HSPF Watershed Modeling Phase 3 for the Crow Wing, Redeye, and Long Prairie Rivers Watersheds: Calibration and Validation of Hydrology, Sediment, and Water Quality Constituents

Final Report

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EXECUTIVE SUMMARY

The United States Environmental Protection Agency (USEPA) requires the Minnesota Pollution Control Agency (MPCA) to carry out the Total Maximum Daily Load (TMDL) Program in the state of Minnesota. In an effort to expedite the completion of TMDL projects, MPCA has decided to construct watershed models to support the simultaneous development of TMDL studies for multiple listings within a cataloging unit or 8-digit Hydrologic Unit Code (HUC) watershed. As part of the model development process AQUA TERRA Consultants was contracted to develop watershed models for the Crow Wing River (HUC - 07010106), the Redeye River (HUC - 07010107), and the Long Prairie River (HUC - 07010108). Both the Long Prairie and Redeye Rivers flow into the Crow Wing River which flows into the Mississippi River.

This project was divided into multiple phases where the first two phases required the compilation and processing of geographical, meteorological, point source, and observed data for model development; proposal of model calibration approach; and completion of initial hydrologic calibration. In this final phase of the project, AQUA TERRA Consultants was contracted to finalize the hydrologic and water quality calibration and validation.

This report documents the final phase of the modeling project that includes:

- the results of hydrology calibration and validation,
- the review for sediment apportionment, and
- the results of water quality calibration and validation that include water temperature, sediment, nitrogen, phosphorus, organics, and chlorophyll A

Overall, the model performance for hydrology calibration and validation was satisfactory based on the model performance criteria, except at the most upstream gage, Straight River in Crow Wing watershed. This station is affected significantly by groundwater flow from outside the watershed, and the management of an upstream lake. Additional data collection and groundwater study may be required to improve the calibration at this location.

The water quality data was available at multiple locations in the watersheds and the model simulated water quality constituents close to the observed data. The observed data was not sufficient to conduct detailed statistical analysis, and therefore the quality of calibration and validation was based on the visual assessment of various graphs.

The watershed model for these three watersheds was developed at a scale so that all the waterbodies included in the draft 2010 TMDL list were modeled explicitly. Thus, the final model can be successfully used for TMDL development of smaller waterbodies in the watershed, and the model outputs can be used for finer scale assessments, or as input to other waterbody models.

As reported by MPCA, additional water quality data was collected after the calibration period (2003 to 2009) and significant water quality data was collected in 2011. Extending the model calibration period to include the additional years could improve model performance and increase the confidence in model results. Model extension should also provide enough data to analyze the model performance statistically. The Crow Wing watersheds have a significant number of lakes, and the water quality simulation of lakes can be improved with better hydraulic information.

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INTRODUCTION

1.1 BACKGROUND

The United States Environmental Protection Agency (USEPA) requires the Minnesota Pollution Control Agency (MPCA) to carry out the Total Maximum Daily Load (TMDL) Program in the state of Minnesota. Minnesota has an abundance of lakes and rivers, many of which will require a TMDL study. In an effort to expedite the completion of TMDL projects, MPCA has decided to construct watershed models. These models have the potential to support the simultaneous development of TMDL studies for multiple listings within a cataloging unit or 8-digit Hydrologic Unit Code (HUC) watersheds within the State. This report documents the modeling of three 8-digit HUC watersheds: Crow Wing River (HUC - 07010106), Redeye River (HUC - 07010107), and Long Prairie River (HUC - 07010108). Both the Long Prairie and Redeye Rivers flow into the Crow Wing River which flows into the Mississippi River.

The objective of this work order is the successful calibration and validation of hydrologic and water quality model applications for the three watersheds using HSPF. These models can simulate the following constituents:

- Hydrology/flow
- Sediment/TSS
- Water Temperature
- Dissolved Oxygen
- Phytoplankton as Chlorophyll A
- Nitrite-Nitrate as Nitrogen
- Ammonia as Nitrogen
- Orthophosphate as Phosphorus
- BOD/Organics, comprised of
    - Labile BOD
    - Refractory Organic Nitrogen
    - Refractory Organic Phosphorus
    - Refractory Organic Carbon

1.2 WATERSHED DESCRIPTIONS

The Crow Wing river watershed (8 Digit HUC: 07010106) is located in the Northern Lakes and Forest, and North Central Hardwoods Forest ecoregions of Minnesota (Figure 1.1). This watershed is largely forested and is about 313 sq. mi. in size. The Redeye watershed (8 Digit HUC: 07010107) is predominantly located within the North Central hardwood Forest ecoregion of Minnesota with small sections in the Northern Lakes and Forests ecoregion. Forest and agriculture are the major land uses in this watershed, and it is about 141 sq. mi. in size. The Redeye watershed discharges into the Crow Wing river watershed. The Long Prairie watershed (8 Digit HUC: 07010108) is primarily located within the North Central Hardwood Forest ecoregion, with a small section in the Northern Lakes and Forests ecoregion. Forest and agriculture are the predominant land uses in this watershed as well. The Long Prairie watershed is about 140 sq. mi. in size, and flows into the Crow Wing river watershed. Some basic facts about the three watersheds are summarized in Table 1.1.

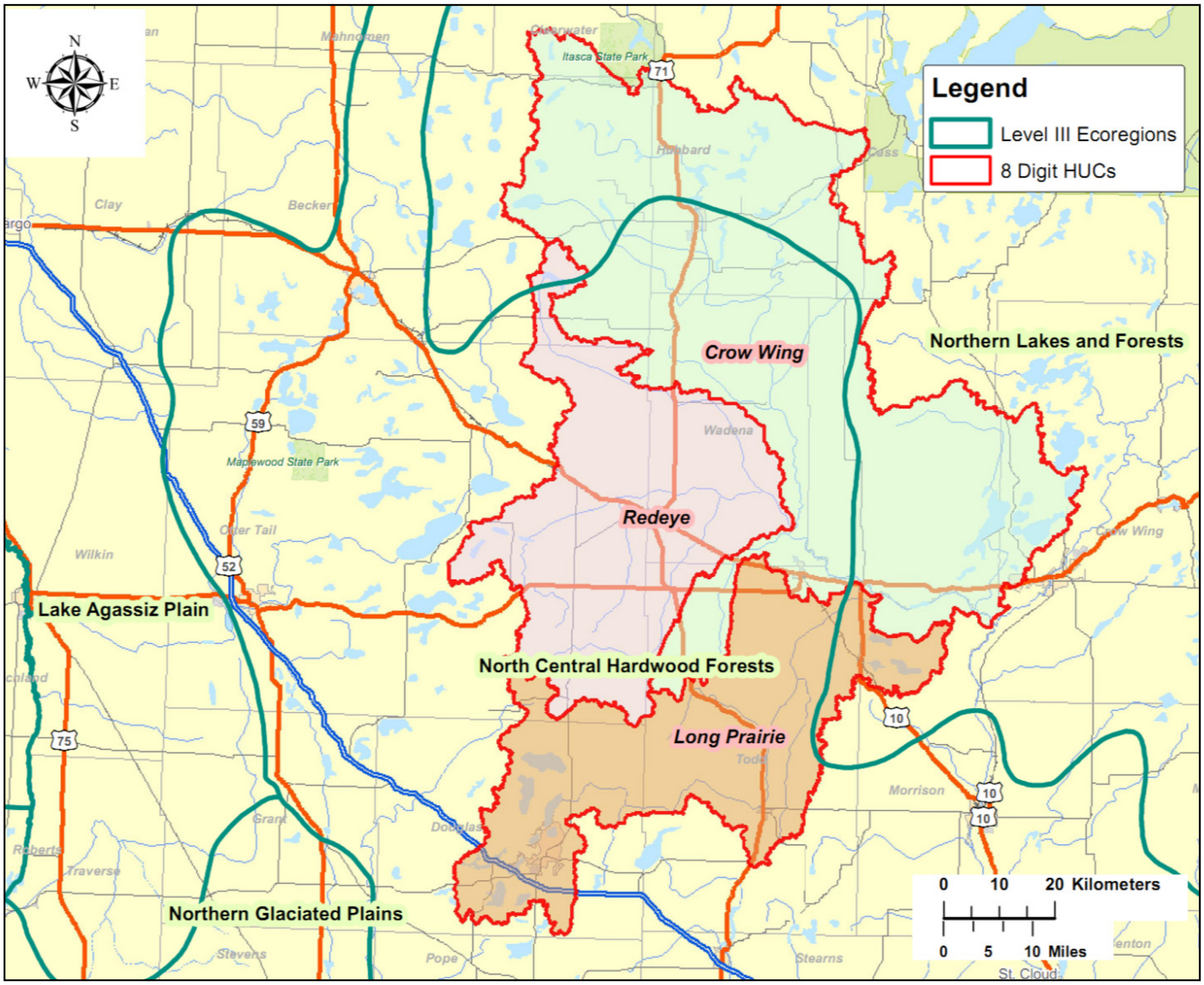


Figure 1.1 Location of Crow Wing, Redeye and Long Prairie watersheds in Minnesota

Table 1.1 Basic facts about Crow Wing, Redeye, and Long Prairie river watersheds

	Crow Wing	Redeye	Long Prairie
Area (sq. mi.)	313.4	141.4	140.0
Average Elevation above mean sea level (ft.)	1,357	1394	1367
Annual Precipitation (in.)	25-27	25-29	25-29
Major Land use(s)	Forest	Forest and Agriculture	Forest and Agriculture
Number of impaired Streams (draft 2010)	15	0	8
Streams needing TMDL (non-mercury)	1	0	3
Number of impaired Lakes (draft 2010)	44	1	19
Lakes needing TMDL (non-mercury)	6	0	3

1.3 OBJECTIVE OF THIS REPORT

This report provides details on final hydrologic and water quality calibration and validation of Redeye, Long Prairie and Crow Wing River watersheds. The earlier portions of this project were completed in FY 2011 and FY 2012, and included model building, data procurement, and initial calibration. The objectives of individual work orders are presented below.

1. Compile both the geographic and timeseries data required to construct the model framework. (FY 2011)
2. Develop representation of watershed area and drainage network. (FY 2011)
3. Model point source representation. (FY 2012)
4. Formulate timeseries from observed flow and water quality monitoring to be used for watershed model calibration and validation. (FY 2012)
5. Perform the initial hydrologic calibration. (FY 2012)
6. Finalize hydrologic calibration, conduct hydrologic validation, and provide water balance. (FY 2013)
7. Define the sources of sediment within the watershed and conduct sediment calibration and validation tests. (FY 2013)
8. Conduct water quality calibration, validation and model evaluation. (FY 2013)

This report includes details on the three work orders completed in FY 2013.

SECTION 2.0
HYDROLOGY CALIBRATION AND VALIDATION

2.1 MODEL SETUP AND DESCRIPTION

The Redeye, Long Prairie, Crow Wing River watershed models were developed as three separate but linked HSPF models. The output in the form of flow and nutrients from the Redeye and Long Prairie models is input into the Crow Wing model at Crow Wing River upstream of Staples and Crow Wing River near Motley respectively (Figure 2.1). The details on model setup are described in earlier memos (AQUA TERRA Consultants, 2011 and 2012). Table 2.1 summarizes the number of subwatersheds in each HSPF model. The land use distribution of each model is presented in Table 2.2. The drainage networks of the three watersheds are shown in Figure 2.2.

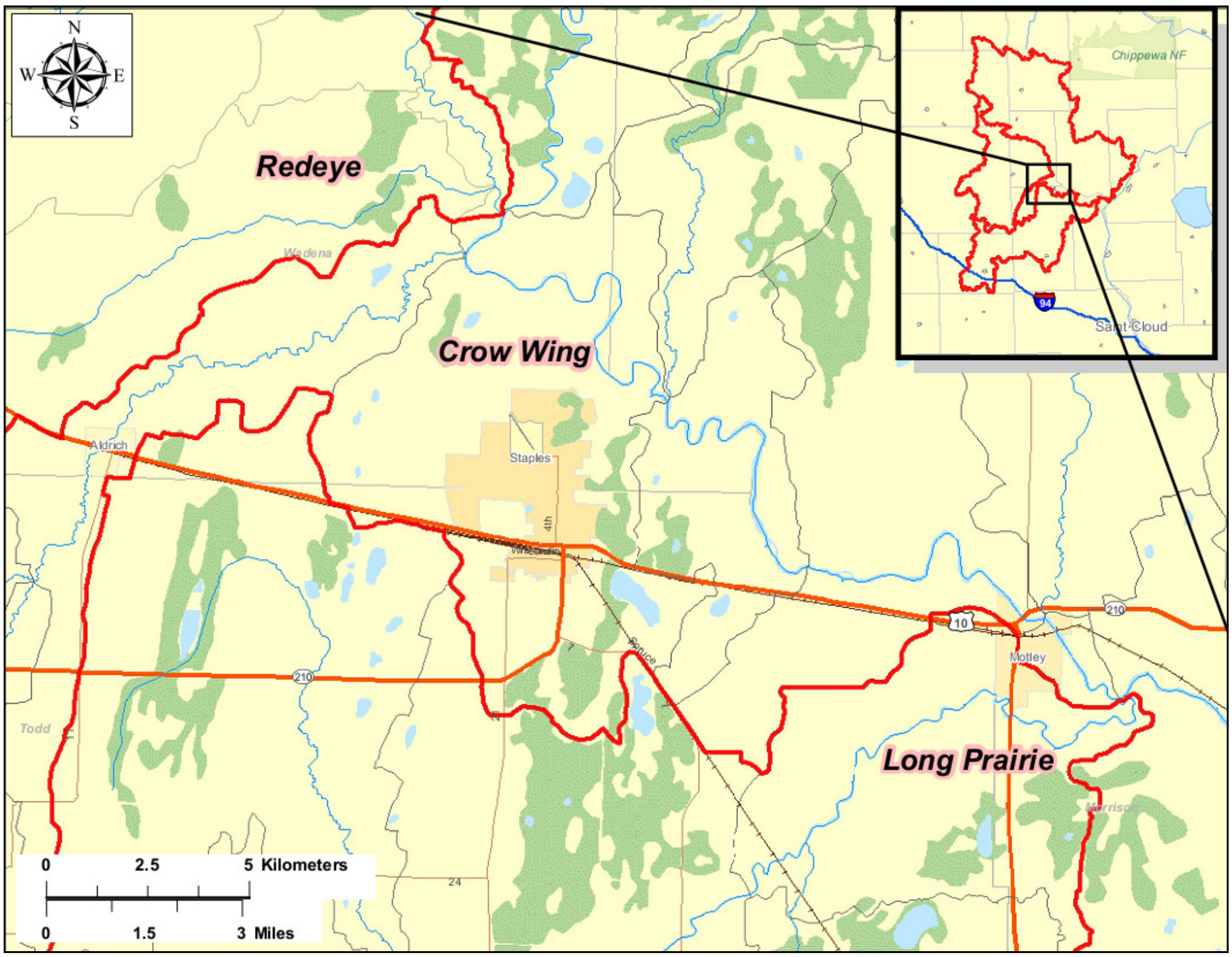


Figure 2.1 Location of Redeye and Long Prairie Rivers flowing into Crow Wing River

Table 2.1 The number and distribution of subwatersheds in the HUC 8 watersheds according to different levels of delineation

HUC 8 Watersheds	Parameters	HUC 12 Watersheds	DNR Level 7 Watersheds	DNR Level 8 Watersheds
Crow Wing	Count	59	136	273
	Mean Area (ac)	21490	9318	4645
	Median Area (ac)	19860	7654	3114
	Minimum Area (ac)	9747	1790	62
	Maximum Area (ac)	43783	30719	28740
Redeye	Count	23	58	83
	Mean Area (ac)	24870	9863	6892
	Median Area (ac)	25730	7558	5341
	Minimum Area (ac)	11468	2258	170
	Maximum Area (ac)	37075	37009	37010
Long Prairie	Count	30	64	129
	Mean Area (ac)	18880	8829	4391
	Median Area (ac)	18210	7400	3191
	Minimum Area (ac)	10320	3051	19
	Maximum Area (ac)	40871	21235	21240

Table 2.2 The number and distribution of subwatersheds in the HUC 8 watersheds after final delineation for model development

HUC 8 Watersheds	Parameters	Subwatershed Segmentation
Crow Wing	Count	103
	Mean Area (ac)	12,311
	Median Area (ac)	11,683
	Minimum Area (ac)	391
	Maximum Area (ac)	43,783
Redeye	Count	33
	Mean Area (ac)	17,335
	Median Area (ac)	15,244
	Minimum Area (ac)	1,115
	Maximum Area (ac)	37,075
Long Prairie	Count	47
	Mean Area (ac)	12,053
	Median Area (ac)	12,241
	Minimum Area (ac)	686
	Maximum Area (ac)	26,368

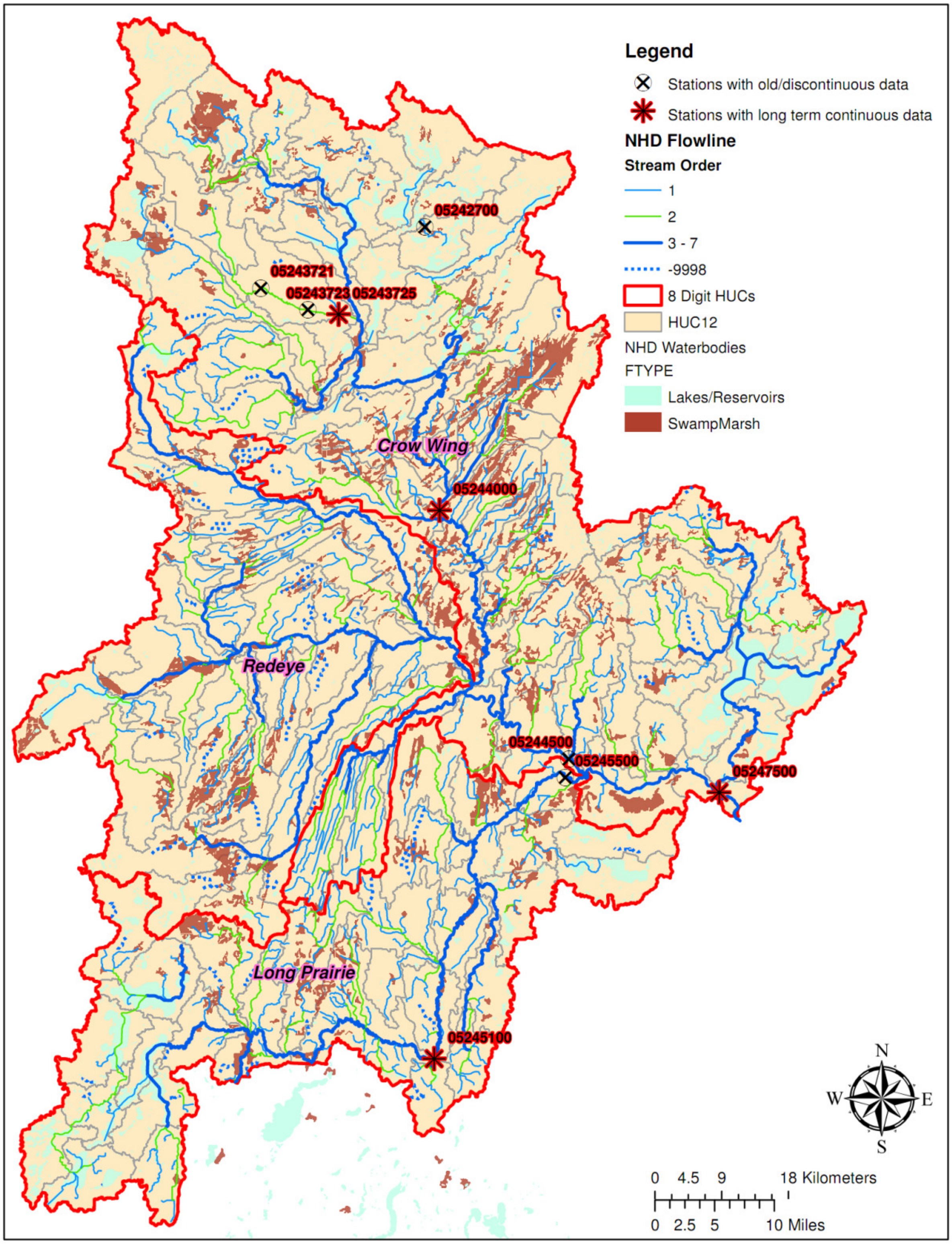


Figure 2.2 Drainage network of Redeye, Long Prairie, and Crow Wing River watersheds

The meteorological input data was obtained from the EPA's BASINS database and local precipitation records were provided by MPCA. The meteorological input data was assigned to the watersheds based on proximity to the station and quality of the data. The watershed maps in Figure 2.3 show the Meteorological stations that were used in the final watershed models. The detailed procedure of processing meteorological data and model segmentation has been described in AQUA TERRA Consultants, 2011.

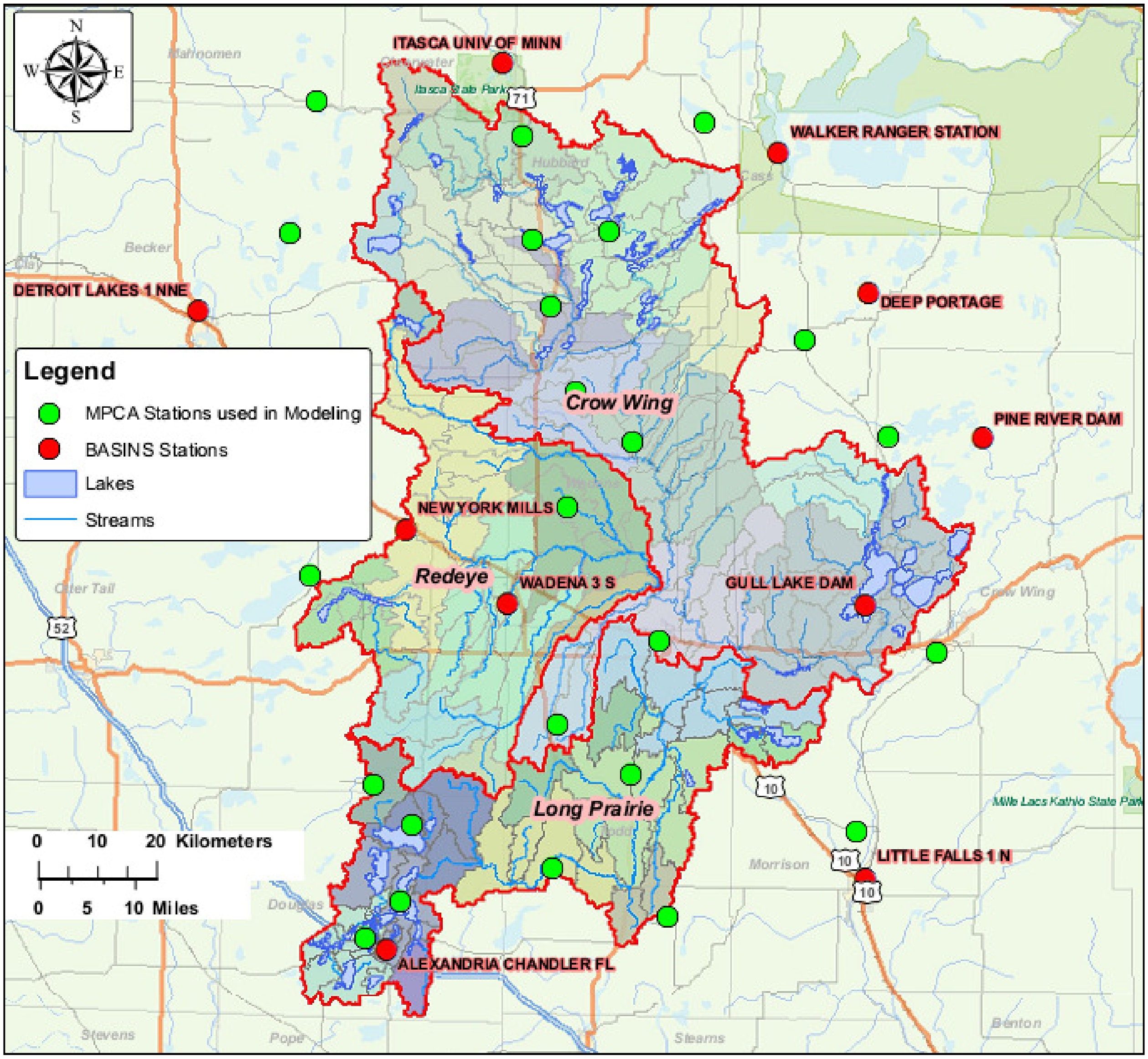


Figure 2.3 Locations of BASINS and MPCA stations with precipitation data

2.2 HYDROLOGY CALIBRATION

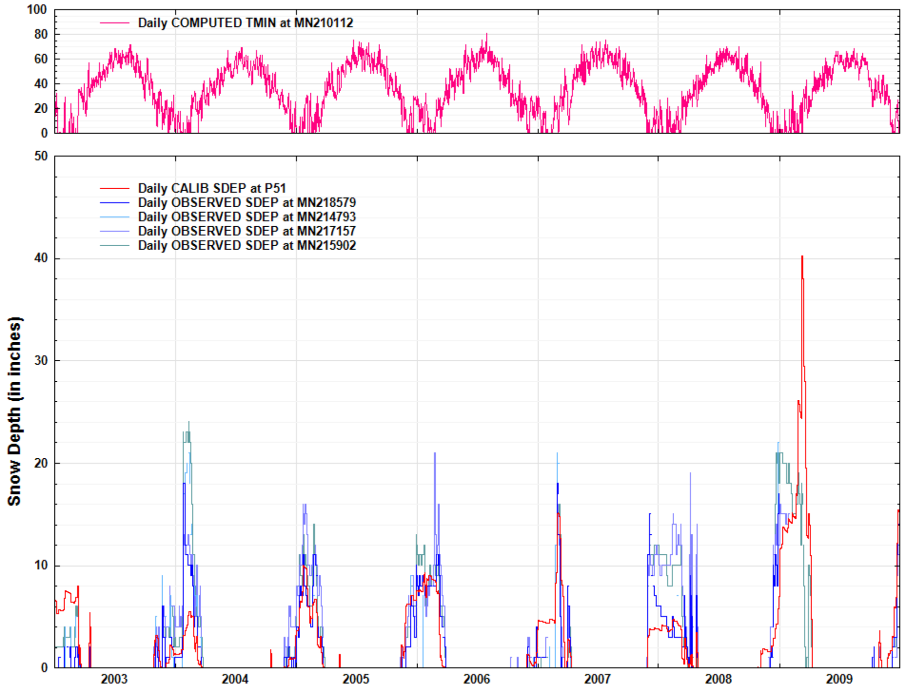
As described in the hydrologic calibration approach memo (AQUA TERRA Consultants, 2012), the calibration process started with the Long Prairie watershed where long term flow data was available at the USGS station (#05245100) on the Long Prairie River. The calibration period extended from 2003 to 2009, whereas the validation period was from 1995 to 2002. The initial parameter sets were obtained from an earlier Crow Wing Watershed Model (AQUA TERRA Consultants, 2005). Following the calibration on the Long Prairie river watershed, the parameters from the Long Prairie model were adapted for the Redeye River watershed. The Redeye River watershed didn't have any long term flow gage data and therefore no extensive calibration was performed for this watershed.

The parameters from the Long Prairie River model were also used as the starting point for the Crow Wing River watershed. The Crow Wing River watershed has long term flow data at three USGS gages. The Straight River gage (#05243725) and the Crow Wing River gage near Nimrod (#05244000) are upstream of the locations where the Redeye and Long Prairie Rivers contribute flow to the Crow Wing River. The Crow Wing River gage near Pillager (#05247500) includes flow from all three watersheds.

2.2.1 Long Prairie River Watershed

The Long Prairie River gage at Long Prairie, MN has a drainage area of 434 square miles which is about half of the total area of the Long Prairie watershed. As noted above, the initial set of parameters for this watershed was adapted from a prior Crow Wing Study (AQUA TERRA Consultants, 2005). The parameters were adjusted to reflect differences among the landuses of these watersheds (AQUA TERRA Consultants, 2012).

If snow is responsible for a dominant part of hydrology, as is the case for Minnesota watersheds, the first step in watershed calibration is to calibrate the snow depth to available observed data.. Snow depth data were available at a few locations in and around the watershed. Since snow depth data are notoriously variable across the landscape (due to wind drifting, exposure, vegetation, etc.) , simulated snow depths at various land segments in the watershed were compared with observed data at multiple locations, including some that are outside the watershed (Figure 2.4). Along with the time series of snow depth simulation, frequency duration curves of snow depth were plotted for the winter months (Figure 2.5) *i.e.* October-April, as another measure of comparison between observed and simulated values.



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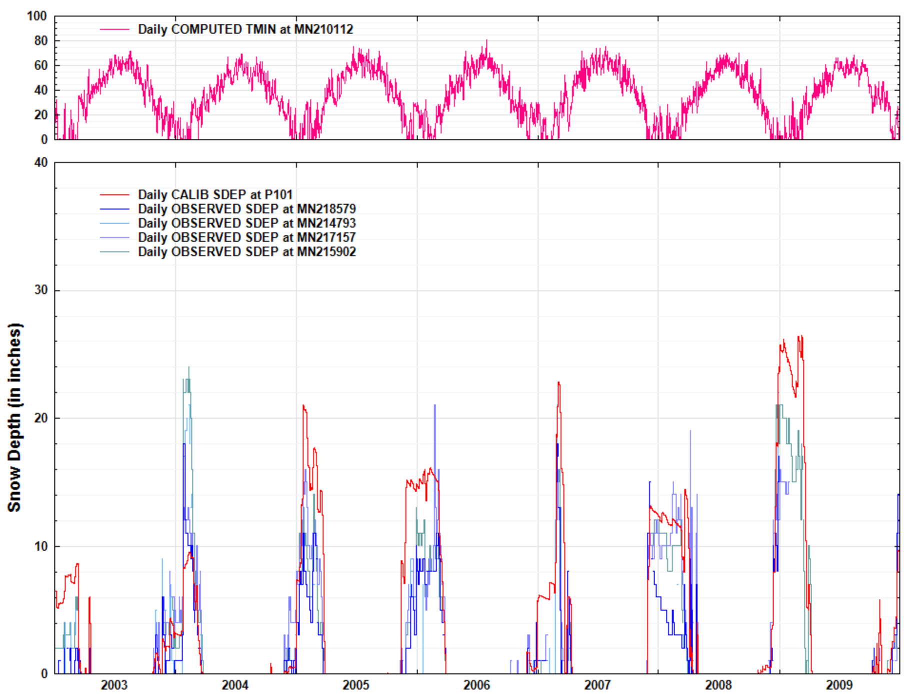
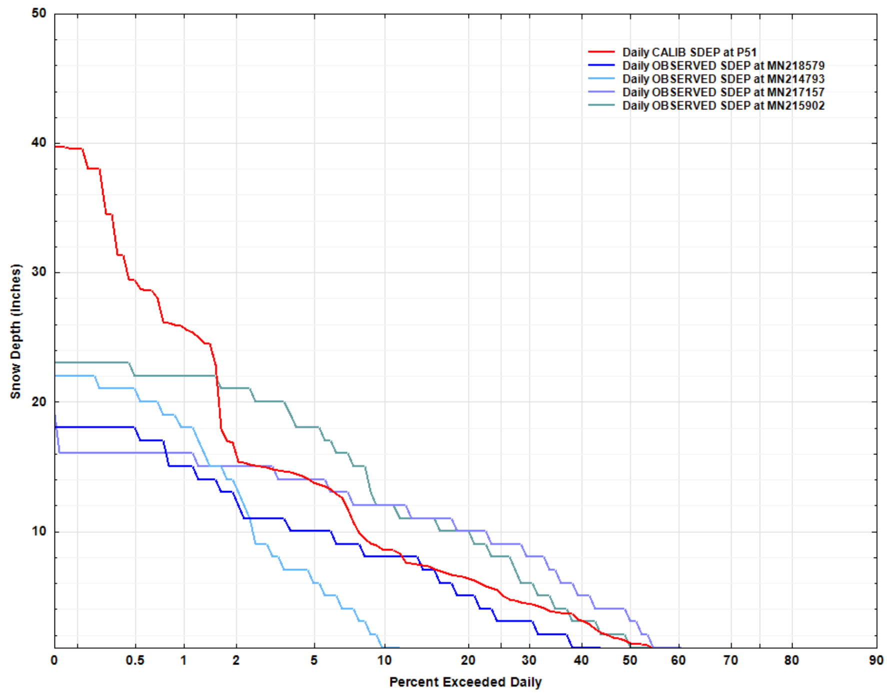
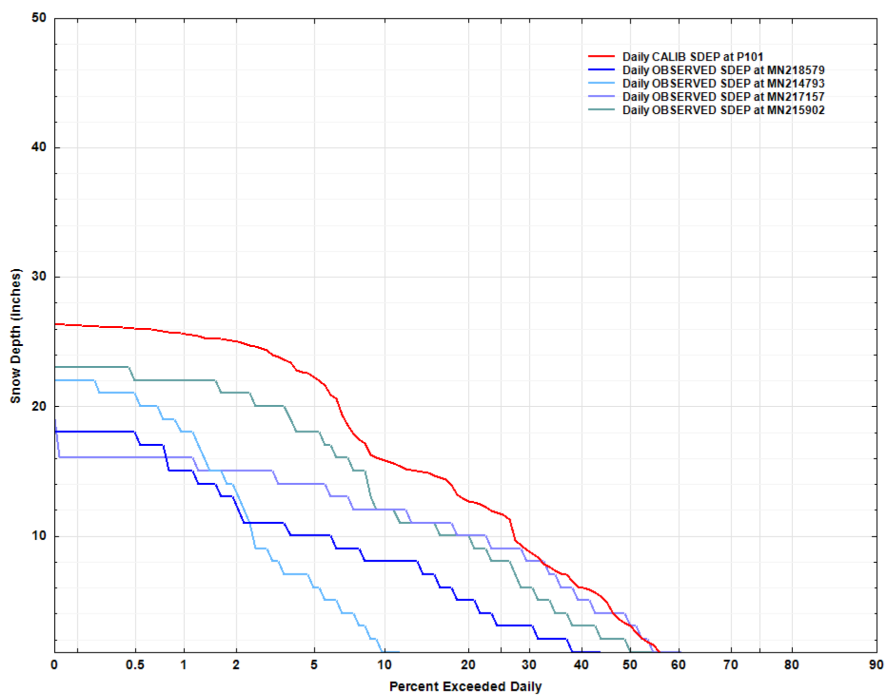


(b)

Figure 2.4 Snow depth simulation at (a) PERLND 51 and (b) PERLND 101 (Forest land areas in two different segment of the Long Prairie watershed) for the calibration period; simulated data is shown in red and observed data is shown in other colors



(a)



(b)

Figure 2.5 Comparison of snow depth frequency simulation for winter months (October to April) at (a) PERLND 51 and (b) PERLND 101 for the calibration period; simulated results are shown in the red curve and observed data is presented in other colors

To calibrate the snow depth, snow parameters including SHADE (fraction of PERLND that is shaded from the sun's direct radiation), SNOWCF (factor by which recorded precipitation is multiplied during snow events to account for poor gage catch efficiency), COVIND (maximum snowpack depth at which entire land segment is covered with snow), TSNOW (wet bulb air temperature below which precipitation occurs as snow), SNOEVP (factor to adjust evaporation from the snowpack), CCFACT (factor to adjust the rate of heat transfer from the atmosphere to the snowpack), MWATER (maximum liquid water holding capacity in the snowpack), and MGMELT (Maximum rate of snowmelt by ground heat) were adjusted. Most of these parameters were in the range recommended by BASINS Technical Note #6, except CCFACT. The lowest recommended CCFACT value is 0.5; however, the calibrated values in this watershed were about 0.1. This was done to delay the timing of snow melt and better match the timing of observed snow depth data, its melt period, and flow data.

In general, the snow depth simulation appears adequate. The snow depth values of the simulation were generally in the range of the observed snow depth. The timing of snow depth was also reasonably simulated. However, in PERLND 51, the snow depth simulation was about 20 inches greater than the observed snow depth for some parts of the year 2009. The excess depth could be explained by greater precipitation at this segment compared to other gages in this watershed. Personal communication with staff at MCPA (Chuck Regan and Doug Wetzstein) suggests that this kind of variation is normal in Minnesota watersheds. Furthermore, the nearest snow depth gage to this segment (PERLND 51) was 28 miles away, so substantial differences are to be expected. Similar snow depth comparisons were conducted at multiple segments in the watershed; all of the graphs are provided in APPENDIX A.

Once the initial snow depth calibration was complete, the streamflow calibration was conducted. To conduct streamflow calibration, multiple parameters were adjusted as recommended by BASINS Technical Note #6. Sometimes, the streamflow calibration required us to revisit the snow calibration and adjust the parameters to better match the snow melt event timings and flow volumes. The hydrograph and frequency duration plots (Figure 2.6) of flow at the Long Prairie gage show a reasonable and good simulation.

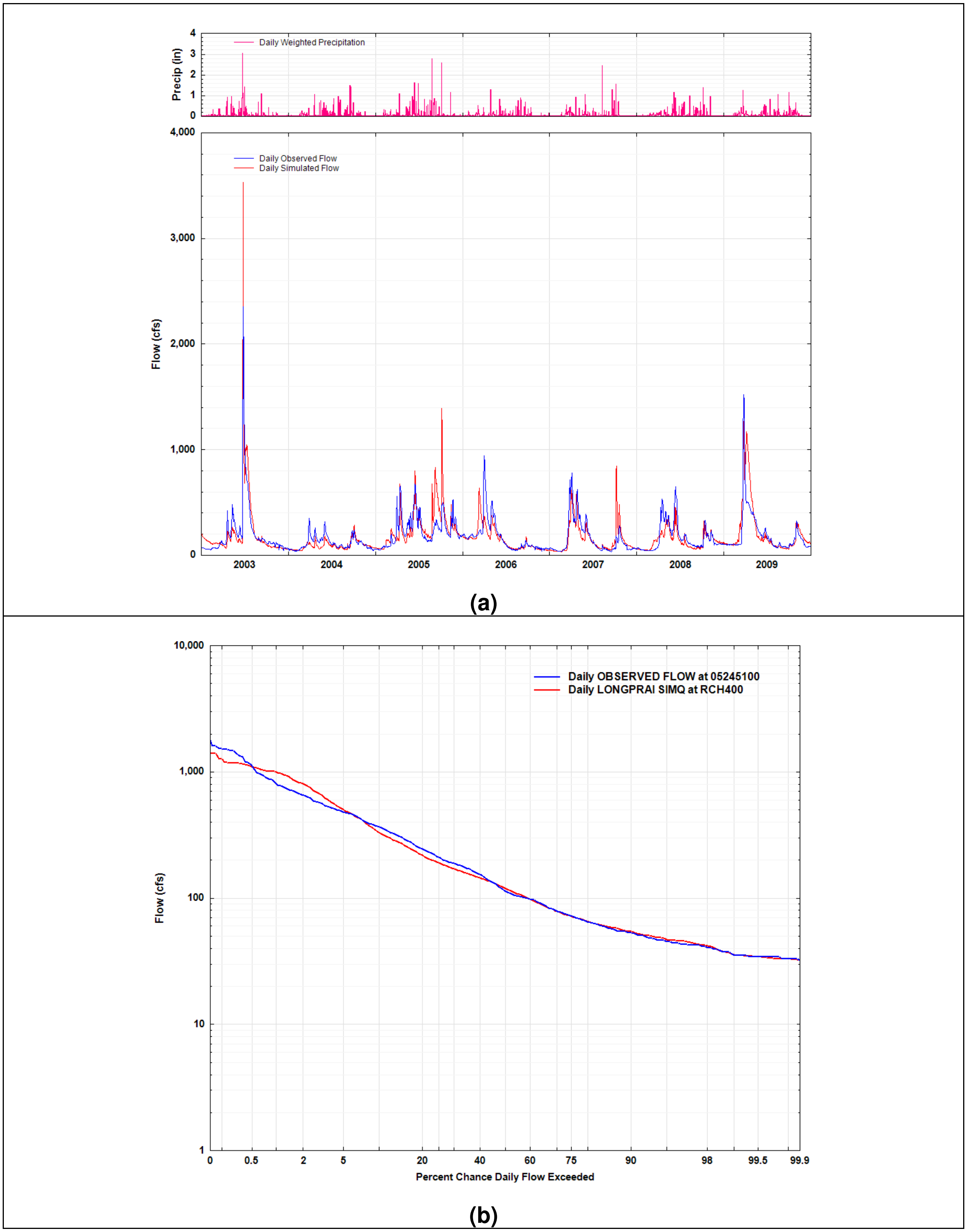


Figure 2.6 Comparison of simulated and observed (a) flow hydrograph and (b) flow duration frequency curves at the Long Prairie River gage in Long Prairie River watershed for the calibration period

Along with graphical comparisons, multiple statistics were calculated to help guide and assess the calibration process. Table 2.3 shows the various flow components (these are also referred to as HSPEXP or expert system statistics, since they are calculated by that program), and Table 2.4 shows the error terms associated with these flows. All of these criteria meet the calibration standards. Also, it should be noted that no storm flows were recorded in the winter months in MN (since precip is snow), so the winter storm volume is often zero. Personal communication with MPCA staff suggests that the gages in these watersheds sometimes freeze and the observed flow volume during winter is estimated, instead of measured. Therefore, the calibration effort should primarily focus on non-winter volumes.

