HSPF Watershed Model Update and Calibration Report for the St. Louis and Cloquet River Watersheds

June 30, 2022

PREPARED FOR

Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, MN 55155

PREPARED BY

Tetra Tech, Inc.
One Park Drive, Suite 200
PO Box 14409
Research Triangle Park, NC 27709
Tel 919-485-8278

wq-iw10-12q

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
1W1P	One Watershed, One Plan
CASTNET	Clean Air Status and Trends Network
CDL	Cropland Data Layer
DNR	Department of Natural Resources
DSN	Data Series Number
EIA	Effective Impervious Area
ET	Evapotranspiration
FEMA	Federal Emergency Management Agency
HRU	Hydrologic Response Unit
HSG	Hydrologic Soil Group
HSPF	Hydrologic Simulation Program FORTRAN
HUC	Hydrologic Unit Code
IMPLND	Impervious Land Unit
LiDAR	Light Detection and Ranging
MIA	Mapped Impervious Area
MPARS	Water Permitting and Reporting System
MPCA	Minnesota Pollution Control Agency
MRLC	Multi Resolution Land Characteristics
NADP	National Atmospheric Deposition Program
NCEP	National Centers for Environmental Protection
NLCD	National Land Cover Database
NLDAS-2	North American Land Data Assimilation System
NSE	Nash Sutcliffe Efficiency
NSIDC	National Snow and Ice Data Center
NWI	National Wetland Inventory
PERLND	Pervious Land Unit
PET	Potential Evapotranspiration
PRISM	Parameter-elevation Relationships on Independent Slopes Model
SNODAS	Snow Data Assimilation System
SSEBop	Simplified Surface Energy Balance
SWE	Snow Water Equivalent
TIA	Total Impervious Area
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USGS	United States Geological Survey
WDM	Watershed Data Management

Acronyms/Abbreviations	Definition
WRAPS	Watershed Restoration and Protection Strategies
WY	Water Year

1.0 INTRODUCTION

This report describes the update and recalibration of a Hydrologic Simulation Program – FORTRAN (HSPF; Bicknell et al., 2014) model of the St. Louis River and Cloquet River watersheds in northeastern Minnesota. These watersheds are designated by the 12-digit Hydrologic Unit Codes (HUC) of 04010201 and 04010202, respectively. The original HSPF model was developed and calibrated to simulate conditions through 2012 (Tetra Tech, 2016a). It was extended in time through 2014 shortly thereafter, though not recalibrated (Tetra Tech, 2016b). This report discusses the extension of the model through Water Year (WY) 2021, updates that were made to several aspects of the model build in an effort to use newly available data (e.g., land use/land cover, hydraulics), and the subsequent recalibration of hydrology and water quality.

The St. Louis River and Cloquet River watersheds predominately span St. Louis County, but also cover portions of Lake, Itasca, Aitkin, and Carlton counties within Minnesota as well as the northwest corner of Douglas County, Wisconsin. The Cloquet River is a tributary of the St. Louis River that drains to Lake Superior in the Duluth area. Other major tributaries include the Floodwood River, Swan River, Embarrass River, Partridge River, and Whiteface River. A large portion of the study area is within the Northern Lakes and Forests ecoregion. Northern hardwood forests, peatlands, wetlands and several hundred lakes span much of the drainage area. The Mesabi Iron Range, a mining district, crosses the north end of the St. Louis River watershed.

This effort was completed because the Minnesota Pollution Control Agency (MPCA) works to keep models of watersheds in the state up-to-date so the models remain viable tools for planning. Under Minnesota's Watershed Approach, HSPF models are used to support the development of Watershed Restoration and Protection Strategies (WRAPS) reports, Comprehensive Watershed Management Plans (One Watershed, One Plan; 1W1P), and Total Maximum Daily Loads (TMDL). MPCA's HSPF models are designed to support biological stressor identification and analysis of pollutant-related impairments.

A watershed model is a tool to aid understanding of processes and consequences of human activities in a river basin, however, it is only one among a variety of tools. A watershed model is not a substitute for direct monitoring of physical and biological conditions in streams and lakes. When properly calibrated to represent observations, a model can, however, provide a reasonable mechanism for the extrapolation of monitoring data in space (to unmonitored locations) and in time (to unmonitored or future time periods). A watershed model also enables experiments to investigate how changes (such as changes in land use, management practices, or climate) may affect conditions in the watershed and allow policymakers and stakeholders to plan accordingly. To be useful for these purposes the credibility of the model (and its associated level of uncertainty) must be established through comparison to real world data, preferably collected in the modeled drainage area, and through local partner input, as described in this report.

2.0 MODEL UPDATES

2.1 DELINEATIONS

When the HSPF model for the St. Louis and Cloquet watersheds was originally developed, the model subbasins were generally specified at the HUC-12 scale; these were refined using high-resolution (Level 8) spatial catchment data obtained from the Minnesota Department of Natural Resources (DNR) geospatial data website and other supplementary information (e.g., locations of flow and water quality monitoring to support calibration efforts). Additional information about the model subbasin and reach delineations can be found in the original model development and calibration report (Tetra Tech, 2016a). A HSPF model was developed for the Duluth urban area after the original development of the St. Louis and Cloquet HSPF model. The Duluth model contains high resolution subbasins that were delineated using additional urban stormwater drainage data. In some areas, the Duluth model subbasin delineations were not well aligned with the subbasins in the St. Louis and Cloquet HSPF model extent. Both models are being updated in parallel in anticipation of modeling support needed for the development of upcoming mercury TMDLs. To support efficient application of the models in combination for the TMDL and other future watershed planning efforts, subbasin delineations in the southeast portion of the St. Louis and Cloquet HSPF model extent were revised to better align with the Duluth model subbasins. This did result in a few new subbasin numbers. The current model subbasin and reach delineations are shown in Figure 2-1.

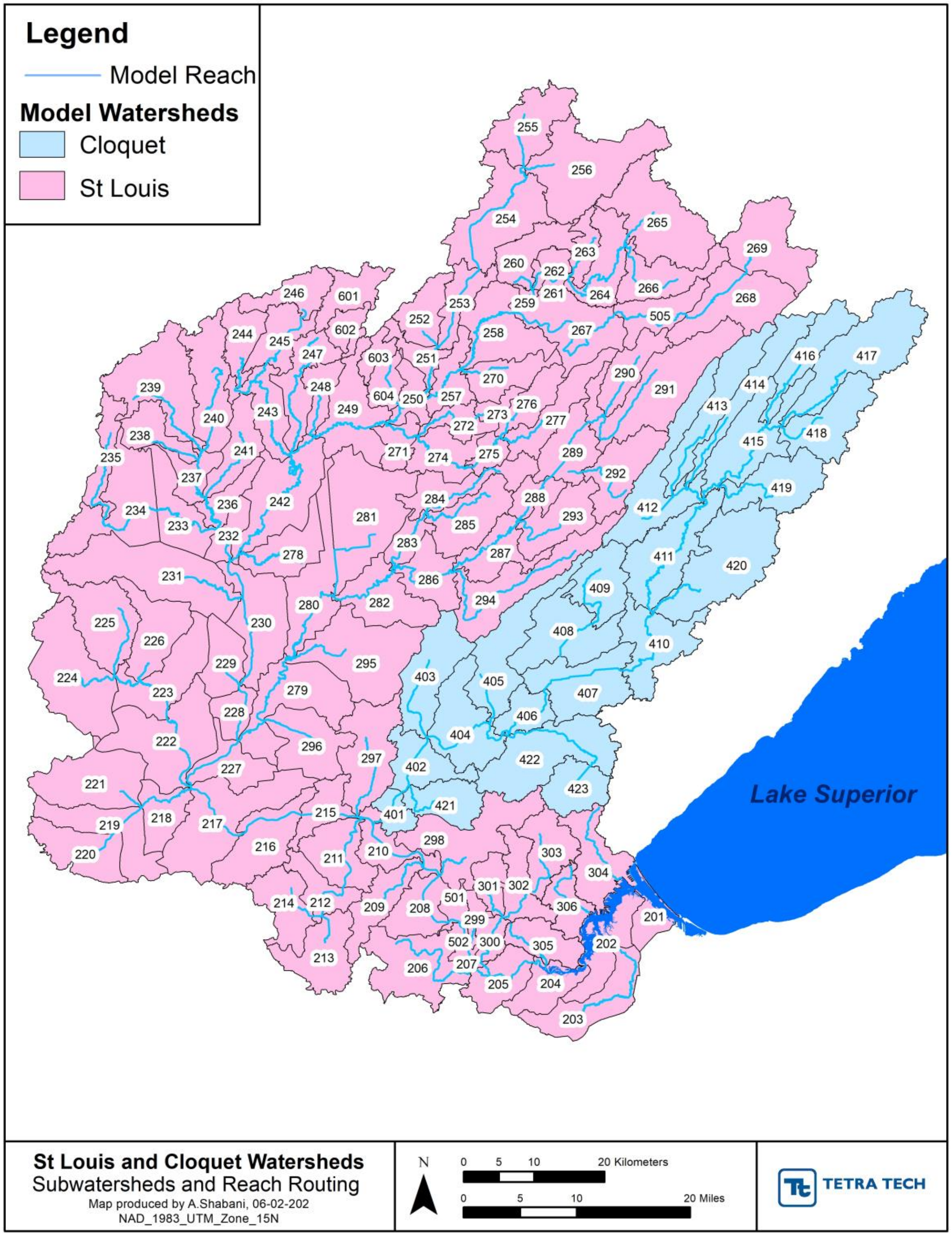

Figure 2-1. HSPF model subbasins and reaches

2.2 WEATHER

Weather zones (also called hydrozones) and subbasin delineations represented in the original HSPF model were refined (Figure 2-2) as were model Hydrologic Response Units (HRUs), which represent unique combinations of land use, soil type, and management practices (e.g., agricultural land under conventional or conservation tillage) for pervious and impervious upland segments. Weather zones were refined to align with updated model subbasin boundaries. Secondly, the weather time series were previously station-based, but Tetra Tech switched to gridded data sources for the extended model. Therefore, the weather zones were modified to align with long-term precipitation and air temperature patterns from the PRISM (Parameter-elevation Relationships on Independent Slopes Model) database.

Because point-in-space station monitoring records are often not representative of integrated weather over a surrounding model area, the St. Louis and Cloquet River watersheds model extension allowed for a switch to gridded meteorological data sources. Gridded weather products can be used to better represent climatic variations across a diverse landscape, and these products also directly provide hourly air temperature, wind, and solar radiation data as well as parameters for computing cloud cover, dew point temperature, and potential evapotranspiration. Another benefit of gridded meteorological products is that these sources provide continuous data without gaps. This is not the case for point-in-space stations. Significant quality control work is required to process station-based records, potentially including patching missing records and developing proximity-based composite time series. Gridded products simplify and streamline the process of extending the spatial domain of the HSPF model and/or lengthening the simulation period.

PRISM provides annual, monthly, and daily gridded precipitation data for the conterminous United States (Daly et al., 2008, 2015; daily output was added to PRISM in 2015). PRISM calculates a climate-elevation regression function for each grid cell and the regression is used to distribute station-based precipitation data to the grid cell. Approximately 13,000 precipitation stations are used in the analysis. For each grid cell, precipitation stations are assigned weights based on location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain; the stations are then entered into the regression function to establish the gridded precipitation product.

Another gridded product is the North American Land Data Assimilation System (NLDAS-2) meteorological time-series (Mitchell et al., 2004). NLDAS-2 (http://ldas.gsfc.nasa.gov/nldas/NLDAS2forcing.php) provides continuous hourly data from 1979 to present on a 1/8-degree grid that has been processed to fill gaps. The precipitation data in NLDAS-2 are based on interpolation of daily gauge precipitation including orographic adjustments based on PRISM and temporally disaggregated using Doppler radar and satellite data. NLDAS-2 also provides solar radiation, wind at 10 m (which can be scaled to wind at 2 m), and absolute humidity plus air pressure, from which dew point can be calculated. Cloud cover (which is only needed to estimate long wave radiation exchange with the atmosphere) is not included in the NLDAS output, but can be back-calculated from the ratio of estimated incident solar radiation to cloud free solar radiation during daylight hours using the regression relationship developed by Davis (1996).

Gridded meteorological data are available through the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR), which is an extension of the NCEP Global Reanalysis. NARR leverages the regional and high-resolution Eta Model, applies the Noah-Multiparameterization Land Surface Model, and incorporates other advancements in data assimilation (Mesinger et al., 2006) to produce gridded meteorological datasets for North America. Temperature, wind, precipitation, and pressure data collected from numerous sources serve as inputs to the model. Data products include 3-hourly, daily, and monthly means from 1979 to present (with a half-month delay in availability), on a 32-km grid. Hundreds of meteorological and hydrological parameters are available through NARR, including total cloud cover, air temperature, precipitation, wind, dew point temperature, potential evapotranspiration (PET), and solar radiation. Additional information is provided on the NARR website: https://www.esrl.noaa.gov/psd/data/gridded/data.narr.html.

Meteorological data from PRISM, NLDAS, and NARR were used to develop hourly weather forcing series for the full simulation period of the St. Louis and Cloquet River watersheds HSPF model (i.e., the original station derived time series were replaced). The basic overview of each meteorological input, data source, and processing notes are provided in Table 2-1 and discussed in more detail in the following sections. The Gridded Weather Data Processing Tool (MetTool), developed by Tetra Tech for MPCA, was used to download, extract, and process data for the grids intersecting the watershed and aggregate time series to the modified model hydrozones. Weather input time series were developed for the entire modeling period of 1/1/1993 to 9/30/2021. A discussion of the methods implemented in the MetTool can be found in Tetra Tech (2020).

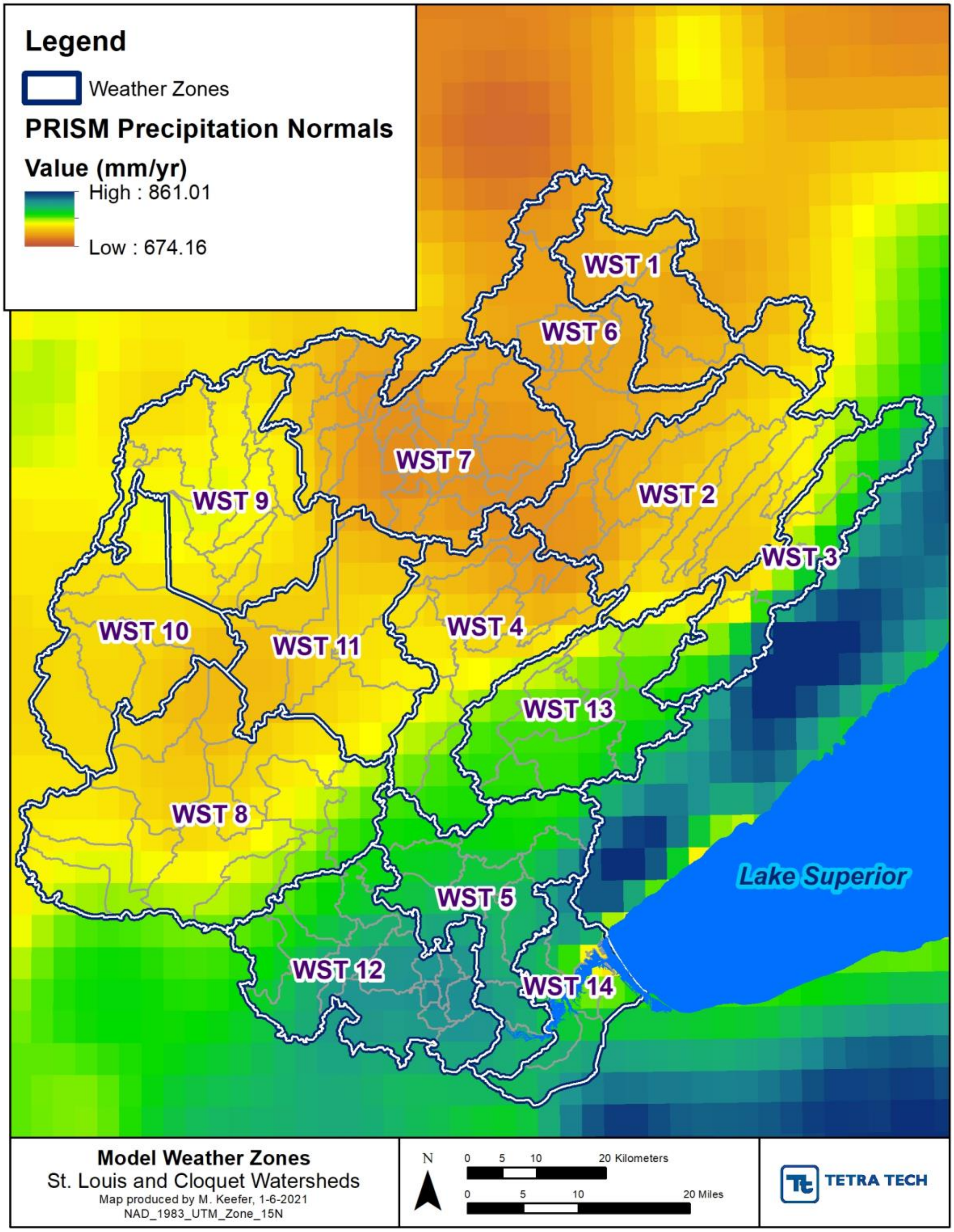

Figure 2-2. St. Louis and Cloquet watersheds HSPF model weather zones

Table 2-1. Summary of HSPF Meteorological Input Time Series

HSPF Model Input	Description (units)	Parameter Source	DSN in WDM (HZ=hydrozone number)	Processing Notes
PREC	Precipitation (in)	PPT (PRISM), APCP (NLDAS)	HZ10	Daily PRISM precipitation data are disaggregated using NLDAS hourly patterns or the random cascade method when NLDAS precipitation is zero
ATEM	Air Temperature (°F)	TMP (NLDAS)	HZ20	Hourly air temperature, used directly
SOLR	Solar Radiation (Ly)	DSWRF (NLDAS)	HZ40	Hourly short-wave radiation, used directly
CLOU	Cloud Cover (tenths; 0-10)	NARR	HZ70	Total cloud cover at a 3-hour temporal resolution were used
DEWP	Dew Point Temperature (°F)	SPFH, PRES, TMP (NLDAS)	HZ60	Function of hourly specific humidity, air pressure, and air temperature
WIND	Wind Travel (mi)	UGRD, VRGD (NLDAS)	HZ50	Net wind travel from component vectors
PEVT	Potential Evapotranspiration (in)	DSWRF, TMP, WIND, SPFH, PRES (NLDAS)	HZ30	Computed from solar radiation, air temperature, wind travel, and dew point temperature

Note: All series were converted to HSPF compatible units.

2.3 UPLAND REPRESENTATION

The HSPF model was set up using a Hydrologic Response Unit (HRU) approach. The HRU concept provides a way to capture landscape variability into discrete units for modeling. An HRU is defined as a unit of land with relatively homogenous hydrologic properties determined by its underlying characteristics. The approach is used because runoff and water quality regimes are strongly influenced by climate, geology, soils, and land use/cover, which are considered in the development of model HRUs. A discussion of HRU development for the original model can be found in Tetra Tech (2016a) and updates to the HRUs are discussed below.

2.3.1 Land Use/Cover

Several land-use coverages are available to set up the HSPF model for St. Louis and Cloquet watersheds. Multi-Resolution Land Characteristic (MRLC) Consortium products NLCD (National Land Cover Database), CDL (Cropland Data Layer), and LANDFIRE are common of land use coverages that are frequently used for hydrology and water quality modeling. These products are generated based on Landsat imageries with 30 m spatial resolution. NLCD is useful in many watersheds and provides a good spatial distribution of developed, agriculture, and undeveloped land in the watershed. CDL provides detailed coverage of crop types which is suitable for studying agricultural watersheds. The LANDFIRE coverage identifies roads and gives additional information on tree canopy type, but does not identify specific agricultural land uses. Given the small fraction of cropland and predominance of forest and urban land cover in the study area, LANDFIRE 2016 was adopted as the basis for model land cover. This is consistent with the previous modeling efforts for the watershed. Wetland areas in the model were defined using the National Wetland Inventory (NWI). The NWI layer is updated twice a year and it provides details information about the characteristics and distribution of wetlands. Using wetland characteristics, NWI classes were grouped into three categories, wetland herbaceous, wetland shrub, and the peatland/bog, for the HSPF modeling. In our classification hardwood and marsh wetlands were classified under shrub and herbaceous wetlands, respectively, and open bog and coniferous bog were grouped into peatland/bog category. The HSPF model land use for St. Louis and Cloquet watersheds is shown in Figure 2-3.

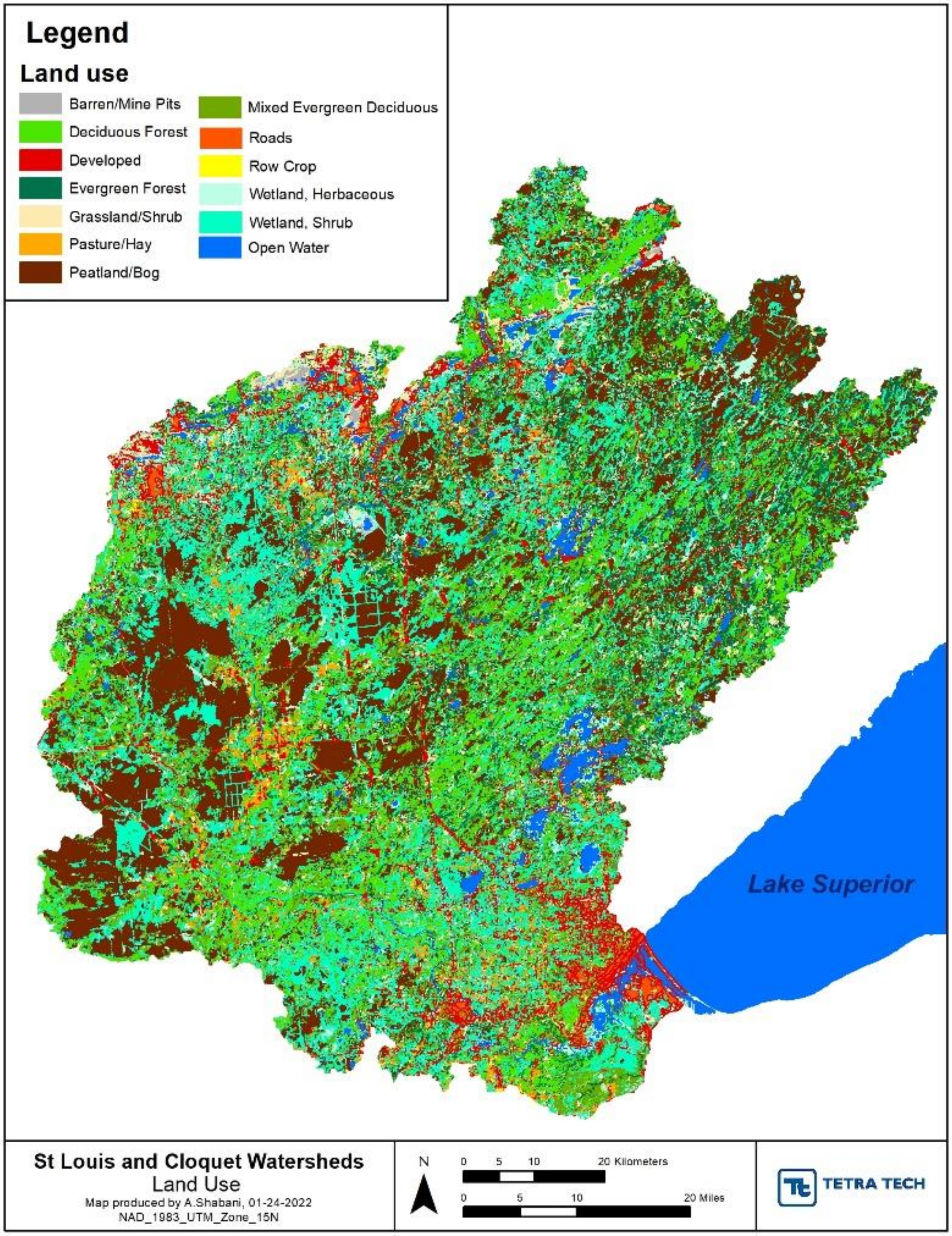

Figure 2-3. HSPF model land use

2.3.2 Land Use Change

Forest, wetland, and peatland/bog cover about 80% of St. Louis and Cloquet watersheds. A small portion of St. Louis and Cloquet watersheds is developed (2.6%) and 0.07% of the watersheds are used for agriculture. Water (3.2%), grassland and pasture (5.7%), and mine pits (0.5%) cover the rest of the watersheds. The St. Louis and Cloquet HSPF model is constucted using 30 m land cover from LANDFIRE EVT 2016 and the National Wetland Inventory GIS shapefile (Figure 2-3). The HSPF model assumes that land cover in the watershed is approximatley steady state over the period of model application (1995-2021). To verify this assumption we used NLCD 2006, 2016, and 2019 to calculate change land covers. The NLCD land covers are derived from Landsat imageries and sophisticated classification methods using spectral signatures of earth surface. Advancement in satelite (Landsat) sensors and classification methods has improved the accuracy of the land cover monitoring (Kumar and Arya, 2021). Compared to the NLCD 2006 product that is derived from Landsat 7 imageries, NLCD 2016 and 2019 land use coverages are produced using Landsat 8 and cutting edge machine learning classifcation and ground truth observations. Due to differences in NLCD products' accuracy, a direct comparison between new (2016 and 2019) and older NLCD land covers might not be entirely accurate (EROS, 2018), therefore, the changes presented here should be interperated as relative values. The results of our analysis showed small changes in area of the primary land covers for the comparison period (2006-2019). For instance, change in forested areas (deciduous, evergreen, and mixed) between 2006 and 2016 are less than 6% (Figure 2-4 and Table 2-2). Change in wetland areas, however, appear to be significant especially between 2006 and 2016. The change in wetland areas could partially be related to misclassification between wetland types (from woody wetland in 2006 to emergent herbaceous wetland in 2016 and 2019). The changes in area of other land covers regardless of the magnitude (like croplands) are insignificant due to their respectively small distribution in the drainage area.

