Modeling Hydrology, Sediment, and Nutrients in the Flathead Lake Watershed

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ACRONYMS

AWC	available water capacity
CASTNET	Clean Air Status and Trend Network
ClimateWNA	Climate Western North America
BMP	best management practice
DEM	digital elevation model
DEQ	Montana Department of Environmental Quality
DMR	discharge monitoring report
DNRC	Montana Department of Natural Resources and Conservation
EC	Environment Canada
EIA	effective impervious area
ET	evapotranspiration
FLBS	Flathead Lake Biological Station
HRU	hydrologic response unit
HSG	hydrologic soil group
HSPF	Hydrologic Simulation Program in FORTRAN
ICIS	Integrated Compliance Information System
LSPC	Load Simulation Program in C++
MDOT	Montana Department of Transportation
MEANSS	Method for Estimating Attenuation of Nutrients from Septic Systems
MIA	mapped impervious area
MPDES	Montana Pollution Discharge Elimination System
MRLC	Multi-Resolution Land Characteristics Consortium
MS4	municipal separate storm sewer system
NCDC	National Climactic Data Center (National Oceanic and Atmospheric Administration)
NDAP	National Atmospheric Deposition Program
NHD	National Hydrography Dataset
NH4	ammonia
NLCD	National Land Cover Dataset
NO3	nitrate
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service (U.S. Department of Agriculture)
PET	potential evapotranspiration
QAPP	quality assurance project plan
SNOTEL	SNOw TELemetry
SSC	suspended sediment concentration
SSURGO	Soil SURvey GEOgraphic database
SWE	snow water equivalent
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TPN	total persulfate nitrogen
TSS	total suspended solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey (U.S. Department of the Interior)

WWTP	wastewater treatment plant
WY	water year (WY 2014 is from October 1, 2013 through September 30, 2014)

UNITS OF MEASURE

cfs	cubic feet per second
in/hr	inches per hour
in/yr	inches per year
lbs/yr	pounds per year
mgd	million gallons per day
mg/L	milligrams per liter

1 INTRODUCTION

In 2001 the Montana Department of Environmental Quality (DEQ) completed a total maximum daily load (TMDL) for nutrients in Flathead Lake. The TMDL specified a 15 percent nutrient (i.e., nitrogen and phosphorus) load reduction. While Flathead Lake and many of its tributaries have been the subject of extensive scientific research for several years, there had not been sufficient data to specifically link all of the potential nutrient sources to the observed water quality problems. As a result, the 2001 TMDL document recommended implementation of an adaptive management strategy, including the development of a watershed loading model to both better quantify loading from all sources and allow for analysis of the potential impacts associated with future land management activities within the Flathead Lake Basin. The U.S. Environmental Protection Agency (USEPA) contracted with Tetra Tech, Inc. to support development of the watershed model.

This report provides details on the setup and calibration of a Loading Simulation Program C++ (LSPC) watershed model for the Flathead Lake watershed, from its headwaters in British Columbia, Canada, to the lake outlet near Polson, Montana. Flathead Lake itself was not modeled.

1.1 WATERSHED SETTING

Flathead Lake is an outstanding aquatic resource of international importance in northwest Montana. It is the largest natural freshwater lake in the western United States, with a maximum depth of 370.7 feet and a surface area of 191 square miles (Flathead Lake Biological Station [FLBS] 2001). Kerr Dam, on the Flathead River just south of the lake, is used to maintain the lake's elevation between 2,883 and 2,893 feet above sea level. The Flathead Lake watershed spans two countries (United States and Canada), the Flathead Indian Reservation, and six counties in Montana (Flathead, Lake, Lewis and Clark, Lincoln, Missoula, and Powell). The watershed has a total area of 7,093 square miles. Major cities in the watershed are Kalispell, Whitefish, Columbia Falls, Polson, and Bigfork (**Figure 1**).

Numerous large and small rivers drain the watershed. The National Hydrography Dataset (NHD) reports 14,055 miles of streams in the watershed, as well as 3,372 lakes (192,114 total acres) (U.S. Geological Survey [USGS] 2008). Major tributaries are the North, Middle, and South forks of the Flathead River, Swan River, Stillwater River, Whitefish River, and Ashley Creek. The North, Middle, and South forks join near the town of Hungry Horse to form the mainstem of the Flathead River. The Stillwater River, Whitefish River, and Ashley Creek discharge into the Flathead River in the vicinity of the city of Kalispell. The Swan River discharges directly into Flathead Lake at the town of Bigfork.

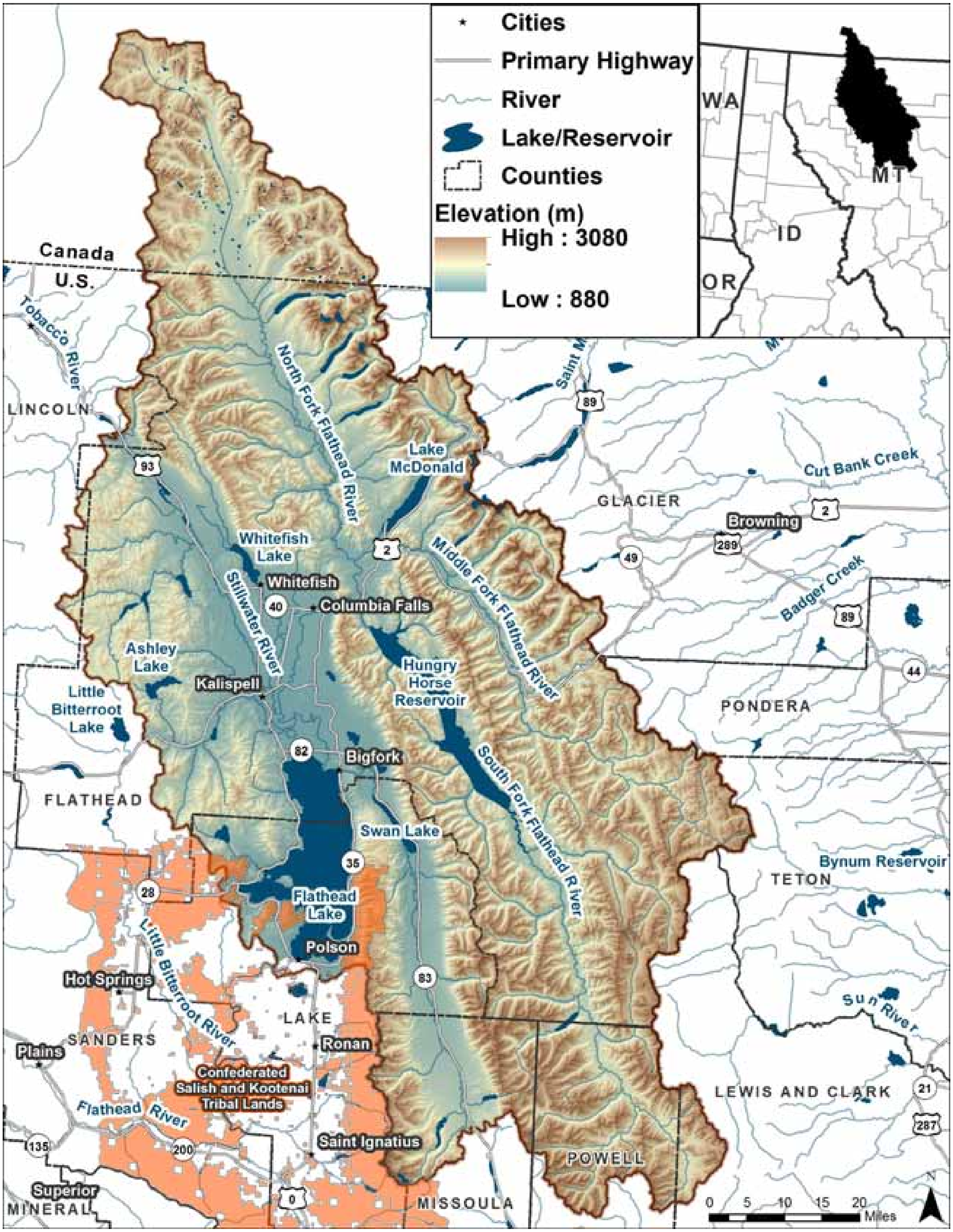

Figure 1. Flathead Lake basin.

1.2 OVERVIEW OF THE LSPC WATERSHED MODEL

Environmental simulation models are simplified mathematical representations of complex real world systems. Models cannot accurately depict the multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigations of how a system would likely respond to perturbations. Models can help answer questions such as:

- What are the pollutant loads and stressors associated with individual sources in the watershed?
- When and where does impairment occur?
- Where can management practices be targeted to address existing sources and stressors?
- What will watershed conditions look like in the future based on current growth patterns and existing protection measures?

A model developed for the Flathead River basin can provide several important lines of information regarding the indicators of watershed function. For example, it can provide the relative upland sediment and nutrient loading by subbasin and land use on multiple temporal scales and transport those loadings throughout the channel network.

The USEPA-approved LSPC model was selected for the Flathead River basin (http://www.epa.gov/athens/wwqtsc/html/lspc.html). LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a fate and transport in streams (Tetra Tech, 2009). The model system automatically links upstream contributions to downstream segments, allowing users to freely model subareas while maintaining a top-down approach (i.e., from upstream reaches to downstream segments). The model simulates watershed hydrology and pollutant transport, as well as stream hydraulics and in-stream water quality. It is capable of dynamically simulating flow, sediments, metals, and temperature, as well as other conventional pollutants for pervious and impervious lands and waterbodies of varying order.

LSPC is distributed by USEPA's Office of Research and Development in Athens, Georgia, and is a component of USEPA's National Total Maximum Daily Load Toolbox (http://www.epa.gov/athens/wwqtsc/index.html). A brief overview of the underlying HSPF model is provided below, and additional detailed discussion of HSPF-simulated processes and model parameters is available in the HSPF User's Manual (Bicknell et al., 2004).

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

- PERLND/IMPLND for simulating watershed processes on pervious/impervious land areas
- SEDMNT/SOLIDS for simulating production and removal of sediment/solids from pervious/impervious land

- PQUAL/IQUAL for simulating production and removal of pollutants from pervious/impervious land
- RCHRES for simulating flow and water quality processes in streams and vertically mixed lakes
- SEDTRN for simulating transport, deposition, and scour of sediment in modeled waterbodies
- RQUAL for simulating transport, transformations, and loss of pollutants in modeled waterbodies

All of these modules include many submodules that calculate hydrologic, sediment, 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. The 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 and impervious fractions. Meteorological forcing data are used to simulate impacts of precipitation, air temperature, and evapotranspiration on runoff and groundwater flow from the land use segments. The stream network links the surface runoff and groundwater flow contributions from each of the land segments in the 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 the major tributary streams and different portions of stream reaches where significant changes in water quality occur.

The model provides comprehensive water quality simulation on the land surface and within waterbodies. Upland sediment production is based on detachment and scour from the soil matrix or buildup processes on impervious surfaces with transport by flow energy. Transport of nutrients and other pollutants from the land surface may be simulated using a buildup/washoff approach and as associated with the movement of sediment. Wet and dry atmospheric deposition can be included as a source to land surfaces and directly to water bodies. Pollutant loads may also be associated with interflow and groundwater discharge. The stream reach simulation includes modules addressing sediment scour, deposition, and transport; dissolved oxygen simulation; complete nutrient and eutrophication kinetics; and a variety of other options. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and objectives.

1.2.1 LSPC Snow and Hydrology

Snowfall and snowmelt have a dominant effect on hydrology and associated water quality in the Flathead Lake watershed. The method used to simulate snow behavior in LSPC is the energy balance method. In addition to precipitation, the energy balance requires air and dew point temperatures, wind speed, and solar radiation as meteorological drivers. The SNOW module uses the meteorological information 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, rain, and conduction from the ground beneath the snowpack. The snowpack essentially acts like a reservoir that has specific thermodynamic rules for the release of water. Melting occurs when the liquid portion of the snowpack exceeds the snowpack’s holding capacity; melted snow is added to the hydrologic cycle. **Figure 2** is a simplified schematic of the snow process in LSPC, showing how it modifies precipitation in the context of the water cycle. Other interactions such as long- and short-wave radiation and processes such as condensation and sublimation are simulated even though they are not explicitly illustrated in the figure.

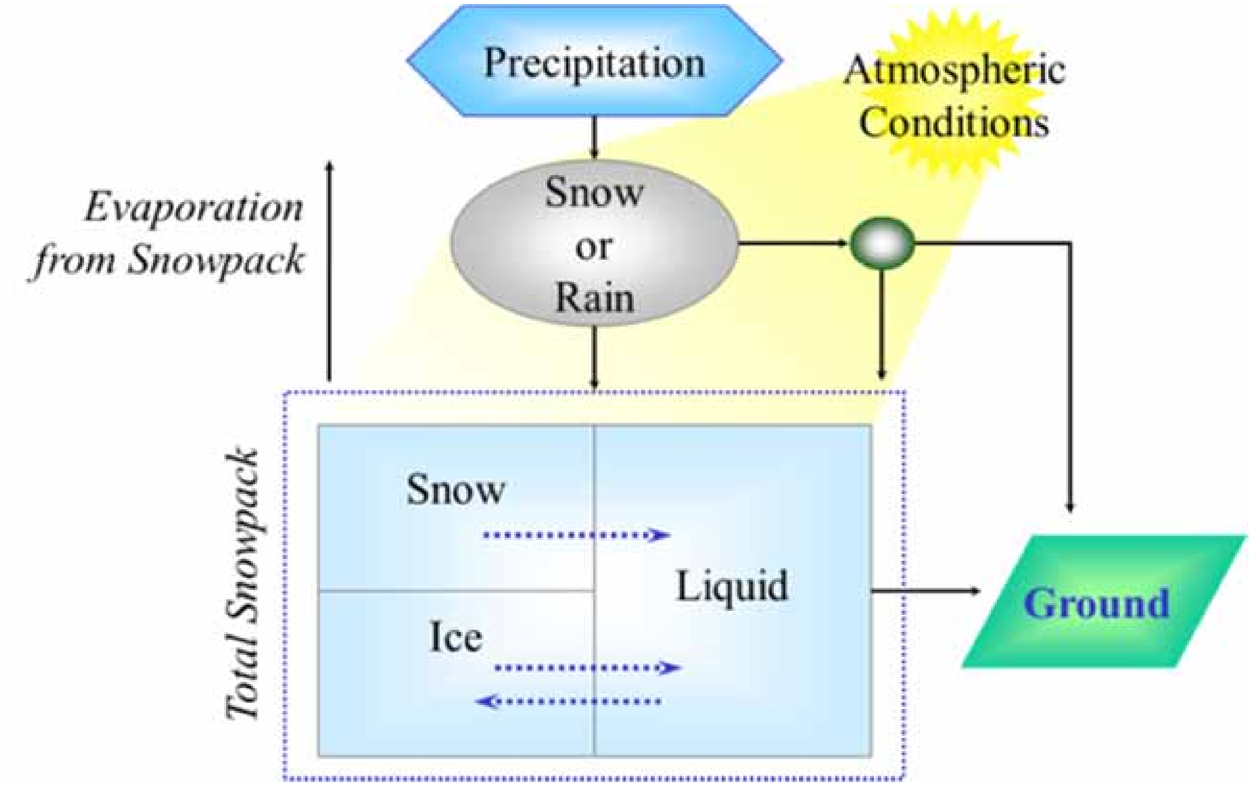

Figure 2. Conceptual Schematic of the Snow Simulation.

The hydrologic (water budget) process representation in LSPC follows HSPF and is comprehensive and flexible. Rainfall or snowmelt is routed to constructed landscapes, vegetation, or soil. Varying soil types (depending on model parameterization by land use) allow water to infiltrate at different rates, while evaporation and plant matter exert a demand on available water. Water flows overland and through the soil matrix. Three flow paths make up the vertical land profile in the LSPC model environment: surface, interflow, and groundwater outflow. The parameters associated with various stages of the LSPC water budget are shown schematically in **Figure 3**, and the corresponding model parameters in the figure are defined in **Table 1**.

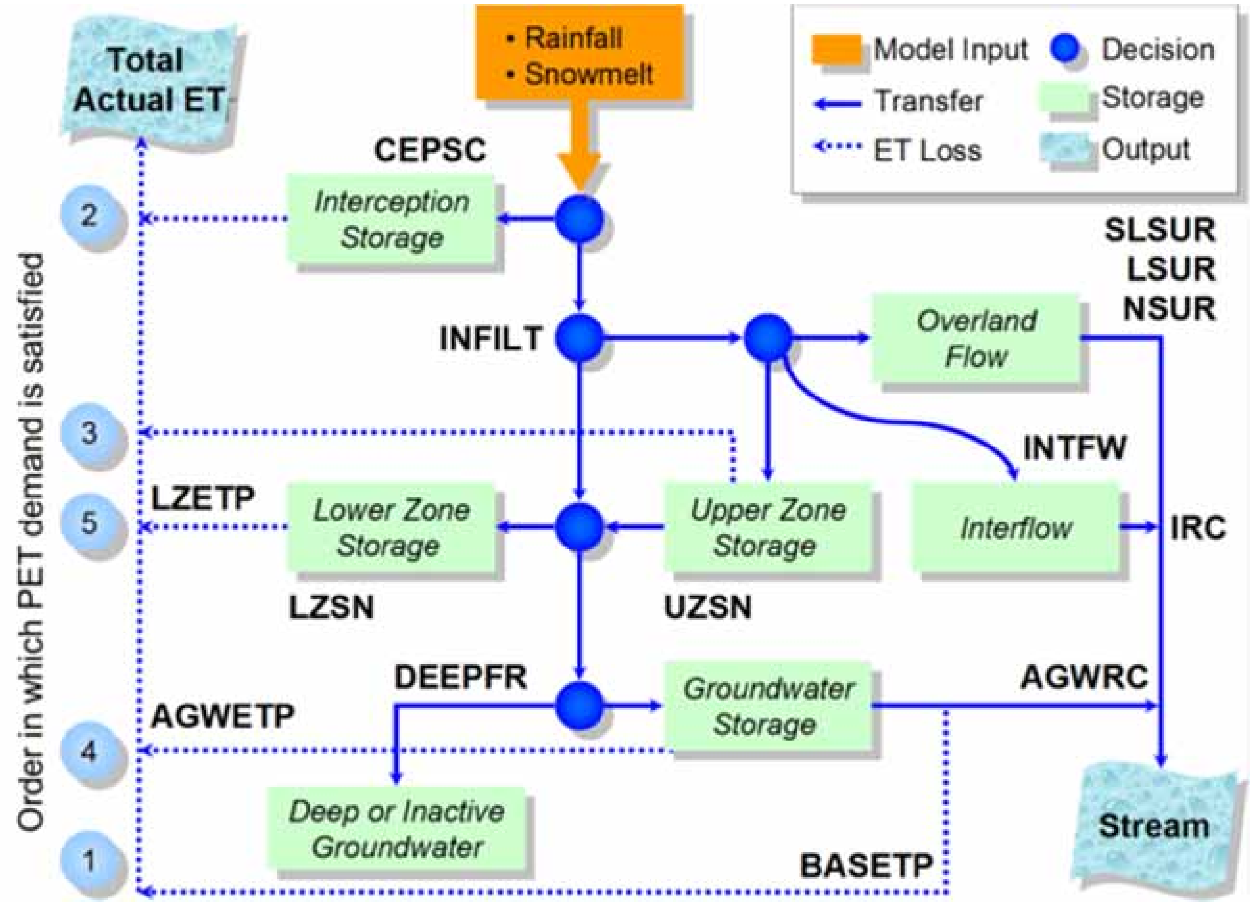

Figure 3. Conceptual Schematic of LSPC's Water Budget.

Table 1. Water Budget Model Parameter Definitions

Layer or process	Parameter name	Definition
Surface or near-surface	CEPSC	Interception storage capacity (inches)
	SLSUR	Slope of overland flow plane (none)
	LSUR	Length of overland flow plane (feet)
	NSUR	Manning's n for the assumed overland flow plane (none)
Interfacial	INTFW	Interflow inflow parameter (none)
	IRC	Interflow recession parameter (none)
	INFILT	Index to infiltration capacity of the soil (inches/hour)
Subsurface	UZSN	Upper zone nominal storage (inch)
	LZSN	Lower zone nominal storage (inch)
	AGWRC	Base groundwater recession (no units)
Sinks/Losses	BASETP	Fraction of remaining potential evapotranspiration (ET) that can be satisfied from baseflow (none)
	AGWETP	Fraction of remaining potential ET that can be satisfied from active groundwater (none)
	LZETP	Fraction of remaining potential ET that can be satisfied from lower zone storage (none)
	DEEPFR	Fraction of groundwater outflow that enters deep groundwater (none)

1.2.2 Select LSPC Quality Components

The following subsections discuss the processes by which the Flathead LSPC watershed model simulates sediment, nitrogen, and phosphorus, the primary constituents within the model.

1.2.2.1 Sediment

The sediment module in LSPC is composed of two models working in tandem: (1) a land-based erosion prediction model, and (2) an in-stream sediment transport model, which are reflective of the energy required for detachment and transport. Parameters in the model can represent various physical processes. **Figure 4** is a conceptual schematic of the sediment model in LSPC. From the land side, these are (1) splash erosion as a function of rainfall intensity; (2) net atmospheric deposition of sediment particles onto the land surface or the snowpack, which considers losses associated with wind mobilization; (3) wash-off of the detached or deposited sediment as a function of runoff energy; and (4) direct scour from the soil matrix, such as gulley or rill erosion on the landscape. All these processes are simulated by model land segment (i.e., land use type), providing some flexibility to represent known or likely differences in erosion potential as a function of land use or vegetative cover. The model simulates mobilization and transport of bulk sediment from the land surface; however, at the point of entry into the stream, the bulk sediment mass is divided into particle size classes (i.e., sand, silt, and clay). Once the sediment mass is divided into those classes, each size class is modeled independently during stream transport.

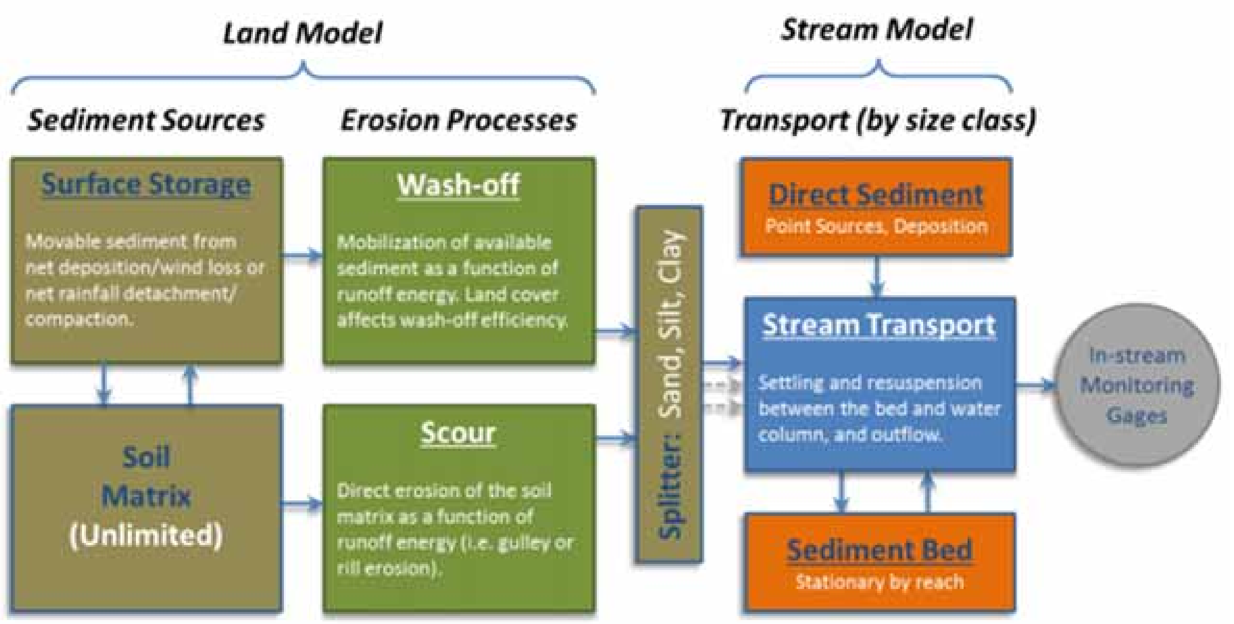

Figure 4. Conceptual Schematic of LSPC Sediment Erosion and Transport Model.

The in-stream transport model simulates each particle class independently of others, which provides the flexibility to simulate preferential deposition of larger particles or perpetual suspension of smaller particles as hydrologic and hydraulic conditions permit. Sand is simulated as non-cohesive, while the silt and clay fractions are simulated as cohesive sediments. The cohesive sediment classes are characterized by critical shear stresses and rates of deposition/scour as a function of shear.

In most cases, the only site-specific data available for sediment model calibration are in-stream samples of total suspended sediment. Literature values for sediment yield (i.e., export coefficients) by land use are also used to validate the intermediate prediction of land-based sediment mass before it is routed for in-stream transport. Having mostly in-stream monitoring data available for calibration places a burden on the modeler to adequately parameterize and justify all the intermediate processes leading up to the ultimate point of comparison between modeled and observed in-stream total suspended solids.

1.2.2.2 Nitrogen and Phosphorus

LSPC models nutrient loading and transport in two stages. First, the pollutants are modeled as general quality constituents (GQUAL) from the land surface. Model parameters for doing so include initial storage mass of the GQUAL on the ground, mass of the GQUAL per mass of eroded sediment (for sediment-associated constituents), accumulation rate and limit of the pollutant on the ground under dry conditions, wash-off capacity under wet conditions, interflow and baseflow concentrations, and atmospheric deposition. Depending on the modeled pollutants, the relative parameter values and whether or not they vary monthly are established during model calibration.

Similar to erosion modeling, nutrients can be modeled as totals from the land and then partitioned into different dissolved or particulate species for in-stream transport. The Flathead model simulates total nitrogen (TN) and total phosphorus (TP) from the upland areas and partitions them into nitrate, ammonia, organic nitrogen, orthophosphate, and organic phosphorus as they enter the stream. The partition coefficients vary depending on the flow pathway (surface, interflow, or active groundwater) and can be calibrated.

Nutrients that enter stream reaches are simulated in LSPC in the reach quality (RQUAL) module from HSPF, which addresses the fate/transport and transformation of nutrient species in the water column. RQUAL includes routines for modeling ammonia volatilization, nitrification/denitrification, and adsorption/desorption of nutrients during transport. Depending on the behavior of the natural system being modeled, the model can also simulate interaction of nutrients with phytoplankton and benthic algae, effect on in-stream biochemical oxygen demand, and dissolved oxygen levels.

2 MODEL SETUP FOR THE FLATHEAD LAKE WATERSHED

The Flathead Lake watershed LSPC model was set up and incrementally calibrated in two phases. In Phase 1, model development was completed in the headwaters region, and in Phase 2 the lower-elevation, valley portion of the watershed was addressed (refer back to **Figure 1**

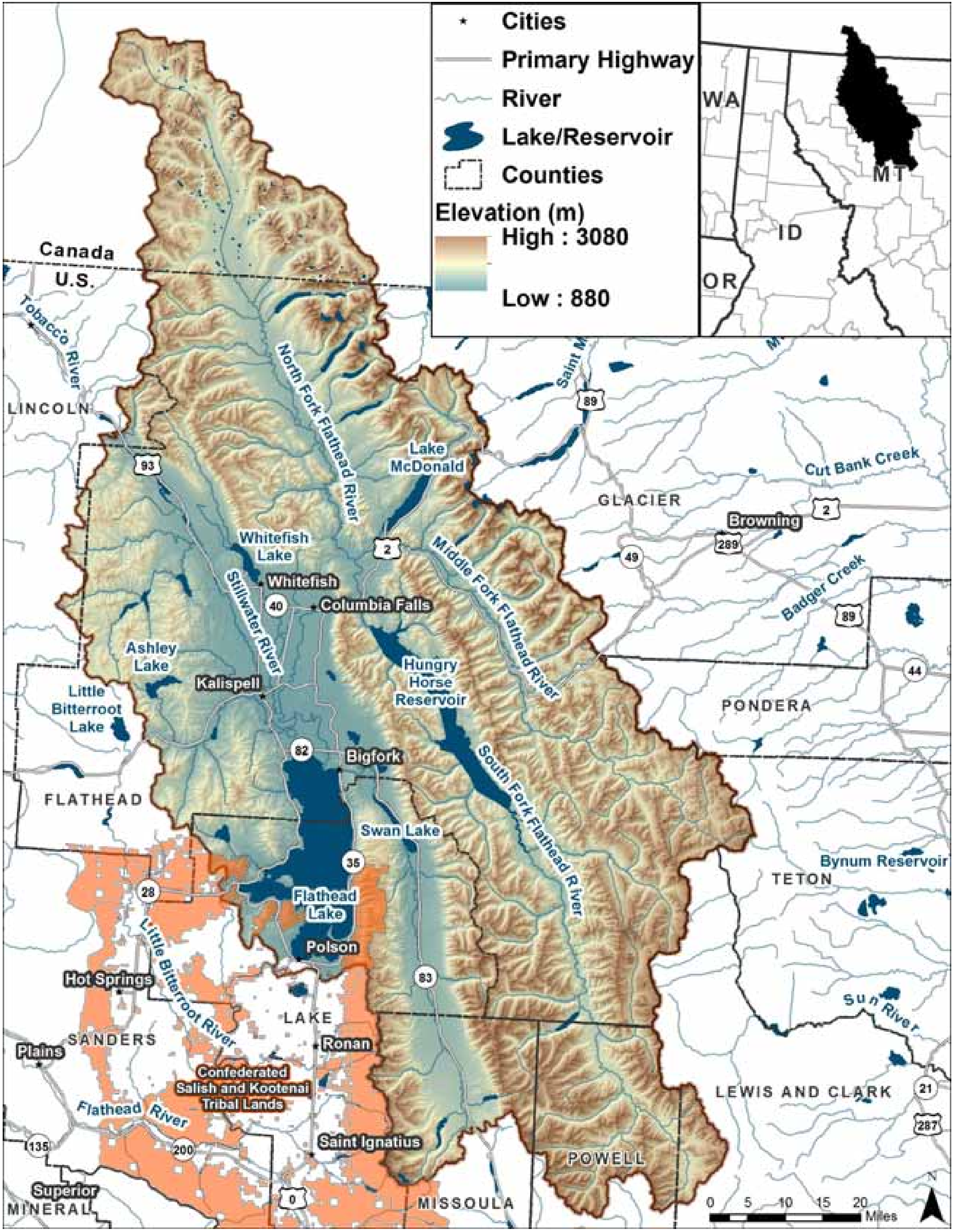

Figure 1 for a map of the Flathead Lake watershed and to **Figure 5** for a map with the phases identified). Also, to facilitate TMDL development, a separate sub-model was created for the Ashley Creek watershed. The Ashley Creek model is discussed in **Appendix A**.

LSPC model configuration for the Flathead Lake watershed relied on a variety of local data sources. The data include detailed elevation data, meteorological time series of precipitation and ET, snowfall and snowpack data, point source discharges, septic system inputs, land cover/land use, soils, and stream monitoring from several sources. The following section discusses the development of these data inputs and describes initial model parameterization.

2.1 MODELED PARAMETERS AND SIMULATION PERIOD

The LSPC model was configured to simulate the following:

- Continuous hydrology
- Sediment, including upland loading, in-stream transport, and bed and bank behavior
- Nutrients (as total phosphorus and total nitrogen), including upland loading and in-stream reduction and transport

The hydrology calibration spans October 1, 2000 through September 30, 2012 and the water quality calibration spans October 1, 2002 through September 30, 2012. The time period reflects the availability of data needed to calibrate the model and use it in a decision-support role. One goal was to have the model represent current conditions in the watershed, which improves the relevance of the model's characterization of current and potential future conditions.

LSPC calibration is improved by having a "spin-up" period prior to the beginning of calibration, which removes initial condition effects; i.e., initial hydrology and pollutant process states are difficult to estimate, and having a spin-up period allows internal model processes to reach equilibrium. As a result, the actual simulation begins January 1, 1998, allowing multiple years of spin-up. Meteorological data are required for spin-up, but model output for the spin-up period is disregarded.

2.2 SUBBASINS AND REACHES

The Flathead Lake watershed was divided into 392 subwatersheds (**Figure 5** and **Appendix B**). This provided more flexibility for characterizing spatial variability in terms of both physical characteristics and associated meteorological conditions. For this effort, increasing the resolution of model subwatersheds was especially meaningful in the portions of the watershed where rapid changes in topography occurred over relatively short distances. This aided in better representing watershed responses overall, in light of the inherent assumptions of the underlying watershed model where certain characteristics are spatially aggregated within subwatershed boundaries. The South Fork Flathead River watershed is not explicitly delineated in the model because the discharge from Hungry Horse Reservoir was represented as a boundary condition to the Flathead River due a high quality flow series, and annual stability in water quality conditions based on two years of intensive monitoring. Details and rationale for that approach are presented in **Section 2.9**.

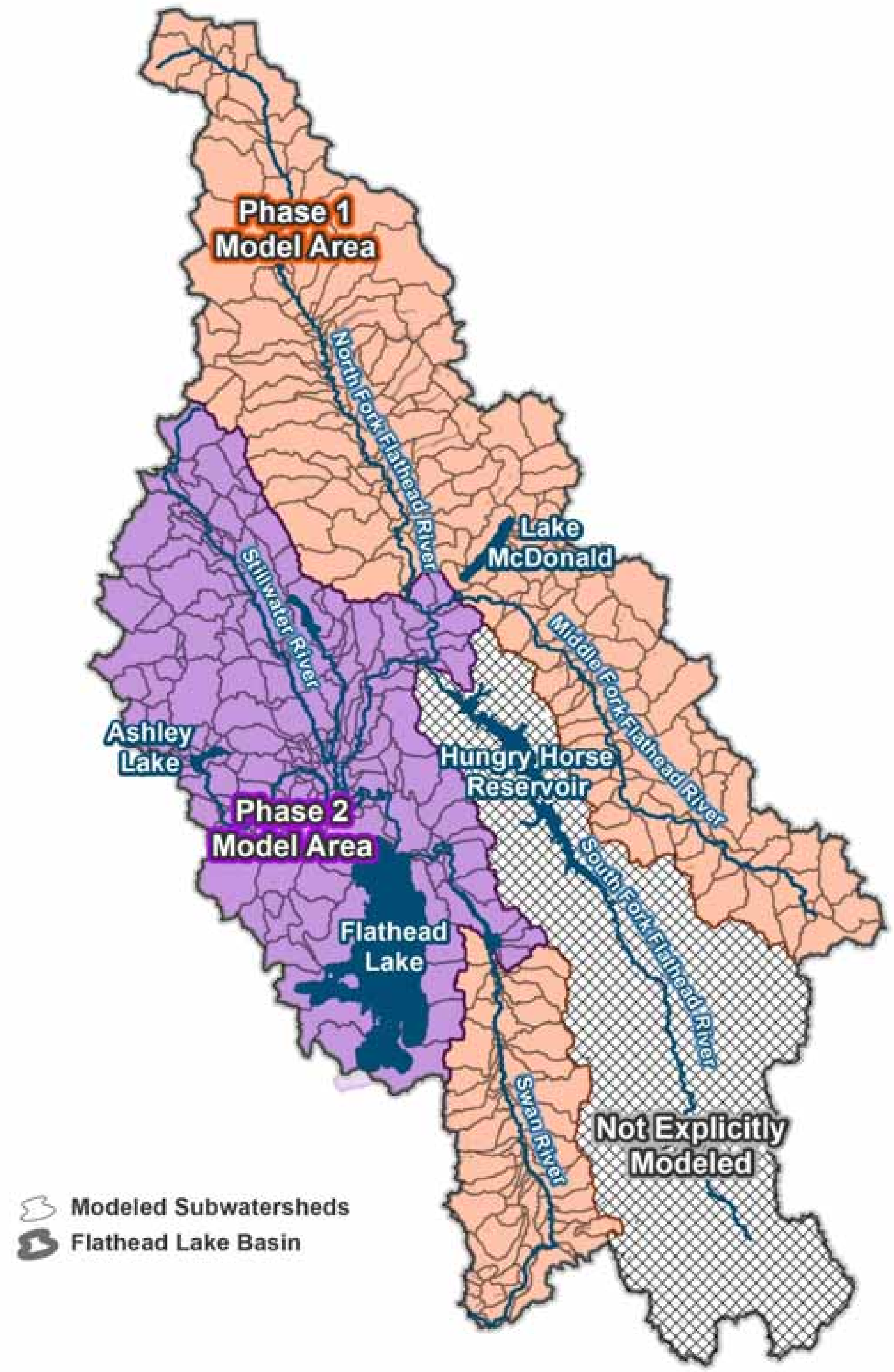

Figure 5. LSPC Phases and Model Subbasins

2.3 WATERBODY REPRESENTATION

LSPC was configured to model both streams and reservoirs in the Flathead Lake watershed. **Section 2.3.1** discusses the information used to model the stream segments, and **Section 2.3.2** discusses the configuration for representing the lakes.

2.3.1 Streams

Each subwatershed was represented with a single stream assumed to be a completely mixed, one-dimensional segment with a trapezoidal cross-section (**Figure 6**). Although function tables (*F-Tables*) can be generated directly from the output of a hydraulic model such as HEC-RAS[1], such models are not available for the majority of streams in the Flathead Lake watershed. Therefore, a simpler method was used to generate *F-Tables* that relies on the size of the upstream area draining to each reach.

The characteristics needed for each reach to estimate an *F-Table* include reach length, reach slope, reach bankfull depth (DEP), reach bankfull width (WID), Manning's *n*, a reach bottom width factor (R1), slope of the sides of the overland flow channel (R2) and a floodplain width factor (W1). Reach length and reach slope were calculated for each reach during the subwatershed delineation process, whereas values for R1, R2 and W2 were left at default values of 0.2, 0.5 and 1.5, respectively. The assumed Manning's *n* value for all reaches was 0.02 in the Phase 1 model and 0.05 in the Phase 2 model. Bankfull width and bankfull depth were estimated by using a Rosgen approach, which uses the contributing upstream drainage area to calculate a theoretical width and depth (Rosgen 1996). The Rosgen equation is as follows:

$$\text{Bankfull Depth, Width} = a*(\text{Contributing\_Area})^{b}$$

Where:

(a) Coefficient: Width default = 14.49 and Depth default = 1.4995

(b) Exponent: Width default = 0.4 and Depth default = 0.2838

The Phase 2 model set-up utilized the above stated default values for the simulation whereas the Phase 1 model set-up used a bankfull width coefficient of 7 and a bankfull depth coefficient of 0.8. The coefficients for the Phase 1 model were modified from the default values to obtain a better relationship between the calculated and observed cross sections. Coefficient modifications in the Phase 2 model were deemed unnecessary.

Reach dimensions for the Flathead Lake watershed LSPC model are included in the LSPC model input file, which is available upon request.

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[1] The U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) developed the River Analysis System (RAS) model.

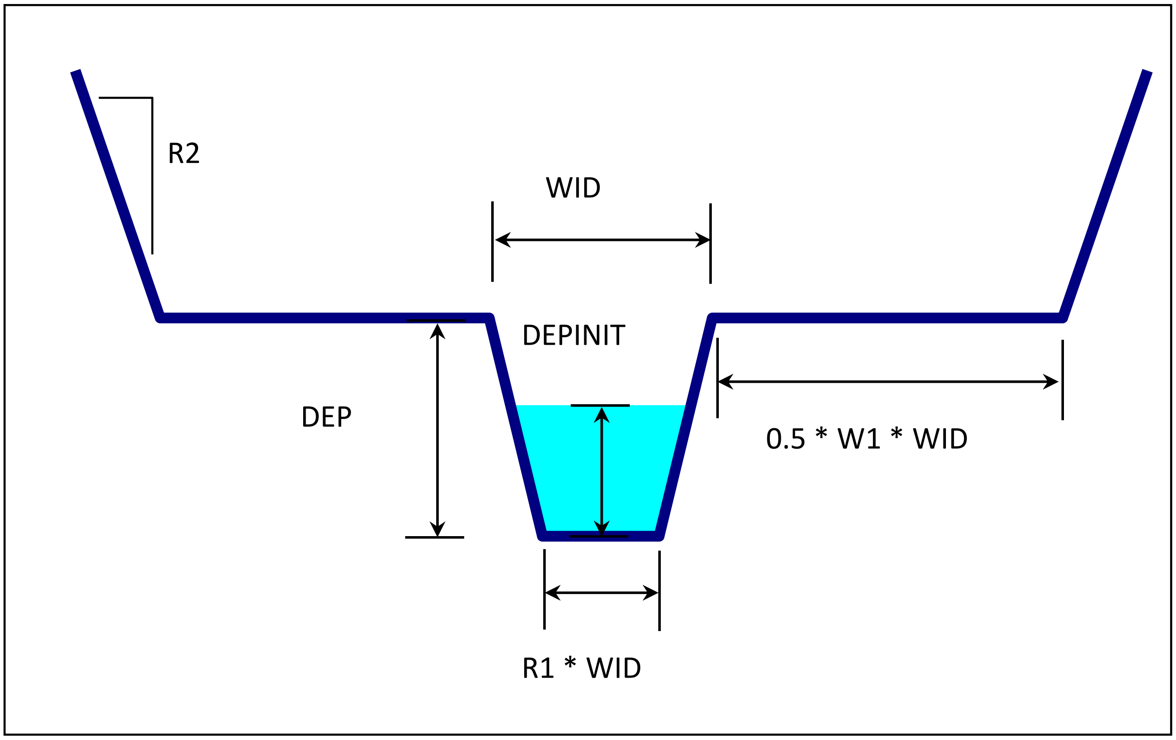

Figure 6. Stream Channel Representation in the LSPC Model.

2.3.2 Lakes and Reservoirs

The Flathead Lake watershed contains numerous lakes and ponds ranging from fractions of an acre to thousands of acres in size. The NHD shows over 3,000 lakes and ponds within the watershed. Most of the lakes were not modeled directly – only lakes that are listed for impairment or are large enough to have measurable effect on the objectives of this study are explicitly modeled. However, the hydrologic impact of the remaining lakes was addressed in the modeling framework. Two approaches were adopted in the project to simplify representation of the lakes, while still allowing the model to have sufficient detail to simulate the most important lake hydrologic processes. The first approach was to represent major lakes directly in LSPC as completely mixed reservoir reaches, with appropriate parameters to describe the reservoir characteristics and stage-discharge *F-Tables*. The second approach was to represent all remaining lakes as internally drained water features.

LSPC allows for the specification of the type of water body as a *stream* reach or a *reservoir* reach. Regardless of whether a water body is a stream or a reservoir/lake, LSPC represents them in essentially the same fashion – as a completely mixed water body with unidirectional flow. There are some minor differences in the way that pollutant processes are calculated, but the hydrologic processes are defined by the same parameters and *F-Table*. The major difference is that in a reservoir/lake reach the *F-Table* is configured to represent the properties of a lake – permanent storage of water, a large surface area and storage volume, and outflow moderated by a channel and/or control structure.

2.3.2.1 Lakes Simulated Directly in the Model

Twenty-seven lakes were selected to be represented explicitly in the model (**Table 2**). The memorandum entitled *Flathead Basin TMDLs Technical Memo – Lakes and Reservoirs* (USEPA, 2011a) provides more information about available data for each of the lakes. As discussed in the memorandum, 51 lakes were initially selected for direct representation in the model based on whether they were directly connected to the natural, perennial stream network or met other criteria. During model preparation, several of the lakes were screened out either because they had surface areas less than 100 acres, or were located in headwater subbasins and had little impact on flow in the larger watershed. In addition, lakes within the South Fork Flathead River watershed were omitted since this area was not included in the LSPC model as discussed in **Section 2.9**.

Table 2. Lakes Represented Explicitly in the Flathead Lake Watershed LSPC Model

Lake	Planning Area	Area (acres)	Method
Bowman Lake	North Fork	1,722	Bathymetry
Kintla Lake		1,713	Bathymetry
Logging Lake		1,114	Hollister method
Lower Quartz Lake		166	Hollister method
Quartz Lake		872	Hollister method
Lake Ellen Wilson	Middle Fork	210	Hollister method
Harrison Lake		404	Hollister method
Hidden Lake		270	Hollister method
Lake McDonald		6,869	Bathymetry
Ashley Lake	Flathead Lake	2,850	Bathymetry
Lake Mary Ronan		1,516	Bathymetry
Smith Lake		453	Hollister method
Dog Lake	Stillwater River	102	Hollister method
Lower Stillwater Lake		250	Bathymetry
Tally Lake		1,211	Bathymetry
Upper Stillwater Lake		592	Bathymetry
Whitefish Lake		3,315	Bathymetry
Crystal Lake	Swan River	187	Hollister method
Elk Lake		118	Hollister method
High Park Lake		220	Hollister method
Holland Lake		413	Bathymetry
Glacier Lake		104	Hollister method
Gray Wolf Lake		339	Hollister method
Lindberg Lake		816	Bathymetry
Lost Lake		110	Hollister method
Swan Lake		3,271	Bathymetry
Turquoise Lake		186	Hollister method

Several lakes had bathymetry data available and the maximum depths as reported in USEPA (2011a) were used for these lakes (**Table 2**). Lake volumes and LSPC *F-Tables* for other lakes were generated using the approaches described in Hollister and Milstead (2010) and Hollister et al (2011). The Hollister and Milstead (2010) and Hollister et al (2011) approach involves estimating lake depth based on the surrounding topography. A 250 meter buffer was created around each lake in a geographic information system (GIS) and 1,000 points were randomly placed within this buffer. Slopes for these points were calculated and the data were then used to estimate a maximum depth for each lake, per Hollister et al. (2011). Comparing depths estimated from this approach to the handful of known depths suggested that the Hollister approach resulted in overestimates. The following formula was used to adjust these depths to something closer the observed depths:

$$Z_{adj} = Z_{calc} \times \alpha + \beta$$

Where Z_{adj} is the adjusted maximum depth for a given lake,
Z_{calc} is the estimated maximum depth of the lake based on the surrounding topography, and
α and β are optimized adjustment factors.

Values for α and β were optimized to maximize the coefficient of determination (R^2) between the observed and calculated depths, with final values for α and β of 0.29 and 86.75, respectively, and an R^2 of 0.3. The results are shown in **Figure 7**. Although the fit displayed in **Figure 7** still indicates a fair amount of potential error in the estimate depths, it is important to note that the impact of this error is lessened as depths are converted to total lake volumes. Once maximum depths had been estimated, polygons were created using the randomly generated points to assign a representative area for the purposes of calculating volume.

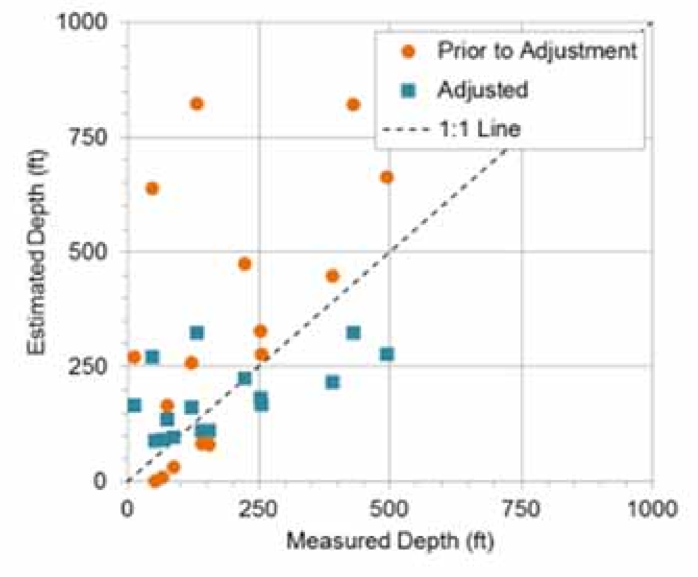

Figure 7. Comparison of Modeled to Observed Maximum Depths Before and After Adjustment

Lakes in the Flathead Lake watershed were assumed to have outlets restricted by the width of the streams at the point they discharge from the lake and a weir equation was used to simulate the stage-discharge relationship. All lakes in the Phase 1 portion of the model were assumed to have uniform weir widths of 100 feet, reflecting a typical width of a channel leaving a lake. The Phase 2 lakes used variable weir widths developed by examining the outlet channel widths in aerial imagery. Many of the Phase 2 lakes were also assumed to have a portion of outflow discharge to deep groundwater. The infiltration rate was used as a calibration factor to achieve water balance compared to flow monitoring data downstream of the lakes.

Lake *F-Tables* for the Flathead Lake watershed LSPC model are included in the LSPC model input file, which is available upon request.

2.3.2.2 Lakes Represented as Internally Drained Water Features

The Flathead Lake watershed contains numerous lakes of various sizes. Many lakes are connected to the stream network, but are remote from the main reach within a subwatershed or are part of a headwaters subwatershed that has little control over flow in the larger watershed. Representing all these lakes as reservoir reaches would greatly complicate the LSPC model, and stage-discharge relationships would be difficult to estimate. These lakes were therefore represented as internally drained lakes to simplify the model while still accounting for their impact.

Internally drained lakes are represented as a pervious land area instead of as a reach in the model, with important changes. A land use representation that satisfies the characteristics of these lakes was achieved by specifying a high infiltration rate coupled with small lower zone storage capacity (LZSN), a high groundwater recession constant, significant evapotranspiration (ET) from groundwater, and no interflow or deep groundwater losses (Appendices D and E). In essence, the base level storage of the lake is assumed to be fixed and static, while incoming precipitation is routed as ET or runoff after storage in what is nominally the subsurface layer. This approach effectively routes much of the water to evaporation, except when large rainfall events exceed the surface storage plus upper zone storage capacity, and the hydrograph shape of water that is released is smoothed – which is how a lake is assumed to behave.