Table 2.3 Annual average statistics of flow at the Long Prairie gage in Long Prairie watershed for the calibration period

	Observed Total Runoff	Simulated Total Runoff	Simulated Surface Runoff	Simulated Interflow
total (inches)	5.33	5.26	0.43	0.91
10% high (inches)	1.74	1.86		
25% high (inches)	2.99	2.98		
50% high (inches)	4.21	4.13		
50% low (inches)	1.12	1.13		
25% low (inches)	0.42	0.42		
10% low (inches)	0.14	0.14		
storm volume (inches)	1.58	1.42	0.25	0.61
average storm peak (cfs)	691.06	700.16	899.5	698.1
baseflow recession rate	0.99	0.99		
summer volume (inches)	1.54	1.48		
winter volume (inches)	0.62	0.69		
summer storms (inches)	0.68	0.65	0.15	0.32

Table 2.4 Error values and criteria for the annual average flow statistics at the Long Prairie gage in Long Prairie Watershed for the calibration period

	Current	Criteria	Meets Criteria
Error in total volume (%)	-1.2	10	OK
Error in 10% highest flows (%)	7.1	15	OK
Error in 25% highest flows (%)	-0.3	10	OK
Error in 50% highest flows (%)	-1.9	10	OK
Error in 50% lowest flows (%)	1.4	10	OK
Error in 25% lowest flows (%)	1.9	15	OK
Error in 10% lowest flows (%)	3.2	20	OK
Error in low-flow recession	0.001	0.03	OK
Error in storm volumes (%)	-9.9	15	OK
Seasonal volume error (%)	-15.3	20	OK
Error in average storm peak (%)	1.3	15	OK
Summer volume error (%)	-4.1	20	OK
Winter volume error (%)	11.2	15	OK
Summer storm volume error (%)	-5.4	15	OK

Annual (Table 2.5) and monthly (Table 2.6) flow volume comparisons were also conducted. Different model statistics were calculated for monthly and daily flow volumes (Table 2.7).

Generally, it can be observed that volumes are slightly under-simulated in dry years and over-simulated in wet years, with the exception of year 2009, when the gage was apparently stuck at approximately 200 cfs for a long period. The monthly flow comparison table suggests that, in general, the flow was over-predicted in winter months and under-predicted in late spring/early summer months. It must be noted that the winter flows were estimated because of freezing flow gages and therefore poor flow comparisons during winter months is expected. The model statistics improved from daily to monthly comparisons, as expected. Overall the model statistics suggest that model performance is fair to good.

Table 2.5 Simulated and observed annual flow volumes (in) for the calibration period at the Long Prairie gage in Long Prairie watershed

Year	Precipitation	Simulated	Observed	Residual	% Error
2003	27.2	6.39	6.27	0.12	1.9
2004	26.6	2.74	3.32	-0.59	-17.6
2005	34.8	8.03	7.25	0.79	10.8
2006	22.4	4.34	4.98	-0.64	-12.9
2007	26.9	4.42	4.58	-0.16	-3.5
2008	27.4	4.11	4.9	-0.80	-16.3
2009	26.0	6.79	5.97	0.82	13.7
Mean	**27.3**	**5.26**	**5.33**	**-0.07**	**-1.2**

Table 2.6 Comparison of simulated and observed average monthly flow volumes (in) at the Long Prairie gage in Long Prairie watershed for the calibration period

Month	Simulated	Observed	Residual	% Error
Jan	0.23	0.20	0.03	13.8
Feb	0.20	0.18	0.02	10.5
Mar	0.55	0.51	0.04	7.5
Apr	0.77	0.88	-0.11	-12.1
May	0.52	0.71	-0.19	-27.0
Jun	0.64	0.76	-0.12	-16.2
Jul	0.55	0.52	0.03	6.4
Aug	0.29	0.26	0.03	10.4
Sep	0.38	0.30	0.08	26.9
Oct	0.52	0.42	0.10	23.1
Nov	0.36	0.35	0.01	2.9
Dec	0.26	0.24	0.02	9.6
Totals	**5.26**	**5.33**	**-0.07**	**-1.2**

Table 2.7 Monthly and daily statistics of flow volume at the Long Prairie gage in Long Prairie watershed for the calibration period

Statistics	Monthly	Daily
Correlation Coefficient	0.86	0.83
Coefficient of Determination	0.73	0.68
Mean Error (cfs)	-2.2	-2.2
Mean Absolute Error (cfs)	47.0	57.6
RMS Error	77.3	110.2
Model Fit Efficiency	0.66	0.61

The water balance components were also calculated at Long Prairie gage and the watershed outlet to ensure that the distribution of water in different storages is reasonable (Table 2.8).

Water balance of all land uses for the entire watershed was also calculated (Table 2.9) to ensure that the properties of different land uses were well represented. The infiltration capacity of soils in group AB is generally greater than the soils in CD group, therefore it is expected that land uses with the AB soils group would have lower runoff than the same land uses within the CD group. However, that was not observed in Forest-AB and Forest-CD, as the slopes of the PERLNDs representing Forest-AB are greater (up to 5-6 times greater) than those of the PERLNDs representing Forest-CD.

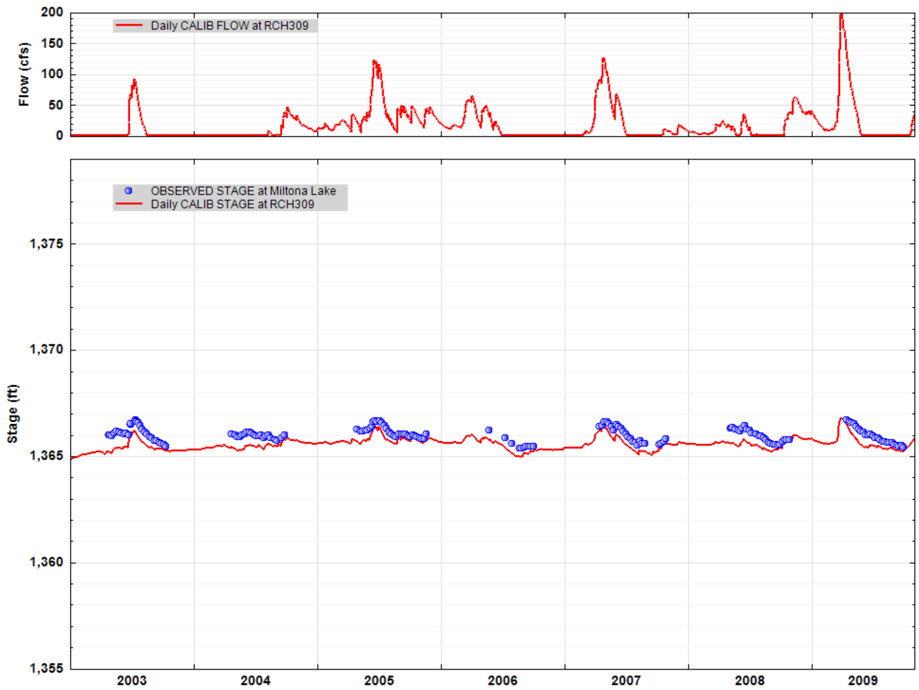
Table 2.8 Water balance components (in) at Long Prairie gage in Long Prairie watershed and the watershed outlet for the calibration period

Influx	R:400 (USGS Gage)	R:347 (Long Prairie River Outlet)
Rainfall	27.32	27.93
Runoff		
Surface-Pervious	0.31	0.24
Surface-Impervious	0.12	0.08
Interflow	0.91	0.94
Base flow	5.24	5.86
Total	6.58	7.12
GW Inflow		
Deep	0.03	0.03
Active	5.81	6.51
Evaporation		
Potential	34.02	31.77
Interception Storage	5.50	5.63
Upper Zone	3.91	4.04
Lower Zone	10.27	9.95
Ground Water	0.32	0.39
Base flow	0.29	0.28
Impervious	0.02	0.01
Total	20.29	20.29

During hydrologic calibration, the observed and simulated lake levels were also compared and the parameters were adjusted to ensure that the model is simulating lake levels adequately. Figure 2.7 shows the simulated and observed lake level at two lakes in the Long Prairie watershed. At this stage the Long Prairie Watershed was considered calibrated.

Table 2.9 Water balance components of different land uses for the Long Prairie Watershed for the calibration period

PERLND		Runoff				GW Inflow		Evaporation						
Land Use	Rainfall	Surface	Interflow	Baseflow	Total	Deep	Active	Potential	Interception Storage	Upper Zone	Lower Zone	Ground Water	Baseflow	Total
Forest - AB	27.78	0.06	0.51	5.36	5.93	0.03	5.99	31.51	6.39	3.48	10.73	0.00	0.41	21.01
Forest - CD	28.12	0.04	0.66	5.63	6.34	0.03	6.25	31.17	6.57	3.55	10.48	0.00	0.40	21.01
Wetlands	27.92	0.00	0.06	4.94	5.00	0.04	8.19	31.18	6.18	2.49	10.46	3.15	0.17	22.44
Grassland - AB	27.72	0.30	1.25	6.34	7.89	0.03	6.52	32.13	5.26	4.31	9.52	0.00	0.26	19.34
Grassland - CD	28.33	0.41	1.76	6.63	8.80	0.03	6.81	30.95	5.41	4.13	9.27	0.00	0.25	19.06
Pasture - AB	27.59	0.29	1.25	6.21	7.75	0.03	6.40	32.62	5.26	4.25	9.58	0.00	0.26	19.35
Pasture - CD	28.35	0.43	1.75	6.63	8.81	0.03	6.81	31.10	5.45	4.08	9.28	0.00	0.25	19.06
Cropland-AB	27.46	0.17	0.73	6.00	6.90	0.03	6.14	33.05	5.11	4.45	10.37	0.00	0.26	20.19
Cropland-CD	28.39	0.24	1.04	6.29	7.57	0.03	6.42	31.01	5.30	5.24	9.64	0.00	0.25	20.42
Cropland-Drained	27.99	0.04	1.30	5.76	7.11	0.03	5.90	32.64	5.27	5.10	9.90	0.00	0.26	20.53
Dev, Open Space	27.87	1.15	1.64	5.46	8.26	0.03	5.59	32.12	5.19	4.50	9.32	0.00	0.25	19.26
Dev, Low Intensity	27.67	1.35	1.57	5.16	8.08	0.03	5.29	33.04	5.14	4.43	9.43	0.00	0.26	19.26
Dev, Medium Intensity	28.03	1.33	1.66	5.28	8.26	0.03	5.41	33.27	5.21	4.49	9.47	0.00	0.26	19.43
Average	27.93	0.25	0.97	5.89	7.10	0.03	6.53	31.77	5.65	4.00	9.99	0.40	0.28	20.31
IMPLND		Runoff	Evaporation											
Land Use	Rainfall	Surface	Potential	Actual										
Dev, Open Space	28.64	24.55	31.91	4.08										
Dev, Low Intensity	28.41	24.35	32.87	4.06										
Dev, Medium Intensity	28.97	24.85	33.11	4.12										
Average	**28.69**	**24.60**	**32.66**	**4.09**										



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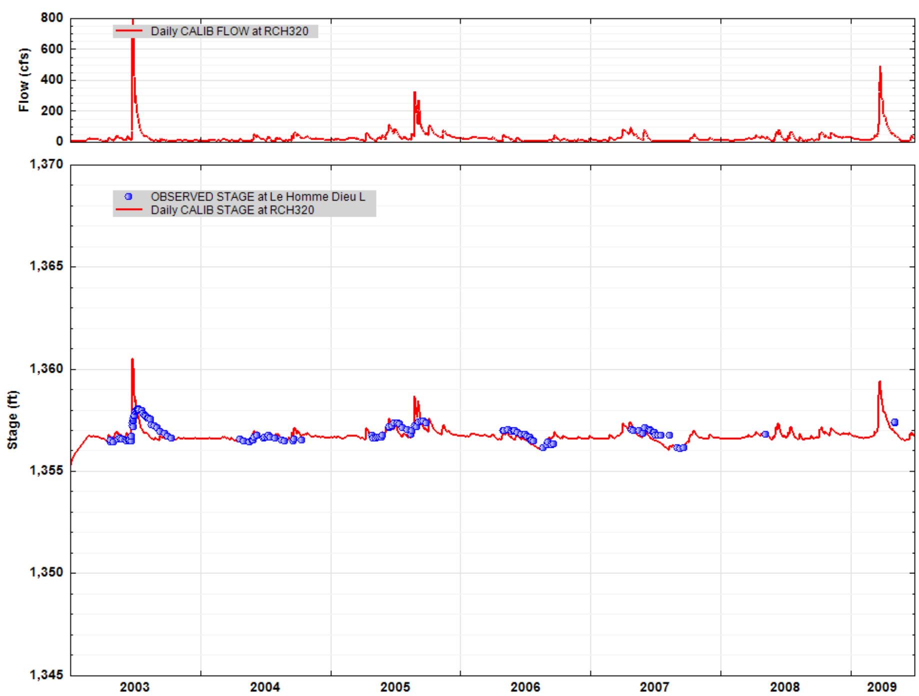


(b)

Figure 2.7 Comparison of observed and simulated lake levels at (a) Miltona Lake and (b) Le Homme Dieu Lake in the Long Prairie River Watershed for the calibration period

2.2.2 Redeye River Watershed

The Redeye River Watershed did not have a long term calibration gage available for detailed streamflow calibration, so the parameters from the Long Prairie River watershed model were used to develop the Redeye River model. There are three stations in the Redeye River watershed with some snow depth data; however, only one station (MN218579) had reliable snow depth data for the calibration and validation periods. Snow depth simulations for various PERLNDs were compared with the limited observed data. Because snow depth data was missing for significant periods of time, no extensive long term calibration was conducted for snow depth in the Redeye River watershed. Figure 2.8 and Figure 2.9 show the snow depth simulation in two PERLNDs. Similar comparisons of observed and simulated snow depth were made at various locations in the watershed; these graphs are provided in APPENDIX A. The snow depth frequency curves show that snow depth was over-predicted for the calibration period. Observed data were not available in the Redeye River watershed for a significant period of time, especially in the year 2009, which caused the discrepancy in the depth duration curve between observed and simulated data. Overall, snow depth and timing in the Redeye River watershed were simulated reasonably well, considering the limited data available.

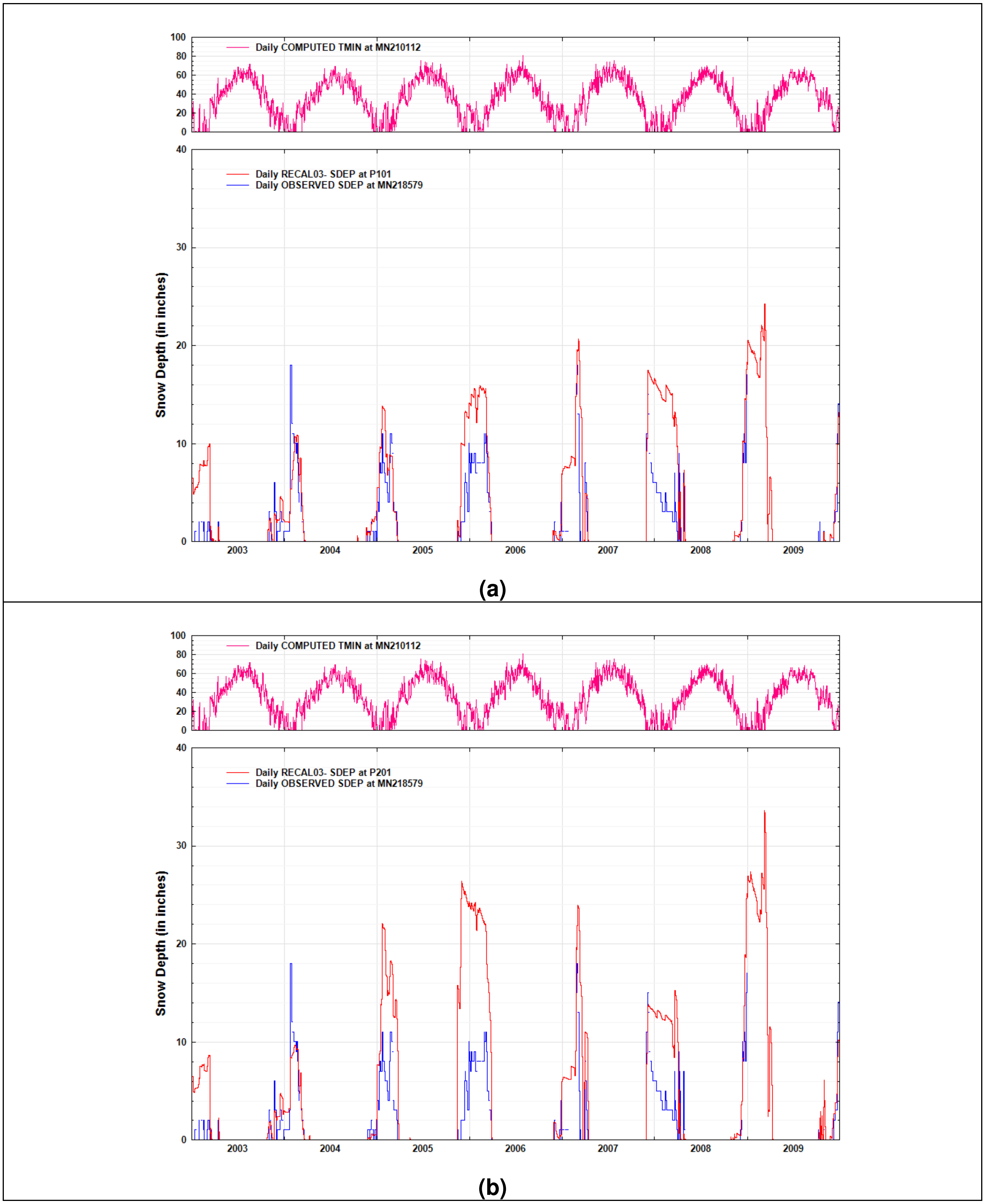
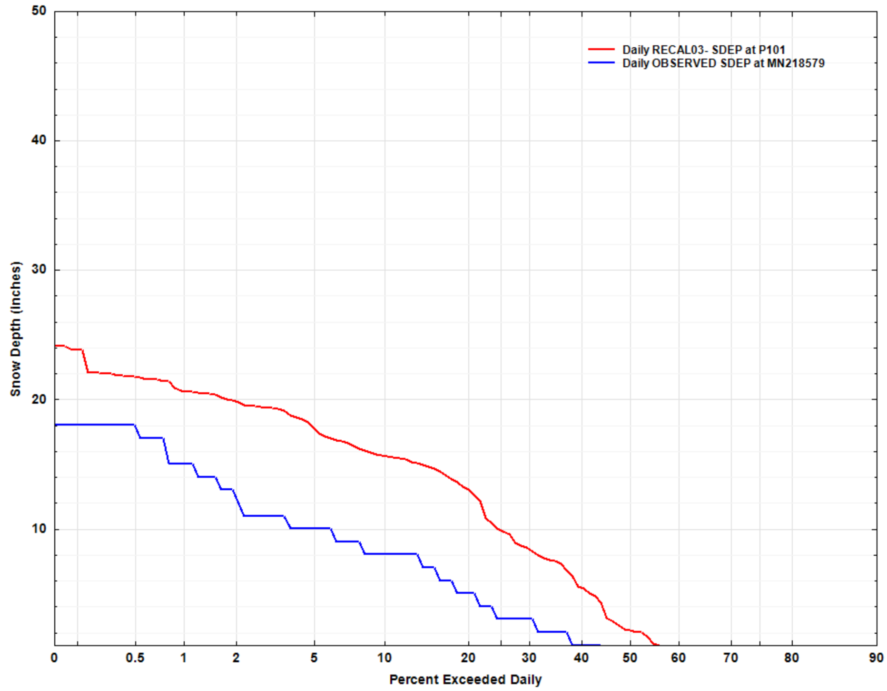


Figure 2.8 Snow Depth Simulation at (a) PERLND 101 and (b) PERLND 201 (Forest land areas in two different segments of the Redeye River watershed) for the calibration period; simulated data is shown by the red curve; observed data is shown in other colors. The auxiliary graph shows the recorded minimum daily temperature



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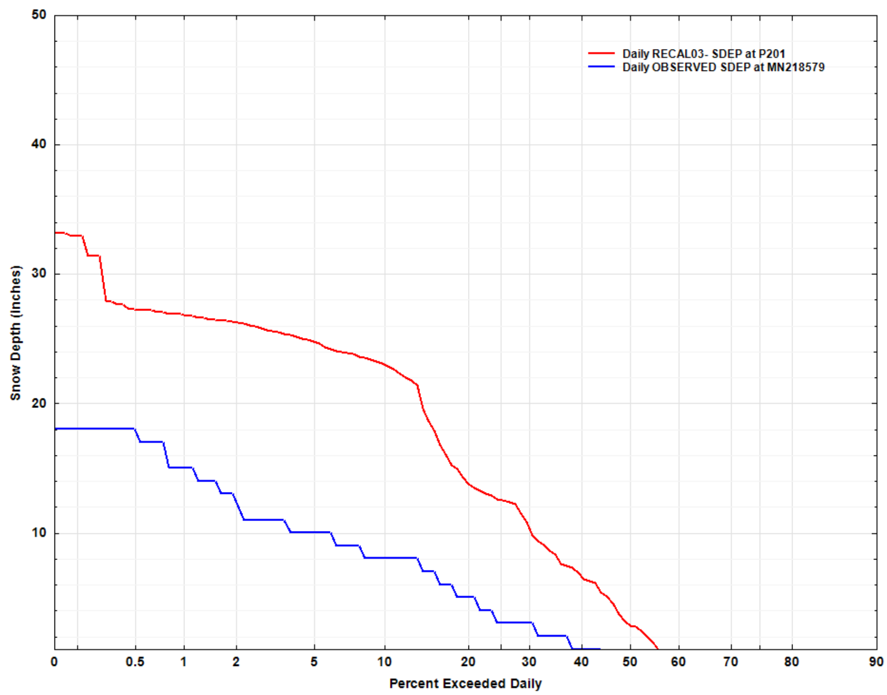


(b)

Figure 2.9 Comparison of snow depth frequency simulation for winter months (October to April) at (a) PERLND 101, and (b) PERLND 201 in the Redeye River watershed for the calibration period; simulated results are shown by the red curve and observed data is presented in other colors

Although no extensive calibration was conducted for the Red River Watershed, the water balance for the entire watershed (Table 2.10) and the water balance by land use (Table 2.11) were reviewed for consistency.

Table 2.10 Water Balance Components (in) in the Redeye River watershed for the calibration period

Influx	R:133 (Redeye River Outlet)
Rainfall	27.11
Runoff	
Surface-Pervious	0.11
Surface-Impervious	0.04
Interflow	0.72
Base flow	5.92
Total	6.78
GW Inflow	
Deep	0.03
Active	6.73
Evaporation	
Potential	30.11
Interception Storage	5.20
Upper Zone	3.63
Lower Zone	9.72
Ground Water	0.53
Base flow	0.26
Impervious	0.01
Total	19.34

Table 2.11 Water balance components by land use for the Redeye River Watershed for the calibration period

PERLND		Runoff				GW Inflow		Evaporation						
Land Use	Rainfall	Surface	Interflow	Baseflow	Total	Deep	Active	Potential	Interception Storage	Upper Zone	Lower Zone	Ground Water	Baseflow	Total
Forest - AB	26.70	0.03	0.40	5.39	5.82	0.03	5.94	30.17	5.83	3.03	10.42	0.00	0.39	19.67
Forest - CD	27.11	0.02	0.48	5.60	6.10	0.03	6.17	29.82	5.85	3.43	10.17	0.00	0.38	19.83
Wetlands	27.12	0.00	0.05	4.82	4.86	0.04	7.99	30.13	5.83	2.08	10.20	3.00	0.16	21.26
Grassland - AB	26.98	0.15	1.10	6.59	7.84	0.03	6.80	30.28	4.87	3.83	9.24	0.00	0.24	18.18
Grassland - CD	27.19	0.21	1.31	6.43	7.94	0.03	6.65	30.09	4.90	4.20	9.01	0.00	0.24	18.35
Pasture - AB	27.01	0.13	1.11	6.63	7.86	0.03	6.84	30.20	4.87	3.87	9.23	0.00	0.24	18.20
Pasture - CD	27.17	0.22	1.30	6.43	7.94	0.03	6.65	29.97	4.90	4.21	8.98	0.00	0.24	18.33
Cropland-AB	27.20	0.06	0.62	6.57	7.25	0.03	6.75	30.30	4.66	4.27	9.88	0.00	0.24	19.04
Cropland-CD	27.21	0.15	0.85	6.09	7.08	0.03	6.26	29.97	4.65	4.96	9.44	0.00	0.23	19.29
Cropland-Drained	27.41	0.03	1.10	6.07	7.20	0.03	6.24	30.07	4.66	5.01	9.47	0.00	0.23	19.37
Dev, Open Space	27.14	0.67	1.67	5.69	8.02	0.03	5.86	30.17	4.74	4.31	9.02	0.00	0.24	18.30
Dev, Low Intensity	27.32	0.64	1.73	5.83	8.19	0.03	6.00	30.19	4.67	4.35	9.07	0.00	0.23	18.32
Dev, Medium Intensity	27.54	0.55	1.82	5.98	8.36	0.03	6.16	30.12	4.65	4.42	9.09	0.00	0.23	18.39
Average	27.11	0.11	0.72	5.93	6.76	0.03	6.74	30.11	5.21	3.64	9.73	0.53	0.26	19.37

IMPLND		Runoff	Evaporation	
Land Use	Rainfall	Surface Runoff	Potential	Actual
Dev, Open Space	27.44	23.82	30.13	3.61
Dev, Low Intensity	27.59	24.04	30.12	3.55
Dev, Medium Intensity	27.86	24.34	30.00	3.52
Average	**27.58**	**24.01**	**30.09**	**3.57**

2.2.3 Crow Wing River Watershed

The hydrology calibration in the Crow Wing River watershed model also started with snow depth calibration. The snow depth comparison in two different PERLNDs is shown in Figure 2.10 and Figure 2.11. The snow depth simulation shown in these figures appears reasonable and acceptable in terms of depth and timing. The snow parameters that were adjusted were similar to the ones adjusted for the Long Prairie watershed.

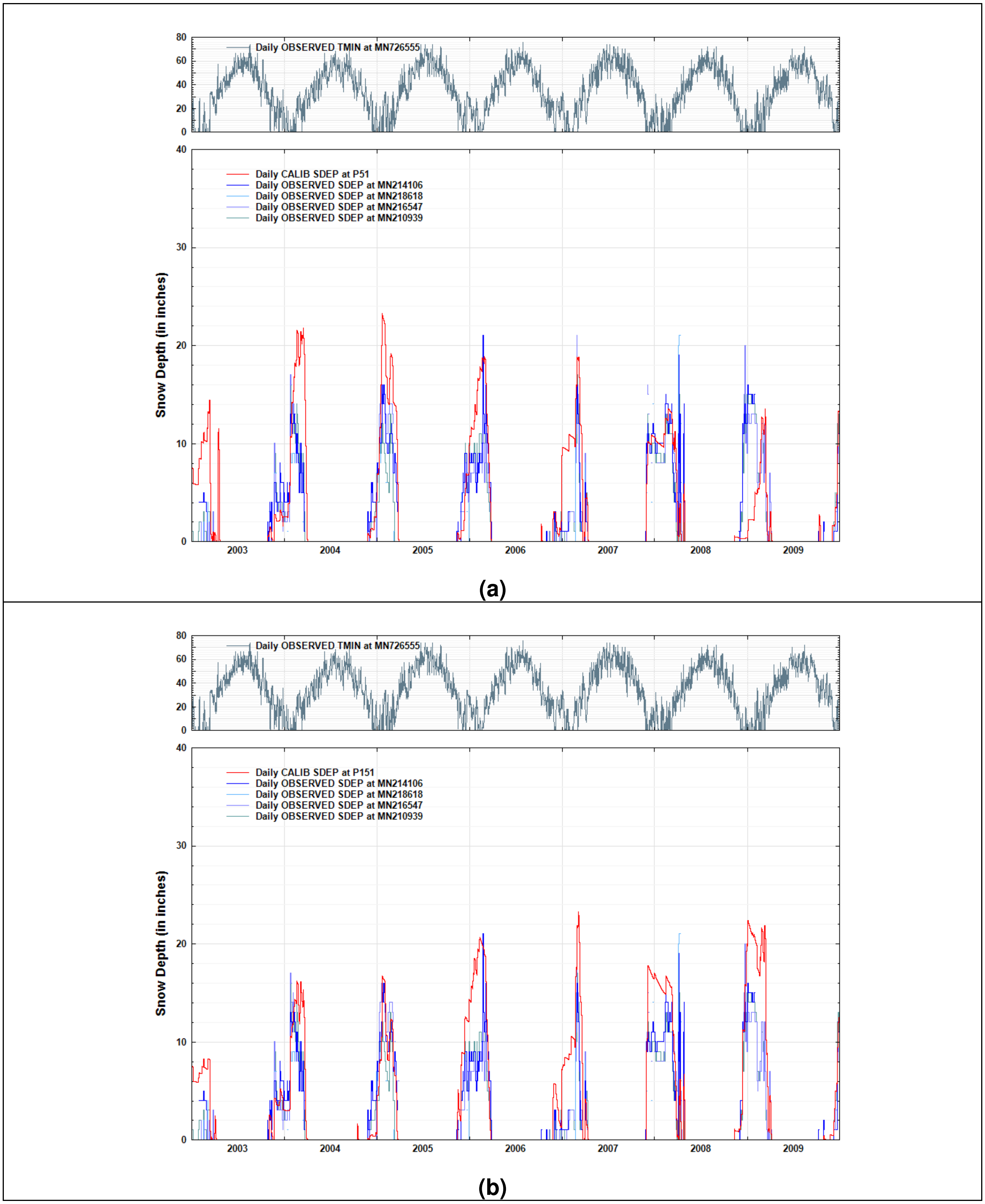
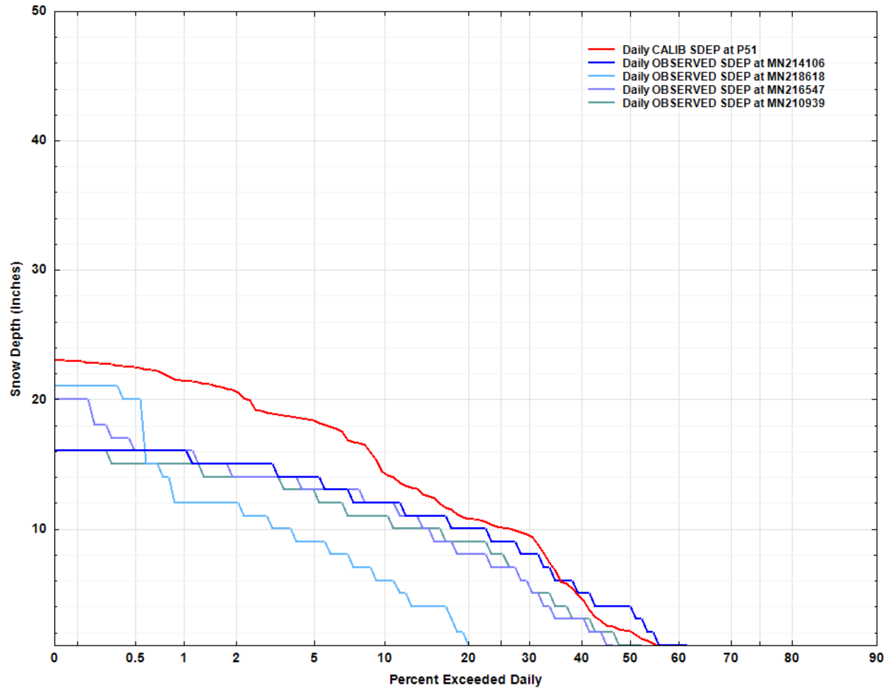


Figure 2.10 Snow depth simulation at (a) PERLND 51 and (b) PERLND 151 (Forest land areas in two different segments of the Crow Wing River watershed) for the calibration period; simulated data is shown by the red curve and observed data is shown in other colors



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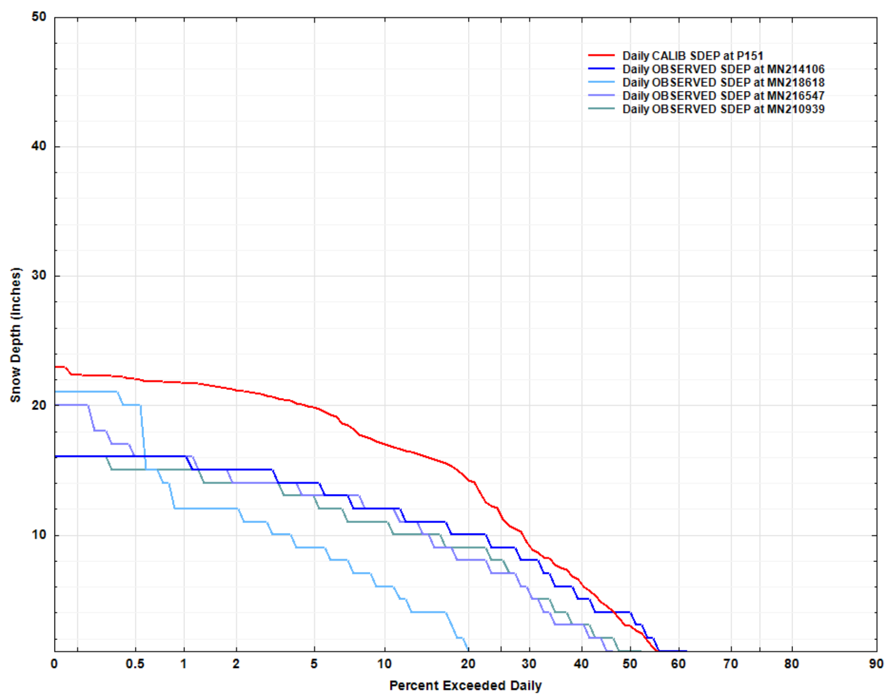
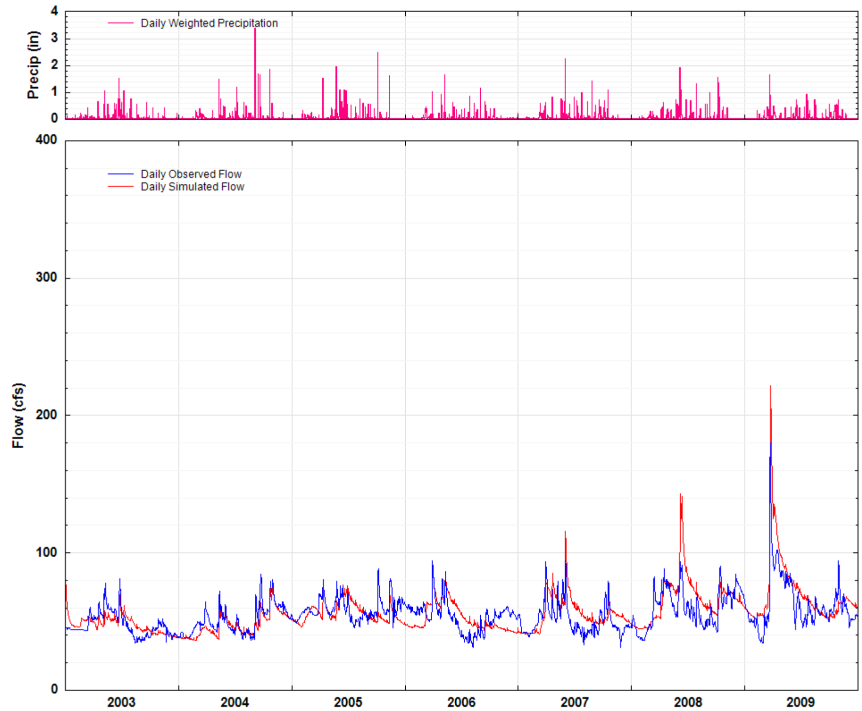


(b)

Figure 2.11 Comparison of snow depth frequency simulation for winter months (October to April) at (a) PERLND 51, and (b) PERLND 151 in the Crow Wing River watershed for the calibration period; simulated results are shown by the red curve and observed data is presented in other colors

Streamflow calibration for the Crow Wing watershed model was initiated using the parameters from the calibrated Long Prairie River watershed model. The most upstream gage in the Crow Wing, the Straight River gage near Park Rapids, was the first to be calibrated. The Straight River gage has a drainage area of about 53 sq. miles and drains only one model segment flows to it. The average observed runoff at the Straight River gage over the calibration period was more than 12", which is 2 to 2.5 times greater than the observed runoff at any of the other gages in the Crow Wing and Long Prairie watersheds. The excess streamflow indicated that the Straight River watershed likely receives flow from groundwater from outside the watershed. This conclusion is also supported by Stark et al. (1995). To simulate the groundwater inflow, a constant inflow of 0.75 ac-ft/hr into Straight Lake and 1.75 ac-ft/hr into Straight River downstream of Straight Lake was assumed. This value was obtained by calibration. There was no additional information about the groundwater flow and its seasonal variation, so a constant flow was assumed.

To conduct the streamflow calibration, parameters were adjusted as recommended in BASINS Technical Note #6. Figure 2.12 shows the hydrograph and the flow frequency duration curve. The Straight River watershed is unique as the flow in the stream stays between 30 and 105 cfs for the entire simulation period; the flow duration curve for the Straight River gage is much flatter than the corresponding flow duration curves for any of the other gages in these watersheds. It is generally difficult to calibrate a watershed with such a low variance in output flow, as the effect of external forcing factors such as precipitation is muted. The model fit efficiency for watersheds like this is generally pretty low and can even be negative (Krause et al., 2005).



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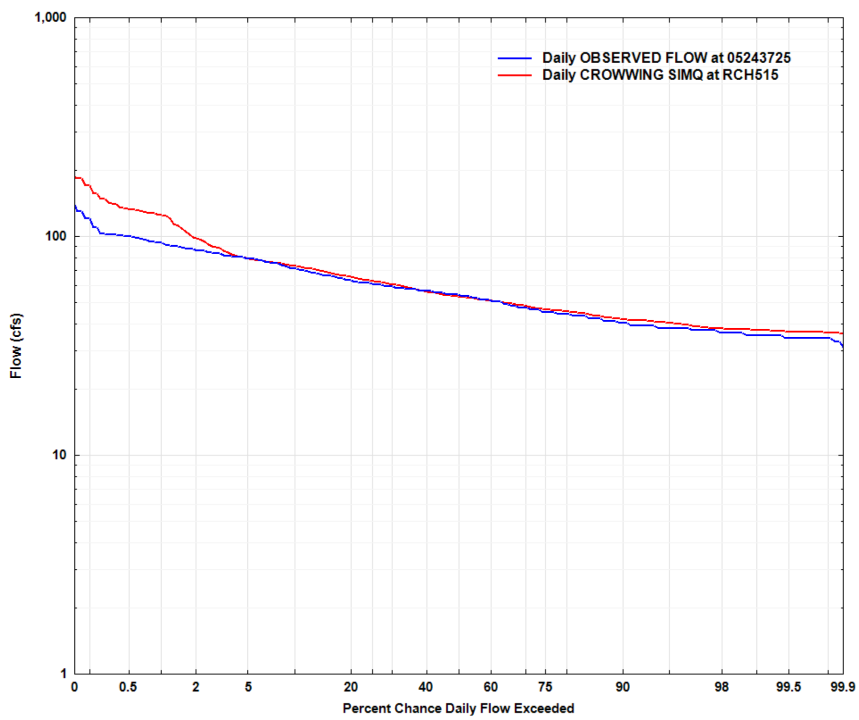


(b)

Figure 2.12 Comparison of simulated and observed (a) flow hydrograph and (b) flow duration frequency curves at the Straight River gage in Crow Wing River watershed for the calibration period

The model calibration statistics are presented in Table 2.12 and Table 2.13. The calibration statistics satisfy all the calibration criteria except the seasonal flow error. The primary reason for the seasonal flow error is the overestimation of flow volume in the summer. This overestimation of summer flow volume is likely the result of constant groundwater inflows from external sources.

Table 2.12 Annual Average Statistics of flow at the Straight River gage in the Crow Wing River watershed

	Observed Total Runoff	Simulated Total Runoff	Simulated Surface Runoff	Simulated Interflow
total (inches)	12.78	13.19	0.049	0.454
10% high (inches)	1.93	2.10		
25% high (inches)	4.20	4.45		
50% high (inches)	7.50	7.79		
50% low (inches)	5.27	5.39		
25% low (inches)	2.38	2.48		
10% low (inches)	0.88	0.92		
storm volume (inches)	2.62	2.72	0.032	0.344
average storm peak (cfs)	77.64	74.61	6.905	24.387
baseflow recession rate	1.00	0.996		
summer volume (inches)	2.98	3.55		
winter volume (inches)	2.89	2.80		
summer storms (inches)	0.79	0.92	0.013	0.100

Table 2.13 Error Terms and Criteria for the Annual Average Flow Statistics at the Straight River gage in the Crow Wing River Watershed

	Current	Criteria	Meets Criteria
Error in total volume (%)	3.2	10	OK
Error in 10% highest flows (%)	9.1	15	OK
Error in 25% highest flows (%)	6.1	10	OK
Error in 50% highest flows (%)	3.9	10	OK
Error in 50% lowest flows (%)	2.3	10	OK
Error in 25% lowest flows (%)	4.0	15	OK
Error in 10% lowest flows (%)	5.1	20	OK
Error in low-flow recession	0.004	0.03	OK
Error in storm volumes (%)	3.9	15	OK
Seasonal volume error (%)	22.2	20	Fails
Error in average storm peak (%)	-3.9	15	OK
Summer volume error (%)	19.2	20	OK
Winter volume error (%)	-3.0	15	OK
Summer storm volume error (%)	15.6	15	OK

Annual (Table 2.14) and monthly (Table 2.15) flow comparisons were also conducted. Model performance statistics were calculated for the daily and monthly flow (Table 2.16). Overall, the yearly and monthly percent errors are small. The monthly and daily statistics show that the model prediction is fair. Model fit efficiency is extremely poor due to the low variance of output flow, as discussed above. Overall, the model outputs for the Straight River gage were considered acceptable.

