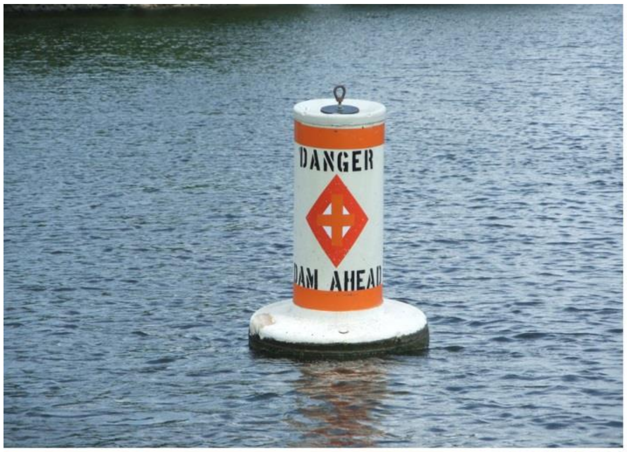



Cannon River Watershed HSPF Model Development Project

Minnesota Pollution Control Agency, One Water Program

Prepared for: Minnesota Pollution Control Agency

FINAL

January 15, 2015

LimnoTech

Water Environment | Scientists Engineers

Blank Page

LimnoTech
Water Environment | Scientists Engineers

501 Avis Drive
Ann Arbor, MI 48108
734.332.1200
www.limno.com

Cannon River Watershed HSPF Model Development Project

FINAL
Prepared for: Minnesota Pollution Control Agency
Internal Use Only

January 15, 2015

Blank page

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

This report describes a project undertaken by LimnoTech under contract to, and in partnership with, the Minnesota Pollution Control Agency (MPCA) to develop, calibrate, and apply a Hydrological Simulation Program - FORTRAN (HSPF) model to the Cannon River watershed, located in southeastern Minnesota. This project is funded by the MPCA under the One Water Program.

1.1 Project Background and Objectives

The MPCA is undertaking a watershed restoration and protection (WRAP) approach at the 8-digit HUC (Hydrologic Unit Code) scale. This effort is an ambitious and comprehensive 10-year statewide effort to assess watershed conditions, develop Total Maximum Daily Loads (TMDLs), and implement watershed protection and restoration strategies for its 81 HUCs8 watersheds.

The Cannon River watershed 8-digit HUC includes waters impaired by excessive bacteria (fecal coliform and Escherichia coliform (*E. coli*)), turbidity, nutrients and eutrophication, and nitrates. The Byllesby Reservoir, a highly valued water resource, and other major lakes in the watershed (Cannon, Jefferson, Tetonka), are impaired by excessive nutrients. A TMDL has been developed for the Byllesby Reservoir (MPCA, 2013) to address the excessive phosphorus levels in the lake impairing aquatic recreation. Many of the smaller lakes in the watershed are also impaired by excessive nutrients. The MPCA has selected the Hydrologic Simulation Program - FORTRAN (HSPF) model to simulate watershed hydrology and water quality. The HSPF model is an important tool in developing an understanding of existing conditions, simulating conditions under various management scenarios and informing the development of implementation strategies and plans to restore and protect streams and lakes. The HSPF model developed for the Cannon River watershed will be used to assist in addressing these management needs.

The goal of the project was to construct, calibrate, and validate an HSPF watershed model for the Cannon River watershed. The calibration and validation for the models developed under the One Water Program are conducted for a 15-year period spanning 1995-2009. The Cannon River watershed HSPF model calibration and validation period was extended through 2012 (18-years total) so that the model captured recent reductions in phosphorus loads discharged from the three major waste water treatment plants (WWTPs) in the watershed. LimnoTech has produced an HSPF watershed model that can readily be used to provide information to support conventional and nutrient parameter TMDLs. The model generates predicted output time series for hydrology, sediment, water temperature, nutrients (phosphorus and nitrogen), biochemical oxygen demand (BOD), dissolved oxygen (DO), phytoplankton and benthic algae that are consistent with available observed datasets. All modeling files, memoranda (LimnoTech 2014a-c, LimnoTech 2014f-k), and this final report comprise the project deliverables. All of the project deliverables have been packaged in the form of electronic files and are referenced throughout this report.

1.2 Project Scope

The following section outlines the major components of the "Cannon River Watershed HSPF Model Development" project.

- **Task 1. Compile both the geographic and time series data required to construct the model framework**. Task 1 included the compilation, evaluation, and modification, if necessary, of the spatial (or geographic) data, the climate data (e.g., rainfall, air temperature, solar radiation, etc.), and the observed streamflow data required to build an HSPF model.
- **Task 2. Develop representation of watershed area and drainage network.** Task 2 consisted of an initial evaluation and formulation of the watershed area and drainage network representation. This task included the following sub-tasks: watershed delineation, land segmentation, selection of lakes for explicit representation in the model, and lake and river channel representation via FTABLES. An initial HSPF model that simulated hydrology was developed under this task.
- **Task 3. Develop and implement a strategy for the representation of point sources within the HSPF model domain.** Task 3 included the identification and representation of major point sources, minor point sources, and atmospheric deposition inputs for nitrogen. Major and minor point sources and atmospheric deposition data were compiled, evaluated, modified (if needed) and formatted for input to the model.
- **Task 4. Formulate time series from observed flow and water quality monitoring to be used for watershed model calibration and validation.** Task 4 consisted of the compilation, evaluation, and formatting of observed streamflow and water quality data required to support the calibration and validation of the Cannon River watershed model.
- **Task 5. Perform the hydrologic calibration, conduct hydrologic validation, and provide a water balance**. Task 5 involved the calibration and validation of hydrology in the Cannon River watershed model. This task is documented as part of this report in Chapter 4.
- **Task 6. Define the sources of sediment within the watershed and conduct sediment calibration and validation tests.** Task 6 included the development of a conceptual site model (CSM) of sediment sources in the Cannon River watershed to support the calibration and validation of the Cannon River watershed HSPF model. The model was calibrated and validated for sediment using the sediment sources and targets outlined in the CSM memorandum (LimnoTech 2014j).
- **Task 7. Conduct water quality calibration, validation, and model evaluation.** Task 7 includes the calibration and validation of the water quality component of the model and a model evaluation. The water quality component of Cannon River watershed HSPF model consists of water temperature, phosphorus (including inorganic and organic species), nitrogen (including inorganic and organic species), BOD, DO, a single phytoplankton group, and a single benthic algae group.

1.3 Scope of Report

This report provides a description of the Cannon River watershed HSPF model developed for and applied to the Cannon River watershed. Chapter 2 provides a discussion of key characteristics of the watershed with respect to physical features, climate, land use, and soils. Chapter 3 provides a description of the model framework and development. Chapter 4 discusses the calibration and validation of the model. Finally, a model evaluation summary and recommendations for future improvement are provided in Chapter 5.

2
Characteristics of the Cannon River Watershed

This chapter provides a brief overview of the key characteristics of the Cannon River watershed.

2.1 Physical Characteristics

The Cannon River watershed drains 1,460 square miles (946,640 acres) in southeastern Minnesota (Figure 2-1) and flows into the Mississippi River at Red Wing. The watershed spans portions of nine counties, including Steele, Rice, Goodhue, Dakota, LeSueur, Waseca, Scott, Blue Earth and Freeborn. The largest urban areas in the watershed are the towns of Faribault, Owatonna and Northfield. The watershed is located within the North Central Hardwoods, Western Corn Belt Plains, and Driftless Area Ecoregions of Minnesota (MPCA 2014a, USDA NRCS 2007).

The Straight River and Cannon River are the two main channels, with the Cannon River travelling 112 miles from roughly west to east and the Straight River travelling 56 miles from south to north through Owatonna to its confluence with the Cannon River in Faribault. The watershed includes 90 lakes and 107 wetlands of 10 acres or more in size, which are concentrated primarily in the upper, western end of the watershed. Lake Byllesby, located near Cannon Falls, is a major water resource and drains approximately 75% of the watershed (MPCA 2013a).

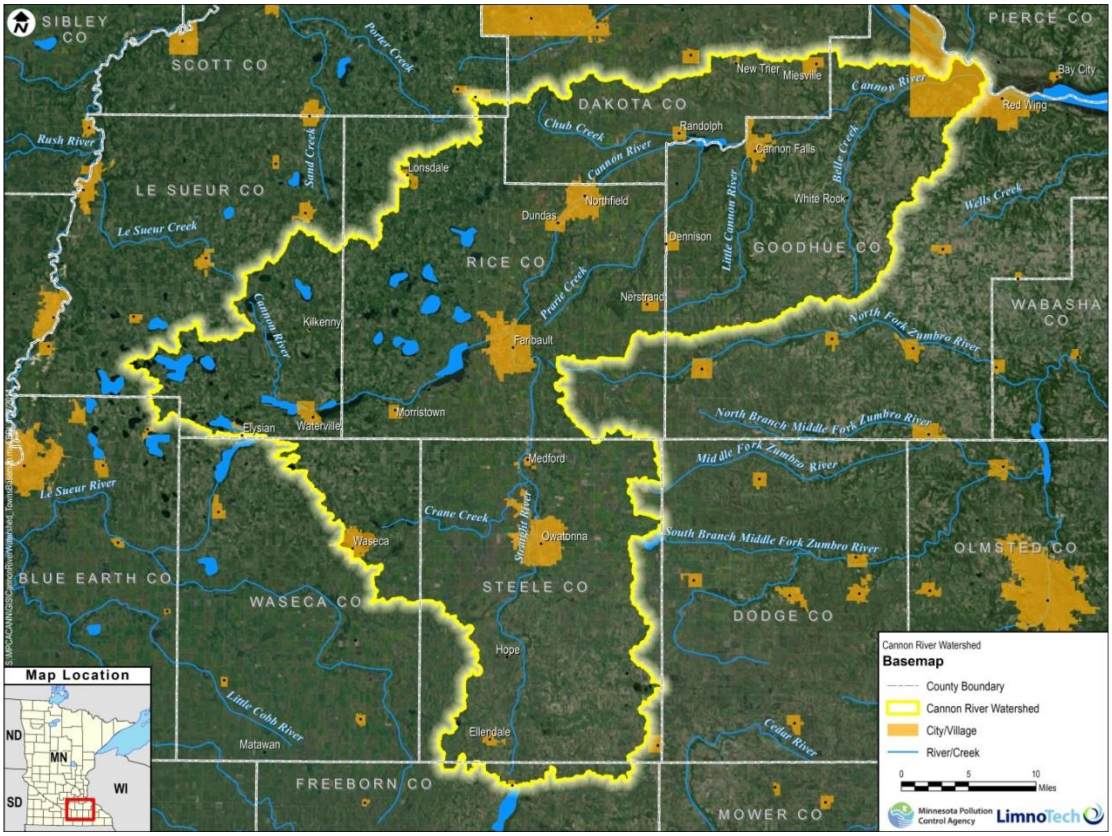

Figure 2-1. Basemap of the Cannon River Watershed, Minnesota

There are four major subwatershed areas comprising the Cannon River watershed (CRWP 2011; CRWP 2007), which are listed and described in Table 2-1.

Table 2-1. Major Subwatersheds Comprising the Cannon River Watershed.

Watershed Portion	Description/ Extent	Mainstem Stream Miles	Key Watershed Characteristics
Straight River	From headwaters to confluence with Cannon River (31% of the Cannon River watershed)	56	Largely agricultural row crop Relatively flat topography Soils are moderately drained and tile drains are common Western Corn Belt Plains predominates
Upper Cannon	From headwaters to confluence with Straight River (23% of the Cannon River watershed)	62	Most of the watershed's lakes and wetlands are in this subwatershed Relatively flat topography and stream channel gradients North Central Hardwoods predominates
Middle Cannon	From Straight River confluence to outlet of Lake Byllesby (24% of the Cannon River watershed)	33	Rolling topography Contains more urban land, receiving most point source discharge volume (Faribault, Northfield and Cannon Falls WWTPs) Some of all three ecoregions present
Lower Cannon	From Lake Byllesby outlet to confluence with Mississippi River (22% of the Cannon River watershed)	25	Steepest slopes in watershed Contains more forested land Most of the Driftless Area is in this part of the watershed

Notes: The watershed area percentages were taken from CRWP, 2007.

The watershed land use is dominated by agriculture, with row crop (60.5%) and pasture/hay (15.7%) comprising more than 75% of the land use (MPCA 2014a). Forest/shrub and urban areas cover approximately 9.4% and 8.4%, respectively, of the watershed. The remaining areas are wetlands (3.1%) and open water (2.9%).

The general climate of the Cannon River watershed is a continental climate with average winter temperatures around 20°F and average summer temperatures around 70°F. Annual precipitation in the Cannon River watershed ranges from 29 to 33 inches (USDA NRCS 2013). A large portion of the lower Cannon River watershed, in the southeastern part of the watershed, is located within a geologic region known as the "Driftless Area", with topography comprised of a unique landform known as "Karst" (MPCA 2014a). Features of Karst are characterized by underground streams, sinkholes, blind valleys and springs. Characteristics of the Driftless Area also include rolling topography, deep valleys, and high bluffs, with some limestone and sandstone outcrops in some streams and rivers (MPCA 2014a). The upper portions of the watershed transition between North Central Hardwoods, found mostly in the upper Cannon River portion of the watershed, and the Western Corn Belt Plains, which predominates in the Straight River portion of the watershed (Figure 2-2).

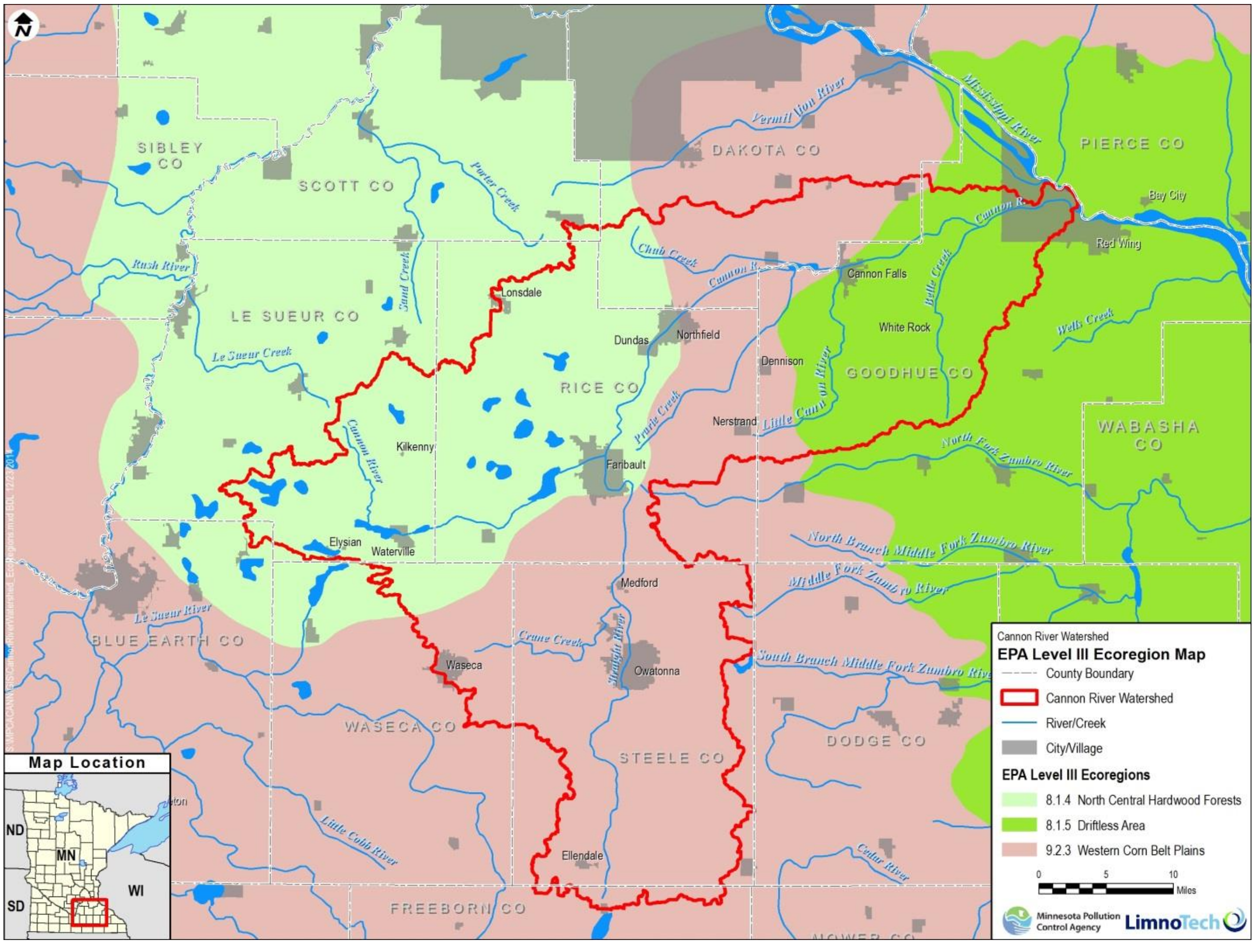

Figure 2-2. Ecoregions of the Cannon River Watershed.

The elevation of the watershed ranges from 1,352 feet to 667 feet above mean sea level (CRWP 2014a; USDA NRCS 2007). The average slope across the watershed is 4.8% and ranges from <1% to >20%. However, the topography in the upper Cannon and Straight River major subwatersheds is characterized by the smallest slopes, averaging 4.3% and 3.2%, respectively. In contrast, the average slope in the lower Cannon subwatershed is 8%, and the highest slopes occur in this portion of the watershed.

The soils in the watershed range from very poorly drained to excessively drained (MPCA 2014a; USDA NRCS 2007; CRWP 2013). The upper Cannon River and Straight River portions of the watershed have the highest percentage of poorly drained soils (Le Sueur County 2010). Most of the land with poorly drained soils is drained for crop production by surface and sub-surface drainage networks (MPCA 2014a; NRCS 2007). Most of the soils in the lower Cannon watershed are well drained.

The Cannon River is designated as a Wild and Scenic River between Faribault and its confluence with the Mississippi River. Many of the lakes and streams are also managed for game fish recreation (MPCA 2014a). The main concerns in the watershed are soil and surface water quality from excessive sheet and rill erosion, animal waste management, stormwater management, sediment and erosion control, groundwater protection, nutrient management and wetland management (USDA NRCS 2007). Many of the resource concerns relate directly to topography, agricultural practices and increasing urbanization as the metropolitan area of the Twin Cities has begun expanding into the watershed (USDA NRCS 2007, Carlson et al. 2004).

2.2 Impairments and Pollution Prevention

The MPCA maintains an inventory of impaired waters, as required by Section 303(d) of the Clean Water Act, for lakes, streams and wetlands. The MPCA has developed a draft list of impaired stream and lake segments in the Cannon River watershed (MPCA 2014b). A total of 59 stream segments and 36 lakes are listed on the MPCA's draft 2014 303(d) list (Table 2-2). Causes of impairment include excessive bacteria (fecal coliform and *Escherichia* coliform (E. coli)), turbidity (sedimentation), nutrients and eutrophication, nitrates, polychlorinated biphenyls (PCBs), and mercury.

A TMDL is required to address the impairments and causes. TMDLs have been completed for turbidity for several impaired segments in the lower Cannon River watershed (CRWP 2007, CRWP 2009). Phosphorus TMDLs have been completed for Lake Byllesby (MPCA 2013a), Lake Volney (MPCA 2014c), and the German-Jefferson Lake chain of lakes (MPCA 2014d).

Table 2-2. List of Impaired Water Bodies in the Cannon River Watershed (MPCA 2014b).

Waterbody Name	Assessment Unit ID	Location Description	Impaired Use[1]	Impairment Cause[2]	Size	Size Units	TMDL Status
Belle Creek	07040002-735	Headwaters to Hwy 19	AQL, AQR	E.coli, T	18.64	miles	
Belle Creek	07040002-734	Hwy 19 to Cannon R	AQL, AQR	E.coli, T	7.85	miles	
Butler Creek	07040002-590	Unnamed cr to Little Cannon R	AQL, AQR	E.coli, M-IBI, T	2.11	miles	
Cannon River	07040002-501	Belle Cr to split near mouth	AQC, AQR	E.coli, PCBF	8.64	miles	
Cannon River	07040002-539	Byllesby Dam to Little Cannon R	AQC, AQL	M-IBI, PCBF	2.75	miles	
Cannon River	07040002-540	Cannon Lk to Straight R	AQR	E.coli	4.97	miles	
Cannon River	07040002-542	Headwaters to Cannon Lk	AQL, AQR	DO, E.coli, M-IBI	52.02	miles	
Cannon River	07040002-508	Heath Cr to Northfield Dam	AQC, AQL, AQR	E.coli, HgF, T	1.59	miles	HgF (2008)
Cannon River	07040002-538	Little Cannon R to Pine Cr	AQC	PCBF	2.59	miles	
Cannon River	07040002-646	North branch of split to Vermillion R	AQC, AQL	PCBF, T	1.65	miles	Turbidity (2007)
Cannon River	07040002-509	Northfield Dam to Lk Byllesby inlet	AQC, AQL, AQR	F-IBI, FC, HgF, M-IBI, T	10.53	miles	HgF (2008), FC (2006)
Cannon River	07040002-502	Pine Cr to Belle Cr	AQC, AQL, AQR	FC, PCBF, T	11.48	miles	Turbidity (2007), FC (2004)
Cannon River	07040002-581	Straight R to T110 R20W S19, SE1/4 line	AQC, AQR	E.coli, HgF	0.85	miles	HgF (2008)
Cannon River	07040002-582	T110 R20W S19, NE1/4 line to Wolf Cr	AQC, AQL, AQR	E.coli, HgF, M-IBI	11.23	miles	HgF (2008)
Cannon River	07040002-507	Wolf Cr to Heath Cr	AQC, AQL, AQR	E.coli, HgF, M-IBI, T	2.99	miles	HgF (2008)
Chub Creek	07040002-528	Headwaters to Cannon R	AQL, AQR	F-IBI, FC, M-IBI	24.74	miles	FC (2006)

Waterbody Name	Assessment Unit ID	Location Description	Impaired Use[1]	Impairment Cause[2]	Size	Size Units	TMDL Status
Chub Creek, North Branch	07040002-566	T113 R19W S19, west line to Chub Cr	AQR	FC	7.06	miles	
County Ditch 63	07040002-621	Unnamed cr to Lk Dora	AQR	E.coli	2.39	miles	
Crane Creek	07040002-516	Headwaters (Watkins Lk 81-0013-00) to Straight R	AQR	FC	16.48	miles	FC (2006)
Devils Creek	07040002-577	Unnamed cr to Cannon R	AQL, AQR	E.coli, M-IBI	2.48	miles	
Falls Creek	07040002-704	Unnamed cr to Straight R	AQR	E.coli	3.8	miles	
Heath Creek	07040002-521	Headwaters (Union Lk 66-0032-00) to Cannon R	AQR	E.coli	13.39	miles	
Little Cannon River (Goodhue County)	07040002-589	T110 R18W S10, west line to T111 R18W S13, east line	AQL, AQR, DW	E.coli, NO3, T	12.05	miles	
Little Cannon River (Goodhue County)	07040002-526	T111 R17W S18, west line to Cannon R	AQL, AQR	E.coli, M-IBI, T	11.87	miles	
MacKenzie Creek	07040002-576	T108 R21W S7, west line to Cannon Lk	AQL, AQR	E.coli, M-IBI	12.32	miles	
Maple Creek	07040002-519	Headwaters to Straight R	AQR	FC	12.85	miles	FC (2006)
Medford Creek	07040002-547	Headwaters to Straight R	AQL	F-IBI, M-IBI	12.06	miles	
Mud Creek	07040002-558	Unnamed cr to Chub Cr	AQR	FC	2.46	miles	
Pine Creek	07040002-520	T113 R18W S26, west line to Cannon R	DW	NO3	6.04	miles	
Prairie Creek	07040002-504	Headwaters to Lk Byllesby	AQL, AQR	FC, M-IBI, T	28.76	miles	FC (2004)
Rush Creek	07040002-505	Headwaters to Straight R	AQL, AQR	FC, T	15.22	miles	FC (2006)
Spring Creek	07040002-569	T112 R15W S18, west line to T113 R15W S34, north line	AQL, AQR	E.coli, T	8.87	miles	
Spring Creek	07040002-571	T113 R15W S27, south line to Hay Cr	AQL	T	3.52	miles	
Spring Creek	07040002-591	Unnamed cr to Unnamed cr	AQL	M-IBI	4.12	miles	

Waterbody Name	Assessment Unit ID	Location Description	Impaired Use[1]	Impairment Cause[2]	Size	Size Units	TMDL Status
Straight River	07040002-517	CD 25 to Turtle Cr	AQR	FC	11.2	miles	FC (2006)
Straight River	07040002-536	Crane Cr to Rush Cr	AQL	M-IBI, T	6.73	miles	
Straight River	07040002-503	Maple Cr to Crane Cr	AQL, AQR	FC, M-IBI, T	5.77	miles	FC (2004)
Straight River	07040002-515	Rush Cr to Cannon R	AQL, AQR	FC, M-IBI, T	13.33	miles	FC (2006)
Straight River	07040002-535	Turtle Cr to Owatonna Dam	AQR	FC	7.41	miles	FC (2006)
Turtle Creek	07040002-518	Headwaters to Straight R	AQR	FC	19.17	miles	FC (2006)
Unnamed creek	07040002-512	Headwaters to Prairie Cr	AQL, AQR	FC, M-IBI, T	2.95	miles	FC (2006)
Unnamed creek	07040002-699	Unnamed cr to Belle Cr	AQR	E.coli	0.55	miles	
Unnamed creek	07040002-638	Unnamed cr to Cannon R	AQL	M-IBI	1.96	miles	
Unnamed creek	07040002-702	Unnamed cr to Cannon R	AQR	E.coli	4.18	miles	
Unnamed creek	07040002-703	Unnamed cr to Cannon R	AQR	E.coli	2.18	miles	
Unnamed creek	07040002-705	Unnamed cr to Cannon R	AQL, AQR	E.coli, F-IBI	2.91	miles	
Unnamed creek	07040002-723	Unnamed cr to Prairie Cr	AQL	M-IBI	2.06	miles	
Unnamed creek	07040002-513	Unnamed cr to Unnamed cr	AQR	FC	5	miles	FC (2006)
Unnamed creek	07040002-587	Unnamed cr to Unnamed cr	AQL	M-IBI	0.79	miles	
Unnamed creek	07040002-731	Unnamed cr to Unnamed cr	AQL	M-IBI	1.85	miles	
Unnamed creek (Spring Brook)	07040002-562	Headwaters to T111 R20W S9, north line	AQR	E.coli	3.71	miles	
Unnamed creek (Spring Brook)	07040002-557	Unnamed cr to Cannon R	AQL, AQR, DW	E.coli, M-IBI, NO3, T	1.9	miles	
Unnamed creek (Trout Brook)	07040002-573	T113 R17W S27, east line to Unnamed cr	AQL	M-IBI	1.56	miles	

Waterbody Name	Assessment Unit ID	Location Description	Impaired Use[1]	Impairment Cause[2]	Size	Size Units	TMDL Status
Unnamed creek (Trout Brook)	07040002-567	Unnamed cr to Cannon R (trout stream portion)	AQL, DW	NO3, T	3.02	miles	
Unnamed creek	07040002-580	Unnamed cr to Unnamed cr	AQL	M-IBI	0.45	miles	
Unnamed ditch	07040002-555	T111 R22W S1, north line to Unnamed cr	AQL	F-IBI, M-IBI	0.57	miles	
Waterville Creek	07040002-560	Hands Marsh to Upper Sakatah Lk	AQL, AQR	E.coli, F-IBI, M-IBI	6.44	miles	
Whitewater Creek	07040002-706	Unnamed cr to Waterville Cr	AQL, AQR	E.coli, M-IBI	0.73	miles	
Wolf Creek	07040002-522	Headwaters (Circle Lk 66-0027-00) to Cannon R	AQL, AQR	E.coli, T	10.1	miles	
Byllesby	19-0006-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	1249.5	acres	HgF (2008), Site specific TP water quality standard approved by EPA (2013)
Cannon	66-0008-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	1599.5	acres	HgF (2008)
Caron	66-0050-00	Lake or reservoir	AQR	Nutrients	311.9	acres	
Cedar	66-0052-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	879.4	acres	HgF (2008)
Chub	19-0020-00	Lake or reservoir	AQR	Nutrients	224.7	acres	
Circle	66-0027-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	829.9	acres	HgF (2008)
Clear	81-0014-01	Lake or reservoir	AQC, AQR	HgF, Nutrients	631.5	acres	HgF (2008)
Dora	40-0010-00	Lake or reservoir	AQR	Nutrients	712.1	acres	
East Jefferson	40-0092-01	Lake or reservoir	AQR	Nutrients	661.5	acres	Nutrients (Draft 2014)
Fox	66-0029-00	Lake or reservoir	AQR	Nutrients	306.6	acres	
Frances	40-0057-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	862.7	acres	HgF (2008)
French	66-0038-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	873.5	acres	HgF (2008)

Waterbody Name	Assessment Unit ID	Location Description	Impaired Use[1]	Impairment Cause[2]	Size	Size Units	TMDL Status
German	40-0063-00	Lake or reservoir	AQR	Nutrients	783.9	acres	Nutrients (Draft 2014)
Gorman	40-0032-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	505.0	acres	HgF (2008)
Horseshoe	40-0001-00	Lake or reservoir	AQR	Nutrients	415.6	acres	
Hunt	66-0047-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	174.2	acres	HgF (2008)
Loon	81-0015-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	122.5	acres	HgF (2008)
Lower Sakatah	66-0044-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	359.6	acres	HgF (2008)
Mabel	40-0011-00	Lake or reservoir	AQR	Nutrients	98.2	acres	
Mazaska	66-0039-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	669.2	acres	
Middle Jefferson	40-0092-04	Lake or reservoir	AQR	Nutrients	613.8	acres	Nutrients (Draft 2014)
Rice	66-0048-00	Lake or reservoir	AQR	Nutrients	313.8	acres	
Roberds	66-0018-00	Lake or reservoir	AQR	Nutrients	615.6	acres	
Sabre	40-0014-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	250.5	acres	
Shields	66-0055-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	933.0	acres	HgF (2008)
Silver	40-0048-00	Lake or reservoir	AQR	Nutrients	15.9	acres	
Sunfish	40-0009-00	Lake or reservoir	AQR	Nutrients	123.2	acres	
Swede's Bay	40-0092-03	Lake or reservoir	AQR	Nutrients	350.4	acres	
Tetonka	40-0031-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	1336.6	acres	HgF (2008)
Toner's	81-0058-00	Lake or reservoir	AQR	Nutrients	111.1	acres	
Tustin	40-0061-00	Lake or reservoir	AQR	Nutrients	101.7	acres	

Waterbody Name	Assessment Unit ID	Location Description	Impaired Use[1]	Impairment Cause[2]	Size	Size Units	TMDL Status
Union	66-0032-00	Lake or reservoir	AQR	Nutrients	399.2	acres	
Upper Sakatah	40-0002-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	876.2	acres	HgF (2008)
Volney	40-0033-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	259.3	acres	Nutrients (Draft 2014)
Wells	66-0010-00	Lake or reservoir	AQC, AQR	HgF, Nutrients	666.3	acres	HgF (2008)
West Jefferson	40-0092-02	Lake or reservoir	AQR	Nutrients	382.8	acres	Nutrients (Draft 2014)

Notes:
[1] Impaired Use categories include: AQC (aquatic consumption); AQL (aquatic life); AQR (aquatic recreation); DW (drinking water supply)
[2] Impairment causes include: DO (dissolved oxygen); E. coli (Escherichia coliform); FC (fecal coliform); F-IBI (impaired fish community); HgF (mercury in fish); M-IBI (impaired macroinvertebrate community); NO3 (nitrate); nutrients; PCBF (PCBs in fish); T (turbidity).

3
Model Development

This chapter provides a brief overview of the development of the Cannon River watershed HSPF model framework and the configuration of the framework to simulate hydrology, sediment and water quality transport and fate for the Cannon River watershed.

3.1 Overview of the Hydrological Simulation Program FORTRAN (HSPF)

HSPF is a watershed scale, semi-empirical, semi-spatially explicit, lumped parameter model that simulates environmental processes in watersheds and receiving waters. HSPF provides a continuous simulation of hydrology and associated water quality processes on land surfaces (for pervious via the PERLND module and impervious via the IMPLND module) as well as stream reaches and well-mixed reservoirs (via the RCHRES module). The model time-step can range from one (1) minute to one (1) day. HSPF can simulate any time period ranging from a few minutes to hundreds of years. In general, the model is used to assess the effects of land-use change, nonpoint source best management practices (BMPs), point source treatment alternatives, flow diversions, and reach restoration on hydrologic and pollutant loading conditions in a watershed.

HSPF uses continuous precipitation (rainfall and snowfall) and other climate input data (e.g., air temperature, wind, solar radiation, etc.) to compute streamflow hydrographs and pollutographs. HSPF can simulate interception, soil moisture, surface runoff, interflow, baseflow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, sediment detachment and transport, general constituent build-up and washoff, channel routing, reservoir routing, sediment routing by particle size, constituent routing, pH, BOD, DO, temperature, pesticides, conservative constituents, bacteria (i.e., fecal coliforms), ammonia, nitrate plus nitrite, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, benthic algae and zooplankton.

HSPF can be applied to watersheds that range from a field plot with a few acres to very small watersheds with a few square miles to large, complex watersheds with areas greater than several thousand square miles. The conceptual construct of HSPF is based on a watershed that is divided into multiple subwatersheds or subbasins, which are then further subdivided into land segments or hydrologic response units (HRUs) that are homogeneous in climate, land use, soil characteristics, and land management. Each land segment represents a portion of a subbasin area that is not spatially explicit within the subbasin; however, an individual subbasin is spatially explicit and possesses a specific geographic location within the watershed representation in the model. HSPF can simulate one or many pervious or impervious land areas discharging to one or many stream reaches or reservoirs.

One important assumption of the land segment or HRU concept in HSPF is that there is no interaction between land segments in a subbasin. Runoff flow, sediment loads and nutrient loads are calculated separately for each individual land segment and then summed together to determine the total load contribution from a subbasin. Each subbasin will contain one reach where flow and loadings from upstream can be added to flow and loadings derived from the local drainage areas. The subbasins and reach network are simulated with simple, one-dimensional routing of water and pollutants.

BASINS and HSPF software is non-proprietary and in the public domain, and these software packages can be accessed and downloaded by any individual via the following web site: http://water.epa.gov/scitech/datait/models/basins/index.cfm. Agency support for HSPF is provided by the United States Environmental Protection Agency (USEPA) via AQUA TERRA. The model user technical expertise or skill level required to develop and apply the model should be at an "advanced" level, including a strong working knowledge and competence in Geographic Information Systems (GIS) and watershed science/processes. The hardware and software computing requirements for BASINS and HSPF are moderate and reasonable. BASINS Version 4.1 provides a suite of plug-ins that customizes MapWindow GIS, providing an application that integrates environmental data, analysis tools, and modeling systems (USEPA 2013).

BASINS can be installed and operated on personal computers (PCs) that meet the hardware and software specifications summarized in Table 3-1 below (USEPA 2013). BASINS 4.1 is 64-bit and Windows 8 compatible (USEPA 2013). Various software programs (i.e., WDMUtil, GenScn, HSPEXP) are available to support data pre-processing, execution and post-processing for statistical and graphical analysis of data saved to the Watershed Data Management (WDM) file format.

Table 3-1. List of Hardware and Software Requirements for BASINS and HSPF (USEPA 2013).

Hardware/Software	Minimum Requirements	Preferred Requirements
Processor	1 GHz processor	2 GHz processor or higher
Available hard disk space	2.0 Gb	10.0 Gb
Random access memory (RAM)	512 Mb of RAM plus 2 Gb of page space	1 Gb of RAM plus 2 Gb of page space
Color monitor	16-bit color, Resolution 1024 x 768	32-bit color, Resolution 1600 x 1200
Operating system	Windows XP, Vista, Windows 7 and Windows 8	Windows XP, Vista, Windows 7 and Windows 8

The data requirements for HSPF are extensive but the necessary datasets are generally available from various public sources such as U.S. Geological Survey (USGS), USEPA, National Oceanic Atmospheric Administration (NOAA), United States Department of Agriculture (USDA), state environmental agencies and local agricultural extension programs. The data inputs include a Digital Elevation Model (DEM); climate data (e.g., daily precipitation, minimum and maximum air temperature, relative humidity, solar radiation, wind speed); land use/land cover; soils; stream network and reach geometry; land management activities; and feedlot and point source contributions of sediment and nutrients.

3.1.1 HSPF Model Version

The number of impaired segments from the draft 2014 303(d) list and the high number of impaired lakes having multiple tributary inflow locations contributed to a complex and highly detailed delineation of subbasins represented in the Cannon River watershed model (219 RCHRES and corresponding subbasins). As a result, one of the arrays (specifically MAXTSF) in the HSPF model WinHSPFLt version 12.3 was exceeded, preventing the full application of the model for hydrology, sediment and water quality. Attempts to obtain the code for this version of the model were unsuccessful as was applying a subsequent compiled version of the model (12.4) provided by the MPCA. LimnoTech resolved the problem by downloading the model code for version 12.2 (dated "August 2010") from AQUA TERRA's HSPF ftp site (http://hspf.com/ftp/hspf/HSPF122sourceAug2010.zip), modifying it to address the array limitation (i.e., increasing MAXTSF from 80,000 to 200,000) and recompiling it into a new executable. Model results presented in this report were generated using the recompiled 12.2 version of HSPF that includes the array dimensioning expansion, and the modeling package provides a copy of this version of the HSPF executable.

3.2 Model Inputs

This section describes the various elements of model input data and development. The Cannon River watershed HSPF model was constructed to simulate streamflow, sediment, water temperature, phosphorus (total and inorganic and organic species), nitrogen (total and inorganic and organic species), BOD, DO, a single group of phytoplankton and a single group of benthic algae for the 1995-2012 time period. All datasets acquired to develop the model were selected based on what would provide the most representative conditions for the 1995-2012 time period.

3.2.1 Climate

Hydrology as well as the transport and fate of sediment and nutrients in the environment are driven by climate forcings (e.g., precipitation, air temperature, wind, etc.). The model requires input of hourly precipitation (PREC), air temperature (ATEM), potential evapotranspiration (PEVT), wind (WIND), dew point temperature (DEWP), cloud cover (CLOU), and solar radiation (SOLR) to robustly simulate the water and energy balance. Meteorological data available from BASINS were downloaded and reviewed for geographic distribution and completeness (i.e., data gaps) to evaluate the stations for potential inclusion in the model. Additional meteorological data for the years spanning 2010 – 2012 were obtained directly from the National Climatic Data Center (NCDC) for the BASINS stations (NCDC 2014). Daily precipitation data from the Minnesota Department of Natural Resources (MNDNR) climatology office were also provided to LimnoTech by MPCA. The data were compiled, formatted and inventoried to evaluate the stations for potential inclusion in the model. The final selection of the BASINS and MNDNR precipitation stations occurred during the land segmentation process as precipitation is an important consideration in defining the land segmentation scheme.

Precipitation data were available through the BASINS tool at five (5) stations for the 1995 - 2009 time period (Table 3-2). Hourly precipitation data for the 2010 – 2012 period for these locations were obtained directly from the NCDC. Eight (8) MNDNR stations were also selected based on spatial location and data completeness for the 1995 – 2012 time period (Table 3-2). Five (5) additional MNDNR stations were used to fill data gaps in the 2010 – 2012 time period of the BASINS gages based on their proximity to the selected stations (e.g. the MNDNR station in Faribault was used to fill the gaps in the 2010 – 2012 dataset for the BASINS station in Faribault). The selected MNDNR daily precipitation stations were disaggregated from daily to hourly time series using the WDMUtil software disaggregation tool and the nearest BASINS precipitation station as the basis for the disaggregation. Subwatersheds were assigned precipitation time series data using a Thiessen network analysis of the 13 stations (Figure 3-1).

Air temperature data were available through BASINS for five (5) stations (Table 3-2). Subwatersheds were assigned air temperature time series data based on the Thiessen network analysis. Wind speed, dew point temperature, cloud cover, and solar radiation data were available through BASINS for five (5) stations (Table 3-2 and Figure 3-2). Additional meteorological data for the five stations for the 2010 – 2012 time period were downloaded directly from the NCDC website.

The standard BASINS meteorological dataset includes potential evapotranspiration time series data calculated using the Hamon method (Hamon 1961). However, per the MPCA modeling guidance document (AQUA TERRA Consultants 2012), the potential evapotranspiration input should be based on pan evaporation calculated using the Penman Pan method. A pan coefficient is then applied to convert the pan evaporation to potential evapotranspiration (AQUA TERRA Consultants 2012). Penman pan evaporation was calculated for five (5) stations (Table 3-2 and Figure 3-2). Subwatersheds were assigned wind speed, dew point temperature, cloud cover, solar radiation, and Penman pan evaporation (potential evapotranspiration) time series data based on a Thiessen network analysis (Figure 3-2).

BASINS climate (precipitation, air temperature, wind speed, dew point temperature, cloud cover, solar radiation, penman pan evaporation) data gaps were filled using data from the nearest station. For smaller data gap periods (e.g. hours vs. days), linear interpolation was used to fill the gaps. The specific strategy used to fill data gaps at each station is provided in Table 3-2. The gap-filling strategy described in detail in the Task 2, Part 1 memorandum (LimnoTech 2014b), which is provided as part of the final model package materials, was deviated from slightly for the final calibration. Gaps in the datasets for the MNDNR stations were filled using the nearest of the five (5) BASINS stations (instead of using one or more MNDNR/BASINS station).

The meteorological input time series data can be found in the WDM file named “Met.wdm” provided in the modeling package.

Table 3-2. Climate Data Inventory for the Cannon River Watershed.

Station ID	Data Source	Station Name	Precipitation	Air Temperature	Other Climate[1]	Period of Record	Comments/Notes
MN212721/ MN726563	BASINS	Faribault	✓	✓	✓	1995 - 2012	Data gaps (2010-2012) filled w/ MNDNR Faribault and BASINS MN215987 (Northfield), MN217004 (Rochester), MN726568 (Owatonna) and MN726585 (Mankato)
MN215987	BASINS	Northfield 2 NNE	✓			1995 - 2012	Data gaps filled w/ Kadlec, Faribault (MNDNR) and MN217004 (Rochester)
MN216287/ MN726568	BASINS	Owatonna	✓	✓	✓	1995 - 2012	Precip. data gaps (2010-2012) filled w/ MNDNR Owatonna and BASINS MN212166 (Dodge Center). Met data filled with MN726563 (Faribault) and MN726585 (Mankato)
MN216822/ MN726564	BASINS	Red Wing Dam 3	✓	✓	✓	1995 - 2012	Precip. data gaps (extended periods in 2010-2012) filled w/ Red Wing (MNDNR) and MN217004 (Rochester). Met data gaps filled with MN726563 (Faribault), MN726585 (Mankato), and MN726568 (Owatonna)
MN218692	BASINS	Waseca	✓			1995 - 2012	Precip. data gaps filled w/ MNDNR Waseca and MN217004 (Rochester)
MN217004	BASINS	Rochester International Airport		✓	✓	1970 - 2012	Data gaps filled with MN 726568 (Owatonna). Precip. data also available but were used only to fill data gaps in other stations' records.
MN726585	BASINS	Mankato (AWOS)		✓	✓	1995 - 2009	Met data gaps filled with MN726563 (Faribault), MN726568 (Owatonna) and MN217004 (Rochester). Precip. data available (1995-2009) at a nearby station in Mankato (MN215073) but were only used to fill data gaps in other stations' records.
25 112N 16W 31-1	MNDNR	Anderson	✓			1995 - 2012	Precip. data gaps filled w/ MN216822 (Red Wing Dam 3)

Station ID	Data Source	Station Name	Precipitation	Air Temperature	Other Climate[1]	Period of Record	Comments/Notes
70 113N 22W 31-1	MNDNR	Bisek	✓			1995 - 2012	Precip. data gaps filled w/ MN215987 (Northfield)
74 105N 19W 25-1	MNDNR	Bloomin	✓			1995 - 2012	Precip. data gaps filled w/ MN216287 (Owatonna)
19 113N 18W 17-1	MNDNR	Drewy	✓			1995 - 2012	Precip. data gaps filled w/ MN215987 (Northfield)
74 106N 21W 1-1	MNDNR	Henke	✓			1995 - 2012	Precip. data gaps filled w/ MN216287
19 113N 20W 15-1	MNDNR	Kadlec	✓			1995 - 2012	Precip. data gaps filled w/ MN215987 (Northfield)
7 109N 25W 27-1	MNDNR	Mettler	✓			1995 - 2012	Precip. data gaps filled w/ MN218692 (Waseca)
40 109N 25W 3-1	MNDNR	West	✓			1995 - 2012	Precip. data gaps filled w/ MN218692 (Waseca)

Note:

[1] Includes Wind Speed, Dew Point, Cloud Cover, Solar Radiation, Penman Pan Evaporation

The model simulation period is 1995-2012.

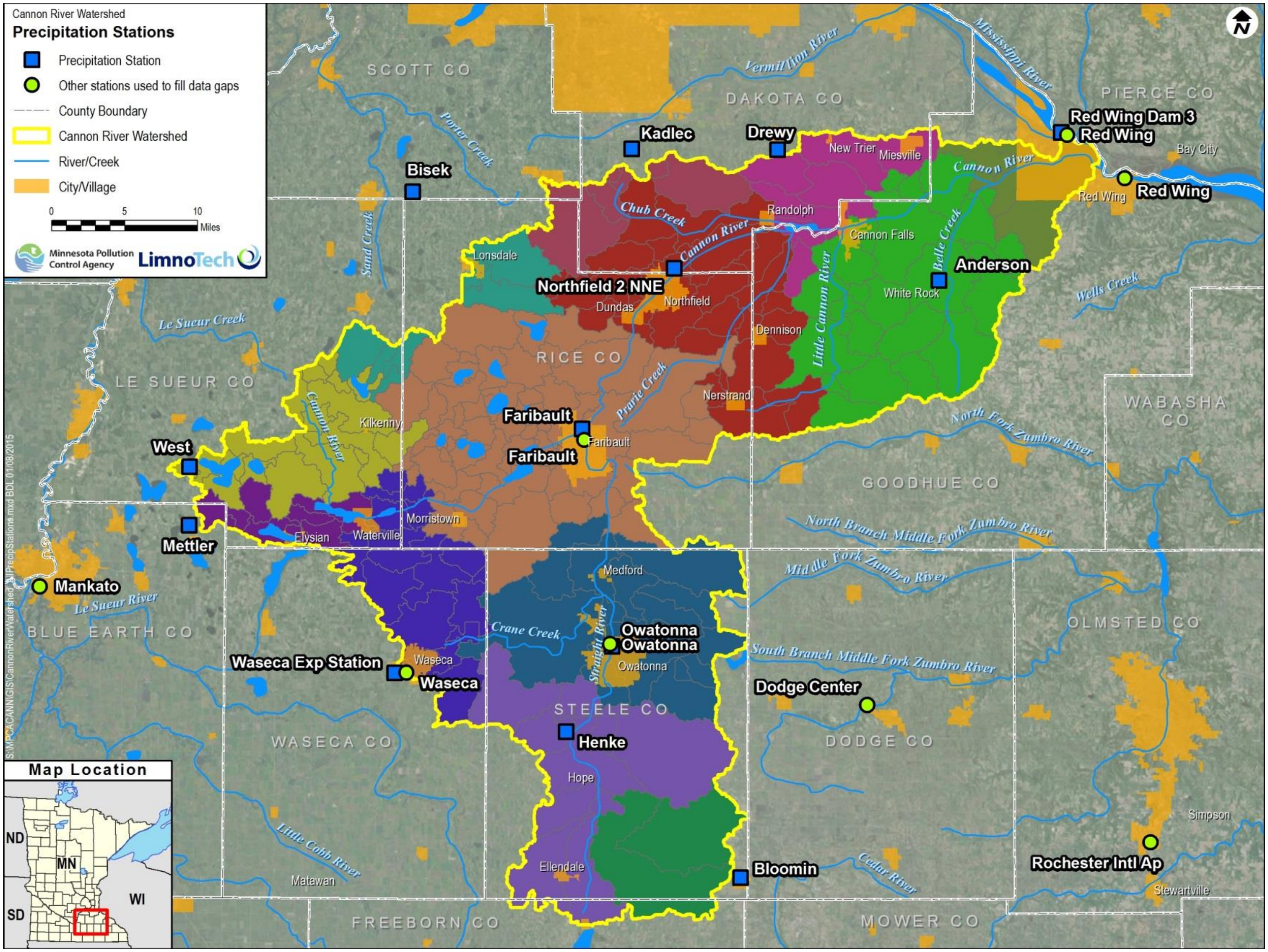

Figure 3-1. Map of Precipitation Stations and Subwatershed Assignments for the Cannon River Watershed HSPF Model.

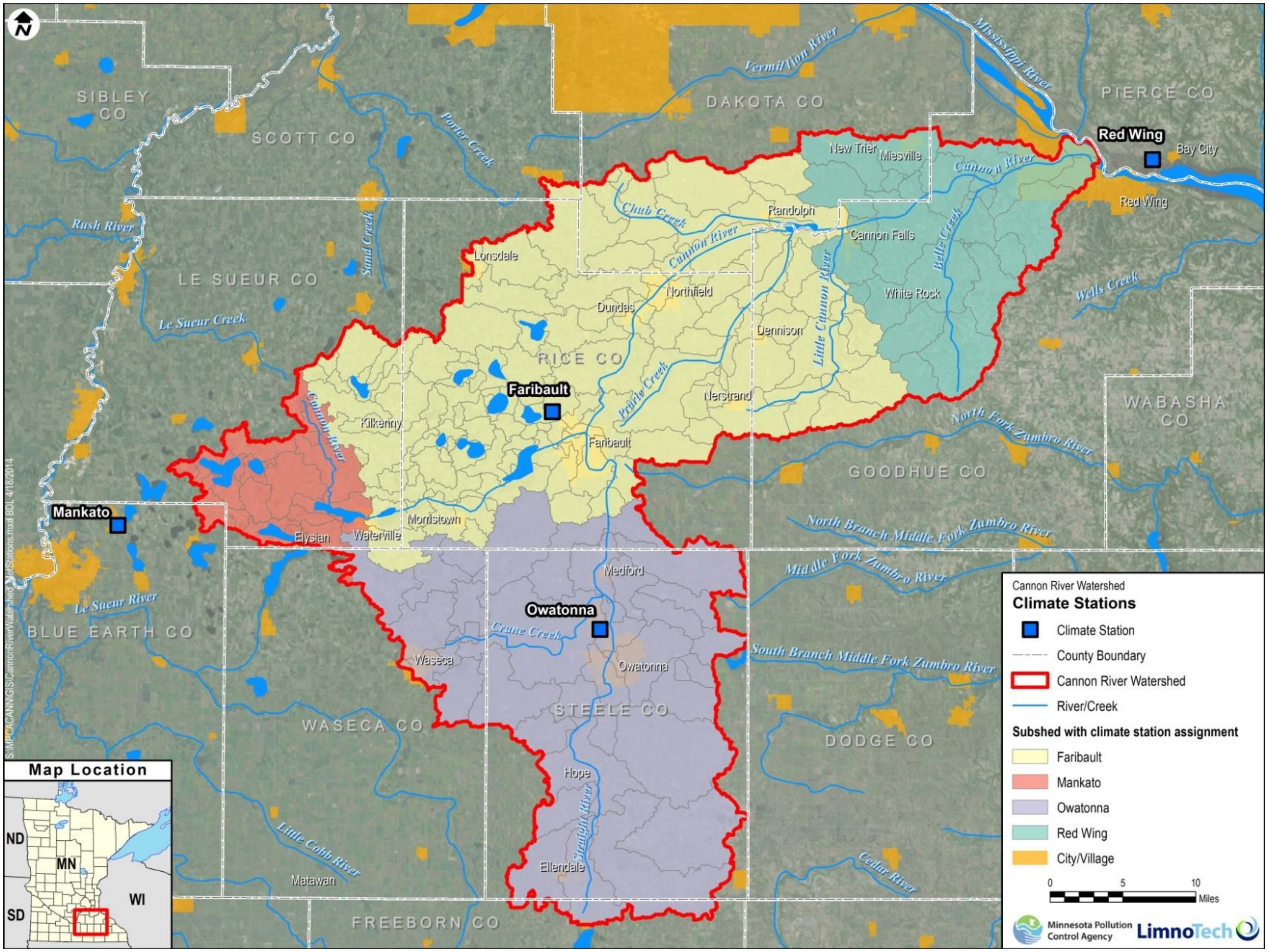

Figure 3-2. Map of Wind Speed, Dew Point Temperature, Cloud Cover, and Solar Radiation Stations and Subwatershed Assignments for the Cannon River Watershed HSPF Model.

3.2.2 Geographic (Spatial) Data

The geographic datasets compiled to build the model framework are described in the sections below. The sections include: watershed boundaries, hydrography, digital elevation model (DEM), land use/land cover, and soils. A brief summary of any data processing and modification is provided. Please see the geodatabase file named "Cannon_GIS.gdb" for the individual geographic data layers. An ArcMap document named "Cannon_GIS.mxd" is also provided to facilitate display of the datasets. All geographic data layers are provided in the NAD 1983 UTM Zone 15N projection.

Watershed Boundaries

Watershed boundary datasets are used to define the watershed and subbasin delineations. Watershed boundary datasets at the HUC8 (8-digit) and HUC12 (12-digit) level were obtained from the USDA Natural Resources Conservation Service (NRCS) Geospatial Data Gateway (USDA NRCS 2013b). The HUC8 boundary served as the watershed boundary for the Cannon River watershed. The HUC12 boundary was used to define the initial delineation of the subwatershed boundaries. The MNDNR HUC14 (14-digit, Level 7) and the HUC16 HUC (16-digit, Level 8) datasets for the Cannon River watershed were used to divide larger subwatersheds into smaller subwatersheds. Cases where further subwatershed division was required included impaired segments, streamflow gage locations, water quality calibration/validation locations, major point sources, river confluences, and morphological changes. Additional subwatershed (or subbasin) delineations were performed via a manual delineation based on the DEM noted below.

Hydrography

A hydrography dataset is needed to define the stream network and reach segmentation in the model. The NHDPlus hydrography layer was acquired from the BASINS tool (USEPA 2010, USGS and USEPA 2012). The NHDPlus stream network is based on the medium resolution National Hydrography Dataset (NHD) and has a scale of 1:100,000. The NHDPlus dataset served as the primary hydrography stream network layer and was modified, as needed, for the subwatershed delineation. The NHD High Resolution hydrography layer was also acquired from the USDA NRCS Geospatial Data Gateway (USDA NRCS 2013b). The NHD High Resolution hydrography layer has a scale of 1:24,000. The NHD High Resolution dataset was used to refine and/or correct the NHDPlus flowline dataset, as needed, to be consistent with the subwatershed delineation.

Digital Elevation Model (DEM)

A DEM is required to characterize the topography of a watershed. A high-quality DEM is essential to accurately representing watershed subbasin boundaries, land slope, and river reaches to support the simulation of sediment and nutrient erosion and transport. A National Elevation Dataset (NED) 10 meter DEM was obtained from the USGS (USGS 2014a). The DEM was downloaded as 3 separate tiles which were mosaicked into a single, seamless DEM. As a final step, the DEM was clipped to the HUC8 watershed boundary.

Land Use/Land Cover

Land use/land cover is an important factor in controlling how water, sediment, and nutrients move through the environment. Land use data were acquired from the National Land Cover Database (NLCD) that is distributed by the Multi-Resolution Land Characteristics (MRLC) Consortium, a partnership of Federal agencies led by the USGS (MRLC Consortium 2014). The NLCD is a 16-class land cover classification scheme that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters. Two land use data layers were obtained, the NLCD 2001 (version 2) and the NLCD 2006. The NLCD 2001 (version 2) was used for the model validation period (1996-2003), and the NLCD 2006 was used for the calibration period (2004-2012). The NLCD 2001 (version 2) and the NLCD 2006 land cover classifications were reclassified per the recommended model land use categories outlined in the MPCA modeling guidance document (AQUA TERRA Consultants 2012) (Table 3-3). The datasets were then clipped to the HUC8 watershed boundary.

Table 3-3. Cannon River Watershed HSPF Model Land Use/Land Cover Categories.

2001/2006 NLCD Categories	HSPF Model Categories	Reclassification Value
Deciduous Forest	Forest	1
Evergreen Forest		
Mixed Forest		
Pasture/Hay	Pasture	4
Shrub/Scrub	Grassland	3
Barren Land (Rock/Sand/Clay)		
Grassland/Herbaceous		
Cultivated Crops	Cropland	5
Developed, Open Space	Developed, Open Space	6
Developed, Low Intensity	Developed, Low Intensity	7
Developed, Medium Intensity	Developed, Medium/ High Intensity	8
Developed, High Intensity		
Woody Wetlands	Water/Wetlands	2
Emergent Herbaceous		
Wetlands		
Open Water	Open Water*	2

"Open Water" was combined with "Wetlands" in the reclassification scheme. In the Cannon River watershed HSPF model, "Open Water" is represented in the RCHRES module; therefore, the Wetland" areas were reduced accordingly by subwatershed during the land segmentation process.

Given the highly agricultural nature of the Cannon River watershed, the cultivated crops category was refined to distinguish between "drained" and "undrained" categories as part of the land segmentation process (Section 3.3.2).

The impervious areas input to the model were based on the NLCD 2001 (version 2) and NLCD 2006 "Percent Developed Imperviousness" grid layers, which are also available from the MRLC Consortium (2014).

Soils

The soil geographic dataset as well as the soil attribute dataset were obtained from the USDA NRCS Soil Survey Geographic Database (SSURGO) (USDA NRCS 2012). The soils data have a spatial resolution of

1:24,000 (USDA NRCS 2012). All nine counties in the Cannon River watershed (Blue Earth, Dakota, Freeborn, Goodhue, Le Sueur, Rice, Scott, Steele, Waseca) had SSURGO data available. The individual county tiles were merged to create a single layer, clipped to the HUC8 boundary, and then joined to the "component" (includes hydrologic soil group (HSG) values) and "chorizon" (includes K-factor values) tables to generate an attributed shapefile.

The soils data were refined to include one of four HSG's (A, B, C, and D) for all land uses with the exception of cropland. Soils with a dual classification (i.e., A/D, B/D, C/D) in a forest, pasture, or grassland land use were reclassified with the higher runoff potential HSG (D). Dual classification soils in cropland were assumed to be "drained" with an artificial drainage system if the average land slope is less than 3% and were grouped into a "drained" land use category. Cropland soils with an average land slope greater than 3% were placed into either a low or high runoff potential category based on the first HSG designation. The four HSG's were then aggregated into two categories per the MPCA modeling guidance document (AQUA TERRA Consultants 2012): a low runoff potential (AB) category and a high runoff potential (CD) category.

Additional Geographic Datasets

The datasets listed above include major spatial datasets required to develop an HSPF model. However, additional datasets were used in the development of the Cannon River watershed HSPF model and include the following:

- Draft 2014 303(d) and 305(b) geographic data for lakes, streams, and wetlands (MPCA 2014b) (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/impaired-waters-list.html);
- Municipal separate storm sewer system (MS4) areas (obtained from J. Watkins, MPCA);
- Karst features (obtained from J. Watkins, MPCA);
- Bathymetry for the lakes in the watershed (obtained from Minnesota Data Deli (MNDNR 2013a) website: http://deli.dnr.state.mn.us/index.html, and the MnDNR LakeFinder (MNDNR 2014) website: http://www.dnr.state.mn.us/lakefind/index.html);
- Lake outlet structure (obtained from Dan Henely, MNDNR);
- Groundwater and surface water withdrawals (MNDNR 2013b) (http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html); and
- Animal feedlots (AFOs) (MPCA 2013b) (http://www.pca.state.mn.us/index.php/data/spatial-data.html?show_descr=1).

3.2.3 Point Sources

Major and minor point source data for years 1995-2012 were provided by the MPCA. The point source data were downloaded and compiled by MPCA from the EPA Permit Compliance System (PCS) database and the Minnesota "Delta" database. Daily data were provided for the major wastewater treatment plant (WWTP) facilities (i.e., Owatonna, Faribault and Northfield WWTPs), and monthly averages and totals were provided for the minor WWTPs and pond facilities. The HSPF model representation of point sources includes the following parameters: flow, water temperature, phosphorus (as individual species), nitrogen (as individual species), total suspended solids (TSS), DO, and BOD. Table 3-4 provides a list of the major and minor point sources represented in the Cannon River watershed HSPF model. A directory of the point source inputs is provided in an Excel file named, “Directory_of_PS_DSNs_CRWHSPF.xlsx”, as part of the project deliverables package.

Table 3-4. Major and Minor Point Sources Represented in the Cannon River Watershed HSPF Model.

Facility Name	Point Source Type	Permit No.
Faribault WWTP	**Major**	**MN0030121**
Northfield WWTP	**Major**	**MN0024368**
Owatonna WWTP	**Major**	**MN0051284**
Amoco Oil Co - Ellendale	Minor	MN0044547
Beatric Cheese Inc	Minor	MNG250011
Cannon Falls WWTP	Minor	MN0022993
CenterPoint Energy - WWTS	Minor	MN0063967
Dennison WWTP	Minor	MN0022195
Driessen Water II Inc	Minor	MN0021911
Ellendale WWTP	Minor	MNG580014
Elysian WWTP	Minor	MN0041114
Faribault Dairy Co Inc - Faribault	Minor	MNG255092
Faribault Woolen Mill Co	Minor	MNG255057
Farmers Mill & Elevator Inc	Minor	MN0063711
Geneva WWTP	Minor	MN0021008
Genova-Minnesota Inc	Minor	MN0046957
Hope - Somerset Township WWTP	Minor	MN0068802
Hope Creamery	Minor	MN0001317
Jennie-O Turkey Store Inc - Faribault	Minor	MN0002500
Kilkenny WWTP	Minor	MNG580084
Lakeside Foods Inc - Owatonna Plant	Minor	MN0001571
Lonsdale WWTP	Minor	MN0031241
Magellan Pipeline Co LP - Faribault	Minor	MNG790120
MDNR Sakatah State Park	Minor	MN0033774
Medford WWTP	Minor	MN0024112
Meriden Township WWTP	Minor	MN0068713
Milestone Materials - Spinler Pit	Minor	MN0063045
Minnesota Malting Co	Minor	MN0001481
MNDOT - Heath Creek Rest Area	Minor	MN0069639
Morristown WWTP	Minor	MN0025895
Multek Flexible Circuits Inc - NCC	Minor	MNG255031
Nerstrand WWTP	Minor	MN0065668
Prairie Ave Leasing Ltd	Minor	MN0057541
SMC - Owatonna Quarry	Minor	MN0041394
Telamco Inc	Minor	MNG255064
Viracon	Minor	MNG255078
Waseca WWTP	Minor	MN0020796
Waterville WWTP	Minor	MN0025208

The section below contains an overview of data processing performed to fill in data gaps for the point source datasets. Point source input assumptions, for cases where data were not available, were intended to be consistent with the assumptions made in other Minnesota watershed models (RESPEC 2012a; TetraTech 2009, 2012, 2013; LimnoTech 2014d).

Major Point Sources

Data were processed using the following rules:

- Outliers in the dataset were revised using linear interpolation between the previous and next reported value.
- Data gaps less than or equal to seven (7) days were filled using linear interpolation between the first and last reported value.
- Data gaps greater than seven (7) days were filled using the average of all values for that month/year.
- Data gaps a month or longer were filled using the long-term average of values for that month, if available; if those values were not available, then the long-term average of the entire dataset was used.

Assumptions applied when data were not available include:

- TSS silt – 40% of TSS;
- TSS clay – 60% of TSS;
- BOD_U –2.5 times BOD_5;
- NO_3 – 10 mg/L;
- NO_2 – 0.1 mg/L;
- ORGN – 4.3 % of BOD_U;
- PO_4 – 72.4 % of TP;
- ORGP – 27.7 % of TP; and
- OGRC – 26.9% of BOD_U.

Minor Point Sources

Data were processed using the following rules:

- Outliers in the dataset were revised using linear interpolation between the previous and next reported value.
- Flow for facilities (e.g., ponds, quarries) reporting a monthly flow volume (MG) and duration of discharge (days) was changed from an average for those days to an average as if that volume was spread out over the entire month (MGD).
- Data gaps were filled as follows:
    - If less than or equal to one (1) monthly observation, the long-term average was used.
    - If less than six (6) long-term observations, the assumptions described below were used.
    - For non-continuously discharging facilities (ponds and quarries and swimming pools), data gaps were assumed to reflect zero discharge.

Assumptions applied when data were not available are as follows:

- TSS data – 5 mg/L for WWTPs/Food-Processing and 1 mg/L for Industrial/Other facilities;

- TSS silt – 40% of TSS;
- TSS clay – 60% of TSS;
- DO – 8 mg/L;
- BOD_5 – 5 mg/L for WWTPs/Food-Processing and 1 mg/L for Industrial/Other facilities;
- BOD_U – 2.5 times BOD_5;
- NO_3 – 10 mg/L for WWTPs/Food-Processing and 1 mg/L for Industrial/Other facilities;
- NO_2 – 0.1 mg/L;
- NH_3 – 1 mg/L;
- ORGN – 4.3% of BOD_U;
- TP – 0.1 mg/l;
- PO_4 – 72.4% of TP;
- ORGP – 27.6% of TP; and
- OGRC – 12.79% of BOD_U.

The annual solids and phosphorus loads for the major point sources were compared to loads calculated by MPCA using the "Delta" database to confirm comparability between the input datasets and resulting loads. This comparison indicated that the total phosphorus loads for 2004 and 2005 for the Faribault WWTP were calculated using influent rather than effluent data. Once the correct data were provided, the annual loads calculated from the time series used in the Cannon River watershed model were comparable to the corresponding annual loads calculated by MPCA.

3.2.4 Atmospheric Deposition

Atmospheric deposition contributes nutrients directly to land and water surfaces. Atmospheric deposition is considered to be a significant source of inorganic nitrogen (as ammonia and nitrate) and is included in the model (AQUA TERRA Consultants 2012, Tetra Tech 2009). Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP) National Trends Network (NTN) (NADP 2012). Data were available at the Wildcat Mountain (WI98) station, located in Vernon County, Wisconsin, for the 1995-2012 time period. Dry atmospheric deposition data were also downloaded from the USEPA Clean Air Status and Trends Network (CASTNET) (USEPA 2012). Data were available at the Perkinstown (PRK134) station, located in Taylor County, Wisconsin, for the 1995-2012 time period. Both the wet and dry atmospheric deposition stations are located outside the Cannon River watershed, but they represent the stations that are closest in proximity to the watershed.

Model input values for ammonium and nitrate were developed for 1995-2012 based on weekly measurements. Input concentrations were developed for wet deposition and unit area loads (UALs) for dry deposition for ammonium. The following assumptions were made in processing the raw datasets:

- If the reported data had a "<" qualifier, the value reported was used; and
- Data gaps were filled in by repeating the reported values from the previous week.

3.3 Model Construction

The Cannon River watershed HSPF model has been developed to run with a recompiled version of HSPF version 12.2 that includes an array dimensioning expansion (see Section 3.1.1 for more detail).

3.3.1 Watershed Delineation

The Cannon River watershed delineation is a customized delineation with a scale between HUC12 and HUC16, where the coarsest resolution is at the HUC12 scale. The watershed delineation was based on the following data layers (see Section 3.2.2 for more detail):

- HUC8 and HUC12 NRCS Watershed Boundaries Datasets (WBD);
- HUC14 (Level 7) and HUC16 (Level 8) MNDNR watershed boundaries;
- NED 10 meter DEM;
- NHDPlus flowlines and NHD high resolution flowlines;
- 303(d) impaired segments;
- Major point source locations; and
- Key streamflow and water quality station locations.

The HUC8 boundary served as the watershed boundary for the Cannon River watershed, and the HUC12 boundary was used to define the initial delineation of the subwatershed boundaries. The MNDNR HUC14 (14-digit, Level 7) and HUC16 HUC (16-digit, Level 8) datasets for the Cannon River watershed were used to divide larger subwatersheds into smaller subwatersheds, in order to provide optimal resolution for model calibration and future application of the model for management scenarios. The 10 meter DEM elevation values were used to inform the subbasin delineation process. The HSPF model framework requires a single stream reach for each delineated subbasin. The NHDPlus dataset served as the primary hydrography stream network layer and was modified, as needed, for the subwatershed delineation. The NHD High Resolution dataset was used to refine and/or correct the NHDPlus flowline dataset, as needed, to be consistent with the subwatershed delineation.

Cases where further subwatershed division was required included 303(d) impaired reach segments, point sources, river confluences, morphological changes, streamflow gage locations, water quality calibration/validation locations and correspondence with MPCA. The most critical element in the subdivision of subbasins was the 303(d) impaired segments data layer. Per the MPCA modeling guidance document (AQUA TERRA Consultants 2012), the Section 303(d) listed segments need to be represented as separate stream reaches in the HSPF models so that flows, water balance, volume, and water quality concentration information can be generated and used directly in TMDL assessments. Separate subwatersheds were developed for each impaired lake and their inflow tributaries, as per the MPCA modeling guidance document (AQUA TERRA Consultants 2012). For six lakes (Clear Lake, Loon Lake, Frances Lake, Mabel Lake, Tustin Lake and Toner's Lake), neither the NHDPlus nor NHD high resolution flowlines included a connection from the lake outlet to a downstream reach. In those cases, the location of the lake outlet and the downstream reach were estimated using DEM data, aerial photograpy and lake bathymetry data. A map of the Cannon River watershed delineation for the Cannon River watershed HSPF model is provided below (Figure 3-3).

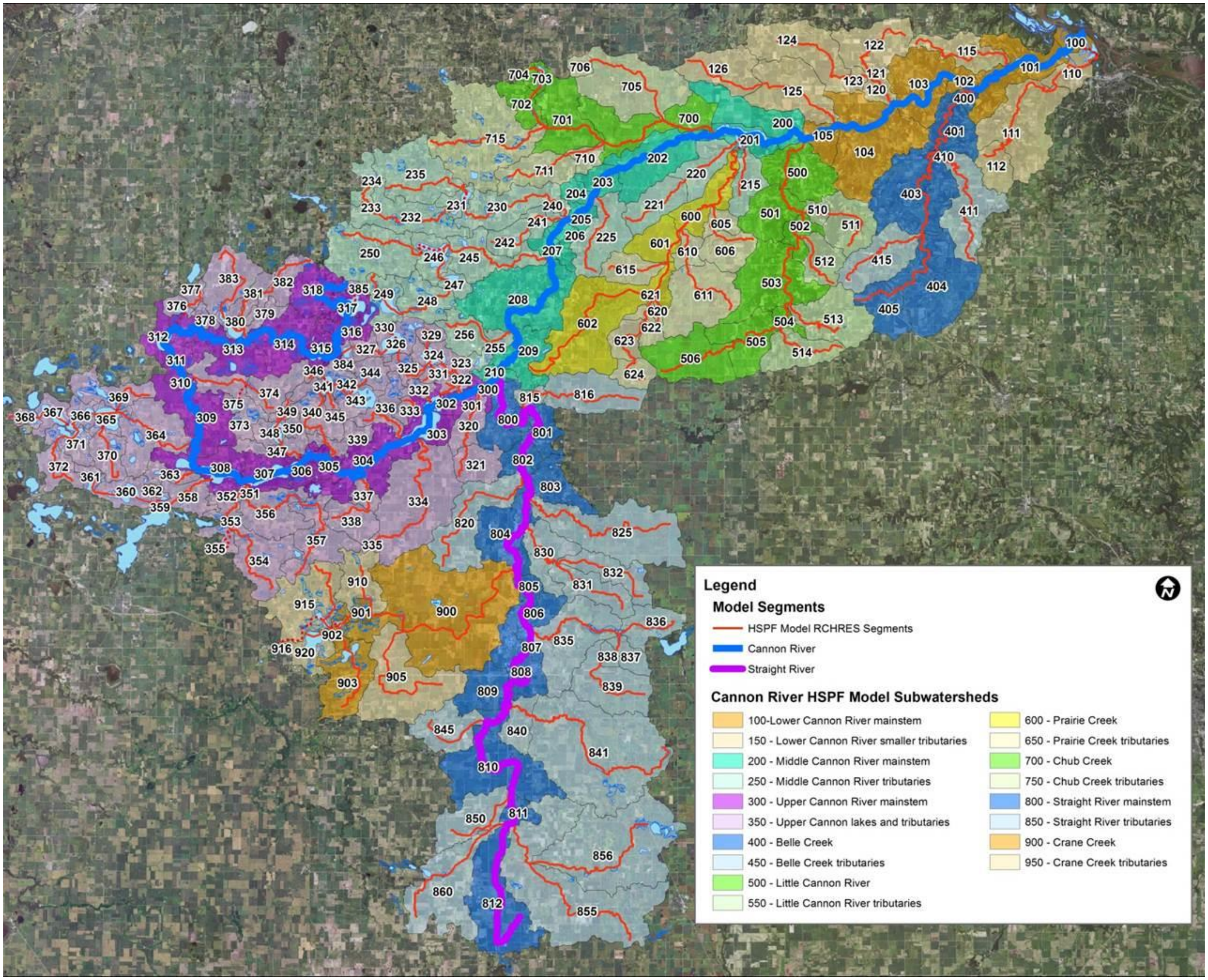

Figure 3-3. Map of the Cannon River Watershed Delineation for the Cannon River Watershed HSPF Model.

3.3.2 Land Segmentation

In the HSPF model, a watershed is comprised of delineated subbasins (or subwatersheds) that have a single, representative reach segment per subbasin. The subbasins and reach segments are networked (or connected) together in the model to represent a watershed drainage area. In HSPF, a subbasin is conceptualized as a group of individual land segments that are all routed to a representative reach (or stream) segment. The individual land segments represent homogeneous land use, soils, topography, climate, and land management activities. It is important to note that the individual land segments are not spatially explicit within a subbasin model. For example, all forest land with a HSG of A/B in a subbasin would be lumped or grouped as a single unit without reference to the varying spatial locations of that hydrologic response unit type scattered across a subbasin. The geographic (or spatial) location of a subbasin is known and maintains a spatially explicit location in the model.

The purpose of the land segmentation step in the model development process is to divide a watershed into individual land segments that are assumed to produce homogeneous hydrologic and water quality responses due to similar land use, soils, topography, climate, and land management activities.

The primary Cannon River watershed characteristics selected for land segment categorization include climate variability (i.e., rainfall), land cover/land use distribution, HSG soil classification, artificial drainage (i.e., tile drained land), animal feedlot operations, MS4 boundaries and percent impervious areas. The data layers used to define the land segmentation include the following (see Section 3.2.2 for more detail):

- NLCD 2001 land cover (version 2) and NLCD 2006 land cover;
- NLCD 2001 percent developed imperviousness (version 2) and NLCD 2006 percent developed imperviousness;
- SSURGO HSG attributes;
- NED 10 meter DEM;
- Precipitation gage locations;
- Animal feedlot point locations;
- MS4 areas; and
- NHDPlus flowlines and waterbodies.

The general approach to the land segmentation development process was to assign precipitation gage locations to subbasins, classify the land cover to the desired model land cover categories, aggregate the soil HSG's to a low runoff potential (AB) category or a high runoff potential (CD) category for each model land cover category, account for animal feedlot areas, account for MS4 areas, and account for the surface water areas modeled explicitly in the RCHRES module. The section below provides a more detailed description of the land segmentation process outlined above.

Subwatersheds were aggregated into precipitation and climate zones based on their proximity to a selected station using the Thiessen polygon method. There were 13 precipitation zones used to define the land segmentation.

As noted above, two land cover data layers were acquired, the NLCD 2001 (version 2) and the NLCD 2006. The NLCD 2001 (version 2) was used for the model validation period (i.e., 1996-2003), and the NLCD 2006 was used for the calibration period (i.e., 2004-2012). The NLCD 2001 (version 2) and the NLCD 2006 land cover classifications were reclassified (or aggregated) per the recommended model land use categories outlined in the MPCA modeling guidance document (AQUA TERRA Consultants 2012) (Table 3-3). For forest, grassland, and pasture, the soil HSG's (A, B, C, and D) were further aggregated to a low runoff potential (AB) or high runoff potential (CD) category per the MPCA modeling guidance document (AQUA TERRA Consultants 2012). The wetland land segment category was not assigned a runoff potential category, which is consistent with the MPCA modeling guidance document (AQUA TERRA Consultants 2012).

For cropland, the segmentation scheme consists of cropland AB, cropland CD, and drained cropland categories. Different tillage practices (i.e., conventional tillage versus conservation tillage) are not distinguished in the model at this time. Given the limited available information on tillage practices in the watershed, this approach is consistent with the MPCA modeling guidance document recommendations (AQUA Terra Consultants 2012, see Section 2.3.7). Specifically, the following lines of evidence led to the representation of all agricultural land as being under conventional tillage in the Cannon River watershed HSPF model:

- Detailed spatial information and data on tillage practices in the watershed are not available at this point in time.
- Information provided in the NRCS Rapid Watershed Assessment Resource Profile for the Cannon River watershed indicates that an average of approximately 73,300 agricultural acres were under residue management over the 1999-2007 time period (USDA NRCS 2007). The area under residue management represents approximately 13% of the cropland acres in the Cannon River watershed.
- The following is noted in the MPCA modeling guidance document: "As suggested in communications with MPCA (Chuck Regan), it is rare for cultivated land in these watersheds to be under conservation tillage" (AQUA TERRA Consultants 2012).

In the future, if tillage practice information does become available, the model can be modified to differentiate between cropland under conventional tillage and cropland under conservation tillage. In addition, the model can be modified to represent conservation tillage practices under various land management scenarios.

Artificial drainage practices in the form of tile drains on agricultural lands can significantly influence hydrology and water quality processes. The inclusion of a drained cropland category allows potentially poorly drained soils to be parameterized in the model as well drained soils based on estimates of land areas likely to have artificial drainage implemented. The calculation of land area under artificial drainage is consistent with the approach outlined in the MPCA modeling guidance document (AQUA TERRA Consultants 2012). The approach assumes that the artificial drainage exists on cropland with dual HSG categories (e.g., A/D) and an average slope of less than 3%. Soils meeting these criteria were grouped into a "drained" land use category. Cropland soils with an average land slope greater than 3% were placed into either a low or high runoff potential category based on the first HSG designation.

Three classes were defined for urban land cover, including developed open space, developed low intensity, and developed medium-high density. A runoff potential category was not assigned to urban land classes, which is consistent with the MPCA modeling guidance document (AQUA TERRA Consultants 2012, see Table 2-6). The urban land classes were divided into pervious and impervious classifications. Within HSPF, it is important to differentiate between the total impervious area (TIA) and what is defined as the effective impervious area (EIA). In HSPF, the EIA represents the impervious land area that is directly connected to a local hydraulic conveyance system (e.g., gutter, curb drain, storm sewer, open channel, or river). For land areas that are impervious but are not part of the EIA land area, the resulting overland flow is transported to pervious land areas and has the opportunity to infiltrate into the soil profile along its respective overland flow path before reaching a stream or waterbody. Impervious non-EIA land areas are represented in HSPF as pervious land areas. The TIA was calculated from the NLCD 2001 (version 2) and NLCD 2006 percent developed imperviousness grids. The EIA portion of the TIA was estimated using the method outlined in the MPCA modeling guidance document (AQUA TERRA Consultants 2012, see Section 2.5), where:

$$EIA = 0.1(TIA)^{1.5}$$

The HSPF models developed under the One Water Program must represent the Municipal Separate Storm Sewer System (MS4) areas. The MS4 areas were separated from the non-MS4 areas during the land segmentation process based on the MS4 data layer provided by MPCA. The MS4 areas were assigned a unique or separate mass link number on the lines in the schematic corresponding to MS4 areas, although the MS4 areas were parameterized the same as non-MS4 areas within the same land classification. This approach facilitates separate waste load allocation for MS4 areas and is consistent with recommendations in the MPCA modeling guidance document (AQUA TERRA Consultants 2012).

Animal Feeding Operations (AFOs) were identified based on the MPCA AFO spatial data layer. The data included a point location and estimated animal units (AU) by animal type for each AFO in the Cannon River watershed. An AFO land area of 300 square feet per AU was assumed (Murphy and Harner 2001), which is consistent with the AFO land area assumption made in other Minnesota HSPF models (RESPEC 2012a). The individual AFO area estimates were shifted from the land category where each AFO was reassigned to the feedlot category. Finally, the open water areas classified as “water/wetland” in the land cover/land use reclassification step, which are actually explicitly represented in the RCHRES module, were subtracted from the water/wetlands category to avoid “double-counting” these areas.

The combination of 13 precipitation zones and 17 land cover/HSG categories results in 221 distinct land segment (i.e., PERLND and IMPLND) types for the Cannon River watershed HSPF model application. The resulting land segment categories for the Cannon River watershed are summarized in Tables 3-5 and 3-6 below for the NLCD 2006 and the NLCD 2001 (version 2), respectively.

Table 3-5. Cannon River Watershed HSPF Land Segments Based on NLCD 2006

Land Segment Category	Impervious (EIA) Land Area	Pervious Land Area	Total Area
Cropland - AB	-	33.26%	33.26%
Cropland - CD	-	6.86%	6.86%
Cropland - Drained	-	22.02%	22.02%
Developed, Low Intensity (MS4)	0.18%	0.69%	0.87%
Developed, Low Intensity (non-MS4)	0.19%	0.98%	1.16%
Developed, Medium and High Intensity (MS4)	0.28%	0.24%	0.52%
Developed, Medium and High Intensity (non-MS4)	0.10%	0.10%	0.21%
Developed, Open Space (MS4)	0.03%	0.74%	0.77%
Developed, Open Space (non-MS4)	0.17%	4.85%	5.02%
Feedlots	-	0.19%	0.19%
Forest - AB	-	5.39%	5.39%
Forest - CD	-	3.67%	3.67%
Grassland - AB	-	4.02%	4.02%
Grassland - CD	-	2.91%	2.91%
Pasture - AB	-	4.86%	4.86%
Pasture - CD	-	5.06%	5.06%
Water/Wetlands	-	3.22%	3.22%
Total Area	**0.95%**	**99.05%**	**100.00%**

Table 3-6. Cannon River Watershed HSPF Land Segments Based on NLCD 2001 (version 2)

Land Segment Category	Impervious (EIA) Land Area	Pervious Land Area	Total Area
Cropland - AB	-	33.35%	33.35%
Cropland - CD	-	6.87%	6.87%
Cropland - Drained	-	22.10%	22.10%
Developed, Low Intensity (MS4)	0.16%	0.63%	0.79%
Developed, Low Intensity (non-MS4)	0.17%	0.97%	1.14%
Developed, Medium and High Intensity (MS4)	0.23%	0.21%	0.43%
Developed, Medium and High Intensity (non-MS4)	0.09%	0.10%	0.19%
Developed, Open Space (MS4)	0.02%	0.68%	0.71%
Developed, Open Space (non-MS4)	0.15%	4.84%	4.99%
Feedlots	-	0.19%	0.19%
Forest - AB	-	5.41%	5.41%
Forest - CD	-	3.66%	3.66%
Grassland - AB	-	4.05%	4.05%
Grassland - CD	-	2.93%	2.93%
Pasture - AB	-	4.90%	4.90%
Pasture - CD	-	5.10%	5.10%
Water/Wetlands	-	3.18%	3.18%
Total Area	**0.82%**	**99.18%**	**100.00%**

3.3.3 River Channel Representation

The HSPF model simulates the hydraulic behavior in river reach segments using a routing method commonly known as storage routing (Bicknell et al. 2005). This method requires that channel properties and a fixed relationship between reach flow and volume are defined for each reach segment. Estimates of surface water inflows (i.e., point source discharges) and water use withdrawals must also be specified to simulate reach segment hydraulics for the period of simulation. It should be noted that no water use withdrawals are currently represented in the Cannon River watershed HSPF watershed model. Point source discharges represented in the model are assumed to account for the inflow of water from the non-irrigation water use categories in the watershed. For the crop and non-crop irrigation categories, the water withdrawals and inflows are assumed to be negligible and are not explicitly represented in the model. Based on a detailed review of surface water and groundwater use data, it was determined that water use for crop and non-crop irrigation was very small (~0.1 acre-feet per year for the entire watershed) over the 1995-2012 time period, which suggested that an explicit representation of water use in the model was not warranted at this time. However, if crop and non-crop irrigation water use withdrawals and inflows become significant in the future, the model can easily be modified and updated to provide an explicit representation of these sources and sinks.

The HSPF model framework uses a hydraulic function table, called an FTABLE, to represent the geometric and hydraulic properties of reach segments and reservoirs (USEPA 1999). The FTABLE describes the hydraulics of a river reach segment or reservoir (RCHRES) segment by defining the functional relationship between water depth, surface area, water volume, and outflow in the segment (USEPA 1999). Data and information used to develop FTABLES included: 1) site-specific reach cross-sections developed during the Lower Cannon River watershed turbidity TMDL (CRWP 2007), 2) the Wolf Creek geomorphology study (Savina date unknown; Charles-Guzman date unknown), 3) United States Army Corps of Engineers (USACE) HEC models developed for flood prediction purposes, 4) the subbasin delineation, and 5) the NHDPlus flowlines data layer.

The primary method for developing FTABLES was based on the BASINS method, which uses a single power function for estimating the mean stream width and depth. The mean stream width and depth are based on the upstream drainage area (USEPA 1999). The method also assumes that reach cross-sections are trapezoidal. Given these assumptions, the Manning's equation can then be used to compute the discharge at various depths. Where available, site-specific data acquired from reach cross-section measurements and the USACE HEC model were used to refine the FTABLE stage-volume-discharge relationships.

3.3.4 Lake Representation

The methodology used to select lakes for explicit representation in the Cannon River watershed HSPF model was consistent with the method outlined in the MPCA modeling guidance document (AQUA TERRA Consultants 2012, see Section 4.2). Based on the selection process, thirty-eight (38) RCHRES were selected for explicit representation in the model as lakes. The majority (35) of these additional segments are listed as impaired lakes by MPCA. Two (2) of the segments modeled as lakes are stretches of the Cannon River behind relatively large impoundments. These impoundments are the Morristown Dam and the Woolen Mill Dam in Faribault. The Malt-O-Meal Dam in Northfield was used to construct the FTABLE for the corresponding HSPF RCHRES segment, but it was not modeled as a lake because, unlike the other dams on the Cannon River, the segment upstream of this dam did not appear to have lake characteristics.