Internally drained lake areas were determined during GIS land cover processing (discussed further in **Section 2.10.1**). All water surface area within each model subbasin was grouped into a single “water unit” – in other words, lakes were represented in aggregate rather than individually. However, the total water surface area tabulated by GIS included lakes simulated explicitly as reservoir reaches as well as any creeks or rivers sufficiently wide to be identified as open water in the GIS data. As a result, the internally drained lake area needed to be reduced to omit reservoir reach area and river/creek area. Since reaches in LSPC occupy area and receive direct precipitation inputs, the water surface area of each reach (including the lakes simulated as reservoir reaches) was subtracted from the total model subbasin water area from GIS, separately for each model subbasin. This prevented double-counting of water surface area in the model; otherwise, precipitation inputs would be overrepresented. Reach surface area was determined using the median depth during simulation and extrapolating area from the *F-Tables* for each reach.

2.4 METEOROLOGICAL DATA

Meteorological data are a critical component of the watershed model because they represent the forcing functions that drive both the hydrology and the water quality response. Models require appropriate representation of weather data constituents such as precipitation, potential ET, and temperature. In cases where an energy balance approach is used for snow simulation or for calculating ET, additional constituents such as dew point temperature, wind speed, cloud cover, and solar radiation must be considered. The two largest terms in the water balance are precipitation input and ET output. Precipitation is specified as a direct external forcing to the model; in general, hourly precipitation (or finer resolution) data are recommended and preferred. ET is either derived as a function of observed pan-evaporation, or (as was done for the Flathead LSPC model) computed as a function of other weather data such as wind speed, air temperature, dew point temperature, and solar radiation. Together, the observed weather constituents make up the external meteorological time series that "drive" the model.

Successful hydrologic modeling in cold weather climates depends on accurately representing the various components of the water balance. For example, the snowfall/snowmelt process acts like a reservoir of stored precipitation during the winter, which is ultimately released during the spring; therefore, it is especially important to capture the volume and timing of this process. Because the snowfall and snowmelt processes are important considerations in the Flathead Lake watershed, and because elevation changes rapidly over short distances in certain areas, increasing the spatial and temporal resolution and quality of the available weather data has beneficial effects on hydrology and water quality representation in the model.

2.4.1 Meteorological Data Sources

For the Flathead Lake watershed LSPC model, eight observed meteorological data sources and two meteorological data models were evaluated for incorporation into LSPC. The observed data served as the foundation for the meteorological representation in the watershed model. Modeled datasets were considered secondary sources (1) used to validate and refine the final input meteorological time series to more accurately reflect monthly and seasonal trends, and (2) used as a basis for spatially interpolating observed data to ungaged areas. **Table 3** summarizes the available temporal resolution of the data and **Table 4** summarizes the available meteorological data constituents from each of the eight primary and two secondary data sources.

Table 3. Inventory and Temporal Resolution of Meteorological Data Sources

Data Source	**Data Type**		**Temporal Resolution**		
(● Yes, - No)	**Observed**	**Model**	**Hourly**	**Daily**	**Monthly**
National Climatic Data Center (NCDC) Summary of Day	●	-	-	●	-
NCDC Local Climatological Data	●	-	●	-	-
NCDC Surface Airways	●	-	●	●	-
Environment Canada (EC)	●	-	●	●	-
SNOTEL	●	-	-	●	-
Agrimet	●	-	●	●	-
Hydromet	●	-	-	●	-
Montana Department of Transportation	●	-	●	-	-
PRISM	-	●	-	-	●
ClimateWNA	-	●	-	-	●

Table 4. Summary of Available Climate Parameters by Source

(●) - Primary data source (♦) - Computed from primary data (○) - Secondary data source (-) - Not available	Precipitation	Temperature	Snowpack	Dew point	Wind speed	Cloud cover	Potential evaporation	Solar radiation
National Climatic Data Center (NCDC) Summary of Day	●	●	-	-	-	-	-	-
NCDC Local Climatological Data	●	●	-	●	●	●	♦	♦
NCDC Surface Airways	●	●	-	●	●	●	♦	♦
Environment Canada (EC)	●	●	-	●	●	●	♦	♦
SNOTEL	●	●	●	-	-	-	-	-
Agrimet	●	●	-	●	●	●	♦	♦
Hydromet	●	●	-	-	-	-	-	-
Montana Department of Transportation	●	●	-	●	●	-	-	-
PRISM	○	○	-	○	-	-	-	-
ClimateWNA	○	○	-	○	-	-	-	-

Of the data sources presented in **Table 3** and **Table 4**, observed data were collected from the National Climatic Data Center (NCDC), Environment Canada (EC), SNOw TELemetry (SNOTEL), Agricultural Meteorology Network (Agrimet), Hydrological and Meteorological Monitoring Stations (Hydromet), and Montana Department of Transportation (MDOT). Daily NCDC data were collected from the Summary of the Day archives. EC maintains the National Climate Data and Information Archive, which provides users with direct access to long-term climate data through an interactive, Web-based mapping and customizable query tool. Only daily precipitation data are available through this Web-based system for bulk download. Temperature, dew point, wind speed, and cloud cover are available at an hourly temporal resolution, but can only be downloaded for a single station and day at a time. SNOTEL, Agrimet, and Hydromet data were collected through Web services that the Natural Resource Conservation Service and Bureau of Reclamation maintain. MDOT data were downloaded from the Road Weather Information System portal.

An initial inventory of stations was created by selecting points within a 15-mile buffer around the Flathead Lake watershed boundaries. **Figure 8** presents a preliminary map of the selected stations using the buffer criteria. Observed precipitation data for these stations were then collected and assessed for quality and completeness of their time series. This analysis involved retrieval of 33 years of rainfall data (October 1, 1979 initially through September 30, 2008, and later extended to December 31, 2012). The results of the analysis are presented spatially in **Figure 9**.

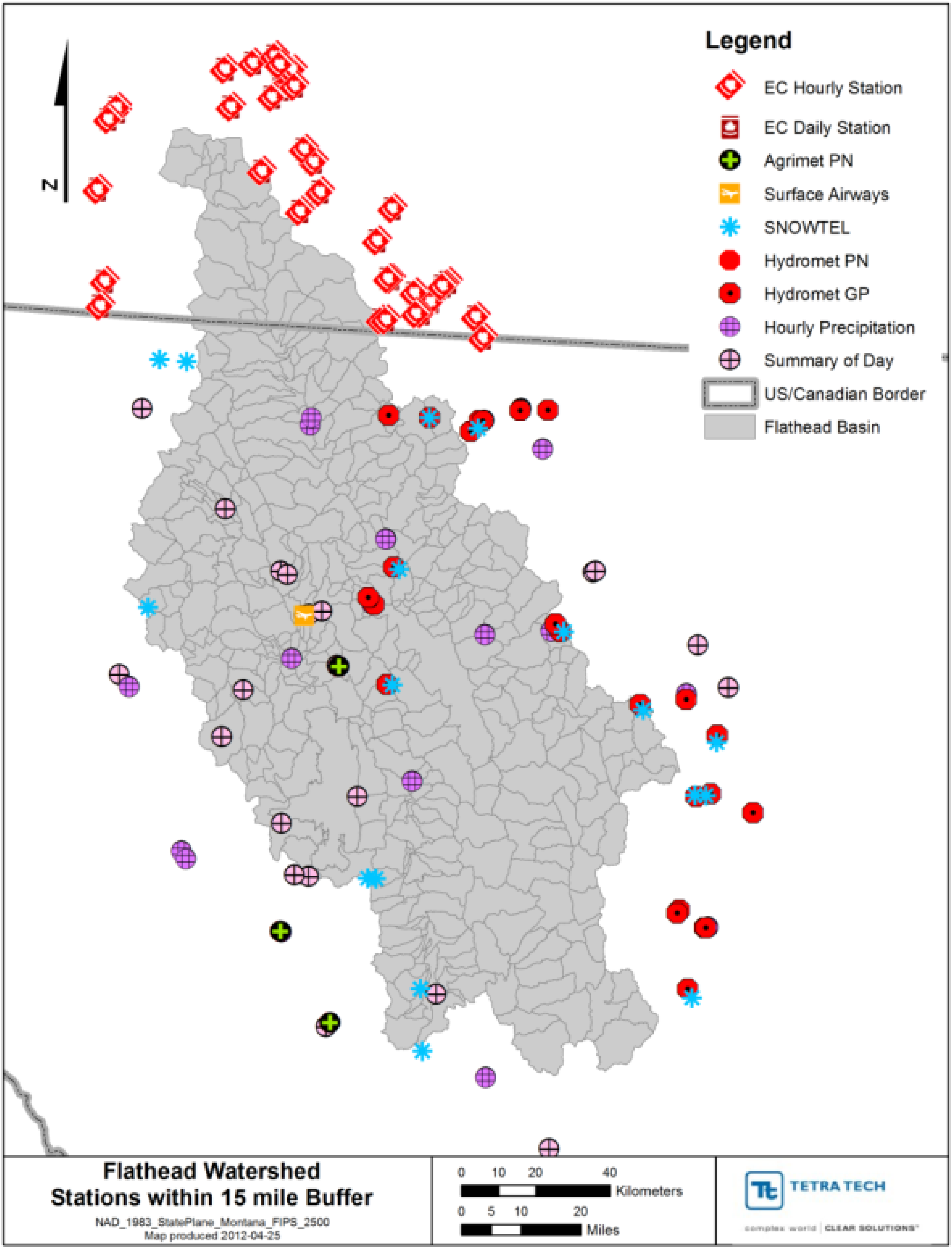

Figure 8. Meteorological Stations In or Near the Flathead Lake Watershed.

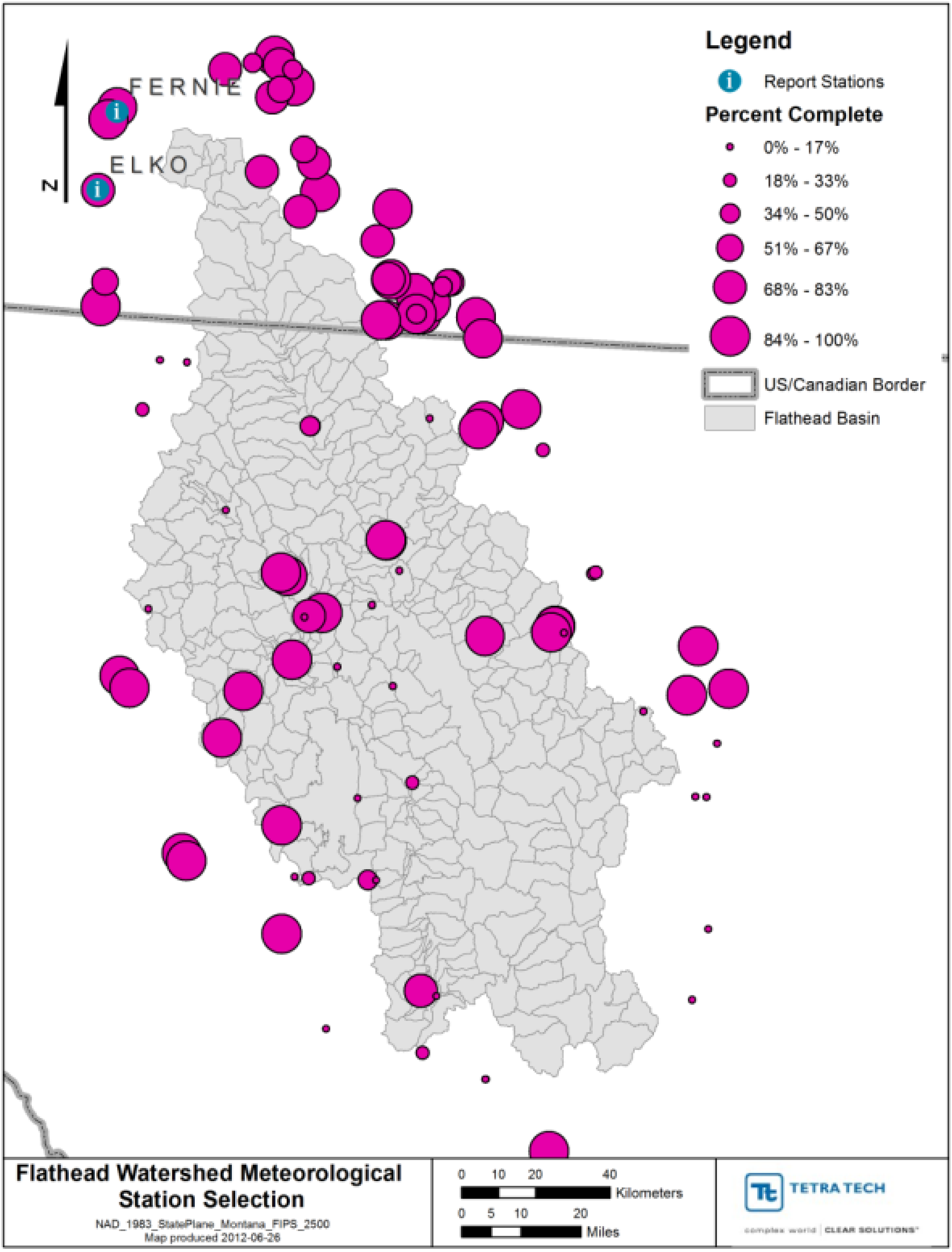

Figure 9. Completeness of Observed Meteorological Data at Selected Locations in the Flathead Lake Watershed.

2.4.2 Meteorological Data Quality Control

The Flathead Lake watershed LSPC model runs at an hourly time step. NCDC Summary of the Day stations provide the best measure of rainfall volume but do not provide an hourly pattern, while NCDC Surface Airways stations provide hourly rainfall, but sometimes underestimate total volume. In other words, reported daily rainfall is a better indicator of volume, but hourly distributions must be used to establish an hourly pattern to drive the model. For this reason, the distributions from hourly stations were used to disaggregate totals from daily stations to hourly precipitation. Many of the observed stations contain various intervals of accumulated data, are impaired with periods of missing/deleted data, or both. Missing or deleted intervals are periods during which either the gage malfunctioned or the data records were lost. Accumulated intervals represent cumulative precipitation over several hours or days, but the exact temporal distribution of the data is unknown.

The Normal Ratio Method (Dunne and Leopold 1978) was used to compute missing and deleted data intervals on a daily time step. Next, the patched daily intervals, along with any remaining accumulated intervals were disaggregated to hourly on the basis of hourly rainfall distributions at nearby gages. For patching purposes, the Normal Ratio Method estimates a missing rainfall value using a weighted average from surrounding stations with similar rainfall patterns according to the relationship:

$$P_A = \frac{1}{n}\left(\sum_{i=1}^{n} \frac{N_A}{N_i} \times P_i\right)$$

where P_A is the missing precipitation value at station A,
n is the number of surrounding stations with valid data at the same point in time,
N_A is the long-term average precipitation at station A,
N_i is the long-term average precipitation at nearby station i, and
P_i is the observed precipitation at nearby station i.

For each missing data record at station A, n consists of only the surrounding stations with valid data; therefore, for each record, n varies from 1 to the maximum number of surrounding stations. When no precipitation is available at the surrounding stations, zero precipitation is assumed at station A.

Two stations were selected with high and low completeness quality, respectively, to demonstrate the quality control process. **Figure 10** presents a summary of annual precipitation totals at the FERNIE (1152850) station for the period October 1, 1979, through September 30, 2008. All periods of missing data (those between 1996 and 2000) were estimated and patched using the Normal Ratio Method. The final hourly precipitation time series was generated by disaggregating the patched daily NCDC data to an hourly time series using a mix of hourly distributions from nearby observed NCDC precipitation gages that had the closest interval total as the interval being disaggregated. The FERNIE station provides relatively high-quality precipitation time series, while the Environment Canada ELKO (1152670) stations **Figure 11** presents show a high degree of impairment.

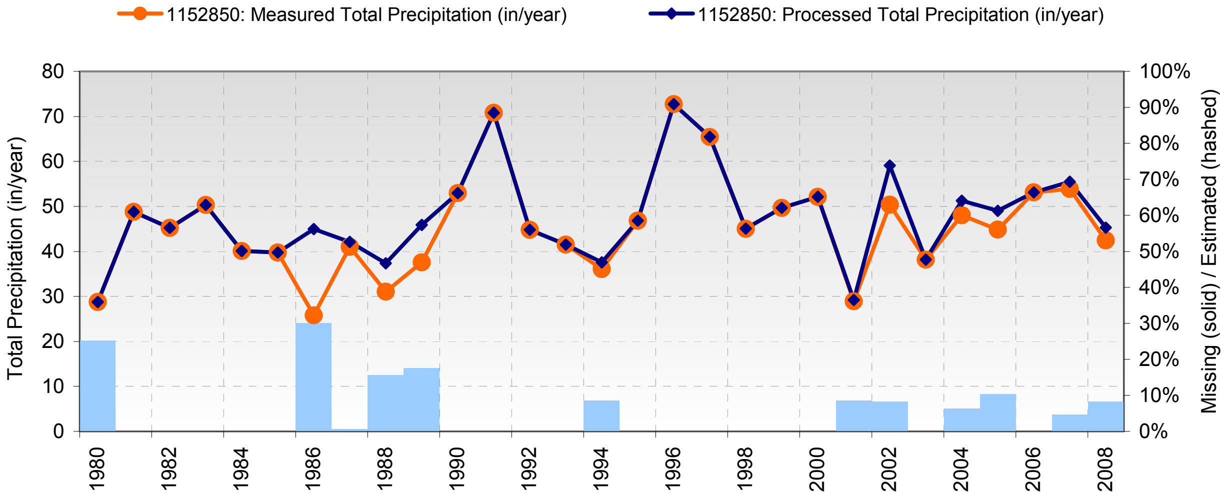

Figure 10. Total Precipitation at FERNIE (1152850), Water Years 1980-2008.

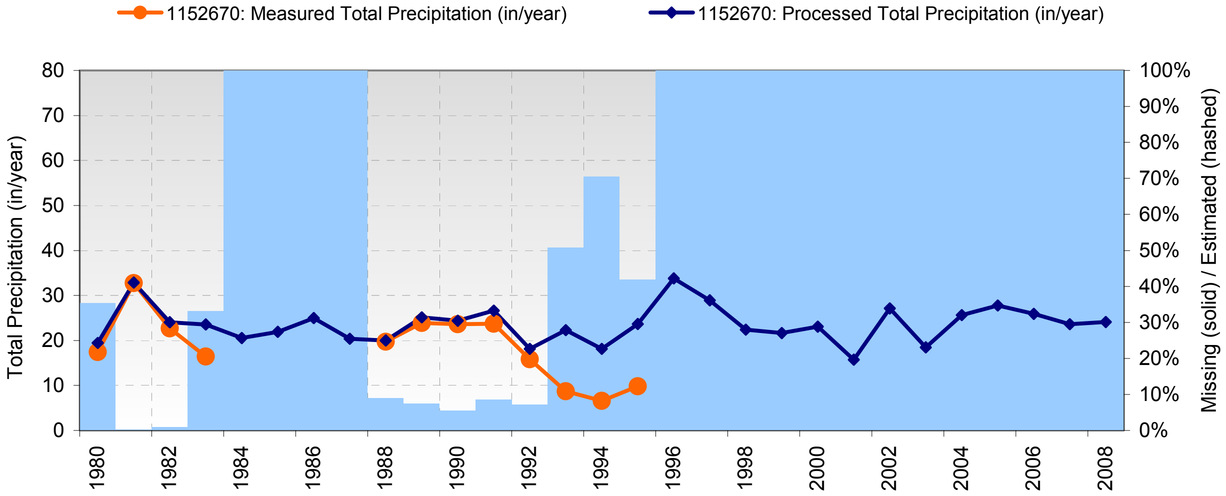

Figure 11. Total Precipitation at ELKO (1152670), Water Years 1980-2008.

Notice the difference in mean annual rainfall between the FERNIE and ELKO gages shown in **Figure 10** and **Figure 11**, respectively. The Normal Ratio Method is a robust approach for patching impairments because it is able to scale patched values to the long-term average of the gage being patched, even if nearby gages have different amounts of rainfall due to orographic influences.

A similar technique was applied to patch and disaggregate daily observed maximum and minimum temperature values to hourly time series. **Figure 12** presents time series of daily maximum and minimum temperature at the FERNIE (1152850) station. A period of missing data in 1988 is highlighted as having been patched with nearby observed temperature records using the Normal Ratio Method.

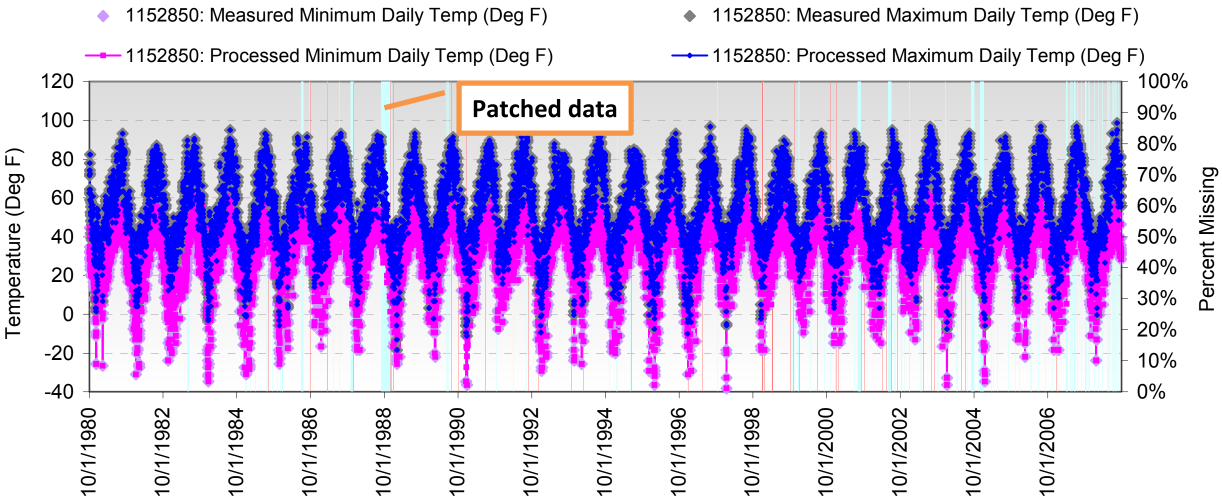

Figure 12. Daily Maximum and Minimum Temperature at FERNIE (1152850), Water Years 1980-2008.

These patching methodologies were applied to correct time series impairments and to perform an assessment of data quality for all inventoried stations. The precipitation record of each station was assessed for completeness with particular interest in stations with less than 30 percent missing records. This threshold assessment was used in conjunction with a visual inspection of annual time series and spatial mapping of gage locations to develop a proposed set of climate stations for representation in LSPC as shown in **Figure 13**, **Figure 14**, and **Table 5**.

These stations provided the set of available high-quality temporal climate data for modeling. Not all of the available data were used in the model, either because of insufficient length/quality of station records or proximity to other stations. Many Hydromet gages, for example, were located coincident with or close to NCDC and SNOTEL gages, with the latter sources having more comprehensive data documentation. The SNOTEL gages also collect and report daily snow pillow data. SNOTEL stations were more concentrated in the higher elevation mountainous areas, while the NCDC stations were more concentrated in the flat, lower elevation areas. The observed snow pillow data at the SNOTEL sites were used for model calibration of the snowpack, as explained in **Section 3.1**.

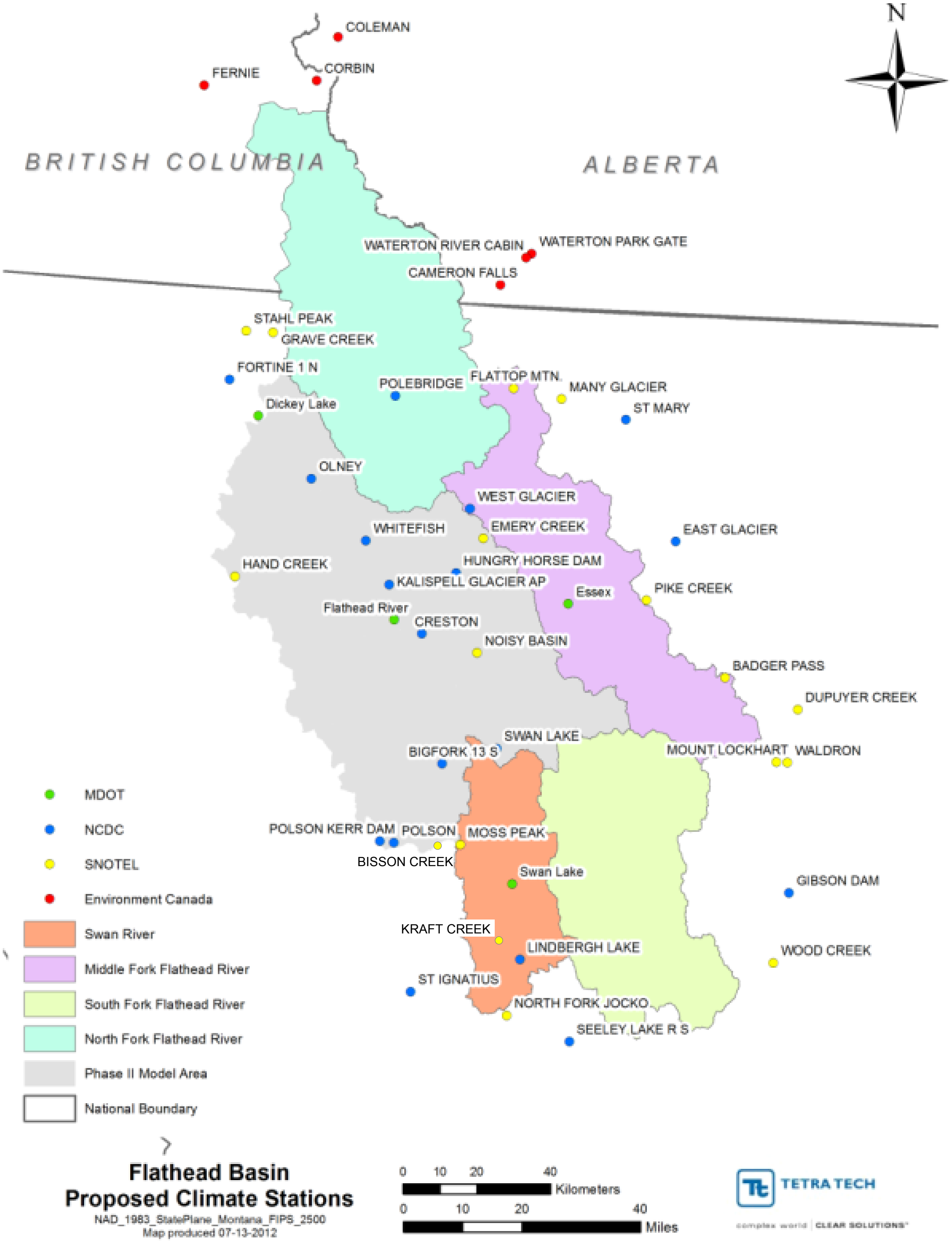

Figure 13. Daily Observed Precipitation and Temperature Sites Selected for Watershed Modeling.

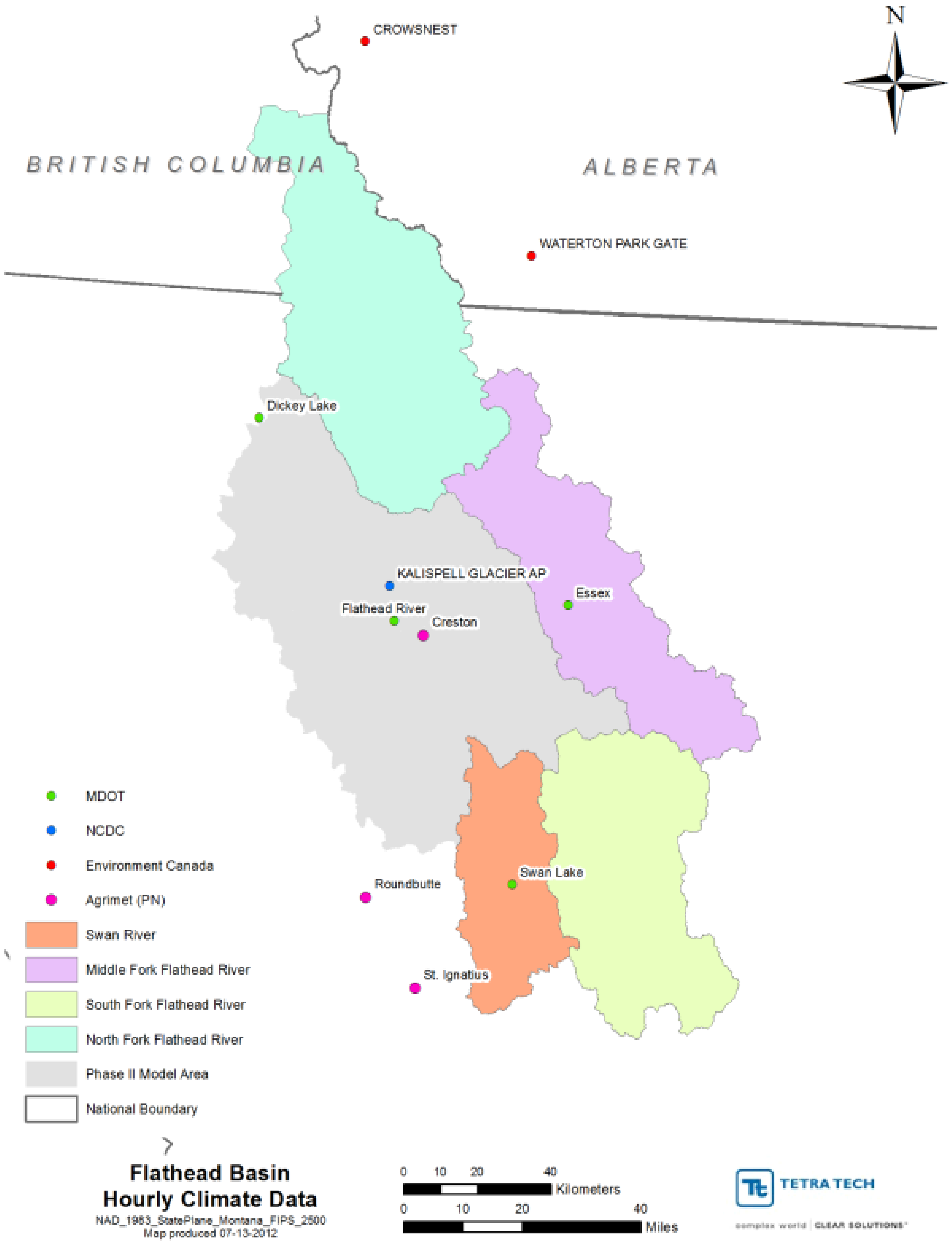

Figure 14. Hourly Observed Climate Data Sites Selected for Watershed Modeling.

Table 5. Inventory of Selected Observed Climate Data Sources for Watershed Modeling

Data source	Station name	Station ID	Elevation (ft)	Precipitation	Temperature and PET
NCDC	BIGFORK 13 S	240755	2,910	X	X
	CRESTON	242104	2,940	X	X
	EAST GLACIER	242629	4,806	X	
	FORTINE 1 N	243139	3,000	X	
	GIBSON DAM	243489	4,590	X	
	HUNGRY HORSE DAM	244328	3,160	X	
	KALISPELL GLACIER AP	244558	2,957	X	
	LINDBERGH LAKE	245043	4,320	X	X
	OLNEY	246218	3,165	X	X
	POLEBRIDGE	246615	3,520	X	X
	POLSON	246635	3,010	X	X
	POLSON KERR DAM	246640	2,730	X	
	ST IGNATIUS	247286	2,900	X	
	ST MARY	247292	4,560	X	
	SEELEY LAKE R S	247448	4,100	X	
	SWAN LAKE	248087	3,100	X	X
	WEST GLACIER	248809	3,154	X	X
	WHITEFISH	248902	3,100	X	X
	KALISPELL GLACIER AP	24146	2,957	X	
SNOTEL	DUPUYER CREEK	12a02s	5,750	X	
	MOUNT LOCKHART	12b12s	6,400	X	
	WALDRON	12b13s	5,600	X	
	WOOD CREEK	12b17s	5,960	X	
	BADGER PASS	13a15s	6,900	X	X
	FLATTOP MTN.	13a19s	6,300	X	X
	EMERY CREEK	13a24s	4,350	X	X
	NOISY BASIN	13a25s	6,040	X	X
	PIKE CREEK	13a26s	5,930	X	X
	MANY GLACIER	13a27s	4,900	X	
	NORTH FORK JOCKO	13b07s	6,330	X	X
	KRAFT CREEK	13b22s	4,750	X	
	MOSS PEAK	13b24s	6,780	X	X
	BISSON CREEK	13b25s	4,920	X	X
	GRAVE CREEK	14a11s	4,300	X	X
	STAHL PEAK	14a12s	6,030	X	
	HAND CREEK	14a14s	5,035	X	X
Environment Canada	FERNIE	1152850	3,284	X	
	COLEMAN	3051720	4,400	X	
	WATERTON PARK GATE	3056214	4,229	X	
	WATERTON RIVER CABIN	3057243	4,203	X	
	CAMERON FALLS	3051165	4,300	X	
	CORBIN	1151915	5,158	X	X
	CROWSNEST	3051R4R	4,274	X	

Data source	Station name	Station ID	Elevation (ft)	Precipitation	Temperature and PET
Agrimet	Creston	CRSM	2,950	X	
	Round Butte (Near Ronan)	RDBM	3,040	X	
	St. Ignatius	SIGM	2,980	X	
Montana Department of Transportation	Essex	-	3,848	X	
	Dickey Lake	-	3,487	X	
	Flathead River	-	2,851	X	
	Swan Lake	-	3,549	X	

2.4.3 Meteorological Models

Two grid-based meteorological models were also evaluated for incorporation into the Flathead Lake watershed LSPC model – PRISM and Climate Western North America (ClimateWNA). Both of these modeled products are derived from observed data, in conjunction with different spatial interpolation techniques. In the context of this study they were used as secondary data sources to help fill gaps in spatial coverage of precipitation over the study area.

The PRISM Climate Group at Oregon State University maintains a meteorological dataset that incorporates observed point data, a digital elevation map, and expert knowledge of complex climatic extremes (including rain shadows, coastal effects, and temperature inversions). The data cover the U.S.-portion of the Flathead Lake watershed at a 4-kilometer resolution. The University of Alberta maintains a counterpart ClimateWNA data product that includes spatial coverage in British Columbia. For that product, efforts using techniques Mitchell and Jones (2005) describe have yielded monthly historical climate data, using digital elevation models (DEMs) as input. Spatial resolution for ClimateWNA is user defined and can be as fine as 250 meters, depending on the resolution of the DEM being used as input. Because the PRISM and ClimateWNA approaches take into account elevation in the spatial interpolation process, the dataset can quantify orographic influences on precipitation in otherwise ungaged areas. Independent validation of these data against observed records has shown them to be reliable.

Figure 15 and **Figure 16** highlight the high degree of variability for the meteorological forcing data in the Flathead Lake watershed. The PRISM data show that average annual temperature varies across the study area by more than 10 degrees Fahrenheit, while the average annual precipitation ranges from less than 15 inches per year (in/yr) at lake level to more than 80 in/yr in certain locations. The lowest temperatures and highest precipitation values are found along narrow bands mostly along the northern high-elevation mountain ridges along the U.S.-Canadian border. The highest average annual temperature is found along the shoreline of Flathead Lake. Because topography plays an important role in influencing climate patterns, supplementing observed NCDC and EC climate data at single points with a wider spatially variable dataset like PRISM is beneficial.

Figure 17 and **Figure 18** confirm the high degree of spatial variability in both annual average precipitation and mean annual temperature seen in the ClimateWNA dataset. While PRISM data ends around the U.S.-Canadian border, ClimateWNA continues grid-based coverage into British Columbia, which is important since the portion of the watershed in Canada had poor spatial coverage of observed precipitation data, as seen in **Figure 9**.

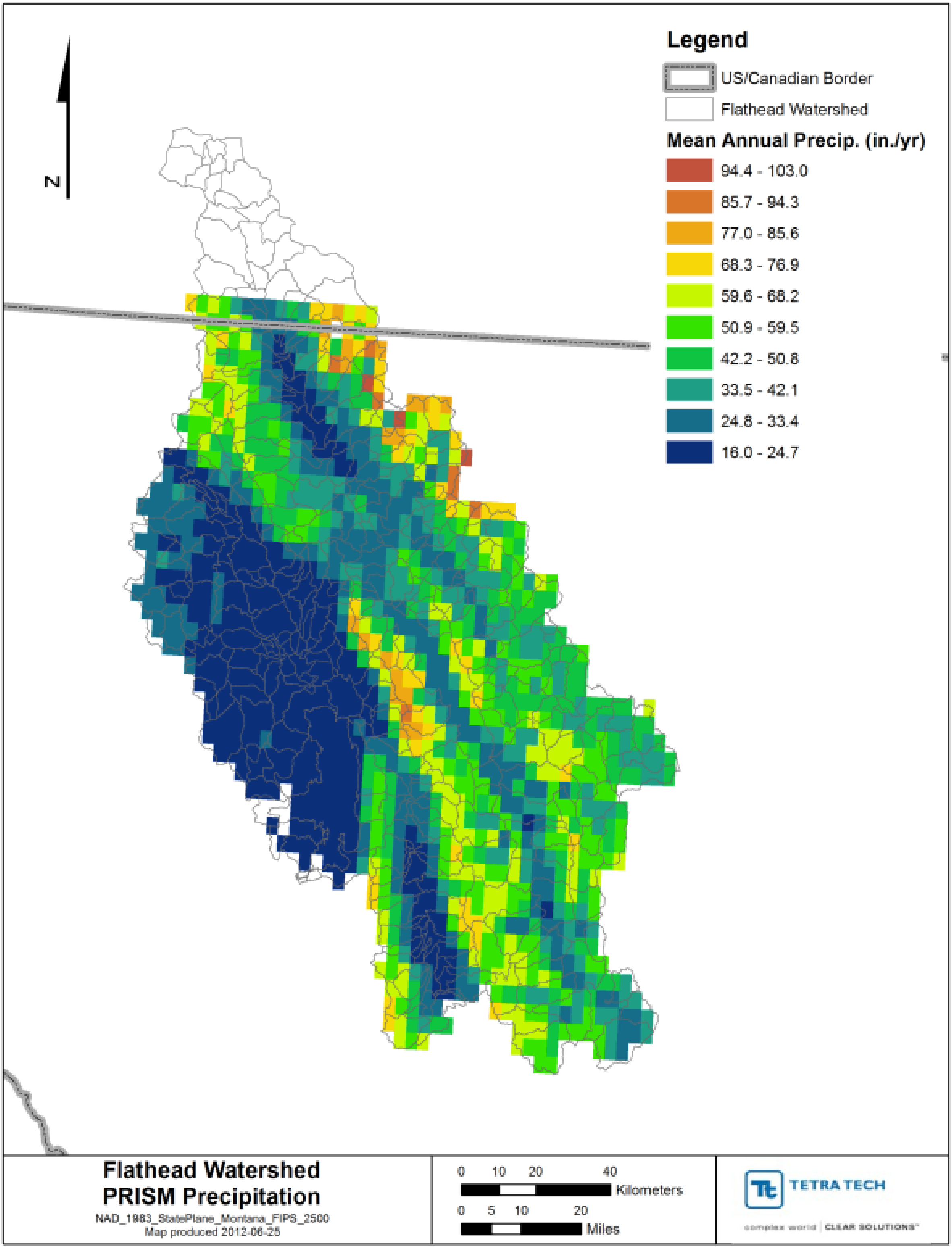

Figure 15. PRISM-Predicted Mean Annual Precipitation (Inches per Year).

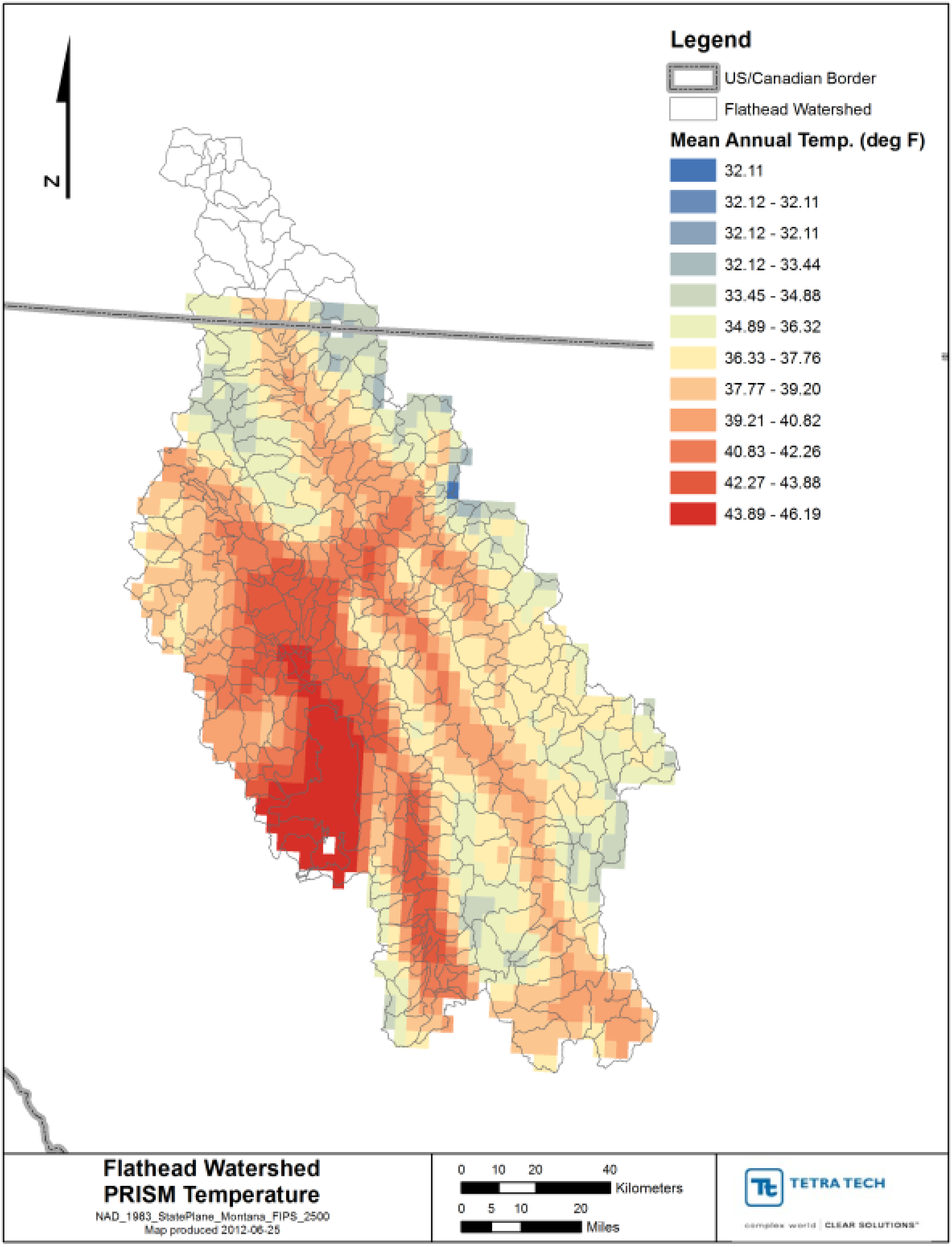

Figure 16. PRISM-Predicted Mean Annual Temperature (Degrees Fahrenheit).

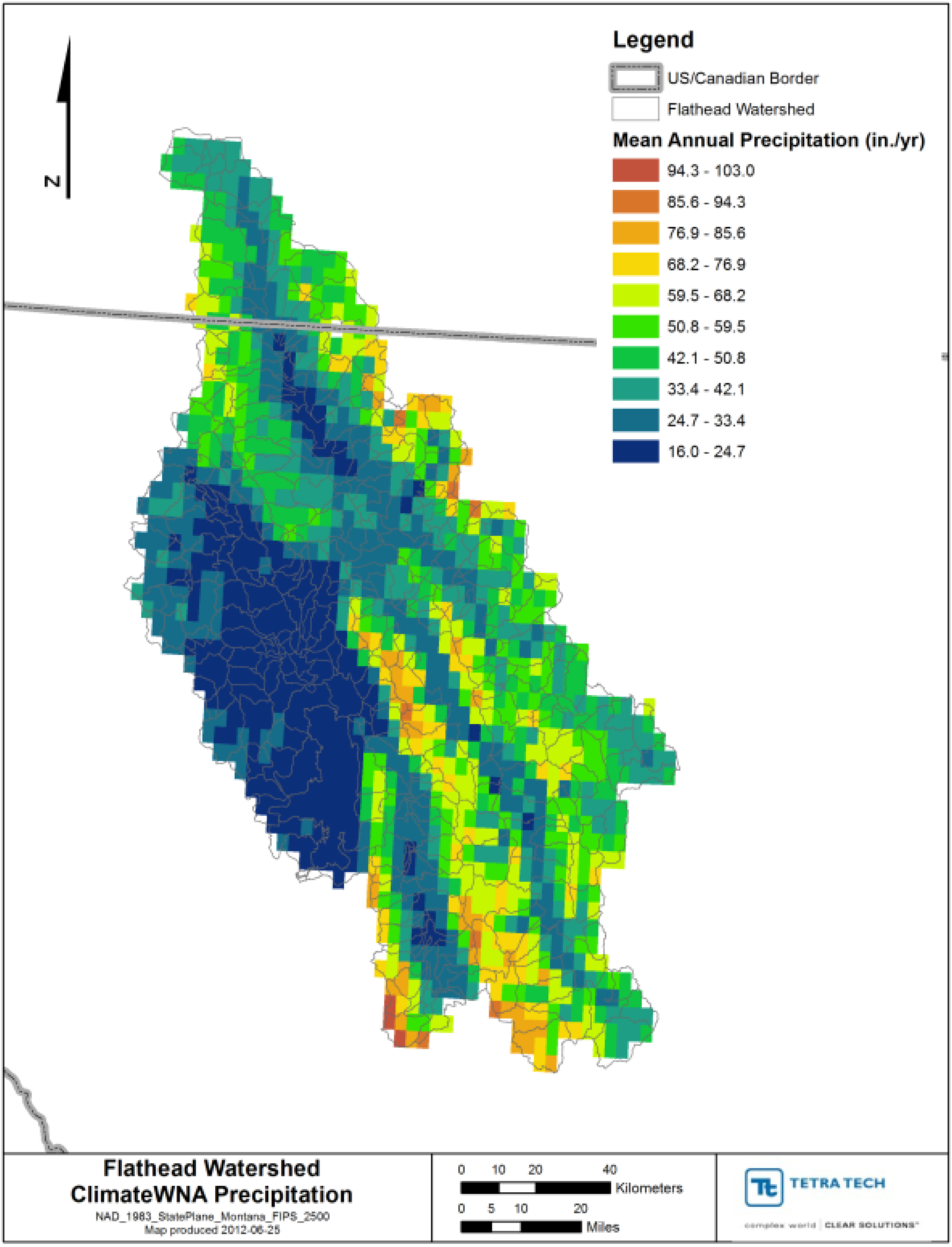

Figure 17. ClimateWNA-Predicted Mean Annual Precipitation (Inches per Year).

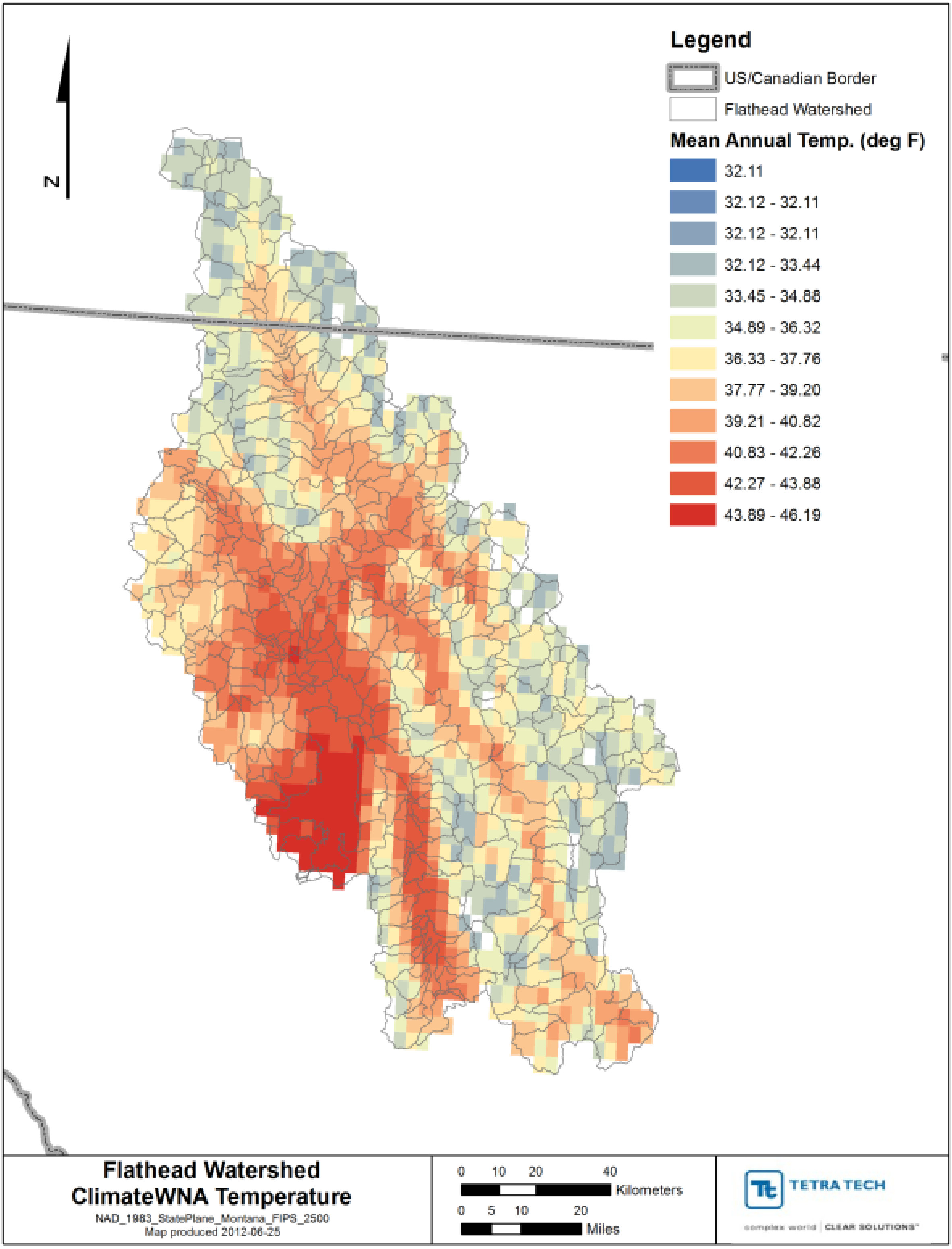

Figure 18. ClimateWNA-Predicted Mean Annual Temperature (Degrees Fahrenheit).

