

EAST CANYON RESERVOIR AND EAST CANYON CREEK

TOTAL MAXIMUM DAILY LOAD (TMDL)



May 7, 2006, Toastforbrekkie. Public Photo Flickr.com 2009

Prepared for
Utah Division of Water Quality
P.O. Box 144870
Salt Lake City, Utah 84114
Attn: Kari Lundeen
(801) 538-6760

Prepared by
SWCA Environmental Consultants
257 East 200 South
Salt Lake City, Utah 84111
Attn: Erica Gaddis
(801) 322-4307

May 2010



**Utah Department of Environmental Quality
Division of Water Quality TMDL Section**

East Canyon Reservoir TMDL

EPA Approval Date:

Waterbody ID	16020102
Location	Summit and Morgan counties, northern Utah
Pollutants of Concern	Low dissolved oxygen (DO) Excess total phosphorus (TP)
Designated Beneficial Uses	Domestic water use (1C) Primary contact recreation (2A) Secondary contact recreation (2B) Cold water game fish (3A) Agricultural water supply (4)
Impaired Beneficial Uses	Class 3A: Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
Current Load	3,350 kgTP/year (9.2 kgTP/day)
Loading Capacity (TMDL)	2,619 kgTP/year (7.2 kgTP/day)
Margin of Safety (MOS)	262 kgTP/year (0.7 kgTP/day)
Defined Targets/Endpoints	Trophic Status and Algae <ul style="list-style-type: none"> - In-reservoir mean seasonal chlorophyll <i>a</i> of 8 µg/L - Nuisance algal threshold of 30 µg/L not to be exceeded >10% of the season - Algal dominance other than blue-green species Dissolved Oxygen (DO) <ul style="list-style-type: none"> - Mixed reservoir periods: 4.0 mg/L DO throughout at least 50% of the water column - Stratified reservoir periods: 2-m layer throughout the reservoir in which DO is maintained above 4 mg/L and temperature below 20°C Phosphorus <ul style="list-style-type: none"> - Mean total phosphorus concentration of 0.031 mg/L - Mean dissolved phosphorus concentration of 0.021 mg/L
Wasteload Allocation	895 kgTP/year
Load Allocation	1,462 kgTP/year <ul style="list-style-type: none"> - Nonpoint sources load allocation: 1,067 kgTP/year - Internal Reservoir load allocation: 395 kgTP/year
Regulated Point Sources	East Canyon Water Reclamation Facility
Watershed Nonpoint Sources	Spring melt runoff from ski resorts and urban areas Stormwater runoff from construction sites and Park City Streambank erosion Agricultural land uses Natural background sources including phosphatic shales



**Utah Department of Environmental Quality
Division of Water Quality TMDL Section**

East Canyon Creek TMDL

EPA Approval Date:

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

Table of Contents

Table of Contents	iii
List of Tables	xi
List of Figures	xv
Foreword	xviii
Acknowledgments	xix
Preparers	xix
1. Introduction	1
1.1 The Total Maximum Daily Load Process	1
1.1.1 Point Sources.....	2
1.1.2 Nonpoint Sources	2
1.1.3 Load Allocations (LA)	2
1.1.4 TMDL Scope.....	2
1.2 Why Should TMDLs Be Written?	2
1.3 Who Is Responsible for Writing TMDLs?	3
1.4 Elements of a TMDL	3
1.4.1 Waterbody and Watershed Assessment	3
1.4.2 Loading Analysis	3
1.4.3 Implementation Plan(s)	4
2. Characterization of Watershed	5
2.1 Physical and Biological Characteristics	7
2.1.1 Climate	7
2.1.2 Hydrology	15
2.1.2.1 Surface Water Hydrology	15
2.1.2.2 Groundwater Hydrology	17
2.1.3 Geology and Soils	18
2.1.3.1 Geology.....	18
2.1.3.2 Soils.....	18
2.1.3.3 Stream Geomorphology	24
2.1.4 Plants, Animals, and Fisheries	25
2.1.4.1 Riparian Plant Community.....	25
2.1.4.2 Dominant Upland Plant Community.....	25
2.1.4.3 Wildlife	27
2.1.4.4 Fisheries	27
2.1.4.5 Special Designations	28
2.2 Cultural Characteristics	29
2.2.1 Land Use and Ownership	29
2.2.2 Population	33

