4. EAST CANYON CREEK MODELING AND DYNAMICS

4.1 SUMMARY OF WATER QUALITY CONCERNS IN EAST CANYON CREEK

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

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

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

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

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

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

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

4.2 ASSESSMENT OF PHYSICAL CONDITIONS IN CREEK

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

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

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

Source: NRCS 1998a.

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

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

Table 4.2. East Canyon Creek SVAP Results

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

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

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

4.2.1 Channel Condition

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

4.2.2 Hydrologic Alteration

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

4.2.3 Bank Stability

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

4.2.4 Pools

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

4.2.5 Canopy Cover

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

4.2.6 Geomorphic Summary

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

4.3 FEASIBILITY STUDY FOR ESTABLISHING A PROTECTED BASE FLOW

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

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

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

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

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

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

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

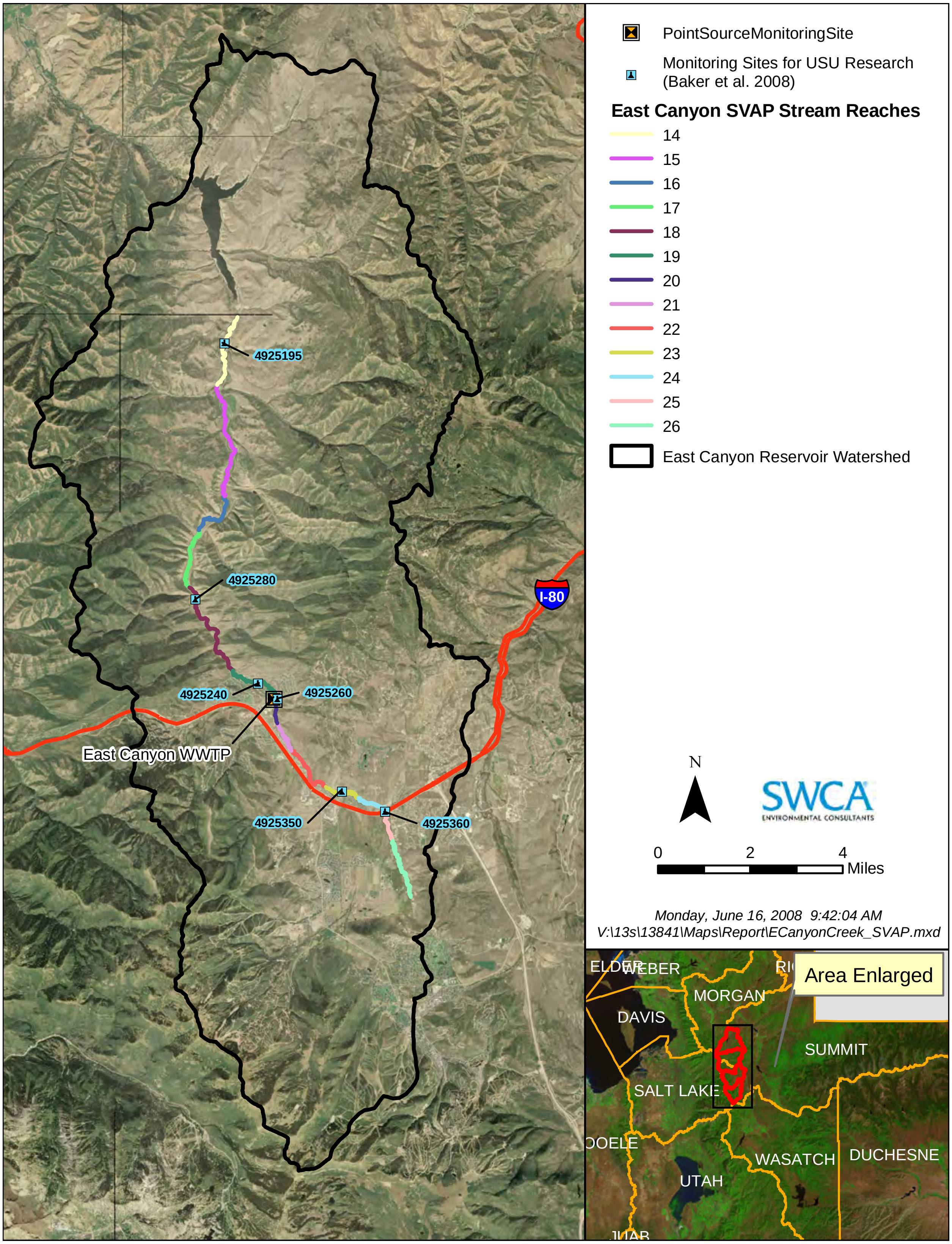

Figure 4.1. Map of SVAP stream reaches and USU/HydroQual research sites and reaches.

