APPENDIX B.

EAST CANYON RESERVOIR CE-QUAL-W2 MODEL. JM WATER QUALITY LLC

East Canyon Reservoir CE-QUAL-W2 Model

2008 Water Quality Assessment

Utah DEQ Phosphorus TMDL

By

JM WATER QUALITY, LLC

For

SWCA

East Canyon Reservoir
2008 CE-QUAL-W2 WATER QUALITY Model
Appendix for

Utah DEQ Phosphorus TMDL
East Canyon Reservoir

Prepared for
SWCA

2008

JM WATER QUALITY, LLC

Jerry Miller

By contract to

SWCA
For
Utah DEQ-Water Quality Division

Table of Contents

1 Reservoir Modeling 5

1.1 Introduction 5

1.1.1 Background 7
1.1.2 Multiple Agency Water Quality Studies 8

1.2 The Development And Components Of Ce-Qual-W2 9

1.3 Model Development For East Canyon Reservoir 11

1.3.1 East Canyon Bathymetry 11
1.3.2 Morphometry 12
1.3.3 Model Configuration, Setup, Assumptions, Allgorithms, And Rate Coefficients For East Canyon Dam 13
1.3.4 Dams, Weirs, And Curtain Configurations To Replicate Hydrodynamics 14
1.3.5 Model Inputs For East Canyon Reservoir 16
1.3.6 Climatic Data Inputs 17
1.3.7 Model Coefficients And W2 Configuraton 18
1.3.7.1 Temperature Coefficients & Configuration Of Old Dams 18
1.3.7.2 Inflow Temperature Of East Canyon Creek 21
1.3.7.3 Sediment Oxygen Demand 22
1.3.7.3.1 First Order Oxygen Demand 23
1.3.7.3.2 Zero Order Oxygen Demand 23
1.3.7.3.3 Combined First Order And Zero Order Dissolved Oxygen Demand 23
1.3.7.4 Temperature Controlled Organic Matter Decay Rates 24
1.3.8 Vertical Phytoplankton Mobility (R & D Code) 24

1.4 Modeled Conditions: Variability, Uncertainty, And Calibration 26

1.4.1 Variability- Simulation Periods 26
1.4.2 Model Calibration And Confirmation 27
1.4.2.1 Calibration Parameters And Rate Coefficients 29
1.4.2.2 Hydrodynamics As Tested By Temperature And Dissolved Oxygen 31
1.4.2.3 Nutrients 39
1.4.2.4 Chlorophyll 50
1.4.2.5 Blue-green Algae 56

1.5 Scenario Modeling: Reservoir Response to Proposed Tributary Concentrations and Comparison to Baseline Calibrated Model 60

1.5.1 Nutrients- Phosphorus 61
1.5.2 Chlorophyll a 65
1.5.3 Blue-Green Algae 68
1.5.4 Turbidity 73
1.5.5 Dissolved Oxygen 74

2 Total Maximum Daily Load Analysis 77

2.1 Internal Versus External Nutrient Loading 77
2.2 Sediment Phosphorus Diagenesis 79
2.3 Nutrients 80
2.4 Chlorophyll a 81
2.5 Blue-Green Algae And Algal Succession 83
2.6 Turbidity 83
2.7 Oxygen Depletion 84
2.8 Uncertainty 87
2.9 Seasonality 89
3 Conclusions And Recommendations 90
3.1 Conclusions 90
3.2 Recommendations 91
4 Bibliography 94
5 Definitions 97

1 Reservoir Modeling

1.1 Introduction

The East Canyon Reservoir CE-QUAL-W2 (W2) model water quality assessment is summarized in this appendix. This appendix is meant to be a companion document to the Draft East Canyon Reservoir TMDL*, (Utah DEQ 2008, prepared by SWCA*) This study utilizes the W2 model to complete a reservoir water quality assessment to assist SWCA and Utah Department of Environmental quality (DEQ) update the East Canyon Reservoir phosphorus TMDL which resides on the Utah DEQ website at: http://www.waterquality.utah.gov/TMDL/East_Canyon_Reservoir_TMDL.pdf

East Canyon Reservoir is an important water resource for agriculture, domestic water use, a sport fishery, and recreation area.

The two main goals of this CE-QUAL-W2 modeling study are: 1) to provide a more detailed assessment of how East Canyon Reservoir (ECR) has responded to the phosphorus reductions that have been implemented, and 2) to determine how it should respond to proposed additional phosphorus reduction scenarios in the future.

The specific objectives of this study are to utilize the CE-QUAL-W2 model to:

1) Quantify reservoir chlorophyll autochthonous production before and after phosphorus reductions from the watershed;
2) Determine the relationships between phosphorus and phytoplankton biomass production, allochthonous organic matter, dissolved oxygen demand, and temperature;
3) Determine if phosphorus reductions can maintain the Utah DEQ cold water fishery water quality standard for temperature and dissolved oxygen (dissolved oxygen greater than 4.0 mg/L in water less than 20°C) in a sufficient quantity of water to carry trout through the summer stagnation period.
4) Qualitatively track seasonal and major long term shifts in algal succession related to phosphorus reductions;
5) Utilize W2 to simulate potential nutrient reduction scenarios to meet specific measurement end-point goals for chlorophyll, reduction or elimination of blue-green algae (Cyanophyta), maintain the cold water fishery water quality standard for temperature and dissolved oxygen, and meet in-reservoir phosphorus concentrations.

Approximately a 60% phosphorus reduction has been realized from the 1990's to 2005-2007 as inflow to East Canyon Reservoir. The phosphorus reduction, particularly the advanced wastewater treatment portion, comes at considerable expense. Continuing to maintain those reductions with future growth also comes at considerable expense. This report documents what has been accomplished in East Canyon Reservoir water quality due to the 60% phosphorus reduction, and what can still be gained in scenarios that would reduce loading by about an additional 11-16%.

This report was not prepared entirely as a standalone document, but as a companion document and appendix to the East Canyon Reservoir TMDL which is being prepared for Utah DEQ(2008) as contracted with SWCA. SWCA contracted the East Canyon Reservoir water quality modeling and assessment portion of this study to JM WATER QUALITY, LLC.

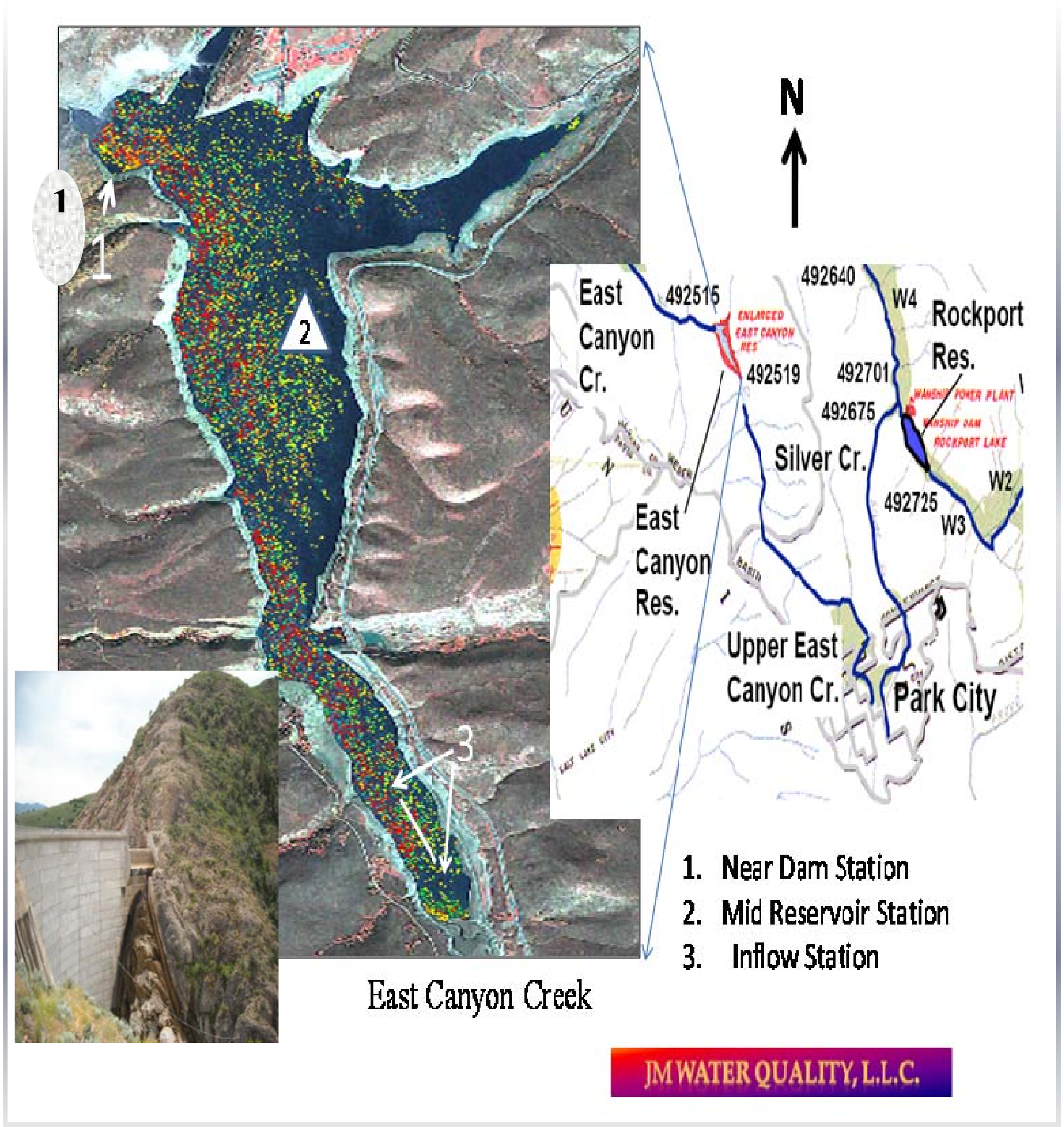

Figure 1. Map and satellite image of chlorophyll studies and primary water quality stations on East Canyon Reservoir, Utah, USA[1]. Photo is East Canyon Dam looking at the spillway from downstream; the reservoir is full, and the wind is seiching water in waves over the top of the spillway (July 4th, 2008). The primary historical sampling locations are designed as 1) near dam, 2) mid-reservoir, and 3) East Canyon Creek Inflow area. An alternative site 1 is also designed just upstream of the old dams.

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[1] The satellite image was produced by Ms Mindy Shearer and associates from the United States Geological Survey(USGS); Cook, Washington as part of a joint Department of the Interior USGS/Reclamation water quality research project on East Canyon Reservoir (unpublished). The hydrologic map was modified from the previous East Canyon TMDL Study (USU, 2000). The satellite image was provided to Jerry Miller (then USBR) as a personal communication from Ms Mindy Shearer just prior to her leaving Federal Service in about 2002.

1.1.1 Background

The Park City, Utah Ski Resort located in the upper end of the East Canyon Reservoir watershed was the location (Figure 1) of many of the outdoor 2002 Winter Olympic Games skiing events. A great deal of construction and growth occurred in this general Synderville Basin area prior to the Olympics. The popularity and development of this area since the 1970's is associated with increasing nutrients from the wastewater treatment plant, construction related erosion, and increased urban storm runoff. Historically over-grazing in the riparian zones and base metal mining in the watershed has also impacted water quality. The decline of mining and mine dewatering activities coupled with the increased demand for water in the Park City area has also resulted in significant reductions in July-September stream flow in East Canyon Creek. The extended drought from 1999-2007 has further exacerbated the lack of sufficient summer stream flow. Livestock use of the stream riparian zones has significantly diminished in the immediate Park City/Synderville Basin area associated with human population growth over the three decades.

Some of the most disturbed lands around Park City occurred on steep slopes with soil derived from the Phosphoria Formation (Olsen, D and Stamp, M. 2000, Biowest). Soils derived from the Phosphoria Formation can be very high in bioavailable phosphorus. The spring snowmelt runoff contains significant sources of water and non-point source nutrients to East Canyon Reservoir. A number of point and non-point source phosphorus reductions have been implemented over the past 10-15 years (Utah DEQ- http://www.waterquality.utah.gov/TMDL/East_Canyon_Reservoir_TMDL.pdf - (USU, 2000-Utah DEQ TMDL), (SWCA, 2008).

It is estimated that nearly a 60% phosphorus reduction to the East Canyon Creek inflow to the reservoir has been implemented since the early 1990s as a result of the W2 simulations from 1991-1998 and 2003-2007 with CE-QUAL-W2. This study will help document the water quality improvements that have been realized by those reductions, and also to analyze the potential benefits of additional load reductions

This study was feasible in a very short time frame because the W2 model application had already been developed by students at Brigham Young University (BYU) in association with the U.S. Bureau of Reclamation, but was not calibrated. JM Water Quality, L.L.C. in association with Environmental Resources Management[2] (ERM) was utilizing this provisional East Canyon model to test research and development code added to W2 for algal succession. Mr. Jerry Miller (JM Water Quality, L.L.C and author of this study) was utilizing East Canyon Reservoir to test this algal succession R&D code in part because the reservoir is near home, and had been studied limnologically or observed for nearly three decades[3]. This reservoir had a TMDL with significant phosphorus reductions, and some data suggesting that important measurement end-point goals were being achieved. However, little had been done to compile the data and document the limnological improvements.

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[2] Dr. Edward Buchak, a former principle associate of J.E. Edinger & Associates- now part of ERM has provided JM Water Quality with assistance in writing the new algal succession code being tested here. The code was written by Mr. Shwet Prakash of ERM with overview from Dr. Ed Buchak and testing by Jerry Miller. Without this assistance Jerry Miller's concepts on algal succession could not have been implemented. Dr. Edward Buchak and Jerry Miller have collaborated in various LARM and W2 research projects since about 1981.

[3] JM Water Quality, L.L.C. and Environmental Resources Management (ERM) were conducting this algal succession study as internal Research and Development (unfunded R&D) to enhance the ability of CE-QUAL-W2 to analyze important reservoir TMDL measurement end-point goals. Jerry Miller (JM Water Quality, L.L.C-sole proprietor and author of this report) has studied East Canyon Reservoir limnology and had observed it as a fisherman and recreationist for over thirty years.

Table 1.1.2 East Canyon Reservoir Limnological statistics

Maximum Depth	60 meters (197 Ft)
Mean Depth	23 meters (75.5 Ft)
Surface Area	277 hectares (685 acres)
Total Capacity	6.291E+07 M^3 (51,000 acre-Ft)
Spillway Elevation	1742 Meters (5705 Ft)
Outlet works	1687 Meter (5535 Ft)
Maximum elevation	1742 Meters (5715 Ft)
Crest Length	133 meters (436 Ft)
Old Concrete Dam	
top of dam	1725 M (5715 Ft)
hole through dam	1697.8 meters (5567 Ft)

The bottom depth behind the old earthen dam is 1687 meters (5535 Ft.) which forms a dead zone or stagnant layer in the hypolimnion. The hydraulic retention time of East Canyon Reservoir can vary significantly from a little over 1/3 year to nearly two years depending on hydrology and the initial pool in March prior to spring runoff. This variation coupled with meteorological conditions can also produce differences in spillway spills, and overall sensitivity to length of summer stagnation, magnitude of algal blooms, dissolved oxygen depletion, and long term retention of phosphorus in the reservoir.

Even though East Canyon Reservoir is nearly 200 feet (60 meters) deep, the maximum length of East Canyon Reservoir is less than 3.5 miles (5.5 kilometers). A 180 degree switch in wind direction can move algal biomasses concentrated near the surface (like blue-green algae) from one-half of the reservoir to the other in about two days. This reservoir is built in a deep canyon with steep gradients to the dam and down the sidewalls.

The U.S. Bureau of Reclamation (referred to as USBR or Reclamation in this report or as BOR in referenced reports) provided the initial East Canyon Reservoir (ECR) model set up for this study and all the data they had collected on ECR for the purpose of supporting Utah DEQ in further improving water quality in the reservoir.

Deer Creek and Jordanelle Reservoirs in the adjacent drainages have been in implementation of similar phosphorus TMDLs for about 27 years. Mr. Jerry Miller had been involved in this and other reservoir water quality improvement projects for more than 30 years previously as a U.S. Bureau of Reclamation and Wyoming DEQ employee.

1.1.2 Multiple Agency Water Quality Studies

East Canyon Reservoir has been studied intermittently for many years; which provided a long history of information, but generally the data is sparse. Critical time periods are often missing both in seasons, years, and spatially within the reservoir. Several ECR water quality studies have also been discontinued due to lack of funding. Water quality data has been compiled from several State, local, and Federal agencies for this analysis. The data available on this reservoir has a longer history than most. The phytoplankton data base coupled with the reduction in phosphorus, and the author's familiarity with this water body over several decades made it most intriguing as an algal succession research and development test case. Major shifts in algal succession associated with phosphorus reduction have been documented since 2005. However, the author has observed significant summer and fall blue-green algal bloom events on this reservoir- particularly throughout the 1990s. The application of a CE-QUAL-W2 study along with compilation and analysis of the data are important steps to improving the future limnological studies of this reservoir.

Several students from Brigham Young University in Provo, Utah helped Reclamation staff develop the W2 model application in part for research to develop preprocessing tools for various U.S. Army Corps of Engineers hydrology and water quality models; and in part to assist Reclamation and the State of Utah to have a W2 model for water quality assessments. A Masters Degree project on utilizing WMS[4] to develop CE-QUAL-W2 bathymetry files and model setup was completed by Mr. Jason Wagoner at BYU[5]. Further advancement on the model had not been made in several years due to lack of funding. This ECR W2 application was updated by Mr. Nick Williams (Reclamation, SLC-Utah, 2008) to the W2 version 3.2, with some slight bathymetry file adjustments in 2007. Reclamation then made this model available for these studies upon request from Utah DEQ. ERM added the new algal succession code to CE-QUAL-W2 Version 3.2 (Prakash, 2008) based on conceptual ideas drafted by Jerry Miller.

Additional data was provided by the East Canyon Water Reclamation Facility (ECWRF) often referred to as the Synderville Basin Waste Water Treatment Plant, Weber River Basin Water District, U.S. Geological Survey (USGS), Utah DEQ, Utah State University, and the East Canyon Water Quality Committee.

The State of Utah in cooperation with the Utah Water Research Laboratory at Utah State University has also cooperated with the U.S. Bureau of Reclamation and the Weber River Basin Water District (Stephenson, Dave; personal communications, 2006 &2007) in preparing a Weber Basin water quality and hydrologic routing model and data base which included East Canyon Reservoir. This model was utilized to prepare the Utah State Water Research Laboratory (USU, 2000) "Technical support for Watershed Water Quality Evaluation for TMDL support for the East Canyon Creek/East Canyon Reservoir system, Summit County, UT". Dr. Sam Rushforth (2003-2006 -Rushforth Phycology, L.L.C.) had years of phytoplankton count data compiled in association with both Utah Department of Environmental Quality- Water Quality Division and with the U.S. Bureau of Reclamation.

The East Canyon Reservoir Water Quality Committee was officially formulated in large measure due to the efforts of Dr. Ray Loveless http://www.eastcanyoncreek.org/mambo/index.php?option=content&task=view&id=27&Itemid=40 ; http://www.waterquality.utah.gov/watersheds/lakes/EASTCYN.pdf). Several studies and watershed improvement projects have been completed by the East Canyon Committee (Olson, D. and Stamp, M. 2000). The various components of these studies had not previously been compiled in one place, particularly as a detailed ECR water quality assessment.

1.2 The Development And Components Of Ce-Qual-W2

The CE-QUAL-W2 model has been in continuous development since the original model hydrodynamics code, known as LARM (***L***aterally ***A***veraged ***R***eservoir ***M***odel) was developed by J.E. Edinger and ED Buchak in 1975 (Edinger, 1975). Additions of the water quality algorithms by the Water Quality Modeling Group at the US Army Engineer Waterways Experiment Station (WES) resulted in the first

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[4] Jason Wagoner completed a Masters project on developing a W2 bathymetry file utilizing WMS while at BYU.

[5] Ms Amy Cutler, U.S. Bureau of Reclamation provided valuable assistance to Jason Wagoner at BYU, in the Masters Degree Project- which developed a manual of instructions on the use of WMS to build a bathymetry file and to set up a CE-QUAL-W2 model.

version named CE-QUAL-W2. An extensive user's manual(Cole and Wells, 2005) is now available which includes a history, algorithms, equations, set up instructions, full descriptions of the model components and operation, and examples of applications. A copy of the Version 3.2 user's manual is attached in the DVD's with this document delivered to SWCA and Utah DEQ. The W2 User Manual (Cole and Wells, 2005) is an integral part of this study and must be utilized in order to use this application for future simulations.

The CE-QUAL-W2 model is currently in the public domain and can be downloaded from the Portland State University website (http://www.ce.pdx.edu/w2/index.html). A new version 3.5 is also now available, but it does not contain the specific algal succession R&D code being tested on East Canyon Reservoir. Version 3.5 does include zooplankton algal grazing algorithms. The algal succession utilized in this code is still in research and development; after several more reservoirs have been tested it will eventually be submitted to the COE and Dr. Scott Wells at Portland State University. The newly formed CE-QUAL-W2 oversight committee will likely review this work to determine if a public domain version of this W2 algal succession R&D code or successors will be added. Additional modifications to the algal succession code utilized in this application are currently envisioned. Many W2 R&D codes have been tested over this four decade process, and development of W2 had been an ongoing private and governmental interagency shared coordination effort throughout. Individual pieces of research code have generally not been made public until several successful test cases have been developed.

CE-QUAL-W2 is a dynamic two dimensional, longitudinal/vertical, hydrodynamic, and water quality model. The reservoir model assumes lateral homogeneity; it is best suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients" (Cole and Wells, 2005). Water is routed through cells in a computational grid and each cell is a completely mixed reactor for each time step. Time steps vary from seconds to minutes depending on the volume of water to be routed in each step.

The application of CE-QUAL-W2 requires knowledge in the following areas:

1. Hydrodynamics
2. Limnology
3. Aquatic biology/ecology
4. Aquatic chemistry/water quality
5. Numerical methods
6. Computer sciences and FORTRAN Program Language (if you wish to modify code)
7. Statistics
8. Data assembly and analysis
9. W2 model construction and calibration

Water quality modeling is in many ways an art requiring not only knowledge in these areas but also experience in their integration. CE-QUAL-W2 is probably best applied with knowledge and practice in each of these areas by a synergistic team. …"***A word of caution to the first time user*** - model application is a complicated and time-consuming task" (Cole and Wells, 2005- W2 User's Manual).

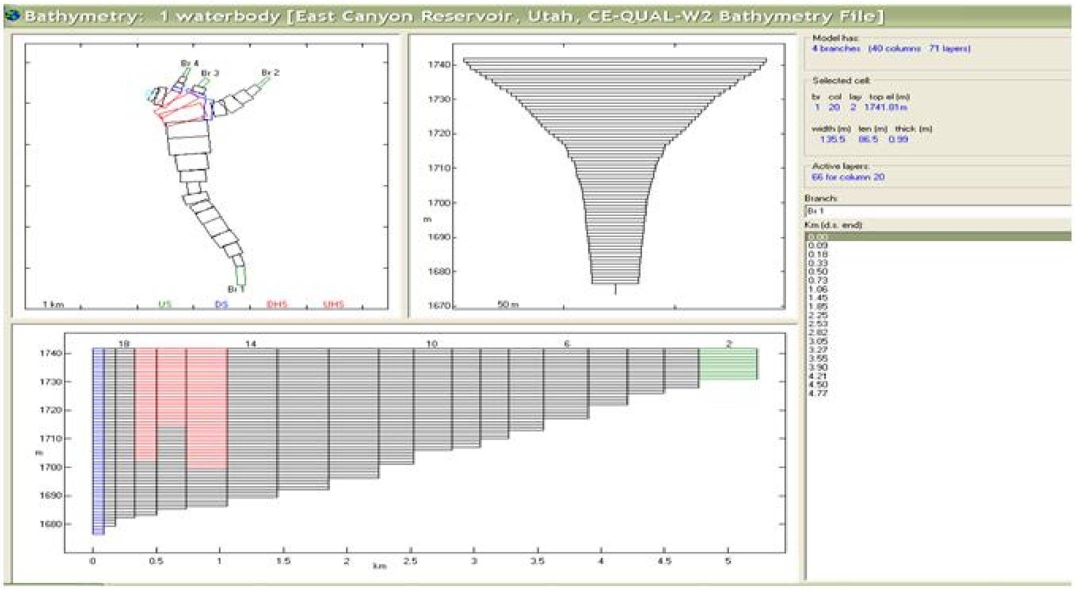
Once the model has been constructed, tested and confirmed; a group with some skills can be trained to rebuild input files and run the model to test new scenarios. However, the output would be better viewed by a good post processor such as AGPM (Hauser, G.2007). Minimal post processing tools are provided with the public version of W2. Calibration with numerous simulations may require extensive time and electronic data storage capacity.

1.3 Model Development For East Canyon Reservoir

1.3.1 East Canyon Bathymetry

Figure 1.3.1-1 is a diagram output from the AGPM CE-QUAL-W2 post processor (Hauser, G., 2007) illustrating the bathymetry file for this East Canyon application. The main branch one has 20 segments with 66 active layers (~ 1 meter thick) at full reservoir pool. There are three branches with ungauged inflows. Including three additional branches gives the model a semi-3rd dimension. CE-QUAL-W2 (W2) is a two dimensional reservoir model, thus all water quality parameters are averaged laterally across a segment. Each layer within a segment acts as a fully mixed reactor for each time step.

The bathymetry file is very important to hydrodynamic calibration. The inflow area of East Canyon Reservoir has been partially filled in by a sediment delta which has built up over the past several decades.



Model has:
4 branches (40 columns 71 layers)

Selected cell:
br col lay top el (m)
1 20 2 1741.01m
width (m) len (m) thick (m)
135.5 86.5 0.99

Active layers:
66 for column 20

Branch:
Br 1

Km (d.s. end)
0.00
0.09
0.18
0.33
0.50
0.73
1.06
1.45
1.85
2.25
2.53
2.82
3.05
3.27
3.55
3.90
4.21
4.50
4.77

Figure 1.3.1-1 AGPM diagram of the East Canyon bathymetry configuration. The reservoir canyon walls are very steep in the lower half of the reservoir to near vertical near the dam (top right panel). The shallow littoral areas are primarily found in the inflow segments (2-6- bottom panel) closest to East Canyon Creek, or in the back of branches.

The deep bathymetric character of this reservoir is very important to water quality assessment, limnology, and tropic status of this reservoir. Branches 2, 3, and 4 have very little inflow, but afford a semi third dimension to this model application.

The model simulation looks ahead and calculates the required time for each time step based on the volume of water that must be moved. Each segment layer goes through a mass balance complete mix with the exchange of water and constituents. Later in this report a number of charts will be generated utilizing the Loginetics AGPM W2 post processor (Hauser, G.. 2007). Each model run is set up to extract time and day interval sequences from each one of these laterally averaged layers with AGPM. Most of these extractions will be once daily, or every two days at approximately 3 p.m. However, some animations will extract six hour sequences to demonstrate phytoplankton daily vertical migration in animation (DVD version only). Study Figure 1.3.1-1 and refer back to it later to better understand a time line extraction. A depth (12 meters deep) extraction will pick the layer that includes 12 meters deep from the surface for the segment specified and at the time sequence specified (generally 1 or 2 days in this report); this extraction must move to different layers in order to stay 12 meters deep. However, sometimes a set elevation is selected to depict conditions at a water/sediment interface or at the depth of the hole in the old concrete dam illustrated later. A time line can chart a once daily sample (example) for the entire time period of simulation from each layer in a segment specified from the bathymetry file. Understanding the time line extraction and the bathymetry file are essential to interpreting and understanding the complex charts and graphics in this report.

1.3.2 Morphometry

The morphometry of East Canyon reservoir is a very steep sided and longitudinal gradient water body as is evident in Figure 1.3.1-1. This morphometry has a small area capacity in the lower elevations, with more than half the total capacity in only about the top 55 feet (17 meters) of the total 197 foot (60 meters) depth.

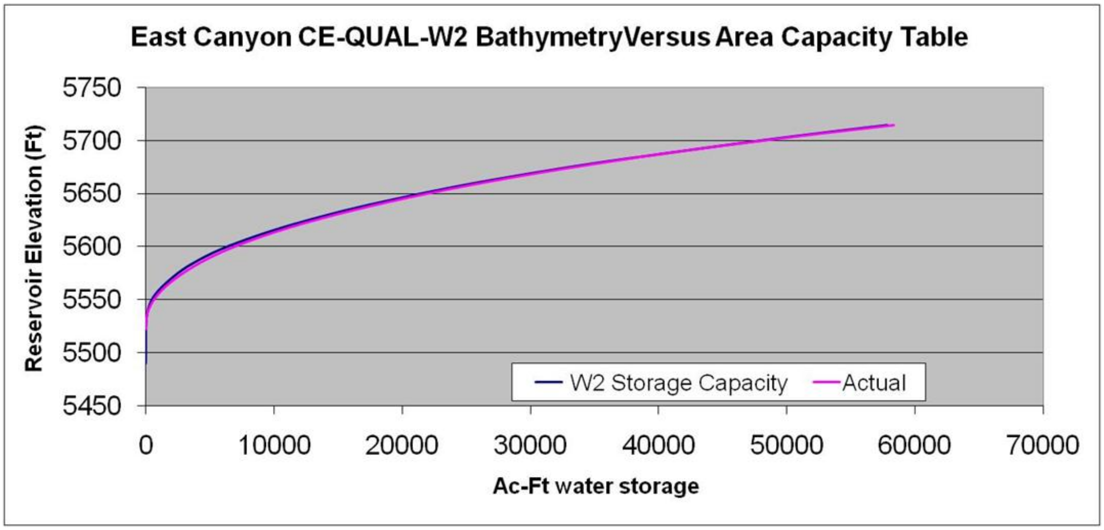


Figure 1.3.2-1 charts the CE-QUAL-W2 model's bathymetry storage capacity versus the U.S. Bureau of Reclamation's area capacity table. The differences are very small. This W2 bathymetry file was constructed and provided by Mr. Nick Williams, U.S.B.R., SLC, Utah.

Figure 1.3.2-2 is a picture of East Canyon Dam spilling in June of 2008, (Provided by Nick Williams, USBR, 2008). Note the outlet discharge left bottom of spillway. Dissolved oxygen is reaerated to saturation at the outlet. This image also helps visualize the steepness of the reservoir and why so much of the storage capacity resides in the upper elevations of the reservoir. The surface spillway skims the warmest water from the epilimnion in June, and may also export spring algal bloom biomass.

All CE-QUAL-W2 input and output is in the metric system, but some graphics are in English units to assist most of readers of this report. It is important when viewing the many charts and graphics with elevation to remember that most of the water resides in the upper elevations of the reservoir. Thus when the reservoir is drawn down and then refilled in spring runoff in about a two month period the dilution of the water in the reservoir is high.

1.3.3 Model Configuration, Setup, Assumptions, Allgorithms, And Rate Coefficients For East Canyon Dam

All ecological models are simplifications of very complex systems. The assumptions of the model need to provide the best fit for the specific problem being analyzed. The bathymetry file and the configuration of older dams inundated in front of the operating East Canyon Dam are essential components to the hydrodynamic operation of this model. Without the **hydrodynamics** depicting the complicated dual level withdrawal functions associated with East Canyon Reservoir, assessment of trophic status and routing of organic matter and nutrients could produce significant errors.

1.3.4 Dams, Weirs, And Curtain Configurations To Replicate Hydrodynamics

The W2 model has algorithms to add weirs and curtains to test skimming affects and various designs to improve water temperature and/or dissolved oxygen released from the dam. Many applications of W2 primarily had hydrodynamic problems such as selective withdrawal, skimmers, weirs, and reaeration as the primary objectives. The W2 model has many years of hydrodynamic development. A major W2 development paradigm has been and still is that "the hydrodynamics have to be correct in order to model water quality"[6] .

The configuration of the East Canyon W2 application attempts to ratio the distance between the various structures and the size of the hypolimnion hole through the old concrete dam with the much larger opening space of the area above the old concrete dam to produce the correct routing affect. An exact sized configuration of these structures required two very short segments which increased the run time of the model several fold. Scaled hydraulic models have been used for years, with great success. The hypolimnion hole and the top of the old concrete structure (See Figures 1.3.4-1 & 1.3.4-2; 1.3.6.1-1) act as two intake elevations into a very large single wet well. The very large single wet well is the space between the operating dam and the inundated old concrete structure. The area of the upper level intake into the wet well (area above the top of the old concrete dam to the water surface) changes as the reservoir is drawn down closer to the top of the old concrete dam, while the area of the hole in the hypolimnion of the old concrete dam remains the same. Thus the ratio of water mixed from these two elevations changes with reservoir elevation. When the reservoir is drawn down below the top of the old concrete dam all the water must move through the hole in this old dam.

A number of simulations tested different configurations looking at temperature releases and temperature and dissolved oxygen profiles in the reservoir before deciding that W2 could be setup to adequately represent both the upper and lower elevation mixing ratios and the associated routing of deep dissolved nutrients versus shallow particulate organic matter including algae.

Figures 1.3.4-1 and 1.3.4.1-2 show the data collected by the Bureau of Reclamation, and the W2 model configuration which attempts to accurately reproduce the overall hydrodynamics in two dimensions.

Figure 1.3.4.1-1 and Figure 1.3.4 -2 below show how the two old dams act as skimmers, meaning they cause a portion of the withdrawal from the reservoir to be skimmed from near the surface. The warm water (red in the temperature diagram- left below) is lower in density and does not mix easily with the higher density cooler water beneath. However, in years when the reservoir is drawn down with the 12-18 °C water just above the top of the old dam, much of the 12-18 °C is skimmed from beneath the thermocline.

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[6] Numerous personal communications to Jerry Miller over three decades from John Edinger, Ed Buchak, Tom Cole, Scott Wells, Robert George, Merlyn Bender, and others).

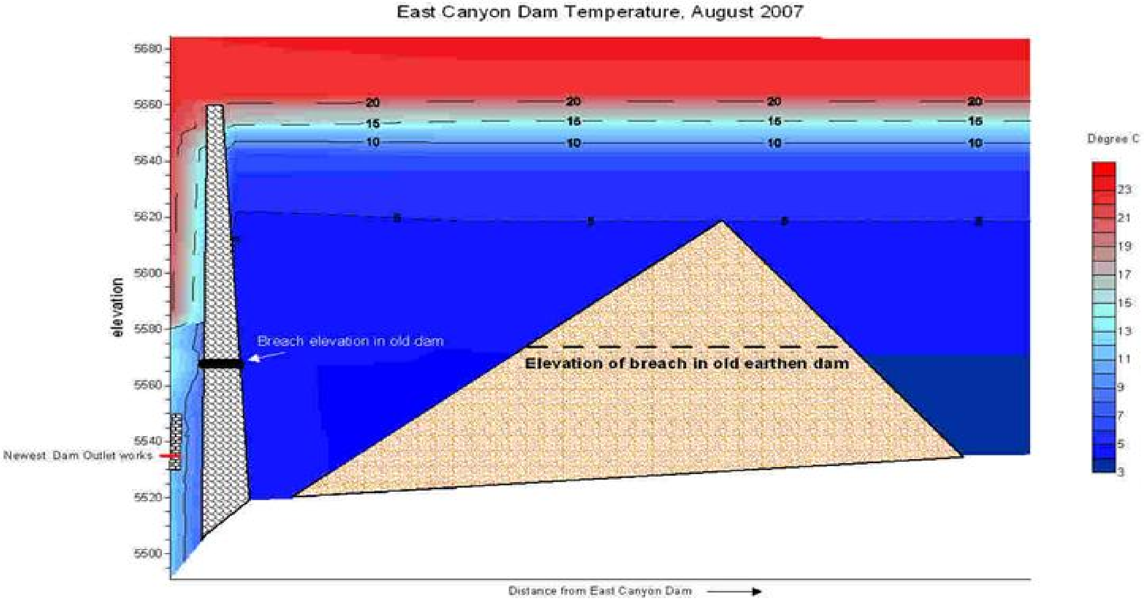

Figure 1.3.4-1 Surfer plots of data collected by Reclamation in August of 2007 from numerous vertical profiles taken in the vicinity of the three dams. Figure provided by Dr. Robert Radtke, 2008; U.S. Bureau of Reclamation, Upper Colorado Region, SLC, Utah.

The near total loss of the 12-18 °C water in the metalimnion in August is a major issue to be addressed in this study. One of the objectives of the phosphorus TMDL is to maintain the Utah DEQ water quality standards to protect a cold water fishery. The water quality standard is to maintain greater than 4 mg/L dissolved oxygen in water less than 20 °C. The low stress and optimal metabolism water for trout is between 12-18 °C. There is so little 12-18°C water left in the reservoir in August; it may be difficult to maintain the cold water fishery as an effect of reducing phosphorus concentrations to the reservoir. At this elevation only the most pristine water quality would maintain dissolved oxygen greater than 4.0 mg/L throughout the summer stagnation period in water less than 20°C. The increasingly warmer climate makes attainment of this cold water fishery water quality standard even more difficult in reservoir below 6,000-7000 feet in elevation.

Water upstream and deeper than the breach in the old earthen dam remains very cold and very stagnant throughout the summer. This allows this hypolimnetic stagnant zone to trap organic matter and phosphorus in a cycle that can build up for several years before it is flushed out due to the greatly increased dilution factor in a wet year coming into a low reservoir pool. **Figures 1.3.2.1-1, 1.3.4-2, and** 1.3.6.1-1 **help** visualize these issues, and should be reviewed several times when reading the later sections in this report.

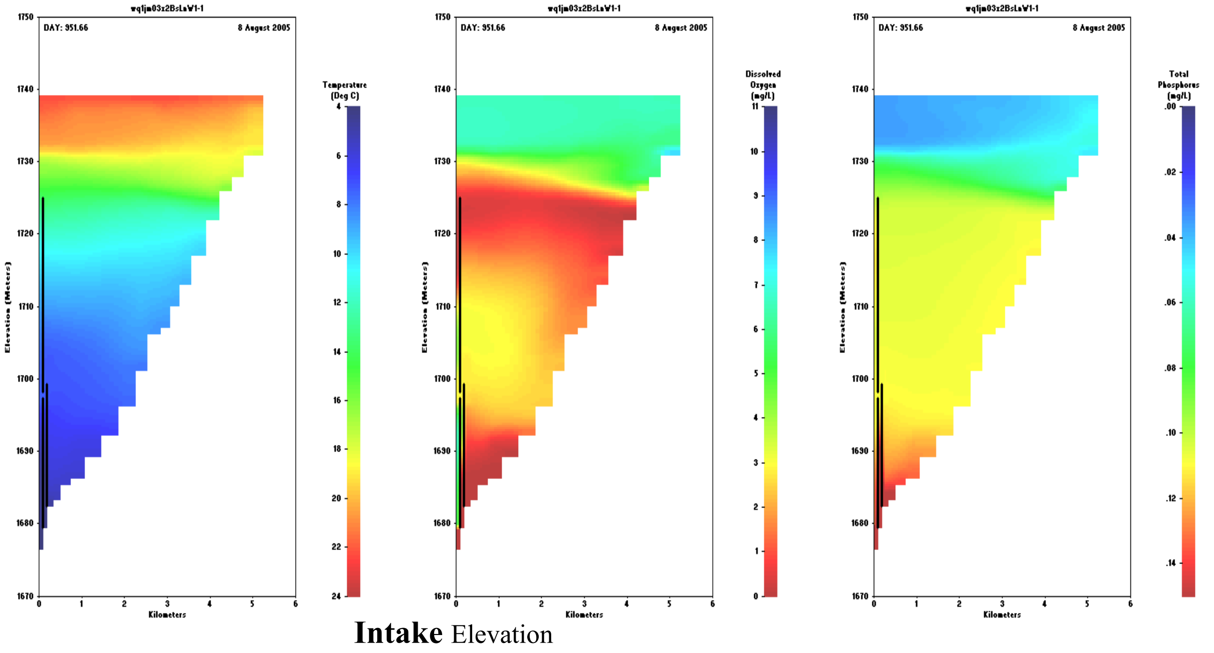

Figure 1.3.4-2 is an AGPM animation cross section snapshot of three frames depicting temperature, dissolved oxygen, and total phosphorus concentrations. It also illustrates the configuration of weirs and curtains in W2 used to simulate two intake elevations mixing to the single dam outlet at elevation 1687 (M). Phosphorus accumulates for several years in the stagnant hypolimnion zone until it spills through the hole in the old concrete dam (frame on right). The left wall is the dam.