2.2.3	History and Economics	33
2.2.4	Recreational Uses of East Canyon Reservoir.....	34
2.2.4.1	Boating and Related Activities	35
2.2.4.2	Hunting and Wildlife Observation	35
2.2.4.3	Camping.....	35
2.2.5	Public Involvement	36
3.	Water Quality Concerns and Status	37
3.1	Beneficial Uses and Impaired Waters	37
3.2	Water Quality Standards Applicable to East Canyon Reservoir	38
3.2.1	Pollutants of Concern.....	41
3.2.1.1	Nutrients.....	41
3.2.1.2	Sediment	42
3.2.1.3	Organic Matter	43
3.2.1.4	Dissolved Solids.....	43
3.2.1.5	Bacteria	43
3.2.2	Indicators of Beneficial Use Impairment	43
3.2.2.1	Nuisance Algal Growth.....	43
3.2.2.2	Cyanobacteria (Blue-green Algae).....	44
3.2.2.3	Dissolved Oxygen (DO).....	45
3.2.2.4	Dissolved Oxygen Saturation.....	46
3.2.2.5	Turbidity and Secchi Depth	47
3.2.2.6	pH.....	47
3.2.2.7	Temperature	48
3.2.2.8	Trophic State Index (TSI)	48
3.3	Analysis of Existing Water Quality and Hydrologic Data	50
3.3.1	Analytical Methods	50
3.3.1.1	Water Quality.....	50
3.3.1.2	Hydrology	51
3.3.1.3	Sediment Chemistry	52
3.3.1.4	Treatment of Nondetects	55
3.3.1.5	Treatment of Errors	56
3.3.1.6	Treatment of Outliers	56
3.3.1.7	Treatment of Duplicate Measures	58
3.3.2	Data Coverage.....	58
3.3.2.1	Temporal Coverage.....	59
3.3.2.2	Hydrological Coverage	61
3.3.2.3	Spatial Coverage	65
3.3.2.4	Identified Data Gaps	66
3.3.2.5	Summary	67
3.4	Beneficial Use Support Assessment for East Canyon Reservoir	67
3.4.1	Direct Exceedance of Numeric Criteria, Thresholds, and/or Reference Conditions.....	67

3.4.1.1	Ammonia (3A)	67
3.4.1.2	Bacteria	67
3.4.1.3	Nuisance Algal Growth	68
3.4.1.4	Dissolved Oxygen (DO) (3A)	69
3.4.1.5	Total Dissolved Gas Saturation (3A)	72
3.4.1.6	Nitrate (3A)	72
3.4.1.7	pH (3A)	72
3.4.1.8	Temperature (3A)	73
3.4.1.9	Total Dissolved Solids (TDS) (4)	73
3.4.1.10	Total Phosphorus (2A, 2B, and 3A)	74
3.4.1.11	Metals (1C, 3A, and 4)	74
3.4.2	Additional Lines of Evidence for Beneficial Use Assessment	75
3.4.2.1	Secchi Depth	75
3.4.2.2	Trophic State Index (TSI)	75
3.4.2.3	Nitrogen-to-phosphorus Ratio	76
3.4.2.4	Algal Communities	77
3.4.2.5	Potential for Toxicity from Cyanobacteria (blue-green algae)	80
3.4.2.6	Fishery Assessment	80
3.4.2.7	Recreation Use Summary	81
3.4.3	Assessment of Domestic Water Use Beneficial Use (1C)	82
3.4.3.1	Key Linkages between Water Quality and Domestic Water Uses	82
3.4.3.2	Support Status Summary	83
3.4.4	Assessment of Contact Recreation Beneficial Uses (2A, 2B)	83
3.4.4.1	Key Linkages between Water Quality and Recreation Uses	83
3.4.4.2	Support Status Summary	84
3.4.5	Assessment of Cold Water Fishery Beneficial Use (3A)	85
3.4.5.1	Key Linkages between Water Quality and Fishery (3A)	85
3.4.5.2	Support Status Summary	86
3.4.6	Assessment of Agricultural Water Supply Beneficial Use (4)	87
3.4.6.1	Key Linkages between Water Quality and Agricultural Uses	87
3.4.6.2	Support Status Summary	88
3.5	Water Quality Improvement Since Previous TMDL	88
3.5.1	East Canyon Water Reclamation Facility	89
3.5.2	Summary of Nonpoint Source Pollution Control Efforts	89
3.5.2.1	Agricultural Land Management	89
3.5.2.2	Park City Stormwater Management	89
3.5.2.3	Implementation of Construction Best Management Practices (BMP)	90
3.5.2.4	Conservation Easements and Open Space Preservation	90
3.5.2.5	Riparian Restoration and Enhancement	90
3.5.2.6	Recreation and Trail Management Changes	91
3.5.2.7	Water Conservation	91
3.5.2.8	Education and Media Programs	91
3.5.3	Water Quality Comparison	92

