

3.3) and may partly explain the persistence of certain "rough species" such as carp and bullheads and low levels of more desirable sport fish such as trout, bass, and sunfish.

Table 3.3. Dissolved Oxygen Concentrations at which Fish Died within 24 Hours

Species	Lowest Concentration (mg/L) at which Fish Survived for 24 Hours	Concentrations (mg/L) at which Fish Died in 24 Hours
Trout	6.0	5.0
Black Crappie	5.5	4.2
Bass	5.5	3.1
Sunfish	4.2	3.1
Yellow Perch	4.4	3.1
Black Bullhead	3.3	2.9
Carp	1.3	<1.0

Source: McKee and Wolf 1963; Wozniewski and Opuszynski 1988; Schofield et al. 2005.

Lethal low oxygen concentrations for carp in a laboratory study varied from 1.3 to 0.7 mg/L (Wozniewski and Opuszynski 1988). In addition to direct effects on aquatic life, low DO concentrations can change water and sediment chemistry, which can then influence the concentration and mobility of nutrients and toxins in the water column (e.g., phosphorus, ammonia, and mercury). Low DO at the bottom can result in substantial releases of adsorbed nutrients to the water column, which in turn can lead to increased algal growth and further decrease the DO concentration in a waterbody.

Anoxic or oxygen deficient conditions (hypoxia), combined with available organic matter, can result in higher rates of methylmercury production. Methylmercury represents a significantly greater threat for bioconcentration and bioaccumulation than elemental or mineralized mercury compounds. Finally, increased water column concentrations of ammonia can result from the chemical changes caused by anoxic conditions. Elevated ammonia levels threaten the health of aquatic life forms and, at extreme concentrations, can result in death.

Low DO often results from high nutrient, organic, or algal loading to a surface water system. Nutrients fuel algal growth, which in turn consumes oxygen from the water column during respiration (D'Avanzo and Kremer 1994). In slow-moving streams, lakes, and reservoirs, when algae die and settle to the bottom of the waterbody, aerobic decomposition of the dead algae and other detritus (nonliving organic material) also depletes the oxygen supply in the overlying water. In systems where suspended solids are primarily organic in origin, low DO levels may be correlated with sediment inputs as well. Dissolved oxygen is also reduced by pollutants that consume oxygen in oxidation processes. BOD is a measure of the oxygen required to oxidize material (usually organic), whether it is naturally occurring or contained in municipal, agricultural, or industrial wastes. Some of the delivered organic material is algae and some is detritus. Both of these organic matter components produce a certain amount of BOD. A substantial organic load may be delivered to the reservoir during high flow events.

3.2.2.4 Dissolved Oxygen Saturation

Dissolved oxygen sampling in an instantaneous fashion does not generally capture the critical time frame for DO sags. The potential for these sags to occur during nighttime hours is directly related to the magnitude of growth occurring in the waterbody. As growth and photosynthesis act to increase DO in the water during daylight hours, the potential for nighttime DO sag to occur is proportional to the occurrence of supersaturation during daylight hours. Thus, exceedance of the DO saturation criteria during daylight discrete sampling events is indicative of low DO conditions during night hours.

The effects of oxygen supersaturation (more than 100% saturation) on fish are not as well as known as the effects of oxygen sags. Oxygen supersaturation appears to be detrimental and sometimes lethal to fish at concentrations of greater than about 150% saturation, primarily because oxygen in water at supersaturated levels tends to form bubbles that destroy cells and membrane—i.e., gas bubble trauma (GBT). However, high concentrations of oxygen (at or slightly above 100% saturation) are often used to treat fish under stress, for transport, to promote growth, or to recover from disease treatment. Fish generally tolerate water supersaturated with oxygen quite well, at least temporarily. When water is supersaturated, fish control their oxygen uptake by reducing blood flow through the gills through reduced respiration.

Only a few studies have attributed GBT to excess oxygen. A bloom of green algae in the genus *Chlamydomonas* increased DO to as high as 30–32 mg/L (>300% saturation) and was associated with a fish kill in which the dead fish exhibited characteristic gill and skin lesions from GBT (Woodbury 1942). A similar situation occurred in Galveston Bay, Texas, where fish mortality was observed after an algal bloom at a DO concentration of 250% (Renfro 1963). Trout and sunfish in a California lake died when oxygen reached 300% saturation because their gills were surrounded by oxygen bubbles (McKee and Wolf 1963). Bass and bluegill exposed to water supersaturated with oxygen showed no effect until concentrations reached 310%–410% (Lassleben 1951). Oxygen supersaturation may add to multiple stressors without being the single cause of mortality. Deaths of trout with whirling disease increased when the fish were subjected to additional stressors, including oxygen supersaturation (Schisler et al. 2000).

The EPA has published dissolved gas supersaturation water quality guidelines, which recommend a maximum total gas pressure of 110% of local atmospheric pressure (EPA 1986). This guideline has been adopted by most of the states, but it does not distinguish concentration requirements of the two primary gases—nitrogen and oxygen. No guidelines have been established for dissolved gas supersaturation or for oxygen supersaturation. Fish losses from dissolved gas supersaturation are most often attributed to excess nitrogen and not oxygen (Lassleben 1951); nitrogen at high concentrations comes out of solution to form gas bubbles around the eyes and in the fins.

3.2.2.5 Turbidity and Secchi Depth

Turbidity is a measurement of the visible clarity of water. Turbidity can be caused by both inorganic particles and suspended algae. Light limitation from large amounts of suspended inorganic particles can limit algal growth; however, turbidity is correlated with phytoplankton density in very productive aquatic systems (Wetzel 2001).

Approximate turbidity is measured by the depth of Secchi disk transparency. Secchi depths are measured using a disk with alternating black and white sections that is lowered into the water. When the disk is no longer visible, the Secchi depth is recorded. For example, a Secchi depth of three feet indicates that the disk was last visible at three feet below the surface. High Secchi depth readings indicate that the water is relatively clear and will allow sunlight to penetrate to greater depths. Low readings indicate turbid water due to algae growth, suspended sediment, or other causes; turbidity can reduce the depth to which sunlight can penetrate. Limited light at lower depths can result in decreased growth of aquatic plants.

3.2.2.6 pH

The pH of a waterbody is a measure of its acidity or alkalinity. A pH value of 7 is neutral, whereas values 0–7 are acidic and 7–14 are alkaline. Extremely acid or alkaline waters can be problematic and directly toxic to fish and other aquatic life. Each species of fish has a distinct range of pH preference, and levels outside of this range will cause health problems. Very high or very low pH levels can cause damage to skin, gills, and eyes. Prolonged exposure to these conditions can cause stress, increase mucus production, and encourage thickening of the skin or gill epithelia, sometimes with fatal consequences. Substantial diurnal shifts in pH that result mainly from photosynthesis are stressful and damaging to the health of aquatic organisms. Changes in pH also affect the toxicity and availability of dissolved compounds such as heavy metals.

Photosynthesis and respiration, discussed in relation to DO above, also play a role in the pH of the water column. During photosynthesis, all plants (including algae) absorb carbon dioxide from the water and produce oxygen. Carbon dioxide in water is slightly acidic, so as plants remove it, the water becomes more alkaline or basic, and the pH increases. The more algae present in the water, the more alkaline the water will become. At night, plants stop photosynthesizing but continue normal respiration. Plants remove oxygen from the water and excrete carbon dioxide, acidifying the water. In some systems, especially shallow, nonstratified waters, this cycle can cause significant diurnal swings (over a period of 24 hours) in pH.

3.2.2.7 Temperature

Water temperature is key to fish and aquatic habitat. It determines whether or not a waterbody can support warm or cold water aquatic species. High water temperatures can be harmful to fish at all life stages, especially if they occur in combination with other habitat limitations such as low DO or poor food supply. Elevated water temperatures can result in lower body weight, poor oxygen exchange, and reduced reproductive capacity of adult fish. Extremely high temperatures can result in death if they persist for an extended length of time. Juvenile fish are more sensitive to temperature variations and duration than adult fish and can experience negative impacts at a lower threshold value than the adults.

Temperature is an important indicator of water and wetland habitat quality. Water temperature is affected by vegetative cover, thermal inputs, flow alterations, ambient air temperatures, groundwater recharge, and direct sunlight.

3.2.2.8 Trophic State Index (TSI)

The health and support status of a waterbody can be assessed using the trophic state index (TSI), a measurement of the biological productivity or growth potential of a body of water. The basis for trophic state classification is algal biomass (estimation of how much algae is present in the waterbody). The calculation of the TSI generally includes the relationship between chlorophyll (the green pigment in algae, where chlorophyll *a* is used as a surrogate measure of algal biomass), transparency using Secchi depth measurements, and TP (commonly the nutrient in shortest supply for algal growth). Its calculation is as follows (Carlson 1977):

- Chlorophyll *a*: $TSI_{CHL} = 9.81 \, Ln (Chl \, a) + 30.6$
- Secchi depth: $TSI_{SD} = 60 - 14.41 \, Ln (SD)$
- Total Phosphorus: $TSI_{TP} = 14.42 \, Ln (TP) + 4.15$

Table 3.4 identifies generally accepted TSI values derived from this relationship. Waterbodies with very low TSI values (less than 30) and low TSI values (30–40) are generally transparent, have low algal population densities, and have adequate DO throughout the water column. Waterbodies with these characteristics are generally supportive of cold water fisheries and are identified as oligotrophic. Waterbodies with low to midrange TSI values (40–50) are moderately clear, and have an increasing chance of hypolimnetic anoxia in summer. Waterbodies with these characteristics are generally supportive of warm water fisheries and are identified as mesotrophic. Waterbodies with midrange TSI values (50–70) commonly experience more turbidity (the water is not as clear) and higher algal population densities than oligotrophic waterbodies. These waterbodies often exhibit low DO levels in mid- to late-summer, with the most extreme conditions observed in the hypolimnetic (deeper) water column. Waterbodies with these characteristics often experience some macrophyte problems (excessive growth) and are generally supportive of warm water fisheries only. These waterbodies are identified as being eutrophic. Waterbodies with high TSI values (70 and greater) are generally observed to have heavy algal blooms, dense macrophyte growth, and extensive DO problems that often occur throughout the water column. Fish kills are often common and recreation is limited under such conditions. Fish populations are generally confined to rough fish species. Such waterbodies are identified as hypereutrophic.

Table 3.4. TSI Values and Status Indicators

TSI	Trophic Status and Water Quality Indicators
<30	Highly oligotrophic; clear water; high DO throughout the year in the entire hypolimnion.
30–40	Oligotrophic; clear water; possible periods of limited hypolimnetic anoxia (DO=0).
40–50	Mesotrophic; moderately clear water; increasing chance of hypolimnetic anoxia in summer; cold water fisheries threatened; supportive of warm water fisheries.
50–60	Mildly eutrophic; decreased transparency; anoxic hypolimnion; macrophyte problems; generally supportive of warm water fisheries only.
60–70	Eutrophic; blue-green algae dominance; scum possible; extensive macrophyte problems.
70–80	Hypereutrophic; heavy algal blooms possible throughout summer; dense macrophyte beds.
>80	Algal scum; summer fish kills; few macrophytes due to algal shading; rough fish dominance.

Source: Carlson and Simpson 1996.

The relationship between TSI values calculated for a specific waterbody is also helpful in identifying factors that limit algal biomass and/or affect the measured water quality parameters. Although every waterbody is unique, a number of common relationships between Secchi depth, chlorophyll *a*, and TP have been identified (Carlson 1992; Table 3.5).

Table 3.5. Relationships between TSI Values

TSI Relationship	Water System Characteristics	TSI Code
TSI(Chl) = TSI(TP) = TSI(SD)	Algae dominate light attenuation; TN/TP ~33:1.	A
TSI(Chl) > TSI(SD)	Large particulates, such as *Aphanizomenon* flakes, dominate.	B
TSI(TP) = TSI(SD) > TSI(CHL)	Nonalgal particulates or color dominate light attenuation.	C
TSI(SD) = TSI(CHL) > TSI(TP)	Phosphorus limits algal biomass (TN/TP > 33:1).	D
TSI(TP) > TSI(CHL) = TSI(SD)	Algae dominate light attenuation but some factors—such as nitrogen limitation, zooplankton grazing, or toxic algal blooms also limit algal growth.	E

Chl = Chlorophyll *a*; TP = Total Phosphorus; SD = Secchi disk depth
Source: Carlson and Simpson 1996.

3.3 ANALYSIS OF EXISTING WATER QUALITY AND HYDROLOGIC DATA

Primary information sources for water quality data include the EPA STORET website, Utah Division of Water Quality (UDWQ), UDWiR, Utah Geological Survey (UGS), Utah Department of Natural Resources (UDNR), USGS, U.S. Forest Service, Natural Resources Conservation Service, BOR, state and local colleges and universities, state and local soil and water conservation services, irrigation districts and their associated databases, and others. Groundwater flow and volume information is general in nature and is available almost exclusively from USGS, UGS, and county studies and reports. Climate information was obtained from the World Regional Climate Center (WRCC) and SNOTEL sites.

The UDWQ, USGS, EPA, and others have been monitoring water quality at a number of sites in the East Canyon Reservoir watershed since the late 1970s. Locations from which water quality information is available include reservoir monitoring sites, major tributary streams, and reservoir outflow, as well as other sites such as groundwater wells. Data for water years 2001–2007 was determined to be most critical to this assessment because it covers the period following the previous TMDL.

Water quality monitoring locations determined to be most critical to the TMDL effort include 5 locations in East Canyon Reservoir, a point on East Canyon Creek representing tributary inflow to the reservoir, East Canyon Creek below the dam, and effluent data from the Snyderville Basin Water Reclamation District WWTP. In total, over 32,839 surface water quality data points were identified and assessed for the East Canyon Reservoir watershed, covering the 1993–2007 water years time period. Hydrologic gaging stations identified to be critical to the study include the station on East Canyon Creek near Jeremy Ranch, the station directly downstream of the reservoir, and reservoir storage volume—all recording daily data. Sediment core data collected around the reservoir in summer 2007 provide insight to in-reservoir sediment contributions to the phosphorus load. Available biological data include phytoplankton, zooplankton, and fish in East Canyon Reservoir (EPA STORET; Rushforth and Rushforth 2005).

3.3.1 ANALYTICAL METHODS

3.3.1.1 Water Quality

Data collected and assessed for East Canyon Reservoir TMDLs consist of samples evaluated by four primary categories of analytical methodology: American Public Health Association (APHA), EPA, UDWQ generic, and UDWQ field methods. It was assumed that data collected by the BOR used standard analytical methods. Water quality sampling sites in the East Canyon Reservoir watershed are shown in Figure 2.1.

3.3.1.1.1 APHA Methods

The APHA-approved methods (1992) are specific to the available database for the East Canyon Reservoir TMDL and include analytical procedures for measuring alkalinity, chemical oxygen demand, chloride, chlorophyll *a*, dissolved solids, fecal coliform bacteria, fecal streptococcus group bacteria, fixed solids, pH, total coliform bacteria, total organic carbon, total suspended solids, volatile solids, and others not pertinent to this TMDL effort.

3.3.1.1.2 EPA Methods

These methods refer to methods approved by the EPA (EPA 1983). The EPA-approved methods specific to the available database for the East Canyon Reservoir TMDL includes analytical procedures for measuring ammonia, biochemical oxygen demand, chloride, nitrate + nitrite, phosphorus, specific conductance, total suspended solids, turbidity, volatile solids, and others not pertinent to this TMDL effort.

3.3.1.1.3 UDWQ Generic Methods (Generic Method and Generic Method 2)

These refer to the UDWQ methods entered in the EPA STORET database. The UDWQ generic methods specific to the available database for the East Canyon Reservoir TMDL include measurements of alkalinity, ammonia, biochemical oxygen demand, chemical oxygen demand, chloride, chlorophyll *a*, nitrate, nitrate + nitrite, nitrite, pH, orthophosphate, phosphorus, specific conductance, total Kjeldahl nitrogen, total organic carbon turbidity, and others not pertinent to this TMDL effort.

Due to the fact that the data in this analysis category were collected, reviewed, and submitted to the EPA STORET database by UDWQ, it was assumed that all sampling protocols and analytical methods employed were carried out in a fashion approved by UDWQ and contained and attained a UDWQ-approved level of quality assurance and quality control.

3.3.1.1.4 UDWQ Field Measures

These refer to UDWQ's *Quality Assurance/Quality Control Manual* (1996). The UDWQ field measures approved methods specific to the available data for the East Canyon Reservoir TMDL include analytical procedures for measuring chlorine, DO, flow, pH, salinity, Secchi depth, specific conductance, and temperature (air and water).

3.3.1.2 Hydrology

Hydrologic characterization is used in describing watershed seasonal dynamics, differentiating critical low-water seasons in the reservoir, calculating pollutant loads (together with measured pollutant concentrations), and estimating annual and seasonal variation in the system. The only USGS stations covering the current time period of interest (water years 2002–2007) are located directly downstream from the SBWRD WWTP near Jeremy Ranch, Utah (#10133800), and directly downstream of the reservoir on East Canyon Creek (#10134500).

The BOR also records reservoir elevation for the entire current time period (water years 2002–2007) and has inflow data to the reservoir calculated using a mass balance of outflow and change in storage—derived from a known relationship between reservoir volume and elevation. These data (available on the BOR website) are the best available for the reservoir itself. However, the record is not corrected for evaporation, precipitation, or seepage gains/losses from the reservoir, and is subject to large daily fluctuations due to water elevation changes caused by wind or other internal movement. For these reasons, this record is best used to calculate period averages rather than to examine day to day fluctuations.

To improve the quality of this record, it was corrected to roughly account for daily precipitation and evaporation. The daily precipitation record was taken from the National Climatic Data Center's (NCDC) Coalville station, which was the closest station of similar elevation and climate with an overlapping period of record. Daily record of evaporation were not available near the reservoir, so monthly data from the WRCC (available online) for the Wanship Dam station were used to estimate a daily average evaporation. The daily "corrected" inflow to the reservoir was calculated as:

- Inflow = Change in storage + outflow +evaporation–precipitation

Because this corrected inflow represents all inflow to the reservoir, including that from small tributaries entering at different points at East Canyon Creek, it was divided proportionally into the inflow from East Canyon Creek and from other tributaries on the basis of basin area. East Canyon Creek drains approximately 77,287 acres at its inlet to the reservoir, or 80% of the watershed. Other tributary inflows to the reservoir were therefore assumed to make up approximately 20% of the total reservoir inflow for the purpose of load analysis.

The discharge record to the reservoir was categorized into four "hydroperiods" describing typical runoff conditions in the basin. These periods were determined both graphically and through the use of specific criteria, using each year's annual hydrograph and daily precipitation records at the Coalville station. First, the dates of the spring snowmelt period were determined for each year through visual inspection of annual hydrographs (Appendix A). Secondly, storm runoff periods were identified by applying a set of rules to each day's precipitation and snow records, and by visually comparing the results with the hydrographs at Jeremy Ranch and reservoir inflow for the best fit. Fit was optimized so that the rules would identify the majority of observed storm-related spikes in discharge, while not misidentifying storms that did not result in observed spikes. Several iterations of rules were tested to ensure the best fit. Unpublished discharge and water quality data (BIO-WEST 2008) were also used to assess whether the hydroperiods determined were representative. The final rules used are as follows:

- Because almost any precipitation during snowmelt periods tends to runoff due to melting and saturated soil conditions, all days (plus one day following) with precipitation greater than 0.1 inch (2.5 mm) were assumed to produce storm runoff.
- Because most precipitation from winter storms (qualified as December 1 to the start of spring runoff) is stored in the snow pack until spring, only events with significant non-snow precipitation (inches of precipitation greater than inches of snow) and total precipitation greater than 0.1 inch (2.5 mm) were assumed to produce runoff during this period.
- Because of drier soil conditions, summer and fall storms (qualified as the end of runoff to December 1) were only considered to produce runoff if they did not have a significant snow component and were greater than 3 to 10 inches (7.6 mm). Storms with a significant snow fraction were not assumed to produce runoff due to storage in the early snow pack, infiltration during melting (due to slower delivery rate), or sublimation.
- The day following any day considered to produce runoff was also considered to have runoff due to the lag in time to reach the reservoir in the channel and time to concentration in the basin.

Once hydroperiods had been established, their average flow was used to calculate loads, which were calculated as the product of each period's average constituent concentration, average discharge, and length. These calculations were computed separately for wet years, dry years, and years that fit within the typical range of discharges. The differentiation of wet and dry years is discussed in Section 3.3.2.2. Although the current time period (water years 2002–2007) did not contain a wet year by the criteria used, 2006 was very near the criteria and was the wettest during the period; it was therefore considered a wet year for the purposes of analysis.

3.3.1.3 Sediment Chemistry

On October 23, 2007 Chesapeake Biogeochemical Associates (CBA) collected sediment core samples in triplicate from four locations (see Table 3.6 and Figure 3.1) in East Canyon Reservoir. Each sample was analyzed in the laboratory to determine oxygen fluxes, soluble reactive phosphorus (SRP) fluxes, and ammonium fluxes. Solid phase analyses were also conducted to determine sand, silt, and clay proportions for each sample site as well as concentrations of inorganic, organic, and total P, organic N and C, acid volatile sulfide, and HCl-extractable Fe.

Table 3.6. Metadata Summary of Sediment Cores Collected in East Canyon Reservoir in October 2007

Sampling Site	Depth (feet)	Latitude (North)	Longitude (West)
1	> 100	40.91986	111.59666
2	33	40.89772	111.58984
3	75	40.90207	111.59126
4	> 100	40.91133	111.59193

For samples collected at sites 1, 3, and 4, the surface of the sediments appeared dark and sulfidic; therefore samples were not aerated prior to incubation (incubation was conducted anaerobically for these samples). Samples collected at site 2 were aerated overnight prior to the start of incubations (incubation was conducted aerobically for these samples). Incubations for all samples from all four sampling sites were conducted in the dark with continuous stirring. A control core without sediment was used to correct for any water column effects. For analysis of SRP and ammonium, 20 mL (typically) of solute were filtered (25 mm diameter, 0.45 mm cellulose acetate syringe filter) into vials with sample water replaced by station water fed into the cores via plastic tubing. Samples were frozen for preservation. For dissolved gas analysis using membrane inlet mass spectrometry samples were taken only from the aerobic incubations. Chemical analyses for ammonium and SRP were conducted using low-level techniques from the Chesapeake Biological Laboratory (CBA 2008). A membrane inlet mass spectrometer was used to analyze DO (Kana et al. 2006). Solid phase analyses on 0 to 2 cm sections from each core were conducted for grain size according to Leventhal and Taylor (1990), for inorganic and total P according to Aspila et al. (1976), and for organic N and C using a CHN analyzer. Iron was analyzed on the inorganic P extracts according to Leventhal and Taylor (1990) with the results being considered "oxide" iron.

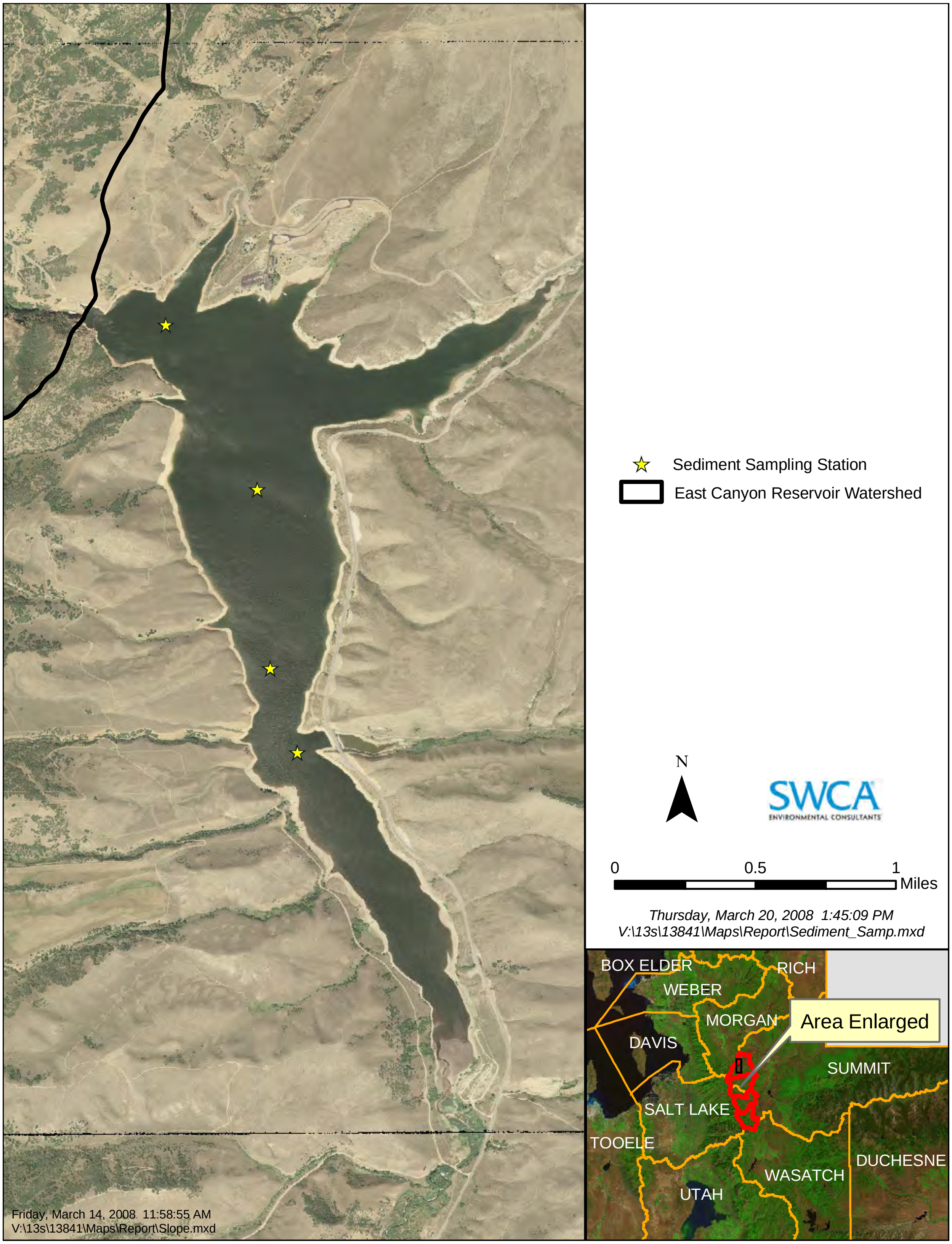


Figure 3.1. Sediment core sampling locations (Chesapeake Biogeochemical Associates 2008).

3.3.1.4 Treatment of Nondetects

Many of the data points (7.25% of the data points from creeks, streams, and the reservoir) collected in this dataset are concentration values identified as "below detection limits," "greater than quantitation limits," or "too numerous to count." For the purpose of analyzing the data, a method must be developed to statistically interpret these values. This is generally accomplished by assigning a numeric value that is one-half of the detection limit (in the case of concentrations identified as below detection limits) or a value that represents the quantitation limit (in the case of concentrations identified as greater than quantitation limits).

Detection limits were reported in the EPA STORET database for most data points and provided specific nondetect values for most data (Table 3.7). If data-point specific detection limits were not provided, detection limits were applied based on specific analytical methods.

Table 3.7. Detection Limits of Methods Found in the EPA STORET Database

Parameter	Sample Fraction	Units	Detection Limit
Arsenic	Dissolved	μg/L	5
	Total	ppm	31
Biochemical Oxygen Demand	Total	mg/L	3
Cadmium	Dissolved	μg/L	1
	Total	ppm	3.1
Chromium	Dissolved	μg/L	5
Chemical Oxygen Demand	Total	mg/L	15
Copper	Dissolved	μg/L	12–20
Lead	Dissolved	μg/L	3
	Total	ppm	31
Mercury	Dissolved	μg/L	0.2
	Total	ppm	0.15
Nitrogen, ammonia as N	Total	mg/L	0.01–0.05
Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	Dissolved	mg/L	0.02–0.1
pH	Total		3
Phosphorus as P	Dissolved	mg/L	0.01–0.02
	Total	mg/L	0.01–0.02
Selenium	Dissolved	μg/L	1
	Total	ppm	31
Silver	Dissolved	μg/L	2
Solids, Total Suspended	Total	mg/L	4

In the case of bacteriological data, where numerous dilutions are used to determine the total counts, an upper quantitation limit cannot be identified directly from the method summary. In cases where total concentrations were listed as being greater than the quantitation limits or "too numerous to count," a value of 1.5 times the highest quantified concentration was substituted. This provides a numeric value that will allow statistical analyses to be performed. Such a substitution most likely represents an underestimation of the total bacteria count present. Because the quantitation limits for the analysis of total coliform and fecal coliform bacteria are higher than the state criteria for contact recreation, the recommended substitution should not result in an unidentified risk to recreationists (no false negatives).

3.3.1.5 Treatment of Errors

An initial assessment of the data was performed to identify transcription and other errors such as inappropriate values (e.g., a pH value of 90), inaccurate sample information (e.g., units of mg/L for specific conductivity data), and errors in physical information (e.g., incorrect county or latitude information for a known sample site). A small number of such errors were identified and corrective action was taken as outlined below.

A number of sample sites included data points of zero. It was not immediately obvious what these values represented. Possible interpretations include

- entry error of an analytical nondetect,
- an error in a spreadsheet used to enter data to EPA STORET,
- an error in the EPA STORET database that did not allow display of appropriate decimal places and resulted in values of "less than one" being displayed and recorded as zero,
- direct transcription errors, and
- a combination of the above and other unknown errors.

Because of this uncertainty, zero values were removed from all datasets, with the exception of measured or estimated flow and measurements of water and air temperature, where a zero value is possible. The total number of zero values removed from the East Canyon Reservoir (including creeks and streams) dataset was 879 (~2.9% of the dataset). Zero values occurred in this dataset for chlorophyll *a*, uncorrected for pheophytin (38 points), fecal coliform (37 points), total suspended solids (485 points), volatile solids (310 points), and total coliform (9 points).

Negative values occurred in datasets for turbidity, representing 0.08% (or 25) of the data points. Values ranged from -0.1 to -0.4 (recorded by the BOR on 6/20/2007) and no analytical method was listed. As turbidity measurements cannot be below zero, the values were determined to be a transcription or entry error and were removed.

Values recorded as ‘present above the quantitation limit’ occurred for DO were assumed to be erroneous because the field equipment used does not have a quantitation limit. Two points were removed from the dataset for this reason.

3.3.1.6 Treatment of Outliers

To identify a final dataset representative of water quality conditions in the East Canyon Reservoir system, a threshold of plus or minus three standard deviations from the mean was applied to the available datasets (Table 3.8 and Table 3.9). This resulted in the removal of approximately 113 data points from the East Canyon Creek dataset (~1.1%) and 61 data points from the East Canyon Reservoir dataset (~0.3%). This mechanism for identifying nonrepresentative data was approved by UDWQ. Those values identified as being outside of the range were removed from the dataset.

Table 3.8. Standard Deviations Used in Outlier Analysis for East Canyon Reservoir Water Quality Data

Characteristic Name	Units	Standard Deviation	Mean	Count
Alkalinity, carbonate as CaCO3	mg/L	10.24	172.08	90
BOD, total	mg/L	4.05	2.91	45
Chloride	mg/L	27.33	81.48	90
DO	mg/L	2.96	5.28	3,251
DO saturation	mg/L	36.02	58.75	2,254
Dissolved solids	%	126.00	419.04	107
Nitrogen, ammonia (NH3) as NH3	mg/L	0.09	0.06	682
Nitrogen, nitrite + nitrate as dissolved N	mg/L	0.14	0.14	683
Phosphorus as P, dissolved	mg/L	0.08	0.08	659
Phosphorus as P, total	mg/L	0.09	0.09	650
Salinity	ppt	0.07	0.41	202
Specific conductance	umho/cm	1,729.93	815.12	2,408
Temperature, water	°C	6.24	11.2	3,335
TSS	mg/L	88.09	14.61	107
TSI Chlorophyll *a*	µg/L	14.16	6.88	278
TSI Phosphorus as P	mg/L	17.58	6.17	356
TSI Secchi disk depth	m	1.22	3.28	226
Turbidity	NTU	8.03	4.08	696
Volatile solids	mg/L	3.15	4.77	104

Table 3.9. Standard Deviations Used in Outlier Analysis for East Canyon Creek Water Quality Data

Characteristic Name	Units	Standard Deviation	Mean	Count
Alkalinity, carbonate as CaCO3	mg/L	27.48	174.39	146
BOD, dissolved	mg/L	-	0.50	1
BOD, total	mg/L	1.04	2.33	63
Chloride	mg/L	53.97	96.96	144
DO	mg/L	1.84	9.92	802
DO saturation	%	16.96	101.10	207
Dissolved solids	mg/L	23.04	33.82	11
Fecal coliform	#/100ml	0.12	0.06	821
Nitrogen, ammonia (NH3) as NH3	mg/L	0.22	0.46	25
Nitrogen, Kjeldahl	mg/L	0.81	0.50	785
Nitrogen, nitrite + nitrate as dissolved N	mg/L	0.26	0.26	36
Nitrogen, nitrite + nitrate as total N	mg/L	27.48	174.39	146
Periphyton	mg/m^2	18.08	11.65	12
Phosphorus as P, dissolved	mg/L	0.30	0.13	720
Phosphorus as P, total	mg/L	0.19	0.13	838
Phosphorus, orthophosphate as P	mg/L	0.01	0.02	37
Salinity	ppt	0.14	0.48	204
Specific conductance	umho/cm	325.46	713.66	934
Temperature, air	°C	8.62	12.23	191
Temperature, water	°C	6.10	9.00	812
Total coliform	#/100ml	361.14	416	11
TSS	mg/L	22.89	16.63	742
Turbidity	NTU	601.90	54.76	147
Volatile solids	mg/L	4.48	6	265

3.3.1.7 Treatment of Duplicate Measures

In the case of all characteristics, several sites had duplicate measures. Duplicate measures were sorted and removed with the use of a Microsoft Excel add-in.

3.3.2 DATA COVERAGE

The available dataset covers a wide range of watershed locations and a variety of physical and chemical water quality constituents and hydrologic information. To better evaluate the existing dataset, available data were divided into several subsets to allow identification of temporal, spatial, and constituent coverage and completeness in both a general and a specific fashion.

3.3.2.1 Temporal Coverage

Water quality monitoring data included in this data summary are from 1993 through 2007, covering a wide range of water years and flow scenarios. As detailed in Table 3.10, some monitoring locations have consistent data throughout this time period, whereas others have experienced only intermittent, single-year, or single-event data collection.

Data available for the TMDL process has been divided into the following two categories: September 1993 to September 2001 (recent, water years 1994–2001) and October 2001 to September 2007 (current, water years 2002–2007) based on water years. Current data will be the primary source of information used to develop pollutant loading calculations and coefficients in the ongoing TMDL process as it represents the period of implementation of the TMDL completed in 2000. It has also been used to determine the support level of designated beneficial uses and will be employed to help define appropriate endpoints or thresholds (if applicable) for the East Canyon Reservoir system (see Section 3.4). Recent data will be used for water quality comparisons to document improvement since the last TMDL was completed.

It should be noted that much of the data from 2000 to 2004 were collected under moderate to extreme drought conditions. Physical water quality characteristics such as temperature and DO concentrations measured during these water years represent critical watershed conditions, as drought generally exacerbates such conditions in the watershed. The most current data (water years 2002–2007) have been used for the assessment of criteria or threshold exceedance, pollutant transport and processing, and pollutant loading analyses.

Table 3.10. Sampling Time Periods for Monitoring Sites Located in East Canyon Reservoir

Station ID	Station Name	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
4925130	East Canyon Reservoir East Arm 04		X	X	X	X	X		X							
4925140	East Canyon Reservoir 100 m off Boat Ramp								X		X					
4925160	East Canyon Reservoir Above the Dam 01	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4925170	East Canyon Reservoir Mid-Lake 02							X	X	X	X	X	X	X	X	X
4925180	East Canyon Reservoir Upper Lake 03		X	X	X	X	X	X	X	X	X	X	X	X	X	X
N/A	BOR data															X

3.3.2.2 Hydrological Coverage

In general, hydrological data are used in the TMDL study to describe seasonal dynamics in the system, to differentiate critical low-water seasons in the reservoir, to calculate pollutant loads, and to estimate variability in the system. As stated earlier, current data (water years 2002–2007) will be the primary source of information used to develop pollutant-loading calculations and coefficients, determine the support level of DBUs, and define appropriate endpoints or thresholds for the East Canyon Creek and East Canyon Reservoir systems. Older data may be utilized in trend analysis and land and water management impact analysis. In addition, in those areas where current data are not available, recent data may be used as appropriate to help develop loading coefficients for nonpoint sources and improve understanding of nutrient transport and cycling in the East Canyon Creek and East Canyon Reservoir systems. Table 3.11 shows the USGS and BOR gages available in the basin and their respective periods of record for discharge (see Figure 3.2).

Table 3.11. Discharge Gages in the East Canyon Watershed and Their Periods of Record

USGS Site Number	Site Name	Begin Date	End Date	Drainage Area (square miles)	Notes
10134500	East Canyon Creek near Morgan, Utah	10/1/1931	1/23/2008	144	Downstream (outflow) of East Canyon Reservoir
10134000	East Canyon Reservoir near Morgan, Utah	10/1/1931	9/30/1999	144	Elevation only
10133895	East Canyon Creek at Big Bear Hollow, near Park City, Utah	10/1/1989	9/30/1996	75	
10133900	East Canyon Creek near Park City, Utah	6/25/1982	9/30/1985	68.9	
10133800	East Canyon Creek near Jeremy Ranch, Utah	10/1/2001	1/23/2008	57.2	Directly above SBWRD/ ECWRF
10133650	East Canyon Creek below I-80 rest stop near Park City, Utah	11/7/2002	1/22/2008	42.1	
10133540	Kimball Creek above East Canyon Creek near Park City, Utah	10/1/1989	9/30/1996	13	
BOR Data	East Canyon Reservoir Inflow*	10/3/89	Present	144	Discontinuous until September 1991

* Calculated from the mass balance of outflow and change in storage, rather than being measured or gaged directly.

The only USGS stations covering the current period of record (water years 2002–2007) are located directly downstream of the SBWRD WWTP near Jeremy Ranch, Utah (#10133800) and directly downstream of the reservoir on East Canyon Creek (#10134500). In addition, the BOR monitors water levels in the reservoir and publishes a dataset of daily inflow to the reservoir based on the daily change in reservoir storage and reservoir outflow. These were the primary datasets used to describe the basin's hydrology. Several methods were used to best estimate total discharge to and from East Canyon Reservoir from East Canyon Creek and from other smaller tributaries discharging to other areas of the reservoir (see Section 3.3.1.2).

Figure 3.2 plots the mean annual discharge at the five regional USGS gages with similar terrain and elevation as the East Canyon basin that had nearly full data records over the last 30 years. This figure illustrates patterns in wet and dry years throughout the region for this time period. One standard deviation above and below East Canyon Creek's mean flow over this period are also shown. Wet and dry years indicated in the graph (and used for subsequent analysis) were defined as years when both East Canyon Creek and one of the other regional creeks were at least one standard deviation above or below its 30-year mean discharge, respectively. The figure is plotted in log scale to better illustrate annual variations in basins of a variety of sizes and annual discharges. The first three years of the current dataset (2002–2004) were drought years, with mean average annual discharges well below the normal (see Figure 3.2). Years 2005–2007 were within the normal range of discharges for the basin and the region, although 2006 had total runoff well above the average for the region. Although the current period (water years 2002–2007) did not contain a wet year by the criteria used, 2006 very nearly met the criteria and was the wettest during the period; it was therefore considered a wet year for the purposes of analysis.

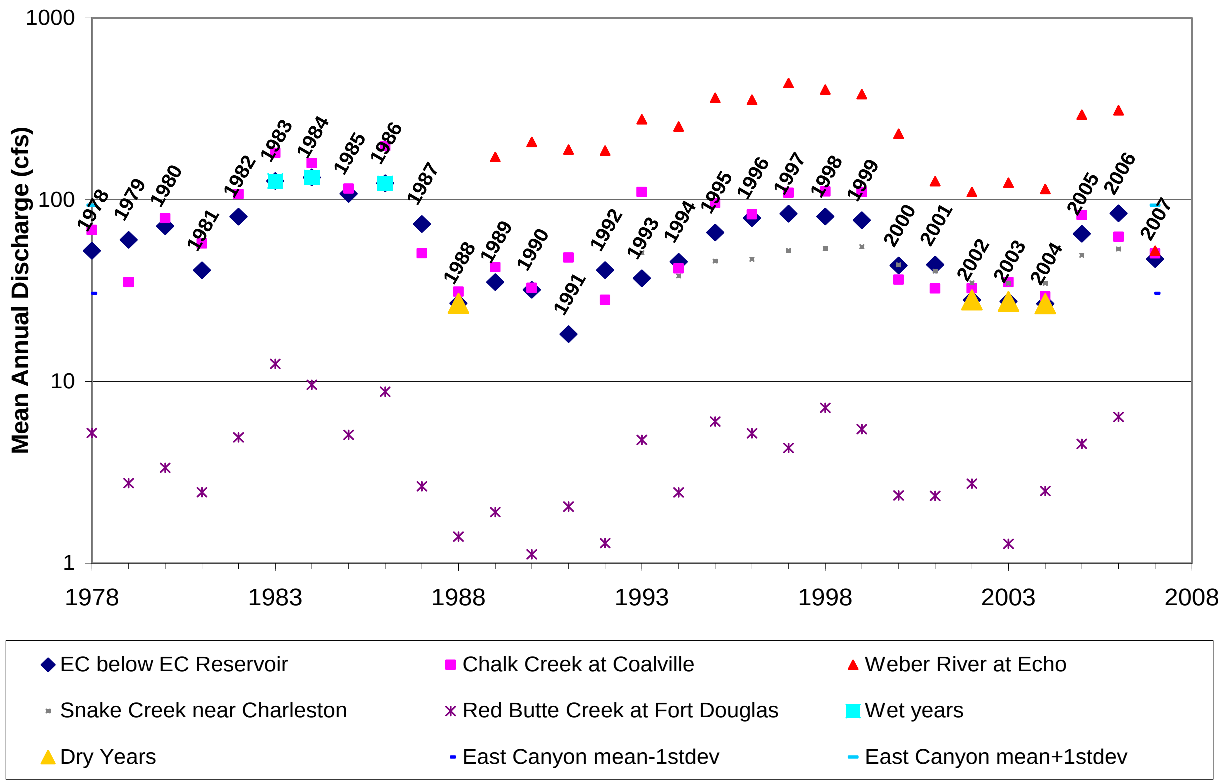


Figure 3.2. 30-year record of mean annual discharges for regional streams used to differentiate wet and dry years.

In general, the hydrology of East Canyon Creek is characterized by a single large period of snowmelt (typically occurring during the period between early March and late May) and an extended period of baseflow interspersed with small storm events. Annual flow volumes and quantitative comparisons relative to the 30-year average for USGS gage #10134500, located near Jeremy Ranch, are displayed in Table 3.12. Data collected during high, average, and low water years were plotted on the individual hydrographs representative of high, average, and low water years (respectively). Figure 3.3 shows the discharge at Jeremy Ranch in the wettest year during the period of interest (2006), the driest year (2004), and a typical year close to the average flow (2007). The volume of inflow to East Canyon Reservoir is represented by the area under the annual hydrograph, meaning that most of the reservoirs volume is provided by snowmelt runoff during the annual 3 to 4 month snowmelt period. This pattern is often altered during wet years by a later onset of snowmelt runoff, a higher peak discharge, a greater flow volume of stored snow, and a later onset of baseflow conditions in the summer. During dry years, baseflow conditions tend to be lower, spring runoff tapers to baseflow conditions earlier in the summer, and dry soils tend to produce fewer runoff events from spring and summer storms than the saturated soils common during wet years.

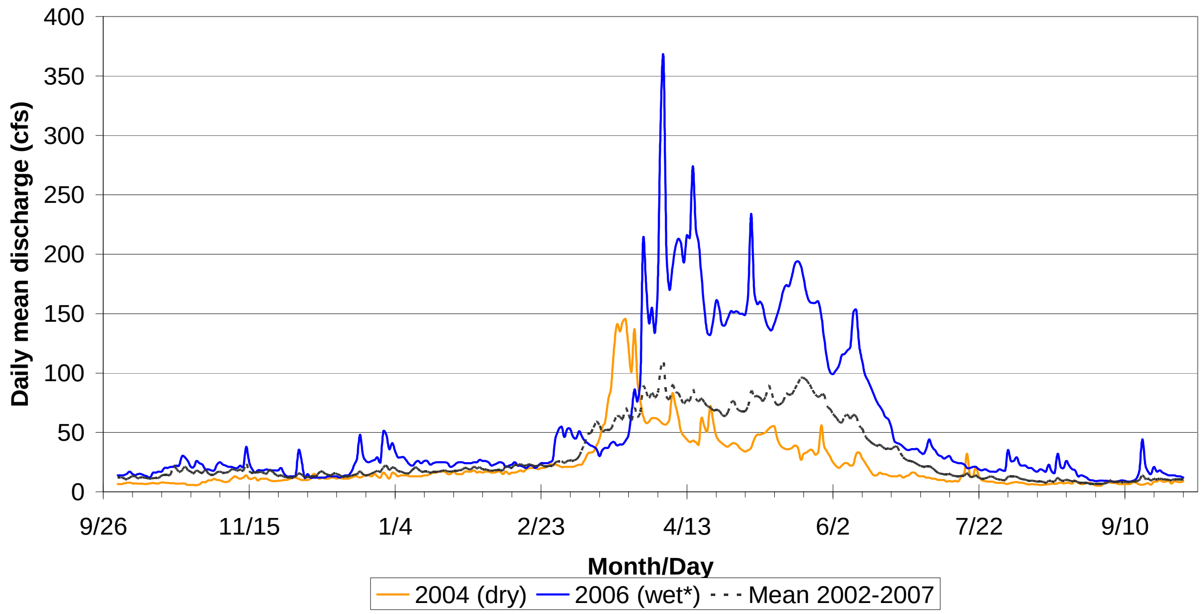


Figure 3.3. Example dry, wet, and average hydrographs for East Canyon Creek near Jeremy Ranch (USGS Station # 10133800).

Table 3.12. Annual Average Flow Rates and Quantitative Comparisons Relative to the 30-year Average for East Canyon Creek at USGS Gage #10134500

Water Year	Flow (cfs)	Percent of 30-year Average Flow	Wet, Dry, or Normal Range
1978	52.4	85	Normal
1979	60.1	97	Normal
1980	71.5	115	Normal
1981	40.9	66	Normal
1982	80.6	130	Normal
1983	126.8	205	Wet
1984	132.5	214	Wet
1985	107.7	174	Normal
1986	123.2	199	Wet
1987	73.5	119	Normal
1988	26.9	43	Dry
1989	35.2	57	Normal
1990	32.0	52	Normal
1991	18.2	29	Normal
1992	41.0	66	Normal
1993	36.9	60	Normal
1994	45.5	73	Normal
1995	66.0	107	Normal
1996	79.1	128	Normal
1997	83.7	135	Normal
1998	80.8	130	Normal
1999	77.1	124	Normal
2000	43.5	70	Normal
2001	43.9	71	Normal
2002	28.1	45	Dry
2003	27.6	45	Dry
2004	26.8	43	Dry
2005	65.0	105	Normal
2006	84.3	136	Normal / Wet*
2007	47.1	76	Normal
30-year Average	**61.9**	**100**	**N/A**

<50% = Dry; 50–150% = Normal ;>150% = Wet

* Because 2006 very nearly fit the criteria and was the wettest during the current time period (water years 2002–2007), it was considered a wet year for the purposes of analysis.

3.3.2.3 Spatial Coverage

Surface water quality data are available for five in-reservoir sites, as well as a tributary inflow site, and a location downstream of East Canyon Dam. Data for the ECWRF is available to characterize the discharge from this point source. Monitoring stations considered to be critical to the TMDL process are listed in Table 3.13. Cumulatively, these monitoring sites represent adequate spatial coverage throughout the watershed. Monitoring stations available to the TMDL process are plotted on Figure 2.1.

Table 3.13. Monitoring Stations and Data Sources Identified as Critical to the East Canyon Reservoir TMDL Process

Station ID	Station Name	Data Source	Use in TMDL Study
4925130	East Canyon Reservoir East Arm 04	UDWQ (EPA STORET)	This site will be used to characterize water quality in the East Arm of East Canyon Reservoir.
4925160	East Canyon Reservoir Above The Dam 01	UDWQ (EPA STORET), BOR	This site represents water quality in the northernmost segment of the reservoir.
4925170	East Canyon Reservoir Mid-Lake 02	UDWQ (EPA STORET)	This site represents water quality in the middle of East Canyon Reservoir. It will be used to characterize water quality in this segment.
4925180	East Canyon Reservoir Upper Lake 03	UDWQ (EPA STORET)	This site represents water quality in the shallowest parts of the reservoir. It will be used to characterize water quality in the southern end of East Canyon Reservoir.
N/A	BOR data	BOR	This data will be used to validate model runs and further characterize water quality throughout the reservoir.
4925150	East Canyon Creek below East Canyon Reservoir	UDWQ (EPA STORET)	This site represents the outflow from the reservoir and the water quality inflowing to the downstream segments of East Canyon Creek. It will be used to characterize reservoir outflow water quality on an annual basis.
4925190	East Canyon Creek above reservoir at second road near USGS Gaging Station	UDWQ (EPA STORET)	This site will be used to characterize total pollutant loading from East Canyon Creek to East Canyon Reservoir. Subtraction of load from ECWRF will provide nonpoint source estimates to be used in unmonitored sections of the watershed that drain directly to the reservoir.
4925240	East Canyon Creek below ECWRF	UDWQ (EPA STORET)	This site, combined with the site above the ECWRF, will be used to check loading estimates determined using effluent data.

Table 3.13. Monitoring Stations and Data Sources Identified as Critical to the East Canyon Reservoir TMDL Process

Station ID	Station Name	Data Source	Use in TMDL Study
4925260	East Canyon Creek above ECWRF	UDWQ (EPA STORET), BIO-WEST	This site, combined with the site below the ECWRF, will be used to check loading estimates determined using effluent data.
4925250	ECWRF	UDWQ (EPA STORET)	This site represents the effluent from the ECWRF. Combined with a more robust dataset provided by SNBWRD, this site will be used to characterize total loading from the ECWRF.

3.3.2.4 Identified Data Gaps

There are no fecal coliform, total coliform, or *E. coli* data available for East Canyon Reservoir. A limited dataset is available for a site upstream of the ECWRF. This site was not considered appropriate for assessment of the recreational beneficial uses in the reservoir itself.

There are no data on recreation use that can be compared across multiple time periods.

There are too few data available for East Canyon Reservoir to assess exceedances of most of the metal related criteria.

Sediment chemistry data are not available for stratification and summer months (only available for October). Sediment-water phosphorus flux in early summer (June) is expected to be much higher than in the fall due to the high influx of phosphorus inflow during spring runoff and iron reduction in early summer following initial stratification of the reservoir. However, no sediment data are available to confirm this hypothesis.

Orthophosphate data were not collected for the current time period (water years 2002–2007).

Few data values are available for the station on East Canyon Creek just above the reservoir (4925190) during storm events.

Very little data are available to characterize organic matter loading to the reservoir from the watershed. Organic matter loads from the watershed may be directly responsible for a large portion of the sediment oxygen demand observed in East Canyon Reservoir. However, without Total Organic Carbon data from East Canyon Creek, the sediment oxygen demand associated with watershed derived organic matter cannot be separated from that associated with algal biomass die-off related to reservoir nutrient concentrations.

Dissolved oxygen profiles are not available for all years, so relationship to survival of fish cannot be determined (e.g., high fish survival rates in 2005 do not have corollary DO data).

The only USGS stations covering the current period of record (water years 2002–2007) are located directly downstream of the SBWRD WWTP near Jeremy Ranch, Utah (#10133800) and directly downstream of the reservoir on East Canyon Creek (#10134500).

3.3.2.5 Summary

According to CWA guidelines, states are to use the best available data in the TMDL process; in those cases where data gaps exist, states are to include an appropriate MOS to account for analytical uncertainty and environmental variability. In most cases, the East Canyon Reservoir system has a complete set of available data for the evaluation of water quality impairment. A robust dataset is available to the TMDL process. An appropriate MOS will also be included.

3.4 BENEFICIAL USE SUPPORT ASSESSMENT FOR EAST CANYON RESERVOIR

Water quality in East Canyon Reservoir was assessed based on a process consistent with the guidelines established by the EPA under the CWA and with the programs and policies established by UDEQ. The assessment process identified the beneficial uses specific to the reservoir and the water quality criteria that apply to the protection of these uses. Water quality was evaluated by comparing the available water quality data to numeric water quality criteria and calculating direct exceedances of numeric criteria. Additional lines of evidence were used to further assess impairment of beneficial uses as follows:

- Nuisance algal growth assessment (Class 1C, 2A, 2B, and 3A)
- Presence of cyanobacteria (Class 1C, 2A, 2B, 3A, and 4)
- Fish population diversity and health (Class 3A)
- Recreation use surveys (Class 2A and 2B)
- TSI (Class 2A, 2B, and 3A)

3.4.1 DIRECT EXCEEDANCE OF NUMERIC CRITERIA, THRESHOLDS, AND/OR REFERENCE CONDITIONS

Exceedances of water quality criteria and thresholds specific to eutrophication and designated beneficial use support are evident in East Canyon Reservoir and the inflowing tributary systems.

A direct assessment was completed for the watershed to describe the available data for exceedance of numeric criteria and to identify pollutant thresholds. A cursory discussion of the level of exceedance observed for pertinent water quality standards and threshold values on a watershed basis is presented in the following parameter-specific sections.

3.4.1.1 Ammonia (3A)

Data show no exceedances of the ammonia criteria for the cold water fisheries designated beneficial use in East Canyon Reservoir (see Table 3.2).

3.4.1.2 Bacteria

Recently, the State of Utah revised the bacteria standard to be specific to *E. coli* (less than 206 *E. coli* organisms per 100 mL as a 30-day geometric mean, and less than 940 *E. coli* organisms per 100 mL as a maximum). The previous standard was specific to fecal coliforms and total coliforms, so the majority of recent and historic bacteria data available for TMDL analyses are fecal coliform counts. The 30-day geometric mean criteria for beneficial uses 1C, 2A and 2B, and 4 are 5,000, 1,000, and 5,000 mean bacteria per 100 ml, respectively, and 2,000, 200 and 200 mean fecal coliform bacteria per 100 ml, respectively. Unfortunately, no established method correlates fecal coliform and *E. coli* data. There are no *E. coli*, total coliform, or fecal coliform data available for East Canyon Reservoir.

3.4.1.3 Nuisance Algal Growth

A common surrogate measure of algal growth is chlorophyll *a*. The State of Utah has not identified numeric water quality criteria for chlorophyll *a*; however, discharges or conditions leading to nuisance algal growth are addressed as narrative criteria (Utah State Code RS317-2-14, see Table 3.2).

Chlorophyll is the green pigment in plants associated with photosynthesis (the process whereby plants combine light energy, nutrients, and carbon to grow). A measure of chlorophyll provides an estimate of the amount of photosynthesizing algae that are in the water column. On average, chlorophyll *a* makes up approximately 1.5% of algal organic matter (Raschke 1993) and if chlorophyll *a* concentrations are known, the phytoplankton biomass in a waterbody can be estimated.

A review of existing literature regarding nuisance thresholds and chlorophyll *a* was undertaken to identify generally accepted values based on current science and other regulatory processes. The review of aquatic life needs (Pilgrim et al. 2001) reported chlorophyll *a* concentrations of 10–15 µg/L to be protective of waters inhabited by salmonids, and 25–40 µg/L for waters inhabited by non-salmonids. A similar review of chlorophyll *a* targets based on public perception, recreational use, and aesthetics identified a range of maximum chlorophyll *a* concentrations of 15–50 µg/L from a number of U.S. states and Canada. Data on water discoloration (Raschke 1994) show that a level of discoloration unacceptable to the average recreational user commonly occurs at chlorophyll *a* concentrations above 30 µg/L. At these concentrations, deep discoloration and formation of algal scum may be observed.

Chlorophyll *a* data available were instantaneous grab samples collected primarily during the summer season (May–October) from water years 2002–2007. The mean values for this dataset are 5.39 µg/L Above the Dam (Station 4925160), 1.36 µg/L at Mid-Lake (Station 4925170), and 2.75 µg/L in the Upper Lake (Station 4925180). The mean of the BOR samples taken in June and August of 2007 was 2.45 µg/L (Table 3.14). The maximum value measured for this dataset was 27.1 µg/L taken Above the Dam. No chlorophyll *a* data were collected from any of the East Canyon Creek monitoring sites, and only recent and historic data are available for the East Arm of the reservoir.

Table 3.14. Summary of Chlorophyll *a* Data in East Canyon Reservoir (water years 2002–2007) during the May–October Algal Growth Season (µg/L)

Station Name	Station ID	N	Mean	Standard Deviation	Maximum	Minimum
East Canyon Reservoir Above the Dam	4925160	51	5.39	8.64	27.1	0.2
East Canyon Reservoir Mid-Lake	4925170	19	1.36	1.27	5.2	0.2
East Canyon Reservoir Upper Lake	4925180	18	2.75	4.58	19.9	0.2
BOR 2007 Sampling Sites	n/a	565	2.45	2.40	24.3	0.1

The mean and maximum chlorophyll *a* concentrations observed in East Canyon Reservoir are below the literature threshold of 30 µg/L identified as protective of recreational activities. Maximum observed chlorophyll *a* concentrations of up to 27.1 µg/L indicate periodic formation of algal scum or water discoloration. These levels are also in excess of concentrations protective for salmonids (10–15 µg/L) in which excessive algal growth can result in supersaturated DO concentrations during daylight hours followed by low DO conditions during nighttime hours. Algal growth also contributes to loading of organic material into the reservoir. Organic material can result in longer-term DO sags as oxygen is removed from the water column through decomposition.

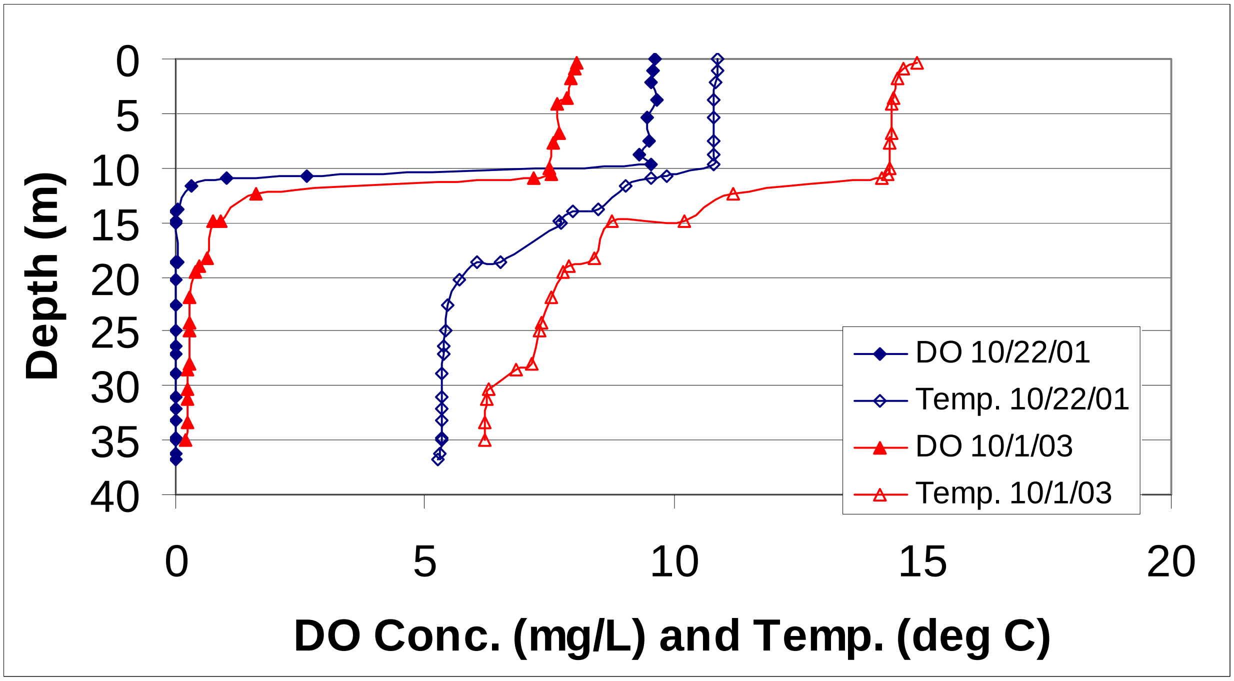
3.4.1.4 Dissolved Oxygen (DO) (3A)

Dissolved oxygen concentrations in the surface epilimnion of East Canyon Reservoir routinely attain all applicable state water quality standards. Average monthly DO concentrations at the surface of East Canyon Reservoir range from 11.23 mg/L in May to 7.17 mg/L in July (these values average data available for the current water quality period from 2001 to 2007). The minimum surface water DO for the reservoir during the same period was 6.62 mg/L in July 2006 at the Dam Site monitoring station. This minimum concentration of 6.62 mg/L is still above the most stringent chronic criteria for cold water fishery when all life stages are present of 6.5 mg/L 30-day average.

Dissolved oxygen concentration exceedances below the minimum criteria for the cold water fishery designated beneficial use (less than 4.0 mg/L) occur routinely in the hypolimnion of East Canyon Reservoir, with 23 to 75% of the water column showing DO concentrations of less than 4.0 mg/L. The observed minimum value (0.1 mg/L) shows that exceedances of the criteria are occurring at a magnitude of concern. Dissolved oxygen profile data was summarized for three East Canyon Reservoir monitoring sites during three years in the current period of record including: 10/22/2001, 10/1/2003, 6/19/2007, 7/10/2007, 8/15/2007, 9/12/2007 (Table 3.15; Figures 3.4, 3.5 and 3.6). Interpretation of water column exceedances is provided by the State of Utah (UDWQ 2006b). A waterbody is given nonsupporting status for cold water game fish when less than 50% of the water column depth exhibits DO concentrations of 4.0 mg/L or greater. Full-support status is given where greater than 50% of the water column depth exhibits DO concentrations of 4.0 mg/L or greater. East Canyon Reservoir Above the Dam Site was found to be in full support, on average, during the month of June and nonsupporting during the months of July, August, September, and October. The Mid-Lake Site was found to be nonsupporting in June, August, and September. The Upper Lake Site, near the tributary inflows, was found to be in full support during all sampling events. Dissolved oxygen profiles in 2003 were found to be higher than those collected in 2001 and 2007. This is likely related to the drought during this period which resulted in lower sediment, phosphorus, and organic matter loading from the watershed.

Table 3.15. Summary of Percent Water Column Exhibiting DO Levels Supportive of Cold Water Fishery (>4 mg/L) and Associated Support Status Based on Profiles Collected in 2001, 2003, and 2007

Month	East Canyon Reservoir Above The Dam 01 (ID 4925160)	East Canyon Reservoir Mid-Lake 02 (ID 4925170)	East Canyon Reservoir Upper Lake 03 (ID 4925180)	Monthly Average
June	77% (Full Support)	39% (Non-Support)	90% (Full Support)	74% (Full Support)
July	40% (Non-Support)			40% (Non-Support)
August	34% (Non-Support)	25% (Non-Support)	56% (Full Support)	36% (Non-Support)
September	37% (Non-Support)	37% (Non-Support)	100% (Full Support)	47% (Non-Support)
October	37% (Non-Support)			37% (Non-Support)



Site Average:	48% (Non-Support)	34% (Non-Support)	82% (Full Support)	52% (Full Support)

Figure 3.4. Observed DO and temperature profiles at East Canyon Dam in 2001 and 2003.

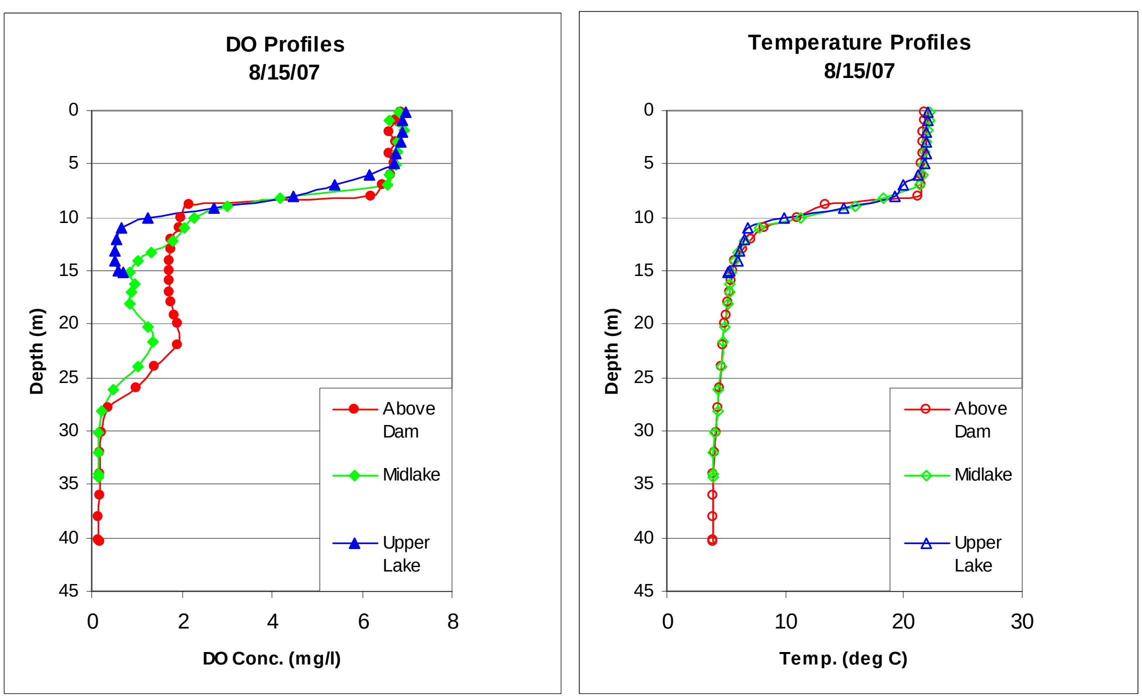


Figure 3.5 DO and temperature profiles at multiple sites in East Canyon Reservoir collected on 8/15/2007.

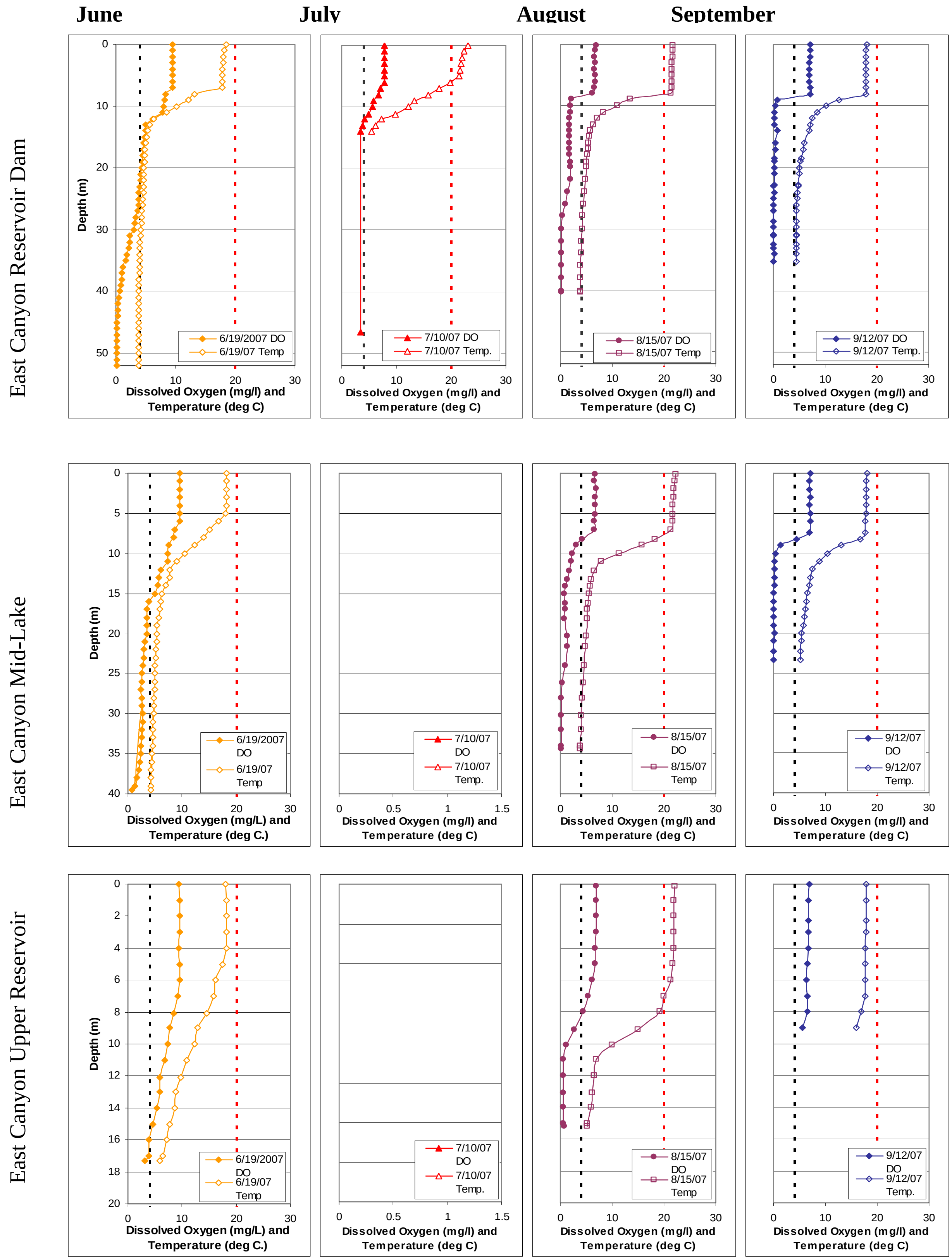


Figure 3.6. DO and temperature profiles at multiple sites in East Canyon Reservoir across the 2007 summer algal growth season.

Oxygen is dissolved in surface waters at equilibrium with the atmosphere and is influenced by water temperature and atmospheric pressure. Oxygen solubility (the amount of oxygen that will dissolve in the water) decreases with increasing water temperature. Thus, the warmer the water is, the less oxygen will dissolve in it. Exceedances of the temperature criteria in the epilimnion are frequent during summer months. Current fisheries data provided by DWR indicate that the fishery is impaired by low DO.

3.4.1.5 Total Dissolved Gas Saturation (3A)

The standard for dissolved gas saturation is 110% for the cold water fishery beneficial use. Dissolved oxygen saturation data rarely exceeded this standard. Overall exceedances in the dataset indicate 3% exceedances, indicating that the low DO observed in the reservoir is primarily related to decomposition processes rather than the diurnal respiration processes of algae.

3.4.1.6 Nitrate (3A)

No total nitrate exceedances were observed from 1994 to 2006 in East Canyon Reservoir.

3.4.1.7 pH (3A)

In the East Canyon Reservoir watershed, pH could be altered to a small degree or in a localized area by ammonia production during organic matter decomposition, inflow of nutrients, or by excessive algal growth due to the carbon dioxide released during respiration. Data applicable to all designated beneficial uses indicate some exceedances of the pH water quality criteria (no greater than 9.0, and no less than 6.5). Data show only very isolated exceedances (~2% of the data) of the water quality criteria. There were eight observed exceedances greater than 9.0 (pH= 9.30–9.57). All exceedance observations were made on August 3, 2007 at the BOR sampling sites. Current (water years 2002–2007) pH values at the Above the Dam Site (Station ID 4925160) are all within the upper (9.0) and lower (6.5) limits of the pH range defined by the state water quality criteria, and are representative of trends at the other two reservoir sampling stations (Figure 3.7).

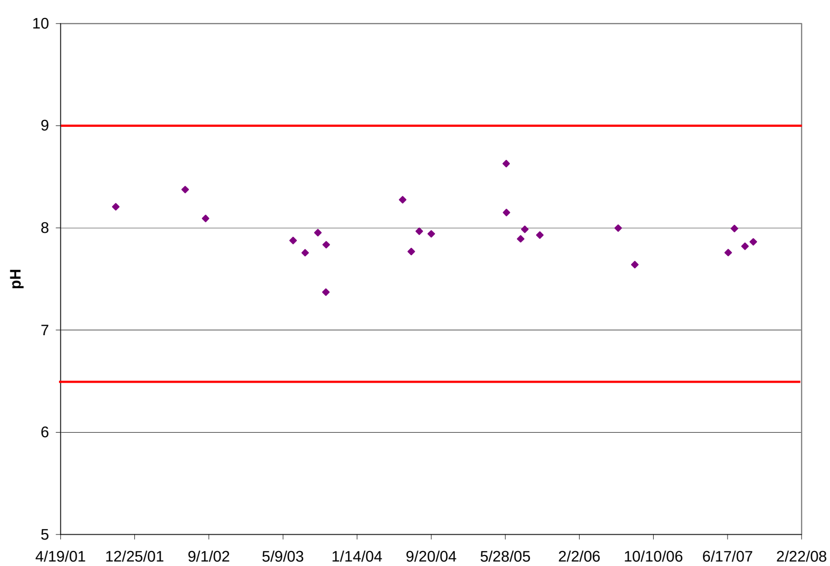


Figure 3.7. Current pH values (water years 2002–2007) at the Above the Dam Site (Station ID 4925160) in East Canyon Reservoir (red lines show upper and lower limits of pH water quality criteria for all beneficial uses).

3.4.1.8 Temperature (3A)

Data applicable to the cold water fisheries designated beneficial use indicate occasional exceedances of the less than 20°C criteria (Figure 3.8). However, the data were from grab samples in which time of day was not considered, so temperatures measured do not necessarily represent the most critical portion of the day (noon to early afternoon) when the highest water temperatures are most likely to occur. Current (water years 2002–2007) maximum measured summertime water temperatures were 23.1°C at the Above the Dam Site on July 10, 2007, and 25.9°C in East Canyon Creek above the ECWRF on August 28, 2003. In total, 15% of the available data for the reservoir showed water temperatures over 20°C. All water temperature measurements were collected during the summer season from May to October. In East Canyon Creek, 7.7% of measurements were in exceedance of the criteria; however, only 30% of these data were collected during the summer season (May–October). The temperature data for the Above the Dam Site are representative of temperature trends elsewhere in the reservoir; however, the Upper Lake sampling site had 19% of data in exceedance of water temperature criteria, whereas the Mid-Lake Site had 11% of temperatures in exceedance, and the Above the Dam Site had 8% in exceedance. The warmest temperatures occurred in closest proximity to the inflow from East Canyon Creek, which may indicate that summer temperature exceedances in the creek are greater and more frequent than available data demonstrate, and that these exceedances are contributing to surface temperatures in the reservoir that are not supportive of the cold water fishery.

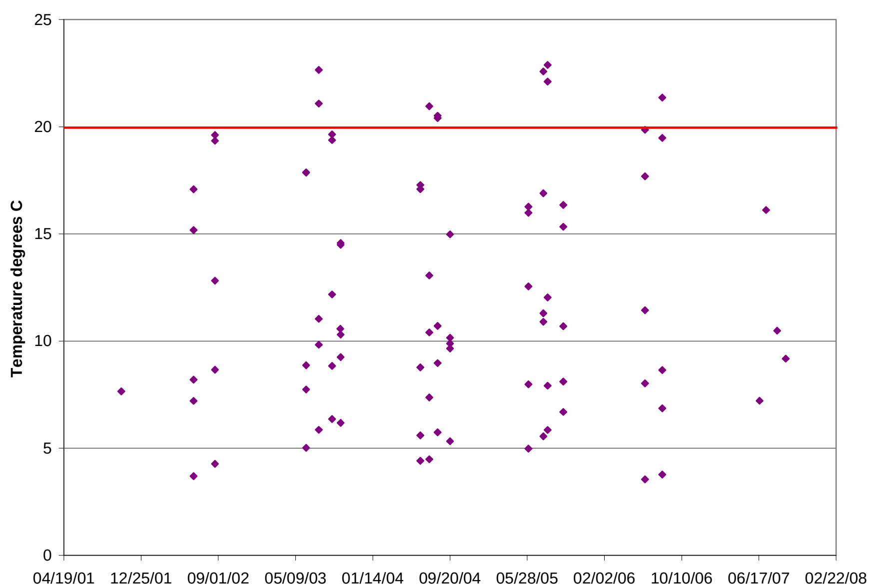


Figure 3.8. Current temperatures (water years 2002–2007) at the Above the Dam Site in East Canyon Reservoir (red line shows upper limits of temperature criteria for cold water fisheries).

3.4.1.9 Total Dissolved Solids (TDS) (4)

No exceedances of TDS criteria (1,200 mg/L) were observed from 1994 to 2007 in East Canyon Reservoir.

3.4.1.10 Total Phosphorus (2A, 2B, and 3A)

The State of Utah has established a threshold indicator value of 0.025 mg/L TP concentration in lakes and reservoirs and 0.05 mg/L in rivers as a trigger for further, in-depth assessment of waterbody condition and needs. This indicator value applies to recreation uses as well as the cold water fishery beneficial use. Total phosphorus exceedances of the designated beneficial use threshold (0.025 mg/L) occur routinely in East Canyon Reservoir with 52% of data showing TP concentrations greater than 0.025 mg/L. Total phosphorus data from the Above the Dam Site are representative of trends at all reservoir sampling sites (Figure 3.9).

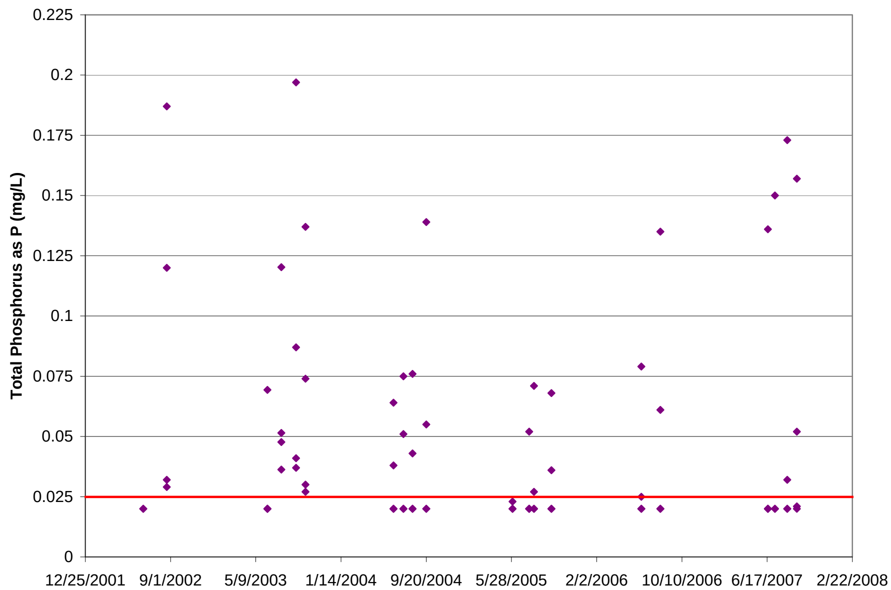


Figure 3.9. Current TP (water years 2002–2007) at the Above the Dam Site in East Canyon Reservoir (red line shows upper limits for TP criteria for recreation and cold water fisheries [2A, 2B, 3A]).

3.4.1.11 Metals (1C, 3A, and 4)

No exceedances of metals were observed for either 1C, 3A, or 4 beneficial uses from 2002 to 2007 in East Canyon Reservoir. Data for arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, and silver were examined for exceedances of water quality criteria for domestic water use (1C) and agricultural withdrawals (4). Beryllium sample data were not available for East Canyon Reservoir. Current (water years 2002–2007) average concentrations of monitored metals and water quality thresholds for designated beneficial uses are given in Table 3.16.