The W2 analysis is designed to improve the reservoir water quality assessment; and to help evaluate the sediment phosphorus release issues. The DVD version of this report will also include avi 2-dimensional animations of portions of some of the W2-simulations[7]. These avi files can be viewed by most media players, but the Apple QuickTime media player allows utilizing the arrow keys to progress forward or back by step.

1.3.5 Model Inputs For East Canyon Reservoir

This section describes the basic model input requirements which are:

1) Hourly meteorological data- preferable from the reservoir site; in this case the meteorological records are from the Salt Lake City Airport, but with interpolations to better represent the reservoir conditions.

2) Hourly stream inflow temperatures are best to correctly simulate density driven placement of the inflow in the reservoir water column. Daily max/min stream inflow temperature records are available from the USGS stream gauge on East Canyon Creek above the Reservoir for portions of the study period. These records are used as a guide with approximately hourly temperature inflow data being generated from relationships to air temperature. (The excel spreadsheet transforming the meteorological data and

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[7] The many W2 scenario and calibration simulations include AGPM W1 output files, from which 2-dimensional animations can be generated as well as time line extractions, dam discharges for each constituent, etc. In order to utilize these W1 files the AGPM post processor must be purchased from **Loginetics (Hauser, G., 2007).**

computing the stream inflow is included in the DVD attached to the SWCA and Utah DEQ copies of the report).

3) Tributary nutrient inputs were provided by SWCA, 2008 Utah DEQ draft TMDL) and include the Utah DEQ total and dissolved phosphorus, ammonia, and nitrates data used in scenario and 2003-2007 baseline calibration simulations. The 1991-1998 nutrient input file was generated by JM Water Quality with minimal data, and a simple monthly seasonality consideration.

4) Dissolved oxygen in the inflow is a generic daily average temperature dependent saturation computation (the model shows little sensitivity to making the inflow D.O. zero or keeping it higher. This is due to D.O. quickly attaining saturation in the first shallow segments of the reservoir which has high reaeration potential.

1.3.6 Climatic Data Inputs

The meteorological data used in the East Canyon CE-QUAL-W2 model is based on Salt Lake City Airport data. The Salt Lake data covers the entire time period from 1991-2007, and it is probably only a fair representation of wind direction patterns that are so important to algae movement over the summer and fall in ECR. Rule based equations are used to interpolate from Salt Lake City to represent East Canyon Reservoir[8]. The rules are not always accurate, some fine tuning of individual periods may also be based on reservoir temperature profiles. The reservoir temperature profiles are also a limnological record of the weather. If the reservoir and W2 simulation attain a common stratified temperature profile within less than about a 10-15 day period, then no additional hand tuning of the met data is made. The spring date when East Canyon sets up a thermocline which prevents reaeration in the metalimnion can vary by as much as 4-5 weeks from year to year. The lack of site specific hourly wind speed and direction is an issue with regard to date specific sample calibration on this reservoir. The number one priority to improve date specific calibration is on-site wind speed, wind direction, and April-November reservoir water surface temperatures.

East Canyon Reservoir is shaded for much of the day in the late fall/ winter/ and early spring time period by the mountains to the South. The sun may actually be visible on most of the reservoir for only a few hours each day in the winter. Cloud cover in the winter is set to a minimum of 3 (equivalent to 30% cloud cover) to help account for this mountain shading affect. The shading by segment in the W2 control file allows a further adjustment to allow for orientation and terrain by segment.

Apparently inversion and city pollution result in Salt Lake Airport data cloud cover being recorded as a three, not as a zero on all but the clearest days. Cloud cover of three (3) in all but the winter time periods are set to zero for East Canyon Reservoir. If it really is cloudy in Salt Lake City, it is generally cloudier in the adjacent mountains and at East Canyon Reservoir. Therefore, cloud cover at SLC airport ranging from 4-7 (meaning 40-70%) is slightly increased at East Canyon Reservoir.

The daily wind patterns are a very important consideration at East Canyon Reservoir. East Canyon Reservoir is very sheltered from direct Westerly winds as compared to the SLC airport. The Great Salt Lake (GSL) also modifies temperature seasonally at the SLC airport. At East Canyon Reservoir's higher elevation and without the temperature moderation of the GSL, night time temperatures drop 10-14 °C lower, while day time temperatures are only a couple of degrees cooler than at the SLC airport. Wind is overall higher at the airport, but somewhat follows a similar daily pattern as observed at East Canyon

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[8] The rule based changes to interpolate the met data were completed by JM Water Quality with some previous input from Mr. Beau Urionia and Mr. Jerry Miller- both from previous work on Deer Creek and Jordanelle Reservoirs, Utah-which are nearby. The skies over the Salt Lake City Airport and East Canyon Reservoir are visible from Jerry Miller's home; professional judgments and years of work and recreational visits to the site were also used for daily wind pattern interpretation of data sets.

Reservoir. The wind directions are not altered from the Salt Lake City Airport data, but this is one of the greatest uncertainties with regard to date specific data calibration with the W2 simulations. The W2 model includes a wind sheltering correction for each segment. The model also considers the compass orientation of each segment with regards to adjustments of wind speed and direction. For further information please refer to the W2 Use Manual.

East Canyon Reservoir is commonly very calm in the early morning hours until between 11:00 a.m. to about noon. Then a fairly strong 10-16 mile per hour wind develops and often lasts until at least 5-6 p.m. The wind at East Canyon is set to zero for mornings associated with lower wind conditions at Salt Lake City, and then is set as a proportion up to a maximum value for the summer time daily patterns at SLC airport. Higher winds usually denote storm front events and are used proportionately, thus over riding the daily pattern at the reservoir. The W2 model provides an additional wind sheltering coefficient by segment to test various increases or reductions to wind speed.

The hourly interpolation of the Salt Lake City meteorological data is not always accurate or precisely timely. For example local summer thunderstorms are common especially in the mountains. The Salt Lake City Airport may not accurately represent these events at the ECR. Missing such events even in a two day period could compromise W2 simulation calibration of date and time specific data sets such as initiation of stratification in spring or turnover in the fall.

1.3.7 Model Coefficients And W2 Configuraton

There are many coefficients in the W2 model. Most of the coefficients are set at the default levels which have been established by the previous calibration of many other reservoirs (personal communication, Tom Cole, 2004). The model algorithms, equations, and coefficients can be viewed in the W2 User Manual (Cole, 2005). Specific coefficient settings of note in the East Canyon model are presented in section 1.4. Examples of these control and coefficient files for the baseline calibration are in Attachment A (DVD version only). The algorithm for the R&D code is also in attachment A, as are a few examples of pertinent algorithms pertaining to phosphorus and algal succession from the W2 User Manual. W2 model coefficients may not be more important than bathymetry, configuration of old dams, inflow stream temperatures, and accuracy of inflow constituents. This section includes discussion of parameters that are important to model calibration.

The Algal Succession R&D code includes additional coefficients which are not included in the W2 User Manual (Cole and Wells, 2005), but are described later with additional detail in Attachment A (DVD version only).

1.3.7.1 Temperature Coefficients & Configuration Of Old Dams

The more critical items to correctly set up this model are not so much the rate coefficients as the configuration of old dams, and intake structures as a set of weirs and a curtain, which is a proportioned compromise from actuality. Creating a physical scaled ratio model has been a common practice in hydraulic laboratories. In this study a set of trial and error configurations were simulated with theW2 model to test various methods to set up an acceptable proportioned compromise to model East Canyon Reservoir. Other alternatives including a three dimensional model, computing two intake elevations to correct hourly temperature data from the release, and smaller layer depths with additional trial and error modeling and calibration of profiles in the reservoir may formulate an improvement. This would take a lot more time and money, and specific monitoring designed for confirmation. Critical items to determine that this alternative is acceptable include in-reservoir temperature profiles, dissolved oxygen profiles, periodic exportation of organic matter when blue-green algal was stacked into the dam, long term spiral down of phosphorus concentrations due to nutrient reductions, and major changes in algal succession.

The CE-QUAL-W2 model configuration includes a weir and a curtain in segment 19 (downstream segments nearest dam) and another weir in segment 18 to reproduce the hydrodynamic skimming affects of the old dams. Segment 20 is the last segment located at the dam. Figures 1.3.2.1-1, 1.3.2.1-2, and 1.3.6.1-1 demonstrate this configuration. The weir in segment 18 is slightly higher than the space between the curtain and the weir in segment 19, thus reducing its affective opening between the curtain and the weir. Segments 20 (nearest to dam) and 19 are 86.5 and 94 meters long, thus the weir and curtain in W2 are 86.5 and 180.5 meters up reservoir from the dam. This W2 configuration of old dams is significantly further back from the dam than actual. The space or opening between the weir and the curtain is much bigger than the hole in the concrete dam in order to be proportionally functional. These combinations apparently provide the correct ratios to approximate the way water enters the intake structure as a mixture from two elevations. This configuration was derived by numerous tests of various configurations.

Shortening the segment distances and trying to more closely emulate the volumes between the two structures results in extremely long simulation times. A run was not completed due to the time it would have taken, and because model calibration and completion of this study was not practical. However, a few long runs with a calibration set up might be feasible for some future studies.

This configuration of old dams functions much like a dual elevation intake into a very large single wet well. The hole in the old concrete dam is configured as a one meter opening (layer 46) between the weir and the curtain. The opening across the entire layer 46 width is 27.1 meters wide. However the weir upstream is slightly higher and somewhat blocks the affective opening because it prevents water velocities from deeper than the weir height from being pulled to the hole from up reservoir.

The large masses of the near vertical walls of the canyon, the old concrete dam, and the operating dam are set in water only 3-7 °C for more than 10 months each year; apparently this has an overall chilling effect on the dam release. The rock wall or dam masses that defines the boundary of the large single wet well are very cold (3-7 °C) except in the top 12 meters of water from about June through October.

W2 cannot currently place a pipe through a weir between two segments in the same branch. If a pipe could be placed through the weir and the correct distances were utilized between the structures, the simulation times would have been too long to successfully complete this study. It would take at least one full year and a lot of research to determine that the results would be improved. The model code would have to be revised. Many test configurations were tried by JM Water Quality prior to initiation of this study, but after retirement from Reclamation, but his one produced far the best overall in-reservoir hydrodynamics.

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 (KBSTR[9]- in the control file) which also acts similar to a weir. The bottom withdrawal zone restriction is set at layer 56 which is just above the intake structure. This KBSTR setting at layer 56 essentially restricts water from beneath that elevation from entering the intake structure and creates a stagnant zone in the bottom between the two structures. This results in a temperature that is to warm during the hottest period in the fall dam release to the tailwater. However, it produces good results in all the critical reservoir calibration parameters like temperature and dissolved oxygen profiles within the reservoir. Dropping the KBST just one layer resulted in too much hypolimnion discharge, too low of temperatures in the dam discharge, to high of temperatures in the hypolimnion, and spoiled the in-reservoir temperature calibration.

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[9] ..”the bottom **[KBSTR]** and top layers **[KTSTR]** below and above which outflow cannot occur can be specified by the user to include the effects of upstream structures that restrict the selective withdrawal zone” (Cole and Wells, 2005).

Some additional future trails could try cutting the layer width in half, and setting the dam release KBSTR a half meter deeper. This may improve the mixing ratio from two elevations, and improve the release temperatures with less impact on in-reservoir calibration; but it will also increase the simulation time to complete a run. Since the other calibration parameters may not need additional adjustment, running limited simulations with much longer run times may be acceptable. If the chilling effect of the old concrete dam setting in very cold water most of the year actually produces the cooler water withdrawal seen below the dam, then these additional tests would not likely produce a better result with regards to downstream temperatures. Tailwater temperature below East Canyon Dam has no bearing on the needs and objectives of this study.

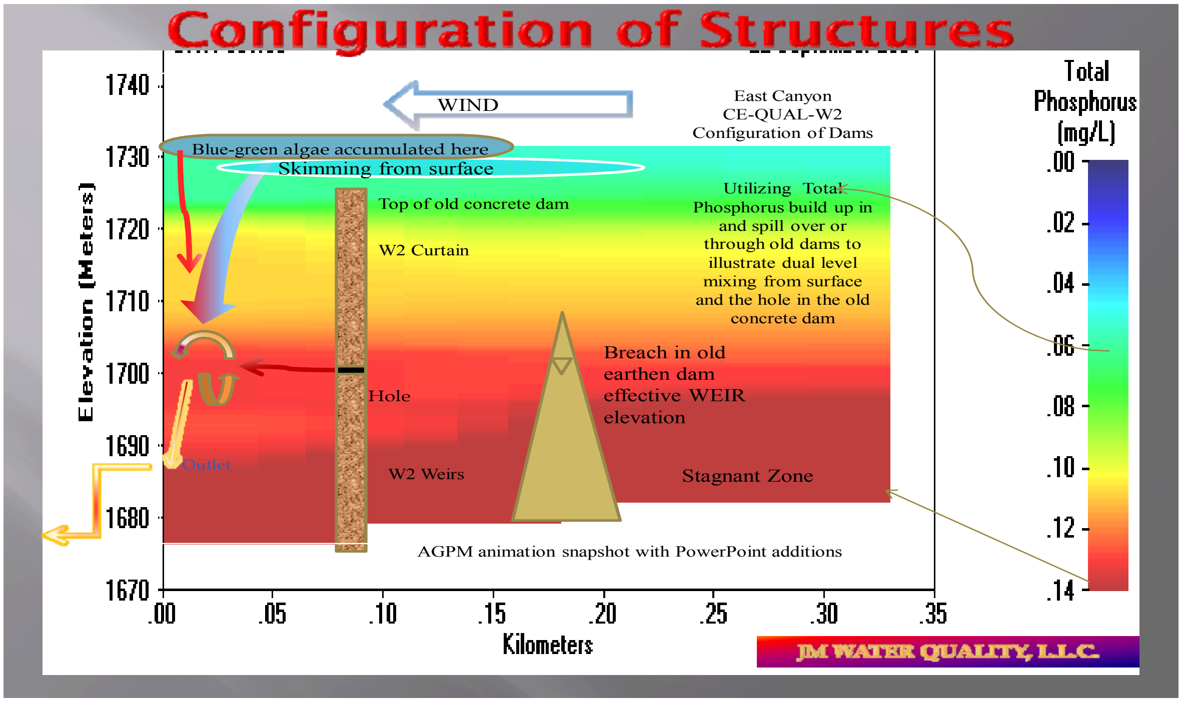

Figure 1.3.6.1-1 illustrates the configuration of W2 weirs and a curtain to simulate the surface skimming and mixing with the hypolimnion withdrawal through the hole in the inundated old concrete dam. The total phosphorus color scale is an AGPM animation W2 simulation post processor extraction in September of 2004. The phosphorus has built to high concentrations above the top of the weir and is spilling through the hole in the old concrete dam. This cycle of phosphorus retention in the stagnant zone and eventual routing in a wetter year is an important new finding of this study.

The Coefficient of Bottom Heat Exchange (CBHE) is also set colder than the defaults to help keep the water in the model below the thermocline cooler (see CBHE in the user's manual). This has a minimal effect, but helps maintain the sharp thermocline break in the summer, and maintain cooler water in the hypolimnion. The apparent chilling effect of the old concrete dam in part justifies this setting.

Figure 1.3.2.1-2 (Robert Radtke, 2008- U.S. Bureau of Reclamation) indicates that 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. Figure 1.3.2.1-2 is based on numerous profiles collected by the USBR in August of 2007.

Reducing the Wind sheltering Coefficients (WSC) to 0.65 from 0.85 (meaning utilizing only 65% of the wind speed) produces excellent in reservoir temperature profiles throughout the summer and fall. Leaving the wind sheltering higher (0.85) increases the temperature profile calibration error, but has minimal impact on phosphorus or dissolved oxygen. The WSC set a 0.85 does gives slightly higher blue-green algal blooms in the fall due to more rapid turnover. Therefore the blue-green algal succession results are utilizing the 0.85 WSC because the author believes the drought data sets of 2003-2007 do not adequately represent hydrology and climatic events that could produce fall blue-green algal blooms adequately.

1.3.7.2 Inflow Temperature Of East Canyon Creek

Figure 1.3.7.2-1 is an illustration of the daily East Canyon Creek inflow temperature pattern over one year. Most mountain streams have significant ground water inflow at around 10-11°C in the vicinity of East Canyon and Park City, Utah. With adequate streamside and mountain terrain shading many streams only attain a maximum daily temperature around 22°C above about 6,500 feet in Utah. However, in the open sun areas of denuded streams with very small flows the temperatures are higher (24°C near Park City even though the elevation is higher). East Canyon Creek has a significant inflow of ground water which helps reduce summer water temperatures and also to dilute nutrients between Park City and ECR (USU, 2000 Utah DEQ- TMDL).

The arching line across the year in Figure 1.3.7.2-1 (stream flow pattern from the annual air and water temperature relationship) is a polynomial equation representing approximately the daily average temperature for the date. The night time air temperature at higher elevations can cool by over 10-12 °C. If a significant portion of the stream flow is actually ground water entering at 10-11 °C, then the night time water temperature can cool by 8-10 °C even in the heat of summer. In May and September the air temperature can fall from around 27°C (82°F) to freezing with heavy snow over a 12-24 hour period. The stream temperatures will also vary accordingly as can be seen by some of the cooling holes in the spring and fall stream inflow temperatures in Figure 1.3.7.2-1

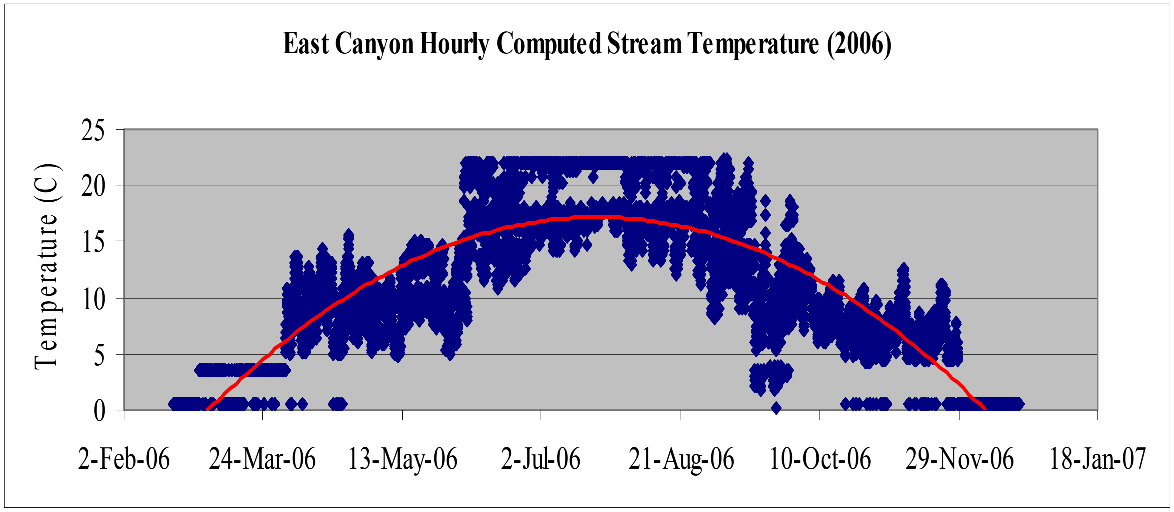

Figure 1.3.7.2-1 the daily East Canyon Creek inflow water temperature is computed with seasonal rule set relationships to air temperature, and also considers flow in May and June. Temperature data is available for some years, and was used to check this cycle (EXCEL file supplied to Utah DEQ in DVD version).

Hydrodynamically the annual stream water temperature Figure (1.3.7.2-1) is also significant. The trend line depicted by the polynomial equation is roughly at the seasonal weekly to daily average temperature. Since cold water is heavier (greater density) than warmer water, it will sink to a similar depth in the reservoir. The streams warm faster in the spring and cool faster in the fall than the reservoir. In the spring the high inflows need only 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, and actually helps set up a thermocline. A thermocline is a denser layer of water which forms a mixing barrier with the colder water beneath (see Figures 1.3.4.1-1 & 2). Less than hurricane winds do not mix through a strong thermocline in deep water bodies without first cooling it as occurs during fall turnover. The spring summer inflow is referred to as an “overflow density current”, the early fall inflow forms an “interflow density current”, and the late fall inflow can form a sharp bottom hugging “underflow density current” (NALMS, 1984, Miller).

Inputting a daily average stream temperature would compromise the hydrodynamics of this model, particularly with regards to evaluating the ability to maintain a suitable zone of habitat to carry a cold water fishery through summer stagnation. This is also an important consideration in physical availability of phosphorus in the reservoir water column. Although not specifically a calibration coefficient, establishing near correct hourly temperatures in the major tributary stream inflow is one of the more critical calibration parameters in a mountain setting like East Canyon Reservoir.

If each data point in the annual stream inflow temperature plot (Figure 1.3.7.2-1) represented a phosphorus mass unit, then most of the data points below the polynomial trend line would end up deep enough in the reservoir so as to be physically unavailable to viable growing phytoplankton. The only time a portion of this phosphorus would become physically bioavailable to the euphotic zone (zone with sufficient light to support photosynthesis) is at complete mixing. Since the reservoir is completely mixed, even then only the phosphorus portions in the shallow water would be physically available. Remember nearly half the reservoir volume resides in only about the top 15 meters of the reservoir.

The physical availability of phosphorus in a deep mountain reservoir is a very important parameter in trophic characterization; density placement of the inflow by temperature, and seasonality of algal blooms are also very dependent on physical as well as biological availability of phosphorus.

1.3.7.3 Sediment Oxygen Demand

The sediment oxygen demand temperature decay rate coefficients are set at the W2 defaults shown in the manual. They are 0.10 at 4 °C and 0.99 at 25 °C in both the first order and in the zero order compartments. Each acronym below can be input into the adobe reader search window and quickly looked up in the W2 User Manual. The example coefficients below turn on first and second order oxygen demand compartments (SEDC) set the initial condition organic matter mass in the first order compartment (SEDCI), etc. All the coefficient files are included in the baseline model run folders and the baseline example control file is printed in attachment A (DVD version only). The user’s manual provides detailed descriptions of these coefficients. Again: “***A word of caution to the first time user*** - model application is a complicated and time-consuming task” (Cole and Wells, 2005- W2 User’s Manual).

```
SEDIMENT    SEDC  SEDPRC   SEDCI     SEDK    FSOD    FSED
WB 1          ON      ON  1.0000 0.090000 0.0600  0.6000

SOD RATE   SODT1   SODT2   SODK1   SODK2
WB 1     4.00000 25.0000 0.10000 0.99000
```

1.3.7.3.1 First Order Oxygen Demand

Two methods are utilized in W2 to compute dissolved oxygen depletion. This is also the first step to computing sediment phosphorus relationships. The first order alternative has a set amount of organic matter as an initial condition in the sediment. The model then accounts for all organic matter mass going into and out of the sediment. The first order dissolved oxygen computations compute mass balances for organic matter in the reservoir water and accumulated to the sediments. However, the first order oxygen demand component does not turn on an anoxic sediment phosphorus release associated with the anaerobic chemical reduction of iron or manganese, and their subsequent release of inorganic dissolved phosphorus. The first order computation includes temperature rate coefficients and a percentage of the organic matter available from the sediment. W2 does not provide a full sediment bio/geochemical equilibrium diagenesis model for metals or phosphorus. However, phosphorus is released as a stoichiometric ratio of first order organic matter decay.

In order to have a seed for algal succession to start, a small inflow concentration of each algae type being modeled is included in the inflow. This essentially adds labile particulate organic matter content to the inflow. The combined algal groups provide a constant 0.02 mg/L of particulate organic matter to the inflow. Eventually this is converted to labile organic matter and biological oxygen demand in the reservoir.

1.3.7.3.2 Zero Order Oxygen Demand

The second alternative is a zero order dissolved oxygen compartment. It generates oxygen demand for each segment from a fixed organic matter (mass) compartment in which the concentration of organic matter is preset. Coefficients include a percent of the Sediment Oxygen Demand organic matter that can be utilized, and a temperature dependent rate coefficient. It is a zero order computation because it is purely temperature rate and coefficient of availability driven; no mass balance computations of organic matter are included. The zero order dissolved oxygen can also be set to start anaerobic release of phosphorus from the sediment. A minimum oxygen limit coefficient is set to initiate this process. A coefficient is also available to determine the quantity of inorganic phosphorus to be released (Grams/M^2). Only the zero order compartments can simulate the anaerobic release of inorganic phosphorus from the sediment; this process cannot be driven from the first order oxygen demand compartment.

If the decay of organic matter does not produce all the phosphorus needed in the profiles or the dam releases, then the phosphorus budget deficit can be made up from the anaerobic release of inorganic phosphorus as a rate per square meter of sediment surface area.

1.3.7.3.3 Combined First Order And Zero Order Dissolved Oxygen Demand

An additional option is to combine the first and zero order alternatives and utilize them both together. There has been quite a bit of success utilizing this method. However, if most of the oxygen demand is driven by first order oxygen computations as in this ECR application; then only a small amount of zero order oxygen demand can be allowed. Since 1st order oxygen depletion accounting for all organic matter produced in the reservoir seems to correctly approximate D.O. and phosphorus; only a small zero order component computation can be allowed in this application. The only reason to turn on zero order oxygen demand is that is the only way to turn on simulation of inorganic sediment anoxic phosphorus release. The actual yield of phosphorus from the zero order compartments anaerobic release coefficient (PO4P) may need to be turned up to attain an appropriate phosphorus concentration if the budget falls short. However, first order organic matter decay accounts for the majority of sediment phosphorus release needed in ECR. This is not always the case. Without vertical daily migration of phytoplankton other applications may simply not be able to produce enough algal biomass due to decreased access to nutrients and sunlight. This may be leading to over use of the zero order compartments in W2, if not in modeling in general. The zero order compartments (by segment) are also commonly used to capture the terrestrial allochthonous input with a slower decay rate.

The zero order does include iron precipitation and adsorption of phosphorus during settling. However, the phosphorus re-adsorption is turned off in the model calibration and scenario runs. In tests with the iron reaeration precipitation and re-adsorption of phosphorus turned on, it is easy to take out as much or more phosphorus than was released. This in fact may occur in East Canyon Reservoir, especially if local red soil erosion runoff events dump a large supply of iron oxides suspended sediment into the reservoir.

1.3.7.4 Temperature Controlled Organic Matter Decay Rates

The organic matter temperature controlled decay rates are set at the model defaults. Organic matter decay is slow in cold water, but it has a long time to decay and contributes a great deal to hypolimnion anoxia even during the winter ice period in the W2 simulations. There is actually little difference in temperature in the deeper parts of the reservoir in summer versus winter. For a brief period lasting only a several weeks the hypolimnion is actually warmed by fall turnover, and may reach a temperature of 8-12°C. This brief warming is the fastest rate of decay in a year in the deepest portions of the reservoir- usually in later October.

Organic matter decay rates are highly variable by reservoir elevation as determined by the temperature rate coefficients. The model accumulates autochthonous organic matter in the sediment compartments by segment. Organic matter tends to accumulate in the deep and stagnant zone of the hypolimnion due to the steep sides of this reservoir. This is also why the W2 simulations get better the longer the time period simulated; because each segment has been loaded with organic matter by the W2 simulation of limnological/hydrodynamic processes, not by a single initial condition concentration. The allochthonous organic matter is set at a constant value by segment in the zero order compartments. Allochthonous organic matter decays at a much slower rate than phytoplankton.

The W2 simulations show that phytoplankton decays very rapidly (10-20 days) in 18-24 °C water, but may take up to 2-3 years or even be permanently buried in the deep hypolimnion with temperatures only exceeding 3-12°C for several weeks each year in the late fall turnover. Woody organic matter (trees) in Lake Powell that were exposed during the 150 foot drawdown during the 1999-2008 droughts have not substantially decomposed in the past forty years[10].

1.3.8 Vertical Phytoplankton Mobility (R & D Code)

The R&D code algorithm (Prakash, 2008) is included in attachment A (DVD version), as are copies of all the files of coefficients that are separate from the control files. Daily vertical algae movement is one of the most important components of the algal succession research code being tested in this East Canyon study. Water quality models may have difficulty reproducing the magnitude of some algal blooms. Vertical migration has been an ongoing topic of discussion among W2 researchers for several years. Many years of personal limnological research and field studies has often revealed significant daily vertical migration, particularly of blue-green algae and dinoflagellates, but is also important for diatoms and other species. There is a significant emerging body of literature quantifying this movement (Reynolds, 2006). C.S. Reynolds' recent publication- "Ecology of Phytoplankton", 2006- provides an excellent summary.

The new code facilitates a daily cycle of rapid sinking at night and the buoyant upward migration into the morning sunshine. This provides phytoplankton exposure to more nutrients and potentially the production of larger biomasses in deep reservoirs. The buoyancy also gets the plankton back up into the euphotic

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[10] Personal communication- Jerry Miller, 2008.

zone for a daily photosynthesis and growth cycle. The daily cycle of rapid sinking and buoyancy does not overcome wind driven velocity hydrodynamics. The wind influence on longitudinal, lateral, and vertical migration varies with season, time of day, and storm events. During summer thermal stratification the daily vertical migration does not sink below the thermocline (view 6 hour avi animation file in DVD set only).

The W2 Users Manual contains a full description of the algal succession included in version 3.2. The coefficients which control algal succession (including blue-greens) in the W2 code and also in the additional R&D code include:

1) W2 code- Blue-green algae are given a zero nitrogen half saturation requirement allowing them to continue to grow if the modeled water reached nitrogen limitation, but not phosphorus limitation;

2) W2 code-Temperature coefficients for optimal growth present advantages and disadvantages to each algal group seasonally;

3) W2 includes growth rates, half saturation for light, settling velocities, nutrient stoichiometry, mortality rates, respiration rates, excretion rates, and nutrient stoichiometric decay ratios, etc. (See the W2 User Manual and Attachment A- DVD version only);

4) The R&D code includes a daily vertical migration setting for each algal group, which provides a daily time period for rapid sinking and for buoyancy;

5) R&D code- includes a date set time varying change in mortality rate to make up for the lack of zooplankton grazing, and other factors influencing mortality;

6) R&D code includes luxuriant uptake of phosphorus (coefficient) when available during the deep descent part of vertical migration;

7) R&D code- example- blue-green algae can be given a greater vertical migration window;

8) R&D code- example- Blue-green algae are given a greater ability to luxuriantly uptake phosphorus during the night time window in deeper water; and

9) R&D code- algae groups have date sets (coefficient) for a coefficient portion of the population to go into and out of settlement to a dormant state in the bottom layer.

10) R&D code prevents “touch and gone” phytoplankton dynamics during vertical migration, but not during settlement cycles- the version 3.2 code puts all phytoplankton that touches the bottom into the organic matter compartment; but the R&D code allows it to touch the bottom luxuriantly uptake phosphorus, and return to the surface up the date set to settle the algal group to the dormant state.

When the R&D code dormant state settlement begins (item 9 above) the W2 control file settling rate restarts; the daily vertical migration is turned off, and dormant algae cells are stored as if they resided in the bottom layer/segment they settle too. Once the algae dormant state compartment is populated, the cells have a mortality rate in dormancy, and when they die they return to the sediment organic matter compartment in the segment they settle in. When the phytoplankton are recalled (date set coefficient- see attachment A), they emerge as a percentage (rate coefficient) of the remaining viable algal mass on a daily basis until they are gone. This allows a quick population reservoir wide (at least in the segment where they settled) rather than each algal group having to start from the seed in an inflow area (W2-code). In some reservoirs starting from a seed in the inflow file is quit sufficient. Since a seed is also provided in the East Canyon Creek inflow constituents file, an algal group can also take off from this source whenever conditions for optimal growth provide for it.

Upon descent and while in dormancy in the settlement compartment phytoplankton adsorbs extra phosphorus (amount and rate coefficient set points- see attachment A DVD version only). Upon recall from dormancy the phytoplankton may have sufficient phosphorus stored to grow and complete 1-2 reproduction cycles. Thus a population can develop reservoir wide very quickly if the conditions for their growth is optimal. A very warm period after release from dormancy in the spring (example) could start a rapid population cycle, but return to very cold conditions could just as effectively shut it down. This in fact happens and is one of many reasons that algal succession varies from one year to the next.

1.4 Modeled Conditions: Variability, Uncertainty, And Calibration

Section 1.4 combines several topics with calibration on East Canyon Reservoir because this CE-QUAL-W2 study should be just the beginning of the utilization of this model to assess this reservoir over many years to come. Sampling in the future should be based on new information provided by this study, and should also be designed to confirm or prove that different approaches should be taken to improve calibration, confirmation, and robustness of the model. Millions of dollars have already been spent towards improvement of water quality in ECR. Park City and Reclamation are actively studying pumping ECR water back to Synderville Basin to meet M&I water needs in the area. The very nature of this growth needs high quality water, and at the same time increases the challenge of maintaining a healthy aquatic ecology in ECR. Precise modeling is an important part of a long term iterative process known as “adaptive management”, in which it is understood that all the science, and the answers are not currently available. The best current science still needs to improve in the future in order to fully understand how to protect water quality in East Canyon Reservoir. This Section (1.4.) is written both to provide an understanding of the current state of calibration and confirmation of this W2 model application at this stage of development, and to be a guide for future work.

The inter-relationships between temperature, wind, algae, nutrient cycles, hydrology, limnology, and season and timing of phosphorus loading in this reservoir are very intricate. Therefore, overlap in discussion of these inter-relationships within the specific sections may be helpful in understanding the whole referred to as an ecological system.

1.4.1 Variability- Simulation Periods

The model utilizes two simulation periods for model calibration and confirmation; 1991-1998, and 2003-2007. It would be incorrect to classify these runs as calibration and then verification as these data sets were not separated for that purpose. Continuous simulations from 1991-2007 would simply have taken too much computer run time for successful initial calibration; and there was insufficient data and time to generate phosphorus reduction scenarios from 1991-2002.

The 1991-1998 time period had both very dry (1991-1992) and very wet periods (1993-1998), and very high phosphorus loading. Addition of biological treatment at the ECWRF in about 1995 reduced phosphorus discharges from 6-8 mg/L to about 4 mg/L. However, erosion from construction activities around Park City, including on steep slopes of Phosphoria Formation derived soils, probably more than made up for the point source phosphorus reductions (Olsen, Biowest, 2000). Never-the-less, the wet and dry cycles and meteorological variance still showed that hydrology produced important differences in total chlorophyll productivity and the length of summer stagnation. This early time period (1991-1998) also provided valuable hydrodynamic calibration information.

The 2003-2007 was set up by one of the longest continuous droughts 1999-2007 on record, with 2002 being an exceptionally hot and dry year. The 2003-2004 hydrologies were dry; 2005-2006 are nearer average/wet, with 2007 a moderately dry year. The advanced wastewater treatment went into full operation over the summer of 2004, and by July of 2005 the East Canyon Reservoir was experiencing epilimnion phosphorus limitation which continued through fall turn over in mid September. Major shifts in algal succession occurred from 2004-2007, with a significant reduction in summer chlorophyll and blue-green algae. However, phosphorus concentrations remain high in the metalimnion and hypolimnion, as well as during spring turnover.

Each of these data sets provided considerable variance in:

- Seasonal meteorology, hydrology, and nutrient loading;
- Long term tracking of phosphorus spiraling down in the reservoir following reductions; and
- Evaluation of the effects of the Phosphorus TMDL on chlorophyll, dissolved oxygen, and blue-green algae reductions.

The coming 2008 runoff appears to be the wettest year since the mid 1990's. Unfortunately this study is not commissioned to capture this important upcoming season. It may take several more wet years to attain a complete dynamic equilibrium with phosphorus from the recent phosphorus reductions.

1.4.2 Model Calibration And Confirmation

Dr. Steve Chapra summarized model calibration, confirmation, and robustness in his book "Surface Water Quality Modeling", (Chapra, 1997; page 324). A few essential points are included here:

> "Once you have developed the calibrated model, all you really know is that the model fits a single data set. But, before the model can be used with confidence to make management predictions, it must be confirmed. … It should be noted that in the past, water-quality modelers referred to this phase as 'verification'. This jargon implied that once the model successfully simulated an independent data set, it represented an establishment of 'truth'; that is it represented an accurate representation of physical reality. In fact this can never really be proved absolutely. At best all that can be concluded is that our testing has not proved the model wrong (Oreskes et al. 1994)."
>
> "This then brings us to the notion of model robustness. If we can never totally verify a model, we are left with the quality or rigor of its confirmation. As put by Oreskes et al. (1994), 'the greater the number and diversity of confirming observations, the more probable it is that the conceptualization embodied in the model is not flawed'. Such a model is said to be ***robust.*** Therefore, the actual goal of the confirmation process should be to establish the model's robustness." (Chapra, 1997).

The following discussion is extracted and/or summarized from the CE-QUAL-W2 User Manual (Cole and Wells, 2005) to further describe the philosophy of model calibration or confirmation just introduced from Dr. Steven Chapra's Textbook "Surface Water Quality Modeling", 1997). Mr. Tom Cole and/or Dr. Scott Wells clarified calibration with this discussion in the W2 User Manual:

> "The next step is to begin calibration runs. Much of the literature refers to this step as calibration and verification in which model coefficients are adjusted to match an observed data set (calibration) and then the model is run on another "independent" data set without adjusting model coefficients to see if the model reproduces observed data in the prototype (verification in most circles, but variously called confirmation, validation, substantiation, etc. as numerous water quality modelers object to the word verification). This separation is artificial and wrong". (Cole and Wells, 2005 Version 3.2, W2 User Manual).

An example data set covering several years follows with a discussion of what would be the correct manner in which to break up this data set for calibration, and then an independent verification. The conclusion is:

> …"Cases could be made for other combinations of calibration/verification years and different modelers would probably choose different calibration/verification years, so there doesn't

> appear to be one “correct” answer. In actuality, there is a correct answer. Model all the years and model them continuously. Modeling them continuously would eliminate separate calibration and verification years or data sets so the model could not be considered “calibrated and verified”. However, if the model reproduces the wide variation in prototype behavior between all the years, a lot more confidence can be placed in the model’s ability to reproduce prototype behavior for the “right” reasons than if the model were calibrated for one year and verified for another year.” (Cole and Wells, 2005 Version 3.2, W2 User Manual).