Data necessary for a lake FTABLE includes volume and area at a variety of depths or water elevations, overflow information (such as spillway width and spill elevation, if applicable), and discharge information (if applicable). Each of these data types is discussed in the following paragraphs. Bathymetry data were available for 27 of the 36 lakes to develop the volume-area-depth relationships needed for the FTABLES. For six of the remaining nine lakes, the maximum depth provided in the MNDNR LakeFinder website was used to estimate the volume-area-depth relationships. The average depth for the three lakes without bathymetry information (Mabel, Sunfish, and Toners) was assumed to be 1 meter, consistent with MPCA assumptions for other models (Justin Watkins, personal communication).

The outlet of each lake was characterized as one of three categories: 1) managed; 2) has a control structure; or 3) no control structure, behaves as "run of the river". Overflow information for lakes is often unavailable. In addition, specific relationships do not exist between parameters such as surface area, depth, and weir length. Therefore, average values for depths and overflows were used when data and information were not available. If additional information becomes available in the future, it can be readily incorporated into the existing model framework.

Lake Byllesby is the only managed lake in the watershed. The FTABLE for Lake Byllesby was developed based on a polynomial regression relationship between observed headwater surface elevations and observed streamflow at the Lake Byllesby outlet HYDSTRA station (H3901800). The FTABLE was further refined to simulate the annual fall drawdown of Lake Byllesby to a target winter pool elevation and operation of the reservoir at the winter pool elevation from approximately November through March. Separate columns were added to the FTABLE for the drawdown period that lasts seven (7) to 10 days and for the winter pool elevation operation. A "special actions" block was implemented in the HSPF "user control input" (UCI) file to specify the dates when Lake Byllesby is operated at summer pool elevation, winter pool elevation, or the transition period.

The methodology used to construct FTABLEs for RCHRES modeled as lakes varied depending on availability of bathymetry data, known maximum depth, and whether or not the lake has a control structure at the outlet. For lakes with known bathymetry, tables of the surface area and volume as a function of depth were constructed from the bathymetry data. For lakes without known bathymetry but with a known maximum depth, area was assumed to be constant with depth (i.e. vertical walls), and the maximum depth was set as the zero flow depth. For lakes without known bathymetry and without a known maximum depth, a depth of five (5) or six (6) feet was assumed, and the surface area was assumed to be constant with depth. For lakes with a control structure at the outlet, outflow as a function of depth above the zero flow depth was estimated using the sharp-crested weir equation based on an estimated weir coefficient of 3.2. If unknown, lengths of the control structures were estimated from satellite imagery. For lakes without a control structure at the outlet, outflow as a function of depth above the zero flow depth was estimated from the stage-discharge relationship developed for the most immediate downstream RCHRES.

4
Model Calibration and Validation

Model evaluation provides information to determine when a model, despite its uncertainties, can be appropriately used to inform an environmental decision. This process addresses the soundness of the underlying science, the quality and quantity of available data, the degree to which model results correspond to observations, and the appropriateness of a model for a given application. Model evaluation includes qualitative and/or quantitative model calibration, validation or corroboration, and sensitivity and uncertainty analyses. This chapter describes the approach and outcomes for calibrating and validating the Cannon River watershed HSPF model.

4.1 Calibration and Validation Approach

Model calibration involves the process of comparing model predictions for state variables (e.g., streamflow, sediment, nitrogen, phosphorus, etc.) of interest to site-specific measurements and iteratively adjusting model parameters, within scientifically-acceptable limits, to achieve an acceptable fit between predicted and observed values. The process of model calibration is important not only in terms of optimizing the model fit to available observed data, but also in terms of developing a better conceptual understanding of how the physical system behaves and responds under different environmental conditions. Model validation is essentially an extension of the calibration process (Donigian 2002, USEPA 2009). In model validation, the model is applied to a time period that is separate and, ideally, representative of environmental conditions that are different from those for the calibration time period, and the model parameters are left unchanged from the calibration. The purpose of model validation is to ensure that the model has been properly calibrated for a range of environmental conditions. A successful model calibration/validation outcome provides confidence to environmental managers in the model's ability to predict system response to various management actions.

The evaluation of model calibration and validation (i.e., model performance) is commonly performed using a "weight of evidence" approach (Donigian 2002, Duda et al. 2012). The "weight of evidence" approach consists of using multiple model comparisons, both graphical and statistical, to assess model performance. The approach includes the consideration of inherent errors, limitations and uncertainty in the model, input data, and observational data. To date, there is not a general consensus on model performance criteria (Duda et al. 2012). Often, model performance criteria are set in the context of model performance targets based on guidelines provided in the literature (Donigian 2000 and 2002, Moriasi et al. 2007, Parajuli et al. 2009, Duda et al. 2012). Additional discussion of the "weight of evidence" approach is provided in the sections below.

4.1.1 Model Calibration and Validation Time Periods

The MPCA modeling guidance document (AQUA TERRA Consultants 2012) provides the following recommendations for the selection of the calibration and validation time periods:

- A split-sample calibration/validation approach is recommended, where approximately half of the available simulation period is used for calibration and the other half for validation;
- A minimum of 5 to 10 years should be set aside for both the calibration and validation periods, if sufficient data are available; and
- The calibration/validation should account for the full range of possible hydrologic conditions (i.e., wet, dry and average years).

The model simulation period is from 1995-2012. The first year (1995) serves as a "warm-up period" to allow the model to equilibrate and not be strongly influenced by the initial conditions. The model calibration was performed over a nine (9) year time period, from 2004-2012, using historical climate conditions and land use based on NLCD 2006. Following model calibration, model validation was performed using a separate, eight (8) year time period, from 1996-2003, using historical climate conditions and land use based on NLCD 2001 (version 2).

The model calibration and validation time periods selected for the Cannon River watershed HSPF model are consistent with the recommendations provided in the MPCA modeling guidance document (AQUA TERRA Consultants 2012). A split sample approach has been used, the time periods fall within the recommended 5 to 10 years, and the model calibration and validation time periods both cover a range of hydrologic conditions (Figure 4-1). Datasets available for observed streamflow were also a key factor in selecting the calibration and validation time periods. Data availability for the calibration period (2004-2012) is very good. Data are more limited for the first part of the validation period (1996-2003); however, this is typical in most watershed model applications (LimnoTech 2014c). The extensive datasets within the calibration period allow for better parameter optimization and greater certainty in the selection of appropriate parameter values during the calibration process.

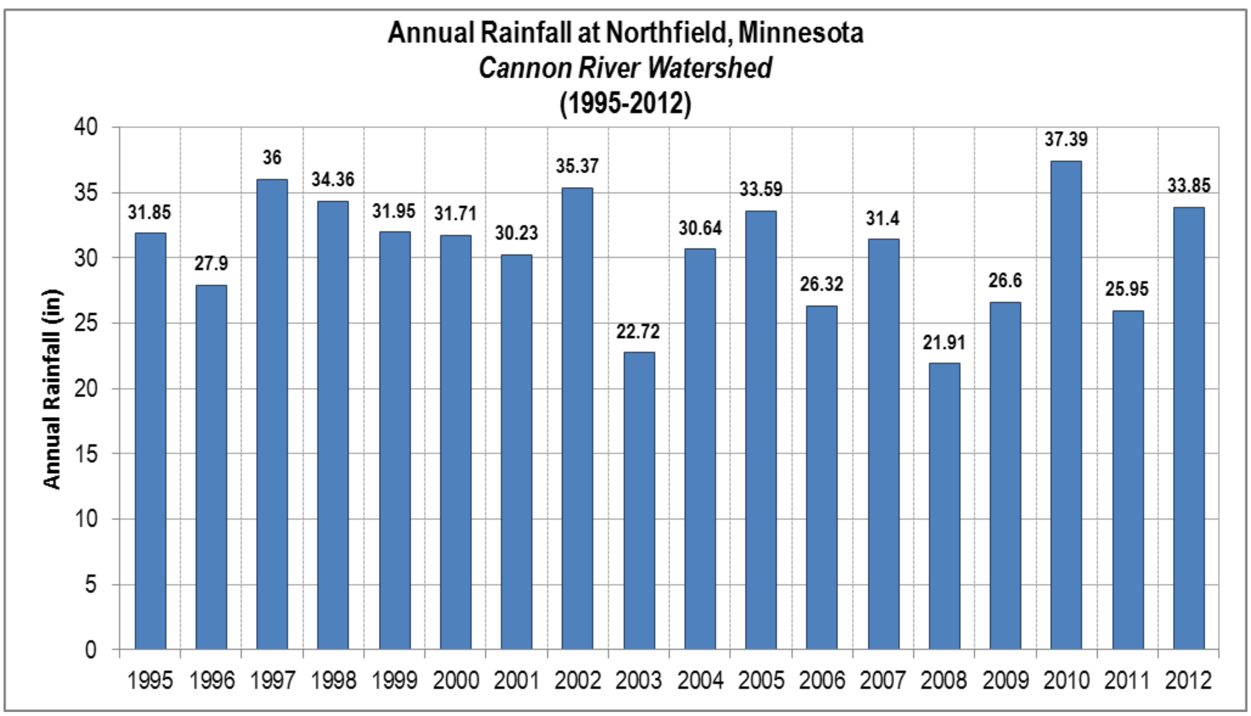

Figure 4-1. Annual Total Precipitation at Northfield, Minnesota Over the 1995-2012 Time Period.

4.1.2 Model Performance Measures

The model evaluation process provides information that can be used to determine when a model, despite its uncertainties, can be appropriately used to inform an environmental decision. It addresses the soundness of the underlying science, the quality and quantity of available data, the degree to which model results correspond to observations, and the appropriateness of a model for a given application. Model evaluation includes qualitative and/or quantitative model calibration, validation, and sensitivity and uncertainty analyses.

The ability of a watershed model to accurately represent hydrologic conditions, streamflow, and sediment and water quality loading and delivery is dependent upon the complexity of the watershed; the temporal and spatial coverage of climate data (e.g., precipitation, temperature); the availability of quality observed datasets (e.g., snow depth, streamflow, TSS, nutrients, chlorophyll *a*); and the availability and quality of the data and information used to develop the model (e.g., soils, topography, point sources, water use, etc.).

As noted above, a "weight of evidence" approach is used to evaluate model performance and includes consideration of the following elements (Duda et al. 2012):

- Models are only approximations of reality and cannot precisely represent natural systems.
- There is no single, accepted statistic or test that determines the overall model performance.
- Both graphical comparisons and statistical tests are required in model calibration and validation.
- Models cannot be expected to be more accurate than the errors (confidence intervals) associated with the input data or observed data.

Model performance was evaluated using both visual and statistical comparison of simulated and observed data. The sections below outline the model performance measures for hydrology, sediment, and water quality.

Hydrology

Visual comparisons for hydrology include annual bar charts, annual/seasonal/monthly/daily time series plots, annual/seasonal/monthly/daily scatter plots, and daily flow duration curves. Statistical metrics for hydrology include the relative average percent difference, relative average percent error, the coefficient of determination (r^2), percent bias (PBIAS) (applied to the monthly interval only) and the Nash-Sutcliffe model efficiency coefficient (NSE).

The total streamflow volume error is calculated for a specific time period by estimating the total volume of water passing through a reach according to the observed flow data and comparing it to the output volume simulated by the model for that period. The streamflow volume is calculated with the following equation:

$$Volume = \sum Q \times \Delta t$$

where Q is the streamflow expressed in volume per time, and t is the time interval over which the streamflow is measured or simulated.

The relative percent difference is the difference between the simulated value and the observed value divided by the mean of the simulated and observed values multiplied by 100. The percent difference is calculated using the following equation:

$$Percent\ (\%)\ Difference\ = \frac{Simulated\ - Observed}{\frac{1}{2}(Simulated + Observed)} \times 100$$

The average percent difference is calculated as the arithmetic mean of the percent difference calculated for each observation.

The relative percent error is the difference between the simulated value and the observed value divided by the observed values multiplied by 100. The percent error is calculated using the following equation:

$$Percent\ (\%)\ Error\ = \frac{Simulated\ - Observed}{Observed} \times 100$$

The average percent error is calculated as the arithmetic mean of the percent difference calculated for each observation.

The coefficient of determination (r^2) is used to evaluate the goodness of fit of the model. It is expressed as a value between zero and one. An r^2 value of one (1), with a regression slope of one (1) and an intercept of zero (0), indicates a perfect correlation between model predictions and observations and a very reliable model for future forecasts. A value of zero (0) indicates no correlation between model predictions and observations, which suggests that the model fails to accurately simulate the observed dataset. The equation for the calculation of r^2 is as follows:

$$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}} \right)^2$$

where O represents observed values and S represents simulated values.

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than the observed data (Gupta et al. 1999, Moriasi et al. 2007). The optimal value of PBIAS is zero (0), with low values indicating an unbiased model simulation. Positive values indicate that the model has an underestimation bias, and negative values indicate that the model has an overestimation bias (Gupta et al. 1999, Moriasi et al. 2007). PBIAS is calculated based on the following equation:

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - S_i) * (100)}{\sum_{i=1}^{n}(O_i)} \right]$$

where O represents observed values and S represents simulated values.

The NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance (Nash and Sutcliffe 1970, Moriasi et al. 2007). NSE indicates how well observed versus simulated data fits a one-to-one (1:1) line. A NSE value of one (1) is the optimal value and indicates a perfect prediction. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas a value less than 0.0 indicates that the mean observed value is a better predictor than the simulated value, which suggests unacceptable performance (Moriasi et al. 2007). The NSE is calculated using the following equation:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

where O represents observed values and S represents simulated values.

The model calibration and validation tolerances or targets for streamflow generally adhere to the target recommendations provided in the MPCA modeling guidance document (AQUA TERRA Consultants 2012). The recommendations are based on Donigian's (2000 and 2002) general assessment of model performance (Table 4-1, Figure 4-2). As noted in the MPCA modeling guidance document (AQUA TERRA Consultants 2012) and in the caveats listed in Table 4-1, the tolerance ranges should be applied to annual or monthly mean values, and individual (e.g., daily) events or observations may show larger differences with the overall model performance still considered to be acceptable.

Table 4-1. General Hydrology Calibration and Validation Targets or Tolerances for HSPF Applications (Donigian 2000, 2002).

Parameter	*% Difference Between Simulated and Recorded Values*		
	Very Good	*Good*	*Fair*
Hydrology/Flow	< 10	10 - 15	15 - 25

CAVEATS: Relevant to monthly and annual values; storm peaks may differ more; Quality and detail of input and calibration data; Purpose of model application; Availability of alternative assessment procedures; Resource availability (i.e. time, money, personnel).

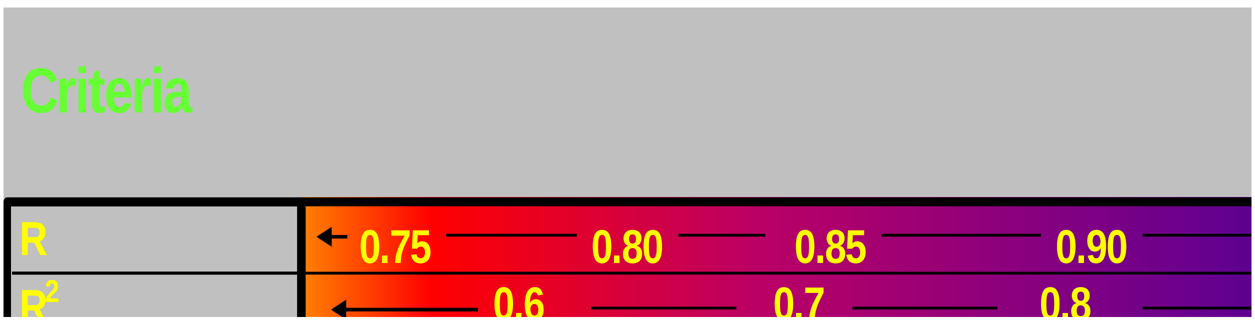

Figure 4-2. R and R^2 Value Ranges for Streamflow Model Performance (Donigian 2000, 2002).

The following target calibration and validation measures used to evaluate the Cannon River watershed HSPF model performance are based on the MPCA modeling guidance document (AQUA TERRA Consultants 2012):

- 'Annual' and 'Monthly' flows should correspond to a 'Good to Very Good' agreement for calibration for the relative average percent difference, relative average percent error and r^2 statistics.
- 'Daily' flows should correspond to a 'Fair to Good' agreement for calibration for the relative average percent difference, relative average percent error and r^2 statistics.
- 'Annual', 'Monthly', and 'Daily' flows should correspond to a 'Fair to Good' agreement for validation for the relative average percent difference, relative average percent error and r^2 statistics.

Model calibration and validation targets for PBIAS, based on monthly streamflow, are summarized in Table 4-2. The targets for monthly flows should correspond to a 'Good to Very Good' agreement for calibration and to a 'Satisfactory to Good' agreement for validation.

Table 4-2. Streamflow Model Performance Ratings for PBIAS at a Monthly Interval (excerpted from Moriasi et al. 2007).

Performance Rating	PBIAS for Streamflow
Very good	PBIAS < ±10
Good	±10 < PBIAS < ±15
Satisfactory	±15 < PBIAS < ±25
Unsatisfactory	PBIAS > ±25

Model calibration and validation targets for NSE applied to annual and monthly streamflow are summarized in Table 4-3. The targets for annual and monthly flows should correspond to a 'Good to Excellent' agreement for calibration and to a 'Fair to Very Good' agreement for validation.

Table 4-3. Streamflow Model Performance Ratings for Nash-Sutcliffe Model Efficiency (NSE) at Annual and Monthly intervals (adapted from Parajuli et al. 2009).

Performance Rating	NSE for Streamflow
Excellent	> 0.90
Very good	0.75 – 0.89
Good	0.50 – 0.74
Fair	0.25 – 0.49
Poor	0.00 – 0.24
Unsatisfactory	< 0.00

The MPCA modeling guidance document (AQUA TERRA Consultants 2012) notes that the model performance target ranges apply to the simulation at the outlet of the HUC8 and that the target ranges for gages interior to the watershed may be more relaxed. The performance targets noted above were applied to the two (2) primary streamflow station locations in the Cannon River watershed (Cannon River at Welch and Straight River at Faribault, see Table 4-6 and Figure 4-3).

Suspended Solids (also referred to as Sediment)

For sediment, the evaluation of model performance often relies more on visual and graphical comparisons rather than on the statistical analyses, as the frequency of observed data is often inadequate to support statistical comparisons, has a higher degree of uncertainty, and/or is more limited for accurate statistical measures (Duda et al. 2012). The relative percent difference model performance target established for the Cannon River watershed HSPF model sediment calibration and validation is summarized in Table 4-4 below. The targets apply to TSS concentrations and loads at annual and monthly time scales at the watershed outlet. 'Annual' and 'Monthly' TSS concentrations or loads should correspond to at least a 'Fair' agreement for calibration and validation for the relative average percent difference statistic. Daily or individual event observations may show larger differences and may be outside the target performance ranges for the annual and monthly time scales with the model performance still considered acceptable.

Additional calibration and validation targets were set in regard to UALs, sediment trapping efficiency for Lake Byllesby, net deposition for the other lakes in the watershed, and annual loading at the watershed outlet. A more detailed description of these targets is provided in Section 4.3 below.

Table 4-4. General Suspended Solids Calibration and Validation Targets or Tolerances for HSPF Applications (Donigian 2000, 2002).

Parameter	% Difference Between Simulated and Recorded Values		
	Very Good	Good	Fair
Total Suspended Solids	< 20	20 - 30	30 - 45

CAVEATS: Relevant to monthly and annual values; storm peaks may differ more; Quality and detail of input and calibration data; Purpose of model application; Availability of alternative assessment procedures; Resource availability (i.e. time, money, and personnel).

Water Quality

Similar to evaluation of total suspended solids, the evaluation of model performance for water quality (i.e., water temperature, nutrients, DO, BOD, chlorophyll *a*) often relies more on visual and graphical comparisons rather than on the statistical analyses, as the frequency of observed data is often inadequate, has a higher degree of uncertainty, and/or is more limited for accurate statistical measures (Duda et al. 2012). For the Cannon River watershed the water quality datasets are generally much more limited compared to streamflow. Therefore, the evaluation of model performance for the simulation of water temperature, nutrients, DO, BOD and chlorophyll *a* requires more reliance on visual and graphical comparisons of simulated and observed data. The targets for calibration metrics apply to water quality concentrations and loads (if available) at annual and monthly time scales at the watershed outlet, or if data were not available at the outlet, the next best station that captures the largest watershed drainage area. 'Annual' and 'Monthly' water quality concentrations or loads should correspond to at least a 'Fair' agreement for calibration and validation for the relative average percent difference statistic. Sufficient data were not available to support a calibration and validation evaluation for BOD, phytoplankton, and benthic algae.

It should be noted that the water quality portion of the Cannon River watershed HSPF model was constructed and calibrated and validated with a unified set of parameters that vary appropriately according to land use, soils, geology, and land management activities. The model was calibrated and validated using different stations across the watered, where data were available, to capture the most broad and representative sample of watershed conditions. The overall calibration strategy (for hydrology, sediment and water quality) avoided arbitrary adjustments to upland parameter values or instream parameter values for the purpose of obtaining better statistics in individual subbasins or reach segments. This is a good modeling practice as it avoids over-fitting or curve-fitting the Cannon River watershed HSPF model to data that are limited in temporal and spatial coverage (e.g., for high flow events).

The calibration approach described above serves to reduce bias in the model by not over constraining the model based on limited data. As a result of this approach, relatively large percentage differences between observations and model predictions may occur across stations, including stations located in the interior of the watershed in particular. These differences are still acceptable at the interior stations as long as the unified parameter set provides reasonable results across stations in aggregate (i.e., at the watershed outlet).

Table 4-5. General Water Quality Calibration and Validation Targets or Tolerances for HSPF Applications (Donigian 2000, 2002).

Parameter	% Difference Between Simulated and Recorded Values		
	Very Good	Good	Fair
Water Temperature	< 7	8 - 12	13 - 18
Water Quality/Nutrients	< 15	15 - 25	25 - 35

CAVEATS: Relevant to monthly and annual values; storm peaks may differ more; Quality and detail of input and calibration data; Purpose of model application; Availability of alternative assessment procedures; Resource availability (i.e. time, money, personnel).

A directory of the stations used to support the Cannon River watershed HSPF model calibration and validation is provided in an Excel file named "Cannon_Data_Inventory.xlsx".

4.2 Hydrology

This section presents the results of the Cannon River watershed HSPF hydrology model calibration and validation. A discussion of the available datasets, parameterization approach, snow calibration, and model performance is provided below.

4.2.1 Calibration and Validation Data

Streamflow data are critical for the hydrologic calibration and validation of a HSPF model. Streamflow data were acquired from the MNDNR HYDSTRA database (hereafter HYDSTRA) and the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) tool (via the USGS, http://waterdata.usgs.gov/nwis/sw). Both daily average and instantaneous streamflow data from the USGS are available at two locations in the Cannon River watershed (Table 4-6). One station is located on the Straight River at Faribault, MN (USGS gage #05353800), and the other station is located on the Cannon River at Welch, MN (USGS gage # 05355200). Daily average streamflow data are available for the entire 1995-2012 time period for both stations.

The MPCA provided LimnoTech with streamflow data from the HYDSTRA database. These data were evaluated with respect to quality and robustness. Records deemed "Good" and "Fair" were considered suitable for consideration as a calibration dataset. Data records flagged with "Unknown External Data", "Linear interpolation", "Data Not Yet Checked" and "Edited data" qualifiers were also included, though these records may require additional scrutiny during the calibration. Daily average streamflow data spanning at least five years within the 2000-2012 time period are available at three (3) stations.

The MPCA also provided LimnoTech with daily lake level (water surface elevation) data collected by the MNDNR. However, the period of record of lake level data varied by lake. Three (3) locations (Lake Byllesby, Jefferson Lake and French Lake) were evaluated as part of the hydrology calibration. These stations have approximately 1,000 observations or more and span 1995-2012.

Overall, the temporal and spatial coverage of the streamflow data is good and acceptable for the development of the HSPF model. The HYDSTRA and USGS streamflow stations and the MNDNR lake level locations provide a good spatial and temporal coverage for the purpose of model calibration and validation. Data availability for the calibration period (2004-2012) is very good. Data are more limited for the first part of the validation period (1996-2003); however, this is typical in most watershed model applications.

The streamflow station locations that were used to support the model calibration and validation are summarized in Table 4-6, and their locations are shown on the map in Figure 4-3.

Table 4-6. Streamflow Watershed Calibration Points for the Cannon River Watershed HSPF Model Calibration and Validation.

Station ID (HYDSTRA/ USGS/MNDNR)	HSPF Reach ID	Agency/ Database	Station Name	Daily Average Streamflow or Lake Level	
				Count of Records	Period of Record
05353800	**802**	**NWIS/USGS**	**Straight River at Faribault, MN**	**6,549**	**1995-2012**
05355200	**103**	**NWIS/USGS**	**Cannon River at Welch, MN**	**6,565**	**1995-2012**
H39016001	501	MPCA/ HYDSTRA	Little Cannon River near Cannon Falls, CR24	1,899	2000-2010
H39091001	305	MPCA /HYDSTRA	Cannon River at Morristown, CSAH16	535	2007-2012
H39069001	204	MPCA/ HYDSTRA	Cannon River at Northfield, 0.3 mi DS MN 19	4,510	2000-2012
19000600	201	MNDNR	Lake Byllesby	3,117	1995-2004
40009202	368	MNDNR	West Jefferson Lake	933	1995-2012
66003800	326	MNDNR	French Lake	1,561	1995-2012

[a]Bolded stations denote the primary calibration and validation stations

The Cannon River at Welch and Straight River at Faribault stations served as the primary calibration and validation stations to evaluate model performance. The remaining stations listed in Table 4-6 were used as auxiliary stations to help parameterize the model.

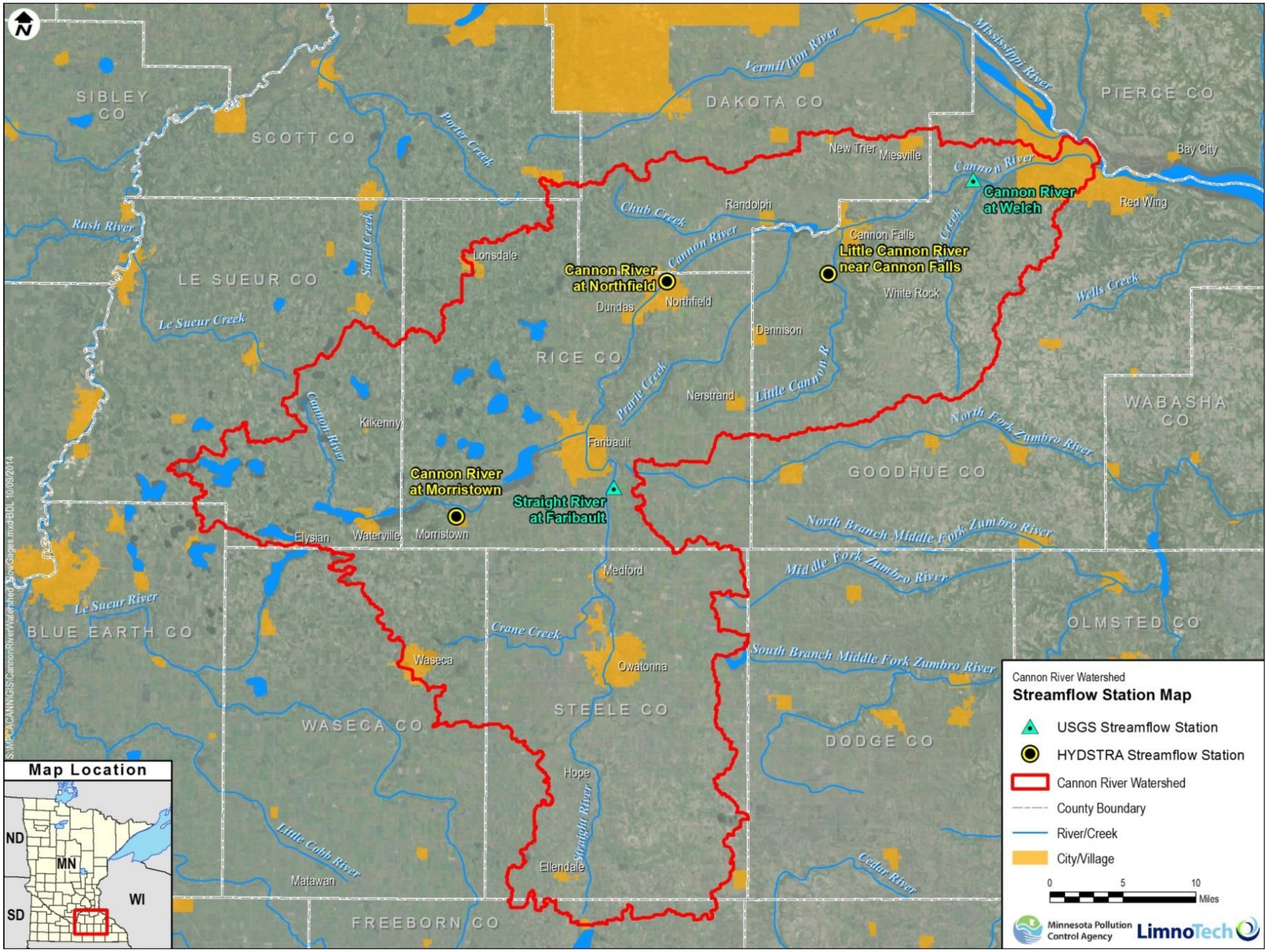

Figure 4-3. Map of Streamflow Calibration and Validation Station Locations in the Cannon River Watershed.

4.2.2 Hydrology Parameterization

The hydrology calibration for the Cannon River watershed HSPF model followed the guidelines provided in the MPCA modeling guidance document (AQUA TERRA Consultants 2012), which is consistent with the standard protocol for the hydrologic calibration of HSPF models (Donigian et al. 1984, Lumb et al. 1994, USEPA 2000, Donigian 2002). The following description of the hydrologic calibration process, including the adjustment of key parameters, is excerpted from the MPCA modeling guidance document (AQUA TERRA Consultants 2012).

"The standard HSPF hydrologic calibration is divided into four phases:

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flow (in inches), and is governed primarily by the input rainfall and evaporation and the parameters LZSN (lower zone nominal storage), LZETP (lower zone ET parameter), and INFILT (infiltration index).
- **Adjust low flow/high flow distribution.** This is generally done by adjusting the groundwater or baseflow, because it is the easiest to identify in low flow periods. Comparisons of mean daily flow are utilized, and the primary parameters involved are INFILT, AGWRC (groundwater recession), and BASETP (baseflow ET index).
- **Adjust stormflow/hydrograph shape.** The stormflow, which is compared in the form of short time step (1 hour) hydrographs, is largely composed of surface runoff and interflow. Adjustments are made with the UZSN (upper zone storage), INTFW (interflow parameter), IRC (interflow recession), and the overland flow parameters (LSUR, NSUR, and SLSUR). INFILT also can be used for minor adjustments.
- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters CEPSC (vegetal interception), LZETP, UZSN. Adjustments to KVARY (variable groundwater recession) and BASETP are also used."

The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. (1984), and the HSPF hydrologic calibration expert system (HSPEXP) documentation (Lumb et al. 1994).

It should also be noted that the HSPF model takes advantage of the ADCALC flag (ADFG) option of 2. This option enforces consistency between the differencing used for hydrology and water quality and is intended to prevent model instability issues that may be encountered when streams experience extreme low flow conditions and either almost or completely go dry. The implementation of this feature resolved model instability issues in hydrology by preventing reach segments from going completely dry. However, this feature did not resolve all model instabilities in the water quality simulation related to low-flow conditions.

Model instabilities in the water quality simulation can still occur when there is insufficient water volume and depth in a reach segment. This issue in the Cannon River watershed HSPF model is infrequent and isolated to smaller reach segments. To address the model instability issues in the water quality simulation, the FTABLEs for the susceptible reaches were adjusted to maintain a small depth of water at low flows. Based on a review of other Minnesota HSPF models developed under the MPCA One Water

Program (i.e., Tetra Tech 2012), apparent model instabilities also exist in those water quality simulations despite the implementation of the ADCALC flag = 2 option.

4.2.3 Snow Calibration

The first step in the hydrologic calibration involved the calibration of snow. Snow accumulation and snowpack melting processes are an important component of the hydrologic system in Minnesota watersheds. Snow was simulated using the energy-balance approach per the MPCA modeling guidance document recommendation (AQUA TERRA Consultants 2012). Observed snow depth data were compared to simulated results to ensure a reasonable representation of snow accumulation and snowpack melt processes in the model. Observed snow depth data were available from the NCDC for four (4) stations across the watershed (NOAA 2014) for the entire 1995-2012 model simulation time period (Table 4-7).

Table 4-7. Inventory of Snow Depth Stations in the Cannon River Watershed.

Station	Period of Record	Number of Snow Depth Records
Faribault	1995 - 2012	6,522
Owatonna	1995 - 2012	6,545
Red Wing Dam	1995 - 2012	6,421
Waseca	1995 - 2012	6,526

Parameter adjustments during the snow calibration were conducted consistent with the calibration guidelines described for snowmelt volumes and timing in the MPCA modeling guidance document (AQUA TERRA Consultants 2012, page 57). All snow parameters were within the range guidelines in BASINS Technical Note 6 (USEPA 2000) with the exception of MWATER and CCFACT, which were set to 0.50 and 0.15, respectively. Setting values for these parameters slightly outside the recommended ranges provided the best simulation of streamflow during months influenced by snow accumulation and melt processes. A comparison of simulated and observed snow depths for the Owatonna snow depth station is shown in Figure 4-4. Additional snow depth comparisons are included in the set of electronic files provided with the deliverable package.

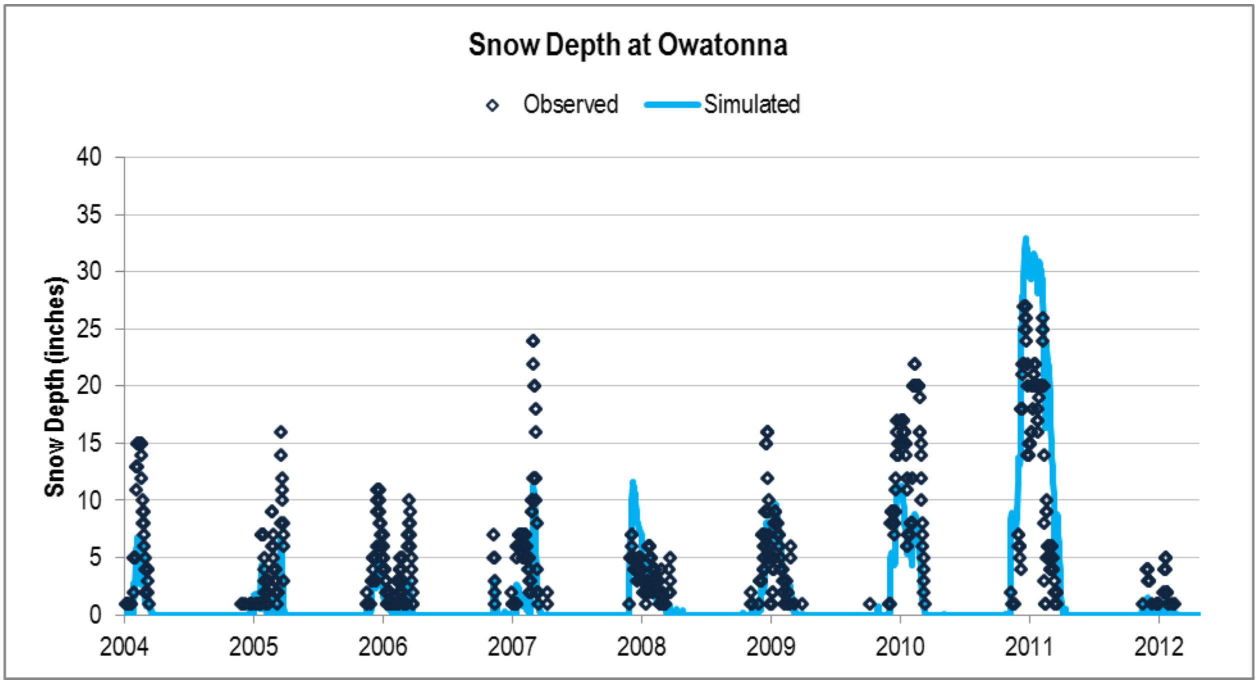

Figure 4-4. Comparison of Observed and Model-Predicted Daily Snow Depth for Owatonna.

4.2.4 Hydrology Calibration

The hydrology calibration for the Cannon River Watershed HSPF model followed the guidelines provided in the MPCA modeling guidance document (AQUA TERRA Consultants 2012), which is consistent with the standard protocol for the hydrologic calibration of HSPF models (Donigian et al. 1984, Lumb et al. 1994, USEPA 2000, Donigian 2002).

Lake Byllesby

The FTABLE for Lake Byllesby was developed based on regression relationships between observed headwater surface elevations and observed streamflow at the Lake Byllesby outlet HYDSTRA station. Separate columns were added to the FTABLE to simulate outflow during three distinct periods: operation at the summer pool elevation, operation at the winter pool elevation, and operation during the annual October-November drawdown period that typically lasts between 30 and 60 days. A polynomial regression relationship was used to specify outflow for operation at the summer pool elevation, and a linear regression relationship was used to specify outflow for operation at the winter pool elevation. Outflow for the drawdown or transition period was adjusted in the FTABLE until a reasonable representation of the annual drawdown rate was achieved. A “special actions” block was implemented in the UCI file to specify the dates when Lake Byllesby is operated at summer pool elevation, winter pool elevation, or the transition period. A comparison of observed and simulated Lake Byllesby water depths is shown in Figure 4-5.

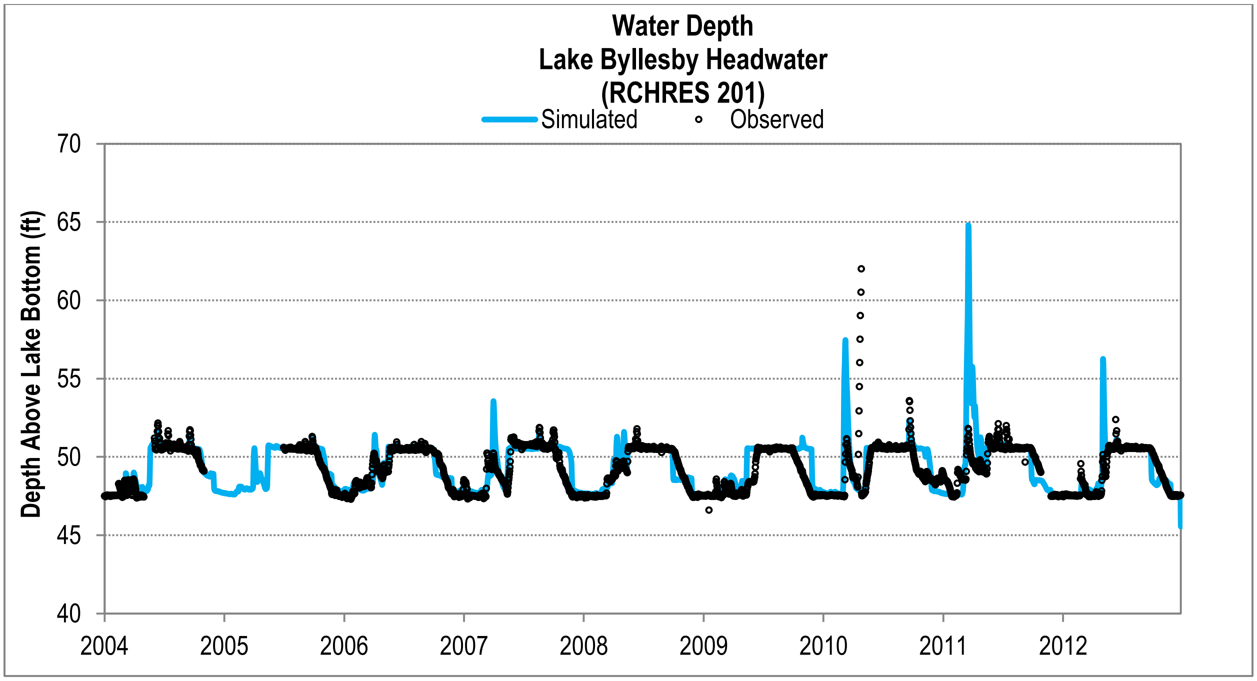

Figure 4-5. Comparison of Observed and Model-Predicted Water Depths for Lake Byllesby.

Lake Levels

The initial calibration process included using visual comparisons of observed and simulated lake depths at a daily time scale to ensure the model was able to reasonably simulate fluctuating lake levels for the entire 1995-2012 model simulation time period. In addition to the comparison for Lake Byllesby shown in Figure 4-5, comparisons for West Jefferson Lake and French Lake were also developed. The model maintained simulated lake depths reasonably close to observed depths for French Lake (Figure 4-6). However, for West Jefferson Lake, beginning in the spring of 2002 the model simulated a drop in lake depth, creating a divergence from the observed depths (Figure 4-7). An investigation revealed that simulated annual evaporation rates for several lakes were well above typical lake evaporation rates for Southeast Minnesota (USGS 2014b). An initial attempt to maintain lake levels was made by reducing the potential evaporation input time series scale factor from 0.80 to 0.70 for all RCHRES modeled as lakes. This adjustment resulted in an improvement in the simulation of lake depth. However, even with this adjustment the lake levels for West Jefferson Lake, Middle Jefferson Lake, and Toner's Lake were still declining during dry years without recovering during wet years. A constant seasonal (March-June) input time series was used to maintain lake levels in these three (3) lakes. Toner's Lake has a relatively small drainage area compared to the surface area of the lake and is located near the edge of the watershed boundary, which may be imprecise in this portion of the watershed. West and Middle Jefferson Lakes also have relatively small drainage areas and share a common surface elevation with East Jefferson Lake, Swede's Bay, and German Lake. These connected lakes may act as a single waterbody, with planimetered boundaries defined at road culverts or natural narrowing features. The complexity of these lake systems including how they interact with the groundwater systems is likely not well understood; therefore, all inflow sources to these lakes cannot be properly accounted for within the HSPF model framework. The constant seasonal input time series solution conceptually represents a spring recharge after the winter thaw that was not adequately represented in the model.

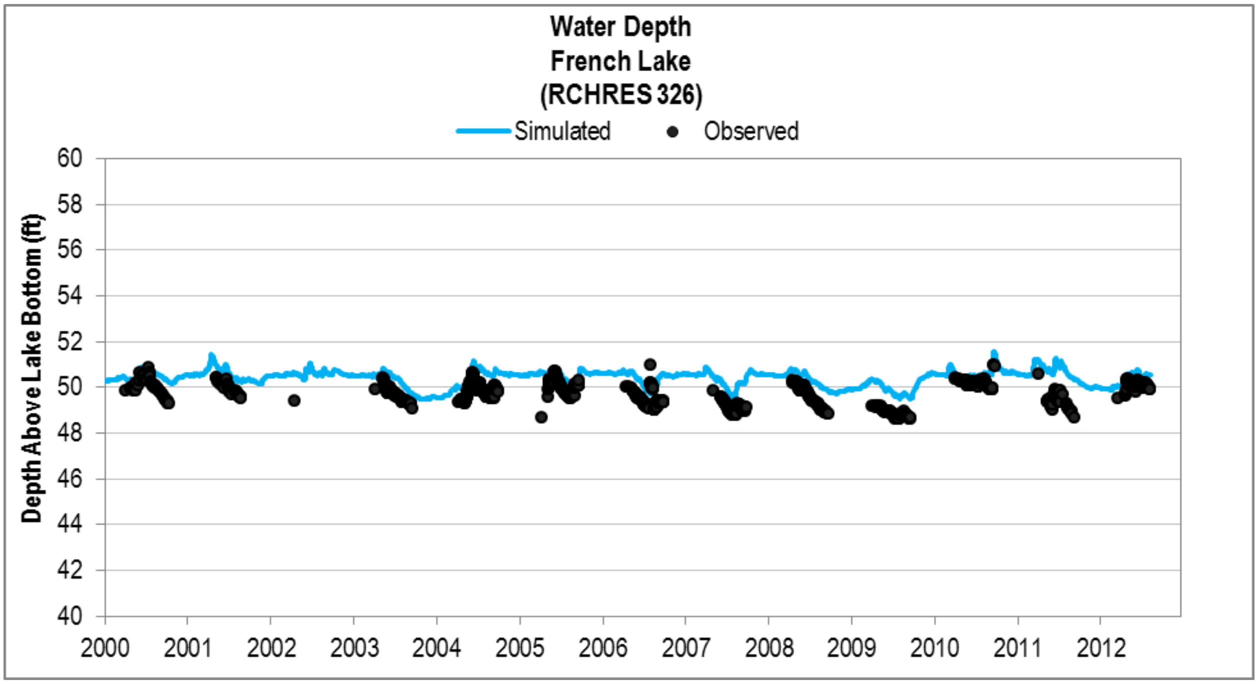

Figure 4-6. Comparison of Observed and Model-Predicted Water Depths for French Lake.

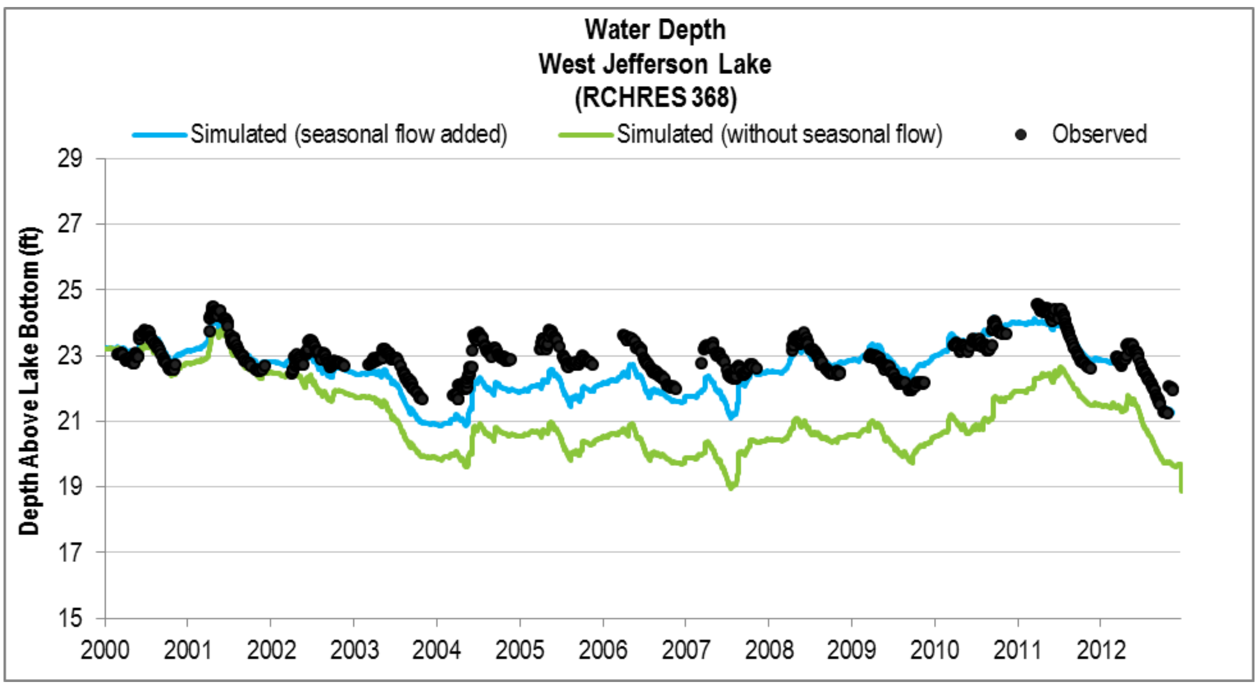

Figure 4-7. Comparison of Observed and Model-Predicted Water Depths for West Jefferson Lake.

Water Balance

Water balance components were reviewed throughout the hydrology calibration to ensure the model properly represents different land uses and soil types (e.g. relatively higher surface runoff from C-D than A-B soils compared for a given land use, higher interception from forested land use than developed open space, etc.). The water balance was also compared to other Minnesota HSPF watershed model applications. Table 4-8 summarizes the drainage area-weighted water balance components for the entire watershed.

Table 4-8. Cannon River Watershed HSPF Model Water Balance for the Calibration and Validation Period (1996-2012).

Water Balance Component	*Description*	*Area-Weighted Watershed Total (inches)*
SUPY*	Water supply to surface	33.21
SURO*	Surface outflow	0.95
IFWO	Interflow outflow	3.76
AGWO	Active groundwater outflow	4.50
PERO*	Total outflow from land segments	9.21
IGWI	Inflow to inactive groundwater	0.00
AGWI	Active groundwater inflow	4.78
PET*	Potential evapotranspiration	42.10
CEPE*	Evapotranspiration from interception storage	8.53
UZET	Evapotranspiration from upper zone	5.33
LZET	Evapotranspiration from lower zone	10.01
AGWET	Evapotranspiration from active groundwater storage	0.10
BASET	Evapotranspiration from active groundwater outflow (baseflow)	0.18
TAET*	Total simulated evapotranspiration	24.15

* Component includes area-weighted proportions from both pervious and impervious land segments

Calibration Model Performance

The model calibration performance is based on the two primary calibration stations: the Cannon River at Welch station and the Straight River at Faribault station. Overall, the calibration of streamflow resulted in “good” to “very good” model performance based on statistical comparison of observed and simulated streamflow (Tables 4-9 and 4-10). A brief summary of the model performance is provided below:

- The model is meeting all of the statistical model performance targets for the calibration period;
- The annual and monthly r^2 and NSE values fall within the “good” to “very good” range;
- PBIAS falls within the “very good” range;
- The average relative percent difference values for the annual, monthly, and daily time scales are within the “very good” range; and
- The daily r^2 values are within the “good” range.

Table 4-9. Cannon River Watershed Hydrology HSPF Model Calibration Statistics Summary (2004-2012).

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault	
		Result	Performance Rating	Result	Performance Rating
Annual	*Count*	9		9	
	R-Squared	0.92	Very good	0.84	Good
	Nash-Sutcliffe Efficiency	0.81	Very good	0.79	Very good
	Relative Percent Difference	-1.5%	Very good	1.1%	Very good
	Relative Percent Error	0.1%	Very good	3.7%	Very good
Monthly	*Count*	108		108	
	R-Squared	0.80	Good	0.79	Good
	Nash-Sutcliffe Efficiency	0.79	Very good	0.78	Very good
	P-Bias	5.08	Very good	4.21	Very good
	Relative Percent Difference	-5.0%	Very good	1.6%	Very good
	Relative Percent Error	1.8%	Very good	12.8%	Very good
Daily	*Count*	3288		3288	
	R-Squared	0.76	Good	0.72	Good
	Nash-Sutcliffe Efficiency	0.73		0.67	
	Relative Percent Difference	-6.7%	Very good	1.6%	Very good
	Relative Percent Error	4.7%	Very good	23.1%	Fair
25th percentile low flow	*Relative Percent Difference*	2.7%		16.0%	
	Relative Percent Error	2.7%		17.4%	
90th percentile high flow	*Relative Percent Difference*	-15.0%		-14.5%	
	Relative Percent Error	-14.0%		-13.6%	

Table 4-10. Cannon River Watershed Hydrology Calibration Observed and Simulated Streamflow Comparison (2004-2012).

Statistic	Cannon River at Welch		Straight River at Faribault	
	Observed cfs	Simulated cfs	Observed cfs	Simulated cfs
Average	911	865	342	328
Minimum	139	42	17	13
10th percentile	235	190	41	41
25th percentile	297	305	71	83
Median	593	554	166	169
75th percentile	1000	893	334	320
90th percentile	1990	1712	761	658
Maximum	20100	25316	12000	14305

In addition to calculating statistics, model performance was evaluated using visual comparisons of observed and simulated streamflow at annual, seasonal, monthly, and daily time scales (Figures 4-8 through 4-25). Overall, the model does a “good” to “very good” job reproducing annual, seasonal, monthly streamflow volumes and daily streamflows. As noted above, the majority of stations in Table 4-6 were used as auxiliary stations to help parameterize the model and were not used to evaluate model performance due to the limited availability of long-term datasets. The calibration process included modifying parameters for land segments in the Driftless ecoregion portion of the watershed where shallow bedrock, karst conditions, and steep slopes result in a different hydrology compared to the Corn Belt Plains and North Central Hardwoods ecoregions. Specifically, changes were made to the index to lower zone evapotranspiration (LZETP), nominal upper zone soil moisture storage (UZSN), and groundwater recession rate (AGWRC) based on visual comparisons of observed and simulated streamflow for stations on the Little Cannon River. Plots for the auxiliary stations are provided in Appendix A.

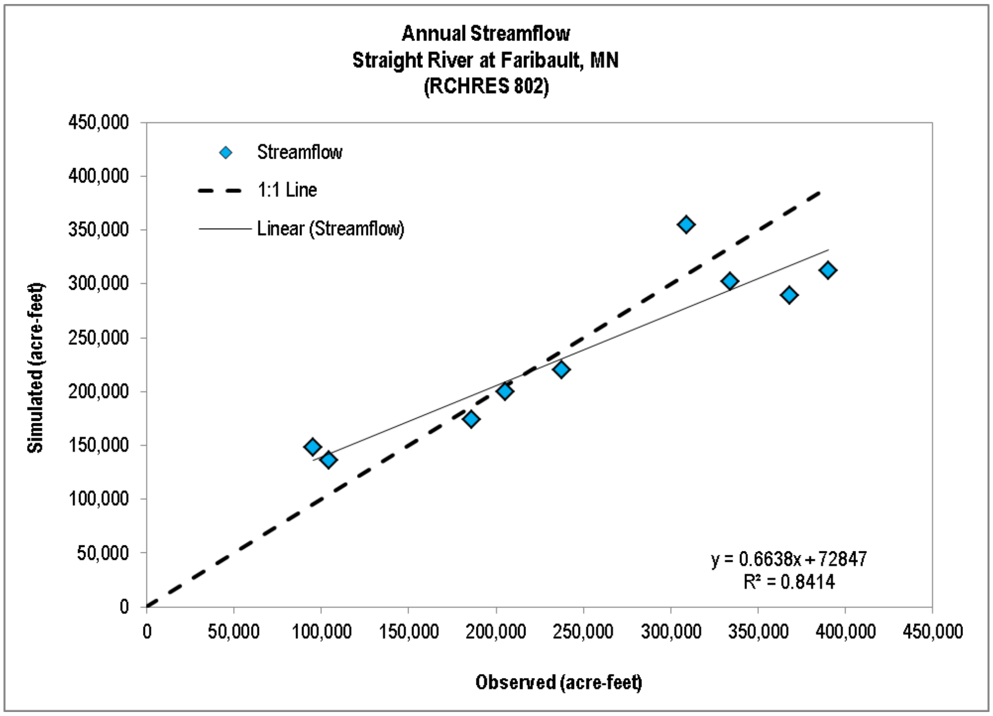

Figure 4-8. Annual Streamflow 1:1 Plot for Straight River at Faribault, 2004-12 (Gage #05353800)

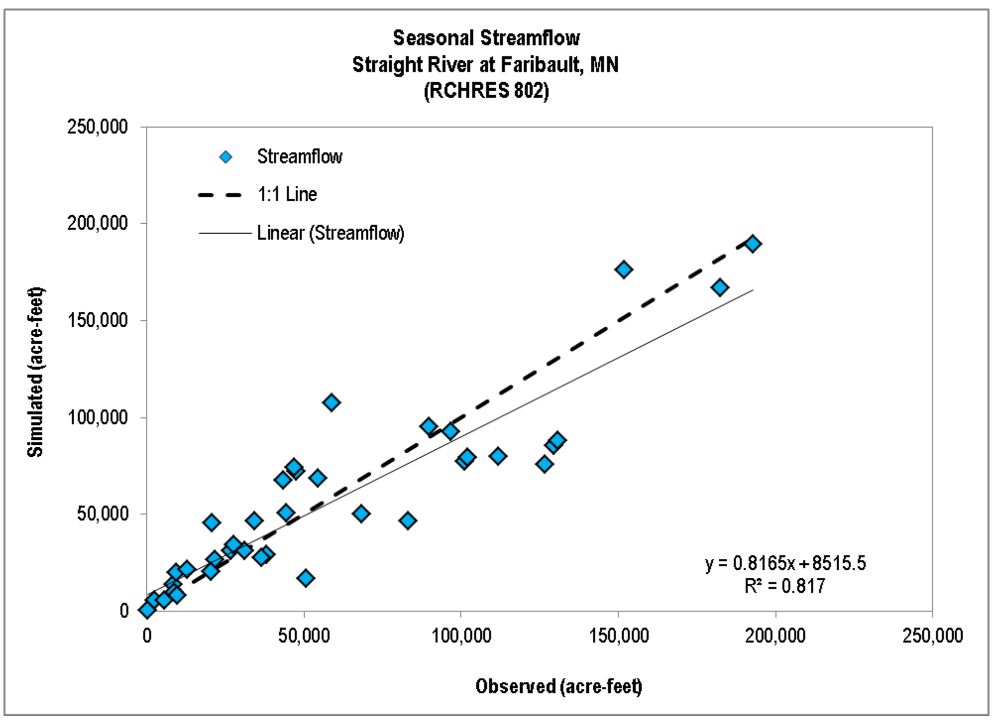

Figure 4-9. Seasonal Streamflow 1:1 Plot for Straight River at Faribault, 2004-2012 (Gage #05353800)

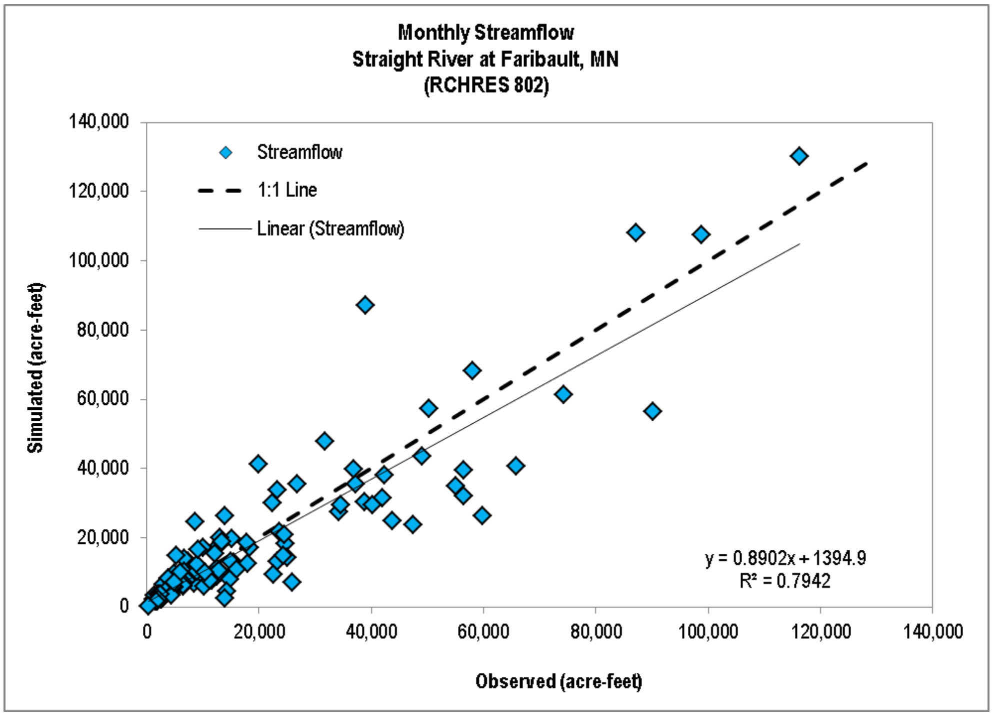

Figure 4-10. Monthly Streamflow 1:1 Plot for Straight River at Faribault, 2004-2012 (Gage #05353800)

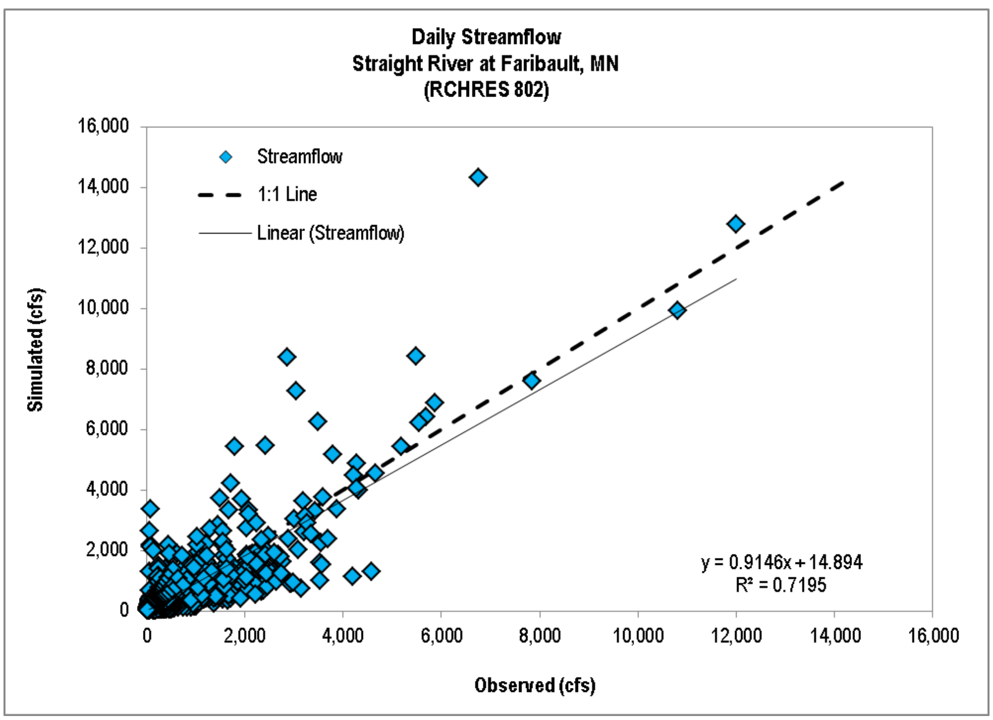

Figure 4-11. Daily Streamflow 1:1 Plot for Straight River at Faribault, 2004-2012 (Gage #05353800)

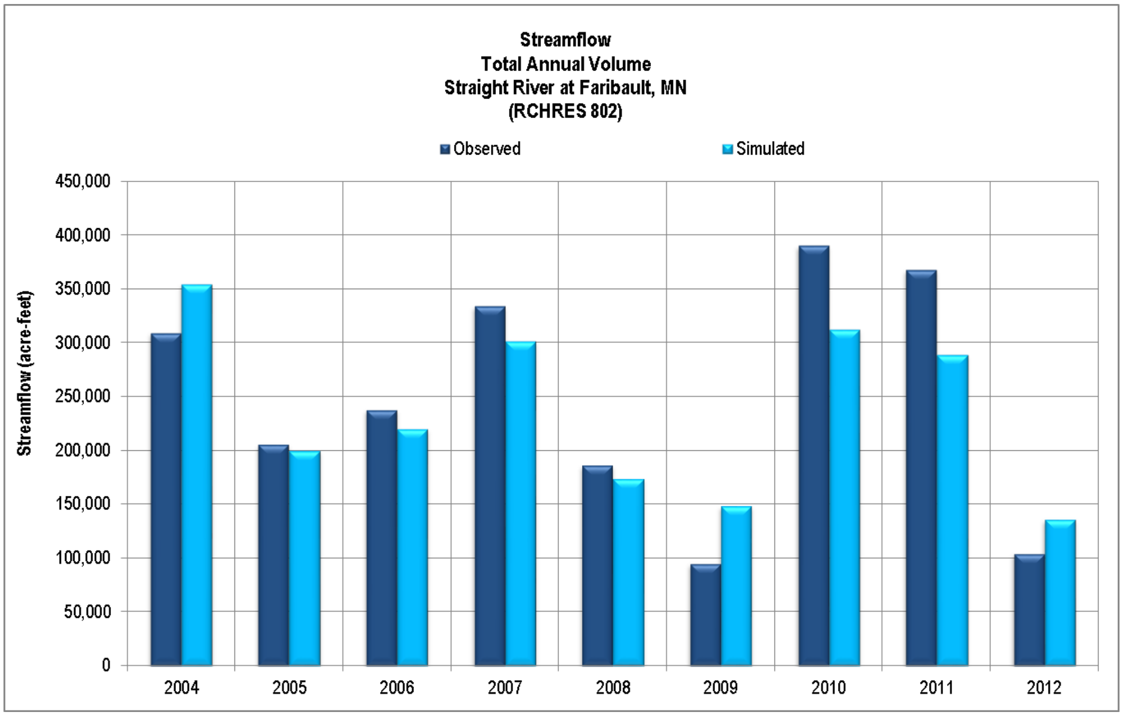

Figure 4-12. Streamflow Total Annual Volume for Straight River at Faribault, 2004-2012 (Gage #05353800)

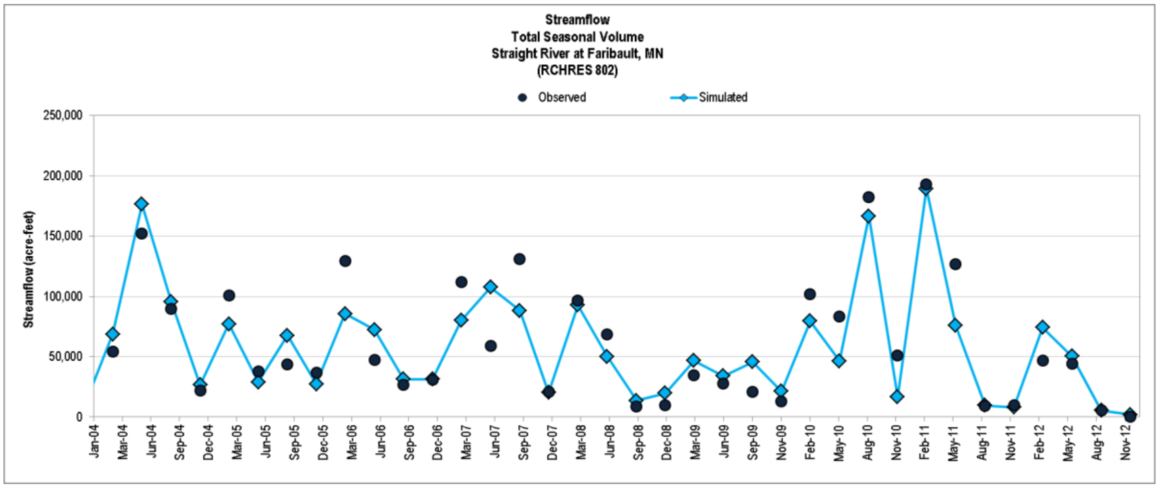

Figure 4-13. Streamflow Total Seasonal Volume for Straight River at Faribault, 2004-2012 (Gage #05353800)

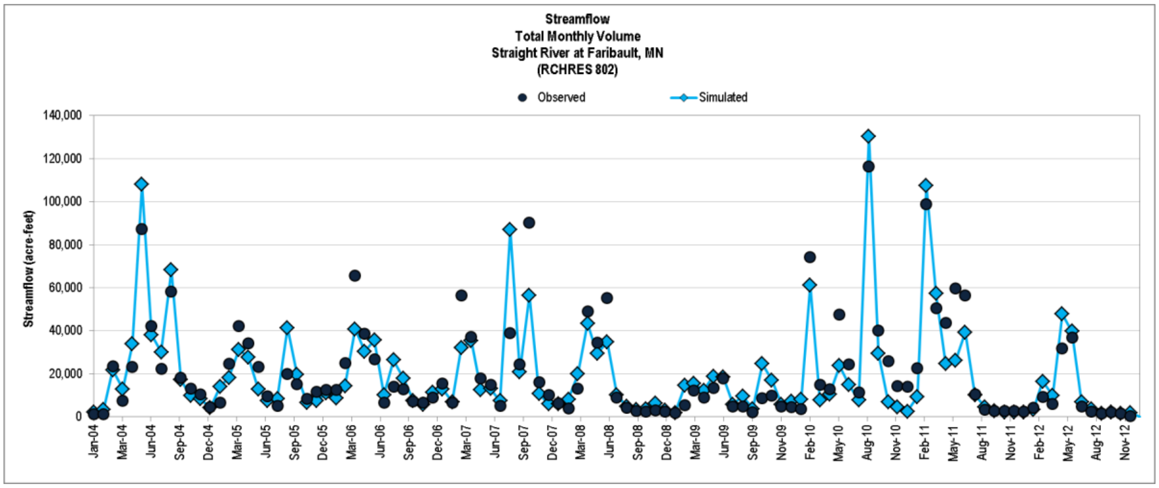

Figure 4-14. Streamflow Total Monthly Volume for Straight River at Faribault, 2004-2012 (Gage #05353800)

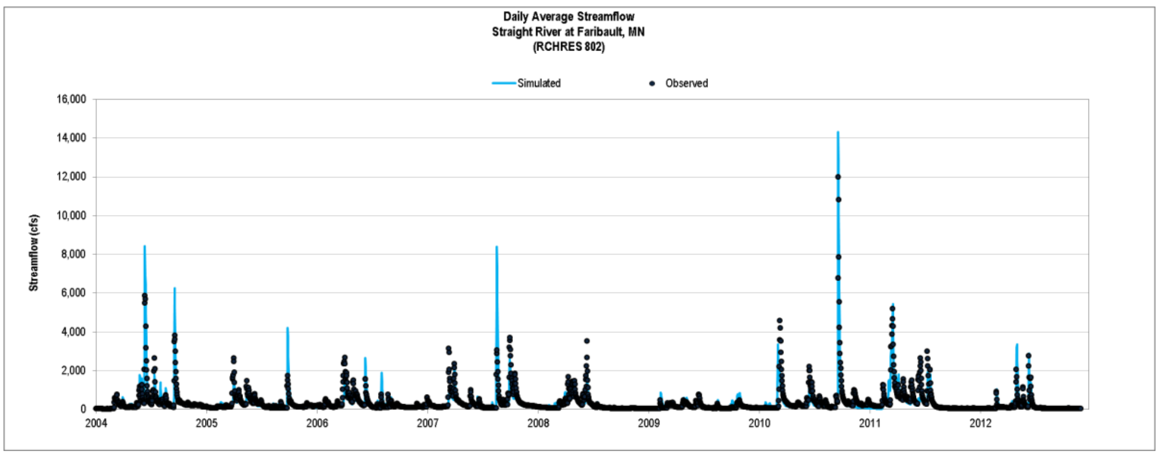

Figure 4-15. Average Daily Streamflow for Straight River at Faribault, 2004-2012 (Gage #05353800)

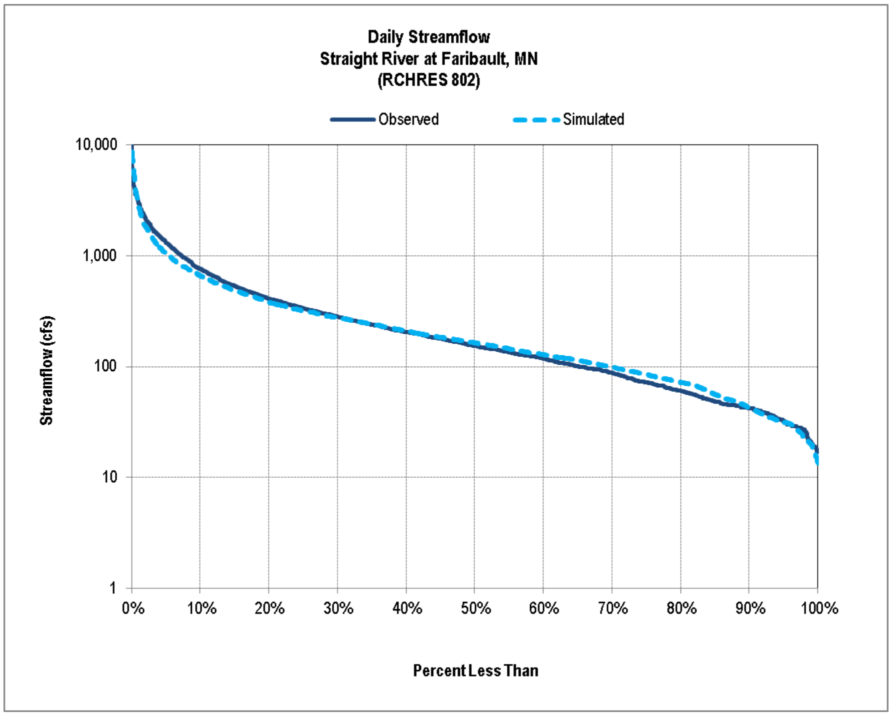

Figure 4-16. Daily Streamflow Cumulative Frequency Distribution for Straight River at Faribault, 2004 - 2012 (Gage #05355200)

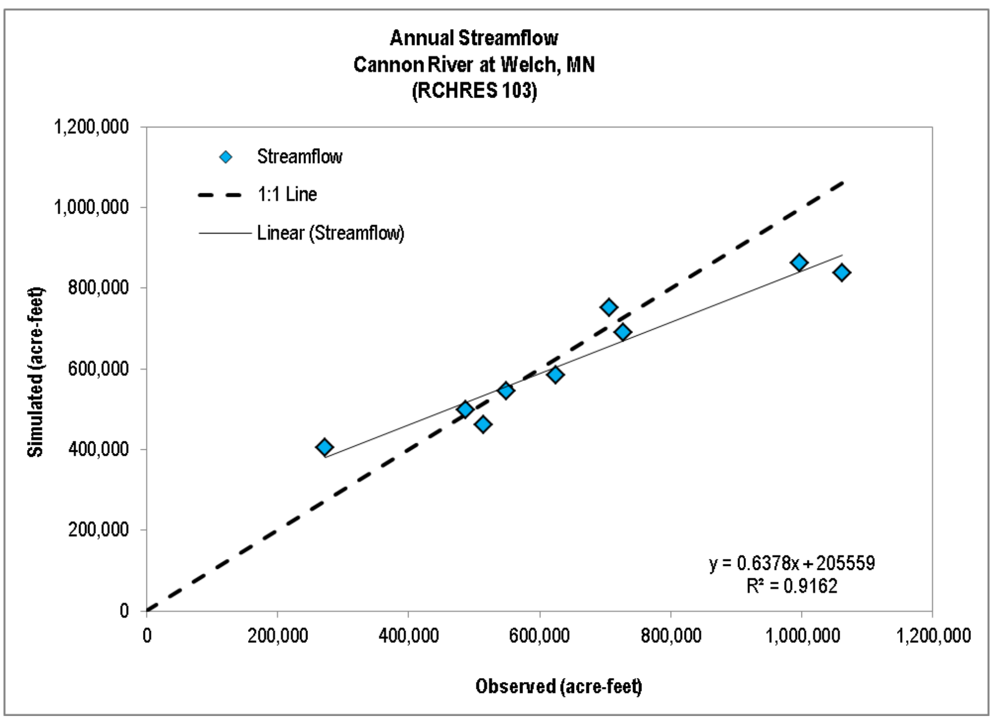

Figure 4-17. Annual Streamflow 1:1 Plot for Cannon River at Welch, 2004-2012 (Gage #05355200)

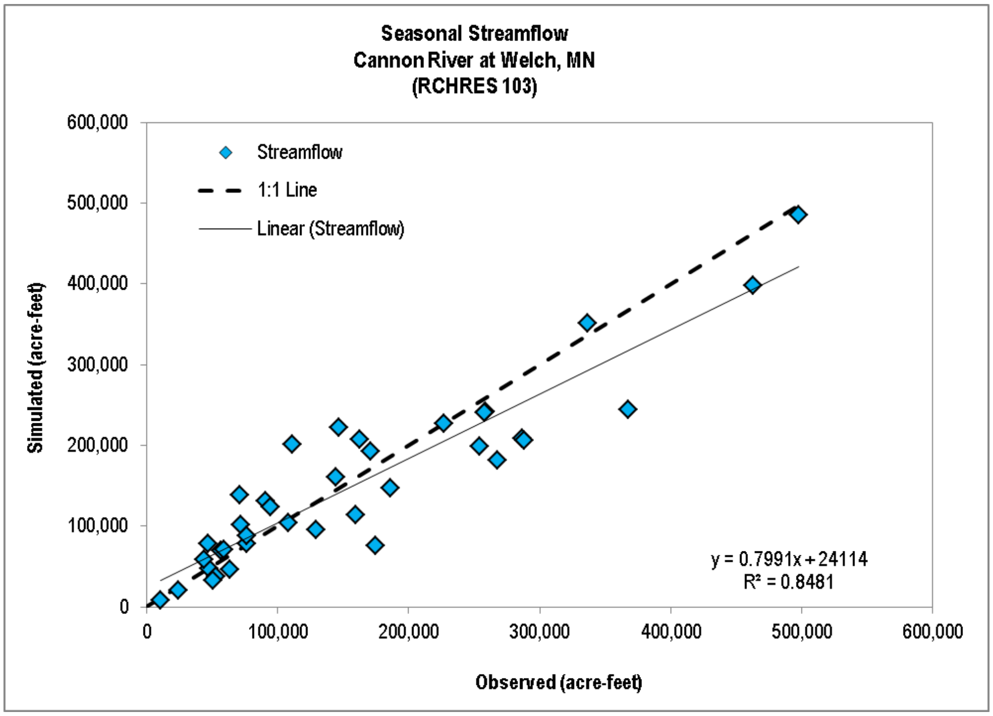

Figure 4-18. Seasonal Streamflow 1:1 Plot for Cannon River at Welch, 2004 - 2012 (Gage #05355200)

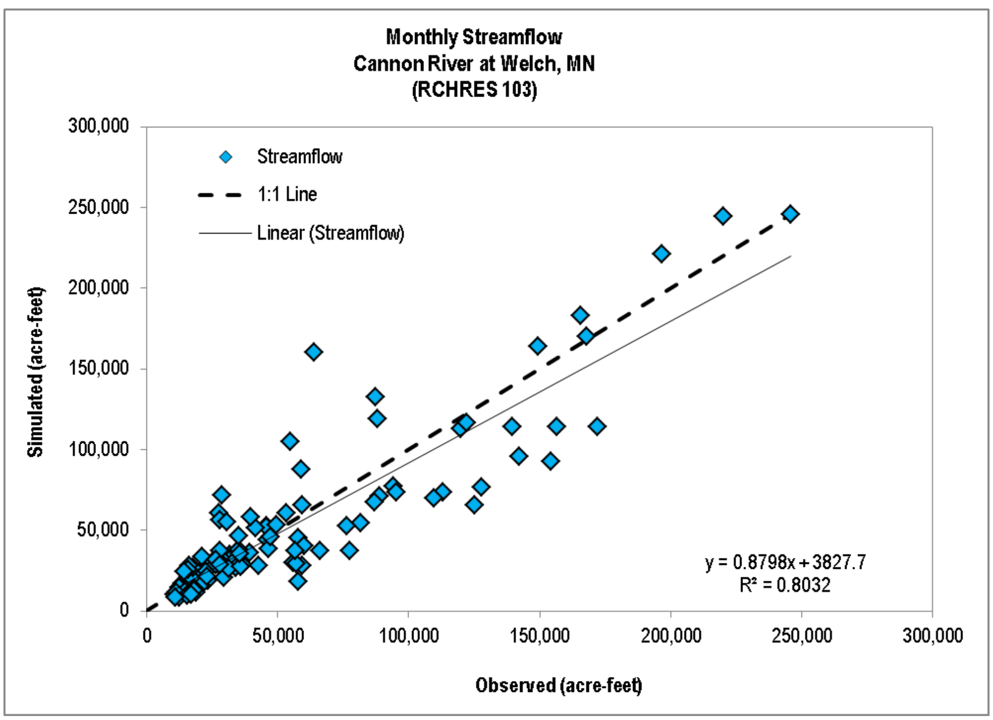

Figure 4-19. Monthly Streamflow 1:1 Plot for Cannon River at Welch, 2004-2012 (Gage #05355200)

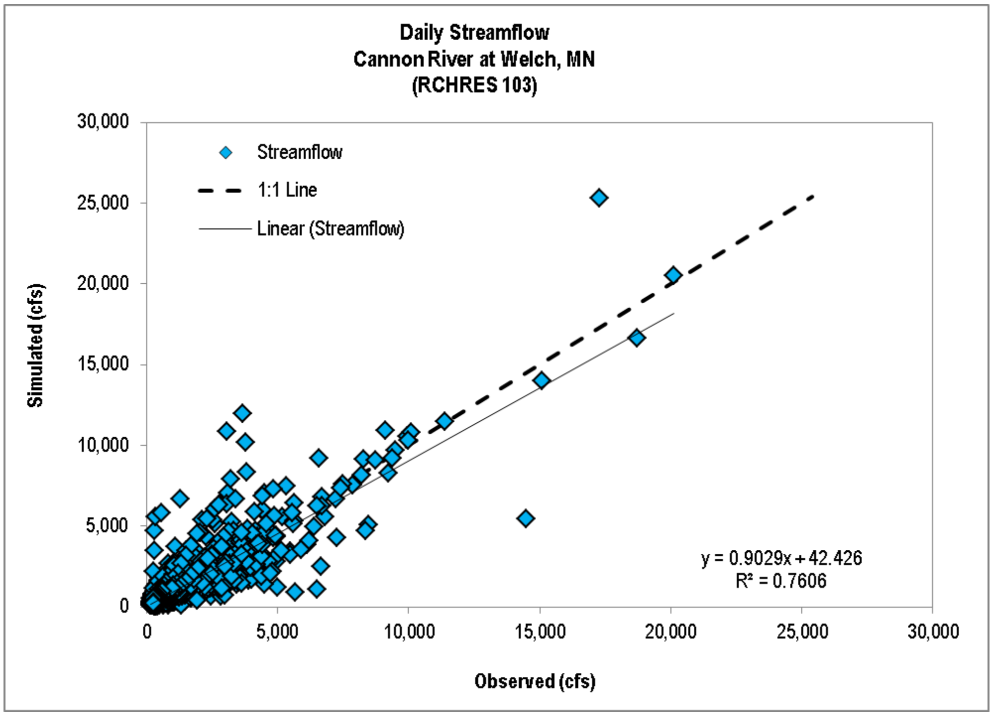

Figure 4-20. Daily Streamflow 1:1 Plot for Cannon River at Welch, 2004 - 2012 (Gage #05355200)

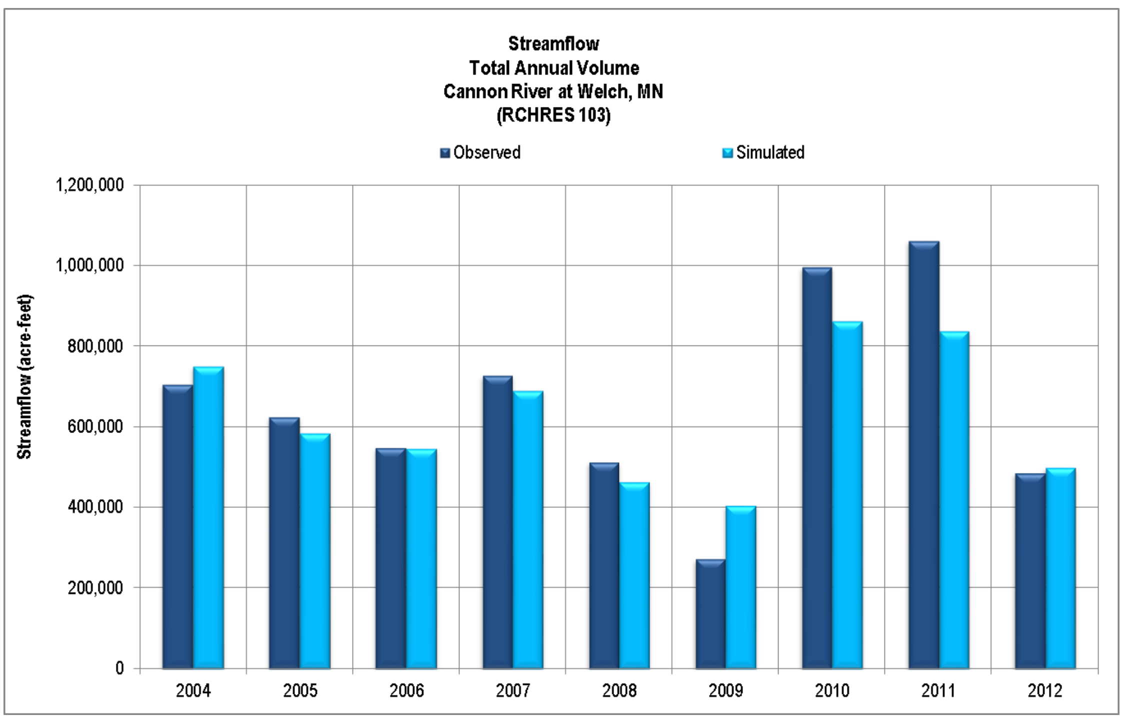

Figure 4-21. Streamflow Total Annual Volume for Cannon River at Welch, 2004 – 2012 (Gage #05355200)

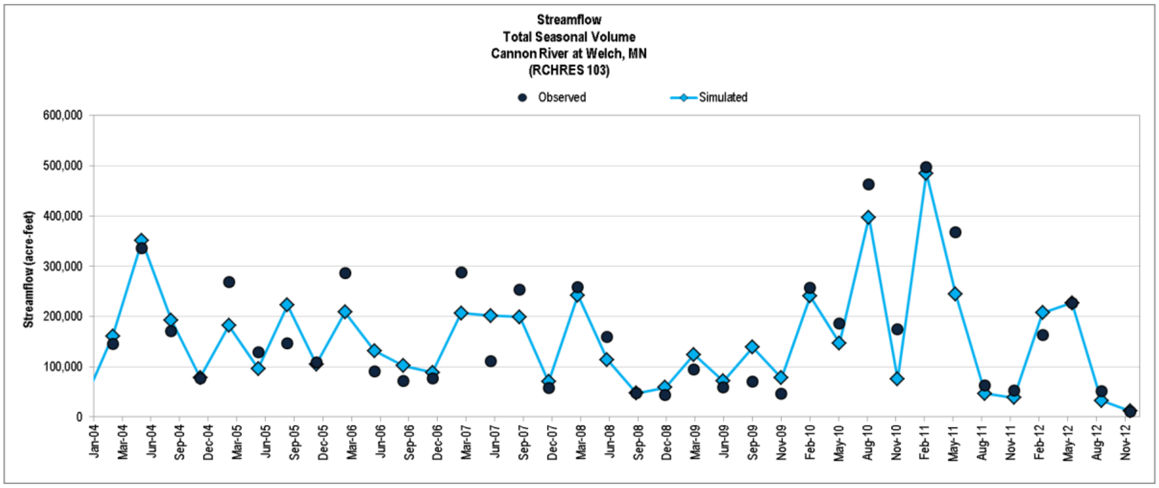

Figure 4-22. Streamflow Total Seasonal Volume for Cannon River at Welch, 2004 – 2012 (Gage #05355200)

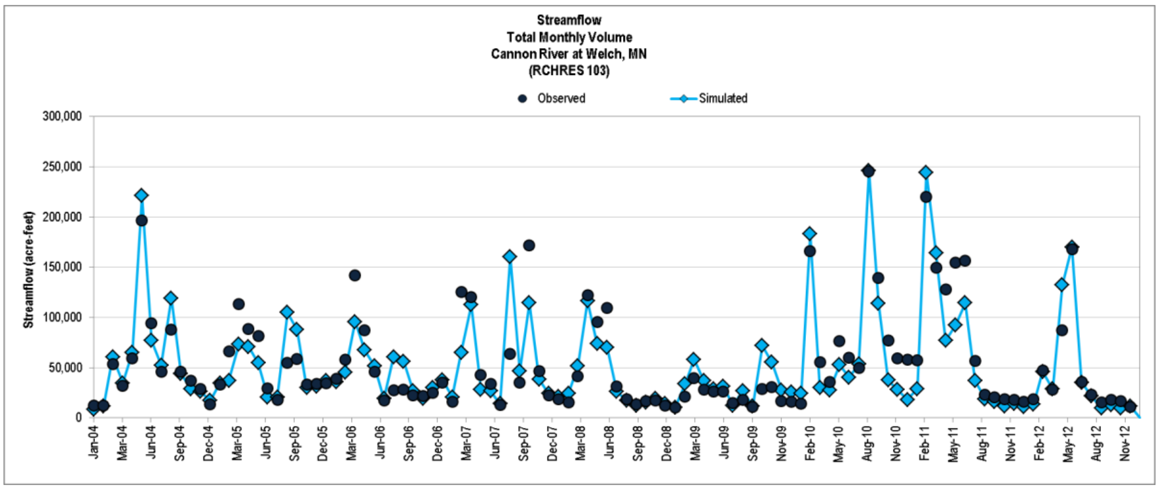

Figure 4-23. Streamflow Total Monthly Volume for Cannon River at Welch, 2004 – 2012 (Gage #05355200)

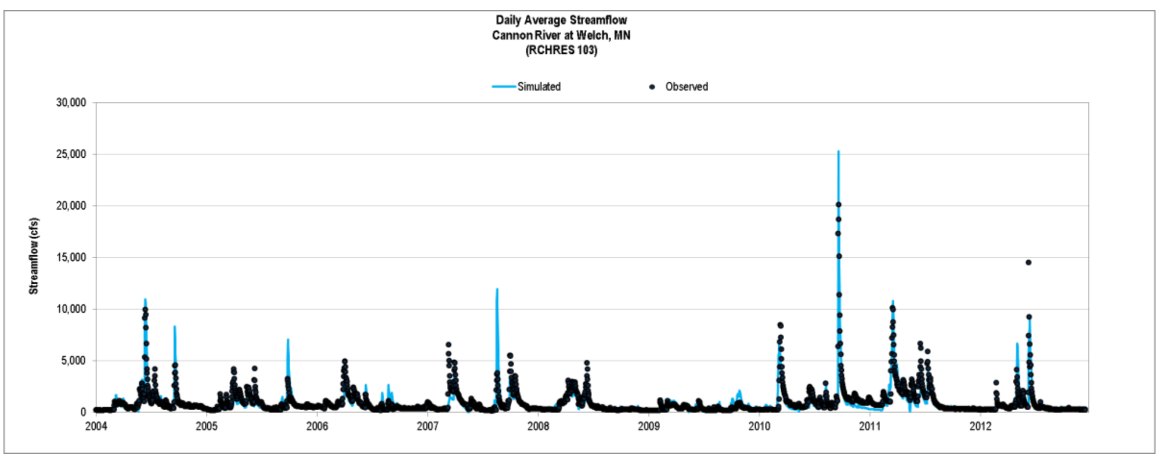

Figure 4-24. Average Daily Streamflow for Cannon River at Welch, 2004 – 2012 (Gage #05355200)

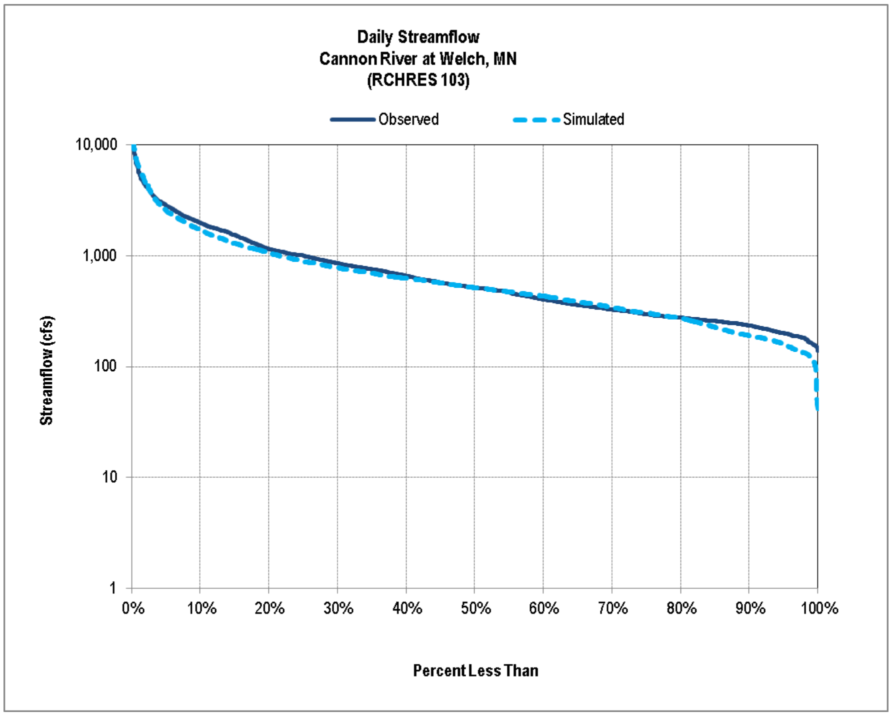

Figure 4-25. Daily Streamflow Cumulative Frequency Distribution for Cannon River at Welch, 2004 – 2012 (Gage #05355200)

Areas of Uncertainty

In some years the model underpredicts the magnitude of baseflow during the October through January period. This is particularly true during years with little precipitation during August and September, and can be seen when observing monthly and daily time series plots and daily cumulative frequency distribution plots for the Cannon River at Welch. One possible explanation for this underprediction of baseflow is the lack of model-predicted outflow from the majority of lake RCHRES during dry periods. Although active groundwater outflow from PERLNDs continues to contribute flow into the lakes during dry periods, most lakes in the model show no surface outflow to downstream RCHRES. In reality these lakes may contribute low flows to downstream reaches through subsurface flow interactions during dry periods; however, this process cannot be directly represented by the HSPF model.