4.4 STREAM METABOLISM AND NUTRIENT DYNAMICS IN EAST CANYON CREEK

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

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

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

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

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

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

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

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

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

4.5 DISSOLVED OXYGEN (DO) MODELING

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

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

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

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

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

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

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

4.6 LINKAGE BETWEEN STREAM CHARACTERISTICS AND DISSOLVED OXYGEN (DO)

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

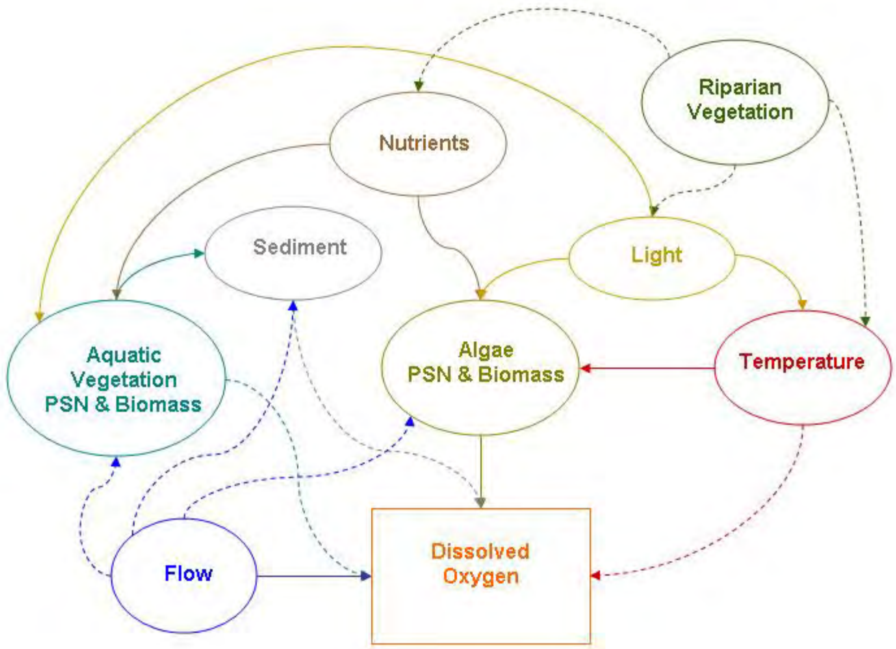

Figure 4.2. Linkages between physical stream characteristics and DO.
Solid arrows indicate a positive (increasing) relationship between parameters; dotted arrows indicate a negative (decreasing) relationship between parameters.

4.6.1 WATER TEMPERATURE

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

4.6.2 STREAM VELOCITY

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

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

4.6.3 Sediment and Nutrient Loads

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

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

4.6.4 Light

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

4.6.5 ALGAE AND MACROPHYTE GROWTH

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

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

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

4.6.6 RIPARIAN VEGETATION

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

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

4.7 SUMMARY OF FACTORS INFLUENCING DISSOLVED OXYGEN (DO) IN EAST CANYON CREEK

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

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

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

Table 4.5 Summary of Reach Level Stream Characteristics and Research Findings

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

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

5. EAST CANYON RESERVOIR MODELING AND DYNAMICS

5.1 GENERAL MODEL DESCRIPTION

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

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

5.2 MODEL GOALS AND OBJECTIVES

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

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

5.3 MODEL DEVELOPMENT FOR EAST CANYON RESERVOIR

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

5.3.1 Temporal Extent of Model Simulations

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

5.3.2 Inputs for East Canyon Reservoir W2 Model

5.3.2.1 Reservoir Morphometry

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

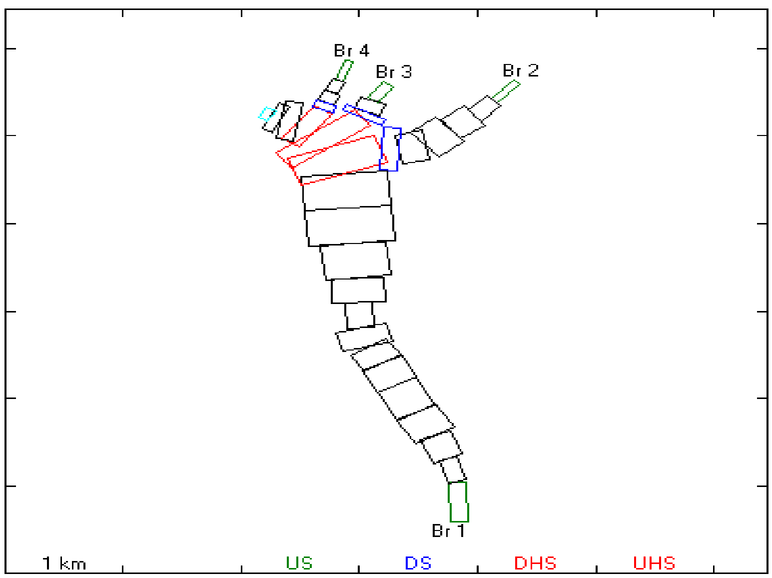

Figure 5.1. Segments of East Canyon Reservoir used in the W2 model.
Graph source: JM Water Quality, LLC. 2008