2.4.4 Spatial Assignment of Meteorological Data

For precipitation, the Thiessen Polygon approach was used for initially assigning daily and hourly records to each model subwatershed. A Thiessen polygon defines an area of influence around its sample point (in this case a precipitation gage), so that any location inside the polygon is closer to that point than any of the other sample points. A subwatershed falling fully within a particular Thiessen polygon was assigned to the precipitation gage associated with the polygon. Subwatersheds falling on the edge of more than one Thiessen polygon were assigned to the polygon (and associated station) with the largest area within the subwatershed. Once stations were assigned to each model subwatershed, the monthly PRISM time series were used to normalize the associated precipitation data. The area-weighted average monthly PRISM precipitation was calculated for each subwatershed. The ratio of PRISM precipitation to assigned station precipitation was then calculated for each subwatershed. Using the ratio, the hourly gage precipitation was normalized to the PRISM precipitation uniquely in each subwatershed. In this way, each subwatershed was simulated with a unique record to capture spatiotemporal differences between subwatersheds that would otherwise have been lost by directly assigning a single weather gage to multiple model subbasins. The ClimateWNA data product was used in portions of Canada that extended beyond the boundary of the PRISM dataset. **Figure 19** provides average annual rainfall in each model subbasin during the model simulation time period. Air temperature was also assigned using Thiessen polygons (**Figure 20**), though fewer stations were used than for precipitation. In addition, some adjustments were made to gage assignment based on elevation. Potential evapotranspiration (PET) time series were calculated coincident with each air temperature station, using the Penman method (1948). The Penman method requires inputs of daily average air temperature, daily average dew point, daily wind movement, and daily solar radiation. Data from Kalispell Glacier International Airport were used to represent dew point, wind movement, and solar radiation for PET calculations at each air temperature station. The daily PET series were then disaggregated to hourly values using a method that assumes a distribution based on latitude and time of year. The Kalispell Glacier International Airport station was also used to provide model inputs of hourly dew point, wind speed, solar radiation, and cloud cover.

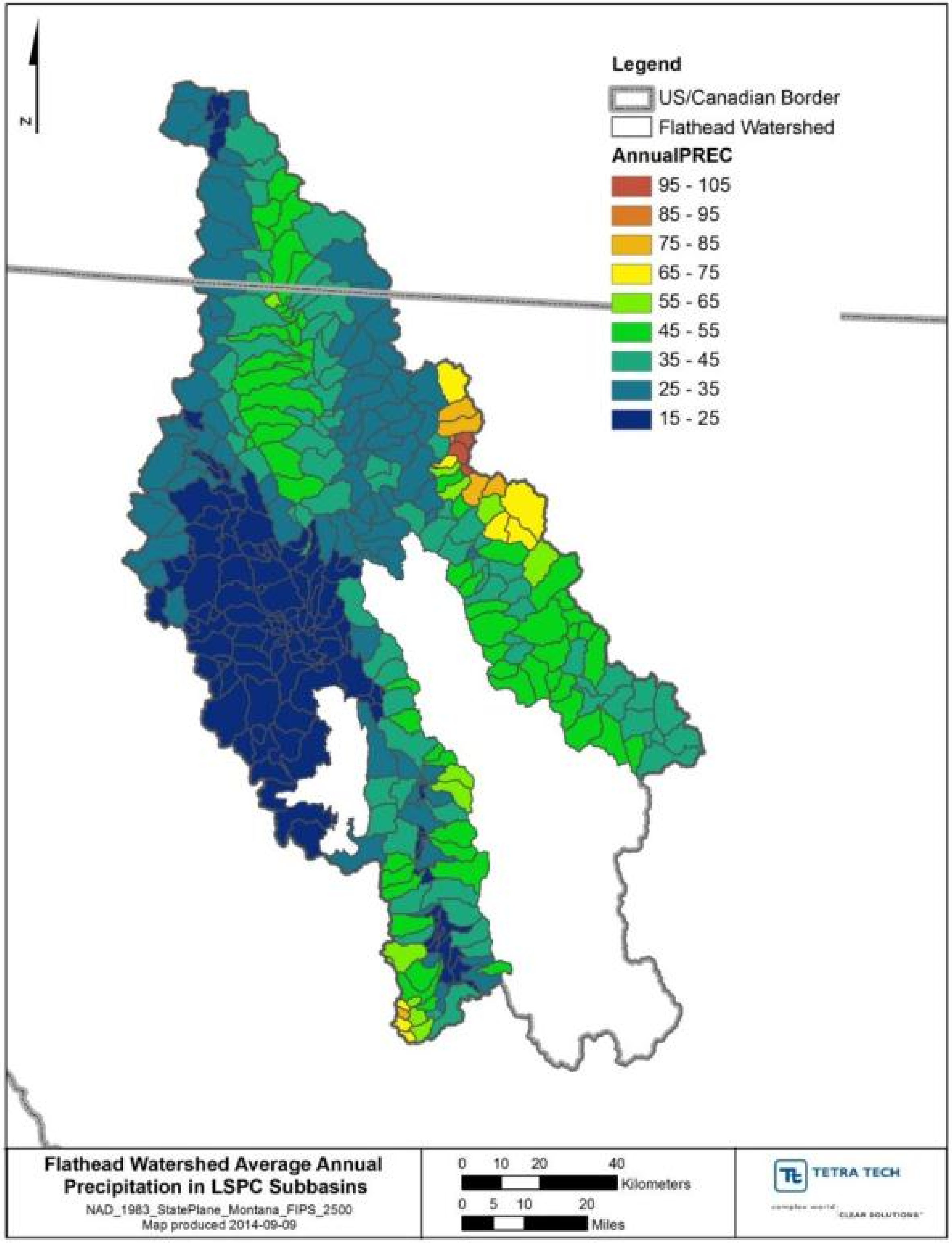

Figure 19. Average Annual Precipitation (Inches) in the LSPC Model Subbasins

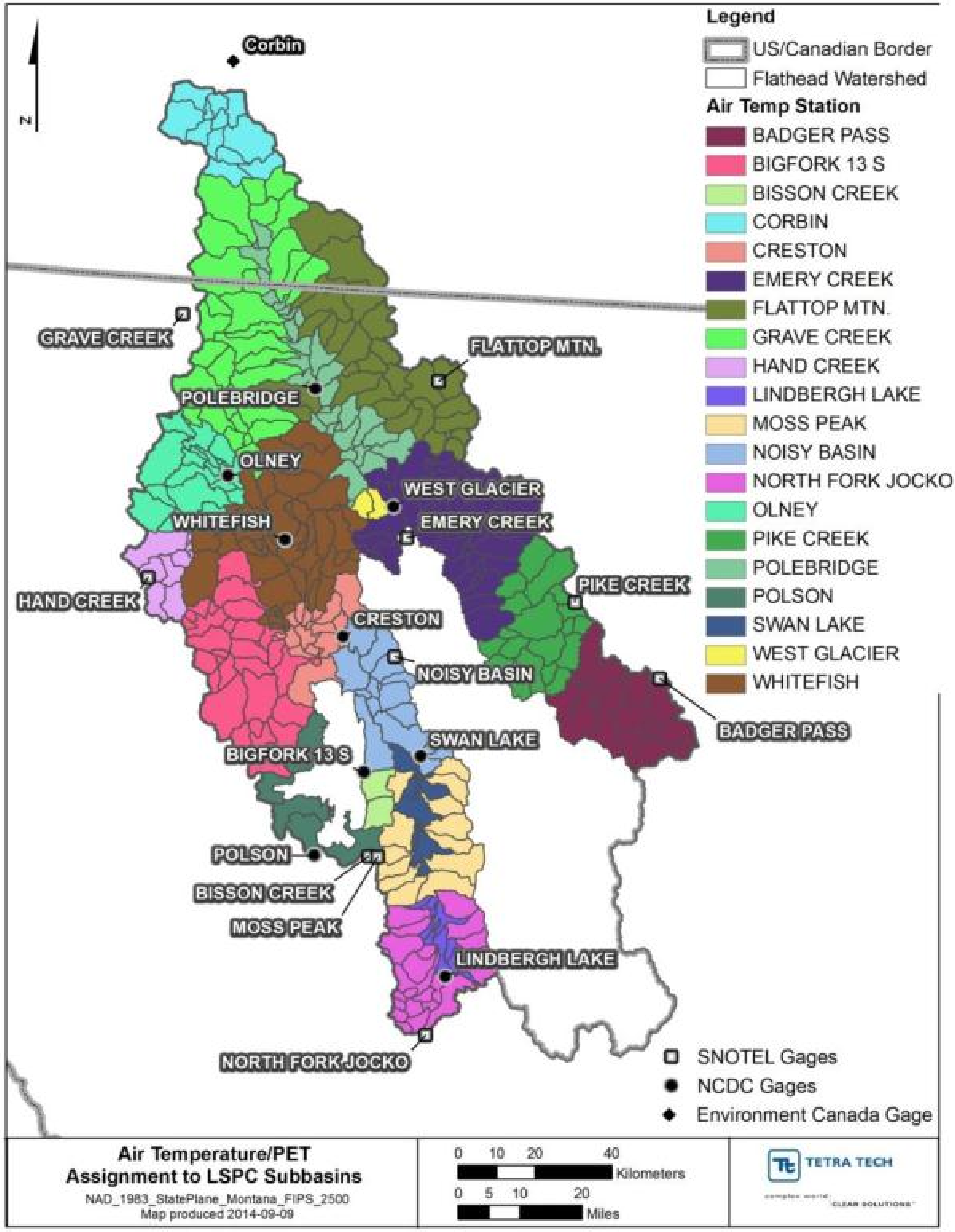

Figure 20. Temperature Gage Assignment to LSPC Model Subbasins

2.5 POINT SOURCES

Point sources (e.g., wastewater treatment plants [WWTPs], industrial facilities, fish hatcheries) are one of many potentially significant sources of pollutants within the Flathead Lake watershed. There are 419 facilities in the Flathead Lake watershed that are permitted to discharge wastewater to surface water or groundwater. Of the 419 permits, 275 are general Montana Pollutant Discharge Elimination System (MPDES) permits for stormwater discharges. The facilities with individual permits consist of publicly owned water and wastewater treatment plants, industrial sites, fish hatcheries, and smaller privately owned treatment systems. Facility size (and design flow) varies from small package plants (e.g., Yellow Bay WWTP, with a design flow of 33,000 gallons per day) to large publically owned treatment plants (e.g., Kalispell WWTP, with a design flow of 5.4 million gallons per day [mgd]). Permit limits vary for each facility and eight facilities have nitrogen or phosphorus permit limits.

While the Flathead Lake watershed contains many permitted point source dischargers, only those with the potential to significantly affect hydrology and/or the simulated water quality parameters were included in the LSPC model. The primary factors for determining inclusion of discharges in the model were the flow volume and the presence of nutrients in the effluent. Discharges with small permitted flows (e.g., less than 0.1 mgd) are frequently not included in simulation models since the flows and loads are minimal at a watershed scale, and often there are no requirements for these discharges to collect monitoring data (e.g., Discharge Monitoring Reports or DMRs). A description of the point sources represented in the Flathead Lake watershed LSPC model is presented in the following subsections.

2.5.1 Point Sources Represented

Ten permitted dischargers were incorporated in the LSPC model (**Table 6**). The discharge locations are shown in **Figure 21**. Flow and water quality data were obtained from discharge monitoring reports (DMRs) and facility records to characterize the effluent. DMR data were obtained from the online Integrated Compliance Information System[2] (ICIS) managed by USEPA and are available upon request.

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[2] http://www.epa.gov/enviro/facts/pcs-icis/index.html

Table 6. Point Sources Represented in the Flathead Lake Watershed LSPC Model

NPDES ID	Facility name	Receiving waterbody	Design flow (cfs) [a]
Individual MPDES Permittees			
MT0000019	Burlington Northern Whitefish Facility	Whitefish River	0.1
MT0020036	Columbia Falls WWTP	Flathead River	1.0
MT0020184	Whitefish WWTP	Whitefish River	2.8
MT0020397	Bigfork Water and Sewer District WWTF	Flathead Lake	0.8
MT0021938	Kalispell WWTP	Ashley Creek	8.4
MT0022578	Hungry Horse Dam WWTP	South Fork Flathead River	<0.11
MT0023388	Yellow Bay WWTP	Flathead Lake	0.1
MT0030601	Lake McDonald (Glacier National Park) WWTP	McDonald Creek & Middle Fork Flathead River [b]	0.4
General MPDES Permittees (Non-Stormwater)			
MTG130007	Creston National Fish Hatchery	Mill Creek	42.3
MTG130014	Flathead Lake Salmon Hatchery	Flathead Lake	0.2 [c]

a. Design flows were originally reported in million gallons per day in the permits and were converted to cfs for this table.

b. Lake McDonald WWTP discharges to groundwater that is hydrologically connected to McDonald Creek and the Middle Fork Flathead River.

c. The permit does not report design flows; the average of available DMR flow records is shown.

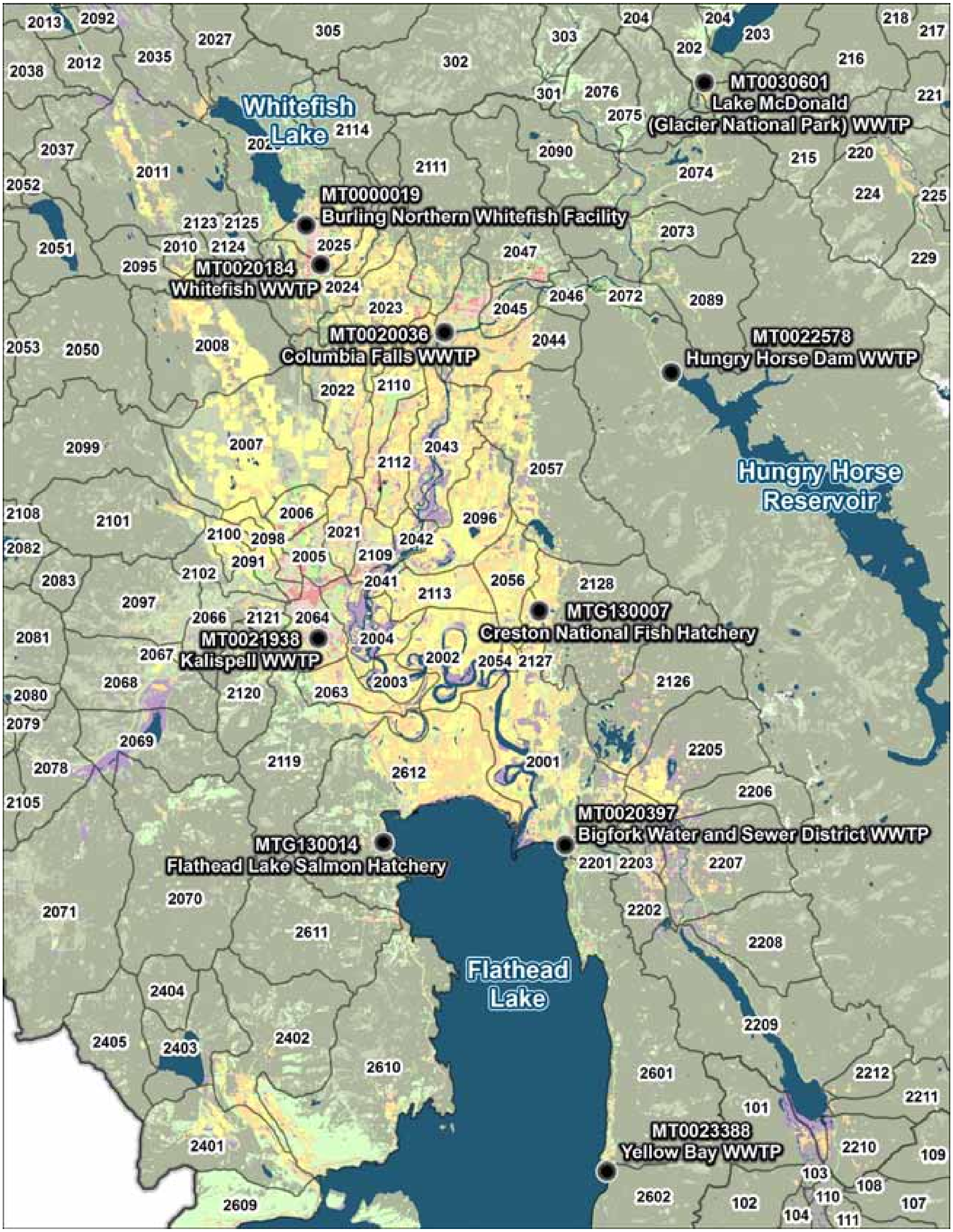

Figure 21. Point Sources Represented in the Flathead Lake Watershed LSPC Model.

2.5.2 Point Source Data Processing/Filling Gaps

Point sources are input into LSPC as time series of flow and pollutant concentration. The Flathead LSPC model includes point source time series of flow, sediment (separately as sand, silt, and clay), dissolved oxygen, nitrate, total ammonia, organic nitrogen, organic phosphorus[3], and water temperature. Within the LSPC model, the flows and loads are input directly into the upstream end of the assigned reach. Having daily (rather than monthly) values improves the accuracy of the model's representation of how the point source flows and loads interact with the reach into which they mix, especially if the point source flows and/or concentrations are highly variable, and also if the point source flow dominates the hydrology of the reach during all or part of the year. However, daily values are frequently not available because monthly average values are often all that is reported. The following summarizes the preparation of point source data for each of the ten facilities, including how daily values were estimated. Time series were developed for the period January 1, 1992 through December 31, 2012. The arithmetic means, medians, and geometric means of subsets of data were each calculated and evaluated for the use as a surrogate to fill data gaps. Typically geometric means were used to create surrogates as they were most representative of the datasets. For example, arithmetic means tended to be more heavily affected by a few outliers in each dataset. In many cases, only one or a few isolated records were missing from a dataset; in such cases, an arithmetic mean of the data in the records before and after were used to fill the data gap.

2.5.2.1 Burlington Northern Whitefish Facility (MT000019)

Flow and all water quality parameters were available in ICIS. DMR data for flow consisted of 35 records from April 2000 through October 2012. Between 22 and 24 records each were available for the water quality parameters from April 2000 through September 2009. No water quality data were available for 2010 to 2012. The geometric means of flow data from 2000 and 2012 were used to estimate the initial (before April 2000) and terminal (after October 2012) time series inputs, respectively. The initial water quality inputs were estimated as the geometric means of water quality records from 2000. Geometric means of 2008 to 2009 data were used to estimate 2010 to 2012 water quality inputs.

2.5.2.2 Columbia Falls WWTP (MT0020036)

The flow input time series was constructed with data provided by the City of Columbia Falls. Reported influent flow data from 1990 through mid-2008 were used as surrogates for effluent flow data. Reported effluent flow data were used for mid-2008 through 2012. The water quality parameters input time series were constructed with ICIS data and data provided by the city of Columbia Falls.

The methods for estimating water quality parameters concentrations (on days where flow was monitored but water quality was not) varied depending on the size of the gap. Daily gaps were filled with the average of the preceding and following days. Larger gaps within a month with monitoring were assigned the average for that month. Months with one reported value were filled with that value. For some parameters, there was an initial period during which no monitoring data were available; in those cases, the values were filled with a geometric mean of the nearest adjacent subset of data.

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[3] Total phosphorus from the permitted facilities was entered in the model as organic phosphorus.

2.5.2.3 Whitefish WWTP (MT0020184)

Data were available from ICIS and directly from the City of Whitefish. Flow records were available from the city through 2008, and were supplemented with ICIS data through 2012. The City's data also provided good coverage of water quality data, though some gaps were addressed with ICIS data. For any date that a water quality parameter was sampled, the analytical results were assigned to that date in the input time series.

The methods for estimating water quality parameters concentrations (on days where flow was monitored but water quality was not) varied depending on the size of the gap. Daily gaps were filled with the average of the preceding and following days. Larger gaps within a month with monitoring were assigned the average for that month. Months with one reported value were filled with that value.

2.5.2.4 Bigfork Water and Sewer District WWTF (MT0020397)

The Bigfork Water and Sewer District WWTF discharges to Flathead Lake. While it is outside the domain of the LSPC watershed model, its load contribution to Flathead Lake was included in the model. Data were available from ICIS and directly from the Bigfork Water and Sewer District. For flow and the majority of water quality parameters, the District data provided good coverage. TSS data from ICIS were used to fill a gap in District monitoring.

The methods for estimating water quality parameters concentrations (on days where flow was monitored but water quality was not) varied depending on the size of the gap. Daily gaps were filled with the average of the preceding and following days. Larger gaps within a month with monitoring were assigned the average for that month. Months with one reported value were filled with that value. For TSS, there was an initial period during which no monitoring data were available; in that case, the values were filled with a geometric mean of the nearest adjacent subset of data.

2.5.2.5 Kalispell WWTP (MT0021938)

The flow component of the time series was developed with daily data provided by the city of Kalispell. Influent daily flow data from the city of Kalispell were used as surrogates for effluent flow data from 1993 through 2008. Daily effluent flow from the city of Kalispell was used for 2008 through 2012. As no flow data of any kind were available for 1992, daily influent flow data for 1993 were used as surrogates for 1992 daily effluent flow. The water quality parameters input time series were also constructed with data provided by the city of Kalispell. Water quality data varied by parameter over time; typically, data were either available as monthly samples or sub-monthly samples. TP and TSS were available as sub-weekly samples.

As flow data were available for every day over the model period, water quality data needed to be estimated on a daily frequency. All available water quality data from the city of Kalispell were input into the time series. Data gaps between samples were filled by linear interpolation. To develop the water quality time series, the first and last samples were used as surrogates for all initial and final dates of the time series. Finally, no data were available for 1992; therefore, 1993 data were used as surrogates for 1992.

2.5.2.6 Hungry Horse Dam WWTP (MT0022578)

Flow and all water quality parameters were available in ICIS. From fall 1995 through spring 2011 the majority of water quality parameters were available in ICIS. Between October 1995 and January 2013, 469 flow records were available. Between December 2008 and January 2013, 58 temperature records were available.

The flow data varied over multiple orders of magnitude and the records appeared to be entered at different units of measure (e.g., thousand gallons per day, gallons per day). Best professional judgment was used to assume what unit of measure each flow record was reported in. The geometric mean of 1995 to 1996 flow data was used to estimate the initial time series input (1992-1994). Flow data gaps were filled by calculating the arithmetic mean of the flow records immediately before and after the missing records.

The initial (1992-1994) water quality time series inputs were estimated as the geometric means of water quality records from 1995 to 1996. Single record data gaps were present for all water quality parameters. The individual record gaps were filled by calculating the arithmetic means of the water quality records immediately before and after the missing records. Data gaps from late 2008 through early 2011 for water quality parameters (with the exception of temperature) were filled using the geometric mean of data from 2008 to 2009. Data gaps from May 9, 2011 through December 31, 2012 were filled using the data from April 29, 2011 as surrogates. The geometric means of 2008 to 2009 data were significantly greater than the data reported for April 29, 2011 (the only date data are reported for from September 2009 through December 2012); therefore, the data from April 29, 2011 were assumed to me more representative than the geometric means and the April 29, 2011 data were used as surrogates for all dates after September 2009. Temperature data gaps from 1995 through 2008 were filled using seasonal geometric means.

2.5.2.7 Yellow Bay WWTP (MT0023388)

Data were available from ICIS and directly from FLBS, which has its wastewater treated by the WWTP. The Yellow Bay WWTP discharges to Flathead Lake, and thus, is outside the domain of the LSPC watershed model. Additionally, the discharge from this facility is relatively small (0.1 cfs). Regardless, its load contribution to Flathead Lake is included in the model.

The flow and water quality input time series were constructed with ICIS data and data provided by FLBS. The methods for estimating water quality parameters concentrations (on days where flow was monitored but water quality was not) varied depending on the size of the gap. Gaps within a month with monitoring were assigned the average for that month. Months with one reported value were filled with that value. For some parameters, there was an initial period during which no monitoring data were available; in those cases, the values were filled with a geometric mean of the nearest adjacent subset of data. As no temperature data were available, a temperature time series was not developed.

2.5.2.8 Lake McDonald WWTP (MT0030601)

Flow and water quality parameters were available in ICIS (except for temperature which was not reported). The flow data varied over multiple orders of magnitude and the records appeared to be entered at different units of measure (million gallons per day, thousand gallons per day, or gallons per day). Best professional judgment was used to assume what unit of measure each flow record was reported in. The geometric mean of 2005 flow data was used to estimate the initial time series input.

The initial water quality time series inputs were estimated as the geometric means of water quality records from 2005. Single record data gaps were present for all water quality parameters. The gaps were filled by calculating the arithmetic means of the water quality records immediately before and after the missing records. Water quality records of zero, assumed to be non-detects, were input as zeroes, as method detection limits are unknown.

2.5.2.9 Creston National Fish Hatchery (MTG130007)

Flow and TSS were available in ICIS. DMR flow data consisted of 13 records from January 2007 through January 2013. DMR TSS data consisted of 11 records over the same time period. The geometric mean of 2007 to 2008 semi-annual flow data was used to estimate the initial time series input. The initial TSS time series input was estimated as the geometric mean of TSS records from 2007 to 2008. Gaps were filled by using surrogate water quality records that were either immediately before or after the missing records. No reporting was available for the remaining water quality parameters, so no series were developed.

2.5.2.10 Flathead Lake Salmon Hatchery (MTG130014)

Flow was available in ICIS. DMR flow data consisted of 13 records from March 2007 through January 2013. This facility discharges directly to Flathead Lake and its discharge is relatively small (0.25 cubic feet per second [cfs]). While it is outside the domain of the LSPC model, its flow contribution to Flathead Lake was included in the model.

2.6 SEPTIC SYSTEMS

Nitrogen and phosphorus loads from septic systems were estimated outside the LSPC platform using an approach developed by DEQ, the Method for Estimating Attenuation of Nutrients from Septic Systems (MEANSS). MEANSS was developed for use in the state's nutrient trading policy (DEQ, 2012). The estimated loads were input into the LSPC model as point sources in each modeling subwatershed. The method for estimating nitrogen and phosphorus loads are summarized below.

MEANSS requires input data pertaining to the distance between septic systems and surface water, soil drainage at the septic system, soil drainage in the riparian zone, and the percent of calcium carbonate that may be present in the soil. Data compilation and processing methods are described in **Table 7**.

Table 7. Generation of MEANSS Input Data

Data Required	Source	Process
Distance to surface water	Montana Structure Framework database and Montana State Department of Revenue county databases	Determine probable septic system locations
	National Hydrography Dataset (NHD)	Identify perennial streams and lakes
Soil drainage at the septic system	NRCS Soils Data (SSURGO)	Classify according to hydrologic soil group
Soil drainage at the riparian zone	NRCS Soils Data (SSURGO) National Hydrography Dataset (NHD)	Develop percentage of riparian zone in each HSG for each model subbasin [a]
Percent calcium carbonate	NRCS Soils Data (SSURGO)	Classify according to $CaCO_3$ 'representative percentage'

[a] Soil drainage characteristics within the riparian zone were averaged according to the proportion of each hydrologic soil group within the 100 foot riparian buffer in each subwatershed

The locations of septic systems were estimated using two databases: the Montana Structure Framework database (Montana State Library, 2012), and the Montana State Department of Revenue databases (Montana State Library, 2013) from Flathead, Lake, and Missoula counties. Properties were selected based on database attributes representing dwellings. Locations within sewer service area boundaries were assumed to not use septic systems and were removed from the spatial database. The distribution and density of septic systems within the Flathead Lake watershed is shown in **Figure 22**. Distance to the nearest NHD perennial water body was calculated for each septic system point using GIS methods. Hydrologic soil group (HSG) developed from Soil SURvey GEOgraphic (SSURGO) spatial databases was queried and assigned to each septic system point. To represent soil drainage in the riparian zone, 100' buffers adjacent to perennial water bodies were queried for HSG, and the percent of each HSG class within the buffer calculated for each model subbasin. Percent calcium carbonate was calculated from SSURGO data for each septic system point.

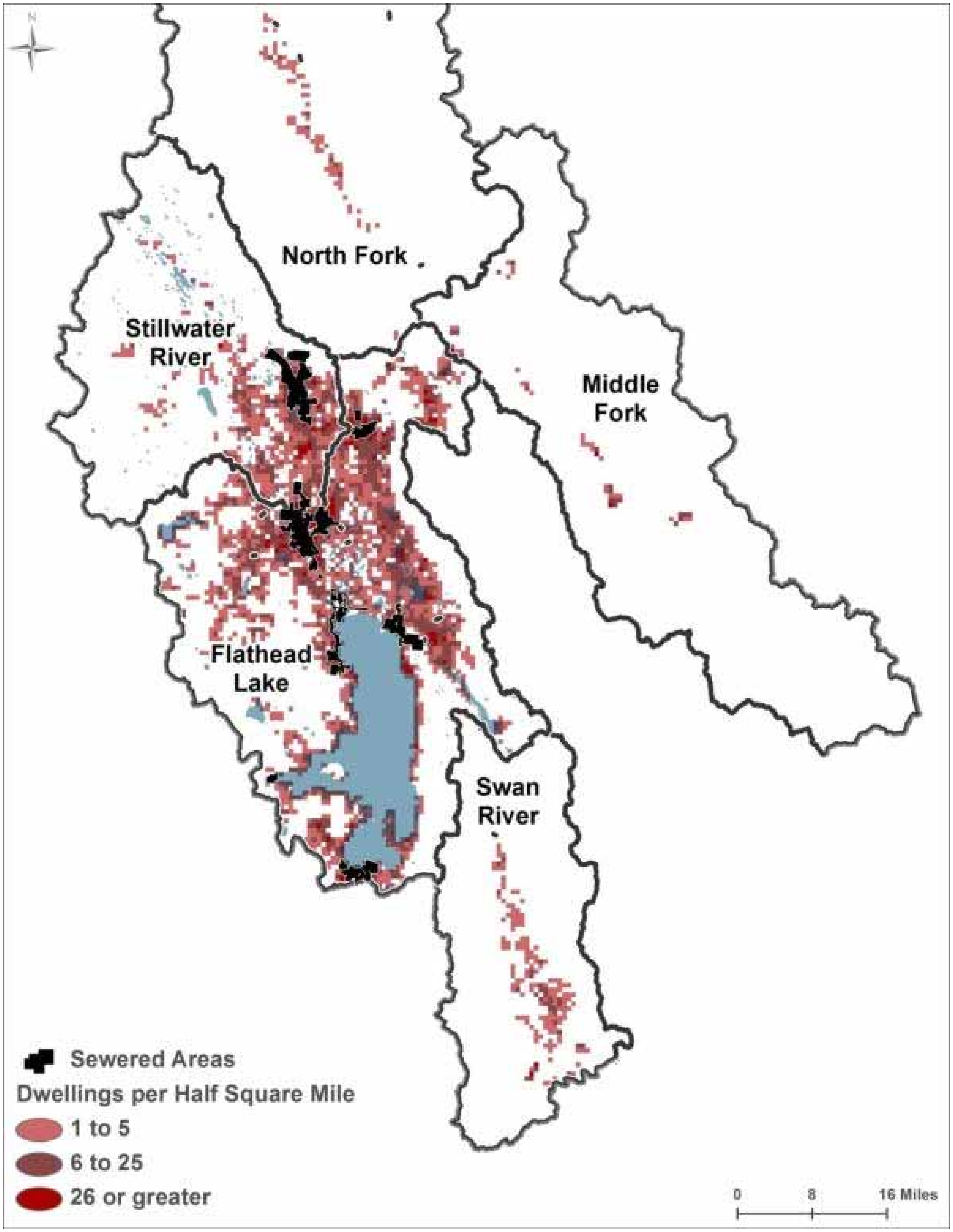

Figure 22. Septic system locations in the Flathead Lake watershed

The MEANSS method for estimating nitrogen loading (in the form of nitrate) from septic systems uses a matrix (**Table 8**) and is based on the three primary factors affecting the amount of denitrification: soil type beneath the drainfield; soil type in the riparian area; and distance to surface water. Each drainfield is assigned a percent denitrification factor for each of the three criteria. The percentages assigned for each column are then summed to provide the total percent nitrogen removal for that septic system. The nitrogen loading rate (30.5 pounds per year for a conventional system) to the surface water is then reduced accordingly. Any system with a percent reduction of 100 percent or more is assumed to contribute no nitrogen to the surface water. This method assumes steady-state conditions exist in that it does not account for the time needed for the nitrogen load to migrate toward the receiving surface water.

Table 8. MEANSS Nitrogen-Loading Matrix

Percent nitrogen load reduction [a]	Soil type at drainfield	Soil type within 100 feet of surface water	Distance to surface water (feet)
0%	A	A	≤100
10%	B	--	> 100–500
20%	C	B	> 500–5,000
30%	D	C	> 5,000–20,000
50%	--	D	> 20,000

a. The total nitrogen reduction is the sum of the individual reductions for each column of the table. For example, the nitrogen load reduction associated with a drainfield in a type C soil that drains to a surface water with type B soil, and is 200 feet from the nearest surface water would be 50% (i.e., 20% + 20% + 10% = 50% or 30.5 lbs/year × 0.5 = 15.25 lbs/year).

The MEANSS method for estimating phosphorus loading to surface waters from septic systems uses a matrix similar to nitrogen (**Table 9**). The matrix combines three factors that have been shown to affect the amount of phosphorus attenuation: soil type beneath the drainfield; calcium carbonate percent in the soil beneath the drainfield; and distance to surface water. Each drainfield is assigned a percent phosphorus reduction for only one of the first three columns (the soil and calcium carbonate type), and then an additional percent phosphorus reduction for the fourth column (distance to surface water). The percentages assigned for each column are then added to provide the total percent phosphorus removal for that septic system. The phosphorus loading rate (6.44 pounds per year for a conventional system) to the surface water is then reduced accordingly. Any system with a percent reduction of 100 percent or more is assumed to contribute no phosphorus to the surface water. This method assumes steady-state conditions exist in that it does not account for the time needed for the phosphorus load to migrate to the receiving surface water.

Table 9. MEANSS Phosphorus-Loading Matrix

Percent phosphorus load reduction	Soil type at drainfield ($CaCO_3$ <= 1%)	Soil type at drainfield ($CaCO_3$ > 1% and < 15%)	Soil type at drainfield ($CaCO_3$ >= 15%)	Distance to surface water (feet)
0%	A	A	A	≤ 100
10%	--	--	B	
20%	--	B	C	
30%	B	--	D	> 100–500
40%	--	C	--	
60%	C	D	--	> 500–5,000
90%	D	--	--	
100%	--	--	--	> 5,000

A summary of the results is shown in **Table 10**. Septic systems in the Flathead Lake watersheds totaled 20,990 units. Of the 392 subwatersheds modeled in the basin, 194 of them were found to contain at least one septic system in 2012. The average percentage of the nitrogen load removed due to soil drainage characteristics and distance from surface waters was 59 percent, while distance, soil drainage, and calcium carbonate contributed to a 74 percent reduction in phosphorus loading. The estimated total delivered nitrogen and phosphorus loads from septic systems in the Flathead Lake watershed are 261,147 and 35,318 pounds per year, respectively.

Table 10. Summary of Nitrate and Phosphorus Loading from Septic Systems

Watershed	No. of Septics	Total Nitrate Loading at Drainfields (lbs/year)	Total Nitrate Loading to Surface Water (lbs/year)	Total Phosphorus Loading at Drainfields (lbs/year)	Total Phosphorus Loading to Surface Water (lbs/year)
North Fork	248	7,564	3,086	1,597	412
Middle Fork	449	13,695	9,199	2,892	1,105
Swan	1,797	54,809	19,563	11,573	2,600
Whitefish	2,369	72,255	26,541	15,256	2,103
Stillwater	2,611	79,636	32,050	16,815	3,275
Ashley	3,028	92,354	38,427	19,500	5,777
Flathead River and Lake Tributaries	10,488	319,884	132,281	67,543	20,046
Flathead Lake	20,990	640,195	261,147	135,176	35,318

The nitrogen and phosphorus loads calculated by MEANSS were input into the LSPC watershed model as individual small point sources for each subwatershed. Individual septic tank flow was calculated by assuming that each septic tank served two people and each person utilized 170 liters per day. The individual septic tank flows were then aggregated to total flow for a subwatershed by factoring in the number of septic tanks contained within the boundaries of each subwatershed. The flows went into the model as a constant and continuous flow in cubic feet per second and were not varied seasonally. For nutrients, LSPC expects the unit to be cfs x mg/L. For nitrogen loading, first the yearly load calculated by MEANSS was converted to a concentration using yearly flow volumes and then turned into the expected

LSPC units by multiplying the concentration by the flow in cubic feet per second. Nitrogen was put into the model as constant and continuous as nitrate+nitrite[4]. For phosphorus loading, first the yearly load calculated by means was seasonally split to have 2/3 of the load occurring in the 75 day wet period (1 Apr – 15 June) and 1/3 of the load occurring in the 290 day dry period (16 June – 31 May). Second the seasonal load was converted to a concentration using seasonal flow volumes and then turned into the expected LSPC units by multiplying the concentrations by the flow in cubic feet per second. Phosphorus was put into the model as seasonally variable as organic phosphorus.

2.7 BANK EROSION

While the Flathead Lake watershed LSPC model does not directly simulate bank erosion, there are two distinct processes in the model that together serve as a proxy for representing bank erosion loading. The first process is land surface scour, which represents gulley erosion on the landscape. In the context of the Flathead Lake watershed LSPC model, the scour component represents headwater gullies that lie between the land surface and the larger receiving streams that are explicitly simulated in the model. Sediment associated total phosphorus (TP) is included with the land surface scour component of bank erosion.

The second process is stream bed degradation. In LSPC, the stream bed is modeled dynamically, and sediment (made up of sand, silt, and clay components) is allowed to settle and re-suspend from the bed based on sediment fall rates, stream shear stress, and critical scour thresholds. Because LSPC is a one-dimensional reach model it does not distinguish between bed incision (i.e., channel degradation) and bank erosion loads. Bed degradation in a one-dimensional reach model serves as a proxy for generalized stream channel erosion, which includes erosion from both the stream bank and the bed. Careful calibration was performed to compare model response to total suspended solids (TSS) monitoring data throughout the watershed. The approach for sediment calibration generally follows the guidance of BASINS Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF (USEPA, 2006) and Sediment Calibration Procedures and Guidelines for Watershed Modeling (Donigian et.al., 2003). First, the model was calibrated to produce average annual upland erosion rates consistent with regional or national sediment export values. Parameters related to both settling and scour were then adjusted to obtain a good overall fit to monitoring data at low and high flows.

It is important to note that settling and scour both occur within a given reach, and may easily change from hour to hour in the simulation based on flow and associated channel velocities (e.g., shear stress). A channel could have high rates of settling and scour, but if they occur in equilibrium then there will be little net change in the bed and little net contribution to downstream sediment load. In this situation, the channel cannot be considered to be eroding, even though sediment is temporarily stored or exchanged between different portions of the stream reach. Likewise, if a channel is aggrading over time, it is not considered to be eroding. For the sediment component of bank erosion, only net channel degradation/scour over the entire course of the simulation is considered to contribute to tabulated sediment loads.

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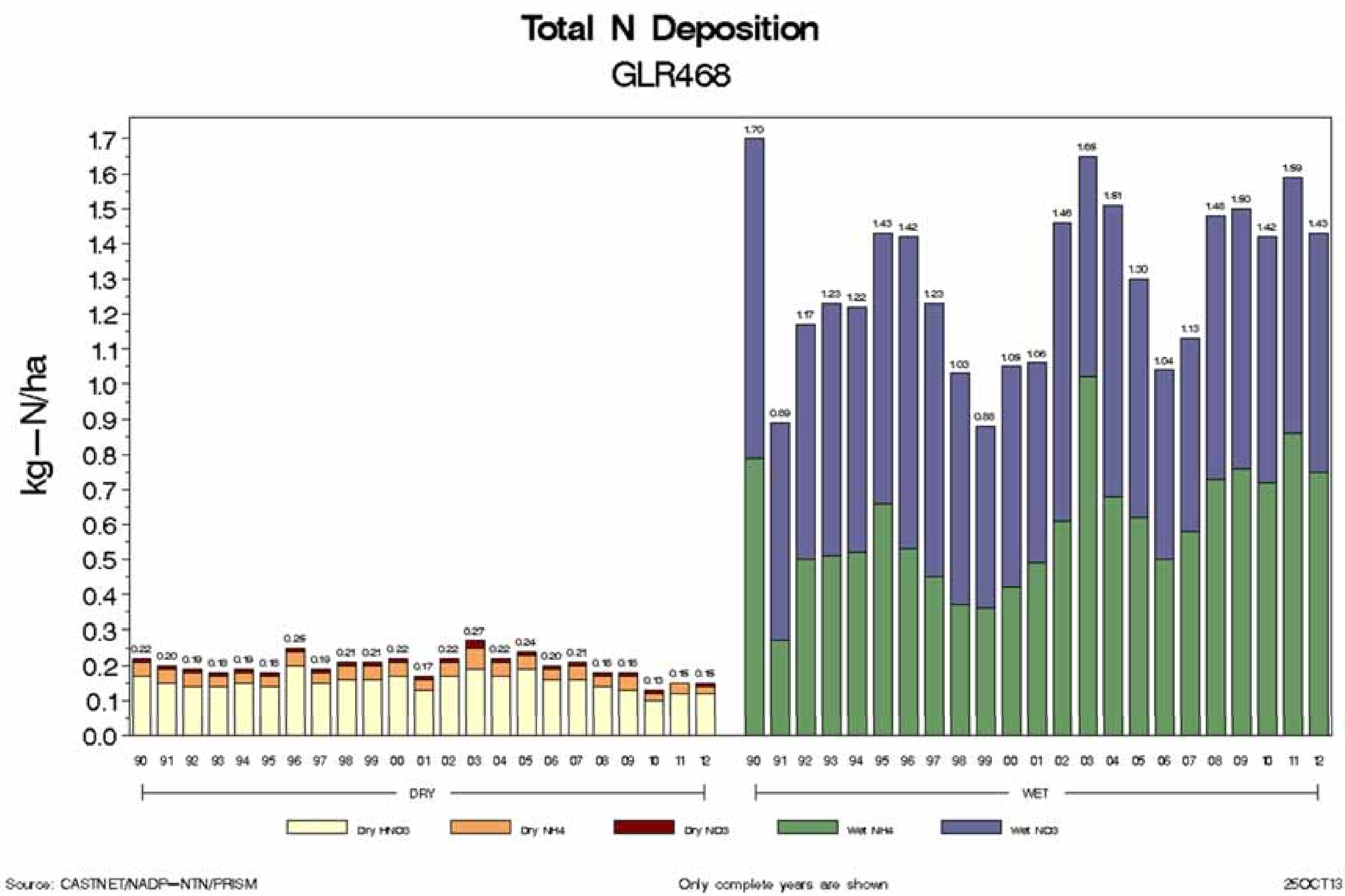
[4] Inorganic N is highly mobile in the subsurface, whereas inorganic P has an affinity for solids. N tends to percolate through the soil profile, whereas P moves primarily during high water table conditions. Therefore P is expected to be more sensitive than N to seasonal changes in the water table elevation and seasonal variations in onsite wastewater system loading is represented only for P. Seasonal variations in N loading from onsite wastewater systems may also be appropriate if data to support such a representation are obtained in the future.

TP associated with sediment is included in the LSPC bed simulation. When sediment scour occurs, the TP mass is specified as a percentage of the sediment mass. TP is also deposited when sediment settles using a formulation that is sensitive to both TP and TSS concentrations in the water column (and is thus variable). TP scour concentrations need not match TP deposition concentrations. TP in the water column attaches at a high concentration to sediment and settles out in slow-moving portions of the stream profile (pools and insides of curves). When scour occurs, it typically happens in a different part of the stream (riffles and outsides of curves). Scour accesses different sediment with a lower background concentration of TP, perhaps associated with parent glacial material. For this reason, the bank erosion component of TP is tabulated as the sum of scour whenever it occurs. Note this is different than the method used for sediment, which is expected to conserve mass balance.

2.8 ATMOSPHERIC DEPOSITION

Dry deposition occurs when pollutants are transported via wind and are deposited due to gravitational force. Dry deposition typically occurs in a more constant manner than wet deposition, where pollutants collide with water in the atmosphere and are transported to the watershed surface during precipitation events. The LSPC model allows the user to input both dry and wet deposition.

The National Atmospheric Deposition Program (NADP) is a cooperative effort between many different federal, state, tribal, and local governmental agencies, educational institutions, private companies, and non-governmental agencies. The NADP provided wet deposition data from the Glacier National Park station (NADP Station ID MT05), located on the Middle Fork of the Flathead River. Dry deposition data were obtained for the same station through the Clean Air Status and Trends Network (CASTNET) database, which is maintained by USEPA. Data collected at this station show that the majority of atmospheric nitrogen is deposited as wet deposition. Observed dry and wet deposition fractions between 1990 and 2012 are shown in **Figure 23**.



Source: CASTNET: http://www.epa.gov/castnet/javaweb/charts/GLR468_wdn.png

Figure 23. Observed Annual Nitrogen Deposition Rates in Glacier National Park .

2.8.1 Data Processing and Model Representation

Weekly wet deposition data were downloaded from NAPD for the 1980 to 2013 timeframe. This timeframe provided 1,308 weekly wet deposition data points each for nitrate (NO3) and ammonia (NH4), which were averaged by month to estimate seasonal wet deposition trends. The NO3 and NH4 fractions were summed to represent total nitrogen. The monthly average concentrations were then applied to all simulated water bodies in the Flathead Lake watershed. Average monthly nitrogen concentrations in wet deposition are shown in **Table 11**.

Table 11. Average Monthly Nitrogen Concentrations in Wet Deposition, 1980-2013

	NO3_CONC	NH4_CONC	TN_CONC
Month	mg/L	mg/L	mg/L
Jan	0.4592	0.0576	0.5168
Feb	0.5514	0.1098	0.6612
Mar	0.6032	0.1625	0.7657
Apr	0.5438	0.1884	0.7323
May	0.5486	0.1782	0.7268
Jun	0.4828	0.1043	0.5871
Jul	0.6745	0.1640	0.8386
Aug	0.9648	0.3256	1.2904
Sep	0.5514	0.1733	0.7247
Oct	0.5198	0.1329	0.6527
Nov	0.3794	0.0804	0.4598
Dec	0.4495	0.0527	0.5023

Weekly dry deposition data were downloaded from CASTNET for the 1980 to 2013 timeframe. This timeframe provided 1,277 weekly dry deposition data points each for nitric acid (HNO3), NO3, and NH4 as unit area loading rates. These data were averaged by month and summed to provide the total nitrogen load. The monthly loading rates shown in **Table 12** were applied to all simulated water bodies (both lakes and streams) in the LSPC model but were not applied to the landscape.

Table 12. Average Monthly Nitrogen Load from Dry Deposition, 1980-2013

	HNO3_FLUX	NO3_FLUX	NH4_FLUX	TN_FLUX
Month	kg/ha/month	kg/ha/month	kg/ha/month	lb/ac/month
Jan	0.0288	0.0019	0.0013	0.0020
Feb	0.0443	0.0028	0.0023	0.0035
Mar	0.0720	0.0027	0.0045	0.0050
Apr	0.0772	0.0028	0.0067	0.0057
May	0.0883	0.0033	0.0070	0.0062
Jun	0.0712	0.0021	0.0048	0.0051
Jul	0.0856	0.0028	0.0048	0.0059
Aug	0.0817	0.0039	0.0056	0.0058
Sep	0.0504	0.0022	0.0036	0.0037
Oct	0.0348	0.0016	0.0024	0.0025
Nov	0.0244	0.0016	0.0015	0.0018
Dec	0.0232	0.0013	0.0010	0.0016

These monthly values are applied to all simulated water bodies; note that freezing in the winter months prevents the atmospheric loads from being introduced to the water column. Successful atmospheric deposition modeling in cold weather climates depends on accurately redistributing these nitrogen loads to warmer months. The nitrogen deposited on the stream surface does not disappear, but instead is stored on or within the ice sheet until the spring thaw. At this time, the nitrogen stored on the ice is introduced to the water column.

To represent cold weather storage of atmospheric nitrogen on frozen water body surfaces, the values in **Table 11** and **Table 12** were reduced to zero for the months of January through March. The loads for these three months were tracked and added to existing loads/concentrations for April through June to maintain the annual totals and increase total nitrogen (TN) loading during the thaw period. This redistribution was investigated in the context of observed data in the watershed, to assess the timing of the thaw and subsequent increase in nitrogen loads. April was assigned a fraction of its calculated loading rate, as climate conditions may offset the spring thaw in some cases. May and June were then increased significantly to represent the thaw process and introduce nitrogen at an accelerated rate during those months. This redistribution of dry deposition loading is shown in **Table 13** and **Figure 24**.