Although the East Canyon data set is being simulated from 1991-1998, and again from 2003-2007; this was not broken up specifically for “calibration” and then for “verification”. Modeling continuously for longer time periods, and testing the overall robustness of the model transitioning through: 1) wet and dry cycles; 2) approximately a 60% phosphorus inflow reduction; 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- is far a better test of model “robustness”. If the model reproduces this wide variation in prototype behavior between all the years, a lot more confidence can be placed in the W2 simulations.

It would have been preferable to have simulated the entire time period from 1991-2007. The 1999 to 2003 time period represents one of the driest periods on record. There was insufficient time to generate all the scenario phosphorus loading for the 1991-2002 time period. A single model simulation with full water quality parameters would have taken 18-24 hours to run. However, since it was modeled in two parts, some clarification is needed. East Canyon was not modeled in two parts for “calibration and verification”. Even modeled in two parts, each part still tested a wide variety of conditions over a significant time period. Few model applications attempt to simulate time periods of either data sets length, or have this great of external phosphorus reductions to test. It is far more common to calibrate 1-2 years, and then verify with 1-2 additional years. Now that extensive work has been accomplished on calibration, it may still be beneficial to incorporate the 1999-2002 data sets and make a single run from 1991-2008. The robustness of the W2 simulation to track trends through the years is considered more important than date specific calibration.

The simulations of the time periods from 1991-1998 and from 2003-2007 do utilize the same methodologies to transform meteorological data from Salt Lake City to East Canyon Reservoir, compute stream temperature inputs hourly, and utilize common coefficients. The two time periods start with the same initial conditions for in reservoir phosphorus concentrations on January 1st, at 0.09 mg/L. The initial condition phosphorus concentration may not be accurate in either case. The W2 simulations approximate the phosphorus data in the water column within about the first 3-6 months, but still improve over about a 12-18 month period. If the initial condition had been in serious error it may have taken longer to approached a dynamic equilibrium. Overall phosphorus reduction within East Canyon Reservoir appears to have been minimal from 1999-2002. Several initial condition phosphorus concentrations were tested.

The longer the model runs the more accurate many of the date specific calibration matches become. This is because the first order sediment oxygen demand storage of organic matter become more correct-changing by segment, than the single value initial condition.

The organic loading in each segment’s First Order Sediment Oxygen Demand Compartment seem to produce better dissolved oxygen results after about two years of simulation; this is not corrected by simply setting a reservoir wide higher initial condition concentration.

Phosphorus equilibrium in the water column due to the spiral down from higher loading in previous years may not occur without some additional flushing from a couple of wet years. Attaining phosphorus equilibrium in the sediment due to loading reductions may also take several more years.

There is considerably greater hydrologic cycle variation in the 1991-1998 data sets; this variation also produces variance in chlorophyll and algal succession and other water quality parameters prior to major phosphorus reduction from the watershed. On a seasonal or annual basis it is difficult to separate the hydrologic variance, the loading reductions, and the internal retention and flushing cycle that occurs in the reservoir. However, from 2003-2007 the decline in phosphorus in the reservoir water column and in the dam release show the correct spiral down due to external loading phosphorus reductions. Never-the-less, a couple more wet years with greater flushing could still alter this analysis, because a long term dynamic equilibrium may not have been reached. A lot of time and simulations where not spent on the 1991-1998 time period. The calibration focused on 2003-2007, and then tested this calibration for reasonableness in 1991-1998. The main concern was algal succession and proportional correctness in phosphorus as a release from the dam. There is so much algal biomass in the 1990s, and its daily placement by wind direction so critical to date specific calibration, that large errors are produced by errors in wind speed and direction.

The Utah DEQ has necessity to update the East Canyon Reservoir TMDL on a very short time frame. Normally such a study with CE-QUAL-W2 should take about a year to complete, but better yet would be two years with data collected specifically to better meet the needs of confirmation of the dynamic model during at least a portion of that time period. Some very specific data needs can be identified through careful study of the W2 modeling results. Significant flushing (phosphorus concentration) should occur in 2008, but will also be accompanied by significant loading due to high inflows; this could add a valuable piece of information to this study. Future limnological studies of East Canyon should be driven by specific issues of higher sensitivity as defined in the W2 study.

There is a tremendous amount to be learned by looking at the differences in the date specific data and the W2 model simulation calibration in this reservoir during the calibration process. These “differences from data and model simulation” are very important in understanding the reservoir sensitivities; in evaluating the current reservoir monitoring program; and in understanding the overall relationships between the watershed and internal phosphorus recycling- fate, transport, bioavailability, and eventual routing of phosphorus through the reservoir. An initial calibration of a dynamic model in any reservoir water quality assessment should emphasize understanding specific reservoir sensitivities.

1.4.2.1 Calibration Parameters And Rate Coefficients

All the rate coefficients are printed out in attachment A. Some of the critical rate coefficients to this model have already been reviewed.

This W2 configuration can approximate the correct answers because two or more errors average out, but for the wrong reasons. The model is a simplification of a very complex system. Figure 1.3.4-1 (Radtke, 2008) provides important clues that the intake structure does skim water from the surface and combine it with a flow through the hole in the old dam. Observation of the dam exporting large quantities of decomposing blue-green algae, and the W2 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 and a long time period. However, it is difficult at this point and with this data set to assure that the model is mixing exactly the correct ratios under all water surface elevations, thermal stratification, and wind seiching conditions. So, there are still some concerns, and extending the model to add future years is an important consideration. However, for this to really be useful data needs to be collected designed specifically to provide better model confirmation, or to prove individual pieces of the model wrong. This is always the appropriate use of aW2 model following initial calibration and confirmation. Running long time periods to analyze data for accumulative errors in the phosphorus budget is an important additional test of the overall robustness of this model.

Pieces of the model can be "calibrated" better than is accomplished here on a date specific basis. However, bringing all the pieces together; dissolved oxygen, temperature, phosphorus, and algal succession simultaneously is no small task. This constitutes finding that the model calibration has the robustness to stand the test of many changes in hydrology, reservoir operational levels, and changing phosphorus loading. This model can be improved, but only with careful study and with careful data collection designed to provide specific information. However, this is also no small task, and it is not without cost. The code in the model will also continue to be improved and expanded, but only in a very methodical way. **This W2 application correctly tracks reductions in phosphorus and changes in algal succession over two decades. It shows us that significant measurement end-point goals have been attained.** It also shows us that attaining future additional goals may come at a slower pace and perhaps at a greater price. The model has sufficient robustness to proceed to the next increment of phosphorus reduction. However, the reservoir does have some memory of its former more eutrophic state. The sediments have stored decades of nutrients and organic matter under this higher trophic state. It may take another thirty years as it has in Deer Creek Reservoir to realize significant improvement in dissolved oxygen during summer stagnation. Correctly modeling all the causes of that slow transition may be years away. However, the model now has sufficient robustness to proceed forward, and to know that enough has already been accomplished to not go backward.

The test of hydrodynamic calibration generally comes from comparison of temperature and dissolved oxygen profiles in the reservoir. The parameters that most affect the hydrodynamic calibration are 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, correct hourly wind speed and wind direction, and finally correct evaporation computation. Individual segment wind sheltering, solar radiation shading and time varying wind function evaporation coefficients (R&D) all help establish an acceptable calibration. East Canyon Reservoir is a tough hydrodynamic calibration because of uncertainty in each critical factor just described. The physical configuration of the two old dams creating two flow fields to the intake structure in a manner that approximates the correct ratios under all reservoir elevations and wind conditions is also difficult. Wind speed and direction determine where algae settle during major transition periods. This establishes the quantity of organic matter in each segment layer which creates varying oxygen demand. Date specific calibrations can only be approximated without on-site wind speed and direction.

The modeling approach is to approximate date specific sample data[11] and to reliably track the long term seasonal, annual, and decadal changes or trends as a test of "robustness" over a wide range of conditions. The primary goals are to:

- Capture changes in phosphorus concentrations over long periods of time associated with reductions from the watershed, but measured as outflows from the dam, or from samples in the water column;
- Approximate transitions in constituent vertical profiles and dam discharge concentrations;
- Reproduce temperature and dissolved oxygen data sufficiently to be confident the limnological processes can be correctly evaluated for the measurement end-point goals, and;
- Gain confidence that the W2 simulations capture the hydrodynamic and limnological processes controlling chlorophyll, algal succession, and phosphorus cycles- then utilize the same years previously simulated to conduct sensitivity studies of new phosphorus TMDL reduction scenarios to identify potential changes to the system to meet the TMDL measurement end-point goals.

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[11] Specifically this means that the model should be within a 2-15 day time period of hitting the temperature and dissolved oxygen profile from the sample.

1.4.2.2 Hydrodynamics As Tested By Temperature And Dissolved Oxygen

East Canyon Reservoir is still holding a few mysteries that will only be resolved by the utilizing the knowledge gained from this W2 study to guide future monitoring. The correct solution is not to run another 20 tests with Wind Sheltering Coefficients(WSC) set between 0.65-0.85 on a time varying basis to find the best compromise; rather the correct solution is to start collecting wind speed and direction data at ECR. This data could help determine a better method to refine the meteorological data at ECR versus the Salt Lake City Airport.

The reservoir temperature shows an extremely sharp thermocline during August with a very thin metalimnion. The model tends to leave 1-3 meters to much 12-18 °C water in the metalimnion at times. It is not unusual to find a 10 °C temperature drop in just 2-3 meters from about 8-11 meters deep in August in the reservoir. The W2 simulation generally approximates this sharp thermocline by mid to late July. The sharpness of the thermocline in this reservoir is greater than occurs in most reservoirs. The temperature and dissolved oxygen profiles match fairly well in July and August with the W2 simulation sometimes having a little more metalimnion oxygen demand in June and early July than the data in the top 12 meters (Figures 1.4.3.2-1, 2, &3 illustrate temperature and dissolved oxygen from the data and W2 simulations). If the W2 simulation stratifies either early or late, it impacts how soon anoxia sets up, particularly in the metalimnion. The W2 simulations are particularly sensitive to spillway spills, wind, night time temperatures, and inflow with regards to thermocline set-up. There are significant uncertainties in each of these areas with regards to model input data.

Quantities of spillway releases are not recorded, and had to be estimated. This can have an effect on stratification in June. It may also affect exportation of spring algal biomass. However, due to the overall length of this W2 simulation period, the model demonstrates sufficient robustness to have confidence in the outcome. For example: extracting day counts on meter layer time lines to determine violations of the cold water fish water quality protection standard is not seriously compromised due to lack of spillway data when simulating this long a time period. Simulating only 1-3 years or modeling this reservoir with a non-dynamic model would leave much greater uncertainty.

An example of a test of "Robustness": The W2 simulations indicate that 2005 is the best year that the cold water fishery might have carried over through the summer stagnation period (see tables 2.6-1 & 2) in two decades. The Utah DWR reports that 2005 is the only year the trout did carry over in recent decades- including 2006 and 2007 (Nadolski , draft UDWR, 2008) . This is actually a bit of calibration information, as the W2 simulations indicate that 2005 is the first year in the simulation data sets that the cold water fishery had a chance to carry over based on attainment of the cold water fishery water quality standards even in just several meters of water through August.

The model does not stratify right on queue on exactly the right day every June or destratify perfectly in September[12]. There are several potential reasons for these temporary miscues: 1) is the dual elevation skimmer affect of the water mixing to the withdrawal may not be perfectly proportioned from the top and bottom layers; and 2) the lack of on-site wind speed and wind direction data, and 3) having to estimate spillway release quantities. Time varying adjustments to wind sheltering coefficients and met data may

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[12] Models not hitting both onset of stratification and fall turnover is actually a common problem. This model uses a **code modification** allowing seasonal time varying changes to the wind evaporation coefficients. A single coefficient tends to get spring or fall correct, but not both. The logic is that one evaporation coefficient when water temperature is much colder than air temperature in the spring, versus water temperature is much warmer than air temperature in the fall may not be accurate. Therefore, seasonal or time varying changes to the wind evaporation function are utilized. It is common practice to use time varying wind sheltering coefficients to improve hydrodynamic calibration. This is not done in this East Canyon application, but the concept is similar to time varying wind sheltering coefficient in terms of evaporation, but without the other effects of changing the wind velocities in WSC. Wind direction and velocity are also important components of algal succession modeling.

make the modeler look better; but probably does not improve the predictability confidence with scenario sensitivity studies. However, matching longer term trends correctly like the first attainment of phosphorus limitation in the epilimnion; tracking phosphorus release trends over a long period of time, the decline in total chlorophyll, and major shifts in algal succession are more important than date specific calibration for the purpose and needs of this TMDL. Tracking these long term trends without obvious accumulative error in the overall phosphorus budget is also an important test of model robustness.

With a great deal of time and effort this model hydrodynamic calibration can probably be improved by manipulating meteorological data, using time varying wind sheltering coefficients, and time varying evaporation coefficients. However, demonstrating the need for spillway flow data, on-site wind data, and lateral average chlorophyll data serves a greater purpose than making the modeler look good. Water Quality regulators and the fish biologists also need to understand how much a dissolved oxygen profile can change in a few hours in the top 12 meters in the midst of a summer/fall blue-green algal bloom.

The wind sheltering coefficients (WSC) set between 0.65-0.75 appears to give the most accurate temperature calibrations shown in Figure 1.4.3.2-1 &2. The WSC set at 0.65 reproduces the phosphorus data in the 2005-2006 time periods best at the discharge. The 0.85 WSC gives slightly less accurate temperature profiles compared to data; however, it yields a slightly more conservative solution for periodic high peak blue-green algal blooms in the fall.

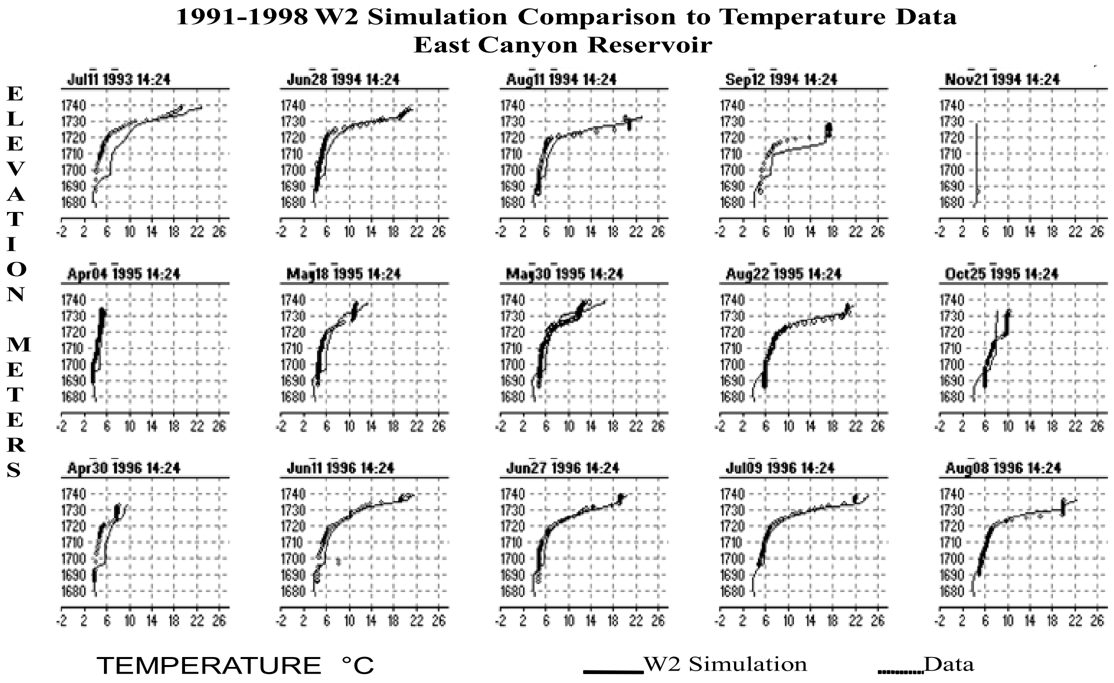

Figure 1.4.3.2-1 W2 Baseline temperature simulations from a station up reservoir from the old dams compared to data collected on these dates labeled the station near the dam and the mid reservoir station - thus the variations in bottom depths of the data. The WSC are set at 0.75 in this W2 simulation.

Although the 0.85 WSC produced less accuracy in temperature profile calibration overall, it is utilized for the chlorophyll and blue-green algal dominance analyses because it is a slightly more conservative solution with regards to late fall blooms[13].

Temperature variations of several degrees in the top 6 meters are generally the difference between morning sampling times, and afternoon model data extraction times. Thunderstorms may also occur in the mountains in the afternoons that are not reflected in the Salt Lake City, Utah meteorological data. Overall the W2 temperature calibrations are very accurate.

During large algal blooms that can move longitudinally, laterally, and vertically with daily and hourly wind patterns; the dissolved oxygen can make large swings in the top 8-10 meters over just a few hours (Figure 1.4.3.2-3). If an algal bloom is concentrated near the surface for several hours between 8-11 a.m. (anytime the sun is shining with no wind) dissolved oxygen can become super saturated in the euphotic zone (zone with sufficient light to support photosynthesis), and occasionally go to zero within a few centimeters below the euphotic zone due to algal respiration.

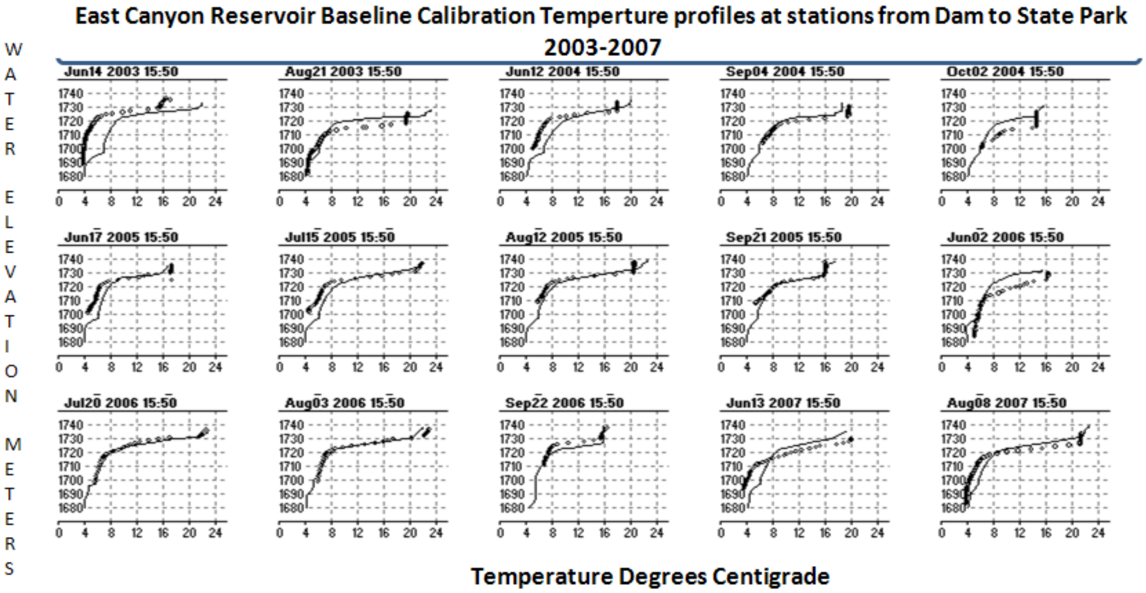

Figure 1.4.3.2-2 Temperature profiles °C (horizontal axis) versus reservoir elevation in meters from the 2003-2007 W2 simulation (Line) comparisons to the data (dots) on the dates when it was available. Differences in the top several meters are time of the model data extraction (~3 p.m.) versus the time the profile was actually taken- usually 10:00-12:00 a.m. The Wind Sheltering Coefficients are set at 0.75 for this 2003-2007 calibration; time varying WSC may improve the calibration- but diminishes the importance of collecting local wind speed and directional data.

Once the wind begins to blow the dissolved oxygen is usually mixed to the thermocline and the wind can also produce significant reaeration. Although some of the dissolved oxygen profiles from the W2 simulations and the data appear quit off at times in the top 8-10 meters (Figure1.1.3.2-3, June12, 2004-

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[13] It is the author's opinion that the 2003-2007 ECR time period does not fully represent the potential for fall and late fall blue-green algal blooms, which in the future will be more dependent on storm runoff accompanied by major September turnover; and then followed by a prolonged warm period. The 85% wind coefficient (0.85) produced a slightly higher probability of these late fall blue-green algal bloom events. Furthermore, the long term retention of phosphorus in the stagnant zone of the hypolimnion will also influence greater fall blooms associated with turnover, and then a prolonged warm fall. In short there will likely be periodic fall/late fall blue-green algal blooms, and utilizing the 0.85 WSC shows this best by producing a little more turnover mixing.

example), this can actually be a difference that occurs over a period of only a few hours. These dramatic shifts in temperature and dissolved oxygen can produce additional stress in fish that will be discussed in later sections.

With on-site wind speed and directional data, correct algal biomass and solar radiation, and a lot of work to output model data to match the precise time of sample collection (assuming that time is available); the W2 model can do a lot better than some of the dissolved oxygen profiles in Figure 1.4.3.2-2 might indicate. Manipulation of meteorological data can improve the date specific calibration profile, which may make the modeler look better; but also losses the opportunity to reveal some important facts- like how big a shift in dissolved oxygen can occur in a few hours. It is important to know that such significant shifts can occur in only a few hours when reviewing the temperature and dissolved oxygen measurement end-point goals to protect a cold water fishery in section 1.5. Understanding the reason for differences in the data and the W2 simulation calibration could also lead to very important adjustments in future monitoring programs.

It is also important to note that the longer the model runs the more accurate the profile calibration becomes in most parameters. After the model has ran for a few years the first order dissolved oxygen compartment has accumulated organic matter at the water sediment interface in each segment. This organic matter can take more than one year to decompose, especially in the colder depths. If the thermocline setup in the W2 simulation is late or early it will affect the dissolved oxygen profile accuracy for up to 2-3 weeks. This is most notable in the June early July sampling dates. It may appear the model does not have sufficient hypolimnion oxygen demand, but the stratification setup date is equally as plausible as cause of error.

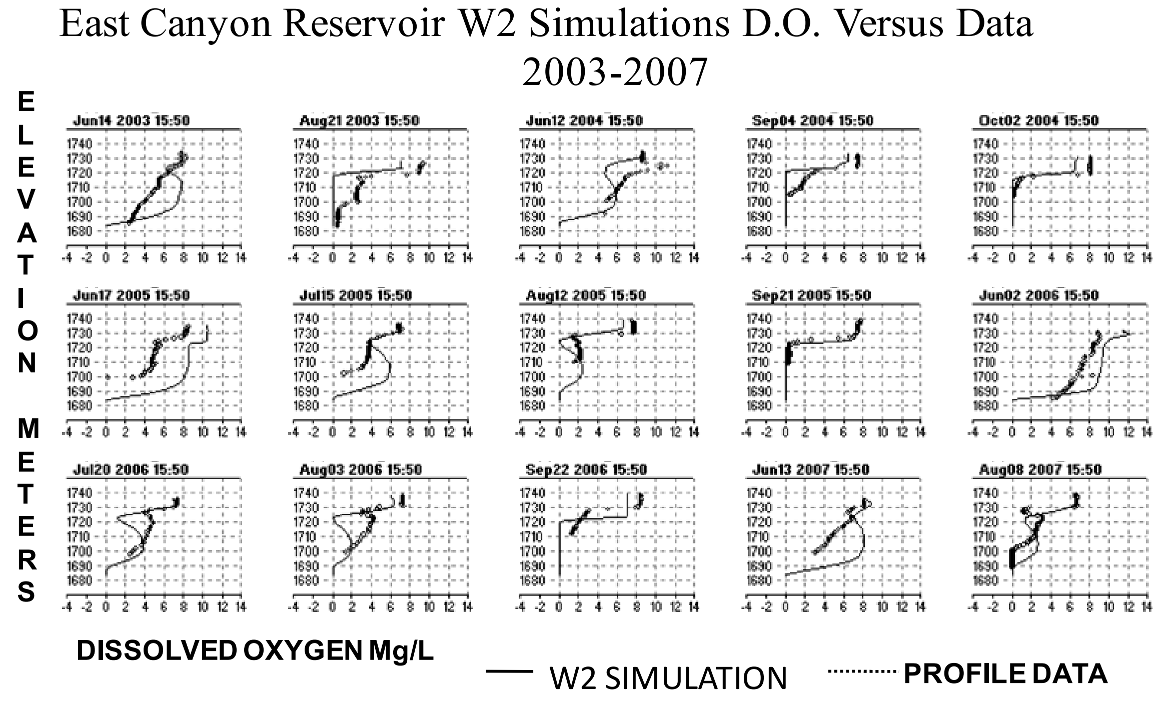

Figure 1.4.3.2-3 charts the W2 baseline dissolved oxygen simulation (line) versus the data points (dots) from 2003-2007.

The 2003 profile errors are caused by the initial condition organic matter content in the sediment oxygen demand in each segment compartment not being accurate. The first order oxygen demand computations accumulate organic matter in each segment at each elevation at the water sediment interface. Thus if the simulations are running correctly, the dissolved oxygen profiles should better match the data after the model has run for some period of time. If the simulation is closing the gap with date specific data within a 15 day time period, the met data is not modified for a correction. Too much over correcting for the wrong reason could diminish future users understanding of the need to collect specific data to better understand the proper way to make these corrections.

In some years the W2 simulations appear to produce a greater metalimnion minimum dissolved oxygen sag than is found in the data. Interestingly, the data seems to show a greater metalimnion minimum in the later years of the 2003-2007 simulation after there has been nearly a 60% reduction in phosphorus. This may be in the seasonal timing of when the samples were collected, since the reservoir goes to anoxia quickly after stratification. This can also occur if the sampler does not leave the logger probes at the rapid changing depth sufficiently long for the dissolved oxygen/temperature in the meter to reach equilibrium. This can be a difficult task in a wave rocking boat with a 6°C temperature drop sometimes occurring in less than a meter. The most uncertainty between data collection accuracy and W2 calibration can also occur in this metalimnion minimum rapid changing zone.

A single Particulate Organic Matter settling velocity (POMS) is used for all forms of organic matter in W2. In reality individual species of phytoplankton and even different terrestrial organic matter have highly variable settling velocities.

How significant are the differences in the dissolved oxygen data and the W2 simulations to the purposes and objectives of this study? Dissolved oxygen decay beneath the thermocline is highly dependent on the set up date of the thermocline- which is in turn highly dependent on wind speed and direction, meteorological conditions, spillway spills, and total inflow volume. The W2 simulations are utilized to compute the number of days that each layer in the epilimnion/metalimnion boundary violates either temperature greater than 20 °C or dissolved oxygen below 4.0 Mg/L later in this report. This is an important measurement end-point goal of the TMDL and purpose for this study. It is preferable that this study over-estimate the number of days this Utah DEQ cold water fishery water quality standard is violated- rather than under estimate it. The sensitivity studies of future potential conditions are not predictions of what would actually occur on any given date. Since thermal stratification can vary by 4-5 weeks, forcing hydrodynamic perfection in calibration, possibly for the wrong reasons, doesn't improve the accuracy of future condition sensitivity analyses. The W2 simulations tend to produce slightly too much metalimnion minimum compared to data in some of the charts in Figure 1.4.3.2-3. However, the "robustness" of the model for the critical needs of this study is defined by the cold water fishery survival. In this regard the model robustness scores high, as was discussed previously, and will be explained later.

The W2 simulations frequently have lower dissolved oxygen than the data in the 10-20 meter metalimnion depths. Low dissolved oxygen in this 10-20 meter depth is called the metalimnion dissolved oxygen minimum. This is more noticeable on the June 12, 2004 and July 20, 2006 profiles in Figure 1.4.3.2-3

The metalimnion dissolved oxygen minimum is an interesting phenomenon referred to in many limnological text books and technical reports (Miller, 2008; Jukka, H. et al, 2004; Shapiro, J. 1960; Williams, N.T. 2008; Wetzel, R.G., 2001) as having different causes, and perhaps as still being a bit of a mystery. In fact in a reservoir with withdrawals at various elevations- hydrodynamics can be a major cause of a metalimnion minimum. The W2 simplification assumptions, coefficient settings (single value for POMS-example), settling velocities, etc for different types of particulate organic matter, and routing assumptions of a laterally averaged model can also over exaggerate a metalimnion minimum. CE-QUAL-W2 can produce metalimnion dissolved oxygen minimums in several different ways- mostly driven by sediment oxygen demand (SOD), interflow/underflow density current hydrodynamics sweeping SOD, and algal growth photosynthesis oxygenation or algal oxygen consumption by respiration in the dark.

Viewing the avi files that include dissolved oxygen helps demonstrate metalimnion minimum hydrodynamics. After the spring algal bloom dies and/or settles to the bottom, the oxygen demand is most rapid in the warmest water. In the epilimnion algal organic matter can decay in 10-20 days(15-24°C), in the metalimnion elevations which can warm rapidly as the reservoir is drawn down the algal organic matter (SOD) can decay in 15-40 days (10-15 °C); while in the cold hypolimnion (3-10°C) algal matter may take months to several years to decay. Since warmer water has less dissolved oxygen solubility than colder water, and colder water has slower decay rates than warmer water; the metalimnion can deplete oxygen faster than the hypolimnion.

It is not uncommon for W2 to over produce metalimnion oxygen decay as seen in several comparative date charts in Figure 1.4.3.2-3. However, it is also important to note that most of the metalimnion and hypolimnion in East Canyon Reservoir attain anaerobic conditions by mid July or earlier depending on the year. The W2 simulations also attain these low dissolved oxygen periods- often referred to as "summer stagnation". Perfectly matching specific date dissolved oxygen profiles in ECR with W2 simulations is very sensitive to thermocline set up date, location of settlement of the spring algal bloom- which is in turn dependent on wind direction in June, meteorology, hydrology, reservoir elevation, dam operation, and spills.

Close examination of the dissolved oxygen profiles versus the data (Figure1.4.3.2-3) when viewed in the animation sequences (included only in the avi files attached to the DVD or electronic versions of this report) reveal that the differences between the model and the data close rapidly from mid June to early July, usually within 5-15 days14. The oxygen demand rates in ECR really have not changed much from year to year even from the 1990s to 2007 (Figure 1.5.4-2). However, the date when the thermocline is established and oxygen depletion begins can vary by more than a month from mid May to nearly July. In late May of 2008 it was over 80 °F (26.6 °C) in the afternoon and snowing the next morning. Sometimes the thermocline can be established, but then at least partially turned over with some reaeration. In some years this process can occur several times in transition from spring to summer- leaving a complex temperature and dissolved oxygen profile from depths of 0-20 meters. Again May temperatures and wind magnitude can greatly influence the date and nature of the thermocline set up. There can be significant difference in wind and overall storm intensity from the Salt Lake City Airport next to the Great Salt Lake, versus in the mountains at East Canyon Reservoir.

The spring algal bloom settles to the sediment in early July. The epilimnion and metalimnion warm much faster, and organic matter decay accelerates in the warmer water. Thus the metalimnion oxygen demand in the warmer metalimnion occurs at a faster rate than in the colder hypolimnion.

A seemingly large difference in data and W2 simulation output in dissolved oxygen in the top 7-10 meters during an algal bloom may not be a bust in calibration. Significant differences can occur in a period of few hours pre and post morning wind.

In most reservoirs with the depth and hydraulic retention time of ECR there is a marked decline longitudinally down the reservoir in algal productivity from the nutrient source in the inflow to the dam. It is also rare for a dam with a deep hypolimnion discharge and these hydraulic retention time characteristics to release particulate organic phosphorus or particulate algal biomass from the dam. The wind in many Intermountain Western United States Reservoirs is often up canyon starting before noon; due to air updraft from the heating of steep vertical canyon bare rock walls. This updraft/up canyon wind pushes algae back into the river inflow on a daily basis. The algae settles in the reservoir transition zone

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[14] The model calibration appears to be reaching anaerobic or at least less than 4.0 mg/L in the metalimnion and hypolimnion with about the correct 2-15 days time period. This is more obvious when viewing the AGPM post processor 2-dimensional animations, which provides a great deal of clarification once studied carefully (animations are included only in the DVD or electronic versions of this report).

near the inflow area, and the major area of oxygen depletion usually develops there. This oxygen depleted or anoxic zone then migrates all summer to the dam, as the hypolimnion releases the coldest water, and pulls the anoxic plume towards the dam. This is a more accurate description of Deer Creek Reservoir nearby than it is at East Canyon15.

East Canyon Reservoir is unique, and does not follow this common reservoir sequence just described. This needs to be kept in mind when reviewing this study, or in using the results of this study as a paradigm for another reservoir. At East Canyon Reservoir the wind pushes the algae back into the inflow during parts of April and May, but then pushes it to the dam from June through much of September. Fall storms in September and October can push large surface accumulations of blue-green algae back into the shallow reservoir inflow area, making the reservoir appear as if turnover produced large algal blooms almost overnight. This reservoir is relatively short in length for its depth and hydraulic retention time. It also follows regional wind patterns more than local canyon updraft patterns. Wind direction over a two day time period can redistribute large portions of the total algal biomass from one end of the reservoir to the other. Major algae movement from one side to the other laterally is even more pronounced on a daily basis with only slight changes in wind direction. Where large algal biomasses are during sampling, and where they settle in the reservoir affect organic matter sediment oxygen demand differently in each ECR W2 segment. The W2 simulation is computing a lateral average algal biomass for each layer in the model. The data represents a single location across a highly variable lateral segment with regards to time/date specific sample data (See Figure1.4.3.5-1). Utilizing a 3-dimensional model certainly does not resolve this issue with limited data sets, but rather multiplies the complexity by an order of magnitude in every respect. The initial problem is the data has to adequately represent the total autochthonous productivity of the reservoir, as well as provide a segment lateral average to calibrate a two dimensional model.

The W2 zero order dissolved oxygen compartments are provided in W2 to establish a constant source of sediment oxygen demand by segment. Often the zero order compartments are used to represent the allochthonous organic matter sources which are often poorly documented in the inflow data. Since the assumptions driving W2 may not properly distribute allochthonous organic with the reservoir properly anyway, sometimes using zero order oxygen demand to place this organic matter is a better solution within the model. When used to represent allochthonous organic matter it is also appropriate to use much slower decay rates. Setting a constant zero order SOD for each segment usually works well because the overall phytoplankton productivity is usually heaviest in the transition zone as is settling of allochthonous organic matter. After settling the turbidity is no longer light limiting in the reservoir transition zone, but inflow nutrients are physically and biologically available. The sediment delta toe or zone of rapid deepening in the reservoir is usually the location of high accumulation of both allochthonous and autochthonous organic matter. An anoxic plume typically builds in this transition zone early during summer stagnation, and then migrates to the dam as hypolimnion water is discharged. This migration to the dam coupled with any interflow events can sometimes quickly establish a metalimnion dissolved oxygen minimum over much of the reservoir. This process can be seen early in the avi file animations (DVD version), but once the spring algal biomass has settled in ECR- anoxia develops quickly reservoir wide as it decays.

In reality the zero order oxygen compartments just make up for errors, while providing some information about why or where the errors might occur. It can make the modeler look good, but may not help in

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[15] This is an accurate description of Deer Creek Reservoir, Utah where the wind pushes the algal biomass to the inflow all summer, the transitions zone develops anoxia first, and it migrates to the dam as the hypolimnion water is discharged. However, it is not an accurate description of East Canyon Reservoir, because the summer wind accumulates much of the algal biomass to the dam, where it can periodically be discharged due to the skimmer affect of the old dams.

developing better monitoring in the future for an improved causal assessment. **The object of this W2 model simulation is to first understand if most of the limnological processes are explained by the first order computations for dissolved oxygen and nutrients driven by the dissolved bioavailable phosphorus budget from the watershed.** If this fails to account for most of the oxygen demand and phosphorus in the reservoir and at the dam discharge, then the search begins for the missing sources. **However, the dissolved phosphorus inflows into ECR have been very large, and they do account for the limnological processes in the reservoir when simulated with CE-QUAL-W2.**

Varying the zero order sediment oxygen demand (SOD) by segment can sometimes lead to very accurate dissolved oxygen calibration in a W2 simulation of a zoned reservoir. This may not tell us where that oxygen demand originates from, but can at least tell provide an idea of how to monitor in the future to find out. However, **to successfully test the potential of future phosphorus or organic matter reductions to change the reservoir, the model cannot be largely zero order oxygen demand driven.** The assumptions of W2 (laterally averaged) may not accurately facilitate the location of settlement of allochthonous organic matter. However, leaving out particulate organic matter from tributary inflow entirely, and replacing by setting a zero order sediment oxygen demand by segment and then giving it an appropriately slow decay rate may be a very appropriate use of the zero order compartments. However, if the particulate organic matter sources from the watershed are significantly reduced as part of the watershed phosphorus TMDL, then those reductions could not be represented without also reducing the zero order oxygen demand contribution. In ECR most of the allochthonous organic matter appears to settle in the first 4 shallow reservoir segments- thus becoming trapped in the sediment delta, or floating particulate organic matter is often seen accumulated at or even on the shorelines. These sources appear to play a minor role in metalimnion/hypolimnion oxygen demand processes in ECR.

The arid Southwestern America water supply reservoirs are drawn down extensively from July through September to provide irrigation, municipal, and industrial water. During summer drawdown the epilimnion and metalimnion elevations may be washed clean of organic matter, especially on steep slopes. This occurs fastest in warm epilimnion water and wave action washed shores on steep slopes loose essentially all their organic matter. Some of this organic matter simply resettles to a deeper location. Unfortunately the simple assumptions of W2 do not scour and relocate all this organic matter, but it does decompose much the autochthonous sources very quickly. The sediment oxygen demand in July and August in ECR) can be highly dependent on the settlement location of the very large spring algal bloom. If the wind speed and direction in May and June are not accurate, then oxygen demand in the model will not perfectly match that in the reservoir. The W2 model may not remove all organic matter from the wave washed drawdown zone in the fall, thus it may leave to much organic matter in the rapidly warming metalimnion in the next July and August. Thus the W2 simulation can produce too much metalimnion oxygen demand from June-August in several different ways. This lack of scouring sediment is discussed as a future need in the W2 User Manual (Cole and Wells, 2005); however, if it were easy it would have been done a long time ago. Furthermore, the assumption of a single settling velocity for all particulate organic matter in the W2 simulations can also compromise oxygen demand in the metalimnion versus the hypolimnion. Additional testing of this parameter may be useful. A code modification allowing individual settling velocities of each algal group after it dies and becomes particulate organic matter may also help.

These W2 simulations initially create too much metalimnion oxygen demand, but do correctly create sufficient reservoir wide oxygen demand to produce metalimnion and hypolimnion anaerobic conditions within about the correct two week time period each year. The settlement and decomposition of the spring algal bloom creates essentially all of this oxygen demand in this W2 model setup. The impact of a higher metalimnion minimum for a few weeks the purposes and needs of this analysis are minimal in part due to the long time periods modeled. In reality scouring the shoreline organic matter by drawdown does result in some organic matter being redeposited into deeper water. The wave action and warm water also lead to rapid decomposition, but with lots of reaeration. The dissolved oxygen calibration charts can be forced to be more correct by manipulation of the wind, but the actual cause of error may be missed. Thus in this model application the over simulation of metalimnion oxygen minimum and under estimation of hypolimnion oxygen demand may not be properly repaired by time varying wind sheltering coefficients. We just recognize the issue, and define the uncertainty upon the critical needs of this study. It is better to leave some differences in the W2 simulations and calibration to drive specific future monitoring to find correct solutions.

