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

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.

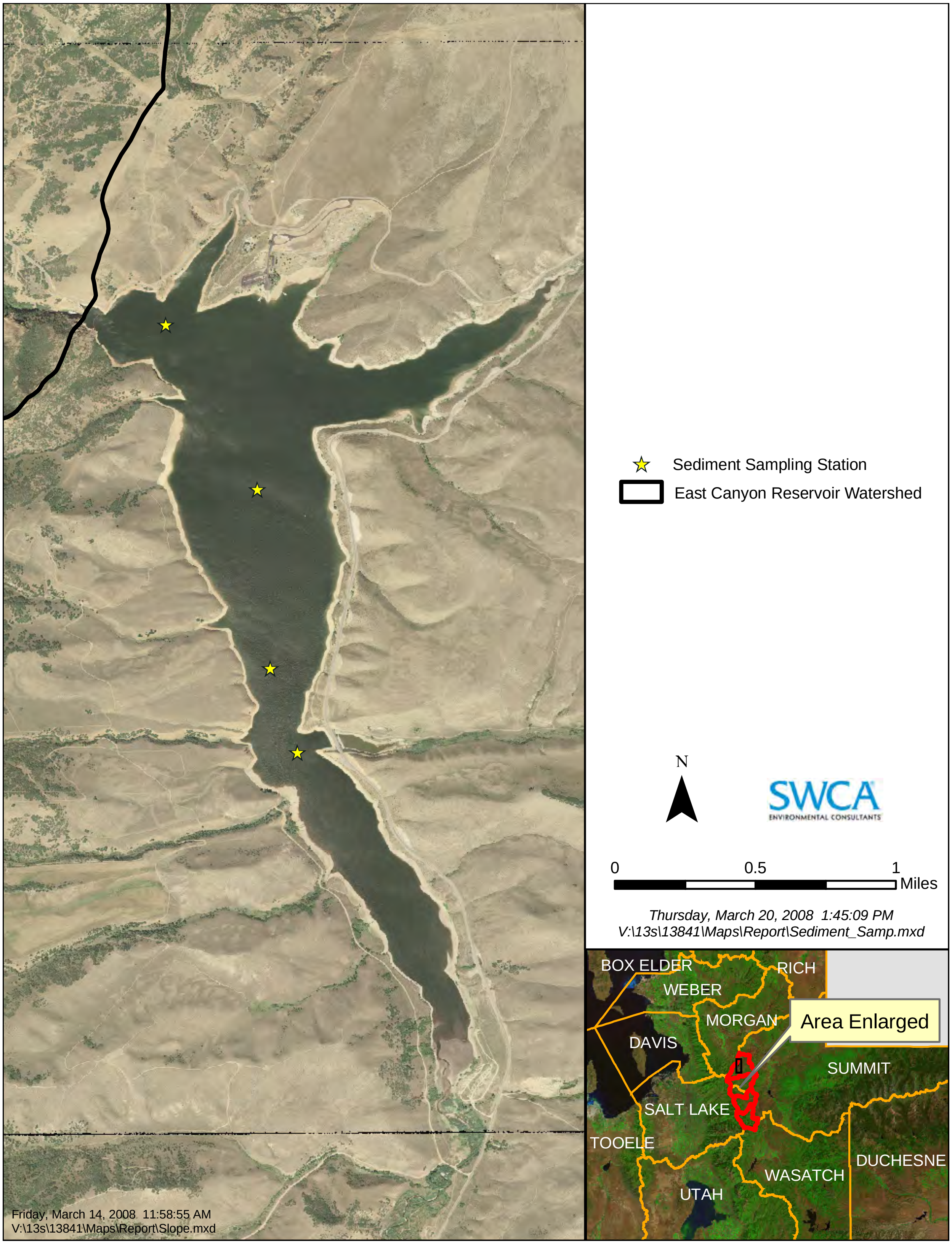
3.3.1.3 Sediment Chemistry

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.



Thursday, March 20, 2008 1:45:09 PM
V:\13s\13841\Maps\Report\Sediment_Samp.mxd

Friday, March 14, 2008 11:58:55 AM
V:\13s\13841\Maps\Report\Slope.mxd

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.

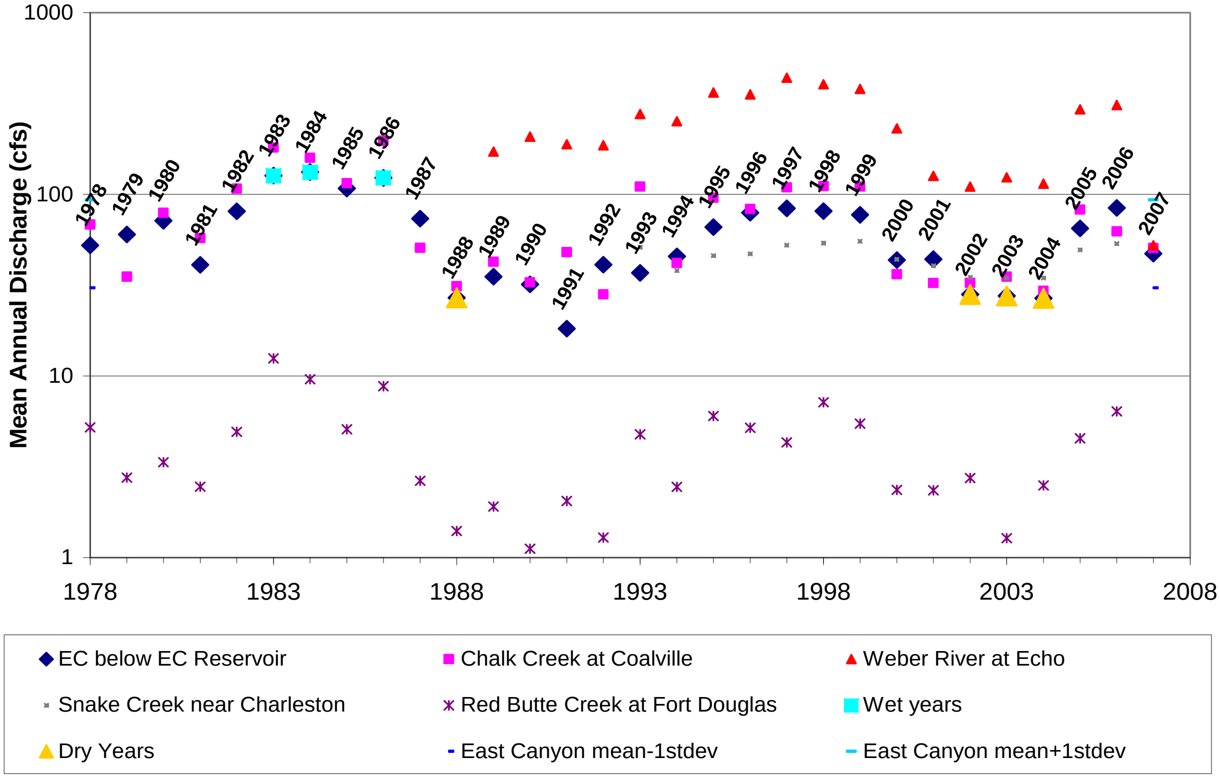


Figure 3.2. 30-year record of mean annual discharges for regional streams used to differentiate wet and dry years.

