Zumbro River Watershed HSPF Model Development Project

Minnesota Pollution Control Agency, One Water Program

Prepared for:
Minnesota Pollution Control
Agency

FINAL
May 12, 2014

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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 Zumbro 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 HUC8 (8-digit Hydrologic Unit Code) scale. This represents 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 HUC8 watersheds.

The Zumbro River watershed includes waters impaired by excessive fecal coliforms, mercury, PCBs, and turbidity. Lake Zumbro, a highly valued water resource, is also impaired by excessive nutrients. The MPCA has selected the 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. This project develops an HSPF model for the Zumbro River watershed to assist in addressing these management needs.

The goal of the project was to construct, calibrate, and validate an HSPF watershed model for the Zumbro River 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 2013a-g, LimnoTech 2014a-b), 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 “Zumbro 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 Zumbro River watershed model (ZRWHSPF).
- **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 ZRWHSPF 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 Zumbro River watershed to support the calibration and validation of the Zumbro River watershed HSPF model. The model was calibrated and validated for sediment using the sediment sources and targets outlined in the conceptual site model (CSM) memorandum (LimnoTech 2013g).
- **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 ZRWHSPF 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 ZRWHSPF model developed and applied to the Zumbro 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 Zumbro River Watershed

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

2.1 Physical Characteristics

The HUC8 Zumbro River watershed covers over 909,000 acres and is located within the Western Corn Belt Plains, North Central Hardwoods, and Driftless Area Ecoregions of Minnesota (MPCA 2012, USDA NRCS 2013a). The major branches of the Zumbro River watershed consist of the South Fork, Middle Fork, North Fork, Lake Zumbro, and the Lower Zumbro River (Figure 2-1). The watershed drains portions of Olmsted, Dodge, Wabasha, Goodhue, Steele, and Rice counties. The South Fork and Middle Fork branches merge near Oronoco. The North Fork branch meets with Zumbro River between Mazeppa and Zumbro Falls before converging with the Mississippi River near Wabasha and Kellogg. The South Fork's course through Rochester has been channelized as part of a flood control project, and is dammed by the Lake Zumbro Hydroelectric Generating Plant, owned by Rochester Public Utilities (RPU), to form Lake Zumbro (USDA NRCS 2013a).

The general climate of the Zumbro River watershed is a continental climate with winter temperatures around 10°F and summer temperatures around 70°F. Annual precipitation in the Zumbro watershed ranges from 29 to 33 inches per year. A large portion of the eastern drainage area is located within a geologic region known as the "Driftless Area", with topography comprised of a unique landform known as "Karst" (MPCA 2012). Features of Karst are characterized by underground streams, sinkholes, blind valleys and springs. The majority of the land use within the watershed is agricultural, with crop and pasture lands accounting for approximately 67% of the overall land area. Predominate land covers /land uses include row crops (55.7%), pasture (11.4%), grassland (12.2%), forest (9.7%), residential/commercial/open space development (8.9%), and water/wetlands (1.9%).

The elevation of the watershed ranges from 900 ft to 1,500 ft above sea level. The predominant average percent slope of the watershed falls within the 4-10% range and covers 50% of the watershed area. The remaining watershed area contains average percent slopes of <2% over 18% of the land area, 2-4% over 19% of the land area, and >10% over 12% of the land area. The soils in the watershed range from very poorly drained to excessively drained (MPCA 2012, USDA NRCS 2013a). The western side of the watershed has a higher proportion of poorly drained soils with most of the land drained for crop production by surface and sub-surface drainage networks (MPCA 2012, ZWP 2012, USDA NRCS 2013a). The central to eastern side of the watershed is dominated by more well drained soils (USDA NRCS 2013a).

The main resource concerns in the watershed are sediment and erosion control, stormwater management, drinking and source water protection, waste management, nutrient management and wetland management (USDA NRCS 2013a). Many of the resource concerns relate directly to topography, agricultural practices and increased development in the region resulting in flooding and increased sediment and pollutant (fecal coliform, nitrogen, phosphorus) loadings to surface and ground waters (MPCA 2012, USDA NRCS 2013a).

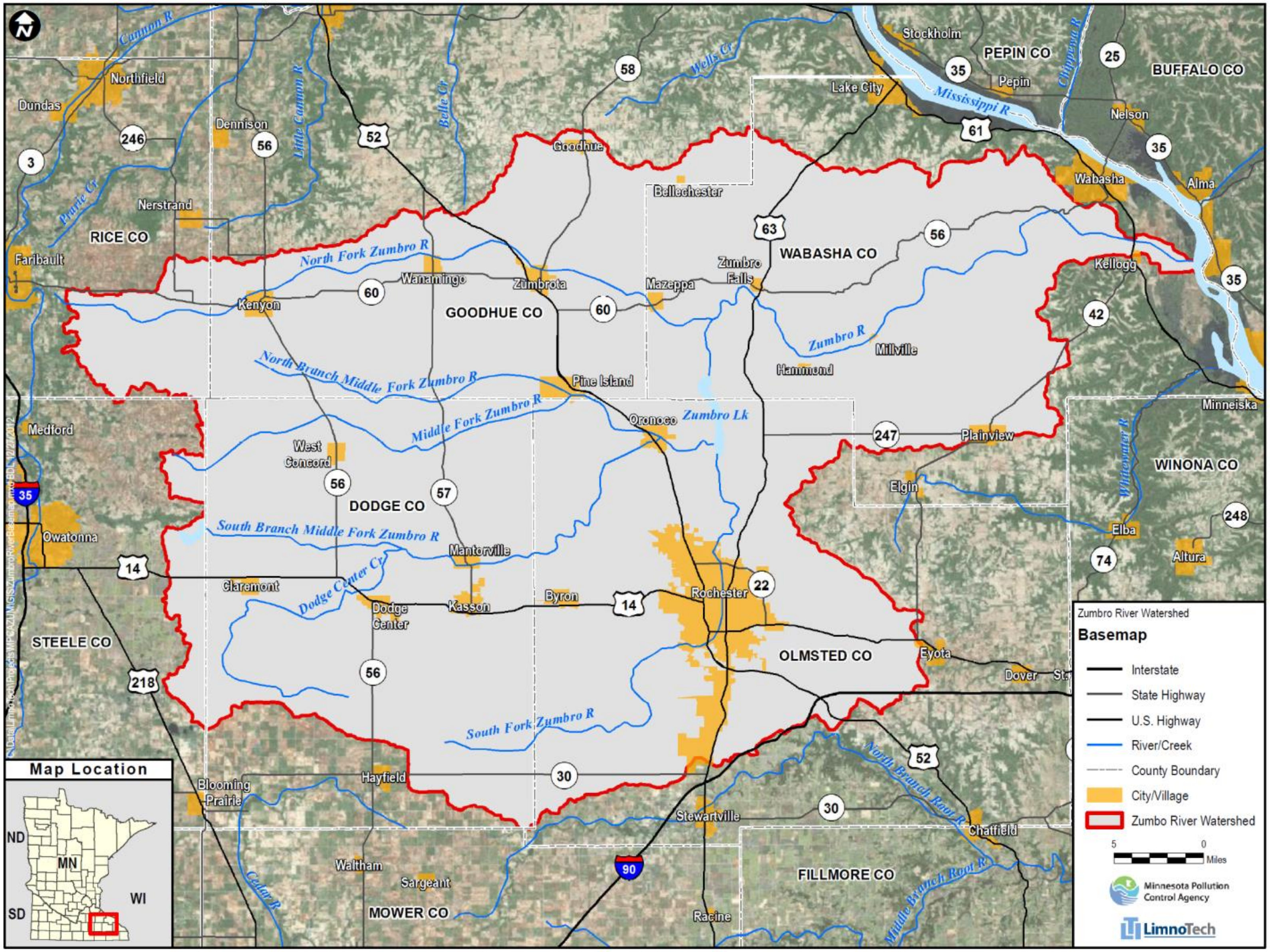

Figure 2-1. Basemap of the Zumbro River watershed, Minnesota

2.2 Impairments and Pollution Prevention

MPCA maintains an inventory of impaired waters, per Section 303(d) Clean Water Act, for lakes and streams, and wetlands. The MPCA lists various stream segments and lakes of the Zumbro River watershed as impaired (MPCA 2013a). Causes of impairment within the watershed include fecal coliforms, mercury, PCBs, turbidity (sedimentation), and nutrients (Table 2-1). It should be noted that another full assessment of the watershed will be executed in 2014, which will likely result in additional stream segments and lakes listed as impaired. A turbidity TMDL has been developed and approved for the Zumbro River watershed (MPCA 2012). A TMDL has not been completed to address nutrients and eutrophication.

Table 2-1. List of impaired water bodies in the Zumbro River watershed for turbidity and nutrients (MPCA 2013a).

Waterbody Name	*Assessment Unit ID*	*Location Description*	*Impaired Use*	*Impairment Cause*	*Miles*	*TMDL Status for Turbidity or Nutrients*
Lake Zumbro	55-0004-00	Olmsted County, 2 Miles Northeast Of Oronoco, MN (55-0004-00)	Aquatic Consumption, Aquatic Recreation	Nutrients, Mercury	Not Applicable	TMDL Required
Zumbro River	07040004-501	West Indian Cr to Mississippi R	Aquatic Consumption, Aquatic Life, Aquatic Recreation	Fecal Coliforms, Mercury, PCBs, Turbidity	24.61	Turbidity TMDL Completed in 2012
Zumbro River, South Fork	07040004-507	Cascade Cr to Zumbro Lk	Aquatic Life, Aquatic Recreation	Fecal Coliforms, Turbidity	12.57	Turbidity TMDL Completed in 2012
Zumbro River, North Fork	07040004-512	Headwaters to Trout Bk	Aquatic Life	Turbidity	54.02	Turbidity TMDL Completed in 2012
Zumbro River, Middle Fork	07040004-519	Shady Lk to Zumbro Lk	Aquatic Life	Turbidity	6.1	Turbidity TMDL Completed in 2012
Zumbro River, Middle Fork	07040004-522	Headwaters to N Br M Fk Zumbro R	Aquatic Life	Turbidity	37.05	Turbidity TMDL Completed in 2012
Zumbro River, Middle Fork, North Branch	07040004-523	Headwaters to M Fk Zumbro R	Aquatic Life	Turbidity	28.58	Turbidity TMDL Completed in 2012
Zumbro River, Middle Fork, South Branch	07040004-525	Dodge Center Cr to M Fk Zumbro R	Aquatic Life	Turbidity	29.29	Turbidity TMDL Completed in 2012
Zumbro River, Middle Fork, South Branch	07040004-526	Headwaters to Dodge Center Cr	Aquatic Life	Turbidity	14.96	Turbidity TMDL Completed in 2012
Zumbro River, South Fork	07040004-534	Old Oakwood Dam to Silver Lk Dam	Aquatic Life	Turbidity	0.8	Turbidity TMDL Completed in 2012
Zumbro River, South Fork	07040004-536	Salem Cr to Bear Cr	Aquatic Life, Aquatic Recreation	Fecal Coliforms, Turbidity	9.18	Turbidity TMDL Completed in 2012

Waterbody Name	Assessment Unit ID	Location Description	Impaired Use	Impairment Cause	Miles	TMDL Status for Turbidity or Nutrients
Bear Creek	07040004-538	Willow Cr to S Fk Zumbro R	Aquatic Life	Turbidity	2.72	Turbidity TMDL Completed in 2012
Bear Creek	07040004-539	Headwaters to Willow Cr	Aquatic Life	Turbidity	15.11	Turbidity TMDL Completed in 2012
Willow Creek	07040004-540	Headwaters to Bear Cr	Aquatic Life	Turbidity	13.83	Turbidity TMDL Completed in 2012
Silver Creek	07040004-552	Unnamed cr to Unnamed cr	Aquatic Life	Turbidity	5.41	Turbidity TMDL Completed in 2012
Silver Creek	07040004-553	Unnamed cr to Silver Lk (S Fk Zumbro R)	Aquatic Life	Turbidity	1.71	Turbidity TMDL Completed in 2012
Milliken Creek	07040004-554	Unnamed cr to Unnamed cr	Aquatic Life	Turbidity	5.35	Turbidity TMDL Completed in 2012
Milliken Creek	07040004-555	Unnamed cr to M Fk Zumbro R	Aquatic Life	Turbidity	4.3	Turbidity TMDL Completed in 2012
Unnamed creek	07040004-556	Unnamed cr to Unnamed cr	Aquatic Life	Turbidity	1.2	Turbidity TMDL Completed in 2012
Cascade Creek	07040004-581	Unnamed cr to S Fk Zumbro R	Aquatic Life	Turbidity	2.71	Turbidity TMDL Completed in 2012
Dodge Center Creek	07040004-592	JD 1 to S Br M Fk Zumbro R	Aquatic Life	Turbidity	24.05	Turbidity TMDL Completed in 2012
Unnamed creek	07040004-601	Unnamed cr to Unnamed cr	Aquatic Life	Turbidity	2.13	Turbidity TMDL Completed in 2012
Cascade Creek	07040004-639	Headwaters to Unnamed cr	Aquatic Life	Turbidity	16.55	Turbidity TMDL Completed in 2012

3

Model Development

This chapter provides a brief overview of the development of the ZRWHSPF model framework and the configuration of the framework to simulate hydrology, sediment, and water quality transport and fate for the Zumbro 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, 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 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 at the following web site: http://water.epa.gov/scitech/datait/models/basins/index.cfm. Agency support for HSPF is provided by 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). 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.

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), United States Environmental Protection Agency (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.

3.2 Model Inputs

This section describes the various elements of model input data and development. The ZRWHSPF 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 1995-2009 time period. All datasets acquired to develop the model were selected based on what would be most representative of the 1995-2009 time period.

3.2.1 Climate

Hydrology and 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 for the watershed. 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. 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 this is an important consideration in defining the land segmentation scheme.

Precipitation data were available through the BASINS tool at 11 stations for the 1995-2009 time period (Table 3-2). Four (4) additional MNDNR precipitation stations were selected for inclusion in the model to fill in spatial data gaps. The MNDNR stations were selected based on spatial location and data completeness for the 1995-2009 time period (Table 3-2). 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 15 stations (Figure 3-1).

Air temperature data were available through BASINS for seven (7) 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 four (4) stations (Table 3-2 and Figure 3-2). 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 four (4) 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. The Faribault climate station was missing one (1) day of precipitation, solar radiation data, and Penman pan evaporation and two (2) hours of cloud cover data. These data gaps were filled using data from the Owatonna station. The Byron 3 N climate station was missing one (1) day of air temperature data. This data gap was filled using data from the Rochester International Airport (AP) station. The Alma Dam climate station was missing one (1) day of precipitation data. This data gap was filled using data from the Wabasha station.

MNDNR precipitation data gaps were filled using data from the nearest station as follows:

- Elgin – 120 days filled with Elgin 2 SSW (MN212486) data; and
- Schmidt – 177 days filled with Zumbrota (MN219249) data.

The meteorological input time series data can be found in the file named “ZUMBRO_Met.wdm”.

Table 3-2. Climate data inventory for the Zumbro River watershed. The model simulation period is 1995-2009.

Station ID	Data Source	Station Name	Precipitation	Air Temperature	Other Climate (Wind Speed, Dew Point, Cloud Cover, Solar Radiation, Penman Pan Evaporation)	Period of Record	Comments/Notes
BORAAS R	MNDNR	Boraas R	✓			1993-2009	
MN212721/ MN726563	BASINS	Faribault	✓	✓	✓	1948-2009	Data gaps filled w/ Owatonna
SCHMIDT	MNDNR	Schmidt	✓			1993-2009	Data gaps filled w/ Zumbrota
MN219249	BASINS	Zumbrota	✓	✓		1947-2009	
MN212166	BASINS	Dodge Center	✓			1986-2009	
MN216287/ MN726568	BASINS	Owatonna	✓	✓	✓	1961-2009	
MN211174	BASINS	Byron 3 N	✓	✓		1993-2009	Data gaps filled w/Rochester International AP
MN212486	BASINS	Elgin 2 SSW	✓			1948-2009	
ROCHESTER	MNDNR	Rochester	✓			1993-2009	
MN217004	BASINS	Rochester International AP		✓	✓	1970-2009	
WI470124	BASINS	Alma Dam 4	✓	✓		1949-2009	Data gaps filled w/ Wabasha
ELGIN	MNDNR	Elgin	✓			1993-2009	Data gaps filled w/ Elgin 2 SSW
MN214438	BASINS	Lake City	✓			1948-2009	
MN218227	BASINS	Theilman 1 SSW	✓			1948-2009	
MN218552	BASINS	Wabasha	✓			1956-2009	
MN726588	BASINS	Winona AWOS		✓	✓	1995-2009	

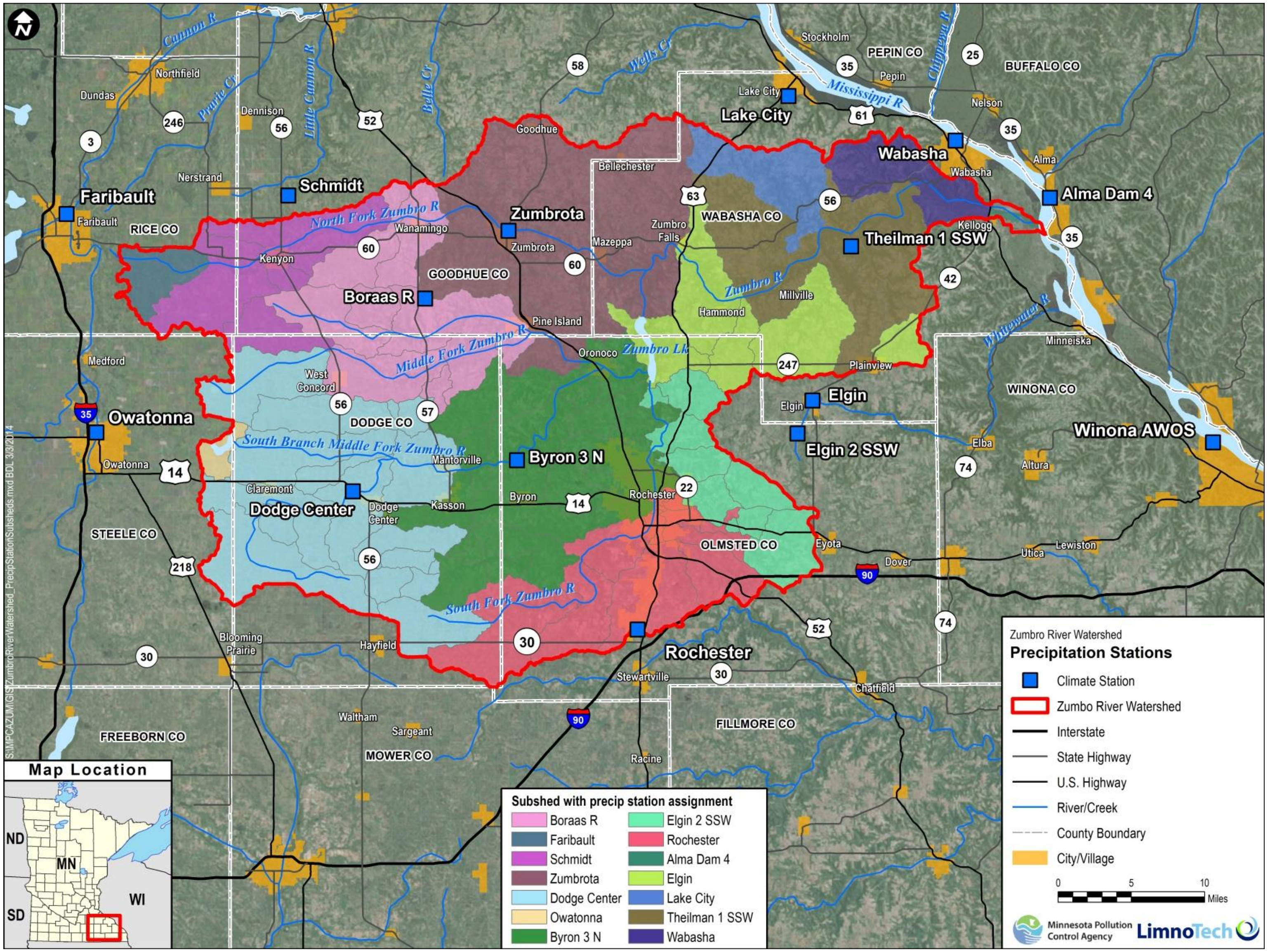

Figure 3-1. Map of precipitation stations and subwatershed assignments.

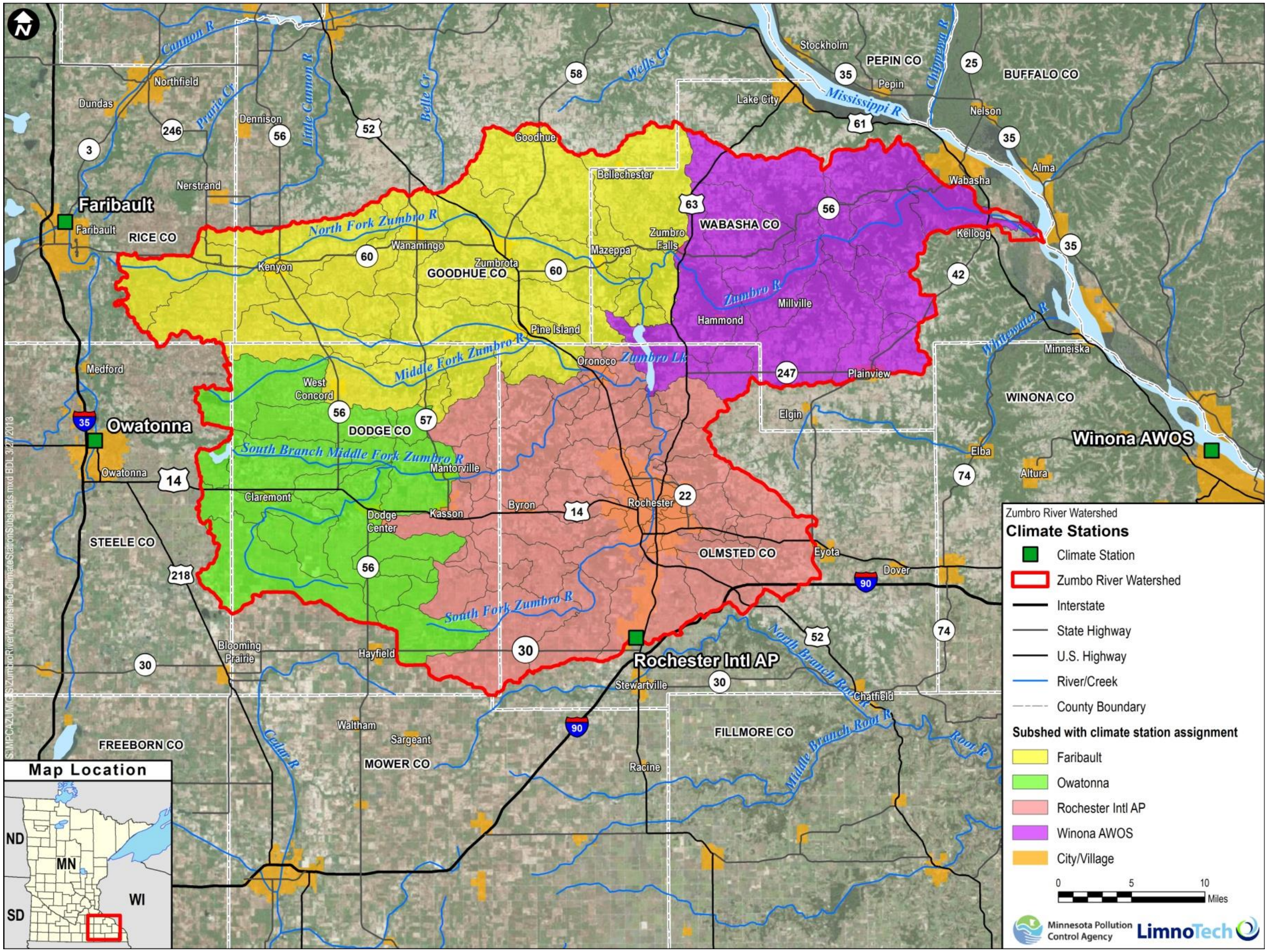

Figure 3-2. Map of wind speed, dew point temperature, cloud cover, and solar radiation stations and subwatershed assignments.

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, DEM, land use/land cover, and soils. A brief summary of any data processing and modification is provided. Please see the geodatabase file named “Zumbro_GIS.gdb” for the individual geographic data layers. An ArcMap document named “Zumbro_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 delineation. 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 Zumbro River watershed. The HUC12 boundary was used to define the delineation of the subwatershed boundaries. The MNDNR HUC14 (14-digit, Level 7) and the HUC16 HUC (16-digit, Level 8) datasets for the Zumbro River watershed were used to divide larger subwatersheds into smaller subwatersheds. Cases where further subwatershed division was required included streamflow gage locations, water quality calibration/validation locations, point sources, river confluences, morphological changes, impaired segments, etc. 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 represent watershed subbasin boundaries, land slope, and river reaches to support the simulation of sediment erosion and nutrient transport. A National Elevation Dataset (NED) 10 meter DEM was obtained from the USDA NRCS Geospatial Data Gateway (USDA NRCS 2013b). The DEM was processed following the guidelines outlined in the in the MPCA modeling guidance document (AQUA TERRA Consultants 2012). A GRID/raster was created from the mosaic dataset. The DEM was then “smoothened” by calculating average elevations for each cell using a window of 3 x 3 cells surrounding the cell (known as “Neighborhood Focal Statistics” in Spatial Analyst of ArcGIS 10) (AQUA TERRA Consultants 2012). 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, and the NLCD 2006 was used for the calibration period. 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. Zumbro 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 ZRWHSPF model, "Open Water" is represented in the RCHRES module; therefore, the Wetland" areas were reduced accordingly by subwatershed during the land segmentation process.*

The impervious areas input to the model were based on the NLCD 2001 (version 2) and NLCD 2006 "Percent Developed Imperviousness" grid layers 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 six counties in the Zumbro River watershed (Dodge, Goodhue, Olmstead, Rice, Steele, and Wabasha) 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 1-2% and were grouped into a "drained" land use category. Cropland soils with an average land slope greater than 2% 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: a low runoff potential (AB) category and a high runoff potential (CD) category per the MPCA modeling guidance document (AQUA TERRA Consultants 2012).

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 ZRWHSPF model and include the following:

- 2010 303(d) and 305(b) geographic data for lakes, streams, and wetlands (MPCA 2013a) (http://www.pca.state.mn.us/index.php?option=com_k2&view=item&id=2211);
- MS4 areas (obtained from J. Watkins, MPCA);
- Karst features (obtained from J. Watkins, MPCA);
- Lake Zumbro bathymetry (obtained from J. Watkins, MPCA);
- Groundwater and surface water withdrawals (MNDNR 2013) (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 1995-2009 were provided by 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., Rochester and Zumbrota 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 ZRWHSPF model. A directory of the point source inputs is provided in an Excel file named, "Directory_of_PS_DSNs_ZRWHSPF.xlsx", as part of the project deliverables package.

Table 3-4. Major and minor point sources represented in the Zumbro River watershed HSPF model.

Facility Name	*Point Source Type*	*Permit No.*
Claremont WWTP	Minor	MN0022187
Al-Corn Clean Fuel	Minor	MN0063002
AMPI Rochester	Minor	MNG255051
Bellechester WWTP	Minor	MN0022764
Byron WWTP	Minor	MN0049239
Camp Victory WWTP	Minor	MN0067032
Dodge Center WWTP	Minor	MN0031016
Franklin Heating Station	Minor	MN0041271
Goodhue WWTP	Minor	MN0020958
Hallmark Terrace	Minor	MN0030368

Facility Name	Point Source Type	Permit No.
Incorporated		
Hammond WWTP	Minor	MN0066940
Hayfield WWTP	Minor	MN0023612
Kasson WWTP	Minor	MN0050725
Kellogg WWTP	Minor	MNG580027
Kemps Milk Plant	Minor	MN0059803
Kenyon WWTP	Minor	MN0021628
Mantorville WWTP	Minor	MN0021059
Mazeppa WWTP	Minor	MN0046752
Milestone Materials Golberg Quarry	Minor	MN0062227
Pine Island WWTP	Minor	MN0024511
Rochester Athletic Club	Minor	MN0062537
Rochester WWTP	**Major**	**MN0024619**
RPU Sliver Lake	Minor	MN0001139
Seneca Food Corporation	Minor	MN0000477
Wanamingo WWTP	Minor	MN0022209
West Concord WWTP	Minor	MN0025241
Zumbro Falls WWTP	Minor	MN0051004
Zumbro Ridge Estates MHP	Minor	MN0038661
Zumbrota WWTP	**Major**	**MN0025330**

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

Major Point Sources

Data were processed using the following rules:

- Outliers in the dataset were revised using linear interpolation using the first and last 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.
- The Zumbrota WWTP was missing flow data for all of 2002. Monthly averages were used to fill in data gaps.

Assumptions applied when data were not available:

- 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
- 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 using the first and last 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 – 1 mg/L
- TSS silt – 40% of TSS
- TSS clay – 60% of TSS
- DO – 8 mg/L
- BOD_5 – 1 mg/L
- BOD_U – 2.5 times BOD_5
- NO_3 – 10 mg/L
- 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

- OGRC – 12.79% of BOD_U

The RPU Silver Lake Plant withdraws and discharges non-contact cooling water. Therefore, this facility is assumed to only contribute a heat load because it only adds heat to the water. The facility withdraws from and discharges to the same model reach segment (RCHRES 606).

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 1995-2009 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 1995-2009 time period. Both the wet and dry atmospheric deposition stations are located outside the Zumbro 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 1995-2009 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 ZRWHSPF model has been developed to run with the latest version of WinHSPFLt as distributed with BASINS4.1.

3.3.1 Watershed Delineation

The Zumbro 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 Zumbro 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 the HUC16 HUC (16-digit, Level 8) datasets for the Zumbro 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, and water quality calibration/validation locations. 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. A map of the Zumbro River watershed delineation for the ZRWHSPF model is provided below (Figure 3-3).

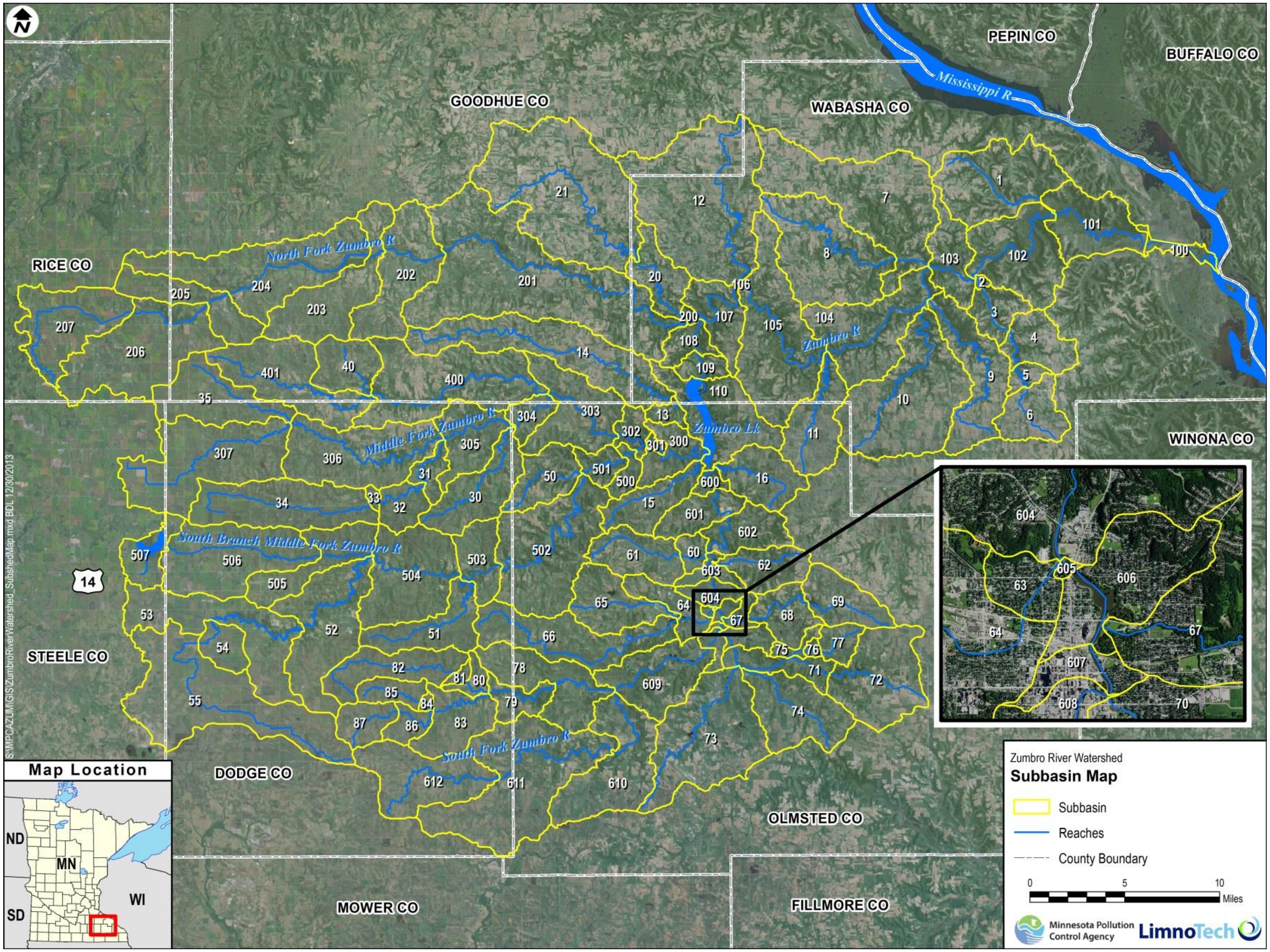

Figure 3-3. Map of the Zumbro River watershed delineation for the ZRWHSPF model.

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 Zumbro 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, 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. Initially there were 15 precipitation zones used to define the land segmentation. However, during the hydrology model calibration, the Steger zone was removed due to a data inconsistency issue when compared to nearby stations. The land segments assigned to the Steger climate zone were reassigned to the Zumbrota precipitation zone as this zone was adjacent to the Steger zone and had almost the same coverage area.

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., 2004-2009). 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 ZRWHSPF 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 Zumbro River watershed indicates that an average of approximately 5,000 agricultural acres were under residue management over the 1999-2007 time period (USDA NRCS 2013a). The area under residue management represents approximately 1% of the cropland acres in the Zumbro 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).
- A tour of the Zumbro River watershed was conducted by MPCA and LimnoTech in November 2012. The amount of plant residue remaining on the majority of the crop fields was indicative of conventional tillage practices per visual observation.

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 a given percentage (i.e., 1-2%). Soils meeting these criteria were grouped into a "drained" land use category. Cropland soils with an average land slope greater than 2% 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 to 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 Zumbro 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 2012). 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 that are actually explicitly represented in the RCHRES module, were subtracted from the water/wetlands category to avoid “double-counting” these areas.

The combination of 15 precipitation zones and 14 land cover/HSG categories results in 210 distinct land segment (i.e., PERLND and IMPLND) types for the ZRWHSPF model application. The resulting land segment categories for the Zumbro 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. ZRWHSPF land segments based on NLCD 2006

Land Segment Category	Impervious (EIA) Land Area	Pervious Land Area	Total Area
Cropland - AB	-	21.59%	21.59%
Cropland - CD	-	17.85%	17.85%
Cropland - Drained	-	16.63%	16.63%
Developed, Low Intensity (MS4)	0.21%	0.94%	1.14%
Developed, Low Intensity (non-MS4)	0.17%	1.16%	1.34%
Developed, Medium and High Intensity (MS4)	0.34%	0.33%	0.67%
Developed, Medium and High Intensity (non-MS4)	0.11%	0.13%	0.24%
Developed, Open Space (MS4)	0.04%	1.23%	1.27%
Developed, Open Space (non-MS4)	0.10%	4.21%	4.31%
Feedlots	-	0.20%	0.20%

Land Segment Category	Impervious (EIA) Land Area	Pervious Land Area	Total Area
Forest - AB	-	6.23%	6.23%
Forest - CD	-	3.53%	3.53%
Grassland - AB	-	7.43%	7.43%
Grassland - CD	-	4.88%	4.88%
Pasture - AB	-	7.35%	7.35%
Pasture - CD	-	4.15%	4.15%
Water/Wetlands	-	1.20%	1.20%
Total Area	**0.97%**	**99.03%**	**100.00%**

Table 3-6. ZRWHSPF land segments based on NLCD 2001 (version 2)

Land Segment Category	Impervious (EIA) Land Area	Pervious Land Area	Total Area
Cropland - AB	-	21.66%	21.66%
Cropland - CD	-	17.89%	17.89%
Cropland - Drained	-	16.64%	16.64%
Developed, Low Intensity (MS4)	0.19%	0.88%	1.06%
Developed, Low Intensity (non-MS4)	0.15%	1.16%	1.32%
Developed, Medium and High Intensity (MS4)	0.27%	0.27%	0.55%
Developed, Medium and High Intensity (non-MS4)	0.09%	0.13%	0.22%
Developed, Open Space (MS4)	0.04%	1.17%	1.20%
Developed, Open Space (non-MS4)	0.09%	4.20%	4.29%
Feedlots	-	0.20%	0.20%
Forest - AB	-	6.25%	6.25%
Forest - CD	-	3.54%	3.54%
Grassland - AB	-	7.47%	7.47%
Grassland - CD	-	4.95%	4.95%
Pasture - AB	-	7.36%	7.36%
Pasture - CD	-	4.18%	4.18%
Water/Wetlands	-	1.22%	1.22%
Total Area	**0.84%**	**99.16%**	**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 ZRWHSPF watershed model. The assumption was made that point source discharges represented in the model will 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 1995-2009 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 for an explicit representation.

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 site-specific reach cross-sections developed during the Zumbro River watershed Turbidity TMDL (MPCA 2012), United States Army Corps of Engineers (USACE) HEC models developed for flood prediction purposes, the subbasin delineation, and 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 ZRWHSPF 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, Rice Lake and Lake Zumbro were selected for explicit representation in the model. 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). Overflow information 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.

The FTABLE for Lake Zumbro was developed based on a polynomial regression relationship between observed headwater surface elevations and observed streamflow at the Lake Zumbro outlet HYDSTRA station. The FTABLE was further refined to simulate the annual fall drawdown of Lake Zumbro 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 UCI file to specify the dates when Lake Zumbro is operated at summer pool elevation, winter pool elevation, or the transition period.

The FTABLE for Rice Lake was developed using the sharp-crested weir equation to estimate discharge for a given depth, based on an estimated weir coefficient of 3.2. The water surface elevation used to compute water head over the dam and weir length were obtained from Rice Lake Dam schematics provided by MPCA. Incremental surface area was computed from bathymetry data, and incremental volumes were computed for each depth interval before totaling the surface area and volume for each depth interval represented in the FTABLE.

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 ZRWHSPF 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, different in environmental conditions from 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 detail on 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.

- 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 1995-2009. 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 six (6) year time period, from 2004-2009, 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 ZRWHSPF 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. The most extensive observed streamflow datasets are for the 2007-2009 time period, which falls within the selected model calibration time period (LimnoTech 2013a). 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.

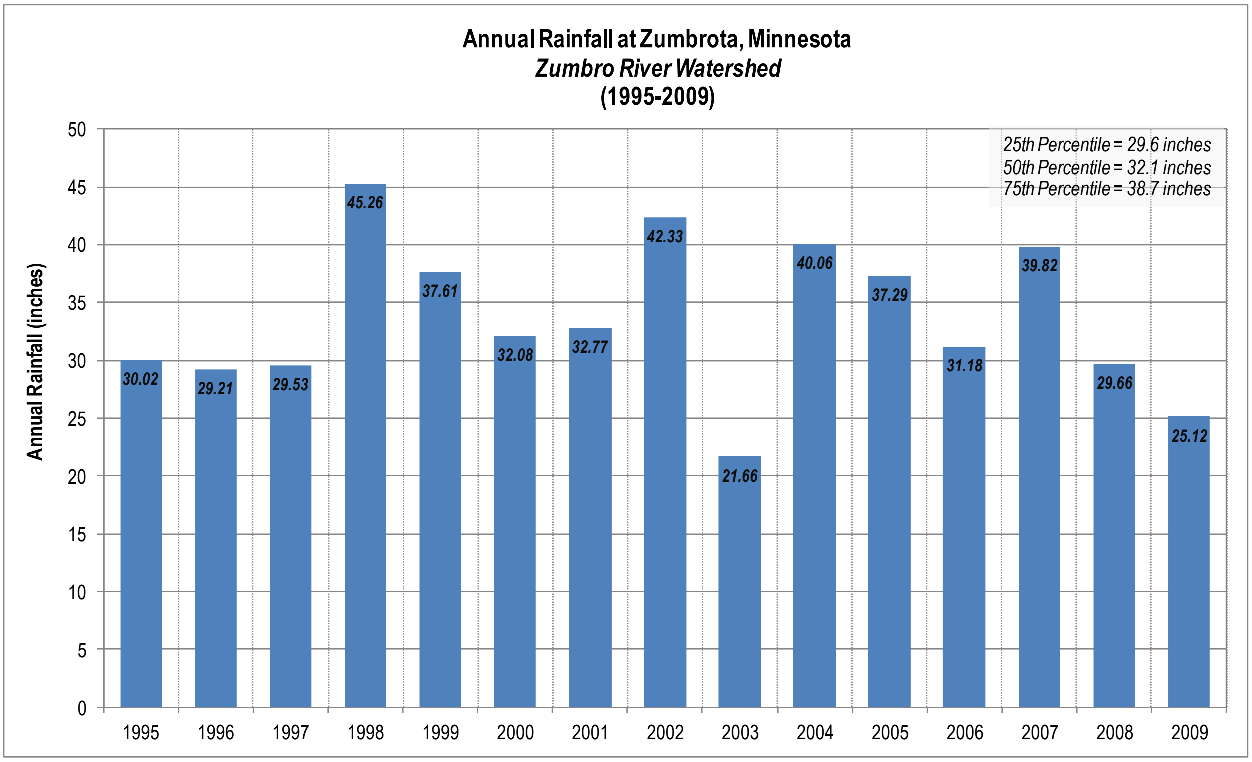

Figure 4-1. Annual total precipitation at Zumbrota, Minnesota over the 1995-2009 time period.

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 the 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 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:

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

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 times 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 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 that 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).

Criteria

R	← 0.75 — 0.80 — 0.85 — 0.90 — 0.95 →
R^2	← 0.6 — 0.7 — 0.8 — 0.9 →
Daily Flows	Poor Fair Good Very Good
Monthly Flows	Poor | Fair | Good | Very Good

Figure 4-2. R and R² Value ranges for streamflow model performance (Donigian 2000, 2002).

The following target calibration and validation measures used to evaluate the ZRWHSPF 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' and 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, based on 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 Zumbro River watershed (South Fork Zumbro River at Rochester and Zumbro River at Kellogg, 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, has a higher degree of uncertainty, or is more limited for accurate statistical measures (Duda et al. 2012). For the Zumbro River watershed, the suspended solids (or TSS) datasets are estimated based on high-frequency measurements of turbidity and regression correlations developed between the turbidity and TSS grab samples. The spatial and temporal coverage for the turbidity measurements is good; however, the estimated TSS datasets have additional uncertainty given that the values are derived based on regression correlations. In addition, the degree of uncertainty in the estimated TSS datasets likely varies across station locations due to varying frequencies of TSS grab sample measurements. Given this additional uncertainty, the evaluation of model performance for the simulation of suspended solids requires more reliance on visual and graphical comparisons of simulated and observed data and other calibration targets.

The relative percent difference model performance target established for the ZRWHSPF 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; however, the model performance is still considered acceptable.

Additional calibration and validation targets were set in regard to UALs, sediment trapping efficiency for Lake Zumbro, net deposition for Rice Lake and small storage reservoirs, 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, personnel).

Water Quality

Similar to suspended solids (TSS), the evaluation of water quality (i.e., water temperature, nutrients, DO, BOD, chlorophyll *a*), 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, has a higher degree of uncertainty, and/or is more limited for accurate statistical measures (Duda et al. 2012). For the Zumbro River watershed the water quality datasets are generally much more limited compared to streamflow or water temperature. Therefore, the evaluation of model performance for the simulation of nutrients and DO requires more reliance on visual and graphical comparisons of simulated and observed data. The targets 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 most 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 ZRWHSPF model was constructed and calibrated and validated with a unified set of parameters that vary 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 ZRWHSPF model to data that are limited in temporal and spatial coverage, in particular, for high-flow events.

This approach 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, in particular, stations located in the interior of the watershed. 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 suspended solids (as TSS) 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 stations used to support the ZRWHSPF model calibration and validation are summarized in an Excel file named “Zumbro_Data_Inventory.xlsx”.

4.2 Hydrology

The ZRWHSPF hydrology model calibration and validation results are described in the sections below. It should be noted that the ZRWHSPF 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.

It appears that the model instabilities in the water quality simulation occur when there is insufficient water volume and depth in a reach segment. This issue in the ZRWHSPF model is infrequent and isolated to smaller reach segments. To address some of the more common and broader model instability issues in the water quality simulation, a small amount of flow volume was added during the most susceptible time periods to reach segments exhibiting instabilities via the “special actions” module. The addition of flow volume is very small and does not have an impact on the overall hydrology simulation. 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 the water quality simulations despite the implementation of the ADCALC flag = 2 option. LimnoTech has had some success with an in-house, customized code modification that addresses the model instability issues in the water quality simulation. In the future, it may be desirable to incorporate this code into the ZRWHSPF model.

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 and the BASINS tool (via the USGS website at URL: http://waterdata.usgs.gov/nwis/sw). The USGS gage on the South Fork Zumbro River at Rochester has a complete record of daily streamflow for the entire calibration and validation period (1996-2009).

Daily streamflow observations from HYDSTRA gages were available for several stations and years. These gages generally only report streamflow for March through November, so evaluation of model-predicted annual and seasonal streamflow volumes was limited for most areas of the watershed. Additionally, HYDSTRA streamflow data that did not have a quality rating of “good” or “fair” were removed from the calibration and validation datasets due to the greater uncertainty associated with those particular measurements. A drainage area ratio (DAR) method was used to estimate streamflow for the Zumbro

River at Kellogg, to help address the limited long-term streamflow data for areas other than the South Fork Zumbro River at Rochester and to also evaluate the model simulated streamflow near the watershed outlet. Observed daily streamflow for the South Fork Zumbro River at Rochester (USGS gage #05372995) was multiplied by the ratio of the area draining to Kellogg to the area draining to the Rochester gage. This estimated dataset was included in the calibration and validation datasets, and it was used to support the model calibration. However, it is important to note that the DAR streamflow data estimation method has some uncertainty associated with it, and the method does not take into account the influence of Lake Zumbro on streamflow at the Kellogg gage.

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

Table 4-6. Streamflow watershed calibration points for the Zumbro River watershed HSPF model calibration and validation.

Station ID (HYDSTRA/ STORET)	HSPF Reach ID	Agency/ Database	Station Name	Daily Average Streamflow		
				Count of Records	*Period of Record*	*Data Used for Calibration/ Validation?*
05372995[a] (S000-333)	**604**	**NWIS/USGS**	**South Fork Zumbro River at Rochester**	**5,114**	**1996-2009**	**Calibration/ Validation**
ZR_Kellogg[a]_ DAR	**101[b]**	**NWIS/USGS**	**Zumbro River at Kellogg (DAR)**	**5,114**	**1996-2009**	**Calibration/ Validation**
H41010001 (S004-383)	203	MPCA/ HYDSTRA	North Fork Zumbro River at Wanamingo	604	2000-2008	Calibration/ Validation
H41015001 (S004-382)	304[c]	MPCA/ HYDSTRA	Middle Fork Zumbro River at Pine Island	256	2007-2008	Calibration
H41043001 (S004-384)	101	MPCA/ HYDSTRA	Zumbro River at Kellogg	200	2008-2009	Calibration
H41050001 (S001-572)	68	MPCA/ HYDSTRA	Silver Creek	487	2007-2008	Calibration
H41051001 (S000-800)	71	MPCA/ HYDSTRA	Bear Creek	1,194	1999-2008	Calibration/ Validation
H41061001 (S004-385)	609	MPCA/ HYDSTRA	South Fork Zumbro River South of Rochester	978	2000-2008	Calibration/ Validation
H41064001 (S001-354)	64	MPCA/ HYDSTRA	Cascade Creek	235	2007	Calibration
H41067001 (S001-729)	503	MPCA/ HYDSTRA	South Branch Middle Fork near Mantorville	91	2007-2008	Calibration
H41071001 (S004-513)	301	MPCA/ HYDSTRA	Middle Fork Zumbro River at Oronoco	166	2007-2008	Calibration

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

[b] Data were estimated from observed streamflow data at South Fork Zumbro River at Rochester USGS gage using the DAR method.

[c] Station is located upstream of the RCHRES outlet. The observed streamflow data was adjusted using the DAR method to account for the small difference in drainage areas.

The South Fork Zumbro River at Rochester, Zumbro River at Kellogg and Zumbro River at Kellogg (DAR) stations served as the primary calibration and validation stations to evaluate model performance. The remaining stations in Table 4-6 were used as auxiliary stations to help parameterize the model but were not used to formally evaluate model performance.

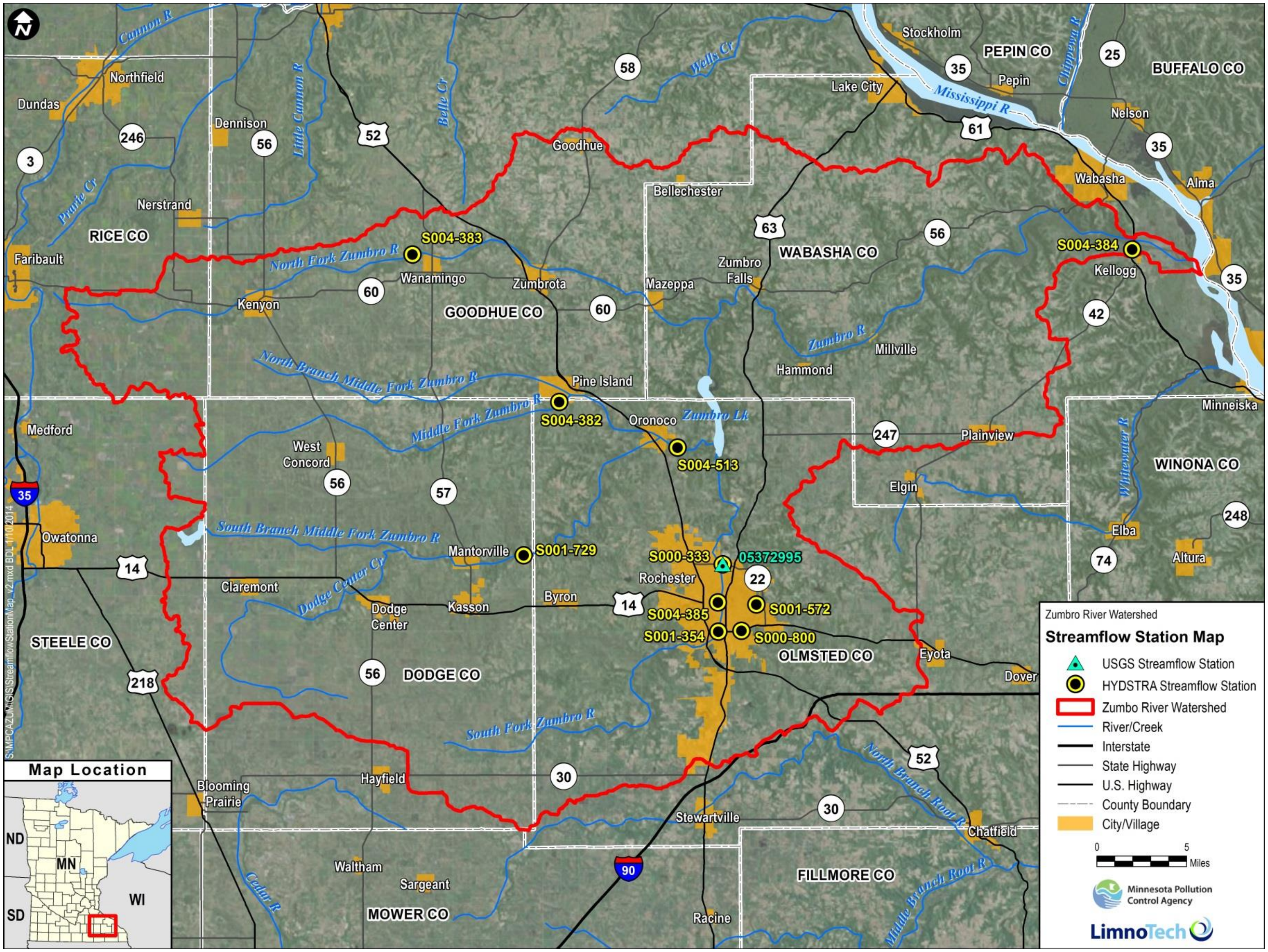

Figure 4-3. Map of streamflow calibration and validation station locations.

4.2.2 Hydrology Parameterization

The hydrology calibration for the Zumbro 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 and 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)."

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 National Climatic Data Center (NCDC) for 12 stations across the watershed (NOAA 2013a). Ten (10) of the 12 stations provide data for the entire 1995-2009 model simulation time period (Table 4-7). 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).

Table 4-7. Inventory of snow depth stations in the Zumbro River watershed.

Station	Period of Record	Number of Daily Snow Depth Records
Alma Dam	1995 - 2009	5,478
Byron	1995 - 2009	4,924
Elgin 2 SSW	1995 - 2009	5,378
Faribault	1995 - 2009	5,328
Lake City	2002 - 2009	2,551
Owatonna	1995 - 2009	5,314
Rochester	2000 - 2009	3,558
Theilman	1996 - 2009	3,641
Wabasha	1995 - 2009	5,447
Zumbrota	1995 - 2009	2,424

Initial simulated snow depths were consistently lower than observed depths for the model land segments surrounding two (2) of the snow depth stations, Rochester and Elgin 2 SSW. The SNOWCF parameter was increased to a value of 1.50 for the land segments corresponding to these precipitation stations. A SNOWCF parameter value of 1.15 was used for all other land segments. All other snow parameters were within the range guidelines in BASINS Technical Note 6 (USEPA 2000) with the exception of MWATER and CCFACT. 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 Zumbrota snow depth station is shown in Figure 4-4.

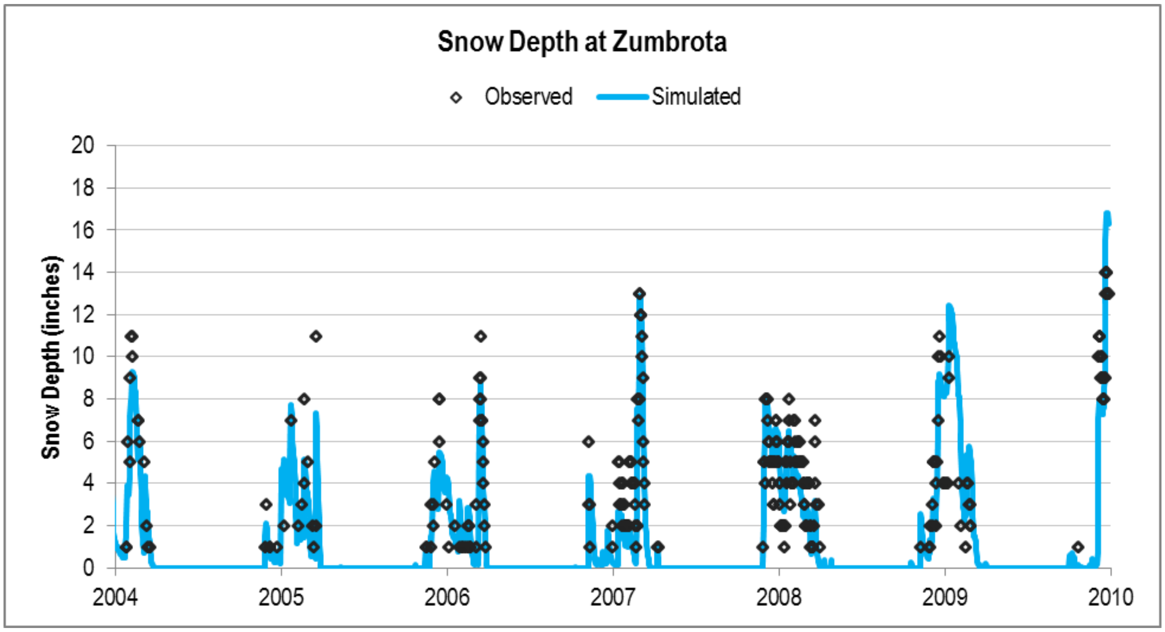

Figure 4-4. Comparison of observed and model-predicted snow depth for Zumbrota.

4.2.4 Hydrology Calibration

The hydrology calibration for the Zumbro 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 Zumbro

The FTABLE for Lake Zumbro was developed based on a polynomial regression relationship developed between observed headwater surface elevations and observed streamflow at the Lake Zumbro outlet HYDSTRA station. The FTABLE was further refined to simulate the annual fall drawdown of Lake Zumbro 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 UCI file to specify the dates when Lake Zumbro is operated at summer pool elevation, winter pool elevation, or the transition period. A comparison of observed and simulated Lake Zumbro water depths is shown in Figure 4-5.

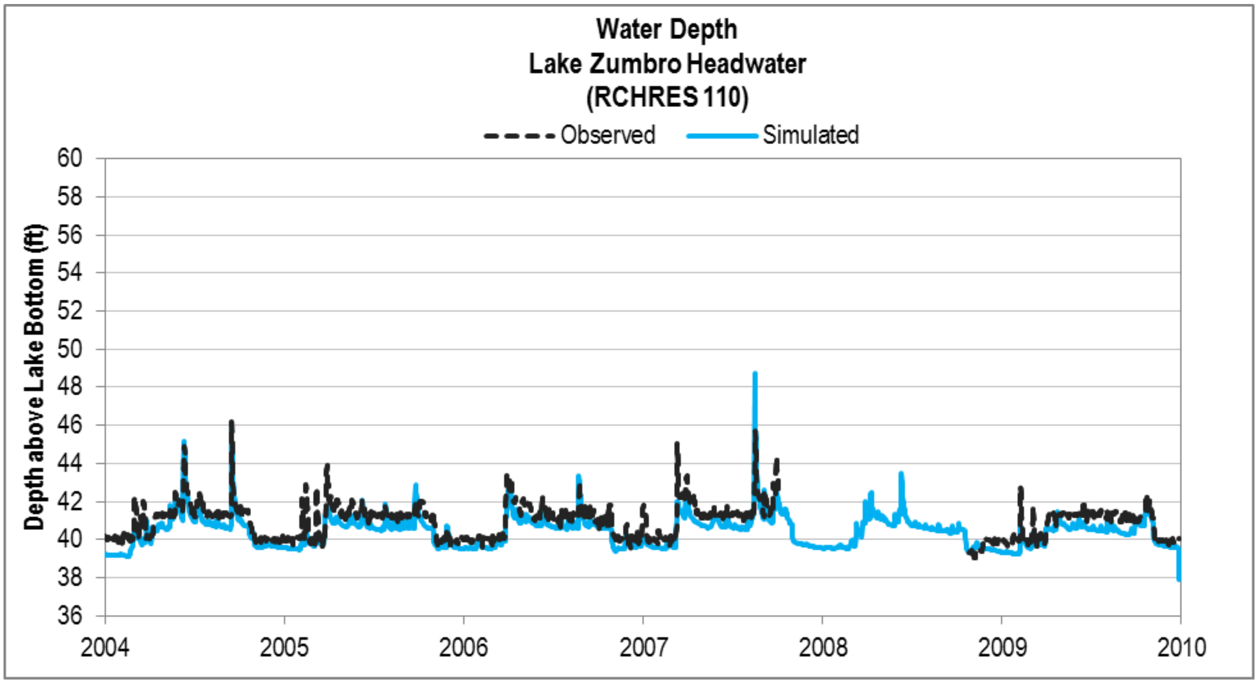

Figure 4-5. Comparison of observed water depths against model predictions for Lake Zumbro.

Flood Control Reservoirs

The NRCS installed seven (7) flood control reservoirs in the Rochester area on streams that flow into the South Fork Zumbro River (including Cascade Creek, Willow Creek, Bear Creek, and Silver Creek) to protect the city from potentially damaging high streamflow events (City of Rochester 2013). A WinTR20 input file developed by NRCS, containing structure rating tables with elevation, discharge, and storage curves for six (6) of the seven (7) flood control reservoirs, was provided to LimnoTech by MPCA. This information was used to develop revised FTABLEs that represent and simulate the storage and slow release of runoff during high flow events for the four (4) model RCHRES corresponding to Cascade Creek, Willow Creek, Bear Creek, and Silver Creek.

The stage-discharge relationships in the HSPF FTABLEs are not identical to those in the WinTR20 input file because several storage reservoirs are located upstream of a RCHRES outlet (i.e., Cascade Creek, Willow Creek, and Bear Creek). In addition, the Cascade Creek and Willow Creek RCHRES segments each have two (2) storage reservoirs located within the RCHRES drainage area. Hybrid FTABLEs were developed that combine the streamflow reduction characteristics of the storage reservoirs with the "run of the river" flow for areas not draining to the storage reservoirs. The Silver Creek storage reservoir is located in close proximity to the HSPF RCHRES outlet for the upper Silver Creek subwatershed, so its stage-discharge relationship closely resembles the WinTR20 structure rating table. Figure 4-6 illustrates modeled streamflow before and after incorporating the Silver Creek storage reservoir compared to observed data for the August 18-20, 2007 storm.

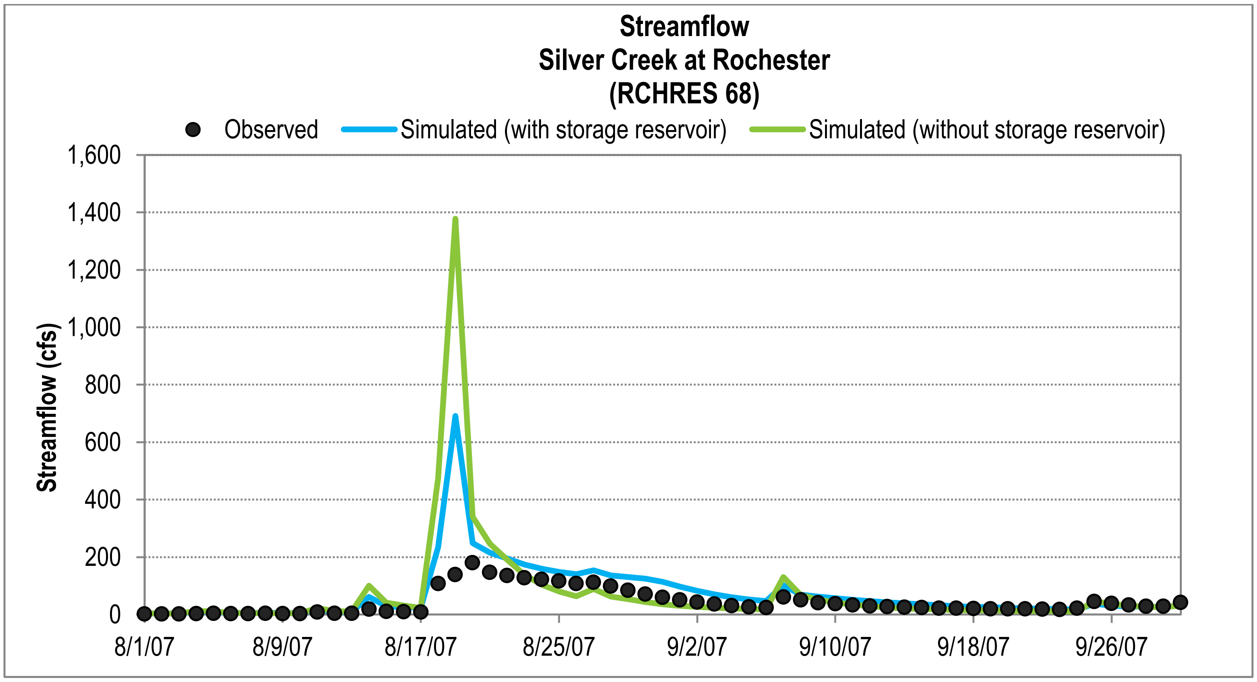

Figure 4-6. Observed and Simulated streamflow at the Silver Creek station.