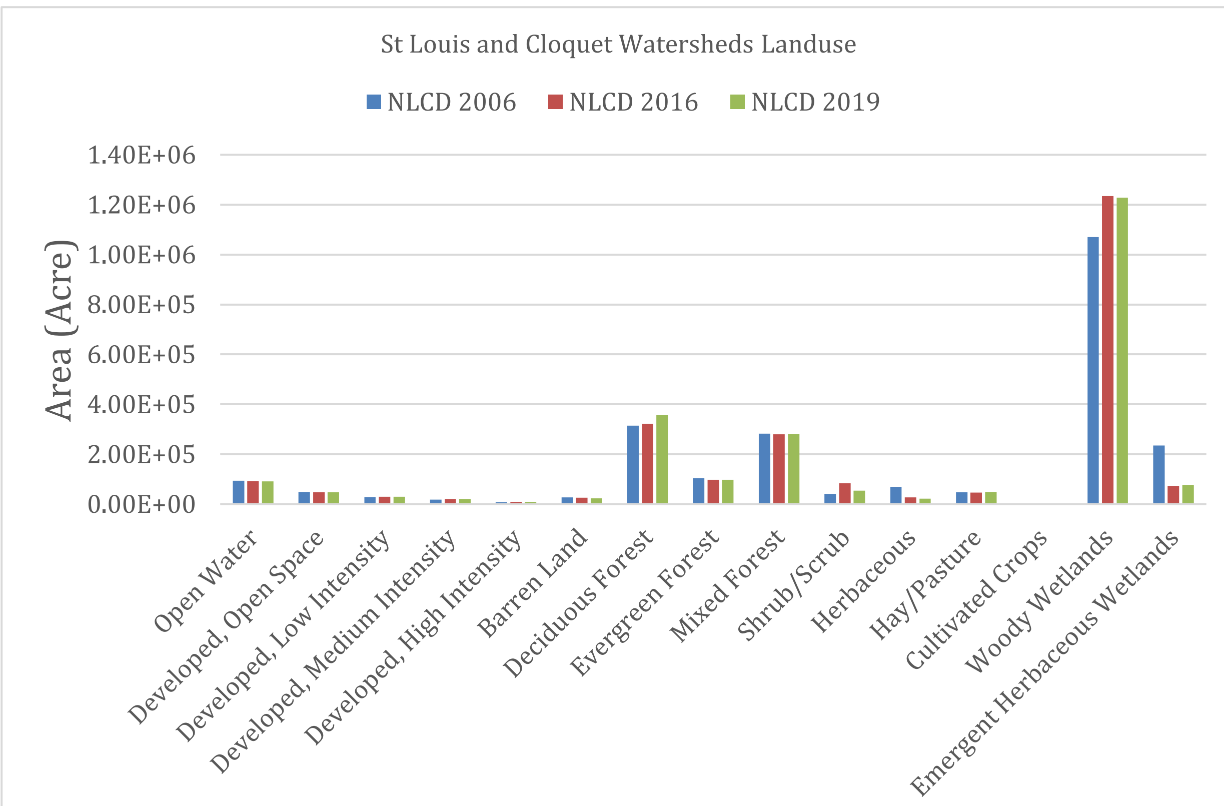

Figure 2-4. St Louis and Cloquet watersheds land use distribution calculated from NLCD products

Table 2-2. Change in St. Louis and Cloquet watersheds land cover calculated using NLCD 2006, 2016 and 2019

NLCD Land use	Area (Acres)			Change (%)	
	2006	2016	2019	2006-2016	2016-2019
Open Water	93,936	93,003	91,630	-1.0	-1.5
Developed, Open Space	49,139	47,319	47,518	-3.7	0.4
Developed, Low Intensity	28,797	29,070	29,452	0.9	1.3
Developed, Medium Intensity	17,652	20,124	20,719	14.0	3.0
Developed, High Intensity	7,484	8,521	8,783	13.9	3.1
Barren Land	26,683	25,753	23,781	-3.5	-7.7
Deciduous Forest	314,574	321,957	357,850	2.3	11.1
Evergreen Forest	103,841	97,814	97,323	-5.8	-0.5
Mixed Forest	282,229	279,827	281,668	-0.9	0.7
Shrub/Scrub	41,599	83,024	53,317	99.6	-35.8
Herbaceous	69,735	26,662	22,248	-61.8	-16.6
Hay/Pasture	47,707	46,728	48,624	-2.1	4.1
Cultivated Crops	1,554	2,277	2,263	46.5	-0.6
Woody Wetlands	1,069,628	1,234,263	1,227,371	15.4	-0.6
Emergent Herbaceous Wetlands	235,421	73,638	77,537	-68.7	5.3

2.3.3 Soil

Soil hydrologic group (HSG) plays a critical role in regulating surface runoff pathways. Soils are assigned to hydrologic groups based on their physical characteristics (texture and structure) or infiltration rate. The HSG defined by the National Soil Survey are A, B, C, D, and dual groups A/D, B/D, and C/D (NRCS, 2007). When soils are thoroughly wet, hydrologic group A has a low runoff potential due to its high infiltration rate. Soils in hydrologic group D exhibit a very slow infiltration rate and higher runoff potential. Dual HSGs (A/D, B/D, and C/D) are given for certain soils that could be sufficiently drained. In these groups the first letter applies to the drained and second to the undrained condition. HSG in National Resources Conservation Service soil datasets, gridded SSURGO (gSSURGO) and STATSGO, provide an index for soil infiltration capacity. Compared to STATSGO, the gSSURGO database provides HSG in a higher spatial resolution and it was primarily used for initial assignment of soil categories in our model. For the areas that HSG was not available in gSSURGO, HSG was defined using STATSGO dataset. Figure 2-4 shows HSG for the study area.

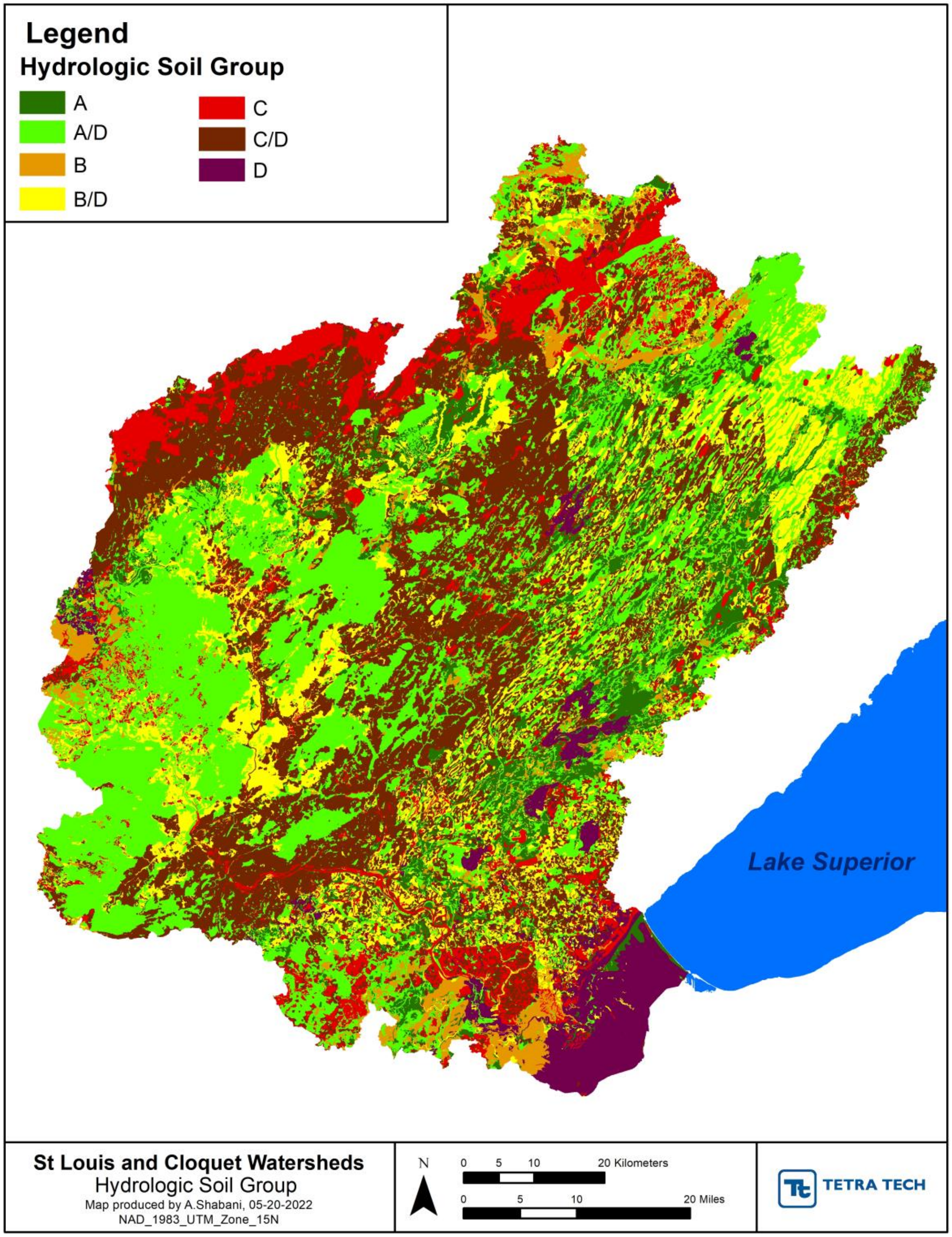

Figure 2-4. Hydrologic soil group categories in the HSPF model

2.3.4 HRUs

As previously mentioned, the basic upland unit of the watershed model is the HRU, which represents a common set of characteristics for land use and soils, along with weather station assignment. HRUs were developed consistent with the methods outlined in Tetra Tech (2016a), with some enhancements to incorporate new data sources, and ‘Modeling Guidance for BASINS/HSPF Applications under the MPCA One Water Program’. Separation into slope classes was deemed not necessary for these watersheds because the slope information is largely redundant with the land use and soil classes (Tetra Tech 2016a).

Model land use/cover and soil HSG were combined in ArcGIS to produce a grid with unique values for each combination. The model was simplified by aggregating HSGs represented. In accordance with Modeling Guidance for BASINS/HSPF Applications (Aqua Terra, 2012) and the past effort (Tetra Tech, 2016a), group A soils were lumped with group B soils, and group C soils were lumped with group D soils. For soils with a dual designation (*e.g.*, “B/D”), the two designators represent performance under drained and undrained conditions. The land use/cover processing uses the first (drained) designator for cropland and the second (undrained) designator for all other land uses. Figure 2-5 shows delineated HRUs for St. Louis and Cloquet watersheds.

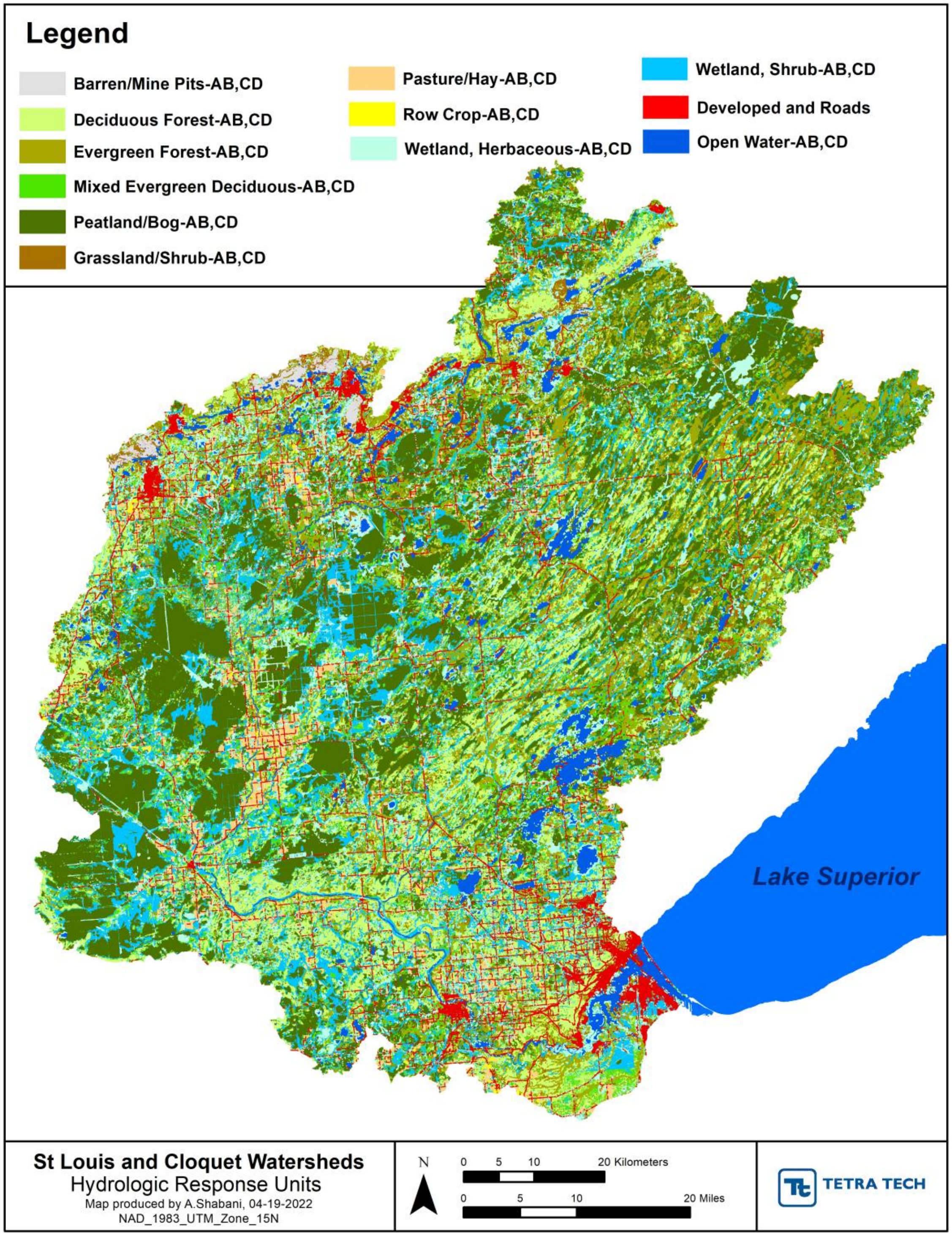

Figure 2-5. HRUs for St. Louis and Cloquet watersheds

Table 2-3. Hydrologic response units for St. Louis and Cloquet watersheds model

Model land use/cover	Soil group	HRU ID range	Area (acres)	Percentage of watershed
Barren/Mine Pits	AB	101 -114	370	0.02
Barren/Mine Pits	CD	115-128	12,522	0.52
Deciduous Forest	AB	130-143	125,873	5.27
Deciduous Forest	CD	144-157	522,851	21.90
Developed	AB	159-172	4,177	0.17
Developed	CD	173-186	20,887	0.87
Evergreen Forest	AB	188-201	94,509	3.96
Evergreen Forest	CD	202-215	175,631	7.36
Grassland/Shrub	AB	217-230	17,604	0.74
Grassland/Shrub	CD	231-244	64,829	2.72
Mixed Evergreen Deciduous	AB	246-259	27,659	1.16
Mixed Evergreen Deciduous	CD	260-273	156,918	6.57
Open Water	AB	275-288	11,700	0.49
Open Water	CD	289-302	64,722	2.71
Pasture/Hay	AB	304-317	9,188	0.38
Pasture/Hay	CD	318-331	44,193	1.85
Peatland/Bog	AB	333-346	22,394	0.94
Peatland/Bog	CD	347-360	551,565	23.10
Roads	AB	362-375	6,533	0.27
Roads	CD	376-389	30,746	1.29
Row Crop	AB	391-404	1,058	0.04
Row Crop	CD	405-418	796	0.03
Wetland, Herbaceous	AB	420-433	4,758	0.20
Wetland, Herbaceous	CD	434-447	73,665	3.09

Wetland, Shrub	AB	449-462	12,723	0.53
Wetland, Shrub	CD	463-476	329,852	13.82

HSPF simulated previous (PERLND) and impervious (IMPLND) surfaces. Previous and impervious HRUs must be calculated and input to the model with a three-digit numeric code for parametrization. To facilitate PERLND parametrization and model calibration a three-digit number was assigned for each base land use (e.g., 100 for barren and 129 for deciduous forest) and it was summed by HSG number (zero for class AB and 14 for class CD) and weather zone number (1-14). This resulted 364 unique three-digit numeric codes for PERLNDs, Table 2-3.

Impervious surfaces accelerate surface runoff generation by reducing infiltration of soil surface layer. Total impervious area (TIA) or mapped impervious area (MIA) is frequently used in rainfall-runoff simulation to calculate impacts of developed/urban lands. Studies have shown that effective impervious area (EIA), or portion of total impervious area that is hydraulically connected to the storm sewer system is a better parameter for runoff simulation in urban areas (Ebrahimian and Wilson, 2015). EIA is usually reported as percentage of total basin and subbasin and it is smaller than TIA, except in highly urbanized basins where EIA could be equal to TIA. NLCD 2016 30 m impervious coverage was used to calculate percentage of MIA within the model HRUs. Sutherland EIA equation for average basin (Equation 1, Sutherland, 1995) was applied to calculate EIA from MIA:

$$EIA = 0.1 \times (MIA)^{1.5} \quad for\ MIA \geq 1 \quad (1)$$

The area of IMPLND for each HRU was then calculated by multiplying EIA and HRU area, and PERLND area was calculated by subtracting IMPLND area from the total HRU area. In the HSPF model IMPLNDs were categorized in a single class and were only differentiated by weather zone. Three-digit numeric codes (101-114) for IMPLND HRUs were defined based on weather zone number.

2.4 POINT SOURCES

There are many permitted major and minor point sources in the St. Louis River watershed (Table 2-4). Time series of permitted point source discharges were extended through WY 2021 for HSPF modeling. Effluent records for the extension period were provided by MPCA and processed for the extension by Tetra Tech. Previously the HSPF model aggregated minor point source inputs by HSPF model subbasin/reach because of the number of facilities in the watershed. To streamline future extensions, and to support the upcoming mercury TMDLs, minor facilities were un-lumped and now each minor facility has separate input time series. In addition to discharge flow, point source discharge loads of carbonaceous biochemical oxygen demand (CBOD), refractory organic N, total ammonia (TAM), nitrate (NO3), orthophosphate (PO4), refractory organic P, dissolved oxygen (DO), total suspended solids (TSS), and heat are simulated by the HSPF model. Time series were derived for the major facilities. For water quality variables for the minor facilities, a constant concentration is assumed and input loads are calculated from discharge flow using a multiplier in the EXT SOURCES block of HSPF. New data were reviewed to update the concentrations for the minor facilities and to develop the extended water quality time series for the major facilities. Point source time series for the full modeling period are stored in the point sources WDM (Watershed Data Management) file that is read in by the model during a run.

Table 2-4. Point sources in the St. Louis and Cloquet watersheds HSPF model

ID	Facility Name	Type
MN0020117	Chisholm WWTP	Major
MN0030627	Hibbing WWTP North Plant	Major
MN0030643	Hibbing WWTP South Plant	Major
MN0030163	Virginia WWTP	Major
MN0049786	WLSSD WWTP	Major
MN0059633	Arcelor Mittal Minorca Mine Inc. - Laurentian	Minor
MN0020494	Aurora WWTP	Minor
MN0020656	Babbitt WWTP	Minor
MN0053279	Biwabik WWTP	Minor
MN0022969	Buhl Kinney WWTP	Minor
MN0041556	Calumet Superior LLC - Duluth Petroleum	Minor
MN0042536	Cleveland Cliffs LLC	Minor
MN0054089	Cliffs Erie, LLC - Hoyt Lakes	Minor
MN0057428	Conrad Fafard Inc.	Minor
MN0060704	Dyno Nobel Inc.	Minor
MNG640031	Eveleth WTP	Minor
MN0023337	Eveleth WWTP	Minor
MNG580048	Floodwood WWTP	Minor
MN0000990	MN Power-Laskin	Minor
MN0046043	Georgia Pacific Wood Products LLC	Minor
MNG250105	Gerdau Ameristeel	Minor
MN0020125	Gilbert WWTP	Minor
MNG250101	Great Lakes Aquarium	Minor
MN0020206	Hoyt Lakes WWTP	Minor

MNG580049	Iron Junction WWTP	Minor
MN0045161	ISD 704	Minor
MN0000337	Jarden Home Brands	Minor
MNG200019	McKinley WTP	Minor
MN0024031	McKinley WWTP	Minor
MNG580034	Meadowlands WWTP	Minor
MN0067687	Mesabi Nugget Delaware LLC	Minor
MN0056979	Miller Hill Mall	Minor
MN0046256	MN Power Arrowhead	Minor
MN0001015	MN Power Hibbard	Minor
MN0040835	Mountain Iron WWTP	Minor
MN0046981	Northshore Mining Co	Minor
MN0001431	Sappi Cloquet LLC	Minor
MNG255070	Tate & Lyle Ingredients Americas LLC	Minor
MN0052116	United Taconite	Minor
MN0044946	United Taconite - Thunderbird Mine	Minor
MN0052493	US Steel Corp	Minor
MNG250102	USG Interiors LLC - Cloquet	Minor
MN0003379	Virginia Department of Public Utilities	Minor
MN0061549	Waupaca North Woods LLC	Minor
MN0053384	Wisconsin Central Ltd - Ore Dock	Minor
MN0000361	Wisconsin Central Ltd - Proctor Railroad Yard	Minor
MN0054089	Poly Met Mining	Minor
MN0069078	Mesabi mining area	Minor
MN0055719	Duluth Steam	Minor

2.5 APPROPRIATIONS

Surface water is withdrawn from rivers and lakes for a variety of purposes, including municipal/domestic supply, industrial processing, and power plant cooling. Monthly or annual records of these appropriations are reported to Minnesota DNR. The cooling water uses, while large, result in a relatively small amount of water consumption through evaporation; however, these are important to include in the model because of their impacts on water temperature, which in turn influences water quality kinetics. The municipal/domestic and industrial processing uses are typically paired with records of waste discharges.

Water use reports for permitted appropriations in the St. Louis and Cloquet watersheds from the Minnesota Permitting and Reporting System (MPARS) were provided by MPCA for the previous modeling period (1993-2014). Monthly water use reported by the permit holders in Table 2-5 are included in the HSPF model with corresponding DSNs shown in the table.

Table 2-5. MPARS permitted appropriations in the HSPF Model

MPARS Permit Number	Permit Holder	Average Monthly Appropriation in 2013-2014 (MG/month)	Model Reach	Source	DSN
1975-2165	Sappi Cloquet LLC	166	208	St. Louis River	2082
1963-0691	United Taconite LLC	175	249	St. Louis River	2492
1962-0182	City of Aurora	7.36	260	St. James Pit	2601
1949-0135	Cliffs Erie LLC	91.1	262	Colby Lake	2622
1954-0036	City of Hoyt Lakes	11.9	262	Colby Lake	2622
1950-0172	Minnesota Power-Laskin[1]	43.7	262	Colby Lake	2623
1987-2036	Virginia Public Utilities	9.18	601	Silver Lake	6012
1984-2191	City of Eveleth	19.4	603	Ely Lake	6030

[1]Minnesota Power is simulated solely as a heat source since it withdraws from and discharges water to the same reach.

To extend the HSPF model time series through 2021, water use reports for 2015-2021 were acquired from MPCA and were processed in the same manner as the previous time series. Monthly flows were calculated for each permit holder for each year in gallons per month, then converted to acre-feet per day for unit compatibility with the HSPF model. Because Cliffs Erie and City of Hoyt Lakes both pull from Colby Lake, these are summed and then used for DSN 2622. The series for Minnesota Power Laskin is turned off in the UCI because it withdraws and then discharges the same amount of flow (through water). After combining the two time periods to extend the model time series for flow appropriations, time series plots for each permit number were created and reviewed for quality assurance.

2.6 ATMOSPHERIC DEPOSITION

The HSPF model simulates wet and dry deposition of ammonia-N and nitrate-N to pervious surfaces, impervious surfaces, and water bodies as well as the wet and dry deposition of phosphorus direct to the model reaches. Atmospheric deposition of phosphorus to the uplands is not simulated because it is implicit in the sediment potency representation of pervious land loading and the buildup/washoff representation of impervious land loading of phosphorus.

Seasonal wet deposition concentrations of ammonia and nitrate N (as mg/L) collected by the National Atmospheric Deposition Program (NADP) station MN16 (Marcell Experimental Forest) were previously used to develop an atmospheric deposition time series for the original modeling period (1993-2014). To extend the HSPF model to current conditions, Tetra Tech downloaded the seasonal wet deposition concentrations of ammonia and nitrate for the NADP MN16 monitoring station, converted to concentrations as N, and extended the model time series through the fall 2021 season (new model end date of 9/30/2021).

The Clean Air Status and Trends Network (CASTNET) monitors the dry deposition of ammonia and nitrate. The closest CASTNET station to the St. Louis and Cloquet watersheds is the Voyageurs National Park (VOY413) and this station has been in operation since 1996. Seasonal dry deposition rates (lb/acre) of ammonia and nitrate from the VOY413 monitoring station were converted to mass-based fluxes of N for use in the HSPF model (i.e., lb-N/acre), with pre-1996 dates filled with monitoring from Perkinstown, WI (PRK134). Where data gaps existed in the VOY413 seasonal time series, monitoring data from PRK134 was used to gap fill missing dates with a long-term ratio of VOY413 to PRK134 data. In recent work, the CASTNET dry deposition rate time series of ammonia and nitrate were extended to the fall 2021 season.

After downloading the NADP wet deposition concentration and CASTNET dry deposition flux data and extending the time series, time series plots were created and reviewed for quality assurance. Figure 2-6 portrays the trend in wet atmospheric deposition over time, and Figure 2-7 shows trends in dry deposition flux over the extended 1/1/1993 to 9/30/2021 model time period. The seasonal time series were then converted to monthly format and imported to a model WDM file for use in the HSPF model.

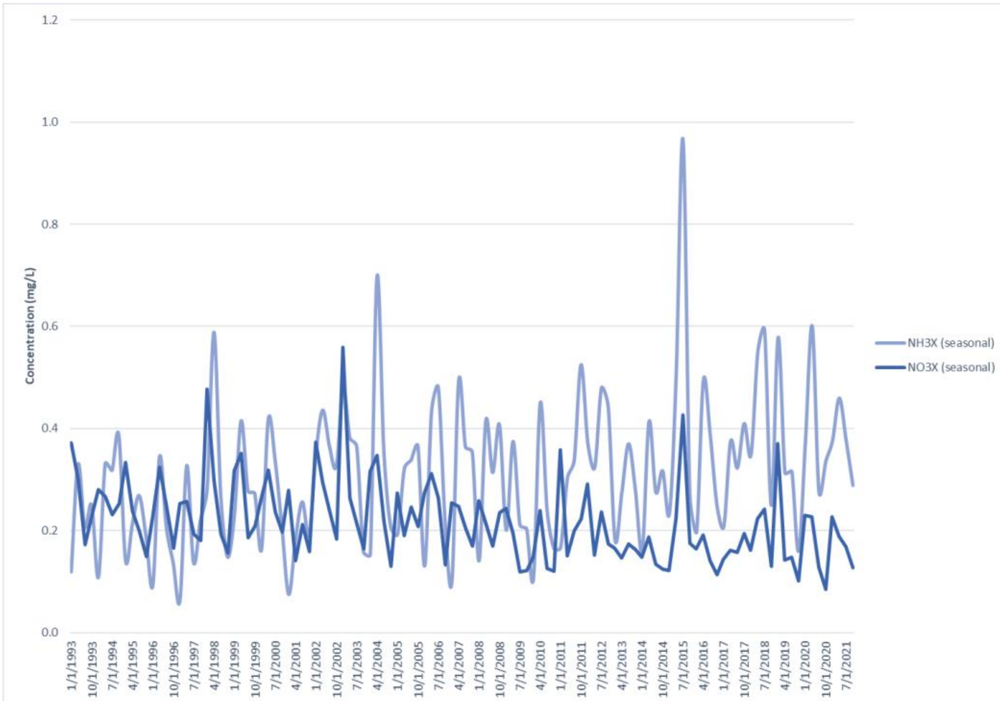

Figure 2-6. Time series of wet deposition concentrations (NH3 and NO3)

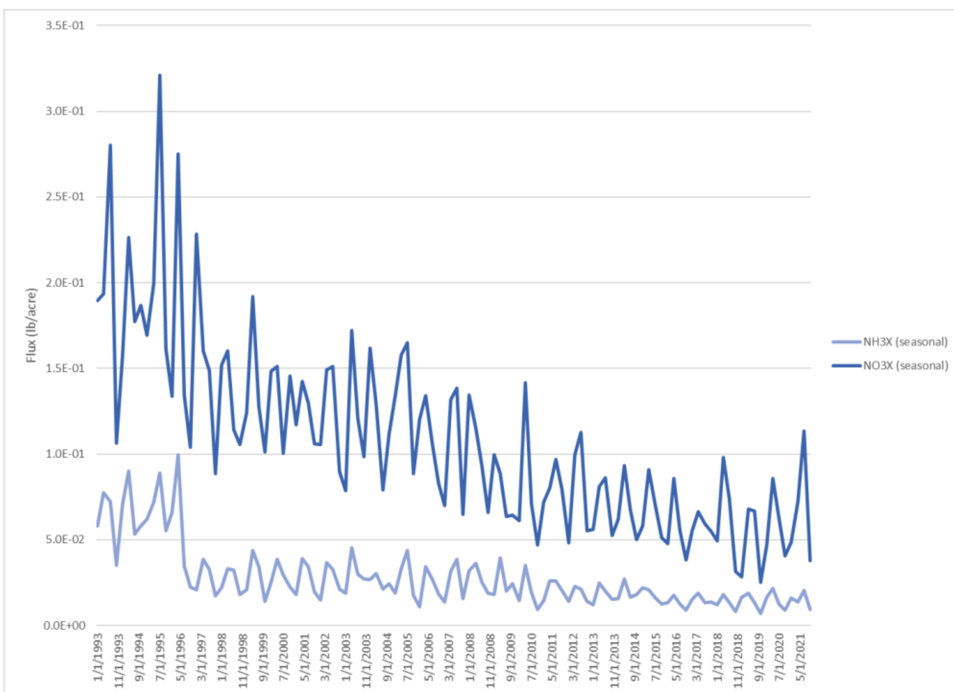

Figure 2-7. Time series of dry deposition fluxes (NH3 and NO3)

2.7 REACH HYDRAULICS

HSPF is a water balance (hydrologic) model and not a hydraulic model. HSPF represents stream reaches as one-dimensional fully mixed reactors and, while maintaining mass balance, does not explicitly conserve momentum. To simulate the details of hydrograph response to storm events HSPF relies on Function Tables (FTables) that describe the relationship of reach discharge, depth, and surface area to storage volume. At stable median flow the model results are not particularly sensitive to the details of the FTable specification, as outflow tends to approximate the net inflows; however, the shape of the response to storm event peaks can be sensitive to FTable details. As part of the model update, new hydraulic information was used to refine select FTables as discussed below.