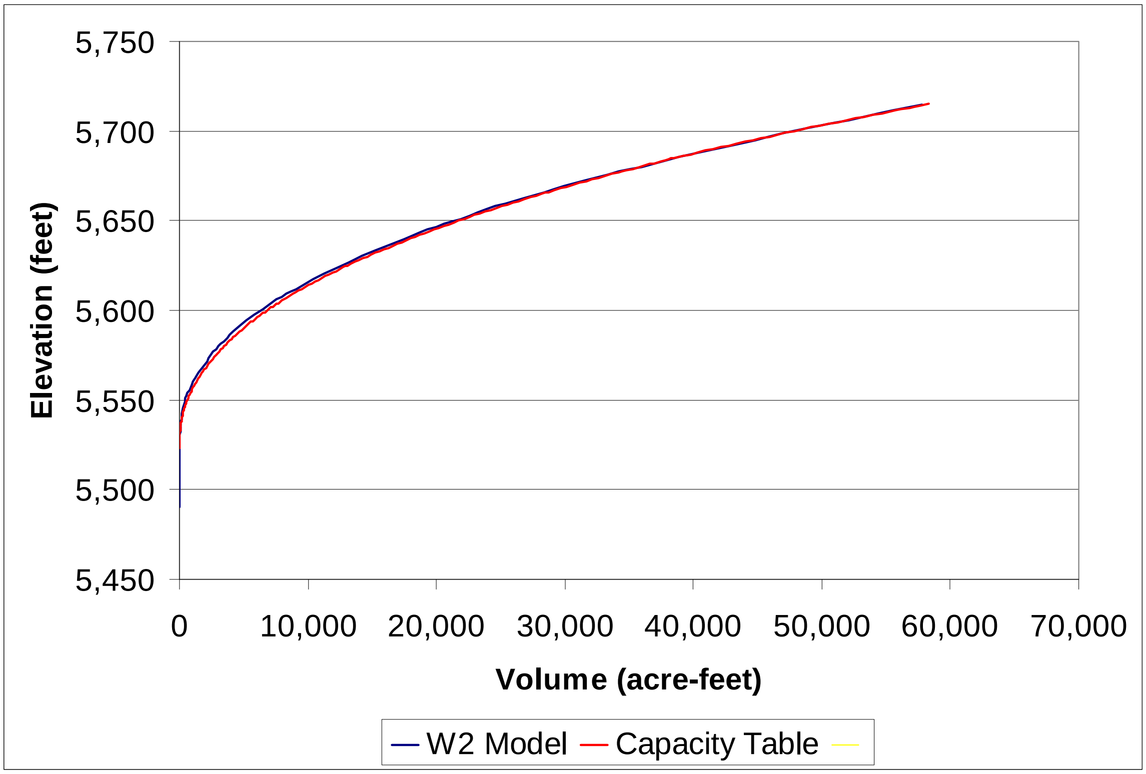

Figure 5.2. East Canyon comparison of the live storage area capacity table (provided by Nick Williams, BOR, 2008) and volumes generated using the W2 model bathymetry file.
Graph source: JM Water Quality, LLC. 2008

5.3.2.2 Tributary Inputs

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

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

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

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

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

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

5.3.2.3 Climatic Data Inputs

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

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

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

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

5.3.3 East Canyon Reservoir Dynamics

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

5.3.3.1 Hydrodynamics

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

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

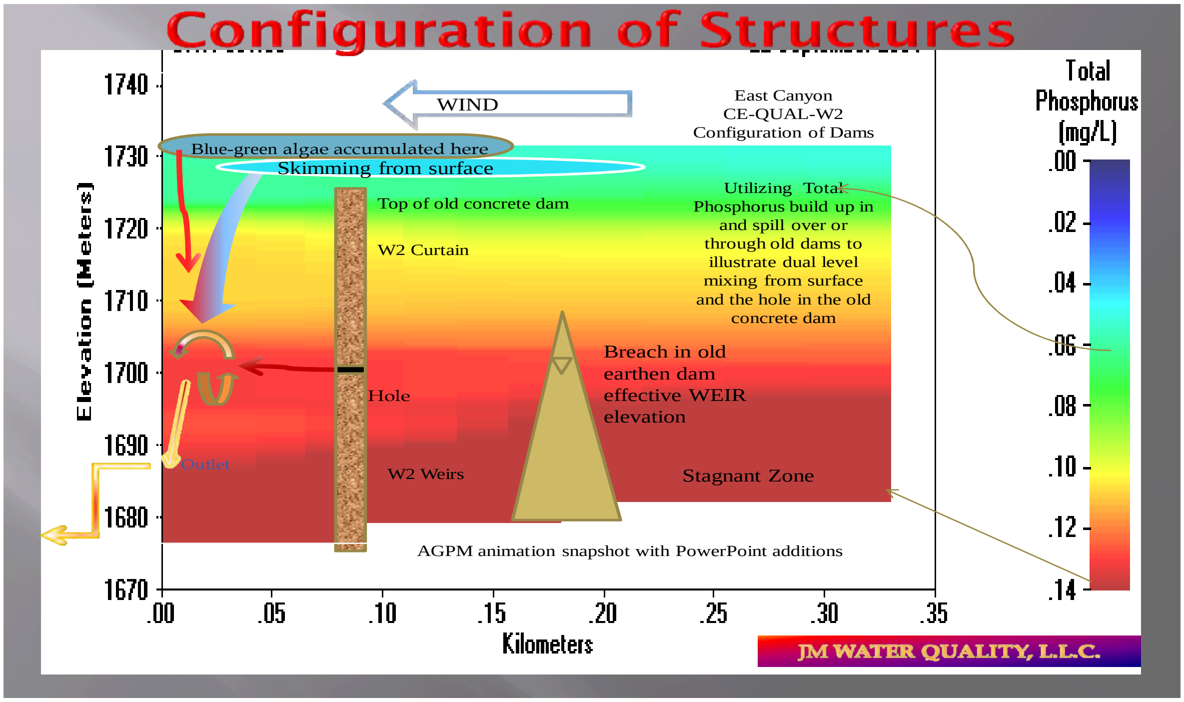

Figure 5.3. Dam configuration and phosphorus distribution during stratification.
Figure source: JM Water Quality, LLC. 2008