Table 13. Redistribution of TN Loading from Dry Deposition

	Atmospheric TN: Dry Deposition		Atmospheric TN Applied to Lakes: Dry Deposition
Month	lb/ac/month	Monthly Multiplier	lb/ac/month
Nov	0.0018	1.0000	0.0018
Dec	0.0016	1.0000	0.0016
Jan	0.0020	0.0000	0.0000
Feb	0.0035	0.0000	0.0000
Mar	0.0050	0.0000	0.0000
Apr	0.0057	0.3000	0.0017
May	0.0062	2.5000	0.0156
Jun	0.0051	2.0000	0.0102
Jul	0.0059	1.0000	0.0059
Aug	0.0058	1.0000	0.0058
Sep	0.0037	1.0000	0.0037
Oct	0.0025	1.0000	0.0025
Total:	**0.0487**		**0.0487**

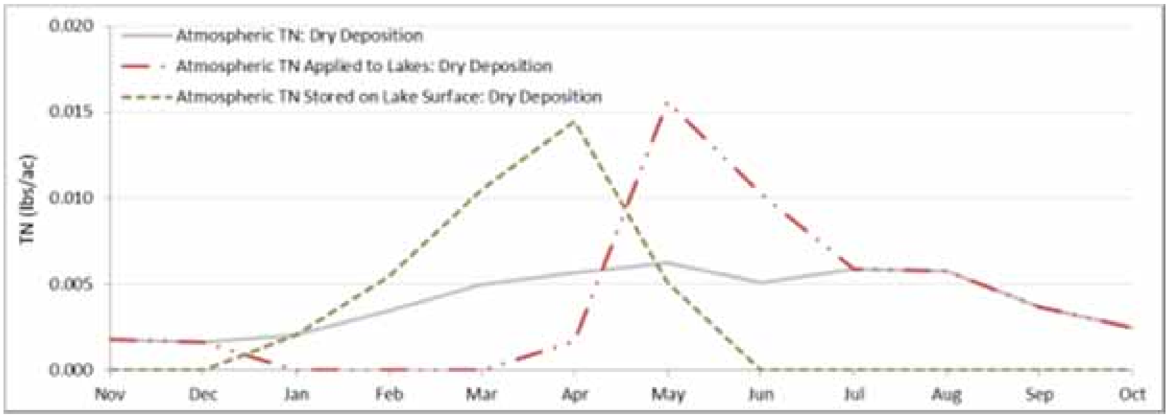


Figure 24. Redistribution of TN Loading from Dry Deposition.

Nitrogen loads from wet deposition were also suspended during the winter months and redistributed to the thaw months. Wet deposition in LSPC is simulated as a concentration applied to precipitation data. This means that wet deposition only occurs during rainfall events. In reality, wet deposition occurs through the winter months and nitrogen is stored on the lake surface. During the spring thaw, the wet deposition loads that were stored on the frozen lake surface are gradually introduced to the water column as the ice sheet melts. Since LSPC applies concentration to precipitation data for wet deposition, the increase in wet deposition during the thaw months can only be applied during rain events. This representation can be accurate if precipitation patterns are uniformly distributed throughout the year. However, it is important to note that if no rainfall occurs during the thaw months, wet deposition nitrogen stored from the winter months will not be simulated. Similarly, if no precipitation occurs during the winter months, simulated spring rains could introduce increased loads that were not observed.

Table 14. Redistribution of TN Loading from Wet Deposition

Month	Atmospheric TN: Wet Deposition mg/L	Monthly Multiplier	Atmospheric TN Applied to Lakes: Wet Deposition mg/L
Nov	0.5168	1.00	0.5168
Dec	0.6612	1.00	0.6612
Jan	0.7657	0.00	0.0000
Feb	0.7323	0.00	0.0000
Mar	0.7268	0.00	0.0000
Apr	0.5871	0.45	0.2636
May	0.8386	2.50	2.0964
Jun	1.2904	2.00	2.5808
Jul	0.7247	1.00	0.7247
Aug	0.6527	1.00	0.6527
Sep	0.4598	1.00	0.4598
Oct	0.5023	1.00	0.5023
Total:	**8.4583**		**8.4583**

2.9 SOUTH FORK FLATHEAD RIVER BOUNDARY CONDITION

While the North and Middle forks of the Flathead River and Swan River were explicitly modeled in LSPC, the South Fork Flathead River upstream of Hungry Horse Dam (**Figure 25**) was modeled as a point source boundary condition. Monitored water quality and flow data from USGS flow gage 12362500 and FLBS long-term sampling site FBC02011 were used to develop a daily time series boundary condition; the time series was input to the model at the location of gage 12362500. The watershed downstream of the gage to the mainstem of Flathead River near Hungry Horse was modeled by LSPC. A map showing the location of the monitoring stations downstream of Hungry Horse Reservoir is presented as **Figure 26**. **Appendix C** provides a detailed discussion of the available data and how the boundary conditions were derived.

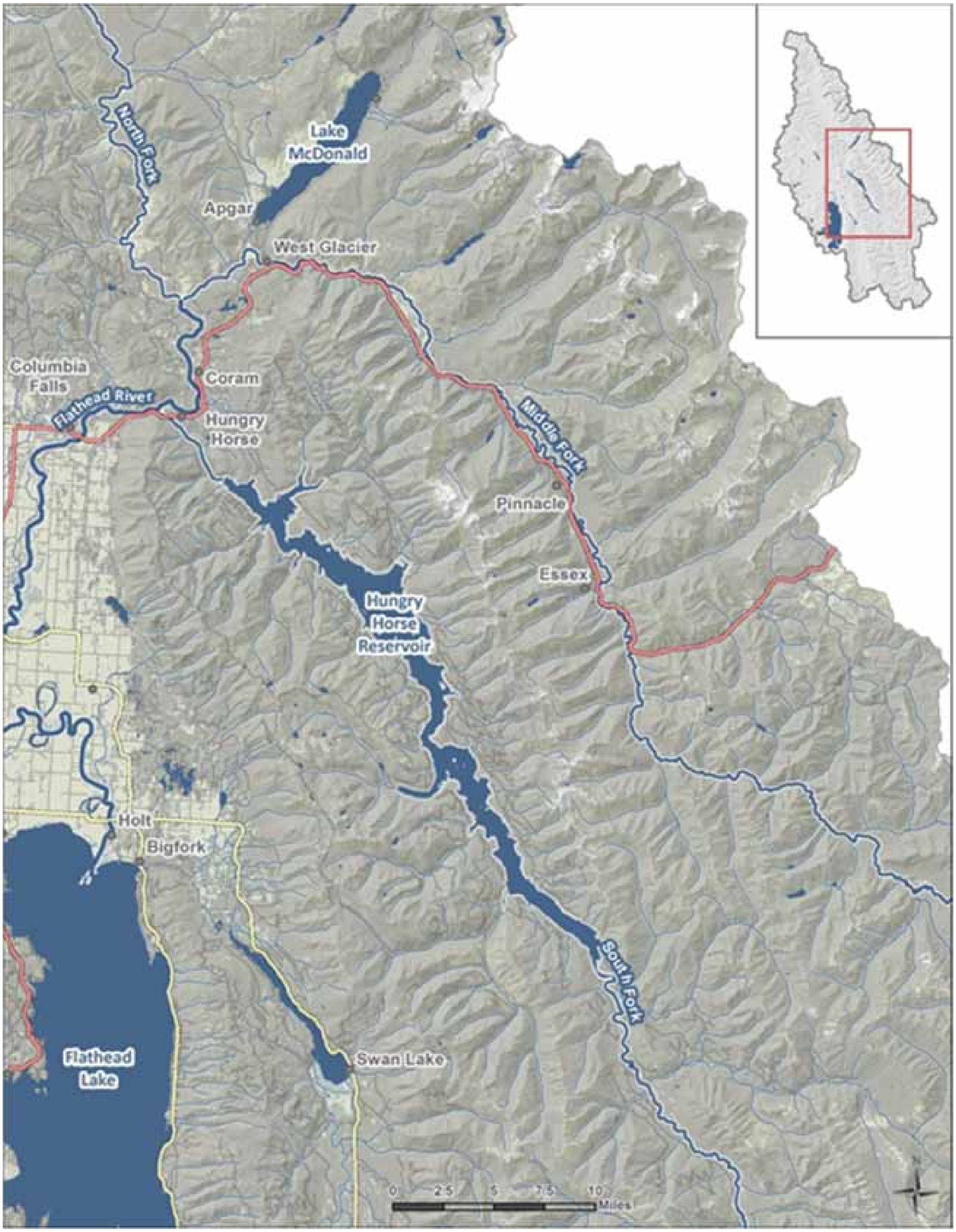


Figure 25. Hungry Horse Reservoir and the North, Middle, and South Forks of the Flathead River.

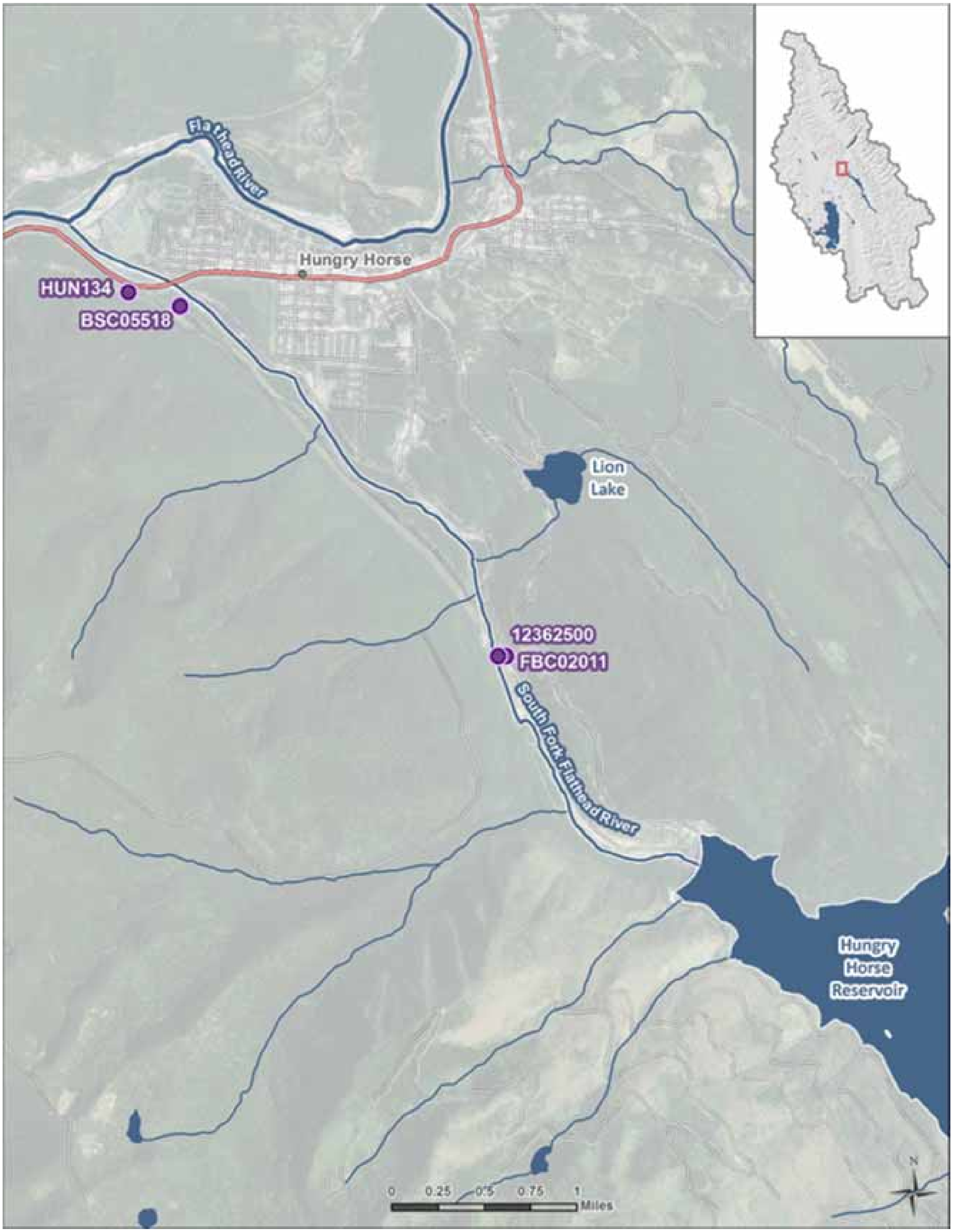


Figure 26. Sample Stations Along the Lower South Fork Flathead River.

2.10 HYDROLOGIC RESPONSE UNITS (HRUS)

Within a given model subbasin (i.e., subwatershed), LSPC requires a basis for assigning and distributing hydrologic and water quality process parameters to land units. The land units must capture the most influential characteristics that reflect variability throughout the watershed. Land unit representation should typically consider features of the landscape that most affect hydrology and pollutant transport, including land cover (e.g., impervious assumptions), soils, and slope. In the Flathead basin, elevation and aspect were thought to be important physical features that have a strong influence on hydrology. This process of combining and layering spatial watershed characteristics creates unique land units, which are also called hydrologic response units (HRUs). This section discusses the steps involved in developing HRUs for the Flathead Basin, which were:

1. Compilation and generalization of land cover data sets, accounting for changing land area through time;
2. Superimposing information on specific categories of land disturbance, such as fire and timber harvest;
3. Adjusting impervious area to account for the proportion that is not directly connected to the hydraulic network;
4. Calculation of and incorporation of aspect;
5. Representing differences in soil properties based on HSG data.

The final set of HRUs used in the Flathead Lake watershed LSPC model incorporate all of these components. The purpose of HRU development is to develop a generalized set of land units to be applied watershed wide; however, the model provides the flexibility to create and assign parameter groups regionally throughout the watershed if there are differentiating factors besides those represented by HRUs. A comparison of unit area loading rates for nutrients and sediment for all the HRUs is provided later in section 3.4. Model input parameters are summarized in Appendix D for Phase 1 and Appendix E for Phase 2.

Just as meteorology varies through time, land use also may change over the course of a model simulation. LSPC provides for the representation of dynamic land use. The user can specify different distributions of land use (or HRUs, in the case of the Flathead Lake watershed LSPC model) for any number of dates. The following sections note the cases where dynamic land use was incorporated into the land use representation.

2.10.1 Land Cover

Two data sources were compiled to develop a general land cover representation for the entire Flathead Basin. The Canadian data source is maintained by Geobase and is a composite of land cover datasets collected by Agriculture and Agri-Food Canada, Canada Center for Remote Sensing, and the Canadian Forest Service. This composite dataset represents the time period circa 2000. Review of current and historical aerial photography of the Canadian portion of the watershed suggests that it is unlikely that land cover has changed significantly through development, but could have changed due to timber harvest, forest fires, or natural resource extraction.

The United States land cover representation utilized the National Land Cover Dataset (NLCD), which is maintained by the Multi-Resolution Land Characteristics Consortium (MRLC). NLCD represents various natural, agricultural, and developed land covers using 30-meter grid cells. NLCD data from two time periods were utilized – 2001 and 2006. The two different time periods were used to represent dynamic land use. The 2001 data were used from the beginning of the model simulation through December 2005, and the 2006 data were used from January 2006 through the end of the simulation. In addition, NLCD data from 1992 were used to characterize land cover to support the forest fire disturbance representation, discussed in **Section 2.10.2.1**.

The Canadian Geobase dataset and United States NLCD datasets were merged in ArcGIS to create a single land cover representation. During the merge process, three categories present in the Canadian Geobase dataset (Unclassified, Cloud, and Shadow) were reclassified using neighboring values. These categories represented only a small fraction of the entire dataset and are merely artifacts of the remote sensing technique used. They were not reflective of any physical condition on the ground. After these datasets were merged, a mapping schema was created to reclassify the two national land cover datasets into a single, generalized land cover dataset. A simplified rendering of this generalized land cover dataset is presented below in **Figure 27**.

Additional GIS datasets were utilized to provide better representation of types of land use known to contribute to sediment and nutrient loading. Each is discussed in the following subsections.

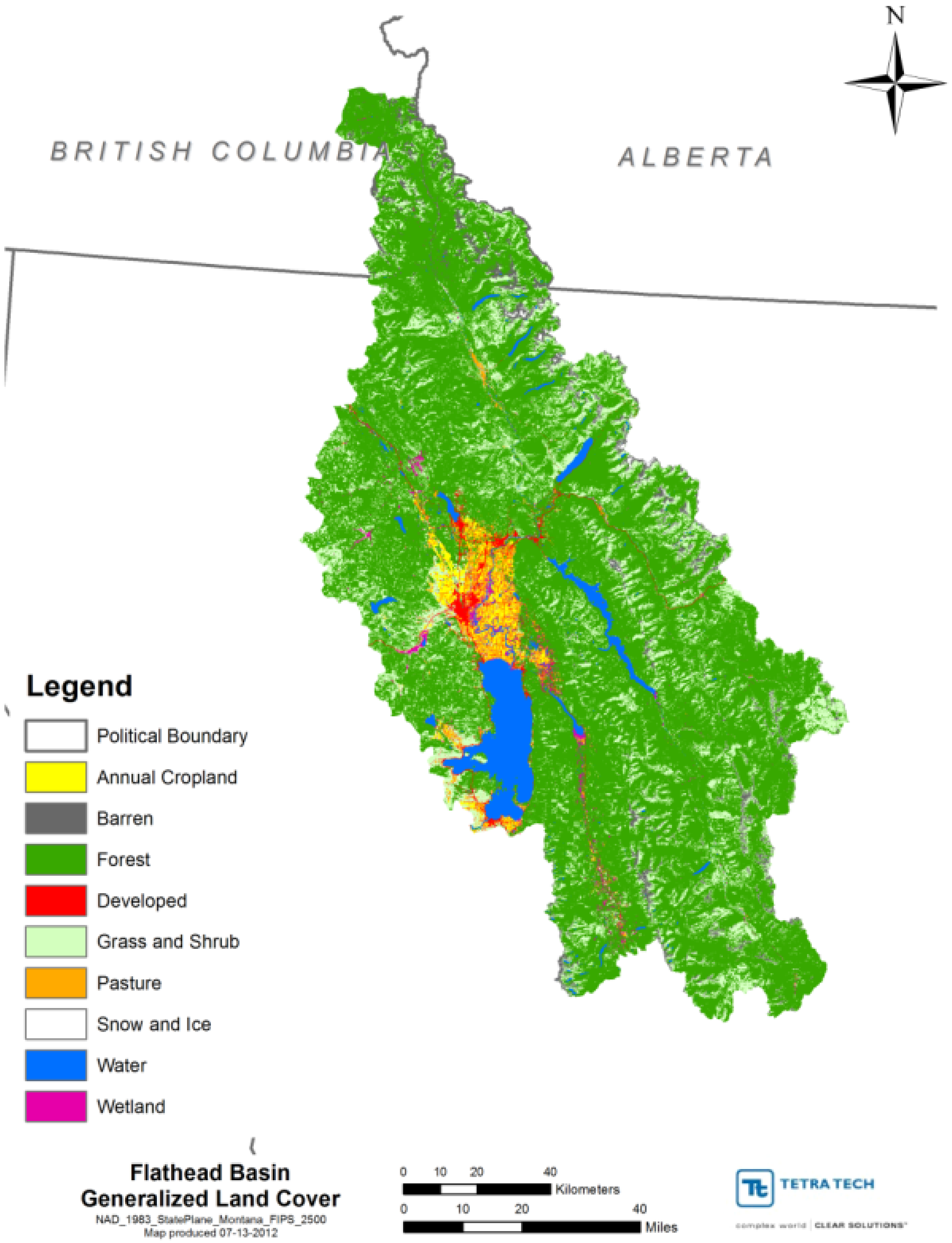


Figure 27. Flathead Lake Watershed Generalized Land Cover Representation.

2.10.1.1 Roads

Some of the factors that affect the degree to which roads impact hydrology and water quality include: proximity of roads to critical features such as water bodies or steep slopes, the type of material used for the road surface, and the extent of implemented best management practices (BMPs). In 2008, road data from multiple sources in the Flathead watershed were collected and combined into a GIS shapefile and attribute database (USEPA, 2010b). That dataset was updated in 2012 to reflect recent changes during the model development process. As shown in **Table 15**, there are approximately 10,000 miles of digitized roads in the database, divided into three categories. Spatial data sources included the U.S. Census TIGER, ITSD transportation framework, Flathead National Forest, Glacier National Park, Flathead County, Lake County, Missoula County, DNRC, and British Columbia.

Table 15. Summary of Road Categories and Distribution in the Flathead Lake Watershed

Category	Description	Length (miles)	Percentage
Primary Roads	Asphalt	0.75	0.01%
	Paved	1,420	13.92%
Secondary Roads	Crushed aggregate & gravel	765	7.50%
	Bituminous surface treatment	0.02	0.0002%
Unpaved Roads	Dirt	28	0.27%
	Native material	3,402	33.35%
	Natural	362	3.55%
	Unknown	4,076	39.95%
	Total	10,202	100.00%

A GIS analysis was conducted to identify the road-stream intersections and the proximity of road segments to perennial streams. Road-stream intersections were identified by overlaying the available road GIS layers from the roads database with the 1:24,000 NHD stream layer. Field investigations have shown that pollutant delivery potential increases the closer the road is to a stream; therefore, all roads that fell within a 100-meter buffer of perennial streams were flagged. This buffer distance was selected on the basis of study findings involving in-stream invertebrate monitoring (McGurk and Fong, 1995). Roads located outside of this critical distance were assumed to have negligible direct sediment and nutrient delivery to streams because there would be more opportunity for trapping or containment of runoff in the watershed. **Figure 28** shows all road segments as well as those falling within the 100-meter buffer. There was not sufficient information to characterize changes in roads through time; as a result, the representation of roads is static in the model to represent the year 2008.

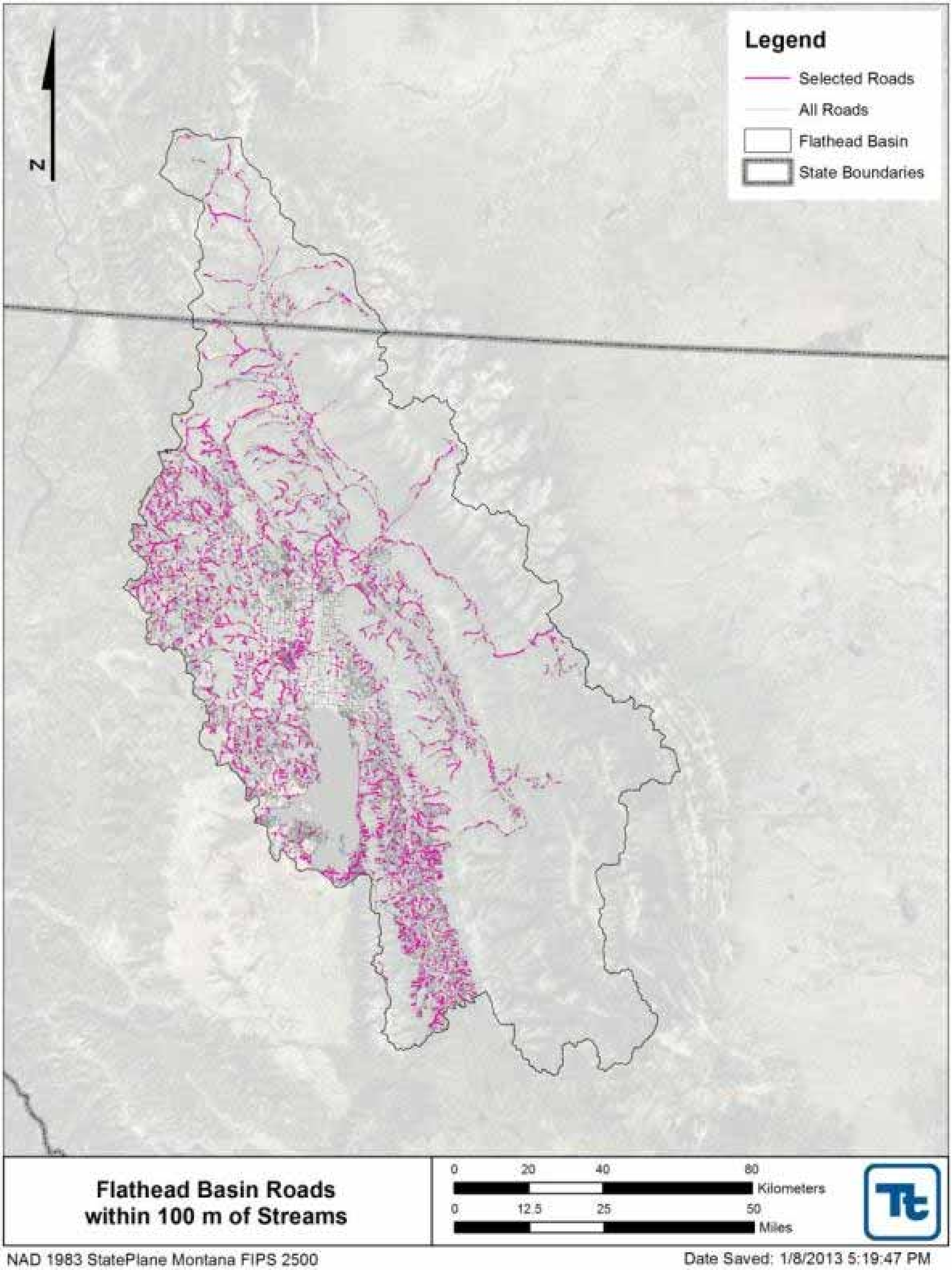


Figure 28. Roads within 100 Meters of Streams in the Flathead Lake Watershed.

2.10.1.2 Agriculture

Based on the 2006 NLCD, approximately three percent (132,000 acres) of the Flathead Lake watershed is comprised of agricultural lands. The most intensive agriculture occurs in an area extending from the mouth of the Flathead River north to approximately Columbia Falls and Whitefish. A more detailed analysis of agriculture was completed in this area and is summarized in The Flathead Valley Agricultural Impacts Report (Wendt, 2011). The Wendt report provides details regarding:

- The types of crops (e.g., hay, cereal grains, oilseeds, pulse crops, seed potatoes, and summer fallow or other agricultural practices) and where they are located.
- The types and numbers of livestock and locations of concentrated animal feeding operations.
- The locations of irrigated lands and types of irrigation.
- The types and magnitudes of fertilizers applied to agricultural lands.
- An assessment of trends in agriculture in the Flathead Valley.

As shown in **Figure 29**, the Wendt study focused on the area of most intensive agriculture in the Flathead basin, but did not include the entire basin. The 2001 and 2006 National Land Cover Datasets (NLCD; MRLC, 2006) were used to characterize agricultural areas outside the Wendt study area, with the two different time periods used to represent dynamic land use. However, a static representation was used for agricultural land within the Wendt study area since data from multiple time periods was not available. A summary of the agricultural lands is provided in **Table 16**. Irrigation of cropland was not simulated in LSPC. It could be added to the model in the future, but the overall impact of cropland irrigation is likely small. For context, cropland from the Wendt study comprises about 2.5% of the total Flathead basin area; irrigated land would be a fraction of the 2.5%.

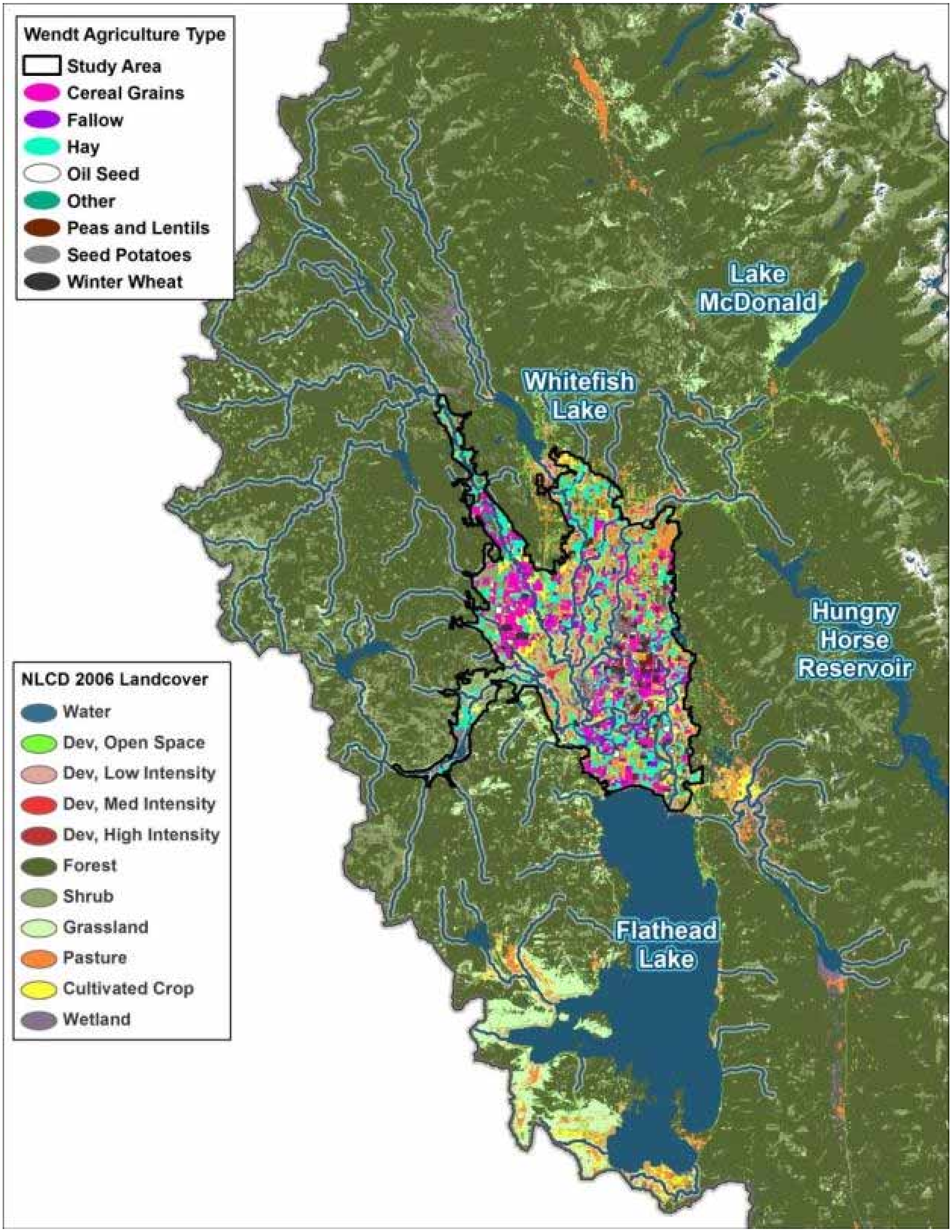


Figure 29. Agricultural Lands in the Flathead Lake Watershed (Showing Boundary of Wendt study area).

Table 16. Area of Crop Types included in the Flathead Lake Watershed LSPC Model

Land use	Data Source	Area (acres)
Cereal Grains	Wendt	20,857
Fallow	Wendt	5,523
Hay	Wendt	26,443
Oil Seed	Wendt	1,505
Other	Wendt	341
Peas & Lentils	Wendt	1,737
Seed Potatoes	Wendt	260
Winter Wheat	Wendt	4,649
Annual Cropland	NLCD 2006	21,965
Pasture/Hay	NLCD 2006	54,272
	Total	**137,552**

As shown in **Table 17**, agricultural lands were placed into three categories (low, medium, and high loading potential) in the LSPC model based on information presented by Wendt (2011). The model was configured to generate increasing nutrient loads in surface runoff across the range of Low to High Cropland categories using variations in build-up rates and storage limits. Areas outside the Wendt study area were assigned to the medium category in the absence of site specific data. It was assumed that livestock grazing occurred primarily on lands classified as pasture by Wendt or NLCD (MRLC ,2006). The number of cattle (13,267), sheep (333), and pigs (1,200) in the Flathead Lake watershed was estimated using Montana agricultural statistics from 2012[5]. Nutrient production from manure by animal unit was obtained online from Natural Resources Conservation Service[6]. Total nutrient loads were calculated and then divided by pasture area to derive model buildup rates in terms of lbs/acre/day. The buildup rates were adjusted upwards during calibration so the areal loading rates from pasture were more comparable to literature values (see Section 3.4). This is not surprising, since the livestock numbers shown above are considered to be an underestimate, and also do not account for horses.

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[5] http://www.nass.usda.gov/Statistics_by_State/Montana/index.asp

[6] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/?&cid=nrcs143_014211

Table 17. LSPC Agricultural Fertilizer Categories.

Crop Type	Fertilization Category
Pasture/Hay	Pasture
Fallow	Cropland Low
Hay	
Annual Cropland	Cropland Medium
Oil Seed	
Other	
Cereal Grain	Cropland High
Peas & Lentils	
Seed Potatoes	
Winter Wheat	

2.10.1.3 Golf Courses

Of the land uses in the urban landscape, turf is the most intensively managed (King et. al., 2007). In many cases, chemical additions on golf courses are similar to, and often greater than, those used in intensive agriculture (Winter et. al., 2006). There are 10 golf courses in the Flathead Lake watershed (**Table 18** and **Figure 30**). Golf courses within the Flathead Lake watershed were simulated as a separate land use category and nutrient concentrations were set based on fertilizer application rates available from the Buffalo Hills Golf Course.

Table 18. Golf courses in the Flathead Lake Watershed

Ownership	Name	Location	Area (acres)
Public	Glacier View Golf Club	West Glacier	85
Private	Iron Horse Golf Club	Whitefish	127
Municipal	Buffalo Hill Golf Club	Kalispell	163
Public	Village Greens Golf Course	Kalispell	120
Public	Whitefish Lake Golf Club	Whitefish	199
Public	Meadow Lake Golf Course	Columbia Falls	109
Public	Eagle Bend Golf Club	Bigfork	199
Public	Big Mountain Golf Club	Flathead	165
Municipal	Polson Country Club	Polson	183
Public	Mountain Crossroads Golf Course	Kalispell	21
		Total	**1371**

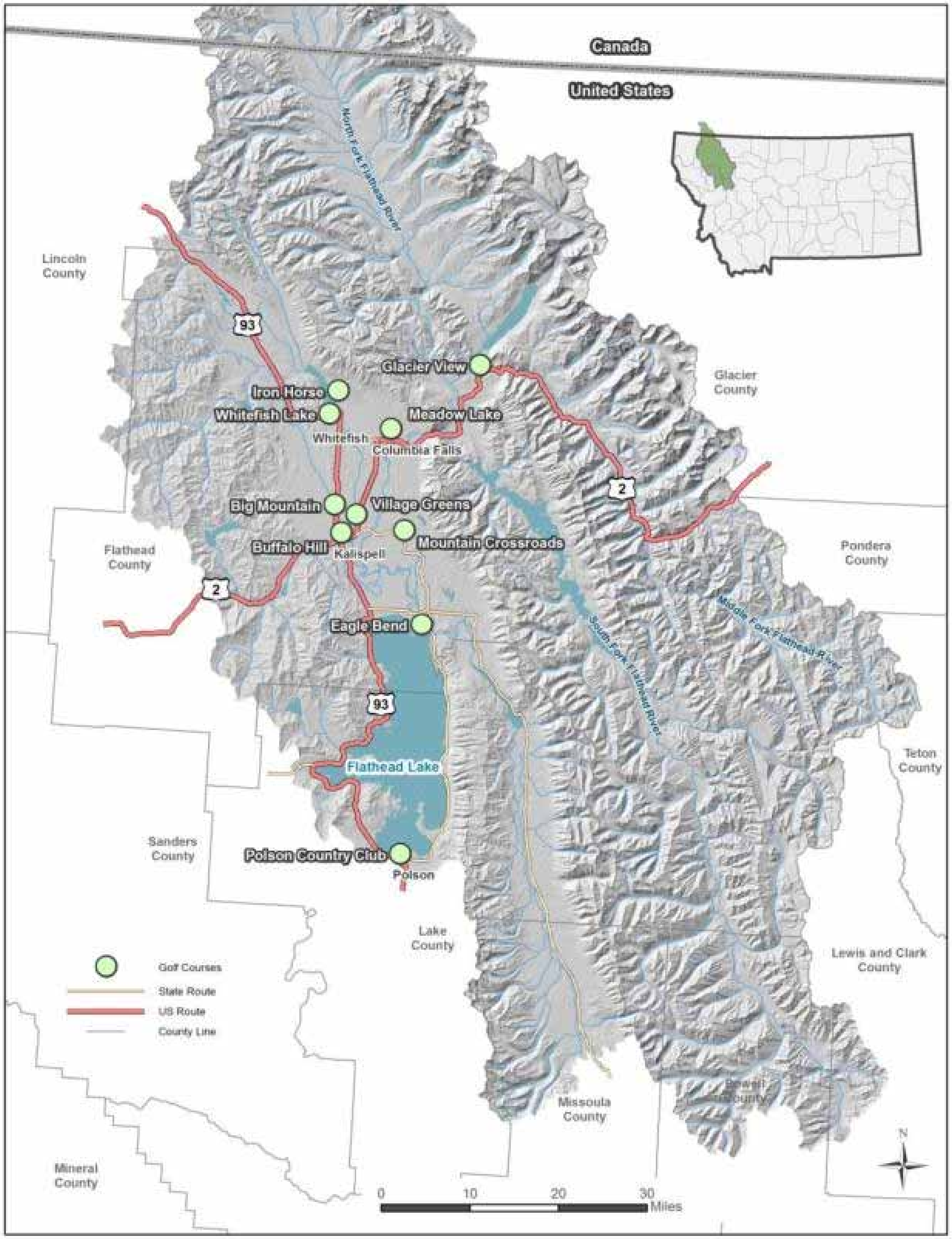

Figure 30. Golf Courses in the Flathead Lake Watershed.

2.10.1.4 Bluffs

Areas of eroding glacial outwash/till terraces are common along all three forks of the Flathead River, Swift Creek, and many of the tributaries of the Middle Fork Flathead River draining the southeastern flank of Glacier National Park. These features were manually digitized in GoogleEarth™. This process involved navigating through the entire Flathead watershed in the GoogleEarth™ viewer, and using the Polygon tool to trace the boundary of the eroded bluff face, as seen in **Figure 31**. The area of bluffs identified using this method is broken out by subwatershed in **Table 19**.

The bluff area was incorporated as a unique HRU. For nutrients the buildup/washoff and subsurface concentrations of were held to minimal values in order to represent bluff areas as having minimal contributions to nutrient loading. For sediment the raindrop impact and particle detachment and subsequent transport coefficients were set to the 2nd highest values (cropland being the highest) in order to promote sediment loading from the bluff areas.

Figure 31. Example of Digitized Eroded Bluffs in the Flathead Lake Watershed.

Table 19. Summary of Bluff Erosion in the Flathead Lake Watershed

Watershed	Area Bluff Erosion (Acres)
Middle Fork	660.2
North Fork	319.6
Flathead Lake	54.3
Whitefish	11.2
Swan	0.2
Total	1,045.5

2.10.2 Disturbance

The two types of disturbance common in the Flathead River watershed are disturbance due to forest fires and disturbance due to timber harvest.

2.10.2.1 Forest Fire

Spatial extents and attribute information of historic fires were used to characterize the footprint, timing, and severity of forest fires. Agency sources included the Flathead National Forest, Montana Department of Natural Resources and Conservation, Glacier National Park, and British Columbia. A composite GIS coverage containing perimeter boundaries of burned areas from the various agencies was first compiled to gain a better understanding of how much area was affected by fire, and when those fires occurred. The period of record for those events was between 1900 and 2008. Additional information about fires occurring after 2008 was incorporated on a case-by-case basis for model calibration purposes. Details of these data and evaluations are presented in *Flathead Basin TMDL Technical Memo— Forest Fires* (USEPA, 2010a). **Table 20** presents a summary of the data.

Table 20. Summary of available forest fire data (USEPA, 2010a)

Analysis summary	Flathead National Forest [a]	Glacier National Park [b]	British Columbia [b]	DNRC [b]
Period of Record (years)	24	41	84	20
Years with Recorded Fires	20	19	24	20
Number of Fires during Period of Record	70	153	44	1,530
Total Area Burned (acres)	390,689	710,022	238,391	3,047
Average Area Burned per year (acres)	5,581	4,461	5,418	152
Median Area Burned per year (acres)	69	270	688	75

a. Flathead National Forest data includes forest fires within the National Forest and surrounding areas but excludes forest fires in Glacier National Park.
b. Dataset only includes fires that occurred within the Flathead Lake Basin.

Historic fire polygons were overlaid with the Flathead Lake watershed model subbasins to assess the magnitude of burned areas within the Flathead Lake watershed. Those data were also used to assess the distribution of underlying HRU types within each burned area, which showed that the HRU areas most susceptible to forest fire were forest and shrub land. A map showing the spatial extent of forest fires within the Flathead Lake watershed is presented as **Figure 32**.

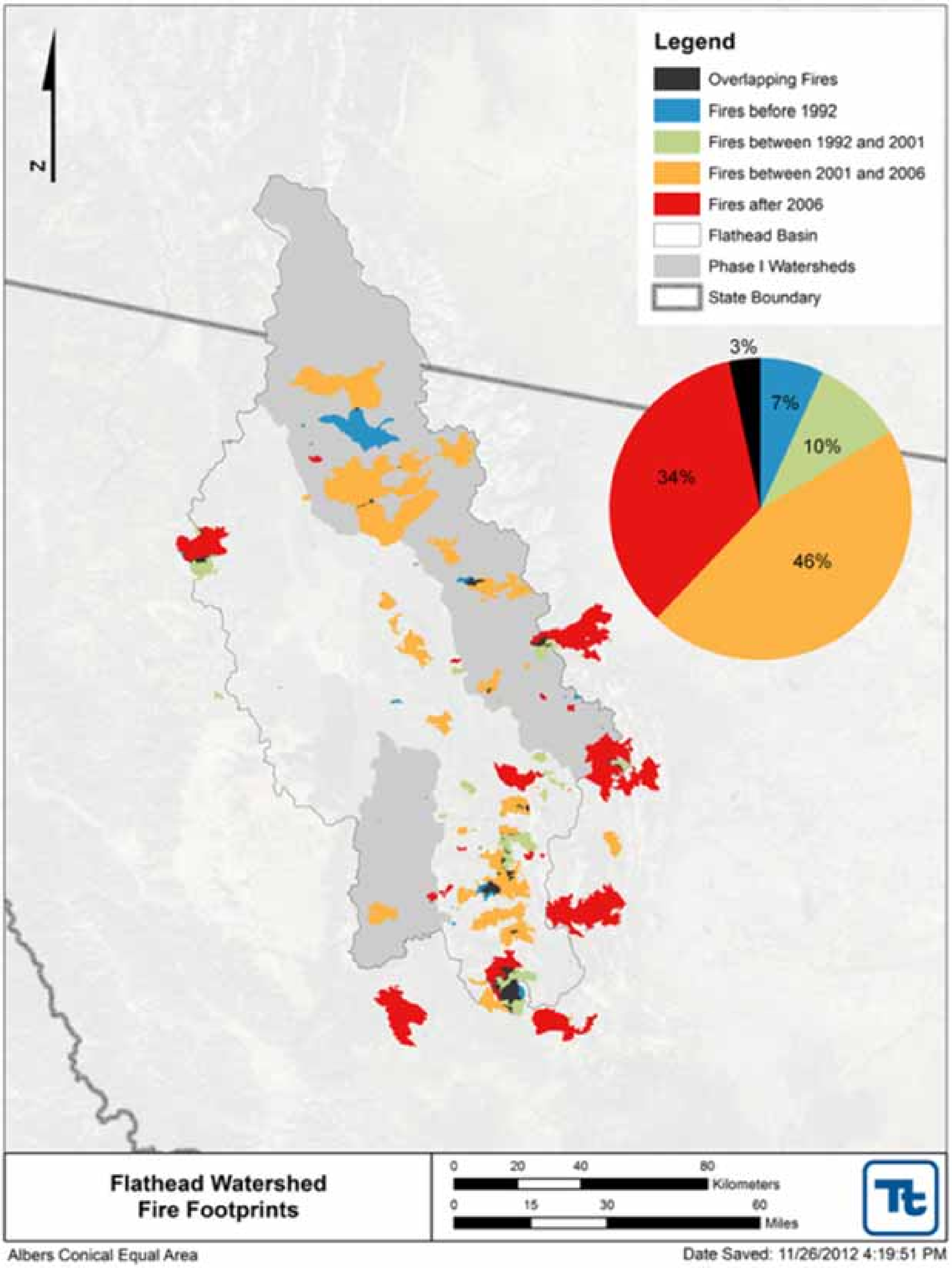

Figure 32. Historic Forest Fire Burn Scars Assessed for the Flathead Lake Watershed LSPC Model.

The time-variable land use feature of LSPC was used to reflect the timing and magnitude of forest fires. Changes in forest canopy are represented as HRU changes between Forest and Herbaceous; however, the HRU categorized as Forest Fire was parameterized to reflect intensely burned ground conditions (i.e. impacts not perceived exclusively as a canopy change) within any given watershed for a short period following the fire. **Figure 33** conceptually illustrates an intense fire occurring in 1997 and the subsequent regrowth pattern. The NLCD canopy change shows a shift from Forest to Herbaceous area but, given the supplemental burn severity characteristics[7], much of the *Herbaceous* land is reclassified as “Forest Fire.” Studies have shown that fire impacts tend to diminish within one to three years; therefore, two recovery trajectories are superimposed to reflect forest regrowth. In this example, 63 percent of the burned area is converted back to *Herbaceous* land after the first year, while the remaining portion reverts to Herbaceous by the end of the fourth year—this is the faster regrowth trajectory. The slower regrowth trajectory reflects the change from Herbaceous to Forest. For this example, the burned area reaches pre-fire canopy condition by the year 2021.

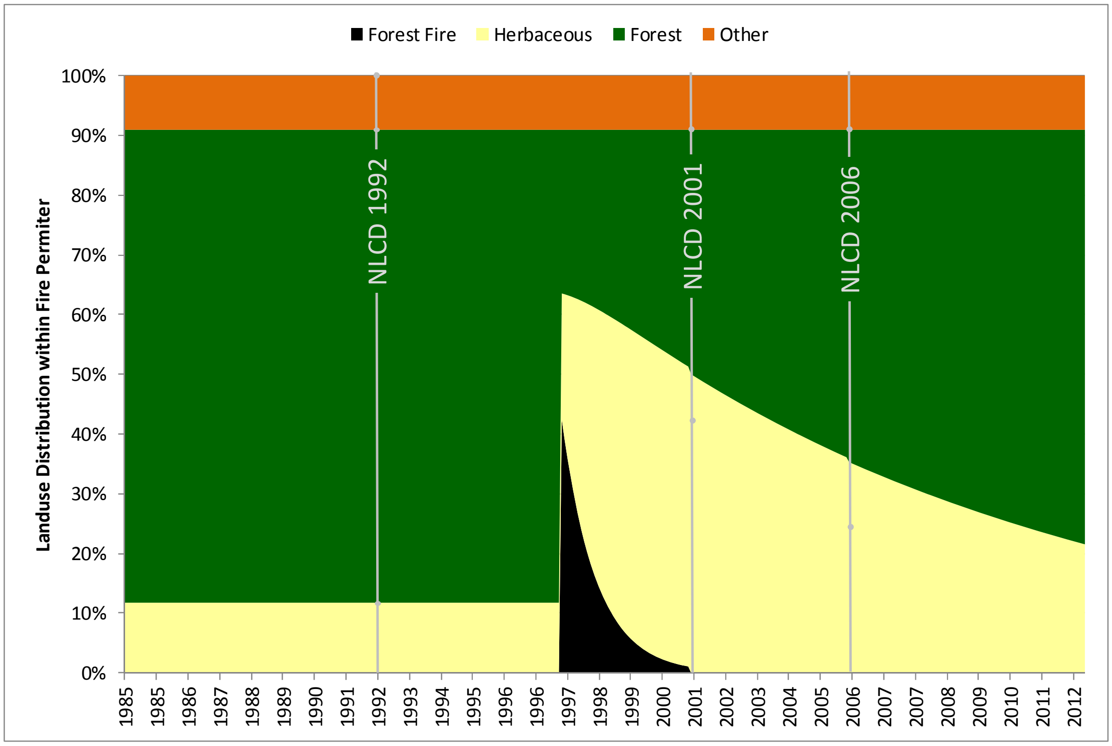

Figure 33. Conceptual Fire Impact Land Use Change Model Projection for a Burn Occurring in 1997, Compared against Three Observed NLCD Snapshots

Burn severity data are not available for all fires, and the interpretation of that severity also cannot be translated into area terms with a high degree of confidence in the precision of that translation. For those reasons, the fast-trajectory of “Forest Fire” area for each fire footprint was set at approximately 60 percent of the burned area for the year the fire occurred with all of the burned area reverted to Herbaceous within two to four years after the fire. Re-growth rates were varied by fire to match

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[7] Burn severity data were obtained from the U.S. Forest Service Monitoring Trends in Burn Severity (MTBS) database. All land classified as “forest loss” that intersected the highest burn category was called ‘forest fire’.

subsequent NLCD snapshots. For example, if a fire occurred in 2003 then the re-growth of Forest Fire to Herbaceous and Herbaceous to Forest were adjusted to best match the NLCD snapshot of 2006.

2.10.2.2 Timber Harvest

The way harvested forest impacts are represented in the model is similar to how burned land is done in terms of changes in canopy cover; however, there are differences in how impacts on hydrology and chemistry are manifested. Burned land is attributed with no cover influencing the impact of shade on snowmelt, and harvested forest has a higher proportion of interflow than burned land. In addition, burned land has higher pollutant and sediment loading rates than harvested forest. Refer to **Appendices D** and **E** for details regarding model parameterization. One thing that complicates the approach is that the known boundaries for harvest activities are not as well defined as the fire boundaries. Commercial harvest boundaries were either unavailable or were considered proprietary by their owners, so they were not provided for incorporation into the model.

Historic harvest data were inventoried from a number of agencies including the Flathead National Forest and DNRC. A partially complete GIS coverage containing combined polygons from each of the above agencies that represented the perimeter of various areas in the Flathead Basin over time was developed (where such data were available). Private lands, however, had very little to no available harvest information save for the boundaries of the property. The period of record considered documented activities occurring between 1990 and 2008. Although spatial footprints of various harvests were represented, associated attribute information about harvest type or classification was limited. A summary of the data is presented below in **Table 21**. A map showing the spatial extent of forest harvest within the Flathead Basin is presented as **Figure 34** and the technical memorandum entitled *Summary of Timber Harvest in the Flathead Lake Basin* (USEPA, 2011b) has been prepared to reflect how these values were incorporated into the modeling.

