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Memorandum

From: Nick Grewe, Derek Schlea, Hans Holmberg

Date: January 29, 2021

To: Justin Watkins, Emily Zanon, Kristen Dieterman, Dennis Wasley, Marco Graziani (MPCA)

Project: **Cannon River Watershed HSPF Model Extension 2019**

Subject: Technical memorandum to document model extension and hydrology recalibration

Statement of Purpose

This memorandum has been prepared for the Minnesota Pollution Control Agency (MPCA) to document Objective 1 of the "Cannon River Watershed HSPF Model Extension 2019" project and serves as a final deliverable, as outlined in the Work Plan, Contract No. 179137. The major tasks for this phase of work include the following:

- Extend the simulation period of the Cannon River Watershed HSPF model to include 2013 through 2019;
- Spatially refine the model to follow HUC-10 and Ecoregion boundaries;
- Update the model hydrology calibration; and
- Review water quality outputs for general reasonableness – no water quality calibration was performed as part of this Work Plan, only a quality assurance review.

Project Background

The MPCA is undertaking a watershed approach at the 8-digit HUC scale to restore and protect Minnesota's surface waters. The Cannon River watershed (CRW) 8-digit HUC includes waters impaired by excessive bacteria (fecal coliform and *Escherichia coliform* (*E. coli*)), chloride, nitrate nitrogen, total suspended solids (TSS), and total phosphorus (lakes only). The Cannon River Watershed Restoration and Protection Strategy (WRAPS) report was approved in October 2016, and the watershed TMDLs were approved by EPA in February of 2017. A site-specific eutrophication standard exists for Lake Byllesby and was approved by EPA in August 2011. The MPCA has selected the Hydrologic Simulation Program FORTRAN (HSPF) model to simulate watershed hydrology and water quality. The HSPF model is an important tool in developing an understanding of existing conditions, simulating conditions under various management scenarios, and informing the development of implementation strategies and plans to restore and protect streams and lakes.

In previous phases of work, an HSPF model of the CRW (hereafter CRWHSPF) was developed to simulate hydrology and water quality for the 1995-2012 period (Phase I; LimnoTech, 2015). The CRWHSPF was then applied to evaluate various management scenarios for reducing sediment and nutrient loading (Phase II; LimnoTech, 2016a), construct TMDLs for impaired stream segments, and inform development of nutrient TMDLs for lakes in the Upper Cannon watersheds (LimnoTech, 2016b).

In the current project (Phase III), LimnoTech extended the CRWHSPF model simulation period through 2019 and updated the hydrology calibration based on new data and information.

Model Refinement and Simulation Period Extension

The primary purpose of the first major task was to compile and process the time series data required to extend the model simulation period through 2019. This objective also included a refinement of the model landside segmentation and updated representation of point sources.

Model Segmentation

The previous CRWHSPF model's grouping of land segments into weather regions was based on a Theissen polygon analysis conducted for meteorological stations with observed precipitation data. This approach was somewhat limiting in that land segments of a common land cover and soil type might cover a vast geographic area spanning multiple ten-digit hydrologic unit code (HUC-10) subwatersheds, varying slope characteristics, and multiple ecoregions. The revised approach used during this model refinement phase involved updating the landside segmentation to better align with HUC-10 subwatershed boundaries and the three major ecoregions spanning the CRW (Western Corn Belt Plains, North Central Hardwoods, and Driftless Area). Switching from the local observed precipitation datasets to a national-scale, gridded precipitation dataset facilitated this refinement. This model segmentation refinement was advantageous for two major reasons: (1) it led to an improved calibration by allowing for more spatially refined parameterization when supported by observed streamflow and/or water quality data, and (2) it allows for better alignment with the nonpoint source management scenarios defined in the Cannon River WRAPS (Wotzka and Watkins, 2016), which were defined based on major lobe boundaries (HUC-10 subwatersheds). Land segments were grouped into the 13 precipitation zones shown in Figure 1.

Meteorological Time Series

Two gridded precipitation datasets were obtained for constructing CRWHSPF model input time series for the entire 1995-2019 simulation period: daily time series from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; PRISM Climate Group, 2019) and hourly time series from the North American Land Data Assimilation System (NLDAS; Xia et al., 2012). An initial processing step involved aggregating the raw time series obtained for individual PRISM and NLDAS grid cells into a unique time series for each of the 13 precipitation zones. The PRISM dataset was found to have annual precipitation patterns more consistent with observations, evaluated for the Faribault Airport and Owatonna Airport stations, than the NLDAS dataset. This finding was consistent with those described in other Minnesota HSPF model development reports (TetraTech, 2016a; TetraTech, 2016b). Therefore, we followed a similar approach of using the NLDAS hourly precipitation time series as the reference time series for disaggregating the PRISM daily precipitation time series into the final, hourly input time series to be used in the model simulations. The disaggregation function in WDMUtil was used for this step.

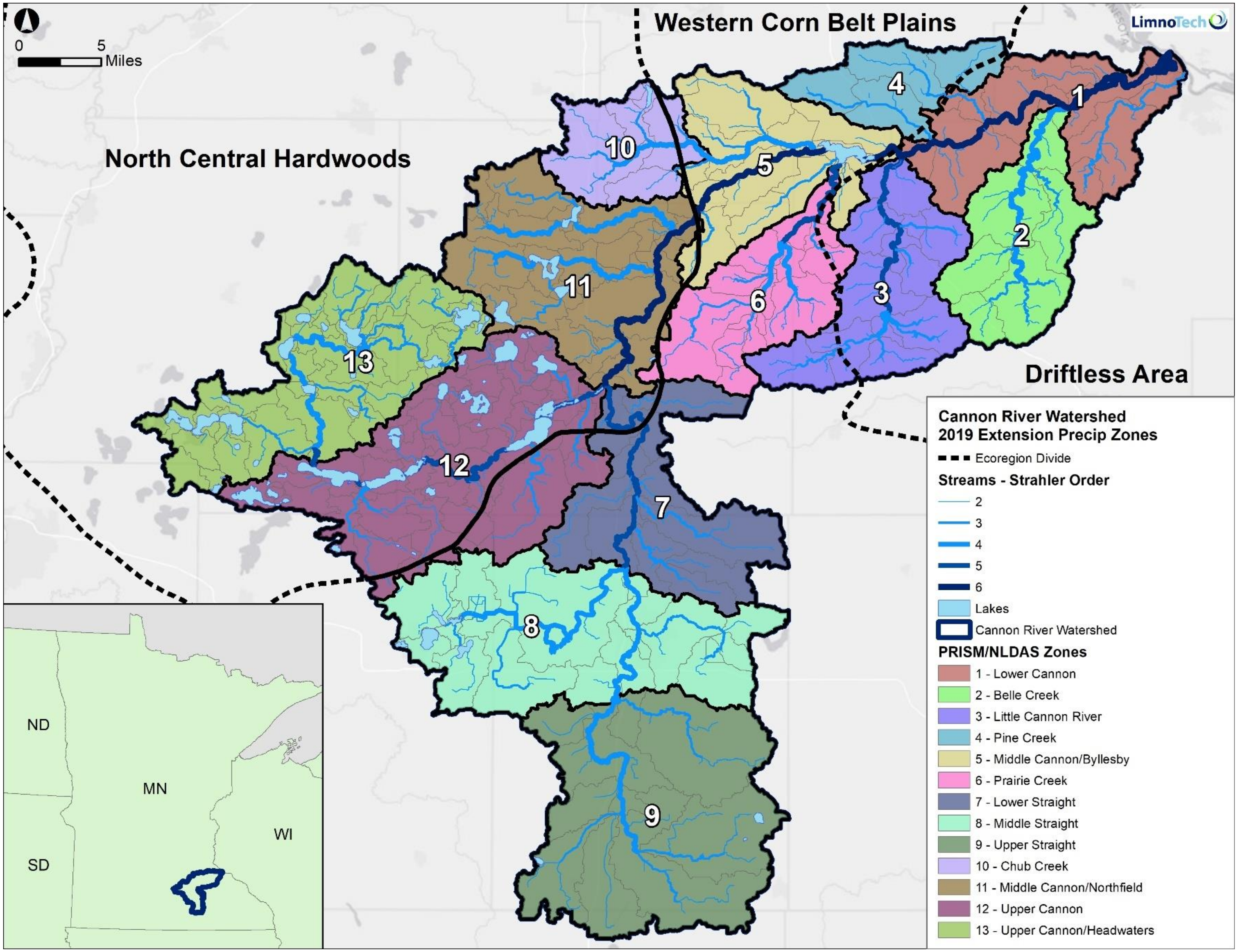

Figure 1: CRWHSPF model subbasin map with revised precipitation regions and major ecoregion divides

Time series for the other meteorological inputs were developed using data obtained from the National Climatic Data Center (NCDC) Climate Data Online (CDO) database for the 2013-2019 extension period (NOAA, 2020). Hourly meteorological datasets were obtained for the same four stations used in the original model: Faribault, Owatonna, Mankato, and Red Wing. Datasets for air temperature, dew point temperature, cloud cover, and wind speed were sufficient for all four stations to append the 1995-2012 input time series with hourly time series for the 2013-2019 extension period. The data format from NCDC differed significantly from previous Legacy Climate Data Online retrievals. This required reformatting, applying scaling factors, and unit conversions (specified in documentation from NCDC) to all meteorological time series. During the initial model development (Phase I), BASINS data were used to cover the 1995 – 2009 period, and NCDC data were used to cover the 2010 – 2012 period. Hourly time series data were compared for the overlapping 2010 – 2012 period to ensure consistency and quality between the old NCDC format and the new format before importing to the WDM. The compute solar radiation function in WDMUtil was used to estimate solar radiation based on the input cloud cover time series. The compute Penman pan evaporation function in WDMUtil was used to estimate potential evaporation based on daily minimum and maximum air temperature, dew point, wind, and solar radiation inputs.

Representation of Point Sources

Point source effluent datasets were provided by MPCA for all CRW facilities to append input time series to cover the 2013-2019 extension period. During this process, LimnoTech worked with MPCA to reevaluate the list of point sources represented in the CRWHSPF model to ensure all permitted facilities that continuously or intermittently discharge to surface waters were represented. In addition to extending the input time series for the 2013-2019 period, the following modifications were made to represent the appropriate facilities and to reflect changes that occurred during the 2013-2019 period:

- OMG Midwest Inc dba Minnesota Paving and Materials (MNG490131), which was not included in the Phase I model but had a permit issued in July 2002, was included in the model (discharging to the Straight River) based on reported surface water discharge data from the Discharge Monitoring Reports (DMR) database beginning Oct. 2014;
- Wondra Pit (MNG490130), which was not included in the Phase I model but had a permit issued in July 2002, was included in the model (discharging to the Straight River) based on reported surface water discharge data from DMR beginning July 2017;
- Waseca WWTP (MN0020796) was included in the Phase I model but MPCA identified during Phase II that it does not discharge to the Cannon River Watershed. The facility was removed from the UCI file, however remained in the point source WDM file. Monthly flow and load time series were deleted from the WDM file to avoid confusion.

Other Input Time Series

The remaining temporally-variable inputs extended for the 2013-2019 period included atmospheric deposition and Lake Byllesby water level controls. Atmospheric deposition of nitrogen was extended using data obtained from the National Atmospheric Deposition Program (NADP) National Trends Network (NTN) (NADP, 2020) and the Clean Air Status and Trends Network (CASTNET) (USEPA, 2020). Dates of raising and lowering of Lake Byllesby water levels to reach summer pool and winter pool target elevations were obtained by MPCA through Dakota County and provided to LimnoTech. These dates were used to extend the SPECIAL ACTIONS block, which was developed in the original model to specify the dates when Lake Byllesby is operated at summer pool elevation, winter pool elevation, or the transition period by using different discharge columns of the FTABLE.

Observed Streamflow and Water Quality Data

The 2013-2019 model extension period had a greater abundance of observed streamflow data, discrete water quality sampling data, and water quality load estimates than the former 1995-2012 simulation period. As discussed in model calibration section below, these additional data facilitated model-data comparisons and led to a better constrained CRWHSPF model hydrology calibration. The following resources were used to obtain the observed streamflow and water quality datasets for the 2013-2019 extension period:

- United States Geological Survey (USGS) National Water Information System (USGS, 2020);
- Minnesota Department of Natural Resources Cooperative Stream Gaging (MNDNR, 2020);
- MPCA EDA Surface Water Data (EDA) (MPCA, 2020a);
- MPCA Watershed Pollutant Load Monitoring Network (WPLMN) (MPCA, 2020b); and
- Monthly and Annual Pollutant Loads, Met Council Environmental Services (MCES) (2017)

The primary model calibration locations were those with the most abundant datasets and/or near the outlets of major subwatersheds: Cannon River at Welch; Cannon River at Cannon Falls; Cannon River at Northfield; Cannon River at Hwy 29; and Straight River at Faribault. Secondary model calibration locations included Cannon River at Morristown and Little Cannon River near Cannon Falls. These secondary locations were used to confirm or further support evaluation of model performance for major subwatersheds but were not intended to be evaluated as critically as the primary calibration locations. Auxiliary calibration locations included tributaries with relatively smaller drainage areas, but a relatively large number of observed streamflow and water quality measurements. These locations were used to confirm model behavior for the sub-drainage areas or evaluate unique hydrologic behavior (e.g., upper reaches of the Little Cannon River), but were not intended to be evaluated as critically as the primary calibration locations.

Model Calibration

Following the model extension and refinement activities, the next objective was to reevaluate the model calibration and recalibrate if necessary. The original CRWHSPF model development project used 2004-2012 as the calibration period and 1996-2004 as the validation period. The first year (1995) served as a "warm-up period" to allow the model to equilibrate and not be strongly influenced by the initial conditions. For this Phase III work, 2010-2019 was used as the calibration period and 2000-2009 was used as a validation period.

The calibration approach followed the procedures described in the MPCA modeling guidance document (AQUA TERRA Consultants, 2012) and the original CRWHSPF model development report (LimnoTech, 2015). Assessments of model performance followed a "weight of evidence" approach, consisting of using multiple model comparisons, both graphical and statistical. Statistical metrics for hydrology included the average relative percent difference (RPD), the coefficient of determination (R-squared), percent bias (PBIAS) (applied to the monthly interval only) and the Nash-Sutcliffe efficiency (NSE). Tolerance ranges described in the MPCA modeling guidance document were used. Appendix A contains the equations used to calculate these performance metrics and the qualitative ratings associated with each.

Hydrology Calibration

The model calibration for hydrology was reevaluated using the additional observational datasets available for the 2010-2019 model calibration period. These datasets included stream gaging locations that were either not established during the first phase of CRWHSPF modeling work or had a limited dataset for the earlier time period. A complete list of stations used in Phase I, new stations, or more robust stations evaluated in this model are summarized in Table 1 and shown in Figure 2. As an outcome of the reevaluation, it was determined that recalibration was necessary because the model tended to underpredict annual volumes and not match the range of observed flows in the primary and secondary gaging stations. These reviews were accomplished by looking at bar charts of total volumes per year, model-paired cumulative frequency distribution (CFD) curves, and key statistical metrics highlighted in the previous section and detailed in Appendix A.

Table 1: Summary of hydrology gaging stations in the Cannon River Watershed used to evaluate hydrology during the 2010 - 2019 calibration period and the number of daily data points available during that period.

Station Name	Gage ID	Priority	Status	Date Range	Count
Cannon River @ Welch	USGS/ 05355200	Primary	Used in Phase I	2010 - 2019	3,651
Cannon River @ Cannon Falls	USGS/ 05355092	Primary	New	2015 - 2019	1,698
Cannon River @ Northfield	USGS/ 05355024	Primary	New	2013 - 2019	2,553
Cannon River @ Hwy 29	USGS/ 05354500	Primary	New	2013 - 2019	1,761
Straight River @ Faribault	USGS/ 05353800	Primary	Used in Phase	2010 - 2019	3,651
Cannon River @ Morristown	HYDSTRA/ H39091001	Secondary	Expanded/ Used in Phase I	2011 - 2019	2,063
Little Cannon River nr Cannon Falls	HYDSTRA/ H39016001	Secondary	Used in Phase I	2015 - 2019 (missing 2011 – 2014)	1,764
Little Cannon River @ Sogn	HYDSTRA/ H39025001	Secondary	Not used in Phase I	2010 - 2019	3,400

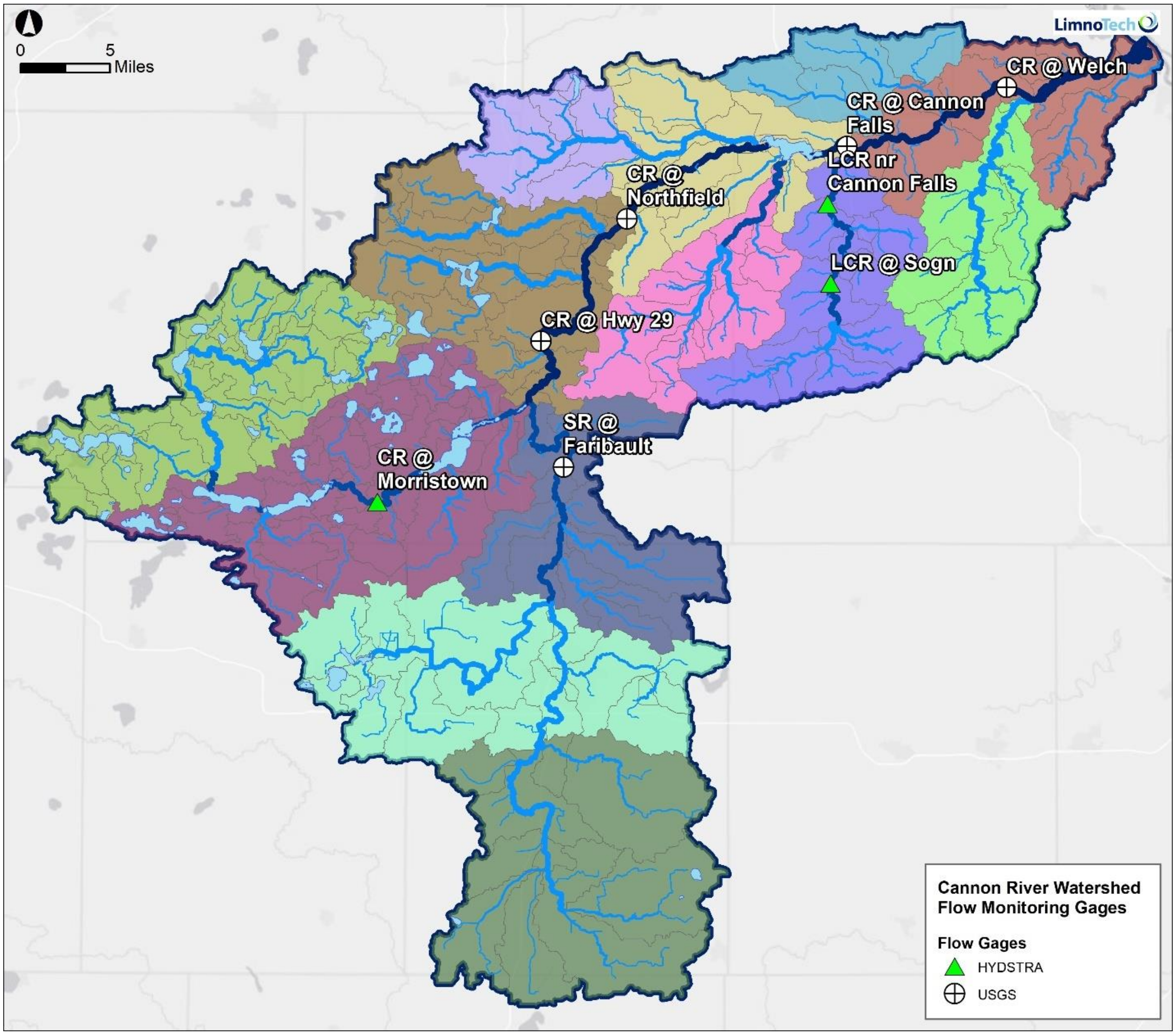

Figure 2: Locations of hydrology gaging stations in the Cannon River Watershed used to evaluate hydrology during the 2010 - 2019 calibration period.

Based on the new data and information available to support the revision of the hydrology calibration, the following revisions were made to the CRWHSPF model:

- The snow simulation parameter CCFACT was increased and produced better streamflow statistics after switching to the gridded precipitation time series;
- LSUR and SLSUR were modified to better represent the difference in ecoregions spanning the CRW, from the relatively flat, longer runoff lengths in the Western Corn Belt Plains transitioning to the relatively steep, shorter runoff lengths in eastern Driftless areas; and
- INFILT, KVARY, AGWRC, UZSN, INTERFLOW, IRC, and LZETPARM were modified to reflect gradients in ecoregions and differences in observed streamflow responses.

Summary performance statistics for the hydrology calibration period are shown in Table 2 for the five primary locations and two secondary stations. Visual comparisons of observed and simulated streamflow for the calibration period are shown in Figures 3 to 6 for the Cannon River at Welch, which is the downstream most station and closely reflects the total flow and loads leaving the Cannon River Watershed (minus contributions from the Belle Creek subwatershed). Additional plots for the other primary and secondary stations are included in Appendix C. Summary performance statistics for the secondary calibration locations are provided in Table B-1 for the calibration period, and validation period statistics are provided in Table B-2. The overall model performance for hydrology in the current model can be summarized as follows:

- The majority of statistical evaluations for the five primary calibration locations and two secondary calibration locations indicate satisfactory model performance, including several "very good" ratings and one "excellent" rating for monthly and annual intervals for the 2010-2019 model calibration period (see Appendix A for quantitative descriptions of these ratings);
- Visual inspection of the annual and monthly flow volume plots, the daily streamflow plot, and the cumulative frequency distribution plots suggest the model is able to reproduce flow volumes, the magnitude and timing of peak flows, and the distribution of flows at all five primary calibration locations very well; and
- Statistical evaluations for the two primary locations and three secondary locations with observed data during the 2000-2009 validation period confirm satisfactory model performance in predicting timing of peak flows and the distribution of flows.
- Overall, most calibration statistics generally improved across multiple metrics and time intervals compared to the Phase I calibration. While some quantitative metrics did not improve, qualitative ratings at the five primary calibration stations remained the same or improved, i.e. no statistic changed from "very good" to "good".

Table 2: Model performance evaluation statistics for primary hydrology calibration locations for the 2010-2019 model extension period.