3.5.3.1	Phosphorus	92
3.5.3.2	Chlorophyll <i>a</i>	96
3.5.3.3	Dissolved Oxygen (DO).....	98
3.5.3.4	Trophic State Index Changes from Recent to Current	99
3.5.3.5	Algal Community Changes from Recent to Current.....	101
3.5.3.6	Nitrogen-to-phosphorus Ratio Changes from Recent to Current.....	104
3.5.4	Summary	105
4.	East Canyon Creek Modeling and Dynamics	107
4.1	Summary of Water Quality Concerns in East Canyon Creek.....	107
4.2	Assessment of Physical Conditions in Creek	108
4.2.1	Channel Condition	110
4.2.2	Hydrologic Alteration	110
4.2.3	Bank Stability.....	110
4.2.4	Pools.....	110
4.2.5	Canopy Cover.....	110
4.2.6	Geomorphic Summary	110
4.3	Feasibility Study for Establishing a Protected Base Flow.....	111
4.4	Stream Metabolism and Nutrient Dynamics in East Canyon Creek	113
4.5	Dissolved Oxygen (DO) Modeling	114
4.6	Linkage Between Stream Characteristics and Dissolved Oxygen (DO).....	116
4.6.1	Water Temperature.....	117
4.6.2	Stream Velocity.....	117
4.6.3	Sediment and Nutrient Loads.....	118
4.6.4	Light.....	118
4.6.5	Algae and Macrophyte Growth.....	119
4.6.6	Riparian Vegetation	119
4.7	Summary of Factors Influencing Dissolved Oxygen (DO) in East Canyon Creek.....	120
5.	East Canyon Reservoir Modeling and Dynamics	122
5.1	General Model Description	122
5.2	Model Goals and Objectives	122
5.3	Model Development for East Canyon Reservoir.....	122
5.3.1	Temporal Extent of Model Simulations	123
5.3.2	Inputs for East Canyon Reservoir W2 Model	123
5.3.2.1	Reservoir Morphometry	123
5.3.2.2	Tributary Inputs	124
5.3.2.3	Climatic Data Inputs	125
5.3.3	East Canyon Reservoir Dynamics.....	126
5.3.3.1	Hydrodynamics	126
5.3.3.2	Stratification.....	127
5.3.3.3	Seasonality and Climatic Drivers of Algal Blooms	128

5.3.3.4	Algal Speciation, Succession, and Vertical Mobility.....	128
5.3.3.5	Phosphorus Availability.....	131
5.3.3.6	Sediment Oxygen Demand.....	132
5.3.3.7	Drivers of Low Dissolved Oxygen (DO) in Hypolimnion.....	132
5.4	Model Calibration and Validation	133
5.4.1	Rate Coefficients.....	135
5.4.2	Temperature.....	135
5.4.3	Evaporation.....	135
5.4.4	Phosphorus Discharge from Dam.....	136
5.4.5	Dissolved Oxygen (DO) and Temperature Profiles.....	137
5.4.6	Algal Growth.....	139
5.4.7	Algal Speciation.....	139
5.4.8	Model Uncertainty.....	140
5.5	Scenario Modeling	140
5.5.1	Future Nutrient Reduction Scenarios.....	140
5.5.2	Nutrients.....	143
5.5.3	Chlorophyll <i>a</i>	145
5.5.4	Blue-green Algae.....	147
5.5.5	Turbidity.....	148
5.5.6	Oxygen Depletion.....	149
6	Phosphorus Source Identification and Load Analysis.....	152
6.1	Major Sources of Nutrient Loading to East Canyon Reservoir	152
6.1.1	Point Sources.....	152
6.1.2	Nonpoint Sources.....	154
6.1.2.1	Urban/Suburban Nonpoint Sources.....	154
6.1.2.2	Agricultural Nonpoint Sources.....	155
6.1.2.3	Recreation Area Nonpoint Sources.....	156
6.1.2.4	Natural Background Nonpoint Sources.....	157
6.1.3	Other Sources.....	157
6.1.3.1	Streambank Erosion.....	157
6.1.3.2	Atmospheric Sources.....	158
6.1.3.3	Internal Reservoir Sources.....	158
6.2	Total Current Load Estimates to East Canyon Reservoir	158
6.2.1	Temporal Extent of Analysis.....	158
6.2.2	Methodology.....	159
6.2.2.1	Calculation of Total Phosphorus Load by Hydroperiod.....	159
6.2.2.2	Characterization of Specific Nonpoint Source Loads by Land Use and Tributary.....	160
6.2.3	Load Summary by Hydrologic Period.....	167
6.2.4	Summary of Watershed Sources.....	170
6.2.4.1	Point Source.....	170
6.2.4.2	Nonpoint Sources.....	171
6.2.5	Internal Load Summary.....	171

6.2.6	Total Load Summary.....	173
7.	Total Maximum Daily Load Summary	174
7.1	Phased TMDL Approach and Rationale	174
7.2	Water Quality Targets and Linkage Analysis.....	175
7.2.1	Dissolved Oxygen Endpoints	176
7.2.1.1	East Canyon Reservoir.....	176
7.2.1.2	East Canyon Creek.....	176
7.2.2	Macrophyte-related and Algae-related Endpoints.....	177
7.2.2.1	East Canyon Reservoir.....	177
7.2.2.2	East Canyon Creek.....	179
7.2.3	Linkage Analyses	179
7.2.3.1	Nutrient Targets and Water Quality Endpoints in East Canyon Reservoir.....	179
7.2.3.2	Stream Characteristics and Water Quality Endpoints in East Canyon Creek	180
7.3	Future Growth	182
7.4	TMDL Analysis	186
7.4.1	Current Load Summary and TMDL.....	186
7.4.2	Margin of Safety (MOS)	186
7.4.3	Load Allocation and Rationale.....	187
7.5	Seasonality	191
7.6	Summary.....	191
7.6.1	East Canyon Reservoir.....	192
7.6.2	East Canyon Creek.....	193
8.	East Canyon Creek Implementation Plan	194
8.1	Introduction.....	194
8.2	Statement of Need	194
8.2.1	Summary of Endpoints.....	195
8.2.2	Description of Ecological Drivers.....	195
8.3	Project Description	196
8.3.1	Project Goals and Objectives	196
8.3.2	Description of Implementation Measures	196
8.3.2.1	Shading	196
8.3.2.2	Establishing a Protected Base Flow	197
8.3.2.3	Channel Narrowing/Bank Stabilization	197
8.3.2.4	Constraints on Implementation	198
8.3.2.5	Summary of Implementation Approaches	199
8.3.3	Prioritization of Stream Reaches.....	199
8.3.3.1	Prioritization for Shading and for Establishing a Protected Base Flow.....	199
8.3.3.2	Prioritization for Bank Stabilization	204
8.3.4	Recommended Implementation Strategy	206
8.3.4.1	Establishing a Protected Base Flow	206

