Appendix A

Watershed and Reservoir Modeling

A-1. MODEL GOALS AND OBJECTIVES

Developing the Total Maximum Daily Load (TMDL) for the Rockport and Echo Reservoirs involved using two models: BATHTUB and Soil Water Assessment Tool (SWAT). BATHTUB is an empirical reservoir model developed by the US Army Corps of Engineers using data from over 500 reservoirs across the United States. SWAT is a watershed model developed by the US Department of Agriculture Agricultural Research Service (USDA-ARS). SWAT estimates nutrient loads from watershed sources and incorporates in-stream routing of sediment and nutrient loads. The models were used together to model nitrogen and phosphorus cycling, determine sources of loading for both nitrogen and phosphorus, and to model potential management scenarios. In particular, SWAT provides an estimate of watershed-generated nutrient inputs and inflow that can be used as inputs for the BATHTUB model. Conversely, output from the BATHUB model for Rockport Reservoir were used as inflow for the Echo Reservoir Watershed SWAT model scenario runs.

The overall goals for the BATHTUB model are to generate estimates of existing nutrient loads and dynamics in the reservoir and to model scenarios to determine if management actions could reduce impairment in the reservoir by increasing dissolved oxygen (DO). Specific objectives include creating baseline reservoir models for nutrients and DO that represent 1) dry weather and low reservoir level conditions, 2) average weather and average reservoir level conditions, and 3) wet weather and high reservoir level conditions. Each of these sets of conditions has occurred since 2000. Scenarios that model different levels of nutrient input from the watershed, as well as changes in reservoir operation, were run and compared to the baseline model to determine the nutrient load reduction needed to meet water quality standards for DO.

The overall goal for the SWAT model is to provide data-driven estimates of the nutrient loads from various portions of the watershed. Nutrient loads and inflow generated by SWAT were used as inputs to BATHTUB. Additionally, these results identified sub-watersheds that contribute the highest proportion of nutrients to the reservoirs. SWAT outputs were used to develop a project implementation plan (PIP) and prioritize projects that will have the most impact on reducing nutrient loads to the reservoirs. Specific objectives include 1) generating estimates of total nitrogen and total phosphorus that reach the reservoir from subwatersheds (Figure A-1); 2) determining the load contribution from the following nonpoint sources: grazing, fertilizer, agricultural land, the Interstate 80 (I-80) and U.S. Route 40 (US-40) road corridors; and 3) determining nutrient loads from future growth and urbanization in the watershed.

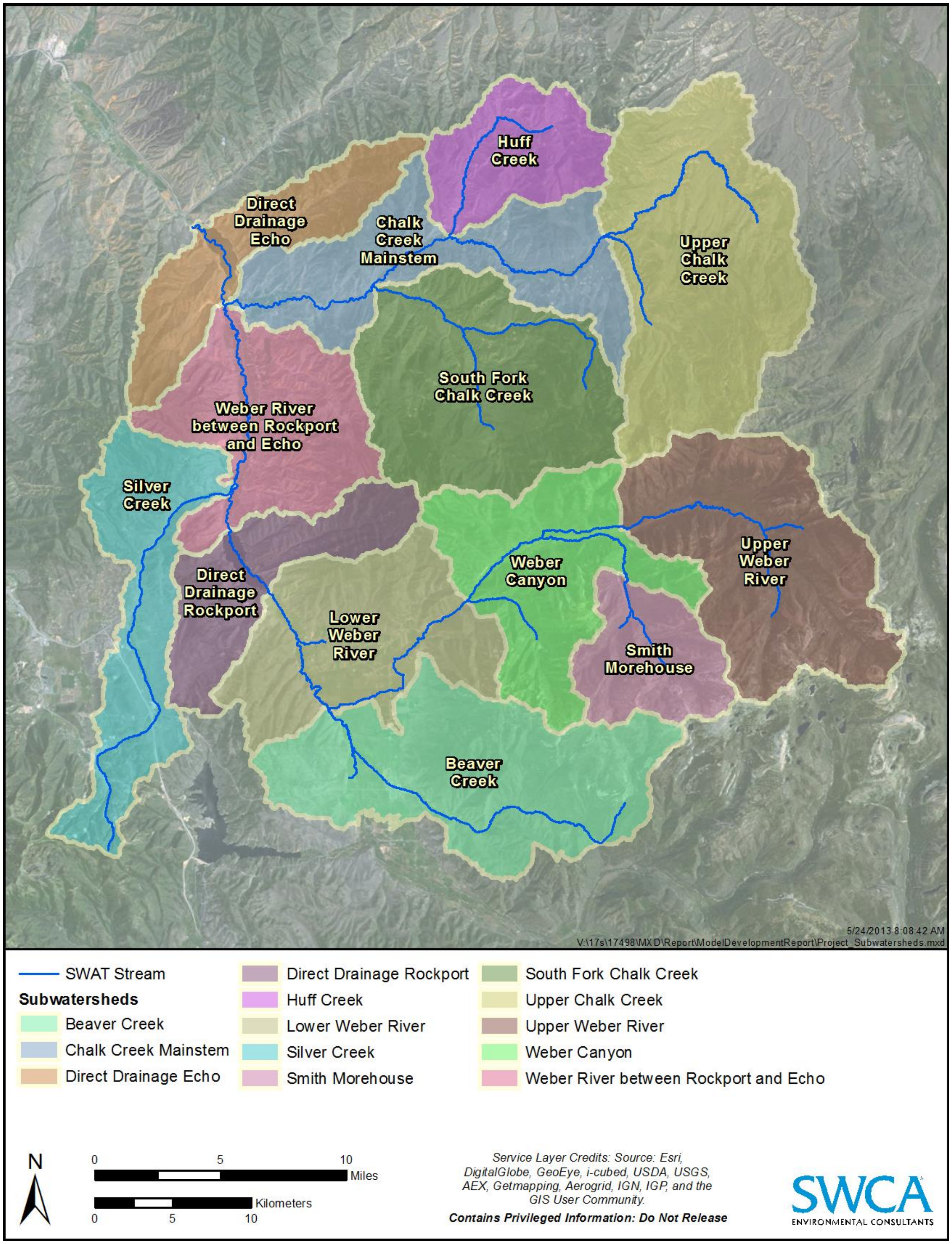

Figure A-1. Subwatersheds in the project area.

A-2. MODELED CONDITIONS

BATHTUB was set up to model representative dry (2004), average or expected normal (2007), and wet (2011) hydrologic conditions (Figure A-2). The SWAT models were set up to run from January 1, 1998, to December 31, 2011 in order to accommodate warm-up years (1998-2001). Warm-up years are the first years run in a model that allow it to initiate processes and are not used in the analysis in order to reduce the effects of initial model conditions on results. 2007 is considered an average year for stream flow and reservoir level, and is used for modeling average conditions in the project area.

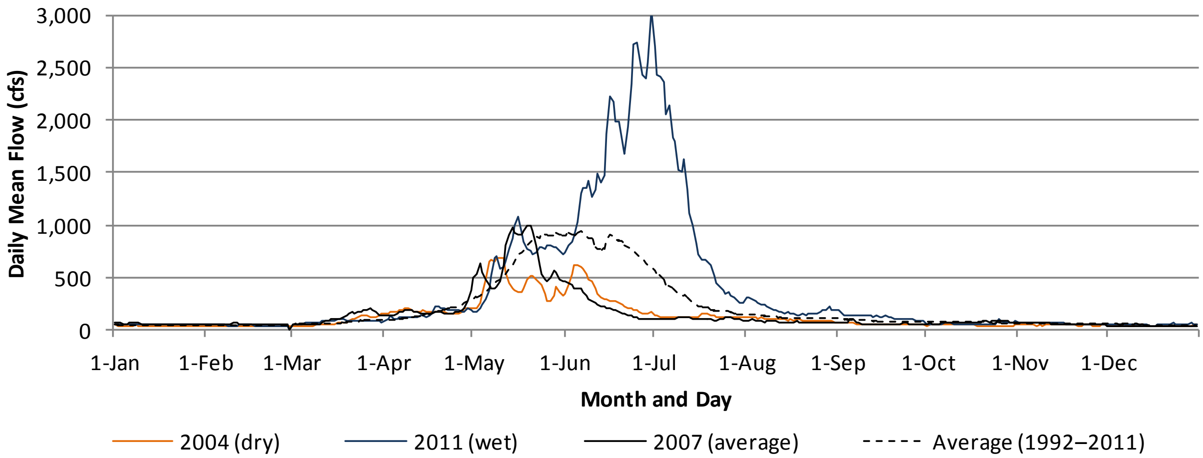

Figure A-2. Dry, wet, and average year hydrographs for the Weber River near Oakley, Utah (U.S. Geological Survey gage number 10128500).

A-3. WATERSHED MODEL: SOIL AND WATER ASSESSMENT TOOL

A-3.1 General Model Description

SWAT is used 'to predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungaged river basins" (www.tamu.edu/SWAT). SWAT is an "interdisciplinary watershed modeling tool" (Gassman 2007) that has been used to conduct a variety of analyses including hydrologic studies, pollutant load assessments, climate change impacts, and support TMDL analyses (Borah et al. 2006, in Gassman 2007). The USDA-ARS created the SWAT model and continues to update the model and provide technical support for users. For the TMDL analysis, SWAT 2012 Version 591 was run using ArcGIS 10.0 SP5.

SWAT was used to assess known point sources and watershed/nonpoint source nutrient loading to the Weber River, Rockport Reservoir, and Echo Reservoir to support development of DO TMDLs for the reservoirs. Determining nutrient loads to the reservoirs is important because increases in nutrient levels can lead to nutrient enrichment and excessive plant growth (eutrophication), which strongly effects DO concentrations in the water column. The TMDL analysis used the hydrology and nutrient load components from SWAT to determine inputs to the reservoir from various sources.

The SWAT model incorporates data on climate, weather, land cover, land use, soils, topography, and known point sources to simulate hydrology and water quality parameters such as nutrients (nitrogen and phosphorus), pesticides, bacteria, erosion/sediment, algae, and DO. SWAT allows users to apply watershed-specific information about fertilization practices, grazing practices, irrigation, and septic systems to model nutrient loading from the watershed. The SWAT model also incorporates monitoring data from known point sources in the watershed such as the Silver Creek and Coalville City wastewater treatment plants. Since SWAT estimates discharge and nutrient loads on a subbasin level within the overall watershed, the SWAT model outputs may identify subbasins with high nutrient loads. This is useful in developing a targeted implementation plan that will meet the criteria for approval by the Water Quality Board and Environmental Protection Agency (EPA).

Weather data generates the hydrology in SWAT. Default weather station data are available in SWAT for the United States. However, the model is generally improved if precipitation and temperature data are provided from weather stations in or near the watershed (see Section A-3.2.3 for climate data used in the Rockport Reservoir Watershed and Echo Reservoir Watershed SWAT models). SWAT uses the weather data to account for several factors. 1) SWAT estimates evapotranspiration from the watershed; 2) SWAT accounts for snowmelt and snowfall effects with snow parameters, which are important in calibrating the timing of the snowmelt in the watershed and subsequent peak and baseflows; 3) SWAT has the ability to separate the watershed into bands based on elevation, which affects precipitation and air temperature. Groundwater and soil water are also components in the SWAT model, with input tables to adjust those portions of the hydrologic cycle. The USGS gage data and the USGS Baseflow Program algorithms were used to estimate baseflow, which is the contribution from groundwater to the stream.

Changes in hydrology from human actions are also simulated in SWAT, either through its point source feature or as a management operation. In SWAT, a point source is a way to add or subtract flow, sediment, and nutrients to a subbasin from a source that is not included in the land use or soil layers. Additional flow from a wastewater treatment plant is one example. However, the SWAT point source may also be used to remove water from a subbasin. The Weber-Provo diversion, which removes water from the watershed, is an example of a point source with negative flow values. Irrigation can be simulated using the management features in SWAT.

Reservoirs can also be included in a model to simulate the effects of storage and release on the hydrology of the watershed. Only the Smith and Morehouse Reservoir was included in the Rockport Reservoir Watershed SWAT model since it affects flow from a subbasin coming into the Weber River. Rockport Reservoir and Echo Reservoir were intentionally left out because reservoirs are not well modeled in SWAT for water quality. Instead, reservoir water quality was modeled using BATHTUB.

SWAT organizes the input data within a watershed using what is called a hydrologic response unit (HRU). The subbasin, in addition to the land use, soils, and slope categories, defines the HRU. An HRU is composed of areas with the same land use, soils, and slope that will generate the same runoff. An HRU might consist of several areas in a subbasin that are not congruous, but they respond to a rainfall event in the same manner. An example of an HRU identifier is 1_ALFA_UT282_0-10, which indicates that this HRU is in subbasin 1, with a land use of alfalfa, soils classified as UT282, and slopes between 0 and 10%.

SWAT will model nutrient transport and transformations in the watershed through the soil, groundwater, and surface water. SWAT estimates loads of nitrogen and phosphorus contributed from traditional nonpoint sources such as soil and land use, but also management and point sources. Management sources include grazing and fertilizer application. Point sources can represent any type of additional nutrient load. The Rockport Reservoir and Echo Reservoir Watersheds include point sources for wastewater treatment plants, fish hatcheries that discharge to a stream, and tunnels carrying stormwater and groundwater from another watershed. The point source inputs include loads for organic nitrogen, nitrite, nitrate, and ammonia as well as mineral phosphorus, and organic phosphorus. SWAT generates output for these nutrient forms on a reach scale.

SWAT models erosion and sediment yield using the Modified Universal Soil Loss Equation. It estimates erosion from hillslopes and channel erosion using rainfall intensity, land use, soil characteristics, and slope. SWAT accounts for both saturated and unsaturated flows. Saturated flow is driven by gravity and the movement is characterized by a storage routine method, which calculates the amount of soil water percolating to an underlying soil layer on a given day. Water in excess of the permanent wilting point or soil field capacity is available for plant growth or infiltration within the soil profile. For unsaturated flow, movement occurs in any direction based on energy gradients from areas of high to low water content. Only saturated flow is simulated; however, water consumed by the plant during growth is simulated indirectly by the evapotranspiration process associated with the plants.

A-3.2 Model Development for the Rockport Reservoir and Echo Reservoir Watersheds

A-3.2.1 General Model Setup

The project watershed contains both Rockport Reservoir and Echo Reservoir, which are located on the mainstem of the Upper Weber River (Figure A-1). For modeling purposes, two SWAT models were created for the TMDL analysis. The project area was split into the Rockport Reservoir Watershed and the Echo Reservoir Watershed based on the location of the Rockport Reservoir outlet. The watershed area upstream of and including Rockport Reservoir is considered Rockport Reservoir Watershed. It includes the headwaters of the mainstem of the Weber River and Beaver Creek, a major tributary to the Weber River. The watershed area between the dam at Echo Reservoir and the dam at Rockport Reservoir is considered the Echo Reservoir Watershed for SWAT modeling. Silver Creek and Chalk Creek are major tributaries that drain the Echo Reservoir Watershed and flow into the Weber River above Echo Reservoir.

There are two reasons for creating the two SWAT models for the TMDL. First, the split allows the BATHTUB model results for Rockport Reservoir to be easily incorporated into the Echo Reservoir Watershed SWAT model as a release from Rockport Reservoir into the downstream watershed, and provides a simple way to incorporate BATHTUB for in-reservoir and reservoir operations modeling. Second, measured outflow data exist for Rockport, which eliminates the need to model and calibrate Rockport Reservoir releases as part of the hydrology in SWAT, thereby removing the uncertainty associated with simulating reservoir releases.

SWAT was set to run for the time period between 1998 and 2011 on a monthly timestep. The first four years were ignored as described above. 2007 is considered an average year, 2004 represents a dry year, and 2011 represents a wet year. Much of the example data presented in this document represents average conditions from 2007.

A-3.2.2 Hydrologic Response units

As mentioned, SWAT characterizes the watershed by generating a HRU. A HRU is defined by the subbasin, land use, soil type, and slope class. From these inputs, the HRU is given specific characteristics that determine the amount of runoff generated from a storm event. Within a subbasin, there can be multiple HRUs. The HRUs are “virtual” in the sense that the only spatial reference is the subbasin. The runoff and nutrient load generated for all HRUs is summed at the outlet of each subbasin. The total represents the entire subbasin. Therefore, SWAT does not account for the location of an HRU relative to the stream within a subbasin, but does account for the location of subbasins relative to each other for routing purposes.

A-3.2.2.1 SUBBASIN DELINEATION

The total project area consists of the combined Echo and Rockport watersheds since Rockport releases are transported to Echo Reservoir via the Weber River. However, for modeling purposes the Echo Reservoir Watershed and Rockport Reservoir Watersheds were split into subbasins based on the stream network, locations of gages for calibration, and locations of known point sources (Figure A-3). If the modeler chooses, the SWAT program will automatically generate subbasins and streams within the watershed using the digital elevation model (DEM) based option. This option was chosen to ensure that subbasins contained only one known point source discharge (with the exception of the Park City tunnels, which were combined into a single point source), and to split large subbasins that drain into small subbasins. Subbasin boundaries were also adjusted to have each reservoir contained within a single subbasin.

Next, the DEM-generated subbasins option was used to generate a stream network along with the subbasins. These stream shapefiles were then adjusted to better fit the modified subbasins described above. The Silver Creek channel was extended into the upper watershed, and the Chalk Creek channel was extended into the upper Echo Reservoir watershed to include a smaller headwater channel not included in the SWAT-generated streams shapefile (Figure A-3).

A-3.2.2.2 LAND USE INPUTS

A land use map was compiled for SWAT from several sources (Figure A-4). The Water Related Land Use (WRLU) dataset was combined with the 2006 National Land Cover Database (NLCD) into a single land use layer for the entire project watershed and used in both the Rockport Reservoir Watershed model and the Echo Reservoir Watershed model. Land use descriptions from the WRLU were used where available because they are more detailed than NLCD. The NLCD was used in areas where WRLU was not available. Information on irrigation type (flood or sprinkler) was incorporated with the land use descriptions using the four-digit codes supplied in the SWAT database. To account for the sprinkler and flood irrigation, new land use categories were added to the crop table in the SWAT database. These new land use categories are the same as the existing land use, but coded differently to reflect the irrigation type (i.e., flood, sprinkler, or no irrigation) (Table A-1). If no information on the type of irrigation was available, as was the case for any areas defined with the NLCD dataset, then the SWAT code was assigned.

The land use layer and SWAT databases were also modified to incorporate a land use type for the I-80 and US40 corridors file to identify nutrient load contributions from these major roads in the project area. A road footprint was estimated by measuring the road width at five locations in the project area, calculating an average width, and applying it to the appropriate subbasins. These roads only pass through the Echo Reservoir Watershed and have no effect within the Rockport Reservoir Watershed.

The land use layer and SWAT database were also modified to indicate areas of barren, forest, or range (brush and grass) that are within an existing U.S. Forest Service (USFS) grazing allotment (Table A-1) to differentiate between areas privately and publicly grazed. This adjustment only affects the Rockport Reservoir Watershed, where both public and private grazing occur in several subbasins. Only a small portion of the Echo Reservoir Watershed area is within a USFS allotment, so public grazing is considered negligible in the Echo Reservoir Watershed.

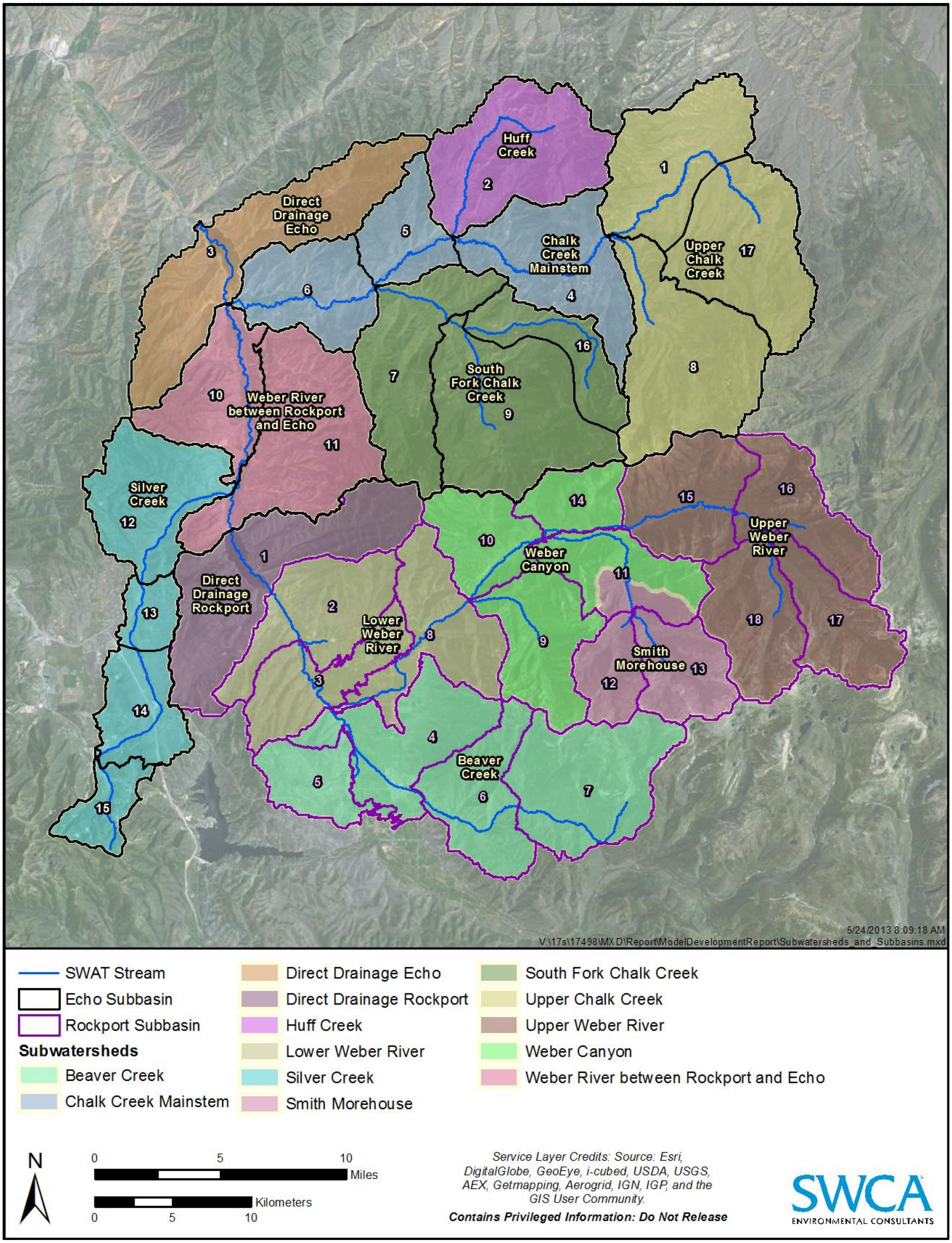

Figure A-3. The SWAT model subbasins and SWAT-generated streams for the Rockport Reservoir and Echo Reservoir Watersheds.

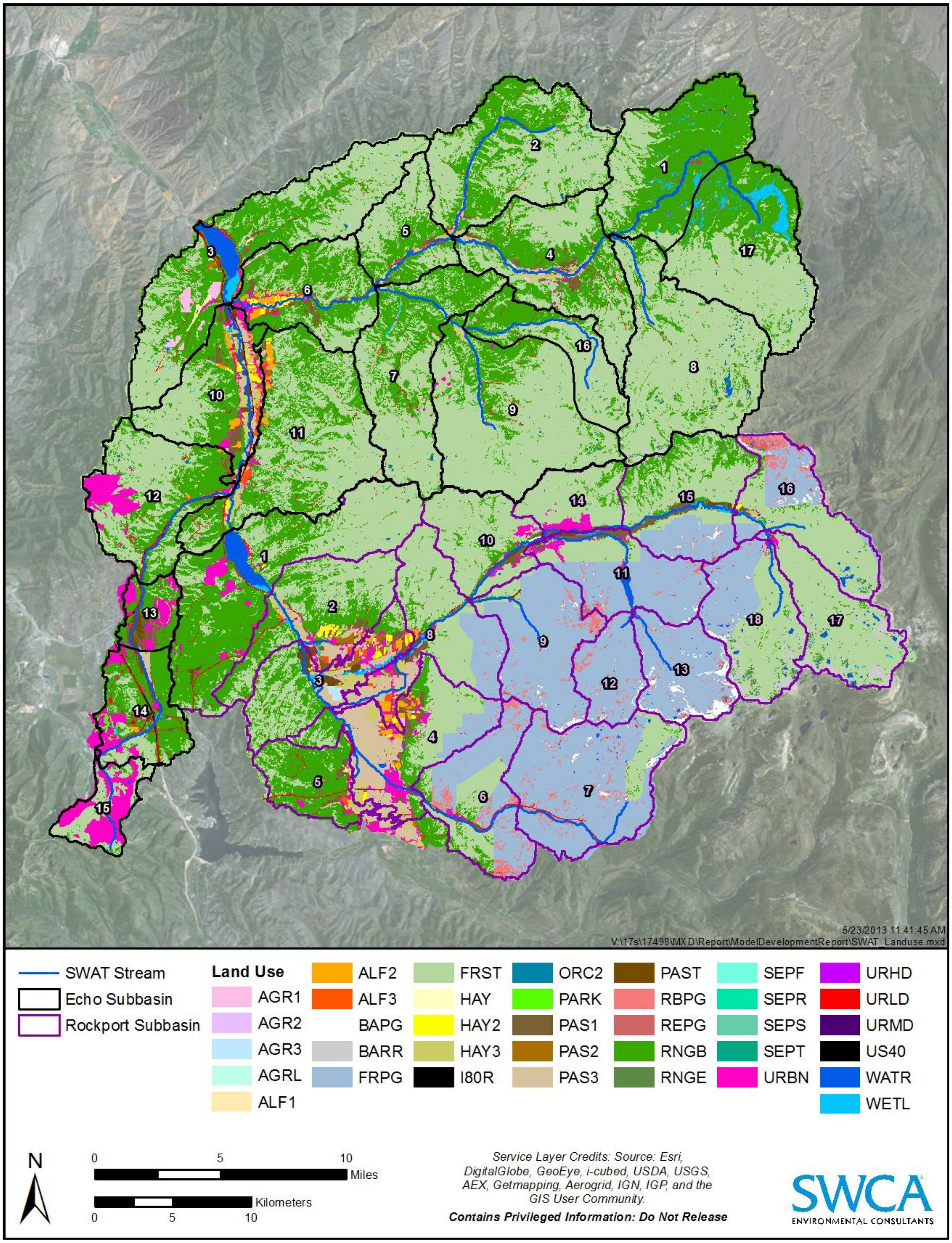

Figure A-4. SWAT land use map.