Time Interval	Statistic	Cannon River @ Welch	Cannon River @ Cannon Falls	Cannon River @ Northfield	Cannon River @ Hwy 29	Straight River @ Faribault
		2010 - 2019	2015 - 2019	2013 - 2019	2013 - 2019	2010 - 2019
Annual	*Count*	10	5	7	7	10
	R-Squared	0.89	0.97	0.90	0.94	0.92
	NSE	0.86	0.94	0.86	0.84	0.86
	RPD	5.2%	-4.6%	-0.3%	-4.7%	3.6%
Monthly	*Count*	120	57	84	65	120
	R-Squared	0.84	0.88	0.86	0.88	0.83
	NSE	0.82	0.87	0.86	0.87	0.83
	P-Bias	-3.16	4.59	2.45	7.32	1.52
	RPD	-3.0%	-2.2%	4.8%	-4.0%	7.8%
Daily	*Count*	3651	1698	2553	1761	3651
	R-Squared	0.77	0.78	0.74	0.77	0.70
	RPD	-3.0%	-2.1%	5.2%	-4.6%	7.2%

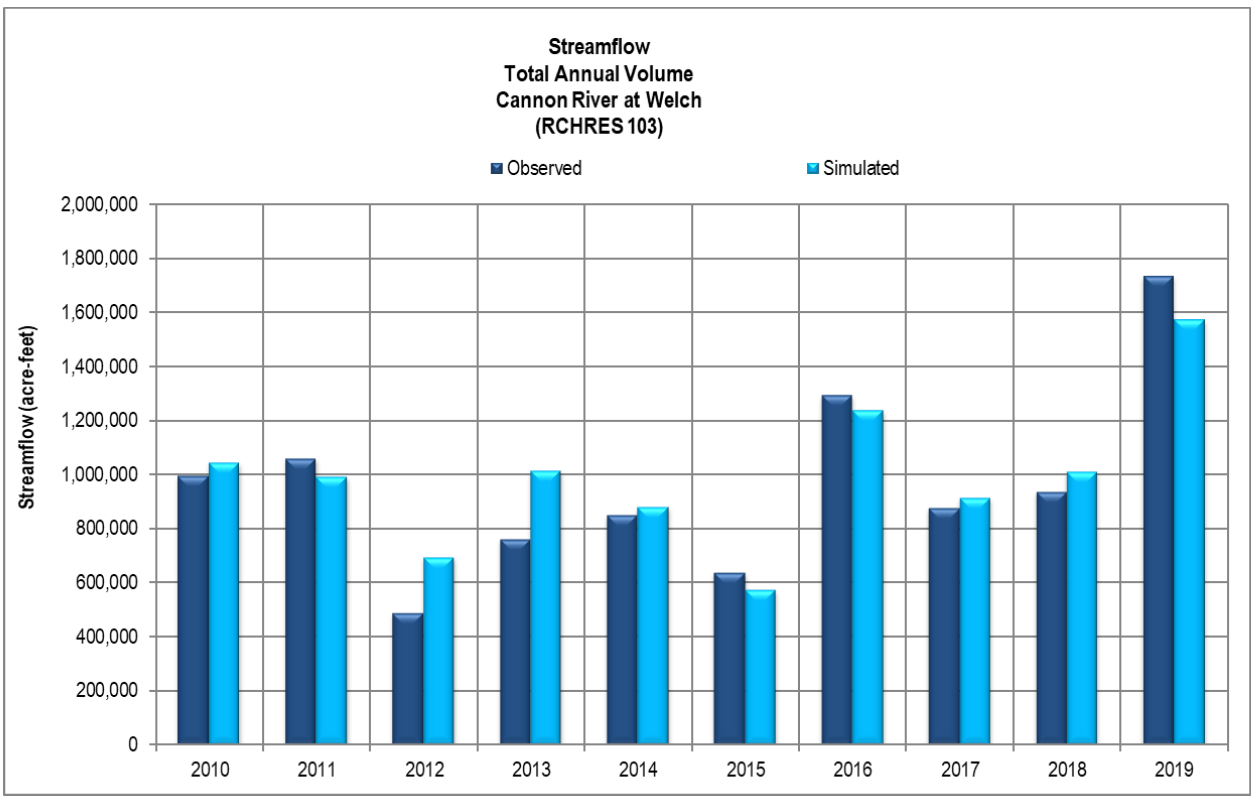

Figure 3: Observed and simulated annual streamflow volumes for Cannon River at Welch.

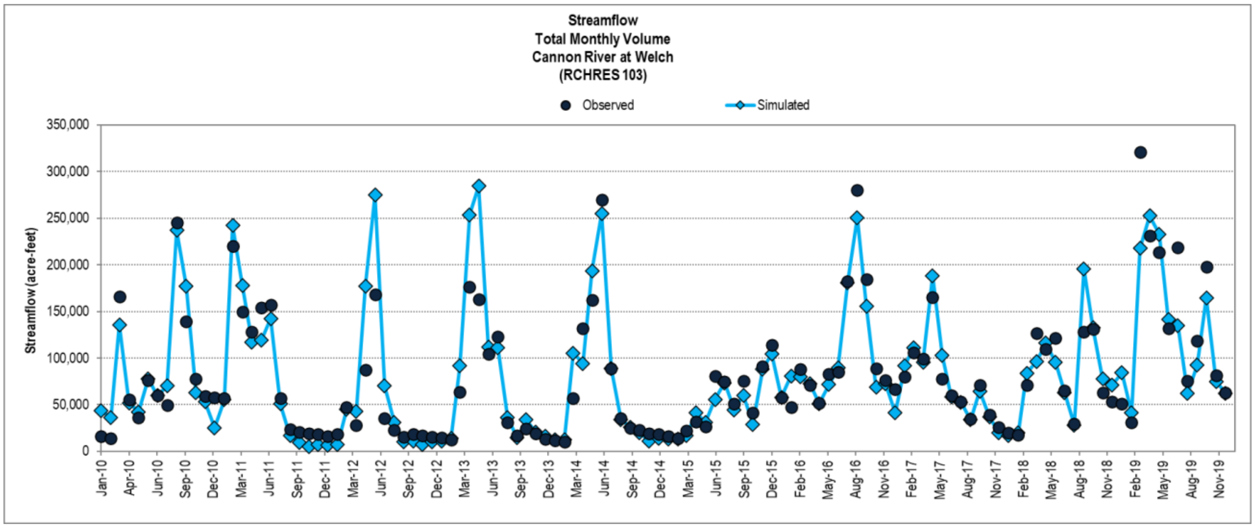

Figure 4: Observed and simulated monthly streamflow volumes for Cannon River at Welch.

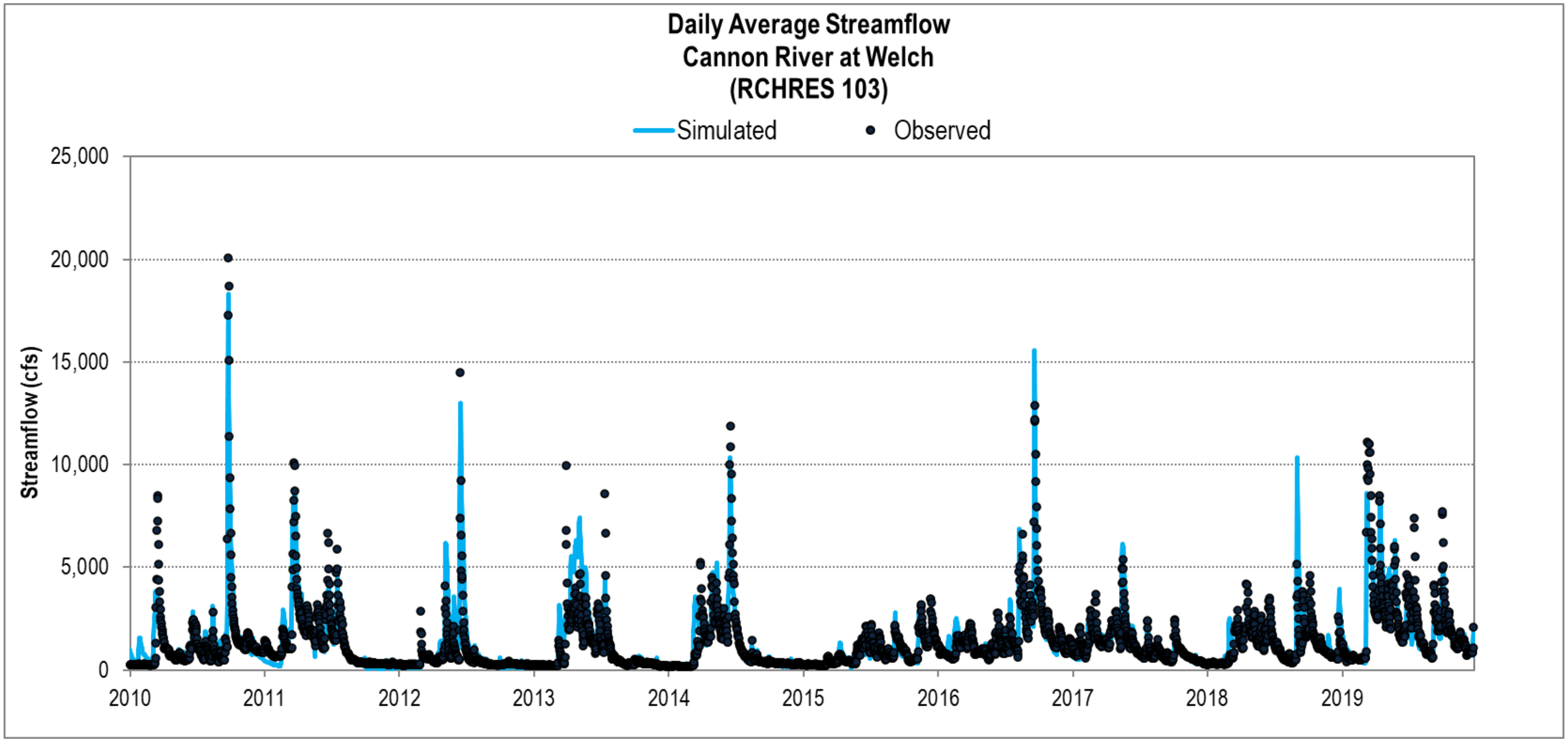

Figure 5: Observed and simulated daily average streamflow for Cannon River at Welch.

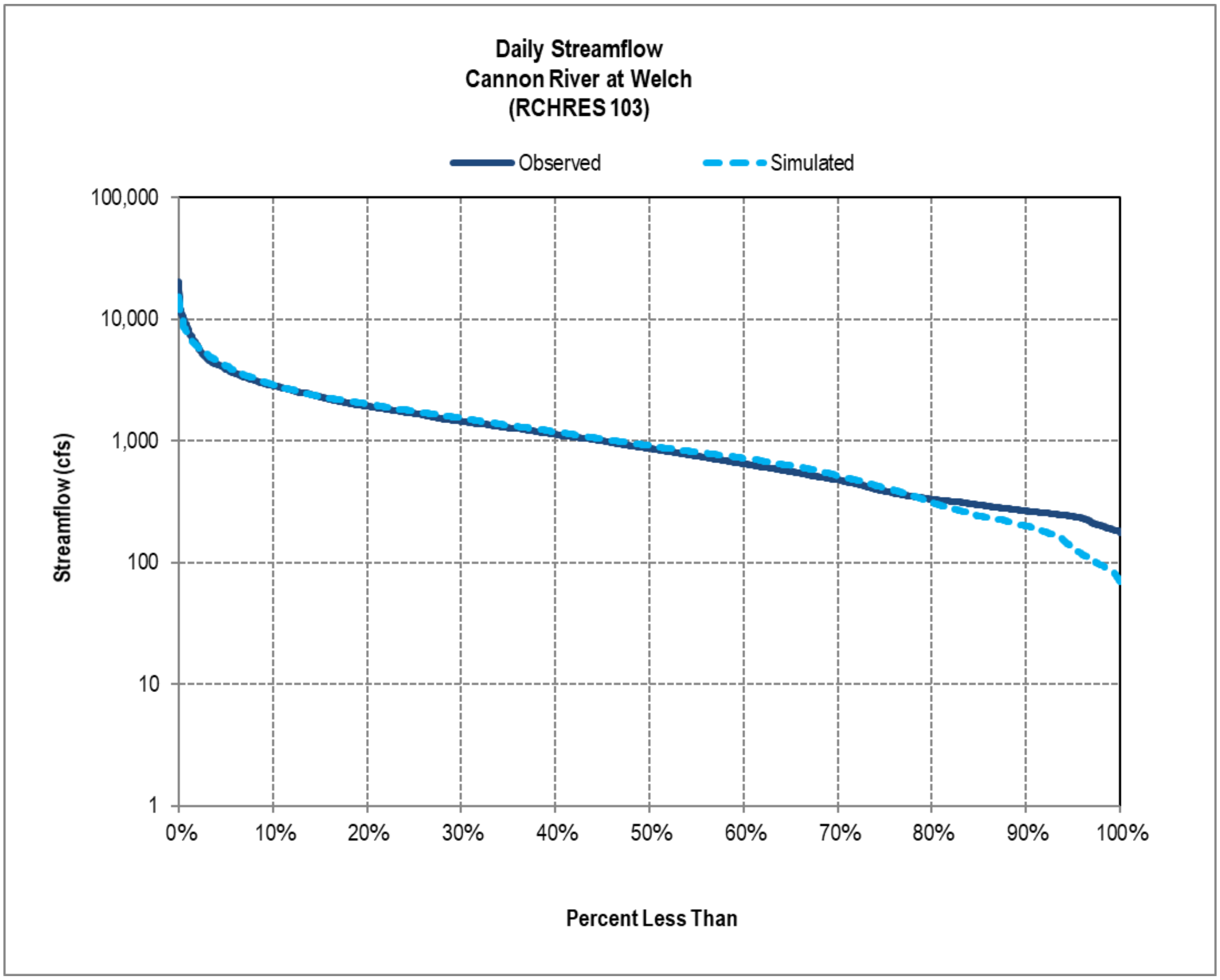

Figure 6: Observed and simulated daily streamflow cumulative frequency distribution for Cannon River at Welch.

Water Quality Evaluation

No water quality calibration was performed under this Work Plan. Instead, a high level assessment was done as a quality assurance check on the model expansion and refinements, and to evaluate general reasonableness of model results following final hydrology calibration. This was achieved by comparing model predicted monthly and annual loads to loads reported by the Watershed Pollutant Load Monitoring Network (WPLMN, MPCA 2020b), Met Council (2017), and LOADEST calculations done during Phase I (through 2012 only) at the three locations available in the Cannon River Watershed: Cannon River @ Welch, Cannon River @ Morristown, Straight River @ Faribault. Visual comparisons of observed and simulated monthly loads and annual loads are shown in Figures 7 to 12 for the downstream most station, Cannon River at Welch. Daily concentrations are shown in Figures 13 to 15 for Straight River at Faribault, which was chosen because it has a more robust dataset through 2019 compared to the other two locations. Appendix D includes the remaining monthly and annual load figures.

In addition to the three stations used in evaluating loads, Cannon River near Northfield was chosen to compare observed vs. simulated daily DO and temperature time series plots (Figure 16 and Figure 17, respectively). This site was chosen because it is the furthest downstream site in the MPCA EDA dataset with a robust dataset through 2019. This site is located approximately 1.5 river miles downstream of the Northfield WWTP outfall. Additional sites with observed concentration data were also evaluated, but not included in this memo for brevity.

Observations from this evaluation of CRWHSPF performance for water quality constituents are summarized below:

- No outliers were identified in the evaluation of CRWHSPF water quality results, indicating the extension and refinement of the model does not contain obvious errors.
- Visual inspection of the time series plots suggests that, overall, the model is able to reproduce the range, annual patterns, and magnitudes of observations for total nitrogen (TN) reasonably well.
- Visual inspection of the time series plots suggests that, overall, the model is able to reproduce the range, annual patterns, and magnitudes of observations for total phosphorus (TP) reasonably well in the Cannon River at Welch, generally underpredicts in the Cannon River at Morristown, and overpredicts in the Straight River at Faribault. Visual inspection of the daily TP concentrations in the Cannon River between Northfield and Lake Byllesby suggest the model is able to produce the range, patterns, and magnitudes of observed data reasonably well, but may slightly overpredict during certain low-flow periods.
- Visual inspection of the time series plots suggests that, overall, the model is able to reproduce the range, annual patterns, and magnitudes of observations for total suspended solids (TSS) in the Cannon River at Welch but tends to overpredict in the Cannon River at Morristown and Straight River at Faribault. One possible explanation for the overprediction in the Cannon River at Morristown is due to the nature of the upstream contributing area, which is dominated by lakes. Because no water quality calibration was done, the updated hydrology parameterization may have resulted in overestimation of the landside contributions of TSS. Additionally, the model may be under-representing settling of suspended sediments in the various lakes and behind impoundments in the CRW.
- Visual inspection of daily time series plots for DO and temperature capture seasonal patterns and magnitudes.

Users of the model should consider, with caution, potential applications without a more thorough review and possible revision of the WQ calibration.

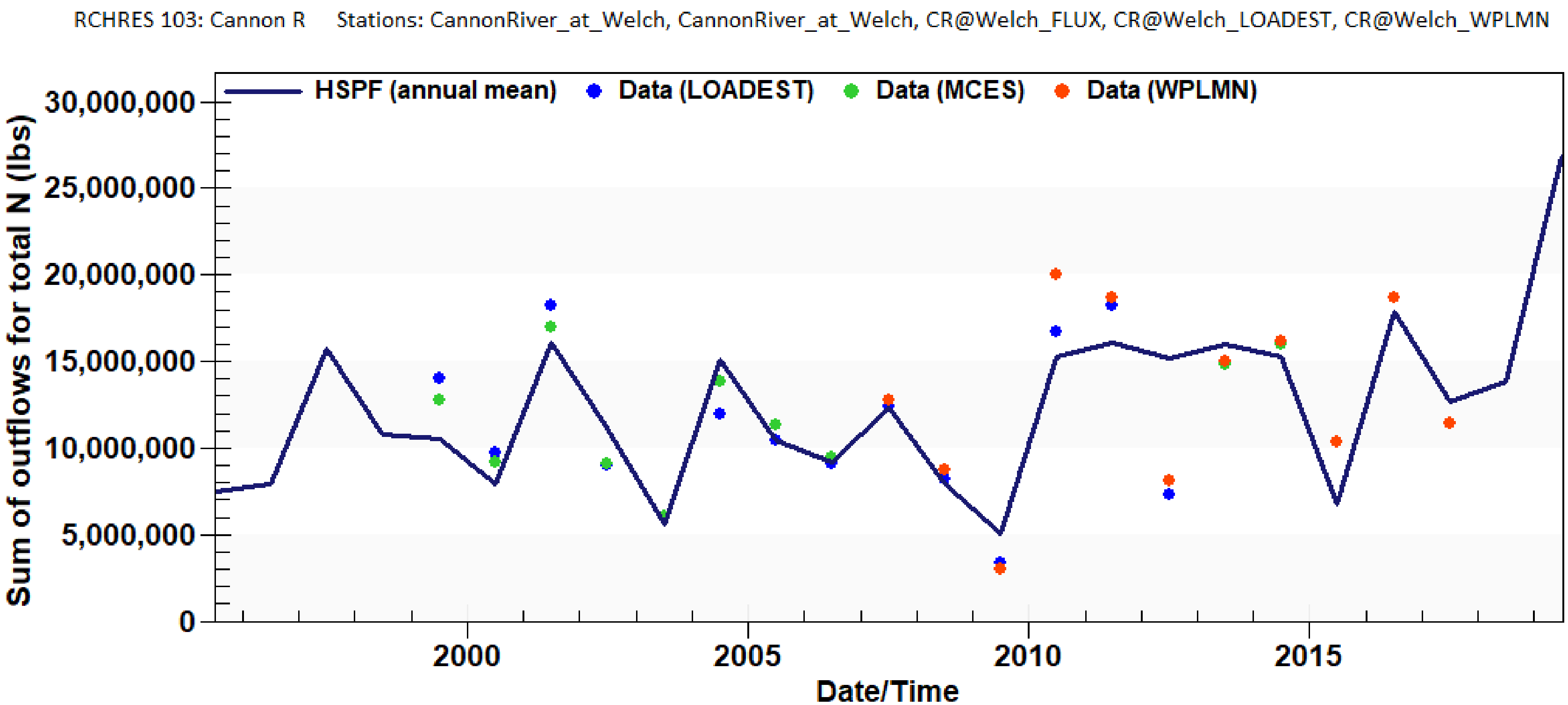

Figure 7: Annual TN loads for Cannon River at Welch for the entire simulation period.

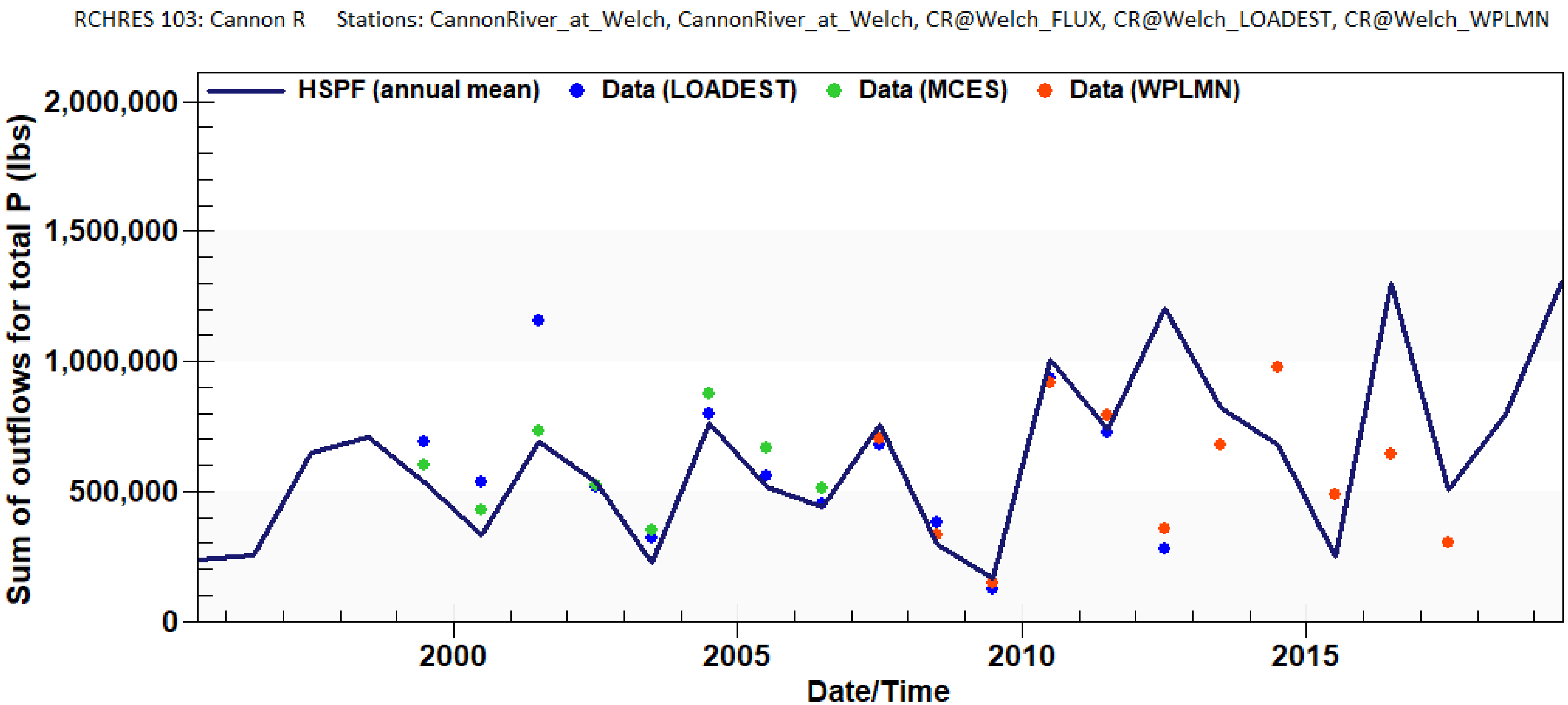

Figure 8: Annual TP loads for Cannon River at Welch for the entire simulation period.