1.4.2.3 Nutrients

The phosphorus inflows from the 1990s to 2007 have been reduced by approximately 60% from over 6,300 kilograms/year in the 1990s to the 2003-2007 baseline calibration average of about 2551 kilograms/year. During many individual years the only phosphorus data comes from the Weber River Basin Water District Laboratory, and this is only dissolved ortho phosphorus data. The initial W2 simulations test the ability of dissolved bioavailable phosphorus to drive most of the autochthonous productivity and dissolved oxygen demand in ECR; therefore, this dissolved phosphorus data is very valuable. This data also suggests that East Canyon Reservoir may have been exporting more dissolved phosphorus than was coming in after about fall of 2004 (Figure 1.4.3.3-1). However, this may also be a seasonality operational mismatch because the lowest release flows from the dam beginning about mid October initiate the lowest phosphorus data points at the downstream sampling location. It appears there is no relationship between reservoir processes in October, and downstream minimum flow release phosphorus data. This is likely due to ground water and dam seepage having very low phosphorus concentrations and biological uptake of phosphorus between the dam and the downstream sampling point. When higher dam releases increase in the spring the relationship between modeled output and

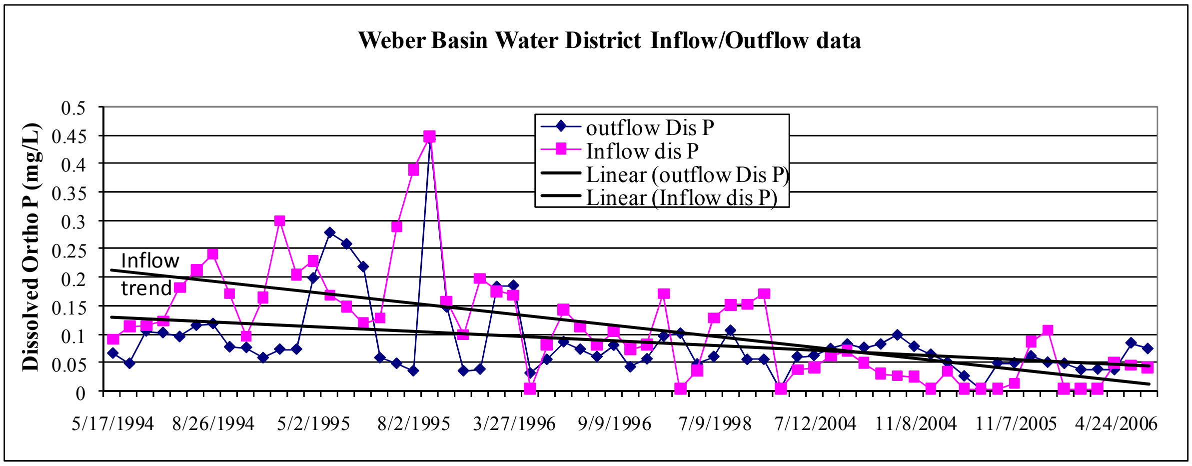

Figure 1.4.3.3-1 charts all the dissolved ortho phosphorus data into and out of East Canyon Reservoir from the Weber River Basin Water District chemical laboratory -data provided by personal communication (Peterson, Scott, 2008). There is a lag time in phosphorus discharge versus higher inputs in 1994-1995 following two years of drought in 1991-92. This is due to temporary retention in the hypolimnion stagnant zone, and the time to decay autochthonous organic matter in cold deep water. The lowest data points occur during minimum release from the dam; seepage and groundwater gains between the dam and the sampling point make up the majority of the flow. Therefore, the lowest dissolved phosphorus concentrations during minimum flow in the winter are not directly related to phosphorus concentrations in the reservoir water column.

downstream phosphorus concentrations returns, and the downstream concentrations go back up. This may also suggest that the modeled output should be a little higher than downstream data.

The long term trends (Figure 1.4.3.3-1) of declining dissolved phosphorus[16] indicate the reductions in phosphorus loading over the past two decades. The outflow responds quickly to major phosphorus reduction implementation projects in about 1995 (biological treatment of wastewater reduced effluent from 6-8 mg/L to less than 4 mg/L, non-point source erosion control related to construction and ski slopes in 2001-2003 around Park City, Utah; and advanced wastewater treatment reducing phosphorus effluent to less than 0.1 mg/L in the summer of 2004. East Canyon Reservoir may still contain some of the legacy phosphorus from previous years of higher loading, particularly trapped in the sediments. It may be several more years with some higher flushing inflows before a long term dynamic equilibrium is achieved. However, the fact that the discharge from the dam responds quickly to reductions of inflow from the watershed strongly suggests that **on a 1-3 year cycle the allochthonous dissolved phosphorus sources are much predominant over perennial long term sustained internal recycling from sediments.** A large phosphorus inflow may take over 1-2 years to be recycled to the discharge point at the dam. This lag time also shows up with outflow versus inflow concentrations following some high loading wet cycle periods, such as 1993-94 (Figure 1.4.3.3-1). The ECR phosphorus retention time, like the hydraulic retention time, is also highly variable. The phosphorus retention is longer than the hydraulic retention time.

The W2 simulations driven by dissolved phosphorus in the inflow approximate the long term trends and concentrations of total phosphorus as measured as a discharge from the dam from the 1990s through 2006. Phosphorus declined from seasonally greater than 0.25 mg/L in the 1990s to about 0.065 mg/L by 2006 at the dam release. Figures 1.4.3.3-2 and 1.4.3.3-3 show the W2 simulation and data point comparisons. The W2 simulation data extractions in Figure 1.4.3.3-1, 2, & 3 show dissolved, total, and particulate organic phosphorus as a discharge at the dam.

It is actually unusual for a reservoir of this depth, hydraulic retention time, and hypolimnion discharge to have significant differences in total and dissolved phosphorus when measured at the dam release. The summer and fall wind pushing the algal biomass to the dam and the skimmer dual elevation withdrawal effect is largely responsible for this difference at ECR, especially prior to 2004. This difference has apparently been greatly reduced as phosphorus inputs and summer algal biomass decrease according to the W2 simulations. The recent reductions in POP discharges from 1991-2003 versus 2004-2007 in the W2 simulations are significant, and POP exportation is significantly reduced after 2005. Observations and data below the dam indicate the W2 simulation is correctly tracking long term trends in total phosphorus and POP from ECR- indicating trophic status improvement in the reservoir.

In the W2 simulations the fate, internal retention cycle, and eventual phosphorus transport out the discharge from ECR changes significantly with the reduction of external loading and the associated reduction of summer algal biomass. The differences (W2 simulations) in the relationship between total and dissolved phosphorus in the tailwater in the 1990s versus 2005-2007 is because the summer/fall exportation of particulate algal biomass is so significantly reduced. The reduction in summer algal blooms, including blue-green algae reduces the accumulation at the dam and exportation of particulate algal biomass in the discharge (Figure 1.4.3.3-1). However, the reduction in export of particulate organic phosphorus also slows down the future responses to additional phosphorus reductions because retention in the reservoir is now longer. We know that the high particulate organic phosphorus was in the dam discharge prior to 2004 more by observations than by data, and has been greatly reduced following

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[16] Dissolved phosphate is from a filtered sample undigested and analyzed within a few days; it is all biologically available phosphorus, and is used as such as the input into W2. The inflows into East Canyon Reservoir have a high ratio of dissolved to total phosphorus in recent years (70>80% commonly dissolved P).

advanced WWTP phosphorus reductions. The really large summer time algal blooms have not been observed stacked into the dam since 2004 at last from July into September.

Collecting several samples per day right at the dam discharge during large algal blooms that include dissolved, total, and particulate organic phosphorus would help improve confidence in the W2 simulations of these algal biomass exportation events. However, the reduction in algal biomass is also associated with a significant reduction in particulate organic matter exportation. The reduction of algal particulate organic biomass accumulations at the dam in the summer and fall at East Canyon Dam since 2005 are so obvious that data is not needed for verification, but would be very helpful for quantification.

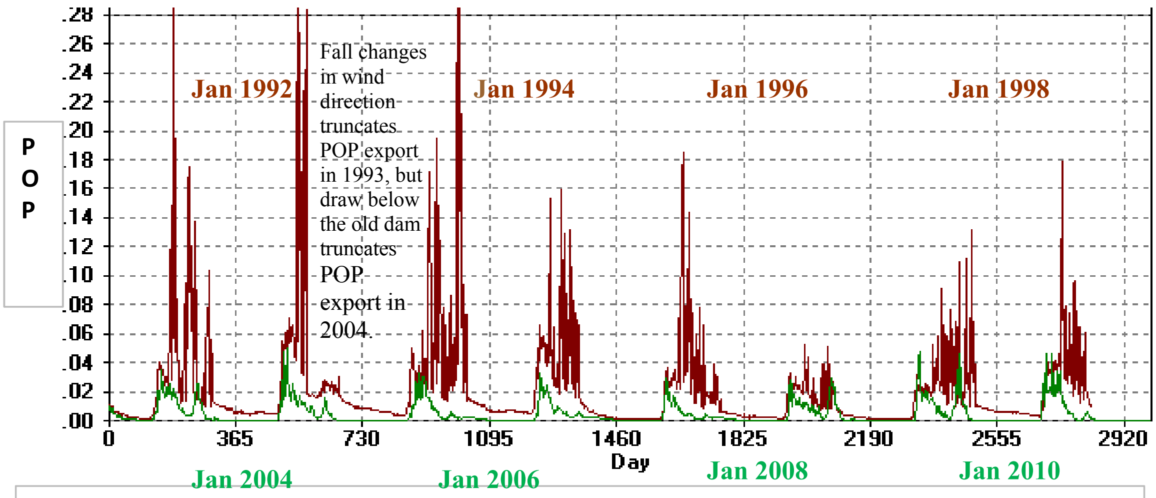
East Canyon Reservoir is in a very significant spiral down from much higher phosphorus loading to the reduced inputs in recent years. The limnological changes with regards to fate, transport, retention, routing, and bioavailability of phosphorus in this reservoir are significant. The model calibration/confirmation over the two time periods captures these long term trends correctly. It may take the dilution of a few more wet years to fully understand how much additional recovery this reservoir can make even at the current loading rates. However, the water quality improvements attained in this reservoir in 2005-2007 are significant.

Tracking the long term phosphorus trends in East Canyon Reservoir is a significant test of this W2 applications robustness- particularly with regards to the critical needs of this TMDL water quality assessment.

Date specific discharges of particulate organic matter from algal blooms building at the dam are very sensitive to wind speed and wind direction. Note the intermittent high peaks in discharge of particulate organic phosphorus (POP) from the W2 simulations in Figure 1.4.3.3-1 and in total phosphorus in Figure 1.4.3.3.-2 & 3 in the data and from W2 simulations below. Thus date specific calibration of data and the modeled total phosphorus discharged from the dam would be difficult (minimal data), but long term trends appear to be tracking correctly. This indicates that on average over the course of the summer the meteorological data interpretations are near correct (as an average for summer), but on specific dates and times the comparisons of the W2 simulations and data may be less well coordinated. The long term “robustness” of the CE-QUAL-W2 ECR model application provides greater confidence than date specific calibration events.

The differences between dissolved and particulate phosphorus (Figure 1.4.3.3-1a) also begin to decline significantly after 2004. The sharp decline in POP discharge in 2003-2004 is in part due to drawdown below the top of the old concrete dam. The gradual decline from 2004-2010 is also due to the phosphorus TMDL reductions. There was also a noted noxious accumulation of summer/fall blue-green algae at the face of the exposed old concrete dam in all the early 2000 drought years with August drawdown below the top of the old concrete dam. However, other time periods with a significant truncation of POP discharge coincide with the fall change in wind direction pushing algal biomass up reservoir and away from the dam. The wind pushing the blue-green algal biomass to and away from the dam is very evident in the erratic pulse of W2 peak POP discharges throughout the 1990s.

East Canyon Reservoir Particulate Organic Phosphorus (POP)
Dam Releases-W2 Simulations



Green is particulate organic phosphorus (POP)in Mg/L as discharged from East Canyon Dam in the baseline calibration W2 simulation from 2003-2011; brown is the same discharge from 1991-1998. The vertical axis is particulate organic phosphorus in mg/L.

Figure 1.4.3.3-1a illustrates the difference in the discharge of particulate organic phosphorus (POP- Mg/L-Dry Wt.) from East Canyon Dam from 1991-1998 versus 2003-2007(2003-2006 wrapped as 2008-2011) based on the W2 simulation. This indicates a significant decrease in POP export due to phosphorus reductions following implementation of the TMDL.

Particulate organic phosphorus peaks as a discharge from the dam in the W2 simulations are concurrent with peak algal blooms in June-early July, and again in September (Figure1.4.3.3-1a). Although prior to summer of 2005 large POP discharges from the dam could occur anytime during the summer and fall as also seen in the intermittent high total phosphorus discharges in Figure 1.4.3.3-2 below, as well as in high intermittent POP discharges. Exceptionally dry years following a wet period, or an exceptionally wet year could also produce smaller overall algal biomasses or differences in POP as a discharge from the dam. That these high POP discharges occurred periodically is confirmed more by the author's observations and people reporting these same observations of algal bloom accumulations at the dam or being discharged from the dam prior to 2004. The discharges from the dam were reported to the author as observations of smelly green slim discharging from the dam in the early morning hours (5-10 a.m.). Large algal blooms stacked into the dam, particularly in July and August have not been observed by the author after 2004. However, the decline in phosphorus concentrations over time below the dam also supports the W2 simulations (Figure 1.4.3.3-3). While phosphorus responded quickly (1-3 years) to initial large loading reductions, the continued decline of phosphorus as measured as a discharge from the dam appear to be occurring at a much slower rate. A phosphorus concentration as a discharge from the dam of 0.030-0.040 mg/L annual average would be a good goal, but assessment of the technical potential to attain these concentrations will take a longer period of observations, and more data in the watershed.

The large blue-green algal mats stacked into the dam in the fall prior to 2004 often had the appearance of fowl smelling turquoise oil based paint, and were obviously in a state of rapid decomposition[17]. The total, POP, and dissolved forms of phosphorus are changing rapidly during this decompositions state, and thus may also change from the reservoir to the downstream sampling location.

The large swings in wet and dry hydrology in 1991-1998 produced significant variance in summer chlorophyll concentrations and annual nutrient loading, but the phosphorus inflow was so high that it was rarely limiting in the epilimnion prior to 2005. This high phosphorus inflow also partially masked the intermittent phosphorus retention and routing cycle that is more obvious now that the overall phosphorus inflow has been reduced (Figure1.4.3.3-3). Figures 1.4.3.3-1, 2, &3 demonstrate how these phosphorus cycles have changed as measured at the dam release, and how the W2 simulations have captured these long term trends. This is an important test of the CE-QUAL-W2 ECR model's "robustness".

Picture 1.4.3.3-1 Cyanophyta or blue-green algal blooms stacked into a small area can become fowl smelling, making some people feel ill, produce skin rashes, and eventually decompose to appear as turquoise oil based paint. An algal bloom with more than 200-400 µg/L chlorophyll a would look like this.

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[17] It has been the authors experience that whenever very large accumulations of blue-green algae occur at a given location-particularly in the shallows near shore, that the mortality rate is high as manifested by the turquoise "oil base paint" appearance and the odor of decomposition. Shoreline wave action and warm temperatures also increases the mortality and decay rates. At night these algal are very adept at sinking as much as 10-15 meters to attain access to nutrients, but ascend rapidly back to the surface between about 8-10 a.m. Phytoplankton stacked into the shallows cannot migrate down even to avoid too much sunlight at mid-day. The morning ascent prior to wind produces large surface scum. At East Canyon Dam this nightly decent probably results in the early morning discharge from the dam. The W2 simulations would probably not capture this release without the daily vertical migration from the R&D algal succession code. The accumulations of algae at the old concrete dam after the water was drawn down below the top in 2003 made any pictures of blue-green algal blooms seen in this report look good- but no pictures of the worst cases observed at ECR are available. Such conditions have not been observed by the author after 2004 in ECR.

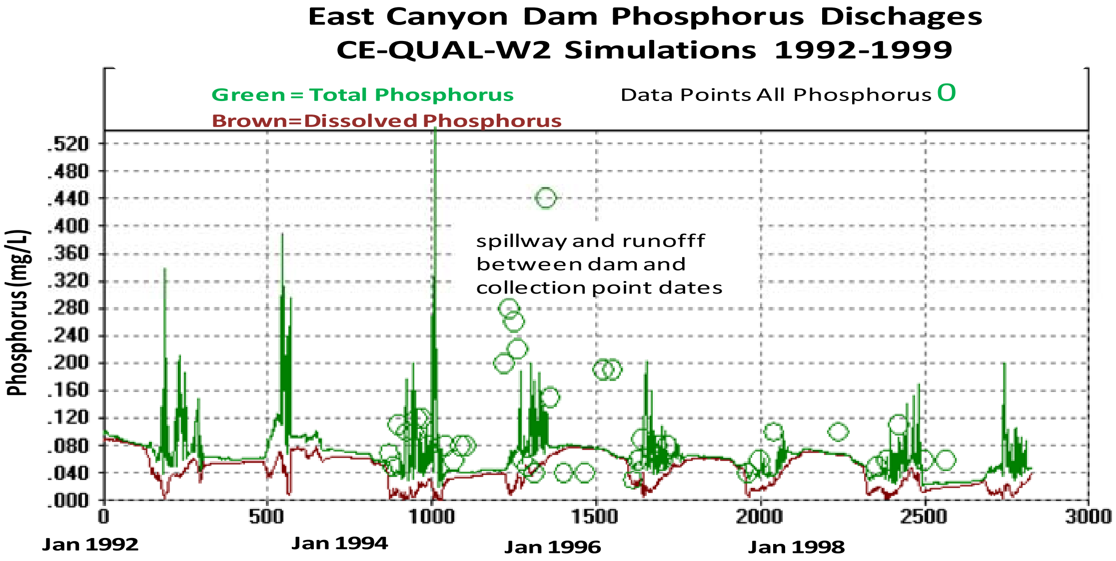

Figure 1.4.3.3-2 the 1993-1997 total and dissolved phosphorus W2 simulations (lines) from 1992-1999 are compared to all phosphorus data points (majority of data is dissolved P), collected downstream 1-2 miles below the dam. Actual releases of particulate organic matter (high total phosphorus) are also very dependent on spills, wind speed and direction. The lowest data points coincide with minimum dam releases and apparently have decreased relationship to reservoir processes.

The greatest amount of phosphorus samples come from the Weber River Basin Water District laboratory, but they include only dissolved ortho phosphorus. Generally only the few highest data points are total phosphorus. However, some of the highest data points also correspond to dates of local snowmelt runoff and/or spillway spills, thus increasing the uncertainty that the data represents only releases from the dam because the station is located downstream. Manipulating wind speed, direction, and spills from wave seiching may also better replicate some of the high data points missed by the W2 simulations.

Figure 1.4.3.3-3 illustrates the spiral down of phosphorus and the W2 simulations tracking of these trends versus the data following advanced wastewater treatment for phosphorus control in 2004. Note that the discharge was still as high as 0.12 mg/L early in 2003, or nearly the same as in 1996. Following a major dilution cycle like 2005, phosphorus concentrations have to rebuild in the stagnant portion of the hypolimnion until they begin to spill over the top of the old earthen dam and through the hole in the old concrete dam (review Figure 1.3.6.1-1 and the computer animations- DVD version only). This will temporarily increase the phosphorus retention in the reservoir, and periodically result in increased fall blue-green algal blooms. The slow decay of organic matter building all summer and fall in the deep cold water of the hypolimnion contribute to this annual seasonal cycle as well. All the organic matter accumulated to the hypolimnion does not decay in a single annual cycle, thus long term buildup occurs. These phosphorus cycles are clearly illustrated in the long term two-dimensional animations on the avi files in the attached AVI files (DVD or electronic versions of this report).

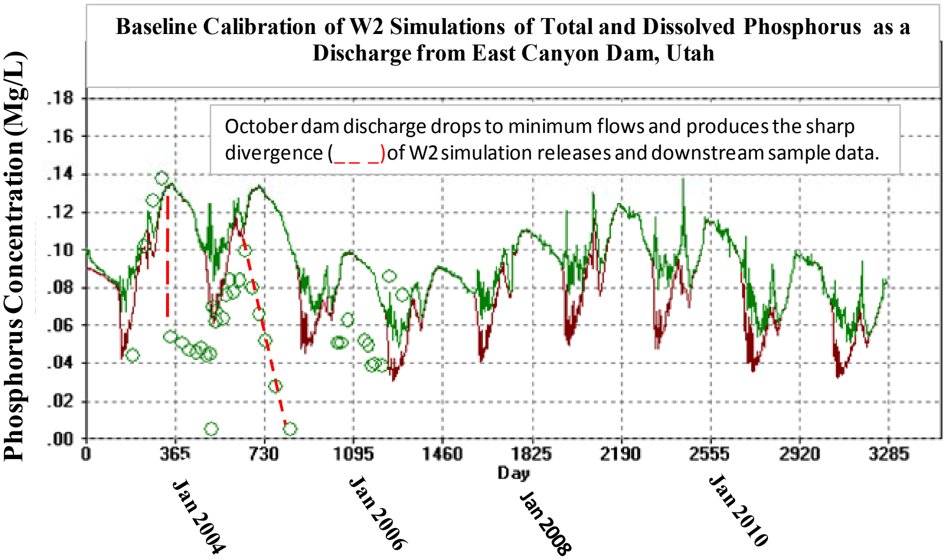

Figure1.4.3.3-3 The W2 baseline calibration simulation of total and dissolved phosphorus as a release from the dam (green line= total phosphorus, brown line = dissolved phosphorus, green dots all phosphorus data- mostly dissolved); the data was collected approximately 2 Km downstream. The majority of the data points are dissolved ortho-phosphorus from the Weber River Basin Water District.

The significant departure of the W2 simulations and the much lower data points (- - -) in Figure 1.4.3.3-3 represent the minimum flow releases from the dam when seepage around the dam and local ground water stream gains to the sample data collection point may be more significant than the dam release, thus minimizing the relationship between the downstream sample and phosphorus concentration in the dam release. In October when the minimum release is initiated the stream aquatic vegetation should be able to absorb nearly all the dissolved phosphorus being released from the dam. Furthermore, local warm day's runoff from snowmelt anytime from November to April with minimum dam releases can also impact the phosphorus concentrations at the downstream sampling location; also impacting the relationship to reservoir processes.

The lowest concentrations from the W2 simulations occur at the end of spring runoff with maximum dilution and aeration, as well as maximum phosphorus removal from the epilimnion by the large spring algal bloom. The maximum W2 concentrations occur at the peak of organic matter decay throughout the entire water column in September and October, as well as the sediment release of anaerobic inorganic phosphorus. The disconnect between downstream data and reservoir process begins with October minimum flow releases from the dam, and ends when higher releases resume in the spring- usually March or April.

The minimum downstream concentrations coincide immediately with minimum flow releases from the dam in October, and seem to have little relationship to phosphorus concentrations in the reservoir or the releases from the dam. As soon as higher dam releases resume in about March/April, the relationship between the W2 releases and downstream data again converge. This data and W2 simulation break in October lead to speculation that the model was not handling anaerobic inorganic phosphorus release and subsequent precipitation and re-adsorption of phosphorus by iron with fall turnover and reaeration. If this were true the phosphorus concentrations measured below the dam would stay low until the reservoir again became anaerobic in about mid-July. Instead, the higher concentrations start again with increased dam releases in March or April, and are again very similar to W2 simulation output. The model could partially be forced to reproduce this downstream low dissolved phosphorus data by large fluctuations induced by changing coefficients for anaerobic inorganic phosphorus release and iron precipitation with reaeration. This appears to be inappropriate, but again, specific data should be collected to prove the W2 model is wrong, or not.

It would be very helpful to obtain dissolved and total phosphorus data right at the dam discharge and at the downstream location in October before and after minimum releases begin and again in the spring before and after higher dam releases resume. It would be best to have a week separating sampling around these changes in dam operation. Most streams in deep mountainous gorges gain groundwater inflow below a dam, and the steep terrain can also gain surface water inflow anytime there is runoff.

During the late fall turnover (October/November) the total and dissolved phosphorus generally converge at the highest homogenous water column concentrations of the year following the temporary warming of the hypolimnion, and the maximum decay of the summer's autochthonous biomass (Figure 1.4.3.3-3). This also coincides with the peak phosphorus concentration released from the dam in September/November. Much of the lower phosphorus concentration water in the metalimnion/epilimnion was released over the summer, leaving the lower water volume to dilute the deep hypolimnion at fall turnover.

The spring runoff, especially in a wet year brings is a large block of water that dilutes the overall reservoir spring turnover phosphorus concentration. The spring runoff carries a large phosphorus load, but it is currently at a lower concentration than the spring turnover concentration in the reservoir. The lowest phosphorus concentrations discharged from the dam occurs just after spring runoff, and at the peak epilimnion spring algal bloom. The phosphorus discharge from the dam drops from April to June due to dilution, and the large algal biomass consumption of dissolved phosphorus. The epilimnion becomes depleted in soluble phosphorus as the spring algal bloom succumbs to heat and settles below the thermocline, but all the phosphorus the phytoplankton takes with it is still bound to the sediment in the dying algal biomass. The cold and still aerobic hypolimnion is still at the low phosphorus concentrations from spring runoff, and the epilimnion remains phosphorus depleted into July. Since the epilimnion/metalimnion is a substantial portion of the dam discharge, the lower but climbing limb of phosphorus concentrations occur in the tailwater from early June into August. The dam releases can also be very high, and spilling during May/June and even July. The phosphorus concentrations of the W2 simulations and samples taken downstream generally are fairly good during the summer, early fall, and again in the spring with resumption of higher dam releases, but runoff between the dam and the downstream sampling points can still cause some exceptions.

The warming of the water and the continued warming of lower elevations with summer drawdown results in decay of organic matter and release of phosphorus. Throughout the fall the development of underflow density currents accumulate this phosphorus and partially decomposed organic matter to the stagnant zone in the deep hypolimnion. The hypolimnion phosphorus concentration can build to 2-3 times the whole reservoir concentration prior to mixing at peak fall turnover. Again, the first test with W2 is to determine if the dissolved bioavailable phosphorus inflow can account for all the algal biomass, oxygen demand, and phosphorus in the reservoir with first order computations. The W2 simulations show that most of the phosphorus either came from the watershed in the current year, or from decomposing autochthonous organic matter from the previous 1-2 years. This is internal reservoir recycling of autochthonous organic matter which will eventually respond to reductions from the watershed. However, with the reduction of summer algal blooms and particulate organic matter export from the reservoir beginning in 2005, the spiral down of total phosphorus releases from the dam becomes a much slower process.

The total phosphorus concentrations below the dam are a mixture of water from two elevations in the reservoir (refer to Figures 1.3.1-1; 1.3.6.1-1, and Figures 1.3.2.1-1 & 2).

The peak metalimnion/hypolimnion oxygen demand and phosphorus release from organic matter decay begins in September after initial fall turnover slightly warms portions of the hypolimnion from 3-7 °C to 9-14°C (see Figure 1.3.6.1-1). Phosphorus concentrations remain fairly homogenous in the reservoir profile and in the discharge from about mid November to spring runoff. Large spillway spills during the peak spring algal blooms in June may also be routing large quantities of biomass downstream and out of the reservoir, but with very high dilution.

The lower the POP discharges are from the dam, the less date specific calibration is dependent on accurate local wind speed and wind direction. Again, learning from the differences in model simulation and the data is an important part of utilizing the model. Impressive complex statistics and careful manipulation of meteorological data may make the model calibration and thus the modeler look better, but often do not help in interpreting limnological mechanisms important to the study goals, or management needs. Some of the most important lessons to be learned from this W2 modeling effort should come from studying the mechanisms of differences in the W2 simulations and the data, and then devising additional monitoring to document these mechanisms and lead to data driven improvements in the W2 simulations. This is always the correct way to use the W2 model following initial calibration. For example, the chlorophyll data collected at a single station location over many years does not support the model "as calibrated" quantitatively in worst case hyper-eutrophic conditions that have been visually observed. There is often more than one way to force the model to calibrate to a sample point. When the specific cause of those differences is not known, it is better to collect data to determine the correct cause and thus the method to improve calibration of the model. The example of the minimum flow phosphorus concentrations versus the W2 model output in this section is an excellent example; data collection should drive any attempt to force the model to equal the downstream data upon minimum flow releases in mid October. It is unlikely that specific data collection will support such an action.

One important improvement in future sampling design might be to collect POP, TP, dissolved ortho-P, TOC, and chlorophyll on an hourly basis for 24 hours should another major blue-green or even a spring diatom exportation event be observed. During such an event the daily variance in discharge of total, particulate organic and dissolved phosphorus sampled 6-12 times may exceed the range of the entire previous phosphorus data set?

The decrease in summer chlorophyll and blue-green algal blooms, the associated decrease in summer discharge of algae and particulate organic matter, and the cyclic retention in the stagnant zone of the hypolimnion changes the annual and long term phosphorus retention in ECR. It may take several more wet years with continued lower phosphorus inflow to fully understand the future fate and transport of phosphorus through East Canyon Reservoir. The W2 simulation demonstration of these changes to date is a significant test of the models robustness.

Even with the significant phosphorus reductions of the past 10 years, the concentrations in the water column still remain well above levels expected to produce seasonal eutrophic conditions (Figure 1.4.3.3-4). However, during the summer and early fall since 2005 the epilimnion has consistently attained phosphorus limitation. The total phosphorus in the epilimnion in Figure 1.4.3.3-4 is largely assimilated into phytoplankton cells. Dissolved phosphorus concentrations in the epilimnion are nearer detection limits of analysis in the summer since 2005. The W2 simulations attainment of phosphorus reaching limitation to phytoplankton production in the epilimnion during summer of 2005 is another important test of model "robustness". There were only periodic dates of epilimnion phosphorus limitation prior to 2005. The W2 simulations capture these major trends.

The decay of organic matter releases most of the phosphorus from the sediment, so much like dissolved oxygen, the concentrations are dependent on wind direction and where algal blooms are placed and autochthonous organic matter settles. Figure 1.4.3.3-4 illustrates the W2 simulation of the baseline comparison of the total phosphorus profiles in the water column in 2007. The longer the W2 simulations run the better the calibration with specific sample dates generally are. The total phosphorus profile comparisons during the 1990s are not as good and phosphorus is seldom limiting to algae production. There are two reasons for this: 1) the longer the simulations run, there is less summer chlorophyll and less blue-green alga; and 2) the less total summer biomass, the less influence the wind has on accumulation to specific locations. Thus on-site wind speed and direction are less sensitive to date specific sample calibration the less eutrophic the reservoir becomes. However, collecting a few additional phosphorus sample depths, particularly at a station just upstream from the old earthen dam would assist in improving future phosphorus W2 simulation confirmation.

Collecting consistent near bottom nutrient and organic matter samples is tricky. Turbulence produced by the moving sampler, especially if it touches the bottom, sets off a cloud of organic matter resuspension. Samples which disturb the bottom may contain much higher phosphorus and labile organic matter concentrations. Samples collected carefully about 2 meters above the bottom-without organic matter or turbidity, and a second sample very near the bottom with organic matter but not sediment can provide additional meaningful information. However, consistency in collecting these two samples from a rocking boat is difficult. At East Canyon Reservoir these samples should be collected immediately up reservoir at the deepest point from the old earthen dam. They should be collected early in the morning on dead calm water before the wind begins to blow.

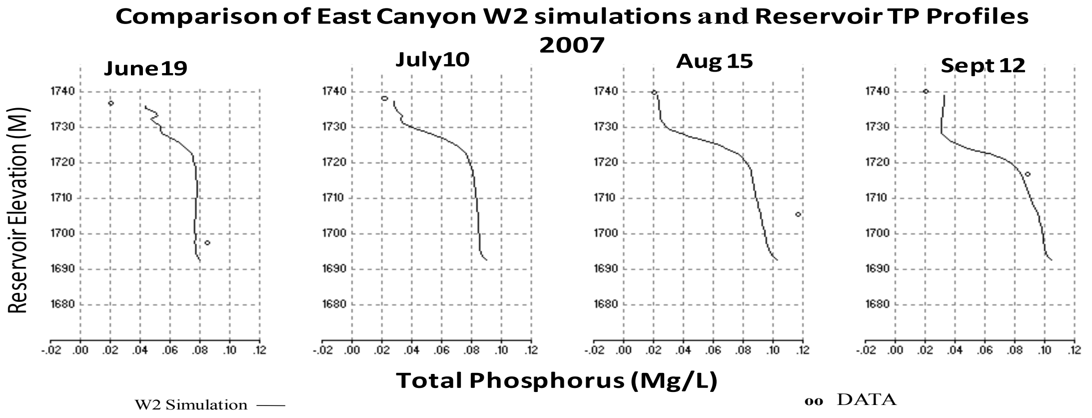

Figure 1.4.3.3-4 charts are reservoir profiles of W2 calibration simulations near the dam of total phosphorus (lines) versus the Utah DEQ data on the common dates shown. The epilimnion surface dissolved phosphorus samples (not shown) remain phosphorus limited and often near or below the laboratory detection limits. Sampling near the bottom is difficult and any disturbance of the bottom will make the sample data higher. Total phosphorus near the surface is highly dependent on local algal biomass, which is in turn highly dependent on recent and local wind speed and direction. Never-the-less, post phosphorus TMDL model date specific calibration is pretty good.

The phosphorus calibration (figure 1.4.3.3-4) may not be perfect, but considering it gets better and not worse the longer the model runs continuously- adds confidence in the model's "robustness". A lot more dissolved, total, and particulate organic phosphorus data may provide improvements in calibration or confirmation. The phosphorus profile calibrations are pretty good in Figure 1.4.3.3-4 by 2007. When there are such large algal biomasses that move so much laterally, longitudinally, and vertically within the reservoir- it is unlikely that a single site /date sample specific calibration should be better than this without on-site wind data. Surface samples at a given location could vary considerably in the summertime depending on algal surface location associated with wind speed and direction. The lower the summer time algal biomass becomes the less sensitive calibration is to on-site wind speed and direction data.

The dissolved phosphorus inflow generated by SWCA drives the W2 simulations as the biologically available phosphorus inflow for the baseline from 2003-2007. The W2 simulation total phosphorus outflow and in-reservoir total phosphorus concentrations are derived computation within CE-QUAL-W2 based on the dissolved phosphorus inflow. The assumption is to start with the known biologically available phosphorus inflow to see how much of the total phosphorus can be accounted for in the reservoir and its discharge. In this case the dissolved phosphorus inflow from 2003-2007 as computed by SWCA actually provides nearly all the needed total phosphorus in the reservoir and its outflow for calibration.

The R&D algal succession code is new, and has the potential to mobilize more phosphorus than might be appropriate during vertical descent in part because it can touch the bottom and return to the surface. The W2 version 3.2 code has a touch and gone algorithm which immediately places any algal biomass that touches the bottom into the particulate organic matter compartment. Therefore, another check of model calibration needs to be an analysis of phosphorus routing versus retention in the baseline simulations. The computations include the entire 2003-2012 simulation with 2003-2007 repeated as 2008-2012. The total phosphorus outflow budget should generally be less than the inflow budget, but when a 60% inflow reduction has been implemented the outflow could at least temporarily exceed the inflow. Table 1.4.3.3-1 provides a total summation of East Canyon Reservoir phosphorus budget from the W2 baseline simulation gauged inflow and outflows and phosphorus loads. .

Table 1.4.3.3-1 is a summation of the W2 baseline simulation dissolved and total phosphorus budget including the repetition of 2003-2007 out to 2012. Therefore this is a ten year- not a one year budget

Total Kg Dissolved Phosphorus Inflow	Total Kg Total Phosphorus INFLOW	Ratio Diss. P/ Total P INFLOW	Total Phosphorus Outfow	Total Phosphorus Export Out/IN	ECR Total Phosphorus Retention
16,189.6	25,489.3	64%	16,044.0	63%	37%

W2 derived Total Phosphorus Outflow/Dissolved Phosphorus Inflow = 1.0091

The budget summation for the entire W2 baseline loading repeated twice in Table 1.4.3.3-1 is a simple accounting of measured inflow and W2 computed outflow, and therefore is not all inclusive, but does catch the majority of the budget. This budget indicates that about the same percentage of dissolved to total phosphorus in the inflow is also eventually routed through. The phosphorus retained in the reservoir is approximately equal to the particulate phosphorus in the inflow. Many major river basins with a lot of suspended iron, manganese, and aluminum in the Southwest U.S. can have dissolved to total phosphorus ratios of less than 10-20% in the inflow. The sediment can trap a much higher percentage of the total phosphorus budget. East Canyon Reservoir has a small suspended solids load inflow by comparison. However, when wastewater is a high percentage of the flow except during major runoff events, the dissolved to total phosphorus ratios can be much higher, such as occurs in East Canyon Reservoir where it is 64%. This does not mean that all the particulate phosphorus entered the sediment without some portion becoming dissolved, nor does it mean that a portion of the dissolved phosphorus was not incorporated into phytoplankton and permanently trapped in the sediment. The inflow budget had decreased significantly immediately before and during this simulation. The efficiency of dissolved phosphorus retention in the future may be higher. Deer Creek Reservoir nearby has similar but somewhat lower phosphorus retention ranges, as would be expected of a true bottom hypolimnion withdrawal reservoir.

This long term phosphorus budget summation confirms that the new algal succession R&D code does not appear to be mobilizing more phosphorus than would be appropriate. However, it also indicates that approximately the same total phosphorus leaves the reservoir as the dissolved phosphorus load that enters over the ten year period.

The W2 model needs a chlorophyll segment cross-sectional average for calibration. In order to accurately quantify total internal algal biomass productivity in this reservoir cross-sectional averaging of chlorophyll and phytoplankton data is needed. Large changes in total algal biomass would also change local total phosphorus date specific surface concentrations. A single deepest over channel reservoir sampling station can significantly bias quantification of algal biomass production as will be better shown in the chlorophyll section to follow. The deep water station has a high probability to bios biomass surface samples low. Remember all data extractions from W2 simulation represent a lateral average of the segment and layer. A low total algal biomass bios would also bios surface total phosphorus low.

The W2 simulations demonstrated in this section are based on proving or disproving the assumption that external dissolved phosphorus loading, not internal loading, drives the annual to semi-annual phosphorus budgets in ECR. The models first order oxygen demand decay is also releasing phosphorus when organic matter decays. **This autochthonous organic matter decay provided most of the phosphorus in the calibration documentation just reviewed. The anaerobic inorganic phosphorus release from sediments is not the driving force or majority source of phosphorus in ECR during this time period in the W2 simulation calibration and confirmation. If anaerobic inorganic internal loading was the major portion of the annual phosphorus budget for example- the W2 simulations would be grossly in error, as would the dissolved oxygen budget**. However, the W2 simulations do carry over autochthonous organic matter to provide this phosphorus. If this reservoir attained most of its bioavailable phosphorus from anaerobic inorganic releases from the sediments these W2 simulations would way under estimate phosphorus concentrations, algal biomass production, and oxygen demand in this reservoir. Unfortunately, the chlorophyll data collection in ECR does not support the need for so much autochthonous algae production as occurs in these W2 simulations. This is an error in the chlorophyll data collection which needs to be addressed in future monitoring, and will be discussed further in the following sections of this report.