The complexity of the hydrologic connections between surface and subsurface land areas and the lakes they drain to, as well as connections among lakes and to downstream reaches, gives rise to another area of uncertainty in the model. Subwatersheds were delineated using a DEM to accurately represent the surface area draining to the lakes, but the subsurface area draining to individual lakes may be quite different from the surface drainage. This was described above as a possible explanation for the water depths dropping in West Jefferson Lake, Middle Jefferson Lake, and Toner's Lake over the course of the simulation.

The simulation of the magnitude and timing of the annual spring snowmelt is another area of uncertainty and is always a challenge in modeling hydrology for northern climates. At times, the model simulates an increase in streamflow a week or two earlier than the observed data. The model occasionally overpredicts the magnitude of spring snowmelt in some years and underpredicts the magnitude in other years.

4.2.5 Hydrology Validation

The Cannon River at Welch and Straight River at Faribault stations served as the primary validation stations for evaluating model performance. Overall, most statistical measures and visual comparisons indicate the model performs in the “good” to “very good” range for the validation period (Tables 4-11 and 4-12, Figures 4-26 to 4-43). A brief summary of the model performance is provided below:

- The model is meeting all of the statistical model performance targets for the validation period;
- The annual and monthly r^2, NSE, and average relative percent difference values are within the “good” to “very good” range for both stations;
- The monthly PBIAS values are within the “very good” range for both stations;
- The daily average relative percent difference values are within the “good” range for the Cannon River at Welch station and within the “very good” range for the Straight River at Faribault station; and
- The daily r^2 value is within the “very good” range for the Cannon River at Welch station and within the “good” range for the Straight River at Faribault station.

Table 4-11. Cannon River Watershed Hydrology HSPF Model Validation Statistics Summary (1996-2003).

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault	
		Result	Performance Rating	Result	Performance Rating
Annual	*Count*	8		8	
	R-Squared	0.83	Good	0.88	Good
	Nash-Sutcliffe Efficiency	0.74	Good	0.88	Very good
	Relative Percent Difference	-8.7%	Very good	-2.8%	Very good
	Relative Percent Error	-7.7%	Very good	-1.8%	Very good
Monthly	*Count*	96		96	
	R-Squared	0.87	Good	0.85	Good
	Nash-Sutcliffe Efficiency	0.87	Very good	0.85	Very good
	P-Bias	7.87	Very good	2.00	Very good
	Relative Percent Difference	-10.3%	Good	4.7%	Very good
	Relative Percent Error	-4.1%	Very good	17.4%	Fair
Daily	*Count*	2922		2922	
	R-Squared	0.81	Very good	0.72	Good
	Nash-Sutcliffe Efficiency	0.80		0.72	
	Relative Percent Difference	-14.3%	Good	2.0%	Very good
	Relative Percent Error	-4.6%	Very good	21.7%	Fair
25th percentile low flow	*Relative Percent Difference*	-15.3%		10.2%	
	Relative Percent Error	-14.2%		10.7%	
90th percentile high flow	*Relative Percent Difference*	1.3%		-4.9%	
	Relative Percent Error	1.4%		-4.8%	

Table 4-12. Cannon River Watershed Hydrology Validation Observed and Simulated Streamflow Comparison (1996-2003).

Statistic	Cannon River at Welch		Straight River at Faribault	
	Observed cfs	Simulated cfs	Observed cfs	Simulated cfs
Average	930	856	319	312
Minimum	150	44	24	20
10th percentile	277	210	51	51
25th percentile	336	289	74	82
Median	632	547	168	173
75th percentile	995	874	311	319
90th percentile	1920	1946	728	693
Maximum	15100	9797	5340	6195

In addition to calculating statistics, model performance was evaluated using visual comparisons of observed and simulated streamflow at annual, seasonal, monthly, and daily time scales (Figures 4-26 to 4-43). Overall, the model does a “fair” to “very good” job reproducing annual, seasonal, and monthly streamflow volumes and daily streamflow.

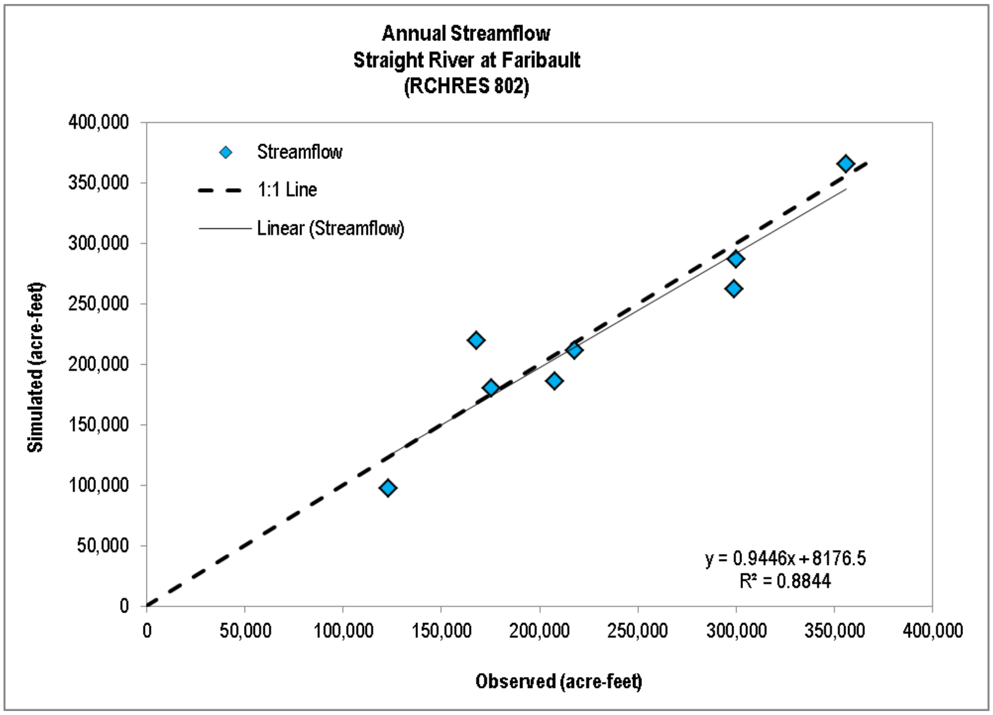

Figure 4-26. Annual Streamflow 1:1 Plot for Straight River at Faribault, 1996-2003 (Gage #05353800)

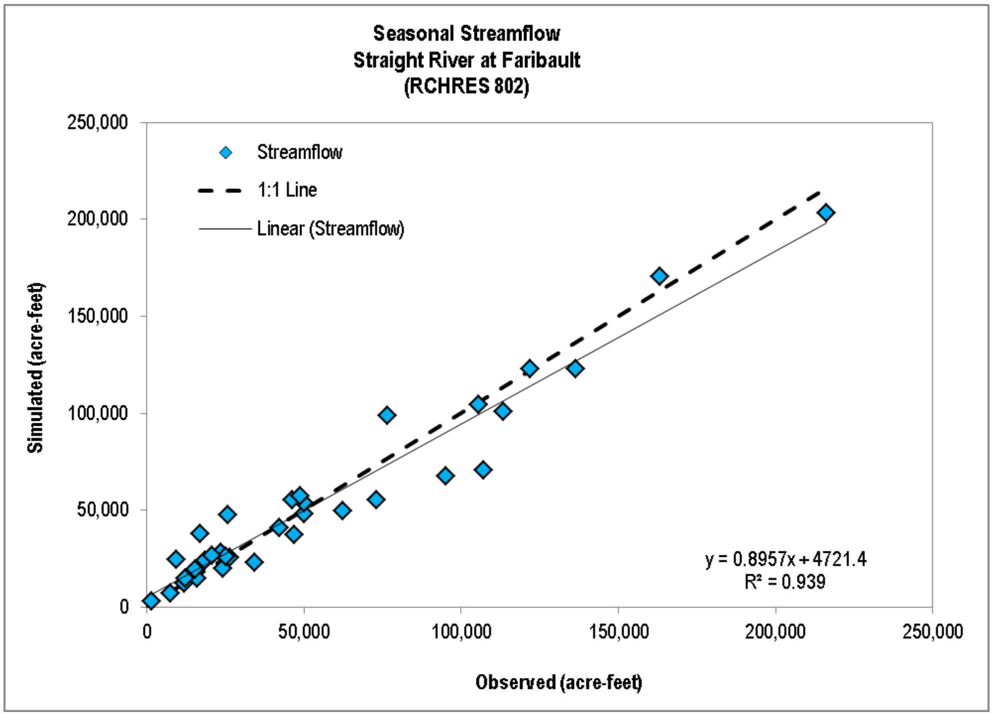

Figure 4-27. Seasonal Streamflow 1:1 Plot for Straight River at Faribault, 1996-2003 (Gage #05353800)

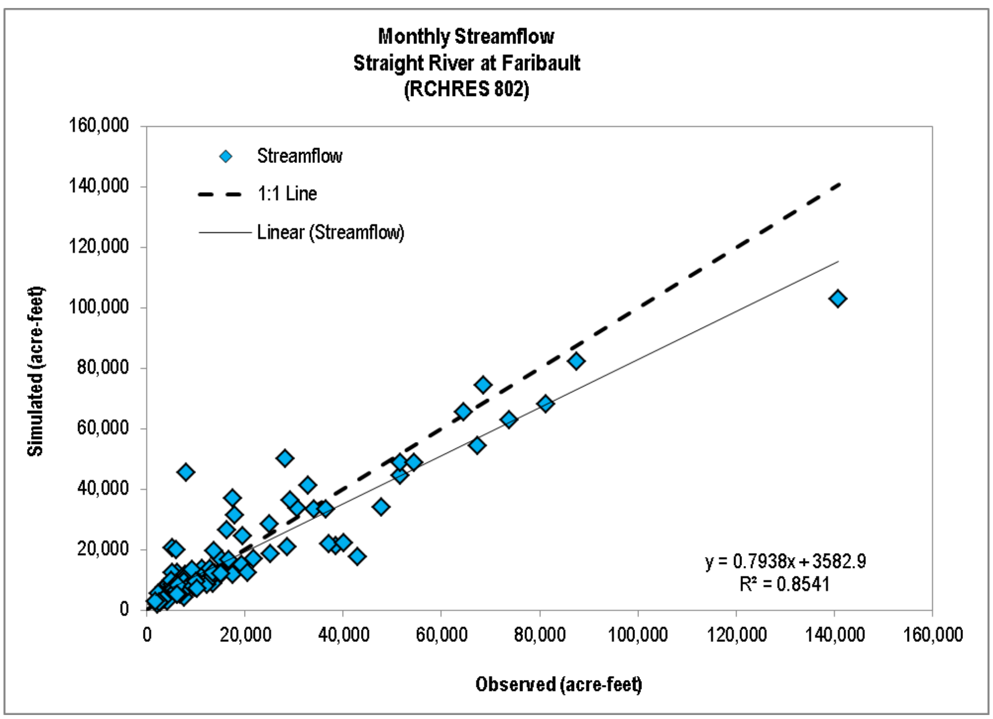

Figure 4-28. Monthly Streamflow 1:1 Plot for Straight River at Faribault, 1996-2003 (Gage #05353800)

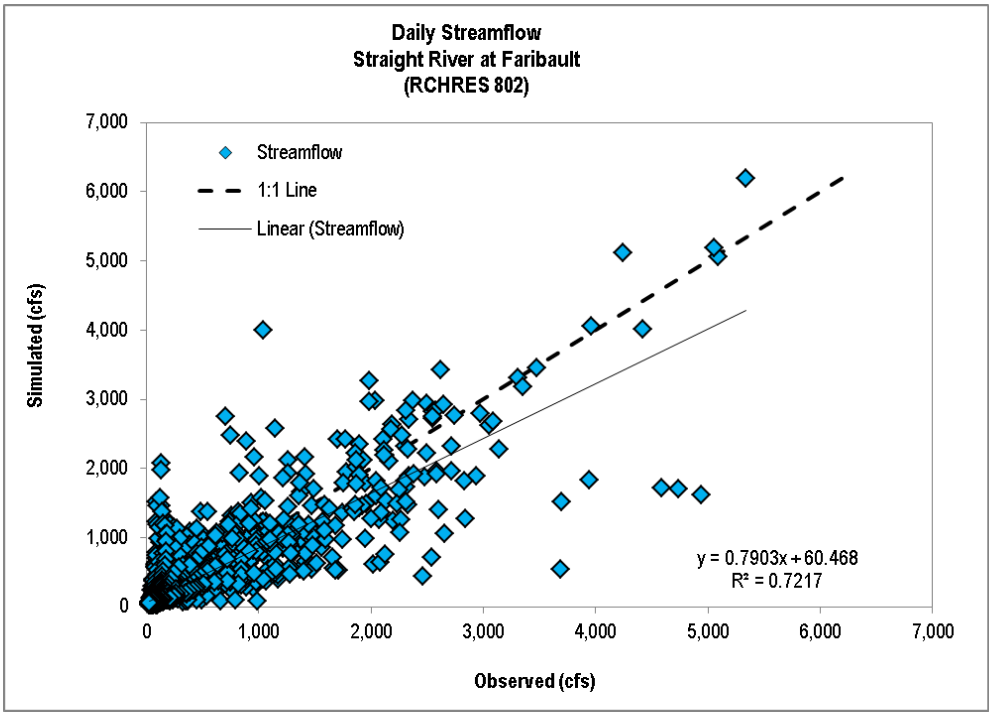

Figure 4-29. Daily Streamflow 1:1 Plot for Straight River at Faribault, 1996-2003 (Gage #05353800)

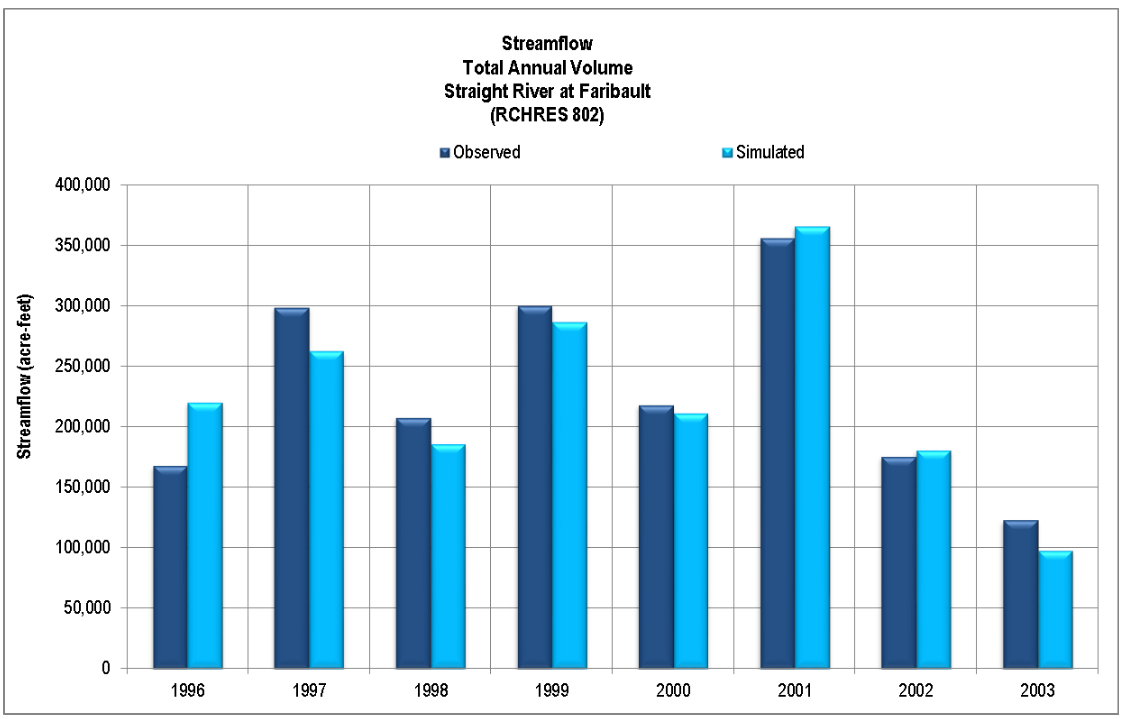

Figure 4-30. Streamflow Total Annual Volume for Straight River at Faribault, 1996-2003 (Gage #05353800)

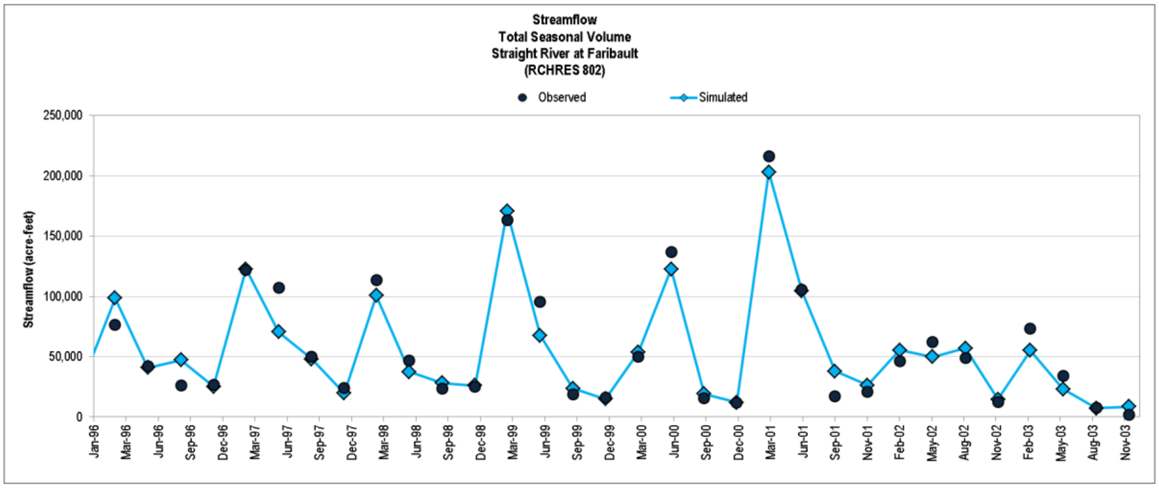

Figure 4-31. Streamflow Total Seasonal Volume for Straight River at Faribault, 1996 - 2003 (Gage #05353800)

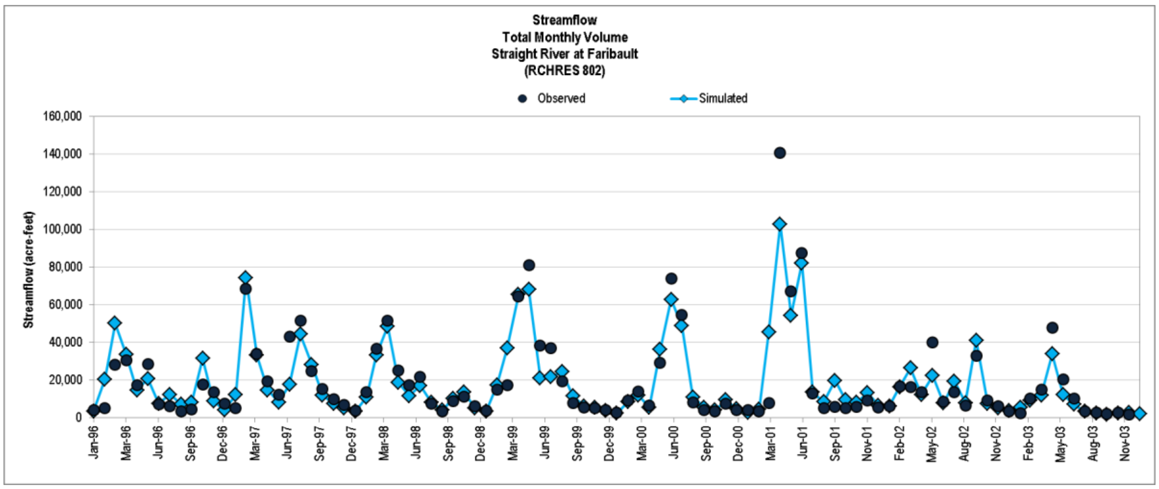

Figure 4-32. Streamflow Total Monthly Volume for Straight River at Faribault, 1996 – 2003 (Gage #05353800)

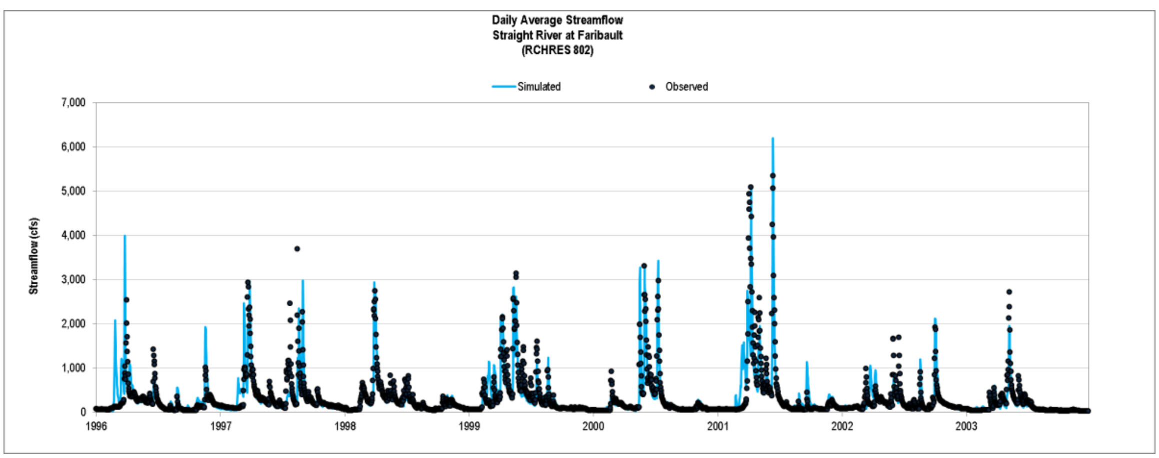

Figure 4-33. Average Daily Streamflow for Straight River at Faribault, 1996 – 2003 (Gage #05353800)

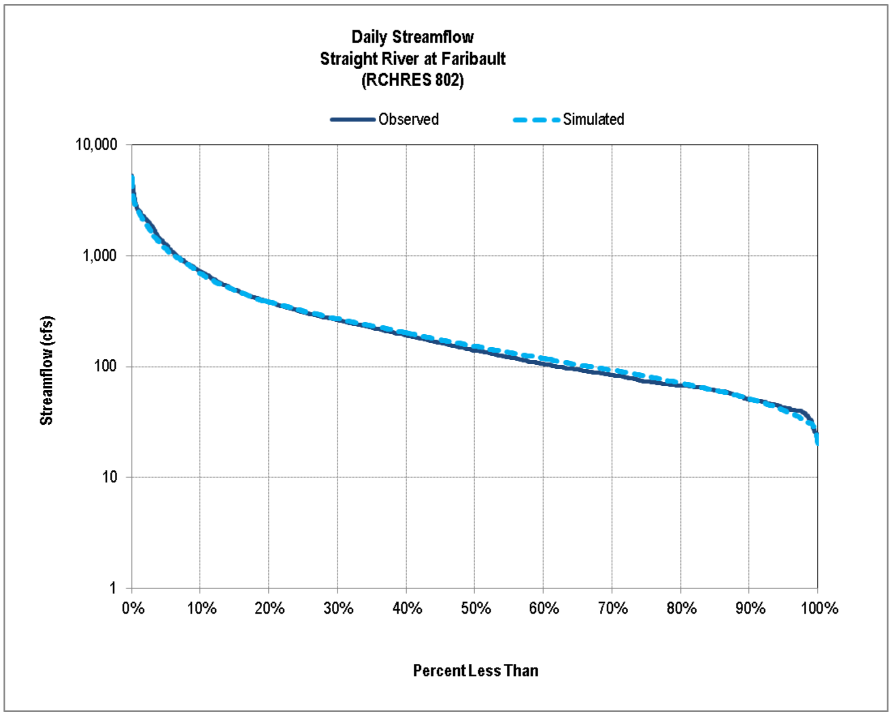

Figure 4-34. Daily Streamflow Cumulative Frequency Distribution for Straight River at Faribault, 1996 - 2003 (Gage #05353800)

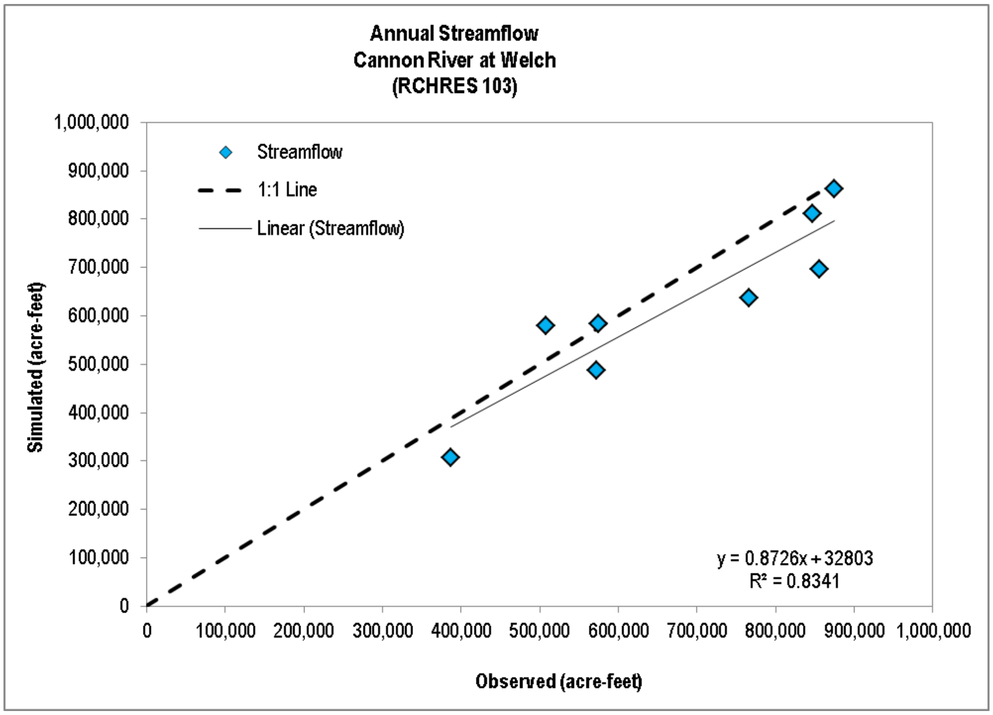

Figure 4-35. Annual Streamflow 1:1 Plot for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

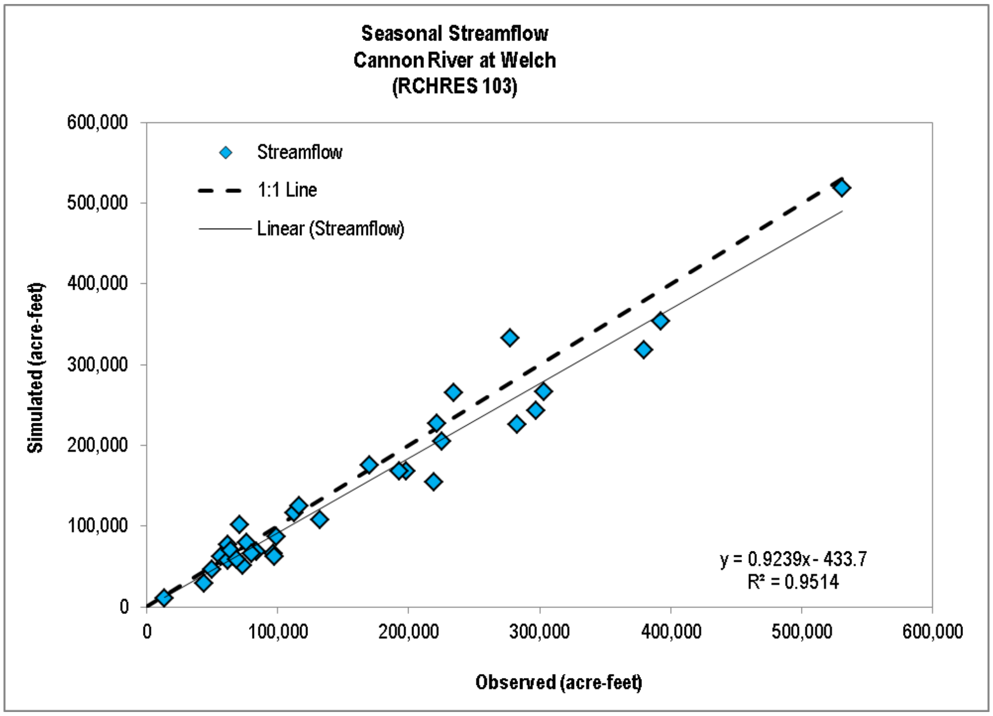

Figure 4-36. Seasonal Streamflow 1:1 Plot for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

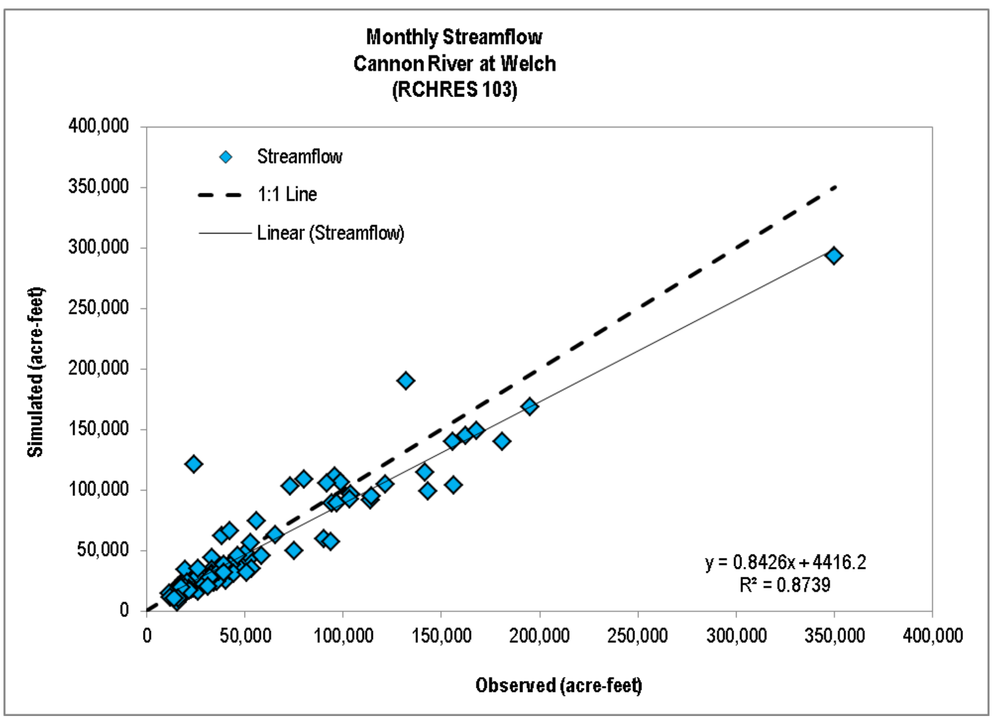

Figure 4-37. Monthly Streamflow 1:1 Plot for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

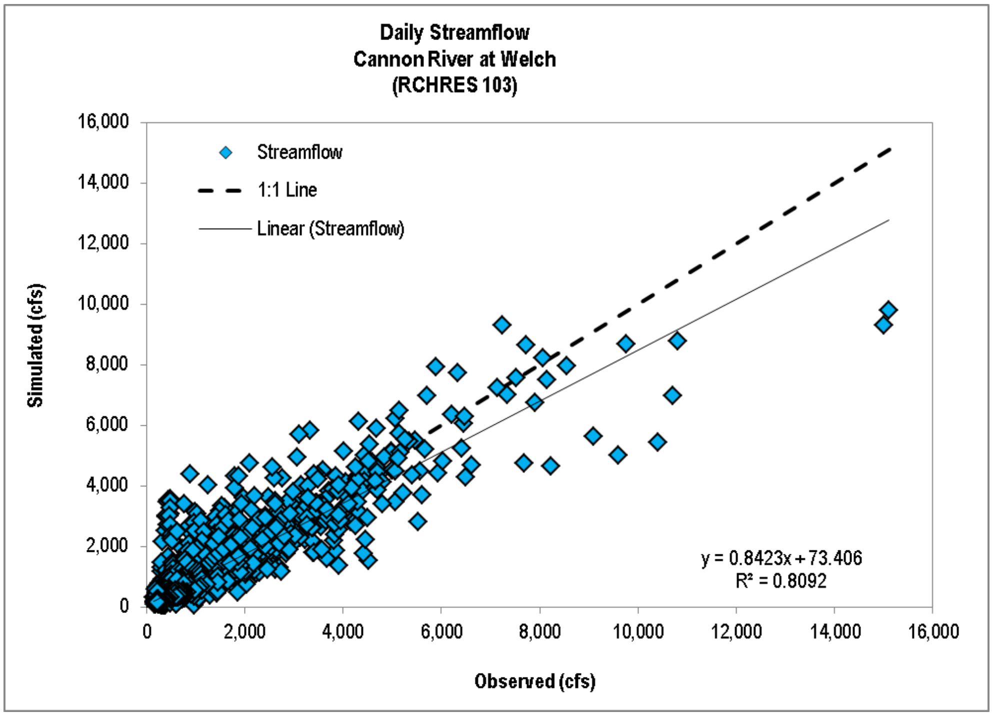

Figure 4-38. Daily Streamflow 1:1 Plot for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

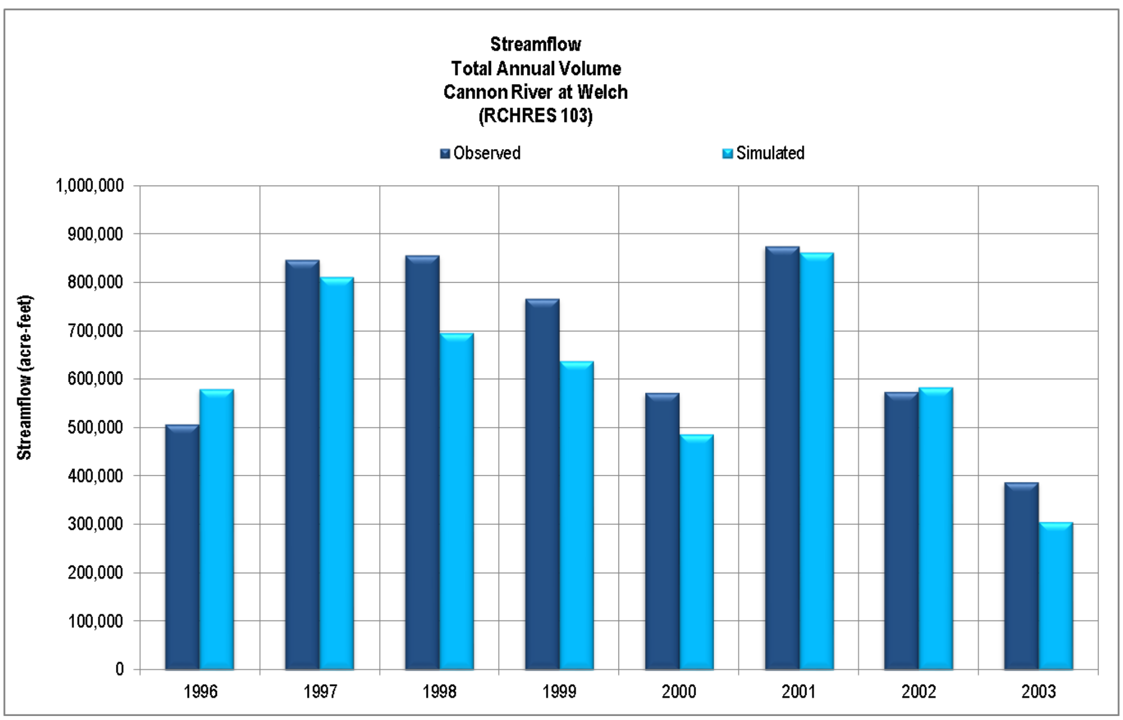

Figure 4-39. Streamflow Total Annual Volume for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

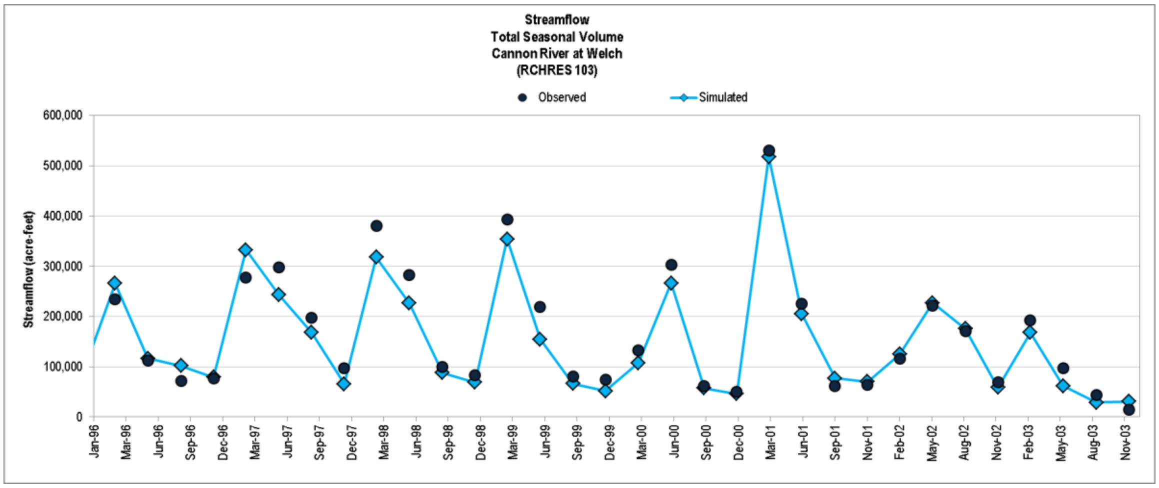

Figure 4-40. Streamflow Total Seasonal Volume for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

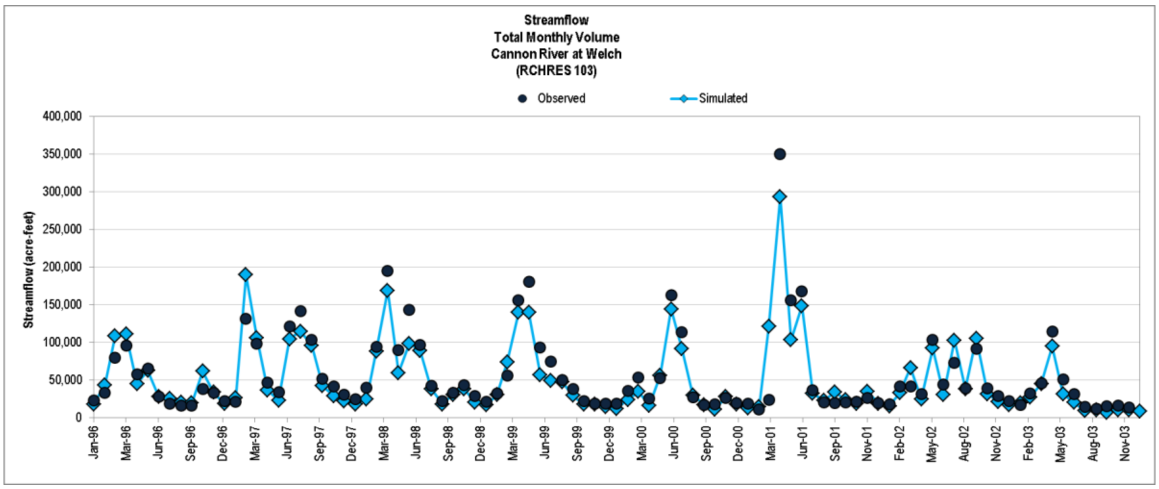

Figure 4-41. Streamflow Total Monthly Volume for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

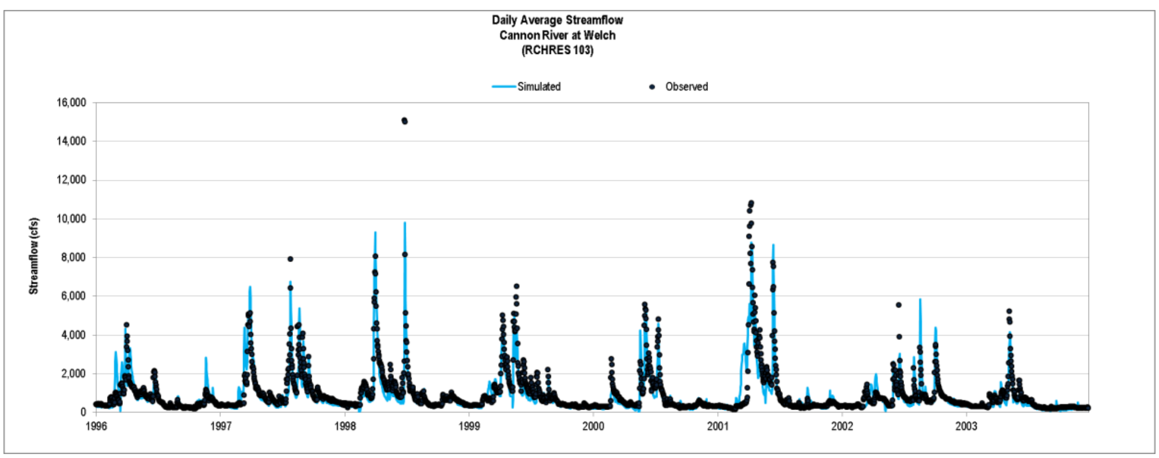

Figure 4-42. Average Daily Streamflow for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

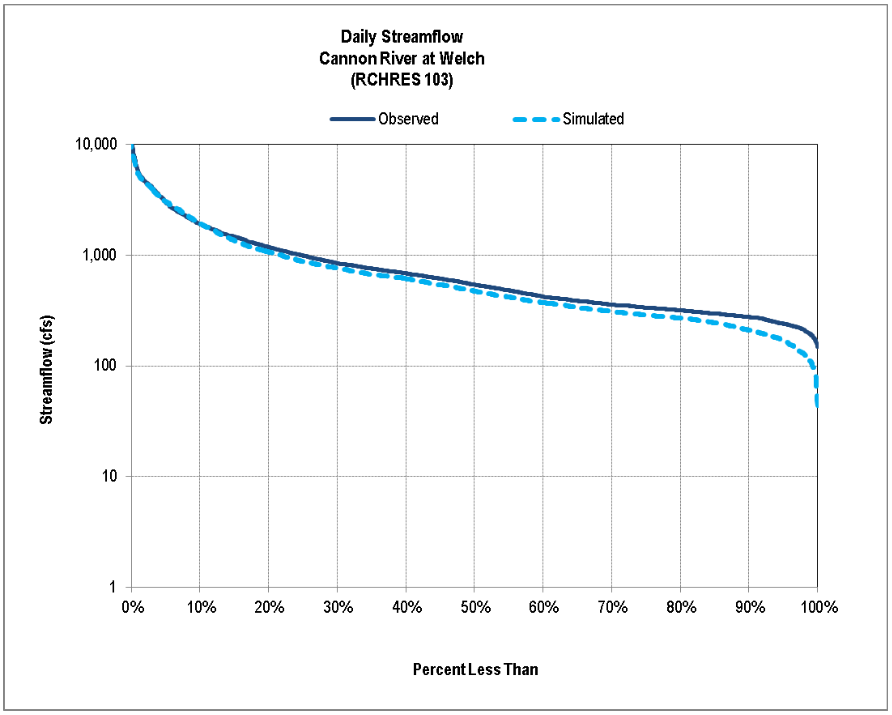

Figure 4-43. Daily Streamflow Cumulative Frequency Distribution for Cannon River at Welch, 1996 – 2003 (Gage #05355200)

4.2.6 Full Hydrology Simulation

Statistical comparisons were also completed for the entire simulation period (1996-2012) for the Cannon River at Welch and Straight River at Faribault stations. Overall, statistical measures indicate the model performs "fair" to "very good" for the full simulation period (Tables 4-13 and 4-14). A brief summary of the model performance is provided below:

- The annual, monthly, and daily r^2 values are within the "good" range;
- The annual and monthly relative average percent difference values are within the "very good" range;
- The daily average relative percent difference values are within the "good" range for the Cannon River at Welch station and within the "very good" range for the Straight River at Faribault station;
- The PBIAS values are in the "very good" range; and
- The annual and monthly NSE values are within the "very good" range.

In summary, the Cannon River watershed HSPF model is able to simulate watershed hydrology and streamflow with an acceptable level of accuracy. Therefore, the model is suitable for use as a simulation tool to evaluate hydrologic response for current conditions and potential management actions in the Cannon River watershed.

Table 4-13. Cannon River Watershed Full Simulation Period (1996-2012) Hydrology Statistics.

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault	
		Result	Performance Rating	Result	Performance Rating
Annual	*Count*	17		17	
	R-Squared	0.85	Good	0.84	Good
	Nash-Sutcliffe Efficiency	0.79	Very good	0.82	Very good
	Relative Percent Difference	-4.8%	Very good	-0.5%	Very good
	Relative Percent Error	-3.5%	Very good	1.3%	Very good
Monthly	*Count*	204		204	
	R-Squared	0.84	Good	0.82	Good
	Nash-Sutcliffe Efficiency	0.83	Very good	0.81	Very good
	P-Bias	6.28	Very good	3.04	Very good
	Relative Percent Difference	-7.3%	Very good	3.3%	Very good
	Relative Percent Error	-0.8%	Very good	15.2%	Good
Daily	*Count*	6210		6210	
	R-Squared	0.78	Good	0.72	Fair
	Nash-Sutcliffe Efficiency	0.76		0.69	
	Relative Percent Difference	-10.2%	Good	1.9%	Very good
	Relative Percent Error	0.4%	Very good	22.7%	Fair
25th percentile low flow	*Relative Percent Difference*	-8.5%		13.7%	
	Relative Percent Error	-8.1%		14.7%	
90th percentile high flow	*Relative Percent Difference*	-7.2%		-9.6%	
	Relative Percent Error	-7.0%		-9.2%	

Table 4-14. Cannon River watershed Full Simulation Period (1996-2012) Observed and Simulated Streamflow.

Statistic	Cannon River at Welch		Straight River at Faribault	
	Observed cfs	Simulated cfs	Observed cfs	Simulated cfs
Average	920	862	331	321
Minimum	139	42	17	13
10th percentile	250	198	45	47
25th percentile	320	294	72	83
Median	611	551	167	171
75th percentile	999	888	324	321
90th percentile	1950	1814	744	676
Maximum	20100	25316	12000	14305

Additional hydrology calibration and validation plots are provided in Appendix A. A complete set of statistics and plots have been provided as a set of electronic files with the deliverable package.

4.3 Sediment

The HSPF model simulates inorganic sediment via three particle-size classes: sand, silt, and clay. Sediment is often not sampled directly in streams. TSS includes inorganic particles (mostly clay and silt) and organic matter (algae, decomposed leaves or other plant material, etc.). All of the data used to conduct the sediment calibration and validation were TSS measurements and no suspended sediment concentration (SSC) analytical results were available to support the calibration. The TSS method does not capture the bedload component of the total sediment as well as the SSC method (USGS 2000). By simulating three particle size fractions, the HSPF model is able to represent a portion of the bedload component of the total sediment but cannot fully account for the fate and transport of sediment in the stream bed and banks. Thus, care is taken to distinguish watershed-specific calibration targets as "*suspended solids*" (SS) when they were derived from TSS data rather than as "*sediment*" targets and results. Nevertheless, the term "*sediment*" is generally used to discuss the HSPF model calibration, despite the model's limited ability to represent the bedload component of the overall sediment budget. HSPF model results are labeled as "*suspended sediment*". This approach is consistent with the language typically used in HSPF modeling and is also consistent with the terminology used in the MPCA modeling guidance document (AQUA TERRA Consultants 2012).

The Cannon River watershed sediment model calibration and validation results are described in the sections below.

4.3.1 Sediment Calibration Targets

The sediment calibration was conducted in a manner that was consistent with the approach described in BASINS Technical Note 8 (USEPA 2006a) and the MPCA modeling guidance document (AQUA TERRA Consultants 2012). Multiple elements of the Cannon River watershed HSPF model were investigated, including watershed sediment loading rates and sources, delivery of eroded sediments to streams, sediment trapping in Lake Byllesby and the lakes in the upper portion of the Cannon River watershed, scour and deposition processes, and TSS concentrations and loads. A set of calibration targets was defined for each of the model elements listed above so that a "weight of evidence" approach could be used to evaluate model performance. The "weight of evidence" approach consists of using multiple types of model-data comparisons, both graphical and statistical, to assess model performance.

Unit Area Loads and Sediment Sources

Site-specific sediment source data (i.e., watershed unit area loads (UALs) for each land use type) were not available for the Cannon River watershed, which is a typical limitation faced by the majority of watershed modeling efforts. The model calibration process instead considered UALs reported in the literature for various land use types.

A number of reports (Belmont 2011, Belmont 2012, Kelly and Nater 2000, Le Sueur County 2010, LimnoTech 2014d, LimnoTech 2014e, MPCA 2005, MPCA 2014a, Schottler 2010, Stout 2012, University of Minnesota 2012) relevant to sediment source apportionment were used to develop an appropriate target for upland contribution to sediment sources in the 25-40% range, with the remaining sediment (i.e., 60-75%) sourced from ravines, gullies, bluffs, and bed/bank erosion (LimnoTech 2014j). It was noted that a higher percentage of HSG "C" soils are present in the upper Cannon River watershed relative to the Root River. HSG "C" soils will tend to produce greater quantities of runoff relative to soils with higher infiltration rates (e.g., HSG A or B), which could potentially result in a larger yield of upland runoff-derived sediment than what is observed in the Root River watershed where soils are predominantly HSG B (LimnoTech 2014j; TetraTech 2009).

In-Stream Calibration Targets

The instream sediment transport calibration targets, which are described in greater detail below, included:

- An annual TSS load ranging from 90,000-120,000 tons/year for the Cannon River at Welch;
- Annual TSS loads at other locations with a relatively abundant TSS dataset, including the Little Cannon River near Cannon Falls, the Straight River at Faribault and the Cannon River near Northfield;
- Observed TSS concentrations;
- A 25-50% sediment trapping efficiency target for Lake Byllesby;
- Net sediment deposition in upper Cannon River lakes and the reaches upstream of the Morristown Dam and the Woolen Mill Dam in Faribault; and
- A general target of maintaining net sediment erosion within the free-flowing reaches.

The TSS load at Welch was estimated with the USGS's LOAD ESTimator (LOADEST) software (Runkel et al. 2004) using observed USGS streamflow data (gage number 05355200) and TSS concentrations measured by the Metropolitan Council of Environmental Services (MCES) from 1999-2012. Although the MPCA Environmental Data Access (EDA) database also included TSS data at Welch, the number of observations and the range of flow and suspended solids concentration conditions were limited compared to the MCES dataset. Figure 4-44 shows a comparison of the MCES and MPCA datasets.

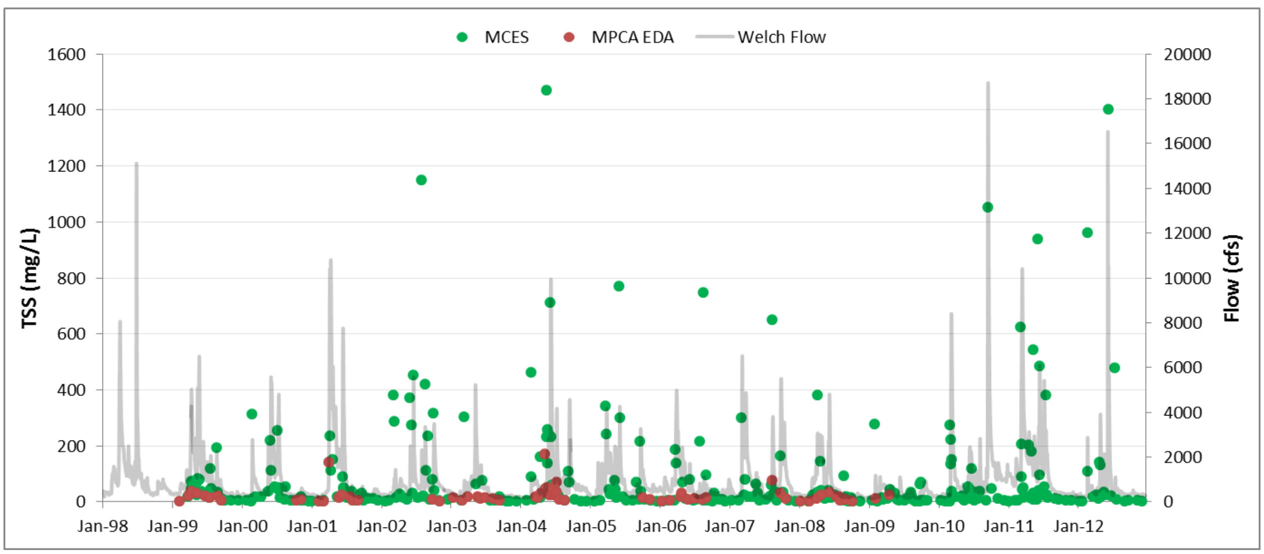

Figure 4-44. Comparison of TSS Measurements at Welch Collected by MCES and Compiled by the MPCA in its EDA Database

Annual TSS loads at Welch estimated using solely the MPCA EDA dataset were significantly lower (approximately 75% lower) than the TSS loads estimated using the MCES dataset. In addition, the annual TSS loads were approximately 30% lower than the estimated annual TSS load from the Little Cannon River watershed, a tributary that contributes to the TSS load at Welch, as calculated by the University of Minnesota (2012). The annual average TSS load calculated using the MCES dataset was

105,000 tons/year. MCES has calculated monthly and annual TSS loads at Welch using the U.S. Army Corps of Engineers (USACE) FLUX32 model (MCES 2014). The MCES-calculated annual average TSS load differed by less than 0.5% from the LOADEST-calculated annual average TSS loads. In recognition that the TSS load in the Cannon River may vary considerably by year and/or evaluation time period and to account for uncertainty associated with the load estimates, a ±15% range was applied to the 105,000 tons/year estimate. This resulted in an annual average TSS load calibration target of 90,000-120,000 tons/year for the Cannon River at Welch.

Annual TSS loads were also estimated for the Straight River in Faribault, the Cannon River at Northfield, and the Little Cannon River near Cannon Falls (LimnoTech 2014e) using LOADEST with TSS data from the MPCA EDA database (note that Welch is the only location in the Cannon River watershed monitored by MCES). Observed streamflow data from the USGS gage (gage #05353800) were used for the Straight River at Faribault analysis. Observed streamflow for Little Cannon River at Cannon Falls and Cannon River at Northfield were obtained from the HYDSTRA dataset. Missing flow records at the Little Cannon River and Cannon River at Northfield stations were estimated by applying drainage area ratios (DARs) to the observed streamflow data at Welch. The average annual TSS load targets are summarized in Table 4-15.

An important caveat to the average annual TSS load targets is that they are based on TSS data, which generally does not capture the bedload component of the total sediment load (USGS 2000) and is likely to underestimate the total sediment load. The percentage of bedload to total load is highly variable (Turowski 2010) but, in general, bedload comprises a larger percentage of the total load as drainage areas decrease and channel slopes increase (USGS 2010). This suggests that the annual load targets at these intermediate points in the watershed, which include areas with smaller drainage and/or higher channel slopes than the Cannon River at Welch, are likely biased low because they do not adequately represent the bedload component of the total sediment load. Using a "weight of evidence" calibration approach that considers multiple watershed and instream targets will ensure that the sediment calibration achieves a reasonable fit across the range of targets, even if the annual total sediment loads at these intermediate points in the watershed are underestimated.

Table 4-15. Annual Average TSS Loads in the Cannon River Watershed Estimated Using LOADEST.

Location (EDA Station ID)	Period	Average Annual Load (tons/year)	Additional Notes
Cannon River at Welch (S000-003)	1999-2012	105,000	LOADEST developed with TSS data from MCES. MCES average annual load estimated using FLUX is 105,000 tons/year.
Little Cannon River at Cannon Falls (S004-512)	2007-2010	26,500	University of Minnesota FLUX estimate is 33,837 tons/year based on TSS data from 1998-2012.
Cannon River at Northfield (S001-582)	2001-2004	27,700	Lake Byllesby, which acts as a sediment trap, is between Northfield and Welch.
Straight River at Faribault (S003-557)	2007-2012	18,400	Cannon River Watershed Management Report (2014) estimates annual average load of 14,151 tons/year based on TSS data from 2008-2011.

[1] *The MCES data were provided in spreadsheet format via personal communication with Terrie O'Dea (MCES)*

Lake Byllesby drains approximately 75% of the Cannon River watershed area and acts as a sediment trap, reducing the influence of sediments derived from the upper watershed on the ultimate sediment delivery to the Cannon River outlet. Sediment trapping efficiency for Lake Byllesby has not been calculated, nor is there sufficient site-specific information to estimate trapping efficiency. A target range of 25-50% trapping efficiency was set for Lake Byllesby, based on the calculation of the trapping efficiency of similar lakes, such as Lake Zumbro, and information from MPCA. A trapping efficiency of 34% was calculated for Lake Zumbro based on site-specific data and calculations (LimnoTech 2014d). A preliminary sediment calibration of the Cannon River watershed resulted in a 20% trapping efficiency in Lake Byllesby, which was deemed too low by MPCA personnel (Justin Watkins, personal communication).

Data were not available to compute target trapping efficiencies for the other lakes in the upper Cannon River or for reaches with control structures (e.g., the Morristown Dam and the Woolen Mill Dam in Faribault). Since these lakes attenuate streamflow and allow suspended particles to settle, a general "net depositional" target was set for the model reaches corresponding to these impoundments. A "net erosional" target was set for the free-flowing reaches of the watershed based on qualitative information described in the documents titled "Straight River Geomorphic Assessment" (Kolander 2010) and "Total Maximum Daily Load (TMDL) Evaluation of Turbidity Impairments in the Lower Cannon River" (CRWP 2007). Most of the sites surveyed in the 2010 "Straight River Geomorphic Assessment", which also included Maple Creek, Crane Creek and Turtle Creek, were observed to have eroding banks and widening channels. The Lower Cannon River TMDL suggested that stream bank erosion and channel scour were a significant source of sediment.

A final step in sediment calibration for watershed modeling usually involves comparing simulated and observed TSS concentrations (USEPA 2006a). Data were generally available for the 2000-2012 time period and limited over the 1996-1999 time period. The water quality station locations that were used to support the sediment model calibration and validation are summarized in Table 4-16.

Table 4-16. TSS Concentration Data for the Cannon River Watershed HSPF Model Calibration.

Station Name	EDA Station ID[1]	HSPF Reach ID	TSS Concentration		Notes
			Count of Records	Period of Record	
Cannon River at Welch	S000-003	103	76	1995-2009	MPCA EDA records
	-	103	322	1999-2012	MCES data[2]
Little Cannon River near Cannon Falls	S004-512	501	94	2007-2012	Full EDA Station ID is *"LITTLE CANNON R AT CSAH-24, 3 MI SW OF CANNON FALLS"*
Cannon River at Canada Ave., near Northfield	S001-582	203	61	2001-2004	Full EDA Station ID is *"CANNON R NEAR CSAH-47, 1 MILE NE OF WATERFORD"*
Straight River at Faribault	S003-557	802	195	2008-2012	Full EDA Station ID is *"STRAIGHT R AT 227 ST E, 2.8 MI SE OF FARIBAULT, MN"*
Crane Creek near Medford	S003-009	900	156	1999-2012	Full EDA Station ID is *"CRANE CK AT CSAH-22 1.5 MI S OF MEDFORD"*
Straight River at Clinton Falls	S000-047	806	165	1998-2012	Full EDA Station ID is *"STRAIGHT R NEAR CSAH-1 1 MI SE OF CLINTON FALLS"*
Maple Creek at Owatonna	S003-011	835	117	1999-2012	Full EDA Station ID is *"MAPLE CK AT CSAH-1 OWATONNA"*
Straight River at Owatonna	S003-015	809	115	2000-2012	Full EDA Station ID is *"STRAIGHT R AT SW 28TH ST 1 MI SW OF OWATONNA"*
Turtle Creek 3 mi SE of Owatonna	S003-016	841	115	2000-2012	Full EDA Station ID is *"TURTLE CK AT CSAH-45 3 MI S OF OWATONNA"*

[1] The Station ID and corresponding TSS concentration information (counts and period of record) are based on a query of MPCA's EDA database.

[2] The MCES data were provided in spreadsheet format via personal communication with Terrie O'Dea (MCES)

4.3.2 Sediment Parameterization

Initial model parameterization was completed following procedures outlined in BASINS Technical Note 8 (USEPA 2006a) and the MPCA modeling guidance document (AQUA TERRA Consultants 2012). Sediment transported in tile drainage was added to the model by using the GENER module to give the interflow component of runoff (INTFW) from drained cropland the sediment concentration of overland flow (SURO) and to account for partitioning into silt and clay and settling of sediment prior to delivery to the stream using the MFACT parameter. This approach was proposed by RESPEC and is outlined in the MPCA modeling guidance document (AQUA TERRA Consultants 2012). A constant sediment concentration of 3 mg/L was assigned to the active groundwater outflow (AGWO) to prevent unrealistically low concentrations of suspended solids in headwater reaches during low flow periods.

The partitioning of sediment loading from matrix scour (SCRSD) was based on an analysis of SSURGO data for the Cannon River watershed (19% sand, 61% silt, and 20% clay). Partitioning of the sediment loading from washoff (WSSD and SOSLD) used the results of the SSURGO data analysis but also considered the relatively higher delivery of clay and lower delivery of sand via overland flow to receiving stream reaches to arrive at 5% sand, 60% silt, and 35% clay.

A preliminary model run was completed to calculate daily average shear stresses for each reach to estimate critical deposition and scour shear stresses. The critical shear stress for silt deposition (TAUCD) was set at the 35th percentile of daily average shear stresses, and the critical shear stress for silt scour (TAUCS) was set at the 95th percentile of daily average shear stresses. TAUCD and TAUCS for clay were set at the 5th and 90th percentiles of the daily average shear stresses, respectively. TAUCD and TAUCS were set at higher percentiles for Lake Byllesby, the lakes in the upper Cannon River watershed, and the reaches upstream of the Morristown Dam and the Woolen Mill Dam in Faribault to simulate the net sediment deposition that occurs in these impounded reach segments. During calibration, TAUCD was set at a higher percentile and TAUCS was set at a lower percentile for reach segments in the Little Cannon River watershed to better match the higher TSS concentrations observed in this stream. These adjustments were also made for reaches representing Prairie Creek and Belle Creek, based on the similarity of their watershed characteristics to the Little Cannon River watershed.

4.3.3 Landside Sediment Erosion

The Cannon River HSPF model sediment calibration and validation results are described in the sections below. As mentioned above, several targets evaluated extend over the entire simulation period (1996-2012) due to a lack of data distinguishing the calibration and validation periods. Instream targets that are specific to the calibration and validation periods are presented separately.

PERLND and IMPLND parameters were adjusted until relative loadings between different land uses were:

- Appropriate based on literature (e.g., cropland with CD soils has a higher UAL than grassland with AB soils),
- UALs were within literature ranges for each land use category,
- The fractions of upland/washoff erosion (WSSD and SOSLD) and gully/ravine erosion (SCRSD) were consistent with calibration targets for sediment sources, and
- The overall watershed annual landside loading was consistent with the annual average sediment loading target for the Cannon River at Welch.

The area-weighted UALs by land use type are shown in Figure 4-45. A comparison of the model-simulated contributions of upland/washoff erosion and gully/ravine erosion to the simulated land use UALs is shown in Figure 4-46.

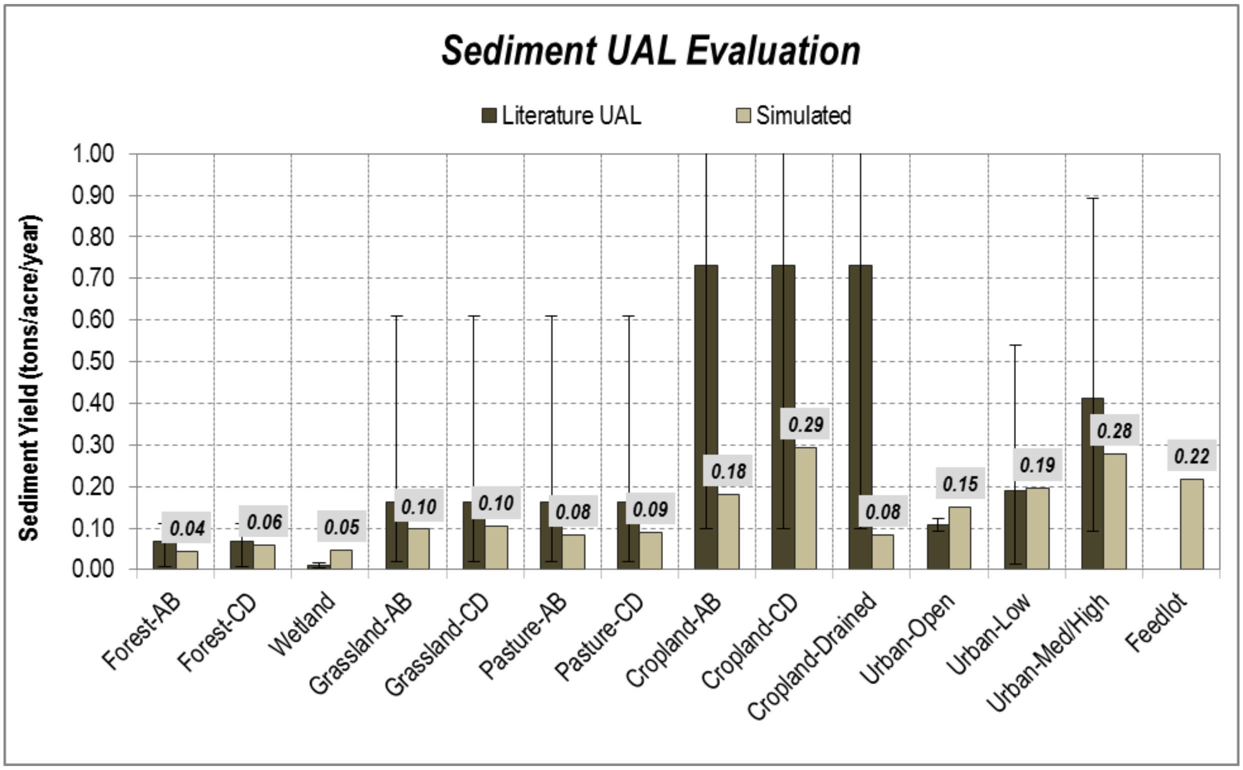

Figure 4-45. Area-weighted UALs for the Cannon River Watershed HSPF Model by Land Use Type Compared to Literature Averages (error bars represent minimum and maximum) (1996-2012).

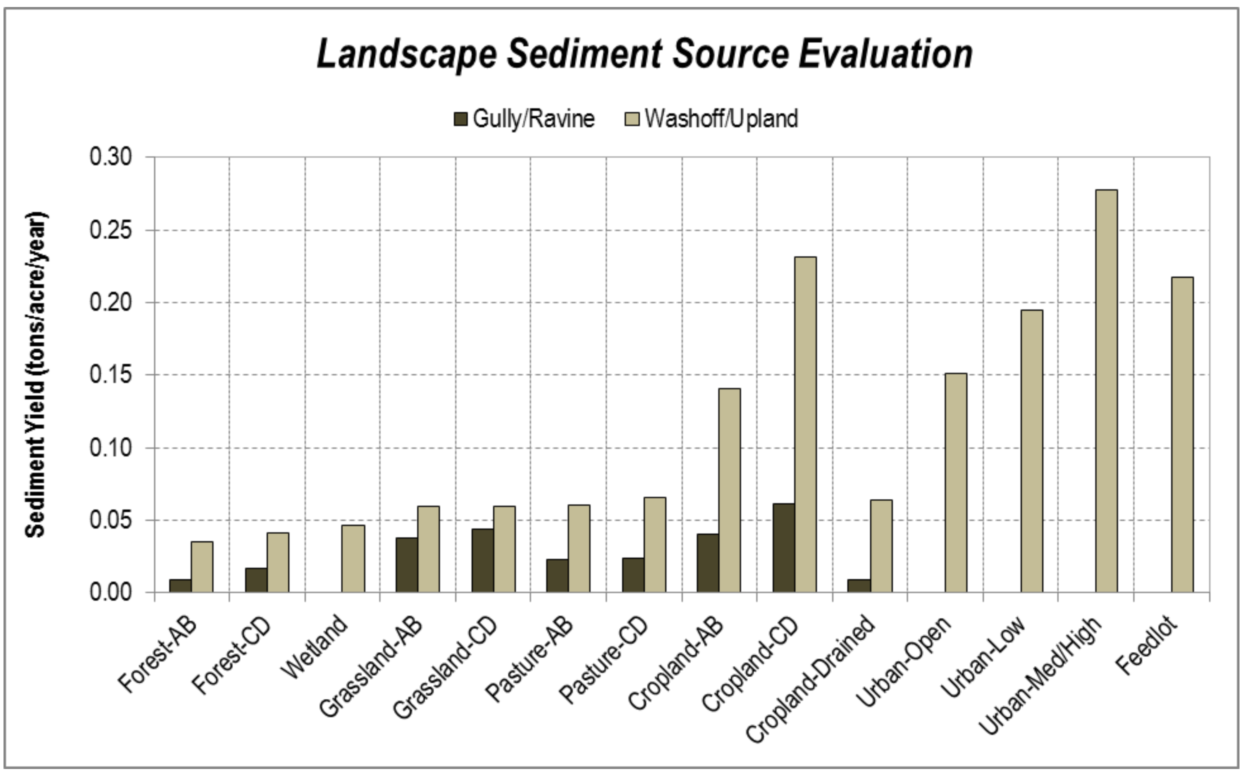

Figure 4-46. Relative Contribution of Gully/Ravine Erosion and Washoff/Upland Erosion to UALs for the Cannon River Watershed HSPF Model by Land Use (1996-2012).

4.3.4 Sediment Source Apportionment

After initial landside UALs were calibrated within reasonable ranges, an iterative process of adjusting PERLND, IMPLND, and RCHRES parameters was followed to meet the source fraction and instream calibration targets defined above including annual load targets and observed TSS concentrations. A brief summary of the model performance is provided below.

The calibrated model simulates that upland sources contribute 41% of the sediment load for the entire watershed. This is slightly higher than the 25-40% range set in the Task 6-1 memorandum (LimnoTech 2014j), but consistent with the observation in that memorandum that a larger upland source percentage may be appropriate for the Cannon River given the predominance of type "C" soils. The highest simulated sediment source is bed and bank erosion at 48%, and the third-largest contributor is gully and ravine erosion at 10%. Point sources, tile drainage, and groundwater outflow pathways each contribute less than 1% to the overall sediment delivery. A breakdown of the sediment sources is shown in Table 4-17 and Figure 4-47.

Table 4-17. Breakdown of Sediment Sources by Major Drainage Area and for the Entire Cannon River Watershed HSPF Model (1996-2012).

Drainage Area	Gully/Ravine	Upland	Tile Drains	Groundwater	Point Sources	Bed/Bank Erosion
Straight River[1]	9%	50%	3%	<1%	<1%	38%
Lakes[2]	10%	86%	1%	2%	<1%	0%
Upper Cannon[3]	9%	62%	1%	1%	<1%	26%
Middle Cannon[4]	4%	35%	<1%	<1%	<1%	59%
Lower Cannon[5]	12%	33%	<1%	<1%	<1%	54%
Entire Watershed	**10%**	**41%**	**<1%**	**<1%**	**<1%**	**48%**

Notes:

[1] Results tallied for free-flowing reaches in the Straight River and includes Maple Creek, Turtle Creek and Crane Creek watersheds.

[2] Results tallied for all lakes, including Byllesby, in the watershed.

[3] Results tallied for free-flowing reaches in portion of Cannon River watershed from the river headwaters to the confluence with the Straight River.

[4] Results tallied for the free-flowing reaches in the portion of the Cannon River watershed from the confluence with the Straight River downstream to the Lake Byllesby outlet and includes the Prairie Creek watershed.

[5] Results tallied for the portion of the Cannon River watershed from the Lake Byllesby outlet to the confluence with the Mississippi River and includes the Lower Cannon River and Belle Creek watersheds.

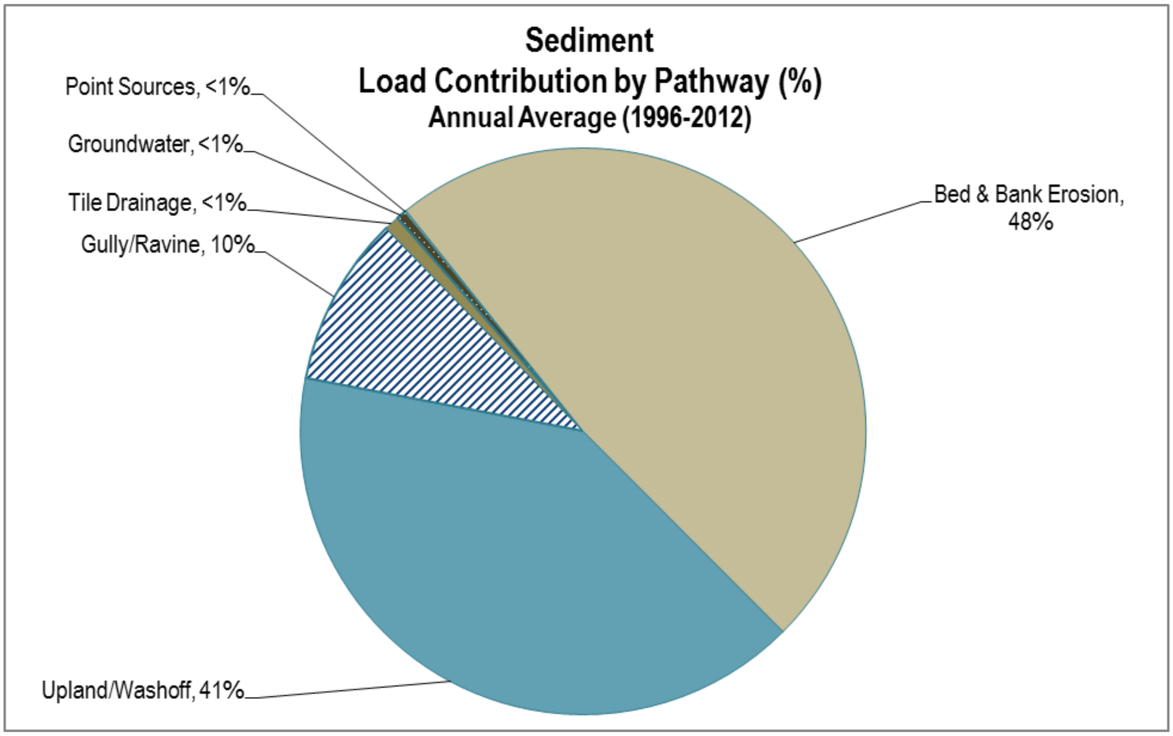

Figure 4-47. Breakdown of Sediment Sources for the Cannon River Watershed HSPF Model (1996-2012)

4.3.5 Instream Sediment Transport

The long-term Lake Byllesby sediment trapping efficiency was simulated as 37%, which is within the target range of 25-50%. Trapping efficiencies for the smaller lakes in the upper Cannon portion of the watershed ranged from 10-99%, as shown in Figure 4-48. The variability in the trapping efficiencies likely reflects the range of watershed areas draining to individual lakes, the amount of sediment delivered to each lake, and the hydraulic retention time and type of control structure in each lake. In addition, the characteristics of the reach immediately upstream of a lake also affected a given lake's trapping efficiency. The lowest trapping efficiencies (~10%) were simulated in Wells Lake and Lower Sakatah Lake. These lakes are immediately downstream of other lake segments (Cannon Lake and Upper Sakatah Lake) that have higher trapping efficiencies (~30%), reducing the amount of sediment overall and increasing the percentage of fine sediment delivered to these downstream lakes. The highest trapping efficiencies (>90%) tended to be in lakes with small drainage areas and a high hydraulic retention time, such as West Jefferson Lake, Sunfish Lake and Toner's Lake.

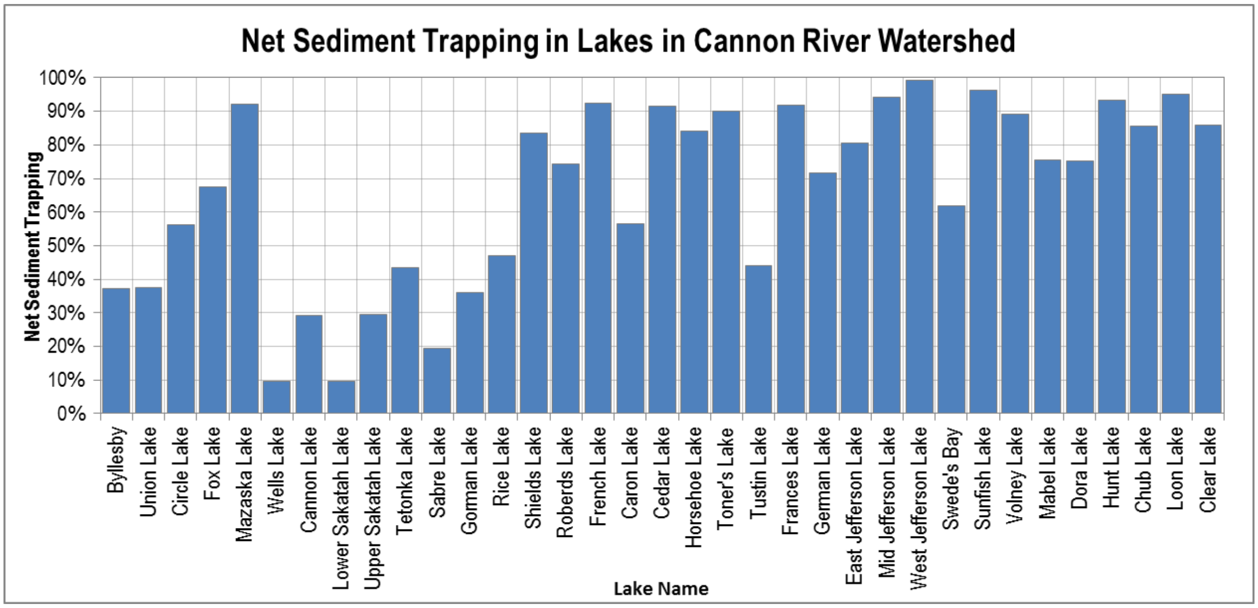

Figure 4-48. Net Sediment Trapping for All Lake Reaches in the Cannon River Watershed HSPF Model (1996-2012)

The majority of the remaining stream reaches were simulated as net erosional over the entire simulation period, with the highest erosion rates simulated in the Little Cannon River and Belle Creek, which are located in the Driftless geological area. The average annual change in bed depth over the entire simulation period is shown for all reaches in Figure 4-49 (note that the RCHRES IDs shown on the x-axis in Figure 4-49 are shown on a map in Figure 3-3). Bed and bank erosion are represented together in HSPF and expressed as a net change in bed elevation. That is, the negative bed depth changes in Figure 4-49 suggest an erosional reach but not necessarily the amount of erosion occurring from the sediment bed itself. The majority of net eroded sediments may be coming from the banks while the bed remains unchanged or even undergoes slight aggradation.