August 2007 Flood

A rainfall event of historic proportions occurred in August 2007 in southeastern Minnesota. Several Zumbro River watershed precipitation stations recorded rainfall depths greater than a 200-year return period, and some areas were estimated to receive depths greater than a 500-year return period (Cooper and Summer 2008). To ensure that the model predicted streamflow for this event as accurately as possible, the August 2007 event was investigated in some detail.

Precipitation totals represented in the model input datasets (originally obtained from BASINS and MNDNR) were compared to nearby stations and to a National Oceanic and Atmospheric Administration (NOAA) estimated radar rainfall map (NOAA 2013b). In general, the South Fork Zumbro River and South Branch Middle Fork Zumbro River received the greatest amount of rainfall, with 24-hour totals ranging from 7 to 10 inches. The northern half of the watershed, including the Middle Fork Zumbro River and North Fork Zumbro River, received approximately 4 to 6 inches. The quality of HYDSTRA streamflow data recorded during this event were also reviewed in detail by MPCA and LimnoTech. Data quality was evaluated, and streamflow measurements rated as "poor" were removed from the calibration dataset.

An NRCS investigation of this rainfall and flood event suggested that observed peak streamflow rates had a surprisingly lower return period when compared to the very high return period of precipitation totals

(Cooper and Summer 2008). These differences may be attributed to dry antecedent conditions, the potential for significant floodplain storage and uncharacteristically high infiltration rates that increased water loss through non-streamflow pathways.

Water Balance

Along with the modeled flow comparisons and performance measures described above (i.e., visual and statistical evaluations of observed and simulated flow), a water balance components (input and simulated) analysis was performed. Developing a water balance is an important step in the calibration process to help inform the adjustment of key model parameters. The review and evaluation of the water balance also ensures that the land segment categories and the overall water balance reflect realistic conditions. The water balance includes the following components for individual land segments described in the MPCA modeling guidance document (AQUA TERRA Consultants 2012):

- Precipitation + Irrigation
- Total Runoff (sum of following components)
    - Overland flow
    - Interflow
    - Baseflow
- Potential Evapotranspiration
- Total Actual Evapotranspiration (ET) (sum of following components)
    - Interception ET
    - Upper zone ET
    - Lower zone ET
    - Baseflow ET
    - Active groundwater ET
- Deep Groundwater Recharge/Losses

Water balance components were reviewed throughout the hydrology calibration to ensure that 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 for forested land use than developed open space, etc.). The water balance was also compared against other Minnesota HSPF watershed model applications. Table 4-8 summarizes the drainage area-weighted water balance components for the entire watershed.

Table 4-8. Zumbro River Watershed HSPF Model Water Balance for the Calibration and Validation period (1996-2009).

Water Balance Component	*Description*	*Area-Weighted Watershed Total (inches)*
SUPY*	Water supply to surface	34.26
SURO*	Surface outflow	1.44
IFWO	Interflow outflow	3.93
AGWO	Active groundwater outflow	4.50
PERO*	Total outflow from land segments	9.87
IGWI	Inflow to inactive groundwater	0.00
AGWI	Active groundwater inflow	4.77
PET*	Potential evapotranspiration	41.23
CEPE*	Evapotranspiration from interception storage	6.94
UZET	Evapotranspiration from upper zone	7.61
LZET	Evapotranspiration from lower zone	9.57
AGWET	Evapotranspiration from active groundwater storage	0.08
BASET	Evapotranspiration from active groundwater outflow (baseflow)	0.18
TAET*	Total simulated evapotranspiration	24.38

** 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 South Fork Zumbro River at Rochester station and the Zumbro River at Kellogg (DAR) station. Overall, the calibration of streamflow resulted in a “good” to “very good” model performance based on statistical and visual comparison of observed and simulated streamflow (Tables 4-9 and 4-10). A brief summary of the model performance is provided below:

- The annual r^2 and NSE values fall within the “very good” range.
- The 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 and monthly time scales are within the “very good” range.
- The daily r^2 values are within the “fair” to “good” range and the average relative percent difference values for the daily time scale are in the “very good” range.

Table 4-9. Zumbro River watershed hydrology HSPF model calibration statistics summary (2004-2009).

Time Interval	Statistic	South Fork Zumbro River at Rochester	Zumbro at Kellogg	Zumbro at Kellogg (Drainage Area Ratio)
Annual	Count	6	2	6
	R-Squared	0.87	1.00	0.85
	Nash-Sutcliffe Efficiency	0.87	0.79	0.84
	Relative Percent Difference	3.1%	1.5%	2.4%
	Relative Percent Error	4.0%	3.6%	3.3%
Monthly	Count	72	10	72
	R-Squared	0.78	0.85	0.79
	Nash-Sutcliffe Efficiency	0.71	0.85	0.76
	P-Bias	-2.17	5.38	-2.06
	Relative Percent Difference	0.6%	-13.2%	3.9%
	Relative Percent Error	6.6%	-7.6%	9.6%
Daily	Count	2192	200	2192
	R-Squared	0.76	0.73	0.69
	Nash-Sutcliffe Efficiency	0.65	0.63	0.66
	Relative Percent Difference	-2.3%	-9.0%	5.4%
	Relative Percent Error	6.4%	-2.6%	16.2%
25th percentile low flow	Relative Percent Difference	0.6%	1.2%	17.3%
	Relative Percent Error	0.6%	1.2%	18.9%
90th percentile high flow	Relative Percent Difference	1.0%	-10.9%	-4.2%
	Relative Percent Error	1.0%	-10.3%	-4.1%

Table 4-10. Zumbro River watershed hydrology calibration observed and simulated streamflow comparison (2004-2009).

Statistic	South Fork Zumbro River at Rochester		Zumbro at Kellogg		Zumbro at Kellogg (Drainage Area Ratio)	
	Observed cfs	Simulated cfs	Observed cfs	Simulated cfs	Observed cfs	Simulated cfs
Average	227	232	1232	1166	1047	1068
Minimum	21	11	429	282	97	76
10th percentile	59	59	499	445	273	311
25th percentile	79	79	641	649	365	434
Median	143	140	1029	941	661	700
75th percentile	236	226	1448	1465	1090	1048
90th percentile	448	452	2473	2217	2069	1985
Maximum	9830	14962	6200	9289	45415	50520

In general, the model satisfies all of the statistical model performance targets with the exception of the daily r^2 value for the Zumbro River at Kellogg (DAR) station. The r^2 value is just slightly below the “good” target range. It is likely that the inherent uncertainty associated with the DAR approach as well as the limitation of this approach not capturing the daily influence of Lake Zumbro is an important factor in the model not quite meeting the daily r^2 calibration target at the Zumbro River at Kellogg (DAR) station.

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 4-7 to 4-24). Overall, the model does a “good” to “very good” job reproducing annual, seasonal, and monthly streamflow volumes and daily streamflow. As noted above, the majority of stations listed in Table 4-6 were used as auxiliary stations to help parameterize the model and were not used to formally evaluate model performance due to the limited availability of long-term datasets. The calibration process included modifying parameters for land segments in the western portion of the watershed where greater tile drainage and a dominance of level and undulating plains result in a slightly different hydrology compared to the eastern portion where Karst features are more prevalent. Specifically, changes were made to the interflow inflow parameter (INTFW), interflow recession parameter (IRC), and groundwater recession rate (AGWRC) based on visual comparisons of observed and simulated streamflow for stations on the Middle Fork Zumbro River and North Fork Zumbro River. Plots for the auxiliary stations are provided in Appendix A.

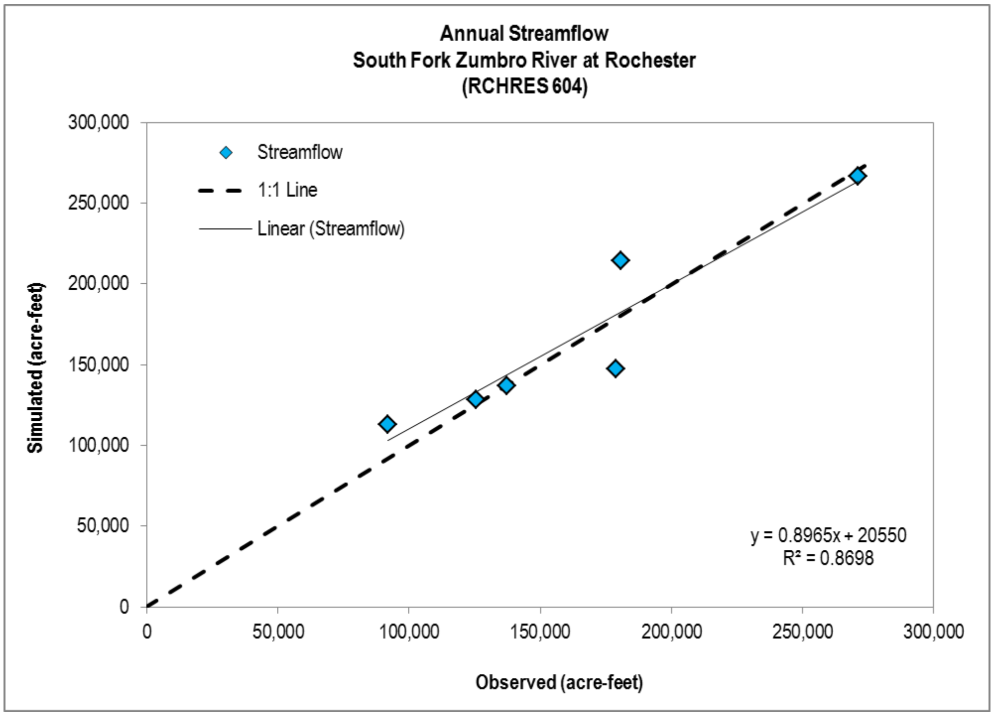

Figure 4-7. Annual Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

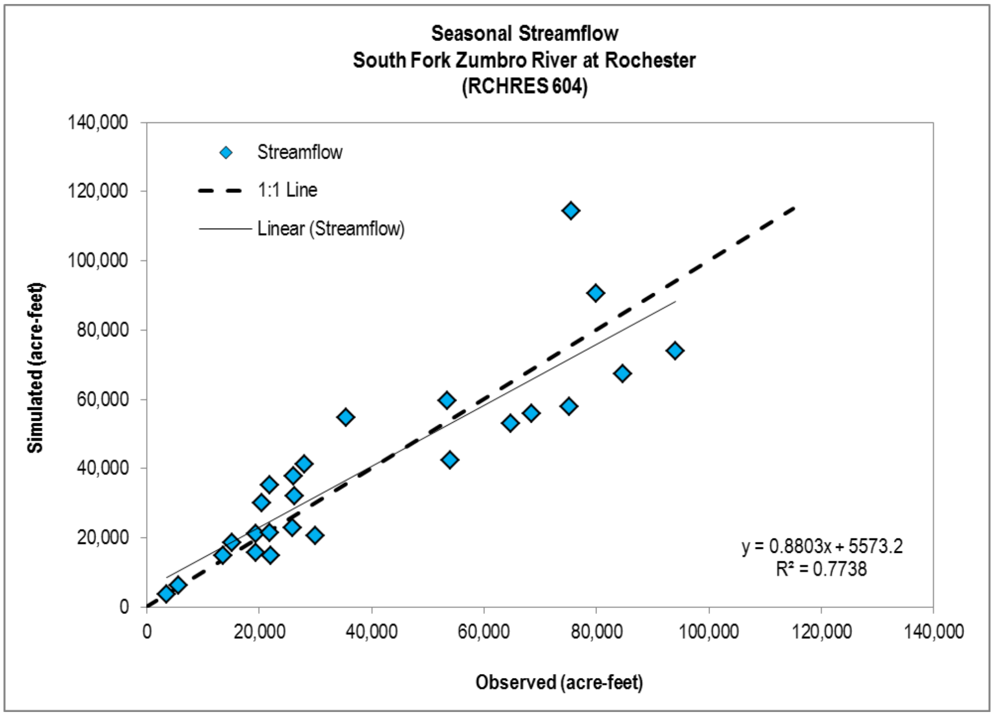

Figure 4-8. Seasonal Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

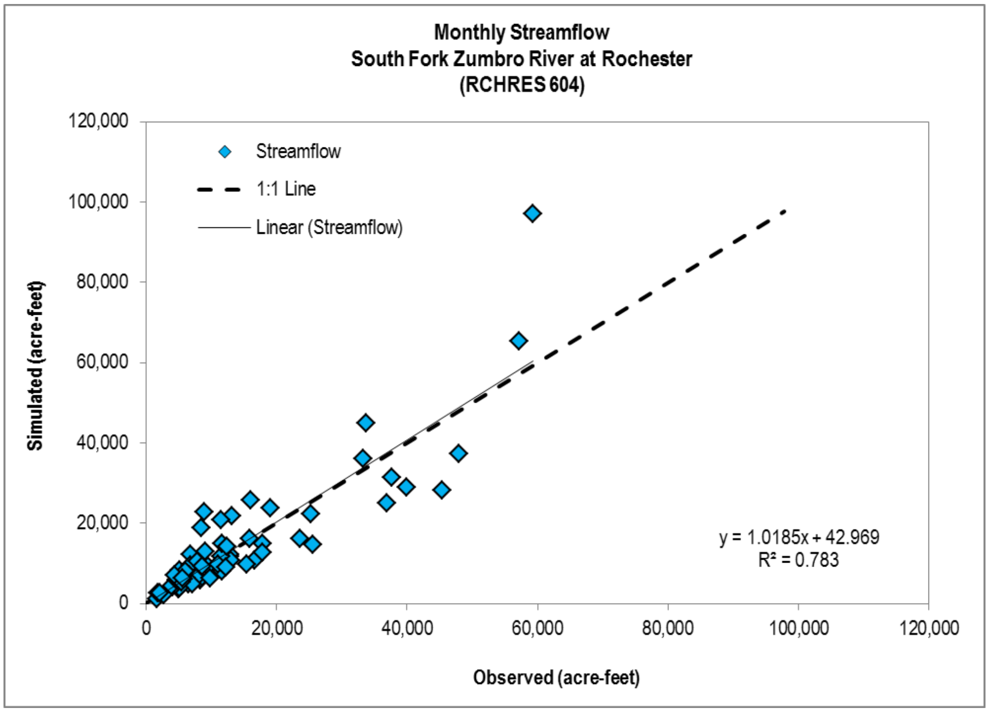

Figure 4-9. Monthly Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

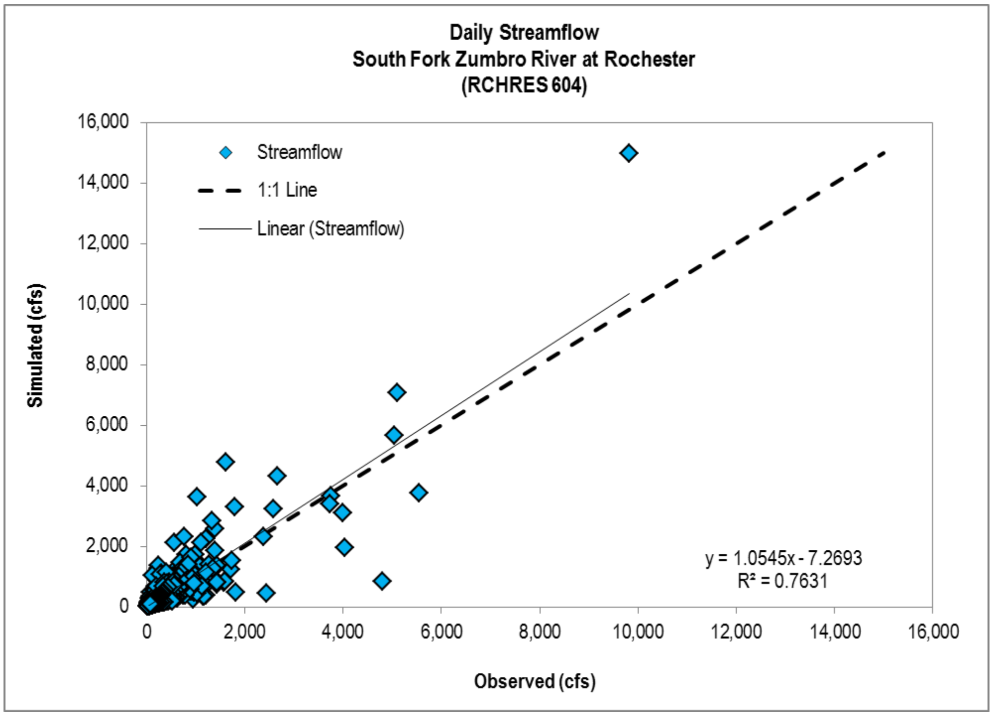

Figure 4-10. Daily Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

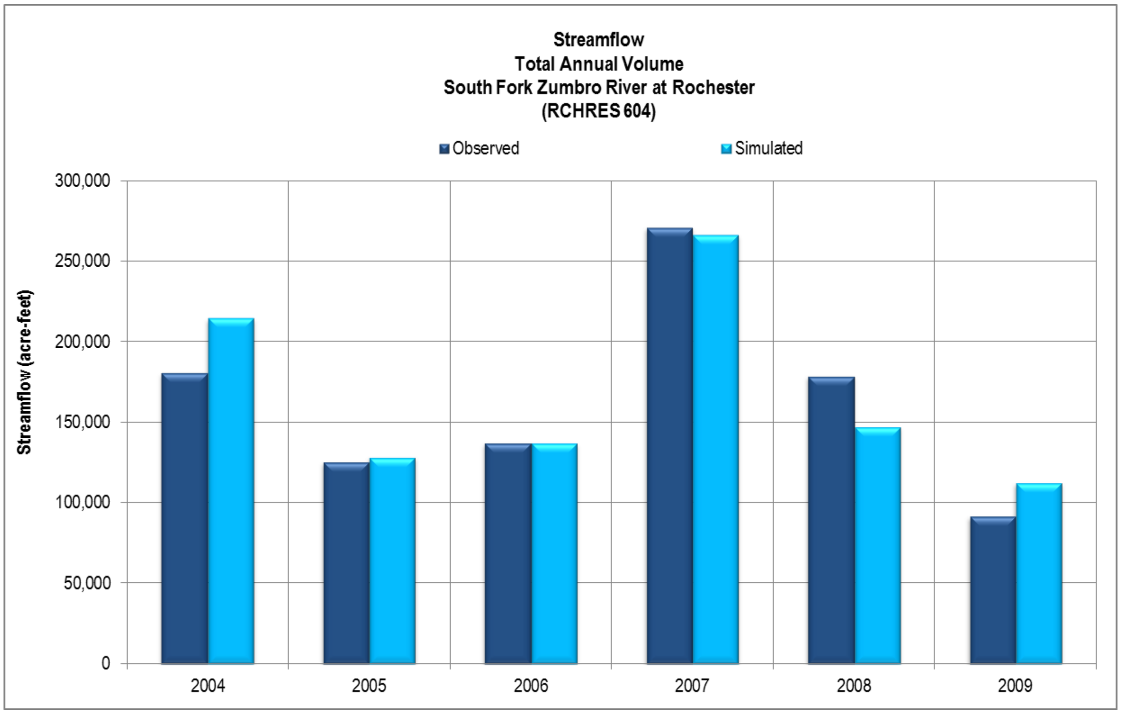

Figure 4-11. Streamflow Total Annual Volume for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

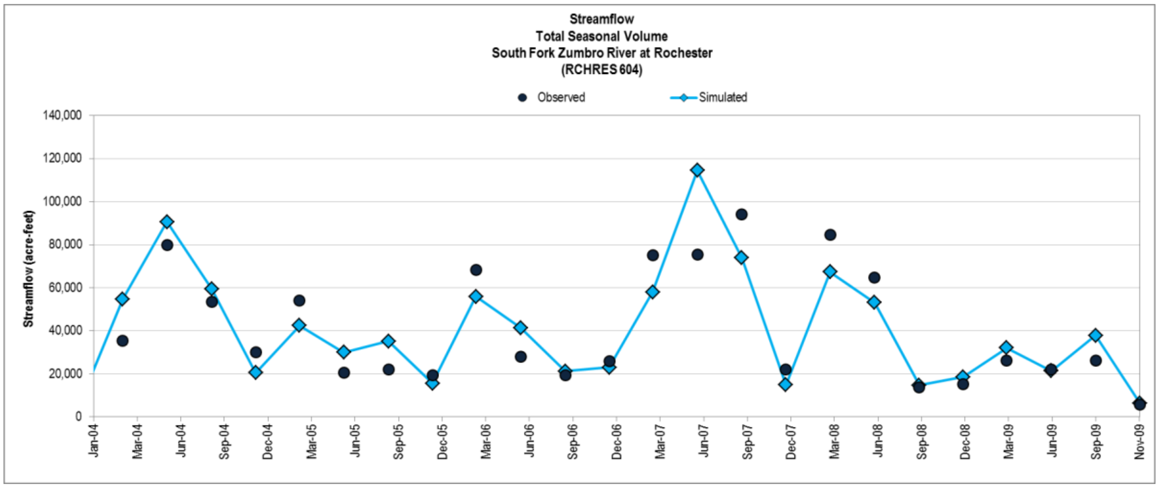

Figure 4-12. Streamflow Total Seasonal Volume for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

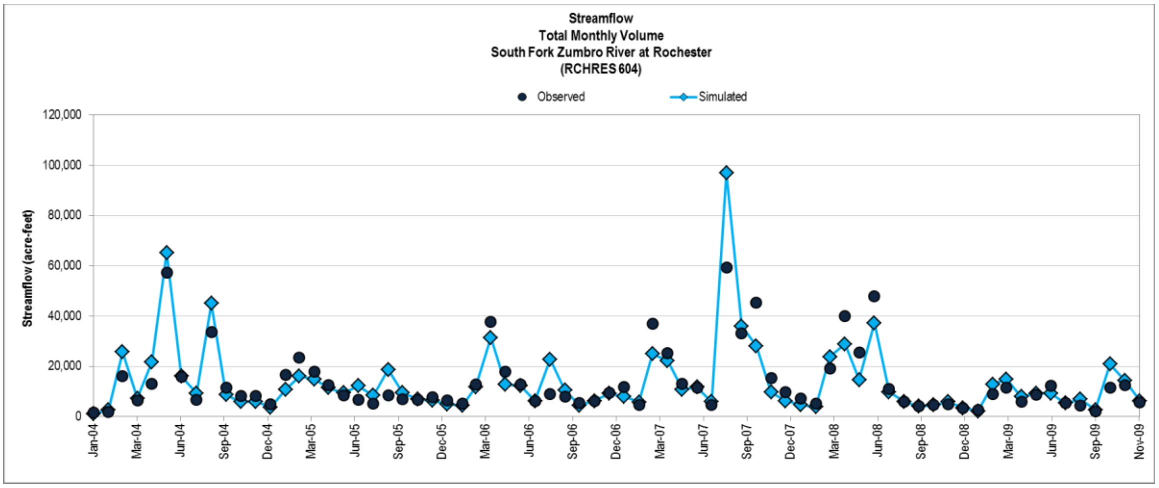

Figure 4-13. Streamflow Total Monthly Volume for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

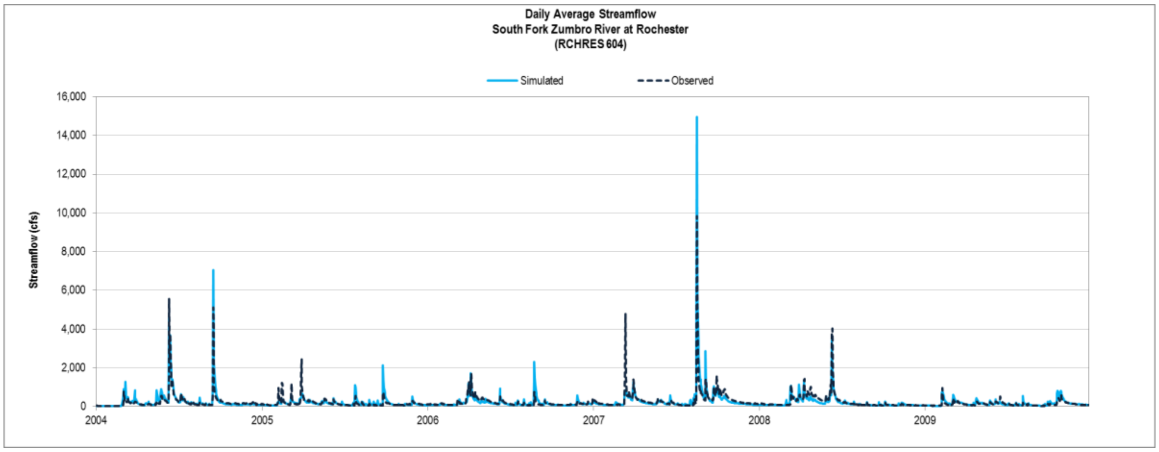

Figure 4-14. Daily Average Streamflow for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

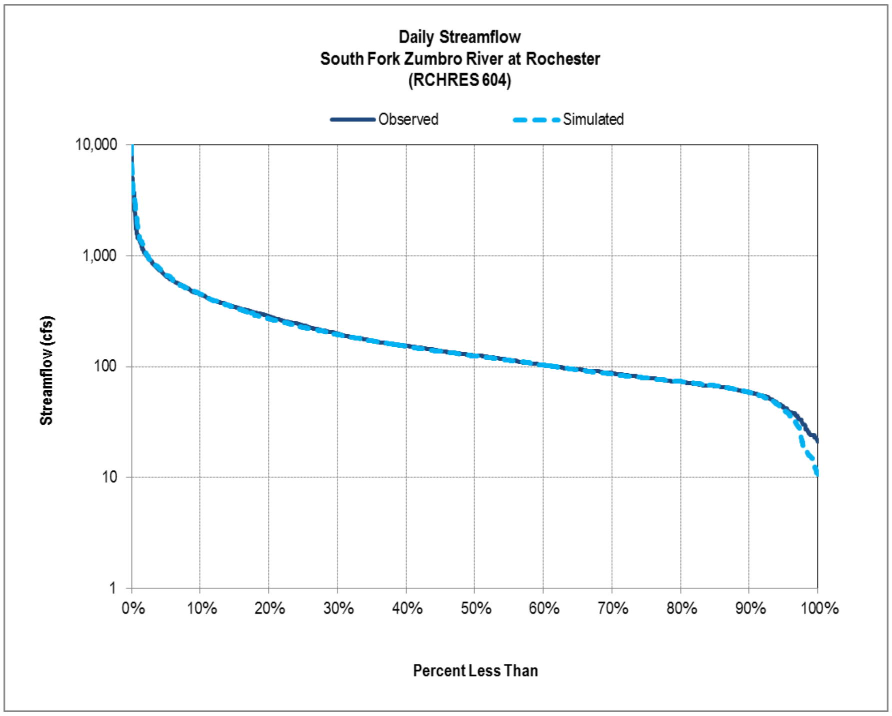

Figure 4-15. Daily Streamflow Cumulative Frequency Distribution for South Fork Zumbro River at Rochester (RCHRES 604) for Model Calibration (2004-2009).

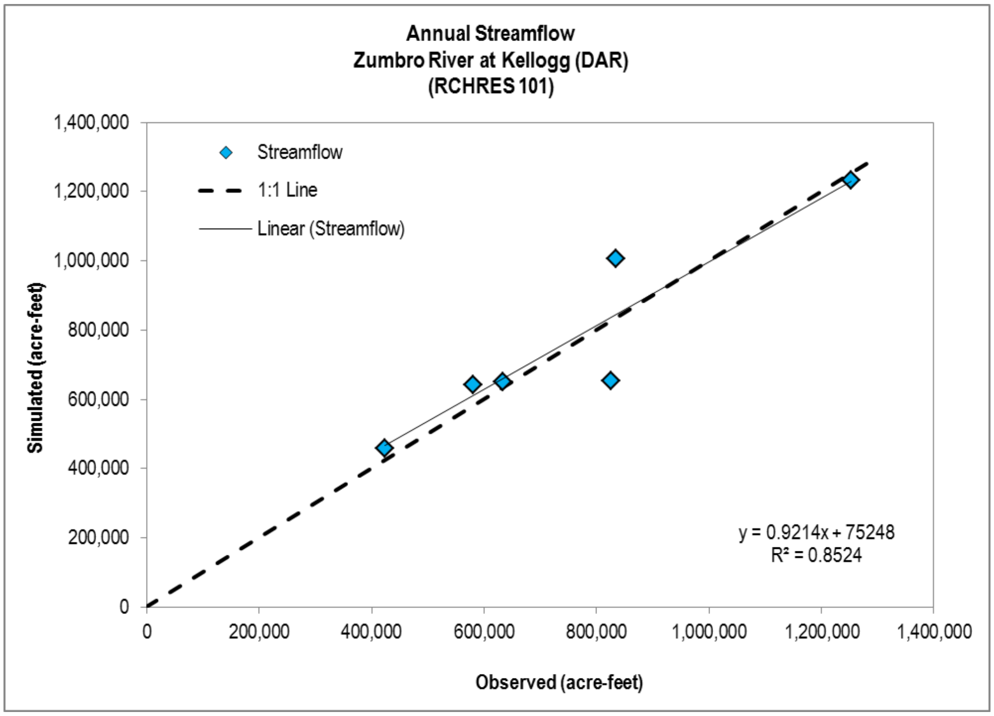

Figure 4-16. Annual Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

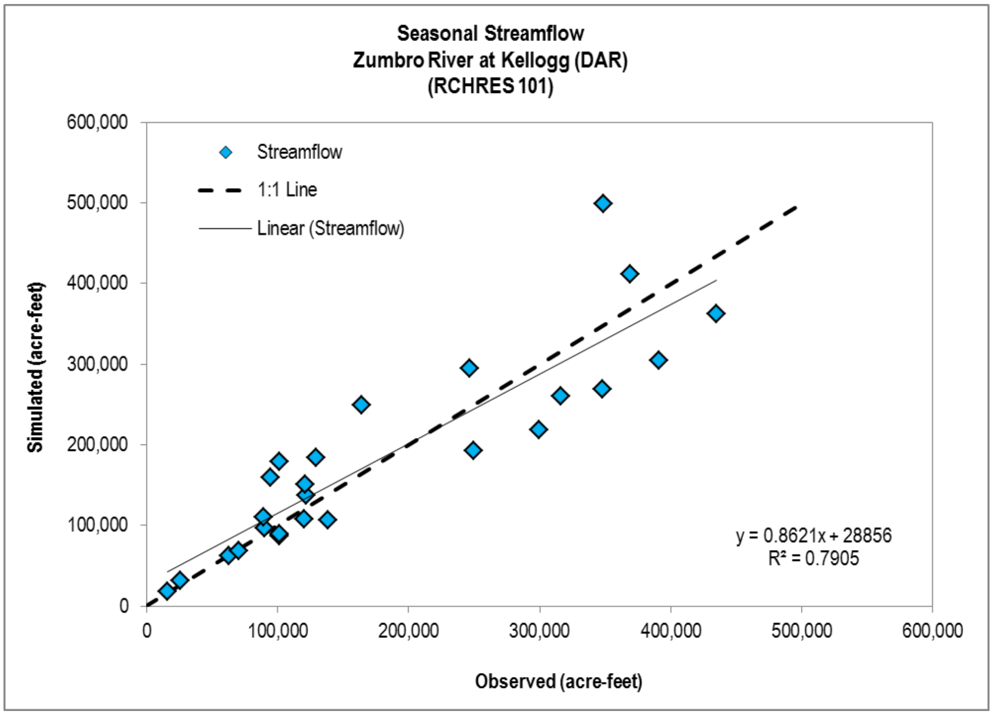

Figure 4-17. Seasonal Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

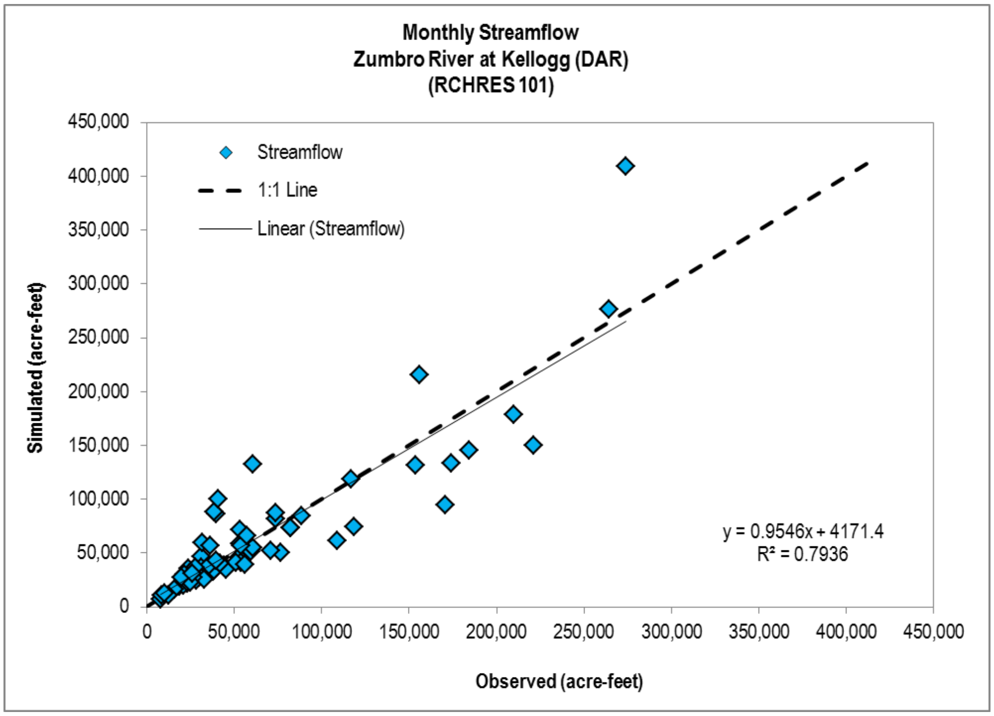

Figure 4-18. Monthly Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

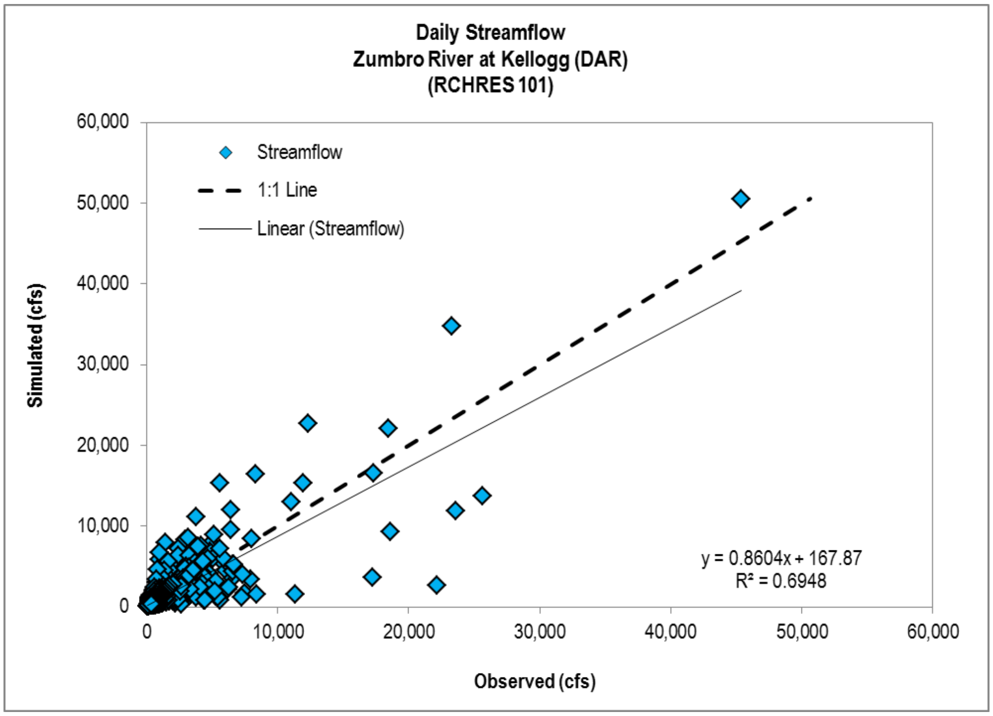

Figure 4-19. Daily Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

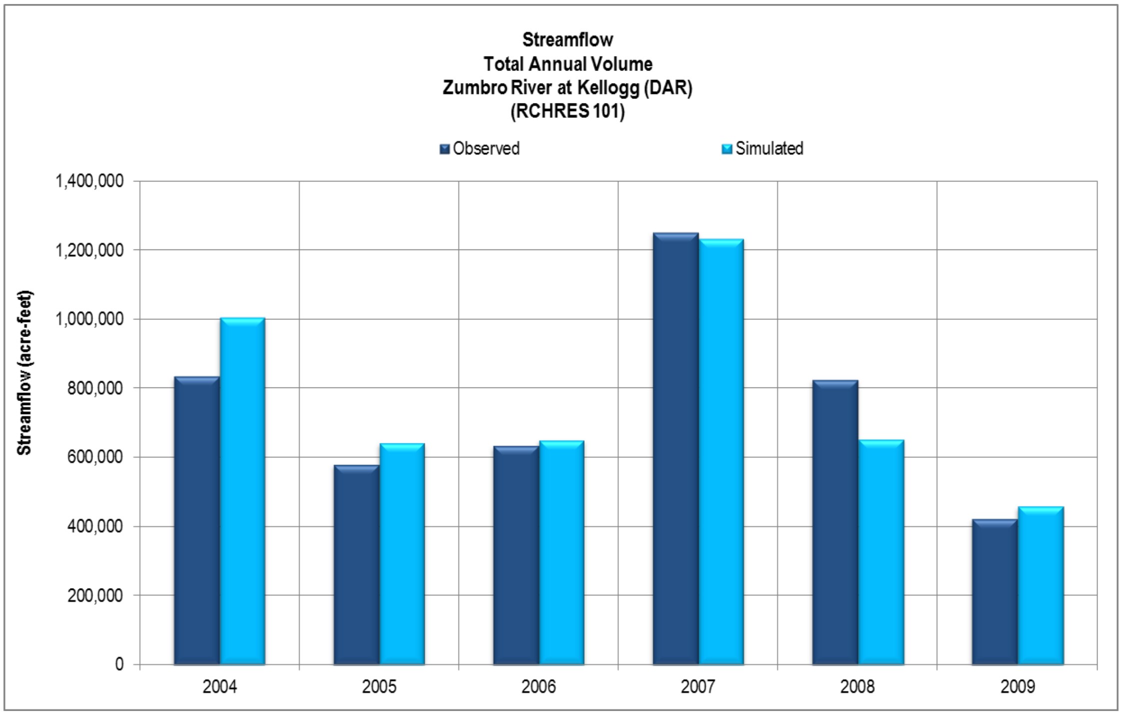

Figure 4-20. Streamflow Total Annual Volume for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

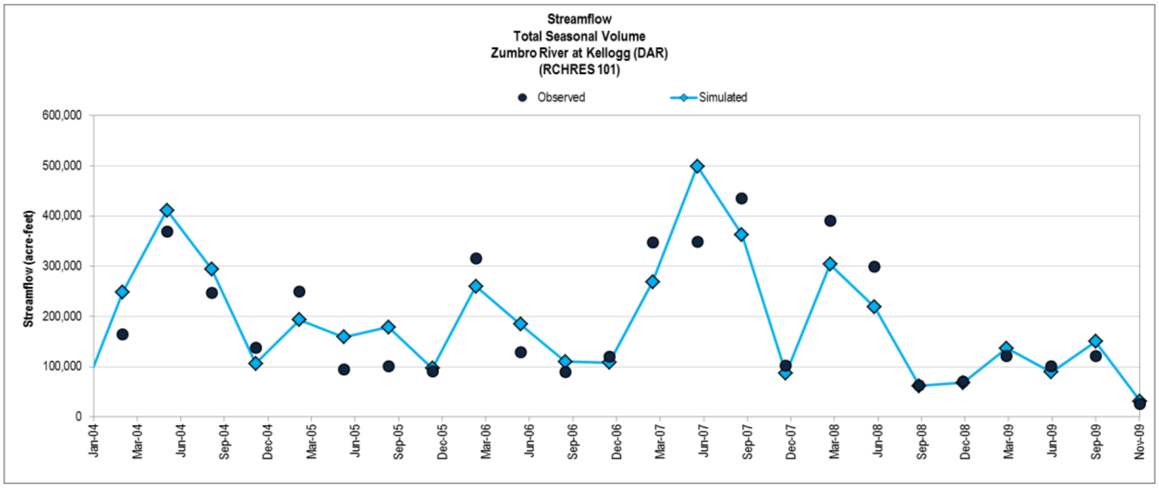

Figure 4-21. Streamflow Total Seasonal Volume for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

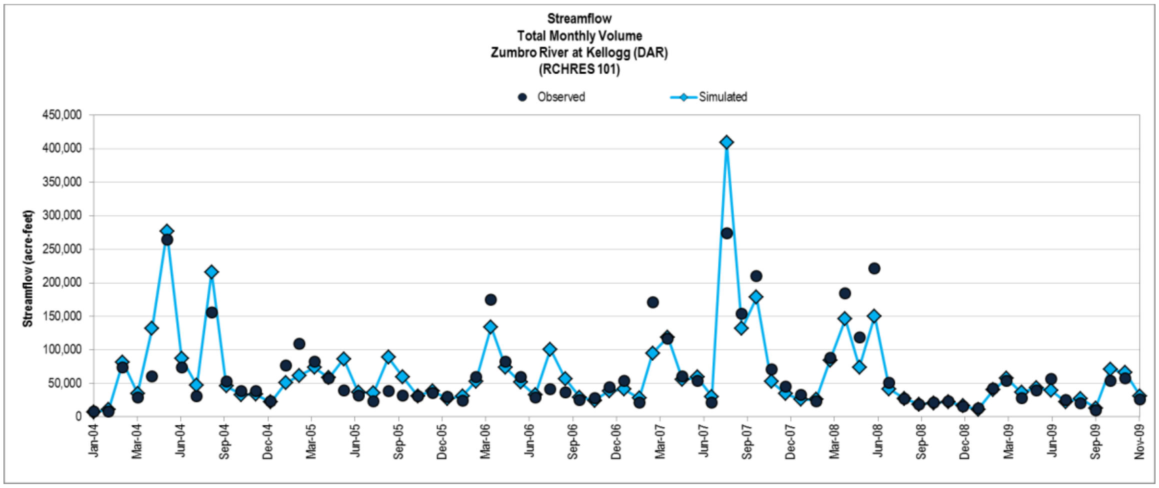

Figure 4-22. Streamflow Total Monthly Volume for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

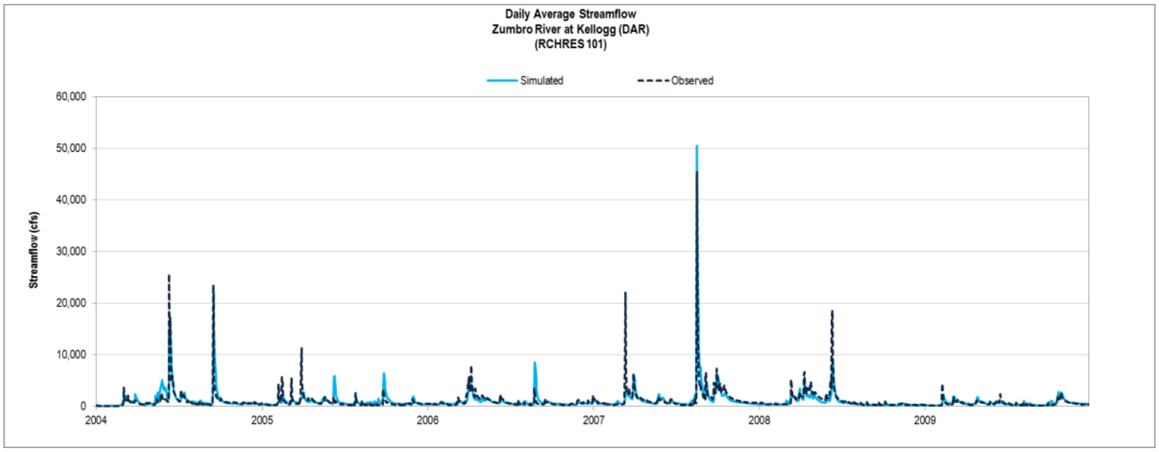

Figure 4-23. Daily Average Streamflow for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

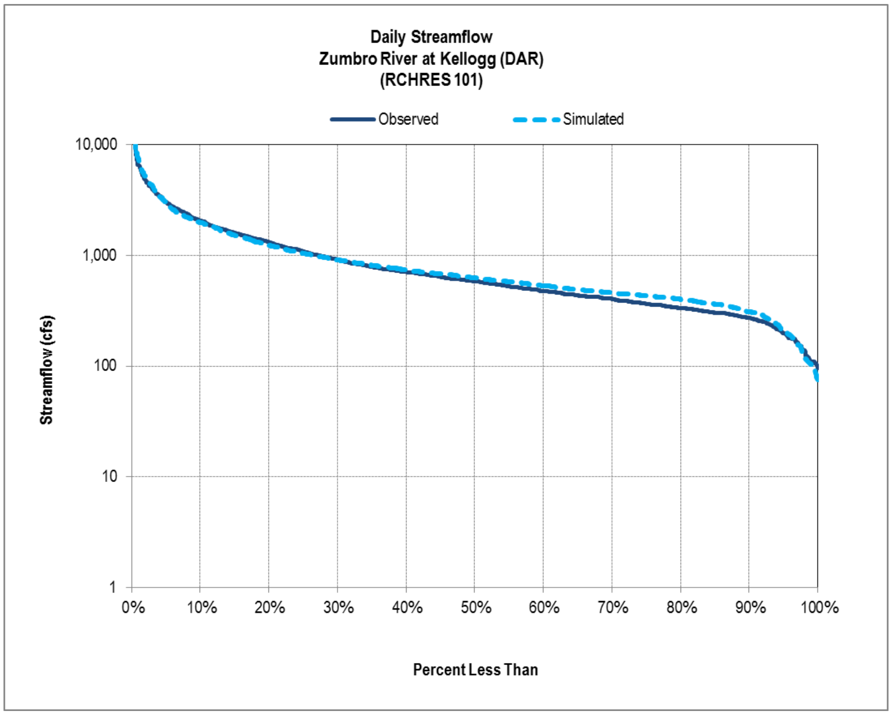

Figure 4-24. Daily Streamflow Cumulative Frequency Distribution for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Calibration (2004-2009).

Areas of Uncertainty

The August 2007 flood is one particular area of uncertainty. The model tends to overpredict the maximum daily average streamflow and the total volume of water delivered during the event compared to observed data at all of the gaged locations in the watershed. As noted above, this particular event was an extreme event with recorded rainfall depths greater than a 200 to 500 year return period (Cooper and Summer 2008). NRCS has noted that the August 2007 flood had observed peak streamflow rates with a surprisingly lower return period when compared to the very high return period of precipitation totals (Cooper and Summer 2008). As noted above, the observed streamflow may have been lower than expected due to dry antecedent conditions, the potential for significant floodplain storage and uncharacteristically high infiltration rates that increased water loss through non-streamflow pathways.

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 streamflow in January and March when observed data show little or no response to precipitation events, even when air temperatures suggest a rainfall event instead of a snowfall event. This situation may be attributed to the inability of HSPF to model frozen stream conditions that occur in the smaller tributaries.

4.2.5 Hydrology Validation

The South Fork Zumbro River at Rochester and Zumbro River at Kellogg (DAR) stations served as the primary validation stations for evaluating model validation performance. Overall, most statistical measures and visual comparisons indicate the model performs “fair” to “very good” for the validation period (Tables 4-11 and 4-12, Figures 4-25 to 4-42). A brief summary of the model performance is provided below:

- The annual r^2 value is within the “very good” range for the South Fork Zumbro River at Rochester station and is within the “fair” range for the Zumbro River at Kellogg (DAR) station.
- The monthly r^2 and NSE values fall within the “good” to “very good” range.
- The daily r^2 values are within the “fair” range.
- The average relative percent difference values for the annual, monthly, and daily time scales are all within the good” to “very good” range.
- The PBIAS values are within the “satisfactory” to “good” range.
- The annual NSE is within the “fair” range for the South Fork Zumbro River at Rochester station.

In general, the model is meeting all of the statistical model performance targets with the exception of the annual NSE value for the Zumbro River at Kellogg (DAR) station. The NSE value is just slightly below the “fair” target range. Although the daily and monthly statistics indicate the model is meeting validation targets for the Zumbro River at Kellogg (DAR) station, an overprediction of annual streamflow volumes may be contributing to the model not meeting this particular performance measure. As noted above, the uncertainty associated with the DAR approach is a likely factor in the model not meeting the annual NSE validation target for the Zumbro River at Kellogg (DAR) station.

Table 4-11. Validation period (1996-2003) statistics.

Time Interval	Statistic	South Fork Zumbro River at Rochester	Zumbro at Kellogg (Drainage Area Ratio)
Annual	Count	8	8
	R-Squared	0.96	0.64
	Nash-Sutcliffe Efficiency	0.50	0.23
	Relative Percent Difference	12.2%	11.3%
	Relative Percent Error	13.4%	13.8%
Monthly	Count	96	96
	R-Squared	0.89	0.82
	Nash-Sutcliffe Efficiency	0.80	0.75
	P-Bias	-14.69	-13.15
	Relative Percent Difference	5.0%	6.9%
	Relative Percent Error	12.9%	14.6%
Daily	Count	2922	2922
	R-Squared	0.61	0.62
	Nash-Sutcliffe Efficiency	0.31	0.45
	Relative Percent Difference	-1.3%	2.7%
	Relative Percent Error	10.1%	14.9%
25th percentile low flow	Relative Percent Difference	-13.3%	-6.3%
	Relative Percent Error	-12.4%	-6.1%
90th percentile high flow	Relative Percent Difference	22.7%	18.8%
	Relative Percent Error	25.6%	20.8%

Table 4-12. Validation period (1996-2003) observed and simulated streamflow.

Statistic	South Fork Zumbro River at Rochester		Zumbro at Kellogg (Drainage Area Ratio)	
	Observed	Simulated	Observed	Simulated
	cfs	cfs	cfs	cfs
Average	204	234	942	1065
Minimum	26	17	120	105
10th percentile	52	40	240	210
25th percentile	72	63	333	312
Median	133	132	615	635
75th percentile	206	234	951	1063
90th percentile	404	507	1866	2254
Maximum	5630	8315	26011	24737

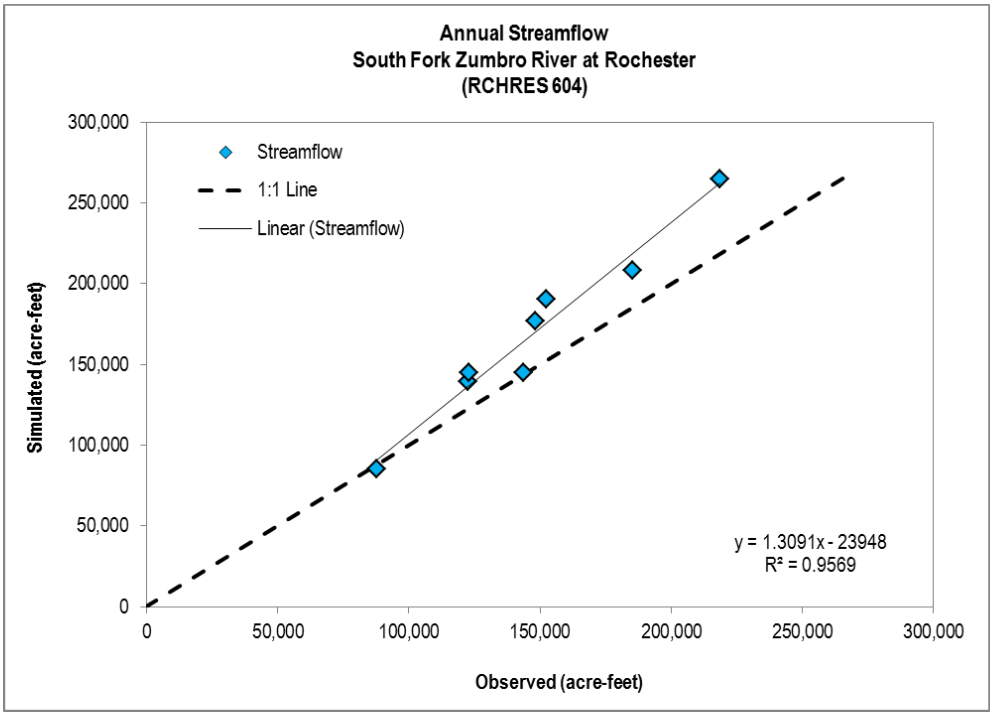

Figure 4-25. Annual Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

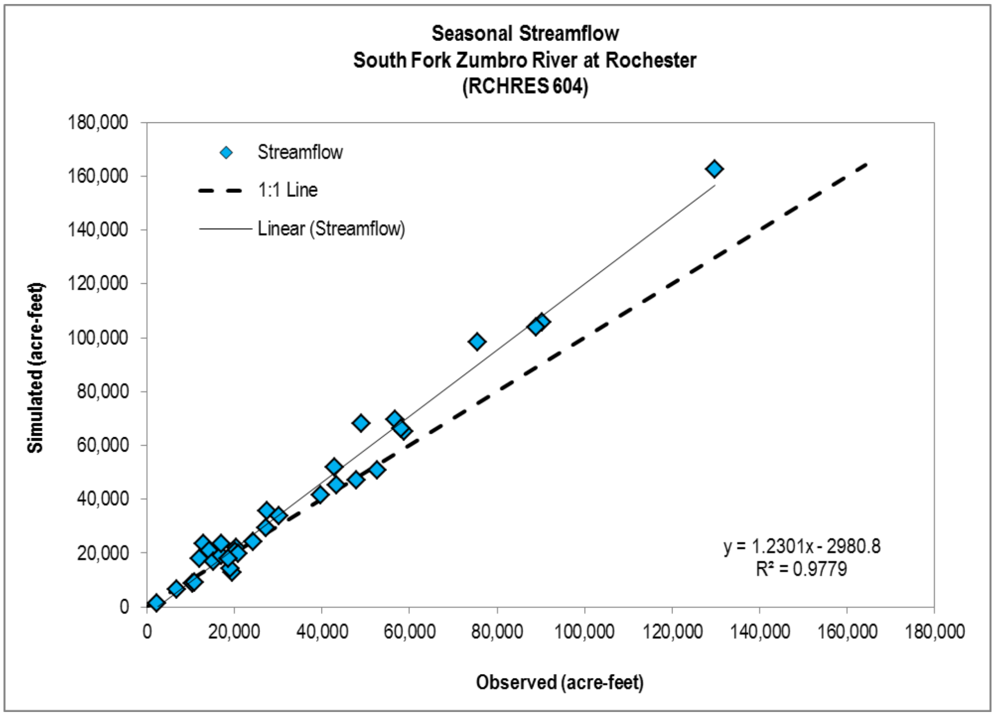

Figure 4-26. Seasonal Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

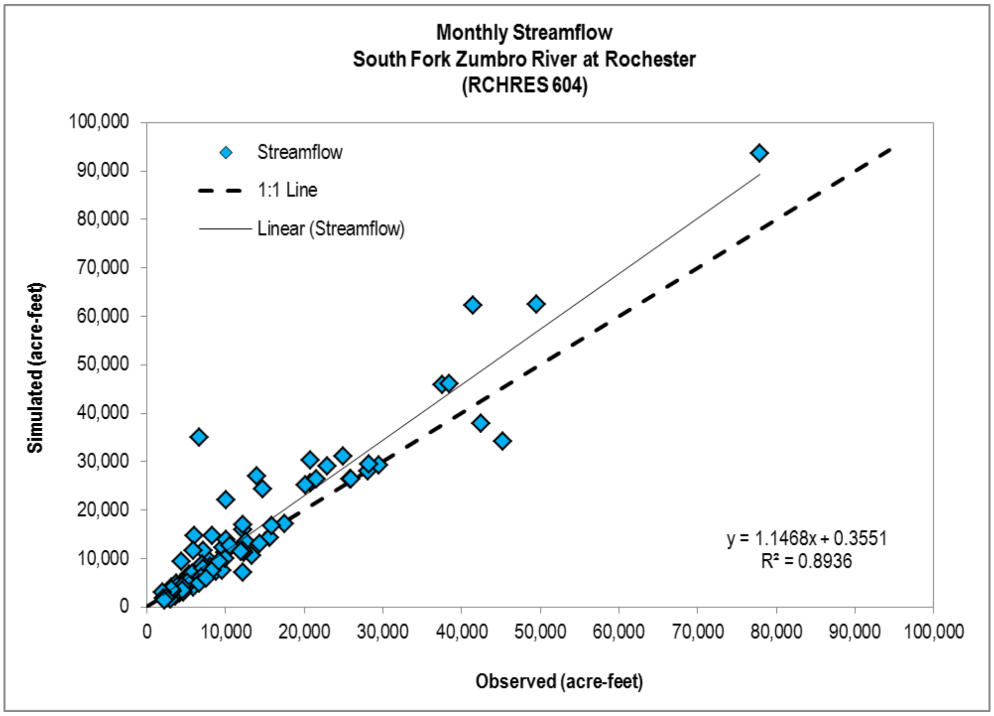

Figure 4-27. Monthly Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

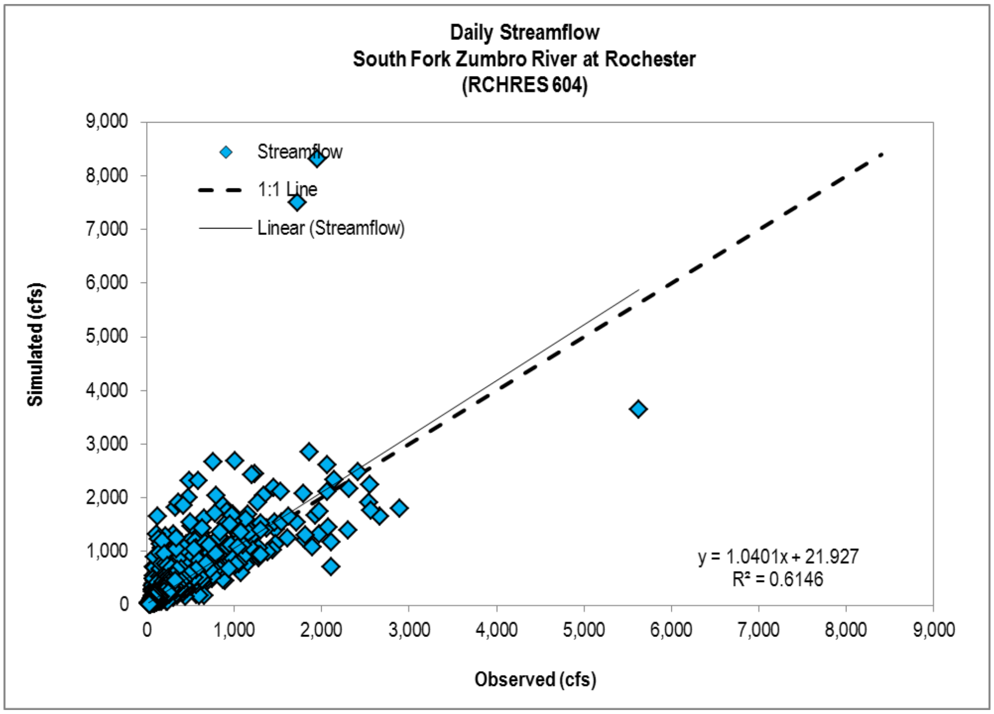

Figure 4-28. Daily Streamflow 1:1 Plot for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

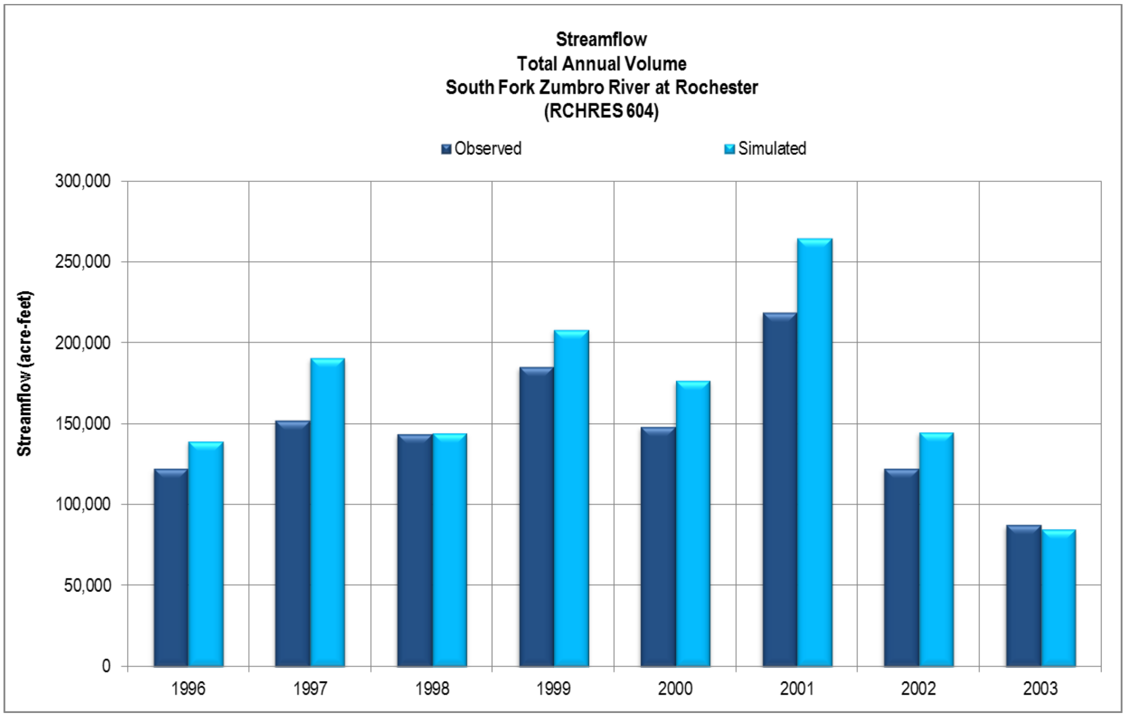

Figure 4-29. Streamflow Total Annual Volume for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

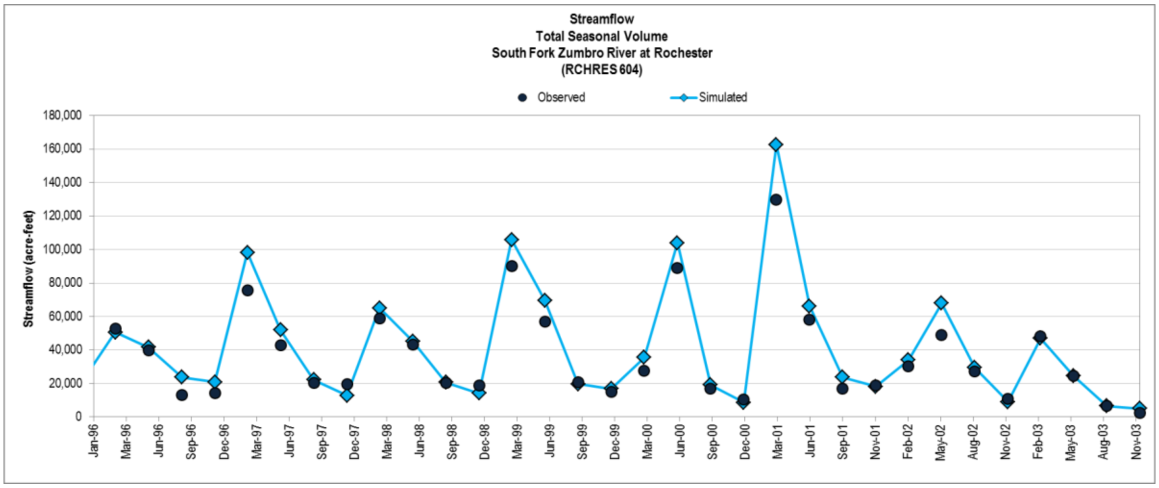

Figure 4-30. Streamflow Total Seasonal Volume for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

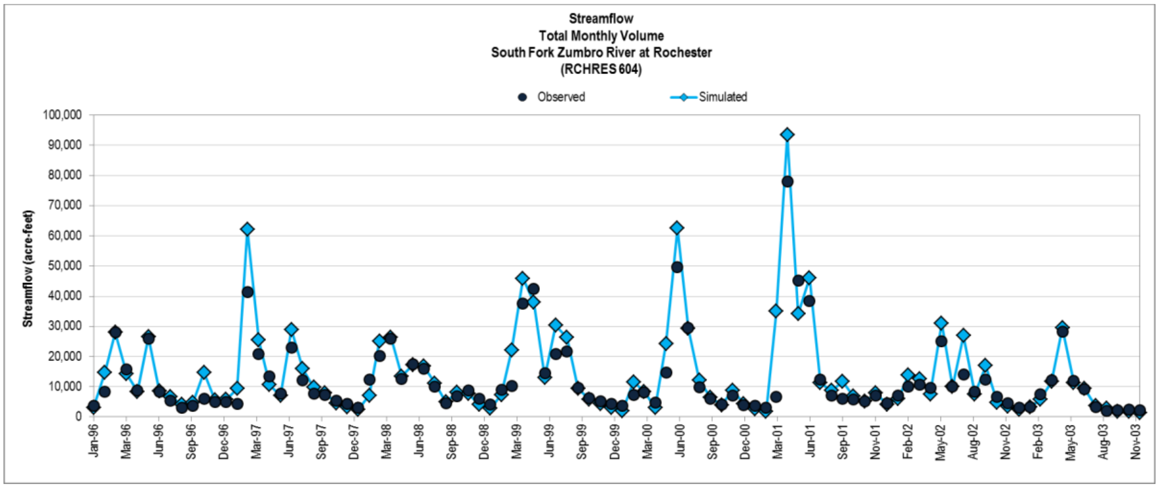

Figure 4-31. Streamflow Total Monthly Volume for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

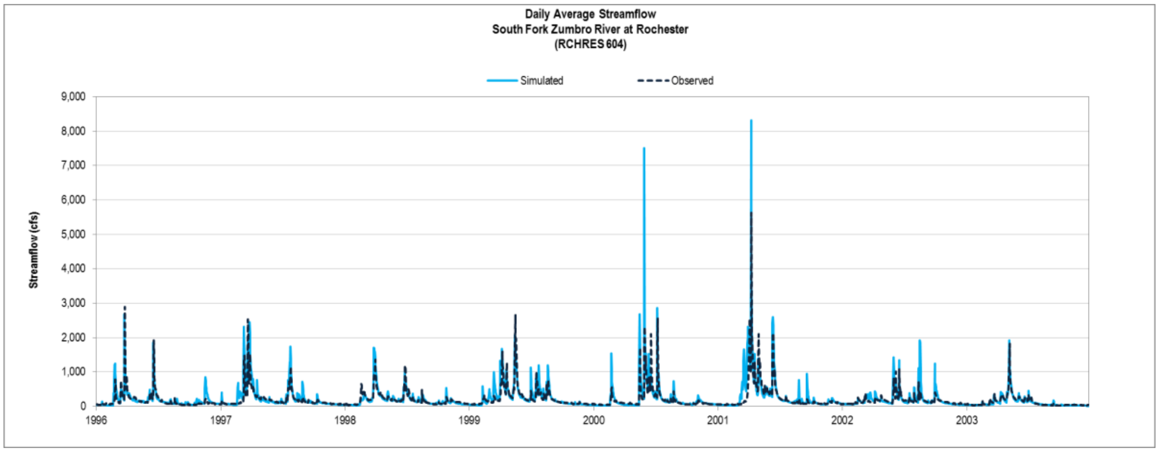

Figure 4-32. Daily Average Streamflow for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

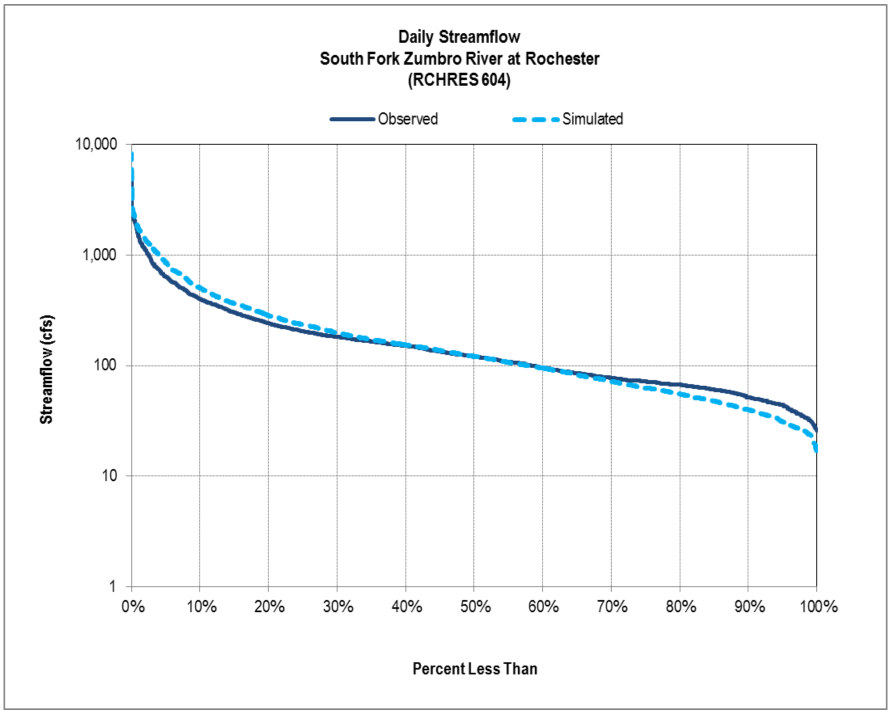

Figure 4-33. Daily Streamflow Cumulative Frequency Distribution for South Fork Zumbro River at Rochester (RCHRES 604) for Model Validation (1996-2003).