The in-reservoir phosphorus concentrations are modeled very well by W2 utilizing only the dissolved phosphorus inflow. The W2 simulation has considerable robustness over a broad range of reservoir elevation, hydrology, and with a 60% phosphorus reduction.

1.4.2.4 Chlorophyll

The chlorophyll a data that has been collected in East Canyon for many years comes from three stations in the reservoir (see Figure 1). They are near the dam, mid, and upper reservoir (near the East Canyon Creek inflow). These stations are placed so as to be over the deepest water in this segment cross-section. This provides the deepest vertical profile location, which is appropriate for most parameters. The upper reservoir station can move depending on the reservoir elevation. The mid- reservoir station is right of mid channel (looking downstream) and just up reservoir from the State Park. Chlorophyll concentrations can vary by nearly two orders of magnitude across a segment as demonstrated by data collected by Reclamation and USGS Scientists in October of 2000 in Figure 1.4.3.4-1 below.

The two dimensional W2 model laterally averages the chlorophyll in each layer across an entire segment. On the date of the satellite imagery study (Figure 1.4.3.4-1) the standard three station reservoir sampling protocol may have under estimated the total algal biomass by ½ to near an order of magnitude[18]. The mid reservoir station (right of center of main channel looking downstream) would have had a chlorophyll concentration between 3 and 5 µg/L. A lateral average across the channel at the mid reservoir segment as represented by the W2 bathymetry file would more likely have been 30-40 µg/L on the satellite imagery collection date. Samples from the Southwest shore would have been 50 to > 100 µg/L, while samples from the North shore near the State Park could have been less than 3µg/L.

Similarly, the maximum chlorophyll at the three protocol sampling sites may have had a range of 4-20 µg/L, while the many samples represented in the satellite image with chlorophyll greater than 20 µg/L actually ranged from >20 µg/L all the way up to greater than 250 µg/L. The satellite imagery in this study could not be calibrated to discern the differences greater than 20 µg/L.

The importance of the influence of wind direction is also a significant feature of this image (Figure 1.4.3.4-1). The large blue-green algal blooms had been stacked in against the dam until just about a week prior to this satellite image study date, when a major fall storm event changed the wind direction and redistributed most of the algal biomass back towards the inflow area. The wind had again reversed and was moving the algal bloom back towards the dam in the immediate 12-24 hour period prior to the image time and date. Viewing the satellite image it is obvious which direction the wind was blowing in at least the previous 6-12 hour period. The first major fall storm event can move large blue-green algal masses from the deeper water near the dam to the shallow water in the upper half of the reservoir, or concentrate it on the shoreline. This can give the appearance of a huge blue-green algal bloom being generated over just a few days. The large algal blooms stacked against the dam are less public and in deeper water than the blooms in the upper reservoir shallow inflow area. Thus a change in wind direction and redistribution of the algal blooms all over the shallower upper reservoir basin can give the impression that fall turnover produced massive algal blooms almost overnight. This wind direction change can also produces the large fluctuations in particulate organic phosphorus discharge observed previously from the dam.

Fall turnover does help generate large algal blooms, but the wind movement and appearance of a fall algal bloom can change dramatically in even a 24 hour period. Without on-site wind speed, direction, and matched times of sample and W2 output, it is very difficult to precisely calibrate date specific data in a laterally averaged model from a single reservoir location sample. However, collecting laterally averaged chlorophyll and phytoplankton samples is just as important to quantitatively represent the reservoir as it is to have a segment laterally averaged data point to calibrate the W2 model. Algal blooms of this magnitude have been observed many times on the reservoir, but seldom appear in the chlorophyll data base.

The satellite chlorophyll study demonstrates that quantitatively utilizing the historical East Canyon Reservoir chlorophyll and phytoplankton sampling data for calibration of the W2 model could lead to some problems. This satellite imagery study was designed to determine if a single deepest channel station did bias the phytoplankton productivity data. This study was designed for this purpose after the author reviewed years of chlorophyll data and was astonished at how low it was overall. If the W2 simulations were forced to match the chlorophyll data for total algal biomass it would way under estimate autochthonous productivity in this reservoir. It would also way under estimate the huge blue-green algal blooms the author observed many times over a thirty year period. In fact, it would be difficult to even

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[18] Jerry Miller (author) wrote the proposal and the workplan for the ECR USGS/USBR Department of the Interior (DOI) funded research project satellite image study of Chlorophyll. The study was specifically designed to determine if the three single chlorophyll sample locations in the reservoir might bias low the total algal biomass estimation. This study was designed because the chlorophyll data was so low compared to the large algal bloom observations made on the reservoir.

force the W2 model to produce as little chlorophyll as is represented in the data base. Thus it is just as important to collect laterally averaged segment chlorophyll and phytoplankton data sets to accurately account for total algal biomass production in the reservoir, as it is produce data that can accurately calibrate the W2 laterally averaged model.

The satellite imagery study was specifically designed to test the sampling programs ability to quantify the total algal productivity. It was intended to process multiple date satellite images to attain more reservoir wide chlorophyll data from this calibration, but total DOI/USGS /USBR program funding was discontinued and the project was not completed. This was a programmatic DOI reduction, and not specific to ECR. However, we have observed many similarly large blue-green algal bloom events as the one on the date the satellite image was taken over the past 30 years. Scenes like the one in Picture 1.4.3.3-1 have been common place during the summer and fall on ECR prior to 2005. However, the large spring diatom blooms tend to concentrate several meters beneath the surface and generally do not form large surface scums like the one in the picture; therefore, the magnitude of organic matter in these spring blooms is often over looked. During many large spring algal blooms the water simply appears very green, and would have very low (less than one meter) Secchi Disk depths, or high turbidity and low water clarity.

It was determined after reviewing the satellite imagery study in an early meeting with Utah DEQ that the W2 model would not be forced to calibrate to the Chlorophyll data, but would try to qualitatively track the trends in shifts in planktonic species (algal succession) from Dr. Sam Rushforth's phytoplankton data qualitatively. However, since many of the samples Dr. Rushforth and Sarah Rushforth examined where also taken from the same aliquot as the chlorophyll samples, they were also just as likely biased low in total cell counts and biovolumes.

In addition to chlorophyll being very biased to the slow side even on a day with a large algal bloom; the total algal biomass varies so much during peaks, in seasonal transitions in algal succession, and even daily in vertical migration that getting representative total algal biomass data to calibrate a laterally averaged model can be a difficult task (see the long term W2 simulation chlorophyll time-line extractions in Figure 1.4.3.3-2). A few sample points per year simply will not adequately represent a hyper-eutrophic biomass without a lot of luck, some understanding of the calibration issues, and some on-site judgments during sampling. However, a 5-7 sample chlorophyll/Secchi Disk transect across a segment to compute an average would help. Collecting sufficient data to adequately represent productivity is not unique to ECR, and in fact this is probably a fairly common issue. Data collection is expensive. That is why local watershed water quality committees often use volunteers to help with data collection. For example, if water clarity, as measured by Secchi Disk transparency can be accurately correlated to chlorophyll data; then a cheaper method to obtain more data can help calibrate the CE-QUAL-W2 simulations.

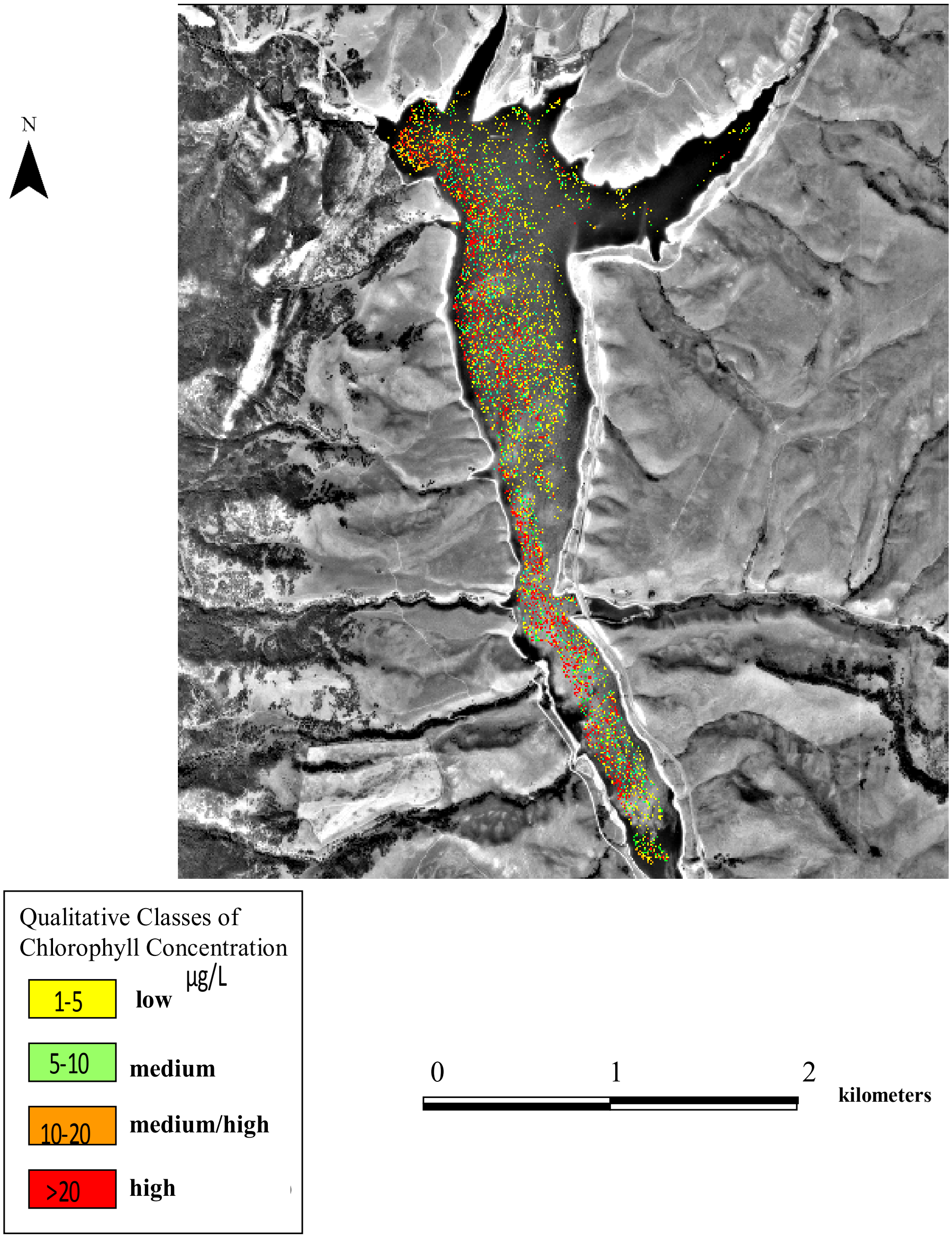

Figure 1.4.3.4-3- IKONIS S Multispectral Satellite Image of East Canyon Reservoir calibrated and processed for Chlorophyll a on October 11, 2000. Red indicates areas where chlorophyll a is greater than 20 µg/L, but samples ranged all the way up to 250 µg/L on this date. This image could not be calibrated for ranges exceeding 20 µg/L. This image was provided by Ms Mindy Shearer, USGS, Cook, Washington from an unpublished joint Department of Interior U.S.G.S./ U.S. B.R. research project(personal communication from Ms Mindy Shearer to Jerry Miller).

The spring algal bloom is attaining light limitation for at least several weeks during most years, especially in the warmer climate of the past two decades. The high phosphorus concentrations at spring turnover and in the East Canyon Creek spring runoff produce these large spring algal blooms. The high phosphorus concentrations during spring turnover do in fact contain input from the past several years primarily being recycled from the autochthonous organic pool. These spring blooms are the common denominator maintaining high metalimnion and hypolimnion dissolved oxygen depletion rates even though nearly 60% of the external phosphorus has been removed. Figure 1.4.3.4-2 demonstrates the large peaks in chlorophyll in the spring with a low in the middle of the summer and another peak in the fall. The fall peak has also been significantly reduced since 2005, and blue-green algal dominance has declined with the decline in the summer and fall chlorophyll. These W2 simulations (Figure 1.4.3.4-2 follows the trends that have been observed from 2003-2007). An astute observer didn't need data to see the difference in summer algal biomass in 2005-2007.

The reservoir produces the very large spring diatom blooms, and this biomass drives the summer metalimnion and much of the hypolimnion oxygen demand. If phytoplankton samples are not collected near the peak of the spring bloom, the biomass production for the year and the relative importance of diatoms will be under estimated. The phytoplankton data counts qualitatively say the summer/fall algal succession has changed from large diatom and blue-green blooms to lower productivity and minimal blue-green algae. Yet the oxygen demand has declined only minimally through the summer. Figure 1.4.3.4-2 indicates that the summer/fall chlorophyll concentrations have declined significantly after 2003, but the spring peak remains through 2007. The fact that the metalimnion dissolved oxygen did not significantly improve in 2006-2007 is the best calibration parameter supporting the total spring algal biomass from the W2 simulations. Again, this is a significant test of model robustness.

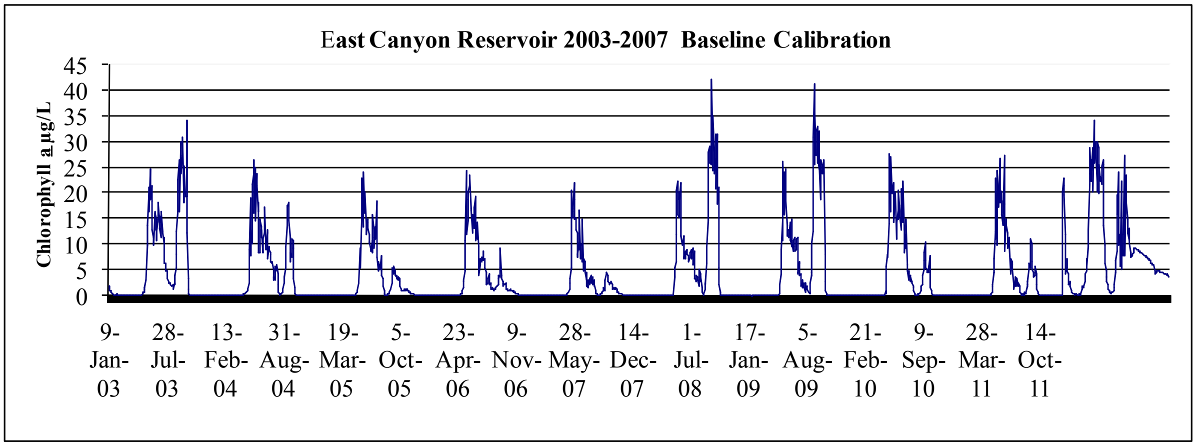

Figure 1.4.3.4-2 is the Baseline or calibration W2 simulation data set from 2003-2007. Notice the larger overall summer algal biomass and the reducing fall peak which includes more blue-green algae. Also notice that the late summer and fall peaks have significantly declined with the removal of additional summer dissolved phosphorus due to advanced wastewater treatment at ECWRF.

The long term phosphorus accumulation (1-3 years) coupled with early fall turnover followed by a prolonged warm late fall could still produce some significant blue-green algal bloom events in the future. Furthermore, a drought following a wetter cycle like 2008-2009 (Figure 1.4.3.4-2 repetitions of 2003-2004) with an additional five meters of drawdown will also quickly warm and recycle additional organic matter and produce the fall algal blooms.

At this point there are some clear chooses; either the W2 simulation produces sufficient algal biomass in the spring to cause the oxygen depletions through the summer, or there is a much smaller overall algal biomass produced in the reservoir, and the metalimnion/hypolimnion oxygen demand comes from some other sources. Since spring runoff is so small it essentially does not occur in 1991-92, 2000-2001, 2003; if the allochthonous particulate organic matter is the primary source of metalimnion and hypolimnion dissolved oxygen demand, then this oxygen demand source should be very small in these severe drought years. Metalimnion oxygen demand should be reduced with such minimal spring runoff. However, the spring algal blooms were still very large-due to spring turnover and high dissolved inflow phosphorus concentrations, The metalimnion/hypolimnion oxygen demand remains high through all ranges of hydrology and with a 60% external phosphorus loading reduction. The W2 simulations, based only on external dissolved phosphorus loading, produce sufficiently large spring algal blooms that the metalimnion and hypolimnion oxygen demands are not a mystery.

It would be difficult to reasonably force W2 to produce a much smaller overall algal biomass. These algal biomasses are produced with the estimated external dissolved phosphorus loading sources, although the internal recycling for autochthonous organic matter production causes much of this phosphorus to be utilized for 2-3 years. A substantial overall reservoir response is documented in this study as a result of the point source reductions beginning in 2004 by July of 2005. However, the 60% phosphorus accumulative reduction since the 1990s also contributed to this overall change in 2005-2007. It is unlikely the reservoir has reached equilibrium with the current phosphorus reductions, and several very wet years of flushing may still help attain lower overall concentrations typical of long term dynamic equilibrium.

The organic matter in the large spring runoff in 2008 did not produce observable turbidity in the reservoir by late May beyond the first three inflow segments in the W2 bathymetry file, even though the reservoir was already spilling. Moderate quantities of organic matter were observed collected on the shoreline in the immediate inflow segments. After thirty years of modeling and conducting limnological research, it is the author's belief that autochthonous productivity provides most of the summer metalimnion oxygen demand from the spring algal bloom. The W2 model simulations strongly support this argument. The only way to document the magnitude of previous decade's algal blooms would be to conduct another spring and fall peak bloom satellite survey of ECR and then purchase and process a lot more satellite images from previous years with that calibration. This is an expensive research proposition. In the years when Dr Rushforth (2003-2007) has spring samples significant diatom blooms are present. This is discussed in detail in section 2.4.

It should be noted that the spring diatom blooms do not present themselves as noxious surface scums as readily as blue-greens do. The water is just green. They also do not accumulate right at the surface and then get stacked into piles on the shoreline- unless the diatom bloom is of huge proportions. The overall reduction in summer algal biomass and the blue-green blooms may also have reduced the sampling protocols low bias from just three sampling locations. However, to calibrate a two-dimensional dynamic model 3-7 chlorophyll samples composited across the segment would be preferable. Digital pictures, field notes, time of day, multiple Seechi Disk depths, and specific personnel training of the sample collection goals would also be helpful.

1.4.2.5 Blue-green Algae

In this East Canyon Reservoir W2 model and with the algal succession research code several important things occur. They are:

1) The ability to create daily vertical phytoplankton migration[19];
2) Which also produces more total algal biomass;
3) To correctly follow shifts in major categories of algal group succession- such as reductions of blue-green algal biomass; and
4) To move algal biomass to and export it through the dam during major summer and fall bloom events.

These are significant pieces of the correct interaction of the W2 simulations and this ecosystem. **This reservoirs ability to route large algal blooms downstream often gave ECR a "lower trophic status presentation" or trophic index than it would have had if the algal biomass was retained in the reservoir. It is not customary in summarizing a water body's trophic status to include the quantities or potential hazards of routing decomposing blue-green algae downstream**. Not accounting for the potential harm of routing decomposing blue-green algae downstream in quantifying the hyper-eutrophic status of East Canyon Reservoir also needs some measurement end-point goal consideration. Utah DEQ has a reduction or preferably an elimination of blue-green algae as a measurement end-point goal for the phosphorus TMDL.

The dissolved oxygen demand is the only way to quantify the presence of the large spring algal biomass. However, Dr. Sam Rushforth's phytoplankton sampling and counts do qualitatively indicate the large spring algal blooms.

Although the 2000 satellite image study was never previously published, the author did share it with Dr. Rushforth and the East Canyon Water Quality Committee in their quarterly meeting in about 2002. Following discussion between Jerry Miller and Dr. Sam Rushforth about the concern of under representing total algal biomass- Dr. Rushforth built an MS EXCEL spreadsheet documenting changes in important species indices from 2002-2005 (Rushforth, 2006- personal communication). The Utah DEQ-Water Quality Division (Utah DWQ- as designated on Dr. Rushforth's charts- see Figure 1.4.3.5-1) ECR data collection was sometimes missing the spring algal bloom in May/June. Reclamation began a joint study program with Dr. Rushforth to add additional samples to the East Canyon data collection, including May/June samples to represent the spring blooms. Dr. Rushforth's analysis was previously only a personal communication between himself and Jerry Miller, although it may also have been presented to the East Canyon Water Quality committee orally during one of their meetings.

Figure 1.4.3.5-1 is extracted from Dr. Rushforth's MS EXCEL spreadsheet communication to Jerry Miller. Not all Utah DWQ ECR samples missed the spring algal bloom entirely, but this is the most extreme example of a year that it did. Missing the importance of the spring algal bloom would also have significant impacts on the algal succession calibration utilizing the new research code in this study. It would also be difficult to force the model to reproduce the algal succession major species relative importance based on the DWQ sample date collections that missed the early spring algal bloom. Since there are rarely sufficient funds to not compromise monitoring, this is likely a common problem.

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[19] The vertical migration is the experimental research and development code being tested by JM Water Quality and ERM.

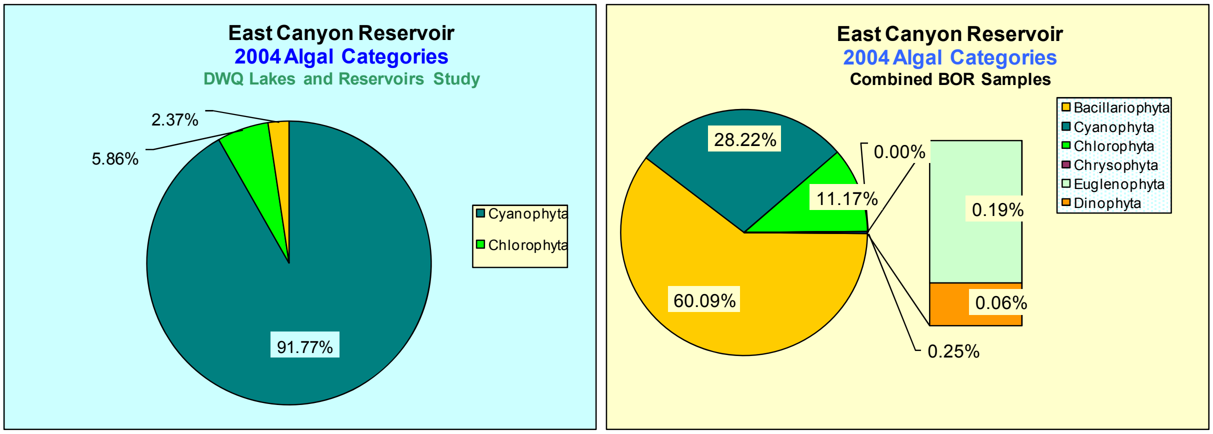

Figure 1.4.3.5-1 Dr. Sam Rushforth's important algal categories analysis (per cent/year) in 2004 when the spring algal bloom is represented in the samples (right- combined), and when only the summer and fall algal blooms are represented (left DWQ). Without inclusion of the spring diatom bloom the seasonal importance of species goes from 92% blue-green to 28% and from 2.4% diatoms (Bacillariophyta) to 60%. This is a significant difference in the limnological trophic state representation of ECR's total productivity and important algal categories. This data was provided by personal communication from Dr. Samuel R. Rushforth (2006) in an MS EXCEL spreadsheet as part of the discussions with Jerry Miller after the Chlorophyll satellite image study (Figure1.4.3.4-1) also strongly suggested that the data collection methodology may be under representing total algal biomass in ECR. These charts are printed by permission of Dr. Sam Rushforth.

Data costs are usually greater than monitoring programs can fund. The evidence presented in this study and from over 30 years of reservoir limnological research and modeling is that most studies have to monitor with significant compromises. The hypothesis is that monitoring methodologies used to collect the minimal amounts of data are far more likely to under represent the water bodies total autochthonous biomass production than to overestimate it. One would think the exception to this would be in focusing on monitoring in the fall maximum blue-green algae production period. But missing the spring algal bloom altogether to focus on this period still argues for the hypothesis that reservoir monitoring methodologies are likely to under estimate total autochthonous productivity. This may be a common problem in reservoir data collection. If this hypothesis is correct, it may have affected the trophic characterization and modeling of many reservoirs. In fact it could even impact many of the equations, algorithms, and paradigms used to develop water quality models. Perhaps many W2 applications may have had to over utilize the zero order oxygen demand compartment to compensate for the lack of first order organic matter. However, if the spring turnover and spring inflow of nutrients are adequately represented, it is difficult to force W2 not to produce these large spring algal blooms.

It has been observed that in the August and September East Canyon Reservoir discharged a "smelly green slime", and some people reported becoming ill being around it (including the author during a sampling trip into the blue-green algal mass stacked into the dam). The potential for these Cyanophyta to produce toxins and then to export those toxins downstream to animal husbandry operations or even to the drinking water system taken from the Weber River is an additional concern. Reducing or eliminating blue-green algae from East Canyon Reservoir is an important measurement end-point goal for the phosphorus TMDL.

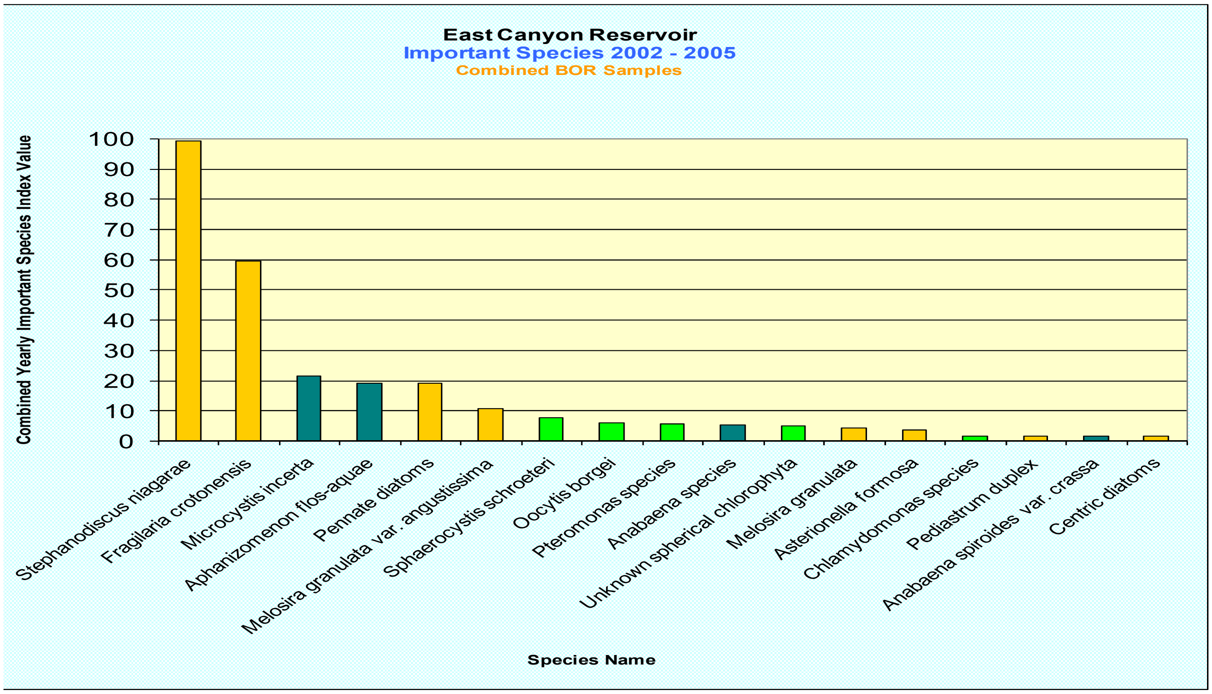

Figure 1.4.3.5-2 is Dr. Sam Rushforth's Important Species chart for the combined DWQ and BOR samples from 2002-2005 (4 years composited). The bulk of the phytoplankton biomass would also be represented by the spring algal bloom (diatoms-orange) from mid May to July according to the W2 simulations, although diatoms are common in all time periods(Rushforth, 2006, Personal communication- printed by permission of Dr. Sam Rushforth).

Figure 1.4.3.5-2 further demonstrates the importance of diatoms, which have their largest productivity in May and June, in understanding the overall autochthonous productivity within East Canyon Reservoir. **The very large fall Aphanizomenon blooms of the 1990s are limited after 2004.** However, the continued presence of Microcystis and Anabaena in the late summer is still a concern because they have a higher potential of producing blue-green algal toxins.

Algal succession modeling is a relatively untested science. The current needs in progress in this science and in the objectives of this East Canyon Reservoir phosphorus TMDL are to get the total algal biomass correct, while at the same time demonstrating when phosphorus reductions will reduce the occurrence of Cyanophyta. Algae are part of a balanced ecological system and are the base of the food chain to feed fish. Too much algae and too much bad algae lead to diminished biological diversity, diminished dissolved oxygen in the water column, aesthetic and health issues for primary body contact recreation, health and cost concerns for treatment of potable water, and drinking water hazards for domestic animals and wildlife. The health concerns associated with Cyanophyta continue to grow as our ability to understand its' role at the bimolecular- neurological, carcinogenic, and DNA code level continues to expand.

The algal succession research in this East Canyon Reservoir W2 Modeling application is aimed specifically at getting the total algal biomass correct, and defining critical bench marks that will reduce blue-green algae populations that fix nitrogen from the atmosphere. Making phosphorus limiting before nitrogen is critical to future success in reducing Cyanophyta populations in East Canyon Reservoir. Attempts are made here to also correctly model diatoms versus greens and dinoflagellates; but the real task needed at East Canyon Reservoir is to determine when Cyanophyta will be significantly reduced.

Certain events such as large August/September runoff, early mixing and turnover, and then a prolonged warm fall are likely to produce significant blue-green algal bloom events in the future. The goal is to reduce or eliminate blue-green algae. The specific hydrologic/climatic sequences that might represent a worst case are probably not included in the current data sets being simulated. However, knowing that such events may occur periodically, it is better to model slightly conservatively with regards to future scenario blue-green algal bloom events.

The data and the W2 simulations agree qualitatively and semi-quantitatively on the Cyanophyta reductions that have occurred over the past 5-6 years. The future scenario sensitivity studies presented hereafter utilize a wind sheltering coefficient of 0.85 (more wind) to help push fall blue-green algal blooms.

The W2 simulation produces phosphorus limitation in the epilimnion in mid-July of 2005, and again in later June to mid September in 2006-2007. Since Cyanophyta can fix nitrogen from the atmosphere, creating phosphorus limitation in the epilimnion during the summer is an important measurement end-point goal. Phosphorus limitation eliminates an important blue-green algae advantage, as nitrogen limitation can greatly advantage Cyanophyta.

The major algal succession changes documented in ECR (Rushforth, S. 2003-2007 “Annual Phytoplankton Floras Reports”) appear to follow these major shifts in the W2 simulations. The potential to produce summer and fall toxic blue-green algal blooms in East Canyon Reservoir may have been significantly reduced overall, but the Anabaena and Microcystis[20] species that are occurring in the late summer and fall have a greater potential to produce toxins. The overall abundance of blue-green algae and chlorophyll has declined significantly from Mid-June to mid September. The continued presence of these particularly troublesome Cyanophyta is still a concern, and could be due to the general climatic increase in temperature. These species seem to be increasing on a regional scale, not just in East Canyon Reservoir.

The typical algal succession in ECR pre-2004 advanced waste water treatment phosphorus reductions was very large spring algal blooms with potential for nitrogen limitation by late June. Onset of hot temperature brings a major shift as spring algal blooms wane due to hot water and decreasing phosphorus. This shift is seen as the drop in early summer chlorophyll concentrations in Figure1.4.3.4-2. Brief periods in the heat of summer may coincide with co-limitation of phosphorus and nitrogen periodically, but large blue-green algal blooms could appear stacked into East Canyon Dam anytime during the summer and fall prior to 2004. Significant diatom populations also inhabited ECR throughout the summer and fall, and dinoflagellates and green algae were also common. After fall turnover very large blue-green algal blooms including Aphanizomenon, Microcystis, and Anabaena flos-aquae could also occur from late August into November if warm enough weather persisted, especially prior to 2004.

Following advanced wastewater treatment at ECWRF and reduction of erosion non-point sources by 2004 the algal succession has changed. The large mid May to mid July spring algal bloom dominated by diatoms is still present. Significant blue-green blooms are missing from July to near mid-September. However, the blue-greens that are present in August/September/October- Microcystis or Anabaena flos-aquae- now tend to out compete Aphanizomenon. **The W2 simulations mostly get this right**. The late fall turnover would seem to still be ideal for Aphanizomenon even without nitrogen limitation. Nitrogen does not have as great a tendency to be limited before phosphorus, thus the advantage to blue-greens is not as great. However, in late October 2007 a short duration but high peak Aphanizomenon bloom did occur, but was missed by W2. The current W2 algal succession research code appears to be following this overall reduction in Aphanizomenon, and periodic appearance of fall Microcystis and/or Anabaena

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[20] I observed more Anabaena and Microcystis in the fall of 2007 in Intermountain West Reservoirs than I had in my previous 30 years of study and research (personal communication from the author- Jerry Miller).

(modeled as a category) approximately correctly through 2007. This will be enumerated more in the next sections.

1.5 Scenario Modeling: Reservoir Response to Proposed Tributary Concentrations and Comparison to Baseline Calibrated Model

The scenarios that have been analyzed are all compared to the baseline. The baseline is the 2003-2007 actual phosphorus loading as computed by SWCA (2008). From 1999-2002 there had already been substantial erosion control put in place with apparent phosphorus reductions. Previous improvements in waste water treatment reduced phosphorus concentrations from 6-8 mg/L to about 4 mg/L in about 1995. In 2004 the advanced treatment implemented at ECWRF achieved a concentration of <0.1 mg/L. At that point East Canyon still contained a legacy phosphorus load, and the dissolved phosphorus in the discharge appears to have temporarily exceeded the concentrations in the inflow during parts of 2004-2006 (Figure 1.4.3.3-1).

During the 2003-2011 baseline loading simulations (2008-2011 repeating 2003-2006 hydrology) and again in the four repetitions of the average year (2008-2011 repeating 2005 hydrology four times in a row); sensitivity studies the cycle of intermittent build up and retention of phosphorus in the hypolimnion begins to show up. In fact the repetitions of the average year (2005) represent a worst case scenario for long term phosphorus retention. This intermittent retention and then routing inserts a question mark about consistently attaining some additional future phosphorus TMDL measurement end-point goals! This cycle was actually always present, but when the phosphorus concentrations were so high it was partially masked, and without the dynamic W2 modeling difficult to see. Again, the CE-QUAL-W2 model cannot predict hydrology or meteorology; therefore, the use of the dates 2008-2011 in the sensitivity studies should not be viewed as predictions for those years, but rather just as references for comparison in the future to similar hydrologic circumstances in the sensitivity studies. For example before final printing of this study it was obvious the spring 2008 inflow would be bigger than an average year in the East Canyon drainage. Therefore, comparisons for 2008 in these charts would best be made to the 2010-2011 year date designations in the sensitivity charts and tables.

The scenarios are all calculated as difference from the baseline, not from the larger phosphorus reductions attained since the mid-1990s. So, a 65% non-point source reduction in scenario C3d (Table 1.5.1-1) is actually nearer an 11% additional total reduction since 1995. Therefore, the differences in attaining new measurement end-point goals should be viewed as 11% overall reductions, rather than as 65-75% reductions. Viewed from this perspective the differences in attainment of new measurement end-point goals are small between the various scenarios presented in Table 1.5.1-1(11-16%), and showing the analysis results of all the scenarios is not a very useful exercise.

The recommended scenario is C3d, but maintaining the lowest practical point source loading in the summer is also an important consideration. Scenario C3d provides the greatest benefits as will be described in the following sections. Several scenarios actually achieve slightly greater overall phosphorus reductions than C3d, but with barely detectable increased improvements in water quality. Within the precision and accuracy of the model there are essentially no additional benefits from the scenarios with greater phosphorus reductions than C3d at least not projected out to 2011.

There are still questions about how much future improvement might yet occur over the next decade due to phosphorus reductions already realized. Certainly they will not be as great as the 60% reduction has yielded to date, but additional improvement may still develop over a longer time period as more legacy phosphorus is either permanently trapped in the sediment or cycled through the reservoir.

1.5.1 Nutrients- Phosphorus

Table 1.5.1-1 shows some of the scenarios that were considered for this analysis. The total loading is highly variable annually, but may have averaged nearly 6300 Kg from 1991-1998. The 1991-1998 time period was also slightly wetter overall, thus would have yielded a little higher load just due to hydrology. The range of phosphorus reductions computed against the baseline in Table 1.5.1-1 would actually be 11-16 % when computed against a 6300 Kg/Year average from 1991-1998. Therefore, the improvements expected in East Canyon Reservoir are small between scenarios, and when compared to the 60% overall reduction.

Table 1.5.1-1 Description of some of the potential future scenarios provided by SWCA and analyzed with CE-QUAL-W2.

Scenario	Load Kg/Yr	% < baseline	Scenario Description
Baseline	2,551	0%	Estimated 2003-2007 phosphorus loading; W2 calibration
Scenario 2a	2,801	+10%	Uses its existing allocation of point source load.
Scenario 2b	3,206	+26%	WWTP goes to 7.2 MGD at 0.1 mg/l TP and 0.03 mg/l ortho P
Scenario 3a:	2,038	-20%	WWTP goes to 7.2 MGD 0.1 mg/l TP; 0.03 mg/l Dissolved P; Nonpoint sources reduce by 50%.
Scenario 3b:	1,579	-38%	WWTP goes to 7.2 MGD at 0.1 mg/l TP and 0.03 mg/l ortho P; 75% nps reduction of TP during spring runoff and rain on snow; 60% nps reduction during baseflow and storms.
Scenario 3c:	1,506	-41%	WWTP goes to 7.2 MGD at 0.1 mg/l TP and 0.03 mg/l ortho P; 75% nps reduction of TP.
Scenario 3d	1,824	-29%	WWTP goes to 8 MGD at .1 mg/l TP and 0.03 mg/l ortho P; 65% nps reduction of both TP and DP.
			nps= non-point sources
Scenario 1a	1,990	-22%	Cap inputs at 0.046 mg/l TP based on East Canyon Creek recommendation.

Figures 1.5.1-1 & 1.5.1-2 have a lot of information in them. A W2 time line in this case is the simulation layer laterally averaged concentration extracted at about 3 p.m. every other day for the entire time period of the simulation. This is a tremendous amount of information as compared to three single location sampling dates 4-8 times per year.

Figure 1.5.1-2 appears difficult to comprehend at first glance, but careful study of this chart reveals a great deal about this reservoir. The top two lines compare the baseline and scenario C3d at the 2 meter depth where the most photosynthesis occurs. The middle chart shows the phosphorus reduction from the baseline versus the C3d scenario at elevation 1700 where phosphorus build up begins to spill through the hole in the old concrete dam and can be discharged. The bottom charts shows the maximum accumulation of phosphorus in the deepest portion of the hypolimnion stagnant zone on the bottom just upstream from the old earthen dam. The TMDL recommended scenario C3d appears to continue to provide slow but long term improvements over the baseline (bottom chart final two years). Careful study of the dam and weir configurations in Figures 1.3.1-1, 1.3.4-1 & 2, and 1.3.6-1 will aid in understanding this next section.

Figure 1.5.1-1 demonstrates the phosphorus reductions expected from Scenario C3d (recommended Plan) versus the baseline loading from 2003-2007. The continued decline of phosphorus even extrapolated out to 2011 suggests that East Canyon reservoir may not quit have reached a long term dynamic equilibrium from the pre-2004 legacy loads.