Table 3.16. Current (water years 2002–2007) Average Concentrations (µg/L) of Metals in East Canyon Reservoir

Metal	1C Threshold	3A Threshold	4 Threshold	2002	2003	2004	2005	2007
Arsenic	10	150/340	100	5.0	3.4	2.5	2.5	2.8
Barium	1000	N/A	N/A	117.0	98.2	106.0	104.0	134.7
Cadmium	10	0.25	10	Nondetect	Nondetect	Nondetect	Nondetect	Nondetect
Chromium	50	11/16	100	9.0	7.8	Nondetect	Nondetect	Nondetect
Copper	N/A	9/13	200	Nondetect	Nondetect	Nondetect	Nondetect	1.9
Lead	15	2.5/65	100	Nondetect	Nondetect	Nondetect	Nondetect	0.46
Mercury	2	0.012/2.4	N/A	Nondetect	Nondetect	Nondetect	Nondetect	Nondetect
Selenium	50	4.6/18.4	500	Nondetect	Nondetect	Nondetect	Nondetect	Nondetect
Silver	50	NA/1.6	N/A	Nondetect	Nondetect	Nondetect	Nondetect	Nondetect

3.4.2 Additional Lines of Evidence for Beneficial Use Assessment

3.4.2.1 Secchi Depth

The Secchi depths recorded for monitoring stations in East Canyon Reservoir were collected throughout the water years from 2002 through 2006 (no data are available for 2007). Secchi depths in the reservoir are mostly from 1 to 6 m with a few readings of less than 1 m or up to 50 m (Table 3.17).

Table 3.17. Summary Statistics for Current Secchi Depth (m) Data (water years 2002–2006) in East Canyon Reservoir Data Collected during the Algal Growing Season (June–October)

Station Name	Station ID	N	Mean	Standard Deviation	Maximum	Minimum
East Canyon Reservoir Above the Dam	4925160	16	3.93	0.94	6.2	2.5
East Canyon Reservoir Mid-Lake	4925170	16	3.51	1.08	6.3	2.2
East Canyon Reservoir Upper Lake	4925180	15	3.16	1.14	6.1	1.7

3.4.2.2 Trophic State Index (TSI)

The composite TSI value for the East Canyon Reservoir has been in the low 50s since 1994 with a slight upward trend each year. The 1997 composite TSI for East Canyon Reservoir was 54.52 (Judd 1999). Current (water years 2002–2007) average TSI values for three East Canyon Reservoir monitoring sites (Table 3.18) were calculated using averaged data available for Secchi disk depth, chlorophyll *a* concentrations, and TP concentrations. Only TSI values for chlorophyll *a* are available from the BOR sampling sites collected in 2007.

Table 3.18. Current (water years 2002–2007) Average TSI Values for East Canyon Reservoir

Monitoring Site[a]	TSI Parameter				
	Secchi Depth	Chlorophyll *a*	Total Phosphorus	Trophic Status	TSI Code
4925160 East Canyon Reservoir Above the Dam	40.5	31.3	55.5	Mildly eutrophic	E
4925170 East Canyon Reservoir Mid-Lake	42.5	29.7	57.3	Mildly eutrophic	E
4925180 East Canyon Reservoir Upper Lake	44.2	33.2	54.3	Mildly eutrophic	E
BOR Sampling Sites	n/a	29.1	n/a	Oligotrophic	n/a

[a] Data from 3 EPA STORET monitoring sites during the 2002–2007 water years; BOR data from 9 monitoring locations in 2007.

Current TSI values indicate that East Canyon Reservoir is predominantly mesotrophic to mildly eutrophic. Total phosphorus TSI values are the highest of the three indices, with Secchi depth generally higher than chlorophyll *a*, but lower than TP. This indicates that algae dominate light attenuation but that some other factor may limit algal growth such as temperature, nitrogen co-limitation, zooplankton grazing, or toxic algal blooms. Alternatively, chlorophyll *a* values may not be reflective of reservoir productivity due to wind patterns that blow suspended algae toward the dam which are then released into East Canyon Creek via dam withdrawal. High TP and TSI values may be due to increasingly high sediment-bound phosphorus loads into the reservoir. The high TSI values in the East Arm of the reservoir are likely due to shallow conditions and/or longer retention times in this isolated portion of the reservoir. Flow constriction at the mouth of the East Arm or the presence of emergent vegetation could also contribute to increased TSI values.

3.4.2.3 Nitrogen-to-phosphorus Ratio

Nitrogen and phosphorus enters East Canyon Reservoir from both point and nonpoint sources in the watershed. Due to their ability to fix atmospheric nitrogen, blue-green algae can increase where low nitrogen limits the growth of other algal species (Sharpley et al. 1984, 1995; Tiessen 1995). As a result, algal blooms in the reservoir can only be controlled through phosphorus limitation. In addition, phosphorus is an important nutrient in controlling N_2 fixation in East Canyon Reservoir, a primarily N-limited system (Wurtsbaugh 1988). The N:P ratio in East Canyon Reservoir (for water years 2002–2007) averages 3.83 and ranges from 0.95 to 7.37 (Table 3.19). There are limited months of N:P data (May–October) available for the current time period; however, N:P ratios peak from May to September with lower N:P ratios in winter months. These data support the apparent nitrogen limitation in East Canyon Reservoir with occasionally co-limitation by nitrogen and phosphorus.

Table 3.19. Current Nitrogen-to-phosphorus Ratios in East Canyon Reservoir (water years 2002–2007)

Month	N:P Above the Dam (ID 4925160)	N:P Mid-Lake (ID 4925170)	N:P Upper Lake (ID 4925180)
January	-	-	-
February	-	-	-
March	-	-	-
April	-	-	
May	5.63	6.25	5.25
June	4.40	4.95	3.20
July	3.88	3.26	3.24
August	3.51	3.72	4.03
September	3.28	3.93	5.00
October	1.74	0.95	2.53
November	-	-	-
December	-	-	-
Mean	**3.78**	**3.96**	**3.76**
Standard Deviation	**1.57**	**1.92**	**1.07**
Maximum	**5.85**	**7.37**	**5.25**
Minimum	**1.68**	**0.95**	**2.34**
		Overall Mean	**3.83**
		Overall Standard Deviation	**1.54**
		Overall Maximum	**7.37**
		Overall Minimum	**0.95**

3.4.2.4 Algal Communities

Blue-green algae can dominate otherwise nitrogen-limited systems, like East Canyon Reservoir, due to their ability to fix atmospheric nitrogen. As a result, blue-green algae can increase where low nitrogen limits the growth of other algal species (Sharpley et al. 1984, 1995; Tiessen 1995) and high phosphorus concentrations can increase the density of blue-green algae. In this sense, blue-green algae are themselves phosphorus limited. Both nitrogen and phosphorus can contribute to algal overgrowth, but the algal species present is determined by the ratio of these nutrients. Excessive growth of algae can result in low DO, elevated pH, and concentrations of cyanotoxins produced by blue-green algae. The relative densities of algal species and diversity of the algal community both serve as surrogate measures of water quality by identifying overall species diversity, excessive algal growth or eutrophication, and the relative density of potentially toxic blue-green algae. Blue-green algae and/or diatoms occur at high densities relative to other taxa during bloom events in East Canyon Reservoir.

This assessment is based on current phytoplankton samples collected from the Above the Dam Site (water years 2002–2006) and samples collected at the State Park Boat Ramp and the Upper End of Big Rock Campground (Rushforth and Rushforth 2007, unpublished data). To estimate overall dominance, samples were grouped by month across the time period and across the reservoir to account for different sampling times and locations. Species abundances were measured as number per milliliter. Species rankings and relative densities are based on cell volumes from EPA STORET and Rushforth and Rushforth (2007). Table 3.20 summarizes mean annual algae abundance by species for current data from the Above the Dam Site (water years 2002–2005) and corresponding Rushforth sampling sites. Over 30 algal species were detected with diatoms dominating algal blooms especially in the early spring and summer seasons (Figure 3.10).

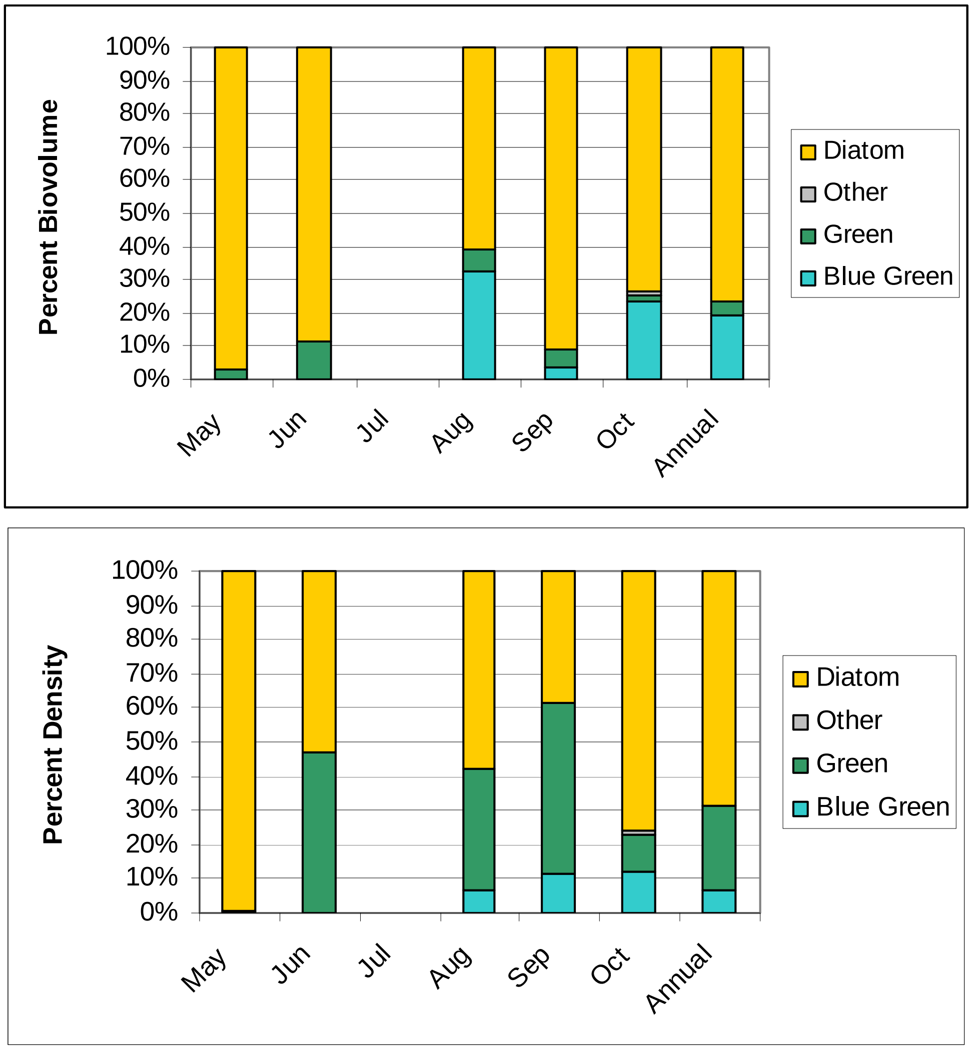


Figure 3.10. Dominance of algal groups measured in percent biovolume and percent density, sampled throughout East Canyon Reservoir from 2002–2007. Data sources: EPA STORET and Rushforth (2007).

Table 3.20. Current (2002–2007) Phytoplankton Abundance above the East Canyon Reservoir Dam (Station ID 4925160) and Corresponding 2007 Rushforth Sampling Sites

Taxon	Avg. Rank	Max. Rank	Min. Rank	Average Relative Density (%)	Average Number per ml	Average Volume (mm^3/ml)
Bacillariophyta (diatoms)						
Asterionella formosa	5.8	11	2	7.3	75.3	0.127
Bacillariophyta	9.1	12	5	0.6	7.5	0.008
Centric diatoms	7.7	12	5	0.3	8.0	0.006
Cyclotella	11.0	14	8	0.1	4.2	0.003
Dinobryon divergens	10.0	11	9	0.4	7.2	0.013
Fragilaria crotonensis	1.8	4	1	25.6	7.9	0.303
Fragilaria virescens	8.0	14	5	2.5	4.5	0.022
Melosira granulata	2.5	4	1	37.0	65.4	0.640
Melosira granulata var. *angustissima*	4.8	8	3	8.4	23.6	0.066
Melosira varians	13.0	13	13	0.2	2.4	0.008
Pennate diatoms	5.4	7	1	12.8	172.2	0.138
Stephanodiscus niagarae	2.1	5	1	28.3	21.2	0.587
Tabellaria fenestrata	3.5	5	2	15.1	24.6	0.086
Chlorophyta (green algae)						
Ankistrodesmus falcatus	10.0	12	8	0.3	4.5	0.003
Chlamydomonas	9.0	10	8	0.4	20.2	0.008
Chlorophyta	11.0	11	11	0.2	6.3	0.001
Cosmarium	6.5	7	6	1.5	4.8	0.067
Lagerheimiella	11.0	11	11	0.1	1.2	0.002
Oocystis borgei	7.6	12	4	2.3	8.0	0.018
Oocystis	7.7	9	7	0.8	9.5	0.014
Pandorina morum	4.0	4	4	11.8	3.6	0.144
Pteromonas	5.9	11	3	2.7	69.1	0.026
Scenedesmus	9.0	9	9	0.3	4.8	0.007
Schroederia setigera	6.0	6	6	1.5	3.6	0.036
Sphaerocystis schroeteri	9.5	10	9	1.5	1.2	0.027
Staurastrum gracile	3.0	3	3	20.5	1.2	0.078
Unknown spherical *Chlorophyta*	7.0	7	7	0.6	4.8	0.005
Volvox species	8.0	8	8	2.3	1.2	0.000
Cyanobacteria (blue-green algae)						
Anabaena species	3.0	3	3	15.3	8.4	0.180
Aphanizomenon flos-aquae	2.6	5	1	20.8	48.4	0.742

Table 3.20. Current (2002–2007) Phytoplankton Abundance above the East Canyon Reservoir Dam (Station ID 4925160) and Corresponding 2007 Rushforth Sampling Sites

Taxon	Avg. Rank	Max. Rank	Min. Rank	Average Relative Density (%)	Average Number per ml	Average Volume (mm^3/ml)
Microcystis incerta	3.8	6	1	22.0	27.5	0.381
Other						
Euglena	9.0	13	5	1.5	2.2	0.016
Phacus	9.0	10	8	0.9	7.2	0.036
Total for All Groups						**3.799**

3.4.2.5 Potential for Toxicity from Cyanobacteria (blue-green algae)

Blooms of potentially toxic blue-green algae occur seasonally in East Canyon Reservoir. There is considerable potential for cyanotoxin poisonings related to these blooms due to the dominance of blue-green algae in the reservoir. The intensity and frequency of large blue-green blooms appears to have been reduced since implementation of the TMDL in 2001. However, three potentially toxic blue-green algal taxa, *Microcystis incerta*, *Aphanizomenon flos-aquae*, and *Anabena* species still occur at very high relative densities at times in the reservoir. On 8/11/2004 these three species composed 49%, 28%, and 15%, respectively, of the algal bloom above the dam. On 9/22/2005 these three species together composed 48% of the algal blooms above the dam. Once the algal population in a reservoir system becomes dominated by blue-green algae species, phosphorus reductions are required to shift the population back to green algal dominance because blue-green species are capable of fixing atmospheric nitrogen (Codd et al. 2005). Blue-green algal blooms can be harmful to recreation users as well as local populations of wild and domesticated animals. The blue-green algal genera that dominate algal communities in the reservoir are known to produce neurotoxins and/or hepatotoxins (anatoxin or microcystin) that can cause paralytic poisoning, respiratory failure, and compromised liver function. According to the Center for Disease Control, the alkaloid toxins and cyclic polypeptides these algae produce can cause skin and eye irritation, numbness or paralysis of the face and other extremities, and respiratory and muscular paralysis (CDC 2006).

3.4.2.6 Fishery Assessment

On the evenings of April 24 and April 25, 2007, standardized gillnet surveys were conducted by Utah Divison of Wildlife Resources biologists in order to evaluate population trends of pan fish and trout species in East Canyon Reservoir (Nadolski and Schaugaard 2008). Eight nets were set over the course of two nights at eight locations. Gillnet locations were chosen as representative sites for the habitat types found at East Canyon Reservoir (Nadolski and Schaugaard 2008). The catch-per-unit-effort (CPUE) was calculated at each sample site for each species of fish, and CPUE trends were evaluated using long-term gillnet data. Overall, thirty rainbow trout were netted (CPUE=3.75 fish per net/night) and two tiger trout were netted (CPUE=0.25 fish per net/night).

East Canyon Reservoir is managed as a basic-yield trout fishery and is maintained by stocking sub-catchable rainbow trout and catchable tiger trout. In the fall, approximately 40,000 rainbow trout (mean total fish length = 152 mm) and 50,000 tiger trout (mean total fish length = 203 mm) are released in East Canyon Reservoir. Overall, the abundance and diversity of fish species netted was low throughout East

Canyon Reservoir. Rainbow trout composed 94% of the total fish biomass, and tiger trout composed the remaining 6%.

A diversity of age and size classes was not present for rainbow trout in East Canyon Reservoir, with a noticeable absence of smaller fish. This is most likely due to poor survival over the 2006–2007 winter (Nadolski and Schaugaard 2008). Compared to 2005 data, size structure of rainbow trout in East Canyon Reservoir has become unbalanced and is now dominated by fish longer than 280 mm (Nadolski and Schaugaard 2008). However, the 2005 reservoir conditions, with large numbers of rainbow trout fingerlings, were atypical compared to other monitored years. Data collected in 2007 is comparable to data collected in 1997 and 2003 and are likely more representative of CPUE and population trends for rainbow trout in East Canyon Reservoir (Nadolski and Schaugaard 2008).

Approximately 11,000 tiger trout fingerlings were stocked into East Canyon Reservoir beginning in 2000, however no tiger trout were sampled with gillnets in 2003, and only two were netted in 2007 (Nadolski and Schaugaard 2008). Further, since the inception of tiger trout stocking in 2000, there have been few confirmed catches of tiger trout (Nadolski and Schaugaard 2008 and references therein). In 2004 and again in 2005, fifty thousand additional tiger trout fingerlings were stocked into East Canyon Reservoir. Since 2004 few anglers have indicated tiger trout fish catches, no tiger trout were captured during 2005 gillnet surveys, and only two were captured during 2007 gillnet surveys. The poor survival of tiger trout may be attributable to water quality and the presence of the anchorworm (Nadolski and Schaugaard 2008).

A historical assessment of the East Canyon Fishery indicates stock rates were much higher in the 1970s (approx 300,000 3-inch fingerlings per year) and that fish survival was generally quite high with approximately 58,000 trout caught by anglers per year with an average size of 254–305 mm (10–12 inches) comparable to the length of fish caught in the reservoir in 2007 (UDWiR 1979).

3.4.2.7 Recreation Use Summary

Reports from the East Canyon State Park manager do not indicate user dissatisfaction in relation to impaired water quality. Discussion with the manager of the East Canyon Reservoir State Park supports this determination. Visitation to the State Park has fluctuated in recent years, with no significant trends over time. Visitation numbers in 2007 was estimated to be approximately 98,000 compared to an estimated 105,000 in 2002 and 57,000 in 2004. The average annual number of visitors is 85,423.

There have been no reports of *E. coli* or fecal coliforms at the park and bacterial contamination has not resulted in any park closures. The park manager did report that algal blooms are present during low-water years, but per visitors report that it does not adversely impact their experience. No visitor reported that they would not swim in the water or return for future visits as a result of the algae (personal communication between John Sullivan, ECSP Manager, and Laura Vernon, SWCA, on February 14, 2008).

Support of the recreational uses appears to have improved since the development of the East Canyon Reservoir TMDL. In 1999, boating and fishing had been in decline due to reductions in water quality and the cold water fishery (Judd 1999). Water quality had affected recreational use by reducing the abundance and quality of fish in the reservoir, and by reduced aesthetic value from water discoloration and algal scums.

3.4.3 Assessment of Domestic Water Use Beneficial Use (1C)

3.4.3.1 Key Linkages between Water Quality and Domestic Water Uses

Chlorophyll *a* exceedances do not apply directly to domestic water quality; however, episodic high chlorophyll *a* levels in East Canyon Reservoir are indicative of blue-green algal blooms (Figure 3.11). Because the system is dominated by blue-green algal genera known to produce toxins, there is potential for the contamination of East Canyon Reservoir. Although episodic cyanotoxin poisonings of humans are very rare, long-term exposure is suspected of causing chronic liver injury, carcinogenesis and tumor growth, and photosensitivity (Chorus and Bartram 1999). *Microcystis* is the most frequently cited organism in human and animal poisonings by blue-green algae, and animal deaths from liver poisoning have been reported in North America and elsewhere (Chorus and Bartram 1999).

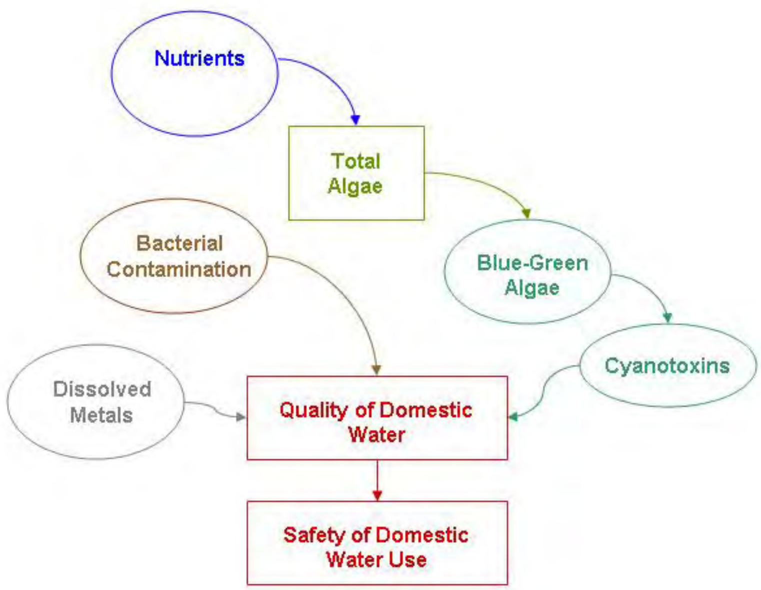


Figure 3.11. Links between water quality and domestic water use.

The presence of *E. coli* in waterbodies is an indicator of fecal contamination. Bacterial contamination, specifically by toxic strains of *E. coli*, is also of concern for domestic water supplies. Most strains of *E. coli* are harmless, but the ingestion of a toxic strain can cause severe gastrointestinal illness, especially in children under 5 years old, the elderly, and those with compromised immune systems. In North America, *E. coli* related illness is most commonly associated with food contamination because most domestic water supplies are treated through chlorination or other methods. Nevertheless, in Ontario, Canada in 2000, seven people died from drinking water contaminated with *E. coli* due to insufficient chlorination levels. The presence of generally harmless coliform bacteria is an indicator that potentially harmful organisms, such as toxic strains of *E. coli*, or other contaminants may be present. No *E. coli* contamination or related illnesses are known to have occurred in East Canyon Reservoir, but the status of *E. coli* in the reservoir is currently unknown because total coliform, fecal coliform and *E. coli* data are not available.

Domestic water supplies can also be threatened by the toxic metals. The distribution of trace or toxic metals is mediated by physical and biological processes (Wetzel 2001). Unlike organic pollutants, metals persist in the system and never degrade once they are mobilized through erosion and moved through the system as airborne particles or sediment (Harte et al. 1991). Dissolved metals may be adsorbed to sediments, but disturbance to or ingestion of sediments can remobilize them. A harmless form of mercury is transformed into methyl mercury by bacteria and concentrated in fish and human tissues when ingested. The chronic accumulation of low levels of toxic metals over time is of greatest concern (Harte et al. 1991).

3.4.3.2 Support Status Summary

The domestic water use beneficial use is fully supported in the East Canyon Reservoir watershed based on numeric water quality standards applicable to this beneficial use. There are no exceedances of criteria for arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, total ammonia, or nitrate. Only isolated exceedances of pH were observed and are limited to one sampling event on August 3, 2007. The water quality standard for bacteria could not be assessed because no data are available for *E. coli*, total coliform, or fecal coliform bacteria for East Canyon Reservoir. The water quality standards for beryllium, bromate, chlorite, and fluoride could not be evaluated due to a lack of data available for these parameters.

3.4.4 Assessment of Contact Recreation Beneficial Uses (2A, 2B)

3.4.4.1 Key Linkages between Water Quality and Recreation Uses

Nutrient effects on water quality are related to the quality, safety, and frequency of recreational use through two key mechanisms. Eutrophication related to nutrient loading is associated with algal overgrowth, which can reduce water clarity (turbidity) and color and increase growth of algal mats (periphyton) both of which reduce the frequency of recreation uses (Figure 3.12). Overgrowth of cyanobacteria is a public health and safety concern in recreational waters. Skin contact can result in irritation, rashes, and hives whereas swallowing water can lead to severe gastroenteritis and organ toxicity in humans (CDC 2006). The CDC advises against recreating in water that is potentially contaminated with cyanobacteria (CDC 2006). Although cyanobacteria may be of low toxicity, cyanotoxins can become highly concentrated in the environment or through bioaccumulation where cyanobacterial overgrowth occurs. Even minimal contact with blue-green algae, such as swimming or wading, can lead to skin irritation and gastrointestinal symptoms (Chorus and Bartram 1999). The primary contact recreation beneficial use indicates surface waters that are used or have the potential to be used for activities where the body may come into prolonged or intimate contact with the water such that water may be accidentally ingested or sensitive body organs (e.g. eyes, ears, nose) may be exposed (CDC 2006). Swimmers can also become ill when contaminated water is accidentally swallowed or inhaled as mist (as could occur during boating or water skiing). Direct contact or breathing airborne droplets containing high levels of blue-green algal toxins during swimming or showering can cause irritation of the skin, eyes, nose and throat, and inflammation in the respiratory tract. Surface scums or water containing high levels of blue-green algal toxins affects primary recreation by exposing swimmers to cyanotoxins inhaled or absorbed through the skin. Consuming water containing high levels of blue-green algal toxins has been associated with effects on the liver and on the nervous system in laboratory animals, pets, livestock, and people. Livestock and pet deaths have occurred when animals consumed very large amounts of accumulated algal scum from along shorelines.

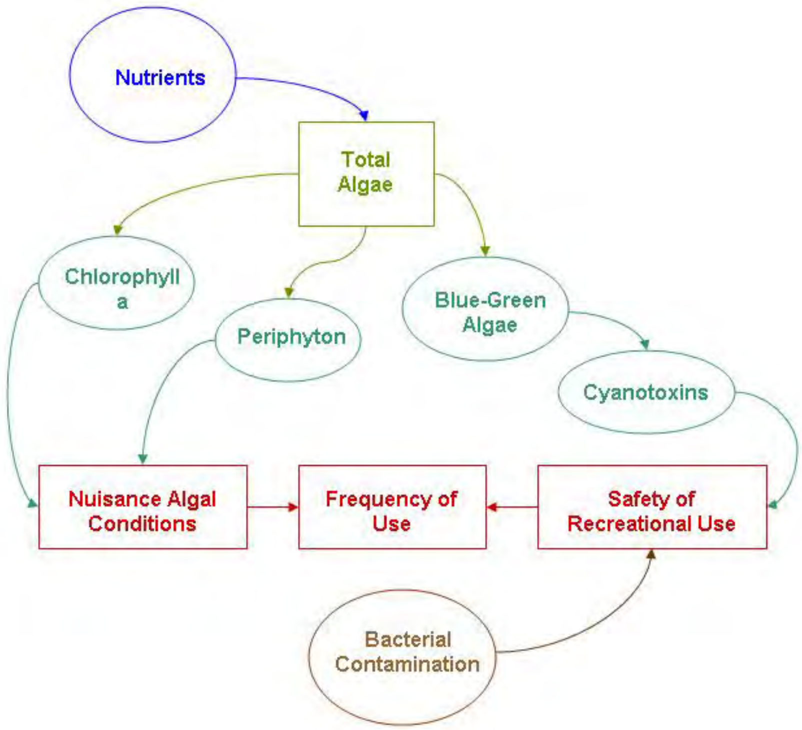


Figure 3.12. Links between water quality and recreation.

Park closures can occur where recreational waters have been contaminated with *E. coli* or other coliform bacteria by wildlife, livestock, or human feces. The presence of *E. coli* in waterbodies is an indicator of fecal contamination. The presence of generally harmless coliform bacteria is an indicator that potentially harmful organisms, such as toxic strains of *E. coli*, or other contaminants may be present.

3.4.4.2 Support Status Summary

The recreation beneficial uses are considered to be in full support for East Canyon Reservoir by the State of Utah (UDWQ 2006a). Reports from East Canyon State Park manager support this determination; however, E. coli and fecal coliform data were not available to assess the use using state water quality criteria. Total phosphorus exceedances of the recreation designated beneficial use indicator threshold of 0.025 mg/L, occur routinely in East Canyon Reservoir, with 52% of data showing TP concentrations greater than 0.025 mg/L. Further examination of East Canyon Reservoir indicates that chlorophyll *a* concentrations are below the literature-based threshold identified as being protective of recreational activities. Nuisance algal growth is therefore not impairing the recreational uses of East Canyon Reservoir. In addition, no *E. coli* contamination or related illness is known to have occurred in East Canyon Reservoir.

The threat of blue-green algal blooms is a serious concern for East Canyon Reservoir, given that blue-green species compose the majority of the algal species by volume in the reservoir and have been known to dominate under higher nutrient conditions than those currently observed. This threat could severely impact the recreational uses of the reservoir.

3.4.5 ASSESSMENT OF COLD WATER FISHERY BENEFICIAL USE (3A)

3.4.5.1 Key Linkages between Water Quality and Fishery (3A)

East Canyon Reservoir currently contains a low abundance and diversity of fish species (Nadolski and Schaugaard 2008). Criteria have been established by the State of Utah to protect the aquatic life needs of cold water fish species. East Canyon Reservoir is designated as a cold water game fishery and is stocked annually with rainbow and tiger trout. The temperature criteria are established as a maximum allowable value that protects critical life-stage requirements. Eutrophication in combination with high water temperatures can impair a cold water fishery through several mechanisms (Figure 3.13).

Elevated water temperature can exacerbate lethal water quality conditions, as it affects both the solubility of oxygen in water and the metabolic requirements of fish. Fish use gill respiration to extract oxygen from the water column. As the temperature of the water increases, oxygen can be more easily extracted from it. However, cold-blooded organisms also have increased metabolic rates and higher oxygen requirements at elevated water temperatures, so the additional oxygen gained at higher temperatures is offset and does not benefit the fish. High water temperatures often occur near the surface, and fish seek deeper levels to avoid the warmer water. In the case of eutrophic waterbodies, however, the deeper waters are more likely to be anoxic or low in DO and do not offer sufficient refugia (EPA 2003).

Developing embryos and young emergent fish are especially sensitive to changes in DO concentrations. Small fish often shelter near the shoreline (littoral) areas, which provide the best vegetative cover. As these areas experience the changeover from photosynthesis to respiration, the shallow water column can become depleted of oxygen quickly and young fish can be stressed or die due to the low concentrations. Low DO levels at the sediment–water interface also represent a concern related to the food chain. Anoxia (low to no DO) can have adverse effects on benthic organisms (lower life forms that live in the bottom sediments) and other macroinvertebrates, both of which are food sources for many fish and bird species.

A recent literature review by Breitburg (2002) summarized field research on the effect of declining DO concentrations on fisheries. The collected works show that as oxygen concentrations decrease, the abundance and diversity of fish species decline. Longer exposure to low oxygen and more severe hypoxia led to avoidance of and migration from the affected area. All larval, juvenile, and adult fish in the surveyed studies responded to low DO by moving upward or laterally away from waters with low DO concentrations. Studies have shown that fish not only avoid lethal conditions, they avoid those that require greater energy expenditures for ventilation, which would result in reduced growth. Field and laboratory studies have documented that DO concentrations routinely avoided are two to three times higher than those that would lead to 50% mortality in a population (Breitburg 1990, 1992; Breitburg et al. 1997, 1999, 2001; Breitburg and Riedel 2005; Whitworth 1968; Seager et al. 2000).

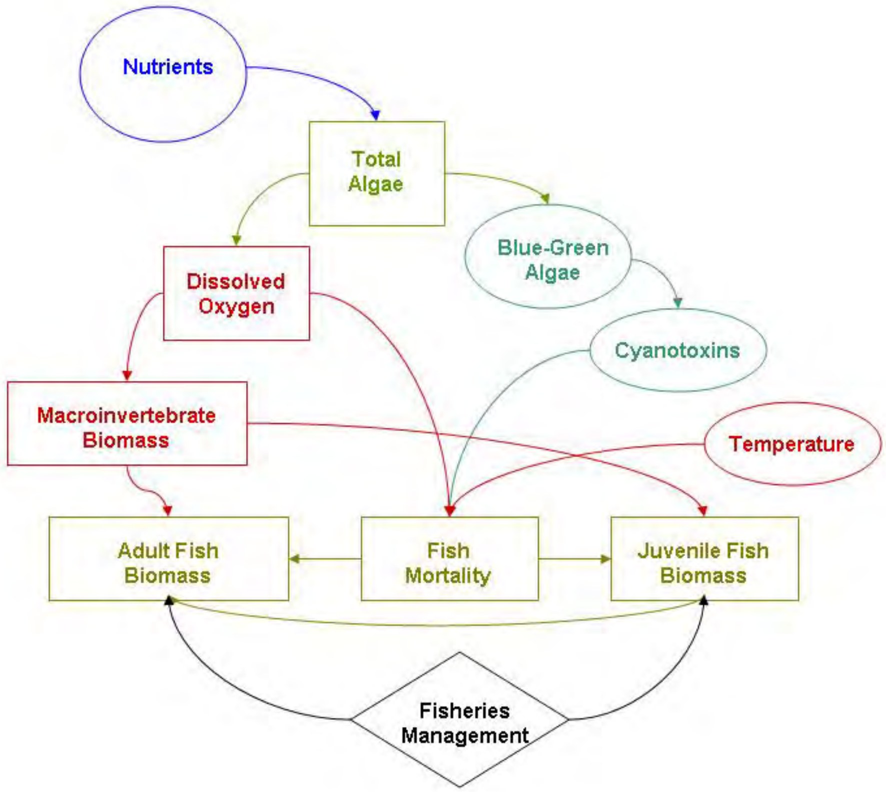


Figure 3.13. Links between nutrients and fisheries.

Fish can also exert an influence on the trophic status of reservoirs through feeding behavior. In eutrophic ecosystems, fish species change from species intolerant of eutrophic conditions to warm water species that are more tolerant of eutrophic conditions. Carp are one example of a tolerant fish species and have been observed to alter the littoral habitat such that submerged macrophytes are eliminated, sediments are disturbed, turbidity increased, and suspended algal growth is reduced due to a lack of light.

3.4.5.2 Support Status Summary

The cold water fishery is listed by the State of Utah as being in non support status for East Canyon Reservoir in 2006 (UDWQ 2006a). The reservoir was determined to be fully supporting in 2004, although the drought this year may have reduced loading of nutrients and organic matter from the watershed. The direct criteria exceedance and a general biological and habitat assessment for cold water fish species conducted in this study support this determination. Exceedances of water quality criteria for DO demonstrate that DO depletions are occurring in the hypolimnion during the summer season. DO concentrations of less than 4.0 mg/L occur routinely in East Canyon Reservoir in more than 50% of the water column. Exceedances of the temperature criteria in the epilimnion are also frequent during summer months.

The State of Utah provides for modification of an initial support status assessment through an evaluation of the TSI, reported fish kills, and the presence of significant blue-green algal species in the phytoplankton community. Indicators for TSI and blue-green algae suggest that East Canyon Reservoir is not fully supporting the cold water fishery beneficial use. TSI values for the reservoir indicate that the system is mildly eutrophic. Episodic high levels of chlorophyll *a* indicate the presence of algal blooms that contribute to drops in DO levels both during and immediately following the blooms due to decomposition. Decomposition of organic matter loaded from the watershed provides another source of oxygen depletion in the reservoir. In addition, blue-green algae species dominate the algal flora of the reservoir system. Water quality improvements in chlorophyll *a* do not correspond to an improvement in the fishery.

The episodic algal blooms that occur seasonally in East Canyon Reservoir are dominated by blue-green algae that can cause fish poisonings when toxins accumulate during these bloom events. Cyanotoxins can cause fish kills due to respiratory paralysis, and can bioaccumulate in fish tissues through direct ingestion or by ingesting contaminated prey species, and can therefore magnify through the food chain (Chorus and Bartram 1999). Furthermore, the collapse and subsequent bacterial decomposition of an algal bloom can deplete DO concentrations and lead to anoxic conditions. Because of the multiple effects of blue-green algae on aquatic habitats, the cause of a fish kill may be difficult to determine.

Mean chlorophyll *a* concentrations did not exceed levels protective of salmonids (10–15 µg/L) but maximum levels from grab samples taken at the Above the Dam Site and at the Upper Lake Site were 27.1 µg/L and 19.9 µg/L, respectively. These maximums likely indicate episodic algal blooms during which DO concentrations may be elevated during the day and depleted at night.

Due to differing methodologies, it is not possible to make direct comparisons between fisheries data from the 2000 East Canyon Reservoir TMDL and current data; however, current fisheries data provided by the Utah Division of Wildlife Resources indicate that the fishery is still impaired by low DO. It is also well known that low DO levels in the reservoir can cause stress to fish, making them further sensitive and susceptive to anchorworm. In addition, the low survival of fingerlings stocked in the reservoir further indicates that the fishery is impaired. Anecdotal evidence indicates that stocking has been more successful in fall versus summer months, which is likely due to low DO occurring in summer. This suggests that low DO is impacting fingerling survival. Finally, there are no other obvious mechanisms that would explain the low survival rates, because stocking rates are high, there is no predation of fish, there should not be food limitations since algal growth is prevalent in the reservoir, and DWR did not find any direct correlation between survival and water volume. No other potential causal factors for low fingerling survival have been identified.

3.4.6 Assessment of Agricultural Water Supply Beneficial Use (4)

3.4.6.1 Key Linkages between Water Quality and Agricultural Uses

Agricultural uses occur throughout the East Canyon Reservoir watershed and downstream. The primary impact of water quality on agriculture is through high levels of dissolved solids which can lead to lower crop yields and lack of weight gain in livestock. Links between nutrients and agricultural uses primarily occur when eutrophication leads to blue-green algal blooms that are harmful and sometimes toxic to livestock (Figure 3.14). In the East Canyon Reservoir watershed, algal blooms continue to be dominated by blue-green algae (*Anabaena*, *Aphanizomenon*, and *Microcystis*). These taxa are known to produce cyanotoxins that can potentially cause paralysis, respiratory failure, liver damage and death to livestock, birds, and other animals that consume water contaminated with these toxins (Sabater and Admiraal 2005). Livestock and pet poisonings have been known to occur where animals have consumed or swam in contaminated waters (Chorus and Bartram 1999), and poisoning can also occur from consumption of crops or pasture irrigated with contaminated water. Microcystins are one of the most common cyanotoxins linked with livestock poisonings (Beasley et al. 1989). The transfer of toxins to livestock is of concern where nutrient inputs are sufficient to produce algal blooms in proximity to areas of livestock access or agricultural withdrawals. Where cyanotoxin contamination of livestock occurs, the bioaccumulation of toxins in animal tissues and subsequent magnification in human tissues is also of concern, but there is limited evidence of this occurring (Chorus and Bartram 1999).

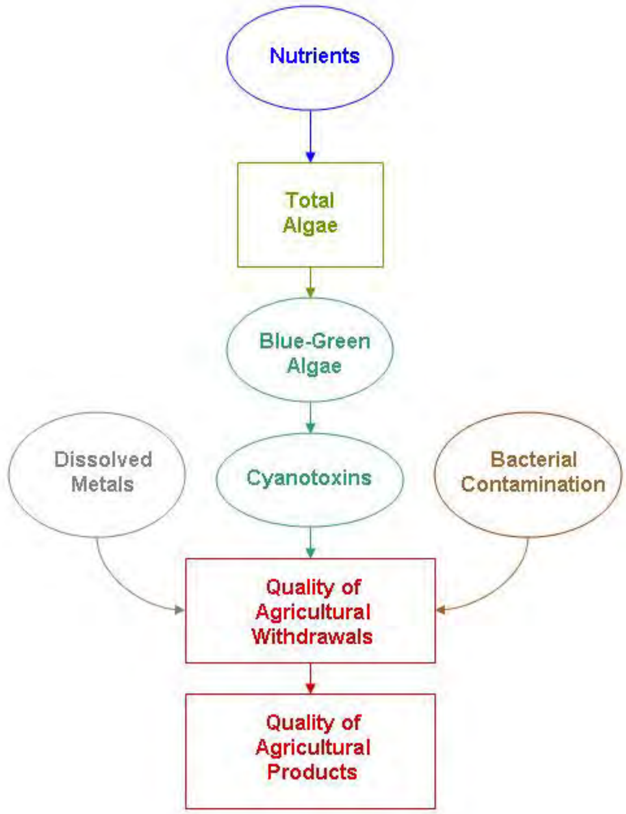


Figure 3.14. Links between nutrients and agricultural use.

Bacterial contamination of agricultural waters can occur where livestock transfer harmful bacteria such as *E. coli* into the watershed. Alternatively, livestock can be contaminated by fecal coliform bacteria transferred to the system by other animals.

3.4.6.2 Support Status Summary

The agricultural uses for East Canyon Reservoir are in full support, according to the State of Utah (UDWQ 2006a). The water quality analysis of TDS and pH supports this determination. No TDS exceedances were identified for East Canyon Reservoir. Blue-green algal blooms threaten the agricultural uses, given that blue-green species do exist in the system and have historically been triggered to dominate under higher nutrient conditions than those currently observed. This threat could impact agricultural uses of the reservoir. It is not known if there has been an exceedance of the bacteria standard because no data are available for *E. coli*, total coliform, or fecal coliform bacteria for East Canyon Reservoir.

3.5 WATER QUALITY IMPROVEMENT SINCE PREVIOUS TMDL

The TMDL developed for East Canyon Reservoir in 2000 identified impairment of the cold water fishery designated beneficial use (3A) due to low DO associated with excess phosphorus (Judd 1999, UDWQ 2000). Since 2000 the only point source in the watershed, the ECWRF, has reduced nutrient loads to East Canyon Creek significantly. In addition, BMPs have been implemented to reduce nutrient runoff from nonpoint sources throughout the watershed. In this section, the success of the phosphorus load reduction measures implemented in the watershed since the 2000 TMDL are summarized and water quality improvements are documented.

3.5.1 EAST CANYON WATER RECLAMATION FACILITY

The Snyderville Basin Water Reclamation District completed an upgrade and expansion project of their ECWRF in September 2002 as part of the implementation of the East Canyon Reservoir TMDL from 2001, adding a chemical phosphorus reduction process to the plant which became effective in July 2003. The process mixes secondary effluent with alum (aluminum sulfate) and a polymer in solids-contact clarifiers, and then filters the liquid through a constant-backwash sand filter. The heart of the process is the use of alum to both pull orthophosphorus out of solution and to bind the phosphorus molecule to the alum. The polymer is designed to join the resultant molecules in a long chain for easier filtering. Effluent then passes though a UV disinfection process.

The plant had previously utilized only a biological phosphorus reduction process (since 1996). The incorporation of chemical phosphorus reduction methods resulted in a substantial reduction in the effluent's phosphorus concentration once the process became fully effective in July 2003. Other constituents (such as TSS, BOD, NH_3) were not significantly reduced by this process, which is very specific to TP (although there was some reduction in TSS).

The current permit for the ECWRF includes a total phosphorous concentration not to exceed 0.1 mg/L and applying only to the months of July, August, and September. This concentration is effective until April 29, 2010. In addition, the permit requires limits to the annual total phosphorus load from the system to 1,462 lbs/year. These effluent limitations were originally developed to protect East Canyon Creek by imposing a phosphorous limitation during the summer growing season. However, the resulting permit also provides the system with flexibility, if necessary, to discharge more during peak ski season and during special events and less during non-tourist times of the year. There have been considerable reductions in phosphorus concentrations below the ECWRF (Station ID 4925250). Average TP concentrations have been reduced from 2.79 mg/L for data collected from 1993 to 1996 to 0.99 mg/L for data collected from 1997 to 2003 prior to the ECWRF expansion taking effect. Following the upgrade and expansion of the ECWRF in July 2003, average TP concentrations dropped to 0.19 mg/L (data collected from August 2003 to August 2007). Total phosphorus loading from the ECWRF has also been dramatically reduced from an average of 9.49 kg/day in 1997–1999, to 2.18 kg/day for data collected from 2002 to 2003 prior to the ECWRF expansion, then decreased to 1.12 kg/day following the ECWRF upgrade and expansion (data collected August 2003 through December 2007). The allocated load for the ECWRF under the original TMDL is 1,462 lbs/year which is equivalent to a daily load of 1.81 kg/day. The current load from the wastewater treatment plant is well below this LA.

3.5.2 SUMMARY OF NONPOINT SOURCE POLLUTION CONTROL EFFORTS

3.5.2.1 Agricultural Land Management

In 2005, with funding from the NRCS Wildlife Habitat Incentive Program (WHIP) and Snyderville Basin Reclamation Projects, businesses, local landowners, and organizations such as Swaner Nature Preserve (SNP) began working to restore habitat in and around East Canyon Creek. Shrubs and plants are being planted to help with streambank erosion, fences are being installed to keep livestock from the riparian areas, water facilities are being added for livestock, and pastures are being reseeded to improve grazing management. The program has 5 years to be fully implemented and must be maintained for 10 years.

3.5.2.2 Park City Stormwater Management

Park City Municipal Corporation (PCMC) reports that for many years, most of their environmental goals have been exceeded each year and they continue to increase their conservation practices to control nonpoint sources of nutrients and sediment (PCMC 2007). Some projects have included requiring all service stations to have an oil/water separator for their water runoff, installing 100 "No Dumping Drains to Watershed" signs on drains throughout the county, adding silt traps to stormwater accumulation structures, the development and maintenance of sediment detention basins, the ongoing soil ordinance capping activity, and a current study to determine the feasibility of an additional detention basin in East Canyon Creek. The Parks and Golf Department manages multiple sediment traps, sediment vaults, and buffer areas.

PCMC has also focused on educating the surrounding community. They conduct training sessions and workshops for local contractors to learn about BMPs for stormwater quality and environmental ordinances and enforce these regulations during building. They have placed signs throughout the watershed detailing proper management of dog waste and stormwater BMPs. PCMC publishes and distributes an "Environmental Information Handbook" and a "Residential Stormwater Brochure" as well as information on invasive weed species and xeriscape gardening.

3.5.2.3 Implementation of Construction Best Management Practices (BMP)

PCMC requires that all construction must adhere to environmental ordinances and mitigation and a signed compliance to environmental ordinances is required for all projects that need a building permit. A "Stop Work" order is issued if stormwater BMPs are not implemented. A contractor must resolve the issue or the permit is revoked (PCMC 2007).

3.5.2.4 Conservation Easements and Open Space Preservation

In 2000, a partnership between Utah State Division of Forestry, Fire, and State Lands and Utah Open Lands set aside a large portion (7,300 acres) of the East Canyon Watershed, known as the Peaceful Valley Ranch, as a conservation easement (UOL 2008). The ranch is south of East Canyon Reservoir along East Canyon Creek. Another portion of land protected by Utah Open Lands as a conservation easement is the Hi-Ute Ranch, located on I-80 just before Kimball Junction. The Hi-Ute Ranch encompasses 200 acres of land including a large section of Threemile Creek, a tributary of East Canyon Creek. A long-term conservation management plan has been implemented.

The Swaner Nature Preserve protects over 1,200 acres of critical habitat in a land trust. The preserve encompasses approximately 350 acres north of I-80 and 850 acres south of I-80 at Kimball Junction. Three creeks, including East Canyon Creek, run through the land that contains many riparian and wetland habitat areas and functions as a groundwater recharge area (SNP 2008). PCMC has procured over 4,000 acres of open space partially funded by a $10 million open space bond. They have tried to focus on riparian and stream buffer zones to help with water infiltration and protection for these areas which will in turn improve stormwater quality (PCMC 2003).

3.5.2.5 Riparian Restoration and Enhancement

The ECRFC conducted an SVAP and SECI on 40 miles of stream in the watershed in August 2001. The stream was divided into 26 sections and rated for riparian habitat, fishery habitat, excess nutrients, channel function, and multiple erosion factors. A breakdown of the cost and actions needed to restore the stream was also included.

Beginning in 2004, Snyderville Basin Reclamation District sponsored the East Canyon In-Stream Flow Study with funding from a CWA Section 319 grant. The final report presented 12 alternatives that individually or in combination enhance streamflow goals. Included in this ongoing process are streambank restoration and a mapping study of phosphoric deposits in the watershed.

Swaner Nature Preserve has multiple projects to restore East Canyon Creek that have been completed or are continuing. Since 2005, 3,000 willows have been planted to stabilize the streambank soils, reduce sediment loads, and aid in reducing temperature along the creek. In 2007, native shrubs were planted and 706 linear feet of tree revetments were installed to help to stop streambank erosion (SNP 2008).

Through funding from the EPA and the NRCS in 2006, the East Canyon Watershed Committee improved the habitat of East Canyon Creek by restoring sections of the creek to reduce the amount of streambank erosion that was occurring. This site is now being used as an example to demonstrate healthy streambank restoration.

In the summer of 2006, with some funding from a CWA Section 319 grant, the PCMC removed 10,000 cubic yards of sediment from a detention basin in Park City Municipal Golf Course.

3.5.2.6 Recreation and Trail Management Changes

There are five winter facilities in the watershed: three ski resorts, a sledding hill, and a ski jumping/winter track venue. Each has an individual Watershed Restoration and Protection Strategy Plan. Their BMPs include erosion and sediment control and stream restoration. There are also year-round efforts made by the facilities themselves to improve the watershed. For example, Park City Mountain Resort reconstructed and enhanced a gully on Treasure Hollow ski run, repaired drop structures and basin, and revegetated the construction area. The repairs resulted in an estimated 69% reduction in sediment and were funded by a CWA 319 grant (ECWC 2008a).

In the watershed, there are five golf courses, another course under construction, and four others proposed. The operating golf courses have individual Watershed Restoration and Protection Strategy Plans. Their BMPs include water quality monitoring, irrigation water management, and fertilizer management. Golf course management employees must also undergo continued education and training on environmental practices (ECWC 2008).

With funding from a CWA 319 grant, Swaner Nature Preserve will be installing fencing along trails near East Canyon Creek to protect riparian areas, dissuade the creation of new trails, and reduce pollution into the watershed (Waterman 2007).

3.5.2.7 Water Conservation

PCMC enforces a Conservation and Drought Management Plan that contains the BMPs for conserving water. The plan also consists of distributing public information about water conservation in brochures, public service announcements on TV and radio, posters, and bus advertisements. The plan also incorporates irrigation ordinances and water management priorities. A Xeriscape garden was planted to demonstrate to the public that landscaping does not always need additional irrigation or the use of culinary water. A pamphlet on the subject is also available for those interested.

3.5.2.8 Education and Media Programs

SNP, East Canyon Watershed Committee, and PCMC all have educational components to their programs. SNP holds annual dog waste clean-up days and continually teaches the public about the pollution it causes and the proper ways to dispose of this waste. They also have an ongoing storm drain marking program. Markers are placed on storm drains reading "No Dumping Drains to Stream" to discourage pollutant dumping into the water (SNP 2008). East Canyon Watershed Committee has an Education Working Group that focuses on educating the public about problems in the watershed. They have worked both with SNP and PCMC on education projects, such as hanging watershed information on resident's doors.

PCMC distributes a large amount of watershed information and literature to the public. A Park City Environmental Information Handbook (environmental ordinances, daily household practices, and stormwater quality information) and a Residential Stormwater Brochure were both circulated. PCMC holds mandatory training and workshops for local contractors about stormwater controls and BMPs for stormwater quality. Educational watershed signs pertaining to stormwater BMPs and dog waste disposal were placed throughout the watershed and "No dumping" markers were placed by PCMC as well (PCMC 2007).

3.5.3 WATER QUALITY COMPARISON

In order to assess the effectiveness of the implementation measures described in the previous sections, the following water quality parameters and metrics were compared for the period prior to and following the previous TMDL: TP, chlorophyll *a*, DO, TSI, algal species composition, and N:P ratios.

3.5.3.1 Phosphorus

Total phosphorus includes all phosphorus (dissolved and particulate-bound) in a sample, and dissolved phosphorus (primarily orthophosphate) includes highly soluble oxidized phosphorus. Orthophosphate is the most bio-available form of phosphorus and is the form that produces rapid algal growth (orthophosphate was not included in the EPA STORET data for the reservoir). Both TP and dissolved phosphorus levels in East Canyon Reservoir continue to be above the indicator used for assessing recreation and cold water fisheries (0.025 mg/L). However, comparison of recent (water years 1996–2001) versus current (water years 2002–2007) surface water quality data indicate an overall decrease ranging from 9% to 23% in water column TP and dissolved phosphorus concentrations across the reservoir (Table 3.21). Mean TP throughout the reservoir remains above the TP water quality endpoint established in the 2000 TMDL (0.025 mg/L). However, TP exceedances of this threshold have markedly decreased from approximately 76% of data (water years 1996–2001) to 52% of data (water years 2002–2007) greater than 0.025 mg/L. It is important to recognize, however, that the recent dataset includes several phosphorus profiles, which are included in the exceedance calculations. Phosphorus concentrations are higher near the sediment-water interface, so inclusion of these profile data leads to a greater number of calculated exceedances.

Table 3.21. Recent (water years 1996–2001) and Current (water years 2002–2007) Total and Dissolved Phosphorus Concentrations in East Canyon Reservoir (mg/L)

Total Phosphorus						
	Above the Dam (Station ID 4925160)		**Mid-Lake (Station ID 4925170)**		**Upper Lake (Station ID 4925180)**	
	Recent (1996–2001)	**Current (2002–2007)**	**Recent (1996–2001)**	**Current (2002–2007)**	**Recent (1996–2001)**	**Current (2002–2007)**
N	68	75	30	46	44	40
Mean	0.063	0.051	0.071	0.058	0.056	0.043
Reduction (%)		19%		18%		23%
Total Phosphorus						
	Above the Dam (Station ID 4925160)		**Mid-Lake (Station ID 4925170)**		**Upper Lake (Station ID 4925180)**	
	Recent (1996–2001)	**Current (2002–2007)**	**Recent (1996–2001)**	**Current (2002–2007)**	**Recent (1996–2001)**	**Current (2002–2007)**
Median	0.048	0.027	0.054	0.030	0.048	0.028
St Dev	0.055	0.046	0.053	0.047	0.045	0.039
Max	0.242	0.197	0.177	0.180	0.202	0.222
Min	0.005	0.020	0.010	0.020	0.005	0.020
Dissolved Phosphorus						
	Above the Dam (Station ID 4925160)		**Mid-Lake (Station ID 4925170)**		**Upper Lake (Station ID 4925180)**	
	Recent (1996–2001)	**Current (2002–2007)**	**Recent (1996–2001)**	**Current (2002–2007)**	**Recent (1996–2001)**	**Current (2002–2007)**
N	78	68	34	32	50	28
Mean	0.057	0.042	0.062	0.055	0.040	0.036
Reduction (%)		25%		12%		9%
Median	0.042	0.021	0.045	0.028	0.038	0.020
St Dev	0.053	0.036	0.048	0.045	0.031	0.027
Max	0.234	0.168	0.174	0.182	0.138	0.119
Min	0.005	0.020	0.006	0.020	0.005	0.020

Since identified tributary load reductions have been achieved (see Section 3.5.1), the elevated levels of TP in-reservoir are primarily associated with nonpoint source watershed loads. Much of the phosphorus load enters the reservoir during the spring runoff period creating a phosphorus rich sediment layer that releases phosphorus during the anoxic summer period. In addition, some legacy sources of internal phosphorus remain from decades of phosphorus loading to the reservoir. Phosphorus profile data are only available for 2007 of the current period, and are compared to profiles for 1996 and 1999 of the recent period in Figure 3.15 (August and September).

The TP load from East Canyon Creek has been reduced significantly since 2001, with annual average loads ranging from 2,547 lbs/year during a dry year (2003) to 9,909 lbs/year during a wet year (2006). The TMDL for total phosphorus for the reservoir set in 2000 is 5,647 lbs/year and the average calculated load since 2001 is 5,603 lbs/year. The average load identified in the period prior to the 2000 TMDL was 9,220 lbs/year. Therefore, there has been a significant reduction in TP load to the reservoir. Current loads are approximately three times lower than the average TP loads to the reservoir during the 1970s which averaged 17,081 lbs/year (Merritt et al. 1980). During this early period TP flowing out of the reservoir was calculated to be 7,972 lbs/year (Merritt et al. 1980). Therefore, during the 1970s and probably the 1980s, the reservoir acted as a sink for approximately 9,109 lbs/year of phosphorus. A key question to be addressed in the modeling and reservoir dynamics section of this study will be to estimate the annual internal load of phosphorus from sediment to the water column associated with this legacy phosphorus in the reservoir.

Despite low DO in the sediment which leads to TP release, phosphorus concentrations at the bottom of the profiles are notably lower in 2007 profiles than in 1996 and 1999 profiles. Total phosphorus concentrations measured in June and August of 1978 were 0.198 mg/L and 0.088 mg/L, respectively, which indicate a lower level of phosphorus release during this period. Lower phosphorus release is expected given the higher oxygen levels observed in the hypolimnion during this same period. This demonstrates that phosphorus is still leaching out of reservoir sediments, but at a slower rate than occurred in the 1990s. It is noteworthy that there may be considerable lag time until existing phosphorus loads are leached from the sediment and a new equilibrium is established in the water column.

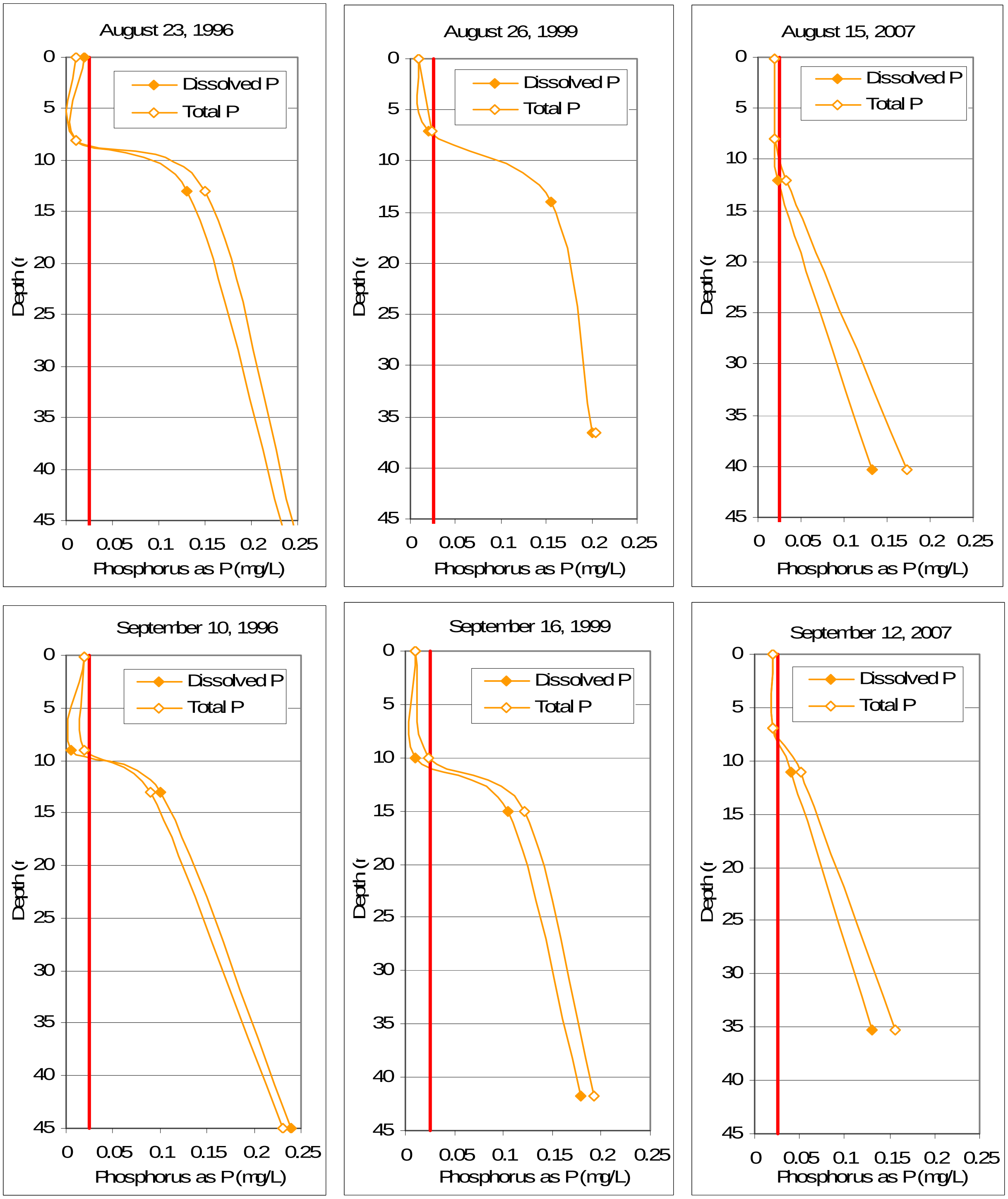


Figure 3.15. Phosphorus profile comparisons for August and September 1996, 1999, and 2007 (Station #4925160) (the red line indicates the 0.025 mg/L water quality indicator value for phosphorus).

3.5.3.2 Chlorophyll *a*

Chlorophyll *a* is a surrogate measure of algal growth and the best overall indicator of trophic conditions in the water column. Both recent and current average chlorophyll *a* concentrations in East Canyon Reservoir are well below nuisance thresholds of 10–15 µg/L for salmonids (Pilgrim et al. 2001) and 15–50 µg/L for recreational use. The chlorophyll *a* data presented here are from grab samples collected during the summer season (May–October) in recent (1996–2001) and current (2002–2007) water years (Table 3.22). The maximum values measured in the recent dataset were 23.2 µg/L at the Above the Dam Site in October 1996, and 27.1 µg/L at the Above the Dam Site in October 2001. At the Above the Dam Site, there have been a greater percentage of chlorophyll *a* samples above the nuisance threshold of 10 µg/L for salmonids in current years than in recent years (19.6% versus 12.9%, respectively). Of current samples taken across the reservoir, 9.1% have been above the 15 µg/L chlorophyll *a* threshold for salmonids. However, these high concentrations all occurred in October 2001, and there appears to have been a reduction in average chlorophyll *a* concentrations since that time. Chlorophyll *a* data collected in East Canyon Reservoir may not be entirely representative of algal bloom intensity, because sampling days may not correspond with algal blooms. In addition, prevailing winds in East Canyon are known to blow algal blooms across the surface to the shore or the dam where they can be discharged downstream. Figure 3.16 shows derived algal bloom intensity from an IKONOS Multispectral Image of East Canyon Reservoir on October 11, 2000. On this particular day, algae are clearly collecting along the west side of the reservoir and near the dam. Samples collected in the East Arm and at the Mid-Reservoir Site would not be indicative of algal bloom intensity throughout the reservoir. Chlorophyll *a* data were determined not to be reliable enough to use for model verification or assessment of bloom intensity. A CE-QUAL-W2 model developed for East Canyon Reservoir will be used to predict current and future chlorophyll *a* concentrations based on hydrodynamics and nutrient loading (see Chapter 5).

Table 3.22. Summary of Recent (water years 1996–2001) and Current (water years 2002–2007) Chlorophyll *a* Data in the Reservoir during the May–October Algal Growth Season (µg/L)

	Above the Dam (Station ID 4925160)		Mid-Lake (Station ID 4925170)		Upper Lake (Station ID 4925180)	
	Recent (1996–2001)	Current (2002–2007)	Recent (1996–2001)	Current (2002–2007)	Recent (1996–2001)	Current (2002–2007)
N	31	51	15	19	30	18
Mean	4.34	5.39	2.61	1.36	4.46	2.75
St Dev	4.90	8.64	2.15	1.27	2.66	4.56
Max	23.20	27.10	5.90	5.20	12.40	19.90
Min	0.20	0.20	0.20	0.20	0.20	0.20

Productivity in the period following the 2000 TMDL appears to be similar to productivity measured in East Canyon Reservoir in the 1970s when productivity measurements indicated a mesotrophic system despite high phosphorus loads to the reservoir (Merritt et al. 1979; Merritt et al. 1980). Recent TSI estimates based on chlorophyll *a* indicate an oligotrophic to mesotrophic system, an improvement since the 1990s when chlorophyll *a* concentrations indicated a mesotrophic to mildly eutrophic system. Chlorophyll *a* data, however, may not be representative of reservoir productivity considering that wind blows algae toward the dam and is released downstream to East Canyon Creek. Merritt et al. (1979 and 1980) offer several other explanations for the low productivity observed during that period, including: a short stratification period and relatively cold epilimnion suppressing algal growth; cold hypolimnetic waters inhibiting primary productivity in the fall following overturn; an unusually large amount of phosphorus chemically precipitated in the lake related to relatively high pH values in surface waters (averaging around 8.5); and short-circuiting of tributary inflows during the summer through the hypolimnion and out via withdrawal at a low elevation in the dam thereby reducing phosphorus concentrations in the epilimnion. The extent to which these processes continue to inhibit productivity in the reservoir will be important questions addressed in the reservoir modeling and dynamics chapter of this study

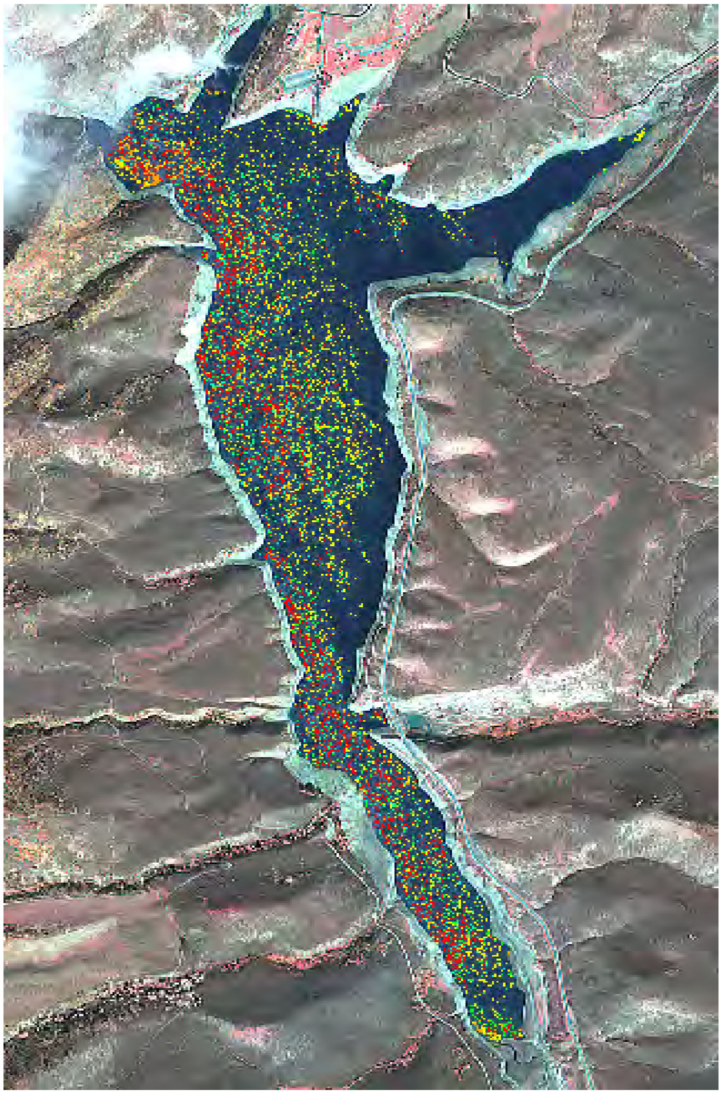


Figure 3.16. IKONOS Multispectral Imagery of East Canyon Reservoir.

In-reservoir colors indicate qualitative derivation of algal biomass distribution for October 11, 2000. Red indicates high algal concentration; orange indicates medium-high; green indicates medium; and yellow indicates low. Source: Jerry Miller, JM Water Quality Ltd, original image from Bureau of Reclamation.

3.5.3.3 Dissolved Oxygen (DO)

Dissolved oxygen concentration exceedances below the minimum criteria for the cold water fishery designated beneficial use (less than 4 mg/L) occur routinely in the hypolimnion of East Canyon Reservoir. At the Above the Dam Site, recent data (water years 1996–2001) showed 41% to 73% of the water column with average DO concentrations of less than 4 mg/L (Table 3.23). Current data (water years 2002–2007) show some improvement, with 23% to 66% of the water column with DO concentrations less than 4 mg/L. Observed minimum values for recent and current data (0.09 and 0.10 mg/L, respectively) show that exceedances of the criteria continue to occur at magnitudes of concern. The East Canyon Reservoir Above the Dam Site was found to have a lower average percentage of the water column in support of cold water fisheries in July and October compared to recent data. There were insufficient data for water years 1996–2001 to provide comparisons for the Mid-Lake and Upper Lake sampling sites.

Table 3.23. Comparison of the Percent of the Water Column Exhibiting DO Levels Supportive of Cold Water Fisheries (>4.0 mg/L) for Recent (1996–2001) and Current (2002–2007) Water Years (Above the Dam–Station ID 4925160)

Month	Recent (1996–2001)	Current (2002–2007)
June	59% (Full Support)	77% (Full Support)
July	50% (Full Support)	40% (Non-Support)
August	33% (Non-Support)	34% (Non-Support)
September	28% (Non-Support)	37% (Non-Support)
October	47% (Non-Support)	37% (Non-Support)
Site Average:	43% (Non-Support)	48% (Non-Support)

Dissolved oxygen profiles in the 1970s indicate that the reservoir can achieve the water quality standard for DO identified for cold water fisheries by the State of Utah. During this period, DO rarely fell below 4 mg/L DO even at the sediment water interface, and productivity was characterized as mesotrophic, comparable to current productivity rates (Merritt et al. 1979; Merritt et al. 1980). This is despite excessively high loads of phosphorus during this period (see Section 3.5.3.1). Together, this evidence indicates additional oxygen depleting compounds in reservoir sediments, most likely organic matter loads from the watershed. Unfortunately, no organic matter loading information is available for the system to further analyze this impact. Modeled hypolimnetic oxygen depletion rates related to algal growth compared to observed oxygen depletion rates could provide a good indication of oxygen depletion related to organic matter loading (see Section 5.3.3.6).

3.5.3.4 Trophic State Index Changes from Recent to Current

There has generally been no change in TSI values from 1994 to present, and only chlorophyll *a* showed a change in average TSI values between recent (1996–2001) and current (2002–2007) water years (Figure 3.17). Recent and current TSI values for the East Canyon Reservoir Above the Dam Site are representative of trends at other sampling locations. The monitoring sites Above the Dam (Station 4925160) and Upper Lake (Station 4925180) have the most complete datasets from 1994 through 2007 and the Mid-Lake Site (Station 4925170) was monitored from 1999 through 2007. The East Arm of the reservoir (Station 4925130) was monitored from 1994 through 1998 and is not included in these comparisons. The Above the Dam Site showed no change in Secchi depth or phosphorus TSI and a decrease in the chlorophyll *a* TSI from recent to current water years (see Figure 3.17). The Mid-Lake and Upper Lake sites showed approximately the same trends as the Above the Dam Site in chlorophyll *a*, TP, and Secchi disk depth TSIs. Because both TP and Secchi disk depth are indirect measures of chlorophyll *a*, it is the best overall indicator of trophic state.

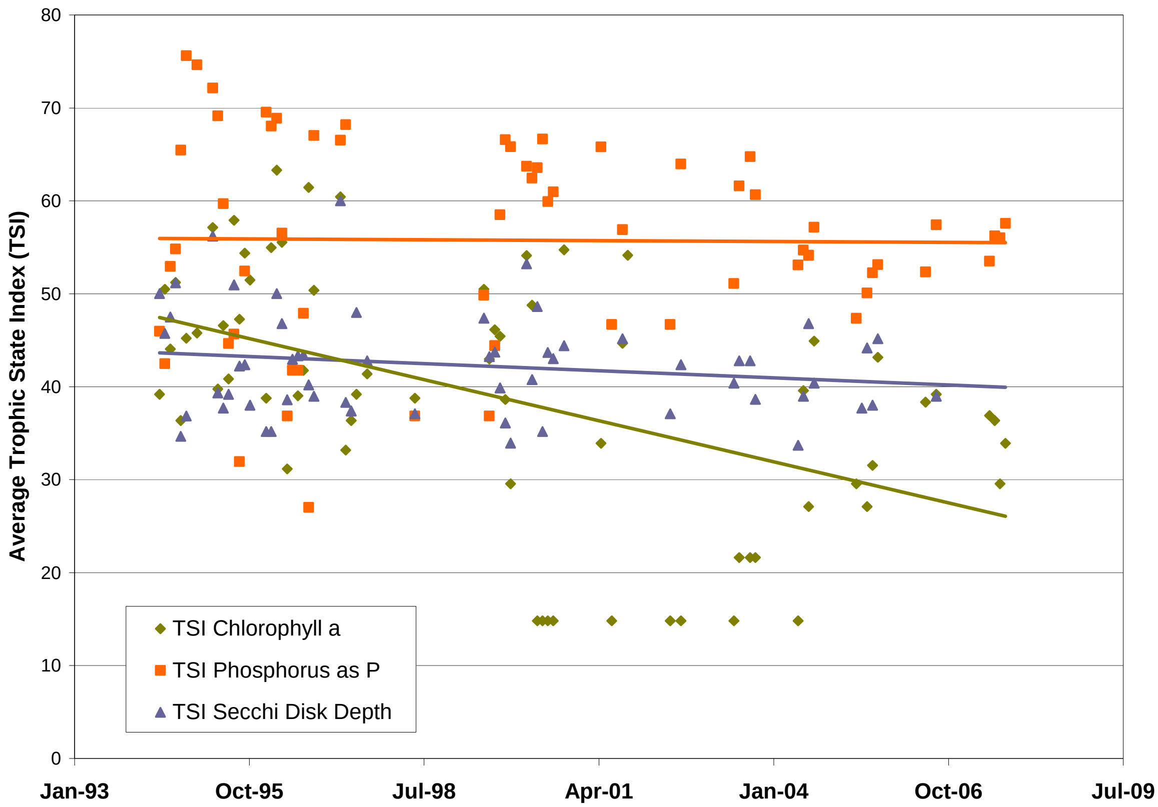


Figure 3.17. Change in TSI values for Chlorophyll *a*, Phosphorus as P, and Secchi disk depth from 1994 to 2007 in East Canyon Reservoir–Above the Dam (Station ID 4925160).

The decreasing trend in chlorophyll *a* with only small reductions in the TSI for TP is indicative of the non-linearity of the TSI calculation (Figures 3.17 and 3.18, Table 3.24). Chlorophyll *a* concentrations and TSI values approximate algal biomass (Carlson 1977, Dillon and Rigler 1974) and should follow trends in dissolved phosphorus concentrations in the reservoir. The difference between TP and dissolved P is sediment, with dissolved phosphorus available for algal growth decreasing with increasing sediment loads. Increasing sediment loads to East Canyon Reservoir are likely due to construction activities and stream erosion above the reservoir. Total suspended solids measurements are limited for the reservoir, so it was not possible to verify that increasing sediment loads to the reservoir follow decreasing chlorophyll *a* concentrations. Several very high TSS measurements were taken at the Above the Dam Site in 2005.

A comparison of recent and current TSI values also indicates a declining trend in chlorophyll *a*, whereas TP and Secchi disk depth values remain static (Figure 3.18). However, the chlorophyll *a* data is not believed to be representative of true bloom intensity throughout East Canyon Reservoir, therefore the observed change may represent an overall decrease in algal concentrations but both values are likely to be low due to data collection methodologies and wind patterns (see Section 3.4.1.3).

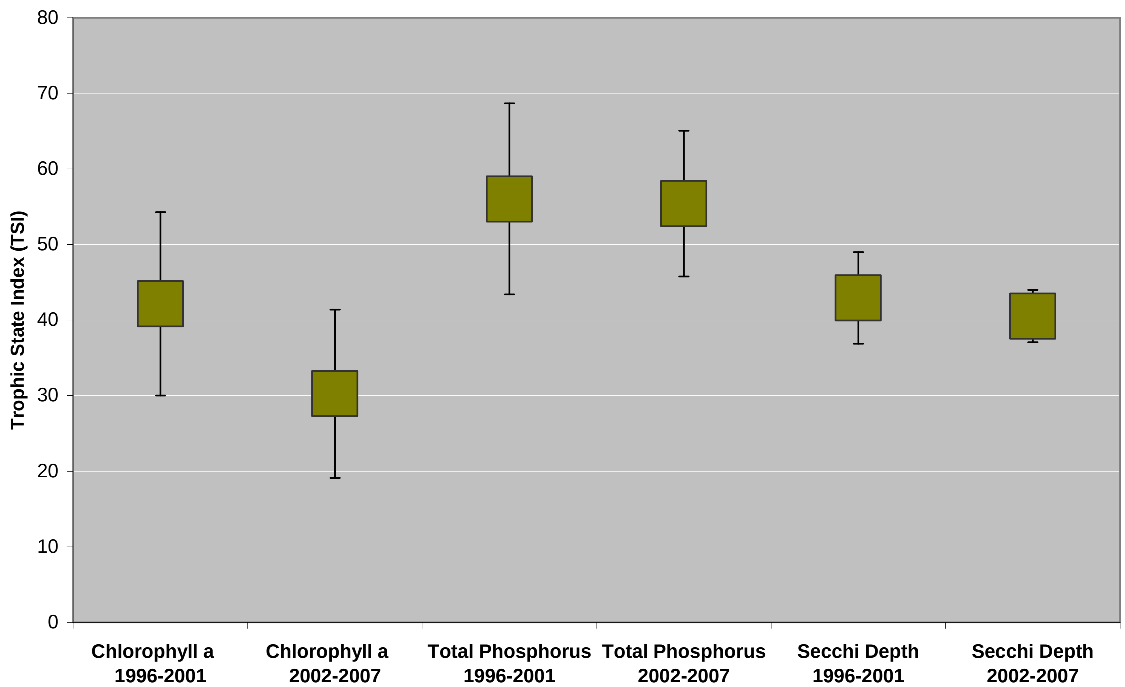


Figure 3.18. Comparison of recent (water years 1996–2001) and current (water years 2002–2007) average TSI values for chlorophyll *a*, total phosphorus, and Secchi disk depth for East Canyon Reservoir–Above the Dam (Station ID 4925160).

