Appendix F

LSPC Metals Modeling

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
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1.0 INTRODUCTION

The Lake Helena Volume I report concluded that multiple segments in the Lake Helena watershed are impaired because of metals (i.e., arsenic, cadmium, copper, lead, and/or zinc), and therefore require total maximum daily loads (TMDLs) (see Table 1-1 and Figure 1-1). The TMDL process identifies the maximum load of a pollutant (i.e., metals) a waterbody is able to assimilate and fully support its designated uses, allocates portions of the maximum load to all sources, identifies the necessary controls that may be implemented voluntarily or through regulatory means, and describes a monitoring plan and associated corrective feedback loop to insure that uses are fully supported. Modeling is often used during the development of TMDLs to help with one or more of these tasks.

The purpose of this appendix is to explain the TMDL modeling approach and results for metals in the Lake Helena watershed. Metals modeling was conducted to help answer the following key questions:

- What is the extent to which current flow and in-stream metals concentrations have been affected by anthropogenic activities?
- What are the expected flow and metals conditions during periods for which no observed data are available?
- What are the existing metals loads from each subwatershed?
- What are the existing metals loads from each source category (i.e., point sources, abandoned mines, natural background)?
- What are allowable metals loads from each subwatershed and source category that will result in the attainment of water quality standards?
- What are the potential benefits of various control options?

The remainder of this document describes the model selection and calibration results. TMDLs for each impaired segment are then presented in the main Volume II document and in Appendix A.

Table 1-1. Waterbodies in the Lake Helena watershed that are impaired because of arsenic, cadmium, copper, lead, and/or zinc[1].

Segment	Waterbody ID	Cause of Impairment				
		Arsenic	Cadmium	Copper	Lead	Zinc
Clancy Creek from Headwaters to the Mouth	MT41I006_120	X	X	X	X	X
Corbin Creek from Headwaters to the Mouth	MT41I006_090	X	X	X	X	X
Golconda Creek, Headwaters to the Mouth	MT41I006_070		X		X	
Jennies Fork from Headwaters to Mouth	MT41I006_210				X	
Lake Helena	MT41I007_010	X			X	
Lump Gulch from Headwaters to the Mouth	MT41I006_130		X	X	X	X
Middle Fork Warm Springs Creek, Headwaters to Mouth	MT41I006_100	X	X		X	X
North Fork Warm Springs Creek, Headwaters to Mouth	MT41I006_180	X	X			X
Prickly Pear Creek from Headwaters to Spring Creek	MT41I006_060				X	
Prickly Pear Creek from Highway 433 Crossing to Helena Waste Water Treatment Plant Discharge	MT41I006_030	X			X	
Prickly Pear Creek from Lump Gulch to Montana Highway 433 Crossing	MT41I006_040	X	X	X	X	X
Prickly Pear Creek from Spring Creek to Lump Gulch	MT41I006_050		X		X	X
Prickly Pear Creek from the Helena Waste Water Treatment Plant Discharge Ditch to Lake Helena	MT41I006_020	X	X		X	
Sevenmile Creek from Headwaters to the Mouth	MT41I006_160	X		X	X	
Silver Creek from Headwaters to the Mouth	MT41I006_150	X				
Spring Creek from Corbin Creek to the Mouth	MT41I006_080	X	X	X	X	X
Tenmile Creek from the Helena Public Water Supply Intake Above Rimini to the Helena Waste Water Treatment Plant.	MT41I006_142	X	X	X	X	X
Tenmile Creek from the Helena Wt Plant to the Mouth	MT41I006_143	X	X	X	X	X
Tenmile Creek, Headwaters to the Helena Public Water Supply Intake Above Rimini	MT41I006_141	X	X	X	X	X
Warm Springs Creek from the Middle Fork to the Mouth	MT41I006_110	X	X		X	X

[1] This table includes waterbodies that are impaired by metals, as determined by the Lake Helena Volume I Report. See Volume I for a discussion of the 303(d) listings and updated metals assessments for all waterbodies in the Lake Helena watershed.

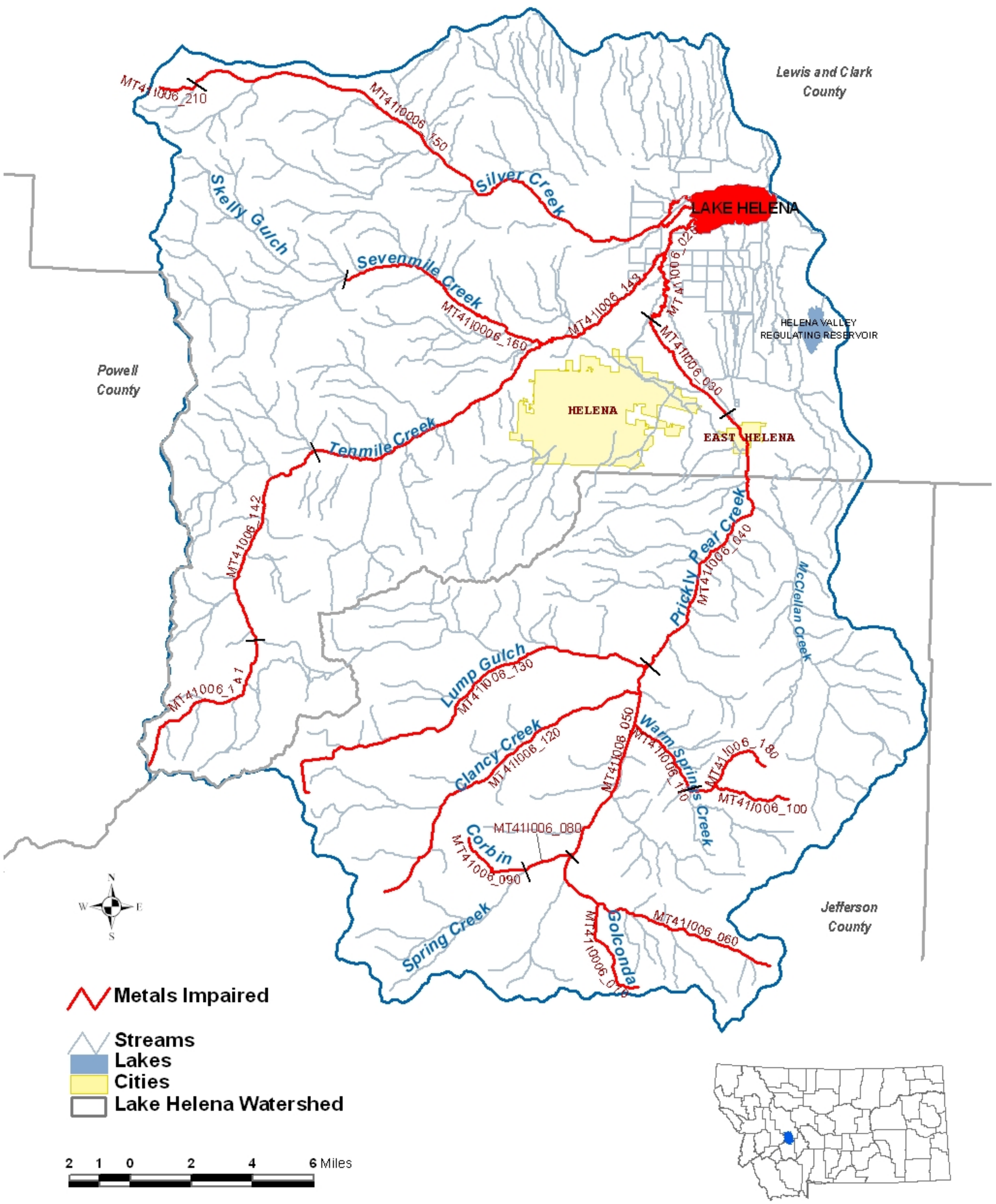


Figure 1-1. Metals impaired segments in the Lake Helena watershed.

2.0 MODEL SELECTION

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes using the land-based and subsurface calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories and also can be used to assess the impacts of a variety of "what if" scenarios. The following criteria were considered and addressed in selecting an appropriate watershed model for the Lake Helena TMDL Planning Area:

- Technical Criteria
- Regulatory Criteria

2.1 Technical Criteria

The following technical factors were critical to selecting an appropriate watershed model for metals:

- The model should be able to address the pollutants of concern (e.g., arsenic, cadmium, copper, lead, and zinc).
- The model should be able to address a watershed with primarily rural land uses.
- The model should be appropriate for simulating large watersheds.
- The model should provide adequate time-step estimation of flow and not over-simplify storm events to provide accurate representation of rainfall events/snowmelt and resulting peak runoff.
- The model should be capable of simulating various pollutant transport mechanisms (e.g., groundwater contributions, sheet flow, etc.).
- The model should include an acceptable snowmelt routine.
- The model should be flexible enough to accommodate issues such as the arid nature of the watershed and the extensive amount of irrigation activities.

2.2 Regulatory Criteria

Regulatory criteria were also a key consideration in selecting an appropriate watershed model. A streams assimilative capacity is determined through adherence to numeric water quality standards. Table 2-1 summarizes the metals water quality standards applicable to the Lake Helena watershed. These tables indicate that the arsenic, cadmium, copper, lead, and zinc standards are applied as both chronic (4-day average) and maximum "not-to-exceed" values. The selected model therefore needed to be able to provide output that can be directly compared to these standards. For example, some models only provide annual or monthly output and would therefore be inadequate for assessing compliance with the component of Montana's standard that is expressed as an instantaneous maximum.

Table 2-1. Montana numeric surface water quality standards for metals used to develop the Lake Helena TMDLs.

Parameter	Aquatic Life (acute) (µg/L)[a]	Aquatic Life (chronic) (µg/L)[b]	Human Health (µg/L)[a]
Arsenic (TR)	340	150	10 [d]
Cadmium (TR)	1.05 at 50 mg/L hardness[c]	0.16 at 50 mg/L hardness[c]	5
Copper (TR)	7.3 at 50 mg/L hardness[c]	5.2 at 50 mg/L hardness[c]	1,300
Lead (TR)	82 at 100 mg/L hardness[c]	3.2 at 100 mg/L hardness[c]	15
Zinc (TR)	67 at 50 mg/L hardness[c]	67 at 50 mg/L hardness[c]	2,000

Note: TR = total recoverable.
[a] Maximum allowable concentration.
[b] No 4-day (96-hour) or longer period average concentration may exceed these values.
[c] The standard is dependent on the hardness of the water, measured as the concentration of $CaCO_3$ (mg/L) (see the Montana DEQ Circular WQB-7 for the equations for calculating standards).
[d] The human health standard for arsenic is currently 18 µg/L, but will change to 10 µg/L in 2006.

2.3 Loading Simulation Program C++ (LSPC) Model

Based on the considerations described in Sections 2.1 and 2.2, the Loading Simulation Program C++ (LSPC) was selected for modeling metals in the Lake Helena watershed. LSPC is essentially a re-coded C++ version of the Hydrologic Simulation Program Fortran (HSPF) model. LSPC integrates a geographical information system (GIS), comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient PC-based windows interface. LSPC's algorithms are identical to a subset of those in the HSPF model. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia. A brief overview of the HSPF model is provided below and a detailed discussion of HSPF simulated processes and model parameters is available in the HSPF User's Manual (Bicknell et al. 1996).

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's. During the past several years it has been used to develop hundreds of USEPA-approved TMDLs and it is generally considered the most advanced hydrologic and watershed loading model available. The hydrologic portion of HSPF is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960's. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious

(IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the waterbodies using storage routing techniques. The stream model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. This method is appropriate for the pollutants of concern (i.e., arsenic, cadmium, copper, lead, and zinc) using decay to represent the net loss due to all processes such as settling and adsorption. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study.

Advantages to choosing LSPC for this application include:

- Simulates all of the necessary constituents and applies to rural watersheds
- A comprehensive modeling framework using the proposed LSPC approach facilitates development of TMDLs not only for this project, but also for potential future projects to address other impairments throughout the basin (e.g., nutrients)
- The time-variable nature of the modeling enables a straightforward evaluation of the cause-effect relationship between source contributions and waterbody response and direct comparison to relevant water quality criteria.
- The proposed modeling tools are free and publicly available. This is advantageous for distributing the model to interested stakeholders and amongst government agencies.
- The model simulates both surface and subsurface impacts to flow and water quality.
- LSPC provides storage of all geographic, modeling, and point source permit data in a Microsoft Access database and text file formats to provide for efficient manipulation of data
- LSPC presents no inherent limitations regarding the size and number of watersheds and streams that can be modeled.
- LSPC provides post-processing and analytical tools designed specifically to support TMDL development and reporting requirements

The setup and calibration of the Lake Helena LSPC watershed model are described in Sections 3.0 and 4.0, respectively.

3.0 MODEL CONFIGURATION

Configuration of the LSPC model involved five major components: watershed subdivision, stream representation, meteorological data, land use representation, and hydrologic and pollutant representation. These components provide the basis for the model's ability to estimate flow and pollutant loadings and are described in greater detail below.

3.1 Watershed Subdivision

LSPC calculates watershed processes based on user defined, hydrologically connected subwatersheds. Subwatersheds were delineated in the Lake Helena TMDL Planning Area to meet the goals of the project. Output was desired at the mouth of each 303(d) listed segment. Therefore, subwatersheds were first delineated to those segments. Subwatersheds were next delineated to flow and water quality gages to facilitate model calibration. Finally, subwatersheds were delineated to areas of concern, such as political boundaries or areas with significant sources. Using this method, 22 subwatersheds were defined for the Lake Helena watershed (Figure 3-1). Table 3-1 summarizes basic characteristics of each watershed (subwatershed area, mean elevation, and corresponding 303(d) segment ID).

Table 3-1. Drainage Area and Mean Elevation of the Lake Helena Subwatersheds

Subwatershed	Watershed Area (ac)	Mean Elevation (m)	Corresponding Waterbody Key
Clancy Creek	21,140	1757.5	MT41I006_120
Corbin Creek	1,715	1685.2	MT41I006_090
Golconda Creek	1,887	1962.2	MT41I006_070
Jackson Creek	2,148	1924.2	MT41I006_190
Jennies Fork	670	1855.5	MT41I006_210
Overland flow to Lake Helena	36,834	1196.0	Overland flow
Lump Gulch	27,762	1722.3	MT41I006_130
Middle Fork Warm Springs	2,180	1796.9	MT41I006_100
Middle Tenmile Creek	24,701	1730.0	MT41I006_142
North Fork Warm Springs Creek	1,343	1721.7	MT41I006_180
Prickly Pear above Spring Creek	17,070	1866.7	MT41I006_060
Prickly Pear above Lake Helena	4,201	1134.6	MT41I006_020
Prickly Pear above Lump Gulch	16,275	1581.2	MT41I006_050
Prickly Pear above WWTP outfall	12,431	1294.0	MT41I006_030
Prickly Pear above Wylie Drive	47,176	1554.9	MT41I006_040
Sevenmile Creek	24,883	1527.6	MT41I006_160
Silver Creek	59,013	1355.4	MT41I006_150
Skelly Gulch	7,834	1700.6	MT41I006_220
Spring Creek	11,620	1758.4	MT41I006_080
Tenmile above Prickly Pear	48,786	1455.1	MT41I006_143
Upper Tenmile Creek	14,106	2068.3	MT41I006_141
Warm Springs Creek	9,670	1688.2	MT41I006_110
Total Watershed Area	*393,445*	*NA*	*NA*

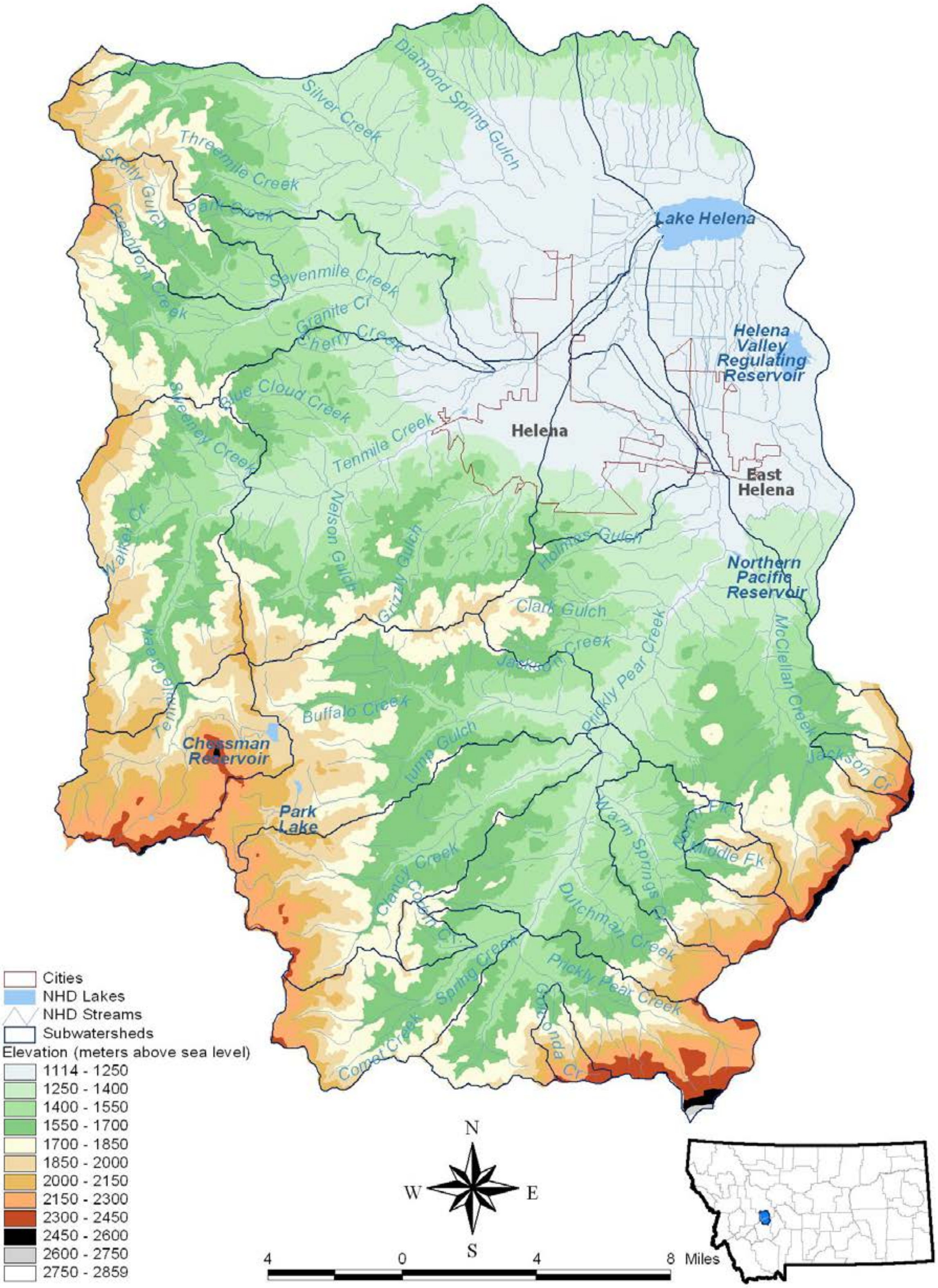


Figure 3-1. Lake Helena subwatershed delineation.