Table 2.14 Simulated and Observed Yearly Flow Volume (in) for the Straight River Gage in the Crow Wing River Watershed for the calibration period

Year	Precipitation	Simulated	Observed	Residual	% Error
2003	19.8	11.13	11.0	0.10	0.9
2004	26.4	11.03	11.8	-0.80	-6.8
2005	26.5	13.15	13.7	-0.56	-4.1
2006	20.8	12.21	12.4	-0.21	-1.7
2007	27.1	12.88	11.8	1.09	9.3
2008	30.4	15.42	14.0	1.38	9.9
2009	25.8	16.47	14.6	1.86	12.8
Mean	**25.3**	**13.2**	**12.8**	**0.41**	**3.2**

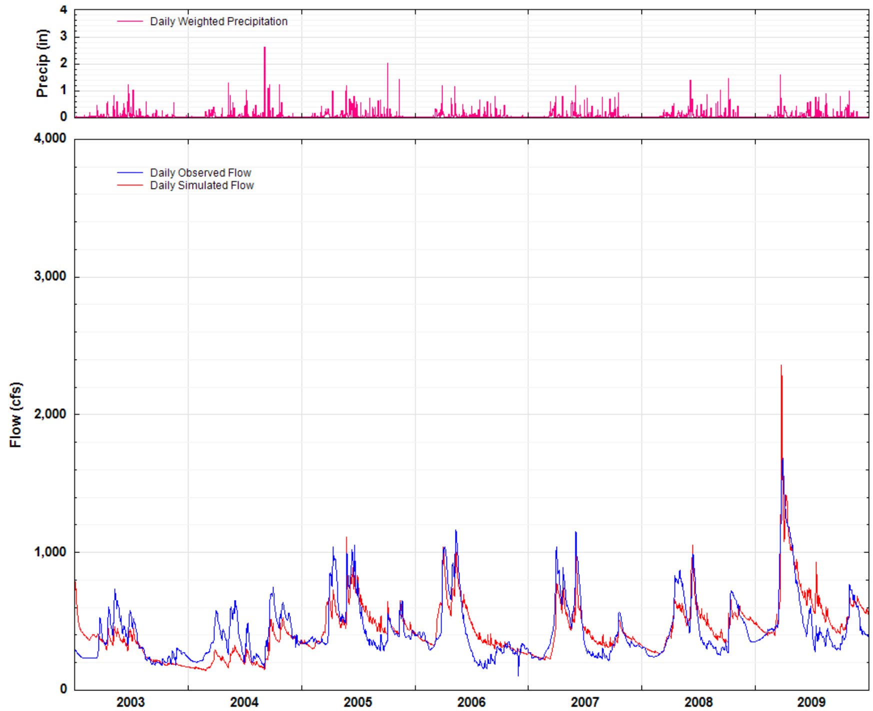
Table 2.15 Comparison of Simulated and Observed Average Monthly Flow Volume (in) for the Straight River Gage in the Crow Wing River Watershed for the calibration period

Month	Simulated	Observed	Residual	% Error
Jan	0.94	0.96	-0.02	-2.0
Feb	0.83	0.84	-0.01	-1.2
Mar	1.15	1.14	0.01	0.5
Apr	1.30	1.26	0.04	3.5
May	1.27	1.26	0.01	0.8
Jun	1.33	1.12	0.21	18.7
Jul	1.18	0.95	0.22	23.2
Aug	1.04	0.90	0.14	15.6
Sep	0.97	0.97	0.00	-0.1
Oct	1.06	1.16	-0.10	-8.5
Nov	1.07	1.11	-0.04	-3.2
Dec	1.03	1.09	-0.06	-5.3
Totals	13.19	**12.8**	0.41	3.2

Table 2.16 Monthly and daily Statistics of flow volume for the Straight River gage in the Crow Wing River Watershed for the calibration period

Statistics	Monthly	Daily
Correlation Coefficient	0.75	0.73
Coefficient of Determination	0.56	0.53
Mean Error (cfs)	1.8	1.8
Mean Absolute Error (cfs)	7.4	8.4
RMS Error	9.4	11.1
Model Fit Efficiency	0.20	0.27

The Crow Wing River gage near Nimrod is downstream of the Straight River gage and has a drainage area of about 1,030 sq. miles. The streamflow calibration at the Nimrod gage followed the streamflow calibration at the Straight River gage. The flow hydrograph and the flow frequency duration curves are presented in the Figure 2.13. The graphs show that the model simulates observed flow well. It must be noted that the hydrology in these watersheds is heavily affected by lakes, of which some are managed and some are not. In addition , there are no detailed records available on the flow management for these lakes. Therefore it is a challenge to calibrate these watersheds to match the regulated observed flow without knowledge of the regulatory operations.



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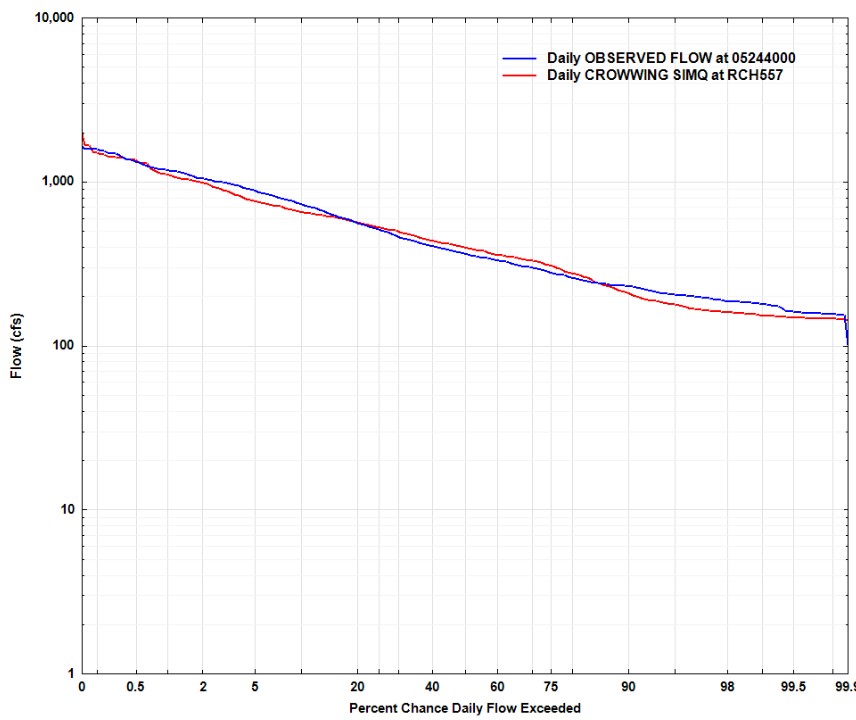


(b)

Figure 2.13 Comparison of simulated and observed (a) flow hydrograph and (b) flow duration frequency curves at the Nimrod Gage on Crow Wing River in Crow Wing River watershed

The expert system statistics are presented in the Table 2.17, and the errors and error criteria are presented in the Table 2.18. The model performs very well on all the error criteria. Simulated and observed flow were also compared yearly (Table 2.19) and monthly (Table 2.20). The model performs very well for all the years; however it under-predicts the flow for the year 2004 and over predicts the flow for the year 2009, significantly. The model also under-predicts the spring flow and over-predicts the summer flow. The monthly and daily statistics (Table 2.21) suggest that model performance is fair to good.

Table 2.17 Annual Average Statistics of flow at the Nimrod gage on the Crow Wing River in the Crow Wing River watershed

	Observed Total Runoff	Simulated Total Runoff	Simulated Surface Runoff	Simulated Interflow
total (inches)	5.4	5.5	0.062	0.369
10% high (inches)	1.2	1.1		
25% high (inches)	2.3	2.2		
50% high (inches)	3.7	3.6		
50% low (inches)	1.8	1.8		
25% low (inches)	0.7	0.7		
10% low (inches)	0.3	0.2		
storm volume (inches)	1.4	1.3	0.041	0.263
average storm peak (cfs)	745.9	667.3	149.99	343.81
baseflow recession rate	0.994	0.994		
summer volume (inches)	1.3	1.5		
winter volume (inches)	1.0	1.1		
summer storms (inches)	0.4	0.4	0.01	0.06

Table 2.18 Error Terms and Criteria for the Annual Average Flow Statistics at the Nimrod gage on the Crow Wing River in the Crow Wing River watershed

	Current	Criteria	Meets Criteria
Error in total volume (%)	1.0	10	OK
Error in 10% highest flows (%)	-8.7	15	OK
Error in 25% highest flows (%)	-5.5	10	OK
Error in 50% highest flows (%)	-0.7	10	OK
Error in 50% lowest flows (%)	4.5	10	OK
Error in 25% lowest flows (%)	-2.4	15	OK
Error in 10% lowest flows (%)	-12.9	20	OK
Error in low-flow recession	0.001	0.03	OK
Error in storm volumes (%)	-13.2	15	OK
Seasonal volume error (%)	6.0	20	OK
Error in average storm peak (%)	-10.5	15	OK
Summer volume error (%)	15.2	20	OK
Winter volume error (%)	9.2	15	OK
Summer storm volume error (%)	-8.0	15	OK

Table 2.19 Simulated and Observed Yearly Flow Volume (in) for the Calibration Period for the Nimrod gage on the Crow Wing River in the Crow Wing River Watershed

Year	Precipitation	Simulated	Observed	Residual	% Error
2003	20.5	3.98	4.1	-0.08	-1.9
2004	28.0	3.30	4.8	-1.50	-31.2
2005	29.3	6.37	6.2	0.17	2.8
2006	22.5	5.60	5.1	0.50	9.9
2007	27.3	5.04	5.2	-0.14	-2.6
2008	27.9	5.93	5.6	0.30	5.3
2009	27.2	8.18	7.1	1.11	15.7
Mean	**26.1**	**5.5**	**5.4**	**0.05**	**1.0**

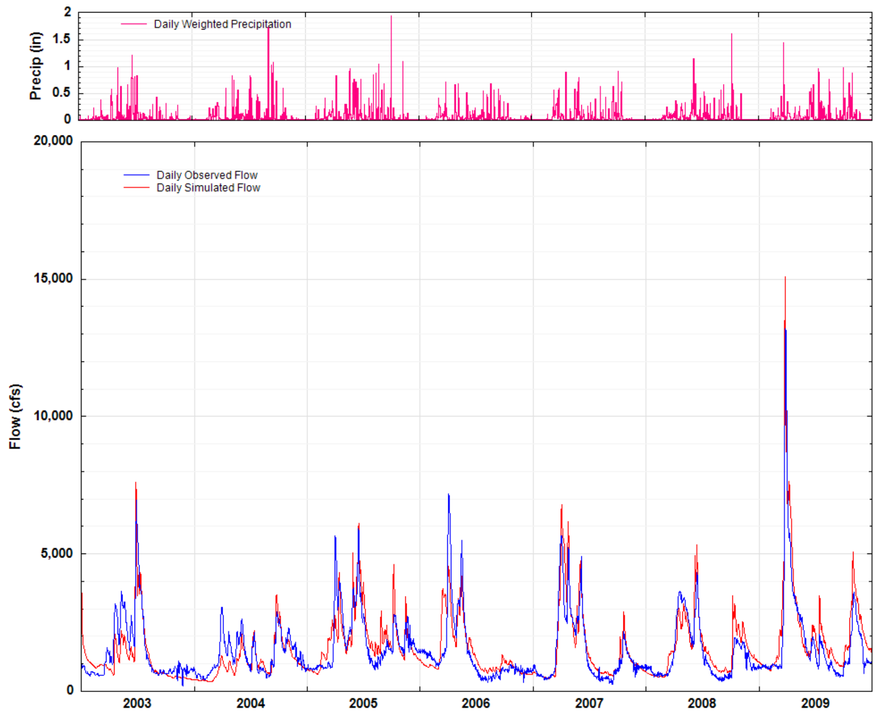
Table 2.20 Comparison of Simulated and Observed Average Monthly Flow Volume (in) for the for the Nimrod gage on the Crow Wing River in the Crow Wing River Watershed

Month	Simulated	Observed	Residual	% Error
Jan	0.37	0.32	0.04	13.8
Feb	0.30	0.29	0.01	3.1
Mar	0.47	0.46	0.00	0.9
Apr	0.64	0.78	-0.14	-18.2
May	0.59	0.70	-0.11	-15.2
Jun	0.59	0.60	-0.01	-1.9
Jul	0.49	0.39	0.11	28.0
Aug	0.40	0.30	0.10	32.8
Sep	0.36	0.31	0.06	18.2
Oct	0.43	0.45	-0.03	-5.8
Nov	0.44	0.46	-0.02	-4.2
Dec	0.41	0.38	0.04	9.9
Totals	**5.49**	**5.43**	**0.05**	**1.0**

Table 2.21 Monthly and daily Statistics of flow volume for the for the Nimrod gage on the Crow Wing River in the Crow Wing River Watershed

Statistics	Monthly	Daily
Correlation Coefficient	0.83	0.82
Coefficient of Determination	0.69	0.67
Mean Error (cfs)	3.92	4.21
Mean Absolute Error (cfs)	90.2	98.9
RMS Error	111.4	128.4
Model Fit Efficiency	0.68	0.66

Following the calibration of the Straight River and the Crow Wing River gage near Nimrod, calibration of the Crow Wing River gage near Pillager was undertaken. This gage includes the inflows from the Redeye and Long Prairie rivers. During the calibration process, it was noted that at least three lakes (Hubert Lake, Edward Lake, and North Long Lake) had greater evaporation loss than the sum of rainfall and total inflow of water from the local drainage area. In other words, the lakes were losing water during the simulation period. It was therefore assumed that they receive some contribution from groundwater, so a constant groundwater inflow, obtained by calibration, was added to these lakes. Figure 2.14 shows the comparison of observed and simulated flows and the flow frequency duration curves at the Pillager gage. The visual comparison suggests that the model simulates flow very well.



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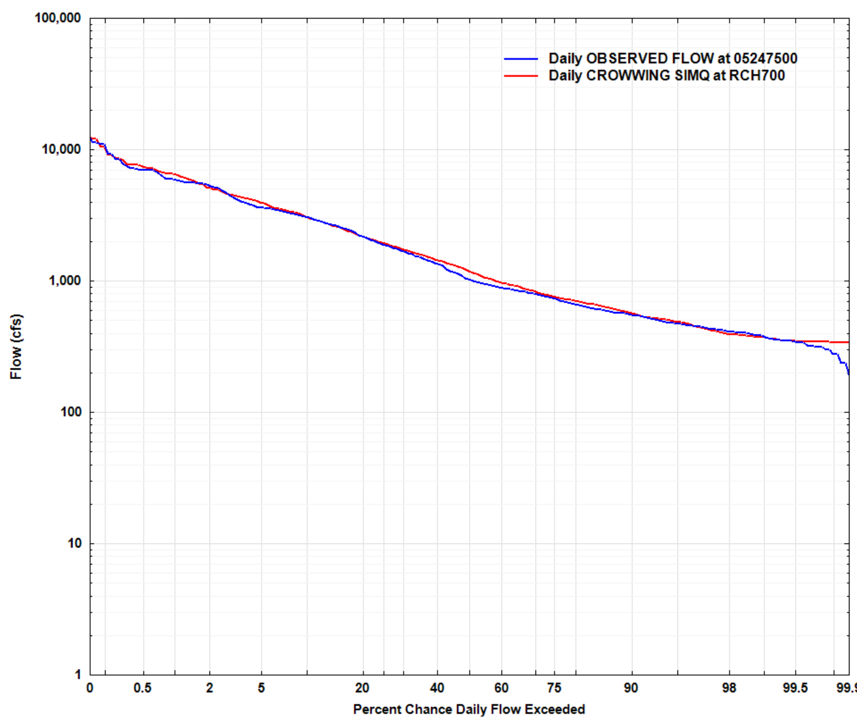


(b)

Figure 2.14 Comparison of simulated and observed (a) flow hydrograph, and (b) flow duration frequency curves at the Pillager Gage on the Crow Wing River in the Crow Wing River watershed for the calibration period

Expert system statistics were also calculated for this gage (Table 2.22 and Table 2.23). The model performs well on all the error criteria for the expert system. The yearly (Table 2.24) and monthly (Table 2.25) comparisons show that the model simulates different hydrologic conditions well. The model generally over-predicts summer flows. It is important to note that the difference in flow regime during different months could be a result of flow management at lakes for which no detailed data is available. Table 2.26 shows that the model performance is good for monthly and daily simulations.

Table 2.22 Annual average statistics of flow at the Crow Wing Gage near Pillager, MN for the calibration period

	Observed Total Runoff	Simulated Total Runoff	Simulated Surface Runoff	Simulated Interflow
total (inches)	5.44	5.70	0.15	0.59
10% high (inches)	1.56	1.63		
25% high (inches)	2.86	2.93		
50% high (inches)	4.15	4.31		
50% low (inches)	1.29	1.39		
25% low (inches)	0.51	0.53		
10% low (inches)	0.17	0.17		
storm volume (inches)	1.88	1.81	0.10	0.43
average storm peak (cfs)	3,690	3,729	1,217.0	1,865.2
baseflow recession rate	1.00	0.99		
summer volume (inches)	1.32	1.55		
winter volume (inches)	0.76	0.77		
summer storms (inches)	0.56	0.57	0.043	0.137

Table 2.23 Error terms and criteria for the annual average flow statistics at the Crow Wing Gage near Pillager, MN for the calibration period

	Current	Criteria	Meets Criteria
Error in total volume (%)	4.7	10	OK
Error in 10% highest flows (%)	4.2	15	OK
Error in 25% highest flows (%)	2.3	10	OK
Error in 50% highest flows (%)	3.9	10	OK
Error in 50% lowest flows (%)	7.3	10	OK
Error in 25% lowest flows (%)	4.6	15	OK
Error in 10% lowest flows (%)	1.6	20	OK
Error in low-flow recession	0.007	0.03	OK
Error in storm volumes (%)	-3.9	15	OK
Seasonal volume error (%)	16.7	20	OK
Error in average storm peak (%)	1.0	15	OK
Summer volume error (%)	17.1	20	OK
Winter volume error (%)	0.4	15	OK
Summer storm volume error (%)	1.2	15	OK

Table 2.24 Simulated and observed yearly flow volume (in) at the Crow Wing River Gage near Pillager, MN for the calibration period

Year	Precipitation	Simulated	Observed	Residual	% Error
2003	23.55	4.41	5.02	-0.60	-12.2
2004	28.17	3.83	4.64	-0.80	-17.5
2005	31.64	7.10	6.65	0.45	6.8
2006	23.42	5.01	4.92	0.10	2.0
2007	26.99	5.60	5.10	0.49	9.7
2008	26.91	5.52	4.90	0.62	12.7
2009	28.36	8.41	6.86	1.55	22.7
Mean	**27.00**	**5.70**	**5.44**	**0.26**	**4.7**

Table 2.25 Comparison of simulated and observed average monthly flow volume (in) at the Crow Wing River Gage near Pillager, MN for the calibration period

Month	Simulated	Observed	Residual	% Error
Jan	0.25	0.25	0.00	-1.4
Feb	0.20	0.21	0.00	-1.3
Mar	0.60	0.50	0.09	18.7
Apr	0.86	0.97	-0.12	-12.0
May	0.65	0.77	-0.13	-16.7
Jun	0.71	0.67	0.03	5.2
Jul	0.52	0.43	0.09	22.2
Aug	0.32	0.22	0.10	43.5
Sep	0.32	0.25	0.07	26.8
Oct	0.51	0.42	0.08	19.9
Nov	0.46	0.43	0.03	5.9
Dec	0.31	0.30	0.01	3.1
Totals	5.70	5.44	0.26	4.7

Table 2.26 Monthly and daily statistics of flow volume at the Crow Wing River Gage near Pillager, MN for the calibration period

Statistics	Monthly	Daily
Correlation Coefficient	0.90	0.89
Coefficient of Determination	0.81	0.79
Mean Error (cfs)	69.64	70.8
Mean Absolute Error (cfs)	365.1	420.2
RMS Error	468.6	604.7
Model Fit Efficiency	0.78	.77

The water balance at all the gages in the Crow Wing River watershed was calculated to ensure that the distribution of water in different storages was reasonable (Table 2.27). The water balance for the entire Crow Wing watershed for each land use was also calculated to ensure that the land uses are represented reasonably (Table 2.28).

Table 2.27 Water balance components (in) at USGS gages in the Crow Wing watershed for the calibration period

Influx	R:515 (Straight River Gage at Straight River)	R:557 (Crow Wing River Gage Near Nimrod)	R:700 (Crow Wing near gage near Pillager)
Rainfall	25.26	26.09	26.55
Runoff			
Surface-Pervious	0.03	0.03	0.04
Surface-Impervious	0.02	0.03	0.03
Interflow	0.45	0.37	0.38
Base flow	5.76	5.20	5.10
Total	6.26	5.63	5.55
GW Inflow			
Deep	0.02	0.04	0.04
Active	6.44	5.92	6.01
Evaporation			
Potential	32.40	32.26	33.24
Interception Storage	5.51	5.85	5.85
Upper Zone	3.04	3.14	3.23
Lower Zone	9.84	10.56	10.79
Ground Water	0.16	0.27	0.45
Base flow	0.33	0.32	0.34
Impervious	0.01	0.01	0.01
Total	18.88	20.15	20.66

Table 2.28 Water balance components of different land uses in the Crow Wing River Watershed for the calibration period

PERLND		Runoff				GW Inflow		Evaporation						
Land Use	Rainfall	Surface	Interflow	Baseflow	Total	Deep	Active	Potential	Interception Storage	Upper Zone	Lower Zone	Ground Water	Baseflow	Total
Forest - AB	25.84	0.01	1.02	5.94	6.97	0.02	6.03	32.39	4.81	4.02	9.93	0.00	0.20	18.96
Forest - CD	26.20	0.01	0.21	4.66	4.88	0.03	5.29	32.88	6.21	2.91	11.31	0.00	0.44	20.87
Wetlands	26.69	0.01	0.26	4.81	5.08	0.04	5.47	33.08	6.20	3.25	11.23	0.00	0.46	21.15
Grassland - AB	26.69	0.00	0.04	4.01	4.06	0.05	7.00	33.83	6.15	1.74	11.58	2.49	0.25	22.22
Grassland - CD	26.54	0.12	0.94	7.10	8.16	0.04	7.35	33.19	5.25	4.83	7.77	0.00	0.23	18.08
Pasture - AB	27.15	0.21	1.10	6.97	8.28	0.06	7.24	33.72	5.28	5.33	7.71	0.00	0.27	18.59
Pasture - CD	26.56	0.05	0.62	5.97	6.64	0.04	6.20	33.52	5.26	3.98	10.23	0.00	0.24	19.72
Cropland-AB	27.40	0.11	0.81	6.00	6.92	0.05	6.23	33.44	5.30	4.50	10.20	0.00	0.26	20.26
Cropland-CD	26.35	0.03	0.60	6.50	7.13	0.03	6.62	32.98	5.00	3.73	10.29	0.00	0.22	19.24
Cropland-Drained	27.55	0.07	0.83	6.09	6.99	0.05	6.20	34.19	5.07	4.64	10.53	0.00	0.26	20.50
Dev, Open Space	26.57	0.37	1.01	5.33	6.71	0.03	5.48	33.53	5.11	4.77	9.68	0.00	0.25	19.80
Dev, Low Intensity	26.55	0.34	1.03	5.33	6.69	0.03	5.48	33.67	5.07	4.77	9.71	0.00	0.25	19.80
Dev, Medium Intensity	26.51	0.25	1.09	5.47	6.80	0.03	5.61	33.40	5.02	4.76	9.66	0.00	0.24	19.68
Average	26.56	0.04	0.38	5.10	5.52	0.04	6.02	33.26	5.86	3.24	10.80	0.45	0.34	20.69

IMPLND		Runoff	Evaporation	
Land Use	Rainfall	Surface	Potential	Actual
Dev, Open Space	25.44	20.13	33.30	5.31
Dev, Low Intensity	25.45	20.18	33.42	5.26
Dev, Medium Intensity	25.60	20.41	33.14	5.18
Average	25.48	20.21	33.30	5.26

During the hydrologic calibration, the simulated and observed lake levels were also compared and the parameters were adjusted to ensure that the model is simulating acceptable lake levels. Figure 2.15 shows the observed and simulated lake levels for two lakes in the Crow Wing River Watershed. The lake level simulation appears to be adequate. The Crow Wing watersheds were considered calibrated at this stage. The validation of all the watershed models was conducted following the calibration.

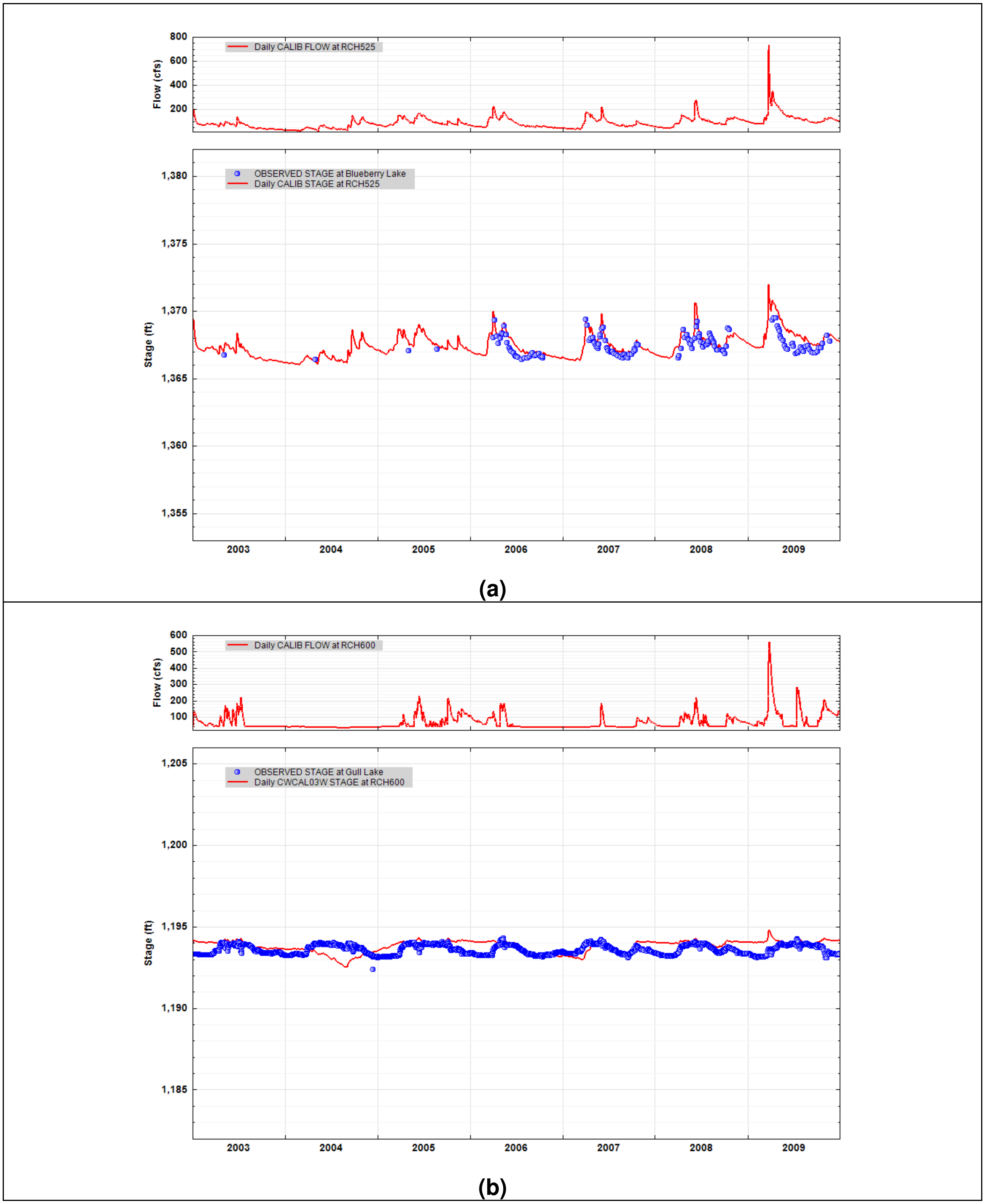


Figure 2.15 Comparison of observed and simulated lake levels at (a) Blueberry Lake and (b) Gull Lake in the Crow Wing River watershed

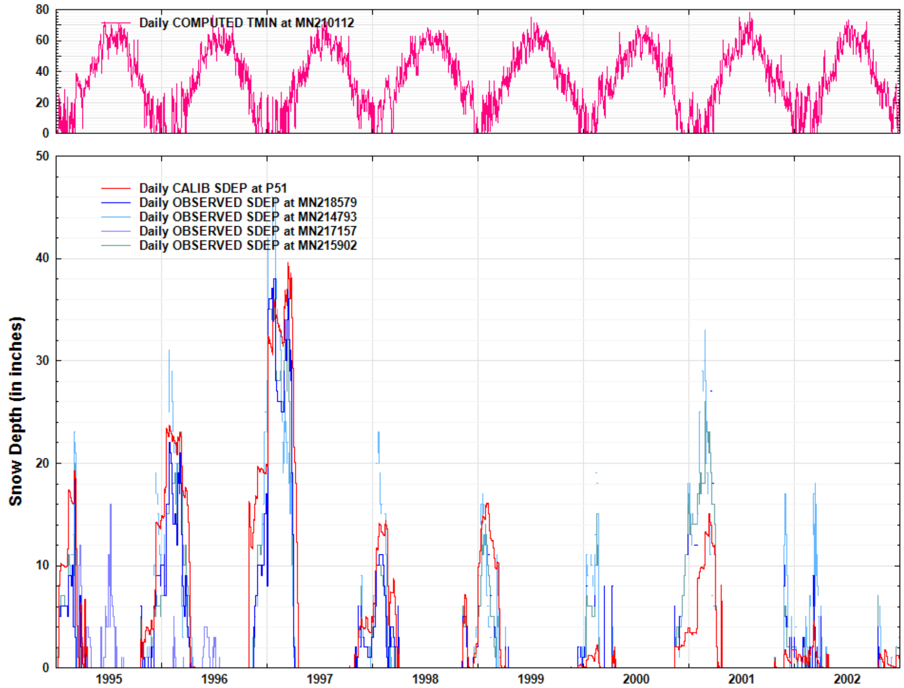
2.3 HYDROLOGY VALIDATION

The hydrology validation followed the hydrology calibration. Based on the data available, the validation period was established as 1995-2002, using the land use data from the year 2001 (AQUA TERRA Consultants, 2012). To conduct hydrology validation, the parameters obtained from hydrology calibration were used and similar statistics calculated. If the validation statistics did not satisfy the criteria, the calibration was revisited. As with the hydrologic calibration, the validation process started with Long Prairie watershed.

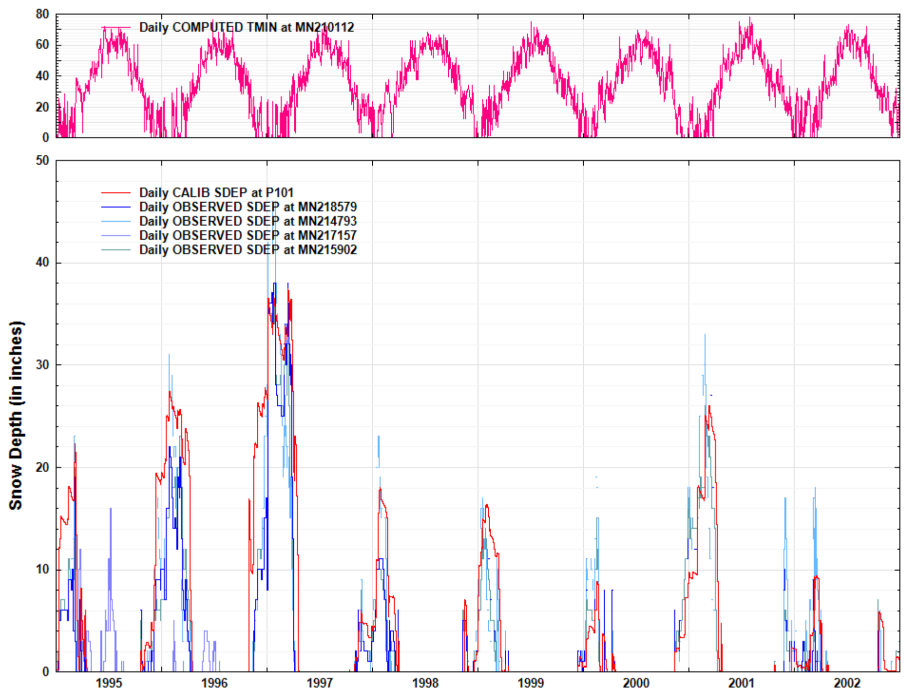
2.3.1 Long Prairie River Watershed

The first step in hydrologic validation was to compare snow depth and snow frequency. The sample graphs in Figure 2.16 and Figure 2.17. show that snow simulation was adequate.

The flow hydrograph and flow frequency curve (Figure 2.18) illustrate a reasonable streamflow simulation. Expert system statistics and errors (Table 2.29) were also calculated for the validation period. The simulation results satisfy all the criteria except the lowest 10% flows. It has been noted before that the observed winter flow was likely estimated rather than measured, which probably accounts for the high error in simulation of low flows and in winter volume. The daily and monthly statistics show that model performance is good to very good. At this stage the model was considered validated.

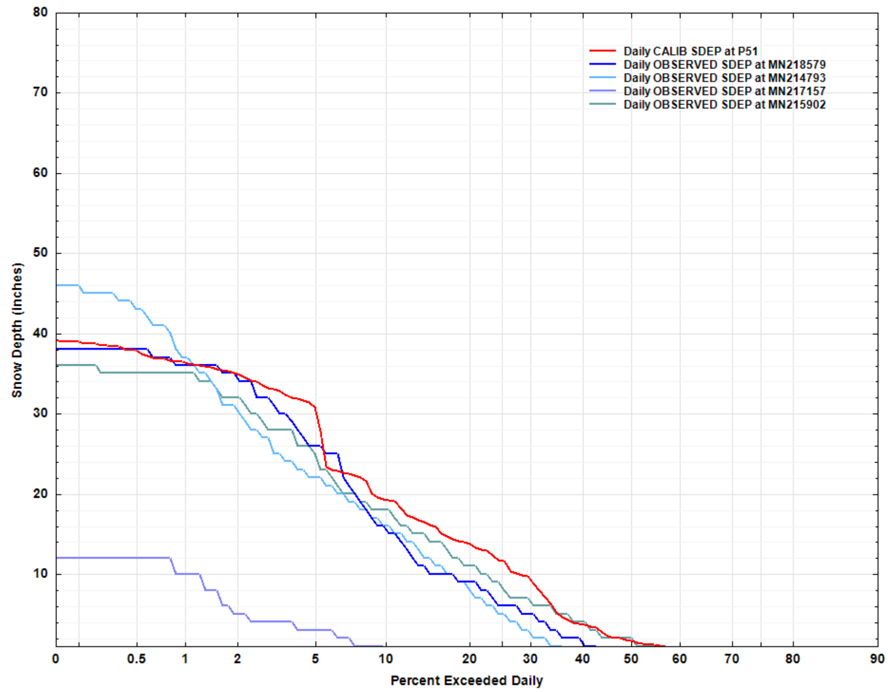


(a)

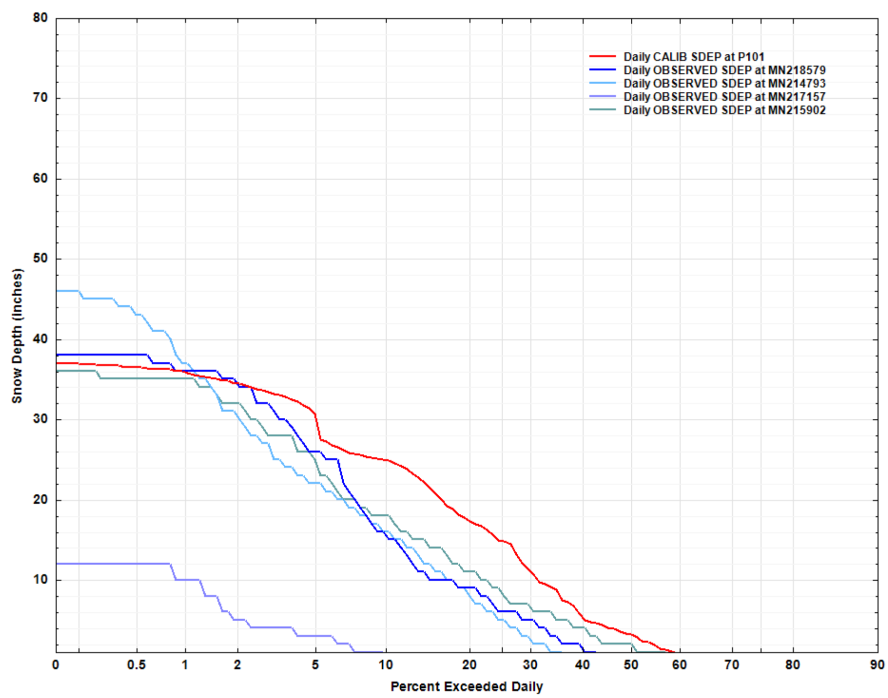


(b)

Figure 2.16 Snow Depth Simulation at (a) PERLND51, and (b) PERLND 101 (Forest land areas in two different segment of the Long Prairie watershed) for the validation period. Red curve shows the simulated data and observed data is shown in other colors.

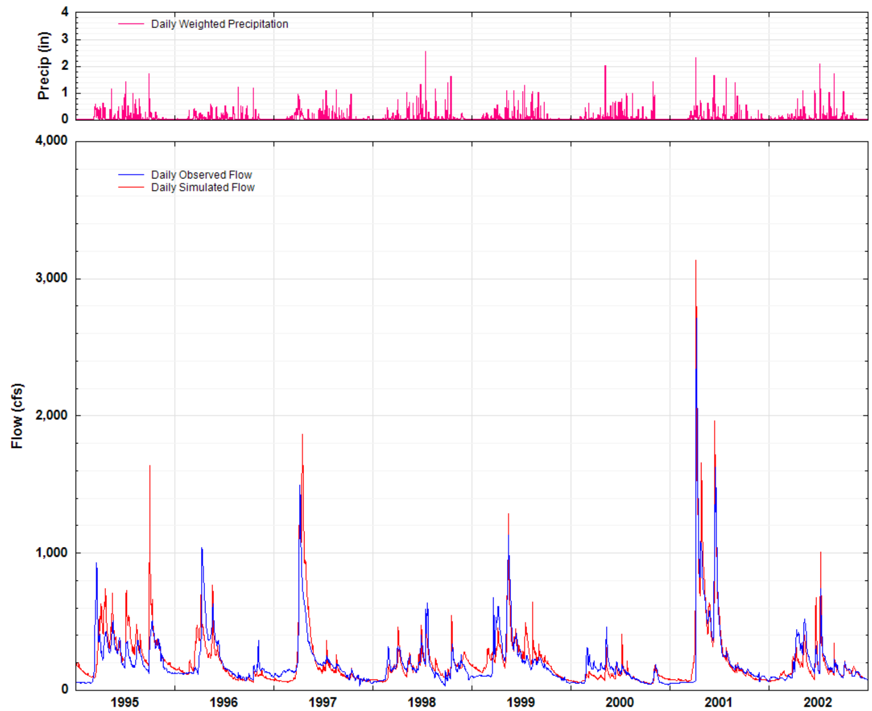


(a)

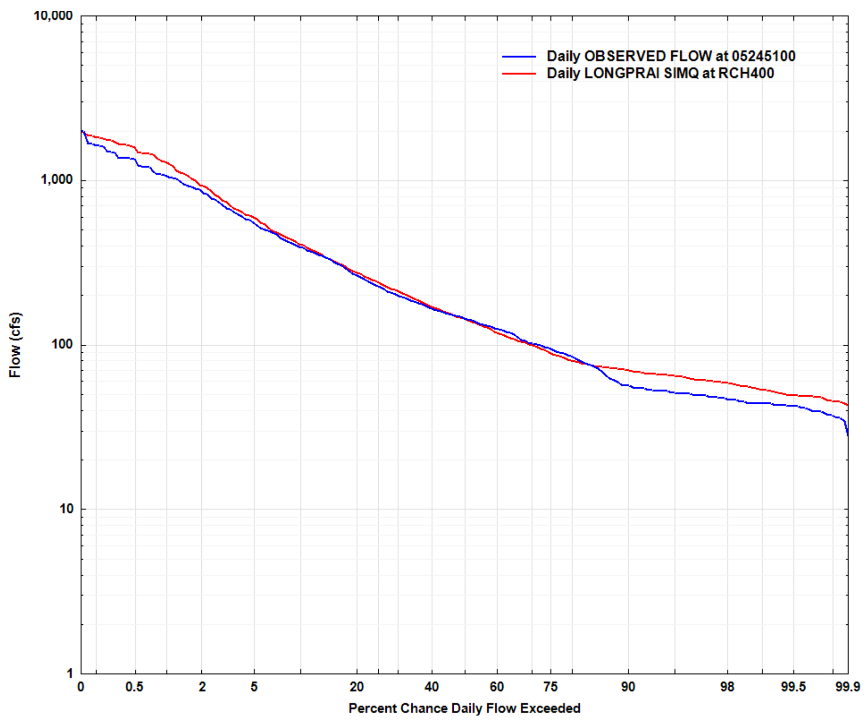


(b)

Figure 2.17 Comparison of snow depth frequency simulation for winter months (October to April) at (a) PERLND 51 and (b) PERLND 101 for the validation period. The red curve shows the simulated results and observed data is presented in other colors.