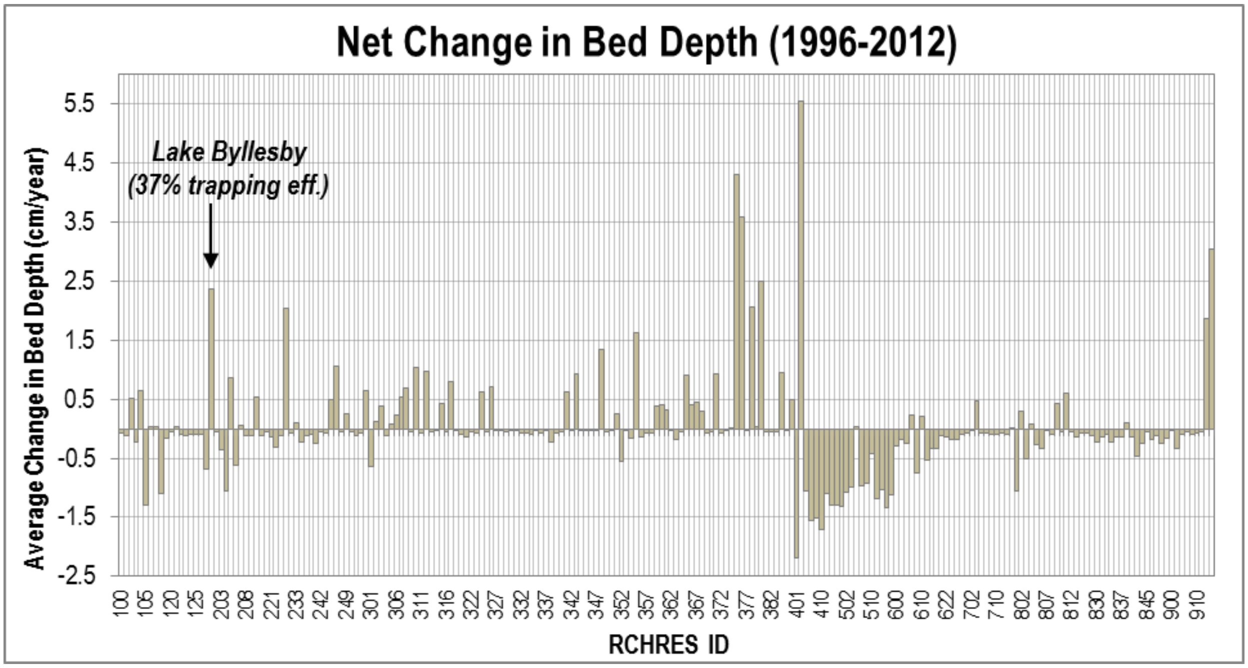

Figure 4-49. Average Annual Change in Bed Depth for All Reaches in the Cannon River Watershed HSPF Model (1996-2012).

4.3.6 Instream Suspended Solids Loads

The average annual TSS load simulated at the Cannon River at Welch was 105,600 tons/year for the period comprising available data (1999-2012), which compares well to the average annual TSS load calibration target of 105,000 tons/year estimated by LimnoTech using LOADEST and by MCES using FLUX. The simulated average annual TSS load falls within the 90,000-120,000 tons/year calibration target. A comparison of the simulated annual suspended sediment loads and the annual TSS loads calculated for the Cannon River at Welch using the LOADEST and FLUX models is shown in Figure 4-50.

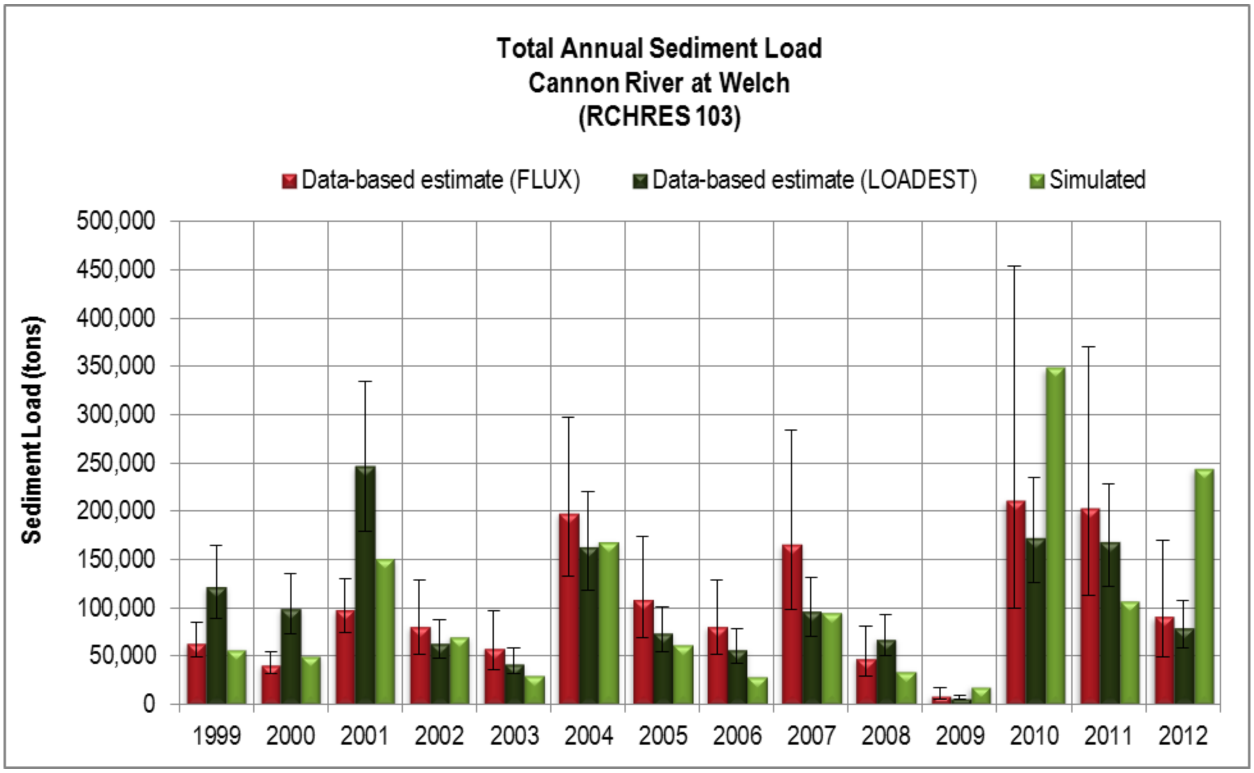

Figure 4-50. Total Annual Simulated Suspended Sediment Load for the Cannon River at Welch Compared with Suspended Solids Loads Estimated from the Cannon River at Welch USGS Streamflow and MCES TSS Concentrations (error bars represent the 95% confidence interval) Using LOADEST and FLUX (1999-2012).

Note: Although the plot title and y-axis label refers to "sediment", the data-based estimates are suspended solids loads and the simulated results are suspended sediment loads.

The variability in the calculated LOADEST and FLUX suspended solids load results for each year reflects differences in each model's regression algorithms. However, taken together, they provide a reasonable range of results for comparison to the model-simulated suspended sediment load. In most years, the simulated suspended sediment load compares favorably to the calculated suspended solids loads. TSS concentration data for high flow conditions were generally lacking, which tends to result in greater uncertainty in the regression model estimates for years with high flow periods or events. These uncertainties must be kept in mind when comparing the loads in Figure 4-50, especially for the years where a significant fraction of the suspended solids loading occurred during higher flow periods, such as 2010 and 2012, which demonstrate a larger difference between "data-based estimates" and "simulated" loads.

The simulated annual average suspended sediment loads at upstream locations in the watershed tend to be higher than the annual average suspended solids loads calculated with LOADEST. Table 4-18 presents a comparison of the LOADEST and HSPF-simulated annual average loads.

It was not possible to parameterize the model to reproduce the LOADEST loads at these locations without sacrificing model performance with respect to other calibration targets (e.g., UALs, lake trapping efficiency) or setting some model parameters outside the range of recommended values. As noted above, it is likely that TSS observations corresponding to a range of conditions, including high flow periods, were generally limited at these locations, which could result in a significant understatement of the annual suspended solids loads for any/all of these sites.

Table 4-18. Comparison of Calculated and Simulated Average Annual Sediment Loads at Upstream Locations in the Cannon River Watershed.

Location (EDA Station ID)	Period	Average Annual Sediment Load (tons/year)	
		LOADEST- Calculated	HSPF Simulated
Little Cannon River at Cannon Falls (S004-512)	2007-2010	26,500	24,000
Cannon River at Northfield (S001-582)	2001-2004	27,700	82,400
Straight River at Faribault (S003-557)	2007-2012	18,400	50,500

4.3.7 Sediment Calibration

The average annual suspended sediment load simulated at the Cannon River at Welch was compared to annual TSS loads calculated by MCES using FLUX for the calibration period (2004-2012). The simulated annual average suspended sediment load of 124,000 tons/year for the calibration period compares well to the annual average TSS load of 124,700 tons/year calculated by MCES and falls within the +/-15% calibration target (106,000 – 143,400 tons/year). A comparison of the simulated annual suspended sediment load and the calculated annual TSS loads is shown in Figure 4-51. The figure also includes the annual TSS loads estimated with LOADEST using USGS streamflow data at Welch and MCES TSS concentration data. PBIAS for the calibration period falls within the "very good" range (0.6%), and the relative percent difference is "very good" (-11.1%).

Comparisons of simulated daily average suspended sediment concentrations and observed TSS concentrations from MPCA and MCES samples for the Cannon River at Welch station are shown in Figure 4-52. Time series plots comparing simulated and observed TSS concentrations for the additional calibration stations listed in Table 4-16 are provided in Appendix B.

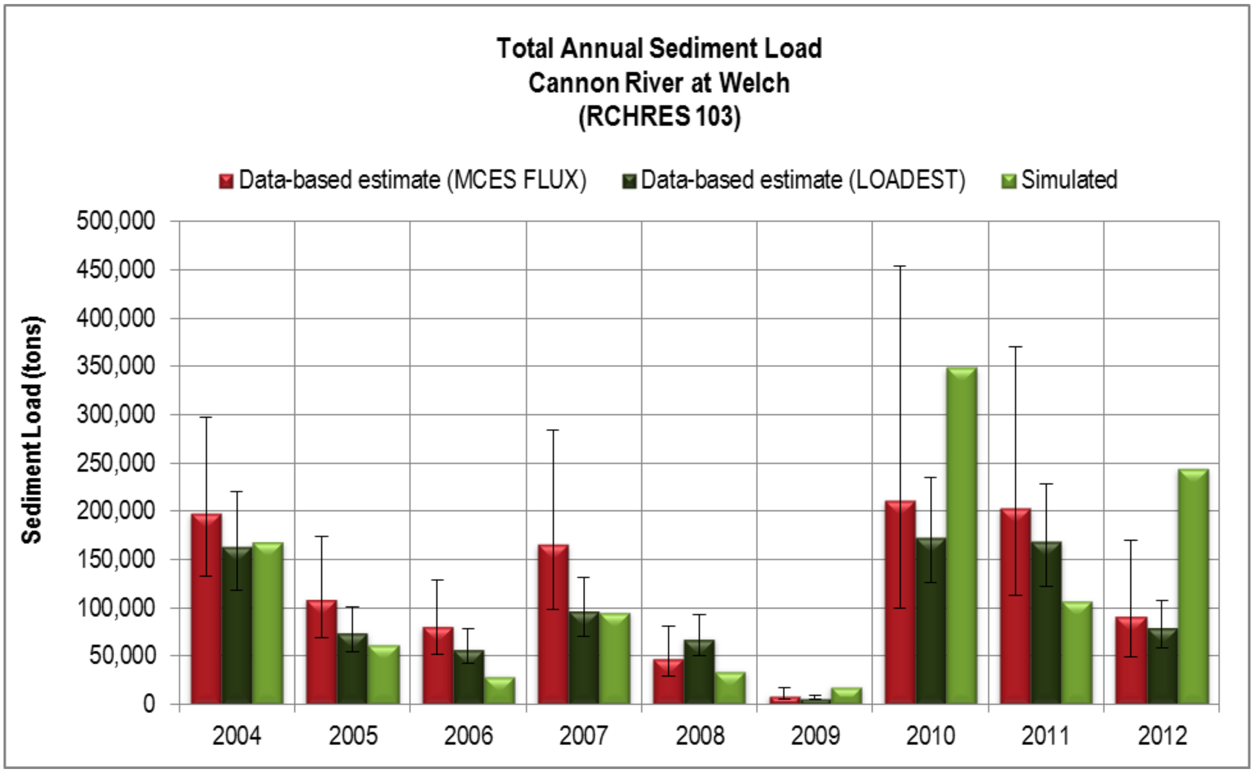

Figure 4-51. Total Annual Simulated Suspended Sediment Loads for the Cannon River at Welch Compared with Loads Estimated from the Cannon River at Welch USGS Streamflow and MCES TSS Concentrations (error bars represent the 95% confidence interval) Using LOADEST and FLUX (2004-2012).

Note: Although the plot title and y-axis label refers to “sediment”, the data-based estimates are suspended solids loads and the simulated results are suspended sediment loads.

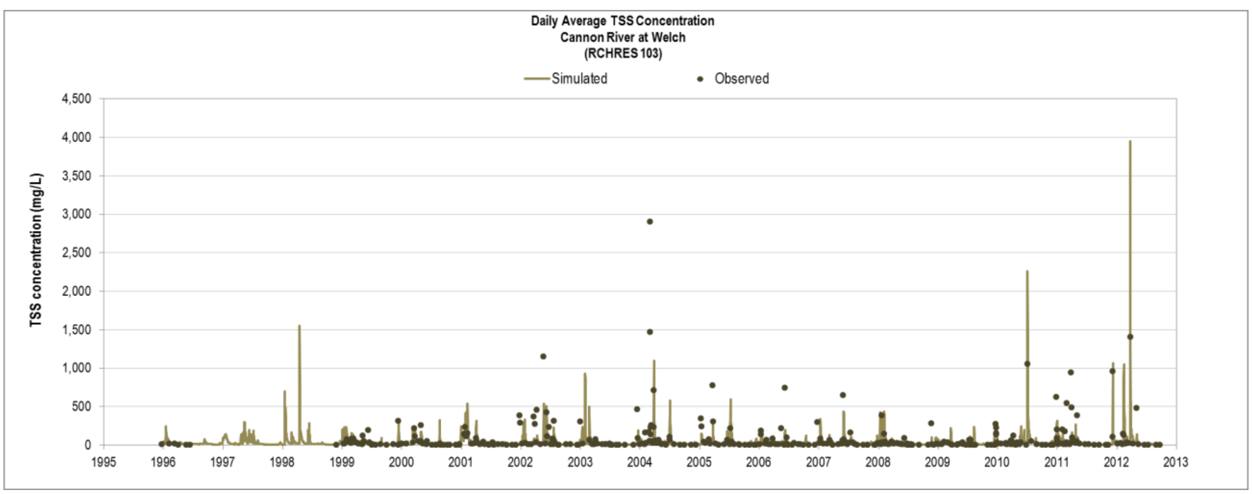

Figure 4-52. Daily Average Simulated Suspended Sediment and Measured TSS Concentrations for the Cannon River at Welch (1996-2012).

In addition to calculating statistics for model-data comparisons for TSS loading, model-data statistics were also computed based on discrete TSS concentration data. Overall, the calibration of sediment resulted in a “very good” to “fair” model performance for the calibration period (2004-2012) based on statistical comparisons of observed TSS and simulated suspended sediment concentrations (Table 4-19). Statistical comparisons for the additional calibration stations are provided in Appendix B.

Table 4-19. Cannon River Watershed HSPF Model TSS Concentration Calibration Statistics Summary (2004-2012).

Time Interval	Statistic	Cannon River at Welch[1]	
		Result	Performance Rating
Annual	Count	9	
	P-Bias	13.4%	
	Relative Percent Difference	-6.0%	Very good
Monthly	Count	105	
	P-Bias	2.1%	
	Relative Percent Difference	41.5%	Fair
Daily	Count	262	
	P-Bias	18.2%	
	Relative Percent Difference	38.3%	Fair

[1] Statistics computed using MCES and MPCA EDA TSS data collected at Welch.

4.3.8 Sediment Validation

The average annual suspended sediment load simulated at the Cannon River at Welch station was compared to annual TSS loads estimated by MCES using FLUX for the portion of the validation period (1996-2003) for which calculated loads were available (1999-2003). The simulated annual average suspended sediment load of 72,400 tons/year for the calibration period compares well to the annual average TSS load of 68,900 tons/year calculated by MCES and is within the +/-15% calibration target (58,600 – 79,200 tons/year). A comparison of the simulated annual suspended sediment loads and calculated annual TSS loads is shown in Figure 4-53. The figure also includes the annual TSS loads estimated with LOADEST using USGS streamflow data at Welch and MCES TSS concentration data. PBIAS for the validation period falls within the "very good" range (-5.0%), and the relative percent difference is "very good" (-4.8%).

Comparisons of simulated daily average suspended sediment concentrations and observed TSS concentrations from MPCA and MCES samples for the Cannon River at Welch station for the validation period were shown in Figure 4-52. The validation resulted in a "very good" to "fair" model performance for the validation period (1996-2003) based on statistical comparisons of observed suspended sediment and simulated TSS concentrations (Table 4-20). Time series plots and statistical comparisons of simulated suspended sediment and observed TSS concentrations for the additional calibration stations listed in Table 4-16 are provided in Appendix B.

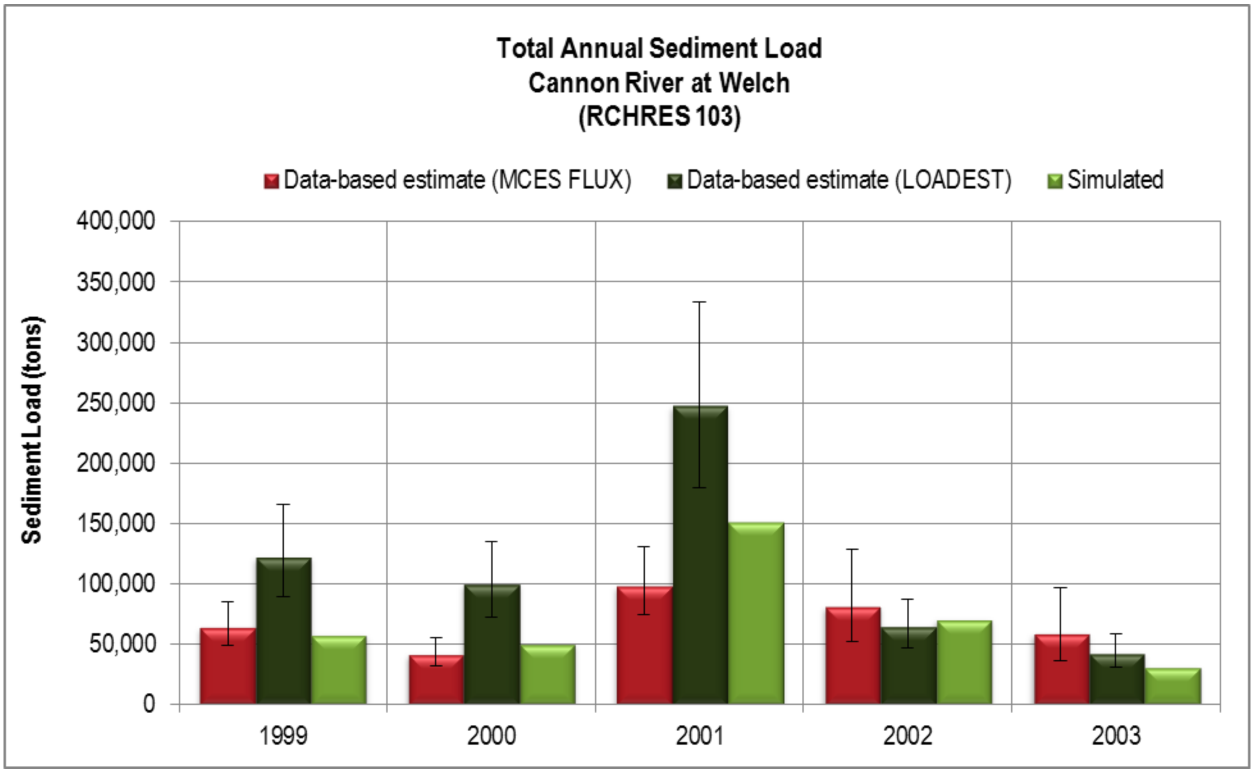

Figure 4-53. Total Annual Simulated Suspended Sediment Loads for the Cannon River at Welch Compared with Loads Estimated from the Cannon River at Welch USGS Streamflow and MCES TSS Concentrations (error bars represent the 95% confidence interval) Using LOADEST and FLUX (1999-2003).

Note: Although the plot title and y-axis label refers to "sediment", the data-based estimates are suspended solids loads and the simulated results are suspended sediment loads.

Table 4-20. Cannon River Watershed HSPF Model TSS Concentration Validation Statistics Summary (1996-2003).

Time Interval	Statistic	Cannon River at Welch[1]	
		Result	Performance Rating
Annual	Count	6	
	P-Bias	4.2%	
	Relative Percent Difference	14.0%	Very good
Monthly	Count	65	
	P-Bias	-4.1%	
	Relative Percent Difference	36.7%	Fair
Daily	Count	134	
	P-Bias	5.3	
	Relative Percent Difference	33.1%	Fair

[1] Statistics computed using MCES and MPCA EDA TSS data collected at Welch.

The Cannon River watershed HSPF model sediment calibration and validation resulted in favorable outcomes for each of the targets assessed. The “weight of evidence” approach undertaken uses several qualitative and quantitative measures to evaluate the model performance and is a valuable and often standard practice in watershed modeling (USEPA 2006a). Given the multiple lines of evidence examined, the Cannon River watershed HSPF model is able to provide a reasonable representation of sediment loading and delivery and can be used with confidence in the future to investigate the impact of potential management actions to reduce sediment loading in the watershed.

Additional TSS calibration and validation plots and statistics are provided in Appendix B. A complete set of statistics and plots have been provided as a set of electronic files with the deliverable package.

4.4 Water Temperature

Water temperature is a critical habitat characteristic for fish and other aquatic organisms. In addition, water temperature can affect the rates of other water quality processes (e.g., denitrification where nitrate is converted to atmospheric nitrogen) as well as the concentration of DO, which is highly dependent on water temperature. For the landside component of HSPF, soil temperatures can be simulated for the surface, upper, and lower/groundwater layers of a land segment, which dictates the temperature of the water transferred from the landside to a reach segment via surface and subsurface pathways. Specifically, the temperature of the surface outflow is equal to the surface layer soil temperature, the temperature of interflow is equal to the upper layer soil temperature, and the temperature of the active groundwater outflow is equal to the lower layer and groundwater layer soil temperature (Bicknell 2005). For the instream component of HSPF, the landside water temperatures in the surface flow, interflow, and groundwater flow are transferred to the reach segments where instream water temperature is simulated using an energy balance method.

Water temperature grab data were available from the EDA database for several stations and years to support HSPF model calibration and validation (Table 4-21).

Table 4-21. Water Temperature Data used to Support the Cannon River Watershed HSPF Model Temperature Calibration and Validation.

EDA Station ID	*HSPF Reach ID*	*Station Name*	*Temperature (Grab)*	
			Count of Records	*Period of Record*
S000-003	**103**	**Cannon River at Welch**	**144**	**1996-2012**
S003-557	**802**	**Straight River at Faribault**	**230**	**2004-2012**
S001-348	**402**	**Belle Creek at Vasa, MN**	**328**	**1999-2012**
S002-532	401	Belle Creek at Red Wing, MN	174	2003-2012
S001-397	245	Wolf Creek SW of Dundas	522	1999-2012
S003-016	841	Turtle Creek 3 mi S. of Owatonna	351	2000-2012
S003-009	900	Crane Creek at Medford	293	2000-2012
S003-011	835	Maple Creek at Owatonna	282	2000-2012
S000-502	825	Rush Creek near Medford	257	2000-2012
S001-785	600	Prairie Creek 4 mi W of Cannon Falls	159	2003-2012
S002-533	700	Chub Creek at Randolph	146	2003-2012
S004-512	501	Little Cannon River 3 mi SW Cannon Falls	89	2007-2012

*The stations in bold denote primary temperature calibration stations

The initial model parameterization for the water temperature simulation was based on the parameterization of other calibrated and validated Minnesota HSPF models (RESPEC 2012; Tetra Tech 2012, 2013; LimnoTech 2014d). Solar radiation and wind inputs were reviewed for reasonableness. Air temperature largely controls the daily average water temperature in shallow streams. The diurnal temperature cycle over the course of a day is affected by heat gain from incoming solar radiation and precipitation; heat gain or loss due to longwave radiation; surface conduction and convection; stream or lake conduction; and heat loss due to evaporation. The extent of tree cover or shading on the stream as well as solar radiation and cloud cover impacts these processes. The HSPF model is not able to explicitly represent or account for stream orientation and vegetative and topographic shading angles. In addition, stream shading varies over the course of the year as canopy density changes across seasons, as trees grow and mature, are cut or harvested, or fall due to senescence or extreme storm events (e.g., high rain and wind event storms or ice storms). HSPF accounts for all of these complex environmental processes through the temporally constant CFSAEX parameter, which is a correction factor for solar radiation to represent the fraction of the RCHRES surface exposed to (full) radiation. The primary calibration parameter was the instream parameter CFSAEX. This is a key parameter because it attempts to account for the large variability in the amount of solar radiation actually reaching the stream.

The model calibration and validation performance evaluation is based on the Cannon River at Welch location near the watershed outlet and the Straight River at Faribault station near the outlet of the Straight River. Because the Cannon River watershed has several coldwater streams, the model calibration and validation evaluation also included the station on Belle Creek at Vasa, which represents a coldwater stream environment. Other stations with available data were used as auxiliary calibration stations to inform the model parameterization. Overall, the calibration and validation of water temperature resulted in “very good” model performance based on statistical and visual comparison of observed and simulated water temperature (Table 4-22 and Figures 4-54 to 4-56). Additional water temperature calibration plots and statistics are provided in Appendix C. A complete set of statistics and plots have been provided as an electronic file with the deliverable package.

Table 4-22. Summary Statistics for the Water Temperature HSPF Model Calibration and Validation.

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault		Belle Creek at Vasa	
		Result	Performance Rating	Result	Performance Rating	Result	Performance Rating
Annual	Count	16		8		13	
	R-Squared	0.88		0.96		0.52	
	Nash-Sutcliffe Efficiency	0.80		0.87		-2.79	
	Relative Percent Difference	-2.1%	Very good	-1.3%	Very good	-8.6%	Good
	Relative Percent Error	-1.9%	Very good	-1.2%	Very good	-8.2%	Good
Monthly	Count	84		72		91	
	R-Squared	0.94		0.94		0.80	
	Nash-Sutcliffe Efficiency	0.93		0.93		0.37	
	P-Bias	1.36		1.79		8.82	
	Relative Percent Difference	-1.7%	Very good	-1.6%	Very good	-10.0%	Good
	Relative Percent Error	-1.5%	Very good	-1.4%	Very good	-9.2%	Good
Daily	Count	142		230		328	
	R-Squared	0.91		0.86		0.71	
	Nash-Sutcliffe Efficiency	0.90		0.86		0.32	
	Relative Percent Difference	-1.3%	Very good	-0.2%	Very good	-8.5%	Good
	Relative Percent Error	-1.1%	Very good	0.3%	Very good	-7.6%	Very good

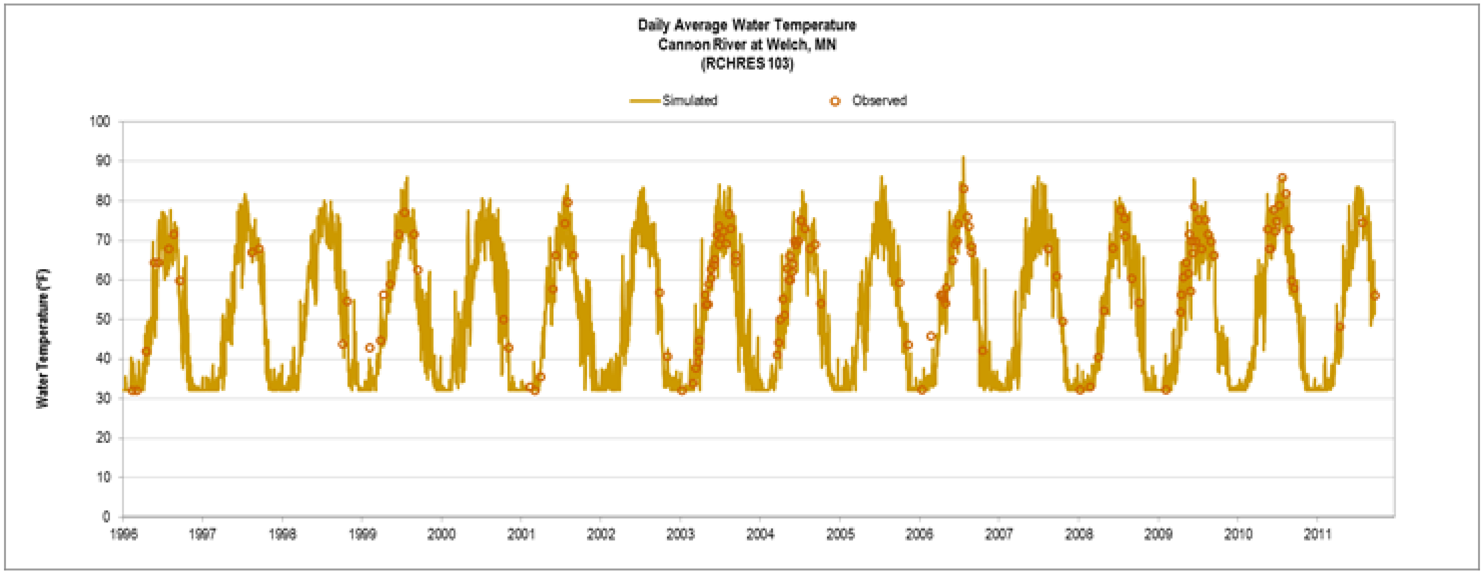

Figure 4-54. Daily Average Water Temperatures for Cannon River at Welch (RCHRES 103).

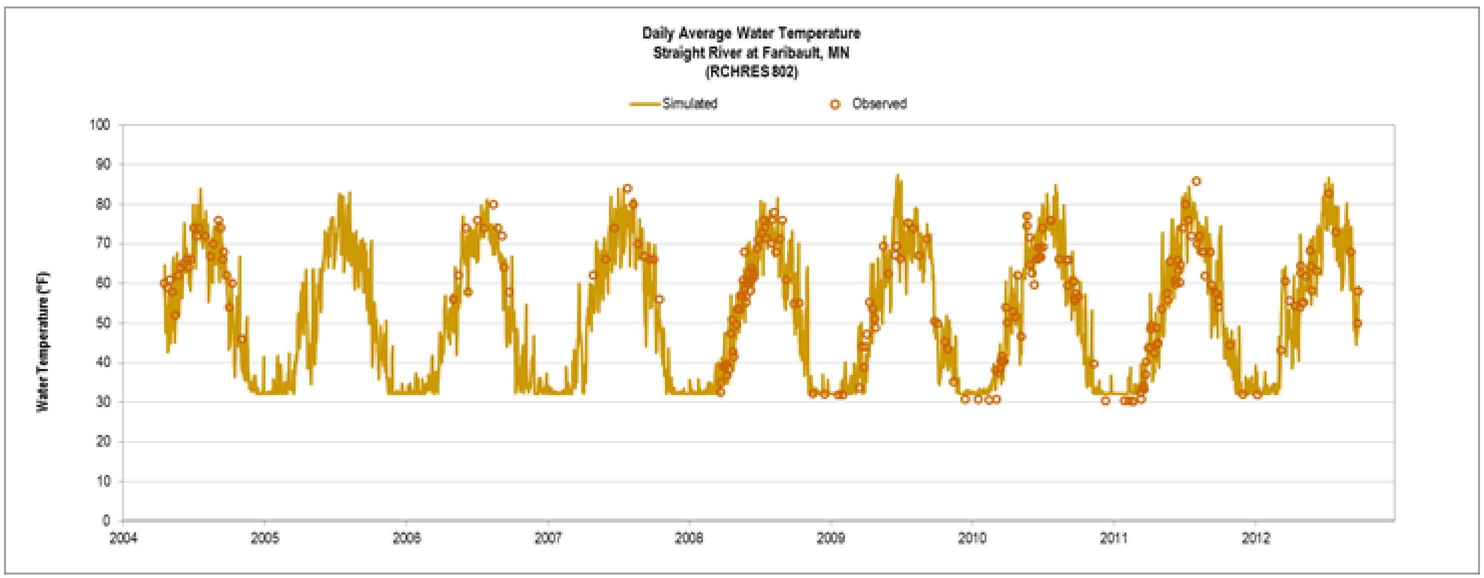

Figure 4-55. Daily Average Water Temperatures for Straight River at Faribault (RCHRES 802).

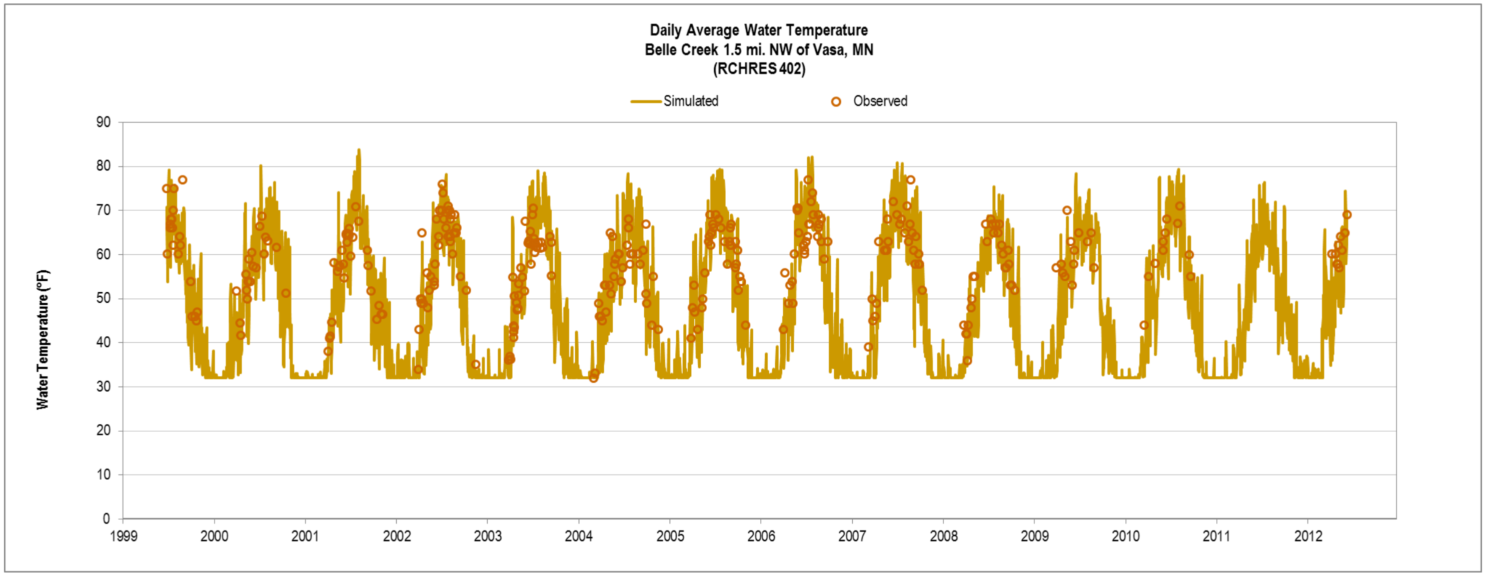

Figure 4-56. Daily Average Water Temperatures for Belle Creek at Vasa (RCHRES 402).

4.5 Nutrients

The general quality constituent approach was taken to simulate nutrient loading from the landside of the Cannon River watershed via the PQUAL and IQUAL modules. The PQUAL (for pervious land areas) and IQUAL (for impervious land areas) modules simulate water quality constituents in the outflows using simple relationships with water and/or sediment yield (Bicknell et al. 2005). Any constituent can be simulated by this module section where the user supplies the name, units and parameter values appropriate to each of the constituents that are needed in the simulation (Bicknell et al. 2005). The general quality constituents represented in the Cannon River watershed HSPF model for nutrients include the following:

- Ammonia (PQUAL/IQUAL = 1);
- Nitrate plus Nitrite (PQUAL/IQUAL = 2);
- Orthophosphate (PQUAL/IQUAL = 3); and
- BOD, which includes organic nitrogen and phosphorus fractions (PQUAL/IQUAL = 4).

The landside transport pathways for the nutrients include surface runoff, interflow (shallow, subsurface lateral flow), and groundwater for pervious land areas, as well as surface runoff for impervious land areas. Surface buildup/washoff loading is considered from both pervious and impervious surfaces. For pervious surfaces, the user specifies concentration values, which may vary monthly for interflow and groundwater.

Each of the simulated general quality constituents is then partitioned or divided, if needed, during the transfer of loads from the landside to the reach segment. The partitioning of nutrients represented in the Cannon River watershed HSPF model is described below:

- Ammonia is transferred to the reach as dissolved ammonia.
- Nitrate plus nitrite is transferred to the reach as dissolved nitrate.
- Orthophosphate is divided into various fractions and is transferred to the reach as dissolved orthophosphate and particulate orthophosphate adsorbed to silt and clay.
- BOD as organic matter (biomass) is divided into various fractions and is transferred to the reach as organic refractory nitrogen (ORN), organic refractory phosphorus (ORP), organic refractory carbon (ORC), and as BOD. In HSPF, the labile organic forms of nutrients are grouped together and added to the state variable BOD. The labile nitrogen, phosphorus, and carbon portions of BOD are calculated from the stoichiometric relationship used in HSPF. Separate state variables are used for the refractory forms of nutrients (i.e., ORN, ORP, ORC).

The model represents individual nutrient species (i.e., orthophosphate, organic phosphorus, ammonia, nitrate, nitrite, and organic nitrogen) within the reach segments. The RCHRES module in the Cannon River watershed HSPF model is implemented with the full nutrient simulation, which includes the uptake and release of nutrients by phytoplankton and benthic algae, decay of organic matter, oxidation of ammonium to nitrite and nitrite to nitrate nitrogen, and bed exchanges of dissolved and sorbed nutrients. Inorganic, labile, and organic refractory components of nitrogen and phosphorus are summed for total nitrogen (TN) and total phosphorus (TP).

The objectives of the nutrient model calibration and validation were to achieve reasonable watershed UALs for nutrients for each land segment category and to achieve a reasonable simulation of instream concentrations for TP and TN as well individual nutrient species (i.e., orthophosphate, nitrate, and ammonia). The model calibration and validation of nutrients followed the approach outlined in the MPCA modeling guidance document and is summarized below (AQUA TERRA Consultants 2012):

(a) Estimate all model parameters, including land use specific accumulation and depletion/removal rates, washoff rates, and subsurface concentrations.

(b) Tabulate, analyze, and compare simulated nonpoint source loadings from each land segment category with the expected ranges presented in the literature, if available. The nonpoint loading rates, sometimes referred to as 'export coefficients', are highly variable, with value ranges sometimes up to an order of magnitude, depending on local and site conditions of soils, slopes, topography, climate, etc.

(c) Compare simulated and observed instream concentrations at each of the calibration stations.

(d) Analyze the results of comparisons in steps 2 and 3 to determine appropriate nonpoint parameter adjustments and/or instream parameter adjustments. The objective of the nutrient calibration is to obtain acceptable agreement of observed and simulated concentrations (i.e., within defined criteria or targets) while maintaining the nonpoint loading rates within the expected ranges from the literature and instream water quality parameters within physically realistic bounds.

Nutrient loading, instream nutrient cycling, phytoplankton growth, death, and decay, and BOD and DO processes are highly interdependent. A change in watershed loading and/or instream parameterization to one nutrient species may have a significant impact on another individual nutrient species. Specifically, in regard to phytoplankton and benthic algae, nutrients contained in algal tissue are accounted for in the nutrient mass balance when death or settling occurs. The nutrients are added to the organic refractory state variables (ORN, ORP, and ORC), or are made available as inorganic nutrients based on user-specified variables. Therefore, the calibration and validation of nutrients were carried out simultaneously with the simulation and calibration (where appropriate) of BOD, DO, phytoplankton and benthic algae.

The evaluation of nutrient simulations presents a number of challenges because, unlike streamflow and water temperature, nutrients are generally not monitored on a continuous basis. Nutrient data are usually based on grab samples at a point in space and time, and individual observations may not be representative of average conditions in a model reach segment on a given day due to spatial and/or temporal uncertainty. In terms of spatial uncertainty, a point in space may not be representative of average conditions across an entire model reach. In terms of temporal uncertainty, an instantaneous measurement likely deviates from the daily average, especially during storm events. Additional uncertainty in nutrient data is also introduced if constituent concentrations are at or below the minimum detection limit or near reporting levels. Finally, accurate information on the daily variability in point source loads is rarely available for all nutrient species and for all point source discharges. Often, these inputs are based on assumptions given limited data and information. In addition, the model itself is limited in its ability to simulate water quality conditions, particularly in eutrophic lakes. Observed vertical gradients in water quality (e.g. phosphorus, DO) cannot be reproduced in HSPF because each RCHRES, including those simulated as lakes, are represented as a single, well-mixed segment. The HSPF model is also limited in fully simulating water quality because it does not mechanistically simulate conditions in the sediment, including sediment release of phosphorus, which can be a very important source in deep, eutrophic lakes like many of the lakes in the upper Cannon River watershed.

4.5.1 Phosphorus

Orthophosphate and BOD (as organic matter) are simulated using the sediment potency method for pervious surfaces and using the build-up/washoff method for impervious surfaces. The sediment potency method transports orthophosphate and BOD as sediment-associated constituents. The surface loading of orthophosphate and BOD is determined by a potency factor applied to the sediment load, which varies on a monthly basis to reflect changes in surface soil concentration associated with the annual plant and crop growth cycle. User-specified concentrations are provided for the subsurface flow pathways (interflow and groundwater) and also vary on a monthly basis. The buildup/washoff method implemented for orthophosphate and BOD uses the basic accumulation and depletion rates together with transport by washoff where surface transport is a function of the surface runoff and orthophosphate and BOD mass storage on the land (Bicknell et al. 2005).

As noted above, the approach to model calibration involved an iterative process of

- Adjusting watershed loads (UALs) until the simulated loads fell within reasonable limits of reported literature ranges and other Minnesota HSPF models (Tetra Tech 2009, LimnoTech 2014d);
- Adjusting various instream parameters within reported literature ranges; and then,
    - Comparing simulation results to instream orthophosphate and TP concentration data;
    - Comparing annual simulated TP loads to data-based estimates at
        1. Cannon River at Welch (near the watershed outlet);
        2. Straight River at Faribault (near the Straight River outlet); and,
        3. Cannon River near Northfield (closest location upstream of Lake Byllesby).

Target TP loads were estimated near the watershed outlet (Cannon River at Welch) using LOADEST (Runkel et al. 2004, Runkel 2013) based on the available streamflow (via USGS) and TP concentration data from MPCA's EDA database and from MCES, which also monitors conditions at this location. TP loads for the Cannon River at Welch were also estimated by MCES using FLUX32, a USACE model (MCES 2014). Finally, target TP loads were estimated near the Straight River outlet (Straight River at Faribault) and the Cannon River near Northfield, which is the closest location upstream of Lake Byllesby, using LOADEST based on available streamflow (USGS/HYDSTRA) and TP concentration data from MPCA's EDA database. LOADEST uses specialized regression techniques to merge continuous streamflow measurements with discrete concentration measurements to generate estimates of annual loads. These calculated loads were compared with loads generated by the Cannon River watershed HSPF model at these locations (i.e., Cannon River at Welch, Straight River at Faribault, Cannon River at Northfield).

The model calibration was performed to ensure that the model reasonably reproduced concentrations and loads at the calibration locations at annual and monthly time scales as well as the timing, magnitude, and range of observed instream orthophosphate and TP concentrations at daily time scales. TP data from 2012 analyzed using Method 4500-P-I were excluded from the comparison because a potential bias in the data was suspected (MPCA 2014e). Water quality station locations that were used to support the model phosphorus parameterization, calibration and validation are summarized in Table 4-23.

Table 4-23. TP and PO4 Concentration Data for the Cannon River Watershed HSPF Model Calibration.

Station Name	EDA Station ID[1]	HSPF Reach ID	TP		PO4		Notes
			Count of Records	Period of Record	Count of Records	Period of Record	
Cannon River at Welch	**S000-003**	**103**	**121**	**1996-2012**	**40**	**2002-2012**	**MPCA EDA records**
	-	**103**	**315**	**1999-2012**	**0**	**-**	**MCES data[2]**
Straight River at Faribault	**S003-557**	**802**	**176**	**2002-2012**	**193**	**2002-2012**	
Cannon River at Canada Ave., near Northfield	**S001-582**	**203**	**96**	**2001-2010**	**61**	**2001-2012**	
Little Cannon River near Cannon Falls	S004-512	501	100	2007-2012	88	2007-2012	
Crane Creek near Medford	S003-009	900	136	1999-2012	193	2000-2011	
Straight River at Clinton Falls	S000-047	806	162	1998-2012	193	2000-2011	
Maple Creek at Owatonna	S003-011	835	118	1999-2012	194	2000-2011	
Straight River at Owatonna	S003-015	809	117	2000-2012	193	2000-2011	
Turtle Creek 3 mi SE of Owatonna	S003-016	841	116	2000-2012	192	2000-2011	
Lake Byllesby	19-0006-00-xxx	201	145	1995-2011	21	2002-2006	Includes data for three locations: 19-0006-00-201, 19-0006-00-202, and 19-0006-00-203
Lake Volney	40-0033-00-101	376	120	1999-2010	54	2009-2010	
East Jefferson Lake	40-0092-01-xxx	366	111	1999-2010	45	2009-2010	Includes data for four locations: 40-0092-01-101, 40-0092-01-201, 40-0092-01-202, 40-0092-01-203
German Lake	40-0063-00-202	365	110	1999-2010	46	2009-2010	

Station Name	EDA Station ID[1]	HSPF Reach ID	TP		PO4		Notes
			Count of Records	Period of Record	Count of Records	Period of Record	
Gorman Lake	40-0063-00-203	312	39	2007-2011	0		
Chub Lake	19-0020-00-401	703	37	1995-2011	0		

[1] The Station ID and corresponding TSS concentration information (counts and period of record) are based on a query of MPCA's EDA database.

[2] The MCES data were provided in spreadsheet format via personal communication with Terrie O'Dea (MCES)

The initial model parameterization for orthophosphate and BOD was based on the parameterization of other calibrated and validated Minnesota HSPF models (RESPEC 2012; Tetra Tech 2012, 2013; LimnoTech 2014d). For pervious land segments, the washoff potency factor (POTFW), the scour potency factor (POTFS), and the interflow concentrations were adjusted to improve the simulation of loading during storm events. The groundwater concentrations were adjusted to improve the simulation of orthophosphate during low flows. For impervious segments, parameter adjustments were made to the rate of accumulation on the surface (ACQOP) and the maximum storage on the surface (SQOLIM).

Once the landside UALs were within reasonable ranges compared to the available literature and other Minnesota HSPF models (Tetra Tech 2009, LimnoTech 2014d), the instream concentrations were reviewed to evaluate predicted concentrations during low flows and storm events. The instream simulation was refined through the adjustment of organic matter settling rates, bottom sediment concentrations of phosphorus and ammonium (due to interdependence with nitrogen via algal interactions), and the growth and death of phytoplankton and benthic algae. Internal lake loading of phosphorus and ammonium under anoxic conditions has been identified as a key source of internal phosphorus loads in Minnesota lakes (RESPEC 2012a, RESPEC 2012b), and the site-specific TP data indicate that this process occurs in many of the lakes in the Cannon River watershed. Bottom sediment release of orthophosphate and ammonium was implemented in the model as a temporally variable flux using the special actions module in HSPF in order to represent internal loading processes.

Once a best possible calibration was achieved, the final TP UALs were calculated for each land segment category (Figure 4-57), and a final comparison was performed against the available literature values as well as the UALs predicted by the Minnesota River HSPF model (Table 4-24) (Tetra Tech 2009). The TP UALs generated by the Cannon River watershed HSPF model are consistent with the available literature and, more importantly, the Minnesota River HSPF model (which is considered to be representative of regional UALs).

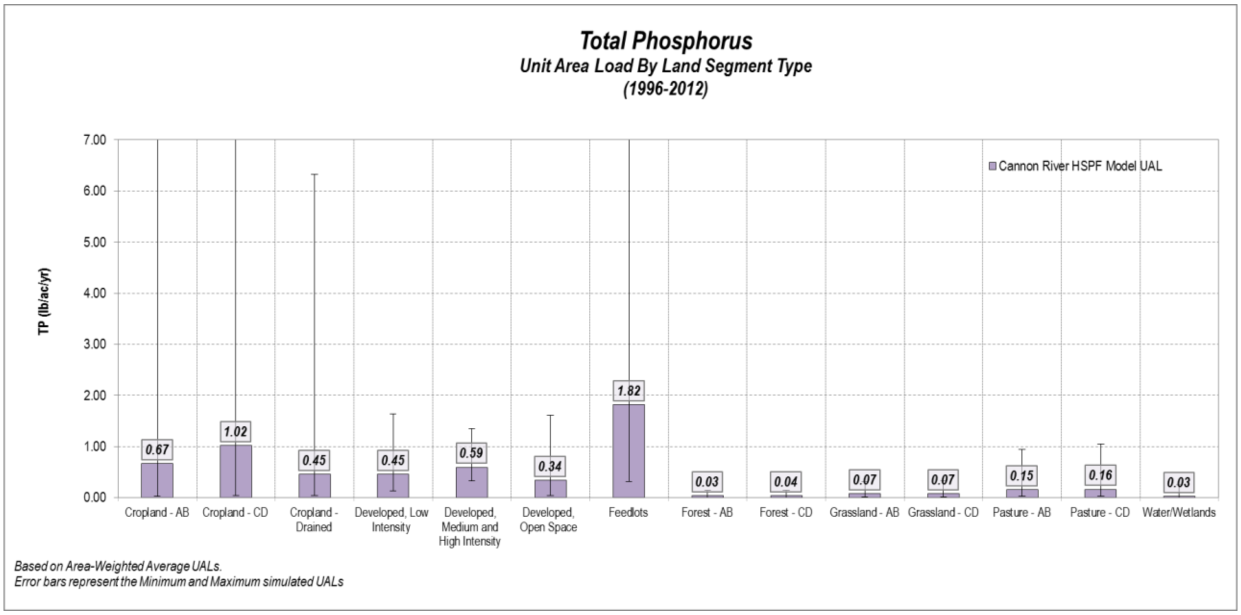

Figure 4-57. Total Phosphorus Unit Area Loads by Land Segment Type for the 1996-2012 Simulation Period.

Table 4-24. Total Phosphorus Loading Rates (lbs/ac/yr) Generated by the Minnesota River Basin Model for 1993-2006 (from Tetra Tech 2009, on page 6-25, Table 6-11).

Basin	Conservation Tillage	Conventional Tillage	Forest	Manured Cropland	Marsh	Pasture	Urban
Blue Earth	0.528	0.817	0.091	2.206	0.022	0.213	0.555
Chippewa	0.292	0.329	0.022	0.733	0.014	0.065	0.354
Cottonwood	0.312	0.366	0.033	0.900	0.024	0.100	0.386
Hawk	0.207	0.249	0.031	0.549	0.019	0.075	0.497
Le Sueur	0.778	0.879	0.188	2.284	0.032	0.276	0.662
Lower MN	0.577	0.678	0.066	1.794	0.029	0.141	0.582
Middle MN	0.328	0.396	0.044	0.987	0.025	0.097	0.529
Redwood	0.271	0.293	0.045	0.772	0.023	0.110	0.450
Watonwan	0.301	0.358	0.043	0.989	0.016	0.086	0.369
Yellow Medicine	0.196	0.225	0.038	0.487	0.016	0.087	0.327

Due to limited data available within the validation period (1996-2003), annual TP loads were evaluated for the full simulation period for the Straight River at Faribault station during the validation period. The average annual TP load simulated at the Cannon River at Welch was 539,000 lbs/year for the period comprising the available data (1999-2012), which compares well to the average annual TP load calibration target of 566,000 lbs/year estimated by LimnoTech using LOADEST and by MCES using FLUX. The average annual TP load is within the 481,000 – 651,000 lbs/year calibration target (i.e., based on a tolerance of +/- 15%). A comparison of the simulated annual TP loads and the annual TP loads calculated for the Cannon River at Welch using the LOADEST and FLUX models is shown in Figure 4-58.

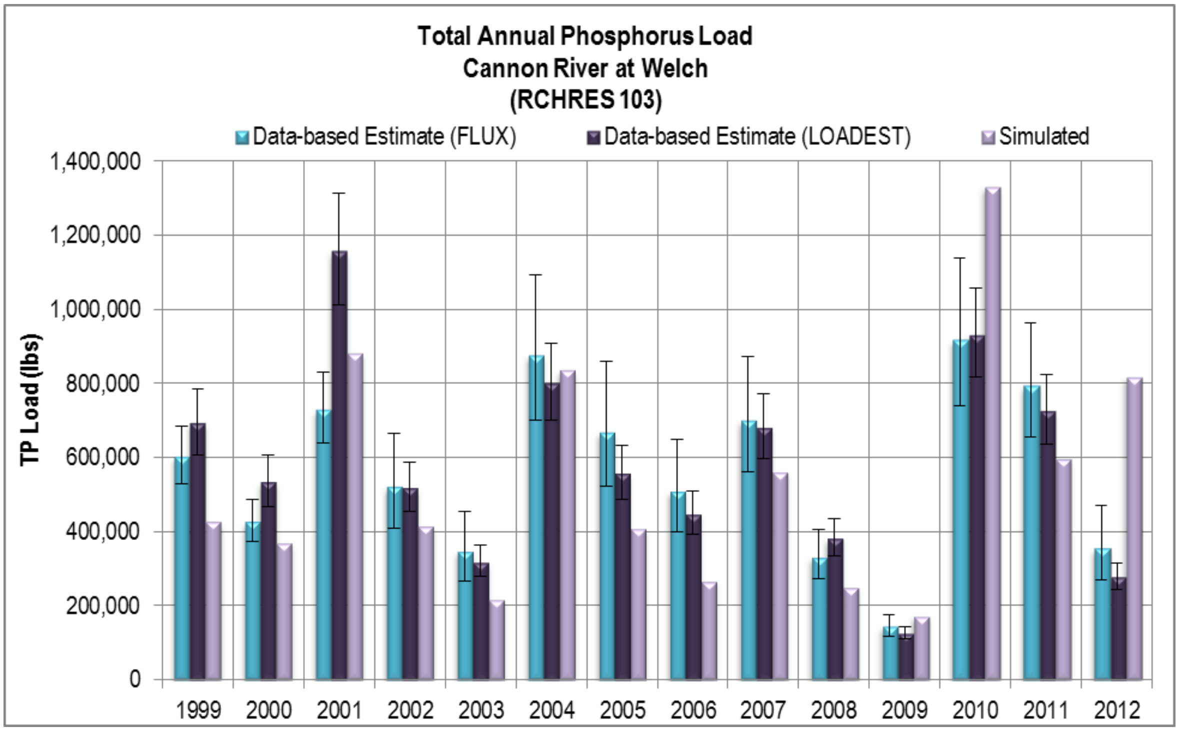

Figure 4-58. Annual Total Phosphorus Load for Cannon River at Welch (RCHRES 103).

The variability in the calculated LOADEST and FLUX TP load results for each year reflects differences in each model's regression algorithms. However, taken together, they provide a reasonable range of results for comparison to the model-simulated TP load. In most years, the simulated TP load compares favorably to the calculated loads. TP concentration data for high flow conditions were generally lacking, which tends to result in greater uncertainty in the regression model estimates for years where a significant fraction of the TP load occurred during high flow periods. These uncertainties must be kept in mind when comparing the loads in Figure 4-58, especially for the years where significant loading occurred during higher flow periods, such as 2010 and 2012, which show a larger difference between "data-based estimates" and "simulated" loads. HSPF is also representing the seasonal and monthly TP loads reasonably well compared to LOADEST and FLUX estimates for the Cannon River at Welch, as shown in Figure 4-59.

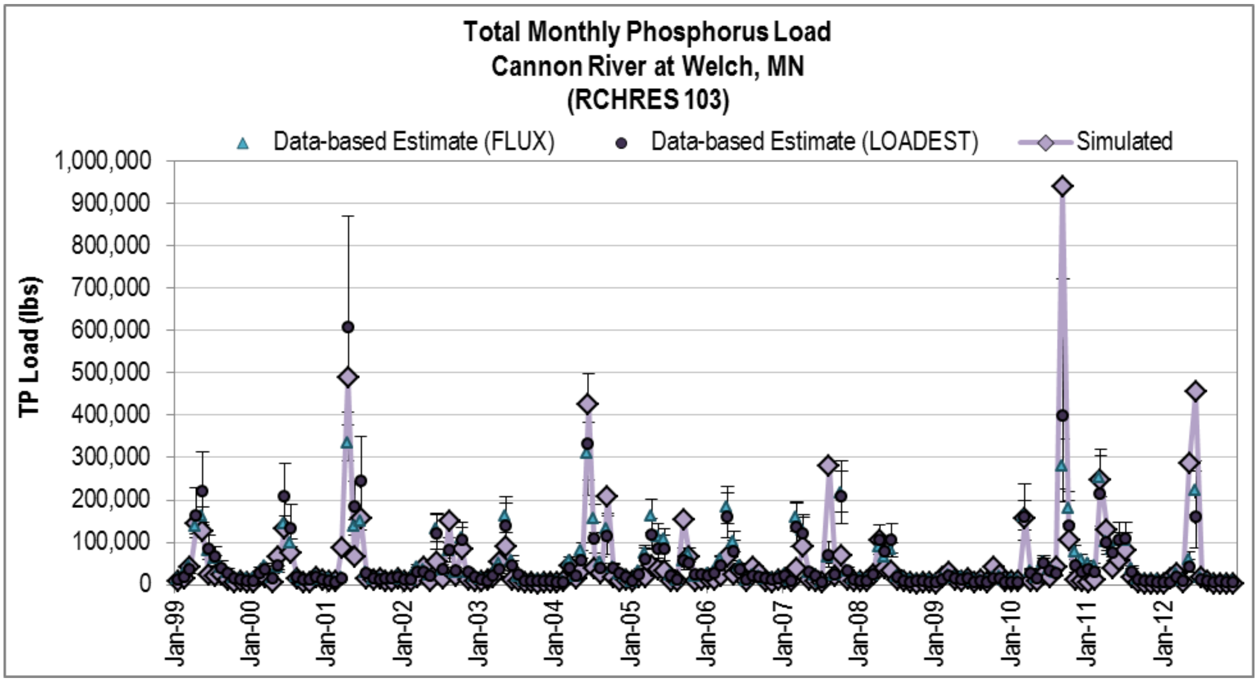

Figure 4-59. Monthly Total Phosphorus Load for Cannon River at Welch (RCHRES 103).

The simulated annual average TP loads at upstream locations in the watershed ranged from “good” to “very good” based on comparisons to the annual average TP loads calculated with LOADEST. Table 4-25 presents a comparison of the LOADEST and HSPF-simulated annual average loads. A comparison of the simulated annual TP loads and the annual TP loads calculated for the Straight River at Faribault and the Cannon River at Northfield using the LOADEST model are shown in Figure 4-60 and Figure 4-61, respectively. A comparison of the monthly TP loads are shown in Figure 4-62 and Figure 4-63 for the Straight River at Faribault and the Cannon River at Northfield, respectively. Additional full period TP load comparisons are included in Appendix D.

Table 4-25. Comparison of Calculated and Simulated Average Annual TP Loads at Locations in the Cannon River Watershed.

Location (EDA Station ID)	Period	Average Annual Phosphorus Load (lbs/year)		Relative Percent Difference
		LOADEST-calculated	HSPF Simulated	
Cannon River at Welch (S000-003)	1999-2012	565,900	539,000	-4.8%
Cannon River at Northfield (S001-582)	2001-2010	408,380	391,940	-4.0%
Straight River at Faribault (S003-557)	2006-2012[a]	188,395	224,200	18.7%

[a] There was only one TP measurement between 2002-2005 in the Straight River at Faribault, which is an insufficient amount of data for that period in developing the LOADEST regression; therefore, the annual loads were calculated and compared for the period shown.

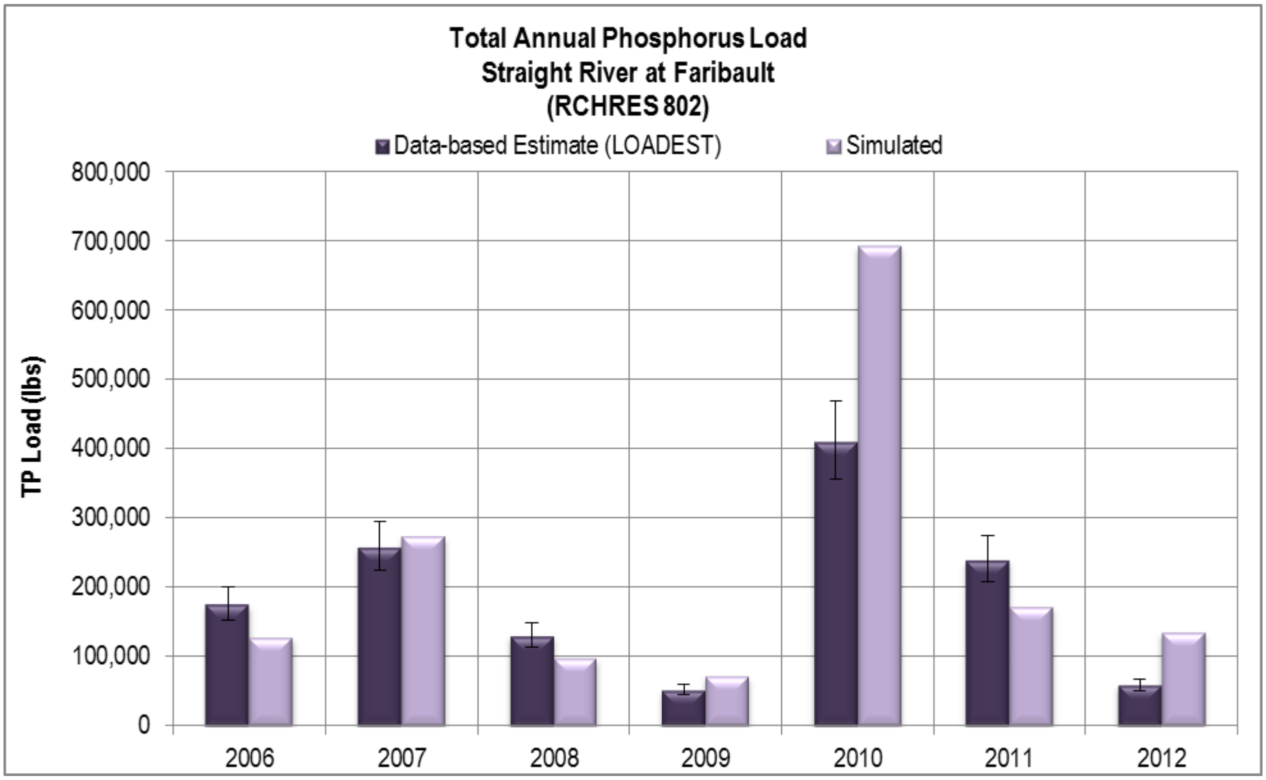

Figure 4-60. Annual Total Phosphorus Load for Straight River at Faribault (RCHRES 802).

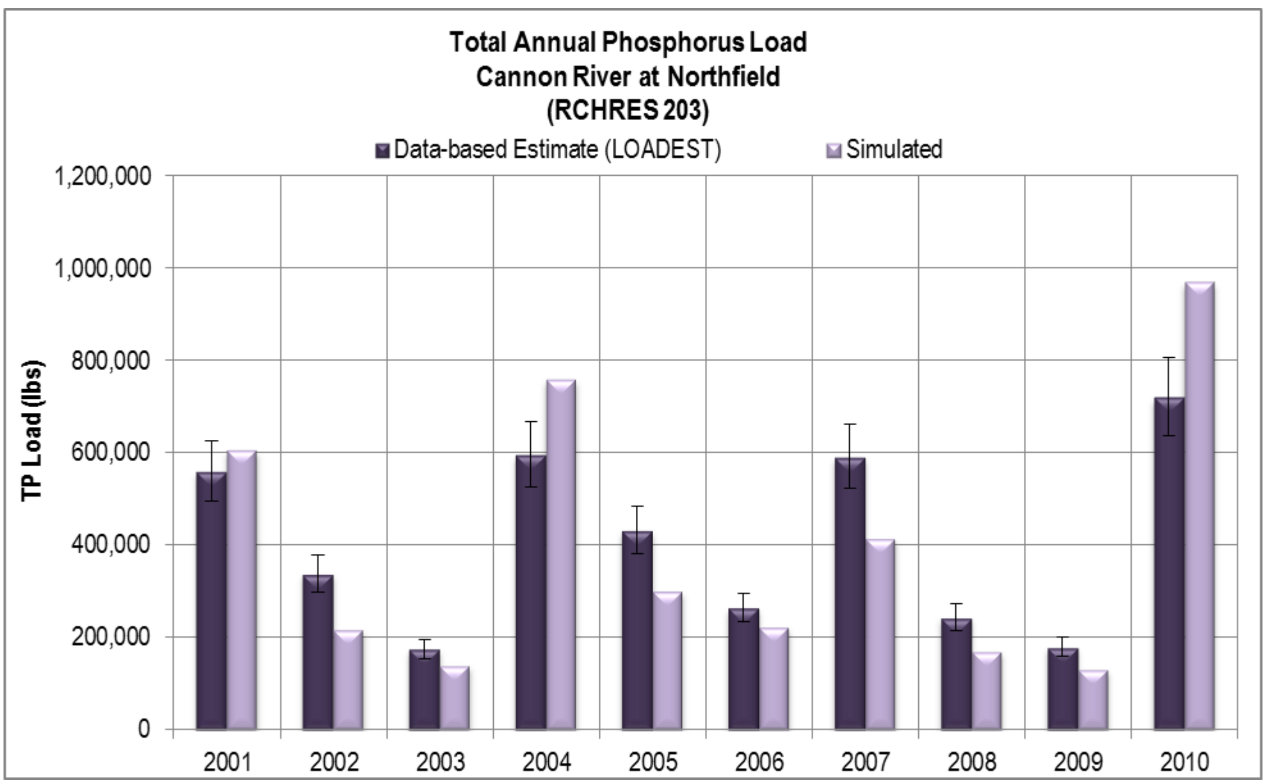

Figure 4-61. Annual Total Phosphorus Load for Cannon River at Northfield (RCHRES 203).

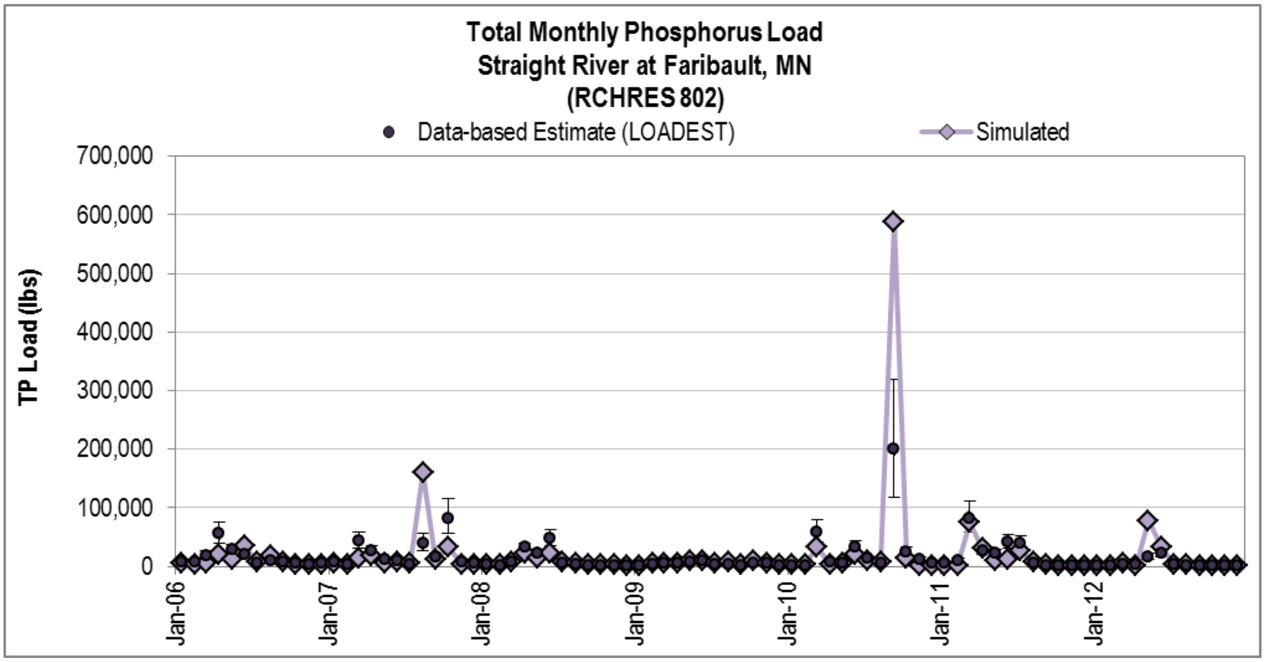

Figure 4-62. Monthly Total Phosphorus Load for Straight River at Faribault (RCHRES 802).

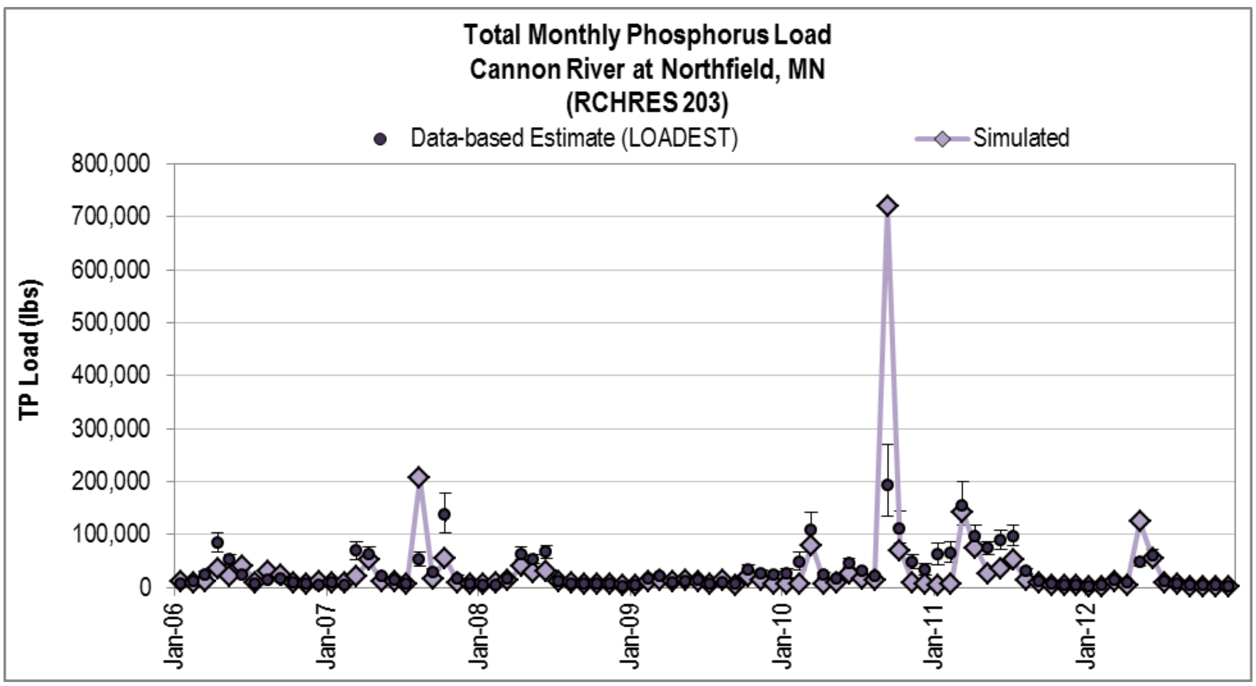

Figure 4-63. Monthly Total Phosphorus Load for Cannon River at Northfield (RCHRES 203).

In general, the calibration for TP ranges from “good” to “very good” based on statistical and visual comparisons of observed and simulated TP concentrations (Table 4-26 and Figures 4-64 through 4-66) and loads (Figures 4-58 through 4-63) at the three calibration locations. The validation for TP ranges from “good” to “fair” based on statistical and visual comparisons of observed and simulation TP concentrations and loads (Table 4-27 and Figures 4-64 through 4-66). Limited data were available at the

Straight River at Faribault station during the validation period so this location was not considered in the model validation.

Table 4-26. Summary Statistics for the Cannon River Watershed HSPF Model Total Phosphorus Concentration Calibration (2004-2012)

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault		Cannon River at Northfield	
		Result	Performance Rating	Result	Performance Rating	Result	Performance Rating
Annual	Count	9		7		4	
	PBIAS	7.00		-11.25		10.22	
	Relative Percent Difference	-5.8%	Very good	9.8%	Very good	-11.0%	Very good
Monthly	Count	105		56		22	
	PBIAS	7.04		-13.77		6.26	
	Relative Percent Difference	3.7%	Very good	6.8%	Very good	-14.1%	Very good
Daily	Count	305		175		48	
	PBIAS	5.52		-13.76		8.38	
	Relative Percent Difference	4.5%	Very good	5.1%	Very good	-17.6%	Good

Table 4-27. Summary Statistics for the Cannon River Watershed HSPF Model Total Phosphorus Concentration Validation (1996-2003)

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault		Cannon River at Northfield	
		Result	Performance Rating	Result	Performance Rating	Result	Performance Rating
Annual	Count	7				3	
	PBIAS	8.49				12.41	
	Relative Percent Difference	-6.2%	Very good			-13.4%	Very good
Monthly	Count	66				23	
	PBIAS	4.62				8.89	
	Relative Percent Difference	0.1%	Very good			-10.9%	Very good
Daily	Count	129				48	
	PBIAS	9.44				14.64	
	Relative Percent Difference	-1.3%	Very good			-12.5%	Very good

[1] There was only one TP measurement between 1999-2003 in the Straight River at Faribault so statistics for the validation period were not computed.

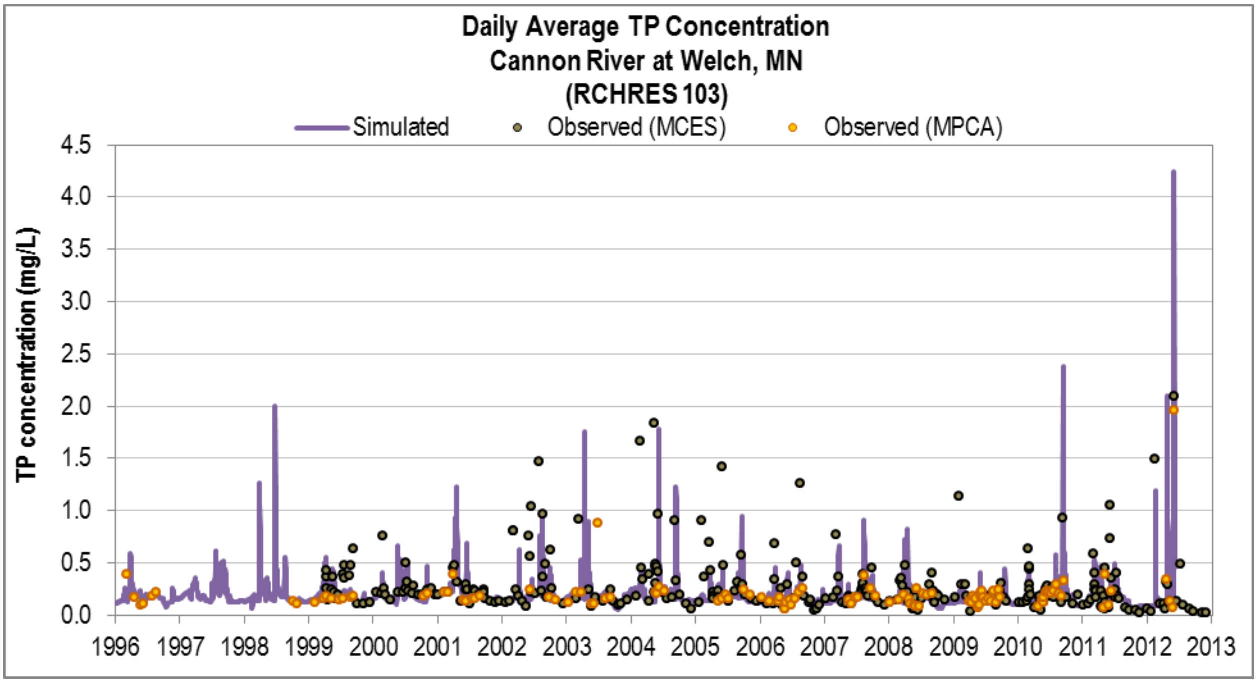

Figure 4-64. Daily Average Total Phosphorus Concentrations for Cannon River at Welch (RCHRES 103).

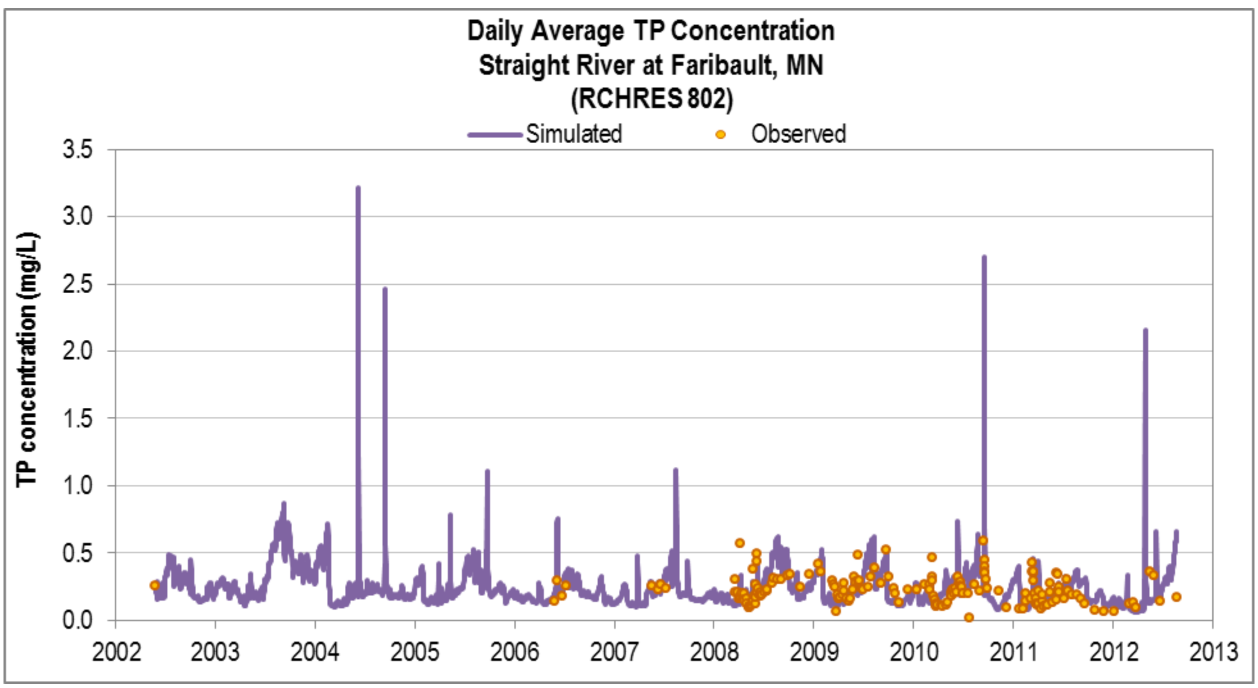

Figure 4-65. Daily Average Total Phosphorus Concentrations for Straight River at Faribault (RCHRES 802).

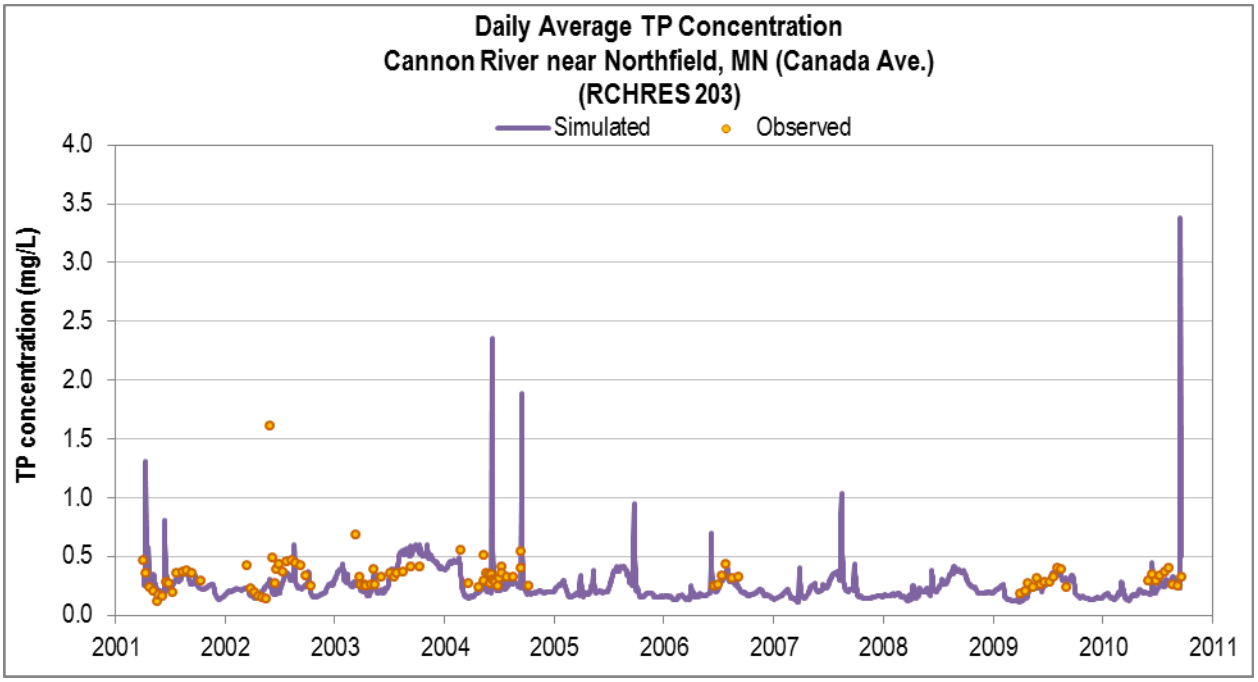

Figure 4-66. Daily Average Total Phosphorus Concentrations for Cannon River at Northfield (RCHRES 203).

Data were limited to evaluate statistics for orthophosphate in the Cannon River mainstem, with only the Cannon River at Welch station having data for a sufficient number of years in the calibration period. None of the Cannon River locations had sufficient orthophosphate data for the validation period. The data record for orthophosphate in the Straight River is more extensive during the model calibration period but it is very limited (<20 samples) for the model validation period. The orthophosphate calibration at the Straight River at Faribault is “very good” based on the statistical comparisons of observed and simulated concentrations (Table 4-28) and visual comparison of observed and simulated orthophosphate concentrations (Figure 4-67). Time series plots and statistics for the additional calibration stations are shown in Appendix D.

Table 4-28. Summary Statistics for the Cannon River Watershed HSPF Model Orthophosphate Concentration Calibration (2004-2012)

Time Interval	Statistic	Cannon River at Welch	Straight River at Faribault
Annual	Count	9	7
	PBIAS	-19.61	-10.25
	Relative Percent Difference	6.4%	11.1%
Monthly	Count	23	59
	PBIAS	-24.40	-9.11
	Relative Percent Difference	-4.1%	10.0%
Daily	Count	39	192
	PBIAS	-21.10	-5.66
	Relative Percent Difference	-16.2%	7.0%

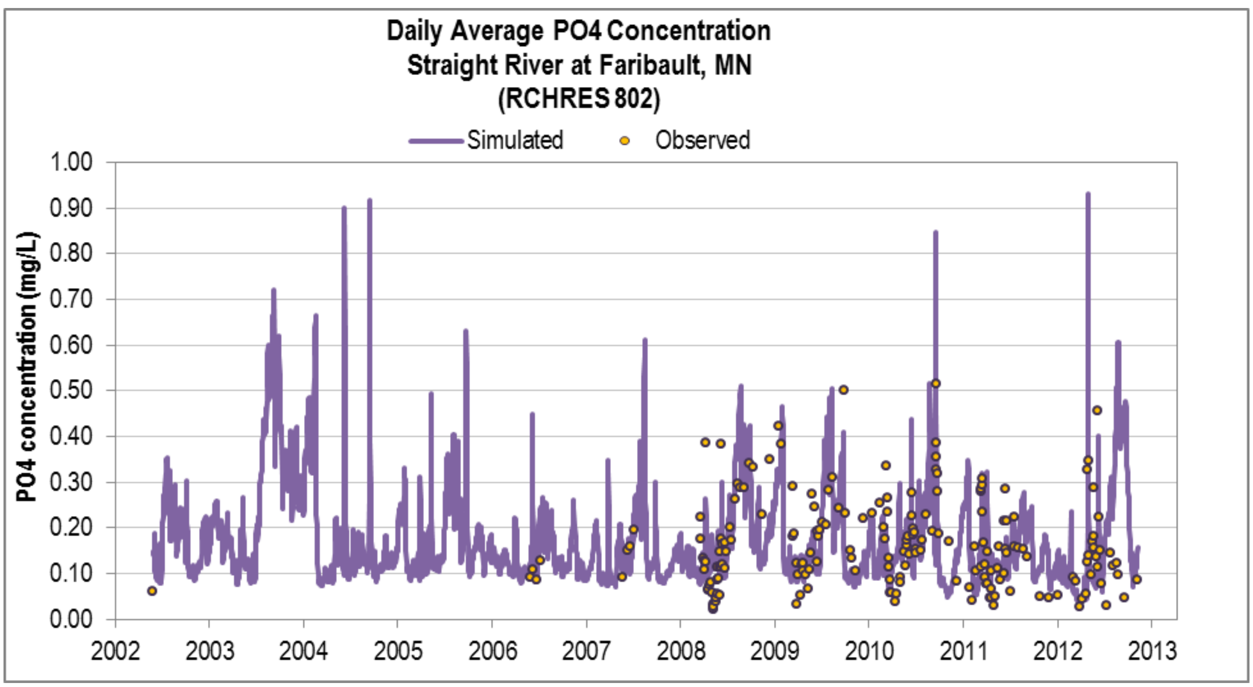

Figure 4-67. Daily Average Orthophosphate Concentrations for Straight River at Faribault (RCHRES 802).