To run population growth scenarios for the TMDL, small portions consisting of approximately 1 acre of each subbasin were digitized as urban-low density (URLD), urban medium density (URMD), and urban high density (URHD). These modifications occurred only if the land use types did not already exist in the subbasin. These areas are on the order of tens of acres—too small to noticeably affect the model. They simply act as placeholders for running scenarios involving urbanization within the watershed for the TMDLs.

Table A-1. Land Use Descriptions and Reclassification Codes

SWAT Class	SWAT Code	Original Description	Original Data Source
Agricultural – Not Irrigated	AGR1	Dry Grain/Seeds Fallow – Irrigated Land	WRLU
Agricultural – Sprinkler	AGR2	Grain	WRLU
Agricultural – Flood Irrigated	AGR3	Grain	WRLU
Cultivated Crops	AGRL	Cultivated Crops	NLCD
Alfalfa – Not Irrigated	ALF1	Dry Alfalfa	WRLU
Alfalfa – Sprinkler	ALF2	Alfalfa	WRLU
Alfalfa – Flood Irrigated	ALF3	Alfalfa	WRLU
Barren Land	BARR	Barren Land (Rock\Sand\Clay)	NLCD
Mixed Forest	FRST	Deciduous Forest Evergreen Forest Mixed Forest	NLCD
Hay	HAY	Grass Hay	NLCD
		Grass Hay – Subirrigated	WRLU
Hay – Sprinkler	HAY2	Grass Hay – Sprinkler	WRLU
Hay – Flood Irrigated	HAY3	Grass Hay – Flood irrigated	WRLU
Orchard – Sprinkler	ORC2	Orchard – Sprinkler	WRLU
Pasture – Not Irrigated	PAS1	Dry Idle Dry Pasture Idle – Irrigated Land Range Pasture	WRLU
Pasture – Sprinkler	PAS2	Pasture – Sprinkler	WRLU
Pasture – Flood Irrigated	PAS3	Pasture – Flood Irrigated	WRLU
Pasture	PAST	Pasture – Subirrigated Idle – Irrigated Land	WRLU
		Pasture/Hay	NLCD
Range – Not Irrigated	RNGB	Shrub/Scrub	NLCD
Urban – Not Irrigated	RNGE	Grassland/Herbaceous	NLCD
Urban	URBN	Urban	NLCD
		Urban – Flood	WRLU
Urban High Density	URHD	Developed – High Density	NLCD
Urban Low Density	URLD	Developed – Low Density	NLCD
Urban Medium Density	URMD	Developed – Open Space	NLCD

Table A-1. Land Use Descriptions and Reclassification Codes

SWAT Class	SWAT Code	Original Description	Original Data Source
Water – Not Irrigated	WATR	Water Lakes and Ponds	NLCD
		Open Water Reservoirs Sewage Lagoon Streams	WRLU
Wetland – Not Irrigated	WETL	Emergent Herbaceous Wetlands Woody Wetlands	NLCD
Interstate 80 Corridor	I80R	Interstate 80 Corridor	User Defined
U.S. 40 Corridor	US40	U.S. 40 Corridor	User Defined
Parks – Sprinkler	PARK	Urban Grass/Parks	NLCD
Barren, within a public grazing allotment	BAPG	Barren (NLCD) intersected with USFS grazing allotment map	NLCD USFS Grazing Allotment
Forest with public grazing allotment	FRPG	Mixed Forest (NLCD) intersected with USFS grazing allotment map	NLCD USFS Grazing Allotment
Range (grass) with public grazing allotment	REPG	Grassland/Herbaceous(NLCD) intersected with USFS grazing allotment map	NLCD USFS Grazing Allotment
Range (brush) with public grazing allotment	RGPB	Shrub/Scrub (NLCD) intersected with USFS grazing allotment map	NLCD USFS Grazing Allotment

A-3.2.2.3 SOILS

The State Soil Geographic (STATSGO) soils dataset was used for the SWAT model because Soil Survey Geographic (SSURGO) data, although available for portions of the watershed, were missing in large areas of the Rockport Reservoir Watershed, primarily in USFS lands (Figure A-5). Soils within the Echo and Rockport Reservoir Watershed and their associated erodibility factor are listed in Table A-2.

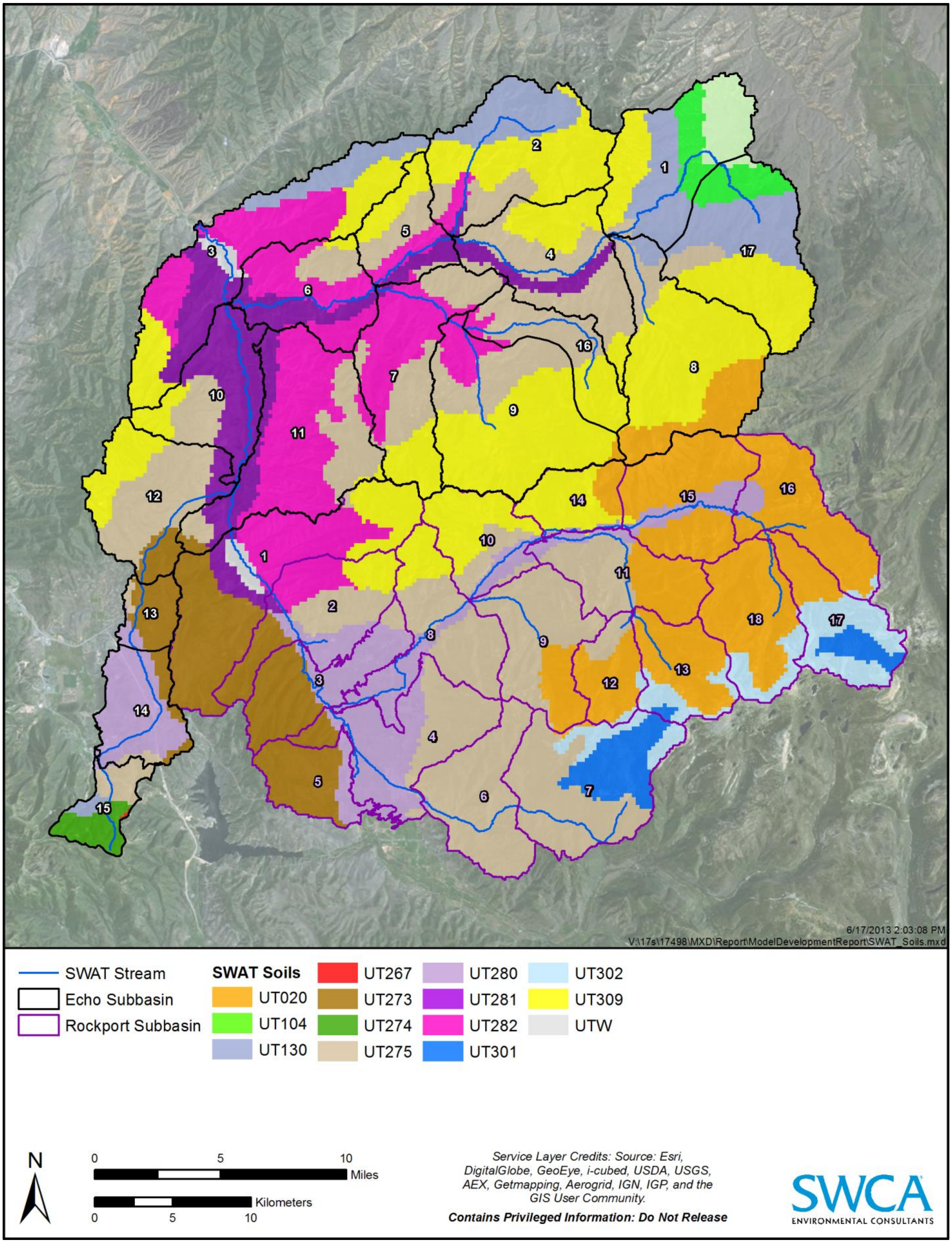

Figure A-5. SWAT soils map showing STATSGO state map unit identification (STMUID) numbers.

Table A-2. Soils in the Rockport and Echo Reservoir Watershed and Associated Erodibility Factor

Soil Group	Soil State Map Unit Identification Code	Soil Surface Texture	Soil Erodibility (K factor) of First Layer
FLUETSCH	UT020	Sandy loam	33.6
KEARL (in Utah)	UT104	Loam	22.8
ANT FLAT	UT130	Loam	14.1
ROUNDY	UT267	Loam	8.8
BROADHEAD	UT273	Loam	15.2
POLELINE	UT274	Gravelly loam	12.8
MANILA	UT275	Loam	26.4
KOVICH	UT280	Loam	12
PRINGLE	UT281	Loam	48-52.8
RICHSUM	UT282	Silty loam	2.8-2.5
SKUTUM	UT309	Loam	43.2
KEARL (in Wyoming)	WY349	Loam	14.4

Initial soil nutrient concentrations were adjusted from SWAT default values based on two existing sources: 1) a phosphatic shale layer that contributes to soil phosphorus concentrations in both the Rockport Reservoir and Echo Reservoir Watershed (Figure A-6), and 2) long-term agricultural activities that have altered soil nutrient concentrations in areas where grazing and farming occur. Both of these sources produce labile phosphorus: the fraction of phosphorus loosely attached to soil and easily converted to other forms. Concentrations of labile phosphorus from these sources were estimated using literature values, measured soil phosphorus concentrations, and rock phosphorus data.

The labile soil phosphorus for the upper two soil layers on agricultural areas was determined using values reported in existing literature. Hay, alfalfa, and pasture were given a value of 25 milligrams of phosphorus per kilogram soil (mg P/kg) (Arnold et al. 2011) in the first two soil layers. The lower soil layers remained at the default value.

Soils classified as UT282 (named Richsum) were given a value of 100 mg P/kg soil. This value is based on a soil sample taken from the Richsum soil in the Fish Creek drainage area of the Chalk Creek watershed.

For the forest, range, and barren land uses and soils, initial values for soil labile phosphorus for other areas were modified based on the percentage of rock phosphorus in the geologic formation. This calculated value was only used if the HRU was not already defined using the previously described protocols. The soil labile P was estimated from percent rock phosphorus by first pairing the SWAT default value for soil labile phosphorus (5 mg/kg soil) with the median rock phosphorus percentage (0.163%). For each value of percent rock phosphorus above 0.163%, a proportional increase was calculated and then applied to the SWAT soil labile phosphorus default value (Table A-3). If the percent rock phosphorus value was less than 0.163%, the SWAT default of 5 mg/kg for soil labile phosphorus was used. The default SWAT value of 5 mg/kg soluble phosphorus was used for all other land uses including those classified as urban, include parks, septic areas, and wetlands.

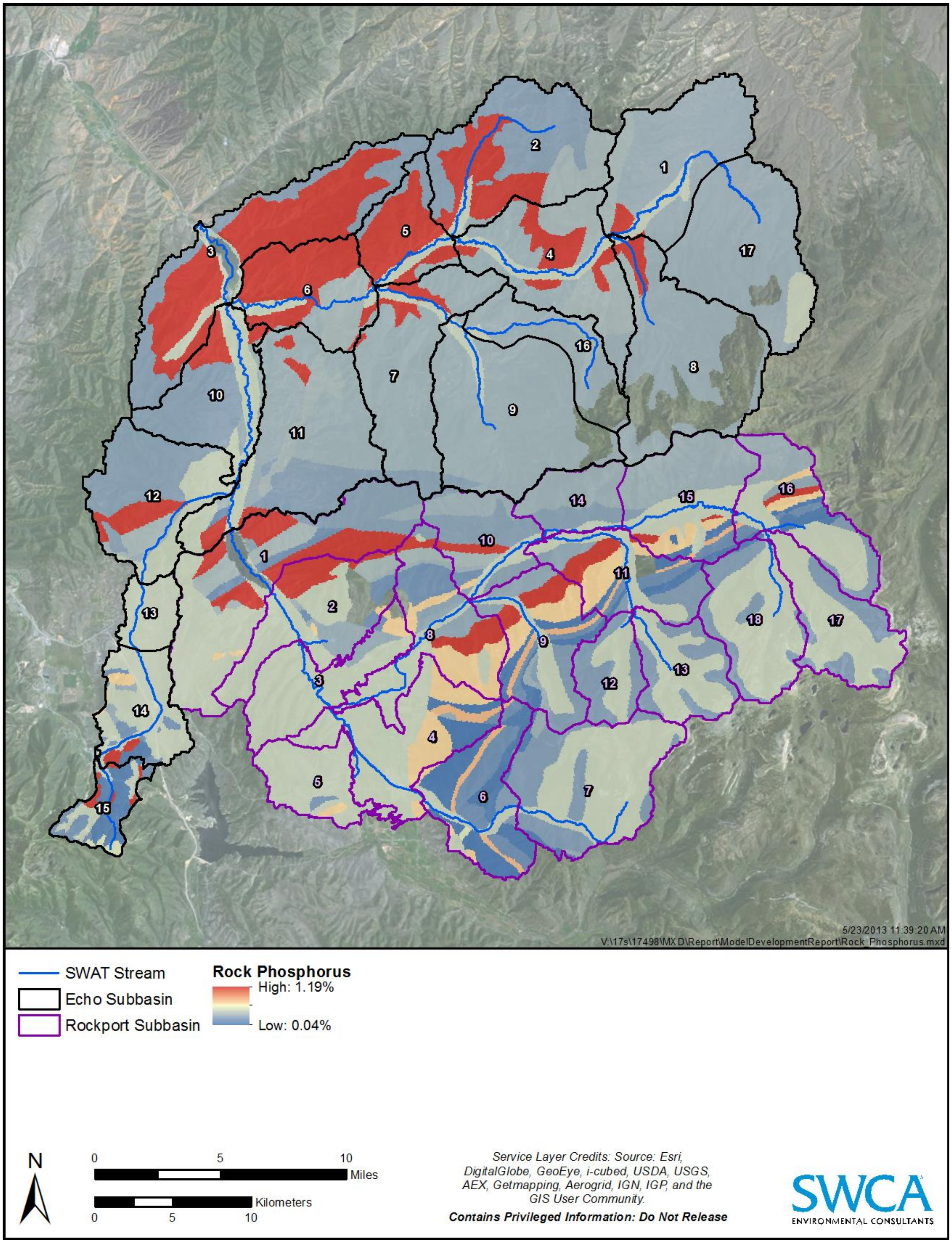

Figure A-6. Percent rock phosphorus in the Rockport Reservoir and Echo Reservoir Watersheds.

Table A-3. Rock Phosphorus Percentages and the Resulting Value Used in SWAT for Initial Labile Phosphorus Concentrations (mg/kg)

Rock Phosphorus Percentage	Proportional Increase to Default Soils	Value (mg labile P/kg soil)
0.163	0.00	5.0
0.165	0.01	5.0
0.180	0.10	5.5
0.220	0.35	6.7
0.316	0.94	9.7
0.535	2.27	16.4

Since each HRU may consist of several polygons that intersect areas of differing rock phosphorus, an area-weighted average was calculated to determine a labile phosphorus value for each HRU in the Echo Reservoir Watershed.

The SWAT model was then run using the estimated soil labile P values, default SWAT values for soil nitrate, soil organic nitrogen, soil organic phosphorus, and the soil carbon default concentrations to determine initial conditions for soil nitrate, organic nitrogen, organic phosphorus and total phosphorus. The SWAT output for soil nutrients was used as initial soil concentrations for nitrate and total nitrogen. (Because the SWAT output is in units of kg/ha, the values were converted to SWAT input units of mg/kg soil using soil depth, HRU area, and bulk density). Each soil may have up to four layers. Because organic nitrogen is present mostly at the surface, it was calculated only for layers 1 and 2. Nitrate was calculated for all layers available for each soil because of its high mobility. The same method was used to generate initial soil conditions for organic P. All initial soil nutrient concentrations were a primary calibration parameter that were adjusted across the watershed to generate model output consistent with measured spring nutrient loads (Table A-4). In addition to adjusting soil nutrients, SWAT allows users to define nitrogen and phosphorus concentrations in the channel. The nitrogen values were not modified. The subbasin average soil labile P (using the soil labile P values calculated using percent rock phosphorus) was used as these inputs.

Table A-4. Initial Soil Nutrient Concentrations

Soil Type	Nitrate (mg/kg)		Organic N (mg/kg)		Soluble P[1] (mg/kg)		Organic P (mg/kg)	
Watershed	Rockport	Echo	Rockport	Echo	Rockport	Echo	Rockport	Echo
UT020	0.1-0.4	0.2	40	113	2.4-3.6	6.0	7.5	46
UT104	-	0.1	-	1,089	-	6.0 - 30.0	-	443
UT130	-	0.4 – 0.6	-	387- 663	-	1.3 -30.0	-	80 - 269
UT267	-	0.3	-	830	-	5.0-5.3	-	337
UT273	0-0.9	0.2 – 0.3	0-774	555-793	2.3-5.0	1.3-25.0	0-145	115- 323
UT274	-	0.6	-	838.2	-	5.0	-	340
UT275	0.2-0.4	0.2- 0.3	220	360- 617	2.4-3.8	1.3- 30.0	41	75-251
UT280	0.4-0.9	0.4	642	1,502	2.4-4.8	5.0- 25.0	120	610
UT281	0.3-0.8	0.5	774	1266-2,171	2.3-4.5	1.3-30.0	145	262- 881

Table A-4. Initial Soil Nutrient Concentrations

Soil Type	Nitrate (mg/kg)		Organic N (mg/kg)		Soluble P[1] (mg/kg)		Organic P (mg/kg)	
UT282	0.2-0.5	0.2-0.3	176	288-493	3.2	25.0-120.0	33	60- 201
UT301	0.1-0.3	-	40	-	2.4-3.6	-	7.5	-
UT302	0.1-0.3	-	40	-	2.4-3.6	-	7.5	-
UT309	0.5-0.6	0.4-0.7	453	741-1,270	2.4-2.6	1.3-12.0	85	153-515
UTW	0	0	0	0	2.4	1.3- 30.0	0	0
WY349	-	0	-	1,027	-	6.0- 30.0	-	417

[1] A value of 25.00 mg/kg was used for all agricultural land uses.

A-3.2.2.4 SLOPES

SWAT allows users to define up to five slope classes. The models for Rockport Reservoir and Echo Reservoir Watersheds include four slope classes: 0–10%, 10–20%, 20–35%, and greater than 35%. The 0–10% classification contains most of the agricultural areas since the 10–20% class is limited in its irrigation capacity. The final two classifications represent areas with increasing potential for erosion, with slopes greater than 35% generally occurring in the steeper mountain areas at higher elevations (Figure A-7).

A-3.2.3 Climate Inputs

Climate data were obtained from the Utah State University Climate Center website (climate.usurf.usu.edu) for the period between January 1, 1998, and May 31, 2012 (Table A-5) for several weather stations in or near the watershed. Data obtained consisted of minimum daily temperature, maximum daily temperature, and precipitation. The same precipitation and temperature datasets were used for both the Rockport Reservoir and Echo Reservoir Watershed models because SWAT chooses a weather station based on location (Figure A-8) to generate weather data for each subbasin, which generates weather statistics that the model uses for calculations.

Table A-5. Weather Stations used in the SWAT Model

Weather Station Name	Weather Station Code	Data Used for Each Watershed	Latitude	Longitude	Elevation (m)
Coalville	USW00024120	Precipitation (R, E), Temperature (R, E)	40.914	-111.398	1,691.6
Coalville 13 East	USC00421590	Precipitation (R, E), Temperature (R, E)	40.938	-111.147	1,984.2
Kamas	USC00424467	Precipitation (R,E), Temperature (R, E)	40.649	-111.285	1,973.6
Echo Dam	USC00422385	Precipitation (R, E), Temperature (R, E)	40.966	-111.435	1,665.7
Park City 1.3 East	US1UTSM0004	Precipitation (E)	40.656	-111.469	2,244.5
Snyderville	USC00427942	Precipitation (E)	40.704	-111.537	1,969.0
Wanship Dam*	USC00429165	Precipitation (R), Temperature (R)	40.791	-111.408	18,10.96

* Wanship Dam is now Rockport Dam.

† R=Rockport, E=Echo

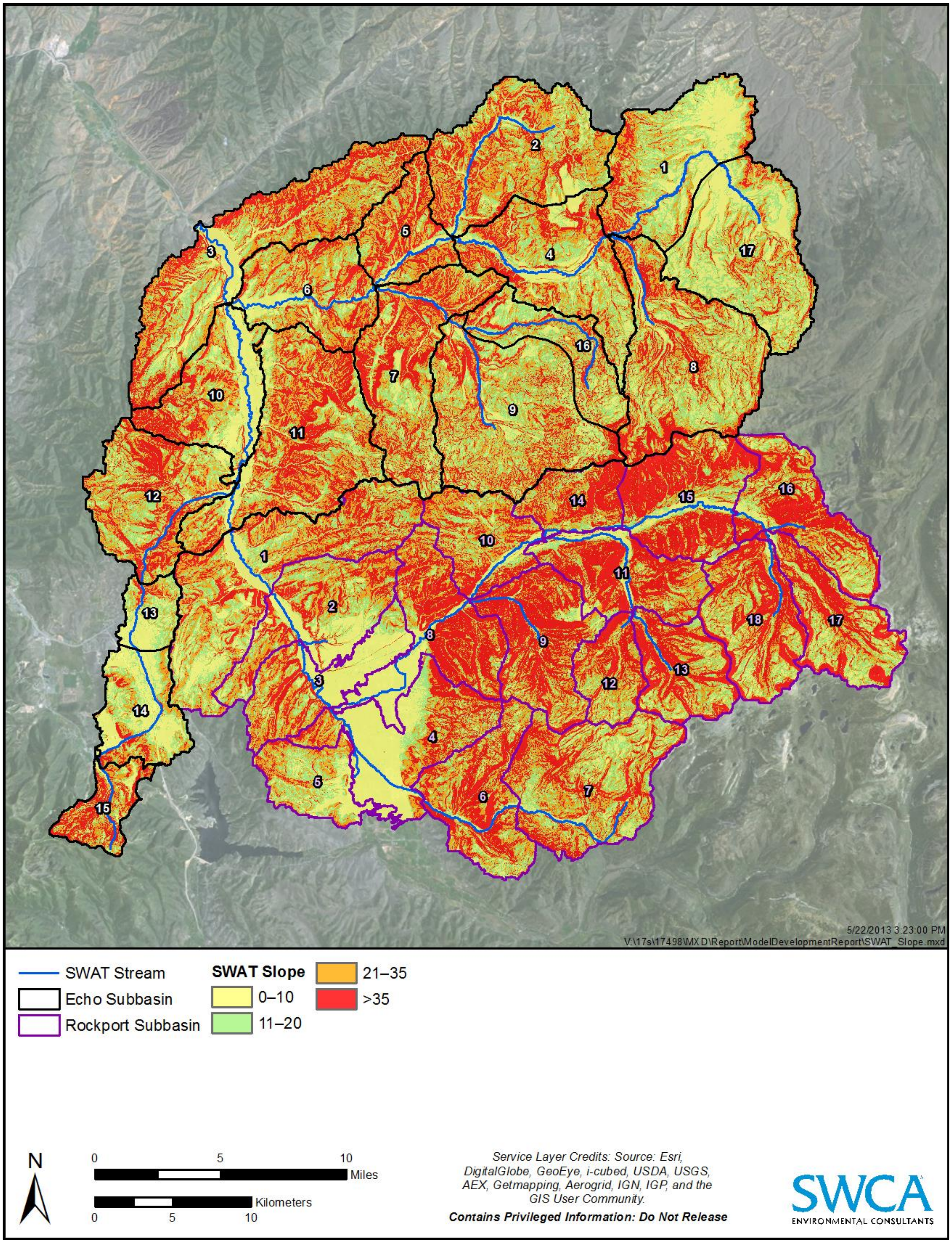

Figure A-7. SWAT-generated slope classes.