(a)



(b)

Figure 2.18 Comparison of simulated and observed (a) flow hydrograph, and (b) flow duration frequency curves at the Long Prairie River gage in Long Prairie River watershed for the validation period.

Table 2.29 Error Terms and Criteria for the Annual Average Flow Statistics at the Long Prairie gage in the Long Prairie watershed for the validation period

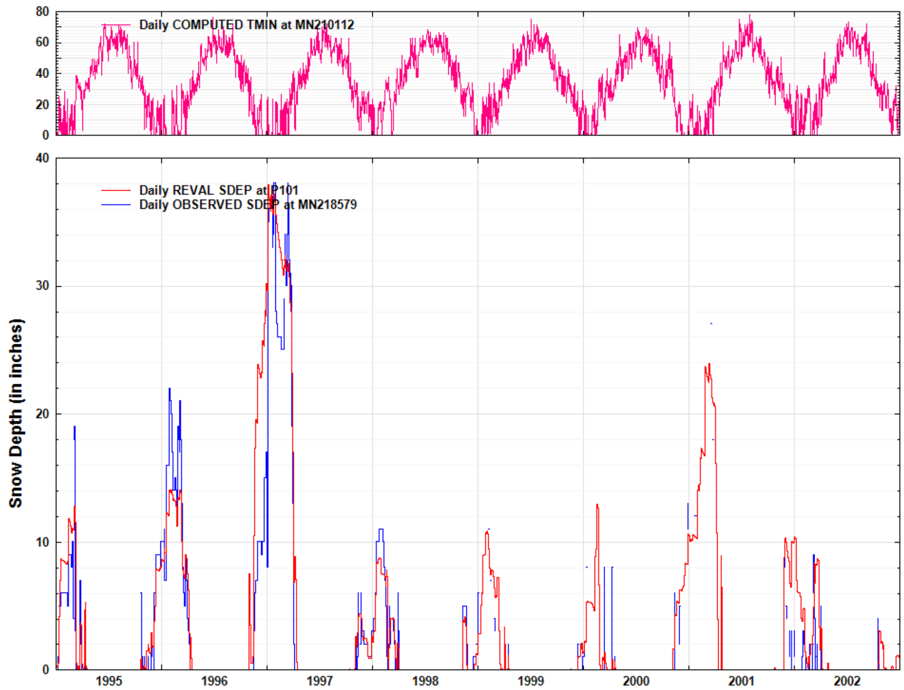
	Current	Criteria	Meets Criteria
Error in total volume (%)	4.6	10	OK
Error in 10% highest flows (%)	9.3	15	OK
Error in 25% highest flows (%)	6.8	10	OK
Error in 50% highest flows (%)	5.8	10	OK
Error in 50% lowest flows (%)	0.8	10	OK
Error in 25% lowest flows (%)	8.5	15	OK
Error in 10% lowest flows (%)	25.1	20	Fails
Error in low-flow recession	0.005	0.03	OK
Error in storm volumes (%)	-0.7	15	OK
Seasonal volume error (%)	-13.0	20	OK
Error in average storm peak (%)	9.4	15	OK
Summer volume error (%)	5.4	20	OK
Winter volume error (%)	18.4	15	Fails
Summer storm volume error (%)	2.6	15	OK

Table 2.30. Monthly and Daily Statistics of Flow Volume

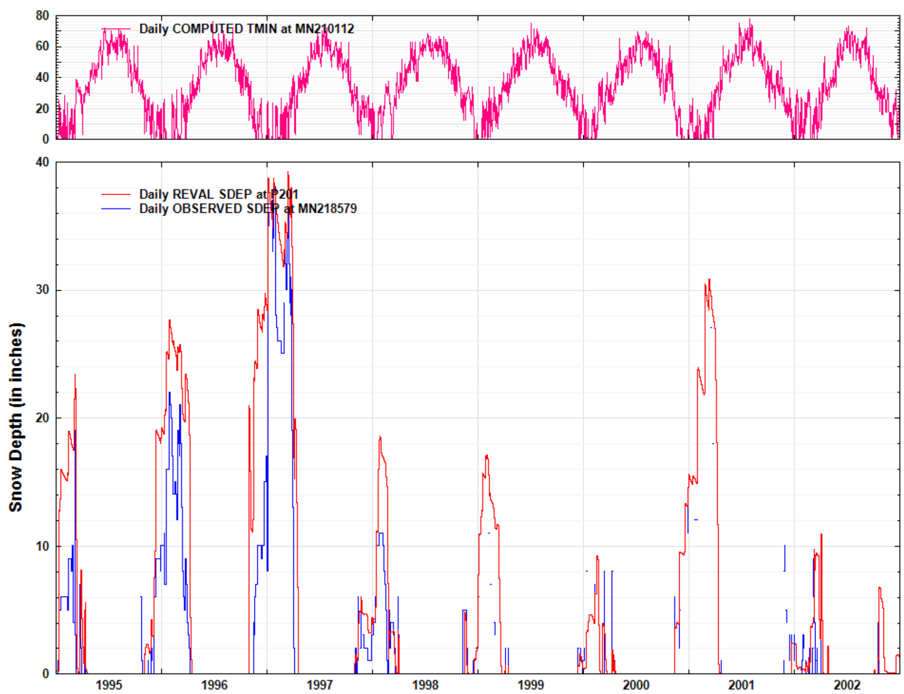
Statistics	Monthly	Daily
Correlation Coefficient	0.93	0.86
Coefficient of Determination	0.87	0.73
Mean Error (cfs)	9.3	9.4
Mean Absolute Error (cfs)	48.7	62.6
RMS Error	73.2	119.4
Model Fit Efficiency	0.82	0.66

2.3.2 Redeye River Watershed

The Redeye River watershed did not have any long term gage; therefore hydrology validation for was not conducted for this watershed. For the Redeye model, the simulated snow depth (e.g. Figure 2.19) and depth frequency (e.g. Figure 2.20) were compared for multiple land segments in the watershed. These graphical comparisons suggest that the model simulates reasonable snow depth.

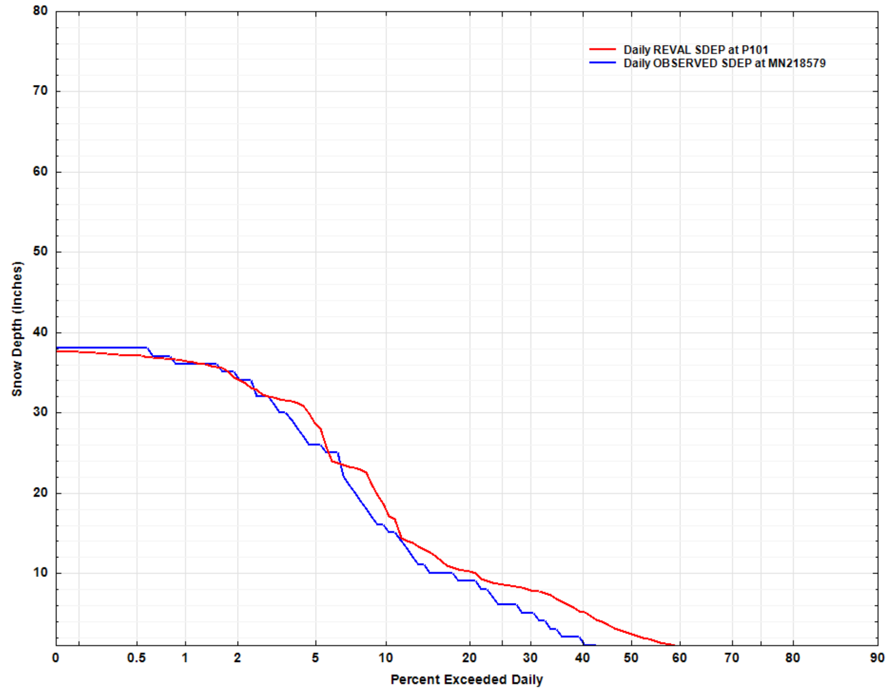


(a)

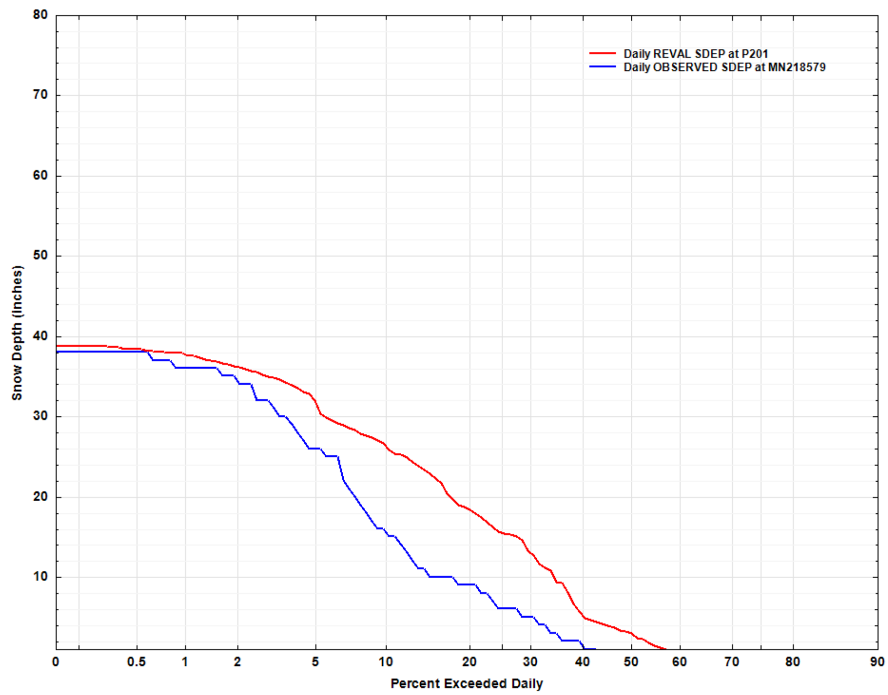


(b)

Figure 2.19 Snow Depth Simulation at (a) PERLND101, and (b) PERLND 201 (Forest land areas in two different segment of the Redeye River watershed) for the validation period. Red curve shows the simulated data and observed data is shown in other colors. The auxiliary graph shows the recorded minimum daily temperature.



(a)



(b)

Figure 2.20 Comparison of snow depth frequency simulation for winter months (October to April) at (a) PERLND 101 and (b) PERLND 201 in the Redeye River watershed for the validation period; simulated results are shown by the red curve and observed data is presented in other colors

2.3.3 Crow Wing River Watershed

Following the validation at the Long Prairie and Redeye River watersheds, the Crow Wing River watershed model was validated. As with the other models, validation started with snow depth simulation (e.g. Figure 2.21 and Figure 2.22). The simulated snow depth in the winters of 1996 and 1997 was greater than the observed snow depth. Higher simulated snow depth during this period also impacts the snow depth frequency curves, as shown in Figure 2.2. Clearly, a large difference in the simulation for one or two years can dramatically impact the agreement shown by the frequency curves. The snow depth simulation for all other years, however was satisfactory, therefore the model was accepted as satisfactory for snow depth simulation.

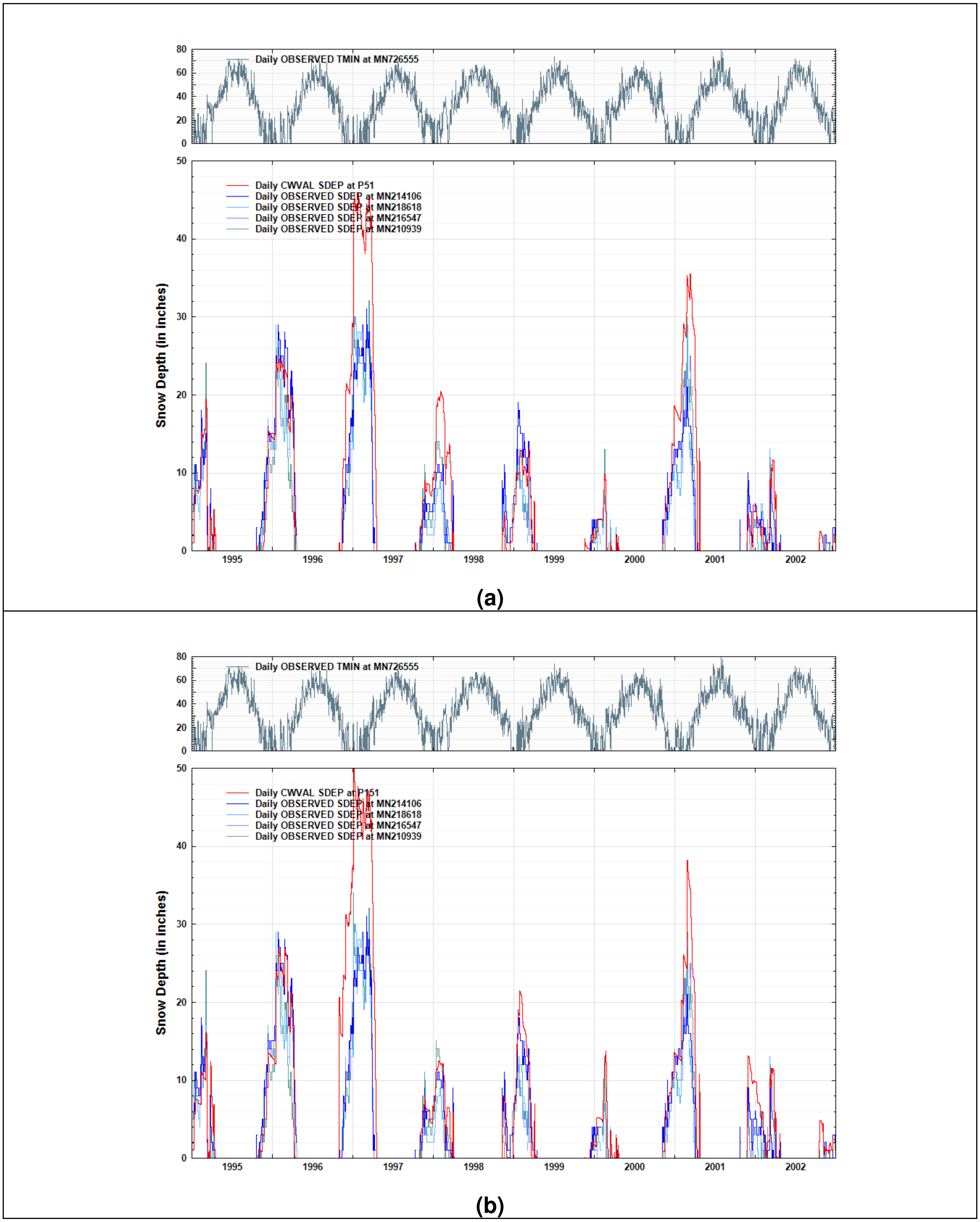


Figure 2.21 Snow Depth Simulation at (a) PERLND 51 and (b) PERLND 151 (Forest land areas in two different segments of the Crow Wing River watershed); simulated data is shown by the red curve and observed data is shown in other colors

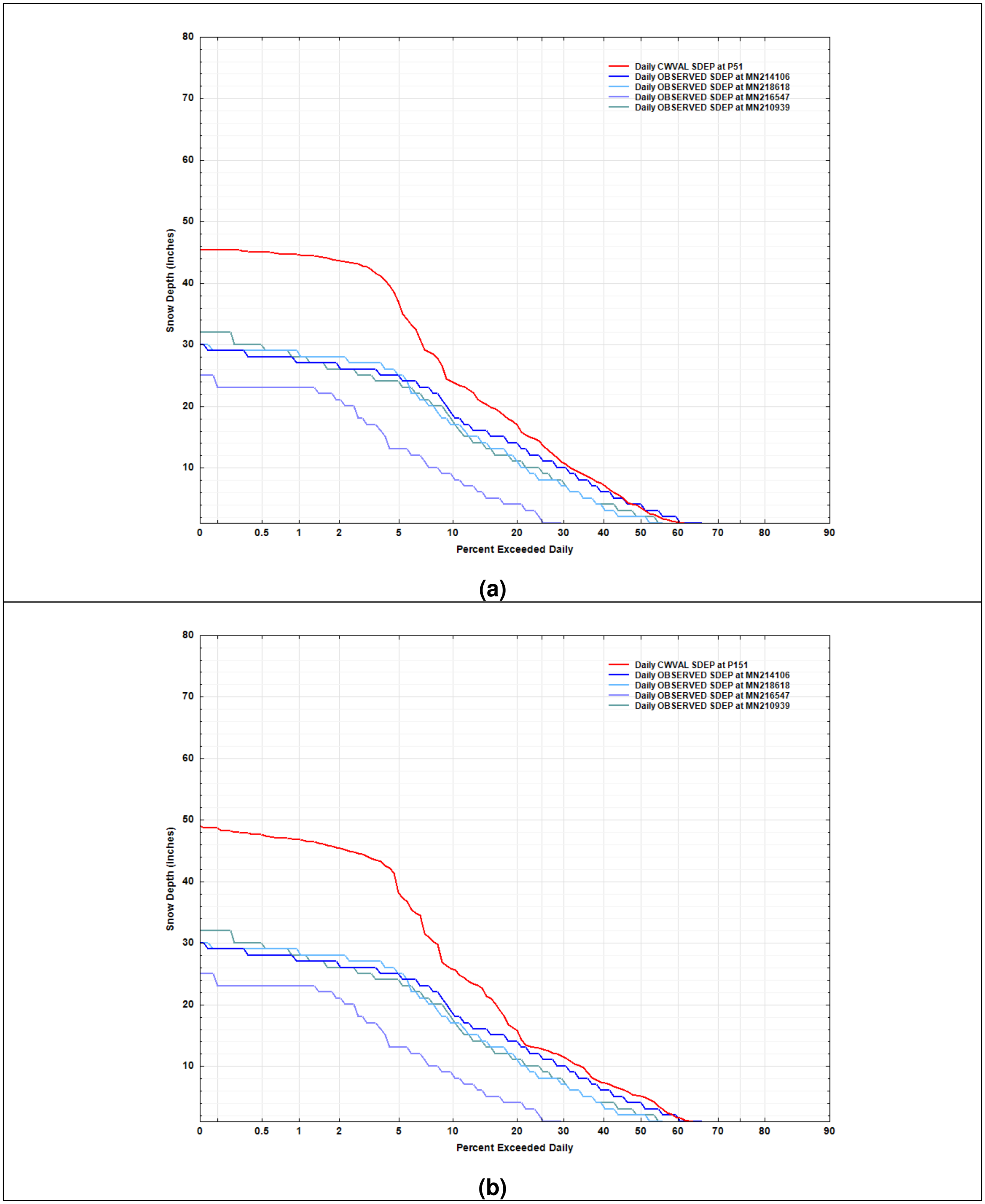
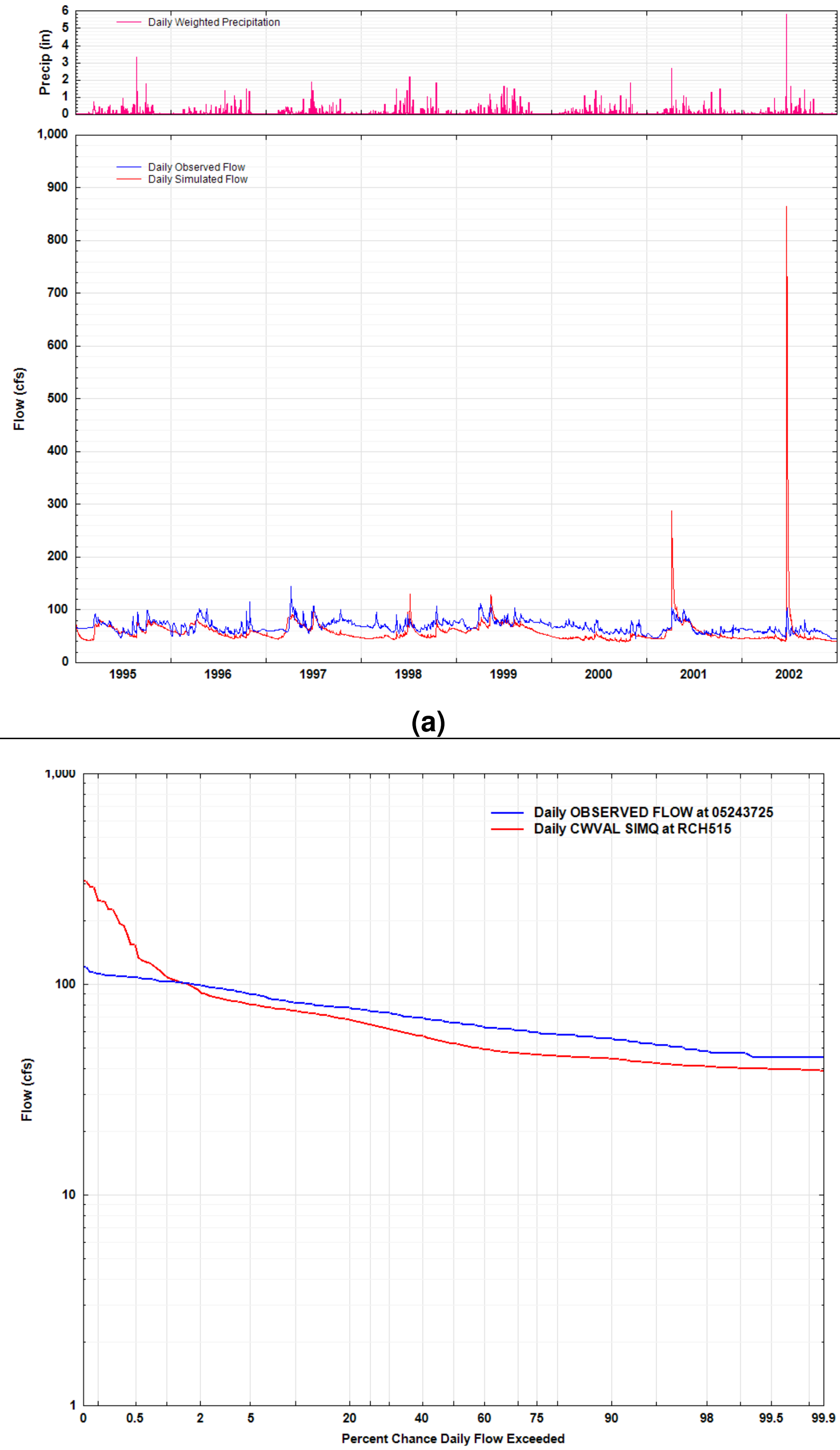


Figure 2.22 Comparison of snow depth frequency simulation for winter months (October to April) at (a) PERLND 51 and (b) PERLND 151 in the Crow Wing River watershed; simulated results are shown by the red curve and observed data is presented in other colors

Following the validation of snow depth simulation, streamflow validation was conducted. As in calibration, streamflow validation started with the Straight River Gage (Figure 2.23). The graphs suggest that the validation results at the Straight River gage were poor. In the year 2002, the simulated flow was 4-5 times greater than the flow observed at any time during the validation period. This was a result of about 6 inches of rainfall occurring in one day in the watershed contributing flow to the Straight River. It is difficult to determine if the rainfall during that time was incorrectly recorded or if there is an error in the observed flow. Also, there is about -14% error in the simulation of average flow volume (Table 2.31) for the validation period. The watershed draining to the Straight River gage received about the same rainfall (25.7 in during the validation period and 25.3 in during the calibration period), but the observed flow volume was about 25% greater (15.7 in during the validation period, and 12.7 in during the calibration period). These results indicate that there are significant errors in the observed rainfall and runoff data for the Straight River gage. As described later, these kinds of errors were not observed for the downstream gages; therefore this was considered to be a local error which led to the inability to validate the model at the Straight River gage.



(a)

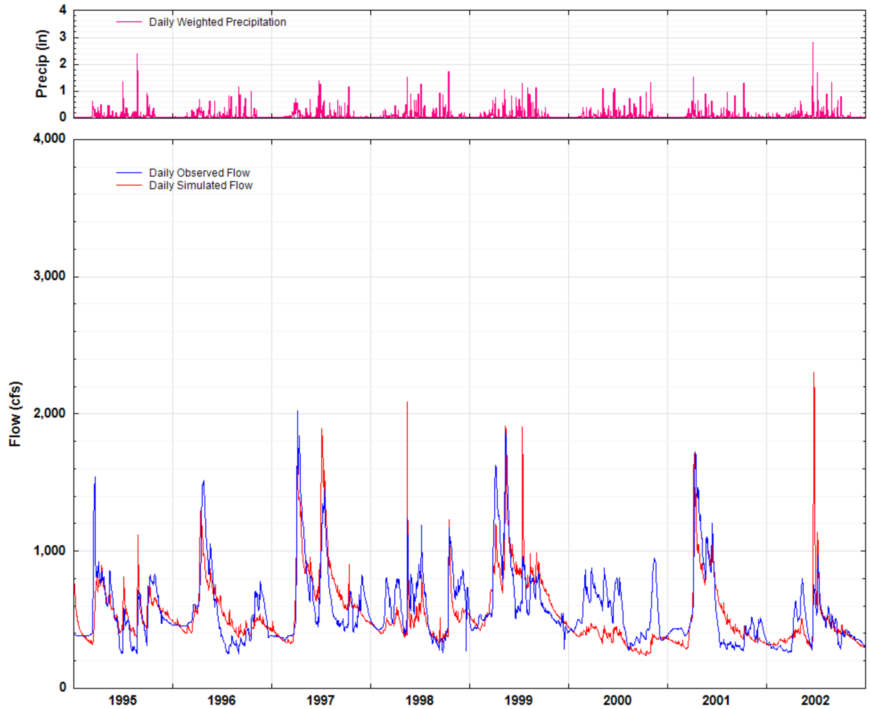
(b)

Figure 2.23 Comparison of simulated and observed (a) flow hydrograph and (b) flow duration frequency curves at the Straight River gage in Crow Wing River watershed for the validation period

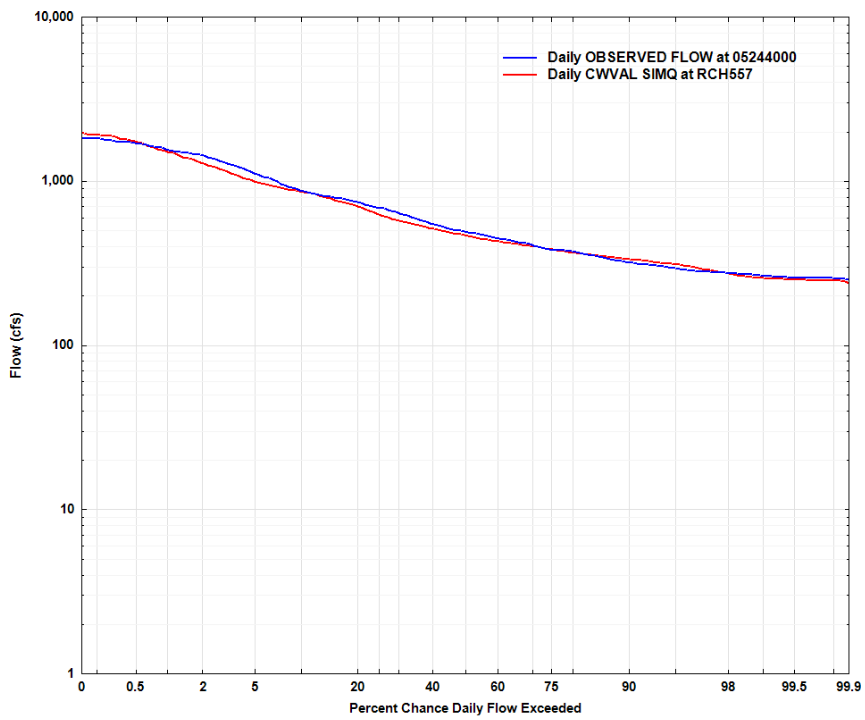
Table 2.31 Error Terms and Criteria for the Annual Average Flow Statistics at the Straight River gage in Crow Wing River Watershed for the validation period

	Current	Criteria	Meets Criteria
Error in total volume (%)	-14.5	10	Fails
Error in 10% highest flows (%)	4.5	15	OK
Error in 25% highest flows (%)	-4.0	10	OK
Error in 50% highest flows (%)	-9.9	10	OK
Error in 50% lowest flows (%)	-20.5	10	Fails
Error in 25% lowest flows (%)	-19.4	15	Fails
Error in 10% lowest flows (%)	-17.5	20	OK
Error in low-flow recession	0.004	0.03	OK
Error in storm volumes (%)	-1.7	15	OK
Seasonal volume error (%)	18.83	20	Fails
Error in average storm peak (%)	35.2	15	Fails
Summer volume error (%)	-2.9	20	OK
Winter volume error (%)	-21.7	15	Fails
Summer storm volume error (%)	20.4	15	Fails

The validation results at the Crow Wing River gage near Nimrod were promising and showed a good match between observed and simulated values (Figure 2.24). When observed closely, the simulated flow during the storm in June 2002 shows greater volume (by about 3 times) than the observed flow. The daily precipitation during this time was the greatest value recorded for the entire validation period. It is possible that the excess precipitation recorded at upstream rain gages caused this unusual increase in simulated flow volume. The error terms calculated for the Expert System Statistics (Table 2.32) show that all the errors are within acceptable limits. The model statistics (Table 2.33) also show that the validation results are fair. The overall model validation results for the Crow Wing River gage near Nimrod were considered acceptable, especially considering the very good agreement of the flow duration curves shown in Figure 2.23. The next step was validation at the Crow Wing River gage near Pillager.



(a)



(b)

Figure 2.24 Comparison of simulated and observed (a) flow hydrograph and (b) flow duration frequency curves at the Nimrod Gage on Crow Wing River in Crow Wing River watershed for the validation period

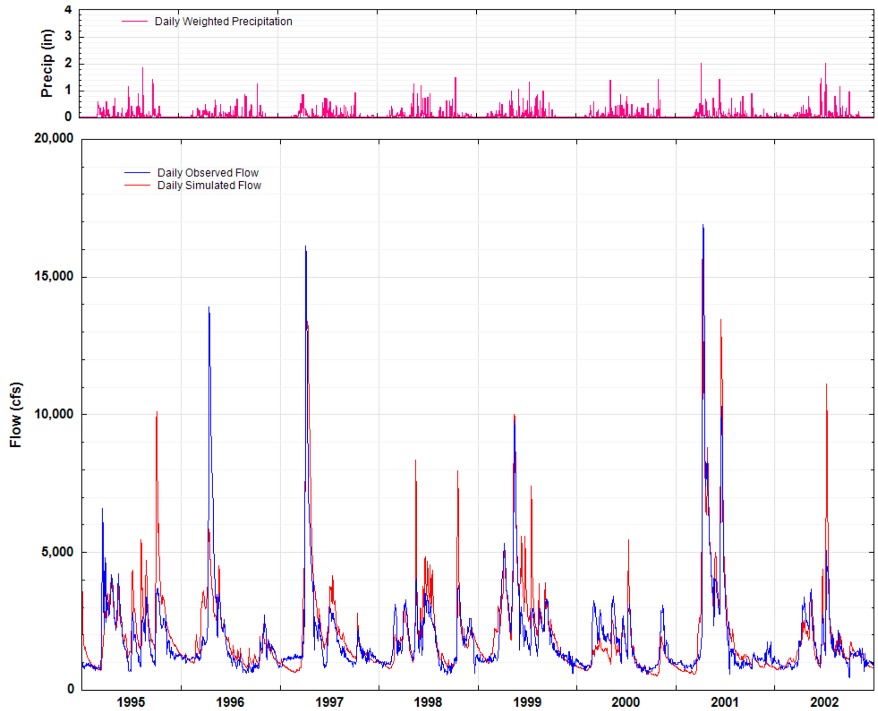
Table 2.32 Error Terms and Criteria for the Annual Average Flow Statistics at the Nimrod gage on Crow Wing River in Crow Wing River watershed for the validation period

	Current	Criteria	Meets Criteria
Error in total volume (%)	-4.6	10	OK
Error in 10% highest flows (%)	-6.4	15	OK
Error in 25% highest flows (%)	-5.3	10	OK
Error in 50% highest flows (%)	-6.2	10	OK
Error in 50% lowest flows (%)	-1.5	10	OK
Error in 25% lowest flows (%)	1.4	15	OK
Error in 10% lowest flows (%)	3.4	20	OK
Error in low-flow recession	0.003	0.03	OK
Error in storm volumes (%)	-13.8	15	OK
Seasonal volume error (%)	18.8	20	OK
Error in average storm peak (%)	0.8	15	OK
Summer volume error (%)	12.9	20	OK
Winter volume error (%)	-5.9	15	OK
Summer storm volume error (%)	7.8	15	OK

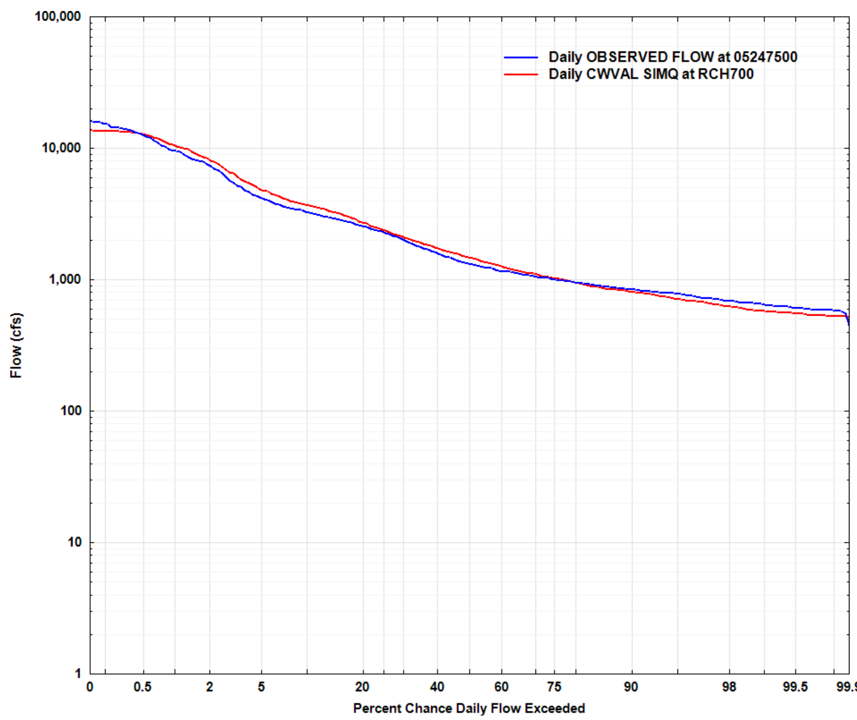
Table 2.33 Monthly, and daily Statistics of flow volume for the for the Nimrod gage on Crow Wing River in the Crow Wing River Watershed for the validation period

Statistics	Monthly	Daily
Correlation Coefficient	0.81	0.77
Coefficient of Determination	0.66	0.59
Mean Error (cfs)	-26.8	-26.4
Mean Absolute Error (cfs)	110.5	125.2
RMS Error	142.8	178.2
Model Fit Efficiency	0.63	0.55

The validation results at the Crow Wing River gage near Pillager show that the model simulated the streamflow well based on the flow duration comparison (Figure 2.25). The error criteria for the expert system are all within acceptable bounds (Table 2.34) except for flow volume in summers and storm volume in summers. The model performance statistics suggest that model performance was fair to good for the validation period. Although further rigorous calibration effort and cleanup of observed meteorological and flow data can be continued to improve the validation results, the model is quite acceptable at this stage and can be used as a sound basis for water quality simulation.



(a)



(b)

Figure 2.25 Comparison of simulated and observed (a) flow hydrograph and (b) flow duration frequency curves at the Pillager Gage on Crow Wing River in Crow Wing River watershed for the validation period

Table 2.34 Error Terms and Criteria for the Annual Average Flow Statistics at Crow Wing Gage near Pillager, MN for the validation period

	Current	Criteria	Meets Criteria
Error in total volume (%)	7.6	10	OK
Error in 10% highest flows (%)	10.5	15	OK
Error in 25% highest flows (%)	10.0	10	OK
Error in 50% highest flows (%)	9.4	10	OK
Error in 50% lowest flows (%)	2.62	10	OK
Error in 25% lowest flows (%)	-3.1	15	OK
Error in 10% lowest flows (%)	-6.8	20	OK
Error in low-flow recession	0.009	0.03	OK
Error in storm volumes (%)	1.4	15	OK
Seasonal volume error (%)	33.4	20	Fails
Error in average storm peak (%)	6.4	15	OK
Summer volume error (%)	29.4	20	Fails
Winter volume error (%)	-4.0	15	OK
Summer storm volume error (%)	30.3	15	Fails

Table 2.35 Monthly and Daily Statistics of flow volume at Crow Wing River gage near Pillager, MN for the validation period

Statistics	Monthly	Daily
Correlation Coefficient	0.92	0.85
Coefficient of Determination	0.84	0.73
Mean Error (cfs)	140.6	143.1
Mean Absolute Error (cfs)	414.3	515.9
RMS Error	615.3	948.1
Model Fit Efficiency	0.80	.67

SECTION 3.0
SEDIMENT CALIBRATION AND VALIDATION

3.1 SEDIMENT TARGETS

One of the objectives for the Crow Wing, Redeye, and Long Prairie Rivers watershed modeling project required defining the sources of sediment loads within the watersheds and conducting sediment calibration and validation tests. In order to define and quantify sediment targets, a literature review was performed.

A study of historical sediment fluxes conducted by Kelley and Nater, 2000, suggests that the sediment contribution in Minnesota River Basin increased by about 12 times in last 160 years which can mostly be attributed to modern cultivation of row crops and animals. A recent effort by Schottler et al. (2010) to apportion the sediment contributions using sediment fingerprinting suggests that non-field sources contribute the majority of the sediment load. They determined that non-field sources contribute 60-85% of the sediment erosion entering the Minnesota River. Non-field loads were greatest in the large and steeply incised Blue Earth-LeSueur watershed. Schotttler et al. (2013) also concluded that the rate of sediment erosion from non-field sources has accelerated in the last 100 years, and they attributed this increase in sediment loading to increase in erosive nature of rivers, which can be attributed to the change in landuse over last couple of centuries. The Minnesota River Turbidity TMDL study estimated that 35% of the sediment load originates from fields, 30% from gullies/ravines, and 35% from bank and bluff erosion (Tetra Tech, 2009).

While the Minnesota River Basin is located in the Western Corn Belt Plains Ecoregion, the Crow Wing Watersheds (focus of the present study) are mostly in the North Central Hardwood Forests Ecoregion, with their northern and eastern sections located in the Northern Lakes and Forests Ecoregion (Figure 3.1). These ecoregions are mostly forested and are less arable than the Western Corn Belt Plains where as much as 80% of the area is used for agriculture. The area under agriculture increases in the southern portion of North Central hardwood Forests. According to the Ecological Classification System of Minnesota, the Crow Wing, Long Prairie, and Redeye River watersheds are primarily in the Pine Moraines & Outwash Plains and Hardwood Hills subsections (Figure 3.2). The Sauk River, Crow River and South Fork Crow River are primarily in Minnesota River Prairie, Hardwood Hills and Big Woods.

In the Sauk River Watershed, 55% of sediment loading was attributed to stream bed, bank, and gully erosion (Reisinger and Love, 2012). In the South Fork River watershed, 45% of sediment loading was attributed to stream bed, bank, and gully sources, and in the North Crow River watershed, 55% of sediment loading was attributed to stream bed, bank, and gully sources.

The rapid watershed assessment report for Long Prairie (USDA, 2010a) suggests that gully erosion along with sheet and rill erosion are responsible for sediment loading in this watershed. However, in the watershed tour conducted in 2011, we did not see any areas that showed significant gully erosion. The MPCA staff also confirmed that gully erosion in the Long Prairie watershed may not be a significant issue requiring explicit modeling. The rapid watershed assessment report for Crow Wing (USDA, 2010b) and Redeye River (USDA, 2010) watersheds suggests that soil erosion due to wind, water, and woodland management are of major concern. For the Crow Wing, Long Prairie, and Redeye River watersheds, the contribution of sediment load from non-field sources should be less than the Southern watersheds, as these watersheds are mostly forested, and the river valleys are not incised.

During a phone conversation with Mr. Chuck Regan from MPCA (April 19, 2013) regarding the sediment source contribution in the Crow Wing watersheds, it was concluded that about 80% of sediment load in these watersheds could be attributed to field sources and the remaining 20% could be attributed to scour processes in the stream. These watersheds are not expected to have any gullies and bluffs; therefore these sources were not included in the model as contributors to total sediment load.