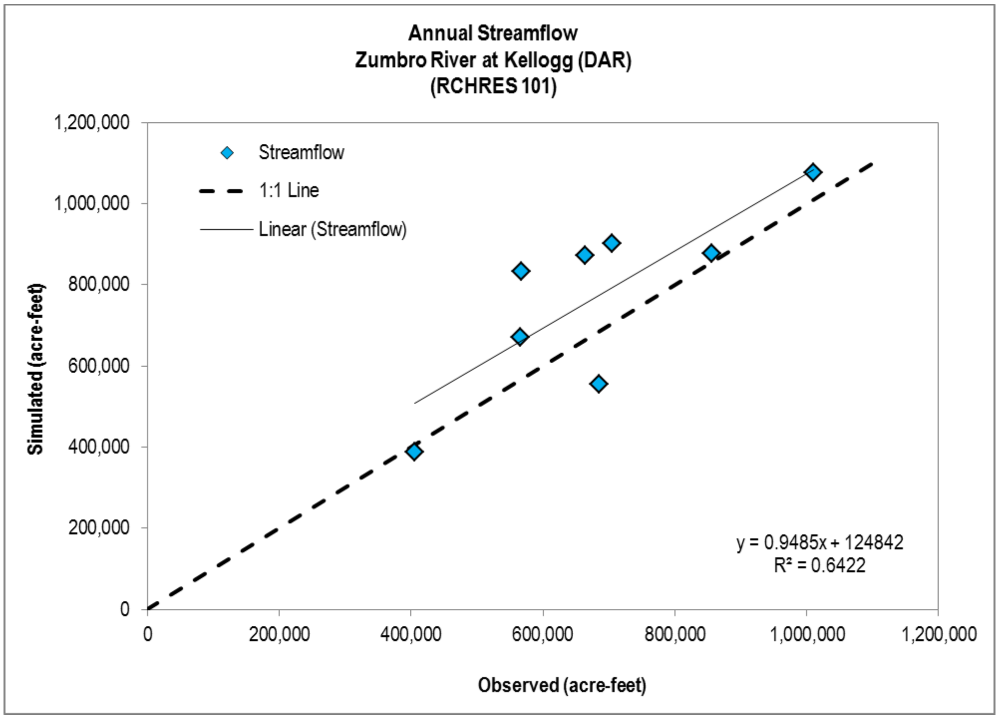

Figure 4-34. Annual Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

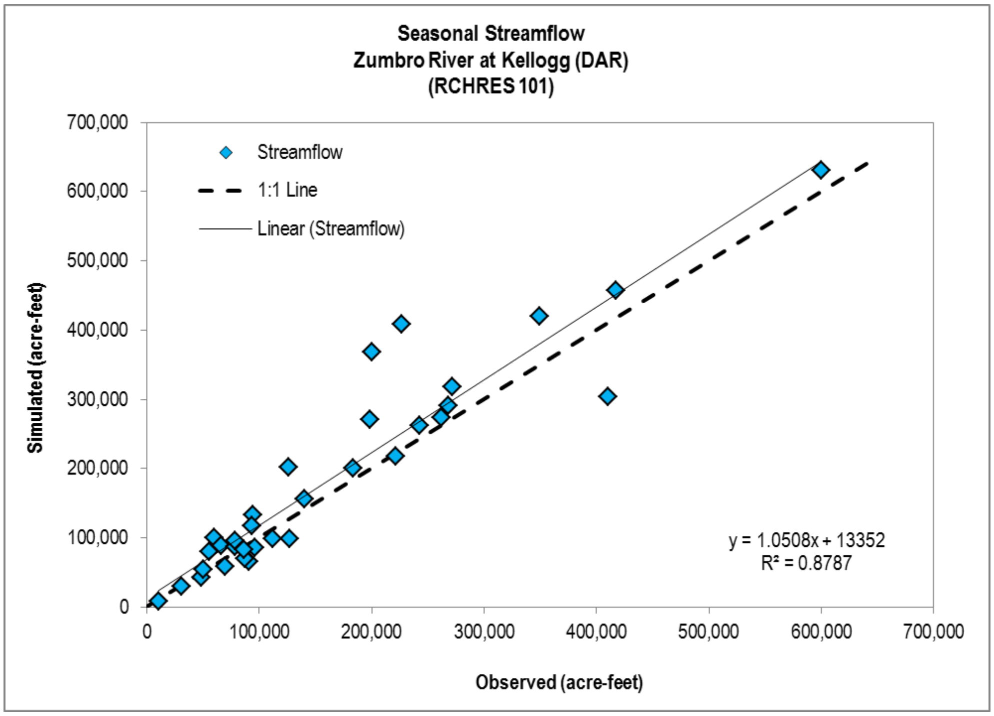

Figure 4-35. Seasonal Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

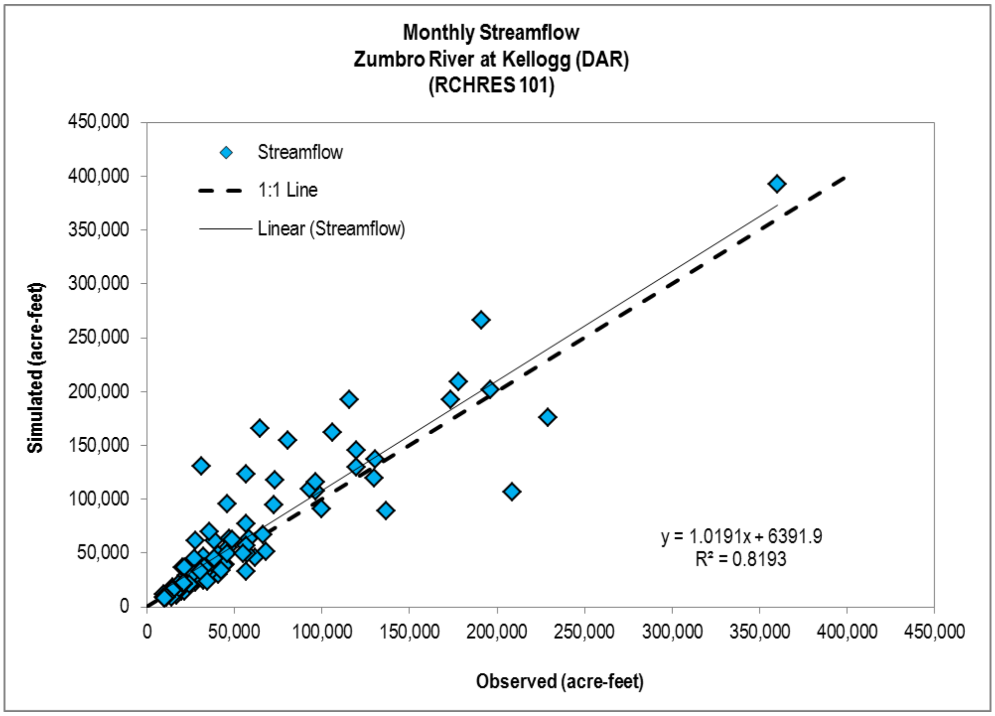

Figure 4-36. Monthly Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

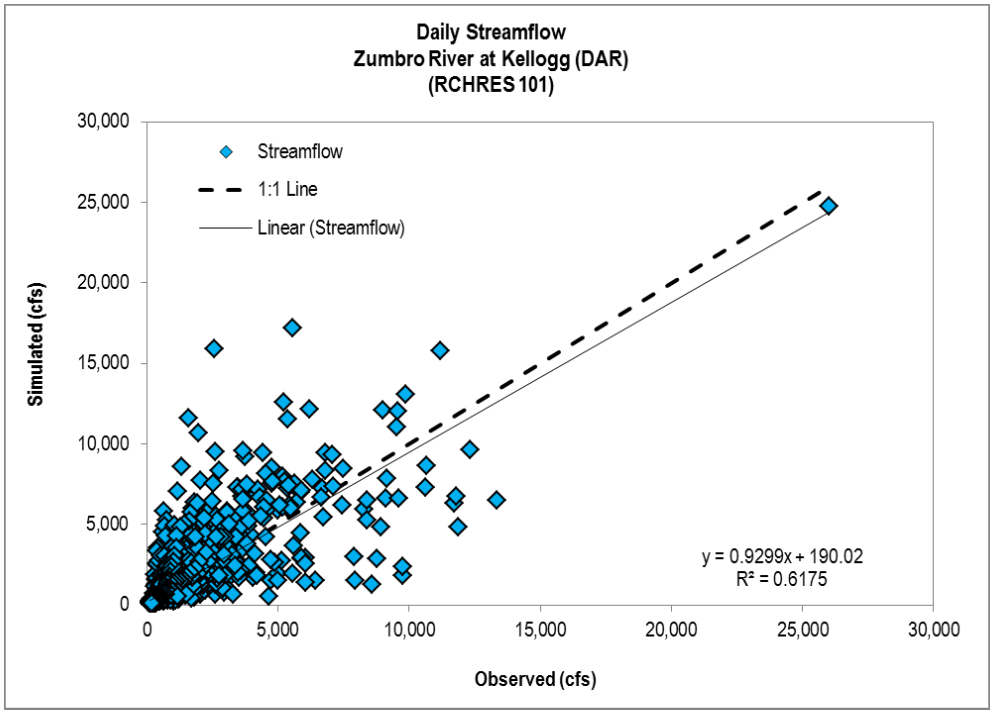

Figure 4-37. Daily Streamflow 1:1 Plot for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

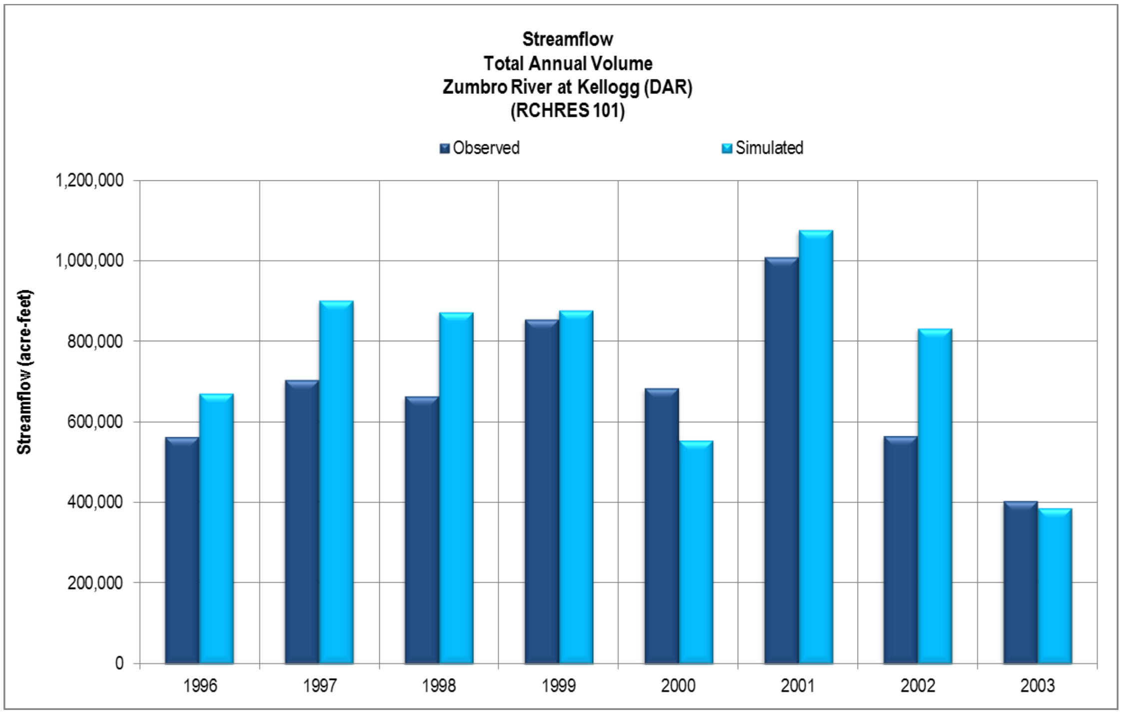

Figure 4-38. Streamflow Total Annual Volume for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

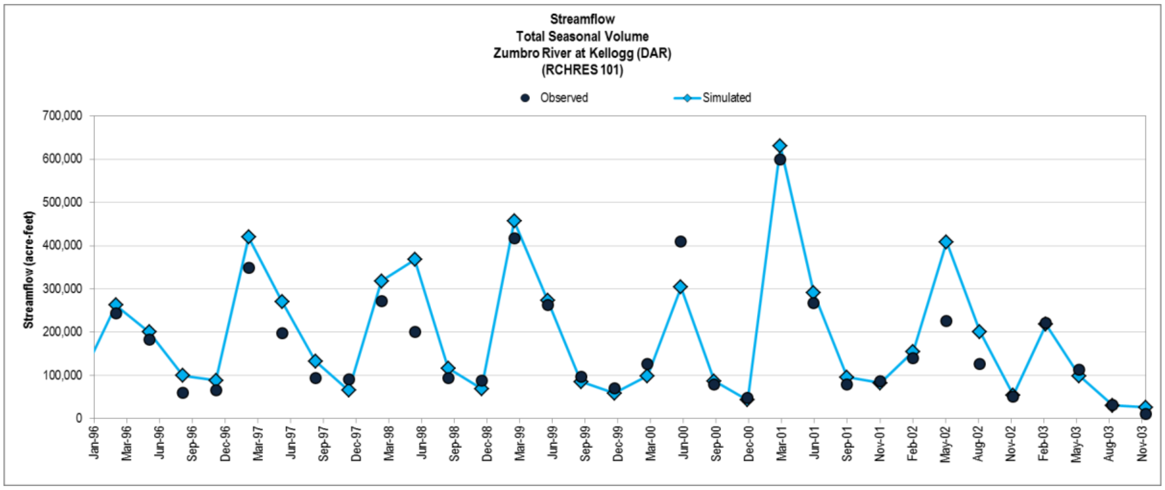

Figure 4-39. Streamflow Total Seasonal Volume for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

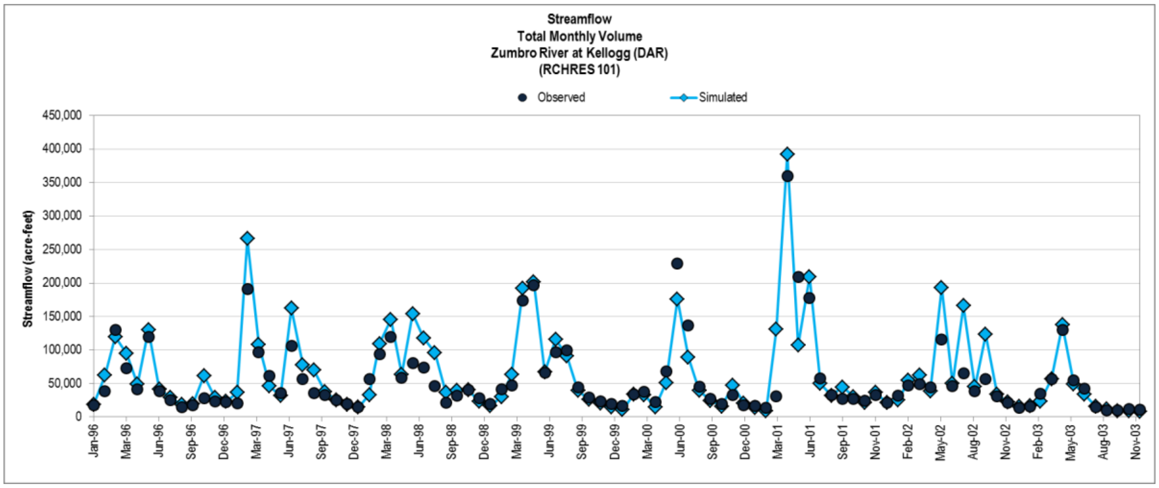

Figure 4-40. Streamflow Total Monthly Volume for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

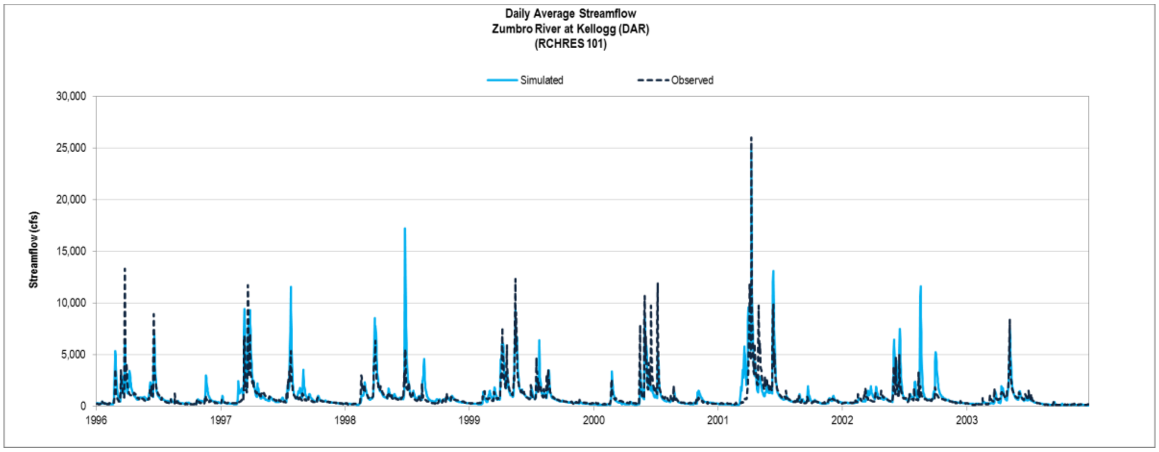

Figure 4-41. Daily Average Streamflow for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

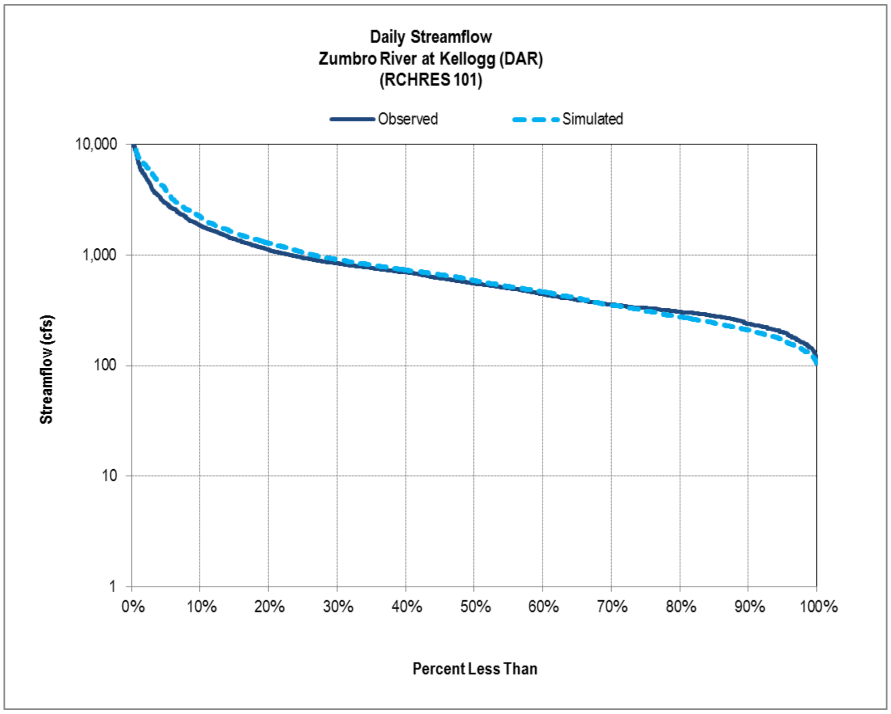

Figure 4-42. Daily Streamflow Cumulative Frequency Distribution for Zumbro River at Kellogg (DAR) (RCHRES 101) for Model Validation (1996-2003).

4.2.6 Full Hydrology Simulation

Statistical comparisons were completed for the entire simulation period (1996-2009) for the South Fork Zumbro River at Rochester and Zumbro River at Kellogg (DAR) stations. Overall, most statistical measures indicate the model performs “good” 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 and monthly r^2 values range from “good” to “very good”.
- The daily r^2 values fall within the “fair” range.
- The annual, monthly, and daily relative average percent difference values are all within the “very good” range.
- The PBIAS values are in the “very good” range.
- The annual and daily NSE values fall within the “good” range, and the monthly NSE values fall within the “very good” range.

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

Table 4-13. Full simulation period (1996-2009) statistics.

Time Interval	Statistic	South Fork Zumbro River at Rochester	Zumbro at Kellogg (Drainage Area Ratio)
Annual	Count	14	14
	R-Squared	0.85	0.73
	Nash-Sutcliffe Efficiency	0.72	0.62
	Relative Percent Difference	8.8%	7.7%
	Relative Percent Error	9.9%	9.5%
Monthly	Count	168	168
	R-Squared	0.84	0.81
	Nash-Sutcliffe Efficiency	0.76	0.76
	P-Bias	-9.48	-8.31
	Relative Percent Difference	3.5%	5.8%
	Relative Percent Error	10.7%	12.6%
Daily	Count	5114	5114
	R-Squared	0.69	0.66
	Nash-Sutcliffe Efficiency	0.51	0.57
	Relative Percent Difference	-1.6%	4.0%
	Relative Percent Error	8.9%	15.6%
25th percentile low flow	Relative Percent Difference	-3.3%	7.5%
	Relative Percent Error	-3.2%	7.8%
90th percentile high flow	Relative Percent Difference	12.4%	5.7%
	Relative Percent Error	13.2%	5.9%

Table 4-14. Full simulation period (1996-2009) observed and simulated streamflow.

Statistic	South Fork Zumbro River at Rochester		Zumbro at Kellogg (Drainage Area Ratio)	
	Observed	Simulated	Observed	Simulated
	cfs	cfs	cfs	cfs
Average	214	234	987	1069
Minimum	21	11	97	76
10th percentile	55	45	254	231
25th percentile	74	72	343	370
Median	137	136	634	663
75th percentile	217	233	1001	1059
90th percentile	426	482	1968	2084
Maximum	9830	14962	45415	50520

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

4.3 Sediment

The HSPF model simulates inorganic sediment in three particle-size fractions: 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.). For this report, the term sediment and TSS are used interchangeably when HSPF modeling is discussed. This approach is consistent with the language typically used in HSPF modeling and is also consistent the terminology used in the MPCA modeling guidance document (AQUA TERRA Consultants 2012).

The ZRWHSPF sediment (including suspended solids) model calibration and validation results are described in the sections below.

4.3.1 Sediment Calibration Targets

The sediment calibration was conducted consistent with the approach described in BASINS Technical Note 8 (USEPA 2006) and the MPCA modeling guidance document (AQUA TERRA Consultants 2012). Multiple aspects of the ZRWHSPF model were investigated including watershed sediment loading rates and sources, delivery of eroded sediments to streams, sediment trapping in Lake Zumbro and Rice Lake, scour and deposition processes, and TSS concentrations and loads. A set of calibration targets was defined for each of the model aspects 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 UALs for each land use type) were not available for the Zumbro 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. The sediment source apportionment review developed by LimnoTech (2013g) suggested an appropriate target for upland contribution to sediment sources in the 30-40% range. It was noted that the presence of a higher percentage of hydrologic soil group type “C” soils in the upper Zumbro River watershed, which will tend to produce greater quantities of runoff, could potentially result in a larger yield of upland runoff-derived sediment than what is observed in the nearby Root River watershed (LimnoTech 2013g).

In-Stream Calibration Targets

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

- A 30-40% sediment trapping efficiency by Lake Zumbro.
- Net sediment deposition in Rice Lake and the reaches with storage reservoirs (i.e., Silver Creek, Cascade Creek, Willow Creek, and Bear Creek).
- Net sediment erosion for the free-flowing reaches.
- An annual suspended solids load ranging from 124,000-167,000 tons/year for the Zumbro River at Kellogg.
- Observed TSS concentrations.

A rough estimate of the sediment trapping efficiency of Lake Zumbro was computed from estimations of the annual sediment load below the lake at Zumbro Falls and the annual sedimentation rate in the lake.

The sediment load at Zumbro Falls was calculated based on the values for average annual sediment yield and drainage area noted in a USGS report on suspended solids in Minnesota streams (Tornes 1986, see Table 2):

$$[Sediment\ Load\ at\ Zumbro\ Falls] = 49.3 \frac{tons}{mi^2 year} * 1{,}130\ mi^2 = 56{,}000 \frac{tons}{year}$$

Romon (2009) estimated the Lake Zumbro sedimentation rate to be 34,000 cubic yards per year. Assuming a dry bulk density of 1 kg/L, the corresponding sediment mass deposition rate was estimated as follows:

$$[Mass\ Deposition\ Rate] = 34{,}000 \frac{yd^3}{year} * \ 1 \frac{kg}{L} * 764.55 \frac{L}{yd^3} * \ \frac{ton}{907.18\ kg} = 29{,}000 \frac{tons}{year}$$

The annual sediment load into Lake Zumbro was calculated as:

$$[Sediment\ Load\ In] = [Mass\ Deposition\ Rate] + [Sediment\ Load\ at\ Zumbro\ Falls]$$
$$= 29{,}000 \frac{tons}{year} + 56{,}000 \frac{tons}{year} = \ 85{,}000 \frac{tons}{year}$$

The sediment trapping efficiency was then calculated as:

$$[Trapping\ Efficiency] = \frac{[Mass\ Deposition\ Rate]}{[Sediment\ Load\ In]} = \frac{29{,}000}{85{,}000} = 34\%$$

A target range of 30-40% trapping efficiency was set for Lake Zumbro based on the above calculations. Although data were not available to compute target trapping efficiencies for Rice Lake or reaches with flood control storage reservoirs, a general “net depositional” target was set for the model reaches corresponding to these impoundments which slow streamflow and allow suspended particles to settle.

A “net erosional” target was set for the free-flowing reaches of the watershed based on qualitative information described in the Zumbro River Watershed TMDL for Turbidity Impairments report (MPCA 2012). Streambank erosion or bed erosion is noted as a primary source and causal factor contributing to sediment loading for nearly all of the impaired reaches listed in Section 3.4 of the TMDL report. Additionally, several of the sites surveyed in 2007 were observed to have eroding banks and widening channels (MPCA 2012, see Appendix E).

Several attempts were made to estimate suspended solids (as TSS) loads with the USGS’s LOAD ESTimator (LOADEST) software (Runkel et al. 2004) using observed HYDSTRA streamflow data and TSS concentrations for the Zumbro River at Kellogg and South Fork Zumbro River South of Rochester USGS gage locations. The TSS concentration values were computed from regression equations developed to convert continuous turbidity measurements to laboratory turbidity, and then laboratory turbidity to TSS (MPCA 2012, see Appendix D). All attempts resulted in warning messages that the LOADEST predictions should not be used for load estimation due to either bias outside of acceptable ranges or unrealistic TSS concentration estimates (e.g. greater than 50,000 mg/L).

The TSS datasets were evaluated in detail to understand why LOADEST did not generate acceptable and valid results. Several iterations were attempted to derive acceptable TSS loads via LOADEST and included using entire datasets regardless of the quality rating (e.g., good, fair, poor), using a dataset that only had data rated as “good” or “fair” quality, and removing outliers. The results of these attempts included the following outcomes: (1) unacceptable model statistics (PBIAS > ±25% or NSE <0), (2) acceptable model statistics but “Not A Number” errors (i.e. the selected model uses LN() formula, and LN(negative number) produced errors), and/or (3) acceptable model statistics but unrealistic concentrations (e.g. >300,000 mg/L) predicted by the LOADEST model for very high flows (there were no concentrations > 50,000 mg/L in the dataset).

To address these issues with estimating suspended solids loads using LOADEST, an average annual suspended solids load for the Zumbro River at Kellogg was calculated from the values for average annual suspended solids yield and drainage area provided in Table 2 of Tornes (1986):

$$[Suspended\ Solids\ Load\ at\ Kellogg] = 104\,\frac{tons}{mi^2 year} * 1{,}400\ mi^2 = 145{,}600\,\frac{tons}{year}$$

In recognition that the suspended solids load in the Zumbro River may vary considerably by year and/or evaluation time period, a ±15% range was applied resulting in an annual average suspended solids load calibration target of 124,000-167,000 tons/year for the Zumbro River at Kellogg.

Also, in the absence of LOADEST estimated suspended solids loads, a linear regression was developed between a drainage area ratio (DAR) estimate of streamflow for the Zumbro River at Kellogg (see Task 5 memorandum, LimnoTech 2014a) and daily average TSS concentrations calculated based on continuous turbidity measurements at the Zumbro River at Kellogg HYDSTRA station (Figure 4-43). This relationship was used to predict annual sediment loads for the Zumbro River at Kellogg for comparison to model-predicted loads. While the regression model provides a reasonable fit, there are important caveats to note. The regression model appears to under-predict TSS concentration at intermediate flows. In addition, there are very limited data available for high flow conditions and peak flows in particular; therefore, there is considerable uncertainty in the performance of the regression model to predict TSS concentration under those conditions. Overall, we anticipate the ZRWHSPF model will tend to over-predict TSS concentrations and loads during years with the highest streamflows relative to the predictions of the regression model.

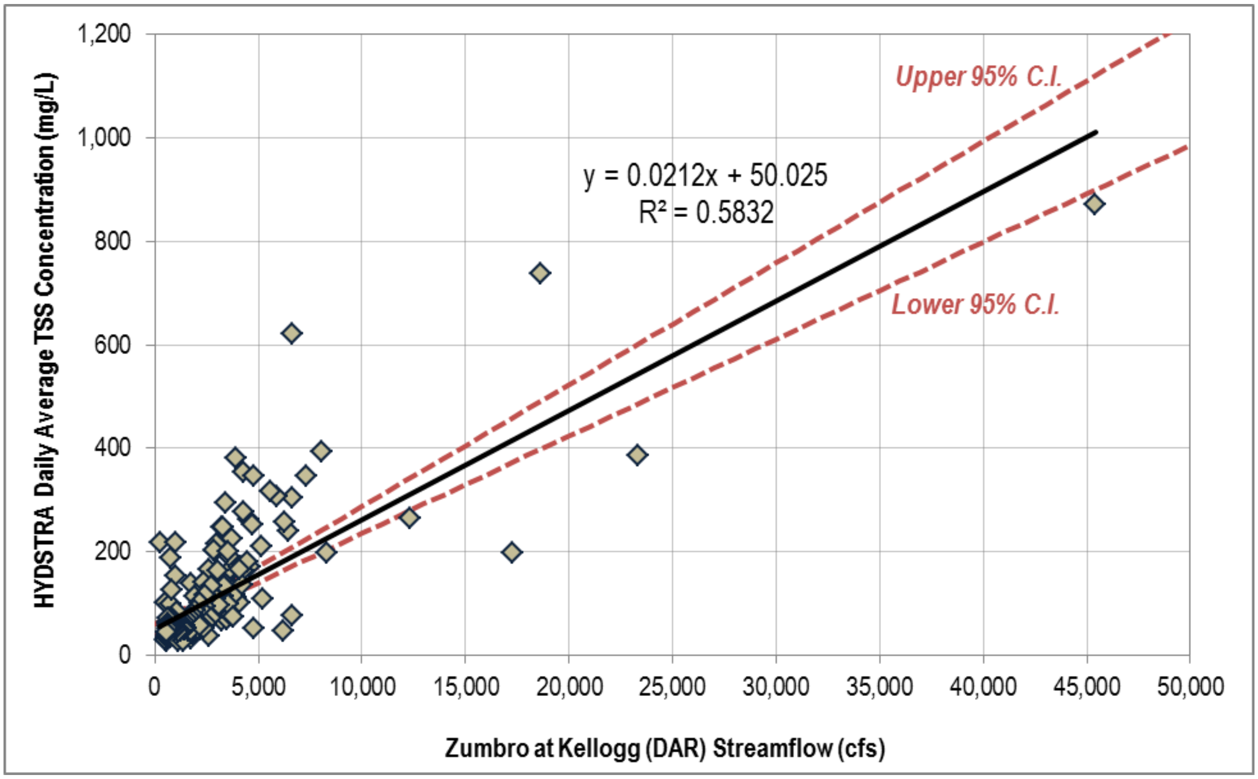

Figure 4-43. Linear regression between a drainage area ratio (DAR) estimate of streamflow for the Zumbro River at Kellogg and daily average TSS concentrations.

A final step in sediment calibration for watershed modeling usually involves comparing simulated and observed TSS concentrations (USEPA 2006). Turbidity data acquired from the HYDSTRA database and TSS data obtained from the MPCA Environmental Data Access (EDA) surface water database were used as calibration targets. The HYDSTRA turbidity data, available at 15-minute intervals, were processed to generate daily averages and then translated to TSS concentration estimates, as described above. In general, the HYDSTRA gages only report turbidity for March through November, so evaluation of model-predicted annual and seasonal TSS concentrations was limited for most areas of the watershed. Additionally, HYDSTRA turbidity data that did not have a quality rating of “good” or “fair” were removed from the calibration and validation datasets due to the greater uncertainty associated with those particular measurements. Data were generally available for the 2007-2009 time period and limited for the 1996-2006 time period. The water quality station locations that were used to support the model calibration and validation are summarized in Table 4-15.

Table 4-15. Daily average turbidity and TSS concentration data for the ZRWHSPF model calibration.

Station ID (HYDSTRA/STORET)	*HSPF Reach ID*	*Station Name*	*HYDSTRA Database Daily Average Turbidity*		*EDA Database TSS Concentration*	
			Count of Records	*Period of Record*	*Count of Records*	*Period of Record*
H41043001 (S004-384)	**101**	**Zumbro River at Kellogg**	**212**	**2007-2008**	**128**	**2007-2009**
H41016001 (S004-486)	33	Milliken Creek	512	2007-2009	47	2009-2009
H41050001 (S001-572)	68	Silver Creek	293	2007-2008	30	2007-2008
H41051001 (S000-800)	71	Bear Creek	194	2007-2008	28	2007-2008
H41061001 (S004-385)	609	South Fork Zumbro River South of Rochester	86	2008	-	-
H41064001 (S001-354)	64	Cascade Creek	119	2007-2008	-	-
W41049001 (S003-802)	601	South Fork Zumbro River at 90th Street	449	2007-2009	51	2007-2009
(S000-286)	609	South Fork Zumbro River at Highway 14	-	-	69	2000-2009

**The station in bold denotes primary watershed outlet station (Zumbro River at Kellogg)*

4.3.2 Sediment Parameterization

Initial model parameterization was completed following procedures outlined in BASINS Technical Note 8 (USEPA 2006) 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 the partitioning into silt and clay and settling of sediment prior to delivery to the stream using the M-FACT. This approach was proposed by RESPEC and is outlined in the MPCA modeling guidance document (AQUA TERRA Consultants 2012). A constant sediment concentration of 5 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 ZRW (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 from overland flow source locations 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 11th percentile of daily average shear stresses, and the critical shear stress for silt scour (TAUCS) was set at the 97th percentile of daily average shear stresses. TAUCD and TAUCS for clay were set at the 5th and 95th percentiles of daily average shear stresses, respectively. TAUCD and TAUCS were set at higher percentiles for Lake Zumbro, Rice Lake, and the storage reservoir reaches to simulate the net sediment deposition that occurs in these impounded reach segments.

4.3.3 Land Side Sediment Erosion

The ZRWHSPF model sediment calibration and validation results are described in the sections below. As mentioned above, several targets evaluated extend over the entire simulation period (1996-2009) due to a lack of data distinguishing the calibration and validation periods. In-stream 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), absolute UALs by land use type were within literature ranges, 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 landscape loading was consistent with the annual average sediment loading target for the Zumbro River at Kellogg. The area-weighted UALs by land use type are shown in Figure 4-44. A comparison of the contribution of upland/washoff erosion and gully/ravine erosion to the land use UALs is shown in Figure 4-45.

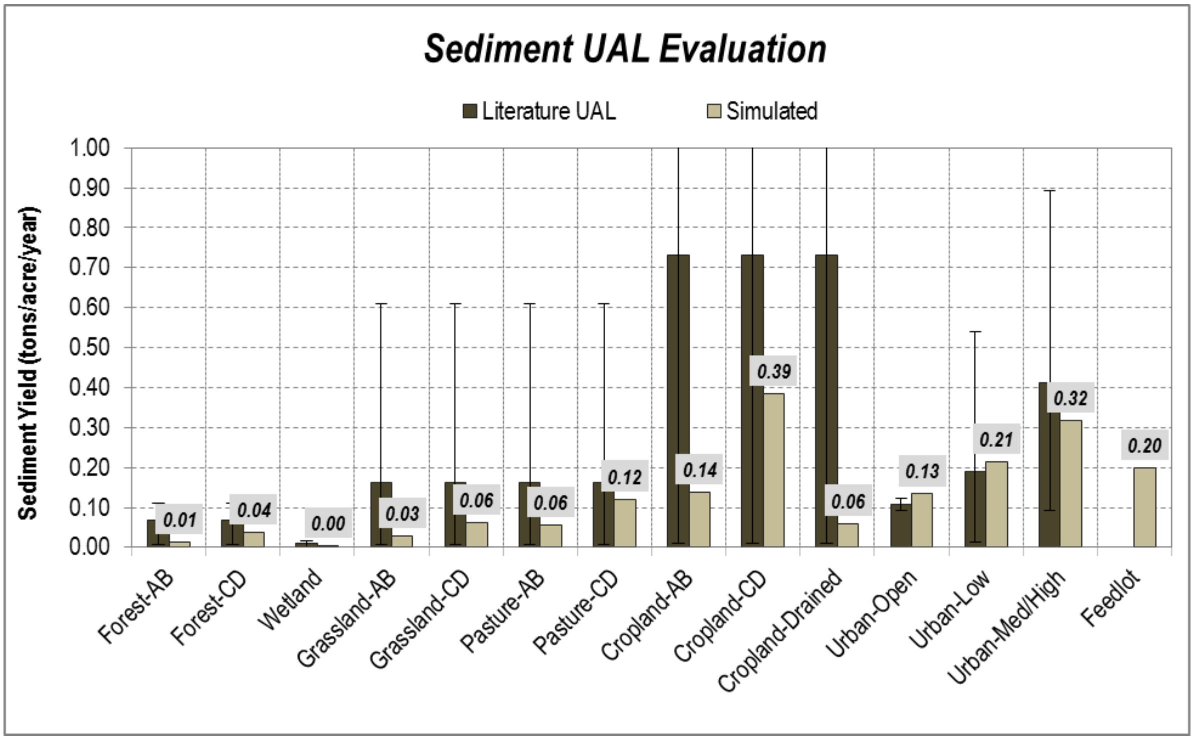

Figure 4-44. Area-weighted UALs for the ZRW HSPF model by land use type compared to literature averages (error bars represent minimum and maximum) (1996-2009).

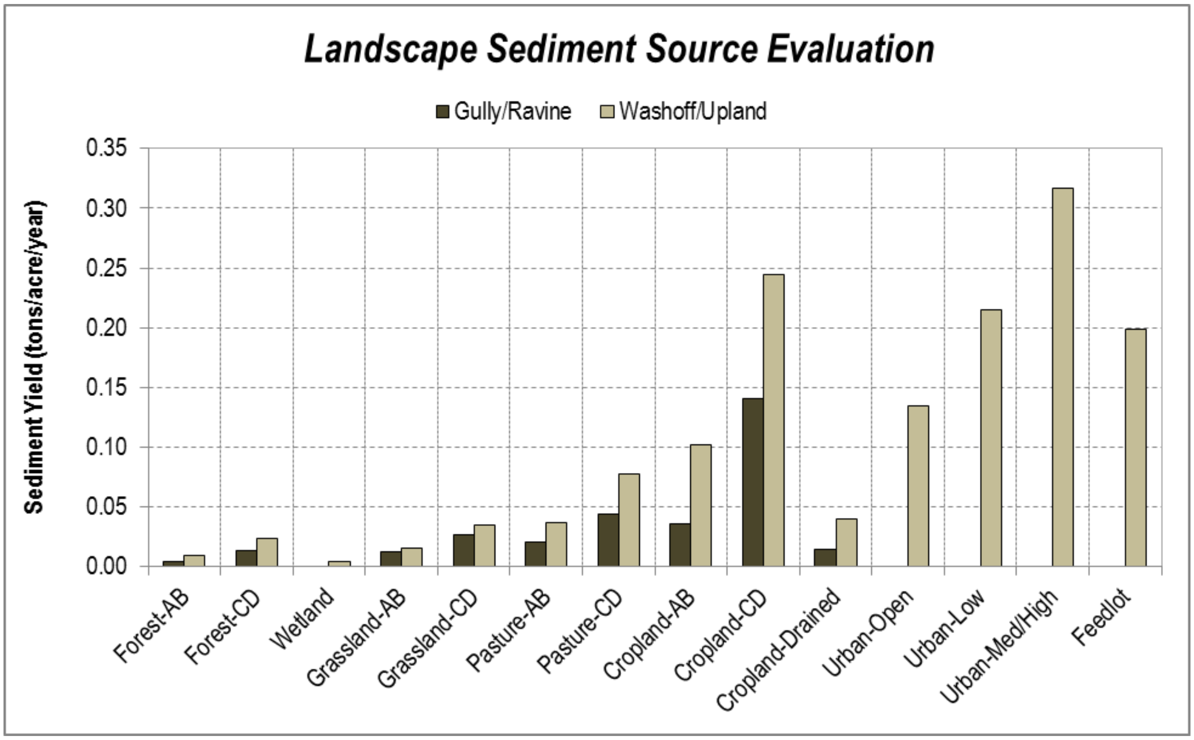

Figure 4-45. Relative contribution of gully/ravine erosion and washoff/upland erosion to UALs for the ZRW HSPF model by land use (1996-2009).

4.3.4 Sediment Source Apportionment

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

Upland sources contribute 42% of the sediment load for the entire watershed. This is slightly higher than the 30-40% range set in the sediment source apportionment memorandum developed by LimnoTech (2013g), but consistent with the observation in that memorandum that a larger percentage may be appropriate for the Zumbro River given the predominance of type “C” soils. The next highest sediment source is bed and bank erosion at 39% followed by gully and ravine erosion at 18%. Point sources and tile drainage contribute relatively small fractions to the overall sediment delivery. The 5 mg/L sediment concentration assigned to groundwater outflow contributed less than 0.01% of the sediment load watershed wide. A breakdown of the sediment sources is shown in Table 4-16 and Figure 4-46.

Table 4-16. Breakdown of sediment sources by major drainage area and for the entire ZRWHSPF model (1996-2009).

Drainage Area	Gully/Ravine	Upland	Tile Drains	Point Sources	Bed/Bank Erosion
South Fork	21%	52%	0.3%	0.4%	27%
Middle Fork	19%	42%	0.8%	0.0%	38%
North Fork	17%	50%	0.2%	0.1%	33%
Mainstem	14%	31%	0.0%	0.0%	55%
Entire Watershed	18%	42%	0.4%	0.1%	39%

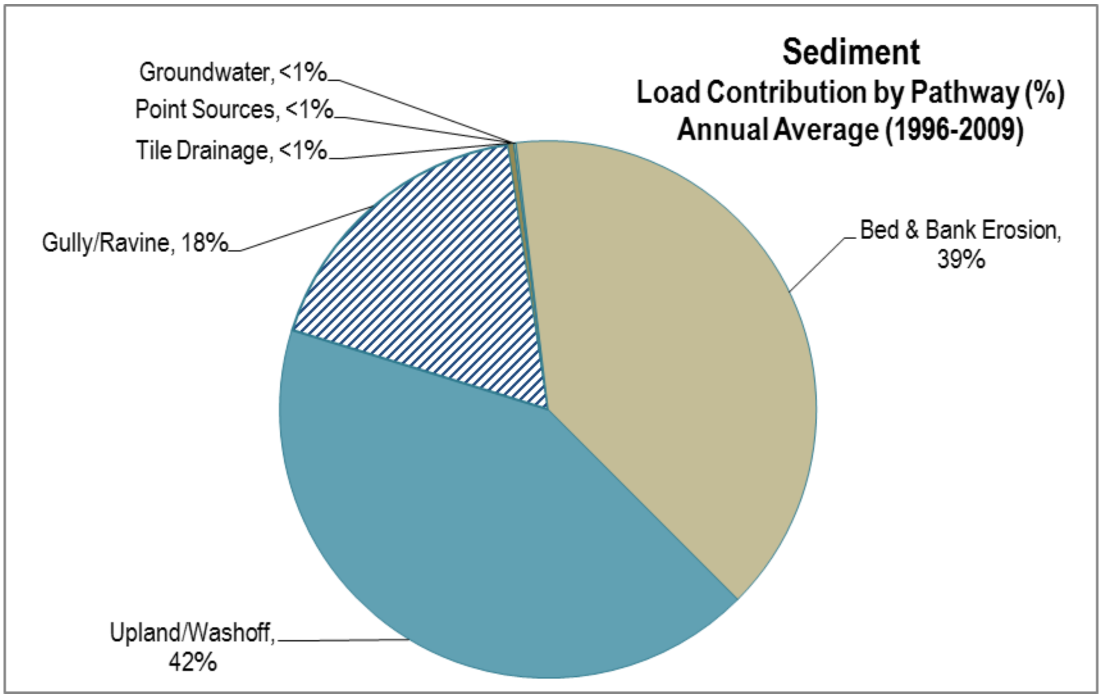

Figure 4-46. Breakdown of sediment sources for the ZRWHSPF model (1996-2009).

4.3.5 In-Stream Sediment Transport

The long-term Lake Zumbro sediment trapping efficiency was simulated as 33%, which is within the target range of 30-40%. Trapping efficiency for the storage reservoirs ranged from 22-33%. The trapping efficiency for Rice Lake was higher at 70%, but this is probably a reasonable number given the relatively small drainage area of the lake and long residence time of water that flows through the impoundment. The majority of the remaining stream reaches were simulated as net erosional over the entire simulation period, with the highest erosion rates observed in headwater reaches. The average annual change in bed depth over the entire simulation period is shown for all reaches in Figure 4-47. 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 4-47 do not necessarily suggest 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.

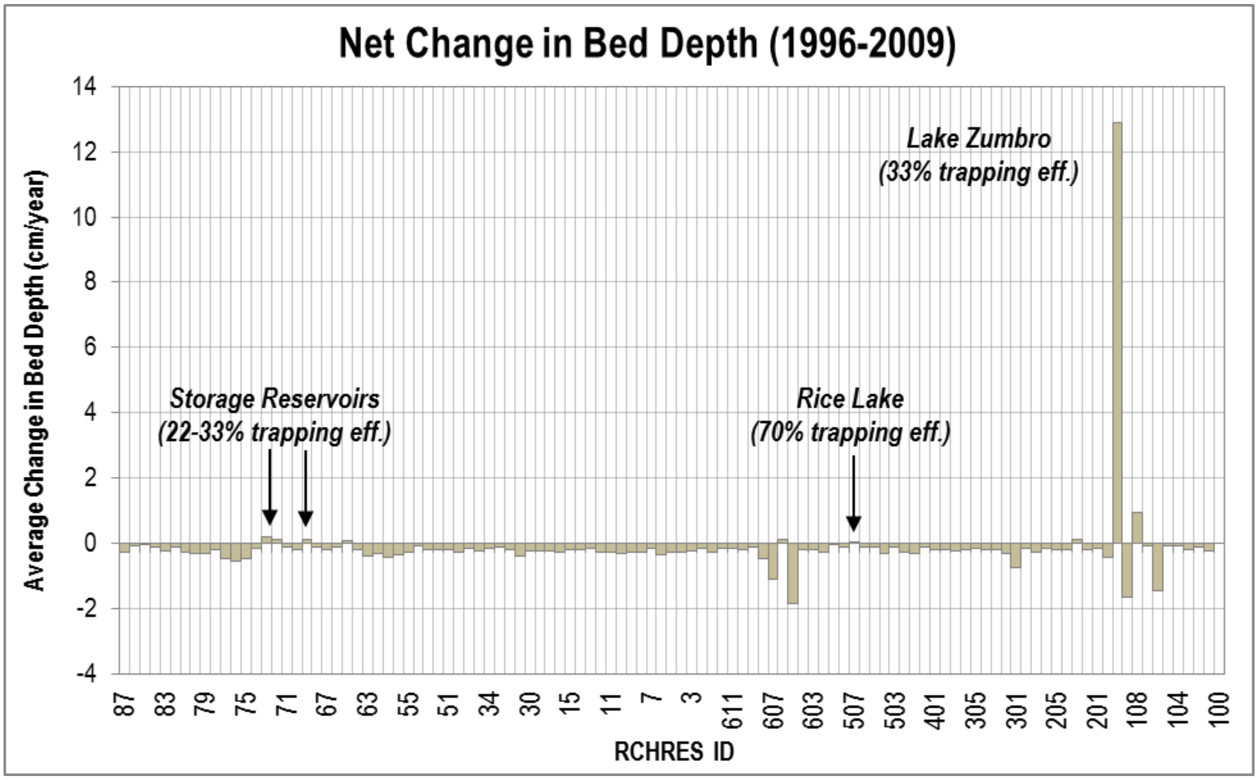

Figure 4-47. Average annual change in bed depth for all reaches in the ZRW HSPF model (1996-2009).

4.3.6 Sediment Calibration

The average annual suspended sediment load simulated at the Zumbro River at Kellogg was 161,000 tons/year for the calibration period (2004-2009), which is within the 124,000-167,000 tons/year calibration target for TSS. A comparison of the simulated annual sediment loads and the annual suspended solids loads calculated from the Zumbro River at Kellogg DAR streamflow and linear regression-derived TSS concentrations is shown in Figure 4-48. PBIAS for the calibration period falls within the “very good” range (-7.7%), and the relative percent difference is “fair” (-36%). The use of DAR-derived streamflow provides only a rough estimate of the streamflow for the Zumbro River at Kellogg, and TSS concentration data for high flow conditions were generally lacking, which tends to result in greater uncertainty in the regression model estimates for higher flow years. These uncertainties must be kept in mind when comparing the loads in Figure 4-48, especially for the higher flow years, which show a larger difference between “observed” and “simulated”. Comparisons of simulated daily average TSS concentrations and observed TSS concentrations from MPCA grab samples and continuous turbidity measurements for the Zumbro River at Kellogg station are shown in Figure 4-49. Time series plots comparing simulated and observed TSS concentrations for the additional calibration stations listed in Table 4-15 are provided in Appendix B.

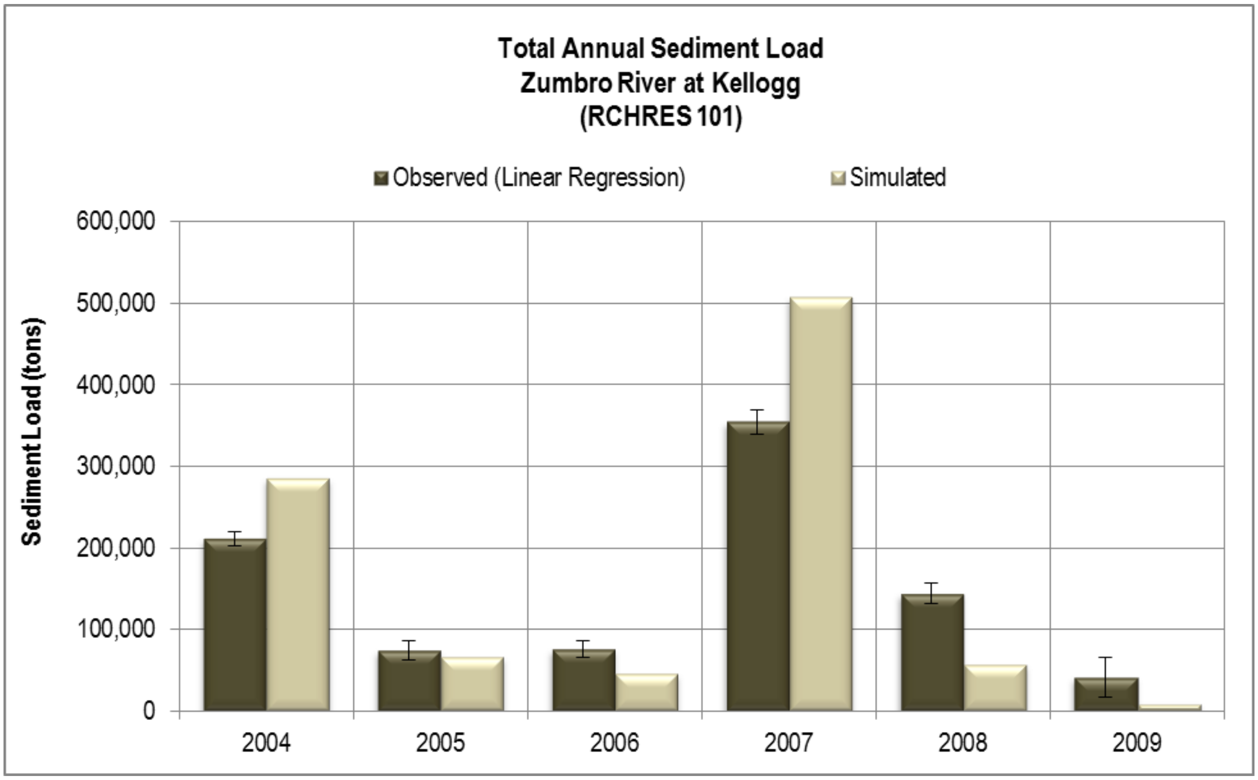

Figure 4-48. Total annual simulated sediment load for the Zumbro River at Kellogg compared with loads estimated from the Zumbro River at Kellogg DAR streamflow and linear regression-derived TSS concentrations (error bars represent the 95% confidence interval) (2004-2009).

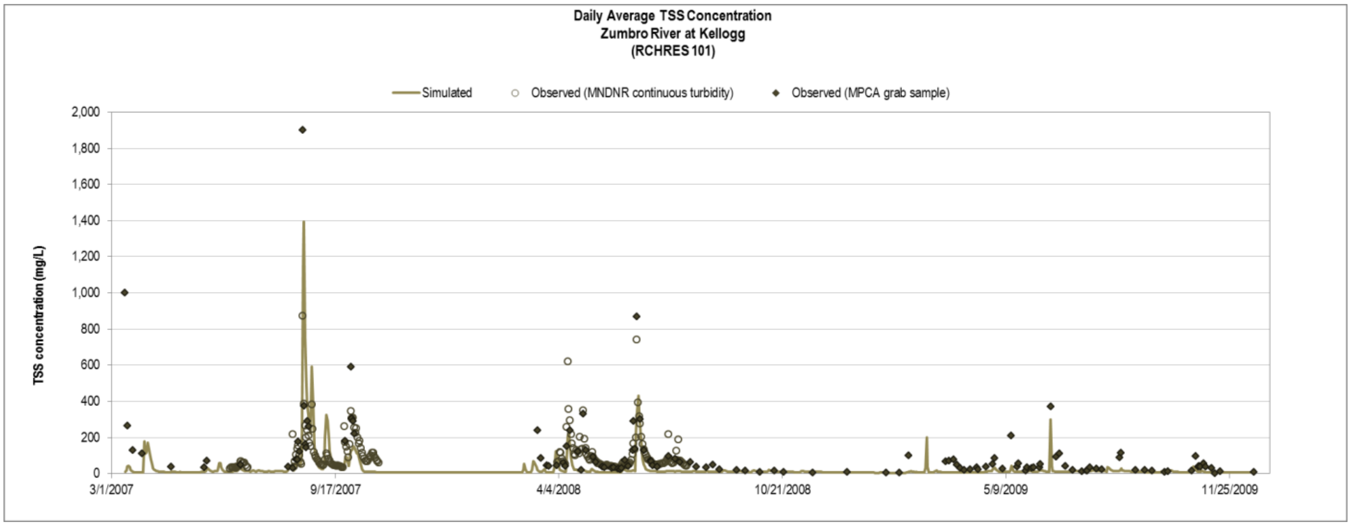

Figure 4-49. Daily average total suspended solids concentrations for the Zumbro River at Kellogg (2007-2009).

4.3.7 Sediment Validation

Limited TSS concentration data were available for the validation period (1996-2003). The average annual sediment load simulated at the Zumbro River at Kellogg was 147,000 tons/year for the validation period (1996-2003), which is within the 124,000-167,000 tons/year target for total suspended solids. A comparison of the simulated annual sediment loads and the annual suspended solids loads calculated from the Zumbro River at Kellogg DAR streamflow and linear regression-derived TSS concentrations is shown in Figure 4-50. The relative percent difference for the validation period is "good" (20.5%).

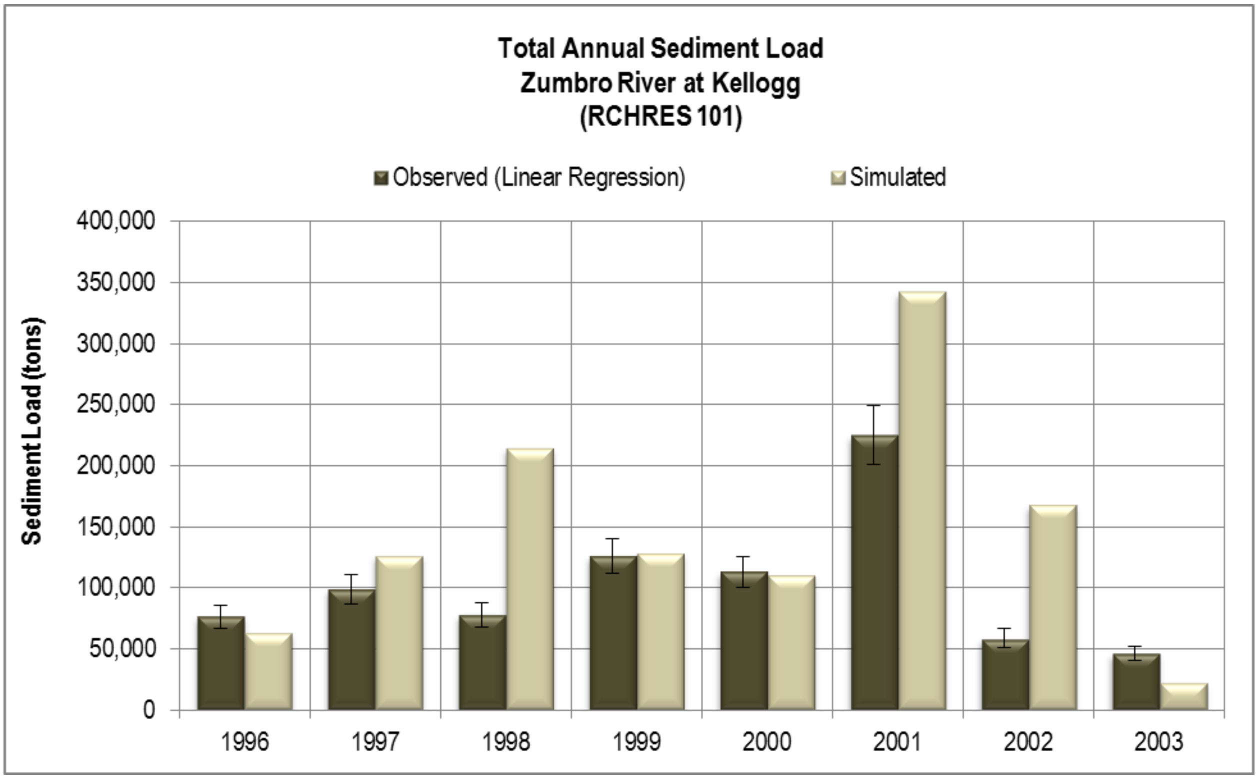

Figure 4-50. Total annual simulated sediment load for the Zumbro River at Kellogg compared with loads estimated from the Zumbro River at Kellogg DAR streamflow and linear regression-derived TSS concentrations (error bars represent the 95% confidence interval) (1996-2003).