2.7.1 Road Culverts

Hydraulics of some reaches are influenced by road culverts. In particular, where road culverts are situated at or near the outlet (i.e., considered the lower one-third of the model reach), the culvert controls the discharge rate, especially at higher flows. During the original model development FTables for select reaches were derived using culvert information. New culvert information in the watershed was reviewed to support revisions to model FTables. The Geospatial Water Resources Team at the Minnesota Department of Natural Resources maintains and publishes the Culvert Inventory Application Suite for the collection, storage, review, and distribution of culvert, bridge, and other data (https://www.dnr.state.mn.us/watersheds/culvert_inventory/index.html). The geospatial culvert inventory was downloaded and applicable culverts were spatially identified. In addition, St. Louis County Public works provided their culvert inventory and culvert design information to support FTable development. Criteria for use in model FTable development included 1) that the culvert aligns with a model reach, 2) that the culvert is located in the bottom one-third of the reach OR is downstream of most of the subbasin's contributing drainage area, 3) adequate design information is available (e.g., culvert shape, span, rise), and 4) there were not better alternatives for the FTable (e.g., rating curves and cross sections downstream).

Calculation of flow through a culvert is complicated because culverts are generally impose a significant on flow and are subject to a range of gradually varied and rapidly varied flow regimes under either outlet control (in which the tailwater elevation has a significant influence) or inlet control (in which the headwater depth at the culvert inlet has a major influence). Culvert calculations must simultaneously address both possibilities. The Federal Highway Administration program HY-8 (https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/) is designed for such applications and Version 7.70 (June 2, 2021) was used for FTable development. Available culvert design information is often limited unfortunately. Thus, supplementary information was derived from LiDAR data. LiDAR data were obtained from the Minnesota IT Services Geospatial Information Office (https://www.mngeo.state.mn.us/chouse/elevation/lidar.html). An overview of the method employed follows:

1. Use the LiDAR to get an approximate estimate of the width of the stream downstream of the culvert (after it widens to a normal width), the length of the road crest (the low portion of the roadway atop the culvert which is the approximate width that will flood if the road is over-topped), road pavement width, length of the culvert, elevation of the water surface upstream and downstream of the culvert, and the water surface grade in the channel downstream of the culvert. Estimate the height (for box culverts) or diameter (for round culverts) as appropriate (unless provided through the culvert data source).
2. Estimate the true bottom elevation of the invert of the partially full culvert. If the culvert top is not discernable in the LiDAR, assume that there is 1.5 ft between the culvert top and the road bed.
3. Use the LiDAR to create a detailed cross-section upstream of the culvert at a location that represents the typical valley cross-section in the area.
4. Open HY-8 and enter culvert information for tailwater data, roadway data, culvert data, and site data. Do the first run with Discharge Method of "Minimum, Design, and Maximum" with arbitrary flows. This yields an estimate of the Overtopping Flow. The model is then run again with the maximum set to a number

rounded above the Overtopping Flow, and a third time with the maximum set to 10 times the Overtopping Flow.

5. Combine the two tables from step 4 to establish the upstream depth to discharge relationship.
6. To estimate the surface area of the reach, first the stream width is approximated for each flow depth. This is done by dividing the discharge by the velocity to obtain the cross-sectional area and then divide the cross-sectional area by depth to estimate the width. Multiply the width by the reach length to obtain the surface area.
7. Multiply the surface area by the depth to estimate the reach volume.

2.7.2 Rating Tables

A rating table is used to convert an observed measurement of gage height to an estimate of flow. Rating tables change over time as the channel shape changes in response to storm events. At the basin-scale of modeling, however, the details of elevation and cross-sectional area within individual stream segments are of less importance; rather, the model needs a reasonable representation of the stage-storage-discharge relationship. This can be obtained from recent rating tables either without or with accompanying cross sections (e.g., via information collected about channel geometry in the field such as width and cross-sectional area as provided at many USGS streamflow monitoring sites). FTables were constructed in the original model from rating tables both with and without cross section information. FTables corresponding with USGS streamflow gages were updated using the latest information available from USGS (e.g., St. Louis River near Skibo, MN, Stoney Brook at Pine Drive near Brookston, MN).

2.7.3 Lakes

There are several reservoirs and lakes within the St. Louis and Cloquet watersheds that influence hydraulics and hydrology. The largest reservoirs are generally used for hydropower production, with the majority owned and operated by Minnesota Power. Lakes and reservoirs typically have outflows governed by dam/weir characteristics and/or active management operations. Lake-based FTables take precedence over other FTable development options. Lake-specific FTables should be included to the extent possible, however, data on storage capacity and operations is often limited. During the development of the original HSPF model, segments for which lake-based FTables should be derived were identified and prioritized. One important aspect of criteria for this decision is that the lake must align with a model reach and be located near the outlet (or towards the downstream end of the model segment). Lakes that do not align with model reaches are typically on smaller streams that are not explicit in the basin-scale model. Such lakes are represented as water land use. This method accounts for the lake area and mass balance dynamics (i.e., precipitation, evaporation) through parameter assignments that capture surface storage and gradual flow release regimes. While this is certainly an approximation, it is sufficient at the scale of modeling a large watershed.

Lake outflows are modeled in the HSPF model in two ways. First, lake-specific FTables were derived from available bathymetric data. Second, stage, storage, and outflow data for several of the reservoirs were provided by Minnesota Power and used to generate demand-based outflow time series for the HSPF model. The methods used to derive lake FTables from bathymetric data are described in the original model report (Tetra Tech, 2016). Lakes with demand-based outflow time series are simulated with two exits. The first exit is set up to compute outflow as the maximum of the volume-based (FTable computed) outflow and the demand outflow. The Ftable has three discharge series (columns 4 through 6), of which columns 4 and 5 are relevant to the first exit. Column 4 is a standard depth-discharge relationship, while column 5 is all zeros. A column index (COLIND) time series is used to switch between columns 4 and 5 during the simulation. For periods when there is non-zero demand outflow, the COLIND time series points to column 5, as a result of which only the measured outflow is represented for this exit. Outflow for exit 2, which is usually very small, is also volume-based, and is a calibration parameter for reservoir storage adjustment.

The Minnesota Department of Natural Resources publishes "Lake Bathymetric Outlines, Contours, and DEM" through the Minnesota Geospatial Commons. Lake contour maps were digitized to generate the bathymetric contours provided in the coverage. For each explicitly modeled lake in the HSPF model, the available bathymetric data were reviewed. Particularly, the source (i.e., map) date from which the digitized contours originate to identify new data for incorporation into the model. All of the source dates pre-date when the FTables for the original model were developed, thus, the lake FTables were maintained (Table 2-6). As part of the model update, the demand-based outflow time series for Whiteface Reservoir, Island Lake Reservoir, Boulder Lake, Fish Lake Flowage, and Wild Rice Lake were extended through WY 2021. Outflow records for the model extension period were provided directly by Minnesota Power (M. Chambers, personal communication, December 16. 2021).

Table 2-6. Explicitly modeled lakes in the St. Louis and Cloquet HSPF model

Lake	Model Reach	Bathymetry Data Date	Outflow Time Series
Fond du Lac Reservoir	205	1993	No
Thomson Reservoir	207	1974	No
Cloquet Reservoir	208	1975	No
West Two River Reservoir	245	1968	No
Esquagama Lake	253	1949	No
Wynne Lake	254	Not listed	No
Colby Lake	262	1940	No
Long Lake	275	1957	No
Whiteface Reservoir	289	1997	Yes
Knife Falls Reservoir	501	1974	No
Scanlon Reservoir	502	1974	No
Mashkenode Lake	601	1963	No
Manganika Lake	602	1963	No
Ely Lake	603	1986	No
Island Lake Reservoir	407	1965	Yes
Boulder Lake	408	1973	Yes
Fish Lake Flowage	422	1994	Yes
Wild Rice Lake	423	1955	Yes

2.7.4 HEC-RAS

The US Army Corps of Engineers maintains the Hydrologic Engineering Center's River Analysis System (HEC-RAS; https://www.hec.usace.army.mil/software/hec-ras/). HEC-RAS simulates hydraulics under steady and unsteady flow conditions. HEC-RAS is the standard model for the Federal Emergency Management Agency (FEMA) flood insurance map studies. HEC-RAS modeling typically involved detailed analyses of stream channel and restricting structure information. HEC-RAS model output can be used to develop FTables for HSPF by evaluating discharge at HSPF model reach outlets and summing water volume and surface area at upstream segments along the reach. HEC-RAS models, however, are typically only available for limited areas.

The Minnesota Department of Natural Resources has launched a web mapping application that allows users to search for and download available HEC-RAS models in the state (https://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/fema_app.html). Within the HSPF model extent for the St. Louis and Cloquet River watersheds, the only HEC-RAS model available is for a small segment of the lower St. Louis River. Unfortunately, the model was developed in 1977 in HEC-2. HEC-RAS replaced HEC-2 in the mid-1990s, modernizing and implementing more robust hydraulic routines and computational procedures. HEC-RAS remains the current standard for FEMA flood modeling. The St. Louis River HEC-2 model has not been updated to HEC-RAS based on the information available. During the original development of the HSPF model, the HEC-2 model files were provided and it was noted these lack georeferencing information rendering the model unusable for the application at hand. In addition, it was noted that this area is largely controlled by dams and other options are available for FTable development. Thus, the HEC-2 model was not employed for FTable development at that time. Given no new HEC-RAS models are available, no FTables were revised with HEC-RAS.

2.7.5 Other Unsurveyed Reaches

During the original model development, a number of reaches did not have the information described in preceding sections to support FTable development. The FTable for an adjacent subbasin is likely a good approximation for the candidate subbasin with appropriate modifications. This involves modifying the depth-cross sectional area-volume-discharge relationship based on the drainage area ratio. The candidate reach length is used to obtain reach-specific surface area and volume. Delineations in the southern portion of the drainage area were refined as discussed in Section 2.1 and this generated two new model reaches – 305 and 306. The adjacent method was applied to develop FTables for these model reaches.

2.7.6 Reach FTable Approaches

The FTable methods applied in the current HSPF model are summarized in Table 2-7.

Table 2-7. Reach FTable methods

St. Louis					Cloquet	Key
201: SFP	224: SFP	247: SFP	270: SFP	293: Adj	401: Adj	Culvert: Analysis with HY-8
202: SFP	225: SFP	248: SFP	271: Culvert	294: RTn	402: RTC	Adj: Extrapolate adjacent FTable
203: SFP	226: Culvert	249: RTn	272: SFP	295: SFP	403: Culvert	Lake: Lake bathymetry FTable
204: SFP	227: SFP	250: Adj	273: SFP	296: SFP	404: Adj	RTC: Rating table with cross section
205: Lake	228: Adj	251: Adj	274: SFP	297: SFP	405: SFP	RTn: Rating table, no cross section
206: Culvert	229: SFP	252: Culvert	275: Lake	298: Culvert	406: Adj	SPF: BASINS standard method
207: Lake	230: Adj	253: Lake	276: SFP	299: Culvert	407: Lake	XS: WinXSPro cross section analysis
208: Lake	231: SFP	254: Lake	277: SFP	300: SFP	408: Lake	
209: Adj	232: Adj	255: SFP	278: SFP	301: SFP	409: SFP	
210: SFP	233: XS	256: SFP	279: RTn	302: SFP	410: SFP	
211: Adj	234: XS	257: Adj	280: Adj	303: Culvert	411: SFP	
212: RTC	235: Culvert	258: RTC	281: SFP	304: RTC	412: Adj	
213: Adj	236: RTC	259: RTC	282: Adj	305: Adj	413: Adj	
214: Adj	237: XS	260: RTC	283: Culvert	306: Adj	414: Adj	
215: SFP	238: Adj	261: Adj	284: SFP	501: Lake	415: Adj	
216: SFP	239: XS	262: Lake	285: SFP	502: Lake	416: Adj	
217: SFP	240: XS	263: SFP	286: Adj	505: RTC	417: RTn	
218: Culvert	241: XS	264: RTC	287: Adj	601: Lake	418: Adj	
219: SFP	242: Adj	265: Adj	288: Adj	602: Lake	419: Adj	
220: SFP	243: SFP	266: Culvert	289: Lake	603: Lake	420: SFP	
221: SFP	244: SFP	267: Adj	290: Adj	604: SFP	421: SFP	
222: Culvert	245: Lake	268: Adj	291: RTn		422: Lake	
223: SFP	246: SFP	269: Adj	292: Adj		423: Lake	

3.0 HYDROLOGIC CALIBRATION AND VALIDATION

3.1 APPROACH

The level of performance and overall quality of the hydrologic calibration is evaluated in a weight of evidence approach that includes both visual comparisons and quantitative statistical measures. The calibration proceeds in a sequential, yet often iterative, manner through (1) general representation of the overall water balance, (2) calibration of snow accumulation and melt, (3) assurance of consistency with satellite-based estimates of actual ET, and (4) detailed calibration relative to flow gaging records for seasonal flows, shape of the flow duration curve, and hydrograph shape.

Given the inherent errors in input and observed data and the approximate nature of model formulations, absolute criteria for watershed model acceptance or rejection are not generally considered appropriate, or widely accepted, by most modeling professionals. In contrast, most decision makers want definitive answers to the questions—"How accurate is the model?" and "Is the model good enough for this evaluation?" Consequently, the current state of the art for model evaluation is to express model results in terms of ranges that correspond to "very good," "good," "fair," or "poor" quality of simulation fit to observed behavior. These characterizations inform appropriate uses of the model: for example, where a model achieves a good to very good fit, decision-makers often have greater confidence in having the model assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit, decision makers may assume a much less prominent role for the model results in the overall weight-of-evidence evaluation of management options.

For HSPF and similar watershed models, a variety of performance targets have been documented in the literature, including Donigian et al. (1984), Lumb et al. (1994), Donigian (2000), and Moriasi et al. (2007). Based on these references and past experience, the HSPF performance targets for simulation of hydrology are summarized in Table 3-1. Model performance is generally deemed fully acceptable where a performance evaluation of "good" or "very good" is attained. It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable (Donigian, 2000).

The model calibration generally attempts to achieve a good balance between the relative error metrics and the Nash-Sutcliffe coefficient of model fit efficiency (NSE; Nash and Sutcliffe, 1970). Unlike relative error, NSE is a measure of the ability of the model to explain the variance in the observed data. Values may vary from $-\infty$ to 1.0. A value of NSE = 1.0 indicates a perfect fit between modeled and observed data, while values equal to or less than 0 indicate the model's predictions of temporal variability in observed flows are no better than using the average of observed data. The accuracy of a model increases as the value approaches 1.0. Moriasi et al. (2007) suggest that achieving a relative error on total volume of 10 percent or better and an NSE of 0.75 or more on monthly flows constitutes a good modeling fit for watershed applications.

Table 3-1. Performance targets for the HSPF hydrologic simulation (magnitude of annual and seasonal relative mean error, and daily and monthly Nash-Sutcliffe Coefficients [NSE])

Model Component	Very Good	Good	Fair	Poor
Error in total volume	≤ 5%	5 - 10%	10 - 15%	> 15%
Error in 50% lowest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%

Error in 10% highest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
Error in storm volume	≤ 10%	10 - 15%	15 - 25%	> 25%
Winter volume error (JFM)	≤ 15%	15 - 30%	30 - 50%	> 50%
Spring volume error (AMJ)	≤ 15%	15 - 30%	30 - 50%	> 50%
Summer volume error (JAS)	≤ 15%	15 - 30%	30 - 50%	> 50%
Fall volume error (OND)	≤ 15%	15 - 30%	30 - 50%	> 50%
NSE on daily values	> 0.80	> 0.70	> 0.60	≤ 0.60
NSE on monthly values	> 0.85	> 0.75	> 0.65	≤ 0.65

3.2 SNOW

Snow accumulation and melt is an important part of hydrology in this northern watershed. The model extension and update switched from station to gridded weather data sources thus snow dynamics were recalibrated. Daily snow depth and snow water equivalent (SWE) simulated by the HSPF model were compared to observed snow datasets available from the National Snow and Ice Data Center (NSIDC). The NSIDC SNOw Data Assimilation System (SNODAS) data products integrate remote sensing snow data from satellites, ground observations and aircrafts to provide estimates of snow cover and associated parameters (Carroll et al., 2001). Snow depth and SWE data are available from September 2003 to present at a spatial resolution of 1 km by 1 km and a temporal resolution of 1 day for the continental United States. HSPF simulated time-series were compared to SNODAS SWE aggregated by weather region to guide the calibration of snow accumulation and melt in the watershed. The calibration focus period was January 2004 through September 2021.

During the snow depth calibration process, values of parameters in the SNOW-PARM1 and SNOW-PARM2 blocks of the HSPF model were configured by land cover type, weather zone, or for the whole study area. The calibrated values of these parameters are provided in Table 3-2. Table 3-3 provides calibration metrics to compare observed and simulated snow water equivalent for each model weather zone and watershed-wide. Graphical comparisons for the watershed are shown in Figure 3-1.

Based on the statistical metrics and visual plots, the snow accumulation and melt simulation is representative of these mechanistic processes in the watershed. It is important to note that snow fall, pack accumulation, and melt in the model are highly sensitive to ambient air temperature. Small inconsistencies in air temperatures may have potentially significant impacts on snow behavior, including whether precipitation is interpreted by the model as snow or rain, as well as when snow melt will occur. The calibration for hydrology incorporated snow catch factors that are greater than 1.0 for some weather regions to compensate for the fact that SWE may be under estimated due to wind effects, characteristics of remote sensing technology, and ground gage efficiency and exposure. Snow melt in the spring seems to occur earlier in the HSPF model compared to the timing indicated by streamflow monitoring. This is partially because the HSPF model is not very sensitive to the few parameters that influence the timing and rate of snow melt. This is consistent with findings from HSPF applications for other Minnesota watersheds. Nevertheless, snow dynamics are represented reasonably well by the HSPF model.

Table 3-2. HSPF snow calibration parameter values

Parameter	Description	Calibrated Value or Range	Recommended Range
SHADE	Fraction shaded from solar radiation, varied by land use/cover	0 – 0.8	0 - 0.8
SNOWCF	Snow gage catch correction factor	1.0 – 1.5	1.0 - 2.0
COVIND	Snowfall required to fully cover surface	1.0 – 8.0	0.1 - 10.0
RDCSN	Density of new snow	0.10	0.05 - 0.30
TSNOW	Temperature at which precipitation becomes snow	34.0	30.0 - 40.0
SNOEVP	Snow evaporation factor	0.0	0.0 - 0.5
CCFACT	Condensation/convection melt factor	0.5	0.5 - 8.0
MWATER	Liquid water storage capacity in snowpack	0.2	0.005 - 0.2

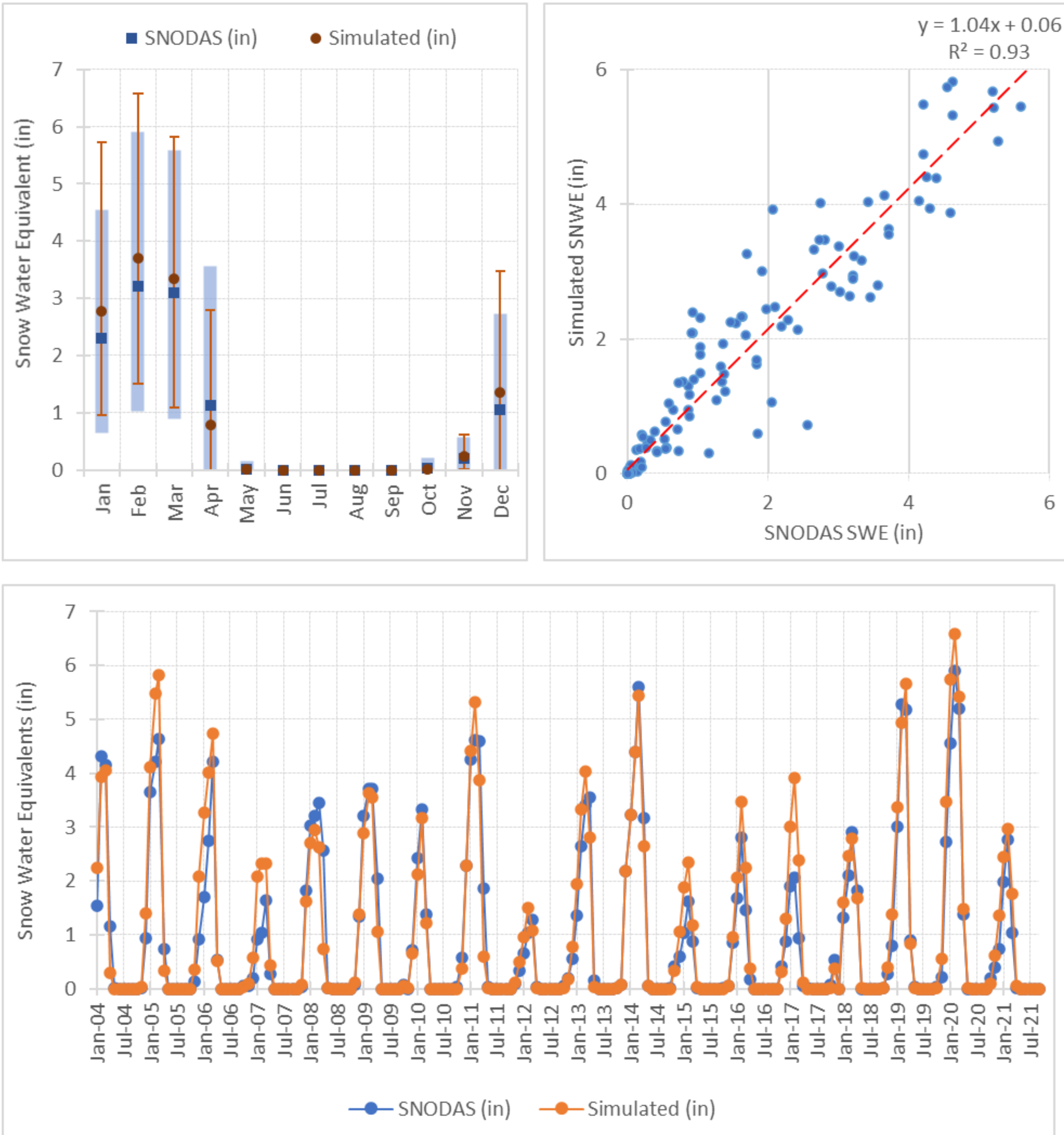

Figure 3-1. Comparison of SNODAS and HSPF simulated snow water equivalent for the watershed

Table 3-3. Comparison of SNODAS and HSPF simulated snow water equivalent by weather zone

Weather Zone	Relative Error	Monthly NSE	Monthly R^2
1	-29%	0.80	0.88
2	0%	0.88	0.88
3	5%	0.87	0.88
4	13%	0.82	0.85
5	22%	0.80	0.86
6	1%	0.91	0.91
7	14%	0.88	0.91
8	20%	0.81	0.88
9	33%	0.80	0.93
10	15%	0.88	0.91
11	18%	0.77	0.85
12	21%	0.80	0.89
13	2%	0.88	0.89
14	24%	0.69	0.83
Watershed	11%	0.91	0.93

3.3 EVAPOTRANSPIRATION

Evapotranspiration (ET) is the sum of transpiration of soil water by plants and evaporation of water from the soil matrix, standing/open water, and leaf surfaces (e.g., intercepted precipitation). ET is crucial to the hydrologic calibration because it is the largest component of the water balance in a watershed. Actual ET has often been unconstrained in watershed models due to a lack of observed data. However, remotely sensed, gridded ET data are now available for model applications, including the Simplified Surface Energy Balance (SSEBop) dataset that provides estimates of global terrestrial ET (Savoca et al, 2013). SSEBop uses the Simplified Surface Energy Balance (SSEB) approach (Senay et al 2007, 2011a, 2011b, 2013) to estimate actual ET as a function of remotely sensed MODIS thermal imagery (acquired every eight days). In some Minnesota HSPF simulations in the past, MODIS ET data have been used directly as a comparison to simulated ET. While both MODIS and

SSEBop perform similarly well on an annual time step, it has been found that SSEBop appears to produce a less biased result than MODIS across different land uses and climate zones (Velpuri et al., 2013). Thus, SSEBop was applied for the hydrologic calibration. SSEBop ET data products are currently available 2000 – 2021 and the entire period was used for model calibration. These data are imprecise because these are not direct measurements of actual ET, however, are useful for checking that modeled ET patterns are realistic, and the estimates are applied as such.

Monthly ET estimates for the watershed were extracted from the global SSEBop dataset. The gridded data were aggregated by model weather region to support the ET calibration. The aggregated monthly data were compared to ET (TAET) simulated by the model and used to inform the pan coefficients that convert Penman Pan PET to land surface PET in the model; this required recalibration because of the switch from station to gridded weather data. The pattern of observed monthly evapotranspiration was also used to refine the precipitation interception (MON-INTERCEP) and lower soil zone ET (MON-LZETPARM) parameter blocks in the HSPF model.

Figure 3-2 shows mean monthly simulated evapotranspiration in comparison with SSEBop estimates for the watershed. Summary statistics are listed in Table 3-4. In general, the simulated ET is representative of SSEBop estimates, with some deviations. SSEBop predicts a slower ramp up of ET in the spring and higher summer peak compared to HSPF; this is similar to results observed in HSPF models developed for other Minnesota watersheds. This may be because the SSEBop MODIS-based algorithm relies on leaf area to approximate ET whereas a significant portion of the total evaporation during periods of snow melt and early plant growth may come directly from the soil surface.