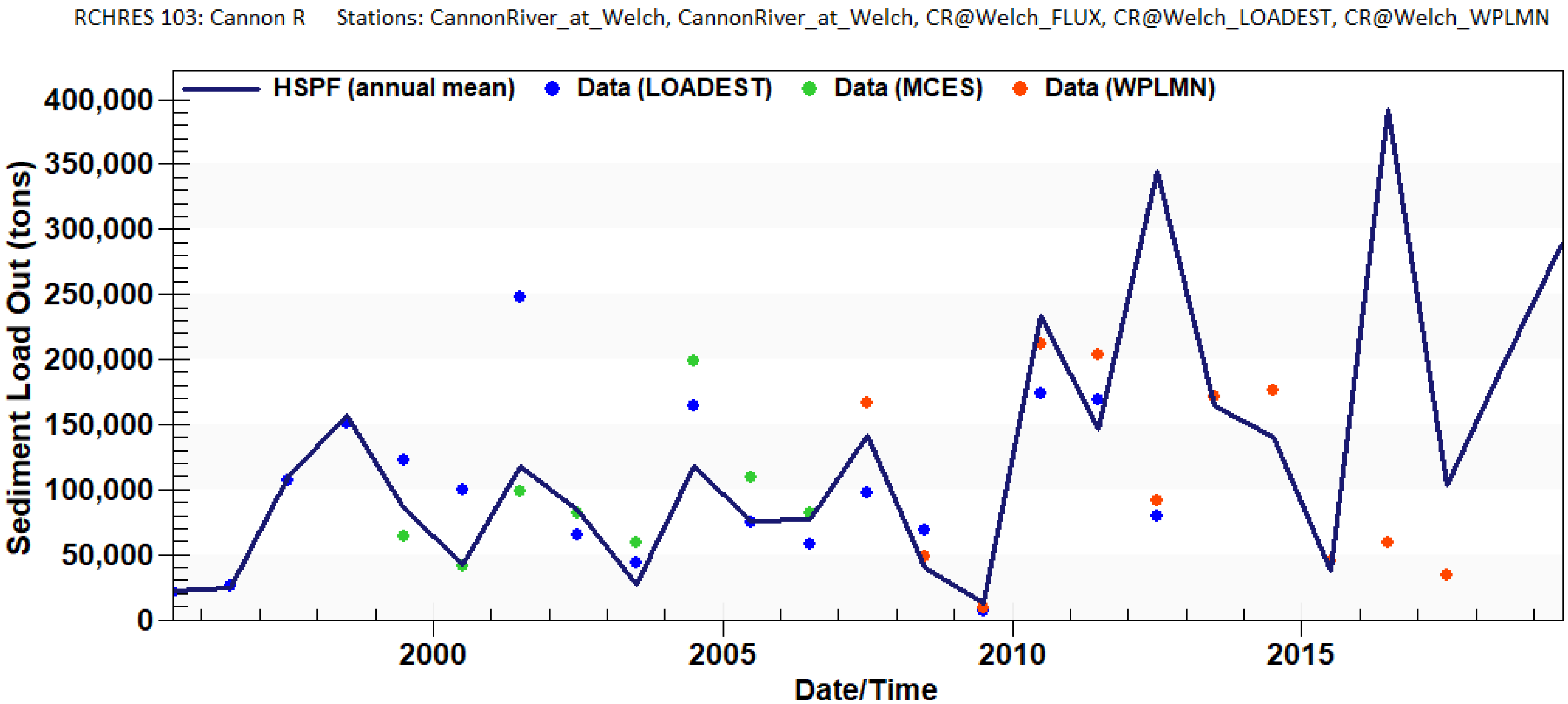

Figure 9: Annual TSS loads for Cannon River at Welch for the entire simulation period.

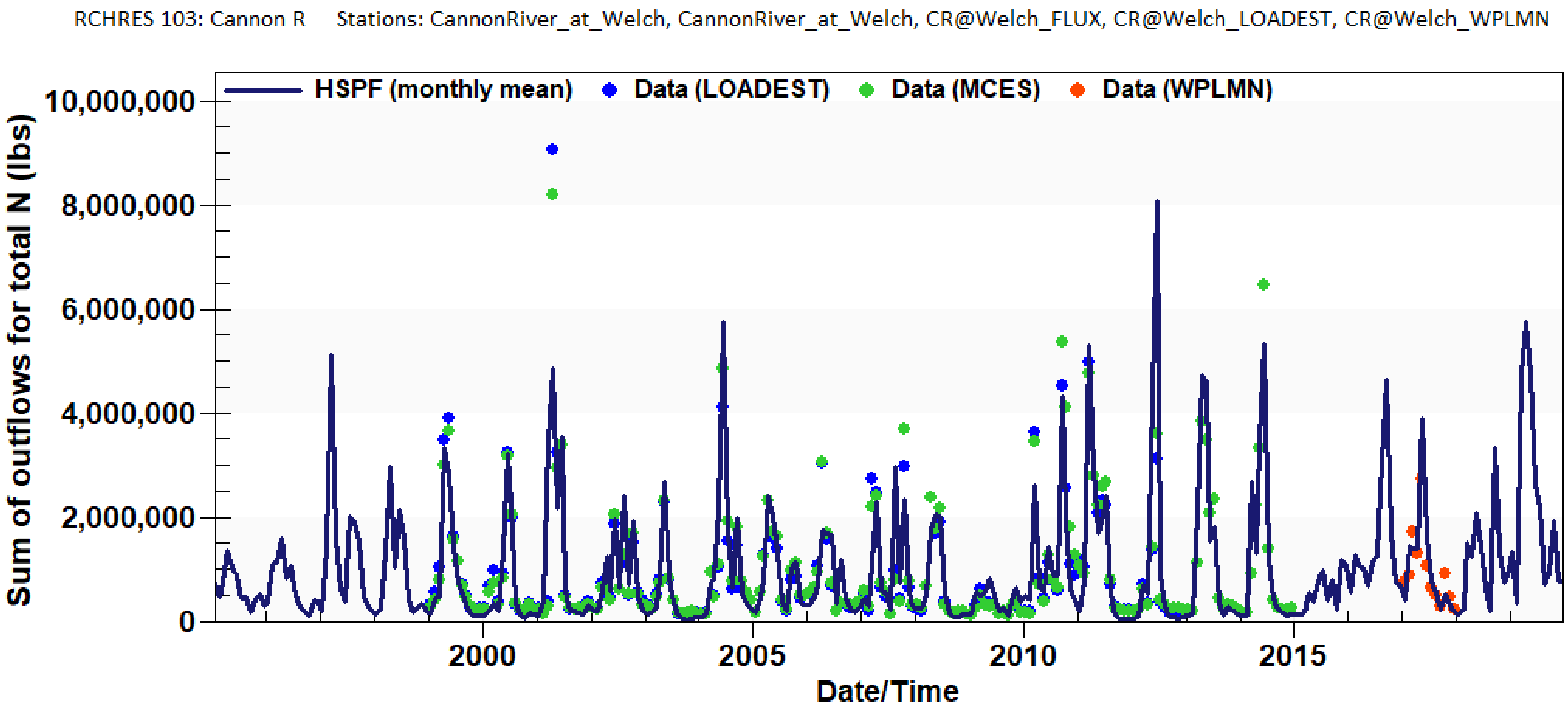

Figure 10: Monthly TN loads for Cannon River at Welch for the entire simulation period.

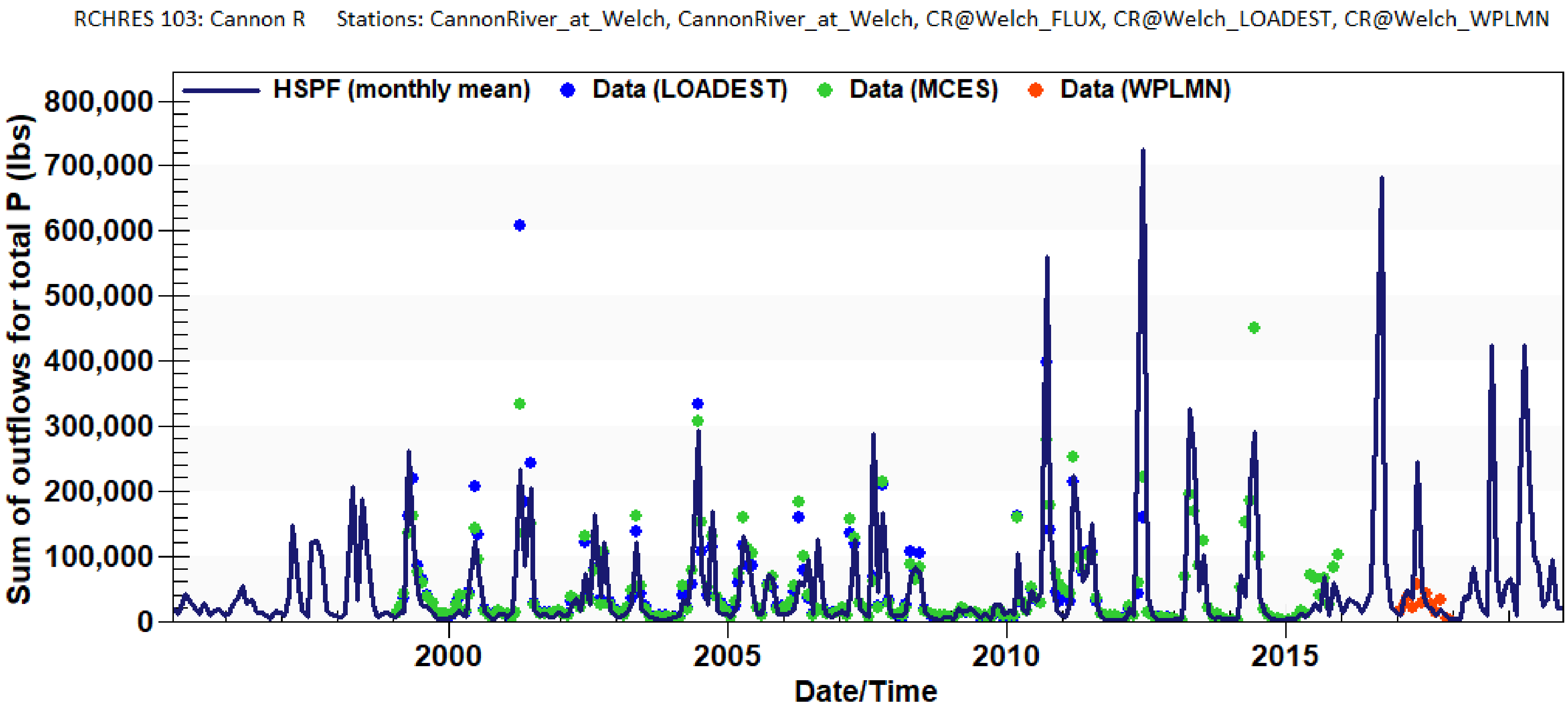

Figure 11: Monthly TP loads for Cannon River at Welch for the entire simulation period.

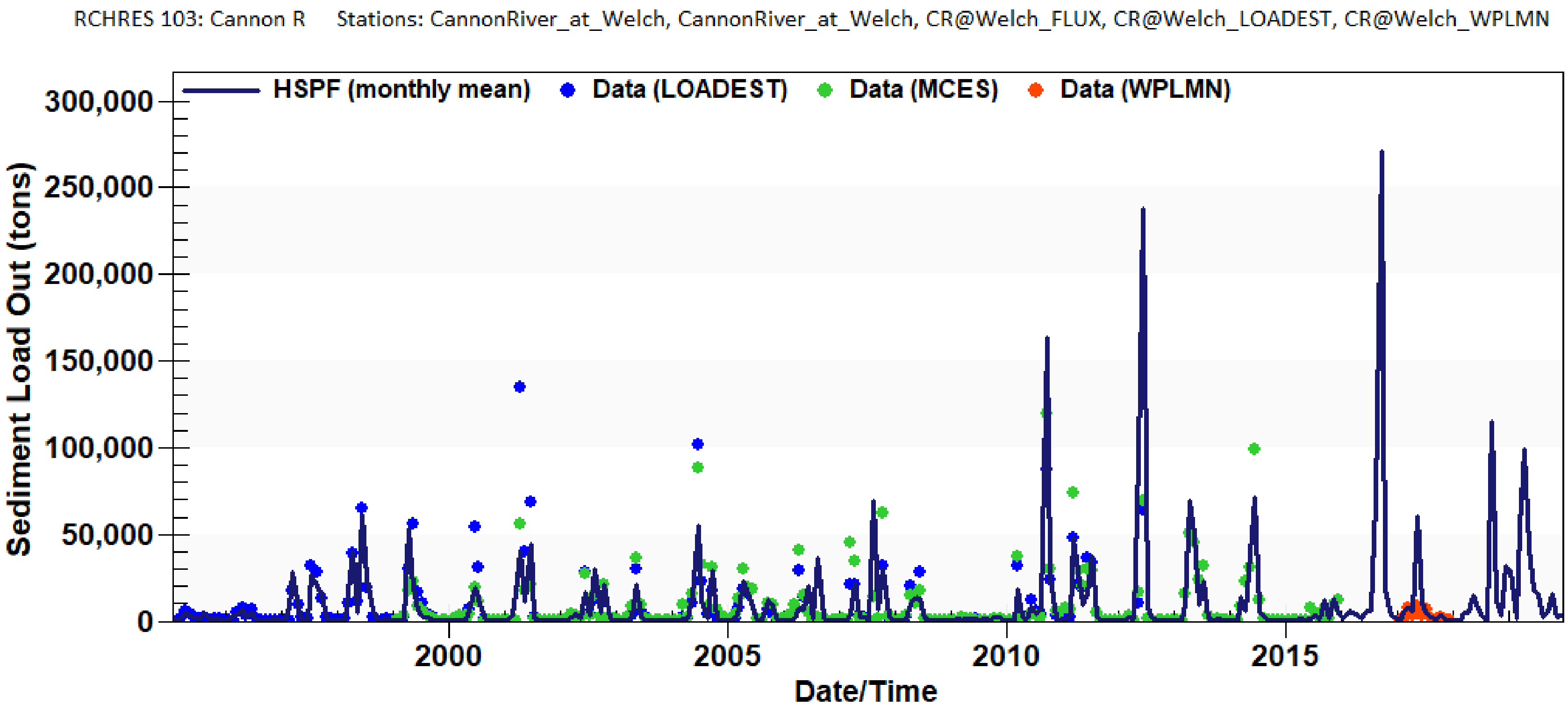

Figure 12: Monthly TSS loads for Cannon River at Welch for the entire simulation period.

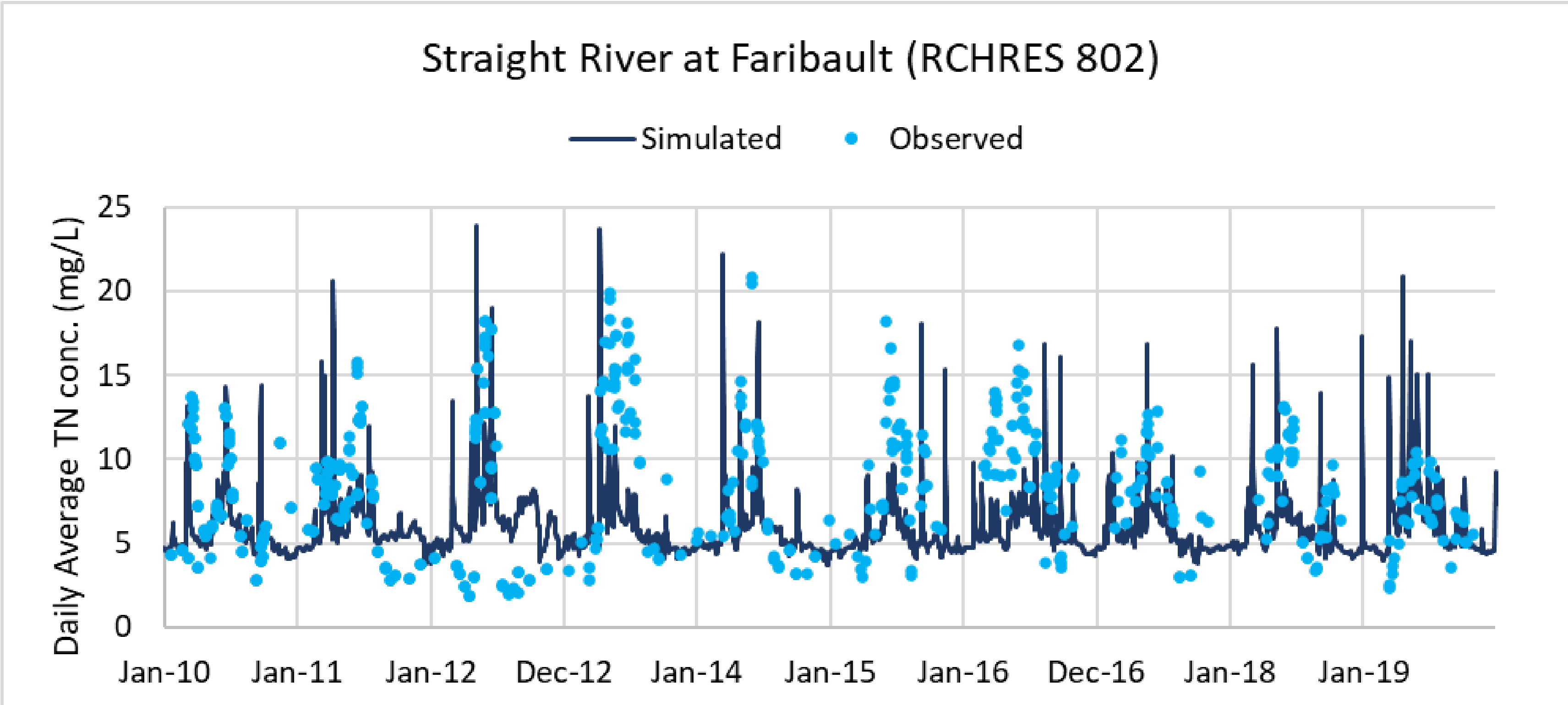

Figure 13: Daily TN concentrations for Straight River at Faribault for the entire simulation period.

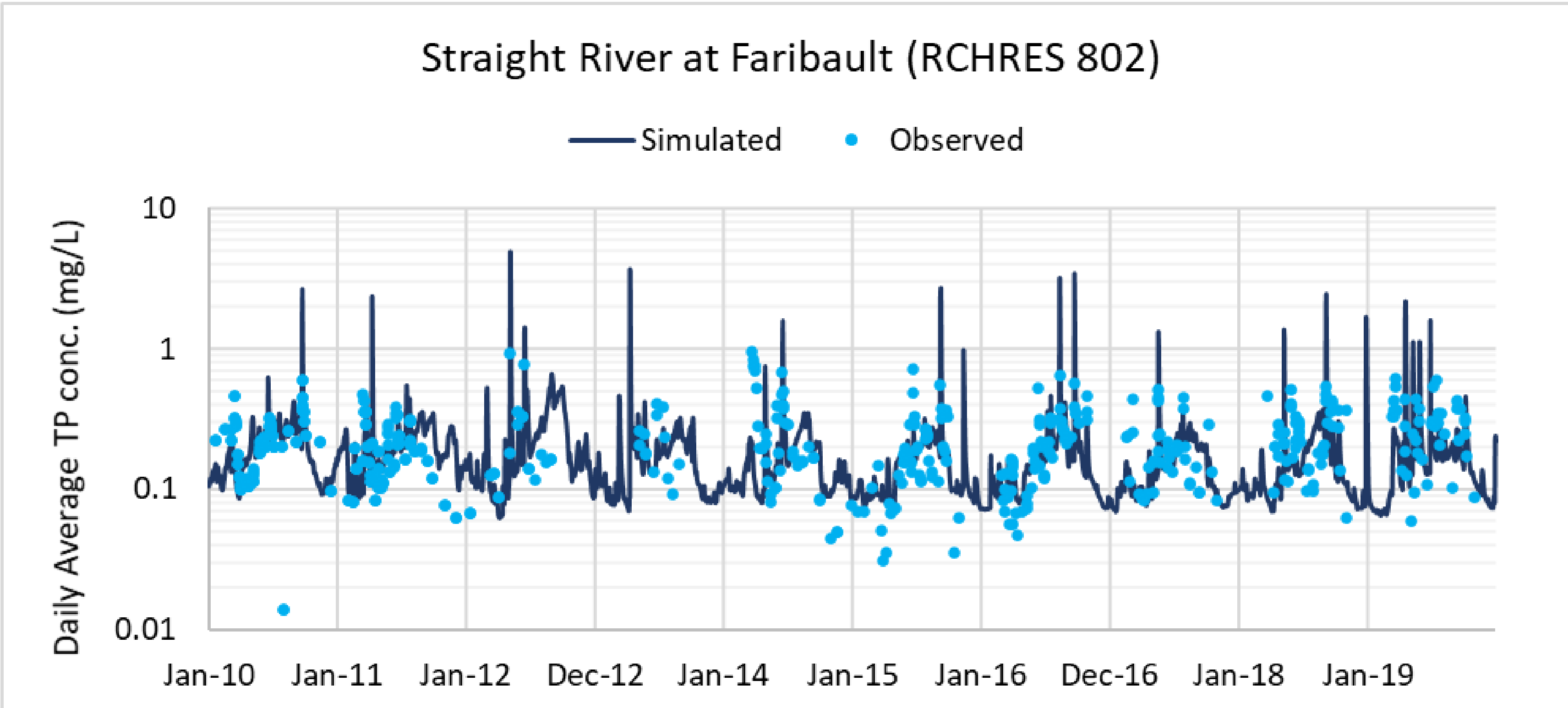

Figure 14: Daily TP concentrations for Straight River at Faribault for the entire simulation period.