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.

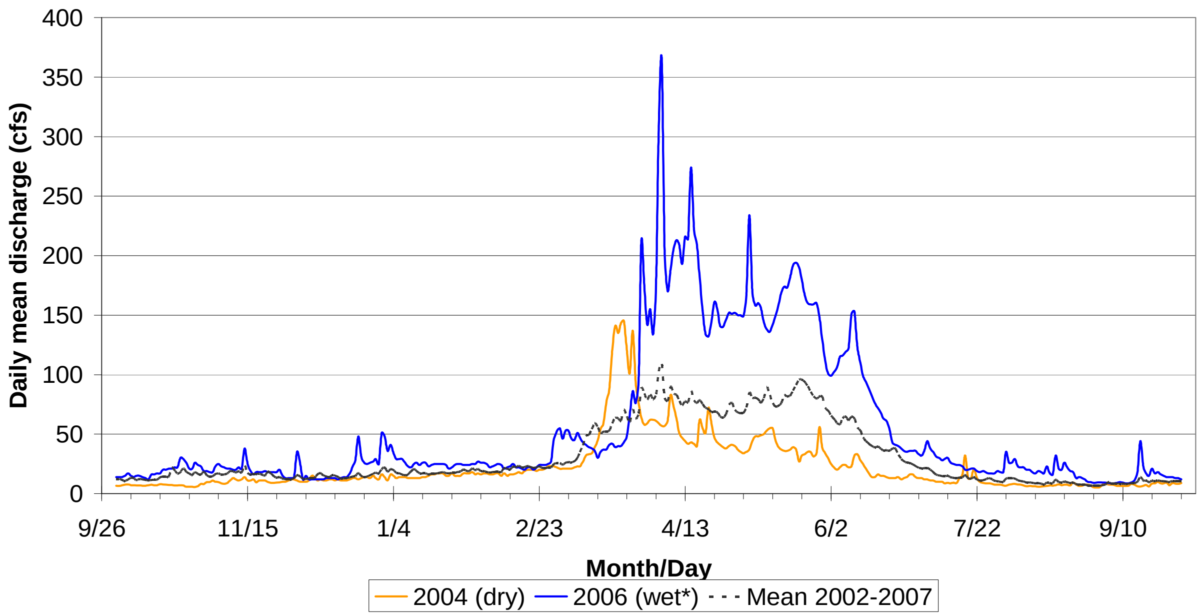


Figure 3.3. Example dry, wet, and average hydrographs for East Canyon Creek near Jeremy Ranch (USGS Station # 10133800).

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.

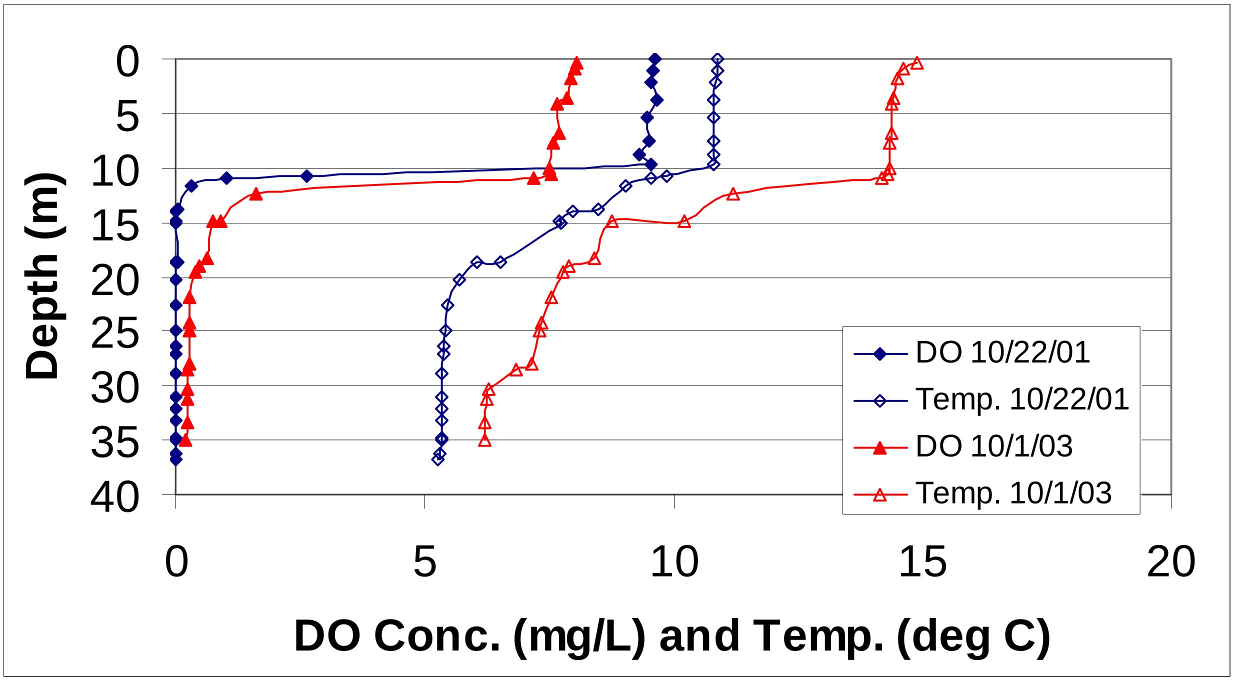
3.4.1.4 Dissolved Oxygen (DO) (3A)

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.