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

5.3.3.2 Stratification

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

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

5.3.3.3 Seasonality and Climatic Drivers of Algal Blooms

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

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

5.3.3.4 Algal Speciation, Succession, and Vertical Mobility

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

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

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

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

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

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

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

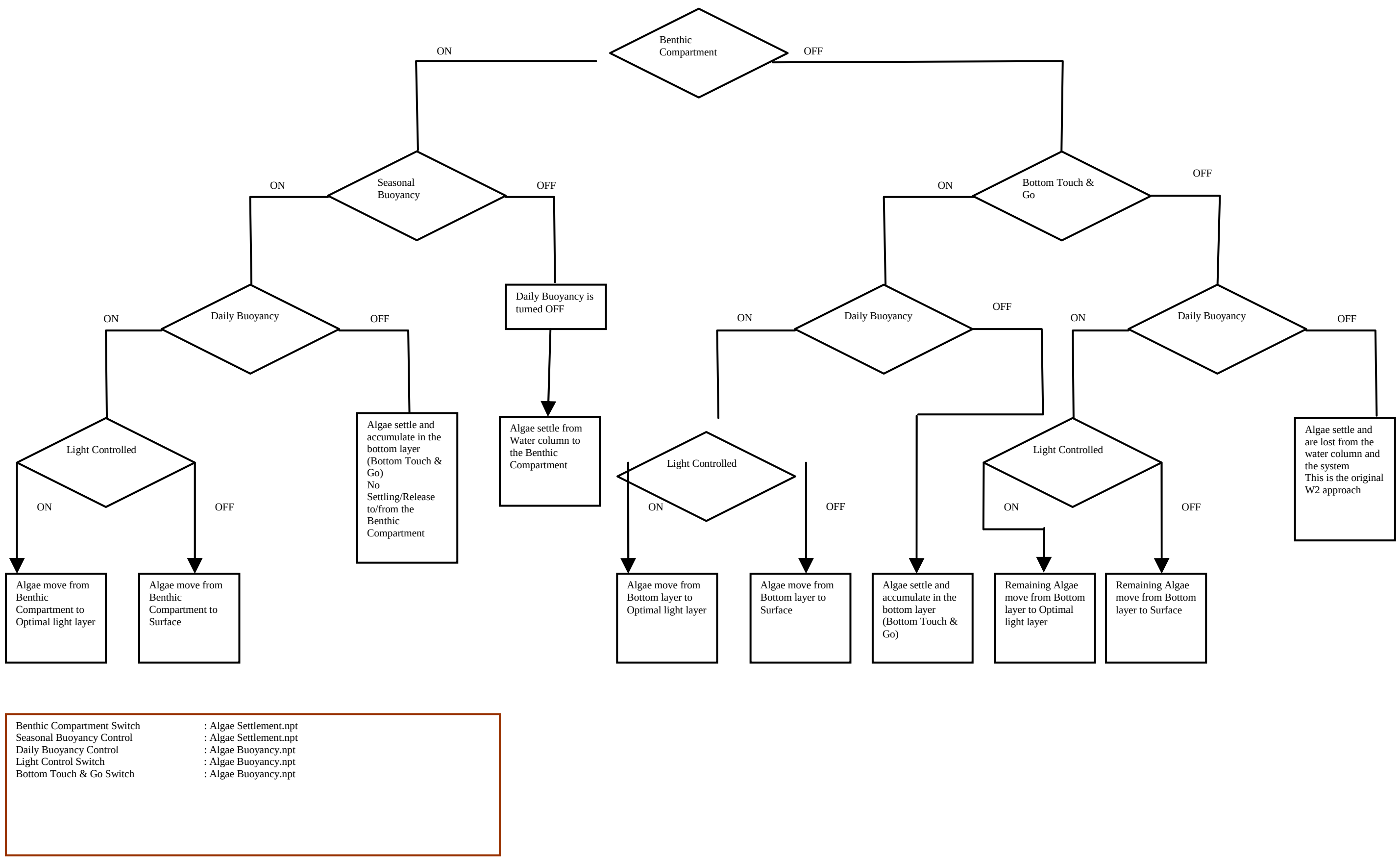

Figure 5.4. Diagram of the algal succession code conceptually developed by Jerry Miller with extensive discussion with Shwet Prakash at ERM.

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

5.3.3.5 Phosphorus Availability

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

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

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

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

5.3.3.6 Sediment Oxygen Demand

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

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

5.3.3.7 Drivers of Low Dissolved Oxygen (DO) in Hypolimnion

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

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

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

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

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

5.4 Model Calibration and Validation

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

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

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

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

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

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

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

5.4.1 Rate Coefficients

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

5.4.2 Temperature

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

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

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

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

5.4.3 Evaporation

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

5.4.4 PHOSPHORUS DISCHARGE FROM DAM

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

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

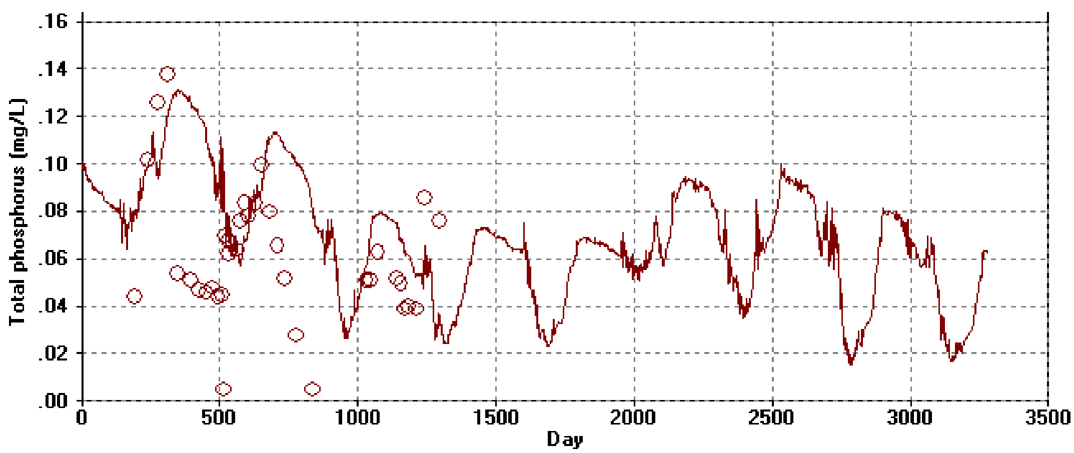

Figure 5.5. Observed (circles) and modeled (line) total phosphorus released from the East Canyon Dam (data is from 2 km downstream) from 2003 to 2006.
Graph source: JM Water Quality, LLC. 2008