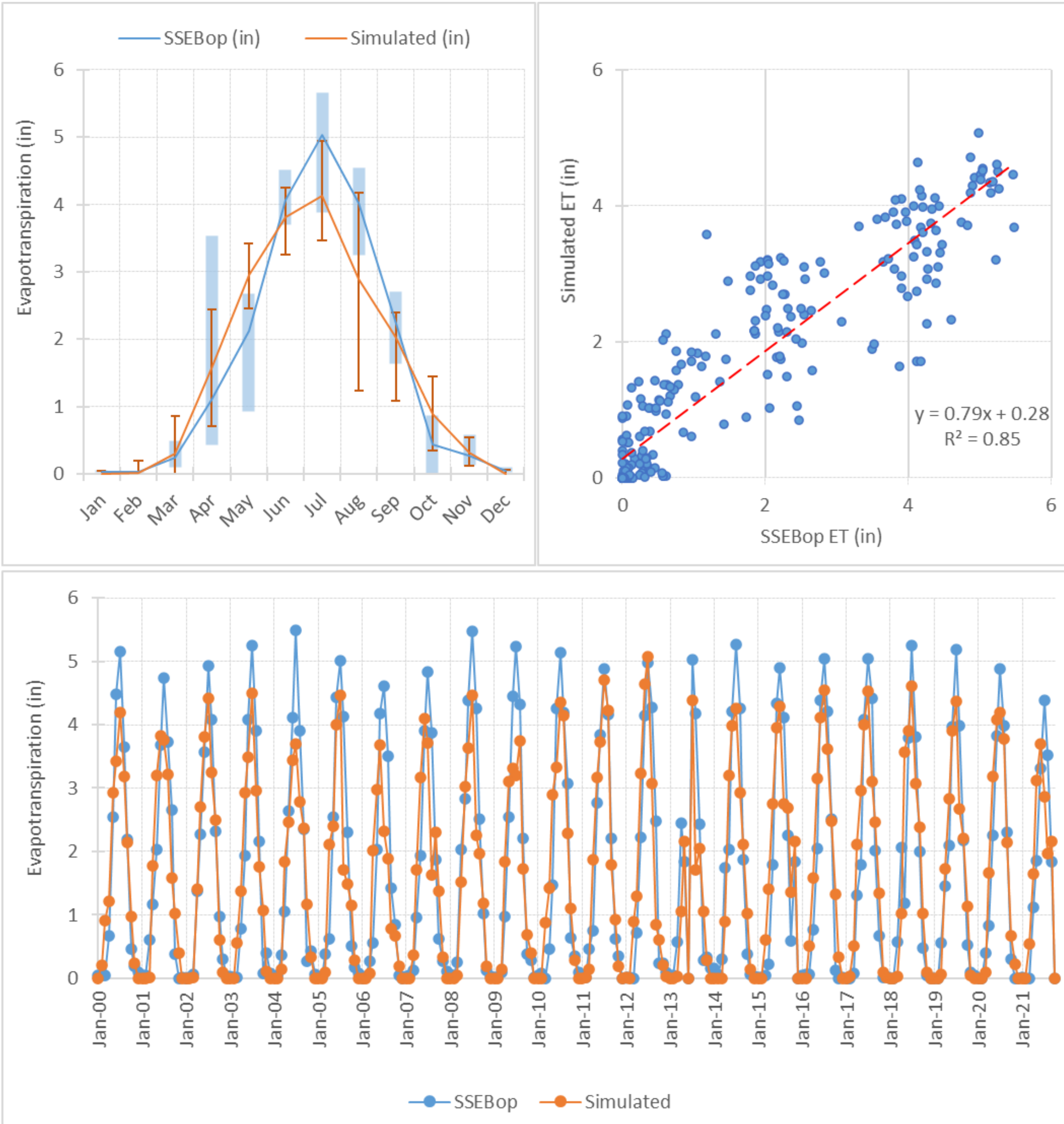

Figure 3-2. Comparison of SSEBop ET and HSPF simulated ET for the watershed

Table 3-4. Comparison of SSEBop ET and HSPF simulated ET by weather zone

Weather Zone	Relative Error	Monthly NSE	Monthly R^2
1	-5%	0.84	0.84
2	-3%	0.84	0.85
3	-5%	0.84	0.85
4	-5%	0.86	0.88
5	-4%	0.87	0.88
6	-3%	0.86	0.87
7	-3%	0.86	0.86
8	-8%	0.83	0.84
9	-2%	0.85	0.85
10	-9%	0.83	0.85
11	-9%	0.82	0.83
12	-6%	0.85	0.86
13	-6%	0.85	0.86
Watershed	-5%	0.86	0.87

SSEBop was missing data for most of the comparison period for weather zone 14 thus it was not evaluated.

3.4 WATER BALANCE

The water balance represented in the St. Louis and Cloquet HSPF model is shown in Figure 3-3. As expected, ET is the highest component at about 60 percent. Simulated ET is near the top end of the range reported by Sanford and Selnick (2013) for northwestern Minnesota, which is expected to be between 50 to 59 percent for this area; and closer to the expected range than the previous model calibration where ET was about 65 percent of the water balance. Groundwater is the next highest component of the water balance at about 30 percent, followed by deep groundwater recharge and interflow. The smallest component of the annual water balance is surface runoff.

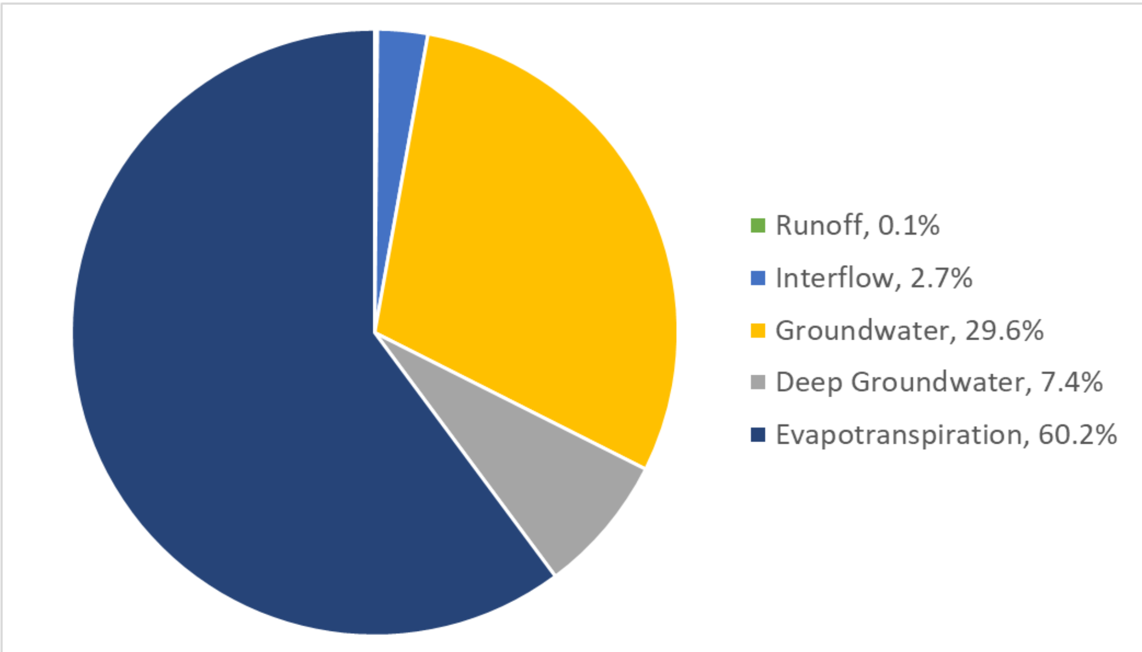

Figure 3-3. Pervious land water balance

3.5 STREAMFLOW CALIBRATION AND VALIDATION

The flow calibration was completed by comparing time-series model results to gaged daily average flow. Key considerations in the hydrology calibration included total flow, the high-flow to low-flow distribution, storm flows, seasonal variations, and daily/monthly NSEs. The criteria in Table 3-1 were used to evaluate the quality of model fit. Parameter values from the original St. Louis and Cloquet HSPF model were applied initially for the recalibration. These starting values were then modified during calibration to optimize model fit while remaining within ranges recommended by USEPA (2000) and AQUA TERRA (2012).

Summary statistics for the hydrology calibration (WY 2012 to WY 2021) and validation (WY 2001 to WY 2011) periods are provided in Table 3-5 and Table 3-6. The Cloquet River near Burnett site is located near the confluence with the St. Louis River. The performance at this location for the calibration is rated very good based on the low relative errors on total flow, 50% lowest flows, 10% highest flows, and both daily and monthly NSEs that are > 0.9. Model performance at the most downstream gaging location on the St. Louis River (near Scanlon) is also rated very good. In addition, the model does a good job of replicating seasonal flows at this location and simulated flow duration curve closely matches observations. Daily and monthly NSEs at both of these locations are higher (i.e., better) for the recalibrated model compared to the original model calibration. Summary plots are provided for these two locations as well as Swan River near Toivola and St. Louis River at Floodwood in Figure 3-4 through Figure 3-19.

The model performs poorest for Colvin Creek near Hoyt Lakes and Second Creek near Aurora. This is not unexpected as these are small headwater streams where local activities and characteristics can have a significant impact on hydrology yet are not feasible to fully represent in a watershed-scale model. The model performs better for the calibration period than the validation period in part because the model represents recent land use/cover and the calibration focused on replicating recent conditions. The overall hydrologic calibration was successful and serves as a solid foundation for the subsequent water quality calibration.

Table 3-5. Hydrologic calibration summary metrics (WY 2012 to WY 2021)

Site Description	Site ID	Model Reach	Relative Error on Total Flow	Relative Error on 50% Lowest Flows	Relative Error on 10% Highest Flows	Daily NSE	Monthly NSE
Cloquet River near Brimson	HYDSTRA 04012001	415	1.4%	18.5%	-2.5%	0.599	0.825
Cloquet River near Burnett	HYDSTRA 04048001	402 + 421	5.1%	2.6%	5.8%	0.905	0.915
Colvin Creek near Hoyt Lakes	HYDSTRA 03143001	266	25.3%	115%	1.1%	0.499	0.628
Embarrass River near Embarrass	HYDSTRA 03153002	254	21.2%	107%	-5.5%	0.696	0.809
Partridge Creek near Hoyt Lakes	HYDSTRA 03149002	262	0.3%	48.2%	-12.8%	0.704	0.826
Second Creek near Aurora	HYDSTRA 03150001	260	18.7%	34.5%	5.32%	0.431	0.387
St. Louis River at Floodwood	HYDSTRA 03034001	227	-7.8%	16.6%	-13.1%	0.853	0.896
St. Louis River near Aurora	HYDSTRA 03138001	267 + 259	-17.1%	5.3%	-19.1%	0.783	0.874
St. Louis River near Forbes	HYDSTRA 03115001	249	-8.9%	2.9%	-5.1%	0.808	0.894
St. Louis River near Scanlon	USGS 04024000	502	-1.7%	2.3%	-9.3%	0.883	0.940
St. Louis River near Skibo	USGS 04015438	505	-9.1%	33.0%	-11.4%	0.500	0.681
Stoney Brook at Pine Drive	USGS 04021520	212	-12.8%	-3.0%	-16.9%	0.727	0.774
Swan River near Toivola	HYDSTRA 03084001	236 + 233	-5.8%	-14.5%	-9.4%	0.709	0.847
Whiteface River nr Meadowlands	HYDSTRA 03055001	279	-1.6%	56.0%	-18.8%	0.834	0.888

Table 3-6. Hydrologic validation summary metrics (WY 2002 to WY 2011)

Site Description	Site ID	Model Reach	Relative Error on Total Flow	Relative Error on 50% Lowest Flows	Relative Error on 10% Highest Flows	Daily NSE	Monthly NSE
Cloquet River near Burnett	HYDSTRA 04048001	402 + 421	13.3%	16.3%	11.8%	0.608	0.644
Partridge Creek near Hoyt Lakes	HYDSTRA 03149002	262	72.5%	207%	21.7%	0.214	0.364
Second Creek near Aurora	HYDSTRA 03150001	260	23.1%	57.6%	11.4%	0.371	0.517
St. Louis River near Aurora	HYDSTRA 03138001	267 + 259	38.1%	75.4%	1.3%	0.640	0.786
St. Louis River near Forbes	HYDSTRA 03115001	249	23.1%	103%	-4.7%	0.826	0.908
St. Louis River near Scanlon	USGS 04024000	502	8.1%	9.6%	-6.3%	0.776	0.876
Stoney Brook at Pine Drive	USGS 04021520	212	6.6%	21.5%	-2.3%	0.455	0.504
Swan River near Toivola	HYDSTRA 03084001	236 + 233	-31.6%	-10.9%	-39.3%	0.655	0.742
Whiteface River nr Meadowlands	HYDSTRA 03055001	279	30.9%	163%	-9.3%	0.676	0.643

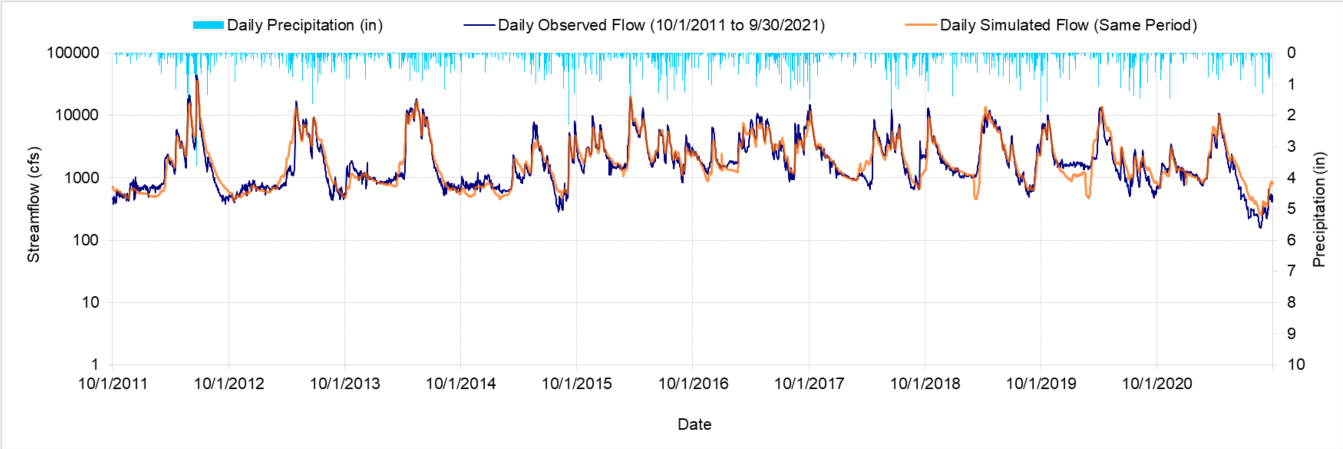

Figure 3-4. Time series of observed and simulated streamflow at St. Louis River at Scanlon

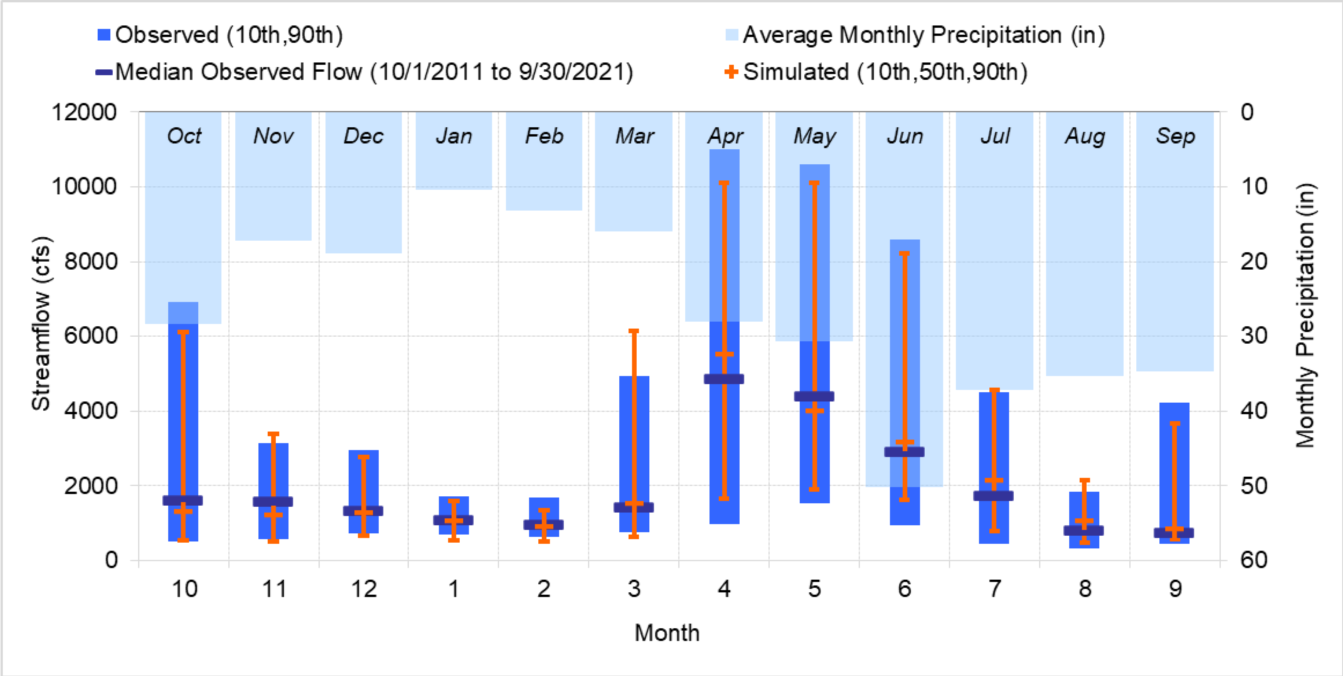

Figure 3-5. Observed and simulated 10th, 50th, and 90th percentile monthly flows for St. Louis River at Scanlon

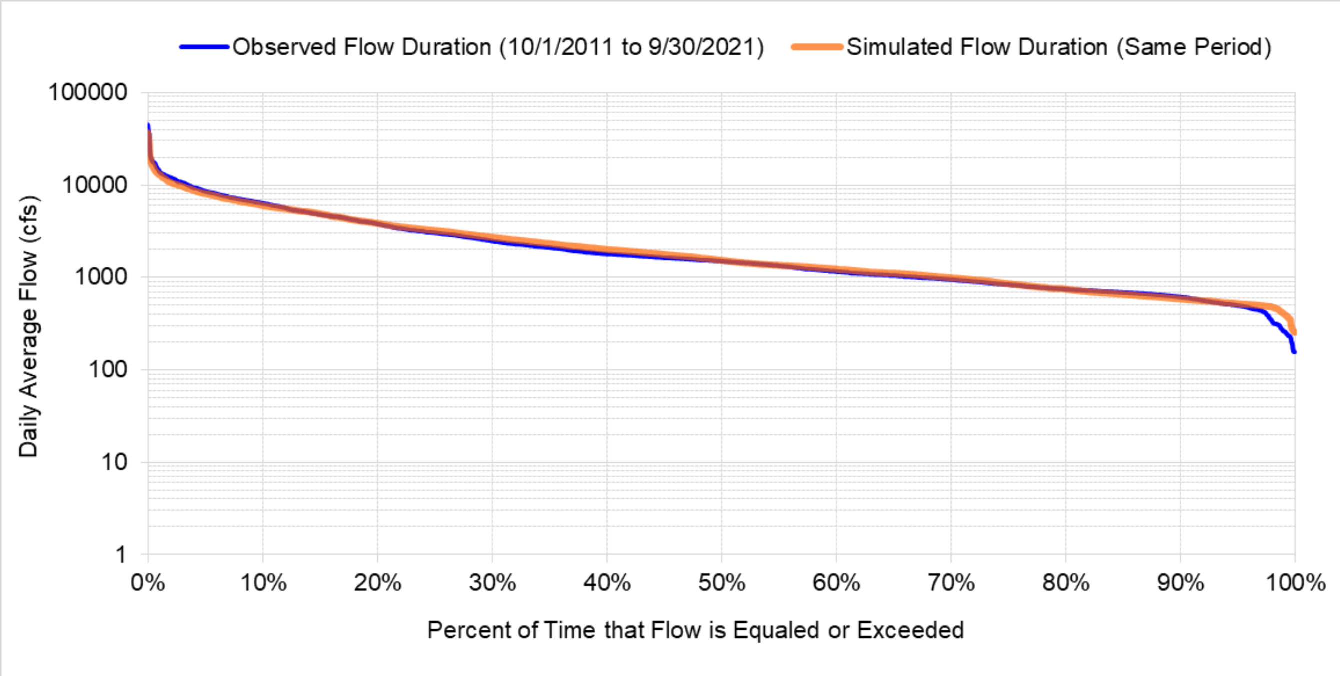

Figure 3-6. Observed and simulated flow duration curves for St. Louis River at Scanlon

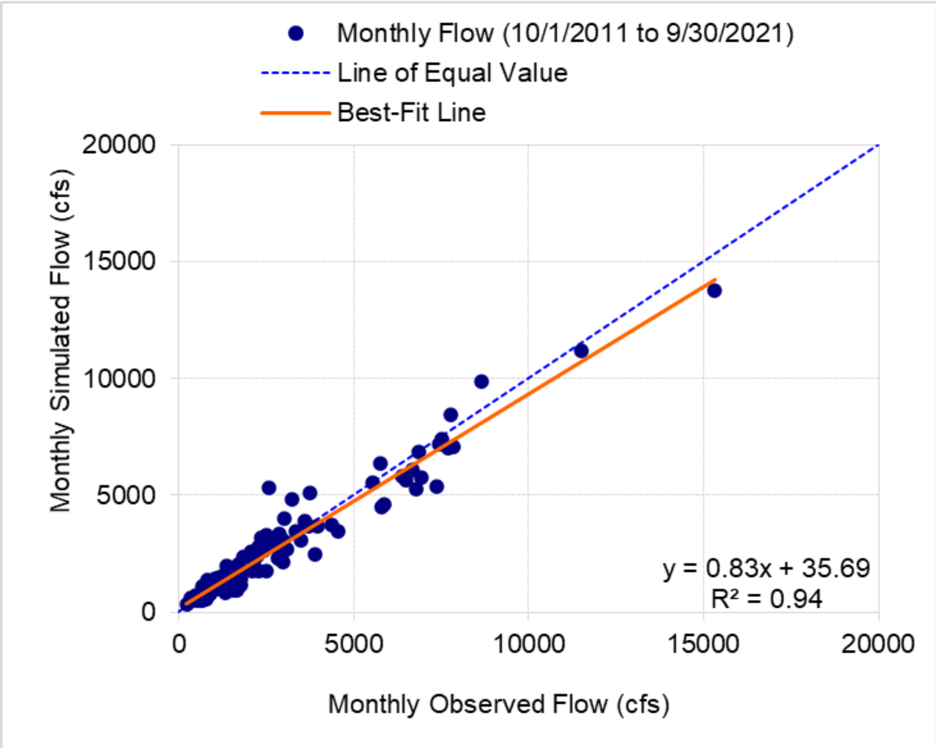

Figure 3-7. Scatterplot of observed and simulated monthly flows for St. Louis River at Scanlon

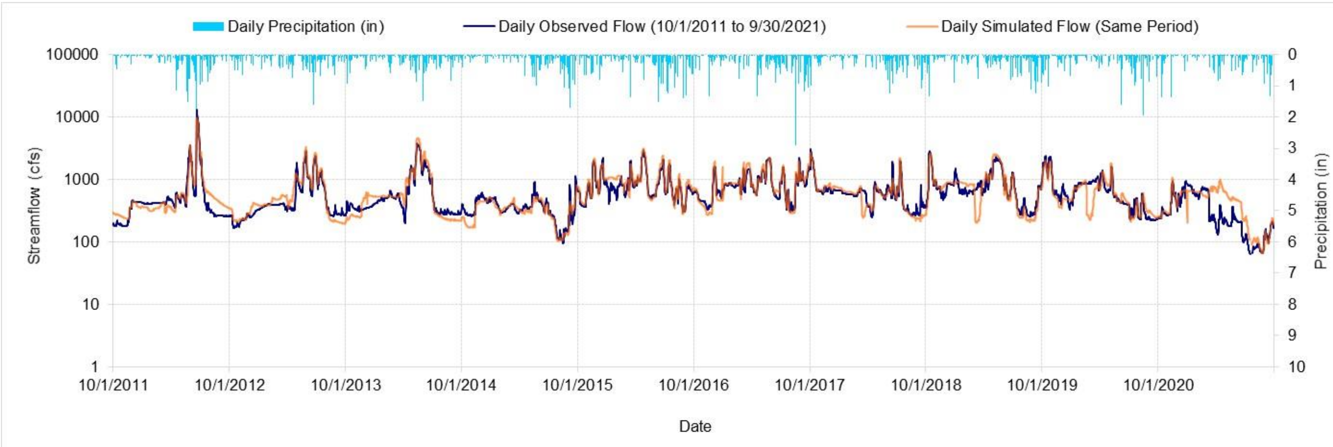

Figure 3-8. Time series of observed and simulated streamflow at Cloquet River near Burnett

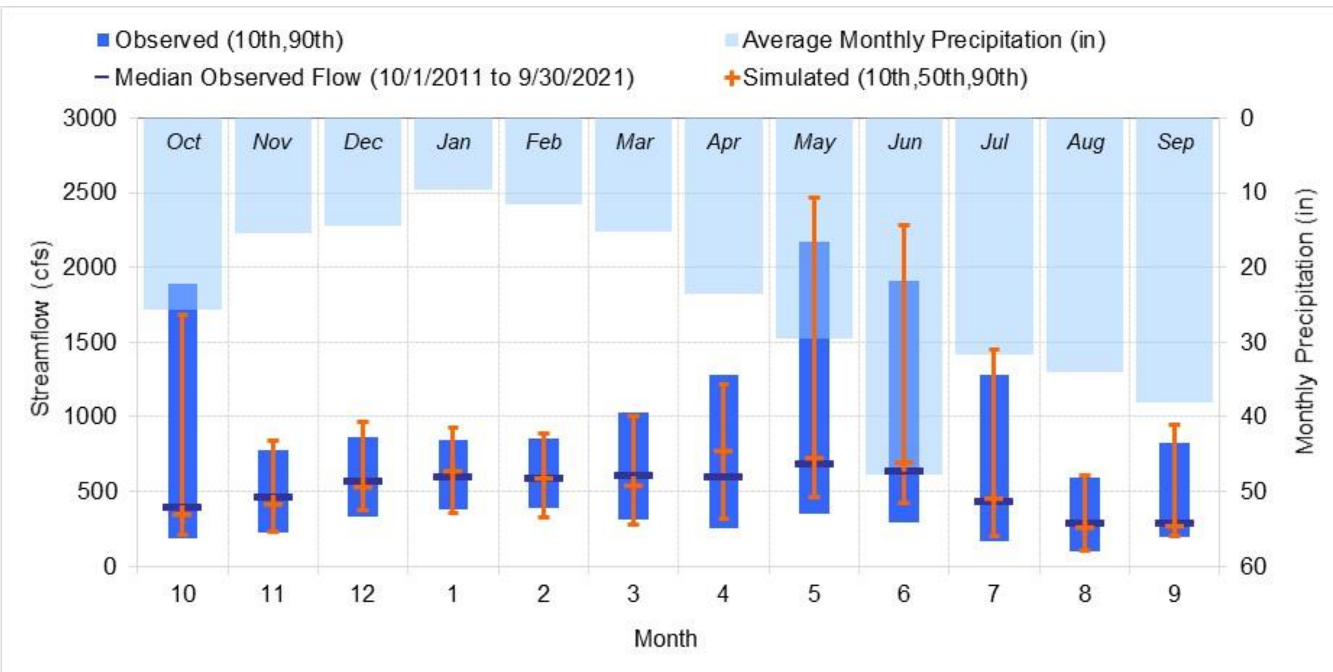

Figure 3-9. Observed and simulated 10th, 50th, and 90th percentile monthly flows for Cloquet River near Burnett

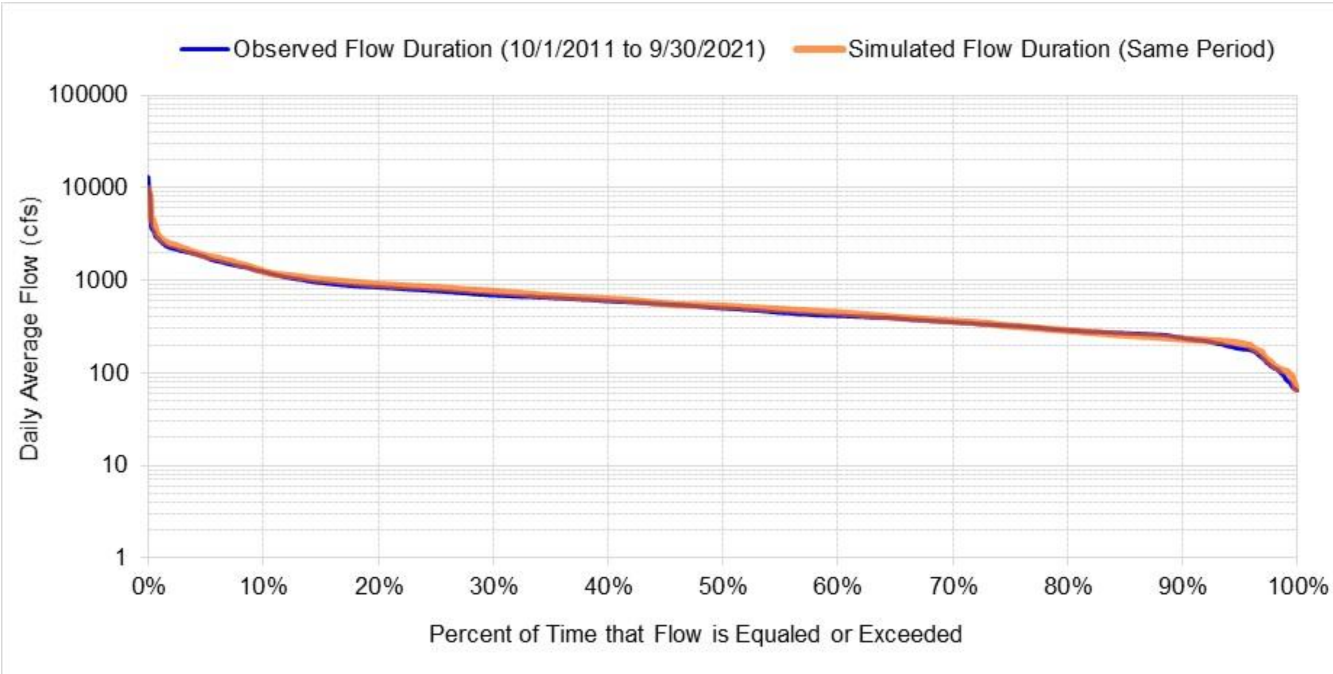

Figure 3-10. Observed and simulated flow duration curves for Cloquet River near Burnett

