Appendix B—Pineview Reservoir TMDL

Description of SWAT Modeling

The Soil Water Assessment Tool

The Soil Water Assessment Tool (SWAT) model was developed to predict the impact of land management practices, such as vegetative changes, reservoir management, groundwater withdrawals, and water transfer, on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. SWAT can analyze large watersheds and river basins (greater than 100 square miles) by subdividing the area into homogenous subwatersheds. The model uses a daily time step, and can perform continuous simulation for a 1- to 100-year period. SWAT simulates hydrology, pesticide and nutrient cycling, erosion, and sediment transport.

Hydrology

The hydrology component of SWAT is based on the water balance equation. A distributed Soil Conservation Services (SCS; now Natural Resources Conservation Service) curve number is generated for the computation of overland flow runoff volume, given by the standard SCS runoff equation (USDA, 1986). The curve number method is empirically based and relates runoff potential to land use and soil characteristics. The curve number method combines infiltration losses, depression storage, and interception into a potential maximum storage parameter called *S*. Runoff depth is given by the following set of empirical relationships:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

where *Q* is the accumulated runoff depth or rainfall excess, P is the accumulated precipitation, and *S* is a maximum soil water retention parameter given by

$$S = \frac{1000}{CN} - 10$$

where *CN* is known as the curve number.

The equation above indicates that precipitation, *P,* must exceed 0.2*S* before any runoff is generated. Consequently, a cumulative rainfall depth of 0.2*S* must fall before runoff is initiated. Furthermore, equation 1 yields a depth of runoff. To calculate runoff volume, the computed depth must be multiplied by area.

The curve number indicates the runoff potential of an area for the combination of land-use characteristics and soil type. Curve numbers are a function of hydrologic soil group, vegetation, land use, cultivation practice, and antecedent moisture conditions. The SCS has classified more than 4,000 soils into 4 hydrologic soil groups according to their minimum infiltration rate for bare soil after prolonged wetting. The characteristics associated with each hydrologic soil group are given in Table 1. The amount of moisture present in the soil is known to affect the volume and the rate of runoff. Consequently, the SCS developed three antecedent soil moisture conditions: Condition I, Condition II, and Condition III (see Table 2.). Dryer antecedent conditions C I) reflect soils that are dry but not to the wilting point. Wetter conditions (Condition III) characterize soils that have experienced heavy rainfall, light rainfall and low temperatures within the last 5 days, or saturated soils. Condition II is known as the average condition.

Table 3 gives curve numbers for average antecedent soil moisture conditions for various land uses, practices, hydrologic conditions and soil groups. For example, the CN for an area of small grain with surficial crop residue and good hydrologic condition on soil group C is 80. For soil group D, the CN would increase to 84. Curve numbers for dryer antecedent conditions (condition I) and for wetter antecedent conditions (condition III) are found in Table 3.

Table 1. Characteristics of hydrologic soil groups[1].

Soil Group	Characteristics	Minimum Infiltration Capacity (in./hr)
A	Sandy, deep, well-drained soils; deep loess; aggregated silty soils	0.30–0.45
B	Sandy loams, shallow loess, moderately deep and moderately well-drained soils	0.15–0.30
C	Clay loam soils, shallow sandy loams with a low-permeability horizon impeding drainage (soils with a high clay content), soils low in organic content	0.05–0.15
D	Heavy clay soils with swelling potential (heavy plastic clays), water-logged soils, certain saline soils, or shallow soils over an impermeable layer	0.00–0.05

[1] Source: SCS, 1972.

Table 2. Seasonal rainfall limits for antecedent rainfall conditions[1].

Antecedent Moisture Condition Class	5-Day Total Antecedent Rainfall (inches)	
	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5–1.1	1.4–2.1
III	Over 1.1	Over 2.1

[1] Source: SCS, 1972.