The ZRWHSPF 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 2006). Given the multiple lines of evidence examined, the ZRWHSPF 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 are provided in Appendix B. A complete set of statistics and plots have been provided as an electronic file 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 land side component of HSPF, soil temperatures can be simulated for the surface, upper, and lower/groundwater layers of a land segment, which impacts the temperature of the water transferred from the land side to a reach segment. 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 land side water temperatures in the surface flow, interflow, and groundwater flow are transferred to the reach segments where water temperature is simulated instream using an energy balance method.

Water temperature data at 15-minute intervals were available from the HYDSTRA gage locations for several stations and years (Table 4-17). Daily and hourly observations were calculated from the 15-minute interval data to support the model calibration. Additional grab data were available from the EDA database.

Table 4-17. Water temperature data used to support the ZRWHSPF model calibration and validation.

Station ID (HYDSTRA/EDA)	*HSPF Reach ID*	*Station Name*	*Temperature (Daily)*	
			Count of Records	*Period of Record*
H41043001 (S004-384)	**101**	**Zumbro River at Kellogg**	**382**	**2007-2009**
H41016001 (S004-486)	33	Milliken Creek	570	2007-2009
H41050001 (S001-572)	68	Silver Creek	293	2007-2008
H41051001 (S000-800)	71	Bear Creek	179	2007-2008
H41061001 (S004-385)	609	South Fork Zumbro River South of Rochester	158	2007-2008
H41064001 (S001-354)	64	Cascade Creek	64	2007-2008
H41067001 (S001-729)	304	Middle Fork Zumbro River at Pine Island	255	2007-2008
W41049001 (S003-802)	601	South Fork Zumbro River at 90th Street	453	2007-2009
(S000-268)	602	Zumbro River South Fork at CSAH-14, 3 Mi N of Rochester	273	1996-2009

**The station in bold denotes primary watershed outlet station (Zumbro River at Kellogg)*

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). 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; steam 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 watershed outlet calibration station, Zumbro River at Kellogg. 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 4-18 and Figures 4-51 to 4-53). Additional water temperature calibration plots are provided in Appendix C. A complete set of statistics and plots have been provided as an electronic file with the deliverable package.

Table 4-18. Summary statistics for the water temperature HSPF model calibration (2004-2009) at the watershed outlet, Zumbro River at Kellogg and validation (1996-2003) at the South Fork Zumbro River at CSAH-14.

Time Interval	*Statistic*	*Zumbro at Kellogg*	*South Fork Zumbro River at CSAH-14*
Annual	*Count*	3	8
	R-Squared	0.99	0.97
	Nash-Sutcliffe Efficiency	0.95	0.79
	Relative Percent Difference	-1.7%	-6.3%
	Relative Percent Error	-1.7%	-6.0%
Monthly	*Count*	16	41
	R-Squared	0.97	0.94
	Nash-Sutcliffe Efficiency	0.95	0.91
	P-Bias	1.1%	3.2%
	Relative Percent Difference	-1.8%	-4.3%
	Relative Percent Error	-1.7%	-3.9%
Daily	*Count*	382	43
	R-Squared	0.95	0.94
	Nash-Sutcliffe Efficiency	0.90	0.90
	Relative Percent Difference	-2.8%	-4.2%
	Relative Percent Error	-2.6%	-3.8%

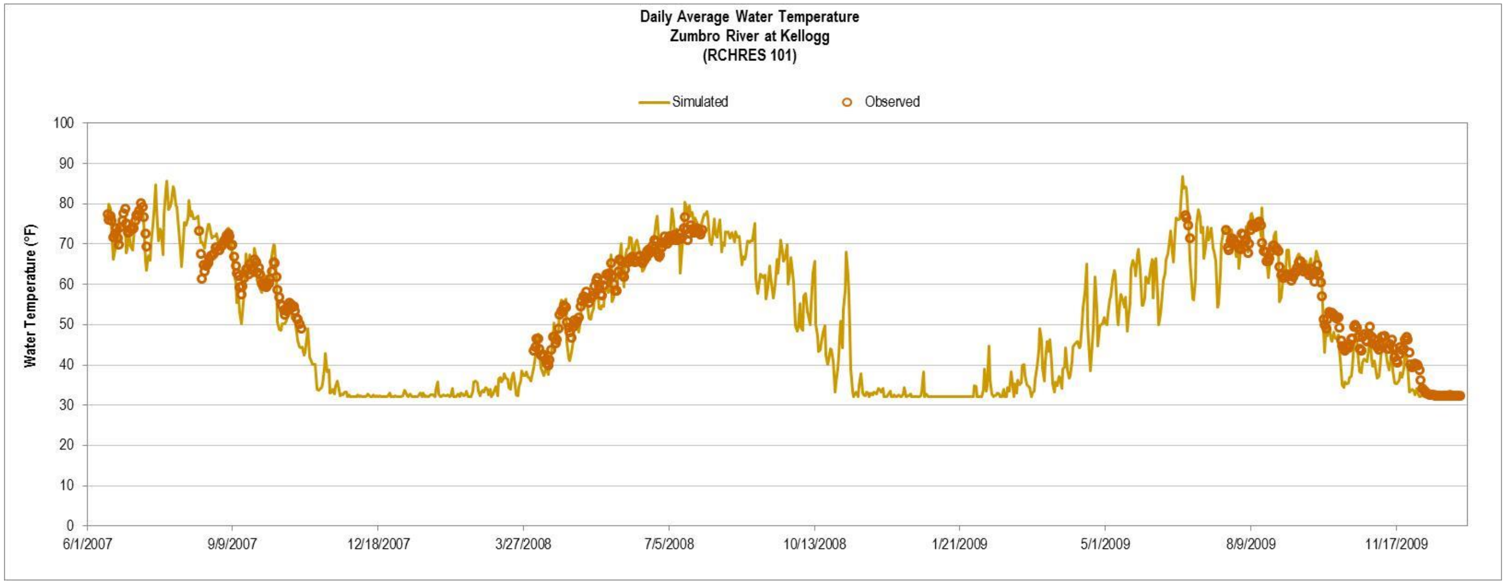

Figure 4-51. Daily Average Water Temperatures for Zumbro River at Kellogg (RCHRES 101).

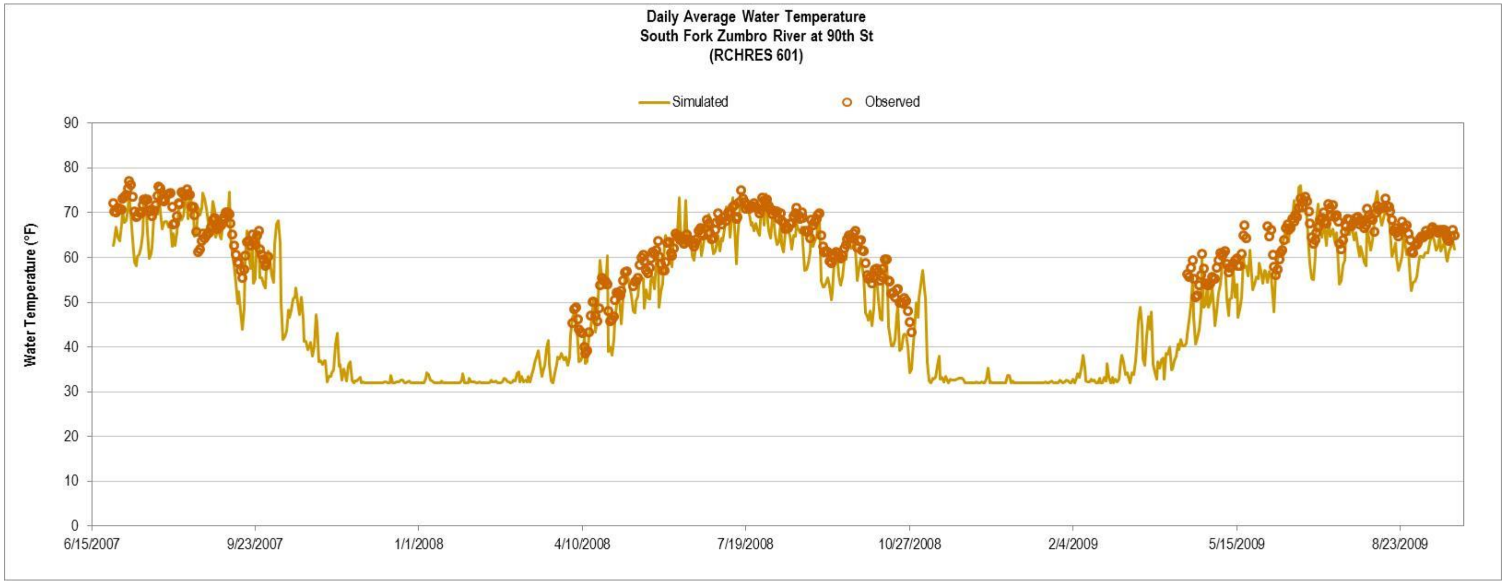

Figure 4-52. Daily Average Water Temperatures for South Fork Zumbro River at 90th Street (RCHRES 601).

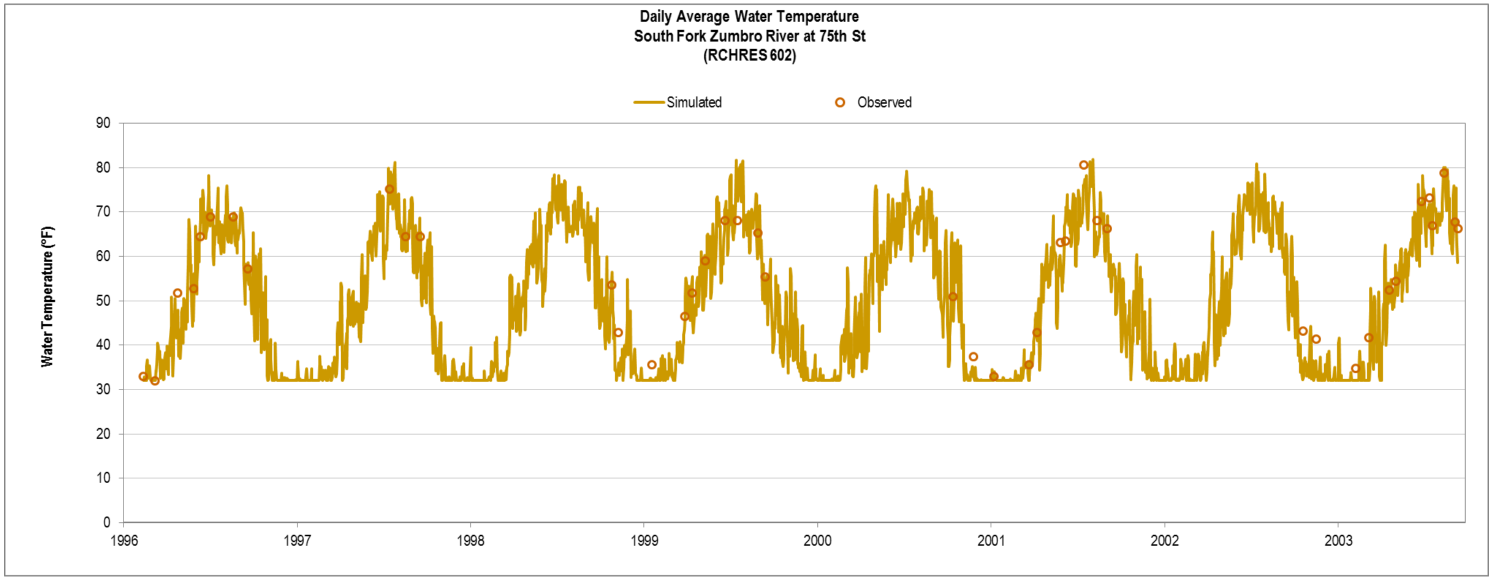

Figure 4-53. Daily Average Water Temperatures for South Fork Zumbro River at 75th Street (RCHRES 602).

4.5 Nutrients

The general quality constituent approach was taken to simulate nutrient loading from the land side of the Zumbro 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 ZRWHSPF 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 land side transport pathways for the nutrients, modeled as general quality constituents, 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 land side to the reach segment. The partitioning of nutrients represented in the ZRWHSPF 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 sorbed on 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 ZRWHSPF 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):

1. Estimate all model parameters, including land use specific accumulation and depletion/removal rates, washoff rates, and subsurface concentrations.
2. 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.
3. Compare simulated and observed instream concentrations at each of the calibration stations.
4. 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 was carried out simultaneously with the simulation 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 either spatial 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.

4.5.1 Phosphorus

Orthophosphate and BOD (as organic matter) are simulated using the sediment potency method on pervious surfaces and are simulated 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 loads fell within reasonable limits of reported literature ranges and other

Minnesota HSPF models (Tetra Tech 2009), adjusting various instream parameters within reported literature ranges, and then comparing the model to instream orthophosphate and TP concentration data. In addition, a daily time series of target TP loads was estimated at the watershed outlet (Zumbro River at Kellogg) using LOADEST (Runkel et al. 2004, Runkel 2013) based on the available streamflow (USGS) and TP concentration data. 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 ZRWHSPF model at the watershed outlet (i.e., Zumbro River at Kellogg). 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 orthophosphate and TP concentrations at daily time scales.

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). For pervious land segments, both the washoff potency factor (POTFW) and the scour potency factor (POTFS) 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).

After adjustments were made to the land side, the instream concentrations were reviewed to evaluate predicted concentrations during low flows and storm events. Once the land side UALs were within reasonable ranges compared to the available literature and other Minnesota HSPF models (Tetra Tech 2009), the instream simulation was refined through the adjustment of organic matter settling rates, bottom sediment concentrations of phosphorus and ammonium, and the growth and death of phytoplankton and benthic algae.

Once a best possible calibration was achieved, the final TP UALs were calculated for each land segment category (Figure 4-54) and a final comparison was performed against the available literature values as well as the UALs predicted from the Minnesota River HSPF model (Table 4-19) (Tetra Tech 2009). The TP UALs generated by the ZRWHSPF model are consistent with the available literature and, more importantly, the Minnesota River HSPF model (which is representative of regional UALs).

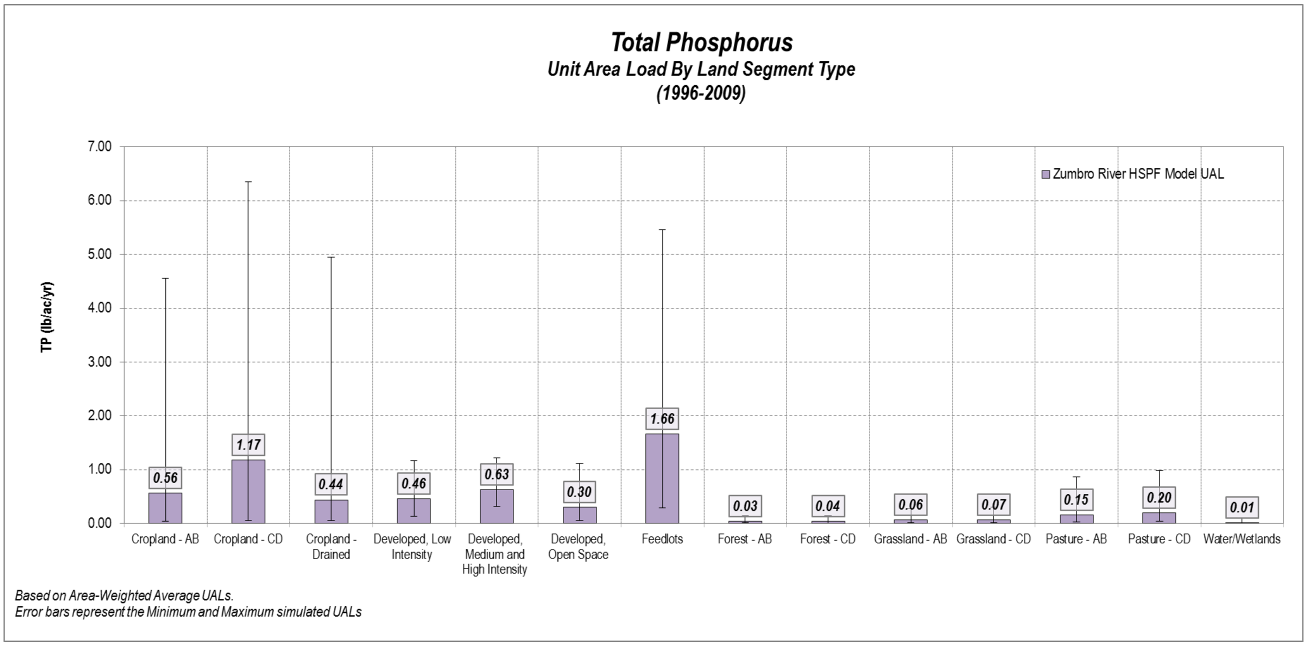

Figure 4-54. Total phosphorus unit area loads by land segment type for the 1996-2009 simulation period.

Table 4-19. 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

In general, the calibration for TP ranges from “good” to “very good” based on statistical and visual comparisons of observed and simulated TP concentrations and loads (Table 4-20 and Figures 4-55 to 4-57). Validation data were not available at the Zumbro River at Kellogg station; however, data were available at the South Fork Zumbro River at 75th Street station. The validation ranged from “fair” to “good” for this station (Table 4-20 and Figures 4-58 to 4-59).

Table 4-20. Summary statistics for the total phosphorus HSPF model calibration (2004-2009) at the watershed outlet, Zumbro River at Kellogg and validation (1996-2003) at South Fork Zumbro River at 75th Street.

Time Interval	Statistic	Calibration		Validation	
		Zumbro at Kellogg (Concentration)	Zumbro at Kellogg (Load)	South Fork at 75th Street (Concentration)	South Fork at 75th Street (Load)
Annual	Count	3	3	4	5
	Relative Percent Difference	-22.4%	-19.8%	33.9%	67.5%
Monthly	Count	29	36	20	60
	Relative Percent Difference	-9.0%	-17.9%	27.3%	46.7%
Daily	Count	121	1096	29	1826
	Relative Percent Difference	-12.2%	-11.6%	22.2%	30.4%

Data were limited to evaluate statistics for orthophosphate. Most stations have fewer than 30 samples for the calibration period, and no stations had data available for the model validation period. Based on the visual comparison of observed and simulated orthophosphate concentrations (Figure 4-60 and Appendix D), the ZRWHSPF model tends to overpredict orthophosphate. The largest discrepancies between the model and data appear to be associated with storm events. Given the limited data, it is not clear if the model is actually overpredicting orthophosphate during storm events or if the data do not capture the peak storm concentrations.

Several parameter adjustments were made to the orthophosphate parameters to reduce the possible overprediction of peak concentrations and included surface washoff of orthophosphate from the land side and the bed concentration of orthophosphate. These adjustments served to reduce the peak orthophosphate concentrations; however, the peak reductions resulted in a poorer overall fit for the TP simulation. In addition, any changes made to compensate for the reduced peak orthophosphate concentrations via an increase in the organic fraction in the TP simulation impacted the TN simulation. Based on the currently available orthophosphate dataset and the “good” to “very good” simulation of TP, the best and most reasonable orthophosphate calibration has likely been achieved. 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.

Using the weight of evidence evaluation approach, the model calibration and validation indicates that the ZRWHSPF model is able to simulate TP within a “good” to “very good” level of accuracy. For orthophosphate, given the current data limitations and uncertainties described above and the complexity of phosphorus transport behavior in the watershed, there is more uncertainty associated with the model predictions. Based on the available data, it appears that the model may overpredict orthophosphate. In order to support further refinement of the orthophosphate and TP simulation in the ZRWHSPF model, the following elements would be necessary: additional data collection (e.g., UALs, long-term instream data of both orthophosphate and TP at the same time and location, chlorophyll *a*); and potential refinement of the HSPF code to represent organic phosphorus and nitrogen as separate state variables to remove dependence on BOD and the user specified stoichiometric relationship that cannot represent the different C:N:P ratios for varying sources of organic matter (e.g., leaf litter, humus, wastewater treatment plant organic matter, phytoplankton, macrophytes, etc.).

Overall, the phosphorus calibration and validation resulted in achieving most of the model performance targets 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 ZRWHSPF 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 Zumbro River watershed.

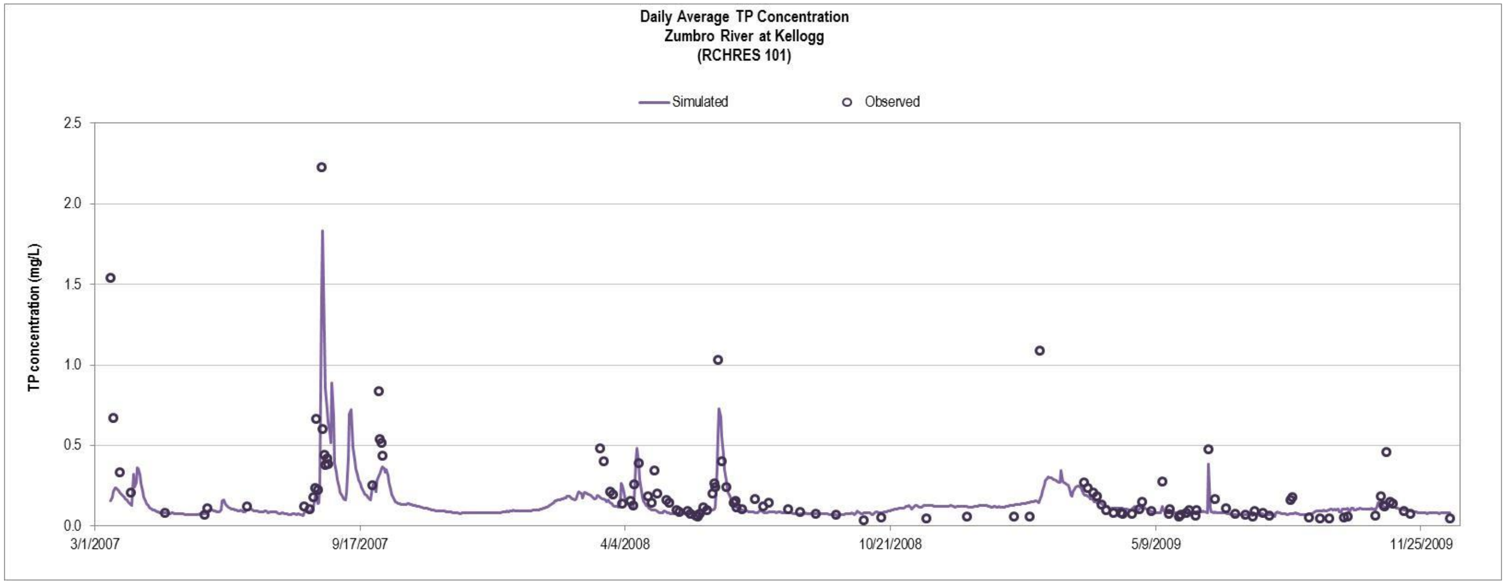

Figure 4-55. Daily Average Total Phosphorus Concentrations for Zumbro River at Kellogg (RCHRES 101).

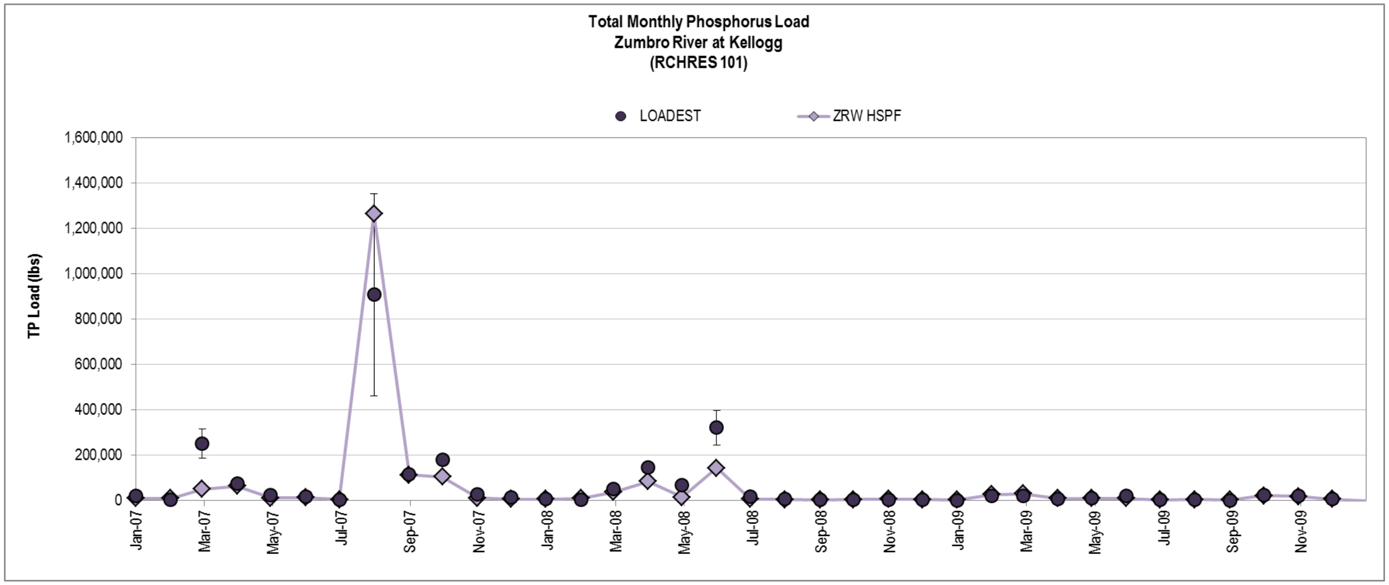

Figure 4-56. Monthly Total Phosphorus Load at Zumbro River at Kellogg (RCHRES 101).

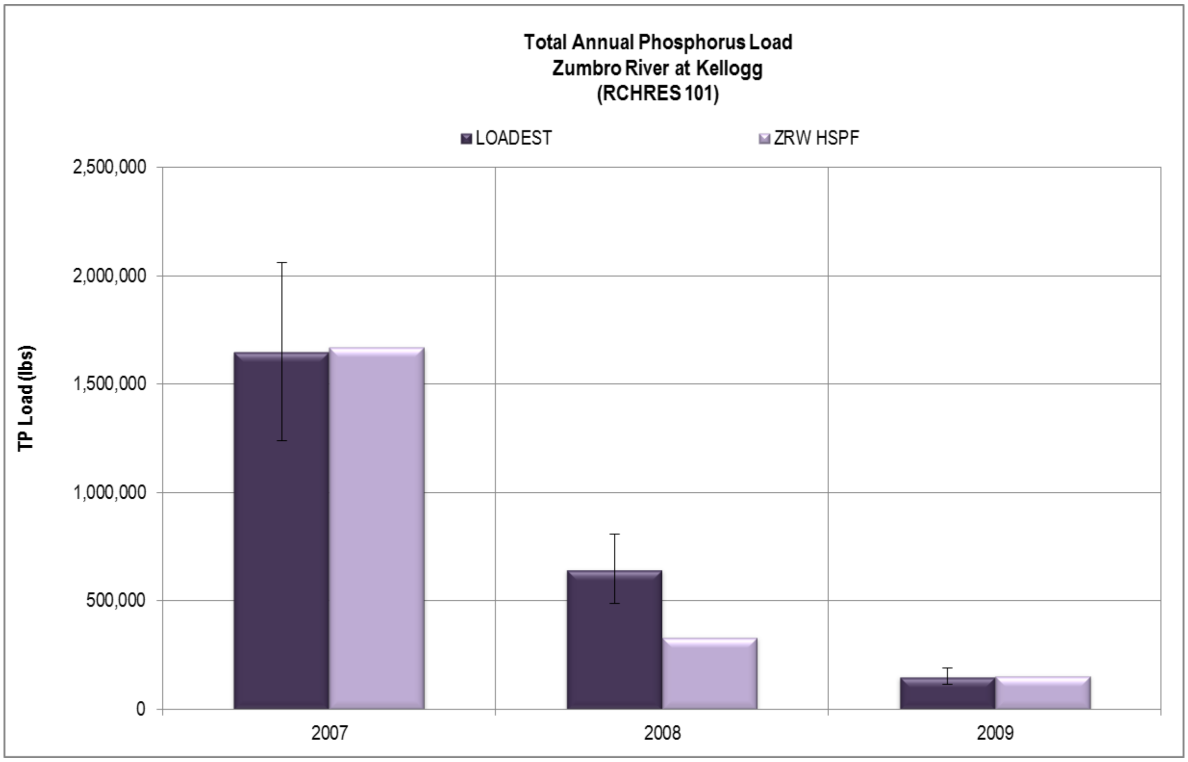

Figure 4-57. Annual Total Phosphorus Load at Zumbro River at Kellogg (RCHRES 101).

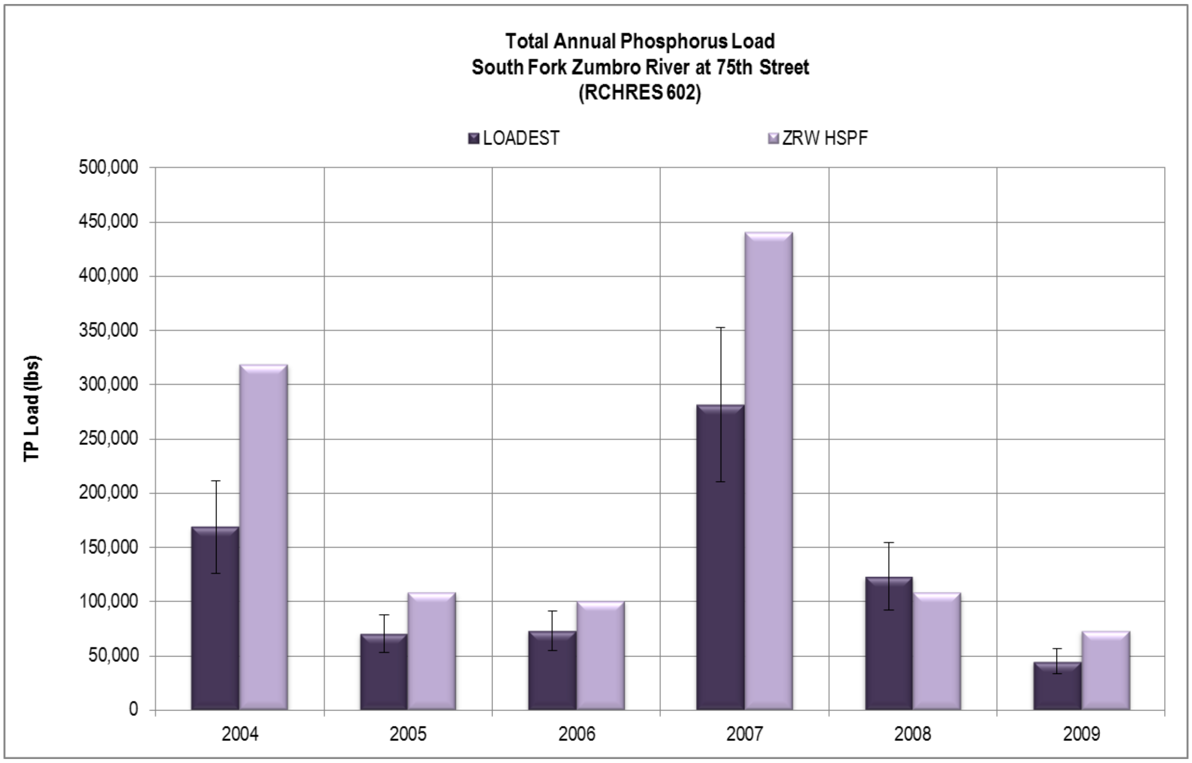

Figure 4-58. Annual Total Phosphorus Load at South Fork River Zumbro River at 75th Street (RCHRES 602).

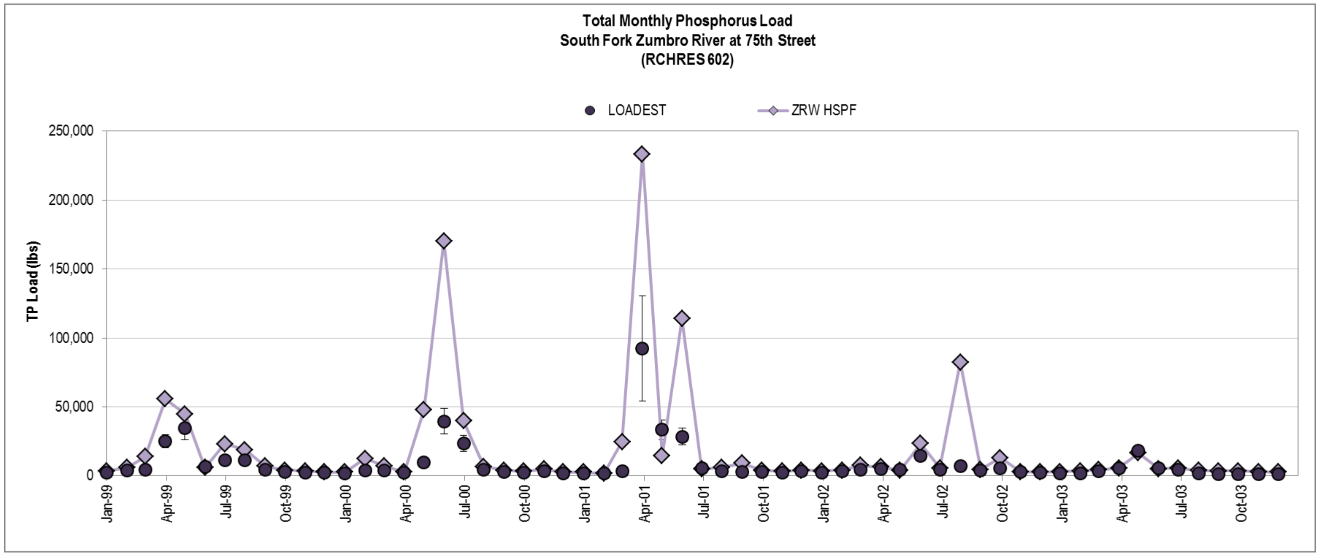

Figure 4-59. Monthly Total Phosphorus Load at South Fork River Zumbro River at 75th Street (RCHRES 602).

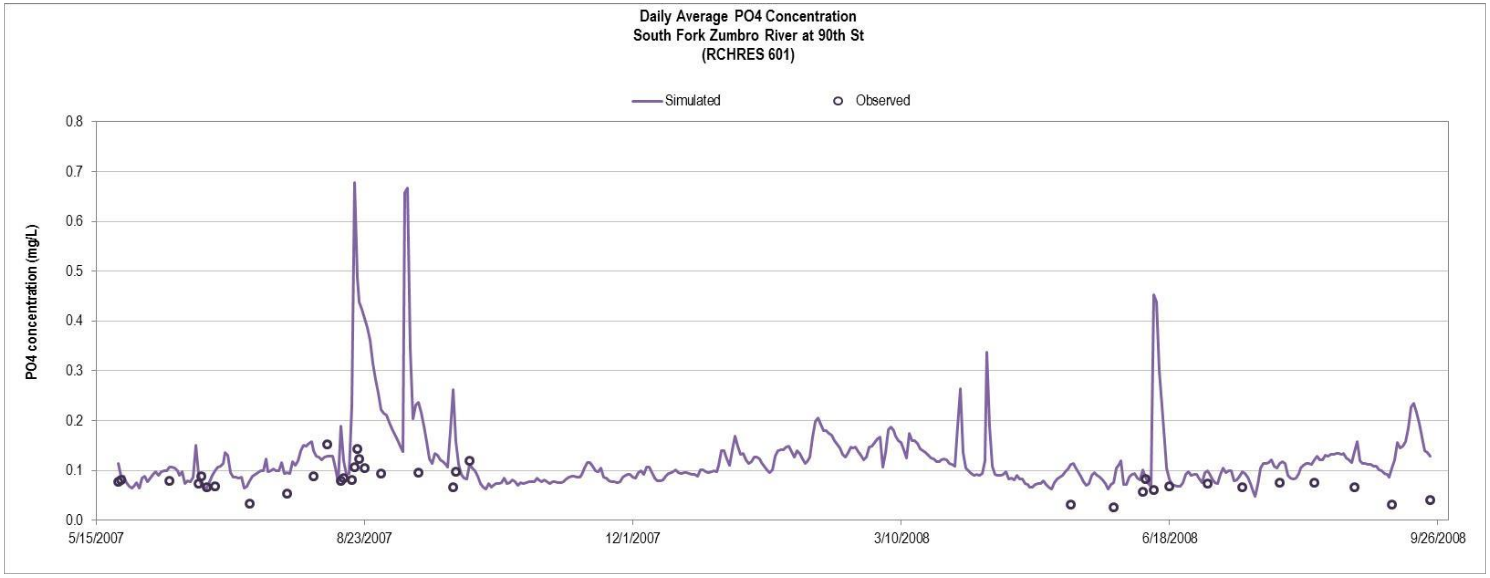

Figure 4-60. Daily Average Orthophosphate Concentrations for South Fork Zumbro River at 90th Street (RCHRES 601).

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 ZRWHSPF model. BOD (as organic matter) is simulated using the sediment potency method on 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 loads fell within reasonable limits of reported literature ranges and other Minnesota models (Tetra Tech 2009), 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, a daily time series of target TN loads were estimated at the watershed outlet (Zumbro River at Kellogg) using LOADEST (Runkel et al. 2004, Runkel 2013) based on the available streamflow (USGS) and TN data. 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.

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). Parameter adjustments were made to the rate of accumulation on the surface (ACQOP) and the maximum storage on the surface (SQOLIM) for 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), the instream simulation was refined through the adjustment of organic matter settling rates, bottom sediment concentrations of phosphorus (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 4-61) and a final comparison was performed against the available literature values as well as UALs predicted by the Minnesota River HSPF model (Table 4-21) (Tetra Tech 2009). The TN UALs generated by the ZRWHSPF model are consistent with the available literature and, more importantly, the Minnesota River HSPF model (which is representative of regional UALs).

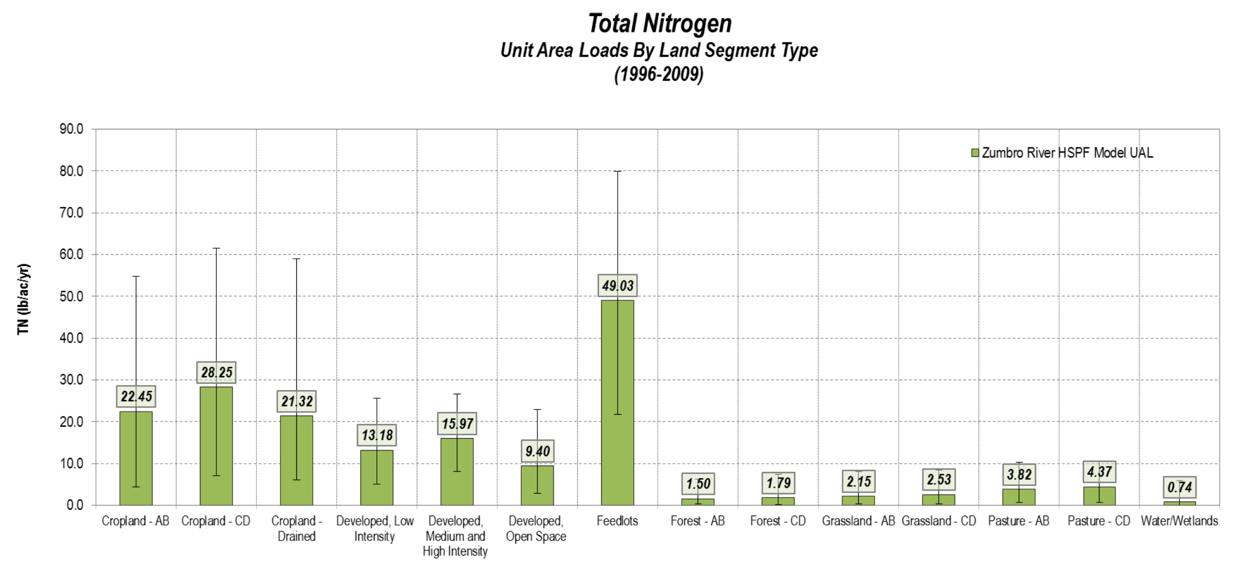

Figure 4-61. Total nitrogen unit area loads by land segment type for the 1996-2009 simulation period.

Table 4-21. 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

In general, the calibration of TN falls within the "very good" range based on statistical and visual comparisons of observed and simulated TN concentrations and loads (Table 4-22 and Figures 4-62 to 4-64). Validation data were not available for TN. The calibration and validation of nitrate plus nitrite ranges from "fair" to "very good" based on statistical and visual comparisons of observed and simulated nitrate plus nitrite concentrations (Table 4-23 and Figures 4-65). The calibration and validation of ammonia ranges from "fair" to "very good" based on statistical and visual comparisons of observed and simulated ammonia concentrations (Table 4-24 and Figures 4-66). 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 4-22. Summary statistics for the total nitrogen HSPF model calibration (2004-2009) at the watershed outlet, Zumbro River at Kellogg station.

Time Interval	Statistic	Zumbro at Kellogg (Concentration)	Zumbro at Kellogg (Load)
Annual	Count	3	3
	Relative Percent Difference	5.3%	-2.2%
Monthly	Count	27	36
	Relative Percent Difference	-2.7%	-2.9%
Daily	Count	97	1096
	Relative Percent Difference	2.6%	-3.4%

Table 4-23. Summary statistics for the nitrate plus nitrite HSPF model calibration (2004-2009) at the watershed outlet, Zumbro River at Kellogg station and validation (1996-2003) at the South Fork Zumbro River at 75th Street station.

Time Interval	Statistic	Calibration	Validation
		Zumbro at Kellogg (Concentration)	South Fork at 75th Street (Concentration)
Annual	Count	3	6
	Relative Percent Difference	26.8%	-41.1%
Monthly	Count	29	35
	Relative Percent Difference	7.1%	-30.5%
Daily	Count	119	35
	Relative Percent Difference	17.2%	-30.5%

Table 4-24. Summary statistics for the ammonia HSPF model calibration (2004-2009) and validation (1996-2003) at the South Fork Zumbro River at 75th Street station.

Time Interval	Statistic	Calibration	Validation
		South Fork at 75th Street (Concentration)	South Fork at 75th Street (Concentration)
Annual	Count	4	6
	Relative Percent Difference	-0.6%	3.5%
Monthly	Count	20	35

	Relative Percent Difference	-25.7%	-2.5%
Daily	*Count*	20	35
	Relative Percent Difference	-25.7%	-2.5%

Overall, the nitrogen calibration and validation resulted in achieving most of the model performance targets 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 ZRWHSPF 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 Zumbro River watershed.

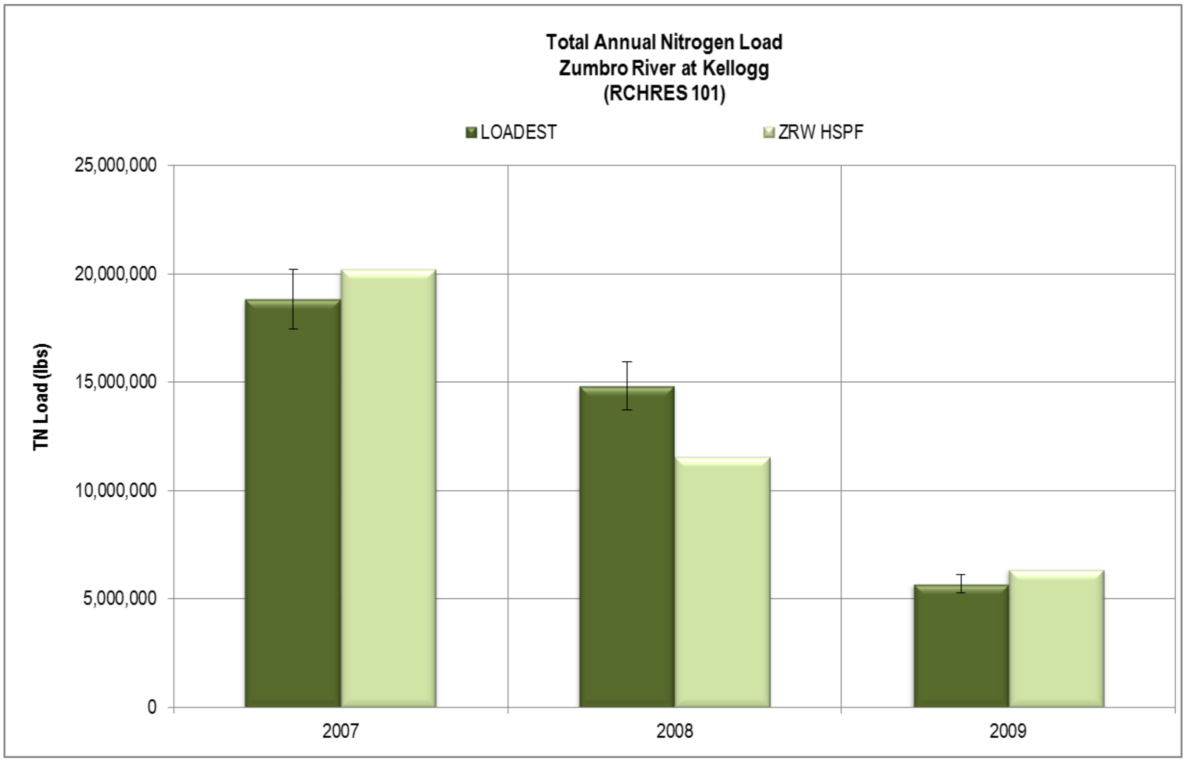

Figure 4-62. Annual Total Nitrogen Load at Zumbro River at Kellogg (RCHRES 101).

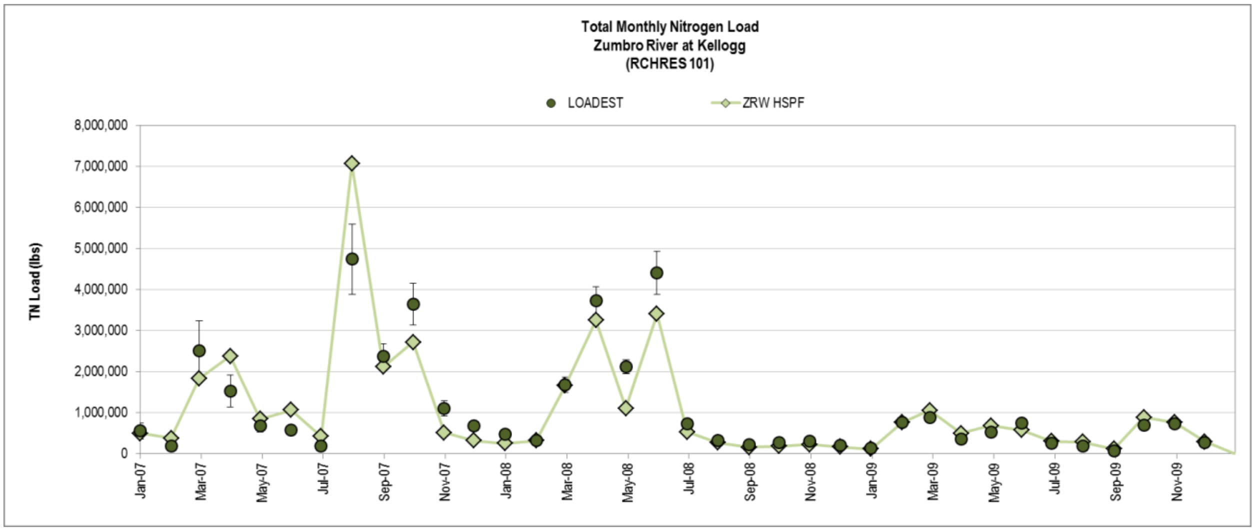

Figure 4-63. Monthly Total Nitrogen Load at Zumbro River at Kellogg (RCHRES 101)

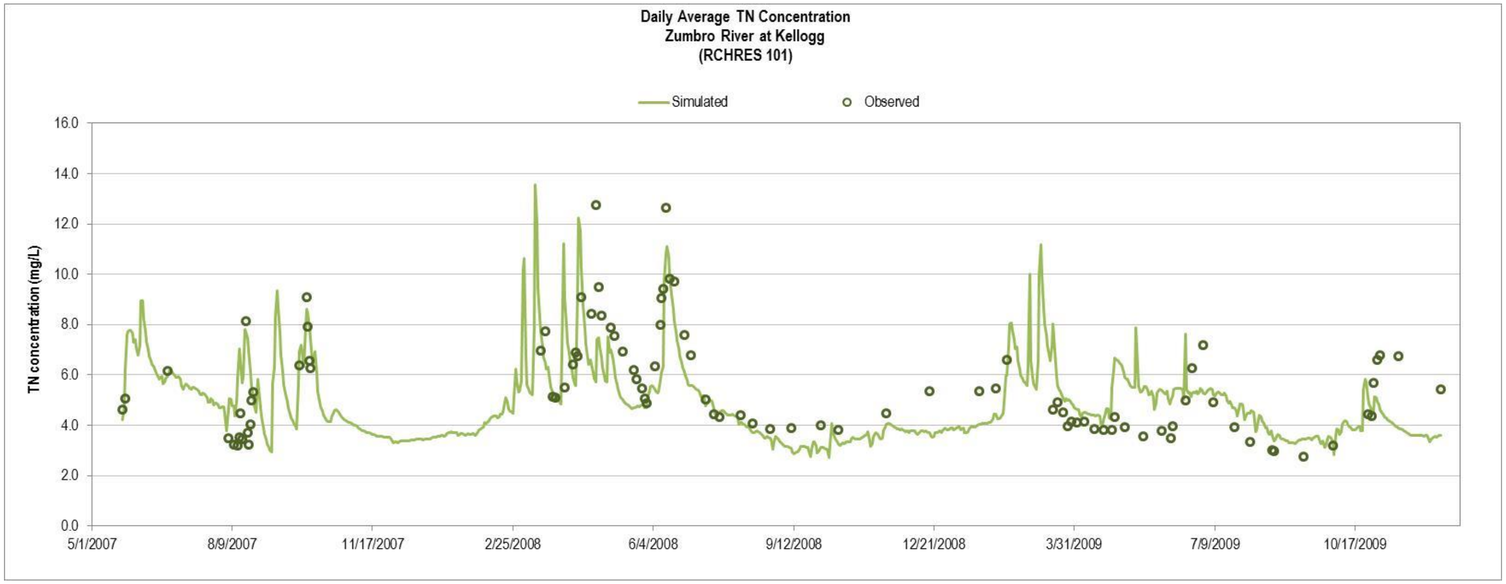

Figure 4-64. Daily Average Total Nitrogen Concentrations for Zumbro River at Kellogg (RCHRES 101).

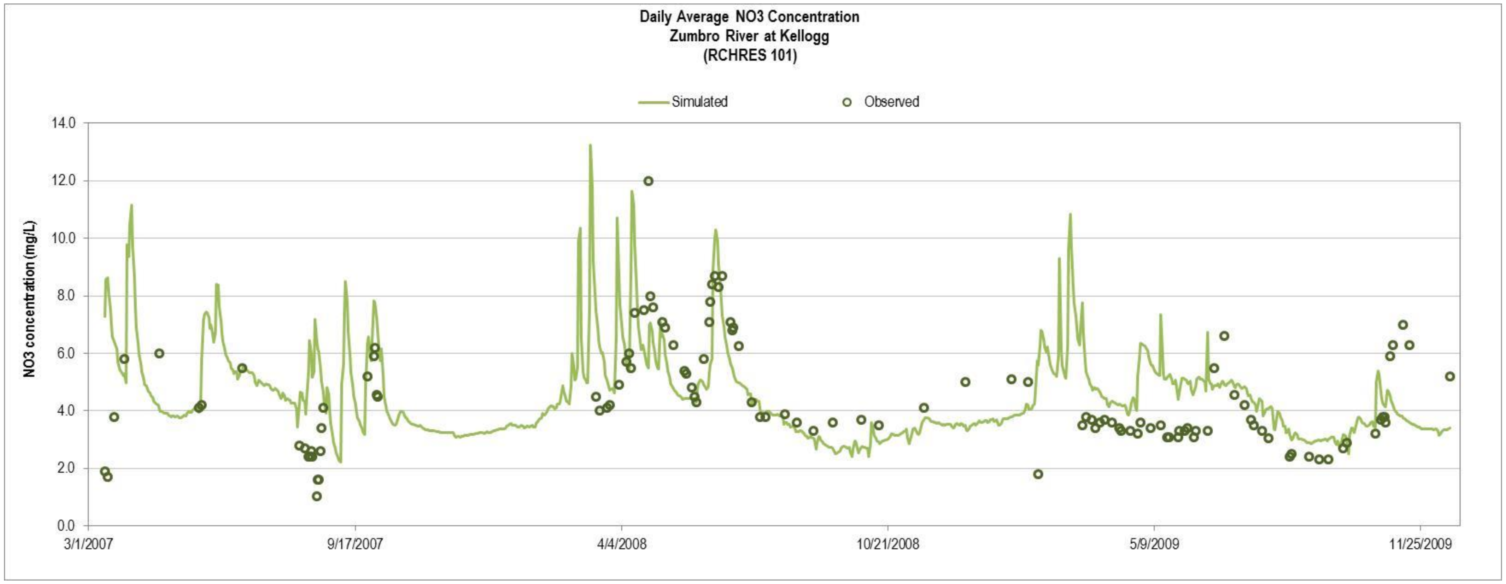

Figure 4-65. Daily Average Nitrate Concentrations for Zumbro River at Kellogg (RCHRES 101).

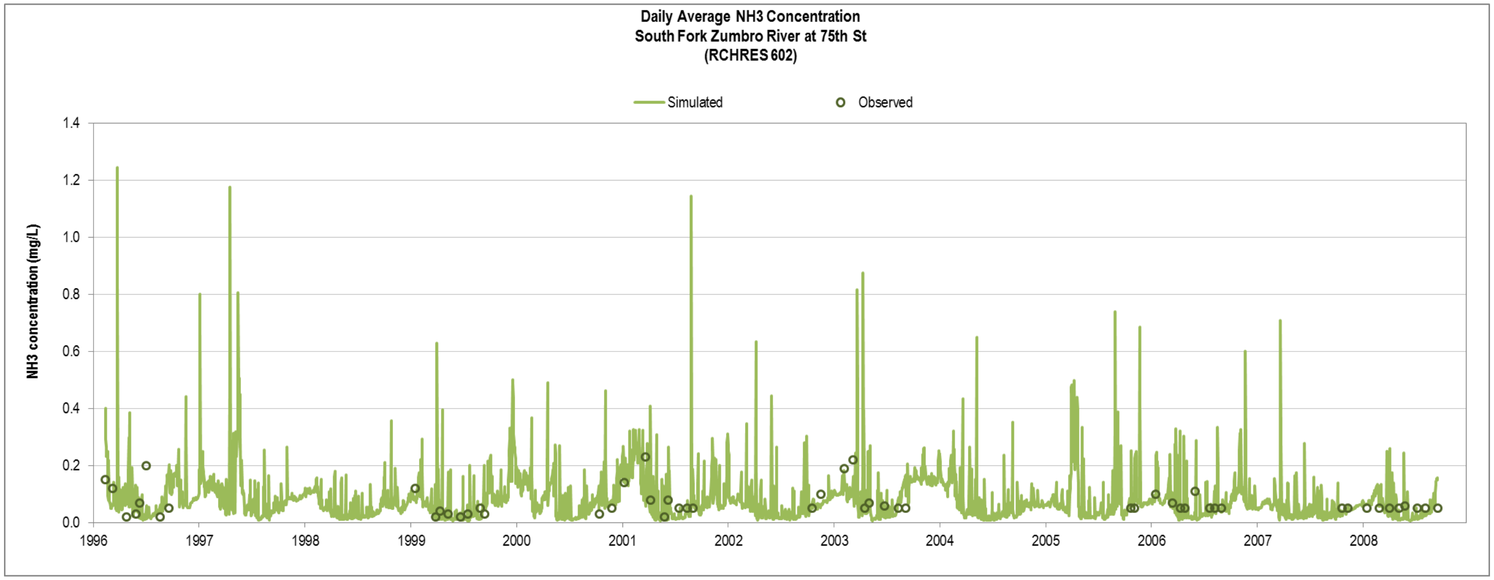

Figure 4-66. Daily Average Ammonia Concentrations for South Fork Zumbro River at 75th Street (RCHRES 602).

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). 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., South Fork Zumbro River at 75th Street had the most data with 16 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 to ensure reasonable BOD concentrations are predicted by the ZRWHSPF model (Figures 4-67 and 4-68).

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 watershed outlet calibration station, Zumbro River at Kellogg. Overall, the calibration of DO resulted in “very good” model performance based on statistical and visual comparison of observed and simulated DO (Table 4-25 and Figure 4-69). The validation of DO was limited as only one station had sufficient data for the evaluation of model performance (i.e., South Fork Zumbro River at 75th Street). 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 “good” model performance (Figure 4-70). A complete set of statistics and plots have been provided as an electronic file with the deliverable package.

Table 4-25. Summary statistics for the dissolved oxygen HSPF model calibration (2004-2009) at the watershed outlet, Zumbro River at Kellogg.

Time Interval	*Statistic*	*Zumbro at Kellogg*
Annual	*Count*	2
	Relative Percent Difference	1.12%
Monthly	*Count*	22
	Relative Percent Difference	3.67%
Daily	*Count*	71
	Relative Percent Difference	1.33%

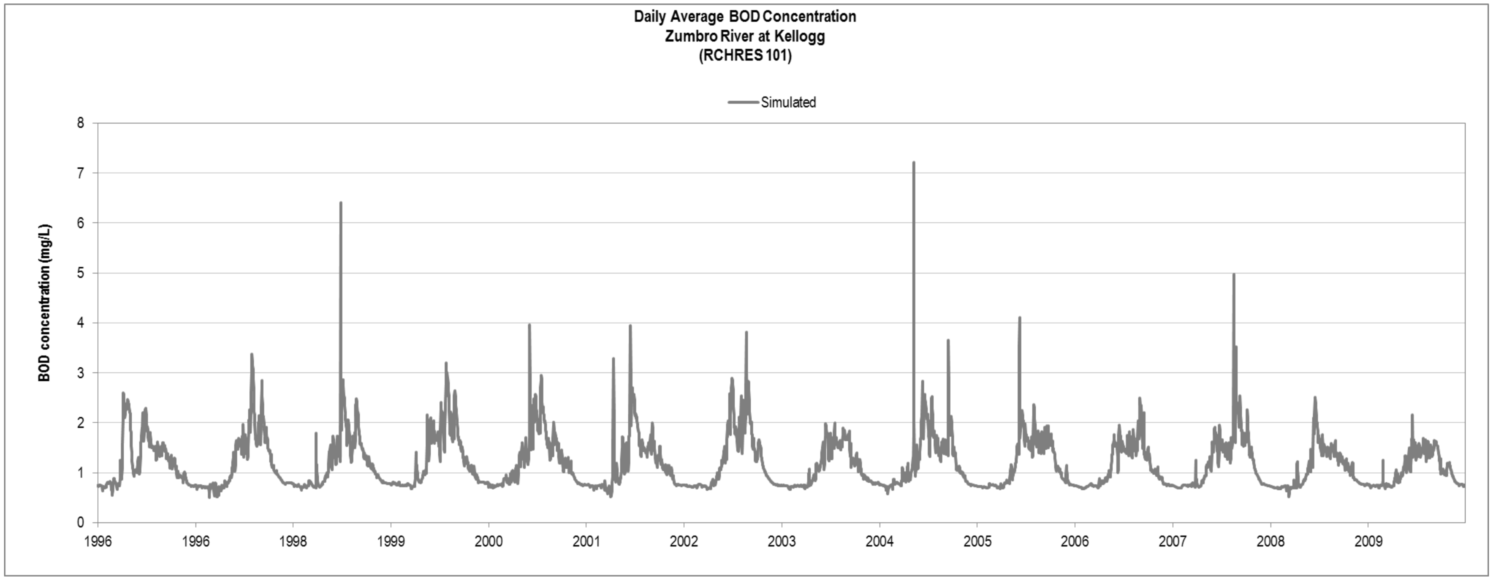

Figure 4-67. Daily Average BOD concentration at Zumbro River at Kellogg (RCHRES 101)

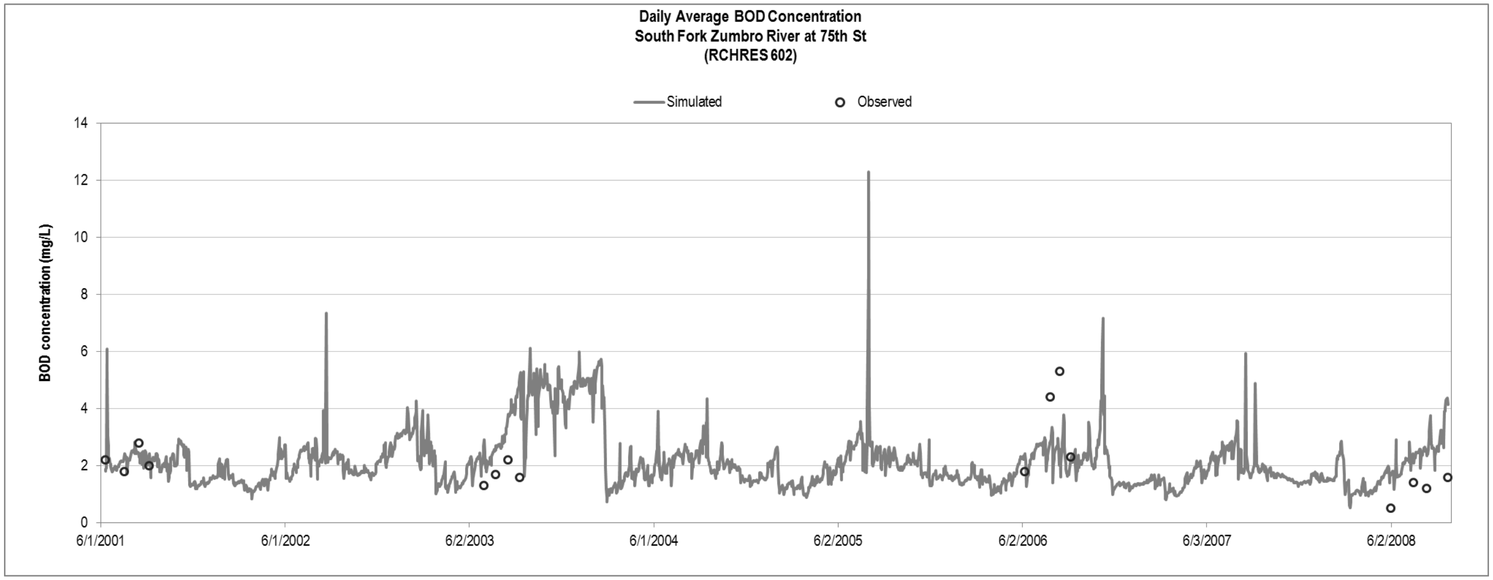

Figure 4-68. Daily Average BOD concentration at South Fork Zumbro River at 75th Street (RCHRES 602)

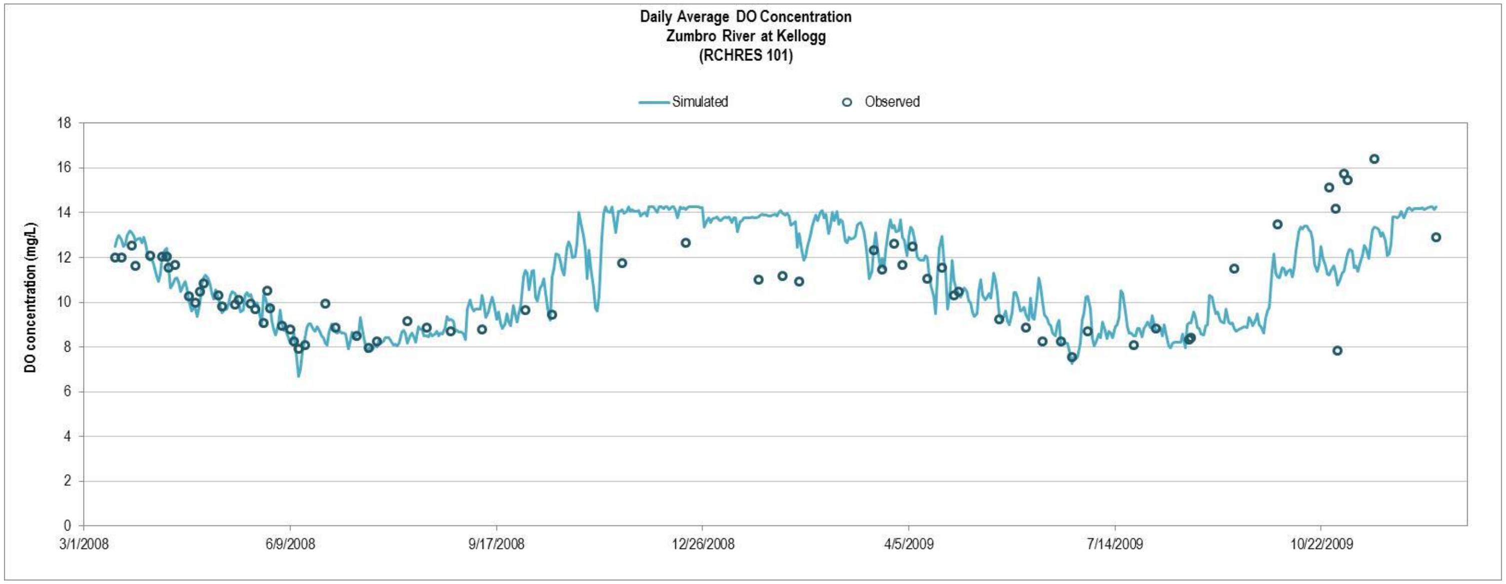

Figure 4-69. Daily Average Dissolved Oxygen Concentrations for Zumbro River at Kellogg (RCHRES 101).