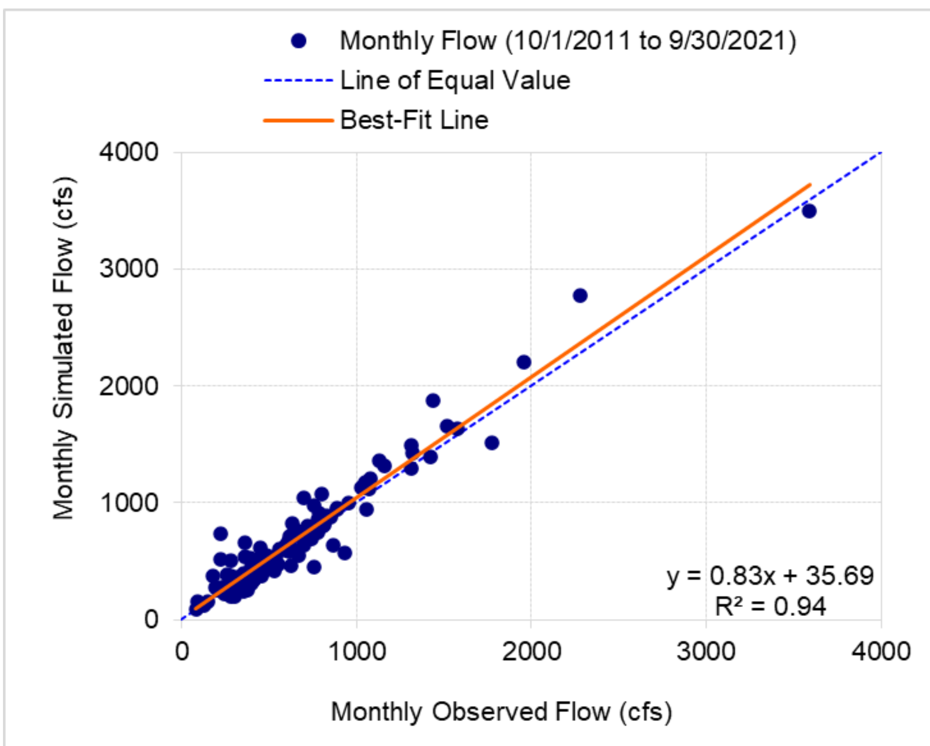

Figure 3-11. Scatterplot of observed and simulated monthly flows for Cloquet River near Burnett

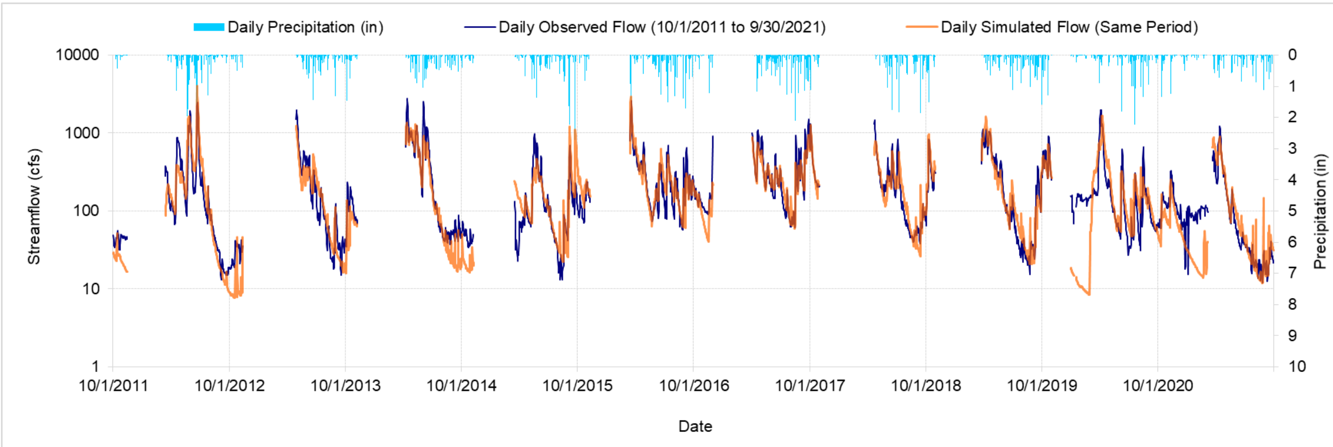

Figure 3-12. Time series of observed and simulated streamflow for Swan River near Toivola

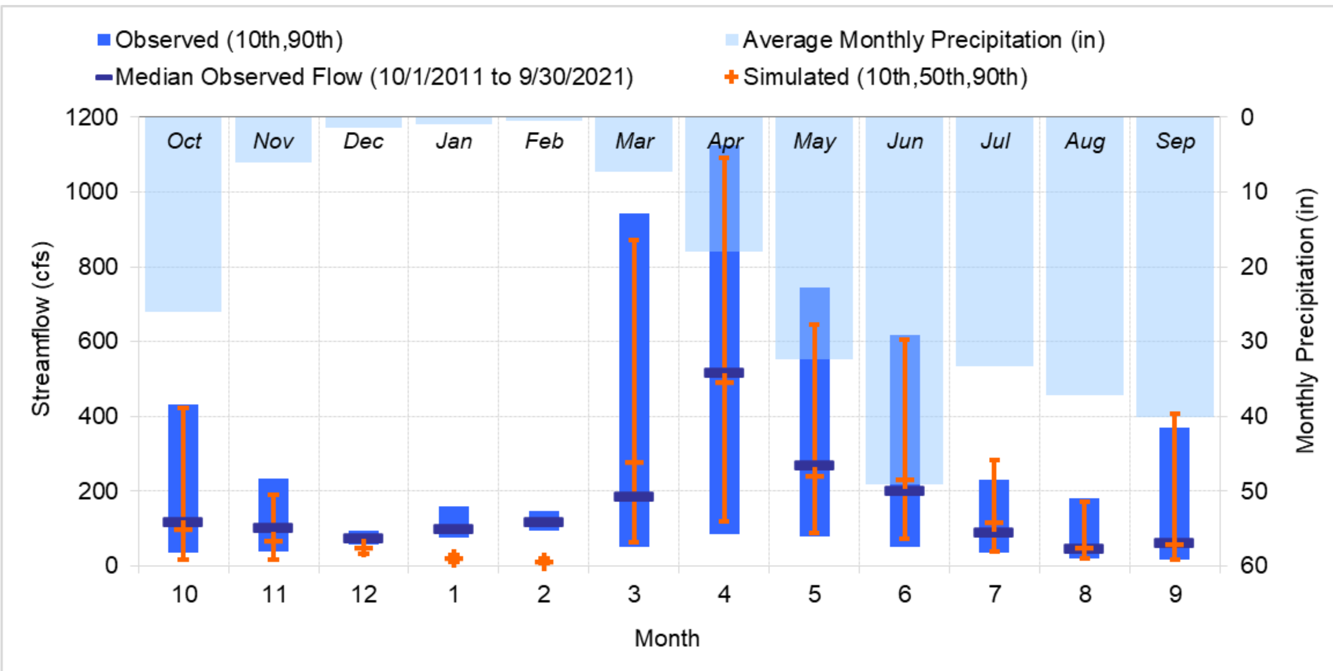

Figure 3-13. Observed and simulated 10^{th}, 50^{th}, and 90^{th} percentile monthly flows for Swan River near Toivola

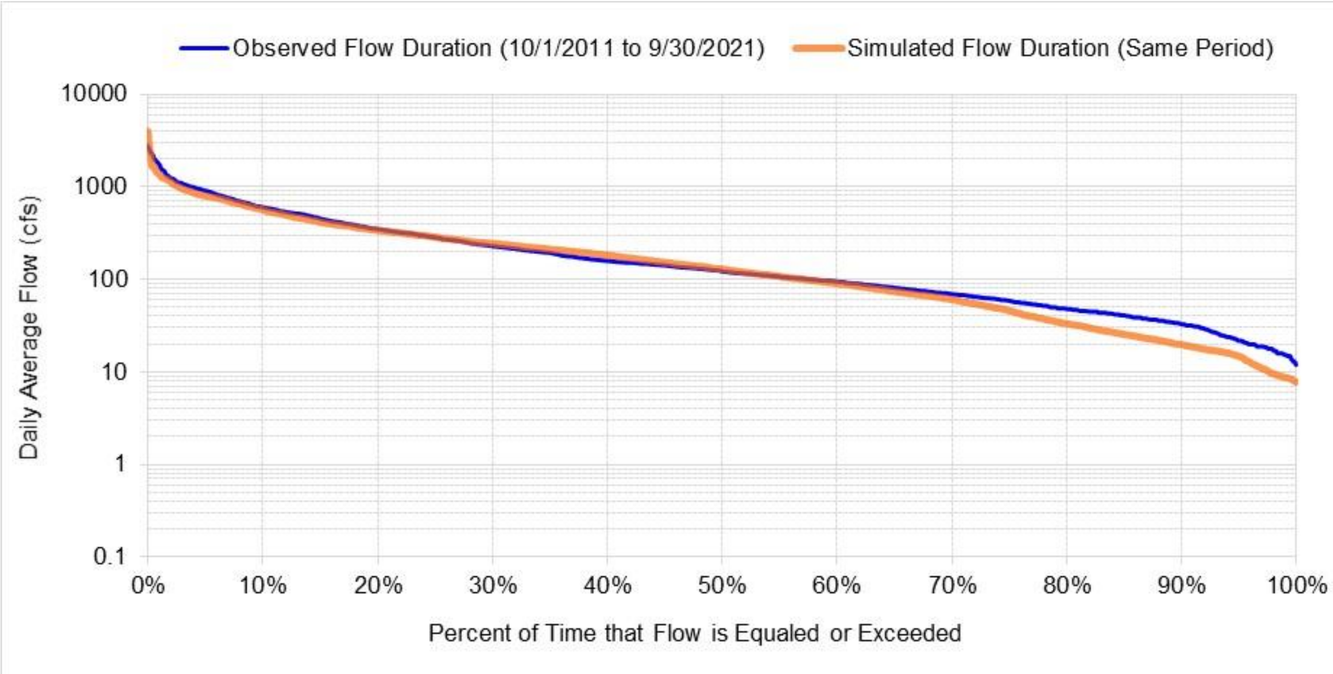

Figure 3-14. Observed and simulated flow duration curves for Swan River near Toivola

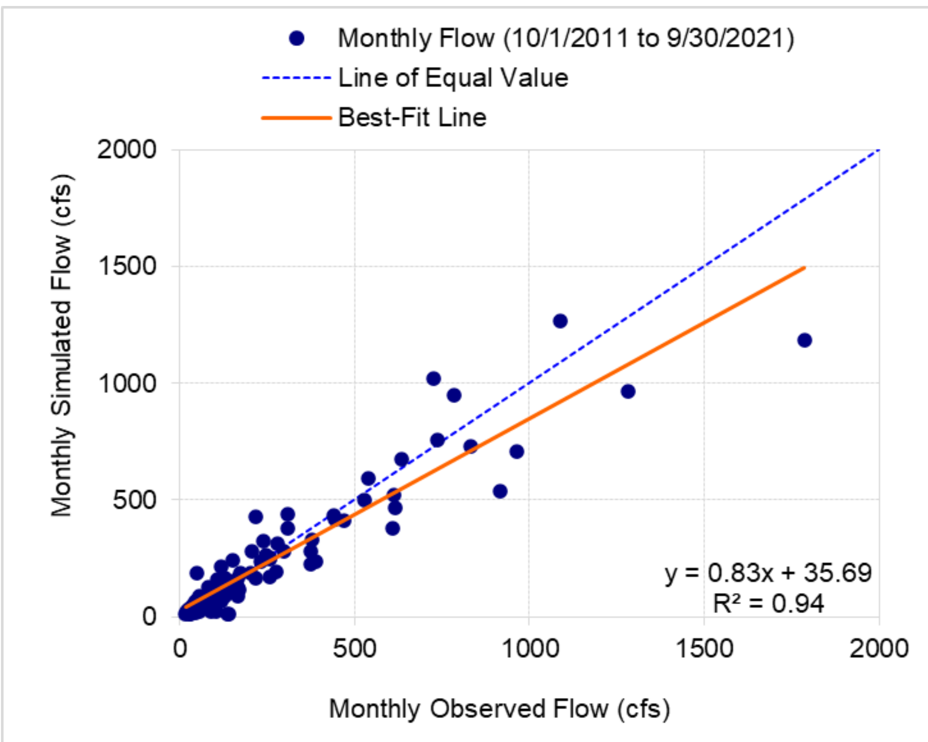

Figure 3-15. Scatterplot of observed and simulated monthly flows for Swan River near Toivola

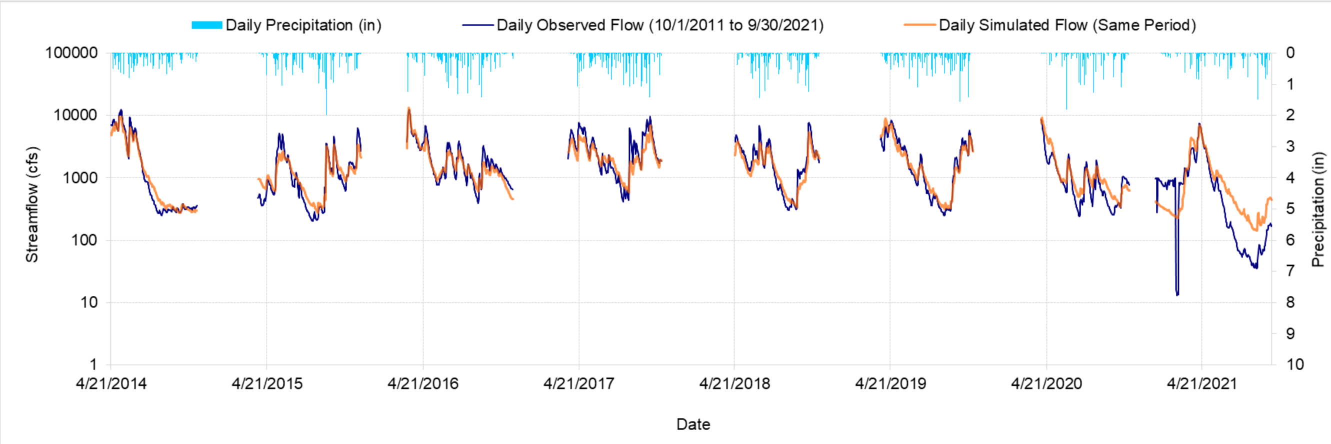

Figure 3-16. Time series of observed and simulated streamflow at St. Louis River at Floodwood

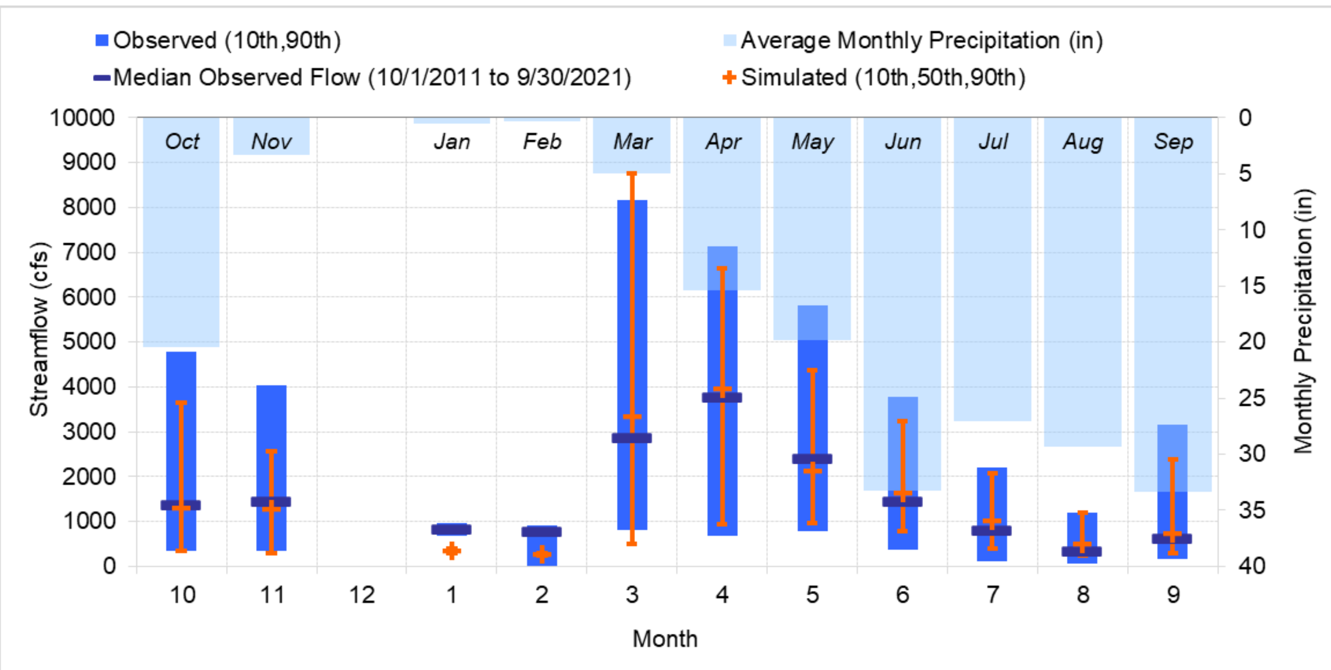

Figure 3-17. Observed and simulated 10th, 50th, and 90th percentile monthly flows for St. Louis River at Floodwood

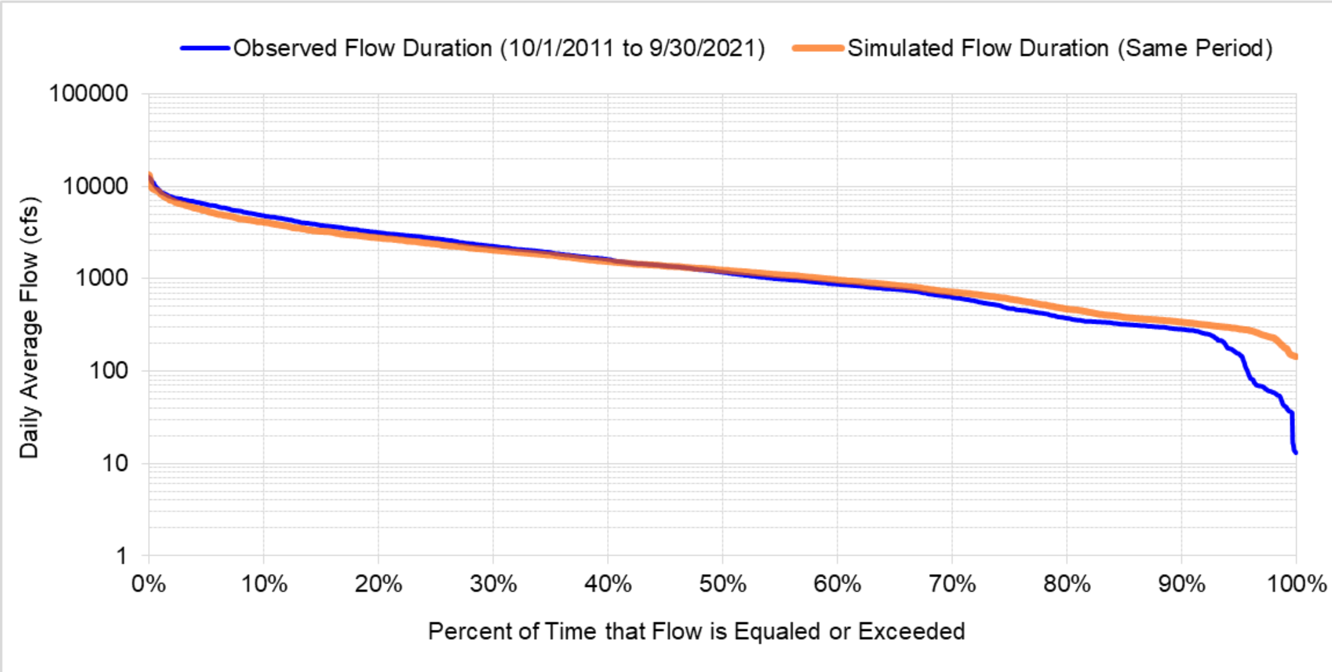

Figure 3-18. Observed and simulated flow duration curves for St. Louis River at Floodwood

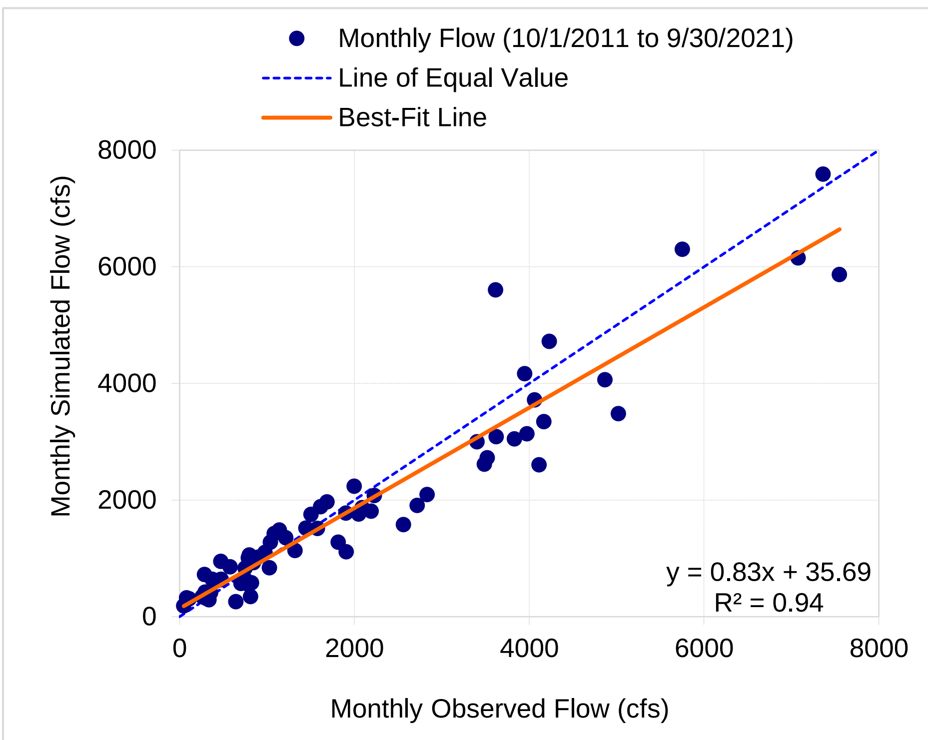

Figure 3-19. Scatterplot of observed and simulated monthly flows for St. Louis River at Floodwood

4.0 SEDIMENT CALIBRATION AND VALIDATION

4.1 APPROACH

Important aspects of sediment behavior within a watershed system include loading and erosion sources, delivery of these eroded sediment sources to streams, drains and other pathways, and subsequent instream transport, scour and deposition processes (USEPA, 2006). Sediment calibration for watershed models involves numerous steps in estimating model parameters and determining appropriate adjustments needed to insure a reasonable simulation of the sediment sources on the watershed, delivery to the waterbody, and transport behavior within the channel system. Rarely is there observed local data at sufficient spatial detail to obtain a unique calibration for all parameters for all land uses and each stream and waterbody reach. Consequently, modelers focus the calibration efforts on sites with observed data and review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from experience (Donigian and Love, 2003, AQUA TERRA, 2012).

Sediment calibration for the St. Louis River watershed was undertaken in accordance with AQUA TERRA (2012) as well as the guidelines in USEPA (2006). The sediment calibration entails multiple elements. Upland sediment yields were refined to align with reference and field data. The instream simulation was also tuned; this involved analyzing the shear stress simulation in the reaches and setting scour and deposition thresholds to expected typical values. The long-term behavior of sediment in the channels was constrained to ensure that degradation or aggradation amounts were physically realistic and consistent with available local information. The sediment calibration also compared and calibrated instream modeled sediment to stream monitoring records. Throughout this process the relative contribution of upland versus channel-derived sediment was evaluated and adjustments were made to achieve a reasonable balance that aligns with information available.

HSPF simulates sediment yield to streams in two stages. First, HSPF calculates the detachment rate of sediment by rainfall (in tons/acre/hour) as

$$DET = (1 - COVER) \cdot \mathrm{SMPF} \cdot KRER \cdot P^{JRER}$$

where *DET* is the detachment rate (tons/acre/hour), *COVER* is the dimensionless factor accounting for the effects of cover on the detachment of soil particles, *SMPF* is the dimensionless management practice factor, *KRER* is the coefficient in the soil detachment equation, *JRER* is the exponent in the soil detachment equation, and *P* is precipitation depth in inches over the simulation time interval. Direct addition of detached sediment (e.g., from wind deposition to the land surface) can also be added via the parameter *NVSI*. Actual detached sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*.

The transport capacity for detached sediment from the land surface (*STCAP*) is represented as a function of overland flow:

$$STCAP = KSER\ (SURS + SURO)^{JSER}$$

where *KSER* is the coefficient for transport of detached sediment, *SURS* is surface water storage (inches), *SURO* is surface outflow of water (in/hr), and *JSER* is the exponent for transport of detached sediment.

DET is similar in concept to the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978), which predicts sediment detachment as a function of is the rainfall erosivity, *RE*, a soil erodibility factor, *K*, a length-slope factor, *LS*, a cover factor, C, and a practice factor, *P*:

$$DET = RE \cdot K \cdot LS \cdot C \cdot P.$$

KRER was estimated as the soil erodibility coefficient provided by SSURGO. The primary upland calibration parameter for sediment is *KSER*, which determines the ability of overland flow to transport detached sediment. HSPF can also simulate gully erosion in which sediment generated from the land surface is not constrained by rainfall detachment.

The key parameters controlling channel erosion, deposition, and sediment transport within streams and rivers are as follows (USEPA, 2006):

***KSAND*:** Sand transport is represented with a power function based on average velocity, such that carrying capacity for sand = *KSAND* x $AVVEL^{EXPSND}$. *KSAND* was adjusted to improve the comparison between simulated and observed suspended sediment concentrations and to ensure a reasonable evolution of sand storage over time.

TAUCD: HSPF calculates bed shear stress (*TAU*) during each model time step for each individual reach. The critical bed shear stress for deposition (lb/ft^2) represents the energy level below which cohesive sediment (silt and clay) begins to deposit to the bed. Initial values of *TAUCD* for silt and clay were estimated by reach by examining the cumulative distribution function of simulated shear stress and setting the parameter to a lower percentile of the distribution in each reach segment, as recommended by USEPA (2006). This was done after the recalibration of hydrology. The 20th percentile was used for clay and the 25th percentile for silt initially for free-flowing streams, and then these were adjusted regionally, and on a reach-by-reach basis during the sediment calibration.

TAUCS: The critical bed shear stress for scour (lb/ft^2) represents the energy level above which scour of cohesive sediment begins. Initial values of *TAUCS* were set, as recommended, at upper percentiles of the distribution of simulated shear stress in each reach (the 90th percentile for clay and the 95th percentile for silt for free-flowing streams). These were adjusted regionally, and on a reach-by-reach basis during the sediment calibration.

M: The erodibility coefficient of the sediment (lb/ft^2-d) determines the maximum rate at which scour of cohesive sediment occurs when shear stress exceeds *TAUCS*. This coefficient is a calibration parameter. It was initially set to values obtained during the original model calibration. These were adjusted regionally, and on a reach-by-reach basis during the calibration.