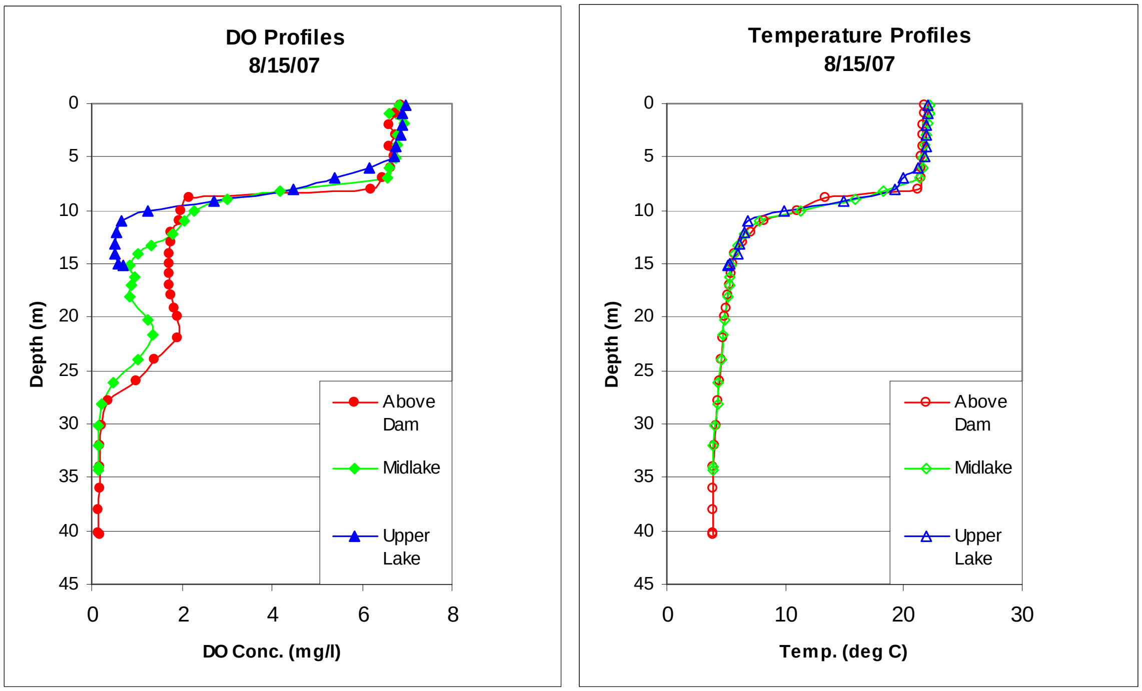


Figure 3.5 DO and temperature profiles at multiple sites in East Canyon Reservoir collected on 8/15/2007.

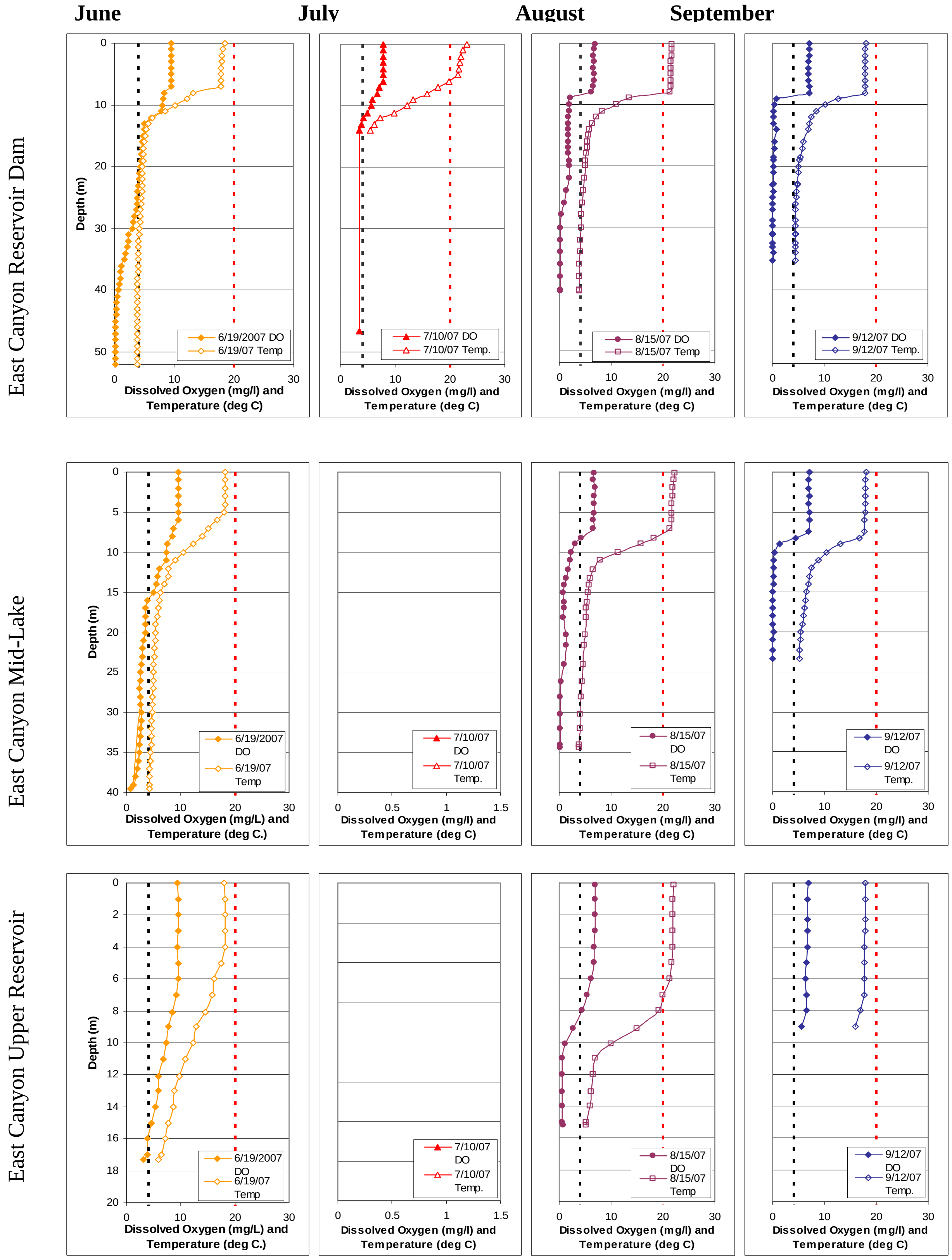


Figure 3.6. DO and temperature profiles at multiple sites in East Canyon Reservoir across the 2007 summer algal growth season.

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).