3.2 Stream Representation

Each delineated subwatershed in the LSPC model (see Section 3.1) was conceptually represented with a single stream assumed to be a completely mixed, one-dimensional segment with a constant cross-section, as defined in Figure 3-2. The National Hydrography Dataset (NHD) stream reach network was used to determine the representative stream length for each subwatershed (Table 3-2). NHD data were obtained from the Montana Natural Resources Information System (NRIS) website (http://nris.state.mt.us/).

Once the representative reach was identified, reach slopes were calculated based on the 30-meter National Elevation Dataset for Montana (Montana State Library, 2002). Reach slope was calculated with the formula shown below. Stream lengths were obtained from the NHD dataset.

$$\frac{(UpstreamElevation - DownstreamElevation)}{\mathrm{Re}\,achLength}$$

Channel dimensions for a number of segments were available from field surveys. Assuming representative trapezoidal geometry for all streams, mean stream depth and channel width were estimated using regression curves that relate upstream drainage area to stream dimensions (Rosgen, 1996), and these estimates were compared with stream surveys at selected locations (Table 3-2). Rating curves consisted of a representative depth-outflow-volume-surface area relationship. Estimated Manning's roughness coefficients of 0.035 were applied to each representative stream reach based on typical literature values for natural streams.

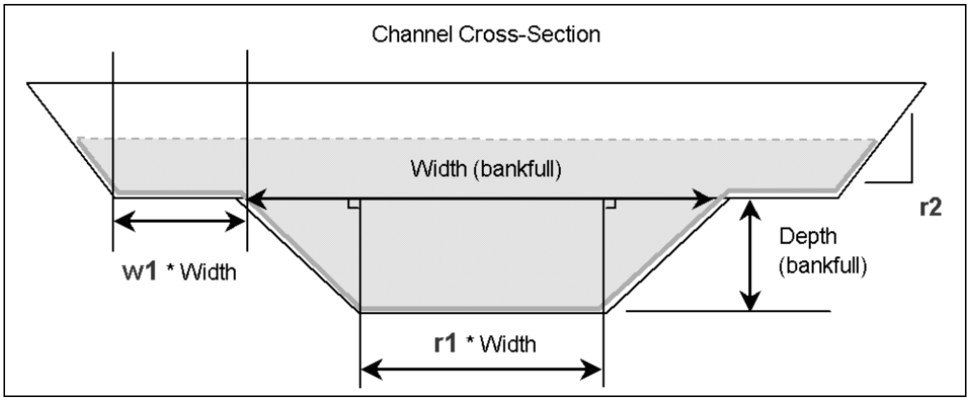


Figure 3-2. Stream channel representation in the LSPC model.

Table 3-2. Stream channel parameters for the LSPC model.

Stream/303(D) Segment	LSPC Watershed ID	Reach Length (Miles)	Bank Full Depth (Feet)	Longitudinal Channel Slope	Manning's Roughness Coefficient	Ratio Of Bottom Width To Bank Full Width	Side Slope Of Flood Plane	Flood Plane Width Factor
Lake Helena	100	2.41	4.16	0.00000	0.035	0.2	0.5	1.5
Prickly Pear above Lake Helena	200	5.97	3.94	0.00177	0.035	0.2	0.5	1.5
Prickly Pear above WWTP outfall	201	4.35	3.55	0.00594	0.035	0.2	0.5	1.5
Prickly Pear above Wylie Drive	202	10.51	3.50	0.02049	0.035	0.2	0.5	1.5
Jackson Creek	203	2.44	1.52	0.09379	0.035	0.2	0.5	1.5
Prickly Pear above Lump Gulch	300	7.05	3.08	0.01004	0.035	0.2	0.5	1.5
Lump Gulch	301	14.34	2.49	0.04085	0.035	0.2	0.5	1.5
Clancy Creek	302	11.49	2.36	0.03104	0.035	0.2	0.5	1.5
Warm Springs Creek	303	7.56	2.16	0.06500	0.035	0.2	0.5	1.5
Middle Fork Warm Springs	304	2.63	1.52	0.08203	0.035	0.2	0.5	1.5
North Fork Warm Springs Creek	305	2.45	1.39	0.08409	0.035	0.2	0.5	1.5
Spring Creek	306	8.35	2.16	0.04817	0.035	0.2	0.5	1.5
Corbin Creek	307	2.52	1.45	0.07739	0.035	0.2	0.5	1.5
Prickly Pear above Spring Creek	308	8.63	2.31	0.05753	0.035	0.2	0.5	1.5
Golconda Creek	309	3.65	1.48	0.15263	0.035	0.2	0.5	1.5
Tenmile above Prickly Pear	400	15.10	3.31	0.00923	0.035	0.2	0.5	1.5
Sevenmile Creek	401	14.39	2.57	0.02701	0.035	0.2	0.5	1.5
Skelly Gulch	402	7.75	1.95	0.05477	0.035	0.2	0.5	1.5
Middle Tenmile Creek	500	7.47	2.66	0.02086	0.035	0.2	0.5	1.5
Upper Tenmile Creek	501	6.79	2.18	0.05513	0.035	0.2	0.5	1.5
Silver Creek	600	21.58	2.88	0.02638	0.035	0.2	0.5	1.5
Jennies Fork	601	1.37	1.21	0.12322	0.035	0.2	0.5	1.5

3.3 Land Use

LSPC requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the watershed, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly related to land practices. Land use typically represents the primary unit for computing both water quantity and quality. In addition to the need for land use data in computing water quantity and quality, nonpoint source management decisions are also frequently based on land use related activity at the subwatershed level. Therefore, it is important to have a detailed land use representation with classifications that are meaningful for load allocation and load reduction. The following sections describe the source and rationale for the land use data used in the modeling effort.

3.3.1 MRLC Land Use Data

Existing land use and land cover in the Lake Helena watershed were determined from the Multi-resolution Land Consortium (MRLC) data and aerial photography. The MRLC data were derived from 30-meter resolution satellite imagery obtained during the early 1990s. The satellite images were classified and rectified by the consortium, and downloaded for this project from the Montana NRIS website. For the purpose of this analysis, the MRLC data were modified to reflect more current conditions in the Lake Helena watershed. Refer to Appendix C for detailed explanation of the creation of the modified MRLC land use coverage developed for all the Lake Helena watershed modeling exercises supporting TMDL development.

Figure 3-3 shows the modified land use data used in the LSPC modeling analysis. Undisturbed areas include full-growth forest, grassland, shrubland, and wetlands. Timber harvest includes recent clear-cut and regrowth areas. Dirt roads are unpaved roads built to legal specification. Illegal or non-system roads are those used for recreational purposes, such as dirt bikes, four wheelers, etc., and are assumed to be constructed without safety or environmental constraints. Quarries include only the portion of the site that does not drain to an internal storage pit. Agriculture includes row crops, small grains, fallow land, and pasture. Urban areas include residential, commercial, industrial, and major highways.

Table 3-3. Land use in the Lake Helena watershed.

Land Use	Existing (ac)	Natural (ac)
Bare Rock	84	84
Low Density Residential[a]	9,067	-
Quarries	234	-
Water	2,875	2,875
Transitional	1,853	-
Deciduous Forest	1,241	1,454
Evergreen Forest	154,204	171,484
Mixed Forest	36	36
Shrubland	37,014	46,787
Grassland	129,060	169,034
Pasture/Hay	14,892	-
Small Grains	16,925	-
Woody Wetland	1,270	1,270
Herbaceous Wetlands	421	421
Recent Clear-cut	522	-
Clear-cut Regrowth	3,571	-
Dirt Roads	3,326	-
Fallow	2,546	-
Row Crop	2,093	-
Non-system Roads	153	-
Low Density Residential[b]	2,950	-
Commercial/Industrial/Transportation	6,203	-
Urban/Recreational Grasses	1,001	-
Secondary Paved Roads	1,904	-
Total Watershed Area	**393,445**	**393,445**

[a] Represents developments detected during the orthophoto analysis or present in the original MRLC data set, with approximately 40 percent impervious area and 60 percent lawn.

[b] Low density residential areas having 40 percent impervious (house, barn, sheds), 24 percent pasture with poor ground cover (animal paddocks), and 36 percent lawn in good condition.

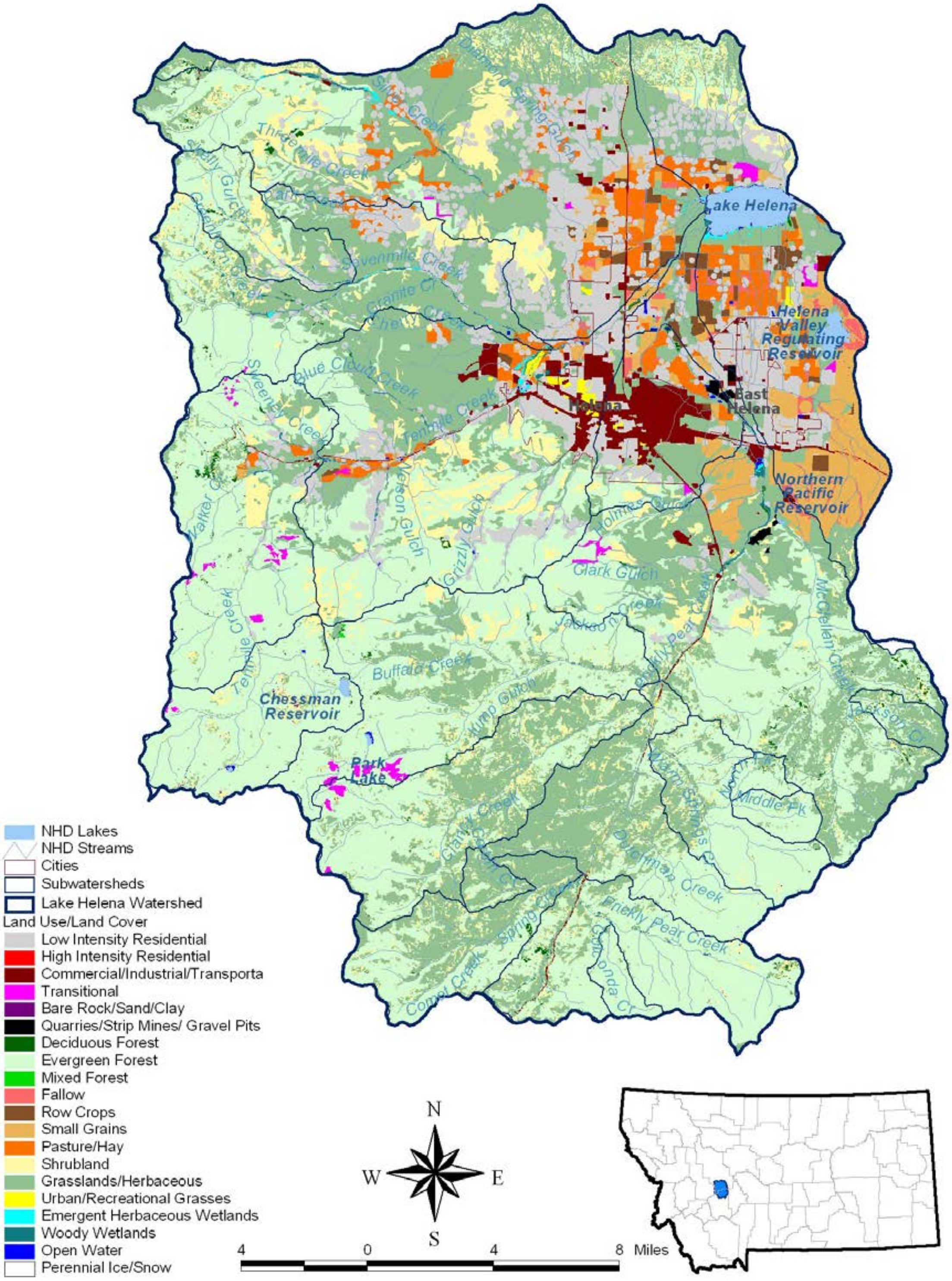


Figure 3-3. Modified MRLC land use coverage.

3.3.2 Mining Land Use

Specific data regarding the location and extent of disturbance from historical mining activities was not available from the MRLC land use coverage. These land-based sources were identified during the preliminary source assessment as critical sources that had to be addressed in the model. A GIS coverage including polygon outlines of priority abandoned hard rock mine sites inventoried by the Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (1997) was used to determine the location and areas of disturbance of priority abandoned mines. In addition, the location of other inactive and abandoned mine sites was obtained from a GIS coverage published by the Montana State Library from data generated from the Abandoned Mines Bureau database in January of 1992. Because this coverage only shows the location of these mines, an area equal to the smallest priority mine was applied to each of the other mines to obtain an area for the model. Figure 3-4 shows the location of the modeled abandoned mines. Finally, two abandoned mine lands categories – Priority and Other – were added to the modeled land uses.

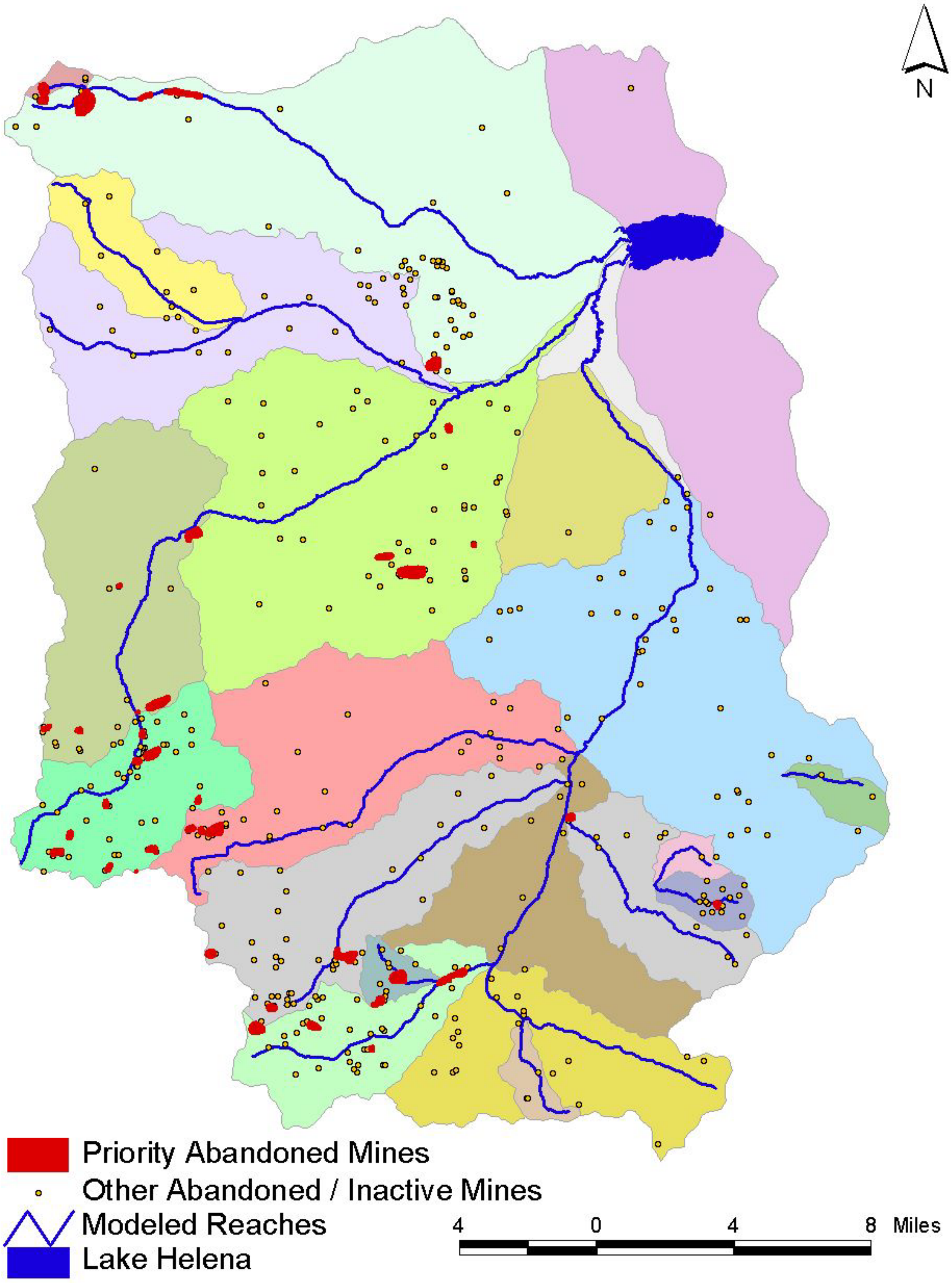


Figure 3-4. Abandoned mines in the Lake Helena watershed.