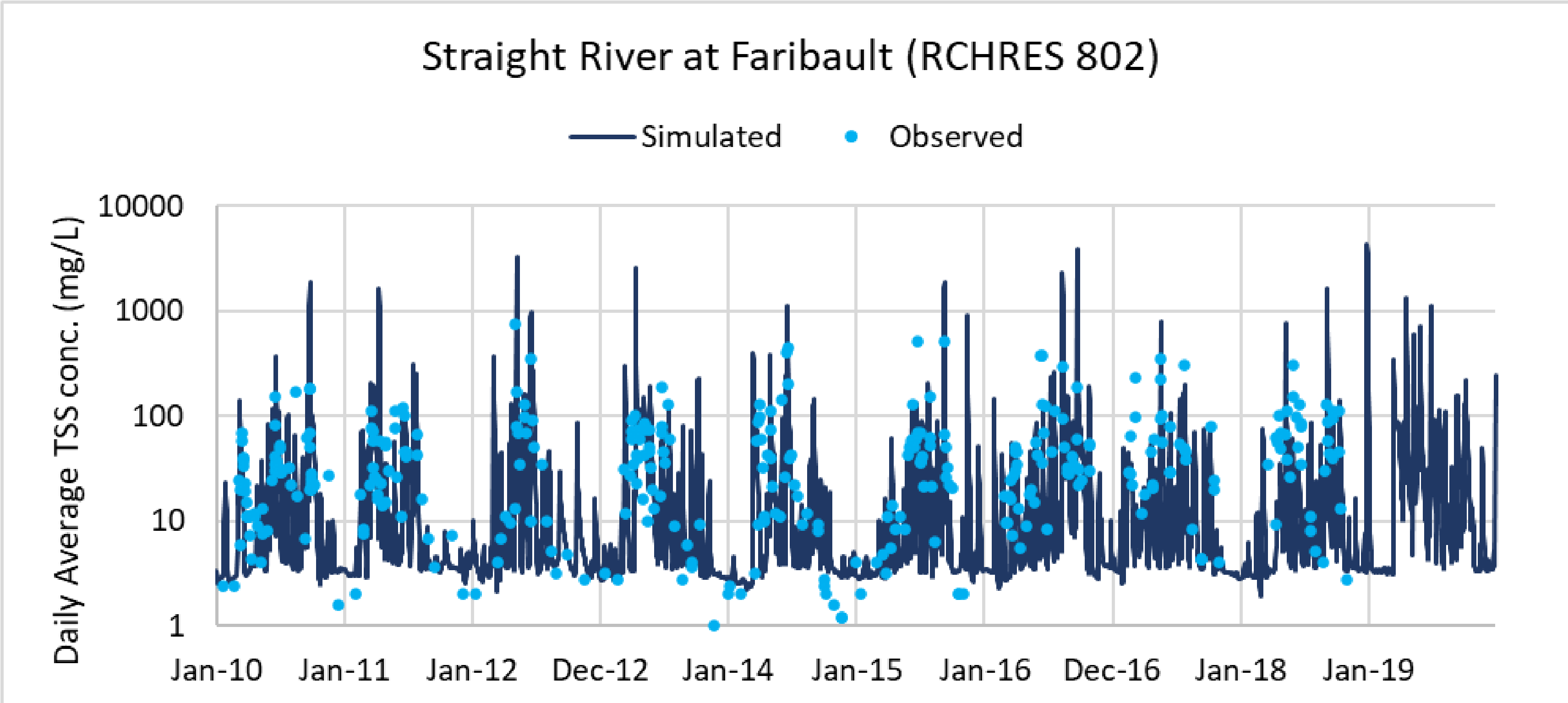

Figure 15: Daily TSS concentrations for Straight River at Faribault for the entire simulation period.

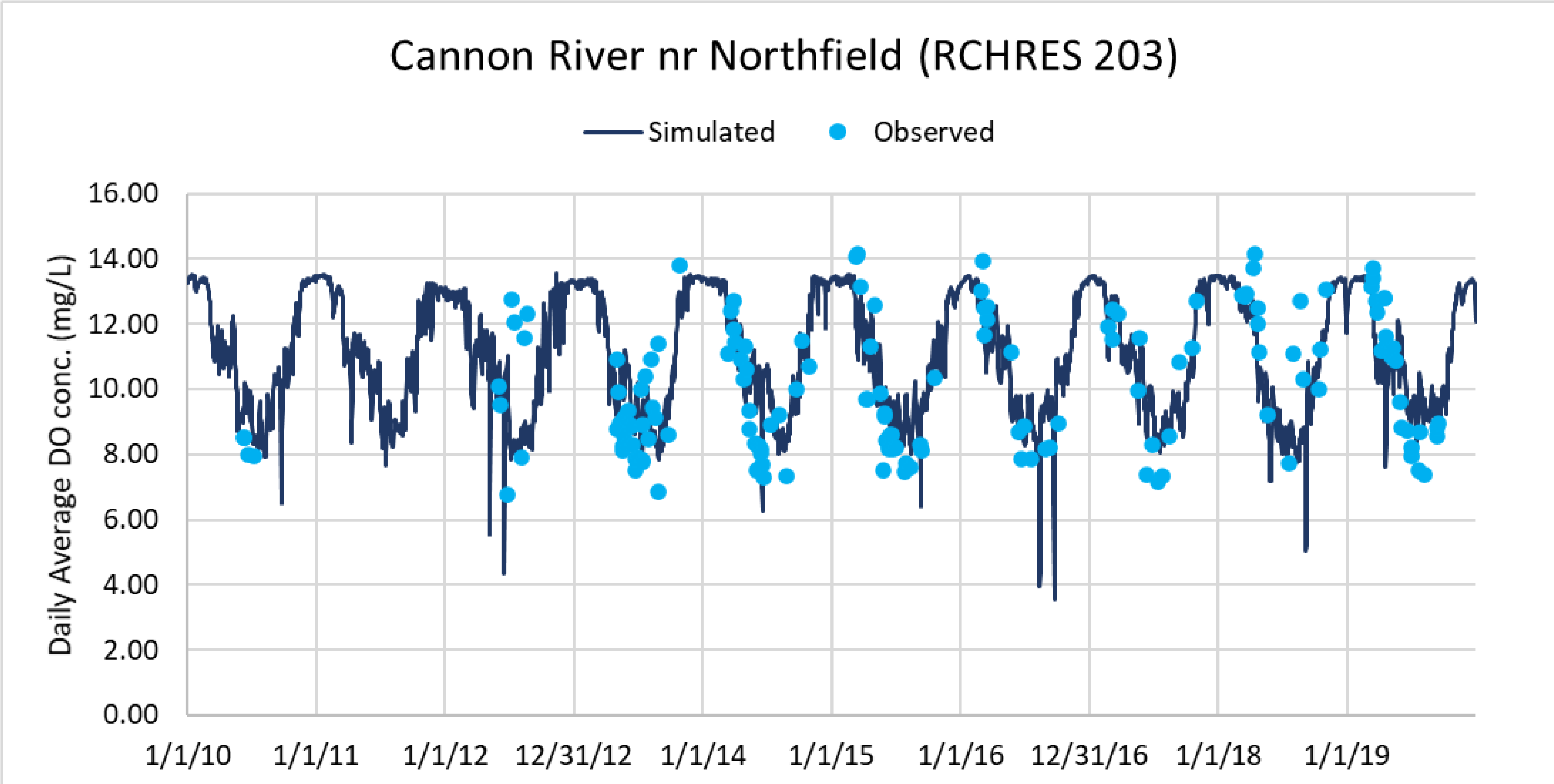

Figure 16: Observed and simulated daily average DO concentration for Cannon River near Northfield.

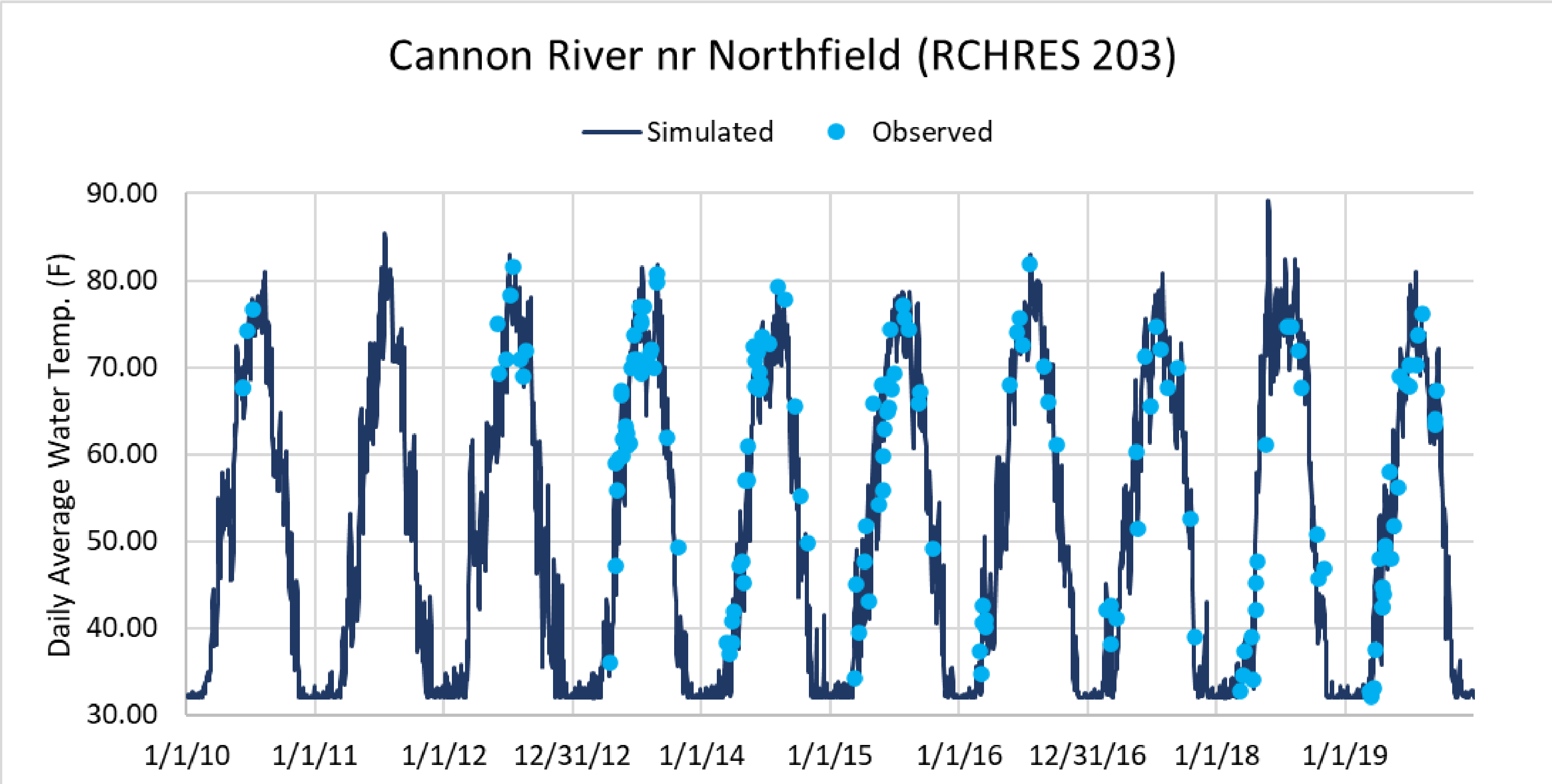

Figure 17: Observed and simulated daily average water temperature for Cannon River near Northfield.

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Appendix A: Performance Metric Equations and Tolerances

Nash-Sutcliffe Efficiency (NSE):

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

Percent Bias (PBIAS):

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

Mean Relative Percent Difference (RPD):

$$RPD = \frac{1}{n}\sum_{i=1}^{n}\frac{S_i - O_i}{\frac{1}{2}(S_i + O_i)} \times 100$$

where:

n is the number of samples
O_i is the observed value
$\bar{O}$ is the mean observed value
S_i is the simulated value

Table A-1: Model performance ratings for R-squared, NSE, PBIAS, RPD and RPE

Performance Rating	R-squared for streamflow (Duda et al., 2012)		NSE for annual and monthly streamflow (Parajuli et al., 2009)	PBIAS for monthly streamflow (Moriasi et al., 2007)	RPD (Duda et al., 2012)		
	Daily	Monthly			Streamflow	Sediment	Water Quality
Excellent			> 0.90				
Very good	>0.80	> 0.85	0.75 – 0.89	< ±10	<10%	<20%	<15%
Good	0.70-0.80	0.75-0.85	0.50 – 0.74	±10 – ±15	10 – 15%	20 – 30%	15 – 25%
Fair / Satisfactory	0.60-0.70	0.65-0.75	0.25 – 0.49	±15 – ±25	15 – 25%	30 – 45%	25 – 35%
Poor	<0.60	0.55-0.65	0.00 – 0.24		>25%	>45%	>35%
Unsatisfactory		< 0.55	< 0.00	> ±25			

Appendix B: Additional Model Performance Evaluation Statistics

Table B-1: Model performance evaluation statistics for secondary and auxiliary hydrology calibration locations for the 2010-2019 model calibration period.

Time Interval	Statistic	Cannon River @ Morristown	Little Cannon River nr Cannon Falls	Little Cannon River @ Sogn
		2011 - 2019	2010 – 2019	2010 - 2019
Annual	*Count*	9	6	10
	R-Squared	0.93	0.88	0.36
	NSE	0.90	0.85	0.29
	RPD	5.5%	7.7%	-4.5%
Monthly	*Count*	78	62	118
	R-Squared	0.72	0.70	0.77
	NSE	0.71	0.59	0.77
	P-Bias	4.27	-7.24	6.43
	RPD	1.1%	4.9%	-2.9%
Daily	*Count*	2063	1764	3400
	R-Squared	0.64	0.53	0.57
	RPD	0.5%	8.8%	10.7%

Table B-2: Model performance evaluation statistics for primary, secondary, and auxiliary calibration locations for the 2000-2009 model validation period.

Time Interval	Statistic	Cannon River @ Welch	Straight River @ Faribault	Cannon River @ Morristown	Little Cannon River nr Cannon Falls	Little Cannon River @ Sogn
		2000 – 2009	2000 - 2009	2007 - 2009	2000 - 2008	2002 - 2009
Annual	*Count*	10	10	3	7	5
	R-Squared	0.66	0.87	1.00	0.57	0.91
	NSE	0.17	0.75	0.76	-1.30	0.79
	RPD	15.2%	13.1%	66.5%	22.5%	30.1%
Monthly	*Count*	120	120	11	63	44
	R-Squared	0.76	0.79	0.83	0.68	0.65
	NSE	0.71	0.77	0.51	0.40	0.51
	P-Bias	-16.47	-12.48	-47.77	-26.84	-18.61
	RPD	10.3%	18.6%	53.9%	20.1%	22.5%
Daily	*Count*	3652	3652	208	1764	1068
	R-Squared	0.67	0.68	0.54	0.53	0.39
	RPD	9.3%	17.9%	41.3%	27.5%	41.4%

Appendix C: Additional Calibration Plots

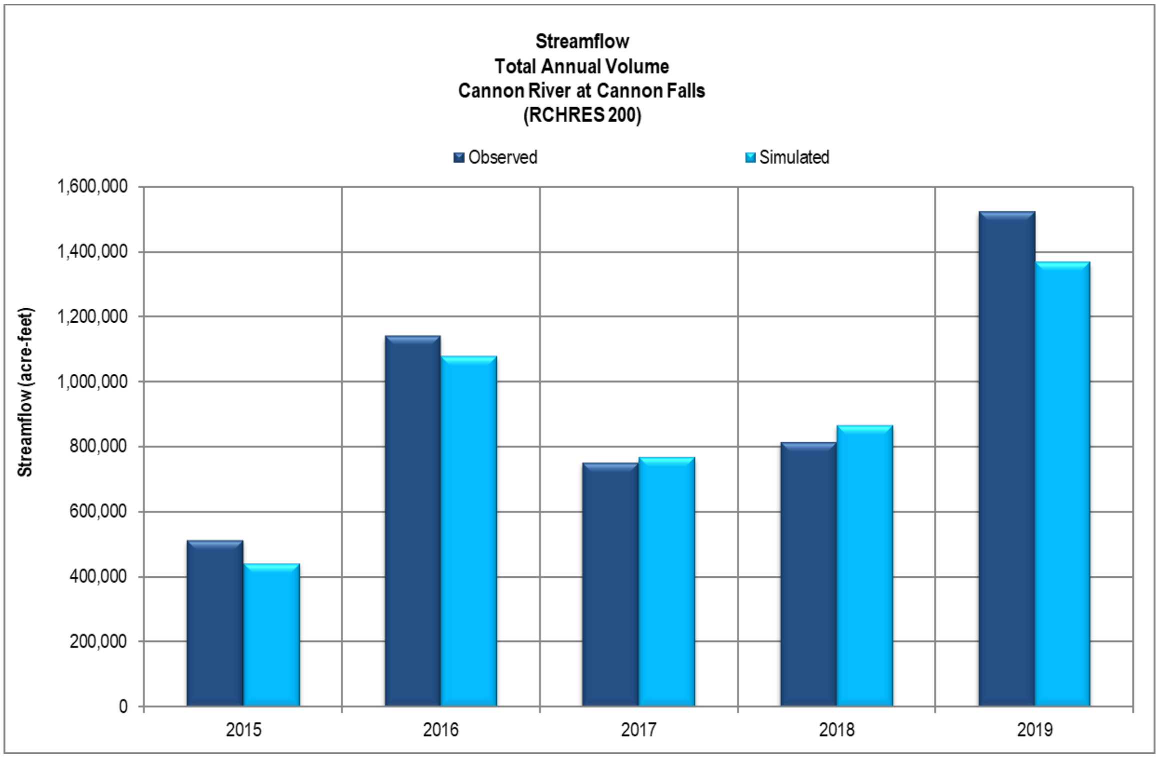

Figure C-1: Observed and simulated annual streamflow volume for Cannon River at Cannon River Falls.

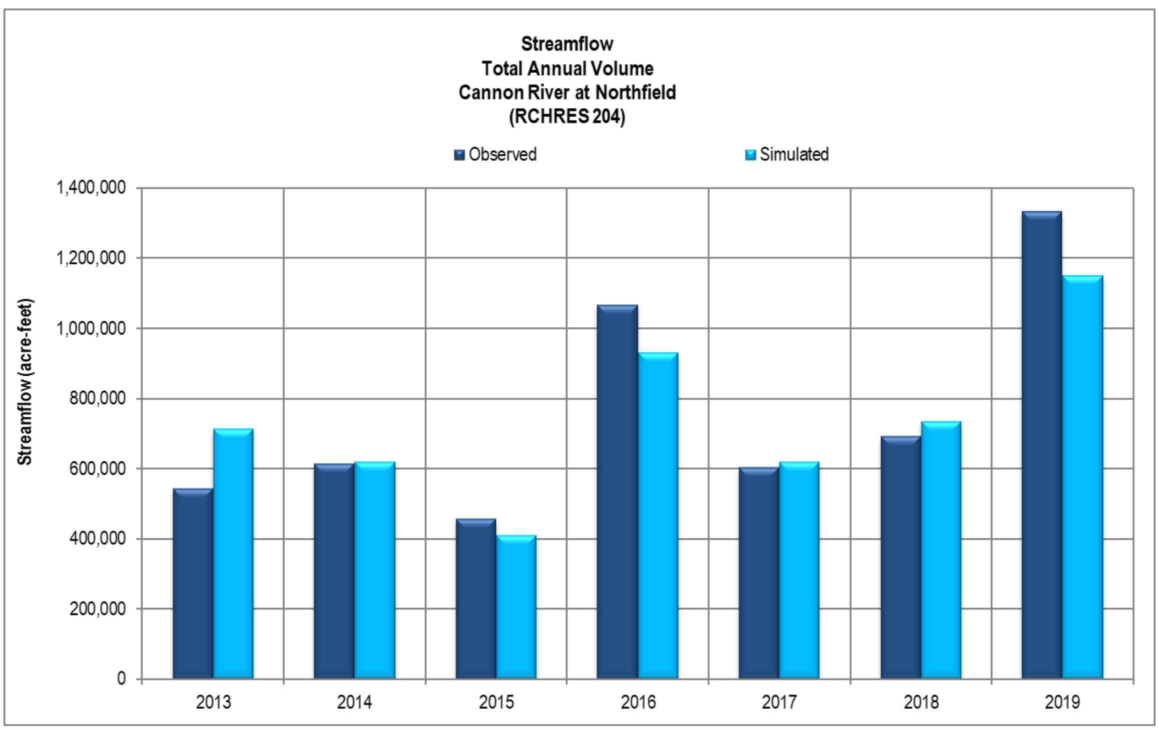

Figure C-2: Observed and simulated annual streamflow volume for Cannon River at Northfield.

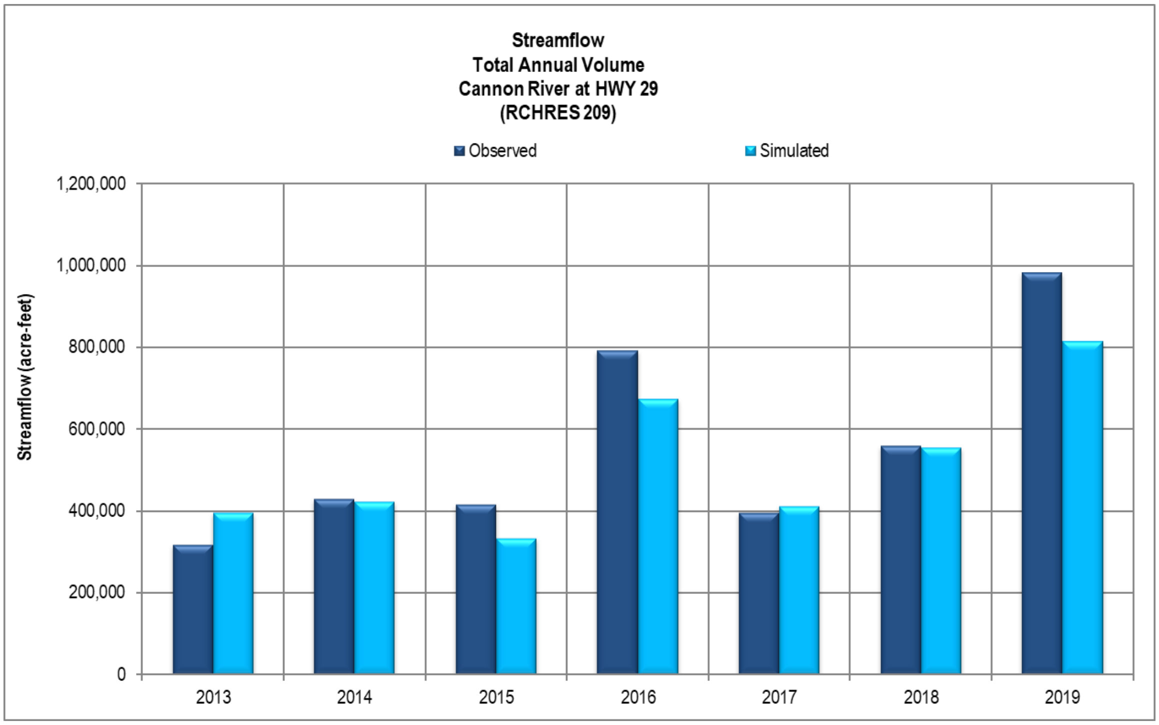

Figure C-3: Observed and simulated annual streamflow volume for Cannon River at Hwy 29.