For the Phase 1 model area forest harvest is specified in the subbasins where the data indicated it occurred and the harvest acreages vary over time. For Phase 2, harvest was modeled as a static land use with one time-step according to the NLCD 2001 and NLCD 2006 data, where any spatial locations that were not burned, but showed conversion from forest to herbaceous land cover were considered harvested.

Table 21. Summary of available timber harvest data.

Land owner/land manger	Location	Areal extent of harvest	Harvest date	Type of harvest
Flathead National Forest	Yes	Yes	Yes	Yes
DNRC	Yes	Yes	Yes	Yes
British Columbia	Yes	Yes	Yes	No
Private non-industrial	Yes [a]	Yes	Yes	No
Private industrial [b]	No	No	No	No
CSKT	No	No	No	No

a. The exact location is not reported. Harvest location may only be reported to the nearest section or quarter section.

b. These data are proprietary on industrial forest lands.

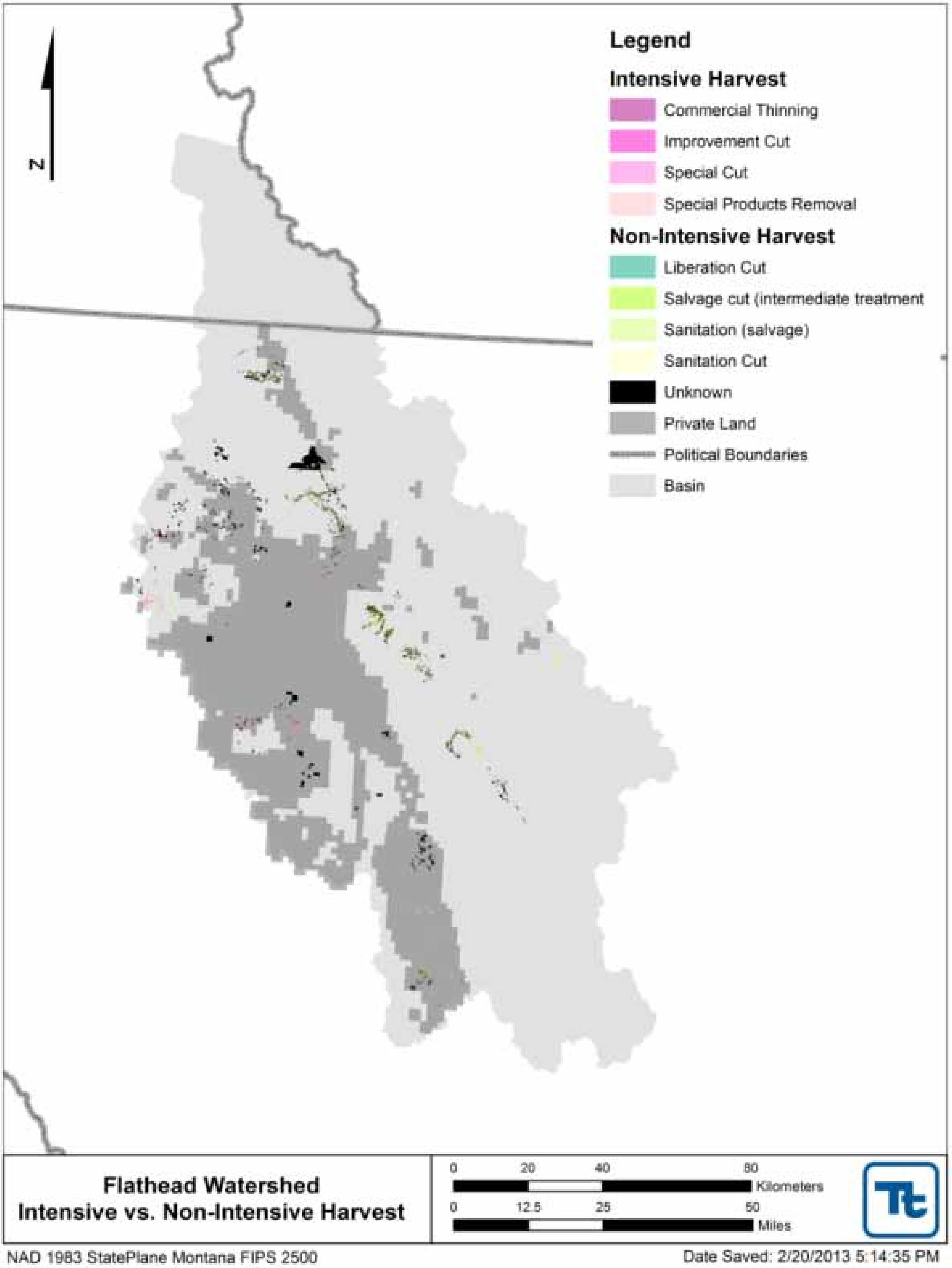

Figure 34. Historic Timber Harvest Areas and Private Lands for the Flathead Basin Watershed.

2.10.3 Impervious Area Adjustment

Stormwater runoff occurs when precipitation from rain or snowmelt saturate the soil and become overland flow. Stormwater runoff is natural in the environment, but can be exacerbated by impervious surfaces (e.g., parking lots, roads, roofs) that reduce infiltration and create excessive overland runoff. When stormwater runoff flows into a surface waterbody, the excess flow and pollutant loads can adversely impact beneficial uses.

The regulated and unregulated stormwater facilities in the Flathead Lake Basin are described in a *Summary of Urban Stormwater Sources in the Flathead Lake Basin* (USEPA, 2010c). This summary document reports that there is one small municipal separate storm sewer system (MS4), six industrial facilities, and approximately 205 construction sites with stormwater permits in the Flathead Lake watershed. In addition, there are numerous unregulated stormwater sources throughout the basin including commercial areas, construction sites less than one acre that are not subject to local ordinances, and municipal and residential areas that fall outside the definition of a regulated small MS4 under the USEPA’s National Pollutant Discharge Elimination System (NPDES) Phase II Stormwater Program. These areas have impervious surfaces that have the potential to contribute similar pollutants via stormwater runoff as those areas covered under the NPDES Stormwater Program.

LSPC does not explicitly model stormwater infrastructure (e.g., pipes, conveyances). However, the LSPC model uses a separate set of parameters for hydrology and contaminant runoff for developed pervious and impervious uses. The Flathead Lake watershed LSPC model represents developed land uses using four categories of development intensity in NLCD (Developed, Open Space; Developed, Low Intensity; Developed, Medium Intensity; Developed, High Intensity). Percent imperviousness for each developed category was calculated using another NLCD data product, the percent impervious area grid. The datasets were combined to produce developed pervious and impervious area, tabulated separately in each model subbasin. The two different NLCD time periods were used to represent urban land use dynamically through time.

Effective Impervious Area (EIA) represents the portion of total, or Mapped Impervious Area (MIA), that is directly connected to the drainage collection system. In LSPC, impervious area should be equivalent to EIA and not MIA. Impervious area that are not connected to the drainage network have the opportunity to flow onto pervious surfaces, infiltrate, and become part of pervious surface overland flow, and disconnected impervious area are often represented as pervious land. In practice, runoff from disconnected impervious surfaces often overwhelms the infiltration capacity of adjacent pervious surfaces, and the runoff may reconnect to nearby impervious surfaces once again. Finding the right balance between MIA and EIA can be an important part of hydrology calibration, especially in urban areas.

Sutherland (1995) describes a series of equations for MIA to EIA relationships spanning four levels of impervious disconnection, from “extremely disconnected basins” to “highly connected basins.” The equations take the form of:

$$EIA = a(MIA)^b$$

where *a* and *b* are empirical factors; as *a* and *b* approach 1, EIA converges to MIA.

Rather than choosing one of Sutherland's relationships over another, all four were utilized to describe the varying levels of impervious area in the Flathead Lake watershed. Instead of choosing thresholds for jumping from one relationship to the next, a regression analysis was performed on the *a* and *b* factors, and unique *a* and *b* factors were assigned to each increment in impervious area. Exceptions were made at the low and high ends of the EIA to MIA relationship; EIA was assumed to equal MIA from 70 percent to 100 percent imperviousness (all impervious area connected). At the low end (1% to 15% imperviousness), the calculated EIA values were increased somewhat. This was done to account for NLCD underestimates of impervious area in rural areas, which rely on using buffered masks of roads (Homer et al, 2007). As a result, a significant fraction of rural development outside of the mask is not captured. The EIA to MIA relationship model is shown in **Figure 35**.

The EIA adjustment was applied to all urban land use in the Phase 2 model set-up, which contains the majority of urban areas within the Flathead Lake watershed. However, the EIA adjustment was not performed within the stormwater boundaries of Kalispell, Bigfork, and Whitefish; the impervious surfaces in these areas were assumed to be fully connected to the drainage network. Outside of these stormwater boundaries, MIA was calculated in each model subbasin. The relationship shown in **Figure 35** was used to calculate EIA from MIA. Impervious land was transferred to developed pervious to make the subbasin percent impervious area equal to the EIA. As a result, there was a significant, though variable reduction in MIA throughout the developed portions of the model. Separate calculations were performed on the NLCD 2001 and NLCD 2006 data sets.

The EIA adjustment was also applied to Primary and Secondary Roads (Unpaved Roads were modeled as a pervious surface as discussed in **Section 2.10.1.1**, so they were excluded from the EIA adjustment). The impervious area of a road is difficult to calculate; in theory, it should include the immediate adjacent pervious area which receives runoff from the road. Best professional judgment was used to estimate the MIA of roads. Primary Roads were assumed to have an MIA of 25 percent (representing a 3x pervious to 1x impervious drainage ratio), while Secondary Roads were assumed to have an MIA of 33 percent (representing a 2x pervious to 1x impervious drainage ratio). The respective EIA values were 9.5 percent and 17.5 percent for Primary and Secondary Roads. The roads areas were adjusted accordingly.

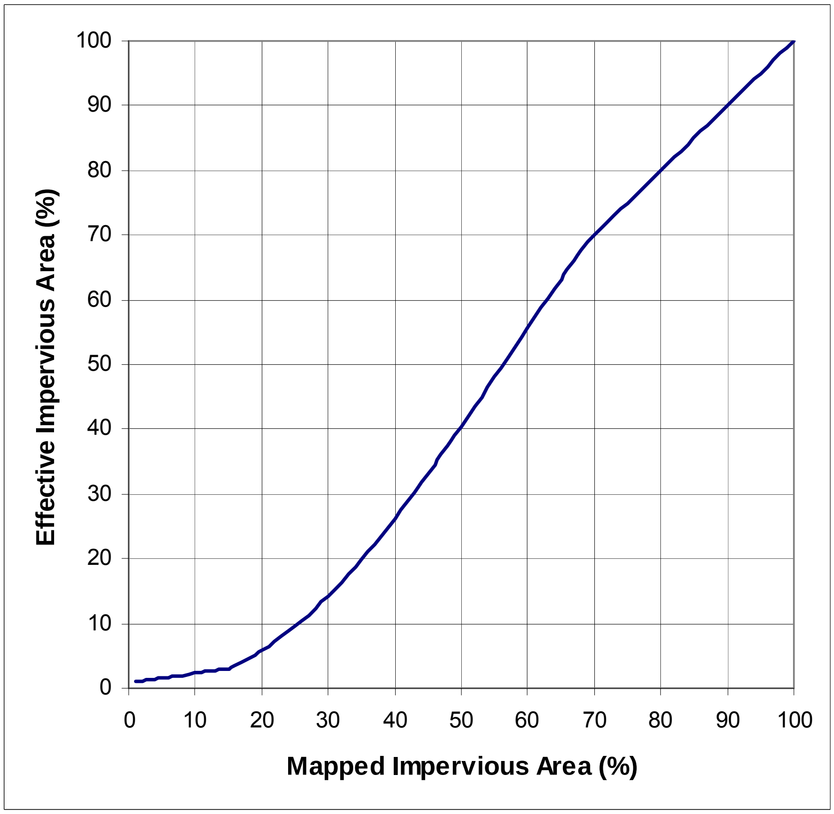

Figure 35. Effective Impervious Area to Mapped Impervious Area Relationship.

2.10.4 Estimation of Aspect

Aspect, or direction of a slope, can play an important role in hydrologic processes in mountainous areas by influencing the amount of sunlight (solar radiation) that a segment of land receives, which in turn can affect snow melt, sublimation, and evapotranspiration. Aspect can be calculated using a digital elevation model (DEM, shown in **Figure 36**) and the ArcGIS Spatial Analyst aspect algorithm. The algorithm follows these calculations:

The rate of change in the x-direction of a cell i, j in the DEM raster is calculated by,

$$\frac{\partial z}{\partial x} = \left[\left(Z_{i+1,j-1} + 2Z_{i+1,j} + Z_{i+1,j+1}\right) - \left(Z_{i-1,j-1} + 2Z_{i-1,j} + Z_{i-1,j+1}\right)\right]/8$$

while the rate of change in the y-direction of a cell i, j in the DEM raster is calculated by,

$$\frac{\partial z}{\partial y} = \left[\left(Z_{i-1,j+1} + 2Z_{i,j+1} + Z_{i+1,j+1}\right) - \left(Z_{i-1,j-1} + 2Z_{i,j-1} + Z_{i+1,j-1}\right)\right]/8$$

where Z is the cell elevation and i, and j are x-, and y-coordinates of the given cell, respectively.

For each cell i,j, **Figure 37** highlights the neighboring cells used to calculate the horizontal and vertical rates of change.

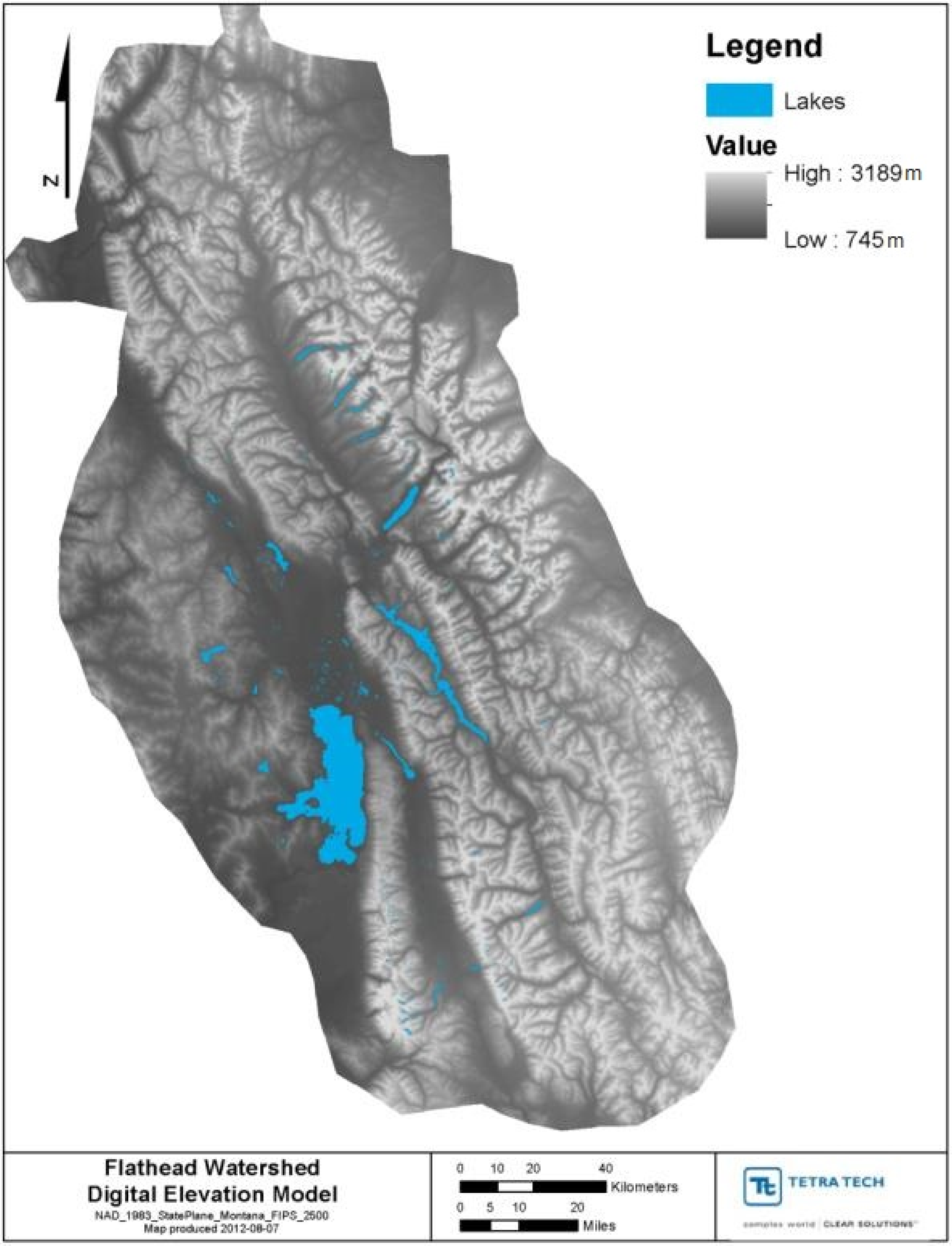

Figure 36. DEM for the Flathead Lake Watershed.

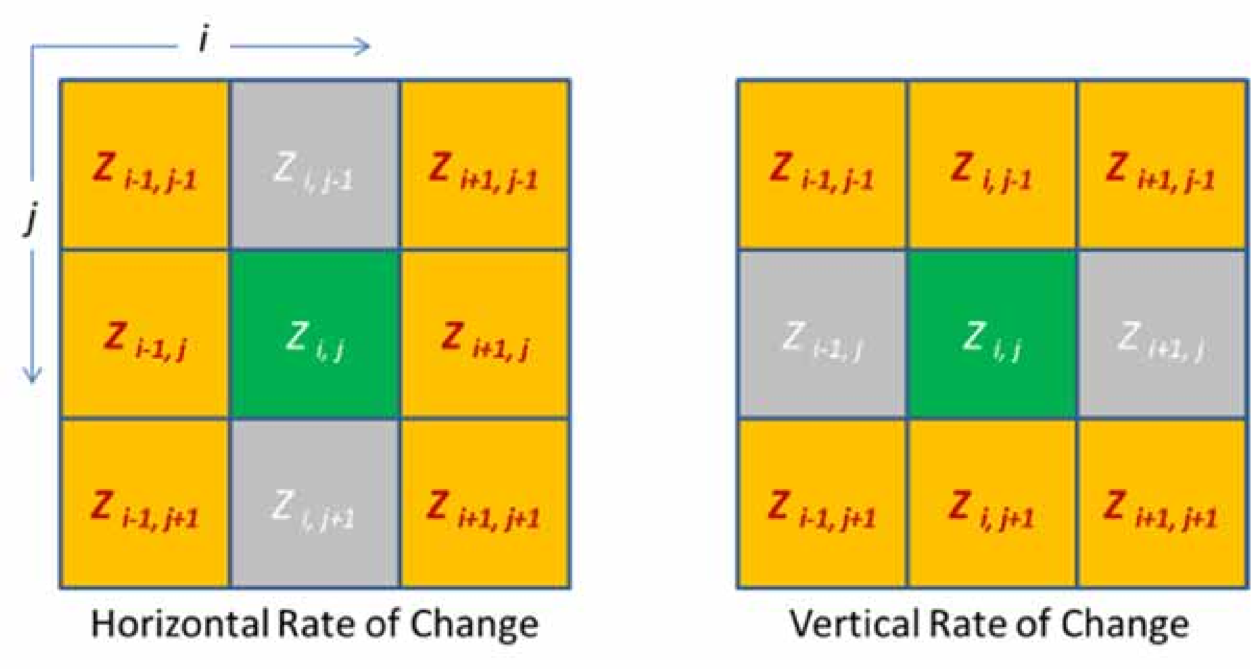

Figure 37. Neighboring Cells Used to Calculate Horizontal and Vertical Rates of Elevation (Z) Change.

Finally, aspect is calculated as

$$A = 57.29578 \cdot 2 \cdot \arctan\left(\frac{\sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2} + \frac{\partial z}{\partial x}}{\frac{\partial z}{\partial y}}\right),$$

this is then converted into compass directions by

$$A_{Compass} = \begin{cases} 90 - A, A < 90 \\ 360 - A + 90, A > 90 \end{cases}$$

where A is the aspect given before conversion.

With the DEM as an input, this series of calculations results in a raster showing the aspect (direction) of all surfaces. Because the north and south aspect divide has the strongest seasonal influence on incoming solar radiation, the results of these calculations were further dissolved resulting in two general aspect categories, northerly and southerly aspects, as shown in **Figure 38**. Aspect has the greatest impact on snowmelt on higher elevation surfaces where there is limited shade from tree canopy (DeWalle and Rango, 2008). Therefore, in the calibrated model, differences in aspect were only applied to the *Herbaceous* category in the Phase 1 portion of the model. Because the Phase 2 area encompassed primarily lower elevation watersheds, aspect ratio was not used for Phase 2 watersheds.

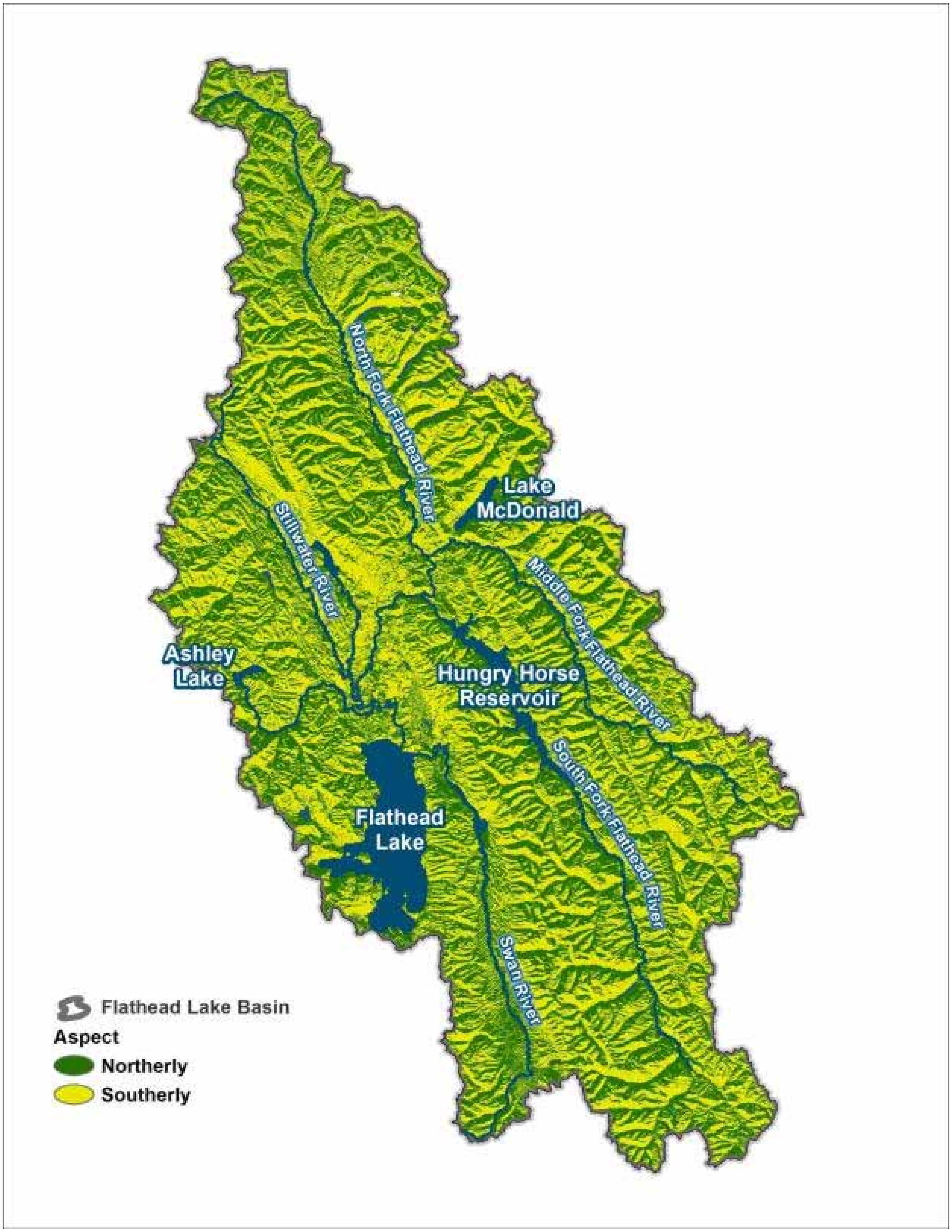

Figure 38. Northerly and Southerly Faces in the Flathead Lake Watershed.

2.10.5 Soil Properties

SSURGO spatial soils datasets were obtained for the United States portion of the watershed from NRCS and for the Canadian portion of the watershed from Agriculture and Agri-Food Canada's Soil Landscape of Canada (SLC) product. Limited relevant attribute data was available in the Canadian portion of Flathead Basin using the SLC dataset so this analysis focused only on the SSURGO dataset.

Soil polygons were classified by dominant HSG and then sampled by elevation using the DEM presented in **Figure 36**. The distribution of soil type between HSG A, B, C, and D was then plotted to assess the hypothesis that a correlation exists between soil and elevation (**Figure 39)**.

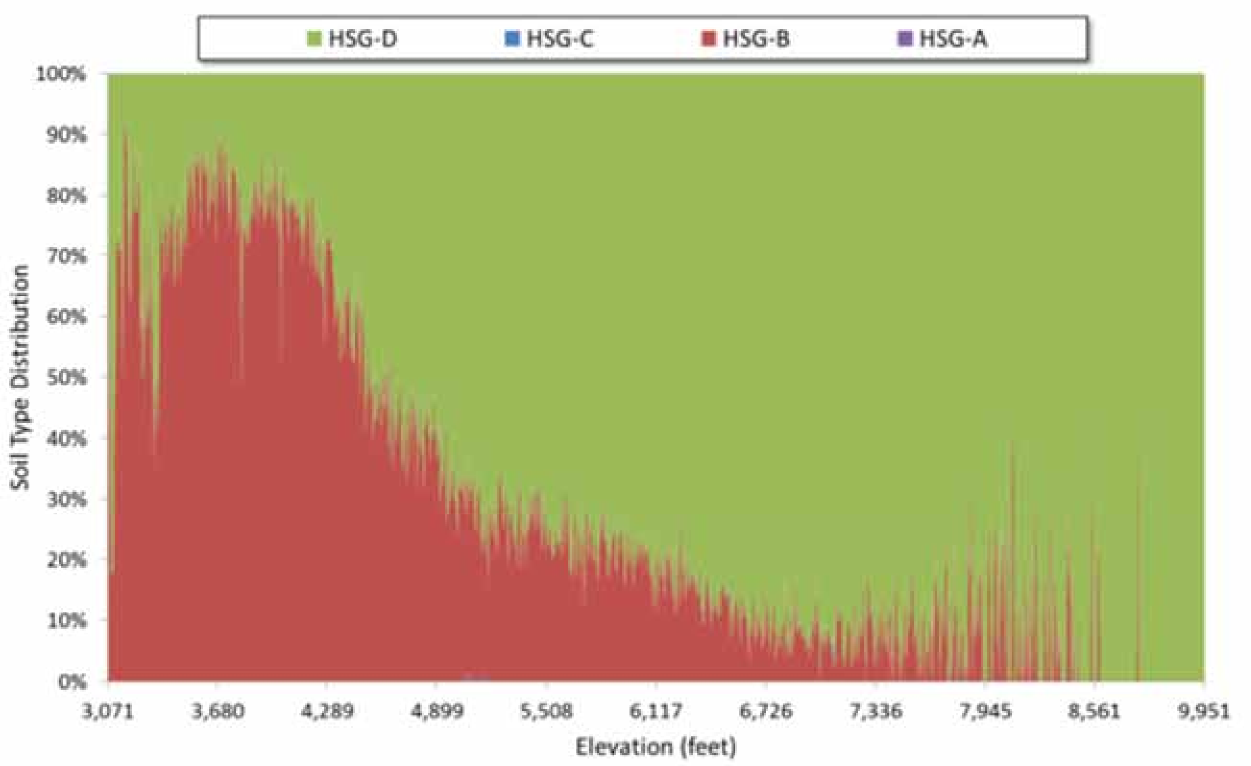

Figure 39. Distribution of Soil Type by Elevation.

The distribution shows the majority of soils in the study area can be generalized as either HSG B or HSG D. HSG B soils are more prevalent at lower elevations while HSG D soils are more prevalent at higher elevations (**Figure 40**). The figure highlights the partitioning of HSG B soils in the valleys and HSG D soils along the higher elevation ridges. Among other parameters, soil HSG is the basis for setting the infiltration index (INFILT) in the LSPC model; the index ranged from higher values for HSG A and B to lower values for HSG C and D. Similar patterns were examined for the spatial distribution of the minimum depth to bedrock (**Figure 40**). The figure shows relatively shallow depth to bedrock at higher elevations, with a strong association to HSG D soils. Shallow depth to bedrock was represented in the model using lower values for the nominal upper zone storage of soil moisture (UZSN) and the nominal lower zone storage of soil moisture (LZSN). Higher values of UZSN and LZSN were used for the other areas. Soil properties of HSG and depth to bedrock were generalized into four parameter groups used in the model (which are specified within the model using DEFID). Group 1 is associated with HSG A soils and is limited to a few model subbasins. Group 2 is associated with HSG B soils. Group 3 is used for subbasins having a mix of HSG B and D soils. Group 4 is associated with HSG D soils. The final specification of model hydrology parameters related to soil conditions was informed in part by model calibration.

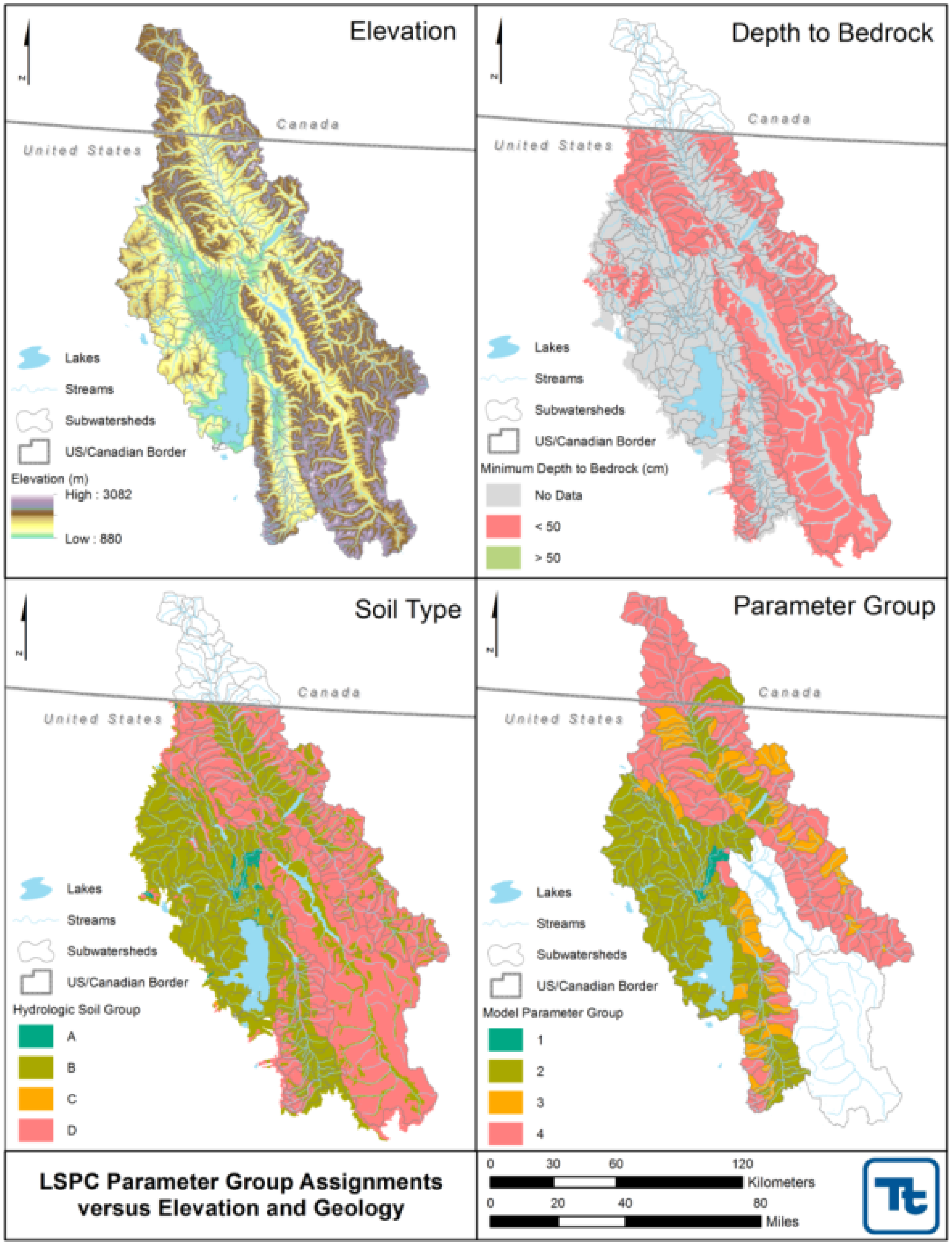

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Figure 40. Map of LSPC Parameter Group Assignments on the Basis of Elevation and Geology

2.10.6 Final Set of Hydrologic Response Units

As previously described HRUs are the primary functional unit in LSPC describing physical surface and subsurface properties. In the Flathead Lake watershed LSPC model, HRUs were developed as an aggregation of (1) land cover, (2) soil properties, and (3) slope aspect for one land cover category (**Figure 40**). Separate categories were developed for each land cover and slope aspect (**Table 22** and **Table 23**) and are numbered within the model using DELUID. The Phase 1 and Phase 2 models differ somewhat, but reflect the specific needs of the geographic areas they encompass.

To account for the influence of soil type, DELUID were divided into four parameter groups according to the dominant soil group as shown in **Figure 40**. Snow, hydrology, sediment, and water quality parameters for the land can be set uniquely by HRU using the combination of land use DELUID and soil group DEFID. Since soil type and elevation are strongly correlated in the watershed, using four soil parameter groups provides flexibility to not only calibrate infiltration parameters to account for the dominant soil composition, but also allows greater resolution when setting other elevation dependent parameters.

Details regarding how HRUs are parameterized are provided in **Appendices D** and **E**.

Table 22. Phase 1 LSPC Land Use/Land Cover Categories

DELUID	Name	Data Source	Percent of Area
1	Urban_Impervious	NLCD	0.02%
2	Urban_Pervious	NLCD	0.11%
3	Road_Primary	See **Section 2.10.1.1**	0.02%
4	Road_Secondary	See **Section 2.10.1.1**	0.02%
5	Road_Unpaved	See **Section 2.10.1.1**	0.06%
6	Golf_Course	Digitized from aerial imagery (USDA Farm Services Agency, 2009)	0.00%
7	Cropland	NLCD	0.00%
8	Pasture	NLCD	0.38%
9	Wetland	NLCD	0.52%
10	Snow_Ice	NLCD	0.30%
11	Water	NLCD	0.25%
12	Bluff	Digitized from aerial imagery (USDA Farm Services Agency, 2011)	0.14%
13	Barren	NLCD	5.17%
14	Herbaceous_North	NLCD; Aspect	8.19%
15	Herbaceous_South	NLCD; Aspect	11.16%
16	Forest	NLCD	72.43%
18	Forest_Harvest	Estimated (see **Section 2.10.2.1**)	0.87%
19	Forest_Fire	Estimated (see **Section 2.10.2.2**)	0.36%

NLCD = National Land Cover Dataset; USDA = U.S. Department of Agriculture.

Table 23. Phase 2 LSPC Land Use/Land Cover Categories

DELUID	Name	Data Source	Percent of Area
1	Water	NLCD	0.59%
2	Herbaceous	NLCD	18.84%
3	Forest	NLCD	63.65%
4	Wetland	NLCD	2.04%
5	Forest_Harvest	Estimated (see **Section 2.10.2.1**)	1.97%
6	Forest_Fire	Estimated (see **Section 2.10.2.2**)	0.00%
7	Bluff	Digitized from aerial imagery (USDA Farm Services Agency, 2011)	0.01%
8	Cropland_High	Wendt (2011) and NLCD	2.28%
9	Cropland_Moderate	Wendt (2011) and NLCD	1.97%
10	Cropland_Other	Wendt (2011) and NLCD	2.65%
11	Pasture	Wendt (2011) and NLCD	3.87%
12	Golf_Course	Digitized from aerial imagery (USDA Farm Services Agency, 2009)	0.11%
13	UrPev_Kalispell	NLCD	0.19%
14	UrPev_Whitefish	NLCD	0.05%
15	UrPev_Bigfork	NLCD	0.01%
17	UrPev_Other	NLCD	1.04%
18	UrImp_Kalispell	NLCD	0.14%
19	UrImp_Whitefish	NLCD	0.03%
20	UrImp_Bigfork	NLCD	0.00%
22	UrImp_Other	NLCD	0.26%
23	Road_Primary	See **Section 2.10.1.1**	0.10%
24	Road_Secondary	See **Section 2.10.1.1**	0.04%
25	Road_Unpaved	See **Section 2.10.1.1**	0.16%

NLCD = National Land Cover Dataset; USDA = U.S. Department of Agriculture.
UrImp = Urban Impervious
UrPev = Urban Pervious

3 MODEL CALIBRATION

The model calibration process involves refining model parameters associated with the underlying physical processes of each parameter group. Calibration refers to adjusting or fine-tuning modeling parameters to reproduce observations on the basis of field monitoring data. The calibration process was a sequential, hierarchical process that began with snow calibration followed by land hydrology calibration, stream transport, and, finally, water quality (**Figure 41**). Because any inaccuracies in the hydrologic simulation propagate forward into the water quality simulation, the accuracy of the hydrology simulation has a significant effect on the accuracy of the water quality simulation.

To help determine the adequacy of the calibration and to evaluate the uncertainty associated with the calibration, models are typically subjected to a corroboration test. Corroboration is often referred to as model validation, although the term corroboration is now preferred (CREM, 2009). In the corroboration step, the performance of the model is evaluated through application to a set of data different from that used in calibration. Due to time constraints and paucity of monitoring data at some key sites in the watershed, model corroboration was not performed. One of the recommendations discussed in **Section 4.3** for future model improvement is to perform corroboration using different or newer monitoring data.

The first part of the hydrology calibration is representing the snow budget. Snow acts as a reservoir of stored precipitation (in the form of snowpack) that is released in the spring. Snow telemetry data (when available) can be used to calibrate the volume and timing of snowpack accumulation and the spring snowmelt. Water released from the snowpack joins the hydrologic cycle with direct precipitation.

Calibrating land hydrology is best achieved by identifying upstream gages that have a predominant land use. Isolating land use responses helps to perform targeted adjustments of associated parameters. Stream transport calibration requires that any special features (such as point sources, reservoirs, or diversions) are represented in the network.

Water quality calibration occurs once the hydrologic representation is completed. Simulating hydrologic processes in such a sequence helps to manage and control the propagation of model uncertainty. The goal of the calibration is to obtain physically realistic model predictions by selecting parameter values that reflect the unique characteristics of the land uses, soils, and receiving streams and lakes.

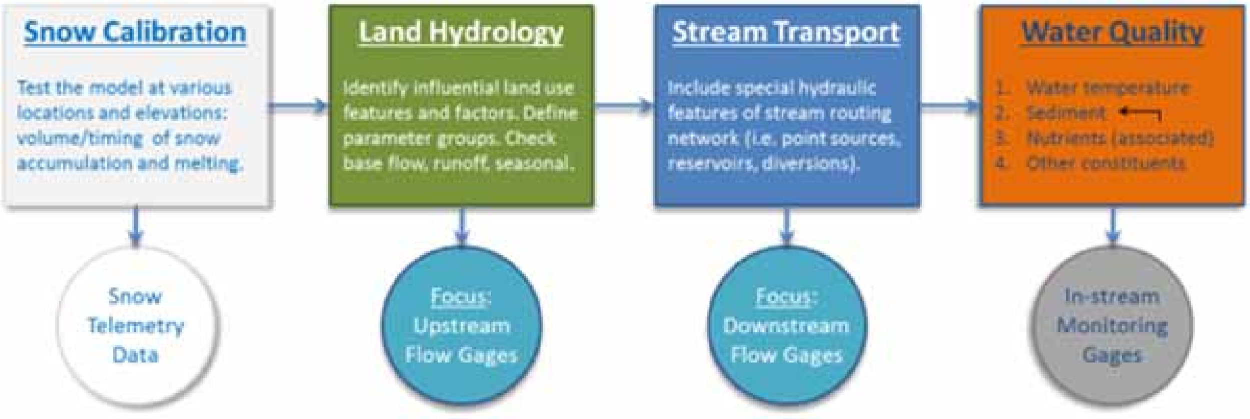


Figure 41. Schematic of the Watershed Model Calibration Process.

3.1 SNOW CALIBRATION

Observed daily snowpack data were available at 17 SNOTEL gages selected within a 10 mile buffer of the Flathead Lake watershed. **Table 24** presents a list of the gages along with key physical characteristics: elevation, aspect, and slope. The location of the gages is shown in **Figure 42**. Before beginning any snow modeling it was hypothesized that these three key site characteristics could play a significant role in affecting snow accumulation and melt processes.

Table 24. SNOTEL Stations and Attributes

Station Name	Station ID	Elevation (feet)	Aspect (compass degrees)*	Slope (%)
GRAVE CREEK	14a11s	4,300	56.9	34.32
EMERY CREEK	13a24s	4,350	239.6	42.02
KRAFT CREEK	13b22s	4,750	0	5.00
MANY GLACIER	13a27s	4,900	329	21.87
BISSON CREEK	13b25s	4,920	222.5	40.70
HAND CREEK	14a14s	5,035	99.2	54.46
WALDRON	12b13s	5,600	338.4	57.80
DUPUYER CREEK	12a02s	5,750	6.3	33.96
PIKE CREEK	13a26s	5,930	310.2	21.29
WOOD CREEK	12b17s	5,960	65.1	77.18
STAHL PEAK	14a12s	6,030	344.1	18.20
NOISY BASIN	13a25s	6,040	231.3	32.02
FLATTOP MTN.	13a19s	6,300	63.4	11.18
NORTH FORK JOCKO	13b07s	6,330	294.4	45.31
MOUNT LOCKHART	12b12s	6,400	119.1	25.74
MOSS PEAK	13b24s	6,780	86.5	61.36
BADGER PASS	13a15s	6,900	223.3	60.13

* Zero degrees represents north

Observed data from each of these locations were obtained through the NRCS SNOTEL website. Daily snow-water equivalent (SWE) was used both to assess physical trends in snow accumulation and melt patterns, and as observed snowpack data for calibrating the LSPC SNOW module at each station. Meteorological data were obtained to provide model inputs to the snow calibration. Daily minimum and maximum temperatures were disaggregated to hourly temperature using hourly diurnal distributions from the Kalispell Glacier International Airport station (WBAN 24146). Daily precipitation was disaggregated to hourly precipitation using nearby hourly observed precipitation from both NCDC and MDOT stations. The snow calibration was performed early in the model development process, so the simulations supporting snow calibration were performed through WY2008.

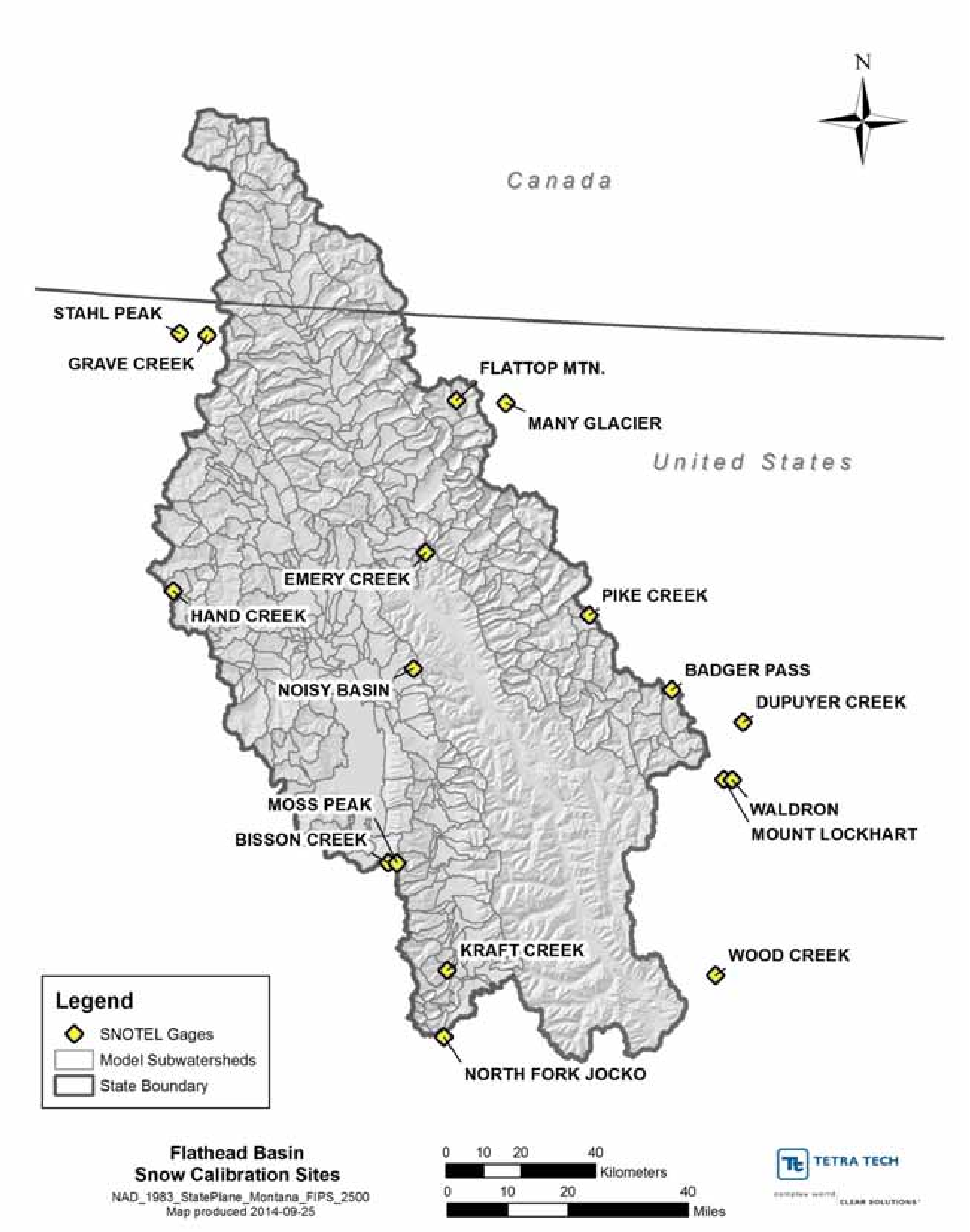


Figure 42. Location of SNOTEL Snow Calibration Sites within the Flathead Lake Watershed Model.

Analysis of observed SWE data at the 17 SNOTEL sites listed in **Table 24** was performed to assess the presence of spatial and temporal signatures. Average monthly snowpack depth was calculated for each station using observations from October 1, 1990 through September 30, 2008. The average monthly distributions for each station were then plotted to assess correlations with (1) aspect (2) slope, and (3) elevation of the site location. **Figure 43** shows the elevation comparison, which had the clearest trend—higher elevations had more snowpack than lower elevation. The two stations (12b17s and 12b12s) that deviated somewhat from that trend were both on east-facing slopes—though they were not the only east-facing stations. The shapes of annual snowpack profiles shows that peak snowpack depth occurs in March at the lower elevations and makes a gradual transition to April for elevations above 5,600 feet. Model calibration mimicked this pattern to predict the timing of peak in-stream flows associated with snowmelt.

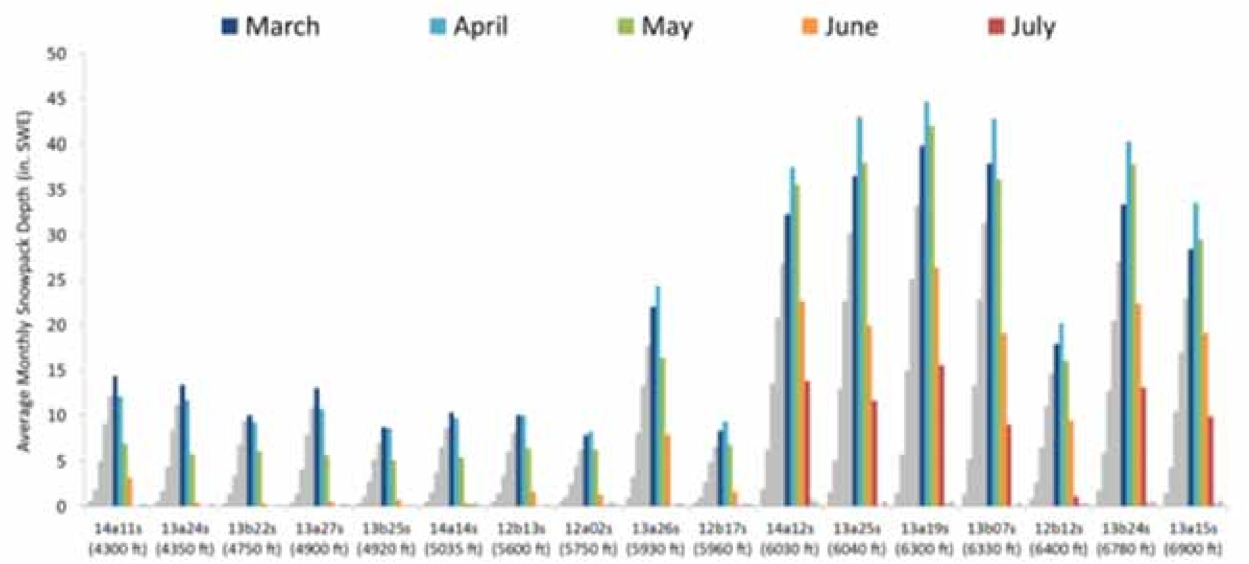


Figure 43. Average Monthly Observed Snowpack (10/1/1990 – 9/30/2008) at SNOTEL Sites Sorted by Elevation.