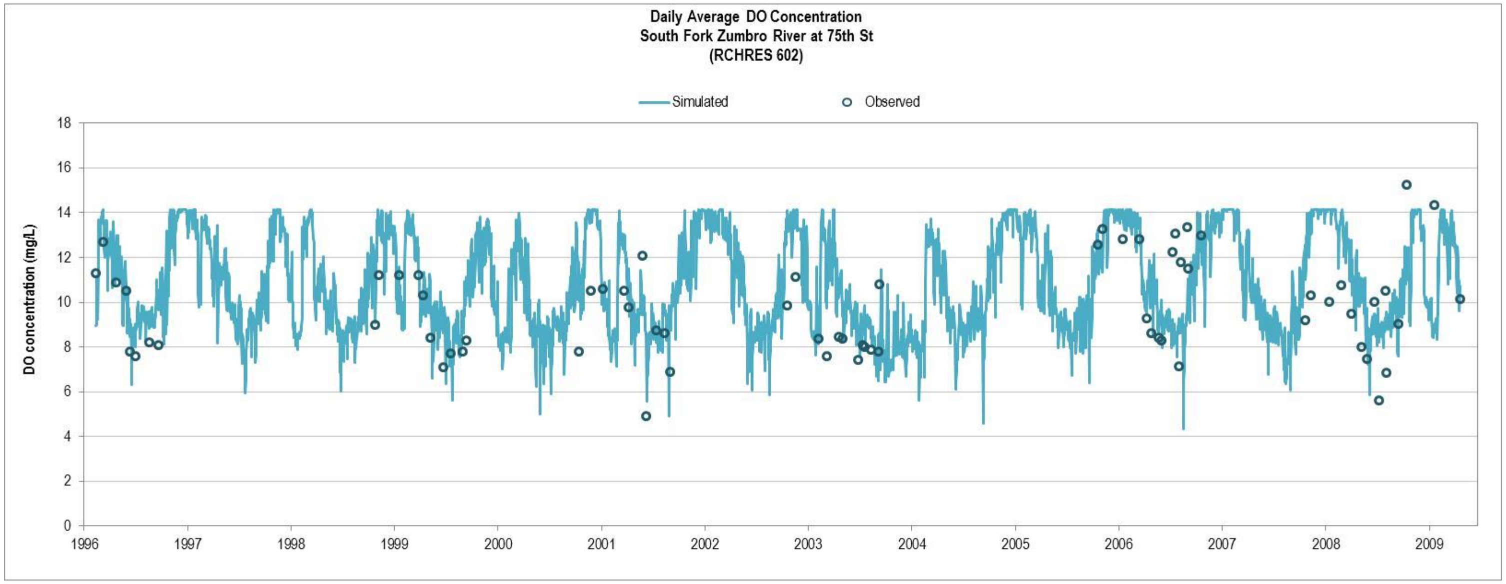

Figure 4-70. Daily Average Dissolved Oxygen Concentrations for South Fork Zumbro River at 75th Street (RCHRES 602)

4.7 Phytoplankton/Benthic Algae

A single phytoplankton group and a single benthic algae group are represented in the ZRWHSPF model. The phytoplankton processes represented in the ZRWHSPF 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). 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), the outflow at which the concentration of plankton is not subject to advection (OREF), and the rate of phytoplankton settling (PHYSET).

Phytoplankton chlorophyll *a* data were very limited to support model calibration and validation. The South Fork Zumbro River at 75th Street station had 16 samples available for the 2001-2008 time period. Lake Zumbro had a total of 71 samples; however, the samples were taken at varying depths and at different locations in the lake. The comparison of Lake Zumbro 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*. 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 ZRWHSPF model (Figures 4-71 to 4-74). 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 Zumbro, 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 to simulate 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.

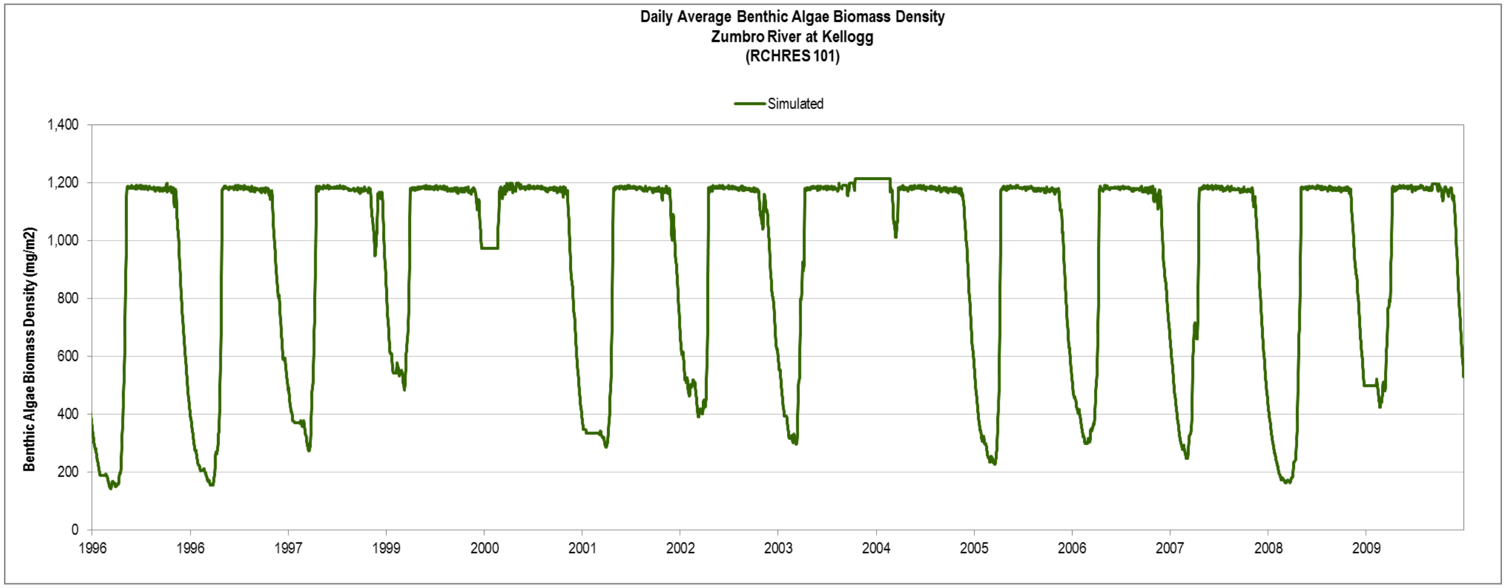

Figure 4-71. Daily Average Benthic Algae Biomass Density for Zumbro River at Kellogg (RCHRES 101)

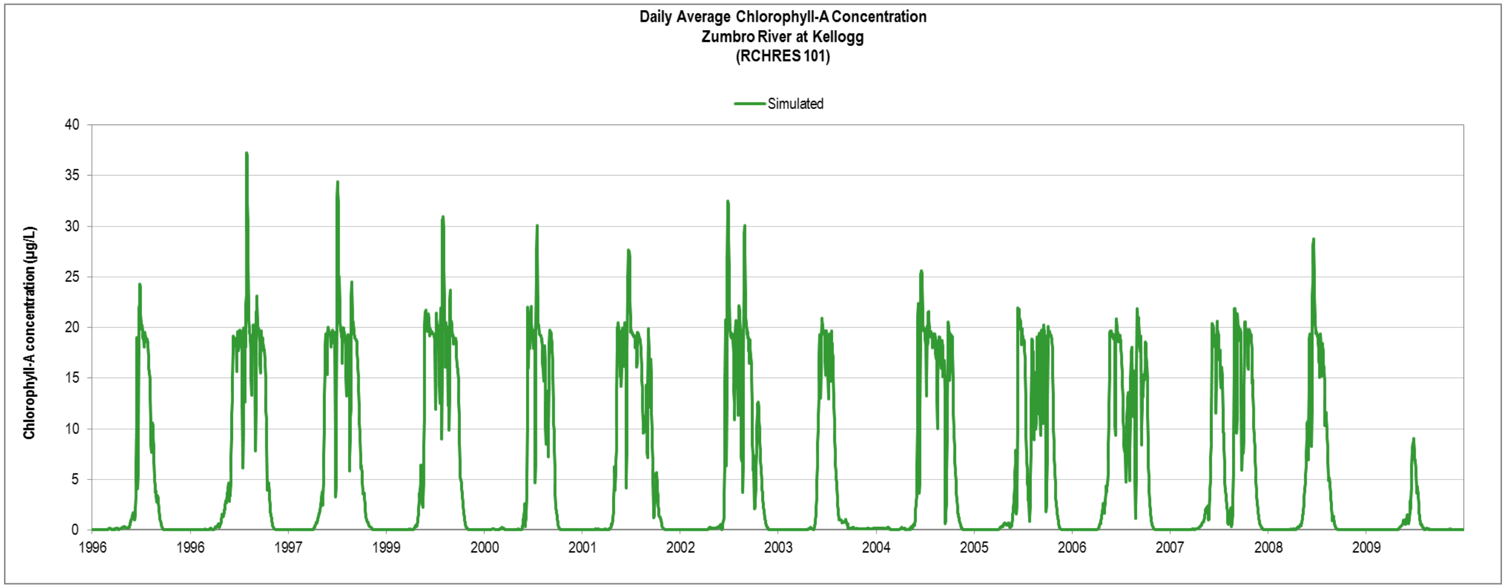

Figure 4-72. Daily Average Phytoplankton Chlorophyll *a* Concentrations for Zumbro River at Kellogg (RCHRES 101)

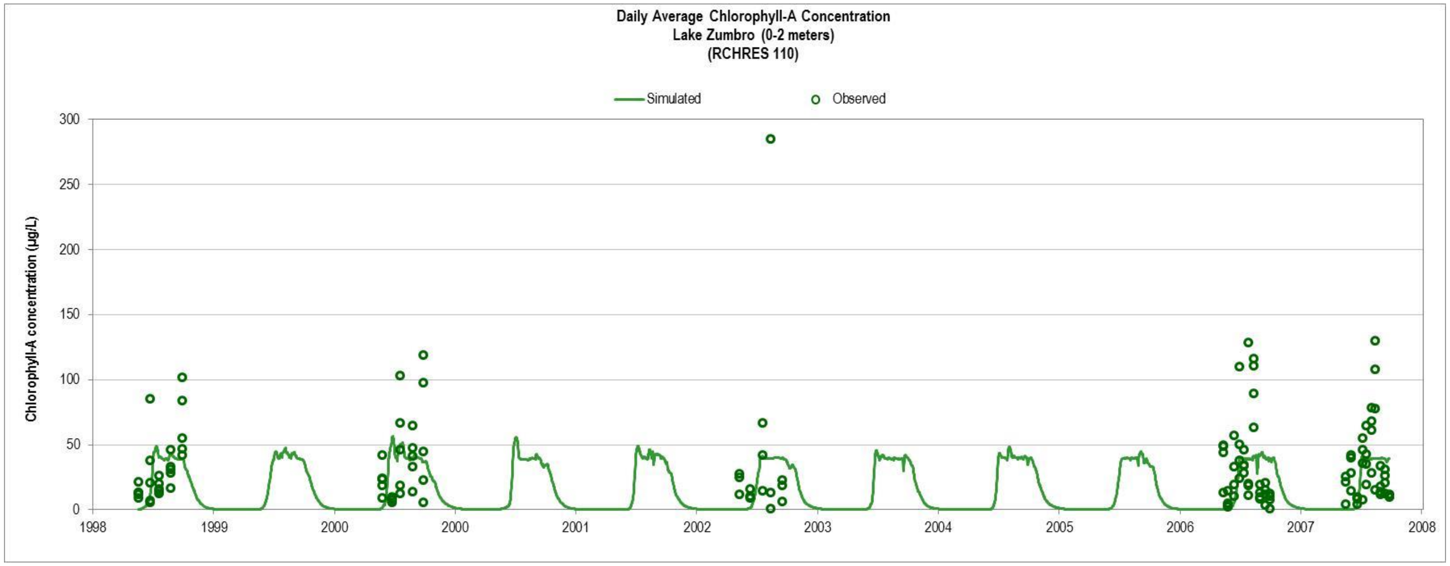

Figure 4-73. Daily Average Chlorophyll *a* Concentrations for Lake Zumbro (RCHRES 110). Note that Chlorophyll *a* concentrations represent whole-lake averages (i.e., samples from multiple locations) from surface depths (i.e., samples from 0-2 meters).

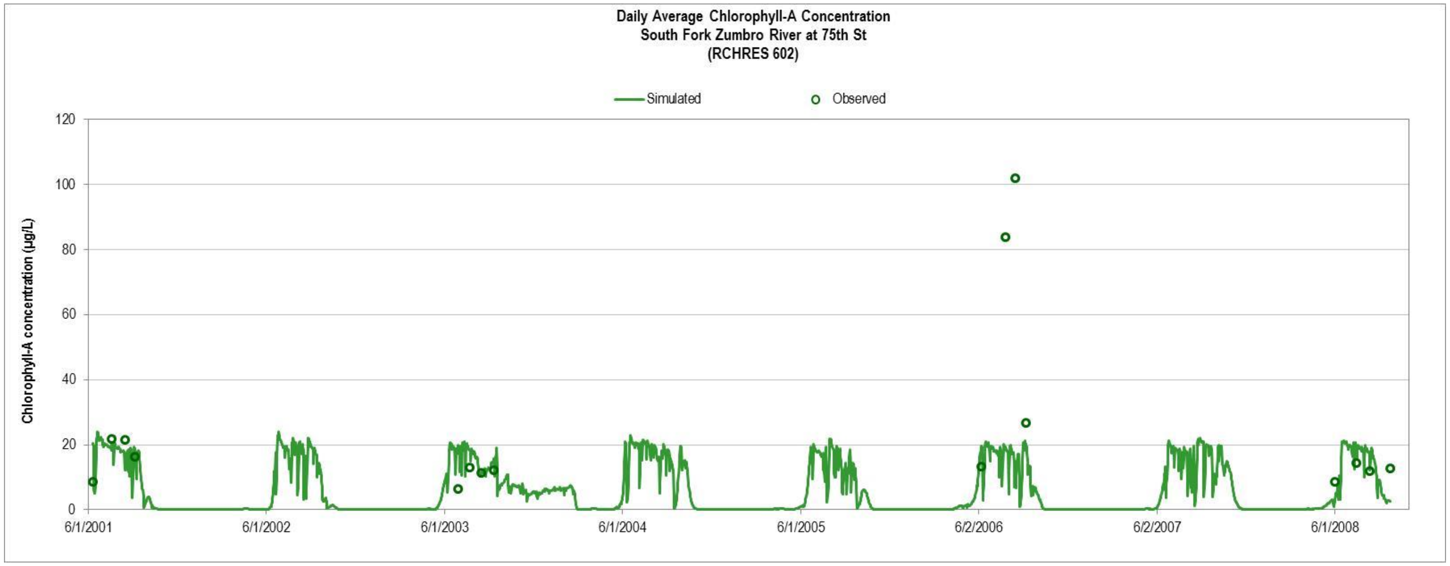

Figure 4-74. Daily Average Chlorophyll *a* Concentrations for South Fork Zumbro River at 75th Street (RCHRES 602)

5

Summary and Recommendations

5.1 Summary

An HSPF model of the Zumbro River watershed has been developed to simulate hydrology, sediment and suspended solids (TSS), 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 1995-2009. The model has been successfully calibrated and validated for hydrology, sediment and suspended solids (TSS), and water quality.

The ZRWHSPF model was calibrated and validated using a "weight of evidence" approach, which uses several qualitative and quantitative measures to evaluate the model performance and is a valuable and often standard practice in watershed modeling (USEPA 2006). Given the multiple lines of evidence examined in this report and past memoranda (LimnoTech 2014a and 2014b), the ZRWHSPF 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) predictions. Therefore, the ZRWHSPF 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.

5.2 Model Limitations and Caveats

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

- UAL targets were based on literature and other Minnesota models. Ideally, UAL targets would be constrained by site-specific data.
- The sediment calibration and validation is constrained by estimated TSS from turbidity. Ideally, long-term, direct measurements of TSS or suspended sediment concentration (SSC) would be used to calibrate and validate the model to reduce the uncertainty introduced in the regression equations developed to estimate TSS concentrations from turbidity measurements.
- 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.
- It appears that the model may overpredict orthophosphate during storm events. However, the apparent model overprediction may be attributed to limited data during storm events or missing peak concentrations in the grab sample monitoring.
- 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 ZRWHSPF model is infrequent and isolated to smaller reach segments. To address some of the more common and broader model

instability issues in the water quality simulation, a small amount of flow was added to susceptible reach segments via the “special actions” module.

- Simulation of nutrient cycling and eutrophication processes in Lake Zumbro 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 Zumbro.

5.3 Recommendations

The following section outlines recommendations for future model refinement and future application of the ZRWHSPF model. Recommendations for future model refinement and application are based on “lessons learned” during the process of developing, calibrating and validating the ZRWHSPF model. These recommendations are provided below.

Model Refinement

- Address the model instabilities in the water quality simulation attributed to extreme low flow conditions (note that this will likely require revisions to the HSPF source code).
- Include a more detailed representation of reservoir operations (i.e., Lake Zumbro, Rice Lake) of operations, drawdowns and releases if additional data becomes available.
- Re-evaluate the sediment calibration if additional data become available. Specifically, site specific data were limited upland versus bed/bank erosion.
- 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 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 ZRWHSPF model’s limitations with respect to simulating water quality and eutrophication conditions in Lake Zumbro are noted above. If sedimentation and/or eutrophication (e.g., persistent algae bloom) issues need to be addressed for Lake Zumbro, 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 the lake. An appropriate modeling framework for Lake Zumbro 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 for Lake Zumbro include LimnoTech's linked EFDC-A2EM modeling framework and USEPA's EFDC-WASP7 linked modeling framework.

6
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Appendix A
Hydrology Simulation for Auxiliary Stations

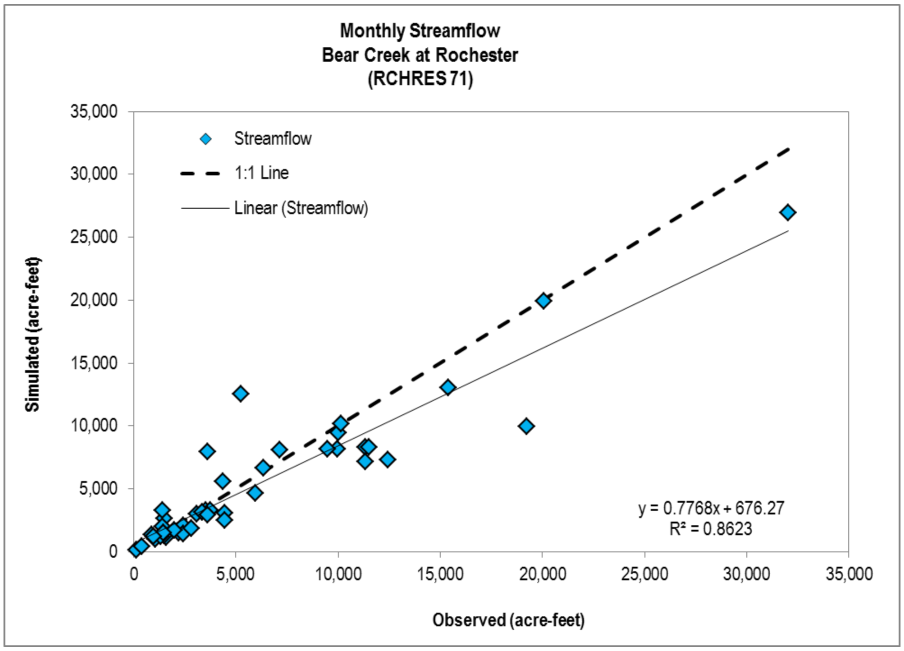

Figure A-1. Monthly Streamflow 1:1 Plot for Bear Creek at Rochester (RCHRES 71)

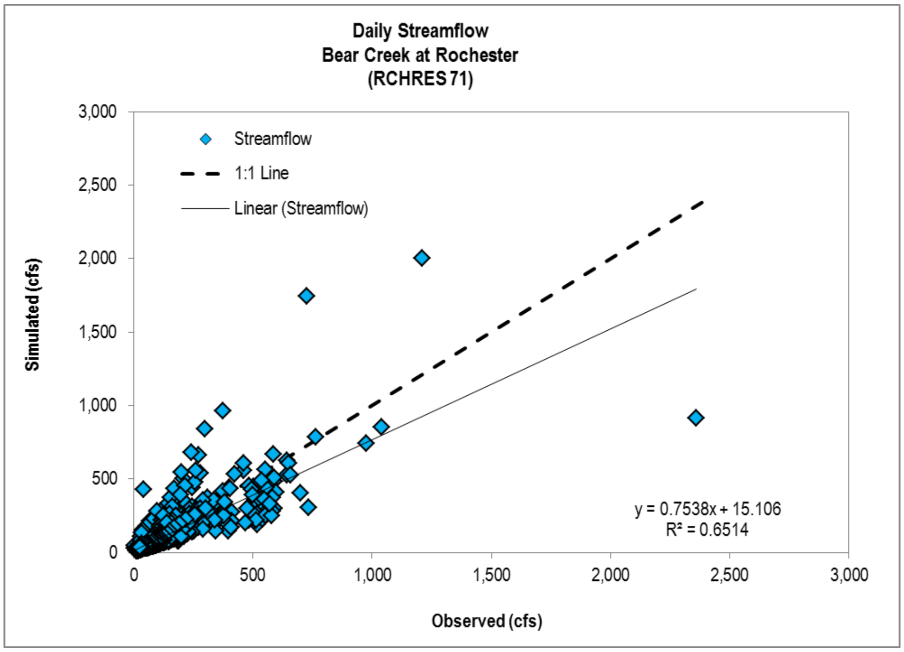

Figure A-2. Daily Streamflow 1:1 Plot for Bear Creek at Rochester (RCHRES 71)

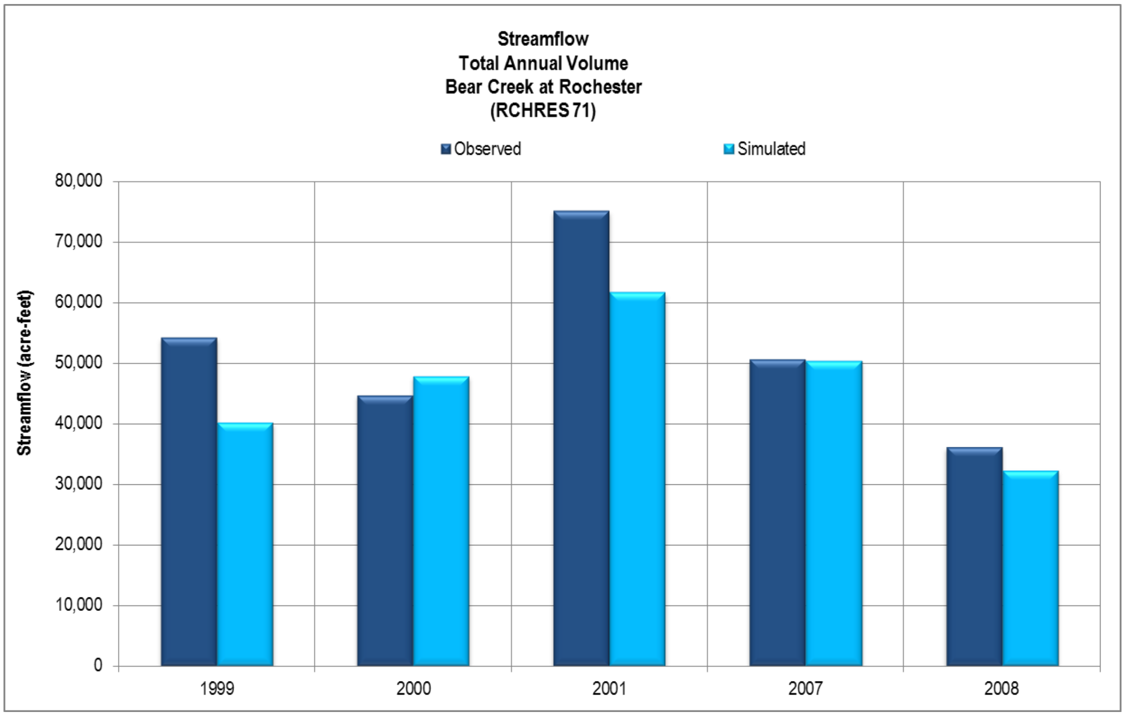

Figure A-3. Streamflow Total Annual Volume for Bear Creek at Rochester (RCHRES 71)

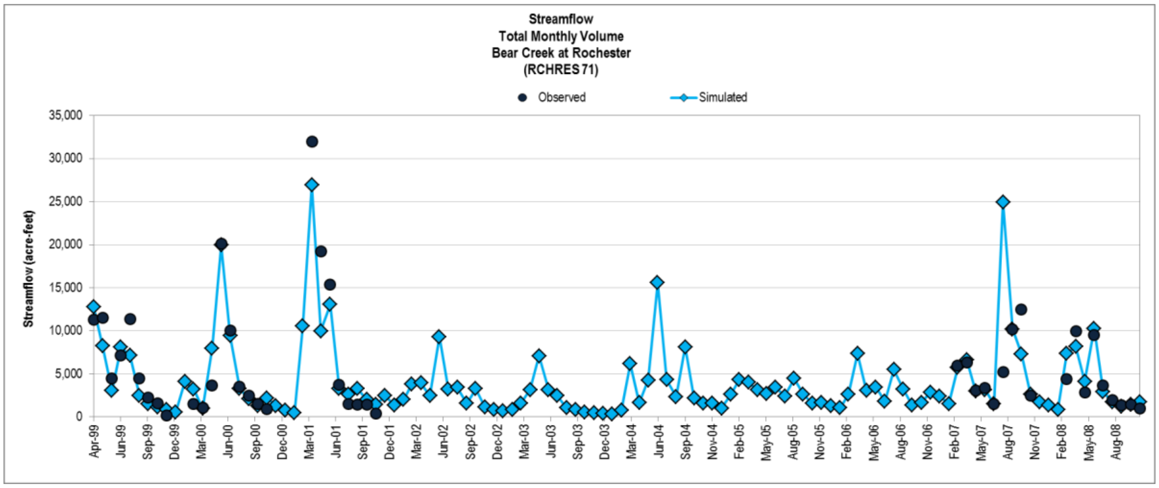

Figure A-4. Streamflow Total Monthly Volume for Bear Creek at Rochester (RCHRES 71)

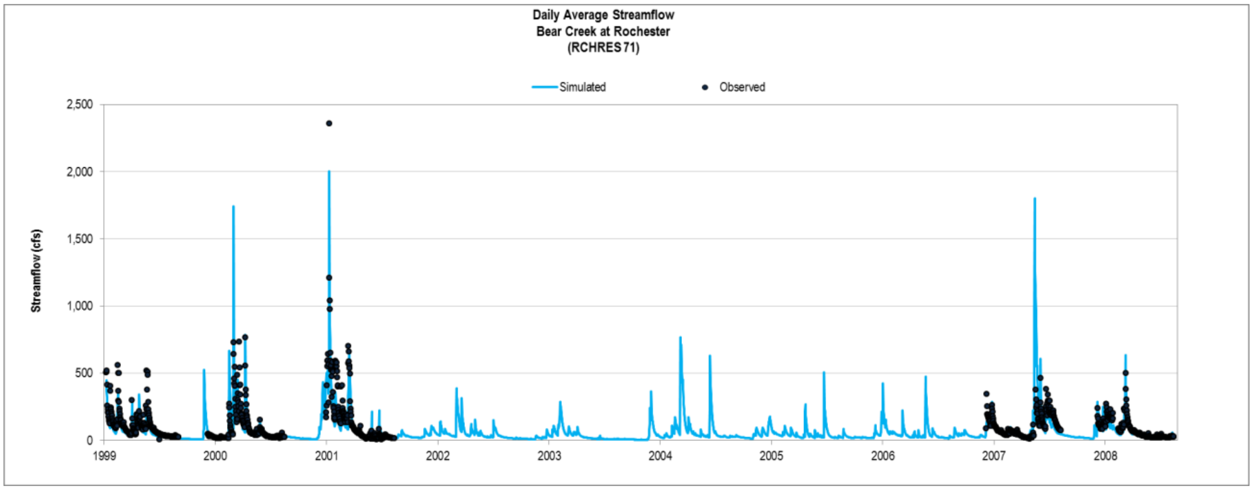

Figure A-5. Daily Average Streamflow for Bear Creek at Rochester (RCHRES 71)

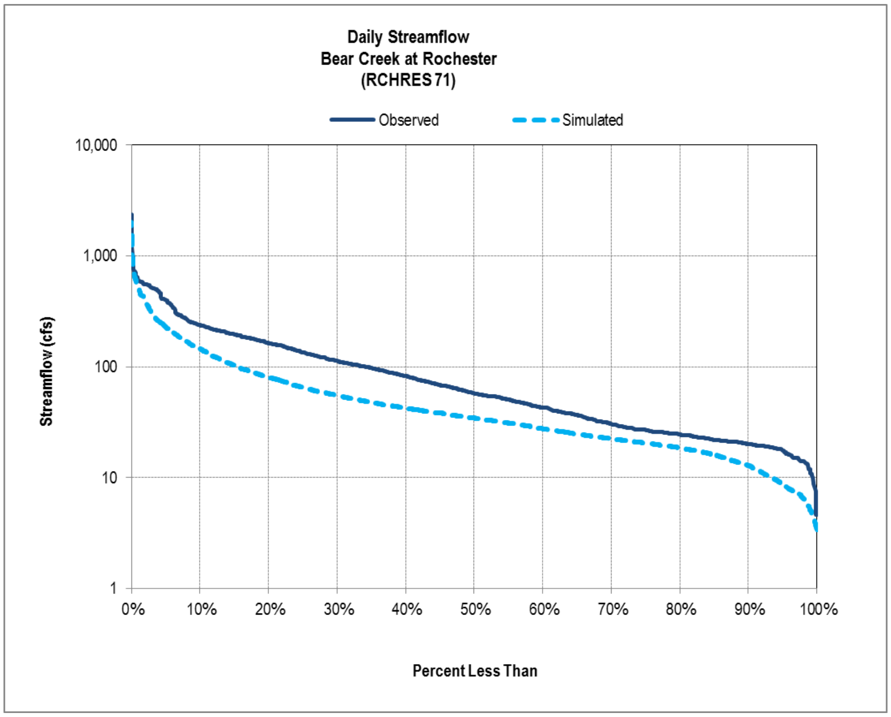

Figure A-6. Daily Streamflow Cumulative Frequency Distribution for Bear Creek at Rochester (RCHRES 71)

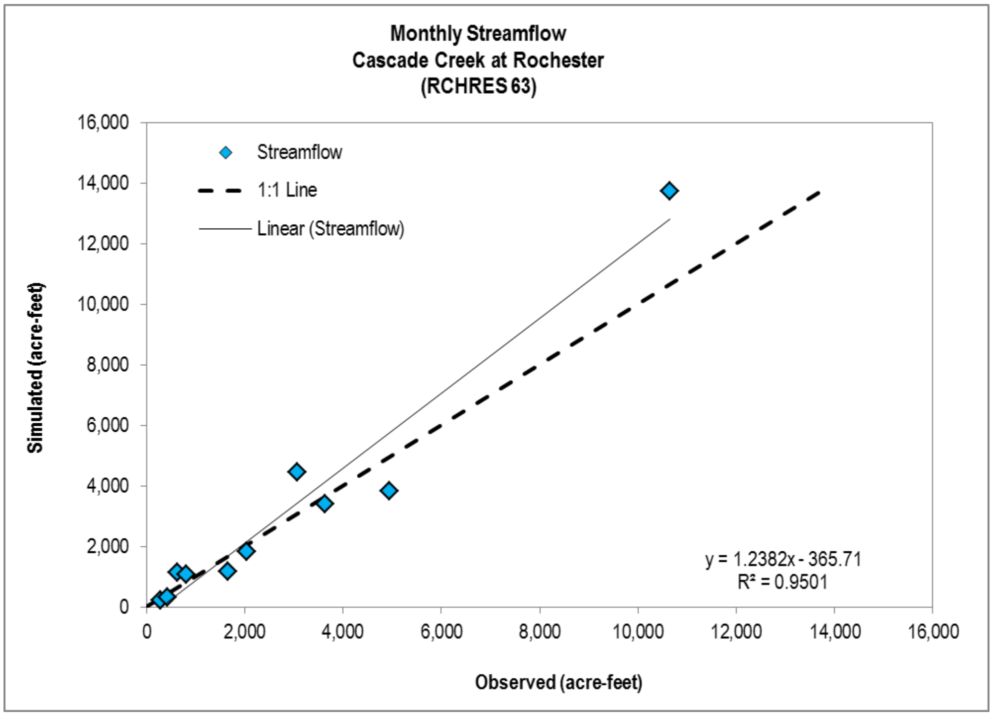

Figure A-7. Monthly Streamflow 1:1 Plot for Cascade Creek at Rochester (RCHRES 63)

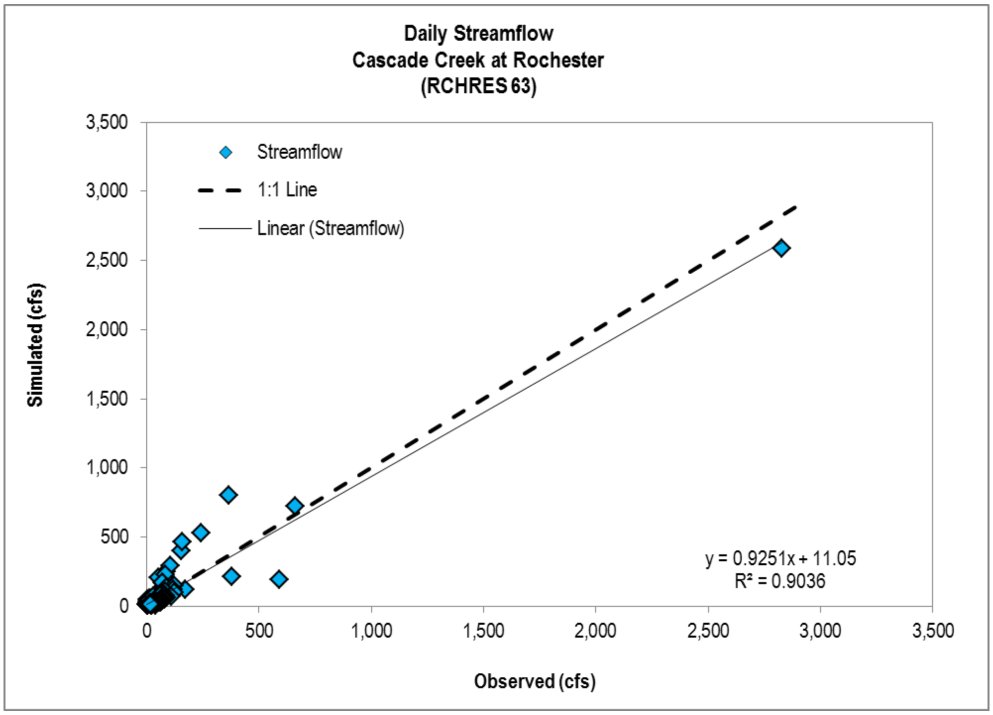

Figure A-8. Daily Streamflow 1:1 Plot for Cascade Creek at Rochester (RCHRES 63)

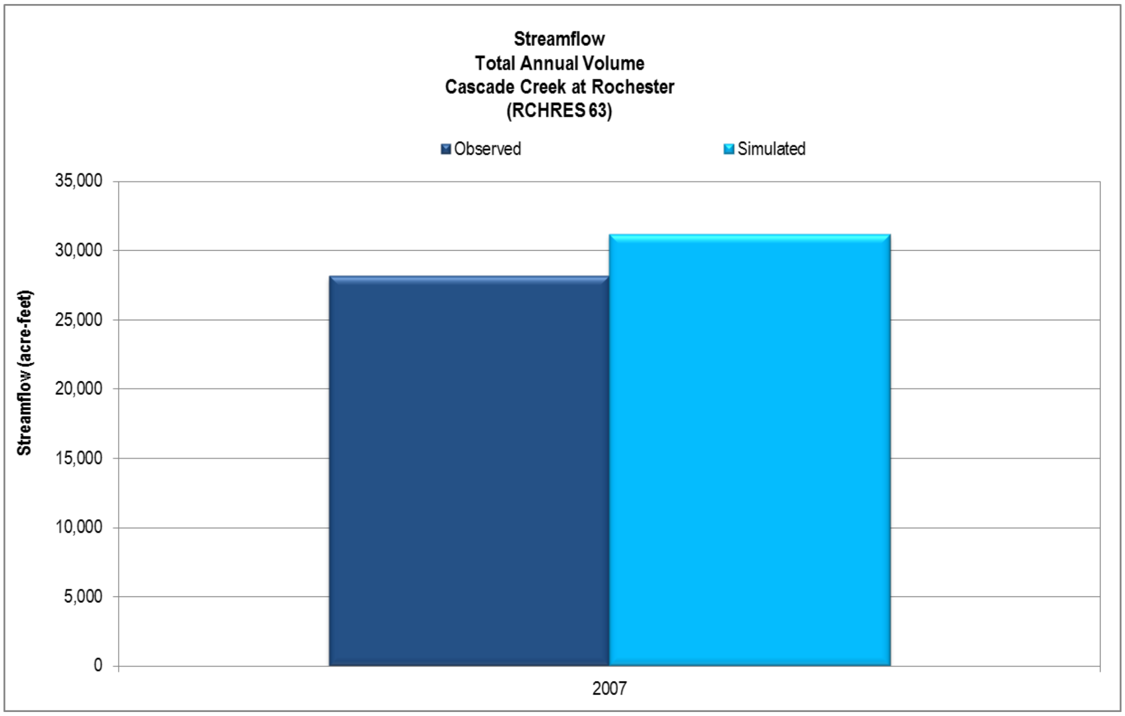

Figure A-9. Streamflow Total Annual Volume for Cascade Creek at Rochester (RCHRES 63)

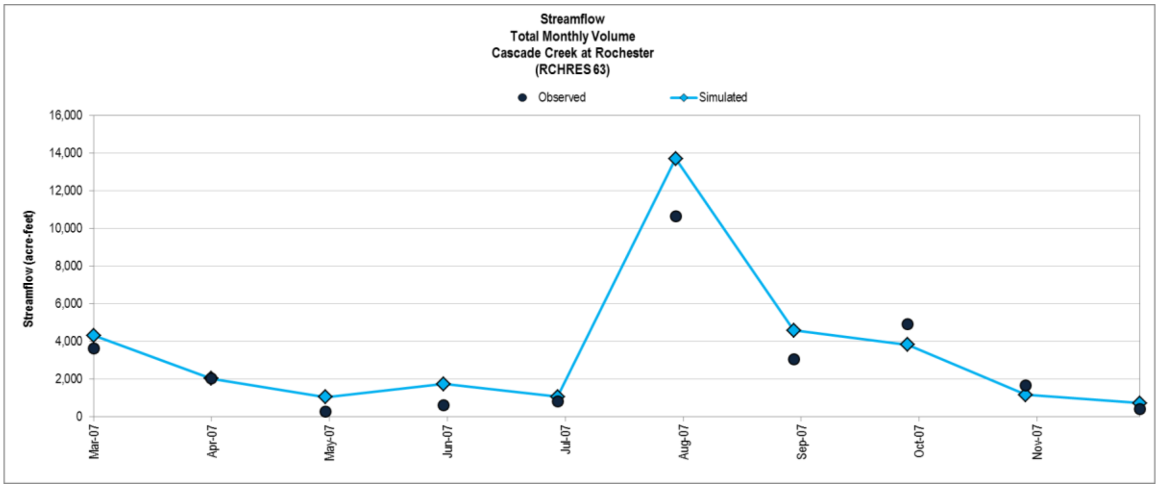

Figure A-10. Streamflow Total Monthly Volume for Cascade Creek at Rochester (RCHRES 63)

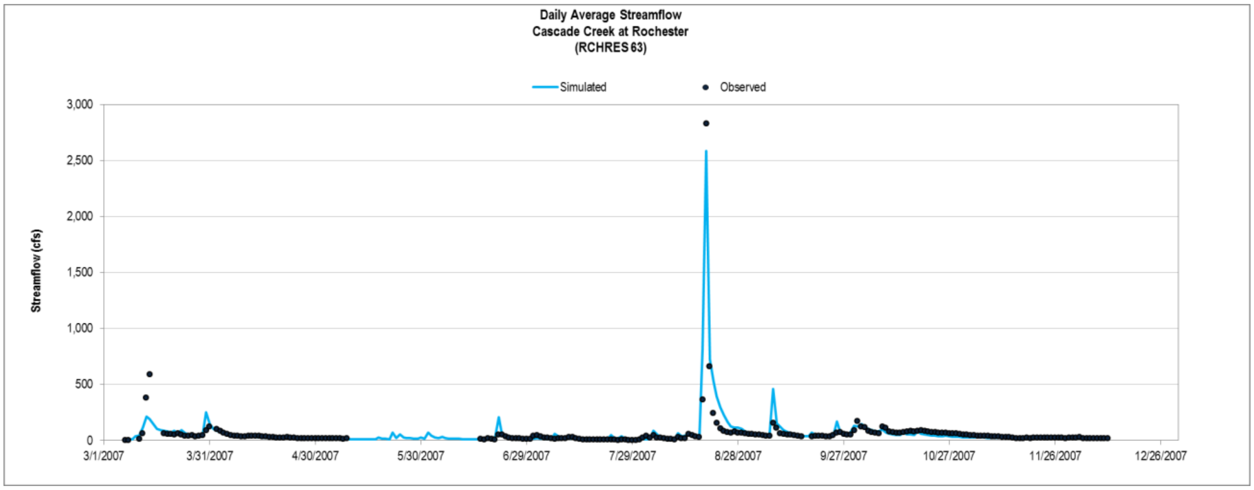

Figure A-11. Daily Average Streamflow for Cascade Creek at Rochester (RCHRES 63)

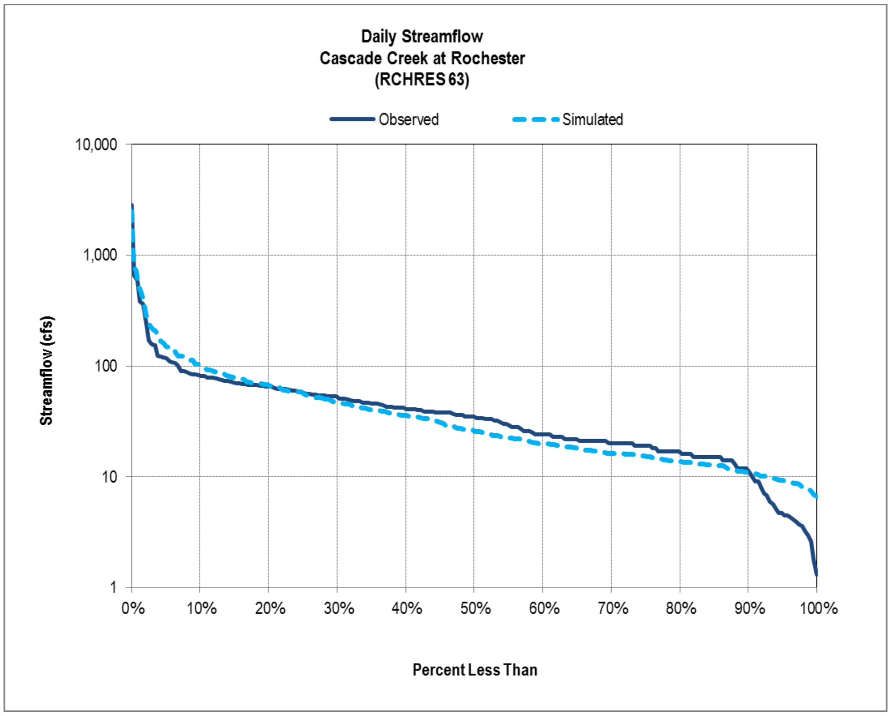

Figure A-12. Daily Streamflow Cumulative Frequency Distribution for Cascade Creek at Rochester (RCHRES 63)

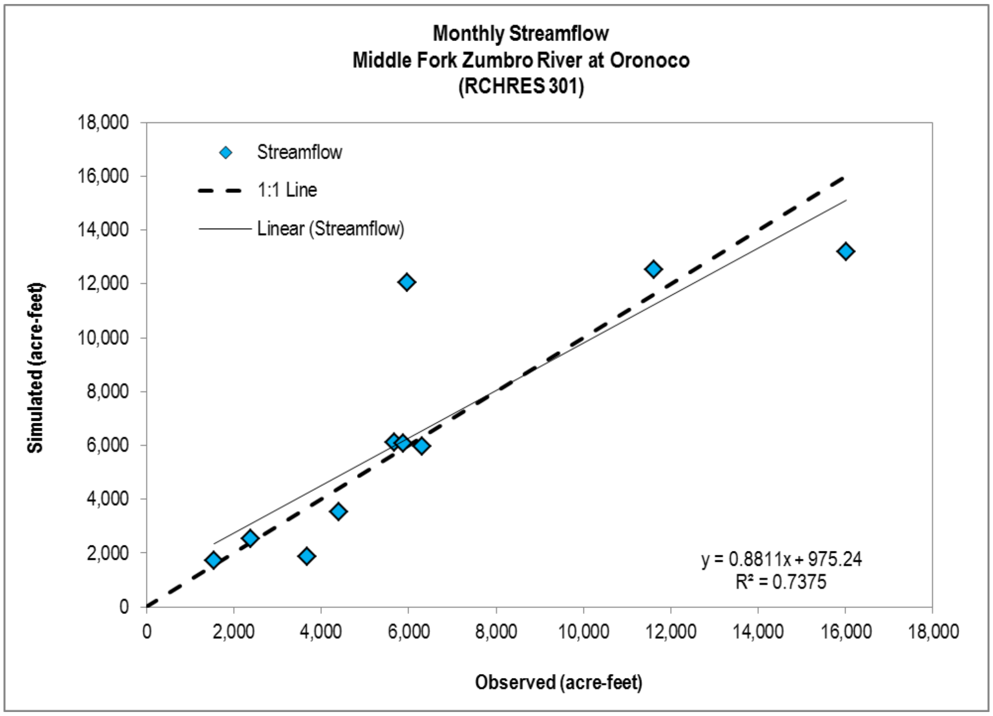

Figure A-13. Monthly Streamflow 1:1 Plot for Middle Fork Zumbro River at Oronoco (RCHRES 301)

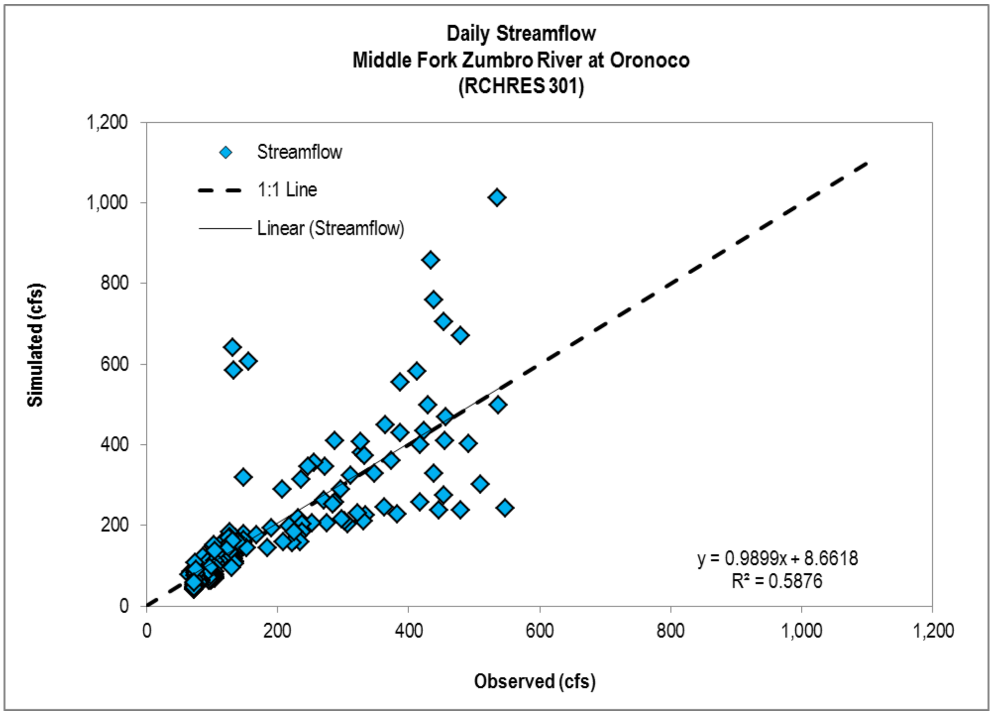

Figure A-14. Daily Streamflow 1:1 Plot for Middle Fork Zumbro River at Oronoco (RCHRES 301)

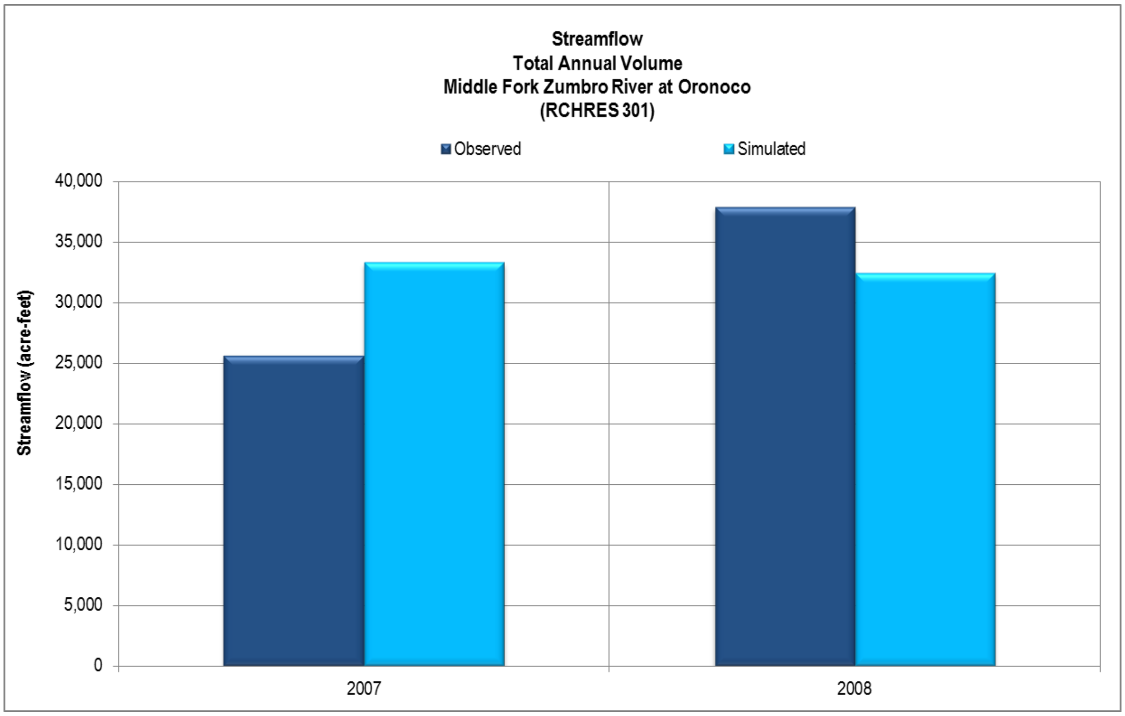

Figure A-15. Streamflow Total Annual Volume for Middle Fork Zumbro River at Oronoco (RCHRES 301)

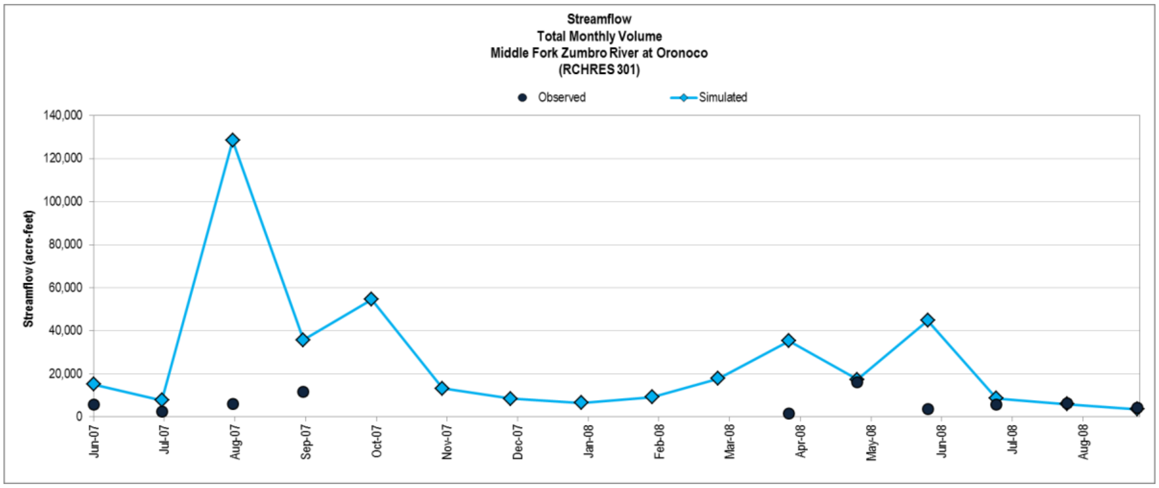

Figure A-16. Streamflow Total Monthly Volume for Middle Fork Zumbro River at Oronoco (RCHRES 301)

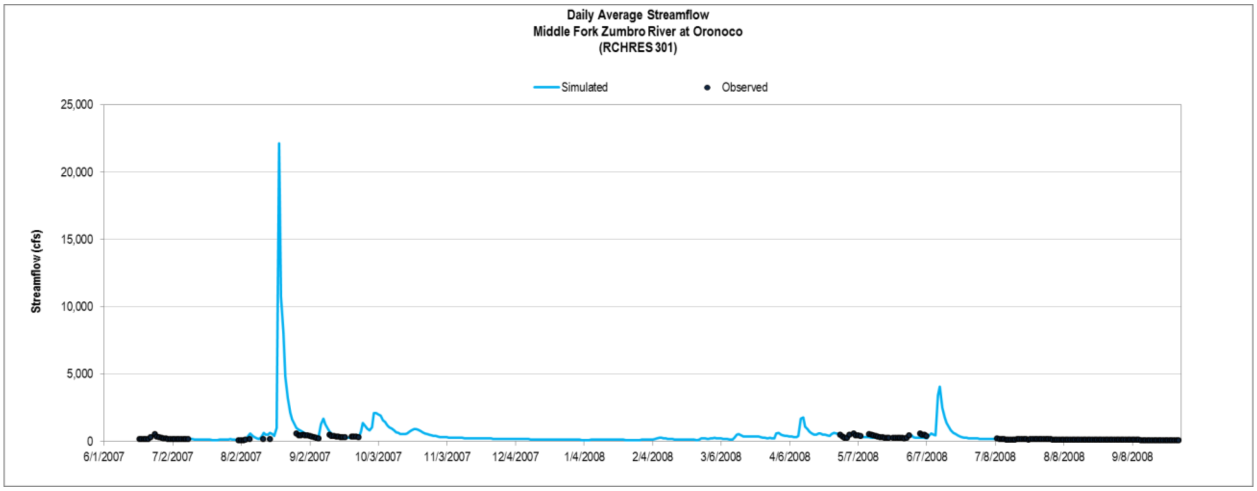

Figure A-17. Daily Average Streamflow for Middle Fork Zumbro River at Oronoco (RCHRES 301)

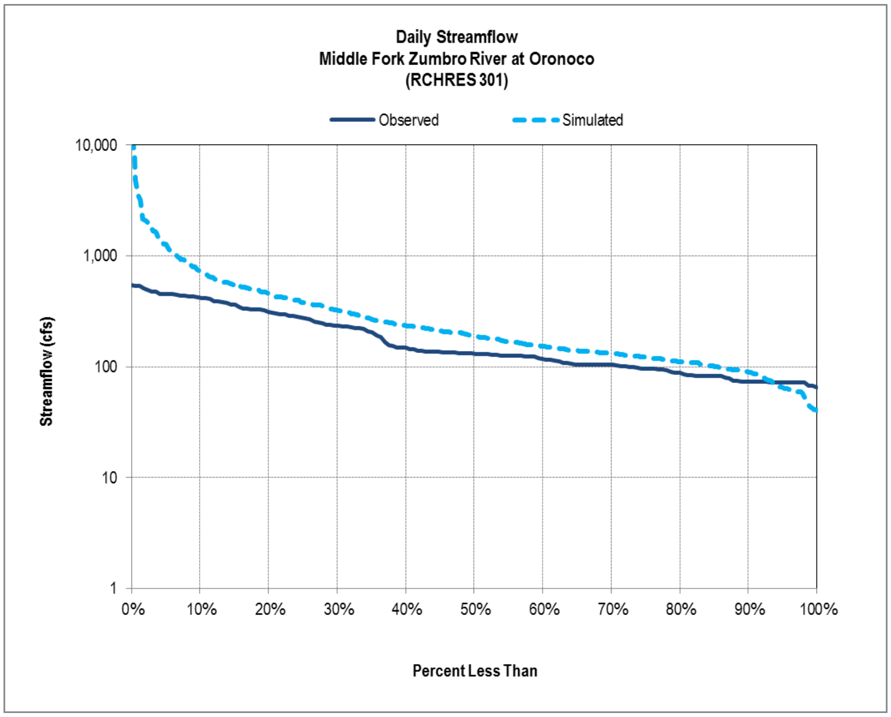

Figure A-18. Daily Streamflow Cumulative Frequency Distribution for Middle Fork Zumbro River at Oronoco (RCHRES 301)

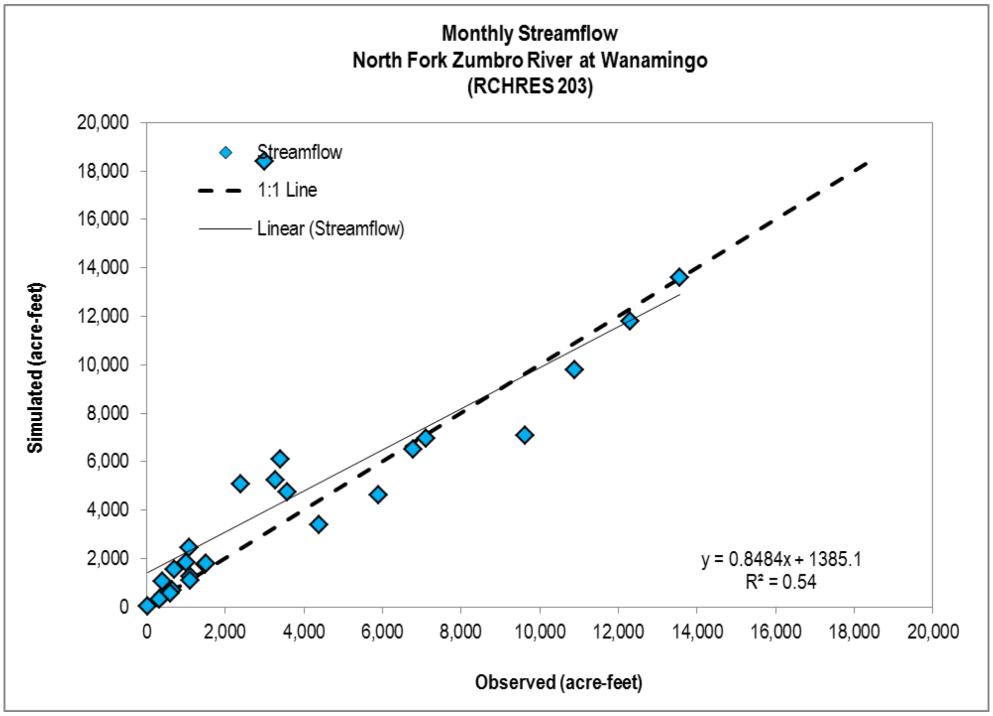

Figure A-19. Monthly Streamflow 1:1 Plot for North Fork Zumbro River at Wanamingo (RCHRES 203)