8.3.4.2	Implementation of Shading	208
8.3.4.3	Implementation of Bank Stabilization	209
8.3.5	Time Frame for Implementation	210
8.3.6	Reasonable Assurance.....	211
8.3.6.1	Linkage between Recommended Implementation Measures and Dissolved Oxygen Impairment	211
8.3.6.2	Feasibility of Riparian Plantings and Bank Stabilization.....	212
8.3.6.3	Feasibility of Establishing a Protected Base Flow	213
8.4	Coordination Plan.....	213
8.4.1	Lead Project Sponsors.....	213
8.4.2	Cooperating Groups	214
8.5	Monitoring.....	214
8.5.1	Sampling Design and Parameters.....	214
8.5.1.1	Monitoring Endpoints	214
8.5.1.2	Monitoring Riparian Shading.....	215
8.5.1.3	Monitoring the Protected Base Flow.....	216
8.5.1.4	Monitoring Bank Stabilization.....	216
8.5.2	Progress Reporting	216
8.6	Budget	217
8.6.1	Projected Costs for Implementation.....	217
8.6.1.1	Costs for Establishing a Protected Base Flow.....	217
8.6.1.2	Costs for Shading and Bank Stabilization.....	217
8.6.2	Financial and Legal Means for Implementation	221
8.6.2.1	Means for Establishing a Protected Base Flow.....	221
8.6.2.2	Means for Shading and Bank Stabilization	221
9.	East Canyon Reservoir Watershed-based Implementation Plan.....	223
9.1	Introduction.....	223
9.2	Key Components of the Implementation Plan	224
9.2.1	Identification of Sources and Current Load Summary.....	224
9.2.1.1	East Canyon Water Reclamation Facility (ECWRF) Discharge.....	224
9.2.1.2	Internal Reservoir Sources	225
9.2.1.3	Nonpoint Sources	225
9.2.2	Load Reduction Estimates.....	229
9.2.2.1	East Canyon Water Reclamation Facility	229
9.2.2.2	Internal Reservoir Sources	229
9.2.2.3	Nonpoint Sources	229
9.2.3	Recommended Management and Implementation Measures.....	232
9.2.3.1	East Canyon Water Reclamation Facility	232
9.2.3.2	In-reservoir Treatments.....	232
9.2.3.3	Nonpoint Source Management Measures	233
9.2.3.4	Critical Areas for Management Measures.....	237

- 9.2.3.5 Land Uses and Recommended BMPs 239
- 9.2.4 Technical and Financial Needs 255
 - 9.2.4.1 Plan Sponsors and Resources..... 255
 - 9.2.4.2 Projected Costs for Implementation..... 256
 - 9.2.4.3 Financial and Legal Vehicles for Implementation 260
- 9.2.5 Information and Education..... 260
 - 9.2.5.1 Define the Driving Forces, Goals and Objectives..... 261
 - 9.2.5.2 Identify and Analyze the Target Audiences..... 262
 - 9.2.5.3 Create the Message 262
 - 9.2.5.4 Package and Distribute the Message..... 262
- 9.2.6 Implementation Schedule..... 262
 - 9.2.6.1 East Canyon Water Reclamation Facility Expansion 262
 - 9.2.6.2 In-reservoir Treatment 263
 - 9.2.6.3 Nonpoint Source Management Measures 263
- 9.2.7 Interim Implementation Milestones 263
 - 9.2.7.1 Sampling Design and Parameters..... 264
- 9.2.8 Loading Reduction Targets 264
- 9.2.9 Monitoring 265
 - 9.2.9.1 Implementation Monitoring 265
 - 9.2.9.2 Progress Reporting in a Centralized Database 267
- 9.3 Conclusions..... 268
- List of Abbreviations and Symbols269**
- References Cited.....273**
- References Consulted but Not Directly Cited283**
- Appendix A. Annual hydrographs for East Canyon Creek.**
- Appendix B. East Canyon Reservoir CE-QUAL-W2 Model. JM Water Quality LLC.**