3.3.3 Final Land Uses for LSPC

For modeling purposes, MRLC land use classes having similar characteristics (i.e., infiltration rates, pollutant loads, etc.) were grouped together. The basis for the groupings was obtained from the MRLC land use definitions and best professional judgment. The final land use groupings provided the basis for estimating and distributing metals loads. Final land use categories included agriculture, shrubland, other abandoned mines, wetlands, priority abandoned mines, paved roads, dirt roads, permitted mines, non-system roads, quarries, full growth forest, timber harvest, grassland, and urban areas (Table 3-4).

Table 3-4. LCPS modeled land uses.

Land Use ID	LSPC Land Use Class	Acres
1	Forest	154,159
2	Grassland	131,525
3	Shrubland	37,015
4	Agriculture	36,456
5	Urban Areas	21,074
6	Paved Roads	1,904
7	Timber Harvest	4,093
8	Dirt Roads	3,326
9	Illegal Roads	153
10	Wetlands	1,691
11	Priority AML	1,272
12	Other AML	201
13	Permitted Mines	394
14	Quarries	182

3.4 Point Sources

Two facilities in the Lake Helena watershed currently have NPDES permits for metals – Montana Tunnels Mine (#MT0028428) and ASARCO (#MT0030147). Detailed information about these point sources can be found in Appendix E (Point Sources). The point sources were incorporated in the land use table as precipitation-driven permitted dischargers. The land infiltration properties were increased to represent settling ponds used to store site runoff. Modeled metals concentrations from these permitted facilities were set at permit limits. Permit limits for the Montana Tunnels facility are 0.29 mg/L for arsenic, 0.004 mg/L for cadmium, 0.01 mg/L for copper, 0.05 mg/L for lead, and 0.12 mg/L for zinc. ASARCO's permit limits are 1.140 mg/L for arsenic, 0.1374 mg/L for cadmium, 1.122 mg/L for copper, 0.239 mg/L for lead, and 0.77 mg/L for zinc. Table 3-5 shows the facility level information for these two point sources.

Table 3-5. Facility Level Information for Point Sources of Metals modeled with LSPC.

NPDES ID	MT0030147	MT0028428
Facility Name	ASARCO INC. (EAST HELENA)	MONTANA TUNNELS MINING, INC
Permit Type	STANDARD	STANDARD
Facility Type	INDUSTRIAL	INDUSTRIAL
SIC Description	PRMRY SMELT/NONFERROUS METALS	METAL ORES, NEC
County Name	LEWIS AND CLARK	JEFFERSON
Receiving Water	PRICKLY PEAR CREEK	PEN YAN CREEK
Latitude	+46 35 040	+46 21 260
Longitude	-111 55 110	-112 06 450

3.5 Soils

The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting (NRCS, 2001). Typically, clay soils that are poorly drained have the worst infiltration rates (D soils), while sandy soils that are well drained have the best infiltration rates (A soils). Hydrologic group data for the Lake Helena watershed were obtained from the State Soil Geographic (STATSGO) database. The data were summarized based on the major hydrologic group in the surface layers of the map unit (see Figure 3-5). Soils in the Lake Helena watershed are primarily classified as B and C, having moderate to slow infiltration rates when saturated. These hydrologic groups served as a starting point for the designation of infiltration and groundwater flow parameters during the LSPC setup.

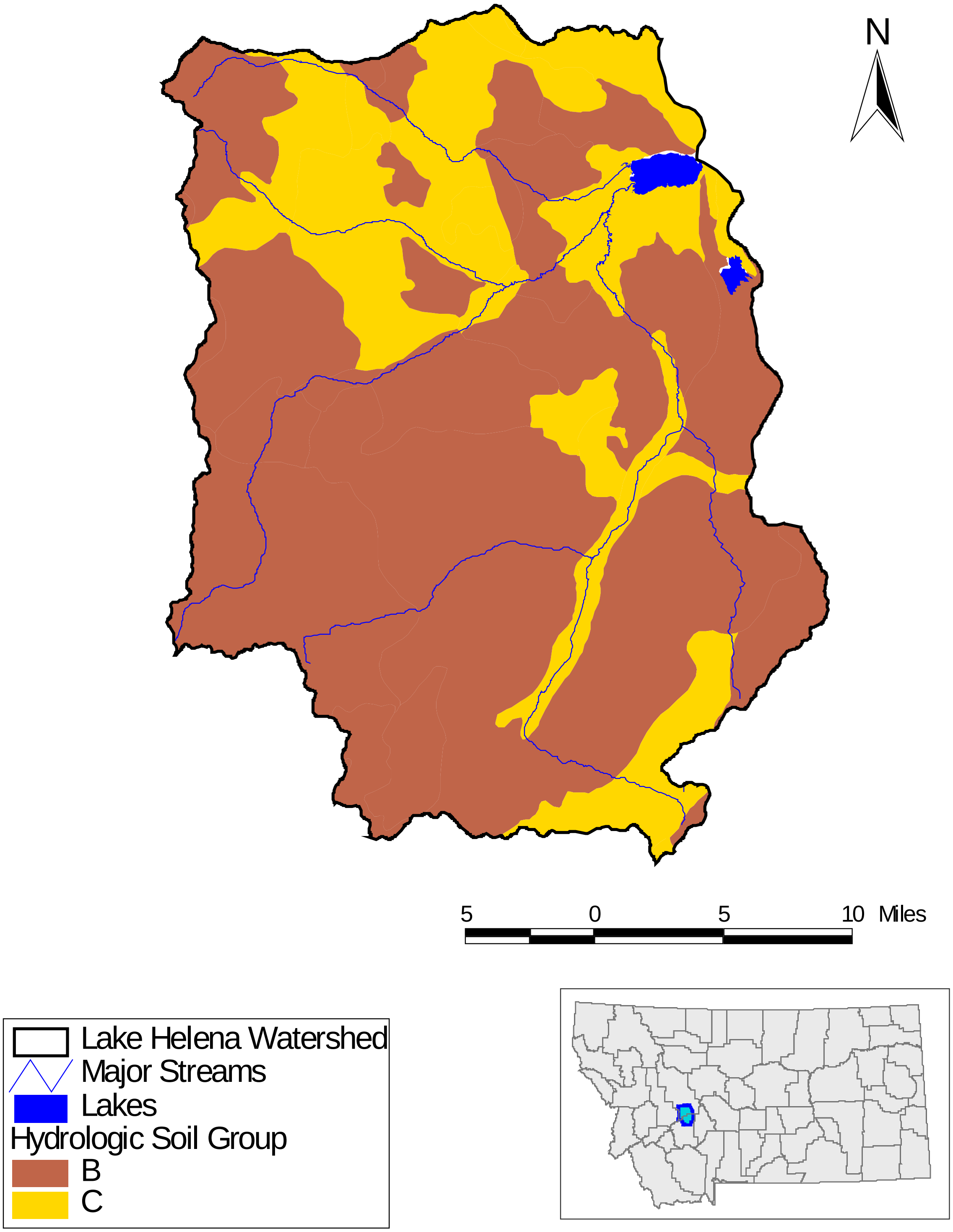


Figure 3-5. Distribution of hydrologic soil groups.

3.6 Meteorological Data

Hydrologic processes are time varying and depend on changes in environmental conditions such as precipitation, temperature, and wind speed. As a result, meteorological data are a critical component of watershed models.

Meteorological conditions are the driving force for non-point source transport processes in watershed modeling. Generally, the finer the spatial and temporal resolution available for meteorology, the more representative the simulation of associated watershed processes will be. At a minimum, precipitation and potential evapotranspiration are required as forcing functions for most watershed models. For the Lake Helena watershed, where the snowfall/snowmelt process is the most significant factor in watershed-wide hydrology, additional data were required for snow simulation. These data are temperature, dew point temperature, wind speed, and solar radiation. Upon reviewing the available weather data, it was concluded that there was only one adequate weather gage for the Lake Helena watershed – Helena Regional Airport Gage #244055.

Weather data from the Helena Regional Airport (elevation 1,167 m) was used to develop a 24-year input file with hourly time-series of data from January 1980 through December 2003. An hourly time step for weather data was required to properly reflect diurnal temperature changes (and the resulting influence on whether precipitation was modeled as rainfall or snow) and provide adequate resolution for rainfall/runoff intensity to drive erosion and water quality processes during storms or snowmelt events. Figure 3-6 and Figure 3-7 show average maximum and minimum daily temperatures and average daily precipitation at this location.

The mean elevation of each subwatershed was used to account for elevation effects on temperature and precipitation based on a comparison of mean annual precipitation and temperature at Austin, Montana (Coop ID 240375; elevation 1,493 m). For each meter increase in elevation, 0.03 cm/yr of precipitation were added and 0.0038 ºC were subtracted from the daily average temperature. SNOTEL data were not adequate to develop daily weather inputs for the high elevation subwatersheds, but annual average precipitation at the Frohner station was used to validate the elevation adjustments cited above. In general, yearly precipitation at Frohner was more stable than at the airport. Even though elevation effects were accounted for, dry years at the airport generally result in an underestimation of precipitation in the high elevation subwatersheds and an over prediction in extremely wet years.

The Helena Regional Airport weather gage is located in the Helena Valley, and it is recognized here that this gage does not necessarily represent weather conditions throughout the entire 620 square mile watershed. This is particularly true in the high elevation regions of the watershed, where precipitation may be more than twice the precipitation in the Helena Valley. The lack of weather stations is believed to be the largest source of error in the LSPC model.

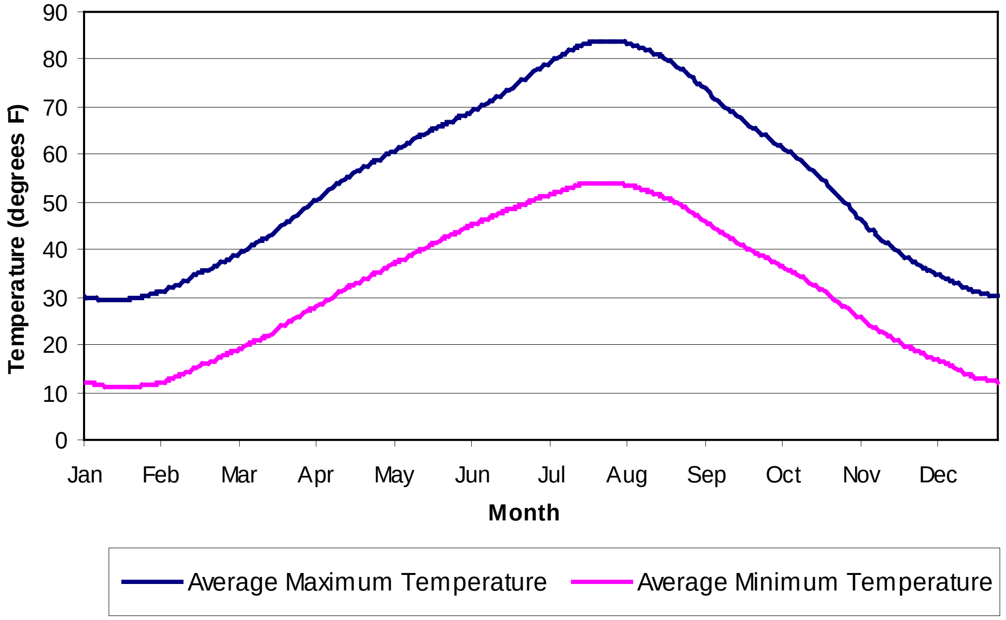


Figure 3-6. Average maximum and minimum temperatures at the Helena Regional Airport weather station.

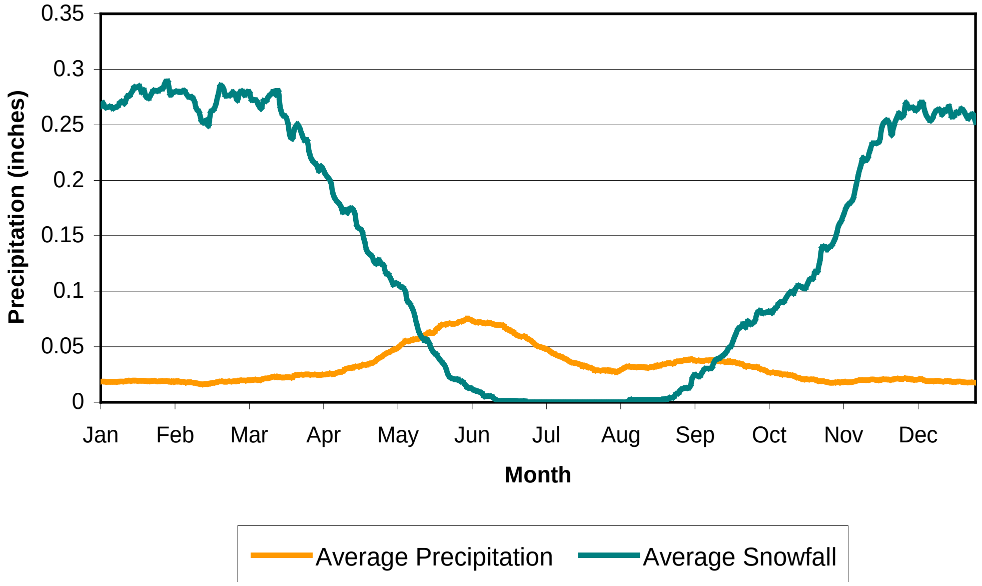


Figure 3-7. Average precipitation at the Helena Regional Airport weather station.

4.0 MODEL CALIBRATION

The model hydrology and water quality calibration process is described in this section. Background information on the locations of available flow and water quality data and the time periods of calibration are first presented, followed by a description of how key parameters were modified.

4.1 Hydrologic Calibration

Hydrologic calibration was performed after the initial model setup. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Calibration is based on several years of simulation to evaluate parameters under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed flows throughout the calibration period.

4.1.1 Hydrologic Calibration Methodology

The hydrologic calibration process involved a comparison of observed data to modeled in-stream flow and an adjustment of key parameters. Calibration gages were selected based on (1) long term period of record, (2) recent data, and (3) location within the Lake Helena watershed. Only one calibration gage was used for the Lake Helena watershed model – USGS gage 06061500 (Prickly Pear Creek near Clancy, Montana). The Tenmile Creek gage (06063000) was then used to validate the results from the Prickly Pear Creek calibration.

Modeling parameters were varied within generally accepted bounds and in accordance with observed temporal trends and soil and land cover characteristics (see Section 4.1.2). An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000).

Graphical results of model performance and error statistics were evaluated following each hydrologic simulation. Model parameters were adjusted following iterations to improve model performance. The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff. The full set of hydrologic parameters is available upon request from the Montana Department of Environmental Quality (see Section 5.0). A discussion of the key parameters and how they were adjusted is presented below in Section 4.1.2.