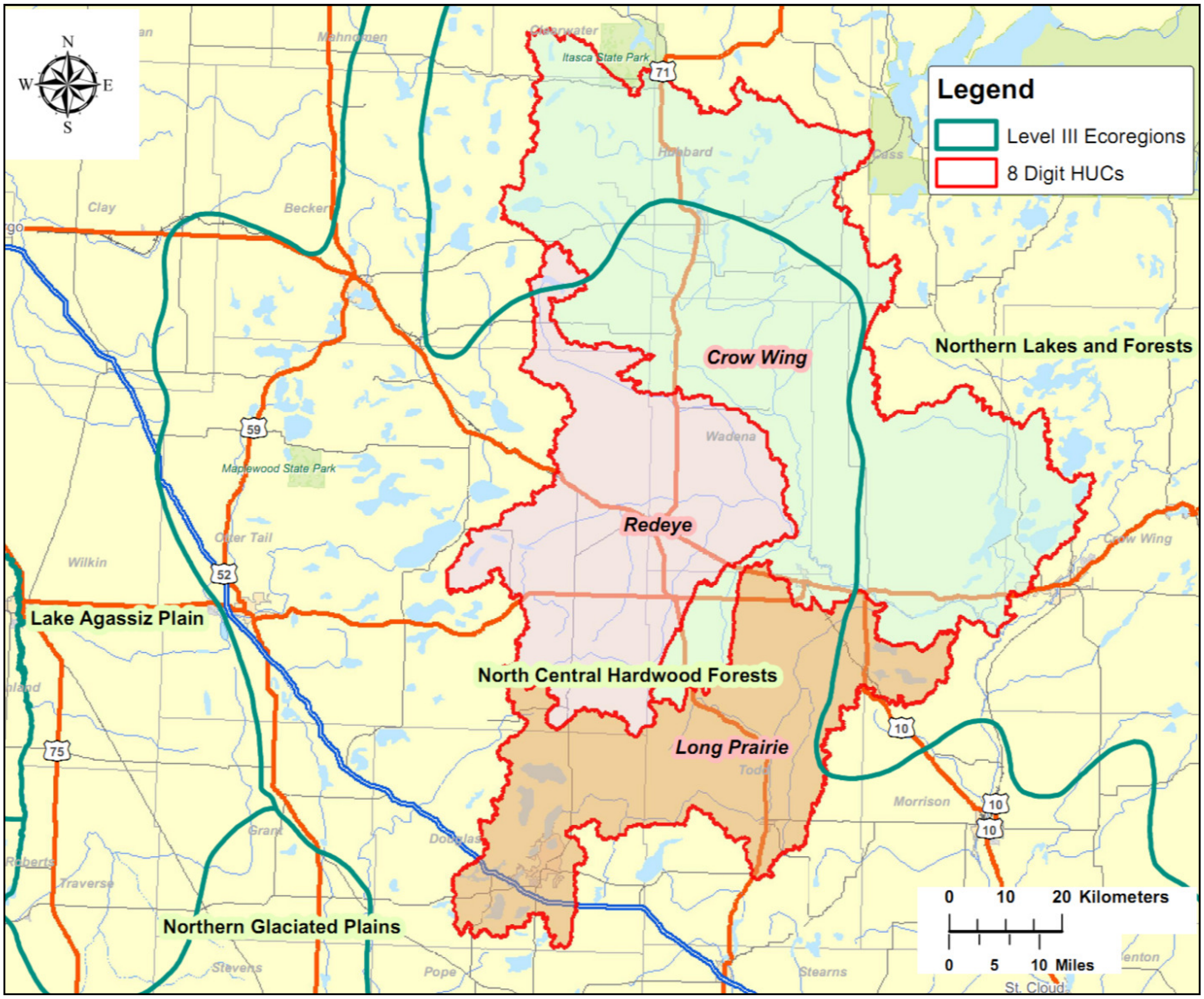


Figure 3.1 Location of Crow Wing, Redeye, and Long Prairie Watersheds and Level III Ecoregions

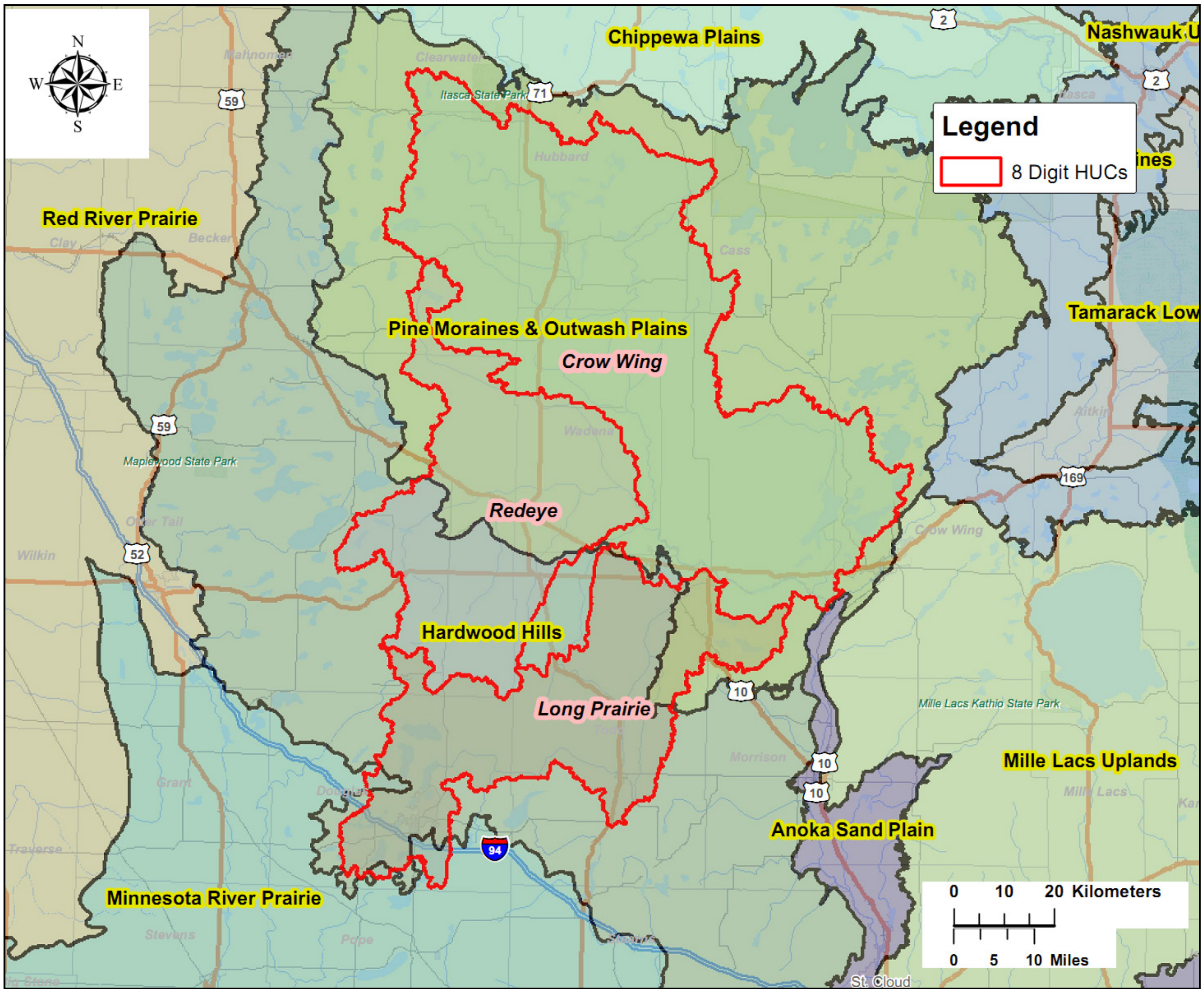


Figure 3.2 Location of Crow Wing, Redeye, and Long Prairie Watersheds and Ecological Subsections of Minnesota

With regards to sediment loading from field sources, the calibrated sediment loading rates from previous studies in the Crow Wing and the Minnesota River watersheds were reviewed and tabulated (Table 3.1). The loading rates from the Crow Wing watershed study were primarily used as the target loading rates for corresponding land uses in the Crow Wing, Redeye and Long Prairie watersheds. In the 1977 Basic Statistics National Resources inventory (USDA 1982), the annual rate of sheet and rill erosion for cropland was 2.5 tons per acre for cropland, 0.5 tons per acre for pasture and 0.5 tons per acre for forest.

Sediment transport through the tile drainage system is expected to be very small in these watersheds as about 2.5% and 2% of the Long Prairie and Redeye River watersheds respectively are under the Cultivated Crops -Drained category (AQUA TERRA Consultants, 2011).

Table 3.1 Calibrated sediment loading from different Watersheds in t/ac-yr (USEPA, 2005 and Tetra Tech, 2009)

	Conservation Tillage	Conventional Tillage	Manured Cropland	Forest	High Till Cropland	Low Till Cropland	Grass / Pasture	Urban	Impervious Area
Crow Wing Watershed				0.012	0.042	0.019	0.007	0.013	0.148
Blue Earth River	0.330	0.396	0.166	0.076			0.137	0.235	
Chippewa	0.055	0.077	0.010	0.007			0.006	0.177	
Cottonwood	0.125	0.192	0.027	0.027			0.032	0.198	
Hawk	0.055	0.083	0.008	0.025			0.033	0.061	
Le Sueur	0.347	0.389	0.204	0.156			0.165	0.357	
Lower MN	0.067	0.146	0.052	0.032			0.034	0.201	
Middle MN	0.041	0.121	0.019	0.025			0.022	0.266	
Redwood	0.086	0.092	0.031	0.039			0.059	0.161	
Watonwan	0.066	0.126	0.009	0.032			0.034	0.215	
Yellow Medicine	0.093	0.101	0.027	0.040			0.068	0.094	

3.2 SEDIMENT CALIBRATION

The sediment calibration and validation periods were same as those for hydrologic calibration (1/1/2003 - 12/31/2009), and validation (1/1/1995 - 12/31/2002). The sediment calibration process started with calculating the KRER (detachment coefficient dependent on soil properties) parameter for all of the PERLNDs. The KRER is similar to the K Factor in the Universal Soil Loss Equation, which is available in the Soils Data Map provided by NRCS. As recommended in the Minnesota River Turbidity TMDL report (Tetra Tech, 2009), the JRER (detachment exponent dependent on soil properties) was set to 1.81. The remaining sediment parameters were adapted from the previous Crow Wing Parameter study (AQUA TERRA Consultants, 2005).

The sediment parameters KSER (coefficient for transport of detached sediment), AFFIX (the fraction by which detached sediment storage decreases each day as a result of soil compaction), and NVSI (the rate at which sediment enters detached storage from the atmosphere) were adjusted to match the overall sediment loading rates from different land uses to the target loading rates compiled from studies of nearby areas. The sediment loading rates for the three watersheds are shown in Table 3.2 along with the target rates. The overall sediment loading rates from all land uses are within the ranges that were obtained by previous studies in the region. The sediment loading rates in the Crow Wing River watershed were lower than the rates in the Long Prairie and Redeye River watersheds. The primary reason for this difference was the lower surface runoff volume in Crow Wing River watershed (Section 2.2.3).

Table 3.2 Sediment loading rates in t/ac from different land uses and the target loading rates for the calibration period

	Forest - AB	Forest - CD	Wetlands	Grassland - AB	Grassland - CD	Pasture - AB	Pasture - CD	Cropland-AB	Cropland-CD	Cropland-Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity
Target Rate (min)	0.007			0.006				0.042			0.013		
Target Rate (max)	0.156			0.165				0.396			0.357		
Met Segment	**Long Prairie Watershed**												
50	0.031	0.021	0	0.132	0.073	0.131	0.092	0.195	0.210	0.037	0.221	0.210	0.205
100	0.001	0.001	0	0.031	0.037	0.026	0.038	0.004	0.020	0.001	0.091	0.090	0.079
150	0.008	0.013	0	0.096	0.123	0.084	0.117	0.068	0.167	0.012	0.177	0.183	0.187
200	0.002	0.002	0	0.056	0.092	0.046	0.092	0.008	0.055	0.002	0.120	0.119	0.113
250	0.006	0.010	0	0.093	0.125	0.092	0.128	0.095	0.203	0.021	0.142	0.133	0.114
300	0.001	0.003	0	0.072	0.123	0.053	0.126	0.008	0.056	0.002	0.180	0.196	0.152
350	0.056	0.046	0	0.135	0.101	0.131	0.112	0.240	0.221	0.096	0.253	0.239	0.227
400	0.027	0.016	0	0.117	0.092	0.116	0.112	0.177	0.256	0.039	0.201	0.207	0.207
450	0.012	0.010	0	0.036	0.049	0.032	0.044	0.047	0.044	0.019	0.083	0.083	0.083
500	0.001	0.001	0	0.072	0.085	0.050	0.113	0.006	0.049	0.002	0.177	0.174	0.129
550	0.030	0.020	0	0.085	0.078	0.080	0.071	0.218	0.128	0.080	0.161	0.150	0.195
Weighted Average	**0.014**	**0.006**	**0**	**0.080**	**0.093**	**0.075**	**0.105**	**0.083**	**0.097**	**0.016**	**0.170**	**0.194**	**0.196**
Minimum	**0.001**	**0.001**	**0**	**0.031**	**0.037**	**0.026**	**0.038**	**0.004**	**0.020**	**0.001**	**0.083**	**0.083**	**0.079**
Maximum	**0.056**	**0.046**	**0**	**0.135**	**0.125**	**0.131**	**0.128**	**0.240**	**0.256**	**0.096**	**0.253**	**0.239**	**0.227**
Met Segment	**Redeye Watershed**												
100	0.001	0.002	0	0.039	0.069	0.052	0.077	0.01	0.04	0.004	0.223	0.201	
200	0.013	0.011	0	0.052	0.043	0.045	0.054	0.056	0.046	0.029	0.137	0.118	0.086
300	0.013	0.011	0	0.111	0.086	0.11	0.097	0.04	0.063	0.017	0.21	0.205	0.196
400	0.003	0.005	0	0.049	0.074	0.042	0.076	0.009	0.037	0.005	0.164	0.15	0.173
500	0.002	0.003	0	0.051	0.049	0.035	0.053	0.017	0.087	0.01	0.149	0.147	0.147
600	0.004	0.007	0	0.022	0.036	0.022	0.038	0.036	0.047	0.024	0.1	0.095	0.086
700	0.001	0.004	0	0.042	0.066	0.042	0.085	0.028	0.236	0.025	0.151	0.155	0.143
800	0.002	0.003	0	0.066	0.093	0.044	0.098	0.007	0.084	0.004	0.22	0.194	0.19
Weighted Average	**0.006**	**0.005**	**0**	**0.05**	**0.052**	**0.043**	**0.060**	**0.034**	**0.090**	**0.018**	**0.145**	**0.126**	**0.102**
Minimum	**0.001**	**0.002**	**0**	**0.022**	**0.036**	**0.022**	**0.038**	**0.007**	**0.037**	**0.004**	**0.100**	**0.095**	**0.086**
Maximum	**0.013**	**0.011**	**0**	**0.111**	**0.093**	**0.110**	**0.098**	**0.056**	**0.236**	**0.029**	**0.223**	**0.205**	**0.196**

	Forest - AB	Forest - CD	Wetlands	Grassland - AB	Grassland - CD	Pasture - AB	Pasture - CD	Cropland-AB	Cropland-CD	Cropland-Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity
Target Rate (min)	0.007			0.006				0.042			0.013		
Target Rate (max)	0.156			0.165				0.396			0.357		
Met Segment	**Crow Wing Watershed**												
50	0.000	0.000	0	0.041	0.037	0.018	0.038	0.002	0.007	0.001	0.056	0.054	0.058
100	0.000	0.000	0	0.048	0.074	0.013	0.057	0.005	0.028	0.004	0.086	0.088	0.093
150	0.000	0.001	0	0.047	0.077	0.016	0.049	0.005	0.029	0.004	0.115	0.099	0.075
200	0.001	0.002	0	0.047	0.082	0.012	0.049	0.007	0.040	0.005	0.110	0.107	0.092
250	0.000	0.001	0	0.049	0.067	0.033	0.042	0.026	0.066	0.012	0.088	0.094	0.060
300	0.001	0.003	0	0.096	0.113	0.057	0.095	0.057	0.099	0.007	0.142	0.142	0.137
350	0.002	0.003	0	0.099	0.162	0.029	0.092	0.012	0.073	0.011	0.163	0.137	0.082
400	0.001	0.002	0	0.022	0.077	0.010	0.025	0.005	0.025	0.002	0.069	0.060	0.047
450	0.000	0.000	0	0.030	0.060	0.010	0.029	0.004	0.020	0.001	0.062	0.062	0.045
500	0.000	0.000	0	0.017	0.098	0.005	0.039	0.003	0.026	0.004	0.066	0.023	
550	0.001	0.002	0	0.096	0.138	0.025	0.082	0.008	0.038	0.006	0.164	0.165	0.169
600	0.000	0.000	0	0.044	0.068	0.021	0.047	0.019	0.056	0.007	0.115	0.092	0.080
650	0.000	0.000	0	0.022	0.049	0.002	0.011	0.001	0.003	0.000	0.049	0.045	0.013
700	0.000	0.001	0	0.051	0.081	0.027	0.054	0.024	0.054	0.007	0.116	0.108	0.100
750	0.000	0.001	0	0.077	0.156	0.046	0.069	0.027	0.068	0.008	0.154	0.155	0.109
Weighted Average	**0.001**	**0.001**	**0**	**0.049**	**0.086**	**0.020**	**0.058**	**0.009**	**0.037**	**0.003**	**0.095**	**0.086**	**0.065**
Minimum	**0.000**	**0.000**	**0**	**0.017**	**0.037**	**0.002**	**0.011**	**0.001**	**0.003**	**0.000**	**0.049**	**0.023**	**0.013**
Maximum	**0.002**	**0.003**	**0**	**0.099**	**0.162**	**0.057**	**0.095**	**0.057**	**0.099**	**0.012**	**0.164**	**0.165**	**0.169**

Once the sediment loading rates were calibrated, the instream transport of sediment, which is affected by stream hydraulics, was calibrated. The eroded sediment from land surface is assumed to be made of 55% silt, 40% clay, and 5% sand. This fractionation is the same as that used in the previous Crow Wing Study (AQUA TERRA Consultants, 2005). In HSPF, the transport of sand is commonly calculated as a power function of average velocity, whereas the transport of silt and clay depends upon the shear stress values calculated in the HYDR module, and the input critical shear stress parameter values for deposition and scour. At every time step, the scour or deposition of sand is calculated based on transport capacity of flow, and the scour and deposition of silt and clay is calculated based on the relative magnitudes of the calculated shear stress compared to the input critical (threshold) shear stress parameters and erodibility rate.

The critical shear stresses of each reach are different for scour and deposition, as each reach has its own FTABLE that affects the hydraulics and therefore shear stress. To calculate critical shear stress for sediment and deposition for each reach for silt and clay, hourly shear stress values for each reach were output and different percentiles were calculated (99, 95, 90, 80, 70, 30, 20, 10, 5, and 1). Reasonable starting values for critical shear stress were chosen based on graphical analysis (Donigian and Love, 2007) of a few reaches. For each reach, 20th and 10th percentiles of hourly shear stress values were used as critical shear stress values for deposition of silt and clay respectively, and 95th and 90th percentiles were used as critical shear stress values for scour of silt and clay respectively.

The shear stress on a lake bed is calculated differently than the shear stress in streams; these values generally are very low and closer to zero. We do not expect any scouring to happen in the lake beds, so we assigned a critical shear stress value of 0.001 lb/ft^2 for all the lakes for silt and clay for deposition and scour.

Following the initial parameter assignment, the annual sediment scour and deposition as well as bed depth for each reach was output and analyzed. The bed depths are generally expected to stay stable for the period of simulation with no dramatic changes unless supported by a physical observation of aggrading or degrading stream reaches. The critical shear stresses for scour and deposition were adjusted until all of the reaches exhibited relatively stable behavior. Bed depth outputs of lakes increased slightly as expected due to deposition.

Based on the research described in Section 3.1, it was postulated that in the three Crow Wing watersheds, about 80% of sediment erosion is contributed by land surfaces and 20% is contributed by streams. We calculated the total sediment erosion for each stream and calculated the percent contribution from land surfaces, point sources, and scour from the streams (Table 3.3). In these calculations, the watersheds draining to the lakes were ignored, as lakes are mostly sediment traps where no scour of bed sediment occurs.

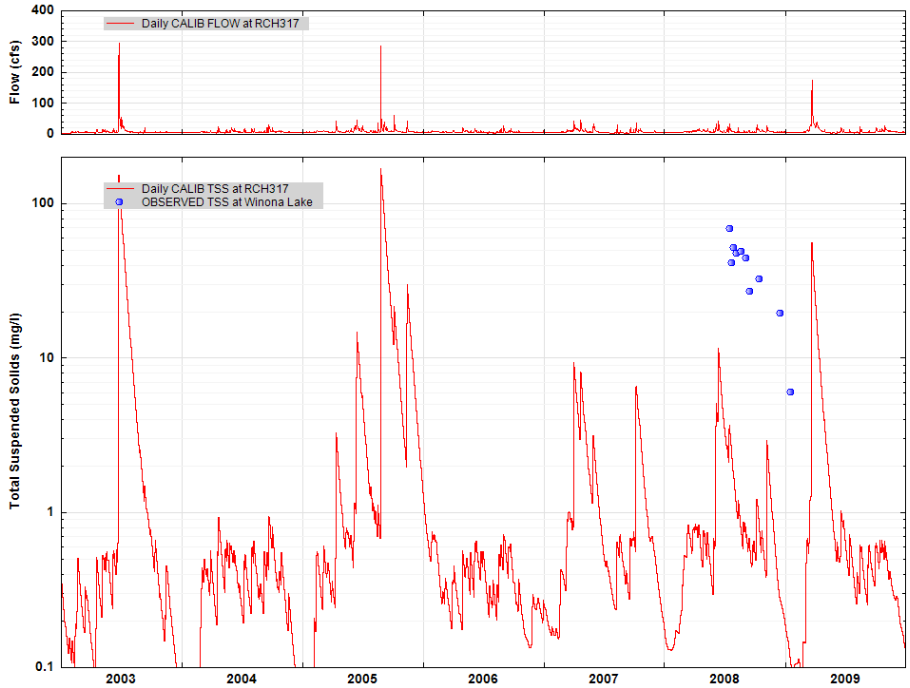
Table 3.3 Sediment erosion from land surface and streams in the watersheds for the calibration period

	Long Prairie River Watershed	Redeye River Watershed	Crow Wing River Watershed
Total sediment erosion in the watershed from the land surface (t/yr)	34,682.6	19,027.6	17,675.7
Total sediment erosion from land surfaces in watersheds with no lakes (t/yr)	20,834.4	17,363.7	13,376.0
Total Point Source Contribution of sediments (t/yr)	43.7	-	25.2
Total Point source contribution of sediments in watersheds with no lakes (t/yr)	24.3	-	25.2

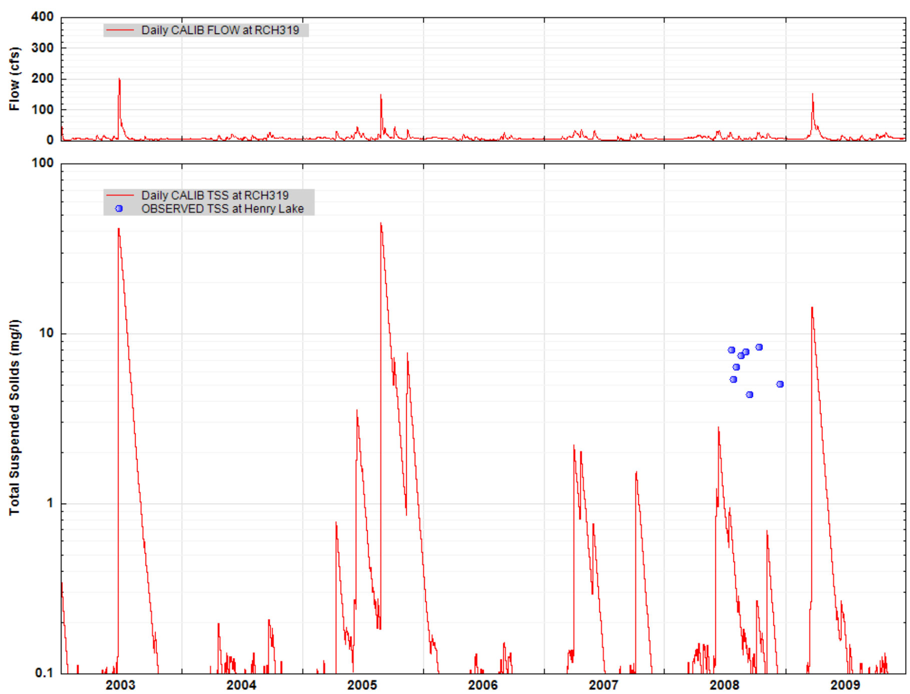
	Long Prairie River Watershed	Redeye River Watershed	Crow Wing River Watershed
Total Deposition (+) / Scour (-) of sediment in all the lakes and streams (t/yr)	10,568.8	-3,011.80	4,000.0
Total Deposition (+) / Scour (-) in streams only (t/yr)	-3,971.53	-5,638.90	-3,652.30
Fraction of sediment from land surfaces in watersheds with no lakes	84%	75%	78%
Fraction of sediment erosion from streams in watersheds with no lakes.	16%	25%	22%

The fraction of sediment loading from land surfaces and streams is close to the fractions that were postulated. Following this step, the simulated total suspended sediment (TSS) concentrations and observed TSS data were plotted for 46 locations in the three watersheds. Parameters affecting sediment loading from land surface and sediment transport were adjusted to obtain a good fit between observed and simulated data. The calibration process required going back to previous steps and readjusting parameters to match the outputs with the target sediment loading and sediment apportionment rates.

A selection of graphs is presented here for illustration (Figure 3.3 to Figure 3.6); the complete set of is provided in APPENDIX E. Because the observed and simulated TSS concentrations are in the same general range, the graphs illustrate that sediment simulation by the model is acceptable. It must be noted that the simulated and observed TSS concentrations are not expected to match exactly, as the observed data is collected at different depths and at different parts of the lake (generally near the outlet), whereas HSPF assumes the whole lake to be a well-mixed reservoir.

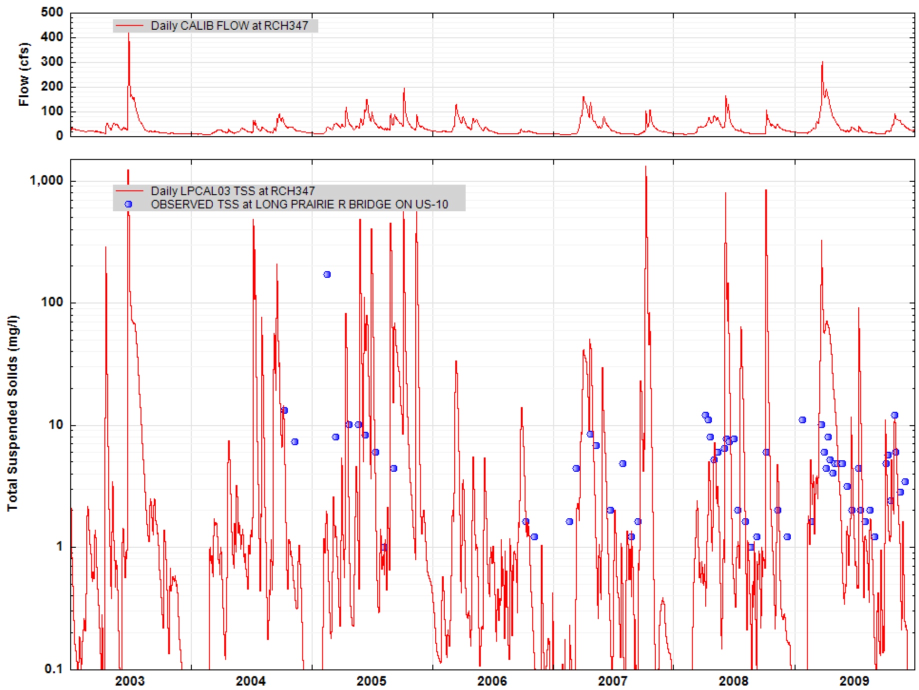


(a)

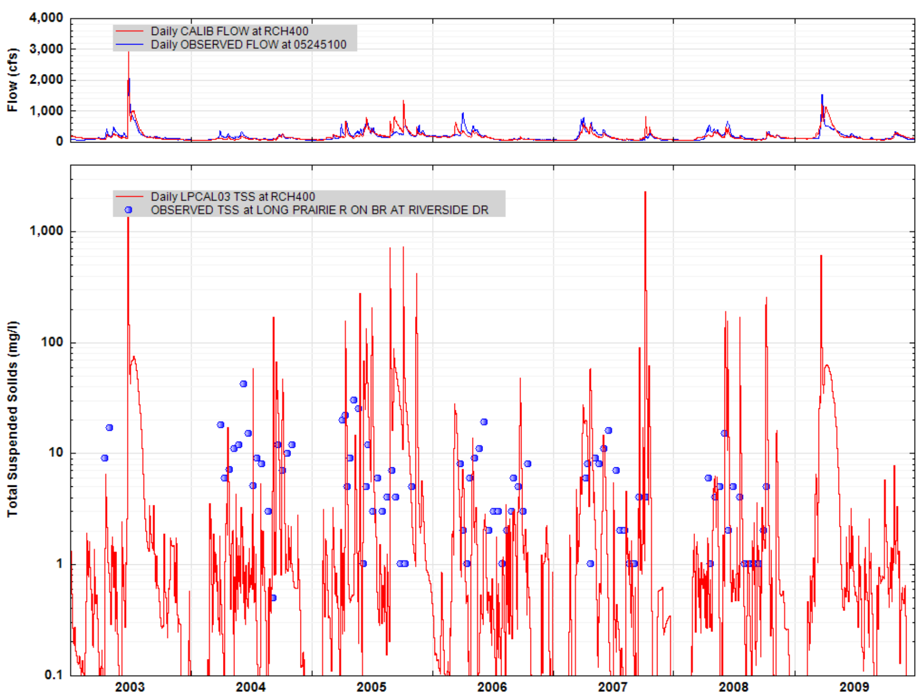


(b)

Figure 3.3 Observed and simulated TSS concentrations in (a) Winona Lake and (b) Henry Lake in Long Prairie River Watershed for the calibration period

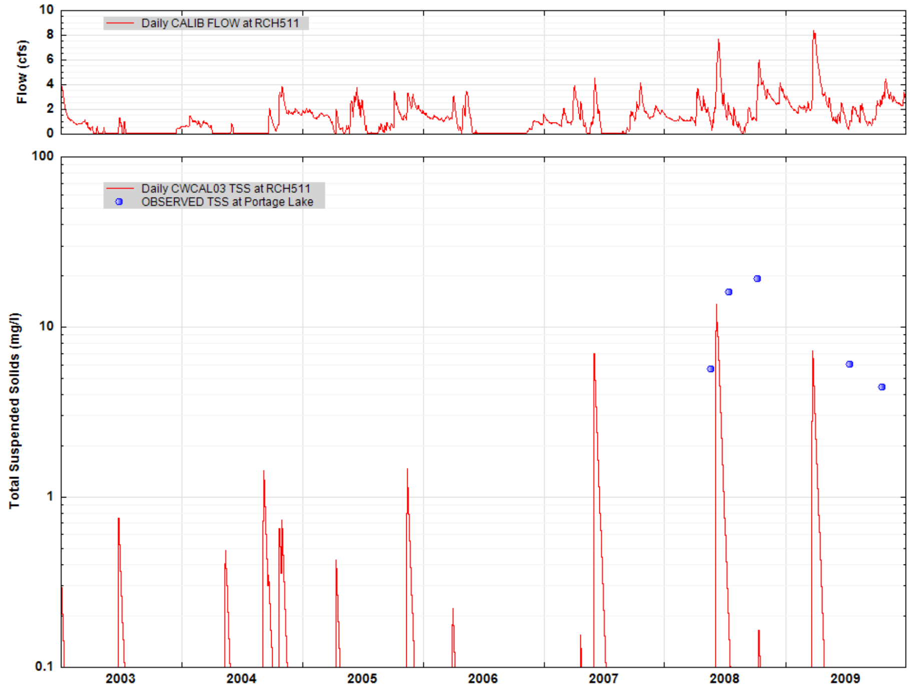


(a)

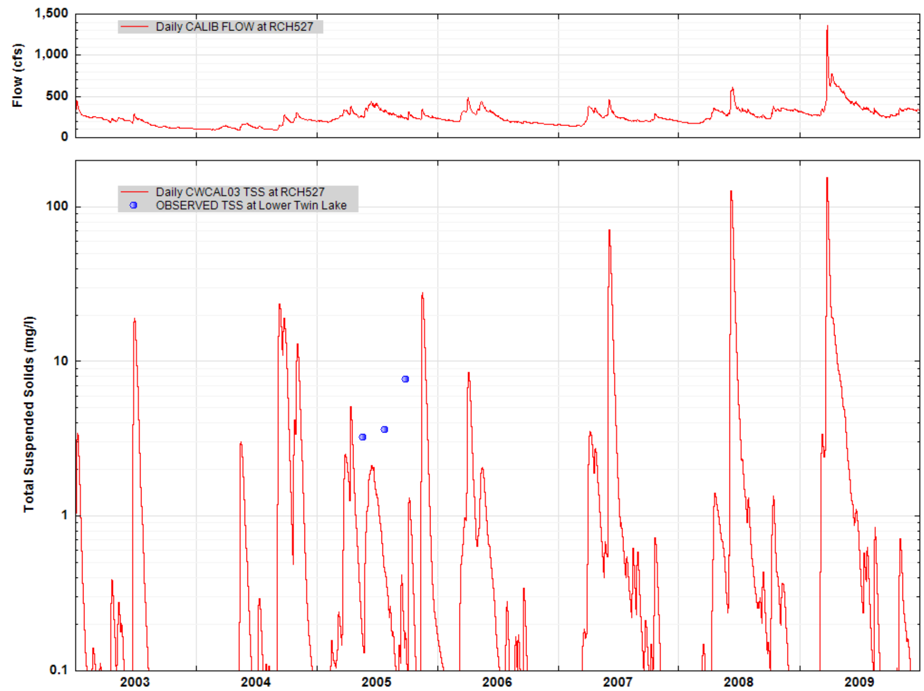


(b)

Figure 3.4 Observed and Simulated TSS Concentrations in Long Prairie River at (a) the outlet of Long Prairie River, and (b) at the USGS gage on Long Prairie River for the calibration period



(a)



(b)

Figure 3.5 Observed and simulated TSS concentrations at (a) Portage Lake and (b) Lower Twin Lake in Crow Wing Watershed

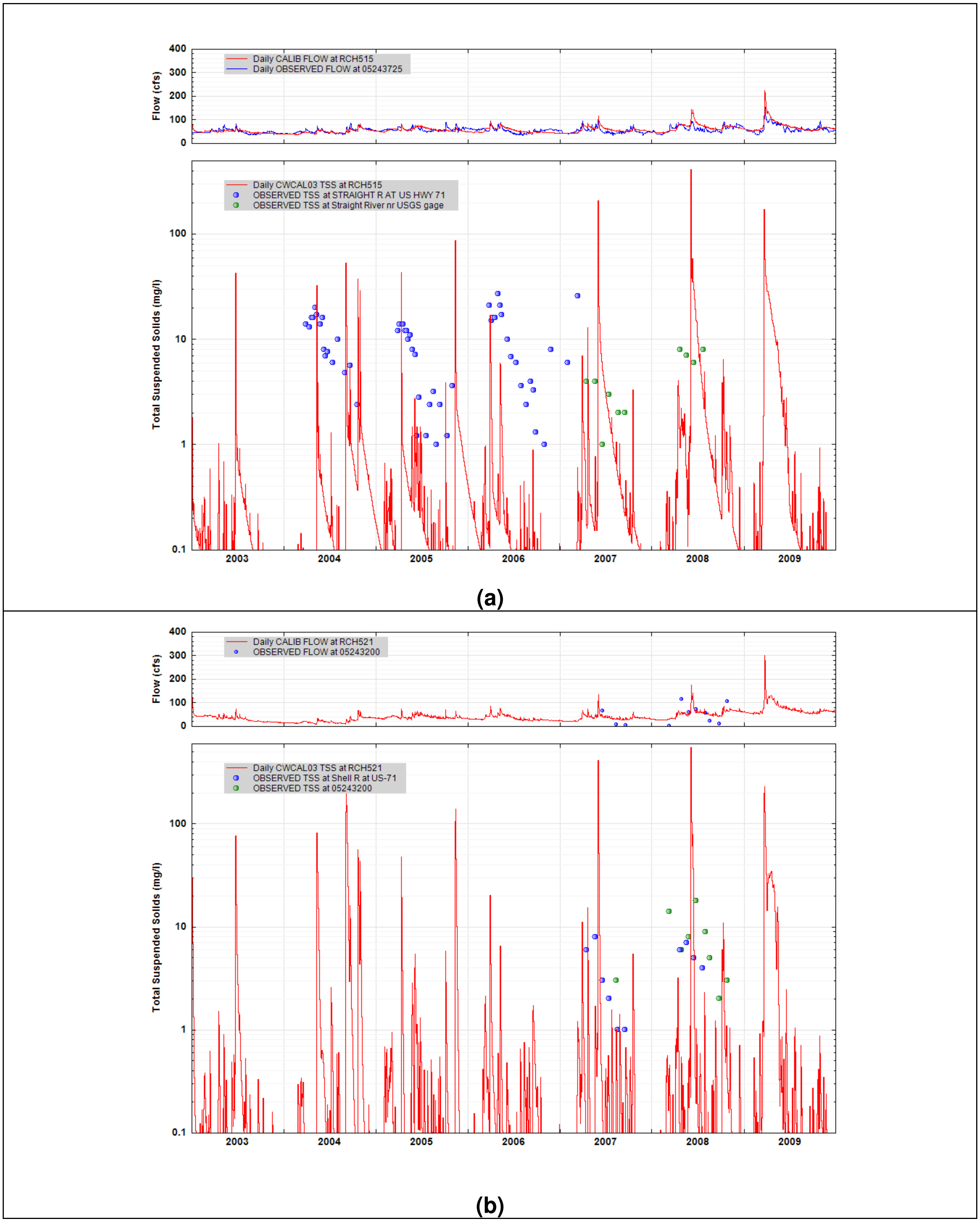


Figure 3.6 Observed and simulated TSS concentrations at (a) Straight River and (b) Shell River in Crow Wing River watersheds

3.3 SEDIMENT VALIDATION

Sediment validation followed sediment calibration. As with hydrology, the sediment parameters from the calibrated model were used in the validation model. Reports similar to the calibrated model were generated (Table 3.4 and Table 3.5). The sediment loading rates of different land uses are generally close to the target sediment loading rate. When the sediment contributions by land surfaces and reaches were compared, the apportionment for the validation period was found to be close to the assumed sediment apportionment. The overall contribution of sediment loading from land surfaces ranged from 79% (Crow Wing River Watershed) to 89% (Redeye River) with the remaining sediment loading coming from the reaches.

Simulated and observed TSS concentrations were plotted at several locations for the validation period (Figure 3.7 and Figure 3.8). The simulated TSS concentrations matched the observed values well. At this stage, the sediment simulation was considered acceptable and the calibration and validation process of the remaining water quality constituents was started.