A unit-area LSPC model was created to represent each of the 17 gages to assist with snow calibration; this was necessary since some of the gages were located outside of the watershed. The primary land use associated with each SNOTEL location was assumed to be forest. The LSPC SNOW module subroutines use a total of 16 parameters derived from physical characteristics such as topography, climate, and geology. **Table 25** summarizes the calibrated LSPC snow parameters and ranges transferred to the Flathead Lake watershed LSPC model. The *Snow Calibration* column shows the assumptions used in the unit area model, while the *Full Model* column shows the assumptions used in the full Flathead Lake watershed LSPC model. In some cases the values differ, primarily because the assumed land use for the unit area model is Forest, while land uses vary in the full model.

Table 25. Snow Module Calibration Parameters

Parameter	Description	Status	Snow Calibration	Full Model
ICEFG	Ice simulation switch, 1 = on or 0 = off	Turned on	1	1
FOREST	Forested land for winter transpiration (fraction)	By land use	0.75	0.00 – 0.75
FZG	Effect of ice on infiltration	Constant	1	1
FZGL	Lower limit of factor that accounts for frozen ground	Constant	0.1	0.1
LAT	Latitude of land segment (degrees)	From GIS	Varies	47.5
MELEV	Mean elevation of land segment (ft)	From GIS	Varies	By elevation
ELDAT	Difference between MELEV and gage elevation (ft)	From GIS	N/A	By subbasin
SHADE	Land shaded from solar radiation (fraction)	By land use	0.5	0.0 – 0.9
SNOWCF	Precipitation-snow catch efficiency (multiplier)	By location	1.0 – 1.4	1.0 – 1.2
COVIND	Water equivalent for complete land coverage (in.)	Constant	1.0 – 3.0	1.0 – 3.0
RDCSN	Density of new snow relative to water (in./in.)	Constant	0.2	0.2
TSNOW	Air temperature for snowfall (degrees F)	By location	34	34
SNOEVP	Snowpack sublimation coefficient (unitless)	Constant	0.15	0.15
CCFACT	Condensation/convection coefficient (unitless)	By location	0.1 – 0.5	0.1 – 0.5
MWATER	Maximum water content of snow (in./in.)	Constant	0.03 – 0.05	0.03 – 0.05
MGMELT	Maximum ground snowmelt rate (in./day)	Constant	0.009 – 0.014	0.009 – 0.014

Of the 16 available snow parameters in the LSPC model, calibration efforts focused on refining five key parameters that were most sensitive by elevation: SNOWCF, COVIND, CCFACT, MWATER, and MGMELT. SNOWCF was increased for higher elevation watersheds. SNOWCF is a measure of the catch efficiency for snow at the precipitation gage. The higher elevation gages, which are also more likely to experience windier conditions, were generally found to under-predict snow capture; therefore, increasing SNOWCF essentially increases the total precipitation volume available during snowfall events. COVIND is the maximum snow depth at which the entire land segment is covered with snow. Higher values were used for the higher elevation watersheds because often those watersheds have steeper topography; therefore, they required a greater depth of snow to completely cover the entire land segment. CCFACT is used to adjust the rate of heat transfer from the atmosphere to the snowpack caused by condensation and convection. Lower values were used for higher elevations and higher values were used for lower elevations. CCFACT is particularly sensitive when adjusting for the timing of snow melt. MWATER and MGMELT were set based on elevation. Higher values of MWATER were used at high elevations. MGMELT values decreased with increasing elevation.

Temperature lapse rate, the rate at which temperature decreases with increasing elevation, significantly influences snowfall prediction, especially when extrapolating snow behavior to subwatersheds without gages. That rate is particularly important in the Flathead Lake watershed, where elevation changes rapidly in certain portions of the watershed. LSPC adjusts the temperature data for each model subbasin according to the mean difference between the gage elevation and the average subwatershed elevation (air temperature gage assignment is discussed in Section 2.4.4). The full model was configured with unique average elevation for each model subbasin, allowing for each subbasin to have an appropriate lapse rate. LSPC uses a wet lapse rate (i.e., during periods of precipitation) of 0.0035 degree F per foot of elevation difference, while dry lapse rates vary from 0.0035 to 0.0050 depending on the time of day.

Examples of daily calibration plots for Stahl Peak and Flattop Mountain are presented in **Figure 44** and **Figure 45**. Detailed snow calibration graphs for all 17 SNOTEL gages evaluated are presented in **Appendix F**.

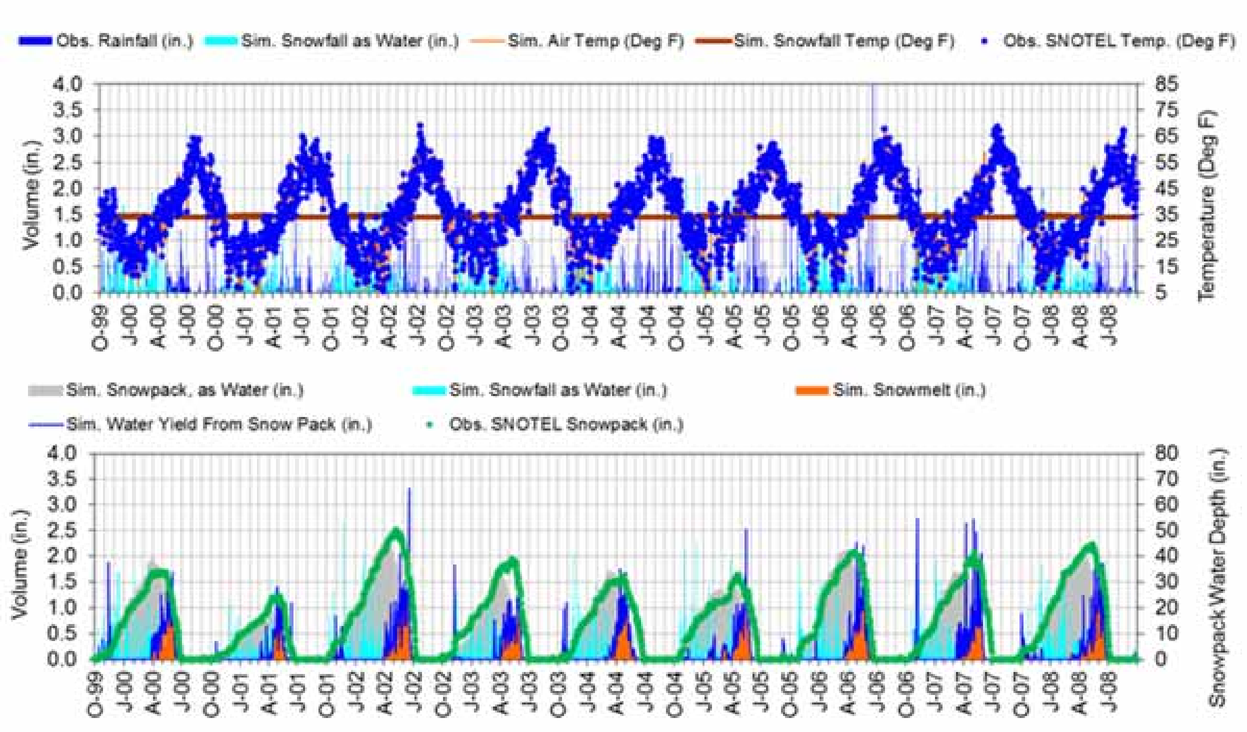


Figure 44. LSPC Snow Calibration at Stahl Peak (10/1/1999 to 9/30/2008).

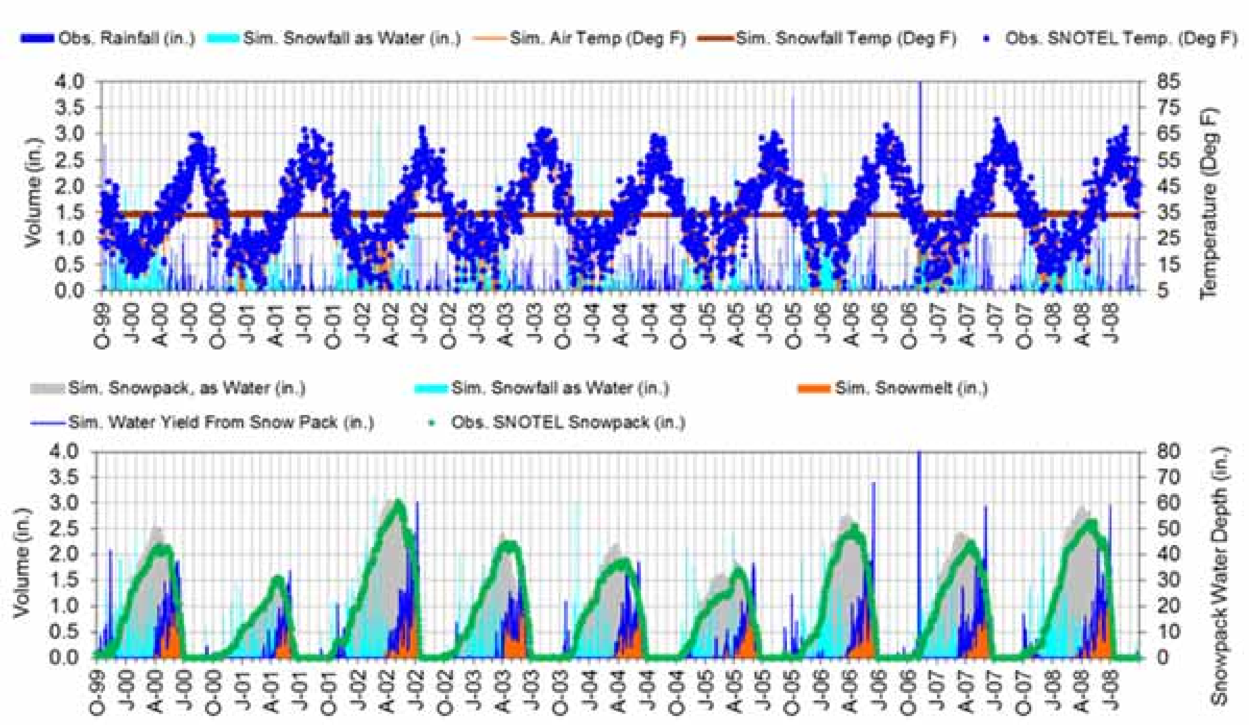


Figure 45. LSPC Snow Calibration at Flattop Mountain (10/1/1999 to 9/30/2008).

Table 26 and **Figure 46** present key metrics for evaluating the model's ability to predict the depth of water equivalent in the snowpack at each of the SNOTEL stations. Nash-Sutcliffe was calculated by comparing modeled and observed data from October 1st through June 30th for each year.

Table 26. Snow Calibration Statistics by Station (October 1, 2000 through September 30, 2008)

SNOTEL Station	Elevation (feet)	Nash-Sutcliffe	Model / Observed Average Snowpack Depth	Model / Observed Peak Snowpack Depth
GRAVE CREEK	4,300	0.72	1.19	1.18
EMERY CREEK	4,350	0.82	0.97	1.00
KRAFT CREEK	4,750	0.82	1.20	0.83
MANY GLACIER	4,900	0.89	0.98	0.93
BISSON CREEK	4,920	0.61	0.99	1.07
HAND CREEK	5,035	0.89	1.03	0.87
WALDRON	5,600	0.83	0.91	0.96
DUPUYER CREEK	5,750	0.67	0.83	0.81
PIKE CREEK	5,930	0.91	1.07	0.98
WOOD CREEK	5,960	0.68	1.05	0.85
STAHL PEAK	6,030	0.90	1.05	0.92
NOISY BASIN	6,040	0.82	1.04	0.89
FLATTOP MTN.	6,300	0.90	1.16	1.02
NORTH FORK JOCKO	6,330	0.90	1.08	0.84
MOUNT LOCKHART	6,400	0.77	1.07	0.97
MOSS PEAK	6,780	0.70	0.94	0.78
BADGER PASS	6,900	0.62	0.92	0.78

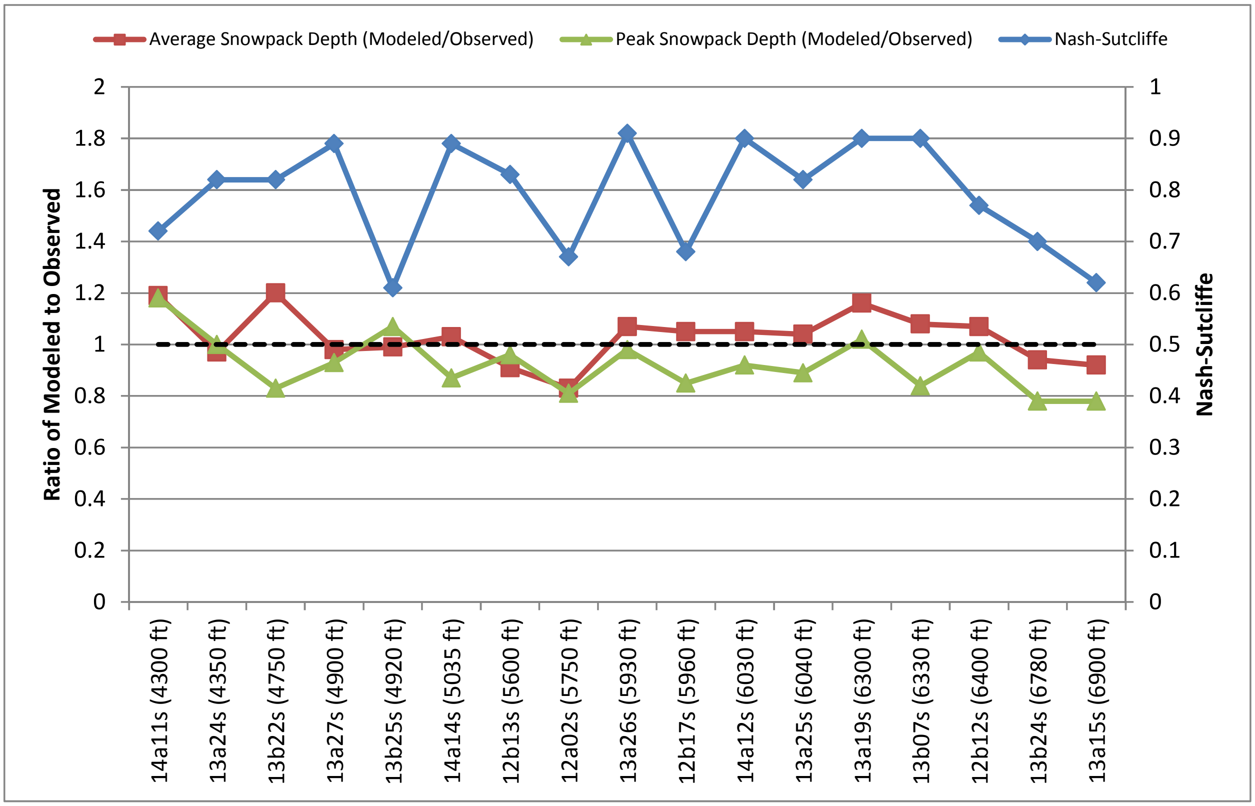


Figure 46. Snow Calibration Statistics Sorted by Elevation (October 1, 2000 through September 30, 2008).

The calibration metrics presented in **Figure 46** show favorable agreement between the observed snowpack data and LSPC modeled snowpack at most locations. The higher elevation SNOTEL sites tend to show slightly higher average modeled snowpack depth vs. observed data although the peak and shape (Nash-Sutcliffe) of snowpack show closer matches. It was more important to match the higher elevation SNOTEL behavior because those gages are responsible for more of the water budget.

The subsequent sections focus on the hydrology calibration *downstream* of snow simulation, with snowmelt and rainfall as water sources and potential evapotranspiration as the primary water sink.

3.2 HYDROLOGY CALIBRATION

Hydrologic calibration for the Flathead Lake watershed followed the standard operating procedures for the model described in Donigian et al. (1984) and Lumb et al. (1994). The general approach begins with replicating the total water balance, followed by adjustments to represent the division between high flows (due mostly to surface runoff) and low flows (due mostly to subsurface flow). Fine tuning is then used to adjust the seasonal balance. Calibration performance was tracked with a spreadsheet tool, which automatically retrieves model output and generates relevant statistics and graphical comparisons. Daily, monthly, seasonal, and total modeled flows were compared to observed data, and error statistics were calculated for the percent difference. The percent errors were then compared to the performance targets identified in the Quality Assurance Project Plan (QAPP) (Tetra Tech 2012) and are provided in **Table 27**.

To aid in the presentation of the model performance results, a color code scheme has been used. The color dark green indicates the value lies within the “very good” range; the color light green indicates the value lies within the “good” range; the color blue indicates the value lies within the “fair” range; and finally the color red indicates the value lies within the “poor” range. The colors utilized in Table 27 are also utilized below in Table 30. Model results were also visually compared to observed data using time series plots, and additional graphical and tabular monthly comparisons were performed.

Table 27. Performance Targets for LSPC Hydrologic Simulation (Magnitude of Annual and Seasonal Relative Mean Error (*RE*); Daily and Monthly R^2)

Model Component	Code	Very Good	Good	Fair	Poor
1. Error in total volume	ETV	≤ 5%	5 - 10%	10 - 15%	> 15%
2. Error in 50% lowest flow volumes	E50%	≤ 10%	10 - 15%	15 - 25%	> 25%
3. Error in 10% highest flow volumes	E10%	≤ 10%	10 - 15%	15 - 25%	> 25%
4. Error in storm volume	EST	≤ 10%	10 - 15%	15 - 25%	> 25%
5. Winter volume error	EW	≤ 15%	15 - 30%	30 - 50%	> 50%
6. Spring volume error	ES	≤ 15%	15 - 30%	30 - 50%	> 50%
7. Summer volume error	ESU	≤ 15%	15 - 30%	30 - 50%	> 50%
8. Fall volume error	EF	≤ 15%	15 - 30%	30 - 50%	> 50%
9. R^2 daily values	R2D	> 0.80	> 0.70	> 0.60	≤ 0.60
10. R^2 monthly values	R2M	> 0.85	> 0.75	> 0.65	≤ 0.65

3.2.1 Available Monitoring Data

Continuous flow data are available at 44 USGS gages; however, 32 of these gages ceased operations prior to water year 1993. Eight active USGS gages were selected for the watershed modeling effort based on having observed data during the model simulation period. **Table 28** presents the USGS gages utilized, the published USGS drainage areas, and the periods of record utilized for each gage for the model. The spatial distribution of the calibration gages is shown in **Figure 53**.

Table 28. USGS Flow Gages used for the Watershed Model

USGS Gage ID	Site Name	Drainage Area (mi^2)	Period of Record Utilized
12355000	Flathead River at Flathead British Columbia.	427	10/1/2000—9/30/2012
12355500	North Fork Flathead River near Columbia Falls, MT	1,548	10/1/2000—9/30/2012
12358500	Middle Fork Flathead River near West Glacier, MT	1,128	10/1/2000—9/30/2012
12363000	Flathead River at Columbia Falls, MT	4,464	10/1/2000—9/30/2012
12365000	Stillwater River near Whitefish, MT	556	10/1/2000—9/30/2006
12366000	Whitefish River near Kalispell, MT	170	10/1/2000—9/30/2006
12369000	Flathead River near Bigfork, MT	5,789	10/1/2008—9/30/2012
12370000	Swan River near Bigfork, MT	671	10/1/2000—9/30/2012

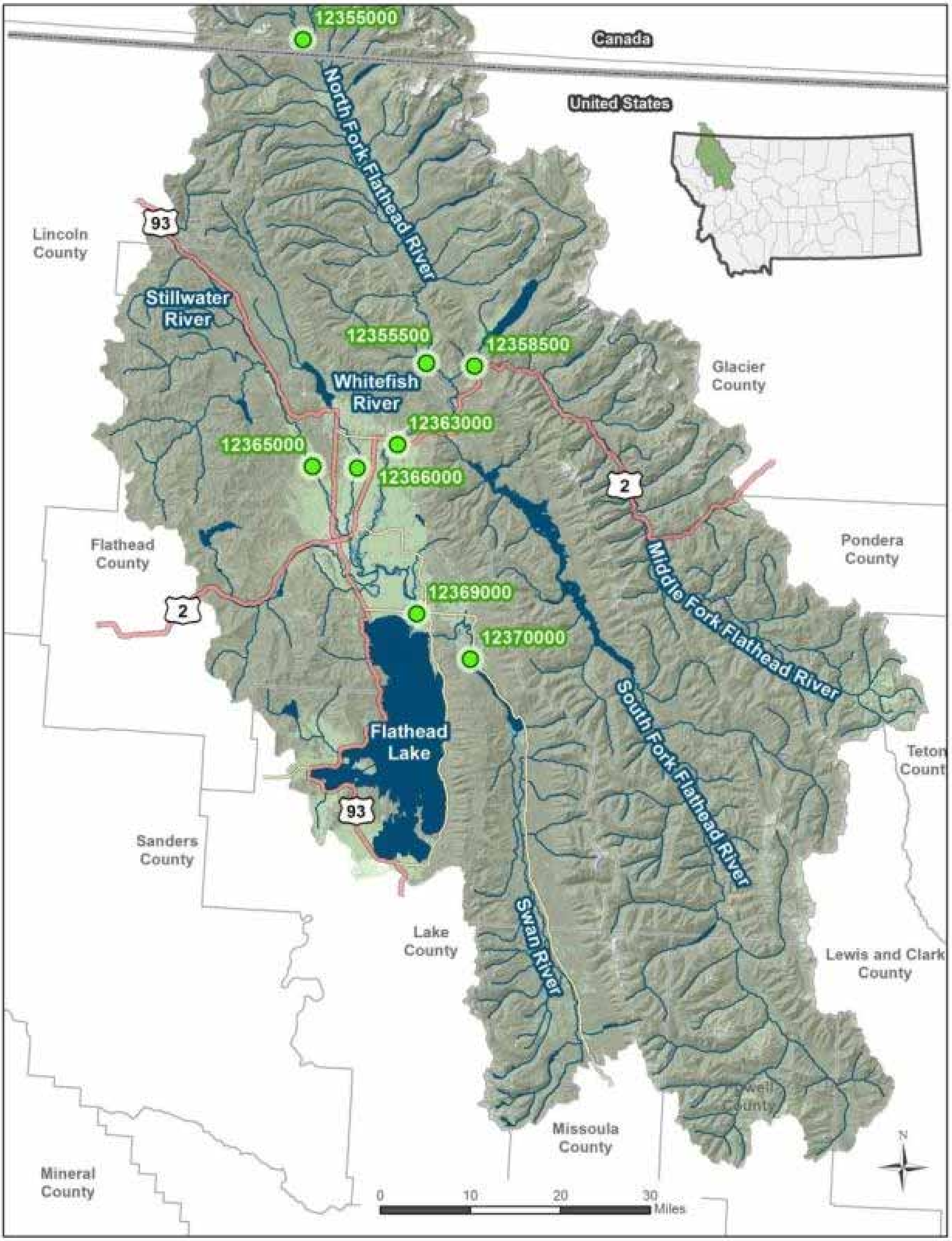


Figure 47. Location of Hydrology Calibration Stations in the Flathead Lake Watershed Model.

3.2.2 Key Parameters and Adjustments

The following discussion provides a summary of the key hydrologic parameters and how they were adjusted during calibration.

LZSN: The LZSN parameter is an index of the lower zone nominal soil moisture storage (inches), where the lower zone is operationally defined as the depth of the soil profile subject to evapotranspiration (ET) losses. LZSN is related, but not equivalent to the available water capacity (AWC) of a soil. It also reflects precipitation characteristics. USEPA (2000) recommends setting initial values at one-eighth of annual mean rainfall plus 4 inches in coastal, humid, and sub-humid regions, but also notes that this formula tends to yield “values somewhat higher than we typically see as final calibrated values”. LZSN was modified throughout the course of calibration to promote (ET) losses to obtain a better fit between simulated and observed values.

INFILT: INFILT is an index to mean soil infiltration rate (inches per hour [in/hr]), which controls the overall division of the available moisture from precipitation (after interception) into surface and subsurface flows. INFILT is not a maximum infiltration rate, nor an infiltration capacity term. As a result, values of INFILT used in the model are expected to be much less than published infiltration rates or permeability rates shown in the soil survey (often on the order of 1 to 10 percent of soil survey values). USEPA (2000) shows acceptable ranges of INFILT for soil hydrologic groups, ranging from a minimum of 0.01 in/hr in group D soils to a maximum of 1.0 in/hr in group A soils. INFILT was modified throughout the course of calibration to more appropriately represent the division between surface and subsurface flows in order to obtain a better fit between simulated and observed values.

AGWRC: The active groundwater recession coefficient was initially set based on baseflow separation and analysis of recession rates. AGWRC was modified slightly throughout the course of calibration in order to obtain a better fit between simulated and observed low flows.

LZETP: The LZETP parameter is a coefficient to define the evapotranspiration opportunity from the soil lower zone and is a function of cover type. Monthly coefficients (MON-LZETP) were specified for all land uses, with a strong seasonal component for crops and forest cover and a weaker seasonal component for herbaceous cover.

PETMULT: The PETMULT parameter is a pan coefficient to modify the supplied Penman pan evaporation PET time series for each HRU in the model to PET for forest and crop cover. This factor should be less than 1. Each land use was supplied a coefficient that reduces the amount of ET supplied by the air file.

Water HRU: The study area contains numerous small ponds and lakes remote from the main LSPC reaches. To allow a full accounting of the water balance to occur, ponds and lakes were represented as internally drained lakes, which are then connected to the reach within the subbasin. The lakes are represented as pervious land area instead of as a reach in the model, with important changes. The land use is parameterized to specify a combination of high infiltration and a small amount of lower zone and upper zone storage. These “soil” storages allow for a significant amount of ET. A baseflow discharge represents gradual releases, while surface flow will occur during large events when lower zone storage is exceeded.

3.2.3 Hydrology Calibration Results

Table 29 provides the calibration results at the USGS flow gages and indicates that Very Good or Good results were obtained at most sites for most calibration criteria. The Nash-Sutcliffe Coefficient of Efficiency is not provided with a colored rating because such criteria were not pre-specified; however, these coefficients generally show a high goodness of fit with all values above 0.78.

Table 29. Performance for the Hydrology Calibration

Calibration Criteria	NF Flathead 12355000	NF Flathead 12355500	MF Flathead 12358500	Flathead 12363000
1. Error in total volume	-11.54%	-2.83%	2.33%	-1.23%
2. Error in 50% lowest flow volumes	4.10%	11.97%	1.28%	-0.90%
3. Error in 10% highest flow volumes	-21.60%	-10.12%	-0.50%	-3.98%
4. Error in storm volume	-15.25%	-4.31%	-0.19%	1.76%
5. Winter volume error	-16.17%	-5.82%	-17.46%	-5.20%
6. Spring volume error	-12.97%	-4.45%	5.47%	-0.20%
7. Summer volume error	-5.05%	-0.31%	1.40%	-1.38%
8. Fall volume error	-9.75%	5.65%	-3.12%	-1.56%
9. R2 daily values	0.810	0.860	0.843	0.904
10. R2 monthly values	0.913	0.946	0.956	0.970
Nash-Sutcliffe Coefficient of Efficiency	0.788	0.859	0.833	0.904

Calibration Criteria	Stillwater 12365000	Whitefish 12366000	Flathead 12369000	Swan 12370000
1. Error in total volume	0.31%	-11.54%	2.83%	7.38%
2. Error in 50% lowest flow volumes	4.31%	-7.13%	0.74%	-5.99%
3. Error in 10% highest flow volumes	-6.30%	-7.69%	3.52%	8.53%
4. Error in storm volume	13.58%	34.69%	10.79%	6.24%
5. Winter volume error	-4.12%	-18.80%	3.59%	-22.09%
6. Spring volume error	-3.30%	-6.47%	7.70%	9.90%
7. Summer volume error	1.65%	-28.50%	-7.08%	22.63%
8. Fall volume error	28.58%	0.70%	0.36%	-3.73%
9. R2 daily values	0.864	0.893	0.927	0.884
10. R2 monthly values	0.925	0.926	0.975	0.945
Nash-Sutcliffe Coefficient of Efficiency	0.864	0.881	0.919	0.843

Error statistics are reported as simulated minus observed therefore negative indicates simulated less than observed.

Graphical results for the calibration at gage 12369000, Flathead River near Bigfork, MT, are shown in **Figure 48** to **Figure 52** because this gage drains almost the entire modeled area (the figures only include the years that monitoring data is available during the model simulation period, October 2008 thru December 2012. The flow-duration plot (plot of flow versus percent-of-time exceeded) shows good agreement across most of the range of flows. The model over predicts flow somewhat between the 50th and 60th percentiles and slightly under predicts in the 90th to 100th. Monthly observed and modeled flows are plotted along with reported monthly rainfall (**Figure 49**) and show a good overall agreement. A plot of flow accumulation (**Figure 50**) shows excellent agreement between modeled and observed flow volume across a range of wet and dry years. Diagnostic plots of the distribution of observed and simulated flows by month are shown in **Figure 51**. The bar ranges indicate the range between the 25th and 75th percentile, while the center point is the median. Generally the medians and the interquartile range are well replicated throughout the year, though spring snow melt tends to be a bit high and summer baseflows tend to be a bit low when comparing the simulation to observed values. **Figure 52** shows a comparison of average monthly flows (rather than median and interquartile flows), which can be useful if large storm events influence seasonal flow balance without affecting most of the flow distribution. Average monthly flow is generally well replicated, though there are some minor deviations for individual months and also shows a slight over estimation in the spring and a slight under estimation in the summer. Generally, these graphical plots indicate very good fit between simulated and observed flows at 12369000, Flathead River near Bigfork, MT. The same plots for other USGS gages are included in **Appendix G**.

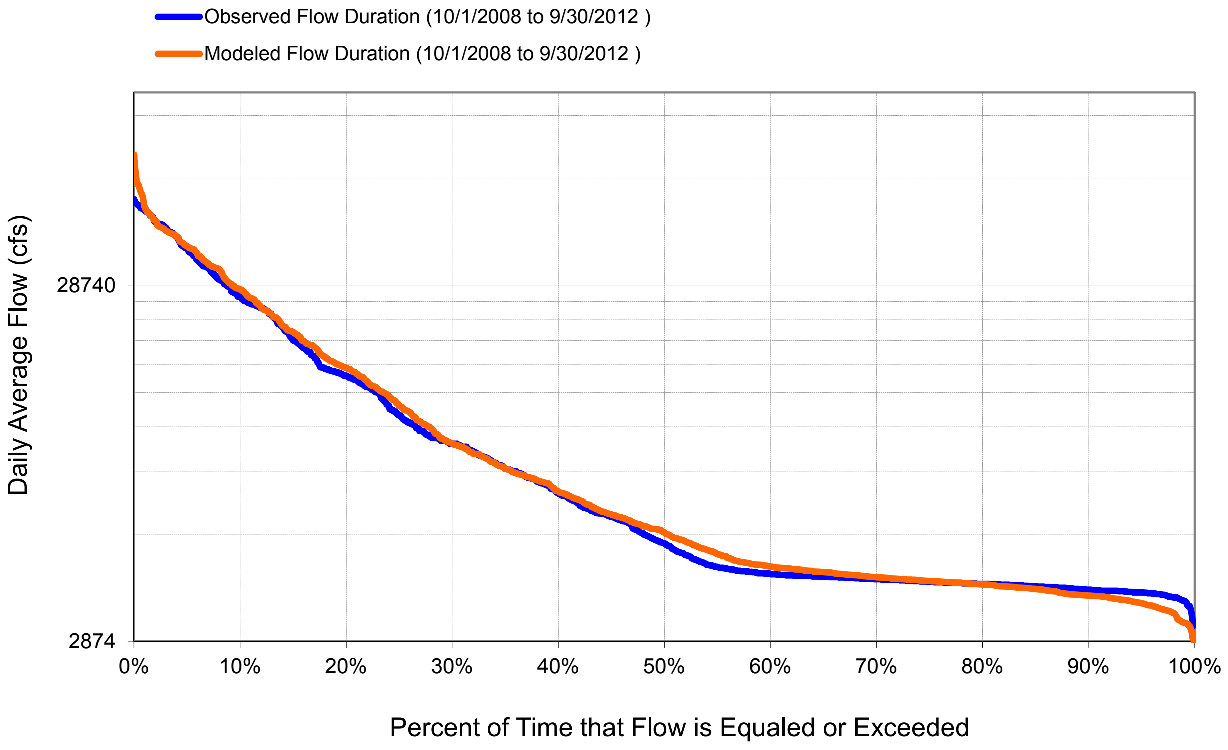


Figure 48. Calibration Observed and Modeled Flow-Duration, USGS 12369000 Flathead River near Bigfork, MT.

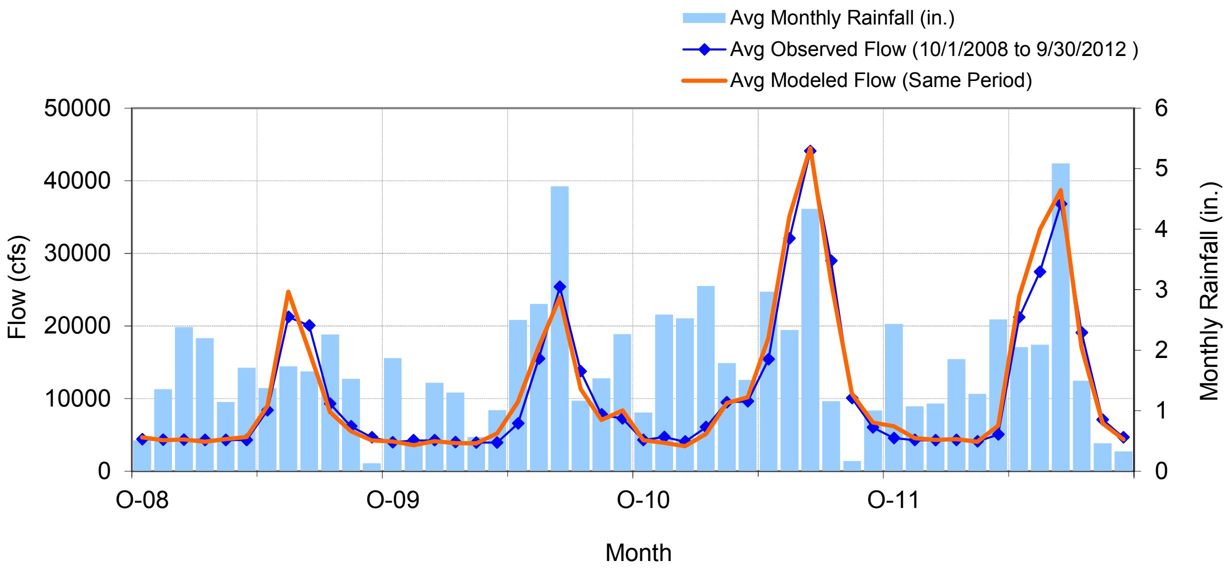


Figure 49. Calibration Time Series of Observed and Modeled Monthly Flows and Monthly Rainfall, USGS 12369000 Flathead River near Bigfork, MT.

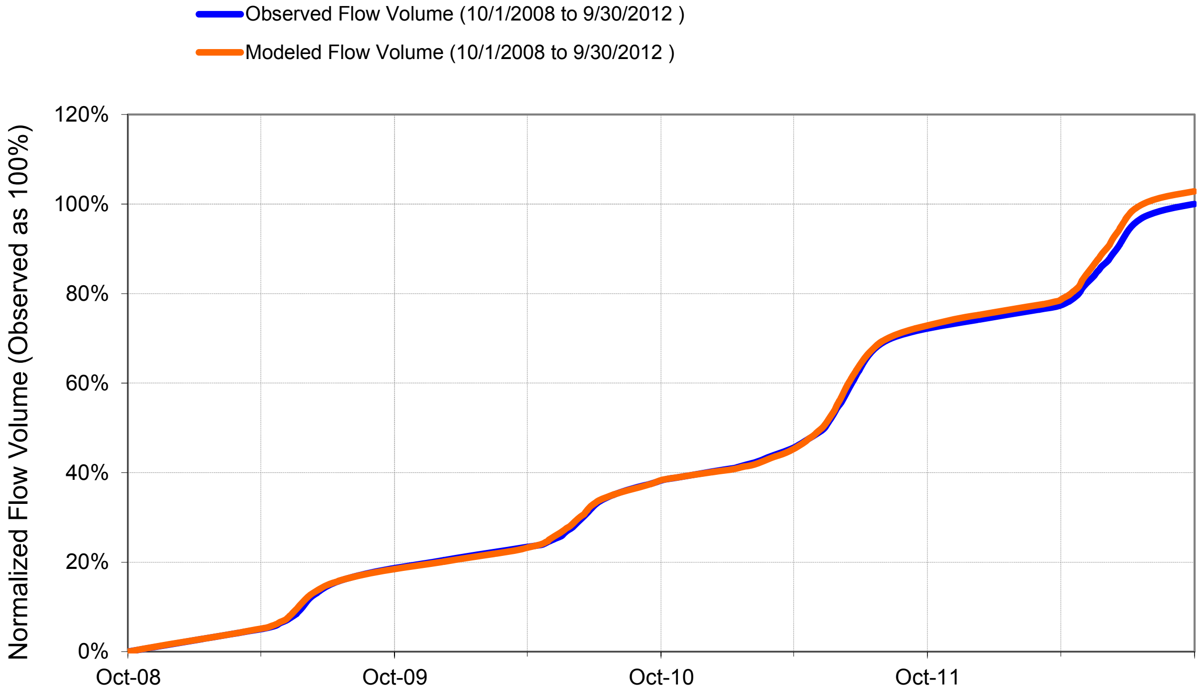


Figure 50. Calibration Cumulative Observed and Modeled Flow Volume, USGS 12369000 Flathead River near Bigfork, MT.

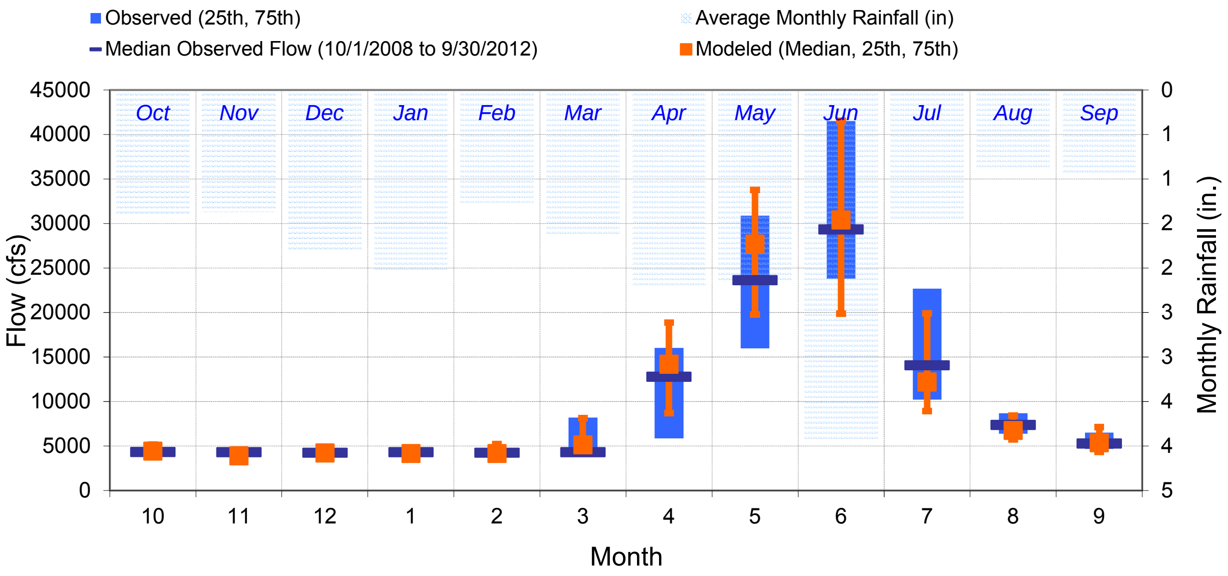


Figure 51. Calibration Observed and Modeled Monthly Flow Distributions with Monthly Rainfall, USGS 12369000 Flathead River near Bigfork, MT.

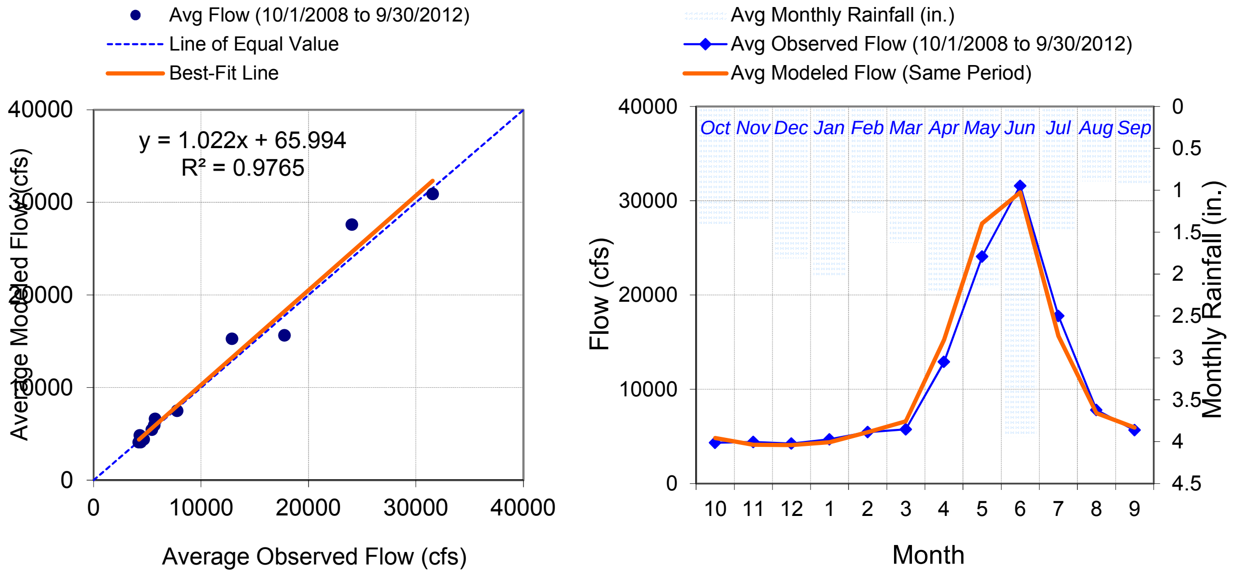


Figure 52. Calibration Observed and Modeled Monthly Average Flow with Monthly Rainfall, USGS 12369000 Flathead River near Bigfork, MT.

3.3 WATER QUALITY CALIBRATION

The model was calibrated for water quality once the hydrologic calibration was complete. Many components of the water quality model were established during hydrology modeling. The water quality model included both point and nonpoint source contributions for nitrogen, phosphorus, and sediment. Pollutant loadings from point sources were represented by developing direct input time series as discussed in **Section 2.5**. Nonpoint source pollutant loadings were represented by build-up and wash off algorithms and by assigning nutrient concentrations to the interflow and groundwater flow paths. Nutrients in the stream experienced dilution, accumulation, assimilation, biochemical cycling, and transport downstream and out of the watershed. Sediment in the stream experienced deposition, scour, and transport downstream and out of the watershed.

As provided in the QAPP (Tetra Tech, 2012), general performance targets for water quality simulation with HSPF/LSPC are also provided by Donigian (2000) and are shown in **Table 30**. These are to be calculated from observed and simulated daily values, and should only be applied in cases where there are a minimum of 20 observations. Model performance is deemed acceptable where a performance evaluation of “good” or “very good” is attained. Similar to hydrology, to aid in the presentation of the model performance results, a table cell color code scheme has been used (**Table 30**).

Table 30. Performance Targets for LSPC Water Quality Simulation (Magnitude of Annual and Seasonal Relative Average Error (*RE*) on Daily Values)

Model Component	Very Good	Good	Fair	Poor
1. Suspended Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%
2. Nutrients	≤ 15%	15 - 25%	25 - 35%	> 35%

3.3.1 Available Monitoring Data

More than 1,000 of the nearly 3,000 sample locations in the Flathead Lake basin have nutrient and sediment monitoring data. However, much of the nutrient and sediment data were collected before the selected model period and are not likely appropriate given the current land use configuration in the model (i.e., they are not coincident with the land use being modeled nor the current extent of development in the watershed). Additionally, many sample locations only include a few samples. For example, total phosphorus data are reported at 546 sample locations, but samples from 338 locations were collected prior to the year 2000. Only 22 of the 546 sample locations have more than 10 samples collected between the years 2000 and 2012.

Fifteen locations were selected for water quality calibration based, in part, upon the number of nutrient and sediment samples collected between the years 2000 and 2012. The following were also considered for the selection of sample locations for water quality site calibration: (1) availability of monitored flow data at the water quality sample location, (2) the spatial distribution and representativeness of the sample locations, and (3) the size of the watersheds draining to the sample locations. **Table 31** presents the water quality calibration sample locations. The spatial distribution of the calibration gages is shown in **Figure 53**.

Table 31. Water Quality Sample Sites Used for the Flathead Lake Watershed LSPC Model

Site ID	Site Name	TP	TN or TPN	TSS or SSC	Period of Record Used
12355000	NFFR at British Columbia	54	44	54	5/21/2003 - 8/8/2012
12355500	NFFR near Colombia Falls, MT	25	14	25	5/21/2003 - 8/25/2008
12358500	MFFR near West Glacier, MT	24	15	24	5/20/2003 - 8/5/2008
12365700	Stillwater River at Lawrence Park at Kalispell, MT	30	20	30	3/28/2007 - 8/26/2010
12366080	Whitefish River near mouth at Kalispell, MT	30	20	29	3/28/2007 - 8/26/2010
12367800	Ashley Creek at Kalispell, MT	20	20	20	3/8/2007 - 8/26/2008
12363000	Flathead River at Columbia Falls, MT	46	46	46	3/27/2002 - 8/8/2012
12369000 [a]	Flathead River near Bigfork, MT	38	20	38	3/29/2007 - 8/7/2012
12370100	Swan River above dam near Bigfork, MT	25	6	25	6/6/2007 - 8/25/2010
482518113420101	Coal Creek near West Glacier, MT	93	101[b]	88	12/20/2003 - 8/31/2007
482520113420201	Pinchot Creek near West Glacier, MT	90	102[b]	86	12/20/2003 - 8/30/2007
FBC05003	Ashley Creek	102	102	15	10/3/2002 - 4/23/2009
FBC05012 [a]	Flathead River mainstem at Holt	148	148	58	9/12/2002 - 3/14/2012
FBC06009	Swan River	107	107	44	10/3/2002 - 6/17/2007
SRSF01	Goat Creek	38	38[b]	38	5/14/2003 - 6/24/2005
STSF05	Middle Swift Creek	123	102[b]	124	5/12/2003 - 6/20/2012

MFFR = Middle Fork Flathead River; NFFR = North Fork Flathead River

a. USGS gage 12369000 and FLBS site FBC05012 are co-located.

b. Sample count is for nitrate; TN data were not available.

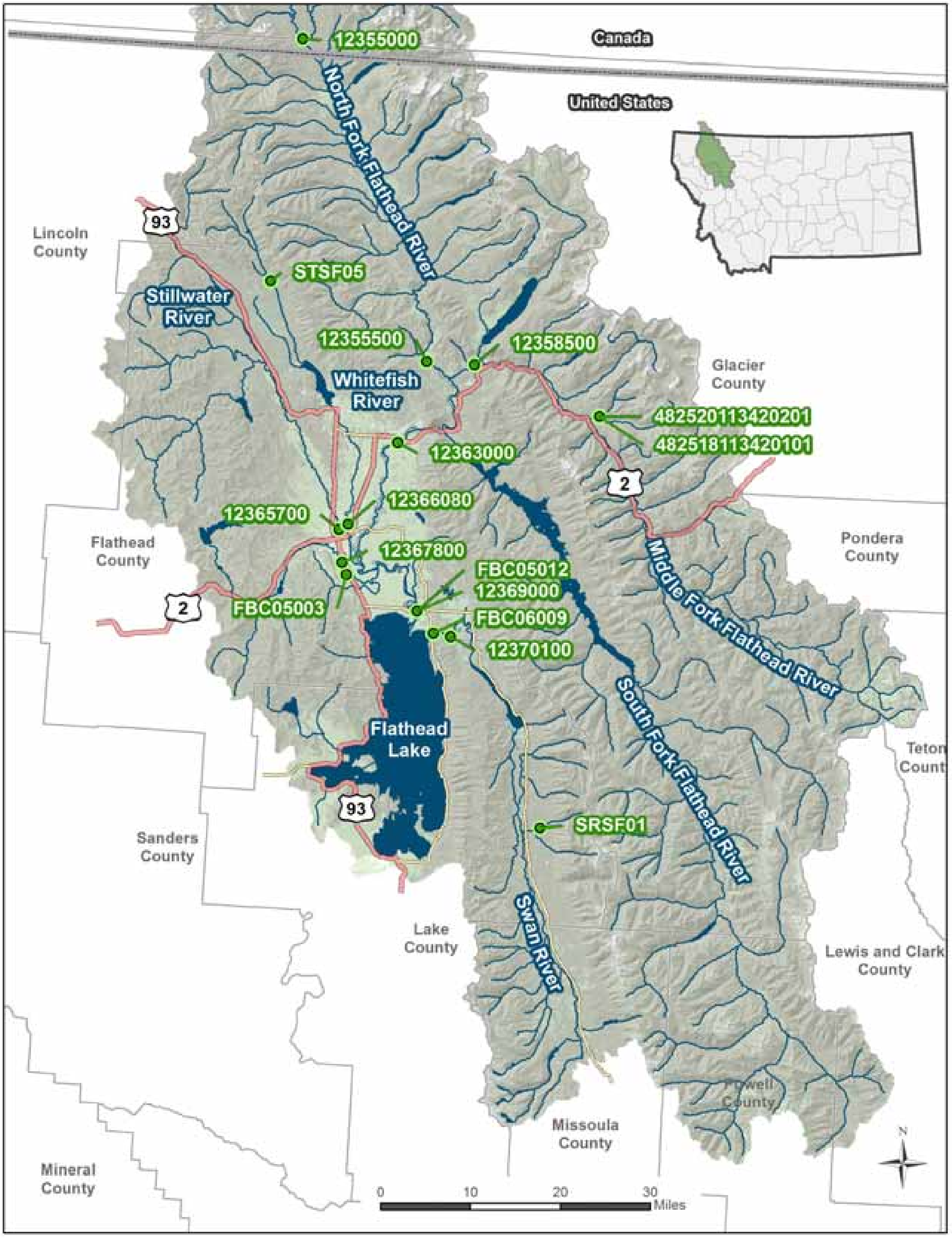


Figure 53. Location of Hydrology Calibration Stations in the Flathead Lake Watershed Model.