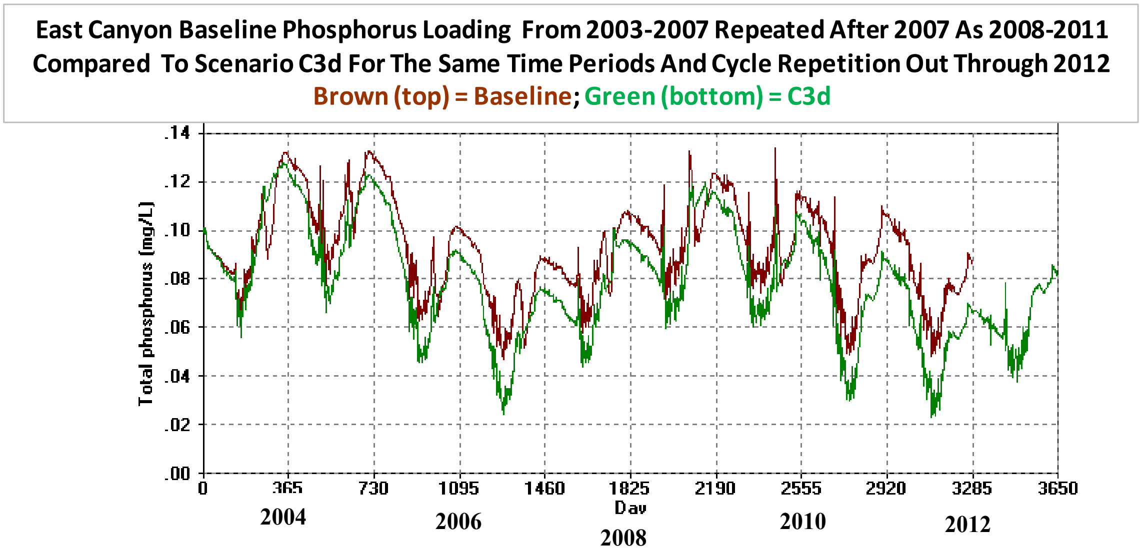
East Canyon Baseline Phosphorus Loading From 2003-2007 Repeated After 2007 As 2008-2011
Compared To Scenario C3d For The Same Time Periods And Cycle Repetition Out Through 2012
Brown (top) = Baseline; Green (bottom) = C3d

Figure 1.5.1-1 Charts the W2 simulation baseline total phosphorus discharge out of the dam (brown-top peaks) and the green line is the W2 simulation scenario C3d with an additional 65% non-point source phosphorus reduction. The C3d simulation continues through 2012 by repeating 2003-2007 hydrology, meteorology, and nutrient loading. In reality 2008 will be a wet year and more comparable to 2010. The low in C3d in 2012 is higher than 2011, but should be compared to the low in 2007 which shows that 2012 is still improving.

Figure 1.5.1-2 illustrates the phosphorus concentration at three depths, including the retention cycle and build up of phosphorus in the very bottom of the stagnant hypolimnion zone. It is important to note the difference between this hypolimnion buildup between the baseline and scenario C3d in the final two years. Scenario C3d is a significant improvement over the baseline. When the hypolimnion is completely mixed in the late fall through spring turnover the concentration at all depths are nearest homogeneous with the lines on all 3 charts nearly converging, but the deepest location near the bottom still remains slightly higher.

The middle chart shows the buildup of phosphorus is topped off by discharge through the hole in the old concrete dam at elevation 1700 M. The top chart shows the overall long term trend of decreasing summer time epilimnion phosphorus concentrations, with the epilimnion becoming more phosphorus limiting. This produces the overall reduction in summer time chlorophyll and in blue-green algae. The bottom chart is right on the bottom just upstream of the old earthen dam. The cycles show phosphorus buildup with flushing occurring only in a wet year on a very low reservoir pool such as 2005 repeated again as 2010. Long term trends should compare 2005 to 2010, 2006 to 2011. Long term phosphorus reductions are still occurring even from the 60% phosphorus reductions already in place.

The ECWRF advanced WWT for phosphorus reduction continues to produce declining summer time epilimnion phosphorus concentrations even though the deep hypolimnion begins to retain and rebuild higher phosphorus concentrations after the 2005 (repeated again in 2010) wetter year following dry years. The significant summer time decline in the top chart, often to less than 0.02 mg/L at the 2 meter depth following 2005, is a major phosphorus TMDL reduction accomplishment.

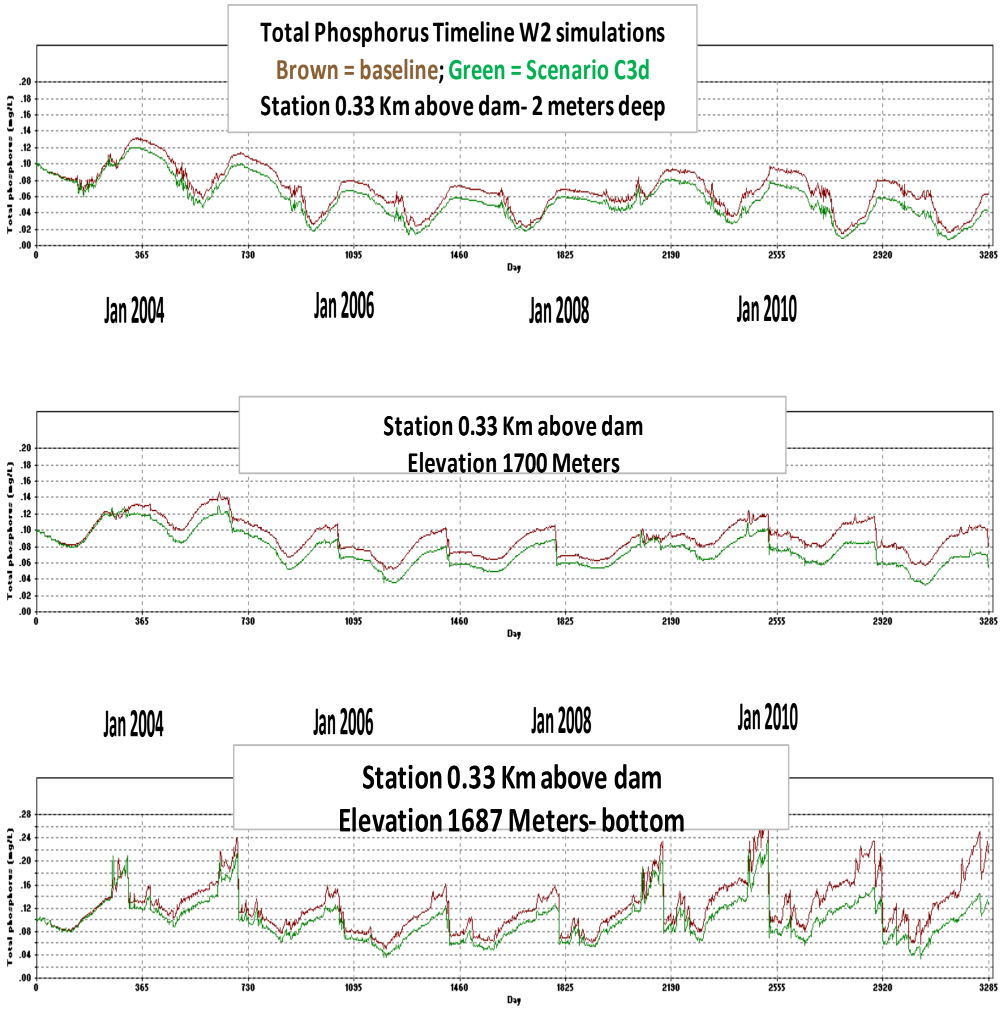

Figure 1.5.1-2 charts a set of time line extractions from the W2 station 0.33 Km upstream from the dam at 2 meters deep, elevation 1700 (approximately the hole through old concrete dam elevation), and at elevation 1687 at the water sediment interface upstream of the old earthen dam in the hypolimnion stagnant zone. The comparisons are to the baseline and to Scenario C3d with an additional 65 % reduction of non-point sources calculated from the baseline loading. The baseline is the top line and the reduction scenario C3d is the bottom line in each chart.

The spring turnover mixes phosphorus to the euphotic zone at concentrations still exceeding 0.08 Mg/L, the spring inflow forms an overflow density current, and the epilimnion both warms and accumulates phosphorus. Phosphorus limitation in the epilimnion is only attained once the spring inflow subsides and the summer thermocline is set up. The large spring algal biomass then utilizes most of the remaining phosphorus in the epilimnion and settles through the thermocline taking the phosphorus with it. The dilution of spring inflow, the cold but still aerobic hypolimnion, and the large algal uptake of dissolved phosphorus from the spring algal bloom results in the lowest phosphorus concentration in most of the water column in June.

The spring algal blooms wane because it becomes too hot for these species, and because they run out of phosphorus-thus phosphorus becomes limiting to algal growth through most of the remaining summer time period in the shallow epilimnion of the reservoir. Maintaining this epilimnion phosphorus limitation in the summer is highly dependent on the wastewater treatment plant maintaining its loading allocation.

Decomposition of organic matter continues slowly in the sediment in the cold water. The W2 simulations indicate that the deep hypolimnion sediments slowly accumulate, bury and trap some organic matter. The turnover of most of the organic matter not buried deeper than about one centimeter in the sediments takes more than one year. This autochthonous organic matter is often considered internal loading and may incorrectly be assigned to the anaerobic inorganic phosphorus release without first order organic matter computations. This 2-3 year time period to recycle the algal biomass and its' phosphorus would produce at least 2-3 year delays in realizing maximum improvements in water quality, but should still be counted as watershed phosphorus that can be managed by the TMDL. The even longer term trends are due to continued reductions of higher legacy phosphorus loads.

The April-June inflow and the phosphorus mixed up to the shallows are utilized by phytoplankton. The phytoplankton that settles to depths less than 12-14 meters deep can decompose in 15-30 days once the temperature is >15 to 24 °C. The nutrients released during this rapid decay process are again biologically available and reutilized by phytoplankton. Thus some phosphorus may go through 2-4 algal uptake/growth/decay cycles in a 4-6 month growing period; while phosphorus deeper than 15 meters may not be incorporated into the phytoplankton cycle once in the next two years. Thus the deeper the water column and the less littoral shallow area, the more resistant the waterbody is to a higher trophic status. **The April-June spring dissolved phosphorus in the spring runoff overflow current are physically and biochemically more available, and may be utilized several times over the summer growing season. These nutrients are a high priority in the seasonality traits of phosphorus inflows into the reservoir.** Scenario C3d targets reductions in this April-June spring runoff non-point source phosphorus load. Scenario C3d also results in an overall phosphorus reduction that produced a long term decline in hypolimnion phosphorus retention as illustrated in Figure 1.5.1-2. While it is true the spring inflow is at a lower concentration than the spring turnover concentration in the water column, this high inflow period is also the high loading period. Never-the-less, the phosphorus concentrations during spring inflow are still too high.

All the potential future scenarios considered, coupled with the recycling build up and retention of phosphorus in the deep stagnant hypolimnion zone, still leave too much phosphorus during the spring turnover. The high load associated with the spring runoff only exacerbates this spring bloom issue. Some additional management options of phosphorus build up in the stagnant hypolimnion may need to be considered. However, any such alternatives would be greatly enhanced by an additional 65% non-point source reduction (scenario C3d), plus any additional annual reductions that could be implemented. Figure 1.5.1-2 demonstrates that the current baseline condition would still result in a rapid rebuild of phosphorus in the hypolimnion, whereas scenario C3d would produce a much slower build up in the hypolimnion. Therefore, scenario C3d might make some alternatives for hypolimnion phosphorus management more feasible.

Aeration of the hypolimnion does not appear to present a significant opportunity for overall bioavailable phosphorus reduction in this reservoir, and consideration of this as a viable alternative would require a lot more sediment phosphorus release studies. **Aeration would be most effective if a large portion of the hypolimnion phosphorus release came from anaerobic release of inorganic phosphorus. However, the W2 simulations strongly indicate that most of the phosphorus release comes from decomposition of autochthonous organic matter. Aeration can actually accelerate organic matter decay.**

1.5.2 Chlorophyll a

The spring algal blooms are still reaching light limitation at least part of the time in late May and early June until phosphorus becomes limiting after stratification sets up a thermocline.

This is true of the baseline and remains true even in all the scenarios tested. The measurement end-point improvements in East Canyon Reservoir in chlorophyll and blue-green algal blooms came fairly quickly (1-3 years) following major phosphorus reductions accumulated to about 60% overall since the1990s. The next increment of reductions contemplated in these scenarios amount to an additional 11-16 percent total phosphorus reduction since the 1990s. Improvement in water quality from future reductions will not be noticed nearly as quickly as the larger reductions have been. East Canyon Dam exported a tremendous amount of algal biomass giving it a lower trophic status presentation. These scenario simulations probably do not reach out far enough to see beyond the legacy phosphorus concentrations of the past. This will especially be true with dissolved oxygen.

BASELINE-

Chlorophyll a mean summer concentration daily extracts 2 Meters deep at the three protocol stations from the Baseline W2 simulation.

2003-2007; repeat 2003-2006 referenced as 2008-2011 at baseline (2003-2006 phosphorus loading rates)

Station Km upstream		Chlorophyll a concentration in **µg/L**								Year	DAYS %>30
of dam	2003	2004	2005	2006	2007	2008	2009	2010	2011	2003	9.9%
St 0.18	6.6	4.6	4.5	4.7	3.4	6.7	7.3	6.4	5.6	2004	7.7%
St 1.45	8.2	6.7	5.8	6.2	4.6	7.6	8.0	7.3	6.5	2005	4.4%
St 3.9	11.9	9.9	7.4	9.6	6.1	6.7	8.5	7.6	6.5	2006	7.7%
Avg	8.9	7.1	5.9	6.8	4.7	7.0	7.9	7.1	6.2	2007	1.1%
St 0.18 Max	45.6	26.7	21.4	30.1	22.5	49.5	44.6	31.7	26.5	2008	6.6%
St. 1.45 Max	31.9	24.6	23.3	25.7	22.3	42.8	40.2	26.7	27.8	2009	13.2%
St. 3.9 Max	73.7	58.6	23.3	64.6	36.7	50.3	49.2	49.7	58.9	2010	5.5%
	2003 based min. initial conditions should not be looked as calibration, but establishing an initial condition									2011	3.3%

Table 1.5.2-1- contains the Baseline calibration simulation from 2003-2007 mean/max/min chlorophyll data from the W2 simulations. The 2008-2011 is the sensitivity study period for the repeat of the baseline conditions from 2003-2006 continuously simulated after 2007. The far right column is the count of the number of days that chlorophyll a would exceed 30 µg/L at any station as a percent of the summer growing season days. The proposed measurement end-point would be not to exceed 10%; which means

there is slim margin of safety at the current conditions. There are still periodic very high peak chlorophyll concentrations. The 2010-2011 peaks are sometimes higher than 2005-2006 peaks due to retention of phosphorus in the hypolimnion in that cycle.

Certain hydrologic cycles and/or storm and runoff conditions could cause exceptions to the data in table's 1.5.2-1 & 2. These are not predictions, but scenario sensitivity tests. We already know that 2008 will be one of the wettest years since the mid 1990s and not a repeat of the 2003 dry year. The best comparison for 2008 in this table might be 2010.

Every 2-3 year set of 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 fall and spring turnover. Some combinations, like four consecutive years repeating an "average year" condition with 2005 hydrology would achieve maximum retention of phosphorus in the stagnant zone of the hypolimnion and would exceed many of the measurement end-point goals for the phosphorus TMDL. Fortunately four consecutive average year runoffs is not a likely condition, because this average year scenario repeated produced a worse case condition.

WWTP goes to 8 MGD at .1 mg/l TP and 0.03 mg/l ortho-P; 65% non-point source reduction of both Total Phosphorus and Dissolved Phosphorus; scenario C3d.

	C3d[21]	2003-2007 repeated 2003-2006 simulating out to 2011									Days
	2003	2004	2005	2006	2007	2008	2009	2010	2011		%>30 µg/L
St 0.18	6.6	4.5	4.3	4.1	3.0	5.8	6.2	5.2	4.4	2003	2.20%
St1.45	8.2	6.6	5.4	5.5	4.0	6.6	6.9	6.2	5.0	2004	0.00%
St 3.9	11.8	9.7	7.0	8.2	5.5	5.6	7.3	6.3	4.6	2005	0.00%
Avg	8.9	6.9	5.6	5.9	4.2	6.0	6.8	5.9	4.7	2006	0.00%
Max St 0.18	46.0	26.9	21.0	23.7	21.0	41.3	34.9	29.0	24.1	207	0.00%
MaxSt1.45	31.6	26.9	22.6	20.7	20.7	37.9	32.7	26.0	30.2	2008	2.20%
Max St 3.9	72.7	58.4	54.8	52.6	33.7	33.5	43.3	47.1	46.9	2009	2.20%
										2010	0.00%
										2011	0.00%

2008 is repeat of 2003 hydrology, but required an "artificial drawdown" to get to right elevations; it also follows a different preceding hydrology, and gives a different result.

Table 1.5.2-2 are the mean/max/min summer chlorophyll's for the W2 simulations of the C3d scenario, which seeks an additional 65% non-point source phosphorus reduction primarily during spring runoff.

Both the baseline and scenario C3d start with the same initial condition phosphorus concentration-making the C3d a conservative scenario. A significant margin of safety is achieved with scenario C3d if the measurement end-point goal is to maintain less than 10% of the days in the summer growing season at

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[21] There is no additional improvement in % days that exceed 30 µg/L chlorophyll from scenario C3d and scenarios with greater reductions of external phosphorus loading like C3b or C3c.

less than 30 µg/L chlorophyll a concentrations at any station. The three stations are daily extractions in the afternoon at 2 meters deep in the same W2 segments as the three protocol sampling stations.

Reducing overall summer chlorophyll will also reduce the occurrence of blue-green algal blooms. Thus scenario C3d will also provide an additional margin of safety in attaining reduction of blue-green algae.

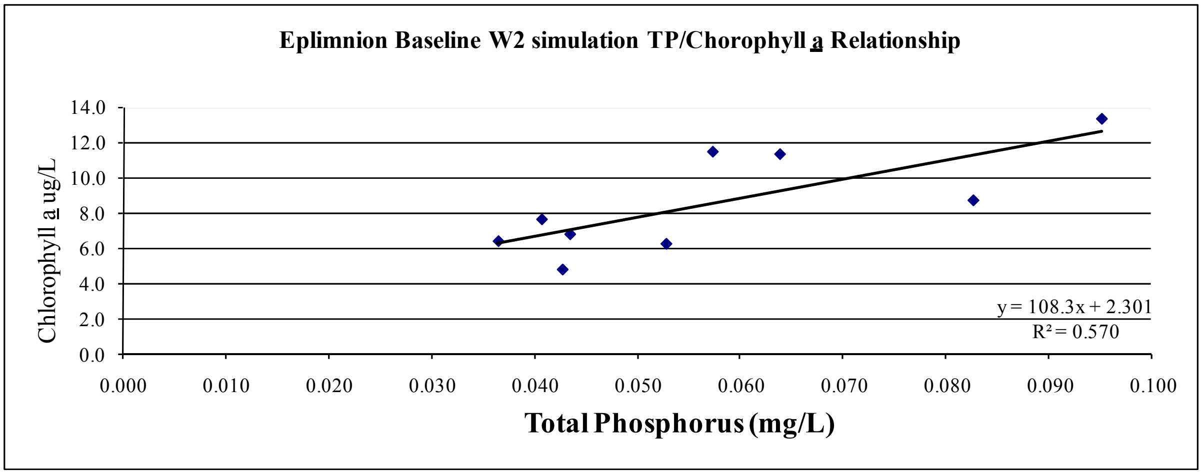


Figure 1.5.2-1 shows the relationship between mean annual summer chlorophyll a concentrations for the baseline W2 simulation versus the mean summer epilimnion total phosphorus concentration. The R^2 of this relationship is not real high because the spring and occasionally the late fall algal blooms are still self shading light limited or periodically nitrogen limited, not phosphorus limited.

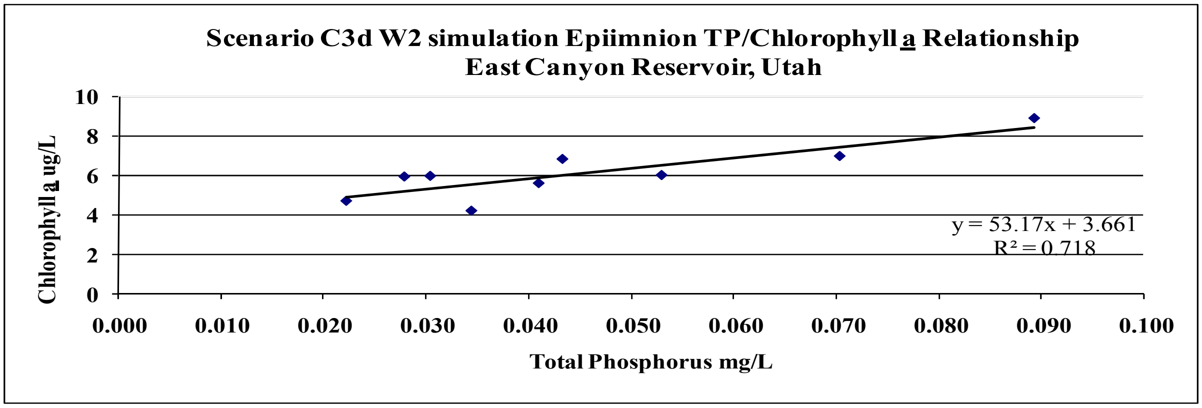


Figure 1.5.2-2 is the relationship between mean summer chlorophyll and epilimnion total phosphorus from the scenario C3d W2 simulation scenarios. The R^2 is better than the baseline because phosphorus is limiting more often.

Although very significant measurement end-point goals have been achieved at East Canyon Reservoir over the past 5 years; the hypolimnion, spring turnover, and late fall turnover phosphorus concentrations remain too high. In 1999-2002 it was visually obvious that construction in the watershed was a significant part of the non-point source pollution problem. Currently it is less obvious that non-point source controls can achieve the scenario alternative goals. Another alternative may need to consider managing the multi-year accumulation of phosphorus in the stagnant zone of the hypolimnion. This could help reduce spring and fall turnover epilimnion phosphorus concentrations.

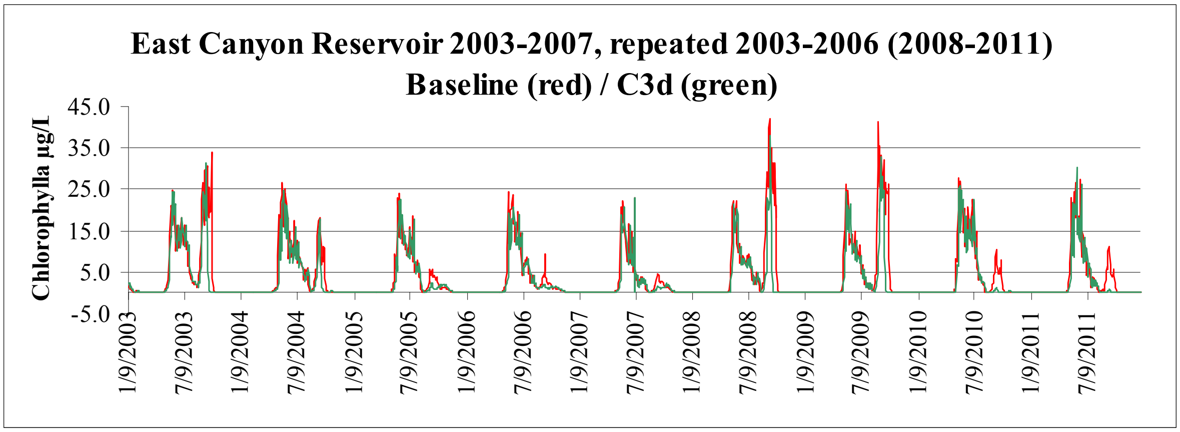


Figure 1.5.2-3 charts the summer chlorophyll relationships between the baseline and Scenario C3d. Note the continued improvements shown as a decline in the second set of peaks each year (late summer/fall) with Scenario C3d versus the baseline. This should also indicate a long term potential reduction in fall blue-green algae if scenario C3d is implemented.

1.5.3 Blue-Green Algae

One of the most significant achievements of the East Canyon Phosphorus TMDL is the reduction of summer and fall Cyanophyta. Five figures demonstrate these reductions as they are computed in the CE-QUAL-W2 simulations with the R&D code for algal succession code previously described. One of the principal purposes for developing this R&D code was to complete reservoir water quality assessments for phosphorus TMDLs, to model the location and magnitude of blue-green algal blooms in the reservoir, and to simulate when Cyanophyta might be expected to subside due to phosphorus limitation. This is one of several reservoirs planned or being tested to determine if the algal succession R&D code can accomplish these goals. Reductions in epilimnion summertime phosphorus and summertime chlorophyll have already been discussed. Scenario C3d provides a significant benefit in chlorophyll with a reduction of about an additional 5% days exceeding 30 µg/L over the baseline.

Figures 1.5.3-1 demonstrates the algal succession from the W2 simulations of the 1991-1998 periods with much higher phosphorus loads from the watershed. Although there is not a lot of phytoplankton data in the 1990s, it basically shows that Cyanophyta blooms occurred from July-November, with Aphanizomenon dominating, especially in the fall. The fall Aphanizomenon dominance has been greatly reduced post phosphorus reductions, especially since 2003. When phosphorus builds up in the hypolimnion stagnation zone over a period of several years, eventually the fall turnover followed by a long warm late fall will produce blue-green algal blooms. Overall the dominance of Cyanophyta in East Canyon Reservoir will decline from approximately 15>30% pre phosphorus control, to nearer 12% in 2003, and finally to 6% or less in the baseline. Scenario C3d has the potential to drop the overall blue-green algae to only about 3% of the total algal biomass (Figure 1.5.3-5).

The summer Cyanophyta group in Figures 1.5.3-2 & 4 includes Microcystis and Anabaena flos-aquae, although the Aphanizomenon group could also include Anabaena. The W2 baseline simulations correctly follow Dr. Rushforth's data with a significant Microcystis bloom in 2004, and a smaller summer Cyanophyta bloom in 2005 (Figure 1.5.3-2).

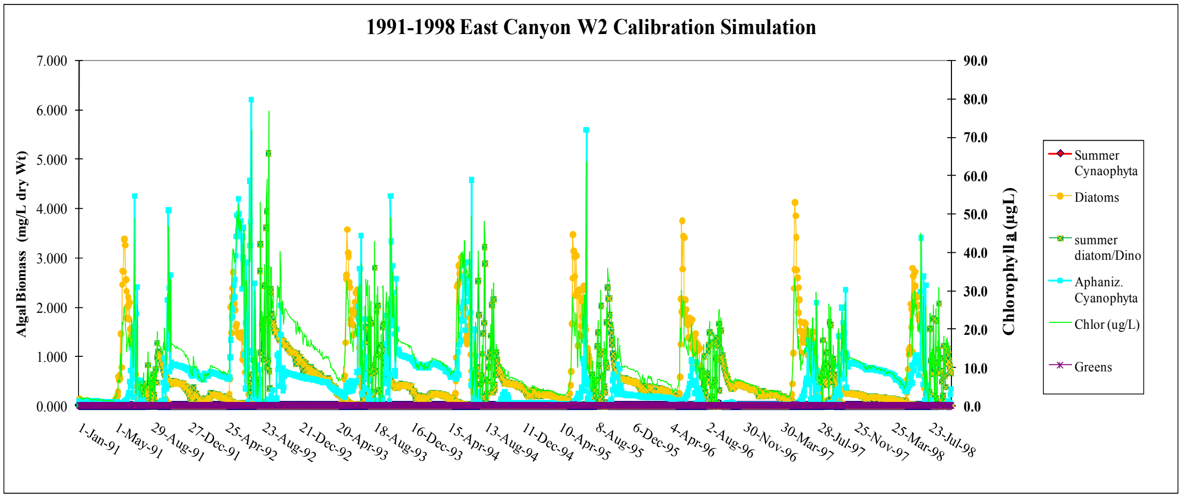


Figure 1.5.3-1 is the W2 simulation algal category succession from 1991-1998. Large Aphanizomenon Cyanophyta (could also include Anabaena) blooms occur anytime from July to November. The sketchy data and personal observations also suggest this is true. The large spring algal blooms dominated by diatoms are also present, but the early appearance of Aphanizomenon dominance throughout the summer and fall suggest nitrogen limitation, thus heavily favoring the nitrogen fixing blue-green algae with the greatest vertical migration and adaptability to reduced light from self shading. The hyper-eutrophic reservoir has less phytoplankton diversity. Nutrients are seldom limiting to algal productivity.

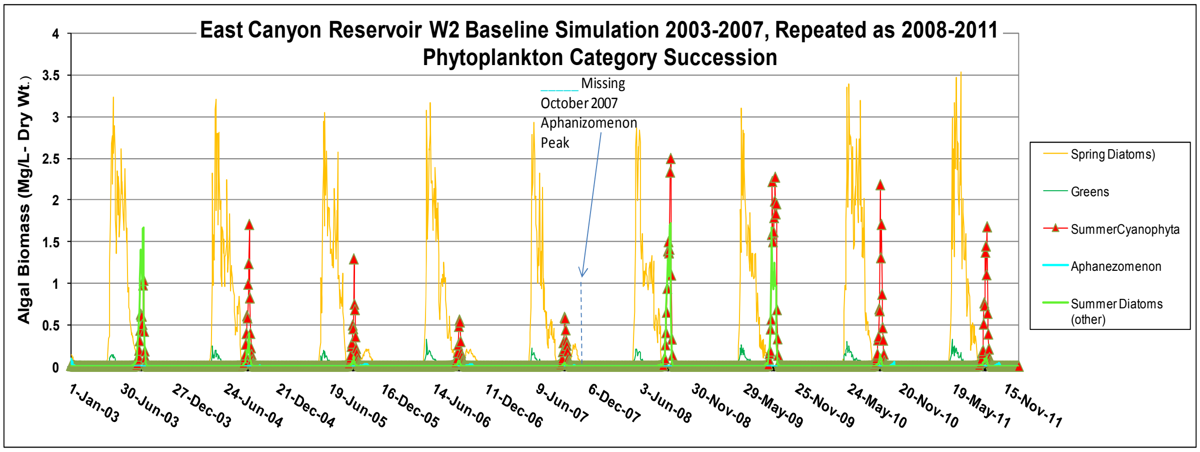


Figure 1.5.3-2 is a summary of the W2 simulation's baseline period algal succession from 2003-2007. The model hits the important data points of a big Microcystis peak in 2004 (included as summer Cyanophyta- red triangle), and shows a huge decline in fall Aphanizomenon. This is a good semi-quantitative reproduction of the data. The concern is the repetitions of summer/fall Cyanophyta out into the future. Remember this is a repeat of the baseline following 2007, thus the 2008-2009 repeats the 2003-2004 hydrology and higher nutrients loads pre-advanced wastewater treatment. However, the calibration misses a short duration Aphanizomenon peak following turnover in later October of 2007. In this case the Summer Diatoms (other) category could include any non-nitrogen hot weather phytoplankton (greens) other than Cyanophyta.

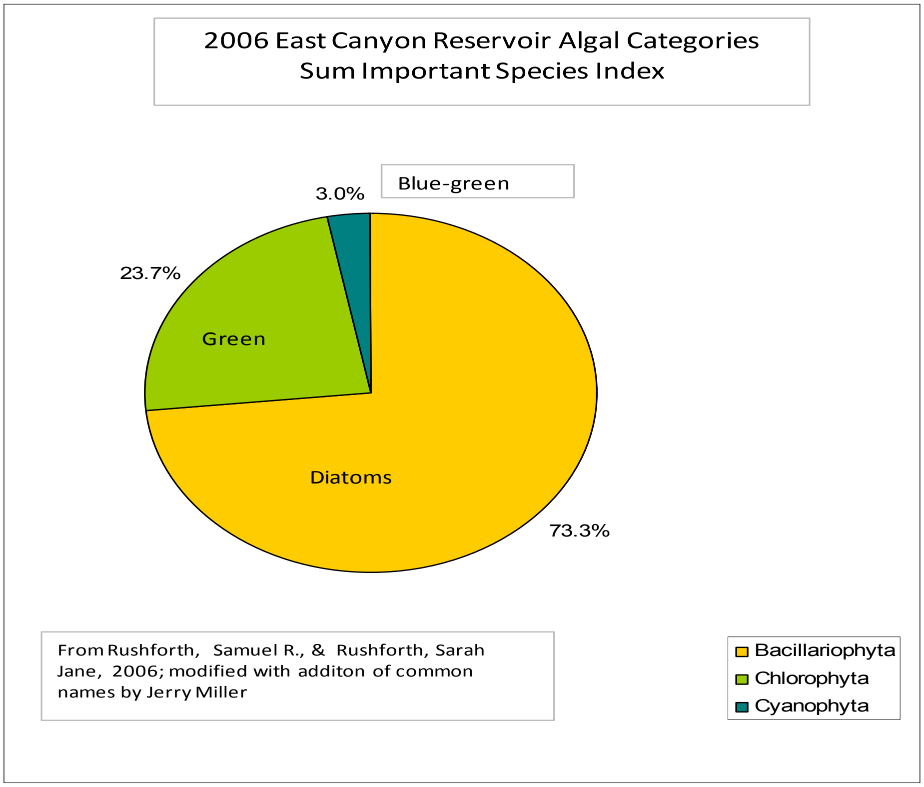


Figure 1.5.3-3 2006 East Canyon Reservoir Algal Categories as a percent of the sum Important Species Index comprised by the major groups of phytoplankton from samples collected from East Canyon Reservoir during 2006. Important Species Indices (ISIs) were calculated by multiplying the percent frequency of the taxon by its average relative density (Kaczmarska and Rushforth 1983). This Figure was modified (addition of common names) from Rushforth, 2007;"A STUDY OF PHYTOPLANKTON FLORAS FROM EAST CANYON RESERVOIR, MORGAN COUNTY, UTAH; SUMMER, 2006".

Table 1.3.3-1 Dr. Rushforth's annual algal category summarized for

Cyanophyta (blue-green algae) in East Canyon Reservoir (Rushforth, 2002-2006- all)

	Percent blue-greens
2002	18.6
2003	9.3
2004	28.0 [Potentially toxin producing ***Microcystis incerta*** (ISI = 20.68)]
2005	10 [1]
2006	3.0

[1] The annual biomass is not only a function of the peaks, but of the duration. The peak is not allows a good indicator of the importance, as some peaks can be high, but with a very short duration. Overall Cyanophyta decreased significantly since July 2005, and Microcystis incerta decreased after 2004. Aphanizomenon flos-aquae have significantly decreased from 1990s. Aphanizomenon flos-aquae were very important in East Canyon Reservoir prior to phosphorus reductions. The W2 simulations show the Aphanizomenon dominance in the fall during the 1990s (Figure 1.5.3-1), but only yield traces after 2003. There was one high but short duration late October Aphanizomenon bloom peak in 2007

which the W2 simulation misses in magnitude showing only a trace. Toxicity caused by Aphanizomenon has not been documented in the author's experience in this region.

The Microcystis and Anabaena blooms (summer Cyanophyta group in W2 figures 1.5.3-2 & 4) are the greatest concern to produce toxins. Unfortunately the W2 simulations indicate that these blooms may persist in both the baseline and C3d scenario during a future drought condition like 2003-2004 repeated in 2008-2009. The extrapolated years have even higher peaks of the summer Cyanophyta group in 2008-2009 than in 2004. This is probably due to a greater buildup of phosphorus in the stagnant zone of the hypolimnion in the wetter hydrologic sequence leading up to 2008. The possibility of toxic blue-green algal blooms cannot be entirely ruled out in the future, nor can the W2 simulation of future blooms be taken lightly because the model follows the past trends to well.

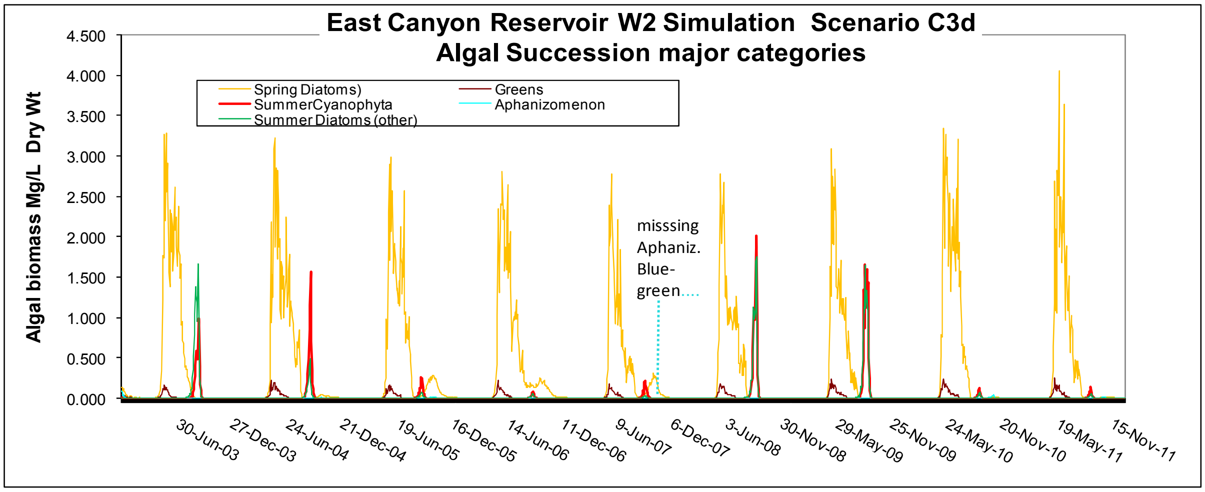
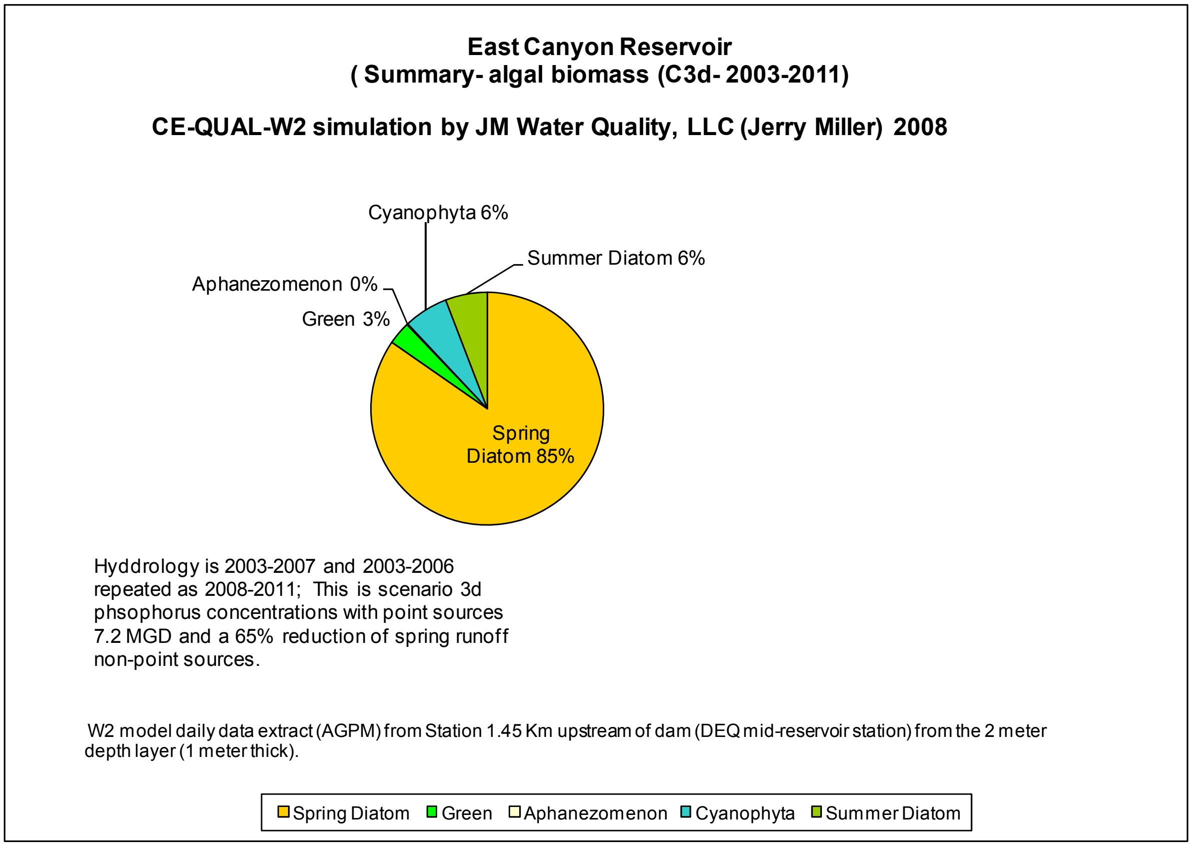


Figure 1.5.3-4 W2 simulations of scenario C3d still indicate that the summer Cyanophyta blooms of 2004 would continue; the even larger peaks in the drought sequence of 2003-2004 extrapolated out to 2008-2009 are a concern. The Summer Cyanophyta category includes Microcystis and Anabaena, which the simulations correctly show in the baseline calibration in 2004, and they are still present in all the scenarios. The only real problem with the major algal category succession in the W2 simulations is the missing short duration Aphanizomenon bloom in late October, 2007 of the baseline calibration. Although a few very small Aphanizomenon peaks are barely visible in the Scenario C3d W2 simulations, it is likely they will occur under the right conditions in the future with any scenarios envisioned. However, the W2 simulations do show the correct trends away from the large Aphanizomenon blooms of the 1990s in the post phosphorus reductions in the 2000s.