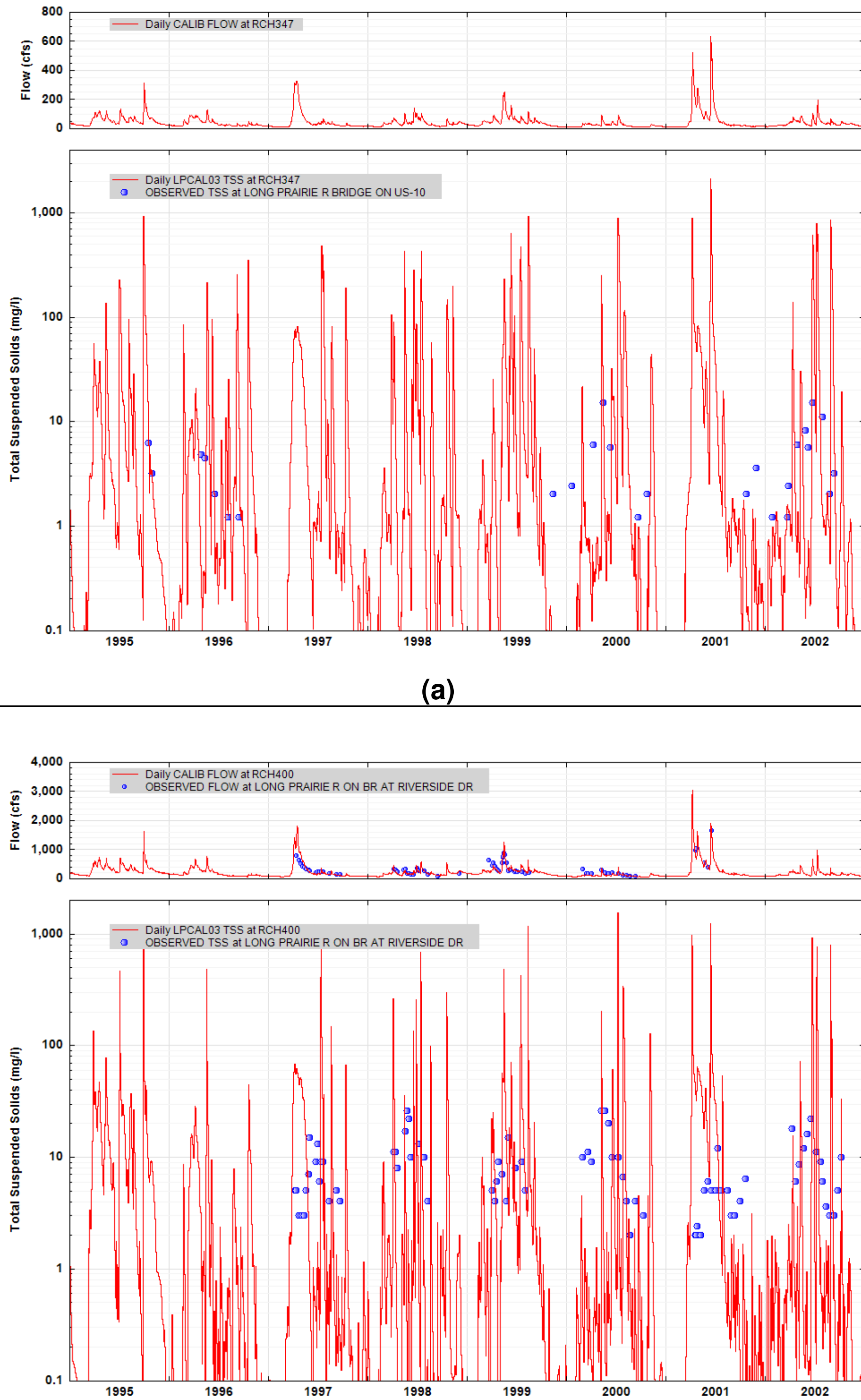
Table 3.4 Sediment erosion from land surface and streams in the watersheds for the validation period

	Long Prairie River Watershed	Redeye River Watershed	Crow Wing River Watershed
Total sediment erosion in the watershed from the land surface (t/yr)	46,132.0	54,997.7	58,497.9
Total sediment erosion from land surfaces in watersheds with no lakes (t/yr)	39,344.9	53,261.1	39,679.6
Total Point Source Contribution of sediments (t/yr)	157.7	-	22.8
Total Point source contribution of sediments in watersheds with no lakes (t/yr)	135.0	-	22.8
Total Deposition (+) / Scour (-) of sediment in all the lakes and streams (t/yr)	3,335.9	-2,767.00	3,904.8
Total Deposition (+) / Scour (-) in streams only (t/yr)	-6,196.60	-6,873.20	-10,662.50
Fraction of sediment from land surfaces in watersheds with no lakes	86%	89%	79%
Fraction of sediment erosion from streams in watersheds with no lakes.	14%	11%	21%

Table 3.5 Sediment loading rates in t/ac from different land uses and the target loading rates for the validation period

	Forest - AB	Forest - CD	Wetlands	Grassland - AB	Grassland - CD	Pasture - AB	Pasture - CD	Cropland-AB	Cropland -CD	Cropland-Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity
Target Rate (min)	0.007			0.006				0.042			0.013		
Target Rate (max)	0.156			0.165				0.396			0.357		
Met Segment	**Long Prairie Watershed**												
50	0.010	0.008	0	0.102	0.108	0.096	0.118	0.036	0.079	0.007	0.181	0.180	0.172
100	0.003	0.003	0	0.085	0.080	0.074	0.088	0.025	0.075	0.006	0.185	0.183	0.173
150	0.002	0.003	0	0.053	0.085	0.049	0.084	0.060	0.092	0.027	0.113	0.126	0.130
200	0.035	0.027	0	0.110	0.139	0.101	0.147	0.210	0.376	0.143	0.241	0.238	0.232
250	0.054	0.054	0	0.244	0.256	0.238	0.263	0.314	0.563	0.105	0.409	0.384	0.353
300	0.001	0.002	0	0.093	0.139	0.075	0.144	0.026	0.099	0.006	0.205	0.216	0.195
350	0.004	0.006	0	0.072	0.064	0.068	0.067	0.028	0.061	0.004	0.142	0.134	0.114
400	0.012	0.007	0	0.092	0.110	0.072	0.120	0.033	0.087	0.008	0.168	0.178	0.164
450	0.041	0.029	0	0.120	0.123	0.117	0.124	0.215	0.323	0.080	0.228	0.229	0.228
500	0.007	0.009	0	0.138	0.151	0.113	0.168	0.033	0.141	0.010	0.256	0.254	0.223
550	0.043	0.030	0	0.134	0.081	0.126	0.072	0.168	0.185	0.030	0.225	0.206	0.268
Weighted Average	**0.017**	**0.015**	**0**	**0.104**	**0.134**	**0.092**	**0.140**	**0.074**	**0.277**	**0.047**	**0.205**	**0.186**	**0.162**
Minimum	**0.001**	**0.002**	**0**	**0.053**	**0.064**	**0.049**	**0.067**	**0.025**	**0.061**	**0.004**	**0.113**	**0.126**	**0.114**
Maximum	**0.054**	**0.054**	**0**	**0.244**	**0.256**	**0.238**	**0.263**	**0.314**	**0.563**	**0.143**	**0.409**	**0.384**	**0.353**
Met Segment	**Redeye Watershed**												
100	0.001	0.002	0	0.060	0.076	0.074	0.09	0.037	0.076	0.012	0.269	0.211	
200	0.048	0.035	0	0.128	0.102	0.121	0.127	0.359	0.187	0.189	0.306	0.289	0.243
300	0.008	0.006	0	0.098	0.071	0.082	0.078	0.047	0.067	0.019	0.23	0.221	0.188
400	0.003	0.003	0	0.101	0.108	0.089	0.113	0.03	0.1	0.015	0.261	0.243	0.288
500	0.016	0.012	0	0.136	0.112	0.122	0.121	0.183	0.279	0.082	0.268	0.266	0.261
600	0.012	0.017	0	0.173	0.169	0.167	0.186	0.11	0.381	0.045	0.355	0.336	0.322
700	0.011	0.019	0	0.100	0.153	0.101	0.175	0.098	0.351	0.042	0.295	0.314	0.304
800	0.009	0.015	0	0.135	0.158	0.113	0.166	0.051	0.285	0.027	0.348	0.312	0.300
Weighted Average	**0.018**	**0.016**	**0**	**0.131**	**0.136**	**0.123**	**0.151**	**0.147**	**0.315**	**0.059**	**0.300**	**0.305**	**0.305**
Minimum	**0.001**	**0.002**	**0**	**0.060**	**0.071**	**0.074**	**0.078**	**0.030**	**0.067**	**0.012**	**0.230**	**0.211**	**0.188**
Maximum	**0.048**	**0.035**	**0**	**0.173**	**0.169**	**0.167**	**0.186**	**0.359**	**0.381**	**0.189**	**0.355**	**0.336**	**0.322**

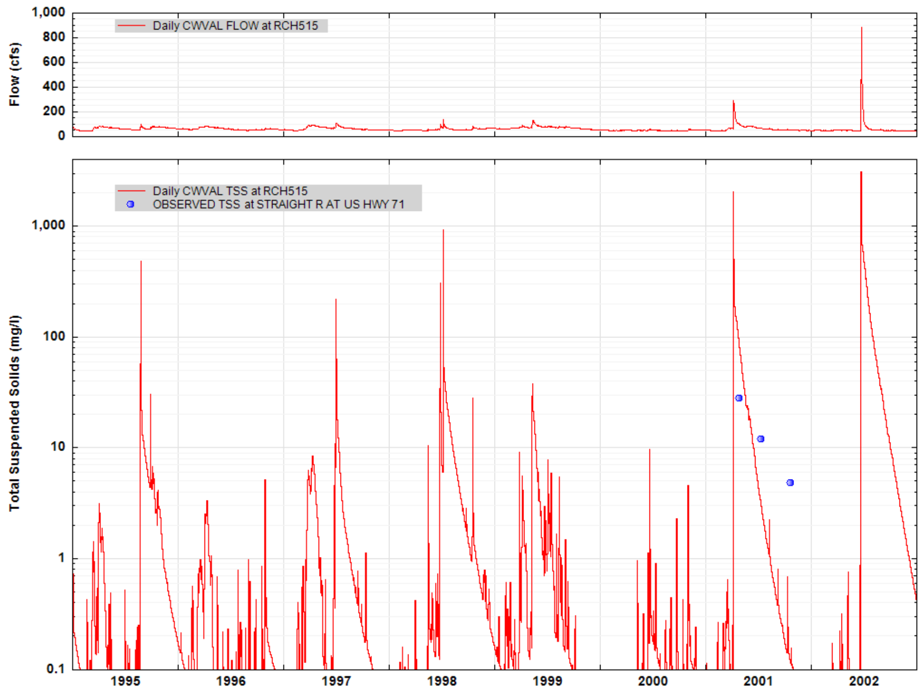
	Forest - AB	Forest - CD	Wetlands	Grassland - AB	Grassland - CD	Pasture - AB	Pasture - CD	Cropland-AB	Cropland -CD	Cropland-Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity
Target Rate (min)	0.007			0.006				0.042			0.013		
Target Rate (max)	0.156			0.165				0.396			0.357		
Met Segment	**Crow Wing Watershed**												
50	0.007	0.011	0	0.202	0.19	0.18	0.195	0.073	0.247	0.049	0.279	0.27	0.272
100	0.001	0.003	0	0.059	0.092	0.043	0.06	0.011	0.049	0.007	0.103	0.106	0.108
150	0.002	0.003	0	0.145	0.165	0.069	0.138	0.024	0.089	0.015	0.226	0.213	0.185
200	0.016	0.022	0	0.143	0.100	0.137	0.091	0.156	0.106	0.075	0.211	0.208	0.208
250	0.024	0.02	0	0.182	0.187	0.122	0.173	0.179	0.211	0.123	0.279	0.299	0.214
300	0.026	0.02	0	0.145	0.164	0.095	0.123	0.158	0.123	0.048	0.24	0.236	0.229
350	0.005	0.01	0	0.196	0.25	0.102	0.183	0.069	0.174	0.045	0.291	0.221	0.136
400	0.000	0.001	0	0.062	0.121	0.026	0.062	0.006	0.030	0.002	0.134	0.119	0.099
450	0.029	0.022	0	0.124	0.119	0.087	0.096	0.201	0.149	0.111	0.184	0.183	0.167
500	0.010	0.024	0	0.164	0.198	0.113	0.186	0.096	0.245	0.076	0.257	0.246	
550	0.001	0.001	0	0.094	0.142	0.047	0.08	0.034	0.104	0.018	0.152	0.153	0.155
600	0.002	0.002	0	0.140	0.128	0.082	0.118	0.032	0.08	0.011	0.213	0.201	0.193
650	0.001	0.001	0	0.090	0.146	0.031	0.087	0.008	0.032	0.004	0.17	0.161	0.088
700	0.033	0.03	0	0.209	0.227	0.146	0.179	0.292	0.427	0.279	0.326	0.309	0.31
750	0.000	0.000	0	0.068	0.131	0.027	0.06	0.004	0.024	0.001	0.138	0.139	0.118
Weighted Average	**0.015**	**0.011**	**0**	**0.149**	**0.173**	**0.105**	**0.125**	**0.101**	**0.11**	**0.037**	**0.214**	**0.201**	**0.158**
Minimum	**0.000**	**0.000**	**0**	**0.059**	**0.092**	**0.026**	**0.060**	**0.004**	**0.024**	**0.001**	**0.103**	**0.106**	**0.088**
Maximum	**0.033**	**0.030**	**0**	**0.209**	**0.250**	**0.180**	**0.195**	**0.292**	**0.427**	**0.279**	**0.326**	**0.309**	**0.310**



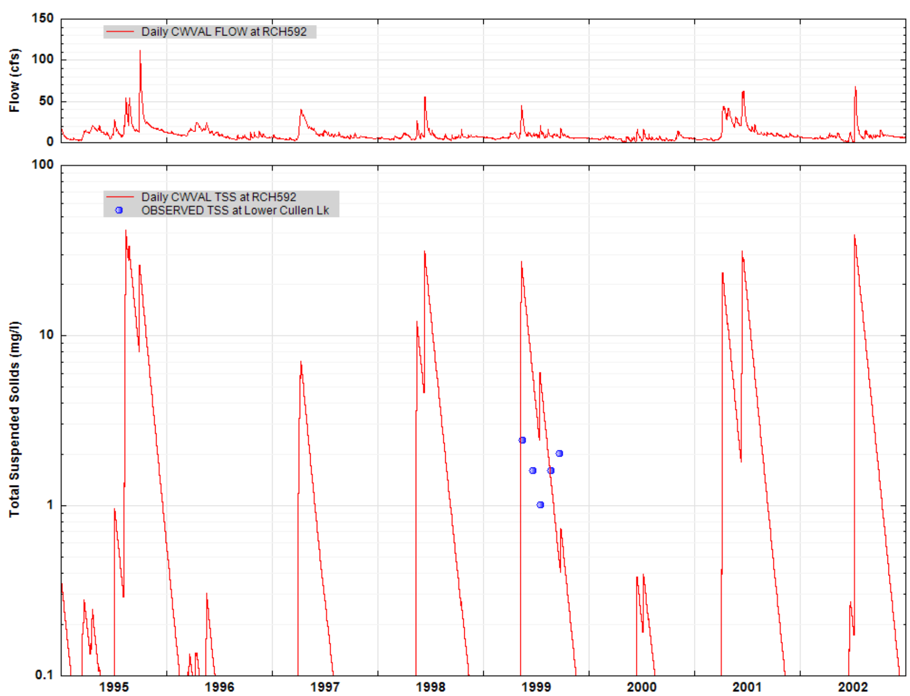
(a)

(b)

Figure 3.7 Observed and Simulated TSS Concentrations in Long Prairie River at (a) the outlet of Long Prairie River to the Crow Wing River and (b) at the USGS gage for the validation period



(a)



(b)

Figure 3.8 Observed and Simulated TSS Concentrations at (a) Straight River and (b) Lower Cullen Creek

SECTION 4.0
WATER QUALITY CALIBRATION AND VALIDATION

In the Crow Wing River watersheds, various forms of Nitrogen (N) and Phosphorus (P), their interactions and transformations, and other associated constituents (water temperature, Dissolved Oxygen, Biological Oxygen Demand, and Phytoplankton) were modeled. The sources of these nutrients include point sources, nonpoint sources, and atmospheric deposition. Nonpoint sources are calculated considering accumulation, depletion/removal, and a first-order washoff rate of the available constituent removed by the overland flow. Quantities of these constituents in the subsurface flow are simulated using monthly varying concentrations. Resulting nonpoint loadings, calculated separately for each land use in each met segment, are input to the reaches and lakes along with the point sources in order to simulate fate, transport, and delivery of the nutrients. Atmospheric deposition on all land surfaces provides a contribution to the nonpoint source load through the runoff/washoff process; deposition onto water surfaces represented in the model is also considered a direct input to the river systems.

Following the estimation of nutrient contributions from all land uses, the modeled hydrological and hydraulic processes are superimposed to provide transport mechanisms, and then water quality modeling is performed to allow adjustments in parameters and evaluation of sources as part of the calibration process. Nonpoint contributions from the watershed include following constituents.

- Sediment
- Heat
- Nitrite-Nitrate as Nitrogen (NO_3-N)
- Ammonia as Nitrogen (NH_4-N)
- Orthophosphate as Phosphorus (PO_4-P)
- Biological Oxygen Demand (BOD)/Organics, comprised of
    - Labile BOD
    - Refractory Organic Nitrogen
    - Refractory Organic Phosphorus
    - Refractory Organic Carbon

Sediment was discussed in previous chapter. All of the remaining constituents are modeled within the stream module, along with algal components of phytoplankton and benthic algae. Water quality calibration is an iterative process; the model predictions are the integrated result of all the assumptions used in developing the model input and representing the model processes. Differences in model predictions and observations require the model user to re-evaluate these assumptions, in terms of both the estimated model input and parameters, and to consider the accuracy and uncertainty in the observations. It must be noted that at the current time, water quality calibration is more an art than a science, especially for comprehensive simulations of nonpoint, point, and atmospheric sources and their impacts on water quality.

The time periods used for water quality calibration/validation were the same as those used for hydrologic calibration and validation. The following steps were performed for water quality calibration.

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 loadings with expected range of nonpoint loadings from each land use and adjust loading parameters as necessary.
3. Calibrate instream water temperature.

4. Compare simulated and observed instream concentrations at all the locations where data is available.
5. Analyze the comparisons in steps 3 and 4 to determine appropriate instream and/or nonpoint parameter adjustments.

The primary instream water quality parameters adjusted were advection and settling rates for phytoplankton and refractory organics, settling rates for BOD, benthal release of BOD, NH_4-N, or PO_4-P with secondary changes to nitrification rates, phytoplankton and benthic algae rates, and algal nutrient update parameters. Initial parameter values were obtained from the Crow Wing Watershed Study (AQUA TERRA Consultants, 2007).

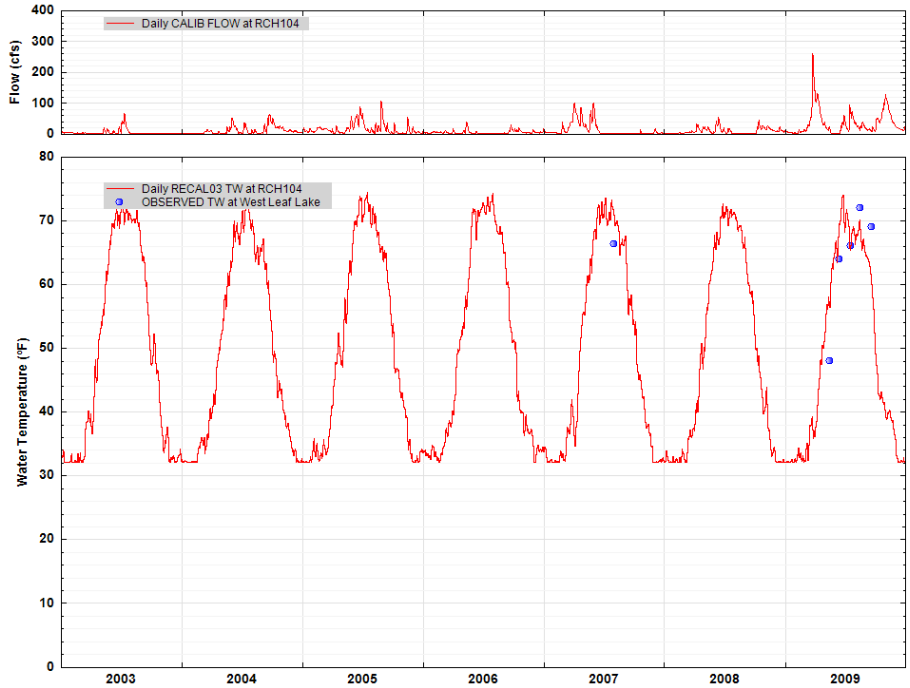
This section discusses each of the water quality constituents individually and presents the calibration and validation results.

4.1 WATER TEMPERATURE

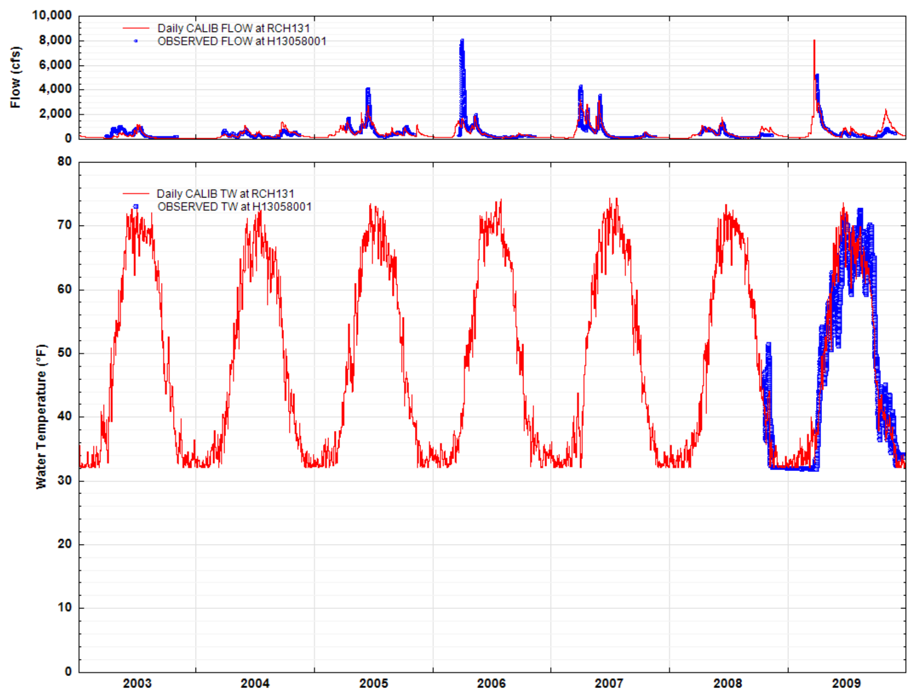
Water temperature controls the instream reaction rates and also determines the saturation concentration of dissolved oxygen; therefore temperature calibration is conducted before calibration of other water quality constituents. To model the instream water temperature, HSPF calculates the heat loadings to a stream reach from all sources and then performs a balance of the heat fluxes across the reach boundaries to arrive at the reach water temperature in each model step. Heat sources/sinks to a reach include upstream or tributary reaches, nonpoint runoff, point sources, heat exchange with the atmosphere, and conduction from streambed. Heat outputs from a reach include downstream advection, losses to the atmosphere, and conduction to the streambed.

The details on heat loading and water temperature simulation are available in the HSPF Manual (Bicknell et al. 2005). To conduct temperature calibration, first the soil temperature parameters are adjusted as the heat content of the runoff is a function of the modeled soil temperatures in each soil layer. The monthly ASLT (Y intercept for surface layer temperature regression equation), BLST (slope for surface layer temperature regression equation), ULTP1 (intercept for upper layer temperature regression equation), ULTP2 (slope for upper layer temperature regression equation), LGTP1 (intercept for lower layer and active groundwater temperature regression equation), and LGTP2 (slope for lower layer and active groundwater temperature regression equation) were adjusted for each PERLND, to improve the soil temperature simulation. After reasonable soil temperatures are attained, the instream parameters of monthly TGRND (ground temperature), CFSAEX (fraction of RCHRES exposed to sun's radiation), KATRAD (longwave radiation coefficient), and KCOND (conduction-convection heat transport coefficient) were adjusted for each RCHRES, in comparison with available stream water temperature data.

Although water temperature data was available at a few locations in the watershed the data was not dense enough to conduct a detailed statistical analysis. However, plotting the data at several locations provided a good indication of how well the model was performing in terms of water temperature simulation. Plots of observed and simulated water temperature, such as those presented in Figure 4.1 to Figure 4.5, show that simulated water temperatures match the observed data very well. It must be recognized that the observed data represents a snapshot of time and a location, whereas simulated data is averaged for the whole day with the assumption that the entire water body (lake or a reach) is a well-mixed reservoir. Therefore, the simulated data demonstrates the water temperature trends and is not expected to match the observed data exactly. All of the graphs prepared for the calibration and validation periods are presented in APPENDIX G and APPENDIX H.

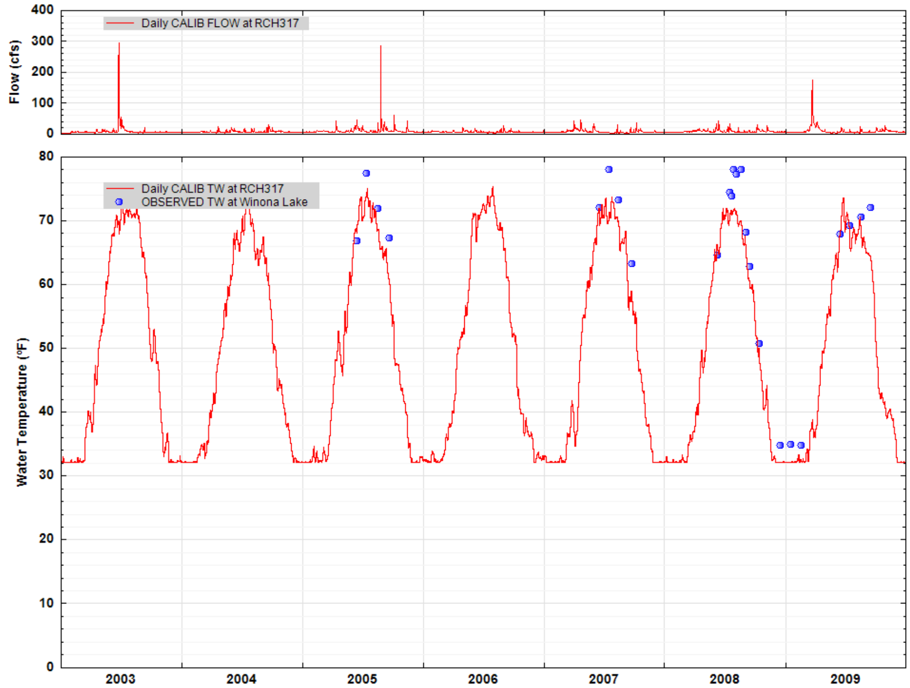


(a)

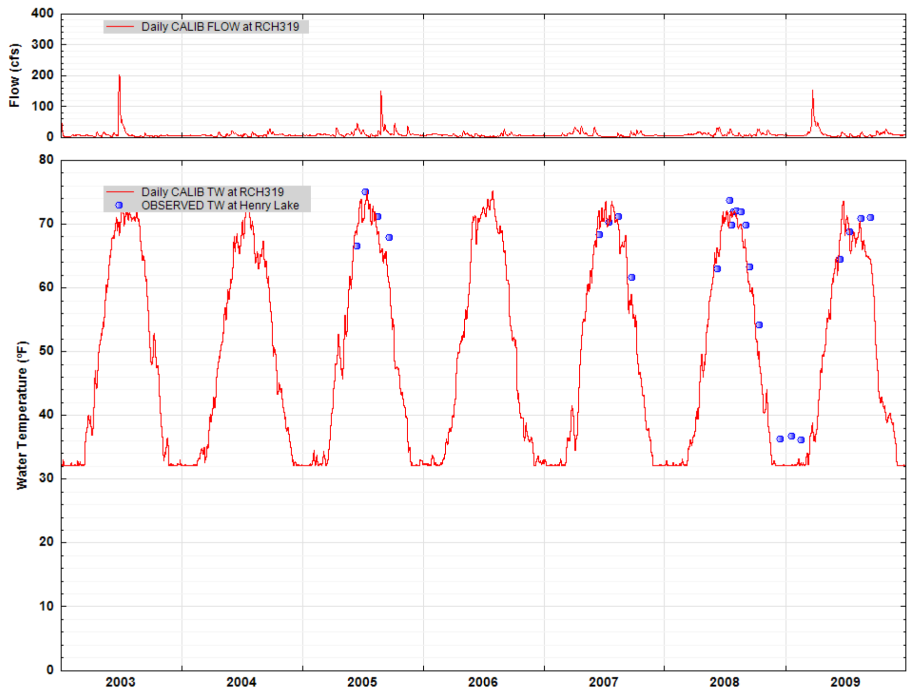


(b)

Figure 4.1 Observed and simulated water temperature at two locations in Redeye River watershed for the calibration period

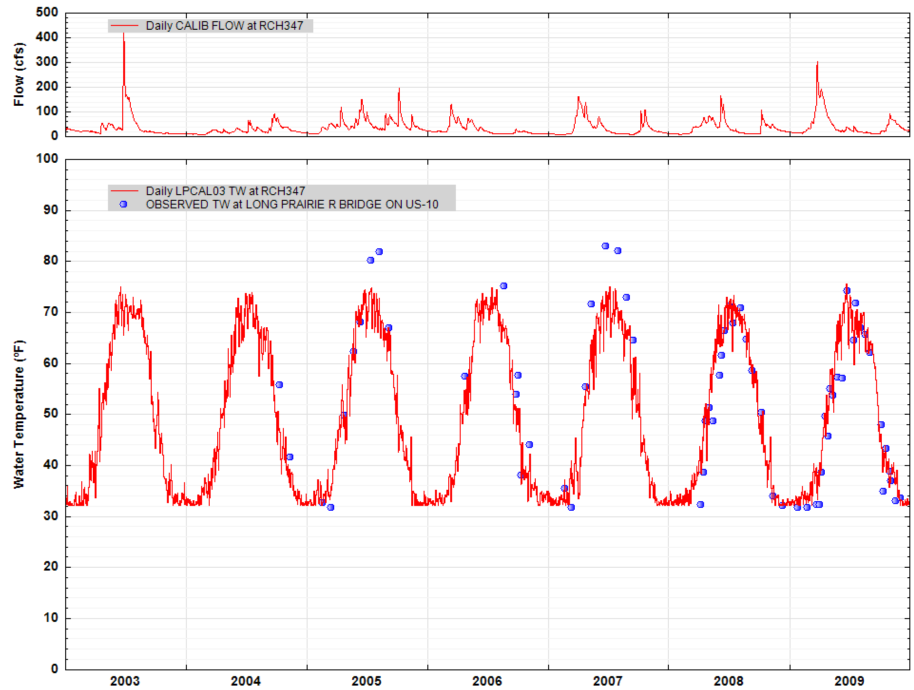


(a)

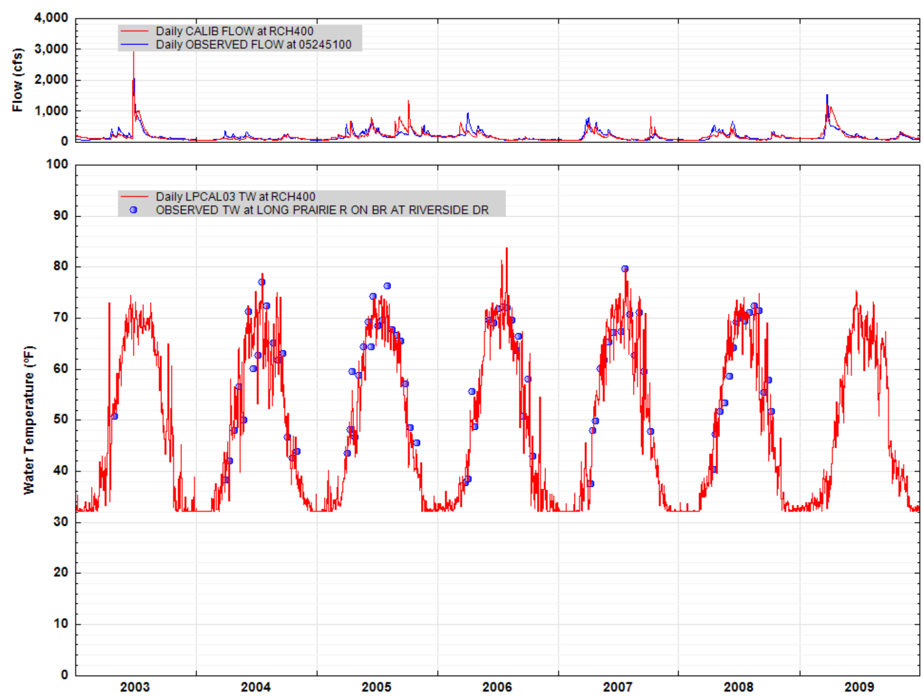


(b)

Figure 4.2 Observed and simulated water temperature at two lakes in the Long Prairie River watershed for the calibration period



(a)



(b)

Figure 4.3 Observed and simulated water temperature at (a) Long Prairie River outlet and (b) USGS gage on Long Prairie River for the calibration period

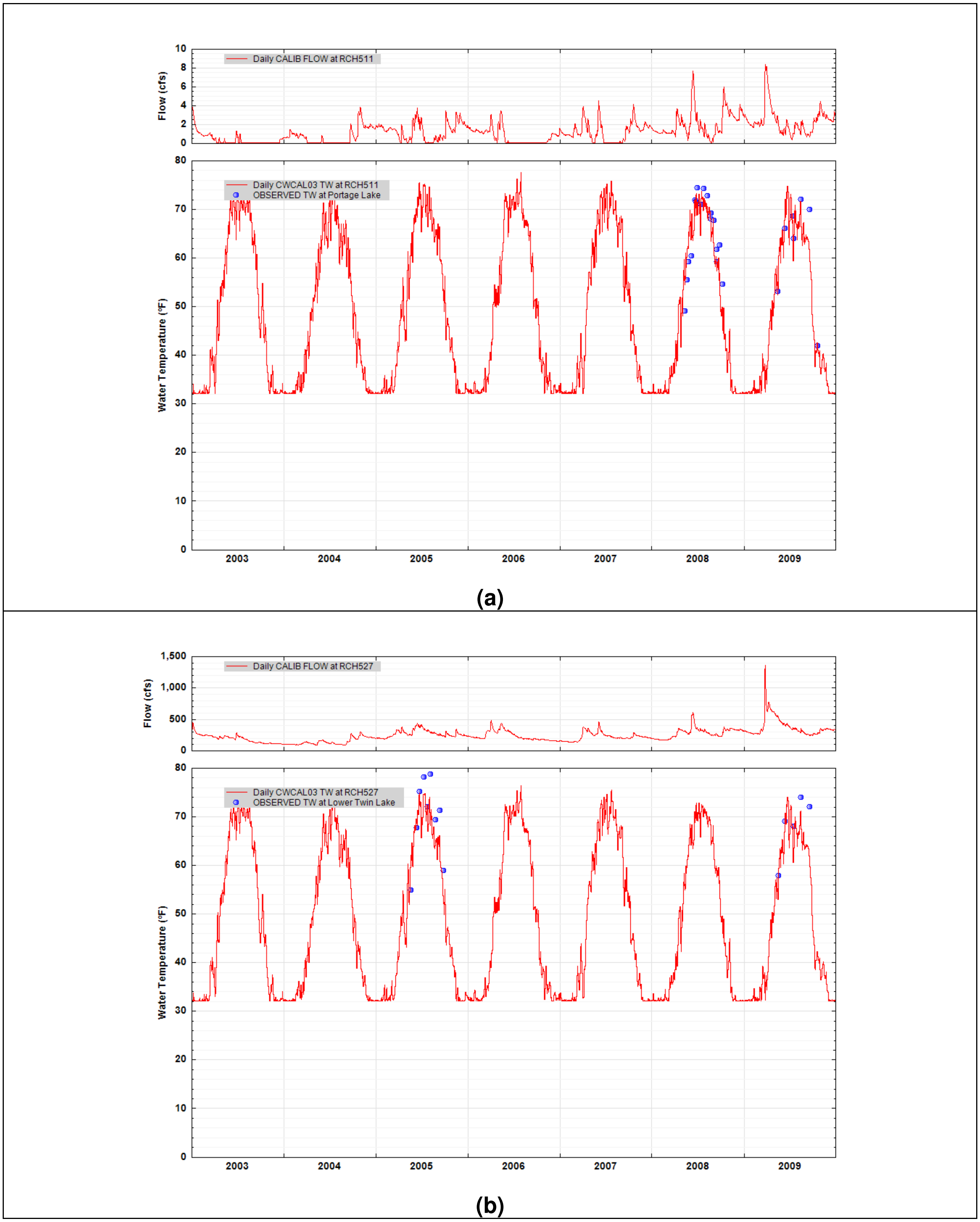
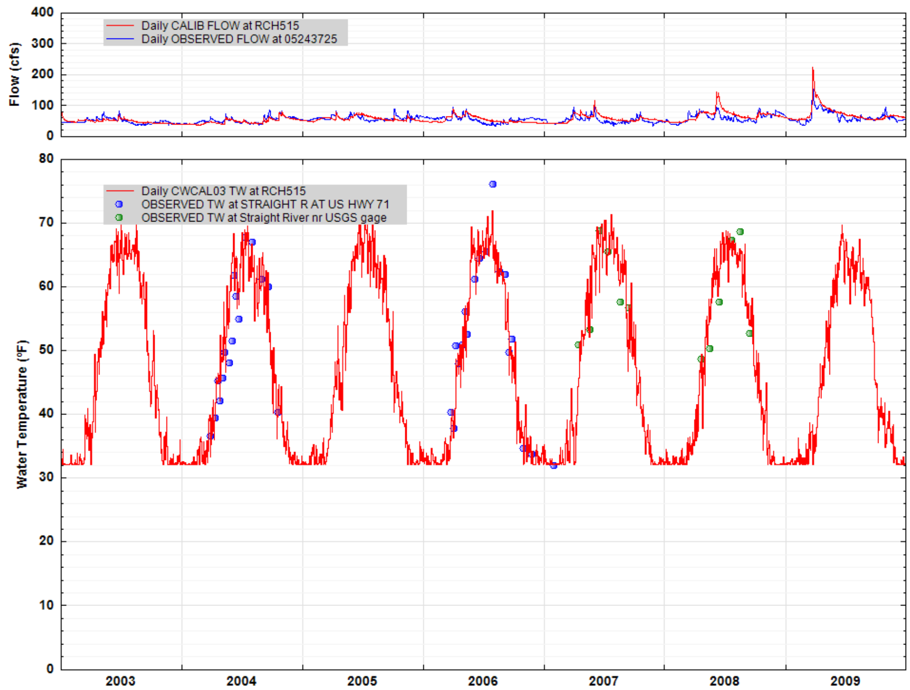
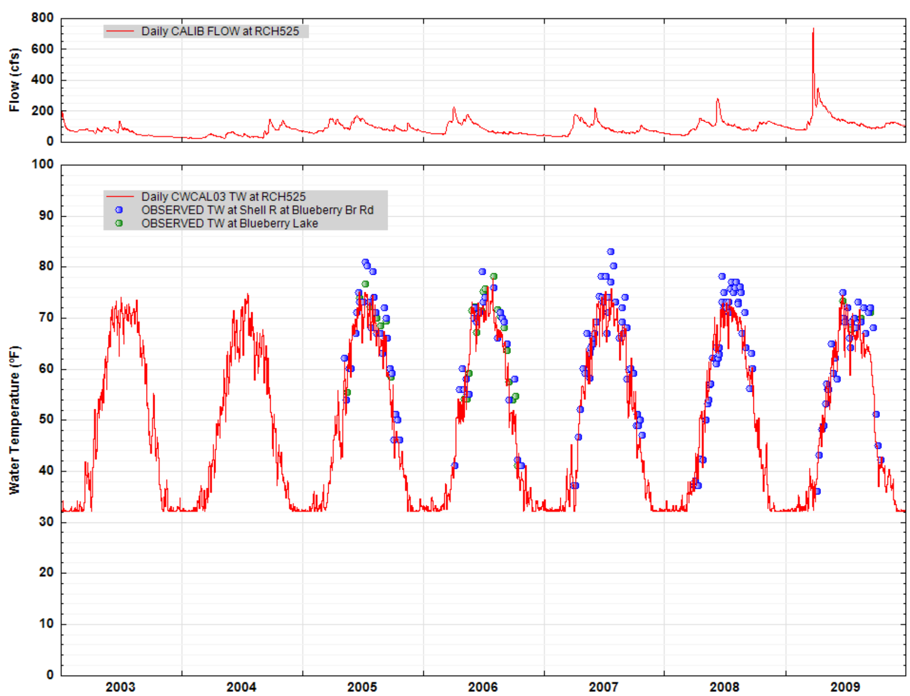


Figure 4.4 Observed and simulated water temperature at (a) Portage Lake and (b) Lower Twin Lake in the Crow Wing River Watershed for the calibration period



(a)



(b)

Figure 4.5 Observed and simulated water temperature at (a) Straight River and (b) Shell River in the Crow Wing River watershed for the calibration period

4.2 DISSOLVED OXYGEN

Dissolved Oxygen (DO) concentration generally indicates the overall ecological well-being of streams and lakes. In relatively unpolluted waters, the sources and sinks of oxygen are in proper balance and the DO concentration remains close to saturation. However, when the water receives pollutants from different sources, this balance may get upset, populations of oxygen-consuming bacteria may increase, and DO concentration may decrease. DO concentration is affected by a combination of water temperature, reaeration, loading of oxygen-demanding wastes, sediment oxygen demand, production of algae, and respiration by algae. The calibration of DO therefore was a iterative process that included the calibration of other water quality parameters (Chlorophyll A, N, P, etc.) in tandem. During calibration, parameters affecting the loading rates of BOD, N, and P (accumulation rate, monthly concentration of interflow and groundwater) were adjusted. Parameters affecting the release of nutrients from reach beds, nutrient transformation, growth and respiration of phytoplankton, and algae were also adjusted. The loading rates of BOD organics from all the land uses are presented in Table 4.1.

Some of these parameters were reach or lake specific and were adjusted accordingly. For example, the lakes downstream of point sources had a greater release of nutrients from their beds. The size and shape of these lakes also affect the total nutrient release from the bed. Better information about the hydraulics of these lakes, bed depth, and sediment distribution would help in improving the calibration of these waterbodies and possible extension of the model for a longer period would also help.

Overall, the DO simulation appeared reasonable and acceptable in the three watersheds (Figure 4.6 to Figure 4.10), with a good representation of seasonal patterns. It must be noted that the observed DO values are a snapshot in time and space, whereas the simulated DO assumes that the whole lake/reach is a completely mixed reservoir where the values are averaged for the day. Further, observed data is not sufficient to conduct a detailed statistical analysis; therefore visual comparison is the best tool available to judge the goodness of fit. Remaining DO plots for calibration and validation are provided in APPENDIX I and APPENDIX J.