Using the “weight of evidence” evaluation approach, the model calibration and validation indicates that the Cannon River watershed HSPF model is able to simulate TP and orthophosphate with an acceptable level of accuracy for the mainstem Cannon River, Straight River, and tributaries throughout the watershed; however, model predictions of TP and orthophosphate concentrations within the lakes throughout the watershed have a greater amount of uncertainty. A seasonal increase in TP and orthophosphate concentrations from approximately May to October, followed by a significant decline over the winter, was observed in data for several relatively deep lakes.

The HSPF model is limited in several ways that prevent it from properly representing the lake processes that result in these observations. HSPF does not mechanistically model conditions in the sediment, including release of orthophosphate and ammonium; it only allows temporally-constant release rates under aerobic and anaerobic conditions to be specified by the user. This was overcome by using the special actions module to introduce a seasonal variation in benthic release rates. HSPF also represents lakes as a single, well-mixed segment; this prevents the observed vertical gradients in lake water quality, which are the result of thermal stratification, from being properly represented. Finally, the dependence of organic phosphorus and organic nitrogen on BOD through a user-specified stoichiometric relationship cannot represent the different C:N:P ratios for various sources of organic matter (e.g., leaf litter, humus, wastewater treatment plant organic matter, phytoplankton, macrophytes, etc.), thus making it difficult to properly simulate phosphorus cycling without compromising the nitrogen, DO, and BOD calibrations. These limitations resulted in the model initially predicting phosphorus concentrations rising to levels inconsistent with observed data for several lakes, especially those with little or no outflow during several years of the simulation period. Therefore, it was necessary to vary and reduce the benthic sediment release rates for several lakes to prevent ongoing phosphorus accumulation in the water column from occurring in the model.

Overall, the phosphorus calibration and validation resulted in achieving “good” to “very good” model performance based on statistical and visual comparisons at the watershed outlet or, if data were not available at the outlet, the next best station that captures the most watershed drainage area. Therefore, the calibrated and validated Cannon River watershed HSPF model is deemed suitable for the simulation of land management scenarios to estimate the potential benefits of BMPs and land conservation management actions to reduce orthophosphate and TP loading in the Cannon River watershed. Additional phosphorus calibration plots are provided in Appendix D. A complete set of statistics and plots have been provided as an electronic file with the deliverable package.

4.5.2 Nitrogen

Ammonia and nitrate plus nitrite are represented on the land side using build-up/washoff processes for both pervious and impervious surfaces. Concentrations associated with subsurface flows (interflow and groundwater) are also included for ammonia and nitrate plus nitrite. The atmospheric deposition of ammonia and nitrate on the land and reach segment surface is also included in the Cannon River HSPF model. BOD (as organic matter) is simulated using the sediment potency method for pervious surfaces and the build-up/washoff method for impervious surfaces.

As noted above, the approach to model calibration was an iterative process of adjusting watershed loads (UALs) until the simulated loads fell within reasonable limits of reported literature ranges and other Minnesota models (Tetra Tech 2009, LimnoTech 2014d), adjusting various instream parameters within reported literature ranges, and then comparing the model to instream ammonia, nitrate plus nitrite and TN concentration data. In addition, target TN loads were estimated near the watershed outlet (Cannon River at Welch) using LOADEST (Runkel et al. 2004, Runkel 2013) based on the available streamflow (USGS) and TN concentration data from MPCA’s EDA database and from MCES, which also monitors conditions at this location. The Cannon River at Welch TN loads were also estimated by MCES using FLUX32, a U.S. Army Corps of Engineers model (MCES 2014). Target TN loads were also estimated near the Straight River outlet (Straight River at Faribault) and the Cannon River near Northfield, which is the closest location upstream of Lake Byllesby, using LOADEST based on available streamflow (USGS/HYDSTRA) and TN concentration data from MPCA's EDA database. LOADEST uses specialized regression techniques to merge continuous streamflow measurements with discrete concentration measurements to generate estimates of annual loads. These calculated loads were compared with loads generated by the Cannon River watershed HSPF model at these locations (i.e., Cannon River at Welch, Straight River at Faribault, Cannon River at Northfield).

The model calibration was performed to ensure that the model reasonably reproduced concentrations and loads at the watershed outlet at annual and monthly time scales as well as the timing, magnitude, and range of observed instream ammonia, nitrate plus nitrite and TN concentrations at daily time scales. Water quality station locations that were used to support the model nitrogen parameterization, calibration and validation are summarized in Table 4-29. The primary calibration locations are indicated in bold. The other locations were used to parameterize the model and/or as secondary calibration locations. Some stations, such as the Cannon River at Northfield, did not have sufficient data for all three nitrogen species for use in calibrating the model.

Table 4-29. TN, NO3+NO2 and NH3 Concentration Data for the Cannon River HSPF Model.

Station Name	EDA Station ID[1]	HSPF Reach ID	TN		NO3+NO2		NH3	
			Count of Records	Period of Record	Count of Records	Period of Record	Count of Records	Period of Record
Cannon River at Welch	**S000-003**	**103**	**24**	**2007-2010**	**120**	**1996-2012**	**58**	**1996-2008**
	MCES	**103**	**322**	**1999-2012**	**324**	**1999-2012**	**323**	**1999-2012**
Straight River at Faribault	**S003-557**	**802**	**196**	**2002-2012**	**196**	**2002-2012**	**52**	**2002-2010**
Cannon River at Canada Ave., near Northfield	S001-582	203	48	2001-2010	48	2001-2010	3	2001
Little Cannon River near Cannon Falls	S004-512	501	102	2007-2012	102	2007-2012	11	2009-2011
Crane Creek near Medford	S003-009	900	51	2000-2011	118	2000-2012	65	2000-2012
Straight River at Clinton Falls	S000-047	806	42	2000-2011	151	1996-2012	112	1996-2012
Maple Creek at Owatonna	S003-011	835	40	2000-2011	94	2000-2012	55	2000-2012
Straight River at Owatonna	S003-015	809	136	2000-2011	94	2000-2012	55	2000-2012
Turtle Creek 3 mi SE of Owatonna	S003-016	841	135	2000-2011	93	2000-2012	56	2000-2012

The initial model parameterization for ammonia, nitrate plus nitrite and BOD was based on the parameterization of other calibrated and validated Minnesota HSPF models (RESPEC 2012; Tetra Tech 2012, 2013, LimnoTech 2014d). Parameter adjustments were made to the rate of accumulation on the surface (ACQOP), the maximum storage on the surface (SQOLIM), and the interflow concentrations of ammonia and nitrate plus nitrite to improve the simulation of loading during storm events. For the nitrogen simulation, adjustments to the BOD parameters and input concentrations are the same as described in the phosphorus section (see Section 4.5.1). Once the land side UALs were within reasonable ranges compared to the available literature and other Minnesota HSPF models (Tetra Tech 2009; LimnoTech 2014d), the instream simulation was refined through the adjustment of groundwater concentrations, organic matter settling rates, the nitrification rate of ammonia, bottom sediment concentrations of nitrogen (due to interdependence with nitrogen via algal interactions) and ammonium, and the growth and death of phytoplankton and benthic algae.

Once a best possible calibration was achieved, the final TN UALs were calculated for each land segment category (Figure 4-68) and a final comparison was performed against the available literature values as well as UALs predicted by the Minnesota River HSPF model (Table 4-30) (Tetra Tech 2009). The TN UALs generated by the Cannon River HSPF model are consistent with the available literature and, more importantly, the Minnesota River HSPF model (which is representative of regional UALs).

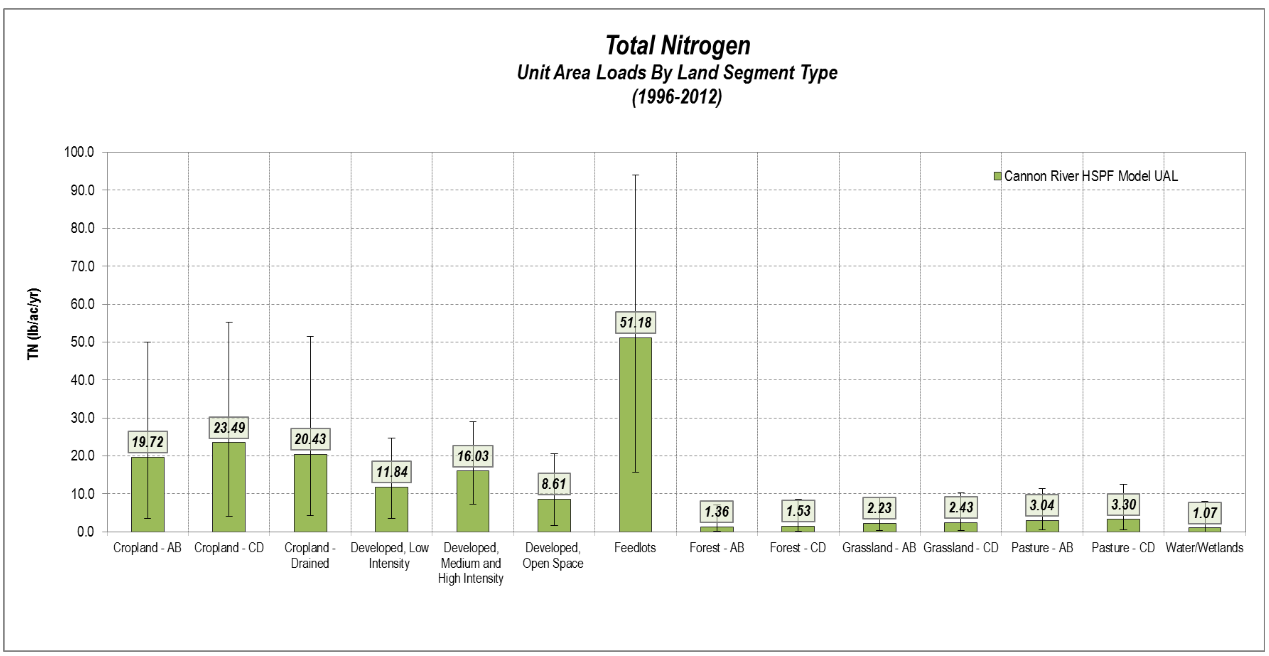

Figure 4-68. Total Nitrogen Unit Area Loads by Land Segment Type for the 1996-2012 Simulation Period.

Table 4-30. Total Nitrogen Loading Rates (lbs/ac/yr) Generated by the Minnesota River Basin Model for 1993-2006 (from Tetra Tech 2009, on page 6-30, Table 6-15).

Basin	Conservation Tillage	Conventional Tillage	Forest	Manured Cropland	Marsh	Pasture	Urban
Blue Earth	29.94	25.08	1.08	32.97	1.02	3.44	7.78
Chippewa	6.34	4.69	0.54	5.60	0.45	1.78	5.17
Cottonwood	12.48	10.94	0. 80	14.42	0.76	2.27	5.95
Hawk	6.30	6.97	0.56	8.78	0.62	1.57	6.43
Le Sueur	28.17	27.96	1.68	38.75	1.00	3.64	8.62
Lower MN	24.73	15.08	0.99	13.00	0.90	2.94	8.06
Middle MN	21.09	13.74	0.78	15.35	0.79	2.27	6.93
Redwood	14.08	12.03	0.76	14.21	0.70	2.22	5.42
Watonwan	23.04	28.22	0.82	29.76	0.76	2.42	6.22
Yellow Medicine	5.56	6.88	0.51	8.64	0.32	1.38	4.09

Due to limited data availability for the validation period (1996-2003), annual TN loads were evaluated for the full simulation period. The average annual TN load simulated at the Cannon River at Welch was 9,976,000 lbs/year for the period comprising the available data (1999-2012), which compares well to the average annual TN load calibration target of 11,425,000 lbs/year estimated by LimnoTech using LOADEST and by MCES using FLUX. The average annual TN load is within the 9,711,000 – 13,138,000 lbs/year calibration target (i.e., based on a tolerance of +/- 15%). A comparison of the simulated annual TN loads and the annual TN loads calculated for the Cannon River at Welch using the LOADEST and FLUX models is shown in Figure 4-69. Figure 4-70 presents a comparison of the simulated and calculated monthly TN loads for the Cannon River at Welch.

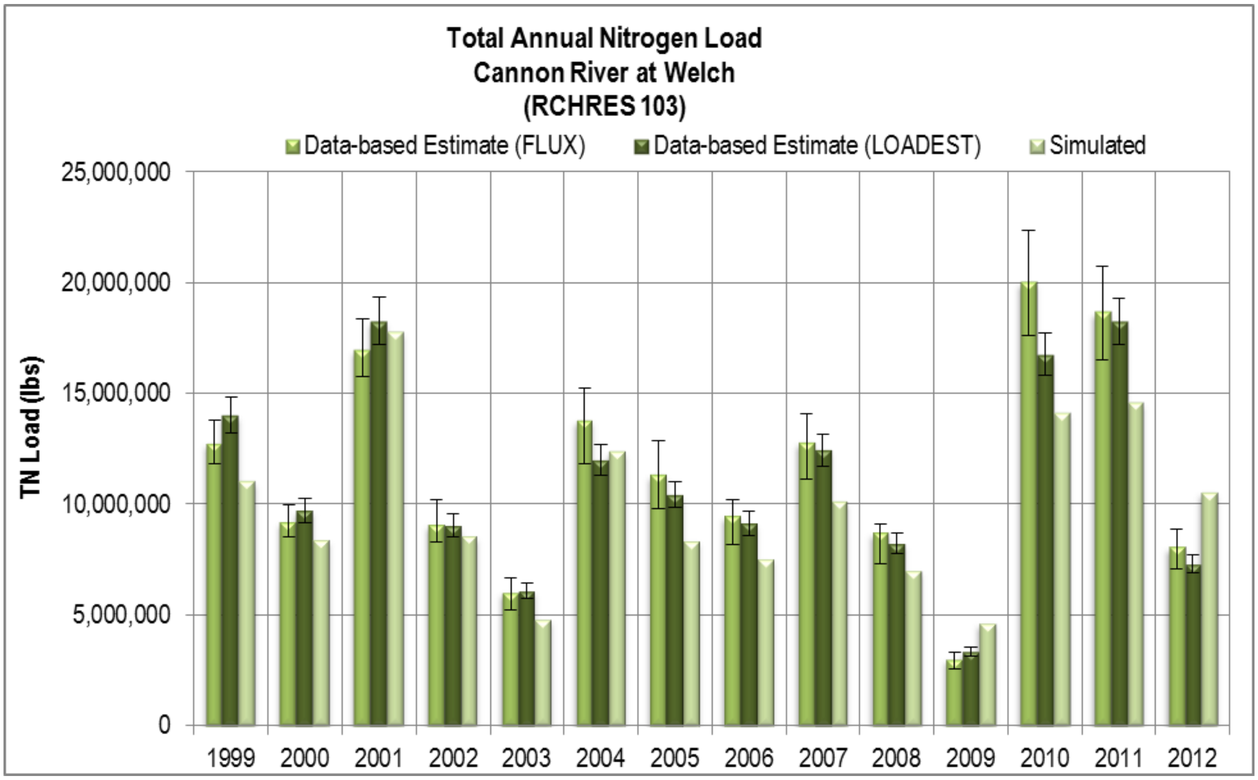

Figure 4-69. Annual Total Nitrogen Load at Cannon River at Welch (RCHRES 103).

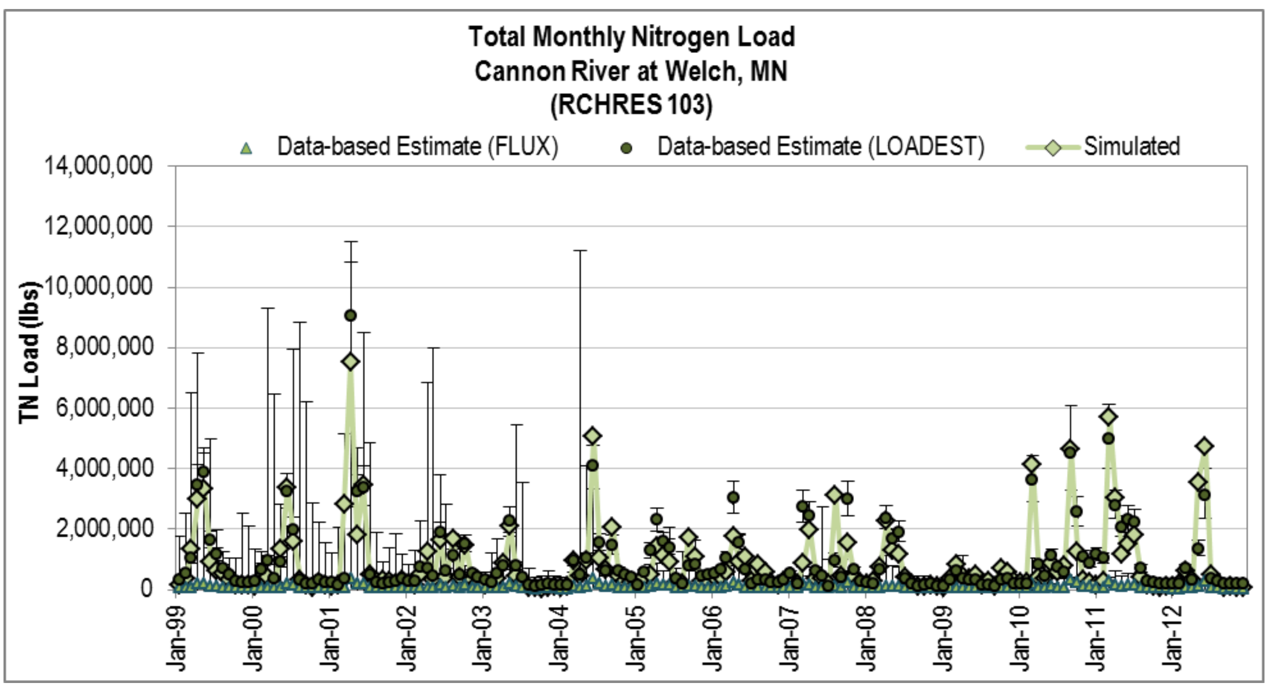

Figure 4-70. Monthly Total Nitrogen Load at Cannon River at Welch (RCHRES 103).

As discussed for other water quality constituents, the variability in the calculated LOADEST and FLUX TN load results for each year reflects differences in each model's regression algorithms. However, taken together, they provide a reasonable range of results for comparison to the model-simulated nitrogen load. In most years, the simulated total nitrogen load compares favorably to the calculated loads.

The simulated annual average total nitrogen loads at upstream locations in the watershed ranged from "good" to "very good" based on comparisons to the annual average TN loads calculated with LOADEST. Table 4-31 presents a comparison of the LOADEST and HSPF-simulated annual average TN loads. A comparison of the simulated and calculated annual TN loads for the Straight River at Faribault and the Cannon River at Northfield using the LOADEST model are shown in Figure 4-71 and Figure 4-72, respectively. A comparison of the simulated and calculated monthly TN loads for the Straight River at Faribault and the Cannon River at Northfield using the LOADEST model are shown in Figure 4-73 and Figure 4-74, respectively. Additional full period TN load comparisons are included in Appendix E.

Table 4-31. Comparison of Calculated and Simulated Average Annual TN Loads at Locations in the Cannon River Watershed.

Location (EDA Station ID)	Period	Average Annual Nitrogen Load (lbs/year)		Relative Percent Difference
		LOADEST-calculated	HSPF Simulated	
Cannon River at Welch (S000-003)	1999-2012	11,425,000	9,976,000	-12.7%
Cannon River at Northfield (S001-582)	2001-2010	7,552,000	6,893,000	-8.7%
Straight River at Faribault (S003-557)	2007-2012[a]	5,950,000	4,542,000	-23.7%

Notes:
[a] There was only one TN measurement between 2002-2006 in the Straight River at Faribault, which is an insufficient amount of data for that period in developing the LOADEST regression; therefore, the annual loads were calculated and compared for the period shown.

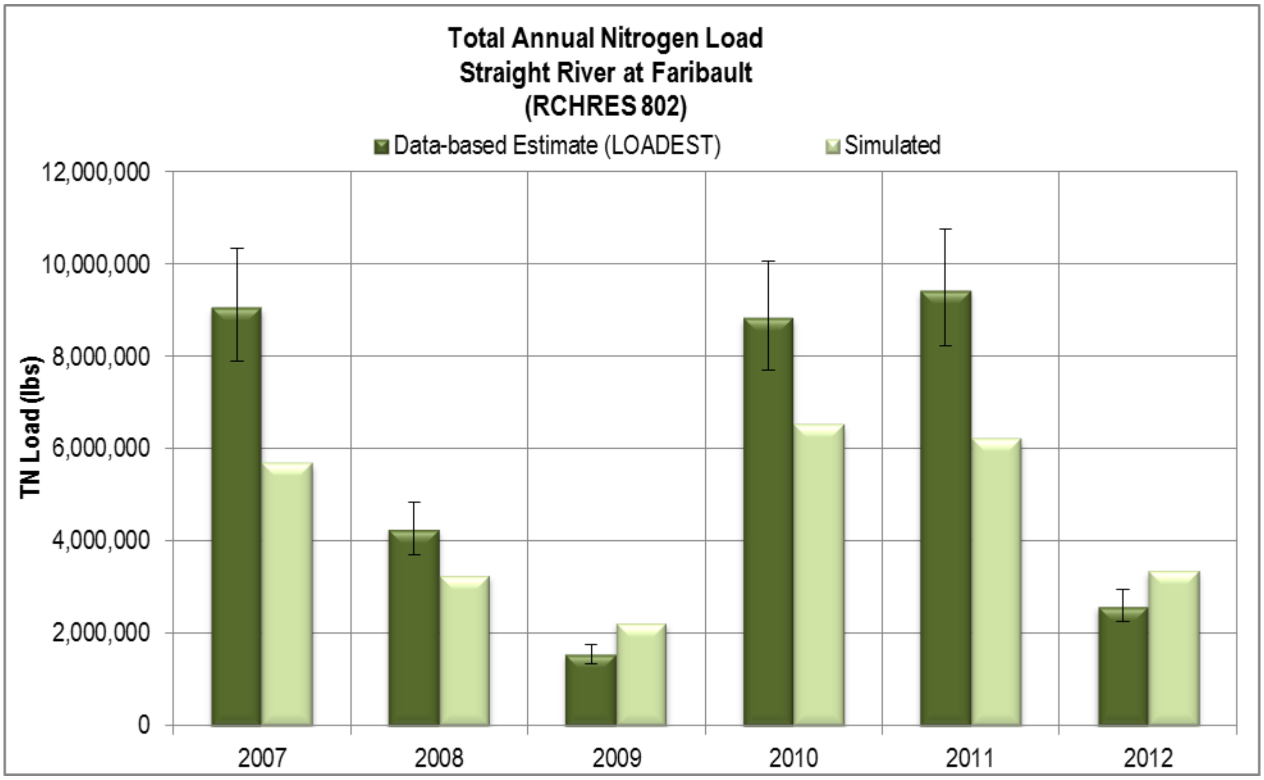

Figure 4-71. Annual Total Nitrogen Load at Straight River at Faribault (RCHRES 802).

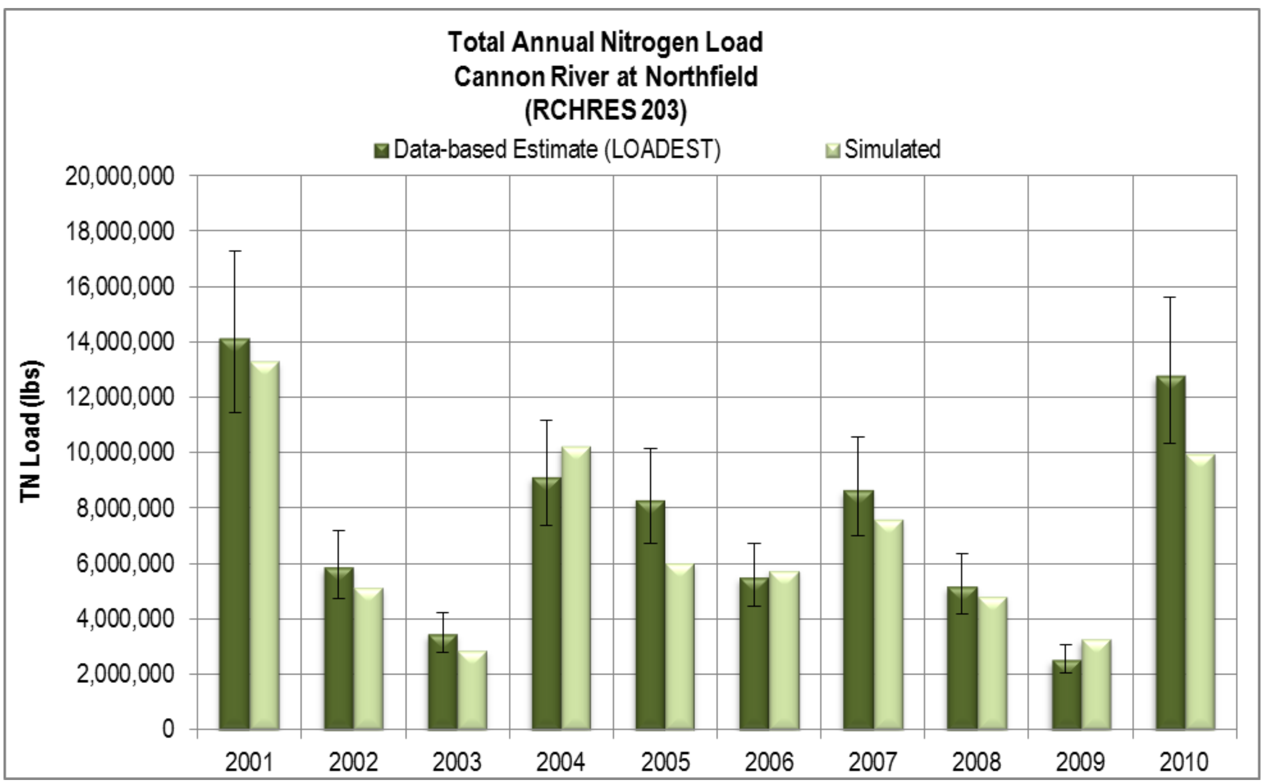

Figure 4-72. Annual Total Nitrogen Load at Cannon River at Northfield (RCHRES 203).

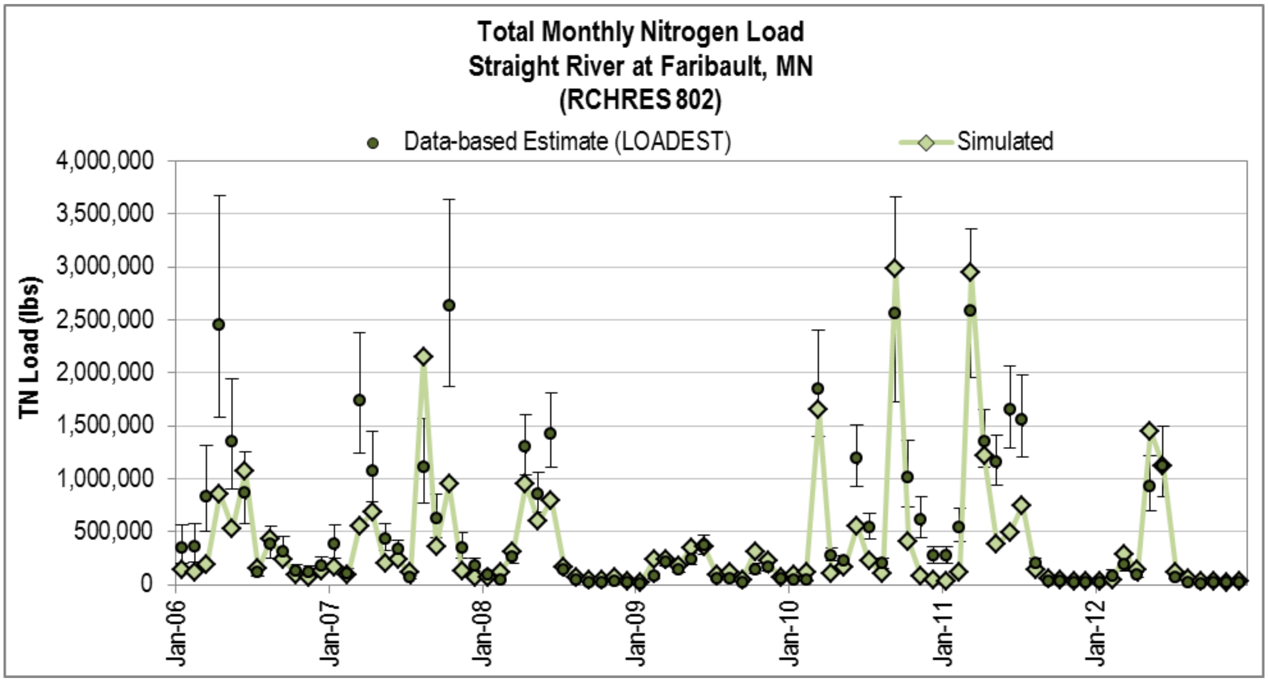

Figure 4-73. Monthly Total Nitrogen Load at Straight River at Faribault (RCHRES 802).

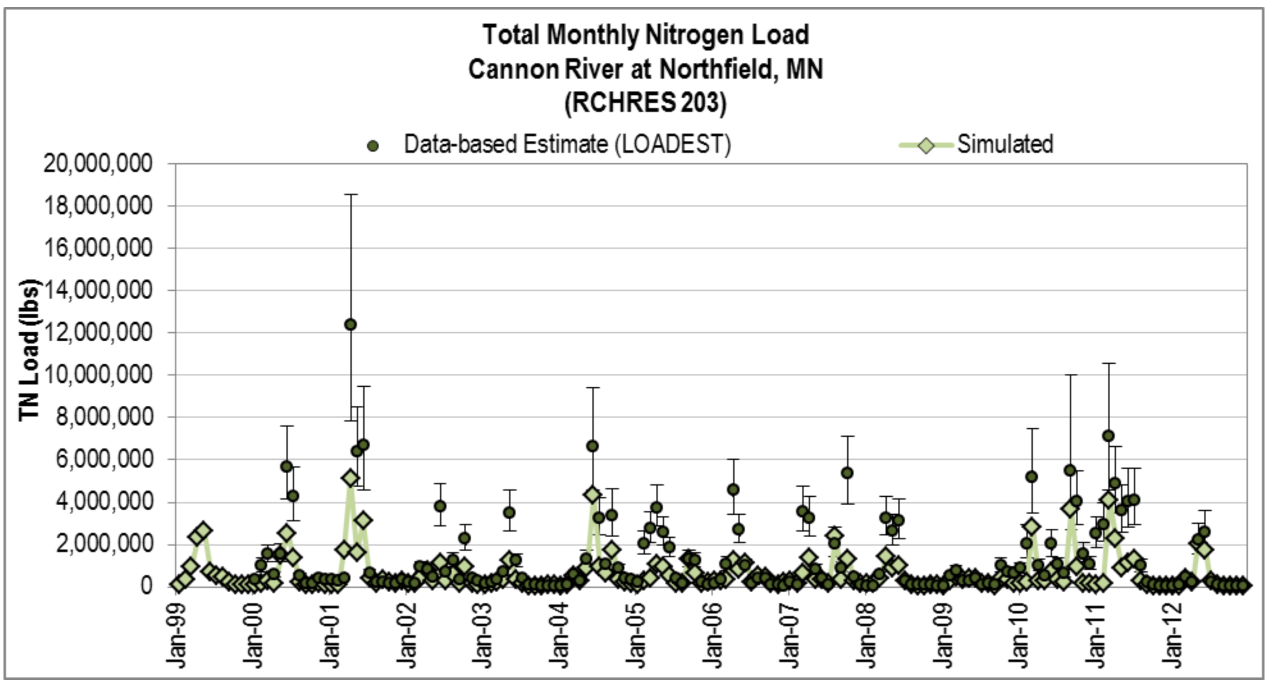

Figure 4-74. Monthly Total Nitrogen Load at Cannon River at Northfield (RCHRES 203).

In general, the calibration of TN falls within the "very good" to "good" range based on statistical and visual comparisons of observed and simulated TN concentrations and loads (Table 4-32 and Figures 4-75 through 4-77). Limited data were available at the Straight River at Faribault station during the validation period so this location was not considered in the validation (Table 4-33 and Figures 4-75 through 4-77). Although the TN data during the calibration and validation periods were limited for the Cannon River at Northfield location, the statistics are included in Table 4-31 for consistency with the TP calibration assessment. The Cannon River at Northfield calibration falls within the “fair” range and the validation falls within the “good” range, based on the statistics calculated from the limited data.

The calibration and validation of nitrate (NO_3) plus nitrite (NO_2) was from “fair” to “very good”, based on statistical and visual comparisons of observed and simulated nitrate plus nitrite concentrations (Table 4-34 and Figures 4-78 through 4-80). The nitrate plus nitrite data available for the calibration period were limited for the Cannon River at Northfield location. The model predictions fall within the “fair” range for this location.

The calibration and validation of ammonia ranges from “fair” to less than “fair” based on statistical and visual comparisons of observed and simulated ammonia (NH_3) concentrations (Table 4-35 and Figures 4-81 through 4-82). The ammonia calibration was confounded by the limited data at each location and the large number of non-detects in the calibration and validation datasets. Detected values tended to be near the detection limit. Additional nitrogen calibration plots are provided in Appendix E. A complete set of statistics and plots have been provided as an electronic file with the deliverable package.

Table 4-32. Summary Statistics for the Cannon River Watershed HSPF Model Total Nitrogen Concentration Calibration (2004-2012)

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault		Cannon River at Northfield	
		Result	Performance Rating	Result	Performance Rating	Result	Performance Rating
Annual	Count	9		7		2	
	PBIAS	3.18		10.87		-23.76	
	Relative Percent Difference	-2.1%	Very good	-10.6%	Very good	22.1%	Good
Monthly	Count	104		59		10	
	PBIAS	9.88		3.59		-30.70	
	Relative Percent Difference	-11.2%	Very good	6.3%	Very good	29.3%	Fair
Daily	Count	247		195		21	
	PBIAS	1.70		10.66		-27.10	
	Relative Percent Difference	-0.8%	Very good	-1.4%	Very good	27.7%	Fair

Table 4-33. Summary Statistics for the Cannon River Watershed HSPF Model Total Nitrogen Concentration Validation (1996-2003)

Time Interval	Statistic	Cannon River at Welch		Straight River at Faribault		Cannon River at Northfield	
		Result	Performance Rating	Result	Performance Rating	Result	Performance Rating
Annual	Count	5				3	
	PBIAS	4.67				-5.22	
	Relative Percent Difference	-5.7%	Very good			10.9%	Very good
Monthly	Count	56				15	
	PBIAS	8.21				10.05	
	Relative Percent Difference	-11.1%	Very good			-4.4%	Very good
Daily	Count	99				27	
	PBIAS	3.30				12.23	
	Relative Percent Difference	-6.1%	Very good			-6.0%	Very good

Notes:

[1] There was only one TN measurement between 1999-2003 in the Straight River at Faribault so statistics for the validation period were not computed.

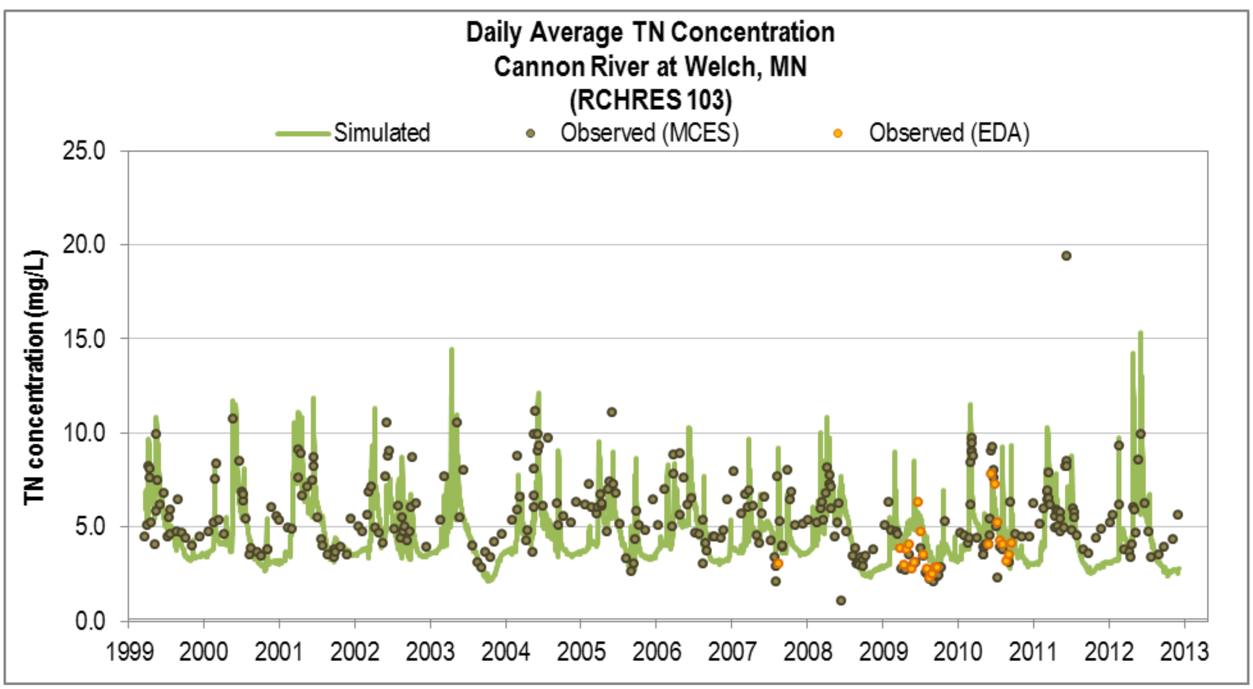

Figure 4-75. Daily Average Total Nitrogen Concentrations for Cannon River at Welch (RCHRES 103).

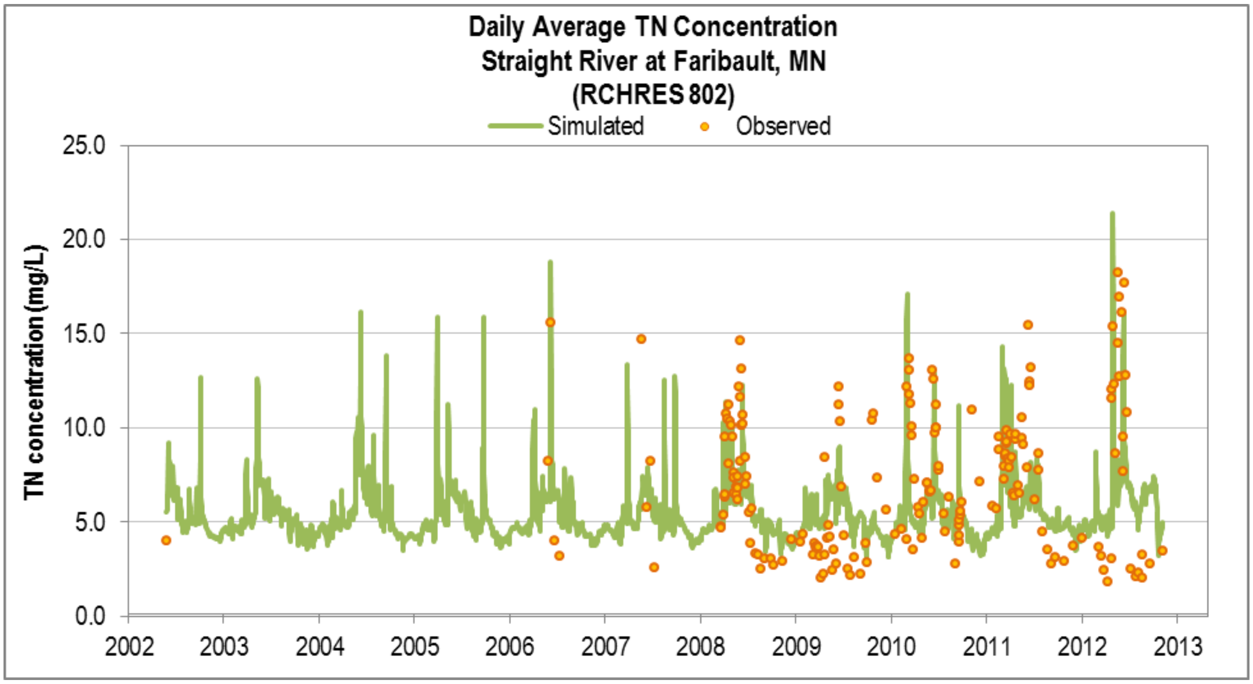

Figure 4-76. Daily Average Total Nitrogen Concentrations for Straight River at Faribault (RCHRES 802).

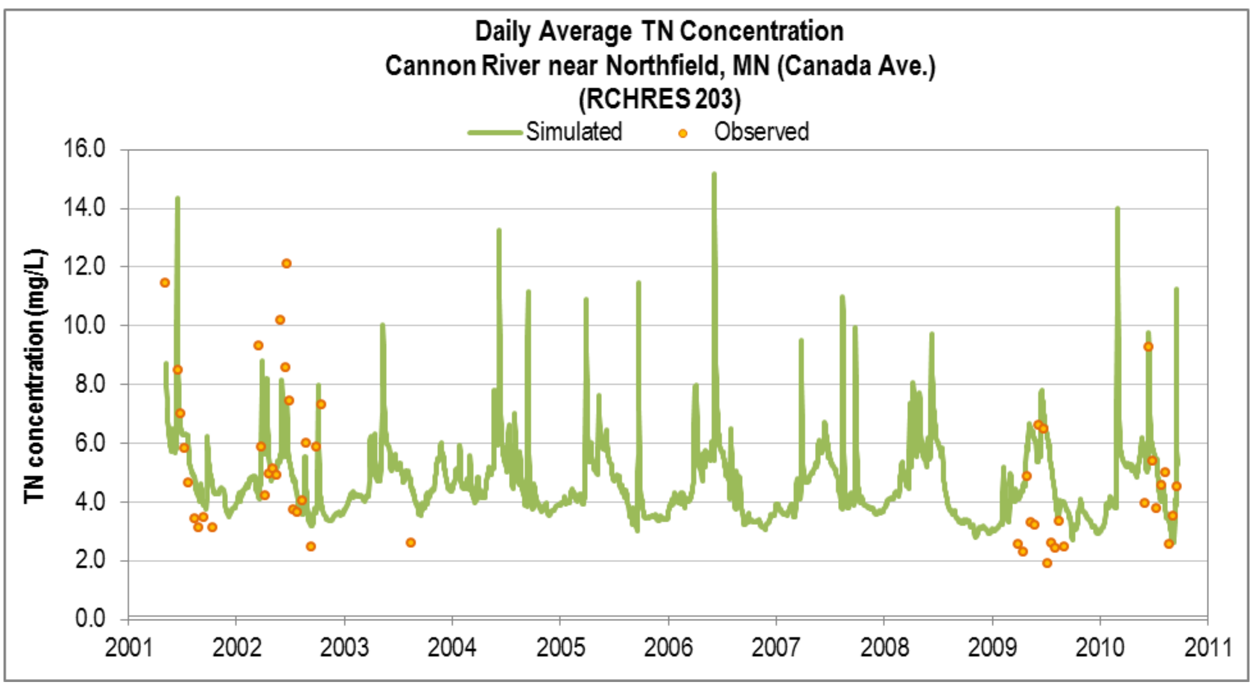

Figure 4-77. Daily Average Total Nitrogen Concentrations for Cannon River at Northfield (RCHRES 203).

Table 4-34. Summary Statistics for the Cannon River Watershed HSPF Model NO_3+NO_2 Concentration Calibration (2004-2012) and Validation (1996-2003)

Time Interval	Statistic	Calibration (2004-2012)			Validation (1996-2003)		
		Cannon River at Welch	Straight River at Faribault	Cannon River at Northfield	Cannon River at Welch	Straight River at Faribault[1]	Cannon River at Northfield
Annual	Count	9	7	2	6		3
	PBIAS	-7.71	11.39	-31.28	-5.41		8.74
	Relative Percent Difference	9.0%	-10.5%	27.9%	5.6%		13.3%
Monthly	Count	104	59	10	67		15
	PBIAS	2.56	-0.17	-41.27	0.17		8.38
	Relative Percent Difference	-3.0%	13.4%	38.7%	-3.2%		-4.9%
Daily	Count	305	195	21	137		27
	PBIAS	-8.66	7.28	-35.48	-2.87		8.17
	Relative Percent Difference	9.7%	5.4%	35.5%	-0.6%		-3.2%

Notes:
[1] There was only one NO3+NO2 measurement between 1996-2003 in the Straight River at Faribault so statistics for the validation period were not computed.

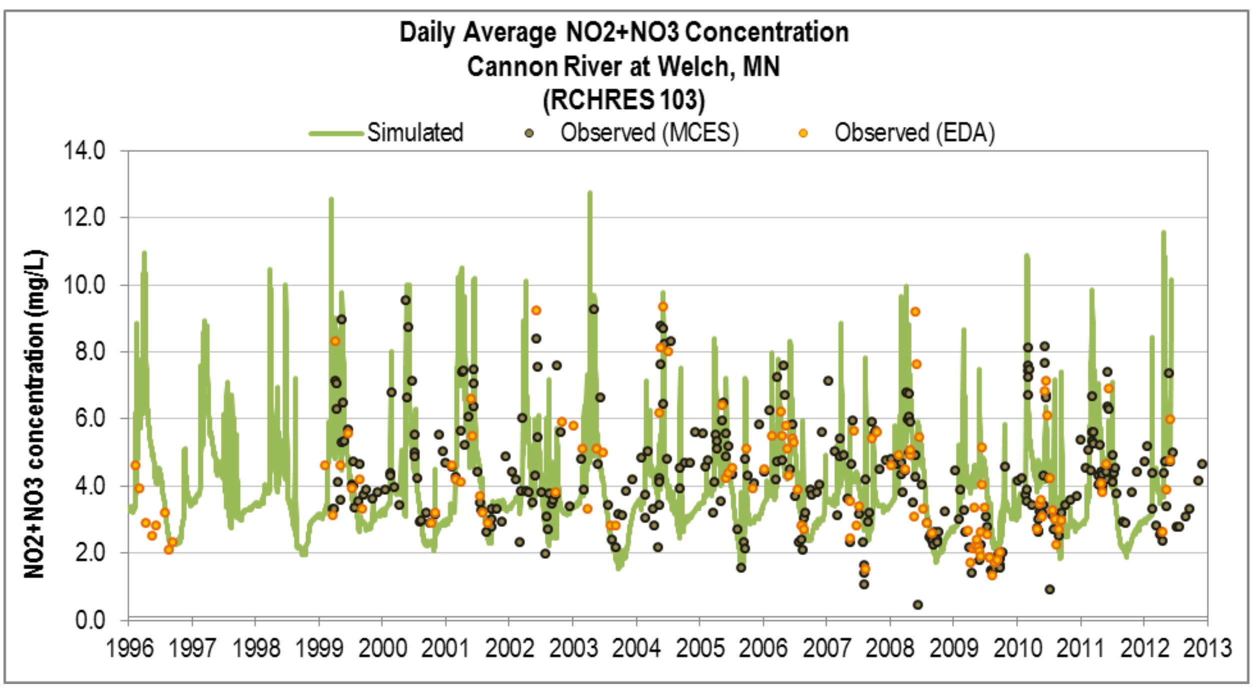

Figure 4-78. Daily Average NO_3+NO2 Concentrations for Cannon River at Welch (RCHRES 103).

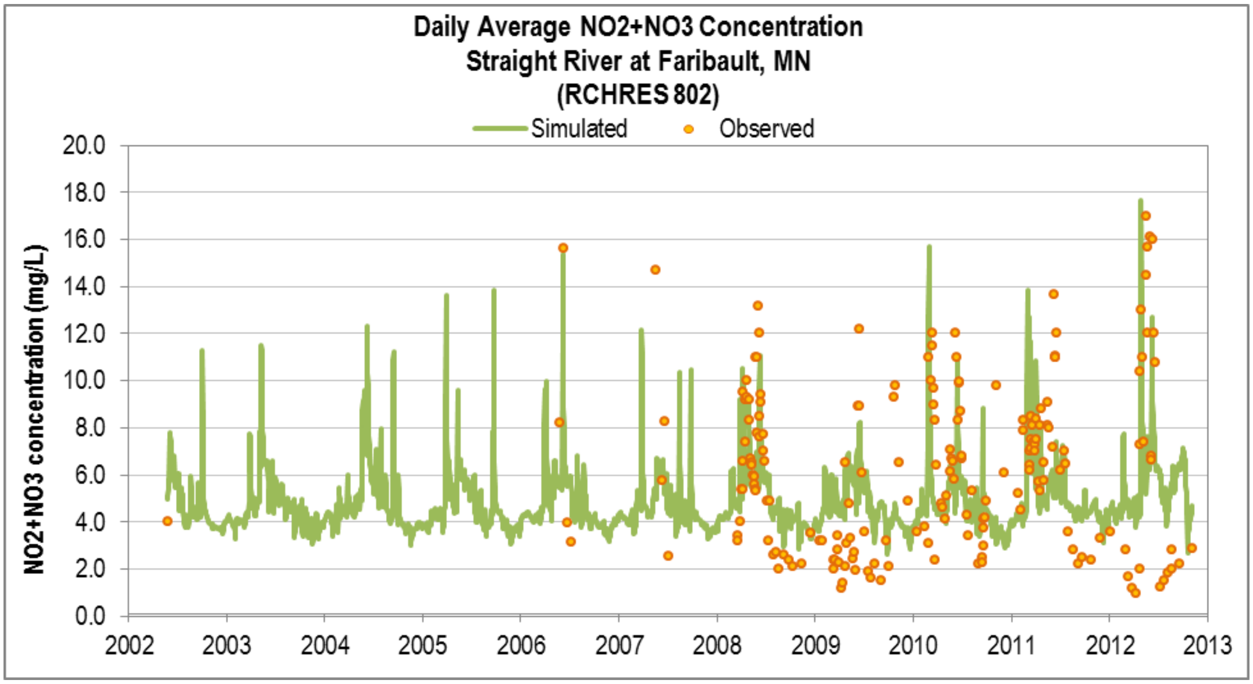

Figure 4-79. Daily Average NO_3+NO_2 Concentrations for Straight River at Faribault (RCHRES 802).

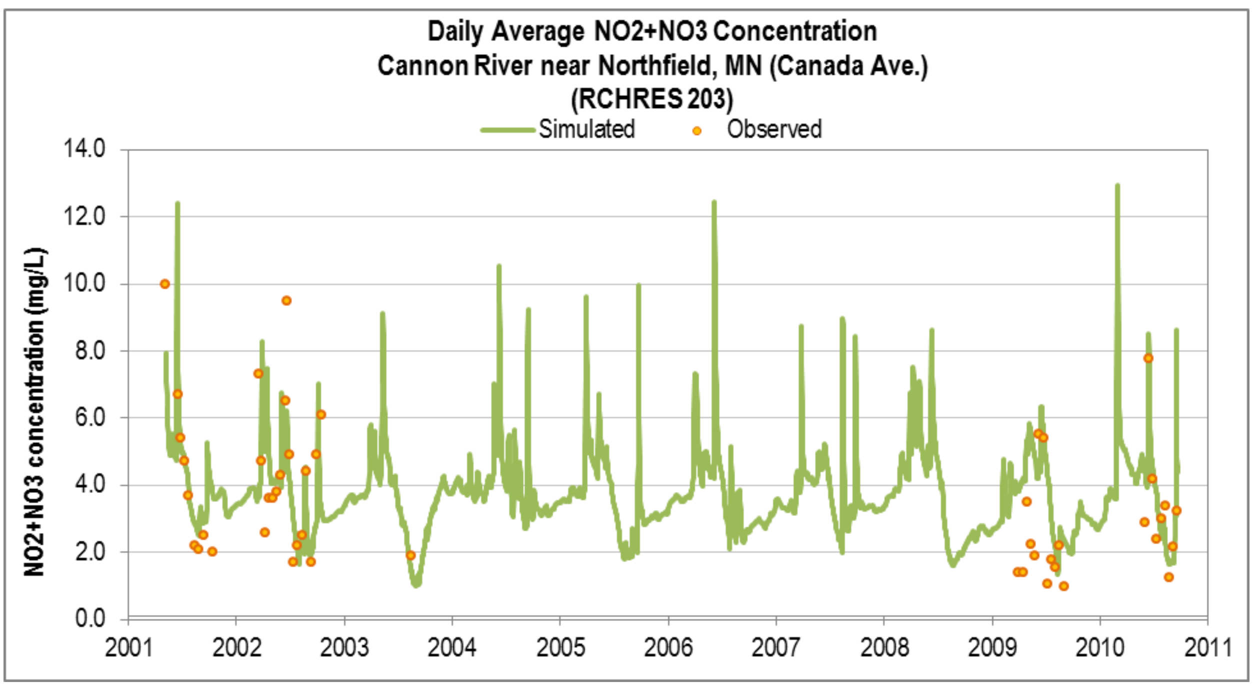

Figure 4-80. Daily Average NO_3+NO_2 Concentrations for Cannon River at Northfield (RCHRES 203).

Table 4-35. Summary Statistics for the Cannon River Watershed HSPF Model NH_3 Concentration Calibration (2004-2012) and Validation (1996-2003)

Time Interval	Statistic	Calibration (2004-2012)			Validation (1996-2003)		
		Cannon River at Welch	Straight River at Faribault	Cannon River at Northfield	Cannon River at Welch	Straight River at Faribault[1]	Cannon River at Northfield
Annual	Count	9	3		6		
	PBIAS	20.5	-32.18		45.4		
	Relative Percent Difference	-21.6%	28.9%		-55.7%		
Monthly	Count	105	20		67		
	PBIAS	22.4	-11.86		47.2		
	Relative Percent Difference	-19.4%	-2.2%		-49.4%		
Daily	Count	244	51		135		
	PBIAS	21.1	-55.93		37.7		
	Relative Percent Difference	-35.1%	17.1%		-45.3%		

[1] There were insufficient NH3 data at the Cannon River at Northfield location during the calibration and validation periods so it was not used to evaluate the NH3 calibration or validation. There was also insufficient NH3 data at the Straight River at Faribault location during the validation period so it was not used to evaluate the NH3 validation.

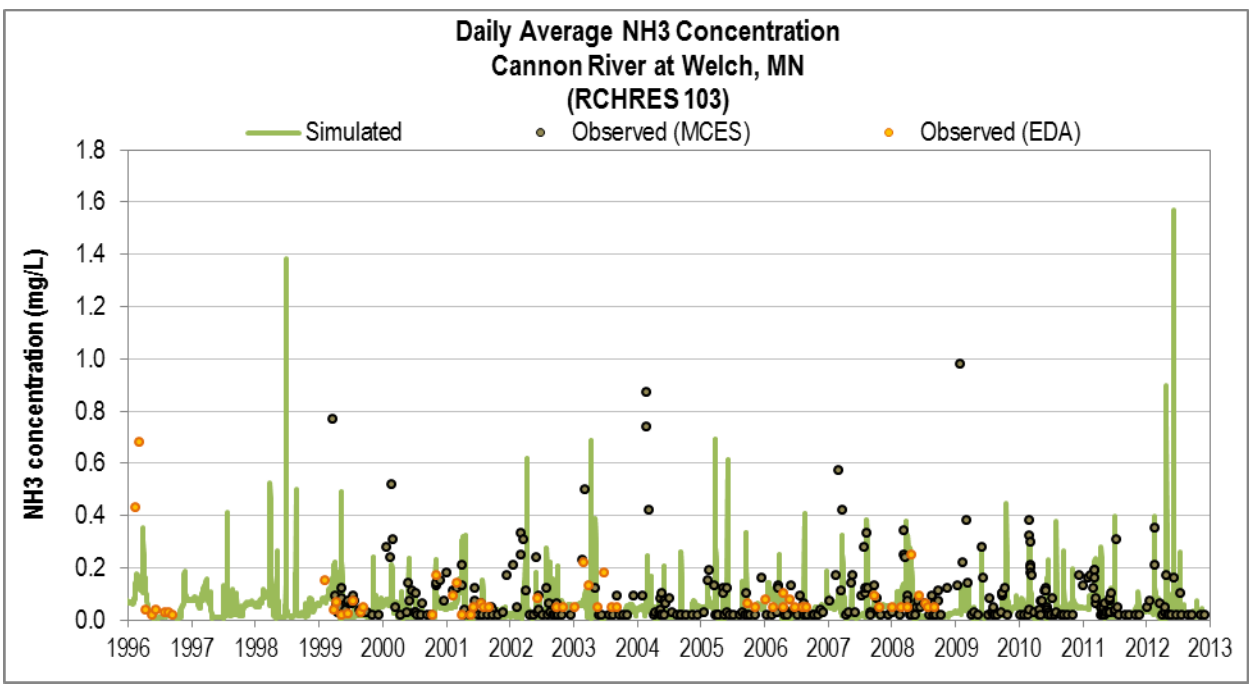

Figure 4-81. Daily Average NH_3 Concentrations for Cannon River at Welch (RCHRES 103).

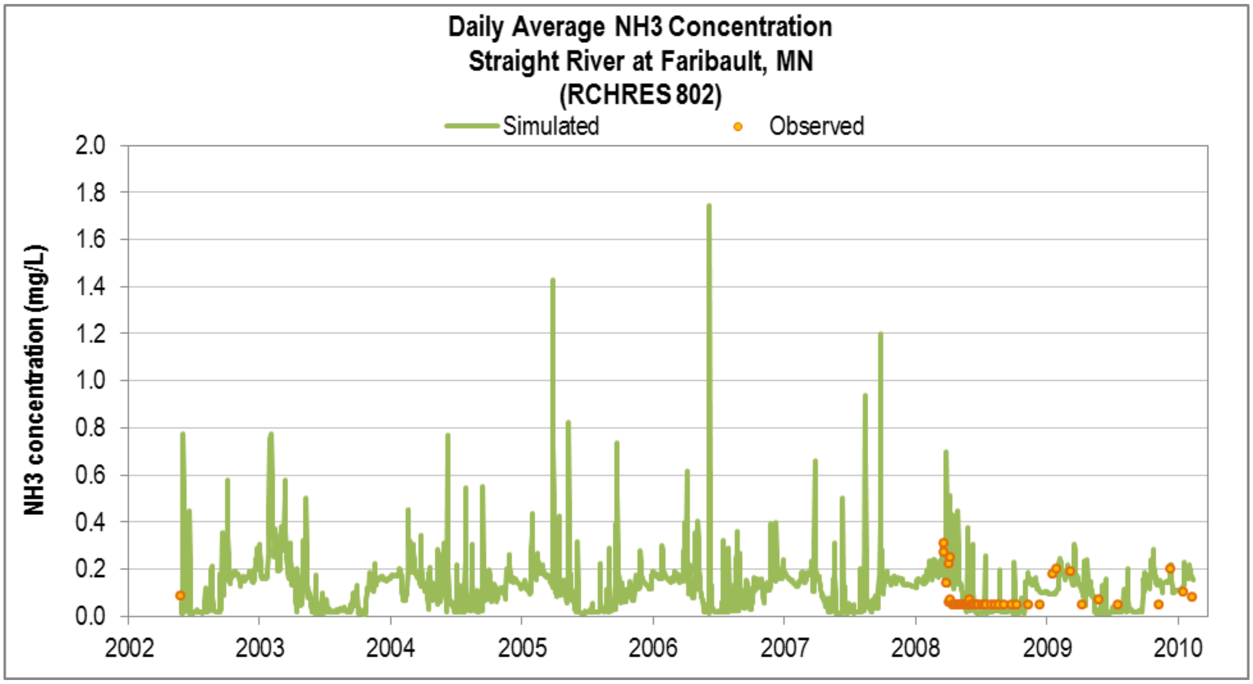

Figure 4-82. Daily Average NH_3 Concentrations for Straight River at Faribault (RCHRES 802).

Overall, the nitrogen calibration and validation resulted in achieving most of the model performance targets near the watershed outlet at Welch (Cannon River) and Faribault (Straight River). The nitrogen calibration also achieved good model performance just upstream of Lake Byllesby. Therefore, the calibrated and validated Cannon River watershed HSPF model is deemed suitable for the simulation of land management scenarios to estimate the potential benefits of BMPs and land conservation management actions to reduce ammonia, nitrate plus nitrite and TN loading in the Cannon River watershed.

4.6 Biochemical Oxygen Demand/Dissolved Oxygen

BOD and DO processes represented in HSPF include reaeration, BOD decay/oxygen depletion, settling of BOD material, benthic oxygen demand, and benthic release of BOD. The instream model parameterization for BOD and DO was based on the parameterization of the other previously calibrated and validated Minnesota HSPF models (RESPEC 2012; Tetra Tech 2012, 2013; LimnoTech 2014d). Parameter adjustments were made to the land side BOD loading during the calibration of nutrients as described above in Section 4.5. Data were very limited (i.e., the Cannon River at Welch station had the most data with 20 samples) to support model calibration and validation; therefore, a complete model calibration and validation of BOD could not be performed. However, the BOD model input parameters and simulation results were reviewed, and it was confirmed that reasonable BOD concentrations are predicted by the Cannon River watershed HSPF model (Figure 4-83).

The calibration and validation of DO was primarily achieved through the calibration of nutrients and the reasonable simulation of phytoplankton and benthic algae. The model calibration performance evaluation is based on the calibration station closest to the watershed outlet, Cannon River at Welch, as well as the station near the outlet of the Straight River at Faribault. Overall, the calibration of DO resulted in "very good" model performance based on statistical and visual comparison of observed and simulated DO (Table 4-36 and Figures 4-84 to 4-85). The validation of DO was limited as only two stations had sufficient data for the evaluation of model performance: Cannon River at Welch and the Straight River at Clinton. Based on statistical comparison (relative percent difference is equal to or less than 15% on annual, monthly, and daily time scales) and visual comparison of observed and simulated DO, the model validation resulted in "very good" model performance (Table 4-36 and Figure 4-84). A complete set of statistics and plots have been provided as an electronic file with the deliverable package [Appendix F].

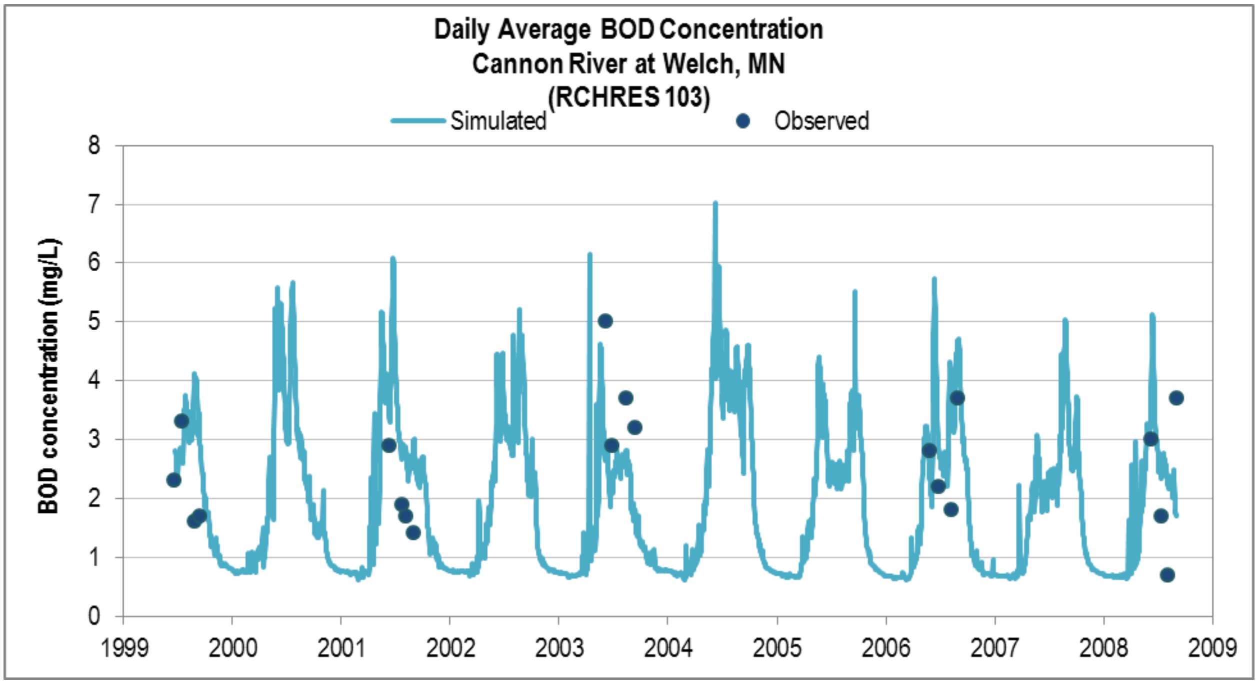

Figure 4-83. Daily Average BOD concentration at Cannon River at Welch (RCHRES 103)

Table 4-36. Summary Statistics for the Cannon River Watershed HSPF Model Dissolved Oxygen Calibration (2004-2012) and Validation (1996-2003).

Time Interval	Statistic	Calibration (2004-2012)		Validation (1996-2003)
		Cannon River at Welch	Straight River at Faribault	Cannon River at Welch
Annual	Count	7	5	7
	PBIAS	-8.75	8.78	-2.88
	Relative Percent Difference	8.3%	-9.0%	2.8%
Monthly	Count	30	51	37
	PBIAS	-7.95	6.44	-1.56
	Relative Percent Difference	8.2%	-5.8%	2.4%
Daily	Count	39	155	38
	PBIAS	-6.88	7.69	-1.19
	Relative Percent Difference	7.1%	-6.9%	2.0%

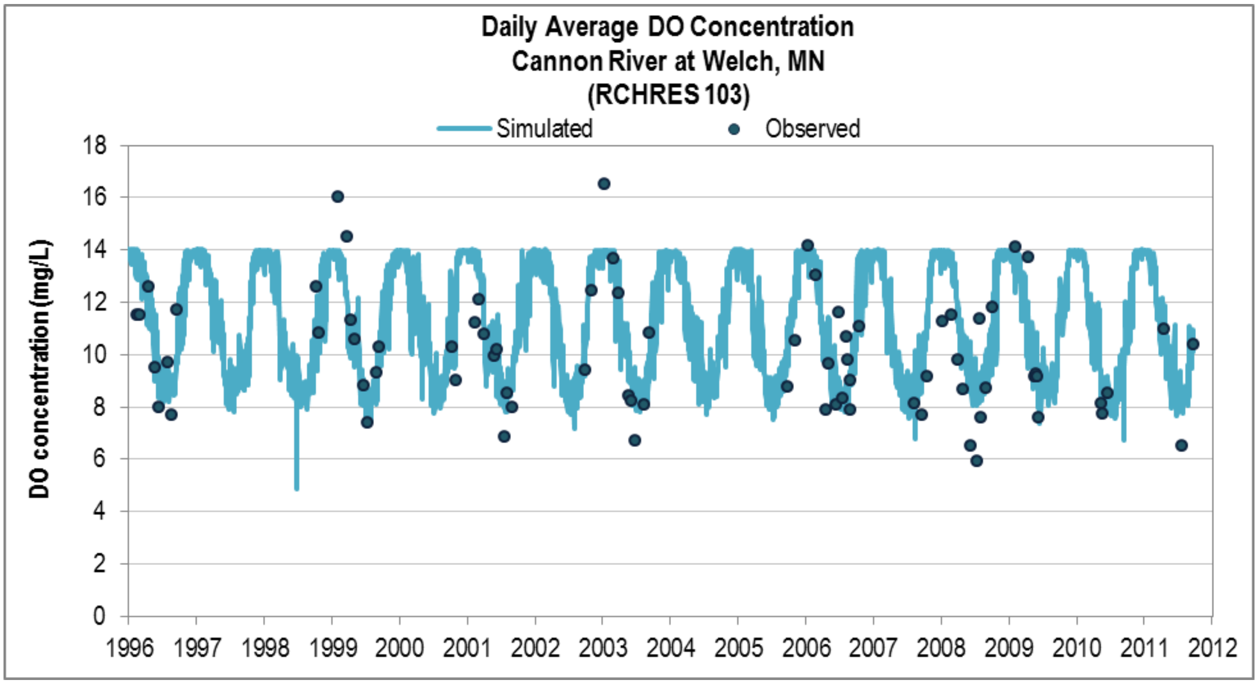

Figure 4-84. Daily Average Dissolved Oxygen Concentrations for Cannon River at Welch (RCHRES 103).

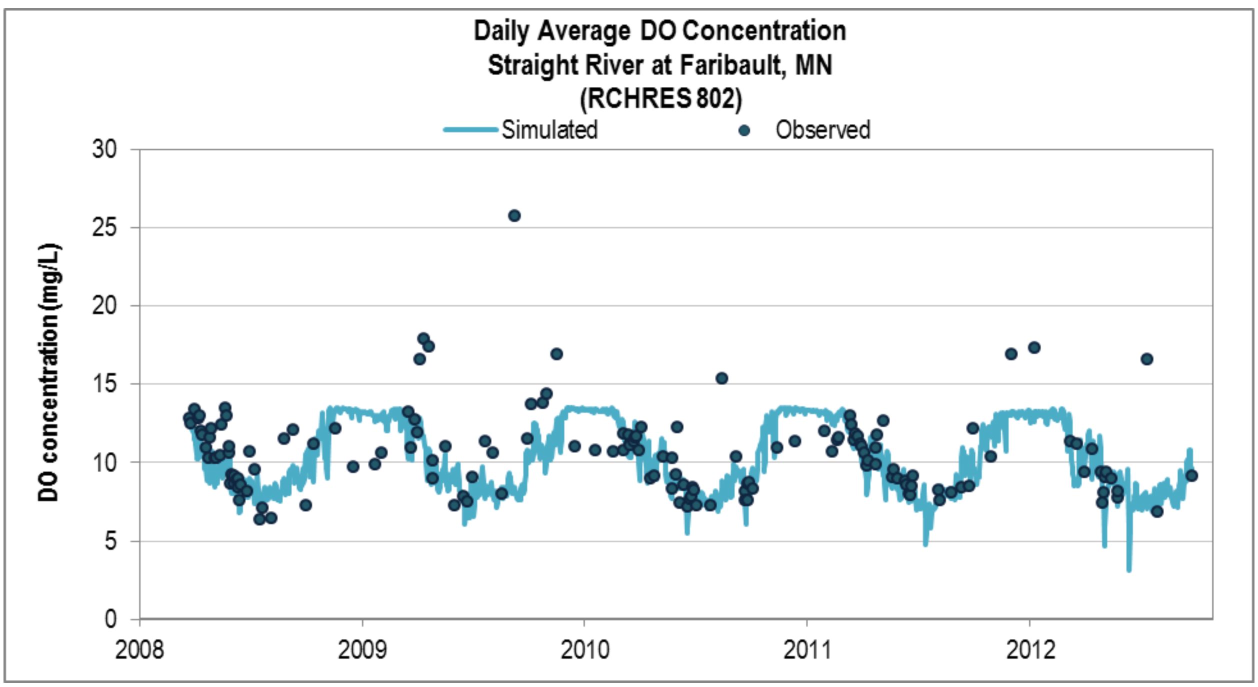

Figure 4-85. Daily Average Dissolved Oxygen Concentrations for Straight River at Faribault (RCHRES 802)

4.7 Phytoplankton/Benthic Algae

A single phytoplankton group and a single benthic algae group are represented in the Cannon River watershed HSPF model. The phytoplankton processes represented in the Cannon River watershed HSPF model include net growth (photosynthesis-respiration), death, settling, and transport. The growth and death of benthic algae are modeled in a manner similar to phytoplankton. The initial instream model parameterization for phytoplankton and benthic algae was based on the parameterization of the other Minnesota HSPF models (RESPEC 2012; Tetra Tech 2012, 2013; LimnoTech 2014d). Parameter adjustments were made to phytoplankton and benthic algae during the calibration of nutrients as described above in Section 4.5. Specific model parameter adjustments were made to improve the phytoplankton simulation and included the maximum unit algal growth rate for phytoplankton (MALGR), the concentration of plankton not subject to advection at very low flow (MXSTAY) and high flow (SEED), the outflow at which the concentration of plankton is not subject to advection (OREF), the rate of phytoplankton settling (PHYSET), and the chlorophyll *a* concentration above which high algal death rate occurs (CLALDH).

Phytoplankton chlorophyll *a* data were limited to one instream location to support model calibration and validation. The Cannon River at Welch station had 42 samples available for the 1999-2010 time period in the EDA database and 143 samples for the 2004-2012 time period from MCES. The remaining instream locations typically had less than 25 observations. A statistical comparison of observed and simulated concentrations over the full simulation period for the Cannon River at Welch location is provided in Table 4-37.

Table 4-37. Summary Statistics for the Chlorophyll *a* HSPF Model Simulation (1996-2012)

Time Interval	Statistic	Cannon River at Welch
Annual	Count	12
	PBIAS	19.14
	Relative Percent Difference	-15.7%
Monthly	Count	106
	PBIAS	29.66
	Relative Percent Difference	-54.3%
Daily	Count	185
	PBIAS	26.57
	Relative Percent Difference	-35.5%

Lake Byllesby had a total of 115 chlorophyll *a* samples; however, the samples were taken at varying depths and at different locations in the lake. Lake Volney had a total of 90 chlorophyll *a* samples; however, the samples were taken at varying depths. The comparison of Lake Byllesby and Lake Volney chlorophyll *a* data to simulated concentrations at the lake outlet is somewhat limited given the spatial variability in the measurements laterally and vertically (i.e., comparison of vertically discrete samples with model predicted depth averaged chlorophyll *a*).

In addition, data were not available for benthic algae in terms of biomass or chlorophyll *a* measurements. Therefore, a complete model calibration and validation of phytoplankton and benthic algae could not be performed. However, the phytoplankton and benthic algae model input parameters and simulation results were reviewed to ensure reasonable estimates of phytoplankton as chlorophyll *a* and benthic algae as biomass are predicted by the Cannon River HSPF model (Figures 4-86 to 4-89). Results are similar to results obtained from previous modeling efforts (USEPA 2006b). As noted previously, the simulation of phytoplankton and benthic algae have a significant impact on the simulation of nutrients, BOD, and DO. Therefore, the simulation of phytoplankton and benthic algae was ultimately optimized to achieve the best and most reasonable simulation of these parameters.

Given the challenges in comparing data and simulated phytoplankton chlorophyll *a* for Lake Byllesby, the phytoplankton model parameters were set to best fit the overall average concentrations. This approach may result in the model underpredicting (i.e., missing peak concentrations) or overpredicting phytoplankton concentrations at times. However, given the variability in the data and the limitation of HSPF with respect to simulating detailed lake conditions, this approach is reasonable. A complete set of statistic and plots have been provided as an electronic file with the deliverable package.

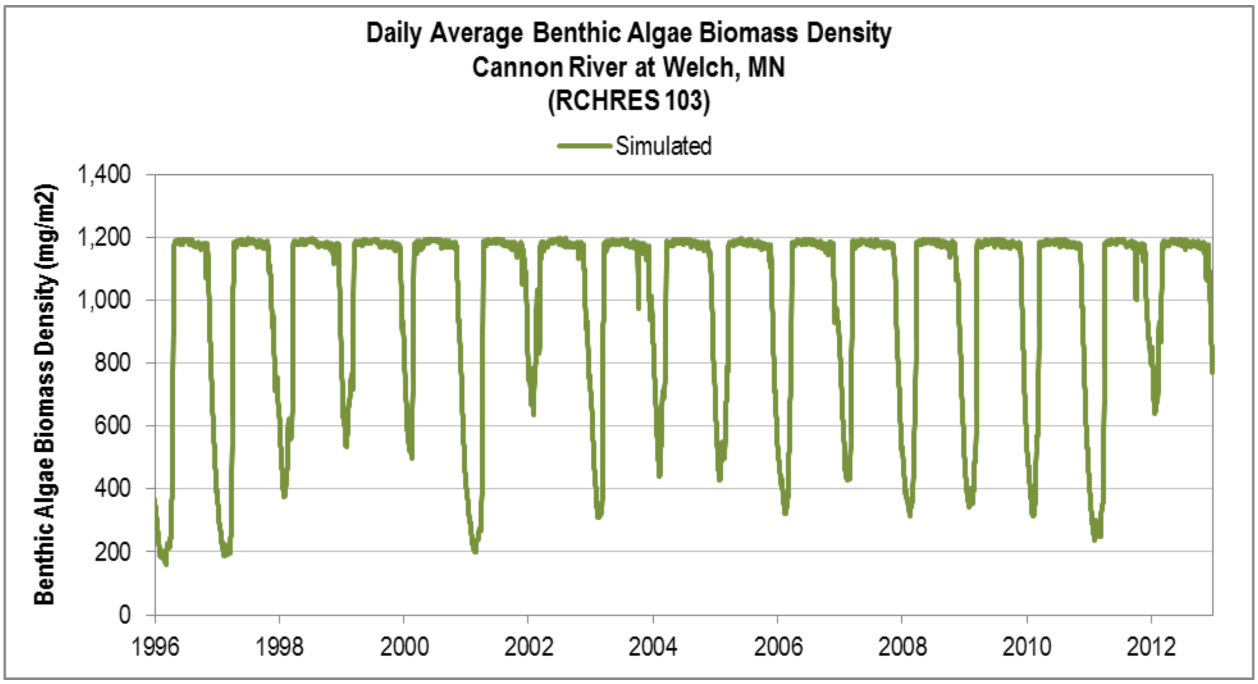

Figure 4-86. Simulated Daily Average Benthic Algae Biomass Density for Cannon River at Welch (RCHRES 103)

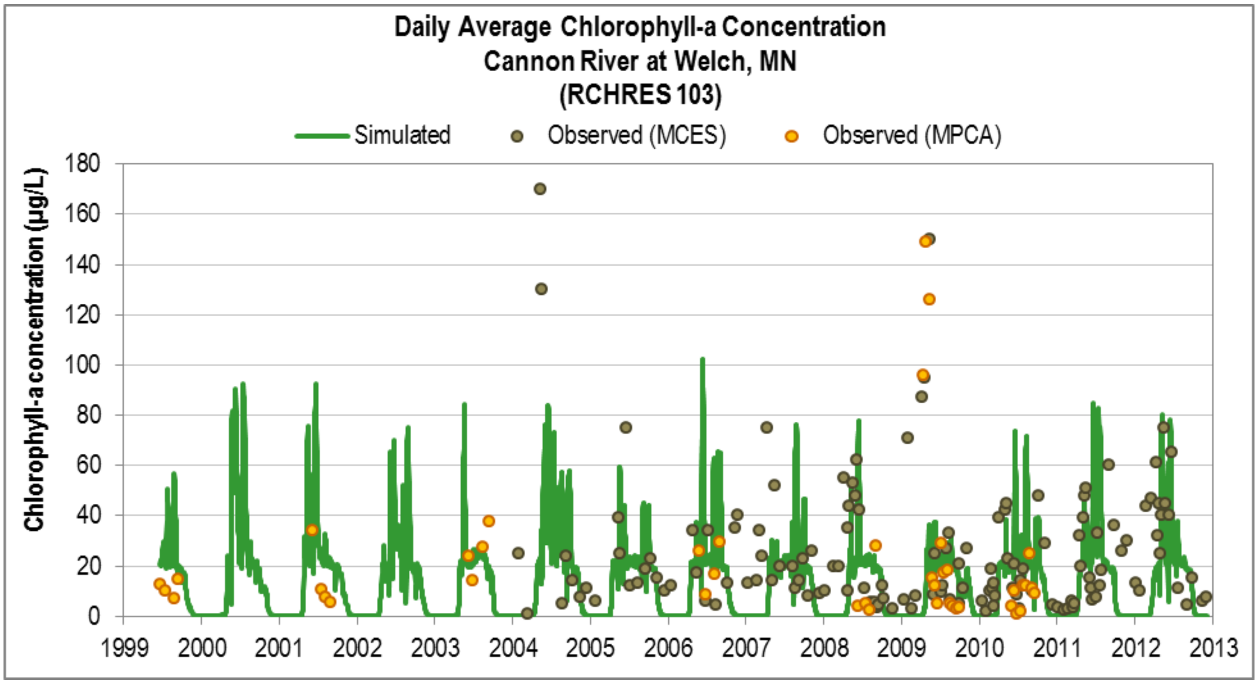

Figure 4-87. Daily Average Phytoplankton Chlorophyll *a* Concentrations for Cannon River at Welch (RCHRES 103)

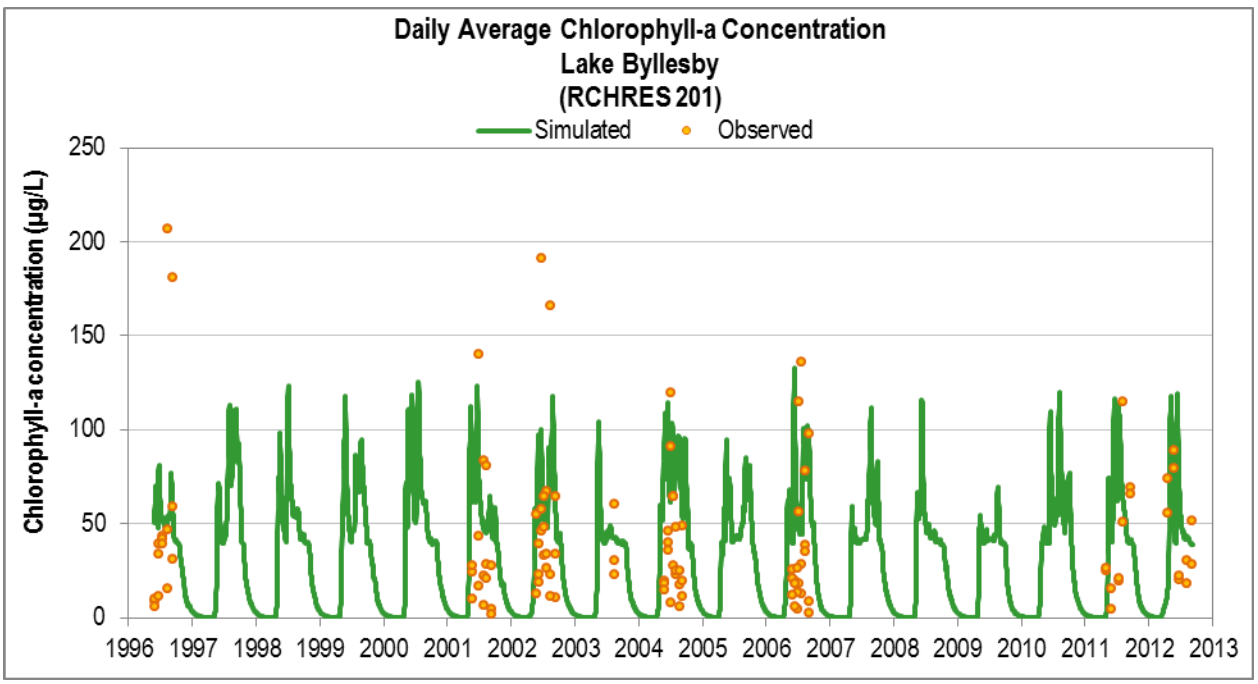

Figure 4-88. Daily Average Chlorophyll *a* Concentrations for Lake Byllesby (RCHRES 201). Note that observed chlorophyll *a* concentrations represent samples from multiple locations from surface depths (i.e., samples from 0-2 meters).

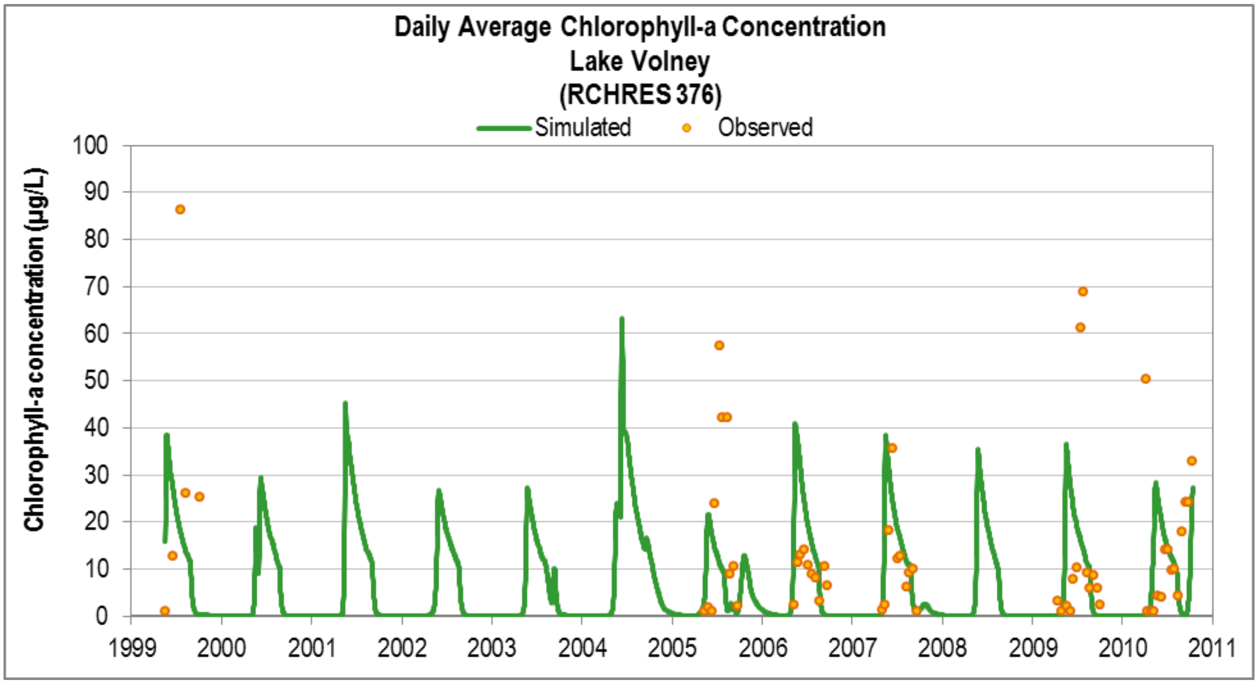

Figure 4-89. Daily Average Phytoplankton Chlorophyll *a* Concentrations for Lake Volney (RCHRES 376). Note that observed chlorophyll *a* concentrations represent samples from surface depths (i.e., samples from 0-2 meters).