Figure 1.5.3-5 is a pie chart summary of the algal categories as simulated by the W2 Scenario C3d over the entire time period from 2003-2011. The Cyanophyta groups represent only 6% of total simulation algal categories, but may slightly under represent the late fall Aphanizomenon potential as seen in the short duration high peak that occurred in late October 2007 (Rushforth, 2008 personal communication). There appears to be a regional trend towards more Microcystis and Anabaena blooms during the extensive drought from 1999-2007. This drought cycle has also been accompanied by very hot summers and falls. Water temperatures were higher during the summer of 2003-2007 (2005 exception) than in the very wet years from 1993-1998. Even though the phosphorus reductions in scenario C3d indicate an overall decline in Cyanophyta blooms, the W2 simulations still show the problem late Summer Cyanophyta category with occasional blooms. The late fall conditions are also very likely to produce Aphanizomenon blooms as well. Overall the W2 simulations are a nice confirmation of the algal succession at East Canyon Reservoir, but actual future conditions also depend on phosphorus and nitrogen ratios being close to the numbers in the model. If the loads and N:P ratios vary, then so may the advantages to blue-green algae.



Hyddrology is 2003-2007 and 2003-2006 repeated as 2008-2011; This is scenario 3d phsophorus concentrations with point sources 7.2 MGD and a 65% reduction of spring runoff non-point sources.

W2 model daily data extract (AGPM) from Station 1.45 Km upstream of dam (DEQ mid-reservoir station) from the 2 meter depth layer (1 meter thick).

Figure 1.5.3-5 charts the summary of the W2 simulation of scenario C3d algal categories from 2003-2011. This chart is similar to Rushforth's phytoplankton report summary from 2003-2005, but with a reduced Cyanophyta; the W2 simulation summer diatom category could also include Chlorophyta (Green algae), which increases in Dr. Rushforth's in the past few years.

The future reduction scenarios with less phosphorus than the baseline are all very similar with regards to chlorophyll, blue-green algal dominance, and dissolved oxygen. They all provide only an additional 11-16% reduction from the historical inflow loadings that occurred through the 1990s. Scenario C3d provides as much benefit as any scenario, but at reduced loading reductions from the more stringent scenarios. The W2 simulations keep showing that the blue-green algae category that would include Microcystis and Anabaena produces periodic late summer blooms carrying over into fall turnover, especially during drought conditions. Since they have been present in recent years there is concern that a buildup of phosphorus coupled with a cold early turnover, a significant runoff event, and then a long fall warm period still have the potential to produce problem Cyanophyta events. The magnitude of such an event would also be influenced by the buildup of phosphorus in the stagnant zone of the hypolimnion over the previous several years.

The probability of significant blue-green algal blooms in July or August should be less since 2005. This is a very significant achievement of the phosphorus TMDL because July and August is the peak of the primary body contact recreation season. The data and the W2 simulations show very large blue-green reductions in July and August in 2005-2007, as compared to the 1990s. The model simulations also track the trends in algal succession away from summer blue-green and total algal production. July and August are also the peak water use months, and peak time for blue-green algae toxins to impact drinking water treatment plants. Again, this July/August reduction of blue-green algae is an important water quality achievement. The W2 simulations also track the switch from Aphanizomenon to Microcystis and Anabaena flos-aquae Cyanophyta species from the 1990s versus 2005-2007. Dr. Rushforth's periodic data from the 1990s did include occasional outbursts of non-Aphanizomenon Cyanophyta in the late summer. **The 1990s W2 simulations of Aphanizomenon could also include Anabaena flos-aquae in that category. The model has sufficient "robustness" to indicate there is still some concern about September/October future cycles and blue-green algae under certain hydrologic and meteorological conditions.**

1.5.4 Turbidity

The 2008 spring runoff events will be the most significant in recent years. However, just as East Canyon Creek peaked it cooled off and snow feel again several times. This reduced the overall maximum peak and produced a runoff with little concern for flooding. East Canyon Dam was spilling by the end of May. With the exception of some accumulations of shoreline organic matter debris there was little visual evidence that the runoff produced turbidity beyond the first 3-4 W2 segments in the inflow area of the bathymetry file. The rest of the reservoir was quite clear, but beginning to turn green by late May. Indications are that allochthonous organic matter settles quickly into the sediment delta in the first 3-4 W2 segments, or the floating organic matter accumulates to shorelines and warm water with active wave mechanical breakdown. Much of the small floating organic matter is actually thrown up on the shore by the wave action. The W2 assumptions would laterally average this allochthonous organic matter and quickly route it down reservoir creating too much metalimnion oxygen demand.

Shoreline wave action appears to produce more reservoir wide turbidity than the inflow. In some areas shoreline wave action turbidity is quit pronounced, and high speed boating and recreation equipment only add to the wave's assault on the shore. In narrow reservoirs with this shoreline wave generated turbidity, the maximum Secchi disk depths are often less than 5-8 meters. Maximum spring Secchi Disk depths rarely exceed 4-6 meters. Once the spring diatom blooms begin Secchi depths are rarely more than one meter. The highest Secchi depths generally occur in the winter under ice with minimal phytoplankton production, and no shoreline wave erosion.

With some adjustments and a rule set cut off at 8 meters, Figure 1.5.4-1 estimates the Secchi Disk depth as a relationship to chlorophyll in East Canyon Reservoir. Shoreline wave action generated turbidity probably does not vary much unless the reservoir is extremely drawn down. There is also a relationship between light limitation to algal growth and the flattening curve of low Secchi depth to high chlorophyll concentrations. Future data collection should consider improving or revising this relationship, and then enrolling volunteers to collect many Secchi Disk transparencies at selected sites in this reservoir to help improve lateral average total algal biomass productivity estimates. This Secchi Depth chlorophyll relationship chart should be checked and/or revised with future data. This would allow volunteers or State employees to take Secchi Disk Depths which could be used to calculate biomass productivity.

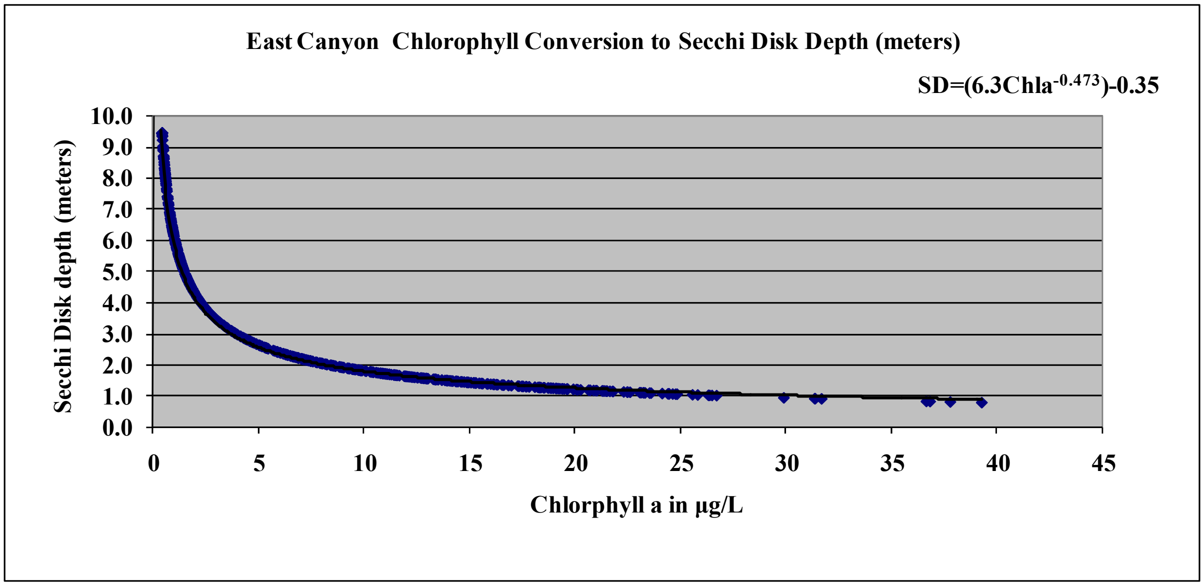


Figure 1.5.4-1 The Secchi Depth chlorophyll relationship follows Chapra (1997) with a slight modification for increased turbidity due to shoreline wave action erosion in the steep sided narrow reservoir, which probably should also truncate this trend line at about a maximum of 7-8 meters. If there is very little inorganic suspended solids or chlorophyll the maximum Secchi Depth can be much higher in deep oligotrophic lakes. Secchi depths greater than 4-5 meters would be rare in ECR due to shoreline wave action and chlorophyll, and would probably only be found right after ice off, when there has been a long period of time with no shoreline wave action erosion.

1.5.5 Dissolved Oxygen

Figure 1.5.5-1 utilizes AGPM to extract W2 simulation timelines of the 1991-1998 calibration with the recommended plan scenario C3d at two stations, the 12 and 20 meters deep (station 1.45 Km upstream from the dam), and at elevation 1687 (station 0.33 Km immediately upstream of the old earthen dam-which is right on the bottom). Figure 1.5.5 depicts the annual cycle of dissolved oxygen in East Canyon Reservoir from the 1990s calibration compared to the C3d scenario. Unfortunately the lack of difference in slope in each year's descending limb (rate of dissolved oxygen depletion) from three metalimnion/hypolimnion locations is what makes this image remarkable. Like Deer Creek Reservoir, East Canyon's greatest memory for hyper-eutrophic status is dissolved oxygen depletion rate during summer stagnation. Additional research is needed to better understand why so many improvements in chlorophyll, blue-green algae, water clarity, and perhaps even fish survival can be documented; with so little improvement in dissolved oxygen. The only solution afforded by these CE-QUAL-W2 simulations is that the spring turnover and the spring inflow still provide sufficient phosphorus to drive spring diatom blooms to light limitation by self shading. The presentation of these spring blooms is so different than the shoreline and surface scums of blue-green algal blooms as to go almost unnoticed. The water is so cold in April and May that little primary body contact recreation occurs. Thus there is also less public concern about the spring blooms. Fish need food to, and the spring blooms provide plenty for optimal fish growth, unfortunately these same blooms also produce maximum summer stagnation dissolved oxygen depletion. The lack of adequate water temperatures and dissolved oxygen in August precludes the cold water fisheries survival in most years.

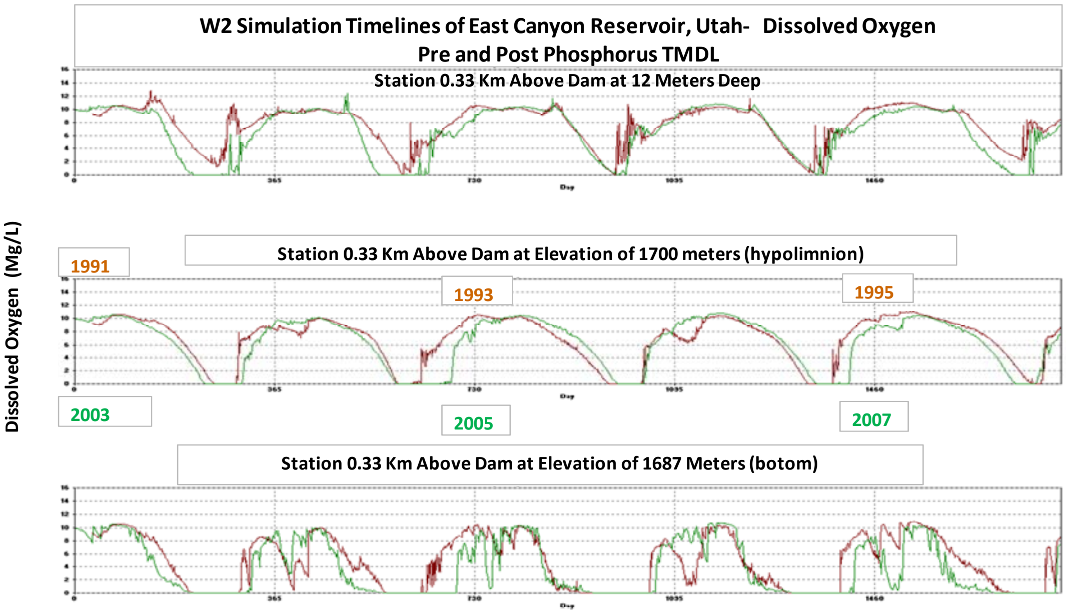


Figure 1.5.4-2 is a time line extraction from the W2 simulations for 1991-1998 (brown) compared to 2003-2007 (green- 2003-2007once per day at about 3 p.m. from the W2 layers representing 12 meters deep (top), Elevation 1700- Outlet in old concrete dam (middle), and the bottom elevation 1687 or bottom of reservoir (bottom-chart). The brown lines are 1991-1998 baseline calibration water quality data, and the green line is the alternative C3d which projects the currents phosphorus reductions plus an additional 65% non-point source reduction in the W2 simulation. The right descending limb from each year represents the slope or rate of dissolved oxygen decay during summer stagnation beginning after the thermocline sets up. Occasionally the bottom at elevation 1687 becomes quit dissolved oxygen depleted even in the winter, and is more likely to do so in dry years. The wetter years during the 1990s may have had much shorter summer stagnation periods, and periodically have better dissolved oxygen than the reduced phosphorus time lines from 2003-2007. Thus the noise of hydrology and summer weather are still as important features in determining what is caused by reductions in phosphorus budget, and what is caused by changes in hydrology and climate. The largest differences in comparative descending limbs of oxygen depletion rates (slope) are unfortunately more controlled by hydrology than by phosphorus reductions even with the recommended scenario C3d.

Station 0.33 Km at elevation 1687 in Figure 1.5.4-2 is the bottom of the hypolimnion stagnation zone illustrated in Figure 1.3.6.1-1, and is just upstream from the old earthen dam. The point of Figure 1.5.4-2 is that the oxygen decay rates or slopes of the falling limbs each year in the charts have changed little even though a 60% phosphorus reduction has been implemented since the 1990s, and with another 11-16% reduction as in scenario C3d that dissolved oxygen will still improve only slightly. At Deer Creek Reservoir just to the South of East Canyon Reservoir in a similar climate zone, the phosphorus has been reduced by about 72% since 1980 (author’s personal estimate), yet the dissolved oxygen in the water column has improved very slowly- but continuously- over the past 3 decades. Although several other important measurement end-points have fared much better than dissolved oxygen at both Deer Creek and East Canyon Reservoir; it appears that dissolved oxygen recovery is a long process. The skimmer affect of the old dams at East Canyon Reservoir exported large algal blooms during the summer, thus lessening its’ eutrophic presentation; these same structures are likely to prolong dissolved oxygen recovery in East Canyon, perhaps longer than occurred in Deer Creek. Therefore, management of the phosphorus and dissolved oxygen in the stagnant zone of the East Canyon hypolimnion may need to be considered.

The hydrographs are somewhat comparable (Figure1.5.4-2) in that 1991-1992 and 2003-2004 are very dry; 1993-1998 are wetter than in the 2000s, and 2005-2007 are near average hydrology.

So, what is the link between dissolved oxygen and phosphorus reduction? Are they that closely linked? Do these deep cold sediments simply retain organic matter which decays at very slow and fixed rates over very long time periods? If we use the Deer Creek example, it would appear that recovery of hypolimnion dissolved oxygen is a several decade process at best. The very slight improvements in Deer Creek Reservoir dissolved oxygen over three decades with over 70% total phosphorus inflow removal is probably the best calibration parameter for these East Canyon Reservoir W2 simulations. Even then the dissolved oxygen improvements that can be documented in Deer Creek may be more closely related to the minimum water inflows with cool temperatures provided from Jordanelle Dam upstream than to phosphorus. The annual phosphorus release downstream of Deer Creek Dam is only aot 0.040 mg/L, which is less than East Canyon. There is still a lot to learn about dissolved oxygen in reservoir limnology and recovery with phosphorus TMDLs. Deep reservoirs obviously must be pristine with very low nutrient inputs to maintain greater than 4.0 Mg/L dissolved oxygen through much of the water column at peak summer stagnation in August.

It is impossible to pick a phosphorus budget and predict that it will produce a dissolved oxygen measurement end-point goal every year at this stage. Therefore dissolved oxygen cannot be the primary criteria to pick a new phosphorus wasteload allocation for the East Canyon watershed. If dissolved oxygen were the only important measurement end-point goal, the phosphorus TMDL would likely be declared a failure. It is not, and it is not.

Organic matter decay below about 15 meters in water depth is very slow, and is rate controlled by temperature. As long as the annual input exceeds the decay rate of organic matter controlled by cold water temperatures, then the rate of oxygen depletion will remain relatively unchanged. In the years of multiple drought- when the reservoir elevation is drawn down an extra 5 meters, the organic matter that built up in cold water is warmed and exposed to motion from shoreline wave action. This results in an extra surge of oxygen demand and nutrients into the reservoir during the year of increased drawdown.

2 Total Maximum Daily Load Analysis

2.1 Internal Versus External Nutrient Loading

The greatest uncertainty in making large expenditures in a watershed to implement a phosphorus TMDL is: has the water body become so eutrophic that its' internal phosphorus recycling has become a greater source of biologically available phosphorus than the input from the watershed? The incorrect answer to this question could lead to extensive expenditure will little benefit in attaining the phosphorus TMDL goals by reducing the external tributary contribution. Benefits from phosphorus reduction could also take several decades, if they ever improved. That is one reason it is very important to assess what has been accomplished with a near 60% phosphorus reduction in East Canyon Reservoir before deciding on the next implementation strategy. Fortunately, this study shows that several important measurement end-point goals have been achieved. East Canyon Reservoir has shown improvement within a 2-3 year period of major phosphorus reductions. However, the hydraulic retention is often greater than 1.4 years, and the phosphorus retention time from wetter and higher loading years may be 3-4 years or longer. Furthermore, additional long term legacy phosphorus loading may still be coming out of the ECR sediments. It could take a decade for ECR to reach a long term dynamic equilibrium with the current phosphorus loading levels. However, in reservoirs that do not respond to external loading reductions, as much as 90% of the bioavailable phosphorus may be recycled from the sediments. This occurs primarily in much shallower reservoirs than East Canyon. It varies considerably with wet and dry hydrologic sequences in ECR, but internal loading is probably 20-50% of the annual biologically available phosphorus for phytoplankton growth. Nearly all of this phosphorus is simulated wit W2 by inputting only the dissolved phosphorus from East Canyon Creek, but with autochthonous organic matter decomposition recycling this phosphorus for several years.

Water depth and hydraulic retention time are major factors in determining how much of the total phosphorus budget is physically available seasonally for phytoplankton production. East Canyon Reservoir is not typical, and in fact the standard riverine, transitional, lacustrine zonation discussion used by this author to classify a reservoir of this depth and hydraulic retention time has not been used in this report. Dissolved oxygen depletion rates by segment are an important component of that riverine/transitional/lacustrine zonal characterization of reservoir limnology (NALMS, 1984; Kimmel; Miller). **The wind driving the algal blooms to the dam at ECR, the skimming affect of the weirs, and exportation of a large portion of the algal biomass is a major consideration in understanding limnological processes. The retention of phosphorus from wetter higher loading years in the stagnant zone of the hypolimnion will also need some consideration in addressing future loading and margins of safety.** However, Internal loading is not preventing water quality improvements from watershed reduction in ECR.

This East Canyon Reservoir study is not a good set of paradigms for understanding many hypolimnion withdrawal reservoirs.

In the case of East Canyon Reservoir there has already been a reduction of phosphorus from the watershed which has resulted in a decrease as a release from the dam from greater than 0.20 mg/L (Figure1.4.3.3-2 &1.5.1-1) to less than 0.065 mg/L. This is roughly estimated to be about a 60% decrease in total phosphorus budget, and is a tentative estimate at that. **The measurement end-point goals that have been attained to this point are not insignificant. The percent of days exceeding 30 µg/L chlorophyll from the W2 simulation of the 1990s to the baseline for 2003-2007 decreases from 21.4% (period averages) to about 6.4% (see Table2.3-1). This is closely related to the estimated decrease in phosphorus loading. There has been a similar reduction in Cyanophyta from 1990s to**

present; this is very significant since the species of blue-green algae has been shifting to a higher potential to produce toxins. Since ECR was also exporting this dying blue-green algal biomasses there was a concern about exporting toxic water downstream as well. The cold water fishery also carried over for the first time in a least several decades in 2005. According to the W2 simulations the epilimnion phosphorus concentrations became significantly limiting to algal production for the first time in July of 2005, and again from Mid June into September in 2006-2007. Blue-green algae reduction is tied to attaining phosphorus limitation before nitrogen limitation. **Correctly forecasting future potential blue-green algal categories is very dependent on nitrogen: phosphorus ratios; and the goals include reaching phosphorus limitation first so as not to advantage Cyanophyta that fix nitrogen from the atmosphere. There is uncertainty about the inflow nitrogen and phosphorus budgets due to sparse data.**

The exportation of summer time algal biomass from East Canyon Reservoir reduced its presentation of just how eutrophic it really was. However, the same hydrodynamics which produced this reduction in overall trophic status is now also in part slowing down realization of attaining additional future measurement end-point goals. The hydrodynamics are now producing a recurring cycle of phosphorus retention with eventual increased routing out of the dam. Viewing the animations illustrates how the phosphorus concentrations build in the deep hypolimnion until it begins to spill over the top of the old dams and through the hypolimnion outlet in the hole in the old concrete dam. After the phosphorus has built up in the reservoir more algal biomass is produced at spring and fall turnover. East Canyon Reservoir has become more efficient at retention of phosphorus with implementation of the TMDL because less particulate organic phosphorus is routed out the dam. This means that future additional phosphorus reductions will produce changes at a much slower rate. Prior to about 2004 ECR continuously spilled high phosphorus concentrated water through the hole in the old concrete dam; now this occurs periodically in cycles.

The cold and deep hypolimnion in ECR simply retains and recycles autochthonous organic matter over more than a one year cycle; and the lower the total inflow budget, the more efficient its' retention becomes. The dynamic equilibrium refers to the relationship of the reservoir cycles to hydrologic cycles; with periods of phosphorus retention, and then flushing. Even though the phosphorus from the watershed may take 2-3 years to cycle into a permanent sediment trap or out of the reservoir; it is still watershed phosphorus that should be viewed as manageable by the TMDL. However, the larger the overall phosphorus reduction, the slower the desired responses will be. In addition, the reservoir also has a portion of the phosphorus recycled each year from anaerobic inorganic sediment release, and a sediment equilibrium phosphorus concentration. The sum of these can be referred to as the water body's memory, or ability to maintain a certain amount to productivity.

On an annual basis the phosphorus that is being incorporated into phytoplankton is provided for by the inflow at about 40-50 % because the spring runoff tends to be an overflow density current. About 30%, on average, of the physically and biologically available phosphorus comes from organic matter decay of the previous 1-2 years inflow recycled. The low summer inflows now have significantly reduced phosphorus, and thus provide only about 20 % of the annual biologically available phosphorus. The remainder (<2-10%) of the annual physically and biologically available phosphorus comes from long term sediment recycling. However, only about 50-60% of the total phosphorus dissolved in the water column is physically and biologically available and incorporated into plankton on an annual basis. These are estimates that would vary considerably annually depending on the previous three years inflow volumes; phosphorus loading; current year hydrology; summertime inflow loading; reservoir operation and drawdown; weather; and finally all these combined into a cycle of deep stagnant hypolimnion retention, recycling, and flushing.

Fortunately, ECR has achieved some significant measurement end-point goals with the 60% reduction of phosphorus. Additional improvements can be realized with another 10-15% phosphorus reduction-especially if they can come from runoff event non-point sources or during the summer. The additional future reduction improvements from an additional 10-15% phosphorus reduction will not be as significant as those already accomplished by the previous 60% reductions. The additional future improvements that can be realized will develop slower than occurred with the earlier 60% phosphorus reduction.

The hypolimnion retention cycle needs to be viewed as an obstruction that may need to be managed in order to reach additional future measurement end-point goals. However, it does not preclude the continued realization of important water quality benefits in most years, especially in July and August.

2.2 Sediment Phosphorus Diagenesis

The more traditional concerns about internal phosphorus recycling relate to sediment/phosphorus diagenesis and the anaerobic release of inorganic iron/manganese adsorbed phosphorus. **The first test in a W2 model related to a phosphorus TMDL should always be to determine if the external dissolved phosphorus loading, and the internal recycling of organic phosphorus from autochthonous phytoplankton production can account for most if not all of the phosphorus, algal succession, and oxygen demand processes**. If a mystery source of phosphorus or oxygen demand is needed to drive the trophic status, W2 simulations driven with the external dissolved phosphorus loading should reveal that need. If most of the dissolved oxygen depletion and phosphorus budget requires utilization of the zero order oxygen demand compartments, then additional information is needed, and other as yet undocumented sources of phosphorus or oxygen demand may be important.

The W2 simulation indicates that the external dissolved phosphorus loading and decomposition of internally produced algal biomass in the ECR supplies most of the phosphorus needed to drive the early spring turnover portion of the spring algal bloom. If the anaerobic sediment release of inorganic phosphorus produced more dissolved phosphorus to the water column than decomposition of organic matter; the W2 model could end up with an overall phosphorus shortage, and the deficit would accumulate over a long period of simulation. However, in steep and deep water bodies much of the anaerobic inorganic sediment phosphorus release can be re-adsorbed to iron which precipitates quickly upon reaeration. Therefore, this source may have limited biological availability, except during early fall turnover. This is an important season for blue-green algae.

There is an internal anaerobic sediment phosphorus release of inorganic iron/manganese bound phosphorus in East Canyon reservoir (Owens, S. O., and Cornwell, J.C.; 2008). The iron/manganese can also be precipitated as sulfides if hydrogen sulfide is present during anoxia. The local watershed around East Canyon Reservoir has a lot of red soil, so oxidized sources of iron could be periodically replenished. There certainly is not sufficient data to account for all the variables associated with the potential to release inorganic phosphorus from the anaerobic sediment. The W2 simulations strongly suggest that such a release is not more important than organic matter decay, nor does it suggest that such a source of phosphorus is an important component of bioavailable phosphorus in at least the spring and summer. Once the reservoir is turning over in the fall most of the iron in anoxic water precipitates back out within hours after reaeration has occurred. As this now particulate iron sinks, it again adsorbs phosphorus and takes it back to the sediment. The anaerobic inorganic phosphorus release would not comprise more than 2-10% of the annual biologically available phosphorus budget in ECR, especially during spring turnover.

The divergence of the W2 simulations and the data collected in East Canyon Creek downstream from the dam starting in October initially raised questions about whether the model was correctly handling iron bound phosphorus release and re-adsorption upon reaeration in fall turnover in October. However, closer examinations of this apparent divergence of W2 simulation output and downstream data revealed that it occurs immediately after the dam goes to minimum flow releases of only about 5 cubic feet/second (0.142 cubic meter/second) in mid October (Figures1.4.3.3-3 &1). The stream flow at the downstream station is probably more heavily influenced by ground water gains, and seepage around the dam at minimum flow releases. The “red soils” in this area would minimize the ground water dissolved phosphorus concentrations in the gaining flows, and sediments from runoff plus biological uptake of the productive stream benthic zone could also significantly reduce dissolved phosphorus concentrations, especially during daylight hours.

In short, there probably is not a disconnect in the model output and downstream stream data during minimum flow releases from October to March. The minimum flows at the downstream station likely have minimal relationship to phosphorus concentration in the reservoir water column or dam releases. Furthermore, any warm days with snow melt or runoff also compromise the comparison of W2 model output and the downstream sampling location. Some additional sampling strategies need to be specifically designed to test several potential differences between the downstream sampling location versus dam release phosphorus concentrations.

The in-reservoir phosphorus concentrations are modeled very well by W2 (see Figure1.4.3.3-4) and the early spring high dam flow release phosphorus concentration are more similar to the late fall complete mixed concentrations than to the very low minimum dam release downstream samples during the late fall and winter.

The fall is also the period of the tributary becoming colder than the reservoir. The underflow density current of the fall inflow and the night time shallow water chilling sweeps the water sediment interface and sends most of the fine organic matter and phosphorus downward into the deep hypolimnion. Again the W2 simulations strongly indicate that the deep and steep sided East Canyon Reservoir does not place most of the anaerobic sediment phosphorus into the physically available pool.

It is assumed that the sensitivity studies utilizing the CE-QUAL-W2 model to test potential future phosphorus reductions against already calibrated hydrology captures the most important limnological processes for phosphorus recycling. The W2 simulations seem to capture the most important processes that drive phytoplankton production, the internal phytoplankton production drives most of the oxygen demand, and the W2 model correctly approximates long term trends that are most important in evaluating future watershed phosphorus reductions. The first 3-4 W2 inflow segments in the reservoir are shallow and highly reaerated. They sediment trap organic matter in the sediment, or simply wave wash allochthonous organic matter up on the shoreline, all with little impact on metalimnion/hypolimnion down reservoir dissolved oxygen depletion. The shallow inflow segments are capable of decaying a lot of organic matter with minimal impact to metalimnion/hypolimnion oxygen demand. In fact the model shows no sensitivity to inputting East Canyon Creek with zero dissolved oxygen because the inflow segments have so much reaeration potential. Recycling of phosphorus from the inflow sediment deltas is highly dependent on reservoir drawdown and high inflow physically resuspending these sediments. This has not been a major process at East Canyon Reservoir, but that could dramatically change in a major fall runoff event into a deeply drawdown water body.

2.3 Nutrients

Many W2 simulations at other reservoirs have been completed to test hydrodynamics, temperature, dissolved oxygen, reaeration, dam operation scenarios, and as a test of the effectiveness of nutrient reductions from the watershed (Cole, 2005). Research and testing of W2 for algal succession with phosphorus TMDLs is a relatively new utilization of CE-QUAL-W2. Modeling algal succession is still in its infancy as a science.

The phosphorus concentration due to unlimited top to bottom vertical mixing from April to June, and the June- September phosphorus inflow determines how big the growing season algal blooms will be. Once the reservoir is thermally stratified the epilimnion should become phosphorus limited within about 3-5 weeks in early summer following implementation of the phosphorus TMDL to date. However, prior to about July of 2005 the epilimnion was rarely phosphorus limiting to phytoplankton growth because the watershed contribution was so large. The ECWRF phosphorus reduction was fully implemented by summer of 2004. The phosphorus reductions became evident by July of 2005, which is a fairly rapid response. In part this is due to the importance of the point source reduction in the summer to attainment of epilimnion phosphorus limitation during the primary growing season. The W2 simulations indicate that the decomposition of the spring bloom drives most of the oxygen demand in the epilimnion and metalimnion in July and August. These same elevations were scoured of sediment organic matter during the previous year's drawdown; so without a renewal of organic matter by the spring bloom, the oxygen demand would be much lower.

The overall annual phosphorus loading is still above a threshold that produces spring diatom and total algal biomass light limitation from about mid May until about 10 days after thermal stratification in about mid June or into July in most years. Once the reservoir does stratify the huge diatom and total spring algal biomass quickly depletes the remaining phosphorus in the epilimnion. The epilimnion becomes phosphorus limited with about 10-15 days of thermal stratification set up since 2005. Once the sharp thermocline is established the algal daily vertical migration is confined to the epilimnion in the W2 simulation and in the reservoir. This limits access to the phosphorus that is only a couple of meters beneath the thermocline. Again, the skimming effect of the old dams exporting algal biomass was limiting the presentation of ECRs former hyper-eutrophic status due to excessive phosphorus in this reservoir. The 60% phosphorus reduction realized after 2004 in the baseline scenario has produced significant reductions in mean annual chlorophyll, and in blue-green algal blooms.

2.4 Chlorophyll a

The chlorophyll a data that has been collected in East Canyon Reservoir for many years comes from 3 stations in the reservoir. They are near the dam, mid-reservoir, and upper reservoir (near the East Canyon Creek inflow). The upper reservoir station can move depending on the reservoir elevation. The mid-reservoir station is right of mid channel (looking downstream) and just up reservoir from the State Park. Chlorophyll concentrations can vary by two orders of magnitude across the channel as demonstrated by data collected by Reclamation and USGS Scientists in October of 2000in Figure 1.4.3.5-3

This information demonstrates that utilizing the historical East Canyon Reservoir chlorophyll and phytoplankton sampling data for calibration of the W2 model could lead to some problems. If the model were forced to match the data, the total algal biomass would be way under estimated, and another source of organic matter to generate oxygen demand would also be needed. The satellite imagery study was designed by the author because observations on the reservoir did not match the overall low chlorophyll concentrations in the data.

If the measurement end-point goal is to have less than 10% of the summer growing season exceeding 30 µg/L; then the baseline is close to the goal without consideration of a significant margin of safety for additional future growth.

Summary of chlorophyll accidence as % of days any station is > 30 µg/L (0.030 mg/L)

Scenario	% days >30 µg/L	TP annual load (Kg)
Baseline	6.6%	2552
3a	5.4%	2038
3b	0.9%	1579

3c	0.7%	1506
3d	0.7%	1824
1b	0.9%	1116
91-96	21.4%	~6300

TABLE 2.3-1 shows the number of days (% of summer growing season) the chlorophyll would have exceeded 30 µg/L at any one of the three standard protocol reservoir stations at the 2 meter depth by W2 simulations. It also shows the total annual phosphorus load for the scenario, but the seasonal distribution of the annual load may also vary with each scenario.

The clearest cut difference in scenarios seems to be with Chlorophyll and perhaps blue-green algal blooms. There are significant improvements in attaining another 50-75 % reduction in non-point phosphorus. **Scenario C3d with a 65% non-point source reduction provides the same chlorophyll benefits as more costly higher reduction scenarios.**

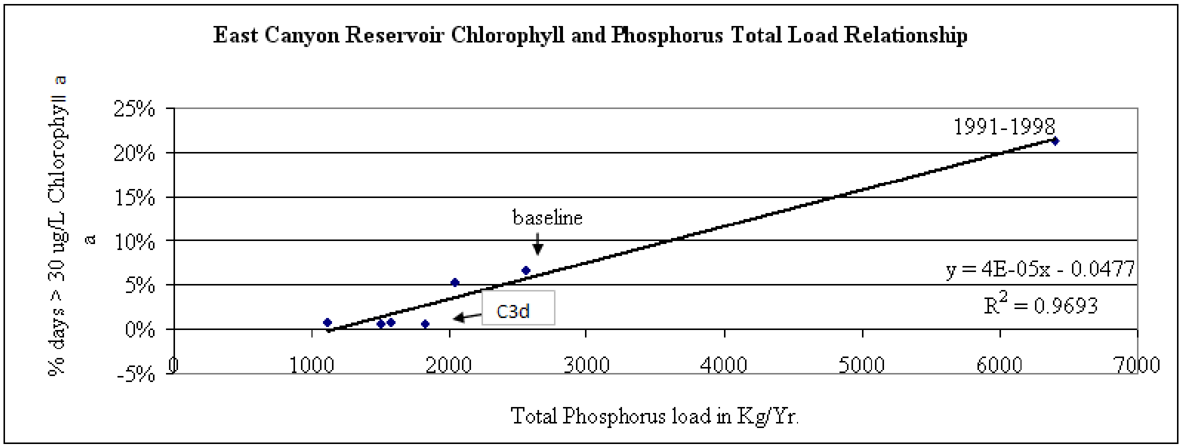


Figure 2.3-1 is an EXCEL chart that shows the relationship between CE-QUAL-W2 scenario simulations (Table 2.3-1) to the annual total phosphorus loading and the number of days (%) that chlorophyll exceeded 30 µg/L at any one the three segments sampling sites in the reservoir.

Figure 2.3-1 indicates that the difference between the baseline and the measurement end-point goal to keep chlorophyll concentrations below 10% as a percentage of days greater than 30µg/L is only about 900 Kg/year. Given the internal phosphorus retention cycling W2 is predicting for the future this is a very narrow threshold if it is used for a margin of safety. As the chlorophyll increases so does the likelihood of significantly high peak blue-green algal blooms. There is clear separation between the baseline and scenario C3a, C3b, c & d. There is no improvement between C3b, c, & d, or 1b (Table 2.3-1). **Again Scenario C3d stands out as providing the most benefit for the least total phosphorus reduction.** It may be very difficult to implement scenario C3d. Additional information can be gained in the future utilizing CE-QUAL-W2 as a guide for data collection. Considerations of cost/benefits of treating the hypolimnion/sediments versus additional costs to treat the watershed should be weighed. In a watershed with natural geologic sources of phosphorus a 65% reduction of spring runoff non-point sources may be difficult to implement. Therefore, some combinations of external source control may need to be combined with some alternatives to manage the hypolimnion retention and accumulation of phosphorus.

2.5 Blue-Green Algae And Algal Succession

The relationships to blue-green algae, chlorophyll, phosphorus loading, and seasonality have already been demonstrated in previous sections of this report. Prior to 2004 Cyanophyta were much more important from about July to the end of October. The major algal succession has shifted substantially away from summer blue-green algal blooms in July to October since the implementation of major phosphorus reduction beginning in the summer of 2004. This is a major measurement end-point goal achievement for the implementation of the phosphorus TMDL to date.