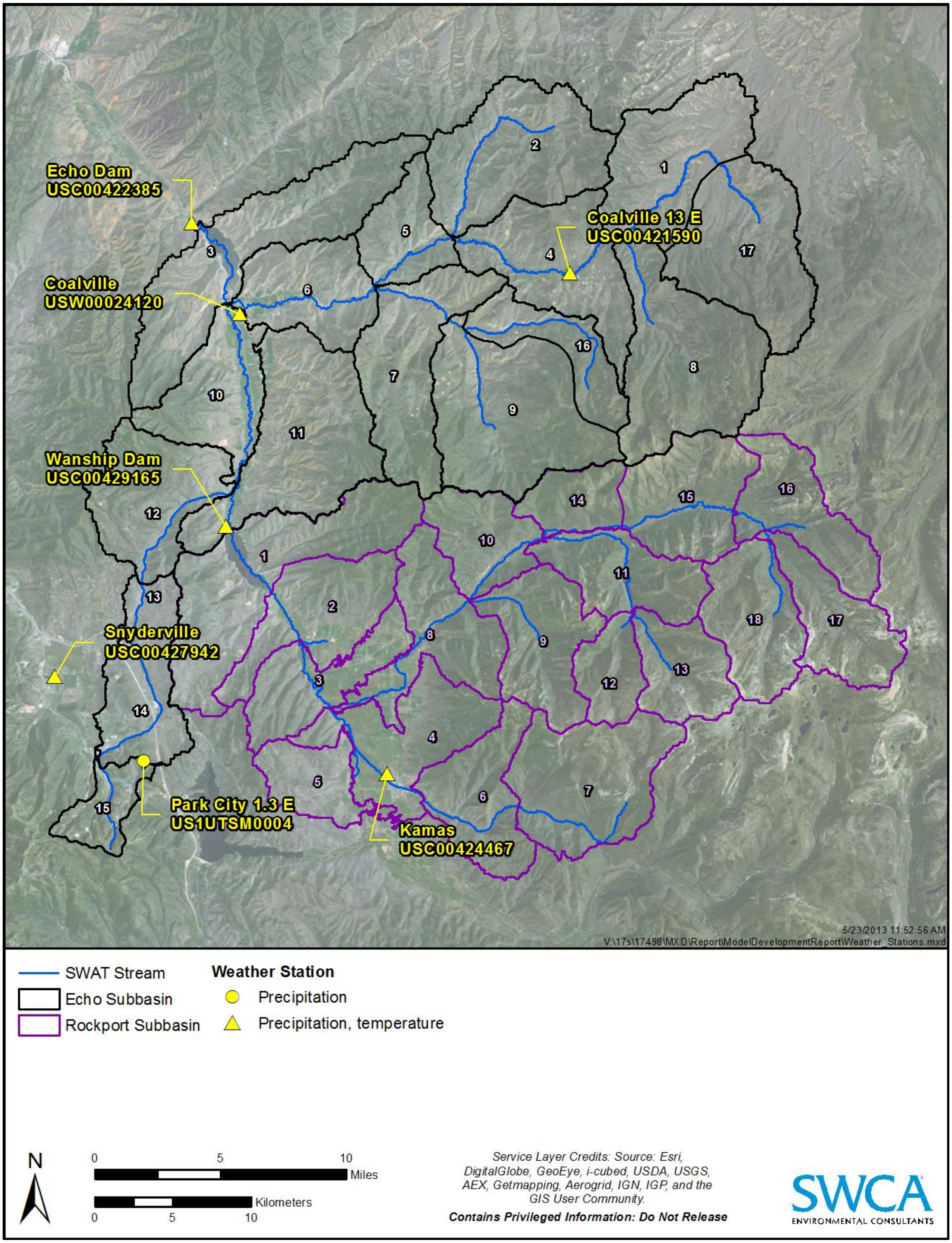

Figure A-8. Location of weather stations accessed for temperature and precipitation data for SWAT.

A-3.2.4 Irrigation inputs

Irrigation activities in the watershed include sprinkler irrigation, flood irrigation, and inter-basin transfers. The Utah Division of Water Rights supplied flow data for known and gaged diversions (Figure A-9). The diversion data were compiled to estimate a total volume of water used for irrigation within each subbasin. Irrigation is included in the model as a management option. For the inter-basin transfers, the Weber-Provo diversion takes water out of the Weber River and delivers it to the Provo River watershed, outside the project watershed. The measured diversion from Weber to Provo was used as a direct input to the hydrologic portion of the SWAT model.

Irrigation rates (mm/day) were developed for each land use and subbasin for specific years based on measured irrigation diversion data for each subbasin (Tables A and B; UDWR 2013) and the range of application rates for sprinkler and flood irrigation provided by Thomas Hoskins in the Natural Resources Conservation Service (NRCS) Coalville Field Office. The total acreage in each subbasin that is irrigated by either flood or sprinkler was obtained from the Water Related Landuse Layer. Generally, the amount of water diverted was assumed to be the same as the amount applied as irrigation, except in cases where the diverted volume exceeded the maximum recommended irrigation rates (24 millimeters per day for sprinkler, and 300 mm/day for flood). A summary of irrigation rates for 2007, the average hydrologic year, is provided in Tables A-6 and A-7 in the units used by the SWAT model (mm/day).

Irrigation diversions were assigned to the most appropriate subbasin based on known irrigation demand and specific monthly diversion rates. Generally, water withdrawn was applied to the subbasin from where it was diverted or to adjacent, downstream subbasins that contain irrigated land uses. In some cases, up-gradient subbasins were irrigated by sprinklers assumed to be under pressure. A summary of the diversions used to irrigate each subbasin is also provided in Tables 7 and 8. SWAT inputs are in millimeters of water, so the acre-feet from the diversion data were converted to millimeters through the total acreage of HRUs within the subbasin to convert the acre-feet of water to millimeters per day (Tables A-8 and A-9).

In addition to providing a range of irrigation rates, the NRCS office in Coalville, Utah, also supplied information on irrigation efficiency and a qualitative assessment of runoff from irrigated lands (low versus high), which SWAT also incorporates in the operations/management file. Irrigation efficiencies were assumed to be 30% for flood-irrigated land and 70% for sprinkler-irrigated land. Surface runoff was assumed to be high for flood-irrigated land and low for sprinkler-irrigated land.

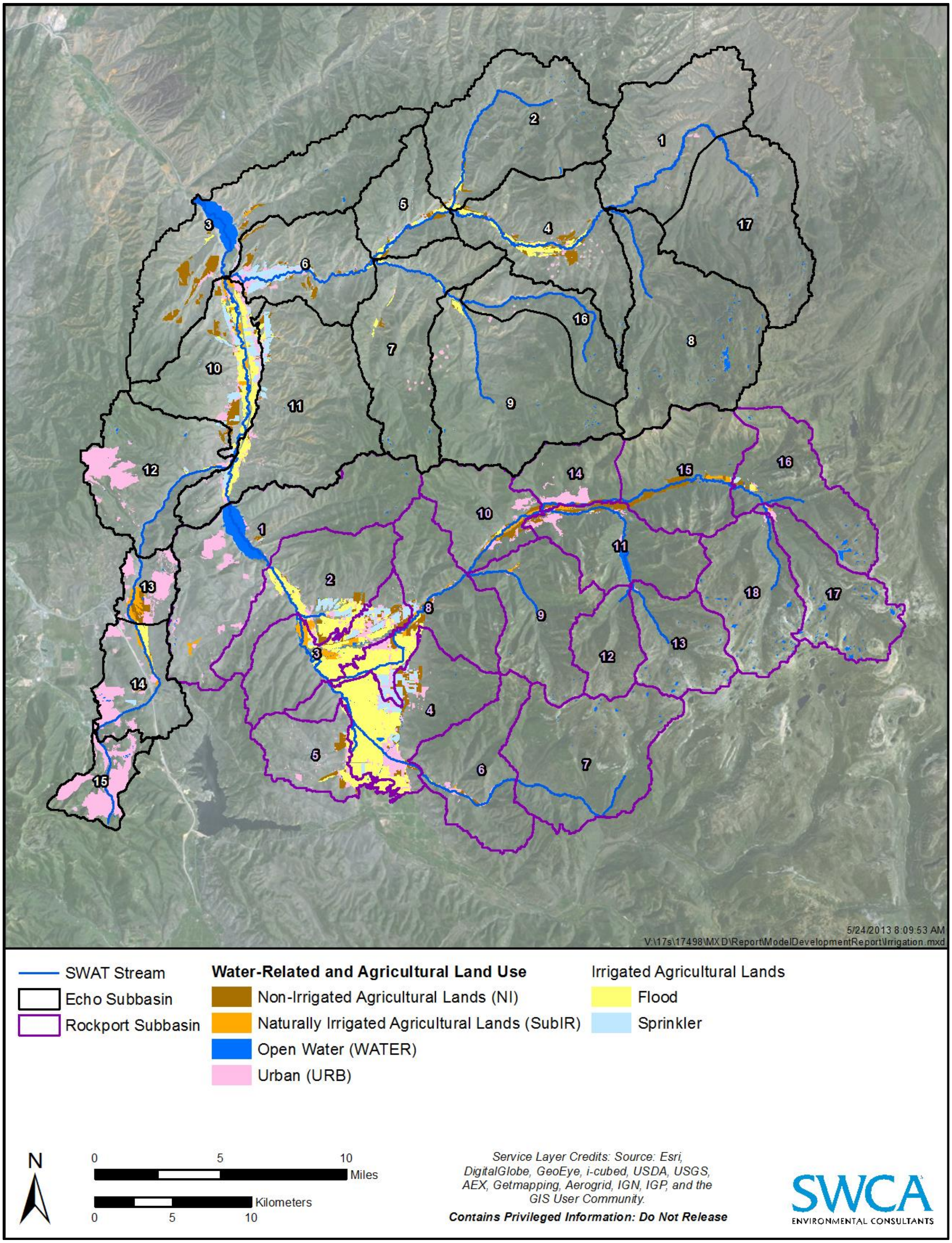

Figure A-9. Location of sprinkler and flood irrigation areas and locations of known diversions.

Table A-6. Monthly Diverted Irrigation Values (Acre-Feet) in Irrigated Subbasins for Rockport Reservoir Watershed

Diversion Subbasin	Irrigated Subbasin	May	June	July	August	September
3	1,2	1,040	1,000	268	240	36
8	3–10	4,900	4,772	396	690	72
11	11–19	150	80	–	–	–

Table A-7. Monthly Diverted Irrigation Values (Acre-Feet) in Irrigated Subbasins for Echo Reservoir Watershed

Diversion Subbasin	Irrigated Subbasin	May	June	July	August	September
4	2,4,7,9	858	806	224	168	131
6	5,6	590	696	374	366	354
10	3,10	1,856	1,852	451	918	925
11	11–12	860	943	644	614	207

Table A-8. Modeled Irrigation Types for Rockport Reservoir Watershed Subbasins and Month as Millimeters Applied Per Day

Subbasin	Irrigation Type	May	June	July	August	September
3	Flood	119.0	115.0	26.7	23.2	–
3	Sprinkler	12.0	12.0	12.0	12.0	9.5
8	Flood	86.0	84.0	3.6	8.8	–
8	Sprinkler	6.0	6.0	12.0	12.0	4.4
11	Flood	175.0	175.0	–	–	–
11	Sprinkler	18.0	18.0	–	–	–

Table A-9. Modeled Irrigation Types for Echo Reservoir Watershed Subbasins and Month as Millimeters Applied Per Day in 2007

Subbasin	Irrigation Type	May	June	July	August	September
4	Flood	120.0	113.0	31.2	23.5	18.2
4	Sprinkler	20.0	12.0	12.0	12.0	12.0
6	Flood	140.0	172.0	83.0	75.0	72.0
6	Sprinkler	12.0	12.0	10.0	12.0	12.0
10	Flood	176.0	175.0	47.5	93.0	94.0
10	Sprinkler	24.0	24.0	–	5.0	4.0
11	Flood	197.0	212.0	157.0	150.0	36.5
11	Sprinkler	16.0	20.0	5.0	5.0	12.0

A-3.2.5 Reservoir Releases

Release of water from Rockport Reservoir is a major input to the Echo Reservoir Watershed. Additionally, Smith Morehouse Reservoir releases water to the Weber River upstream of Rockport Reservoir, which is also an important input to the watershed. Because both Rockport and Smith and Morehouse are managed releases, daily flow release data are available and used as direct inputs to the SWAT model. Water quality from each reservoir is estimated using available data from the reservoir itself, or in the case of Rockport release, in the Weber River below.

A-3.2.5.1 ROCKPORT RELEASES

The U.S. Bureau of Reclamation (BOR) provided flow release data from Rockport Reservoir and the UDWQ provided water quality data. Where water quality data are not available for a specific month, either the monthly or seasonal average across the entire dataset (1998–2011) was used. Only data for 2007 are shown in the table below (Table A-10). Remaining input data are available in spreadsheet form.

Table A-10. 2007 Flow and Water Quality Data (mg/L) for Rockport Reservoir as Monthly Averages or Seasonal Averages

Flow (cfs)	Ammonia –N	Dissolved Oxygen	Inorganic –N	Organic Nitrogen	Phosphate-Phosphorus	Total Suspended Solids (TSS)
76.50	0.03	26.09	0.32	0.65	0.020	5.87*
68.79	0.04	11.66	0.22	0.35	0.023	5.87*
43.72	0.03	11.50	0.11	0.42*	0.028	5.87*
46.67	0.03	9.78	0.45	0.42*	0.020	4.00
109.33	0.04*	10.99	0.20*	0.48*	0.021	8.65
224.55	0.06	9.45	0.13	0.48*	0.035	4.80
213.84	0.04*	5.80	0.27	0.48*	0.050	4.80
206.98	0.03	5.69	0.29	0.48	0.067	10.58*
176.24	0.03	5.38	0.18	0.38	0.038	10.58*
94.18	0.03	5.49	0.20*	0.48*	0.043	9.29
85.55	0.03	8.83	0.44*	0.25	0.02*	8.00
85.75	0.03	11.59	0.15	0.42*	0.020	5.60

* Indicates average is seasonal.

A-3.2.5.2 SMITH AND MOREHOUSE RELEASES

Since the Smith and Morehouse Reservoir releases water into the Weber River system, it was included in the Rockport Reservoir Watershed SWAT model to better calibrate the hydrology. The Weber Basin Water Conservancy District provided monthly reservoir outflow data. Water quality data available from UDWQ were used to estimate initial reservoir water quality conditions: nitrate (0.05 milligrams per liter [mg/L]), ammonia (0.0392 mg/L), organic phosphorus (0.005 mg/L), and soluble phosphorus (0.005 mg/L). Other inputs left as default values and monthly releases from the reservoir are shown in Table A-11. The other reservoirs are modeled in BATHTUB and therefore are not included in the SWAT model.

Table A-11. 2007 Monthly Releases from Smith and Morehouse Reservoir

Release	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Acre-feet	706	704	1,220	880	12,700	630	2,030	1,890	740	310	300	198
cfs	11.4	12.6	19.7	14.7	204.8	10.5	32.7	30.5	12.3	5.0	5.0	3.2

A-3.2.6 Grazing

Grazing, primarily of cows and sheep, is a common agricultural activity in the Rockport Reservoir and Echo Reservoir Watersheds. In the Rockport Reservoir Watershed, grazing occurs on both private property and public USFS-managed grazing allotments. In the Echo Reservoir Watershed, all land except a small portion of a USFS allotment is privately owned. Therefore, only private grazing is considered present in the Echo Reservoir Watershed. SWAT inputs related to grazing impacts were estimated from the total number of animal units within a subbasin and land use.

The Uinta-Wasatch-Cache National Forest office and the Heber Ranger District office in Kamas, Utah, provided information on public grazing use for each USFS allotment in the Rockport Reservoir Watershed. Data available include the allotment locations in a geographic information system (GIS) layer and permit documents describing the allotment and grazing permit conditions. The permit documents contain information about the number and type of animals as well as the dates that the allotment can be grazed. Employees from the NRCS at the Coalville office supplied information on private grazing, including estimates of the animal units by season in the watershed zones (Figure A-10) for both Rockport Reservoir and Echo Reservoir Watersheds.

Grazing numbers from the 2011 USFS allotment permits were assumed typical for those allotments, and used to calculate the SWAT grazing inputs that were used for all years modeled, including 2007. Grazing allotment boundaries do not match the SWAT subbasin boundaries, and in some cases extend outside the project area boundary. Therefore, the animal unit numbers for each subbasin were estimated using the proportion of the allotment area within the subbasin to the total allotment area. The estimate is also based on land use types, with specific land uses assumed grazed during each season. Partitioning the land uses and seasons for grazing calculations reflects the movement of animals to pastures and valley areas during winter months and up to forests and rangelands in the summer and fall months, according to the NRCS. This method also assumes that the grazing animals are evenly distributed in the HRUs that have grazing as a management operation. For winter and spring, only pasture land uses were included in the grazing calculations. The forest and range lands on USFS property were used for estimating summer grazing inputs. Pasture and range land use types (as either private land or USFS allotments) were used to calculate grazing inputs for fall.

A similar procedure using NRCS zones instead of USFS allotments was used to calculate the number of animal units on private land in a subbasin (Figure A-10). The NRCS zones incorporate several subbasins. The total animal units for the NRCS zone were distributed among the subbasins using the proportion of private grazeable land within a subbasin to the total private grazeable land in the NRCS zone. The same assumptions about land uses by season were used for private grazing.

Each subbasin except Rockport 8 is wholly contained within a single NRCS zone. In order to generate grazing numbers for Rockport 8, the subbasin was split into two parts, 8a and 8b. The acreage of private grazeable areas and USFS allotment area was calculated for both 8a and 8b. Since 8a only contained public grazing on a USFS allotment, public grazing animal unit numbers calculated from 8a are used directly for subbasin 8.The private grazing numbers from 8a and 8b were combined using an area-weighted average to determine the total animal units grazed on private property for the entire Rockport 8 subbasin.

The estimates of animal units for each season were used to calculate the biomass consumed (kilograms per hectare per day), biomass trampled (kg/ha/day) and manure deposited (kg/ha/day) for each season using the ratio of 10-7-5 for biomass consumed-biomass trampled-manure deposited (personal communication between Thomas Hoskins, NRCS, and Erica Gaddis, SWCA, December 12, 2013) and a starting estimate of 30 pounds per day consumed per animal unit. Grazing inputs are summarized in Table A-12.

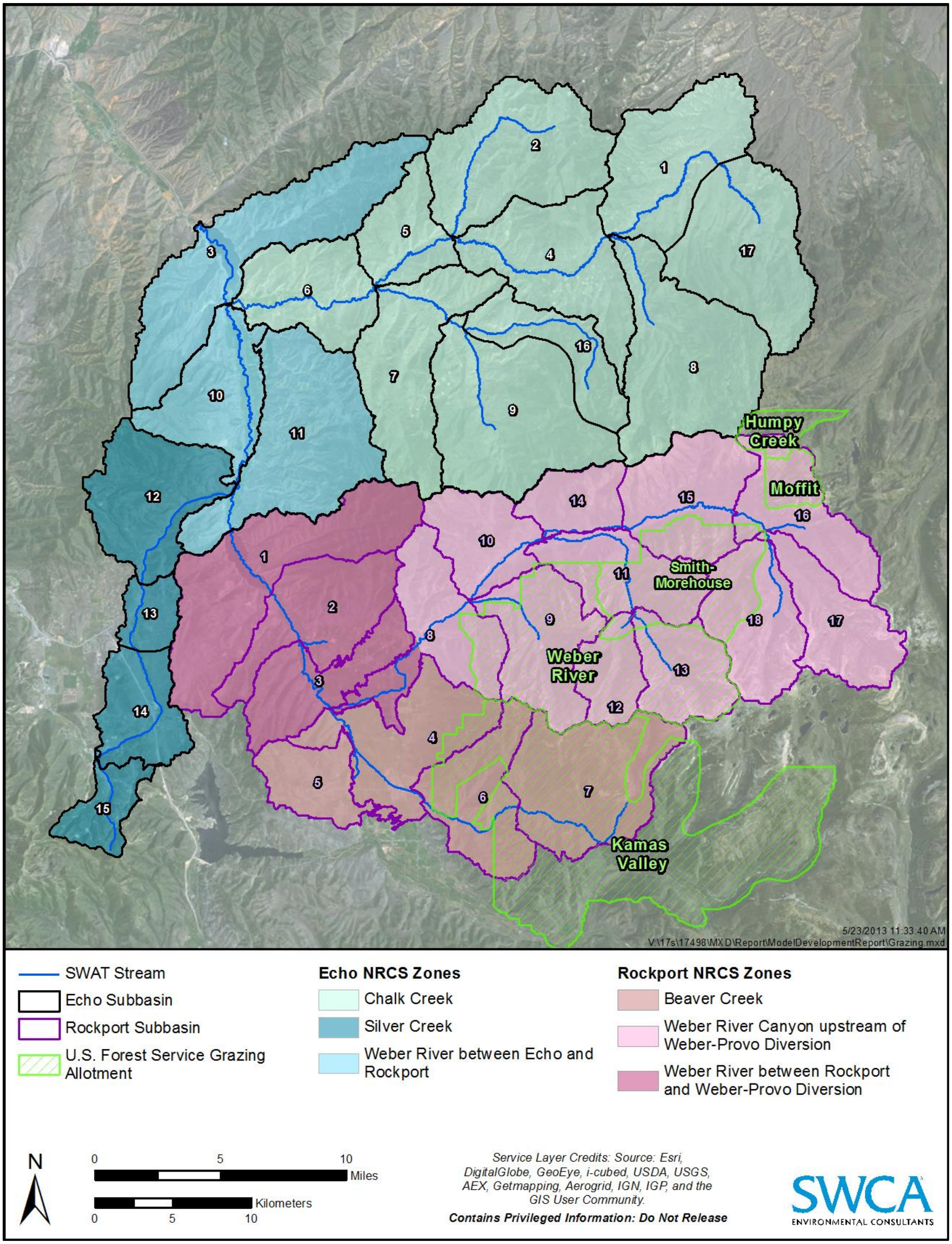

Figure A-10. Zones used to broadly quantify the number of grazing animals on private property (NRCS zones) and the locations of USFS allotments within the Rockport Reservoir and Echo Reservoir Watershed.

Table A-12. Grazing Inputs Used for SWAT

Watershed and Subbasins	Allotment or NRCS Zone	Grazing Start Date/Season	Land Uses Included (if present in a subbasin) [1]	Dry Weight of biomass Consumed for Cows/Sheep (kg/ha/day)	Dry Weight of Biomass Trampled by Cows/Sheep (kg/ha/day)	Dry Weight of Manure Deposited Daily by Cows/Sheep (kg/ha/day)
Rockport Subbasins 4, 6, 7	Kamas Valley (USFS allotment)	June 10	Mixed Forest, Range	0.45/0	0.31/0	0.22/0
Rockport Subbasins 9, 12, 13, 8a	Weber River (USFS allotment)	June 21	Mixed Forest, Range	0.22/0	0.15/0	0.11/0
Rockport Subbasin 16	Humpy Creek (USFS allotment)	July 25	Mixed Forest, Range	0/3.72	2.60/0	1.80/0
Rockport Subbasin 16	Moffit Creek (USFS allotment)	July 11	FRPG, RGPG, RBPG	0/3.58	0/2.50	0/1.73
Rockport Subbasins 4, 5, 6, 7	Beaver Creek (NRCS Zone)	Winter (Dec 22–March 21)	PAST, PAS1, PAS2, PAS3	9.11/4.56	6.38/3.19	4.56/2.20
		Spring (March 22–June 21)	Pasture	9.11/4.56	6.38/3.19	4.56/2.20
		Summer (June 22–September 21)	Mixed Forest, Range	7.29/3.64	5.10/2.55	3.64/1.76
		Fall (September 22–December 21)	Range, Pasture	4.99/2.50	3.49/1.75	2.50
1.21 Rockport Subbasins (8), 9, 10, 11, 12,13, 14	Weber Canyon above the Weber-Provo Diversion (NRCS Zone)	Winter (December 22–March 21)	Pasture	(1.29/0.65) 5.89/2.95	(0.90/0.45) 4.13/2.06	(0.65/0.31) 2.95/1.42
		Spring (March 22–June 21)	Pasture	(1.71/0.86) 11.79/5.89	(1.20/0.60) 8.25/4.13	(0.86/0.41) 5.89/2.85
		Summer (June 22–September 21)	Mixed Forest, Range	(3.86/1.93) 4.96/2.48	(2.70/1.35) 3.47/1.74	(1.93/0.93) 2.48/1.20
		Fall (September 22–December 21)	Range, Pasture	(1.41/0.71) 6.13/3.06	(0.99//0.71) 4.29/2.14	(0.71/0.34) 3.06/1.48
Rockport Subbasins 1, 2, 3	Weber River between Rockport and Weber-Provo Diversion (NRCS Zone)	Winter (December 22–March 21)	Pasture	4.53/2.27	3.17/1.59	2.27/1.10
		Spring (March 22–June 21)	Pasture	4.53/2.27	3.17/1.59	2.27/1.10

Table A-12. Grazing Inputs Used for SWAT

Watershed and Subbasins	Allotment or NRCS Zone	Grazing Start Date/Season	Land Uses Included (if present in a subbasin) [1]	Dry Weight of biomass Consumed for Cows/Sheep (kg/ha/day)	Dry Weight of Biomass Trampled by Cows/Sheep (kg/ha/day)	Dry Weight of Manure Deposited Daily by Cows/Sheep (kg/ha/day)
		Summer (June 22–September 21)	Mixed Forest, Range	2.40/1.20	1.68/0.84	1.20/0.58
		Fall (September 22–December 21)	Range, Pasture	2.65/1.32	1.85/0.93	1.32/0.64
Echo Subbasins 12, 13, 14, 15	Silver Creek (NRCS Zone)	Winter (December 22–March 21)	Pasture	1.88/0.94	1.31/0.66	0.94/0.45
		Spring (March 22–June 21)	Pasture	1.88/0.94	1.31/0.66	0.94/0.45
		Summer (June 22–September 21)	Mixed Forest, Range	2.64/1.32	1.85/0.93	1.32/0.64
		Fall (September 22–December 21)	Range, Pasture	1.42/0.71	0.99/0.50	0.71/0.34
Echo Subbasins 10,11	Weber River between Rockport Reservoir and Echo Reservoir (NRCS Zone)	Winter (December 22–March 21)	Pasture	16.17/8.09	11.32/5.66	8.09/3.91
		Spring (March 22–June 21)	Pasture	2.49/1.25	1.74/0.87	1.25/0.60
		Summer (June 22–September 21)	Mixed Forest, Range	2.49/1.25	1.74/0.87	1.25/0.60
		Fall (September 22–December 21)	Range, Pasture	6.09/3.04	4.26/2.13	3.04/1.47
Echo Subbasins 1, 2, 4, 5, 6, 7, 8, 9, 16, 17	Chalk Creek (NRCS Zone)	Winter (December 22–March 21)	Pasture	5.89/2.94	4.12/2.06	2.94/1.42
		Spring (March 22–June 21)	Pasture	5.89/2.94	4.12/2.06	2.94/1.42
		Summer (June 22–September 21)	Mixed Forest, Range	1.15/0.57	0.80/0.40	0.57/0.28
		Fall (September 22–December 21)	Range, Pasture	2.37/1.18	1.66/0.83	1.18/0.57

1 FRST = forest, RNGE = grass range, RNGB = shrub range, PAST = pasture no irrigation identified, PAS1= pasture not irrigated, PAS2 = pasture sprinkler irrigated, PAS3 = pasture flood irrigated, FRPG = forest on USFS allotment (public grazing), RGPG = grass range on USFS allotment (public grazing), RBPG = brush range on USFS allotment (public grazing). If individual land uses were not present for a given subbasin, no grazing was present and no values were applied.