List of Tables

Table 2.1. Mountain Dell Dam: Average Monthly Air Temperature Data Summary (1948–2007)	9
Table 2.2. Mountain Dell Dam: Average Monthly Precipitation Data Summary (1948–2007).....	9
Table 2.3. Wanship Dam: Average Monthly Air Temperature Data Summary (1957–2007)	11
Table 2.4. Wanship Dam: Average Monthly Precipitation Data Summary (1957–2007).....	11
Table 2.5. Park City Fire Station 31: Average Monthly Air Temperature Data Summary (1992– 2007)	13
Table 2.6. Park City Fire Station 31: Average Monthly Precipitation Data Summary (1992–2007).....	13
Table 2.7. Climate Summaries for the East Canyon Reservoir Watershed	15
Table 2.8. East Canyon Watershed Average Flow and Drainage Area.....	16
Table 2.9. East Canyon Reservoir Inflow and Retention Times from 2001 to 2007.....	17
Table 2.10. Soil Types and Characteristics in the East Canyon Reservoir Watershed.....	21
Table 2.11. Soil Texture in the East Canyon Reservoir Watershed	22
Table 2.12. Utah Sensitive Species in Morgan and Summit Counties	28
Table 2.13. Land Use in the East Canyon Creek Watershed.....	30
Table 2.14. Land Ownership in the East Canyon Creek Watershed	30
Table 2.15. Population in East Canyon Reservoir Watershed.....	33
Table 2.16. East Canyon Reservoir State Park Visitation	34
Table 3.1. Summary of Use Designations for Waters of the State of Utah (Rule Code R317-2)	37
Table 3.2. Selected Water Quality Criteria for Designated Uses in East Canyon Reservoir	38
Table 3.3. Dissolved Oxygen Concentrations at which Fish Died within 24 Hours	46
Table 3.4. TSI Values and Status Indicators	49
Table 3.5. Relationships between TSI Values.....	49
Table 3.6. Metadata Summary of Sediment Cores Collected in East Canyon Reservoir in October 2007.....	53
Table 3.7. Detection Limits of Methods Found in the EPA STORET Database	55
Table 3.8. Standard Deviations Used in Outlier Analysis for East Canyon Reservoir Water Quality Data	57
Table 3.9. Standard Deviations Used in Outlier Analysis for East Canyon Creek Water Quality Data	58
Table 3.10. Sampling Time Periods for Monitoring Sites Located in East Canyon Reservoir.....	60
Table 3.11. Discharge Gages in the East Canyon Watershed and Their Periods of Record	61
Table 3.12. Annual Average Flow Rates and Quantitative Comparisons Relative to the 30-year Average for East Canyon Creek at USGS Gage #10134500	64
Table 3.13. Monitoring Stations and Data Sources Identified as Critical to the East Canyon Reservoir TMDL Process.....	65
Table 3.14. Summary of Chlorophyll <i>a</i> Data in East Canyon Reservoir (water years 2002–2007) during the May–October Algal Growth Season ($\mu\text{g/L}$).....	68

Table 3.15. Summary of Percent Water Column Exhibiting DO Levels Supportive of Cold Water Fishery (>4 mg/L) and Associated Support Status Based on Profiles Collected in 2001, 2003, and 2007	69
Table 3.16. Current (water years 2002–2007) Average Concentrations (µg/L) of Metals in East Canyon Reservoir.....	75
Table 3.17. Summary Statistics for Current Secchi Depth (m) Data (water years 2002–2006) in East Canyon Reservoir Data Collected during the Algal Growing Season (June–October).....	75
Table 3.18. Current (water years 2002–2007) Average TSI Values for East Canyon Reservoir.....	76
Table 3.19. Current Nitrogen-to-phosphorus Ratios in East Canyon Reservoir (water years 2002–2007)	77
Table 3.20. Current (2002–2007) Phytoplankton Abundance above the East Canyon Reservoir Dam (Station ID 4925160) and Corresponding 2007 Rushforth Sampling Sites	79
Table 3.21. Recent (water years 1996–2001) and Current (water years 2002–2007) Total and Dissolved Phosphorus Concentrations in East Canyon Reservoir (mg/L).....	93
Table 3.22. Summary of Recent (water years 1996–2001) and Current (water years 2002–2007) Chlorophyll <i>a</i> Data in the Reservoir during the May–October Algal Growth Season (µg/L)	96
Table 3.23. Comparison of the Percent of the Water Column Exhibiting DO Levels Supportive of Cold Water Fisheries (>4.0 mg/L) for Recent (1996–2001) and Current (2002–2007) Water Years (Above the Dam–Station ID 4925160)	98
Table 3.24 Comparison of Trophic State Indices (TSI) Before (water years 1996–2001) and After (water years 2002–2006) Implementation of East Canyon Reservoir TMDL	100
Table 3.25. Comparison in Algal Species Composition between Pre-TMDL (1996–2001) and Post-TMDL (2002–2007) Periods for East Canyon Reservoir	103
Table 3.26. Recent (water years 1996–2001) and Current (water years 2002–2007) N:P Ratios above the East Canyon Reservoir Dam (Station ID 4925160).....	105
Table 4.1. SVAP Conditions and Scores Used to Evaluate Stream Condition	108
Table 4.2. East Canyon Creek SVAP Results	109
Table 4.3. Study Site Locations Used in USU Research on East Canyon Creek	113
Table 4.4. Projected Average and Minimum DO Concentrations from DIURNAL Model (SBWRD 2008).....	115
Table 4.5 Summary of Reach Level Stream Characteristics and Research Findings.....	121
Table 5.1. Median Water Quality in East Canyon Creek by Hydroperiod Used to Create Daily Tributary Input Files for W2 Model.....	125
Table 5.2. Future Nutrient Reduction Scenarios for East Canyon Reservoir.....	142
Table 5.3. Predicted Average Phosphorus Concentrations in East Canyon Reservoir Epilimnion.....	143
Table 5.4. Predicted Average and Maximum Summer Chlorophyll <i>a</i> Concentrations (µg/l) in the Epilimnion in East Canyon Reservoir	145
Table 5.5. Summary of Model Results Related to Percent Exceedance of a Chlorophyll <i>a</i> Value of 30 µg/l in East Canyon Reservoir	145
Table 5.6. Number of Days During Stratified Period in which DO is Not Maintained above 4 Mg/L in a 2-m Zone where Temperature is also Less than 20°C.....	151