Table 3. Curve number adjustments from antecedent moisture condition II to antecedent moisture conditions I and III. (Source: SCS, 1972)

CN for Antecedent Moisture Condition II	CN for Antecedent Moisture Condition I	CN for Antecedent Moisture Condition III
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79
55	35	75
50	31	70
45	27	65
40	23	60
35	19	55
30	15	50
25	12	45
20	9	39
15	7	33
10	4	26
5	2	17
0	0	0

[1] Source: SCS, 1972

Curve numbers are updated daily as a function of initial soil moisture storage. A soil database is used to obtain information on soil type, texture, depth, and hydrologic classification. Figure 1 shows the distribution of hydrologic soils within the Pineview Reservoir watershed. The figure shows that "B" and "C" hydrologic soil groups dominate the watershed. In SWAT, soil profiles can be divided into 10 layers. Infiltration is defined in SWAT as precipitation minus runoff. Infiltration moves into the soil profile where it is routed through the soil layers. A storage routing flow coefficient is used to predict flow through each soil layer, with flow occurring when a layer exceeds field capacity. When water percolates past the bottom layer, it enters the shallow aquifer zone (Arnold et al., 1993). Channel transmission loss and pond or reservoir seepage replenishes the shallow aquifer while the shallow aquifer interacts directly with the stream. Flow to the deep aquifer system is effectively lost and cannot return to the stream (Arnold et al., 1993). The irrigation algorithm developed for SWAT allows irrigation water to be transferred from any reach or reservoir to any other in the watershed. Based on surface runoff calculated using the SCS runoff equation, excess surface runoff not lost to other functions makes its way to the

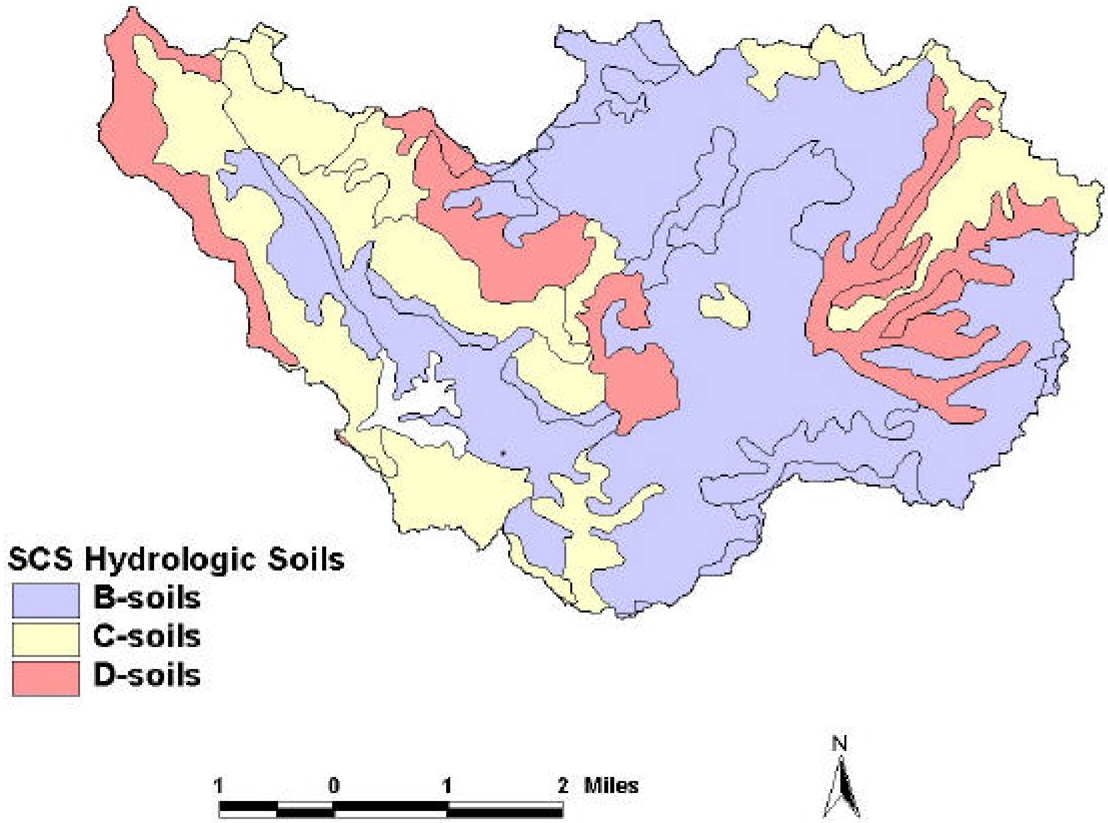

Figure 1. Hydrologic soil groups in the Pineview Reservoir watershed.

channels where it is routed downstream.