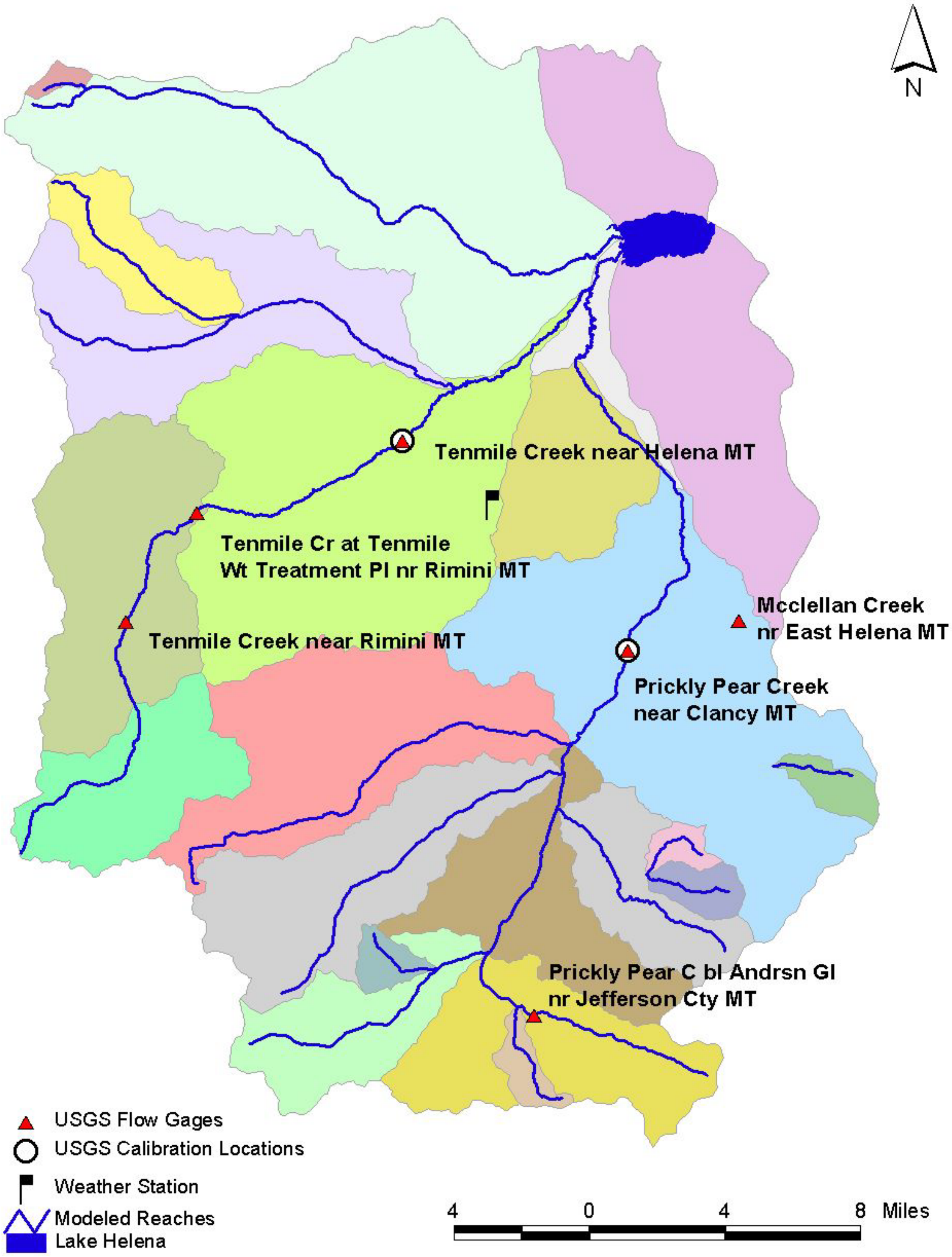


Figure 4-1. Location of hydrology and water quality calibration gages.

4.1.2 Hydrologic Calibration Parameters

The model performance is sensitive to the specification of the water-holding capacity of the soil profile (expressed through the nominal lower-zone storage, LZSN) and the infiltration rate index (INFILT), which together control the partitioning of water between surface and subsurface flow. The calibrated LZSN value was set at 6 inches. INFILT in HSPF is an *index* of infiltration rate and is not directly interpretable from measured field infiltration rates. BASINS Technical Note 6 recommends values in the range of 0.1 to 0.4 inches per hour for B soils, 0.05 to 0.1 inches per hour for C soils, and 0.01 to 0.05 inches per hour for D soils (USEPA, 2000). Values were re-optimized by starting from the center of the recommended ranges and modifying the value for each soil class proportionately. Final calibrated values ranged from 0.15 to 0.30 inches per hour.

Key parameters for the subsurface flow response include the ground water recession coefficient (AGWRC), and the interflow inflow and recession parameters (INTFW and IRC). AGWRC was set by optimizing model performance for baseflow recession. A final value of 0.999 (unitless) was determined for the Lake Helena watershed. Interflow recession should be fairly high in this landscape, and the interflow recession parameter was calibrated at 0.60 (unitless). Interflow was also calibrated at 0.60 (unitless).

Deep aquifer infiltration (DEEPFR) represents the fraction of infiltrating water that percolates to deep aquifers and is therefore “lost” water removed from the system. Within this watershed, DEEPFR was calibrated at 0.01 (unitless), suggesting that little water is lost from the system.

Monthly variability in hydrologic response was specified by setting monthly values the lower zone evapotranspiration parameter based on monthly weather conditions. Values specified are consistent with the range recommended in BASINS Technical Note 6 (0.1 to 0.9 unitless) (USEPA, 2000).

The parameters discussed above were the most sensitive in the hydrologic calibration, meaning that small changes had the largest effect on watershed hydrology. Other parameters, and their final calibrated values, are available upon request from the Montana Department of Environmental Quality (see Section 5.0).

Figure 4-2 is a schematic of how the snow process is simulated in LSPC. LSPC uses the Energy Balance method to simulate snowmelt contributions from the land surface derived from the fall, accumulation, and melting of snow (COE, 1956; Anderson Crawford, 1964; Anderson, 1968). The LSPC SNOW module uses information on atmospheric conditions to determine whether precipitation falls as rain or snow, how long the snowpack remains, and when snowpack melting occurs. Heat is transferred into or out of the snowpack through net radiation heat, convection of sensible heat from the air, latent heat transfer by moist air condensation on the snowpack, from rain, and through conduction from the ground beneath the snowpack. Melting occurs when the liquid portion of the snowpack exceeds its holding capacity and melted snow is added to the hydrologic cycle.

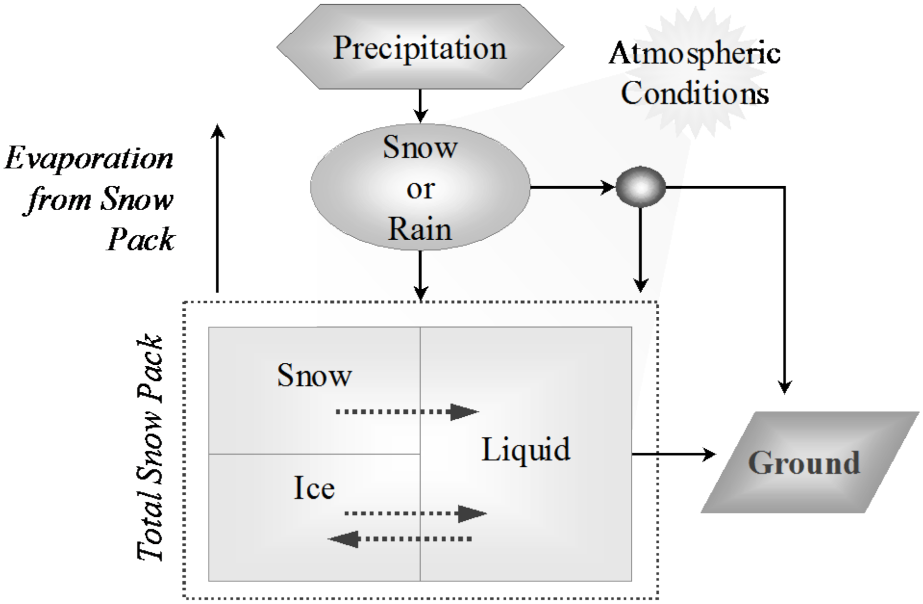


Figure 4-2. Snow simulation schematic.

Table 4-1 below summarizes the snow parameters and adjusted ranges for the Lake Helena watershed. Key calibration parameters for the winter snow simulation were revised from defaults during optimization and included the snow catch factor (SNOWCF, ratio that accounts for under-catch of snow in standard precipitation gages), the field adjustment parameter for heat accumulation in the snow pack (CCFACT), the maximum rate of snow melt by ground heating (MGMELT), and the difference between the mean elevation of a subwatershed and the gage elevation (ELDAT, to correct for temperature changes between the gage elevation and subwatershed elevation).

Table 4-1. Summary of snow module calibration.

Parameter	Description	Status	Default	Calibrated
ICEFG	Ice simulation switch, 1 = on or 0 = off	Turned on	1	1
FOREST	Forest land for winter transpiration (fraction)	By land use	N/A	0.1 – 0.8
LAT	Latitude of land segment (degrees)	From GIS	N/A	From GIS
MELEV	Mean elevation of land segment (ft)	From GIS	N/A	From GIS
ELDAT	Difference between MELEV and gage elevation (ft)	From GIS	N/A	From GIS
SHADE	Land shaded from solar radiation (fraction)	By land use	N/A	0.1 – 0.9
SNOWCF	Precipitation snow catch efficiency (multiplier)	By location	1.1 – 1.5	1.35
COVIND	Water equivalent for complete land coverage (in)	Constant	1.0 – 3.0	2.0
RDCSN	Density of new snow relative to water (in/in)	Constant	0.1 – 0.2	0.15
TSNOW	Air temperature for snowfall (degrees F)	By location	31 – 33	32.0
SNOEVP	Snowpack sublimation coefficient (unitless)	Constant	0.1 – 0.15	0.15
CCFACT	Condensation/convection coefficient (unitless)	By location	1.0 – 2.0	2.0
MWATER	Maximum water content of snow (in/in)	Constant	0.01 – 0.05	0.01
MGMELT	Maximum ground snowmelt rate (in/day)	Constant	0.01 – 0.03	0.01

4.1.3 Evaluation of Hydrologic Calibration

Hydrologic calibrations were evaluated by using a time series comparison of daily, monthly, seasonal, and annual values; storm events, low flows and high flows. Composite comparisons (e.g., average monthly values over the period of record) were also made. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters.

4.1.3.1 Graphical Comparisons

Graphical comparisons are extremely useful for judging the results of model calibration because time-variable plots of observed versus modeled flow provide insight into the model’s representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. Graphical comparisons consisted of time series plots of observed and simulated values for flows, observed versus simulated scatter plots with a 45^o linear regression line displayed, and observed versus simulated seasonal flows.

Figure 4-3 shows the observed data and graphical calibration model results for station 06061500 (Prickly Pear Creek near Clancy, Montana). The first plot (upper left) shows monthly-average simulated flow versus monthly average observed flow. The closer the data comes to the 45° angle line, the better the two data sets match. The plot suggests that some months are well correlated, and others are not. The plot does not provide information about which months are well or poorly calibrated. The second plot (upper right) shows the water balance between the observed and simulated monthly flows. In this plot, the 50 percent line indicates that the observed and modeled flows are equal. As shown in the graph, the water balance varies from month to month, but generally varies about the 50 percent line. This suggests that as a whole (all months), monthly flows are well calibrated. The third graph (middle center) shows a time series of average modeled and observed flow. Average flows are well correlated during the baseflow months (October through March). However, it appears that snowmelt is less calibrated. The initial simulated snowmelt, occurring in April of each year, is well correlated with the observed snowmelt. Later in the season (July and August), snowmelt is still occurring in the modeled flows, but not in the observed flows. The fourth plot (bottom center) verifies this. The fourth plot also suggests that there are errors with the storm event simulation. This is expected because of the limited weather data, and lack of high elevation weather stations.

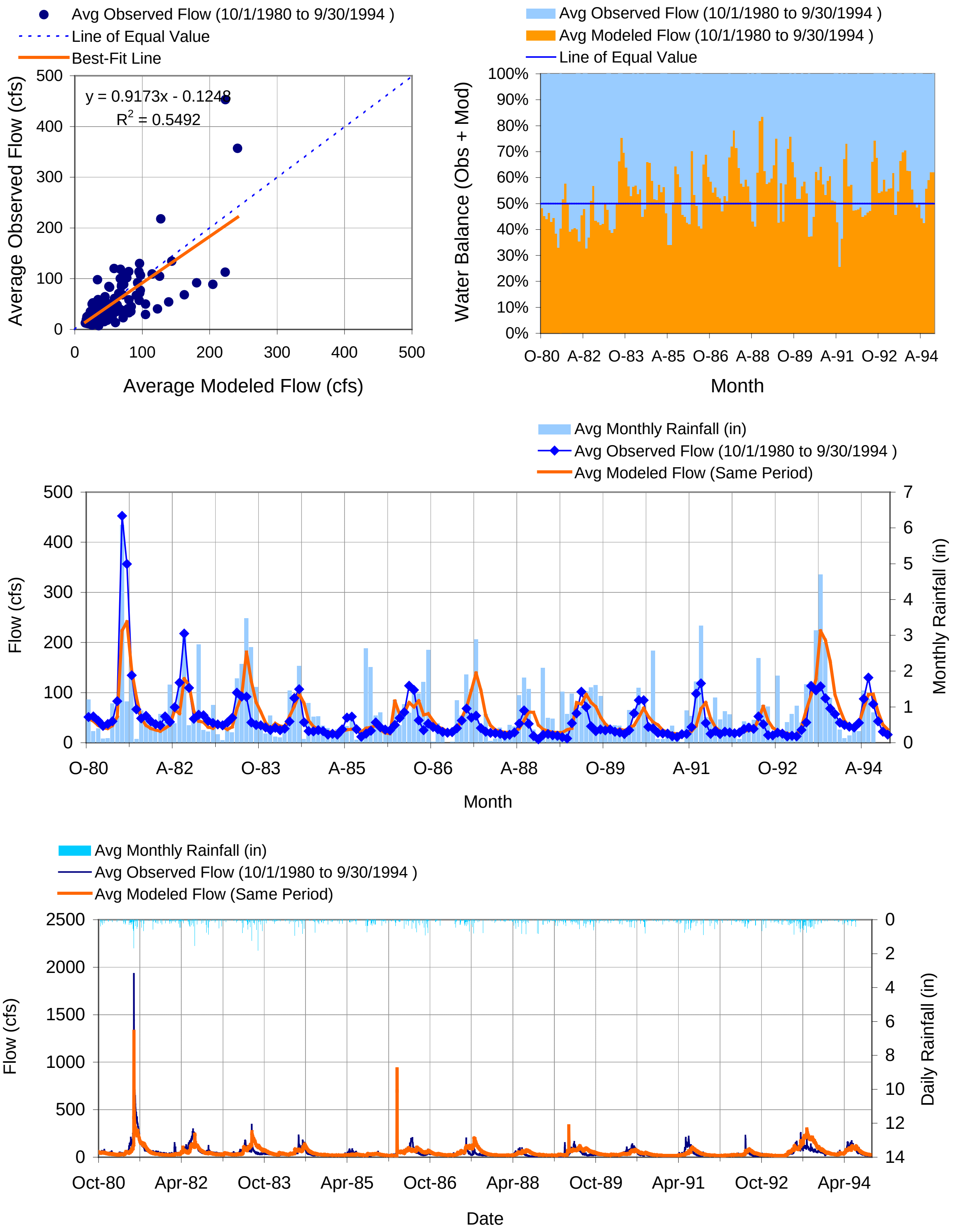
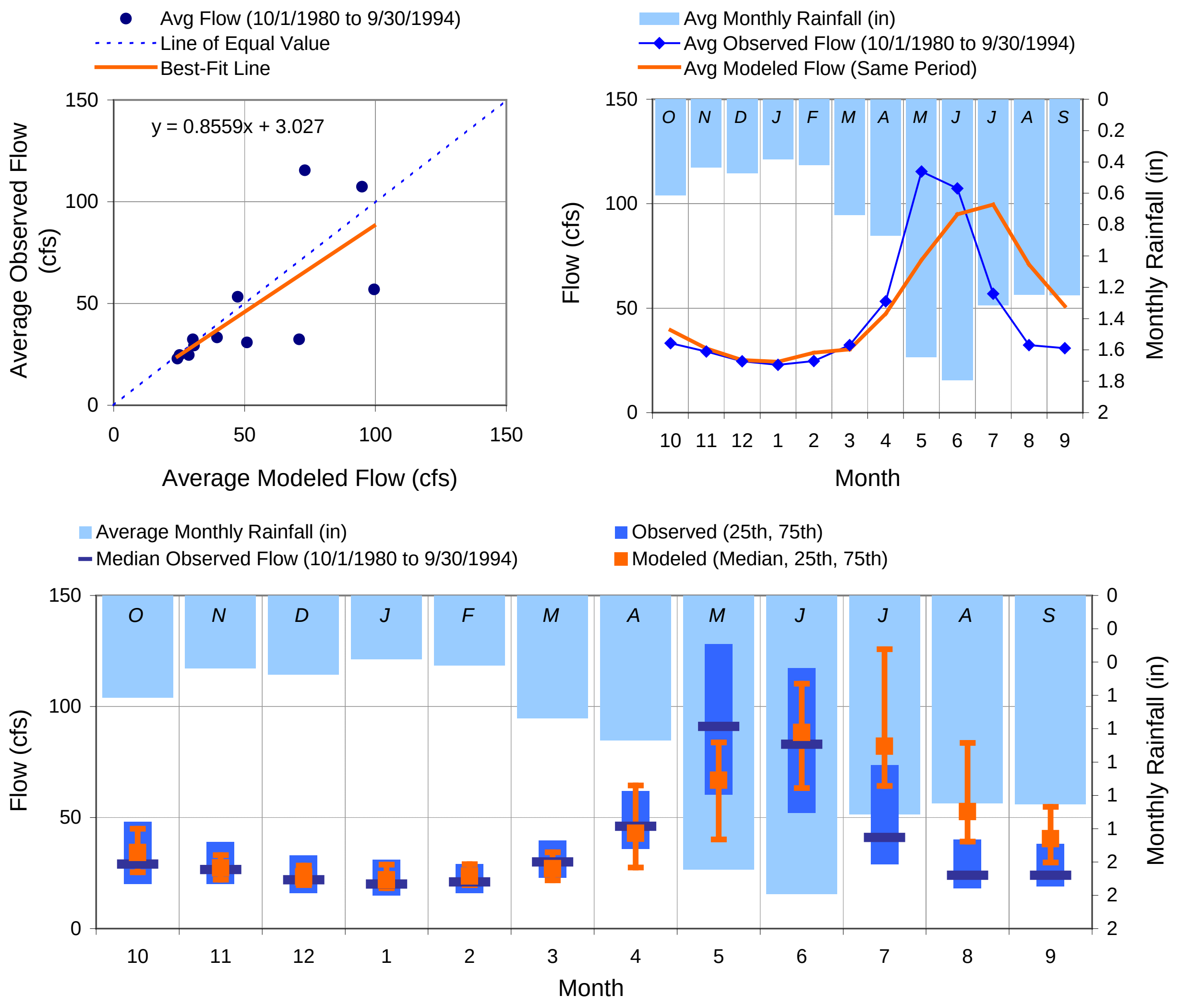


Figure 4-3. Observed versus modeled flows at USGS gage 06061500 – Prickly Pear Creek near Clancy MT.