Table 3.24 Comparison of Trophic State Indices (TSI) Before (water years 1996–2001) and After (water years 2002–2006) Implementation of East Canyon Reservoir TMDL

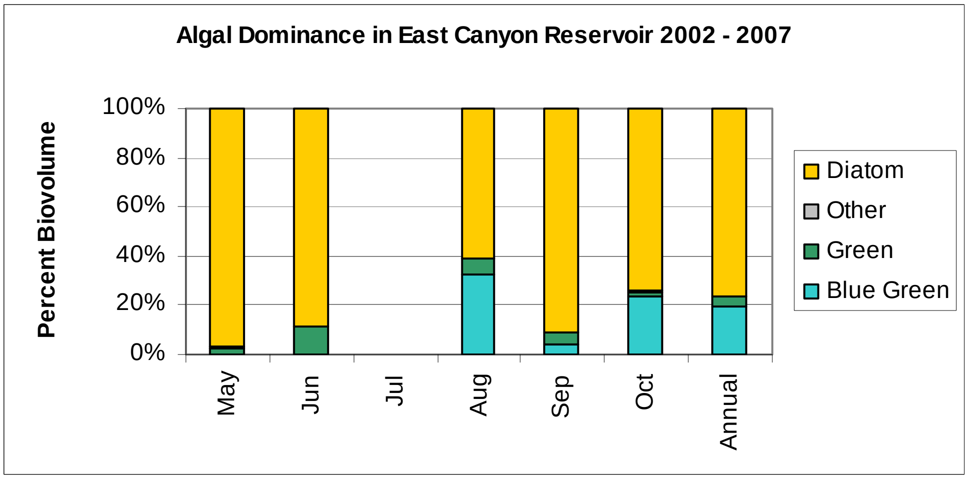
TSI Chlorophyll *a*						
Sampling Site	**Period**	**N**	**Mean**	**Median**	**Max**	**Min**
East Canyon Reservoir Above the Dam 01	Current	22	31.34	30.55	57.03	14.81
	Recent	43	41.57	42.01	66.36	14.81
East Canyon Reservoir Mid-Lake 02	Current	19	29.72	30.60	46.77	14.81
	Recent	20	37.15	40.68	57.36	14.81
East Canyon Reservoir Upper Lake 03	Current	18	33.23	35.79	59.94	14.81
	Recent	40	44.13	44.79	58.95	14.81

Table 3.24 Comparison of Trophic State Indices (TSI) Before (water years 1996–2001) and After (water years 2002–2006) Implementation of East Canyon Reservoir TMDL

TSI Phosphorus						
Sampling Site	**Period**	**N**	**Mean**	**Median**	**Max**	**Min**
East Canyon Reservoir Above the Dam 01	Current	76	55.50	50.95	79.17	46.69
	Recent	68	57.48	59.12	82.09	27.00
East Canyon Reservoir Mid-Lake 02	Current	46	57.29	52.45	77.86	46.69
	Recent	30	60.37	60.66	77.65	36.85
East Canyon Reservoir Upper Lake 03	Current	40	54.30	51.47	80.87	46.69
	Recent	45	57.81	59.70	92.34	27.00
TSI Secchi Depth						
Sampling Site	**Period**	**N**	**Mean**	**Median**	**Max**	**Min**
East Canyon Reservoir Above Dam 01	Current	15	40.53	40.39	46.80	33.71
	Recent	42	42.41	42.37	60.00	33.94
East Canyon Reservoir Mid-Lake 02	Current	16	42.47	43.02	48.64	33.48
	Recent	18	43.29	43.70	54.16	33.94
East Canyon Reservoir Upper Lake 03	Current	15	44.22	43.24	52.35	33.94
	Recent	36	44.71	44.91	58.63	36.24

3.5.3.5 Algal Community Changes from Recent to Current

Prior to the implementation of the East Canyon Reservoir TMDL in 2000, a total of 35 algae species were detected (water years 1996–2001), with the blue-green algae species comprising 44% of algal volume averaged over all sampled algal blooms in the reservoir. Dominance peaked at 85% during October (Table 3.25), although this estimate is based on only one sample. Dense *Aphanizomenon*, *Anabaena*, and *Microcystis* blooms during summer stratification were noted by Wurtsbaugh (1988). Diatoms (i.e. *Fragilaria crotonensis*, *Melosira granulata* and *Stephanodiscus niagarae*) composed an average of 27% of algal volume and green algae composed approximately 20% of algal biovolume on average. Since 2002 there has been a noticeable shift in dominance from blue-green algae to diatoms especially during spring and early summer months. In samples gathered between 2002 and 2007, blue-green algae composed only 19% of algal volume averaged over all sampled algal blooms in the reservoir a substantial reduction from 44% during the previous period. During this period diatoms composed 74% of the algal blooms by biovolume, a substantial increase from 27% (Figure 3.19 and Table 3.25). Based on these data, there appears to have been a shift in dominance from blue-green algal species to diatoms since implementation of the 2001 TMDL. However, phytoplankton sampling data from the recent period and Rushforth and Rushforth (2007) indicate that blue-green algae blooms occur in spring and late summer/fall and diatom blooms occur mostly in spring. Because phytoplankton sampling from 2000 to 2005 occurred only in August or September, any spring diatom blooms that occurred during this time period were not captured. Due to limited sampling events in both the recent and current periods, it is not possible to determine trends in the frequency or intensity of either seasonal or annual algal blooms. In addition to seasonal influences on algal density, wind patterns may also influence the distribution of algae by blowing surface algae across the reservoir. The movement and concentration of algae caused by wind patterns can contribute to high volume, heterogeneous blooms.



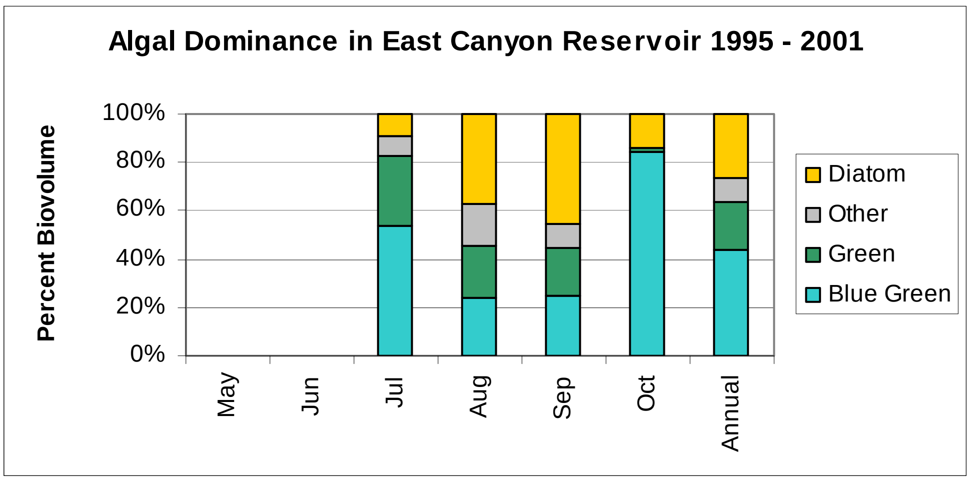


Figure 3.19. Dominance of algal groups measured in percent biovolume sampled throughout East Canyon Reservoir from 2002–2007 and 1995–2001. Data sources: EPA STORET and Rushforth (2007).

Table 3.25. Comparison in Algal Species Composition between Pre-TMDL (1996–2001) and Post-TMDL (2002–2007) Periods for East Canyon Reservoir

Algal Group	Month	CURRENT			RECENT		
		Biovolume (%)	Sample Days (N)	Species Richness	Biovolume (%)	Sample Days (N)	Species Richness
Blue-green	May	0%	1	0		0	0
	Jun	0%	1	0		0	0
	Jul		0	0	54%	3	3
	Aug	33%	3	3	24%	5	1
	Sep	4%	2	3	24%	4	3
	Oct	23%	2	2	85%	1	3
	Annual	19%	9	4	44%	13	4
Green	May	3%	1	1		0	0
	Jun	11%	1	4		0	0
	Jul		0	0	29%	3	12
	Aug	6%	3	10	21%	5	12
	Sep	5%	2	9	20%	4	10
	Oct	2%	2	4	1%	1	3
	Annual	4%	9	17	20%	13	19
Diatom	May	97%	1	6		0	0
	Jun	89%	1	6		0	0
	Jul		0	-	9%	3	8
	Aug	61%	3	9	37%	5	8
	Sep	91%	2	8	45%	4	7
	Oct	74%	2	11	14%	1	7
	Annual	76%	9	14	27%	13	9
Other	May	0%	1	1		0	0
	Jun	0%	1	0		0	0
	Jul		0	0	8%	3	3
	Aug	0%	3	1	18%	5	1
	Sep	0	2	0	10%	4	1
	Oct	1%	2	2	0%	1	0
	Annual	0%	9	4	9%	13	3
Total			**9**	**39**		**13**	**35**

Recent versus current mean TSI values for chlorophyll *a* (41.6 and 31.3, respectively) and average total algal volume (21.9 mm^3/ml and 3.8 mm^3/ml, respectively) suggest that the frequency and intensity of algal blooms has been reduced at the Above the Dam Site. However, there has been little change in the average relative densities of blue-green algae species and a marked increase in the average relative densities of diatom species from 8% to 15.1%. Further, the overall average relative density of green algae species has been reduced from 4.4% to 2.5%, with only *Staurastrum gracile* notably increasing in average relative density from the recent to current period (see Table 3.25). These results indicate that the water quality endpoint of shifting algal dominance from blue-green algae species to green algae species has only been partially achieved in that blue-green algae are no longer dominant and diatoms, not green algae, are the dominant algal group.

Species diversity for recent and current data was calculated using mean relative densities for each species. Species diversity and evenness were slightly higher and richness slightly reduced (Shannon Index or H' = 2.76, E = 0.80, R = 31) for the current period versus the recent period (H' = 2.70, E = 0.77, R = 33) (see Table 3.25). The Shannon Index takes into account the number of species and the evenness of species abundances, with higher values representing more species and/or greater species evenness. In both recent and current data, the algal community is dominated by a few species and most species occur at very low relative densities. However, the slight differences in species diversity, evenness and richness between recent and current years do not indicate any shifts in algal diversity. The decline in overall abundance (biovolume) from 21.9 to 3.8 mm^3/ml may be in response to decreasing available phosphate relative to TP (see Figure 3.15 in Section 3.5.3.1). This demonstrates that the reduction of phosphorus TMDL to the reservoir has been effective in reducing eutrophic conditions.

3.5.3.6 Nitrogen-to-phosphorus Ratio Changes from Recent to Current

East Canyon Reservoir is a N-limited system, where nitrogen has been shown to be the most important nutrient limiting algal growth and only additions of nitrogen cause significant increases in chlorophyll *a* (Wurtsbaugh 1988). In systems where blue-green algae are dominant, nitrogen is not a limiting agent because those organisms have the ability to fix atmospheric nitrogen and can grow where low nitrogen concentrations may inhibit the growth of other algal species (Sharpley et al. 1984, 1995; Tiessen 1995). Reductions in phosphorus levels are therefore required to reduce the growth of blue-green algae. In addition, phosphorus, iron, and molybdenum could also be important in controlling N_2 fixation in East Canyon Reservoir (Wurtsbaugh 1988). Nitrogen to phosphorus ratios in East Canyon Reservoir are generally very low. Current N:P ratios are higher than recent N:P ratios (Table 3.26), which reflects the reduction in phosphorus achieved by the 2000 TMDL. However, N:P are still well below 10:1, the upper N:P limit for a nitrogen-limited system. Occasional N:P ratios greater than 7:1 (EPA 2000) suggest that co-limitation by N and P of algal growth can occur in the reservoir.

Table 3.26. Recent (water years 1996–2001) and Current (water years 2002–2007) N:P Ratios above the East Canyon Reservoir Dam (Station ID 4925160)

Month	Recent N:P Ratios (1996–2001)	Current N:P Ratios (2002–2007)
January	-	-
February	0.38	-
March	1.62	-
April	2.30	-
May	2.32	5.63
June	1.76	4.40
July	3.32	3.88
August	2.61	3.51
September	2.22	3.28
October	1.47	1.74
November	1.25	
December	1.48	
Mean	**2.14**	**3.78**
Std Dev	**1.02**	**1.57**
Maximum	**5.37**	**5.85**
Minimum	**0.38**	**1.68**

3.5.4 SUMMARY

Substantial efforts have been made to reduce tributary TP loads to East Canyon Reservoir since 2001 including the upgrade of the ECWRF, restoration of riparian areas and wetlands in the watershed, and implementation of BMPs for nonpoint source control on construction sites, recreational areas, and agricultural land uses. The allocated load for the ECWRF of 1,462 lbs/year has been achieved since the upgrade of the treatment facility. However, the total allocated TMDL load of 5,647 lbs TP per year has only been achieved during average and low flow years, as evidenced by data collected in water years 2004 and 2007. During high flow years, such as water years 2005 and 2006, total LAs for nonpoint sources were exceeded. Annual TP loads to East Canyon Reservoir in water years 2005 and 2006 are estimated to have been 8,420 lbs/year and 9,910 lbs/year, respectively, of which approximately 10% (925 lbs/year) comes from the wastewater treatment plant. Total phosphorus loads to the reservoir will be assessed in more detail in the load analysis section of this TMDL.

Load reduction efforts have been reflected in improved water quality in East Canyon Reservoir. Mean in-reservoir phosphorus concentrations have been significantly reduced since 2001, which has lead to corresponding reductions in algal bloom intensity during summer months. This has corresponded with a shift in dominance away from blue-green species toward diatoms since the implementation of the TMDL. This shift was an identified target endpoint for the previous TMDL. However, none of the other water quality endpoints identified in the 2000 TMDL have been achieved, including the in-reservoir mean TP concentration of 0.025 mg/L, mean TSI values ranging from 40 to 50, and 50% of the water column maintaining DO concentrations of 4.0 mg/L or more.

An assessment of East Canyon Reservoir conducted in the 1970s provides insight to the internal dynamics of the East Canyon Reservoir system, and potential drivers for the lower than expected productivity in the epilimnion (both then and now) and higher than expected DO depletion rates in the hypolimnion which have developed since 1980. Annual TP load to the reservoir was approximately 3 times higher in the 1970s than it is today. However, despite this high load, productivity levels in the reservoir were maintained at mesotrophic levels, a condition also observed in the most current data collected for the reservoir (2003–2007). Mean chlorophyll *a* values may slightly underestimate productivity in the reservoir due to wind patterns, which blow suspended algae in the epilimnion to the dam as they accumulate. Nonetheless, overall productivity has not increased dramatically since the 1970s. Several explanations for low productivity are offered by the authors of the 1970s study (Merritt et al. 1979 and Merrit et al. 1980). These include temperature suppression of algal growth in both summer and fall, high rates of chemical precipitation associated with high pH in the reservoir at the time, and short-circuiting of tributary inflow during the summer through the hypolimnion and out via withdrawal at the bottom of the dam. Due to the variable strong wind patterns at East Canyon Reservoir, grab samples for chlorophyll *a* are not believed to be representative of true algal bloom intensity in the reservoir. A CE-QUAL-W2 model has been developed to predict current and future algal bloom intensity and composition for East Canyon Reservoir (see Chapter 5).

The most dramatic change in the reservoir is hypolimnetic DO concentrations in late summer. In the 1970s, DO was maintained above 4 mg/L throughout the water column and throughout the summer season. In 2007, oxygen concentrations drop below 4 mg/L just below the thermocline, indicating a high hypolimnetic oxygen depletion rate. Because productivity rates have not changed dramatically between the two periods, another oxygen depleting mechanism may be responsible for increased depletion rates. Unfortunately, no data are available to quantify this impact or to compare organic matter loads to the 1970s. Regardless of the source of oxygen depletion in the hypolimnion, it is clear that anoxic conditions are associated with the release of sediment bound phosphorus. Alternatively, changes in hydrology and reservoir management may account for these changes. During the 1970s flow from East Canyon Creek was substantially higher than it is today. Higher flows provide more opportunity for flushing and brought more cold water into the reservoir during the summer period, potentially explaining the rise in reservoir temperature since the 1970s. Another likely mechanism is oxygen depletion related to organic matter loading from the watershed. The BOR used to allow more spilling of reservoir volume during the spring and early summer in the 1970s which led to release of more spring algal blooms. This release would have led to a reduction in hypolimnetic oxygen demand later in the summer. A key question to be addressed in the modeling portion of this study is how much of the annual phosphorus released from sediments is associated with the annual spring runoff phosphorus load and how much is associated with the legacy phosphorus load in the reservoir. During the 1970s, the reservoir acted as a net sink for approximately 9,000 lbs of phosphorus per year. However, during this period phosphorus release from the sediment was notably lower than it is today. In 1978, TP concentrations at the bottom of the reservoir at the dam sampling site were 0.088 mg/L compared to 0.173 mg/L today. A mass balance analysis based on current water quality data will identify whether the reservoir is still a net sink or source of phosphorus to the water column.

4. EAST CANYON CREEK MODELING AND DYNAMICS

4.1 SUMMARY OF WATER QUALITY CONCERNS IN EAST CANYON CREEK

Water quality studies conducted as part of the East Canyon Creek and Reservoir TMDLs in 2000 (Judd 1999; Olson and Stamp 2000b) cited elevated total phosphorus (TP) and high sediment loads from both point and nonpoint sources, elevated water temperatures, and corresponding low DO as the primary causes of water quality impairments in the watershed. Point source TP loading to East Canyon Creek was significantly reduced following the implementation of biological treatment of phosphorus (P) at the ECWRF in 1996 and chemical removal of phosphorus implemented in early 2003 and optimized in late 2004. As a result there have been considerable reductions in phosphorus concentrations below the ECWRF (Station ID 4925250). Average TP concentrations have been reduced from 2.79 mg/L for data collected from 1993 to 1996 to 0.99 mg/L for data collected from 1997 to 2003 prior to the ECWRF expansion taking effect. Following the upgrade and expansion of the ECWRF in July 2003, average TP concentrations dropped to 0.19 mg/L (data collected from August 2003 to 2007).

Nonpoint source pollution of both nutrients and sediments remains a serious concern, and sediment should be considered in future water quality endpoints established for East Canyon Creek (Bell et al. 2004). Ongoing, rapid growth and development in the upper East Canyon watershed is a significant nonpoint source of nutrient and sediment loads to the creek. Polluted stormwater runoff is of particular concern (BIO-WEST 2008). Residential and commercial development has increased the number of impervious surface areas and construction sites, both of which increase loads associated with stormwater. Stormwater runoff has been identified as one of the largest remaining sources of water quality impairment in Summit County (EPA 2000a). Large areas of impermeable surface and disturbance contribute to higher peak flow for a shorter duration and with lower baseflow due to reduced groundwater recharge (BIO-WEST 2008). Flash peak flows contribute to increased erosion and channel destabilization, and to lower summertime flows by reducing infiltration and groundwater recharge (BIO-WEST 2008). There are limited records of long-term streamflow for the creek. Records from current USGS gaging stations from 2001–2003 indicate low flows in summer and the dewatering of the creek in October of 2003. Diminished flows from July through September concentrate nutrients and amplify water quality problems (i.e., high temperatures, low DO) in the creek, reservoir, and downstream. Bell et al. (2004) noted that water quality conditions could be improved with augmentation of summertime flows.

The deposition of sediment in the creek provides rooting sites for macrophytes, which then capture fine fraction sediments in the dense growth of roots and shoots. Dense macrophyte stands in the creek contribute to reduced DO concentrations both through the respiration and decomposition of plant material, and by contributing to chemical and biological oxygen demand associated with stored sediments. Historical DO analyses and the USU study results (Baker et al. 2008) indicate that creek DO concentrations and macrophyte levels are not controlled by water column nutrients, but rather by sediment nutrients and physical stream characteristics. Water column nutrients do contribute to the impairment identified downstream of East Canyon Reservoir.

The primary sources of TP and TSS in the upper East Canyon watershed are phosphatic shales, active construction, stormwater runoff, and agriculture (BIO-WEST 2008). Total suspended solid loads reported in the 2007 subbasin water quality monitoring study (BIO-WEST 2008) were lower than loads estimated from samples collected in 2000 (Olsen and Stamp). However, 2007 was considered to be a drought year and was not necessarily representative of all hydrologic conditions in the watershed. BIO-WEST (2008) found that most tributaries to East Canyon Creek regularly have TP concentrations greater than 0.05 mg/L during spring runoff. Total phosphorus concentrations have increased from 2000 levels (Olsen and Stamp 2000) in four tributaries and have decreased in four tributaries of East Canyon Creek. Only Radisson Creek and Spiro Tunnel were found to have TP concentrations consistently below 0.05 mg/L (BIO-WEST

2008). Annual TP loads were generally lower in 2007 compared to 2000; a change attributable to fewer samples collected during storm events and reduced storm intensity during the 2007 drought year, and/or the implementation of BMPs (BIO-WEST 2008). However, BIO-WEST's 2007 assessment of TP yields and loads in three subbasins of the upper watershed indicate that changes in TP yield reflect changes in land use from 2000 to 2007, whereas TSS yield estimates were similar between 2000 and 2007. Their results also indicate that erosion- and sediment-control BMPs have reduced TP and TSS loads where implemented.

The Snyderville Basin Water Reclamation District (SBWRD) (2008) water quality and modeling study conducted in 2007 by HydroQual on approximately 19 miles of East Canyon Creek found that nutrient levels followed a fairly uniform pattern over a six-month sampling period. Organic nitrogen levels were approximately 0.6 mg/L, with nitrite/nitrate levels ranging from 0.2 mg/L to 0.5 mg/L upstream of the ECWRF for all months. The highest nitrogen levels were found at the ECWRF discharge, with lower levels returning approximately 7 miles downstream (SBWRD 2008). Typically, TP levels were less than 0.06 mg/L, total dissolved phosphorus levels were less than 0.04 mg/L, and phosphate (PO_4) concentrations were less than 0.02 mg/L. There was an increase in phosphorus levels downstream of the ECWRF that was not related to discharge, which indicates other sources of phosphorus loading to the creek including phosphorus releases from creek sediments and/or plant material (SBWRD 2008).

The implementation of BMPs, particularly in construction areas, would likely provide the most efficient method for reducing TP and TSS loading into East Canyon Creek (BIO-WEST 2008). In addition, because the system appears to be nitrogen limited (see Section 4.2, below), the implementation of BMPs in agricultural, recreational, and urban nonpoint source areas would help to maintain or reduce N:P ratios that will limit the growth, respiration and subsequent decomposition of algae and macrophytes largely responsible for low DO and poor water quality in the creek.

4.2 ASSESSMENT OF PHYSICAL CONDITIONS IN CREEK

An assessment of physical stream condition and its relationship to water quality, stream channel, and the riparian corridor was completed August 13–17, 2001 by the East Canyon Water Quality Steering Committee. The assessments were based on the SVAP, which relies on qualitative rankings of several variables related to stream channel condition and stability. The SVAP method consists of 14 ranking categories, each of which can be associated with a numeric value. Each of the categories are then averaged to provide a final score that is used to rate the overall condition of the reach. Values used to rank stream reaches are provided below in Table 4.1. In addition to the SVAP inventory, a SECI developed by the Idaho Natural Resources Conservation Service (NRCS) was conducted at the same time.

Table 4.1. SVAP Conditions and Scores Used to Evaluate Stream Condition

SVAP Condition	Average Score
Poor	<6.0
Fair	6.1–7.4
Good	7.5–8.9
Excellent	>9.0

Source: NRCS 1998a.

The assessment was conducted by a group of volunteers from the East Canyon Water Quality Steering Committee. Three teams of three to five people each completed the inventory. The teams were made up of individuals from various disciplines among the partners associated with the East Canyon Water Quality Steering Committee. People specializing in soil science, range science, wetland ecology, engineering, wildlife biology, fisheries biology, wastewater management, water quality, and geology were all part of the inventory teams.

Table 4.2 shows the results of the 14 different criteria evaluated in the SVAP for the 13 reaches that were assessed above East Canyon Reservoir (reaches 14–26; Figure 4.1). An additional 13 reaches (reaches 1–13) were assessed downstream of the reservoir, but are not discussed here as they are outside of the spatial scope of this study. The scale for all of the ratings is 1 through 10 except for the "Macroinvertebrates Observed" criteria, which was rated between -3 and 15. The "Manure Presence" criteria was only rated on those reaches where manure was present, otherwise it was not rated (hence the empty cells for this criteria on some reaches).

Table 4.2. East Canyon Creek SVAP Results

Reach Number	Channel Condition*	Hydrologic Alteration*	Riparian Zone	Bank Stability*	Water Appearance	Nutrient Enrichment	Fish Barriers	Fish Cover	Pools*	Invertebrate Habitat	Canopy Cover*	Manure Presence	Macro-invertebrates
14	9	3	8	8	7	5	3	8	3	10	3		3
15	7.5	7	4	3	7	2	10	8	3	10	1	3	2
16	5	6	9	3	7	1	3	10	3	9	1	4	2
17	9	3	9	5	8	3	10	10	7	10	1	5	6
18	7	3	8	6	8	3	10	7	3	10	1	5	6
19	2	8	1	8	2	2	3	5	6	5	1		4
20	9	9	9	7	4	4	3	5	3	6	1		3
21	6	9	6	5	7	5	3	6	3	7	1		6
22	7	9	6	6	8	6	3	5	3	7	1		6
23	8	8	5	6	9	6	3	5	6	3	1		5
24	8	6	1	4.5	7	3	3	5	4	7	1	5	2
25	9	9	8	10	9	5	10	8	7	7	1	5	10
26	8	9	2	8	9	4	10	3	2	4	1	5	6

*Criteria most relevant to a discussion of current physical conditions in East Canyon Creek (see Sections 4.2.1–4.2.5)

Five of the fourteen criteria are most relevant to a discussion of current physical conditions in East Canyon Creek and are discussed in further detail below. They are Channel Condition, Hydrologic Alteration, Bank Stability, Pools, and Canopy Cover.

4.2.1 Channel Condition

Under the SVAP protocol, channel condition is assessed based on a stream's qualitative naturalness or level of alteration, proper function (as evidenced by downcutting, aggradation, or lateral movement), restriction of floodplain access (by dikes or levees), and the amount of riprap and channelization present (NRCS 1998a). In general, this criterion was ranked as fair to excellent, with only Reach 16 and Reach 19 scoring as poor. Reach 16 appears to be affected by sediment deposition (Bell et al. 2004), whereas Reach 19 is highly engineered with multiple armored banks and runs through a golf course (East Canyon Watershed Committee 2002).

4.2.2 Hydrologic Alteration

Under the SVAP protocol, hydrologic modification is assessed on the basis of the effects any withdrawals have on a reach's habitat, as well as the streams' connection to floodplains in the reach (NRCS 1998a). Three reaches were ranked poor for this criterion: Reaches 14, 17, and 18. The assessment of Reaches 17 and 18 noted that withdrawals from upstream were assumed to contribute to hydrologic modification. It is unclear why these reaches were singled out for this alteration. It is assumed that much of the creek is highly affected by withdrawals, particularly during summer low-flow conditions.

4.2.3 Bank Stability

Under the SVAP protocol, bank stability is qualitatively assessed on the basis of perceived stability, root protection of eroding areas, and the extent of observed erosion. A total of five reaches were rated as having poor bank stability: Reaches 15, 16, 17, 21, and 24. Reaches 15, 16, and 17 run through rangeland downstream of Jeremy Ranch. Reaches 21 and 24 run mainly north of I-80 between Jeremy Ranch and the eastern edge of Swaner Nature Preserve.

4.2.4 Pools

Under the SVAP protocol, pools are qualitatively assessed according to their depth and abundance. Pools were scored with a poor ranking on 9 of the 13 reaches for which they were ranked, indicating that they are of low quality and abundance along most of the creek. Pools are often important cool-water refugia during low-water conditions.

4.2.5 Canopy Cover

Under the SVAP protocol, canopy cover is semi-quantitatively assessed on the basis of the percentage of the stream that is shaded by riparian canopy and the degree of shading in upstream reaches. This criterion was rated as poor along the entire length of the stream, with all but one reach (14) rated as having less than 20% of the water surface shaded. Canopy cover is essential for mediating water temperatures, limiting algal growth, and increasing the water's capacity to hold DO.

4.2.6 Geomorphic Summary

Overall, physical stream conditions in East Canyon Creek are relatively poor. The upper part of the watershed is characterized by poor riparian habitat, fish habitat, and channel function. Riparian habitat and fish habitat in the lower part of East Canyon Creek (upstream of the reservoir) are considered to be in moderate condition and channel function is considered to be poor.

4.3 Feasibility Study for Establishing a Protected Base Flow

Residential and commercial development (and associated demands for public water supply) has greatly increased over the past 20 years. These water diversions have greatly reduced flows in East Canyon Creek, Kimball Creek, and McLeod Creek, such that minimum summer flow rates now dip below rates considered to be protective of the cold water fishery. Low summer flow rates due to water diversions are further exacerbated by below-average precipitation during drought years. The SBWRD retained Kleinfelder and others for the East Canyon Creek flow augmentation feasibility study (2005), which detailed the feasibility of establishing a protected base flow to improve water quality in East Canyon Creek. Minimum streamflow goals for East Canyon Creek, Kimball Creek, and McLeod Creek (the upper main stem of East Canyon Creek) were based primarily on flows required to maintain water quality and fish habitat (SBWRD 2005) and that mimic the natural historic minimum flows in the creek.

Minimum flow goals recommended for East Canyon Creek are as follows:

- 3.5 cfs (2,533.9 acre-feet/year) in upper McLeod Creek
- 5 cfs (3,619.8 acre-feet/year) in lower McLeod Creek (3.5 cfs under extreme conditions)
- 6 cfs (4,343.8 acre-feet/year) in East Canyon Creek (3.5 cfs under extreme conditions)

East Canyon Creek below Kimball Creek and above the ECWRF was impacted by illegal water diversions in 2003, and this section of the creek often does not achieve minimum streamflow rates during summers of dry years. Effluent Discharge from the ECWRF significantly increases flow. Minimum streamflow objectives could be met with better management of water diversions, enforcement of water rights, and the addition of less than 300 acre-feet of water over a period of two to three months (equivalent to 1.6 cfs to 2.5 cfs [1,158–1,810 acre-feet/year]) during the summer of dry years. However, continued development pressure on the limited water resources in the basin is likely to further reduce flow in East Canyon Creek. Attainment of the streamflow goals listed above will require establishing in-streamflow rights of the desired minimum flow. The maximum amount of additional flow (or in-stream water rights) required to meet the in-stream flow goals is calculated to be 1,095 acre-feet (equivalent to 6 cfs [4,343.8 acre-feet/year]) over the months of July, August and September.

The Kleinfelder study (2005) examined 12 alternatives to improve minimum streamflow goals in East Canyon Creek, Kimball Creek, and McLeod Creek. No single alternative was found to be sufficient to meet the in-stream flow goals. Among the recommended alternatives in the short-term were the following:

- Improve management of water rights and diversions
- Purchase or lease irrigation water rights for in-stream flow
- Reduce diversions to the Silver Creek watershed

These alternatives could provide an estimated 0.5 cfs to 3 cfs (362–2171.9 acre-feet/year) of flow to East Canyon Creek during critical periods, and the feasibility of implementing them in the short-term was found to be high (SBWRD 2005). In addition, a proposal to divert water from East Canyon Creek back to Snyderville Basin for residential, commercial, and agricultural use is currently under consideration. The proposed pipeline would divert 5,000 acre-feet per year. As part of the agreement related to this project, Summit Water Distribution Company has agreed to provide a limited water right to the Utah Division of Wildlife Resources up to 2 cfs (1448 acre-feet/year) (SBWRD 2005). However, this water would not be treated by the treatment plant before being discharged back into the creek. This plan would not provide for increased flow above the treatment plant. The alternatives discussed in the East Canyon Creek Flow Augmentation Study will be discussed in further detail in the East Canyon Creek implementation plan.

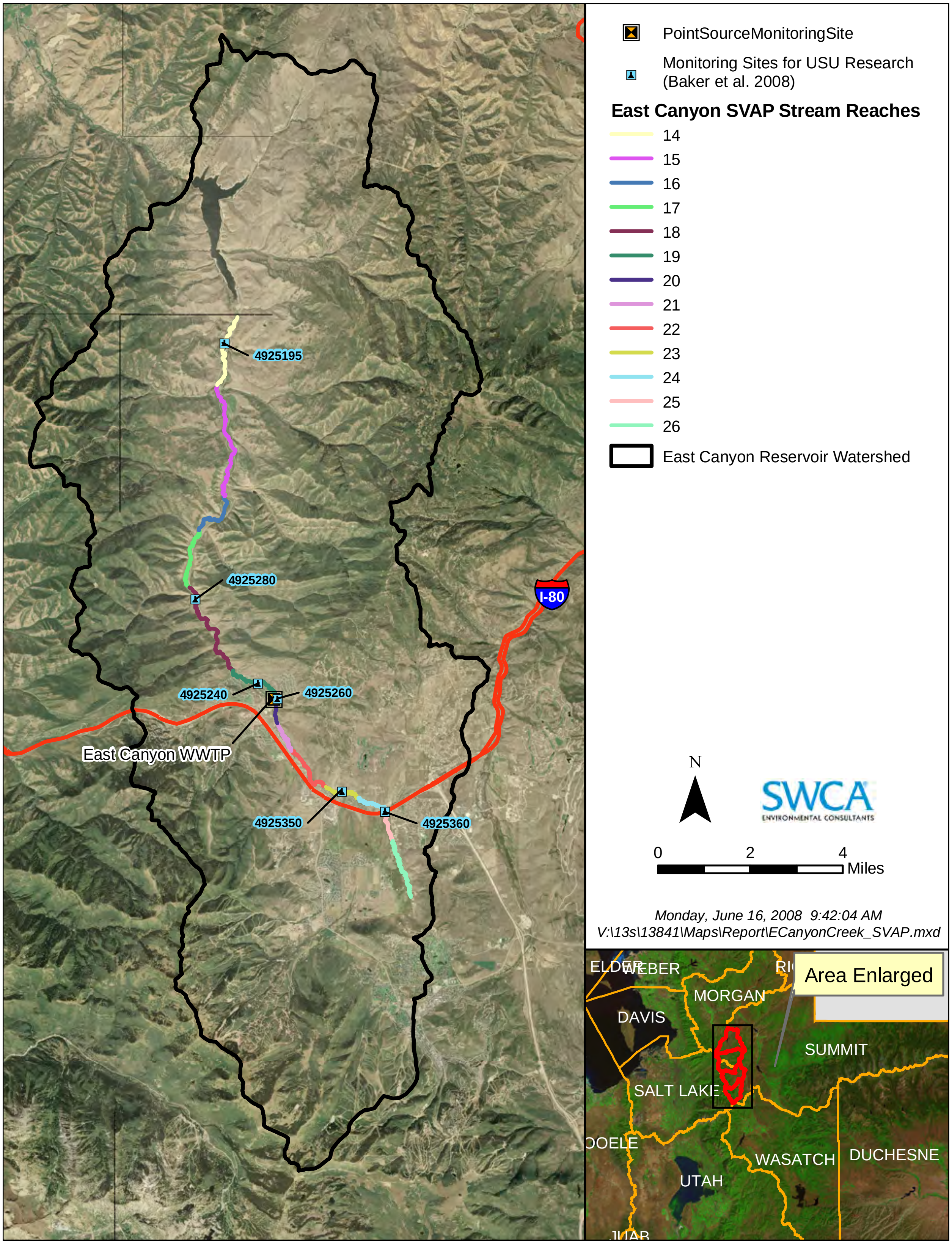


Figure 4.1. Map of SVAP stream reaches and USU/HydroQual research sites and reaches.

4.4 STREAM METABOLISM AND NUTRIENT DYNAMICS IN EAST CANYON CREEK

The UDWQ recently sponsored research conducted by researchers at Utah State University to examine the relationships between nutrients, primary productivity, and metabolic processing in East Canyon Creek. This study, in conjunction with the DO modeling described in the following section, provide the basis for identifying the driving processes of low DO in impaired reaches of East Canyon Creek.

The study examined six reaches of East Canyon Creek that correspond to EPA STORET water quality monitoring sites (Table 4.3 and Figure 4.1). Researchers measured a variety of parameters related to stream ecology and function including reach flow, autotroph (macrophyte and periphyton) biomass and cover, water quality parameters (TP, total nitrogen, nitrate, ammonium, SRP, and dissolved organic carbon), and sediment chemistry. A series of phosphorus extractions were performed on the sediment samples to determine both TP and phosphorus availability to macrophytes. Ash-free dry mass (AFDM) was also estimated. Reaeration rates were calculated using solute releases including conservative tracers (salts) and a volatile tracer gas. Measures of DO, temperature, and stream physical characteristics were used to compute reach-level ecosystem metabolism measured as community respiration and gross primary production (GPP) (Baker et al. 2008). Nutrient diffusing substrates were used to examine the nutrient limitation to periphyton growth in each stream reach. Results were analyzed using analysis of variance (ANOVA) and regression statistical methods (Baker et al. 2008).

Table 4.3. Study Site Locations Used in USU Research on East Canyon Creek

EPA STORET	Reach
4925360	Kimball Creek
4925350	Blackhawk
4925260	Above WWTP
4925240	Below WWTP
4925280	Bear Hollow
4925195	RV Park

Sediment analyses indicate that sediment organic matter (measured as AFDM) was highest in the upper reaches of East Canyon Creek and was reduced downstream. Baker et al. (2008) estimate that eroding banks along East Canyon Creek could contribute 2.3–7.2 tons per year of organic matter. Overall, organic matter content is higher in streambanks than in sediments along East Canyon Creek, which suggests that decomposition of organic matter in sediments is an important oxygen demanding process in the creek. The majority of phosphorus in sediment samples was found to be biologically unavailable. Concentrations of nutrients and organic carbon in sediment pore water were very high throughout East Canyon Creek (Baker et al. 2008). For example, pore water TP ranged from 0.38 mg/L to 0.82 mg/L (Baker et al. 2008).

Two reaches, Kimball and Blackhawk, were found to be dominated by macrophytes during July and August 2007. The other reaches were dominated by epilithon at the same time, with dry biomass values ranging from 354 g/m^2 in the reach above the WWTP to 70 g/m^2 at Bear Hollow. Based on N:P ratios in the water column, nitrogen limitation would be expected at all of the sites except Bear Hollow. Biomass of macrophytes and periphyton were not found to correlate with nutrient water column concentrations. Similarly, chlorophyll *a* was not correlated with water column nitrogen or phosphorus nor was it correlated with sediment pore water quality parameters. Results from the nutrient diffusing substrate experiments also indicate that water column nutrients do not limit or contribute significantly to periphyton or macrophyte growth in East Canyon Creek. More specifically, stream periphyton are not phosphorus limited in East Canyon Creek (Baker et al. 2008).

Nutrient uptake in stream segments was used to develop nutrient saturation models based on the Michaelis-Menten curve. Estimates of ecosystem metabolism indicate that Kimball and Blackhawk reaches were autotrophic (rates of photosynthesis exceed respiration) in early summer but became heterotrophic (respiration exceeds photosynthesis) later in the season. Bear Hollow was the only reach with a gross primary productivity (GPP) rate above 10 gO_2/m^2/day, a threshold that is associated with eutrophication in streams (Baker et al. 2008).

In summary, the East Canyon Creek TMDL endpoint study authors (Baker et al. 2008) concluded that:

- Streambank erosion contributes a significant amount of organic matter and nutrients to the stream, contributing to oxygen demand and low DO concentrations.
- Phosphorus reduction is unlikely to reduce macrophyte and periphyton biomass in East Canyon Creek.
- Nitrogen control could reduce macrophyte and periphyton biomass in East Canyon Creek. Nitrogen was found to be the most likely limiting nutrient in the water column, pore waters, and sediments. Bioassays confirm that phosphorus does not limit stream periphyton. Nutrient uptake indicates that demand for nitrogen is higher than demand for phosphorus. The authors recommend the establishment of nitrogen criteria for East Canyon Creek.
- The saturation point for TP was estimated to be twice the Km value for SRP at 0.046 mg/L, similar to the TP endpoint already established for East Canyon Creek (0.05 mg/L).
- Reaches with low DO (below the threshold value of 4 mg/L) are tightly correlated with percent cover of macrophytes. These sites are Kimball, Blackhawk, and Bear Hollow. The linkage between macrophyte cover and low DO is likely related to both respiration by macrophytes at night as well as degradation of organic matter trapped by the macrophytes.

4.5 DISSOLVED OXYGEN (DO) MODELING

Following the 2003 upgrade at the ECWRF, HydroQual was retained by SBWRD to review water quality study results and to perform model simulations to identify linkages between diurnal oxygen fluctuations and other creek parameters including water quality (organic matter and nutrients) and physical stream habitat characteristics (SBWRD 2008). The steady-state creek model DIURNAL was selected for its ability to address physical and biochemical reactions and to calculate diurnal DO fluctuations (SBWRD 2008). The model included carbonaceous biochemical oxygen demand (CBOD), DO, organic N, ammonia as N, nitrite plus nitrate as N, TP, and conductivity (kinetics) (SBWRD 2008). The DIURNAL model was used to evaluate three potential management strategies to improve DO levels in East Canyon Creek. The scenarios addressed in the modeling report addressed physical changes to the creek such as: 1) establishing or increasing riparian canopy shading along the creek; 2) changing creek geometry (narrowing and deepening); and 3) modifying creek flow (SBWRD 2008).

Increased riparian canopy and shading was evaluated by reducing the photosynthesis rate (P_{max}) in the model to 25% and 50% of the current calibrated rate in order to simulate the impact of reducing sunlight available for macrophyte growth, thereby decreasing productivity and increasing DO concentrations. The model demonstrated reduced diurnal DO swings in response to reduced sunlight. The worse-case month, August, showed improvements in minimum DO levels from 3.7 mg/L to 4.5 mg/L for the 25% reduction in P_{max}, and to 5.3 mg/L for the 50% reduction at the Bear Hollow station (Table 4.4).

Table 4.4. Projected Average and Minimum DO Concentrations from DIURNAL Model (SBWRD 2008)

Average	Baseline	25% P_{max} Reduction	50% P_{max} Reduction	25% Width Reduction	33% Width Reduction	5 cfs Flow Increase	10 cfs Flow Increase
Blackhawk Reach Average DO Concentrations (mg/L)							
April	9.5	9.4	9.2	9.5	9.5	9.5	9.5
May	8.7	8.7	8.6	8.7	8.7	8.7	8.7
June	8.3	8.2	8.1	8.2	8.2	8.3	8.3
July	7.4	7.3	7.3	7.4	7.4	7.4	7.3
August	6.8	6.9	6.9	6.9	6.9	6.9	6.9
September	8.8	8.8	8.7	8.8	8.8	8.8	8.8
Bear Hollow Reach Average DO Concentrations (mg/L)							
April	9.4	9.4	9.3	9.4	9.4	9.4	9.4
May	9.0	8.9	8.7	8.9	8.9	9.0	8.9
June	8.2	8.1	8.0	8.1	8.2	8.2	8.2
July	7.5	7.5	7.4	7.5	7.5	7.5	7.5
August	6.7	6.7	6.8	6.6	6.6	6.7	6.8
September	8.9	8.8	8.7	8.9	8.9	8.9	8.8
Blackhawk Reach Minimum DO Concentrations (mg/L)							
April	7.5	7.8	8.1	7.5	7.5	7.6	7.6
May	6.9	7.2	7.5	7.1	7.2	7.0	7.1
June	6.3	6.7	7.0	6.1	6.6	6.3	6.2
July	5.7	6.1	6.5	5.9	6.0	6.0	5.9
August	3.4	4.3	5.3	3.9	4.1	4.6	5.0
September	7.5	7.7	7.9	7.7	7.6	7.5	7.5
Bear Hollow Reach Minimum DO Concentrations (mg/L)							
April	7.9	8.1	8.4	7.9	7.9	7.9	8.0
May	7.5	7.6	7.8	7.5	7.5	7.5	7.5
June	6.2	6.6	6.9	5.9	6.5	6.3	6.4
July	3.7	4.6	5.5	4.2	4.3	4.2	4.6
August	3.7	4.5	5.3	4.2	4.3	4.3	4.6
September	7.0	7.3	7.7	7.0	7.0	7.2	7.3

Similar changes were predicted for the Blackhawk station. The shading scenario of 50% reduction in the P_{max} rate predicted an increase in minimum DO by 0.4 mg/L and 1.9 mg/L in July and August respectively. Daily average DO levels along the creek did not change significantly with reduced P_{max} rates, because in addition to increased minimum oxygen levels, maximum oxygen was reduced, thereby maintaining a similar average concentration. Therefore, reduction of photosynthesis by 25% should achieve the minimum water quality standard of 4.0 mg/L DO identified by the State of Utah for East Canyon Creek. The feasibility of attaining a 25% reduction in photosynthetic rate is evaluated in the implementation plan accompanying this TMDL (SBWRD 2008). Changes to creek width and depth were modeled in areas exhibiting low DO levels and where creek restoration was determined to be feasible. These reaches were identified as areas upstream of the ECWRF (Blackhawk) and near Bear Hollow. Reductions to creek width and increased creek depth serve to reduce macrophyte and algal growth per volume of water, thereby reducing the impact of respiration on DO concentrations. This process is simulated in DIURNAL by predicting P_{max} rates based on changes in creek geometry and then assessing the impact on DO. Decreases in stream width of 25% and 33% with proportional increases in stream depth, velocity, reaeration, and volumetric primary productivity were also evaluated. Daily average DO levels in the identified stream reaches were found to change significantly in response to changes in physical stream characteristics. Reductions in P_{max} resulted in increased minimum DO levels from the baseline DO of 3.4 mg/L to 3.9 mg/L for the 25% width reduction and to 4.1 mg/L for the 33% width reduction. July and August minimum DO concentrations increased 0.2 mg/L to 0.7 mg/L with changes to creek geometry (see Table 4.4). Therefore, if creek geometry alone was used to attain the water quality criteria of 4.0 mg/L minimum DO, a width reduction of 33% would be required (SBWRD 2008).

Increased upstream flow was used to assess the response of DO concentrations and other creek parameters to potential increases in upstream base flow. Upstream flow additions of 5 cfs and 10 cfs (3,619.8 and 7,239.6 acre-feet/year, respectively) were analyzed, with significant response in DO concentrations (see Table 4.4) (SBWRD 2008). Minimum August DO concentrations near the Blackhawk station increased from the baseline of 3.4 mg/L to 4.6 mg/L for the 5 cfs (2619.8 acre-feet/year) flow increase, and to 5.0 mg/L for the 10 cfs (7239.6 acre-feet/year) increase. Minimum August DO concentrations near Bear Hollow increased from the baseline of 3.7 mg/L to 4.3 mg/L with the 5 cfs (3619.9 acre-feet/year) flow increase, and to 4.6 mg/L for the 10 cfs (7239.6 acre-feet/year) flow increase. July and August minimum DO concentrations increased 0.3 mg/L to 1.6 mg/L. Based on these results, the proposed 6.9 cfs (4995.4 acre-feet/year) flow increase for the pipeline project could potentially increase the lowest minimum August DO concentrations in the creek approximately from 0.7 mg/L to 1.3 mg/L (SBWRD 2008).

All three model scenarios—increased stream shading, reduced width/increased depth of the channel and increased upstream flow—resulted in improvements to DO concentrations in East Canyon Creek. Attainment of water quality criteria with any one scenario would require either a reduction in Pmax (associated with shading) of 25%, a stream width reduction of 33% in reaches where restoration was identified as feasible, or minimum flows were increased to 5 cfs (3,619.8 acre-feet/year). These scenarios are unlikely to be additive because they all impact the same two key parameters: photosynthetic rate (related to algal and macrophyte biomass) and stream reaeration rate. However, an optimal and achievable combination of the three scenarios will be identified and incorporated into the implementation plan to the Creek (SBWRD 2008).

4.6 Linkage Between Stream Characteristics and Dissolved Oxygen (DO)

This section summarizes linkages between physical and biological stream characteristics and DO concentrations in the stream. This summary will help link the creek research conducted by USU and the DO modeling completed by HydroQual to reach specific recommendations that will attain the DO criteria established for East Canyon Creek. Dissolved oxygen concentrations are directly influenced by water temperature, photosynthetic rate, sediment oxygen demand, stream velocity, depth, and stream flow. Therefore, other physical features of the system, particularly minimum stream flow levels, indirectly affect DO by influencing water temperature and velocity, water chemistry, and the abundance and biological activity of aquatic organisms. These features consist of sediment and nutrient loads, solar radiation, temperature, channel morphology, flow rate, topographic shade, aquatic vegetation, and riparian vegetation (Figure 4.2).

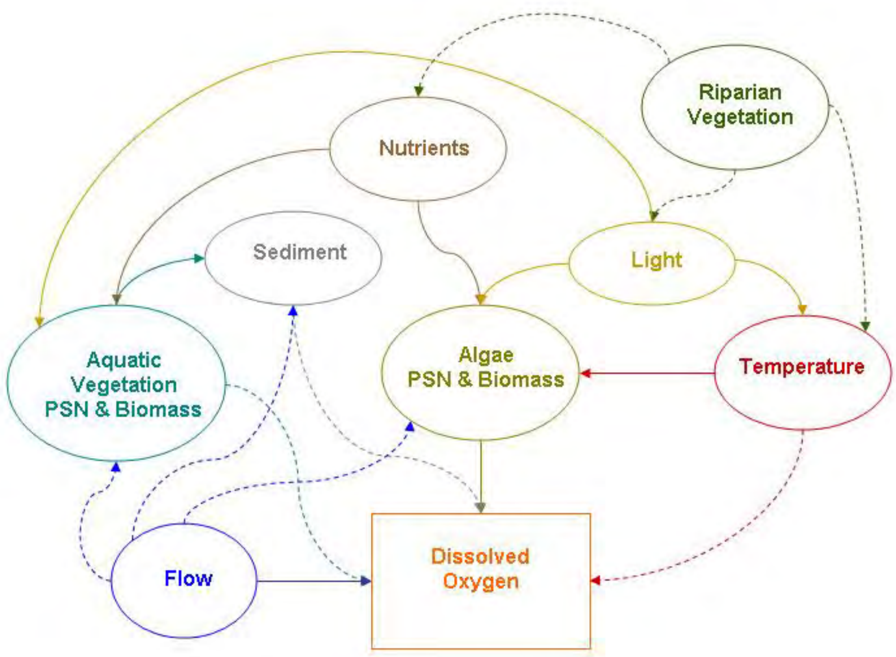


Figure 4.2. Linkages between physical stream characteristics and DO.
Solid arrows indicate a positive (increasing) relationship between parameters; dotted arrows indicate a negative (decreasing) relationship between parameters.

4.6.1 WATER TEMPERATURE

Solar radiation is a primary driver of stream temperatures (Wetzel 2001). Stream morphology and riparian vegetation influence the amount of solar energy entering the system and therefore also affect water temperature. Elevated water temperature decreases oxygen solubility and availability, while at the same time increases the metabolic rates and oxygen requirements of fish and aquatic invertebrates. Algae and other aquatic plants photosynthesize and respire at higher rates in warmer stream temperatures, thus increasing both primary productivity and oxygen consumption. Increased photosynthesis and primary production often produced dramatic fluctuations in diurnal DO concentrations due to increased photosynthetic oxygen production during the day and oxygen uptake during respiration at night. Shading by riparian vegetation reduces stream temperatures by blocking solar radiation and reducing air temperatures (Hill et al. 1995). The removal of riparian vegetation produces the opposite effect, and can destabilize streambanks, increase erosion and sedimentation, and result in channel widening and reduced channel depth, all of which contribute to increased water temperatures.

4.6.2 STREAM VELOCITY

Dissolved oxygen concentrations increase with water-current velocity and turbulence. Aeration of water generally corresponds to flow, with higher DO concentrations occurring during high flow and lower DO occurring during low flow. More oxygen dissolves into water when turbulence caused by rocky bottoms or steep gradients brings more water into contact with air. The greater water volume inherent to increased flow also reduces heating and cooling and associated fluctuations in DO concentrations. Increased flow causes the channel to deepen and thereby reduces the amount of photosynthetically available light. As a result, there is less light available to aquatic plants under higher flows and there is reduced DO fluctuations from photosynthesis and respiration. Surface water diversions and decreased flows contribute to lower DO concentrations by decreasing water volume and depth, limiting aeration, reducing temperature stability, and decreasing scouring of algae, macrophytes, and sediments.

Current velocity is also an important factor controlling aquatic vegetation and sediment accumulation. Submerged and emergent aquatic plants trap fine sediment and organic material (Welch 1992), and can thereby contribute to oxygen demand and facilitate the establishment and expansion of algae and macrophytes. Generally, aquatic macrophytes are more adapted to slow moving river systems, however, periphyton can remain attached at higher current velocities. At high stream velocities, frictional shearing can remove attached algae and emergent vegetation (Welch 1992). The removal of aquatic vegetation affects DO concentrations by decreasing both photosynthetic oxygen gain and respiratory oxygen loss. As scouring and displacement washes aquatic plant material downstream, there may be a decrease in the oxygen demand on upstream reaches and a corresponding increase in oxygen demand on lower stream reaches and in the reservoir.

4.6.3 Sediment and Nutrient Loads

High sediment and nutrient loading and its associated organic and nutrient content contributes to low DO. Nutrients promote algal growth and associated oxygen consumption during respiration and anaerobic decomposition (Wetzel 2001). Construction and development associated with residential growth in the upper East Canyon watershed has resulted in increased impervious surface area causing greater stormwater generation and pollutant loads (BIO-WEST 2008). Stormwater runoff is a primary source of nutrient and sediment loads to East Canyon Creek, and contributes to water quality degradation, increased flooding, increased erosion, and channel instability (BIO-WEST 2008). Irrigation return flow can also contain pollutants, particularly ammonia and nitrate, which are directly available to aquatic plant life and contribute to total biomass and oxygen demand.

High levels of suspended solids and organic carbon increase biochemical oxygen demand (BOD) and contribute to low DO concentrations (Baker et al. 2008). Organic sediments include algae, detritus, and other carbon rich material. Biochemical oxygen demand is the oxygen required to oxidize material (usually organic), whether it is naturally occurring or contained in municipal, agricultural, or industrial wastes.

4.6.4 Light

Direct solar radiation is a significant driver of stream temperatures in summer months, whereas stream shading provides a limitation on the amount of energy entering the system. Shade is created by riparian canopy and streamside buffer vegetation, and by small and large-scale topographic features such as channel banks, ridges, and surrounding terrain. In small, deep streams, the shade created by an incised channel bank can provide significant shading. Riparian vegetation blocks or filters light through shading provided by canopy trees and streambank buffer vegetation. Light has been found to be the primary abiotic constraint on photosynthesis and algal community structure in most shaded streams (Hill et al. 1995; Steinman and McIntire 1987). Plant growth and the subsequent respiration and decomposition that contribute to diurnal fluctuations in DO can be controlled by reducing light availability (EPA 2000b).

4.6.5 Algae and Macrophyte Growth

Oxygen is released during photosynthesis and consumed during respiration and decomposition. High aquatic plant biomass (algae and macrophytes) can result in severe diurnal fluctuations in DO, where high rates of photosynthesis and oxygen release during the day are offset by continuous oxygen consumption through respiration by, and decomposition of, aquatic plants. The 2000 BIO-WEST Study (Olsen and Stamp 2000) concluded that creek reaches with stable banks, abundant overhanging vegetation, and low percent fine sediment particles had less than 30% macrophyte coverage. The study also concluded that macrophyte coverage was relatively high in reaches where water depth was less than 1 foot, whereas coverage was relatively low where water depth was greater than 2 feet during low flow. In addition, the recent USU nutrient study of East Canyon Creek (Baker et al. 2008) found higher photosynthesis rates in regions of low gradient (low slope) in the creek. The USU study found a strong positive correlation between the number of days with DO less than 4.0 mg/L and macrophyte coverage, which further supports a link between macrophyte biomass and DO fluctuations. The study did not find a correlation between water column nutrients and primary productivity, macrophyte coverage, or biomass, which suggests that changes to water column nutrient concentrations are not likely to affect macrophyte growth.

There are different photosynthetic responses in phytoplankton vs. periphyton due to extensive vertical development in a densely packed matrix in periphyton communities (Boston and Hill 1991). Increasing cell densities negatively influence photosynthesis due to filtering and shading effects (Hudon et al. 1987) and due to changes in cell physiology between the surface and lower layers (Paul and Duthie 1989). However, periphyton in shaded streams has been demonstrated to be two times more efficient at fixing carbon (photosynthesis) than unshaded periphyton (Hill et al. 1995). Higher respiration rates in algal cells grown in high light (Richardson et al. 1983) can also affect DO concentrations. Despite increased photosynthetic efficiency in shade-adapted periphyton, both photosynthesis and respiration rates are higher in high light environments, with greater impacts on DO than algae in shaded sites.

Because macrophytes can obtain nutrients from the sediment, it is not surprising that macrophyte coverage has not changed in response to reduced phosphorus inputs into the creek (Baker et al. 2008). Further, macrophyte coverage was not found to be substantially different above or below the ECWRF discharge. It appears that other environmental factors are controlling macrophyte growth and associated low DO concentrations in the creek. Potential causal factors include nutrient–rich fine sediments facilitating macrophyte growth, high light levels due to shallow water depth and minimal canopy shading, and algae and macrophyte growth along stream reaches with low velocities due to reduced flow and low stream gradient (Baker et al. 2008).

4.6.6 Riparian Vegetation

Riparian vegetation reduces the amount of light energy entering the stream system. Riparian canopies can intercept over 95% of ambient light, resulting in photosynthetically active radiation (PAR) levels that limit plant growth (Steinman 1992, Hill et al. 1995). In deciduous forest streams, leaf emergence and abscission can cause dramatic changes in PAR over relatively short time periods (Hill and Dimick 2002). A study of streams in British Columbia found that solar radiation (measured as mean solar flux) was 58 times greater in stream reaches with no riparian buffer than in stream reaches with intact riparian buffers (Kiffney et al. 2003). These researchers also found riparian shade to be the primary constraint on periphyton growth, with periphyton mass in unshaded stream reaches six times that of shaded stream reaches. The limiting effect of riparian shading on periphyton growth has been well demonstrated (Hill and Knight 1988, Steinman 1992). In general, periphyton growth has been shown to increase as a non-linear function of light due to increases in photosynthetic rate (Hill 1996). Feminella et al. (1989) found a significant negative relationship between riparian canopy cover (15–98%) and periphyton biomass ($y = 7.75–0.06x$; $r = –0.67$, $p<0.0001$) where x = % riparian shading and y = algal biomass (mg/cm^2). This relationship will be used to correlate required photosynthetic reduction (corresponding to reduction in photosynthesis) with shading recommendations for specific reaches in East Canyon Creek. The substantial research conducted in this area demonstrates that aquatic productivity, and thereby the magnitude of DO fluctuations, will be less in shaded stream reaches compared to unshaded reaches.

Riparian vegetation conditions were rated as poor along East Canyon Creek, with many stream reaches with little or no riparian cover (see Section 4.2). Topographic shading is also limited in the East Canyon watershed.

4.7 Summary of Factors Influencing Dissolved Oxygen (DO) in East Canyon Creek

A variety of recent studies have been conducted on East Canyon Creek including a stormwater quality study (BIO-WEST 2008), stream metabolism and nutrient dynamics (Baker et al. 2008), flow augmentation feasibility (SBWRD 2005), a geomorphic assessment (East Canyon Watershed Committee 2002), and DO modeling (SBWRD 2008). A summary of the findings from each report is displayed in Table 4.5.

Sediment loading from nonpoint sources, elevated water temperatures, overgrowth of algae and macrophytes, and corresponding low DO are currently the primary causes of water quality impairments in the East Canyon Reservoir watershed. Growth and development in the upper East Canyon watershed is a significant source of nutrient and sediment loads to the creek. Although nutrients were not found be the source of impairment in East Canyon Creek, phosphorus loading from the creek is a significant source to East Canyon Reservoir. Low DO, high temperatures, erosion, and channel destabilization are the caused in part by stormwater runoff from impervious surfaces and construction sites (BIO-WEST 2008). Stabilization of flows to the creek would improve these water quality conditions (Bell et al. 2004).

Historical and recent studies of DO in the creek indicate that DO concentrations and macrophyte levels are controlled by sediment nutrients and nonpoint source TP and TSS (BIO-WEST 2008). Because the single point source of pollutants in the watershed (ECWRF) has been minimized, nonpoint sources are now the primary contributors of TP and TSS to the creek (BIO-WEST 2008). Loading of nutrients and sediment into the creek facilitates dense macrophyte and algal growth, increased sediment oxygen demand, and reduced DO concentrations as a result of respiration and decomposition of plant tissues. Baker et al. (2008) studied water quality conditions in the creek and found that macrophyte density was strongly correlated with DO concentrations of less than 4.0 mg/L, and that macrophyte photosynthesis rates were higher in slow (low gradient) portions of the creek. The DIURNAL model (SBWRD 2008) demonstrated that riparian shading, increased streamflow, and changes to stream geometry were all effective in decreasing macrophyte productivity and increasing DO concentrations. These recent studies strongly indicate that low DO and DO fluctuations in East Canyon Creek are being driven by macrophyte and algal overgrowth, and that plant production is being facilitated by high light, wide and shallow stream geometry, low gradients, and reduced summertime flow conditions in the creek.

Table 4.5 Summary of Reach Level Stream Characteristics and Research Findings

SVAP Reach	EPA STORET Site	Reach Name (USU/HydroQual)	SVAP	Aug Stream Metabolism (gO2/m2/day)	Stream Reaeration Coefficient Ka (1/day)	Autotroph Biomass				DO (min Aug DO (mg/L)	Sediment Organic Matter (% AFDM)	BIO-WEST WQ Study
							Epilithon Chl *a* (g/m2)	Epiphyton Chl *a* (g/m2)	Macrophyte Chl *a* (g/m2)			
ECRFC 2002	Baker et al. 2008; SBWRD 2008	Baker et al. 2008; SBWRD 2008	ECRFC 2002	Baker et al. 2008	Baker et al. 2008	Baker et al. 2008	Baker et al. 2008	Baker et al. 2008	Baker et al. 2008	SBWRD 2008	Baker et al. 2008	BIO-WEST 2008
26	4925360	Kimball Creek at I-80	Good channel condition. Poor canopy cover. Minimal hydrologic alteration.	4.22	16.1	Macrophyte dominated.	202	3.0	56.1	n/a	4.40	0.05 tons TP/yr/mi2 10.02 tons sediment/year/mi2
23	4925350	Black-hawk	Good channel condition. Poor canopy cover. Average hydrologic alteration.	7.86	17.7	Macrophyte dominated.	168	52.0	157.0	3.4	2.30	
21	4925260	Above WWTP	Highly engineered. Poor canopy cover. Poor channel condition.	9.85	13.7	Epilithon dominated.	354	8.1	32.3	3.6	1.30	0.027 tons TP/yr/mi2 6.61 tons sediment/year/mi2
19	4925240	Below WWTP	Highly engineered. Poor canopy cover. Poor channel condition.	3.63	10.8	Epilithon dominated.	116	7.5	66.6	4.8	0.570	
18	4925280	Bear Hollow	Hydrologic modification related to upstream withdrawals.	21.4	21.3	Macrophyte dominated.	70	5.5	45.7	3.7	1.10	
14	4925195	EC Resort	Good channel condition. Minimal canopy cover.	7.16	54.8	Epilithon dominated.	73	14.0	51.4	6.2	0.84	

* Gross Primary Productivity values greater than 10 gO2/m2/day indicates eutrophication (Baker et al. 2008)

5. EAST CANYON RESERVOIR MODELING AND DYNAMICS

5.1 GENERAL MODEL DESCRIPTION

Water quality and hydrodynamics were simulated for East Canyon Reservoir with the CE-QUAL-W2 model, hereafter referred to as the W2 model. The modeling was conducted by Jerry Miller of JM Water Quality LLC. Unless otherwise noted, this chapter is a condensed version of the report submitted by Jerry Miller to SWCA. This, more comprehensive modeling report, is included as Appendix B to the TMDL study. The W2 model is a longitudinally segmented, vertically layered, and laterally averaged reservoir model that was adopted and modified by the US Army Corps of Engineers. There are numerous iterations of the model, as coordination of test codes and model development has been jointly shared by private and public model developers for many years. At this time, over 200 applications worldwide have used the W2 model. The version of CE-QUAL-W2 utilized for this analysis is Version 3.2.

The W2 model is especially appropriate for long, narrow waterbodies that exhibit longitudinal and vertical gradients. The model assumes lateral homogeneity (Cole and Wells n.d.). The W2 model simulates reservoir behavior across a longitudinal and depth gradient on a daily time step. The model routes water through cells in a computational grid and each cell is a completely mixed reactor for each time step. Input parameters for the W2 model include reservoir morphometry, sediment release rate, tributary hydrologic and water quality data, and climatic data.

5.2 MODEL GOALS AND OBJECTIVES

The following are the W2 model goals and objectives as they pertain to the East Canyon Reservoir TMDL study:

1. Provide a more detailed assessment of how East Canyon Reservoir has responded to the phosphorus reductions that have been implemented since the previous TMDL.
2. Describe key reservoir dynamics for management. This over-arching goal includes objectives for determining:
    - Sediment oxygen demand related to annual algal blooms, legacy organic matter, and annual organic matter washed into the system;
    - DO profiles after phosphorus and carbon flush from reservoir sediments; and
    - Seasonal and annual patterns and their effect on reservoir productivity.
3. Identify phosphorus reduction required to attain DO criteria.
4. Determine the total phosphorus (TP) concentration that corresponds with 8 µg/L mean seasonal chlorophyll *a.*
5. Quantify uncertainty for use in MOS.

5.3 MODEL DEVELOPMENT FOR EAST CANYON RESERVOIR

The initial East Canyon W2 model was set up by Jerry Miller at the BOR. Since retiring from the BOR, Jerry Miller has continued to develop the W2 model for East Canyon Reservoir, including the development of algorithms specific to reservoirs like East Canyon. Several students from Brigham Young University in Provo, Utah helped BOR staff assemble the W2 model. The East Canyon W2 model was updated in 2007 by Nick Williams (BOR, Salt Lake City) to the W2 Version 3.2. Data inputs for the model were provided by the Weber Basin Water Conservancy District, the USGS, the Snyderville Basin Water Reclamation District (SBWRD), and the UDEQ.

5.3.1 Temporal Extent of Model Simulations

The 2003–2007 time period represents 'current' post-TMDL water quality for this study and is used as the primary time frame for the W2 model. The East Canyon model was initially run for the 1991–1999 time period to set up initial model parameters and calibration. The 1991–1999 model simulation was primarily used to determine the initial condition in 2003. It was also used to help determine if there was sufficient legacy phosphorus in the water column to indicate whether the reservoir had reached a new steady state following reductions achieved since the 1990s. Although model output is generated on a daily time step, the model was generally used to evaluate seasonal trends and improvement across years.

5.3.2 Inputs for East Canyon Reservoir W2 Model

5.3.2.1 Reservoir Morphometry

Reservoir morphometry used in the W2 model is derived from a bathymetry file which is built using the Watershed Modeling System (WMS), a program developed at BYU. The reservoir is divided into 20 segments with 66 active vertical layers (each less than 1 m deep) at full pool (Figure 5.1). There are three reservoir branches on the northeast side of the reservoir. The bathymetry file was checked for accuracy by comparing predicted storage to the reservoir storage capacity table maintained by the BOR (Figure 5.2).

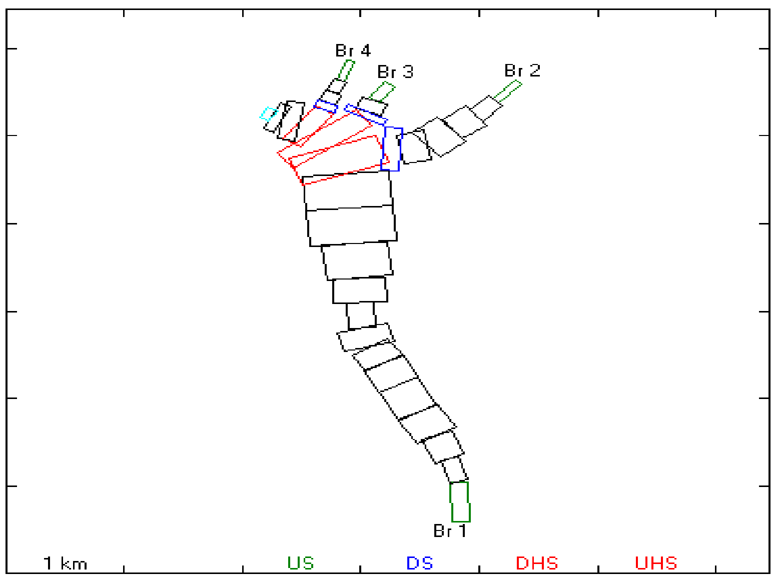


Figure 5.1. Segments of East Canyon Reservoir used in the W2 model.
Graph source: JM Water Quality, LLC. 2008

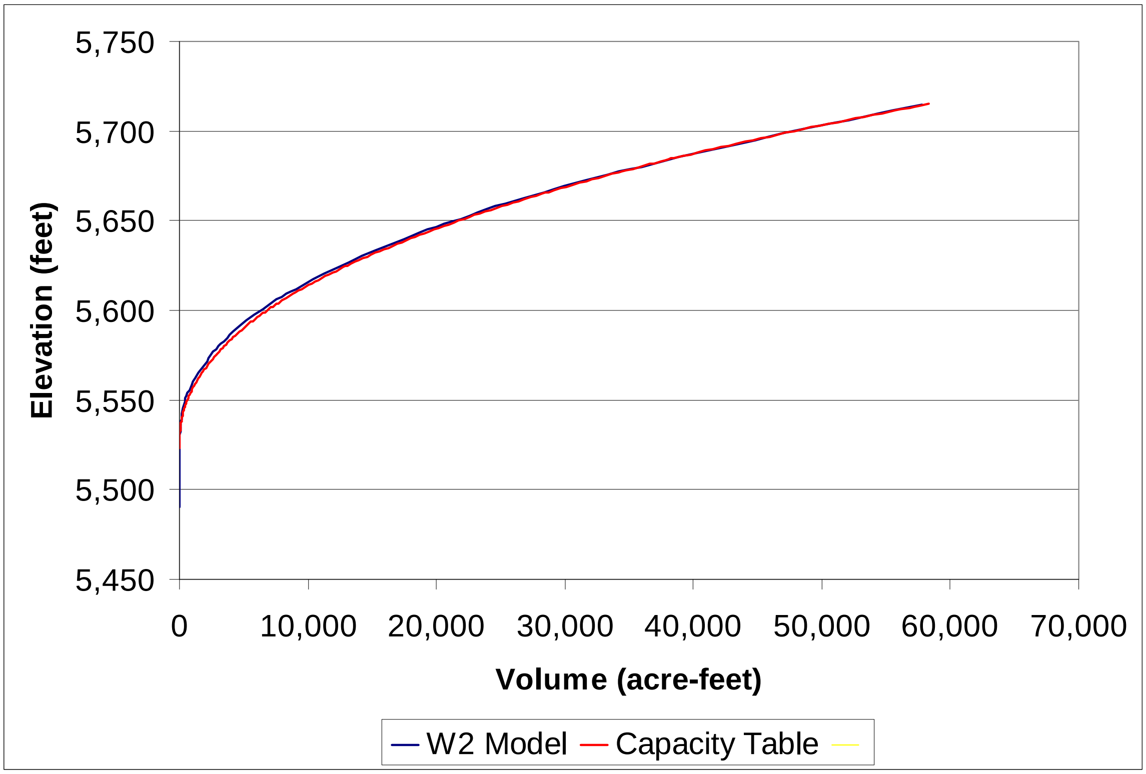


Figure 5.2. East Canyon comparison of the live storage area capacity table (provided by Nick Williams, BOR, 2008) and volumes generated using the W2 model bathymetry file.
Graph source: JM Water Quality, LLC. 2008

5.3.2.2 Tributary Inputs

The East Canyon Reservoir W2 model was run on a subdaily timestep. Daily streamflow, water quality, and field parameters were used as an input to the East Canyon W2 model.

Median water quality concentrations were estimated using water quality data obtained from Utah DEQ (EPA STORET), Weber Basin Water Conservancy District, SBWRD, and BIO-WEST (BIO-WEST 2008). During the post-TMDL period (2003–2007), each day was categorized into a hydroperiod: storm, spring melt, base flow, or rain on snow. The methods used to define hydoperiods are described in Section 3.3.1.2. Median water quality concentrations from Site 4925190 (furthest downstream site on East Canyon Creek) were determined for each hydroperiod based on available samples. Stormwater data was only available for selected sites, none of which were at the mouth of East Canyon Creek. Median event mean concentrations for stormwater parameters were taken for all East Canyon Creek sites and applied to the downstream site. Median water quality data was then used to derive daily water quality concentrations in East Canyon Creek, according to each day's categorized hydroperiod (Table 5.1).

Table 5.1. Median Water Quality in East Canyon Creek by Hydroperiod Used to Create Daily Tributary Input Files for W2 Model

	Base Flow	Spring Melt	Storm	Rain or Snow
BOD (mg/L)	3.000	3.000	3.000	3.000
Nitrate (NO3) as N (mg/L)	0.290	0.550	0.340	0.640
Nitrogen, Ammonia as N (mg/L)	0.050	0.050	0.100	0.100
Phosphorus as P, Dissolved (mg/L)	0.033	0.035	0.027	0.025
Phosphorus as P, Total (mg/L)	0.045	0.069	0.071	0.080
Total Suspended Solids (mg/L)	4.200	22.800	32.600	32.000
Total Organic Carbon (mg/L)	2.760	4.100	4.190	4.190

Daily flow from East Canyon Creek into East Canyon Reservoir was generated from USGS and BOR gages and reservoir elevation data as described in Section 3.3.1.2. Daily loads from 2003 through 2007 are calculated by multiplying daily flow values by median water quality concentrations estimated for each day (based on hydroperiod). Daily loads in East Canyon Creek were then divided into point and nonpoint sources. Point source loads were estimated directly with effluent data from the ECWRF. Nonpoint source loads were estimated by subtracting the ECWRF load from the total daily load. The nonpoint source concentrations were then area weighted and applied to the direct drainage area (approximately 20% of the total area) around the reservoir to estimate a total load to East Canyon Reservoir. The additional estimated nonpoint source load for the direct drainage area was included in the tributary input files built for the W2 model. Tributary water quality inputs derived using this method include total and dissolved phosphorus (TP and DP respectively), BOD, ammonia as N, nitrate as N (NO_3), and TSS. Dissolved oxygen in the tributary inflow is a generic daily average based on a temperature-dependent saturation estimates.

Daily maximum and minimum stream temperature was used to approximate hourly temperature inflow data based on daily fluctuations in air temperature. Data was transformed from daily maximum and daily minimum to hourly estimates of temperature in the inflow input files.

5.3.2.3 Climatic Data Inputs

The meteorological inputs for the East Canyon W2 model were derived from climatic data collected at the Salt Lake City International Airport (NCDC COOP ID 427598) and include temperature, precipitation, and wind data for the entire model simulation period. Adjustments were made to better represent conditions at the reservoir. The Salt Lake City International Airport station provided the most accurate wind direction patterns, which are an important driver of algal movement in East Canyon Reservoir. Alternative meteorological stations did not accurately represent conditions at East Canyon Reservoir.

Due to particulate matter and other airborne pollution, Salt Lake City Airport cloud cover was adjusted to better represent cloud conditions at East Canyon Reservoir. The mountains surrounding East Canyon Reservoir shade the water during late fall, winter, and early spring. Direct sunlight on the reservoir can be limited to a few hours a day during winter months. In the W2 model, cloud cover in the winter was set at a minimum level to account for this shading effect. The shading by segment in the control file of the W2 model allows adjustment for orientation and terrain by segment.

Unlike Salt Lake City International Airport, East Canyon Reservoir is sheltered from direct westerly winds. At East Canyon Reservoir, the wind is usually very calm in the early morning hours with 10 to 16 mile per hour winds developing in the afternoon and continuing until 5 or 6 p.m. Wind directions were not altered from the Salt Lake City International Airport data. Differences between the two sites explain some uncertainty identified during model calibration. The W2 model includes a wind sheltering correction for each segment. The model also adjusts wind speed and direction based on the compass orientation of each segment. The wind at East Canyon Reservoir was set to zero for mornings with lower wind speeds at the Salt Lake City International Airport, and then set proportionally up to a maximum value for summertime daily wind speeds. Higher winds generally indicated storm-front events and were used proportionately, thus overriding the daily pattern at the reservoir. The hourly interpolation of wind data was not always accurate; however, algal movements associated with seasonal wind patterns can be approximated. During late fall and spring storm events, there are frequent 180 degree shifts in wind patterns. Wind direction is highly variable and can differ significantly between sampling locations, dates and times, affecting the accuracy of the date-specific W2 model simulation calibration.

Meteorological data from East Canyon Reservoir would increase the accuracy of the model particularly on the daily-to-hourly time scale. Seasonally, this interpolation appears to be adequate to correctly approximate the major shifts in phosphorus limitation in the epilimnion and algal succession shifts in the reservoir.

5.3.3 East Canyon Reservoir Dynamics

One goal of the East Canyon Reservoir W2 model is to better describe unique dynamics in the reservoir that relate to hydrodynamics, stratification, algal growth and speciation, and nutrient dynamics. The following sections describe patterns observed in East Canyon Reservoir by Jerry Miller and simulated using the W2 model.

5.3.3.1 Hydrodynamics

The unique arrangement of dams and structures in East Canyon Reservoir and the location where water is withdrawn have resulted in unique hydrodynamic patterns which have shifted over time under different reservoir management scenario. There are two old inundated dams directly upstream of the operating dam. These hydrologic features control much of the limnology in East Canyon Reservoir. The dam configuration greatly restricts vertical mixing and thereby contributes to a depletion of DO during stratification.

The relatively shallow thermocline depth is unique for a dam that withdraws from the bottom of the hypolimnion. Although the dam is designed to withdraw water from the bottom, the dam configuration results in a portion of the daily withdrawal being drawn directly from the water surface (Figure 5.3). There is also a hole in the old concrete dam that is located in the middle of the hypolimnion during stratification. This hole serves as another withdrawal location for water discharged from the dam, and leads to the removal of much of the 12°C–18°C metalimnetic water during summer months, and contributes to the narrow metalimnion observed in East Canyon Reservoir. Together these two sources mix in the area between the new and old dams (Figure 5.3). The area of the upper level intake point (surface water) changes as the reservoir is drawn down, whereas the hypolimnetic hole remains the same. Therefore the relative contribution of water discharged from the dam from the hypolimnion and water surface changes with reservoir level.

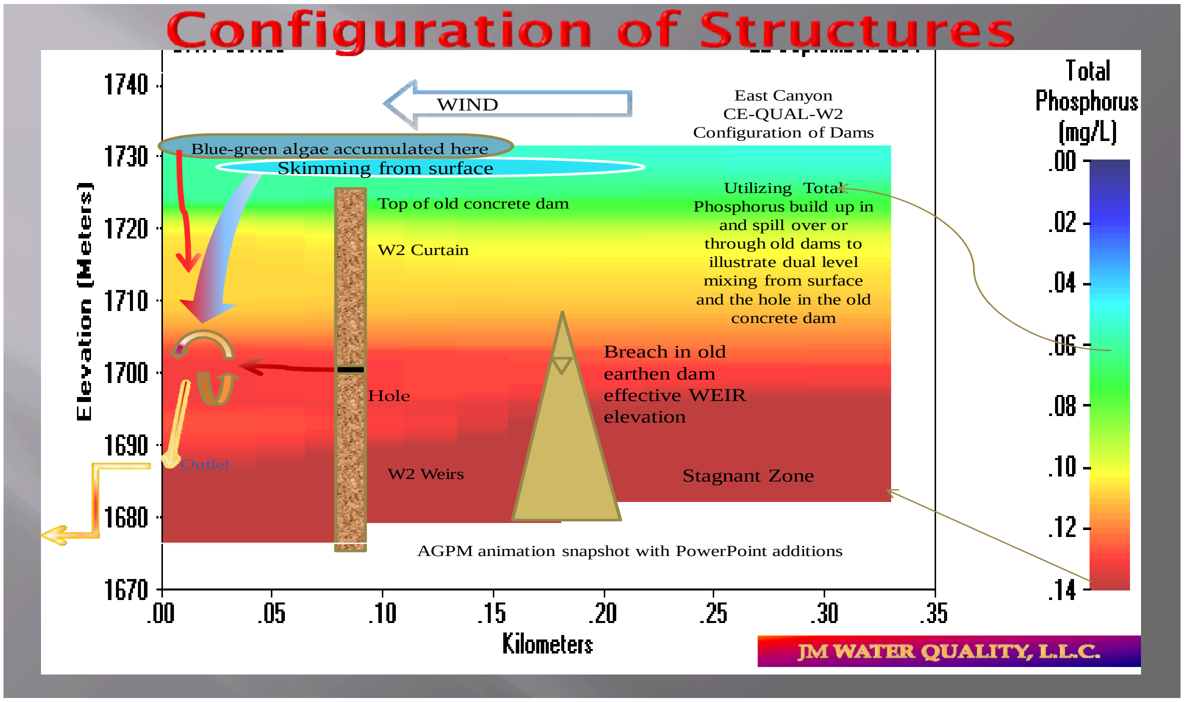


Figure 5.3. Dam configuration and phosphorus distribution during stratification.
Figure source: JM Water Quality, LLC. 2008

The W2 model has algorithms to add weirs and curtains to test skimming affects and various designs to improve water temperature and/or DO released from the dam (Cole and Wells n.d.). Hydraulic routines were tested in the East Canyon W2 model to represent both the upper and lower elevation mixing ratios and the associated routing of deep dissolved nutrients versus shallow particulate organic algae. The W2 model accurately reproduced the hydrodynamic effects discussed above.