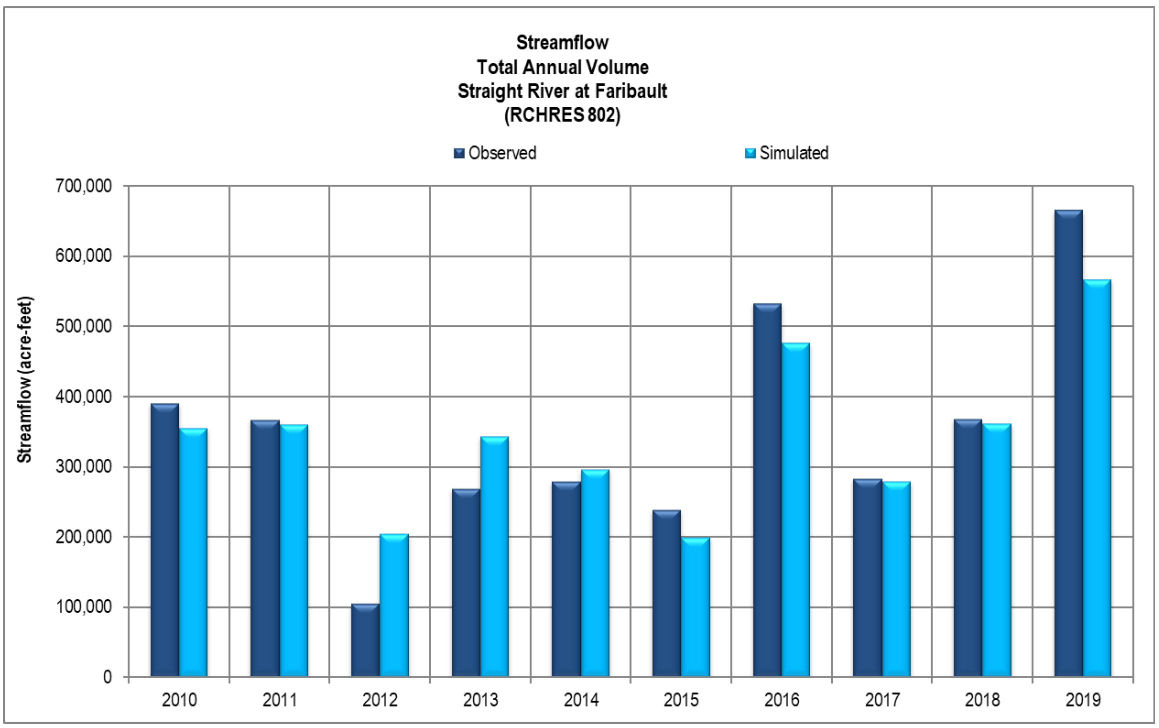

Figure C-4: Observed and simulated annual streamflow volume for Straight River at Faribault.

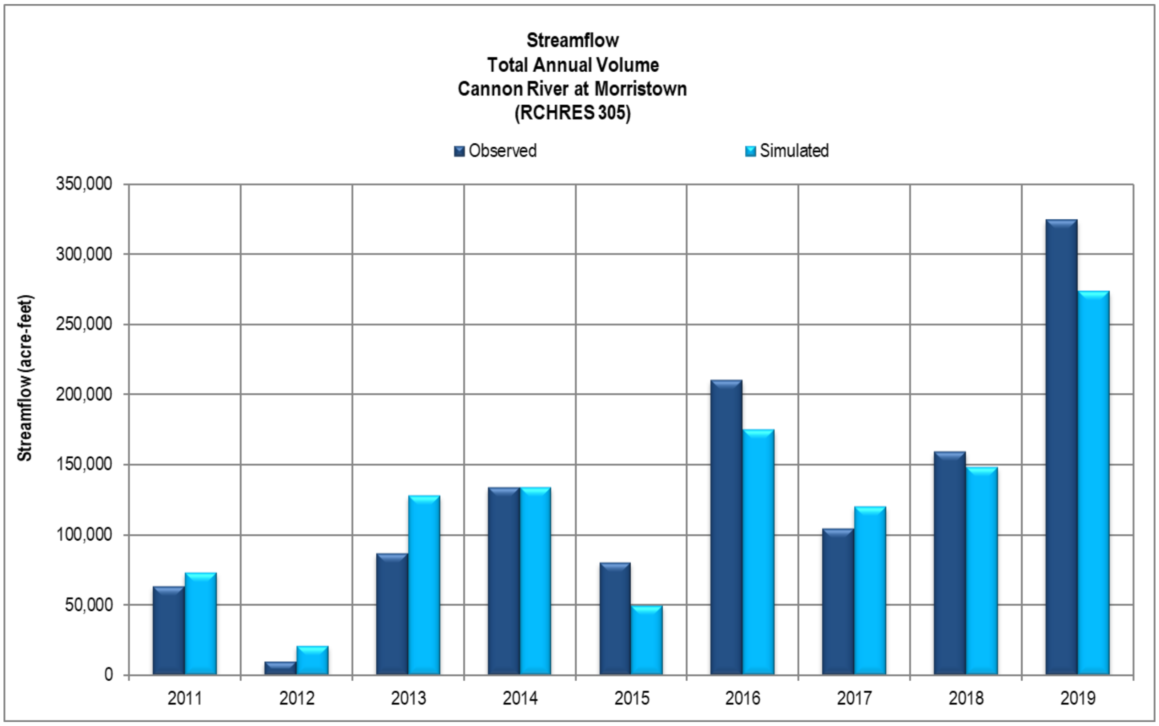

Figure C-5: Observed and simulated annual streamflow volume for Cannon River at Morristown.

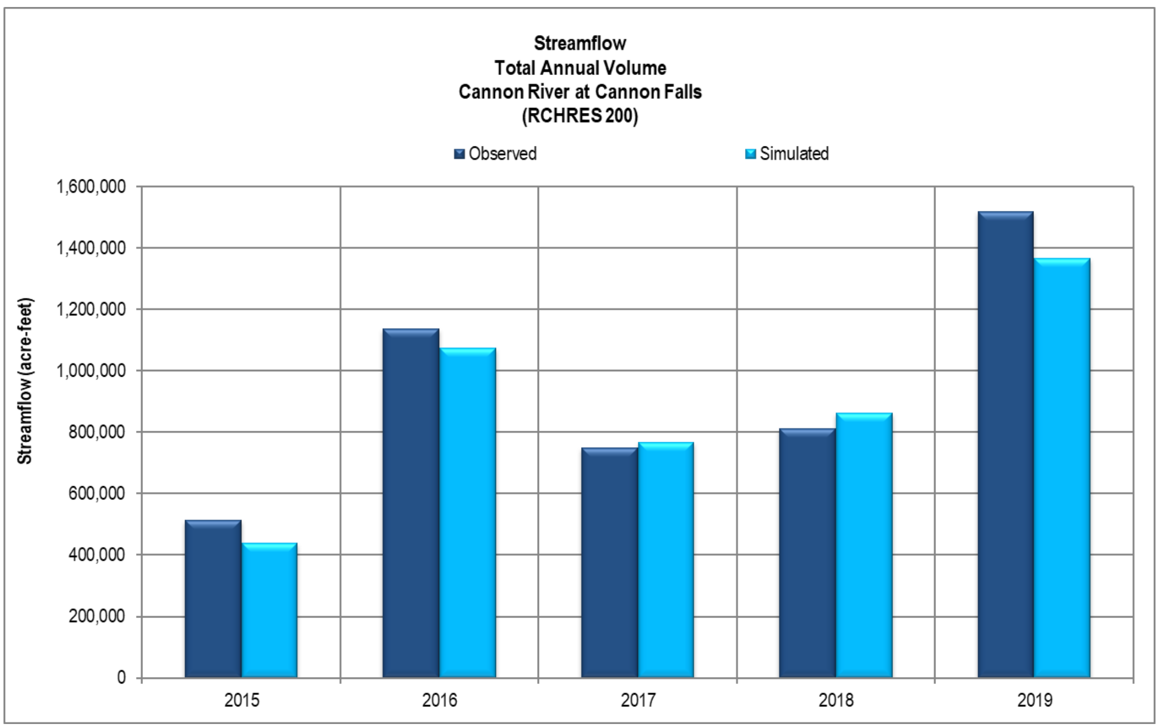

Figure C-6: Observed and simulated annual streamflow volume for Little Cannon River nr Cannon Falls.

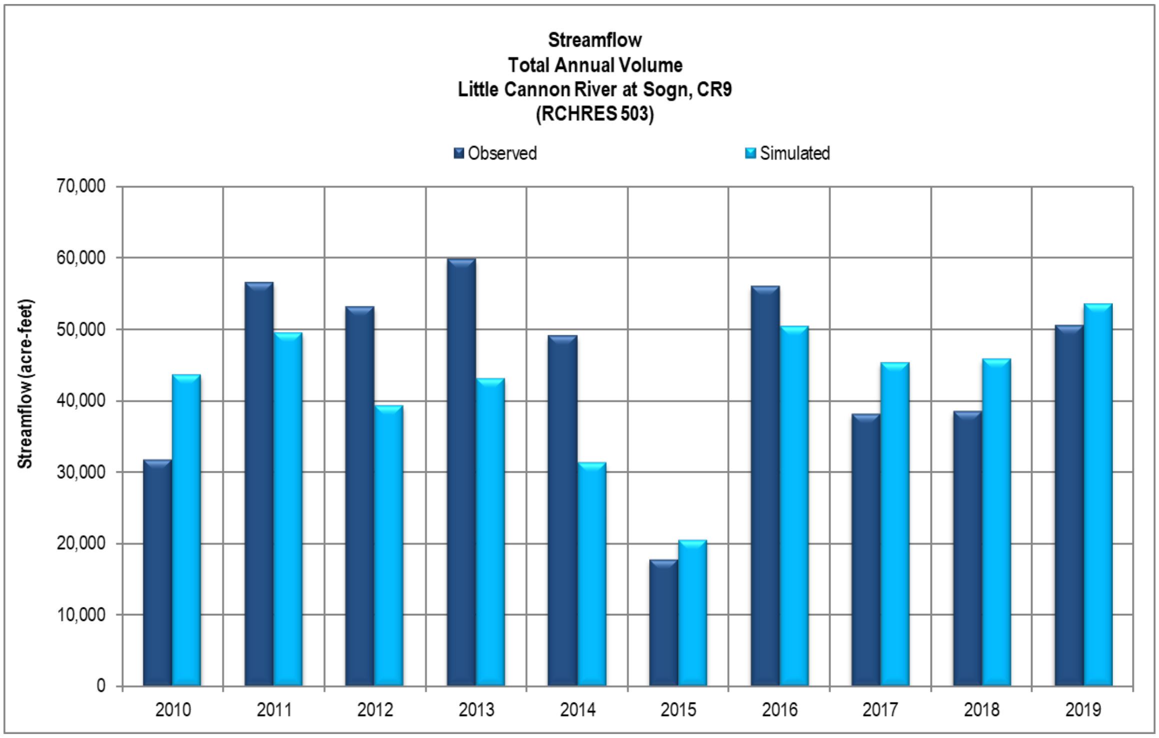

Figure C-7: Observed and simulated annual streamflow volume for Little Cannon at Sogn.

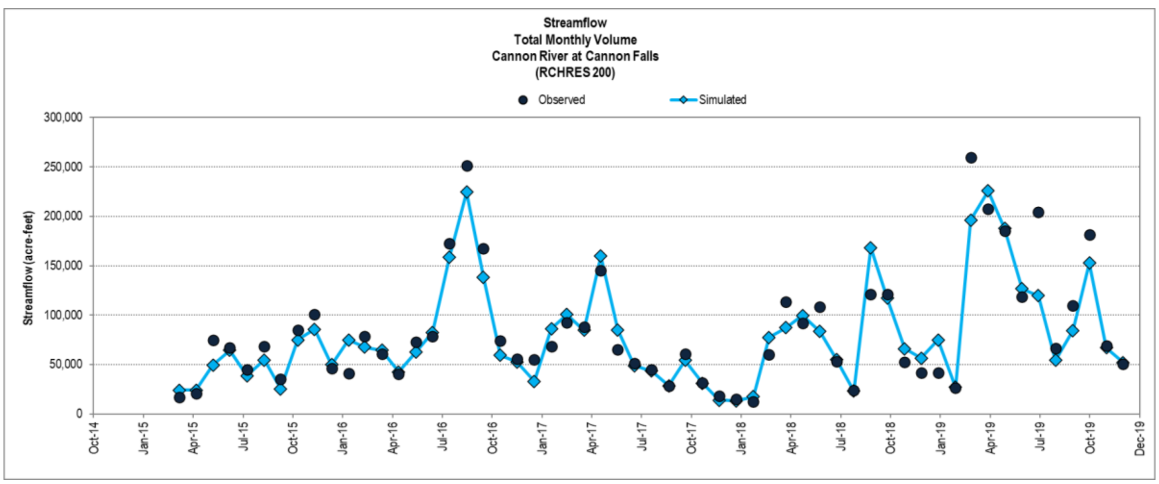

Figure C-8: Observed and simulated monthly streamflow for Cannon River at Cannon River Falls.

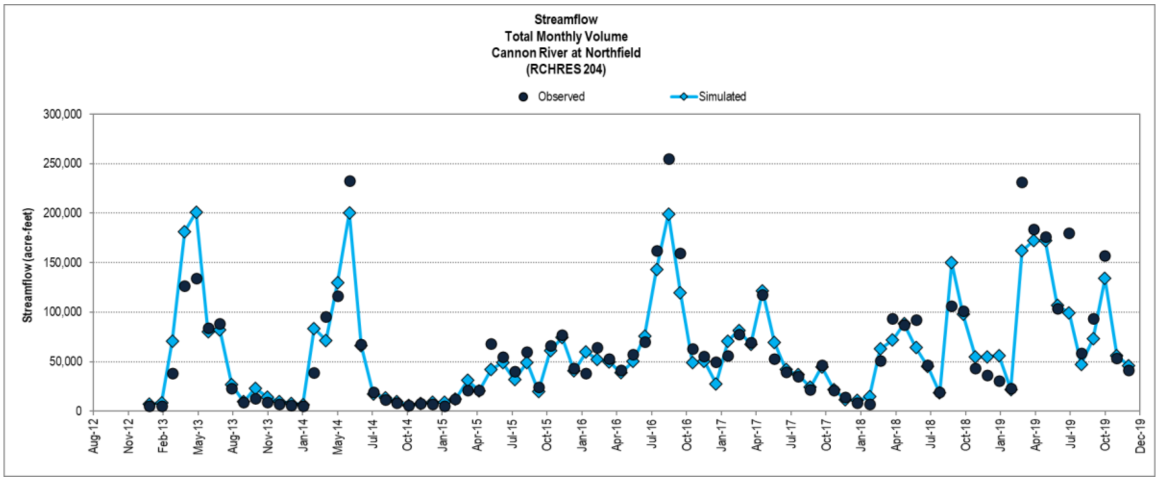

Figure C-9: Observed and simulated monthly streamflow for Cannon River at Northfield.

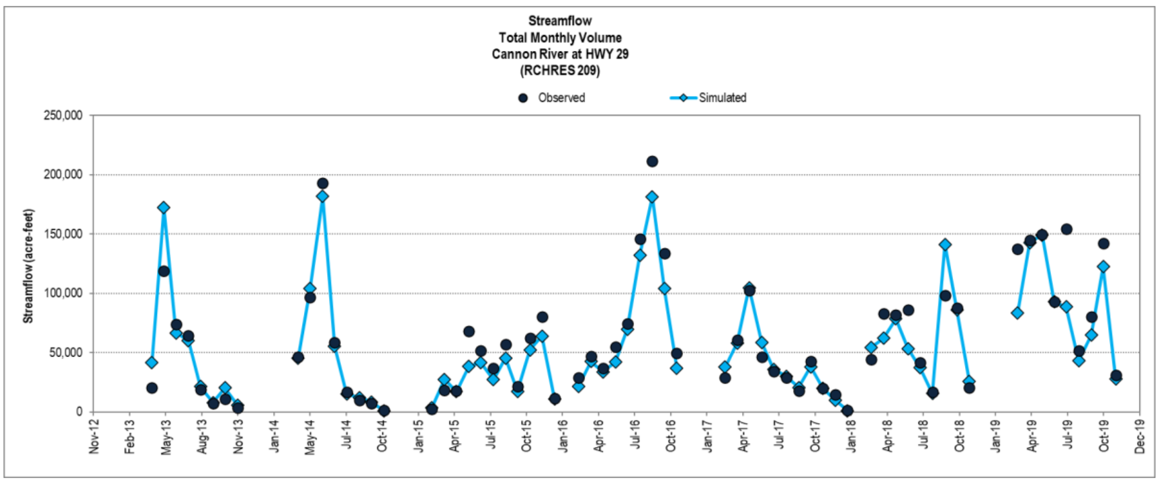

Figure C-10: Observed and simulated monthly average streamflow for Cannon River at Hwy 29.

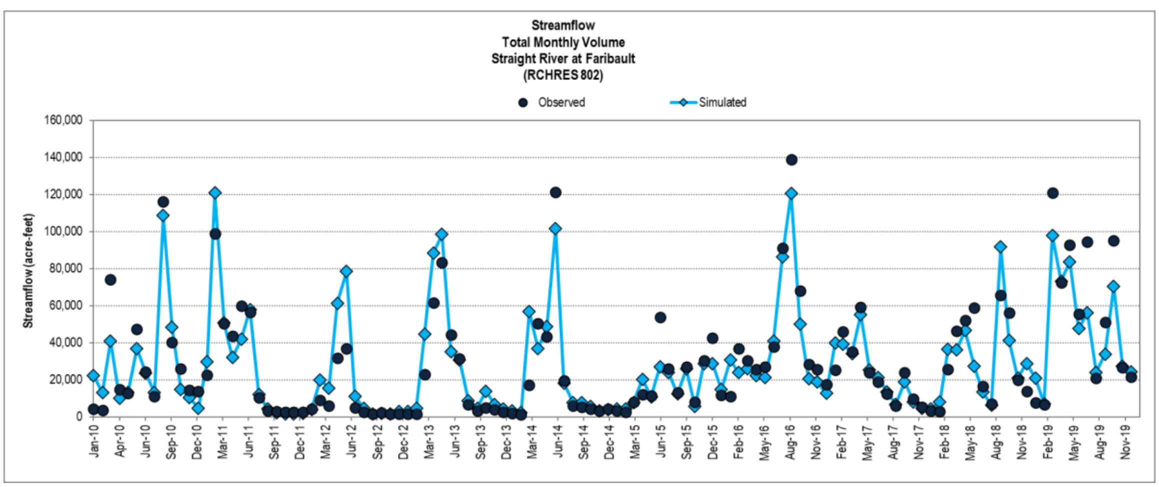

Figure C-11: Observed and simulated monthly average streamflow for Straight River at Faribault.

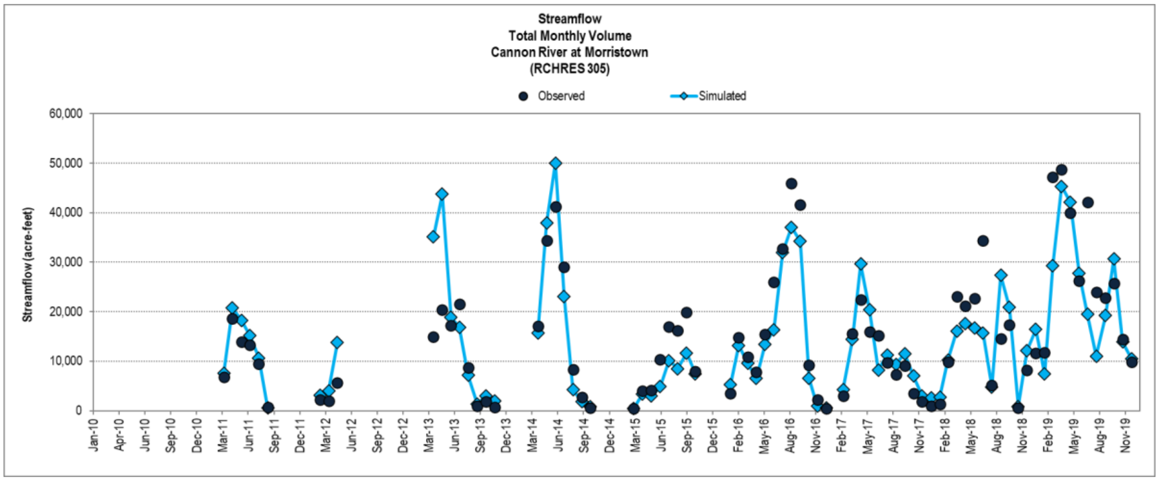

Figure C-12: Observed and simulated monthly average streamflow for Cannon River at Morristown.

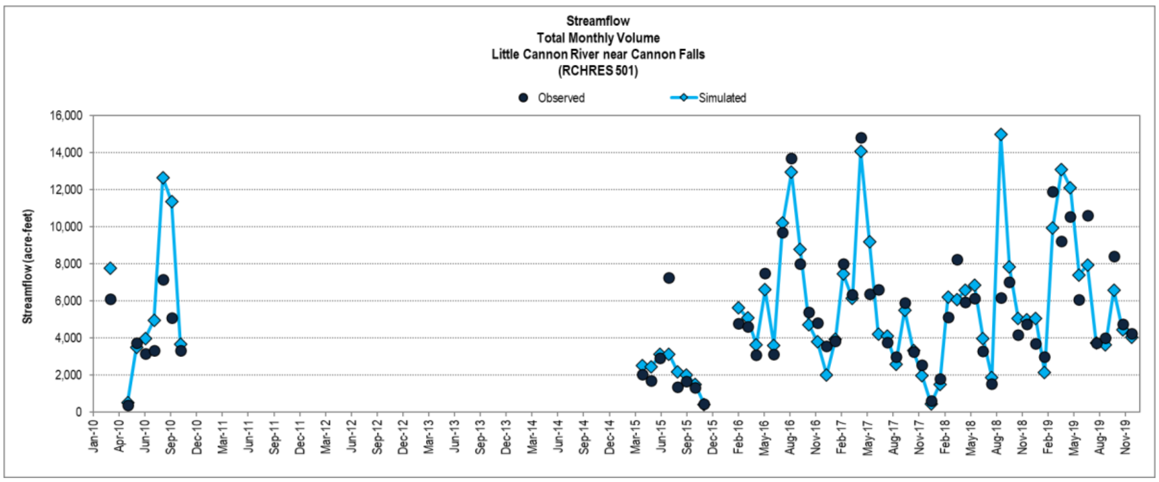

Figure C-13: Observed and simulated monthly average streamflow for Little Cannon River nr Cannon Falls.