Another important model parameter obtained from the soils database is the Universal Soil Loss Equation (USLE) erodibility factor, *k*. The erodibility factor is an empirically derived value reflecting a soil's inherent erodibility. The USLE is used in SWAT to estimate initial soil detachment and upland erosion. Figure 2 shows the distribution of the *k*-factor within the watershed. The figure shows that most of the soils in the Pineview Reservoir watershed are classified as moderately susceptible to erosion. Sediment yield used for instream transport is determined from the Modified Universal Soil Loss Equation (MUSLE) (Arnold, 1992). For sediment routing in SWAT, deposition calculation is based on fall velocities of various sediment sizes. Rates of channel degradation are determined from Bagnold's (1977) stream power equation. Sediment size is estimated from the primary particle size distribution (Foster et al., 1980) for soils the SWAT model obtains from the STATSGO (USDA 1992) database. Stream power also is accounted for in the sediment routing routine, and is used for calculation of reentrainment of loose and deposited material in the system until all of the material has been removed. Data input requirements are relatively high, and experienced personnel are required for successful simulations.

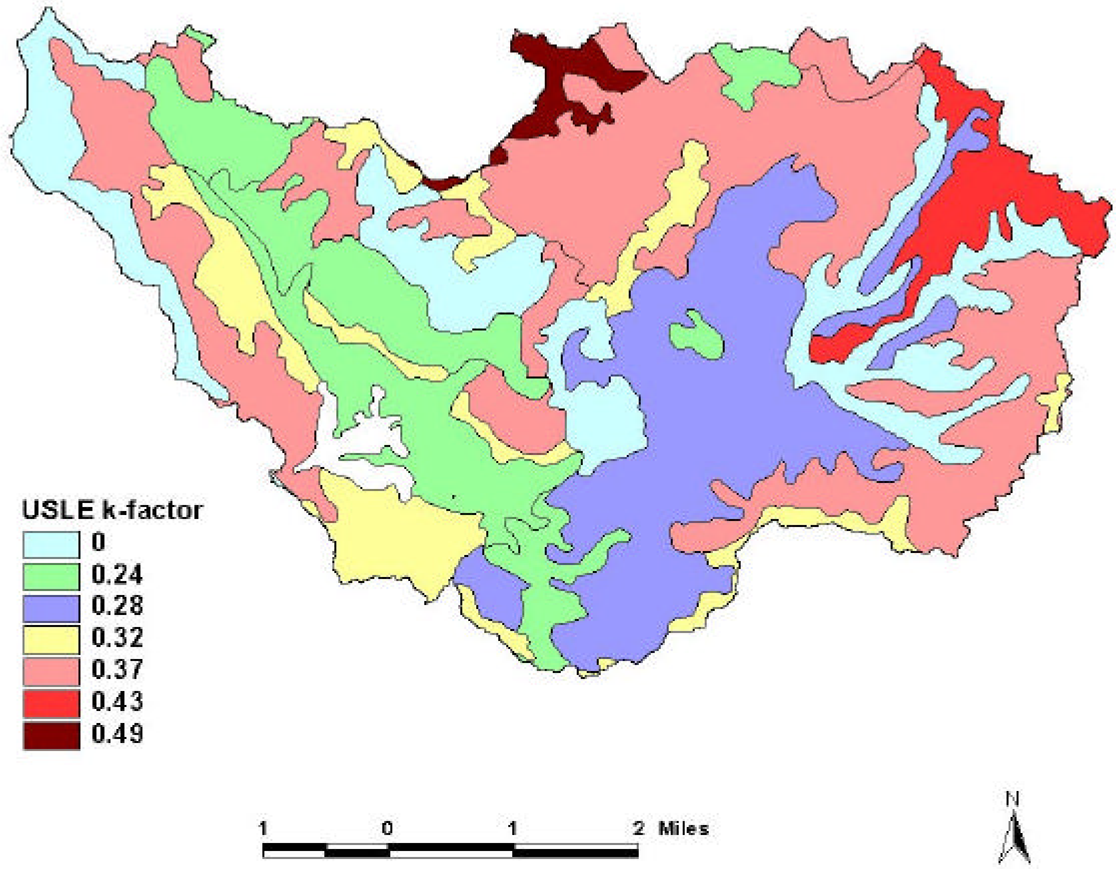

Figure 2. Distribution of the USLE *k*-factor in the Pineview Reservoir watershed.

Data Description

The primary inputs for creation of a watershed model include spatial coverages of land use, land cover, soils, slopes, hydrography, and meteorological data. The assembly of these data is described in the Detailed Sources Report (Tetra Tech, 2001). As described in that document, land use and land cover were assembled from USGS MRLC (1992) data. A detailed, up-to-date land use coverage, however, is not available.

Soils data are derived from the USGS STATSGO coverages, while slopes were obtained from USGS in the form of a digital elevation model. Hydrography is based on USEPA's Reach File 3. All these spatial coverages were processed using the SWAT interface.

Meteorological data was obtained from the Huntsville Monastery station. However, it is understood that precipitation and temperature vary strongly across the basin, primarily due to elevation effects, and the single station's reach relative to the size of the watershed is sufficiently small as to introduce significant uncertainty into the prediction of hydrologic response to individual weather events. To compensate for this relatively sparse coverage, the influence of elevation on temperature and precipitation was accounted for in the model through use of lapse rates, which estimate the change in precipitation and temperature per change in elevation relative to a monitoring station. A standard temperature lapse rate of -6 ºC per km was used for the model. Use of this correction improves the performance of the model relative to a direct use of nearest station records. However, the elevation corrections do not take into account other effects, such as rain shadow, and the ability of the model to reproduce observations would likely be improved significantly through use of a denser network of meteorological stations.