Figure 4-4 shows the yearly composite calibration analysis for USGS gage 06061500 (Prickly Pear Creek near Clancy, Montana), which represents seasonal hydrologic patterns. All data within the time period is collapsed into a representative-year profile. Average flows, as well as monthly medians, and percentile ranges are used to evaluate the general tendency of the model to represent the observed seasonal variability.

The first plot (upper left) shows the correlation between yearly average observed and modeled flows. Years with less flow (i.e., less snowpack) are most similar, having a strong correlation. As average yearly flows increase, the correlation between simulated and observed average yearly flows decreases. This is mostly because of the errors in the snowmelt simulation, as described in the previous paragraphs. The snowmelt issues are further exemplified in the second plot (upper right). Total yearly flow appears to be similar between the observed and simulated data. The observed data shows that the majority of snowmelt occurs in April, May, and June, while the simulated data suggests that snowmelt occurs primarily in May through August – a longer time period, and later in the year. The third plot (middle center) confirms this analysis. The model is well calibrated from October through April.



MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	33.25	29.00	20.00	48.00	39.47	34.25	25.37	45.00
Nov	29.28	26.50	20.00	39.00	30.70	27.28	22.10	33.13
Dec	24.62	22.00	16.00	33.00	25.20	23.26	19.60	28.38
Jan	22.84	20.00	15.00	31.00	24.40	21.93	18.17	28.84
Feb	24.64	21.00	16.00	29.00	28.69	23.68	19.58	29.01
Mar	32.31	30.00	23.00	39.75	30.30	26.99	21.75	34.34
Apr	53.25	46.00	36.00	62.00	47.36	42.94	27.53	64.42
May	115.38	91.00	60.25	128.00	73.02	66.83	40.15	83.87
Jun	107.31	83.00	52.00	117.25	94.89	88.29	63.31	110.27
Jul	56.92	41.00	29.00	73.75	99.54	82.12	64.24	125.86
Aug	32.37	24.00	18.00	40.00	70.86	52.66	39.14	83.58
Sep	30.83	24.00	19.00	38.00	50.94	40.45	29.78	54.83

Figure 4-4. Composite analysis of observed versus modeled flow at USGS gage 06061500 – Prickly Pear Creek near Clancy MT.

4.1.3.2 Statistical Evaluation

Error statistics for USGS gage 06061500 (Prickly Pear Creek near Clancy, Montana) were calculated and compared to criteria recommended for HSPF. Errors are determined by comparing simulated flow values to observed flow values for various time periods (e.g., for the highest flow periods) using the following equation:

$$\text{Re}\,lativeErro\mathbf{r} = \frac{\mathbf{SimulatedValue - ObservedValue}}{\mathbf{ObservedValue}} \times 100$$

One goal of the calibration process is to reduce the relative error to less than the recommended criteria for as many flow categories as possible. The following recommended criteria (i.e., accepted level of error between modeled and observed flows) were used:

- Error in total volume: ±10%
- Error in 50% lowest flows: ±10%
- Error in 10% highest flows: ±15%
- Seasonal volume error - Summer: ±30%
- Seasonal volume error - Fall: ±30%
- Seasonal volume error – Winter: ±30%
- Seasonal volume error - Spring: ±30%
- Error in storm volumes: ±20%
- Error in summer storm volumes: ±50%

These error statistics were chosen to insure that the hydrologic calibration was adequate for the entire period evaluated, for all seasons, and for all flow events.

Table 4-2 shows the error statistics for USGS gage 06061500. Modeled flows from 1980 to 1994 were compared to the observed flows during the same time period. The total volume of water was well correlated, with the simulated volume only having 8.57 percent more water than observed. Simulated low flows (50th percentile and lower) were 17.40 percent higher than observed flows. This is expected, as irrigation, diversions, and dams regulate much of the low flow events in the Lake Helena watershed, and there were limited data to properly simulate these conditions. Additional detailed data about diversions and dams would improve this error. During high flow events (highest 10 percent of flows), modeled flows were 5.80 percent lower than observed flows. As shown by the graphs, this is primarily due to the limited weather station coverage, and the resulting storm event errors. This is verified by the storm event statistics. Simulated storm volumes were 89.73 percent less than measured, and summer storm volumes were 59.34 percent less than measured.

Seasonal statistics revealed that the hydrologic calibration was good for the winter and fall (October through March), when base flows and lack of diversions help to insure a well-calibrated model. Summer flows were highly over predicted (45.78 percent more than observed), again because the simulated snowmelt was delayed (see Section 4.1.3.1). For the same reason, the spring error statistic indicated that simulated volumes were less than observed.

Table 4-2. Error statistics for observed versus modeled flows at USGS gage 06061500 – Prickly Pear Creek near Clancy MT.

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 202 14-Year Analysis Period: 10/1/1980 - 9/30/1994 Flow volumes are normalized, with total observed as 100		**USGS 06061500 Prickly Pear Creek near Clancy MT** Jefferson County, Montana Hydrologic Unit Code 10030101 Latitude 46°31'09", Longitude 111°56'45" NAD27 Drainage area 192.00 square miles	
Total Simulated In-stream Flow:	**109.37**	Total Observed In-stream Flow:	**100.00**
Total of simulated highest 10% flows:	**33.34**	Total of Observed highest 10% flows:	**35.28**
Total of Simulated lowest 50% flows:	**26.44**	Total of Observed Lowest 50% flows:	**21.83**
Simulated Summer Flow Volume (months 7-9):	**39.68**	Observed Summer Flow Volume (7-9):	**21.52**
Simulated Fall Flow Volume (months 10-12):	**17.05**	Observed Fall Flow Volume (10-12):	**15.57**
Simulated Winter Flow Volume (months 1-3):	**14.60**	Observed Winter Flow Volume (1-3):	**14.01**
Simulated Spring Flow Volume (months 4-6):	**38.05**	Observed Spring Flow Volume (4-6):	**48.90**
Total Simulated Storm Volume:	**2.47**	Total Observed Storm Volume:	**4.68**
Simulated Summer Storm Volume (7-9):	**0.73**	Observed Summer Storm Volume (7-9):	**1.16**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	8.57	10		
Error in 50% lowest flows:	17.40	10		
Error in 10% highest flows:	-5.80	15		
Seasonal volume error - Summer:	45.78	30		
Seasonal volume error - Fall:	8.66	30		
Seasonal volume error - Winter:	3.99	30		
Seasonal volume error - Spring:	-28.52	30		
Error in storm volumes:	-89.73	20		
Error in summer storm volumes:	-59.34	50		

4.1.3.3 Hydrologic Calibration Summary

Overall, the hydrologic calibration for Prickly Pear Creek (USGS gage 06061500) is adequate for the goals of this project. At a yearly scale, water volume is well calibrated, and well suited for calculating yearly loads. October through March are also well calibrated for flow, and could be used to calculate monthly loads. Months typically associated with high flows resulting from snowmelt are not as well calibrated at the monthly scale. Snowmelt and storm event errors prevent management decisions based on daily or weekly loads. At the yearly scale, the model is appropriate for evaluating the extent and location of pollutant loads and sources. The model is also appropriate for assigning TMDLs (calculated at a yearly scale) to pollutant sources. Additional model uncertainties and uses are discussed in Section 4.3.

4.2 Water Quality Calibration

After hydrology was sufficiently calibrated, water quality calibration was performed. The water quality calibration consisted of running the watershed model, comparing water quality output to available water quality observation data, and adjusting pollutant loading and in-stream water quality parameters within a reasonable range. Figure 4-5 shows the 114 stations that were analyzed during the water quality calibration process. Recent data (1997-2003) were used for the calibration process to insure that current conditions were simulated. Most of the data was collected by USGS, USEPA, and Montana DEQ. In-stream water quality data from other sources was limited to a few segments.

The objective was to best simulate low flow, mean flow, and storm peaks at water quality monitoring stations representative of different regions of the basin (and different land uses, in particular). Modeling parameters were varied within generally accepted bounds and in accordance with observed temporal trends and soil and land cover characteristics. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000).

Graphical results of model performance were evaluated following each water quality simulation. Model parameters were adjusted following iterations to improve model performance. The full set of water quality parameters are included in Section 5.0 and a discussion of the key parameters and how they were adjusted is presented below in Section 4.2.1.

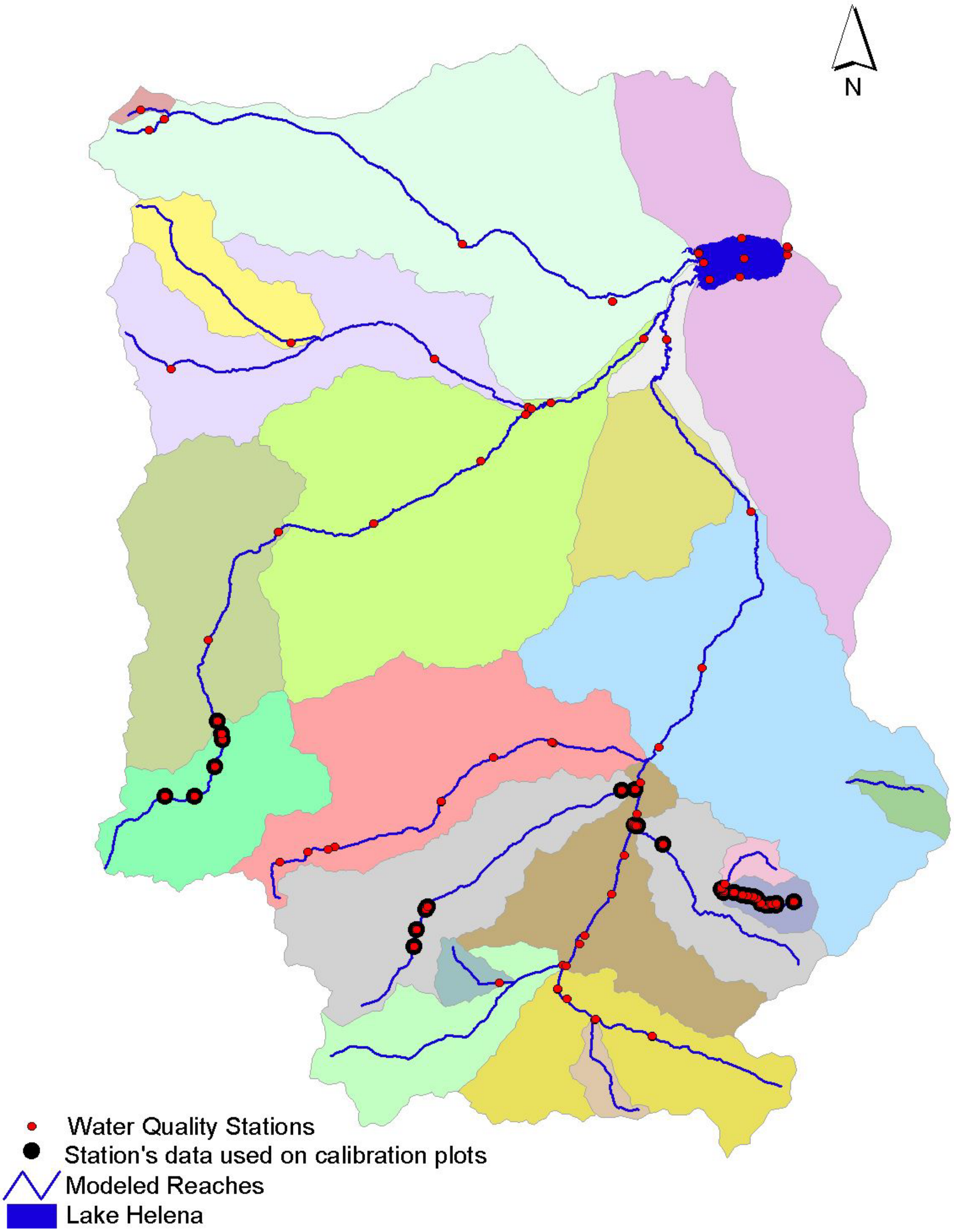


Figure 4-5. Location of water quality monitoring stations in the Lake Helena watershed.

4.2.1 Water Quality Calibration Parameters

In this modeling exercise, the results of the GWLF sediment model (see Appendix C) were replicated with LSPC for the different land use categories modeled. Once the sediment loads were matched, a distribution parameter, K_d, along with the average concentration of each metal in bottom sediments (Table 4-3) were applied as "potency factors" to estimate sediment-related metals loading by land use. All sediment was assumed to have the same concentration of metals.

Table 4-3. Distribution Parameter and Average metals sediment concentration.

Metal	Distribution Parameter, K_d (L/kg)	Average concentration in sediment (ug/g)
Arsenic	1×10^5	28.61
Cadmium	1×10^5	1.61
Copper	3×10^5	200.93
Lead	2×10^5	39.95
Zinc	1×10^5	158.66

Once the link between sediment sources and metals was established, additional pathways of metals loading were modeled from abandoned mine lands. This was done using the GQUAL parameters of the PERLND module of LSPC. The objective was to model additional source loading from the mines that occurs almost constantly (i.e. not-sediment related loads) and would correspond to metals in dissolved form, (e.g. seeps and adit discharges).

LSPC's PERLND module simulates water quality processes that occur on pervious land surfaces. The module simulates the movement of water and constituents in overland flow, interflow, and groundwater flow. Important calibration parameters included the pollutant concentration adjustment associated with interflow (IOQC) and the pollutant concentration adjustment associated with groundwater flow (AOQC). All other land uses were assumed to add metals to the stream channels only through the sediment loading, so the IOQC and AOQC values for all the other land uses were set to zero. During calibration, the parameter values of IOQC and AOQC for abandoned mines were adjusted so that the modeled stream concentrations during baseflow would closely match the observed baseflow concentration of metals in the streams. The parameter that most influenced the calibration was that of AOQC. Finally, permitted mines were modeled with their permitted concentrations at all times.

Table 4-4 presents the average calibrated IOQC and AOQC parameter values for the metals of concern.

Table 4-4. Average IOQC and AOQC Parameter Values for Abandoned Mines.

Metal	IOQC (mg/L)	AOQC (mg/L)
As	7.155	7.526
Cd	0.134	0.183
Cu	1.844	3.286
Pb	1.797	2.838
Zn	19.753	43.948

4.2.2 Evaluation of the Water Quality Calibration

Results of the water quality calibration at selected gages are shown in Figure 4-6 through Figure 4-25 and are discussed below.

Measured metals data (arsenic, cadmium, copper, lead, and zinc) indicate that metals concentrations are relatively constant during base flow events at all stations. Concentrations appear to vary mostly in response to storm events, with summer storm events producing the highest recorded metals concentrations. The calibration plots indicate that metals concentrations during baseflow events were well simulated with the LSPC model.

High metals concentrations appear to be correlated with high flows, and specifically from intense storm events producing overland runoff. The result is a “first flush” of metals with the storm event, producing short but intense concentrations spikes. As described in Section 4.1, it was difficult to model storm events and snowmelt because of the lack of weather gages, particularly at higher elevations. This resulted in a poor hydrologic match during some time periods. However, the total water volume was well correlated at the flow calibration gage in Prickly Pear Creek (8.57 percent error statistic) (see Table 4-2). The result of over and under predicting storm events and snowmelt over a long period of time is that the total volume of water is well calibrated. The same phenomenon appears to be true with the water quality data.