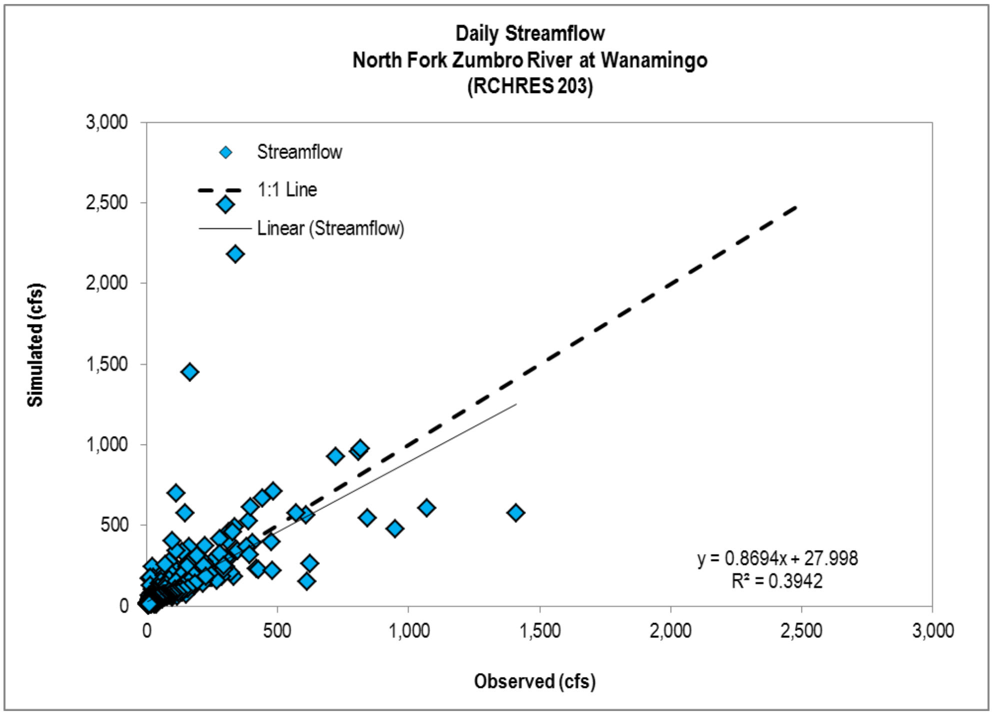

Figure A-20. Daily Streamflow 1:1 Plot for North Fork Zumbro River at Wanamingo (RCHRES 203)

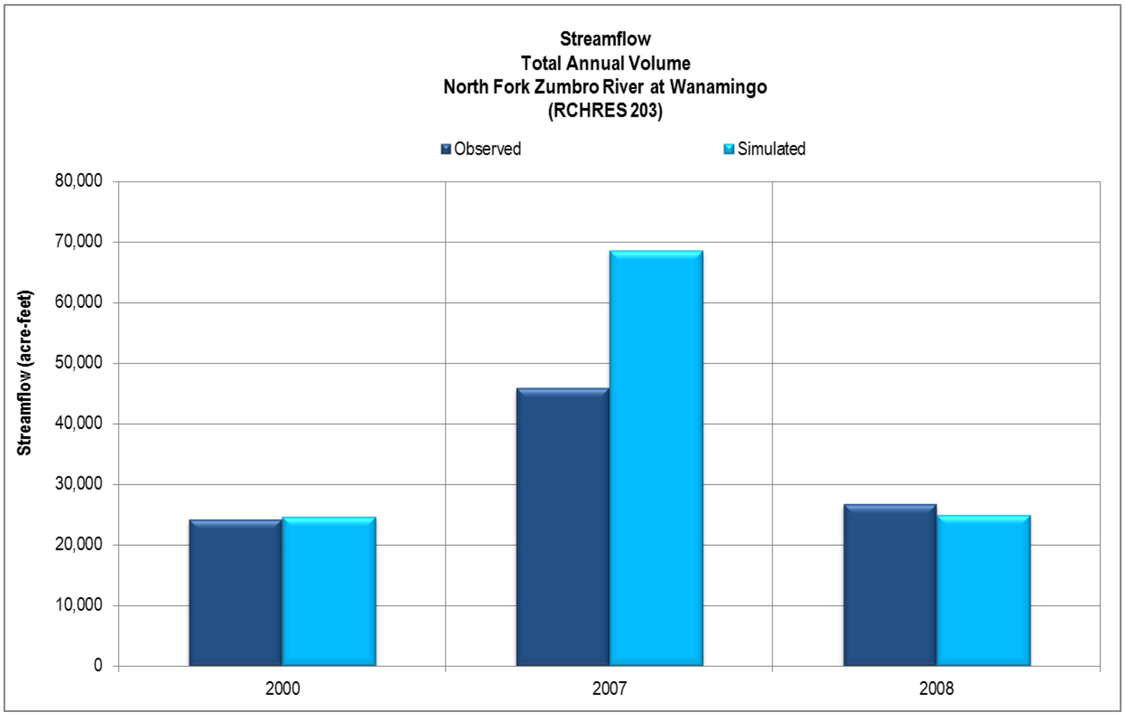

Figure A-21. Streamflow Total Annual Volume for North Fork Zumbro River at Wanamingo (RCHRES 203)

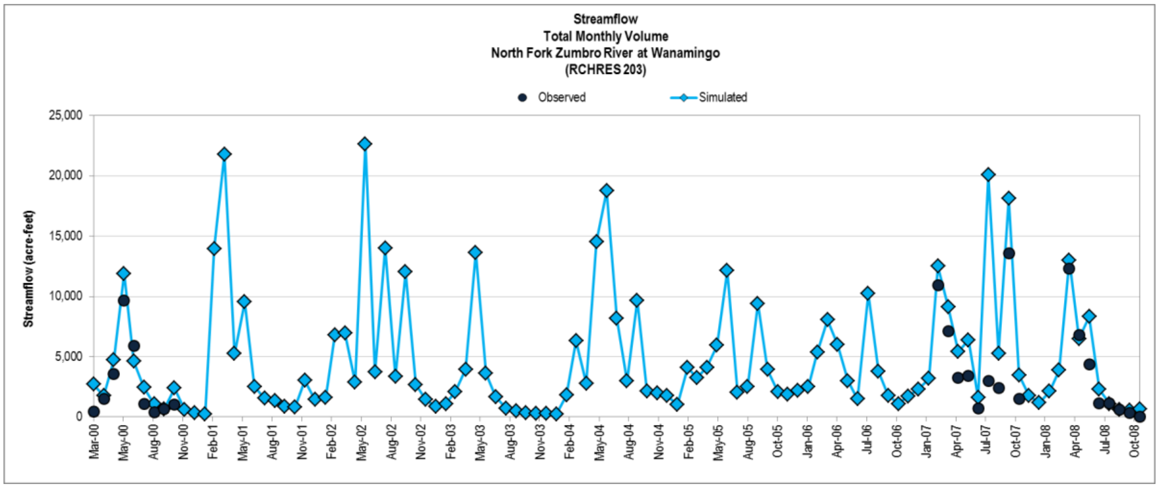

Figure A-22. Streamflow Total Monthly Volume for North Fork Zumbro River at Wanamingo (RCHRES 203)

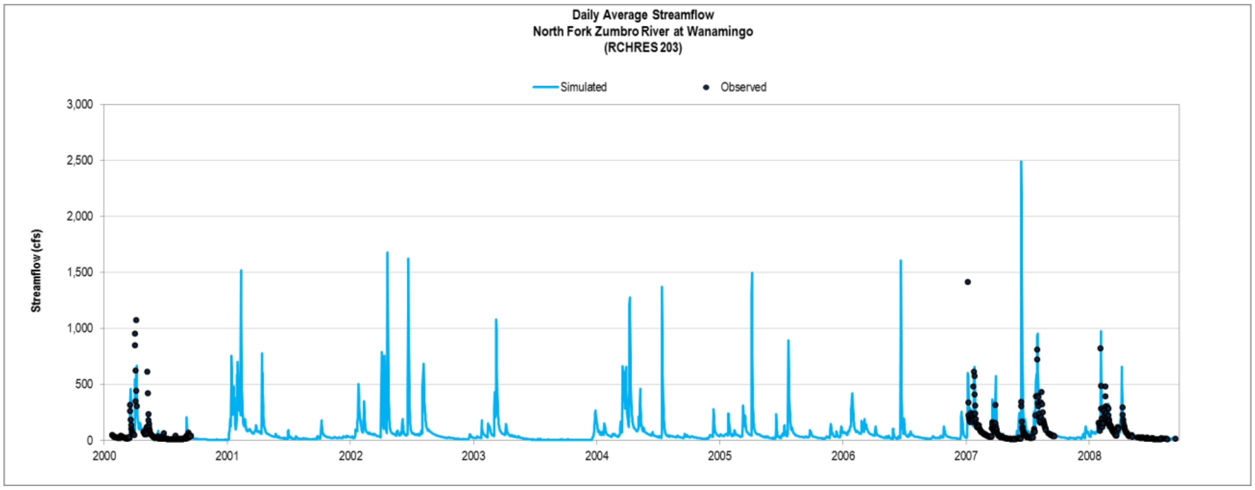

Figure A-23. Daily Average Streamflow for North Fork Zumbro River at Wanamingo (RCHRES 203)

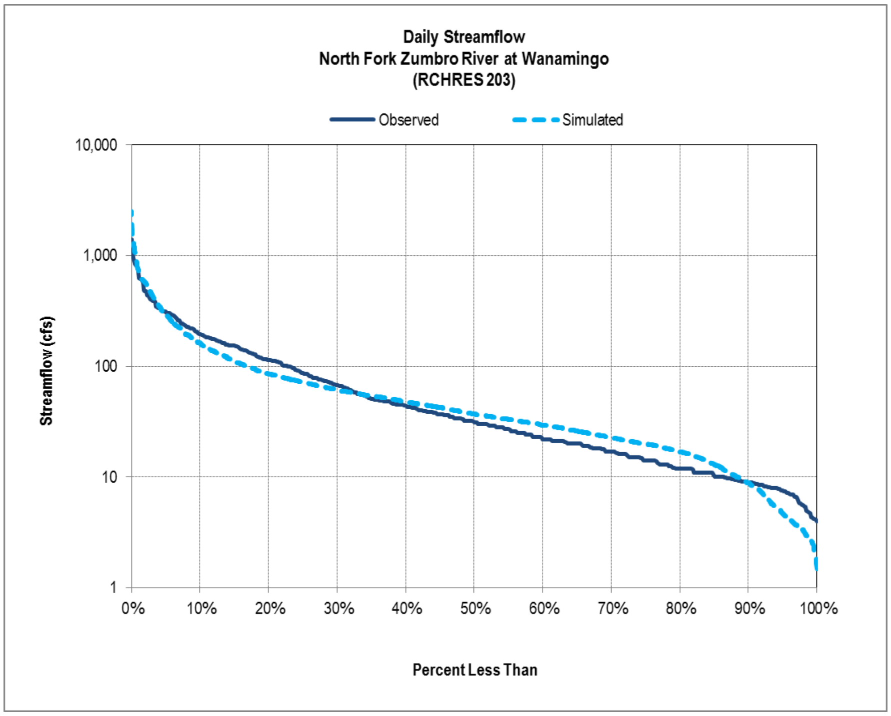

Figure A-24. Daily Streamflow Cumulative Frequency Distribution for North Fork Zumbro River at Wanamingo (RCHRES 203)

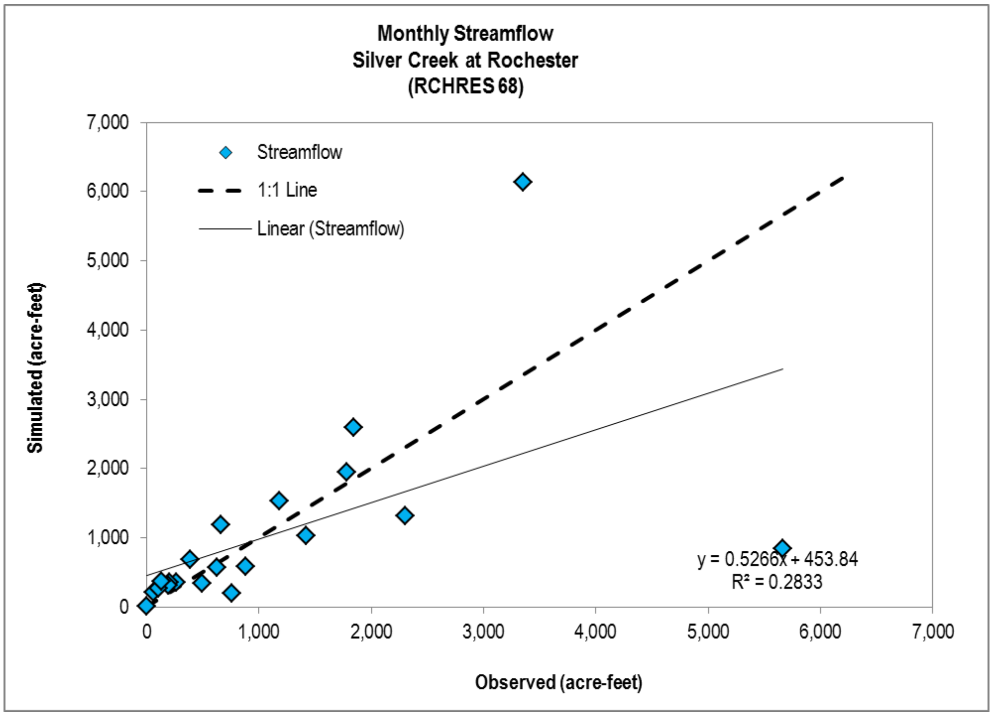

Figure A-25. Monthly Streamflow 1:1 Plot for Silver Creek at Rochester (RCHRES 68)

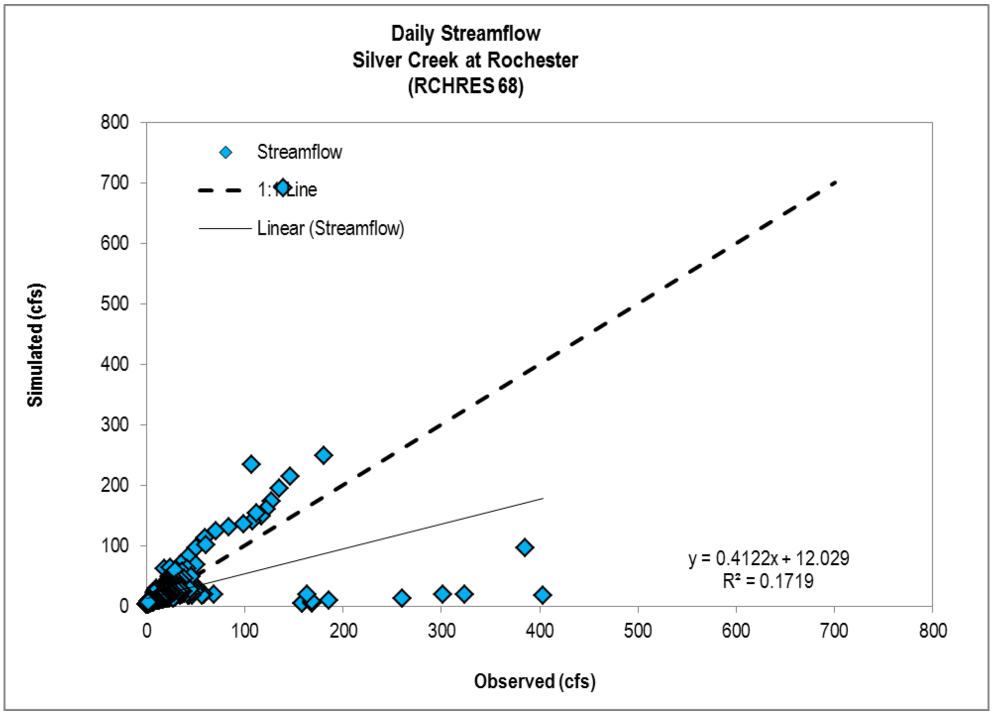

Figure A-26. Daily Streamflow 1:1 Plot for Silver Creek at Rochester (RCHRES 68)

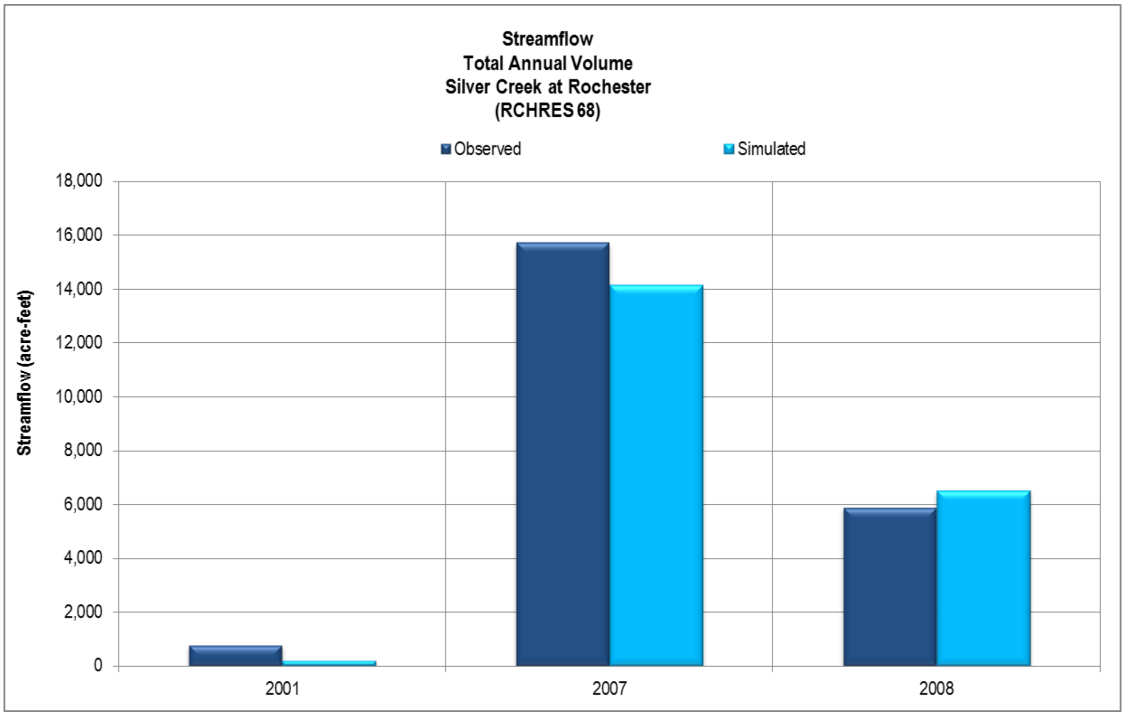

Figure A-27. Streamflow Total Annual Volume for Silver Creek at Rochester (RCHRES 68)

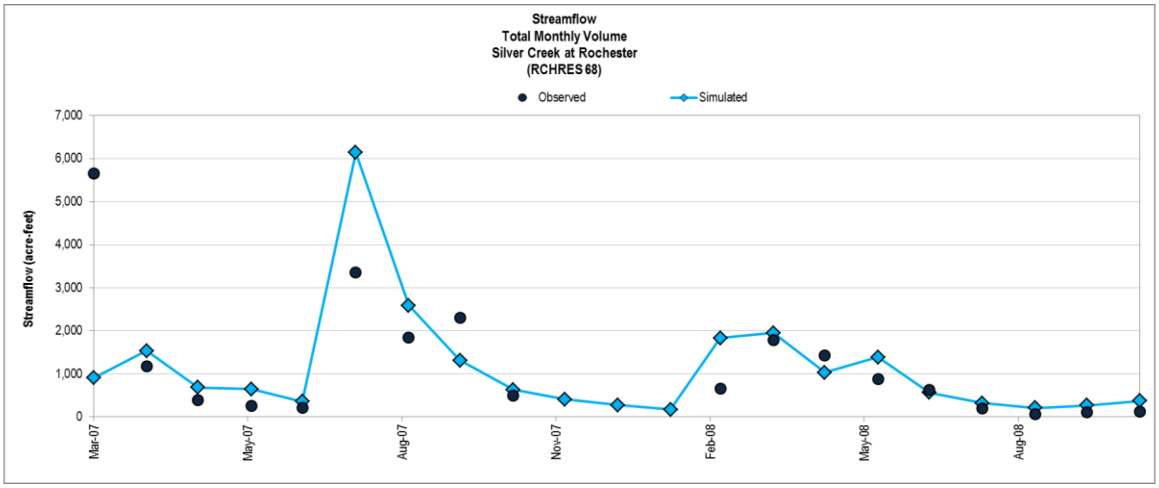

Figure A-28. Streamflow Total Monthly Volume for Silver Creek at Rochester (RCHRES 68)

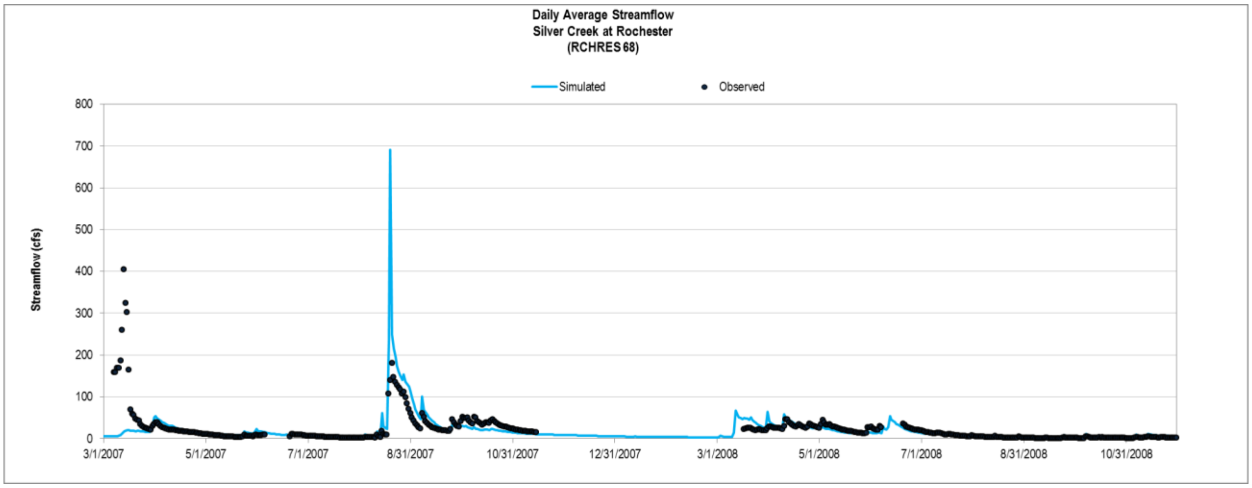

Figure A-29. Daily Average Streamflow for Silver Creek at Rochester (RCHRES 68)

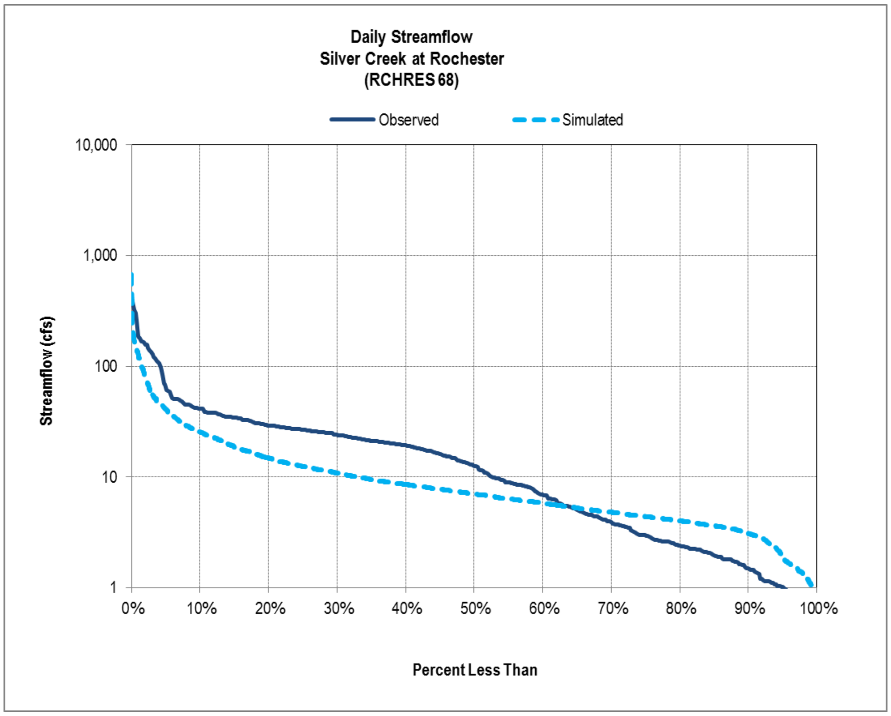

Figure A-30. Daily Streamflow Cumulative Frequency Distribution for Silver Creek at Rochester (RCHRES 68)

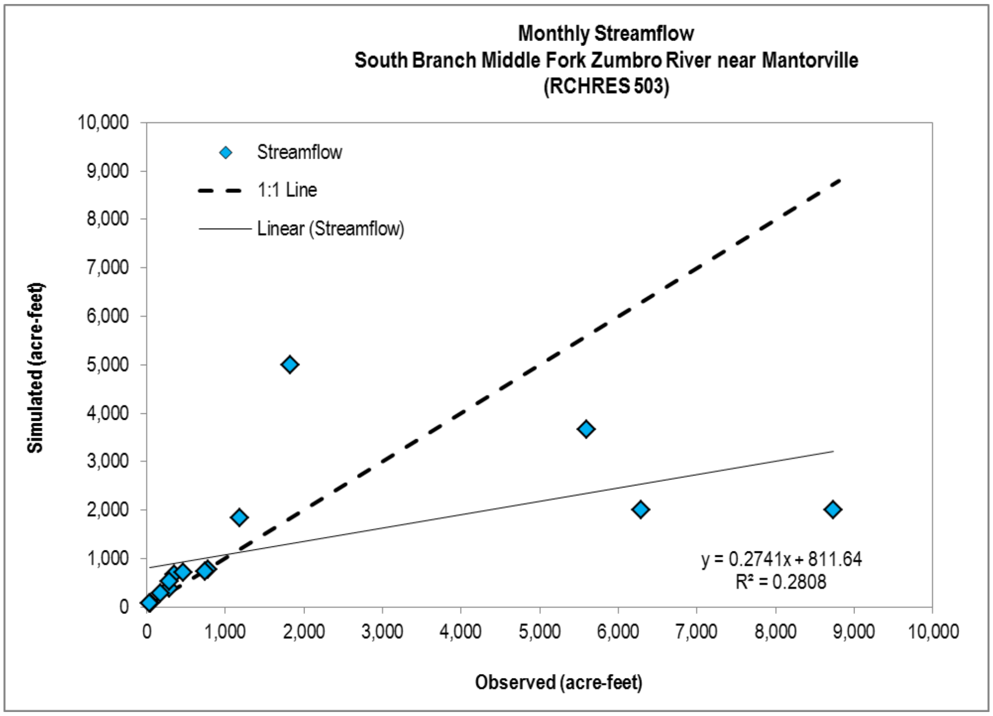

Figure A-31. Monthly Streamflow 1:1 Plot for South Branch Middle Fork Zumbro River near Mantorville (RCHRES 503)

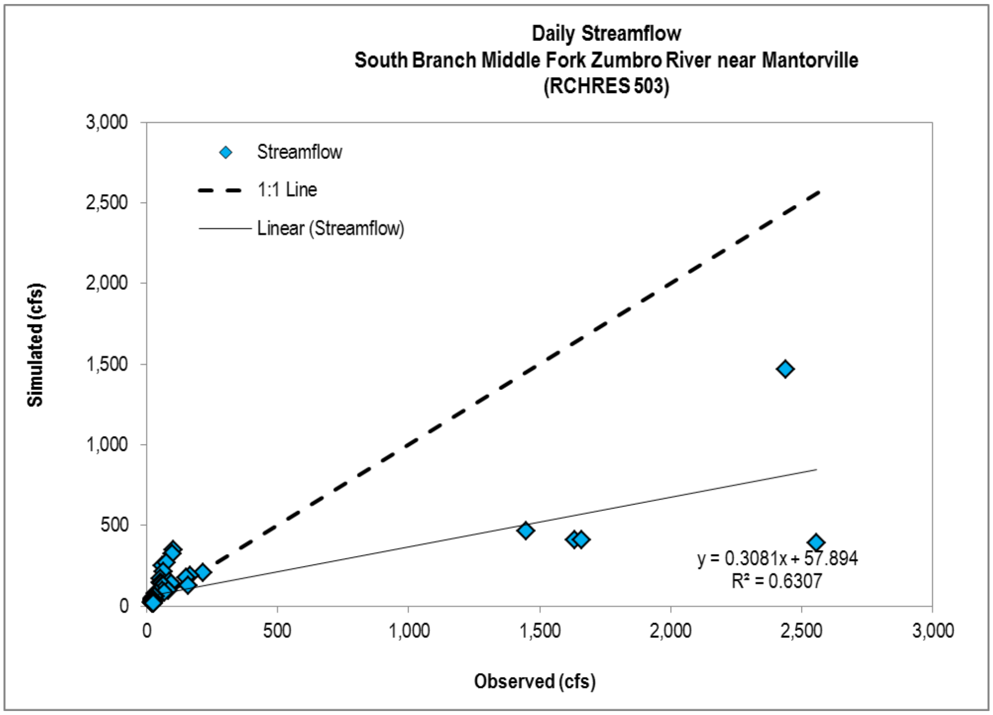

Figure A-32. Daily Streamflow 1:1 Plot for South Branch Middle Fork Zumbro River near Mantorville (RCHRES 503)

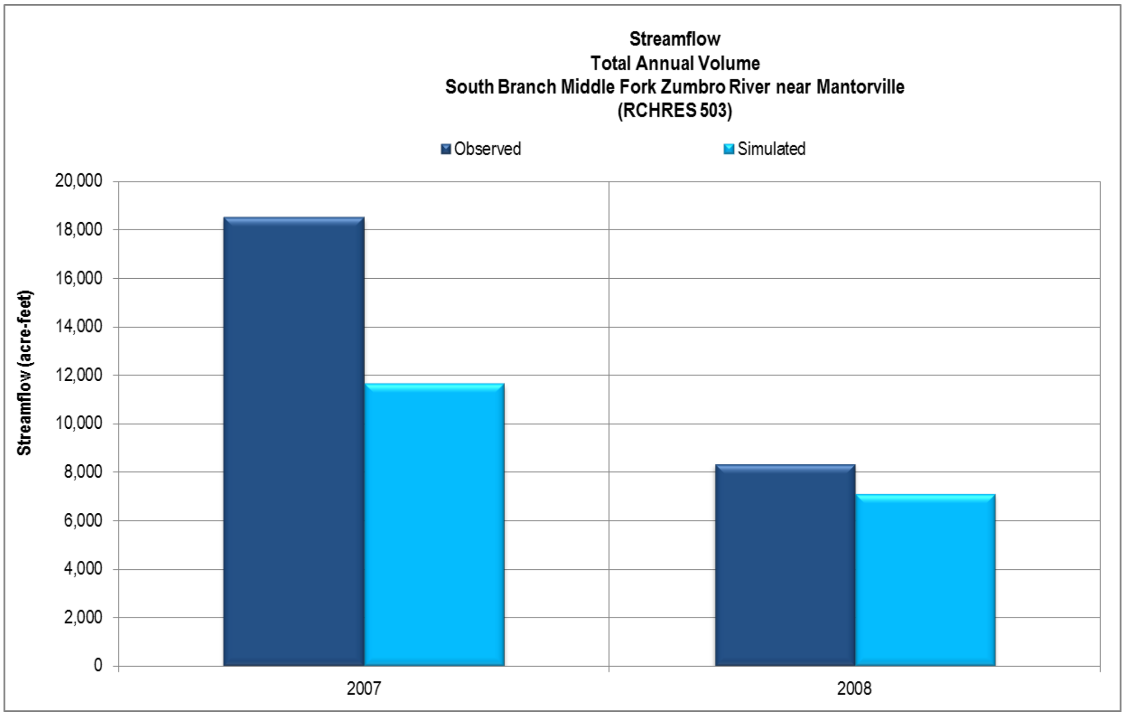

Figure A-33. Streamflow Total Annual Volume for South Branch Middle Fork Zumbro River near Mantorville (RCHRES 503)

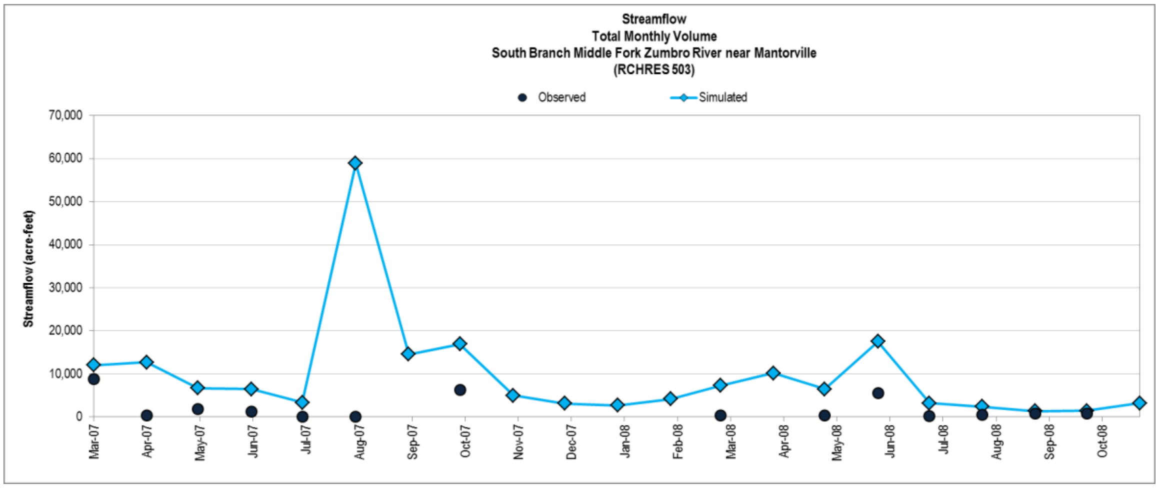

Figure A-34. Streamflow Total Monthly Volume for South Branch Middle Fork Zumbro River near Mantorville (RCHRES 503)

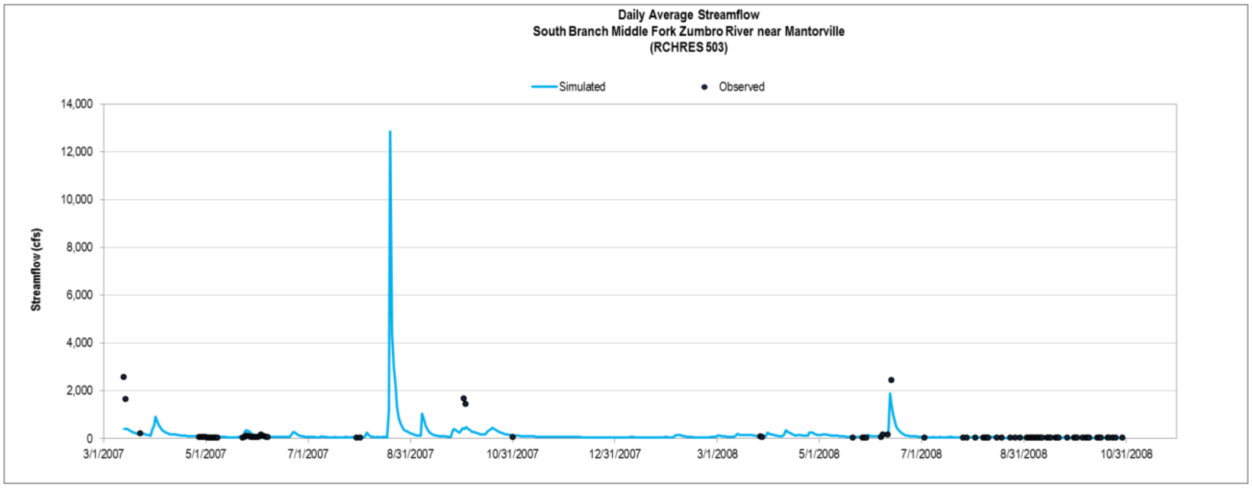

Figure A-35. Daily Average Streamflow for South Branch Middle Fork Zumbro River near Mantorville (RCHRES 503)

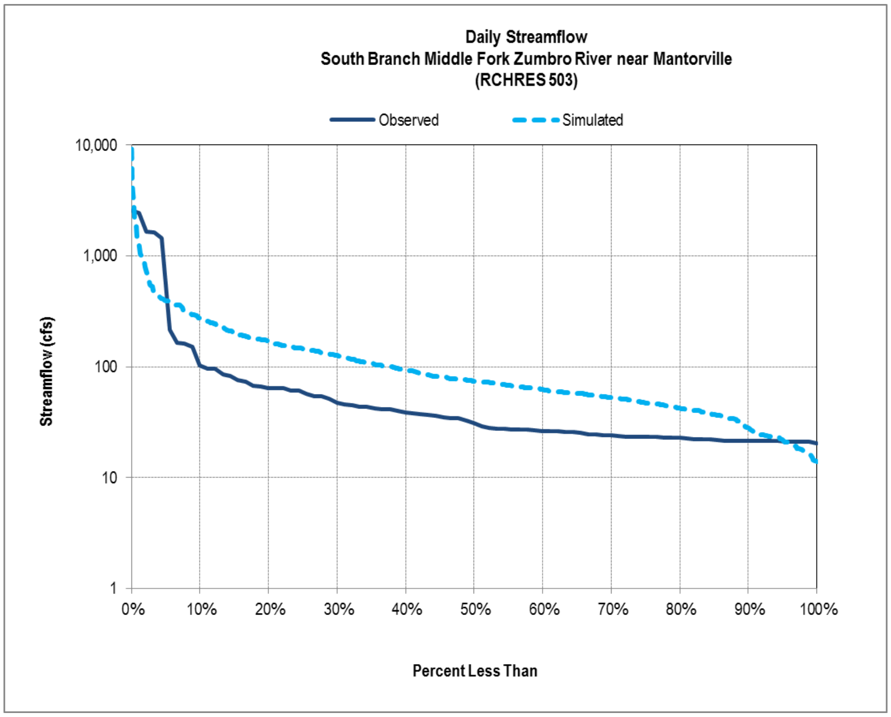

Figure A-36. Daily Streamflow Cumulative Frequency Distribution for South Branch Middle Fork Zumbro River near Mantorville (RCHRES 503)

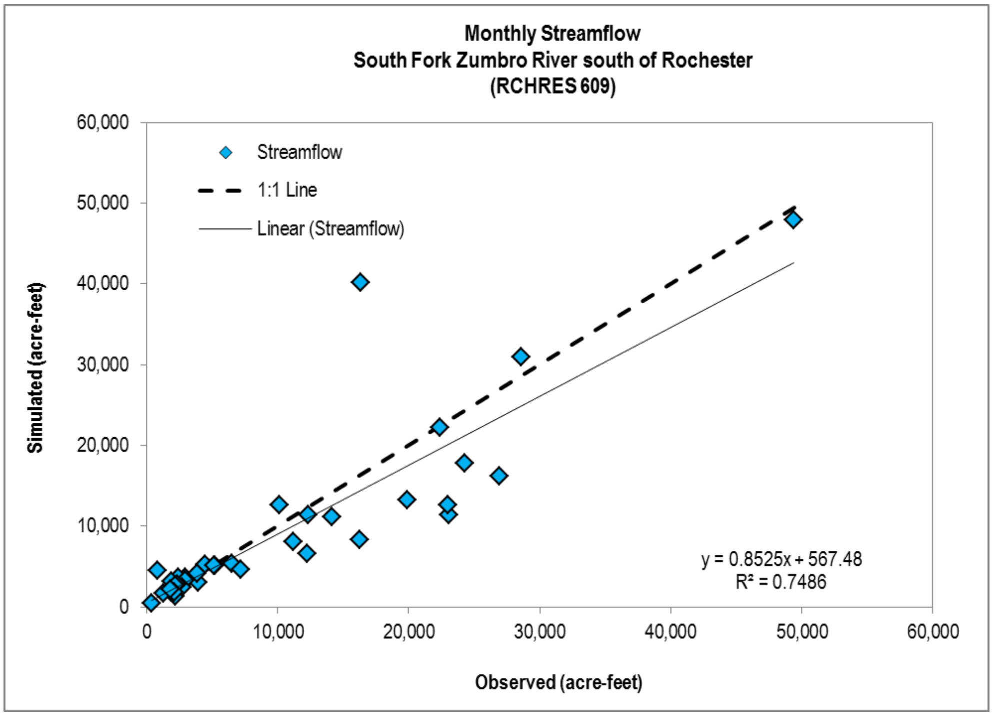

Figure A-37. Monthly Streamflow 1:1 Plot for South Fork Zumbro River south of Rochester (RCHRES 609)

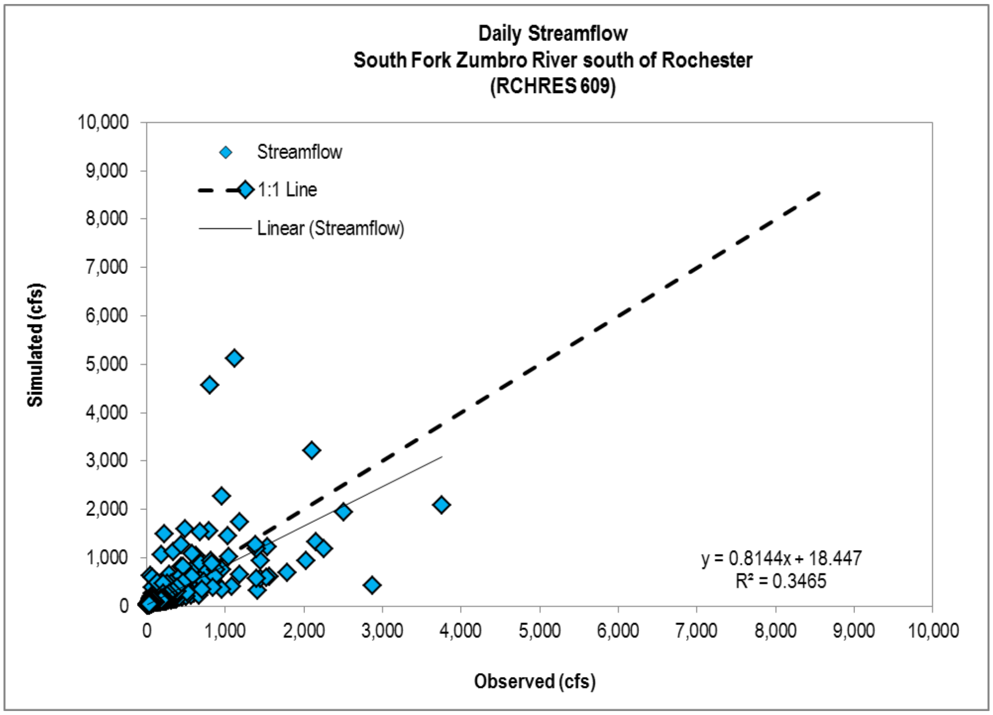

Figure A-38. Daily Streamflow 1:1 Plot for South Fork Zumbro River south of Rochester (RCHRES 609)

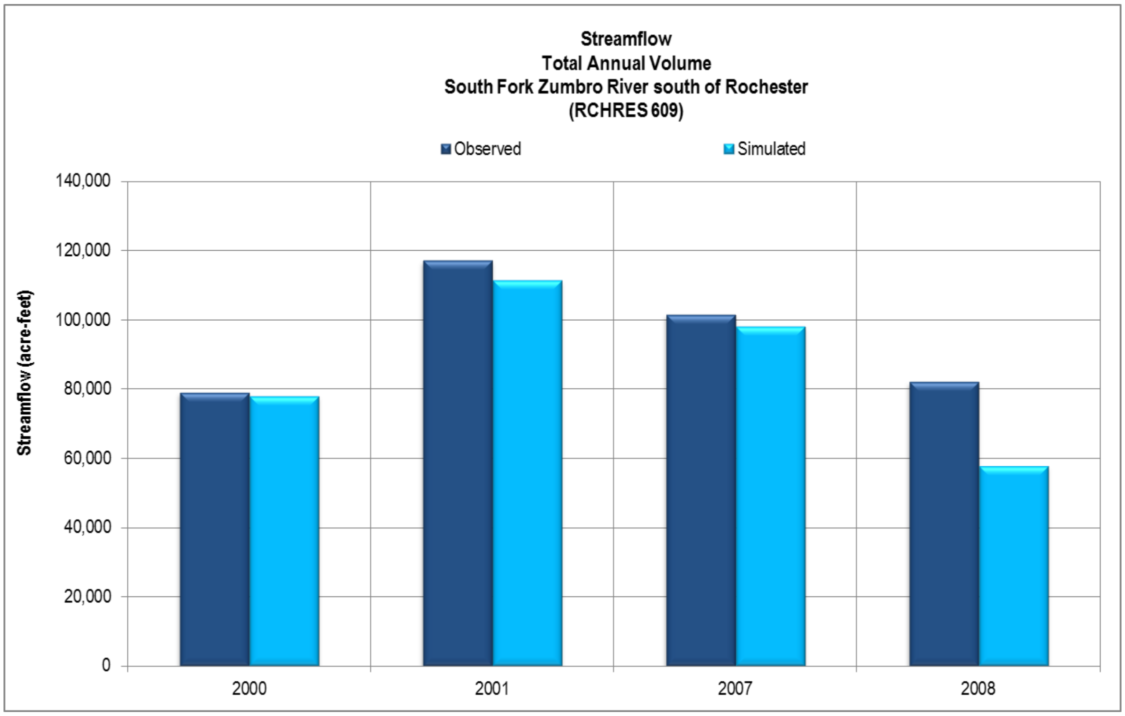

Figure A-39. Streamflow Total Annual Volume for South Fork Zumbro River south of Rochester (RCHRES 609)

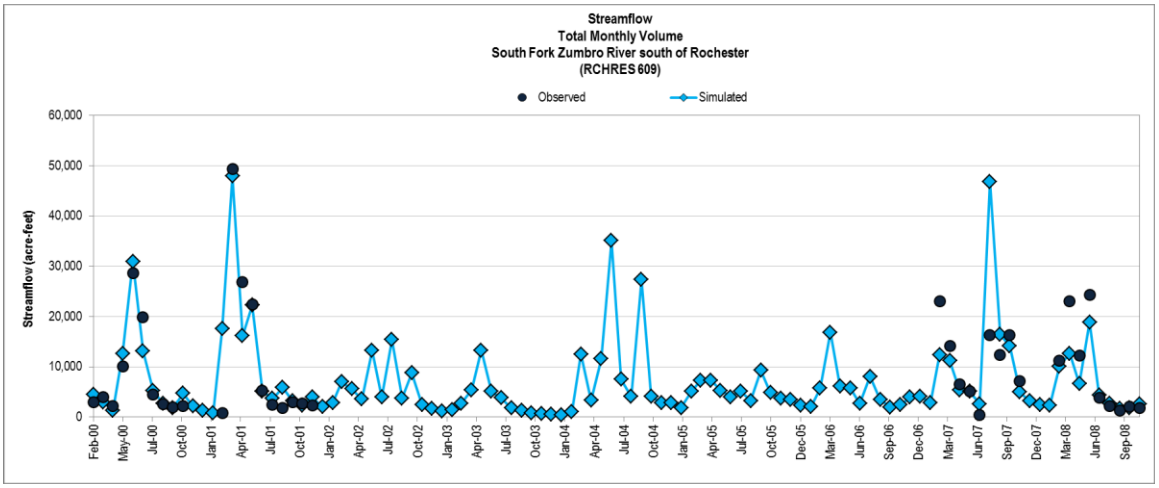

Figure A-40. Streamflow Total Monthly Volume for South Fork Zumbro River south of Rochester (RCHRES 609)

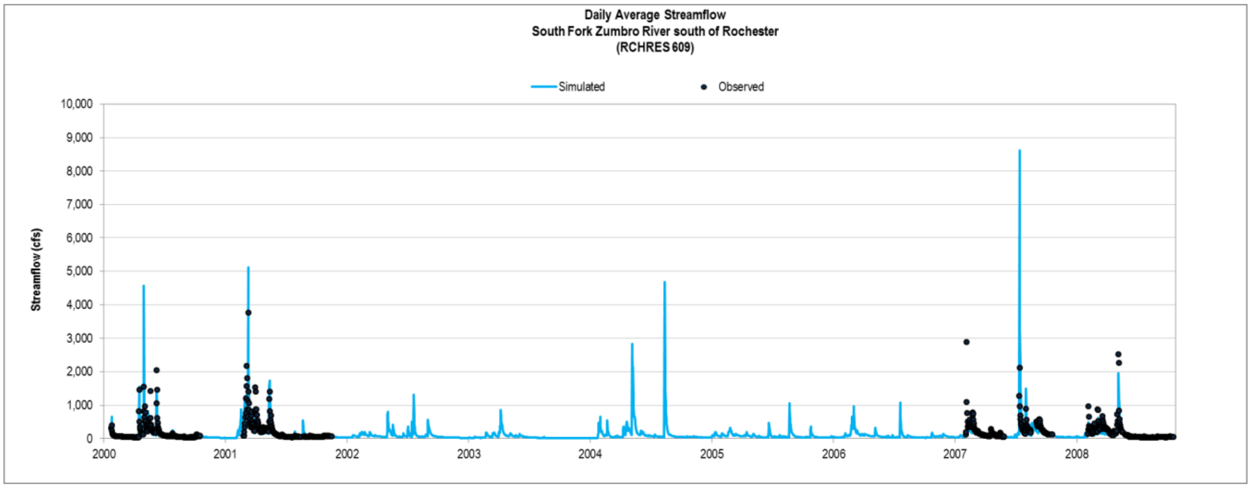

Figure A-41. Daily Average Streamflow for South Fork Zumbro River south of Rochester (RCHRES 609)

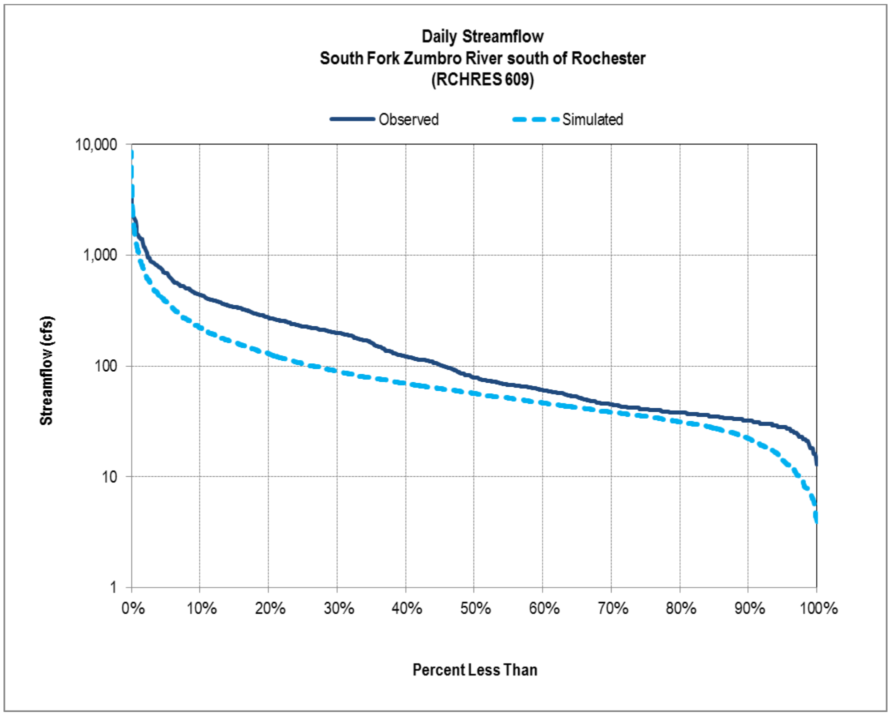

Figure A-42. Daily Streamflow Cumulative Frequency Distribution for South Fork Zumbro River south of Rochester (RCHRES 609)

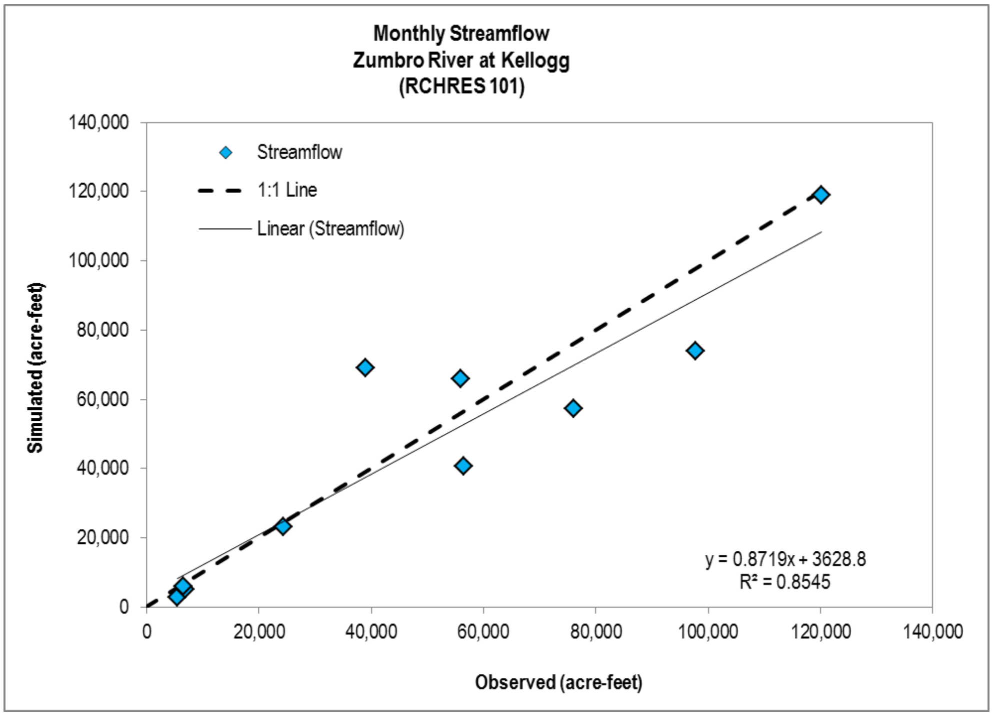

Figure A-43. Monthly Streamflow 1:1 Plot for Zumbro River at Kellogg (RCHRES 101)

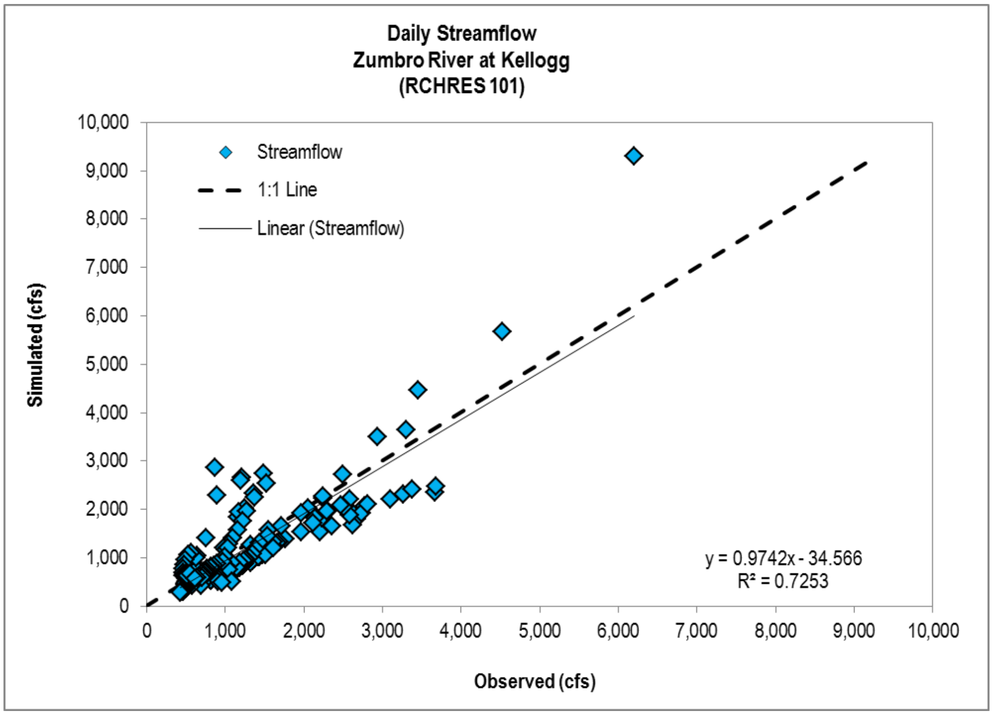

Figure A-44. Daily Streamflow 1:1 Plot for Zumbro River at Kellogg (RCHRES 101)

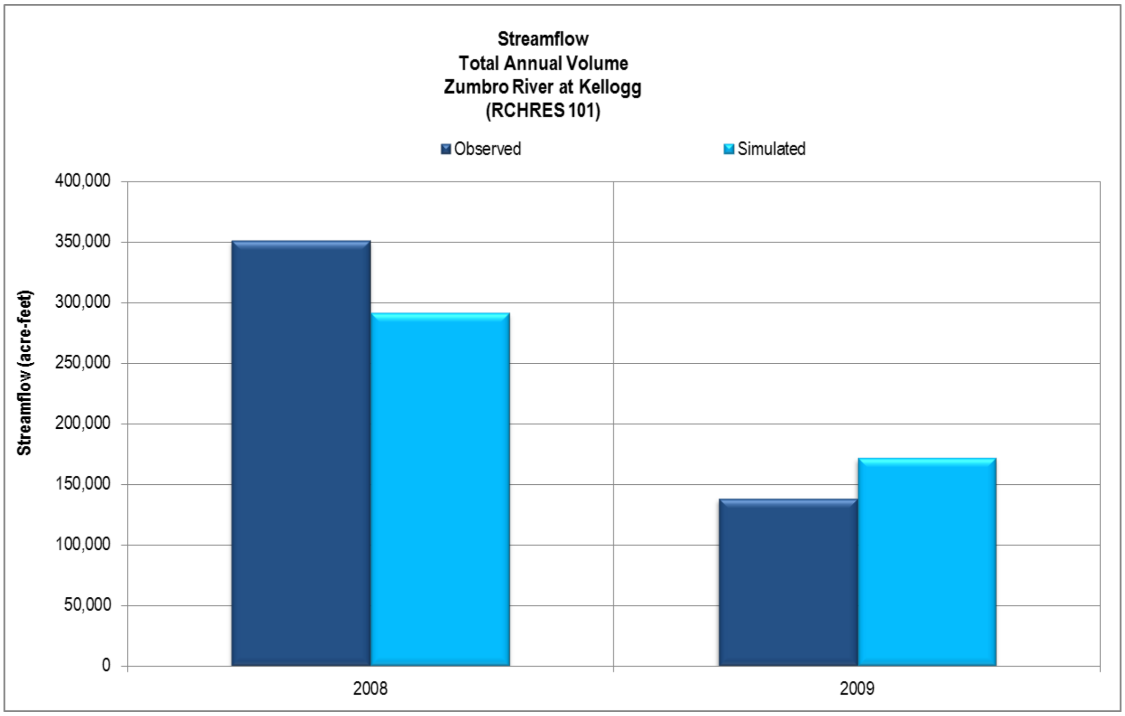

Figure A-45. Streamflow Total Annual Volume for Zumbro River at Kellogg (RCHRES 101)

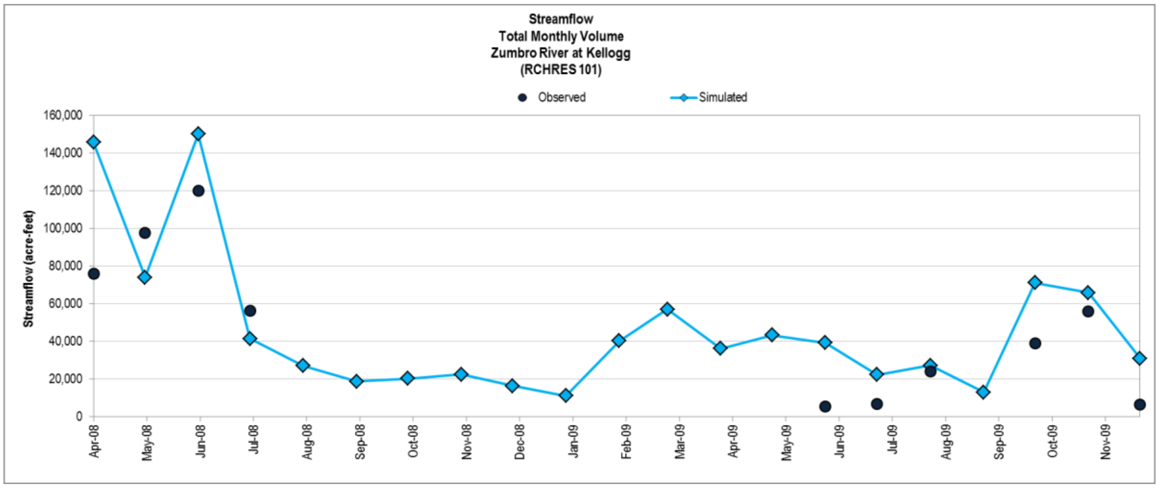

Figure A-46. Streamflow Total Monthly Volume for Zumbro River at Kellogg (RCHRES 101)

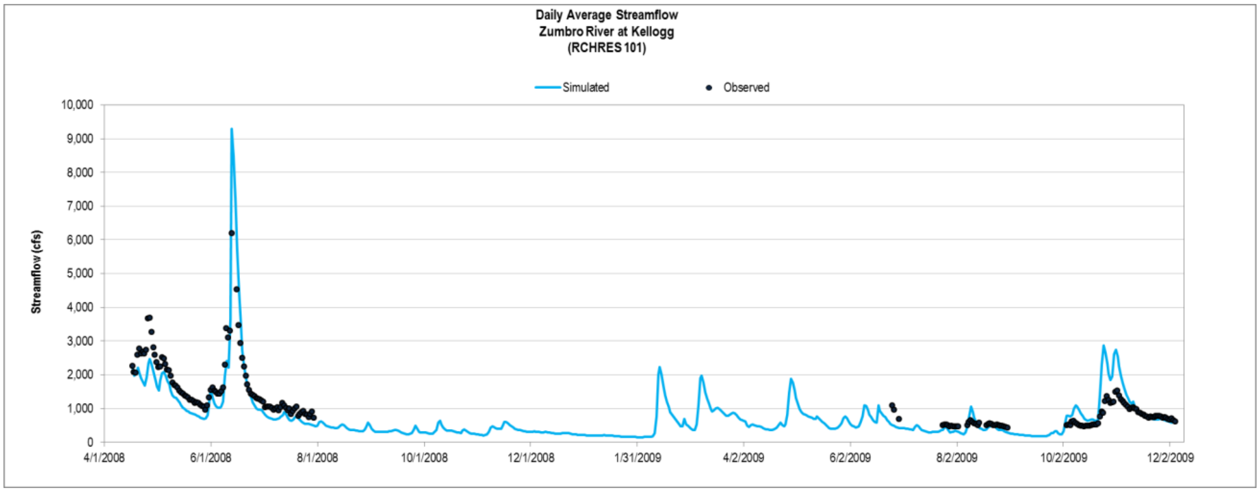

Figure A-47. Daily Average Streamflow for Zumbro River at Kellogg (RCHRES 101)

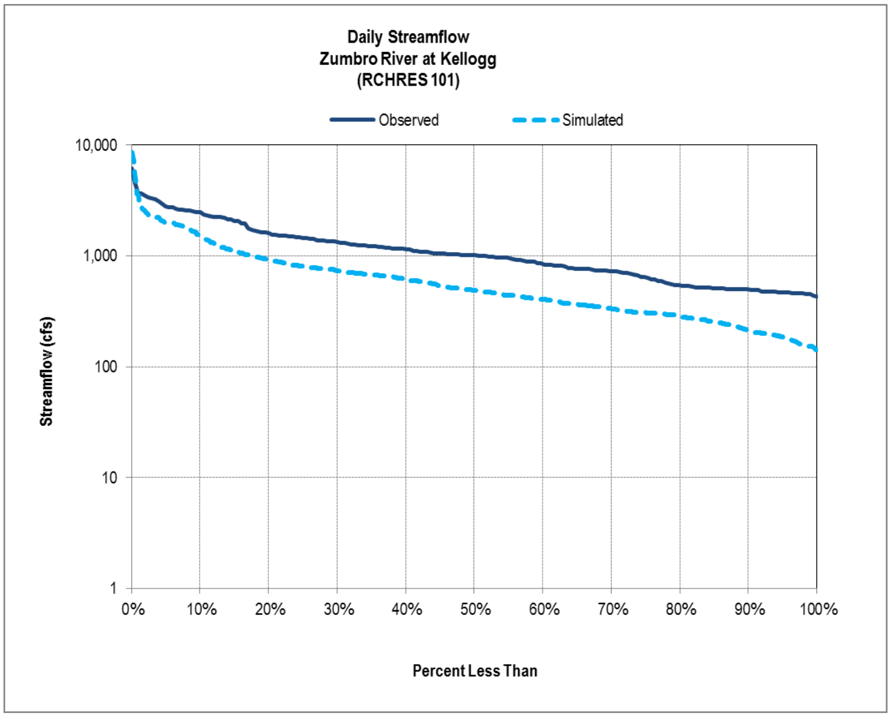

Figure A-48. Daily Streamflow Cumulative Frequency Distribution for Zumbro River at Kellogg (RCHRES 101)