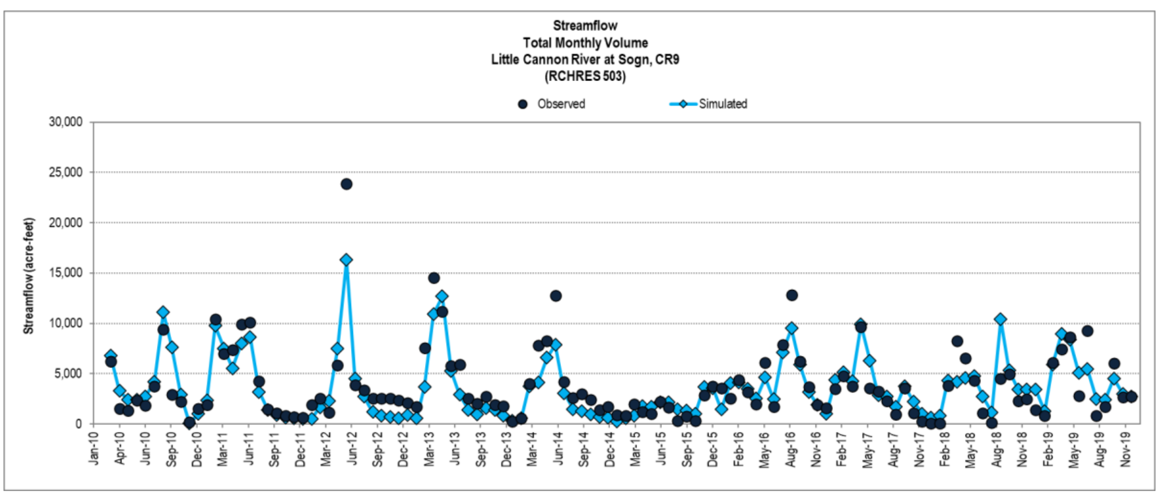

Figure C-14: Observed and simulated monthly average streamflow for Little Cannon River at Sogn.

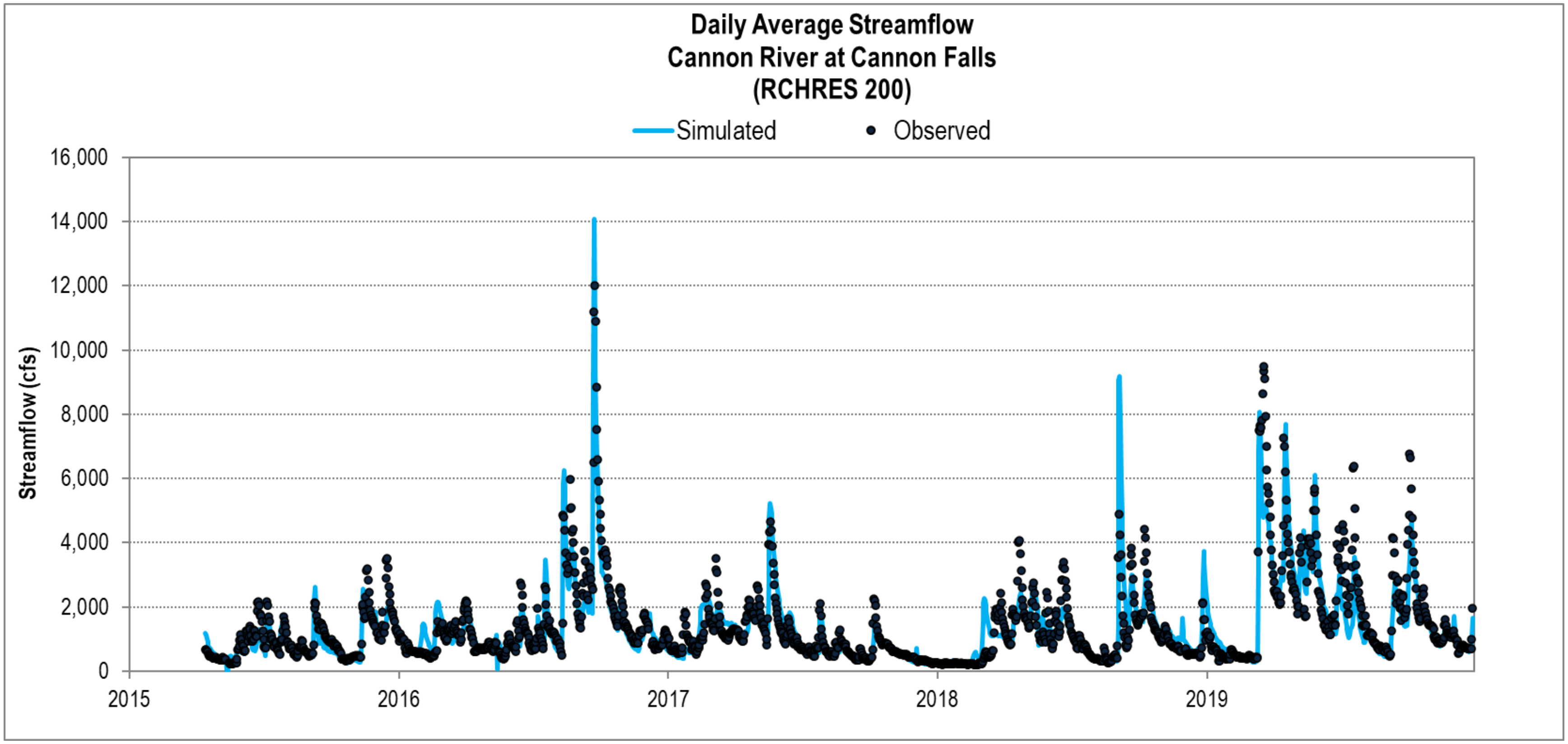

Figure C-15: Observed and simulated daily streamflow for Cannon River at Cannon River Falls.

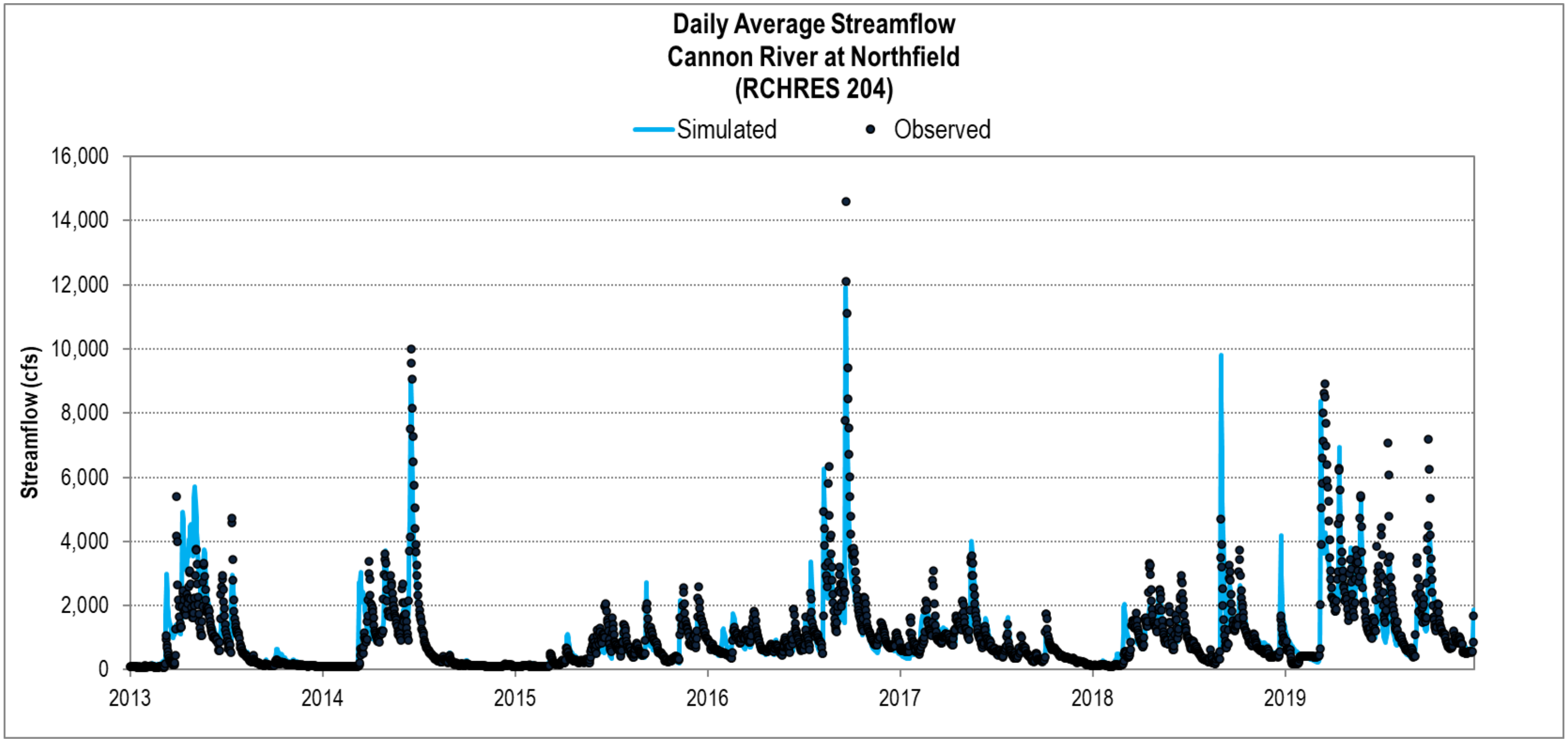

Figure C-16: Observed and simulated daily streamflow for Cannon River at Northfield.

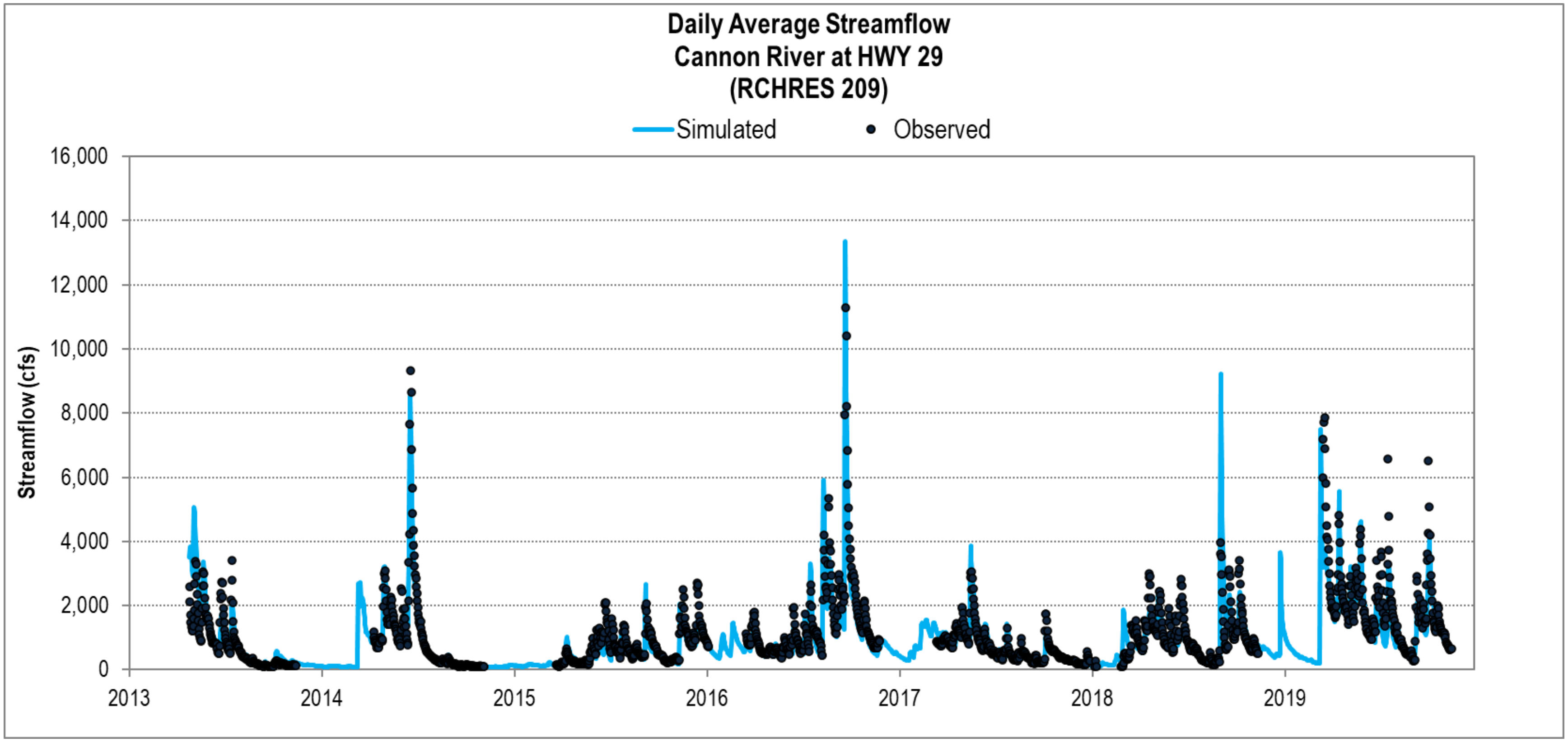

Figure C-17: Observed and simulated daily streamflow for Cannon River at Hwy 29.

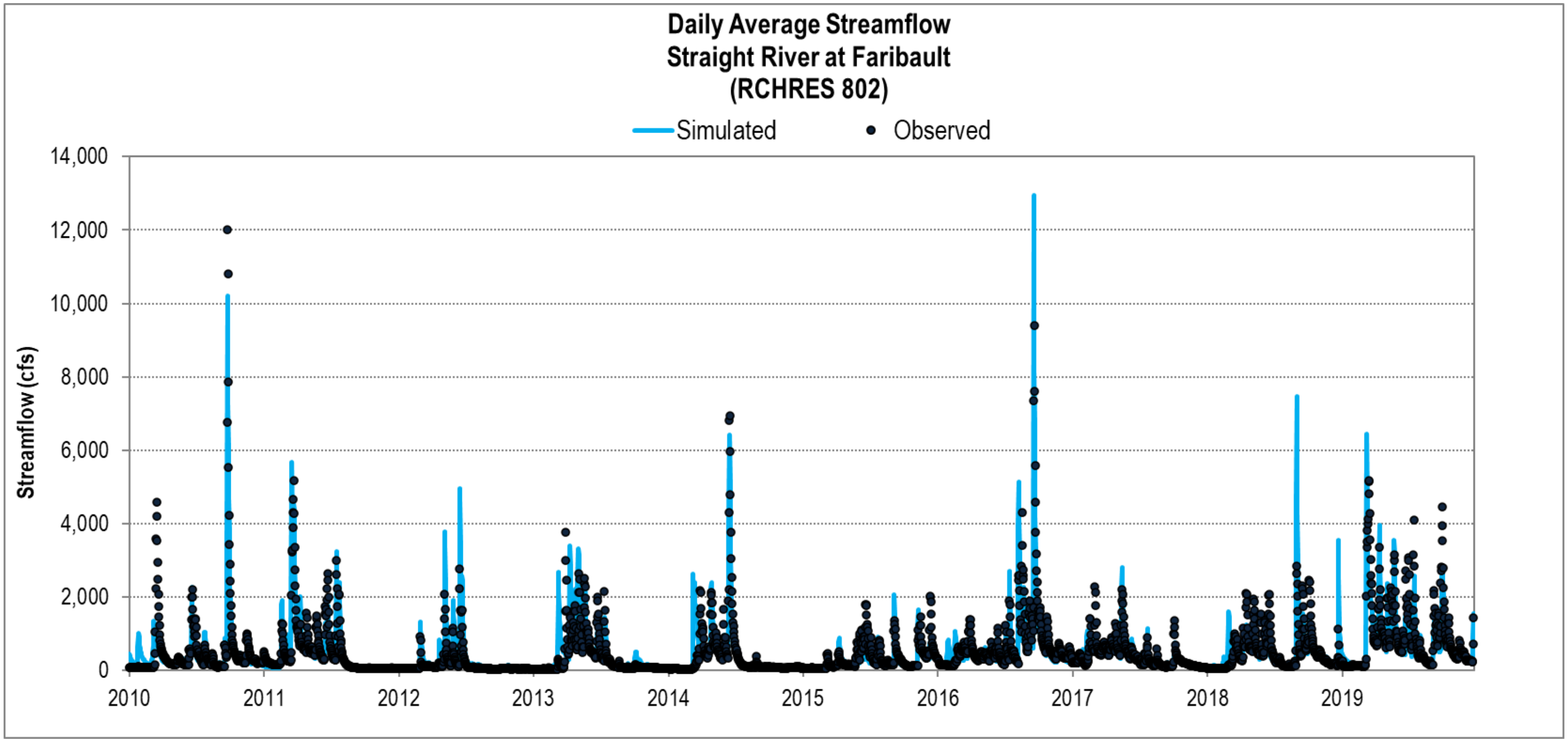

Figure C-18: Observed and simulated daily streamflow for Straight River at Faribault.

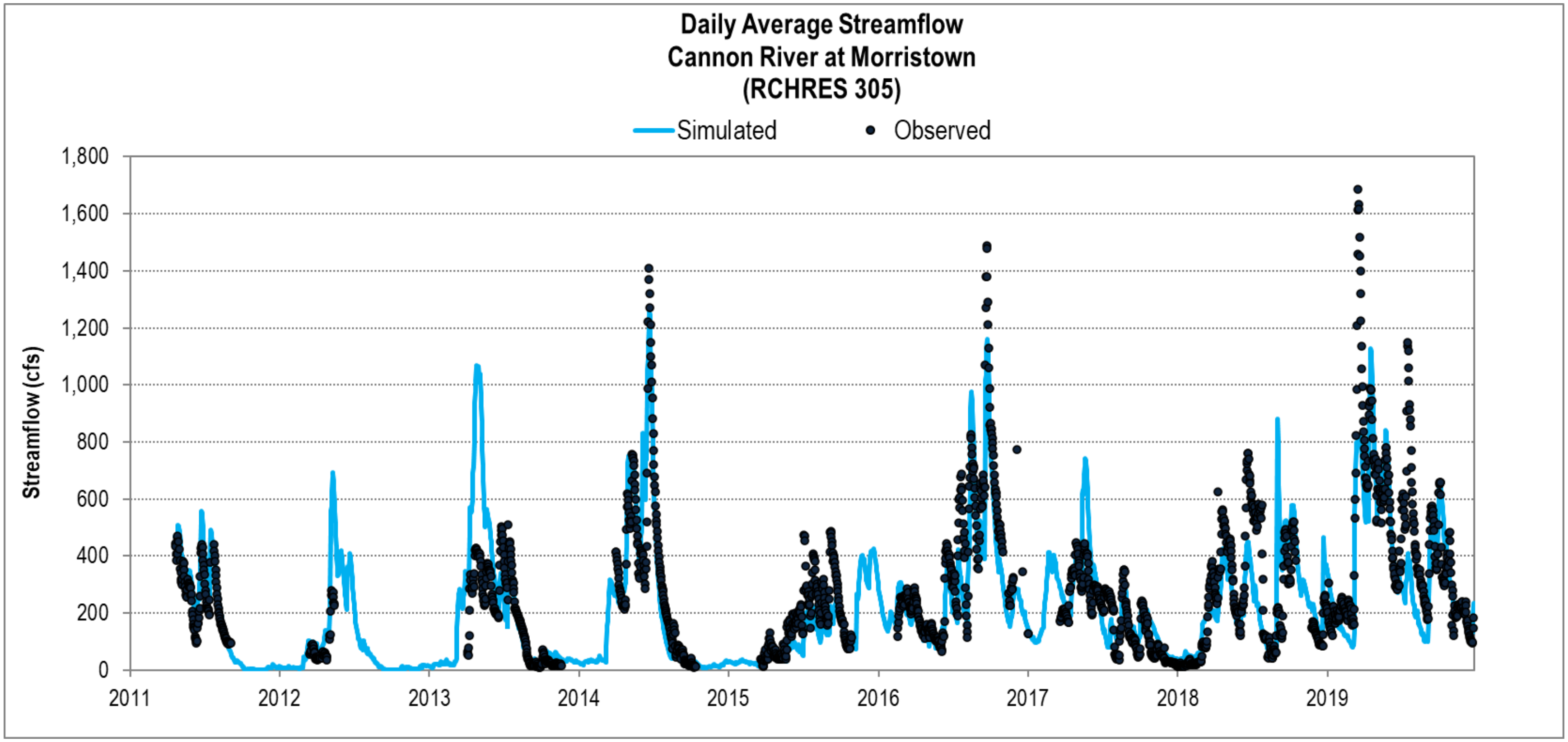

Figure C-19: Observed and simulated daily streamflow for Cannon River at Morristown.

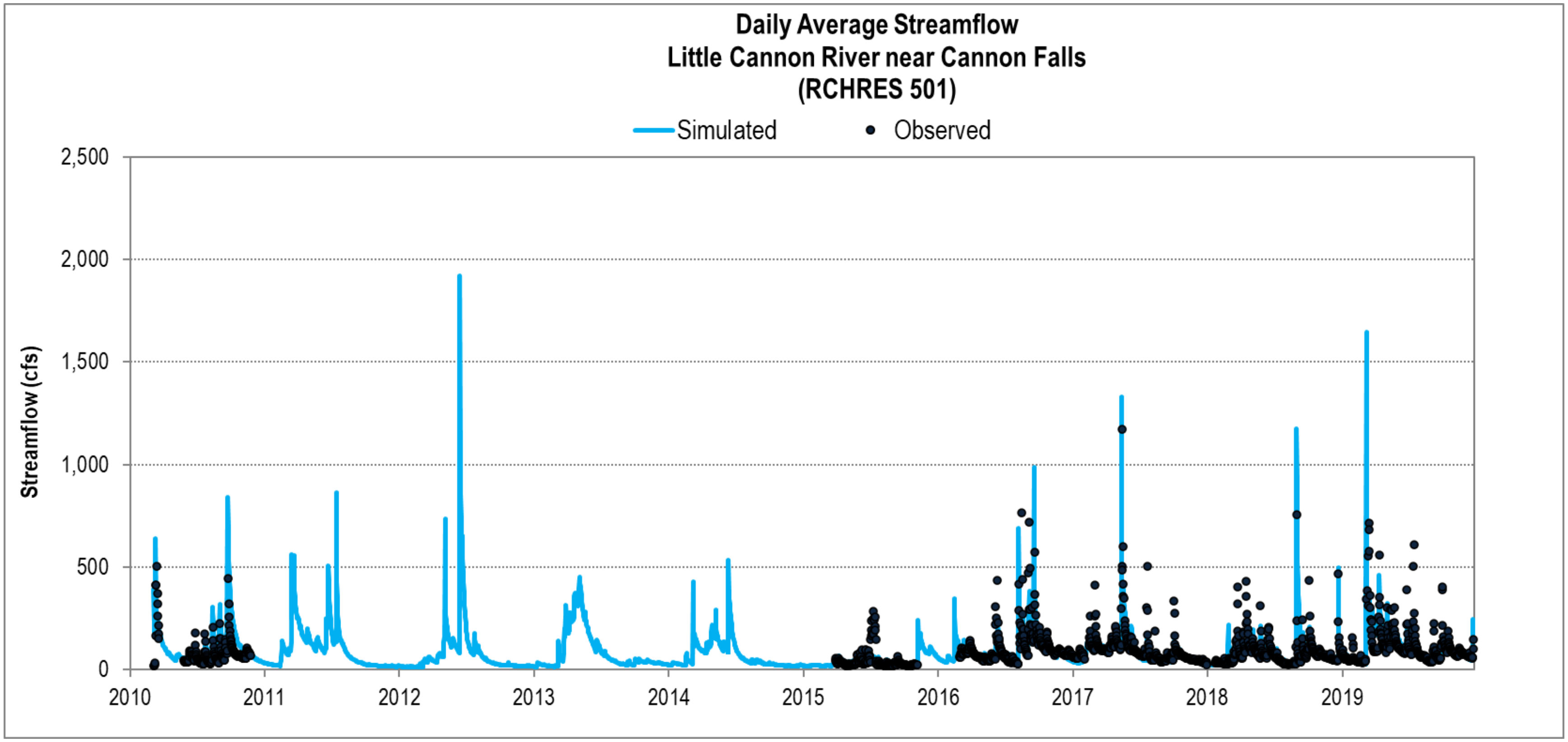

Figure C-20: Observed and simulated daily streamflow for Little Cannon River nr Cannon Falls.