5.3.3.2 Stratification

East Canyon is over 50 m deep at the dam and has a sufficiently long hydraulic retention time to retain a very cold hypolimnetic pool through the entire summer. A strong thermocline persists all summer at a depth of only 6 to 10 m. East Canyon Creek generally warms faster than the reservoir in the spring and cools faster in the fall. Because cold water is denser than warmer water, the difference in stream and reservoir temperatures contributes to stratification in the reservoir. In the spring, the high inflows need only to be slightly warmer than the reservoir to form an overflow density current. Therefore, the warmer and lower density spring inflow rides over the top of the reservoir to set up the initial thermocline in early summer. This thermocline barrier between the surface layer (epilimnion) and the hypolimnetic deeper water until the upper layer cools during the fall turnover. In the fall, after turnover, cold water from East Canyon Creek flows along the bottom of the reservoir.

The depth of the metalimnion, or thermocline, is further reduced by wind that pushes a seiche (standing wave) longitudinally across the reservoir. Seiching causes the thin metalimnion—the layer of water with the best DO and temperature conditions for trout—to move, and forces them to move with it to avoid stress from high water temperature, rapid temperature changes, and low DO.

5.3.3.3 Seasonality and Climatic Drivers of Algal Blooms

The water level of East Canyon Reservoir fluctuates seasonally. The reservoir elevation can rise more than 10 m during spring runoff and can fall nearly as much during heavy summer water use from July to October. Annual hydrologic variability leads retention time of reservoir water from 0.4 to 1.6 years. During a drought, the reservoir can be drawn down by an additional 5 m. Shifts in seasonal elevation, variability in hydraulic retention time, and patterns of hydrologic cycles drive the variation in limnological characteristics from year to year.

When the reservoir is drawn down (during the summer season or drought years), shoreline wave action sweeps all organic matter and reservoir sediment away, leaving only the coarser material to armor steep shoreline slopes. When the reservoir is refilled, the newly inundated water/sediment interface has very little stored sediment oxygen demand (SOD). Shoreline organic matter may settle in the next 5 m depth increment and may add to oxygen demand in the metalimnion during drawdown of the following summer. However, in a drought sequence with an additional 5 m elevation drop, the storage of organic matter over several years at these depths may also add significantly to summertime oxygen demand and epilimnetic nutrient loads. When the water temperature increases, and increased shoreline wave action scours previously buried organic matter, the organic matter will quickly decay. The decay of organic matter consumes oxygen and releases nutrients. As a result, seasonal blue-green algae blooms are much more likely to occur during multiple drought years. Wind is also an important driver of algal distribution in East Canyon Reservoir because summer winds blow predominantly toward the dam and blue-green algae are easily blown downwind.

5.3.3.4 Algal Speciation, Succession, and Vertical Mobility

The ability of blue-green algae, dinoflagellates, and diatoms to vertically migrate within the water column allows them to utilize deeper nutrient sources whereas other algal groups are limited to nutrient availability in the surface layer. There is an emerging body of literature quantifying algal movement (Reynolds 2006). *Aphanizomenon* species are especially proficient at moving into deep, nutrient-rich water at night to absorb phosphorus, and can produce huge biomasses in the late fall in many western reservoirs (personal communication between Sam Rushforth, phycologist UVSC, and Jerry Miller, JM Water Quality LLC, 2008). The algorithms used to simulate this process in the East Canyon W2 model incorporate the following dynamics:

1. Algal seasonal dormancy and emergence cycles, with separate mortality rates for algae during dormancy; at a preset date, the algal group goes into or out of dormancy as a daily percent increment.
2. Movement of dead algal biomass to the organic matter compartment.
3. Algal nutrient uptake and mortality during dormancy; dormant algae absorb a constant amount of nutrients.
4. Seasonal adjustments to algal mortality rates to compensate for not having zooplankton population and grazing dynamics.
5. Maintenance of algae in the epilimnion during stratification; algae's ability to control its density in a daily vertical migration pattern is overridden by wind-driven velocity dynamics.

The W2 model simulation tracks algal bloom intensity as well as blue-green algal dominance. JM Water Quality LLC in association with ERM, an environmental consulting firm, developed and utilized an algal succession code for the East Canyon W2 model. The code is still under research and development and therefore has not yet been fully adopted by the W2 modeling suite. This code is summarized in Figure

5.4. The coefficients that control algal succession (including blue-green algae) in the W2 code and also in the additional research and development code include the following:

1. Zero nitrogen, half saturation requirement for blue-green algae to allow continued growth if the modeled water chemistry reaches nitrogen limitation but not phosphorus limitation.
2. Temperature coefficients for optimal growth to control each algal group seasonally.
3. Algal growth rates, half saturation for light, settling velocities, nutrient requirements, mortality rates, and respiration rates.
4. Daily vertical migration rates for each algal group.
5. Date set change in mortality rate to make up for the lack of zooplankton grazing.
6. Luxury uptake of nutrients if they are available during descent as part of vertical migration.
7. A deeper vertical migration depth for blue-green algae.
8. Greater ability for luxury uptake of phosphorus during the night in deeper water for select blue-green algae.

Algal groups have a date set for a portion of the population to go into a dormant state, a mortality rate in dormancy, and are recalled from dormancy as a percentage of remaining mass on a daily basis when the set date is reached. Algae groups adsorb extra phosphorus on descent to dormancy, and return to SOD organic matter upon death. To prevent over prediction of summer blooms in the W2 model simulations, the vertical migration code does not send phytoplankton below the thermocline in the summer.

Blue-green algae create surface scums which are unsightly, smell bad, and can produce toxins that are harmful to animals. They can also cause problems to recreationists in the summer. Blue-green algae fix their own nitrogen from the atmosphere; whereby, if the epilimnion becomes nitrogen-limited before becoming phosphorus-limited in the summer and fall, it can produce very large blue-green algae blooms and dominate the algal flora. When the wind increases in the morning and blue-green algae are heavily concentrated at the surface, they are easily transported by wind movements and will concentrate along the shoreline, against the dam, or into the inflow area, depending on wind speed and direction during the previous few hours and/or several days.

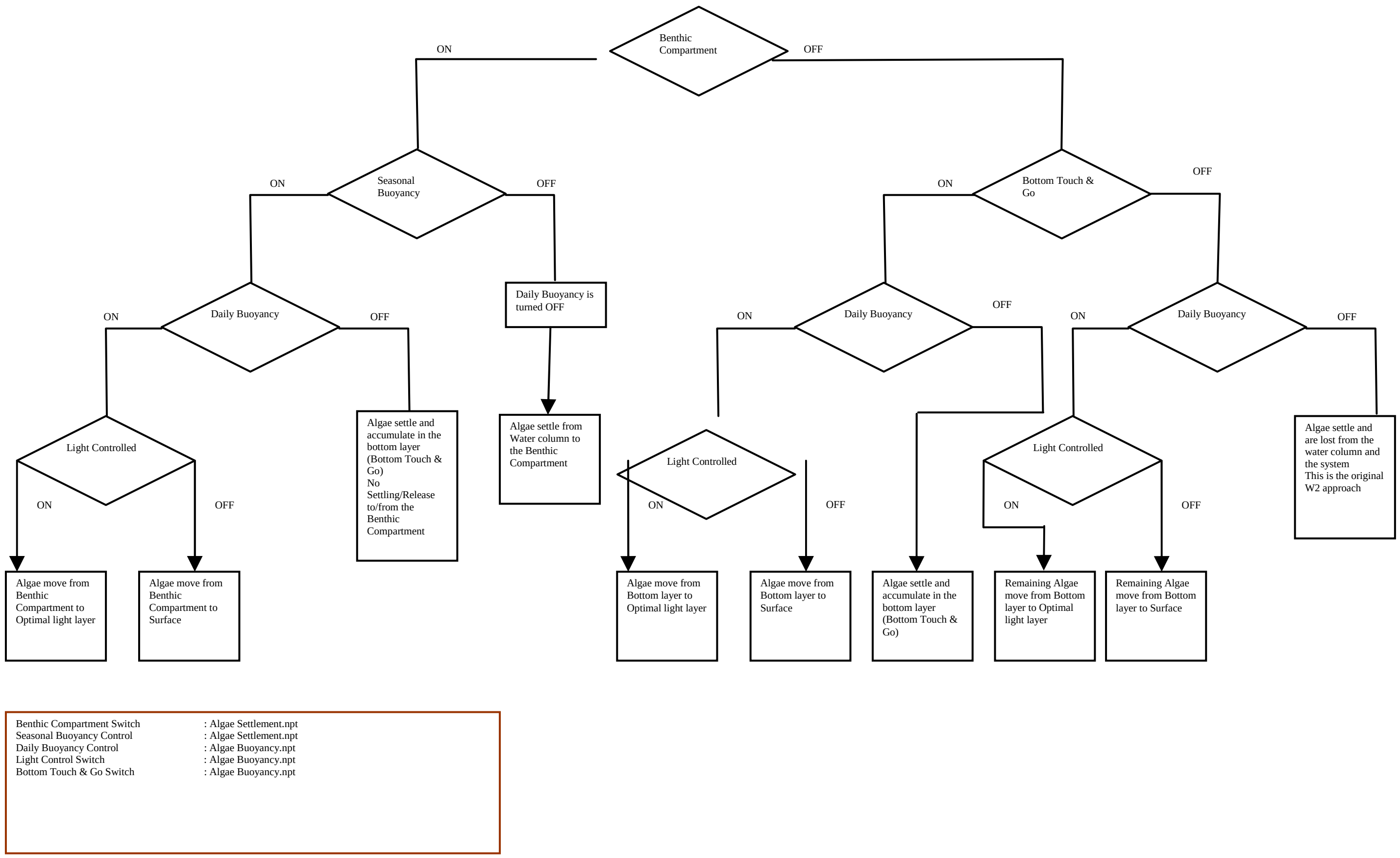


Figure 5.4. Diagram of the algal succession code conceptually developed by Jerry Miller with extensive discussion with Shwet Prakash at ERM.

Diagram source: Shwet Prakash, ERM personal communication with Jerry Miller, JM Water Quality LLC, 2008.

5.3.3.5 Phosphorus Availability

In order for phosphorus to be available for algal growth, it has to be both biologically and physically available to algae. This means it needs to be in a dissolved biologically available form and located in the surface layer (epilimnion) where algae grow. Phosphorus is delivered to the epilimnion through three different processes: tributary flow directly to the epilimnion, sediment release and diffusion up to the epilimnion, and mixing of the water column during fall turnover. Each of these processes dominates delivery of phosphorus to the epilimnion during different times of the year.

Seasonal inflow hydrodynamics play an important role in determining the importance of phosphorus to spring, summer, and fall algal blooms. During the spring, warm melt water flows along the surface of East Canyon Reservoir, which is much colder at deeper levels. Phosphorus contained in spring runoff provides the primary source of phosphorus for algal blooms in the spring and early summer. Although most of the nutrients in the reservoir are physically unavailable below the strong summer thermocline, nutrients released from the shallow decomposing spring diatom biomass may be recycled several times. As much as one third to one half of the annual dissolved bioavailable phosphorus entering a deep reservoir like East Canyon may not be assimilated by phytoplankton in a 1- to 2-year period because it is located too deep and is physically unavailable. Algae sinking to the bottom may adsorb portions of this phosphorus and temporarily move it to the sediment. In fall, the cooling of the epilimnion induces the beginning of fall turnover and phosphorus is replenished in the surface waters through mixing from deeper layers of the reservoir. Blue-green algal species capable of deep daily vertical migrations can access phosphorus down to about 14 m once the thermocline is sufficiently weakened. Nutrients in deeper water are mixed to depths of less than 14 m and become physically and biochemically available to algae. Algal biomasses can increase very quickly in the fall, especially if a long period of relatively warm weather follows the first fall chill and turnover.

Organic matter, and the phosphorus contained within it, located in deep cold water in the reservoir is released slowly via biological decomposition. The resulting anoxia leads to the release of iron-bound phosphorus also in the sediments. The East Canyon watershed contains large amounts of ferric soil from which oxidized sources of iron could be periodically replenished; therefore the release of phosphorus during anoxia is likely to be an important process which has been captured by the W2 model. However, phosphorus released from reservoir sediments only becomes biologically available if it migrates up to the zone of algal growth. The configuration of the dams is such that high concentrations of phosphorus in the hypolimnion are removed through the hole in the old concrete dam. Only a small portion of the phosphorus diffuses to the epilimnion during the summer stratification period. Therefore, phosphorus released from sediments does not contribute significant quantities of total phosphorus to the epilimnion during stratification, and therefore does not contribute significantly to summer algal blooms.

However, when the reservoir turns over in the fall phosphorus that was released during anoxia initially becomes available to algae in the surface layers of the reservoir. This process provides the largest source of phosphorus for fall algal blooms. Fall algal blooms also contribute to DO depletion in subsequent summers. Eventually, most of the phosphorus introduced into the epilimnion during the fall turnover makes its way back to the sediment either through precipitation or as algal biomass during die-off. During this time, phosphorus contained in tributary inflow, which is now colder than the reservoir, falls to the bottom of the reservoir where it is unavailable for algal growth. These patterns have been successfully simulated with the W2 model.

5.3.3.6 Sediment Oxygen Demand

The most dramatic changes in the reservoir since the 1970s are lower hypolimnetic DO concentrations in late summer. In the 1970s, DO was maintained above 4 mg/L throughout the water column and throughout the summer season. In 2007, oxygen concentrations dropped below 4 mg/L just below the thermocline, indicating a high hypolimnetic oxygen depletion rate. It is difficult to assess to what extent productivity rates have changed between the two periods due to a lack of data. However, another oxygen depleting mechanism may be responsible for some of the increased depletion rates. The bulk of watershed derived organic matter is delivered to the reservoir during the spring where it is primarily deposited in the inflow segments of the reservoir. The inflow segments are shallow, warm, and continuously aerated. The inflow area traps and buries most of the suspended solids flowing into the reservoir. A portion of organic matter delivered to the reservoir accumulates on the shoreline is physically broken down by wave action, and decays in the very warm shallow water. Reservoir drawdown and sediment scouring in the drawdown zone leaves little organic matter on the steep and armored slopes following weeks of shoreline wave erosion. The zones just below the drawdown zone accumulate some shoreline washout during drawdown. However, this process does not contribute significantly to oxygen depletion in the hypolimnion.

The W2 model was used to estimate the contribution of sediment oxygen demand associated with organic matter generated in the reservoir during algal blooms (autochthonous) and in the watershed outside of the reservoir (allochthonous). Several methods of incorporating sediment oxygen demand were tried in the W2 model. The combination of equations that produced the best match to observed oxygen depletion rates was selected. Separate equations were used to simulate oxygen demand from autochthonous and allochthonous sources because the former breaks down at a much faster rate than the latter. Oxygen demand from the breakdown of autochthonous (reservoir generated) organic matter uses a first-order decay rate that is temperature dependent. The first-order computation includes temperature-rate coefficients and a percentage of the organic matter available from the sediment. Breakdown of allochthonous organic matter is accounted for using a zero-order constant rate which is temperature dependent, but is independent of organic matter availability. Sensitivity analyses with the W2 model indicate that the first-order oxygen depletion calculations, which accounts for all organic matter produced in the reservoir, correctly estimated DO depletion rates. This suggests that watershed sources of organic matter play a small role in hypolimnetic oxygen depletion.

5.3.3.7 Drivers of Low Dissolved Oxygen (DO) in Hypolimnion

The primary drivers of low DO concentrations in East Canyon Reservoir are spring nutrient rich inflows, spring diatom blooms and subsequent decay, summer stagnation, and phosphorus retention and cycling in wet and dry years. The W2 model appeared to capture the most important processes that drive internal phytoplankton production and oxygen demand, and correctly approximated the long-term trends that are most important in evaluating future watershed phosphorus reductions. Model simulations strongly support the hypothesis that annual phosphorus inflow, assimilation by phytoplankton, and later decomposition account for nearly all DO demand and phosphorus cycling in East Canyon Reservoir. Specific mechanisms contributing to oxygen depletion in the hypolimnion include the following:

- Phosphorus retention cycles in the stagnant portion of the hypolimnion cause high spring turnover phosphorus concentrations and drive algal blooms in May and June.
- Accumulation of spring algal biomass in the shallow portions of the reservoir epilimnion, metalimnion, and the sediment-water interface produce high oxygen demand in the hypolimnion.
- High spring inflow phosphorus loads cause an overflow density current across the top of the epilimnion in May and June, and further add to bioavailable phosphorus in the epilimnion.

- Unique reservoir hydrodynamics created by the old dam skims a significant portion of 12°C–20 °C water from the reservoir and limit summer refugia for fish in August; especially when the reservoir is drawn to lower levels.
- Organic matter stored in cold water just beneath the metalimnion over several years of high reservoir elevations quickly warms and decays when the reservoir is drawn down to lower levels.
- July and August inflows are two to three times lower compared to earlier decades when mines discharged large volumes of water into the creek in the upper watershed from June to August.

Nutrient cycling over multiple years is dependent on reservoir hydrology and water levels. The bioavailability of phosphorus and resulting biomass of the spring diatom blooms are tied to hydrologic cycles and water levels from the previous three years. At the peak of the cycle, more phosphorus is available during both spring and fall turnovers. However, the continued reduction of loading during spring runoff from nonpoint sources in the W2 model simulations indicates promising additional future reductions in epilimnion total phosphorus concentrations in June, July, and August, with a corresponding reduction in summer mean chlorophyll *a* concentrations.

Diurnal DO cycles are dependent on the magnitude of algal blooms, wind mixing, reaeration, and the depth that light can penetrate sufficiently to sustain photosynthesis. Algal growth in the epilimnion is currently phosphorus-limited in July and August. Metalimnetic oxygen demand is primarily still driven by the decomposition of dense spring algal blooms.

5.4 MODEL CALIBRATION AND VALIDATION

The East Canyon Reservoir dataset was simulated for the 1991–1998 time period and again for the 2003–2007 time period. Tests of model robustness were achieved by modeling continuously for longer time periods, and testing the overall robustness of the model transitioning through: 1) wet and dry cycles; 2) an approximately 60% phosphorus inflow reduction associated with improvements made by the ECWRF; 3) major shifts in algal biomass production; 4) tracking trends in reservoir and dam release phosphorus concentrations; and 5) seasonally tracking changes in algal succession. More confidence can be placed in the W2 model simulations if they are able to reproduce wide variation in prototype behavior between years. There were large data gaps from the 1999–2002 time period and a record dry period from the 1999–2003 time period that prevented modeling of the entire 1999–2007 time period. Simulations for both 1991–1998 and 2003–2007 time periods were conducted using the same model coefficients and methodologies for transforming meteorological data and computing hourly stream temperature inputs. Water quality parameters are averaged laterally across a segment. Each layer within a segment acts as a fully mixed reactor for each time step.

Calibration data were generally restricted to two to five sampling events per year. Chlorophyll *a* data may have underestimated the total algal productivity biomass; particularly as the model outputs a laterally averaged value across a reservoir segment. This sampling bias was probably greater when the reservoir had larger July–August algal blooms than during the past two to three years when the reservoir had very low summer chlorophyll *a* concentrations. The significant flushing that should occur in 2008 could also add a valuable piece of information to this study. Nutrient data were collected about 1 mile below the dam, and the phosphorus concentrations are subject to changes in form, biological uptake in the stream, and dilution—especially during runoff events. However, the data were adequate to track major seasonal, annual, and decadal shifts in trophic status of the reservoir.

The modeling approach was to approximate date-specific sample data and to reliably track the long-term seasonal, annual, and decadal changes as a test of "robustness" over a wide range of hydrologic conditions. The primary goals were to:

- Accurately capture changes in phosphorus concentrations over long periods of time associated with reductions from the watershed, but measured as outflows from the dam;
- Validate assumptions regarding vertical profiles and dam discharge concentrations;
- Reproduce temperature and DO data sufficiently to be confident that the model can reliably predict changes under future reduction scenarios; and
- Gain confidence that the W2 model simulations capture the hydrodynamic and limnological processes controlling algal and phosphorus cycles.

Long-term model robustness was considered more important than the daily/date-specific calibration. The predicted occurrence of major events simulated by the model generally occurred within a few days to no more than a couple of weeks from the actual time of the event. Major seasonal thermal stratification and turnover predicted in W2 model simulations occurred within 2 to 10 days of the correct timing. Spring and fall meteorological adjustments may be needed for some years, which underlines the need for local wind speed, direction, and surface water temperatures for May and June. Seasonal algal successional shifts were difficult to calibrate, but were generally predicted within a few days to two weeks of the actual timing. Predicted algal succession was closely related to the set up of stratification and the beginning of turnover, along with onset of the major snowmelt runoff event. Predicted major algal succession shifts due to reductions in phosphorus also appeared to be occurring in the simulations in the appropriate year and within approximately two weeks of the correct time period. Additional calibration data and analysis for temperature, DO, phosphorus, algal succession, and chlorophyll *a* are included in Appendix B. Rate coefficients are also included in Appendix B. Some of the critical rate coefficients to this model have already been reviewed.

Dams and intake structures were configured as a set of weirs and a curtain in the W2 model. In hydraulic laboratories, this type of problem has been evaluated by creating a proportioned ratio. In this study, a set of trial and error configurations were simulated with the W2 model to test various approaches for East Canyon Reservoir. The W2 model simulations replicate temperature profiles fairly well on both sides of the old concrete dam. Observation of the dam exporting large quantities of decomposing blue-green algae, and the W2 model simulations approximating the phosphorus concentration in the reservoir and in the discharge all indicate that the model is demonstrating good robustness over a wide range of conditions. Extending the model to include future years' data could help to address model limitations.

The test of hydrodynamic calibration comes from comparison of temperature and DO profiles in the reservoir. Hydrodynamic calibration requires establishing correct water velocities due to vertical placement of inflow by temperature (density), correct mixing from two elevations to the intake structure, correct air temperature and solar radiation, and correct hourly wind speed and wind direction. Wind sheltering coefficients and solar radiation shading settings for each segment, and time varying wind function evaporation coefficients are also critical for establishing an acceptable calibration. East Canyon Reservoir is difficult to calibrate because of the uncertainty associated with the factors described above. The physical configuration of the two old dams creates two flow fields to the intake structure in a manner that approximates the reservoir profiles for temperature and DO. These two flow fields likely change in mixing ratio in response to wind speed and direction, seiching, reservoir elevation, and thermal stratification.

5.4.1 RATE COEFFICIENTS

There are numerous model coefficients related to hydrodynamics, nutrient processing, and mixing in the W2 model. Most of the model coefficients were set to default levels established by the previous calibration of approximately 200 reservoirs and are described in detail in the CE-QUAL-W2 user's manual along with model algorithms and equations (Cole and Wells n.d.). For East Canyon Reservoir W2 model calibration, model coefficients that were adjusted relate to thermal dynamics, evaporation, dam configuration, and sediment digenesis.

5.4.2 TEMPERATURE

The model includes a weir and a curtain to simulate the configuration of the dam at the outlet of the reservoir. This reproduces the skimming affects of the old dam on the hydrodynamics of the reservoir. The model configuration places the modeled old dam segments considerably further back from the operating dam than actually occurs. The space or opening between the weir and the curtain is bigger than the hole in the concrete dam. The effective opening between the weir in Segment 18 and the curtain and weir in Segment 19 was reduced to approximate the manner in which water enters the intake structure and to reduce simulation times.

In order to calibrate the reservoir temperature profiles, the water movement to the intake structure had to be further restricted by a coefficient in the model which behaves similarly to a weir. The restriction was set 8 m above the intake structure and slightly above the hole in the old dam. Calibration of a coefficient (KBSTR) was used to restrict water beneath that elevation from entering the intake structure and created a stagnant zone in the bottom between the two structures. This produced good results in critical reservoir calibration parameters, such as temperature and DO profiles, including temperature profiles between the two structures and in the reservoir.

This configuration of dams and canyon walls appears to have a 5°C to 8°C chilling affect on the overall mixture being discharged, which is difficult to simulate in the model. It could also indicate that the mixing ratio is not perfect. The large vertical masses of the dams and the canyon walls surrounding this very large, single wet well have water that is in a range of 3°C to 5°C for more than 10 months each year. The reservoir calibration parameters may not be improved with considerable additional effort. The temperature of the dam discharge was determined not to be a significant issue. The Coefficient of Bottom Heat Exchange (CBHE) was set below the defaults to help keep the water in the model below the thermocline cooler (see CBHE in the user's manual). This had a minimal effect, and the reservoir still has a sharper thermocline break in the summer by 2 to 3 m than in the W2 model simulation.

The water temperature in front of the intake structure at 1,687 m elevation does not exceed the range of 6°C to 8°C all summer, yet the water discharged from the dam is normally between 10°C and 16°C in the summer. Water is entrained down the canyon wall from the surface and apparently mixes with the water coming through the hole in the old dam. This mixture of shallow and deep water apparently drops from above into the intake structure to produce the temperature and organic matter found at the discharge.

5.4.3 EVAPORATION

Evaporation is one of the primary variables affecting vertical mixing in the reservoir. The W2 code was modified for the East Canyon Model to vary the wind evaporation coefficients on a monthly basis. This code modification was based on previous modeling in the reservoir, as described in the Reclamation Quality of Water Report (BOR 2005). Monthly values were used because they best reflected seasonal conditions, such as in the spring when the air temperature is much higher than the water temperature, versus in the fall when the water temperature is higher than the air temperature.

5.4.4 Phosphorus Discharge from Dam

One of the best indicators of phosphorus processing in the reservoir is the discharge of dissolved phosphorus from the dam outlet. Seasonal and long-term phosphorus discharge trends from the dam are also good indicators of reservoir trophic condition. The relationship between inflow-and outflow-dissolved phosphorus appears to have changed over the calibration time period, and phosphorus discharges from East Canyon Dam have declined significantly over the past two decades. Internal load estimates on a monthly and annual basis are described in more detail in Section 6.2.4. The reservoir generally acts as a sink during the winter and spring and as a source of phosphorus during the summer and fall period. On average, the reservoir exports a net of 795 kg of total phosphorus per year. Results from the W2 model indicate that this net export is declining over time as the reservoir reaches a new long-term dynamic equilibrium.

The W2 model simulations were calibrated to best approximate the long-term trends and concentrations of dissolved phosphorus as measured as discharge from the dam from the 1990s through to 2006. Dissolved phosphorus declined from near 0.25 mg/L in the 1990s to approximately 0.06 mg/L by 2007. Figure 5.5 shows the modeled (W2) and collected data-point comparisons for total phosphorus from 2003–2006.

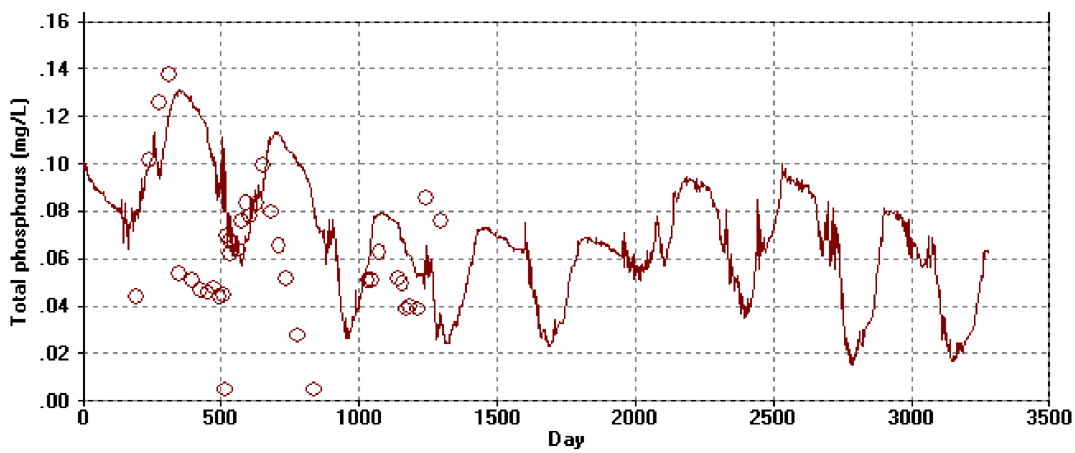


Figure 5.5. Observed (circles) and modeled (line) total phosphorus released from the East Canyon Dam (data is from 2 km downstream) from 2003 to 2006.
Graph source: JM Water Quality, LLC. 2008

The model reproduces phosphorus discharge from the dam well at some times and poorly at others. Poor calibration of phosphorus discharge can be explained by several factors. Iron-rich local soils and sediment may absorb phosphorus; however, the W2 model simulation in this application could not reproduce this type of event. The W2 model simulations may also be a bit slow in complete mixing and in reaeration in the fall. This would also create a temporary divergence in calibration; however, they reconverge at the important spring turnover.

A period of dry years, without significant mixing, may have caused significant phosphorus accumulation in the deep hypolimnion and may have also contributed to model divergence. The movement of algal biomass influences observed phosphorus concentrations and is affected by wind speed and direction. The models' use of data from the Salt Lake City Airport may have also contributed to some model error.

Finally, the build-up and retention of phosphorus behind the old earthen and concrete dam is difficult to accurately model.

The W2 model baseline calibration assumes that less than 2% of the total mean annual phosphorus in the water column originates from inorganic phosphorus release associated with anoxic sediments. The model error in autochthonous internal organic matter production could be on the order of 10%, and the phosphorus release from anoxic sediment inorganic phosphorus could be as high as 10% of the annual average. There is no evidence of a systematic error in the overall phosphorus budget in the W2 simulations over the two decade period. Since the model ends up at the right place in the critical spring turnover, these date-specific calibration discrepancies are considered acceptable for the principle study objectives.

5.4.5 Dissolved Oxygen (DO) and Temperature Profiles

In order to calibrate stratification dates the following coefficients were modified. Adjusting wind sheltering coefficients and climatic data improved model performance considerably but did not provide sufficient confidence for prediction into the future. The predictive ability of this model was improved by the following modifications: 1) longer term data was used to identify when the epilimnion first becomes phosphorus limited; 2) phosphorus release trends were tracked over a long period of time; and 3) model output indicates a decline in total chlorophyll *a* in the correct time period. The model is conservative in underestimating the depth of water that will provide suitable habitat for trout through August.

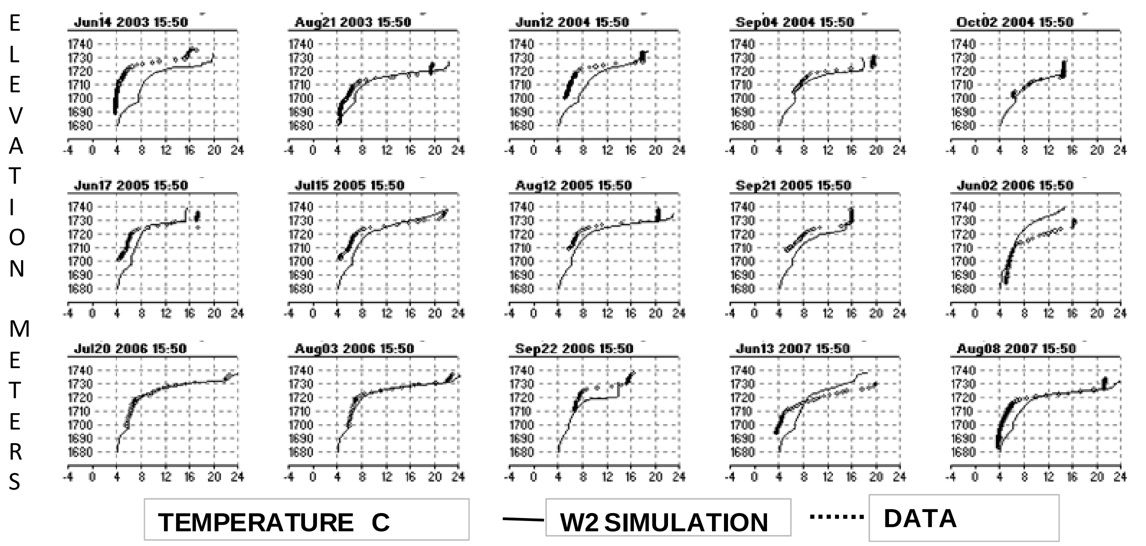


Figure 5.6. Modeled (line) and observed (dot) temperatures at the dam and mid-reservoir stations.
Graph source: JM Water Quality, LLC. 2008

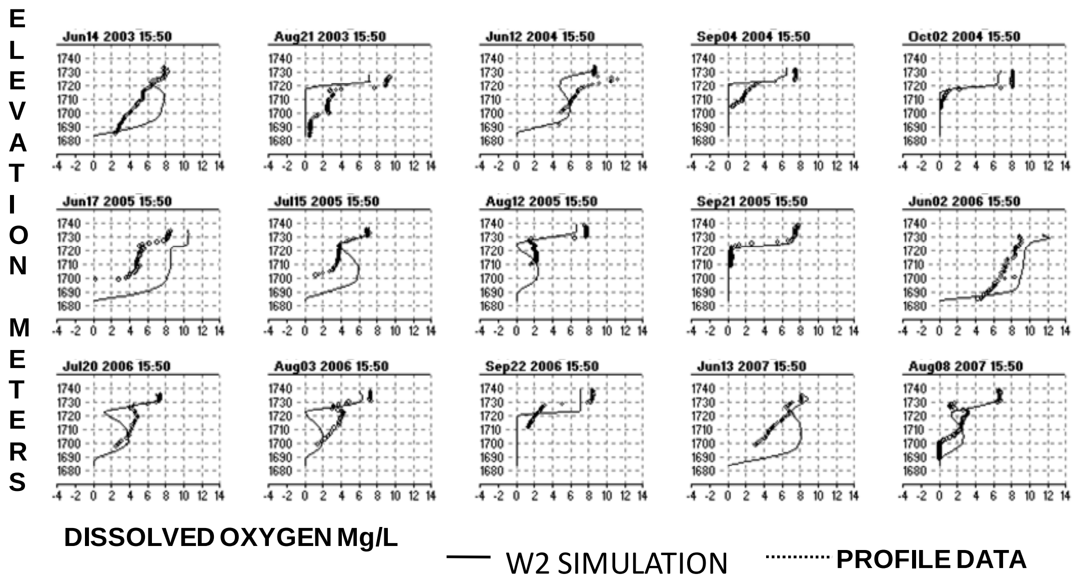


Figure 5.7. Calibration curves of modeled (line) and observed (circles) DO near the dam.
Graph source: JM Water Quality, LLC. 2008

Figures 5.6 and 5.7 show the calibration data for temperature and DO near the dam during the summer season of 2003–2008. The X axis represents DO measured in mg/L; the line represents the W2 model simulation, and the dots represent field data points. In June, the temperature profiles may be 5 to 10 days late in setting up stratification during some years. The temperature shows a sharp thermocline during August and September. The DO profiles match fairly well in July and August with the model predicting a little more metalimnetic oxygen demand than the data (Figure 5.7). This causes the model to over predict days that violate the greater than 4.0 mg/L DO with less than 20°C water. However, the model is either very close or has lower metalimnion DO in July and August. This would make the model conservatively estimate the number of days that DO would be greater than 4.0 mg/L with water that is less than 20°C. Figure 5.8 presents a calibrated modeled of DO above the dam at three different depths, representing the epilimnion, hypolimnion, and bottom before and after implementation of the 2000 TMDL.

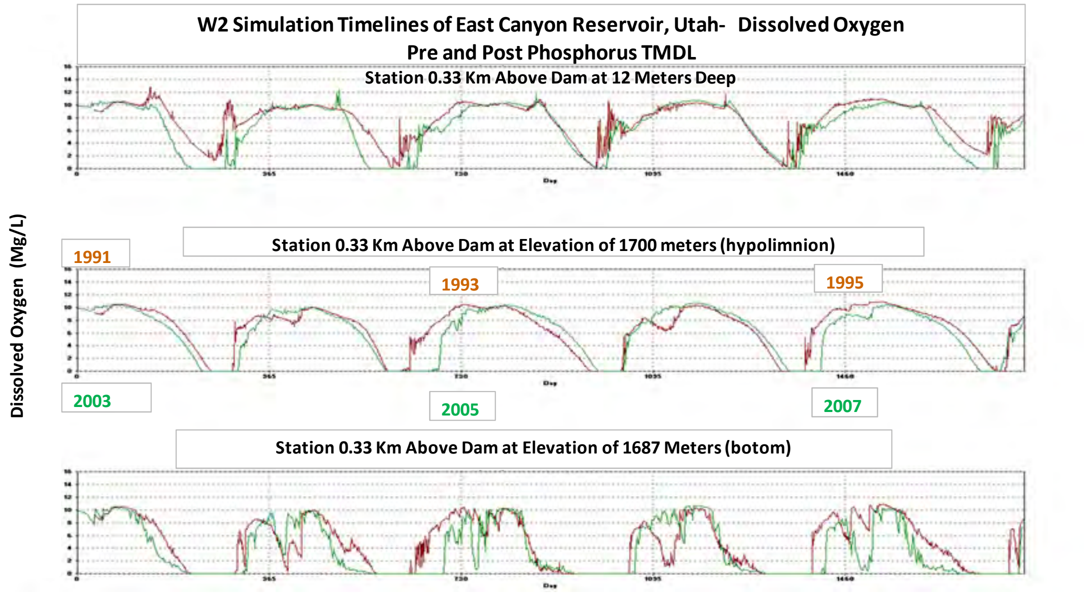


Figure 5.8. Annual cycle of DO in East Canyon Reservoir before and after implementation of the 2000 East Canyon Reservoir TMDL.

5.4.6 Algal Growth

Chlorophyll *a* data collected in East Canyon Reservoir may not be entirely representative of algal bloom intensity, because sampling days may not correspond with algal blooms. In addition, prevailing winds in East Canyon are known to blow algal blooms across the surface to the shore or the dam where they can be discharged downstream. Chlorophyll *a* concentrations can vary by two orders of magnitude across the reservoir as demonstrated by data collected by the BOR and USGS in October of 2000 (see Figure 3.16 and Section 3.5.3.2). On this particular day, algae are clearly collecting along the west side of the reservoir and near the dam. Samples collected in the East Arm and at the Mid-Reservoir Site would not be indicative of algal bloom intensity throughout the reservoir. Chlorophyll *a* data were determined not to be reliable enough to use for model calibration or assessment of bloom intensity. The W2 model was used to predict current and future chlorophyll *a* concentrations based on hydrodynamics and nutrient loading.

5.4.7 Algal Speciation

The W2 model simulates vertical migration and movement of blue-green algae, wind movement of all algal species and discharge from the reservoir. Algal speciation and succession was calibrated to data obtained from Sam Rushforth that characterize algal blooms in the spring, summer, and fall seasons. The phytoplankton count and speciation dataset was used to calibrate algal succession in the W2 model simulations. After 2004, the W2 model simulations qualitatively match an observed decrease in summer and fall blue-green algal dominance. There is also a large decrease in blue-green algal dominance from the 1990s to 2005. After 2006, blue-green algae are estimated to be less than 5% of the total annual algal biomass both in the phytoplankton count data (Rushforth and Rushforth 2000–2007 reports) and in the W2 model simulations.

5.4.8 Model Uncertainty

Uncertainty in this study involves a number of interrelated items. Scarcity of tributary input nutrient and organic matter data is a primary source of uncertainty. However, extrapolation to hydroperiods provided a good alternative to a continuous dataset. Small chlorophyll and plankton datasets, particularly in May and June during the peak spring algal bloom, is another source of uncertainty. The limited chlorophyll *a* and biomass data appears to be biased too low for use in calibrating the W2 model. The satellite image of chlorophyll in October of 2000 provided enough information to decide to not force the W2 model to calibrate to the available chlorophyll *a* data. The location of climatic data stations outside of the East Canyon Reservoir watershed reduced the ability to calibrate the W2 model to the actual date and hour samples taken at the reservoir. The Synderville Wastewater Treatment District is now sponsoring a USGS gaging station on East Canyon Creek at the reservoir with temperature measurements.

The W2 model also has inherent uncertainty due to complicated hydrodynamics. For instance, the mixture of water going into the outlet from above the top of the old concrete dam versus through the hole in that dam is probably not perfect; and certainly could vary in accuracy with change in water elevation and discharge volume as well. All of these uncertainties have been incorporated into a MOS for the TMDL.

5.5 Scenario Modeling

The East Canyon Reservoir W2 model was used to simulate water quality into the future in order to assess the impacts of phosphorus-reduction scenarios on reservoir water quality. Hydrologic and climate data from the 2003–2007 period were run two times consecutively in order to simulate a 10-year period. A simulation period of 10 years was considered sufficient to capture the expected lag time in reservoir response to phosphorus reduction. The 2003–2007 period was selected because it represents variable hydrologic conditions. The years 2003 and 2004 are considered dry (less than 50% of the 30-year mean annual flow). The years 2005 and 2007 are considered normal water years, representing 105% and 76%, respectively, of the 30-year average annual flow. The annual flow during the wettest year in the modeled period, 2006, was 136% of the 30-year annual flow. Model simulations using consecutive "average" year hydrologic and water quality inputs were found to be unrealistic and required correction of the water balance for each year. Maintaining a nearly full reservoir for multiple years without substantial drawdown resulted in the delivery of a high phosphorus load with a low dilution factor. The dry and wet cycles used in the scenario modeling provide for a more realistic sequence of flushing and phosphorus accumulation.

There are several limitations to using the East Canyon Reservoir W2 model to simulate phosphorus-reduction scenarios into the future. First, because the model runs on a daily time step, time lags beyond the modeled 10-year period cannot be evaluated. As a result, a new steady-state for the reservoir cannot be determined. Reservoir response to phosphorus reduction is likely to extend beyond 10 years. However, a 10-year period is an appropriate time frame for a TMDL document, which is revisited periodically on a rotating schedule. Lag times can be reassessed when this document is revisited in the future. Due to the embedded model equations and lack of organic carbon data as an input to the model, the relative role of organic matter on hypolimnetic oxygen depletion rates cannot be assessed. Finally, internal phosphorus is set at a constant rate in the model and does not respond to changes in particulate phosphorus loads from tributaries. The model is driven by dissolved phosphorus only.

5.5.1 Future Nutrient Reduction Scenarios

Descriptions of potential future scenarios analyzed with CE-QUAL-W2 are given in Table 5.2. The baseline scenario represents current loading to the reservoir simulated for a 10-year time period as discussed above. Scenarios 1a and 1b utilized the current daily load files as inputs to the W2 model but with a cap on concentration of 0.046 mg/L and 0.025 mg/L, respectively. Scenario 1b serves to set a lower bound on attainable water quality in East Canyon Reservoir over the next 10 years. Scenarios 1c and 1d set a static concentration in the tributary flow to East Canyon Reservoir of 0.05 mg/L and 0.1 mg/L, respectively. The latter serves to set an upper bound on future loads to East Canyon Reservoir. Scenario 2a simulates the impact of the ECWRF using its currently allocated load. Currently, the ECWRF discharges less than the allocated load in the East Canyon Reservoir TMDL by a large margin. Scenario 2b simulates increases from the ECWRF to East Canyon Reservoir that represent expected growth of the treatment plant (7.2 million gallons per day [MGD]). This scenario assumes no change in nonpoint source loads and therefore was intended to provide a good assessment of the impact of the ECWRF alone on changing water quality in East Canyon Reservoir. Scenarios 3a through 3d represent a variety of combinations of increases to the ECWRF, in order to account for expected future growth, as well as necessary reductions in nonpoint source loads to attain water quality endpoints identified for the reservoir.

The nutrient-reduction scenarios were all compared to the baseline simulation to evaluate the impact of phosphorus reductions on the following in-reservoir water quality parameters: turbidity, algal growth intensity, algal bloom frequency, algal speciation, hypolimnetic oxygen depletion, and epilimnetic total phosphorus concentrations. Through analysis of scenario model output, it was determined that Scenario 3d represented a threshold in terms of improvement in water quality. Compared to the baseline, this scenario results in improved water quality and an attainment of water quality standards. Additional reductions (i.e., Scenario 3c) did not result in substantial, additional water quality improvements. Therefore, Scenario 3d was selected as the recommended load scenario for the TMDL (see Chapter 7 for a more extensive discussion). Model results could not be summarized for all of the modeled scenarios (personal communication between Jerry Miller, JM Water Quality LLC, and Erica Gaddis, SWCA, on June 18, 2008). Therefore, the presentation of results in the subsequent sections reflects the baseline model results and results from Scenario 3d.

Table 5.2. Future Nutrient Reduction Scenarios for East Canyon Reservoir

Scenario	Watershed Load (Kg/year)	Total Reservoir Load	Change from mBaseline Load	% <Baseline Reservoir Load	Scenario Description
Baseline	2,555	3,350	0	0%	Estimated 2003–2007 phosphorus loading; W2 calibration/verification.
Scenario 1a	1,990	2,785	-565	-17%	Cap inputs at 0.046 mg/L TP based on East Canyon Creek recommendation.
Scenario 1b	1,116	1,911	-1,439	-43%	Cap inputs at 0.025 mg/L.
Scenario 1c	2,232	3,027	-323	-10%	Daily concentration = 0.05.
Scenario 1d	4,464	5,259	1,909	57%	Daily concentration = 0.10.
Scenario 2a	2,801	3,596	246	7%	ECWRF uses its existing allocation of load.
Scenario 2b	3,206	4,001	651	19%	ECWRF goes to 7.2 MGD at 0.10 mg/L TP and 0.03 mg/L orthoP.
Scenario 3a	2,038	2,833	-517	-15%	ECWRF goes to 7.2 MGD 0.10 mg/L TP; 0.03 mg/L dissolved P; nonpoint sources reduce by 50%.
Scenario 3b	1,579	2,374	-976	-29%	ECWRF goes to 7.2 MGD at 0.10 mg/L TP and 0.03 mg/L orthoP; 75% nps reduction of TP during spring runoff and rain on snow; 60% nps reduction during baseflow and storms.
Scenario 3c	1,506	2,301	-1,049	-31%	ECWRF goes to 7.2 MGD at 0.10 mg/L TP and 0.03 mg/L orthoP; 75% nps reduction of TP.
Scenario 3d	1,824	2,619	-731	-22%	ECWRF goes to 8 MGD at 0.10 mg/L TP and 0.03 mg/L orthoP; 65% nps reduction of both TP and DP.

Note: Scenarios are run as net load reductions from the watershed load only because manipulation of the internal load was not possible with the W2 model. However, in the load allocation the recommended reductions identified in Scenario 3d are split between internal load and nonpoint sources in the TMDL analysis (see Section 7.4). Furthermore, Scenario 3d was selected as the appropriate total reservoir reduction but some load allocation was shifted from the ECWRF point source to nonpoint sources in the final load allocation Table 7.4.

5.5.2 NUTRIENTS

The modeled nutrient reduction scenarios (Table 5.3) are described in terms of their difference from 2003–2007 baseline calibration simulation estimates of actual loadings in CE-QUAL-W2. Predicted mean total and dissolved phosphorus concentrations under the baseline condition are 0.045 mg/L and 0.033 mg/L, respectively, in the epilimnion across East Canyon Reservoir. Phosphorus concentrations are estimated to be reduced by 31% to 0.031 mg/L TP and 0.021 mg/L DP under Scenario 3d. Additional reductions achieved through Scenario 3b are minimal.

Table 5.3. Predicted Average Phosphorus Concentrations in East Canyon Reservoir Epilimnion

	Dam Site		Mid Reservoir		Upper Reservoir		Average	
	TP	DP	TP	DP	TP	DP	TP	DP
Baseline	0.044	0.032	0.044	0.032	0.046	0.034	0.045	0.033
Scenario 3a	0.034	0.024	0.034	0.023	0.035	0.025	0.034	0.024
Scenario 3b	0.029	0.019	0.029	0.019	0.030	0.020	0.029	0.019
Scenario 3d	0.031	0.021	0.031	0.021	0.032	0.022	0.031	0.021

Note: Averages represent the last 3 years of the 10-year model simulation.

Total and dissolved phosphorus are also predicted to be substantially lower in Scenario 3d when compared to the baseline (Figure 5.9). Total phosphorus release from East Canyon Dam is displayed in Figure 5.8 over a 10-year simulation. The baseline concentrations (brown line) are substantially higher than the predicted concentrations during Scenario 3d (green line).

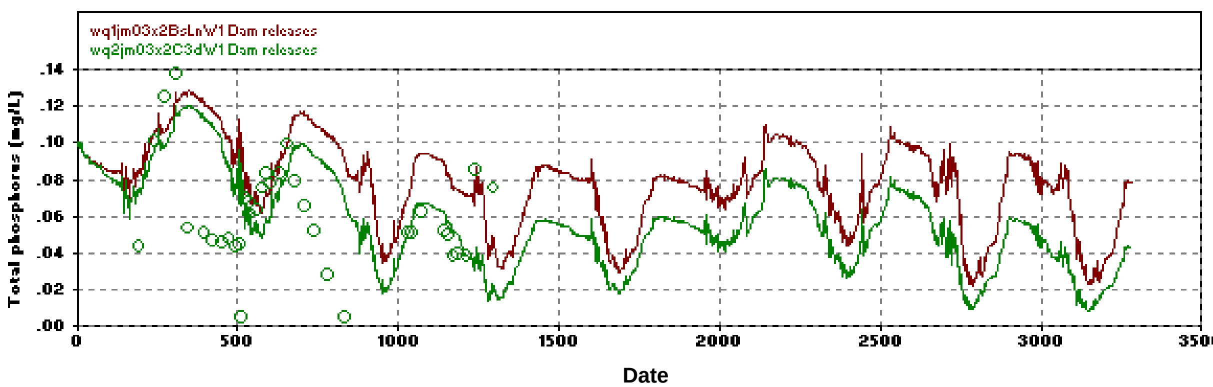


Figure 5.9. Total phosphorus discharge from the dam under baseline (brown line) and reduction scenario (3d) conditions.

Graph source: JM Water Quality, LLC. 2008

The discharge from the dam is composed of approximately 75% water from near the surface and 25% water coming from the hole in the old concrete dam. Figure 5.10 illustrates the phosphorus concentration from these depths plus the retention cycle and buildup of phosphorus in the very bottom of the stagnant hypolimnetic zone upstream from the old dams. The top two lines represent phosphorus concentrations at the sediment-water interface just upstream from the old earthen dam under baseline (brown line) and

Scenario 3d conditions (green line). The middle two lines represent phosphorus concentrations in the hypolimnion near the hole under baseline (black line) and Scenario 3d conditions (dark blue line). In order to leave the reservoir, phosphorus must go through this hole in the concrete dam; therefore, during stratified periods, high-phosphorus water can only be discharged from the dam when phosphorus is high at this level. Otherwise the deep hypolimnion stagnant zone retains and builds up phosphorus.

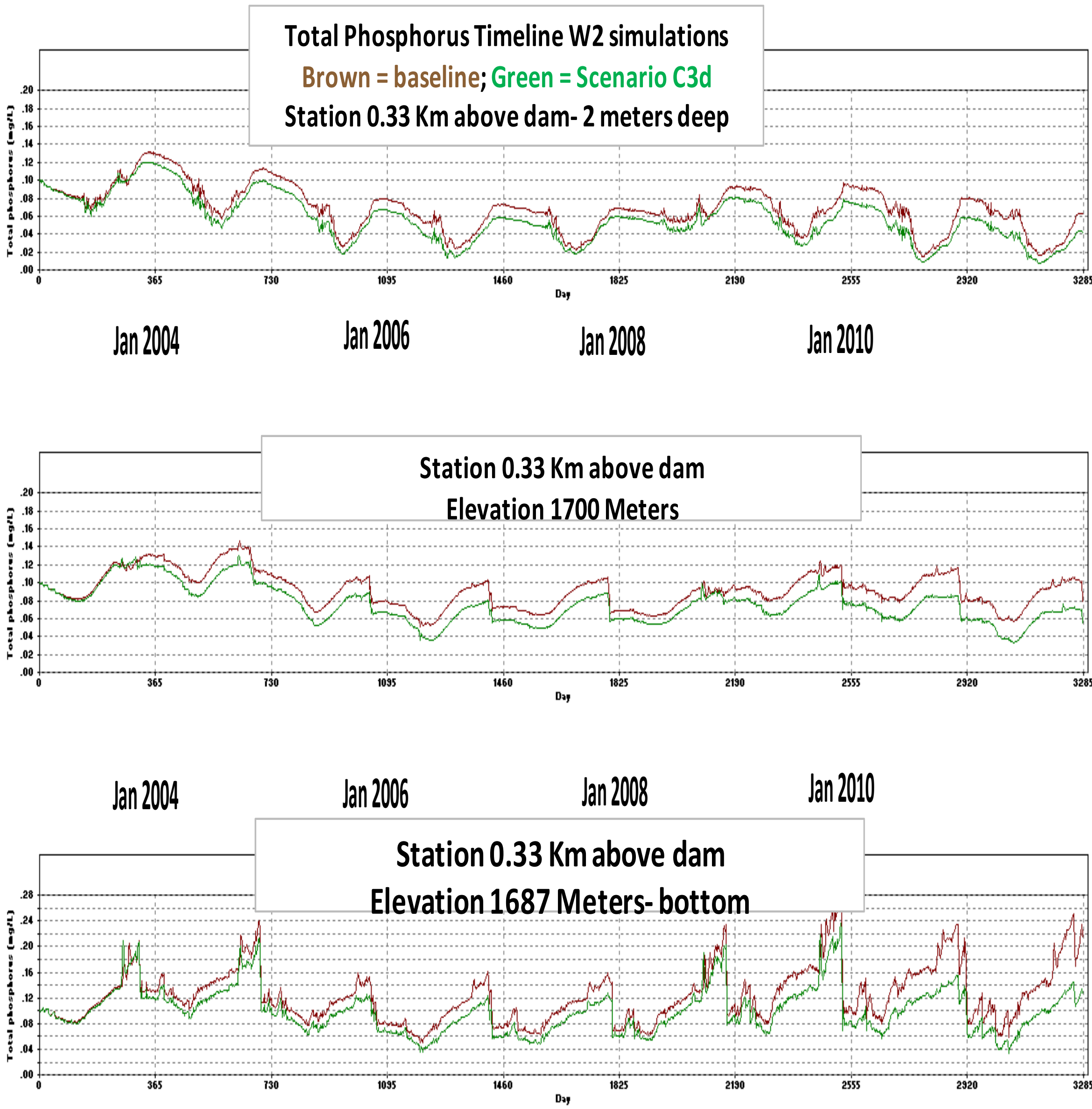


Figure 5.10. Display of total phosphorus in the water column, including the sediment-water interface, upper level of the hypolimnion, and epilimnion in East Canyon Reservoir under baseline and Scenario 3d conditions.

The graph represents model results for a 10-year simulation period driven by hydrologic and climatic data from 2003 to 2007. Graph source: JM Water Quality, LLC. 2008

5.5.3 CHLOROPHYLL *a*

The East Canyon Reservoir W2 model predicts the frequency and intensity of algal blooms in the reservoir under different nutrient-loading scenarios. Table 5.4 summarizes the difference in mean and maximum chlorophyll *a* concentrations for baseline conditions and for Scenarios 3a, 3b, and 3d. The averages and maximums represent the last 3 years of model output in a 10-year simulation. Predicted mean chlorophyll *a* under the baseline model is 8.5 µg/l. This is less than the current mean chlorophyll *a* concentration because it reflects expected improvement in the reservoir under current phosphorus loads (baseline). The reservoir is still in a period of readjustment to the reductions that have been realized since the 1990s. However, the baseline scenario also indicates that at peak algal blooms, chlorophyll *a* concentrations would continue to reach a concentration of 82 µg/l at the Upper Reservoir Site. Under Scenario 3d, mean chlorophyll *a* concentrations are predicted to be 32% lower than the baseline at 5.8 µg/l. Likewise, during peak algal blooms, chlorophyll *a* is only expected to reach a concentration of 47 µg/l, a reduction of 42% from the baseline.

Table 5.4. Predicted Average and Maximum Summer Chlorophyll *a* Concentrations (µg/l) in the Epilimnion in East Canyon Reservoir

	Dam Site		Mid Reservoir		Upper Reservoir		Average	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Baseline	7.5	42.4	8.4	41.2	9.5	82.1	8.5	82.1
Scenario 3a	5.6	39.7	6.4	36.8	6.6	54.2	6.2	54.2
Scenario 3b	5.3	36.2	6.1	33.4	6.1	48.8	5.9	48.8
Scenario 3d	5.3	34.9	6.0	32.7	6.0	47.1	5.8	47.1

Note: Averages represent the last 3 years of the 10-year model simulation.

A summary of percent exceedance of a nuisance algal threshold of 30 µg/l is another informative output of the East Canyon Reservoir W2 model (Table 5.5). Nuisance algal thresholds are discussed in more detail in Chapter 7. The table summarizes percent exceedance during the 3-year period at the end of the 10-year model simulation. Under baseline conditions, the 30 µg/l concentration would be exceeded 13% of the time.

Table 5.5. Summary of Model Results Related to Percent Exceedance of a Chlorophyll *a* Value of 30 µg/l in East Canyon Reservoir

	Maximum	Minimum	Average
Baseline	13%	3%	7%
Scenario 3a	9%	2%	5%
Scenario 3b	2%	0%	1%
Scenario 3d	3%	0%	1%

Note: The results represent the last 3 years of model output in a 10-year simulation.

Under all scenarios, the spring algal blooms are still expected to be partially light-limited in late May and early June until phosphorus becomes limiting following thermal stratification. Certain hydrologic cycles and/or storm and runoff conditions could cause exceptions to the predicted chlorophyll *a* values. The model simulates normal conditions defined by variable hydrologic conditions across consecutive years with annual flow within 50% of the 30-year average. Alternative hydrologic cycles will have a different build up and flushing of phosphorus from the stagnant zone of the hypolimnion, which will result in different concentrations of phosphorus during both spring and fall turnover. However, the model simulations conducted for this TMDL are believed to account for the more typical and normal hydrologic and climatic patterns in the watershed.

The East Canyon Reservoir W2 model also predicted algal growth to become more frequently limited by phosphorus under Scenario 3d when compared to the baseline. Figure 5.11 and 5.12 show the correlation between total phosphorus in the epilimnion and chlorophyll *a* values. The correlation has a higher R^2 value (and therefore a tighter relationship between phosphorus and chlorophyll *a*) for Scenario 3d compared to the baseline. Under the baseline condition, algal blooms in the spring and late fall are often light-limited or co-limited with nitrogen.

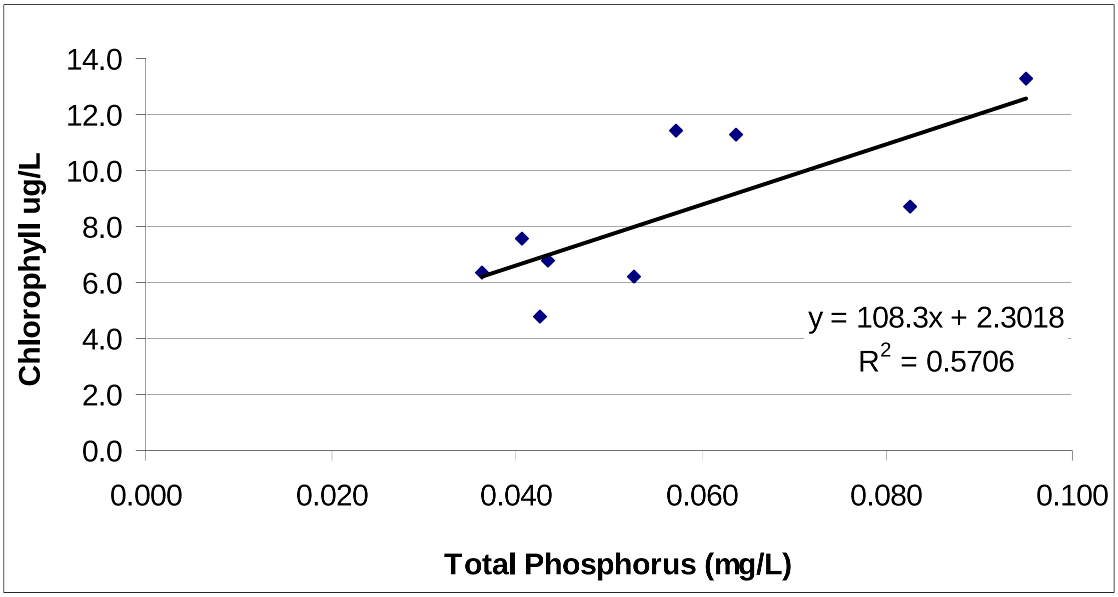


Figure 5.11. Relationship between mean annual summer chlorophyll concentrations and mean summer epilimnion total phosphorus concentration for the baseline East Canyon Reservoir W2 simulation.

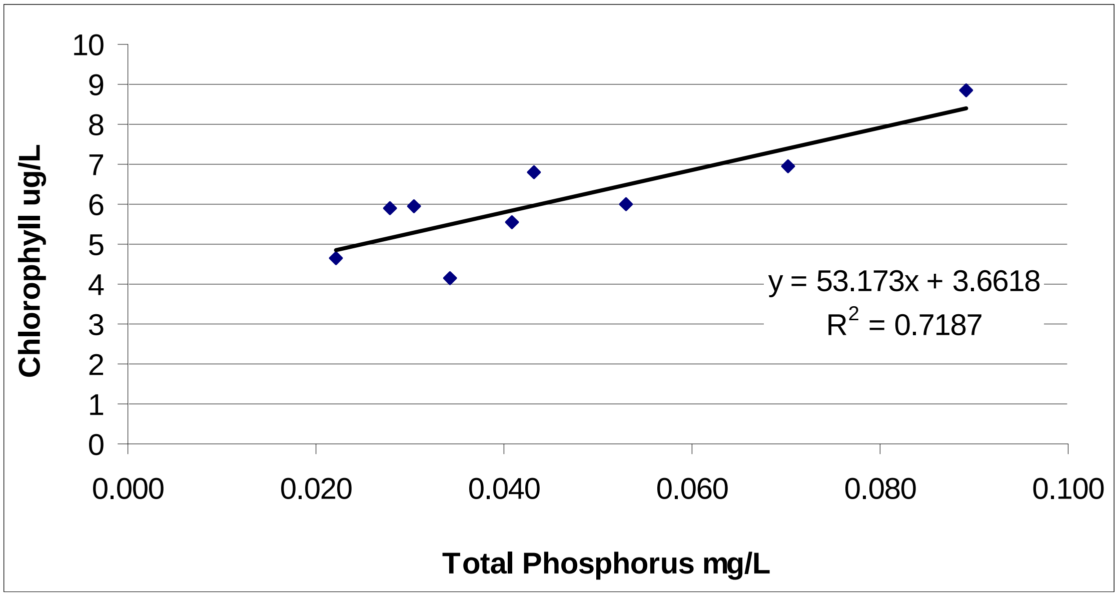


Figure 5.12. Relationship between mean annual summer chlorophyll concentrations and mean summer epilimnion total phosphorus concentration for the Scenario 3d East Canyon Reservoir W2 simulation.

5.5.4 Blue-green Algae

In addition to algal bloom frequency and intensity, the composition of algal blooms is also an important water quality characteristic of concern at East Canyon Reservoir. Blue-green algal blooms have the potential to become toxic to recreationists, fish, and wildlife. The East Canyon Reservoir W2 model predicts algal composition. The epilimnion of East Canyon Reservoir has been phosphorus-limited since about mid July of 2005, and summer cyanophyta have declined significantly in both the data and in the W2 simulations as a result. All of the future reduction scenarios show very similar patterns of algal speciation (Figure 5.13.).

Under all scenarios, *Microcystis* sp. and *Anabaena flos-aquae* occasionally occur during the fall turnover events; however, *Aphanizomenon* sp. is no longer predicted to be a significant component of the late fall biomass (Figure 5.13). Recent data and future-model simulations predict reductions in blue-green as well as total algal production especially during summer months. All of the W2 simulations assume no change in nitrogen loads to the reservoir. If nitrogen loads are reduced significantly and the reservoir returns to a nitrogen-limited system, dominance of algal blooms by blue-green species could recur.

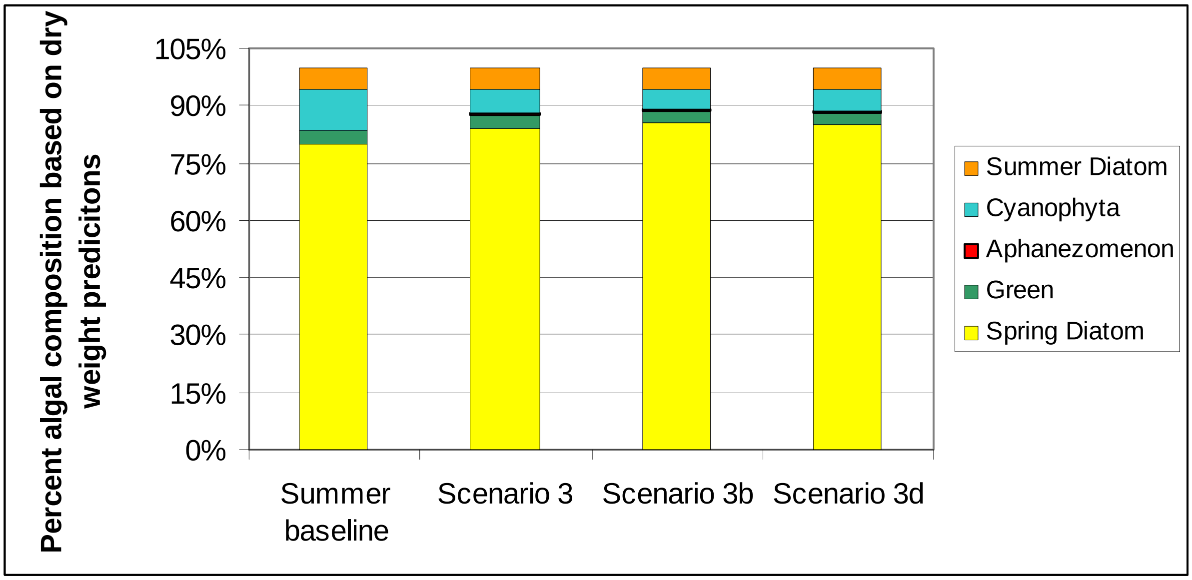


Figure 5.13. Predicted summer algal speciation in East Canyon Reservoir under baseline and future nutrient reduction scenarios.

5.5.5 TURBIDITY

The major influences on turbidity in East Canyon Reservoir are the spring diatom blooms and, in the past, the summer and fall algal blooms. Due to the long retention time in East Canyon Reservoir, inflow from East Canyon Creek has little influence on water turbidity in the majority of the reservoir. The water in East Canyon Reservoir can be very clear with visibility greater than 3 meters. CE-QUAL-W2 does not predict measures of turbidity directly; however, conversion between chlorophyll a and turbidity can be made using the relationship displayed in Figure 5.14. The relationship comes from Chapra (1997) but was modified to account for increased turbidity due to shoreline wave action erosion in the steep-sided narrow reservoir. Shoreline wave action appears to produce more reservoir-wide turbidity than do inflows. Maximum early spring Secchi disk depths rarely exceed 4–6 m. Once the spring diatom blooms begin, Secchi depths are rarely more than 1 m.

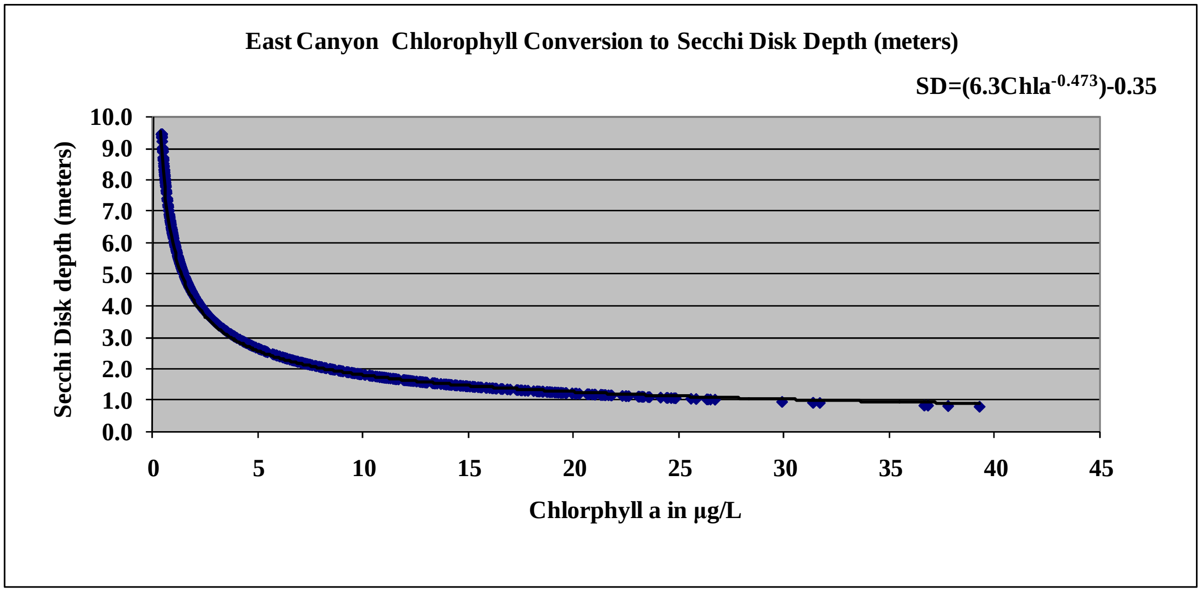


Figure 5.14. Relationship between Secchi disk depth and chlorophyll *a* in East Canyon Reservoir.

5.5.6 Oxygen Depletion

Oxygen depletion and oxygen profiles in East Canyon Reservoir were simulated throughout the reservoir and throughout the year using the W2 model. East Canyon Reservoir's water-sediment interface is maintained at less than 9°C for more than 9–10 months each year. Therefore, bacteriological decay is temperature-limited most of the time. Different types of organic matter decay at different rates in reservoir sediments. Larger terrestrial organic matter that is buried in the sediment may take decades to decay whereas organic matter that originated from phytoplankton decays much faster. However, even organic matter derived from phytoplankton does not completely decay over a 1-year cycle in East Canyon Reservoir, leaving a build-up of residual organic matter in reservoir sediments. Some of this organic matter may flush from the reservoir during wet years. Improvements in DO for Scenario 3d begin to show up near the end of the model simulations, which lends further support to the extensive lag-time (>10 years) expected for the reservoir to respond to reduced phosphorus loading.

A comparison between DO profiles in mid August at the end of the 10-year model simulation indicates improvement in DO conditions in the hypolimnion at the Mid-reservoir Site (Figure 5.15). However, low DO is still expected in the metalimnion layer, a fairly common phenomenon in deep intermountain reservoirs. Although the mechanism for minimum metalimnetic DO rates is still being researched, one plausible explanation is that algae from the epilimnion migrate into the metalimnion, which is still in the photic zone in East Canyon, and cause DO depletion during nocturnal respiration (Jerry Miller, JM Water Quality LLC personal communication with Erica Gaddis, SWCA on June 23, 2008).

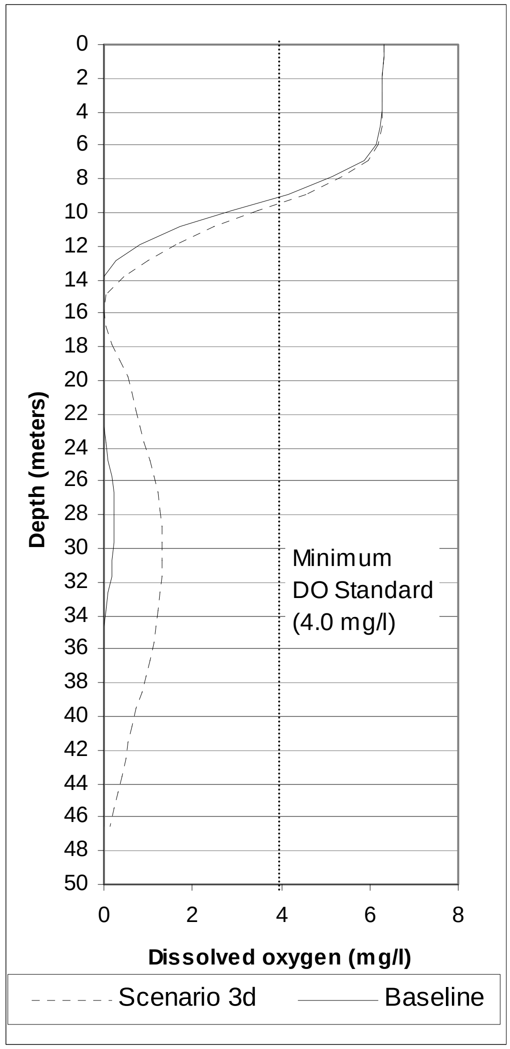


Figure 5.15. Predicted DO profile at the Mid-reservoir Site in mid August at the end of the model simulation period.

A comparison of DO profiles from the 1990s with projected DO profiles in the future indicates that the oxygen depletion rate does not change significantly over time nor does it change with reduced nutrient loads to the reservoir. Analysis of W2 model results also indicates that hydrodynamics play an important role in oxygen depletion, especially in terms of occurrences of summer stratification and reservoir stagnation during the spring and summer. The build-up and slow release of phosphorus and organic matter in reservoir sediments contributes to a long lag-time for the reservoir to fully respond to nutrient load reductions.

The baseline W2 simulation indicates that DO profiles in the reservoir are still improving as a result of phosphorus reductions achieved in recent years. Scenario 3d shows additional improvements as a result of reduced algal blooms (Table 5.6). It is expected that if the model were run for a longer period of time, DO profiles would continue to improve into the future.

However, there is significant uncertainty in this analysis as it pertains to fish habitat and survival. It should be noted that low DO levels and high temperatures are not the only stressors to fish health. Likewise, reduction of phosphorus alone may not achieve desired DO profiles without changes in reservoir management and reductions to summer epilimnetic temperatures driven by flow and creek temperature.

Table 5.6. Number of Days During Stratified Period in which DO is Not Maintained above 4 Mg/L in a 2-m Zone where Temperature is also Less than 20^{o}C

	Year 6	Year 7	Year 8	Year 9
Baseline	44	62	12	0
Scenario 3a	26	42	0*	0
Scenario 3b	26	42	0*	0
Scenario 3c	22	40	0*	0
Scenario 3d	24	40	0*	0

* Predicted days were found not to be significantly greater than 0.

6. PHOSPHORUS SOURCE IDENTIFICATION AND LOAD ANALYSIS

This section discusses pollutant sources that contribute to the impairment of East Canyon Reservoir. The DO impairment in East Canyon Creek is caused by poor physical stream conditions that promote high densities of rooted aquatic plants (macrophytes). The lack of shade provided by large, mature woody riparian vegetation along the majority of the stream channel allows excessive light and heat inputs to support these dense plant beds, especially in low gradient, depositional areas such as at the Blackhawk and Bear Hollow monitoring sites.

East Canyon Reservoir has historically been co-limited by nitrogen and phosphorus; recent reductions in phosphorus have pushed the system to stronger phosphorus limitation. This section focuses exclusively on phosphorus because control of blue-green algae, required to support the Reservoir's beneficial uses, can only be achieved through phosphorus control.

6.1 MAJOR SOURCES OF NUTRIENT LOADING TO EAST CANYON RESERVOIR

The East Canyon Reservoir Watershed encompasses 92,498 acres in Summit and Morgan counties. Over 96% of the watershed area is privately owned. Forested and meadow lands are the largest land cover type in the watershed with over 65,668 acres (71%).

East Canyon Reservoir is fed by East Canyon Creek and its contributing 145 square mile watershed. With an average volume of over 41,000 acre-feet per year flowing into the reservoir and the average active storage volume of the reservoir at 48,100 acre-feet, a significant proportion of nutrients present in the reservoir at a given time are derived from current upstream land uses and human activities. Anoxic conditions during the summer at the sediment-water interface result in the release of iron-bound phosphorus from reservoir sediments that becomes available to algae during the fall turnover period. The area directly draining into the reservoir (as opposed to inflow from East Canyon Creek) includes an area of 20,163 acres, or 22% of the watershed. Identified sources of phosphorus to East Canyon Reservoir are as follows:

- ECWRF discharge
- Forest land management, including ski area management
- Pasturing of livestock
- Runoff from agricultural lands
- Stormwater runoff, including urban/suburban areas, golf courses, and active construction sites
- Onsite wastewater treatment systems (septic systems)
- Stream erosion and reservoir shoreline erosion
- Atmospheric sources, e.g. dust
- Natural background sources including phosphatic shales lithology and wildlife
- Reservoir bottom sediments

6.1.1 POINT SOURCES

The only permitted point source discharge located in the East Canyon Reservoir watershed is the ECWRF operated by the Snyderville Basin Water Reclamation District (SBWRD). The ECWRF is located near East Canyon Creek just upstream of Jeremy Ranch. The treatment plant discharges its treated effluent to East Canyon Creek and operates under Utah Pollution Discharge Elimination System (UPDES) permit #UT0020001. The population of the watershed increases in the winter due to crowds attracted to several ski resorts in the area. Several annual and one-time special events lead to additional, temporary increases in the normal, yearly winter resort population. These include ski competitions and the Sundance Film

Festival. The permit for the ECWRF reflects this seasonality. A total phosphorus concentration not to exceed 0.1 mg/L applies to the months of July, August, and September. This concentration is effective until April 29, 2010. In addition, the permit requires limits to the annual total phosphorus load from the system to 1,462 lbs/year. These effluent limitations were originally developed to protect East Canyon Creek by imposing a phosphorous limitation during the summer growing season. However, the resulting permit also provides the system with flexibility, if necessary, to discharge more during peak ski season and during special events and less during non-tourist times of the year.

Upgrades to the ECWRF in September 2002 involved adding a chemical phosphorus reduction process to the plant that became fully effective in July 2003. The process mixes secondary effluent with alum (aluminum sulfate) and a polymer in solids-contact clarifiers, and then filters the liquid through a constant-backwash sand filter. Effluent from the treatment system meets tertiary treatment standards, the highest effluent quality attainable with currently available technology. For water years 2003 through 2007 the average total phosphorus concentration from ECWRF was 0.12 mg/L and 0.024 mg/L for orthophosphate. Phosphorus concentrations range from nondetectable (< 0.02 mg/L) to 2.8 mg/L (5/23/2003). The median total phosphorus concentration of ECWRF effluent is 0.06 mg/L. The treatment plant consistently meets its summer effluent permit standard of 0.1 mg/L. A summary of total phosphorus concentrations in ECWRF effluent is shown in Figure 6.1.