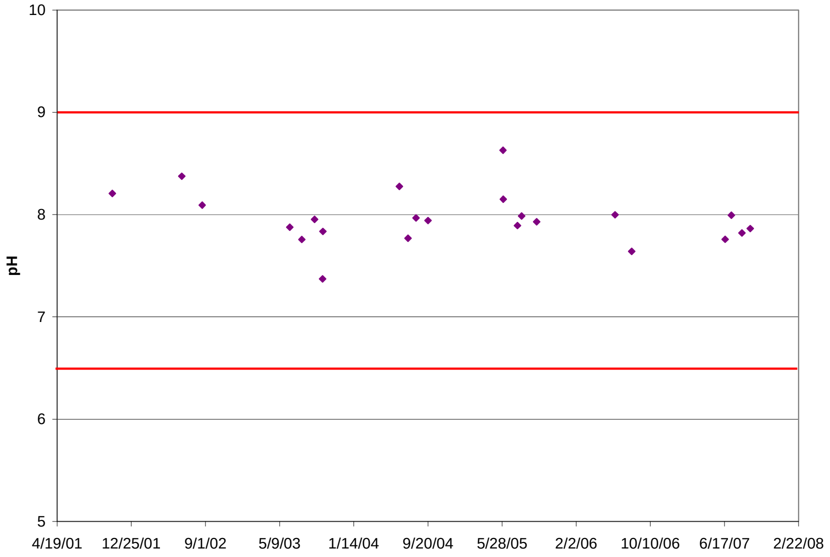


Figure 3.7. Current pH values (water years 2002–2007) at the Above the Dam Site (Station ID 4925160) in East Canyon Reservoir (red lines show upper and lower limits of pH water quality criteria for all beneficial uses).

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.

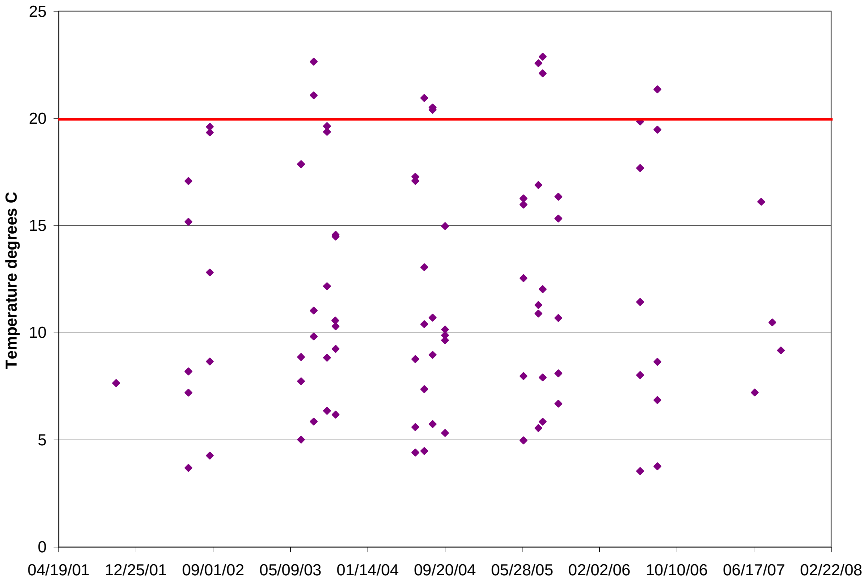


Figure 3.8. Current temperatures (water years 2002–2007) at the Above the Dam Site in East Canyon Reservoir (red line shows upper limits of temperature criteria for cold water fisheries).

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).

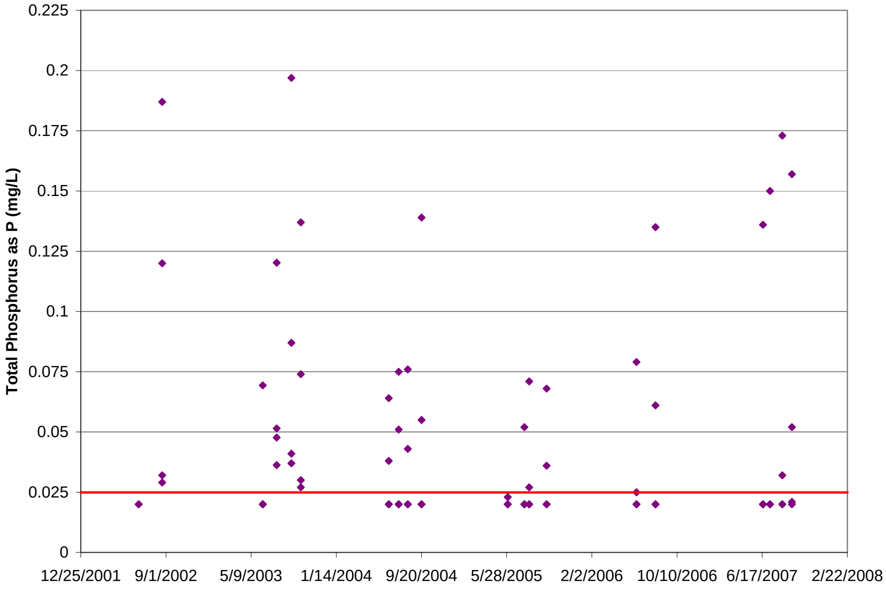


Figure 3.9. Current TP (water years 2002–2007) at the Above the Dam Site in East Canyon Reservoir (red line shows upper limits for TP criteria for recreation and cold water fisheries [2A, 2B, 3A]).

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).