Table 4.1 Average loading of BOD Organics from different land uses in the Long Prairie, Redeye, and Crow Wing River Watersheds

Long Prairie Watershed														
Land Use	**Forest - AB**	**Forest - CD**	**Wetlands**	**Grassland - AB**	**Grassland - CD**	**Pasture - AB**	**Pasture - CD**	**Cropland-AB**	**Cropland-CD**	**Cropland-Drained**	**Dev, Open Space**	**Dev, Low Intensity**	**Dev, Medium Intensity**	**Watershed Avg.**
Area (ac)	61,920	55,045	66,715	21,689	25,795	46,932	71,722	88,702	47,003	14,007	26,787	5,210	1,211	532,736
SOQUAL	0.358	0.167	0	2.06	2.405	1.935	2.694	2.136	2.507	0.412	4.366	4.989	5.043	1.66
IOQUAL	0.234	0.261	0.025	1.729	1.941	1.728	1.924	2.044	2.827	3.705	4.882	4.745	5.015	1.623
AOQUAL	2.129	2.215	1.905	6.195	6.416	6.073	6.414	33.948	35.038	32.004	11.132	10.524	10.762	12.949
POQUAL	2.722	2.644	1.93	9.984	10.761	9.737	11.032	38.127	40.372	36.12	20.38	20.258	20.82	16.232
IMPLND														
Landuse	**Dev, Open Space**	**Dev, Low Intensity**	**Dev, Medium Intensity**	**Watershed Avg.**										
Area (ac)	547	579	658	1,784										
SOQUAL	30.62	30.50	30.64	30.59										

Redeye River Watershed														
Land Use	**Forest - AB**	**Forest - CD**	**Wetlands**	**Grassland - AB**	**Grassland - CD**	**Pasture - AB**	**Pasture - CD**	**Cropland-AB**	**Cropland-CD**	**Cropland-Drained**	**Dev, Open Space**	**Dev, Low Intensity**	**Dev, Medium Intensity**	**Watershed Avg.**
Area (ac)	46,871	83,838	100,799	18,787	29,542	51,299	65,232	110,788	23,285	11,703	22,285	2,266	415	567,110
SOQUAL	0.147	0.121	0	1.298	1.337	1.115	1.539	0.865	2.319	0.463	3.733	3.25	2.638	0.856
IOQUAL	0.156	0.19	0.018	1.389	1.642	1.405	1.628	1.383	1.871	2.543	4.905	5.187	5.526	1.107
AOQUAL	2.082	2.155	1.807	6.307	6.146	6.335	6.12	36.657	33.387	33.401	11.229	11.671	12.058	12.336
POQUAL	2.385	2.465	1.824	8.994	9.126	8.855	9.287	38.904	37.577	36.407	19.868	20.108	20.222	14.298
IMPLND														
Landuse	**Dev, Open Space**	**Dev, Low Intensity**	**Dev, Medium Intensity**	**Watershed Avg.**										
Area (ac)	455	252	224	930										
SOQUAL	30.92	31.17	31.28	31.07										

Crow Wing River Watershed														
Land Use	**Forest - AB**	**Forest - CD**	**Wetlands**	**Grassland - AB**	**Grassland - CD**	**Pasture - AB**	**Pasture - CD**	**Cropland-AB**	**Cropland-CD**	**Cropland-Drained**	**Dev, Open Space**	**Dev, Low Intensity**	**Dev, Medium Intensity**	**Watershed Avg.**
Area (ac)	393,204	201,743	218,953	53,581	34,151	72,855	70,611	99,169	196	27,067	37,387	4,315	739	1,213,970
SOQUAL	0.017	0.029	0	1.251	2.211	0.509	1.504	0.23	0.955	0.068	2.437	2.215	1.671	0.37

IOQUAL	0.082	0.103	0.014	1.18	1.378	0.783	1.013	1.301	1.968	2.299	2.994	3.031	3.22	0.498
AOQUAL	1.829	1.886	1.564	6.864	6.728	5.809	5.823	35.672	33.27	32.114	10.857	10.86	11.142	6.408
POQUAL	1.927	2.017	1.577	9.294	10.316	7.1	8.34	37.203	36.193	34.481	16.289	16.106	16.033	7.276
IMPLND														
Landuse	**Dev, Open Space**	**Dev, Low Intensity**	**Dev, Medium Intensity**	**Watershed Avg.**										
Area (ac)	762	478	398	1,638										
SOQUAL	29.40	29.35	29.48	29.41										

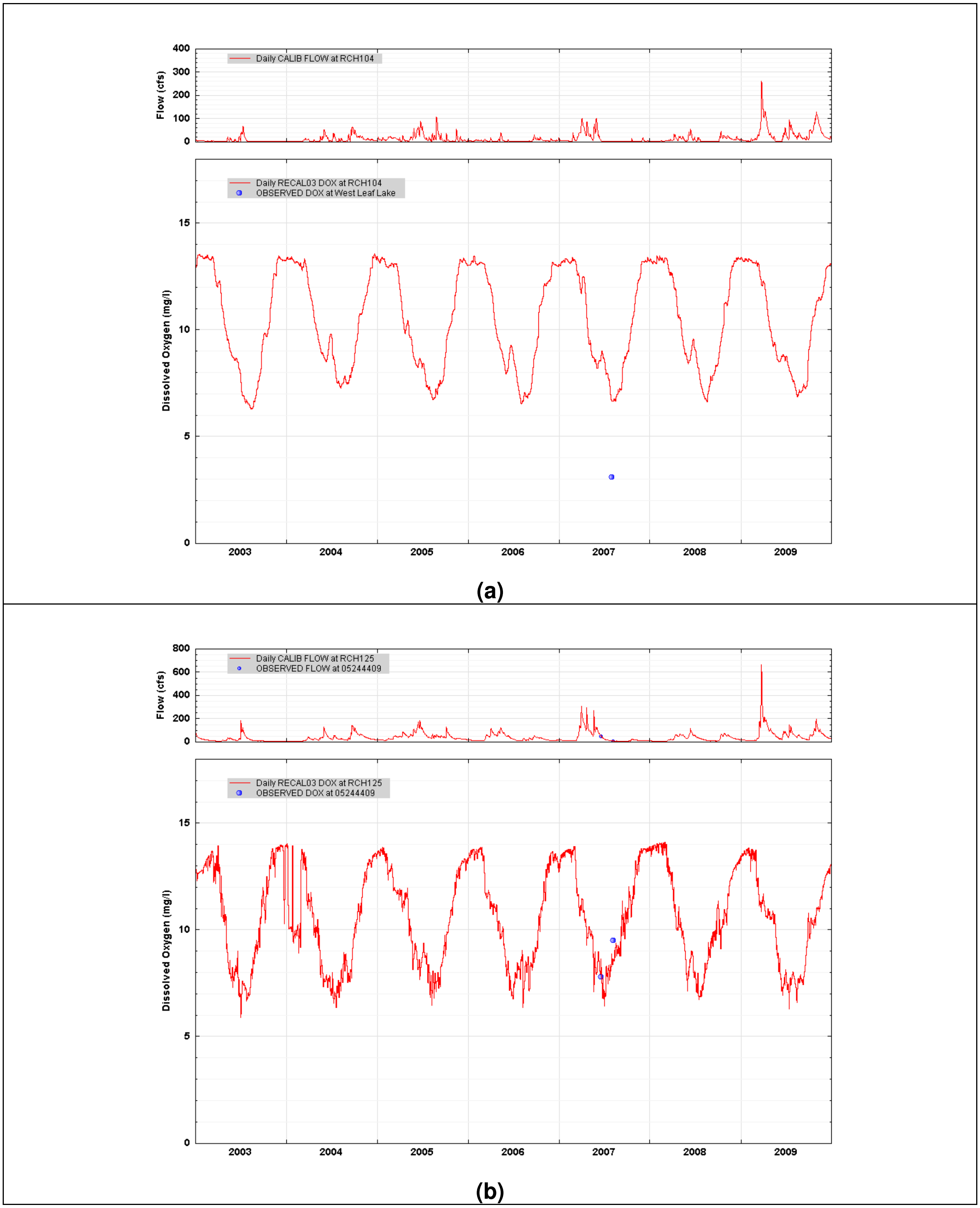
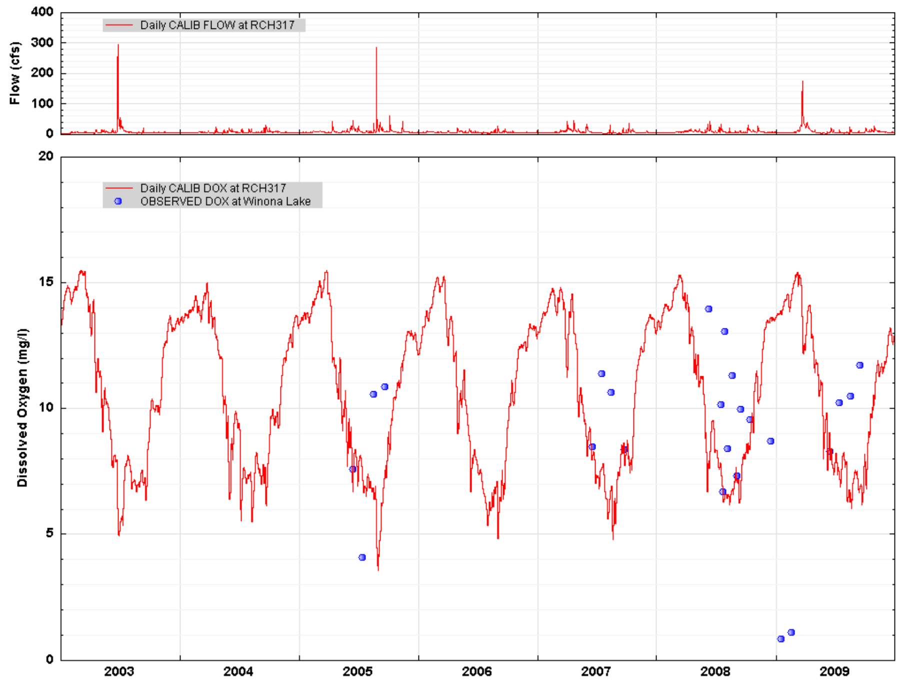
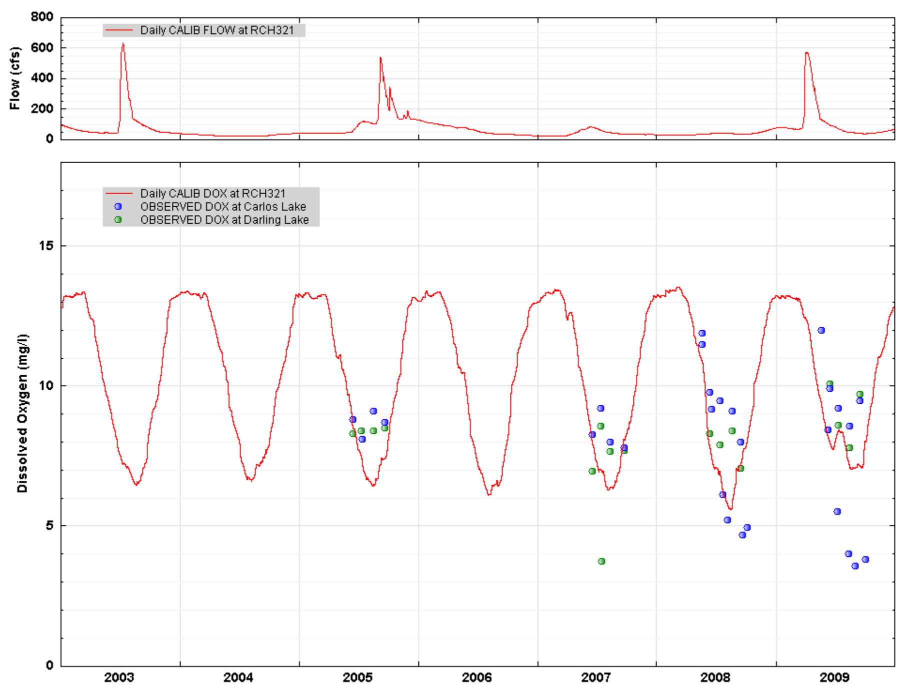


Figure 4.6 Observed and simulated DO concentrations at two locations in the Redeye River watershed

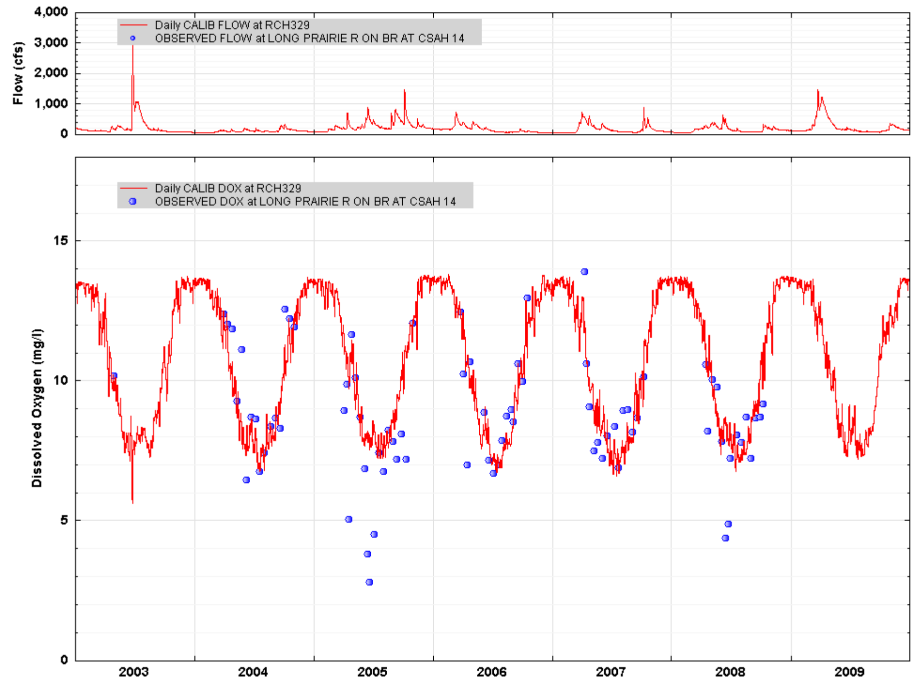


(a)



(b)

Figure 4.7 Observed and simulated DO concentrations at (a) Winona Lake and (b) Carlos lake in the Long Prairie River watershed



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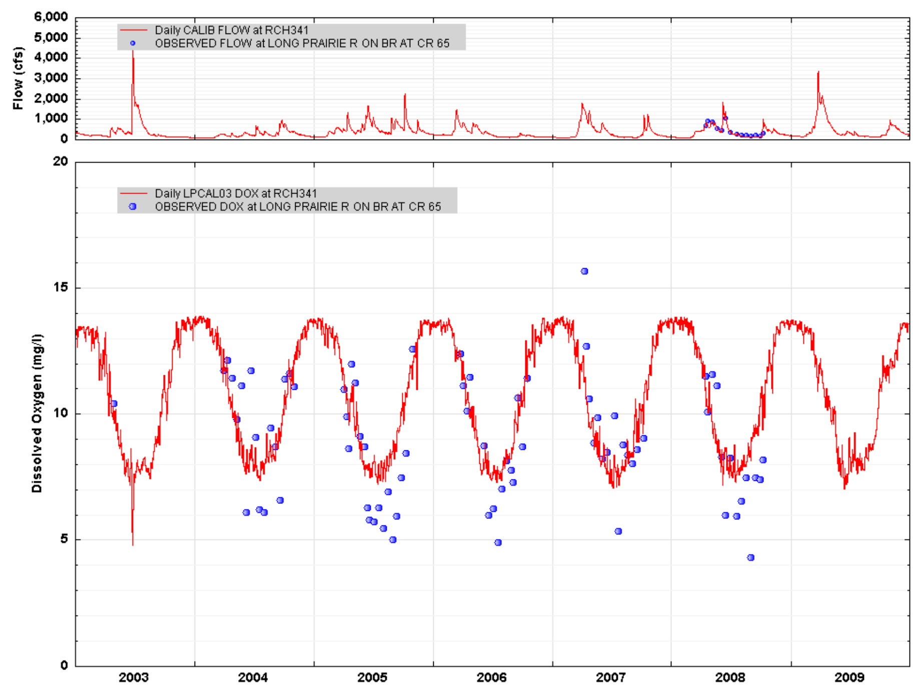
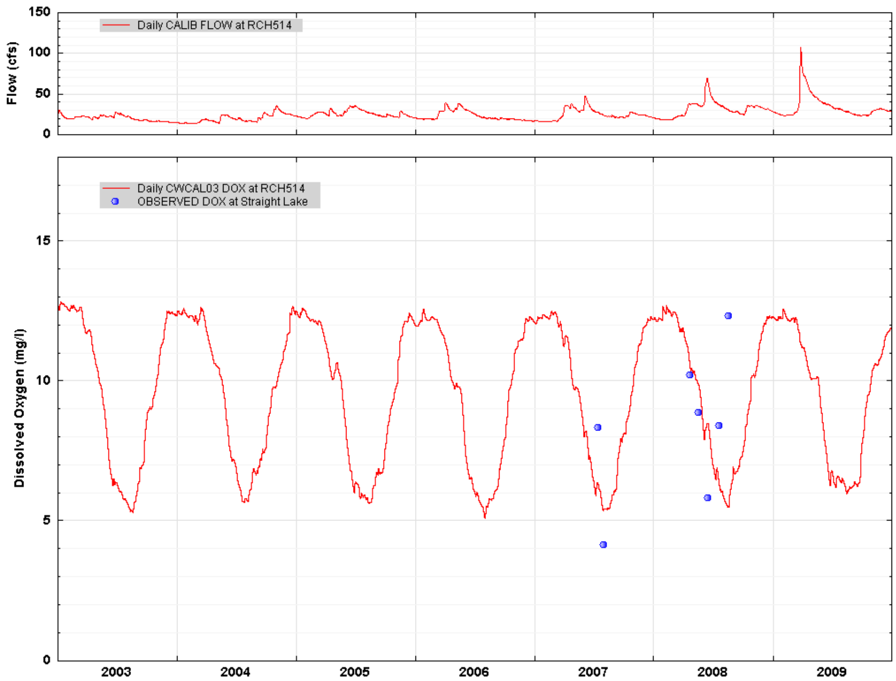
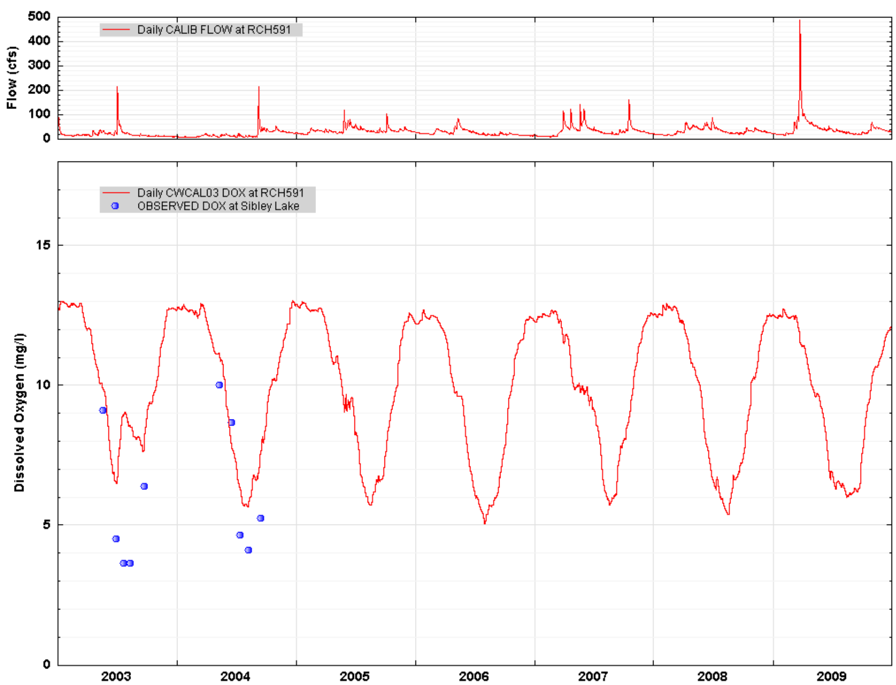


(b)

Figure 4.8 Observed and simulated DO concentrations at two locations on the Long Prairie River in the Long Prairie River watershed

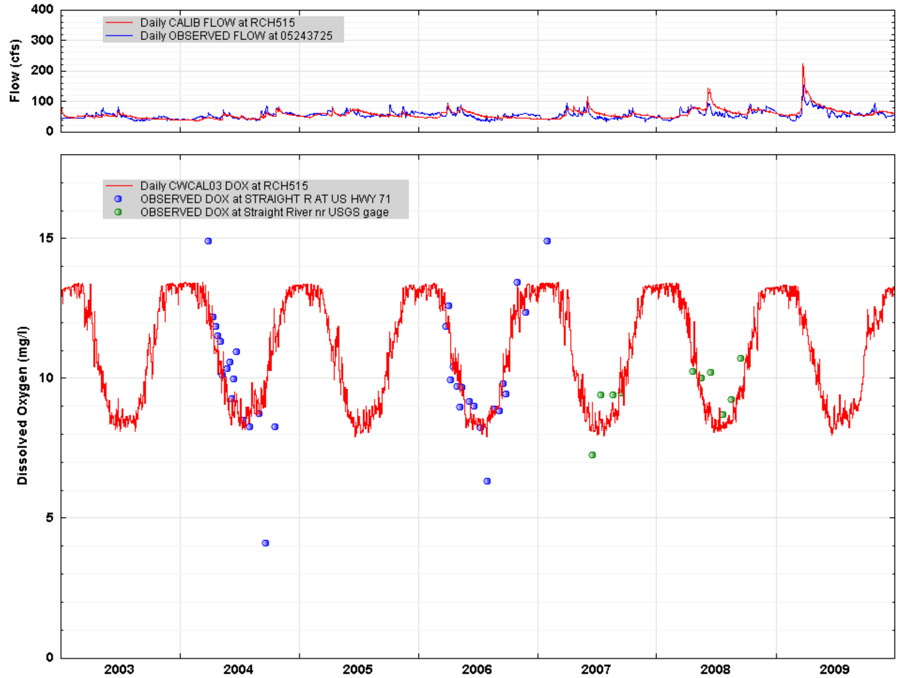


(a)

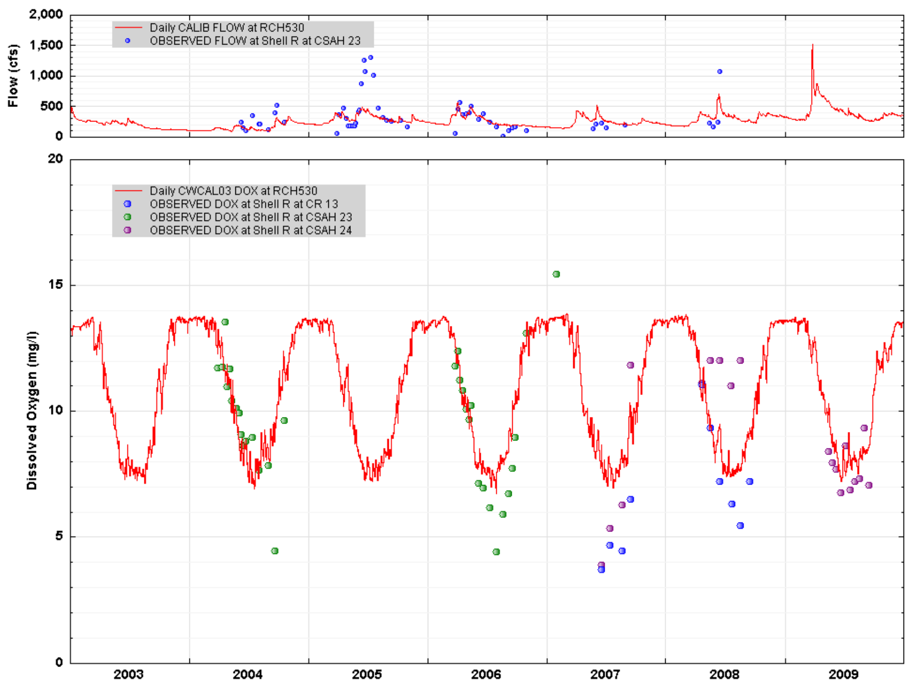


(b)

Figure 4.9 Observed and simulated DO concentrations at (a) Straight Lake and (b) Sibley Lake in the Crow Wing River watershed



(a)



(b)

Figure 4.10 Observed and simulated DO concentrations at (a) Straight River and (b) Shell River in the Crow Wing River Watershed

4.3 NITROGEN

Nitrogen (N) is simulated as Nitrate-Nitrogen (NO_3-N) and Ammonia-Nitrogen (NH_4-N) on the land surfaces. Organic N is calculated as a fraction (0.048) of total BOD-Organics entering into streams. NO_3-N, NH_4-N, and BOD are represented as buildup-washoff parameters on the land surface. The buildup and washoff of these constituents, as represented by the parameters ACCUM and SQOLIM, was adopted from the Minnesota River Turbidity TMDL report (Tetra Tech, 2002) for all the land uses except agriculture as explained below, as there was no reason to believe that the loading of these nutrients in Crow Wing River watersheds would differ from Minnesota River watersheds.

The ACCUM and SQOLIM parameters for agricultural areas were calculated in the Minnesota River TMDL based on the type of tillage (conventional and conservation) and manure application. In the Crow Wing watersheds, there was no evidence of conservation tillage (personal communication, Chuck Regan); therefore all the agriculture area was considered under conventional tillage, and under manure application if enough manure was available in the area.

Manure availability was estimated based on the number of animal units in each model segment of the three watersheds. A GIS file obtained from MPCA provided the locations of feedlots, type of animals, and number of animal units in each watershed (Figure 4.11). About 511 out of 1549 feedlots had less than 50 animal units and totaled about 6% of total animal units in the three Crow Wing Watersheds. These feedlots were ignored in the estimation of manure application to cropland and pasture land areas to simplify the calculation. Adapting from the previous studies, an average animal manure application area per animal unit was assumed at 1.29623 acres/animal unit (memo dated June 27, 2002 by Nick Gervino from MPCA to the watershed support unit). The number of acres on which animal manure was applied was calculated by simply multiplying the number of animal units in each model segment by the 1.29623 acres/animal unit factor. The resulting acreage was then compared with the total cropland area in each model segment. A weighted average of ACCUM and SQOLIM based on ACCUM and SQOLIM rates for conventional tillage and manured land as estimated by Tetra Tech (2002) was calculated (e.g., Table 4.2). If the total cropland area was less than the area on which manure could be applied to (5 out of 34 Met segments), the ACCUM rate for manured land was used, and the ACCUM rate for Pasture areas was doubled assuming that the remaining manure will be applied to pasture areas.

The concentration of NO_3-N, and NH_4-N in interflow and groundwater was adopted from Tetra Tech, 2002 and USEPA, 2005. The concentrations of interflow and groundwater for some model segments were adjusted (mostly decreased) during the calibration process to match well with the observed data. In some model segments, the accumulation rate of nutrients was also reduced to better match the observed data.

Overall loading of NO_3-N, and NH_4-N, Refractory and Organic N are presented in Table 4.3 to Table 4.5 for all the three watersheds. In general, the NO_3-N, and NH_4-N loadings are greatest from croplands. The lowest loadings are from forested areas. Table 4.6 shows nitrogen loads and percentages from various sources in each watershed.

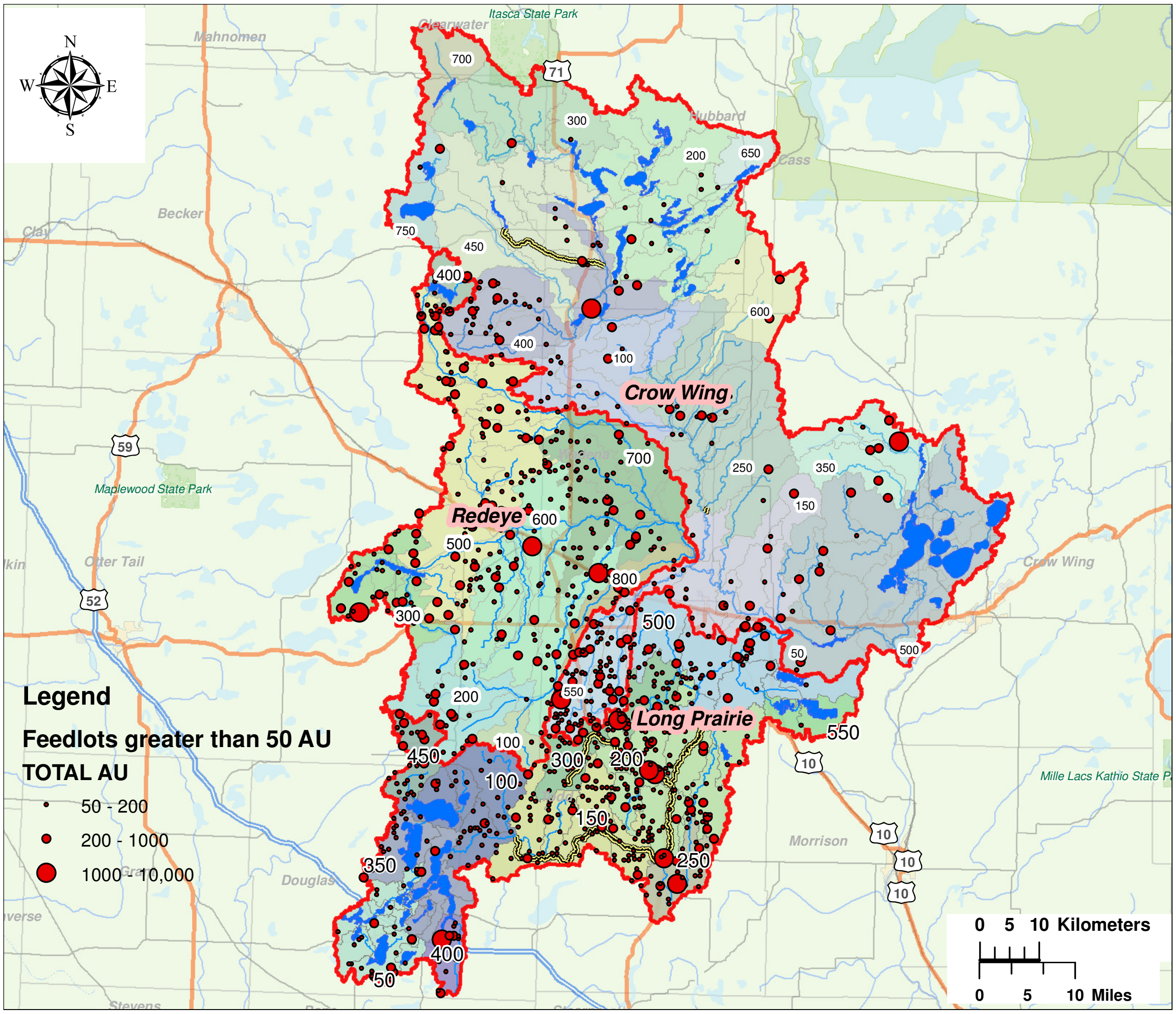


Figure 4.11 Locations of feedlots with more than 50 animal units in the Redeye, Long Prairie, and Crow Wing Watersheds

Table 4.2 Example calculation for ACCUM rate of NO_3-N at one of the Met Segments in Crow Wing River Watershed

Total Cropland (ac)	Area on which the manure can be applied (ac)	Ratio
6987.5	5929.7	0.849
NO_3-N ACCUM Rate for Conventional Cropland for January (lbs/ac)		0.297
NO_3-N ACCUM Rate for Manured Land in January (lbs/ac)		0.461
Weighted NO_3-N ACCUM Rate in January (lbs/ac)		0.461 * 0.849 + 0.297 * (1-0.849)
		0.436

Table 4.3 Loadings of various forms of nitrogen from different landuses in lbs/ac in the Long Prairie River Watershed for the calibration period

Land Use	Forest AB	Forest CD	Wetland	Grass-land AB	Grass-land CD	Pasture AB	Pasture CD	Crop-land AB	Crop-land CD	Crop-land - Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity	Water-shed Average
PERLND														
Area (ac)	61,920	55,045	66,715	21,689	25,795	46,932	71,722	88,702	47,003	14,007	26,787	5,210	1,211	532,736
NO_3-N														
Surface Flow	0.024	0.014	0.003	0.117	0.133	0.113	0.141	0.468	0.765	0.154	0.857	0.847	0.772	0.247
Interflow	0.026	0.027	0.002	0.252	0.264	0.262	0.267	0.899	1.219	1.581	0.644	0.652	0.698	0.427
Groundwater Flow	0.180	0.167	0.144	1.015	0.979	1.033	0.991	1.927	1.898	1.806	1.654	1.723	1.814	1.009
Total	0.230	0.208	0.150	1.384	1.376	1.407	1.398	3.295	3.882	3.541	3.154	3.223	3.284	1.684
NH_3 + NH_4 as N														
Surface Flow	0.024	0.011	0.003	0.085	0.090	0.085	0.106	0.074	0.128	0.025	0.503	0.511	0.477	0.090
Interflow	0.008	0.009	0.001	0.032	0.038	0.032	0.038	0.042	0.063	0.079	0.090	0.085	0.089	0.033
Groundwater Flow	0.062	0.064	0.056	0.103	0.106	0.101	0.106	0.126	0.132	0.122	0.191	0.181	0.185	0.101
Total	0.094	0.085	0.060	0.220	0.234	0.218	0.250	0.242	0.324	0.226	0.783	0.776	0.750	0.224
Labile Organic N														
Surface Flow	0.008	0.004	0.000	0.044	0.051	0.041	0.057	0.045	0.053	0.009	0.092	0.106	0.107	0.035
Interflow	0.005	0.006	0.001	0.037	0.041	0.037	0.041	0.043	0.060	0.078	0.103	0.100	0.106	0.034
Groundwater Flow	0.045	0.047	0.040	0.131	0.136	0.129	0.136	0.719	0.742	0.678	0.236	0.223	0.228	0.274
Total	0.058	0.056	0.041	0.211	0.228	0.206	0.234	0.807	0.855	0.765	0.432	0.429	0.441	0.344
Refractory Organic N														
Surface Flow	0.017	0.008	0.000	0.099	0.115	0.093	0.129	0.103	0.120	0.020	0.210	0.239	0.242	0.080
Interflow	0.011	0.013	0.001	0.083	0.093	0.083	0.092	0.098	0.136	0.178	0.234	0.228	0.241	0.078
Groundwater Flow	0.102	0.106	0.091	0.297	0.308	0.292	0.308	1.630	1.682	1.536	0.534	0.505	0.517	0.622
Total	0.131	0.127	0.093	0.479	0.517	0.467	0.530	1.830	1.938	1.734	0.978	0.972	0.999	0.779
Total Nitrogen	**0.513**	**0.476**	**0.344**	**2.294**	**2.355**	**2.298**	**2.412**	**6.174**	**6.999**	**6.266**	**5.347**	**5.400**	**5.474**	**3.031**
IMPLND														
Area (ac)											547	579	658	1,784
NO_3-N (Surface Flow)											5.319	5.307	5.351	5.327
NH_3 + NH_4 as N (Surface Flow)											3.496	3.493	3.540	3.511
Labile Organic N (Surface Flow)											0.648	0.646	0.649	0.648
Refractory Organic N (Surface Flow)											1.470	1.464	1.471	1.468
Total N											**10.933**	**10.910**	**11.011**	**10.954**

Table 4.4 Loading of various forms of nitrogen from different landuses in lbs/ac in the Redeye River Watershed for the calibration period

Land Use	Forest AB	Forest CD	Wetland	Grass-land AB	Grass-land CD	Pasture AB	Pasture CD	Crop-land AB	Crop-land CD	Crop-land - Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity	Water-shed Average
Pervious Landuses														
Area (ac)	46,871	83,838	100,799	18,787	29,542	51,299	65,232	110,788	23,285	11,703	22,285	2,266	415	567,110
NO_3-N														
Surface Flow	0.006	0.005	0.002	0.055	0.071	0.047	0.076	0.230	0.625	0.145	0.611	0.580	0.512	0.121
Interflow	0.017	0.019	0.002	0.187	0.207	0.183	0.201	0.773	0.998	1.329	0.620	0.650	0.671	0.308
Groundwater Flow	0.157	0.139	0.133	0.999	0.923	0.985	0.910	1.950	1.717	1.744	1.455	1.509	1.432	0.884
Total	0.180	0.163	0.136	1.240	1.202	1.216	1.186	2.954	3.340	3.218	2.685	2.739	2.615	1.312
NH_3 + NH_4 as N														
Surface Flow	0.003	0.002	0.002	0.029	0.039	0.026	0.041	0.025	0.067	0.015	0.313	0.294	0.258	0.032
Interflow	0.006	0.007	0.001	0.026	0.031	0.025	0.031	0.036	0.049	0.065	0.090	0.093	0.097	0.024
Groundwater Flow	0.059	0.063	0.055	0.104	0.102	0.104	0.102	0.134	0.125	0.125	0.196	0.201	0.207	0.096
Total	0.068	0.072	0.057	0.159	0.171	0.155	0.173	0.194	0.241	0.206	0.599	0.588	0.562	0.153
Labile Organic N														
Surface Flow	0.003	0.003	0.000	0.027	0.028	0.024	0.033	0.018	0.049	0.010	0.079	0.069	0.056	0.018
Interflow	0.003	0.004	0.000	0.029	0.035	0.030	0.034	0.029	0.040	0.054	0.104	0.110	0.117	0.023
Groundwater Flow	0.044	0.046	0.038	0.134	0.130	0.134	0.130	0.776	0.707	0.707	0.238	0.247	0.255	0.261
Total	0.051	0.052	0.039	0.190	0.193	0.188	0.197	0.824	0.796	0.771	0.421	0.426	0.428	0.303
Refractory Organic N														
Surface Flow	0.007	0.006	0.000	0.062	0.064	0.054	0.074	0.042	0.111	0.022	0.179	0.156	0.127	0.041
Interflow	0.007	0.009	0.001	0.067	0.079	0.067	0.078	0.066	0.090	0.122	0.235	0.249	0.265	0.053
Groundwater Flow	0.100	0.103	0.087	0.303	0.295	0.304	0.294	1.760	1.603	1.603	0.539	0.560	0.579	0.592
Total	0.114	0.118	0.088	0.432	0.438	0.425	0.446	1.867	1.804	1.748	0.954	0.965	0.971	0.686
Total N (Pervious)	**0.413**	**0.405**	**0.320**	**2.021**	**2.004**	**1.984**	**2.002**	**5.839**	**6.181**	**5.943**	**4.659**	**4.718**	**4.576**	**2.454**
Impervious Landuses														
Area (ac)											455	252	224	930
NO_3-N (Surface Flow)											6.893	6.954	7.000	6.935
NH_3 + NH_4 as N (Surface Flow)											3.432	3.456	3.483	3.451
Labile Organic N (Surface Flow)											0.655	0.660	0.662	0.658
Refractory Organic N (Surface Flow)											1.484	1.496	1.501	1.492
Total N (Impervious)											**12.464**	**12.566**	**12.646**	**12.536**

Table 4.5 Loading of various forms of Nitrogen from different landuses in lbs/ac in the Crow Wing River Watershed for the calibration period

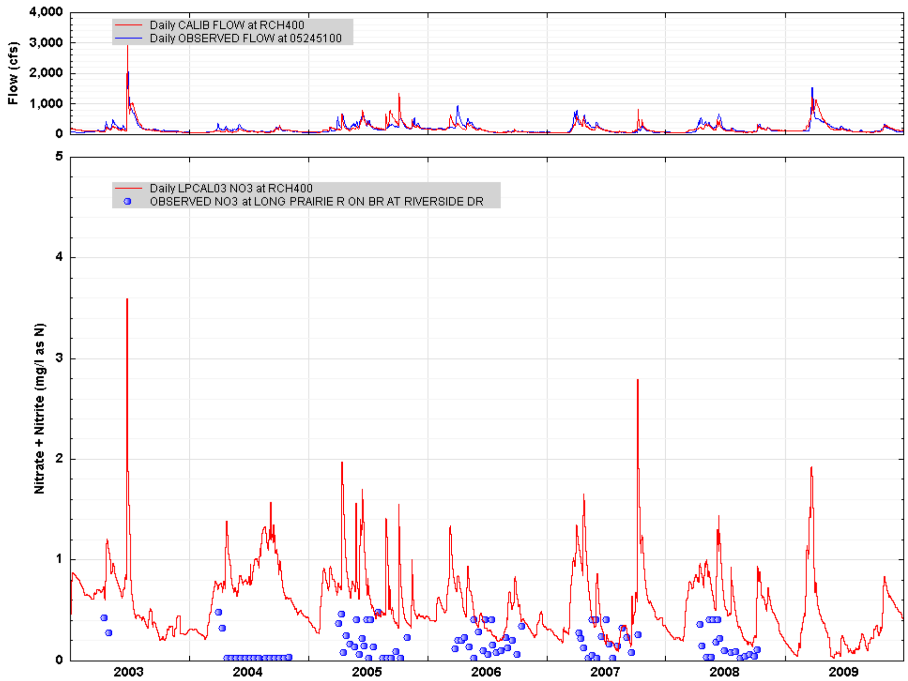
Land Use	Forest AB	Forest CD	Wetland	Grass-land AB	Grass-land CD	Pasture AB	Pasture CD	Crop-land AB	Crop-land CD	Crop-land - Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity	Water-shed Average
PERLND														
Area (ac)	196	393,204	201,743	218,953	53,581	34,151	72,855	70,611	99,169	27,067	37,387	4,315	739	1,213,970
NO_3-N														
Surface Flow	0.060	0.002	0.002	0.001	0.045	0.077	0.022	0.067	0.111	0.411	0.407	0.382	0.320	0.043
Interflow	1.272	0.013	0.015	0.003	0.200	0.238	0.132	0.171	0.807	1.188	0.447	0.446	0.448	0.149
Groundwater Flow	1.919	0.191	0.191	0.172	1.320	1.326	1.118	1.118	2.397	2.422	2.168	2.077	1.852	0.678
Total	3.250	0.206	0.208	0.175	1.564	1.641	1.272	1.356	3.316	4.021	3.022	2.905	2.620	0.869
NH_3 + NH_4 as N														
Surface Flow	0.006	0.001	0.001	0.001	0.024	0.046	0.010	0.029	0.009	0.044	0.208	0.200	0.171	0.014
Interflow	0.068	0.004	0.004	0.001	0.025	0.029	0.016	0.021	0.039	0.055	0.059	0.060	0.064	0.013
Groundwater Flow	0.138	0.065	0.067	0.055	0.130	0.128	0.108	0.108	0.150	0.140	0.208	0.208	0.213	0.087
Total	0.212	0.069	0.072	0.057	0.179	0.203	0.135	0.158	0.198	0.238	0.475	0.468	0.448	0.114
Labile Organic N														
Surface Flow	0.001	0.000	0.001	0.000	0.026	0.047	0.011	0.032	0.005	0.020	0.052	0.047	0.035	0.008
Interflow	0.049	0.002	0.002	0.000	0.025	0.029	0.017	0.021	0.028	0.042	0.063	0.064	0.068	0.011
Groundwater Flow	0.680	0.039	0.040	0.033	0.145	0.142	0.123	0.123	0.755	0.705	0.230	0.230	0.236	0.136
Total	0.730	0.041	0.043	0.033	0.197	0.218	0.150	0.177	0.788	0.766	0.345	0.341	0.340	0.154
Refractory Organic N														
Surface Flow	0.003	0.001	0.001	0.000	0.060	0.106	0.024	0.072	0.011	0.046	0.117	0.106	0.080	0.018
Interflow	0.110	0.004	0.005	0.001	0.057	0.066	0.038	0.049	0.062	0.094	0.144	0.146	0.155	0.024
Groundwater Flow	1.542	0.088	0.091	0.075	0.329	0.323	0.279	0.280	1.712	1.597	0.521	0.521	0.535	0.308
Total	1.655	0.092	0.097	0.076	0.446	0.495	0.341	0.400	1.786	1.737	0.782	0.773	0.770	0.349
Total Nitrogen	**5.847**	**0.408**	**0.420**	**0.341**	**2.386**	**2.557**	**1.898**	**2.091**	**6.088**	**6.762**	**4.624**	**4.487**	**4.178**	**1.486**
IMPLND														
Area (ac)											762	478	398	1,638
NO_3-N (Surface Flow)											6.441	6.432	6.463	6.444
NH_3 + NH_4 as N (Surface Flow)											3.258	3.259	3.263	3.259
Labile Organic N (Surface Flow)											0.623	0.621	0.624	0.623
Refractory Organic N (Surface Flow)											1.411	1.409	1.415	1.411
Total N											**11.733**	**11.721**	**11.765**	**11.737**

Table 4.6 Nitrogen loads (lbs) and percentages from various sources in each watershed

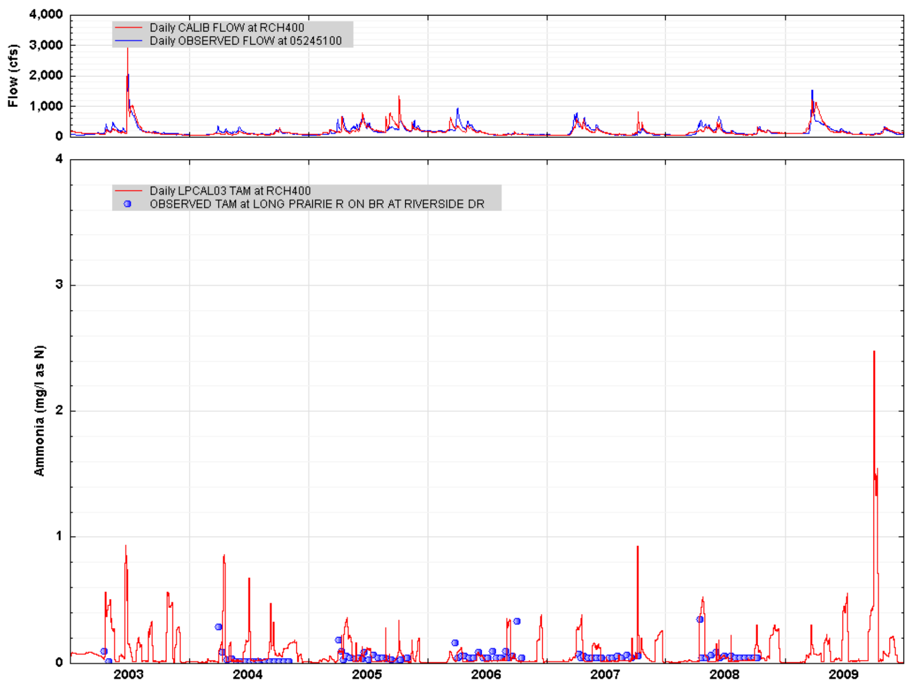
	Long Prairie		Redeye		Crow Wing	
	Load	Percent	Load	Percent	Load	Percent
Pervious	1,614,723	93.3%	1,391,688	98.3%	1,803,959	47.6%
Impervious	19,541	1.1%	11,658	0.8%	19,225	0.5%
Point Sources	95,752	5.5%	12,024	0.8%	130,785	3.5%
Upstream Watersheds	0	0.0%	0	0.0%	1,835,150	48.4%
Total	1,730,015		1,415,370		3,789,119	

The calibration of N components (NO3-N, NH4-N, Org-N, and Total N) was conducted in tandem with other water quality constituents. For example, if enough P is not available, then not enough phytoplankton and algae can grow and N concentration keeps increasing during the period of simulation, and vice versa. In some cases, the input of N from point sources was also reduced to better match with the observed data. The Figure 4.12 and Figure 4.13 show example plots of N constituents in the Long Prairie and Crow Wing River watersheds. Remaining plots for all the constituents are available in APPENDIX K. As evident in the graphs, the simulated constituent values are very close to the observed values and are within the margin of expected errors in measurements and recording. Some outliers could not be explained well by the model.