Table 6.1. BIO-WEST Load Coefficients (Olsen and Stamp 2000; BIO-WEST 2008) Used for East Canyon Watershed Subbasins	160
Table 6.2. East Canyon Watershed Land-use Areas and Annual Phosphorus Loads.....	161
Table 6.3. East Canyon Watershed Subbasin Phosphorus Loads.....	165
Table 6.4. Acre-Feet of Runoff from Each Hydroperiod during the Post-TMDL Period	167
Table 6.5. Summary of Total Phosphorus Load (kgTP/year) by Hydroperiod for the Post-TMDL Period	168
Table 6.6. Summary of Dissolved Phosphorus Load (kgDP/year) by Hydroperiod for the Post-TMDL Period	169
Table 6.7. Summary of Total Phosphorus Load to East Canyon Reservoir from Point and Nonpoint Sources (kg/year)	170
Table 6.8. Summary of Dissolved Phosphorus Load into East Canyon Reservoir from Point and Nonpoint Sources (kg/year)	170
Table 6.9. Estimated Internal Load during the Post-TMDL Period	172
Table 6.10. Summary of Total Phosphorus Load to East Canyon Reservoir from Point, Nonpoint, and Internal Sources (kg/year)	173
Table 7.1. Summary of Support of Swimming Designated Use at Varying Frequencies of High ¹ Algal Levels	178
Table 7.2. Summary Statistics for Chlorophyll <i>a</i> ($\mu\text{g/L}$) Data from Lakes and Reservoirs in the Western Forested Mountains Ecoregion	179
Table 7.3. Projected Minimum Dissolved Oxygen (mg/L) in August for the Blackhawk and Bear Hollow Reaches of East Canyon Creek under Baseline Conditions and Management Scenarios	181
Table 7.4. Summary of Maximum Total Phosphorus Seasonal and Daily Loads for Attainment of Water Quality Standards in East Canyon Reservoir	186
Table 7.5. Summary of Current Total Phosphorus Load (kg/year) and Load Allocations Identified for the Revised East Canyon Reservoir TMDL	188
Table 8.1. Trade-offs in Time Frame, Uncertainty, and Feasibility for East Canyon Creek Implementation Measures	199
Table 8.2. Summary of Reach-specific SVAP, DIURNAL Model Output, and Baker et al. (2008) Study Results and Priority Rank: Shade	201
Table 8.3. Summary of Reach-specific SVAP, DIURNAL Model Output, and Baker et al. (2008) Study Results and Priority Rank: Bank Stabilization.....	201
Table 8.4. Summary of Shading and Base Flow Protection Prioritization	204
Table 8.5. Summary of Bank Stabilization Prioritization.....	204
Table 8.6. Additional Flow Needed to Maintain a 7.7-cfs Discharge Upstream of the ECWRF during the Critical Summer Period (July 1–September 15)	208
Table 8.7. Shading Implementation.....	209
Table 8.8. SECI Results with Priority Rankings and Length of Stabilization Recommended by Reach.....	210
Table 8.9. Sampling Design and Monitoring Activities for Riparian Shading.....	215
Table 8.10. Sampling Design and Monitoring Activities for Bank Stabilization.....	216
Table 8.11. Potential Cost to Secure 500 Acre-feet for Establishing a Protected Base Flow	217

Table 8.12. Cost Ranges by Priority Reaches for Stream Shading Enhancement BMPs..... 219

Table 8.13. Total Costs Associated with Priority Reaches for Streambank Protection..... 220

Table 8.14. Costs for Associated Best Management Practices..... 221

Table 9.1. Summary of Load Reductions Resulting from BMPs Implemented by Loading Source..... 230

Table 9.2. Summary of Land Uses and Associated Phosphorus Nonpoint Loads..... 234

Table 9.3 Summary of Implementation Planning in the East Canyon Reservoir Watershed 236

Table 9.4. Priority Subbasins and Recommended BMPs for Active Construction Areas in the East Canyon Reservoir Watershed 240

Table 9.5. Priority Subbasins and Recommended BMPs for Residential Land Uses in the East Canyon Reservoir Watershed 242