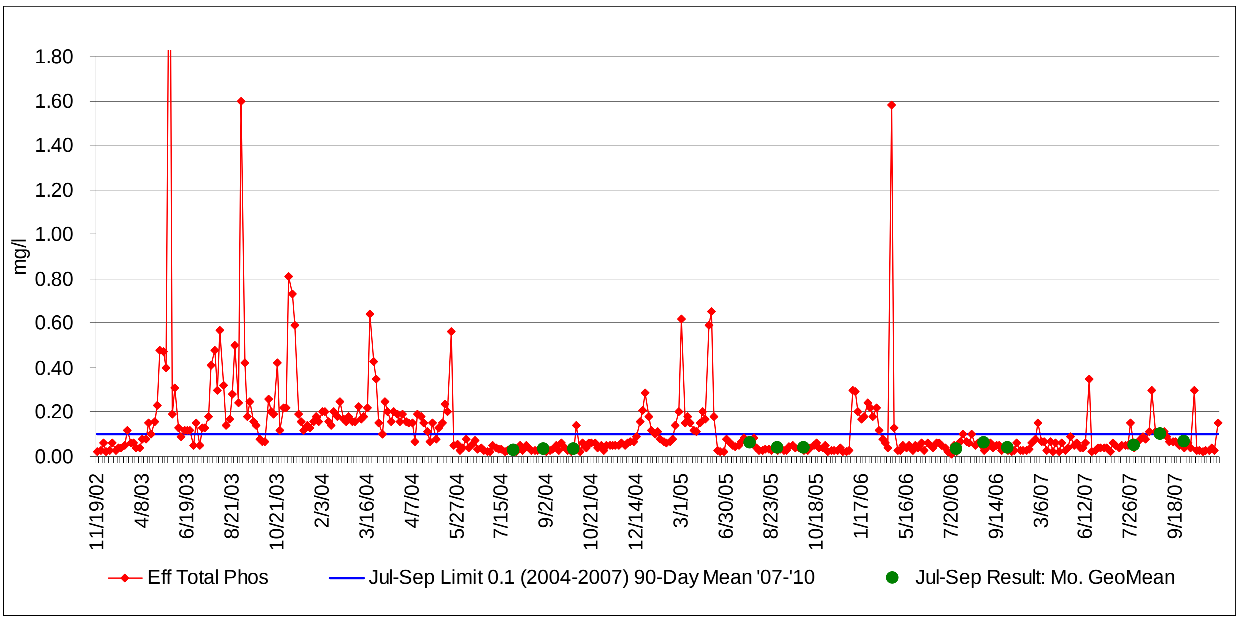


Figure 6.1 Total phosphorus concentrations in ECWRF effluent during water years 2002–2007.

Discharge volume from ECWRF has ranged from a minimum of 1.33 MGD to 6.06 MGD during the peak tourist ski season. Average effluent volume has been 2.61 MGD during water years 2003–2007. ECWRF effluent is sampled and analyzed on a weekly basis. Average monthly effluent concentrations and discharge were used to build a daily load estimate for the ECWRF. Daily loads were summarized by water year and averaged to estimate an annual average total phosphorus load to East Canyon Creek from ECWRF.

6.1.2 NONPOINT SOURCES

A number of nonpoint pollutant sources in the watershed contribute to the impairment of East Canyon Reservoir. For the purposes of this characterization, nonpoint sources in the watershed were grouped into five major categories: urban/suburban development, agriculture, recreation, natural background and finally, other nonpoint sources. The corresponding land-use categories reported by BIO-WEST (2008) are given for each land use in the sections that follow. All of these sources contribute to the impairment in the watershed. Land uses, including agricultural production and urban development, have increased the amount of sediment and nutrient loading into surface waters. Specific sources include excessive fertilizer applications on turf and agricultural lands, construction sites that don't implement Storm Water Pollution Prevention Plans (SWPPPs), and streambank erosion. Natural events can also produce high sediment and nutrient loads to the reservoir such as large floods.

6.1.2.1 Urban/Suburban Nonpoint Sources

The East Canyon Reservoir watershed had an estimated population of 68,173 in 2005. Summit County has had an explosive population increase of nearly 92% since the 1990 census. This population growth is more than double the average growth rate for the State of Utah during the same period. Almost 70% of the population growth has occurred in unincorporated areas of Summit County. Based on past trends, population growth in the watershed, specifically in Summit County, is likely to continue. A small proportion of the lower watershed occurs in Morgan County, and contains a population of 8,525 or 12.5% of the watershed's total population. The 29% population growth rate in Morgan County is more in line with the Utah average.

The upper East Canyon watershed contains urban areas, suburban neighborhoods, and small ranchettes. Sediment and nutrient loads from rural subdivisions originate from roadway and impervious surface runoff, over-watering of landscaped areas and pet wastes. In the Snyderville Basin, developable lands in the basin are restricted to 1 unit per 20-acre parcels. The unincorporated areas of Snyderville Basin in Summit County are under the jurisdiction of the Snyderville Basin General Plan (Snyderville Basin Planning Commission 2002). Specific sources significant to the attainment of water quality goals for the East Canyon Reservoir watershed are discussed in the following sections.

6.1.2.1.1 Municipal Stormwater Runoff

Stormwater discharges from urban areas consist of concentrated flows which accumulate from streets, parking areas, rooftops, and other impervious surfaces. Constituents transported during storm events can include oil and grease from vehicles, sediment, nutrients, and organic matter such as litter, yard clippings and pet wastes. Discharges from Municipal separate Storm Sewer Systems (MS4s) are permitted under the Utah General Stormwater Permit for Small Dischargers issued on December 9, 2002. Under the General Permit, a municipality is authorized to discharge stormwater to waters of the State as long as the discharge does not impair the receiving waterbody.

Summit County has developed an ordinance (Summit County Ordinance No. 519) to protect water resources from illicit discharges within the county boundaries. Park City has the largest amount of high density development in the watershed, with a total average density of 781.4 residents per square mile. Park City Municipal Corporation (PCMC) has actively engaged in stormwater pollution prevention activities including the education and enforcement of the construction, golf, and ski industries and the implementation and management of BMPs for the protection of surface water resources. According to Park City's General Plan (Park City 2000), existing natural hydrologic features such as wetlands, depressions, and drainages will be managed to protect the hydrologic conditions in the watershed.

PCMC has exceeded their environmental goals for multiple years and continues to expand their efforts to control nonpoint source nutrients and sediment (PCMC 2007). Their projects include requiring all service stations to have an oil/water separator for their stormwater runoff, installing 100 "No Dumping Drains to Watershed" signs on drains throughout the county, adding silt traps to stormwater accumulation structures, and the development and maintenance of sediment detention basins. They have placed signs throughout the watershed detailing proper management of dog waste and stormwater and publish an Environmental Information Handbook, a Residential Stormwater Brochure, and information on invasive weed species and Xeriscape gardening.

6.1.2.1.2 Onsite Wastewater Treatment Systems (Septic Systems)

Most of the urban and residential development in the watershed is located in the Park City, Kimball Junction and Jeremy Ranch areas where there is sewer system access. Septic tanks in the watershed are allowed in areas where central sewer systems are not feasible or present. The majority of these systems are found in the Silver Creek subbasin, which flows south into East Canyon Creek. Onsite septic systems have the potential to contribute nutrient loads to surface waters via leachfield contamination of groundwater that recharges streams, or directly when leachfields fail. Septic system leachfields can protect ground and surface waters from nutrient and bacterial contamination if they are constructed and maintained properly.

6.1.2.1.3 Active Construction

PCMC conducts BMP and environmental ordinance training sessions and workshops for local contractors and enforces these regulations during construction. PCMC requires that all construction activities must adhere to environmental ordinances and mitigation requirements. A signed agreement to comply with environmental ordinances is required for all projects that need a building permit. A "Stop Work" order is issued if stormwater BMPs are not implemented. A contractor must resolve the issue in a timely manner or the building permit is revoked (PCMC 2007).

6.1.2.2 Agricultural Nonpoint Sources

Approximately 2,200 acres of agricultural lands are present in the watershed. Primary sources of pollutants associated with agriculture consist of sediment and nutrient loads from irrigation, cropping, and pasturing. The following influences the generation and transport of pollutants from agricultural nonpoint sources:

- The ecological health of riparian areas
- Overland flow from runoff and snowmelt
- Irrigation practices
- Pasture and rangeland management
- Fertilizer application
- Consumptive water use

6.1.2.2.1 Animal Feeding Operations

Feedlots and corrals, hereinafter referred to as Animal Feeding Operations (AFOs), pose risks to water quality from manure and other animal wastes that can contribute nutrients and sediments directly to nearby surface waters such as streams and canals. At present, there are several AFOs located in the watershed, most of which are associated with horse properties.

Sediment and nutrient loads from AFOs can be controlled through the implementation of BMPs and Comprehensive Nutrient Management Plans that address animal waste and grazing management.

6.1.2.2.2 Irrigation Return Flow

Irrigation water applied to pasture and hay lands in excess of the soil infiltration rate will wash soil and nutrients off the field and ultimately into a receiving water. Irrigation return flows are usually enriched with organic matter, sediment, and nutrients.

Over-irrigation of pasture and hayland will also raise the water table and lead to changes in the mobility of phosphorus in soils. Phosphorus has been observed to move more easily through soils that are consistently waterlogged because the majority of the iron present in these soils is reduced and sorption potential is decreased (Sharpley et al. 1995). Waterlogged soils are also prone to the loss and transport of fine, lightweight soil particles such as silt and clay to receiving waters. These fine particles represent the primary phosphorus sorption sites in the soil. These particles carry a significant amount of phosphorus with them when they are removed and leave the remaining soil deficient in phosphorus holding capacity (Hedley et al. 1995).

6.1.2.2.3 Pasture Land

Livestock, including horses, sheep, cattle and other grazing animals are located on ranch lands and pastures in the watershed. The majority of grazing animals are found along and adjacent to streams, resulting in a greater potential for direct transport of manure into surface waters. The phosphorus contained in manure is in a highly soluble, readily bioavailable form. A small portion of the available phosphorus in plant material is used by grazing animals for growth and maintenance, whereas 60% to 95% of phosphorus intake is excreted into the environment as manure (Magdoff et al. 1997). Because of the high solubility of phosphorus in manure, loading and transport from a field with livestock manure on it can exceed loads from a non-manured field by as much as 67 times (Omernik et al. 1981, Sharpley et al. 1992, Hedley et al. 1995).

Reduced cover from overgrazing of grasses and other forage species results in increased sediment transport to streams and channels. Similarly, overuse of pasture land can result in soil compaction due to hoof action. During storm events and spring snowmelt, water is prevented from soaking into this compacted layer and the volume and velocity of overland flow is increased, as are the total suspended sediment and nutrient loads (NRCE 1996).

6.1.2.2.4 Livestock Grazing

Livestock grazing along streambanks and in stream channels can exacerbate erosion if improperly managed. Livestock tend to congregate where water is readily available and forage is plentiful such as in riparian areas. Increased erosion results from the grazing of riparian vegetation and from the shearing action of hooves on streambanks.

Livestock impact riparian areas and stream channels through increased sediment and nutrient loading and the deposition of manure and urine in surface waters (Mosely et al. 1997). Removal and damage of riparian vegetation leads to streambank instability and prevents the capture and entrainment of sediment at the edges of the stream channel. As a result, streambanks have become unstable in many stream reaches in the watershed (see Section 4.2).

6.1.2.3 Recreation Area Nonpoint Sources

6.1.2.3.1 Ski Areas and Forested Lands

The majority of the forested land in the upper part of the East Canyon Watershed is managed by several ski resorts. The resorts have constructed numerous roads on their properties to access and maintain facilities including ski lifts and lodges. Sediment washed from forest roads is transported to receiving waters during high flow events (Megahan 1972 and 1979, Mahoney and Erman 1984, Whiting et al. 1997). Careful management and BMPs can minimize the impact of sediment loads from roads including the restriction of OHV use and service vehicles to designated routes away from waterways and drainage areas.

6.1.2.3.2 Golf Courses

Golf courses can contribute to sediment and pollutant loads by increasing the number of impermeable (concrete) and semipermeable (turfgrass) surfaces and through over-irrigation, which washes fertilizers and pesticides into storm drains or streams.

There are currently five golf courses in the watershed, a sixth under construction, and four more golf courses proposed in the watershed. Each operating golf course currently has an individual Watershed Restoration and Protection Strategy Plan. Golf course BMPs include irrigation water management and fertilizer management. Golf course management employees must also undergo continued education and training on environmental practices (ECWC 2008b). The Parks and Golf Department manages multiple sediment traps, sediment vaults, and vegetated buffer areas.

6.1.2.4 Natural Background Nonpoint Sources

6.1.2.4.1 Phosphatic Shale

Permian phosphatic shales (Park City Phosphoric Limestone Formation) occur in two distinct locations: the Threemile and Upper Spring Creek subbasins along the southern side of Threemile Canyon, and the Treasure Hollow and Willow Draw subbasins in the extreme southeastern corner of the watershed in Park City. Many of these subbasins have been recently developed or are in active development, which has increased the erosion of phosphatic parent material into East Canyon Creek and East Canyon Reservoir (Olsen and Stamp 2000a). The phosphatic shale is a naturally occurring geologic formation that is easily eroded and contributes phosphorus adsorbed to sediment particles and has been identified as a primary source of total phosphorus loading in the watershed (BIO-WEST 2008).

6.1.2.4.2 Other background sources

Natural background loads are defined as those nutrient loads that would naturally occur under undisturbed conditions. Natural processes that contribute to background sources consist of weathering of bedrock, atmospheric deposition (dust), wildlife, natural erosion of soils, and stream channel development. Local lithology for the East Canyon watershed is primarily composed of sedimentary rock (including phosphatic shales), fine-grained alluvium and glacial outwash deposits (Olsen and Stamp 2000a).

6.1.3 OTHER SOURCES

6.1.3.1 Streambank Erosion

Population growth has lead to a rise in development in the watershed. The increase in impermeable surface area associated with residential and commercial development in the upper East Canyon watershed has resulted in flashy peak flows that contribute to streambank erosion and inputs of organic matter, nitrogen and phosphorus to receiving waters (BIO-WEST 2008). Sources of sediment and pollutants include stormwater runoff from paved areas, erosion from construction sites, and sediment and nutrients from roads and livestock. Ski areas, golf courses and livestock grazing also contribute to the potential of increased runoff and the transport of nutrients and sediment as discussed previously. Developments bordering streams have resulted in the removal and disruption of riparian vegetation, and peak storm flows have caused stream down cutting in some areas and widening in others (Bell et al. 2004).

Eroding streambanks have been estimated to contribute 2.3–7.2 tons of organic matter a year to East Canyon Creek (Baker et al. 2008). Differences in the chemical composition of streambanks and in-stream sediments suggest that approximately half of the streambank organic matter inputs are stored after entering the channel, and that organic matter may substantially increase chemical and/or biological oxygen demand (Baker et al. 2008). Sediment analyses indicate that sediment organic matter in 2000 was highest in the upper reaches of East Canyon Creek and lower downstream (Baker et al. 2008). The BIO-WEST (2008) nonpoint source study identified several stream channel reaches that are degraded and are contributing excessive amounts of sediment and phosphorus. Management actions to restore and stabilize streambanks are likely to improve DO conditions by reducing nutrient and organic matter inputs. Improvements to riparian vegetation and canopy cover would also promote the achievement of DO endpoints by reducing available light for algae and macrophyte growth and the accumulation of sediments in dense macrophyte beds. Stream channel improvements to reduce channel width and increase depth would similarly improve DO levels by increasing flow rates, scouring algae and macrophytes from the stream bed, increasing reaeration rates, and reducing light and water temperatures through deepening of channels and pools. Continued work is needed with landowners to implement and maintain stream channel restoration and rehabilitation efforts. Specific measures should include fencing the stream channel and riparian areas from livestock, channel restoration to narrow and deepen the stream, and restoration of riparian vegetation and increasing canopy cover.

6.1.3.2 Atmospheric Sources

Dust particles in the atmosphere can contribute phosphorus loads to the landscape and directly to waterbodies, although the amount depends on long term climatic and short term weather patterns and therefore varies greatly from year to year.

6.1.3.3 Internal Reservoir Sources

Phosphorus contained in reservoir bed sediments represents a significant loading source to the overlying water column of East Canyon Reservoir. The deposition, release, and dissolution of this phosphorus are dependent on both physical and chemical processes in the watershed and reservoir. Physical processes transport phosphorus contained within and adsorbed to sediment and particulate matter. Chemical processes transform phosphorus from one form (i.e., free or adsorbed) to another.

Phosphorus in the water column of East Canyon Reservoir can be divided into two major sources: suspended sediment-bound phosphorus and dissolved phosphorus. Suspended matter can be colloidal in nature (under 0.45 um in diameter) and resist settling forces because the ratio of surface area to mass is high enough that internal buoyancy counteracts gravity. Sediment and organic matter that has settled to the reservoir bottom may also become re-suspended and act as a source of dissolved phosphorus. Dissolved phosphorus may be present in tributary inflow or as phosphorus released from bottom sediments. Significant phosphorus release from bed sediments has been observed under anaerobic conditions. Phosphorus sorption sites are related to the charge state and concentration of iron and aluminum in sediment particles. Under anaerobic conditions, iron and aluminum are reduced and sorption potential is decreased, which allows the release of bound phosphorus to the water column (Sharpley et al. 1995). Low DO levels therefore lead to sediment release of bound phosphorus in this manner.

Reservoir operations that control water depth may affect the availability of sediment-bound phosphorus and its potential leaching into surface water. Fluctuating water levels that periodically expose lake sediments or alter the aerobic/anaerobic conditions at the sediment-water interface can contribute to the release of sediment-bound nutrients.

6.2 Total Current Load Estimates to East Canyon Reservoir

6.2.1 Temporal Extent of Analysis

The time period considered representative of current loads to East Canyon Reservoir comprises the 2003–2007 water years. A water year runs from October 1 through September 31. All summaries of water quality and hydrologic data in this load analysis are specific to these time periods. Annual loads have been separated into four hydrologic periods: spring melt, storms, rain on snow, and base flow. Seasonal patterns of algal growth correspond to the hydrologic periods described above. However, internal loads from sediments play an important role in algal growth during the fall season and this load is related to watershed loads in previous seasons and years. This, in combination with the long retention time of the reservoir, has led to the decision to base the load analysis on total annual loads rather than seasonal loads.

6.2.2 Methodology

Apportionment of the total nonpoint source load among sources identified in the watershed (see Section 6.1) was achieved through application of load coefficients derived by BIO-WEST for the Upper East Canyon watershed. Total load estimates with land-use specific load coefficients were then scaled proportionally among all sources to match the calculated total load into the reservoir corresponding to the hydroperiods described above.

6.2.2.1 Calculation of Total Phosphorus Load by Hydroperiod

Total phosphorus load to East Canyon Reservoir was estimated for water years 2003 through 2007 by multiplying daily flow values by water quality concentrations extrapolated into a daily dataset based on each date's hydrologic category or hydroperiod.

A daily discharge record to East Canyon Reservoir was derived from BOR reservoir elevation and the USGS station near Jeremy Ranch, UT (#10133800). The BOR reservoir elevation dataset was corrected for evaporation and precipitation with data from the NCDC's Coalville station (see Section 3.3.1.2). This corrected inflow represents all inflow to the reservoir, including that from small tributaries entering at different points along East Canyon Creek. The corrected inflow was then divided proportionally into the inflow from East Canyon Creek and from other tributaries on the basis of basin area. The discharge record to the reservoir was categorized into four "hydroperiods" describing typical runoff conditions in the basin: spring melt, storms, rain on snow, and base flow. These periods were determined both graphically and through the use of specific criteria, using each year's annual hydrograph and daily precipitation records at the Coalville station. The methodology used for hydroperiod classification is described in Section 3.3.1.2.

Median water quality concentrations were estimated using water quality data obtained from Utah DEQ (EPA STORET), Weber Basin Water Conservancy District, SBWRD, and BIO-WEST (BIO-WEST 2008). During the post-TMDL period (2003–2007), each date was categorized into a hydroperiod as described above. Median water quality concentrations from Site 4925190 (furthest downstream site on East Canyon Creek) were determined for each hydroperiod based on available samples. Stormwater data were only available for selected sites, none of which were at the mouth of East Canyon Creek. The median storm event concentrations sampled upstream (BIO-WEST 2008) were taken for all East Canyon Creek sites and applied to the downstream site to characterize the "storm" hydroperiod. Median water quality data was then used to derive daily water quality concentration in East Canyon Creek, according to each day's hydroperiod (see Table 5.1).

Daily loads from 2003 through 2007 are calculated by multiplying daily flow values by median water quality concentrations estimated for each date (based on hydroperiod). Daily loads in East Canyon Creek were then divided into point and nonpoint sources. Point source loads were calculated directly from effluent data collected at the ECWRF. Nonpoint source loads were estimated by subtracting the ECWRF load from the total daily load in East Canyon Creek. East Canyon Creek drains approximately 72,335 acres at its inlet to the reservoir, or 78% of the watershed. Other tributary inflows to the reservoir were therefore assumed to make up approximately 22% of the total reservoir inflow for the purpose of load analysis.

6.2.2.2 Characterization of Specific Nonpoint Source Loads by Land Use and Tributary

Detailed analyses of the Summit County portion of the watershed (Upper East Canyon) were completed by BIO-WEST in 2000 and 2007. The BIO-WEST analyses estimated subbasin loads based on monitoring data and regression analysis. In addition, BIO-WEST developed load coefficients specific to the East Canyon watershed for use in determining the relative contribution of various land uses to subbasin loads. As part of this work, the NLCD land-use classes were further divided to include ski resorts, active construction, and golf courses in the analysis. These subcategories of NLCD are important contributors of nonpoint source phosphorus in the watershed.

The land-use coefficients developed for the Upper East Canyon (Summit County) portion of the watershed were applied to the Morgan County portion of the watershed based on NLCD land-use acreages. Land-use coefficients were not derived by BIOWEST for some subbasins. In these subbasins the average land-use coefficient for either phosphatic shale subbasins or nonphosphatic shale subbasins was applied as appropriate (Table 6.1). Land uses were not subdivided for the Morgan County portion of the watershed because ski resorts, golf courses, and active construction are not located in this portion of the watershed, which is dominated by agricultural and forested land uses. Instead, NLCD land-uses acreages were matched with appropriate BIOWEST land-use coefficients based on Appendix D of the BIO-WEST 2008 report. Background loads were calculated by applying the average forested/meadow land-use coefficients from the Upper East Canyon subbasins (White Pine, Kimball Creek, and Silver Creek) to the entire watershed. The difference between total loads and estimated background loads of phosphorus was assumed to be caused by land-use specific changes due to anthropogenic activities. Loads estimated from the land-use coefficients do not account for in-stream processing, rather, this process is captured by the final load estimate from East Canyon Creek as it enters East Canyon Reservoir. Loads were adjusted proportionally to match the observed load into East Canyon Reservoir from 2003–2007.

The largest proportion of the total annual nonpoint source phosphorus load (kg/year) into East Canyon Reservoir is from background sources (30%) (Figure 6.2, Table 6.2). When normalized for area, active construction, golf courses, commercial/urban areas, and ski areas compose the largest nonpoint phosphorus sources in the watershed (0.32, 0.24, 0.24, and 0.11 kg/ha, respectively) (Figure 6.3).

Table 6.1. BIO-WEST Load Coefficients (Olsen and Stamp 2000; BIO-WEST 2008) Used for East Canyon Watershed Subbasins

Subbasin	Corresponding BIO-WEST Load Coefficient
Lower East Canyon	Average of all subbasins without phosphatic shales
Direct Drainage	Middle East Canyon Watershed
Kimball Creek	Kimball Creek
Lower Springs	Spring Creek
Middle East Canyon	Middle East Canyon Watershed
Park City	Average PC Nonphosphatic
Park Meadows	Park Meadows
Red Pine	White Pine
Silver Creek/Parley's Park	Silver Creek (UEC)
Spiro Tunnel	Average of Park City subbasins with phosphatic shales
Thaynes Canyon	Average of Park City subbasins without phosphatic shales
Three Mile	Three Mile
Toll Canyon	Toll Canyon

Table 6.1. BIO-WEST Load Coefficients (Olsen and Stamp 2000; BIO-WEST 2008) Used for East Canyon Watershed Subbasins

Subbasin	Corresponding BIO-WEST Load Coefficient
Treasure Hollow	Average of Park City subbasins with phosphatic shales
Two Mile	Two Mile
Unnamed # 1	Spring Creek
Unnamed # 2	Spring Creek
Unnamed Meadow	Middle East Canyon Watershed
Upper East Canyon	Average of Upper East Canyon subbasins without phosphatic shales
Upper Spring Creek	Spring Creek
White Pine	White Pine
Willow Draw	Willow Draw
Bear Hollow	Average of all subbasins without phosphatic shales
Mann Creek	Average of all subbasins without phosphatic shales

Table 6.2. East Canyon Watershed Land-use Areas and Annual Phosphorus Loads

Land Use	Total Hectares	Percent of Watershed	Percent of Land Use Found in Subbasins with Phosphatic Shales	Annual P Load (kg/year)	Normalized P Load (kg/ha)	Percent of Annual Load
Background	26,575	71.0%	4.3%	474.7	0.0	22.9%
Forested/ Meadow	26,575	71.0%	4.3%	474.7	0.0	22.9%
Residential	5,715	15.3%	2.8%	354.2	0.1	17.1%
Ski Areas	2,982	8.0%	22.9%	315.7	0.2	15.2%
Ag/Grazing	572	1.5%	15.1%	54.5	0.1	2.6%
Golf Courses	893	2.4%	6.3%	136.9	0.3	6.6%
Active Construction	71	0.2%	24.6%	26.1	0.5	1.3%
High Use Rec	57	0.2%	0.0%	8.5	0.1	0.4%
Commercial Urban	333	0.9%	28.7%	85.3	0.3	4.1%
Open Water	235	0.6%	0.0%	-	-	0.0%
Grand Total	37,433	100.0%	6.0%	2072	n/a	100.0%

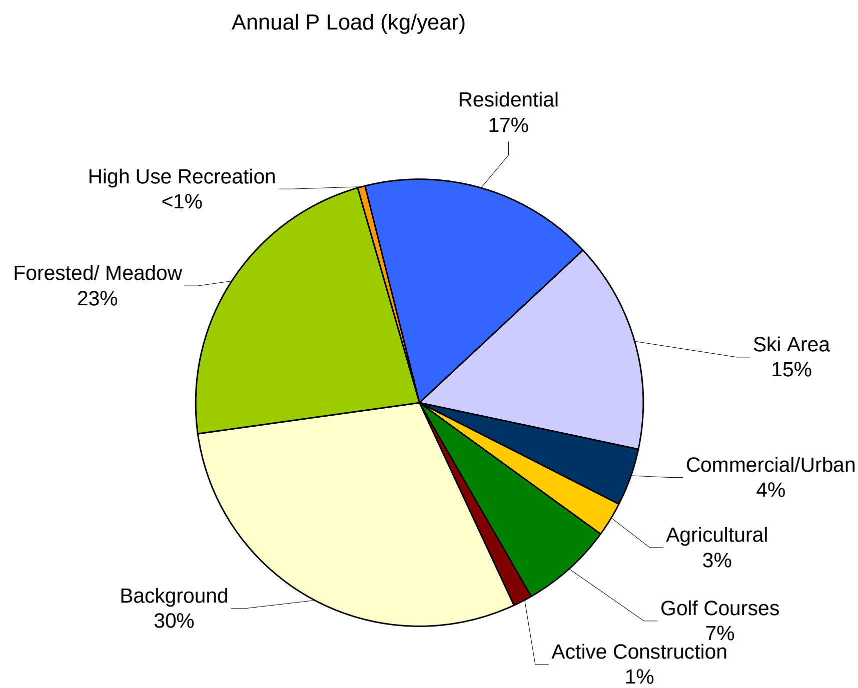


Figure 6.2. Total Annual Nonpoint source phosphorus loads (kg/year) by land use.

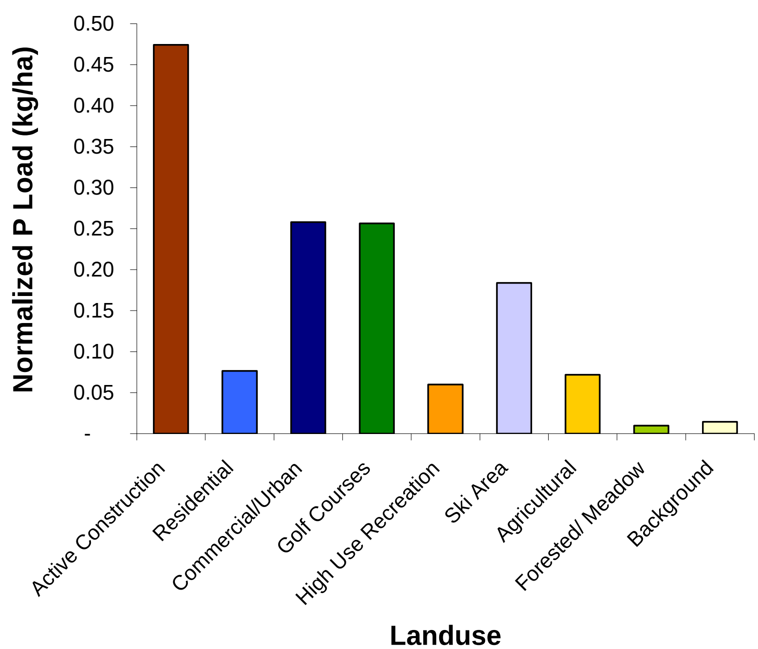


Figure 6.3. Normalized nonpoint source phosphorus loads (kg/ha) by land use.

6.2.2.2.1 Background Sources

Background or natural nonpoint source areas include the estimated natural load from all 23 subbasins. Background sources contribute 616 kg/year (0.01 kg/ha) of phosphorus, or 30% of the total annual nonpoint source load. In the East Canyon watershed, phosphatic shales occur in the Treasure Hollow, Spiro Tunnel, Upper Spring Creek, Willow Draw and Three Mile subbasins. Subbasins with phosphatic shales contribute 7% (44 kg/year) of the background annual nonpoint source phosphorus load.

6.2.2.2.2 Forested and Meadow Land Uses

Forested and meadow land-use areas compose 26,575 hectares (71%) of the watershed and includes 22 subbasins. Only the Willow Draw subbasin contains phosphatic shales. These land uses contribute 475 kg/year (0.01 kg/ha) of phosphorus, or 23% of the total annual nonpoint source phosphorus load in the watershed. Subbasins with phosphatic shales contribute 1% (7 kg/year) of the annual phosphorus load from these land uses.

6.2.2.2.3 Residential Land Use

Residential land use composes 5,715 hectares (15%) of the watershed across all 23 subbasins, including those with phosphatic shales (Treasure Hollow, Spiro Tunnel, Willow Draw and Three Mile subbasins). This land use contributes 354 kg/year (0.08 kg/ha) of phosphorus, or 17% of the total annual nonpoint source phosphorus load in the watershed. Subbasins with phosphatic shales contribute 6% (21 kg/year) of the annual phosphorus load from this land use. The residential land-use category includes loads associated with onsite wastewater treatment systems (septic systems). A groundwater study of the Silver Creek Estates area estimated that groundwater contributes an annual load of 41 to 53 kg/year of dissolved phosphorus to East Canyon Creek, some of which is associated with background concentrations (UDEQ 2003). The estimated load from the Silver Creek subbasin, using the methodology described in this section, is 103 kg/year. The majority of this load is associated with residential land uses and therefore incorporates the estimated load from groundwater described in the groundwater study (UDEQ 2003).

6.2.2.2.4 Commercial and Urban Land Uses

Commercial and urban land uses compose 333 hectares (1%) of the watershed across 14 subbasins, including those with phosphatic shales (Treasure Hollow, Spiro Tunnel, Willow Draw and Three Mile subbasins). These land uses contribute 85 kg/year (0.26 kg/ha) of phosphorus, or 4% of the total annual nonpoint source phosphorus load in the watershed. Subbasins with phosphatic shales contribute 52% (44 kg/year) of the annual phosphorus load from this land use.

6.2.2.2.5 Ski Areas

Ski areas occupy approximately 2,982 hectares (8%) of the watershed in nine subbasins, including those with phosphatic shales (Treasure Hollow, Spiro Tunnel and Willow Draw subbasins). The ski area land use contributes 316 kg/year of phosphorus, or 8% of the total annual nonpoint source load in the watershed. Subbasins with phosphatic shales compose approximately 23% of ski areas and contribute 98% (309 kg/year) of the annual phosphorus load from ski area land uses.

6.2.2.2.6 Agricultural Land Uses

Agricultural land uses (including hayland, pasture land, and irrigated crops) compose 572 hectares (1.5%) of the watershed in 12 subbasins, including high nonpoint source areas in the Direct Drainage, Middle East Canyon and Kimball Creek subbasins. The agricultural land uses are not found in any of the subbasins with phosphatic shales. These land uses contribute 54 kg/year (0.07 kg/ha) of phosphorus, or 2.6% of the total annual nonpoint source phosphorus load in the watershed.

6.2.2.2.7 Golf Courses

Golf courses compose approximately 893 hectares (2.4%) of the watershed. Golf courses contribute 137 kg/year (0.26 kg/ha) of phosphorus, or 6.6% of the total annual nonpoint source phosphorus load in the watershed. Subbasins with phosphatic shales contribute 28.37% (28.4 kg/year) of the annual phosphorus load from golf course land uses.

6.2.2.2.8 Active Construction

Active construction land-use areas compose 71 hectares (0.2%) of the watershed. Active construction contributes 26.1 kg/year (0.47 kg/ha) of phosphorus, or 1.3% of the total annual nonpoint source phosphorus load in the watershed. The majority of this load comes from the Willow Draw subbasin, which contains phosphatic shales and delivers an annual phosphorus load of 17.6 kg/year.

6.2.2.2.9 High Use Recreation

High use recreation land-use areas compose 57 hectares (0.2%) of the watershed in the Silver Creek/Parley's, Lower Springs and Murnin Creek subbasins. There are no phosphatic shales in these subbasins. This land use contributes 8.5 kg/year (0.06 kg/ha) of phosphorus, or 0.4% of the total annual nonpoint source phosphorus load in the watershed.

6.2.2.2.10 Summary of Nonpoint Source Load by Land Use

Background sources contribute the greatest proportion (30%) of nonpoint source phosphorus loads in the East Canyon watershed. Agricultural lands compose 1.5% of the watershed and contribute 54 kg/year (2.6%) of the total annual nonpoint source phosphorus load. This land use produces low phosphorus loads per hectare (0.07 kg/ha). Golf courses, ski areas, and active construction compose 10.5% (3,933 ha) of the watershed and contribute 461 kg/year (22%) of the total annual nonpoint source phosphorus load. These land uses are concentrated in the upper portion of the watershed in subbasins containing phosphatic shales, which contributes to high normalized phosphorus loads (0.18–0.47 kg/ha). Residential and commercial urban land uses compose 16.2% (6,047 ha) of the watershed and contribute 439 kg/year (21%) of the total annual nonpoint source phosphorus load. The commercial and urban land uses are concentrated in the upper portion of the watershed in subbasins containing phosphatic shale, which contributes to the high normalized phosphorus load (0.26 kg/ha) associated with land use. Residential land uses are distributed throughout the watershed at a much lower density which accounts for the relatively moderate normalized phosphorus load (0.08 kg/ha).

6.2.2.2.11 Summary of Nonpoint Source Load By Subbasin

The annual phosphorus loads associated with East Canyon watershed subbasins demonstrate both the large proportion of nonpoint source phosphorus from background, forested and meadow land uses in middle and lower subbasins (Middle East Canyon, Lower East Canyon, Direct Drainage), and the concentration of phosphatic shale, construction and development in upper subbasins (Treasure Hollow, Willow Draw, Kimball Creek) (Table 6.3; see also Figure 6.4). As discussed above, land uses associated with higher normalized phosphorus loads (kg/ha) are concentrated in subbasins in the upper portion of the watershed.

Table 6.3. East Canyon Watershed Subbasin Phosphorus Loads

East Canyon Watershed Subbasin	Hectares	Annual P Load (kg/year)	Normalized P Load (kg/ha)	Percent of Total Annual P
Bear Hollow	279	17.4	0.06	1%
Direct Drainage	8,160	345.8	0.04	17%
Kimball Creek	1,067	139.8	0.13	7%
Lower East Canyon	11,376	409.0	0.04	20%
Lower Springs	441	29.0	0.07	1%
Middle East Canyon	2,580	110.9	0.04	5%
Park City	107	13.7	0.13	1%
Park Meadows	239	41.2	0.17	2%
Red Pine	1,031	22.4	0.02	1%
Silver Creek/Parley's Park	3,049	102.8	0.03	5%
Spiro Tunnel	138	55.4	0.40	3%
Thaynes Canyon	1,333	46.8	0.04	2%
Three Mile	890	14.1	0.02	1%
Toll Canyon	1,353	72.9	0.05	4%
Treasure Hollow	268	200.6	0.75	10%
Two Mile	538	106.3	0.20	5%
Unnamed # 1	62	4.6	0.07	0%
Unnamed # 2	19	1.3	0.07	0%
Unnamed Meadow	82	3.7	0.05	0%
Upper East Canyon	1,845	110.5	0.06	5%
Upper Spring Creek	265	15.2	0.06	1%
White Pine	1,621	16.4	0.01	1%
Willow Draw	688	192.4	0.28	9%
Total	**37,433**	**2,072**	**n/a**	**100%**

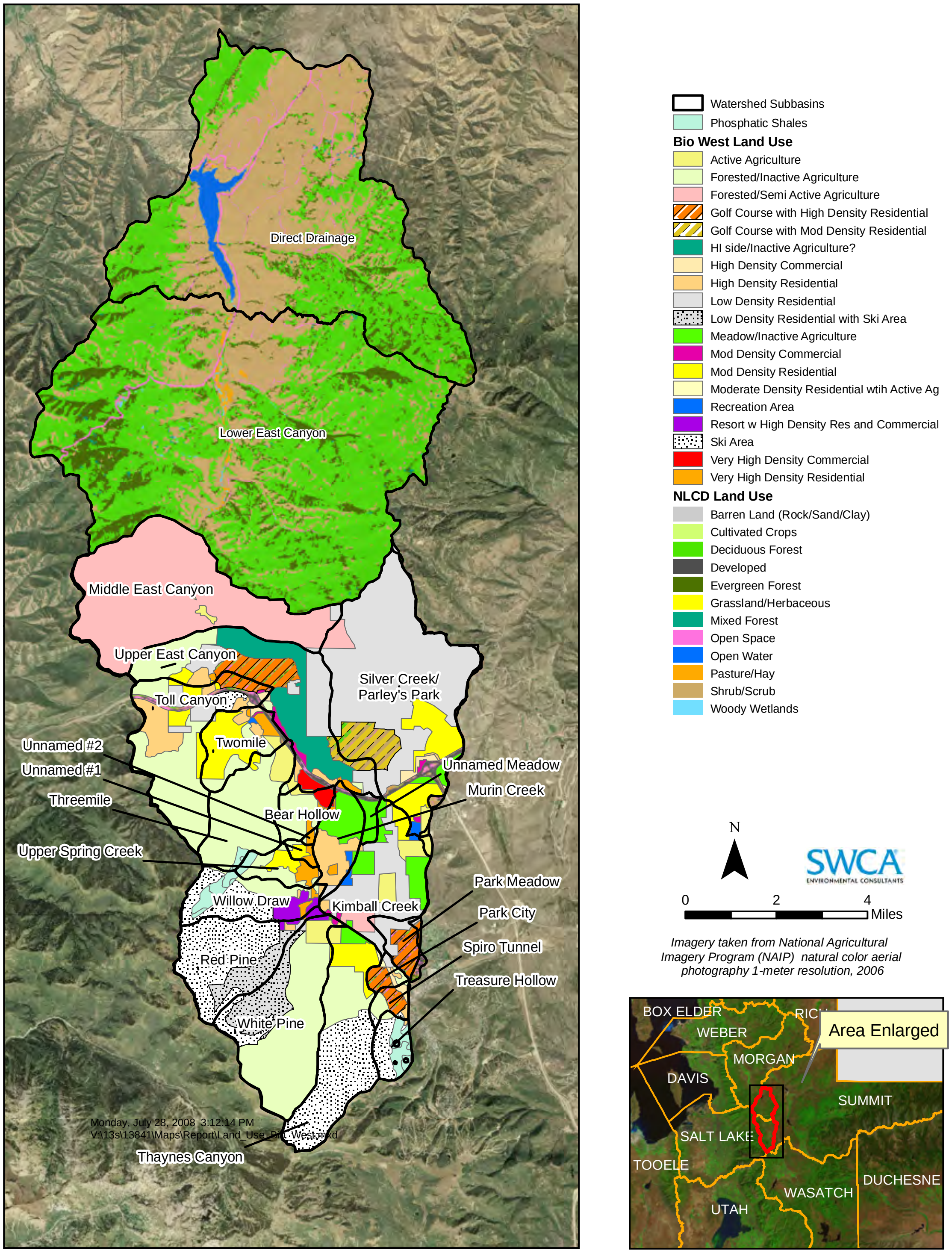


Figure 6.4. Map of land-use coverage and subbasins used in estimating nonpoint source loads to East Canyon Reservoir.

Data sources: BIO-WEST 2008 and NLCD dataset.

6.2.3 LOAD SUMMARY BY HYDROLOGIC PERIOD

The load that occurs in each hydroperiod is determined by the median concentration present and the hydroperiod's discharge magnitude and flow duration. Spring melt and base flow supply the majority of both water and nutrients from the East Canyon Reservoir watershed. Spring melt accounts for, on average, 47% of all runoff from the watershed due to the accumulation of winter snow in the upper reaches of the watershed. Despite its relatively low magnitude discharges, base flow accounts for an additional 33% of all runoff, largely due to its long duration. Rain on snow events and storms account for 16% and 4% of runoff, respectively (Figure 6.5, Table 6.4).

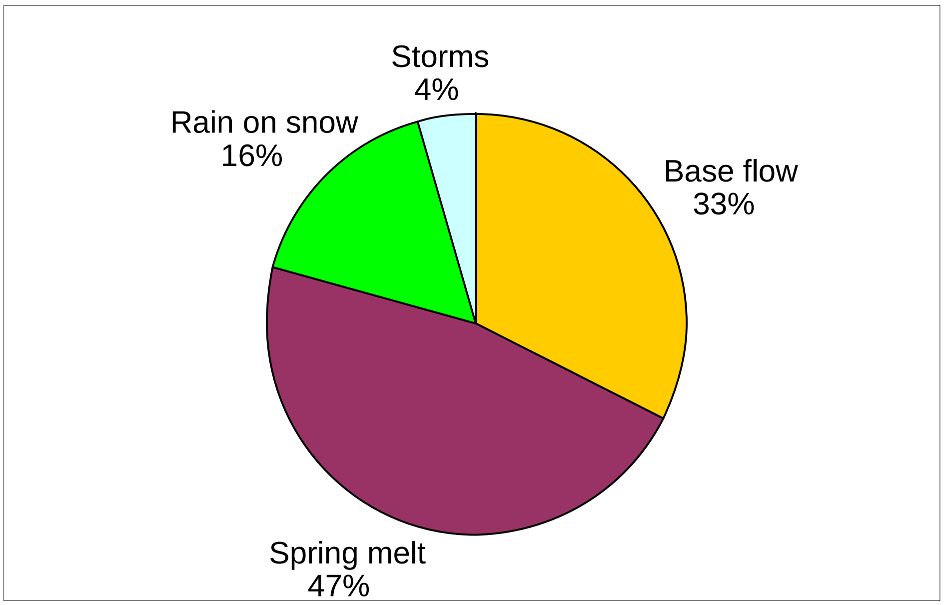


Figure 6.5. Percentage of total basin discharge (volume) from each hydroperiod.

Table 6.4. Acre-Feet of Runoff from Each Hydroperiod during the Post-TMDL Period

Water Year	Hydrologic Year	Base Flow	Spring Melt	Storm	Rain on Snow
2003	Dry	8,197	6,661	1,946	910
2004	Dry	10,734	11,340	3,348	1,947
2005	Normal	13,313	23,837	13,644	1,276
2006	Normal/Wet	16,371	32,062	8,644	2,550
2007	Normal	10,197	10,445	2,136	1,392
Average	**Normal**	**11,763**	**16,869**	**5,943**	**1,615**

As shown in Table 6.5 and Figure 6.6, the snowmelt period is the dominant source of the annual load of total phosphorus in East Canyon Creek. Mean annual precipitation in the East Canyon drainage is 26 to 37 inches (66–94 cm) per year, 73% of which occurs as snow from October to April, The high elevation snow and spring runoff from snowmelt provide most of the water to East Canyon Creek, with the highest flows occurring in April and May (BOR 2003). This runoff carries a significant load of sediment and nutrients to the stream and reservoir. In addition to high flows and a relatively long duration, the spring melt hydroperiod is characterized by the highest average concentrations of DO and much higher concentrations of total phosphorus than the base flow period (0.069 vs. 0.045, respectively, see Table 5.1). The spring melt period delivers an average of 51% of the total phosphorus from the watershed; this figure ranged from 41% of the load during a dry year (2003) to 60% of the load in a relatively wet year (2006). In addition, the spring melt period delivers an average of 53% of the dissolved phosphorus from the watershed (Table 6.6, Figure 6.7); this figure ranged from 39% of the load during a dry year (2003) to 63% of the load in a relatively wet year (2006). As such, this period will be a major target for nonpoint source phosphorus reduction from the basin.

Table 6.5. Summary of Total Phosphorus Load (kgTP/year) by Hydroperiod for the Post-TMDL Period

Water Year	Hydrologic Year	Base Flow	Spring Melt	Rain on Snow	Storms	Total	Acceptable TMDL Load (kg/year)
2003	Dry	467.41	464.77	128.23	65.28	1,125.68	1,232.34
2004	Dry	466.83	814.99	254.91	44.35	1,581.07	1,196.62
2005	Normal	702.43	1,869.76	1,122.57	124.30	3,819.06	2,902.25
2006	Normal/Wet	939.09	2,684.29	700.24	171.03	4,494.65	3,764.00
2007	Normal	737.68	752.83	155.93	108.44	1,754.88	2,103.02
Average Post-TMDL	**Normal**	**662.69**	**1,317.33**	**472.38**	**102.68**	**2,555.07**	**2,239.64**

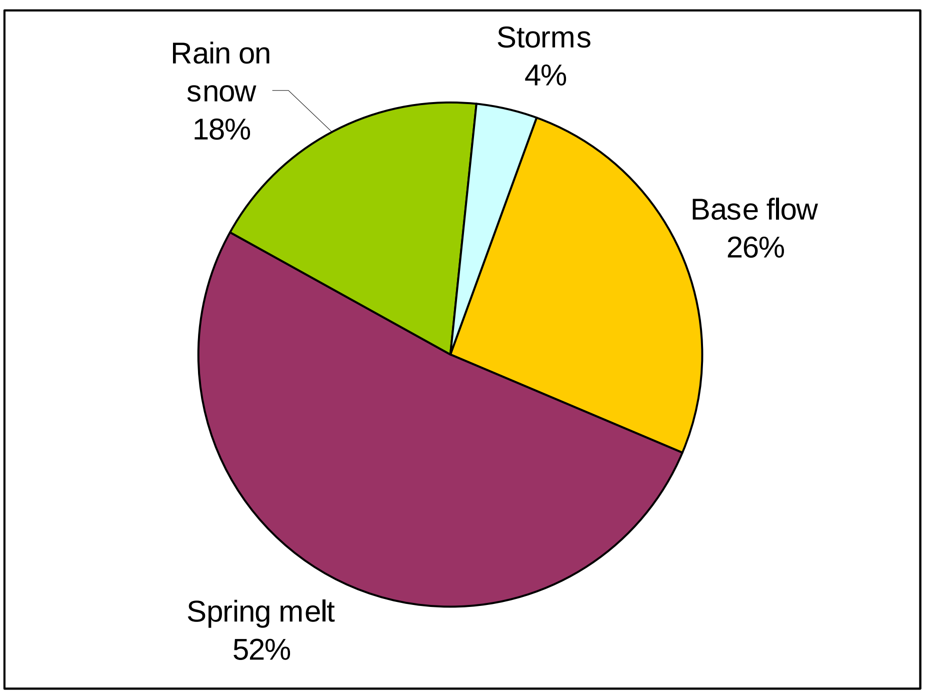


Figure 6.6. Percentages of total phosphorus load to East Canyon Reservoir summarized by hydroperiod.

Table 6.6. Summary of Dissolved Phosphorus Load (kgDP/year) by Hydroperiod for the Post-TMDL Period

Water Year	Hydrologic Year	Base Flow	Spring Melt	Rain on Snow	Storms	Total
2003	Dry	330.91	311.29	66.01	32.32	802.24
2004	Dry	365.52	535.75	114.58	24.45	1,040.30
2005	Normal	511.78	1,158.21	454.15	73.84	2,197.98
2006	Normal/Wet	695.99	1,836.67	299.33	101.22	2,933.21
2007	Normal	514.68	488.52	71.61	62.59	1,137.40
Average Post-TMDL	**Normal**	**483.78**	**866.09**	**201.14**	**58.88**	**1,622.23**

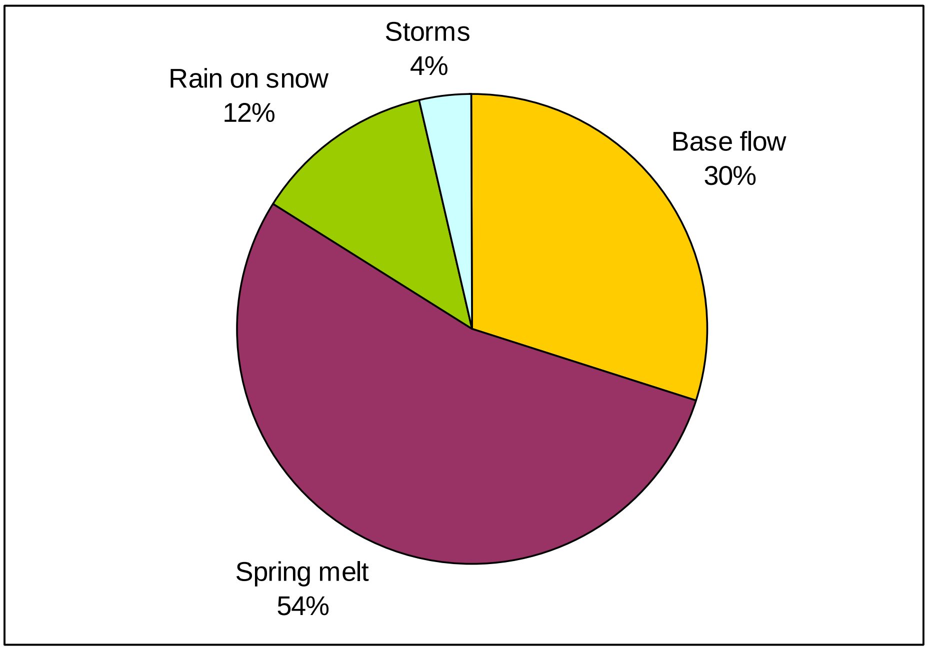


Figure 6.7. Percentages of dissolved phosphorus load to East Canyon Reservoir summarized by hydroperiod.

The second largest load of both water and phosphorus is delivered during the base flow hydroperiod. Base flows are responsible for 33% of all discharge, 26% of total phosphorus, and 30% of dissolved phosphorus, on average. Base flows follow a pattern opposite of spring melt in relatively wet and dry years; base flows tend to carry a far greater percentage of the total load in dry years (up to 42% of the TP and 45% of the DP) and a lesser percentage in wetter years (18% of TP and 23% of DP). This pattern can be explained by the relatively constant phosphorus load from ECWRF. Base flow phosphorus loads from year to year vary by approximately a factor of 2, whereas the load carried by the spring melt varies by more than a factor of 5.

Storm events occurring in the summer months produce short duration high flow events with a high load carrying capacity and significant erosion potential. However, due to their relative infrequency and low duration, storm flows account for only 4% of runoff, TP, and DP. As such, the reduction of storm flow loads will have a limited role in the TMDL implementation plan. Summer storm events are limited sources of flow as the vegetation present in the watershed may limit the amount of precipitation that actually produces runoff.

Rain on snow events account for a far greater percentage of discharge and phosphorus loading than summer storms, mainly due to their increased runoff efficiency (they occur on saturated soils and during periods of runoff) and therefore larger magnitudes. Rain on snow events account for 16% of all flows, 18% of the watershed's TP load, and 12% of the DP load.

6.2.4 SUMMARY OF WATERSHED SOURCES

The total annual watershed phosphorus load to East Canyon Reservoir includes both point and nonpoint sources. A summary of total dissolved phosphorus loads from point and nonpoint sources is shown in Tables 6.7 and 6.8.

Table 6.7. Summary of Total Phosphorus Load to East Canyon Reservoir from Point and Nonpoint Sources (kg/year)

Water Year	Hydrologic Year	ECWRF	Nonpoint	Total	Acceptable TMDL Load (kg/year)†
2003	Dry	755.04	370.64	1,125.68	1,232.34
2004	Dry	542.33	1,038.74	1,581.07	1,196.62
2005	Normal	418.87	3,400.19	3,819.06	2,902.25
2006	Normal/Wet	419.96	4,074.68	4,494.65	3,764.00
2007	Normal	277.03	1,477.85	1,754.88	2,103.02
Average Post-TMDL	**Normal**	**482.65**	**2,072.42**	**2,555.07**	**2,239.64**
Allocated Load		**663.0**	**2,723.0***	**3,386.0**	

† Load based on annual flow x 0.05 mg/L TP.

* Includes allocation for future growth.

Table 6.8. Summary of Dissolved Phosphorus Load into East Canyon Reservoir from Point and Nonpoint Sources (kg/year)

Water Year	Hydrologic Year	ECWRF	Nonpoint	Total
2003	Dry	75.52	726.72	802.24
2004	Dry	57.07	983.23	1,040.30
2005	Normal	199.95	1,998.04	2,197.98
2006	Normal/Wet	94.31	2,838.89	2,933.21
2007	Normal	38.97	1,098.44	1,137.40
Average Post-TMDL	**Normal**	**93.16**	**1,529.06**	**1,622.23**

6.2.4.1 Point Source

Discharge volume from ECWRF has ranged from a minimum of 1.33 MGD to 6.06 MGD during the peak, tourist ski season. Average effluent volume was 2.61 MGD during water years 2003–2007. In general, data are collected four times per month from the ECWRF effluent. Average monthly effluent concentrations and discharge were used to build a daily load estimate for the ECWRF. Daily loads were summarized by water year and averaged to estimate an annual average total phosphorus load to East Canyon Creek from ECWRF.

The ECWRF is the only point source in the watershed. On average, it contributes 483 kg of total phosphorus per year to East Canyon Creek, or 19% of the total load (see Table 6.7). On average, it contributes 93 kg of dissolved phosphorus as well, or 6% of the total watershed load (see Table 6.8). However, the percentage of the total phosphorus (TP) and dissolved phosphorus (DP) load that the ECWRF contributes is largely dependent on the amount of runoff. In higher water years, such as 2006, ECWRF contributed a similar total load (420 kg TP and 94 kg DP), but represented only 9% of the total TP load and 3% of the total DP load. In dry years such as 2003, the relative contribution was 67% of the TP watershed load and 9% of the DP watershed load.

In general, the load from the ECWRF is far more constant than the load from nonpoint sources and has varied by less than a factor of 3. As shown in Table 6.7, the total phosphorus load in the creek has exceeded the existing TMDL in three out of the last five years. The point source load has generally been a relatively small component of the total load, and has not exceeded the TMDL's point source allocation over that period.

6.2.4.2 Nonpoint Sources

Nonpoint sources of total phosphorus are derived from land uses and human activity in the watershed. These land uses and activities are described in Section 6.1.2, and will also be addressed in this TMDL's implementation plan. Overall, nonpoint sources of phosphorus in the watershed account for 81% of the annual load of total phosphorus, and 94% of the dissolved load (see Tables 6.7 and 6.8). Unlike the ECWRF, both the total and relative contribution of nonpoint source loads vary greatly between wet and dry years. In general, nonpoint sources produce far greater total and relative loads of TP and DP in wet years due to greater runoff and increased erosion. Dry years tend to result in far fewer nonpoint source phosphorus inputs because there is little runoff and less in-stream sediment is mobilized.

The nonpoint source load of TP has been slightly reduced since implementation of the existing TMDL from an annual load of 3,760 lbs/year to 2,072 lbs/year (UDEQ 2000b and Table 7). The nonpoint source phosphorus allocation in the existing TMDL is 1,895 lbs/year for existing nonpoint sources and 1,516 lbs/year that are reserved for growth. Assuming that the entire future growth allocation is intended for nonpoint sources, then the total nonpoint source allocation in the existing TMDL is 3,411 lbs/year. This load allocation has been achieved in every year since the 2002 with the exception of 2006 (see Table 6.7). Nonpoint sources continue to add an average of more than 2,000 kg of TP to the creek's load each year, as well as over 1,500 kg of DP.

6.2.5 Internal Load Summary

A phosphorus mass balance model was developed for East Canyon Reservoir to calculate monthly and annual net internal load from reservoir sediments. To calculate the net internal load, the total load (monthly or annual) into the reservoir was subtracted from the total load (monthly or annual) out of the reservoir. It was assumed that any phosphorus exported from the reservoir that is an input to the reservoir represents a net internal load from the sediments. Due to the long hydraulic retention time of the reservoir, internal load estimates are generally more reliable when calculated over a longer period of time. Annual internal load estimates are summarized in Table 6.9. Annual internal load is 795 kg/year on average although annual internal loads are estimated to be as high as 1,780 kgTP/year and as low as 294 kgTP/year. The high internal load observed in 2007 likely represents the high phosphorus load to the reservoir during the previous two years which were wetter the other years in the analysis. Net internal load over the entire 2003–2007 periods is 4,772 kg of total phosphorus.

Table. 6.9. Estimated Internal Load during the Post-TMDL Period

Water Year	Hydrologic Year	Percent 30-year Flow	Total P Inflow (kg/year)	Total P Outflow (kg/year)	Internal Load (kg/year)	Percent of Total that is Internal
2003	Dry	45%	1,125.67	1,877.38	751.71	40%
2004	Dry	43%	1,581.07	1,875.47	294.4	16%
2005	Normal	105%	3,819.06	4,344.63	525.58	12%
2006	Normal/Wet	136%	4,494.65	5,121.35	626.71	12%
2007	Normal	76%	1,754.88	3,532.99	1,778.12	50%
Average	**Normal**	81%	2,555.06	3,350.37	795.3	26%
Total			12,775	16,752	3,977	24%

The bulk of the internal load comes during the summer period when anoxic hypolimnetic waters facilitate the release of phosphorus into the water column. The majority of this phosphorus originated in the watershed and was washed into the reservoir during the previous spring. In other words, reservoir sediments act as a sink during the spring and a source during the summer (Figure 6.8). In addition, some legacy sources of internal phosphorus remain from decades of phosphorus loading to the reservoir. The reservoir appears to be flushing these legacy sources as it begins to establish a new steady state. The expected time for reservoir sediment flushing is estimated to be longer than 10 years, based on the W2 model simulation results.

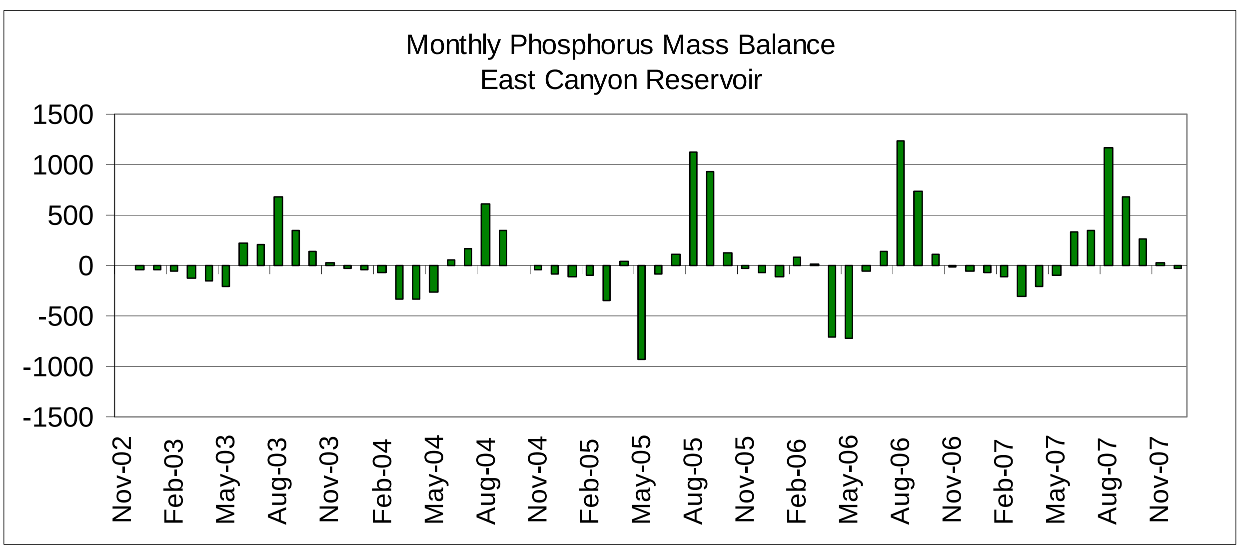


Figure 6.8. Monthly phosphorus mass balance for East Canyon Reservoir for water years 2003–2007.

Positive values represent internal load sources and negative values indicate that the reservoir is acting as a sink.

6.2.6 TOTAL LOAD SUMMARY

In total, 3,350 kgTP/year were delivered to East Canyon Reservoir on average between 2003 and 2007. This total represents an annual average watershed load of 2,555 kgTP/year (67% of the total) and an average internal sediment load of 795 kgTP/year (23% of the total). Loads and their apportionment between point, nonpoint, and internal sources varies between dry and wet/normal hydrologic years (Table 6.10).

Table 6.10. Summary of Total Phosphorus Load to East Canyon Reservoir from Point, Nonpoint, and Internal Sources (kg/year)

Water Year	Hydrologic Year	ECWRF	Nonpoint	Internal Load	Total
2003	Dry	755	371	752	1,877
2004	Dry	542	1,039	294	1,875
2005	Normal	419	3,400	526	4,345
2006	Normal/Wet	420	4,075	627	5,121
2007	Normal	277	1,478	1,778	3,533
Average Post-TMDL	**Normal**	483	2,072	795	3,350

Of the external watershed sources of phosphorus load to East Canyon Creek and Reservoir, far and away the greatest percentage (47%) come from nonpoint sources generated during the snowmelt period each spring (Figure 6.9). As such, these sources will be a major target for implementing load reductions. The second greatest load source is nonpoint phosphorus transported by rain on snow events. This is also an area that is ripe for implementing reductions. Finally, the last major sources are nonpoint and point sources transported during base flow.

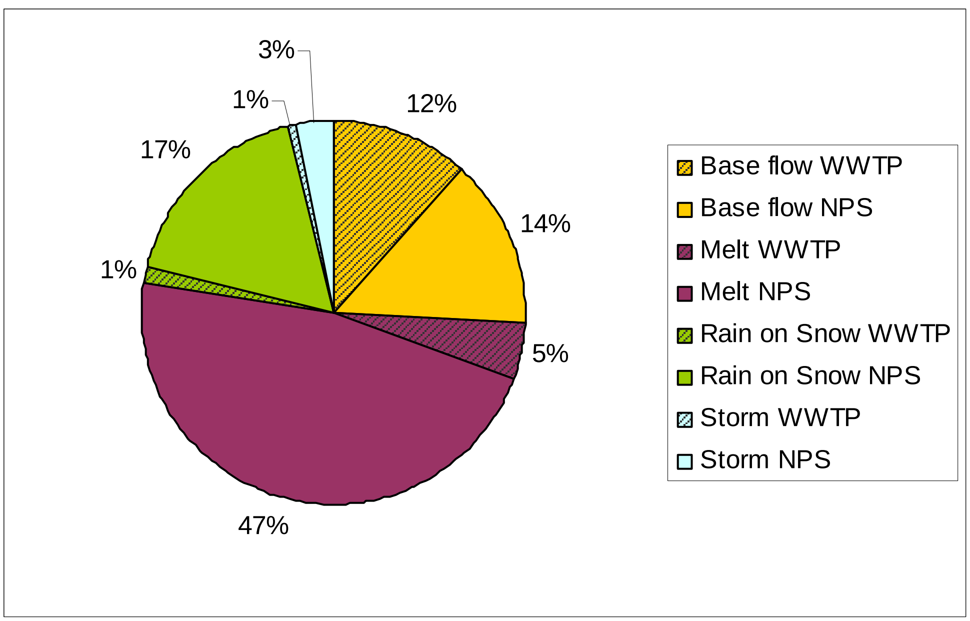


Figure 6.9. Average annual total phosphorus load by hydroperiod and source.

7. TOTAL MAXIMUM DAILY LOAD SUMMARY

7.1 PHASED TMDL APPROACH AND RATIONALE

UDWQ is currently in the process of revising the assessment methodology for DO criteria applicable to deep reservoirs that stratify during the summer season. New assessment methods will affect the monitoring strategy for deep reservoirs, the frequency of recorded water quality exceedances associated with DO, potentially the impairment status of the reservoir, and therefore the attainment of water quality standards and assessment of TMDL targets.

The current DO criteria for cold water fisheries includes 4.0 mg/L as a 1-day minimum acute criteria, a chronic criteria of 5.0 mg/L as a 7-day average, and 6.5 mg/L as a 30-day average. When early life stages of cold water fish are present, the chronic criteria are more stringent. Under these conditions the 7-day average standard is 9.5 mg/L and the acute criteria is 8.0 mg/L minimum daily DO. Although the all-life-stage criteria are routinely attained in the epilimnion of the reservoir (see Section 3.4.1.4), the current assessment methodology requires attainment in 50% of the water column. During stratified periods the hypolimnion becomes anoxic and accounts for more than 50% of the water column. Furthermore, although the epilimnion has sufficient levels of DO for fish, the water temperature in this upper layer is too warm for most cold water fish species.

In the interim, although new assessment methods are developed, site-specific assessment methods have been identified for East Canyon Reservoir, in conjunction with the Utah Division of Wildlife Resources, for the purposes of developing this TMDL. These assessment methods, described in Section 7.2.1.1, are specific to the intersection of the acute DO standard of 4.0 mg/L and the temperature standard of 20^{o}C in 2 m of the metalimnion. Establishing a 2-m refuge for cold water game fish in the metalimnion, where both temperature and DO criteria are simultaneously attained, is believed to be protective of the existing cold water fishery in East Canyon Reservoir.

EPA guidance recommends the development of a phased TMDL when water quality standards are expected to be revised in the near future. A phased TMDL allows for TMDL revisions to comply with new standards (or in this case assessment methodology) in the future. For this reason, the UDWQ has elected a phased TMDL approach for the East Canyon Reservoir TMDL. EPA guidance also recommends the use of a phased TMDL when there is uncertainty associated with the TMDL analysis. Uncertainty in the East Canyon Reservoir TMDL is associated with the following factors:

- Total phosphorus and DO linkage
- Nonpoint source reduction effectiveness
- Time required to achieve all water quality standards

EPA recommends that phased TMDLs include implementation and monitoring plans as well as a scheduled time frame for revision of the TMDL. The implementation plan (see Chapter 9) developed to attain the load reductions to East Canyon Reservoir identified in this TMDL includes all of the required components of a watershed-based plan (EPA 2008), including a monitoring plan. Interim water quality milestones have also been identified in the watershed-based implementation plan.

In addition, UDWQ has scheduled the East Canyon Reservoir TMDL to be reevaluated in 2019. Ten years is believed to be an appropriate amount of time for revisiting the East Canyon Reservoir TMDL for the following reasons:

- Ten years provides sufficient time for implementation of nonpoint source management measures and for monitoring their effectiveness in improving water quality.

- Expansion of the ECWRF, the point source in the watershed, is expected to commence in 2011 with a completion date of 2015. Ramp up to full capacity of the expanded treatment facility is not expected until 2038 under current growth conditions, so there is no immediate threat of a higher phosphorus wasteload associated with this source.
- Ten years is a sufficient period of time for the reservoir to flush the majority of excess phosphorus residing in bottom sediment and/or for sediments that are less phosphorus rich to cover the top of the existing sediment. Release of excess phosphorus has been documented in the past five years and is associated with reduced total phosphorus inputs to the reservoir.
- Revisions to water quality standards and assessment methodology will be completed in this time frame.

If water quality targets have not been achieved by 2019, UDWQ will reevaluate the East Canyon Reservoir TMDL and consider the following additional steps:

- Use Attainability Analysis
- Site-specific water quality standards
- examination of other causative factors of the low DO water quality impairment such as water management or organic matter loading

These steps would only be taken after nonpoint source reduction projects have been fully implemented. At this point, further phosphorus reductions would be difficult to attain due to the high background load of phosphorus in the watershed associated with naturally occurring phosphatic shales. If nonpoint source projects have not been fully implemented by 2019, a formal water quality trading program would be considered.

7.2 WATER QUALITY TARGETS AND LINKAGE ANALYSIS

Setting water quality endpoints is critical in the TMDL development process. The goal of the East Canyon Creek and East Canyon Reservoir TMDLs is to achieve state water quality criteria to bring designated beneficial uses into full support as quickly as possible. Setting appropriate water quality endpoints is a key prerequisite to the calculation and apportionment of current pollutant loads and the necessary load reductions to support designated beneficial uses. Several methods were employed to derive water quality endpoints for East Canyon Creek and East Canyon Reservoir.

The State of Utah has designated East Canyon Reservoir and East Canyon Creek as protected for cold water game fish (Class 3A). This designated beneficial use was identified as impaired on the State of Utah 1998 303(d) list for the reservoir and the 1992 303(d) list for the creek. Dissolved oxygen endpoints are based on State Water Quality criteria and, together with warm temperatures, are the direct cause of the impairment of cold water fisheries (3A) in the creek and reservoir. Low DO in the reservoir is related to the decomposition of algae and subsequent depletion of DO in the hypolimnion. Low DO in the creek is primarily related to respiration of macrophytes and periphyton, in addition to sediment oxygen demand from decaying organic matter. Macrophyte- and algae-related endpoints were selected based on the direct and indirect influence of plant biomass on DO concentrations in both waterbodies and identified nuisance algal thresholds that are considered to be protective of recreational beneficial uses in the reservoir. These endpoints were based on several recent studies of water quality in the East Canyon watershed (East Canyon SVAP; SBWRD 2005; BIO-WEST 2008; Baker et al. 2008; SBWRD 2008; see Chapter 4 for summary), a review of relevant scientific literature, and results from the East Canyon Reservoir W2 model developed by JM Water Quality LLC. Total phosphorus endpoints for the reservoir are based on the correlation between chlorophyll *a* targets and mean seasonal total phosphorus concentration derived from the W2 modeling results. No nutrient targets have been established for East Canyon Creek because the DO impairment in East Canyon Creek was found to be due to physical stream conditions characterized as light, temperature, and low flow ***pollution*** rather than by nutrient ***pollutants***.

7.2.1 DISSOLVED OXYGEN ENDPOINTS

Dissolved oxygen is important to the health and viability of the cold water fishery beneficial use (3A). High concentrations of DO (6.0–8.0 mg/L or greater) are necessary for the health and viability of fish and other aquatic life. Low DO concentrations (less than 4.0 mg/L) cause increased stress to fish species, lower resistance to environmental stress and disease, and result in mortality at extreme levels (less than 2.0 mg/L).

7.2.1.1 East Canyon Reservoir

The DO endpoints for East Canyon Reservoir are consistent with existing Utah water quality criteria and were developed in collaboration with the Utah Division of Wildlife Resources. During periods of complete mixing in the reservoir, all life-stage water quality criteria identified by the State of Utah will be maintained across the reservoir and throughout at least 50% of the water column. The DO criteria include 4.0 mg/L as a 1-day minimum, 5.0 mg/L as a 7-day average, and 6.5 mg/L as a 30-day average. Cold water sport fish species are not known to reproduce in the reservoir, therefore the early life-stage criteria do not apply. These criteria are all currently attained in the epilimnion of the reservoir. However, the epilimnion routinely exceeds temperature criteria during the summer season due to solar radiation (see Section 3.4.1.4). To protect the fishery from the intersecting pressures of high temperature in the epilimnion and low DO in the hypolimnion, the following site-specific assessment methodology was selected for this TMDL: During periods of thermal stratification, the minimum DO criteria of 4.0 mg/L and maximum temperature of 20^{o}C shall be maintained in a 2-m layer across the reservoir to provide adequate refuge for cold water game fish. These criteria were determined to provide sufficient support for the cold water game fish beneficial use (3A) designated by the State of Utah for East Canyon Reservoir.

These endpoints apply to normal climatic conditions defined by variable hydrologic conditions across consecutive years, with annual flow within 50% of the 30-year average and current water management regimes. Under conditions of consecutive drought or wet-flow years, the criteria may not be achieved. In addition, periods of extreme spring runoff flows or summer storms may produce conditions that periodically do not attain the criteria. These criteria were used to derive total and dissolved phosphorus endpoints for the reservoir as well as algal-related endpoints. Water quality could also be affected, both positively and negatively, in the future under different water management practices. For example, the Bureau of Reclamation is currently considering a proposal by Summit Water to withdraw up to 12,500 acre-feet/year of water from East Canyon Reservoir for use in Snyderville Basin and Park City area (BOR 2008).

7.2.1.2 East Canyon Creek

The DO criteria identified for creeks and streams requires that DO be maintained above 4.0 mg/L DO to fully support the cold water fishery beneficial use. Attainment of the acute 1-day criterion of 4 mg/L is considered to also represent compliance with the 7-day and 30-day criteria. Therefore, the 1-day criterion was used to assess proposed scenarios using the DIURNAL model.

The only cold water game fish found to spawn in East Canyon Creek is Brown Trout (personal communication between Erica Gaddis, SWCA and Paul Burnett, Utah Division of Wildlife Resources, September 18, 2008). Brown trout spawn in late fall (November or early December) and hatch in late February or early March. The small alevins remain in the nest for five to six weeks before emerging from the gravel as fry around mid-April. The period following emergence from the gravel is the most critical period of the life cycle which continues through mid-May. The trout remain in their natal stream as juveniles for the first year of the life cycle. The most critical period for high DO during the spawning period is while the eggs are in the nest (Elliott 1994). Therefore, early life-stage criteria for DO apply from November through May in East Canyon Creek. These criteria require that DO be maintained above 8.0 mg/L DO. Attainment of the acute 1-day criterion of 8 mg/L is considered to also represent compliance with the 7-day and 30-day criteria. There are currently no documented exceedances of the early life-stage criteria during the period of November through May. Because spawning does not occur during summer months (June, July, and August) these early life-stage criteria do not apply. The all life-stage criteria, which do apply during summer months, have been used as the primary endpoints for the East Canyon Creek TMDL.

7.2.2 Macrophyte-related and Algae-related Endpoints

Overgrowth of algae violates the narrative standard for waters established by the State of Utah, which requires waters to be maintained such that they do not become offensive by "unnatural deposits, floating debris, oil, scum, or other nuisances such as color, odor or taste…or result in concentrations or combinations of substances which produce undesirable human health effects…" (Utah State Code, Title R317).

Macrophyte and algae can have both beneficial and detrimental impacts on aquatic life in shallow freshwater ecosystems. Macrophytes and algae provide habitat and food; however, diurnal oxygen fluctuations related to nocturnal plant respiration are stressful to fish. Plant overgrowth and high water temperatures can exacerbate water quality conditions. High rates of plant growth and respiration cause diurnal DO fluctuations, and elevated temperature reduces the solubility of oxygen in water while increasing the metabolic requirements of fish. High water temperatures often occur near the surface, and fish seek deeper levels to avoid the warmer water, but deeper waters in the systems addressed here are more likely to be anoxic or low in DO and therefore are of limited use as refugia for fish. Developing embryos and young emergent fish are especially sensitive to changes in DO concentrations. Small fish would likely seek shelter along creek shoreline (littoral) areas, which provide the best vegetative cover. As these areas experience the changeover from photosynthesis to respiration at night, the shallow water column can quickly become depleted of oxygen and young fish can be stressed or die due to low DO concentrations.

In addition to algal overgrowth, algae speciation is important for protection of beneficial uses in East Canyon Creek and East Canyon Reservoir. Blue-green algae blooms can cause the formation of surface scums and the potential release of toxins harmful to humans, livestock, and pets. Although there are no reports of toxic cyanobacteria blooms in the East Canyon watershed, the potential for blooms has been demonstrated by the episodic dominance of blue-green algae species in the reservoir (see Sections 3.2.2.2 and 3.4.2.5). Macrophyte- and algae-related endpoints were selected to reduce the direct and indirect effects of plant overgrowth on DO concentrations, and to be protective of recreational beneficial uses.

7.2.2.1 East Canyon Reservoir

Macrophyte-related and algae-related water quality endpoints were selected to reduce the direct and indirect influence of decomposition associated with degradation of algal bloom biomass on DO concentrations. Periodic overgrowth of algae violates the narrative standard for waters established by the State of Utah. Therefore, algal endpoints were also selected for their protection of recreational beneficial uses. Three algal related endpoints were identified for East Canyon Reservoir:

1. Mean seasonal chlorophyll *a* values of 8.0 μg/L (based on a mean TSI value of less than 50)
2. Chl *a* concentrations to exceed nuisance threshold of 30 μg/L less than 10% of the season.
3. Maintain dominance by algal species other than blue-green algae

The mean seasonal chlorophyll *a* endpoint was derived from the Carlson Trophic State Index equation and corresponds to a chlorophyll *a* TSI of 50. Analysis of current data for the reservoir indicates that total phosphorus and Secchi depth TSIs may not be appropriate for East Canyon Reservoir due to the unique hydrodynamic characteristics of the system. Therefore, only the chlorophyll *a* TSI was used to derive endpoints for the reservoir.

A review of the recreational use literature indicates that nuisance algal concentrations for recreational beneficial uses range from 25 μg/L (Walker 1985; Raschke 1994) to 40 μg/L, with severe nuisance concentrations recognized as occurring above 60 μg/L (Heiskary and Walker 1995). Human perceptions of aesthetics and swimability are subjective and dependent on the expectations and tolerances of the public. One way to quantify the effect of chlorophyll *a* on these uses is to survey users of a waterbody and correlate their responses to water quality variables (e.g., chlorophyll *a*, Secchi disk depth, and phosphorus). This method has been used by several authors. Heiskary and Walker (1988) collected user-perception data from three groups of lake monitors in Minnesota. User survey responses were used to assign four support levels of the "swimmable" designated use (Smeltzer and Heiskary 1990). The four support levels are presented in Table 7.1.

Table 7.1. Summary of Support of Swimming Designated Use at Varying Frequencies of High[1] Algal Levels

Frequency of High Algal Levels	Support Levels of the Recreation Designated Uses
<10%	Fully supporting
11–25%	Fully supporting—threatened
26–50%	Partial support—impaired
>50%	Nonsupport—impaired

Source: Smeltzer and Heiskary 1990.
[1] The perception of 'high' algal levels was found to differ by region.

Mean chlorophyll *a* concentrations detected in East Canyon Reservoir from 2002 to 2007 ranged from 1.4–5.4 μg/L with a maximum concentration of 27.1 μg/L, which is below the literature-based threshold identified as protective of recreational activities (15–30 μg/L). However, these data are considered to be an underrepresentation of chlorophyll *a* in the reservoir due to wind patterns and sampling frequency. Nonetheless, there have been no visitor reports of "unswimmability" or aesthetic complaints related to algae in East Canyon Reservoir (see Sections 3.4.2.7 and 3.4.4).