Since many of the phytoplankton data sets are either collected from the same single location three reservoir sample sites, or from shore line wade out grab samples (North shore accessible from the highway- Rushforth, 2007, personal communication), the phytoplankton counts are just as likely biased low as the chlorophyll data. Never-the-less, the phytoplankton count speciation is a very good qualitative data set to calibrate the algal succession in the W2 simulations. The best way to comprehend the algal succession, thermal stratification, wind influence on algal biomass is to view avi files of two dimensional animations (contained in DVD version of this report) on a media player.

The W2 simulations indicate a shift after 2004 away from summer and fall blue-green algal dominance. There is also a big shift away from summer and fall blue-green algal dominance from the 1990s to 2005. After 2006 the Cyanophyta are estimated to be less than 6% of the total annual algal biomass both in the phytoplankton count data (Rushforth 2000-2007 reports) and in the W2 simulations. Never-the-less, there is still a fairly high probability of a significant blue-green algal bloom in September in drought or certain sequences of runoff and weather in the fall in the future. Implementation of Scenario C3d provides the best alternative to minimize these events. It is important that phosphorus remains limiting over nitrogen in order to avoid Cyanophyta having a big advantage. This needs to remain a part of the future monitoring program.

2.6 Turbidity

The spring inflow into East Canyon Reservoir provides the bulk of the annual water supply. However, with a hydraulic retention time varying from about 0.4 to 1.4 years- the inflow has little influence on water turbidity beyond the first three inflow segments in the W2 model. The exception to this might be the long term maximum peak inflow flood period. The major influences on turbidity are the spring diatom blooms, and in the past the summer and fall algal blooms including the large blue-green blooms such as the one illustrated by the satellite imagery study in Figure 1.4.3.4-3. For example the water appeared quit clear with the bottom visible to depths of about ten feet over most of the reservoir on May 16, 2005 even though the diatom bloom was beginning, and the spring runoff had been going on for several weeks.

The spring diatom bloom reduces Secchi disk transparency to less than one meter by its peak around May 20 until early July. The water appears emerald green to the eye, but only small patches of algal scum are seen because the diatom blooms do not ascend and remain on the surface as much as the blue-green algae. Even though the water clarity is greatly reduced, the spring diatom blooms are not as aesthetically unpleasant as the blue-green or dinoflagellates blooms which accumulate much more right on the surface and on the shoreline. The very low transparencies often found in the East Canyon data base are also associated with large algal blooms and high chlorophyll. In fact the spring diatom bloom which is still producing Secchi disk transparencies of only a few feet (< 1 meter) are still attaining a state of light limitation based on the W2 simulations from about later May until nearly July even after 2005. Therefore more spring turnover and inflow phosphorus reductions are needed before any difference will be noted in water transparency or dissolved oxygen demand during the summer. However, the past three years the July/August peak chlorophyll has significantly decreased, and the summer time water transparency has increased. Additional reductions in chlorophyll will also improve summertime water transparency as has already been described in the Chlorophyll section.

Turbidity will improve if chlorophyll continues to be reduced, and the total maximum daily loading analysis for turbidity therefore defers to the previous analysis for chlorophyll.

Never-the-less, summertime Secchi Disk water transparency measurement depth at mid reservoir are not likely to exceed 4-5 meters due to suspended sediment from shoreline erosion, and chlorophyll concentrations of 3-12 µg/L. Several shoreline areas may need some work to reduce erosion. Again, scenario C3d provides the most improvement for the least reduction.

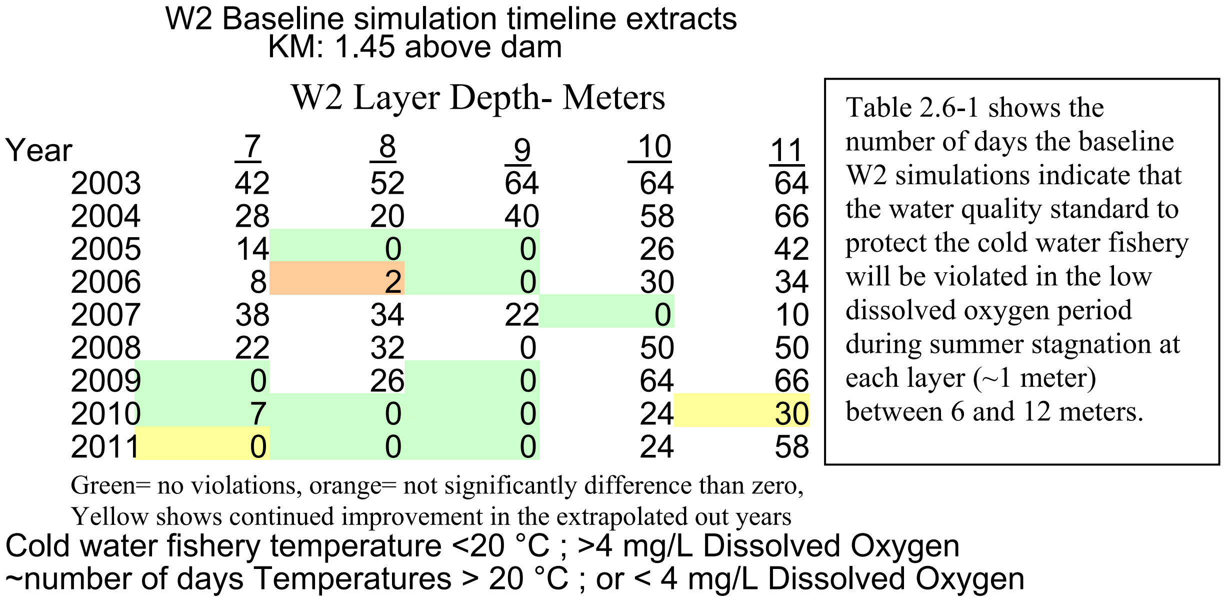
2.7 Oxygen Depletion

The oxygen depletion in the reservoir has been extensively studied with the W2 modeling simulations.

East Canyon Reservoir's water/sediment interfaces are less than 9 °C over most of the reservoirs water column depth for more than 9-10 months each year. Bacteriological decay is temperature limited most of the time in this situation. Different types of organic matter decay differently in this cold water. Larger woody terrestrial organic matter that is buried in the sediment can remain there relatively unchanged for decades. Anything larger than a small piece of a tree leaf buried in the cold sediment decays very slowly. However, the much smaller phytoplankton organic matter decays much faster even in the cold water. Never-the-less, the W2 model simulations show a substantial increase in deep cold water/sediment interface organic matter that remains throughout the simulation periods. It appears that all the phytoplankton organic matter does not completely decay in a one year cycle in East Canyon Reservoir.

Organic matter and nutrients build in a cyclic manner in the stagnant hypolimnion zone at elevations beneath the old dam and the hole in the old concrete dam, and are only partly flushed periodically with wet years and increased dilution factors. Terrestrial woody matter buried in the sediment decay only very slowly on a decadal scale.

W2 simulation time line extractions at depths of 6 to 12 meters with day count violations of the Utah DEQ water quality standard to protect a cold water fishery are in Table 2-2.



W2 Baseline simulation timeline extracts
KM: 1.45 above dam

W2 Layer Depth- Meters

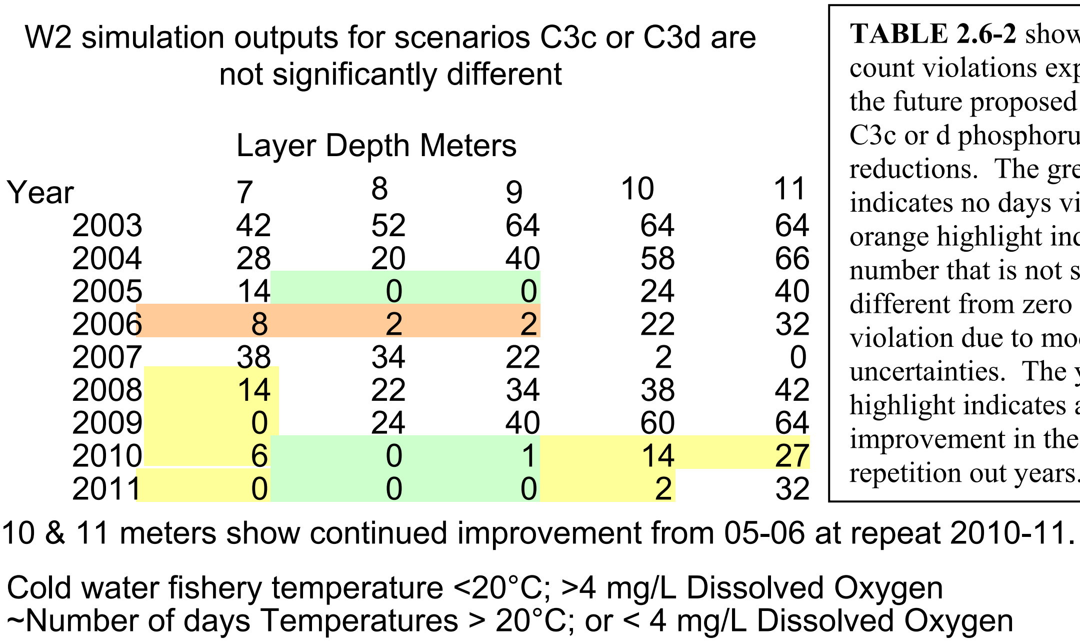
Year	7	8	9	10	11
2003	42	52	64	64	64
2004	28	20	40	58	66
2005	14	0	0	26	42
2006	8	2	0	30	34
2007	38	34	22	0	10
2008	22	32	0	50	50
2009	0	26	0	64	66
2010	7	0	0	24	30
2011	0	0	0	24	58

Table 2.6-1 shows the number of days the baseline W2 simulations indicate that the water quality standard to protect the cold water fishery will be violated in the low dissolved oxygen period during summer stagnation at each layer (~1 meter) between 6 and 12 meters.

Green= no violations, orange= not significantly difference than zero,
Yellow shows continued improvement in the extrapolated out years

Cold water fishery temperature <20 °C ; >4 mg/L Dissolved Oxygen
~number of days Temperatures > 20 °C ; or < 4 mg/L Dissolved Oxygen

The cold water fishery in East Canyon Reservoir has only carried over one year in recent decades, that being 2005. Prior to sometime in about the 1970s a self sustaining kokanee salmon fishery was present in East Canyon Reservoir. The W2 simulations do not indicate that such a fishery is likely to exist even with the most stringent future potential phosphorus controls such as in scenario C3c or d. The reduction of summer time inflow with cooler night time temperatures may also be a factor, as is increased water use and reservoir drawdown. The extraction of 12-18°C by the skimmer affect of the old dams also reduces the potential trout habitat optimal survival temperature zone during summer stagnation. **The W2 simulations indicate that 2005 is the first year in decades that the cold water fishery may have survived summer stagnation. The fisheries data suggests that 2005 was the only year the trout did carryover** (Nadolski, B.K. and Schaugaard, C.J.; 2007- draft; personal communication, 2008. The fish survival in 2005 is another confirmation of the models robustness.



W2 simulation outputs for scenarios C3c or C3d are not significantly different

Layer Depth Meters

Year	7	8	9	10	11
2003	42	52	64	64	64
2004	28	20	40	58	66
2005	14	0	0	24	40
2006	8	2	2	22	32
2007	38	34	22	2	0
2008	14	22	34	38	42
2009	0	24	40	60	64
2010	6	0	1	14	27
2011	0	0	0	2	32

10 & 11 meters show continued improvement from 05-06 at repeat 2010-11.

Cold water fishery temperature <20°C; >4 mg/L Dissolved Oxygen
~Number of days Temperatures > 20°C; or < 4 mg/L Dissolved Oxygen

TABLE 2.6-2 shows the day count violations expected with the future proposed scenario C3c or d phosphorus reductions. The green highlight indicates no days violated. The orange highlight indicates a number that is not significantly different from zero days violation due to model and data uncertainties. The yellow highlight indicates an improvement in the future repetition out years.

The yellow highlight in Table 2-3 also indicates that there are less violations in the future when repeating a previous year with W2 simulations; for example 2010 and 2011 repeat 2005-2006 as sensitivity studies. In 2010 and 2011 trout should survive the summer stagnation period; however, during the drought sequence repeat of 2003-2004 in 2008-2009 the cold water fishery would not be expected to carry over through the summer months. It takes more than an additional 50% reduction of non-point source phosphorus to produce improving conditions in the future year sensitivity study. **However, because fish have not carried over since 2005, and since it appears they perhaps could have in 2006; there is a significant uncertainty that this analysis adequately represents all the stressors that may be preventing fish from carrying over and surviving the summer low dissolved oxygen period. The assumption that reduced phosphorus concentrations alone can reach a measurement end-point goal to carry a cold water fishery through the summer may not be correct.**

There are several additional stressors on the fish that may influence their ability to survive the stress of summer stagnation. These stressors may include parasites (East Canyon fish can be heavily infested with anchor worm); whirling disease may have been in the drainage by 2006, but is now present(Nadolski, B.K. and Schaugaard, C.J.; 2008; personal communication) ; and the general lack of lower stress water temperatures between 12-18 °C over most of July and August.

In a low inflow year a minimal supply of 12-18 °C water is found in the reservoir going into thermal stratification. When the reservoir is really drawn down to the top of the old concrete dam in multiple drought years, most of the 12-18 °C water in the reservoir has been withdrawn by the skimmer affect of the old dams. The thermocline is so sharp in August that the temperatures can drop from 20 °C to less than 12°C in less than three meters of metalimnion. The depth of low stress temperature water is in very short supply during drought years, and dissolved oxygen is not found at depths greater than 10-11 meters. Viewing four hour time steps with marked zones in the avi files for 2005 versus 2006 reveals that the less than 20 °C and greater than 4.0 mg/L water moves in such a manner that fish would also have to move to survive. This seiching movement of the metalimnion could cause rapidly changing temperatures that may also produce thermal shock. Viewing the avi files (attached CD) greatly expands the appreciation of thermal and dissolved oxygen stressors to a cold water fishery.

This begs the question- how did a self sustaining kokanee salmon fishery survive for a number of years in East Canyon Reservoir prior to about 1975? The answer to that question may be in the big reduction in July/August inflow into East Canyon Reservoir. When the Park City Mining District was actively mining; the mines had to be dewatered to be workable. Ground water is recharged with each year's spring snow melt in April-June, and ground water tables rise. In order to maintain workable conditions water had to be pumped out of the mines. More water had to be pumped out from May through September than during the rest of the year. Essentially all mining has ceased to add water to East Canyon Creek. During the long extended drought from summer of 1999 to 2005, and still carrying on through 2007 the summer inflow to East Canyon Reservoir has been 2-3 times less than in previous decades when the mines where more active.

The mine water had low phosphorus concentrations and was usually fairly cold (10-14 °C), although some of the mines had reached depths with much warmer geothermal water. If East Canyon had 2-3 times more July/August inflow with night time temperatures of 14-18 °C; the inflow would have helped sustain an extra 1-3 meters of 12-18 °C water depths in the reservoir. This may have been enough to barely carry the cold water fishery through summer stagnation. At any rate temperature issues alone make survival problematic over the past couple of decades and extending into the future with lower July/August inflows. Phosphorus reductions alone cannot completely remediate all the other stressors which fish in East Canyon Reservoir now have to contend with, water temperature being one of the major issues.

The only year that the cold water fishery apparently survived summer stagnation was in 2005. However, the total phosphorus loading in 2005 was high; and the spring diatom bloom in 2005 was very large. In 2005 the reservoir operated at higher elevations through July and August. The reservoir didn't really stratify until early July, and then the shallow epilimnion cooled to below 20°C by about August 24th. The weather and the fuller reservoir left a couple meters more water in the metalimnion between the temperature ranges of 12-18°C in 2005. In 2006-2007 there was again significant reduction in the 12-18°C zones in July and August. The day count of violations suggests that trout should have had a couple of meters to survive through the worst of summer stagnation period in 2006, but apparently they did not. The 2006 zone of 12-18°C water was minimal- even though a wetter year, and it was moving during high winds in ways that would require fish to move more in 2006 than in 2005 (See AVI file animations in the attached DVD version). The summer stagnation period produced by weather was longer in 2006 than in 2005. During the dry years with a greater drawdown, the shortage of a 12-18 °C zone is a major control in attainment of the cold water fish protection water quality criteria or not. Reservoir drawdown in July and August, lack of a cool quantity of sufficient inflow, and a much longer summer stagnation period in 2006 was more significant than phosphorus loading.

2.8 Uncertainty

Uncertainty in this study involves a number of interrelated items. The sparse tributary input nutrient and organic matter data is a major concern. If the W2 simulations indicated a shortage in the overall long term phosphorus budget, there would be no way to determine if this shortage was due to inadequate inputs from the watershed or from internal loading in the reservoir. There certainly are indications that major runoff events from some sub watersheds could produce significant errors in the overall input watershed phosphorus budget (Olson and Stamp-Biowest, 2000). When there is so much phosphorus that light and not nutrients are limiting to algal production, it is also more difficult for W2 to determine that there is a shortage in the phosphorus budget. This is the case with the 1990s W2 approximations. However, there is still a brief period during the peak spring algal blooms before stratification when light and not phosphorus is limiting to biomass production even after a 60% phosphorus reduction. This light limitation is due to self shading from the algal bloom and not due to turbidity from the spring runoff. This common denominator of attaining light limitation during the peak spring bloom is also the common denominator maintaining metalimnion oxygen depletion rates in July and August even with the phosphorus reductions.

The advantage of running the W2 simulations for major portions of two decades with >60% phosphorus reductions is that in that time period a major shortage in understanding the phosphorus budget should show up as an accumulative error. However, if perhaps the tributary budget over-estimates phosphorus input, then the internal recycling of inorganic phosphorus from the sediments could be underestimated. This seems unlikely as the major runoff events may be under represented in the database. Never-the-less, the spring runoff and annual turnover events still provide too much phosphorus. In order to implement another non-point source reduction with large enough loads to hope to attain some additional measurement end-point goals will require a much better data set. These improved data sets are essential to find the sources and to devise best management practices to control them.

The lack of chlorophyll and plankton data, particularly in May and June during the peak spring algal bloom is a significant uncertainty. The chlorophyll and biomass data is in general too sparse, does not provide a lateral average for model calibration, and appears to be biased to low to use to calibrate 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 chlorophyll biomass numbers. However, that single date event (Figure 1.4.3.4-3) certainly leaves some uncertainty. The personal observations of the author who devised that satellite image study for this purpose and of Dr. Sam Rushforth support the hypothesis that this October 2000 event was not an unusual algal bloom in this reservoir. This further supports the decision to allow the W2 model to determine if internal algal production could account for the important limnological processes. Since the author and Dr. Rushforth have devoted a career to limnological studies of reservoirs, there several decades of observing this reservoir are worth noting.

A future approach to reduce uncertainty should be to conduct monitoring to prove the W2 model is wrong, or not. That means that studying the W2 model results should be a major input driving future monitoring considerations.

The W2 model also has uncertainty. 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. Collecting more hourly temperature and dissolved oxygen; as well as collecting more dissolved phosphorus, total phosphorus, and organic phosphorus data right at the dam discharge over several years could help reduce this uncertainty. Collecting Doppler velocity measurements between the two sets of structures and on both sides of the hypolimnion hole through the old concrete dam could also confirm the hydrodynamics.

Again, if a major error was occurring in the movement of hypolimnion water through the hole in the old concrete dam, the hypolimnion would continually get warmer over the course of the summer. This is exactly what does happen in numerous simulations to test various W2 configurations that do pull to much hypolimnion water through the hole in the old dam. However, the exact location of the surface layer withdrawal versus wind seiching and thermal buoyancy blocks from water above the thermocline could also contain errors.

The very sharp thermocline with temperature dropping as much as 6 °C in only one meter depth increase somewhere in the 6-8 meter range, especially when the reservoir is drawn down to place the metalimnion just above or at the elevation of the top of the old dam is a pretty strong calibration point. The model is not perfect in the metalimnion, but it certainly isn't too bad. The model is maintaining the very cold temperatures in the hypolimnion on both sides of the old concrete structure which is also a strong calibration point.

The lack of local wind speed, wind direction, and daily surface water temperatures at East Canyon Reservoir greatly reduces the ability to calibrate the W2 model to the actual date and hour samples taken at the reservoir. The strength of this W2 application is in being able to approximate long term multiple year trends. The weakness is in the lack of local meteorological and stream inflow temperature data; the ECWRF is now sponsoring a USGS gauging station on East Canyon Creek at the reservoir with temperature measurements.

Figure 2.3-1 charts the relationship between chlorophyll as a percent of days count that exceed 30 µg/L versus load for some of the more important future scenario phosphorus reductions and the baseline. The loads were calculated by Dr. Erica Gaddis of SWCA independently of this W2 study. The exception being that the author estimated the 1991-1996 overall average loads with a very simplified method. The 1991-1998 W2 simulation is more for algal succession confirmation, and is not used in scenario assessments.

Whenever an electronic computer model is doing millions of computations in a dynamic simulation, there will be some errors. Some of that is evident in the noise in the day count violation tables of < 20 °C and > than 4.0 mg/L dissolved oxygen tables. There probably is not a significant difference in a count of zero versus a count of 6-8 days. This puts a little more uncertainty on future small improvements in reductions of those counts with future phosphorus reduction scenarios.

There is sufficient uncertainty in the data used to drive this analysis, and in unknowns about reservoir hydrodynamics to leave no guarantees that the sensitivity studies of potential future conditions are precisely accurate. There is definitely a need to increase the confidence in attaining future measurement end-point goals. These W2 simulations reveal some very important facts with regards to uncertainty. The W2 simulations confirm the observations that internal algal production is the major driving force for dissolved oxygen dynamics in East Canyon Reservoir, and it strongly supports the hypothesis that external dissolved phosphorus loading drives that phytoplankton production. The W2 model also reveals some very important information about the hydrodynamics and hydrologic cycles with regards to temporary retention of phosphorus that can produce some upset years in the future. Several slightly wet/average years in a row could produce a return to fall blue-green algal blooms due to this hydrologic cycles high phosphorus retention in the stagnant zone of the hypolimnion. The model also strongly suggests that a management method to reduce this hypolimnion phosphorus accumulation may be as important as attaining future additional watershed reductions of phosphorus. The W2 analysis puts a high uncertainty on the assumption that phosphorus reduction alone can guarantee maintaining a cold water fish protection water quality standard of <20 °C with more than 4.0 mg/L of dissolved oxygen in two or more consecutive meter zones of water every year. The W2 model provides a lot of information, and future studies should in part be designed to prove the model is wrong, or not.

2.9 Seasonality

The importance of the May-June time period has been stressed several times. The turnover bioavailable phosphorus from the complete mixing in the spring, coupled with the high inflow during runoff drives very large spring algal bloom biomasses. The overflow nature of the spring inflow puts the phosphorus that is chemically bioavailable into the epilimnion where it is physically available. When the reservoir is fullest, the largest shallow surface areas occur, and it accumulates a significant portion of the settling spring algal bloom by late June. **These algal biomasses settling in the epilimnion or metalimnion will decay in 10-20 days in 18-24 °C water with near complete recycling of phosphorus. The metalimnion zone at 10-20 °C will decay in about 30-50 days, but as the reservoir elevation drops, fall temperatures increase with depth; the warming and ripe algal masses will also accelerate in decomposition. Near 50 % of the phosphorus in the reservoir will likely be utilized in any given year. The April-September inflows will have the greatest utilization, and some of the April-June runoff inflows will be recycled to algae > complete decay > back to algae as many as 3-4 times over 5 months. Therefore the April-June bioavailable phosphorus inflow is a priority to continue to reduce overall phytoplankton productivity. However, it is equally as important to maintain low summer bioavailable phosphorus inflows.**

Fall blue-green algae fix nitrogen and then decompose all winter and into the spring. The nitrogen added to the water from the decomposition of the previous fall blue-green algal blooms then helps build the spring algal blooms to light limitation. Maintaining phosphorus limitation during all time periods is important. The model may not properly represent future nitrogen/phosphorus ratios, and thus blue-green algal advantages.

3 Conclusions And Recommendations

3.1 Conclusions

The W2 simulations of East Canyon Reservoir accomplish several very important water quality assessment goals:

1) The W2 simulations affectively demonstrate that internal phytoplankton productivity produces most of the oxygen demand in the reservoir metalimnion and hypolimnion;
2) The annual dissolved phosphorus inflow can drive all these processes although nutrient retention and algal biomass recycling over 2-3 years can also be an important factor;
3) The decay of autochthonous organic matter produces most of the sediment phosphorus release, and is very temperature dependent-this process takes more than one year;
4) The W2 simulations can approximate/ calibrate the 1990s and 2003-2007 East Canyon Reservoir limnology including major shifts in phosphorus concentrations in the reservoir and in the dam releases;
5) The W2 simulations can approximate the major algal succession shifts seasonally (generally within about the appropriate 10 day period), and annually with major shifts away from summer time Cyanophyta dominance after 2004;
6) The W2 simulation correctly indicates these major algal succession shifts occur because the epilimnion becomes phosphorus limited by about July of 2005, and from late June to early September in 2006-2007 as a result of phosphorus reductions;
7) The W2 simulations indicate that future measurement end-points from additional phosphorus reductions will be realized more slowly and over a much longer period of time than occurred with the much larger reductions from the mid 1990s to summer of 2004;
8) The W2 simulations adequately represent the major skimming and other hydrodynamic affects of the old dams inundated in front of the new dams to conduct sensitivity studies of potential future limnological scenarios by repeating the 2003-2007 hydrology continuously after 2007 with future proposed additional phosphorus reduction scenarios;
9) The W2 simulations of these future sensitivity studies indicates that a cycle of phosphorus retention and eventual routing with increased dilution following a drought will offset attaining all the measurement end-point goals during at least some years in the future even with additional phosphorus reduction;
10) The W2 simulations indicate that the watershed phosphorus reductions to date have produced very significant measurement end-point goals by maintaining less than 6-9% of the days in the summer that chlorophyll would exceed 30 µg/L;
11) The W2 simulations indicate the reservoir was rarely phosphorus limited prior to 2005, during the 1990s calibration period summer time chlorophyll exceeded 30 µg/L from 20-50 % of the days commonly;
12) The data and W2 simulations indicate that substantial reductions in blue-green algal biomass have occurred since implementation of phosphorus controls starting about summer of 2004;
13) The cold water fishery carried over for the first time in decades in 2005, and the W2 simulations captured this change correctly and on time;
14) The W2 simulations indicate that greater than an additional 50 % reductions of non-point source phosphorus plus maintaining very low point source phosphorus concentrations into the future are required to realize any substantial additional improvements with

15) W2 simulations indicate that future reductions in chlorophyll accidences of 10 % of summer days greater than 30 µg/L reductions can be attained with a 65-75 % reduction of non-point source phosphorus (with chlorophyll decreasing from 6-8 % to less than 2-4 % accidence), providing a margin of safety;
16) W2 simulations indicate that an additional 65-75 % reduction of non-point source phosphorus in the future will also reduce risks of blue-green algae seasonal dominance and decrease Cyanophyta to less than 3-6% of total annual algal biomass; and
17) W2 simulations indicate that phosphorus alone cannot achieve carryover of a cold water fishery every year by attaining the measurement end-point goals to not violate a water quality standard to maintain 2-3 meters of less than 20 °C water with greater than 4.0 mg/L dissolved oxygen, but a future phosphors decrease > 65% of non-point sources may improve trout carry over to around 50 % of the years.

East Canyon Reservoir was spilling by late May in 2008. If it warms up, the wind switches and come from the South, and the reservoir continues to spill; then a significant portion of the spring algal bloom may to pushed to the dam and exported. If higher inflows continue through the summer of 2008 trout may carry over again. If it turns very hot and the reservoir has maximum summer stagnation from late June to mid September, and the inflow drops to the low levels of previous years; then the cold water fishery is not likely to survive again through the summer of 2008. The phosphorus TMDL is not by its self going to restore a cold water fishery consistently, and other stressors and factors may prevent the phosphorus TMDL from attaining this goal.

The appropriate way to view the sensitivity studies in this report is not to look at 2008 and say he sure missed that. The sensitivity studies wrap the drought year 2003 behind 2007 and refer to it as 2008. It is a sensitivity study- not a prediction of 2008. To compare the sensitivity studies with the data at the end of 2008- look to the 2010 and 21011 repeat of 2005-2006 hydrology which will at least be similar to 2008 actual hydrology. Even then the hydrologic and dam elevation sequence that established the amount of phosphorus retained in the previous couple of years will not be same as the 2010 sensitivity study with 2005 data. The 2008 hydrology and water quality data should be added to the W2 simulations because the 2003-2007 time period is overall to dry, and needs another wet year to help look into the future with more confidence.

3.2 Recommendations

Scenario C3d is recommended based on W2 simulations indicating that this scenario provides the greatest benefits for the least phosphorus reduction. There are clear separations in benefits with this scenario and C3a, while the W2 simulations show very little continued benefits from higher phosphorus reductions. However, some additional studies of the cycle of accumulation of phosphorus in the deep stagnant hypolimnetic zone also need to be done, and some management options should be considered to either trap or move some of this phosphorus and organic matter. The rate of oxygen depletion is controlled by organic matter temperature rate of decay, burial, and annual accumulation. Until the annual rate of total organic matter accumulating to the sediment is less than the decay rate, the decay rate will remain the same. Future additional studies utilizing W2 simulations as a guide are needed to properly weigh cost, benefits, and feasibility of implementation against internal hypolimnion intervention and control of phosphorus in the watershed.

The phosphorus reductions that have been realized to date have accomplished very important measurement end-point goals in East Canyon Reservoir. There is only a small margin of safety (probably less than a 900 Kg/year) increase in annual phosphorus loading before some of these measurement end-point goals will begin to slide back to less desirable conditions. This would be particularly true if the increases were very large from April to October. It will require an additional 65 % non-point source reduction of biologically available forms of phosphorus to attain additional significant measurement end-point goals with regards to decreasing days exceeding 30 μg/L chlorophyll, and in keeping a low probability of nuisance and potentially even toxic blue-green algal blooms in September-October. There appears to be some potential to attain the water quality standards to protect a cold water sport fishery in at least 2-5 meters of water (depending on water year hydrologic cycles and reservoir elevations over the past several years) up to about 50 % of the years with an additional 65% non-point source phosphorus reduction. However, hydrodynamics and other stressors could preclude trout survival through summer stagnation in any given year. If the cold water fishery does not carry over in 2008, this issue may need additional evaluation because other stressors like whirling disease, parasites, and spawning may also be additive. This reservoir has a limited ability to support a cold water fishery.

The deep stagnant zone of the hypolimnion will retain substantial amounts of phosphorus that will build up over several years before being flushed by the high dilution factor wet hydrology on low reservoir elevation cycle. If an additional 50-65% or greater reduction in non-point sources can be realized, this hypolimnion phosphorus loading and recycling may require some mitigation to attain some of the future measurement end-point goals. Without an additional 50-65 % non-point source phosphorus reduction, the hypolimnion chemical treatment would probably not be effective for more than 3-5 years depending on hydrologic cycles.

The recommendations for additional future phosphorus reductions and other potential remediation options include:

1) Reductions of non-point source phosphorus sources in this order of priority: a) spring runoff and summer time dissolved phosphorus, b) spring runoff and summer time organic phosphorus, c) annual iron or manganese adsorbed phosphorus, and d) all forms of potentially bioavailable phosphorus within a two year time frame input into the reservoir.
2) A total annual reduction of 65% additional phosphorus is required to see further measureable improvements with regards to chlorophyll, blue-green algae, and improving the chances of a cold water fish carrying over in around 50 % of the years; this is referred to as Scenario C3d.
3) Utilize the findings of the W2 model simulations to drive monitoring methodologies in the future.
4) Obtain more spring runoff dissolved, organic and total phosphorus data, as well as nitrogen data.
5) Conduct a reservoir sediment phosphorus release study that is properly placed at 1-3 locations, starts immediately after oxygen depletion begins, and ends before anoxia so that Sediment Oxygen Demand rates can be calculated, and provides sufficient information to assess future hypolimnion phosphorus/sediment treatment alternative analysis data. This is a priority if a chemical treatment of the sediment or stagnant zone of the hypolimnion is seriously considered in the future.
6) Collect sufficient chlorophyll samples to represent a lateral segment average, and enough phytoplankton data to continue to assess potential hazards from blue-green algae.

7) Maintain the existing phosphorus TMDL as there is ample opportunity to cause additional erosion and phosphorus loading in this watershed; it is imperative to not increase loading in the future. In addition to a

need to reduce future non-point source loading; there is also a significant need to prevent additional future non-point source loading. This requires an aggressive land use management planning and BMP program forever in this watershed. The erosion control BMPs on the Phosphoria Formation soils on steep slopes is particularly a priority.

In addition to the above, the W2 simulations make it very obvious that attaining future improvements may depend on reducing the build up and retention of hypolimnion phosphorus. Moving high phosphorus water from the stagnant zone of the hypolimnion may present some opportunities to accomplish some things with regards to decreasing the hypolimnion phosphorus concentrations and periodic build up. Should Park City decide to pump water back from East Canyon Reservoir, there may be opportunity to optimize water quality in the alternatives considered. The W2 model as presently constituted could greatly assist in this analysis of alternatives. The Bureau of Reclamation provided the frame work for this model, and they will also receive this model back. They have personnel trained to use it, and are tentatively scheduled to conduct NEPA compliance studies of various alternatives for Park City to withdraw water from East Canyon Reservoir. They may also have opportunity to continue to partner with Utah DEQ and provide them with additional assistance in utilizing the CE-QUAL-W2 model.

An alternative of chemical treatment to bind phosphorus load into the sediment, particularly in the deep hypolimnion stagnation zone may provide some opportunity for long term benefits with minimal hazards. However, such an alternative would be fruitless without an additional annual phosphorus reduction of 50-65 % from the watershed. Otherwise the benefits of a hypolimnion treatment might not be more than 3-5 years.

Lastly, the phosphoria formation soils on steep slopes need careful future management and study to understand the relationship between erosion and movement of **bioavailable phosphorus** into East Canyon Reservoir. Studies of this relationship must include sampling and extraction procedures that find the most bioavailable forms for reduction for the dollars spent. Reduction of aluminum or apatite mineral forms of phosphorus will yield little improvement in East Canyon Reservoir. The Phosphoria Formation bedrock contains phosphorus primarily in the form of apatite which is a very insoluble mineral. However, oxidation and chemical weathering of this bedrock can also produce soils that are very high in bioavailable phosphorus. Extensive study of spring snow melt phosphorus loading needs to begin immediately starting with utilization of the Biowest Study (Olsen, D. Stamp, M.; 2000) as a guide.

The study of non-point source and spring runoff phosphorus loading in this watershed is essential to quantifying the potential for future additional phosphorus reductions. However, it may also be essential to define the preventative best management practices needed just to maintain the phosphorus loading with future development at the current levels. A non degradation policy is an important consideration because there is currently a very small margin of safety.

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5 Definitions

Autochthonous- refers to matter generated within the reservoir basin, such as phytoplankton.

Allochthonous- refers to matter imported from the watershed.

ECR- acronym for East Canyon Reservoir
ECWRF- East Canyon Water Reclamation Facility

Eutrophication- is a process of aging in a lake or reservoir signified by deposition of sediment, shallowing, increasing nutrient content, decreasing dissolved oxygen, and over productivity of phytoplankton. This is a natural process that is often greatly accelerated by human impacts.

Epilimnion- signifies the summer time warm water above the thermocline which is generally only about top 8 meters in East Canyon Reservoir.
Metalimnion- is the zone of rapidly changing water temperatures from just beneath the thermocline to cooler water more representative of the deeper hypolimnion.
Hypolimnion- is the zone of cold water beneath the metalimnion- in ECR this is usually from about 14-18 meters deep to the bottom.
Thermocline-is the depth at which the water temperature drops more than 1°C through one meter of water forming a density barrier to mixing of oxygenated water from the surface. In ECR a very sharp thermocline begins at 7-8 meters with temperatures sometimes dropping more than 6°C in only 2-3 meters of water.
Seechi Disk is a measurement of water clarity with a stand white and black disk lowered into the water to the measured depth where it is no longer visible.

WWTP- wastewater treatment plant
M&I water- Municipal and Industrial water

CMS- cubic meters/second
Mg/L- milligrams per liter or parts per million which is also equal to grams/cubic meter
µg/L – micrograms per liter or parts per billion

Phytoplankton and algae- used interchangeably
Cyanophyta and blue-green algae used interchangeably

A final note from the Author:

This report was prepared in a very short time frame and on a very short budget. It provided me with an opportunity to share thirty years of experience on this and other reservoirs in the region. The report is a little long and has some redundancy in order to emphasize the inter-relationships between elements. In ten to fifteen years someone will appreciate more information than less provided here. Over the past three decades I have helped build several dams, and modeled and wrote environmental impacts statements on their trophic status before they were built. I survived sticking around and being accountable for those predictions. However, in reviewing my work over thirty years, I always find mistakes, errors, and things were additional knowledge improved our understanding. One of those errors was in under estimating the Deer Creek Reservoir's oxygen depletion rate memory nearly 30 years ago. I don't believe I made any promises about recovery of dissolved oxygen in Deer Creek, but I did propose that a minimum flow entering Deer Creek at night with colder water released upstream from the selective withdrawal structure I conceptually designed on Jordanelle Dam upstream would provide a refuge to carry trout through summer stagnation. Tremendous good has come from the Deer Creek phosphorus TMDL and the operation of the Jordanelle selective withdrawal structure is a significant portion of this success. Governor Scott Matheson believed in me and set up the committee to implement this pioneering watershed phosphorus TMDL. The cold water fishery in Deer Creek has thrived since operation of the Jordanelle selective withdrawal structure began operation.

There are some errors from lack of understanding in this report as well. There are few attempts to complete algal succession in dynamic models as was attempted here. I have attempted to share as much information as I could, so that ten to fifteen years from now you might be able to take what I offer and expand upon it- **Good luck to you**.

Over the past thirty years many people have freely exchanged ideas, reviewed and offered constructive criticism of my work, and respected my abilities sufficiently to fund many water quality studies in the Intermountain West. Ms. Sharon Campbell (USGS) and Dr. Ed Buchak provided extensive comments and encouragement on the first draft of this document, and Mr. Nick Williams and Beau Urionia my former students at Reclamation also found some critical errors or suggested some improvements in this W2 model application. Without Loginetics AGPM post processor it would have taken months more to complete the analyses contained in this report- thanks to Mr. Gary Hauser for his help with this. CE-QUAL-W2 is a model with wonderful capacities, and still needing improvement. Algal succession will still be an ongoing progressive work for years to come. Remember this was a first attempt to harness the power of W2 to vertical daily phytoplankton migration and seasonal dormancy reproductive cycles. Without the programming of Mr. Shwet Prakash, this would not have been possible. I Thank all my colleagues and friends for even tolerating, let alone considering all my "out of the box ideas". Dr. Sam Rushforth and his daughter Sarah Jane's long years of phytoplankton work and personal inspiration, friendship, and assistance make this study a possibility- that otherwise couldn't have even began- a special thanks to you.

Sincerely

Jerry Miller- JM Water Quality LLC, jbmtall49@gmail.com

Blue-green algae blooms on Deer Creek Reservoir before the phosphorus TMDL. The Algal blooms stacked into East Canyon Dam before the TMDL made this look good at times.