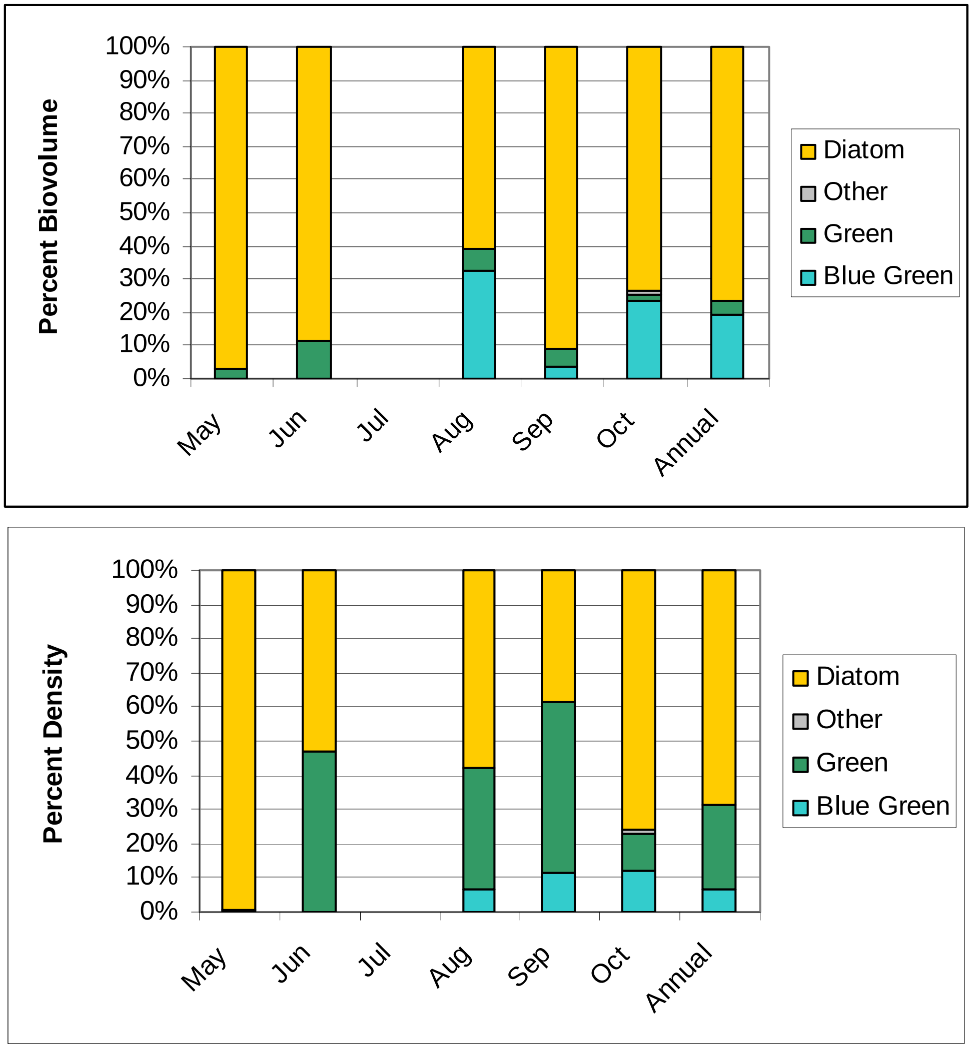


Figure 3.10. Dominance of algal groups measured in percent biovolume and percent density, sampled throughout East Canyon Reservoir from 2002–2007. Data sources: EPA STORET and Rushforth (2007).

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).

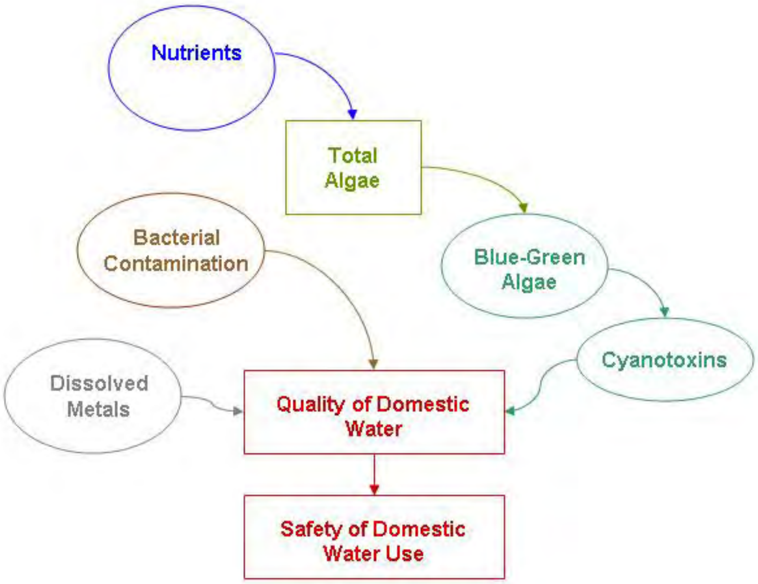


Figure 3.11. Links between water quality and domestic water use.

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.

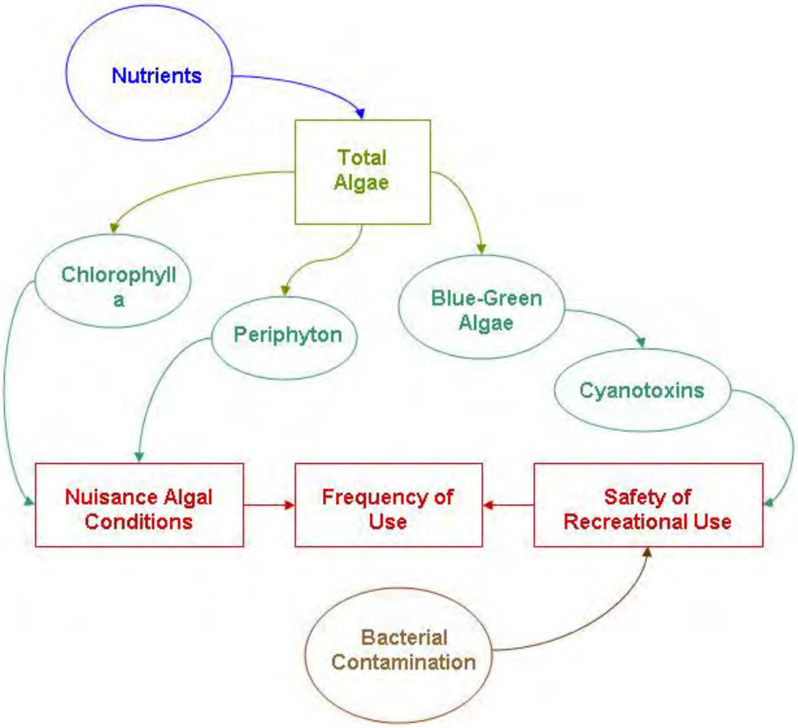


Figure 3.12. Links between water quality and recreation.

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).