A summary of chlorophyll *a* data from 1990 to 1998 in Ecoregion 2 (Western Forested Mountains) is provided below (Table 7.2). The statistical summaries are based on data from 441 lakes and reservoirs and include 3,931 records for chlorophyll *a*. The nutrient criteria technical guidance manual (EPA 2000) suggests that the lower 25th percentile of ecoregional data is representative of the reference condition, when not all lakes and reservoirs are considered to be in the reference condition. The 25th percentile data for ecoregion range from a low of 1.4 μg/L in the summer to a high of 3.5 μg/L in the winter. These values are below the range of the chlorophyll *a* endpoint recommended for East Canyon Reservoir and provide assurance that the targets are achievable and are not excessively low.

Table 7.2. Summary Statistics for Chlorophyll *a* (*µg*/L) Data from Lakes and Reservoirs in the Western Forested Mountains Ecoregion

Season	25th Percentile	Median	75th Percentile
Fall	1.8	3.1	6.7
Spring	2.1	4.4	8.6
Summer	1.4	2.9	5.9
Winter	3.5	5.8	6.2

Prior to 2003, blue-green algae dominated the East Canyon Reservoir system from approximately July to the end of October. Since phosphorus reductions were implemented in 2004, algal succession has shifted from July blue-green algal blooms to late October blooms. After 2006, blue-green algae were estimated to compose less than 5% of the total annual algal biomass both in the phytoplankton count data (Rushforth 2001, 2003, 2005, 2007 reports) and in the W2 model simulations. This indicates an attainment of one of the endpoints identified in the 2000 TMDL, which required algal dominance to be other than blue-green. This endpoint remains for the 2008 TMDL.

7.2.2.2 East Canyon Creek

Excessive biological activity during the growing season in the form of periphyton and macrophyte growth was indicated as the cause of low nocturnal DO levels in the original East Canyon Creek TMDL (UDEQ 2000). The 2000 TMDL also listed a maximum macrophyte coverage endpoint of 25–50%. August 2007 macrophyte cover was as high as 80–90% in 2 of 6 reaches sampled (Baker et al. 2008). A TMDL endpoint was not established for periphyton in 2000 (UDEQ 2000a).

July and August 2007 periphyton cover ranged from approximately 5% to 75% cover in the 6 stream reaches sampled (Baker et al. 2008). Baker et al. (2008) found the number of days below 4.0 mg/L DO to be highly correlated with August macrophyte cover (R^2 = 0.93) (2000 monitoring data). This correlation is supported by the DIURNAL model results (SBWRD 2008), which showed reduced diurnal DO swings in response to reduced sunlight. A 25% reduction in maximum photosynthesis P_{max} resulted in an increase in modeled minimum August DO concentrations from 3.7 mg/L to 4.5 mg/L, and a 50% P_{max} reduction increased minimum DO to 5.3 mg/L. Similar responses were predicted for both the Bear Hollow and Blackhawk water quality monitoring stations. A 25% reduction in photosynthesis is expected to achieve the 1-day water quality standard of 4.0 mg/L minimum DO identified by the State of Utah for East Canyon Creek.

Baker et al. (2008) measured total biomass for macrophytes, epiphyton, and epilithon in 6 reaches in East Canyon Creek. A 25% reduction of photosynthetic rate (and biomass) requires total periphyton and macrophyte biomass to be reduced to a maximum of 6.3 mg/cm^2. The recommended biomass was derived from modeled increases in DO with a 25% reduction in photosynthetic rates (P_{max}) and current total periphyton and macrophyte biomass in reaches with minimum DO concentrations less than 4.0 mg/L.

7.2.3 LINKAGE ANALYSES

7.2.3.1 Nutrient Targets and Water Quality Endpoints in East Canyon Reservoir

The primary contributors to low DO in East Canyon Reservoir are sediment oxygen demands related to annual algal blooms, legacy organic matter, and annual organic matter washed into the system. The W2 model found that decomposition of watershed-derived organic matter represented a minor component of oxygen depletion in the hypolimnion (see Section 5.3.3.7). Model simulations indicate that internal phytoplankton production is driven by dissolved phosphorus concentrations in the epilimnion and upper sections of the hypolimnion during stratified periods and in the surface water layers of the reservoir during mixed periods. Algal blooms throughout the year contribute to sediment oxygen demand and oxygen depletion in the reservoir. Dissolved phosphorus is delivered to the epilimnion through three processes: tributary flow directly to the epilimnion (dominates in the spring/summer), sediment release and diffusion up to the epilimnion, and mixing of the water column during fall turnover (dominates in the fall). Reduction of all of these sources is required to reduce the trophic state of the reservoir and improve DO profiles especially during stratification.

The W2 model was used to correlate DO endpoints and chlorophyll *a* endpoints with mean seasonal nutrient concentrations (see Section 5.5). A mean seasonal chlorophyll *a* target of 8 *µg*/L is correlated with a mean total and dissolved phosphorus concentration in the reservoir of 0.04 mg/L and 0.03 mg/L respectively. However, attainment of the DO endpoints specific to East Canyon Reservoir correlate with mean seasonal total and dissolved phosphorus concentrations of 0.03 mg/L and 0.02 mg/L respectively. These concentrations will therefore serve as the nutrient endpoints for East Canyon Reservoir.

7.2.3.2 Stream Characteristics and Water Quality Endpoints in East Canyon Creek

The primary impairment on East Canyon Creek relates to low nocturnal DO caused by respiration of macrophytes and periphyton. The 2000 TMDL had assumed that excess macrophyte and periphyton growth was driven primarily by excessive nutrients (principally phosphorus) in the water column (UDEQ 2000). Phosphorus reductions were intended to produce significant reductions in nuisance macrophyte and/or algal growth that impairs water quality and stream habitat. However, implementation of the 2000 TMDL does not appear to have reduced macrophyte and periphyton biomass. Baker et al. (2008) and HydroQual (SBWRD 2008) determined that the overabundance of aquatic macrophytes in the creek is currently driven by sediment accumulation, widened channel conditions, shallow water levels, low streamflow during the summer, and a lack of stream shading. Phosphorus concentrations were not identified as a controlling factor in algae and macrophyte densities.

Since the 2000 TMDL, there have been dramatic reductions in point source phosphorus, whereas rapid growth and development in the upper watershed have resulted in increased water demand and nonpoint source nutrient and sediment inputs. Sediment loading from nonpoint sources, elevated water temperatures, and overgrowth of algae and macrophytes is currently the primary cause of water quality impairments in East Canyon Creek. Nitrogen has been identified as the most likely limiting nutrient in the water column, pore waters, and sediments, and it appears that phosphorus is no longer the primary factor contributing to low DO concentrations in the creek (Baker et al. 2008). Olsen and Stamp's 2000 study of East Canyon Creek water quality found 30% less macrophyte cover in stream reaches with stable banks, abundant overhanging vegetation, and low percentage of fine sediments. Further, Baker et al.'s 2008 study of East Canyon Creek water quality identified a strong correlation between macrophyte density and low DO concentrations (<4.0 mg/L). Baker et al. (2008) also found higher photosynthetic rates in low-gradient, slow-flowing portions of the creek (see Sections 4.4 and 4.6.5). In support of these findings, the SBWRD (2008) DIURNAL model demonstrated that increased streamflow, increased riparian shading, and changes to stream geometry were all effective in reducing macrophyte productivity and increasing DO concentrations.

Management of physical stream conditions contributing to reduced flows, sediment inputs, and overgrowth of aquatic vegetation will be required to achieve these endpoints. Improvements to stream water quality can be achieved through the following mechanisms: reducing sediment inputs from nonpoint sources and streambank erosion, reducing sediment accumulations, improving stream channel geometry, increasing flows, and increasing riparian stream shading. A 4.0 mg/L daily minimum was used to model water quality and diurnal DO concentrations in response to three potential channel management strategies for East Canyon Creek (SBWRD 2008): increased streamside shading, changes to channel width/depth; and increased base flow using the Bear Hollow and Blackhawk water quality monitoring stations for evaluation (see Table 4.4). For the worst-case month (August), there were improvements in minimum DO levels at all reaches predicted to be impaired using the baseline calibration from 2007 for all of the modeled management scenarios (Table 7.3; SBWRD 2008). A 25% reduction in photosynthetic rate (P_{max}) or an increase in flow of 5 cfs during August would lead to attainment of the DO standard throughout East Canyon Creek.

Table 7.3. Projected Minimum Dissolved Oxygen (mg/L) in August for the Blackhawk and Bear Hollow Reaches of East Canyon Creek under Baseline Conditions and Management Scenarios

	Blackhawk (SVAP rch 23)	Above WWTP (SVAP rch 21)	Bear Hollow (SVAP rch 18)	Mormon Flat (SVAP rch 17)
Baseline				
2007 calibration	3.4	3.6	3.7	3.7
Stream Shade Scenarios (reduction in photosynthetic rate)				
25% P_{max} reduction	4.3	4.5	4.5	4.6
50% P_{max} reduction	5.3	n/a	5.3	n/a
Channel Width Reduction Scenarios				
25% width reduction	3.9	4.1	4.2	4.3
33% width reduction	4.1	n/a	4.3	n/a
Increased Base Flow Scenarios				
5 cfs additional flow	4.6	4.7	5.0	4.4
10 cfs additional flow	4.3	n/a	4.6	n/a

Multiple studies (Feminella et al. 1989; Hill et al. 1995; Kiffney et al. 2003) have demonstrated the effectiveness of riparian shading in limiting aquatic vegetation growth, and have direct applicability to identifying target conditions in East Canyon Creek. Feminella et al. (1989) found a significant negative relationship between periphyton biomass and riparian canopy % cover ($r = -0.67$, $P<0.0001$) for a range of 0–15 mg/cm^2 ash free dry mass (AFDM) and 15–98% canopy cover. The empirical model described in this study was used to link the recommended 25% reduction in photosynthesis (SBWRD 2008) to a recommendation for stream shading. It is assumed that the correlation between periphyton and % riparian shading identified by Feminella et al. (1989) is similar to the relationship between macrophytes and percent shade. The equation developed by Feminella et al. (1989) is

$$y = 7.75 – 0.06x$$

where x = % riparian cover and y = AFDM measured in mg/cm^2. Assuming a macrophyte biomass of 6.8 mg/cm2 (a value that is within the range of macrophyte biomass observed in East Canyon Creek), the model estimated that increasing riparian percent cover from 16% to 44% would reduce macrophyte AFDM by 25%.This model will be applied on a reach-by-reach basis to determine the amount of riparian shading needed to reduce aquatic vegetation cover to levels supportive of a minimum 4.0 mg/L DO concentration.

Chlorophyll *a* concentrations can vary with changing light and self-shading conditions, so AFDM accounts for all components of periphyton growth (algae, fungi, bacteria, detritus) (Feminella et al. 1989). Presumably, macrophytes could be similarly affected by dense cover of epiphyton on leaves or other photosynthetic structures. Periphyton growth in the creek is composed of both epilithon growth attached to structures in the stream channel and epiphyton growth attached to macrophyte structures. Epilithon has been shown to have reduced ratios of photosynthetic rates to biomass due to self-shading (Hill et al. 1995).

The SBWRD (2008) DO modeling study also found a 33% reduction in channel width to be effective in achieving the 4.0 mg/L DO endpoint due to increased depth, increased stream velocity, increased reaeration, and reduced productivity by algae and macrophytes.

Minimum streamflow goals for East Canyon, Kimball, and McLeod creeks were identified in the East Canyon Creek flow augmentation feasibility study to maintain water quality and fish habitat (SBWRD 2005). The recommended flows are 3.5 cfs in upper McLeod Creek; 5 cfs in Kimball Creek (3.5 cfs under extreme conditions); and 6 cfs in East Canyon Creek (3.5 cfs under extreme conditions). These minimum flow goals could be met with the addition of less than 300 acre-feet of water over 2–3 months, an addition of 1.6–2.5 cfs during summer months of dry years. These goals are not attainable with management of existing flows, and will require acquisition of in-stream water rights or direct addition of flow to the creek. The increasing growth and water use demands in the upper East Canyon watershed further limit the feasibility of attaining minimum streamflow goals without explicit changes to water management in the basin. The proposed East Canyon pipeline would pump 5,000 acre-feet of water per year from East Canyon Reservoir back to Snyderville Basin, but would not provide flow augmentation above the Summit Water treatment plant. Increased flow in the creek is expected to increase DO concentrations due to reduced macrophyte and periphyton densities, reduced build-up of sediments, and increased reaeration. The SBWRD (2008) DO model found the proposed 6.9-cfs pipeline flow increase could potentially increase the lowest minimum August DO concentrations in the creek by approximately 0.7–1.3 mg/L. Increased flows are also likely to initially cause the transport of nutrients and organic matter into the reservoir until accumulated sediments, algae, and macrophyte biomass have been removed.

The SBWRD (2008) DIURNAL model recommendations (increased shading, channel modification, and establishing a protected base flow) will be evaluated on a reach-by-reach basis in the implementation phase of this project. An optimal combination of the recommended model parameters (25% reduction in P_{max}, 33% reduction in stream channel width, and a 5-cfs increase in flow) will be developed for each reach based on cost effectiveness and attainability.

Sediment reductions, associated with nonpoint source controls required for the phosphorus reductions identified for East Canyon Reservoir, will provide further improvement to DO and stream geomorphology in East Canyon Creek. Because these reductions were not included in the analysis, they provide an additional conservative assumption to attainment of DO criteria using physical means described above (shade, establishing a protected base flow, and bank stabilization).

7.3 FUTURE GROWTH

The population in Synderville Basin is expected to more than double by 2030. Population estimate reports show Park City growing from 7,497 in 2005 to 16,312 in 2030, a 54% increase. Summit County lands in the Snyderville Basin are expected to accommodate 31,887 people by 2030; a 51% increase from 15,734 people in 2005 (see Section 2.2.2 for population projections). The majority of new residential development is likely to occur on the basin floor and on hillsides with less than a 25% slope. Commercial development will be concentrated along Interstate 80 and Highways 224, 40, and 248. A large portion of the Snyderville Basin is primarily zoned for residential development. The Rural Residential Zone District (Figure 7.1) allows existing residential uses to continue and allows for the construction of new single family dwelling units. The base density is 1 unit/per 20 acres on developable lands and 1 unit/40 acres on sensitive lands. The Hillside Stewardship Zone District accommodates residential development in areas that contain slopes ranging from 15% to 25% with a base density of 1 unit/30 acres on developable lands and 1 unit/40 acres on sensitive lands. Lands in this zone are more susceptible to erosion, and development in these areas may negatively affect water quality. Residential development in the Mountain Remote Zone District is minimal (1 unit/120 acres on developable and sensitive lands) because the location and terrain do not allow for easy access to local service providers. Development in the Mountain Remote Zone is also minimized in order to protect the natural environment and water quality, to lessen fire danger, to minimize viewshed disturbances, and to promote the open space values of the Snyderville Basin (Summit County 2008). Commercial development and light industry are concentrated along I-80 and Highways 224, 40, and 248. Densities for the Community Commercial Zone and Service Commercial/Light Industrial Zone are not specified. In the Neighborhood Commercial Zone, no single structure will contain more than 5,000 square feet.

New residential and commercial development in the Snyderville Basin will require additional connections to the East Canyon Water Reclamation Facility (ECWRF). The service area for the Snyderville Basin Water Reclamation District (Figure 7.2) is virtually identical to the boundaries delineated in Summit County's Snyderville Basin Zoning Map (see Figure 7.1). As evidenced by the land-use map (see Figure 2.14), the majority of undeveloped land is shrub/scrub, agricultural land, open space, or forest. SBWRD has determined that anticipated growth in their service district will require expansion of ECWRF. Current average daily flow from the ECWRF is 2.65 MGD with peak flows of approximately 6 MGD during the peak recreation season in the winter. Accommodation of the expected population growth in the basin will require expansion of the treatment system with an average discharge of 7.2 MGD. The expanded treatment system will be designed such that the concentration of nutrients will remain low, as they are today, with projected average total and dissolved phosphorus concentrations of 0.10 and 0.03 mg/L. The load allocated to the ECWRF is based on these flow and concentration assumptions.

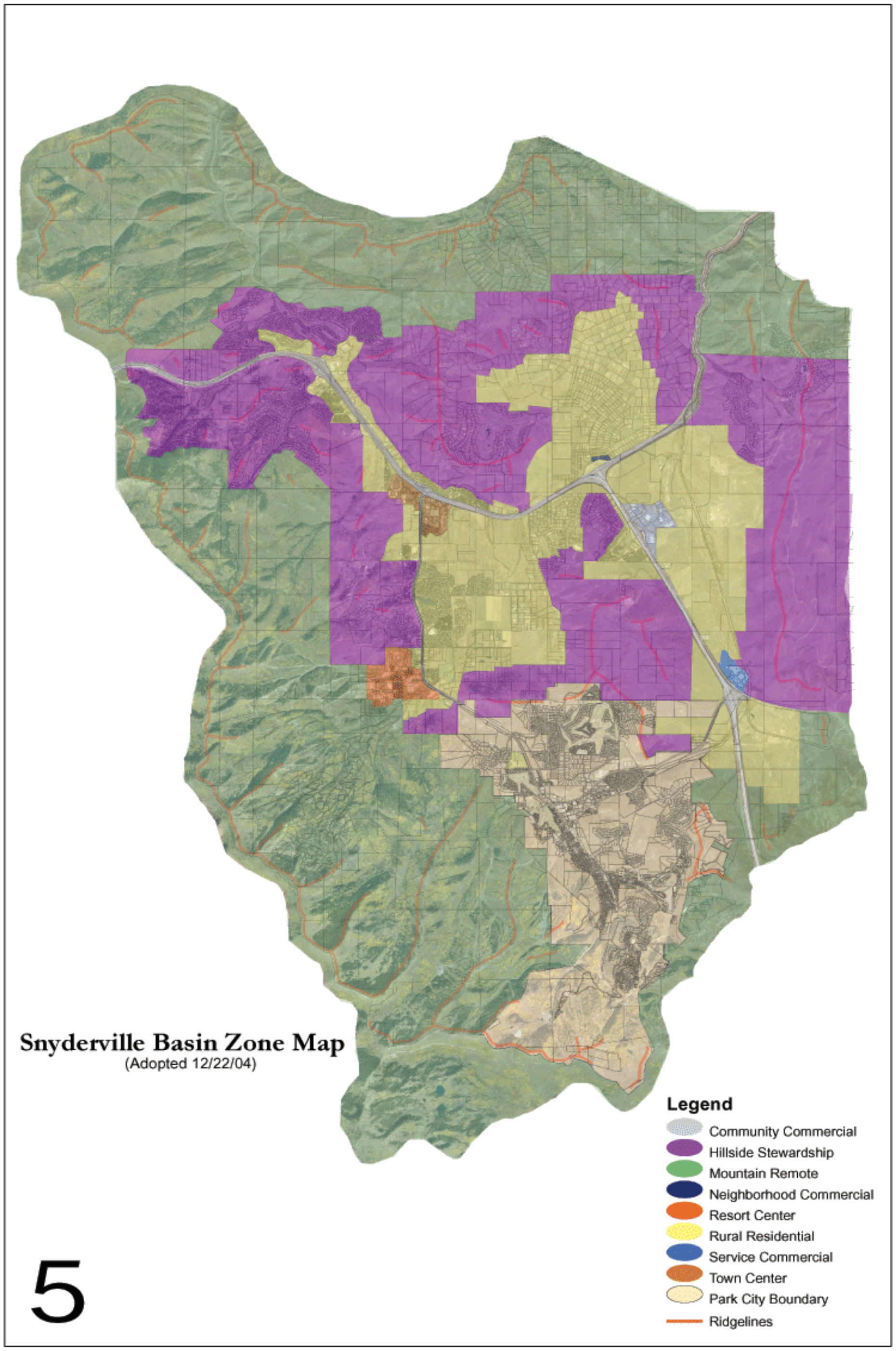


Figure 7.1. Snyderville Basin zoning map (Summit County 2008).

Figure 7.2. Synderville Basin Water Reclamation District (SBWRD) service area.

7.4 TMDL ANALYSIS

7.4.1 CURRENT LOAD SUMMARY AND TMDL

Current loads and TMDL loads, expressed as daily and annual averages, are summarized for East Canyon Reservoir in Table 7.4. Although daily loads are presented in Table 7.4, annual loads are considered to be the most appropriate averaging period for this TMDL. Annual, rather than daily total maximum loads, are the most appropriate for establishing discharge UPDES permits associated with this TMDL. The current total phosphorus load to East Canyon Reservoir is 3,350 kgTP/year (9.2 kgTP/day), including a watershed load of 2,555 kgTP/year (7.0 kgTP/day) and an internal load of 795 kgTP/year (2.2 kgTP/day). The watershed load is currently made up of 483 kgTP/year (1.3 kgTP/day) from the ECWRF and 2,072 kgTP/year 5.7 kgTP/day) from nonpoint sources in the watershed. Results from the East Canyon Reservoir W2 model (see Chapter 5) indicate that attainment of water quality endpoints identified for the waterbody requires a reduction of the total phosphorus load to the reservoir of 730 kgTP/year, which represents an overall reduction of 22% and a total annual phosphorus load of 2,619 kgTP/year. The total annual load corresponds to an average daily load of 7.2 kgTP/day. However, this average could vary with hydrology over the year and is expected to be attained only on average over the course of the year.

Table 7.4 Summary of Maxiumum Total Phosphorus Seasonal and Daily Loads for Attainment of Water Quality Standards in East Canyon Reservoir

	Current Load (2003–2007)		2008 TMDL Load	
	Average Annual (kg/year)	Average Daily (kg/day)	Average Annual (kg/year)	Average Daily (kg/day)
Total Nonpoint Sources	2,072	5.7	1,067	2.9
Total Point Sources (including future growth)	483	1.3	895	2.5
MOS		-	262	0.7
Total Watershed Load	**2,555**	**7.0**	**2,224**	**6.1**
Total Internal Load	**795**	**2.2**	**395**	**1.1**
Total Load To Reservoir	**3,350**	**9.2**	**2,619**	**7.2**

7.4.2 MARGIN OF SAFETY (MOS)

The Clean Water Act requires that the total load capacity "budget" calculated in TMDLs must also include a margin of safety (MOS). The MOS accounts for uncertainty in the loading calculation. The MOS may not be the same for different waterbodies due to differences in the availability and strength of data used in the calculations. The MOS can be incorporated into TMDLs via the use of conservative assumptions in the load calculation or be specified explicitly as a proportion of the total load. The East Canyon Creek TMDL relies on conservative assumptions to meet the MOS requirement. The most important conservative assumption is the exclusion benefits likely to be observed from sediment reduction (associated with nonpoint source controls required for the phosphorus TMDL in the reservoir) on DO and macrophyte growth in East Canyon Creek. The recommendations for physical changes to the creek (establishing a protected base flow, shading, and bank stabilization) should, according to the HydroQual modeling, attain water quality endpoints. Additional improvement associated with sediment reduction provides a margin of safety associated with the analysis. The East Canyon Reservoir TMDL uses an explicit MOS of 10% or 262 kgTP/year.

7.4.3 Load Allocation and Rationale

The changes in allocated and monitored loads from the pre-TMDL period of the 1990s to the implementation of the 2000 TMDL as well as the allocated loads identified for the revised 2008 TMDL for East Canyon Reservoir are summarized in Table 7.5 and Figure 7.3. The 2000 East Canyon TMDL does not account for internal load in the calculation of total current load to the reservoir or in the load allocation for the TMDL (the load was calculated based on the long term annual yield of the watershed to the reservoir at an average total phosphorus concentration of 0.05 mg/L). This is despite numerous acknowledgements of internal loading contributing to the total reservoir load in the Clean Lakes report, upon which the TMDL based most of its findings (Judd 1999). The exclusion of internal sources in the 2000 TMDL was one of the primary critiques of that TMDL. In response to these critiques, UDWQ has sought to improve the 2000 TMDL by including internal sources in the revised 2008 TMDL. For comparison purposes, an internal load has been estimated for the pre-2000 period by calculating the difference in median concentrations of phosphorus at the dam between the pre-2000 TMDL period and the current TMDL period (2003–2007). It was assumed that the outflow load in pre-2000 is proportional to the change in concentration between the two periods (therefore eliminating hydrologic differences from the calculation). Hydrologic data from the pre-2000 period were not used in this estimate, and therefore these estimates should be used only for purposes of comparing loads and allocations between the two TMDLs. Due to the incorporation of internal load in the 2008 TMDL, the total allocated load to the reservoir requires a 40% reduction from the 2000 allocated loads (assuming an allocation to internal sources of the full estimated load occurring prior to 2000).

Future growth projections for the ECWRF require additional allocation to this source above the allocation identified in the 2000 TMDL (663 kgTP/year). In order to compensate for the required increase identified for the point source in the watershed, a 50% reduction from current loads (2003–2007) of other sources (nonpoint and internal reservoir load) has been identified (Table 7.5). Load allocations (LA) require equal reductions from nonpoint sources and internal reservoir sources. Load allocations are distributed among nonpoint source categories in the implementation plan for East Canyon Reservoir watershed. Recommendations for nonpoint source reductions will include all sources and will be based on effectiveness, attainability, BMPs cost, and the goal of spreading the responsibility for water quality improvement among all stakeholders of the watershed.

Table 7.5. Summary of Current Total Phosphorus Load (kg/year) and Load Allocations Identified for the Revised East Canyon Reservoir TMDL

	2000 TMDL Allocated Load	Current Load (2003–2007)	2008 TMDL Allocated Load	Change from Current Load (2003–2007)		Change from Allocated Load (2000)	
	kg/year	(kg/year)	(kg/year)	(kg/year)	Percent	(kg/year)	Percent
Total Nonpoint Sources	1,857	2,072	1,067	-1,005	-49%	-790	-43%
Nonpoint sources	*1,031*						
Reserved for growth	*825*						
Point sources*	663	483	895	412	85%	232	35%
Margin of safety	42	NA	262	262	NA	220	524%
Total Watershed Load	2,562	2,555	2,224	-331	-13%	-338	-13%
Internal reservoir load	**Not calculated** (Estimated 1,744)**	**795**	**395**	**-400**	**-50%**	**-1,379 (Estimated**)**	**-78% (Estimated**)**
Total Load to Reservoir	**Not calculated** (Estimated 4,336)**	**3,350**	**2,619**	**-731**	**-22%**	**-1,717 (Estimated**)**	**-40% (Estimated**)**

**Including future growth for ECWRF*

*** The 2000 East Canyon TMDL does not account for internal load in the calculation of total current load to the reservoir or in the load allocation for the TMDL. For comparison purposes, an internal load has been estimated for the pre-2000 period by calculating the difference in median concentrations of phosphorus at the dam between the pre-2000 TMDL period and the current TMDL period (2003–2007). It was assumed that the outflow load in pre-2000 is proportional to the change in concentration between the two periods (therefore eliminating hydrologic differences from the calculation). Hydrologic data from the pre-2000 period were not used in this estimate and therefore should be used only for purposes of comparing loads and allocations between the two TMDLs.*

Figure 7.3 summarizes the change in allocated and monitored loads from the pre-TMDL period of the 1990s to the implementation of the 2000 TMDL as well as the allocated loads identified for the current 2008 TMDL for East Canyon Reservoir. Overall, ECWRF has been responsible for all of the reductions observed in East Canyon Creek in recent years. ECWRF continues to operate well below its allocated load from the 2000 TMDL. Internal reservoir sources were not considered in the previous TMDL study, therefore total load estimates prior to the TMDL are likely to be higher than those summarized in this revised TMDL.

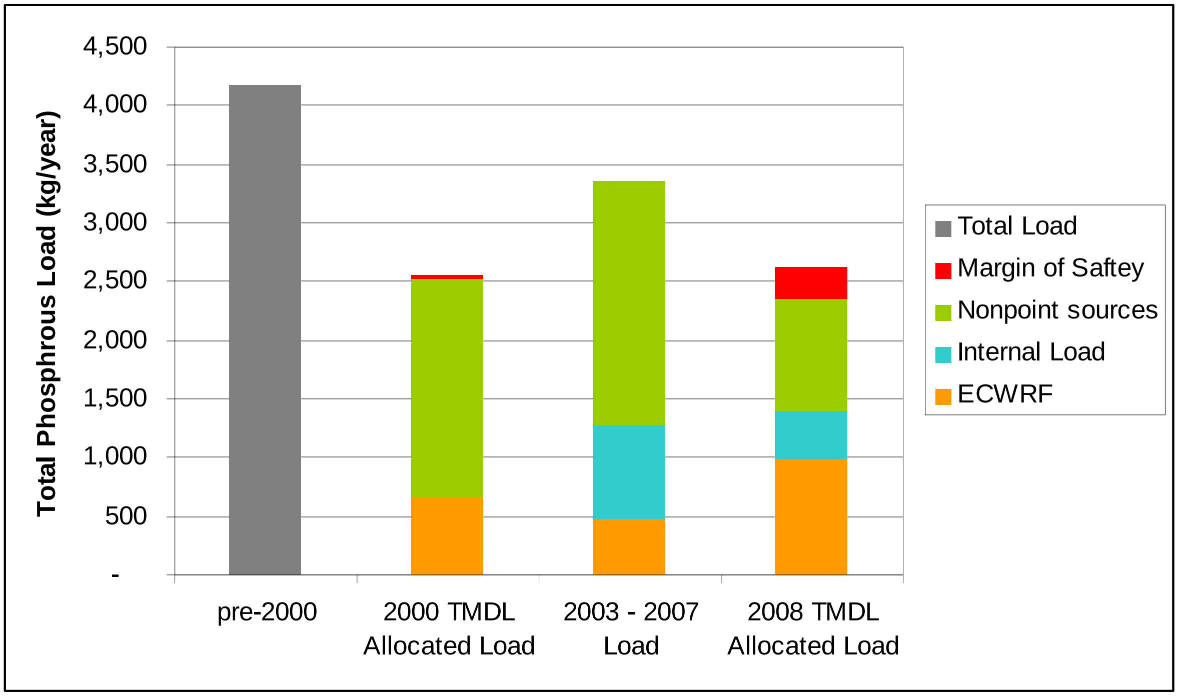


Figure 7.3. Change in total phosphorus load and allocations for the East Canyon Reservoir TMDL.

EPA provides guidance in allocating loads to point and nonpoint sources in TMDLs (EPA 1999). The *Protocol for Developing Nutrient TMDLs* states that dividing the assimilative capacity of a given waterbody among sources should consider the following issues: economics, political considerations, feasibility, equitability, types of sources and management options, public involvement, implementation, limits of technology, and variability in loads and effectiveness of BMPs. All of these have been considered in determining load allocations for the East Canyon Reservoir TMDL. Those that are particularly applicable to the wasteload allocation assigned to ECWRF are limits of technology, feasibility, and economics.

The ECWRF has one of the highest levels of phosphorus treatment of any treatment system in the State of Utah, and their staff is proud of their performance in reducing phosphorus loads to East Canyon Creek, beyond that required by their permit in recent years. In 2007 the average annual effluent concentration was 0.07 mg/L. The low concentrations can be attributed to ECWRF's well-equipped treatment facilities and outstanding management practices. The revised TMDL allocated load for ECWRF of 895 kg/year is based on a 0.09 mg/L permit limit and a flow of 7.2 MGD, which is the projected flow required to accommodate growth in Snyderville Basin over the next 20 to 30 years.

As the ECWRF approaches capacity, consistent attainment of concentrations less than 0.09 mg/L will become more difficult. ECWRF's biological phosphorus (bio-P) removal system relies on the equalization of influent flow to stabilize the food-to-microorganism ratio and to produce the volatile fatty acids necessary for biological phosphorus removal. Consistent attainment is difficult to guarantee due to influent variability and the reduced capacity of the equalization process. The strength, volume, and temperature of the influent wastewater to the system are highly variable due to the seasonality of the resort community served and the high elevation climate of the area. Although the biological phosphorus removal system is relatively stable, significant shifts in flow and strength can jeopardize consistent attainment of concentrations below 0.09 mg/L. Finally, analytical variability at concentrations below 0.1 mg/L TP increases as concentration decreases. The margin-of-error of the analyses can overwhelm the perceived 'actual' result as attempts are made to measure concentrations at very low levels. For these reasons, allocation of a load less than 895 kg/year would result in a higher likelihood of permit exceedance. Exceedance of a permit limit based on a 0.05 mg/L would be almost guaranteed for the system, and exceedance of a limit based on 0.07 mg/L would be highly likely (personal communication between Michael Boyle, SBWRD and Erica Gaddis, SWCA, April 2, 2009).

The use of chemicals is a fundamental component in maintaining the ECWRF average annual concentrations. The chemical phosphorous removal system at the end of the treatment train relies on the optimal mixing of precise amounts of alum and polymer with secondary effluent to ensure the dissolved phosphorus is extracted from the solution. If the mixing process is upset, time would be required to resume optimal chemical phosphorus removal and thus reach the required concentration limit. Further, meeting a concentration limit below 0.09 mg/L would require additional chemical use. The increase in chemicals required to reduce total phosphorus below 0.09 mg/L is non-linear and increases dramatically at each incremental reduction in total phosphorus. This results in significantly more chemical sludge production, which requires hauling and disposal resulting in a significant increase in the waste and carbon footprint of the system. The cost of solids handling and disposal to reduce total phosphorus concentration from 0.09 mg/L to 0.05 mg/L is estimated to be $26,000 per MGD treated. At full capacity, this would represent an additional $187,200 in annual operating costs for the system.

This TMDL has been developed as a phased TMDL in recognition of revisions to assessment methodology by UDWQ that are currently underway. During the first ten-year phase of the TMDL, nonpoint source implementation is expected to achieve water quality targets and to offset the increased load allocated to ECWRF. If water quality targets have not been achieved by 2019, UDWQ will reevaluate the East Canyon Reservoir TMDL and consider the following additional steps:

- Use Attainability Analysis
- Site-specific water quality standards
- examination of other causative factors of the low DO water quality impairment such as water management or organic matter loading

These steps would only be taken after nonpoint source reduction projects have been fully implemented. At this point, further phosphorus reductions would be difficult to attain due to the high background load of phosphorus in the watershed associated with naturally occurring phosphatic shales. If nonpoint source projects have not been fully implemented by 2019, a formal water quality trading program would be considered.

7.5 SEASONALITY

There are two important temporal aspects to the East Canyon Reservoir TMDL: the distribution of phosphorus load across hydrologic periods, and the availability of phosphorus for algal growth during different seasons.

The phosphorus loads from the ECWRF tend to increase during the wintertime recreation season when the population of the watershed increases. Efforts to reduce tributary loads become more of a challenge during the winter months as temporary increases in population provide additional challenges to the naturally occurring processes that occur in the watershed. Fortunately, these peak loading events do not occur during the critical algal growth season. The current permit for ECWRF includes a concentration limit of 0.1 mg/L during the summer months of July, August, and September. Although this seasonal component of the permit was based on the 2001 East Canyon Creek TMDL, it is also protective of the reservoir during the summer seasons when stratified conditions result in direct discharge of tributary dissolved phosphorus to the epilimnion where algal blooms occur.

The distribution of phosphorus load varies considerable with hydrologic events. Spring melt and rain-on-snow events in early spring deliver the majority of the nonpoint source phosphorus load to East Canyon Reservoir. Following stratification during the summer anoxic conditions result in the release of iron-bound phosphorus from sediments. Most of this phosphorus originated in the watershed during the previous year, although some phosphorus represents a historic legacy. Load from the wastewater treatment plant is relatively constant across the year with peak loads occurring during the winter season when tourism related to winter recreation peaks in the area.

Phosphorus is delivered to the photic zone through three different processes: tributary flow directly to the epilimnion, sediment release and diffusion up to the epilimnion, and mixing of the water column during fall turnover. Each of these processes dominates delivery of phosphorus to the epilimnion during different times of the year. Phosphorus contained in spring runoff provides the primary source of phosphorus for algal blooms in the spring and early summer. Most of the nutrients released from sediments in the summer are physically unavailable below the strong thermocline. However, the chilling of the thermocline induces the beginning of fall turnover, and phosphorus is replenished by mixing from deeper layers to the shallow portions of the reservoir. Algal biomass can increase very quickly in the fall, especially if a long period of relatively warm weather follows the first fall chill and turnover.

Therefore, efforts to reduce tributary loads to East Canyon Reservoir should focus on nonpoint source runoff during the spring melt period. Efforts to minimize internal sources of phosphorus should be focused on late summer and early fall.

7.6 SUMMARY

This document represents the revised TMDL analysis for East Canyon Reservoir and East Canyon Creek in north-central Utah. The watershed drains 145 square miles that includes Park City, several major ski resorts, and a portion of Snyderville Basin from the Morgan–Summit county line to the headwaters of East Canyon Creek. The lands in the watershed are almost entirely privately owned. The reservoir shoreline is owned by the State of Utah with unrestricted public access to East Canyon State Park on the eastern side of the reservoir, and restricted vehicle access to the west side of the reservoir. The historical agricultural irrigation use of water has decreased in recent years with a corresponding increase in culinary water use due to increasing population growth, recreation use, and development in the watershed.

The overall goal of the TMDL process is to restore and maintain water quality in East Canyon Reservoir and Creek to a level that protects and supports the designated beneficial uses (domestic water use, primary and secondary contact recreation, cold water game fish, and agricultural water supply). The cold water game fish designated use (3A) was identified as partially supported on the State of Utah 1998

303(d) list (UDEQ 2000a). This led to the development of a TMDL for East Canyon Reservoir in 2000. Since 2000 the only point source in the watershed, the East Canyon Water Reclamation Facility, has reduced nutrient loads to East Canyon Creek significantly. In addition, BMPs have been implemented to reduce nutrient runoff from nonpoint sources throughout the watershed. Load reduction efforts have been reflected in improved water quality in East Canyon Reservoir.

Population in the study area is projected to increase from approximately 24,000 in 2001 to approximately 64,000 in 2030 and to 86,000 by the year 2050. New residential and commercial development in the Snyderville Basin will require additional connections to the East Canyon Water Reclamation Facility (ECWRF). Accommodation of the expected population growth in the basin will require expansion of the treatment system to an average discharge of 7.2 MGD. The expanded treatment system will be designed such that the concentration of nutrients will remain low, as they are today, with projected average total and dissolved phosphorus concentrations of 0.10 and 0.03 mg/L, respectively. Nonpoint sources of pollutants include urban runoff, streambank erosion, agricultural land use, residential and commercial development, and stormwater. Additional phosphorus sources in the watershed consist of naturally occurring phosphatic shales of the Phosphoria Formation located in the southeastern and southwestern portions of the watershed, and phosphorus loading from reservoir sediments due to anoxic conditions.

7.6.1 East Canyon Reservoir

Water quality endpoints identified for the revised East Canyon Reservoir TMDL aim to improve conditions for the cold water fishery beneficial use while also protecting recreational uses of the reservoir. The DO endpoints identified for the reservoir are consistent with existing State Water Quality criteria and were developed in collaboration with the Utah Division of Wildlife Resources. During periods of thermal stratification, the minimum DO criteria of 4.0 mg/L and maximum temperature of 20^{o}C shall be maintained in a 2 meter layer across the reservoir to provide adequate refuge for cold water game fish. These criteria were determined to provide sufficient support for the cold water game fish beneficial use (3A) designated by the State of Utah for East Canyon Reservoir. Macrophyte- and algae-related water quality endpoints were selected to reduce the direct and indirect influence of decomposition associated with degradation of algal bloom biomass on DO concentrations and for the protection of recreational beneficial uses. Three algal related endpoints were identified for East Canyon Reservoir: a mean seasonal chlorophyll *a* value of 8.0 μg/L (based on a mean TSI value of less than 50); chlorophyll *a* concentrations not to exceed a nuisance threshold of 30 μg/L more than 10% of the season; and to maintain dominance by algal species other than blue-green algae. A reservoir model (CE-QUAL-W2) was developed to correlate DO and algal related endpoints to total phosphorus, as well as to describe reservoir dynamics related to seasonality of observed impairments and reservoir dynamics. Attainment of the DO endpoints specific to East Canyon Reservoir correlate with mean seasonal total and dissolved phosphorus concentrations of 0.03 mg/L and 0.02 mg/L, respectively. These concentrations are also predicted to be sufficient to meet all of the algal related endpoints.

The current total phosphorus load to East Canyon Reservoir is 3,350 kgTP/year (9.2 kgTP/day), including a watershed load of 2,555 kgTP/year (7.0 kgTP/day) and an internal load of 795 kgTP/year (2.2 kgTP/day). The watershed load is currently made up of 483 kgTP/year (1.3 kgTP/day) from the ECWRF and 2,072 kgTP/year from nonpoint sources in the watershed. Results from the East Canyon Reservoir W2 model indicate that attainment of reservoir water quality endpoints requires a reduction of the total phosphorus load to the reservoir of 730 kgTP/year, which represents an overall reduction of 22% and a total annual phosphorus load of 2,619 kgTP/year. The total annual load corresponds to an average daily load of 7.2 kgTP/day. However, this average could vary with hydrology over the year and is expected to be attained only on average over the course of year. In addition, future growth projections for the ECWRF require additional allocation to this source above the allocation identified in the 2000 TMDL (663 kgTP/year). To compensate for the required increase identified for this point source, a 50% reduction of other sources (nonpoint and internal reservoir load) has been identified. The East Canyon Reservoir Project Implementation Plan (PIP) that accompanies this TMDL provides reasonable assurance that these load reductions can be attained through implementation of BMPs throughout the watershed in addition to in-reservoir treatments. The PIP identifies land use specific BMPs, priority subbasins for implementation, a time frame for implementation, a coordination plan, a monitoring plan, and unit costs associated with recommended structural BMPs.

7.6.2 East Canyon Creek

The primary impairment on East Canyon Creek relates to low nocturnal DO caused by respiration of macrophytes and periphyton. The 2000 TMDL had assumed that excess macrophyte and periphyton growth was driven primarily by excessive nutrients (principally phosphorus) in the water column (UDEQ 2000b). Phosphorus reductions were intended to produce significant reductions in nuisance macrophyte and/or algal growth that impair water quality and stream habitat. However, implementation of the 2000 TMDL does not appear to have reduced macrophyte and periphyton biomass. Baker et al. (2008) and HydroQual (SBWRD 2008) determined that the overabundance of aquatic macrophytes in the creek is currently driven by sediment accumulation, widened channel conditions, shallow water levels, low streamflow during the summer, and a lack of stream shading. Phosphorus concentrations were not identified as a controlling factor in algae and macrophyte densities.

Results of scenario modeling for East Canyon Creek indicate that the DO endpoint of 4.0 mg/L as a daily minimum would be achieved, even during the worst month (August), with a 25% reduction in photosynthetic rate (P_{max}) or an increase in flow of 5 cfs. The former can be reasonably achieved through riparian plantings that achieve 50% shade of the creek and through the establishment of a protected base flow, both of which are being actively pursued in the watershed to address the latter. The East Canyon Creek PIP that accompanies this TMDL identifies priority reaches for riparian planting, streambank stabilization, and establishment of a protected base flow. The PIP also includes a time frame for implementation, a coordination plan, a monitoring plan, and costs associated with the project.

8. EAST CANYON CREEK IMPLEMENTATION PLAN

8.1 INTRODUCTION

The East Canyon Creek Implementation Plan outlines a strategy to achieve water quality endpoints identified in the TMDL analysis (Chapter 7) for DO and macrophytes. The implementation plan combines recommendations for reduced primary productivity (macrophytes and periphyton) and establishment of a protected base flow in East Canyon Creek during the critical summer period when DO concentrations are too low.

The plan also describes regulatory and voluntary measures needed to achieve pollutant reductions specified by the TMDL. A schedule of BMP implementation, measurements, and milestones will be defined in the implementation plan, but it is not static. The plan is a dynamic document open to changes as new information becomes available. This implementation plan is designed to be a flexible tool for restoring water quality in the East Canyon watershed.

Implementation will be accomplished through the cooperation and assistance of many agencies, organizations and individual stakeholders. The organizations involved include the East Canyon Creek Watershed Committee, the Natural Resources Conservation Service (NRCS), the Utah Association of Conservation Districts (UACD), Kamas Valley Conservation District, the Park City Municipal Corporation, Summit County, Morgan County, the Snyderville Basin Water Reclamation District, and Trout Unlimited, as well as individual landowners and managers located in the watershed.

The implementation proposal includes:

- a description of management actions recommended for implementation to achieve water quality endpoints defined in the TMDL,
- a schedule for implementation to achieve water quality endpoints in a timely manner,
- a follow-up plan for monitoring water quality to determine the effectiveness of the management actions, and
- identified measurable outcomes, which will be reviewed to assess the success of implementation and achievement of water quality endpoints.

8.2 STATEMENT OF NEED

The Federal Water Pollution Control Act (FWPCA) is the primary federal legislation that protects surface waters such as lakes and rivers. This legislation, originally enacted in 1948, was further expanded and enhanced in 1972; at this time it became known as the Clean Water Act (CWA). The main purpose of the CWA is the improvement and protection of water quality through restoration and maintenance of the physical, chemical, and biological integrity of the nation's waters. The CWA provides a statutory means to designate beneficial uses for waterbodies, establish criteria to protect those uses, and to evaluate and report on the health of the nation's waters.

Under Section 303(d) of the CWA, East Canyon Creek has been identified by the State of Utah as water quality–limited due to low DO associated with poor physical stream conditions that allow excessive inputs of light and heat from the sun. The State of Utah has designated the beneficial uses of the creek as domestic water use (1C), primary contact recreation (2A), secondary contact recreation (2B), cold water game fish and the associated food chain (3A), and agricultural water supply (4). The cold water game fish designated use (3A) was identified as impaired on the State of Utah 2006 303(d) list.

8.2.1 SUMMARY OF ENDPOINTS

Two endpoints have been defined for East Canyon Creek: (1) total biomass for macrophytes and periphyton of 6.3 mg/cm^2 (measured as ash-free dry mass) and (2) a minimum (acute) DO of 4 mg/L. A reduction of algal growth and subsequent night time respiration reflected by an ash-free biomass of 6.3 mg/cm^2 was determined through observation and modeling as protective of the fisheries beneficial use, leading to support of the acute DO criteria. The recommended algal biomass was derived from modeled increases in DO with a 25% reduction in photosynthetic rates (P_{max}) and current total periphyton and macrophyte biomass in reaches with minimum DO concentrations less than 4.0 mg/L (see Chapter 7).

8.2.2 DESCRIPTION OF ECOLOGICAL DRIVERS

DO concentrations in water are influenced by water temperature, stream velocity, photosynthetic rate of algae and other aquatic plants, and oxygen demand from decomposing organic matter in the bottom sediments. As a result, solar radiation, air temperature, channel shape, water volume and flow, sediment and nutrient loads, riparian shading, and the amount of aquatic vegetation can all influence DO concentrations.

Stream shading reduces stream temperatures by blocking solar radiation and reducing air temperatures (Hill et al. 1995). Shade is created by riparian vegetation and by topographic features such as channel banks, ridges, and surrounding hills. Macrophyte and periphyton growth, respiration and decomposition contribute to diurnal fluctuations in DO and can be controlled by reducing light availability (EPA 2000b). Riparian vegetation can intercept over 95% of ambient light, resulting in reduced photosynthetically active radiation (PAR) levels that limit plant growth (Steinman 1992; Hill et al. 1995).

DO concentrations increase when stream velocity and turbulence bring more water into contact with air. Aeration of water generally corresponds to flow rate, with higher DO concentrations occurring during periods of high flow and lower DO concentrations occurring during periods of low flow. High water volume and increased flow also decreases the amount of heating and cooling and associated fluctuations in DO concentrations. Increased flow through a healthy riparian area also promotes the channel to deepen, further reducing the amount of photosynthetically available light. As a result, there is less light available to aquatic plants under higher flows and a reduction in DO fluctuations from night to day. Water diversions and decreased streamflow contribute to lower DO concentrations by decreasing water volume and depth, limiting aeration, increasing water temperatures, and decreasing scouring of algae, macrophytes, and sediments.

Following the 2003 upgrade at the ECWRF, HydroQual was retained by the Snyderville Basin Water Reclamation District (SBWRD) to model the linkages between diurnal oxygen fluctuations and other creek parameters including water quality and physical stream habitat characteristics (SBWRD 2008). The steady-state model DIURNAL was selected for its ability to address physical and biochemical reactions and to calculate diurnal DO fluctuations (SBWRD 2008). The scenarios addressed in the modeling include physical changes to the stream such as (1) increasing riparian canopy shading along the creek, (2) changing creek geometry (narrowing and deepening), and (3) modifying creek flow (SBWRD 2008).

The East Canyon Creek implementation plan is based on a 25% reduction in primary productivity and an increase in flow of 5 cfs over baseflow during the critical season of 2007, which were found to be sufficient to achieve the acute DO criteria of 4 mg/L during critical summer low-flow periods (SBWRD 2008). This level of biomass reduction and increased minimum flow recognizes the uncertainty inherent in modeling water quality in a creek affected by various climatic and anthropogenic factors. Following the establishment of a protected base flow and implementation of riparian plantings and bank stabilization, the creek will be reassessed iteratively as part of an adaptive management plan to evaluate water quality improvement.

8.3 PROJECT DESCRIPTION

8.3.1 PROJECT GOALS AND OBJECTIVES

The East Canyon Creek Implementation Plan has been developed to assist in defining the means and methods to achieve water quality endpoints in the watershed. The proposal includes the following:

- Implementation of stream shading (through stream plantings) and establishment of a protected base flow to attain DO and primary production endpoints
- Reduction of sediment load (a substrate for macrophyte growth) through bank stabilization
- Projected costs for implementation
- Funding mechanisms and a proposed schedule of implementation
- Reasonable assurance that the proposed measures are feasible
- Monitoring and progress reporting
- Requirements for Interagency and Stakeholder coordination and cooperation

8.3.2 DESCRIPTION OF IMPLEMENTATION MEASURES

Based on the observed water quality impairments, TMDL endpoints, and the environmental factors discussed above, three primary implementation measures are proposed for East Canyon Creek: increased shading, establishment of a protected base flow, and streambank stabilization. The first two implementation measures are derived from results of the DIURNAL model conducted by HydroQual in 2007 (SBWRD 2008). Bank stabilization will reduce sediment loads to the creek, and thereby reduce macrophyte growth. Bank stabilization will also facilitate narrowing of the stream channel, another recommendation from the DIURNAL model. Each of these measures is described in more detail below, along with a discussion of their benefits and limitations.

8.3.2.1 Shading

Plantings of native willows, cottonwood, and other woody riparian species adjacent to East Canyon Creek will provide additional shade to the creek, reducing light and heat inputs. Shading reduces the growth of macrophytes and algae by limiting photosynthesis, which increases the amount of DO in the creek at night and reduces the amount of fluctuation between daytime and nighttime DO concentrations. Shading also decreases water temperature, thereby increasing the stream's ability to retain oxygen in solution.

Shading via riparian plantings is a relatively inexpensive and effective method for reducing primary productivity in streams. Short reference reaches along East Canyon Creek with dense riparian canopies, (e.g., the Kimball Creek section studied by Baker et al. [2008] within SVAP Reach 25) exhibit relatively high levels of night-time DO. The SVAP inventory of East Canyon Creek (ECRFC 2002) showed that most reaches had less than 20% canopy cover, meaning that there is good potential for increasing shading along the creek. Riparian plantings are included in the following NRCS Conservation Practice Standard Methods and Codes:

- Channel bank vegetation (322)
- Riparian forest buffer (391)
- Stream habitat improvement and management (395)
- Streambank and shoreline protection (580)
- Riparian herbaceous cover (595)

Riparian plantings can be accomplished in sensitive areas without the need for heavy machinery. Other methods to increase riparian shading include pest management (595), irrigation systems and microirrigation (441). Vegetation commonly used in the area for riparian plantings includes several native willows, narrowleaf cottonwood, hawthorn, Woods' rose, and water birch.

A healthy riparian zone provides shade to its stream thereby reducing water temperature and evaporation (National Research Council 2002). Dense riparian vegetation does increase transpiration of water from leaf surfaces, but anecdotal evidence suggests that healthy riparian areas actually increase the duration of flows in intermittent creeks whereas denuded streams run dry more often (Gordon et al. 1992).

8.3.2.2 Establishing a Protected Base Flow

Increases to the "normal" summer flows of East Canyon Creek would help stabilize water temperature, decrease the width-to-depth ratio of the channel, and increase reaeration rates via increased stream velocity. All of these outcomes would also increase the nighttime (nocturnal) DO levels in the creek and reduce primary productivity through scouring of rooted macrophytes.

Establishing a protected base flow in East Canyon Creek could be achieved through enforcement of existing water rights and agreements (thereby reducing diversions) and through acquisition of in-stream water rights with early priority dates. Base flow restoration with an in-stream water right could also prevent future incidences of extremely low flow if the in-stream right had a sufficiently senior priority date, or was from a new water source that superseded existing rights.

Establishing a protected base flow, more than any other implementation measure, would address the lack of water in East Canyon Creek during the critical summer months. If provided in sufficient quantity during critical summer periods, augmented flows would likely prevent impairments associated with low DO almost immediately. The DIURNAL model assessed the effectiveness of increased flows as an implementation measure under two scenarios: (1) the addition of 5 cfs and (2) the addition of 10 cfs to the conditions which the model was calibrated (SBWRD 2008). The worst case modeled scenario occurred in August 2007, when the flow above the ECWRF was approximately 2.7 cfs. DO impairments were observed in multiple reaches when data were collected in August, and the calibrated model showed exceedances in multiple reaches as well, with nocturnal DO readings as low as 3.4 mg/L (see Figure 8.1, Table 8.2). The DIURNAL model predicted that all reaches would be maintained above 4.0 mg/L with an additional 5 cfs, or a total of 7.7 cfs above ECRWRF during this time (SBWRD 2008).

8.3.2.3 Channel Narrowing/Bank Stabilization

Narrowing the low-flow channel of East Canyon Creek was examined as a possible implementation measure by the HydroQual modeling study (SBWRD 2008). Narrowing the low-flow channel of the creek would have many of the same effects as augmenting flow: it would reduce the width-to-depth ratio, increase reaeration of the creek, and increase velocity. As with increased flow, channel narrowing was assessed within the DIURNAL model for its effectiveness in raising DO. Two scenarios were modeled: a 25% narrowing and a 33% narrowing of the channel to which the model was calibrated (SBWRD 2008). Narrowing was not as effective as the other measures that were modeled (reduction of photosynthesis and establishment of a protected base flow). Under the 25% width reduction, the acute standard for DO was not met in all reaches. The standard was barely met (a minimum of 4.1 mg/L) under the 33% reduction scenario. As discussed in Section 8.3.2.4 (Constraints on Implementation), channel narrowing would require acquisition of additional hydraulic and geomorphic information in order to assess feasibility.

Although channel narrowing is not currently feasible, further channel widening could be prevented through bank stabilization. Bank stabilization is recommended as a means to protect riparian plantings and vegetation, prevent further channel widening, and reduce fine sediments in the creek. The Stream Erosion Condition Inventory (SECI) conducted in conjunction with the SVAP (ECRFC 2002) documented extensive active erosion along East Canyon Creek. Bank stabilization measures would not directly improve the DO conditions in the creek, but would prevent further degradation as other implementation strategies take effect. Baker et al. (2008) found that streambank erosion contributes a significant amount of organic matter (2.3 to 7.2 tons/year) and nutrients to the stream, contributing to oxygen demand and low DO concentrations.

Bank stabilization would also protect riparian vegetation that provides shade from erosion as well as new plantings. Stabilizing riparian banks would also reduce sediment delivery to East Canyon Creek, suitable substrate for macrophyte growth and hence macrophyte biomass. Although this effect has not been quantified in the TMDL, it provides additional assurance that a 25% reduction in primary productivity could be achieved through the implementation measures outlined in this plan.

It is recommended that only "soft" armoring approaches and streambank bioengineering techniques be used for bank stabilization projects. Numerous technical references, such as the NRCS's (1998b) Practical Streambank Bioengineering Guide, are available that document these approaches. Techniques may include, but are not limited to, willow fascines, conifer revetments, vegetated soil lifts, and willow walls.

8.3.2.4 Constraints on Implementation

8.3.2.4.1 Constraints on Shading

Although stream shading through establishment of riparian vegetation is relatively effective and feasible, its implementation has several limitations. First, the growing season in the area is short, and riparian plantings are slow to mature. Thus, plantings can take many years before they effectively shade the creek. Second, plantings may require considerable maintenance. Herbivory by beavers and smaller rodents can limit the establishment and growth of plantings, and may require regular mitigation (e.g. fencing, wrapping, or painting plantings with sandy paint). The time required to establish mature vegetation and reduce depredation from herbivory could be reduced through planting larger stock; however, this approach has a higher cost for the plant materials. Plantings are also affected by seasonal climate fluctuations, and can suffer high mortality rates during drought years if they are not irrigated. The local Conservation District has had recent success with stream plantings during the fall season, which avoids high water levels in the spring and dry summer conditions (personal communication between Brendan Waterman, Kamas Valley CD, and Greg Larson, SWCA, on July 21, 2008). Finally, shading is only effective when there is sufficient water in the creek. During extreme low-flow periods (such as 2003, when the creek dried up completely), even 100% canopy cover cannot prevent impairment of beneficial uses.

8.3.2.4.2 Constraints on Establishing a Protected Base Flow

Several obstacles have prevented base flow protection from occurring to date, and could limit its future implementation. Until recently, in-stream flow rights in Utah could only be held by the Utah Division of Wildlife Resources and the Division of State Parks and Recreation. Currently Trout Unlimited (TU), a nonprofit organization, may lease in-stream flow rights from willing sellers. Second, because of the rapid development in the East Canyon watershed and a lack of storage, water rights are extremely expensive due to high demand. Thus, securing "wet" water rights (that can actually deliver water during the extremely high demand of the critical summer months) is very difficult and expensive.

8.3.2.4.3 Constraints on Channel Narrowing

Channel narrowing has several limitations on its effective implementation. First, implementation would require significant hydraulic and geomorphic data that are not currently available. Although narrowing the channel may improve DO levels during low-flow periods, the channel must be large enough to convey large spring runoff flows. Although a typical summer low-flow above the ECWRF outlet may only be 4 cfs, spring runoff often runs at greater than 200 cfs. Thus, any reduction of channel width and capacity must account for high flows in order to prevent excessive flooding, property damage, and increased erosion downstream. Anecdotal evidence suggests that the creek's channel has become wider and shallower than it was historically, but there are no data to document this. Detailed geomorphic data would be required to appropriately design projects that do not threaten downstream segments with downcutting or flooding. Second, channel narrowing would likely require significant disturbance and heavy equipment in order to be implemented. For these reasons, narrowing is not included in this implementation plan, although it is recommended that it be considered for future implementation if needed.

8.3.2.5 Summary of Implementation Approaches

Each of the implementation approaches described above has different time frames for implementation, certainty of success, and feasibility for implementation (Table 8.1). In general, shading has the lowest risk of failure due to its high feasibility and high certainty of success. However, it has a long time frame for effectiveness, particularly if young stock or cuttings are used. Once implemented, base flow protection has the fastest and most certain level of effectiveness. However, the feasibility of securing senior water rights is not very good, as well as the long-term sustainability of in-stream flow rights. Narrowing the stream channel has a low level of certainty and is not recommended at this time. Its feasibility and time frame depend on the techniques selected and future studies of the creek.

Table 8.1. Trade-offs in Time Frame, Uncertainty, and Feasibility for East Canyon Creek Implementation Measures

Measure	Time Frame	Certainty	Feasibility
Shading	Slow	High	High
Base Flow Restoration	Fast	High	Moderate
Channel Narrowing	Variable	Low	Moderate

8.3.3 PRIORITIZATION OF STREAM REACHES

8.3.3.1 Prioritization for Shading and for Establishing a Protected Base Flow

The reaches defined in the SVAP study are used in this implementation plan to divide the creek into homogeneous segments. Results from the Baker et al. (2008) study and the DIURNAL modeling results conducted by HydroQual (SBWRD 2008) were matched to these SVAP reaches to provide a more comprehensive understanding of each reach. Whereas the SVAP data provides an overall summary of geomorphic condition, the Baker et al. (2008) study provides detailed information on macrophyte and periphyton biomass and nutrient cycling for 6 of the 14 SVAP reaches (reaches 14, 18, 19, 21, 23, and 25). The DIURNAL model was calibrated to the same 6 reaches studied by Baker et al. (2008); however, model output was generated for each of the SVAP reaches under baseline (current) conditions as well as for the shading and increased flow scenarios. Together, the results from these three studies were used in prioritizing reaches for shading and base flow protection in East Canyon Creek.

Each SVAP reach was assigned a priority of 1 (high) to 5 (low) for implementation of shading and flow augmentation measures. These prioritizations were based on several factors: (1) observed and modeled DO levels and impairment, (2) riparian zone condition from the SVAP, (3) location relative to the ECWRF, and (4) canopy cover. Because canopy cover was almost uniformly less than 20% in each SVAP reach, the rankings were largely determined by the other parameters. Reaches with DO impairments were prioritized as either a priority 1 or a priority 2 on the basis of their position relative to the ECWRF.

Because reaches downstream of the ECWRF are less prone to extremely low (or zero) flow conditions due to the discharge of treated effluent, those reaches were assigned a slightly lower priority. Reaches without impairments were prioritized on the basis of their DO levels and the condition of their riparian zone (SVAP). These categories and the resulting prioritization are shown in Figure 8.1 and Table 8.2, along with selected values from the SVAP (ECRFC 2002) and the Baker and HydroQual studies associated with each reach. The prioritizations are further summarized in Table 8.4.

Table 8.2. Summary of Reach-specific SVAP, DIURNAL Model Output, and Baker et al. (2008) Study Results and Priority Rank: Shade

			SVAP Results[a]							SVAP Combined Ratings				USU/HydroQual Findings													
Shade Priority Rank	SVAP Reach Number	Length (miles)	Channel Function	Channel Condition	Hydrologic Alteration	Bank Stability	Pools	Canopy Cover	Canopy Cover (%)	Excess Nutrients	Fisheries Habitat	Riparian Habitat	Channel Function	USU/HydroQual Site	Stream Metabolism (August GPP, gO2/m2/day)	Stream Reaeration Coefficient	Baseline Min DO in August (reach minimum)	Baseline Min DO in August (reach average)	Observed DO Impairment	Modeled DO Impairment	25% Reduction in Pmax (Min DO in August)	25% Reduction in Channel Width (Min DO in August)	5 cfs Additional Flow (Min DO in Aug)	Epilithon Chl a (g/m2)	Epiphyton (g/m2)	Macrophyte (g/m2)	Sediment Organic Matter
1	22	1.5	Good	7	9	6	3	1	<20%	6.67	4.43	3.5	7.33				3.6	3.6		Yes	4.5	4.1	4.6				
1	23	1.3	Good	8	8	6	6	1	<20%	6.67	4.14	3.0	7.33	Blackhawk	7.86	17.7	3.4	3.8	Yes	Yes	4.3	3.8	4.5	168	52	157	0.30
1	21	1.0	Good	6	9	5	3	1	<20%	6.00	4.43	3.5	6.67	Above ECWRF	9.85	13.7	3.6	4.4	No	Yes	4.5	4.1	4.7	354	8	32	1.30
2	17	1.6	Poor	9	3	5	7	1	<20%	5.50	7.00	5.0	5.67				3.7	3.7		Yes	4.6	4.3	4.4				
2	18	3.0	Poor	7	3	6	3	1	<20%	5.50	6.14	4.5	5.33	Bear Hollow	21.4	21.3	3.7	4.5	Yes	Yes	4.7	4.0	4.6	70	6	46	1.10
3	19	1.3	Poor	2	8	8	6	1	<20%	2.67	4.57	1.0	6.00	Below ECWRF	3.63	10.8	4.8	4.8	No	No	5.5	4.9	5.3	116	8	67	0.57
3	24	0.9	Poor	8	6	5	4	1	<20%	4.25	3.79	1.0	6.17				4.8	4.8		No	4.9	4.6	4.9				
3	26	2.2	Good	8	9	8	2	1	<20%	6.00	4.86	1.5	8.33				n/a	n/a		n/a	n/a	n/a	n/a				
4	16	1.5	Poor	5	6	3	3	1	<20%	3.50	4.43	5.0	4.67				5.1	5.2		No	5.1	4.5	4.9				
4	20	0.9	Good	9	9	7	3	1	<20%	3.67	4.00	5.0	8.33				5	5.6		No	5.3	4.8	5.4				
4	15	2.9	Poor	7.5	7	3	3	1	<20%	3.50	5.29	2.5	5.83				5.4	6.2		No	5.4	4.8	5.2				
5	14	1.9	Good	9	3	8	3	3	20–50%	5.00	5.43	5.5	6.67	RV Park	7.16	54.8	6.2	6.4	No	No	6.5	6.3	6.4	73	14	51	0.84
5	25	1.0	Good	9	9	10	7	1	<20%	7.25	7.57	4.5	9.33	Kimball Creek	4.22	16.1	n/a	n/a	No	n/a	n/a	n/a	n/a	202	3	56	4.40

Table 8.3. Summary of Reach-specific SVAP, DIURNAL Model Output, and Baker et al. (2008) Study Results and Priority Rank: Bank Stabilization

			SVAP Results[a]						SECI[b]	SVAP Combined Ratings				USU/HydroQual Findings													
Bank Stabilization Priority Rank	SVAP Reach Number	Length (miles)	Channel Condition	Hydrologic Alteration	Bank Stability	Pools	Canopy Cover	Canopy Cover (%)	Tons/Year/Mile Erosion	Excess Nutrients	Fisheries Habitat	Riparian Habitat	Channel Function	USU/HydroQual Site	Stream Metabolism (August GPP, gO2/m2/day)	Stream Reaeration Coefficient	Baseline Min DO in August (reach minimum)	Baseline Min DO in August (reach average)	Observed DO Impairment	Modeled DO Impairment	25% Reduction in Pmax (Min DO in August)	25% Reduction in Channel Width (Min DO in August)	5 cfs Additional Flow (Min DO in Aug)	Epilithon Chl a (g/m2)	Epiphyton (g/m2)	Macrophyte (g/m2)	Sediment Organic Matter
1	24	0.9	8.0	6	5	4	1	<20%	168.8	4.25	3.79	1.0	6.17				4.8	4.8		No	4.9	4.6	4.9				
1	21	1.0	6.0	9	5	3	1	<20%	155.9	6.00	4.43	3.5	6.67	Above ECWRF	9.85	13.7	3.6	4.4	No	Yes	4.5	4.1	4.7	354	8	32	1.30
2	15	2.9	7.5	7	3	3	1	<20%	145.4	3.50	5.29	2.5	5.83				5.4	6.2		No	5.4	4.8	5.2				
2	18	3.0	7.0	3	6	3	1	<20%	140.0	5.50	6.14	4.5	5.33	Bear Hollow	21.40	21.3	3.7	4.5	Yes	Yes	4.7	4.0	4.6	70	6	46	1.10
3	16	1.5	5.0	6	3	3	1	<20%	121.2	3.50	4.43	5.0	4.67				5.1	5.2		No	5.1	4.5	4.9				
3	17	1.6	9.0	3	5	7	1	<20%	118.6	5.50	7.00	5.0	5.67				3.7	3.7		Yes	4.6	4.3	4.4				
3	20	0.9	9.0	9	7	3	1	<20%	78.6	3.67	4.00	5.0	8.33				5.0	5.6		No	5.3	4.8	5.4				
4	23	1.3	8.0	8	6	6	1	<20%	44.3	6.67	4.14	3.0	7.33	Blackhawk	7.86	17.7	3.4	3.8	Yes	Yes	4.3	3.8	4.5	168	52	157	0.30
4	22	1.5	7.0	9	6	3	1	<20%	42.0	6.67	4.43	3.5	7.33				3.6	3.6		Yes	4.5	4.1	4.6				
5	19	1.3	2.0	8	8	6	1	<20%	7.2	2.67	4.57	1.0	6.00	Below ECWRF	3.63	10.8	4.8	4.8	No	No	5.5	4.9	5.3	116	8	67	0.57
5	14	1.9	9.0	3	8	3	3	20–50%	5.7	5.00	5.43	5.5	6.67	RV Park	7.16	54.8	6.2	6.4	No	No	6.5	6.3	6.4	73	14	51	0.84
5	25	1.0	9.0	9	10	7	1	<20%	4.4	7.25	7.57	4.5	9.33	Kimball Creek	4.22	16.1	n/a	n/a	No	No	n/a	n/a	n/a	202	3	56	4.40
5	26	2.2	8.0	9	8	2	1	<20%	1.1	6.00	4.86	1.5	8.33				n/a	n/a		No	n/a	n/a	n/a				

[a]SVAP ranking definitions (NRCS 1998a): Channel condition refers to a stream's qualitative naturalness or level of alteration, proper function (as evidenced by downcutting, aggradation, or lateral movement), restriction of floodplain access (by dikes or levees), and the amount of riprap and channelization present. Hydrologic alteration refers to the effects withdrawals on a reach's habitat, as well as the streams' connection to floodplains in the reach. Bank stability incorporates measures of perceived stability, root protection of eroding areas, and the extent of observed erosion. Pools are measured in terms of depth and abudance. Canopy cover is assessed on the basis of the percentage of the stream that is shaded by riparian canopy and the degree of shading in upstream reaches. Rankings are from 1(low) to 5(high). Combined SVAP rankings incorporate severate SVAP results into one overall measure.

[b]SECI: The Stream Erosion Condition Inventory (SECI) was conducted in conjunction with the SVAP study and documented extensive active erosion along East Canyon Creek.

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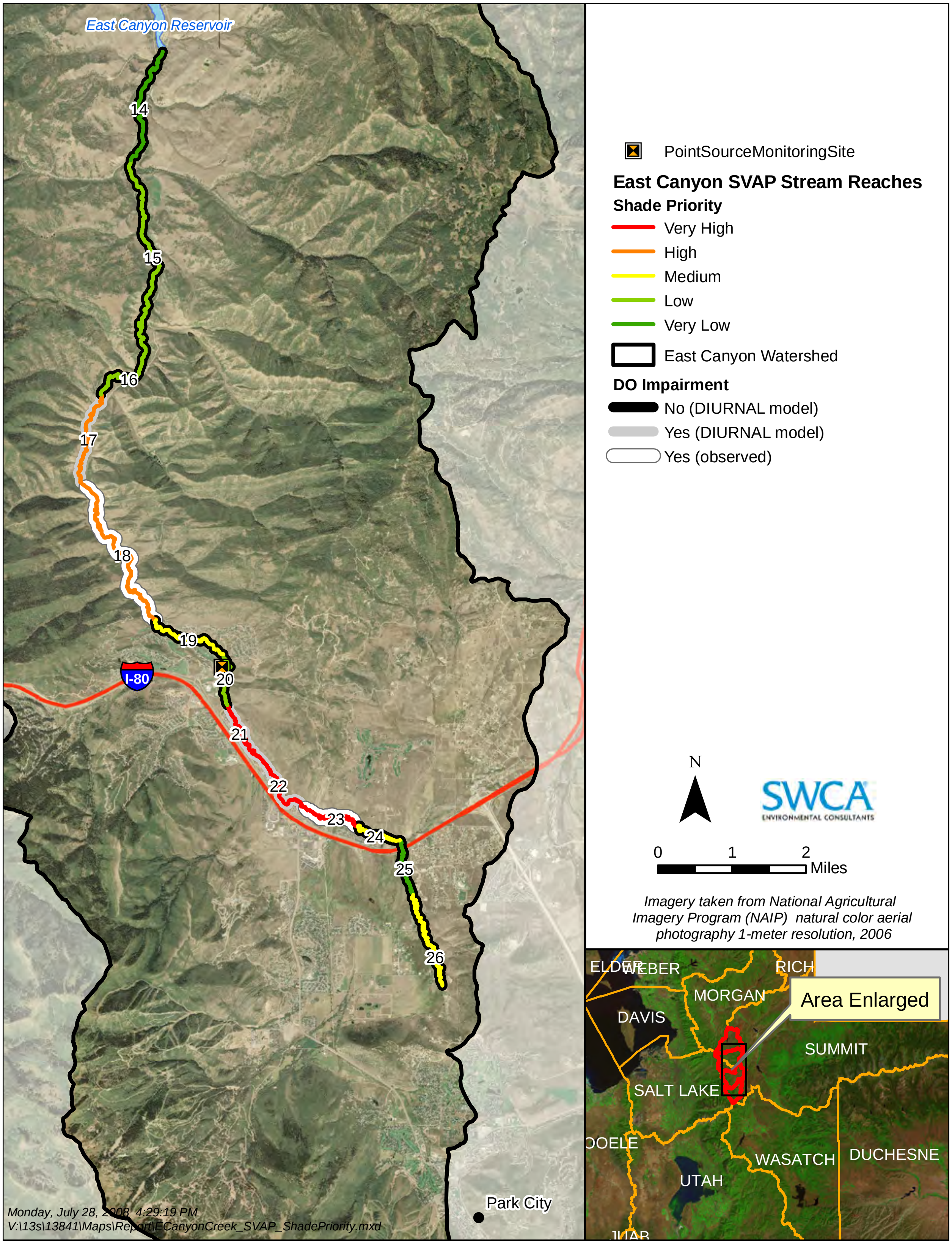

Figure 8.1 Map of priority reaches for shading and base flow protection.

Table 8.4. Summary of Shading and Base Flow Protection Prioritization

Priority	SVAP Reaches	Total Stream Length (miles)	Rationale
1 (high)	22, 23, 21	3.8	Dissolved oxygen impairment, downstream of ECWRF
2	17, 18	4.6	Dissolved oxygen impairment, upstream of ECWRF
3	19, 24, 26	4.4	Minimum DO <5.0, poor riparian zone
4	16, 20, 15	5.3	Minimum DO <6
5 (low)	14, 25	2.9	Minimum DO >6 with good riparian habitat and good channel function (SVAP)

8.3.3.2 Prioritization for Bank Stabilization

Each SVAP reach was assigned a separate priority ranking for bank stabilization. As with shading and with establishing a protected base flow, the priority levels ranged from 1 (high) to 5 (low). Two factors were considered for these prioritizations: (1) the estimated bank erosion in tons/year/mile, as identified in the 2001 Stream Erosion Condition Inventory (SECI) that was completed as part of the SVAP study (ECRFC 2002); and (2) bank stability ratings from the SVAP. Because the SECI protocol involved direct measurement of the eroding area in each reach, it is far more robust than the SVAP bank stability ranking. Therefore, the rankings were determined exclusively by the SECI erosion estimates. The prioritization categories and the resulting rankings are summarized in Table 8.5 and shown in more detail in Figure 8.2 and Table 8.3, along with selected values from the SVAP (ECRFC 2002) and Baker/HydroQual (Baker et al. 2008; SBWRD 2008) studies associated with each reach.

Table 8.5. Summary of Bank Stabilization Prioritization

Priority	SVAP Reaches	Total Stream Length (miles)	Rationale
1 (high)	21, 24	1.9	>150 tons/year/mile active bank erosion
2	15, 18	5.9	125–150 tons/year/mile active bank erosion
3	16, 17, 20	4.0	50–125 tons/year/mile active bank erosion
4	22, 23	2.8	10–50 tons/year/mile active bank erosion
5 (low)	14, 19, 25, 26	6.4	<10 tons/year/mile active bank erosion

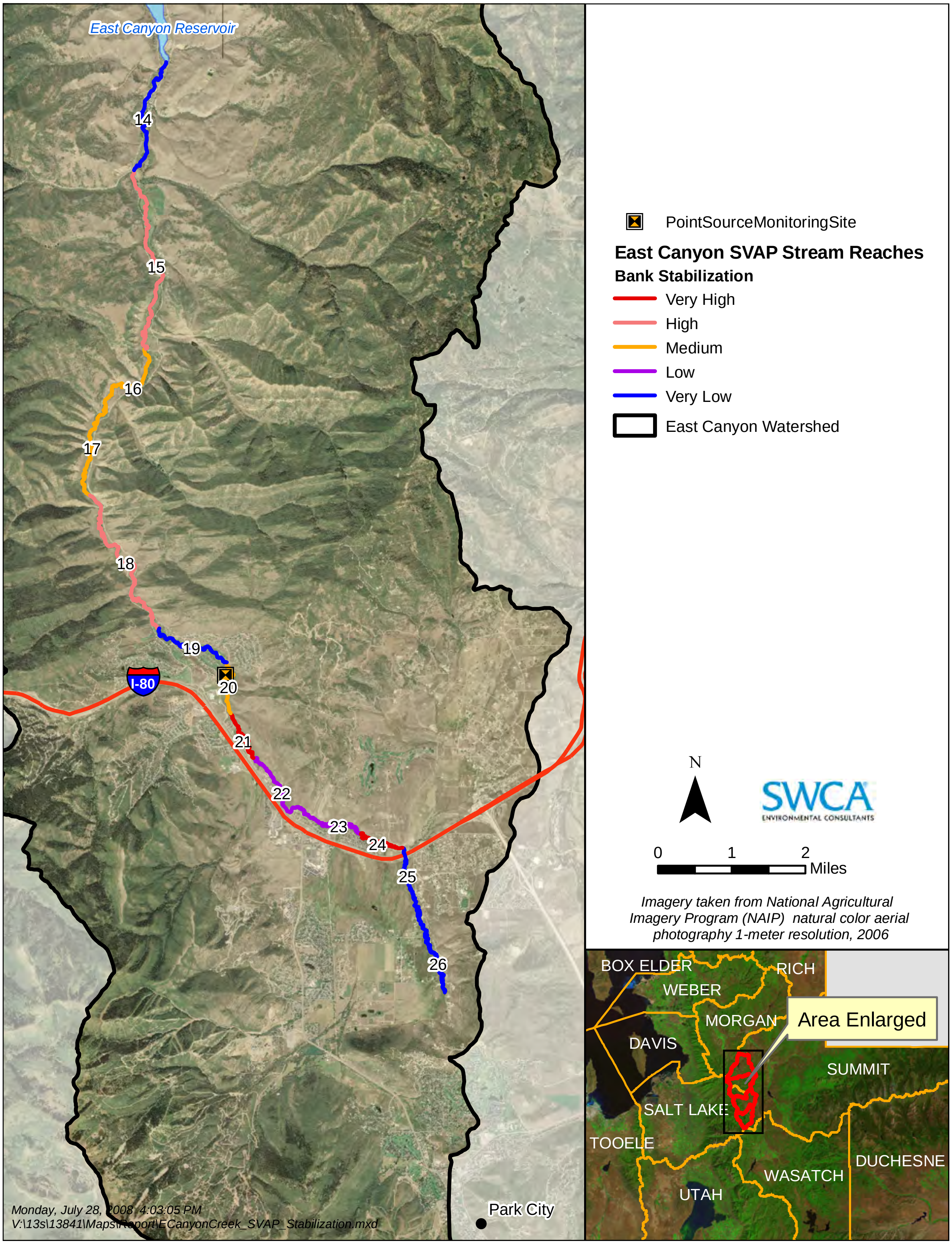

Figure 8.2 Map of priority reaches for bank stabilization.

8.3.4 Recommended Implementation Strategy

The recommended implementation strategy for meeting the water quality goals of East Canyon Creek includes establishing a protected base flow, shading by riparian plantings, and bank stabilization. Because each of these measures has a different timescale over which they will become effective, as well as different limitations on their implementation, the overall strategy relies on concurrent implementation and monitoring.