Model Subbasins

Application of the SWAT model begins by breaking the watershed down into subbasins. These subbasins represent the degree to which the simulation is assigned to spatial locations. Sub-basin delineation used the automated routines available in BASINS 3. The delineation was based on a 1:24,000 digital elevation model of the watershed (obtained by USGS) coupled with a "burn-in" of USEPA's Reach File 3 spatial database of stream reaches. This approach assures that the subbasins conform to topography while requiring that catalogued stream segments connect in the proper order and direction.

Breaking the area of interest into multiple subbasins allows a detailed representation of the spatial distribution of land use and meteorology in the Pineview Reservoir watershed. It also provides a framework within which the accuracy of the model can be improved in future through calibration to multiple points within the drainage network.

Hydrologic Response Units

Each of the model subbasins was further subdivided into Hydrologic Response Units (HRUs) using automated GIS processing. HRUs are intended to be summed areas of similar land use/land cover and soils within a subbasin. The individual land parcels included within an HRU is expected to possess similar hydrologic and load generating characteristics, and can thus be simulated as a unit. The HRUs were created from a GIS overlay of land use class (as defined in Tetra Tech, 2001) and dominant soil type, as defined in the USDA STATSGO database. HRUs are treated as a fraction of the area of a subbasin (representing the sum of the area of the land use/soil overlay in that subbasin), and so are not assigned a spatial location more exact than that of the subbasin.

It is not feasible to include every small area representing a land use/soil combination in the model. Cutoff criteria were therefore defined. These required first that a land use must constitute 1 percent or more of the land area in a subbasin to be included in the model. Soils associated with a given land use within a subbasin were only included if they represented at least 5 percent of the area in that land use in a subbasin. Areas are then renormalized so that the whole land area of a subbasin is assigned to HRUs. Most model parameters are specified on an HRU basis, which can require a significant effort. Fortunately, the BASINS 3 SWAT interface automates this process to a large extent, deriving many of the relevant parameters from the STATSGO soils database, land-use coverage, and digital elevation model (DEM).