3.3.2 Key Parameters and Adjustments

The following subsections describe the key model parameters that were adjusted during model calibration.

3.3.2.1 Sediment

LSPC models sediment by using algorithms identical to those in HSPF. The LSPC/HSPF modules used to represent sediment include SEDMNT (production and removal of sediment from a pervious land segment), SOLIDS (accumulation and removal of solids by runoff and other means from the impervious land segment), and SEDTRN (transport, deposition, and scour of inorganic sediment in free-flowing reaches and mixed reservoirs). A detailed description of relevant sediment algorithms is presented in the HSPF Version 12 User's Manual (Bicknell et al. 2004). In short, sediment is detached from the soil matrix on pervious lands via raindrop impact and then subsequently the detached sediment is carried to the stream as a function of flow depth on the land surface. For impervious land, buildup and removal rates are applied and solids are washed into the stream via impervious land surface flow during rain events. Once the sediment and solids are in the stream they either deposit or scour dependent on the conditions in the water column for each reach.

The approach for sediment calibration generally follows the guidance of BASINS Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF (USEPA, 2006) and Sediment Calibration Procedures and Guidelines for Watershed Modeling (Donigian et.al., 2003). Calibration for sediment is carried out after hydrologic calibration because sediment production and transport is dependent on hydrology. Note that this means that any uncertainty in the hydrologic calibration will propagate into the sediment simulation.

Suspended sediment concentrations observed in-stream are the result of both upland and channel processes, so there are multiple sets of parameters that control results. The general strategy for sediment calibration, following the above referenced literature, consists of the following steps:

1) Specify initial upland parameter values based on external information (e.g., soils data).
2) Adjust upland sediment erosion to approximate unit loading calibration targets available from other studies.
3) Examine sediment balance in each model reach to ensure qualitatively reasonable representations.
4) Adjust instream/channel parameters to match observed sediment and TSS concentrations and loads.

A series of diagnostic graphs were prepared for both load and concentration, with a focus on patterns across the range of flows, and comparisons of paired simulated-observed values. Select graphs are shown here, and all of the graphs for all of the calibration stations are available in **Appendix H**.

KRER and JRER are key factors for soil detachment on pervious surfaces during rainfall events. KRER is the coefficient in the soil detachment equation and JRER is the exponent in the soil detachment equation. In the LSPC model these parameters are sensitive chiefly to soil erodibility and slope. Fixed values of SMPF and monthly COVER were also used. COVER is the dimensionless factor accounting for the effects of cover on the detachment of soil particles, and SMPF is the dimensionless management practice factor. Values were based on literature guidance and professional experience, and are analogous to their USLE equivalents. Other parameters were varied to achieve initial HRU loading rate goals consistent with land use monitoring studies. The remaining pervious land parameters control how much of the detached sediment reaches the stream. Impervious land parameters control how quickly sediment builds up on surfaces, a factor that sets an asymptote for buildup, and a delivery factor for transport to streams.

LSPC simulates sediment delivery from the land surface in a single class; this is partitioned at the edge of the reach into sand, silt, and clay fractions. The fractional distribution in part reflects the parent soils in a watershed; however, it is also strongly affected by transport processes. Specifically, the fine fraction is enriched relative to the total sediment load. The specification of fractionation of eroded material in LSPC is an imprecise art, subject to revision during model calibration. Guidance (USEPA, 2006 and Donigian et.al., 2003) recommends only that "the fractions should reflect the relative percent of the surface material available for erosion in the surrounding watershed, but should also include an enrichment factor of silt and clay to represent the likelihood of these finer materials reaching the channel." Guidance provides an example where the sand fraction is reduced to one-third of its value in the watershed's surface soils. The speciation of sediment delivery in the LSPC model was configured with approximately 40 percent sand, 58 percent silt, and 2 percent clay with small variability dependent on the underlying land use classification. The speciation was initially assigned based on best professional judgment and then further refined during sediment calibration

TSS or SSC observed instream during storm events are often not a direct reflection of upland loads, but instead represent the net exchange from both the uplands and sediment with the channel bed. In the absence of sediment particle analyses of the bed material, based on best professional judgment the initial reach conditions were set to a composition of 30 percent sand, 45 percent silt, and 25 percent clay. Once the total sediment delivery was calibrated, the reach parameters were adjusted to match the relationship between flow and load. Because LSPC is a one-dimensional stream model, shear stresses estimated by the model would be only loosely related to actual channel stresses. Therefore, critical shear stress parameters are determined by calibration.

For simulation of the movement of the sand fraction, the power function option was used in LSPC. Movement of cohesive sediments (silt and clay) is controlled by the specification of critical shear stresses for deposition and scour and by the specification of fall velocities and maximum re-suspension rates. During baseflow conditions, there is minimal scour within stream reaches; however, suspended sediment concentrations in most streams do not go to zero during such periods. This reflects a combination of fine sediment loading in baseflow (groundwater discharge) and other non-flow related processes that contribute sediment, such as animal activity, and local re-suspension in areas of turbulent flow. To represent this phenomenon in the model, a fine sediment concentration of 0.5 mg/L was assigned to the groundwater discharge to the reaches.

3.3.2.2 Nitrogen and Phosphorus

LSPC models nutrients, plankton and benthic algae by using algorithms identical to those in HSPF. The LSPC/HSPF modules used to represent nutrients and plankton include PQUAL (quality constituents from pervious surfaces using simple relationships), IQUAL (wash-off of quality constituents from impervious surfaces using simple relationships), NUTRX (primary inorganic nitrogen and phosphorus balances), and PLANK (plankton populations and associated reactions). A detailed description of relevant nutrient algorithms is presented in the HSPF (version 12) User's Manual (Bicknell et al., 2004).

Accumulation and wash-off rates play an important role in the determination of nonpoint source loadings to a water body. The watershed model must appropriately represent the spatial and temporal variability of hydrological characteristics within a watershed. It must also appropriately represent the rate at which nutrient components build-up between rain events and wash off during rain events. Key water quality parameters include initial storage, wash-off and scour potency, accumulation rates, and asymptotic maximum storage amounts. The water supplied to a stream from groundwater and through interflow also plays an important role in loading to a water body. The Flathead LSPC model is configured to supply groundwater and interflow concentrations, by hydrologic soil group/elevation (DEFID) and land use (DELUID), by month. The accumulation and wash-off and interflow strongly influence peak flow water quality while groundwater reflects base flow water quality.

Biochemical in-stream processes play an important role on nutrient concentrations spatially and temporally. Biochemical processing can also have a large influence on dissolved oxygen and ultimately water quality. The watershed model should appropriately represent some of the major biochemical processes occurring within in the stream, including dissolved oxygen balances, organic and inorganic nutrient balances, and plankton populations. To accurately represent biochemical processing, temperature must be modeled because all transformation rates are temperature dependent. Key processes for oxygen include: benthic oxygen demand and reaeration. Key processes for nutrients include: nitrification, denitrification, sediment adsorption/desorption of ammonia and ortho-phosphorus, assimilation, and plankton respiration.

The approach for nutrient calibration is similar to that of sediment, but with fewer steps. Calibration for nutrients is carried out after sediment calibration, because 1) phosphorus in this LSPC model is simulated as sediment-bound for pervious land runoff and 2) orthophosphate and ammonia experience sediment adsorption and desorption during stream transport. Note that this means that any uncertainty in the sediment calibration will propagate into the nutrient simulation.

Nutrient concentrations observed in-stream are the result of both upland and channel processes, so there are multiple sets of parameters that control results. However, the magnitude difference between storm event and low flow concentrations is not nearly as great as for sediment. The general strategy for nutrient calibration consists of the following steps:

1) Specify initial upland parameter values based on external information, if known, for TN and TP.
2) Adjust upland parameter to approximate nutrient unit loading calibration targets available from other studies.
3) Partition upland total nutrients into species at the edge of stream.
4) Compare to instream monitoring data and adjust upland and reach parameters to obtain as good a fit as is practicable.

A series of diagnostic graphs was prepared for both load and concentration, with a focus on patterns across the range of flows, and comparisons of paired simulated-observed values. Select graphs are shown here in the main report, and all of the graphs are available in **Appendix H**.

The LSPC model was configured to simulate surface washoff of phosphorus from pervious land using a potency factor approach. Phosphorus load is estimated as a fraction of sediment yield (expressed as a potency factor with units of pounds of phosphorus per ton of sediment). Note that because phosphorus movement is a function of sediment movement, the sediment delivery ratio is automatically incorporated into the estimate of phosphorus loading. During periods without surface runoff, instream phosphorus concentrations might be dominated by point sources, but also are affected by dissolved inorganic phosphorus transported in interflow and groundwater. Concentrations for interflow and groundwater were set to values consistent with low flow monitoring data (see Appendices D and E).

In contrast to phosphorus, inorganic nitrogen is highly soluble and loading in surface runoff occurs independent of sediment movement. Therefore, nitrogen loading from pervious surfaces is represented via a buildup-washoff process in which the user specifies a rate of accumulation, an accumulation limit, and a flow rate sufficient to remove 90 percent of the accumulated material. Wet and dry deposition of nitrogen were included as separate inputs, as discussed in **Section 2.8**. Nitrogen is also present in interflow and groundwater. As was done with phosphorus, concentrations for interflow and groundwater were set to values consistent with low flow monitoring data (see Appendices D and E). In contrast with phosphorus, variation by HRU type was incorporated and followed a hierarchy of land uses most likely to have higher concentrations of nitrogen in ground water to land uses least likely to have higher concentrations of nitrogen in groundwater. For example, crop and pasture land are parameterized with larger concentrations of nitrogen in groundwater than forest land.

After the land based simulation of the total constituents were calibrated to the approximate nutrient unit loading calibration targets, a flow path associated partitioning was incorporated as the nutrients entered into the stream. This partitioning assigned percentages of each constituent making up the total to the land based simulated total value. TN was broken down into nitrate plus nitrite (NOx), ammonia (TAM), and organic nitrogen (ORN), and TP was broken down into orthophosphate (PO4), organic phosphorus (ORP), and sediment adsorbed orthophosphate (SPO4). The associated flow paths were impervious surface flow, pervious surface flow, pervious interflow, and pervious groundwater flow. The partitioning by flow path was adjusted during calibration to obtain a better fit between simulated and observed nutrient species.

The instream biochemical cycling parameters were supplied default values from the HSPF (version 12) User's Manual (Bicknell et al., 2004). A few of the parameters were modified (e.g., nitrification rate of ammonia and nitrification rate of nitrite) to be more consistent with *Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling* (USEPA, 1985). All streams within the model were parameterized identically for the biochemical cycling parameters (see **Appendices D** and **E**).

The Flathead Lake watershed has numerous lakes simulated within the modeling domain. LSPC is a one-dimensional model and assumes that everything is vertically, horizontally, and longitudinally mixed. For simulating plankton growth LSPC uses the average depth of the reach for light extinction calculations. Many of the lakes are very deep so the algorithms were producing no growth of plankton and therefore no nutrient assimilation in the lakes. To address this, both of LSPC's light extinction coefficients were set to zero in deep lengths to allow algal growth in the volume fraction corresponding to the surface layer. Plankton growth was subsequently controlled by setting the chlorophyll a concentration above which high algal death rate occurs (claldh) to an appropriate ratio of the stream claldh which reflected the portion of the lake volume that coincides with the photic zone.

3.3.3 Water Quality Calibration Results

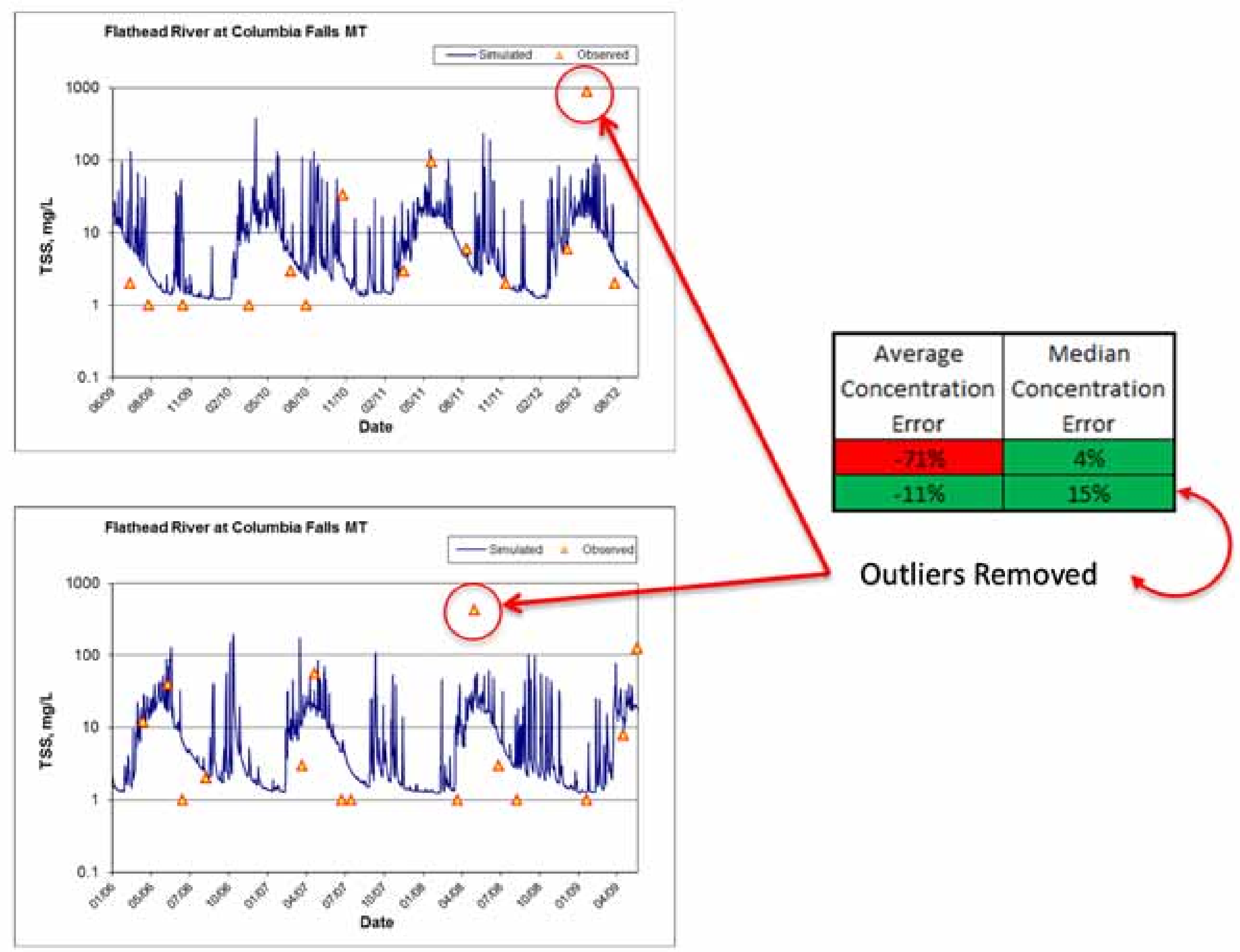
Table 32 summarizes the water quality calibration results. Only median errors have been shown because, in many cases, average errors appear to be strongly influenced by “outliers” in the observed data sets. For example, **Figure 54** shows an example where two high TSS samples were removed from the observed dataset and the average concentration error between simulated and observed went from being *poor* at 71 percent low to *very good* at only 11 percent low. LSPC Source load results (annual unit area loads per land use) are presented with available literature data and results from regional and local studies in **Section 3.4**.

Model performance for TSS was generally good to very good. The daily paired median concentration error was rated as *very good* (12 stations) and *good* (4 stations). The daily paired median load error was rated as *very good* (15 stations), and one station was rated *poor*. The station with the *poor* rating (Goat Creek) has a *good* rating for concentration so the *poor* rating is mostly attributable to simulated and observed flow differences on days when samples were collected at this location.

For TN the daily paired median concentration error ratings varied: *very good* (6 stations), *good* (5 stations), *fair* (2 stations), and *poor* (3 stations). The daily paired median load error ratings also varied: *very good* (10 stations), *good* (2 stations), *fair* (3 stations), and *poor* (1 station). Two of the stations (Coal Creek and Middle Swift Creek) rated as *poor* for concentration only have nitrate plus nitrite data and have opposite responses with one being high and one being low. There are two other stations that only have nitrate plus nitrite data and both of these stations are rated *very good*. The other station (NFFR at British Columbia) rated as *poor* for concentration is in the headwater areas near the Canadian border and it is hypothesized that imprecise weather information may be affecting the model in that area. One station (Middle Swift Creek) rated as *poor* for load because of concentration also being poor.

For TP the daily paired median concentration error was rated as *very good* (11 stations), *good* (3 stations), and *poor* (2 stations). The daily paired median load error was also rated *very good* (11 stations), *good* (3 stations), and *poor* (2 stations). Both stations rated as poor for concentration are downstream of Swan Lake and it is theorized the one dimensional representation of Swan Lake is causing the high TP simulation. The two stations rated as poor for load (Ashley Creek and Goat Creek) are due to flow as discussed above in the TSS section for Goat Creek.

A sub-watershed model was completed for Ashley Creek that provided improved water quality calibration and is presented in Appendix A.



Average Concentration Error	Median Concentration Error
-71%	4%
-11%	15%

Figure 54. TSS Outlier Removal for Flathead River at Columbia Falls, MT.

Table 32. Summary of Water Quality Calibration Results

Site ID	Site Name	TSS		TN		TP	
		Conc. Median Error	Load Median Error	Conc. Median Error	Load Median Error	Conc. Median Error	Load Median Error
12355000	NFFR at British Columbia	1%	0%	204%	32%	-6%	-1%
12355500	NFFR near Colombia Falls, MT	9%	1%	17%	1%	-15%	-1%
12358500	MFFR near West Glacier, MT	3%	0%	-17%	-5%	-13%	-1%
12365700	Stillwater River at Lawrence Park at Kalispell, MT	21%	2%	10%	7%	4%	0%
12366080	Whitefish River near mouth at Kalispell, MT	-20%	-6%	34%	25%	25%	6%
12367800	Ashley Creek at Kalispell, MT	-20%	18%	-22%	34%	17%	102%
12363000	Flathead River at Columbia Falls, MT	4%	1%	6%	1%	1%	0%
12369000*	Flathead River near Bigfork, MT	5%	1%	7%	2%	-2%	0%
12370100	Swan River above dam near Bigfork, MT	-20%	-6%	-10%	-5%	56%	25%
482518113420101**	Coal Creek near West Glacier, MT	1%	2%	-43%	-18%	0%	4%
482520113420201**	Pinchot Creek near West Glacier, MT	0%	0%	10%	5%	9%	15%
FBC05003***	Ashley Creek	-4%	-5%	-25%	-26%	-2%	0%
FBC05012*	Flathead River mainstem at Holt	15%	10%	23%	9%	6%	1%
FBC06009	Swan River	-13%	-6%	31%	12%	40%	16%
SRSF01**	Goat Creek	26%	48%	-14%	6%	13%	56%
STSF05**	Middle Swift Creek	-15%	-10%	55%	35%	13%	3%

MFFR = Middle Fork Flathead River; NFFR = North Fork Flathead River

* USGS gage 12369000 and FLBS site FBC05012 are co-located.

** TN is actually nitrate; TN data were not available.

*** Calibration results for Ashley Creek were improved in a sub-model that are presented in Appendix A.

Note: Error statistics are reported as simulated minus observed therefore negative indicates simulated less than observed.

A detailed analysis of the water calibration at gage 12369000, Flathead River near Bigfork, MT, is provided in the following sections because this gage drains almost the entire modeled area. Water quality calibration results for all stations are provided in **Appendix H**.

3.3.3.1 Sediment

The time series plot in **Figure 55** shows the overall temporal trend and magnitude of the calibration. It is very difficult to get an indication of the goodness of fit from just the time series plots so additional approaches to looking at the same data are employed. Observed and simulated concentrations are plotted against flow (**Figure 56**) and generally show a good overall agreement; however, they also indicate the model may be simulating high in the lower 25 percent of flows and simulating low in the upper 75 percent of flows.

Daily paired observed and simulated concentrations are plotted against one another (**Figure 57**) and show the simulation slightly overestimates low observed concentrations and under estimates high observed concentrations. Daily paired observed and simulated concentration errors are plotted against flow (**Figure 58**) and show the model under predicts concentrations during times of higher flow. Observed and simulated loads are plotted against flow (**Figure 59**) and generally show good agreement but indicate the model slightly overestimates load at low flow and under estimates load at high flow. Daily paired observed and simulated loads are plotted against one another (**Figure 60**) and similar to concentration show the simulation slightly overestimates low observed loads and under estimates high observed loads.

Generally, these graphical results along with the performance statistical summaries (**Table 32**) indicate reasonable and adequate fit for TSS at 12369000, Flathead River near Bigfork, MT.

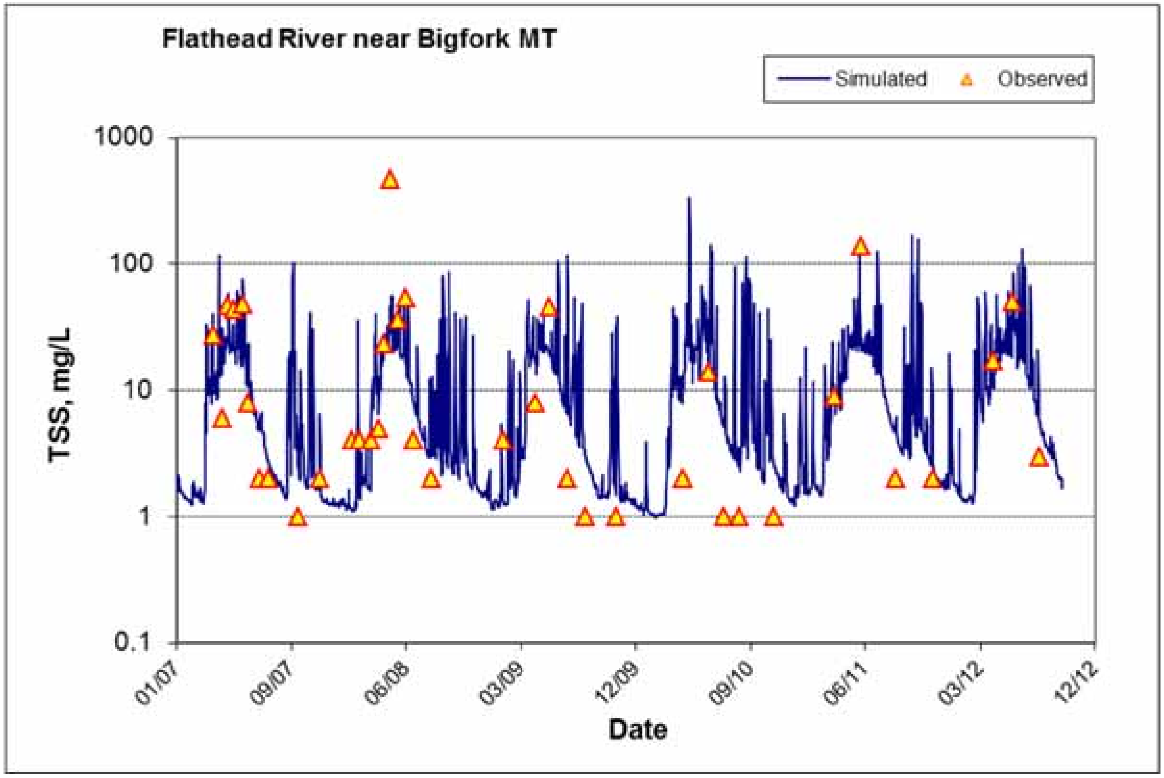


Figure 55. Calibration Observed and Modeled TSS Time series June 2009 through Sept. 2012, USGS 12369000 Flathead River near Bigfork, MT.

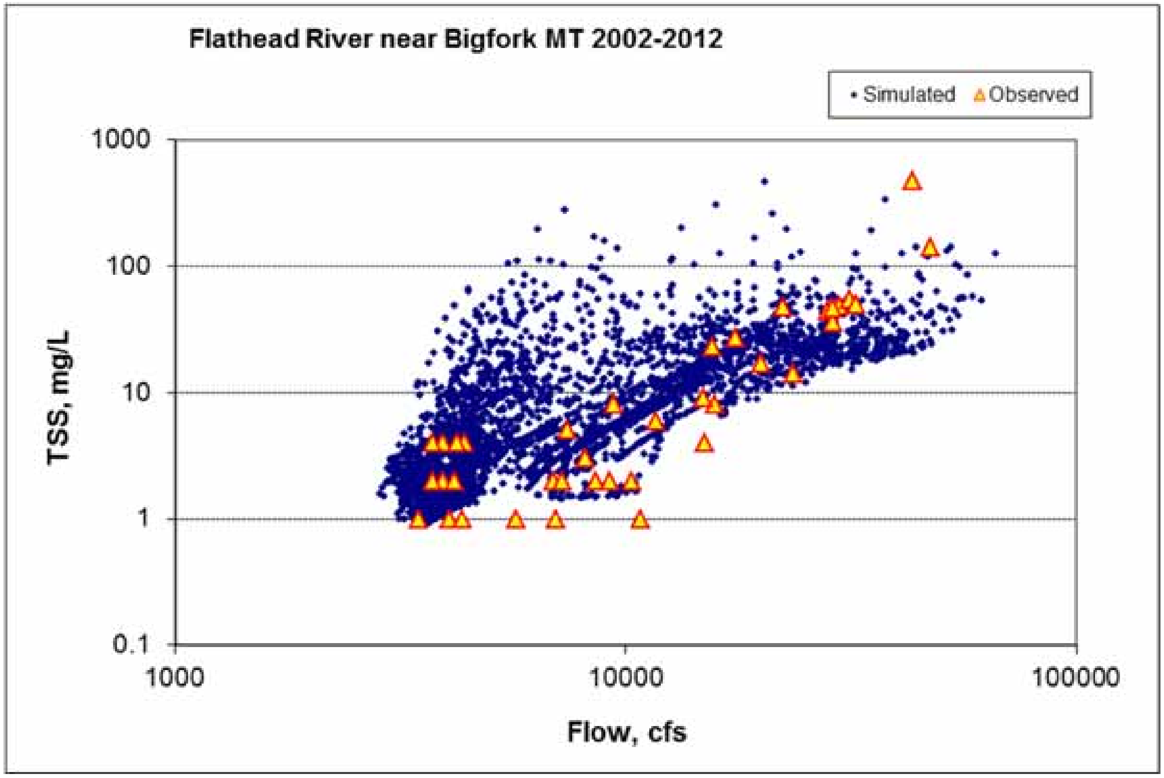


Figure 56. Calibration Observed and Modeled TSS Concentration vs. Flow Regression, USGS 12369000 Flathead River near Bigfork, MT.

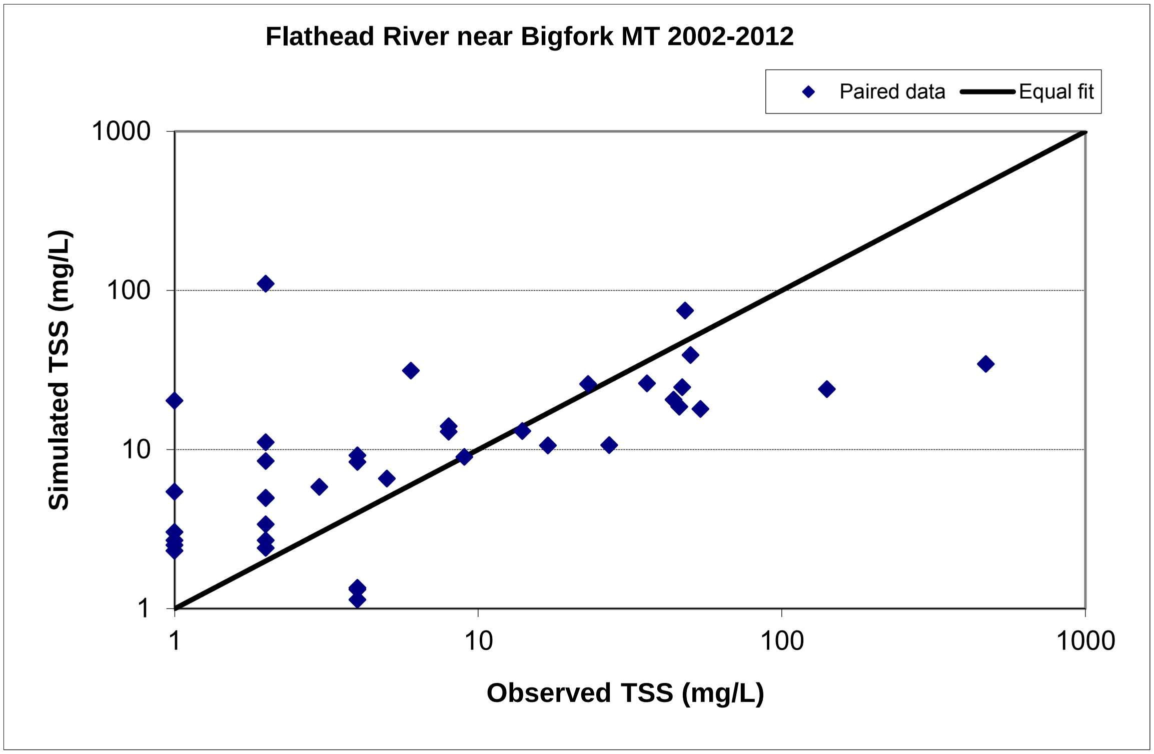


Figure 57. Calibration Observed and Modeled TSS Daily Paired Concentration Regression, USGS 12369000 Flathead River near Bigfork, MT.

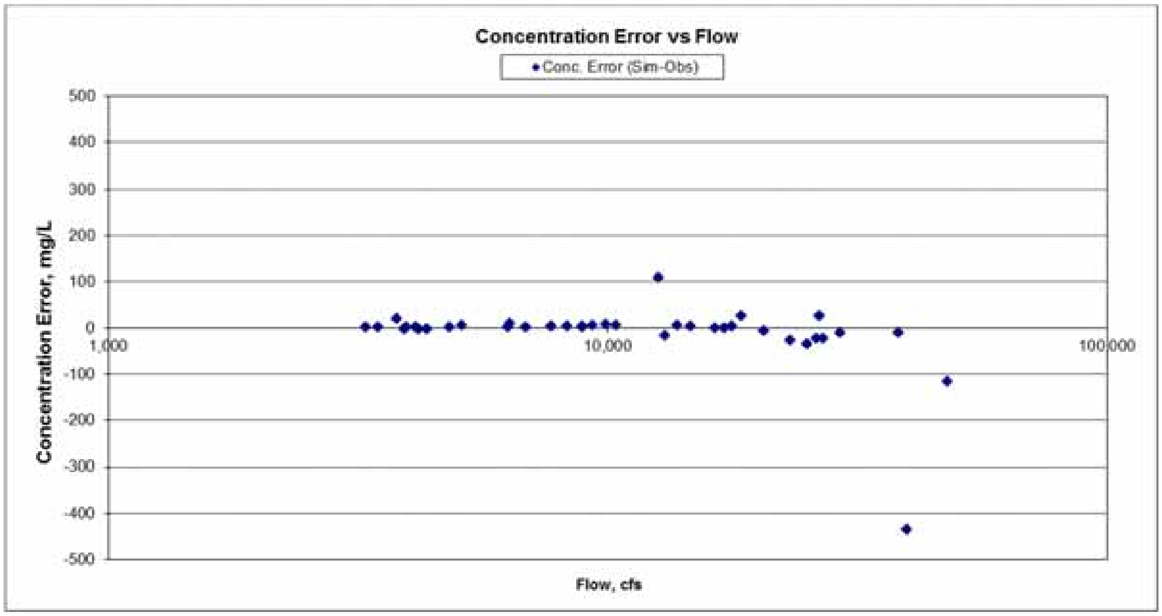


Figure 58. Calibration Observed and Modeled TSS Daily Paired Concentration Error vs. Flow, USGS 12369000 Flathead River near Bigfork, MT.

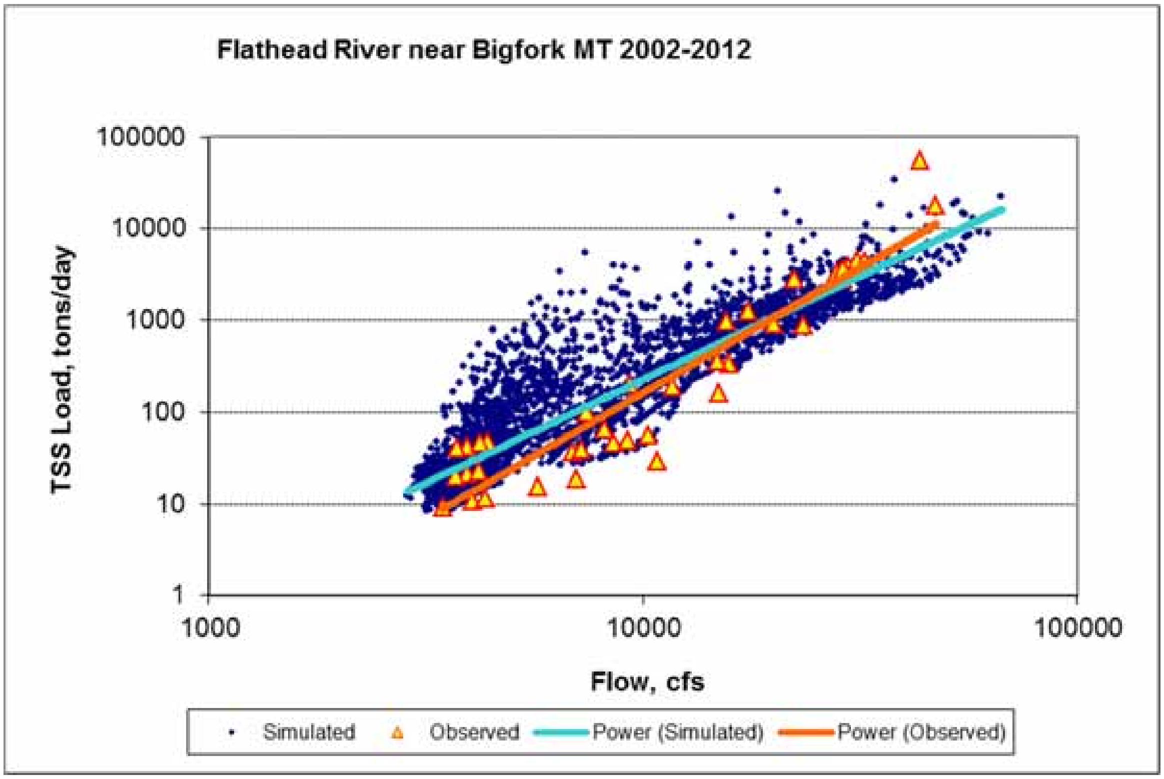


Figure 59. Calibration Observed and Modeled TSS Load vs. Flow Regression, USGS 12369000 Flathead River near Bigfork, MT.

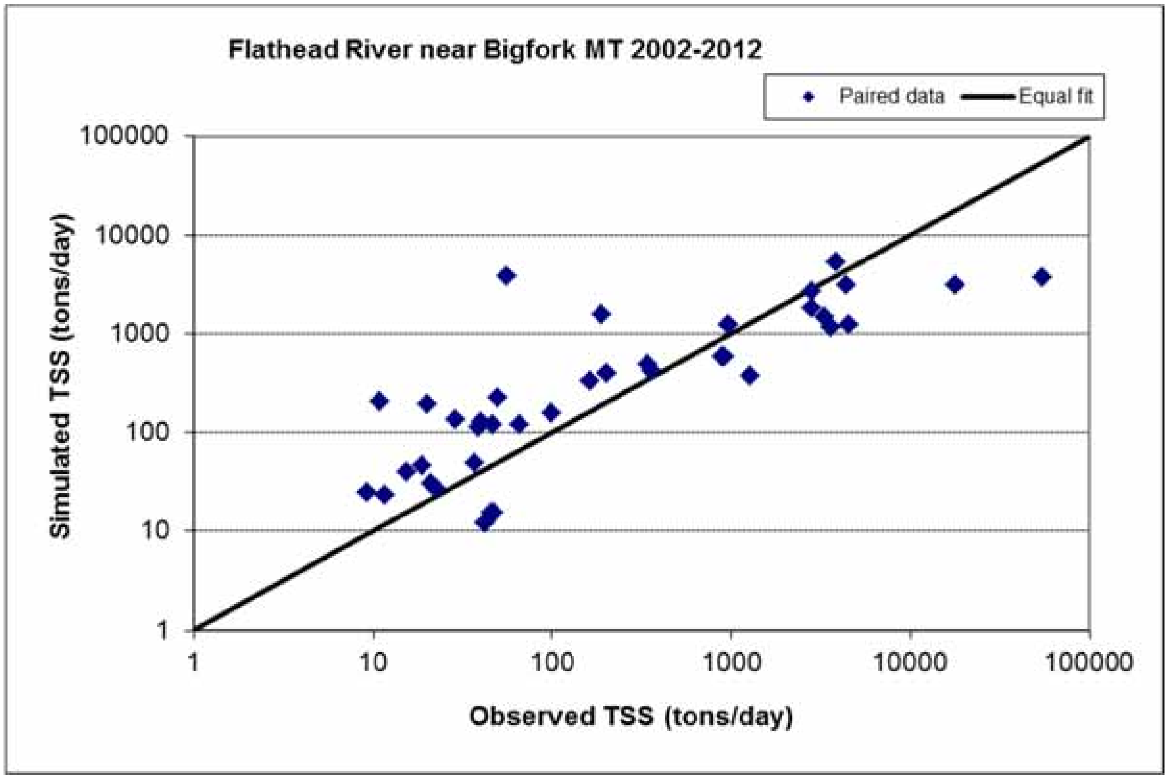


Figure 60. Calibration Observed and Modeled TSS Daily Paired Load Regression, USGS 12369000 Flathead River near Bigfork, MT.

3.3.3.2 Nitrogen

The time series plots in **Figure 61** show the overall temporal trend and magnitude. Observed and simulated concentrations are plotted against flow (**Figure 62**) and generally show a good overall agreement. Daily paired observed and simulated concentrations are plotted against one another (**Figure 63**) and show the simulation has a tendency to slightly over estimate concentration. Daily paired observed and simulated concentration errors are plotted against flow (**Figure 64**), but no definitive trend is apparent. Observed and simulated loads are plotted against flow (**Figure 65**) and generally show good agreement but indicate the model slightly overestimates load at low flow and under estimates load at high flow. Daily paired observed and simulated loads are plotted against one another (**Figure 66**) and similar to concentration the simulation has a tendency to slightly over estimate load.

Generally, these graphical along with the performance statistical summaries (**Table 32**) indicate reasonable and adequate fit for TN at 12369000, Flathead River near Bigfork, MT.

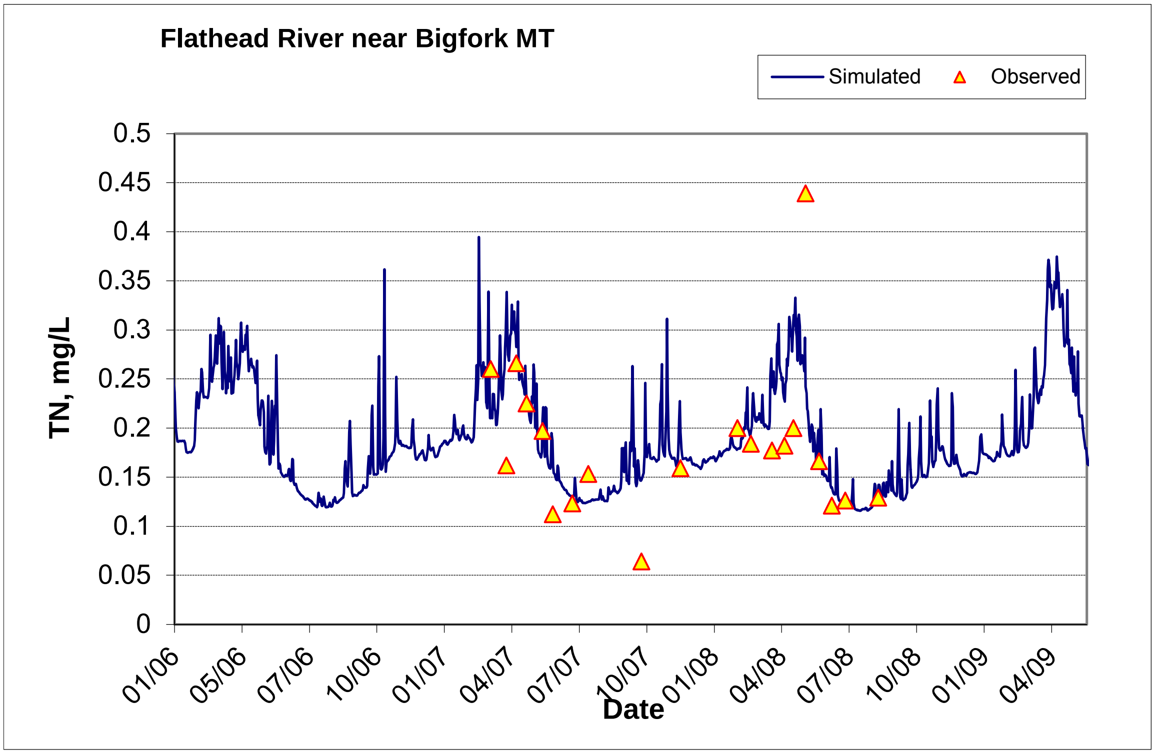


Figure 61. Calibration Observed and Modeled TN Time series Feb. 2006 through May 2009, USGS 12369000 Flathead River near Bigfork, MT.

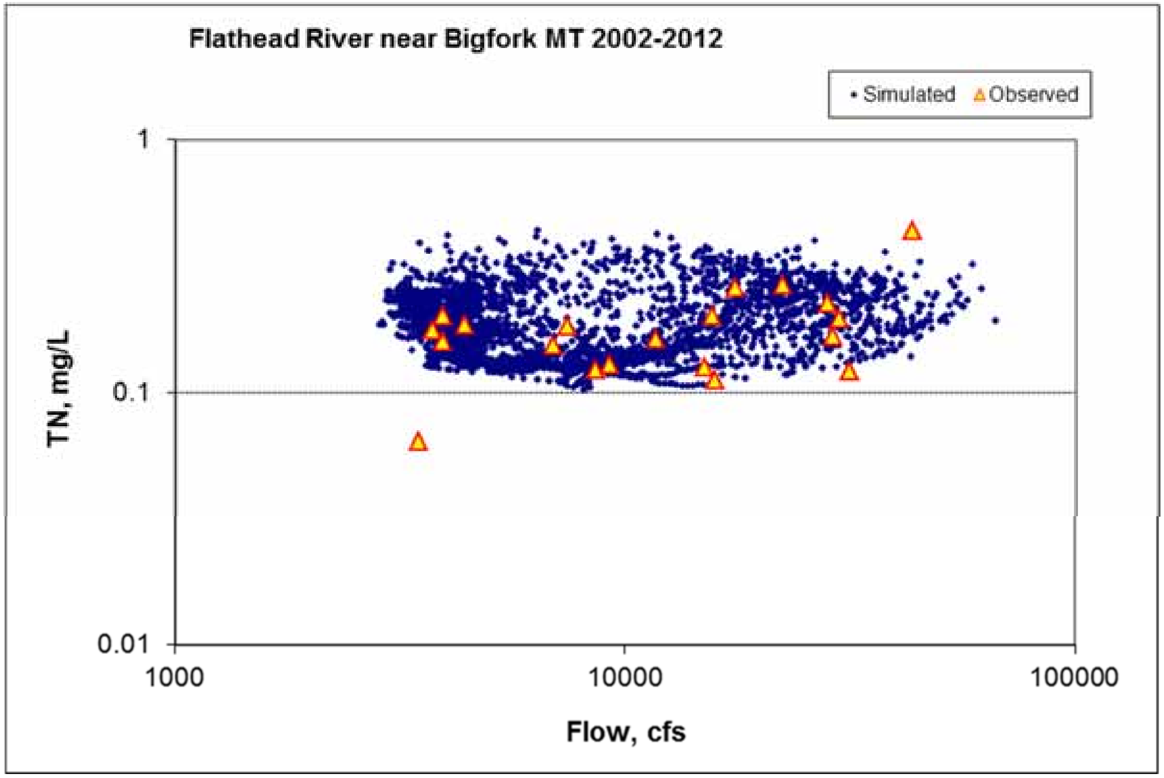


Figure 62. Calibration Observed and Modeled TN Concentration vs. Flow Regression, USGS 12369000 Flathead River near Bigfork, MT.

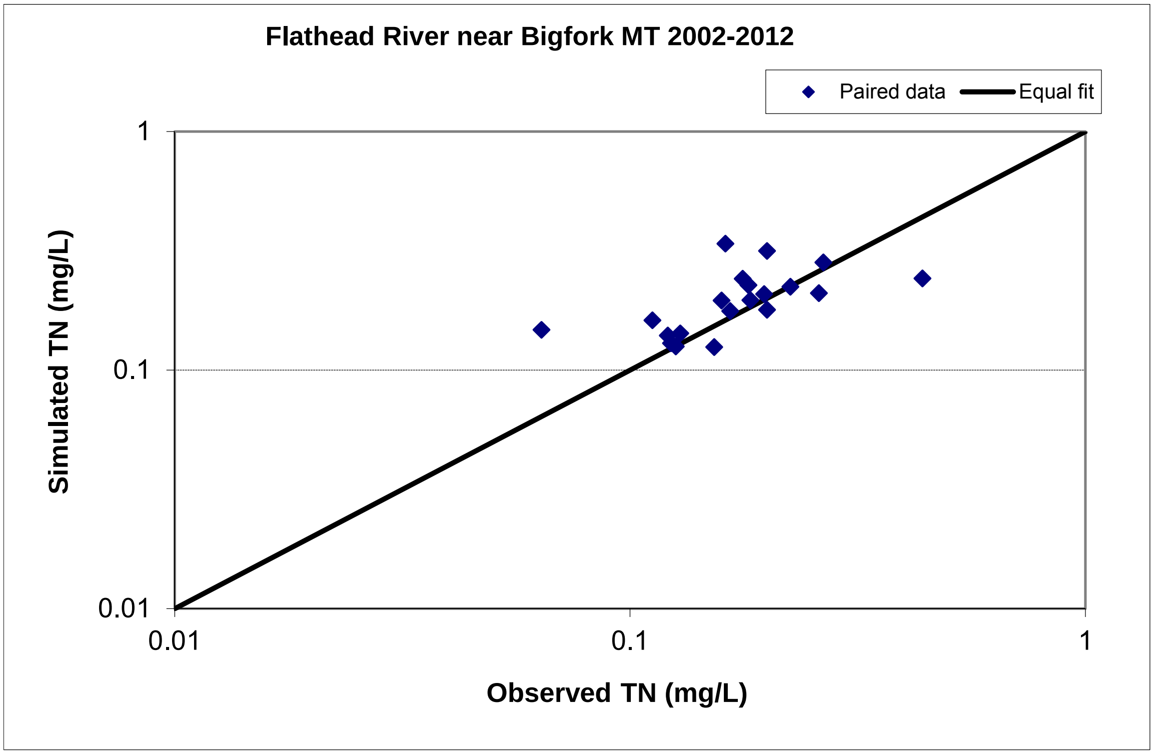


Figure 63. Calibration Observed and Modeled TN Daily Paired Concentration Regression, USGS 12369000 Flathead River near Bigfork, MT.

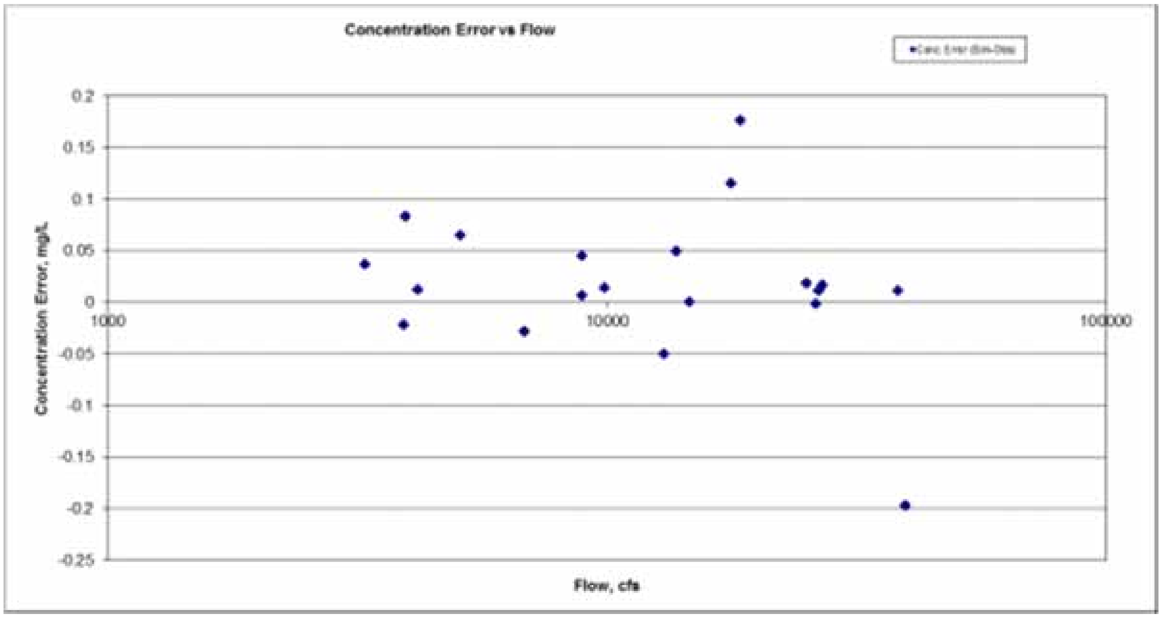


Figure 64. Calibration Observed and Modeled TN Daily Paired Concentration Error vs. Flow, USGS 12369000 Flathead River near Bigfork, MT.