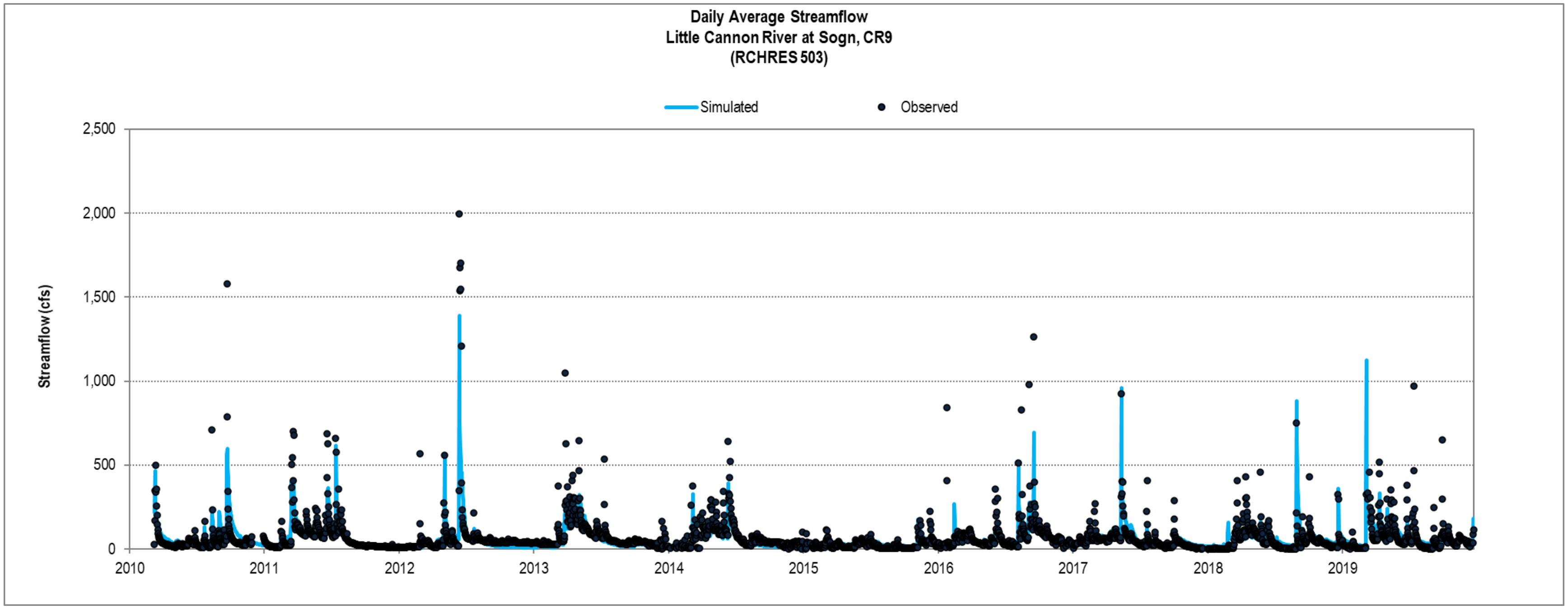

Figure C-21: Observed and simulated daily streamflow for Little Cannon River at Sogn.

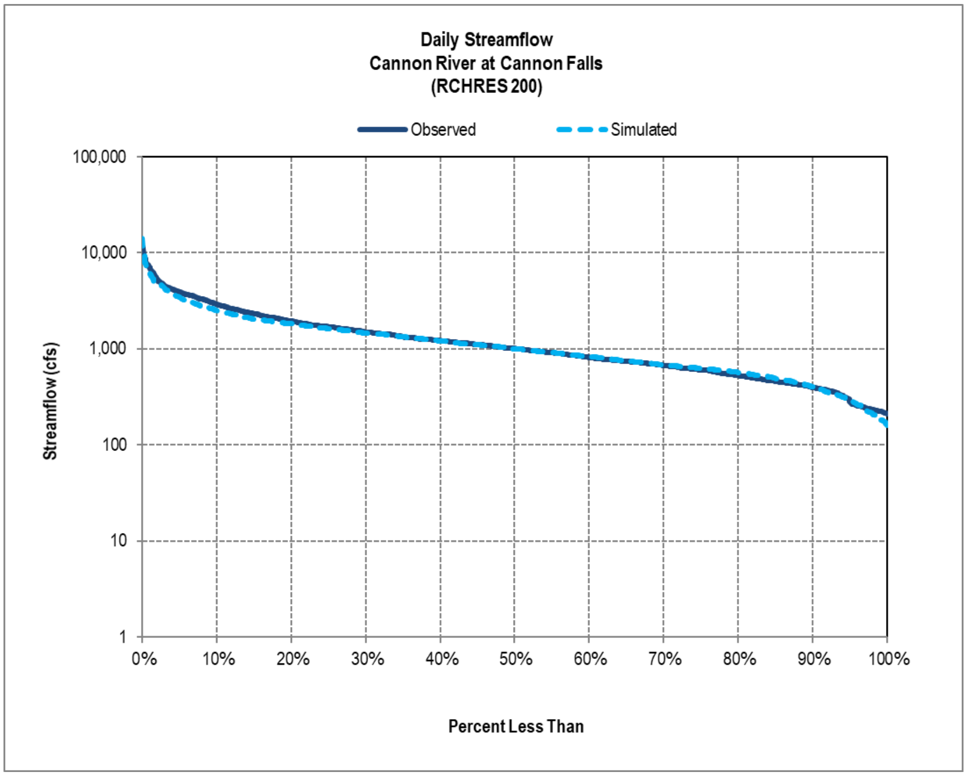

Figure C-22: Observed and simulated daily streamflow cumulative frequency distribution for Cannon River Falls.

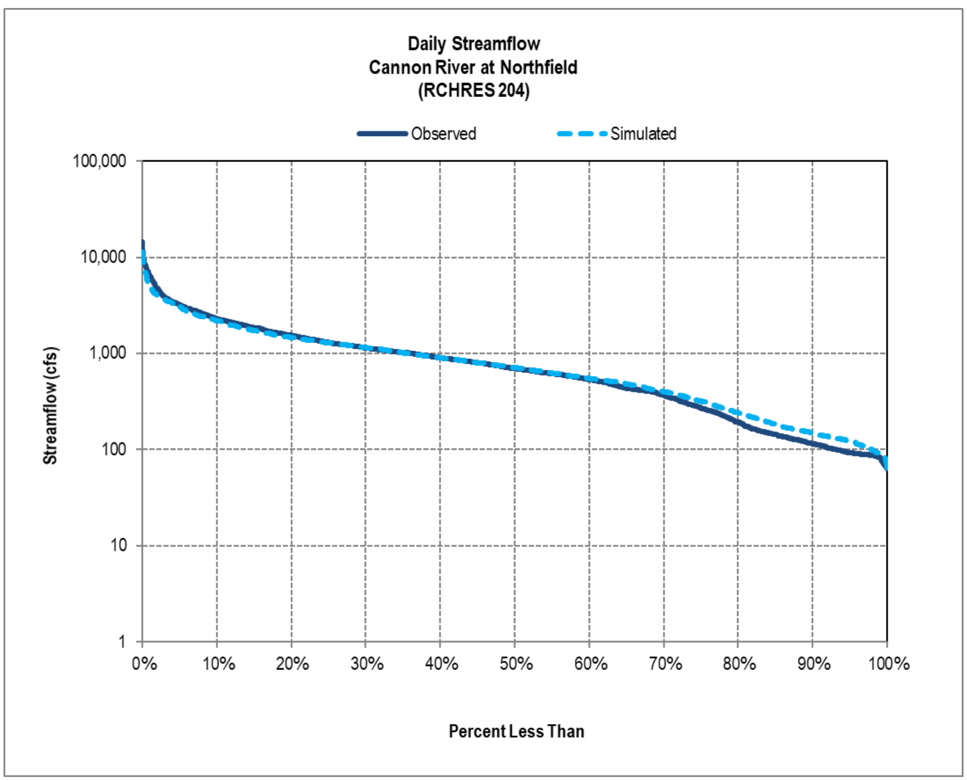

Figure C-23: Observed and simulated daily streamflow cumulative frequency distribution for Cannon River at Northfield.

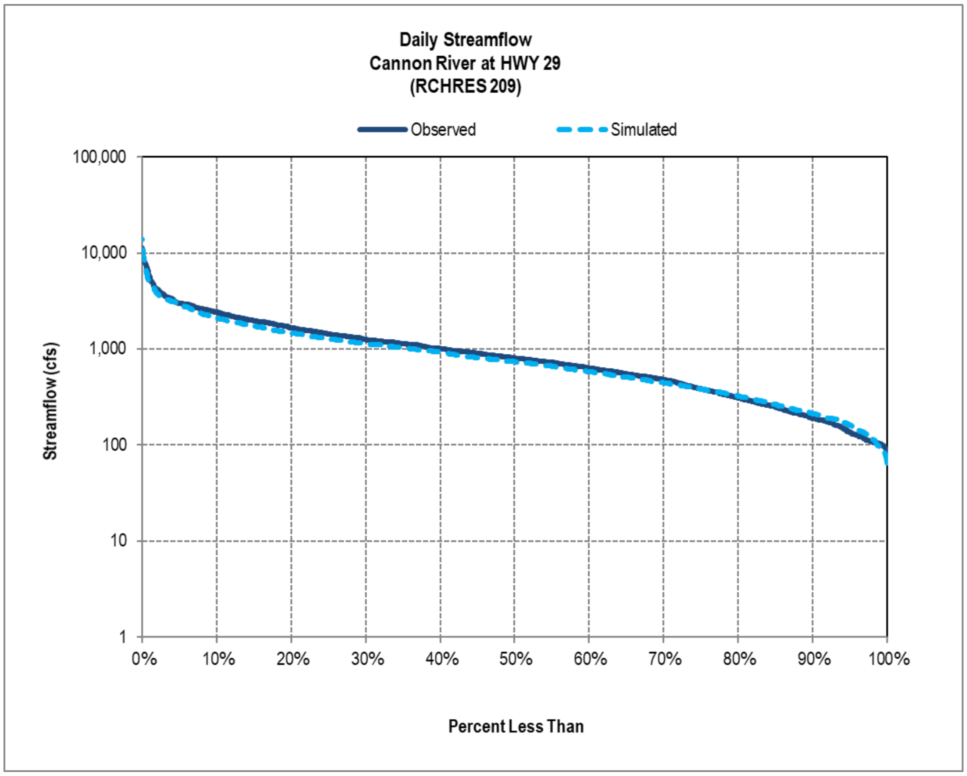

Figure C-24: Observed and simulated daily streamflow cumulative frequency distribution for Cannon River at Hwy 29.

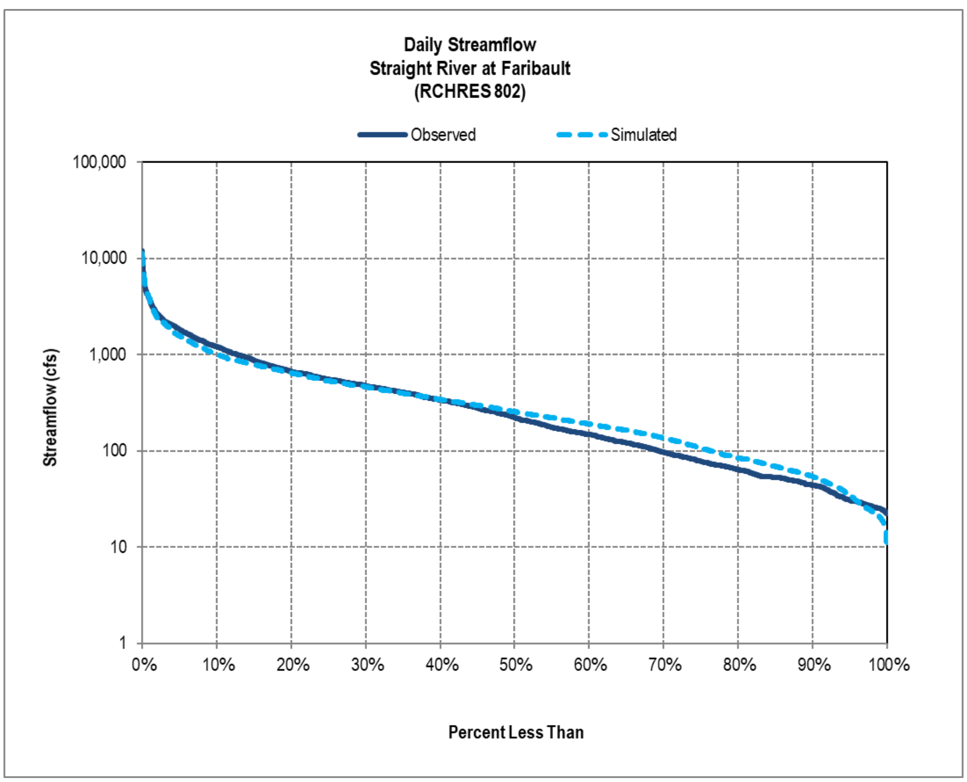

Figure C-25: Observed and simulated daily streamflow cumulative frequency distribution for Straight River at Faribault.

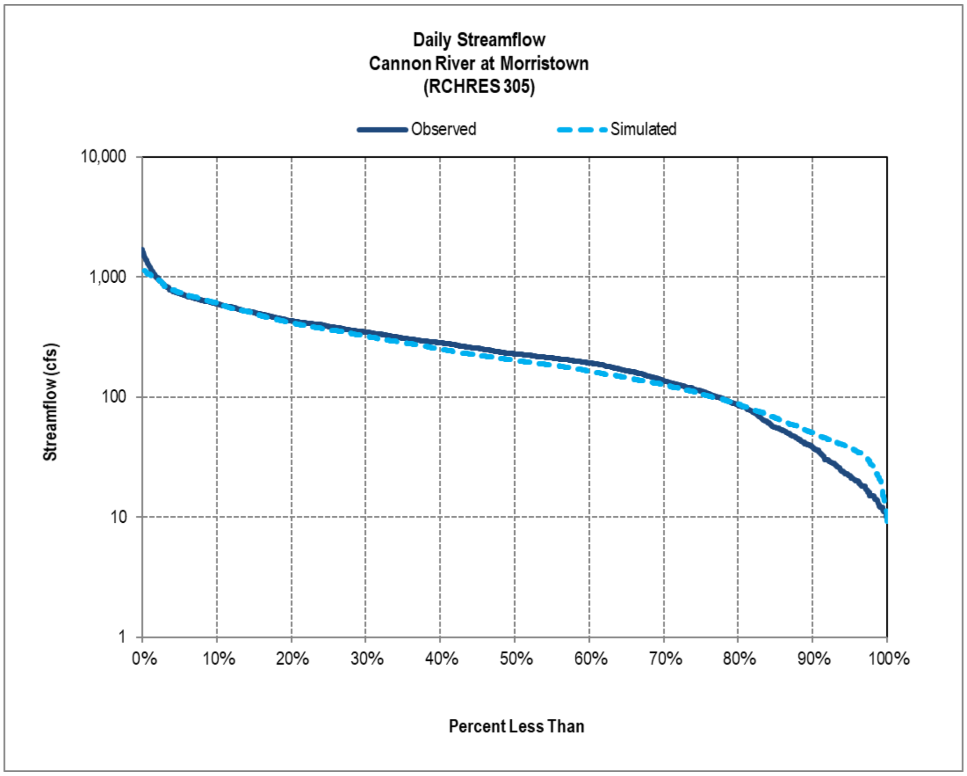

Figure C-26: Observed and simulated daily streamflow cumulative frequency distribution for Cannon River at Morristown.

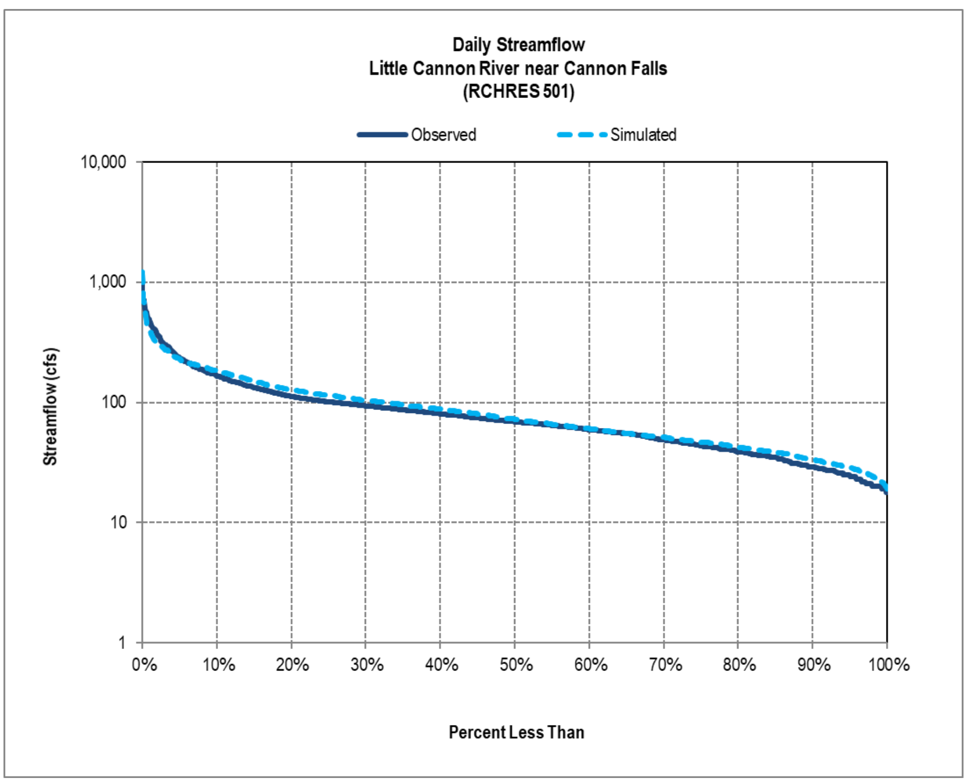

Figure C-27: Observed and simulated daily streamflow cumulative frequency distribution for Little Cannon River nr Cannon Falls.

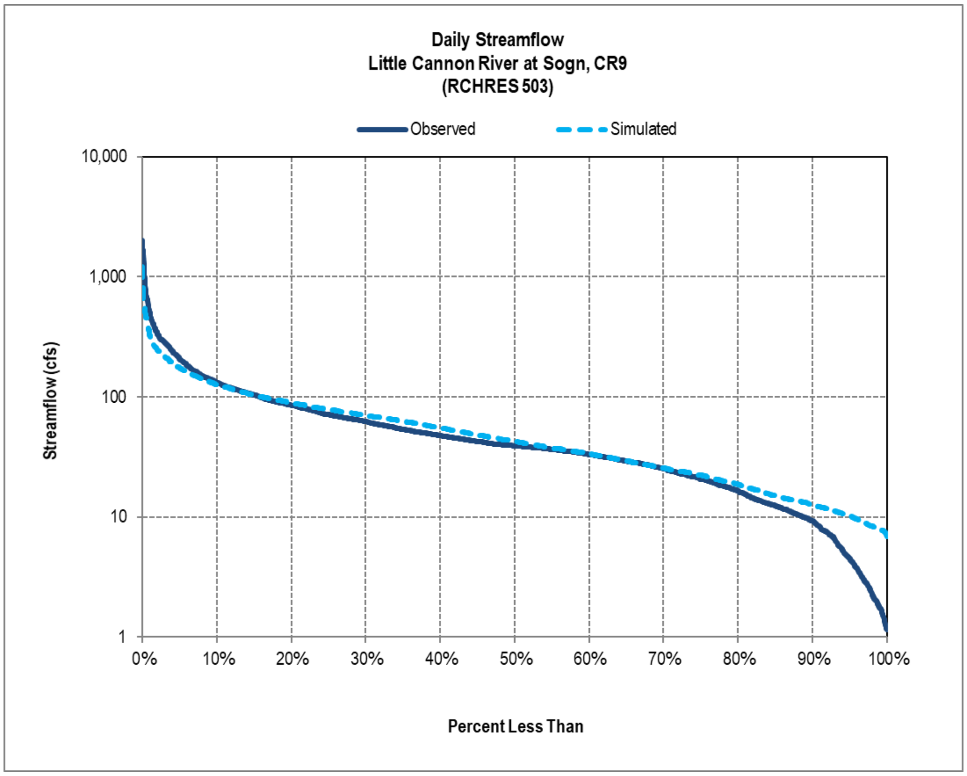

Figure C-28: Observed and simulated daily streamflow cumulative frequency distribution for Little Cannon River at Sogn.