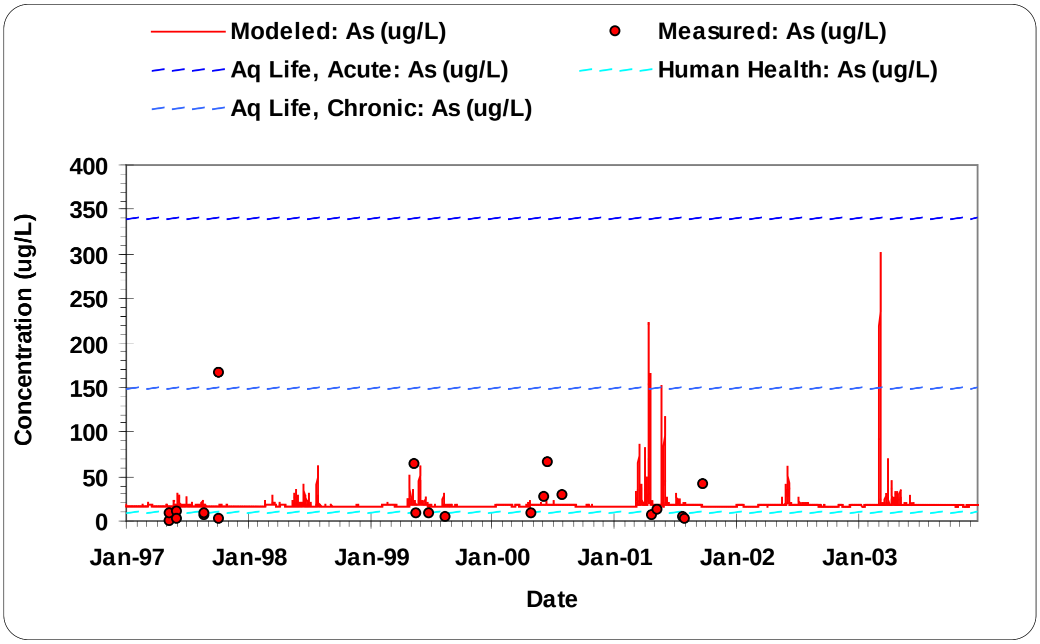


Figure 4-6. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Arsenic.

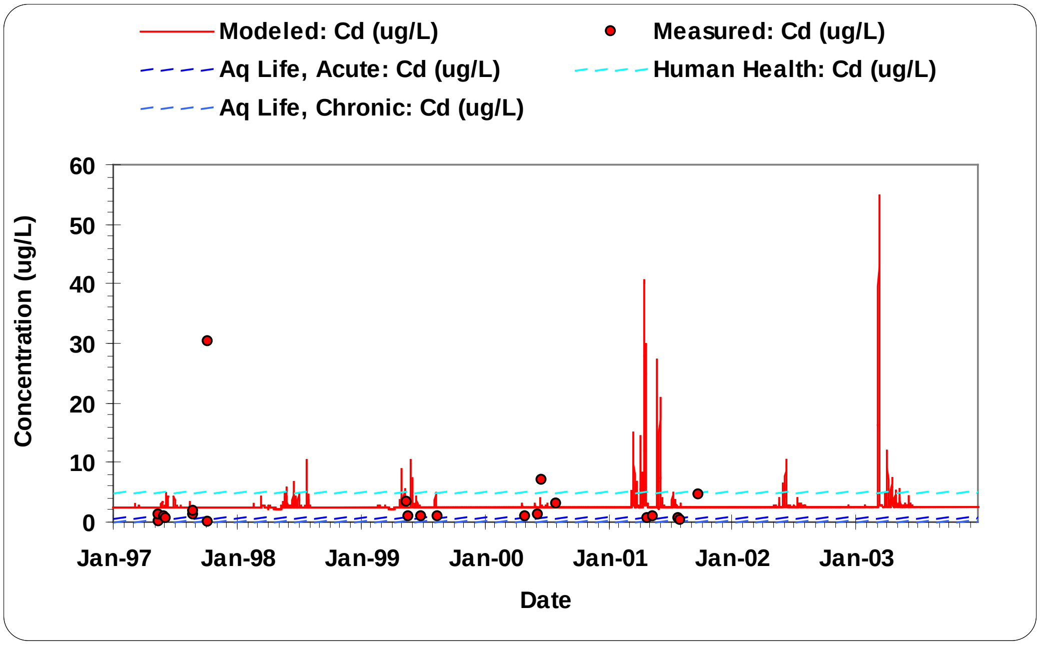


Figure 4-7. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Cadmium.

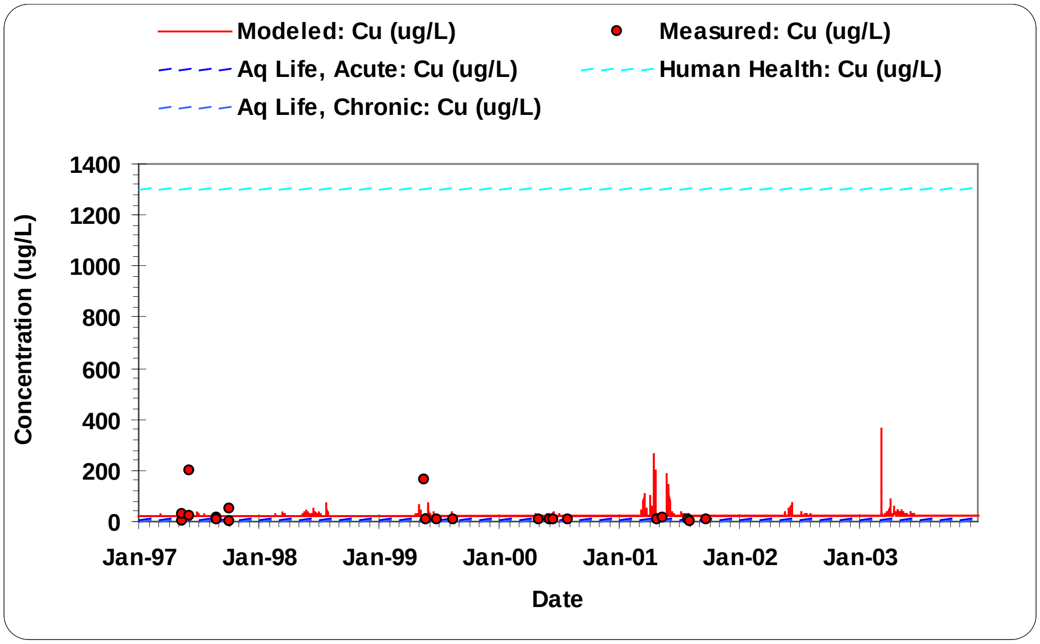


Figure 4-8. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Copper.

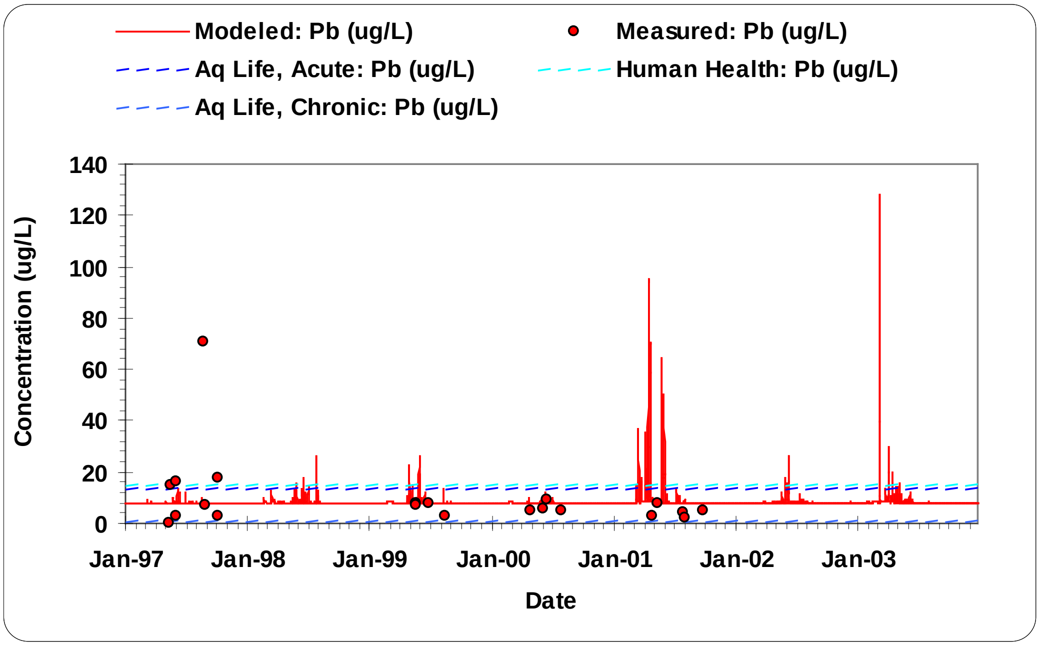


Figure 4-9. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Lead.

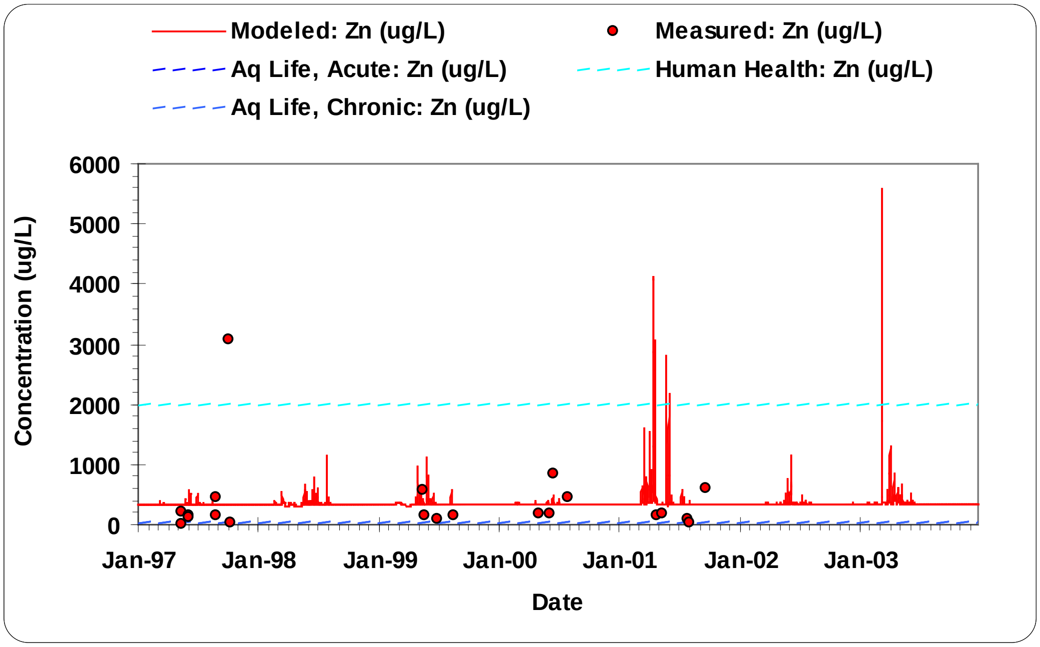


Figure 4-10. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Zinc.

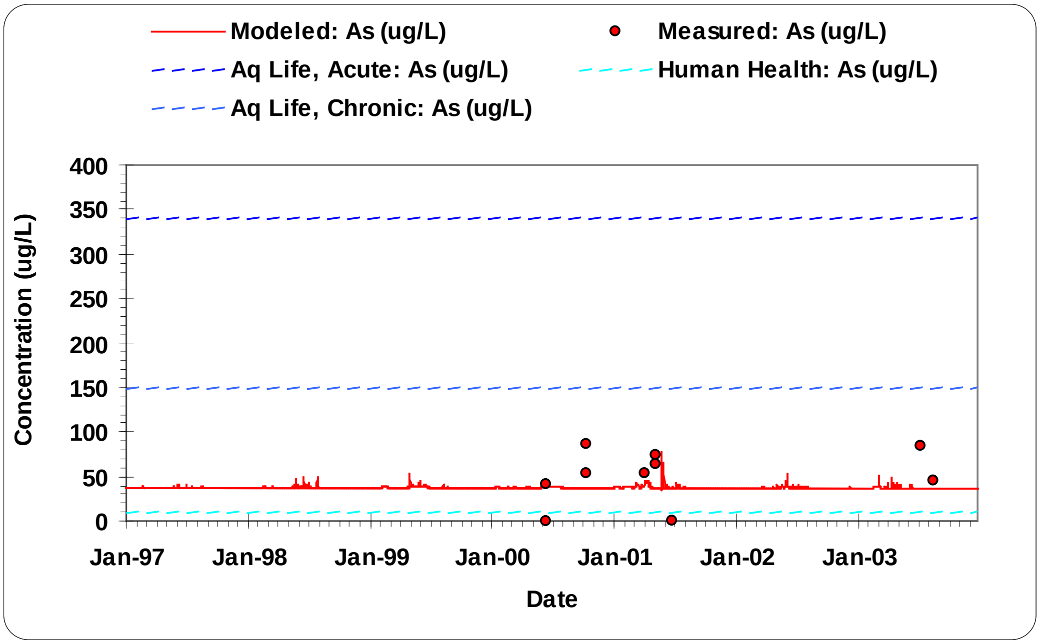


Figure 4-11. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Arsenic.

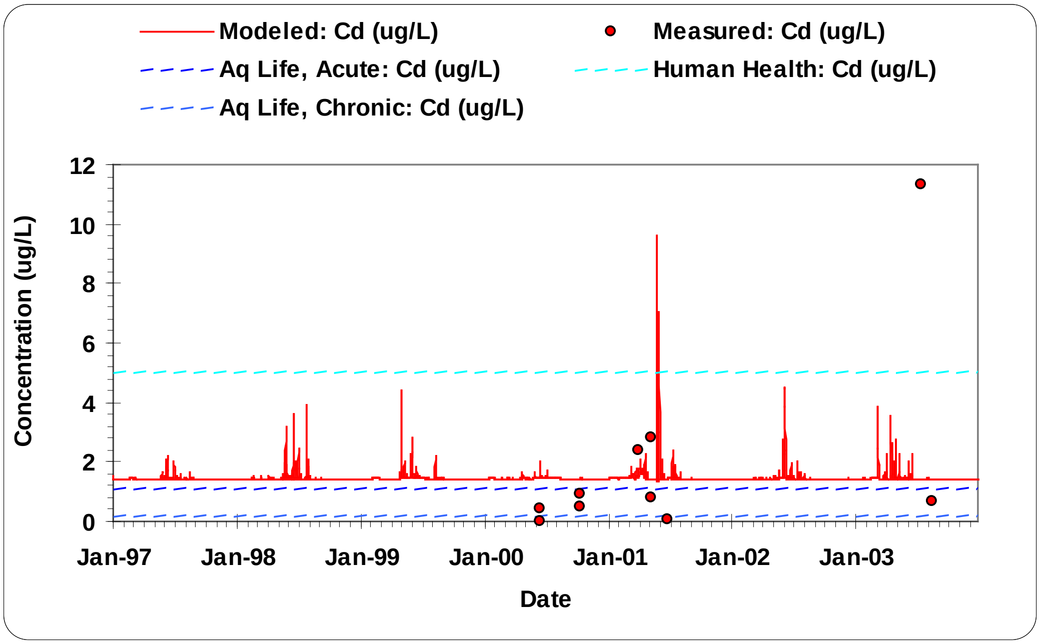


Figure 4-12. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Cadmium.

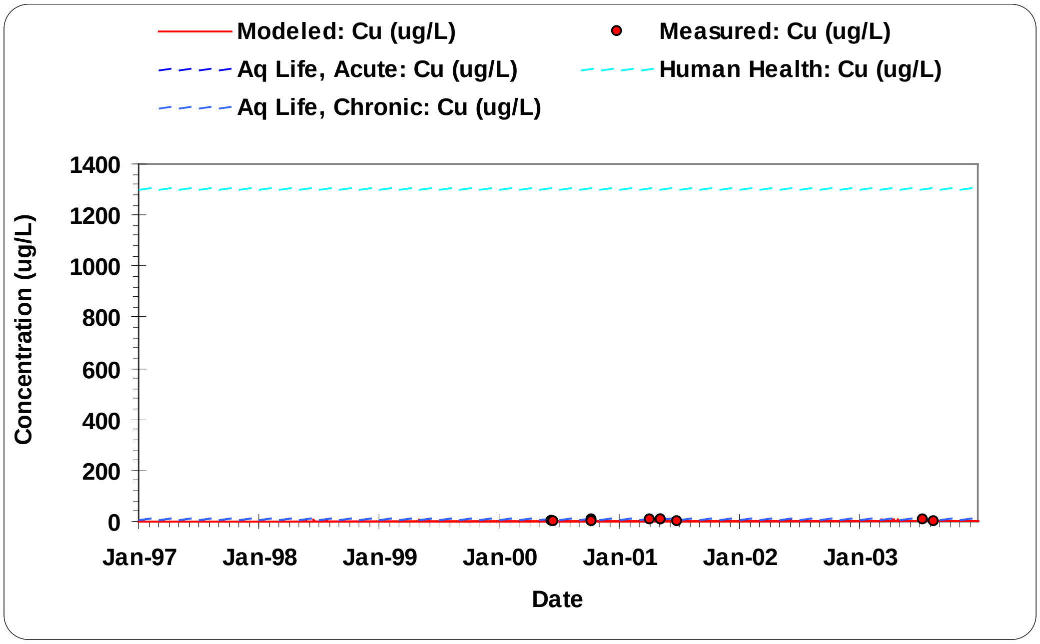


Figure 4-13. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Copper.