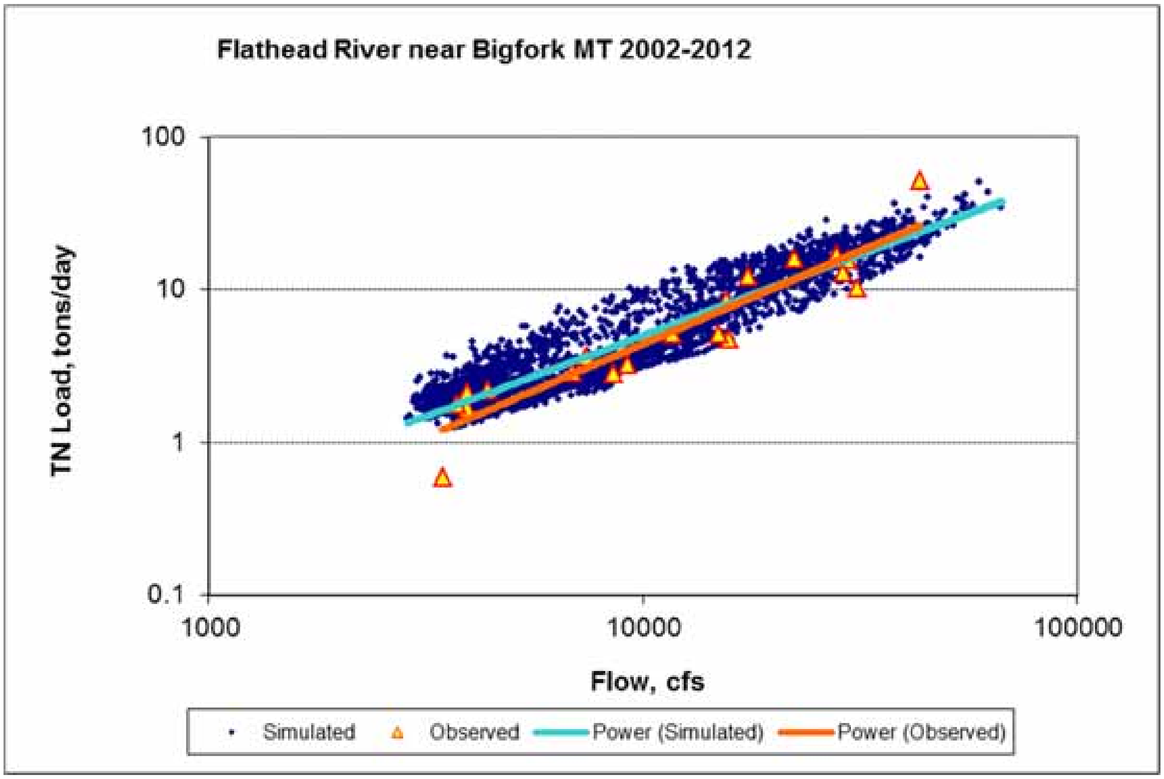


Figure 65. Calibration Observed and Modeled TN Load vs. Flow Regression, USGS 12369000 Flathead River near Bigfork, MT.

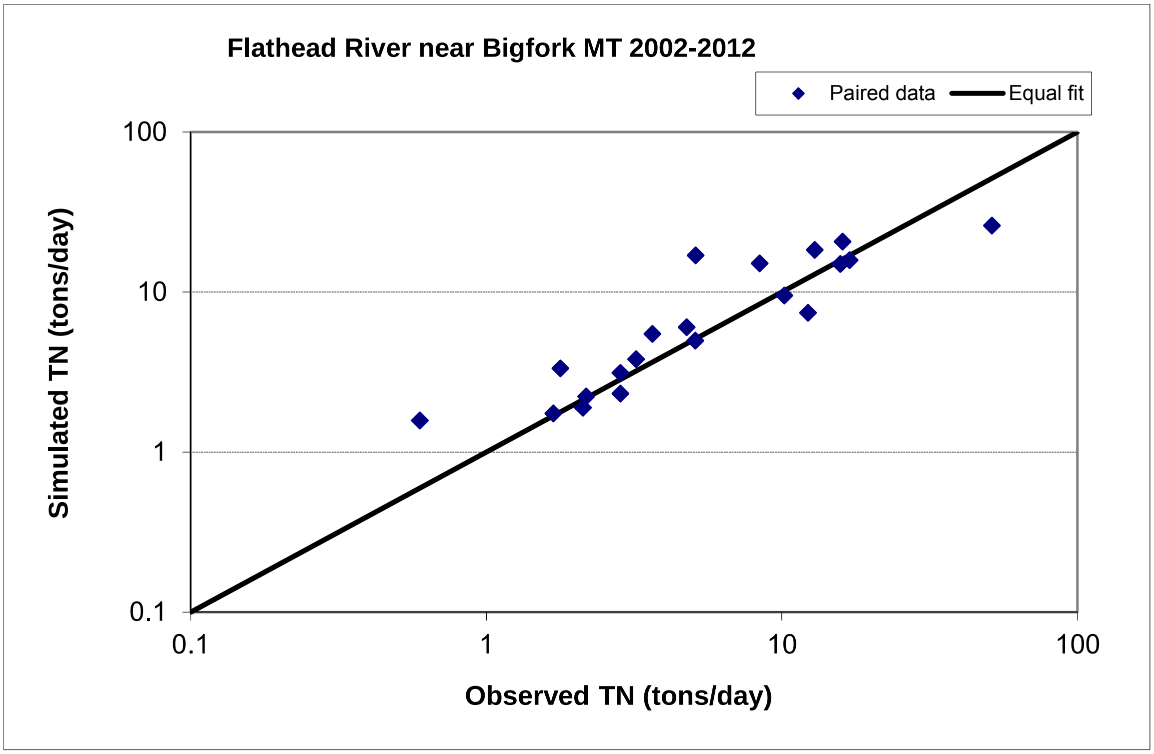


Figure 66. Calibration Observed and Modeled TN Daily Paired Load Regression, USGS 12369000 Flathead River near Bigfork, MT.

3.3.3.3 Phosphorus

The time series plots in **Figure 67** show the overall temporal trend and magnitude of the phosphorus calibration. Observed and simulated concentrations are plotted against flow (**Figure 68**) and generally show a good overall agreement; however, the model may be simulating high in the lower 25 percent of flows and simulating low in the upper 75% of flows. Daily paired observed and simulated concentrations are plotted against one another (**Figure 69**) and show the simulation slightly overestimates low observed concentrations and under estimates high observed concentrations. Daily paired observed and simulated concentration errors are plotted against flow (**Figure 70**) and show the model under predicts concentrations during times of higher flow. Observed and simulated loads are plotted against flow (**Figure 71**) and generally show good agreement but indicate the model slightly overestimates load at low flow and under estimates load at high flow. Daily paired observed and simulated loads are plotted against one another (**Figure 72**) and similar to concentration show the simulation slightly overestimates low observed loads and under estimates high observed loads.

Generally, these graphical along with the performance statistical summaries (**Table 32**) indicate reasonable and adequate fit for TP at 12369000, Flathead River near Bigfork, MT.

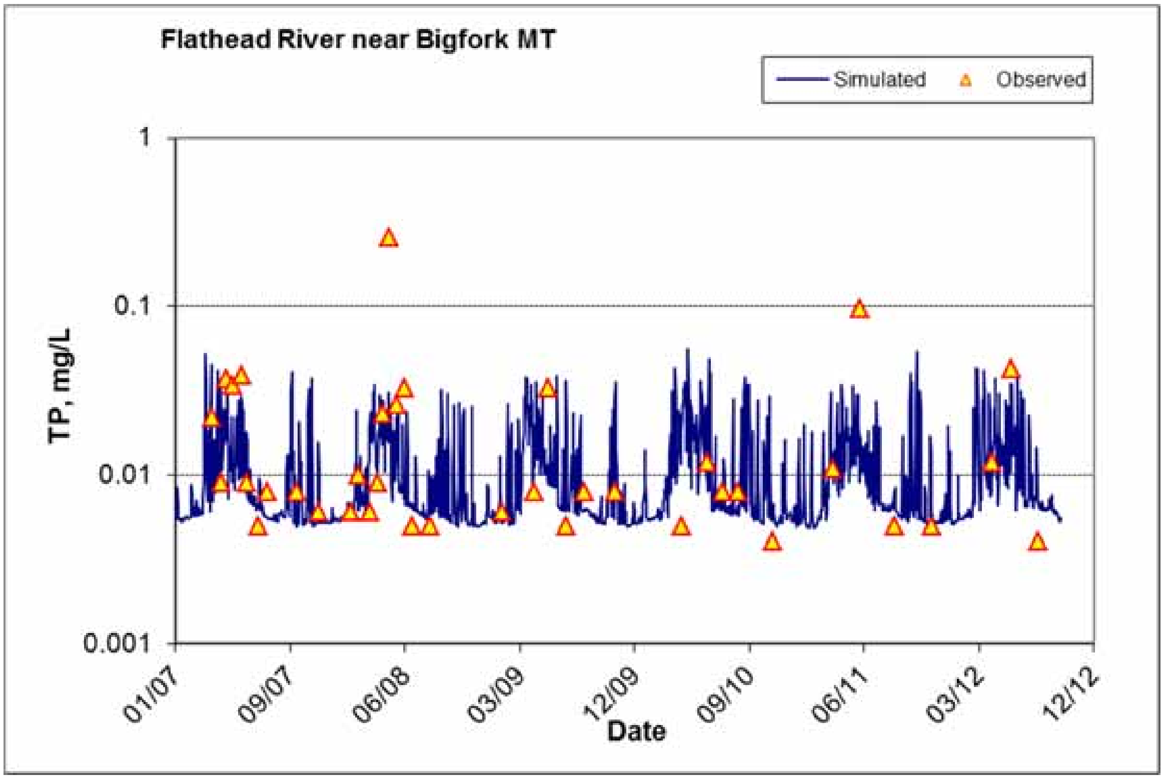


Figure 67. Calibration Observed and Modeled TP Time series June 2009 through Sept. 2012, USGS 12369000 Flathead River near Bigfork, MT.

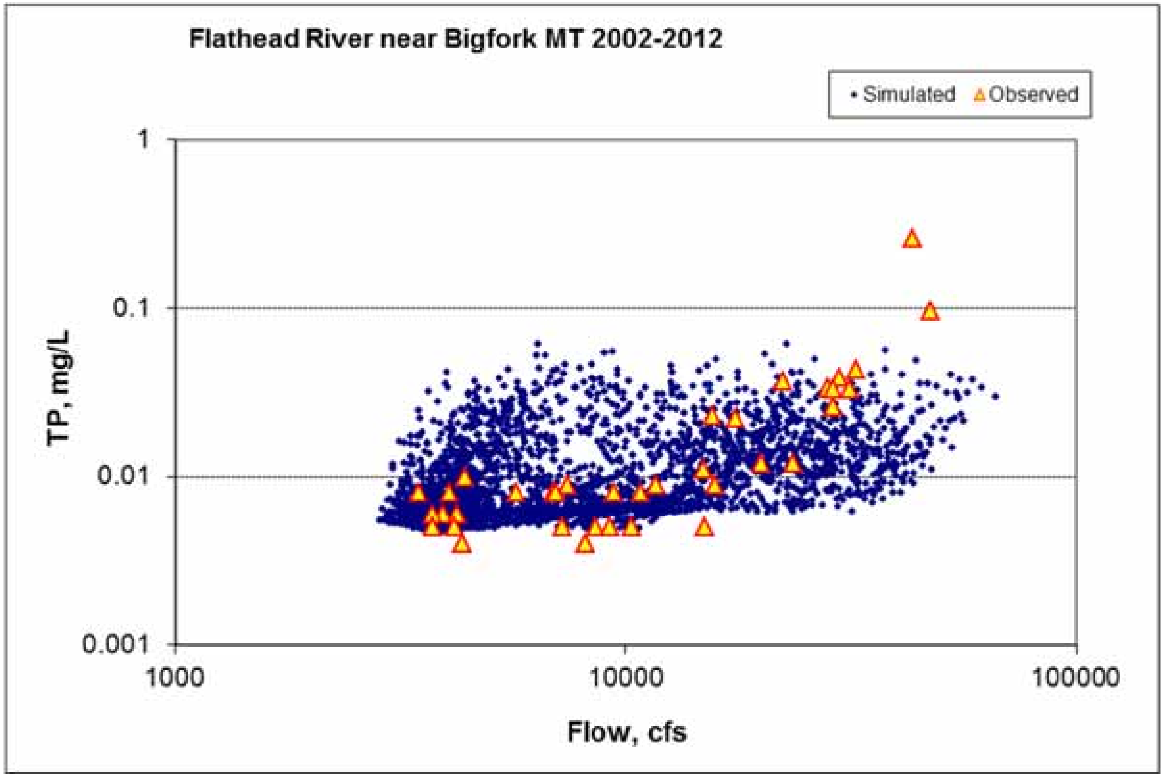


Figure 68. Calibration Observed and Modeled TP Concentration vs. Flow Regression, USGS 12369000 Flathead River near Bigfork, MT.

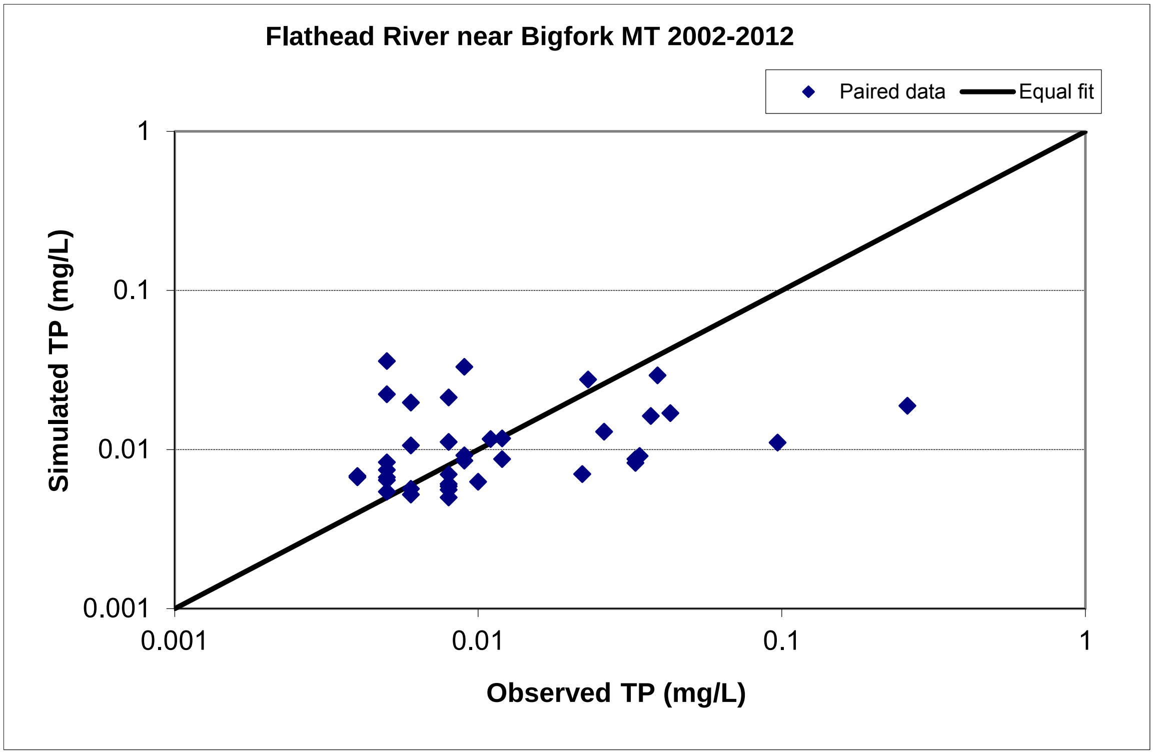


Figure 69. Calibration Observed and Modeled TP Daily Paired Concentration Regression, USGS 12369000 Flathead River near Bigfork, MT.

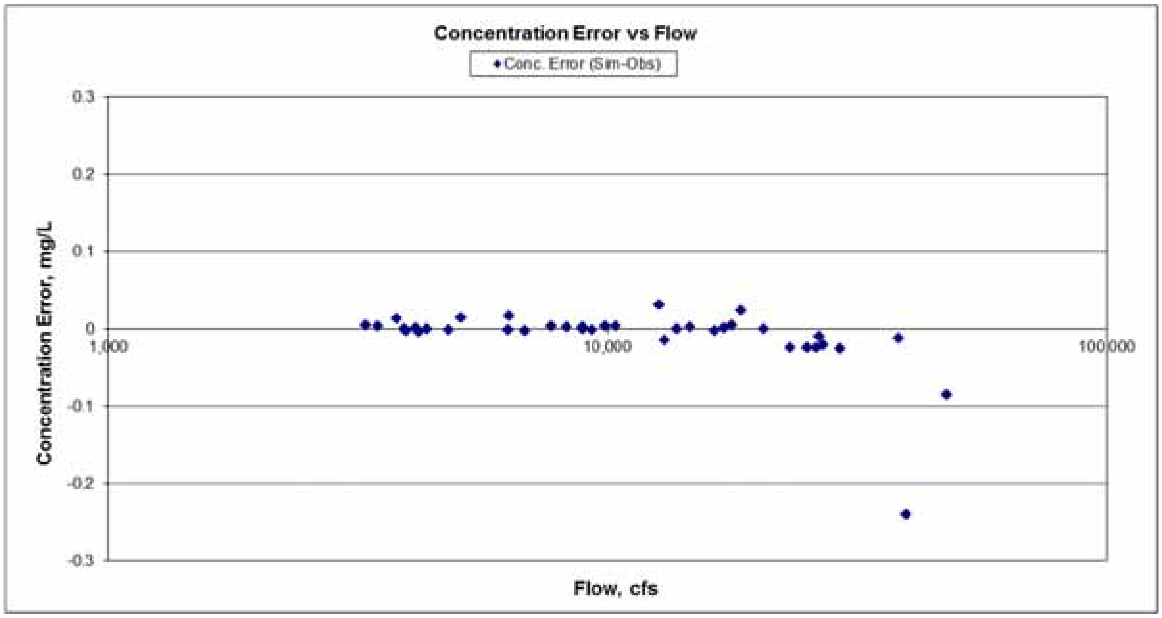


Figure 70. Calibration Observed and Modeled TP Daily Paired Concentration Error vs. Flow, USGS 12369000 Flathead River near Bigfork, MT.

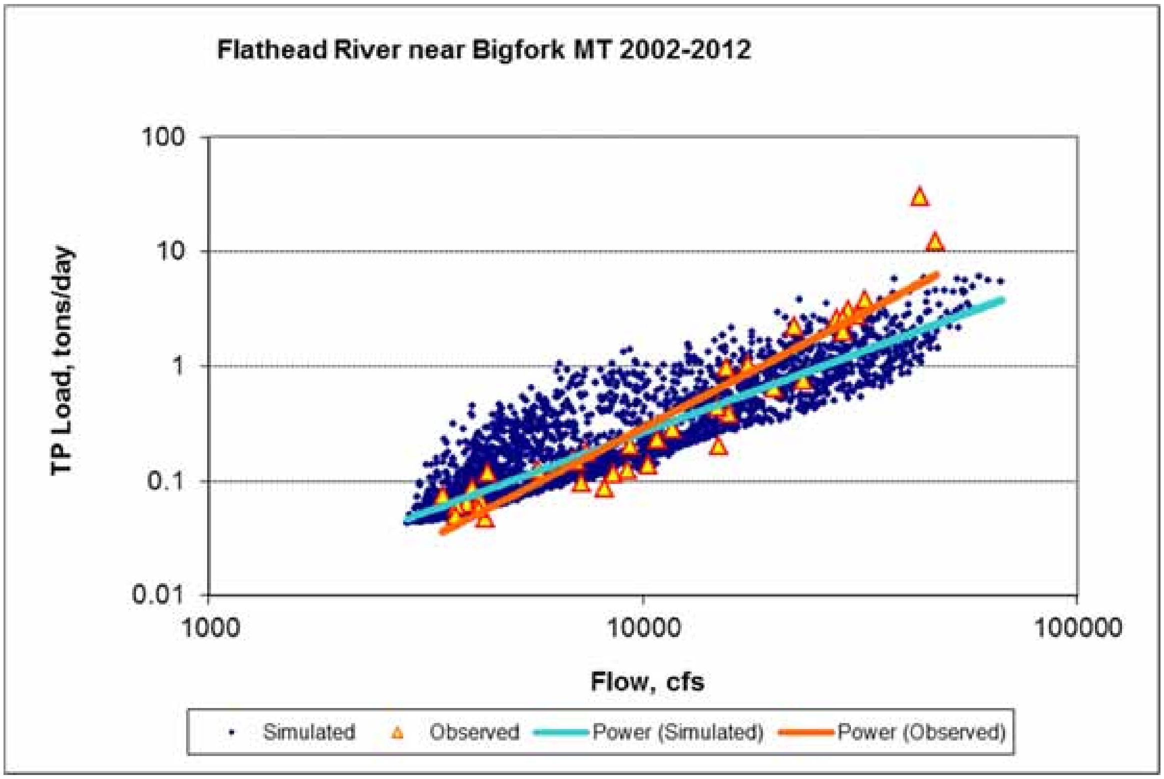


Figure 71. Calibration Observed and Modeled TP Load vs. Flow Regression, USGS 12369000 Flathead River near Bigfork, MT.

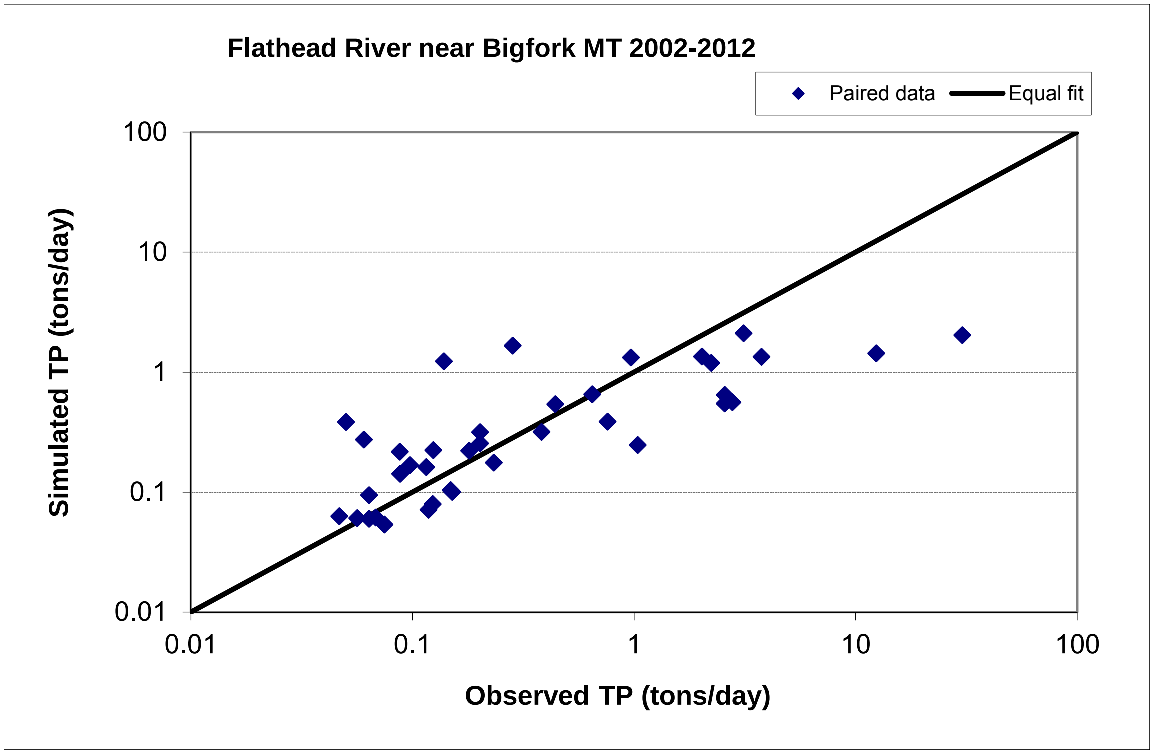


Figure 72. Calibration Observed and Modeled TP Daily Paired Load Regression, USGS 12369000 Flathead River near Bigfork, MT.

3.4 SOURCE LOAD SIMULATION

LSPC source loads are sorted from highest to lowest by model constituent and simulation area in **Table 33** and **Table 34**. Very few studies have been conducted on source loads in and around the Flathead Lake watershed. As a result, values from the literature were used (Lin (2004), Tetra Tech (2001), the Cadmus Group (1998)) as a starting point and supplemented with local/regional data where available. Comparisons of modeled unit area TP and TN loads to the literature and local values are presented in **Figure 73** and **Figure 74**. Only those land uses for which literature values were available are shown. Note that variation in rates between Phase 1 and Phase 2 is likely due to variation in HSG composition and annual rainfall total.

Table 33. Phase 1 average unit area loads by land use

TN (lbs/ac/yr)	
Forest Fire	19.53
Urban Impervious	9.46
Pasture	9.16
Golf Course	4.99
Road Primary	4.91
Road Secondary	4.81
Cropland	4.56
Urban Pervious	3.74
Forest Harvest	3.63
Road Unpaved	3.61
Wetland	3.31
Herbaceous North	2.67
Snow/Ice	2.62
Herbaceous South	2.58
Barren	1.70
Bluff	1.64
Water	1.50
Forest	0.81

TP (lbs/ac/yr)	
Forest Fire	1.163
Road Primary	0.940
Road Secondary	0.920
Golf Course	0.818
Pasture	0.815
Urban Impervious	0.632
Road Unpaved	0.442
Urban Pervious	0.416
Herbaceous North	0.321
Herbaceous South	0.300
Forest Harvest	0.285
Bluff	0.243
Cropland	0.195
Barren	0.193
Forest	0.081
Wetland	0.069
Water	0.012
Snow/Ice	0.000

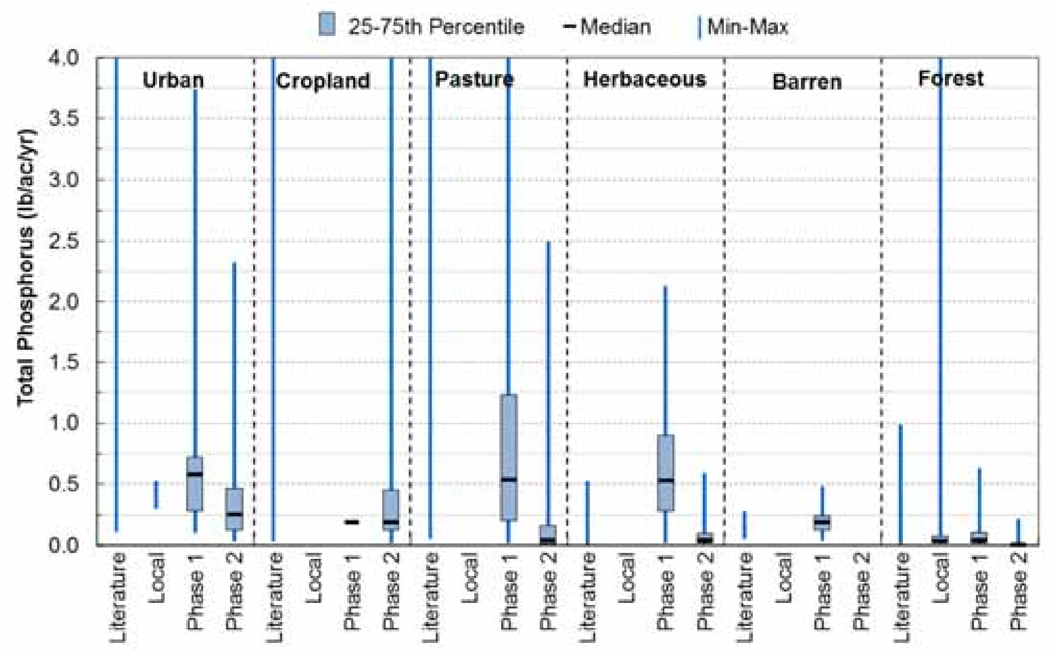
TSS (tons/ac/yr)	
Bluff	0.842
Road Unpaved	0.736
Urban Pervious	0.440
Forest Fire	0.436
Urban Impervious	0.407
Road Primary	0.270
Road Secondary	0.243
Pasture	0.225
Forest Harvest	0.216
Barren	0.148
Herbaceous North	0.122
Herbaceous South	0.118
Golf Course	0.082
Cropland	0.053
Wetland	0.032
Forest	0.029
Snow/Ice	0.000
Water	0.000

Table 34. Phase 2 average unit area loads by land use

TN (lbs/ac/yr)	
Urban Imp. Whitefish	8.16
Urban Imp. Other	7.91
Urban Imp. Bigfork	7.89
Forest Fire	7.31
Urban Imp. Kalispell	6.78
Road Secondary	3.98
Road Primary	3.97
Road Unpaved	3.79
Cropland	3.31
Pasture	3.01
Golf Course	1.60
Forest Harvest	1.20
Urban Perv. Other	1.19
Urban Perv. Whitefish	1.16
Bluff	1.02
Herbaceous	1.00
Water	0.90
Wetland	0.56
Urban Perv. Bigfork	0.45
Urban Perv. Kalispell	0.34
Forest	0.25

TP (lbs/ac/yr)	
Road Secondary	0.755
Road Primary	0.754
Urban Imp. Whitefish	0.537
Urban Imp. Other	0.518
Urban Imp. Bigfork	0.507
Road Unpaved	0.486
Urban Imp. Kalispell	0.437
Forest Fire	0.299
Cropland	0.203
Pasture	0.184
Golf Course	0.106
Bluff	0.098
Urban Perv. Other	0.095
Urban Perv. Whitefish	0.091
Herbaceous	0.083
Forest Harvest	0.070
Forest	0.017
Urban Perv. Bigfork	0.012
Urban Perv. Kalispell	0.011
Wetland	0.010
Water	0.008

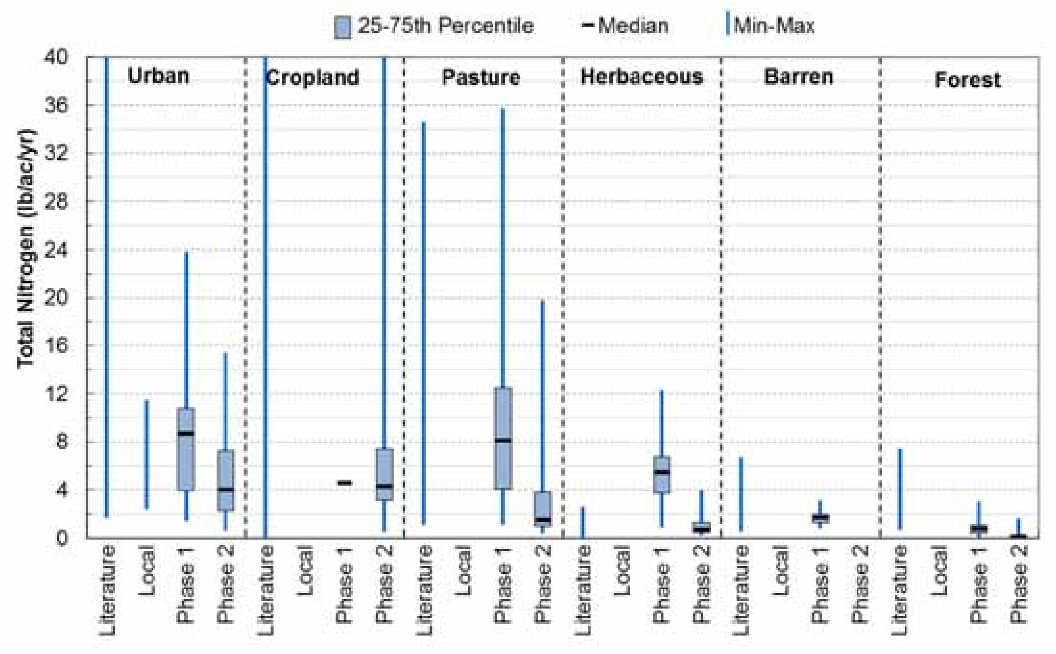
TSS (tons/ac/yr)	
Urban Imp. Whitefish	0.266
Urban Imp. Other	0.240
Road Unpaved	0.231
Bluff	0.225
Urban Imp. Bigfork	0.143
Urban Imp. Kalispell	0.137
Road Secondary	0.130
Road Primary	0.119
Urban Perv. Other	0.099
Urban Perv. Whitefish	0.095
Cropland	0.077
Pasture	0.056
Forest Fire	0.052
Forest Harvest	0.036
Herbaceous	0.023
Urban Perv. Kalispell	0.012
Golf Course	0.010
Urban Perv. Bigfork	0.007
Forest	0.005
Wetland	0.004
Water	0.000



Source:

Urban and barren-land loading rates compiled from Lin (2004)
Cropland, pasture and forest loading rates compiled from Lin (2004) and Tetra Tech (2011)

Figure 73. Comparison of modeled annual TP loads to literature values.



Source:

Urban and barren-land loading rates compiled from Lin (2004)
Cropland, pasture and forest loading rates compiled from Lin (2004) and Tetra Tech (2011)

Figure 74. Comparison of modeled annual TN loads to literature values.

Very few studies have been conducted on source loads in and around the Flathead Lake watershed. Therefore, LSPC source loads are not compared to literature values but instead are sorted from highest to lowest by model constituent and simulation area in **Table 33** and **Table 34**. However, where local data were available, loading rate comparisons were made to ensure that modeled loads were within an acceptable range. Local/regional data were available to facilitate a comparison between modeled and observed data for forested areas, urban areas, and unpaved roads, which is discussed in the following sub-sections.

3.4.1 Urban

The modeled TP and TN loads **Figure 73** and **Figure 74** are within the low end of the range reported in the national literature. Modeled values were scaled down based on data collected by the Whitefish Lake Institute and 48 North Engineering (2012) in Big Fork, Montana. Samples were collected from three sites that convey effluent to the Big Fork stormwater system via impervious surfaces. The observed values from Big Fork are generally within the interquartile range of the model results.

3.4.2 Cropland and Pasture

The literature reports a broad range of values for cropland and pasture **Figure 73** and **Figure 74**. No local or regional data are available. Modeled TP and TN loads are within the low end of the literature ranges for both of these land uses[8]. The literature values were measured primarily in the mid-western and eastern United States where TP and TN loading would likely be higher than in the Flathead region where agricultural activities are less intensive and storm events that produce runoff are much less frequent than in the mid-western and eastern states.

3.4.3 Herbaceous

There were only two values reported in the literature **Figure 73** and **Figure 74** for this land use category, and they were both for grassland (i.e., mixed grass and foothills fescue [Tetra Tech 2011]). The model lumps the NLCD grassland and shrub/scrub categories together so a direct comparison between modeled loads and the literature values is not possible. In general, the Phase 1 results are higher than those reported in the literature. This is likely a result of higher slopes in the Phase 1 area producing more runoff, and hence, a greater load than that reported in the literature. For Phase 2, where slopes are gentler and there is likely a greater proportion of grassland, the model results are generally within the range reported by the literature.

3.4.4 Barren

Barren lands were only modeled in the Phase 1 area and model results are within the range reported by the literature.

3.4.5 Forest

Literature values for TP and TN were primarily from mid-western and eastern forests. Modeled loads were generally at the low end of the literature range, but this is not unexpected given differences in forest community type/structure, soils, and precipitation patterns in the Flathead region as compared to the mid-western and eastern United States. Loading rates calculated from a total of 227 paired flow and

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[8] Note that there is only a single value for modeled cropland under Phase 1. The reason is that cropland in Phase 1 is limited to a single sub basin.

TP samples collected within the Flathead watershed by USGS (Quartz and Pinchot Creeks) and DNRC (Goat, Soup, South Fork Lost, and Woodward Creeks) between 2003 and 2008 were used to fine-tune modeled TP loading rates to local forests. Modeled TP loads in both Phase 1 and Phase 2 compare favorably to local measured loads (**Figure 73**), although the range of measured loads is greater.

3.4.6 Unpaved Roads

TP and TN loading data from unpaved roads were not available locally or in the literature. However, sediment loading data were reported in the literature and used as a surrogate to guide TP and TN parameterization. The WEPP:Road model was also used to generate sediment loading data to guide model parameterization for this land use.

Sugden and Woods (2007) measured sediment yields from 20 unsurfaced (i.e., constructed with native materials or unpaved roads as represented in LSPC) road plots in Belt Supergroup and glacial till parent materials of western Montana, and investigated the factors controlling erosion. The sites in the glacial till are likely to be the most representative of sites within the Flathead Basin. Sites in the glacial till ranged in elevation between 3,320 and 4,580 feet mean sea level (MSL). Annual sediment yields in the glacial till ranged from 0 tons/acre/year to 43.1 tons/acre/year. The median sediment yield for glacial till sites was 0.44 tons/acre/year.

WEPP:Road results from 240 road segments in the Swan River watershed were obtained from Atkins (2012) and the Flathead National Forest (Craig Kendall, U.S. Forest Service, personal communication. February 19, 2013). On a unit area basis, the estimated average annual sediment load from the 240 road segments (i.e., from the road surface and not the delivered load) ranged from 0 tons/acre/year to 4.35 tons/acre/year (Table 4). The estimated median average annual sediment load from native and gravel surface roads was 0.28 and 0.21 tons/acre/year, respectively.

Modeled unit area loads for unpaved roads are well within the range of values measured by Sugden and Woods and similar to the WEPP:Road estimates (**Table 35**).

Table 35. Comparison of observed to modeled road sediment loading

	Road Surface Sediment Load[a] (tons/acre/year)		Modeled (tons/acre/year)	
Source of data	**Range**	**Median**	**Phase 1**	**Phase 2**
Sugden and Woods (2007)	0 – 6.31	0.44	0.74	0.23
WEPP:Roads estimates	0 – 0.44	0.27		

Notes

a. This comprises the load from the road surface and does not consider the potential effects of buffers.

4 CONCLUSIONS AND LIMITATIONS

This section of the document discusses model performance relative to the modeling objectives and principal study questions presented in the Quality Assurance Project Plan (Tetra Tech 2012).

4.1 MODEL PERFORMANCE

At the scale of the Flathead Lake watershed, as represented by model output at the mouth of the Flathead River (near USGS gage12369000), the model performs well, predicting flow within specified tolerances across a range of flows and seasons/months. Model performance relative to water quality at the mouth of the Flathead River is also very good, with median concentration and load errors for TSS, TN and TP all less than 10 percent.

The fit between observed and simulated hydrology and water quality suggest that there may be model limitations at the subwatershed scale in some cases. In Ashley Creek, for example, median load errors were 34 and 102 percent for TN and TP, respectively. As described in **Appendix A**, a sub-model was created for the Ashley Creek watershed to improve the fit between observed and simulated values.

In addition to simulating hydrology and water quality constituents, the model was set up to simulate loads from the various nonpoint and point sources of TSS, TN, and TP. Measured concentrations and flows from the WWTPs were loaded directly into the model as time series using the available monitoring data. As such, simulated point source concentrations and loads are likely very representative of the actual concentrations and loads, both in magnitude and temporally. The relative magnitude of point source loads in comparison to the nonpoint source loads, therefore, is also likely representative of the real world conditions.

Nonpoint sources were parameterized in the model using the best available external information and/or methods, and then calibrated to observed in-stream data. Septic system loads, for example, were generated using the MEANSS method; a method used by DEQ on a statewide basis. Loads from forested and urban land uses were fine-tuned to observed data from the Flathead Lake watershed. Loads from unpaved roads were adjusted to literature values and WEPP:Roads results from 240 road/stream crossings in the Swan River watershed. Loading from golf courses and agricultural lands was refined based on reported fertilizer application rates from within the local area. Nonetheless, there is uncertainty associated with the simulated loading results from many of the nonpoint sources. Given the lack of source-specific monitoring data, quantifying this uncertainty is not possible.

4.2 MODEL LIMITATIONS

The purpose of this modeling exercise was to create a tool to support the development of answers to a series of principal study questions relative to the 303(d) nutrient and sediment impaired waterbodies within the Flathead Lake watershed. The principal study questions are listed below, along with a summary of model performance and limitations.

1. **What are the overall loads of nitrogen, phosphorus, and sediment?**

At the scale of the Flathead Lake watershed and many of the primary tributaries, the model is well suited to answering this study question. As exemplified in **Appendix A**, model refinements may be necessary at the sub-watershed scale to improve the simulation relative to observed values.

2. **What are the significant sources of nitrogen, phosphorus, and sediment loading?**

The significant sources of nitrogen, phosphorus, and sediment were identified during mode setup and incorporated into the model design. Calibration confirmed that most of the sources were adequately identified and incorporated into the model.

3. **What is the magnitude of the nitrogen, phosphorus, and sediment loads generated by each of the significant sources?**

The point source loads and the relative split between point and nonpoint source loads can likely be derived with confidence from the model results. Although the estimates of nonpoint source loading were developed using the best available information and accepted methods, site-specific data with which to verify nonpoint source loadings do not exist. As a result, uncertainty exists relative to the estimates of nonpoint source loads.

4. **What is the significance of the various pathways (e.g., baseflow, interflow, or surface runoff) for the transport of nitrogen and phosphorus within the basin?**

While the proportions of nutrient loading by flow pathway were not calculated during model development, the model can be used to determine relative contributions from surface flow, interflow, and baseflow. This can be done in aggregate, by land use, by water year, or using whatever grouping method is needed for the analysis. To perform the calculations, monthly model output of interflow and baseflow volumes by subwatershed and land use would be combined with monthly interflow and baseflow concentrations by land use (DELUID) and soil group (DEFID) to produce separate baseflow and interflow loads. These would be subtracted from total loads to produce surface runoff loads. Relative proportions would then be calculated from the three flow pathways.

5. **By how much do the loads need to be reduced to meet the applicable TMDL targets?**

At the scale of the Flathead Lake watershed and for many of the primary tributaries, the model is well suited to answering this question relative to the total load, load from point sources, and the load from all of the nonpoint sources combined (including natural background loading). Although the model was informed by the literature and local/regional data, where available, as with all models, uncertainties exist with the quantification of individual nonpoint source loads (e.g., loads from the wetland complex in the vicinity of Smith Lake) and differentiation between anthropogenic and natural background loads. It is assumed that the loads from barren lands, forest, herbaceous, snow/ice, water, and wetland are natural in origin. Additionally, a considerable portion of the contributions from bank erosion, atmospheric deposition, and forest fire are also likely natural in origin. The fractions attributable to natural and anthropogenic sources have not been defined at this time. As a result, additional work outside of this modeling framework would be necessary to quantify the split between natural and anthropogenic nonpoint source loads.

6. **What are the potential benefits of best management practices (BMPs) relative to achievement of the applicable water quality targets?**

BMPs are not currently explicitly modeled using the Flathead Lake LSPC model. However, the model is well suited, in combination with literature values representing BMP performance, to examine the potential water quality benefits of alternate BMP implementation strategies.

4.3 SUGGESTED MODEL IMPROVEMENTS

As originally envisioned, the primary objective of the Flathead Lake watershed LSPC model was to create a tool to answer a set of study questions (see above) at the scale of the *entire* Flathead Lake watershed. A court order- imposed TMDL schedule resulted in time and budget constraints that limited model development and set-up. Work at the watershed-scale was discontinued during model set up and calibration to focus on TMDL priorities in the Ashley Creek watershed. As a result, a number of opportunities are available for future improvements of the Flathead Lake watershed LSPC model. These are listed and briefly described below.

Corroboration

Corroboration is often referred to as model validation. In the corroboration step, the performance of the model is evaluated through application to a set of data different from that used in calibration. Due to time constraints and paucity of observed data, model corroboration was not performed, but is recommended as one of the next steps prior to application of the model at the Flathead Lake scale. Corroboration may also provide insights that lead to improvements in the model configuration.

Reach/Subwatershed Scale Refinements

A subset LSPC model of Ashley Creek was created from the Flathead Lake LSPC watershed model to facilitate development of the Ashley Creek TMDLs (**Appendix A**). Revisions were made to enhance model representation of hydrology and sediment/nutrient transport at the reach and subwatershed scale based on site-specific data collected in Ashley Creek. Some subwatersheds in the Flathead Lake watershed, including Ashley Creek and the Stillwater and Whitefish rivers, are well-studied with many flow and water quality sample sites. The revisions made to address the unique properties of the Ashley Creek watershed exemplify revisions that could be made to the entire Flathead Lake LSPC model to improve its performance at the reach and subwatershed scale. Notable changes to the Ashley subset model included incorporation of losing reaches in select areas, addition of loads from a wetland complex that shows evidence of exporting nutrients, and modification of the method used to estimate phosphorus loads from septic systems.

Time and budget constraints limited the number of monitoring stations that were used to conduct the calibration. The Ashley Creek subset model provides a good example where additional monitoring data in a specific geographic area was used successfully to improve localized model performance. Using additional data would allow the model to respond to local variation in hydrology and pollutant loading that is currently not captured by the larger Flathead model. The model would need to be reconfigured to allow for regional parameter variation, as discussed below in the *Parameter Groups and Soils Data* recommendation.

Reach Deposition and Scour

LSPC models bed dynamics by simulating channel deposition and scour depths. Localized refinements to the parameters influencing bed behavior have been made during calibration to achieve a better fit to instream monitoring data. However, deposition and scour in all model reaches should be examined over the course of the simulation, and any unreasonable changes should be addressed by judicious parameter modification.

Lakes

LSPC allows for the specification of the type of water body as a *stream* reach or a *reservoir* reach. Regardless of whether a water body is a stream or a reservoir/lake, LSPC represents them in essentially the same fashion – as a completely mixed water body with unidirectional flow. This simple representation of lakes has likely limited model performance, especially downstream from the larger, deeper lakes. Model performance could be improved by incorporating 2D lake models for the deep lakes (e.g., CE-QUAL-W2). Bathymetry and water quality data at various depths are available for many lakes. A few lakes' datasets include very fine-scale bathymetry data (e.g., Tally and Whitefish lakes bathymetry from the Whitefish Lake Institute) and many rounds of water quality samples at various depths.

Parameter Groups and Soils Data

SSURGO spatial soils datasets were obtained for the United States portion of the watershed from NRCS and for the Canadian portion of the watershed from Agriculture and Agri-Food Canada's Soil Landscape of Canada (SLC) product. Soil polygons were classified by *dominant* HSG, which is one of a few methods to represent HSGs spatially. A *weighted average* approach for HSG classification may result in a more accurate representation of HSGs.

Soil properties of HSG, depth to bedrock, and elevation were then generalized into four parameter groups used in the model to simplify the hydrologic calibration process at the scale of the Flathead Lake watershed. However, this simplification limits the ability to include regional variation in hydrology and pollutant loading response. The model could be reconfigured to include regions using parameter groups to refine and improve model performance at the sub-watershed scale.

Land Use/Land Cover

NLCD (1992, 2001, and 2006) and the land cover datasets collected by the Agriculture and Agri-Food Canada, Canada Center for Remote Sensing, and the Canadian Forest Service (representing the time period circa 2000) served as the foundation for representation of land use/land cover in the Flathead Lake watershed for the model simulation period. As described in Section 2.10.1, these were augmented to provide enhanced resolution for roads, forest fire, timber harvest, agriculture, golf courses, and bluffs. Many of the data sets from which land use/land cover data were obtained have since been updated (e.g., the 2011 NLCD was released in 2014, the U.S. Forest Service continuously updates its roads, forest fires, and timber harvest datasets). As a result, consideration should be given to updating land use/land cover representation prior to future use of the model. Data compilation efforts should be considered since datasets will need to be obtained from many entities, including county, state, federal, and Canadian government agencies.

Livestock and Pasture

Data regarding the number and distribution of livestock in the watershed were based on county-level statistics. During model development, livestock were equally distributed throughout the watershed on lands classified as pasture by the NLCD. This approach likely represents the overall magnitude of nutrient loading from livestock at the scale of the Flathead Lake watershed. However, this approach may underestimate loading at smaller spatial scales since there are likely many areas where livestock have direct access to perennial water bodies for periods of time throughout the year. Representation of livestock nutrient loading could be improved at the subwatershed-scale through the collection of more site-specific data that characterize the number and spatial distribution of livestock.

Septics

The estimated septic nutrient loadings should be reviewed in the future as additional local information on the condition of septic systems becomes available and as better methods for estimating septic loadings to surface waters become available.

Stream Channel Representation

As discussed in Section 2.3.1, there are several stream hydraulic characteristics defined in the model used to generate *F-Tables*. Some were calculated using GIS, others were estimated using an approach that takes uses upstream contributing area, while the remainder were given fixed assumptions for all reaches. The representation could be improved upon by using additional external data and assumptions. Aerial photography could be used to provide a better estimate of bankfull channel width, and bankfull depth could be adjusted to produce the same cross-sectional area. Tiered assignments could also be used for Manning’s *n*, with higher values in headwater streams and lower values in larger rivers. Barnes (1967) provides an overview of roughness coefficients for streams across the US, and could be used to inform Manning’s *n* values.

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