A-3.2.7 Agricultural Assumptions

The NRCS office in Coalville supplied information on crops grown in the Rockport Reservoir and Echo Reservoir Watersheds. Three zones in each watershed were created to allow the NRCS to broadly estimate the type of crops grown in areas of each watershed. Zones in the Echo Reservoir Watershed include Chalk Creek, Silver Creek, and the Weber River between Rockport Reservoir and Echo Reservoir. The Rockport Reservoir Watershed is split into zones covering the Beaver Creek watershed, the Weber River Canyon Upstream of the Weber-Provo Diversion, and the Weber River between Rockport and the Weber-Provo Diversion. The NRCS submitted estimates of crop percentages in each zone and general assumptions for alfalfa crops including the planting date, rotation, and average crop yield. The NRCS assumed a general planting date of May 15. However, to make the planting date fit better with estimated dates for start of irrigation and fertilizer application, the planting date was adjusted to May 1. The NRCS estimated two cuttings per year for alfalfa, a rotation of 9 years, and an average crop yield of 2,000 kilograms. Crops were not rotated in the model; therefore, the crops assigned to each land use remain the same for the duration of the simulation.

A-3.2.8 Fertilizer Data Inputs

Fertilizer was applied to alfalfa, generic agriculture, and hay land use types and for all soil types at a uniform application rate of 35 kg/year. Fertilizer application was limited to slope classes 0–10% and 10–20%. The NRCS identified commercial fertilizer and dairy manure as the primary fertilizer types that farmers use in the watershed. A commercial fertilizer with an N:P:K ratio of 11-52-00 was applied to alfalfa and agriculture. Although the NRCS suggested a fertilizer ratio of 11-52-11, the 11-52-00 ratio was used because SWAT does not model potassium inputs. Areas identified as hay were assumed to be fertilized with 130 kg N/60 kg P based on additional discussion with NRCS personnel.

The NRCS also estimated that while about 80% of the watershed is fertilized with commercial fertilizer, 20% of the agricultural areas are fertilized with dairy manure (personal communication between Thomas Hoskins, NRCS, and Erica Gaddis, SWCA, December 12, 2012). The locations of dairies in the watershed determined which areas in a subbasin would likely use dairy manure based on the assumption that alfalfa and agriculture areas within a 1-mile radius of a dairy would likely use dairy manure for fertilizer.

Low and medium density urban land uses were assumed to use the SWAT provided fertilizer type, with an application rate of 5 kg/ha. Fertilizer was not applied to high density urban land uses.

A-3.2.9 Septic Systems

The Summit County Health Department supplied paper records with information about known septic systems in the project watershed, and the Summit County GIS department supplied additional information about septic systems in the watershed in a GIS format. The paper dataset was added to the GIS data by scanning the paper records and creating an Excel table from the scanned records. The Parcel ID was used to combine records from each dataset. The merged dataset contains information about buildings including age, size, and type of building as well as more detailed information for some records including the type of trench and building/septic location in latitude and longitude. This dataset, along with the National Hydrography Dataset (NHD), were used to determine the number of septic systems within a subbasin and the average distance from either a stream or reservoir within a subbasin. The total number of septic systems is used to calculate the density of septic systems in the HRU.

The septics dataset with additional input from the Summit County Health Department (personal communication, telephone call between Brent Ovard and Bob Swensen, Summit County Health

Department, and Erica Gaddis, SWCA, November 2012) was used to create three groups of septic systems: Primary, Secondary, and Recreational. The Primary category contains buildings known to be primary residences and other buildings that are likely operating all year. Buildings listed as other or unknown, including those identified as Farmland Assessment Act (FAA) buildings were included in the Primary category to maintain a conservative estimate of septic systems and their operations within the watershed. If the county data categorized a building as a secondary residence (defined as occupied six months or less), it was classified as Secondary residential for SWAT. Buildings that the county considers recreational have less than three months of occupancy over the year. Septic systems associated with recreational buildings are also categorized as Recreational septic systems in the SWAT septic tables (Figure A-11).

Nutrient loads from Primary, Secondary, and Recreational septic systems were assumed proportional to the estimated amount of time a residence is occupied. The default values for a conventional drain field were used for primary residences. For Secondary and Recreational septic systems, new SWAT categories with unique four-digit codes were created that contain the default nutrient concentrations but proportionally reduced discharges (Table A-13). The discharge values were reduced by the proportion of the year the septic system is assumed active to reduce the annual nutrient loads from septic systems. Secondary residences are assumed occupied for 6 months, therefore the load inputs are 50% of the default values. Recreational residences load inputs are 25% of the default values since these buildings are assumed occupied for only 3 months per year. This approach only reduces the annual load for Secondary and Recreational inputs because SWAT runs on a daily timestep. Therefore, SWAT models these septic systems as contributing on a daily basis; the loads are just reduced. The approach does not account for an increase or decrease of septic system inputs based on when the septic systems are active and/or on a seasonal basis.

Table A-13. Input Values for SWAT to Model Septic System Loads

Parameter	Primary Residence	Secondary Residence	Recreational Use
Septic tank effluent flow rate m^3/capita/day	0.227	0.1135	0.05675
Seven-day biological oxygen demand mg/L	170	170	170
Total suspended solids in septic effluent mg/L	75	75	75
Total nitrogen in septic effluent mg/L	60	60	60
Ammonia in septic effluent mg/L	58	58	58
Nitrate in septic effluent mg/L	0.2	0.2	0.2
Nitrite in septic effluent mg/L	0	0	0
Organic N in septic effluent mg/L	14	14	14
Total phosphorus in septic effluent mg/L	10	10	10
Phosphate in septic effluent mg/L	9	9	9
Organic P in septic effluent mg/L	1	1	1
Fecal coliform in septic effluent cfu/100mL	10,000,000	10,000,000	10,000,000

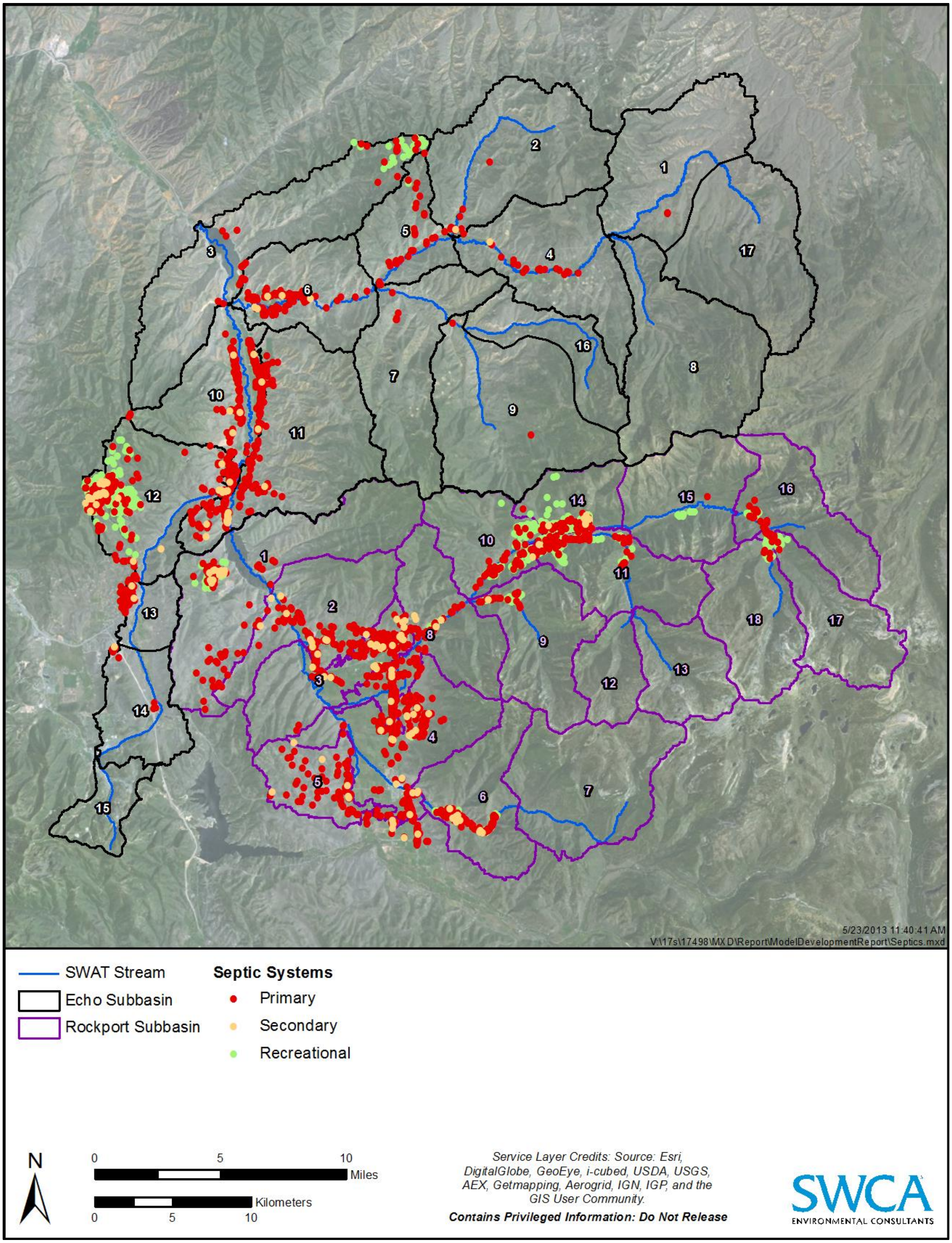

Figure A-11. Known septic systems in the Rockport Reservoir and Echo Reservoir Watersheds.

SWAT will model a septic system as a hydraulic failure where septic effluent is discharged onto the ground surface and any runoff reaching a waterbody is essentially untreated. SWAT models functioning septic systems by infiltrating the effluent through the soil layers and allowing the soil to uptake and transform nutrients (Arnold et al. 2011). This difference allows for differentiation of loads from functional septic systems and failing septic systems. No data documenting the number or location of failing septic systems in the watershed were available for the project area. From discussions with the Summit County Health Department and results from bacteria and human bacteroides sampling that occurred in late 2012, an EPA-recommended septic system failure rate of 10% was used (EPA 2000).

SWAT does not allow an HRU to have both functional and failing septic systems, so identifying 10% of the total number of septic systems in each HRU was not feasible. Instead, 10% of septic systems were designated as failing by randomly selecting 10% of the total number of septic systems (including Primary, Secondary, and Recreational) over the entire watershed and creating HRUS with failing septic systems as a land use.

The SWAT model allows the septic system to fail for up to 10,000 days. Septic systems designated as failing were allowed to fail continuously for 6,000 days to cover the entire model time period between 1998 and 2012.

A-3.2.9.1 URBAN LAND USE HYDROLOGY

SWAT applies the USGS urban regression equations to model stormwater runoff from urban land uses. The USGS developed these equations for ungaged urban watersheds using a national urban water quality database described in the model documentation (Arnold et al. 2011). The SWAT variables adjusted for the Rockport Reservoir and Echo Reservoir Watersheds include the fraction of total area that is impervious and the percent of the impervious surface area that has a direct hydrologic connection, for example, a stormwater outfall that discharges to a stream. These values were adjusted for the I-80 and US40 corridors runoff from the road surfaces will drain to grassy swales that are adjacent to the road shoulder. The values were also adjusted for other urban land use categories to reflect the existing conditions in the Rockport Reservoir and Echo Reservoir Watersheds. Table A-14 shows the values used in the SWAT model by urban land use type.

Table A-14. Urban Land Use SWAT parameters

Urban Land Use Category	Land Use Code	Percent Impervious Surface (FIMP)	Percent Impervious Surface With Direct Hydrologic Connection (FCIMP)
Urban	URBN	0.2	0.07
Urban Residential High Density	URHD	0.44	0.11
Urban Residential Medium Density	URMD	0.23	0.07
Urban Residential Medium-Low Density	URML	0.14	0.06
Urban Residential Low Density	URLD	0.07	0.03
Urban Park	PARK	0.07	0.03
Interstate 80 Corridor	I80	0.7	0.2
US Highway 40 Corridor	US40	0.07	0.2

A-3.2.10 Point Source Inputs

Point sources of pollution are characterized by specific points of discharge (e.g. pipes) that convey wastewater into a waterbody. Point sources are regulated under Utah Pollutant Discharge Elimination System (UPDES) permitting program. In the Rockport Reservoir Watershed, point sources include the Kamas City WWTP, Oakley City WWTP, and the UDWR Fish Hatchery near Kamas. The UDWR hatchery is only used in scenarios to develop a load allocation for future operations. The hatchery was offline much of the time period used for the SWAT model. The Silver Creek Water Reclamation Facility (WRF); the Park City drains, which include Judge Tunnel, the Spiro Tunnel, the Prospector Drain and the Biocell; and the Coalville WWTP are treated as point sources in the Echo Reservoir Watershed (Figure A-12). Because SWAT allows only one point source per subbasin, the Judge Tunnel, Spiro Tunnel, Prospector Drain, and Biocell discharges were combined into a single point source for the SWAT model.

All point source files were generated using monthly data. SWAT inputs include the mineral and organic fractions of phosphorus and nitrogen, with nitrogen further partitioned into ammonia, nitrite, and nitrate. For all WWTPs, the 30-day average or monthly average value for each calendar month was based on available data from 2002 – 2012. If the required data were not available, specific assumptions were made for each wastewater treatment plant in order to complete the SWAT input files. If a blank record existed between two months with values, the blank record was populated with an average of the two adjacent values. There were no available data from the Oakley, Kamas, and UDWR hatchery sources for several parameters. SWCA worked closely with UDEQ to develop appropriate assumptions for those treatment plants that are discussed in individual sections below.

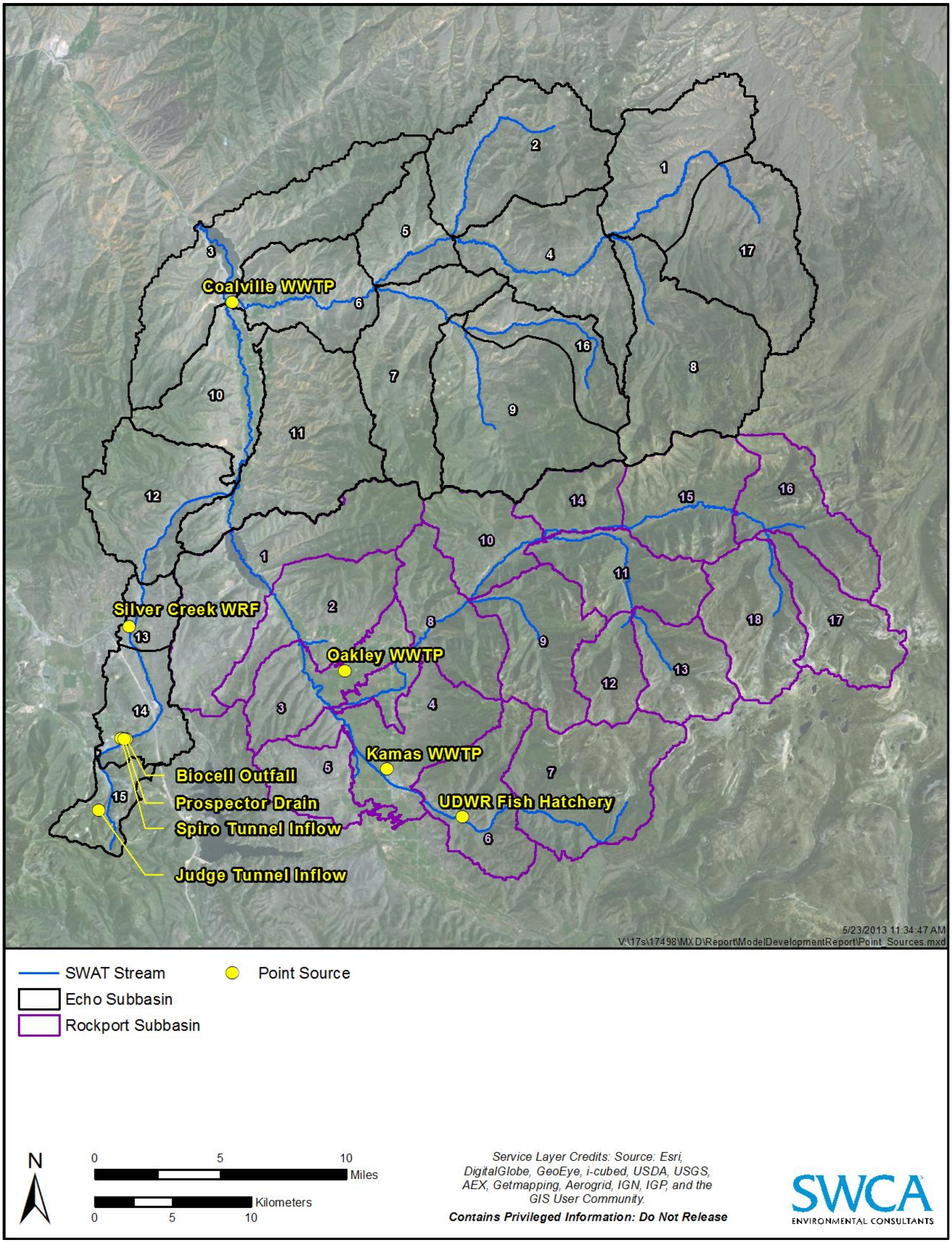

Figure A-12. Location of point source discharges in the Rockport Reservoir and Echo Reservoir Watersheds.

A-3.2.10.1 KAMAS CITY WASTEWATER TREATMENT PLANT

The Kamas City Wastewater Treatment Plant (UPDES UT0020966) serves a population of approximately 1,500 people. The Kamas plant was most recently upgraded in 1991. Current design includes an 18-inch inlet pipe leading to five waste stabilization ponds, the first three of which are aerated with seven 20-horsepower aerators. Effluent is treated with ultraviolet light disinfection. The five lagoons cover approximately 18.8 acres. The plant was designed for average daily flows of 1.0 million gallons per day (MGD) and recent analysis suggests it can treat 1,750 pounds of biological oxygen demand (BOD) per day.

Several assumptions were made to develop SWAT inputs that characterize the effluent from the Kamas City WWTP for the model. Total phosphorus concentration was assumed to be 3.5 mg/L with a negligible organic component. A total nitrogen concentration of 16 mg/L was assumed, 30% of which was assumed to be organic. These values were based on effluent data from other lagoon systems in Utah that are located in a similar climate and have a similar retention time and were provided by Paul Krauth of UDEQ. The system found to be most similar to the Kamas system is the Midway lagoon system. Total suspended solids and BOD inputs were based on average monthly data specific to each year. The loads for 2007 are summarized in Table A-15.

Table A-15. Average Monthly SWAT Point Source Inputs for the Kamas City WWTP

Month	Flow (m^3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Jan	238.48	0.002	1.15	0.0	2.00	0.67	0.0	0.84	1.55
Feb	302.83	0.005	1.45	0.0	2.54	0.85	0.0	1.06	7.87
Mar	359.61	0.006	1.73	0.0	3.02	1.01	0.0	1.26	5.39
Apr	416.40	0.017	2.00	0.0	3.50	1.17	0.0	1.46	8.33
May	776.01	0.017	3.723	0.0	6.52	2.17	0.0	2.72	13.46
Jun	1,135.62	0.006	5.45	0.0	9.54	3.18	0.0	3.98	1.14
Jul	454.25	0.002	2.18	0.0	3.82	1.27	0.0	1.59	0.23
Aug	264.98	0.001	1.27	0.0	2.23	0.74	0.0	0.93	0.13
Sep	208.20	0.001	1.00	0.0	1.75	0.58	0.0	0.73	2.52
Oct	227.12	0.001	1.09	0.0	1.91	0.67	0.0	0.80	1.36
Nov	283.91	0.001	1.36	0.0	2.39	0.80	0.0	0.99	0.28
Dec	293.37	0.002	1.41	0.0	2.46	0.82	0.0	1.03	1.91

A-3.2.10.2 OAKLEY CITY WASTEWATER TREATMENT PLANT

The Oakley City Wastewater Plant (UPDES UT0020061) was designed for daily flows of 0.25 mgd. The plant treatment train includes a 2-mm screen and compactor, grit removal, aeration basin and a membrane bioreactor for microfiltration. Waste is treated with an ultraviolet disinfection system before being discharged into the Weber River.

The membrane bio-reactor effectively removes all solids from the effluent. Thus, the TSS concentration was assumed to be 0, as reported on monthly DMR reports. Phosphorus data available for Oakley City WWTP consists of daily maximum values and could not be used to estimate an average monthly value.

An average total phosphorus concentration of 1.5 mg/L was assumed for the Oakley City WWTP, which represents a conservative monthly average for the type of treatment system used in Oakley. All of the phosphorus was assumed to be mineral. Nitrogen data were not available and the only BOD data available for the Oakley City WWTP was from 2001 to 2003, which does not reflect the effluent characteristics of the recently upgraded facility. The total nitrogen concentration in the Oakley effluent was assumed to be 10 mg/L, 30% of which was assumed to be organic. BOD was assumed to be 4 mg/L. These values (Table A-16) were based on design effluent for the upgraded Oakley City WWTP and provided by Paul Krauth of UDEQ and confirmed with Bob Johnson of Oakley on December 7, 2012.

Table A-16. Average Monthly SWAT Point Source Inputs for the Oakley City WWTP

Month	Flow (m3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Jan	427.75	0	1.28	0	2.25	0.75	0	0.64	1.71
Feb	3,217.60	0	9.65	0	16.89	5.63	0	4.83	12.9
Mar	416.40	0	1.25	0	2.19	0.73	0	0.63	1.67
Apr	658.66	0	1.98	0	3.46	1.15	0	0.99	2.64
May	586.74	0	1.76	0	3.08	1.03	0	0.88	2.35
Jun	541.31	0	1.62	0	2.84	0.95	0	0.81	2.17
Jul	427.75	0	1.28	0	2.25	0.75	0	0.64	1.71
Aug	416.4	0	1.25	0	2.19	0.73	0	0.63	1.67
Sep	707.87	0	2.12	0	3.72	1.24	0	1.06	2.83
Oct	2,876.91	0	8.63	0	15.10	5.04	0	4.32	11.51
Nov	3,520.428	0	10.561	0	18.482	6.161	0	5.281	14.082
Dec	2,937.134	0	8.811	0	15.42	5.14	0	4.406	11.749

A-3.2.10.3 UDWR FISH HATCHERY NEAR KAMAS

Monthly total phosphorus and flow data for the UDWR Fish Hatchery were used directly in the SWAT input file for this point source, with some data gaps. No total nitrogen data were available for this source. As a conservative assumption, total nitrogen was assumed to be 16 mg/L (same as the Kamas City WWTP) with the same organic fractions as those assumed for Kamas. However, because the hatchery was in operation intermittently during the past 10 years and not in 2007 (the baseline model year), this point source will only be used for future scenarios and load allocations and for baseline model development.

A-3.2.10.4 COALVILLE CITY WASTEWATER TREATMENT PLANT

The Coalville City Wastewater Plant (UPDES UT0021288) serves a population of approximately 1,470 people. It was originally designed as a trickling filter plant in 1964. Since then, three upgrades have been completed. First, in 1985, the plant was modified to an extended aeration/activated sludge plant. Subsequent additions include two biosolids drying beds in 1992, and the addition of a Somat screw press for dewatering, a composting pad, and alterations to existing drying beds in 1995. Plant design allows for an average daily flow of 0.35 MGD and peak flow of 0.42.

Average monthly DMR data and additional data provided by JUB, consulting engineer to Coalville City, were used to develop inputs for SWAT (Table A-17). Although historic data is used to calibrate the watershed model, design values for the new wastewater treatment plant were used for scenario analyses.

Table A-17. Average Monthly Point Source Inputs for the Coalville City WWTP

Month	Flow (m3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Jan	738.15	0.003	0.23	0.0	4.04	0.369	0.021	0.54	0.74
Feb	757.08	0.003	0.50	0.0	4.45	0.303	0.018	0.53	3.79
Mar	632.16	0.002	0.19	0.0	3.68	2.529	0.015	0.23	0.63
Apr	654.88	0.003	0.56	0.0	3.26	0.262	0.033	2.82[1]	0.66
May	825.22	0.003	0.17	0.0	4.52	0.330	0.041	0.30	2.48
Jun	870.64	0.004	0.67	0.0	5.03	0.348	0.044	0.37	4.35
Jul	776.01	0.003	1.12	0.0	4.25	0.310	0.039	0.27	0.78
Aug	859.29	0.003	0.32	0.0	3.61	0.344	0.043	1.26	2.58
Sep	942.57	0.004	0.46	0.0	4.83	0.377	0.047	1.36	2.83
Oct	870.64	0.005	0.65	0.0	5.29	0.348	0.026	1.48	2.61
Nov	741.94	0.004	1.38	0.0	4.42	0.297	0.022	0.72	2.27
Dec	723.01	0.003	0.32	0.0	3.92	0.289	0.013	0.48	2.89

[1] Includes a high value of 7.4 mg/L form April 2011.

A-3.2.10.5 SILVER CREEK WATER RECLAMATION FACILITY

The Snyderville Basin Water Reclamation District operates the Silver Creek WRF (UPDES UT0024414), a conventional, secondary treatment plant that services residential areas and permitted Significant Industrial Users in portions of the watershed, including areas of Park City. Constituents with specific effluent limitations are DO, BOD, total suspended solids, ammonia, *E. coli*, oil and grease, and pH (Snyderville Basin Water Reclamation District 2013). Phosphorus is not regulated with a specific effluent limitation, but is sampled on a monthly basis under the existing permit, which is currently in the process of being renewed. No flow limit is indicated in the UPDES permit, but the current facility has a capacity of 2.0 MGDMGD. An average monthly flow is approximately 2 cubic feet per second (cfs), or 1.3 mgd. Upgrades are currently being planned, with final designs based on a discharge of 4.0 MGD. The designs and technology included in the upgrades depend on the effluent concentrations identified in the UPDES permit. DMR data and supplemental data provided by the Snyderville Basin Water Reclamation District were used to develop average monthly inputs for SWAT (Table A-18).