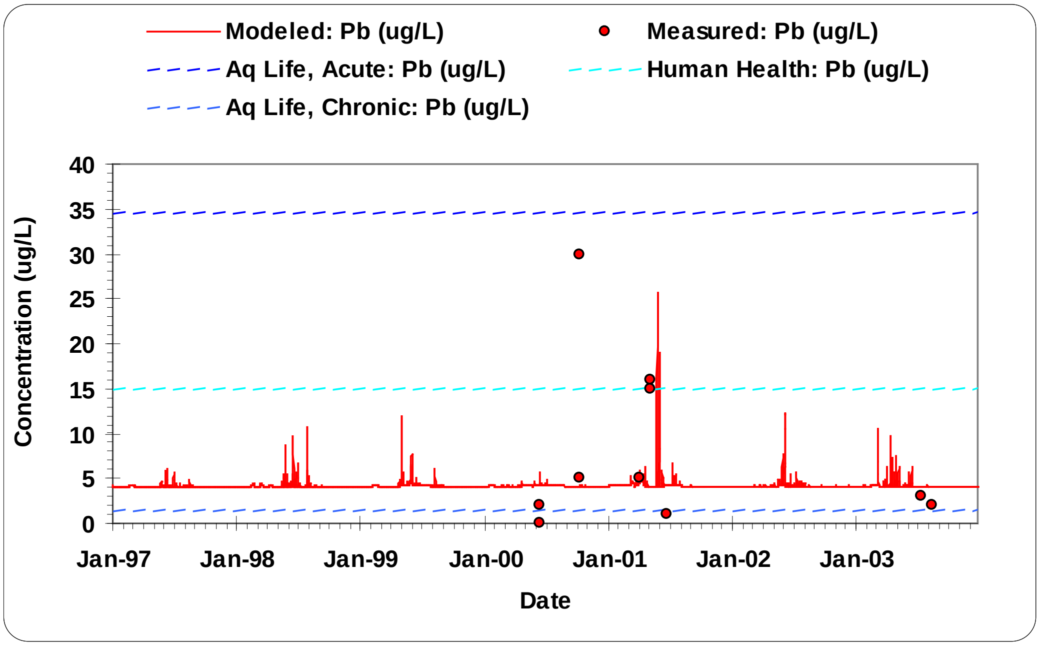


Figure 4-14. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Lead.

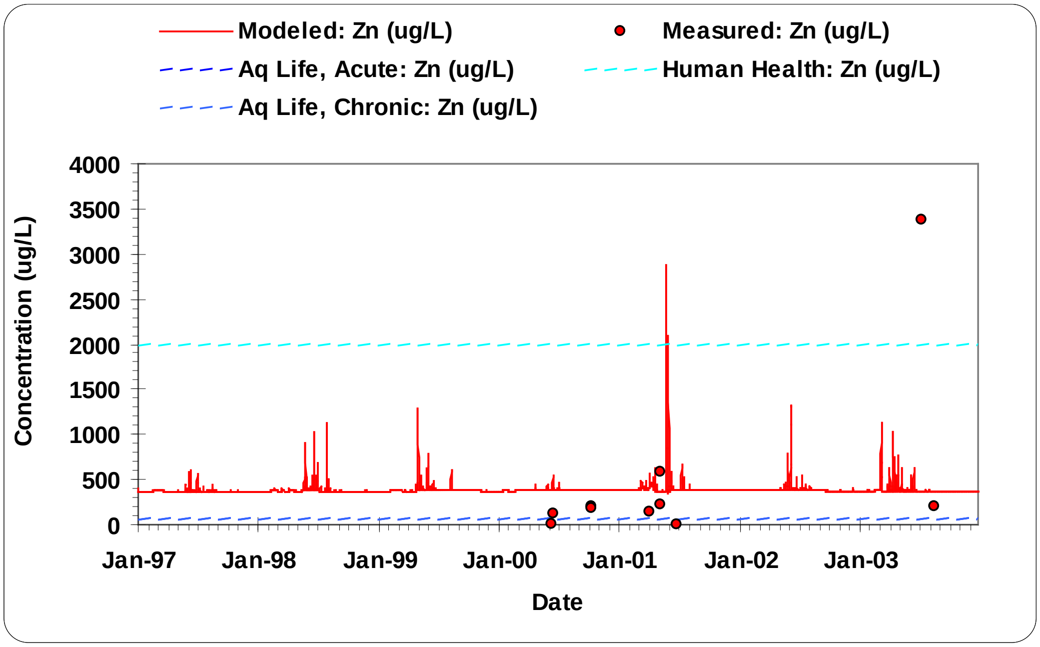


Figure 4-15. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Zinc.

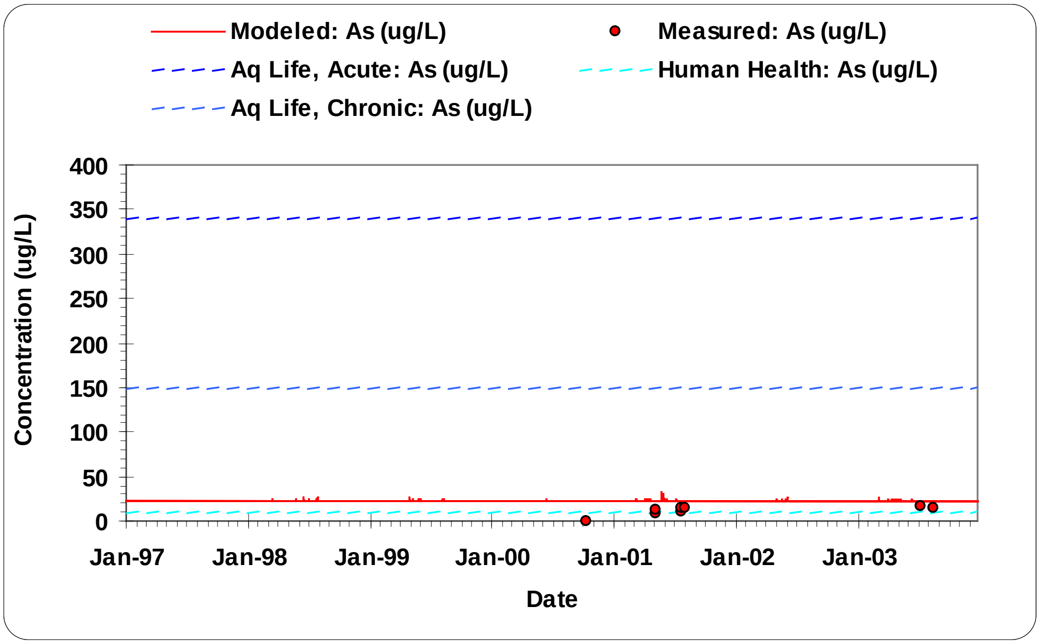


Figure 4-16. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Arsenic.

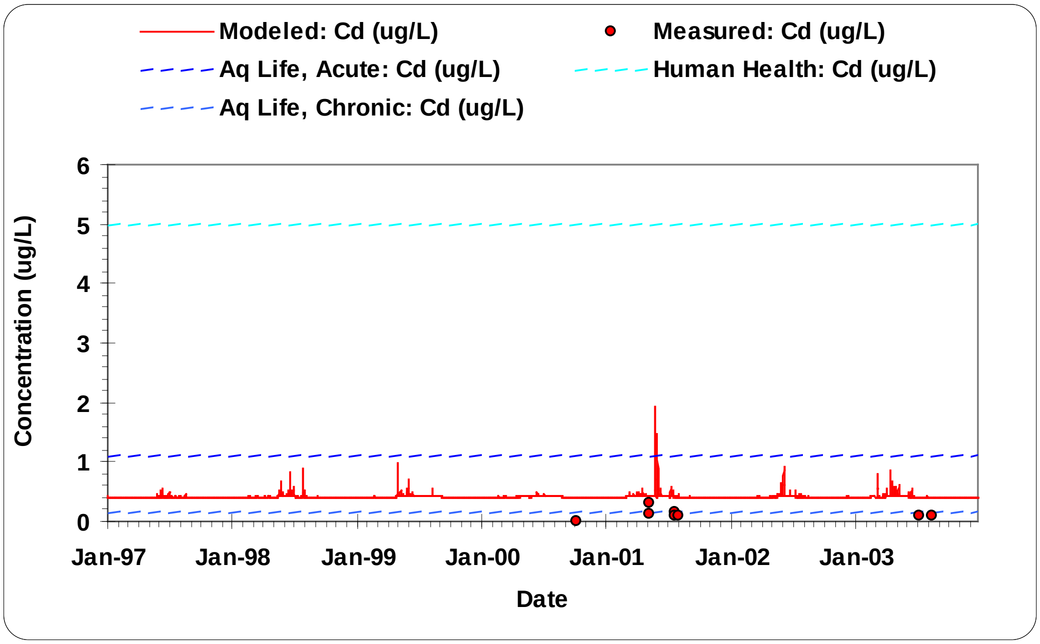


Figure 4-17. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Cadmium.

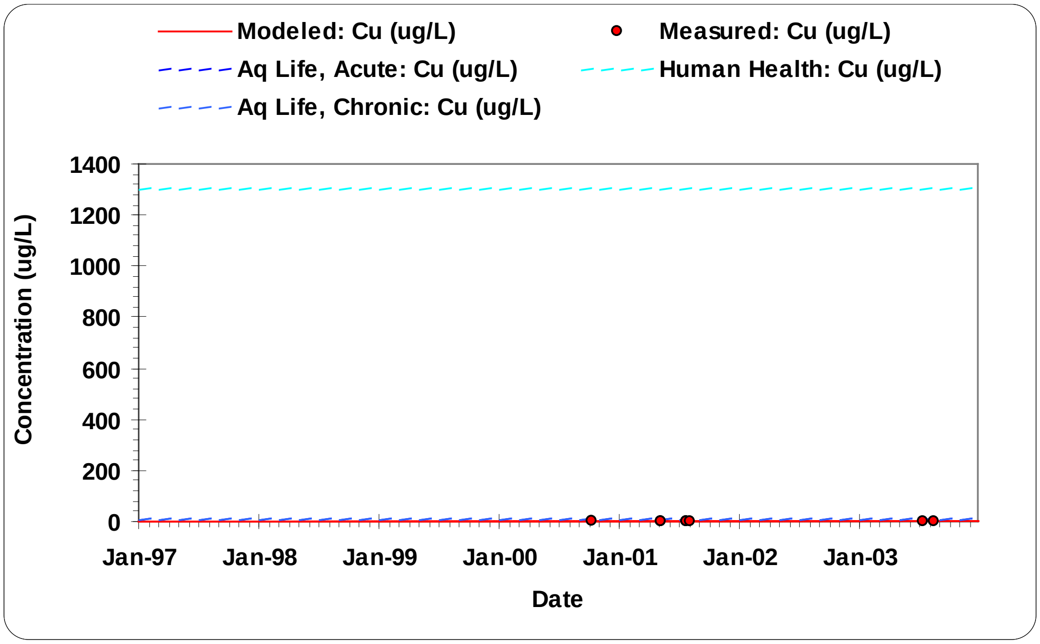


Figure 4-18. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Copper.

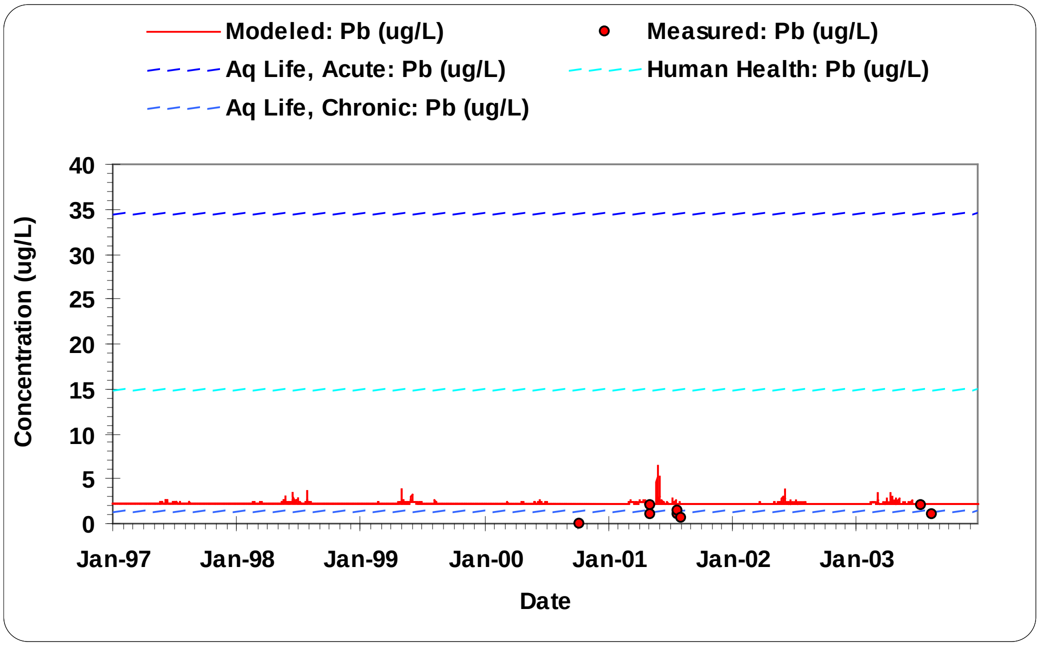


Figure 4-19. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Lead.

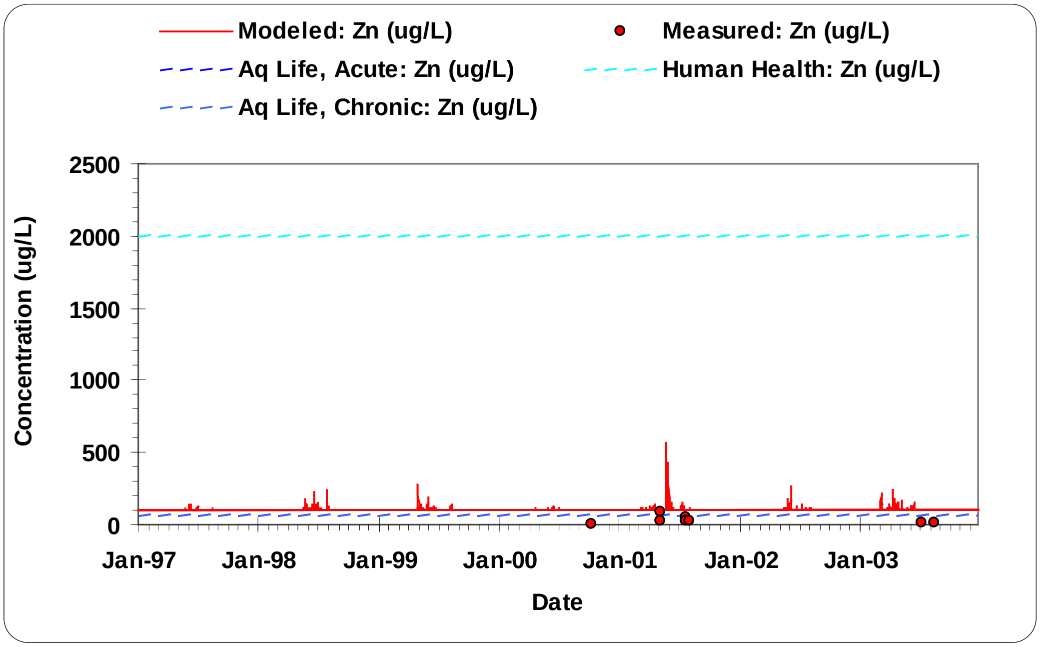


Figure 4-20. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Zinc.

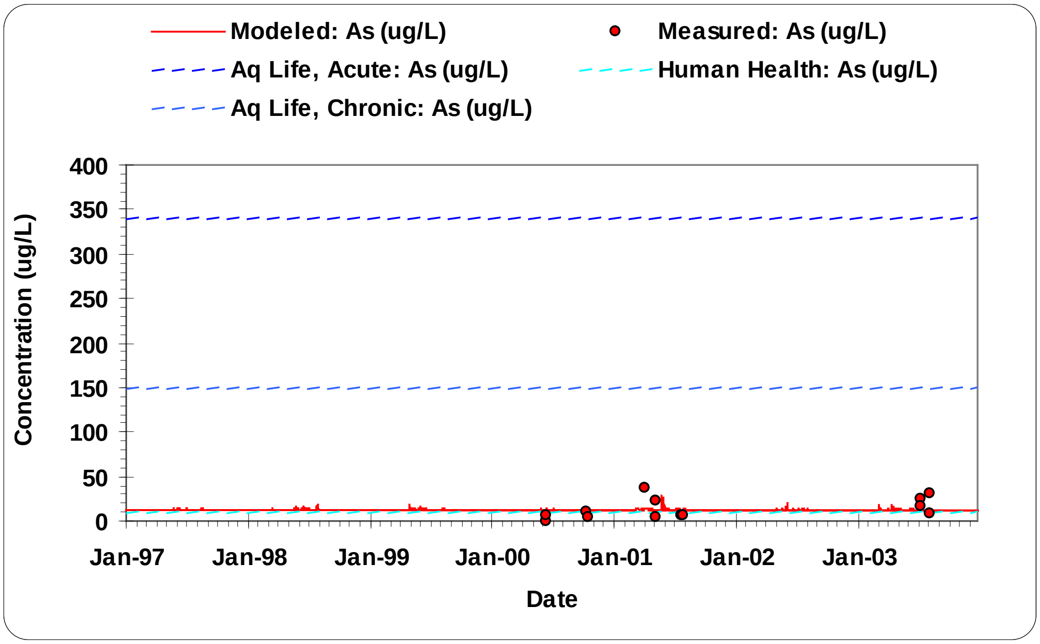


Figure 4-21. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Arsenic.