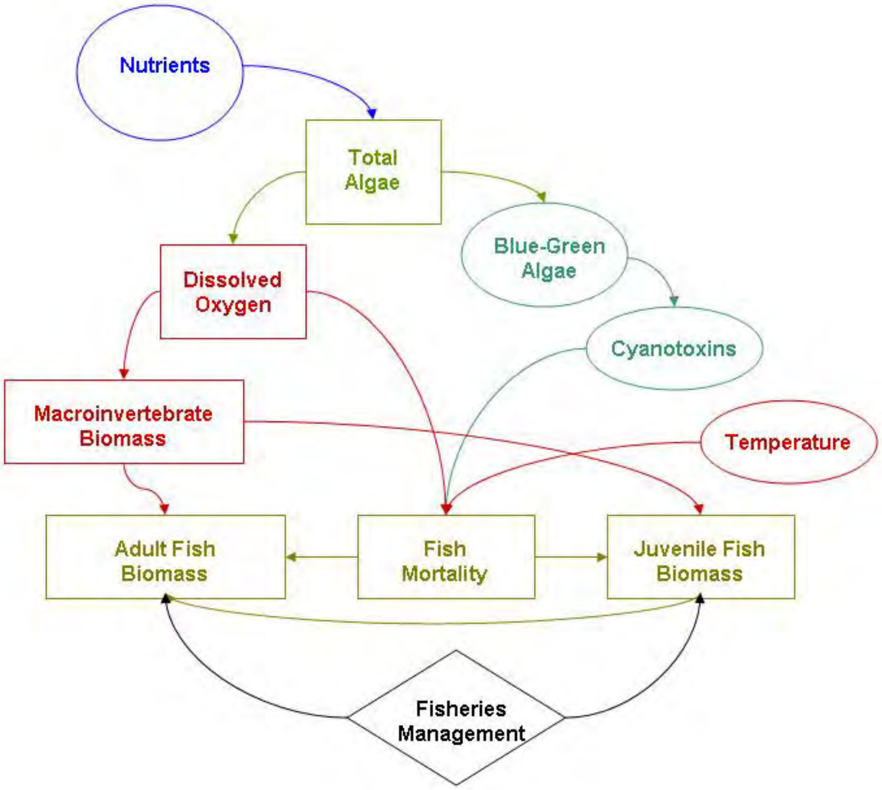


Figure 3.13. Links between nutrients and fisheries.

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).

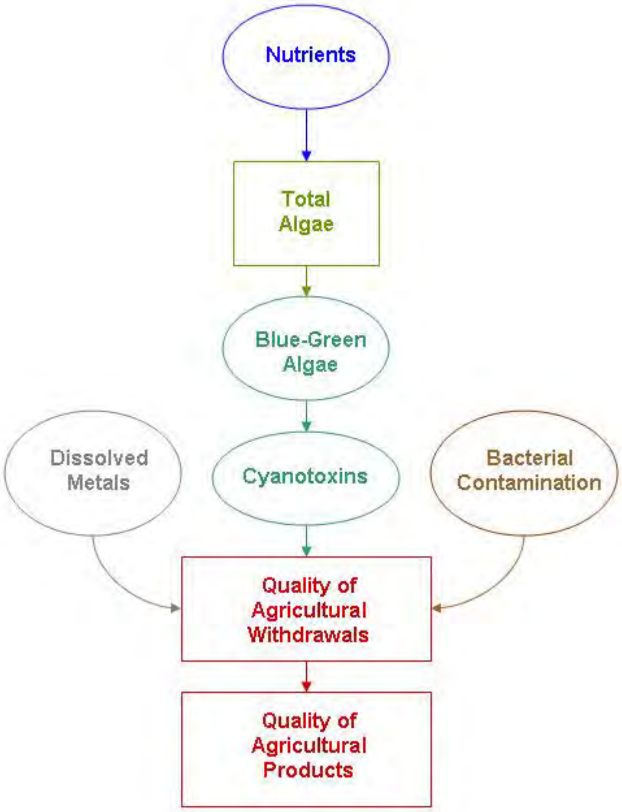


Figure 3.14. Links between nutrients and agricultural use.

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.

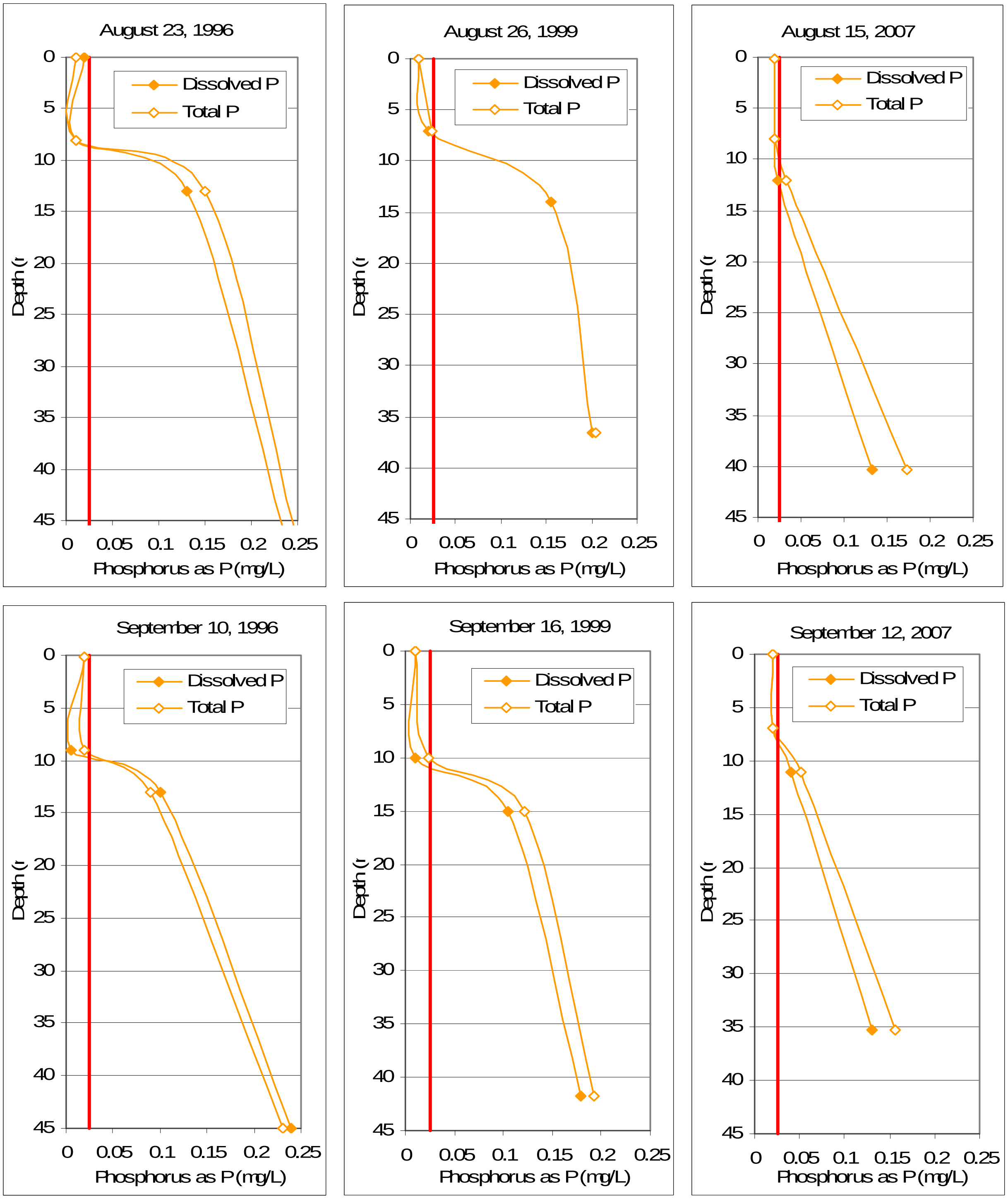


Figure 3.15. Phosphorus profile comparisons for August and September 1996, 1999, and 2007 (Station #4925160) (the red line indicates the 0.025 mg/L water quality indicator value for phosphorus).