Table A-18. Average monthly SWAT point source inputs for the Silver Creek WRF

Month	Flow (M3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Jan	4,455.42	0.027	6.85	0.0	82.74	0.45	0.84	14.04	17.82
Feb	4,913.46	0.025	5.85	0.0	90.88	0.98	0.92	17.20	19.65
Mar	6,900.80	0.028	10.78	0.0	126.07	1.38	1.27	17.48	20.70

Table A-18. Average monthly SWAT point source inputs for the Silver Creek WRF

Month	Flow (M3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Apr	4,762.04	0.019	3.75	0.0	57.78	1.91	0.58	5.40	23.81
May	4,213.16	0.025	6.17	0.0	51.18	0.84	0.52	5.76	16.85
Jun	3,951.96	0.016	4.63	0.0	87.61	0.40	0.89	7.91	19.76
Jul	4,379.72	0.018	4.11	0.0	81.04	0.88	0.82	12.59	13.14
Aug	4,580.34	0.032	8.00	0.0	90.46	1.37	0.91	12.83	22.90
Sep	3,550.71	0.014	3.88	0.0	67.92	0.36	0.69	9.01	10.65
Oct	4,182.87	0.025	5.22	0.0	76.69	0.84	0.78	10.77	25.10
Nov	4,186.66	0.020	5.22	0.0	74.53	1.26	0.75	12.98	20.93
Dec	4,890.75	0.038	8.71	0.0	81.51	4.40	0.82	15.75	34.24

A-3.2.10.6 JUDGE TUNNEL

Judge Tunnel carries groundwater from a series of mine tunnels to a chlorination vault where the flow is treated and becomes drinking water for Park City (Figures A-12 and A-13). If the turbidity is too high (approximately 1–2 nephelometric turbidity units[NTUs]), the water bypasses the vault and is released into Empire Creek, a tributary to Silver Creek (personal communication between Kyle MacArthur, Park City Municipal Corporation and Erica Gaddis, SWCA, December 19, 2012). Judge Tunnel’s average monthly flow is somewhat variable with increased discharges during months with increased precipitation, but generally small compared to mainstem flows. The average monthly discharge is 0.4 cfs. The data used were compiled primarily from monitoring data provided by UDEQ and Park City Municipal Corporation. This included monthly flows from 2004 to 2011. Gaps in this dataset were populated by average monthly values. Little water quality data existed for the Judge Tunnels, so four samples from 2010 and 2011 were averaged for TSS, nitrate, and total phosphorus, while two samples from 2010 were averaged for BOD (site JT-9). Organic nitrogen and ammonia concentrations were estimated using data from Spiro Tunnel (Park City monitoring sites ST-23, ST- 24, and ST-26) because no data were available for Judge Tunnel (Table A-19).

Table A-19. SWAT point source inputs for the Judge Tunnel for model year 2007

Month	Flow (m^3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Jan	1,118.17	0.003	0.335	0.0	0.145	0.112	0.0	0.045	2.80
Feb	1,470.64	0.004	0.441	0.0	0.191	0.147	0.0	0.059	3.68
Mar	1,364.95	0.004	0.409	0.0	0.177	0.136	0.0	0.055	3.41
Apr	1,907.35	0.005	0.572	0.0	0.248	0.191	0.0	0.076	4.77
May	3,361.95	0.009	1.009	0.0	0.437	0.336	0.0	0.134	8.41
Jun	109.78	0.000	0.033	0.0	0.014	0.011	0.0	0.004	0.27
Jul	41.76	0.000	0.013	0.0	0.005	0.004	0.0	0.002	0.10
Aug	63.74	0.000	0.019	0.0	0.008	0.006	0.0	0.003	0.16

Table A-19. SWAT point source inputs for the Judge Tunnel for model year 2007

Month	Flow (m^3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Sep	14.01	0.000	0.004	0.0	0.002	0.001	0.0	0.001	0.04
Oct	239.95	0.001	0.072	0.0	0.031	0.024	0.0	0.010	0.60
Nov	1,213.23	0.003	0.364	0.0	0.158	0.121	0.0	0.049	3.03
Dec	466.58	0.001	0.140	0.0	0.061	0.047	0.0	0.019	1.17

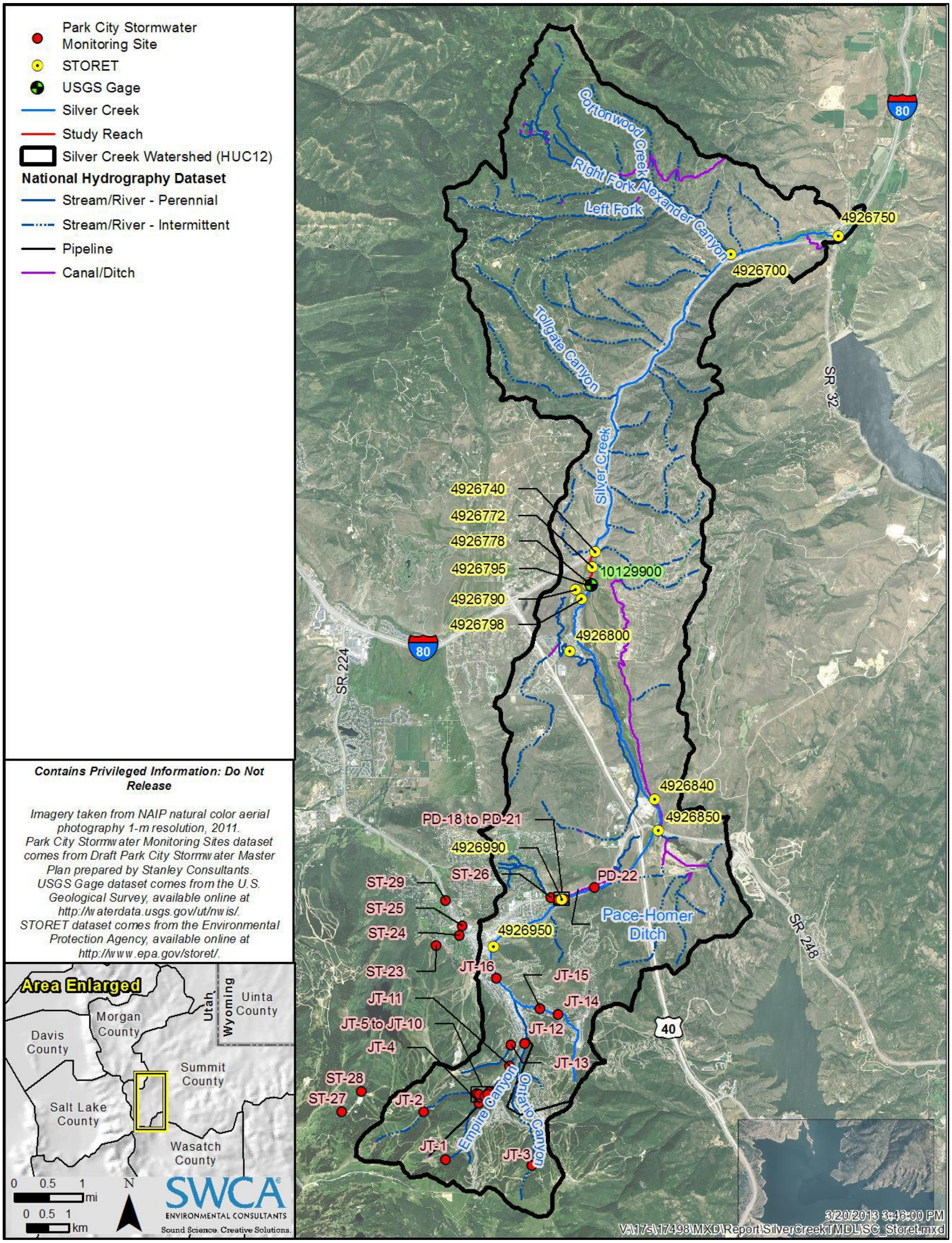

Figure A-13. Location of tunnels and Park City monitoring sites used to estimate flows and loads.

A-3.2.10.7 SPIRO TUNNEL

Like Judge Tunnel, Spiro Tunnel collects groundwater from mine tunnels (Figure A-13). Spiro Tunnel discharges water into two irrigation ditches in the Silver Creek watershed: the Bates, Snyder, Dority Ditch and the Pace Homer Ditch. Spiro Tunnel discharges directly into Silver Creek at the Pace Homer Ditch (Park City Municipal Corporation 2012). Spiro Tunnel average discharge is approximately 1.5 cfs.

At location ST-25, the pipe splits flow into the Bates, Snyder, Dority Ditch, which takes flow to the Silver Creek drainage. There is also a diversion approximately 750 feet east and downstream of ST-29, which carries water into the Silver Creek drainage. The two diversions comingle before reaching ST-26. At ST-26, spring water and stormwater has mixed in with the mine drainage, at which point it becomes the Pace Homer Ditch. This site is the direct discharge into Silver Creek. Flow measurements taken at the ST-23 site and the ST-30 were used to characterize inflow to Silver Creek from Spiro Tunnel only. Both sites are needed because flow is partitioned between Silver Creek and East Canyon at ST-25 (personal communication between Joan Card, Park City Corporation, and Erica Gaddis, SWCA on December 19, 2012).

The data used were compiled from monitoring data provided by UDEQ and Park City Municipal Corporation. Average data for the following parameters from site ST-23 were used to characterize the water quality of flow to Silver Creek that originates from Spiro Tunnel: Ammonia as Nitrogen, Biological Oxygen Demand, Nitrate, Nitrite, Phosphorus, Orthophosphate, Total Kjeldahl Nitrogen, and Total Suspended Solids. Organic nitrogen was calculated as TKN minus ammonia for an average value of 0.3 mg/L.

Flow values for Spiro Tunnel were provided by Park City. This included monthly flows from 2004 to 2011. Gaps in this dataset were populated by average monthly values. Water quality values for Spiro Tunnel were averaged based on available samples (Table A-20).

Table A-20. 2007 SWAT Point Source Inputs for the Spiro Tunnel

Month	Flow (m3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic Phosphorus (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
Jan	72.26	0.000	0.022	0.0	0.009	0.007	0.0	0.001	0.18
Feb	315.43	0.001	0.095	0.0	0.038	0.032	0.0	0.006	0.79
Mar	285.14	0.001	0.086	0.0	0.034	0.029	0.0	0.006	0.71
Apr	97.46	0.000	0.029	0.0	0.012	0.010	0.0	0.002	0.24
May	8004.71	0.017	2.401	0.0	0.961	0.800	0.0	0.160	20.01
Jun	7490.40	0.016	2.247	0.0	0.899	0.749	0.0	0.150	18.73
Jul	7396.61	0.016	2.219	0.0	0.888	0.740	0.0	0.148	18.49
Aug	9538.87	0.020	2.862	0.0	1.145	0.954	0.0	0.191	23.85
Sep	6362.60	0.013	1.909	0.0	0.764	0.636	0.0	0.127	15.91
Oct	2971.78	0.006	0.892	0.0	0.357	0.297	0.0	0.059	7.43
Nov	537.72	0.001	0.161	0.0	0.065	0.054	0.0	0.011	1.34
Dec	304.11	0.001	0.091	0.0	0.036	0.030	0.0	0.006	0.76

A-3.2.10.8 PROSPECTOR DRAIN AND BIOCELL

Prospector Drain collects shallow groundwater impacted by mine tailings. This drain also collected stormwater until 2012 when Park City eliminated cross-connections from stormwater sources.

A portion of flow from Prospector Drain goes into the Biocell, which treats the water for metal contamination. The Biocell contains organic matter in the form of manure, which may explain the high nutrient concentrations in the Biocell discharge, which goes to Silver Creek. The remaining water in Prospector Drain flows untreated to Silver Creek (Park City Municipal Corporation 2012). These sources contribute a relatively small quantity of flow to Silver Creek. The Prospector Drain discharges an estimated 0.07 cfs (site PD-18), of which approximately half (0.036 cfs) is routed through the Biocell (Site PD-19) (see Figure A-13).

The Biocell and Prospector Drain are expected to be part of an Environmental Protection Act (EPA)–directed *Comprehensive Environmental Response, Compensation, and Liability Act* removal action in the foreseeable future. The discharges from these sources will be addressed pending EPA approval of a removal action. Therefore, no UPDES permit will be issued for these point sources until the EPA-directed removal action is complete (Park City Municipal Corporation 2012).

The data used were compiled primarily from data provided by the UDEQ and Park City Municipal Corporation. Water quality values for Prospector Drain and Biocell were averaged from available data or assumed to be zero. However, Prospector Drain and Biocell data were combined as weight-based averages for inputs into SWAT (Table A-21).

Table A-21. Combined SWAT Point Source Inputs for the Prospector Drain and Biocell

Flow (m^3/day)	TSS (metric tons/day)	Organic Nitrogen (kg/day)	Organic P (kg/day)	Nitrate (kg/day)	Ammonia (kg/day)	Nitrite (kg/day)	Mineral P (kg/day)	BOD (kg/day)
265	0.002	0.09	0.0	0.54	0.03	0.0	0.2	1.3

A-3.2.10.9 COMBINED POINT SOURCES IN SWAT

SWAT allows the user to place a single point source in each subbasin. Therefore, the values generated for Judge Tunnel, Spiro Tunnel, Prospector Drain, and the Biocell were added together and a single file was created for SWAT. For wastewater treatment plants with multiple discharge locations, the flow and loads for individual discharge points were added to estimate a total flow and load discharged from the facility.

A-3.2.11 Hydrologic Parameters

A-3.2.12 Snow and Evapotranspiration Parameters

SWAT users can assign evapotranspiration parameters and snow parameters for the watershed or at the subbasin level. This allows better simulation of snow-melt dominated watersheds, where changes in elevation affect precipitation and temperature, thereby affecting the hydrology. Evapotranspiration parameters are used to adjust how SWAT meets evaporative demand from the soil and how deep in the soil plants are allowed to obtain water. For this model, the Penman-Montieth equation was chosen to estimate potential evapotranspiration. Snow parameters include the threshold temperature at which snow melts and whether precipitation occurs either as rain or snow. The adjusted snow parameters and the values used for all subbasins are shown in Table A-22.

Table A-22. Watershed Level Snow and Evapotranspiration Parameters used in the SWAT Model

Parameter Name	Parameter Description	Final Value used for Rockport	Final Value used for Echo
ESCO	Soil evaporation compensation factor	0.95	0.8
EPCO	Plant uptake compensation factor	1.0	1.0
SNOCOVMX	Areal snow coverage threshold (cov100)	500	100
SNO50COV	Areal snow coverage threshold (cov50)	0.7	0.1

Subbasins can be split into elevation bands, allowing SWAT to adjust some snow parameters based on elevation within a subbasin (Table A-23). Elevations bands are topographic intervals that cover a 350 m elevation range. The base of the lowest band equals the minimum elevation for a subbasin. Segments are added until the maximum elevation is reached. Because the final elevation band may not cover exactly 350 m, the maximum elevation of the subbasin becomes the upper bound.

SWAT uses the midpoint elevation for each elevation band and it is calculated as the average of the upper and lower elevation limit. The percent of the subbasin area within each elevation band is determined using the topographic report that SWAT generates after completing the initial subbasin delineation. Elevation bands were created in both Rockport Reservoir and Echo Reservoir Watersheds to account for these effects and better simulate the snow-melt dominant hydrology present in the Rockport Reservoir and Echo Reservoir Watersheds.

Snow parameters adjusted by elevation band for specific subbasins are shown in Table A-24. The precipitation lapse rate adjusts the amount of precipitation as elevation increases. The temperature lapse rate decreases temperature as elevation increases. The snowfall temperature is the point at which precipitation turns to snowfall. The maximum melt coefficient is the amount of snowmelt on June 21 while the minimum snowmelt coefficient is the amount of snowmelt that occurs on December 21. The snowpack temperature lag factor affects how the snow melts while the snowpack temperature melt threshold determines at what temperature melt begins.

Table A-23. Elevation Bands Used for the SWAT Model

Subbasin	Zone 1 Mid Elevation (m)	Zone 2 Mid Elevation (m)	Zone 3 Mid Elevation (m)	% of Subbasin Area in Zone 1	% of Subbasin Area in Zone 2	% of Subbasin Area in Zone 3
Rockport Reservoir Watershed						
1	2,015	2,365	2,698	76.1%	16.8%	7.1%
2	2,017	2,367	2,615.5	69.9%	28.5%	1.6%
3	2,051	2,325.5	0	83.2%	16.8%	0.0%
4	2,088	2,438	2,864	73.2%	17.3%	9.5%
5	2,097	2,348.5	0	93.8%	6.2%	0.0%
6	2,172	2,522	2,906	45.1%	43.3%	11.6%
7	2,321	2,671	3,085	33.8%	34.1%	32.1%
8	2,088	2,438	2,864.5	44.1%	41.3%	14.6%

Table A-23. Elevation Bands Used for the SWAT Model

Subbasin	Zone 1 Mid Elevation (m)	Zone 2 Mid Elevation (m)	Zone 3 Mid Elevation (m)	% of Subbasin Area in Zone 1	% of Subbasin Area in Zone 2	% of Subbasin Area in Zone 3
9	2,235	2,585	2,997.5	18.9%	39.6%	41.5%
10	2,235	2,585	2,809	70.2%	28.8%	0.9%
11	2,320	2,670	3,034	33.6%	35.1%	31.4%
12	2,526	2,876	3,149.5	20.2%	69.4%	10.4%
13	2,525	2,875	3,257.5	15.2%	48.4%	36.4%
14	2,333	2,683	3,021.5	45.2%	46.5%	8.3%
15	2,430	2,780	3,134	35.8%	44.5%	19.8%
16	2,537	2,887	3,259.5	23.5%	50.9%	25.6%
17	2,572	2,922	3,340	17.2%	34.8%	48.0%
18	2,583	2,933	3,310.5	16.4%	55.4%	28.2%
Echo Reservoir Watershed						
1	2,218	2,568	2,773.5	88.4%	11.4%	0.2%
2	2,040	2,390	2,684.5	57.0%	40.3%	2.8%
3	1,859	2,209	2,583	55.9%	41.8%	2.3%
4	2,040	2,390	2,622.5	67.4%	31.8%	0.7%
5	1,971	2,280	2,281	65.9%	34.1%	0.0%
6	1,868	2,215.5	2,216	75.9%	24.2%	0.0%
7	1,971	2,321	2,677	47.1%	39.9%	13.0%
8	2,220	2,570	3,030	21.3%	38.2%	40.5%
9	2,049	2,399	2,879.5	35.4%	48.6%	16.0%
10	1,868	2,218	2,610	71.1%	19.4%	9.5%
11	1,915	2,265	2,579	50.0%	44.6%	5.4%
12	1,951	2,301	2,652	46.7%	44.8%	8.6%
13	2,144.5	2,568	2,773.5	100.0%	0.0%	0.0%
14	2,150	2,332	2,332	100.0%	0.0%	0.0%
15	2,251	2,601	2,911	46.8%	47.0%	6.3%
16	2,066	2,416	2,864	47.8%	29.2%	23.0%
17	2,324	2,674	2,976.5	64.7%	29.3%	6.0%

Table A-24. Subbasin Specific Snow Parameter Values (unitless constants)

Subbasin	Precipitation lapse rate (PLAPS)	Temperature lapse rate (TLAPS)	Snowfall temperature (SFTMP)	Maximum melt coefficient (SMFMX)	Minimum melt coefficient (SMFMN)	Snowpack temperature lag factor (TIMP)	Snowpack temperature melt threshold (SMTMP)
Rockport 1-7 (Beaver Creek and Inflow subbasins)	300	-6.5	1	6.5	4	0.5	1
Rockport 8-18 (Mainstem Weber River)	300	-6.5	1	8/7/6[1]	4/3/2	0.5	1
Echo 7,8,9,16,17 (Upper Chalk Creek)	100	-6.5	1	8/7/6	4/3/2	0.5	0
Echo 1,2,4,5,6,16,17 (Lower Chalk Creek)	175	-6.5	1	8/7/6	4/3/2	0.5	0
Echo 3,10,11(Mainstem Weber River)	0.5	-6.5	1	4.5	4.5	1	1
Echo 12,13,14,15 (Silver Creek)	0	-6.5	1	5/4.5/4.5	5/4.5/4.5	0.1/0.5/0.5	1

[1]Numbers indicate the value used for elevation band1/elevation band2/elevation band 3. The same value is used for all three bands if only one value is listed.

A-3.2.12.1 GROUNDWATER PARAMETERS

In gaining streams, groundwater supports baseflow, which is the flow during the drier period of year with no inputs from snowmelt or precipitation. When the groundwater table is low, streams may become losing streams as water in the stream seeps back to the groundwater table through the stream bed. Other factors include the existing hydraulic conductivity, the ability of the stream bed to transmit water, and karst features such as sinkholes that may capture streamflow and direct it to the deep aquifers. In the SWAT model groundwater includes flow from soil water and shallow aquifers, and also the deep aquifer. These components consist of water entering the stream through lateral flow from the soil and additions from shallow groundwater.

SWAT groundwater parameters were adjusted by subbasin in the Echo Reservoir Watershed to calibrate hydrology for the Silver Creek and Chalk Creek drainages separately. The hydrologic responses in Chalk Creek and Silver Creek drainages are different because of different geologic and groundwater characteristics. Silver Creek was particularly problematic to calibrate because of sinkholes that appeared in 2008, which captured the flow in Silver Creek. The stream is also a losing stream in the upper reaches (Laughlin 2009). Such flow losses, combined with the lack of daily data for the Park City point sources, make calibrating Silver Creek to a monthly and daily time step difficult. To address these issues, the hydraulic conductivity in the upstream subbasins was set to 5 mm/hour. The Park City point sources were combined into a single point source in subbasin 15, and a proportion of flow was removed to address the water loss and nutrient load loss associated with the upper Silver Creek reach to better match flow recorded at the USGS gage. Rockport groundwater parameters are shown in Table A-25 while Echo Reservoir Watershed parameters used for monthly calibration are shown in Table A-26.

Table A-25. Groundwater Parameters Used in the Rockport Reservoir Watershed Model

Groundwater Parameter	Parameter Definition	Lower Weber River and Beaver Creek (subbasins 1-7)	Weber River (subbasins 8-18)
SHALLST (mm)	Initial depth of water in the shallow aquifer	1000	1000
DEEPST (mm)	Initial depth of water in the deep aquifer	9000	9000
GW_DELAY (days)	Groundwater delay	7.0	14.75
ALPHA_BF (days)	Baseflow alpha factor (a factor representing groundwater response to recharge)	0.1	0.0055
GWQMN (mm)	Threshold depth of water in the shallow aquifer required for return flow to occur	170.625	170.625
GW_REVAP (unitless)	Describes movement of water into the root zone from the shallow aquifer	0.1303	0.1303
REVAPMN (mm)	Threshold depth of water in the shallow aquifer for movement into the root zone or deep aquifer to occur	327.25	327.25
RCHRG_DP (unitless)	Deep aquifer percolation fraction	0.05	0.05
GWHT (m)	Groundwater height	1.00	1.00
LONG-TERM GROUNDWATER[1]	Describes the long-term groundwater contribution		

[1] The long-term groundwater parameter was added in the calibration phase and is not available in the ArcSWAT interface.

Table A-26. Groundwater Parameters Used in the Echo Reservoir Watershed Model

Groundwater Parameter	Parameter Definition	Value
SHALLST (mm)	Initial depth of water in the shallow aquifer	1000
DEEPST (mm)	Initial depth of water in the deep aquifer	9000
GW_DELAY (days)	Groundwater delay	31
ALPHA_BF (days)	Baseflow alpha factor (a factor representing groundwater response to recharge)	0.048
GWQMN (mm)	Threshold depth of water in the shallow aquifer required for return flow to occur	0
GW_REVAP(unitless)	Describes movement of water into the root zone from the shallow aquifer	0.02
REVAPMN (mm)	Threshold depth of water in the shallow aquifer for movement into the root zone or deep aquifer to occur	1.00

Table A-26. Groundwater Parameters Used in the Echo Reservoir Watershed Model

Groundwater Parameter	Parameter Definition	Value
RCHRG_DP (unitless)	Deep aquifer percolation fraction	0.050
GWHT (m)	Groundwater height	1.00
LONG-TERM GROUNDWATER[1]	Describes the long-term groundwater contribution	0.005[2]

A-3.2.13 Channel Characteristics

A-3.2.13.1 CHANNEL ROUTING PARAMETERS (RTE)

Adjustments to the channel routing are done primarily through channel dimensions: width to depth ratio and channel slope and are important in calibrating hydrology. SWAT generates initial estimates of the channel parameters using the ArcMap programs, the stream layer, and the DEM. These parameters were adjusted by subbasin in both the Rockport Reservoir and Echo Reservoir Watersheds. The adjustments primarily affect the time of concentration, which will affect timing and quantity of peak flows and helped improve model calibration, particularly for timing of peak flows and instream sediment dynamics. Tables A-27 and A-28 show the routing parameters used for Rockport Reservoir and Echo Reservoir Watershed models, respectively.