Calibration for sediment and other water quality parameters differs from calibration for hydrology in that pollutant concentrations are in most cases not continuously monitored. Instead, observations typically provide measurements of conditions at a point in time and point in space via a grab sample. The discrete nature of these samples presents problems for model calibration: A sample that represents a point in time could have been obtained from a system where conditions are changing rapidly over time – for instance, the rising limb of a storm hydrograph. Such samples cannot be expected to be matched by a model prediction of a daily average concentration. On the other hand, there may be large discrepancies between dynamic model predictions of hourly concentrations and data that are a result of small timing errors in the prediction of storm event flow peaks. Spatially, grab samples reflect conditions in one part of a stream reach (which may or may not be composited over the width and depth of a cross section). HSPF model results, in contrast, represent average concentrations over the length of a stream reach which is assumed to be fully mixed. Model predictions and field observations inevitably have some degree of mismatch in space and time and, even in the best models, will not fully match. Accordingly, a statistical best fit approach is needed to guide the calibration and rate the performance.

Performance targets for sediment calibration, based on Donigian (2000) and Duda et al. (2012), are summarized in Table 4-1. These performance targets are evaluated for both concentration and load, where load is estimated from concentration on paired data, and should only be applied in cases where there is a minimum of 20 observations. Model performance is generally deemed acceptable where a performance evaluation of “good” or “very good” is attained.

Table 4-1. Performance targets for HSPF sediment simulation (magnitude of annual and seasonal relative error on daily values)

Model Component	Very Good	Good	Fair	Poor
Suspended Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%

4.2 SEDIMENT SOURCES

4.2.1 Upland Sheet, Rill and Gully Erosion

HSPF predicted unit area sediment loading rates from land uses/covers in the watershed are listed in Table 4-2. Developed land and cropland exhibit the highest unit area sediment loading rates, as expected, though these land uses make up less than two percent of the overall watershed area. Peatlands and wetlands account for almost half of the watershed area and exhibit relatively low sediment loading rates compared to other land uses/covers. HSPF is likely underpredicting sediment loading from barren land, however, increasing loads from barren lands would require parameter values outside of recommended ranges so that was not remedied. Sediment loading rates are comparable to ranges predicted by HSPF for other watersheds in the state.

Table 4-2. HSPF simulated average annual unit area sediment loading rate by land use/cover category

Category	Average Annual Unit Area Sediment Loading Rate (lb/ac/yr)	Percent of Watershed Area
Barren	5	0.4%
Cropland	107	0.1%
Developed	113	1.5%
Forest	9	46.3%
Pasture	52	2.2%
Peatlands	5	24.1%
Roads	52	1.3%
Shrub	29	3.4%
Water	10	3.1%
Wetland	5	17.5%

4.2.2 Reach Sediment Dynamics

Net sediment scour and deposition was analyzed on a reach-by-reach basis consistent with recommendations in USEPA (2006) to ensure that significant amounts of scour and deposition occur only in areas where reasonably expected (e.g., accumulation of sediment in reservoirs). Because HSPF is a one-dimensional reach model, the simulated change in bed depth encompasses changes in channel width (i.e., bank erosion) as well as bed depth. Stream power during large storm events can suspended bed sediment and transport it downstream, and powerful flows may also reshape the channel, removing sediment from the streambanks. During lower flow periods suspended sediment settles, contributing to bed and bank storages. Sediment settles more readily through the water column of slow moving or stagnant waters, depositing and accumulating in the bed. Change in simulated stream bed depth for reaches in the model is shown in Figure 4-1. The average change across the reaches is -0.03 ft for the length of the 28-year simulation. Net changes in reach sediment of this magnitude are quite reasonable.

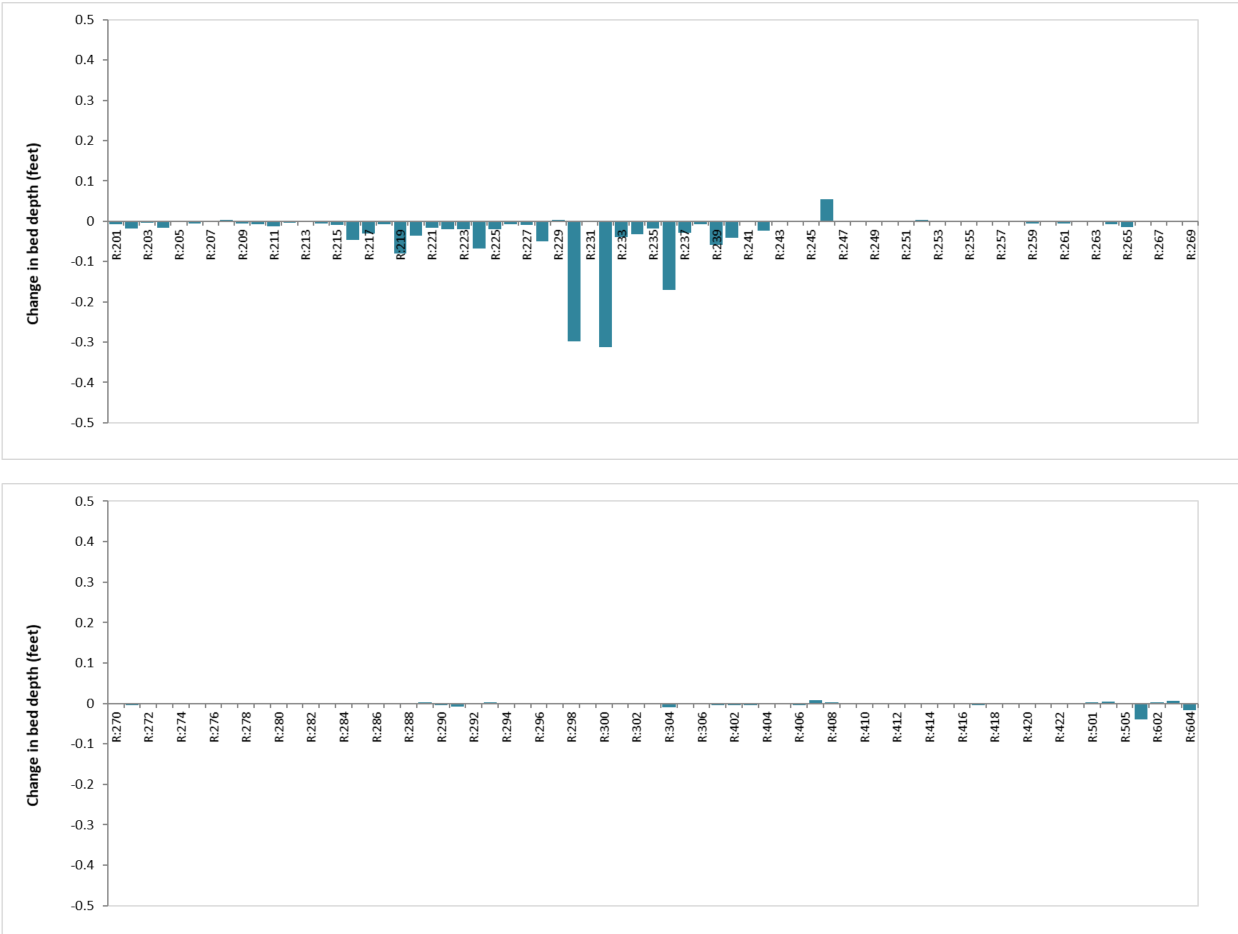

Figure 4-1. Net change in bed depth (ft) for HSPF model reaches

4.2.3 Sediment Source Apportionment

Sediment source contributions simulated by the model are shown in Figure 4-2. Sediment sources include near-channel sources (i.e., the net scouring and deposition of the sediment bed and bank) and upland sediment sources (i.e., sheet and rill erosion and sediment associated with resurfacing groundwater).

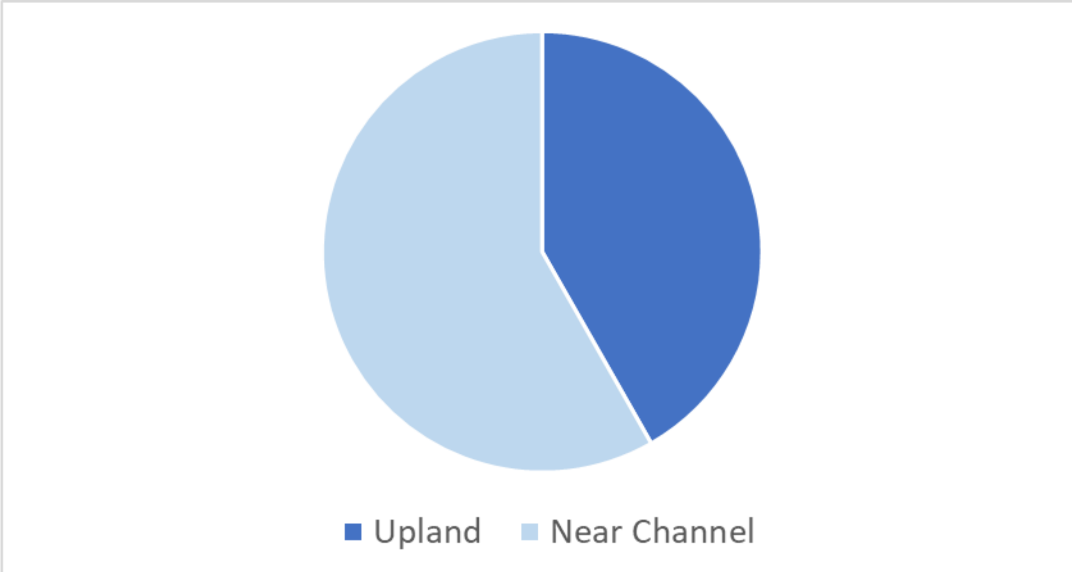

Figure 4-2. Sources of sediment simulated by the HSPF model

4.2.4 FLUX Comparison

MPCA provided statistically modeled TSS loads derived from observed concentrations and streamflows with FLUX software (personal communication, Chuck Regan, April 26, 2022). The daily FLUX estimated loads were compared to HSPF simulated loads for the same period of record and location. Results are shown in Table 4-3. Comparison of average FLUX estimated and HSPF predicted TSS loads. HSPF simulated and FLUX predicted TSS loads are similar for some locations, such as the St. Louis River near Scanlon. FLUX estimates higher TSS loads compared to some locations. TSS samples applied in FLUX can include both inorganic and organic solids. It may be that many of the TSS measurements include substantial amounts of organic detritus derived from wetlands and bogs that are not included in HSPF's simulation of organic solids. If this is the case, that may in part explain the difference between the loads.

Table 4-3. Comparison of average FLUX estimated and HSPF predicted TSS loads

Location	FLUX (kg/day)	HSPF (kg/day)
Cloquet River nr Brimson, CSAH44	1,349	2,086
Cloquet River nr Burnett, CR694	6,080	14,737
Second Creek nr Aurora, 0.6mi us of CSAH110	173	350
St. Louis River at Floodwood, CSAH8	179,163	100,819
St. Louis River at Scanlon, MN	119,472	129,621
St. Louis River nr Forbes, US53	28,415	18,782
Whiteface River nr Meadowlands, CSAH5	35,761	44,365

4.3 CALIBRATION AND VALIDATION TO OBSERVED SUSPENDED SOLIDS

Suspended sediment calibration took place at multiple stations in the watershed and used both visual and statistical approaches. The calibration effort attempted to replicate the observed time series while at the same time minimizing relative errors associated with both concentration and load (as inferred from concentration and flow). Attention was paid to matching observed and simulated relationships between concentration and flow using power plots, while also examining the distribution of error terms relative to both season and flow. It is not uncommon for relative average error to be strongly leveraged by one or more outliers (especially for load, which tends to be determined by concentrations at high flows); therefore, the median error, which is not sensitive to outliers, is reported as well as the average error.

One piece of the calibration focused on fitting observed values at low flows. The reason this was necessary is that the reach simulation allows sediment to settle out to very low concentrations at lower flows when shear stresses are insufficient to mobilize fine sediment particles. Sediment is usually present in waterbodies at measurable concentrations due to localized turbulent flow and disturbance by animals, bottom-feeding fish, dust deposition, and human activities. In addition, groundwater may carry fine sediment into water bodies. To address these low-flow sources of sediment, the model represents sediment associated with baseflow. Sediment associated with groundwater discharge (i.e., AGWO) was specified in the model MASS-LINK blocks using a multiplier on AGWO to represent a fixed concentration (but variable mass) of sediment entering the reach. To represent varied conditions across the watershed, concentrations ranged from 1-7 mg/L.

A summary of the TSS calibration is provided in Table 4-4 and calibration plots are provided for the St. Louis River at Scanlon in Figure 4-3 through Figure 4-5. Relative error on median concentrations are less than +/- 30 percent at the calibration sites, which classify the calibration as “Good” for median concentration, except for the St. Louis River at Forbes. Relative error on median concentration is less than five percent at the most downstream location, St. Louis River at Scanlon, and the rating for this location is “Very Good”. As previously discussed, average concentration errors are more sensitive to outliers and the model overpredicts high TSS concentrations for some of the northern tributaries including Embarrass River and Partridge River. However, the model somewhat underestimates average TSS concentrations at St. Louis River near Forbes situated downstream of these tributaries in the northern portion of the drainage area. The calibration aimed to generate the best fit across all of the sites, with particular interest in obtaining a good fit for the St. Louis River.

Table 4-4. TSS summary for the calibration period (WY 2015-2021)

Station ID(s)	Description	HSPF Reach	Average Concentration (mg/L)		Relative Error on Concentration	
			Observed	Simulated	Average	Median
S007-610	Cloquet River at Brimson Rd	415	4.1	3.6	-11%	6%
S005-147	Cloquet River near Burnett	402 + 421	4.1	5.0	22%	8%
S005-751	Embarrass River	251	3.5	4.3	22%	-3%
S005-752	Partridge River	260 + 261	2.0	2.6	26%	19%
S007-023	Second Creek near Aurora	260	4.0	4.8	20%	-23%
S005-303	St. Louis River at Floodwood	227	30.4	25.1	-18%	-13%
S000-568 + S000-119	St. Louis River at Forbes	249	13.1	6.6	-50%	-39%
S005-089	St. Louis River at Scanlon	502	14.9	14.2	-4%	-2%
S000-641 + S006-192	Swan River near Toivola	233 + 236	35.6	29.9	-16%	-17%
S005-763	Whiteface River	279	21.1	20.2	-4%	-21%

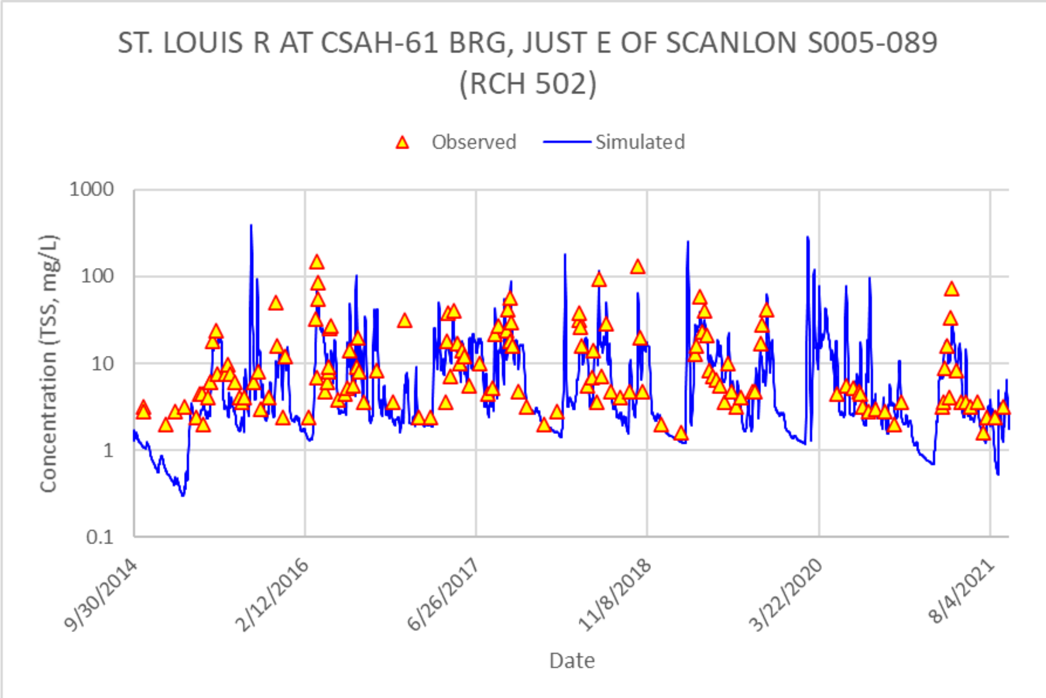

Figure 4-3. TSS time series plot for St. Louis River at Scanlon

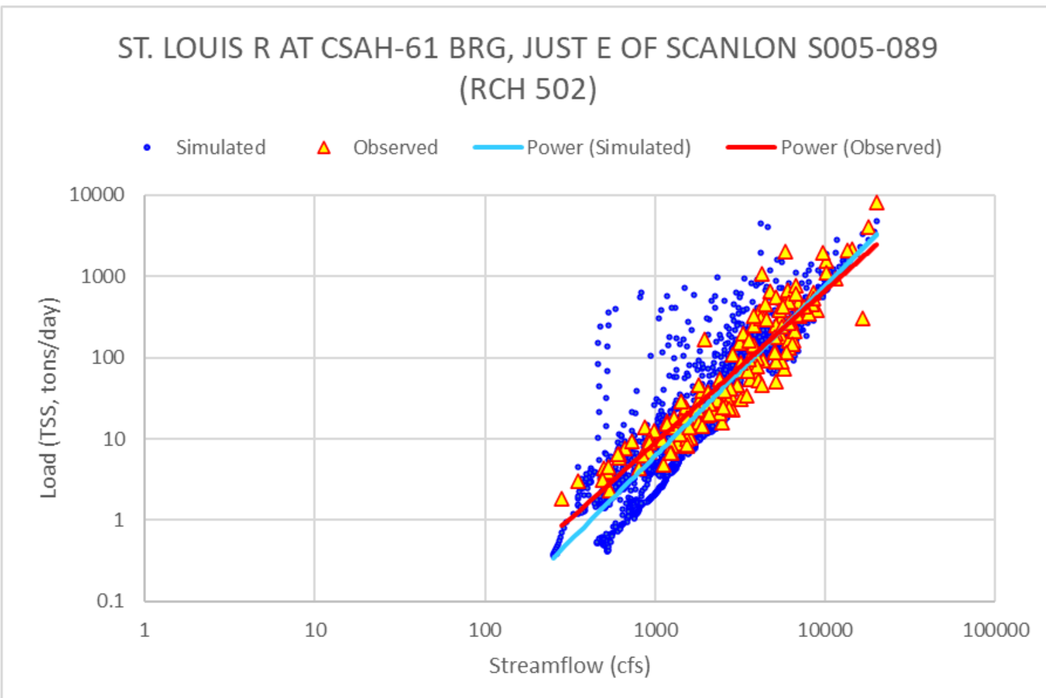

Figure 4-4. Simulated and observed suspended sediment load versus flow for St. Louis River at Scanlon

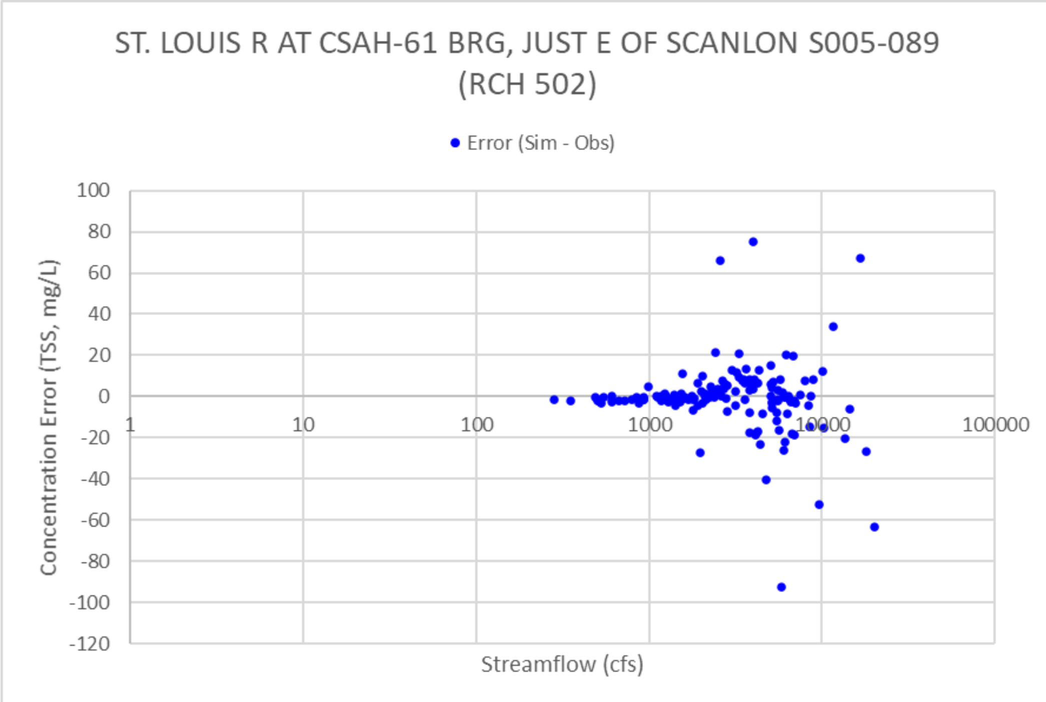

Figure 4-5. Distribution of concentration error versus flow for TSS for St. Louis River at Scanlon

5.0 WATER QUALITY CALIBRATION AND VALIDATION

5.1 APPROACH

The representation of water quality and associated processes on the landscape and in streams largely depends on the simulation of hydrology and sediment transport, and the recalibration of those components is discussed in previous sections. This section presents and discusses the calibration of nutrients and organic carbon.

The HSPF model represents four nutrient constituents on the land surface as general quality constituents (GQUALs): ammonia, nitrate + nitrite, inorganic phosphorus (total orthophosphate), and organic matter. Each of these constituents is then partitioned into alternative species at the point-of-entry to the reach network:

- Inorganic nitrogen is partitioned into dissolved nitrate, dissolved ammonium, and sorbed ammonium. Fractions of the dissolved constituents are set to reproduce observed data, while sorption of ammonium is simulated using equilibrium partitioning assumptions (the model connects ammonia from the land surface to dissolved N in the stream reach, but equilibrium partitioning to the sorbed form occurs instantaneously). Partitioning of ammonium between dissolved and sorbed forms depends on local suspended sediment concentrations.
- Inorganic phosphorus is partitioned into dissolved and sorbed fractions using equilibrium partitioning assumptions. As with ammonium, the fraction that becomes sorbed depends on the local suspended sediment concentration.
- Organic matter (biomass) is partitioned into labile and refractory organic carbon, organic nitrogen, and organic phosphorus components.

All four upland components (ammonia, nitrate + nitrite, inorganic phosphorus, and organic matter) may be loaded through either surface flow or subsurface flow (interflow discharge and resurfacing shallow groundwater). The HSPF GQUAL algorithms do not maintain a full mass balance of subsurface constituents (which would require linkage to a groundwater quality model); rather, the user specifies concentration values, which may vary monthly, for interflow and groundwater for each constituent. Surface loading is considered from both pervious and impervious surfaces.

For most water quality constituents, it is unreasonable to propose that the model predict all temporal variations in concentration and load. The model should, however, provide an accurate representation of long-term and seasonal trends in concentration and load for important constituents, and correctly represent the relationship between flow and load. To ensure this, it is important to use statistical tests of equivalence between observed and simulated concentrations, rather than relying on a pre-specified model tolerance on difference in concentrations.

Ideally, average errors and average absolute errors should both be low, reflecting a lack of bias and high degree of precision, respectively. In many cases, the average error statistics will be inflated by a few highly discrepant outliers. It is therefore also useful to compare the median error statistics, which are less influenced by outlier values.

General performance targets for water quality simulation with HSPF are provided by Duda et al. (2012) and are shown in Table 5-1. These are calculated from observed and simulated daily concentrations and should only be applied in cases where there is a minimum of 20 observations to reduce impact of anomalous outliers.

Table 5-1. Performance targets for HSPF water quality simulations (magnitude of annual and seasonal relative average error (RE))

Model Component	Very Good	Good	Fair	Poor
Water quality/nutrients	≤ 15%	15 - 25%	25 - 35%	> 35%

Evaluation of water quality simulations presents many challenges because, unlike flow, water quality is generally not monitored continuously. Grab samples at a point in space and time may not be representative of average conditions in a model reach on a given day due to either spatial or temporal uncertainty (i.e., an instantaneous measurement in time may deviate from the daily average, especially during storm events, while a point in space may not be representative of average conditions across an entire model reach). Where constituent concentrations are near reporting levels, relative uncertainty in reported results is naturally high. Accurate information on daily variability in point source loads is also rarely available, particularly for minor facilities.

5.2 NUTRIENTS

5.2.1 Upland Calibration

Mean annual simulated TN and TP unit area loading rates are provided for the HSPF model in Table 5-2. TN loading rates tend to be towards the lower end of reference ranges described in Tetra Tech (2016c), Table 3-1. For example, the reference range for forest land cover is 1.97 to 4.2 lb/ac/yr and the simulated annual average loading rate for forest in the St. Louis River watershed is 2.1 lb/ac/yr. Peatlands/wetlands tend to be at the higher end of the range (0.5 to 5 lb/ac/yr) at 4.3 lb/ac/yr; this is predominately N associated with organic matter, which was tuned using available TKN (and TP and DOC) monitoring samples. Factors to convert from organic matter to BOD, dead refractory organic C, organic N and organic P in the Mass-Link blocks were adjusted during the model calibration to align with observations of the variables in the watershed. The upland TP loads simulated by the HSPF model tend to be lower than reference ranges listed in Table 3-1 of Tetra Tech (2016c). For example, the forest range is 0.05 to 5 lb/ac/yr. White et al. (2015) estimate TP loading from forests in the Northern Lakes and

Forest Level III Ecoregion that are much lower, however, with a range from 0 to 0.56 lb/ac/yr and an average of 0.015 lb/ac/yr. The HSPF simulated TP load for forest is within this range. As anticipated, the lowest TP rates are simulated by wetlands, peatlands, and forest.

Table 5-2. Mean annual simulated upland nutrient loading rates

Land use/cover	TN (lb/ac/yr)	TP (lb/ac/ry)
Barren	1.0	0.015
Cropland	3.0	0.016
Developed	4.8	0.117
Forest	2.1	<0.010
Pasture	2.2	0.012
Peatlands/Wetlands	4.3	<0.010
Shrub	0.6	0.007

5.2.2 Calibration and Validation to Observed Nutrients

Comparisons between model predictions and sample observations are made to evaluate the ability of the model to represent conditions in the watershed. Relative error on median and average concentration are listed in Table 5-3 and Table 5-4. Four sites served as the main calibration locations; three along the mainstem St. Louis River and another near the outlet of the Cloquet River. Four other sites served as secondary calibration locations (e.g., tributaries). At the four primary calibration sites, the calibration to median concentration is classified as “Good” to “Very Good” (Table 5-1) for all water quality variables except for NO_2+NO_3 at St. Louis River at Forbes. Errors on average concentration are more heavily influenced by outliers, thus, are higher though still often classified as “Good” to “Very Good”. The nutrient calibration was completed in tandem with the DOC calibration, which is discussed in Section 5.5, and attempted to achieve the best fit across all water quality parameters and sites. In general, the model does a reasonable job of predicting water quality dynamics in Swan River and Whiteface River, two secondary calibration sites that are on main tributaries of the St. Louis River. Second Creek reflects a very small drainage area (a single HSPF model subbasin) that is included by local conditions and is thus more challenging to accurately replicate. Figure 5-1 to Figure 5-12 provide an example of the visual comparisons used to calibrate nutrients using monitoring records available at each site. This set of example plots show the N and P calibration at St. Louis River near Scanlon and Cloquet River near Burnett.