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

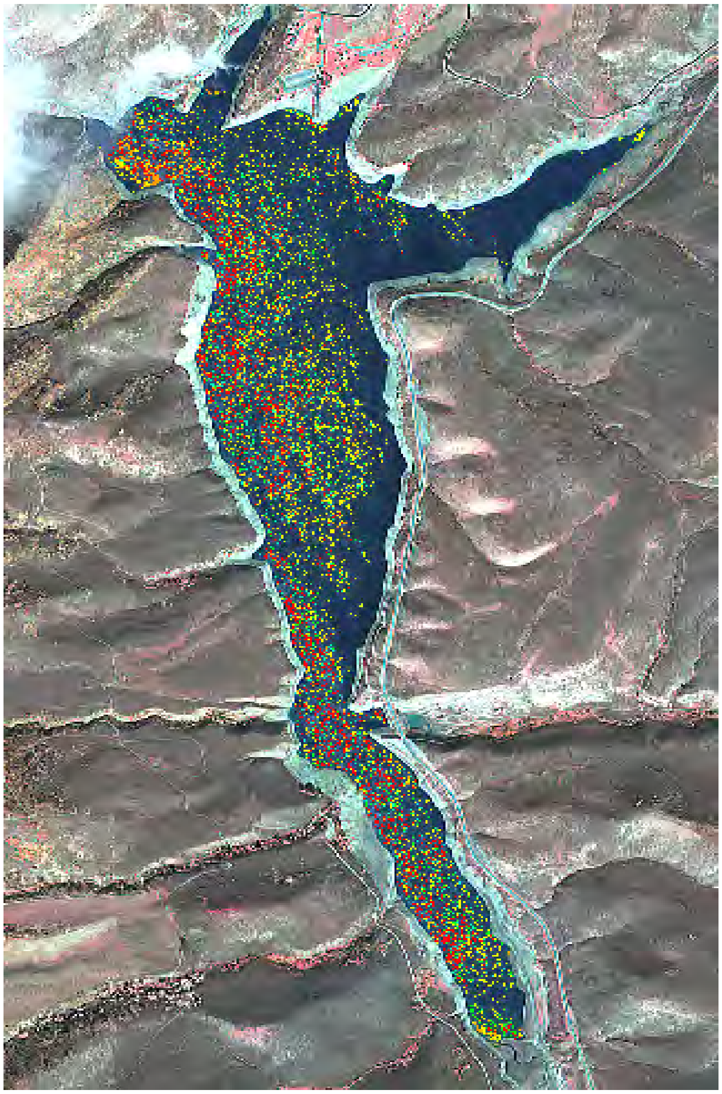


Figure 3.16. IKONOS Multispectral Imagery of East Canyon Reservoir.

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.

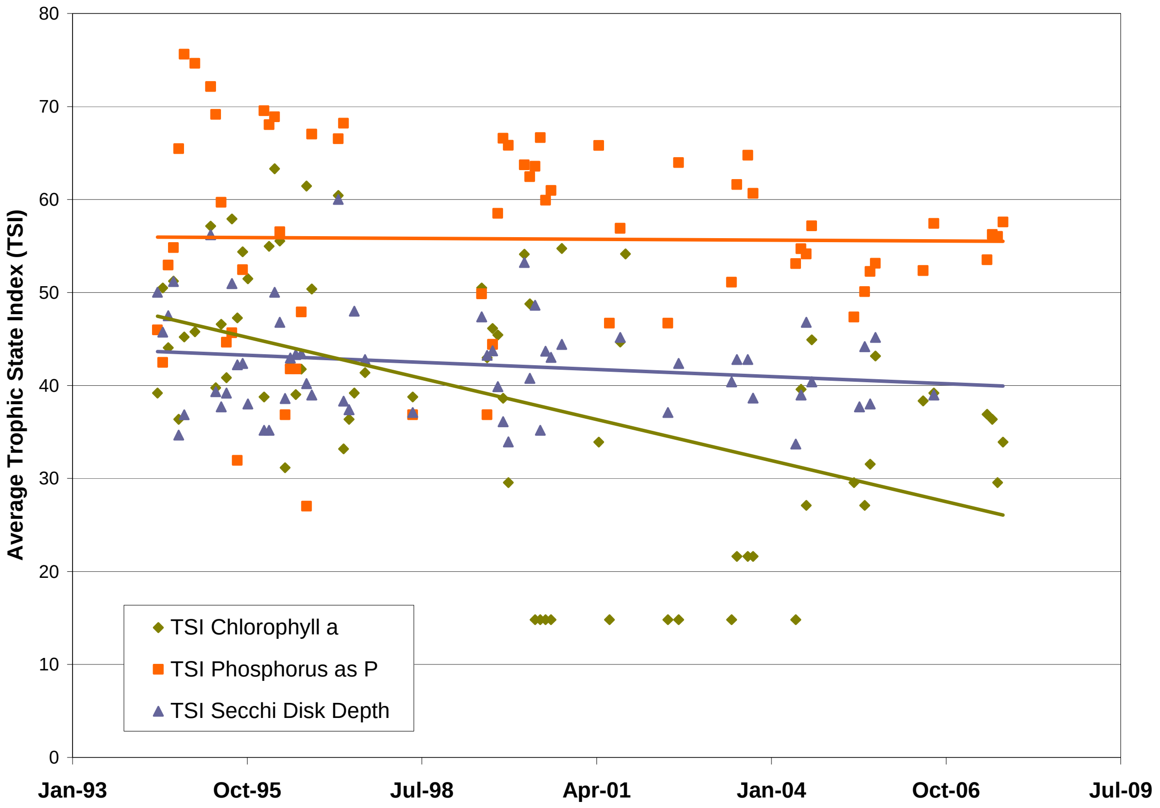


Figure 3.17. Change in TSI values for Chlorophyll *a*, Phosphorus as P, and Secchi disk depth from 1994 to 2007 in East Canyon Reservoir–Above the Dam (Station ID 4925160).

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).