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

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

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

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

5.4.5 Dissolved Oxygen (DO) and Temperature Profiles

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

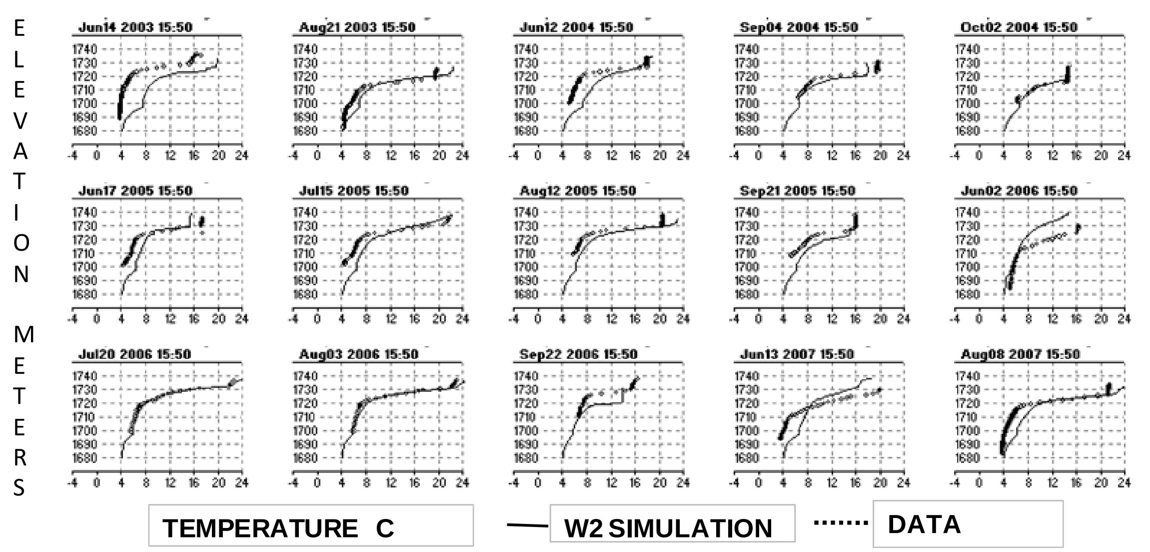

Figure 5.6. Modeled (line) and observed (dot) temperatures at the dam and mid-reservoir stations.
Graph source: JM Water Quality, LLC. 2008

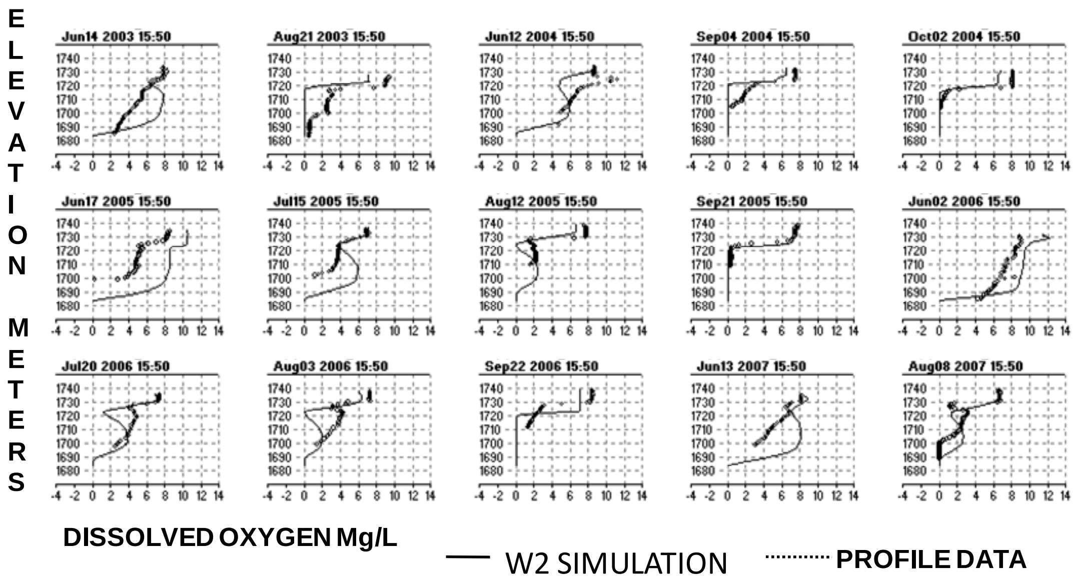

Figure 5.7. Calibration curves of modeled (line) and observed (circles) DO near the dam.
Graph source: JM Water Quality, LLC. 2008

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

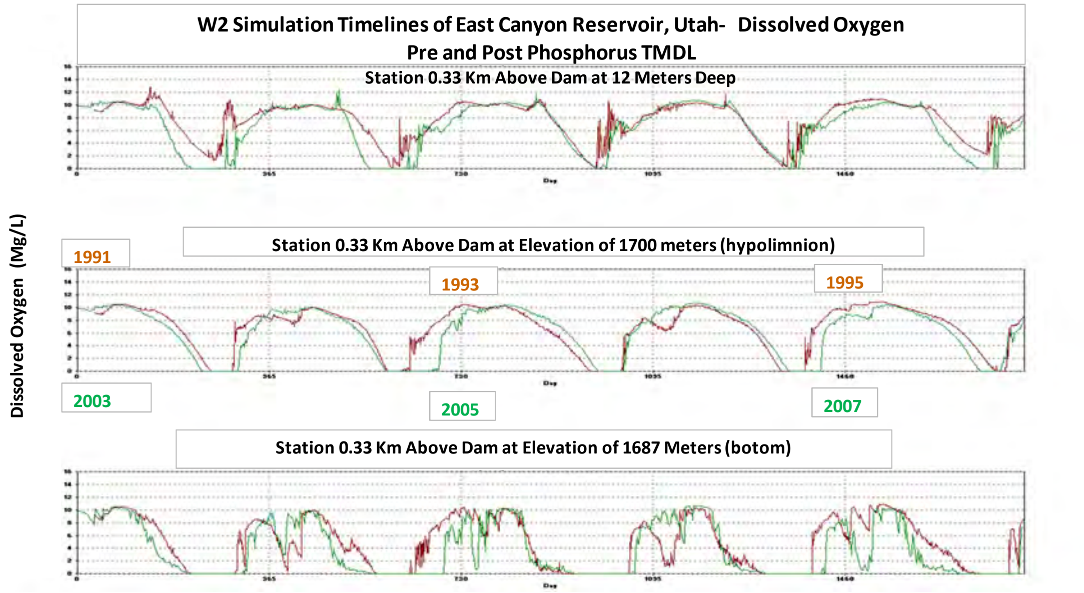

Figure 5.8. Annual cycle of DO in East Canyon Reservoir before and after implementation of the 2000 East Canyon Reservoir TMDL.