5 Summary and Recommendations

An HSPF model of the Cannon River watershed has been developed to simulate hydrology, sediment and suspended solids, water temperature, nutrients (phosphorus and nitrogen), BOD, DO, phytoplankton and benthic algae. The scale of the watershed model is at the HUC8 watershed level with a subbasin delineation intermediate between the HUC12 and HUC16 scale. The model simulation period is from 1995-2012. The model has been successfully calibrated and validated for hydrology, sediment and suspended solids, and water quality.

The Cannon River watershed HSPF model was calibrated and validated using a "weight of evidence" approach, which relies upon several qualitative and quantitative measures to evaluate model performance and serves as a valuable and often standard practice in watershed modeling (USEPA 2006a). Given the multiple lines of evidence examined in this report and past memoranda (LimnoTech 2014a-c, LimnoTech 2014f-k), the Cannon River watershed HSPF model is able to provide a reasonable representation of hydrology, sediment and nutrient loading and delivery, and instream water quality (i.e., water temperature, BOD, DO, algae). Therefore, the Cannon River watershed HSPF model can be used with confidence in the development of future TMDLs, future instream nutrient criteria, and future permitting of MS4 areas and wastewater discharges.

5.1 Model Limitations and Caveats

The following section outlines model limitations and caveats that should be noted in the future application of the Cannon River HSPF model.

- UAL targets were based on broad literature values and other Minnesota models. Ideally, UAL targets would be constrained by site-specific data.
- The sediment calibration and validation is constrained by the limits of TSS data, as well as the limitations of the HSPF model itself, in capturing bedload sediment. Ideally, long-term, direct measurements of suspended sediment concentration (SSC) would be used to calibrate and validate the model to reduce the potential low bias in TSS concentration data and resulting model uncertainty with respect to total sediment transport.
- Limited or no data were available to calibrate and validate orthophosphate, ammonia, BOD, DO, phytoplankton and benthic algae, which means there is more uncertainty associated with the model predictions for these parameters.
- The model cannot represent the complex temperature, nutrient and algal dynamics observed in the lakes, and in particular the thermal stratification of the lakes and resulting gradients of nutrient and DO concentrations. A seasonally variable phosphorus mass flux was added to the model using the "special actions" module to represent the release of phosphorus from the bottom sediments during anoxic conditions. However, these release rates are static and are not

modified by feedback from other model components as they would be if they were represented mechanistically. Therefore, it is important to recognize that these rates will not be adjusted by HSPF if/when the Cannon River model is applied to simulated watershed response to nutrient loading reductions and/or other management scenarios.

- Model instabilities in the water quality simulation were attributed to extreme low flow conditions existing in the model. As noted above, this issue in the Cannon River watershed HSPF model is infrequent and isolated to smaller reach segments. Small adjustments were made to the FTABLES to maintain a small depth of flow at extreme low flow conditions and maintain model stability.
- Simulation of nutrient cycling and eutrophication processes in Lake Byllesby and the upper Cannon lakes are limited by the HSPF model framework. In HSPF, lakes are assumed to be completely mixed with unidirectional flow. Therefore, the variability in vertical lake profiles and horizontal gradients in water quality cannot be represented. A separate modeling effort involving a two- or three-dimensional, linked hydrodynamic/water quality model would be needed to adequately characterize water quality and eutrophication processes in Lake Byllesby and/or the other lakes in the watershed.

5.2 Recommendations

This section outlines recommendations for future model refinement and future application of the Cannon River watershed HSPF model. Recommendations for future model refinement and application are based on “lessons learned” during the process of developing, calibrating and validating the Cannon River watershed HSPF model. These recommendations are provided below.

Model Refinement

- Include a more detailed representation of lake outlet structures, operations, drawdowns and releases if additional data become available.
- Re-evaluate the sediment calibration if additional data become available. Specifically, site specific data were limited with respect to quantifying targets for upland versus bed/bank erosion sources.
- Incorporate new code to represent OLN and OLP as state variables.
- Re-evaluate the nutrient, BOD, DO and phytoplankton and benthic algae simulation if additional data become available.
- Incorporate more detailed point source data, if available, to improve upon current model input assumptions.

Model Application

- The model is suitable to support the development of nutrient TMDLs.
- The model is suitable to address temperature TMDL and reach restoration efforts to reduce temperature and nutrient impairments.
- The model can support the development of wastewater discharge permits.
- The model can support the development of MS4 permits.

- The model is suitable for assessing the impact of reach restoration for flood control on land side load reduction and instream water quality.
- The model could be used to evaluate future instream nutrient criteria.

The Cannon River watershed HSPF model's limitations with respect to simulating water quality and eutrophication conditions in the lakes in the watershed (e.g. Lake Byllesby, etc.) are noted above. If sedimentation and/or eutrophication (e.g., persistent algae bloom) issues need to be addressed for Lake Byllesby and/or other lake(s) in the watershed, and if supporting water quality data are deemed to be sufficient, it is recommended that a separate, targeted modeling study be conducted to support evaluations for those lake(s). An appropriate modeling framework for Lake Byllesby (or other lakes in the watershed) would include linked hydrodynamic/sediment transport/water quality models and either a two- or three-dimensional gridded representation of the lake. Modeling frameworks that meet these criteria and could potentially be developed, calibrated, and applied include LimnoTech's linked EFDC-A2EM modeling framework and USEPA's EFDC-WASP7 linked modeling framework.

6 References

AQUA TERRA Consultants. 2012. Modeling Guidance for BASINS/HSPF Applications Under the MPCA One Water Program. Submitted to Charles Regan, Ph.D., Minnesota Pollution Control Agency, St. Paul, MN. MPCA Contract No. 20625, Work Order No. 37684, ATC Project No. 21 003-04. June 29, 2012.

Bicknell, B.R, Imhoff, J.C., Kittle, J.L. Jr., Jobes, T.H. and A.S. Donigian. 2005. HYDROLOGICAL SIMULATION PROGRAM – FORTRAN, HSPF Version 12.2 User's Manual. Prepared by AQUA TERRA Consultants, Mountain View, CA. In Cooperation with the U.S. Geological Survey, Reston, VA and the U.S. Environmental Protection Agency, Athens, GA. July 2005.

Belmont, P. 2011. Sediment fingerprinting for sources and transport pathways in the Root River, southeastern Minnesota. Final project report.

Belmont, P. 2012. Tracing sediment sources with meteoric 10Be: Linking erosion and the hydrograph. Final project report. June 20, 2012.

Cannon River Watershed Partnership (CRWP). 2007. Total Maximum Daily Load Evaluation of Turbidity Impairments in the Lower Cannon River. Final report prepared for Minnesota Pollution Control Agency (MPCA). June 26, 2006, Final July 2007.

Cannon River Watershed Partnership (CRWP). 2009. Lower Cannon River Turbidity TMDL Implementation Plan. Submitted to the Minnesota Pollution Control Agency. October 2009.

Cannon River Watershed Partnership (CRWP). 2011. Cannon River Watershed Management Strategy 2011-2015. June 30, 2011.

Cannon River Watershed Partnership (CRWP). 2013. Rice Creek Assessment Project Resources Investigation, Clean Water Partnership. Part 1 – Diagnostic Study. July 13, 2013. Sponsored by Bridgewater Township (Rice County).

Carlson, B., Jasperson, J., Kjerland, T. and N. Smits. 2004. The Cannon River: An Overview of the Physical Characteristics and Management of the Watershed. Prepared by students in BIO 285: Water Resources Management at St. Olaf College.

Charles-Guzman, K., Cooper, J., Hodo, R., Kaba, C. and E. Kim. 200X. Geomorphology and Water Quality of the Wolf Creek Basin Within the Cannon River Watershed, Minnesota. Provided to LimnoTech by MPCA May 13, 2014.

Donigian, A.S. 2000. HSPF Training Workshop Handbook and CD. Lecture #19. Calibration and Verification Issues, Slide #19-22. EPA Headquarters, Washington Information Center, 10-14 January, 2000. Presented and prepared for U.S. EPA, Office of Water, Office of Science and Technology, Washington, D.C.

Donigian, A.S. 2002. Watershed Model Calibration and Validation: The HSPF Experience. WEF National TMDL Science and Policy 2002, November 13-16, 2002. Phoenix, AZ. WEF Specialty Conference Proceedings on CD-ROM.

Donigian, A. S., Imhoff, J.C., B. R. Bicknell, B.R. and J. L. Kittle. 1984. Application Guide for the Hydrological Simulation Program–FORTRAN, EPA 600/3-84-066, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Duda, P.B., Hummel, P.R., Donigian, A.S. and J.C. Imhoff. 2012. BASINS/HSPF: Model Use, Calibration, and Validation. American Society of Agricultural and Biological Engineers, 55(4): 523-1547.

Gupta, H.V., Sorooshian, S., and P.O. Yapo.1999. Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. Journal of Hydrologic Engineering, 4(2): 135-143.

Hamon, R.W. 1961. Estimating Potential Evapotranspiration. Proceedings of the American Society of Civil Engineers; Journal of the Hydraulic Division, 87(HY3):107-120.

Kelly, D.W. and E.A. Nater. 2000. Source apportionment of lake bed sediments to watersheds in an Upper Mississippi basin using a chemical mass balance method. Catena, 41:277-292.

Kolander, T. 2010. Straight River Geomorphic Assessment. Power Point provided by MPCA, undated.

Le Sueur County. 2010. Upper Cannon River Watershed Assessment Report Diagnostic Report. April 2010.

LimnoTech. 2014a. Task 1 – Compile Geographic and Time Series Data Required to Construct Model Framework. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). January 31, 2014.

LimnoTech. 2014b. Task 2 Part 1 – Develop Representation of Watershed Area and Drainage Network. Part 1: Inventory of Climate Data. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). April 28, 2014.

LimnoTech. 2014c. Task 4 – Formulate Time Series from Observed Streamflow and Water Quality Monitoring for Watershed Model Calibration and Validation. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). April 28, 2014.

LimnoTech. 2014d. Zumbro River Watershed HSPF Model Development Project. Final report prepared for Minnesota Pollution Control Agency (MPCA). May 12, 2014.

LimnoTech. 2014e. Little Cannon River Watershed SWAT Modeling Task 1 – Complete the Construction, Calibration and Confirmation of the SWAT Model. Technical memorandum prepared for MPCA. June 20, 2014.

LimnoTech. 2014f. Task 2 Part 2 - Develop Representation of Watershed Area and Drainage Network. Part 2: Functioning Cannon River HSPF Model for Hydrology . Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). June 30, 2014.

LimnoTech. 2014g. Task 3 – Develop Major and Minor Point Source Inputs. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). August 21, 2014.

LimnoTech. 2014h. Task 5 Part 1: Perform Hydrologic Calibration and Validation, and Provide Water Balance. Part 1: Summarize Calibration Approach. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). July 17, 2014.

LimnoTech. 2014i. Task 5 Part 2-3 – Perform Hydrologic Calibration and Validation, and Provide Water Balance Part 2-3: Conduct Hydrologic Calibration and Validation. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). October 13, 2014.

LimnoTech. 2014j. Task 6-1: Representation of Sediment Sources and Dynamics for the Cannon River Watershed HSPF Model. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). October 27, 2014.

LimnoTech. 2014k. Task 6 – Define Sources of Sediment within the Cannon River Watershed and Conduct Sediment Calibration and Validation Tests, Task 6-2: Conduct Sediment Calibration and Validation. Memorandum prepared by LimnoTech for the Minnesota Pollution Control Agency (MPCA). December 5, 2014.

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

Metropolitan Council Environmental Services (MCES). 2014. River Pollutant Load Data. Annual and monthly Excel files downloaded from http://es.metc.state.mn.us/eims/ExcelLoads/index.asp. Last updated 1/17/2014.

Minnesota Department of Natural Resources. 2013a. The DNR Data Deli. URL: http://deli.dnr.state.mn.us/index.html. Accessed November 2013.

Minnesota Department of Natural Resources. 2013b. Water use - Water Appropriations Permit Program. ArcView shapefiles of water appropriation installation locations. URL: http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html. Accessed [June 14, 2013].

Minnesota Department of Natural Resources. 2014. LakeFinder. URL: http://www.dnr.state.mn.us/lakefind/index.html. Accessed March-April 2014.

Minnesota Pollution Control Agency (MPCA). 2005. 2003 Lake Assessment Program of Lake Tetonka, Upper Sakatah Lake, Lower Sakatah Lake. Report prepared by MPCA and Waterville Lakes Assocation. August 2005.

Minnesota Pollution Control Agency (MPCA). 2013a. Byllesby Reservoir Phosphorus TMDL Report. Report prepared by MPCA and CRWP. May 2013.

Minnesota Pollution Control Agency (MPCA). 2013b. Spatial Data. Animal Feedlots. URL: http://www.pca.state.mn.us/index.php/data/spatial-data.html?show_descr=1. Accessed [January 8, 2013].

Minnesota Pollution Control Agency (MPCA). 2014a. Cannon River Watershed Monitoring and Assessment Report. June 2014.

Minnesota Pollution Control Agency (MPCA). 2014b. Map shapefiles which represent the current Inventory of Impaired Waters (per Section 303(d) Clean Water Act), including lakes, streams, and wetlands. URL: http://www.pca.state.mn.us/index.php?option=com_k2&view=item&id=2211. Accessed [April 2014].

Minnesota Pollution Control Agency (MPCA). 2014c. Upper Cannon Lakes Excess Nutrient Total Maximum Daily Load Study: Lake Volney. July 2014. Prepared by Joe Pallardy, Water Resources Center, Minnesota State University, Mankato, MN.

Minnesota Pollution Control Agency (MPCA). 2014d. Upper Cannon Lakes Excess Nutrient Total Maximum Daily Load Study: Jefferson-German Lake Chain. July 2014. Prepared by Joe Pallardy, Water Resources Center, Minnesota State University, Mankato, MN.

Minnesota Pollution Control Agency (MPCA). 2014e. “Minnesota Department of Health 2012 Change in Total Phosphorus Analytical Method”. Memorandum from Steve Heiskary to Glenn Skuta, August 1, 2014.

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

Multi-Resolution Land Characteristics (MRLC) Consortium. 2014. National Land Cover Database (NLCD). URL: http://www.mrlc.gov/index.php. Last Updated [March 13, 2014].

Murphy, P. and J. Harner, 2001. Lesson 22: Open Lot Runoff Management Options, Livestock and Poultry Environmental Stewardship Curriculum, Kansas State University, Midwest Plan Service, Iowa State University, Ames, IA.

Nash, J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part 1. A discussion of principles. Journal of Hydrology, 10(3): 282-290.

National Atmospheric Deposition Program (NADP). 2012. National Trends Network (NTN). URL: http://nadp.sws.uiuc.edu/data/ntndata.aspx. Accessed [June 29, 2014].

National Oceanic and Atmospheric Administration (NOAA). 2013a. National Climatic Data Center (NCDC). URL: http://www.ncdc.noaa.gov/. Accessed [December 24, 2013].

Parajuli, P.B., Nelson, N.O., Frees, L.D. and K.R. Mankin. 2009, Comparison of AnnAGNPS and SWAT model simulation results in USDA-CEAP agricultural watersheds in south-central Kansas. Hydrological Processes, 23: 748- 763.

RESPEC. 2012a. HSPF Modeling of the Sauk River, Crow River, and South Fork Crow River. Prepared by RESPEC Consulting & Services, Rapid City, SD. Prepared for Minnesota Pollution Control Agency, St. Paul, MN. Topical Report RSI-2292. July 2012.

RESPEC. 2012b. Internal Lake Loading for the Sauk, North Crow, and South Crow HSPF Watershed Models. Memorandum prepared for MPCA. July 6 2012.

Runkel R.L., Crawford, C.G. and T.A. Cohn. 2004. Load Estimator (LOADEST): A Fortran Program for Estimating Constituent Loads in Streams and Rivers. U.S. Geological Survey, Techniques and Methods Book 4, Chapter A5.

Runkel R.L. 2013. Revisions to LOADEST, April 2013. URL: http://water.usgs.gov/software/loadest/doc/loadest_update.pdf [Accessed September 30, 2014]

Savina M.E., Gardner, T. and H. Bereket . 200X. Geomorphology and Watershed Studies of the Cannon River and its Tributaries: Wolf Creek, Rice Creek and Heath Creek. Provided to LimnoTech by MPCA May 13, 2014.

Schottler, S.P., Engstrom, D.R., and D. Blumentritt. 2010. Fingerprinting Sources of Sediment in Large Agricultural River Systems. Final report prepared by the St. Croix Watershed Research Station. August 1.

Stout, J.C. 2012. Identifying and quantifying sediment sources and sinks in the Root River, southeastern Minnesota. Final thesis submitted to Utah State University in partial fulfillment of requirements for a M.S. in Watershed Science.

Tetra Tech. 2009. Minnesota River Basin Turbidity TMDL and Lake Pepin Excessive Nutrient TMDL, Model Calibration and Validation Report. Prepared by Tetra Tech, Research Triangle Park, NC. Prepared for Minnesota Pollution Control Agency, St. Paul, MN. June 5, 2009.

Tetra Tech. 2012. Chippewa River Detailed HSPF Model. Prepared by Tetra Tech, Research Triangle Park, NC. Prepared for Minnesota Pollution Control Agency, St. Paul, MN. June 29, 2012.

Tetra Tech. 2013. Root River Model Calibration. Prepared by Tetra Tech, Research Triangle Park, NC. Prepared for USEPA Region 5 and Minnesota Pollution Control Agency, Rochester, MN. April 10, 2013.

Turowski, J.M., Rickenmann, D., and Dadson, S.J. 2010. The Partitioning of the Total Sediment Load of a River Into Suspended Load and Bedload—a Review of Empirical Data. Sedimentology. Volume 57, Issue 4, pp. 1126-1146.

University of Minnesota. 2012. Assessment of Non-point Sediment Sources in the Little Cannon River and Belle Creek Subwatersheds. Draft Report prepared for submission to the Cannon River Watershed Partnership. December 2012.

U.S. Department of Agriculture National Resource Conservation Service (USDA NRCS). 2007. Rapid Watershed Assessment Cannon River (MN) HUC: 07040002. Retrieved from http://www.mn.nrcs.usda.gov/technical/rwa/Assessments/07040002.html.

U.S. Department of Agriculture National Resource Conservation Service (USDA NRCS). 2012. Soil Survey Geographic (SSURGO) Database. URL: http://datagateway.nrcs.usda.gov/. Accessed [November 1, 2013].

U.S. Department of Agriculture National Resource Conservation Service (USDA NRCS). 2013. The Geospatial Data Gateway (GDG).URL: http://datagateway.nrcs.usda.gov/. Accessed [November 1, 2013].

U.S. Environmental Protection Agency (USEPA). 1999. Technical Note 1 Creating Hydraulic Function Tables (FTABLES) for Reservoirs in BASINS. U.S. Environmental Protection Agency, Office of Water. EPA-823-R-99-006. January 1999.

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

USEPA. 2006a. BASINS Technical Note 8 Sediment Parameter and Calibration for HSPF. U.S. Environmental Protection Agency, Office of Water. January 2006.

USEPA. 2006b. WASP7 Benthic Algae -Model Theory and User's Guide. Supplement to Water Quality Analysis Simulation Program (WASP) User Documentation. U.S. Environmental Protection Agency, Office of Research and Development. EPA 600/R-06/106. September 2006.

USEPA. 2009. Guidance on the Development, Evaluation, and Application of Environmental Models. Council for Regulatory Environmental Modeling, U.S. Environmental Protection Agency, Washington, DC.

USEPA. 2010. Better Assessment Science Integrating Point and Nonpoint Sources, BASINS Version 4.0 User's Manual. United State Environmental Protection Agency, Office of Water, EPA-823-C-07-001, March 2007. URL: http://www.epa.gov/ost/basins. Last Updated [April 2010].

USEPA. 2012. Clean Air Status and Trends Network (CASTNET) URL: http://epa.gov/castnet/javaweb/index.html. Accessed [June 29, 2014].

USEPA. 2013. BASINS Download and Installation. URL: http://water.epa.gov/scitech/datait/models/basins/download.cfm. Last Updated [September 18, 2013].

U.S. Geological Survey (USGS) and USEPA. 2012. NHDPlus Version 2: User Guide (Data Model Version 2.1). URL: http://www.horizon-systems.com/nhdplus/. Accessed [November 11, 2013].

U.S. Geological Survey (USGS). 2000. USGS Policy: Collection and Use of Total Suspended Solids Data, November 27, 2000. Offices of Water Quality and Surface Water Technical Memorandum.

U.S. Geological Survey (USGS). 2010. Bedload-Surrogate Monitoring Technologies. Scientific Investigations Report 2010-5091.

U.S. Geological Survey (USGS). 2014a. The National Map (USGS). URL: http://nationalmap.gov/ Accessed [November 5, 2014].

U.S. Geological Survey (USGS). 2014b. Evapotranspiration and Droughts. URL: http://geochange.er.usgs.gov/sw/changes/natural/et [Accessed October 8, 2014].

Appendix A
Hydrology Simulation for Auxiliary Stations

Table A-1. Calibration period (2004-2012) statistics.

Time Interval	Statistic	Cannon River at Northfield	Cannon River at Morristown	Little Cannon at Cannon Falls
Annual	*Count*	9	5	6
	R-Squared	0.69	0.93	0.64
	Nash-Sutcliffe Efficiency	0.65	0.84	0.48
	Relative Percent Difference	11.9%	36.9%	-6.0%
	Relative Percent Error	15.9%	75.9%	-5.4%
Monthly	*Count*	108	25	54
	R-Squared	0.75	0.78	0.54
	Nash-Sutcliffe Efficiency	0.74	0.77	0.43
	P-Bias	-6.41	-3.25	6.19
	Relative Percent Difference	23.3%	49.2%	-9.1%
	Relative Percent Error	49.5%	840.4%	0.1%
Daily	*Count*	3201	535	1444
	R-Squared	0.66	0.60	0.33
	Nash-Sutcliffe Efficiency	0.62	0.54	0.21
	Relative Percent Difference	26.3%	47.0%	-9.5%
	Relative Percent Error	64.7%	1595.5%	8.2%
25th percentile low flow	*Relative Percent Difference*	57.0%	143.8%	-6.4%
	Relative Percent Error	79.7%	512.0%	-6.2%
90th percentile high flow	*Relative Percent Difference*	-11.7%	2.9%	-3.0%
	Relative Percent Error	-11.0%	3.0%	-2.9%

Table A-2. Calibration period (2004-2012) observed and simulated streamflow.

	Cannon River at Northfield		Cannon River at Morristown		Little Cannon at Cannon Falls	
	Observed	*Simulated*	*Observed*	*Simulated*	*Observed*	*Simulated*
	cfs	*cfs*	*cfs*	*cfs*	*cfs*	*cfs*
Average	546	581	120	124	67	62
Minimum	27	39	0	1	9	18
10th percentile	69	103	0	14	22	22
25th percentile	107	192	4	24	27	25
Median	270	359	27	68	47	43
75th percentile	653	623	207	187	72	58
90th percentile	1370	1219	303	312	127	123
Maximum	7054	9440	471	897	1810	888

Table A-3. Validation period (1996-2003) statistics.

Time Interval	Statistic	Cannon River at Northfield	Little Cannon at Cannon Falls
Annual	*Count*	4	2
	R-Squared	0.98	1.00
	Nash-Sutcliffe Efficiency	0.98	0.49
	Relative Percent Difference	1.1%	7.2%
	Relative Percent Error	1.5%	7.5%
Monthly	*Count*	42	17
	R-Squared	0.90	0.92
	Nash-Sutcliffe Efficiency	0.88	0.88
	P-Bias	-2.97	-7.68
	Relative Percent Difference	12.0%	1.2%
	Relative Percent Error	26.7%	4.6%
Daily	*Count*	1259	455
	R-Squared	0.80	0.77
	Nash-Sutcliffe Efficiency	0.80	0.72
	Relative Percent Difference	10.6%	-1.2%
	Relative Percent Error	29.4%	4.7%
25th percentile low flow	*Relative Percent Difference*	14.5%	-4.8%
	Relative Percent Error	15.6%	-4.7%
90th percentile high flow	*Relative Percent Difference*	6.8%	24.2%
	Relative Percent Error	7.0%	27.5%

Table A-4. Validation period (1996-2003) observed and simulated streamflow.

	Cannon River at Northfield		Little Cannon at Cannon Falls	
	Observed	Simulated	Observed	Simulated
	cfs	cfs	cfs	cfs
Average	511	526	49	52
Minimum	66	30	15	17
10th percentile	94	94	19	20
25th percentile	144	166	24	23
Median	265	298	37	37
75th percentile	348	503	49	45
90th percentile	1128	1207	81	104
Maximum	7032	8473	729	609

Table A-5. Full simulation period (1996-2012) statistics.

Time Interval	Statistic	Cannon River at Northfield	Cannon River at Morristown	Little Cannon at Cannon Falls
Annual	Count	13	5	8
	R-Squared	0.79	0.93	0.78
	Nash-Sutcliffe Efficiency	0.77	0.84	0.72
	Relative Percent Difference	8.7%	36.9%	-2.7%
	Relative Percent Error	11.6%	75.9%	-2.2%
Monthly	Count	150	25	71
	R-Squared	0.80	0.78	0.61
	Nash-Sutcliffe Efficiency	0.80	0.77	0.54
	P-Bias	-5.59	-3.25	3.59
	Relative Percent Difference	20.3%	49.2%	-6.6%
	Relative Percent Error	43.3%	840.4%	1.2%
Daily	Count	4460	535	1899
	R-Squared	0.70	0.60	0.38
	Nash-Sutcliffe Efficiency	0.68	0.54	0.27
	Relative Percent Difference	21.9%	47.0%	-7.5%
	Relative Percent Error	54.9%	1595.5%	7.4%
25th percentile low flow	Relative Percent Difference	42.8%	143.8%	-4.9%
	Relative Percent Error	54.5%	512.0%	-4.8%
90th percentile	Relative Percent Difference	-9.9%	2.9%	2.9%
	Relative Percent Error	-9.4%	3.0%	3.0%

high flow				

Table A-6 . Full simulation (1996-2012) observed and simulated streamflow.

	Cannon River at Northfield		Cannon River at Morristown		Little Cannon at Cannon Falls	
	Observed	*Simulated*	*Observed*	*Simulated*	*Observed*	*Simulated*
	cfs	*cfs*	*cfs*	*cfs*	*cfs*	*cfs*
Average	536	566	120	124	62	60
Minimum	27	30	0	1	9	17
10th percentile	76	101	0	14	21	21
25th percentile	120	186	4	24	26	25
Median	269	341	27	68	44	41
75th percentile	555	596	207	187	68	54
90th percentile	1339	1215	303	312	115	119
Maximum	7054	9440	471	897	1810	888

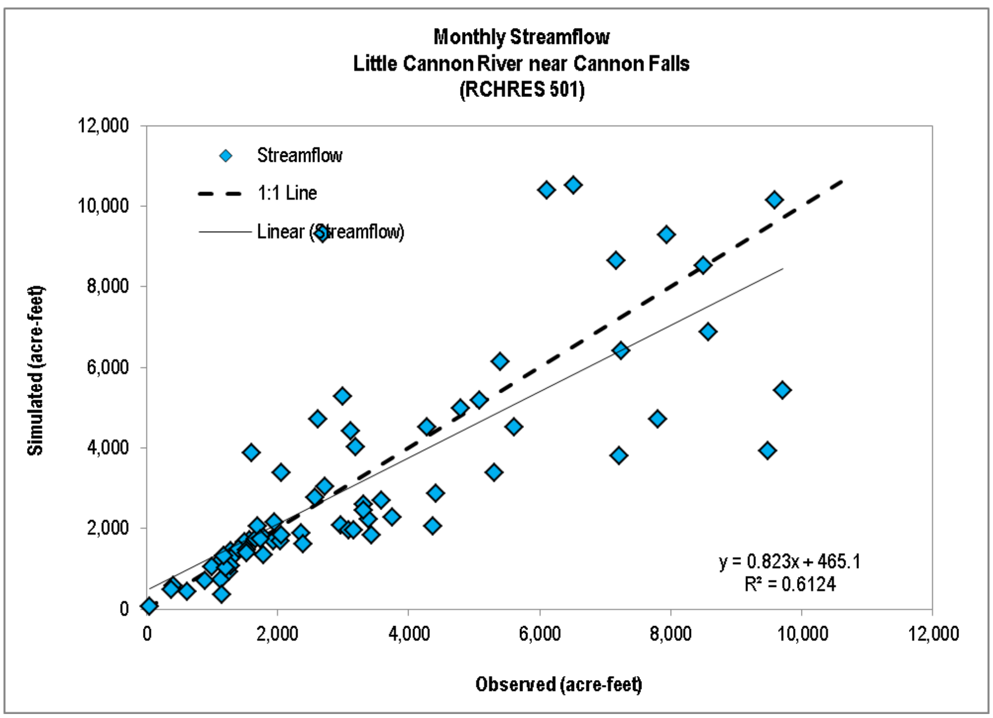

Figure A-1. Monthly Streamflow 1:1 Plot for Little Cannon River near Cannon Falls (Gage #H39016001)

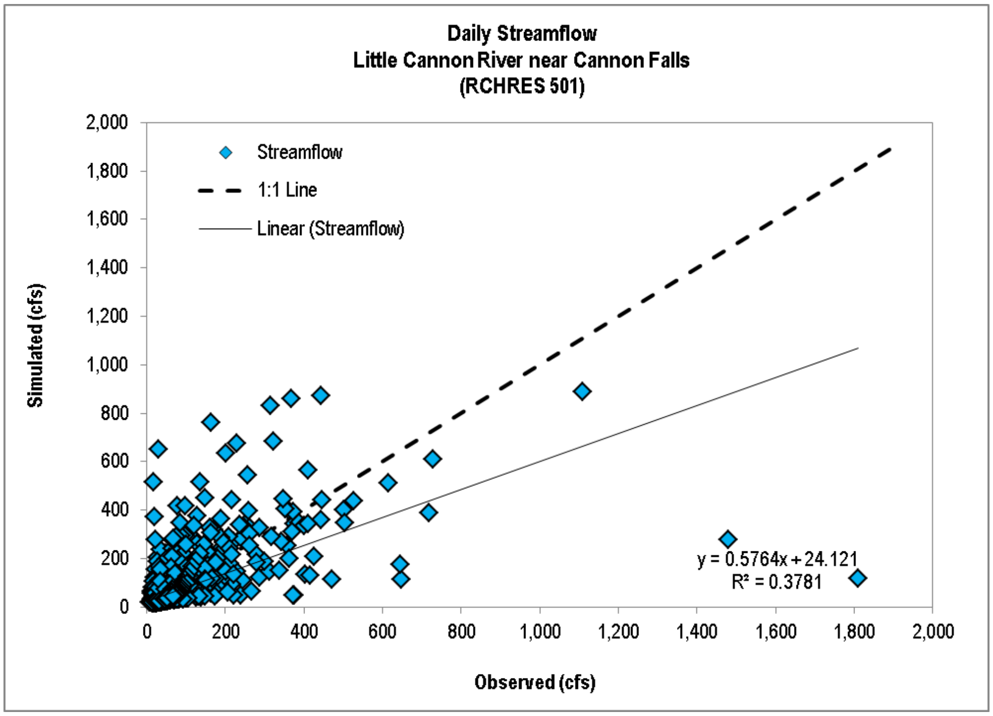

Figure A-2. Daily Streamflow 1:1 Plot for Little Cannon River near Cannon Falls (Gage #H39016001)

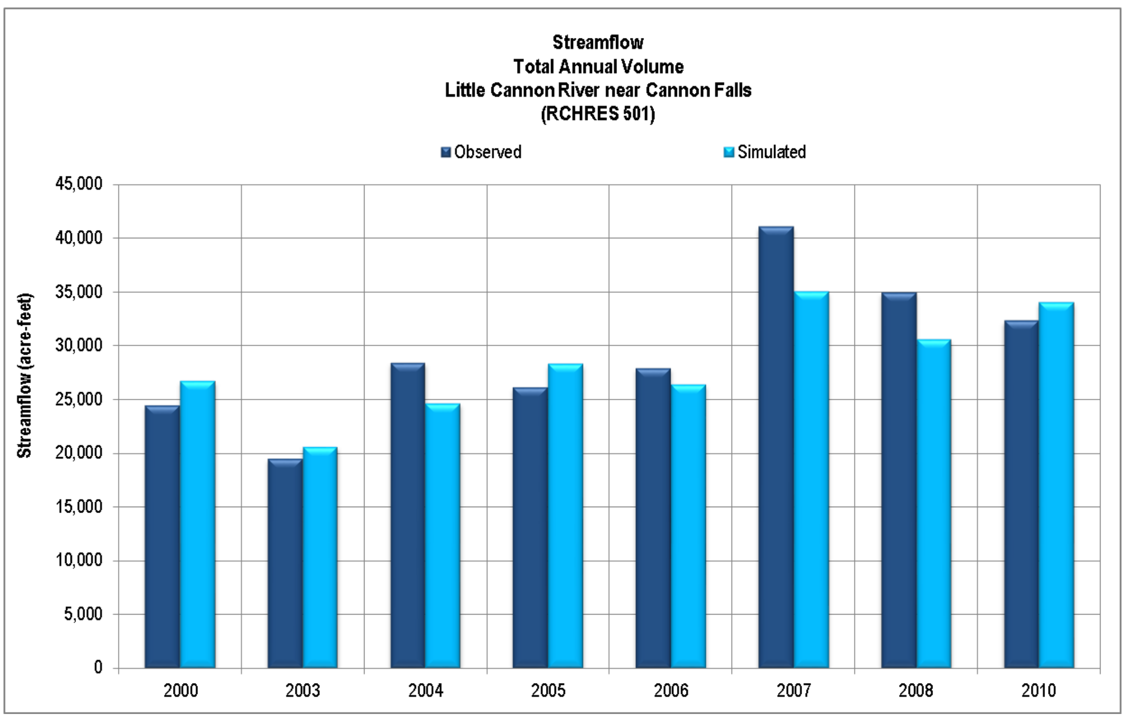

Figure A-3. Streamflow Total Annual Volume for Little Cannon River near Cannon Falls (Gage #H39016001)

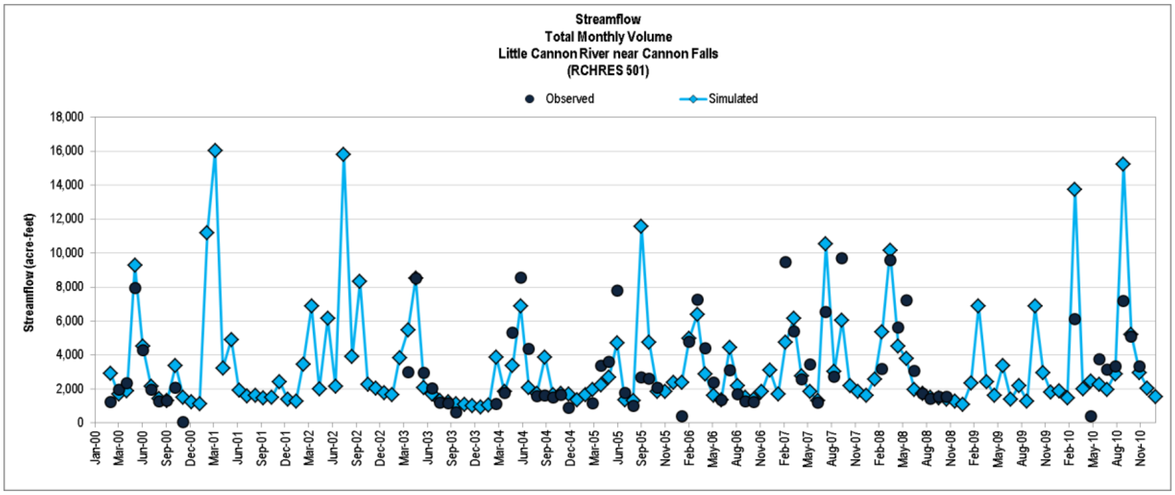

Figure A-4. Streamflow Total Monthly Volume for Little Cannon River near Cannon Falls (Gage #H39016001)

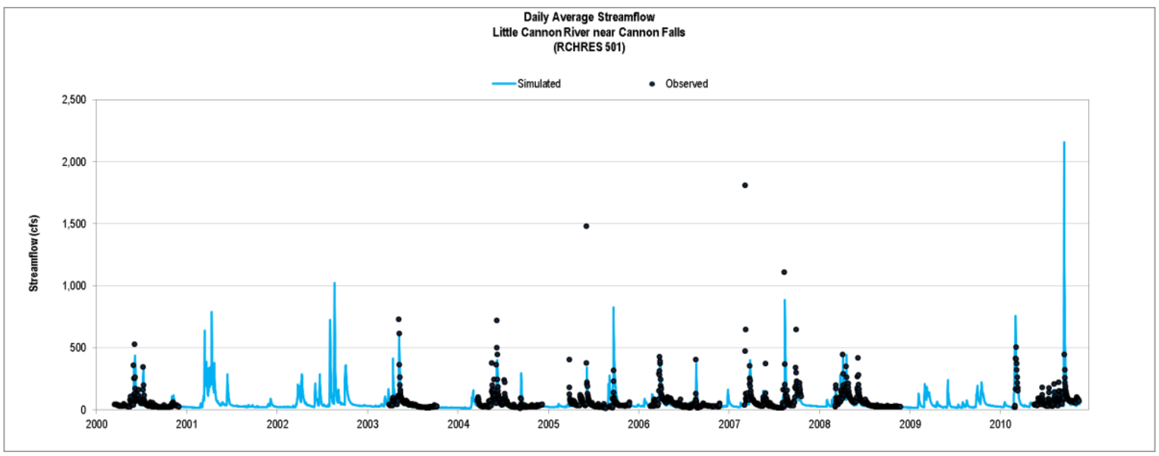

Figure A-5. Streamflow Total Daily Volume for Little Cannon River near Cannon Falls (Gage #H39016001)

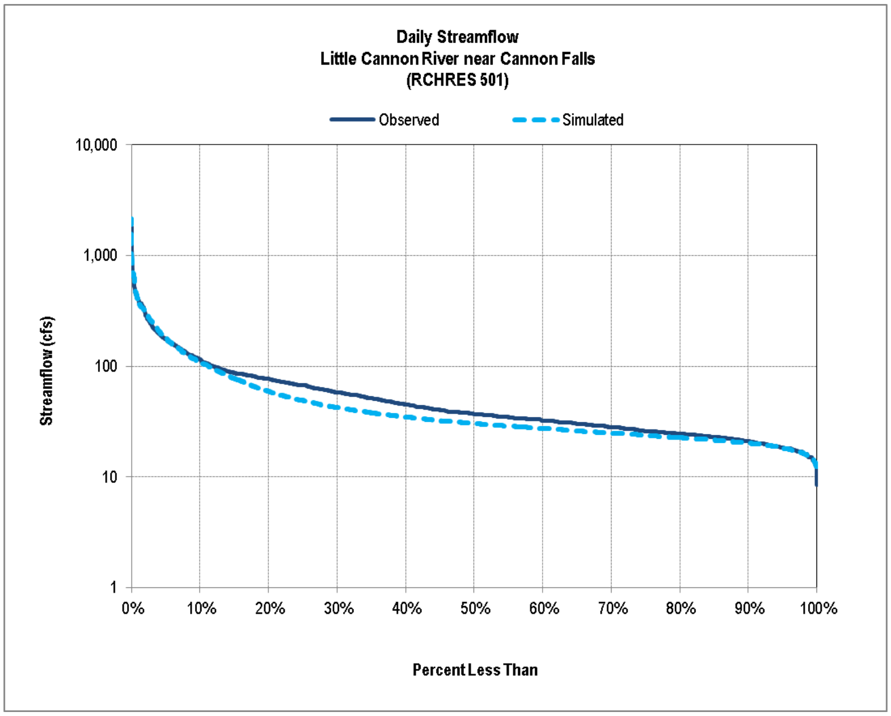

Figure A-6. Daily Streamflow Cumulative Frequency Distribution for Little Cannon River near Cannon Falls (Gage #H39016001)

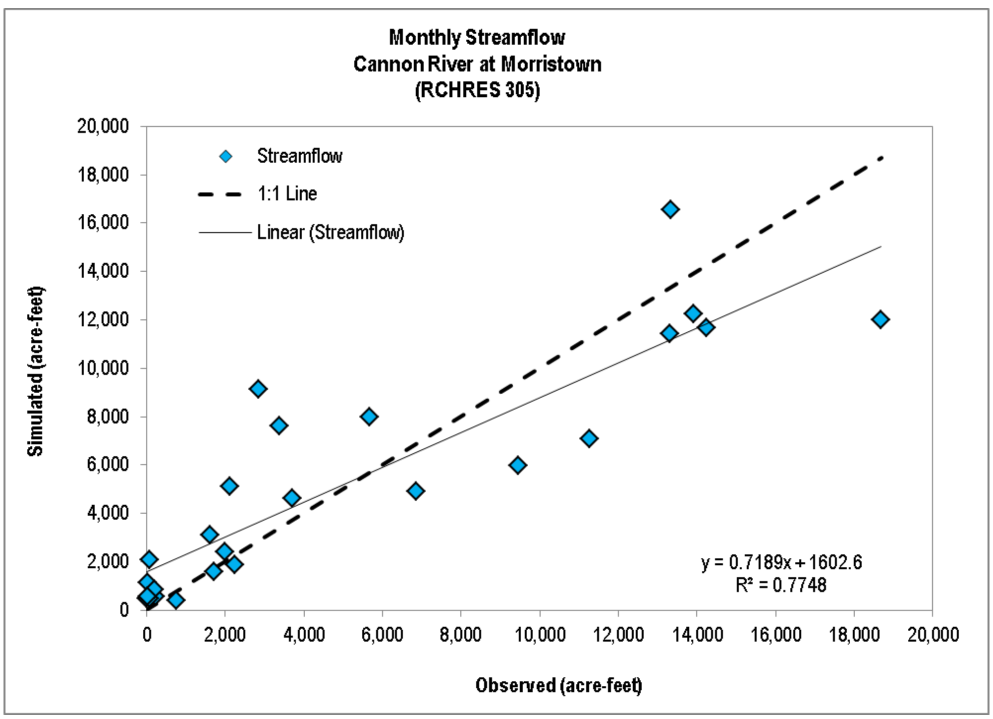

Figure A-7. Monthly Streamflow 1:1 Plot for Cannon River at Morristown (Gage #H39091001)

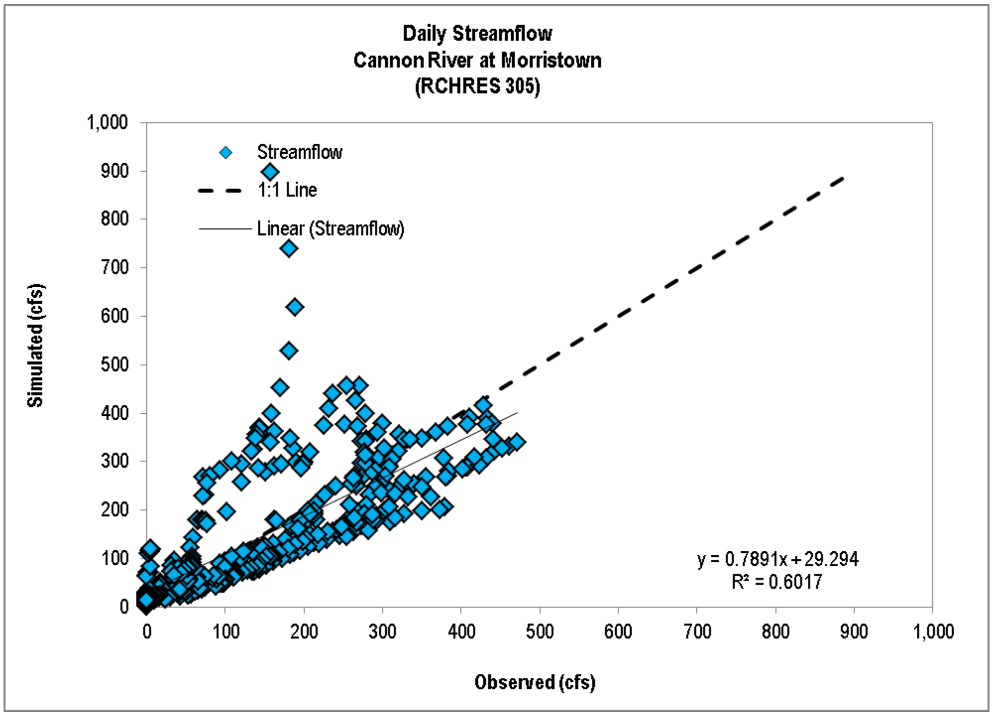

Figure A-8. Daily Streamflow 1:1 Plot for Cannon River at Morristown (Gage #H39091001)

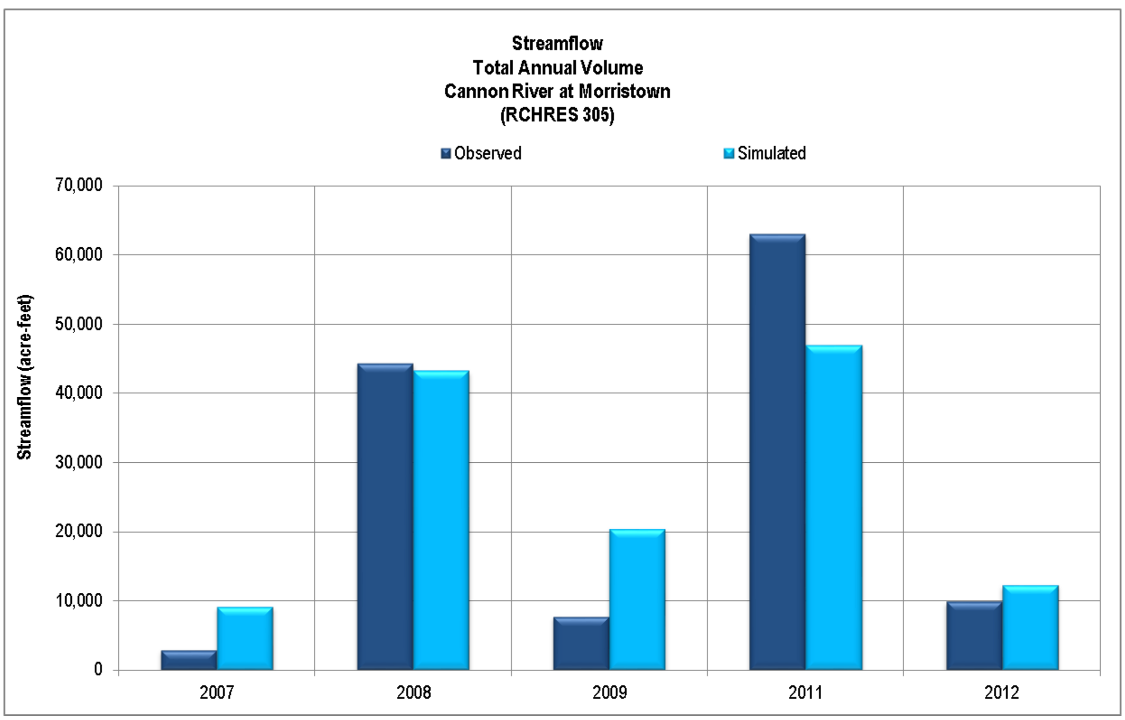

Figure A-9. Streamflow Total Annual Volume for Cannon River at Morristown (Gage #H39091001)

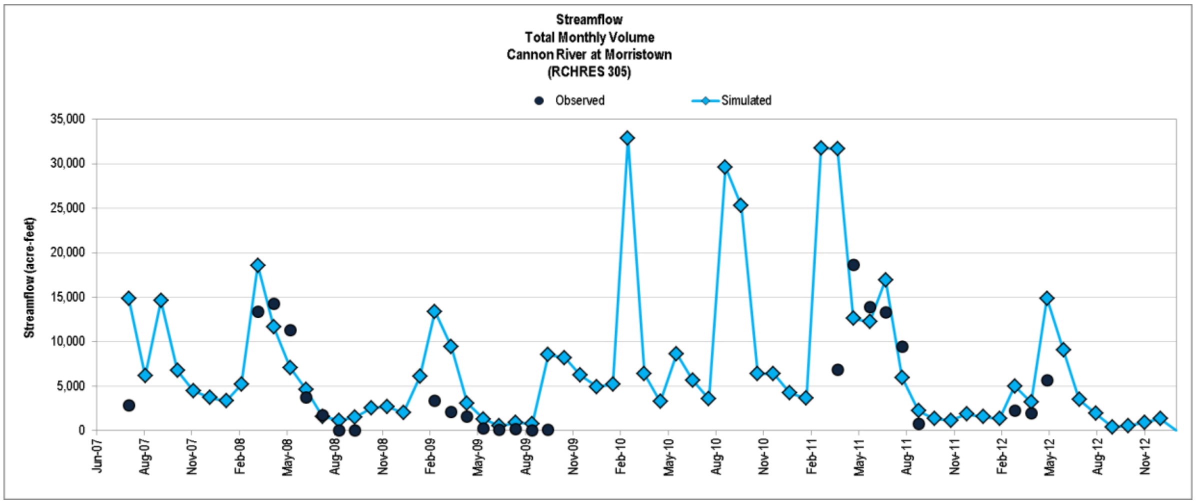

Figure A-10. Streamflow Total Monthly Volume for Cannon River at Morristown (Gage #H39091001)

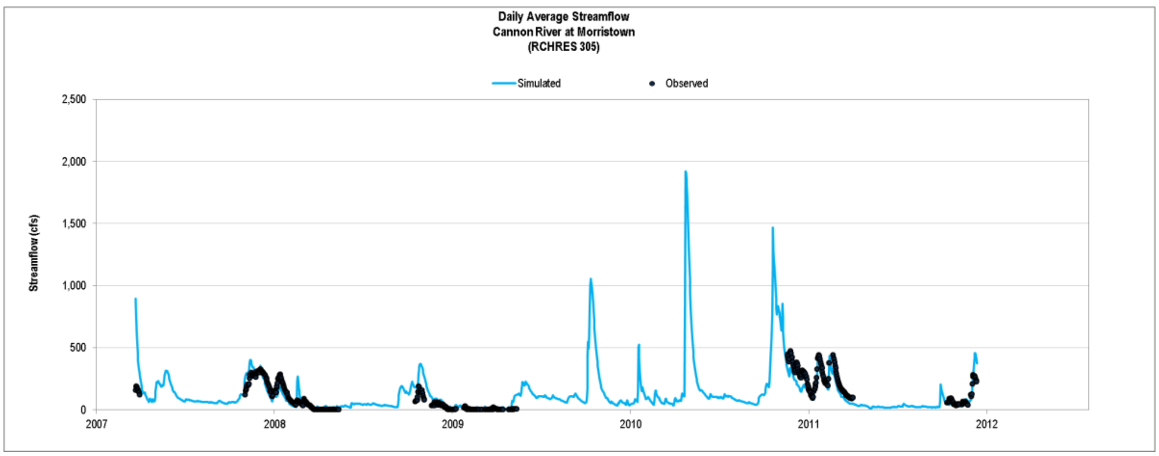

Figure A-11. Streamflow Total Daily Volume for Cannon River at Morristown (Gage #H39091001)

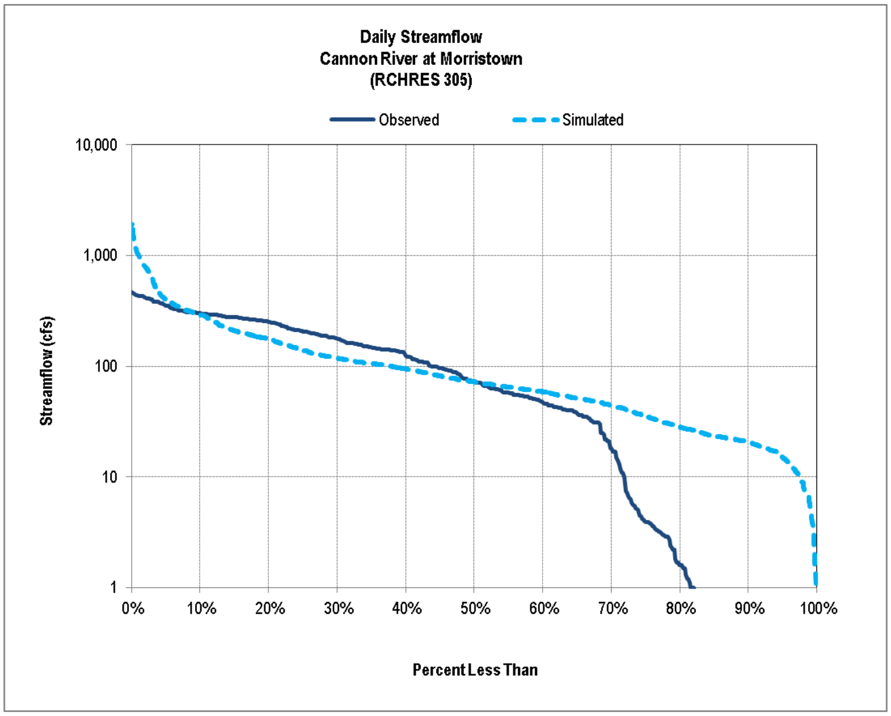

Figure A-12. Daily Streamflow Cumulative Frequency Distribution for Cannon River at Morristown (Gage #H39091001)

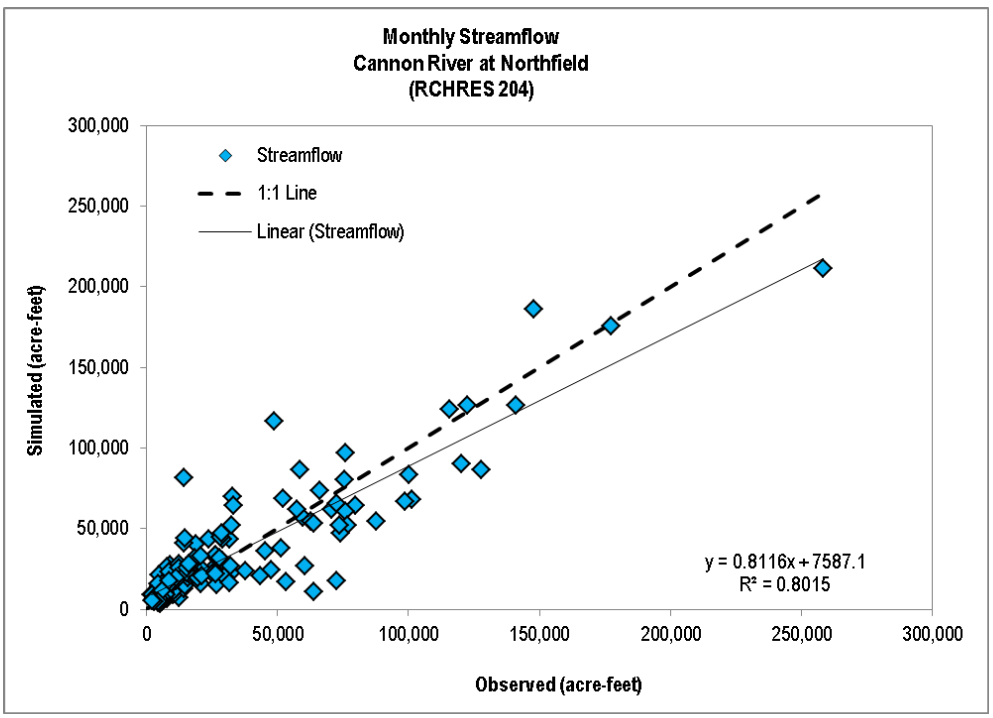

Figure A-13. Monthly Streamflow 1:1 Plot for Cannon River at Northfield (Gage #H39069001)

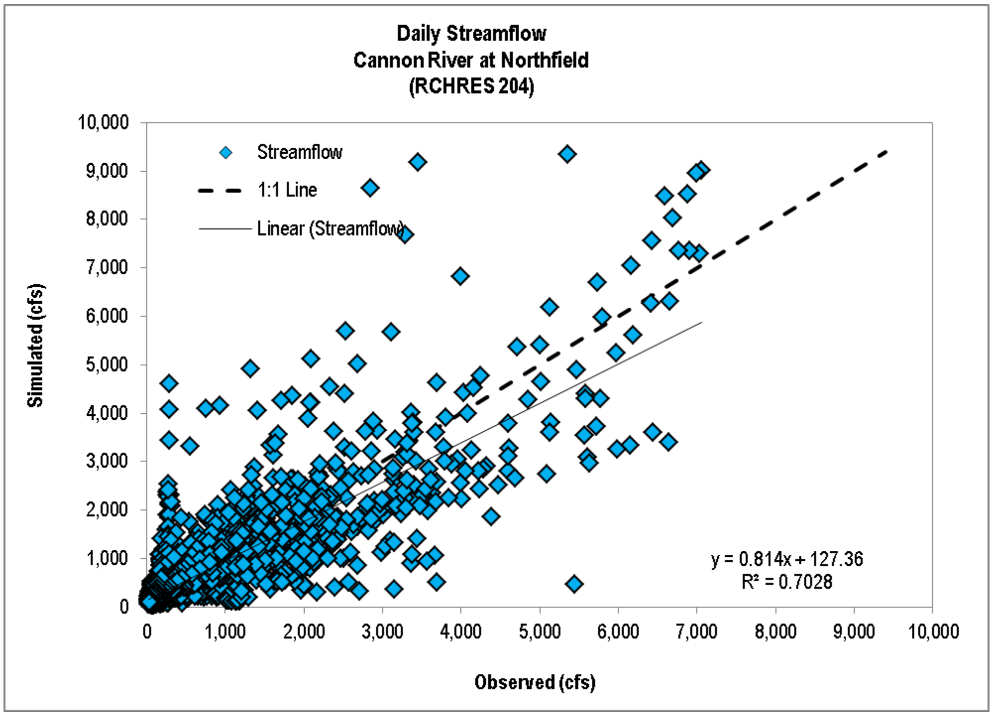

Figure A-14. Daily Streamflow 1:1 Plot for Cannon River at Northfield (Gage #H39069001)

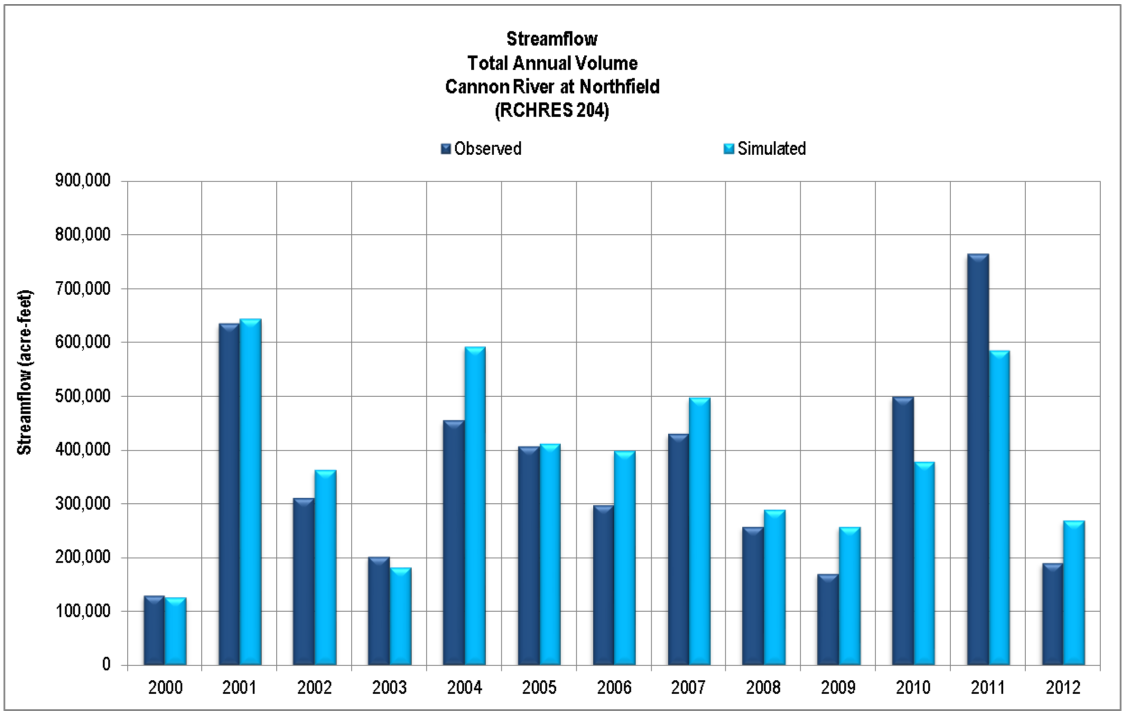

Figure A-15. Streamflow Total Annual Volume for Cannon River at Northfield (Gage #H39069001)

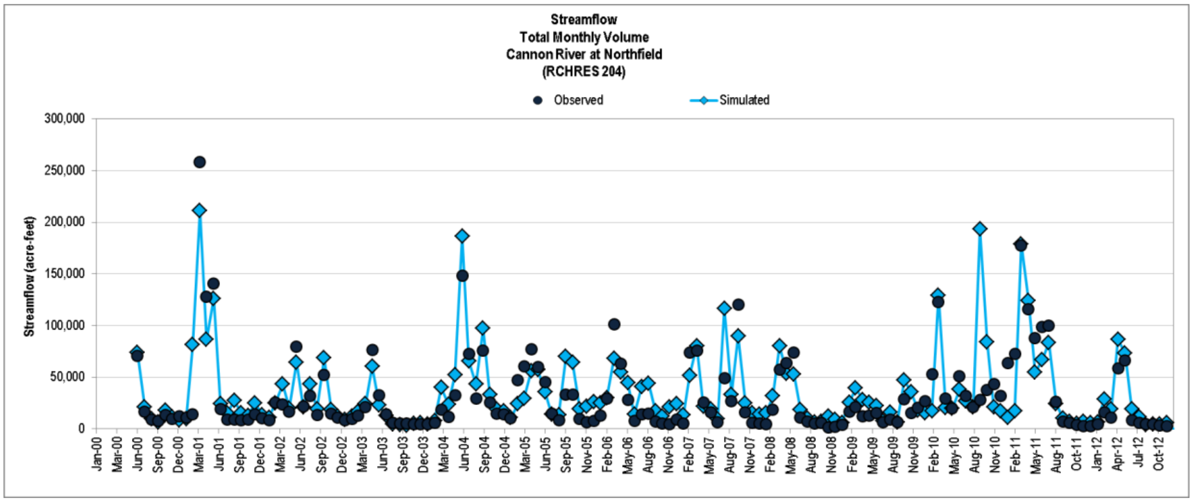

Figure A-16. Streamflow Total Monthly Volume for Cannon River at Northfield (Gage #H39069001)

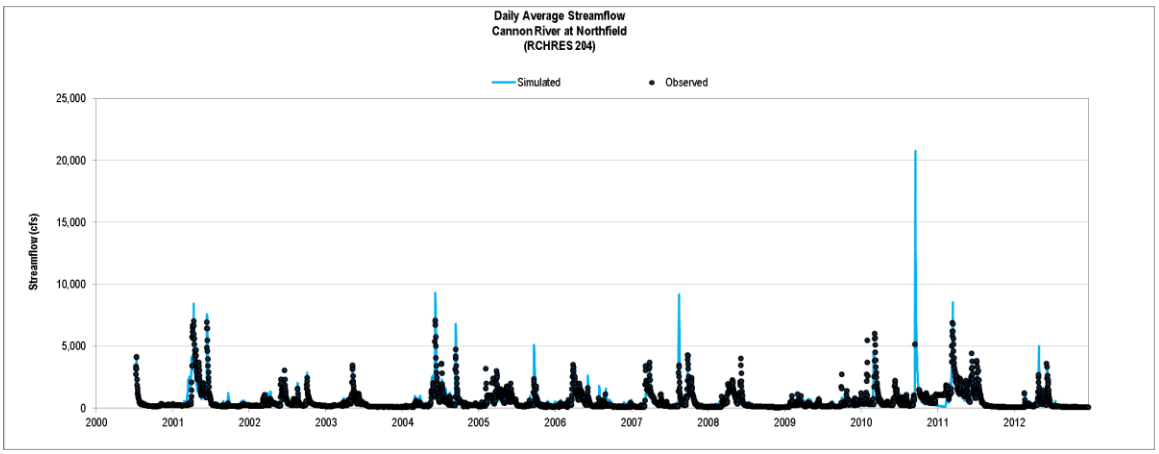

Figure A-17. Streamflow Total Daily Volume for Cannon River at Northfield (Gage #H39069001)

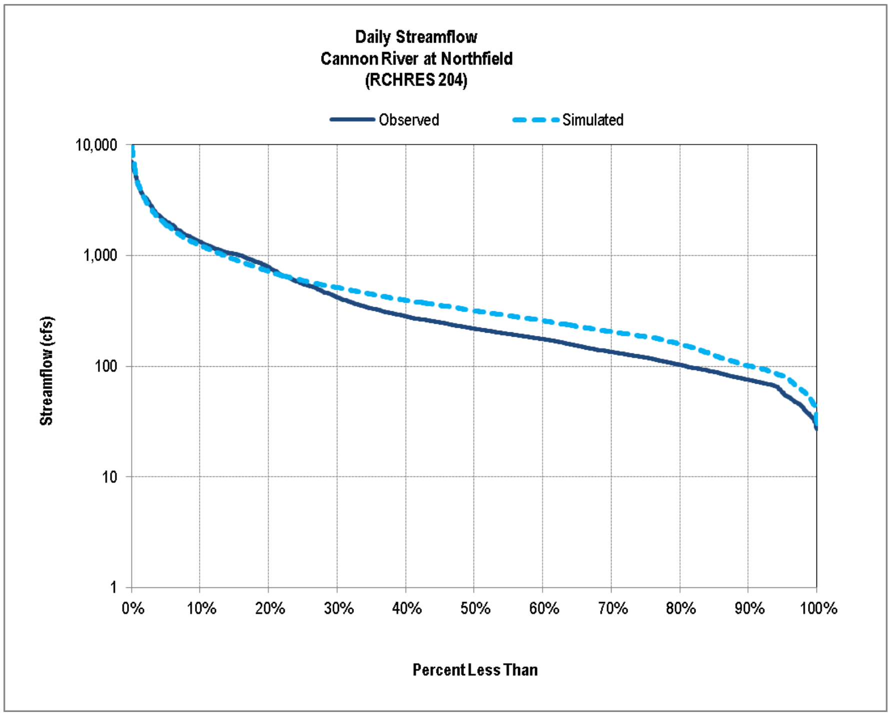

Figure A-18. Daily Streamflow Cumulative Frequency Distribution for Cannon River at Northfield (Gage #H39069001)

Appendix B
Sediment Simulation for Auxiliary Stations

Table B-1. Sediment Calibration Statistics for Additional Calibration Stations (2004-2012).

Time Interval	Statistic	Cannon River at Welch	Cannon River at Canada Ave, near Northfield	Little Cannon near Cannon Falls	Straight River at Faribault	Straight River at Clinton Falls	Straight River at Owatonna	Crane Creek near Medford	Maple Creek at Owatonna	Turtle Creek 3 mi SE Owatonna
Annual	*Count*	9		6	6	9	9	9	9	9
	P-Bias	13.4		49.9	-16.7	-2.3	13.1	-32.0	-32.2	29
	Relative Percent Difference	-6.0%		-40.7%	13.3%	-5.1%	-25.1%	7.6%	26.7%	-21.0%
Monthly	*Count*	105		38	54	58	43	47	42	43
	P-Bias	2.1		48.3	-14.6	-8.8	29.7	-31.2	-33.1	27
	Relative Percent Difference	41.5%		-32.1%	-3.2%	-10.3%	-51.9%	-12.6%	15.9%	-28.3%
Daily	*Count*	262		94	195	124	99	136	98	99
	P-Bias	18.2		46.1	-28.6	-5.3	26.3	-64.5	-29.1	16
	Relative Percent Difference	38.3%		-16.4%	-14.6%	-24.6%	-60.0%	-17.0%	4.4%	-29.4%

Table B-2. Sediment Validation Statistics for Additional Calibration Stations (1996-2003).

Time Interval	Statistic	Cannon River at Welch	Cannon River at Canada Ave, near Northfield	Little Cannon near Cannon Falls	Straight River at Faribault	Straight River at Clinton Falls	Straight River at Owatonna	Crane Creek near Medford	Maple Creek at Owatonna	Turtle Creek 3 mi SE Owatonna
Annual	*Count*	6	3			6	3	4	4	
	P-Bias	4.2	1.1			29.5	53.2	34.8	18.7	
	Relative Percent Difference	14.0%	-7.2%			-37.9%	-91.7%	-55.9%	-7.4%	
Monthly	*Count*	65	22			29	9	11	11	
	P-Bias	-4.1	16.0			1.8	42.1	27.1	17.3	
	Relative Percent Difference	36.7%	20.8%			-13.7%	-82.2%	-41.6%	12.3%	
Daily	*Count*	134	43			41	16	20	19	
	P-Bias	5.3	4.2			18.7	41.9	26.5	17.5	
	Relative Percent Difference	33.1%	16.0%			-34.2%	-103.8%	-56.5%	-18.1%	

Table B-3. Average Deposition Rates in Cannon River Lakes Simulated by the HSPF Model.

Lake Name	Deposition Rate (cm/year)
Byllesby	2.376
Union Lake	2.051
Circle Lake	0.487
Fox Lake	1.062
Mazaska Lake	0.253
Wells Lake	0.126
Cannon Lake	0.379
Lower Sakatah Lake	0.235
Upper Sakatah Lake	0.536
Tetonka Lake	0.683
Sabre Lake	1.041
Gorman Lake	0.975
Rice Lake	0.419
Shields Lake	0.798
Roberds Lake	0.630
French Lake	0.704
Caron Lake	0.624
Cedar Lake	0.928
Horsehoe Lake	1.333
Toner's Lake	1.632
Tustin Lake	0.379
Frances Lake	0.411
German Lake	0.903
East Jefferson Lake	0.414
Mid Jefferson Lake	0.454
West Jefferson Lake	0.298
Swede's Bay	0.921
Sunfish Lake	4.318
Volney Lake	3.583
Mabel Lake	2.055
Dora Lake	2.494
Hunt Lake	0.950
Chub Lake	0.479
Loon Lake	1.869
Clear Lake	3.052

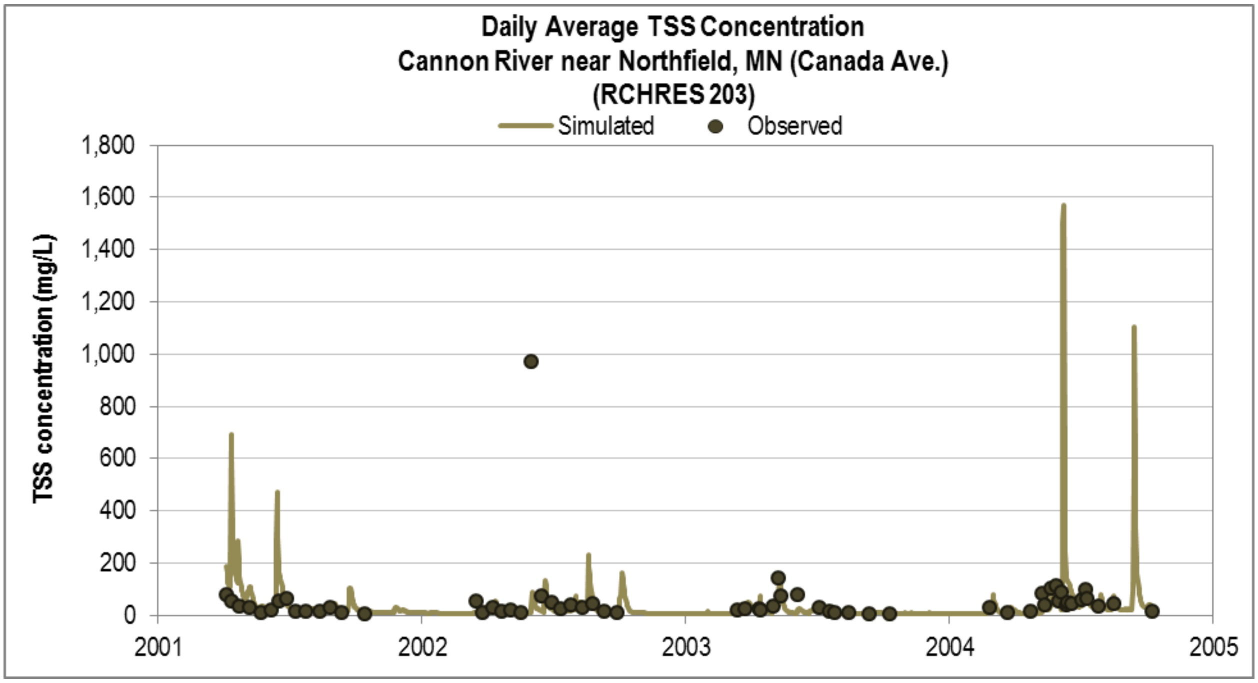

Figure B-1. Daily Average TSS Concentrations for Cannon River near Northfield (RCHRES 203)

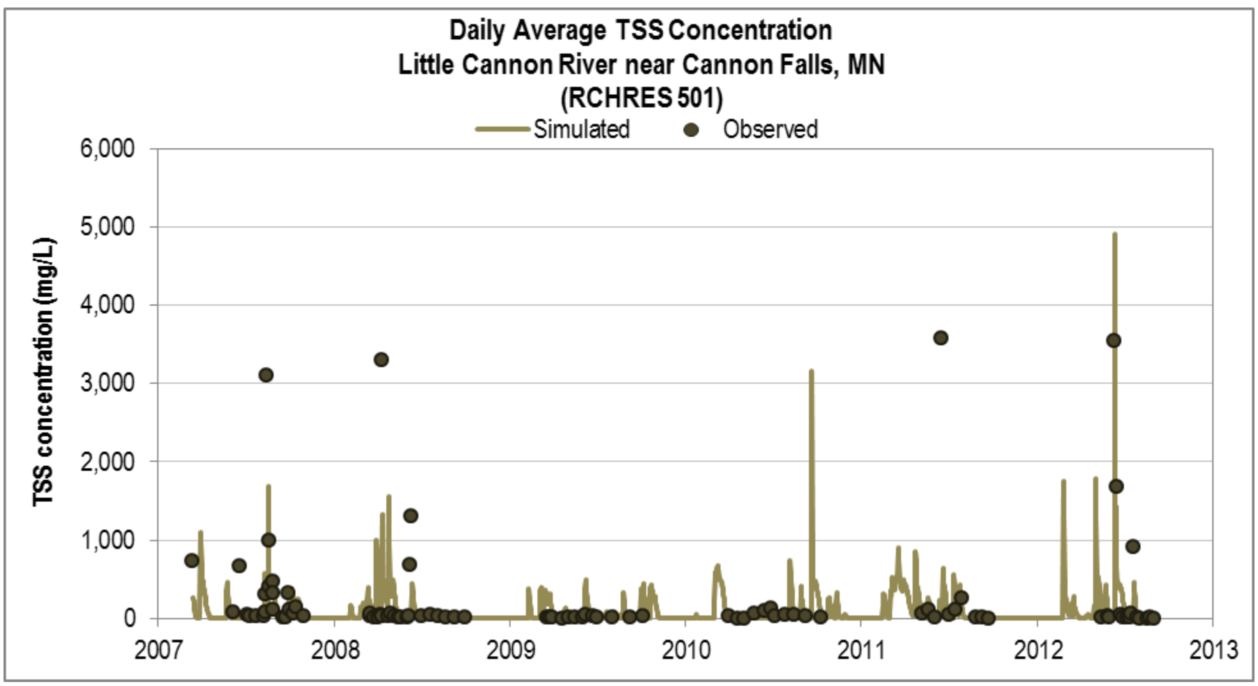

Figure B-2. Daily Average TSS Concentrations for Little Cannon River near Cannon Falls (RCHRES 501)

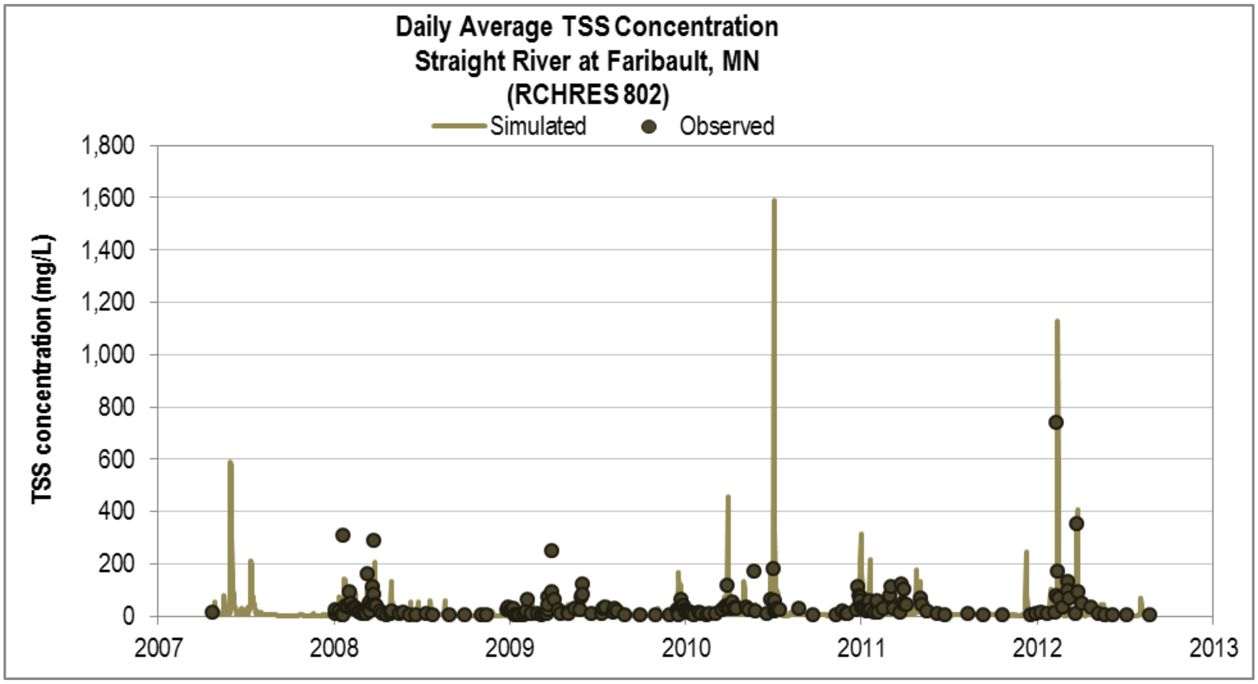

Figure B-3. Daily Average TSS Concentrations for Straight River at Faribault (RCHRES 802)

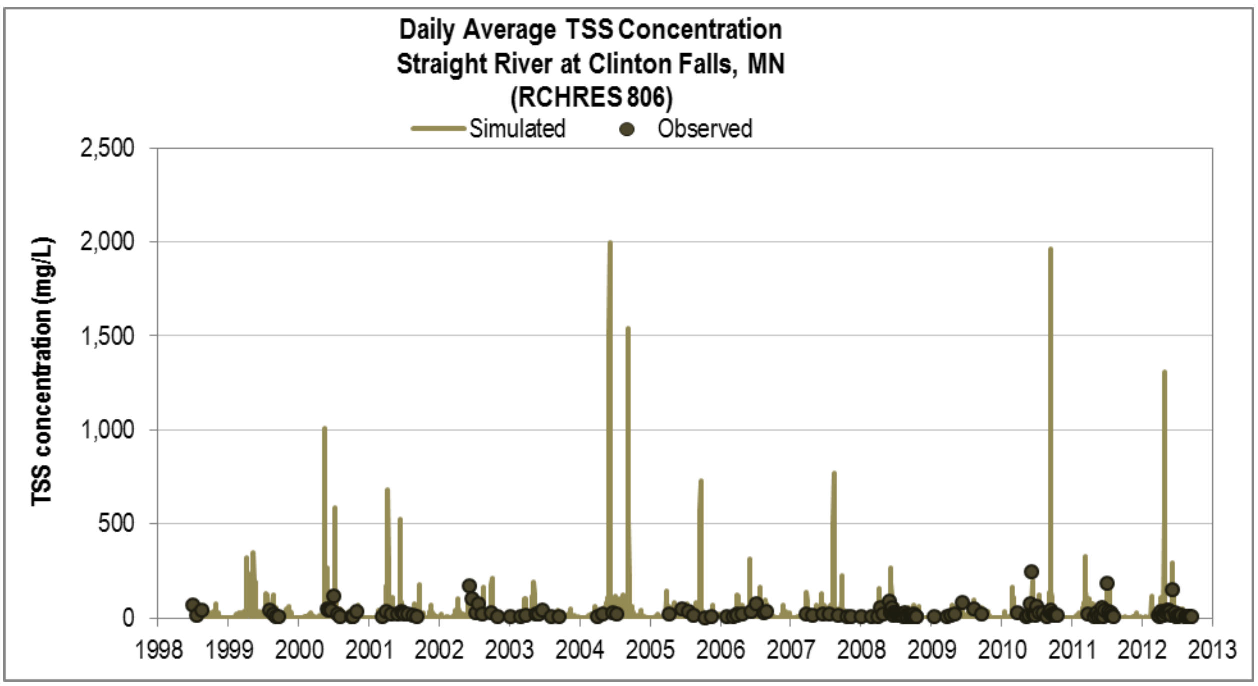

Figure B-4. Daily Average TSS Concentrations for Straight River at Clinton Falls (RCHRES 806)

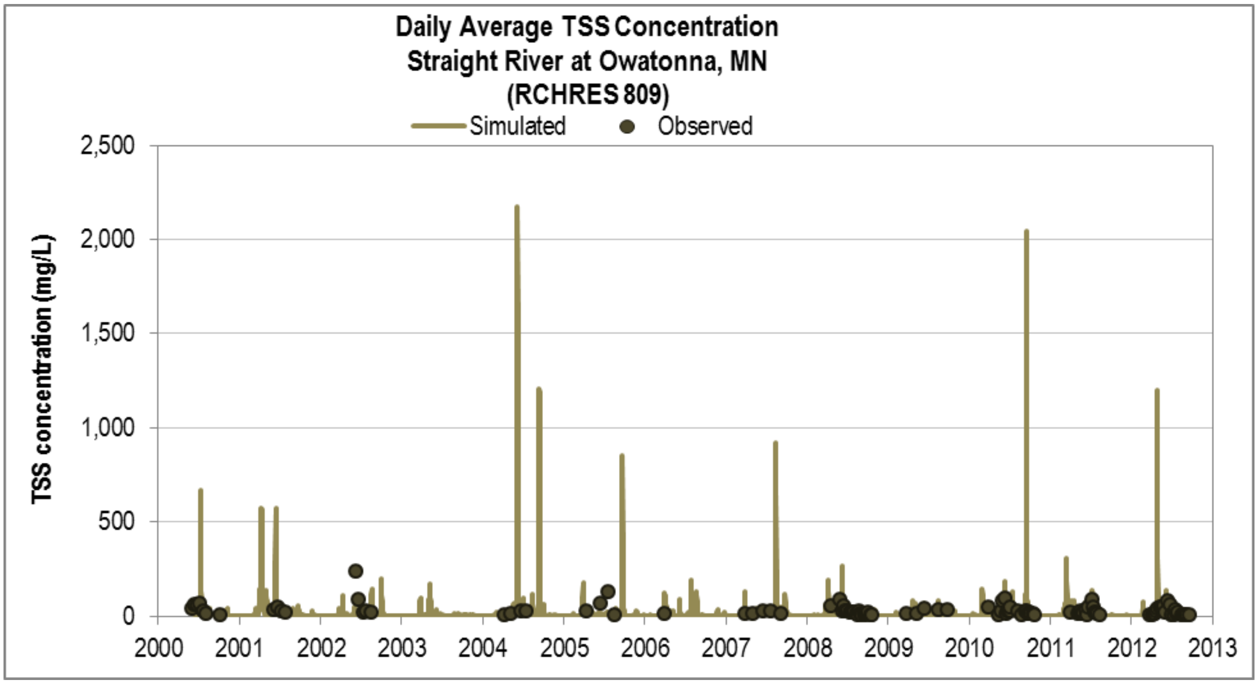

Figure B-5. Daily Average TSS Concentrations for Straight River at Owatonna (RCHRES 809)

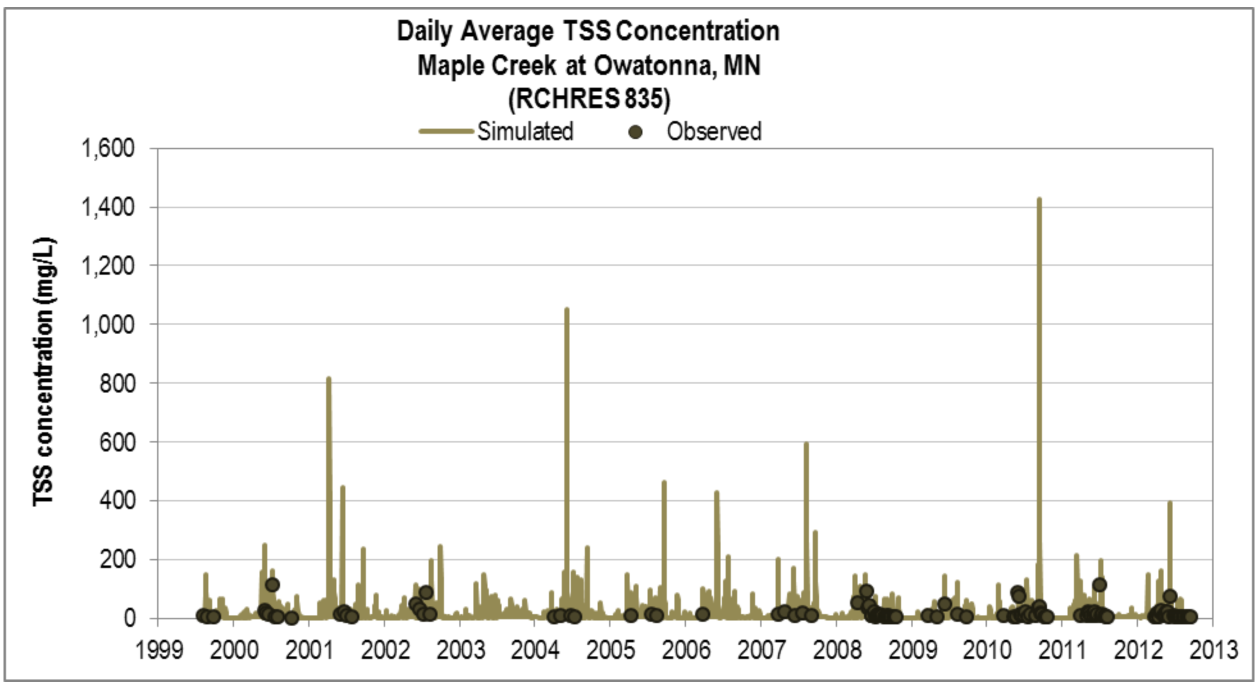

Figure B-6. Daily Average TSS Concentrations for Maple Creek at Owatonna (RCHRES 835)

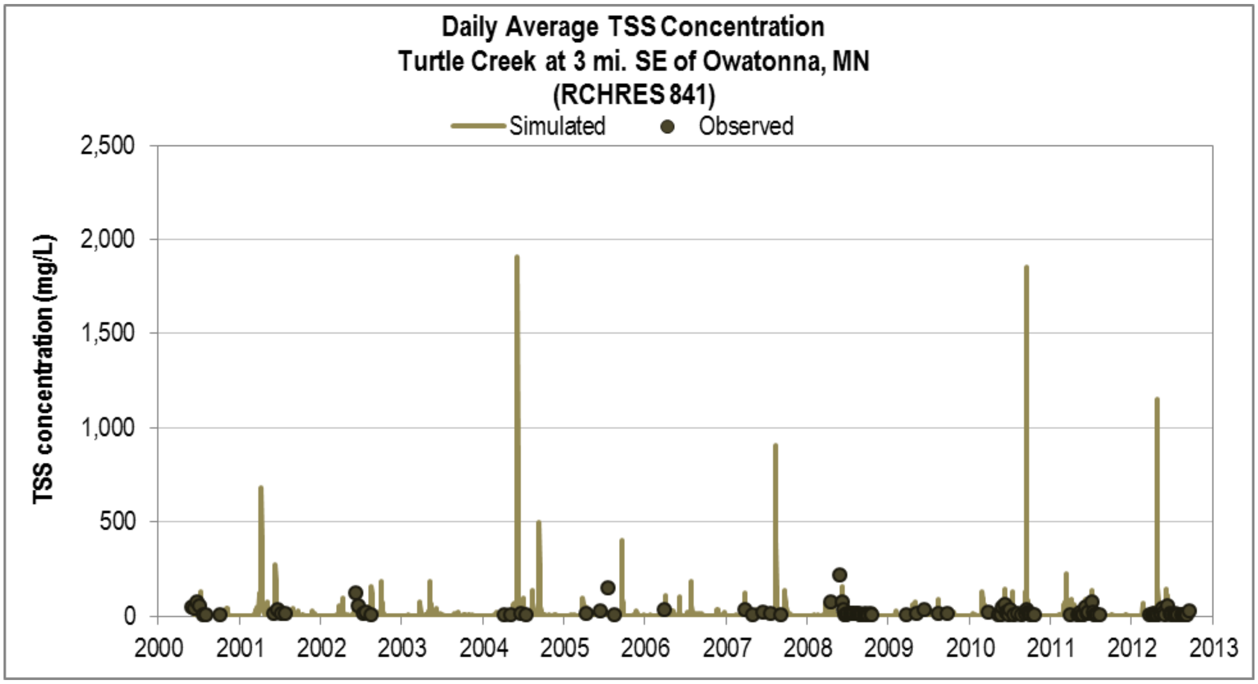

Figure B-7. Daily Average TSS Concentrations for Turtle Creek 3 mi. SE of Owatonna (RCHRES 841)

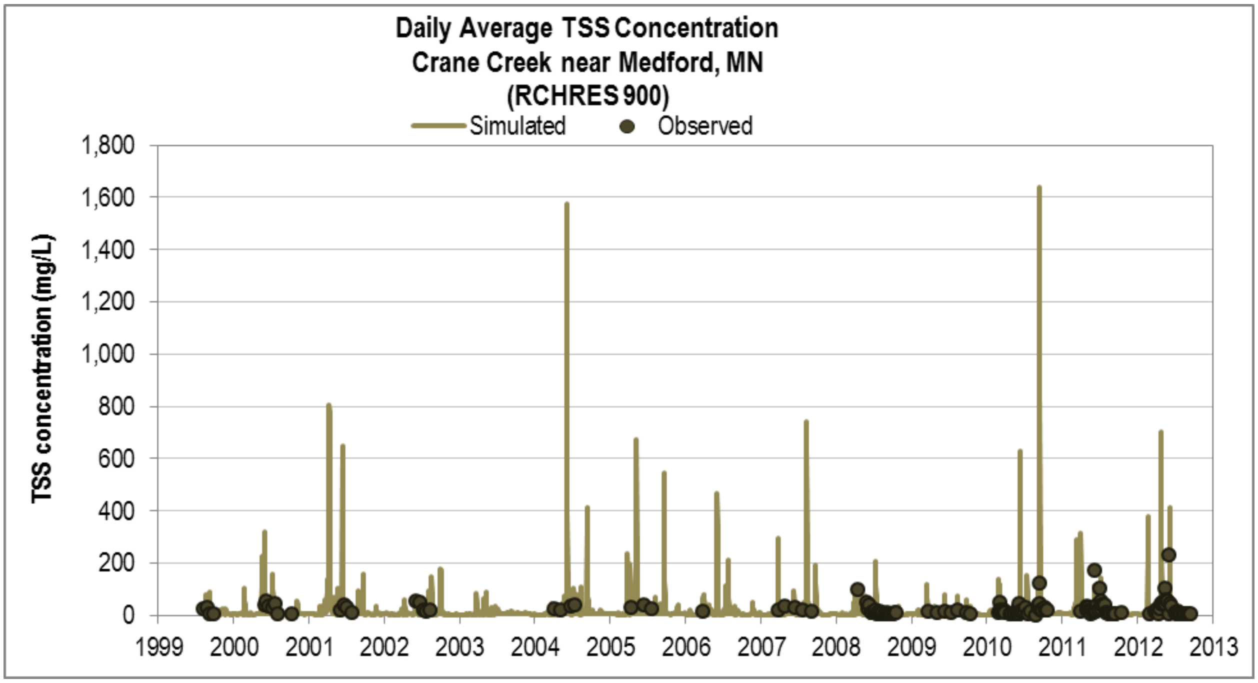

Figure B-8. Daily Average TSS Concentrations for Crane Creek near Medford (RCHRES 900)

Appendix C
Water Temperature Simulation for Auxiliary Stations

Table C-1. Daily Average Water Temperatures Statistics for Additional Calibration Stations (1996-2012)

Time Interval	Statistic	Little Cannon near Cannon Falls	Wolf Creek near Dundas	Prairie Creek 4 mi W of Cannon Falls	Chub Creek at Randolph	Rush Creek near Medford	Maple Creek at Owatonna	Turtle Creek 3 mi S of Owatonna	Crane Creek at Medford
Annual	Count	6	12	9	8	13	12	12	12
	R-Squared	0.89	0.47	0.72	0.28	0.62	0.72	0.86	0.77
	Nash-Sutcliffe Efficiency	0.03	-0.41	0.68	0.06	0.42	0.60	0.74	-0.02
	Relative Percent Difference	-8.2%	-3.6%	-1.0%	0.2%	0.4%	-0.9%	-1.8%	-6.2%
	Relative Percent Error	-7.9%	-3.5%	-0.9%	0.3%	0.4%	-0.8%	-1.8%	-5.9%
Monthly	Count	34	79	56	55	73	71	73	71
	R-Squared	0.75	0.90	0.82	0.82	0.82	0.81	0.89	0.78
	Nash-Sutcliffe Efficiency	0.32	0.84	0.76	0.75	0.75	0.68	0.85	0.55
	P-Bias	8.63	3.62	1.55	0.87	0.06	1.95	2.59	6.35
	Relative Percent Difference	-9.6%	-3.9%	-1.9%	-1.4%	-0.4%	-2.4%	-2.8%	-6.8%
	Relative Percent Error	-8.8%	-3.7%	-1.6%	-1.0%	-0.2%	-2.1%	-2.6%	-6.3%
Daily	Count	89	522	159	146	257	282	351	293
	R-Squared	0.73	0.80	0.77	0.82	0.65	0.71	0.75	0.65
	Nash-Sutcliffe Efficiency	0.41	0.72	0.67	0.76	0.49	0.55	0.66	0.46
	Relative Percent Difference	-9.1%	-3.7%	-1.7%	-1.1%	0.0%	-2.1%	-2.6%	-6.2%
	Relative Percent Error	-8.2%	-3.3%	-1.4%	-0.8%	0.5%	-1.6%	-2.2%	-5.5%

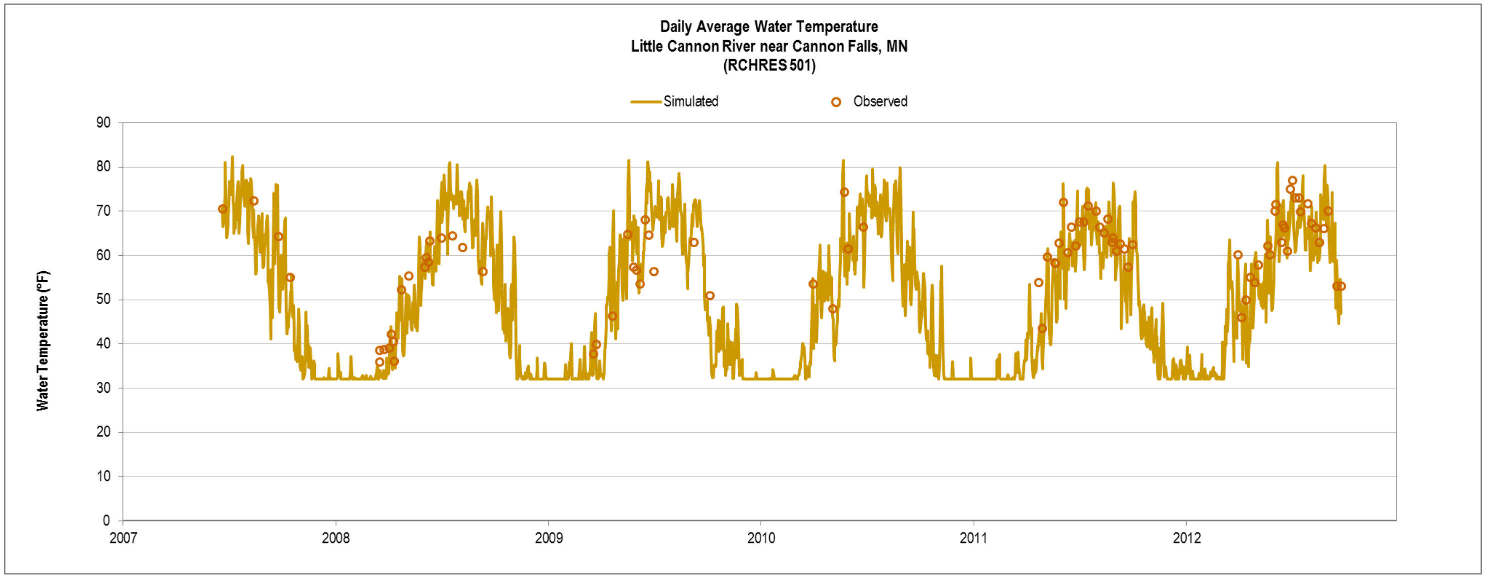

Figure C-1. Daily Average Water Temperatures for Little Cannon River near Cannon Falls (RCHRES 501).