Table 9.6. Priority Subbasins and Recommended BMPs for Commercial and Urban Land Uses in the East Canyon Reservoir Watershed 244

Table 9.7. Priority Subbasins and Recommended BMPs for Golf Courses in the East Canyon Reservoir Watershed 245

Table 9.8. Priority Subbasins and Recommended BMPs for Ski Areas in the East Canyon Reservoir Watershed 248

Table 9.9. Priority Subbasins and Recommended BMPs for High Use Recreation in the East Canyon Reservoir Watershed..... 249

Table 9.10. Priority Subbasins and Recommended BMPs for Agricultural and Grazing Land Uses in the East Canyon Reservoir Watershed 251

Table 9.11. Priority Subbasins and Recommended BMPs for Forested and Meadow Land Uses in the East Canyon Reservoir Watershed 254

Table 9.12. Summary of Costs Associated with Project Implementation Plan 257

Table 9.13. Example of Implementation Tracking Matrix 266

List of Figures

Figure 2.1. East Canyon Reservoir watershed boundary and hydrologic features map.	6
Figure 2.2. East Canyon Reservoir watershed slope map.	8
Figure 2.3. Average monthly air temperature conditions at the Mountain Dell Dam meteorological site, Utah (Source: WRCC 2008).	10
Figure 2.4. Average monthly total precipitation at the Mountain Dell Dam meteorological site, Utah (Source: WRCC 2008).	10
Figure 2.5. Average monthly air temperature conditions at the Wanship Dam meteorological site, Utah (Source: WRCC 2008).	12
Figure 2.6. Average monthly total precipitation at the Wanship Dam meteorological site, Utah (Source: WRCC 2008).	12
Figure 2.7. Average monthly air temperature conditions at the Park City Fire Station 31 meteorological site, Utah (Source: WRCC 2008).	14
Figure 2.8. Average monthly total precipitation at the Park City Fire Station 31 meteorological site, Utah (Source: WRCC 2008).	14
Figure 2.9. East Canyon Reservoir watershed geology map.	19
Figure 2.10. East Canyon Reservoir watershed soil classifications.	20
Figure 2.11. East Canyon Reservoir watershed soil textures.	23
Figure 2.12. East Canyon Reservoir watershed vegetation and land cover.	26
Figure 2.13. East Canyon Reservoir watershed land ownership.	31
Figure 2.14. East Canyon Reservoir watershed land use.	32
Figure 3.1. Sediment core sampling locations (Chesapeake Biogeochemical Associates 2008).	54
Figure 3.2. 30-year record of mean annual discharges for regional streams used to differentiate wet and dry years.	62
Figure 3.3. Example dry, wet, and average hydrographs for East Canyon Creek near Jeremy Ranch (USGS Station # 10133800).	63
Figure 3.4. Observed DO and temperature profiles at East Canyon Dam in 2001 and 2003.	70
Figure 3.5. DO and temperature profiles at multiple sites in East Canyon Reservoir collected on 8/15/2007.	70
Figure 3.6. DO and temperature profiles at multiple sites in East Canyon Reservoir across the 2007 summer algal growth season.	71
Figure 3.7. Current pH values (water years 2002–2007) at the Above the Dam Site (Station ID 4925160) in East Canyon Reservoir (red lines show upper and lower limits of pH water quality criteria for all beneficial uses).	72
Figure 3.8. Current temperatures (water years 2002–2007) at the Above the Dam Site in East Canyon Reservoir (red line shows upper limits of temperature criteria for cold water fisheries).	73
Figure 3.9. Current TP (water years 2002–2007) at the Above the Dam Site in East Canyon Reservoir (red line shows upper limits for TP criteria for recreation and cold water fisheries [2A, 2B, 3A]).	74