Table A-27. Routing Parameters Used in the Rockport Reservoir Watershed Model

Subbasin	Average Width of Main Channel at top of Bank (m)	Depth of Main Channel from Top of Bank to Bottom (m)	Average Slope of Main Channel along the Channel Length (m/m)	Manning's Roughness coefficient, n, for Main Channel	Channel Width to depth Ratio
1	74	1.93	0.001	0.014	38.23
2	69	1.84	0.012	0.014	37.37
3	66	1.79	0.005	0.014	36.84
4	32	1.10	0.010	0.014	28.84
5	10	0.50	0.006	0.014	19.37
6	23	0.88	0.016	0.014	25.85
7	17	0.72	0.028	0.014	23.38
8	51	1.51	0.010	0.014	33.78
9	13	0.62	0.038	0.014	21.69
10	44	1.36	0.014	0.014	32.07
11	21	0.83	0.017	0.014	25.04
12	9	0.46	0.046	0.014	18.69
13	11	0.54	0.046	0.014	20.22
14	32	1.11	0.016	0.014	29.04
15	30	1.06	0.011	0.014	28.36
16	25	0.93	0.043	0.014	26.55
17	19	0.79	0.016	0.014	24.44
18	13	0.61	0.039	0.014	21.57

Table A-28. Routing Parameters Used in the Echo Reservoir Watershed Model

Subbasin	Average Width of Main Channel at Top of Bank (m)	Depth of Main Channel from Top of Bank to Bottom (m)	Average Slope of Main Channel along the Channel Length (m/m)	Manning's Roughness Coefficient, n, for Main Channel	Channel Width to Depth Ratio
1	7.5	0.94	0.007	0.014	7.97
2	2	0.74	0.017	0.014	2.68
3	15	2.07	0.001	0.014	7.25
4	3	1.26	0.011	0.014	2.37
5	3.5	1.44	0.011	0.014	2.44
6	4	1.73	0.007	0.014	2.31
7	2	1.06	1.067	0.014	2.31
8	2	0.77	0.027	0.014	2.57
9	1.5	0.90	0.022	0.014	1.67
10	15	1.21	0.005	0.014	12.34
11	15	0.78	0.019	0.014	19.11
12	3	0.91	0.017	0.014	3.30
13	2	0.71	0.002	0.014	2.80
14	2	0.64	0.012	0.014	3.01
15	1.5	0.43	0.099	0.014	3.47
16	1.5	0.53	0.046	0.014	2.80
17	2	0.73	0.011	0.014	2.74

A-3.2.14 Channel Erodibility and Nutrients

SWAT allows users to specify parameters to describe channel erodibility, which is based on channel bed and bank materials. Included in these parameters are channel cover to describe the amount of vegetation on the stream bed and a monthly channel erosion factor that allows the user to increase erosion during certain months of the year. SWAT also contains four channel erosion equations to choose from based on channel and sediment types (Table A-29). SWAT also allows the user to specify organic nitrogen and organic phosphorus in the channel sediment (Table A-30). These parameters were adjusted in the Chalk Creek subbasins to account for human activities such as oil and gas development, past grazing practices, logging and farming, and development activities that have accentuated channel erosion in a drainage that is also naturally more erodible. Such adjustments make the SWAT output better match loads calculated from water quality monitoring samples. Channel erodibility factors in the Rockport Reservoir Watershed model were not increased from the default values, which are the minimal values allowed because the initial model simulations overestimated sediment and nutrients.

Table A-29. Channel Erodibility Factors Used in Echo Reservoir Watershed Model

Subbasin	Channel Erodibilty Factor (unitless)[1]	Equation used for Sediment Routing
1	0	1[2]
2	1	2[2]
3	0	1
4	0	1
5	0	1
6	0	1
7	1	2
8	0	1
9	1	2
10	0	1
11	0	1
12	0	1
13	0	1
14	0	1
15	0	1
16	1	2
17	0	1

[1] The CH_ERODMO was applied for all months.

[2] 1= Simplified Bagnold Equation, 2=Kodatie Model

Table A-30. Channel Nutrient Concentrations Used in Echo Reservoir Watershed Model

Subbasin	Organic Nitrogen Concentration in the Channel Sediments (ppm)	Organic Phosphorus Concentration in the Channel Sediments (ppm)
1	0	5.15
2	0	6.37
3	0	7.87
4	0	5.9
5	0	8.17
6	0	7.8
7	0	25
8	0	5.32
9	0	5
10	0	5.57
11	0	5.28
12	0	5.57

Table A-30. Channel Nutrient Concentrations Used in Echo Reservoir Watershed Model

Subbasin	Organic Nitrogen Concentration in the Channel Sediments (ppm)	Organic Phosphorus Concentration in the Channel Sediments (ppm)
13	0	5.02
14	0	5.55
15	0	6.09
16	0	5
17	0	5

A-3.3 Model Calibration and Validation

A-3.3.1 Hydrology

SWAT generates surface water hydrology using a DEM and weather data from weather stations in or near the watershed. The curve number approach was chosen to estimate runoff volume from the watershed, while a modified rational method was used to calculate a peak flow. The algorithms used in the SWAT model to generate hydrology are explained in detail in Neitsch et al. 2009. Measured USGS flow data and BOR data for inflow and outflow at the reservoirs are used to calibrate the model.

The USGS gages used to for calibration were the Weber near Coalville (10130500), Silver Creek at Silver Creek Junction (10129900), Chalk Creek near Coalville (10131000) and the Weber near Oakley (10128500). In addition, the BOR provided estimates of total inflow to Rockport Reservoir and Echo Reservoir, which were used for calibrating inflow to the reservoirs. These estimates are calculated from reservoir volume. Calibrating hydrology was completed in Rockport Reservoir and Echo Reservoir Watersheds separately because the watersheds were separate project areas for SWAT.

Rockport Reservoir had only two gages with a dataset that included 1998-2011. The Weber at Oakely gage was used to calibrate hydrology at subbasin 8 in the Rockport Reservoir Watershed while the inflow estimates from the BOR were used to calibrate flow into the reservoir. The Weber River at Oakely gage is located above the Weber-Provo diversion, but because the outflow from subbasin 8 is used for calibration, the flow diverted is returned to better match flow measured at the gage. The outflows from Rockport Reservoir are known and included in the Echo Reservoir Watershed as a point source.

In the Echo Reservoir Watershed, Silver Creek was calibrated at the Silver Creek gage, located in subbasin 13. The Weber mainstem above Chalk Creek was calibrated at the Weber River near Coalville gage in subbasin 10. Chalk Creek was calibrated at the Chalk Creek near Coalville gage in subbasin 6. The inflow to Echo Reservoir was calibrated at subbasin 3 using the BOR estimated inflow data (Figure A-14).

The calibration was done as a comparison of model output to measured discharges in the subbasin where the gage is located, measured as a percent. The monthly average values were used for calibration. The hydrology calibration was based on comparing the flow amounts measured to flow simulated in SWAT between the years 2002 and 2007. Model year 2007 was used for the calibration, with 2004 used as validation. The Nash-Sutcliffe efficiency (NSE) value was also calculated for the 2002-2007 (Table A-31). This value determines how well the model matched the existing data. According to Moriasi et al.

(2007), an NSE value of at least 0.5 indicates a satisfactory calibration. An efficiency value of 1 indicates a perfect match between observed and modeled values.

These watersheds are extremely complex. Weather and elevation are important in generating hydrologic responses. There is a substantial elevation difference in both watersheds, neither of which have a long-term weather station in the upper watershed. The weather stations that do exist are located in the lower elevation valley areas. Additionally, the groundwater contribution and baseflow were not wellcharacterized. As such, the model developer, Dr. Srinivasan, was approached to provide assistance. Dr. Srinivasan performed an initial calibration of hydrology for the SWAT models for Rockport Reservoir and Echo Reservoir to monthly averages using the SWAT-CUP program, and added a long-term groundwater component to the calibration parameters. This variable was not available in SWAT when the calibration was completed in 2012. Hydrology was calibrated primarily by adjusting the snow parameters and temperature and precipitation lapse rates as well as groundwater parameters.

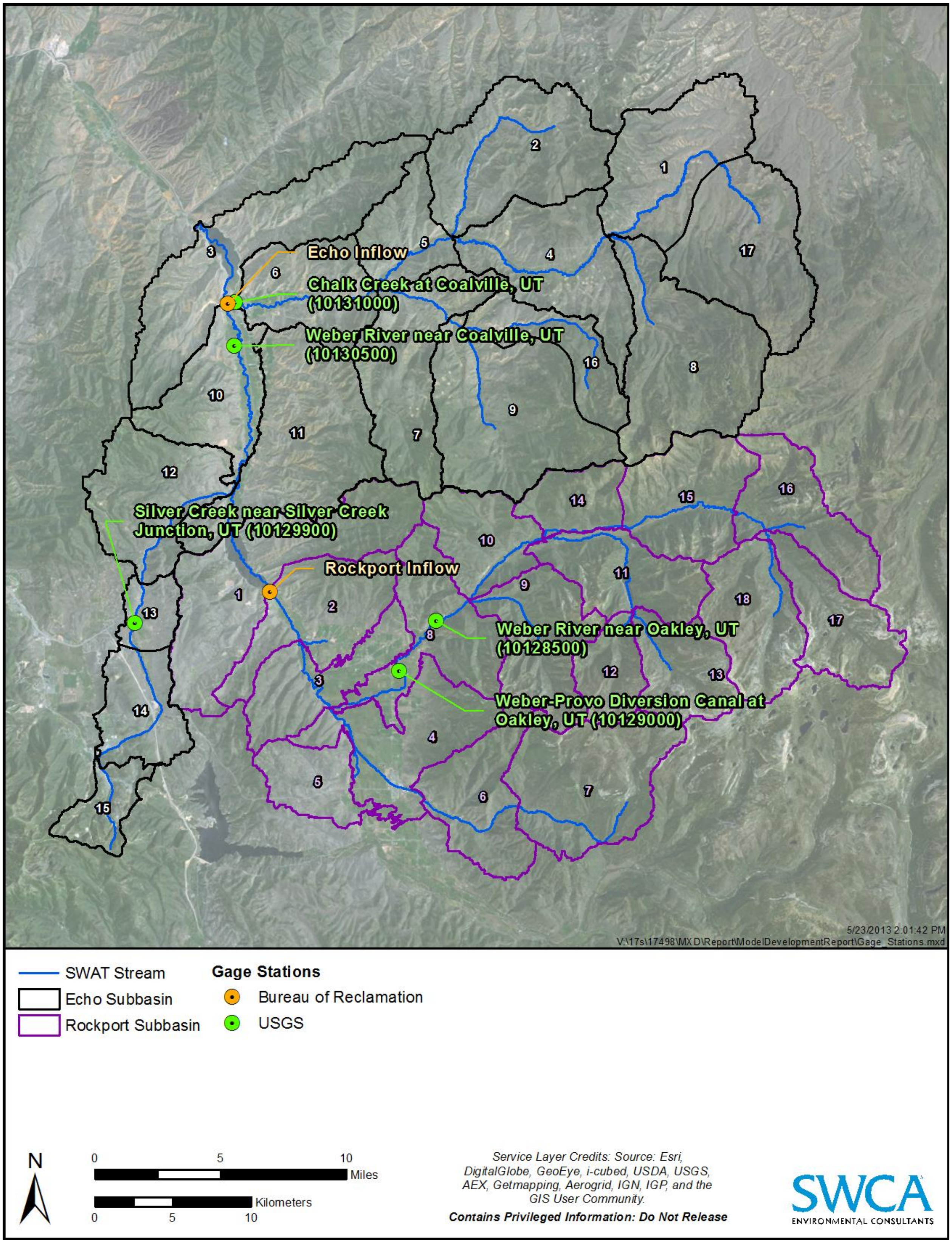

Figure A-14. Location of stream gages in the Rockport Reservoir and Echo Reservoir subbasins.

As noted earlier, the Silver Creek drainage has areas where the stream contributes to groundwater as a losing stream or sinkholes and underlying geology allow water to move into the deep aquifer. The calibrations show that the Silver Creek (subbasin 13) simulated nutrient loads are higher than the observed values. However, the flows are small enough that small increases in nutrients can translate into large proportional increases. The calibration is strong in Echo Reservoir subbasins 3 and 10 because the outflow from Rockport Reservoir is measured and is a large proportion of the total flow in the Weber mainstem in between the reservoirs. In addition, the BOR back-calculates the inflow from volume estimated using bathymetry. The bathymetry may change with sediment deposition occurring over the years, reducing the accuracy of inflow measurements. The minimum value for a satisfactory calibration was achieved for subbasin 1 (the inflow) to Rockport Reservoir and all subbasins used for calibration in the Echo Reservoir Watershed. The results of the calibration statistics are shown in Table A-31.

Table A-31. Hydrologic Calibration Results for Rockport and Echo Reservoir Watershed Models

SWAT Generated Output From Subbasin	Measured Flow	Percent of Measured Flow 2002-2007	Percent of Measured Flow 2007	Nash-Sutcliffe Efficiency value (2002-2007)	Performance Rating for the Nash-Sutcliffe Efficiency Value[1]
Rockport 8	USGS Weber at Oakley	96%	113%	0.87	Very good
Rockport 1	BOR calculated inflow	93%	94%	0.75	Very good
Echo 3	BOR calculated inflow	97%	105%	0.77	Very good
Echo 6	USGS Chalk Creek at Coalville	107%	127%	0.63	Satisfactory
Echo 10	USGS Weber River at Oakley	90%	96%	0.85	Very good
Echo 13	USGS Silver Creek at Silver Creek Junction	141%	158%	0.52	Satisfactory

[1]The Nash-Sutfliffe efficiency values are from Moriasi et al. 2007.

A-3.3.2 Nutrients

Calibration for nutrient loads was completed for nitrate and total phosphorus. Calibration was not done for total nitrogen because the water quality monitoring dataset is much stronger for nitrate. SWAT output was used to estimate the loads entering the reservoir from each of the tributaries. For the Rockport Reservoir Watershed, nutrient loads were calibrated at the inflow. The SWAT simulated loads were compared to measured loads at locations where data were available. For the Echo Reservoir Watershed, nutrient loads were calculated for Chalk Creek at the Coalville/Chalk Creek USGS gage (and combined with loads from the Coalville WWTP), the Weber River at the Coalville/Weber River USGS gage, and Echo Reservoir inflow using BOR estimated flow data into the reservoir. The simulated loads were then compared to calculated loads from water quality data at each location (Table A-32). Calibration was done by adjusting the nutrient-related and erosion-related parameters noted in previous sections. The primary adjustments were to initial soil nutrient concentrations, channel erodiblity factors, and urban connectivity to streams. These calibration efforts are reflected in the final tables discussed in section 2.2.

Table A-32. Nutrient Calibration Results for Echo Reservoir Watershed SWAT Model, Spring 2007 (April 1–July 15)

SWAT Subbasin	Total Phosphorus Load based on Measured data (kg)	Total Phosphorus Load based on SWAT Output (kg)	Total Nitrate Load based on Measured data (kg)	Total Nitrate Load based on SWAT Output (kg)
Rockport 2 (Weber River)	1,790	1,889	11,924	9,775
Echo 6 (Chalk Creek)	1,056	1,070	8,702	8,044
Echo 10 (Weber River at Coalville)	864	1,775	6,693	8,725
Echo 3 (Total Echo Reservoir Watershed)	2,000	2,865	16,006	16,858

[1]Water quality data used to calculate this load does not appear to be representative of spring flow conditions.

A-4. RESERVOIR MODEL: BATHTUB

A-4.1 General Model Description

The BATHTUB reservoir model was developed by the U.S. Army Corps of Engineers as a sophisticated empirical model for predicting eutrophication in reservoirs. The model predicts nutrient concentrations, chlorophyll a, Secchi depth (water column transparency), and other eutrophication indices in a spatially segmented reservoir under steady-state conditions (Walker 1999).

Model inputs include reservoir morphometry (mean depth, length, width, and mixed-layer depth), hydraulic connectivity (between reservoir segments and tributaries), tributary water quality (total nutrients, dissolved nutrients, and flow), climatic parameters (precipitation and evapotranspiration), and atmospheric deposition of nutrients. The model uses empirical equations for physical processes, including advective transport, diffuse transport, and nutrient sedimentation to predict nutrient concentrations and reservoir water quality.

A-4.2 Model Inputs and Assumptions for Rockport Reservoir and Echo Reservoir

The BATHTUB model was set up for five climatic conditions and subsequent reservoir conditions, which represent expected variability in both climate and management. These conditions represent a dry year, an average year, and one wet year with similar water level conditions at both Rockport Reservoir and Echo Reservoir.

- **Condition A**: A dry water year; note that although 2004 was a dry year for most of the Weber River basin, the flows above Rockport Reservoir are higher than in 2007.
- **Condition B**: An average water year (2007)
- **Condition C**: A wet water year (2011)

The BATHTUB model inputs are climate variables, definition of the stratification season, reservoir and segment shape, internal nutrient loading, and water quality parameters for tributaries. Each set of inputs (above) had specific sources and required individual assumptions which are discussed below. The model was run for the stratification season. The period during the summer season when the reservoir is stratified is the most critical for DO concerns because the thermal stratification prevents oxygen from being introduced into the lower parts of the reservoir (hypolimnion) through mixing. Algal growth also occurs during the summer season, the decomposition of which leads to low DO in the hypolimnion. Calibration of the BATHTUB model requires estimates of reservoir water quality parameters, which are discussed below.

A-4.2.1 Stratification Season

It was assumed that the reservoirs are thermally stratified from May 15 to September 30. These dates were selected based on evaluation of all of temperature and DO profile data available for the reservoirs and result in a 137-day stratification season. Dissolved oxygen and temperature profile data from the years 2004, 2007, and 2011 were used to further validate the use of this stratification season assumption for all of the conditions modeled (see Figure 11 in the Data Summary Report).

These dates were used to determine reservoir elevation at the beginning and ending of stratification using data available from the BOR (2011). Elevation at both reservoirs is significantly lower at the end of the season for 2004 and 2007, though the change in elevation is greater at Echo Reservoir because it only stores a one-year supply of water whereas Rockport Reservoir stores a two-year supply. In 2007, the water level in Rockport Reservoir began at 1,839.4 meters and ended at 1,829.6 meters (Figure A-15). 2011 was a wet year, and end-of-season elevation was slightly higher than at the beginning for Echo Reservoir and significantly higher for Rockport Reservoir.

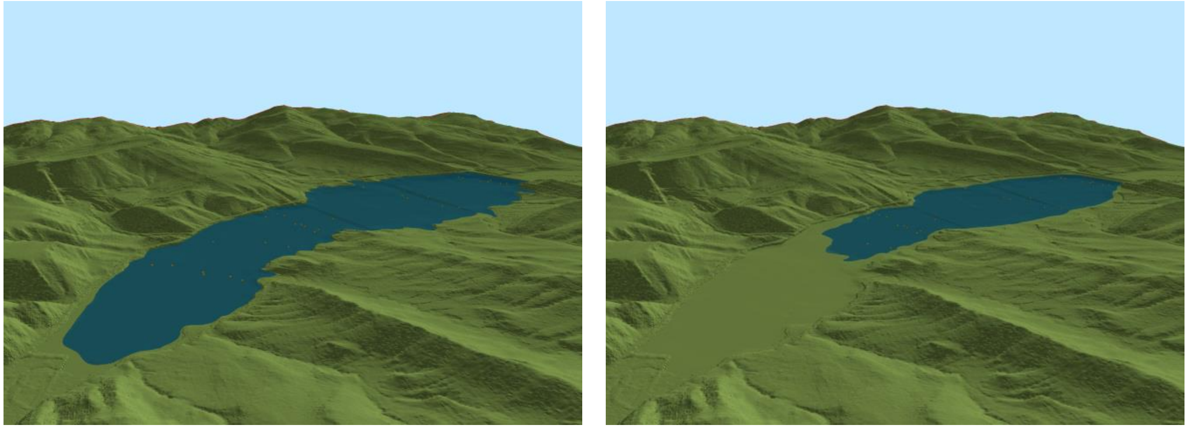

Figure A-15. Rockport Reservoir water level on May 15, 2007 (1,839.4 meters), and September 30, 2007.

A-4.2.2 Reservoir Shape and Segmentation

Rockport Reservoir and Echo Reservoir were each divided into a Mid-Upper Pool segment and a Dam segment (Figures A-16 and A-17). Chalk Creek and Weber River are tributaries to the Echo Reservoir Mid-Upper Pool segment; Weber River is the only tributary to the Mid-Upper Pool for Rockport Reservoir. Tributary inputs for each of the Dam segments are based on direct discharge into the reservoirs. Reservoir shape includes seasonal starting and ending elevations; average length, width, and depth; surface area; depth at stratification of mixed layer and hypolimnion; and volume (Table A-33 and Table A-34). An updated (2007) bathymetry dataset was available for Rockport Reservoir but no bathymetry data were available for Echo Reservoir. Depth measurements collected throughout Echo Reservoir in summer 2007 by the Weber Basin Water Conservancy District were used, together with contour data available at the surface of the reservoir, to generate a simplistic bathymetry dataset for purposes of estimating reservoir shape at varying elevations. Spatial analysis tools in ArcGIS, including volumetric estimation, were used to calculate all reservoir dimensions except hypolimnetic depth. Hypolimnetic depth was determined through examination of depth profiles of temperature and DO collected during each year at various times during the stratification season (see Figure 11 in the Data Summary Report). From these data the percent of the total depth that is represented by the hypolimnion and metalimnion was determined for both the Mid-Upper Pool and Dam segments.

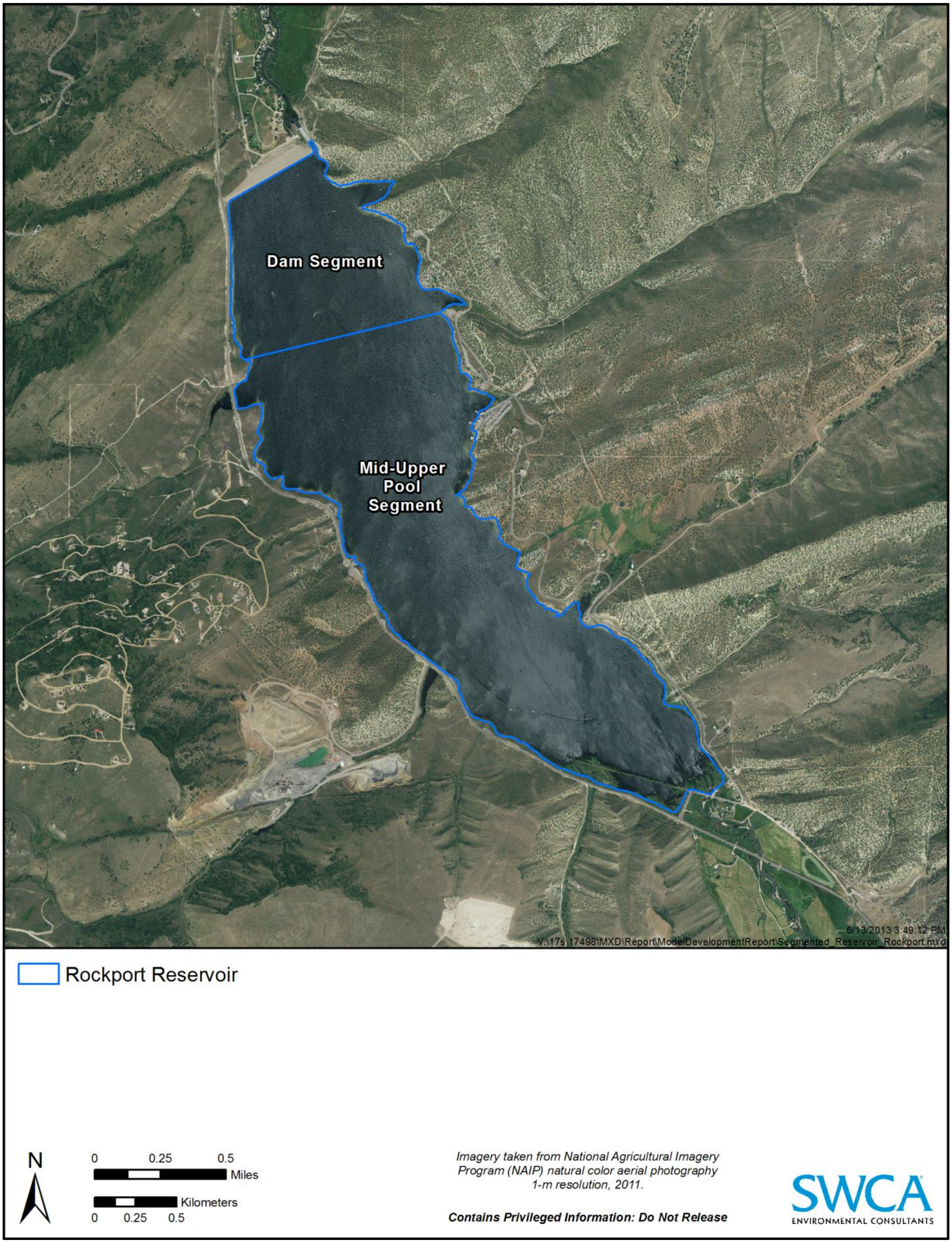

Figure A-16. Rockport Reservoir model segments.

Figure A-17. Echo Reservoir model segments.