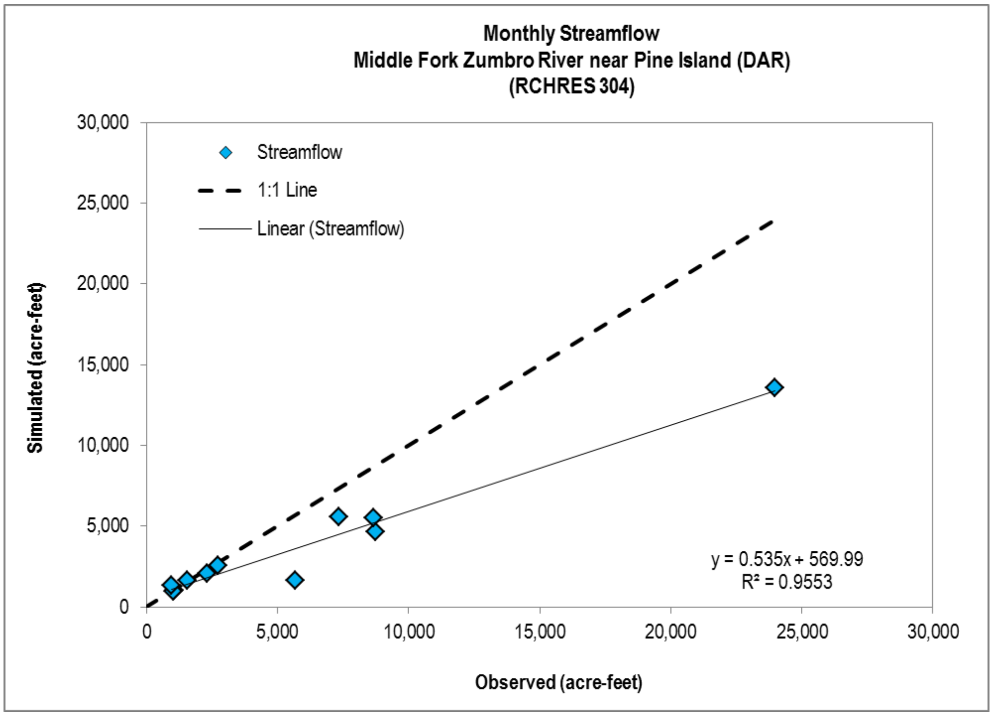

Figure A-49. Monthly Streamflow 1:1 Plot for Middle Fork Zumbro River near Pine Island (DAR) (RCHRES 304)

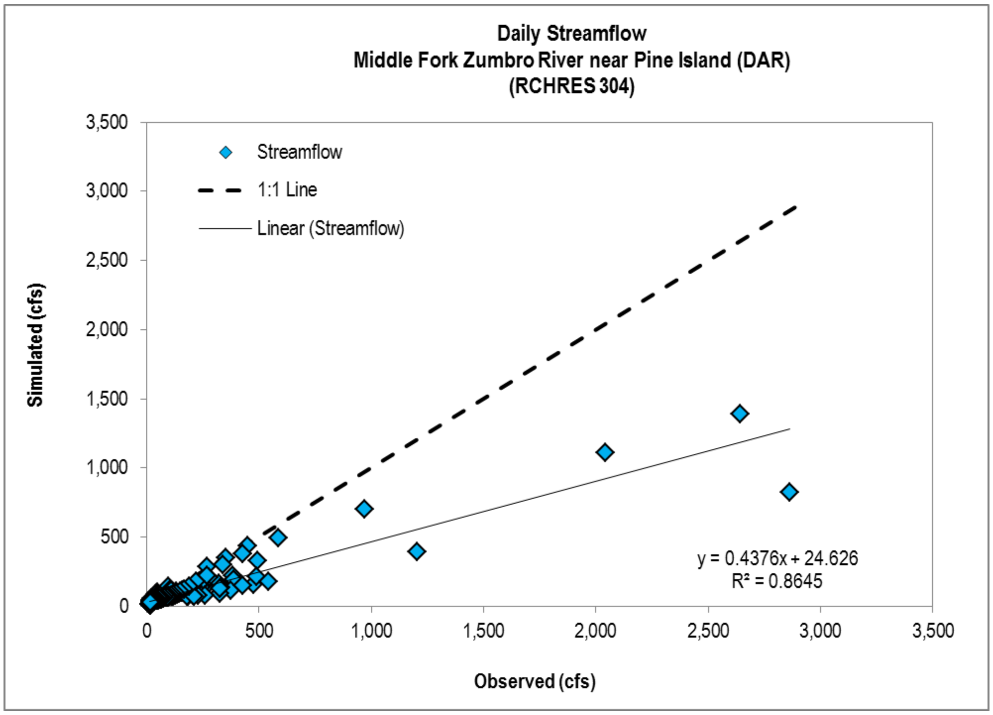

Figure A-50. Daily Streamflow 1:1 Plot for Middle Fork Zumbro River near Pine Island (DAR) (RCHRES 304)

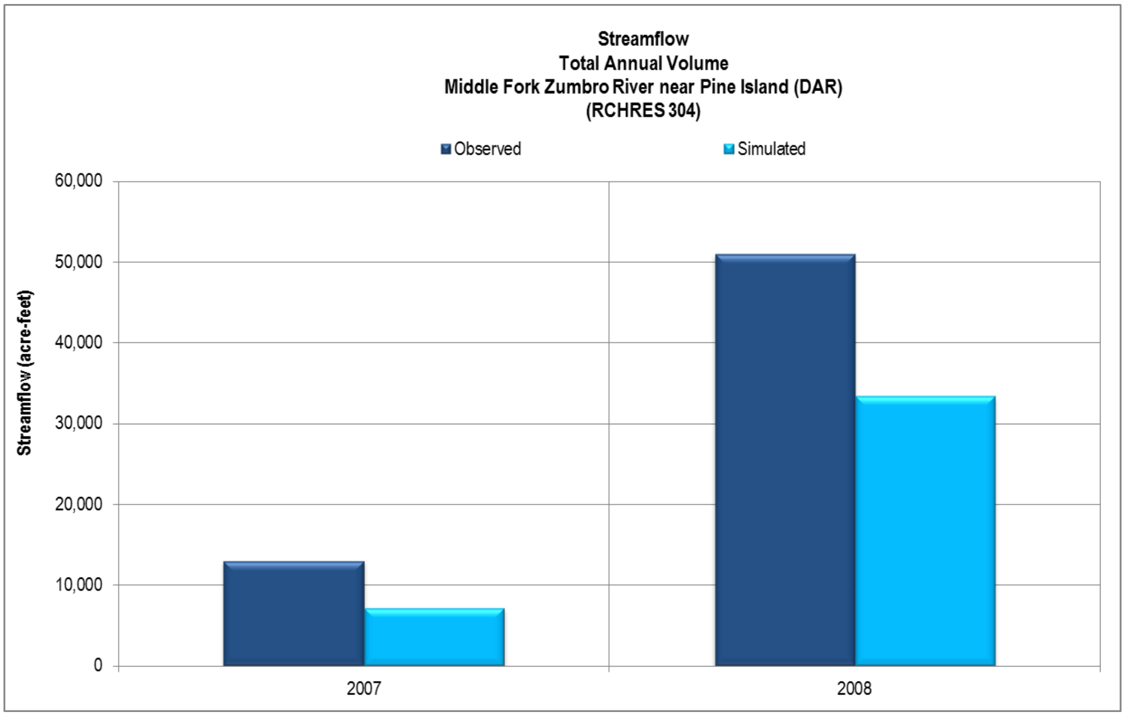

Figure A-51. Streamflow Total Annual Volume for Middle Fork Zumbro River near Pine Island (DAR) (RCHRES 304)

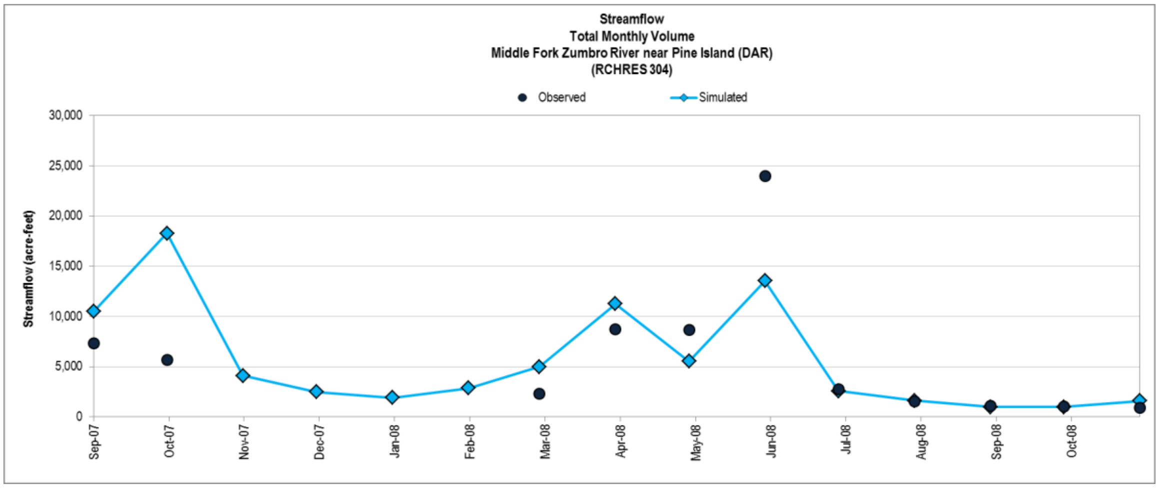

Figure A-52. Streamflow Total Monthly Volume for Middle Fork Zumbro River near Pine Island (DAR) (RCHRES 304)

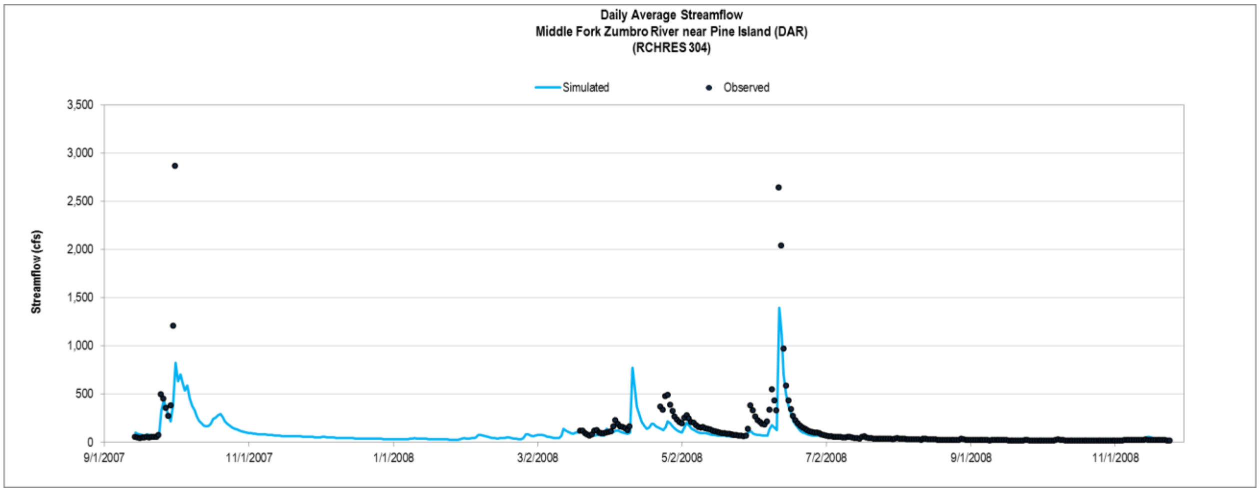

Figure A-53. Daily Average Streamflow for Middle Fork Zumbro River near Pine Island (DAR) (RCHRES 304)

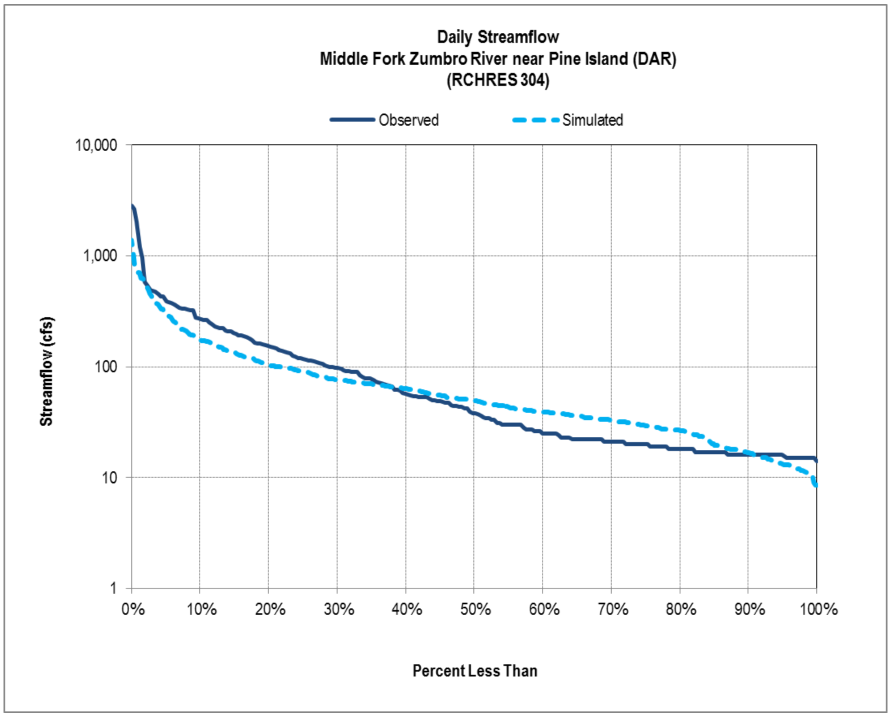

Figure A-54. Daily Streamflow Cumulative Frequency Distribution for Middle Fork Zumbro River near Pine Island (DAR) (RCHRES 304)

Appendix B
Sediment Simulation for Auxiliary Stations

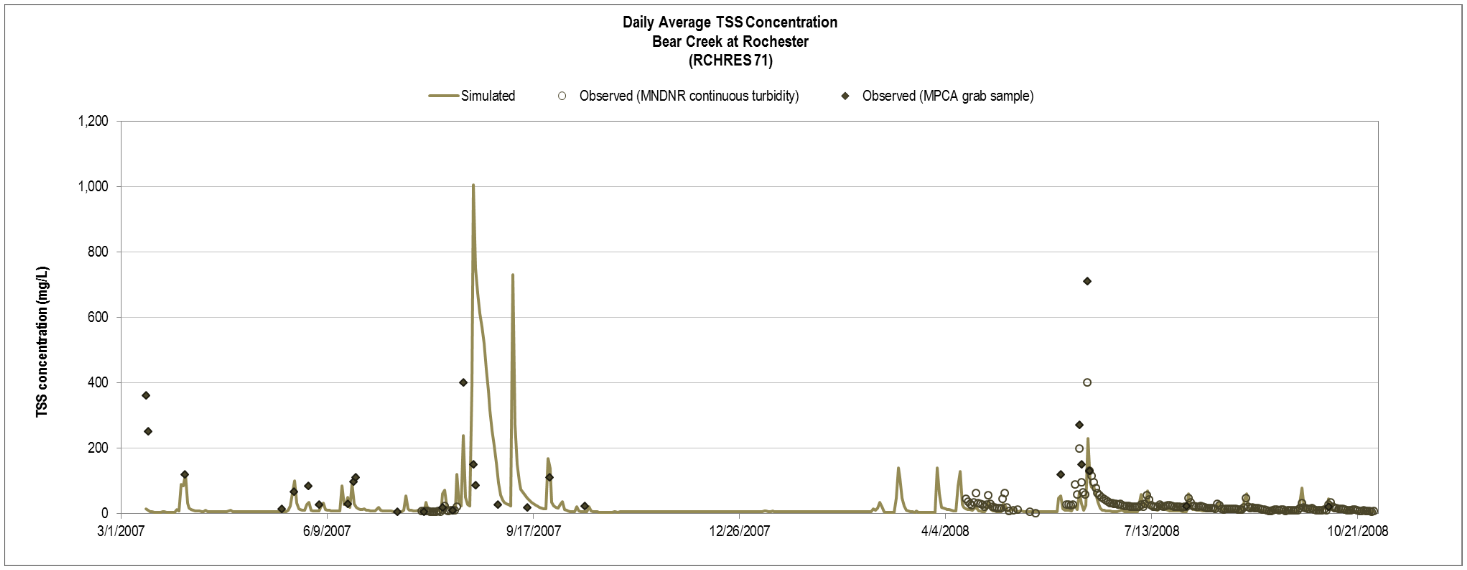

Figure B-1. Daily Average Total Suspended Sediment Concentrations for Bear Creek at Rochester (RCHRES 71)

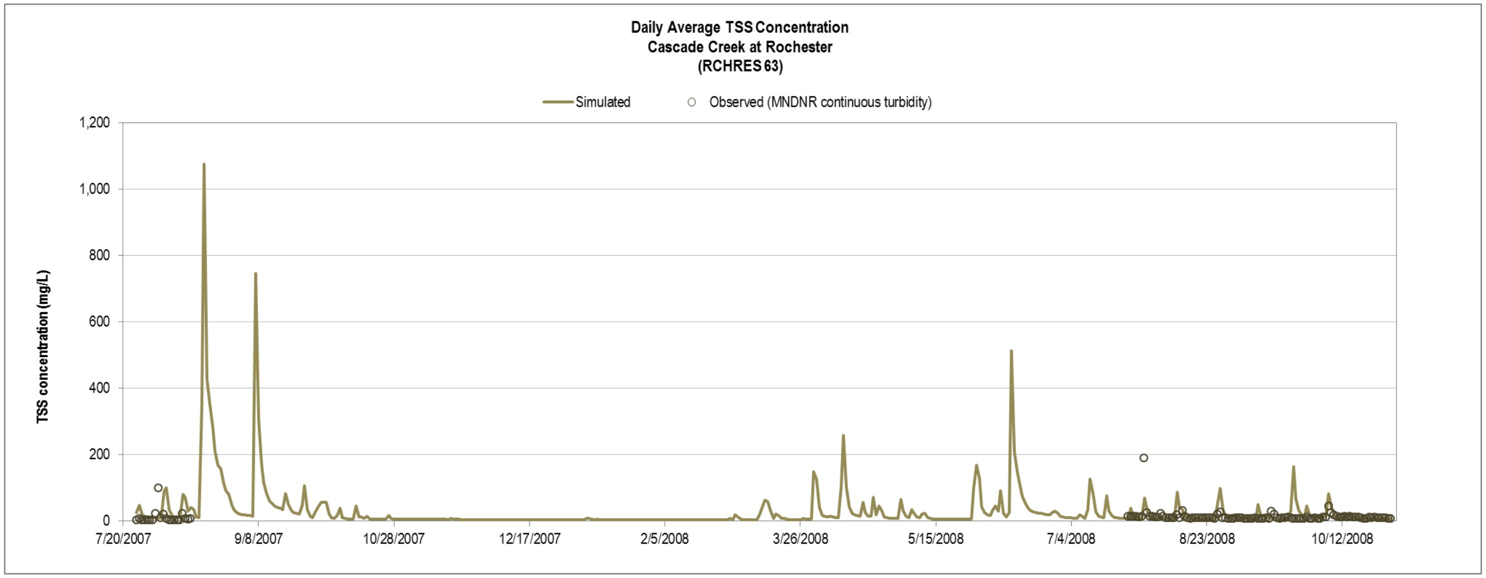

Figure B-2. Daily Average Total Suspended Sediment Concentrations for Cascade Creek at Rochester (RCHRES 63)

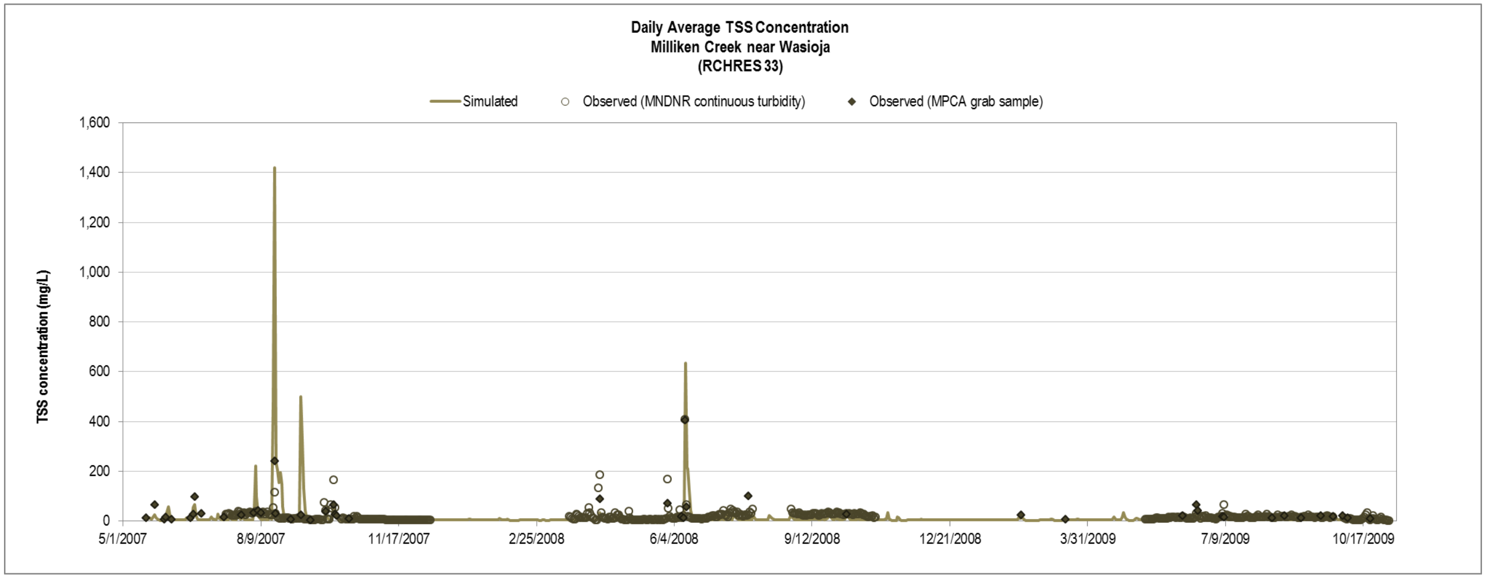

Figure B-3. Daily Average Total Suspended Sediment Concentrations for Milliken Creek near Wasioja (RCHRES 33)

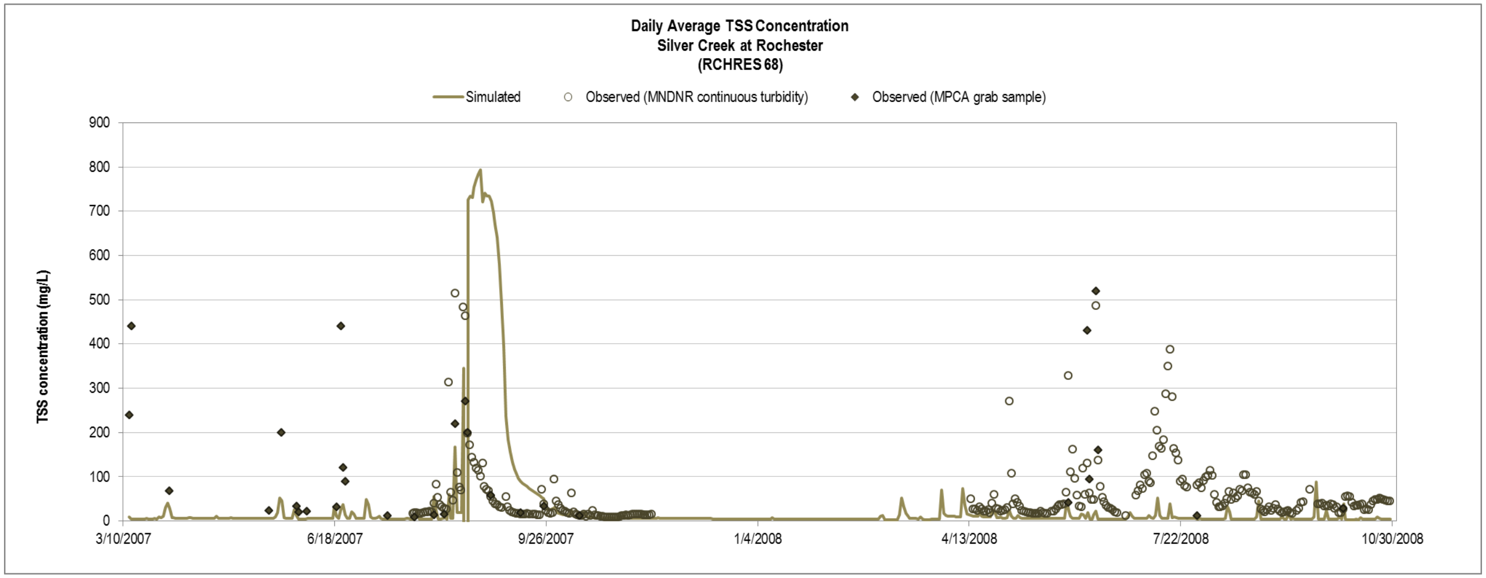

Figure B-4. Daily Average Total Suspended Sediment Concentrations for Silver Creek at Rochester (RCHRES 68).

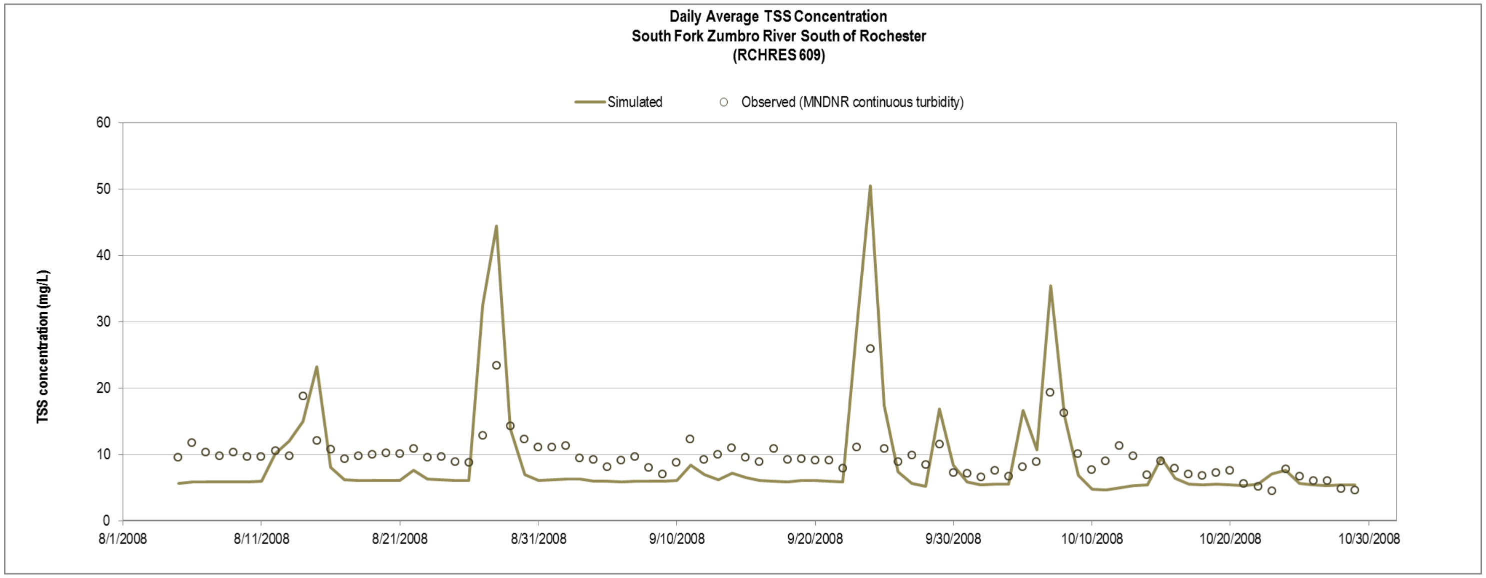

Figure B-5. Daily Average Total Suspended Sediment Concentrations for South Fork Zumbro River South of Rochester (RCHRES 609)

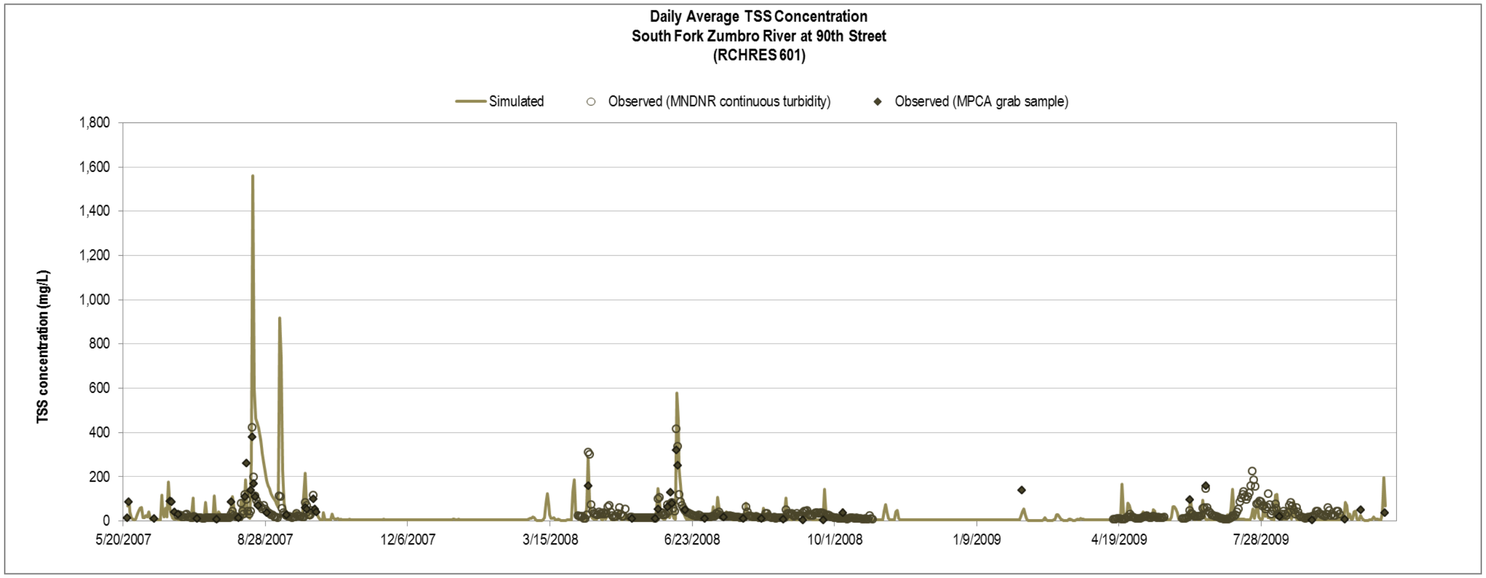

Figure B-6. Daily Average Total Suspended Sediment Concentrations for South Fork Zumbro River at 90th Street (RCHRES 601)

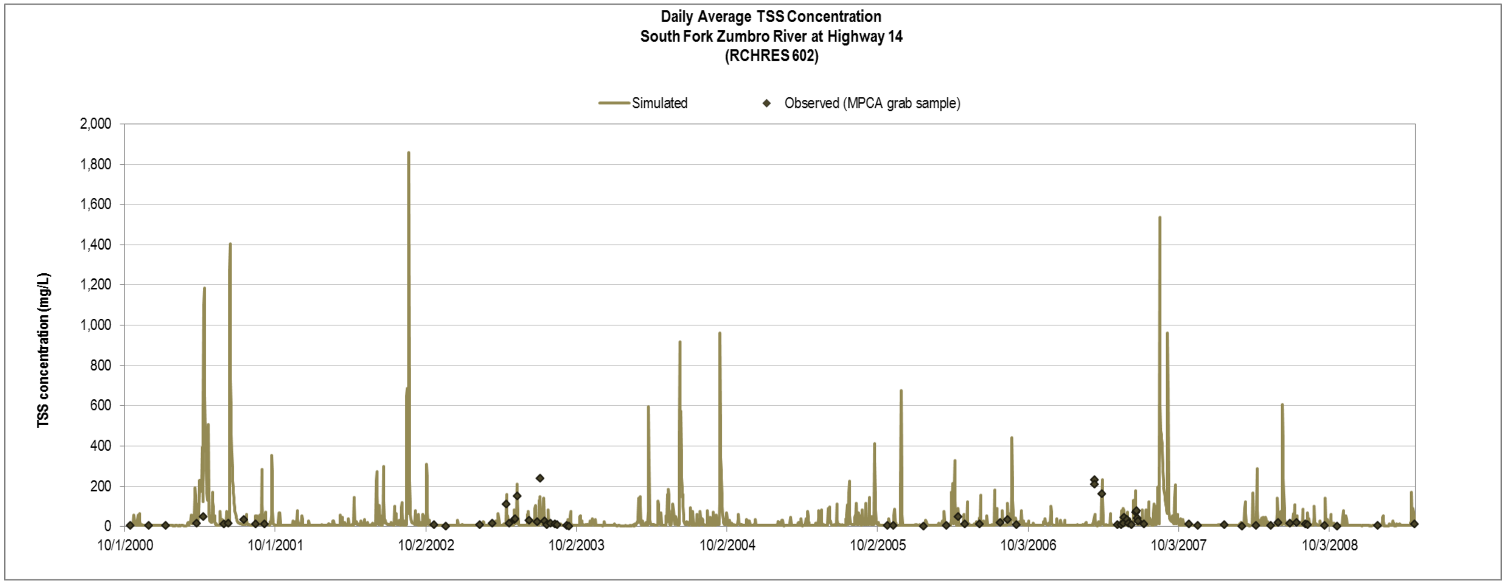

Figure B-7. Daily Average Total Suspended Sediment Concentrations for South Fork Zumbro River at Highway 14 (RCHRES 602)

Appendix C

Water Temperature Simulation for Auxiliary Stations

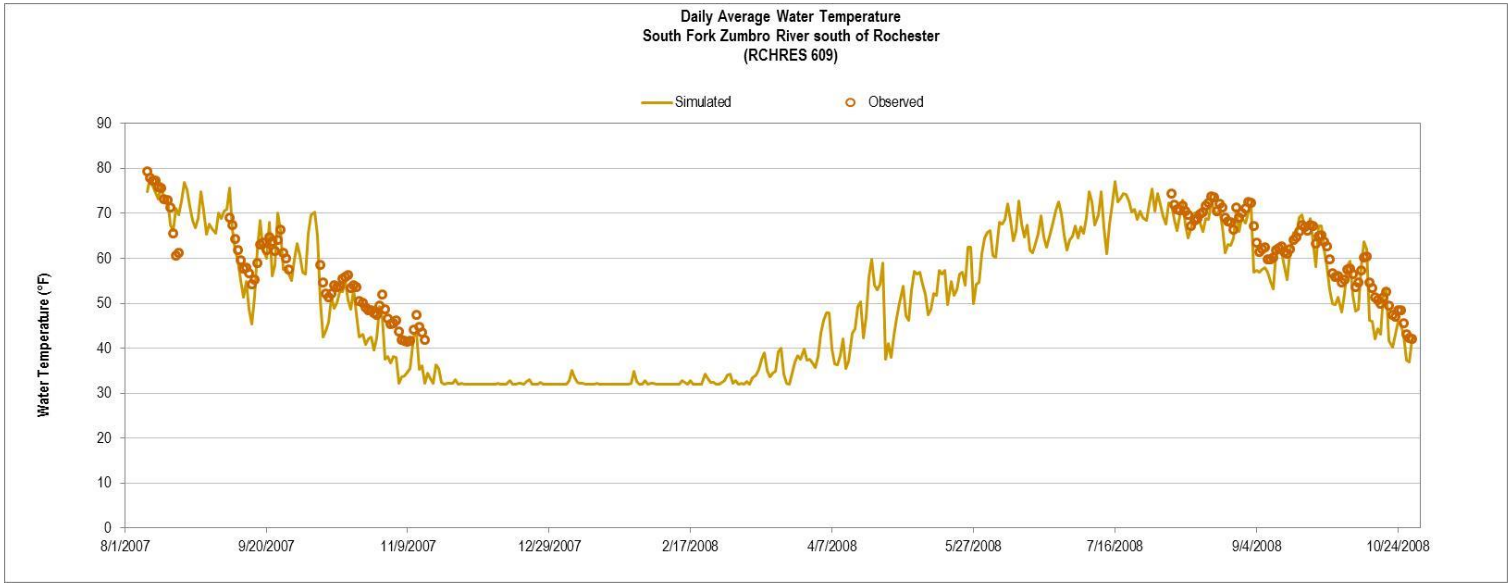

Figure C-1. Daily Average Water Temperatures for South Fork Zumbro River South of Rochester (RCHRES 609)

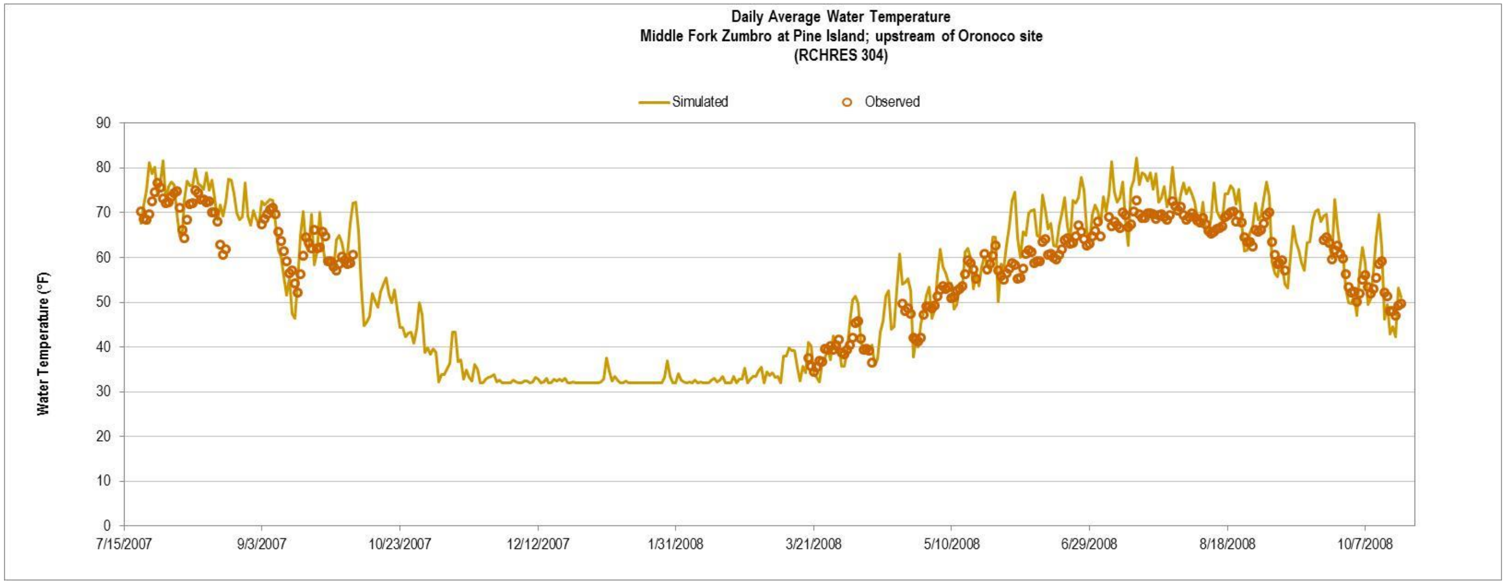

Figure C-2. Daily Average Water Temperatures for Middle Fork Zumbro River at Pine Island (RCHRES 304)

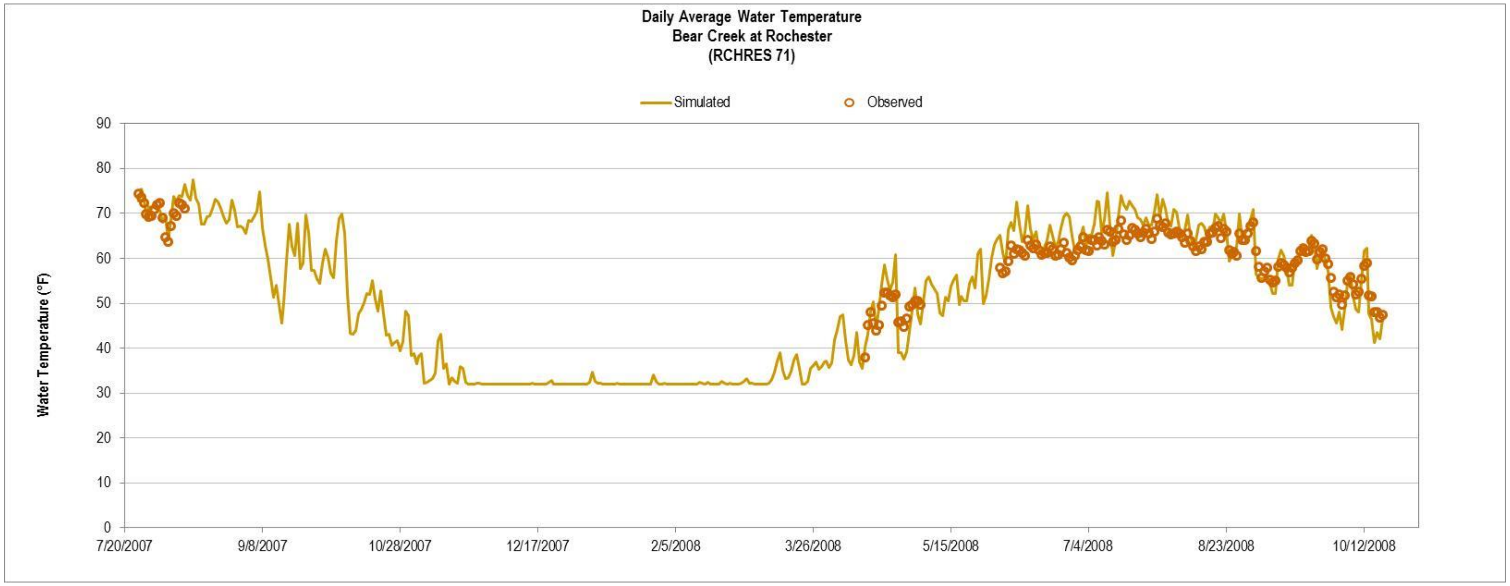

Figure C-3. Daily Average Water Temperatures for Bear Creek at Rochester (RCHRES 71)

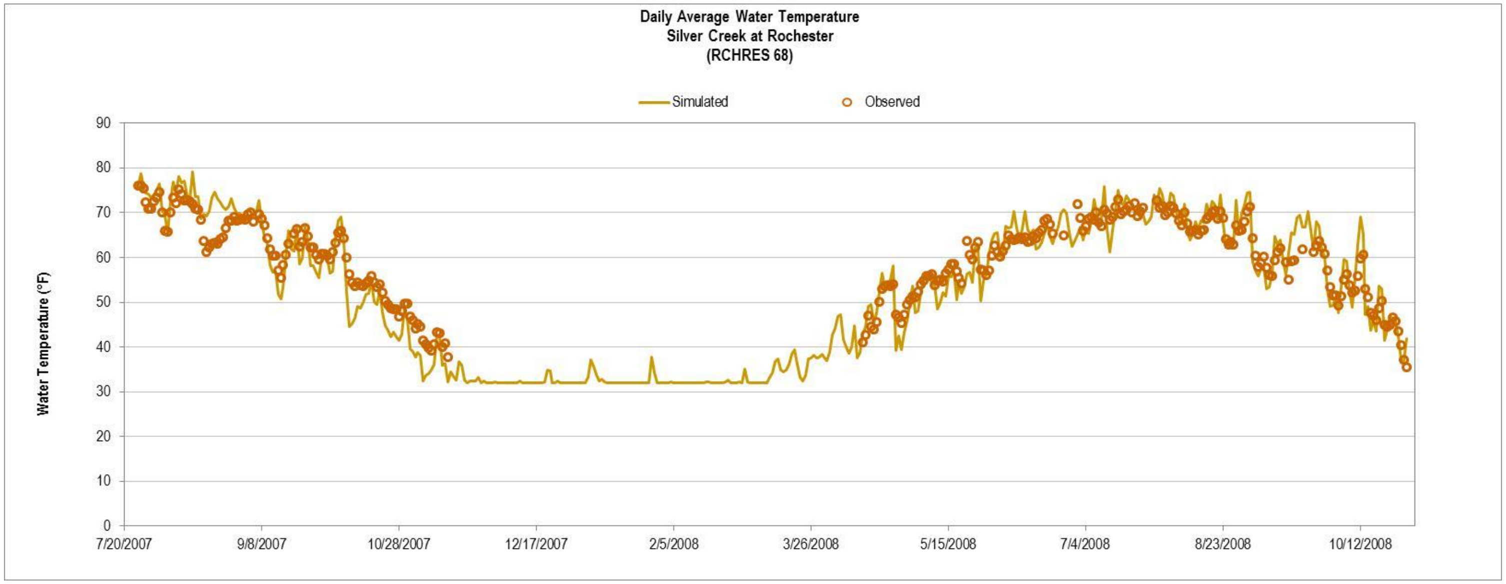

Figure C-4. Daily Average Water Temperatures for Silver Creek at Rochester (RCHRES 68)

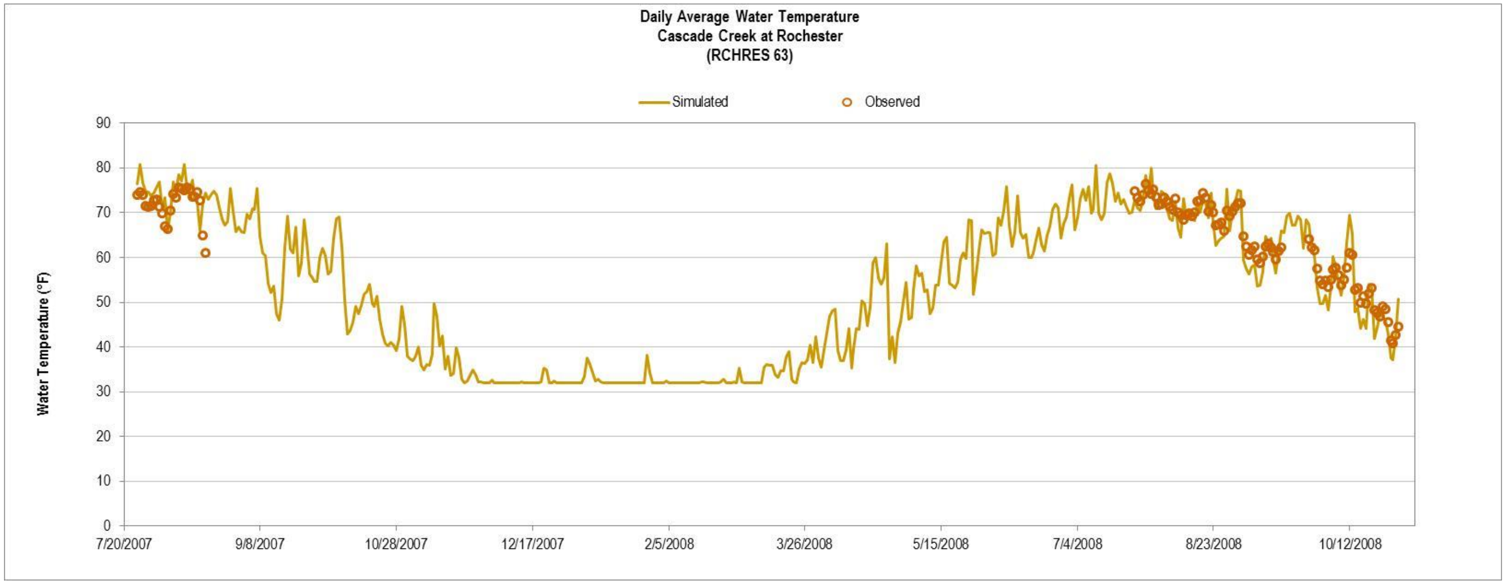

Figure C-5. Daily Average Water Temperatures for Cascade Creek at Rochester (RCHRES 63)

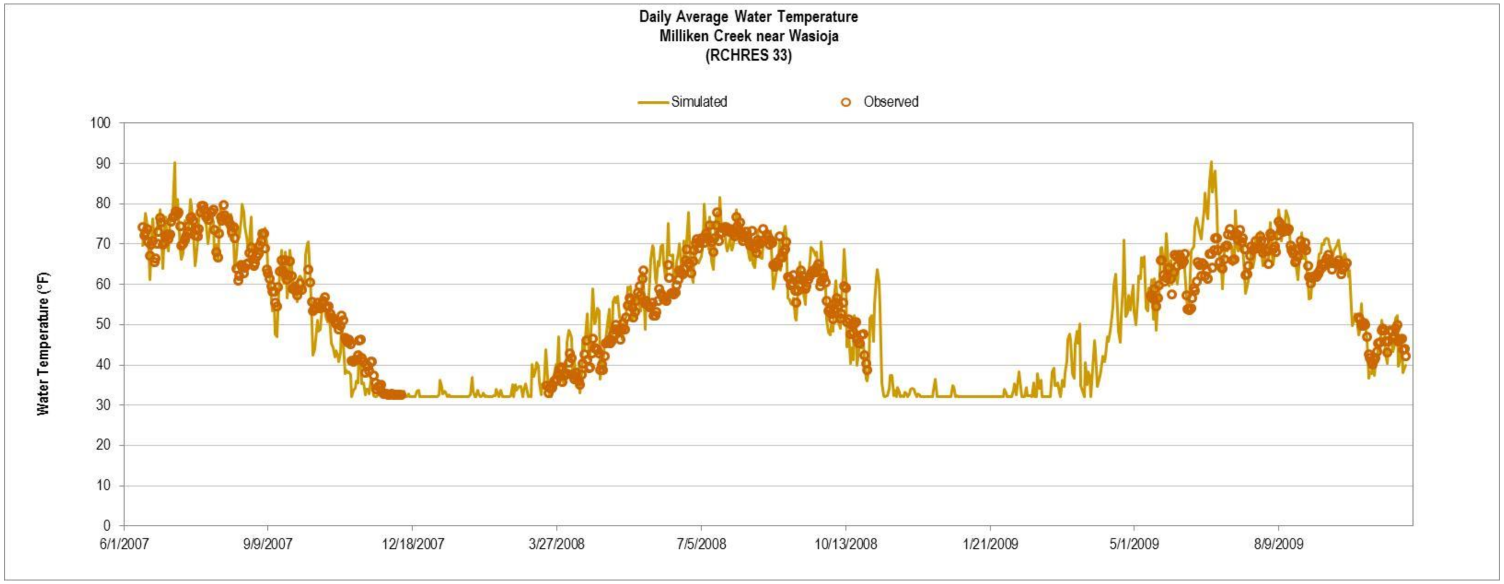

Figure C-6. Daily Average Water Temperatures for Milliken Creek near Wasioja (RCHRES 33)

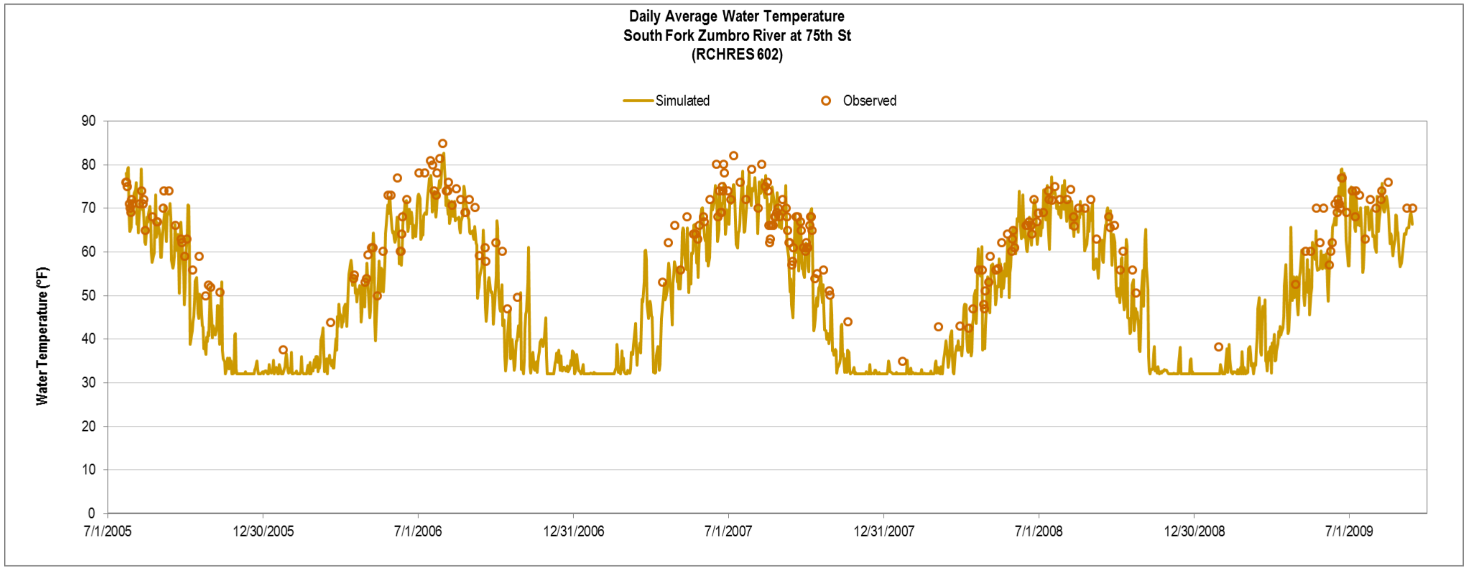

Figure C-7. Daily Average Water Temperatures for South Fork Zumbro River at 75th Street (RCHRES 602).

Appendix D
Phosphorus Simulation for Auxiliary Stations

Total Phosphorus

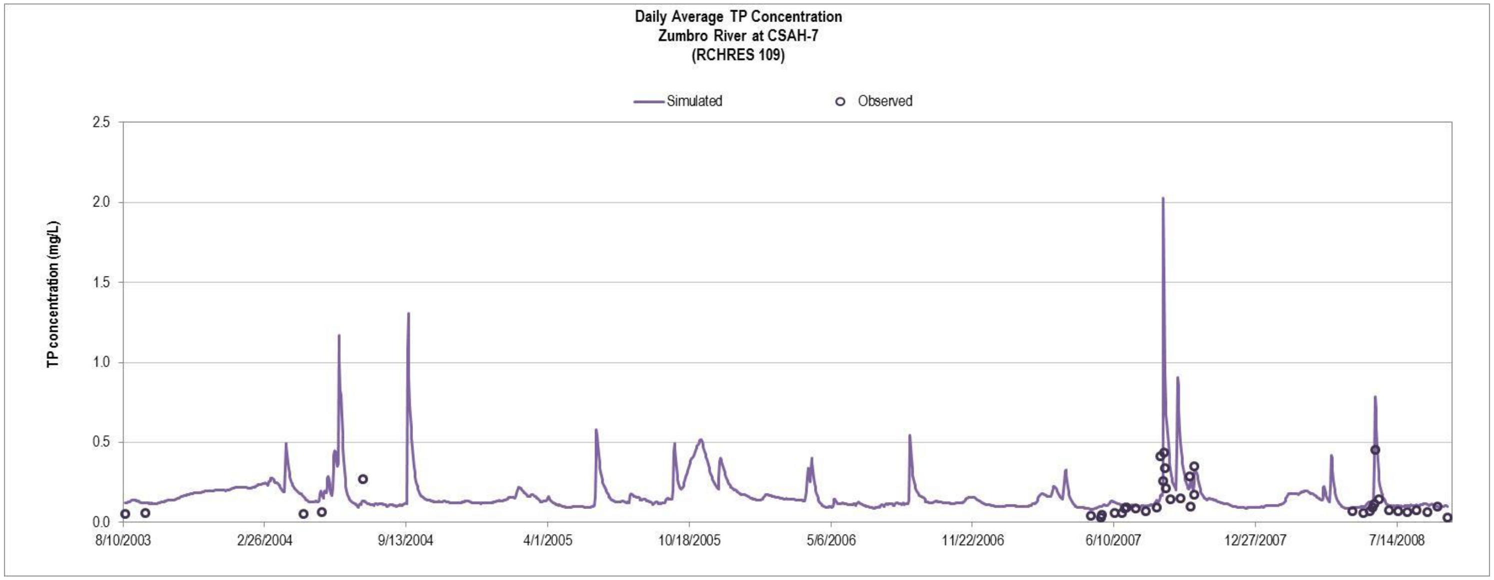

Figure D-1. Daily Average Total Phosphorus Concentrations for Zumbro River at CSAH-7 (RCHRES 109)

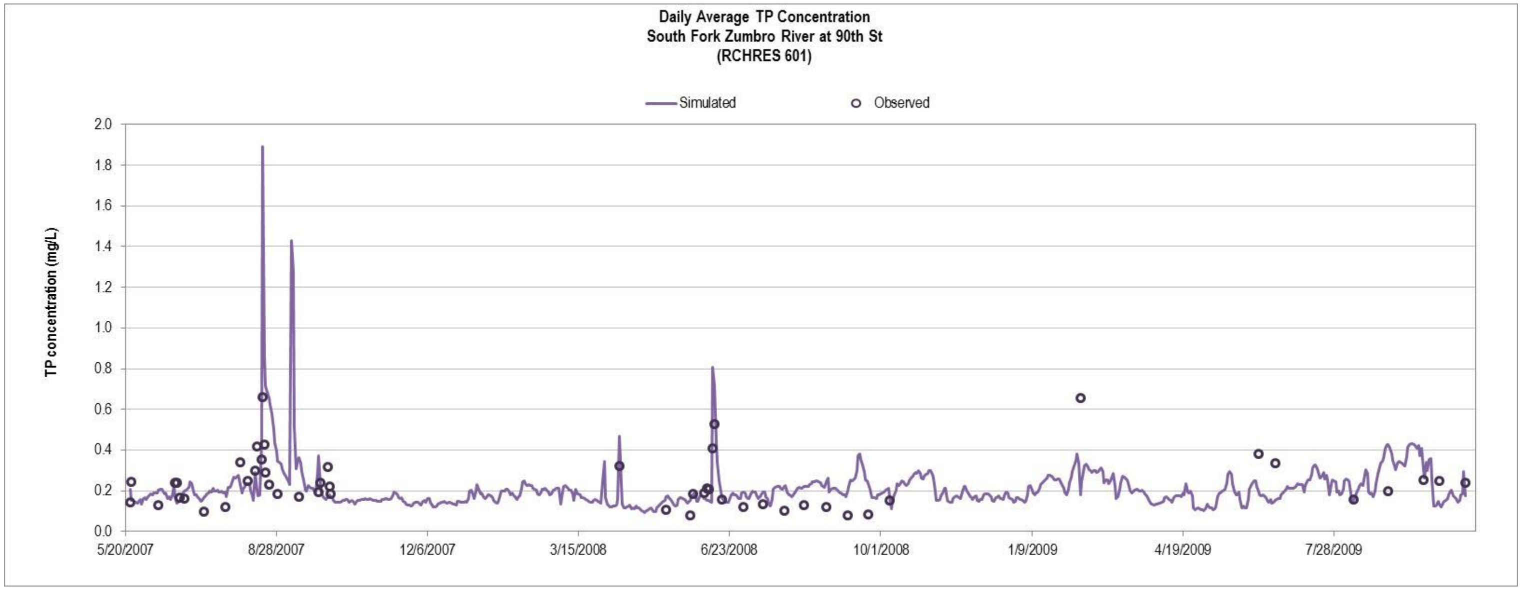

Figure D-2. Daily Average Total Phosphorus Concentrations for South Fork Zumbro River at 90th Street (RCHRES 601)

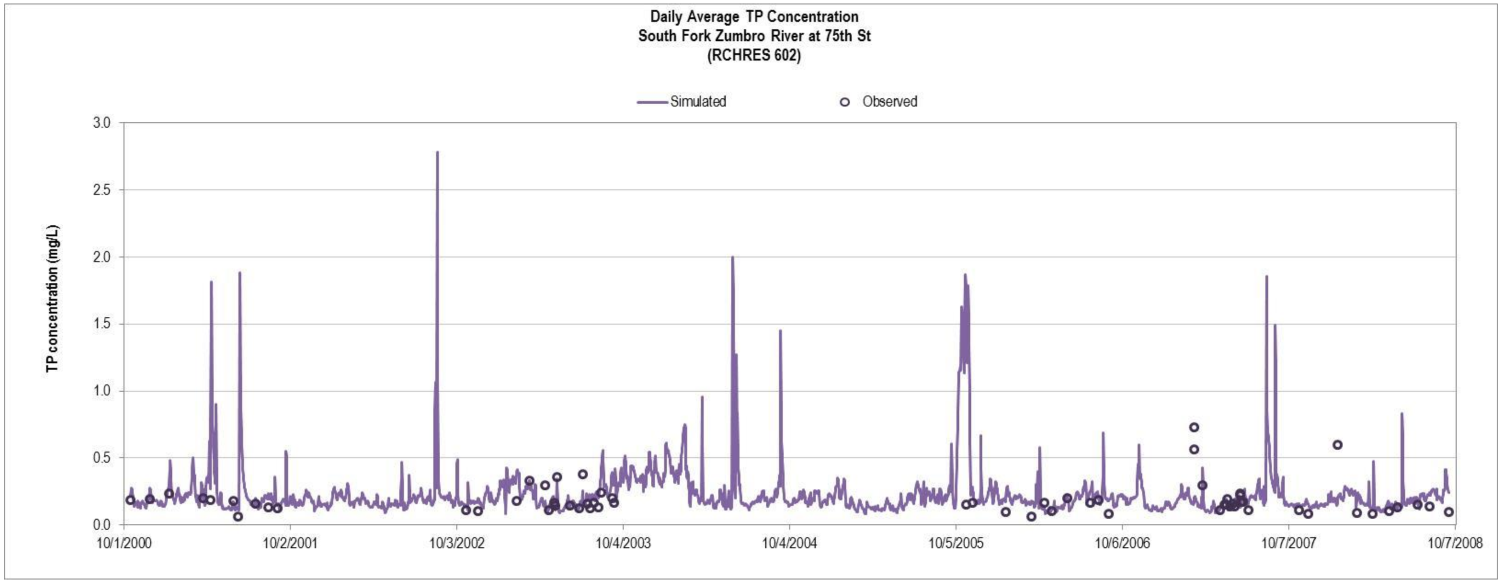

Figure D-3. Daily Average Total Phosphorus Concentrations for South Fork Zumbro River at 75th Street (RCHRES 602)

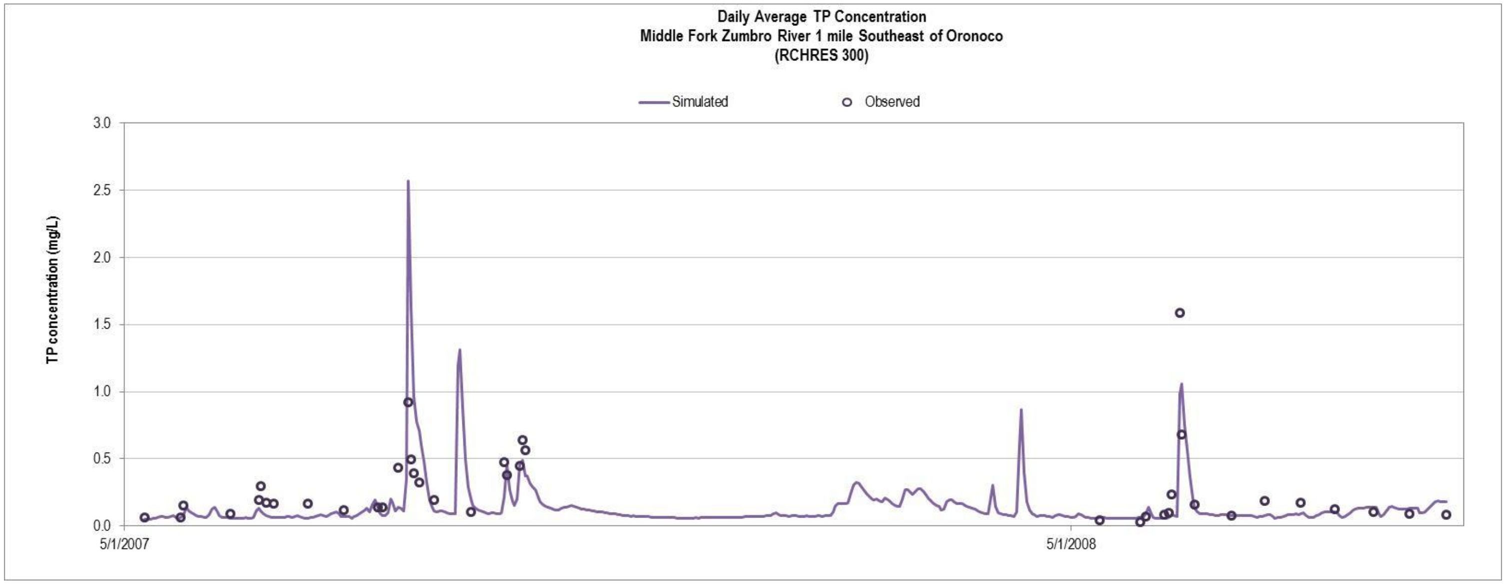

Figure D-4. Daily Average Total Phosphorus Concentrations for Middle Fork Zumbro River 1 mile Southeast of Oronoco (RCHRES 300)