Table 5-3. Nutrient calibration summary – relative errors on median concentration

Site	HSPF Reach	TKN	NO_2 + NO_3	PO_4	TP
Primary calibration locations					
St. Louis River at Scanlon	502	6%	-24%	20%	-1%

St. Louis River at Floodwood	227	10%	-3%	3%	-19%
St. Louis River at Forbes	249	15%	-31%	8%	16%
Cloquet River near Burnett	421	7%	-12%	-8%	14%
Secondary calibration locations					
Cloquet River near Brimson	415	101%	-49%	-66%	153%
Swan River	233+236	67%	-3%	-18%	-8%
Whiteface River	279	8%	-19%	30%	-5%
Second Creek	260	229%	21%	-9%	247%

Table 5-4. Nutrient calibration summary – relative errors on average concentration

Site	HSPF Reach	TKN	$NO_2 + NO_3$	PO_4	TP
Primary calibration locations					
St. Louis River at Scanlon	502	12%	-20%	25%	-9%
St. Louis River at Floodwood	227	13%	11%	3%	-34%
St. Louis River at Forbes	249	26%	-37%	8%	9%
Cloquet River near Burnett	421	16%	-1%	21%	29%
Secondary calibration locations					
Cloquet River near Brimson	415	105%	-93%	-73%	155%
Swan River	233+236	77%	2%	-26%	-16%
Whiteface River	279	18%	-33%	93%	-16%
Second Creek	260	210%	32%	3%	244%

Table 5-5. Nutrient validation summary

Site	HSPF Reach	TKN	$NO_2 + NO_3$	PO_4	TP
Relative errors on median concentration					
St. Louis River at Scanlon	502	-0%	-16%	-24%	-2%

St. Louis River at Floodwood	227	11%	1%	64%	-16%
St. Louis River at Forbes	249	11%	-38%	60%	41%
Cloquet River near Burnett	421	4%	6%	-10%	28%
Relative errors on average concentration					
St. Louis River at Scanlon	502	3%	-53%	-14%	-20%
St. Louis River at Floodwood	227	8%	-36%	38%	29%
St. Louis River at Forbes	249	11%	-31%	86%	31%
Cloquet River near Burnett	421	4%	-3%	27%	14%

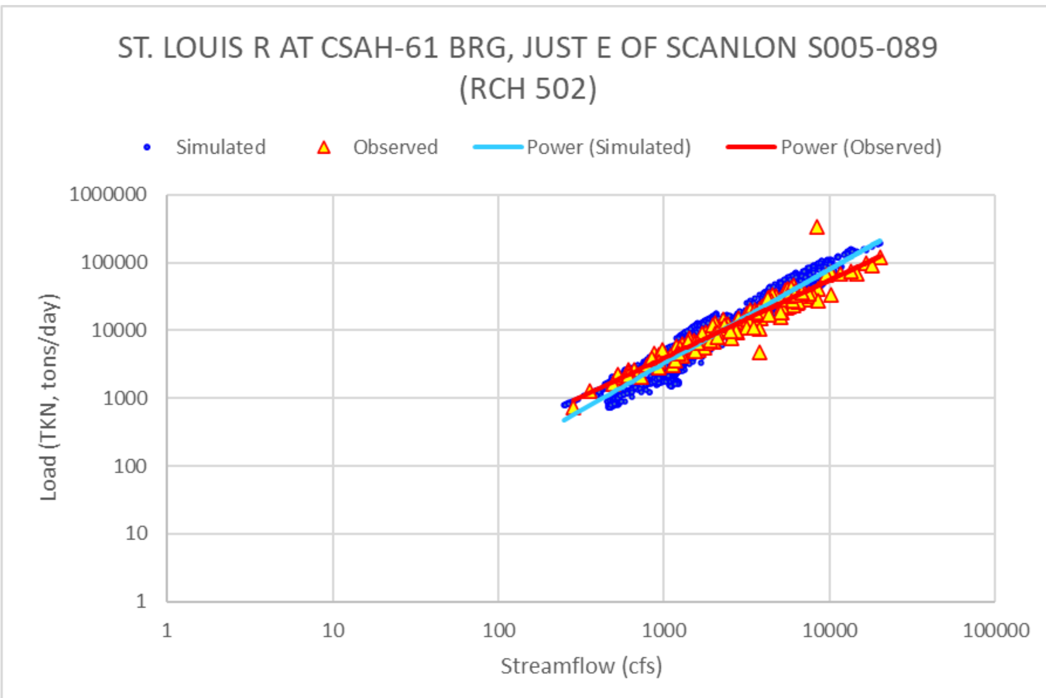

Figure 5-1. Load versus streamflow (TKN) at St. Louis River near Scanlon

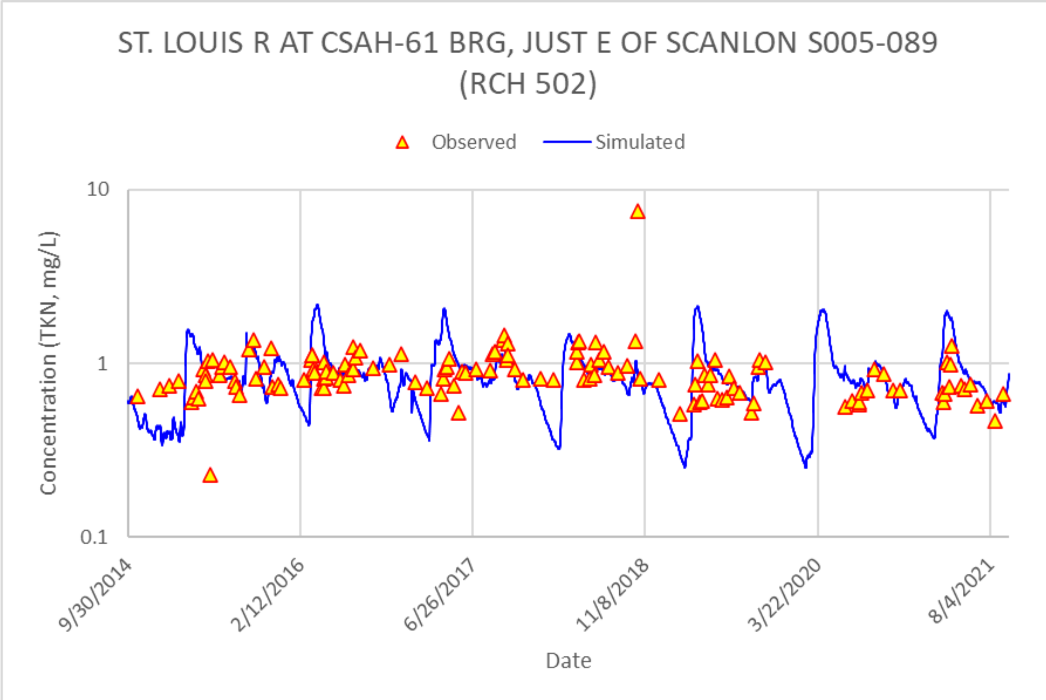

Figure 5-2. Concentration time series (TKN) at St. Louis River near Scanlon

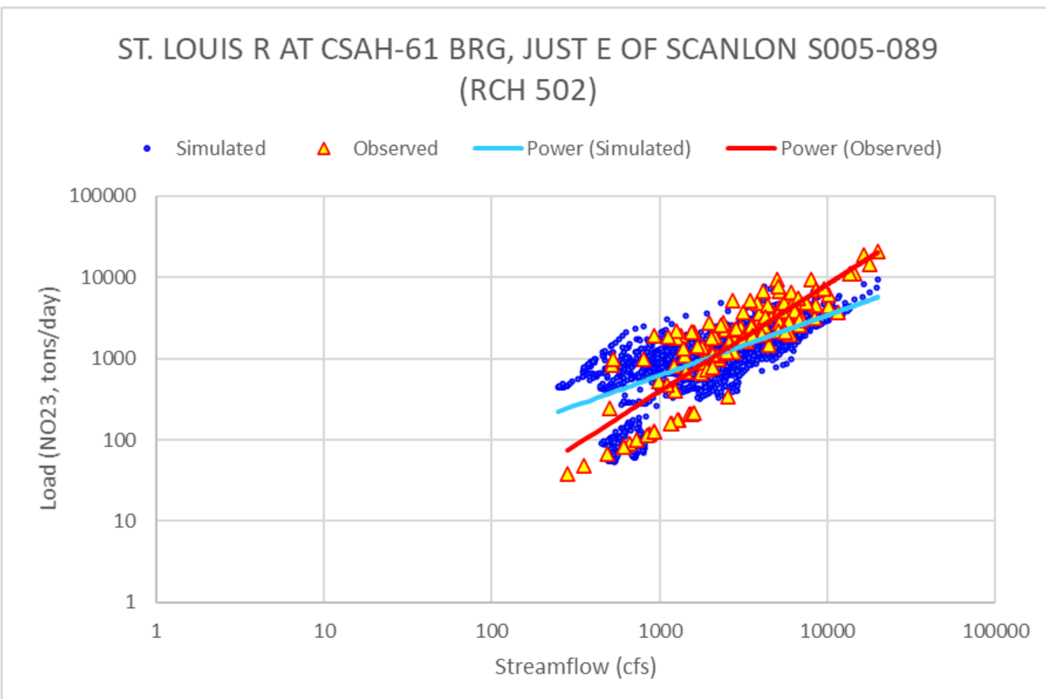

Figure 5-3. Load versus streamflow (NOx) at St. Louis River near Scanlon

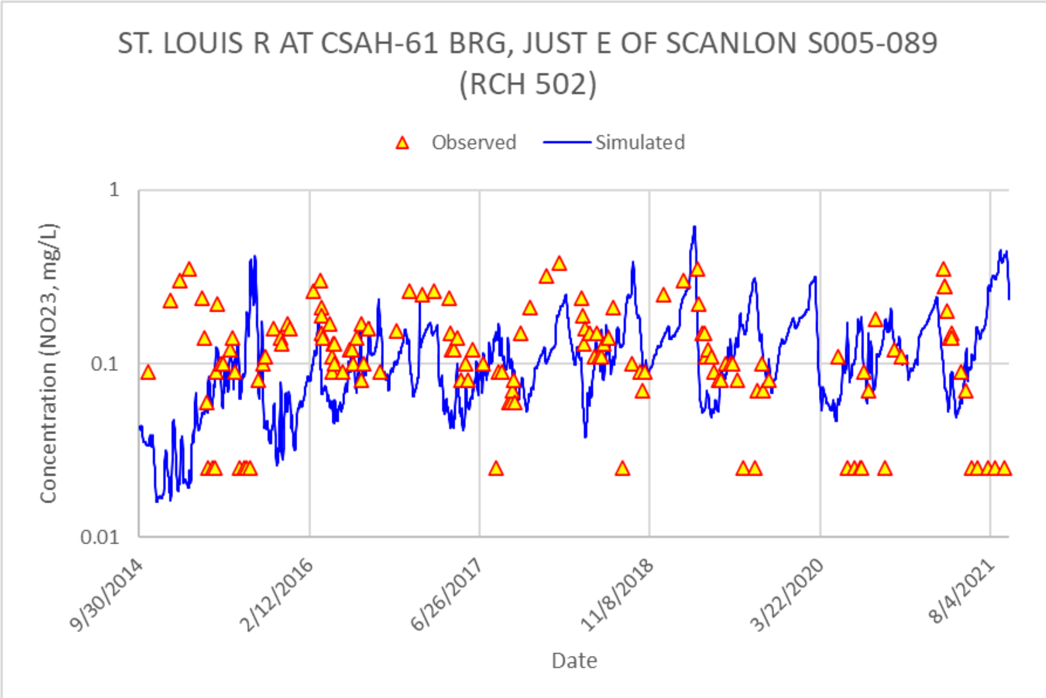

Figure 5-4. Concentration time series (NOx) at St. Louis River near Scanlon

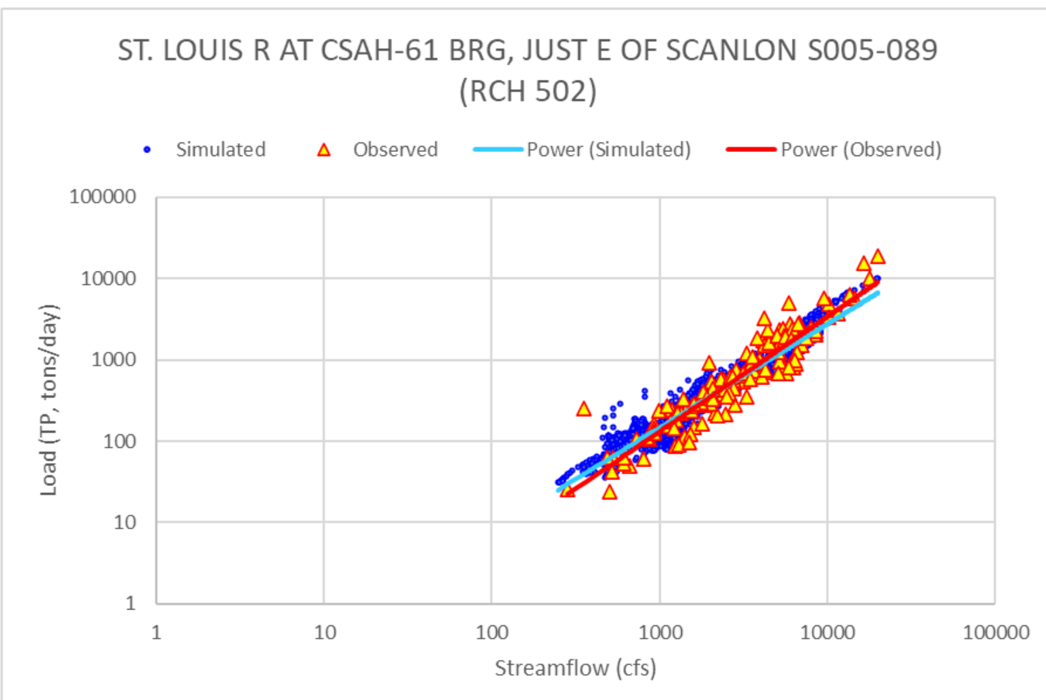

Figure 5-5. Load versus streamflow (TP) at St. Louis River near Scanlon

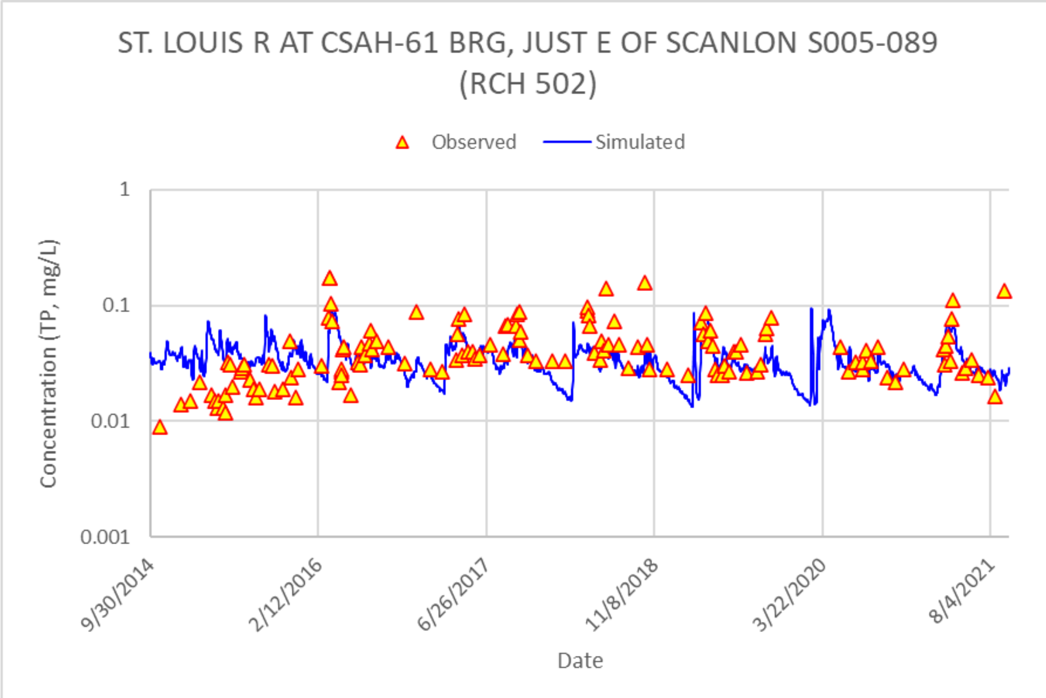

Figure 5-6. Concentration time series (TP) at St. Louis River near Scanlon

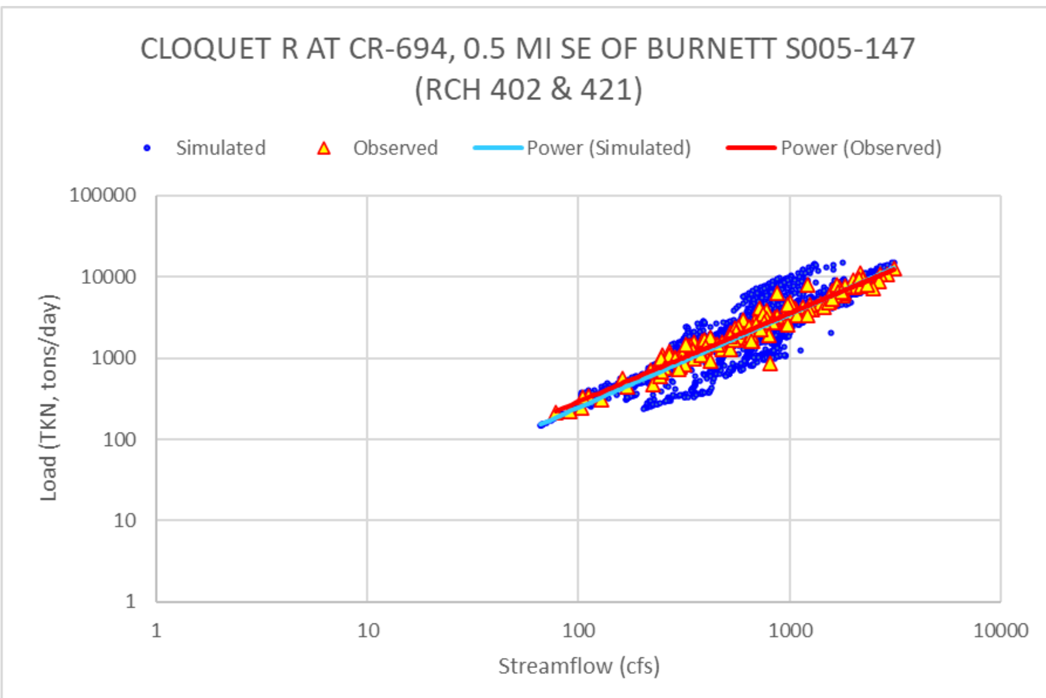

Figure 5-7. Load versus streamflow (TKN) at Cloquet River near Burnett

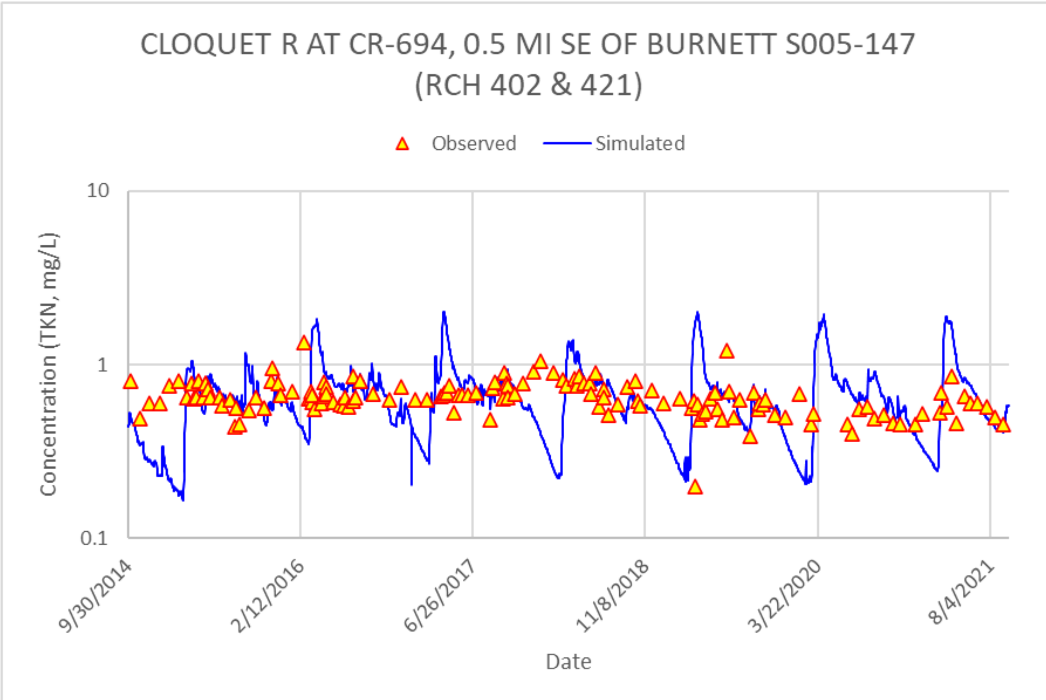

Figure 5-8. Concentration time series (TKN) at Cloquet River near Burnett

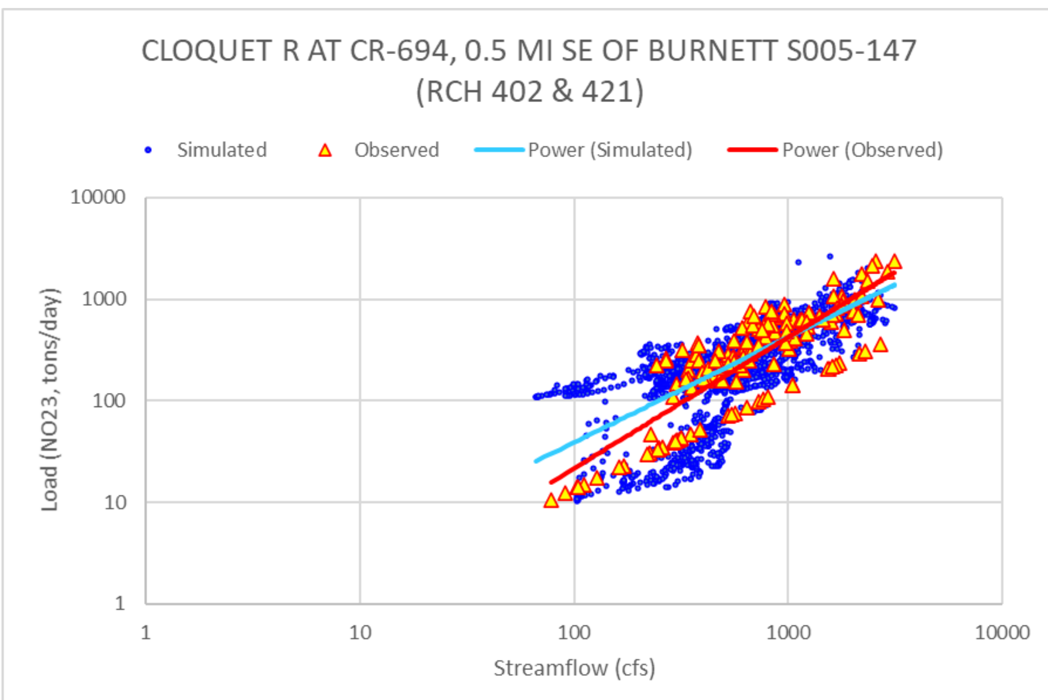

Figure 5-9. Load versus streamflow (NOx) at Cloquet River near Burnett

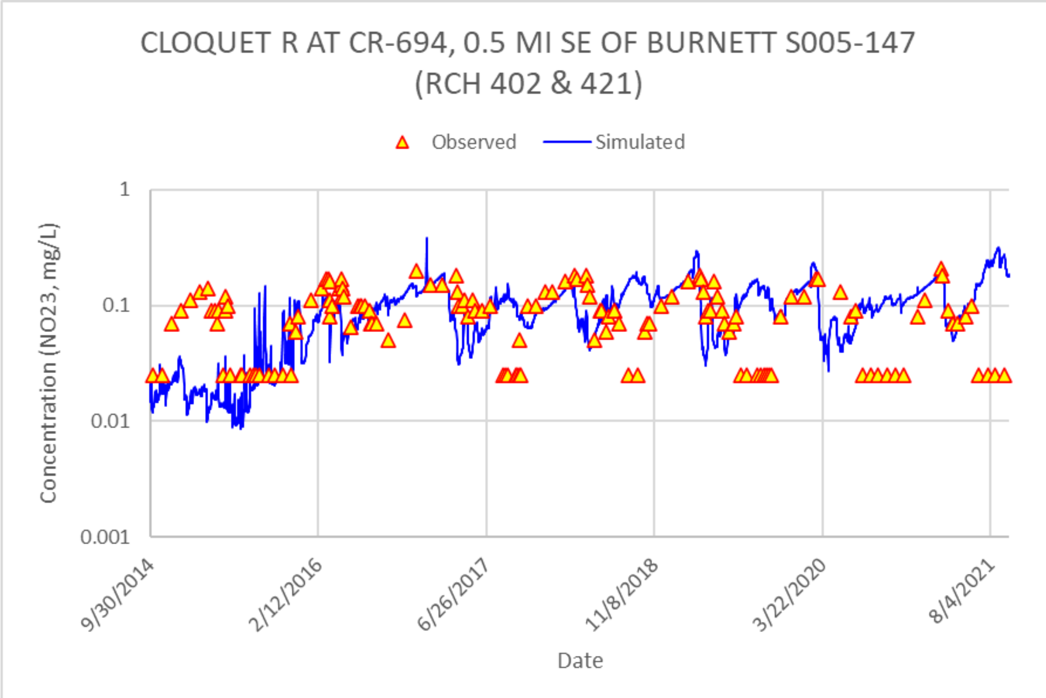

Figure 5-10. Concentration time series (NOx) at Cloquet River near Burnett

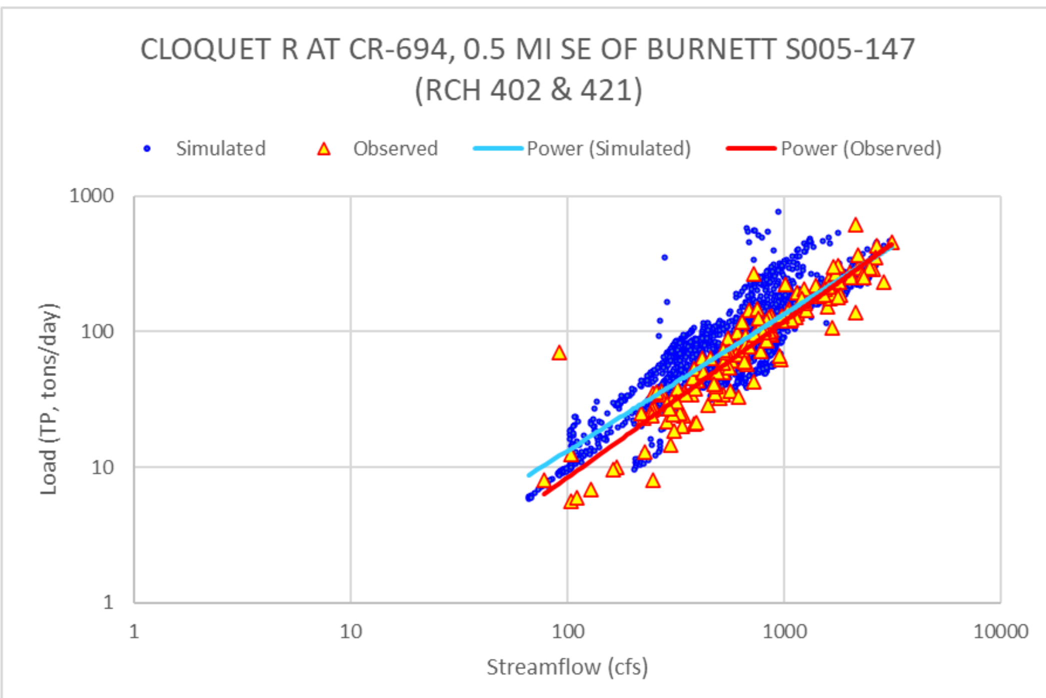

Figure 5-11. Load versus streamflow (TP) at Cloquet River near Burnett

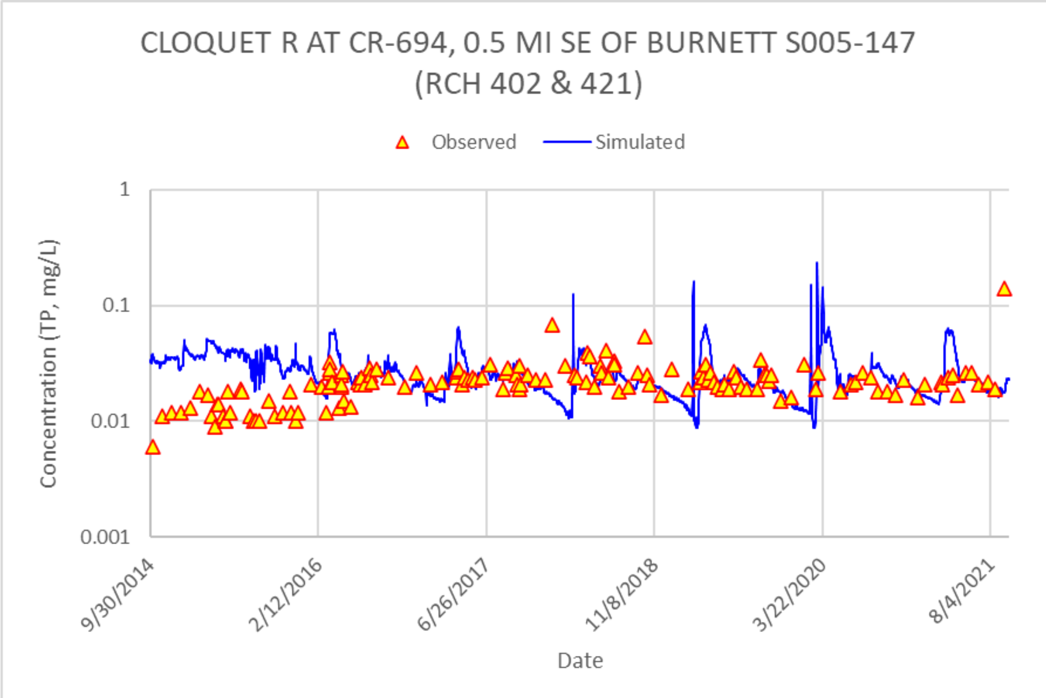

Figure 5-12. Concentration time series (TP) at Cloquet River near Burnett

5.3 FLUX COMPARISON

MPCA provided statistically modeled nutrient loads derived from observed concentrations and streamflows with FLUX software (personal communication, Chuck Regan, April 26, 2022). The daily FLUX estimated loads were compared to HSPF simulated loads for the same period of record and location and used to guide model calibration along with the instream water quality samples. Results are shown in Table 5-6 through Table 5-9 for NO_2+NO_3, PO_4, TKN, and TP. FLUX estimates were available between 2009 and 2019, though the exact dates with available FLUX estimates differ by site.