Table A-33. Summary of Reservoir Characteristics for Rockport Reservoir BATHTUB Model

	2004	2007	2011
Dam Segment			
Starting elevation on May 15 (m)	1,835.0	1,839.4	1,827.8
Ending elevation on September 30 (m)	1,833.2	1,829.6	1,838.1
Starting length (km)	1.05	1.06	1.02
Starting width (km)	0.94	1.03	0.86
Starting depth (m)	22.18	24.23	17.27
Starting surface area (km^2)	0.99	1.09	0.89
Depth of Mixed layer at stratification (m)	8.00	1.46	1.00
Hypolimnetic depth at stratification (m)	12.18	12.03	9.27
Volume (hm^3)	21.96	26.52	15.30
Mid-Upper Pool Segment			
Starting elevation on May 15 (m)	1,835.0	1,839.4	1,827.8
Ending elevation on September 30 (m)	1,833.2	1,829.6	1,838.1
Starting length (km)	2.85	3.61	1.87
Starting width (km)	0.83	0.88	0.82
Starting depth (m)	11.58	12.46	8.86
Starting surface area (km^2)	2.36	3.18	1.53
Depth of mixed layer at stratification (m)	8.00	1.90	1.00
Hypolimnetic depth at stratification (m)	1.58	3.35	0.86
Volume (hm^3)	27.37	39.62	13.55

Table A-34. Summary of Reservoir Characteristics for Echo Reservoir BATHTUB Model

	2004	2007	2011
Dam Segment			
Starting elevation on May 15 (m)	1,691.3	1,694.3	1,686.0
Ending elevation on September 30 (m)	1,679.3	1,677.5	1,686.7
Average length (km)	1.25	1.26	1.23
Average width (km)	0.68	0.70	0.65
Average depth (m)	18.89	21.19	14.77
Surface area (km^2)	0.85	0.88	0.80
Depth of mixed layer at stratification (m)	4.00	4.57	1.00
Hypolimnetic depth at stratification (m)	8.89	11.99	9.77
Volume (hm^3)	16.14	18.70	11.79

Table A-34. Summary of Reservoir Characteristics for Echo Reservoir BATHTUB Model

	2004	2007	2011
Mid-Upper Pool Segment			
Starting elevation on May 15 (m)	1,691.3	1,694.3	1,686.0
Ending elevation on September 30 (m)	1,679.3	1,677.5	1,686.7
Average length (km)	4.20	5.15	3.47
Average width (km)	1.00	0.95	0.96
Average depth (m)	11.29	12.50	8.16
Surface area (km^2)	4.22	4.87	3.34
Depth of mixed layer at stratification (m)	4.00	3.84	1.00
Hypolimnetic depth at stratification (m)	1.29	3.30	3.16
Volume (hm^3)	47.59	60.88	27.30

A-4.2.3 Atmospheric and Climate Parameters

Atmospheric and climate parameter inputs to BATHTUB are precipitation, evaporation, and nutrient deposition (Table A-35). Precipitation data were downloaded from the Utah State University Climate Center: specifically, sites USC00429165 and USC00422385 for Rockport Reservoir and Echo Reservoir, respectively (USUCC 2011). Monthly values are the sum of precipitation for all days per month for each of the three conditions. Evaporation data were downloaded from the Western Regional Climate Center (WRCC 2011). Values represent monthly averages for Wanship Dam for the entire period of record from 1955 to 2005; thus, values are the same for each of the five conditions.

Atmospheric deposition of nitrogen data were taken from the National Atmospheric Deposition Program website (NADP 2011). Values were estimated from the NADP atmospheric deposition map by year. Phosphorus deposition values were not available from NADP; these were obtained from California Department of Environmental Protection (CDEP 2011), who reported an annual phosphorus deposition rate of 0.05 kg/ha/yr from a study at Lake Tahoe, California. All phosphorus values went into this pool and no values were put into the orthophosphate (ortho-P) category. All annual values for nitrogen and phosphorus deposition were divided by 12 to derive monthly rates, which assumes deposition rates are not seasonally variable.

Table A-35. Summary of Atmospheric and Climate Variables Used in BATHTUB Models

	2004	2007	2011
Rockport			
Precipitation (m)	0.15	0.02	0.14
Evaporation (m)[1]	0.73	0.73	0.73
Total phosphorus deposition (mg/m^2-yr)	1.89	1.89	1.89
Total n deposition (mg/m^2-yr)	93.74	74.97	74.97
Echo Reservoir			

Table A-35. Summary of Atmospheric and Climate Variables Used in BATHTUB Models

	2004	2007	2011
Precipitation (m)	0.12	0.12	0.12
Evaporation (m)	0.73	0.73	0.73
Total phosphorus deposition (mg/m^2-yr)	1.89	1.89	1.89
Total nitrogen deposition (mg/m^2-yr)	74.97	74.97	74.97

[1] Evaporation rates are measured in units of meters for the season. They are applied to the average area of the reservoir during that season to estimate total evaporative volume lost.

A-4.2.4 Tributary Water Quality

Tributary inputs for BATHTUB are flow, total and inorganic nitrogen, total phosphorus, orthophosphate, and chloride. Water quality parameters were summarized for each year (2004, 2007, and 2011) based on three seasons: early spring (April 1–May 15), late spring (May 16–July 15), and summer (July 15–September 30). Additionally, The BATHTUB model uses the mean coefficient of variation (CV) as a measure of error. The CV is calculated as the standard error divided by the mean result value. Where possible (sample size > than 1) the CV was calculated and used in model calibration.

The primary tributary input for Rockport Reservoir is the Weber River. In addition, direct runoff from the area surrounding the reservoir was input as a separate source. Measured water quality and flow for each of the three seasons (early spring, late spring, and summer) were used as direct inputs to the Rockport Reservoir BATHTUB models Table 56). These loads may be updated once nutrients are calibrated for the SWAT model output from the Rockport Reservoir Watershed. SWAT output will also be used in the source identification portion of the TMDL to assess the relative load contribution of various nonpoint sources to the reservoir.

Tributary inputs to Echo Reservoir are the Weber River, Chalk Creek, and the direct runoff from the area surrounding the reservoir. Modeled (SWAT) loads for tributaries to Echo Reservoir for the dry (2004) and average (2007) conditions were used as inputs to the BATHTUB models (Table A-36). Loads were converted to concentrations using measured flow because the gage data for both tributaries is very good. The modeled loads were found to be more accurate than loads calculated with measured water quality data because the measured data does not incorporate the loads from storm events, an important load during the dry and average flow conditions. Further, there are multiple known loads to the Echo Reservoir Watershed including Silver Creek WWTP, Coalville WWTP, and the output from Rockport Reservoir that could not be accounted for in calculated loads. The SWAT model was used to route these loads to the reservoir to determine the amount of nutrients lost between the source and the reservoir (e.g. delivery ratio). The SWAT model was not calibrated for the high flow event of 2011. Instead, tributary water quality and flow data were used directly as inputs for the 2011 Echo Reservoir BATHTUB model (Table A-37).

Table A-36. Tributary Inputs (Weber River and Direct Drainage) to Rockport Reservoir BATHTUB Model

	2004	2007	2011
Weber River			
Flow (hm^3/season)	52.1	45.6	262.2

Table A-36. Tributary Inputs (Weber River and Direct Drainage) to Rockport Reservoir BATHTUB Model

	2004	2007	2011
Total Phosphrous (µg/L)	57	45	97
Orthophosphate (µg/L)	21	13	8
Total Nitrogen (µg/L)	339	343	253
Inorganic Nitrogen (µg/L)	242	272	141
Direct Drainage			
Flow (hm^3/season)	6.3	5.5	31.6
Total Phosphrous (µg/L)	40	56	400
Orthophosphate (µg/L)	4	6	14
Total Nitrogen (µg/L)	642	370	732
Inorganic Nitrogen (µg/L)	583	289	189

Table A-37. Tributary Inputs to Echo Reservoir BATHTUB model

	2004	2007	2011
Weber River			
Flow (hm^3/season)	62.6	73.0	324.3
Total Phosphrous (µg/L)	74	53	44
Orthophosphate (µg/L)	37	41	34
Total Nitrogen (µg/L)	575	419	393
Inorganic Nitrogen (µg/L)	287	222	133
Chalk Creek			
Flow (hm^3/season)	19.8	31.1	160.3
Total Phosphrous (µg/L)	24	44	54
Orthophosphate (µg/L)	9	8	16
Total Nitrogen (µg/L)	215	377	276
Inorganic Nitrogen (µg/L)	196	346	119
Direct Drainage			
Flow (hm^3/season)	3.0	4.8	25
Total Phosphrous (µg/L)	41	39	44
Orthophosphate (µg/L)	41	27	34
Total Nitrogen (µg/L)	62	85	342
Inorganic Nitrogen (µg/L)	62	51	117

A-4.2.5 Reservoir Water Quality

BATHTUB was populated with water quality data for each reservoir segment and condition using available data for purposes of model calibration (Table A-38). Individual parameter values represent summer season averages using only values from samples taken at the surface. Surface samples were used because they were more readily available compared to stratified reservoir samples and because surface nutrients contribute more to algal growth. Each reservoir was divided into two segments representing inflow and near dam conditions. Reservoir water quality data used for model calibration include total nitrogen and total phosphorus, organic nitrogen, orthophosphate, chlorophyll a, Secchi depth, hypolimnetic and metalimnetic depth (discussed below), and chloride. Note that values for all inputs were not equally available for both reservoirs and segments.

Table A-38. Reservoir Surface Water Quality (Dam Segment)

	2004	2007	2011
Rockport Reservoir			
Total Phosphorus (µg/L)	37.0	16.8	36.0
Orthophosphate (µg/L)	32.1	16.3	27.6
Total Nitrogen (µg/L)	369	382	348
Chlorophyll-a (µg/L)	2.2		2.1
Organic Nitrogen (µg/L)	481.2	238.2	251.0
Echo Reservoir			
Total Phosphorus (µg/L)	18.4	18.3	35.9
Orthophosphate(µg/L)	13.5	13.0	34.5
Total Nitrogen (µg/L)	657.1	413.5	714.9
Chlorophyll-a (µg/L)	1.6	3.5	4.3
Organic Nitrogen (µg/L)	526.5	319.4	572.8

A-4.2.6 Oxygen Depletion Rates

The rate of oxygen depletion during stratification in each reservoir for the three modeled conditions (dry, wet, and average) was calculated using DO profile data available for the dam segment of each reservoir. Due to the change in reservoir volume over the course of the stratification season, it was not possible to differentiate metalimnetic oxygen depletion (MOD) rates from hypolimnetic oxygen depletion rates. Rather, a combined oxygen depletion rate below the thermocline (metalimnion and hypolimnion) was calculated.

Water from beneath the thermocline is released from both reservoirs when the reservoirs are thermally stratified. Through this process some nutrients and oxygen are also released from the reservoirs. Net oxygen losses via water withdrawals from the hypolimnion were calculated using the hypolimnetic volume lost and the average DO concentration in the hypolimnion during the withdrawal period (Tables A-39 and A-40). The volume of the hypolimnion at each profile date was used to calculate the volume lost. The remaining change in hypolimnetic oxygen mass then represents oxygen depletion over the course of the stratification season. Oxygen depletion rates are calculated by dividing the net oxygen loss by the number of days between the two profiles. Whenever possible, profiles earlier in the stratification season. During the early part of the stratification season, the depletion of oxygen is limited by oxygen demand in the hypolimnion. Later in the stratification season, when oxygen levels are already low, oxygen depletion can be limited by the availaibty of oxygen itself. As a result, the oxygen depletion rates are lower even if oxygen demand remains high. Therefore, oxygen depletion rates calculated using profile data earlier in the season are more representative of the true oxygen demand that is linked to algal growth and nutrients in the upper water column.

Table A-39. Hypolimnetic Oxygen Depletion Calculations for Rockport Reservoir BATHTUB Model Calibration

	2004	2007	2011
Dam Segment			
Profile dates	**June 14/August 10**	**June 27/July 10**	**June 20/August 25**
Depth of thermocline at second profile (m)	10	4.7	8
Change in reservoir level between profiles (m)	-3.1	-6.25	+ 1.5
Change in hypolimnetic volume between profiles (1,000 m^3)	-3,612	-1,235	+ 9,161
Total oxygen mass at first profile (kg)	86,104	121,843	128,856
Oxygen lost or gained via water withdrawals or fill (kg)	-7,189	-44,596	+30,386
Total oxygen mass at second profile (kg)	18,793	101,242	83,304
Oxygen depletion rate (mg/m^3/day)	59.2	50.3	64.4

Table A-40. Hypolimnetic Oxygen Depletion Calculations for Echo Reservoir BATHTUB Model Input

	2004	2007	2011
Dam Segment			
Profile dates	**June 15/August 11**	**May 22/July 10**	**June 8/July 13**
Depth of thermocline at second profile (m)	7	5	3
Change in reservoir level between profiles (m)	-4	-4.6	+3
Change in reservoir volume between profiles (1,000 m^3)	-6,071	-5,288	+2,387
Total oxygen mass at stratification (kg)	64,437	110,036	135,435
Oxygen lost or gained via water withdrawals or fill (kg)	-6,800	-21,876	+15,233
Total oxygen mass at turnover	19,011	54,508	34,219
Oxygen depletion rate (mg/m^3/day)	53.8	49.5	58.0

A-4.3 Model Calibration

Model calibration is an important step in the modeling process. Separate BATHTUB models were developed and calibrated for each of the climate conditions (wet, average, and dry) for Rockport

Reservoir and Echo Reservoir. BATHUB offers users a choice of several sub-models or sets of equations to simulate nutrients and chlorophyll a. Whenever possible, calibration was achieved by selecting the empirical sub-model for nutrients and chlorophyll a that best fit the data, recognizing that reservoir dynamics are largely driven by climatic conditions and management. Therefore, different combinations of empirical sub-models better represent the conditions of each reservoir during a dry, wet, and average year. The sub-models summarized in Table A-41 were found to best fit the dry, average, and wet conditions for Rockport Reservoir and Echo Reservoir. Once the best empirical sub-model was found, additional calibration to nutrient decay rates and oxygen depletion rates were made as needed. Nutrient decay rates were calibrated first and oxygen depletion rates were only calibrated if discrepancies remained between the measured oxygen depletion rates in the reservoir and the model predicted rates (Table A-42).

Table A-41. Empirical Sub-Models Selected for Reservoir BATHTUB Model of Rockport or Echo Reservoir

Parameter	Model Selected	Justification
Conservative substance	Not computed	Default and insufficient data
Total phosphorus	Second order, available total phosphorus (Echo 2004, 2007, 2011; Rockport Reservoir 2007 and 2011) First order (Rockport Reservoir 2004)	Default
Total nitrogen	Second order, available total nitrogen (Echo 2004, 2011; Rockport Reservoir 2011) First order (Rockport Reservoir 2004, 2007; Echo Reservoir 2007)	Reservoirs are co-limited
Chlorophyll *a*	P, N, Light, and Temperature	Reservoirs are co-limited.
Transparency	Chlorophyll-a and turbidity	Default
Longitudinal dispersion	Fischer-numeric	Default

Table A-42. Nutrient Decay Rates Calibration Coefficients used for BATHTUB Model of Reservoir

Parameter	Rockport Reservoir	Echo Reservoir
Total Phosphorus	 2011: 3.1	2004: 2.7 2011: 4
Total Nitrogen	2011: 23.9	2004: 0.8

Reservoir water quality data are not used directly in the BATHTUB model but are used to validate the model assumptions and tributary input loads used to configure the reservoir model, as shown in Figure A-18.

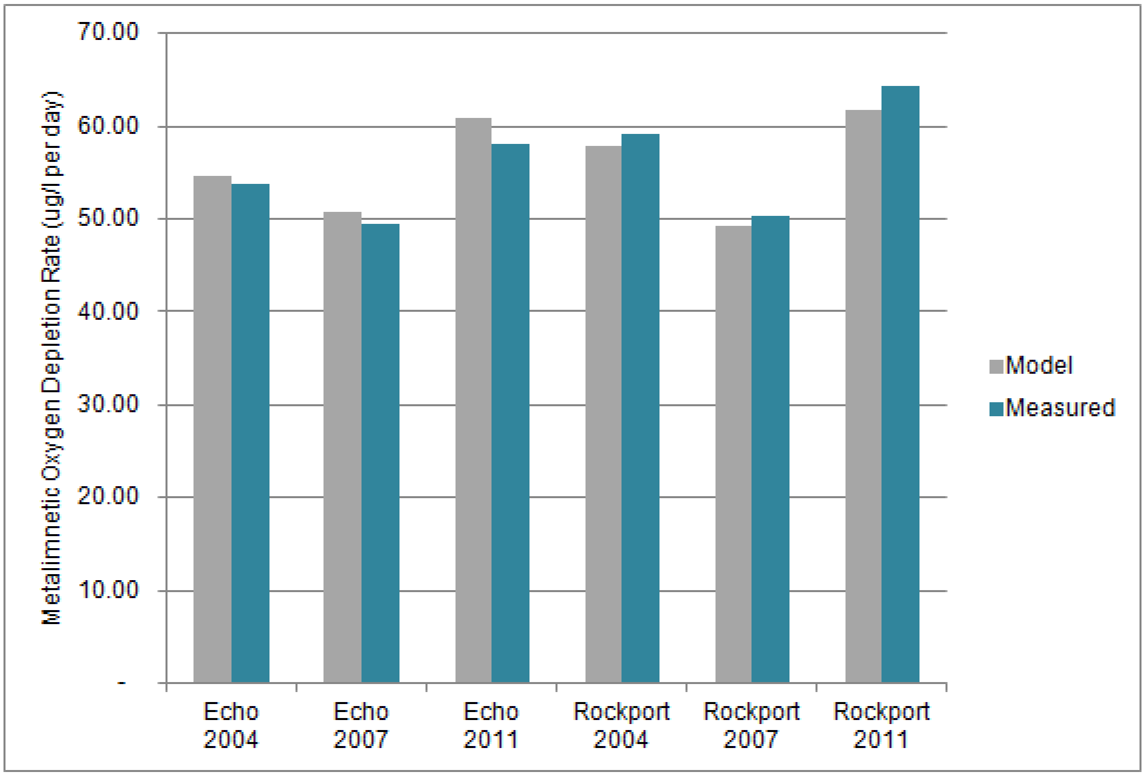

Figure A-18. Model validation of MOD rates for dam segment during stratification.

A-5. MODEL RESULTS

A-5.1 Current Nutrient Loads

The calculated total phosphorus and total nitrate loads to Rockport Reservoir under the average climatic and reservoir management conditions range from 2,337 to 3,230 kg/season and 13,969 to 16,279 kg/season respectively. The loads during the wet condition, represented by 2011, are significantly higher than the average condition (Tables A-43 and A-44). Rockport Reservoir received nearly four times the flow in 2011 as it did in 2004 and 2007. There are no representative 'dry' condition years for Rockport Reservoir and the flows into Rockport Reservoir in 2004, the dry year for Echo Reservoir, are higher than the flows in 2007, the average condition for Echo Reservoir. The total load is split relatively evenly between spring and summer.

Table A-43. Summary of Calculated Current Total Phosphorus Loads to Rockport Reservoir during the Spring (April 1 – July 15) and Summer Seasons (July 16 – September 30)

	Average (2004)	Average (2007)	Wet (2011)
Spring Loads			
Weber River	2,285	1,358	11,378
Direct Drainage	227	114	1,370
Total Watershed	2,512	1,471	12,748

Table A-43. Summary of Calculated Current Total Phosphorus Loads to Rockport Reservoir during the Spring (April 1 – July 15) and Summer Seasons (July 16 – September 30)

	Average (2004)	Average (2007)	Wet (2011)
Summer Loads			
Weber River	691	673	2,180
Direct Drainage	27	193	262
Total Watershed	717	866	2,442
Total Loads			
Weber River	2,976	2,031	13,558
Direct Drainage	254	306	1,632
Total Watershed	**3,230**	**2,337**	**15,190**

Table A-44. Summary of Current Total Nitrate Loads to Rockport Reservoir during the Spring (April 1 – July 15) and Summer Seasons (July 16 – September 30)

	Average (2004)	Average (2007)	Wet (2011)
Spring Loads			
Weber River	9,164	10,218	65,865
Direct Drainage	3,062	1,541	7,931
Total Watershed	12,226	11,759	73,796
Summer Loads			
Weber River	3,459	2,163	12,419
Direct Drainage	595	47	1,495
Total Watershed	4,054	2,210	13,914
Total Loads			
Weber River	12,623	12,381	78,284
Direct Drainage	3,657	1,588	9,426
Total Watershed	**16,279**	**13,969**	**87,710**

The average total phosphorus and total nitrate loads for Echo Reservoir under the average climatic and reservoir management conditions are 5,387 kg/season and 27,228 kg/season respectively. The loads during the dry condition, represented by 2004, are slightly lower and the loads during the wet condition, represented by 2011, are two to four times higher than the average condition (Tables A-45 and A-46). The total load is split relatively evenly between spring and summer; however, the source of loads during these two seasons is significantly different. The majority of the Chalk Creek load occurs during the spring, whereas the majority of the Weber River load occurs during the summer. This reflects the snow-melt dominated hydrology characterizing the Chalk Creek watershed in the spring and the release of water from Rockport Reservoir into the Weber River, primarily during the summer season. While there is significant flow into Rockport Reservoir during the spring period, this flow is primarily being retained in Rockport Reservoir for release later in the summer season.

Total loads are calculated as the sum of the spring (April 1-July 15) and summer (July 16- September 30) seasonal loads.

The seasonal loads are important because spring runoff and summer storm events tend to generate the majority of sediment and nutrients from these watersheds. Nutrient loads from the watershed are minimal during the winter, which is not a critical period for algal growth or oxygen depletion in the reservoirs.

Partitioning the load estimates into spring and summer seasons also highlights how loads change between the seasons. Over 50% of the total phosphorus load enters the reservoir during the spring, while just under 40% is delivered during the summer. The seasonal differences are also apparent in individual tributaries. As noted earlier, Chalk Creek contributes more of its total nutrient load during the spring, while summer releases from Rockport Reservoir increase the load from the Weber River during the summer. Chalk Creek delivers 30% of the total phosphorus entering Echo Reservoir in the spring and only 10% in the summer.

Table A-45. Summary of Current Total Phosphorus Loads to Echo Reservoir during the spring and summer seasons (April 1 – September 30)

	Dry (2004)	Average (2007)	Wet (2011)
Spring Loads			
Chalk Creek	345	1,070	8,130
Weber River	3,168	1,775	10,858
Direct Drainage	16	20	967
Total Watershed	3,529	2,865	19,955
Summer Loads			
Chalk Creek	134	285	750
Weber River	1,452	2,070	3,348
Direct Drainage	17	165	126
Total Watershed	1,603	2,521	4,223
Total Loads			
Chalk Creek	480	1,355	8,880
Weber River	4,620	3,845	14,206
Direct Drainage	33	186	1,093
Total Watershed	5,133	5,387	24,179

Table A-46. Summary of Current Total Nitrate Loads to Echo Reservoir during the spring and summer season (April 1 – September 30)

	Dry (2004)	Average (2007)	Wet (2011)
Spring Loads			
Chalk Creek	2,277	8,066	9,898
Weber River	10,186	8,728	25,584
Direct Drainage	138	90	2,278
Total Watershed	12,601	16,885	37,760
Summer Loads			
Chalk Creek	1,594	2,678	9,205
Weber River	7,806	7,512	17,449
Direct Drainage	51	153	655
Total Watershed	9,450	10,343	27,309
Total Loads			
Chalk Creek	3,871	10,745	19,103
Weber River	17,992	16,240	43,033
Direct Drainage	188	243	2,933
Total Watershed	**22,051**	**27,228**	**65,069**

The total loads are significantly lower than other estimated loads to Echo Reservoir presented in past studies (DWQ 2004). This difference relates to a significant reduction in phosphorus concentrations in both Chalk Creek and the Weber River since 2000. Figure A-19 shows the average concentrations of phosphorus in both tributaries in the late 1990s (the values used in previous load calculations) compared to all of the available data since 2001. After 2001, there are only a handful of data points that are above the historic average concentrations. Significant work on reducing nonpoint sources in the watershed, especially Chalk Creek, could explain the reduced nutrient concentrations. Other potential explanations could be changes in monitoring protocol such as inclusion or exclusion of storm events or changes in methods. Such potential explanations are beyond the scope of this project to explore. It was assumed that the current water quality data are representative of spring runoff and summer baseflow conditions in both tributaries.

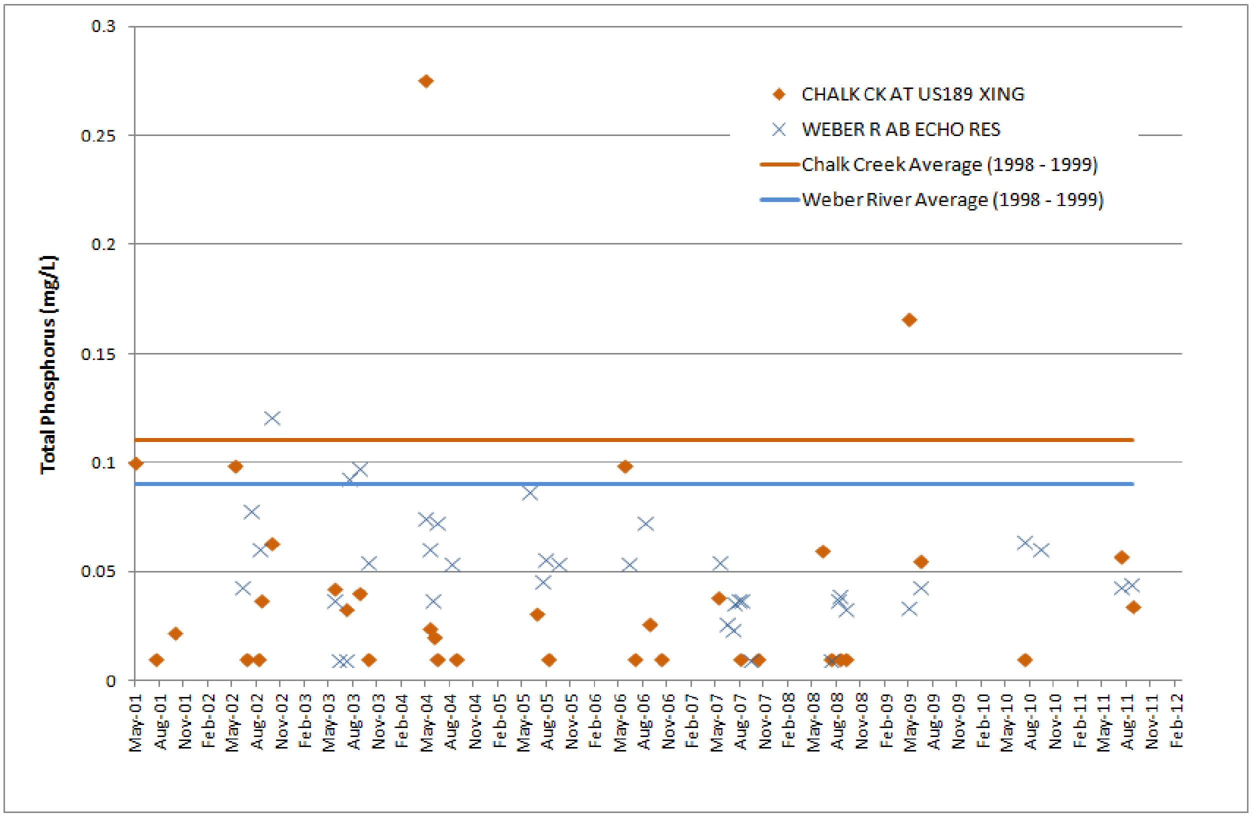

Figure A-19. Summary of total phosphorus data in Weber River from 2001 – 2012 and comparison to averages in the late 1990s.