8.3.4.1 Establishing a Protected Base Flow

The first step toward base flow restoration in East Canyon Creek would be to enforce existing water rights and agreements pertaining to stream flows in the creek. In addition, it is recommended that an in-stream flow right be secured to augment base flows in East Canyon Creek during the critical summer months. The delivery of this water right would ideally be based on the flow and DO conditions observed in the creek, with water delivery adjusted to ensure a flow of 7.7 cfs above the ECWRF during the critical late summer period. That flow was selected based on the HydroQual modeling results showing that approximately 5 cfs of additional flow is needed to meet the 4.0 mg/L acute DO standard with a small margin of safety (Figure 8.3). The amount of water required to maintain a 7.7-cfs minimum flow and the length of time additional flow would be needed depends on the climatic conditions and snowpack of that particular year. A variety of scenarios are included in Table 8.6, which shows the amount of water that would be needed to maintain a discharge of 7.7 cfs under different conditions, including different baseflow levels.

The scenarios assume that the critical summer period is from July 1 until September 15 each year. This period was selected because the low flow period begins as early as late June (Figure 8.3) and no exceedances of DO criteria have been observed in late September. However, there is considerable variation in the beginning and end dates of the critical period from year to year. The beginning of the critical period is controlled largely by the timing of snowmelt runoff. As the summer progresses and the length of time because runoff increases, warmer water temperatures, increased macrophyte growth, and lower discharge all contribute to deteriorating DO levels. The end of the critical period is controlled by fall precipitation, temperature, and slowing productivity as the days become shorter.

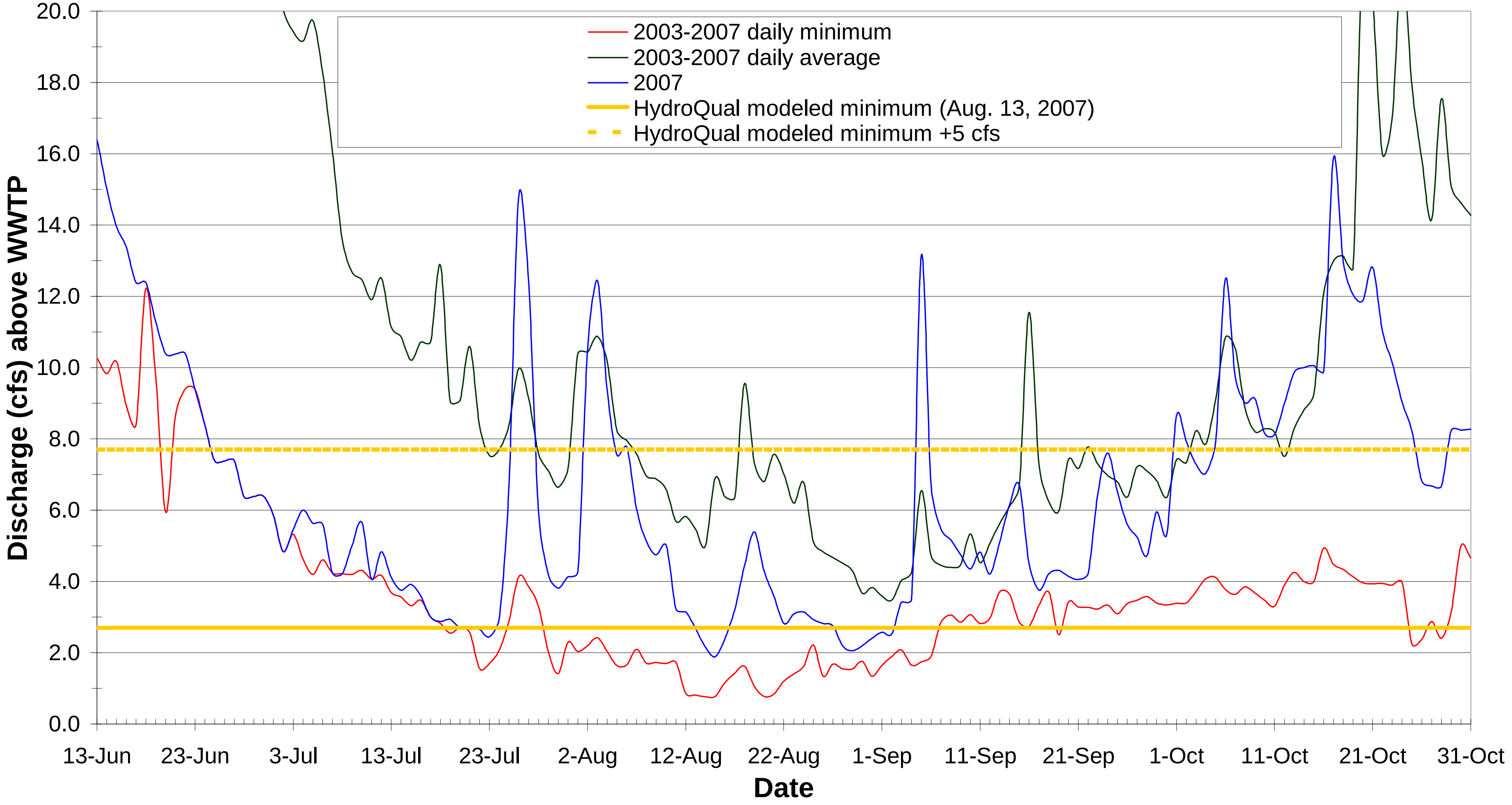

Figure 8.3 Modeled and study-period hydrology.

Table 8.6. Additional Flow Needed to Maintain a 7.7-cfs Discharge Upstream of the ECWRF during the Critical Summer Period (July 1–September 15)

Conditions Scenarios	Acre-feet of Augmentation Needed	Equivalent Average Augmentation Discharge (over 77 days)	Date Discharge First Below 7.7 cfs	Date Discharge Last Below 7.7 cfs
Average[1] 2003–2007	379	2.5 cfs	July 23	October 3
Worst Case[2] 2003–2007	793	5.2 cfs	June 25	November 10
2007[3]	504	3.3 cfs	June 25	October 2
2003[4]	765	5.0 cfs	July 2	November 10

[1] Based on the 2003–2007 average discharge for each date (as shown in GRAPH).

[2] Based on the 2003–2007 minimum discharge for each date (as shown in GRAPH).

[3] 2007 was the year modeled by HydroQual (SBWRD 2008). The year 2007 was within the normal range historically and was not a "wet" or "dry" year.

[4] 2003 was a historically "dry" year.

Based on this analysis, it is recommended that a minimum of 500 acre-feet be secured to augment summer flows in East Canyon Creek. This augmentation would add an average of 3.3 cfs to the creek during the critical period of July 1 to September 15, and in most "average" years would be protective of the cold water fishery use in the creek. Securing approximately 793 acre-feet for base flow protection would ensure the creek would meet water quality endpoints immediately, even in very dry years (worst case). Establishment of a protected base flow should be implemented upstream of SVAP reach 23, and the in-stream flow should remain in the creek until at least reach 17. This conclusion generally agrees with the findings of the flow augmentation study (SBWRD 2005), which suggested that approximately 408 acre-feet per year would be required to maintain a flow of 6 cfs in East Canyon Creek near its confluence with Kimball Creek. However, the report also concluded that less than 300 acre-feet would be needed to maintain 6 cfs, if done in conjunction with better management of water diversions and enforcement of water rights (SBWRD 2005). In fact, the report found that improved management and enforcement of water rights are important under any augmentation scenario in order to assure the protection of in-stream flow rights and other water rights. Water rights secured for this purpose should either be from new water sources that do not depend on a priority date, or should have a priority date of no later than 1865. Rights with priority dates later than 1865 are not likely to be senior enough to keep flow in the stream during periods of drought.

A variety of means could be used to establish a protected base flow, as described by the SBWRD report (2005). The simplest mechanism is to enforce existing water rights and agreements in the watershed. For instance, water could be purchased, leased during low flow periods, pumped from wells, diverted from another basin, or pumped from lower parts of the basin.

8.3.4.2 Implementation of Shading

It is recommended that all priority 1 and priority 2 reaches (23, 22, 21, 18, and 17) be vegetated to achieve a 50% canopy cover of the creek. The 50% canopy cover recommendation was derived through a correlation between the biomass-reduction recommendations (25%) and riparian shade using an equation obtained from Ferminella et al. (1989). As estimated in the DIURNAL model (SBWRD 2008), this level of shading is needed in impaired reaches in order to meet the TMDL endpoints. Increasing canopy cover should be an iterative process of planting, maintenance, and monitoring. Planting should be continued and monitored until at least 50% canopy cover is measured in each priority reach, as measured by aerial photography or in the field with a spherical densitometer. Other reaches of lower priority should also be planted as funding permits. Reduction of water temperature and primary productivity in upstream reaches will also benefit downstream reaches. All wide and/or shallow segments of priority 3 and priority 4 reaches should be planted to at least 50% canopy cover as well, in order to ensure that water quality endpoints are met during warm and dry summers. Wide and/or shallow segments can be determined relative to the average conditions of the reach, focusing on areas less than 1 foot deep and greater than 15 feet wide at low flow, as well as areas with heavy macrophyte growth.

Due to potential damage from beavers and other herbivores, all plantings should be monitored and protected. Protection measures may include exclosures and covering stems and trunks with fencing or sanded paint. Irrigation may be necessary in some locations or during drought years. Finally, because of the slow rate of growth in the area, shade plantings of larger trees should be considered for greater success. It is recommended that 100% of the length of the priority reaches be planted at sufficient density to account for 50% mortality over time. Mortality above 50% should be replaced. If monitoring reveals that 50% canopy cover has not been reached in segments of the priority reaches those areas should be replanted.

It's important that shade plantings should be initiated as soon as possible along the creek, and should continue even if an in-stream flow right is secured. Riparian canopy cover is only effective if there is water in the creek to shade, so base flow protection may be required in perpetuity.

Table 8.7. Shading Implementation

Priority	SVAP Reaches	Total Stream Length (miles)	Action
1 (high)	22, 23, 21	3.8	Plant 100% of stream length to achieve 50% canopy cover along entire reach.
2	17, 18	4.6	
3	19, 24, 26	4.4	Plant to achieve 50% cover of all wide, shallow, or slow reaches, as needed where planting occurs in shading priority reaches.
4	16, 20, 15	5.3	
5 (low)	14, 25	2.9	None

As shown in Table 8.7, approximately 8.4 stream miles (priority 1 and 2) are recommended for riparian planting (other than already shaded areas) with the goal of achieving 50% canopy cover along their length. An additional 9.7 miles are recommended for plantings in the widest, shallowest, or slowest reaches, which have the greatest potential for macrophyte growth and heat inputs.

8.3.4.3 Implementation of Bank Stabilization

Reaches were prioritized for bank stabilization on the basis of their annual erosion rate per stream mile, which indicates the relative severity of active erosion in each reach. In the SECI reaches (the same as the SVAP reaches), anywhere from 0.7% to 19.7% of the banks were inventoried as actively eroding (Table 8.8).

Table 8.8. SECI Results with Priority Rankings and Length of Stabilization Recommended by Reach

From SECI (ECRFC 2002)					Computed
SECI Reach	Total Length Actively Eroding Bank (feet)	% Banks Actively Eroding	Lateral Recession Rate (feet)	Tons/Yr/Mile from Actively Eroding Banks	Length Stabilization (feet) Needed to Reach 50 Tons/year/mile
14	338	1.5%	0.15	6	-
15	3,346	11.1%	0.40	145	2,195
16	2,751	11.3%	0.45	121	1,616
17	2,966	14.0%	0.45	119	1,716
18	4,424	14.7%	0.48	140	2,844
19	145	0.7%	0.38	7	-
20	1,390	13.2%	0.30	79	506
21	3,512	19.7%	0.35	156	2,386
22	846	7.1%	0.25	42	-
23	1,926	11.3%	0.18	44	-
24	944	13.2%	0.53	169	664
25	279	2.4%	0.10	4	-
26	158	0.7%	0.13	1	-
Total					**11,927**

As of the 2001 SECI study, the average erosion rate along East Canyon Creek was approximately 82 tons/year/mile (ECRFC 2002). There is no endpoint for the creek that is directly associated with bank stability, but a reduction in bank erosion will indirectly reduce thermal and light pollution, as well as stream sedimentation. Bank stability would also help to limit macrophyte overgrowth by reducing the amount of sediment that provides substrate for growth. Submerged and emergent aquatic plants trap fine sediment and organic material that facilitate the establishment and expansion of algae and macrophytes. Baker et al. (2008) and HydroQual (SBWRD 2008) determined that the overabundance of aquatic macrophytes in the creek is primarily driven by sediment accumulation and widened channel conditions. This plan recommends a 40% reduction in the average erosion rate along the creek's length, to 50 tons/year/mile or less, as measured by the SECI methods. To achieve this goal, approximately 11,927 linear feet of streambank will need to be treated to prevent erosion (see Table 8.8). Bank stabilization projects in priority reaches should be targeted at severely eroding areas, wide and shallow portions of the stream that are prone to macrophyte growth, and areas planted with woody riparian vegetation.

8.3.5 Time Frame for Implementation

Base flow protection is recommended for immediate establishment because it has the greatest potential for meeting the TMDL endpoints quickly. Enforcement of existing water rights and agreements could and should occur immediately. Acquisition of in-stream rights will take more time due to legal, logistical, and financial obstacles. More complex solutions (such as trading of flow rights for downstream rights) may be pursued over time. It is expected that establishing a protected base flow may take from one to five years to implement, depending on the availability of funds for purchasing senior rights, the potential for water right donations in the basin, and the timescale for development of new water sources. New water sources likely have the longest timescale for implementation, due to the legal and technical complexities associated with construction and water rights. The purchase or donation of senior water rights is unlikely to meet the full 500 acre-feet of senior rights needed, but would provide a benefit in improving DO conditions and progressing toward the creek's endpoints.

Due to its importance as a long-term solution for meeting water quality endpoints in the creek, shading should also be pursued immediately, with reaches treated in their order of priority. Shading should also be pursued as quickly as possible due its relatively long timescale for improving in-stream conditions. Shading will be implemented iteratively, with additional plantings in response to monitoring results. Where photo points and canopy monitoring reveal high mortality or insufficient growth, additional plantings must continue. Riparian vegetation plantings should be pursued regardless of progress toward securing in-stream flow rights. Shading is the most secure means of long-term improvement of creek conditions, and would provide assurance that endpoints could be met as additional water development occurs in the basin or in the event that in-stream flow rights can no longer legally be held for the creek.

As with shading, bank stabilization efforts should be ongoing. However, it is anticipated that fewer areas will need ongoing treatments if stabilization projects are well designed and coordinated with plantings. Bank stabilization should be prioritized according to the recommendations previously mentioned, with the goal of preventing further impairment rather than directly improving DO conditions.

8.3.6 Reasonable Assurance

UDWQ recently sponsored research conducted by researchers at USU to examine the relationships between nutrients, primary productivity, and metabolic processing in East Canyon Creek. This study (Baker et al. 2008), in conjunction with the DO modeling study (SBWRD 2008) and Kleinfelder flow augmentation study (SBWRD 2005) provide strong support and assurance for the implementation measures proposed in this plan to address DO impaired reaches in East Canyon Creek.

8.3.6.1 Linkage between Recommended Implementation Measures and Dissolved Oxygen Impairment

The impairment of East Canyon Creek is related to low nighttime DO caused by excess macrophyte and periphyton growth. The East Canyon Creek TMDL (2000) had assumed that excess macrophyte and periphyton growth was driven primarily by high nutrient concentrations (principally phosphorus) in the water column (UDEQ 2000b). Phosphorus reductions were intended to produce significant reductions in nuisance macrophyte and algal growth. However, implementation of the 2000 TMDL does not appear to have reduced macrophyte and periphyton biomass. Baker et al. (2008) and HydroQual (SBWRD 2008) determined that the excessive growth of aquatic macrophytes in the creek is currently driven by sediment accumulation on the stream bed, widened channel conditions, shallow water levels, low streamflow during the summer, and a lack of stream shading. Phosphorus concentrations were not identified as a controlling factor in macrophyte and algae densities.

Since the TMDL there have been dramatic reductions in point source phosphorus loads, whereas rapid growth and development in the upper watershed have resulted in increased water demand and nonpoint source nutrient and sediment inputs. Sediment loading from nonpoint sources, elevated water temperatures, and overgrowth of algae and macrophytes is currently the primary cause of water quality impairment in East Canyon Creek. Nitrogen has been identified as the most likely limiting nutrient in the water column, pore waters, and sediments, and phosphorus is no longer the primary factor contributing to low DO concentrations in the creek (Baker et al. 2008). Olsen and Stamp's 2000 study of East Canyon Creek water quality found 30% less macrophyte cover in stream reaches with stable banks, abundant overhanging vegetation, and low percentage of fine sediments. Further, Baker et al.'s 2008 study of East

Canyon Creek water quality identified a strong correlation between macrophyte density and low DO concentrations. Baker et al. (2008) also found higher photosynthetic rates in low-gradient, slow-flowing portions of the creek (see Sections 4.4 and 4.6.5). In support of these findings, the SBWRD (2008) DIURNAL model demonstrated that increased streamflow, increased riparian shading, and changes to stream geometry were all effective in reducing macrophyte productivity and increasing DO concentrations.

Improvement of physical stream conditions including increased flows, reduced sediment inputs, and increased shading will be required to achieve these endpoints. A 4.0 mg/L daily minimum was used to model water quality and diurnal DO concentrations in response to three management strategies for East Canyon Creek (SBWRD 2008): increased streamside shading, changes to channel width/depth; and base flow protection using the Bear Hollow and Blackhawk water quality monitoring stations (see Table 4.4). For the critical month of August there were modeled improvements in minimum DO levels at all impaired reaches using the baseline calibration from 2007 for all of the management scenarios (SBWRD 2008). A 25% reduction in photosynthetic rate (P_{max}) or an increase in flow of 5 cfs during August would lead to attainment of the DO standard throughout East Canyon Creek.

Multiple studies (Feminella et al. 1989; Hill et al. 1995; Kiffney et al. 2003) have demonstrated the effectiveness of riparian shading in limiting macrophyte and algal growth, and have direct applicability to identifying target conditions in East Canyon Creek. Feminella et al. (1989) found a significant negative relationship between periphyton biomass and riparian canopy percent cover ($r = -0.67$, $P<0.0001$) for a range of 0–15 mg/cm^2 ash free dry mass (AFDM) and 15–98% canopy cover. The empirical model described in this study was used to link the recommended 25% reduction in photosynthesis (SBWRD 2008) to a recommendation for stream shading. It is assumed that the correlation between periphyton and percent riparian shading identified by Feminella et al. (1989) is similar to the relationship between macrophytes and percent shade. The equation developed by Feminella et al. (1989) is

$$y = 7.75 – 0.06x$$

where x = % riparian cover and y = AFDM measured in mg/cm^2. Assuming a macrophyte biomass of 6.8 mg/cm2 (a value that is within the range of macrophyte biomass observed in East Canyon Creek), the model estimated that increasing riparian percent cover from 16% to 44% would reduce macrophyte AFDM by 25%.This model will be applied on a reach-by-reach basis to determine the amount of riparian shading needed to reduce macrophyte and algae cover to levels that support a minimum 4.0 mg/L DO concentration.

8.3.6.2 Feasibility of Riparian Plantings and Bank Stabilization

The East Canyon Watershed Committee, Upper Weber River Watershed Coordinator, Park City Corporation, Synderville Basin Water Reclamation District (SBWRD), and other stakeholders and landowners in the watershed have been actively engaged in riparian plantings and bank stabilization projects along East Canyon Creek and its tributaries. This work is expected to continue with emphasis on the priority reaches identified in this implementation plan. A federal earmark for East Canyon Creek restoration is being administered by the SBWRD with oversight and technical guidance provided by the Utah Association of Conservation Districts' Resource Coordinator for Summit County. This funding, in conjunction with other future funding opportunities (discussed in Section 8.6.2) will facilitate the implementation of riparian plantings and bank stabilization projects along the creek in the identified priority reaches. Because these reaches currently have less than 20% shade cover, plantings are expected to result in a significant improvement in stream shading. Stream shading of 50% overall shade is recommended for priority reaches based on the DIURNAL model and correlation between macrophyte/periphyton biomass and stream shade (Feminella et al. 1989).

8.3.6.3 Feasibility of Establishing a Protected Base Flow

The SBWRD retained Kleinfelder and others for the East Canyon Creek flow augmentation feasibility study (2005), which detailed the feasibility of adding flow to the creek to protect base flows and water quality for East Canyon Creek. Minimum streamflow goals for East Canyon Creek and Kimball Creek (the upper main stem of East Canyon Creek) were based primarily on flows required to maintain water quality and fish habitat (SBWRD 2005).

The Kleinfelder study (SBWRD 2005) examined 12 alternatives to improve minimum streamflow goals in East Canyon Creek, Kimball Creek, and McLeod Creek. No single alternative was found to be sufficient to meet the in-stream flow goals. Among the recommended alternatives in the short-term were the following:

- Improve management of water rights and diversions
- Purchase or lease irrigation water rights for in-stream flow
- Reduce diversions to the Silver Creek watershed

These alternatives could provide an estimated 0.5 cfs to 3.0 cfs (362–2,172 acre-feet/year) of flow to East Canyon Creek during critical periods with a high feasibility of implementation in the short-term (SBWRD 2005). In addition, a proposal to pump water from East Canyon Reservoir back to Snyderville Basin for residential, commercial, and agricultural use is currently under consideration. The proposed pipeline would deliver 5,000 acre-feet per year. As part of the agreement related to this project, Summit Water Distribution Company has agreed to provide a limited water right to the Utah Division of Wildlife Resources of up to 2 cfs (1,448 acre-feet/year) (SBWRD 2005). This water would be treated by the treatment plant and then discharged back into the creek. The plan would not increase base flows above the treatment plant.

Trout Unlimited has recently secured the legal ability to lease in-stream water rights on a trial basis. With the support of the Utah Division of Wildlife Resources and the East Canyon Watershed Committee, Trout Unlimited is actively pursuing opportunities for such leases and water donations. In addition, Park City Municipal Corporation is exploring the possibility of importing (from a trans-basin diversion) and/or storing water in the upper areas of the watershed, some of which could be released during the critical summer period to provide flow in East Canyon Creek.

8.4 COORDINATION PLAN

8.4.1 LEAD PROJECT SPONSORS

The East Canyon Watershed Committee has brought together citizens, stakeholders, and agencies to guide research and implementation directed to improve water quality in East Canyon Creek and Reservoir. This committee will continue to be the coordinating body and provide oversight on project conceptualization, cooperator selection, volunteer efforts during implementation, and sharing of information generated by projects with the wider East Canyon watershed community.

The Technical Advisory Committee, a subcommittee to the East Canyon Watershed Committee will oversee detailed project development, planning, implementation, administration, and reporting, and creation of fact sheets and educational materials. The Upper Weber River Watershed Coordinator will continue to facilitate communication between the East Canyon Watershed Committee, the Division of Water Quality, and stakeholders in the watershed.

The Utah Division of Wildlife Resources and the Snyderville Basin Water Reclamation District will act as the lead project sponsors for establishing a protected base flow for East Canyon Creek. The sponsors will work closely with the state engineer, the Utah Division of Water Rights, and other existing parties to water agreements to negotiate and enforce in-stream water rights in the watershed. The Utah Division of Wildlife Resources is willing to hold in-stream rights secured in the watershed.

8.4.2 Cooperating Groups

The East Canyon Watershed Committee anticipates coordinating efforts for stream shading and bank stabilization with the following entities, agencies, and organizations, most of which are members of the committee itself:

- UACD–Technical planting design and oversight
- Utah Division of Water Quality –Monitoring and technical assistance
- Snyderville Basin Water Reclamation District–Administration of federal earmark for creek restoration
- NRCS–Administration of CRP and EQIP programs
- Utah Conservation Corps–labor and technical assistance with riparian plantings
- US Fish and Wildlife Program–WHIP program funding
- Park City Corporation–Funding and coordination of riparian plantings within city limits
- EPA–319 Funding for nonpoint source reduction

Snyderville Basin Water Reclamation District anticipates coordinating efforts for base flow restoration with the following other entities, agencies, and organizations:

- Utah Division of Wildlife Resources–Support for in-stream rights to protect fish. UDWR can hold permanent in-stream flow rights secured through funding by the legislature or donation
- Trout Unlimited–Support for in-stream rights to protect fish. Trout Unlimited can hold a 10-year in-stream flow right to improve habitat for one of three species
- Utah State Engineer's office–Advisory
- Utah Division of Water Resources–Advisory
- Utah Division of Water Rights–Administration and enforcement of existing water rights, existing agreements, and future in-stream water rights

8.5 Monitoring

The monitoring goals of this project are to:

- Document progress in achieving water quality endpoints as implementation measures are completed,
- Document and review the effectiveness of implementation measures, and
- Identify the need for additional implementation of any of the measures.

These three goals provide the basis for the sample design and sample parameters described below.

8.5.1 Sampling Design and Parameters

8.5.1.1 Monitoring Endpoints

Annual monitoring of progress toward achieving water quality endpoints is recommended, with sampling focused on the critical summer low-flow period.

Diurnal DO monitoring should be conducted in mid to late August in those reaches with priorities 1, 2, or 3 (see Table 8.4). DO monitoring should be continuous (with a data sonde left in place to log data) for a 1–2 week period, in order to ensure than nighttime DO readings are recorded. The placement of additional sondes in segments where bank stabilization projects or riparian plantings have been completed is also recommended as a means of assessing the effectiveness of these projects.

Algal and macrophyte samples should also be collected annually to determine reductions in primary productivity, measured as ash-free dry mass (AFDM). Sampling of AFDM should also be conducted in all reaches of priority 1, 2, or 3 for shading and establishment of a protected base flow. Sampling is recommended twice per summer, in mid July and mid August.

8.5.1.2 Monitoring Riparian Shading

The goals of monitoring riparian shading are to document its effectiveness and determine the need for additional implementation or replacement of unsuccessful plantings. Sampling design and monitoring activities for riparian shading are shown in Table 8.9.

Table 8.9 Sampling Design and Monitoring Activities for Riparian Shading

Monitoring Activity	Sites	Frequency	Timing	Use
Photo-point monitoring	In all planting sites	Annually	Growing season (July–August)	Document planting success and growth of plantings.
GIS and aerial photo interpretation	All planting sites	GIS extent of all planting reaches at implementation; photo interpretation of canopy cover every 3 years or when new aerial photos are available	Dependent on aerial photos	Document aerial extent of canopy cover over time. Relate to direct canopy measurement.
Direct canopy measurement (spherical densitometer)	Representative sample of all planting sites	Every 2 years	Growing season (July–August)	Document change in canopy cover over time. Relate to photo interpretation.
Mortality assessment	In all planting sites	Annually	Growing season (July–August)	Direct replanting efforts where mortality is high. Guide mitigation efforts for herbivory, drought, etc.

8.5.1.3 Monitoring the Protected Base Flow

Monitoring the protected base flow should be implemented to document reaching the 7.7-cfs goal set for the creek above the ECWRF. Stream levels can be monitored through the USGS gage maintained by SBWRD and subtracting daily ECWRF effluent inputs to the creek. The volume of flow discharged to increase base flow will depend on the discharge point and may include staff gages and calibrated weirs.

8.5.1.4 Monitoring Bank Stabilization

The goal of monitoring bank stabilization projects is to document their effectiveness and determine the need for any repairs. Sampling design and parameters for bank stabilization are shown in Table 8.10.

Table 8.10 Sampling Design and Monitoring Activities for Bank Stabilization

Monitoring Activity	Sites	Frequency	Timing	Use
Photo-point monitoring	In all stabilization sites	Annually	Growing season (July–August)	Document stabilization success and need for maintenance.
Repeat Stream Erosion Condition Inventory (SECI)	Entire length of original survey	Once in 2 years; repeated in 7 years	Low flow	Document changes in SECI score and bank erosion following bank treatments and other implementation measures.
Channel cross sections	Representative sample of all stabilization sites. At repeatable monument locations.	Every 2 years	Low flow	Document change in channel cross section over time.

8.5.2 Progress Reporting

Annual reports from project sponsors should provide details about riparian plantings, base flow protection, in-stream DO concentrations, and percent shade achieved. Project-specific reporting will come from the East Canyon Watershed Committee, Utah Association of Conservation Districts, and Trout Unlimited. Progress toward achieving water quality goals will be reported by the Division of Water Quality every two years in the Integrated Report–Assessment of Water Quality for the State of Utah. Reports should be reviewed by the East Canyon Watershed Committee–Technical Advisory Subcommittee. The website maintained by the East Canyon Watershed Committee should be used as a forum for dissemination of progress reports to the public.

8.6 BUDGET

8.6.1 PROJECTED COSTS FOR IMPLEMENTATION

8.6.1.1 Costs for Establishing a Protected Base Flow

A search of water rights publicly available for sale in the East Canyon Basin (on http://waterrightexchange.com) showed prices in the Park City area to average approximately $15,000 per acre-foot. Assuming this cost is reflective of water costs on the open market, securing the recommended 500 acre-feet of water on the open market would cost approximately $7,500,000. However, the likelihood of this amount of water being available for sale is low. This means that water secured as part of new water developments, combined with some purchases and donations, is a more likely source for securing water for base flow protection. Although new water projects such as trans-basin diversions or an intra-basin reuse pipeline would have large associated costs, water for the protected base flow could be included as a form of mitigation for the identified environmental impacts of such a project, or to enjoy the economies of scale and financing associated with a major development project. The SBWRD augmentation report (SBWRD 2005) indicated several alternatives with acre-foot costs closer to $200, which would equate to approximately $100,000 in implementation costs. Finally, the BOR (2006) estimated a cost-per-acre-foot between $1,440 and $7,560, for a total cost of $720,000–$3,780,000 for 500 acre-feet. A range of cost estimates for various proposals is included in Table 8.11.

Table 8.11. Potential Cost to Secure 500 Acre-feet for Establishing a Protected Base Flow

Water Source	Cost Estimate Source	Cost per Acre-foot	Total Cost	Additional Major Capital Costs
Purchased irrigation water	SBWRD 2005	$7,000	$3,500,000	
Developed well water	SBWRD 2005	$6,500	$3,250,000	$400,00 per 2-cfs well
East Canyon pipeline	BOR 2006	$7,275	$3,637,500	Capital costs included in per acre-foot estimate
Lost Creek Canyon pipeline	BOR 2006	$7,560	$3,780,000	Capital costs included in per acre-foot estimate
Weber River via Weber-Provo Canal	BOR 2006	$1,440	$720,000	Capital costs included in per acre-foot estimate

8.6.1.2 Costs for Shading and Bank Stabilization

Implementation of the shading and bank stabilization BMPs, necessary to meet the water quality goals outlined in the East Canyon Creek TMDL, will require a significant allocation of financial resources from multiple sources. The total estimated costs for each of the recommended practices are listed in Table 8.12, 8.13, and 8.14. The sources of potential funds are described below in Section 8.6.2.

Unit-cost estimates listed for each BMP were obtained from the 2007 NRCS' Electronic Field Office Tech Guide cost sheet located at the Utah NRCS website. The practices used in the cost analysis were BMPs specific to the goals outlined in this implementation plan and are applied to enhance stream shading and provide for streambank stabilization. Other costs associated with implementation and operation and maintenance are listed in Table 8.12

The BMP costs in Table 8.12 for stream shading are listed by recommended planting densities in each priority reach based upon plant type, such as bare root shoots or 1-gallon potted plants. The planting densities listed are general guidelines for the establishment of dogwood, willow, or cottonwood trees (USDA 1993; and Carlson et al. 1995). Plant-specific specifications for establishment in the region may be found at the USDA plant database website at (see http://plants.usda.gov/checklist.html). This web page provides users the ability to search for fact sheets of individual plants appropriate for the Intermountain region's riparian areas. The costs are calculated based upon the priority reach goal and the range of plant density recommended from the literature.

The per-acre riparian forest buffer costs are taken from the NRCS cost list for that practice. Priority linear stream miles are converted to riparian acres based on an assumed riparian buffer width of 25 feet on each side of the stream (USDA July 2004). An average 50% mortality of all plantings has been assumed and calculated into the total planting costs. An example would be the priority 1 reaches 21 and 24. A treatment goal of 100% of the reach area will be planted with 50% canopy coverage. The ranges of total cost for the bare or potted plants are listed for each specific plant type. If a mixture of bare-root and potted plants is used in the reach, the total cost will be adjusted according to the percentage of each plant type installed. The range of costs for the plantings will vary greatly dependent upon the plant type used, the spacing of the planting, and plant mortality. Table 8.12 lists associated costs that will be included in the final cost of planting the riparian buffer. The associated costs may include chemical treatment, installation of a drip irrigation system, and/or fencing to limit access of livestock and wildlife to riparian plantings. Mechanical preparation of the riparian area is also included in the cost for the riparian forest buffer establishment.

Table 8.12. Cost Ranges by Priority Reaches for Stream Shading Enhancement BMPs

Reach Number	Total Length of Reaches (mi)	Area of Reach Treatment (ac)	% of Area Treated[3]	Riparian Forest Buffer (391)					
				Bare Plant[1]		1-gallon plants[2]		Soil Preparation–Mechanical Treatment	
				Low	High	Low	High	Low	High
22, 23, 21	3.8	11.5	100	$111,467	$1,003,200	$27,821	$111,467	$887	$1,520
17, 18	4.6	13.9	100	$134,933	$1,214,400	$33,678	$134,933	$1,073	$1,840
19, 24, 26	4.4	13.3	50	$64,533	$580,800	$16,107	$64,533	$1,027	$1,760
16, 20, 15	5.3	16.1	50	$77,733	$699,600	$19,401	$77,733	$1,237	$2,120
14, 25	2.9	8.8	0	$0	$0	$0	$0	$0	$0
Total	21.0	63.6		$388,667	$3,498,000	$97,006	$388,667	$4,223	$7,240

[1]Planting rates are based upon density of 1- to 3-foot spacing (1 sq feet=43,560 plantings per acres; 9 sq feet=4,840 plantings per acre).
[2]Planting rates are based upon density of 6- to 12-foot spacing (36 sq feet=1,210 plantings per acres; 144 sq feet=302 plantings per acre).
[3]Percentage of area treated as well as a 50% mortality rate for initial plantings (ranges from 8–100% mortality, USDA Plant Database).

To reduce streambank erosion and channel migration associated with streambank erosion, vegetative or structural features in the riparian area will be installed to stabilize and protect the streambank against scour and erosion. Practices may include the installation of vegetative plantings, installation of grasses or vegetative mats, and mechanical treatment of the shoreline including streambank shaping and fabric installation. The total cost for each of the treatments is for total linear feet of streambank on both sides of the stream and installation of the practice along that total distance. Costs for each type of streambank protection are listed in Table 8.13.

Table 8.13. Total Costs Associated with Priority Reaches for Streambank Protection

Reach Number	Total Length of Reaches (mi)	Area of Reach Treatment (ft)(1)	% of Area Treated	Streambank & Shoreline Protection (580)		
				Vegetative Plantings	Bank Protection (revetment, etc.)	Mechanical Treatment[2]
14	2.2	-	100	$0	$0	$0
15	2.9	2,195	100	$2,415	$7,245	$43,908
16	2.3	1,616	100	$889	$2,667	$32,322
17	2.0	1,716	100	$472	$2,831	$34,312
18	2.8	2,844	100	$782	$4,693	$56,880
19	2.0	-	100	$0	$0	$0
20	1.0	506	100	$139	$835	$10,116
21	1.7	2,386	100	$656	$3,936	$47,713
22	1.1	-	100	$0	$0	$0
23	1.6	-	100	$0	$0	$0
24	0.7	664	100	$183	$1,096	$13,288
25	1.1	-	100	$0	$0	$0
26	2.3	-	100	$0	$0	$0
Total	23.7	11,927		$5,536	$23,302	$238,537

[1]Area of reach treatment is linear feet of streambank on both sides of stream

[2]Mechanical treatment includes streambank excavation, shaping, geosynthetic fabric treatment, and vegetative planting. Total cost/per foot estimated at $20/foot.

Other costs will also be incurred with the installation of streambank BMPs, including costs associated with operation and maintenance. This includes the treatment of invasive weeds, the application of irrigation water to protect against drought and plant mortality, fencing to protect against depredation, and herbaceous cover to reduce erosion. If fencing is installed and livestock are present, offsite watering will be required to provide water to the livestock. Offsite watering costs will be determined based on the gallons of water storage provided offsite. Offsite water facilities are assumed to hold 1,000 gallons of water each. The cost associated with each offsite tank facility is approximately $2,000. The practices are listed in Table 8.14 Not all of the acres or linear feet of the streambank or riparian area will be treated, and the associated practices and costs of implementation will be adjusted accordingly.

Table 8.14. Costs for Associated Best Management Practices

Reach Number	Total Length of Reaches (mi)	Area of Reach Treatment (ac)	% of Area Treated	Chemical treatment (595)		Irrigation System, Micro-irrigation (441)	Fencing (382)	Riparian Herbaceous Cover (390)
				Low	High	Drip Irrigation	4-Wire, Wood Posts	Seeding Rate = 6 lbs/acre
22, 23, 21	3.8	11.5	100	$114	$203	$19,576	$54,775	$1,750
17, 18	4.6	13.9	100	$138	$245	$23,697	$66,306	$1,101
19, 24, 26	4.4	13.3	50	$132	$235	$11,333	$31,712	$40
16, 20, 15	5.3	16.1	50	$159	$283	$13,652	$38,198	$96
14, 25	2.9	8.8	0	$0	$0	$0	$0	$0
Total	21.0	63.6		$543	$965	$68,258	$190,991	$2,988

8.6.2 Financial and Legal Means for Implementation

8.6.2.1 Means for Establishing a Protected Base Flow

Currently, several different tools for establishing a protected base flow exist for East Canyon Creek. First, the Utah Division of Wildlife Resources or Division of Parks and Recreation may also hold permanent flow rights for the propagation of fish or to preserve or enhance the natural stream environment. In addition, Trout Unlimited may legally lease in-stream flow rights (for up to 10 years) to protect or restore habitat for three native trout species in Utah (under Utah code 73-3-30), and can actively pursue the lease or donation of water rights for this purpose. Division rights may be purchased with funds approved by the legislature, or donated by other entities. Securing favorable water rights for an in-stream flow by either of these agencies, or Trout Unlimited, may require complex agreements or trading of water rights in order to secure water in the critical reaches of the creek relative to other users' points of diversion. SBWRD has explored the donation of an in-stream flow right supplied by a well near Kimball Junction, which could augment flows above the ECWRF by approximately 2.5 cfs in times of critical need. A variety of proposals and scenarios have been studied by the BOR (2006), Summit Water Company, and SBWRD (2005) for trans-basin and intra-basin diversions or pumping projects. Finally, Park City has considered the development of additional water storage in the upper basin, which could be used to augment flows during critical low water periods.

8.6.2.2 Means for Shading and Bank Stabilization

Since the majority of land in the watershed is privately owned, BMP implementation is a voluntary, incentive-based effort. Various programs are available to assist private landowners with the implementation of BMPs through cost-share incentive programs, grants, or low-interest loans. Program funds come from multiple sources such as EPA, NRCS, and the State of Utah. All programs require voluntary signup for participation, and some require eligible lands to qualify based on program requirements.

The NRCS administers a number of cost share programs to assist agricultural producers in installing BMPs on their privately owned lands such as the Environmental Quality Incentive Program (EQIP). EQIP is a Farm Bill program that offers technical and financial assistance in the design and implementation of conservation practices, paying up to 50–75% of the project's cost.

Other federal cost-share programs administered by the NRCS are the Wildlife Habitat Incentives Program (WHIP) and the Wetland Reserve Program (WRP), which are provided to establish habitat for wildlife and fish and to restore wetlands, respectively. Another federal cost-share program is the Conservation Reserve Program (CRP), which encourages farmers to convert highly erodable farmland or other highly sensitive acreages to permanent vegetative cover. The CRP is administered by the Farm Service Agency (FSA).

The State of Utah offers a low-interest loan program called the Agriculture Resource Development Loan (ARDL), which is administered by the Utah Department of Agriculture and Food (UDAF). The program offers loans for projects that conserve soil and water resources and improve water quality. Another UDAF program is the Grazing Improvement Program (GIP), which offers a competitive grant for fence repairs, reseeding of grazing land, and the replacement or development of water projects.

The Section 319 NPS program funded by EPA and administered through the Division of Water Quality may be employed to implement nonpoint source projects for the protection and improvement of water quality. The 319 program is a cost-share program that requires a 60:40 grant-to-cost share match.

Finally, the Snyderville Basin Water Reclamation District is currently administering a federal earmark for restoration of East Canyon Creek. The total funds available for implementation are approximately $278,000 and do not require cost-share. This program will permit installation of stream shading and bank stabilization projects beginning in the fall of 2008. This funding program will target over 9,000 feet of actively eroding streambank and will allow for the installation of practices such as streambank protection, channel vegetation, fencing, and associated watering facilities. Information and education for landowners will also be part of the program.

9. EAST CANYON RESERVOIR WATERSHED-BASED IMPLEMENTATION PLAN

9.1 INTRODUCTION

The East Canyon Reservoir watershed-based implementation plan outlines a strategy for reducing phosphorus in East Canyon Reservoir to attain water quality endpoints and to restore East Canyon Reservoir to full support status. When combined with existing implementation planning, management measures, and phosphorus reduction efforts, completion of the proposed implementation plan will result in a cleaner and healthier East Canyon Reservoir for current and future generations.

This implementation plan, in conjunction with portions of the TMDL, includes the nine key elements identified by EPA that are considered critical for achieving improvements in water quality (EPA 2003). EPA requires that these nine elements be addressed in watershed plans funded with incremental Clean Water Act Section 319 funds, and strongly recommends that they be included in all watershed plans intended to address water quality impairments. Although there is no formal requirement for EPA to approve watershed plans, the plans must address the nine elements discussed below if they are developed in support of Section 319-funded projects (EPA 2008).

EPA's nine elements are listed below in the order they appear in the guidelines; however, it should be noted that although they are listed as *a* through *i* because they do not necessarily need to be completed sequentially.

a. An identification of the sources that will need to be controlled to achieve the load reductions identified in the TMDL

b. An estimate of the load reductions expected for the management measures recommended in the implementation plan

c. A description of the nonpoint source management measures that will need to be implemented to achieve the load reductions required by the TMDL and an identification of the critical areas for implementation

d. An estimate of the amount of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan

e. An information/education component that will enhance public understanding of the project and encourage their early and continued participation in implementation

f. A schedule for implementing the nonpoint source management measures identified in this plan

g. A description of interim, measurable milestones for determining whether the recommended nonpoint source management measures are being implemented

h. A set of criteria that can be used to determine whether loading reductions are being achieved and whether substantial progress is being made toward attaining water quality standards and, if not, the criteria for determining whether the implementation plan needs to be revised

i. A monitoring component to evaluate the effectiveness of the implementation efforts over time

The East Canyon Reservoir implementation plan has been developed based on a 50% phosphorus reduction from nonpoint sources and a 50% reduction from internal reservoir sources. These source reductions have been determined to be sufficient to achieve DO criteria established for the reservoir. Future growth projections for the ECWRF require an additional allocation of 232 kg/year (35% increase) for this point source above the allocation provided in the 2000 TMDL (663 kgTP/year). The 50%

reduction from both nonpoint and internal reservoir sources has been identified to compensate for the increased phosphorus load required by ECWRF.

Recommendations for nonpoint source reductions consider all sources and are based on management measures that consider BMPs, effectiveness, attainability, cost, and the goal of distributing the responsibility for water quality improvement among all users in the watershed. Recommendations for reducing the internal sediment phosphorus released in the reservoir by 50% include alum treatment and hypolimnetic aeration.

Management strategies and BMPs compose the primary means for achieving phosphorus load reductions. This implementation plan is based on a review of other TMDLs written for reservoirs and watersheds in the Intermountain West with similar characteristics, and with consideration of implementation actions ongoing in the watershed. This plan also describes regulatory and voluntary management measures needed to achieve pollutant reductions specified by the TMDL.

A schedule with interim milestones for implementation of management measures and BMPs is provided in the implementation plan; however the plan is not static. It is a dynamic plan subject to modification as new information and data become available throughout the life of the plan. This implementation plan is designed to be a flexible tool for BMP implementation guidance and management. Actual implementation will be accomplished through the assistance of natural resource agencies, municipalities, land owners, and local conservation activities.

The following sections describe the implementation plan for East Canyon Reservoir in accordance with the nine elements recommended in EPA guidelines (EPA 2008).

9.2 KEY COMPONENTS OF THE IMPLEMENTATION PLAN

9.2.1 IDENTIFICATION OF SOURCES AND CURRENT LOAD SUMMARY

The East Canyon Reservoir watershed encompasses 92,498 acres in Summit and Morgan counties. Over 96% of the watershed area is privately owned and under private control. Forested and meadow (shrub/scrub) land cover types occur on 65,668 acres or 71% of the watershed area. The majority of the surface inflow into East Canyon Reservoir is from East Canyon Creek, which drains a 145-square-mile watershed. The total annual phosphorous load to East Canyon Reservoir from all sources is 3,350 kg/year. The East Canyon Water Reclamation Facility currently accounts for 483 kg (14%) of the total annual phosphorus load to East Canyon Reservoir. Nonpoint sources account for an additional 2,072 kg/year or 62% of the total load to the reservoir, and internal sources account for 795 kg (24%) of the annual total load to the water column.

9.2.1.1 East Canyon Water Reclamation Facility (ECWRF) Discharge

The only point source located in the East Canyon Reservoir watershed is the ECWRF, which is operated by the Snyderville Basin Water Reclamation District. The facility discharges to East Canyon Creek just north of I-80 below the confluence with Kimball Creek from the south and the unnamed creek from the north. During dry summer months, the effluent from the facility makes up the majority of flow in the creek. The Snyderville Basin Water Reclamation District completed an upgrade and expansion project of the ECWRF in September 2002. The upgrade included the addition of a chemical phosphorus reduction process to the plant which became effective in July 2003. The process mixes secondary effluent with alum (aluminum sulfate) and a polymer in solids-contact clarifiers, and then filters the liquid through a constant-backwash sand filter. The heart of the process is the use of alum to pull orthophosphorus out of solution by binding the phosphorus molecule to the alum. The polymer then joins the resultant molecules in a long chain for easier filtering. Finally, effluent passes though a UV disinfection process. Phosphorus-reduction upgrades to the ECWRF became effective in July 2003, with an average total phosphorus effluent of 0.12 mg/L. Median total phosphorus effluent from the ECWRF was 0.06 mg/L for water years 2003 through 2007. Orthophosphate concentrations were 0.024 mg/L during this same period.

On average, the ECWRF contributes 483 kg of total phosphorus per year to East Canyon Reservoir of which 93 kg is in the form of dissolved phosphorus. In general, the load from the ECWRF is far more constant than the load from nonpoint sources and has varied by less than a factor of 3.

9.2.1.2 Internal Reservoir Sources

Phosphorus contained in reservoir bed sediments could represent a significant loading source to the water column. The deposition, release, and dissolution of this phosphorus depend on both physical and chemical processes in the watershed and reservoir. Phosphorus in the water column of the reservoir occurs as suspended sediment-bound phosphorus and dissolved phosphorus. Suspended sediments, comprising particulate and organic matter, can act as a source of dissolved phosphorus due to changes in water chemistry as water depth increases. Significant release of iron-bound phosphorus from bed sediments has been observed under anoxic conditions. Operational conditions that control water depth may affect the availability of sediment-bound phosphorus and its potential to leach into surface water. Fluctuating water levels that periodically expose lake sediments or alter the redox at the sediment-water interface can contribute to the release of sediment-bound nutrients.

A phosphorus mass balance model was developed for East Canyon Reservoir to calculate monthly and annual total and net internal load from reservoir sediments. A net internal load refers to the total load that leaves the reservoir over a given period time (i.e. one year, one month) minus the total load that entered the reservoir during the same period of time. If the amount of phosphorus that leaves the reservoir is greater than that that entered during the same period of time, there is a net internal load. Conversely, if the amount of phosphorus leaving the reservoir is less than that that entered, the reservoir is acting as a sink during this time period. The phosphorus associated with a net internal load can be considered legacy or historic as it represents a previous phosphorus sink in reservoir sediments. The average annual net internal load is 795 kgTP/year, although annual net internal loads are estimated to be as high as 1,780 kgTP/year and as low as 294 kgTP/year. Attainment of water quality endpoints in East Canyon Reservoir requires that the internal reservoir load be reduced by 50%.

9.2.1.3 Nonpoint Sources

9.2.1.3.1 Forest Land Management, including Ski Area Management

The majority of the forested land in the upper part of the East Canyon Reservoir watershed is managed as part of several ski areas. Road construction and road use on forested lands associated with ski areas and off-highway vehicle (OHV) use can contribute to dissolved and sediment-bound phosphorus. Sediment and pollutants from forest roads deposited in streams during low flow can be rapidly re-suspended and transported to the reservoir during high flow events (Megahan 1972 and 1979; Mahoney and Erman 1984; Whiting 1997). Some agricultural grazing takes place on forested lands downstream of Jeremy Ranch. Grazing practices alter forested lands through soil compaction, manure deposition, and increased sediment and nutrient loading due to destabilization and erosion of forest soils.

There are two ski areas in the watershed that occupy approximately 2,982 hectares (7,369 acres) or 8% of the watershed in seven subbasins, including phosphatic shale areas in the Treasure Hollow, Spiro Tunnel, and Willow Draw subbasins. The Canyons Ski Resort is located in Summit County, and Park City Mountain Resort is located in Park City. Gorgoza Park, near Kimball Junction, is a tubing and sledding hill. The main source of phosphorus from ski areas is stormwater runoff containing sediment and nutrients. Stormwater runoff occurs as either overland flow or as concentrated flow in drainage ditches, ruts, trails or roads. Both types of flow can cause erosion and increase sediment and nutrient loads to streams. In particular, poorly designed, located, constructed, and maintained trails can cause significant erosion and sedimentation. Impervious cover associated with ski resort facilities also contributes to stormwater runoff in the watershed. The ski area land use contributes 316 kg/year of phosphorus, or 15% of the total annual nonpoint source phosphorus load in the watershed. Subbasins with phosphatic shales, (Treasure Hollow, Willow Draw, and Spiro Tunnel) contribute 98% (309 kg/year) of the annual phosphorus load from ski areas.

9.2.1.3.2 Golf Courses and other High Use Recreation

Pollutant sources from golf courses include sediment runoff and the erosion of exposed areas, excess fertilizer use, and nutrient release associated with flood irrigation. When phosphorus fertilizer is applied unnecessarily, stormwater washes away the excess phosphorus to local waterways. In addition, irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions is a major transporter of nonpoint source pollutants. Excessive water use can also contribute to reduced water levels and associated water quality issues such as increased nutrient concentrations, reduced flows, and increased water temperatures.

Golf courses comprise approximately 894 hectares (2,207 acres) or 2.4% of the watershed in six subbasins. There are currently four golf courses (Glenwild, Jeremy Ranch, Park City Municipal, and Park Meadows) in the watershed, a fifth under construction (The Canyons), and four additional golf courses proposed. Surface disturbance during golf course development can contribute sediment and pollutant loads directly to surface waters. Golf course operations can contribute to sediment and pollutant loads through surface irrigation and associated pollutant release, pollutant transport by overland flows, fertilizers and pesticide use, and increased runoff from impermeable (concrete) and semi-permeable (turf grass) surfaces. Golf courses contribute 137 kg/year (0.26 kg/ha) of phosphorus, or 7% of the total annual phosphorus load in the watershed. The Spiro Tunnel subbasin contains phosphatic shales and contributes 21% (28.4 kg/year) of the annual phosphorus load from golf course land uses.

High use recreation, including parks, soccer fields, ball fields, and bike trails, comprise 57 hectares (142 acres) or 0.2% of the watershed in the Silver Creek/Parley’s Park, and Lower Springs subbasins. There are no phosphatic shales in these subbasins. This land use contributes 8.51 kg/year (0.06 kg/ha) of phosphorus, or <0.1% of the total annual phosphorus load in the watershed.

9.2.1.3.3 Agricultural Management and Grazing

Grazing occurs on large areas in the watershed, including forested land, ranch land, pasture, and horse properties, but it occurs almost exclusively on private lands. The phosphorus contained in manure is in a highly soluble and readily bioavailable form. Reduced vegetative cover from overgrazing and sheet and rill erosion from storm events both result in increased sediment transport to streams and channels. Similarly, overuse of pasture land can result in subsurface soil compaction, compression of the soil profile, and the formation of a dense low-permeability layer below the upper soil horizon. During storm events and spring snowmelt, water infiltration into this compacted layer is limited while the volume and velocity of overland flow is increased, as is the total suspended sediment and nutrient load. Vegetation in overused pasture areas is often insufficient to retain sediment, and deposited manure is easily transported directly into water or downstream in existing stream and irrigation channels (NRCE 1996).

Cattle affect riparian areas and stream channels through increased sediment and nutrient loading and the deposit of manure and urine in surface waters (Mosely et al. 1997). The loss or removal of riparian vegetation reduces bank stability due to reduced root mass, and prevents settling and sedimentation at the edges of the stream channel. As a result, streambanks have become unstable in many stream reaches. Cattle grazing in riparian areas is most common downstream of Jeremy Ranch. The removal of streamside vegetation results in increased water temperatures and promotes the dissolution of adsorbed phosphorus and other nutrients from sediment-bound forms. Erosion occurs from the removal or reduction of riparian vegetation by grazing cattle, and from the shearing action of hooves on streambanks, which destabilizes the soil and promotes the rapid erosion of loose sediments by flowing water.

Irrigation of pasture and hayland occurs in the valley floor of the watershed. To irrigate crop land, either surface water is diverted from numerous streams into developed delivery canal systems, or groundwater is pumped from the regional aquifers into canals or directly to irrigation systems. Irrigation recharge and surface runoff is diverted to local streams or returns via canal seepage, shallow groundwater flow, surface water bypass flow, or irrigation tail water. Irrigation practices that substantially increase subsurface flow facilitate phosphorus transport. In addition, inefficient irrigation water management practices can reduce stream flows unnecessarily and result in increased water temperatures. Surface irrigation practices can substantially lower the water table and may lead to changes in the mobility of phosphorus in shallow subsurface waters. These waters generally contain high concentrations of phosphorus and nitrogen compared to the ambient concentrations in local streams (Omernik et al. 1981; Shewmaker 1997).

Flood irrigation waters cause soil erosion and delivery of sediments and nutrients directly to waterways. Lands that are irrigated using water diverted from surface waters have the potential to carry sediment as well as nutrients from multiple sources (Omernik et al. 1981; Shewmaker 1997). Waters that infiltrate the subsurface can increase the soil delivery rate of phosphorus to the stream from subsurface flow (Hedley et al. 1995). Pollutant loading from grazing is influenced by the intensity, timing, duration, proximity to the riparian vegetation community, and location of watering areas. Impacts from pasturing and grazing include soil compaction (increasing runoff), manure deposition, and increased sediment and nutrient loading due to erosion resulting from loss of vegetation and hoof action (Platts and Nelson 1995; Mosely et al. 1997; Khaleel et al. 1980; Hedley et al. 1995; Sharpley et al. 1992).

Agricultural management and grazing land uses compose 572 hectares (1,414 acres) or 2.4% of the watershed in 13 subbasins. There are phosphatic shales in only one of these subbasins: Three Mile. These land uses contribute 54 kg/year (0.07 kg/ha) of phosphorus, or 1.5% of the total annual nonpoint source phosphorus load in the watershed.

9.2.1.3.4 Stormwater Runoff from Developed Lands and Construction Sites

Stormwater discharges from urban areas consist of concentrated flows that accumulate from streets, parking areas, rooftops, and other impervious surfaces. Primary sources of pollutants associated with rural subdivisions are sediment and nutrients present in both dissolved and sediment-bound forms from roadway and impervious-surface runoff and snowmelt, irrigation practices, and yard and vehicle maintenance. Park City and other subbasins in the upper portion of the watershed contain the highest density of development and associated stormwater runoff volume in the watershed.

The primary pollutant sources from active construction sites are stormwater and sediment runoff, mud and dirt deposition on streets, and stockpiled soils. Active construction land-use areas comprise 71 hectares (175 acres) or 0.2% of the watershed. The majority of the construction is occurring in Summit County, primarily in Snyderville Basin. Active construction contributes 26.1 kg/year (0.47 kg/ha) of phosphorus, or 1% of the total annual nonpoint source phosphorus load in the watershed. The only active construction that occurs near phosphatic shales is in the Willow Draw subbasin.

Residential land use comprises 5,715 hectares (14,121 acres) or 15% of the watershed across 23 subbasins, including areas with phosphatic shales in the Treasure Hollow, Spiro Tunnel, Willow Draw, and Three Mile subbasins. The primary sources of pollutants from residential land use are from runoff over impermeable and semi-permeable surfaces such as pavement and lawns. Nutrient-rich runoff from precipitation or snowmelt can enter the stormwater system from roadways and impervious surfaces and discharge to surface waters in the watershed. Septic systems have the potential to contribute nutrients indirectly to surface waters due to poor design, inadequate sizing, improper maintenance, and/or seasonal high groundwater tables. Excess application of phosphorus fertilizer can be washed from lawns and gardens to local waterways. Irrigation water in excess of what can infiltrate the soil surface can be similarly washed away and is a major transporter of nonpoint source pollutants. Some road de-icer products have been identified as potentially significant sources of phosphorus pollution, and sand may contain substantial amounts of phosphorus. These land uses contribute 354.2 kg/year (0.08 kg/ha) of phosphorus, or 17% of the total annual phosphorus load in the watershed. Subbasins with phosphatic shales contribute 6% (21 kg/year) of the annual phosphorus load from these land uses.

The primary sources of pollutants from commercial and urban land uses are from runoff over impermeable surfaces, such as pavement, excess fertilizer application, excess irrigation, and road de-icers and sand. Nutrient and snowmelt runoff from roadways and impervious surfaces can enter the stormwater system and discharge to surface waters in the watershed. Excess application of phosphorus fertilizer can be washed from landscaping to local waterways. Irrigation water in excess of what can infiltrate the soil surface can be similarly washed away and is a major transporter of nonpoint source pollutants. Some de-icer products have been identified as potentially significant sources of phosphorus pollution, and sand may contain substantial amounts of phosphorus. Commercial and urban land uses comprise 333 hectares (822 acres) or 1.0% of the watershed across 13 subbasins, including phosphatic shale areas in the Spiro Tunnel, Willow Draw and Three Mile subbasins. These land uses contribute 85 kg/year (0.26 kg/ha) of phosphorus, or 4% of the total annual phosphorus load in the watershed. Phosphatic shale areas contribute 52% (44 kg/year) of the annual phosphorus load from these land uses.

9.2.1.3.5 On-site Wastewater Treatment Systems (septic systems)

Large tracts of urban and residential development have been completed in the Snyderville Basin of the watershed. Most of this development is associated with the Park City and Kimball Junction areas, where the majority of urban and residential developments have access to sewer hookups. Septic tanks in the watershed are allowed in areas where central sewer systems are not feasible or present. The majority of these systems are found in the Silver Creek subbasin, which flows south into East Canyon Creek. Subdivisions located near areas of perennial surface water have the potential to contribute nutrient loads to surface waters in the watershed via leachfield contamination of groundwater that recharges streams, or they may contribute nutrient loads directly when leachfields fail. Well designed leachfields typically remove phosphorus through the process of adsorption and precipitation.

Construction sites have a very high potential to mobilize phosphorus to surface waters, especially in locations where sediment runoff and erosion control measures are either not installed or not functioning properly. Construction vehicles can cause debris and mud to be deposited on streets as they exit the construction site. Additionally, developers may stockpile topsoil that typically contains relatively high levels of phosphorus. Sand used on construction sites may also contain substantial amounts of phosphorus.

9.2.1.3.6 Stream Erosion and Reservoir Shoreline Erosion

Population growth has led to a rise in moderate- and high-intensity urban and commercial development in the watershed. The increase in impermeable surface area associated with development in the upper East Canyon Reservoir watershed has resulted in flashy peak flows that cause streambank erosion. Changes in land use from forest to ski areas or golf courses also contribute to the potential for increased runoff and erosion. Development of land adjacent to streams often results in the removal and disruption of riparian vegetation, as well as peak stormwater flows, which cause stream incising in some areas and stream widening in others. Eroding streambanks could be contributing 2.3–7.2 tons of organic matter a year to East Canyon Creek (Baker et al. 2008). Because there is limited agricultural activity on the lands immediately surrounding East Canyon Reservoir, erosion due to agricultural practices, such as pasturing animals, is minimal.

9.2.1.3.7 Natural Background Sources including Phosphatic Shales and ***Atmospheric Deposition***

Natural background loads are those nutrient loads that would naturally occur under undisturbed conditions. Natural processes that contribute to background sources consist of weathering of rock outcrops, atmospheric deposition, mobilization of plant based nutrients via wildlife excretion, natural sheet and rill erosion of soils, and stream channel formation. Local lithology for the East Canyon Reservoir watershed is primarily composed of sedimentary rock, fine-grained alluvial deposits, and glacial outwash, all of which contribute high sediment loads in East Canyon Creek (Olsen and Stamp 2000). Natural background sources include phosphatic shales and native forests throughout the watershed.

Permian phosphatic shale (Meade Peak Member of the Phosphoria Formation) occurs along the southern side of Threemile Canyon and in the extreme southeastern corner of the watershed in Park City. The Meade Peak Member generally forms slopes and is easily eroded. The phosphate-rich sediments of the Meade Peak Member formed in a warm, shallow, marine shelf environment where prolific marine life extracted and concentrated phosphate from upwelling ocean currents (Stokes 1986). Given these characteristics, Meade Peak Member has been identified as a primary source of total phosphorus in the watershed (BIO-WEST 2008). A large proportion of phosphatic shale areas have been disturbed by active developments that have likely increased the erosion of the shales and increased phosphorus loading in East Canyon Creek and East Canyon Reservoir (Olsen and Stamp 2000).

Phosphorus does not have a gaseous state; however, phosphorus contained in dust particles in the atmosphere can contribute a small load of phosphorus to the landscape and directly to waterbodies.

Background or natural nonpoint source areas include the estimated natural load from all 23 subbasins. Background sources contribute 616 kg/year (0.01 kg/ha) of phosphorus, or 30% of the total annual nonpoint source load. In the East Canyon watershed, phosphatic shales occur in the Treasure Hollow, Spiro Tunnel, Upper Spring Creek, Willow Draw and Three Mile subbasins. Subbasins with phosphatic shales contribute 7% (44 kg/year) of the background annual nonpoint source phosphorus load.

9.2.2 LOAD REDUCTION ESTIMATES

9.2.2.1 East Canyon Water Reclamation Facility

The load allocation for ECWRF in the revised East Canyon Reservoir TMDL is 895 kg/year. This is a 35% increase over the 2000 TMDL load allocation and is due to projected growth in the service district for the treatment facility.

9.2.2.2 Internal Reservoir Sources

Alum treatment has been effective on numerous other lakes with phosphorus control lasting for an average of 8 years and reducing internal phosphorus loading by more than 80% (Welch and Cooke 1999). Alum treatment on this scale will reduce internal phosphorus loads by more than 50%, as required by the TMDL.

9.2.2.3 Nonpoint Sources

Load reductions for the East Canyon Reservoir Watershed Implementation Plan rely heavily on nonpoint source reductions to achieve desired water quality and to protect designated beneficial uses. Estimated percent reduction values, and therefore estimated load reductions, are based on values from the peer-reviewed literature. Implementation of a suite of BMPs, as described in this and other plans, provides reasonable assurance that load reductions will be achieved and designated beneficial uses will be restored. Furthermore, the extent of implementation planning, participation, and activity in the watershed is very encouraging. Full implementation of recommendations in existing plans should result in attainment of TMDL goals. The lag time associated with BMP implementation and observed water quality improvement may have led to an overestimation of total load from nonpoint sources. Water quality improvement trends are expected to continue for East Canyon Reservoir. Monitoring and reporting will be conducted to verify effectiveness of implemented BMPs. If monitoring shows that load reductions are not occurring to the extent necessary, BMPs should be modified accordingly. This monitoring and modification "feedback loop" provides further assurance that estimated load reductions will be achieved by continuing implementation of BMP suites. In addition, in-stream erosion sources are expected to be reduced as a result of the East Canyon Creek TMDL. These reductions have not been quantified and are in addition to the estimated load reductions summarized in Table 9.1.

Table 9.1. Summary of Load Reductions Resulting from BMPs Implemented by Loading Source

Loading Source	Current Estimated Load from Source (kg/year)	Recommended BMPs	Land-use Acreage	Estimated Combined BMP Effectiveness	Load Reduction (kg/year)
Active Construction	26.1	• Continue enforcement of stormwater pollution prevention plans and erosion control plans for construction activities • Detention basins • Soil stabilization and management • Vehicle wash-down pads • Street sweepers	175	60%–90%	15.7–23.5
Residential	333.1	• Installation of new, properly functioning systems (I&E) • Soil testing and fertilizer rate reduction (I&E) • Stormwater management plans • Alternative de-icing methods • Test phosphorus content of de-icers	14,121	55%–85%	194.8–301.1
Commercial and Urban	85.3	• Stormwater management plans • Detention basins • Dry basins • Infiltration/ retention basin • Wetland • Sand filter • Improve irrigation ordinances and encourage water mgmt through I&E • Alternative de-icing methods. • Test phosphorus content of de-icers • Porous pavement	822	55%–85%	46.9–72.5

Table 9.1. Summary of Load Reductions Resulting from BMPs Implemented by Loading Source

Loading Source	Current Estimated Load from Source (kg/year)	Recommended BMPs	Land-use Acreage	Estimated Combined BMP Effectiveness	Load Reduction (kg/year)
Golf Course	136.9	• Continue O&M of detention ponds • Grass swales • Filter strip • Soil testing; nutrient mgmt plan • Irrigation management	2,207	45%–75%	61.6–102.7
Ski Area	315.7	• Trail design • Access road treatment • Road realignment/ decommissioning • Infiltration/retention basin	7,369	65%–90%	205.2–284.1
High Use Recreation	8.5	• OHV restrictions • Trail design • Septic tank maintenance	142	35%–55%	3.0–4.7
Agricultural Management and Grazing	54.5	• Irrigation system management • Pasture and hayland planting • Nutrient management • Prescribed grazing • Livestock exclusion from riparian areas • Off-site watering • Channel bank revegetation • Stream crossings • Riparian forest buffer	1,414	60%–85%	32.7–46.3
Forested and Meadow	474.7	• Access road treatment • Road realignment • Trail design • OHV restrictions • Prescribed grazing	65,668	55%–85%	261.1–403.5
Total Load (excluding Background Sources)	1,455.8		92,498		820.9–1,238.3
Average Expected Reduction					**1,030**
Target Reduction					**1,005**

9.2.3 Recommended Management and Implementation Measures

9.2.3.1 East Canyon Water Reclamation Facility

The Snyderville Basin Water Reclamation District is currently designing an expansion and upgrade project of the ECWRF. The ECWRF will be expanded from the current capacity of 4.0 MGD to 7.2 MGD. Several new features and pieces of treatment equipment will be included in the project. First, an additional bioreactor will be added (joining two existing), along with an additional clarifier (joining three existing). Both of these treatment components remove phosphorus biologically. Second, the existing equalization basin will be expanded to improve the biological removal of phosphorus for the entire 7.2-MGD treatment train. Third, the existing sand filters will be replaced with a pressure membrane system capable of treating the entire actual flow. Use of a membrane will increase the stability and reliability of chemical phosphorus removal (to meet TMDL allocations and permit limits).

9.2.3.2 In-reservoir Treatments

The reduction of external sources of phosphorus should eventually lead to a change in the trophic state of East Canyon Reservoir. However, this response may be delayed by the slow flushing rate, associated with the size and management of the reservoir, and the high recycling rate of phosphorus from the sediments into the water column during stratification. This lag time between watershed nutrient load reductions and trophic state change has been documented in other lakes and reservoirs with similarly slow flushing rates and high internal phosphorus recycling rates (Ahlgren 1977; Cooke et al. 1993).

Lakes and reservoirs similar in type to East Canyon Reservoir often require additional in-reservoir treatments to attain trophic change in a relatively short period of time (Cooke et al. 1993). In-reservoir treatments include inactivation of phosphorus in the sediment through the use of aluminum salts and/or the direct aeration of the hypolimnion to provide an interim refuge for cold water fish while the reservoir responds to nutrient reductions. However, in-reservoir treatments are only truly effective in the long term when they are combined with the reduction of external phosphorus loads (Ryding and Rast 1989) through the implementation measures outlined in the previous sections.

9.2.3.2.1 Phosphorus Inactivation Using Alum

The addition of aluminum salt in the form of alum (aluminum sulfate) or sodium aluminate to the water column is the most common method for sediment phosphorus inactivation in lakes and reservoirs. Alum inactivates sediment phosphorus through chemical binding and sorption, thereby reducing internal cycling of phosphorus during periods of anoxia. Alum treatment of East Canyon Reservoir would effectively seal the sediment layer at the sediment-water interface by binding to the phosphorus in the top several centimeters of sediment. As a secondary benefit, the formation of aluminum hydroxide ($Al(OH)_3$) would also remove particulate organic and inorganic matter with phosphorus from the water column, improving water clarity immediately (Cooke et al. 1993). In lakes with very low alkalinity (less than 50 mg/L $CaCO_3$), the addition of aluminum salts can cause a shift in pH (Cooke et al. 1993). The alkalinity of East Canyon Reservoir ranges from 144 to 192 mg/L $CaCO_{3,}$ and so the reservoir should not be susceptible to pH shifts.

Estimating the dose of alum required to reduce internal phosphorus load to the water column of East Canyon Reservoir will require detailed design and study. However, typical dose rates for alum, in order to completely seal the sediments, are typically estimated to be five times the average summer internal phosphorus load. The average total phosphorus released from sediments in East Canyon Reservoir is 2,013 kg/season. This total includes phosphorus that has been in sediments for more than a year as well as the sediment phosphorus associated with spring inflows (of this 2,013 kg/year, only 795 is phosphorus that did not originate in the watershed during the previous year). Approximately 10,065 kg of alum (aluminum sulfate) would be required based on this typical dose rate for East Canyon Reservoir. This dose, spread across the entire reservoir, would result in an aerial application of 36.5 kg/ha (32.5 lbs/acre). Dose rates would be higher in the most phosphorus-rich areas of East Canyon Reservoir and slightly lower in less phosphorous-rich areas. Generally, alum treatment is not recommended in the shallow parts of the reservoir (less than 10 feet) because wind action can disturb sealed sediments.

9.2.3.2.2 Hypolimnetic Aeration

Hypolimnetic aeration aims to raise the oxygen level of the hypolimnion while preserving stratification (maintaining the thermocline) thus not releasing nutrients into the epilimnion (Cooke et al. 1993; Ryding and Rast 1989; Singleton and Little 2006). Oxygenation of anaerobic sediments disrupts the sediment-water interface and provides oxygen to microorganisms that break down organic sediments (Moore et al. 1996). This results in an increased sediment oxygen demand (SOD) for some time until organic sediments become saturated with oxygen and SOD levels taper off (Moore et al. 1996). In East Canyon Reservoir, as with other similar waterbodies, this process could provide immediate habitat and food supply for cold water fish species. Furthermore, aerobic sediments do not release iron-bound phosphorus. Hypolimnetic aeration is restricted to lakes deeper than 12–15 m (Cooke et al. 1993).

Hypolimnetic aeration can be accomplished with the use of airlifts, diffusers, or injection of compressed air (Singleton and Little 2006). Medium bubble diffusers would provide sufficient oxygen transfer in East Canyon Reservoir, because the reservoir is quite deep. The design of a hypolimnetic aeration system depends on the bathymetry of the reservoir, the extent of anoxia (across the reservoir during summer and winter), and specific project goals. The model developed by McCord et al. (2000) could be used to design an effective aeration system that maintains stratification in the summer and also prevents winter fish kills.

In the case of East Canyon Reservoir, hypolimnetic aeration would enhance the cold water fishery habitat in the interim while phosphorus reduction efforts in the watershed take effect. Reestablishment of the blue-ribbon trout fishery in East Canyon Reservoir may require hypolimnetic aeration indefinitely. Aeration should be used primarily when the reservoir is stratified in the summer and winter seasons. Aeration is only recommended where the deep hypolimnion experiences extended periods of anoxia, from the dam through the mid-lake monitoring site. In East Canyon Reservoir, an aeration system would likely be needed near the dam extending up the reservoir for at least 1/3 of a mile to cover the deepest and most anoxic sections of the reservoir. An aeration system of this size would typically require one to two blowers with motors that are 200–300 hp (personal communication between Erica Gaddis, SWCA, and Theron Miller, UDWQ).

9.2.3.3 Nonpoint Source Management Measures

All land uses in the East Canyon Reservoir watershed contribute dissolved and/or sediment-bound nutrient loads to the reservoir. The nonpoint source reduction implementation plan describes existing plans and additional BMPs that could be implemented and/or maintained for the purpose of reducing phosphorus and sediment loading to the reservoir and its tributaries. If the recommended and existing BMPs for load reduction are designed, installed, and maintained properly, the greatest possible phosphorus reduction will be achieved at the least cost. This could be achieved through full implementation of existing source-specific plans in the watershed. The systemization of individual BMPs (i.e., the designing of BMPs in cohesive systems rather than as stand-alone practices) further facilitates watershed planning and phosphorus reduction. Land uses identified in the East Canyon Reservoir watershed and associated phosphorus loads are listed in Table 9.2.

Table 9.2. Summary of Land Uses and Associated Phosphorus Nonpoint Loads

Land Use	Area Hectares (acres)	Area Weighted Phosphorus Load (kg/ha/year)	Total Phosphorus Load (kg/year)
Active Construction	71 (175)	0.47	26.1
Residential	5,715 (14,121)	0.08	354.2
Commercial and Urban	333 (822)	0.26	85.3
Golf Courses	893 (2,207)	0.26	136.9
High Use Recreation	57 (142)	0.06	8.5
Ski Areas	2,982 (7,369)	0.18	315.7
Agriculture/Grazing	572 (1,414)	0.07	54.5
Forested and Meadow	26,575 (65,668)	0.01	474.7

The overall project goals are to reduce nonpoint source phosphorus loading to East Canyon Reservoir by decreasing the amount of phosphorus runoff from the land uses identified above. Additional reductions in phosphorus loading can be achieved by informing and educating the community concerning nonpoint source pollution and the importance of managing natural resources in the watershed. Specifically, the project goals and objectives for the East Canyon Reservoir watershed are as follows:

Goal 1: Continue to improve site control for active construction sites to reduce sediment runoff to East Canyon Creek, its tributaries, and East Canyon Reservoir.

Goal 2: Improve golf course management practices to reduce nutrient and sediment loading to East Canyon Creek, its tributaries, and East Canyon Reservoir.

Goal 3: Continue to improve ski area management practices to reduce nutrient and sediment loading to East Canyon Creek, its tributaries, and East Canyon Reservoir.

Goal 4: Reduce nutrient and sediment loading to East Canyon Creek, its tributaries, and East Canyon Reservoir by implementing BMPs on agricultural and grazing lands.

Goal 5: Inform and educate the community concerning nonpoint source pollution and the importance of maintaining and improving water quality in the watershed.

Goal 6: Centralize implementation plan reporting in a database available to the public and stakeholders in the watershed. This database should include implementation monitoring (e.g. progress reporting), effectiveness monitoring (e.g. water quality monitoring results), and documentation of progress.

9.2.3.3.1 Overview of Best Management Practices (BMPs) and Implementation Planning

For the purposes of this implementation plan, BMPs refer to any action or measure implemented or maintained in the watershed to control nonpoint sources of phosphorus to East Canyon Reservoir. These include traditional structural and nonstructural BMPs as defined by the NRCS, the USFS, and in stormwater management plans, as well as actions and measures related to planning, education of landowners, and enforcement of stormwater ordinances.

Structural BMPs applied to the East Canyon Reservoir watershed may include practices such as installing construction silt traps (silt screen fencing, sock, straw bales), installing and maintaining detention basins, designing new trails or redesigning existing trails, treating access roads, stabilizing slopes, restricting cattle access to stream channels, and reinforcing or stabilizing eroded areas along East Canyon stream.

Nonstructural techniques include development of stormwater management plans; improving the operation, maintenance, and enforcement of existing stormwater management plans; testing soils and developing nutrient management plans; restricting OHV use and enforcing those policies; and implementing irrigation water management plans.

Implementation and maintenance of BMPs in the East Canyon Reservoir watershed is necessary to achieve water quality targets and TMDL endpoints. Installed BMPs are either structural or nonstructural practices used to protect the physical and biological integrity of waterbodies. These practices are most effective when installed in combination as a system of BMPs rather than in isolation. Some BMPs follow standards established by the USDA NRCS Field Office Technical Guide (NRCS 2007).

9.2.3.3.2 Existing Watershed Planning and Implementation

Numerous efforts have been made in the East Canyon Watershed to reduce nonpoint source sediment and phosphorus runoff. These efforts are detailed in management plans specific to municipal stormwater (PCMC 2003, Summit County Ordinance 281), ski resorts (MAG 2003, The Canyons Ski Resort 1999), golf courses (MAG 2003, Jeremy Golf and Country Club 2001), construction (MAG 2003), agriculture (ECWC 2004), in-stream erosion (ECWC 2004), and recreation (MAG 2003), and generally cover all of the major sources of phosphorus loading in the watershed. Each plan is currently in the process of being implemented with varying levels of completion. The plans themselves detail BMP implementation that is relevant, appropriate, and specific to locations throughout the watershed. The implemented BMPs are included in the calculated load reductions required for each source, as they are reflected in the load coefficients derived from monitoring data by subbasin collected in 2007 (BIO-WEST 2008). Generally, full implementation of each of these plans should result in attainment of the TMDL loads allocated to nonpoint sources in the East Canyon Reservoir. However, monitored loads in the East Canyon Watershed in 2007 (BIO-WEST 2008) indicate that full implementation has not yet been completed. A summary of the types of BMPs recommended for each land use are included in this nonpoint source reduction implementation plan for the watershed, however the reader is referred to the more detailed source-specific plans listed in Table 9.3 for more information. The watershed would benefit from a centralized database that tracks the progress and success of implementation projects throughout the reservoir. The East Canyon Watershed Committee hosts a website that currently serves as a clearing house for documents, contacts, and meetings. This website would be a good place to host a database of progress reporting, monitoring data, and load reduction estimates.

Table 9.3 Summary of Implementation Planning in the East Canyon Reservoir Watershed

Plan	Date	Phosphorus Source	Organization	Monitoring Plan	Status of Implementation	Schedule for Implementation?
East Canyon Watershed Restoration Action Plan	2004	All watershed sources	East Canyon Watershed Committee	Yes.	Implementation of most projects documented in 104(b) 3 Project Progress reports available from the NRCS.	No.
Park City Municipal Corporation Storm Water Management Plan	2003	Commercial, urban, residential, and active construction	Park City Municipal Corporation	Construction site visits and water quality testing.	Annual Reporting. Environmental Information Handbook (2003)	Ongoing. Annual projects prioritized as funding permits.
Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project	2003	Recreation and Construction Industry	Mountainland Association of Governments. 2003	Yes.	Unknown.	Yes.
Golf Course Environmental Management Plan for The Jeremy Golf and Country Club	2001	Golf courses	Jeremy Golf and Country Club	No.	Unknown.	No.
Willow Draw Watershed Master Plan	1999	Ski resorts	The Canyons Ski Resort	No.	Unknown.	Completion target date: 2005.
Summit County Storm Water Ordinance (Ordinance 381)	Not available	Active Construction	Summit County	Construction site visits	Ongoing.	Ongoing.