Table 5-6. Comparison of average FLUX estimated and HSPF predicted NO_2+NO_3

Location	FLUX (kg/day)	HSPF (kg/day)
Cloquet River nr Brimson, CSAH44	21,216	1,980
Cloquet River nr Burnett, CR694	57,744	58,132
Second Creek nr Aurora, 0.6mi us of CSAH110	852	763
St. Louis River at Floodwood, CSAH8	226,237	156,465
St. Louis River at Scanlon, MN	324,543	201,018
St. Louis River nr Forbes, US53	77,647	33,565
Whiteface River nr Meadowlands, CSAH5	54,592	30,589

Table 5-7. Comparison of average FLUX estimated and HSPF predicted PO_4

Location	FLUX (kg/day)	HSPF (kg/day)
Cloquet River nr Brimson, CSAH44	777	350
Cloquet River nr Burnett, CR694	2,460	5,602
Second Creek nr Aurora, 0.6mi us of CSAH110	115	56
St. Louis River at Floodwood, CSAH8	22,326	20,059
St. Louis River at Scanlon, MN	21,624	32,197
St. Louis River nr Forbes, US53	5,031	7,639
Whiteface River nr Meadowlands, CSAH5	6,307	13,698

Table 5-8. Comparison of average FLUX estimated and HSPF predicted TKN

Location	FLUX (kg/day)	HSPF (kg/day)
Cloquet River nr Brimson, CSAH44	129,094	200,896
Cloquet River nr Burnett, CR694	399,462	402,210
Second Creek nr Aurora, 0.6mi us of CSAH110	9,133	21,539
St. Louis River at Floodwood, CSAH8	2,086,572	2,101,289
St. Louis River at Scanlon, MN	2,158,234	2,330,912
St. Louis River nr Forbes, US53	656,097	714,900
Whiteface River nr Meadowlands, CSAH5	640,718	702,979

Table 5-9. Comparison of average FLUX estimated and HSPF predicted TP

Location	FLUX (kg/day)	HSPF (kg/day)
Cloquet River nr Brimson, CSAH44	3,592	7,574
Cloquet River nr Burnett, CR694	12,572	16,539
Second Creek nr Aurora, 0.6mi us of CSAH110	268	855
St. Louis River at Floodwood, CSAH8	156,483	90,085
St. Louis River at Scanlon, MN	104,976	95,641
St. Louis River nr Forbes, US53	28,988	30,018
Whiteface River nr Meadowlands, CSAH5	39,463	33,818

5.4 LAKE CHLOROPHYLL-*A*

Lakes with the most abundant chlorophyll-*a* records are identified to support model development, however, records are fairly limited in the watershed. Observed and simulated chlorophyll-*a* concentration range and average were compared for dates with records available and are shown below in Table 5-10.

Table 5-10. Comparison of observed and simulated lake chlorophyll-*a* concentration (µg/L)

Lake	Observed sample count	Observed range (average)	Simulated range (average)
West Two Rivers Reservoir	26	4.3 - 28.6 (12.9)	0.1 – 7.4 (1.3)
Wynne	17	0.5 – 7.4 (3.1)	0.1 – 14.7 (9.8)
Colby	32	1.0 – 5.7 (3.4)	8.0 – 17.0 (13.1)
Long Eveleth	10	3.8 – 39.8 (13.8)	0.1 – 19.0 (5.7)
Whiteface Reservoir	41	0.67 – 14.9 (6.0)	0.1 – 20.6 (4.0)
Manganika	30	1.0 – 190 (47.4)	3.2 – 32.8 (16.3)

5.5 ORGANIC CARBON

The St. Louis HSPF model will be used to develop TMDLs for waterbodies impaired for water column and/or fish tissue mercury. Dissolved organic carbon (DOC) will serve as a surrogate for upland transport of mercury. Thus, available organic carbon records were used to calibrate DOC and total organic carbon (TOC). The RQUAL module of HSPF simulates dead refractory organic carbon and total inorganic carbon, and total organic carbon can be computed as the dead refractory organic carbon plus the carbon hidden in phytoplankton and in BOD. HSPF does not split organic carbon into dissolved and particulate portions. Therefore, the model was calibrated such that phytoplankton associated organic carbon is assumed as particulate organic carbon whereas the organic carbon in BOD and dead refractory organic carbon were considered as the dissolved portion. A comparison of observed and simulated TOC is in Table 5-11 and DOC is in Table 5-12. Time series plots are also provided for DOC at several locations in Figure 5-13 and Figure 5-17. Overall, the model does a good job of predicting TOC and DOC.

Table 5-11. Comparison of observed and simulated TOC concentration (mg/L)

Site	Model reach	Sample count	Observed median concentration (average concentration)	Simulated median concentration (average concentration)	Relative error on median concentration (average concentration)
St. Louis River near Superior Bay	202	5	13 (18)	15 (15)	19% (-17%)
St. Louis River at Forbes	249	5	14 (17)	14 (17)	3% (-2%)
St. Louis River at Scanlon	502	21	23 (23)	21 (21)	-7% (-8%)
Cloquet River at Burnett	402+421	20	14 (14)	15 (16)	5% (14%)

Table 5-12. Comparison of observed and simulated DOC concentration (mg/L)

Site	Model reach	Sample count	Observed median concentration (average concentration)	Simulated median concentration (average concentration)	Relative error on median concentration (average concentration)
St. Louis River near Superior Bay	202	6	15 (19)	20 (19)	34% (2%)
St. Louis river near Hwy 33	208	15	25 (23)	20 (19)	-22% (-18%)
Floodwood River	222	15	34 (35)	31 (31)	-10% (-11%)
Swan River	232	15	25 (23)	31 (31)	25% (34%)
West Two River	243	15	13 (14)	8 (8)	-37% (-39%)
St. Louis River at Forbes	249	15	24 (23)	22 (19)	-7% (-17%)
Embarrass River	251	15	16 (16)	17 (15)	6% (-2%)
Whiteface River	279	14	33 (32)	23 (24)	-30% (-25%)
St. Louis River at Scanlon	502	19	20 (21)	16 (17)	-20% (-20%)
St. Louis River near Seven Beaver Lake	505	15	32 (31)	40 (37)	25% (18%)
Partridge River	260+261	14	27 (30)	27 (26)	0% (-12%)
Cloquet River at Burnett	402+421	29	16 (15)	14 (14)	-11% (-11%)

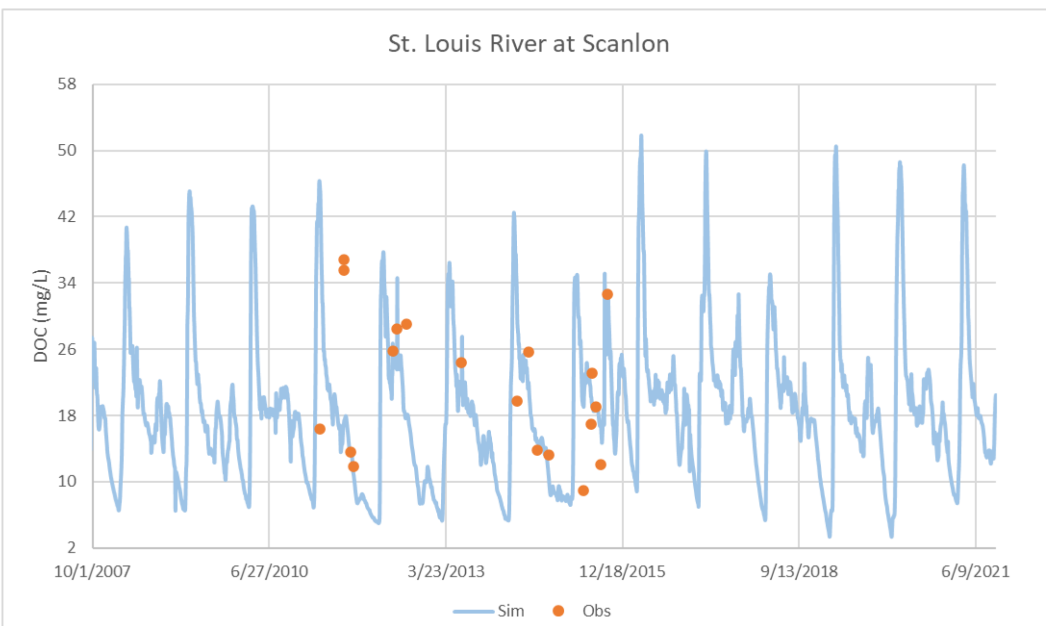

Figure 5-13. Observed and simulated DOC for St. Louis River at Scanlon

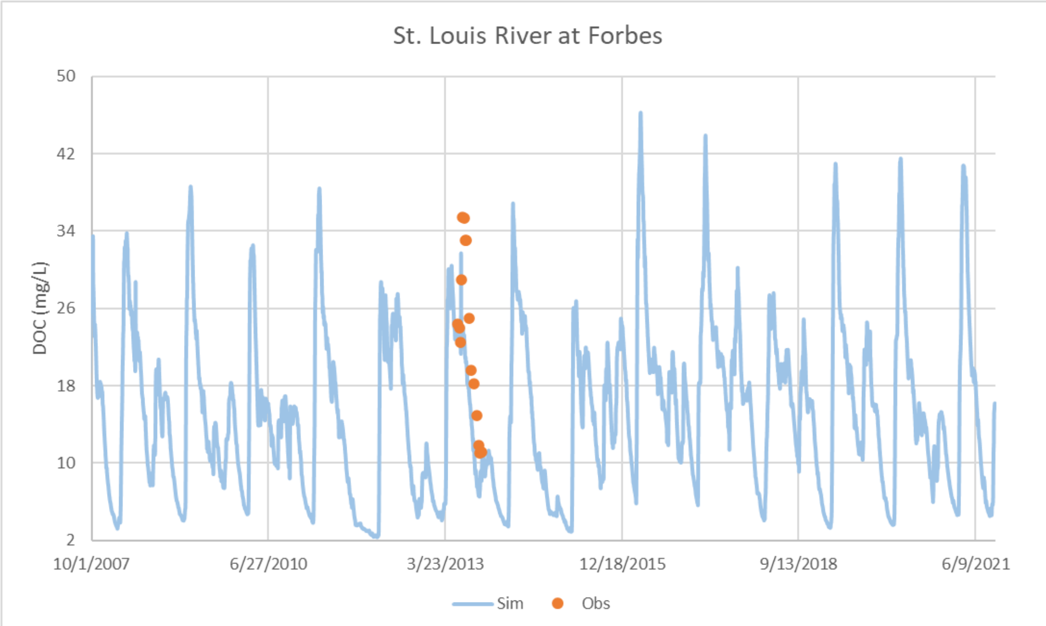

Figure 5-14. Observed and simulated DOC for St. Louis River at Forbes

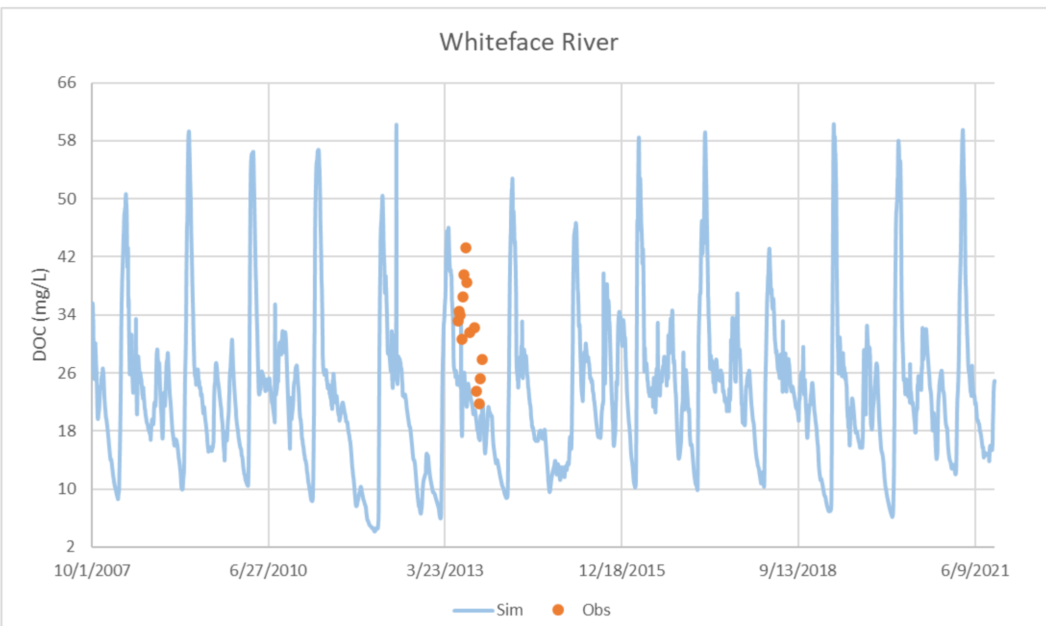

Figure 5-15. Observed and simulated DOC for Whiteface River

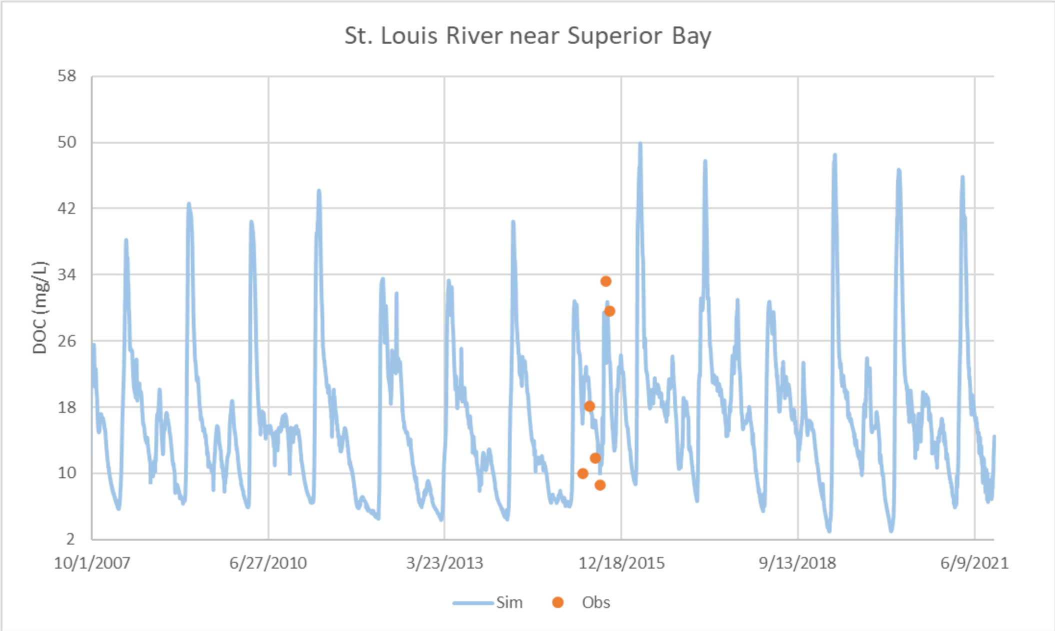

Figure 5-16. Observed and simulated DOC for St. Louis River near Superior Bay

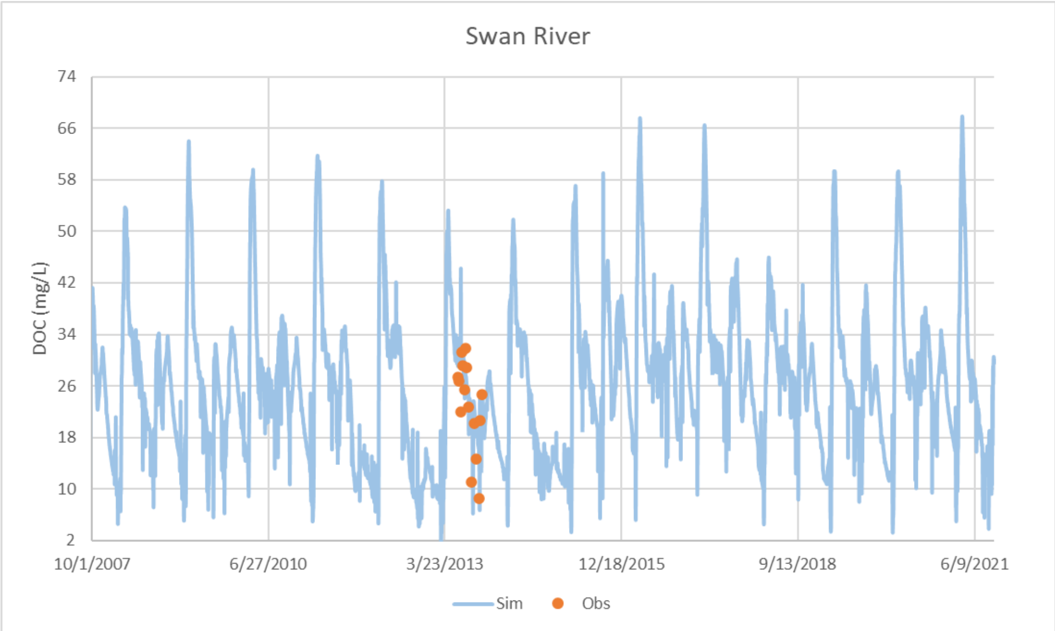

Figure 5-17. Observed and simulated DOC for Swan River

6.0 SUMMARY AND RECOMMENDATIONS

The HSPF model of the St. Louis and Cloquet River watersheds was extended to simulate conditions through WY 2021. Weather input time series were originally derived from station data. For the model extension and update, weather time series were derived from publicly available gridded weather datasets for the full simulation period. Other model input time series, such as hydropower releases and permitted point source discharges, were also extended. Previously input time series for minor point sources were aggregated by model subbasin; as part of this update these were un-lumped and each minor facility now has its own input time series (similar to the major facilities). Land use/cover was updated using LANDFIRE and the National Wetland Inventory, which was used to identify and differentiate peatlands/bogs and other wetlands. A recent coverage of mine features in the Mesabi Range was reviewed. It showed identical features to the coverage used in the original model development, thus mining features were maintained as represented in the original model. Newly available hydraulic and geometric information for stream reaches (e.g., culverts, rating tables) were incorporated in the model and used to derive new FTables for applicable reaches.

Following the model updates and extension, the model was recalibrated for hydrology and water quality. The hydrology calibration collectively evaluated the simulation of snow, evapotranspiration, and streamflow. Metrics for the hydrologic calibration (e.g., NSEs) were often better for the recalibrated model compared to the original version. The overall hydrologic calibration was successful and serves as a solid foundation for water quality simulation. The water quality calibration was evaluated and tuned with instream monitoring records and FLUX-estimated loads as described in Sections 4.0 and 5.0. In addition to typical variables, the model calibration also focused on DOC. The HSPF model is going to be used in the development of TMDLs for lakes and streams impaired for water column and/or fish tissue mercury, and to support development of a mercury TMDL for the Harbor/Estuary. Past research has found that water column concentrations of mercury and methylmercury are strongly correlated with DOC in the watershed, thus, DOC will serve as a landscape transport surrogate for mercury. To support that upcoming phase of work, available DOC and TOC records were used for model calibration. The model does a good job replicating average and median concentrations and it is suitable for the follow-on mercury TMDL work.

7.0 REFERENCES

AQUA TERRA Consultants. 2012. Modeling Guidance for BASINS/HSPF Applications under the MPCA One Water Program. Prepared for Minnesota Pollution Control Agency by AQUA TERRA Consultants, Mountain View, CA.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., T.H. Jobes, P.B. Duda, and A.S. Donigian, Jr. 2014. HSPF Version 12.4 User's Manual. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, GA.

Carroll, T., D. Cline, G. Fall, A. Nilsson, L. Li, and A. Rost. 2001. NOHRSC Operations and the Simulation of Snow Cover Properties for the Conterminous U.S. Proceedings of the 69th Annual Meeting of the Western Snow Conference, pp. 1-14.

Daly, C., M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis, and P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. International Journal of Climatology, doi:10.1002/joc.1688.

Donigian, A.S. Jr., and J.T. Love. 2003. Sediment Calibration Procedures and Guidelines for Watershed Modeling. Presented at the Water Environment Federation Total Maximum Daily Load Conference, November 16–19, 2003, Chicago, IL.

Donigian, A.S., Jr. 2000. HSPF Training Workshop Handbook and CD. Lecture #19. Calibration and Verification Issues. Prepared for and presented to the U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell, and J.L. Kittle, Jr. 1984. Application Guide for Hydrological Simulation Program – FORTRAN (HSPF). EPA-600/3-84-965. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Duda, P.B., P.R. Hummel, A.S. Donigian, Jr., and J.C. Imhoff. 2012. BASINS/HSPF: Model use, calibration, and validation. Transactions of the ASABE, 55(4): 1523-1547.

Ebrahimian and Wilson. 2015. *Determination of Effective Imprevious Area In Urban Watersheds .* St. Paul: Minesota Department of Transportation.

EROS, U. 2018. *National Land Cover Database*. Retrieved from USGS : https://www.usgs.gov/centers/eros/science/national-land-cover-database

Kumar and Arya. 2021. Change Detection Techniques for Land Cover Change Analysis Using Spatial Datasets. *Remote Sens Earth Syst Sci*, 172-185.

Lumb, A.M., R.B. McCammon, and J.L. Kittle, Jr. 1994. User's Manual for an Expert System (HSPEXP) for Calibration of the Hydrological Simulation Program – FORTRAN. Water-Resources Investigation Report 94-4168. U.S. Geological Survey, Reston, VA.

Mesinger, F. et al. 2006. North American Regional Reanalysis. *Bulletin of the American Meteorological Society*, doi:10.1175:BAMS-87-3-343.

Mitchell, K. E., et al. 2004. The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system. J. Geophys. Res., 109, D07S90.

Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, and T.L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3): 885-900.

Nash, J.E. and J.V. Sutcliffe. 1970. River flow forecasting through conceptual models part I – A discussion of principals. Journal of Hydrology, 10(3): 282-290.

NRCS. 2007. *National Engineering Handbook, Hydrologic Soil Group.* United States Department of Agriculture.

Sanford, W.E. and Selnick, D.L. 2013. Estimation of Evapotranspiration across the Conterminous United States Using a Regression with Climate and Land-Cover Data. Journal of the American Water Resources Association, 49(1), pp.217-230.

Savoca, M.E., Senay, G.B., Maupin, M.A., Kenny, J.F., and Perry, C.A. 2013. Actual evapotranspiration modeling using the operational Simplified Surface Energy Balance (SSEBop) approach: U.S. Geological Survey Scientific Investigations Report 2013-5126, 16 p., http://pubs.usgs.gov/sir/2013/5126.

Senay, G.B., Bohms, Stefanie, Singh, R.K., Gowda, P.H., Velpuri, N.M., Alemu, Henok, and Verdin, J.P. 2013. Operational evapotranspiration modeling using remote sensing and weather datasets—A new parameterization for the SSEB ET approach: Journal of the American Water Resources Association, v. 49, no. 3, p. 577–591.

Senay, G.B., Budde, M.E., and Verdin, J.P. 2011a. Enhancing the Simplified Surface Energy Balance (SSEB) approach for estimating landscape ET-Validation with the METRIC model: Agricultural Water Management, v. 98, no. 4, p. 606–618.

Senay, G.B., Leake, S.A., Nagler, P.L., Artan, G.A., Dickinson, J.E., Cordova, J.T. and Glenn, E.P. 2011b. Estimating basin scale evapotranspiration (ET) by water balance and remote sensing methods: Hydrological Processes, v. 25, p. 4,037–4,049.

Senay, G.B., Budde, M.E., Verdin, J.P., and Melesse, A.M. 2007. A coupled remote sensing and simplified surface energy balance approach to estimate actual evapotranspiration from irrigated fields: Sensors, v. 7, p. 979–1,000.SSURGO: Digital soils data produced and distributed by the Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center (NCGC). http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627

Sutherland. 1995. *Methodology for Estimating the Effective Imprevious Area of Urban Watersheds .* Watershed Protection Technique, Vol 2, No.1.

Tetra Tech. 2020. Gridded Weather Data Processing (MET)Tool: User Guide for Hydrologic Simulation Program FORTRAN (HSPF) Application. Prepared for Minnesota Pollution Control Agency by Tetra Tech, Research Triangle Park, North Carolina.

Tetra Tech. 2016a. St. Louis, Cloquet, and Nemadji River Basin Models Volume I: Hydrology and Sediment Model Calibration. Prepared for Minnesota Pollution Control Agency by Tetra Tech, Research Triangle Park, North Carolina.

Tetra Tech. 2016b. St. Louis, Cloquet, and Nemadji River Basins HSPF Model Extension [Memorandum]. Prepared for Minnesota Pollution Control Agency by Tetra Tech, Research Triangle Park, North Carolina.

Tetra Tech. 2016c. St. Louis, Cloquet, and Nemadji River Basin Models, Volume 2 Water Quality Calibration. Prepared for Minnesota Pollution Control Agency by Tetra Tech, Research Triangle Park, North Carolina.

USEPA. 2006. BASINS Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

USEPA. 2000. Estimating Hydrology and Hydraulic Parameters for HSPF. BASINS Technical Note 6, EPA-823-R00-012. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Velpuri, N.M., G.B. Senay, R.K. Singh, S. Bohms, and J.P. Verdin. 2013. A comprehensive evaluation of two MODIS evapotranspiration products over the conterminous United States: Using point and gridded FLUXNET and water balance ET. Remote Sensing of Environment, 139: 35-49.

White, M, Harmel, D, Yen, D, Arnold, J, Gambone, M. and R. Haney. 2015. Development of sediment and nutrient export coefficients for U.S. ecoregions. Journal of the American Water Resources Association, 51(3), 758-775.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agricultural Handbook, 537. U.S. Governmentl Printing Office, Washington, DC.