Appendix D: Additional Water Quality Load Plots

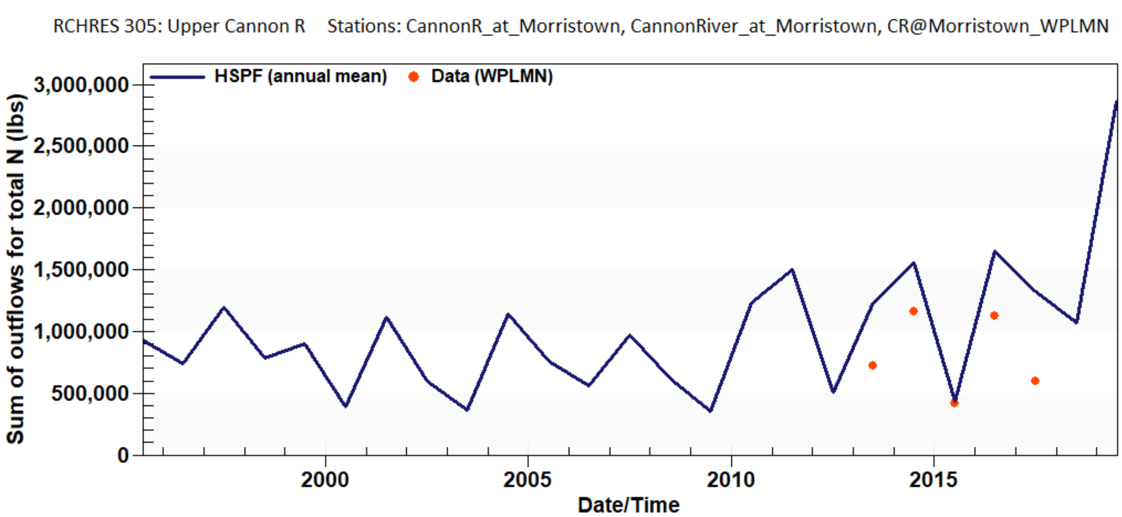

Figure D-1: Annual TN loads for Cannon River at Morristown for the calibration period.

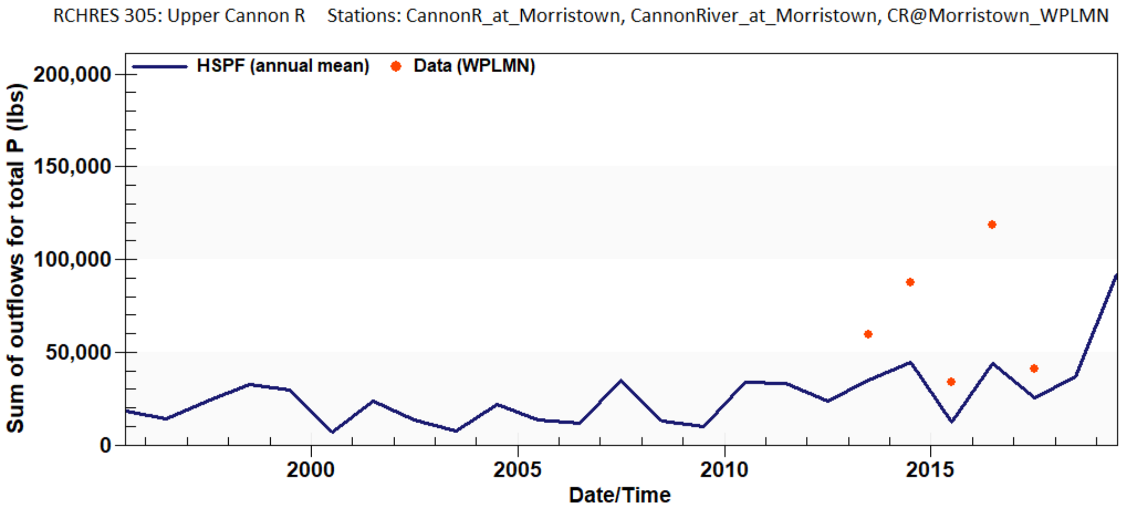

Figure D-2: Annual TP loads for Cannon River at Morristown for the calibration period.

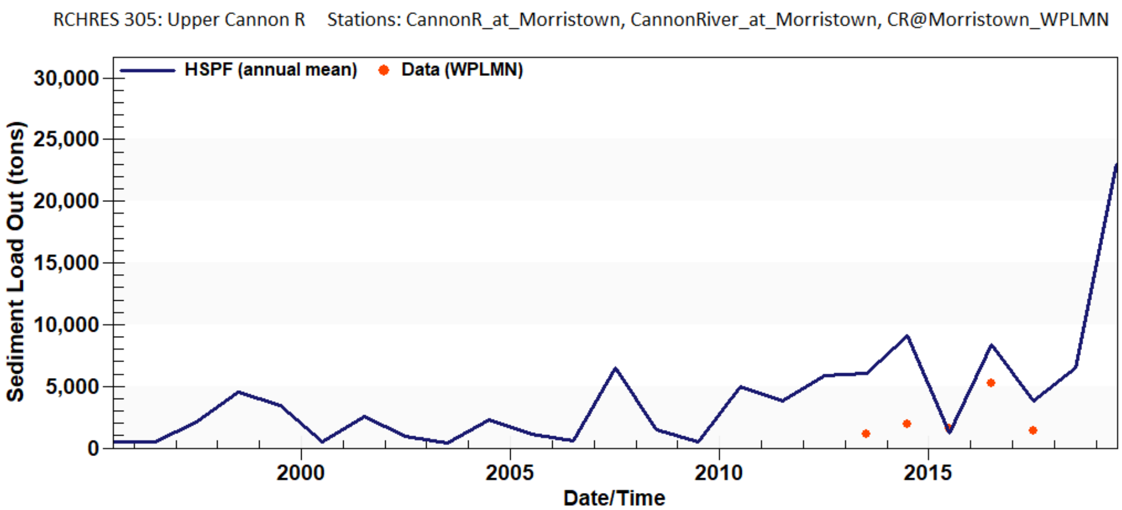

Figure D-3: Annual TSS loads for Cannon River at Morristown for the calibration period.

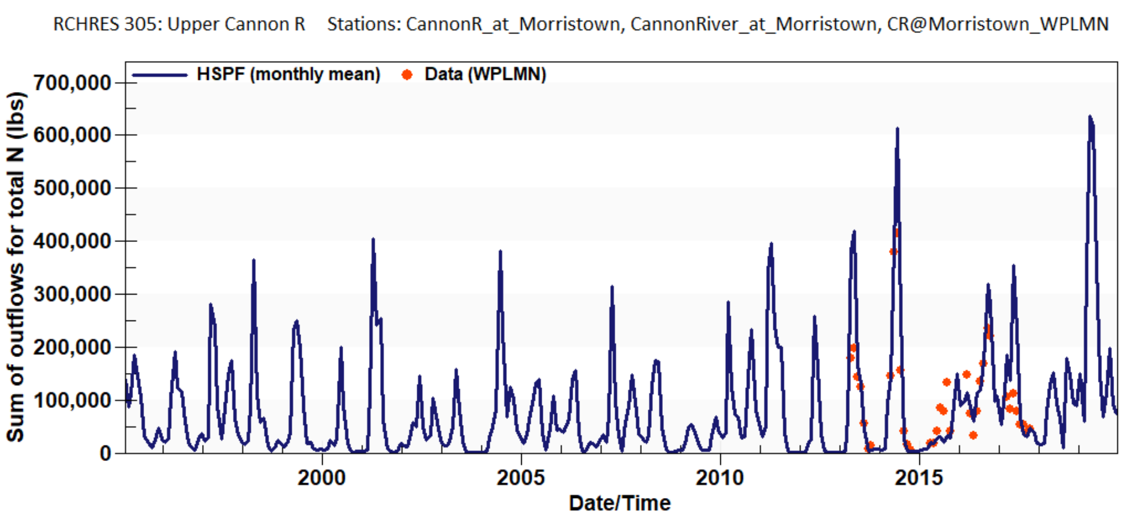

Figure D-4: Monthly TN loads for Cannon River at Morristown for the calibration period.

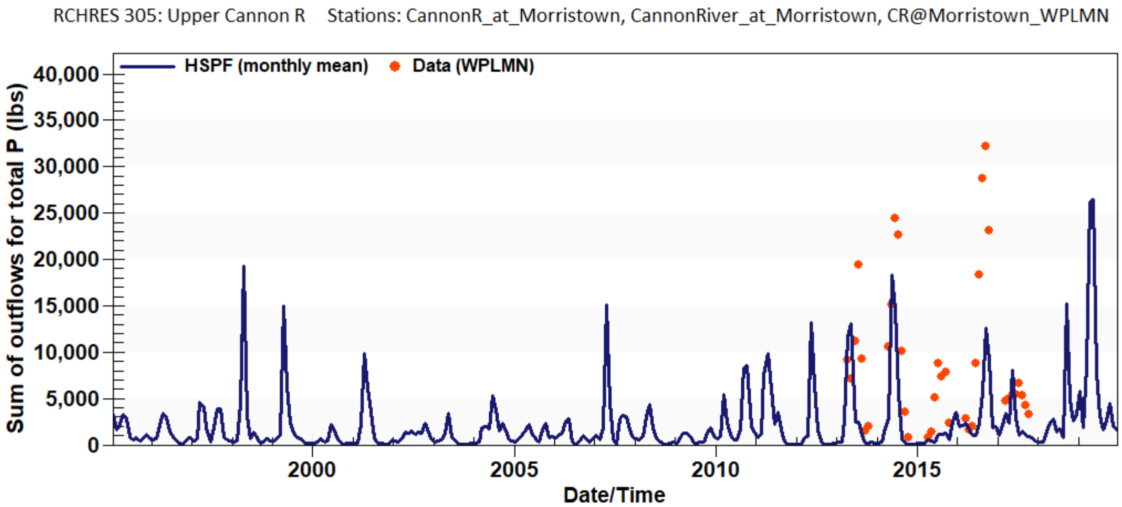

Figure D-5: Monthly TP loads for Cannon River at Morristown for the calibration period.

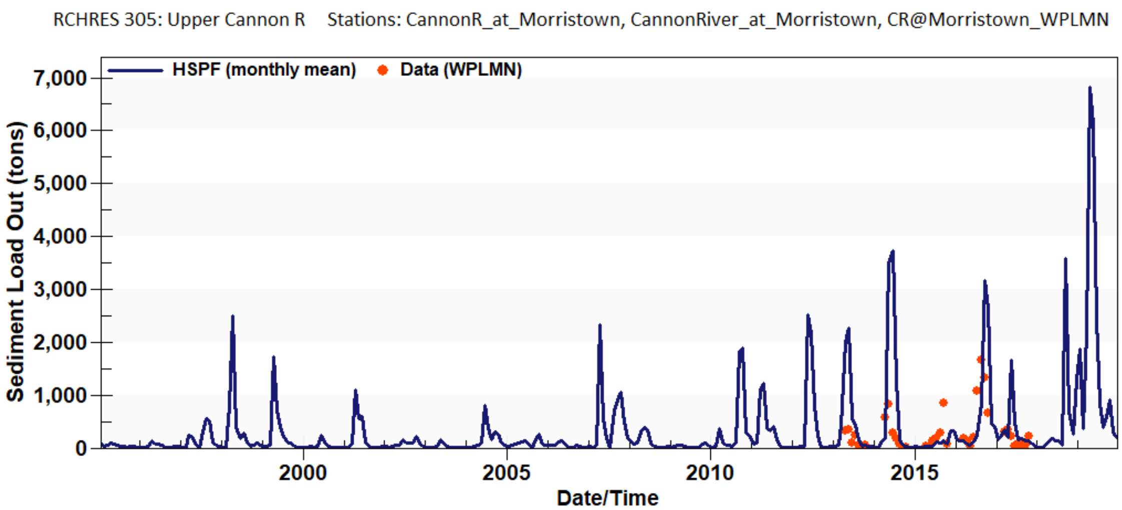

Figure D-6: Monthly TSS loads for Cannon River at Morristown for the calibration period.

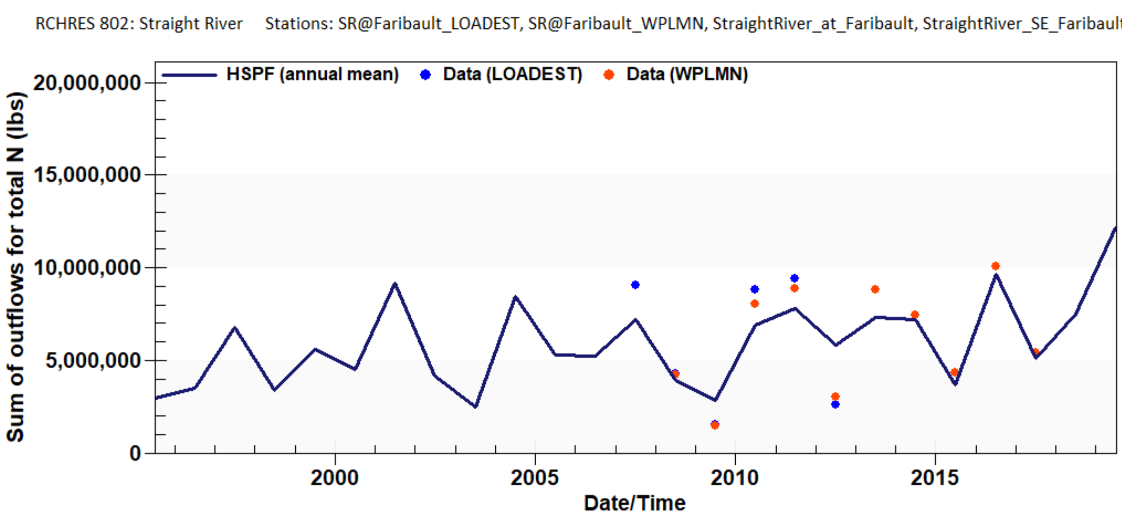

Figure D-7: Annual TN loads for Straight River at Faribault for the calibration period.

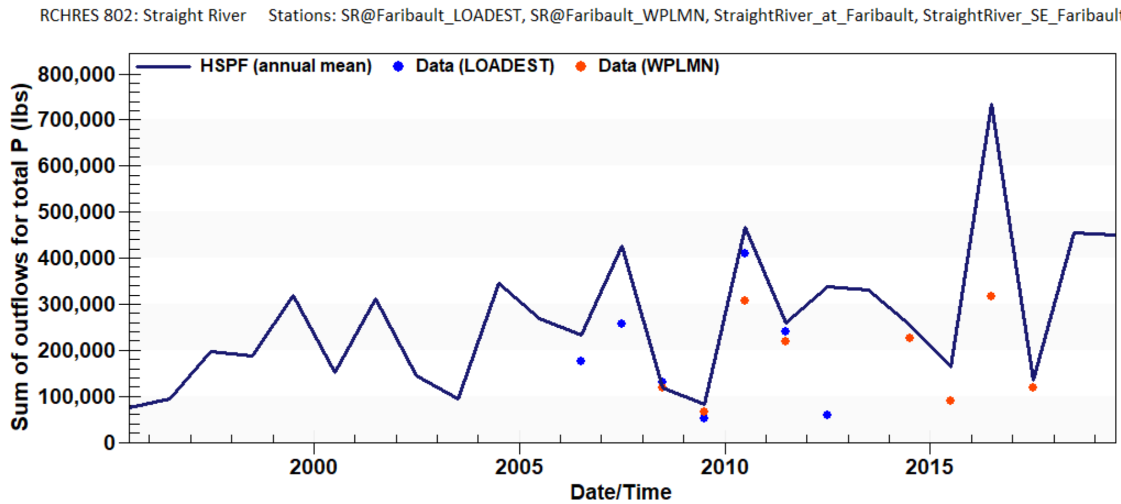

Figure D-8: Annual TP loads for Straight River at Faribault for the calibration period.

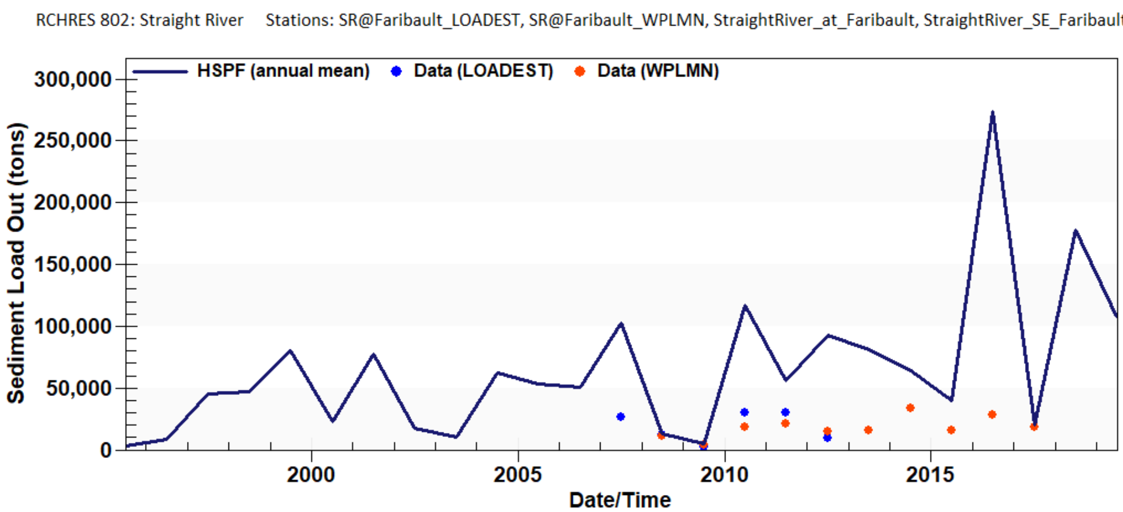

Figure D-9: Annual TSS loads for Straight River at Faribault for the calibration period.

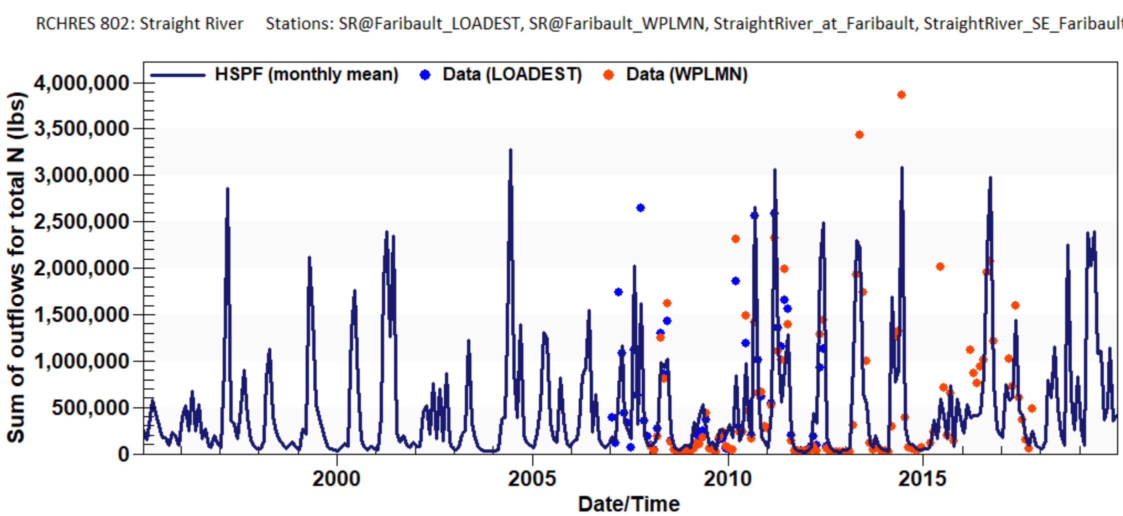

Figure D-10: Monthly TN loads for Straight River at Faribault for the calibration period.

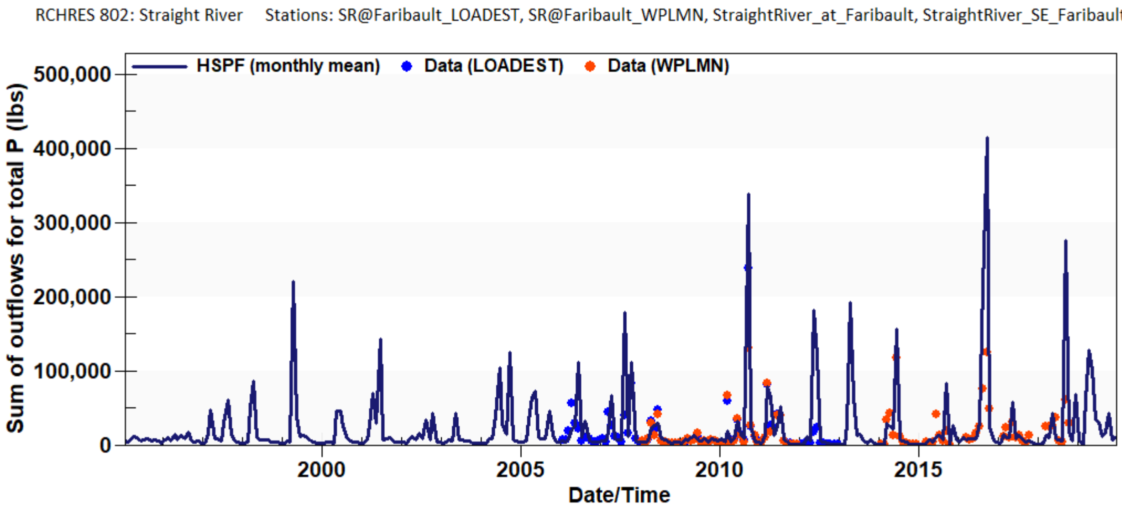

Figure D-11: Monthly TP loads for Straight River at Faribault for the calibration period.

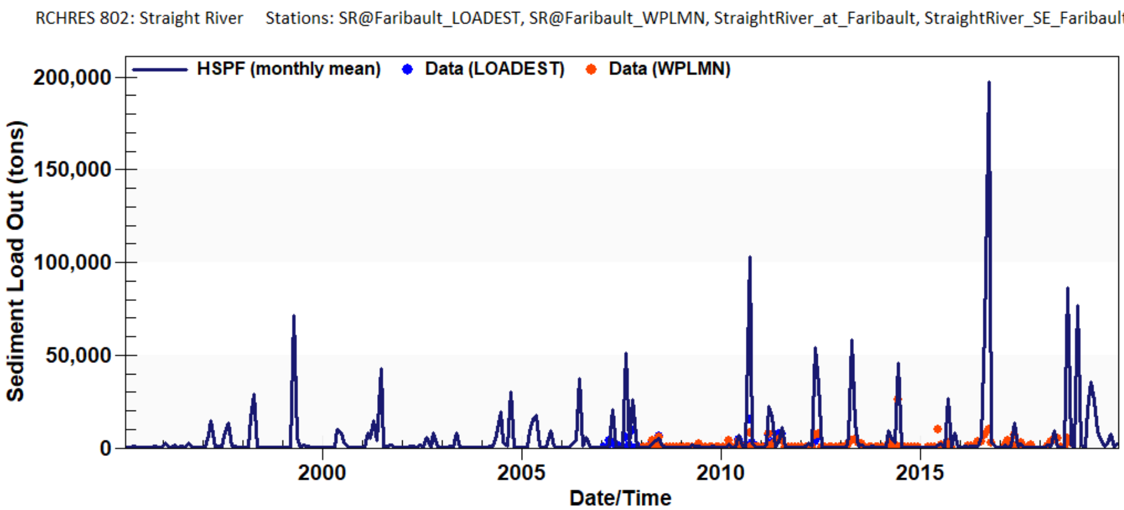

Figure D-12: Monthly TSS loads for Straight River at Faribault for the calibration period.