9.2.3.4 Critical Areas for Management Measures

Total phosphorus loads have been summarized by land use in each of 23 subbasins in the East Canyon Reservoir watershed based on loads derived using load coefficients from the BIO-WEST watershed monitoring project in 2007 (BIO-WEST 2008) and adjusted proportionally to match total load to the reservoir observed from 2003 - 2007. Loads are summarized both as total load from each landuse-subbasin combination and as area-weighted loads (the total load divided by the area). Areas with high area-weighted loads indicate a large load per area and therefore an opportunity to address more loads with less implementation. These areas are generally more cost-effective to target for phosphorus reduction in terms of kg of phosphorus reduced per dollar spent. However, many of the areas with high area-weighted loads compose a very small proportion of the watershed and therefore do not contribute a significant load to the reservoir. Likewise, the largest contributor of total load in the watershed, forested and meadow land uses, have the lowest area-weighted load but the largest total land area. Therefore, these areas must be addressed, even though so doing many cost more per kg of phosphorus reduced. Both total load and area-weighted load were used in prioritizing critical areas to focus further implementation efforts. High priority areas (landuse-subbasin combinations) are those that have both a high area-weighted load (greater than 0.1 kg/ha/year) as well as a significant total load (greater than 10 kg/year). Medium priority areas are those that have either a high area-weighted load or a significant total load. Low priority areas have both low area-weighted loads (less than 0.1 kg/ha/year) and low total loads (less than 10 kg/year). A spatial summary of high, medium, and low critical priority areas, based on these criteria is displayed in Figure 9.1.

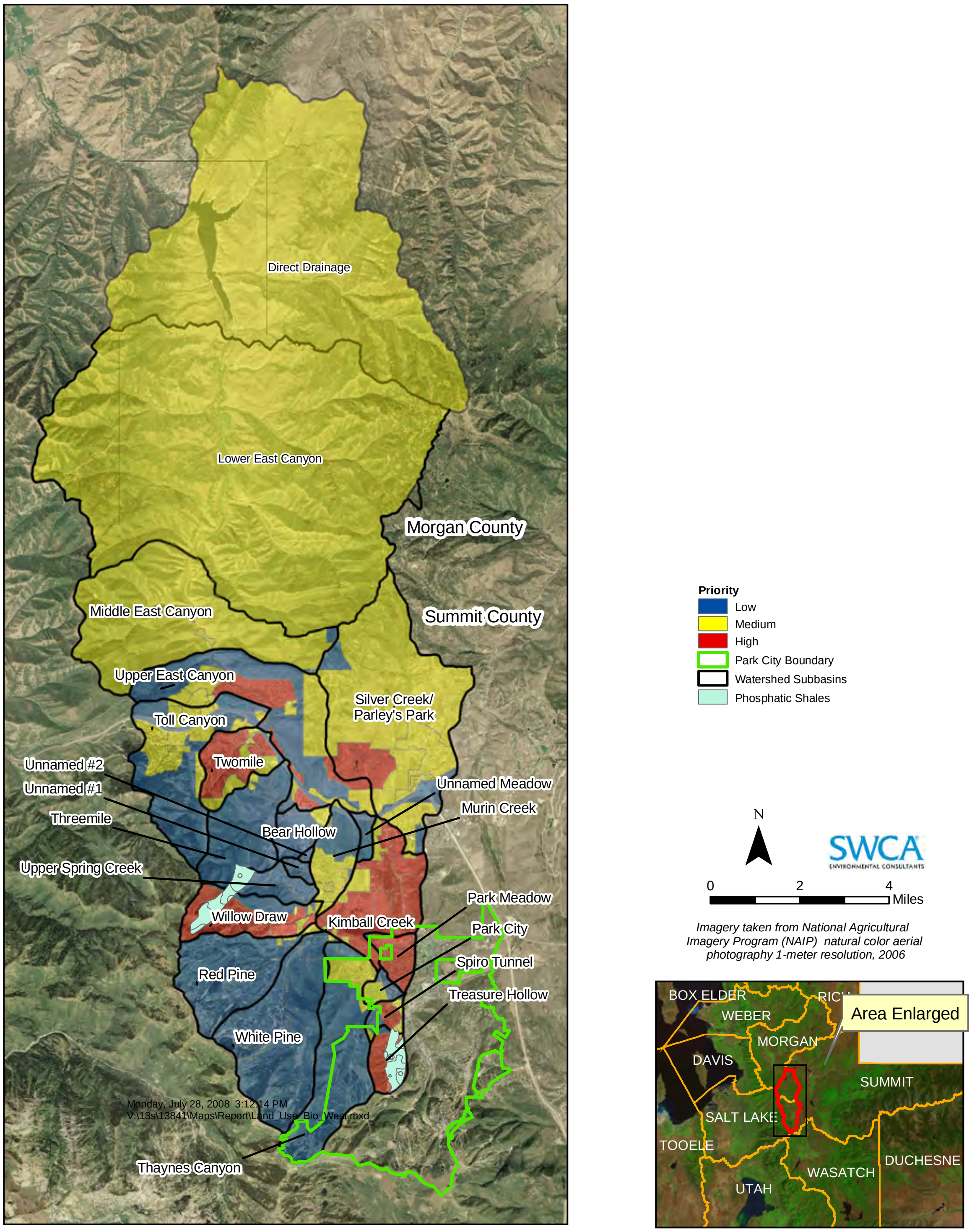

Figure 9.1 Map of critical priority areas for additional implementation for phosphorus reduction in the East Canyon Reservoir watershed.

9.2.3.5 Land Uses and Recommended BMPs

9.2.3.5.1 Active Construction

Summary of Construction BMP Implementation, Planning, and Enforcement

BMPs designed to reduce pollutant loads from construction sites include preservation of existing vegetation, installation of silt traps (silt screen fencing, sock, and straw bales), temporary stabilization of stockpiled soils, use of vehicle wash stations, and use of street sweepers. Infiltration basins are used on larger construction projects. Stormwater and sediment runoff from construction sites can be limited by continuing enforcement of requirements of a Storm Water Pollution Prevention Plan (SWP3) and Erosion Control Plan (ECP).

Summit County and Park City Municipal Corporation (PCMC) have numerous programs and regulations in place for construction controls. No significant construction activities are present in Morgan County. Summit County and PCMC have been coordinating with DWQ in developing SWP3s and each plan contains chapters that directly relate to water quality. Summit County Ordinance 381 and Park City’s Storm Water Management Plan (PCMC 2003) contain BMPs for Construction Site Runoff Controls and Post Construction Runoff Controls. Additional plans that address control of construction runoff include the East Canyon Watershed Restoration Action Plan (East Canyon Watershed Committee 2004) and the Snyderville Basin Recreation & Construction Industry Water Quality Improvement Project (MAG 2003).

In addition, PCMC conducts training sessions and workshops for local contractors to learn about BMPs for stormwater quality and environmental ordinances. PCMC requires that all construction must adhere to environmental ordinances and mitigation, and signed compliance to environmental ordinances is required for all projects that need a building permit. A "stop work" order is issued if stormwater BMPs are not implemented. A contractor must resolve the issue or the permit is revoked. In 2005, PCMC made 665 construction site inspections and issued 78 Stop Work Orders due to stormwater violations. Reductions in current pollutant loads from construction sites can be achieved by continued application and enforcement of these existing plans, programs, and ordinances.

Priority Areas for Continued BMP Implementation, Maintenance, and Enforcement

Implementation of BMPs to control active construction in the Willow Draw subbasin of Summit County is the highest priority for this source. Phosphatic shales in this subbasin contribute to the very high area-weighted load for active construction. Enhanced and additional BMPs may be required to control phosphorus load from these areas. The Kimball Creek, Park City, Two Mile, and Upper East Canyon subbasins are all medium priority areas for implementation of active construction BMPs. Although these subbasins have relatively high area-weighted loads for active construction, the small acreage associated with this land use results in a small total load contribution to the reservoir. Active construction in the White Pine subbasin is a low priority.

Table 9.4. Priority Subbasins and Recommended BMPs for Active Construction Areas in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Willow Draw	Summit Co.	Yes	17	17.6	1.01	High
Kimball Creek	Summit Co.	No	4	2.0	0.44	Medium
Park City	Park City	No	19	4.3	0.22	Medium
Two Mile	Summit Co.	No	3	0.6	0.20	Medium
Upper East Canyon	Summit Co.	No	8	1.2	0.16	Medium
White Pine	Summit Co.	No	19	0.4	0.02	Low

The effectiveness of total phosphorus reduction for BMPs applied to sources associated with active construction depends on the extent of application, the proportion of phosphorus that is particulate (bound to sediments), and operation and maintenance of the BMPs. Infiltration/sedimentation basins generally reduce total phosphorus by 50% to 80% (WDEQ 1999). Street sweepers are able to remove approximately 75% of phosphorus associated with dirt or sand from construction vehicles (USDOT 2008). Installation of silt traps, stabilization of stockpiled soils, and the use of vehicle wash stations would further reduce phosphorus load associated with construction activities. Assuming the appropriate BMPs are implemented a 60% – 90% of total phosphorus from current loads associated with active construction sources was assumed (15.7 to 23.5 kg/year).

9.2.3.5.2 Residential

Summary of BMP Implementation and Planning

The East Canyon Watershed Restoration Plan (ECWC 2004) contains goals and objectives to develop and implement residential homeowner BMPs to minimize contributions of nutrients from residential land uses. These goals and objectives include ongoing information and education programs targeted at homeowners, and development of a Comprehensive Information and Education Plan for the East Canyon Watershed. A residential outreach program is included in the comprehensive plan for the watershed. A detailed outline for the Comprehensive Information and Education Plan for the East Canyon Watershed has been developed and is available in the East Canyon Watershed Restoration Plan (ECWC 2004).

Park City Municipal Corporation has procured over 4,000 acres of open space partially funded by a $10 million open space bond. They have tried to focus on riparian and stream buffer zones to improve water infiltration and protection in these areas, which will in turn improve stormwater quality. PCMC has also installed 100 "No Dumping Drains to Watershed" signs on drains throughout the city and added silt traps to stormwater accumulation structures. The development and maintenance of sediment detention basins are ongoing projects. PCMC has also focused on educating the surrounding community. PCMC enforces a Conservation and Drought Management plan that includes BMPs for conserving water. The plan incorporates irrigation ordinances and water management priorities. The plan also recommends the distribution of public information about water conservation in brochures, in public service announcements on TV and radio, on posters, and on bus advertisements. The PCMC also publishes and distributes an

"Environmental Information Handbook" and a "Residential Stormwater Brochure" as well as information on invasive weed species and xeriscape gardening. In addition, they have placed signs throughout the watershed detailing proper management of dog waste and stormwater BMPs.

Runoff from impervious surfaces would be further limited by maintaining the Stormwater Management plans in place in the watershed and continuing to implement recommendations in the East Canyon Watershed Restoration Plan. These recommendations include the following specific actions. Nutrient loads from semi-permeable surfaces, lawns, and gardens should be limited by encouraging pre-fertilization soil testing and reduction of the use of residential fertilizer based on soil test recommendations. Reductions in pollutant loads from runoff and irrigation return flow may be achieved through the maintenance of irrigation ordinances and by encouraging water management through landscaping information and education. Also recommended are alternative de-icing methods that require testing of phosphorus content of de-icers and road sand and a resulting change of source if the phosphorus content is high.

BMPs designed to reduce pollutant loads from on-site wastewater treatment systems include repair of existing systems, addition of sand or recirculating filters, improved rates of regular maintenance of systems, or the complete removal of a malfunctioning system and replacement with properly functioning system. Installation of new, properly functioning systems has been found to be prohibitively expensive and to lead to very little progress in load reduction. However, a study of groundwater in the Silver Creek Estates development indicates that subsurface flow may be an important conveyance of phosphorus from residential land uses. This phosphorus could have originated from septic systems, or infiltration from heavily fertilized turf. Generally, there are no recommended BMPs for improving phosphorus treatment in septic tanks or leachfields. However, tanks and drainfields that are not installed correctly or not operating as designed should be modified, repaired, or fixed. Due to the high potential for growth in the watershed, an I&E program concerning the design, installation, and maintenance of on-site wastewater treatment systems should be initiated by the agency responsible for overseeing the permitting of new or replaced systems.

Priority Areas for Continued BMP Implementation

Residential development in the Kimball Creek, Park Meadows, and Two Mile subbasins are all high priority areas for implementation due to both high area-weighted loads and significant total load. Kimball Creek incorporates much of the recent development in Snyderville Basin. All of these areas, with the exception of Park Meadows, are under the jurisdiction of Summit County. Eleven additional subbasins are ranked as medium priority areas for stormwater BMP implementation. These areas span the watershed and include residential areas in Morgan County, unincorporated Summit County, and Park City. Several of these subbasins (Willow Draw, Treasure Hollow, Three Mile and Spiro Tunnel) contain phosphatic shales that should be considered concentrated source areas where enhanced BMPs may be required to mitigate naturally high soil phosphorus levels. The relatively low area-weighted load from residential areas in Park City, the most densely populated area of the watershed, is noteworthy and indicative of the efforts this municipality has made to treat stormwater and reduce impacts on water quality.

Table 9.5. Priority Subbasins and Recommended BMPs for Residential Land Uses in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Kimball Creek	Summit Co.	No	595	87.4	0.15	High
Park Meadows	Summit Co./Park City	No	89	14.7	0.17	High
Two Mile	Summit Co.	No	367	74.8	0.20	High
Direct Drainage	Morgan Co.	No	255	23	0.09	Medium
Lower East Canyon	Morgan Co.	No	156	14.1	0.09	Medium
Lower Springs	Summit Co.	No	222	14.5	0.07	Medium
Silver Creek / Parley's Park	Summit County	No	2,559	42.4	0.02	Medium
Spiro Tunnel	Park City	Yes	10	5.0	0.48	Medium
Thaynes Canyon	Summit Co./Park City	No	161	14.3	0.09	Medium
Three Mile	Summit County	Yes	16	2.9	0.17	Medium
Toll Canyon	Summit County	No	472	11.8	0.03	Medium
Treasure Hollow	Park City	Yes	3	1.6	0.48	Medium
Upper East Canyon	Summit County	No	527	26.3	0.05	Medium
Willow Draw	Summit County	Yes	27	7.2	0.27	Medium
Bear Hollow	Summit Co.	No	18	1.6	0.09	Low
Middle East Canyon	Summit Co.	No	27	2.5	0.09	Low
Park City	Park City	No	11	1.0	0.09	Low
Unnamed # 1	Summit Co.	No	48	3.2	0.07	Low
Unnamed # 2	Summit Co.	No	13	0.9	0.07	Low
Unnamed Meadow	Summit Co.	No	5	0.5	0.09	Low
Upper Spring Creek	Summit Co.	Yes	106	4.4	0.04	Low

The effectiveness of total phosphorus reduction for BMPs applied to sources associated with active construction depends on extent of application, the proportion of phosphorus that is particulate (bound to sediments), and operation and maintenance of the BMPs. Infiltration/sedimentation basins generally reduce total phosphorus in stormwater by 50% to 80% (WDEQ 1999). Other stormwater mitigation structures and practices (reduced fertilizer, alternative de-icing methods, and sediment traps) would further reduce total phosphorus associated with residential areas (International Stormwater Database 2007). Assuming the appropriate BMPs are implemented a 55% – 85% reduction of total phosphorus from current loads associated with residential areas was assumed. With the implementation of the recommended BMPs applied to treat stormwater from residential areas, the estimated phosphorus load reduction ranges from approximately 195 to 301 kg/year.

9.2.3.5.3 Commercial and Urban

Summary of BMP Implementation and Planning

The implementation measures employed by Park City Municipal Corporation to reduce stormwater impacts to East Canyon Creek and Reservoir are described in the residential land uses section and apply equally to commercial and urban land uses. Stabilization of eroding segments from streambanks has been accomplished by working with private landowners to implement stream erosion BMPs. In addition, the East Canyon Watershed Committee has supported the development and implementation of site specific private landowner management plans (East Canyon Watershed Restoration Plan (East Canyon Watershed Committee 2004).

An East Canyon Watershed Stream Restoration Project has been implemented by Mountainland Association of Governments. The accomplishments made in this project are summarized in the Nonpoint Source 319 (h) Project Progress Reports dated August 20, 2007 and September 21, 2007. With respect to urban land uses, these progress reports indicate that land owners between East Canyon Reservoir and the East Canyon Creek headwaters were contacted and the majority of them are interested in participating in the restoration efforts. Five implementation plans have been written, two have completed their projects and two are in progress. In coordination with the Swaner Nature Preserve, three additional restoration plans have been written for property owners adjacent to the preserve to restore approximately 5 miles of East Canyon Creek above the ECWRF.

Runoff from impervious surfaces could be further reduced by maintaining the Stormwater Management plans in the watershed and fully implementing recommendations contained in the plans. These recommendations include the following specific actions: 1) Nutrient loads from semi-permeable surfaces and landscaping should be limited by encouraging pre-fertilization soil testing and reduction of the use of landscape fertilizer based on soil test recommendations. 2) Reductions in pollutant loads from runoff and irrigation return flow may be achieved through the maintenance of irrigation ordinances and by encouraging water management through landscaping information and education. 3) Alternative de-icing methods that require testing of phosphorus content of de-icers and road sand and a corresponding change in the source if the phosphorus content is high.

Priority Areas for Continued BMP Implementation

Implementation of BMPs on commercial and urban land uses in the Willow Draw and Upper East Canyon subbasins is ranked as a high priority for the watershed (Table 9.5). Willow Draw contains phosphatic shales that contribute to the very high area-weighted phosphorus loads observed in those areas. The high priority areas are under the jurisdiction of Summit County. Spiro Tunnel, Two Mile, Toll Canyon, Three Mile, Silver Creek/Parley’s Park, White Pine, Bear Hollow, Kimball Creek, and Red Pine subbasins are a medium level priority for implementing additional stormwater BMPs. Phosphatic shales are found in several subbasins with commercial and urban land uses including Spiro Tunnel (Park City), Three Mile (Kimball Junction), and Willow Draw (Summit County). The phosphatic shale portions of these subbasins should be considered concentrated source areas where enhanced BMPs may be required to mitigate the naturally high soil phosphorus levels in the area. The very low area-weighted load and total load from commercial and urban areas in Park City, the most densely developed area of the watershed, is noteworthy and indicative of the efforts this municipality has made to treat stormwater and reduce impacts on water quality.

Table 9.6. Priority Subbasins and Recommended BMPs for Commercial and Urban Land Uses in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Willow Draw	Summit Co.	Yes	80	37.2	0.47	High
Upper East Canyon	Summit Co.	No	72	12.0	0.17	High
Spiro Tunnel	Park City	Yes	14	6.9	0.48	Medium
Two Mile	Summit Co.	No	14	3.4	0.25	Medium
Toll Canyon	Summit Co.	No	15	2.8	0.20	Medium
Three Mile	Summit Co.	Yes	1	0.2	0.18	Medium
Silver Creek / Parley's Park	Summit Co.	No	46	8.3	0.18	Medium
White Pine	Summit Co.	No	14	2.5	0.18	Medium
Bear Hollow	Summit Co.	No	37	6.2	0.17	Medium
Kimball Creek	Summit Co.	No	3	0.5	0.17	Medium
Red Pine	Summit Co.	No	28	4.6	0.17	Medium
Lower Springs	Summit Co.	No	5	0.4	0.09	Low
Park City	Park City	No	3	0.1	0.04	Low

The effectiveness of total phosphorus reduction for BMPs applied to sources associated with commercial and urban land uses depends on extent of application, the proportion of phosphorus that is bound to sediments, and operation and maintenance of the BMPs. Infiltration/sedimentation basins generally reduce total phosphorus in stormwater by 50% to 80% (WDEQ 1999). Other stormwater mitigation structures and practices (reduced fertilizer, alternative de-icing methods, and irrigation management) would further reduce total phosphorus associated with commercial and urban areas (International Stormwater Database 2007). Assuming the appropriate BMPs are implemented, in addition to those already completed, a 55% – 85% reduction of total phosphorus from current loads associated with commercial and urban areas was assumed (47 to 73 kg/year). Though any single BMP may be applied, greater reductions are achieved when BMPs are implemented in conjunction with others.

9.2.3.5.4 Golf Courses

Summary of BMP Implementation and Planning

Potential projects for each golf course are outlined in the Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project (MAG 2003) and adopted in the East Canyon Watershed Restoration Action Plan as implementation strategies for golf courses. Each golf course in the watershed has existing strategies and management practices (WRAPS Plans) in place. Based on interviews conducted with the respective golf course superintendents and managers, these strategies and management practices are consistent with those recommended in the Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project (MAG 2003).

For example, Glenwild Golf Club has not applied phosphorus fertilizer to most of the course in the past three years and runoff from the golf course is filtered by natural areas, including wetlands (personal communication between Erica Gaddis, SWCA, and David Willis, Glenwild Golf Course, August 14, 2008). PCMC's Parks and Golf Department manages multiple sediment traps, sediment vaults, and buffer areas. In 2006, PCMC removed 10,000 cubic yards of sediment from a detention basin in Park City Municipal Golf Course.

It is noteworthy that two of the four golf courses, Glenwild Golf Club and Park City Municipal Golf Club, are currently or in the process of becoming "Audubon Certified Golf Courses". To become an Audubon Certified Golf Course, the superintendent of the golf course must complete a rigorous program and implement procedures that include Environmental Planning, Wildlife and Habitat Management, Chemical Use Reduction and Safety, Water Conservation, Water Quality and Management, and Outreach and Education (MAG 2003). Golf course employees must also undergo continued education and training on environmental practices.

Given that the golf courses in the watershed are currently following the BMPs outlined in the Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project (MAG 2003), continuation of these BMPs for existing golf courses and implementation of these BMPs by new golf courses is recommended. These BMPs include: the continued operation and maintenance of detention ponds to reduce or prevent sediment runoff; pre-fertilization soil testing and reduction of fertilizer use based on soil test recommendations; the implementation of a nutrient management plan and continued irrigation management to reduce nutrient runoff; and the creation of riparian buffers and filter strips to filter nutrients from runoff before it enters receiving waters (MAG 2003).

Priority Areas for Continued BMP Implementation

Portions of each of the four golf courses in the watershed lie in a priority subbasin. Some of these areas are recommended for additional BMP implementation (Table 9.7). The portion of Jeremy Ranch that is in Toll Canyon is considered to be a low priority for additional implementation, whereas the Park City Golf Course, located in the Park City subbasin, is a medium priority for additional implementation The two high priority areas for improving golf course BMP implementation are at the Park City Golf Course and the Park Meadows Golf Course in the Spiro Tunnel and Park Meadows subbasins respectively. In particular, the Park City Golf Course in the Spiro Tunnel subbasin has a very high area weighted load (0.50 kg/ha/year). Because this golf course sits on phosphatic shales, enhanced BMPs may be required to fully mitigate the impacts of disturbance of this concentrated source.

Table 9.7. Priority Subbasins and Recommended BMPs for Golf Courses in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Spiro Tunnel	Park City Golf Course	Yes	56	28.0	0.50	High
Park Meadows	Park Meadows Golf Course	No	142	22.1	0.16	High
Silver Creek/Parley's Park	Glenwild Golf Course	No	264	36.8	0.14	High

Table 9.7. Priority Subbasins and Recommended BMPs for Golf Courses in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Upper East Canyon	Jeremy Ranch / Glenwild	No	304	38.3	0.13	High
Park City	Park City Golf Course	No	57	6.1	0.11	Medium
Toll Canyon	Jeremy Ranch Golf Course	No	71	5.1	0.07	Low

Detention basins have already been installed on many golf courses in the watershed. Total phosphorus through these basins is reduced by 30 to 90% depending upon the proportion of phosphorus that is bound to sediments, and operation and maintenance of the BMPs (International Stormwater Database 2007). Continued operation and maintenance of these basins will further improve total phosphorus removal effectiveness. Enhanced BMPs may include installation of grass swales and filter strips and would reduce associated total phosphorus loads by 20% – 40% and 30% to 80% respectively (International Stormwater Database 2007). Soil testing, nutrient management planning, reduced fertilizer application rates, and irrigation management would further reduce total phosphorus loads associated with golf courses. Assuming the appropriate BMPs are implemented and maintained, a 45% to 75% reduction of total phosphorus from current loads associated with golf courses is projected (62 to 103 kg/year)

9.2.3.5.5 Ski Areas

<u>Summary of BMP Implementation and Planning</u>

Currently each ski area in the watershed has an ongoing Watershed Restoration Action Plan (WRAP) that includes actions such as erosion control, re-vegetation of areas disturbed by construction, water bar control on roads and ski slopes, stormwater pond use, compliance with City and County erosion control ordinances, road reclamation, historic mine activity stabilization where applicable, and water quality monitoring (except Gorgoza Park and Park City Mountain Resort) (MAG 2003).

One of the objectives of the East Canyon WRAP is to implement the supplemental recommendations and projects identified for ski hills in the Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project (MAG 2003). Projects that are applicable to multiple resorts include water quality monitoring, development of a guidance document for mountain roads, and supervisor training. More specifically, the Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project (MAG 2003) identifies the following potential projects for ski resorts:

- *Water Quality Monitoring.* Participation in a water quality monitoring program is a potential project for all ski resorts. There is currently no consistent data collection method or database to evaluate the effectiveness of water quality BMPs. Participation in a water quality monitoring program using standardized parameters, sampling locations, and frequency would provide the appropriate data which could then be compiled in a database.
- *Mountain Road Guidance Document.* The development of a guidance document for mountain roads would identify both construction and long term criteria for mountain roads. Criteria to be

included are water bar construction, drainage issues, roadway widths, and roadway decommissioning.

- *Ski Area Supervisor Training.* The purpose of providing ski area supervisor training would be to educate personnel about water quality issues on the mountain and how their operations affect water quality.

Additional resort-specific projects are described in the Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project (MAG 2003) and summarized below:

Park City Mountain Resort

- *Thaynes Canyon Stream Stability Survey*. The Thaynes Canyon drainage has been impacted by historic mining activities and grazing access. The channel area should be surveyed to determine the appropriate remedial action.
- *Restoration of Upper Treasure Hollow drainage.* The upper portion of the drainage (above 7,800 feet) has been impacted by mining activity, work roads and past snowmaking construction practices. Runoff is not well controlled and results in erosion of slopes.
- *Management plan for surface parking lots.* The surface parking lots are scheduled for replacement with underground parking. Prior to the development of underground parking, runoff from the ski runs needs to be diverted away from the lower lot to reduce sediment entering the storm drain system. Access to the mountain via the parking lots needs to be controlled to single points and combined with an improved, on-going lot sweeping program.
- *Utilize mapped phosphoric shale deposits.* A portion of the surficial material at Park City Mountain Resort consists of a phosphorus rich shale outcrop and its associated soils. Recent detailed mapping of these phosphorus-bearing deposits using GIS should serve as a guide to avoid disturbing these areas as much as possible.

The Canyons Resort

- *Completion of Upper Willow Draw restoration (Basin Hydrology, 1999).* Work to reduce erosion and improve channel stability in the vicinity of the Canis Lupis ski run should be evaluated and completed.
- *Possible re-activation of old detention structures.* The water detention pond near the Super Condor lift could be considered for activation as stormwater detention for runoff below the Sun Lodge.
- *Surfacing and semi-permanent storm water BMP's for ski area parking.* The upper employee and skier parking areas should have additional controls installed to reduce migration of material off-site from runoff and/or vehicle tracking. This will reduce the sediment load on the existing detention structure.
- *Utilize mapped phosphoric shale deposits.* A portion of the surficial material at The Canyons Resort consists of a phosphorus rich shale outcrop and its associated soils. Recent detailed mapping of these phosphorus-bearing deposits using GIS should serve as a guide to avoid disturbing these areas as much as possible.

Utah Olympic Park

- *Roadway slope stabilization.* The roadway cut and fill slopes require additional stabilization.
- *Jump slope stabilization.* The jump slopes require stabilization.

Gorgoza Park

- *Develop WRAPS*. Development of a WRAP will identify existing and proposed control measures that are being implemented at Gorgoza.

Priority Areas for Continued BMP Implementation and Maintenance

The highest priority areas for reducing total phosphorus load from ski areas are the portion of the Park City Mountain Resort located in the Treasure Hollow subbasin and the portion of the Canyons Resort in the Willow Draw subbasin. These areas both contain phosphatic shales. Enhanced BMPs and special caution to minimize disturbance are required for these concentrated source areas. Loads from Gorgoza Park are very low, thus additional BMP implementation in this area is a low priority for the watershed. Similarly, the portions of The Canyons Resort that are in the White Pine, Red Pine, and Thaynes Canyon subbasins also have low area-weighted loads and are low priorities for additional BMP implementation.

Table 9.8. Priority Subbasins and Recommended BMPs for Ski Areas in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Treasure Hollow	Park City Mountain Resort	Yes	254	186.6	0.74	High
Willow Draw	The Canyons	Yes	417	112.5	0.27	High
Spiro Tunnel	Park City Mountain Resort	Yes	13	9.3	0.74	Medium
Toll Canyon	Gorgoza Park	No	51	0.7	0.01	Low
White Pine	The Canyons	No	425	5.6	0.01	Low
Thaynes Canyon	Park City Mountain Resort	No	829	0.3	<0.01	Low
Red Pine	The Canyons	No	986	0.4	<0.01	Low

Sediment control has already been improved from ski resorts in the watershed. The effectiveness of additional implementation will further reduce phosphorus loads from these areas. Improved trail design can reduce total phosphorus load by 30% to 50%, whereas access road treatment in forested areas results in higher phosphorus reduction rates (80% to 95%) (Burroughs and King 1989). The use of infiltration and sedimentation basins reduces phosphorus runoff by 50% to 80% (Burroughs and King 1989; WDEQ 1999). Effectiveness of all of these measures is generally improved with routine maintenance. Assuming the appropriate BMPs are implemented, in addition to those already completed, a 65% to 90% reduction of total phosphorus from current loads associated with ski areas was assumed (205 to 284 kg/year).

9.2.3.5.6 High Use Recreation

Summary of Implemented BMPs

Swaner Nature Preserve will be installing fencing along trails near East Canyon Creek to protect riparian areas, dissuade users from creating new trails, and reduce pollution into the watershed. No other known efforts have been made to reduce the phosphorus load from high use recreation.

Recommended Additional BMP Implementation and Maintenance

Off-highway vehicles should be restricted to designated routes away from waterways to prevent bank destabilization and soil erosion along tributaries and in reservoir shorelines. Trail design should ensure that runoff water and drainage from the trail is collected in a stabilized area or sediment basin, thus handling runoff volume and velocity without risk of erosion or of sedimentation into waterways. Natural drainage patterns should not be disrupted or moved, as the runoff water and surface water may be providing moisture to wetlands downslope or downstream. Surveying the trail during wet months will help determine drainage patterns and the location of wetlands and saturated soils.

Priority Areas for Implementation

All of the high use recreation land-use areas are considered to be a medium level priority for the watershed because, although area-weighted loads are high, the total load from this land use is quite small, composing less than 1% of the total load to the reservoir. Subbasins are ranked based on normalized load in Table 9.9.

Table 9.9. Priority Subbasins and Recommended BMPs for High Use Recreation in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Silver Creek / Parley's Park	Summit Co.	No	18	2.9	0.16	Medium
Kimball Creek	Summit Co.	No	23	3.3	0.15	Medium
Lower Springs	Summit Co.	No	11	1.6	0.15	Medium
Two Mile	Summit Co.	No	5	0.6	0.12	Medium

Calculation of Load Reduction

With the implementation of the recommended BMPs applied in high use recreation land-use areas, the estimated phosphorus load reduction ranges from 4.5 to 7.1 kg/year (Table 9.9). Though any single BMP may be applied, greater reductions are achieved when BMPs are implemented in conjunction with others.

Improved trail design would reduce erosion and associated phosphorus on hiking and biking trails by 30% to 50% (Burroughs and King 1989). Implementation of the recommendations for reducing phosphorus load from high use recreation is assumed to result in a 35% to 55% reduction in total phosphorus from this source (3.0 to 4.7 kg/year).

9.2.3.5.7 Agricultural Management and Grazing

Summary of BMP Implementation

The East Canyon WRAP (2004) includes plans to address livestock grazing by implementation of site specific private land owner management plans such as fencing of riparian areas, rotational grazing, and creation of vegetative buffer zones to protect streambank and riparian areas from erosion or degradation. The East Canyon WRAP (2004) also recognizes the need to develop Comprehensive Nutrient Management Plans (CNMP) for landowners determined to have Animal Feeding Operations (AFO) or Confined Animal Feeding Operations (CAFO). A total of about 11 CNMP plans are anticipated to be completed in the watershed. All landowners with a CAFO/AFO are expected to have an individual plan by (2008).

A conservation management plan has been developed for the Peaceful Valley Ranch operated by Mike McFarlane. The ranch encompasses about 7,800 acres in the East Canyon Watershed and has several miles of East Canyon Creek on the property. The plan includes streambank fencing totaling 12,773 feet, prescribed grazing on 371.5 acres, wildlife fencing totaling 9,820 feet, riparian forest buffer totaling 41.5 acres, use exclusion for 21.5 acres and streambank and shoreline protection for 500 feet on East Canyon Creek. A tour of the project area was conducted to highlight the success of fencing off the stream and allowing the natural vegetation to re-establish itself (2002 Nonpoint Source 319(h) Project Progress Report).

The Wildlife Habitat Incentives Program and Snyderville Basin Water Reclamation project have involved businesses, local landowners, and organizations such as Swaner Nature Preserve (SNP) in restoring habitat in and around East Canyon Creek. Shrubs were planted to reduce streambank erosion, fences were installed to keep livestock from the riparian areas, water facilities were added for livestock, and pastures were reseeded to improve grazing management. In addition, SNP planted 3,000 willows to stabilize streambank soils, reduce sediment loads, and aid in reducing temperatures along the creek. In 2007 SNP planted native shrubs and installed tree revetments on 706 linear feet of the creek near the preserve (SNP 2008).

Additional Recommended Implementation Measures

Recommended BMPs for irrigated lands include filter strips, sprinkler irrigation, and pasture and hayland planting (NRCS code 512). Irrigation system management (NRCS codes 442, 443, 444, 449) and nutrient management (NRCS code 590) are also recommended. Together, these BMPs will reduce water use, increase pasture productivity, and reduce animal pressure on grazing lands. When sediment and nutrients are transported overland, filter strips installed at the field border will reduce sediment and nutrient inputs. Recommended BMPs for managing grazing in riparian areas and streams include livestock exclusion from streams and riparian areas (NRCS code 472), off-site watering (NRCS code 614), stream crossings and channel bank revegetation (NRCS code 578), riparian forest buffer (NRCS code 391), and prescribed grazing (NRCS code 528). All of these BMPs have proven effective in reducing phosphorus and sediment loading due to riparian area grazing in other watersheds (Line et al. 2000; Osmond et al. 2007; Miner et al. 1992).

Included in the prescribed grazing practices are management techniques, such as fencing and hardened crossings, which encourage animals to drink or cross at specified points. Hardened crossings may be installed in riparian areas where cattle show a tendency to cross the stream. Crossings may also be developed to protect the streambank and bed from tire damage from all-terrain vehicles and 4-wheel vehicles when they attempt to cross the stream. Hardened crossings create a layer of rock in the stream bed and provide protection directly from any contact, and thereby protect a stream reach from sediment and nutrient releases. The hardened crossing may also be developed in conjunction with watering structures and facilities such as riparian fencing and water gaps, providing livestock with watering areas that have easy access with limited sediment entering into the stream flow (Hoorman and McCutcheon, nd). Livestock have been shown to prefer watering sites where ease of access is provided including hardened crossings, and these BMPs have been shown to reduce trampling of streambanks (MSU 2000; Hoorman and McCutcheon, nd).

Priority Areas for Implementation

Addressing phosphorus load from agricultural land uses in the Kimball Creek subbasin is considered to be a high priority for the watershed. Additional installation of BMPs on agricultural property in the area draining directly to the reservoir, Two Mile subbasin, and Middle East Canyon subbasin are considered to be medium level priorities. Agricultural management in the remaining parts of the watershed contributes a very small phosphorus load to the reservoir and is therefore considered to be a low priority for the watershed.

The BMPs recommended from agricultural land uses primarily focus on nonstructural management. These BMPs have a range of effectiveness in reducing total phosphorus. Installation of vegetative buffers along fields has been found to be effective in reducing total phosphorus by 85% (Osmond et al. 2007). A heavily stocked dairy loafing pasture demonstrated a 79% reduction of TP (Line et al. 2000) and an 82% reduction in total suspended sediment in a stream after cattle were fenced out of a riparian area and a buffer was established (Osmond et al. 2007). Pollutant loads from cattle using streams as water sources were also significantly reduced when alternative water systems were provided (Miner et al. 1992). Cattle preferred to drink from a trough 92% of the time when alternative water systems were installed; this suggests that installation of troughs reduces the time that cattle spend in riparian areas and the overall impact they have on the stream. In this study, streambank erosion was reduced by 77%, total suspended solid concentrations in grab samples were reduced by 54%, and average concentrations of TP were reduced by 81% (Miner et al. 1992). Installation of irrigation management systems reduces total phosphorus by 70% to 90% (NRCE 1996). Prescribed grazing generally reduces phosphorus by 55% to 82% (Osmond et al. 2007). Assuming the appropriate BMPs are implemented a 60 to 85% reduction of total phosphorus from current loads associated with agricultural land uses was assumed (32.7 to 46.3 kg/year).

Table 9.10. Priority Subbasins and Recommended BMPs for Agricultural and Grazing Land Uses in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Kimball Creek	Summit Co.	No	140	20.7	0.15	High
Two Mile	Summit Co.	No	21	4.4	0.21	Medium
Middle East Canyon	Summit Co.	No	23	3.4	0.15	Medium
Direct Drainage	Morgan Co.	No	20	3.0	0.15	Medium
Lower East Canyon	Morgan Co.	No	109	9.7	0.09	Low
Bear Hollow	Summit Co.	No	14	1.2	0.09	Low
Three Mile	Summit Co.	Yes	86	6.9	0.08	Low

Table 9.10. Priority Subbasins and Recommended BMPs for Agricultural and Grazing Land Uses in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/yr)	Area Weighted Load (kgTP/ha/yr)	Priority
Upper East Canyon	Summit Co.	No	20	1.5	0.08	Low
Park City	Park City	No	3	0.1	0.05	Low
Thaynes Canyon	Summit Co. / Park City	No	33	1.7	0.05	Low
Silver Creek / Parley's Park	Summit Co.	No	34	0.6	0.02	Low
White Pine	Summit Co.	No	69	1.2	0.02	Low

9.2.3.5.8 Forested and Meadow

Pollutant Sources and Load

Pollutant sources from forested and meadow land uses include runoff and sedimentation from road construction and use, and erosion and sediment release from trail and OHV use. Runoff intercepted by roads becomes concentrated and channelized in drainage ditches or ruts. As a result, sediment is transported down-gradient as overland flow. Roads near streams become a direct conduit of increased flow and sediment to the stream channel and can increase sediment and nutrient loads. Road and trail erosion associated with forestry management and recreational use can also contribute to phosphorus loading via increased flows and sediment load to waterways (Daniels et al. 2004; Rashin et al. 1999).

Grazing in the upland areas can be a significant source of sediment and nutrient loads if the timing and intensity of the grazing are not controlled (Osmond et al. 2007). Over-grazing causes loss of vegetation and soil compaction due to hoof action, both of which increase sediment and nutrient loads (Mosley et al. 1997). Finally, manure deposition from the livestock subsequently delivers phosphorus from the forested areas to stream channels, which is then ultimately transported to the reservoir.

Forested and meadow land-use areas compose 26,575 hectares (65,668 acres) or 71% of the watershed and include 13 subbasins. Only the Willow Draw subbasin contains phosphatic shales. These land uses contribute 475 kg/year (0.01 kg/ha) of phosphorus, or 23% of the total annual phosphorus load in the watershed. Phosphatic shale areas contribute 1% (7 kg/year) of the annual phosphorus load from these land uses.

Summary of Implemented Source Controls

The East Canyon WRAP (2004) identifies the need to inventory road drainage controls along dirt road segments that are impacting East Canyon Creek and tributaries. This plan also proposes to develop and implement BMPs that reduce contributions of sediment and phosphorus from roads.

Summit County has made progress implementing some road drainage erosion BMPs by hardening the surface of the road from the Jeremy Ranch Golf Course up to the Summit/Morgan County line. Summit County has further improved road drainage by installing small berms along some sections of road (Nonpoint Source 319 (h) Project Progress Report dated September 21, 2007).

Recommended Implementation Measures

The first step in addressing nonpoint source phosphorus load from forested and meadow land uses is to conduct a detailed inventory of this source, similar to the inventories completed for other sources and land uses in the watershed (MAG 2003, ECWC 2004). Key items that should be addressed in the inventory include the following:

- Length and width of roads.
- Road condition (e.g., loose, exposed, non-vegetated, guttering/gully erosion).
- Road proximity to streams.
- Extent of logging.
- Extent of public access and OHV.
- Inventory of trails, frequency of use, and condition (bike, hiking, OHV).
- Extent of grazing.
- Field data sheets and photographic record.

Significant reduction of phosphorus load resulting from road-related erosion could be achieved through Access Road Treatment (NRCS code 560). Depending on local conditions road treatment can involve alignment to reduce road slope, installation of drainage structures, stabilization of side slopes, reduction of road width, and/or surfacing the road with gravel or other material. All of these efforts are aimed at reducing erosion from roads (NRCS code 560). In some cases, road realignment may be required to protect the stream channel and permanently reduce sediment loading. Off-highway vehicles should be restricted to designated routes away from waterways to prevent bank destabilization and soil erosion along tributaries and within reservoir shorelines. Trail design should ensure that runoff water and drainage from the trail is collected in a stabilized area or sediment basin, thus handling runoff volume and velocity without risk of erosion or of sedimentation into waterways. Natural drainage patterns should not be disrupted or moved, as the runoff water and surface water may be providing moisture to wetlands downslope or downstream. Surveying the trail during wet months will help determine drainage patterns and the location of wetlands and saturated soils.

Additional road improvement and management practices are provided in the Snyderville Basin Recreation & Construction Industry Water Quality Improvements Project (MAG 2003) and include:

- Create vegetative buffers between the edge of roadways and top edge of banks closest to waterways.
- Eliminate practice of grading road to top edge of bank.
- Plant vegetation and secure slopes at eroded areas.
- Suppress dust on road.
- Narrow roadways in close proximity to creek.
- Designate drainage pipe locations along roadways to prevent clogging of entrances during grading.
- Place rip-rap below drain pipe outlets to prevent scouring.
- Secure eroding roadside banks that were cut steeply.
- Direct sheet flow runoff to vegetated buffer areas, not directly to the waterways.
- Prevent unnecessary footpaths to waterways by limiting recreational access to designated areas.

Priority Areas for Implementation

All of the forested or meadow land-use subbasins are medium and low priority areas for implementation. These land uses contribute a significant load to East Canyon Reservoir due to their large areal extent; however, these land uses have the lowest area-weighted loads in the watershed. Furthermore, reducing nonpoint source phosphorus runoff from forests and meadows will be more difficult to assess, implement, and monitor due to the variety of phosphorus sources on private parcels and the extremely diffuse nature of the load.

Total phosphorus reductions associated with access road treatment range from 80 to 95%. Reductions associated with trail design range from 30 to 50% (Burroughs and King 1989). Together, the recommendations for forested land uses were assumed to result in a 55 to 85% reduction in total phosphorus or 261 to 404 kg/year.

Table 9.11. Priority Subbasins and Recommended BMPs for Forested and Meadow Land Uses in the East Canyon Reservoir Watershed

Subbasin	Jurisdiction	Phosphatic Shales in Subbasin?	Area of Land Use in Watershed (hectares)	Annual Load (kgTP/year)	Area Weighted Load (kgTP/ha/year)	Priority
Direct Drainage	Morgan County	No	7,650	186.1	0.02	Medium
Middle East Canyon	Summit County	No	2,530	61.5	0.02	Medium
Lower East Canyon	Summit County	No	11,111	193.2	0.02	Medium
Willow Draw	Morgan County	Yes	147	6.3	0.04	Low
Park Meadows	Summit County	No	9	0.3	0.03	Low
Kimball Creek	Park City	No	302	7.8	0.03	Low
Thaynes Canyon	Summit County/ Park City	No	310	8.0	0.03	Low
Park City	Park City	No	8	0.2	0.03	Low
Unnamed Meadow	Summit County/ Park City	No	77	1.9	0.02	Low
Unnamed # 2	Summit County	No	5	0.1	0.02	Low
Lower Springs	Summit County	No	203	4.9	0.02	Low
Unnamed # 1	Summit County	No	14	0.3	0.02	Low
Bear Hollow	Summit County	No	211	3.7	0.02	Low

9.2.4 Technical and Financial Needs

This section identifies the types of technical assistance needed to implement the plan and the agencies, resources, and authorities that may be relied on for implementation. Funding and technical assistance are critical factors for implementing the plan, long-term operation, and maintenance of management measures, information//education activities, monitoring, and evaluation activities

9.2.4.1 Plan Sponsors and Resources

9.2.4.1.1 East Canyon Water Reclamation Facility

The Snyderville Basin Water Reclamation District has completed the initial design phase for the upgrade of the ECWRF and is in the process of securing funding for construction. SBWRD will coordinate, as necessary, with UDWQ to ensure that the expansion will continue to meet the phosphorus load allocated to this point source.

9.2.4.1.2 In-reservoir Treatment

The project sponsor for in-reservoir treatments would be UDWQ. However, the Bureau of Reclamation, as the federal agency responsible for reservoir management, would need to approve any in-reservoir treatment plans. This would require compliance with NEPA, most likely in the form of an environmental assessment. Cooperating agencies would likely include the Utah Division of Wildlife Resources and the Utah Division of State Parks and Recreation.

9.2.4.1.3 Nonpoint Source Management Measures

The East Canyon Watershed Committee will be the lead project sponsor for nonpoint source improvements. The committee is a coalition of public and private concerns that have a vested interest in restoring the watershed to a healthy state. The committee has several working groups including education, monitoring, and stream restoration. In addition, the committee maintains a web site as a public service to educate and inform those interested in the issues surrounding the East Canyon Creek Watershed.

Stakeholders that will be involved in technical assistance and execution of the implementation plan include:

- East Canyon Watershed Committee
- Snyderville Basin Water Reclamation District
- Park City Municipal Corporation
- Utah Association of Conservation Districts (UACD)
- Kamas Valley Conservation District
- Summit County Conservation District
- Utah Department of Environmental Quality, Division of Water Quality
- Utah Department of Natural Resources, Division of State Parks and Recreation
- individual golf courses
- individual ski resorts
- private land owners

Interagency coordination is an integral part of this implementation plan. Coordination between the Utah Department of Environmental Quality–Division of Water Quality, the Department of Natural Resources–

Division of State Parks and Recreation, and the Bureau of Reclamation is critical to ensuring implementation of the proposed BMPs on state and federal lands managed by these agencies.

The NRCS will assist in coordination between the State of Utah and private landowners regarding available funding to implement BMPs on private land. For agriculture, BMP implementation is a voluntary, incentive-based program. Federal cost-share incentives are available to agricultural producers. These programs include NRCS's Conservation Reserve Program (CRP), Wetland Reserve Program (WRP), WHIP, and the Environmental Quality Incentive Program (EQIP). The State of Utah also offers some loan and grant programs to agricultural producers for the installation of conservation BMPs. Participation from individual landowners, managers, and all stakeholders in the watershed is important to the successful outcome of the implementation plan.

9.2.4.2 Projected Costs for Implementation

9.2.4.2.1 East Canyon Water Reclamation Facility

The total cost of the expansion and upgrade project is estimated at $40,074,626. Although the SBWRD is currently in design, the construction date of the project will be determined by growth in their service area. Until then, the SBWRD's current phosphorus removal system will continue to meet both existing permit limits/TMDL allocations and the proposed allocations/permit limits in the revised TMDL.

9.2.4.2.2 In-reservoir Treatment

The cost of in-reservoir alum treatment is generally site-specific and depends on the length of phosphorus inactivation desired, the alum dose required, local availability and cost of alum, and the mechanism used for dispensing alum into the reservoir. Generally, the cost of alum treatment ranges from $280/acre treated to $700/acre treated (WDNR 2003). Based on this cost range, treatment of the entire acreage of East Canyon Reservoir would cost between $191,000 and $477,000. Treatment of only a portion of the reservoir is probably more realistic, because only the deep sections of the reservoir routinely experience hypolimnetic oxygen depletion, and associated phosphorus release. Treatment of one-half of the reservoir acreage is therefore estimated to cost between $95,000 and $238,000. This is a one-time cost that should inactivate sediment phosphorus for at least a 5-year period.

The cost of hypolimnetic aeration is also highly dependent on the design, spatial extent, and seasonal use of the system. The design of the system is likely to cost $5,000–$10,000 if designed internally by UDWQ. The cost of external engineering design would be higher. Initial estimates for a system sized for the needs of East Canyon Reservoir range from $250,000 to $1,000,000 for installation, operation, and maintenance over a 10-year period.

9.2.4.2.3 Nonpoint Source BMP Implementation

Implementation of the BMPs necessary to meet the water quality goals outlined in the TMDL will require a significant allocation of financial resources from multiple sources. Cost-benefit studies are recommended as a tool for identifying the most cost-effective strategies to prioritize throughout the reservoir. The implementation plan and costs outlined here is a general guide and not intended to be a comprehensive list of potential BMPs, priority areas, or required resources. Final decisions on project implementation will be made by land managers and owners based on their intricate knowledge of the watershed. Estimated costs for most recommendations are listed in Table 9.12. The sources of potential funds are described below in Section 9.3.4.2. Unit-cost estimates listed for each BMP are based on two separate sources. The agricultural costs were obtained from the NRCS electronic field office technical guide (eFOTG) cost sheet located at http://efotg.nrcs.usda.gov/efotg_locator.aspx?map=UT.

Table 9.12. Summary of Costs Associated with Project Implementation Plan

Land Use	Source	Management Strategy	Resources Needed	Who	Units	Unit Cost
Stormwater, Erosion, and Sediment Runoff	Continue enforcement of requirements for a Storm Water Pollution Prevention Plan (SWP3) and Erosion Control Plan (ECP) for construction activities in Summit and Morgan counties.	County administrative staff and building inspectors to continue plan reviews, on-site inspections, and SWP3 enforcement	Morgan and Summit counties	Summit and Morgan Co		Not est.
Residential, Commercial, and Urban	Stormwater, erosion, and sediment runoff	Continue enforcement of stormwater management plans for Summit and Morgan counties		Summit and Morgan Co		
		Construct additional detention basins		Summit and Morgan Co	Acre	$100,000
	Septic sewage	Continue enforcement of county ordinances and provide I&E concerning the design, installation, and maintenance of new systems	Annual review and submission of grant applications to fund education efforts	Summit and Morgan Co		Not est.
	Excess fertilizer use	Fertilizer application I&E		Summit County Conservation District		Not est.
		Soil testing and fertilizer rate reduction		Homeowners	Test	$10
	Excess irrigation	Maintain and improve irrigation ordinances and encourage water mgmt through I & E		Summit and Morgan Co		Not est.
	Road de-icers and sand	Test phosphorus content of de-icers and sand		Summit and Morgan Co	Test	$10

Table 9.12. Summary of Costs Associated with Project Implementation Plan

Land Use	Source	Management Strategy	Resources Needed	Who	Units	Unit Cost
		Investigate alternative de-icing methods		Summit and Morgan Co	Ton	$650
Golf Courses	Sediment runoff	Continue operation and maintenance of detention ponds	No additional resources needed	Local golf courses		Not est.
		Install grass swales			Acre	$130,000
		Install filter strips			Acres	$275
	Excess fertilizer use	Soil testing and fertilizer rate reduction (I&E)			Test	$10
		Comprehensive nutrient management plan			Each	$4,000
	Excess irrigation	Irrigation water management			Acre	$5
Ski Areas	Sediment runoff intercepted by trails and roads and concentrated in ditches	Trail design		Local ski resorts	Acres of harvested land	$500
		Access road treatment			Miles of road	$500
		Road realignment/decommissioning			Miles of road	$9,500
		Infiltration/retention basin			Acre	$100,000
High Use Recreation	Reduced riparian cover and erosion caused by OHVs	OHV restrictions				Not est.
	Sediment runoff intercepted by trails and roads and concentrated in ditches	Trail design			Acres of harvested land	$500

Table 9.12. Summary of Costs Associated with Project Implementation Plan

Land Use	Source	Management Strategy	Resources Needed	Who	Units	Unit Cost
		Access road treatment			Miles of road	$500
		Road realignment/decommissioning			Miles of road	$9,500
Agricultural Management and Grazing	Flood irrigation	Irrigation system management	Secure grant funding	NRCS, Kamas Valley Conservation District, Local Landowners	Acres of agricultural land	$1,000
		Pasture and hayland planting			Acres of agricultural land	$110
	Pasturing and grazing	Comprehensive nutrient management plan			Each	$4,000
		Prescribed grazing			Acres of grazing	$4
	Grazing in riparian areas	Livestock exclusion from streams and riparian areas			Acres of riparian	$15
		Off-site watering			1,000-gallon trough	$1,650
		Stream crossings and channel bank revegetation			Crossings	$2,000
		Riparian forest buffer			See East Canyon Creek PIP	
		Prescribed grazing			Acres of forest	$4
Forested and Meadow	Sediment runoff from roads and trails	Access road treatment		Private land owners	Miles of road	$500
		Road realignment/decommissioning			Miles of road	$9,500
		OHV restrictions				Not est.
		Trail design			Acres	$500
	Grazing	Prescribed grazing			Acres of forest	$4

9.2.4.3 Financial and Legal Vehicles for Implementation

9.2.4.3.1 East Canyon Water Reclamation Facility

Funding for the ECWRF will come entirely from impact fees levied against new developments in Snyderville Basin. A portion of the required impact fees have already been collected. A 25-year revenue bond will fund the rest of the capital costs and will be repaid through collection of future impact fees. Funding for the ECWRF is available from the State of Utah Revolving Loan Fund. A loan for $22,000,000 has already been authorized by the Water Quality Board.

9.2.4.3.2 In-reservoir Treatment

In-reservoir treatment measures will be funded through UDWQ in the form of private grants or state or federal project funds. All in-reservoir treatment plans will require collaboration and approval with the Bureau of Reclamation.

9.2.4.3.3 Nonpoint Source BMP Implementation

Various programs are available for private landowners to assist with the implementation of BMPs through cost-share incentive programs, grants, or low-interest loans. The program funds come from multiple sources such as the EPA, the NRCS, and the State of Utah. All programs require voluntary signup for participation, whereas some require eligible lands to qualify, depending on program requirements.

The NRCS administers a number of programs for funding to assist agricultural producers in installing BMPs on their privately owned lands. One program is the EQIP, which is a federal Farm Bill program that offers assistance in the installation or implementation of conservation practices such as stream buffers and riparian restoration; cost-sharing incentives pay for 50%–75% of the costs.

Other federal cost-share programs administered by the NRCS are the WHIP, designed to establish habitat for wildlife and fish, and the Wetland Reserve Program (WRP), designed to restore wetlands. Another federal cost-share program is the Conservation Reserve Program (CRP), which encourages land owners to convert highly erodable farmland or other highly sensitive acreages to vegetative cover. The CRP is administered by the Farm Service Agency. All of the federal programs require landowners to voluntarily sign up, and all land enrolled must qualify based on rules associated with the respective programs.

The State of Utah offers a low-interest loan program titled the Agriculture Resource Development Loan (ARDL), which is administered under the Utah Department of Agriculture and Food (UDAF). The programs offer loans for projects that conserve soil and water resources and maintain and improve water quality. Another UDAF program is the Grazing Improvement Program (GIP), which offers a competitive grant for fence repairs, reseeding of grazing land, and the replacement or development of water projects.

The State of Utah Section 319 grant program is another financial program that may be employed by agricultural producers or conservation districts to implement nonpoint source projects for the protection or improvement of water quality. The 319 program is a cost-share program that requires a 60:40 grant-to-cost share match. The program is administered by the UDAF and funded through the UDWQ from an EPA Clean Water Act grant program.

9.2.5 INFORMATION AND EDUCATION

The information and education plan (I/E plan) described in this section is adapted from the plan outlined in the *East Canyon Watershed Restoration Action Plan* (WRAP), prepared by the East Canyon Watershed Committee (WRAP 2004). The I/E plan developed in the WRAP follows EPA's *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (EPA 2008). The plan also includes education initiatives that other entities have or are planning to implement. The goals and objectives of the I/E plan include contractor training, onsite training, employee training, age-appropriate school curriculum, and residential outreach. The I/E plan aims to a) develop a training program for winter sports area supervisors, b) draft a guidance document for road maintenance, and c) develop educational information regarding water quality and golf courses (ECWC 2004).

9.2.5.1 Define the Driving Forces, Goals and Objectives

The driving force of the I/E plan includes attainment of water quality standards through a) implementation of TMDL target phosphorus load reductions, b) the impairment to the cold water fishery, and c) engaging an environmentally conscious community in action items for the watershed. The goals of the I/E plan are as follow:

1. Contractor Training: Educate and train local contractors and builders and their employees on the stormwater control requirements for Summit County and Park City in accordance with the Storm Water Programs for these two entities.

   Objective 1: Conduct an annual mandatory training session in the spring of each year to educate local contractors and builders on the regulatory requirements of the Summit County and Park City Storm Water Programs.

2. On-Site Training: Provide field-based stormwater controls training for local builders and contractors to ensure proper selection, installation, and maintenance of BMPs for construction sites.

   Objective 2: Conduct a semi-annual, “hands on” seminar hosted by vendors to demonstrate proper selection, installation, and maintenance of stormwater control methods for local contractors and builders.

3. Employee Training: Provide stormwater training for municipal personnel involved in plan review and inspection to insure a clear understanding of requirements and standards for applicable stormwater programs.

   Objective 3: Conduct an annual training session for municipal personnel involved in building permits issuance, inspections, or stormwater compliance.

4. Residential Outreach: Develop a residential outreach program to educate homeowners on the BMPs for residential use of fertilizers to minimize nutrient contributions from residential areas.

5. School Age Education Program: An age-appropriate schools, curriculum will be developed to target 4th grade students in the watershed. This program will coordinate and support Goal #4 in regard to homeowner practices.

6. Winter Sports Supervisor Training: Develop a training program for winter sports area supervisors to facilitate selection, installation, and maintenance of appropriate BMPs for water quality improvement at each of the five winter sports venues in the East Canyon Reservoir Watershed.

7. Mountain Road Guidance Document: Develop a guidance document for maintenance of roads on winter sports venues to minimize water quality impacts.

8. Provide critical priority areas map to municipalities, contractors, residents, and employees of recreational industries to focus efforts to reduce erosion and phosphorus loss.

9.2.5.2 Identify and Analyze the Target Audiences

The target audience for the I/E plan consists primarily of contractors and builders, residential homeowners, and employees of recreational industries (golf and winter sports). Residential homeowners will be divided into neighborhoods in subwatersheds that are identified as critical priority areas in the watershed. Contractors operating in the Willow Draw subbasin will be the primary target of the I/E plan. Contractors operating in medium priority subbasins will also be included in the I/E plan. These subbasins include Kimball Creek, Park City, Two Mile, and Upper East Canyon subbasins. The highest priority areas for residential land uses are neighborhoods in the Kimball Creek, Park Meadows, and Two Mile subbasins. The highest priority golf courses for I/E plan are Park City Golf Course and the Park Meadows Golf Course, because they operate in subbasins with phosphatic shales and high phosphorus loss potential. Both ski resorts in the watershed, the Park City Mountain Resort and the Canyons Resort, are high priority areas for the I/E plan.

9.2.5.3 Create the Message

Specific messages will be developed for each I/E plan effort as implementation proceeds. However, the following are the primary messages that will be communicated in all I/E plan efforts:

1) Phosphorus contributes to the water quality impairments observed in East Canyon Reservoir.
2) Point source reduction of phosphorus by Snyderville Basin Water Reclamation District has resulted in substantial improvements in water quality in the reservoir in the past eight years.
3) Remaining phosphorus reduction requirements rely on nonpoint source management measures.
4) Phosphorus loss from the East Canyon Reservoir watershed occurs as a result of human activities on the landscape and naturally high phosphorus soils in some areas of the watershed.
5) Activities on phosphatic shale areas in the watershed should be limited and erosion control enhanced as a first priority.
6) Erosion control and reduction in fertilizer usage are the primary means by which individual residents and managers in the watershed can reduce phosphorus.

More specific appropriate message(s) for the identified target audiences will be developed for each I/E plan effort as implementation proceeds. The information obtained from the survey work to be completed to assess current levels of knowledge regarding water quality impairments will be utilized to develop the message(s).

9.2.5.4 Package and Distribute the Message

Each I/E plan component will require a different means to package and distribute the message. Successful I/E plan efforts already undertaken in the watershed relied primarily on workshops, trainings, and short informational materials.

9.2.6 IMPLEMENTATION SCHEDULE

9.2.6.1 East Canyon Water Reclamation Facility Expansion

The load allocated to the ECWRF is expected to account for 20 to 30 years of growth in the area. The ECWRF expansion is scheduled to begin in 2011. The construction period required for the expansion is expected to be 3 years. Therefore, additional wastewater treatment capacity will be available to SBWRD beginning in 2015. However, based on current growth estimates for the service area the system is not expected to reach design capacity (7.2 MGD) until 2038. Should growth rates increase in the coming years, this date could be pushed to as early as 2030.

9.2.6.2 In-reservoir Treatment

In-reservoir treatment will be initiated by UDWQ by 2011, with a project completion target date of 2014. This five-year design and implementation window is a reasonable amount of time to identify targeted funding, design the system, and complete the necessary permitting and/or environmental compliance (i.e. NEPA) associated with the project. This will also provide an additional five years to monitor the impact of the actions on reservoir water quality before the TMDL is revisited in 2019.

9.2.6.3 Nonpoint Source Management Measures

Nonpoint source management measures are currently underway in the watershed. DWQ is currently in the process of hiring a watershed coordinator for the area who will be responsible for facilitating implementation of the watershed plan. Development of a detailed project-specific schedule for implementation will be among the first tasks assigned to the new watershed coordinator. Nonpoint source reductions are scheduled to continue at an aggressive rate through 2014 in order to allow for a five year period of monitoring to document improvement resulting from these efforts before the TMDL is revisited in 2019. The prioritization of nonpoint source measures identified in this implementation plan identifies areas for which implementation will be the most cost and time efficient.

9.2.7 Interim Implementation Milestones

Effectiveness monitoring is used to check if the selected strategies are reducing pollutant loading. Effectiveness monitoring may be quantitative (e.g., laboratory analysis of phosphorus concentrations in water from specific subbasins, or in water exiting private property or developments) or qualitative (e.g., visual observation of sediment reduction in the water passing through a fenced riparian area), depending on the BMP implemented and the overall scope of the project. Although quantitative monitoring methods will document progress toward improved conditions, qualitative methods can also provide an effective measurement of implementation progress. Other examples of qualitative effectiveness monitoring include photo documentation of improvement in streambank vegetation/cover in high use recreation areas, or vegetated grass swales at golf courses. Qualitative monitoring could also include documentation of relative sediment volume (i.e., high, medium, or low) collected from detention ponds or filters in stormwater treatment systems. Although these methods do not provide quantitative information on the effectiveness of the projects, they do illustrate progress and can be combined with other monitoring efforts to show success of implementation activities.

Quantitative effectiveness monitoring is required to document actual progress toward improved water quality conditions and can only be achieved through water quality assessments. Therefore, the success in reducing the load of phosphorus and sediment will be measured by contributions monitored at or near the mouths of major tributary points.

Monitoring of in-reservoir treatments should include detailed profiles of DO, temperature, and total phosphorus during periods of stratification throughout the reservoir. These data should help ensure that the thermocline is maintained during aeration such that the cold water fishery habitat, defined by low temperature and high DO, is maintained.

In-stream monitoring is scheduled to occur periodically throughout the year by UDEQ and includes physical, chemical, and biological parameters. In-reservoir monitoring is scheduled to occur periodically during the algal growth season and includes physical, chemical, and biological parameters. Each organization should monitor and report on the implementation and effectiveness of their management strategies, but not every organization is expected to implement its own water quality monitoring program. The following subsection outlines the proposed procedures for quantitatively monitoring the effectiveness of the proposed management strategies.

9.2.7.1 Sampling Design and Parameters

The quantitative monitoring plan requires water quality monitoring of sites located throughout the watershed that contribute directly to the annual phosphorus load. To assist in achieving the water quality goals, the initial monitoring plan should include the following:

- Seasonal monitoring throughout the year at reservoir monitoring sites and tributaries into the reservoir. Monitoring the selected sites for phosphorus, nitrogen, chlorophyll a, temperature, total suspended sediment, total organic carbon, in-reservoir DO profiles, green algae, and cyanobacteria.
- Monitoring streams above and below large BMP installation projects in order to determine effectiveness of individual projects.

The objectives of this monitoring plan consist of the following:

- Obtaining information necessary for ensuring that water quality loading and concentration targets for phosphorus are met
- Obtaining a detailed record of water quality data to assess whether the established target levels and threshold values are protective of beneficial uses
- Evaluating BMP effectiveness and load reductions resulting from implementation efforts

Successful development and implementation of the monitoring plan will provide flexibility for adapting changes to the implementation plan as the need arises.

9.2.8 Loading Reduction Targets

The primary contributor to low DO in East Canyon Reservoir is sediment oxygen demand related to annual algal blooms, legacy organic matter, and annual organic matter washed into the system. Modeling of the reservoir indicates that watershed-derived organic matter is a minor contributor to oxygen depletion and that internal phytoplankton production throughout the year is the primary contributor to oxygen depletion in the reservoir.

Algae-related endpoints were selected for East Canyon Reservoir based on the direct and indirect influence of algal biomass on DO concentrations in the hypolimnion during stratification and on nuisance algal thresholds protective of recreational beneficial uses. Nutrients fuel algal growth, which in turn consumes oxygen from the water column during respiration (D'Avanzo and Kremer 1994). In East Canyon Reservoir, when algae die and settle to the bottom of the waterbody, aerobic decomposition of the dead algae and other detritus (nonliving organic material) also depletes the oxygen supply in the overlying water, leading to oxygen depletion in the lower water column (hypolimnion). Due to reservoir stratification, mixing does not occur during the summer months so there is no natural means by which additional oxygen could be introduced to the hypolimnion. The mean seasonal chlorophyll *a* endpoint was derived from the Carlson Trophic State Index equation and corresponds to a chlorophyll *a* TSI of 50. A review of the recreational use literature indicates that nuisance algal concentrations for recreational beneficial uses range from 25 μg/L (Walker 1985; Raschke 1994) to 40 μg/L, with severe nuisance concentrations recognized as occurring above 60 μg/L (Heiskary and Walker 1995). Exceedance of a perceived nuisance threshold less than 10% of the time was found to be fully supportive of recreational beneficial uses (Smeltzer and Heiskary 1990). Periodic overgrowth of algae violates the narrative standard for waters established by the State of Utah. These endpoints were derived from a water quality analysis of the reservoir (see Chapter 3), a review of relevant scientific literature (see Chapter 7), and results from the East Canyon Reservoir W2 model developed by JM Water Quality LLC (see Chapter 5). Three algal-related endpoints were identified for East Canyon Reservoir:

- Mean seasonal chlorophyll *a* values of 8.0 µg/L (based on a mean trophic state index (TSI) value of less than 50).
- Chlorophyll *a* concentrations to exceed nuisance threshold of 30 µg/L less than 10% of the season (May – October).
- Dominance by algal species other than blue-green algae.

High concentrations of DO (6.0–8.0 mg/L or greater) are necessary for the health and viability of fish and other aquatic life. Low DO concentrations (less than 4.0 mg/L) increase stress to fish species, diminish their resistance to environmental stress and disease, and result in mortality at extreme levels (less than 2.0 mg/L). The DO endpoints for East Canyon Reservoir are consistent with existing water quality criteria and were developed in collaboration with the Utah Division of Wildlife Resources. During periods of complete mixing in the reservoir, all life-stage water quality criteria, established by the State of Utah, will be maintained across the reservoir and throughout at least 50% of the water column. The DO criteria include 4.0 mg/L as a 1-day minimum, 5.0 mg/L as a 7-day average, and 6.5 mg/L as a 30-day average. Cold water sport fish species are not known to reproduce in the reservoir, therefore the early life-stage criteria do not apply. During periods of thermal stratification, the minimum DO criteria of 4.0 mg/L and maximum temperature of 20^{o}C shall be maintained in a 2-m layer across the reservoir (aerial) to provide adequate refuge for cold water game fish. These criteria were determined to provide sufficient support for the cold water game fish beneficial use (3A) designated by the State of Utah for East Canyon Reservoir. Attainment of the acute 1-day criterion of 4 mg/L is considered to represent compliance with the 7-day and 30-day criteria. Therefore, the 1-day criterion was used to assess proposed reduction scenarios using the W2 model.

Total phosphorus endpoints for the reservoir are based on correlation between chlorophyll *a* targets and mean seasonal total phosphorus derived from the W2 modeling results. A mean seasonal chlorophyll *a* target of 8 µg/L has been correlated with reservoir mean total and dissolved phosphorus concentrations of 0.04 mg/L and 0.03 mg/L, respectively. Because attainment of DO endpoints specific to East Canyon Reservoir requires mean seasonal total and dissolved phosphorus concentrations of 0.03 mg/L and 0.02 mg/L, respectively, these concentrations are the nutrient endpoints for East Canyon Reservoir.

9.2.9 MONITORING

The monitoring goals of this project are to document progress in achieving improved water quality conditions in East Canyon Reservoir as nonpoint source control management strategies are implemented. To document this progress, a monitoring program is needed to examine and report on the performance of each management strategy. Two types of performance monitoring are proposed in this implementation plan: 1) implementation monitoring and 2) effectiveness monitoring. Implementation monitoring assesses whether the proposed management strategies were implemented and, if they have been implemented, the progress that has been achieved. Effectiveness monitoring is used to check if the selected strategies are effectively reducing pollutant loading. The following subsections present implementation and effectiveness monitoring methods proposed for organizations that will be involved in execution of this implementation plan.

9.2.9.1 Implementation Monitoring

Each organization should monitor implementation of management strategies by tracking the progress and accomplishments of each activity. The implementation tracking matrix in Table 9.13 is an example of a tool that could be developed into a centralized database and used by organizations to monitor implementation of the proposed management strategies. A status column should be added to the database to track actual implementation progress.

Table 9.13. Example of Implementation Tracking Matrix

Land Use	Source	Management Strategy	Resources Needed	Methods of Measure	Timeline
Active Construction	Stormwater, erosion, and sediment runoff	Continue enforcement of stormwater ordinances and implementation of plans.	County administrative staff and building inspectors to continue plan reviews, on-site inspections, and SWP3 enforcement.	Track number of inspections and violations	On-going
Residential, Commercial, and Urban	Stormwater, erosion, and sediment runoff	Construct additional detention basins;	County or municipal funding for construction.	Track number of ponds and quality of water released.	On-going
	Excess fertilizer use	Soil testing and fertilizer rate reduction (I & E)	Review and submission of grant applications to fund education efforts.	Track reviews and submissions	Ongoing
Golf Courses	Sediment runoff	Continue implementation of WRAPs	No additional resources needed.	Track inspection reports	Ongoing
Ski Areas	Sediment runoff from trails and roads	Continue implementation of WRAPs	No additional resources needed.	Track inspection reports	Ongoing
High Use Recreation	Sediment runoff from trails	Trail design			
Agricultural Management and Grazing	All sources	Continue implementation of watershed plans	Secure grant funding and matching funds.		
Forested and Meadow	Sediment runoff from roads and trails	Inventory forested land uses and identify key sources of phosphorus load	Resource personnel for data collection and summary.		
Reservoir	Sediment release during anoxic periods	Alum treatment Hypolimnetic aeration	Engineering design of in-reservoir treatments. Secure implementation funding.		

9.2.9.2 Progress Reporting in a Centralized Database

Annual reports will provide details about sediment and phosphorus reduction measures, operation efficiencies, and projected load reductions; reports should be submitted to the appropriate organization and agencies for their review. The watershed would benefit from a centralized database that tracks the progress and success of implementation projects throughout the reservoir. The East Canyon Watershed Committee hosts a website that currently serves as a clearing house for documents, contacts, and meetings. This website would be a good place to host a database of progress reporting, monitoring data, and load reduction estimates. The database would initially include water quality data and implementation planning efforts gathered as part of this implementation plan but could be expanded to incorporate implementation monitoring and other types of data generated in the watershed. Examples of the types of information that should be tracked in this database include:

Implementation monitoring

- Project lead agency/organization and contact information
- Coordinating plan under which project is implemented (i.e. MAG 2003, ECWC 2004)
- Source addressed, land use, and specific location (e.g., golf course, ski resort, or other landowner)
- Resources spent, secured, or needed
- Type of funding/matching funds
- Methods planned to measure success
- Timeline
- Status

Effectiveness monitoring

- Quantitative
    - Project specific water quality plans and results indicating BMP effectiveness (pre- and post- project if possible, and up and down stream of project)
    - Estimated total phosphorus reduced as a result of the project
- Qualitative (examples)
    - Photographic documentation (pre- and post- project; up and down stream of project)
    - Development and distribution of Information and Education materials
    - Documentation of irrigation control system upgrades
    - Record changes in sediment volume in collection basins (i.e., high, medium, or low)
    - Compile and publish ski resort and golf course Watershed Restoration Action Plans
    - Track enforcement and violation of Construction Storm Water Pollution Prevention Plans and Erosion Control Plans

9.3 CONCLUSIONS

Attainment of the East Canyon Reservoir TMDL endpoints requires continued reduction of phosphorus loads from nonpoint sources and internal reservoir sources, as well as the continued phosphorus removal efficiency of the East Canyon Water Reclamation Facility. This implementation plan recognizes that although the concentration of phosphorus in the ECWRF effluent will not increase significantly, future growth requires additional discharge from the facility and corresponding increased total phosphorus load. Allocation of this future load can be accomplished through implementation of existing watershed restoration action plans (WRAPs). The East Canyon Watershed Committee and various stakeholders have existing WRAPs that address significant nonpoint phosphorus sources. Priority areas for additional implementation efforts include enhanced BMPs on phosphatic shale areas of the watershed found in the Treasure Hollow, Willow Draw, Three Mile, and Spiro Tunnel subbasins, particularly those areas that are also on steep slopes and more susceptible to erosion. Specific land uses that require continued or improved BMP implementation include golf courses, construction sites, ski resorts, and residential and commercial areas. Forested land uses make up more than 70% of the watershed and represent the largest total load of nonpoint source phosphorus in the watershed. An inventory of potential phosphorus loads on forested lands (e.g., road and trail conditions and proximity to streams) is necessary to properly address the potential sources and BMPs for this land use.

Recommended in-reservoir treatments are anticipated to effectively and efficiently improve water quality in East Canyon Reservoir, thereby mitigating the lag-time associated with watershed source reductions. In-reservoir treatments would also improve cold water fish habitat. In-reservoir treatment is relatively inexpensive and when combined with implementation of existing WRAPs is expected to be successful in obtaining full support status for East Canyon Reservoir.

More systematic tracking and monitoring of projects throughout the watershed is necessary to prioritize additional future projects. Interest and involvement in the implementation of projects that will reduce phosphorus loading is very high among stakeholders, municipalities, and businesses in the East Canyon Reservoir Watershed. These efforts are expected to result in a cleaner, healthier watershed for current and future generations.

List of Abbreviations and Symbols

Acronym or Symbol	Definition
~	approximate
§303(d)	Refers to section 303 subsection (d) of the Clean Water Act, or a list of impaired waterbodies required by this section
µ	micro, one to one thousandth
µg	microgram
§	Section (usually a section of federal or state rules or statutes)
^{o}C	degrees Celsius
^{o}F	degrees Fahrenheit
ac	acre
APHA	American Public Health Association
AUM	animal unit month
AWS	agricultural water supply
BAG	Basin Advisory Group
BLM	United States Bureau of Land Management
BMP	best management practice
BOD	biochemical oxygen demand
BOR	United States Bureau of Reclamation
BURP	Beneficial Use Reconnaissance Program
CFR	Code of Federal Regulations
cfs	cubic feet per second
cm	centimeters
CN	curve number
CPUE	catch-per-unit-effort
cts	counts
CWA	Clean Water Act
CWAL	cold water aquatic life
DBU	designated beneficial use
DEM	digital elevation model

Acronym or Symbol	Definition
DEQ	Department of Environmental Quality
DGL	digital graph line
DGS	dissolved gas supersaturation
DO	dissolved oxygen
DOI	U.S. Department of the Interior
DWS	domestic water supply
ECRFC	East Canyon Riparian and Fisheries Committee
ECWRF	East Canyon Water Reclamation Facility
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
ET	evapotranspiration rate
FWS	U.S. Fish and Wildlife Service
FWPCA	Federal Water Pollution Control Act
GBT	gas bubble trauma
GIS	Geographical Information Systems
GOPB	Utah Governor's Office of Planning and Budget
h	hectare
HOD	hypolimnetic oxygen depletion
HRU	hydrologic response unit
HUC	Hydrologic Unit Code
INFISH	Federal Inland Native Fish Strategy
kg	kilogram
km	kilometer
km^2	square kilometer
L	liter
LA	load allocation
LC	load capacity
m	meter
m^3	cubic meter

Acronym or Symbol	Definition
MBI	macroinvertebrate biotic index
MGD	million gallons per day
mg	milligram
mg/L	milligrams per liter
mL	milliliter
mm	millimeter
MOD	metalimnetic oxygen depletion rate
MOS	margin of safety
MRLC	Multi-resolution Land Characteristics Consortium
MUSLE	Modified Universal Soil Loss Equation
MWMT	maximum weekly maximum temperature
n.a.	not applicable
N	nitrogen
NA	not assessed
NB	natural background
NCDC	National Climatic Data Center
nd	no data (data not available)
NED	National Elevation Dataset
NFS	not fully supporting
NHD	National Hydrography Dataset
N:P	nitrogen to phosphorus ratio
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NTU	nephlometric turbidity unit
ORW	Outstanding Resource Water
PCMC	Park City Municipal Corporation
P	phosphorus
PCB	polychlorinated biphenyls
PCR	primary contact recreation
PFC	proper functioning condition
pH	measure of acidity: pH 1–6 = acidic, pH 7 = neutral, pH 8–14 = basic

Acronym or Symbol	Definition
ppm	part(s) per million
QA	quality assurance
QC	quality control
RHCA	riparian habitat conservation area
SBA	subbasin assessment
SBWRD	Synderville Basin Water Reclamation District
SCR	secondary contact recreation
SCS	Soil Conservation Service
SNOTEL	snow telemetry
SRP	soluble reactive phosphorus
SS	salmonid spawning
SSOC	stream segment of concern
SSURGO	Soil Survey Geographic (SSURGO) Database
STATSGO	State Soil Geographic (STATSGO) Database
STORET	EPA water quality database
SU	standard units
SWReGAP	Southwest Regional Gap Analysis Project
T	ton
TDG	total dissolved gas
TDS	total dissolved solids
T&E	threatened and/or endangered species
Tier 1	All land within 150 feet of either side of a stream
Tier 2	Low land, mostly irrigated crop and pastureland
Tier 3	Upland, mostly nonirrigated pasture
TIN	total inorganic nitrogen
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TP	total phosphorus
TS	total solids
TSI	trophic state index
TSS	total suspended solids

Acronym or Symbol	Definition
t/y	tons per year
UDEQ	Utah Department of Environmental Quality
UDNR	Utah Department of Natural Resources
UDWiR	Utah Division of Wildlife Resources
UDWQ	Utah Division of Water Quality
UDWaR	Utah Division of Water Resources
UDWRi	Utah Division of Water Rights
UGS	Utah Geological Survey
U.S.	United States
U.S.C.	United States Code
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture

Acronym or Symbol	Definition
USDI	United States Department of the Interior
USFS	United States Forest Service
USGS	United States Geological Survey
WAG	watershed advisory group
WBID	waterbody identification number
WLA	wasteload allocation
WQLS	water quality limited segment
WQMP	water quality management plan
WQS	water quality standard
WBWCD	Weber Basin Water Conservancy District
WRCC	Western Regional Climate Center
WWTP	wastewater treatment plant

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