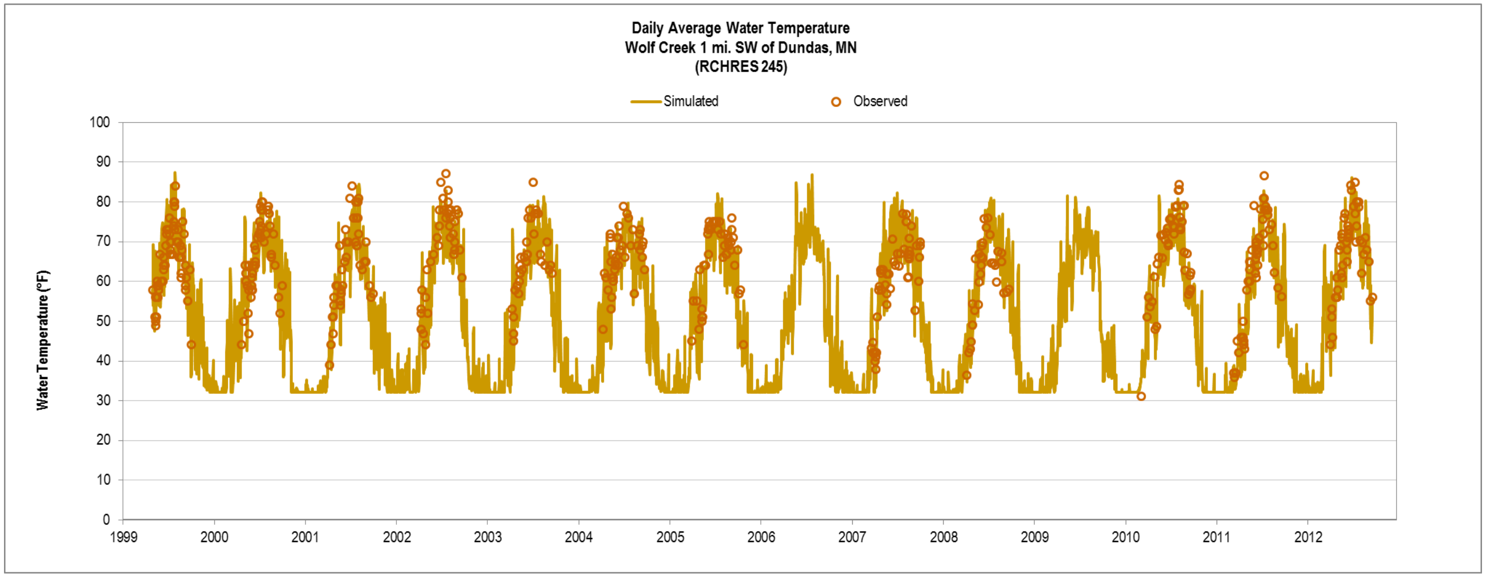

Figure C-2. Daily Average Water Temperatures for Wolf Creek near Dundas (RCHRES 245).

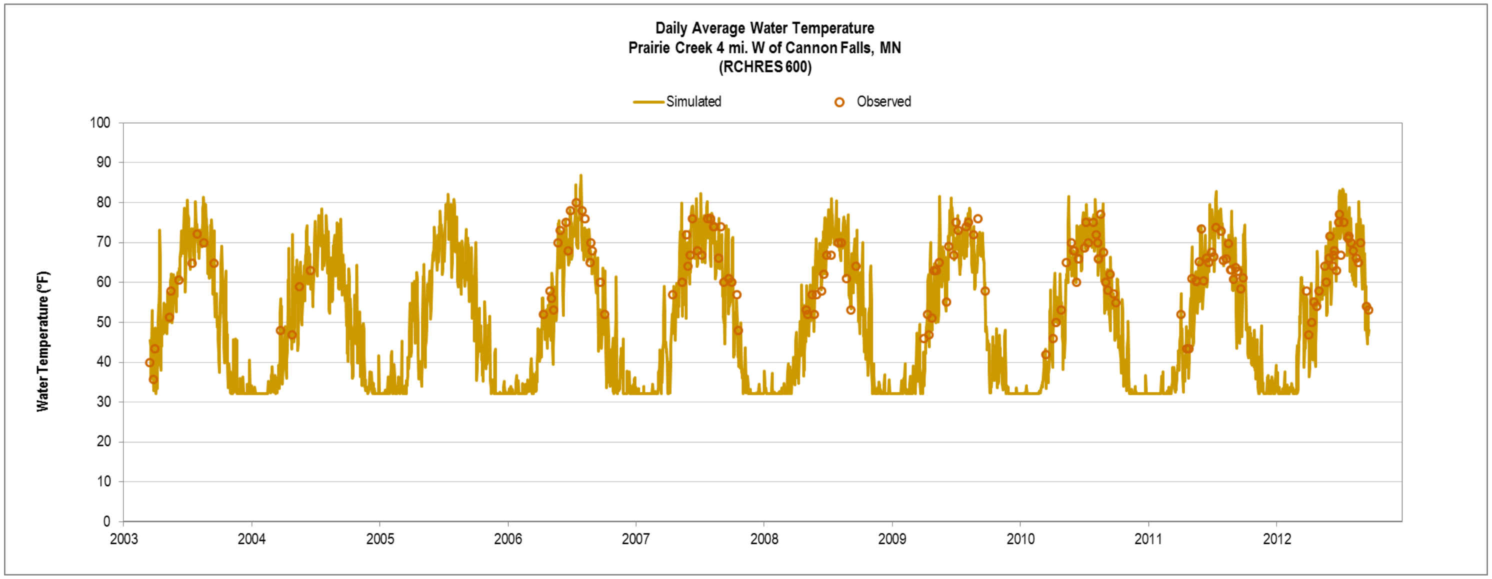

Figure C-3. Daily Average Water Temperatures for Prairie Creek 4 mi. W of Cannon Falls (RCHRES 600).

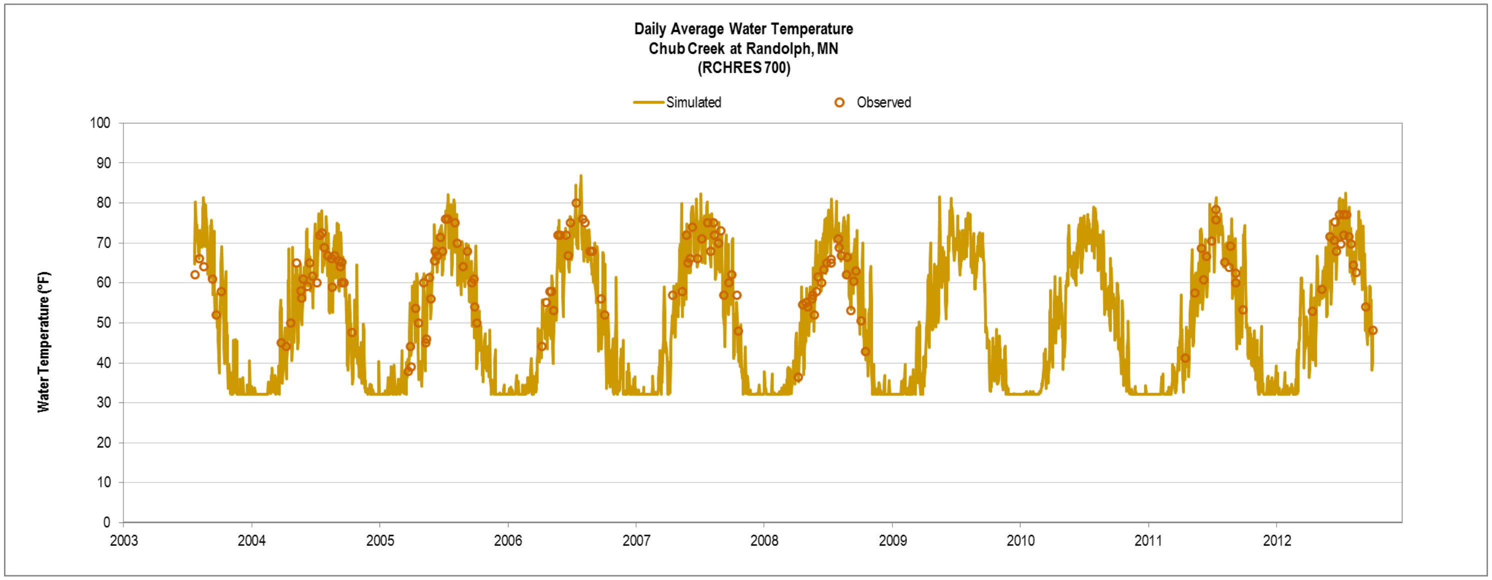

Figure C-4. Daily Average Water Temperatures for Chub Creek at Randolph (RCHRES 700).

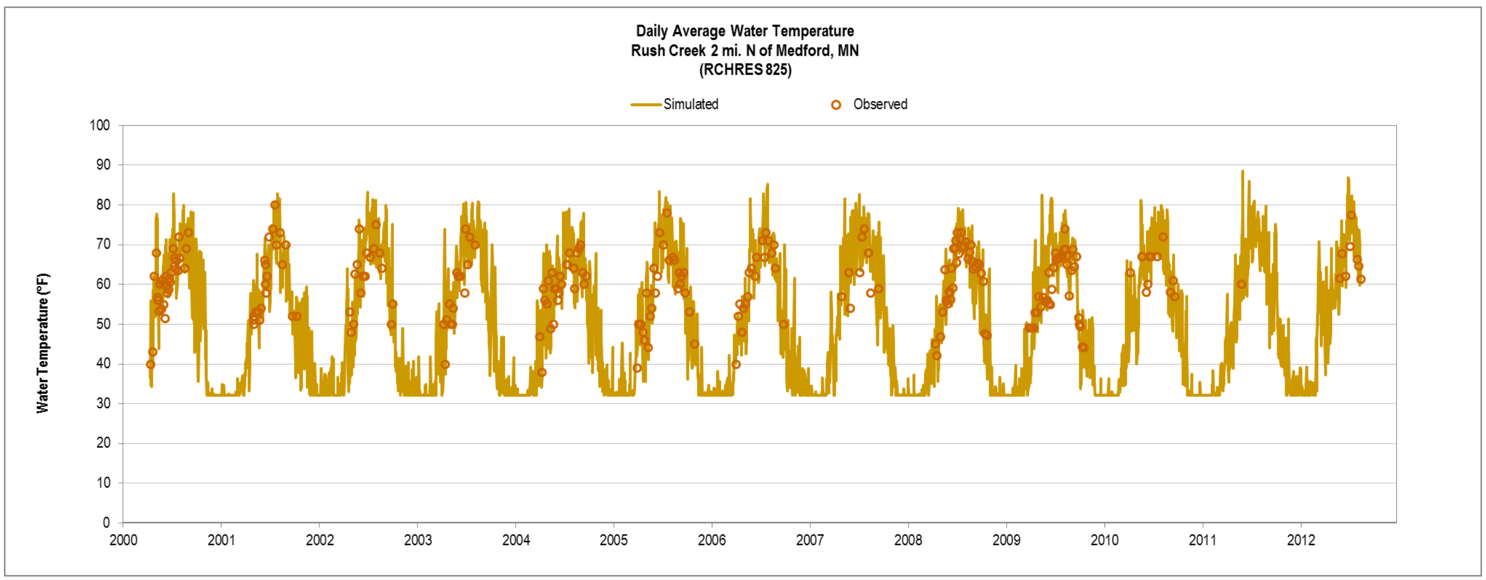

Figure C-5. Daily Average Water Temperatures for Rush Creek near Medford (RCHRES 825).

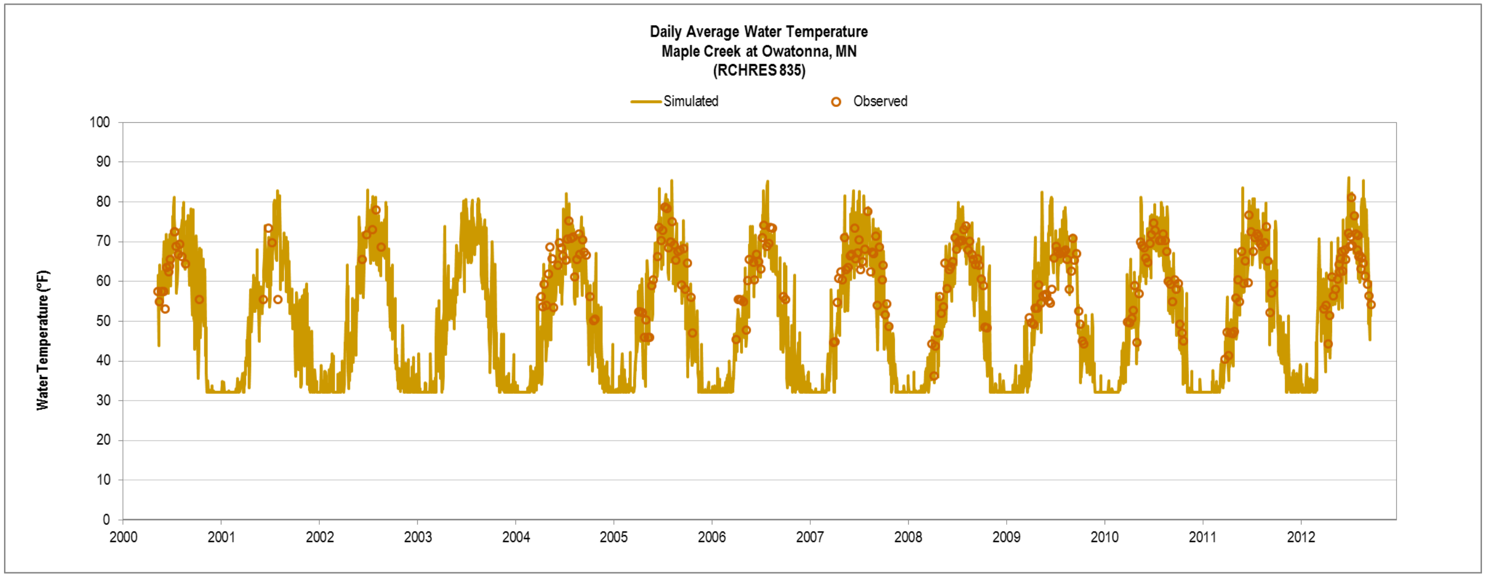

Figure C-6. Daily Average Water Temperatures for Maple Creek at Owatonna (RCHRES 835).

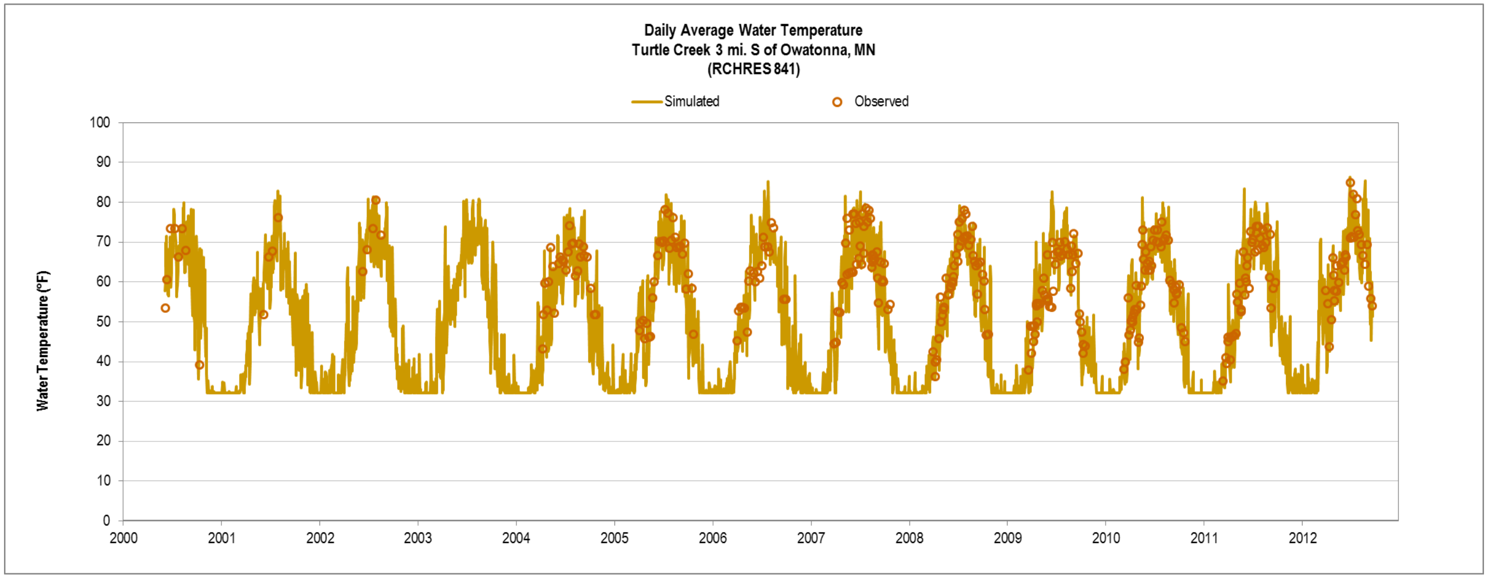

Figure C-7. Daily Average Water Temperatures for Turtle Creek 3 mi. S of Owatonna (RCHRES 841).

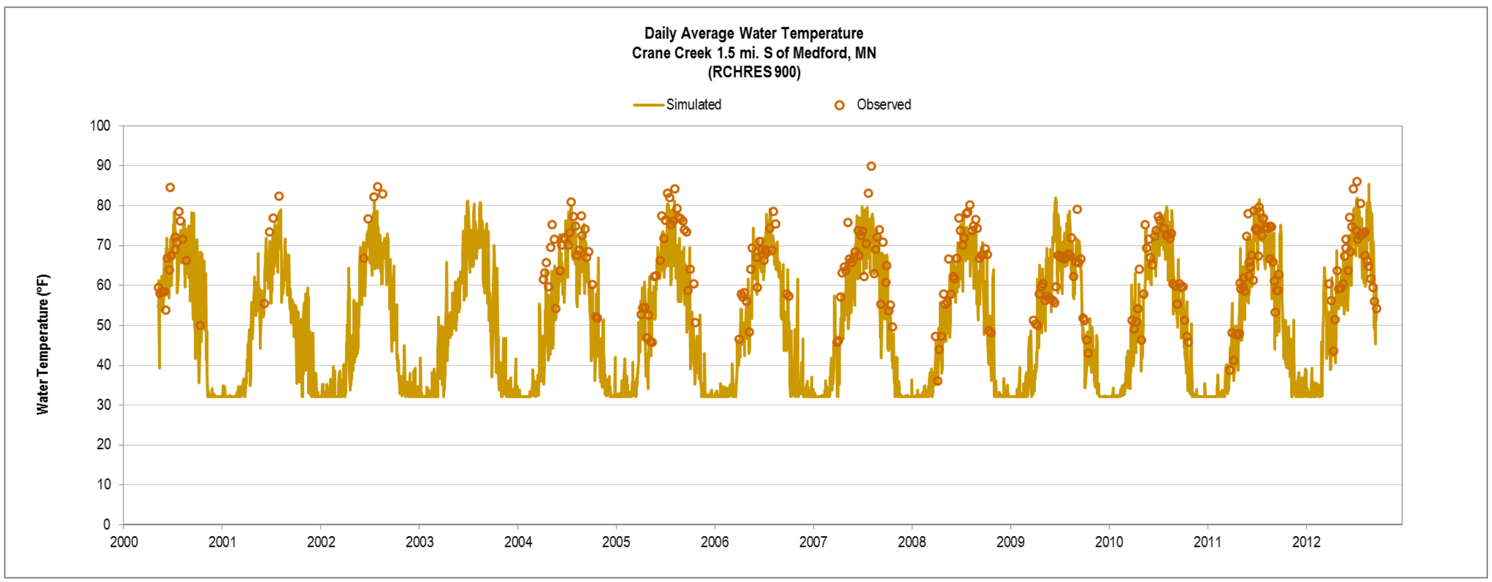

Figure C-8. Daily Average Water Temperatures for Crane Creek at Medford (RCHRES 900).

Appendix D
Phosphorus Simulation for Auxiliary Stations

Total Phosphorus

Table D-1. Total Phosphorus Calibration Statistics for Additional Calibration Stations (2004-2012).

Time Interval	*Statistic*	Little Cannon River near Cannon Falls	Straight River at Clinton Falls	Straight River at Owatonna	Maple Creek at Owatonna	Turtle Creek 3 mi SE of Owatonna	Crane Creek near Medford
Annual	*Count*	6	9	9	9	9	9
	PBIAS	-0.49	-9.10	-2.87	23.28	32.64	35.46
	Relative Percent Difference	-2.1%	7.5%	4.2%	-26.1%	-37.6%	-29.3%
Monthly	*Count*	37	55	43	41	42	44
	PBIAS	4.77	-10.87	-0.53	21.69	33.84	33.22
	Relative Percent Difference	-20.2%	8.1%	0.5%	-23.2%	-34.5%	-11.5%
Daily	*Count*	100	122	102	100	101	117
	PBIAS	2.29	-23.93	0.68	19.52	32.73	24.11
	Relative Percent Difference	-12.8%	19.4%	5.3%	-20.4%	-30.2%	-12.0%

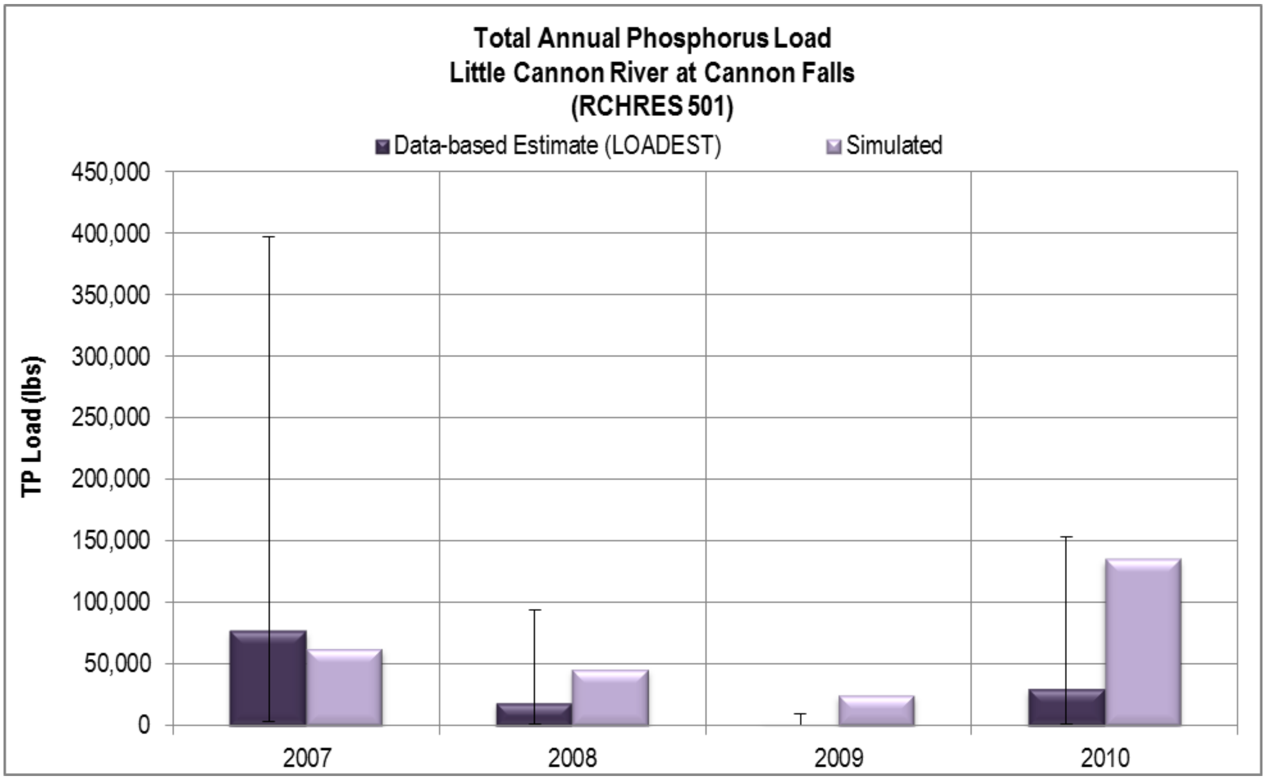

Figure D-1. Annual TP Loads for Little Cannon River near Cannon Falls (RCHRES 501)

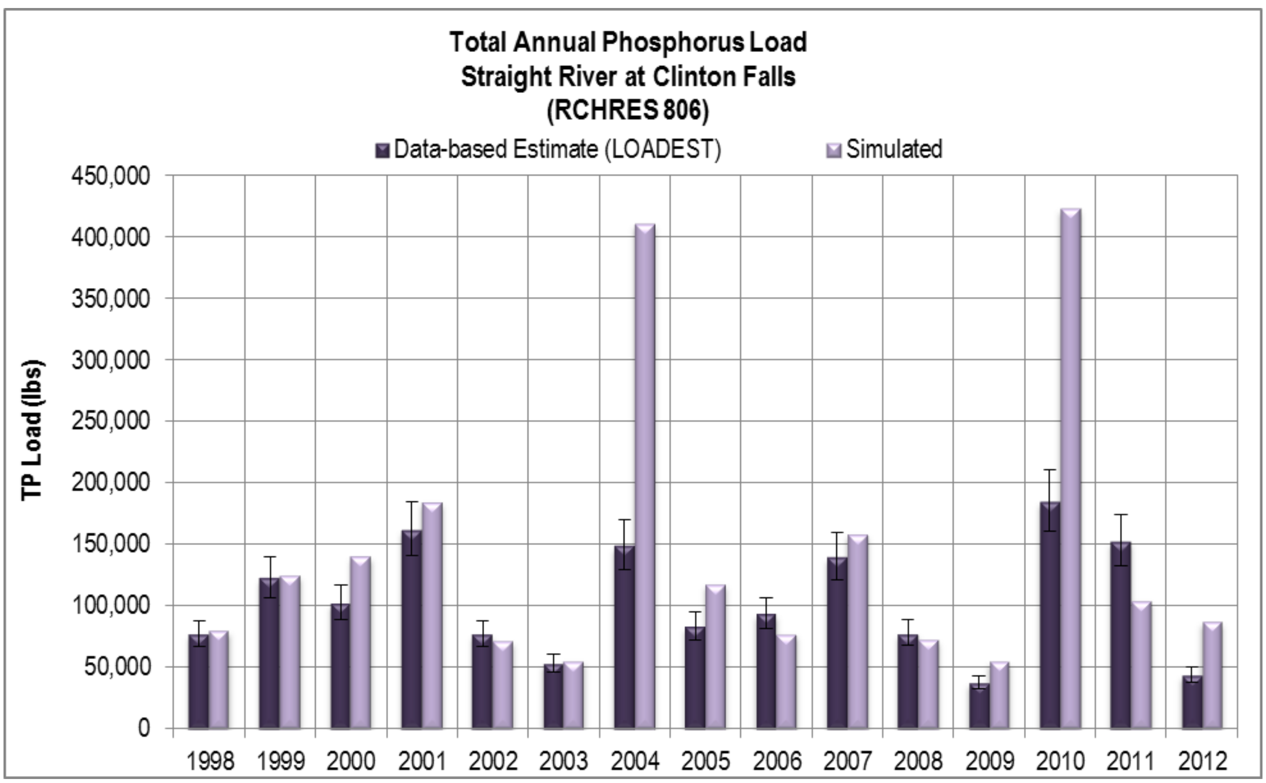

Figure D-2. Annual TP Loads for Straight River at Clinton Falls (RCHRES 806)

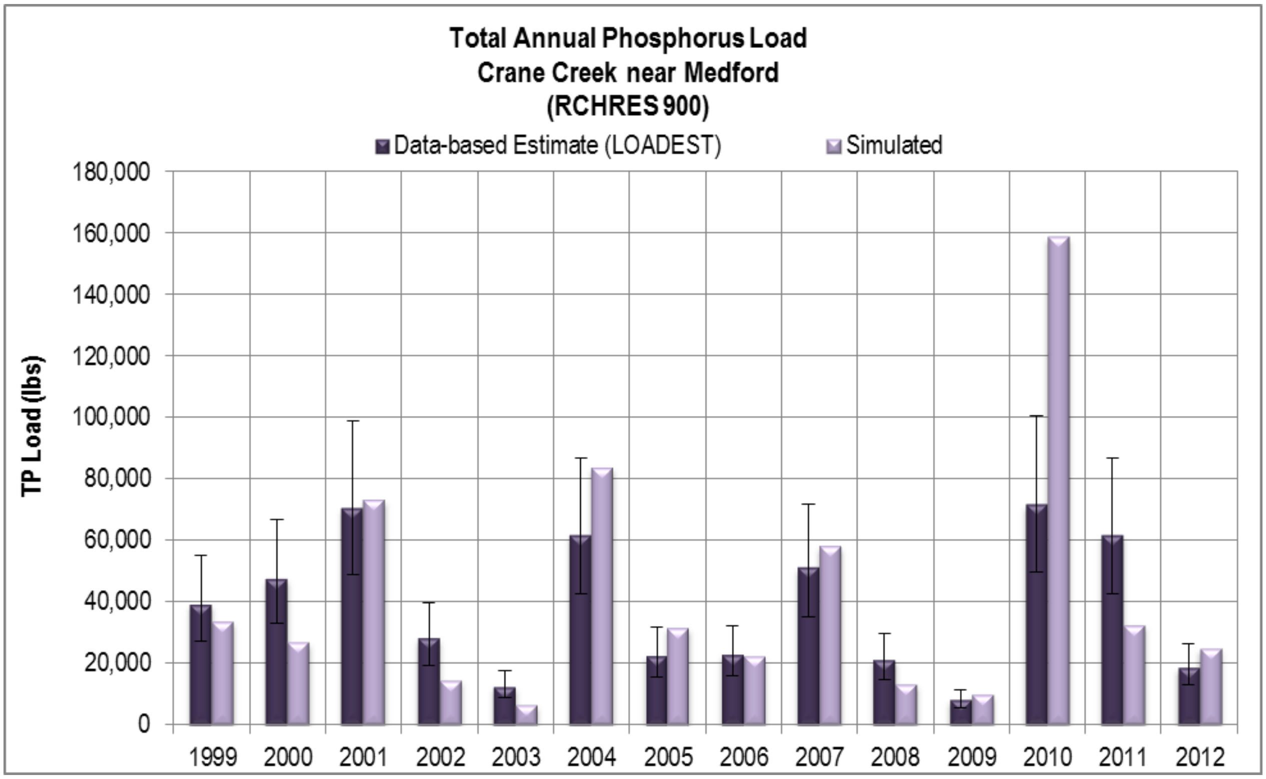

Figure D-3. Annual TP Loads for Crane Creek near Medford (RCHRES 900)

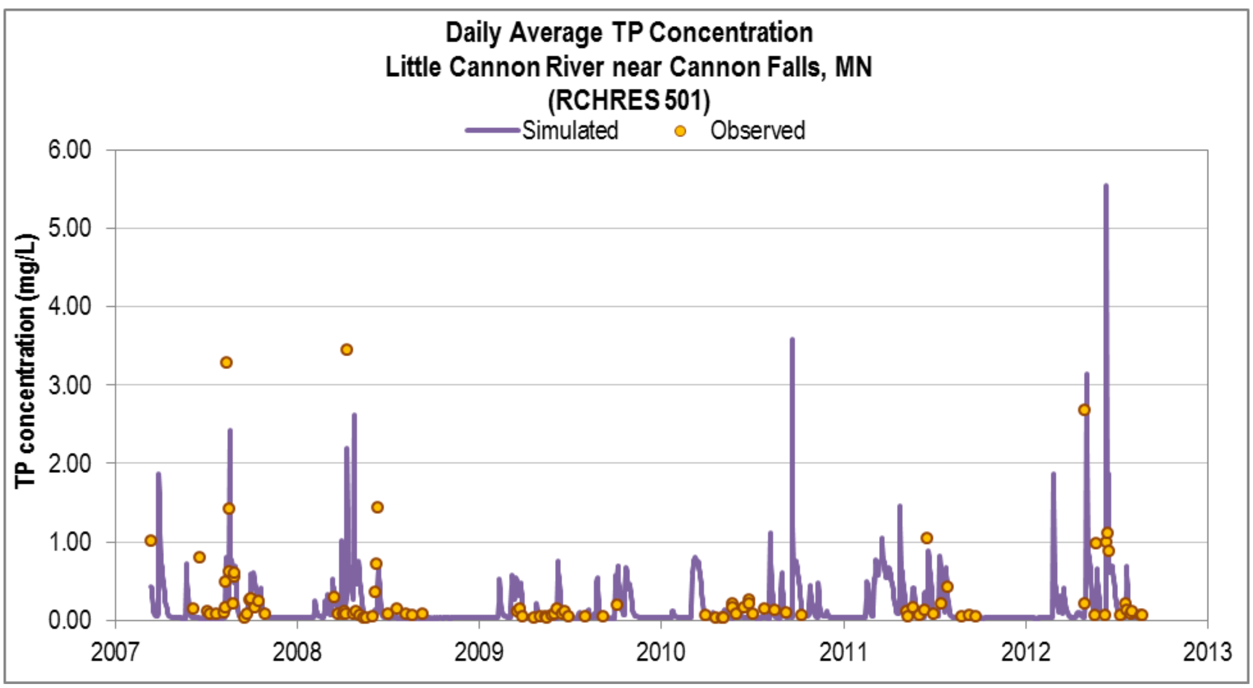

Figure D-4. Daily Average TP Concentrations for Little Cannon River near Cannon Falls (RCHRES 501)

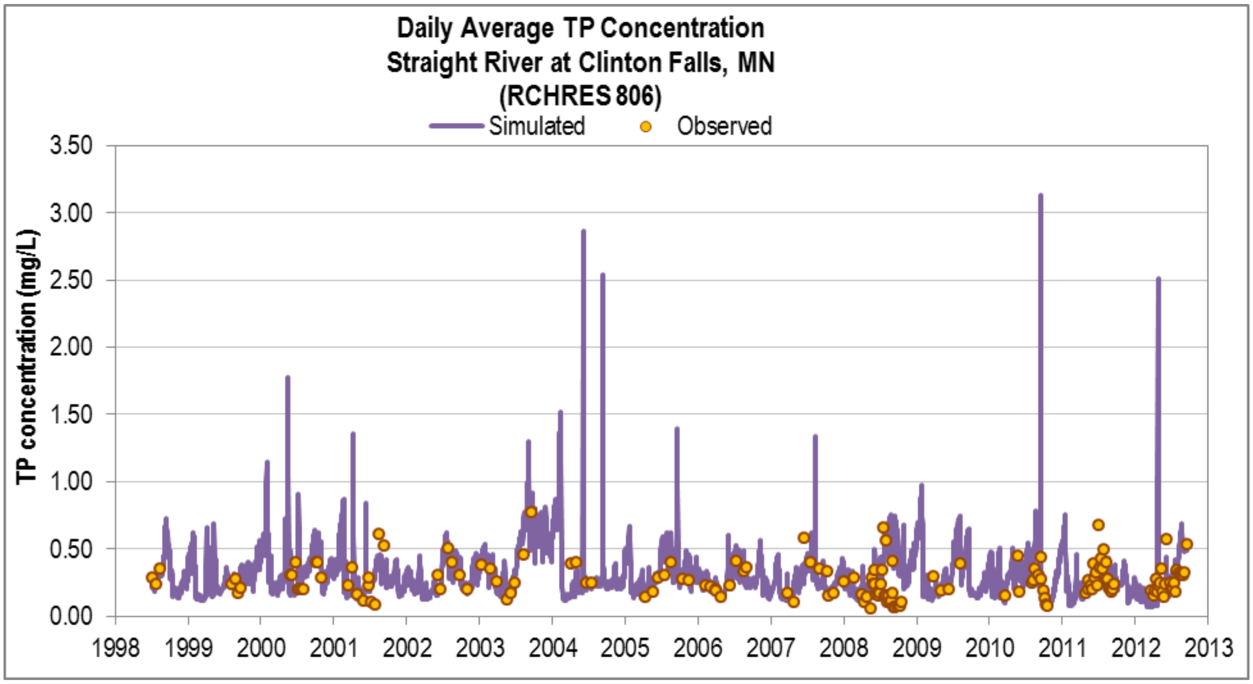

Figure D-5. Daily Average TP Concentrations for Straight River at Clinton Falls (RCHRES 806)

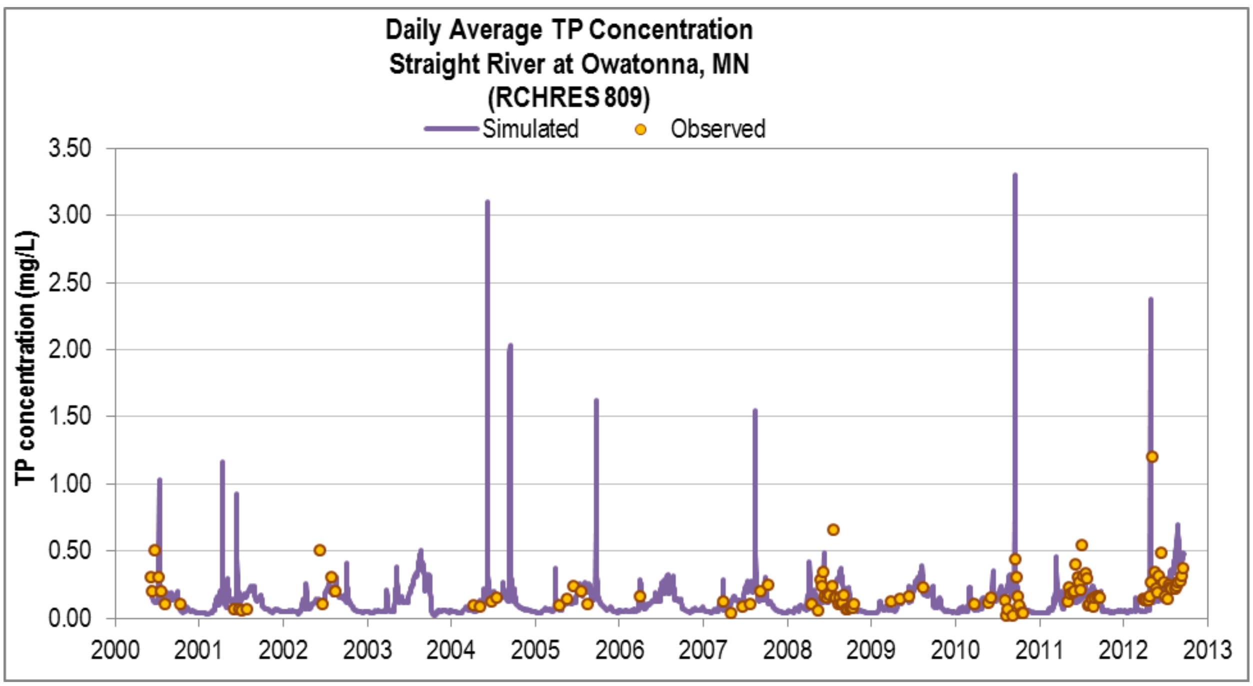

Figure D-6. Daily Average TP Concentrations for Straight River at Owatonna (RCHRES 809)

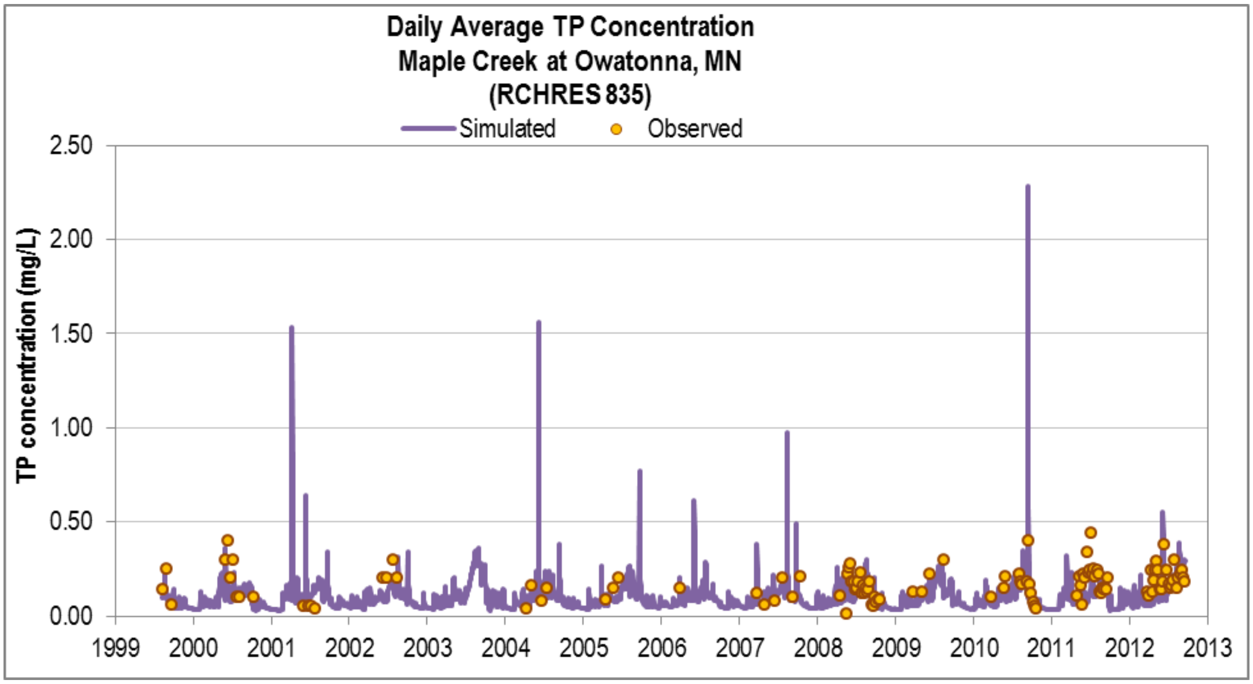

Figure D-7. Daily Average TP Concentrations for Maple Creek at Owatonna (RCHRES 835)

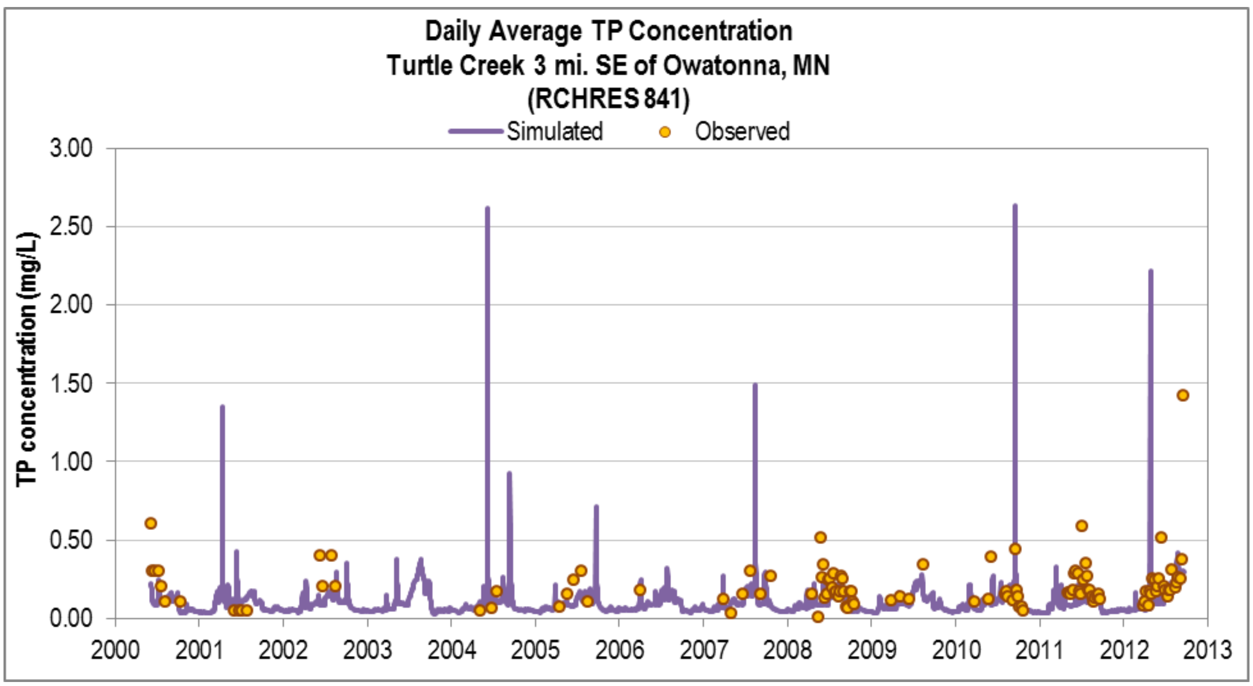

Figure D-8. Daily Average TP Concentrations for Turtle Creek 3 mi. SE of Owatonna (RCHRES 841)

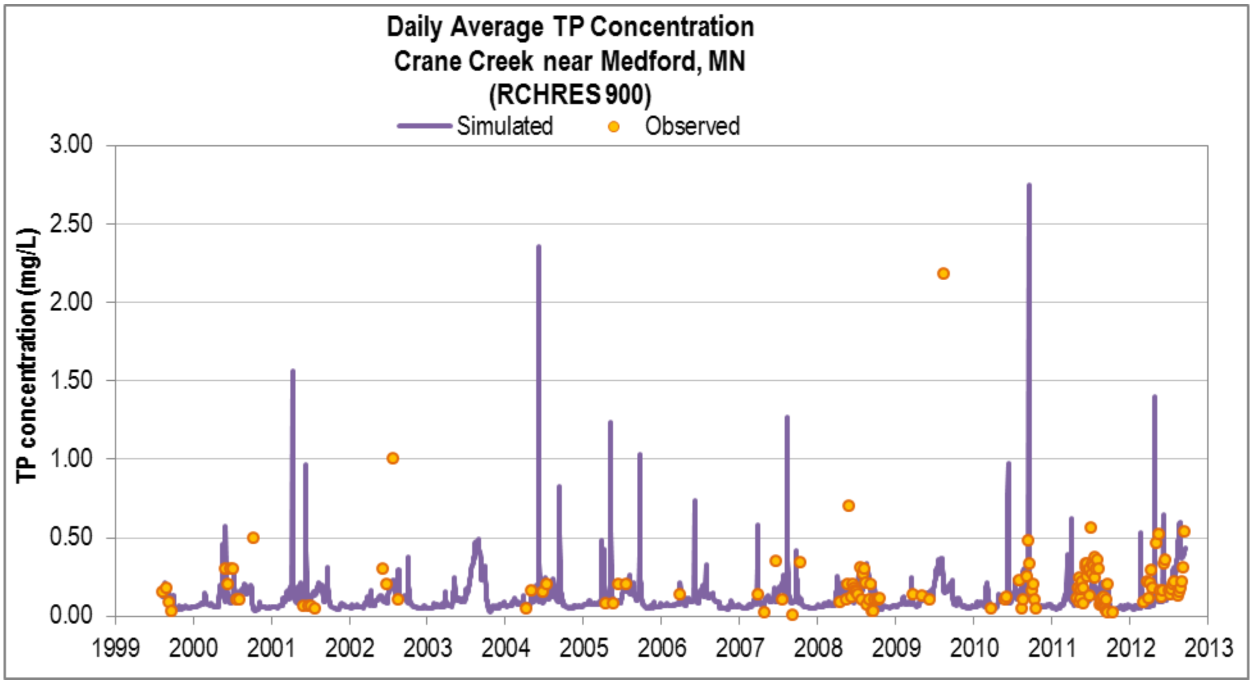

Figure D-9. Daily Average TP Concentrations for Crane Creek near Medford (RCHRES 900)

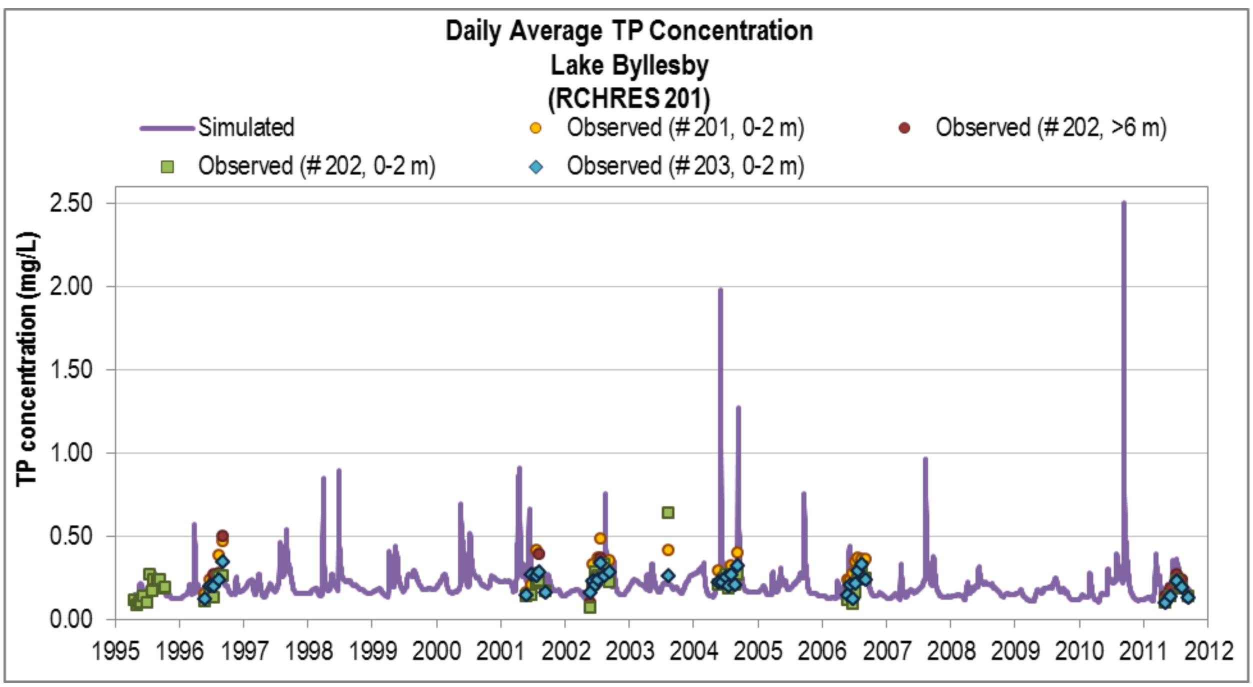

Figure D-10. Daily Average TP Concentrations for Lake Byllesby (RCHRES 201)

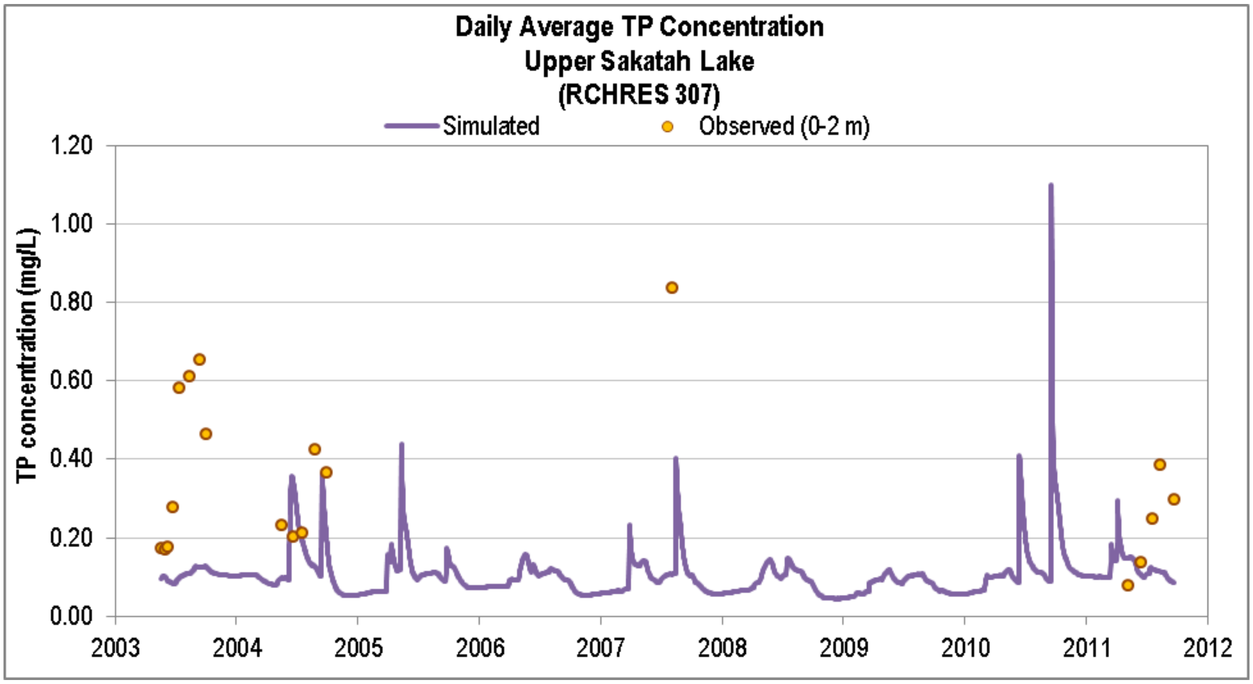

Figure D-11. Daily Average TP Concentrations for Upper Sakatah Lake (RCHRES 307)

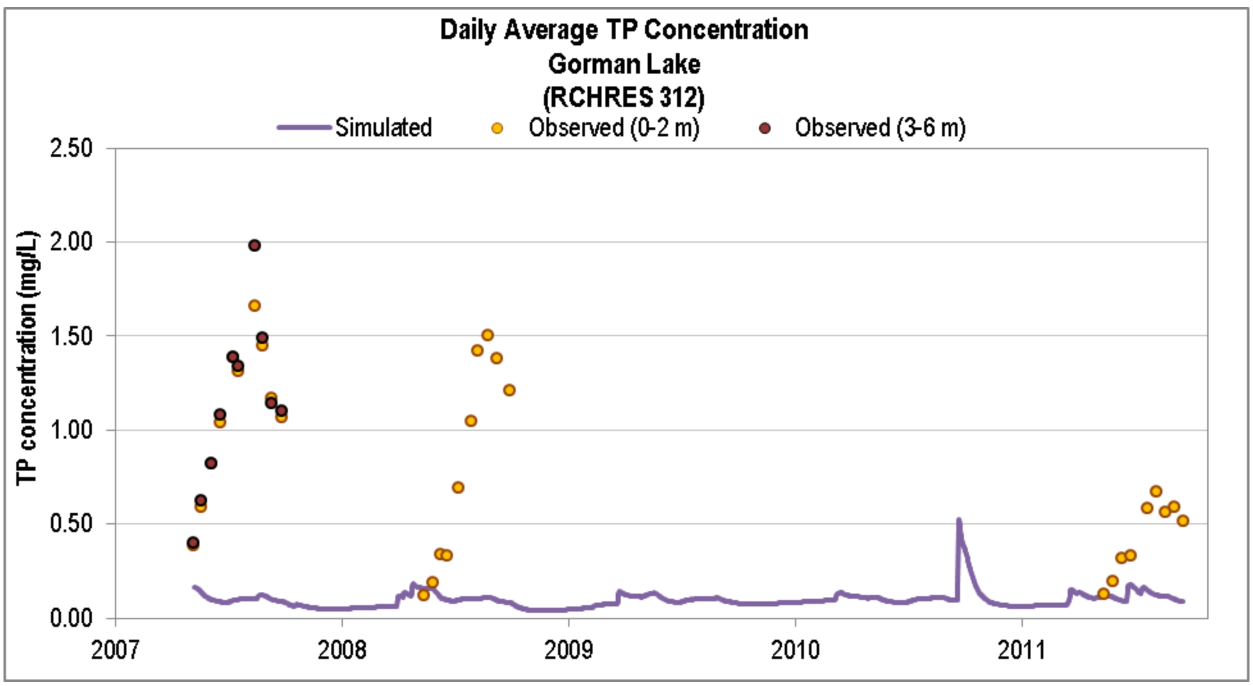

Figure D-12. Daily Average TP Concentrations for Gorman Lake (RCHRES 312)

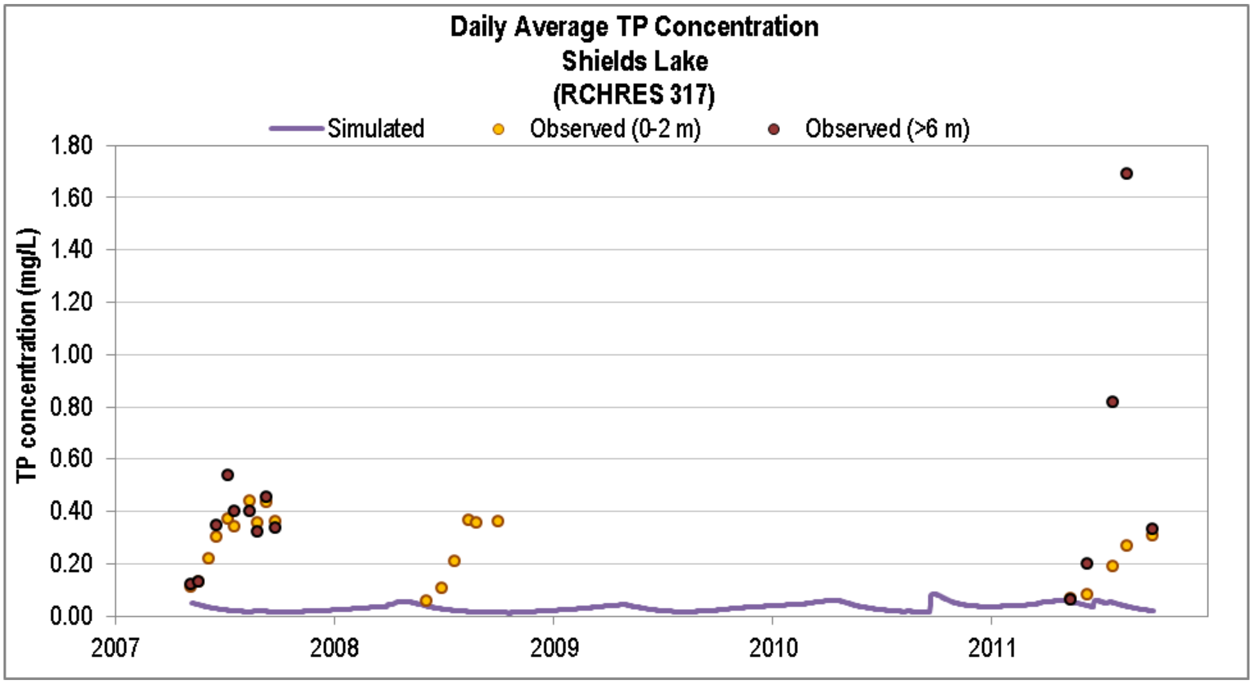

Figure D-13. Daily Average TP Concentrations for Shields Lake (RCHRES 317)

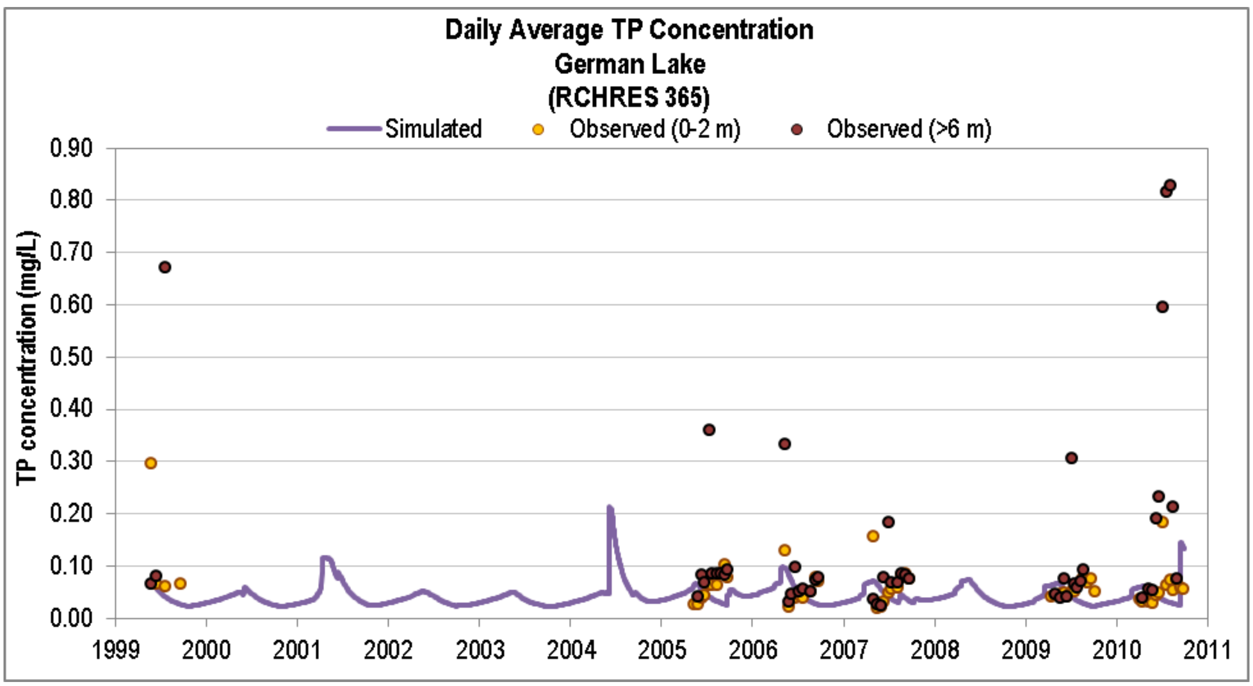

Figure D-14. Daily Average TP Concentrations for German Lake (RCHRES 365)

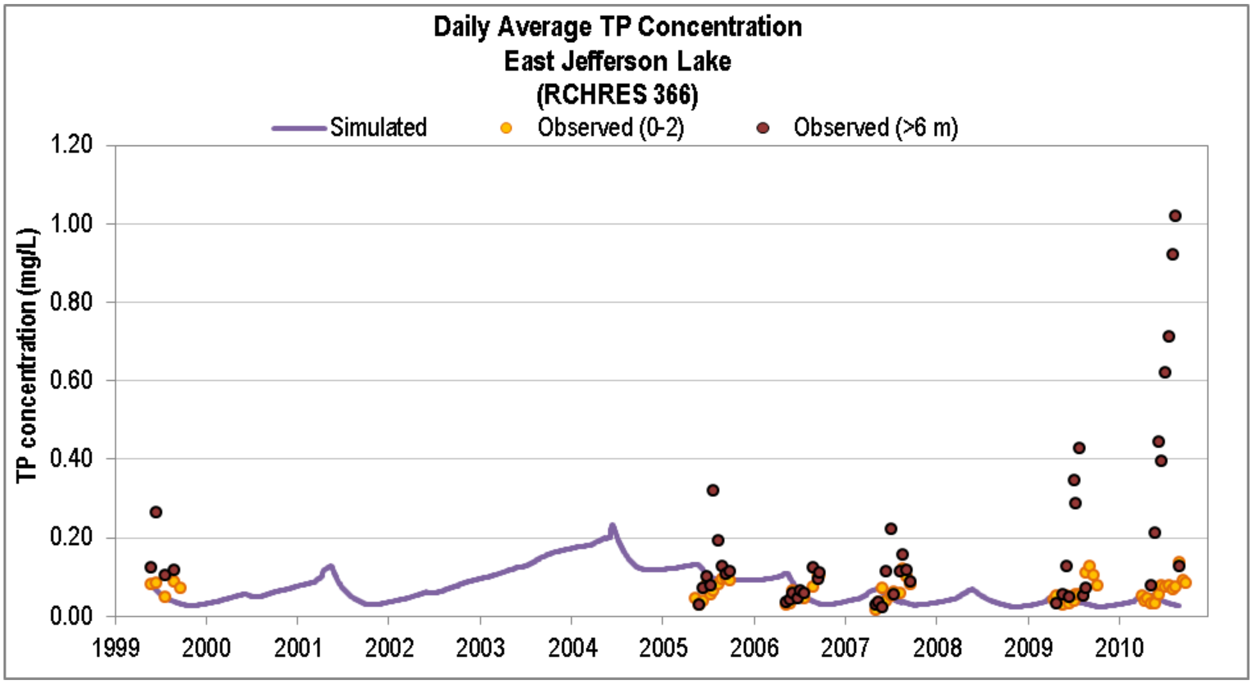

Figure D-15. Daily Average TP Concentrations for East Jefferson Lake (RCHRES 366)

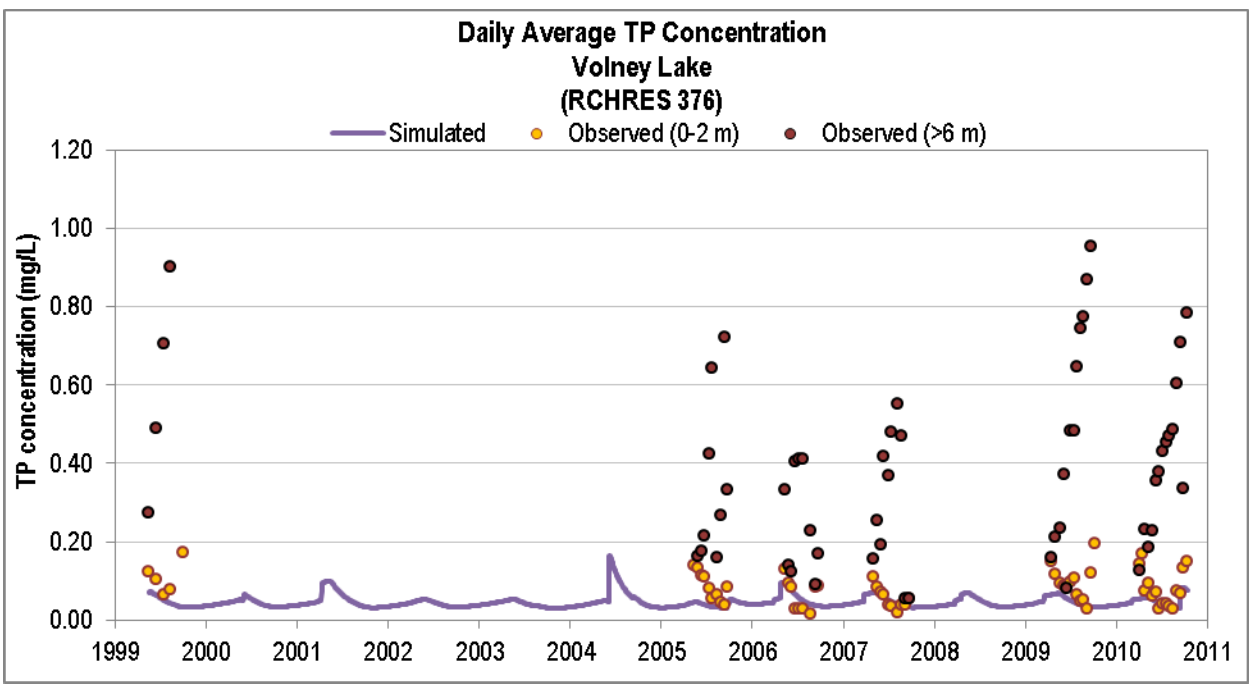

Figure D-16. Daily Average TP Concentrations for Volney Lake (RCHRES 376)

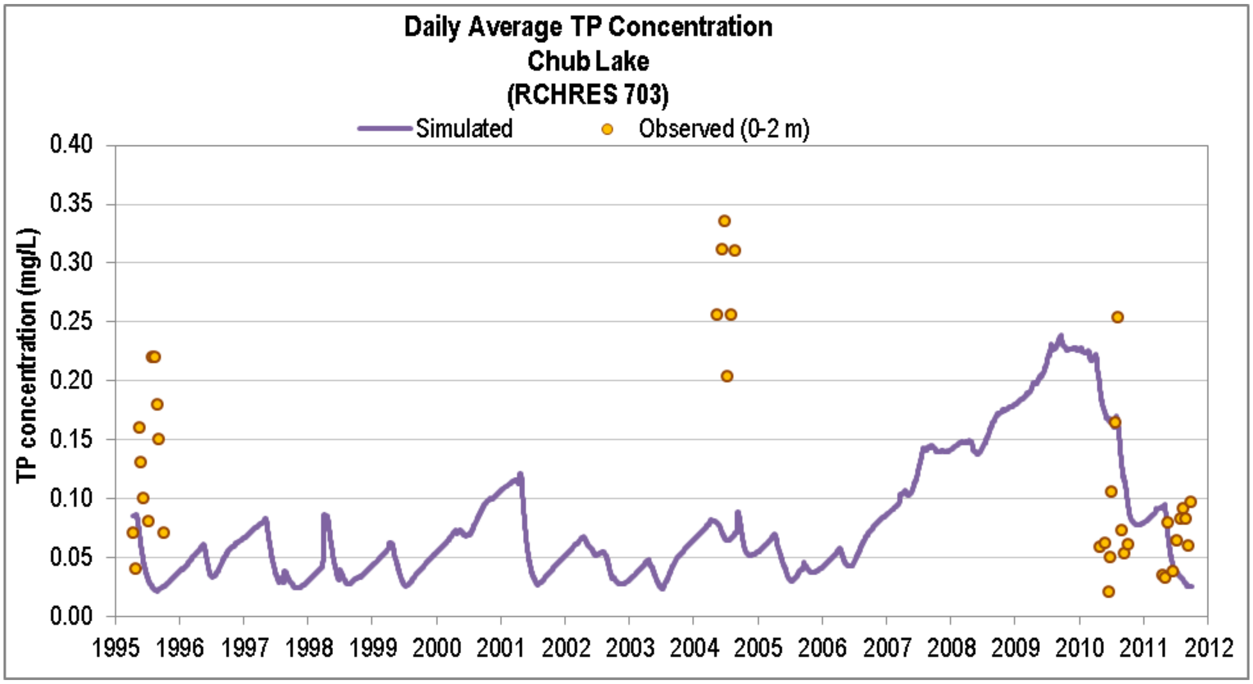

Figure D-17. Daily Average TP Concentrations for Chub Lake (RCHRES 703)

Orthophosphate

Table D-2. Orthophosphate Calibration Statistics for Additional Calibration Stations (2004-2012).