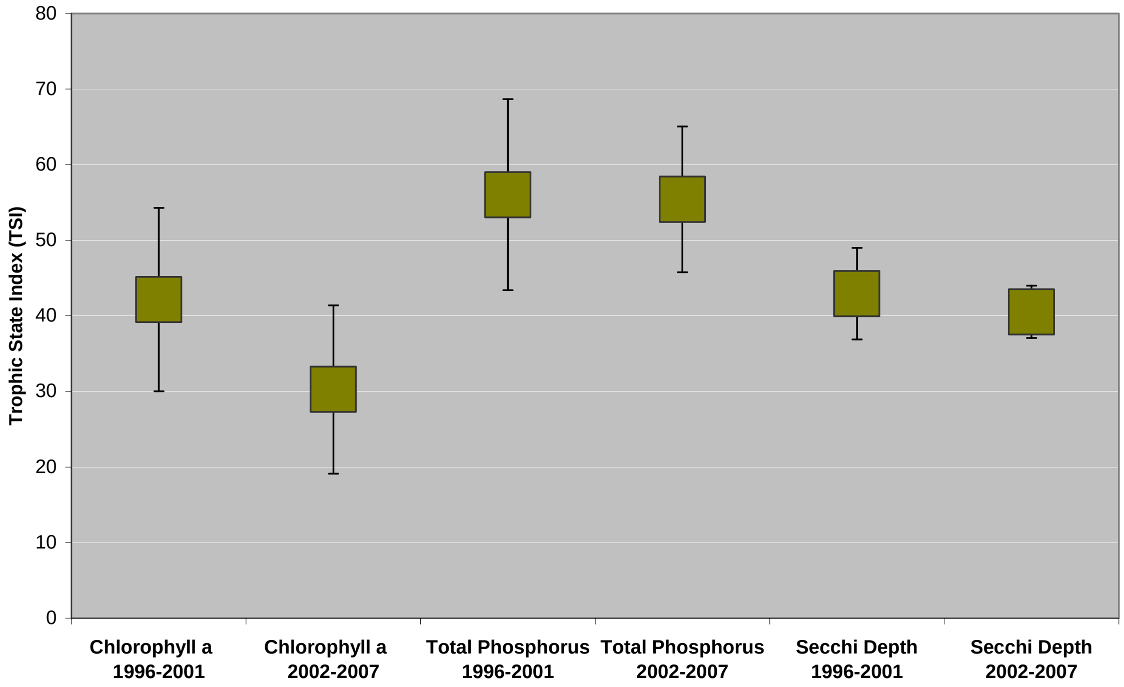


Figure 3.18. Comparison of recent (water years 1996–2001) and current (water years 2002–2007) average TSI values for chlorophyll *a*, total phosphorus, and Secchi disk depth for East Canyon Reservoir–Above the Dam (Station ID 4925160).

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

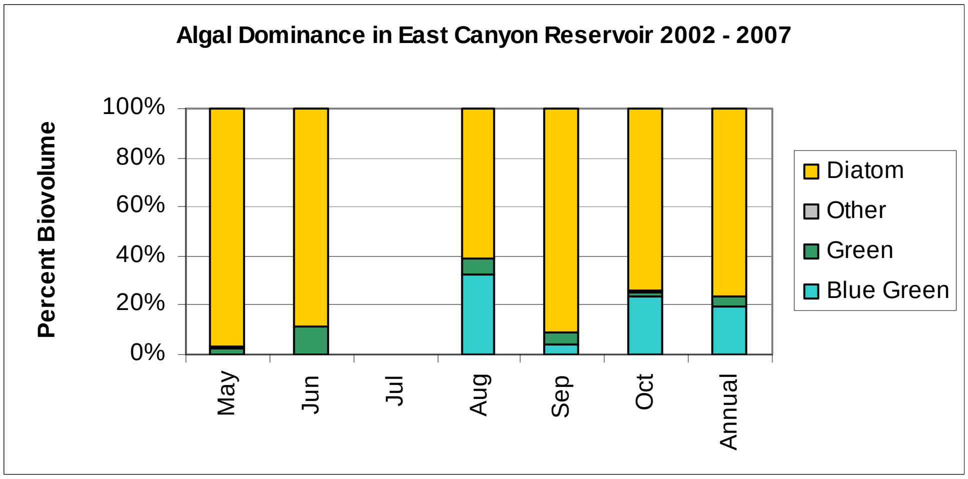
TSI Chlorophyll *a*						
Sampling Site	**Period**	**N**	**Mean**	**Median**	**Max**	**Min**
East Canyon Reservoir Above the Dam 01	Current	22	31.34	30.55	57.03	14.81
	Recent	43	41.57	42.01	66.36	14.81
East Canyon Reservoir Mid-Lake 02	Current	19	29.72	30.60	46.77	14.81
	Recent	20	37.15	40.68	57.36	14.81
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.



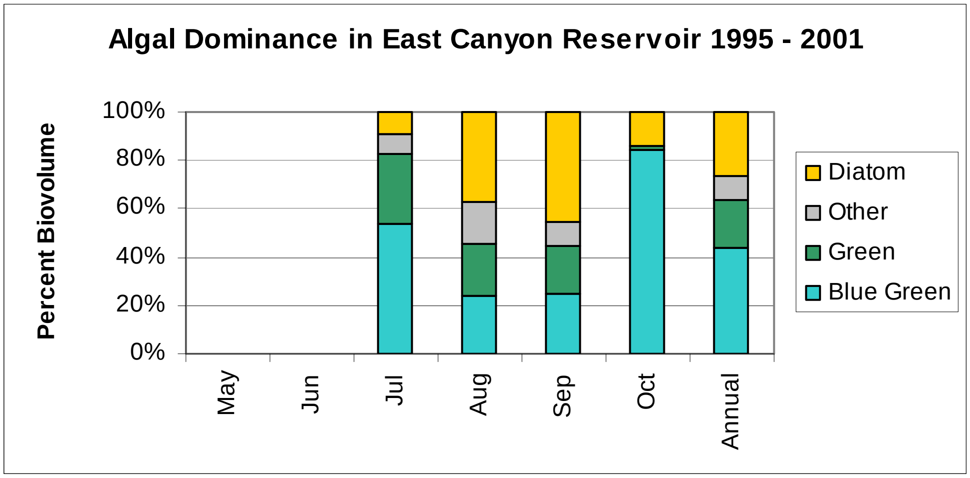


Figure 3.19. Dominance of algal groups measured in percent biovolume sampled throughout East Canyon Reservoir from 2002–2007 and 1995–2001. Data sources: EPA STORET and Rushforth (2007).

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.