5.4.6 ALGAL GROWTH

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

5.4.7 ALGAL SPECIATION

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

5.4.8 MODEL UNCERTAINTY

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

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

5.5 SCENARIO MODELING

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

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

5.5.1 FUTURE NUTRIENT REDUCTION SCENARIOS

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

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

Table 5.2. Future Nutrient Reduction Scenarios for East Canyon Reservoir

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

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

5.5.2 NUTRIENTS

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

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

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

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

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

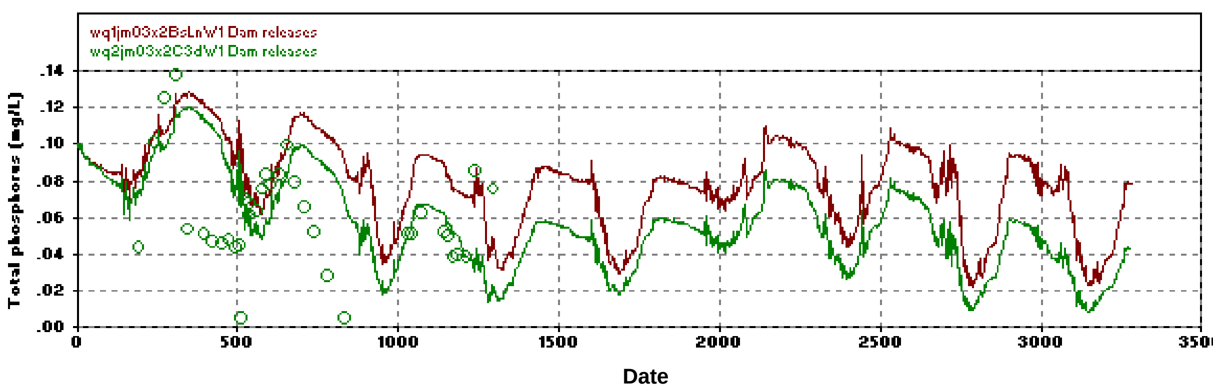

Figure 5.9. Total phosphorus discharge from the dam under baseline (brown line) and reduction scenario (3d) conditions.

Graph source: JM Water Quality, LLC. 2008

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

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

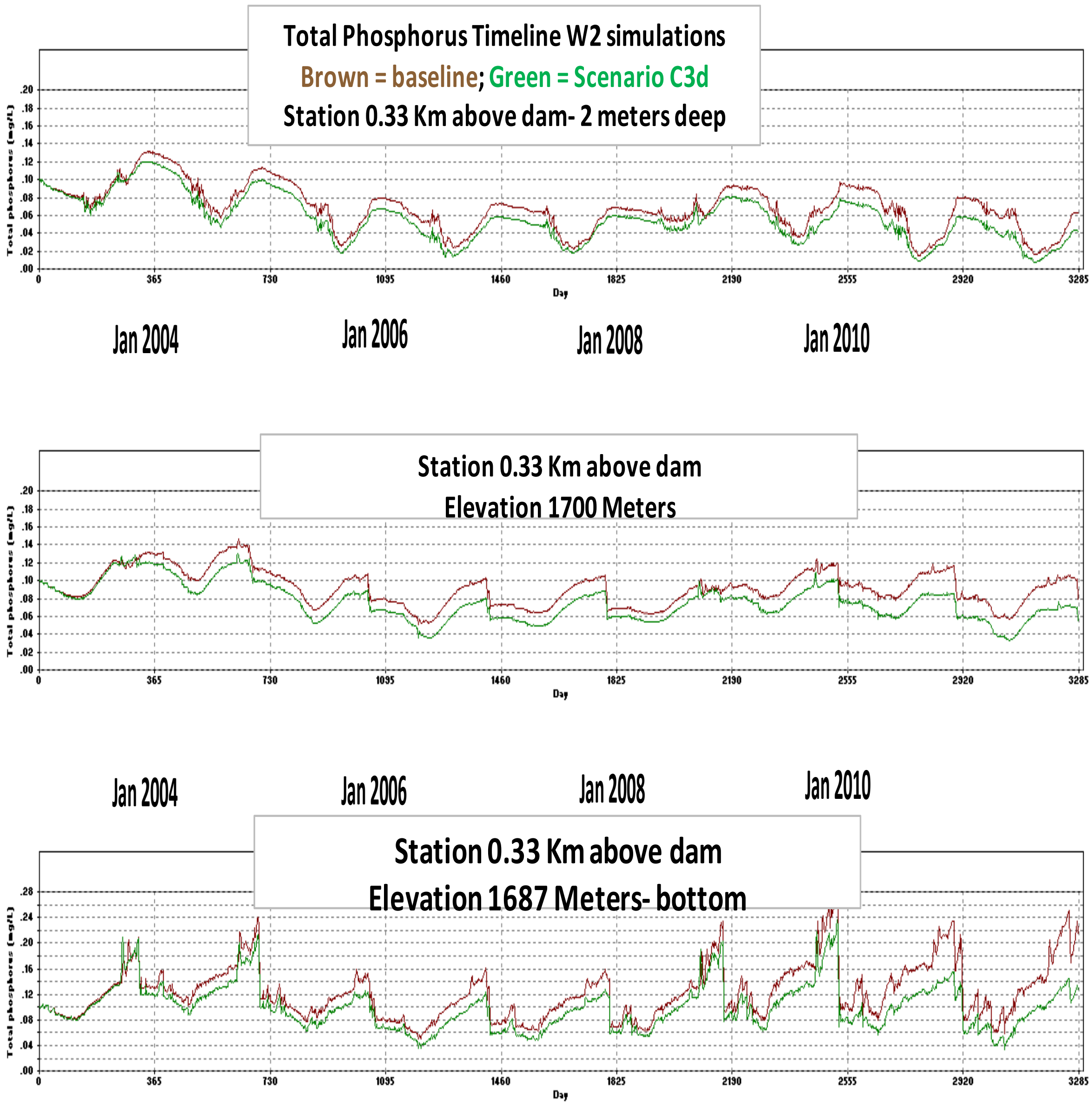

Figure 5.10. Display of total phosphorus in the water column, including the sediment-water interface, upper level of the hypolimnion, and epilimnion in East Canyon Reservoir under baseline and Scenario 3d conditions.