An important consequence of the minimum area requirement in SWAT is that residential and commercial lands were typically omitted from the model. Thus, pollutant loading estimates are available for comparison with the projected growth scenarios of the years 2010 and 2020. Also, the MRLC data have a spatial resolution of 80- meters (imagine a square 80 meters wide and 80 meters high). This resolution is not adequate to represent all of the land uses and land covers that occur within the 80- meter area. Much of the residential impervious areas, such as roof tops, driveways, and sidewalks, are neglected in favor of the more dominant surrounding cover types that also occur within the 80 square meter area. Therefore, the MRLC data typically underestimates urban and residential land use in less-heavily developed areas.

Diversions and Irrigation

Diversions of surface water for irrigation are important in several areas of the basin, particularly in the lower portions of the North, Middle and South Fork subbasins. Such diversions have several impacts. First, they remove water from a stream reach. However, irrigation also returns water to the soil moisture profile and shallow groundwater, some of which is eventually returned to surface flow, while the higher saturation of the soil increases runoff during rain events. In addition, many of the diversions are through gravity-fed channels that remain open for most of the growing season, with excess water returning to the river. This has the effect of slowing and dampening the rate of flow of water through the system, while increasing evaporative and percolation losses.

Little information is available about the volume of irrigation diversions in the Pineview Reservoir watershed. Diversions occur in the lower sections of the North, Middle, and South Fork subbasins, and typically all stream flow is removed from April through September. In the South Fork Subbasin, releases from Causey Reservoir to the South Fork of the Ogden River are the dominant control on stream flow. The model is specified to represent these controlled releases to the river coupled with diversion and irrigation based on crop water deficit within the adjacent subbasin. Similarly, diversion and irrigation requirements in the North Fork and Middle Fork subbasins are based on crop water deficits within the adjacent subbasin.

Land use/land cover data were obtained from the MRLC archive for the State of Utah. The MRLC land use/land cover classifications do not exactly match those required by SWAT, and therefore some of the MRCL classifications had to be slightly altered. Table 4 gives the MRLC land use/land cover classification and the SWAT classifications used in the Pineview Reservoir watershed. Table 5 lists the curve numbers applicable to the Pineveiw Reservoir watershed.

Table 4. Comparison of MRLC and SWAT land use and land cover classifications.

MRLC Land Use/Land Cover Classification	SWAT Land Use/Land Cover Classification
Water	Water
Perennial ice and snow	Water
Low-intensity residential	Urban residential low-density
High-intensity residential	Urban residential high-density
Commercial/industrial/transportation	Urban commercial
Barren rock/sand	Barren
Deciduous rorest	Deciduous forest
Evergreen rorest	Evergreen forest
Mixed rorest	Mixed forest
Shrubland	Rangeland—shrubs
Grassland	Rangeland—grasses
Pasture/hay	Pasture
Row crop	Agricultural Land—row crop
Small grain	Alfalfa
Fallow	Fallow
Urban/recreational grasses	Bermuda grass
Woody wetlands	Wetlands—forested
Emergent Herbaceous Wetlands	Wetlands-nonforested

Table 5. SCS curve numbers (CN-II) for land use and land cover in the Pineview Reservoir watershed.

SWAT Land Use/Land Cover Classification	SCS Curve Numbers for Land Use and Hydrologic Soil Group			
	A	**B**	**C**	**D**
Water	100	100	100	100
Urban residential low density	46	65	77	82
Urban residential high density	63	77	85	88
Urban commercial	89	92	94	96
Barren	75	85	90	94
Deciduous forest	45	66	77	83
Evergreen forest	25	55	70	77
Mixed forest	36	60	73	79
Rangeland—shrubs	39	61	74	80
Rangeland—grasses	49	69	79	84
Pasture	49	69	79	84
Agricultural land—row crop	67	78	85	89
Alfalfa	62	73	81	84
Fallow	75	84	89	91
Bermuda grass	31	59	72	79
Wetlands—forested	45	66	77	83
Wetlands—nonforested	49	69	79	84