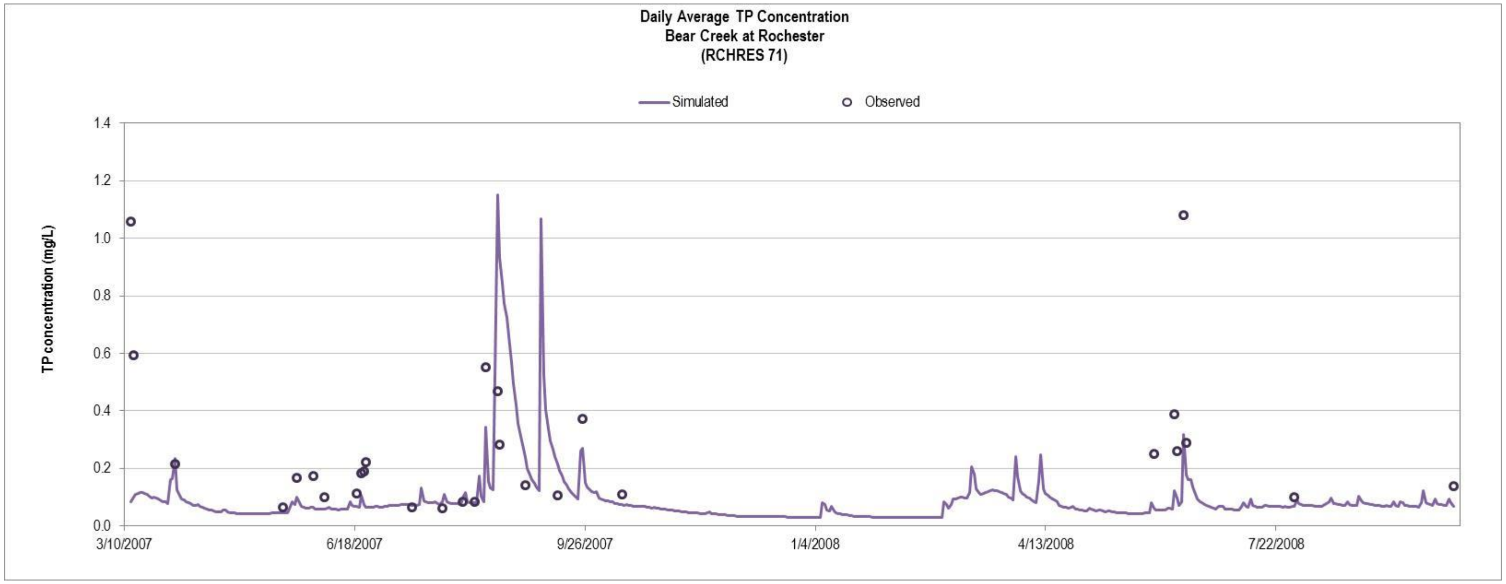

Figure D-5. Daily Average Total Phosphorus Concentrations for Bear Creek at Rochester (RCHRES 71)

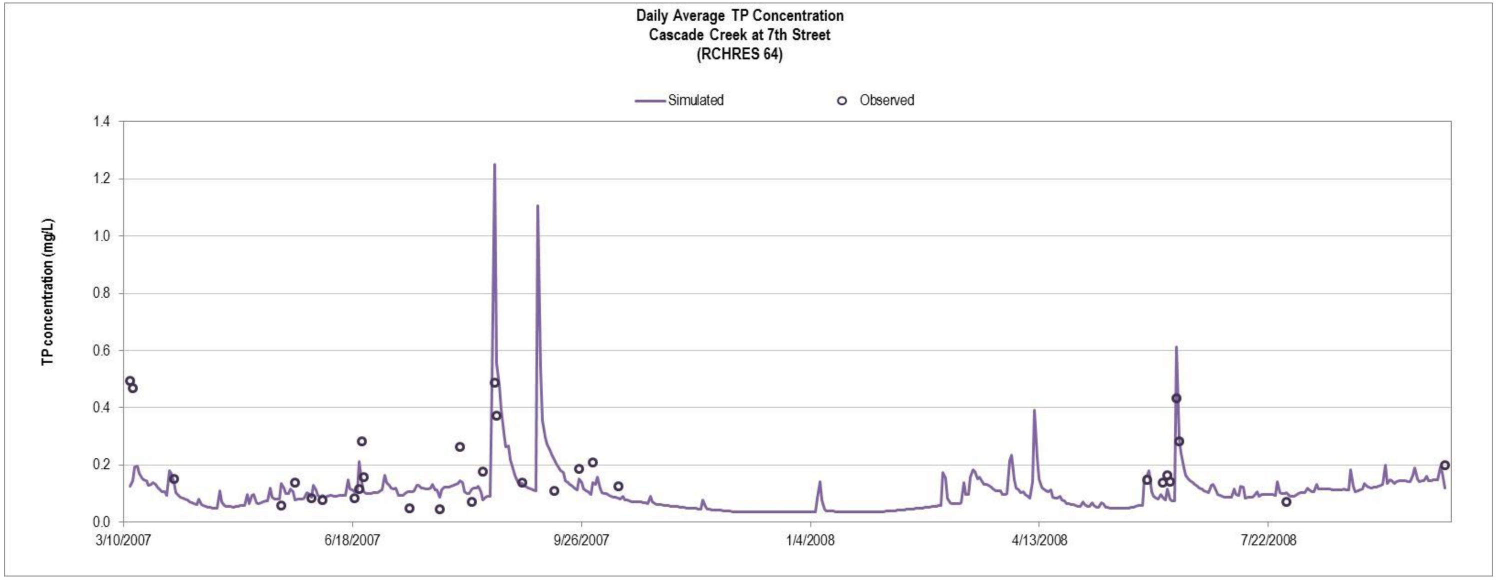

Figure D-6. Daily Average Total Phosphorus Concentrations for Cascade Creek at 7th Street (RCHRES 64)

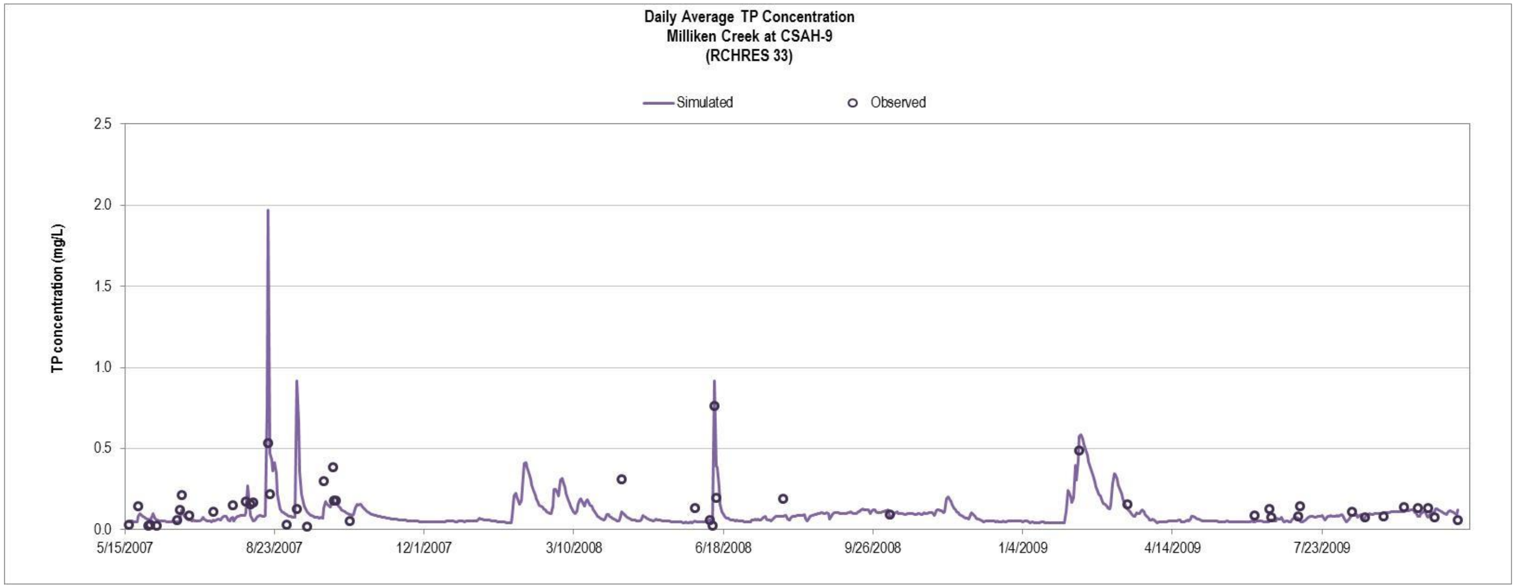

Figure D-7. Daily Average Total Phosphorus Concentrations for Milliken Creek at CSAH-9 (RCHRES 33)

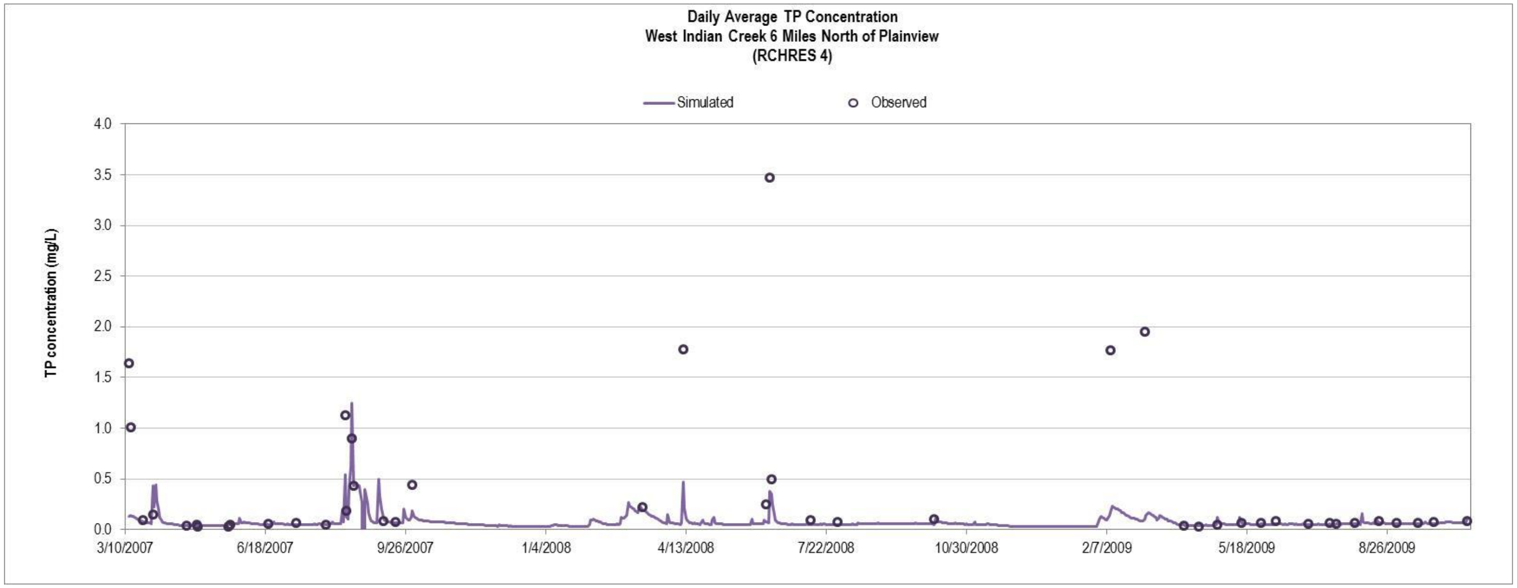

Figure D-8. Daily Average Total Phosphorus Concentrations for West Indian Creek 6 miles North of Plainview (RCHRES 4)

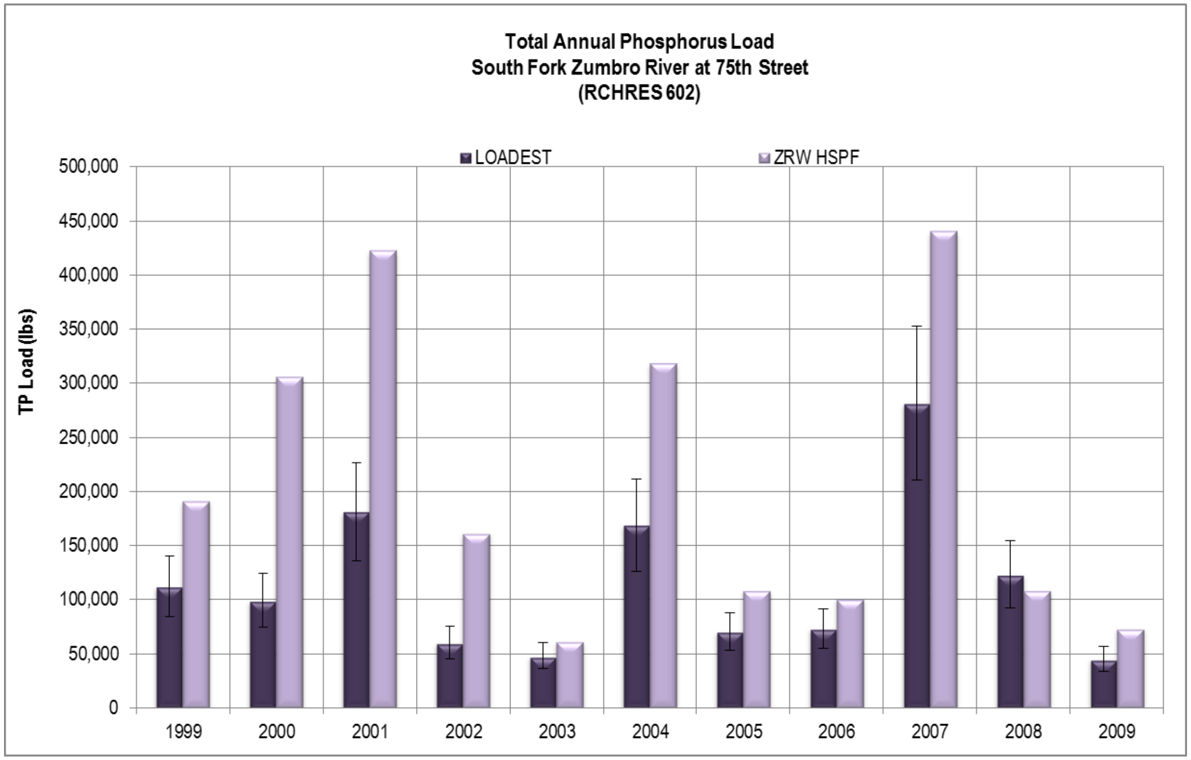

Figure D-9. Annual Total Phosphorus Load at South Fork Zumbro River at 75th Street (RCHRES 602)

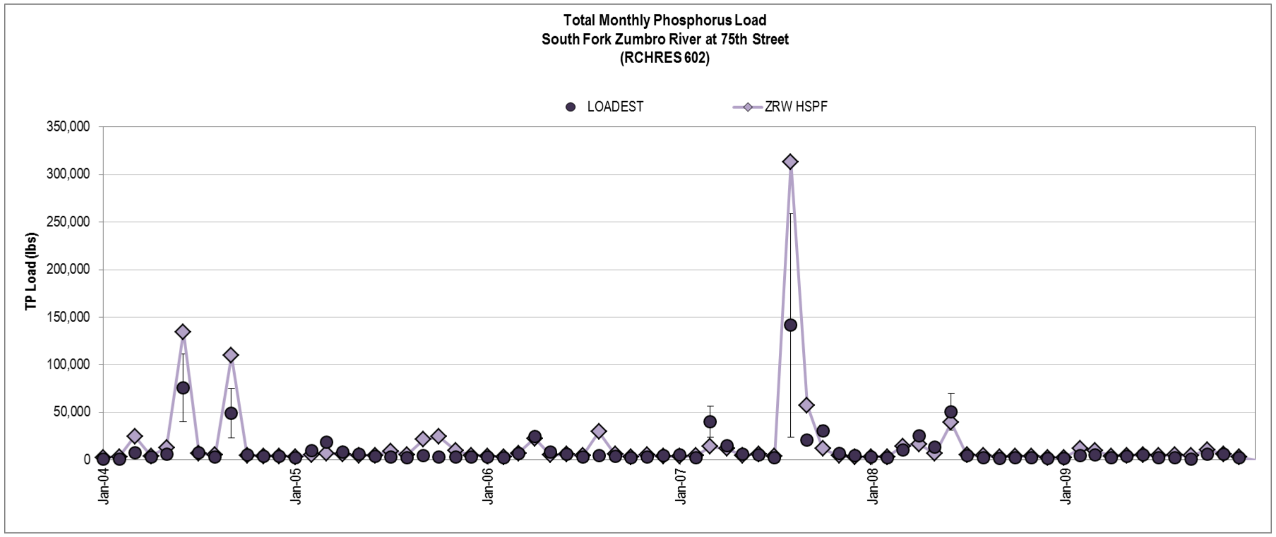

Figure D-10. Monthly Total Phosphorus Load at South Fork Zumbro River at 75th Street (RCHRES 602)

Orthophosphate

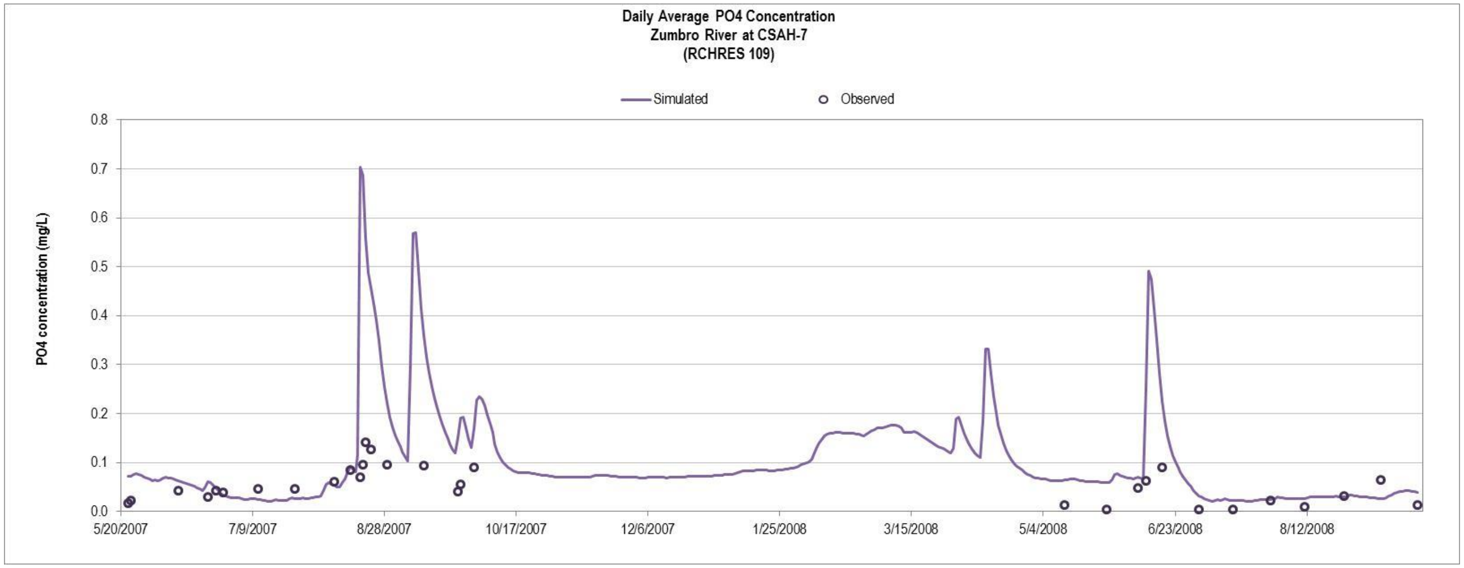

Figure D-11. Daily Average Orthophosphate Concentrations for Zumbro River at CSAH-7 (RCHRES 109)

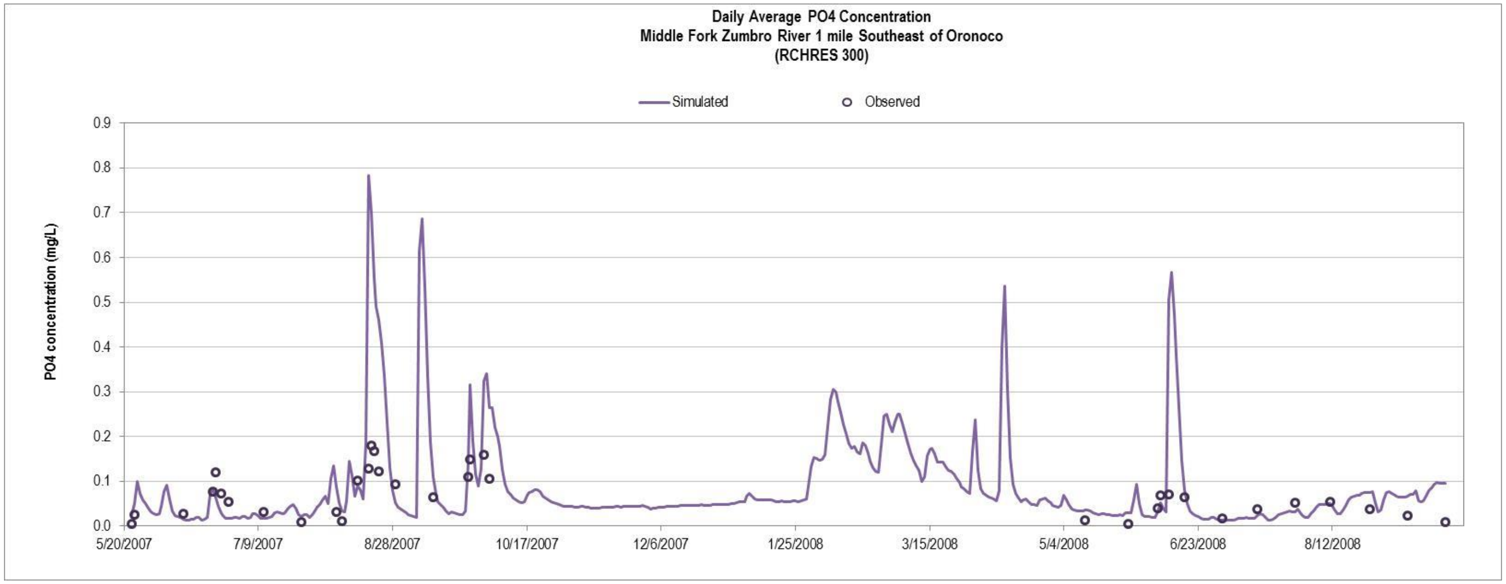

Figure D-12. Daily Average Orthophosphate Concentrations for Middle Fork Zumbro River 1 mile Southeast of Oronoco (RCHRES 300)

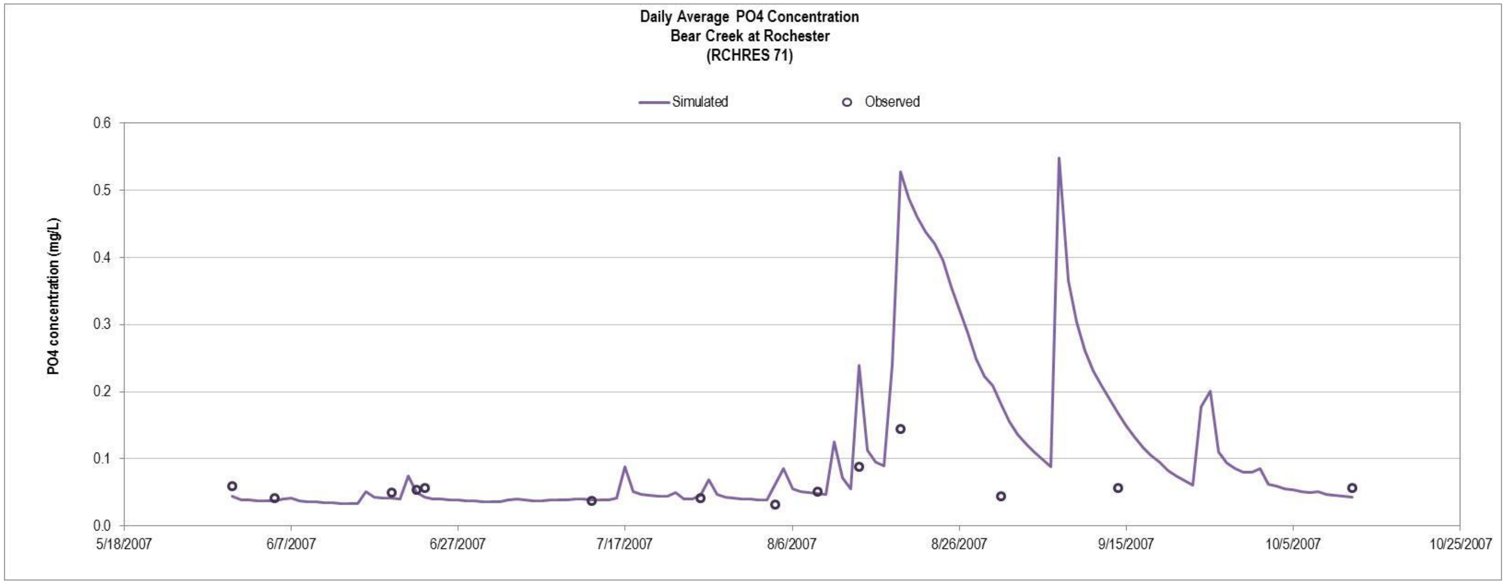

Figure D-13. Daily Average Orthophosphate Concentrations for Bear Creek at Rochester (RCHRES 71)

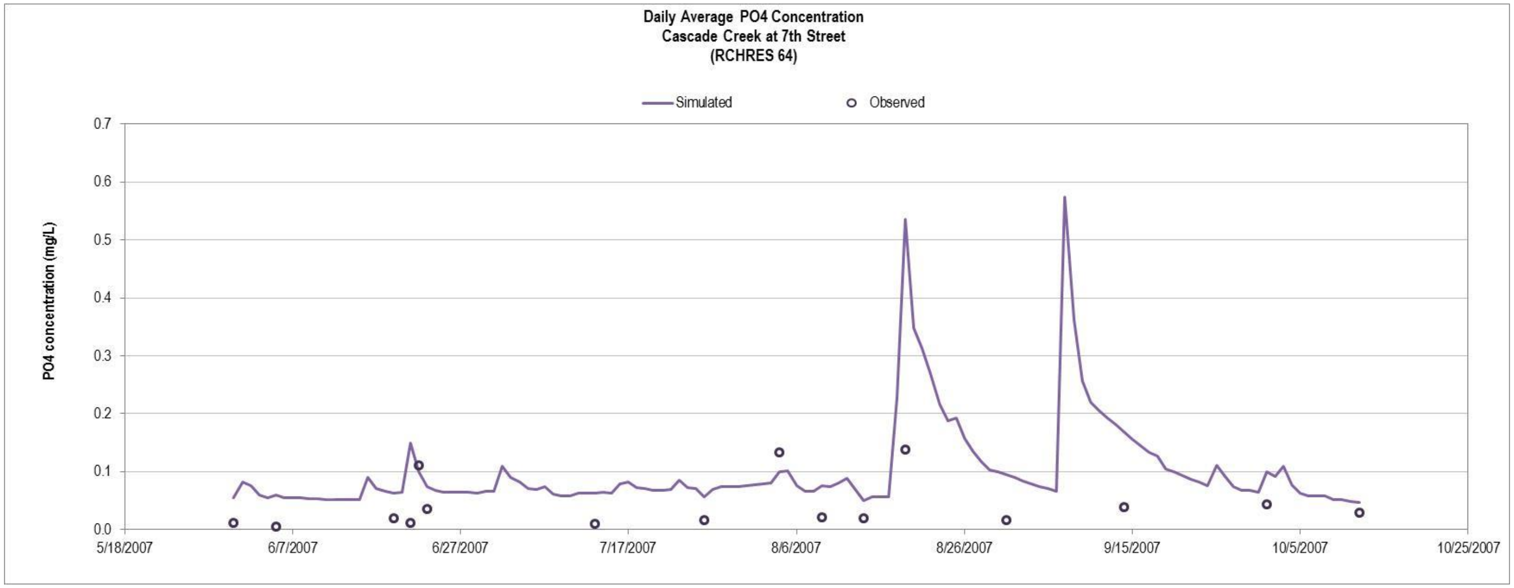

Figure D-14. Daily Average Orthophosphate Concentrations for Cascade Creek at 7th Street (RCHRES 64)

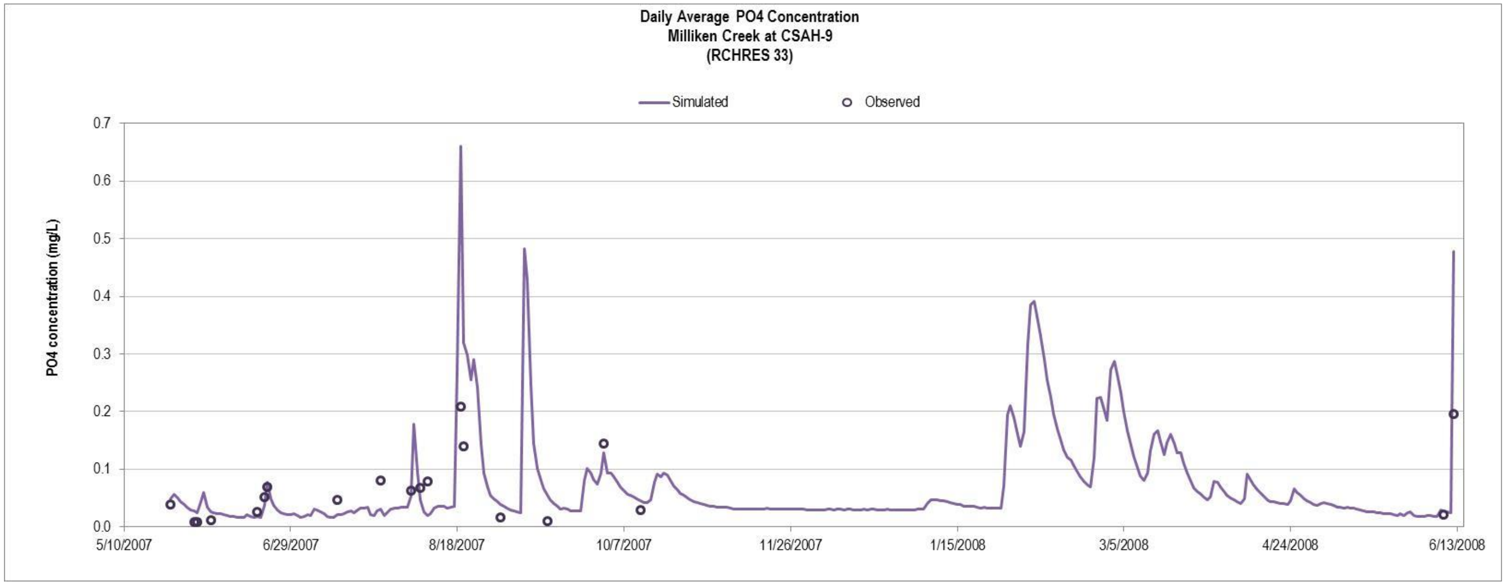

Figure D-15. Daily Average Orthophosphate Concentrations for Milliken Creek at CSAH-9 (RCHRES 33)

Appendix E
Nitrogen Simulation for Auxiliary Stations

Total Nitrogen

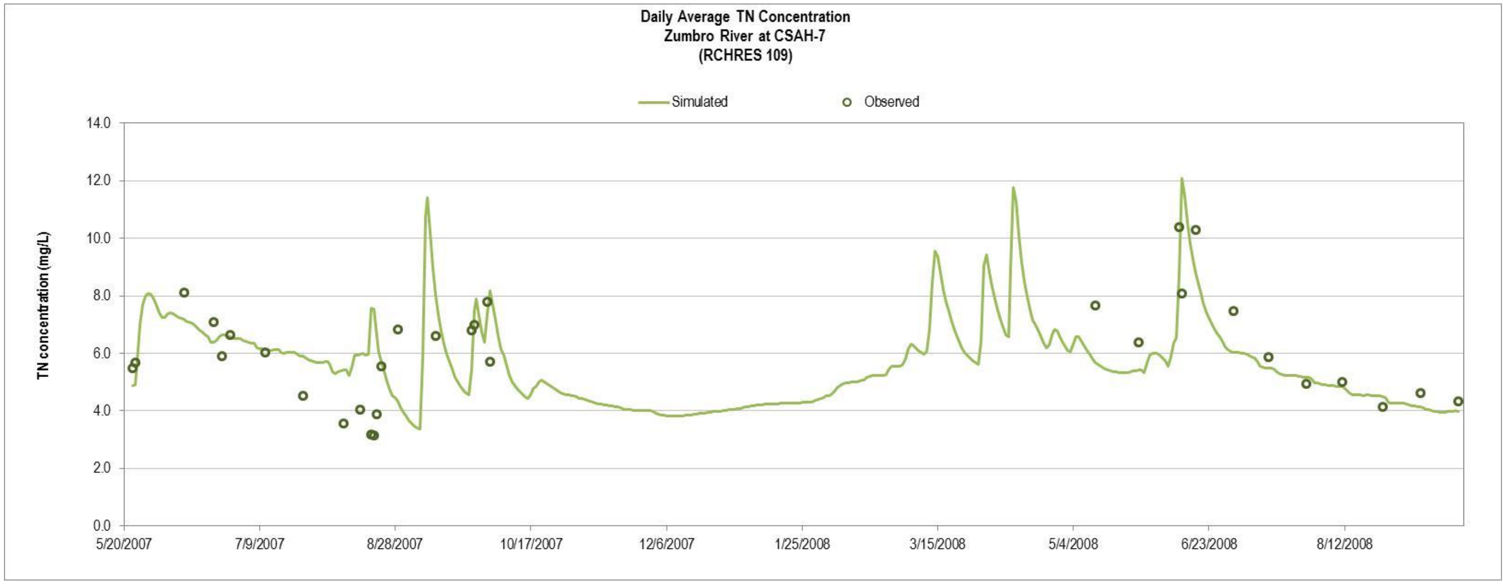

Figure E-1. Daily Average Total Nitrogen Concentrations for Zumbro River at CSAH-7 (RCHRES 109)

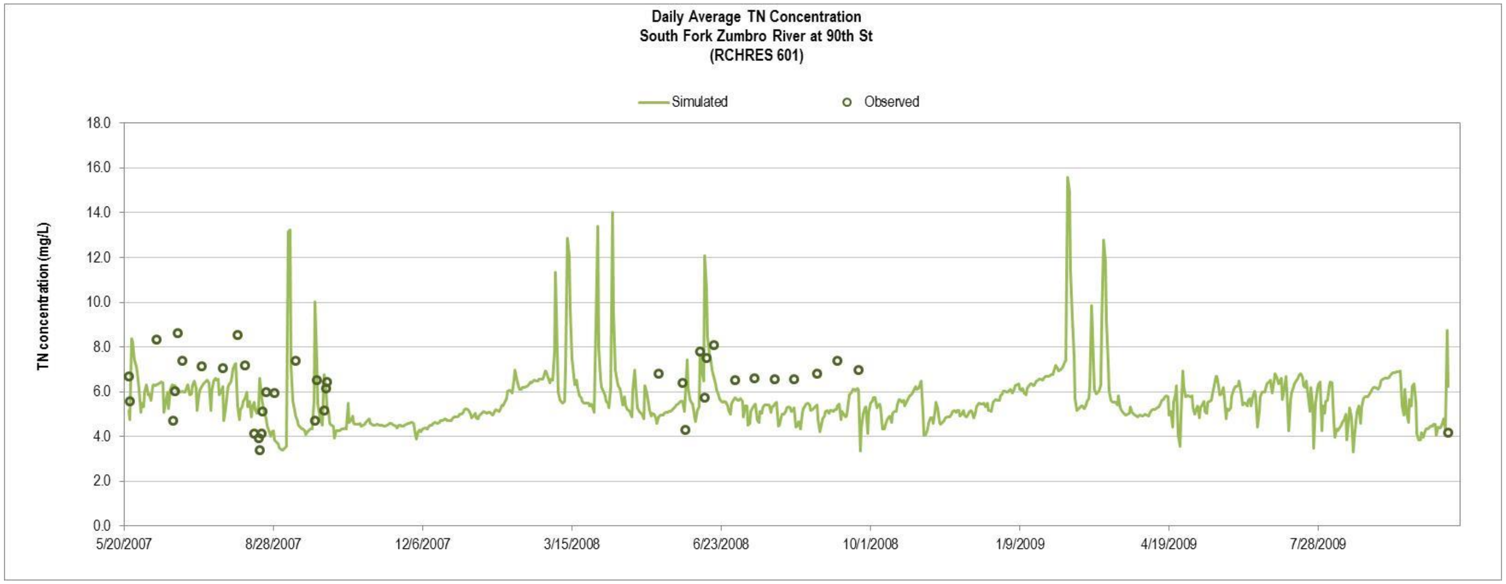

Figure E-2. Daily Average Total Nitrogen Concentrations for South Fork Zumbro River at 90th Street (RCHRES 601)

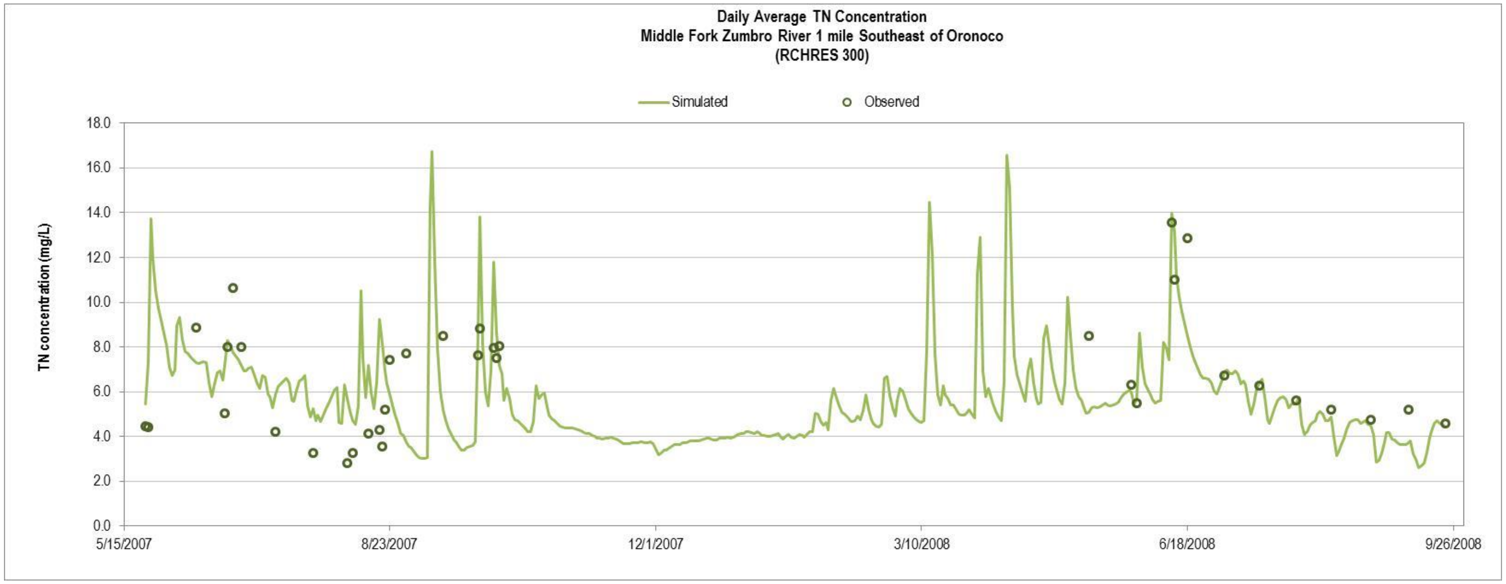

Figure E-3. Daily Average Total Nitrogen Concentrations for Middle Fork Zumbro River 1 mile Southeast of Oronoco (RCHRES 300)

Nitrate

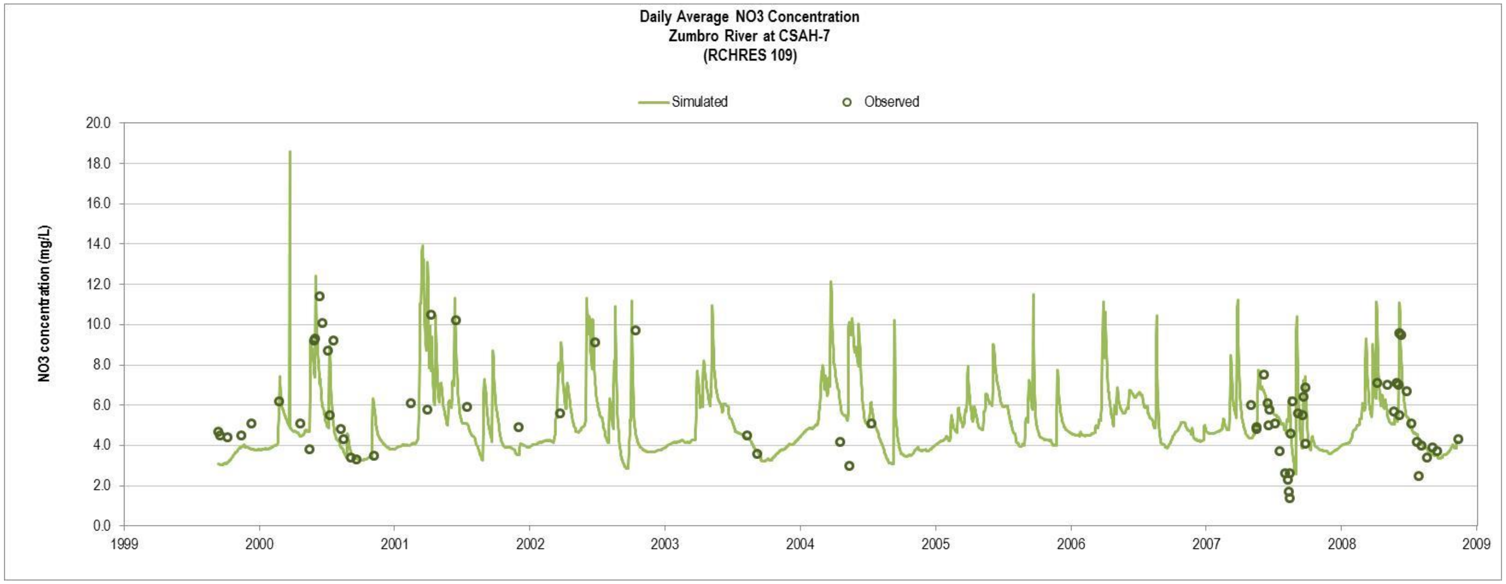

Figure E-4. Daily Average Nitrate Concentrations for Zumbro River at CSAH-7 (RCHRES 109)

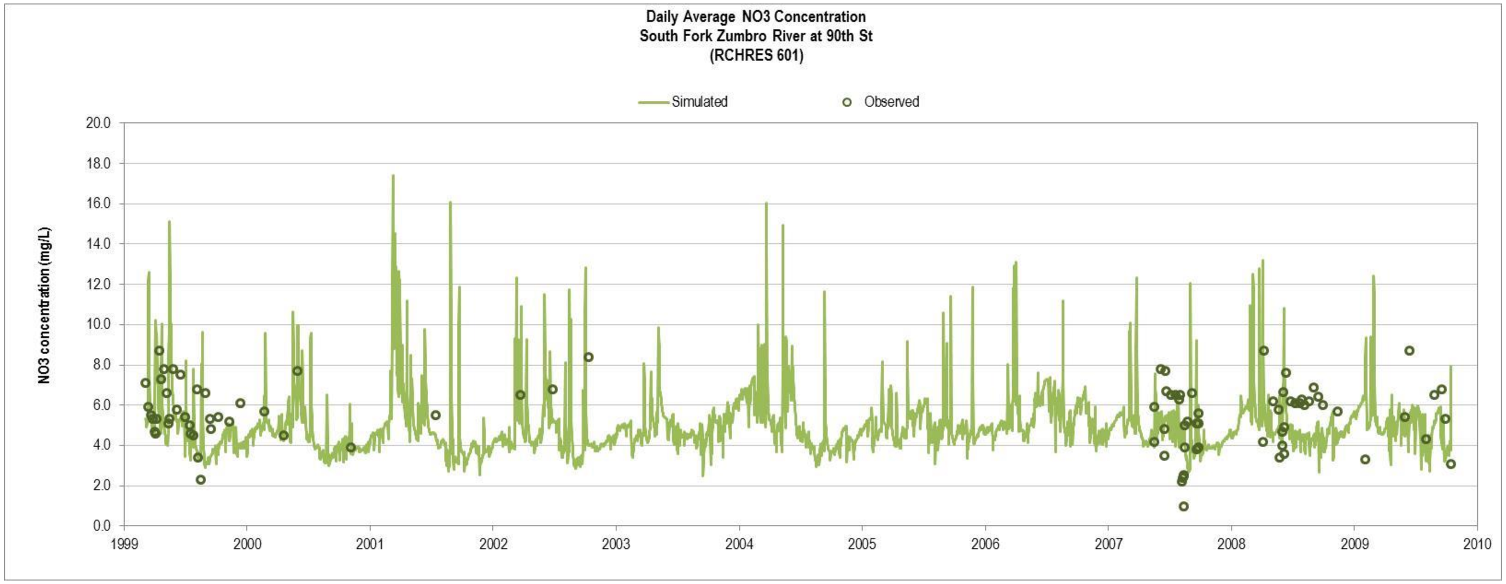

Figure E-5. Daily Average Nitrate Concentrations for South Fork Zumbro River at 90th Street (RCHRES 601)

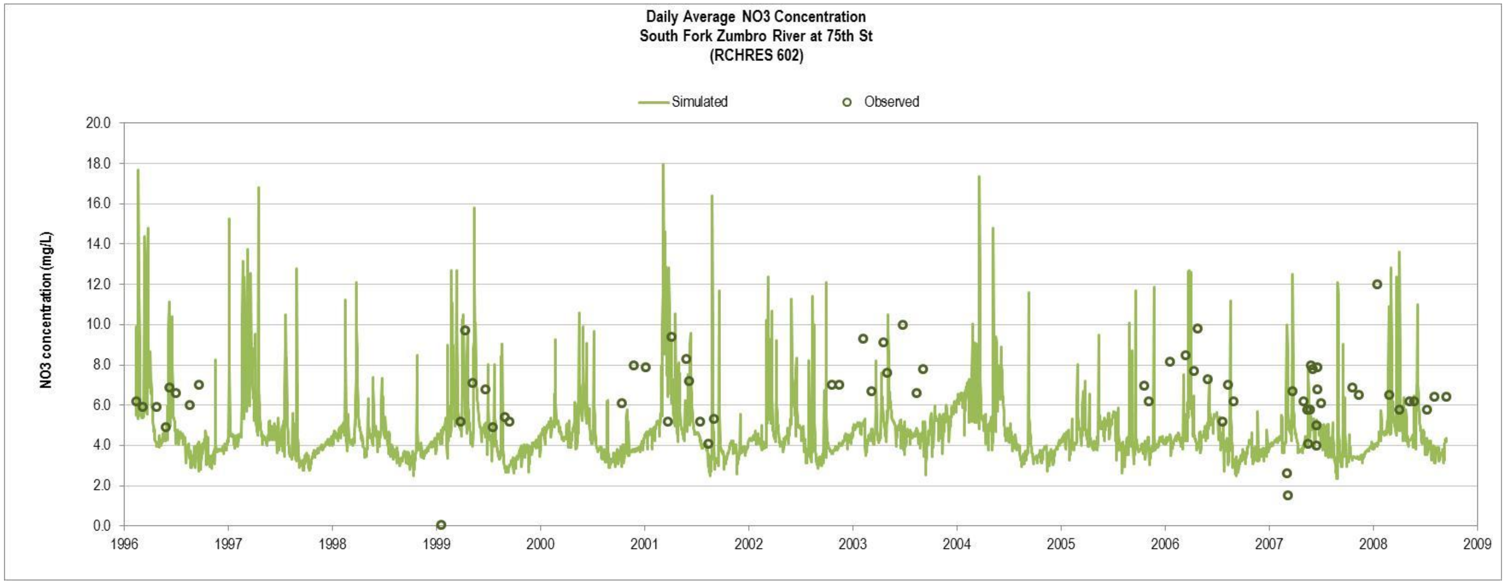

Figure E-6. Daily Average Nitrate Concentrations for South Fork Zumbro River at 75th Street (RCHRES 602)

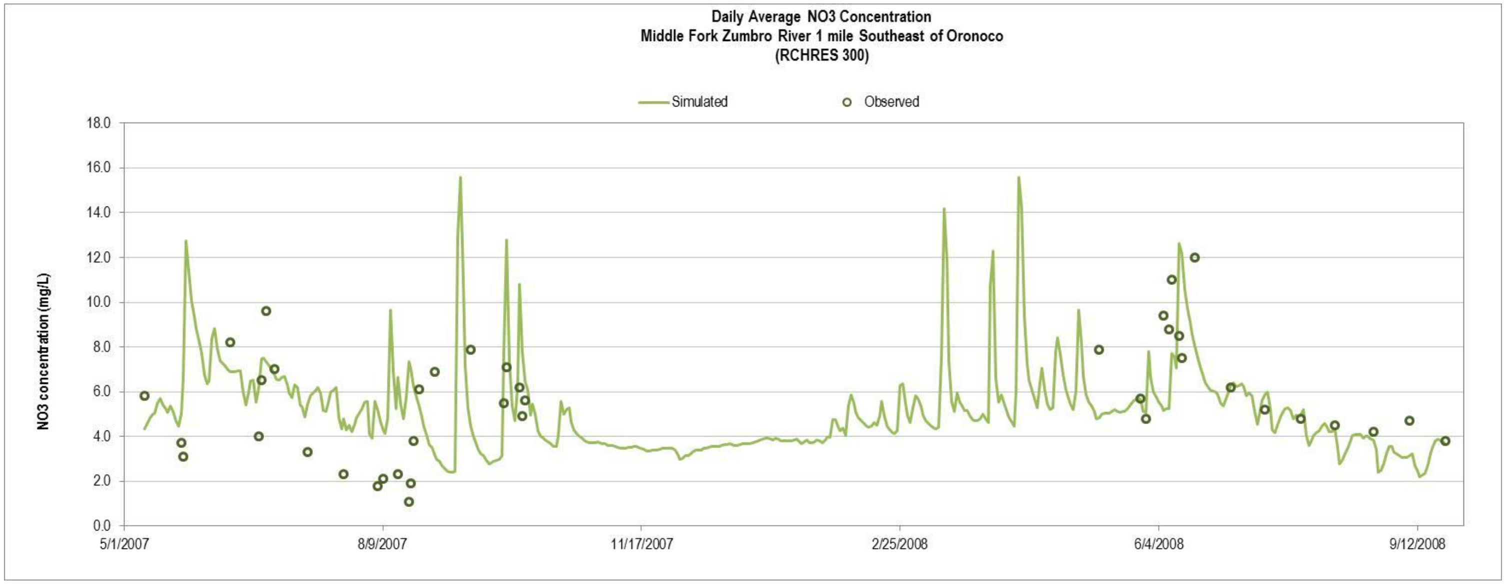

Figure E-7. Daily Average Nitrate Concentrations for Middle Fork Zumbro River 1 mile Southeast of Oronoco (RCHRES 300)

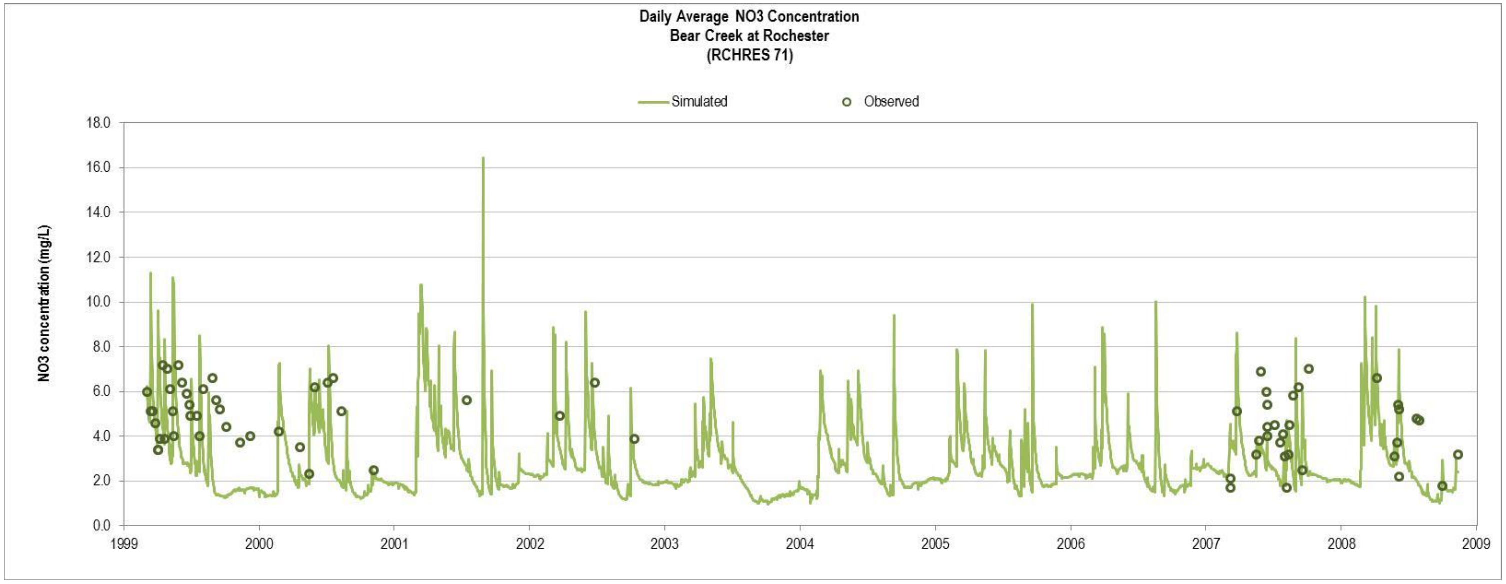

Figure E-8. Daily Average Nitrate Concentrations for Bear Creek at Rochester (RCHRES 71)

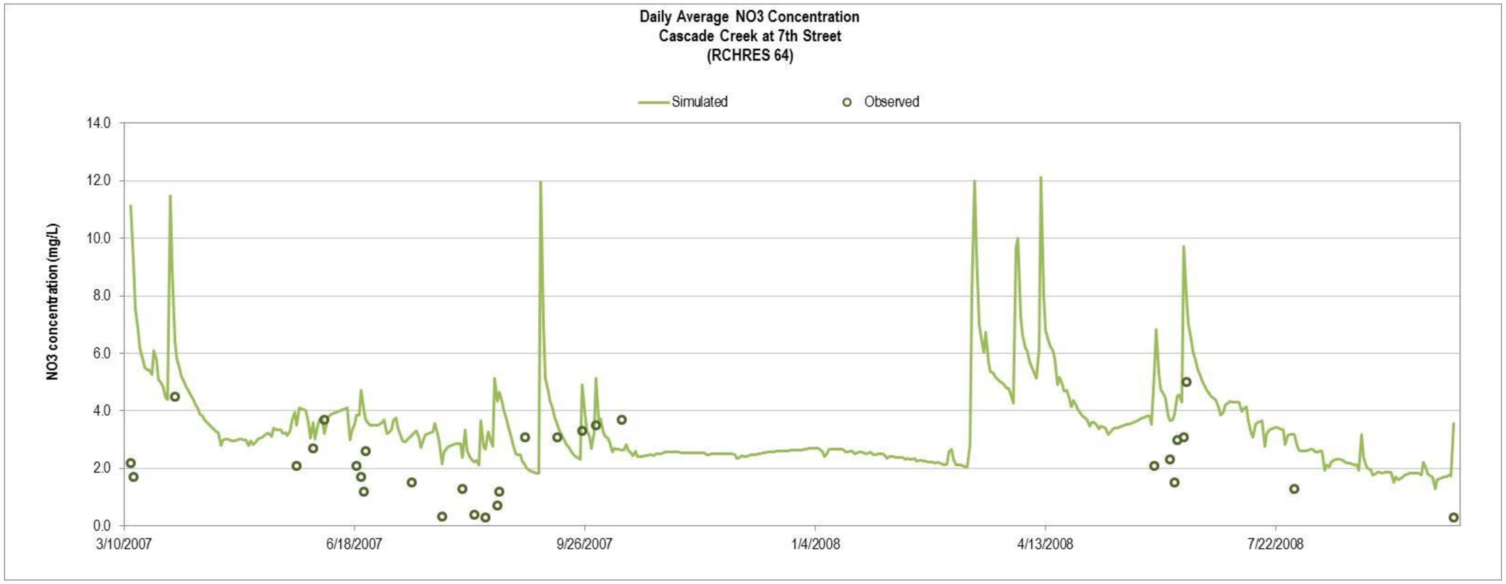

Figure E-9. Daily Average Nitrate Concentrations for Cascade Creek at 7th Street (RCHRES 64)

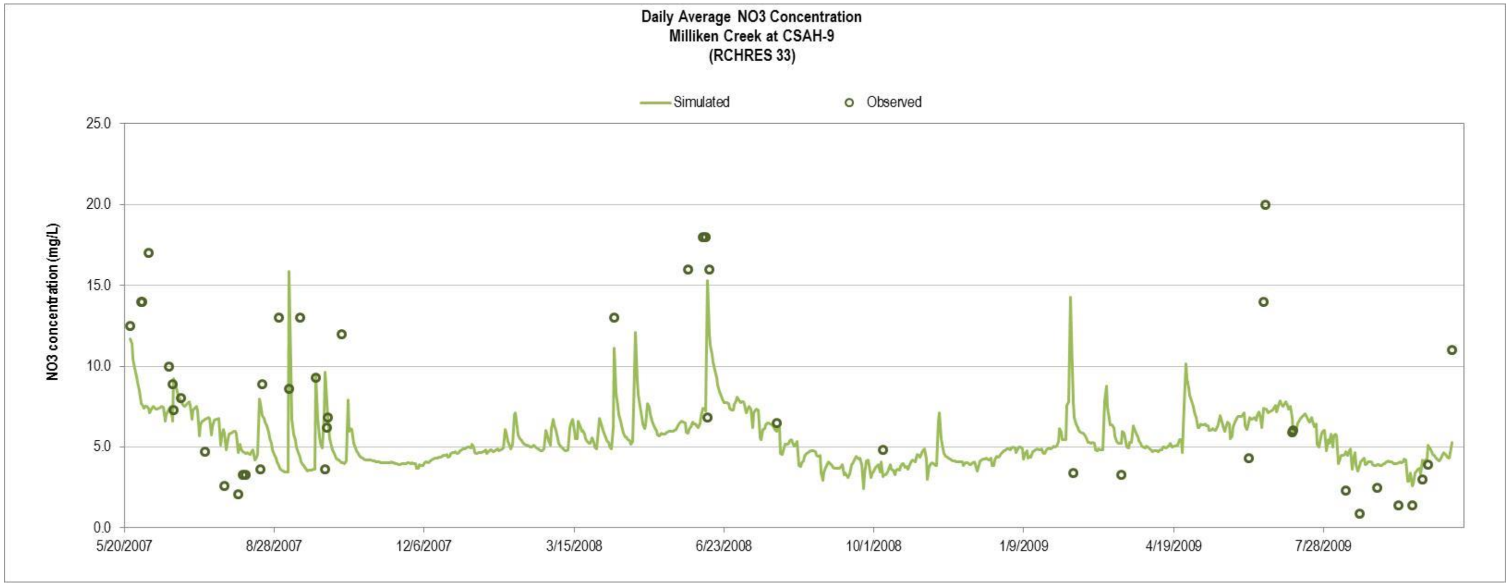

Figure E-10. Daily Average Nitrate Concentrations for Milliken Creek at CSAH-9 (RCHRES 33)

Ammonia

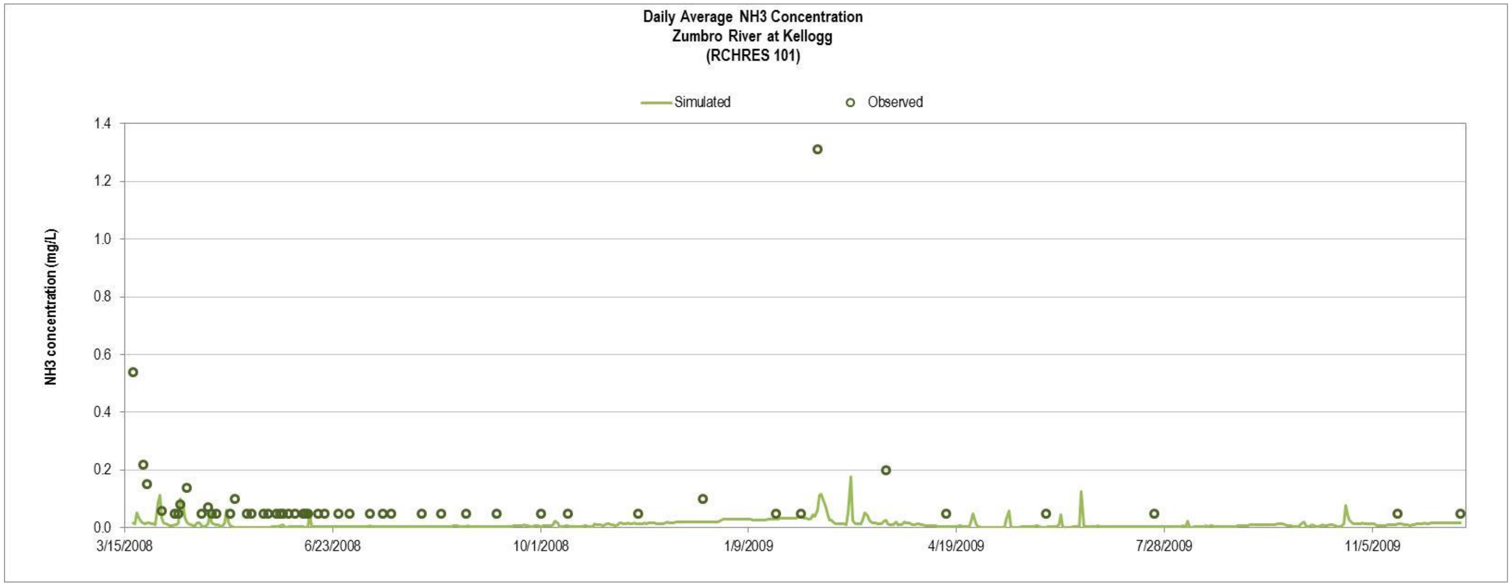

Figure E-11. Daily Average Ammonia Concentrations for Zumbro River at Kellogg (RCHRES 101).