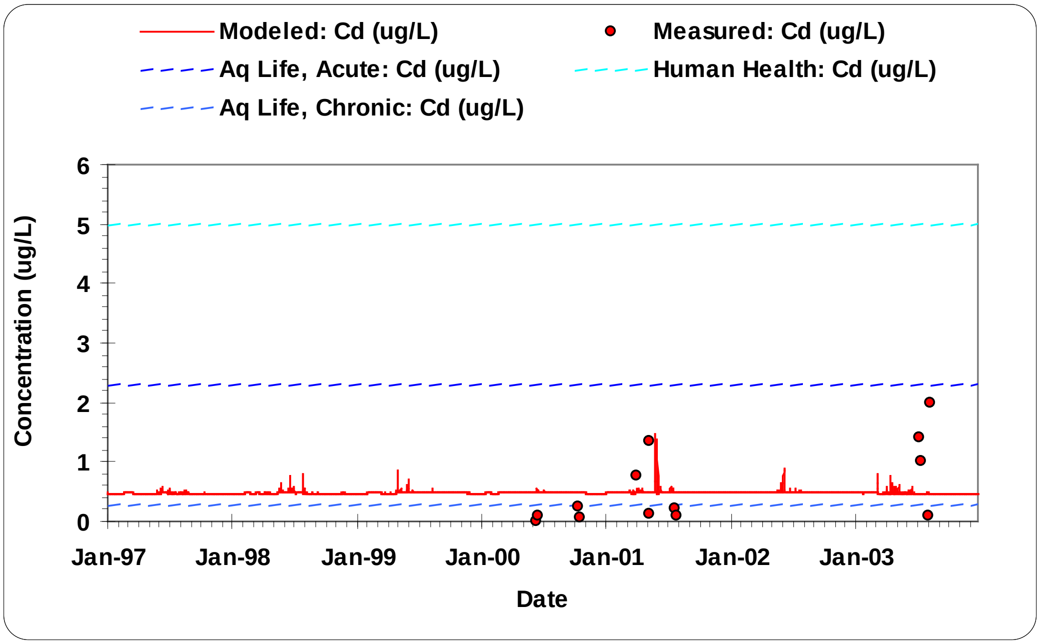


Figure 4-22. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Cadmium.

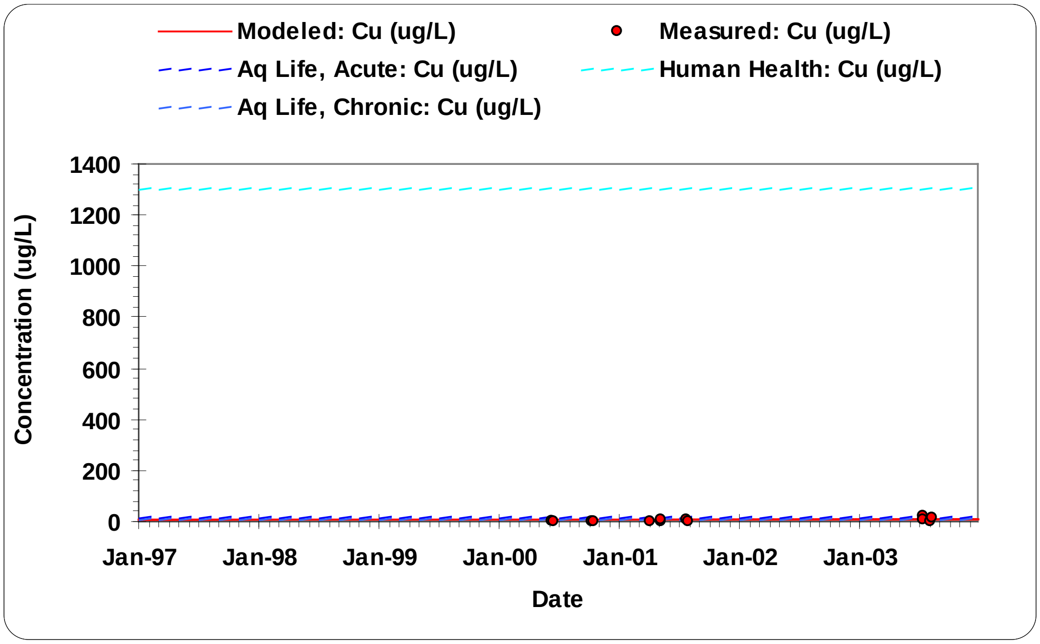


Figure 4-23. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Copper.

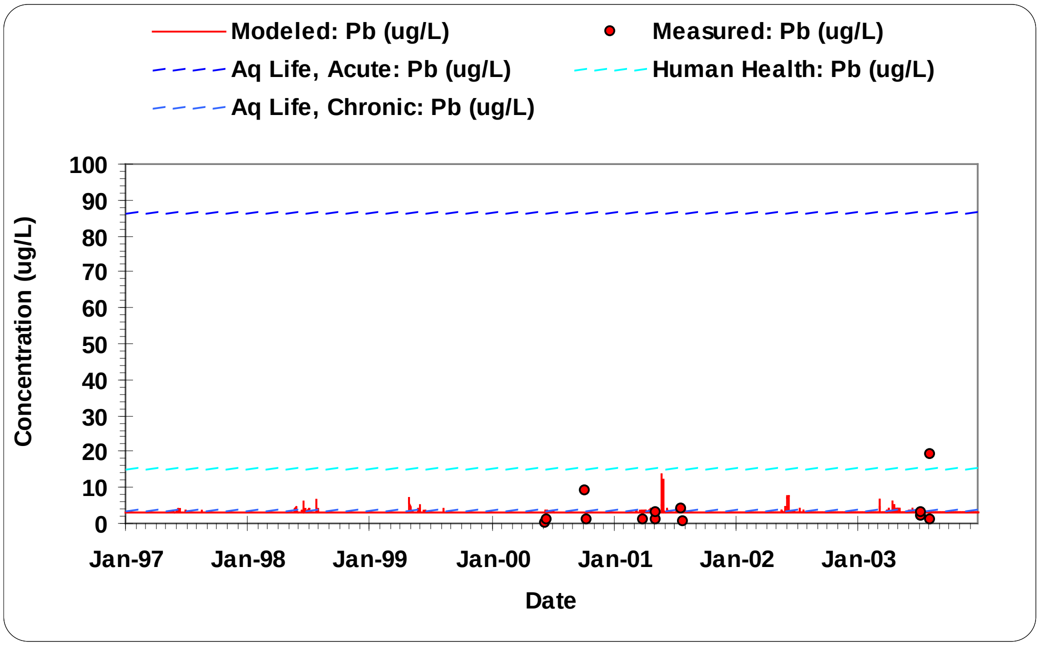


Figure 4-24. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Lead.

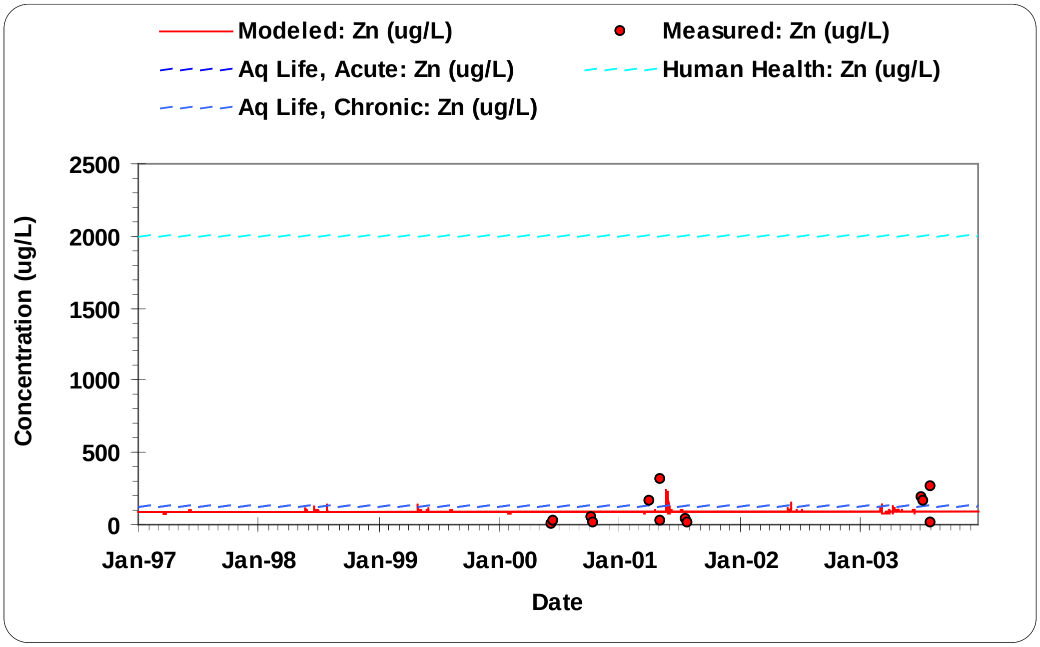


Figure 4-25. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Zinc.

4.3 Model Uncertainty and Use

As described in Section 1.0, modeling was conducted to help answer the following key questions:

- What is the extent to which current flow and in-stream metals concentrations have been affected by anthropogenic activities?
- What are the expected flow and metals conditions during periods for which no observed data are available?
- What are the existing metals loads from each subwatershed?
- What are the existing metals loads from each source category (i.e., point sources, abandoned mines, natural background)?
- What are allowable metals loads from each subwatershed and source category that will result in the attainment of water quality standards?
- What are the potential benefits of various control options?

Based on the calibration results, the model is better suited to answer some of these questions than others. The following first presents an evaluation of the model's ability to address each of the above listed questions, followed by a summary of the potential sources of model error.

4.3.1 Model Limitations and Use

1. <u>What is the extent to which current flow and in-stream metals concentrations have been affected by anthropogenic activities</u>?

In the absence of synoptic monitoring data from each of the potential sources of metals (e.g., various natural sources, mining, agriculture, etc.), modeling provides the only means by which to determine the relative contribution of metals loading from anthropogenic versus natural sources of metals.

All of the potential sources of error described in Section 4.3.2 introduce error into these results. However, when combined with best professional judgement it is felt that the results provide a reasonable approximation of the <u>relative</u> importance of annual metals loading from the various source categories. While the actual calculated loads should be used with caution, the percent load reductions reported in Appendix A, provide a reasonable starting point from which to begin implementing measures to attain water quality standards.

2. <u>What are the expected flow and metals conditions during periods for which no observed data are available</u>?

Based on the calibration results, it appears that the model is capable of producing reasonable results on an annual or long-term basis. However, in the absence of additional calibration data, the results should not be used for smaller time scales (e.g., daily, storm event, or monthly).

3. What are the existing metals loads from each subwatershed?

Given limited data, hydrologic calibration was based on one site on Prickly Pear Creek (USGS gage 06061500) near Clancy (i.e., in the middle of the Lake Helena Watershed). The total volume of water was well correlated, with the simulated volume only having 8.57 percent more water than observed. On an annual basis, it can be assumed that the results from subwatersheds upstream of the USGS gage on Prickly Pear Creek near Clancy are similar.

In the absence of actual monitoring data, the model results provide the only means to estimate subwatershed scale metals loading. It is felt that the results provide a reasonable first approximation of metals loads from each subwatershed. Additional long-term monitoring would be necessary to verify and/or fine-tune the results.

4. What are the existing metals loads from each source category (i.e., point sources, abandoned mines, natural background)?

See Number 1, above.

5. What are allowable metals loads from each subwatershed and source category that will result in the attainment of water quality standards?

In and of itself, answering this question is straight forward and not subject to its own set of errors. The allowable loads are calculated by multiplying the water quality standard (concentration) by flow to obtain a load. However, the results are subject to the errors associated with the prediction of existing subwatershed and/or source category flows and loads. The model limitations associated with this are described above under Numbers 1 and 3.

In spite of the limitations, this method provides the only means for estimating allowable loads and/or necessary load reductions by subwatershed or source category in the absence of monitoring data.

6. What are the potential benefits of various control options?

The potential benefits of various control options were assessed as a post-processing step. The uncertainties associated with the estimation of load reductions that may be achievable are described in the TMDL tables presented in Appendix A. In general, the estimated achievable load reductions are likely over estimates.

4.3.2 Potential Sources of Model Error

Weather Data

Weather gages are most likely the largest source of model error. The Helena Airport had the only weather gage available for the modeling analysis, and it was responsible to generating precipitation data for 620 square miles. The lack of weather gages significantly increases model error in terms of amount and timing of water flowing through the system. Lack of weather gages particularly increases model error during storm events (timing and volume of water).

Flow Alterations

Flow alterations (diversions, storage, releases) are pervasive throughout the watershed, and can be a source of error in the model. The location of the flow alteration, as well as the volume and timing of flow, is required to accurately model stream flows and water quality. The best available information was used to account for all flow alterations; however, it is acknowledged here that many diversions, ponds, reservoirs, and returns may not be accurately represented in the model. Reservoirs, and reservoir storage, timing, and release, also had limited data. Combined, these uncertainties affect model output in several ways. Primarily, the timing and amount of stream flows may have errors, particularly during the irrigation season (April–September) when diversions and reservoirs are most active. Flow alterations, by nature, have a more pronounced effect on stream flow and water quality during low flows, when a larger percentage of water in the river is diverted. This translates into greater model uncertainties during low flow periods, and particularly during critical low flow summer periods.

Point Source Discharge Data

Point source discharges have the potential to affect flow and water quality in a stream. The LSPC model can account for these sources by using time-series inputs of flow and concentrations. However, most point sources only report data on a monthly basis (or less), and data was extrapolated to provide daily model input. In other cases, very little information was available about the point sources, and best professional judgment was used to estimate flow, timing, water quality, and/or outfall location. Point source uncertainties have the greatest potential to affect model output during low flow events, when point sources make up a larger percentage of the load.

Land Use Data

Each LSPC/HSPF model is driven by the basic physiographic characteristics that make up a watershed – land use, soils, slopes, and geology (see Section 3.2). Therefore, physiographic data must be accurate and complete for each subwatershed. Potential errors were introduced into the model because several of these physiographic characteristics were simplified to facilitate modeling (see Section 3.2). Also, physiographic characteristics change over time, and may or may not be represented by the available data and the chosen calibration period. However, this process most likely does not introduce much modeling error when compared to the other potential sources or error.

Due to the large watershed sizes and model limitations, large areas of land were lumped together as modeling subwatersheds. This process, inherent with all LSPC/HSPF models, potentially creates errors due to the simplification of watershed characteristics. However, this process most likely introduces little modeling error when compared to the other potential sources or error.

Insufficient Hydrology Calibration Data

Hydrology calibration data were one source of model error. Only one flow gage met the LSPC calibration criteria – Prickly Pear Creek near Clancy, Montana. Other gages had too little data, not enough recent data, and/or were located downstream of major flow diversions. Model calibration parameters (such as infiltration, lower zone evaporation, etc.) were calibrated to flows at the Prickly Pear Creek gage, and every subwatershed was then modeled using these parameters. This assumes that surface and subsurface hydrology throughout the entire Lake Helena watershed is similar to that occurring upstream of the Prickly Pear Creek station. However, the Prickly Pear Creek gage is not necessarily representative of hydrology throughout the entire watershed. In particular, this gage does not capture the change in hydrology as streams flow into the Helena Valley. This gage is also not representative of flows in small, high altitude subwatersheds (such as Golconda Creek or Corbin Creek). The result of the lack of flow gages is that varying flow errors are introduced throughout the Lake Helena watershed. The errors are not quantifiable, simply because there are no other flow gages with which to validate the hydrologic calibration. A plan to address this data deficiency is presented in Appendix H.

Insufficient Water Quality Calibration Data

While there were over 100 stations with water quality data in the Lake Helena watershed, most had few recent metals data. Stations with the most data were used to calibrate water quality (see Section 4.2.2). The available data generally consisted of discrete grab samples collected over a period of several years. This type of data provides a poor means for calibrating a model. As a result, there was insufficient data to calibrate to all potential watershed conditions, such as storm events, low flows, high flows, and spring snowmelt. A plan to address this data deficiency is presented in Appendix H.

4.3.3 Model Use

Taking into account the known uncertainties, the model is best used to:

- Calculate and allocate yearly metals loads.
- Run scenarios to evaluate the likely relative impact of various alternative model inputs at the watershed scale.

Due to model uncertainties, the model should not be used to predict the flow and/or concentrations at a specific point in the watershed on a specific day. Rather, the model is best suited for evaluating long-term trends (yearly or greater), or long-term patterns of exceedances.

5.0 LSPC INPUT PARAMETERS

The final LSPC input file contains 255 pages of code and includes all data necessary for running the LSPC model. The most sensitive parameters (such as infiltration or groundwater concentrations) are discussed in Sections 3.0 and 4.0 of this document. An input file and database containing all information used to run the LSPC model is available upon request from the Montana Department of Environmental Quality.

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