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

5.5.3 Chlorophyll *a*

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

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

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

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

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

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

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

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

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

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

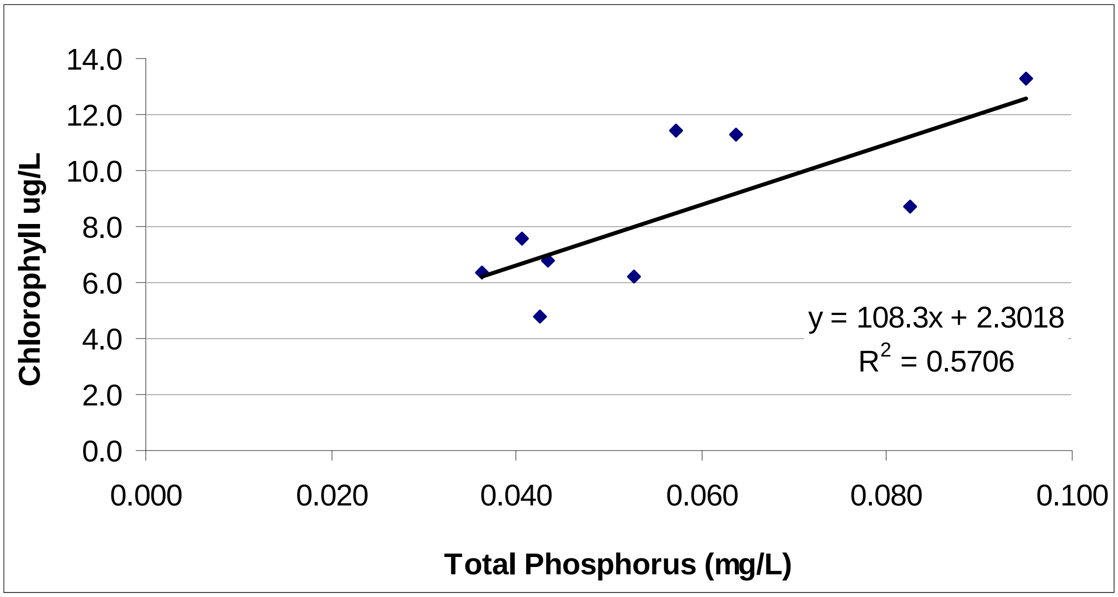

Figure 5.11. Relationship between mean annual summer chlorophyll concentrations and mean summer epilimnion total phosphorus concentration for the baseline East Canyon Reservoir W2 simulation.

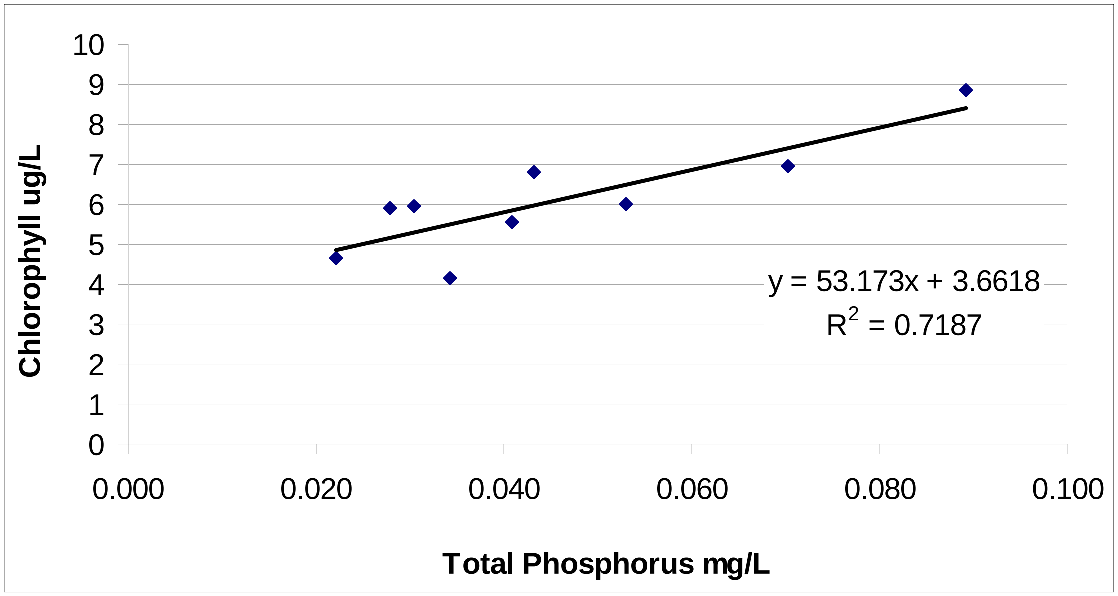

Figure 5.12. Relationship between mean annual summer chlorophyll concentrations and mean summer epilimnion total phosphorus concentration for the Scenario 3d East Canyon Reservoir W2 simulation.