A-5.2 Dissolved Oxygen Targets

Dissolved oxygen is important to the health and viability of the cold-water fishery beneficial use (3A), designated by the State of Utah for Rockport Reservoir and Echo Reservoir. High concentrations of DO (6.0–8.0 mg/L or greater) are necessary for the health and viability of fish and other aquatic life. Low DO concentrations (less than 4.0 mg/L) cause increased stress to fish species, lower resistance to environmental stress and disease, and result in mortality at extreme levels (less than 2.0 mg/L). Low DO in the reservoir is related to the decomposition of algae and other organic matter and subsequent depletion of DO in the hypolimnion.

A-5.2.1 Dissolved Oxygen Concentration Targets

The goal of the Rockport Reservoir and Echo Reservoir TMDLs is to increase concentrations of oxygen in the reservoir such that the designated beneficial uses are fully supported. Cold-water sport fish species are not known to reproduce in the reservoir, therefore the early life-stage criteria do not apply. The state DO criteria for all life-stages of cold-water fish are: 4.0 mg/L as a 1-day minimum, 5.0 mg/L as a 7-day average, and 6.5 mg/L as a 30-day average.

All of these criteria are currently attained in the epilimnion of the reservoirs and violated in the hypolimnion of the reservoirs at the end of the summer stratification season. The State of Utah applies the 4.0 mg/l standard to a minimum of 50% of the water column in assessing attainability of this standard in deep stratified lakes and reservoirs. In addition, the epilimnion in each reservoir routinely exceeds temperature criteria during the summer season due to solar radiation. To protect the fishery from the intersecting pressures of high temperature in the epilimnion and low DO in the hypolimnion, the following site-specific assessment methodology is proposed for the Rockport and Echo Reservoir TMDLs:

During periods of thermal stratification, the minimum DO criteria of 4.0 mg/L and maximum temperature of 20^{o}C shall be maintained in a 2-m layer across the reservoir to provide adequate refuge for cold-water game fish. This layer is represented by the metalimnion. These criteria were determined to provide sufficient support for the cold-water game fish beneficial use (3A) designated by the State of Utah for East Canyon Reservoir TMDL approved by EPA in 2010. During periods of complete mixing in the reservoir, all life-stage water quality criteria identified by the State of Utah will be maintained across the reservoir and throughout at least 50% of the water column.

The DO endpoints for Rockport and Echo Reservoirs are consistent with existing Utah water quality criteria and are based on similar endpoints derived for the East Canyon Reservoir TMDL, also in the Upper Weber River watershed. The East Canyon endpoints were developed in collaboration with the Utah Division of Wildlife Resources (DWR) and determined to be protective of the fish species found in the reservoirs. The DEQ and DWR will have an opportunity to review and comment on this approach for these reservoirs prior to completing the final TMDL.

These endpoints apply to normal climatic conditions defined by variable hydrologic conditions across consecutive years, with annual flow within 50% of the 30-year average and current water management regimes. Under conditions of consecutive drought or wet-flow years, the criteria may not be achieved. In addition, periods of extreme spring runoff flows or summer storms may produce conditions that periodically do not attain the criteria.

Reservoir management is another factor that may result in failure to achieve DO concentrations that meet state standards. Releases from Rockport Reservoir occur through the bottom of the reservoir which contains colder water with low DO concentrations. There is also a likelihood of water releases containing high concentrations of dissolved phosphorus because of the anoxic conditions. If Echo Reservoir is already stratified, the releases from Rockport Reservoir may not fully mix and instead may deliver colder water carrying dissolved phosphorus to the lower portions (hypolimnion) of the reservoir. Conversely, reservoir management could help achieve attainment if increased reservoir depths during the critical period create conditions that allow the metalimnion to develop to two meters and at temperatures that fish and aquatic species require.

A-5.2.2 Metalimnetic Oxygen Depletion Rate Targets

The goal of attaining a DO concentration of at least 4 mg/l in the metalimnion is correlated with a target MOD rate, a parameter that has been calculated for current reservoir conditions and can be predicted using the BATHTUB model. The target MOD rate (mg/m^3/day) is calculated by comparing the oxygen concentration below the thermocline at stratification with the target of 4 mg/l to determine how much oxygen can be depleted from the metalimnion. This value is then divided by the total number of days in the stratification season to determine an acceptable target MOD rate. The target MOD rate is therefore related to the starting oxygen concentration in the reservoir and the number of days in the stratification season. A higher initial oxygen concentration and/or a shorter stratification season would result in a higher target MOD rate (Figure A-20). The proposed MOD target for Echo Reservoir and Rockport Reservoir is 36.5 mg/m^3/day based on an assumed initial DO concentration of 9.0 mg/L. If accepted, this target will be used to derive total and dissolved phosphorus targets for the reservoir as well as algal-related targets.

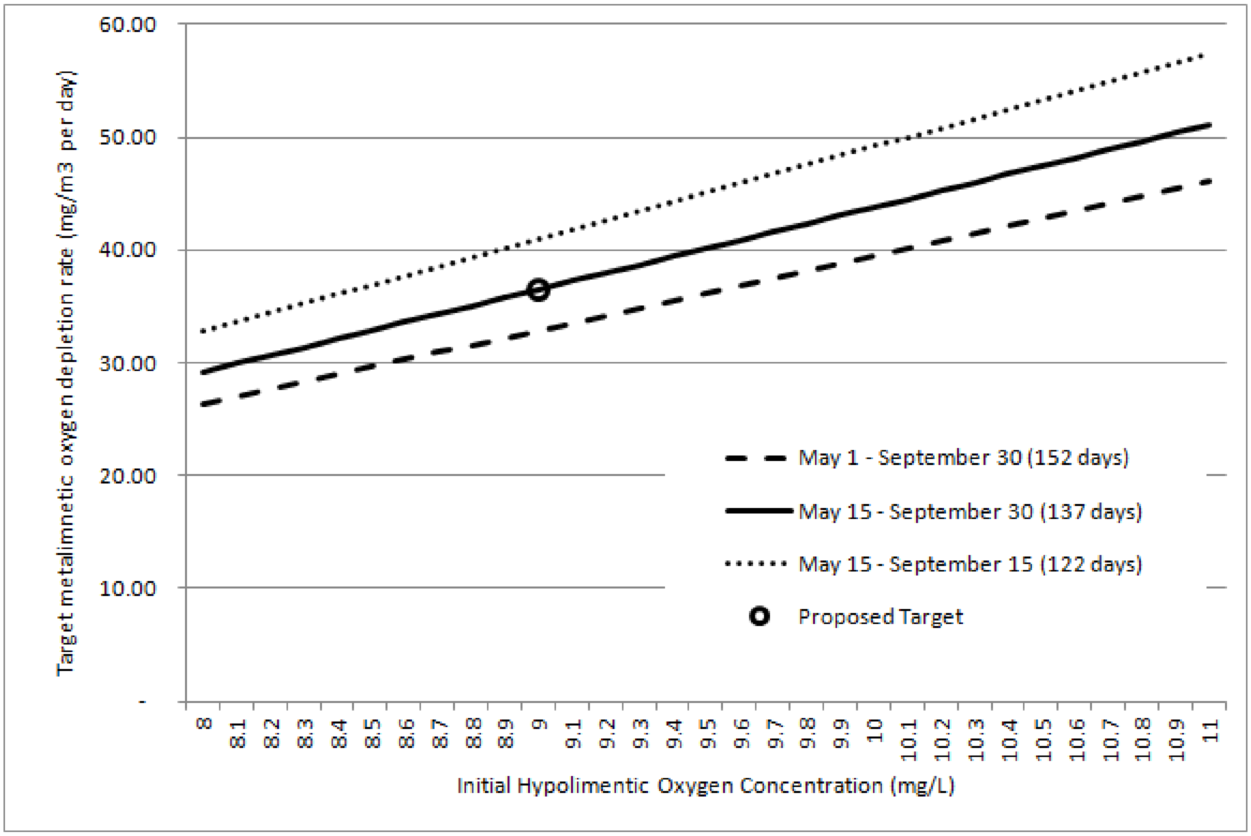

Figure A-20. Relationship between metalimnetic oxygen depletion rate targets and initial hypolimnetic oxygen concentration for three different assumed stratification seasons and proposed target for Rockport Reservoir and Echo Reservoir.

The stratification season for both reservoirs is assumed to be 137 days in length extending from May 15 to September 30. The concentration of DO at the start of stratification, as opposed to during the stratification period, is more difficult to estimate. There are no DO data in early spring, prior to stratification. The earliest spring measurements were taken in Echo Reservoir on May 22, 2007 and on May 29, 2007 for Rockport Reservoir. The average and maximum surface DO concentrations on those dates were 9.1 mg/L and 9.45 mg/L for Echo Reservoir and 7.9 and 8.0 mg/L for Rockport Reservoir, respectively. Although there is very little DO data for either reservoir at stratification, there are more DO data available for the tributaries into and out of the Reservoirs in early spring. These concentrations also provide some perspective on hypolimnetic oxygen depletion rates, especially the concentrations in the Weber River directly downstream of each dam (recognizing that some aeration of the water will occur prior to the monitoring site). A summary of these data is provided in Table A-47 below and indicates the initial concentration of oxygen in the hypolimnion could be as high as 10 mg/L in Echo Reservoir. The use of 9.0 mg/L in deriving the MOD rate target is a conservative assumption for the TMDL analysis.

Table A-47. Summary of Early Spring DO Data in Tributaries to and from Rockport Reservoir and Echo Reservoir

	Chalk Creek	Weber River Above Rockport Reservoir	Weber River Below Rockport Reservoir	Weber River Above Echo Reservoir	Weber River Below Echo Reservoir
April					
2004	9.6	10.9	9.8	9.8	12.8
2005	9.5	10.0			
2006	9.8	10.2			
2008	11.0	10.3			
2009	1.8	10.0	9.8	11.4	9.4
Average	**8.3**	**10.3**	**9.8**	**10.6**	**11.1**
May					
2001	10.8	11.1			
2002	8.8	8.9			
2003	8.7	7.9		10.3	
2004	8.9	9.5	10.8	10.6	11.3
2006	15.2	12.0			
2007	11.2	10.6	11.0	12.0	9.2
2009	9.8	9.8	9.1	11.5	9.4
Average	**10.3**	**10.0**	**10.4**	**11.0**	**10.3**

A-5.3 Nutrient Reduction Scenarios

Attainment of the DO endpoints under various nutrient loading scenarios can be derived by comparing the MOD rate predicted using BATHTUB to the target MOD rate. All nutrient loading scenarios represent equal reductions in nitrogen and phosphorus to the reservoirs. Multiple nutrient reduction scenarios were run using the calibrated BATHTUB models specific to the three conditions (dry, average, and wet) including the minimum nutrient reduction required to attain the proposed MOD target. The nutrient reductions required range from 32% to 35% for the average condition and 48% for the wet condition in Rockport Reservoir. The nutrient reductions needed range from 34 to 40% for the average and dry conditions to 44% for the wet condition for Echo Reservoir. (Figure A-21).

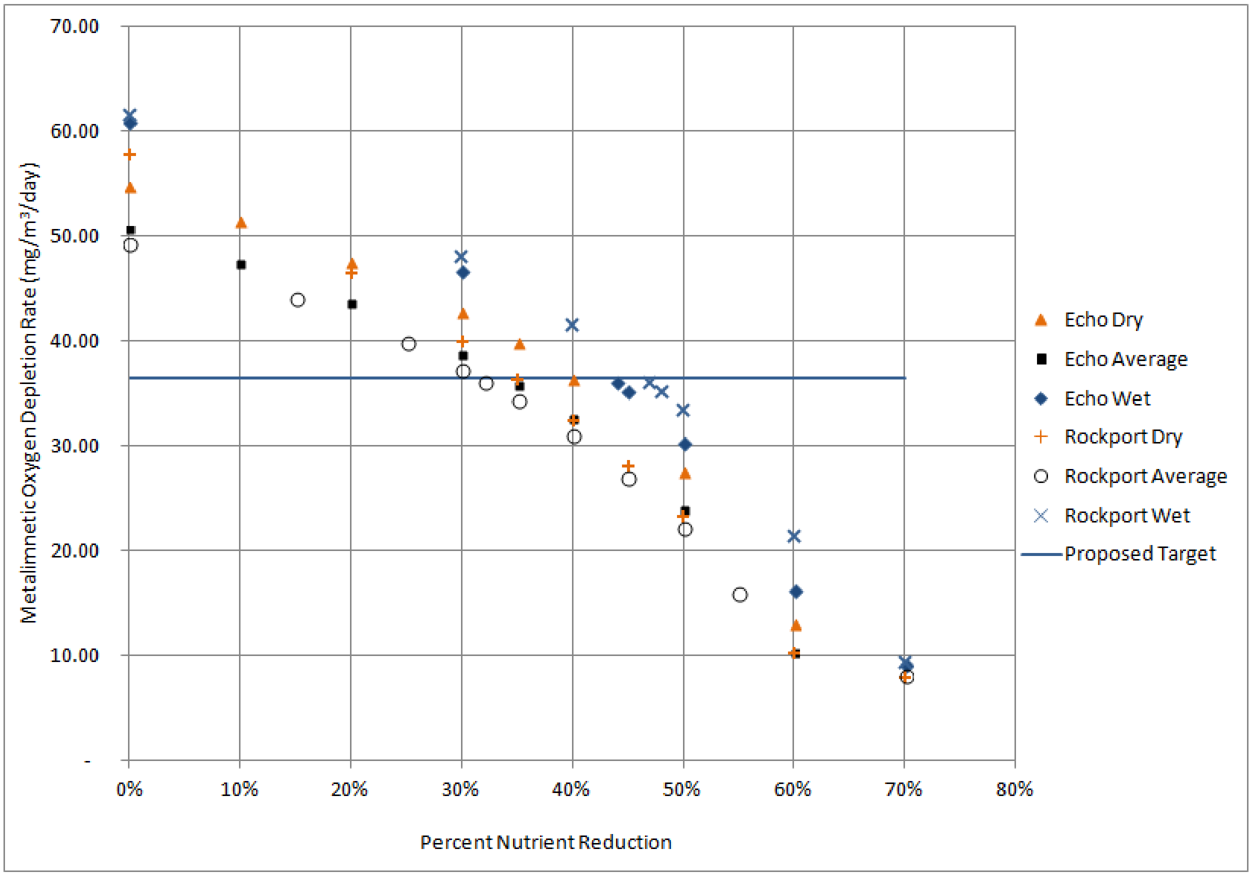

Figure A-21. Predicted MOD rates under various nutrient reductions scenarios.

A-5.4 Predicted Reservoir Water Quality

Average seasonal water quality in the reservoirs, based on the nutrient reduction scenarios for each condition that would achieve the targeted metalimnetic oxygen depletion rate, are presented in Tables A-48 and A-49 below.

Table A-48. Predicted Rockport Reservoir Water Quality under Proposed Nutrient Load Reductions

	2004	2007	2011
Current			
Total Phosphorus (µg/L)	37.0	16.8	36
Total Nitrogen (µg/L)	369	382	348
Chlorophyll-a (µg/L)	2.2	No data	2.1
Organic Nitrogen (µg/L)	481.2	238.2	251.0
Orthophosphate (µg/L)	32.1	16.3	27
Nutrient reduction to reach proposed MOD target	35%	32%	47%
Target Water Quality			

Table A-48. Predicted Rockport Reservoir Water Quality under Proposed Nutrient Load Reductions

	2004	2007	2011
Total Phosphorus (µg/L)	27.1	14.7	19.3
Total Nitrogen (µg/L)	267.6	268.9	223.3
Chlorophyll-a (µg/L)	3.2	3.7	2.3
Secchi depth (m)	6.2	5.8	7.2
Organic Nitrogen (µg/L)	236.2	238.5	216.2
Orthophosphate (µg/L)	3.5	4.3	1.9

Table A-49. Predicted Echo Reservoir Water Quality under Proposed Nutrient Load Reductions

	2004	2007	2011
Current			
Total Phosphorus (µg/L)	18.4	18.3	35.9
Total Nitrogen (µg/L)	657.1	413.5	714.9
Chlorophyll-a (µg/L)	1.6	3.5	4.3
Organic Nitrogen (µg/L)	526.5	319.4	572.8
Orthophosphate (µg/L)	13.5	13.0	34.5
Nutrient reduction to reach proposed MOD target	40%	34%	44%
Target Water Quality			
Total Phosphorus (µg/L)	13.5	18.7	21.9
Total Nitrogen (µg/L)	230.7	269.9	237.8
Chlorophyll-a (µg/L)	2.3	3.7	2.9
Secchi depth (m)	7.2	5.8	6.5
Organic Nitrogen (µg/L)	215.9	247	229.9
Orthophosphate (µg/L)	1.9	4.3	3.0

A-5.5 Uncertainty and Variability

Sources of uncertainty and variability associated with all models including SWAT and BATHTUB can be generalized into three categories: data representativeness or the uncertainty and variability for data used for calibration; uncertainty and variability in the values used to characterize parameters; and uncertainty in the understanding of the processes occurring and the equations and parameters used in the model to simulate processes. These issues are discussed with respect to the Rockport Reservoir and Echo Reservoir TMDLs in the following sections.

A-5.6 Data Representativeness

While much of the data available for the Rockport and Echo Reservoir TMDL analysis are robust and comprehensive, there are some deficiencies in data representativeness that contribute to the uncertainty associated with the modeling output. These data deficiencies are summarized in Table A-50 with a summary of how the deficiency has been handled in the current modeling analysis. While these deficiencies do not prevent development of the TMDL, they represent important aspects of uncertainty and should be used to frame additional monitoring efforts in the future.

Table A-50. Identified Data Gaps for Rockport and Echo Reservoir TMDLs

Data Deficiency	Importance	Procedure Used to Address the Data Deficiency
High elevation climate data	The SWAT model generates climate data based on elevation bands in the watershed using available climate data from multiple climate stations. Although the climatic data generated by SWAT based on valley climate includes algorithms to account for elevational changes, there is significant uncertainty at the daily timescale of the predicted high elevation climate. This uncertainty prevented better calibration of hydrology.	Snow parameters and coefficients related to high elevation climate predictions were modified to best match the hydrologic data. Remaining uncertainty was somewhat mitigated through calibration of nutrient loads at a seasonal time scale. In this way, while the timing of load delivery to the reservoirs is not perfect, the seasonal loads to the reservoirs are reasonable.
Water quality data collected during storms	Loads calculated for average and dry conditions using measured water quality and flow data were unrealistically low for Echo Reservoir, based on known loads from Rockport Reservoir releases and point source discharges. Further examination of data collected in the summer in Chalk Creek and the Weber River indicate that only one sample was collected during a storm event since 2002. The bulk of the summer nutrient load is likely to occur during storm events when erosion occurs in the watershed and stream channels. Samples collected during storms in summer 2012 in the Chalk Creek watershed demonstrate that nutrient concentrations are several times higher during storms than base flow water quality. This results in a “missing load” in the calculated seasonal loads to the reservoirs.	Loads calculated using measured flows and water quality during spring runoff are more representative of actual loads. The SWAT model for the Echo Reservoir watershed was calibrated to the measured spring runoff load. The summer loads were then predicted using the calibrated model. This approach will also be taken for Rockport Reservoir watershed and total loads to Rockport Reservoir will be revised accordingly for the final TMDL.
Initial soil nutrient concentrations	The SWAT model is relatively sensitive to initial soil nutrient concentrations, both organic and dissolved forms. No soil nutrient data is available for the watersheds.	Soil nutrient values were initially generated by SWAT based on the organic components of the soil, data available in STATSGO. These values were modified for phosphorus based on the concentration of phosphorus in the underlying geology. This provided good differentiation of soil phosphorus conditions between soils. Soil nutrient concentrations were then used as a primary calibration tool for nutrient calibration of loads to the reservoirs.
Reservoir DO data from early spring	The concentration of oxygen in the hypolimnion at stratification is a critical assumption in calculating an acceptable oxygen depletion rate for each reservoir. No hypolimnetic oxygen data is available for either reservoir in April or early May.	Dissolved oxygen data from reservoir surfaces in late May and in the Weber River below each reservoir in April and May were used to develop an assumed initial DO concentration for the reservoirs; 9.0 mg/L for Rockport Reservoir and 10.0 mg/L for Echo Reservoir.

Table A-50. Identified Data Gaps for Rockport and Echo Reservoir TMDLs

Data Deficiency	Importance	Procedure Used to Address the Data Deficiency
Organic matter loading to reservoirs	The BATHTUB models were calibrated to oxygen depletion rates driven by algal growth and nutrients in the reservoirs. However, organic matter loading to the hypolimnion from the watersheds could also contribute to oxygen depletion. There are very few data related to organic matter loading from the Weber River to the reservoirs.	Contribution to oxygen depletion from organic matter is not accounted for in the analysis. This is a protective assumption, in that all of the improvement in oxygen depletion will be achieved through nutrient reductions. Any BMPs implemented to reduce nutrients in the watershed would likely also reduce organic matter loading.

A-5.6.1 Model Parameterization

The parameters used in developing models and the values chosen for those parameters can affect model results and contribute to uncertainty. Model parameters should be assigned values that are representative of conditions present during the time period modeled. The SWAT parameters remained within the SWAT default ranges and were based on information generated from raw data or provided by local watershed stakeholders including land management agencies. Some parameters such as snow, routing, and groundwater parameters were used to calibrate the model and therefore the values used for these parameters were those that created a best fit for either the simulated hydrology or the simulated nutrient loads. Other parameter values, in particular the values used to describe agricultural and irrigation operations, were generalized based on available data and input from agencies. The values used for these parameters have more uncertainty associated with them because they are based on observations or numbers for a single year that are attributed to all years included in the simulation. In addition, some model parameters required values for which there was data for some parameters, but not all. For example, nitrogen and phosphorus data had to be partitioned into various components such as organic nitrogen or mineral phosphorus for input files that describe point sources for SWAT. The initial soil nutrient conditions also are a source of uncertainty for two reasons: agricultural inputs and high rock phosphorus concentrations affect nutrient levels, particularly phosphorus, in the soil; and there are no known standard methods to estimate the contributions from underlying rock over time to soil nutrient concentrations. Therefore, these values were adjusted as part of calibration. BATHTUB parameters were based on measured data or estimated from existing data such as bathymetry. Uncertainty will exist in the volumes calculated from bathymetry because of annual sediment filling that slowly reduces the total reservoir volume over time. Uncertainty also exists in the length of stratification season and the parameters used to predict the MOD rates. However, the values used are based on measurements at these reservoirs for the specific year modeled, which reduces the uncertainty and addresses variability between the reservoirs and years. Uncertainty in model parameterization also exists for the BATHTUB model because values for all inputs were not equally available for both reservoirs and segments.

A-5.6.2 Physical and Chemical Processes

Our understanding of the physical and chemical processes that are simulated in the model is somewhat limited, thereby increasing uncertainty in the model results. In both the SWAT and BATHTUB models, users have the option to choose different equations for the model to use, for example, in channel sediment generation or predicting MOD rates. There is some uncertainty associated with the equation itself and how well it simulates specific conditions and whether the equation was developed for conditions within the project area. For example, in SWAT, the Penman-Monteith Equation may provide more accurate estimates of potential evapotranspiration, but relies heavily on weather statistics. The model also offers four equations for estimating channel erosion, each having been developed for specific conditions. With

BATHTUB, different combinations of empirical sub-models better represent the conditions of each reservoir during a dry, wet, and average year. Using different equations, sub-models, or combinations of either create uncertainty because they generate slightly different results. Throughout the analysis, best professional judgment was used to select the most appropriate model equation or submodel for each process.

A-5.6.3 Reservoir Dynamics

The target water quality for nutrients, based on the BATHTUB modeling, results in very low nutrient concentrations in the surface of both reservoirs, especially Echo Reservoir, and may not be attainable. It should be further noted that the average seasonal phosphorus concentrations in some years in which DO impairments have been observed are already below the threshold value (0.025 mg/L) identified by the State of Utah to indicate a nutrient concern. This points to the possibility of another driver of oxygen depletion, other than algal growth responding to nutrients.

One possibility is that organic matter loading to the hypolimnion from the watersheds could be contributing to oxygen depletion. Organic matter serves as a food source for heterotrophs, which respire, die, and decompose. These reactions are aerobic and use oxygen if available, thereby contributing to oxygen depletion in the reservoir water column and increasing sediment oxygen demand at the bottom of the reservoir. Thermal stratification may confine these effects to the hypolimnion during the spring-summer season. The water temperature of the Weber River is lower than the surface temperature of the reservoirs in the summer. Accordingly, much of the water delivered to the reservoirs in the summer may bypass the surface and sink to the hypolimnion directly. While the effect of this phenomenon on nutrient loads to the epilimnion has been accounted for through calibration of nutrient sedimentation rates in the reservoir, the BATHTUB model does not account for additional oxygen depletion associated with organic matter. Further, there are very few data related to organic matter loading from the Weber River to the reservoirs that could be used in any analysis of this potential driver. Thus, contribution to oxygen depletion from organic matter is not accounted for in the current analysis. This is a protective assumption, in that all of the improvement in oxygen depletion will be achieved through nutrient reductions. Any BMPs implemented to reduce nutrients in the watershed would likely also reduce organic matter loading as both nutrient and organic matter transport are associated with soil erosion and sediment transport from the watershed.