Figure 3.10. Dominance of algal groups measured in percent biovolume and percent density, sampled throughout East Canyon Reservoir from 2002–2007. Data sources: EPA STORET and Rushforth (2007).	78
Figure 3.11. Links between water quality and domestic water use.	82
Figure 3.12. Links between water quality and recreation.....	84
Figure 3.13. Links between nutrients and fisheries.	86
Figure 3.14. Links between nutrients and agricultural use.	88
Figure 3.15. Phosphorus profile comparisons for August and September 1996, 1999, and 2007 (Station #4925160) (the red line indicates the 0.025 mg/L water quality indicator value for phosphorus).	95
Figure 3.16. IKONOS Multispectral Imagery of East Canyon Reservoir.	97
Figure 3.17. Change in TSI values for Chlorophyll <i>a</i> , Phosphorus as P, and Secchi disk depth from 1994 to 2007 in East Canyon Reservoir–Above the Dam (Station ID 4925160).	99
Figure 3.18. Comparison of recent (water years 1996–2001) and current (water years 2002–2007) average TSI values for chlorophyll <i>a</i> , total phosphorus, and Secchi disk depth for East Canyon Reservoir–Above the Dam (Station ID 4925160).	100
Figure 3.19. Dominance of algal groups measured in percent biovolume sampled throughout East Canyon Reservoir from 2002–2007 and 1995–2001. Data sources: EPA STORET and Rushforth (2007).	102
Figure 4.1. Map of SVAP stream reaches and USU/HydroQual research sites and reaches.	112
Figure 4.2. Linkages between physical stream characteristics and DO.	117
Figure 5.1. Segments of East Canyon Reservoir used in the W2 model.	123
Figure 5.2. East Canyon comparison of the live storage area capacity table (provided by Nick Williams, BOR, 2008) and volumes generated using the W2 model bathymetry file.	124
Figure 5.3. Dam configuration and phosphorus distribution during stratification.	127
Figure 5.4. Diagram of the algal succession code conceptually developed by Jerry Miller with extensive discussion with Shwet Prakash at ERM.	130
Figure 5.5. Observed (circles) and modeled (line) total phosphorus released from the East Canyon Dam (data is from 2 km downstream) from 2003 to 2006.	136
Figure 5.6. Modeled (line) and observed (dot) temperatures at the dam and mid-reservoir stations.	137
Figure 5.7. Calibration curves of modeled (line) and observed (circles) DO near the dam.	138
Figure 5.8. Annual cycle of DO in East Canyon Reservoir before and after implementation of the 2000 East Canyon Reservoir TMDL.....	139
Figure 5.9. Total phosphorus discharge from the dam under baseline (brown line) and reduction scenario (3d) conditions.	143
Figure 5.10. Display of total phosphorus in the water column, including the sediment-water interface, upper level of the hypolimnion, and epilimnion in East Canyon Reservoir under baseline and Scenario 3d conditions.	144
Figure 5.11. Relationship between mean annual summer chlorophyll concentrations and mean summer epilimnion total phosphorus concentration for the baseline East Canyon Reservoir W2 simulation.....	146

Figure 5.12. Relationship between mean annual summer chlorophyll concentrations and mean summer epilimnion total phosphorus concentration for the Scenario 3d East Canyon Reservoir W2 simulation.....	147
Figure 5.13. Predicted summer algal speciation in East Canyon Reservoir under baseline and future nutrient reduction scenarios.....	148
Figure 5.14. Relationship between Secchi disk depth and chlorophyll <i>a</i> in East Canyon Reservoir.....	149
Figure 5.15. Predicted DO profile at the Mid-reservoir Site in mid August at the end of the model simulation period.....	150
Figure 6.1 Total phosphorus concentrations in ECWRF effluent during water years 2002–2007.....	153
Figure 6.2. Total Annual Nonpoint source phosphorus loads (kg/year) by land use.....	162
Figure 6.3. Normalized nonpoint source phosphorus loads (kg/ha) by land use.....	162
Figure 6.4. Map of land-use coverage and subbasins used in estimating nonpoint source loads to East Canyon Reservoir.....	166
Figure 6.5. Percentage of total basin discharge (volume) from each hydroperiod.....	167
Figure 6.6. Percentages of total phosphorus load to East Canyon Reservoir summarized by hydroperiod.....	168
Figure 6.7. Percentages of dissolved phosphorus load to East Canyon Reservoir summarized by hydroperiod.....	169
Figure 6.8. Monthly phosphorus mass balance for East Canyon Reservoir for water years 2003–2007.....	172
Figure 6.9. Average annual total phosphorus load by hydroperiod and source.....	173
Figure 7.1. Snyderville Basin zoning map (Summit County 2008).....	184
Figure 7.2. Snyderville Basin Water Reclamation District (SBWRD) service area.....	185
Figure 7.3. Change in total phosphorus load and allocations for the East Canyon Reservoir TMDL.....	189
Figure 8.1 Map of priority reaches for shading and base flow protection.....	203
Figure 8.2 Map of priority reaches for bank stabilization.....	205
Figure 8.3 Modeled and study-period hydrology.....	207
Figure 9.1 Map of critical priority areas for additional implementation for phosphorus reduction in the East Canyon Reservoir watershed.....	238

Foreword

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

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

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

Acknowledgments

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

Preparers

- Carl Adams, UDEQ, Review
- Linda Burfitt, SWCA, Technical Editing
- Kari Chalker, SWCA, Technical Editing
- Catherine Chatfield, SWCA, GIS
- John Christensen, SWCA, Project Implementation Plan
- Doug Davidson, SWCA, Source Identification and Project Implementation Plan
- Erica Gaddis, SWCA, Project Manager, Water Quality Analysis and Load Analysis
- J. Hope Hornbeck, SWCA, Water Quality Analysis, Watershed Characterization, Linkage Analysis, and Project Implementation Plan
- Greg Larson, SWCA, Hydrology, Geomorphology, and Project Implementation Plan
- Kari Lundeen, UDEQ, Project Manager
- Audrey McCulley, SWCA, Data Management and Technical Writing
- Jerry Miller, JM Water Quality LLC, Reservoir Modeling
- Megan Nelson, SWCA, Soils and Geology, Watershed Characterization
- David Reinhart, SWCA, GIS
- Laura Burch Vernon, SWCA, Recreation Use Assessment, Land Use and Land Cover, Population Growth

This Page Intentionally Left Blank