Time Interval	*Statistic*	Little Cannon River near Cannon Falls	Straight River at Clinton Falls	Straight River at Owatonna	Maple Creek at Owatonna	Turtle Creek 3 mi SE of Owatonna	Crane Creek near Medford
Annual	*Count*	6	8	8	8	8	8
	PBIAS	-97.47	14.15	11.79	24.18	33.42	18.59
	Relative Percent Difference	66.2%	-11.7%	-11.2%	-26.1%	-40.0%	-18.4%
Monthly	*Count*	32	49	49	49	49	49
	PBIAS	-52.91	17.35	13.33	26.69	35.02	22.69
	Relative Percent Difference	-11.1%	-16.2%	-14.9%	-27.9%	-40.4%	-11.5%
Daily	*Count*	88	181	181	181	180	181
	PBIAS	-74.54	18.13	12.99	25.97	33.60	21.85
	Relative Percent Difference	6.9%	-17.1%	-13.3%	-24.3%	-34.6%	-2.0%

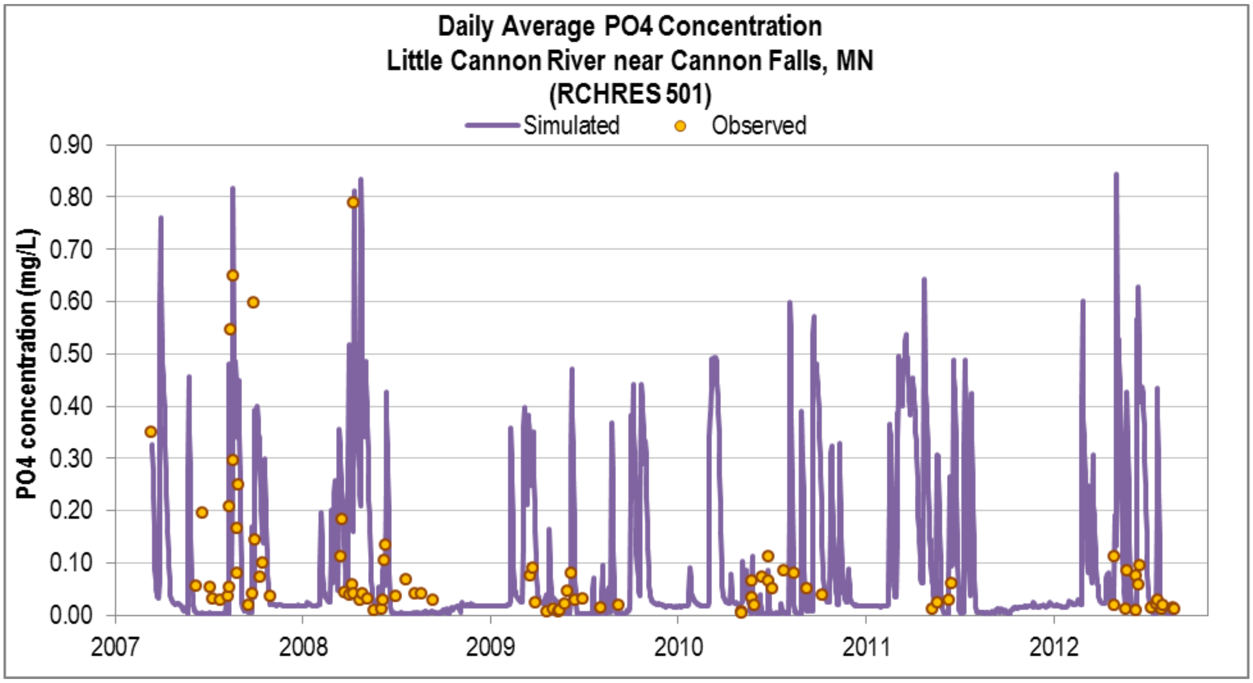

Figure D-10. Daily Average PO4 Concentrations for Little Cannon River near Cannon Falls (RCHRES 501)

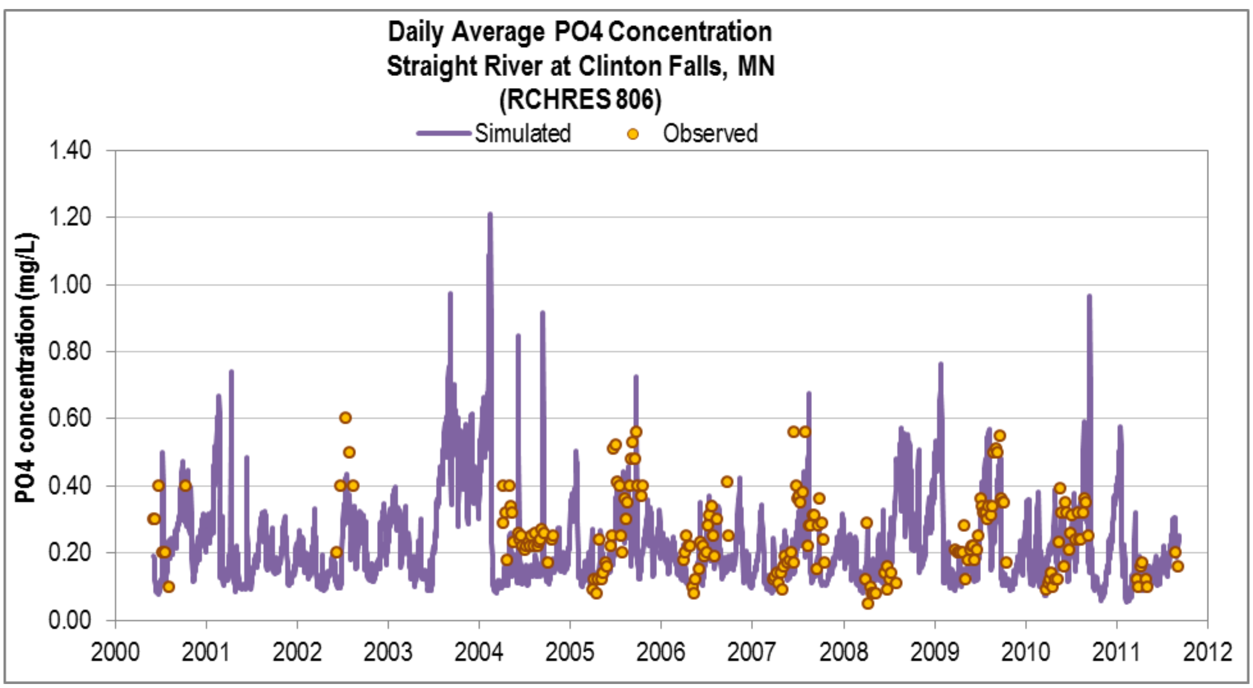

Figure D-11. Daily Average PO4 Concentrations for Straight River at Clinton Falls (RCHRES 806)

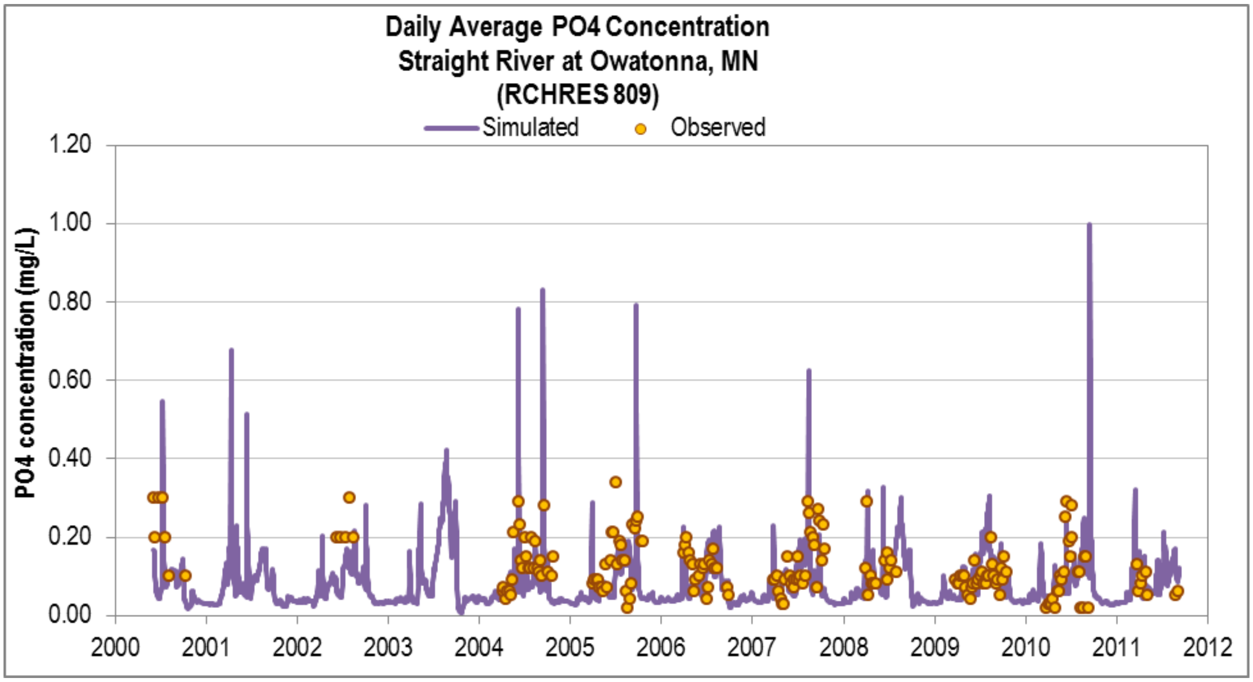

Figure D-12. Daily Average PO4 Concentrations for Straight River at Owatonna (RCHRES 809)

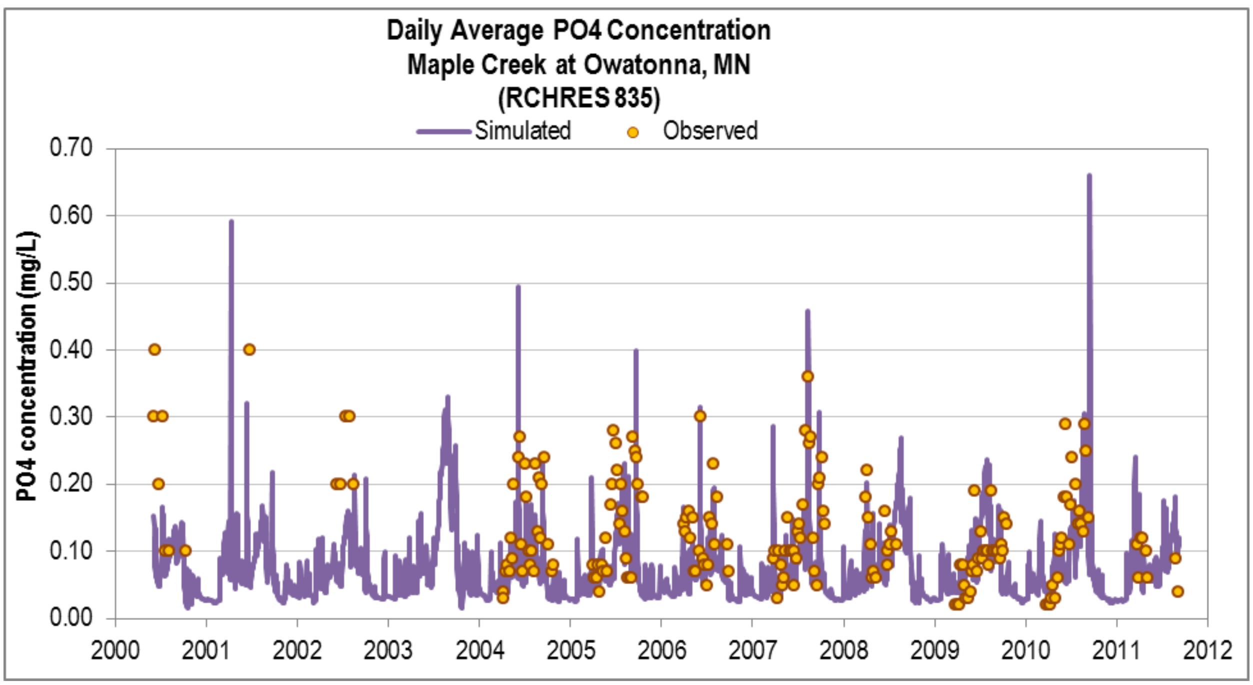

Figure D-13. Daily Average PO4 Concentrations for Maple Creek at Owatonna (RCHRES 835)

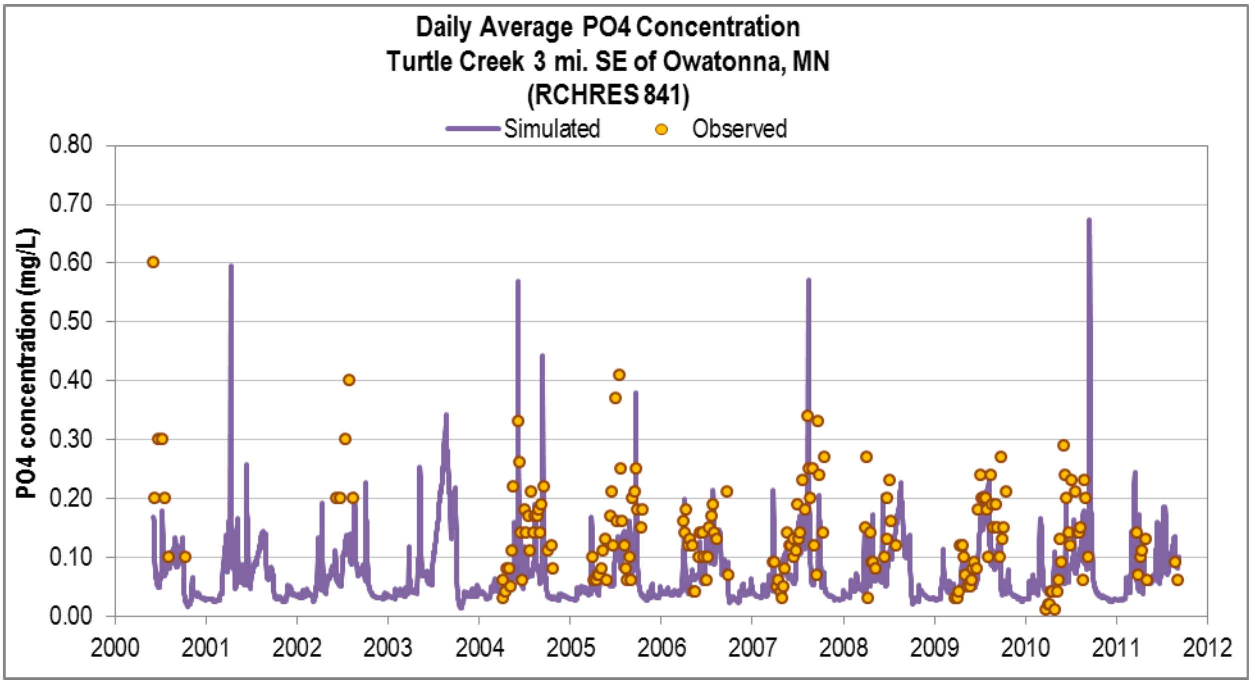

Figure D-14. Daily Average PO4 Concentrations for Turtle Creek 3 mi. SE of Owatonna (RCHRES 841)

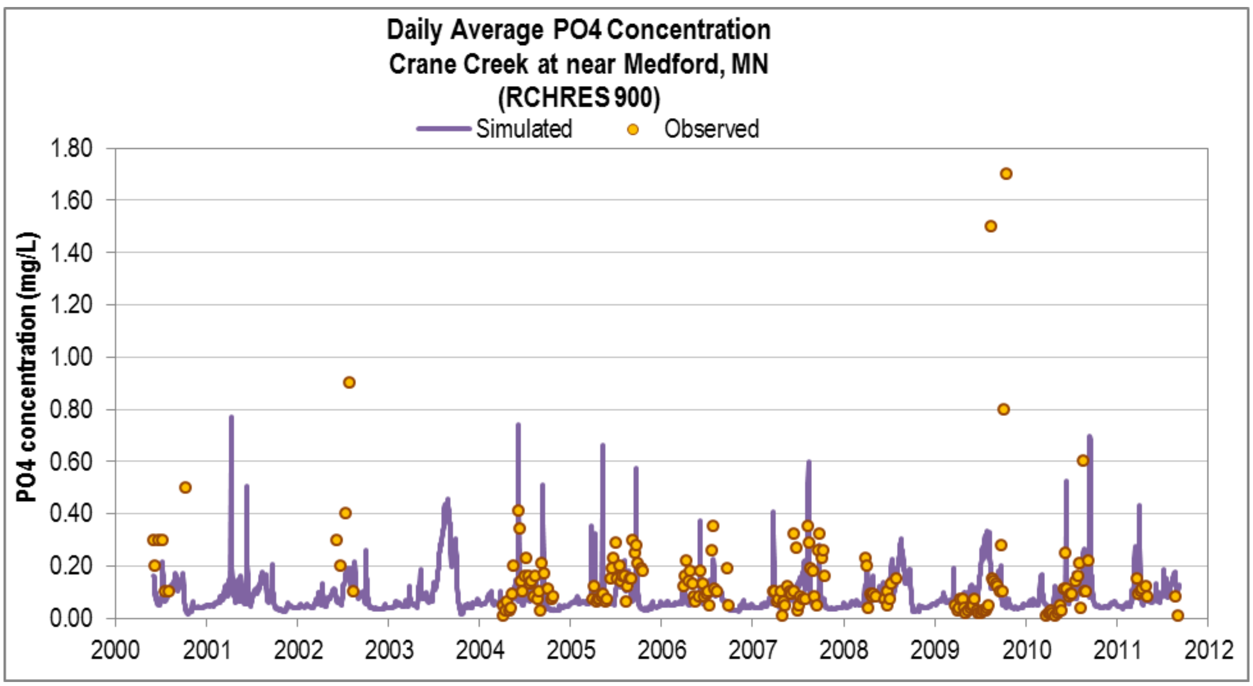

Figure D-15. Daily Average PO4 Concentrations for Crane Creek near Medford (RCHRES 900)

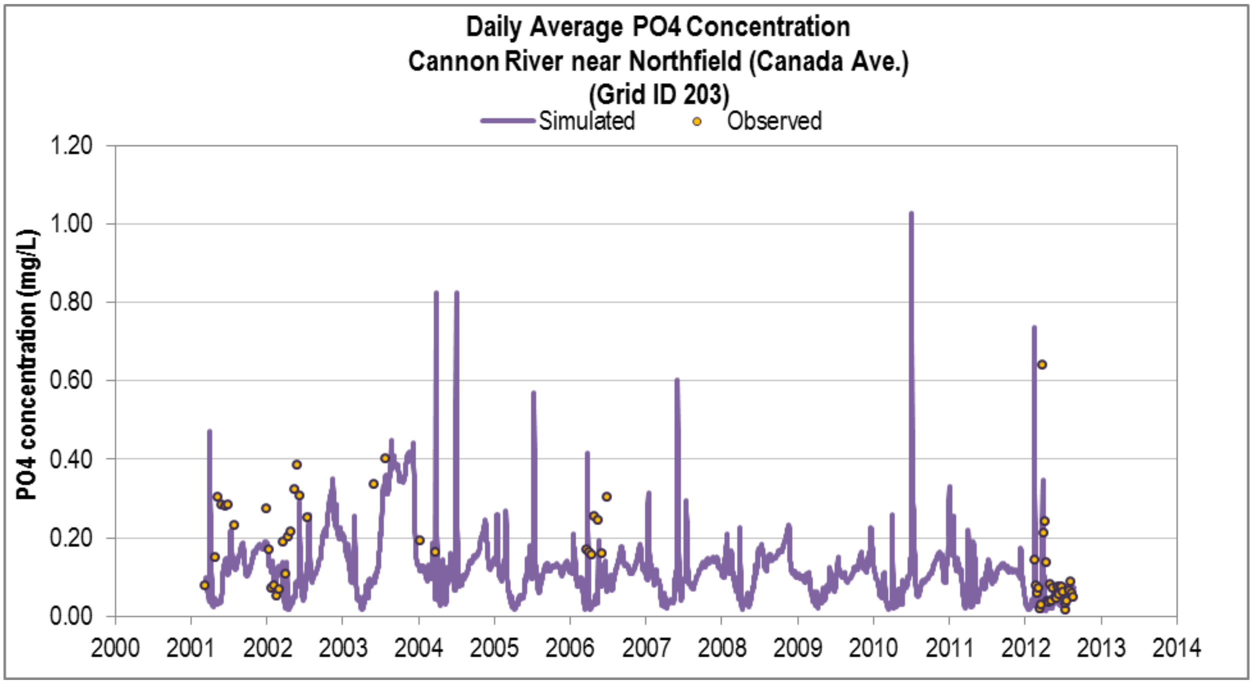

Figure D-16. Daily Average PO4 Concentrations for Cannon River near Northfield (RCHRES 203)

Appendix E
Nitrogen Simulation for Auxiliary Stations

Total Nitrogen

Table E-1. Total Nitrogen Calibration Statistics for Additional Calibration Stations (2004-2012).

Time Interval	*Statistic*	Little Cannon River near Cannon Falls	Straight River at Clinton Falls	Straight River at Owatonna	Maple Creek at Owatonna	Turtle Creek 3 mi SE of Owatonna	Crane Creek near Medford
Annual	*Count*	6	9	9	9	9	9
	PBIAS	-9.58	2.15	-14.63	-5.15	16.57	-7.00
	Relative Percent Difference	12.4%	-0.7%	15.9%	8.6%	-12.3%	10.0%
Monthly	*Count*	37	60	46	46	46	48
	PBIAS	-6.48	0.58	-10.15	0.02	18.22	-4.31
	Relative Percent Difference	13.3%	10.9%	27.9%	22.0%	6.4%	34.1%
Daily	*Count*	102	142	122	122	121	144
	PBIAS	-11.06	-2.11	-9.55	-2.43	16.57	5.52
	Relative Percent Difference	13.8%	13.2%	28.1%	24.2%	8.7%	26.3%

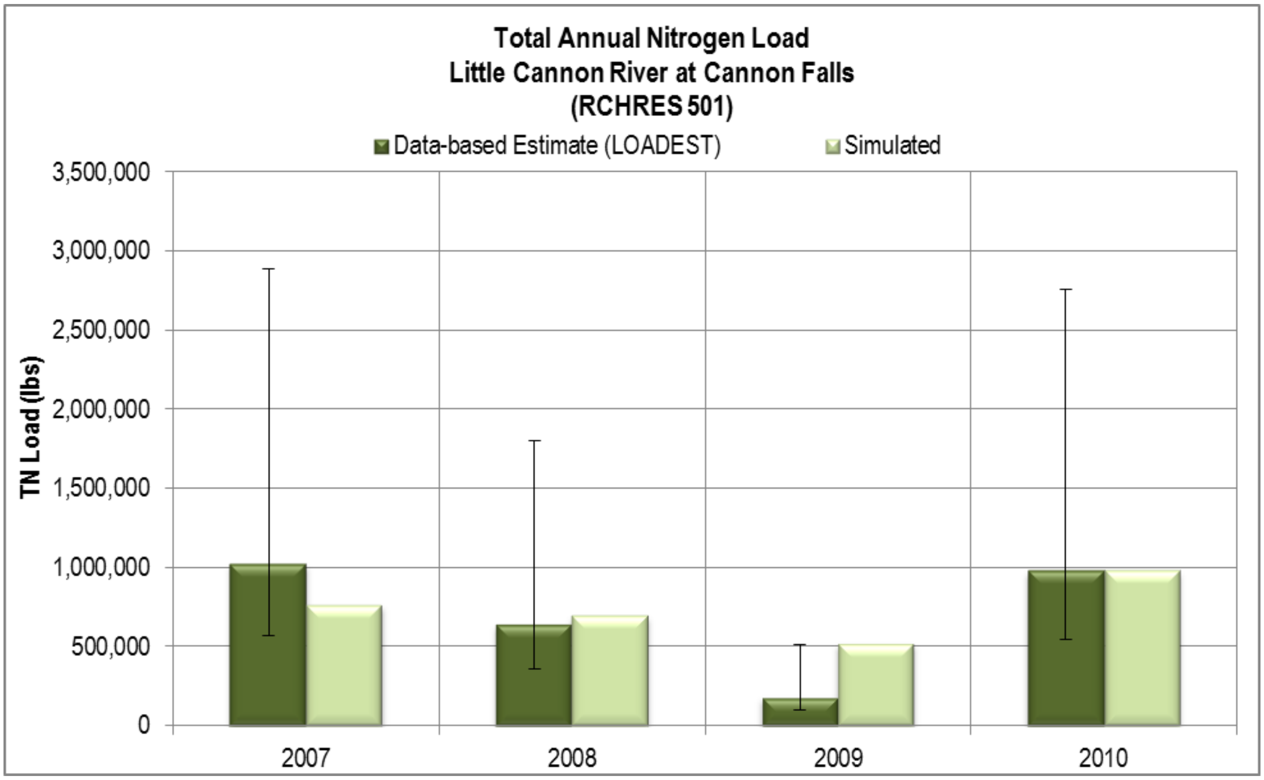

Figure E-1. Annual TN Loads for Little Cannon River near Cannon Falls (RCHRES 501)

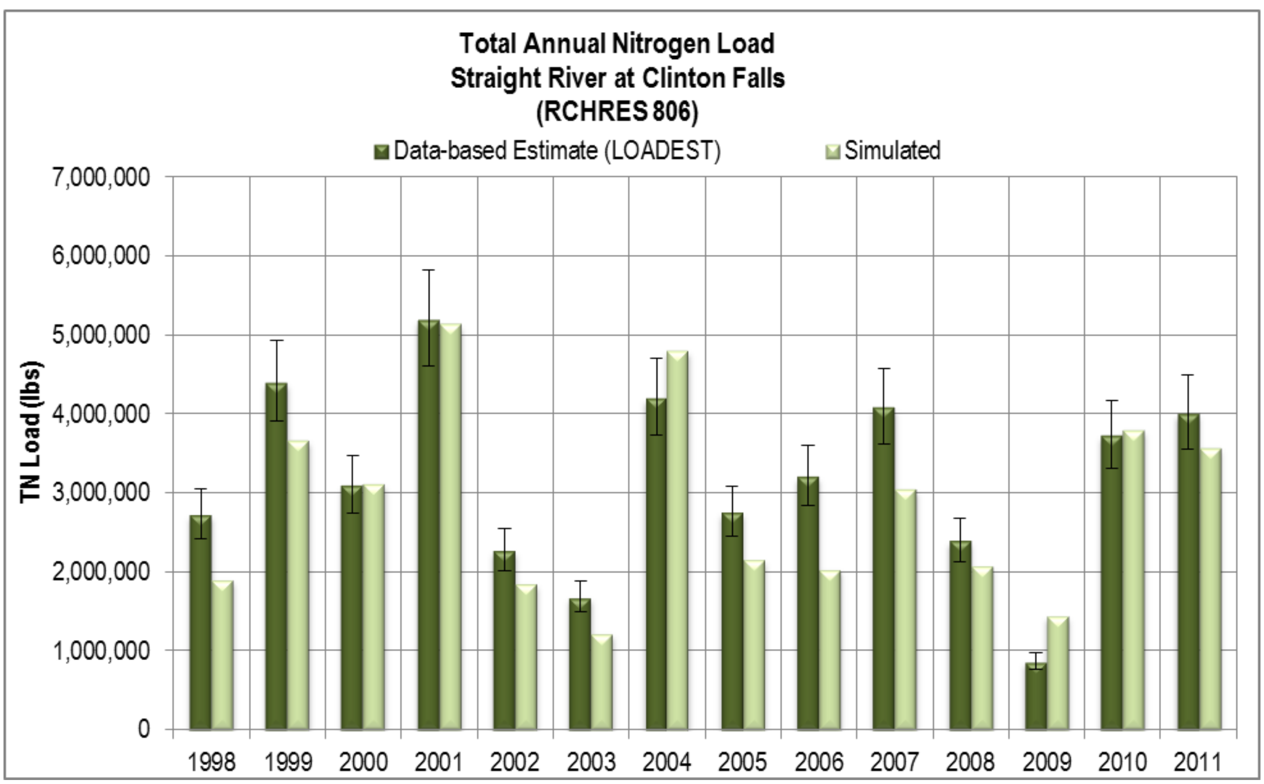

Figure E-2. Annual TN Loads for Straight River at Clinton Falls (RCHRES 806)

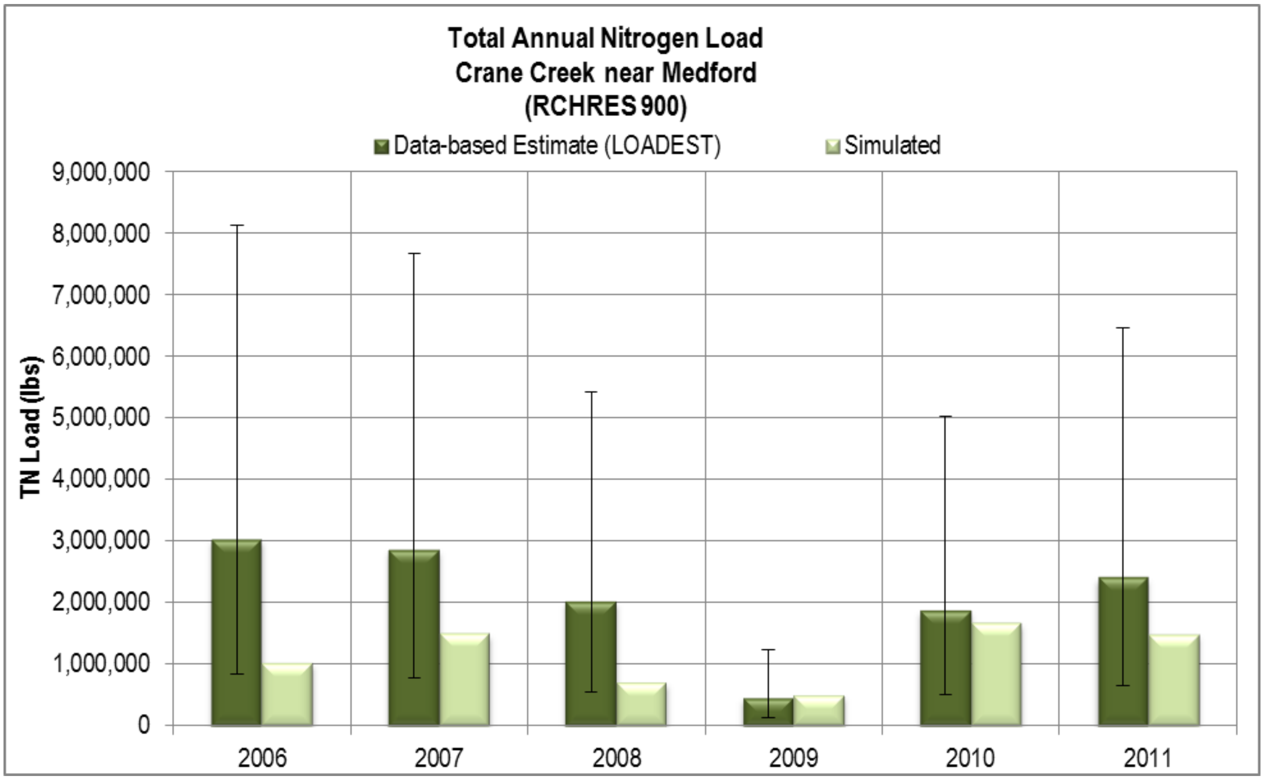

Figure E-3. Annual TN Loads for Crane Creek near Medford (RCHRES 900)

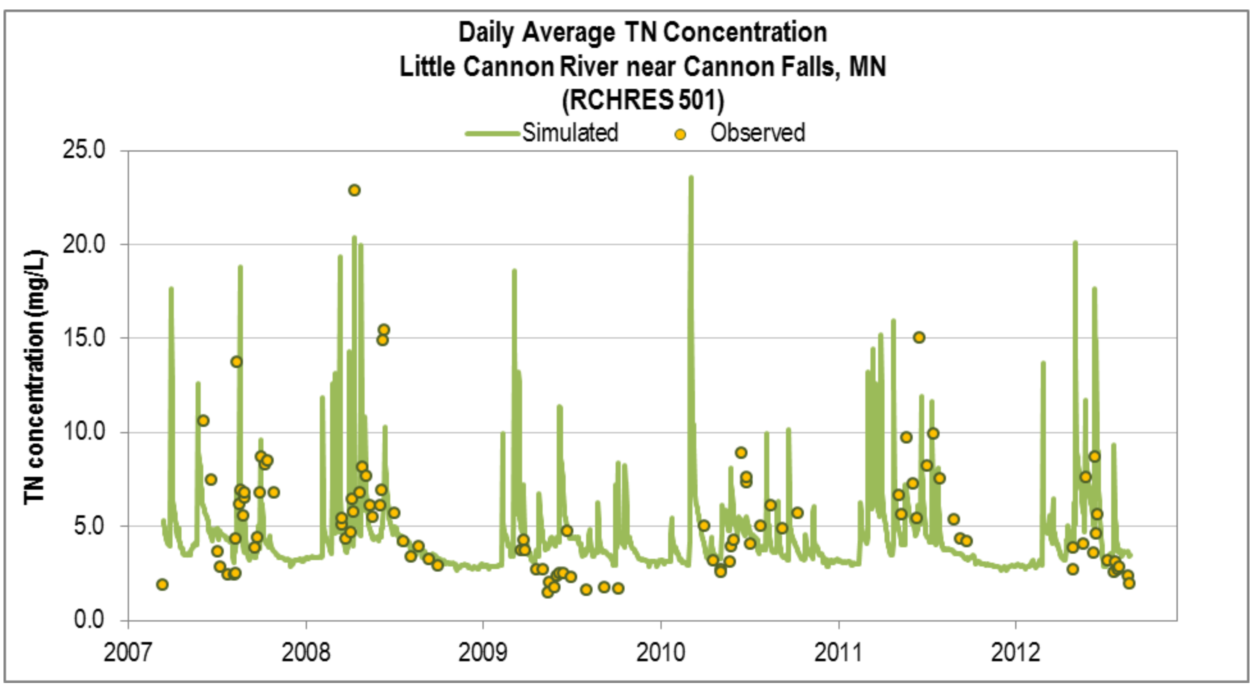

Figure E-4. Daily Average TN Concentrations for Little Cannon River near Cannon Falls (RCHRES 501)

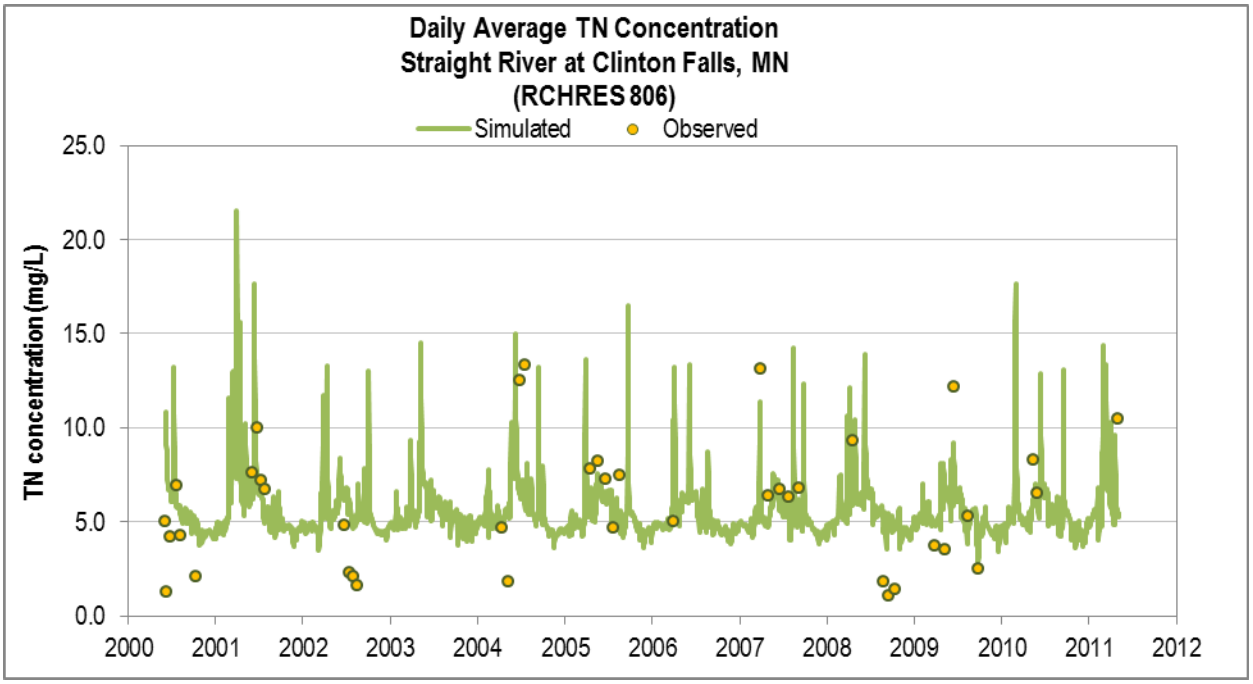

Figure E-5. Daily Average TN Concentrations for Straight River at Clinton Falls (RCHRES 806)

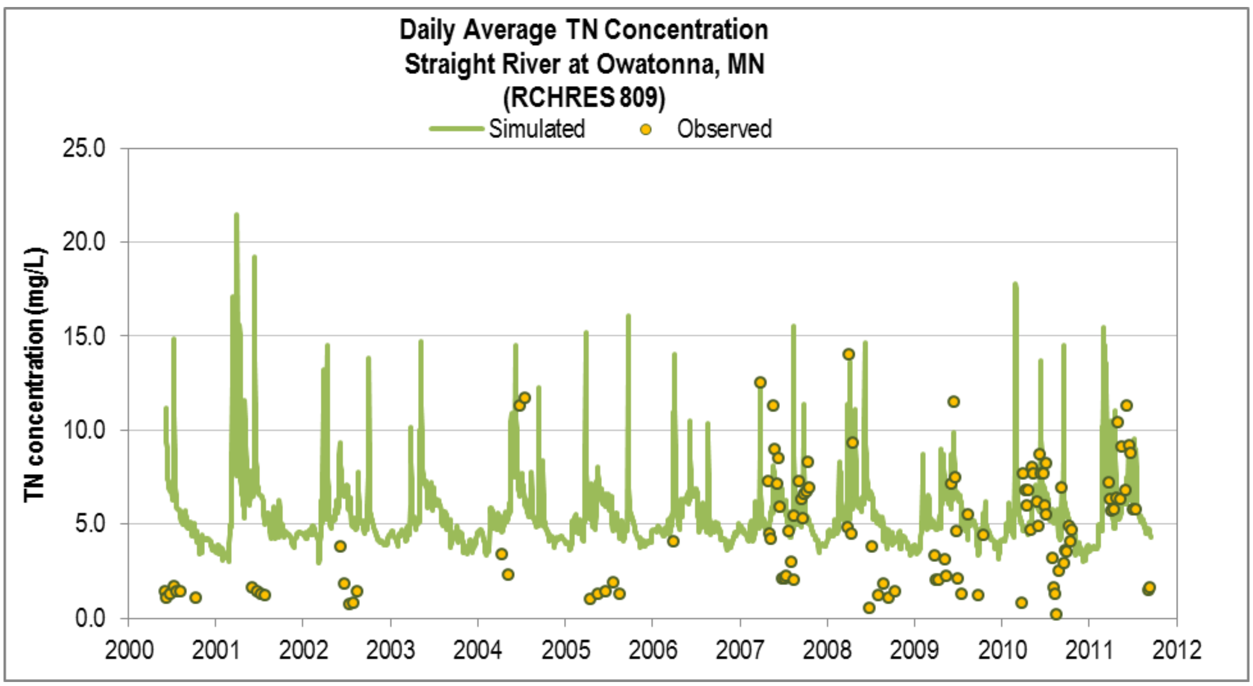

Figure E-6. Daily Average TN Concentrations for Straight River at Owatonna (RCHRES 809)

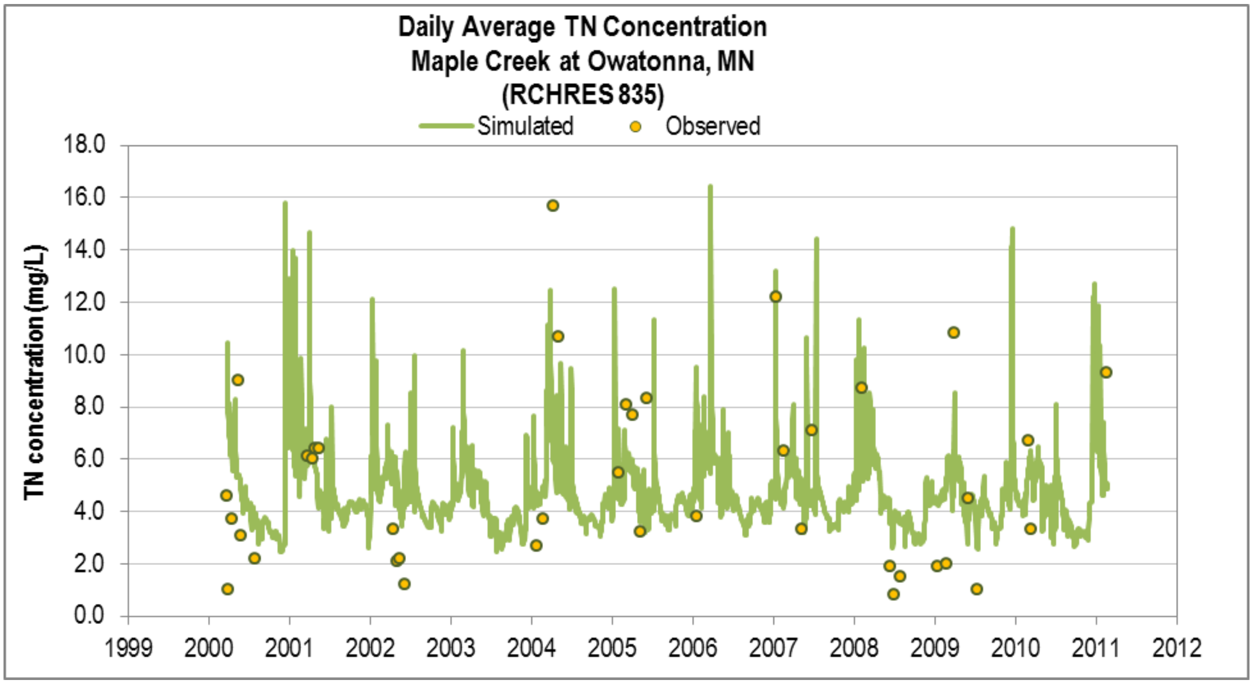

Figure E-7. Daily Average TN Concentrations for Maple Creek at Owatonna (RCHRES 835)

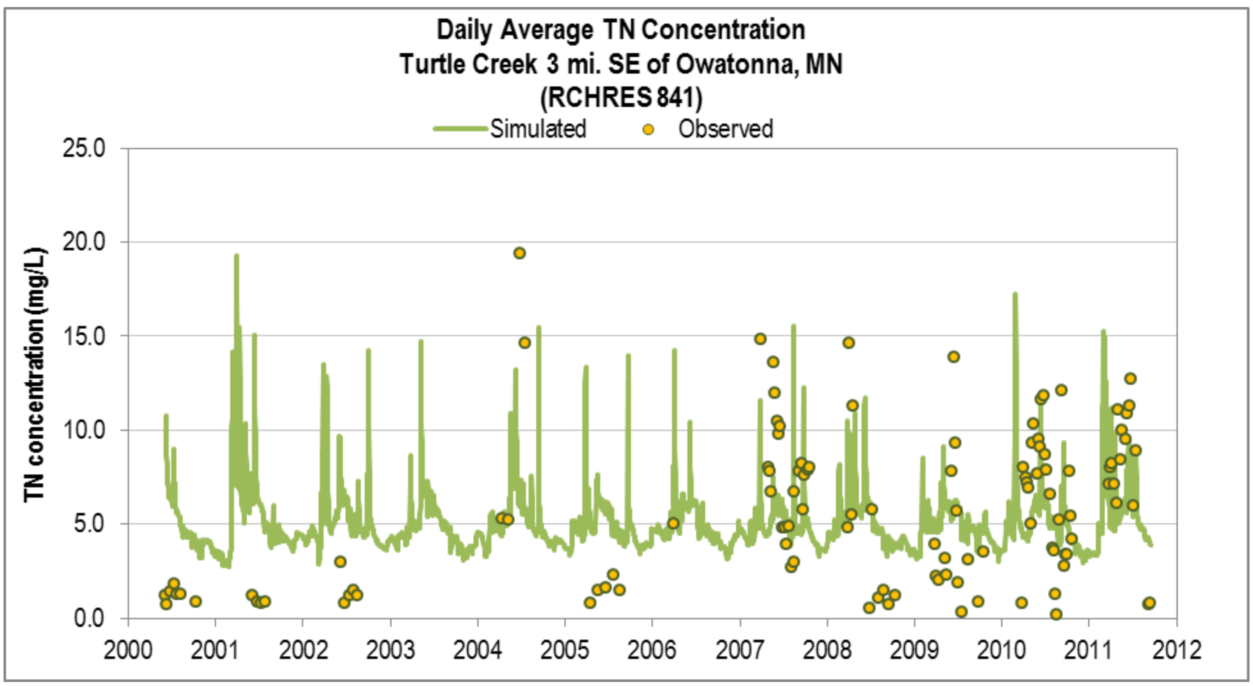

Figure E-8. Daily Average TN Concentrations for Turtle Creek 3 mi. SE of Owatonna (RCHRES 841)

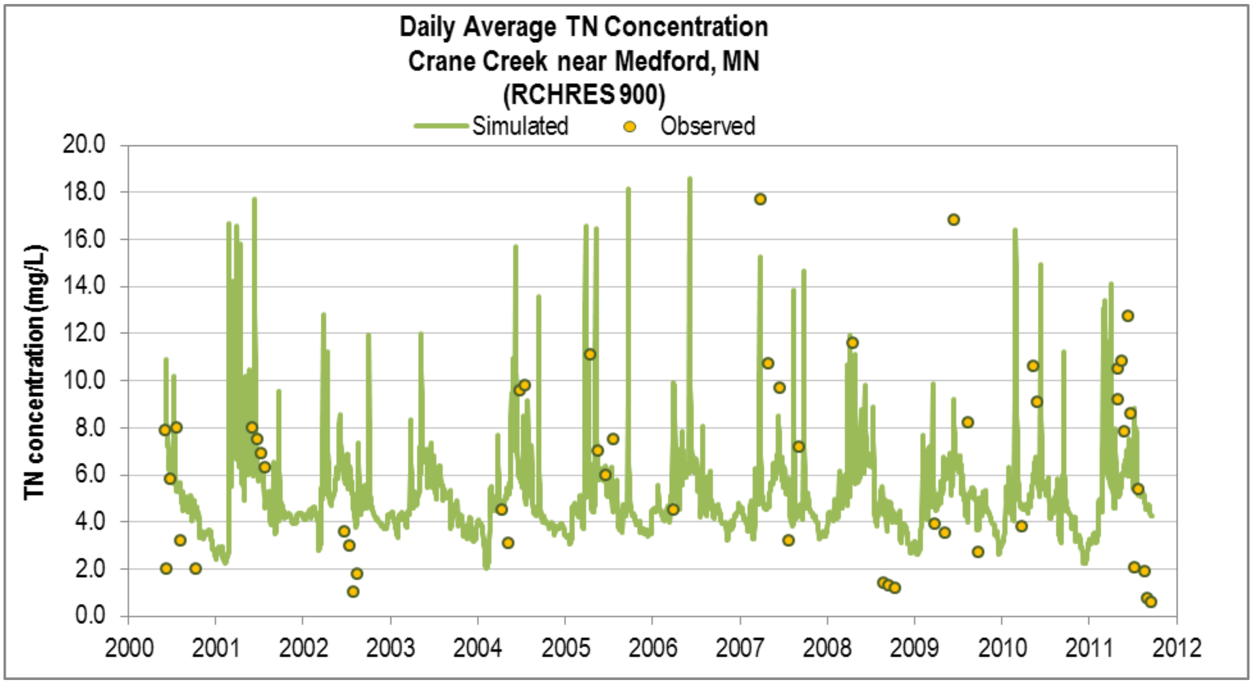

Figure E-9. Daily Average TN Concentrations for Crane Creek near Medford (RCHRES 900)

Nitrate

Table E-2. Nitrate Calibration Statistics for Additional Calibration Stations (2004-2012).

Time Interval	Statistic	Little Cannon River near Cannon Falls	Straight River at Clinton Falls	Straight River at Owatonna	Maple Creek at Owatonna	Turtle Creek 3 mi SE of Owatonna	Crane Creek near Medford
Annual	Count	6	8	7	7	7	8
	PBIAS	-9.58	6.32	-15.06	-6.84	16.46	-10.51
	Relative Percent Difference	12.4%	-5.3%	16.1%	10.9%	-11.9%	13.5%
Monthly	Count	37	49	35	35	35	42
	PBIAS	-6.48	2.97	-8.54	0.12	19.32	-7.59
	Relative Percent Difference	13.3%	9.3%	26.5%	20.9%	4.9%	40.0%
Daily	Count	102	114	94	94	93	118
	PBIAS	-11.06	2.34	-2.88	0.89	21.84	7.97
	Relative Percent Difference	13.8%	8.6%	18.4%	16.4%	-2.7%	21.4%

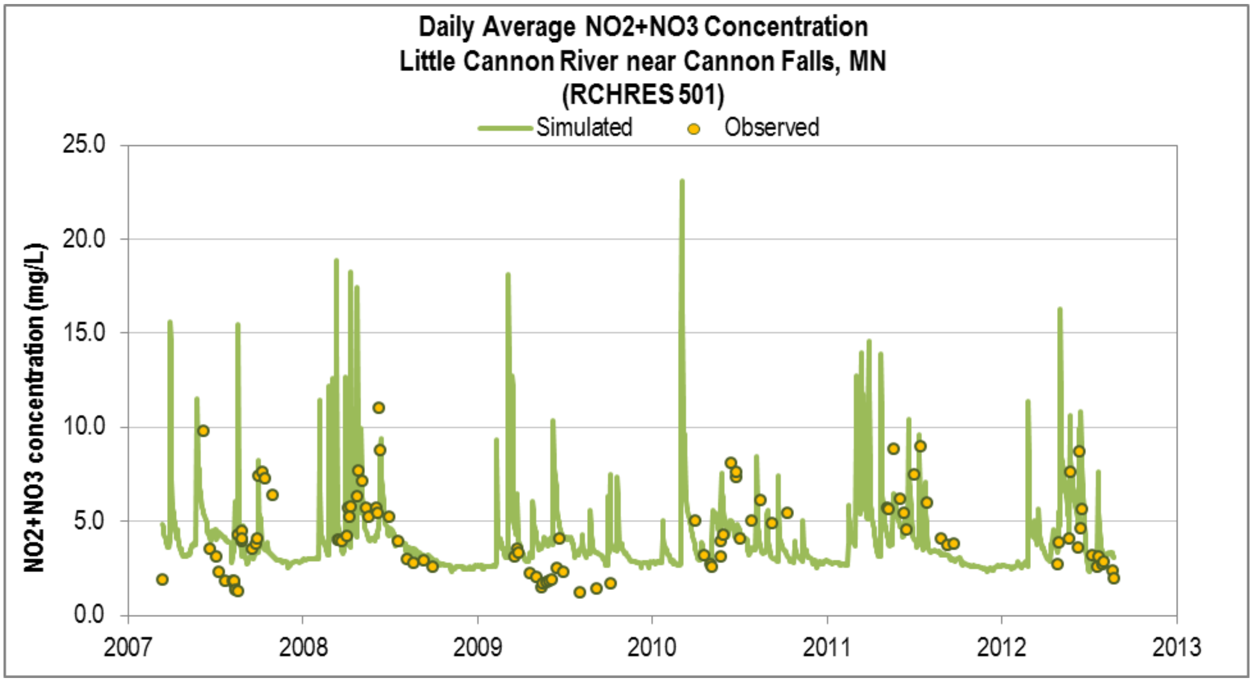

Figure E-10. Daily Average NO3+NO2 Concentrations for Little Cannon River near Cannon Falls (RCHRES 501)

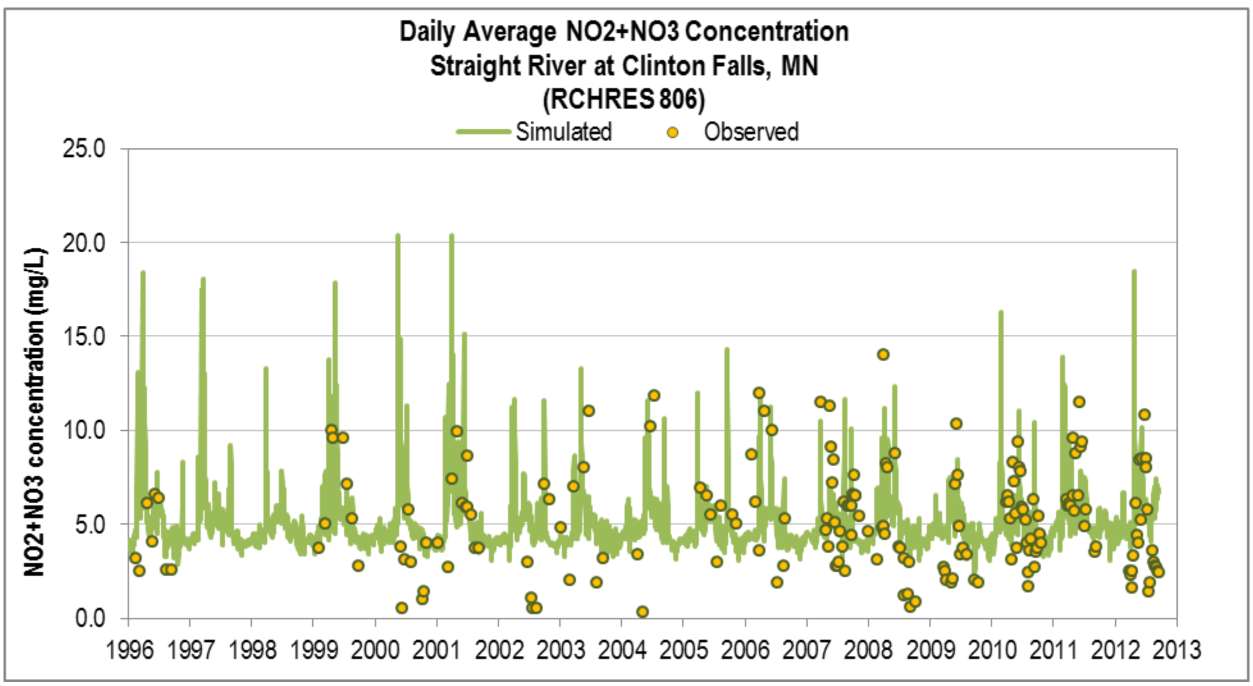

Figure E-11. Daily Average NO3+NO2 Concentrations for Straight River at Clinton Falls (RCHRES 806)

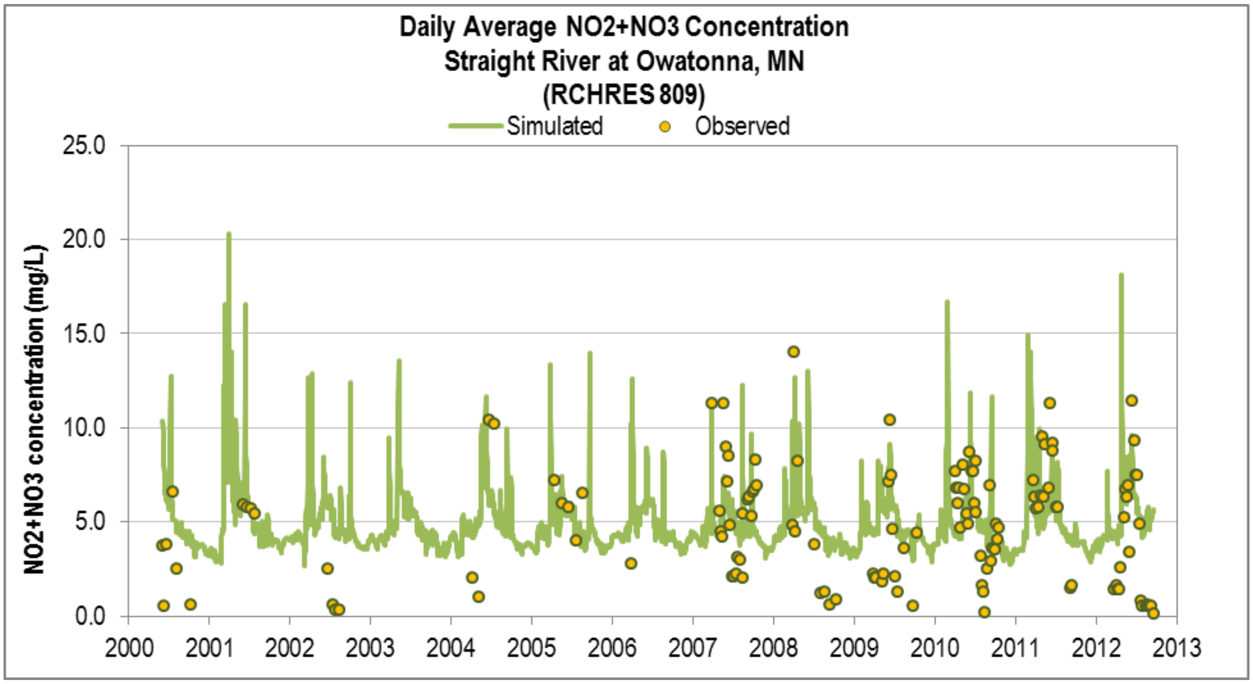

Figure E-12. Daily Average NO3+NO2 Concentrations for Straight River at Owatonna (RCHRES 809)

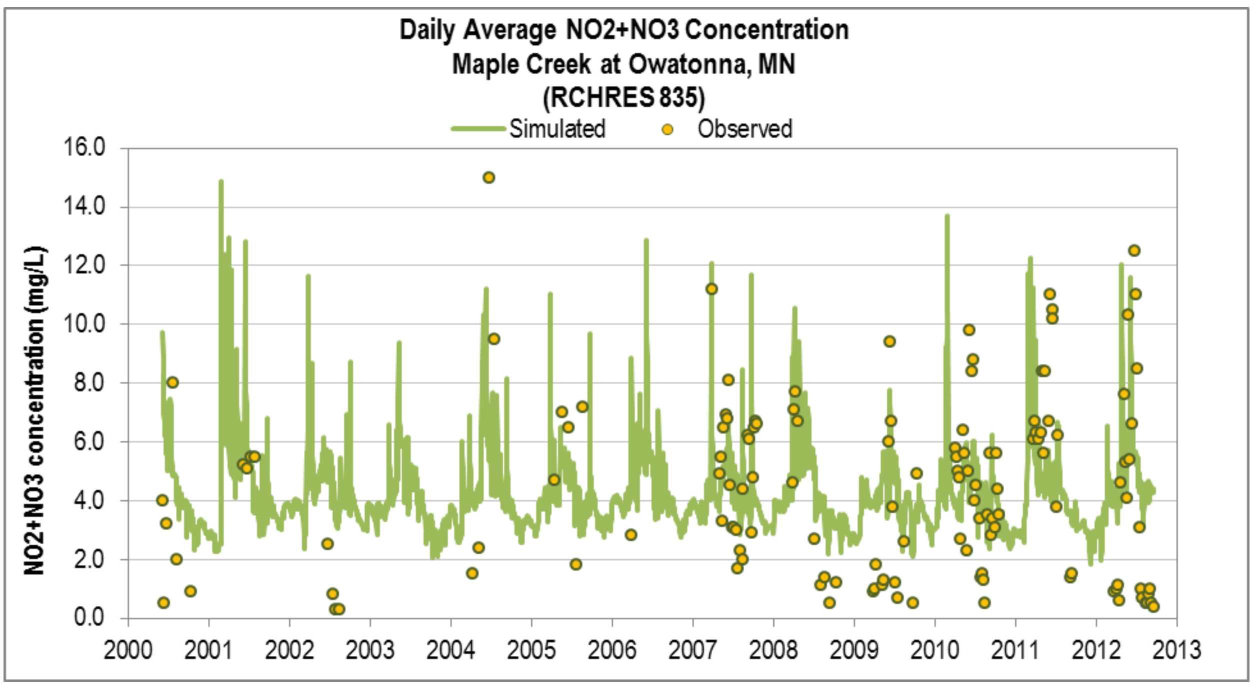

Figure E-13. Daily Average NO3+NO2 Concentrations for Maple Creek at Owatonna (RCHRES 835)

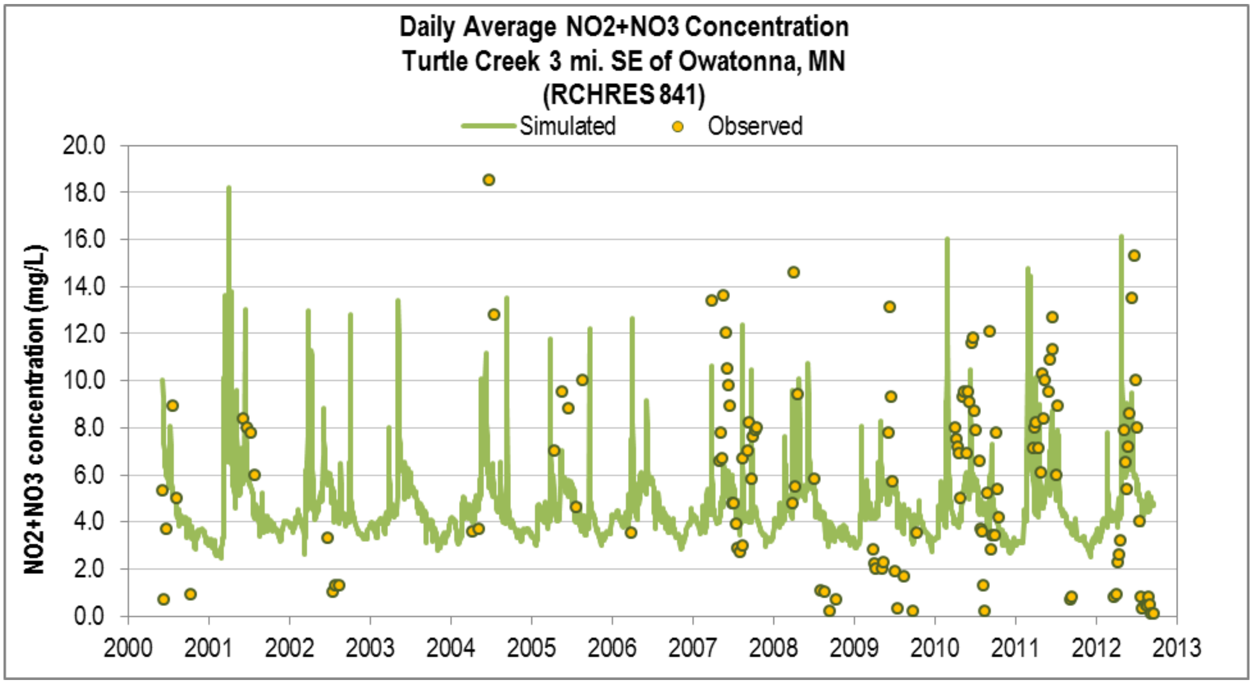

Figure E-14. Daily Average NO3+NO2 Concentrations for Turtle Creek 3 mi. SE of Owatonna (RCHRES 841)

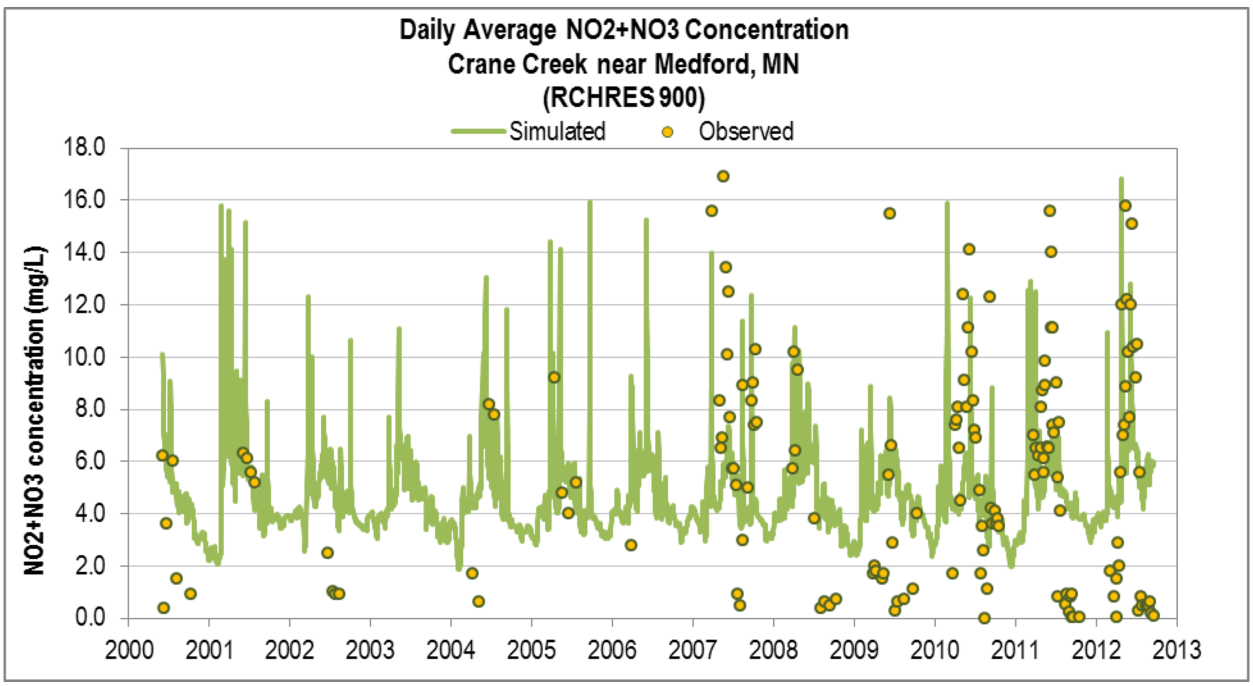

Figure E-15. Daily Average NO3+NO2 Concentrations for Crane Creek near Medford (RCHRES 900)

Ammonia

Table E-3. Ammonia Calibration Statistics for Additional Calibration Stations (2004-2012).

Time Interval	Statistic	Straight River at Clinton Falls	Straight River at Owatonna	Maple Creek at Owatonna	Turtle Creek 3 mi SE of Owatonna	Crane Creek near Medford
Annual	Count	8	8	8	8	9
	PBIAS	-132.79	-93.71	-235.16	-137.80	51.54
	Relative Percent Difference	76.6%	60.3%	106.1%	91.1%	23.7%
Monthly	Count	44	28	28	29	33
	PBIAS	-128.02	-85.00	-258.12	-138.76	48.13
	Relative Percent Difference	69.8%	60.2%	112.7%	107.4%	54.8%
Daily	Count	60	39	39	40	49
	PBIAS	-131.12	-101.82	-282.58	-170.83	26.45
	Relative Percent Difference	73.7%	61.1%	119.5%	110.0%	54.3%

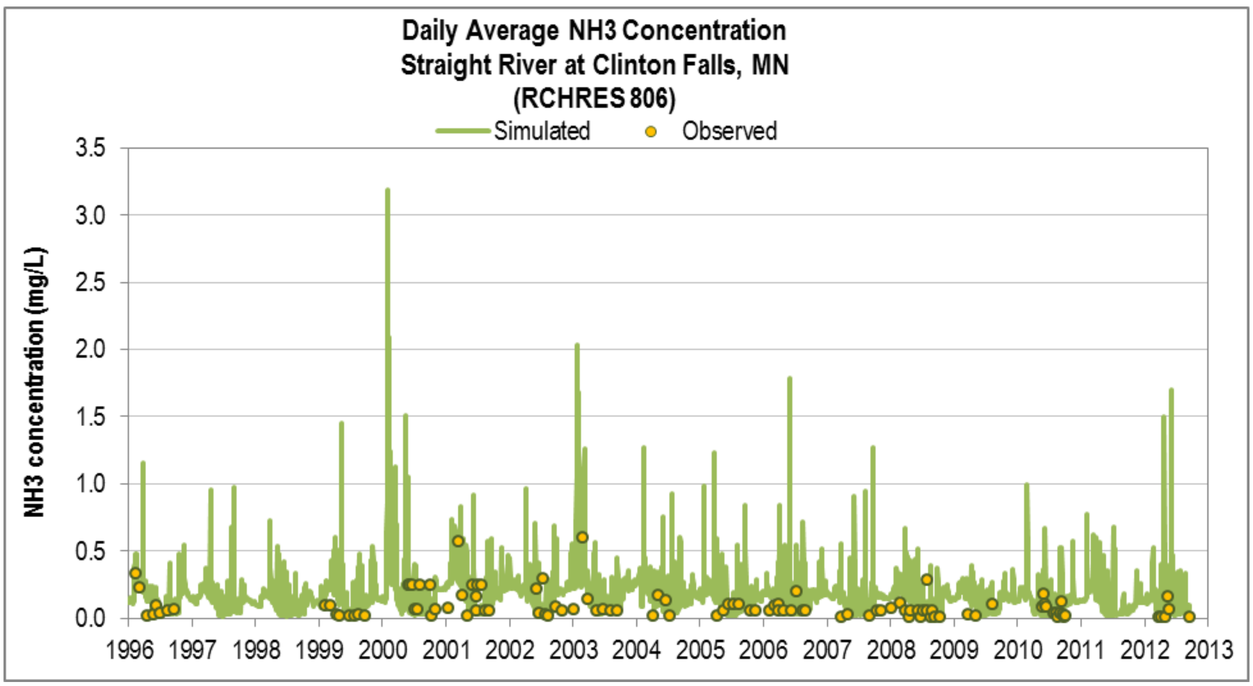

Figure E-16. Daily Average NH3 Concentrations for Straight River at Clinton Falls (RCHRES 806)

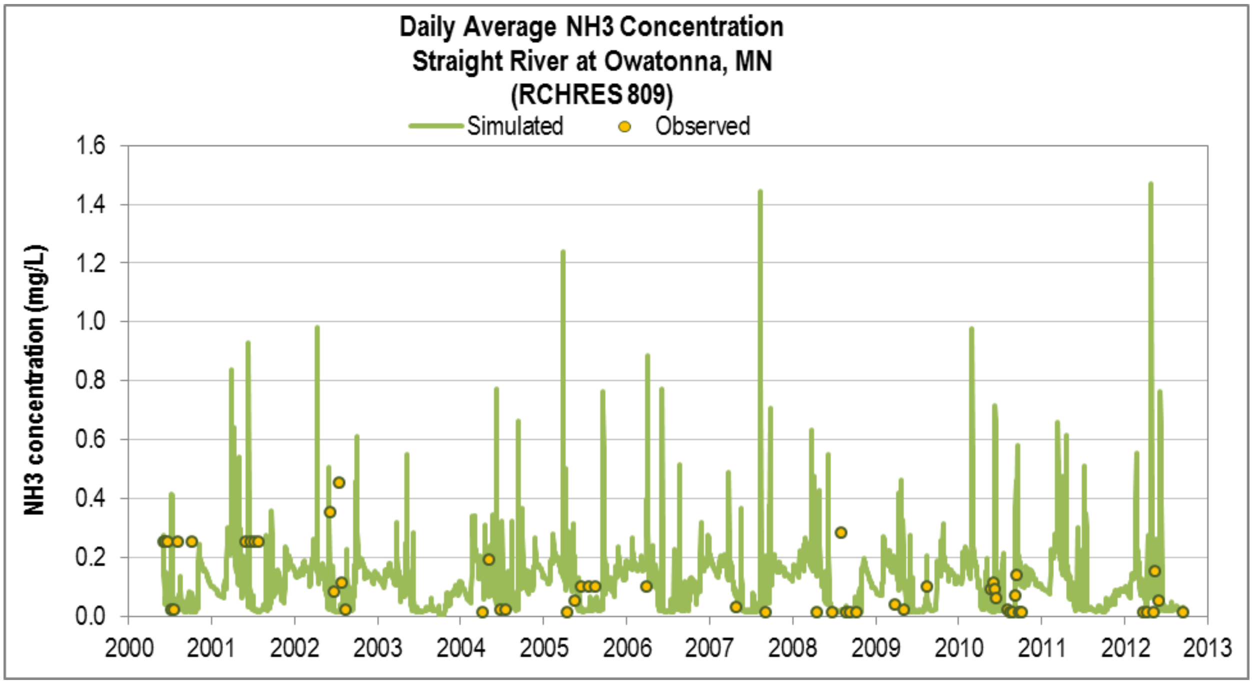

Figure E-17. Daily Average NH3 Concentrations for Straight River at Owatonna (RCHRES 809)

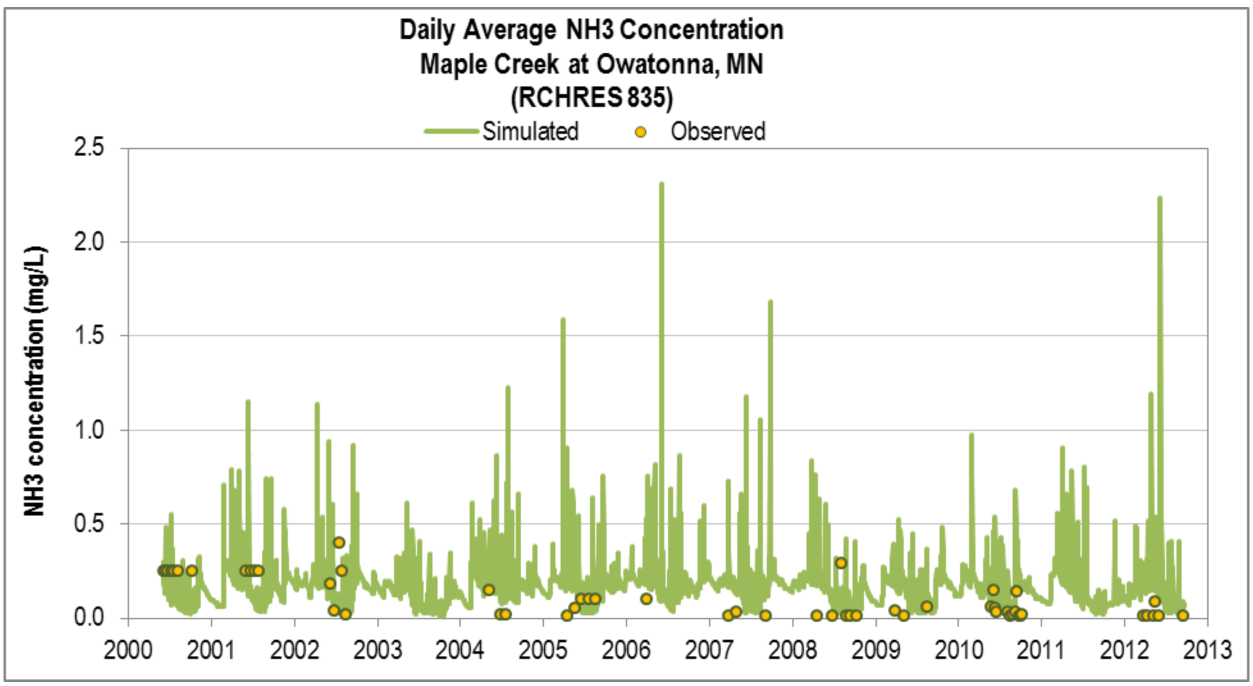

Figure E-18. Daily Average NH3 Concentrations for Maple Creek at Owatonna (RCHRES 835)

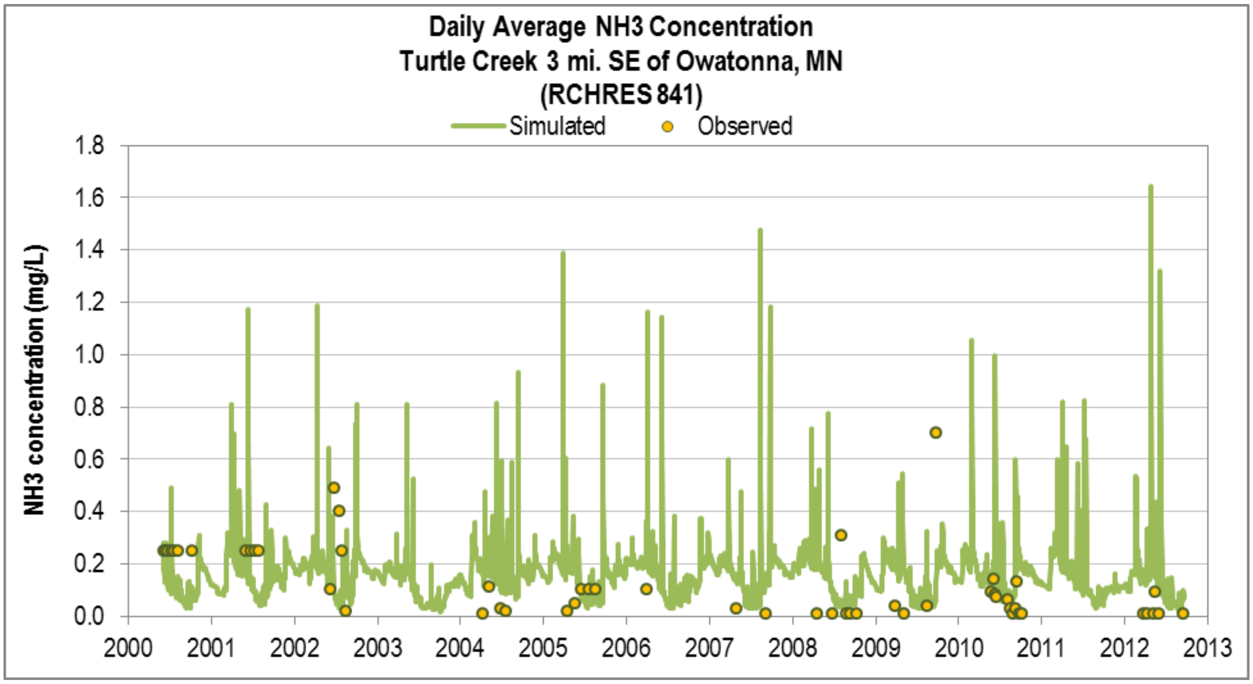

Figure E-19. Daily Average NH3 Concentrations for Turtle Creek 3 mi. SE of Owatonna (RCHRES 841)

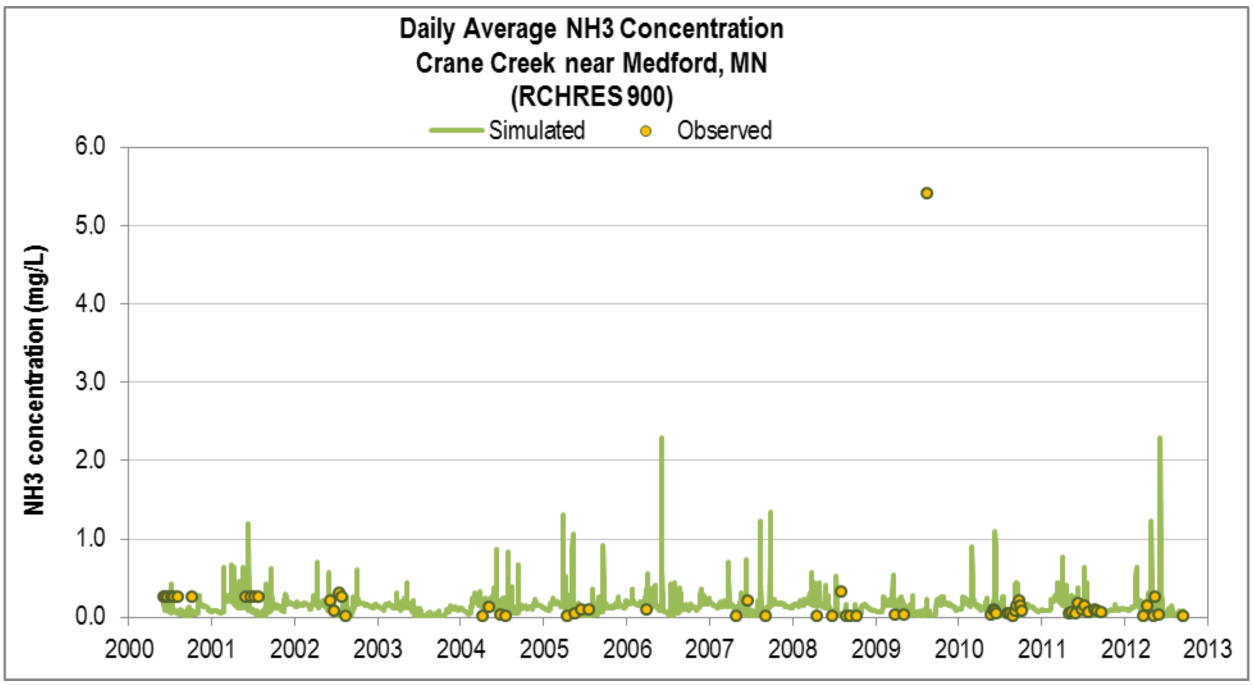

Figure E-20. Daily Average NH3 Concentrations for Crane Creek near Medford (RCHRES 900)

Appendix F
Dissolved Oxygen Simulation for Auxiliary Stations

Table F-1. Dissolved Oxygen Calibration Statistics for Additional Calibration Stations (2004-2012).

Time Interval	*Statistic*	Little Cannon River near Cannon Falls	Chub Creek at Randolph	Straight River at Clinton Falls
Annual	*Count*	6	5	5
	PBIAS	-4.30	-3.42	-8.76
	Relative Percent Difference	4.5%	3.9%	8.7%
Monthly	*Count*	31	29	24
	PBIAS	-1.05	-3.95	-7.04
	Relative Percent Difference	2.8%	4.7%	7.8%
Daily	*Count*	68	55	32
	PBIAS	-3.58	-4.24	-6.89
	Relative Percent Difference	4.5%	5.1%	7.6%

Table F-2. Dissolved Oxygen Validation Statistics for Additional Calibration Stations (1996-2003).

Time Interval	*Statistic*	Little Cannon River near Cannon Falls	Chub Creek at Randolph	Straight River at Clinton Falls
Annual	*Count*			7
	PBIAS			-8.15
	Relative Percent Difference			7.7%
Monthly	*Count*			38
	PBIAS			-5.01
	Relative Percent Difference			5.8%
Daily	*Count*			38
	PBIAS			-5.01
	Relative Percent Difference			5.8%

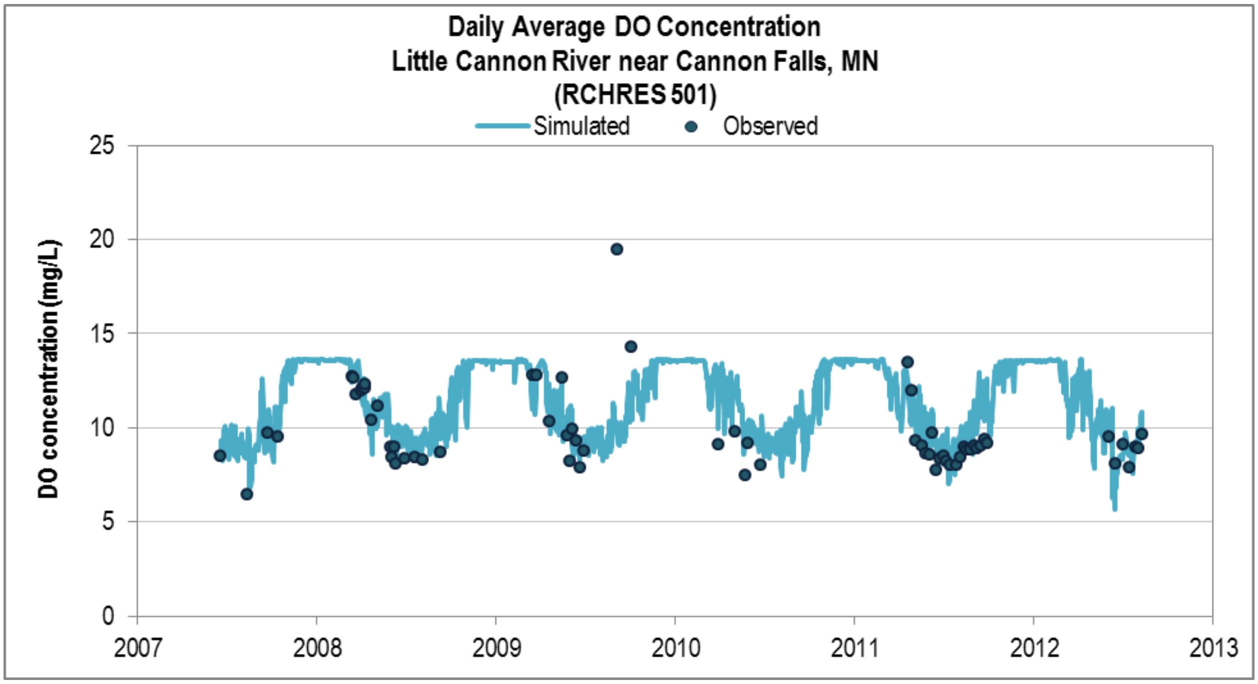

Figure F-1. Daily Average DO Concentrations for Little Cannon River near Cannon Falls (RCHRES 501).

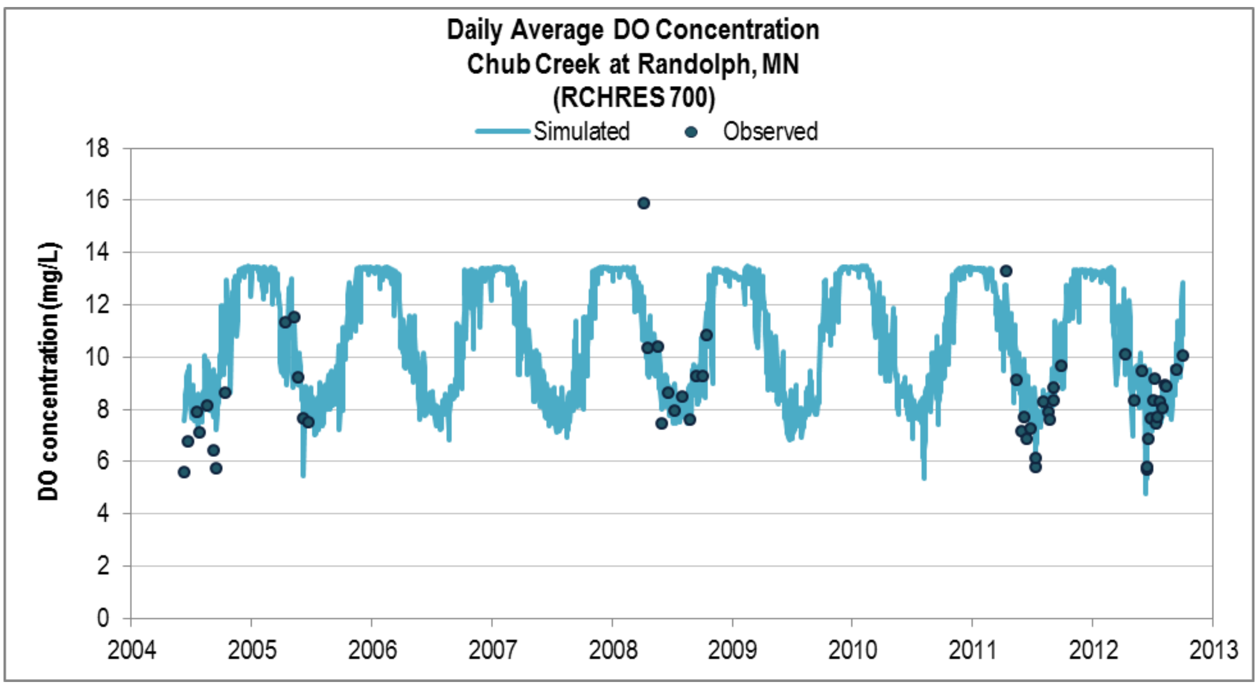

Figure F-2. Daily Average DO Concentrations for Chub Creek at Randolph (RCHRES 700).

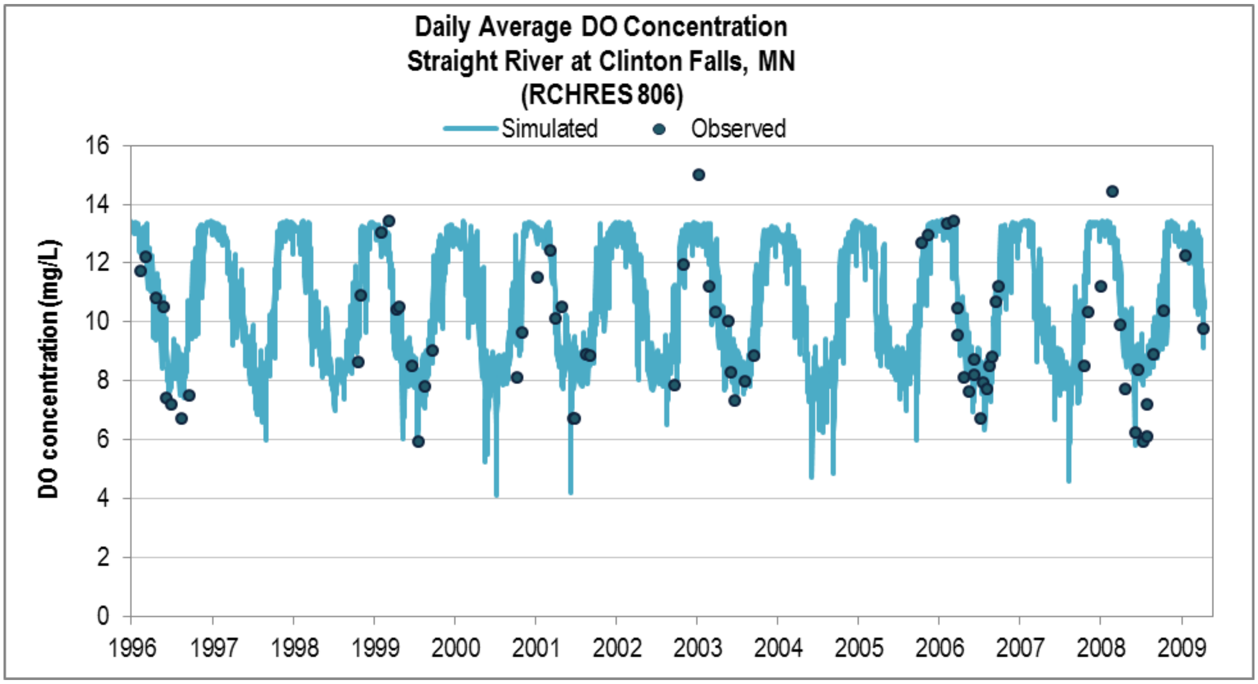

Figure F-3. Daily Average DO Concentrations for Straight River at Clinton Falls (RCHRES 806).