5.5.4 Blue-green Algae

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

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

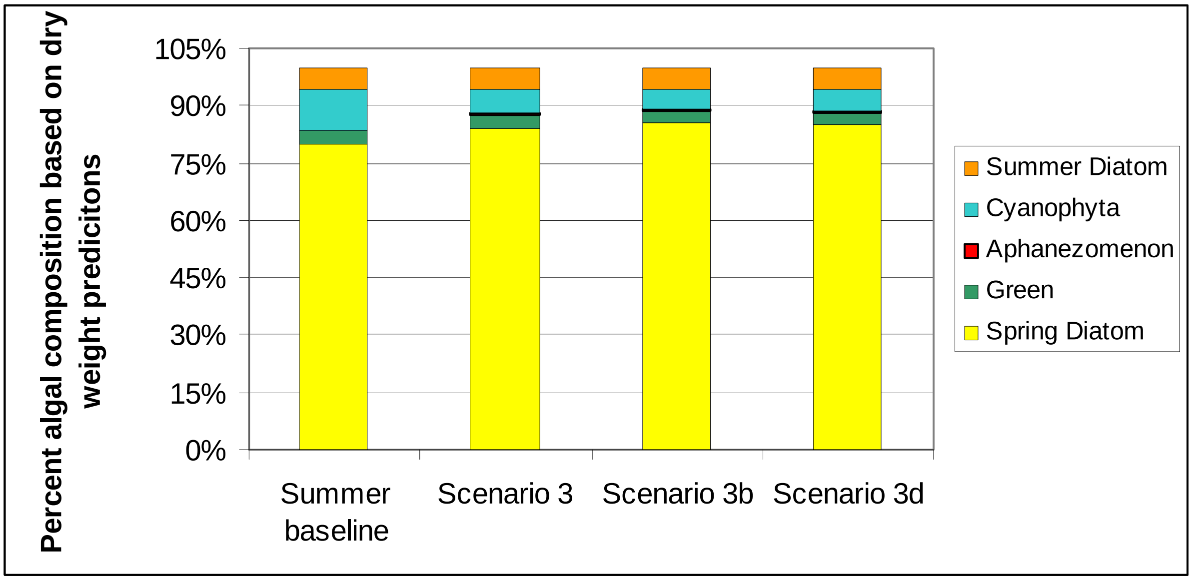

Figure 5.13. Predicted summer algal speciation in East Canyon Reservoir under baseline and future nutrient reduction scenarios.

5.5.5 TURBIDITY

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

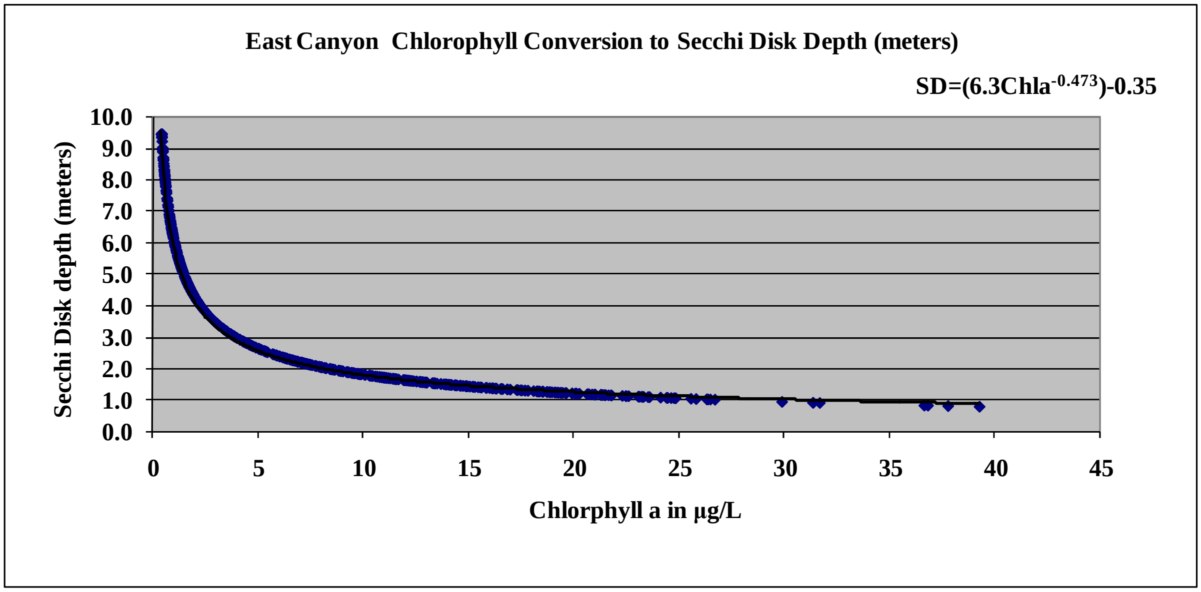

Figure 5.14. Relationship between Secchi disk depth and chlorophyll *a* in East Canyon Reservoir.

5.5.6 Oxygen Depletion

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

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

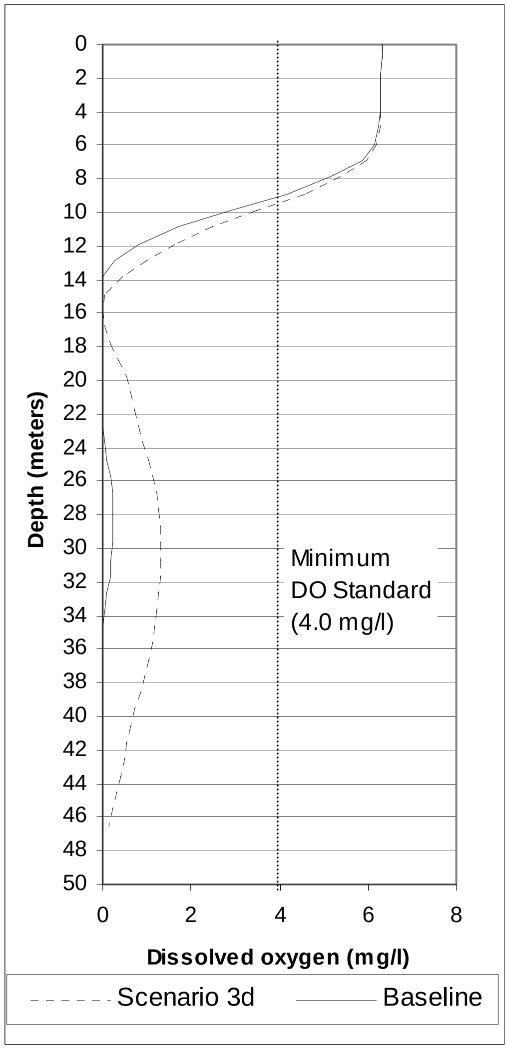

Figure 5.15. Predicted DO profile at the Mid-reservoir Site in mid August at the end of the model simulation period.

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

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

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

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

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

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