It must be noted here that the quality of water quality simulation depends largely on the quality of hydrology simulation. The hydrology simulation was conducted on the four different USGS gages, but the water quality data is available at several additional locations without detailed hydrology data. Also, these watersheds were dominated by lakes, and the hydrology of lakes depends heavily on the outlet structure about which we had very little information. The water quality calibration can be further improved when extending the model, by collecting more information about the hydraulic structures in the watershed.



(a)



(b)

Figure 4.12 Observed and Simulated (a) Nitrate-Nitrogen, and (b)Total Ammonia concentration at USGS gage 05245100 on the Long Prairie River

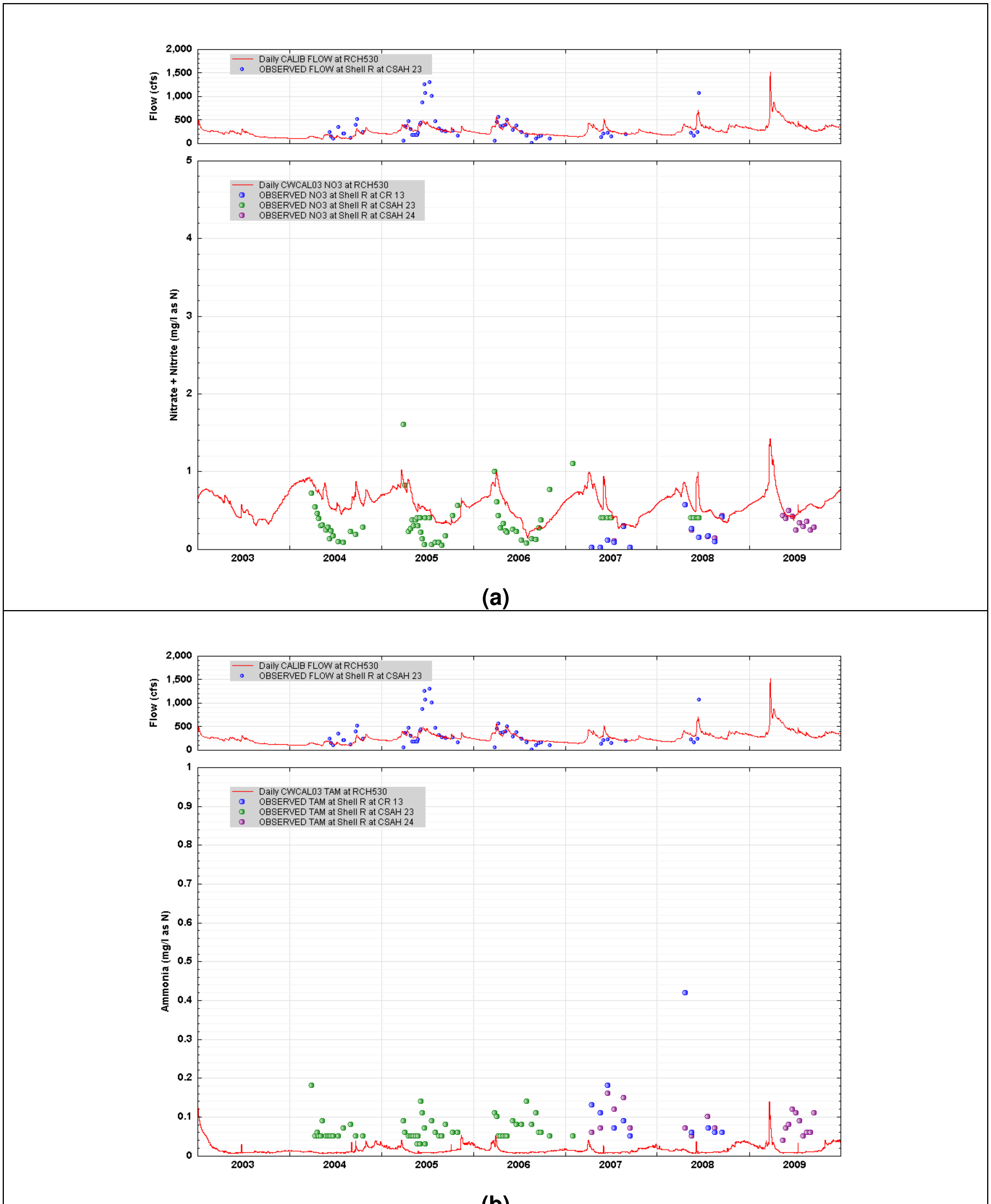


Figure 4.13 Observed and Simulated (a) Nitrate-Nitrogen, and (b)Total Ammonia concentration at Shell River in the Crow Wing River Watershed

4.4 PHOSPHORUS

HSPF simulates surface washoff of inorganic P using a potency factor approach, where the inorganic P load is estimated as a fraction of sediment yield. Organic P is calculated as a fraction (0.0023) of total BOD-Organics entering into streams.. The potency factors for all the land uses were adopted from the previous models (Tetra Tech, 2009 and AQUA TERRA Consultants, 2005). To calculate the potency factor of inorganic phosphorus and organic matter for agricultural areas, methodology similar to the calculation of ACCUM and SQOLIM for NO_3-N, and NH_4-N was used.

The loading of different P components from land surfaces is presented in Table 4.7 to Table 4.9. As noted above, simulation of P depends upon other water quality constituents as well; therefore calibration of all water quality constituents was conducted in tandem. Table 4.10 shows phosphorus loads from various sources in each watershed. Figure 4.14 and Figure 4.15 show the simulation of Ortho P and Total P at two locations in the Long Prairie and Crow Wing River watersheds. All the remaining graphs for calibration and validation periods are available in APPENDIX M and APPENDIX N. Overall, the model simulates the P concentration reasonably well.

Table 4.7 Loading of various forms of phosphorus from different landuses in lbs/ac in the Long Prairie River Watershed for the calibration period

Land Use	Forest AB	Forest CD	Wetland	Grass-land AB	Grass-land CD	Pasture AB	Pasture CD	Crop-land AB	Crop-land CD	Crop-land - Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity	Water-shed Average
PERLND														
Area (ac)	61,920	55,045	66,715	21,689	25,795	46,932	71,722	88,702	47,003	14,007	26,787	5,210	1,211	532,736
Ortho P														
Surface Flow	0.012	0.005	0.000	0.067	0.078	0.063	0.088	0.083	0.094	0.016	0.142	0.162	0.164	0.057
Interflow	0.001	0.001	0.000	0.004	0.005	0.004	0.005	0.013	0.016	0.021	0.010	0.010	0.011	0.006
Groundwater Flow	0.004	0.004	0.003	0.018	0.018	0.017	0.018	0.055	0.057	0.052	0.022	0.021	0.021	0.024
Total	0.016	0.010	0.003	0.089	0.102	0.085	0.111	0.151	0.168	0.089	0.174	0.193	0.196	0.088
Refractory Organic P														
Surface Flow	0.001	0.000	0.000	0.005	0.006	0.004	0.006	0.005	0.006	0.001	0.010	0.011	0.012	0.004
Interflow	0.001	0.001	0.000	0.004	0.004	0.004	0.004	0.005	0.007	0.009	0.011	0.011	0.012	0.004
Groundwater Flow	0.005	0.005	0.004	0.014	0.015	0.014	0.015	0.078	0.081	0.074	0.026	0.024	0.025	0.030
Total	0.006	0.006	0.004	0.023	0.025	0.022	0.025	0.088	0.093	0.083	0.047	0.047	0.048	0.037
Labile Organic P														
Surface Flow	0.001	0.000	0.000	0.006	0.007	0.006	0.008	0.006	0.007	0.001	0.013	0.015	0.015	0.005
Interflow	0.001	0.001	0.000	0.005	0.006	0.005	0.006	0.006	0.008	0.011	0.014	0.014	0.015	0.005
Groundwater Flow	0.006	0.006	0.006	0.018	0.019	0.018	0.019	0.099	0.103	0.094	0.033	0.031	0.032	0.038
Total	0.008	0.008	0.006	0.029	0.032	0.029	0.032	0.112	0.118	0.106	0.060	0.059	0.061	0.048
Total Phosphorus	**0.030**	**0.024**	**0.013**	**0.141**	**0.159**	**0.136**	**0.168**	**0.351**	**0.379**	**0.278**	**0.281**	**0.299**	**0.305**	**0.173**
IMPLND														
Area (ac)											547	579	658	1,784
Ortho P (Surface Flow)											0.401	0.396	0.399	0.399
Refractory Organic P (Surface Flow)											0.070	0.070	0.070	0.070
Labile Organic P (Surface Flow)											0.090	0.899	0.090	0.090
Total P											**0.561**	**0.555**	**0.559**	**0.559**

Table 4.8 Loading of various forms of phosphorus from different landuses in lbs/ac in the Redeye River Watershed for the calibration period

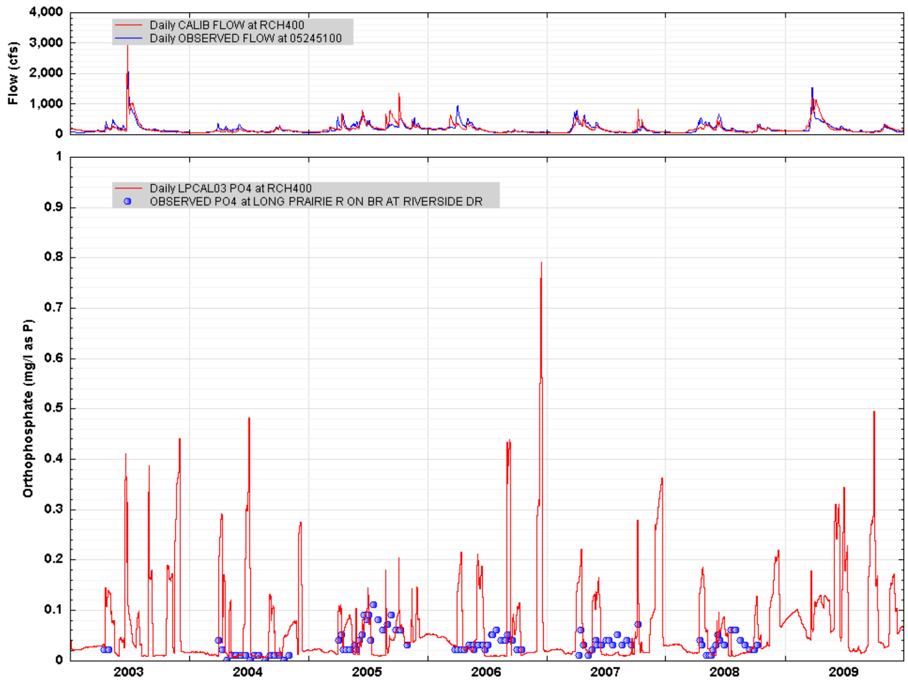
Land Use	Forest AB	Forest CD	Wetland	Grass-land AB	Grass-land CD	Pasture AB	Pasture CD	Crop-land AB	Crop-land CD	Crop-land - Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity	Water-shed Average
PERLND														
Area (ac)	46,871	83,838	100,799	18,787	29,542	51,299	65,232	110,788	23,285	11,703	22,285	2,266	415	567,110
Ortho P														
Surface Flow	0.005	0.004	0.000	0.042	0.043	0.037	0.050	0.094	0.323	0.053	0.121	0.106	0.086	0.052
Interflow	0.001	0.001	0.000	0.003	0.004	0.003	0.004	0.010	0.013	0.017	0.011	0.011	0.012	0.005
Groundwater Flow	0.004	0.004	0.003	0.018	0.018	0.019	0.018	0.061	0.056	0.056	0.023	0.024	0.024	0.023
Total	0.009	0.009	0.003	0.064	0.066	0.059	0.072	0.164	0.393	0.126	0.155	0.140	0.122	0.079
Refractory Organic P														
Surface Flow	0.000	0.000	0.000	0.003	0.003	0.003	0.004	0.002	0.005	0.001	0.009	0.007	0.006	0.002
Interflow	0.000	0.000	0.000	0.003	0.004	0.003	0.004	0.003	0.004	0.006	0.011	0.012	0.013	0.003
Groundwater Flow	0.005	0.005	0.004	0.015	0.014	0.015	0.014	0.084	0.077	0.077	0.026	0.027	0.028	0.028
Total	0.005	0.006	0.004	0.021	0.021	0.020	0.021	0.089	0.086	0.084	0.046	0.046	0.047	0.033
Labile Organic P														
Surface Flow	0.000	0.000	0.000	0.004	0.004	0.003	0.005	0.003	0.007	0.001	0.011	0.010	0.008	0.003
Interflow	0.000	0.001	0.000	0.004	0.005	0.004	0.005	0.004	0.005	0.007	0.014	0.015	0.016	0.003
Groundwater Flow	0.006	0.006	0.005	0.018	0.018	0.019	0.018	0.107	0.098	0.098	0.033	0.034	0.035	0.036
Total	0.007	0.007	0.005	0.026	0.027	0.026	0.027	0.114	0.110	0.107	0.058	0.059	0.059	0.042
Total Phosphorus	**0.021**	**0.022**	**0.012**	**0.111**	**0.114**	**0.105**	**0.120**	**0.367**	**0.589**	**0.317**	**0.259**	**0.245**	**0.228**	**0.154**
IMPLND														
Area (ac)											455	252	224	930
Ortho P (Surface Flow)											0.397	0.401	0.403	0.400
Refractory Organic P (Surface Flow)											0.071	0.072	0.072	0.071
Labile Organic P (Surface Flow)											0.091	0.091	0.092	0.091
Total P											**0.559**	**0.564**	**0.567**	**0.562**

Table 4.9 Loading of various forms of phosphorus from different landuses in lbs/ac in the Crow Wing River Watershed for the calibration period

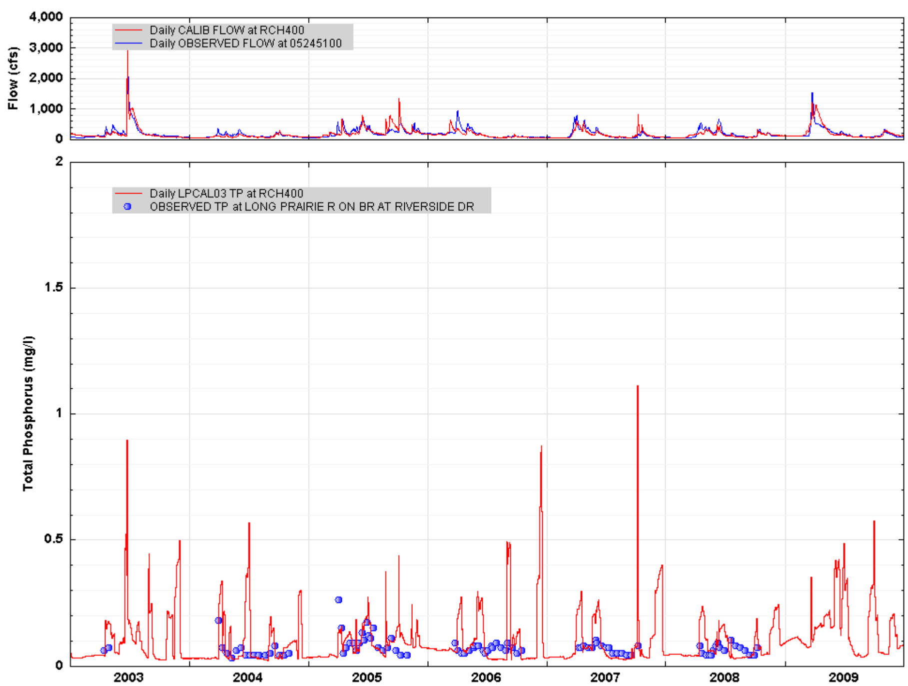
Land Use	Forest AB	Forest CD	Wetland	Grass-land AB	Grass-land CD	Pasture AB	Pasture CD	Crop-land AB	Crop-land CD	Crop-land - Drained	Dev, Open Space	Dev, Low Intensity	Dev, Medium Intensity	Water-shed Average
PERLND														
Area (ac)	196	393,204	201,743	218,953	53,581	34,151	72,855	70,611	99,169	27,067	37,387	4,315	739	1,213,970
Ortho P														
Surface Flow	0.007	0.001	0.001	0.000	0.041	0.072	0.018	0.064	0.021	0.156	0.079	0.072	0.054	0.017
Interflow	0.014	0.000	0.000	0.000	0.003	0.003	0.002	0.002	0.009	0.012	0.006	0.006	0.007	0.002
Groundwater Flow	0.054	0.003	0.003	0.003	0.020	0.019	0.017	0.017	0.060	0.056	0.022	0.022	0.023	0.012
Total	0.075	0.004	0.004	0.003	0.063	0.095	0.036	0.084	0.089	0.224	0.107	0.100	0.083	0.031
Refractory Organic P														
Surface Flow	0.000	0.000	0.000	0.000	0.003	0.005	0.001	0.003	0.001	0.002	0.006	0.005	0.004	0.001
Interflow	0.005	0.000	0.000	0.000	0.003	0.003	0.002	0.002	0.003	0.005	0.007	0.007	0.007	0.001
Groundwater Flow	0.074	0.004	0.004	0.004	0.016	0.015	0.013	0.013	0.082	0.077	0.025	0.025	0.026	0.015
Total	0.079	0.004	0.005	0.004	0.021	0.024	0.016	0.019	0.086	0.083	0.037	0.037	0.037	0.017
Labile Organic P														
Surface Flow	0.000	0.000	0.000	0.000	0.004	0.006	0.001	0.004	0.001	0.003	0.007	0.006	0.005	0.001
Interflow	0.007	0.000	0.000	0.000	0.003	0.004	0.002	0.003	0.004	0.006	0.009	0.009	0.009	0.001
Groundwater Flow	0.094	0.005	0.006	0.005	0.020	0.020	0.017	0.017	0.105	0.097	0.032	0.032	0.033	0.019
Total	0.101	0.006	0.006	0.005	0.027	0.030	0.021	0.024	0.109	0.106	0.048	0.047	0.047	0.021
Total Phosphorus	**0.255**	**0.014**	**0.015**	**0.012**	**0.111**	**0.149**	**0.073**	**0.127**	**0.284**	**0.413**	**0.192**	**0.184**	**0.167**	**0.069**
IMPLND														
Area (ac)											762	478	398	1,638
Ortho P (Surface Flow)											0.368	0.367	0.369	0.368
Refractory Organic P (Surface Flow)											0.068	0.068	0.068	0.068
Labile Organic P (Surface Flow)											0.086	0.086	0.086	0.086
Total P											**0.522**	**0.521**	**0.523**	**0.522**

Table 4.10 Phosphorus loads (lbs) and percentages from various sources in each watershed

	Long Prairie		Redeye		Crow Wing	
	Load	Percent	Load	Percent	Load	Percent
Pervious	92,163	81.9%	87,335	92.2%	83,764	35.4%
Impervious	997	0.9%	523	0.6%	855	0.4%
Point Sources	19,359	17.2%	6,869	7.3%	11,027	4.7%
Upstream Watersheds	0	0.0%	0	0.0%	140,931	59.6%
Total	112,520		94,727		236,577	



(a)



(b)

Figure 4.14 Observed and simulated (a) Orthophosphorus as P, and (b) Total P concentration at USGS gage 05245100 in Long Prairie River

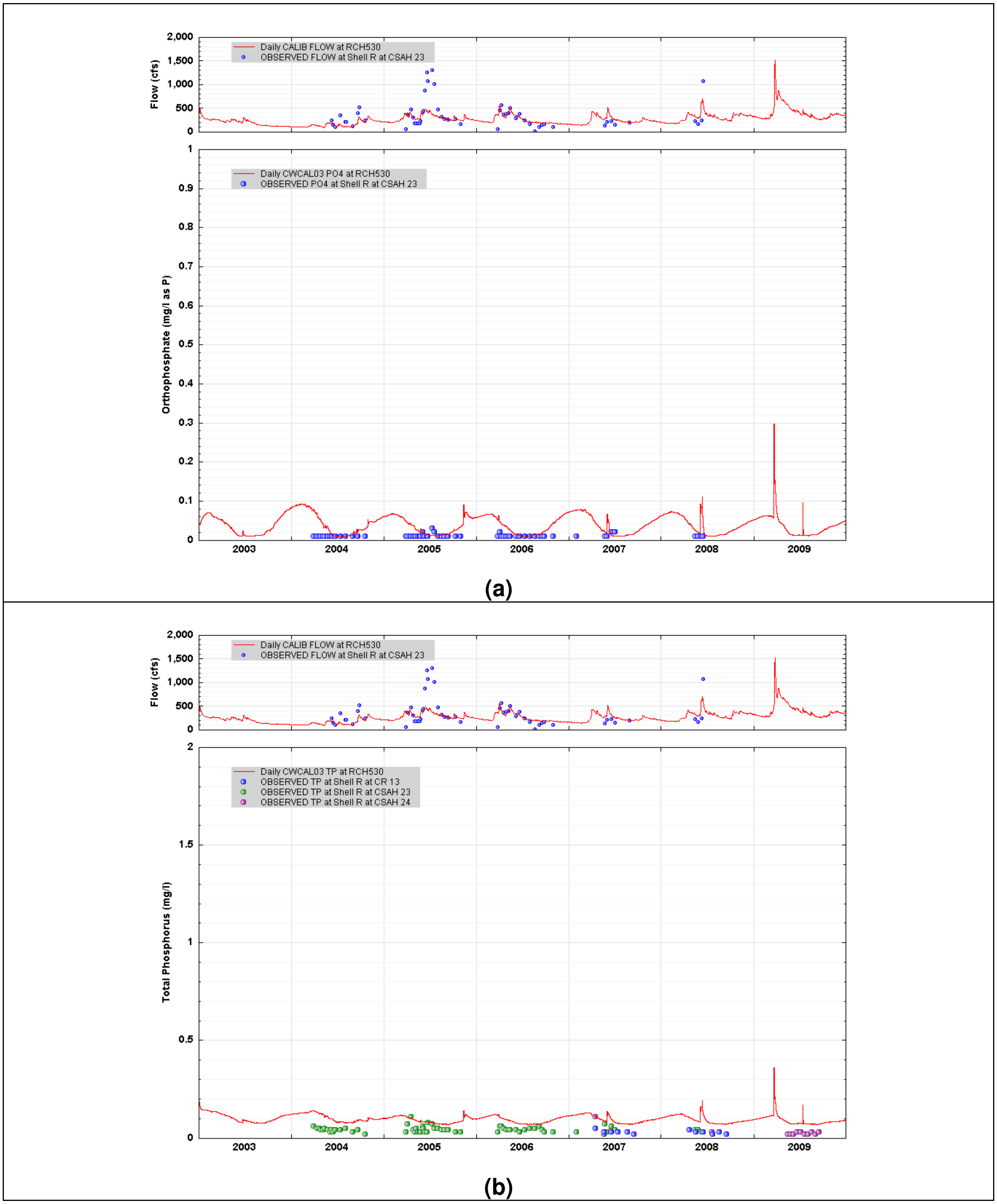


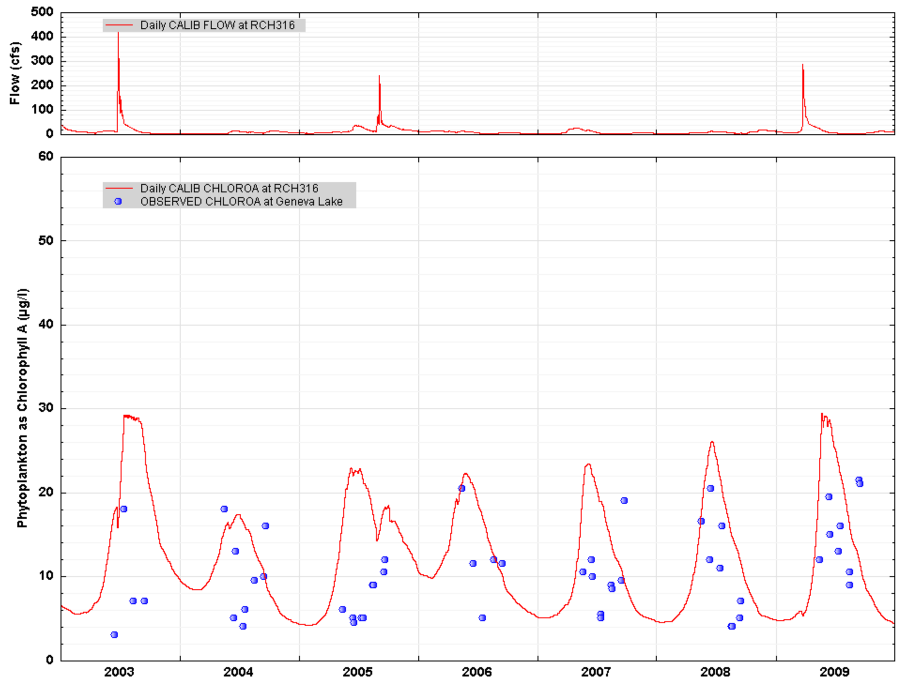
Figure 4.15 Observed and Simulated (a) Orthophosphorus as P, and (b) Total P at Shell River in Crow Wing River Watershed

4.5 PHYTOPLANKTON AS CHLOROPHYLL A

Phytoplankton is simulated in HSPF as a representation of algae that floats in the water of each RCHRES. Biological activity of the aquatic ecosystem depends upon the rate of primary production by these photosynthetic organisms, which in turn depends upon the physical environment, including nutrient availability, temperature, light, etc. The process of photosynthesis consumes carbon-dioxide (CO_2) and releases oxygen (O_2), while the process of respiration consumes O_2 and releases CO_2. Phytoplankton consume the nutrients in water, and through assimilation, these nutrients are transformed into organic materials. These organic materials serve as a food source for higher trophic levels. The portion of organic matter not used for food decomposes, which further affects the nutrient and organic level in the water.

With excessive phytoplankton growth, much of the oxygen supply in the water may be depleted by decomposition of dead algae and by respiration. Phytoplankton, when excessive, can place a serious stress on the system. HSPF assumes that the entire phytoplankton population consists of a single species whose mean behavior is defined through a series of generalized mathematical formulations. The details on these formulations can be obtained in the HSPF Manual (Bicknell, 2005).

Calibration of the concentration of phytoplankton is achieved through several parameters that control the conversion of one nutrient form to another and the release of these nutrients from the bed of the RCHRES. As with other water quality constituents, the calibration of phytoplankton is conducted in tandem with other nutrients as these nutrients interact with each other, and influence the phytoplankton simulation. Figure 4.16 and Figure 4.17 show the observed and simulated concentration of Phytoplankton as Chlorophyll A in two lakes in the Long Prairie and Crow Wing River watersheds. Winona Lake in the Long Prairie watershed is especially interesting as it has the greatest amount of phytoplankton recorded in the three Crow Wing River Watersheds. This lake is downstream of a point source, so it is possible that a significant amount of nutrients has settled in the bed over time, which is being released regularly to cause such a high production of chlorophyll A. There are no waterbodies upstream of this lake. During calibration, we increased the simulated release of nutrients from the bed of Winona Lake, but were still unable to match the very high observed concentrations. To improve the simulation of Winona lake, additional information is need to accurately represent the hydraulics, hydrology, sediment bed depth, and sediment nutrient concentrations. For most other lakes, and waterbodies, the simulation of phytoplankton is acceptable. Remaining graphs are available in APPENDIX Q and APPENDIX R.



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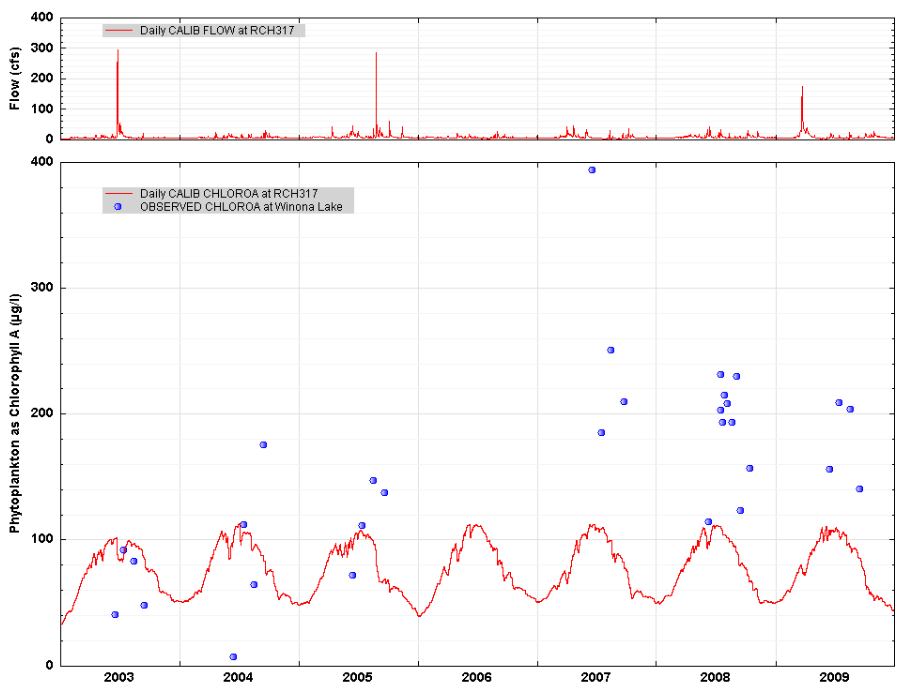
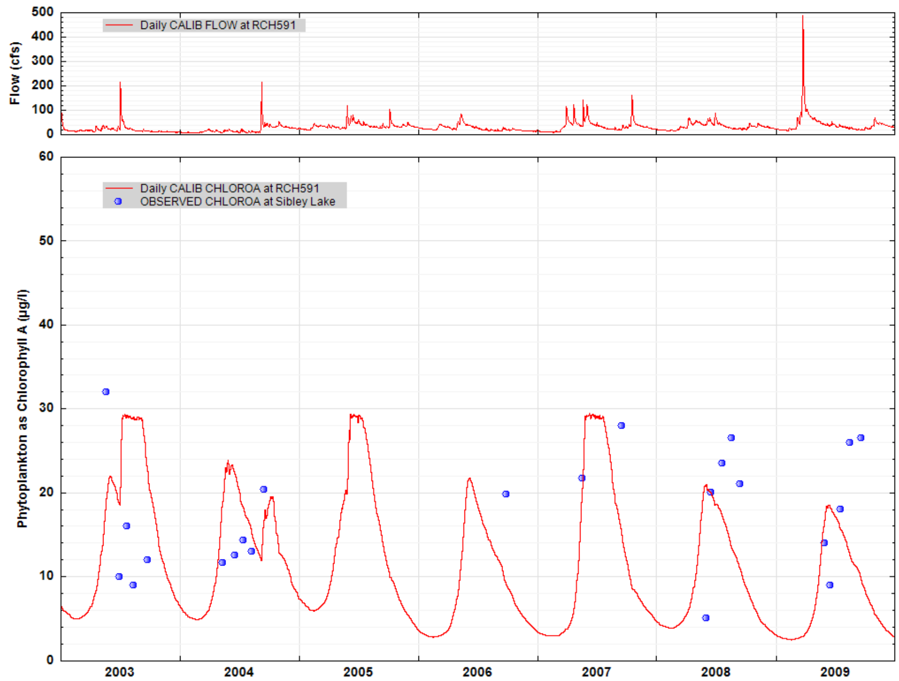


(b)

Figure 4.16 Observed and simulated Chlorophyll A as Phytoplankton in (a) Geneva Lake, and (b) Winona Lake in the Long Prairie River Watershed



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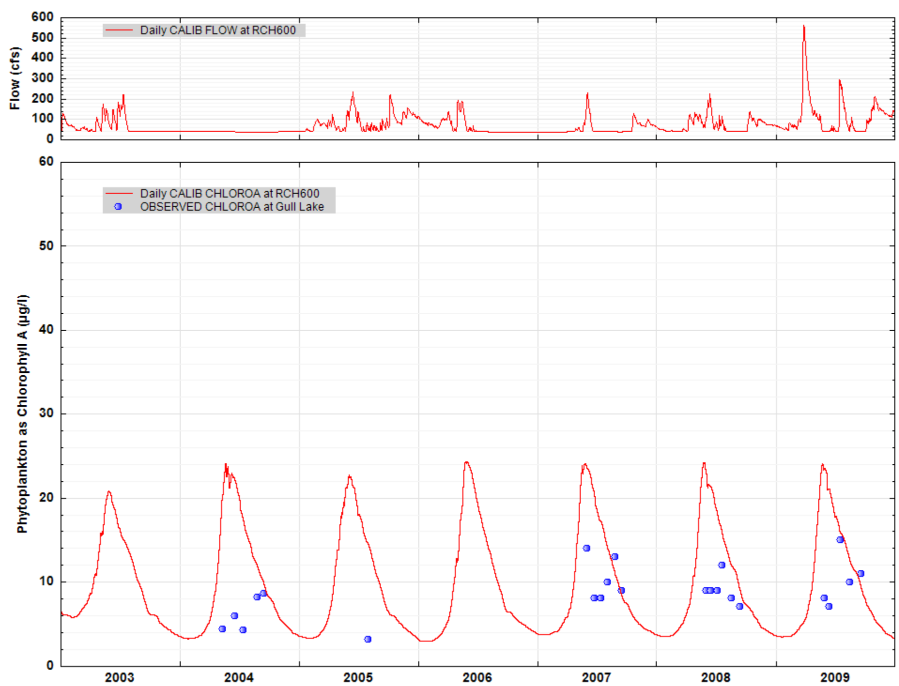


(b)

Figure 4.17 Observed and simulated Chlorophyll A as Phytoplankton in (a) Sibley Lake, and (b) Gull Lake in the Crow Wing River Watershed

SECTION 5.0
SUMMARY AND CONCLUSIONS

To support the TMDL development of several impaired waterbodies in Minnesota, MPCA has decided to develop watershed models of all the HUC-8 watersheds in MN. As a part of this ongoing effort, watershed models were developed for the Redeye, Long Prairie, and Crow Wing River Watersheds. The project was divided into several phases with a concluding phase that required AQUA TERRA Consultants to develop fully functional water quality models, and to calibrate and validate them. This report presents the details of hydrology and water quality calibration and validation results. The model files are submitted separately as part of this phase.

Overall, the hydrology calibration and validation was fair to good at all of the gages where continuous data was available. One of the long term gages, Straight River directly downstream of Straight Lake, was difficult to calibrate and validate due to seasonal input of groundwater into the system. Detailed information about the groundwater interaction can be used to improve the hydrology simulation results. Some other lakes were also suspected of having regular groundwater input, the amount of which was generally obtained by calibration The USGS gages also have a regular issue of freezing in winter which makes flow estimation in winter very difficult. These watersheds have a detailed network of precipitation gages, but regular and reliable data at some of these gages was an issue.

The presence of a significant number of lakes affects the hydrology of the watershed. Some of these lakes are managed and their flow is altered based on local requirements. However, details of the lake management were not available or were difficult to obtain. In light of some of these limitations, the hydrology calibration and validation results were satisfactory.

The hydrology simulation was sufficiently sound to provide a strong basis for water quality simulation in these watersheds. Water quality calibration included the calibration of sediment, water temperature, dissolved oxygen, nitrogen, phosphorus, and phytoplankton as chlorophyll A. Water quality data was available for multiple locations in the watershed. Although the water quality data was not sufficient to conduct a detailed statistical analysis, it was sufficient to observe trends at different parts of the watershed. The water quality calibration and validation were satisfactory.

The final hydrology and water quality model for the Redeye, Long Prairie, and Crow Wing River watersheds can be used for TMDL development. As more water quality data becomes available, the model can be extended and refined to increase the confidence in the water quality simulation.

SECTION 6.0
REFERENCES

AQUA TERRA Consultants. 2012. Summary of Hydrology Calibration Approach for Crow Wing, Redeye, and Long Prairie River Watersheds; Project deliverables for Tasks 3-1 and 2-1. Submitted to Minnesota Pollution Control Agency, St. Paul, MN.

AQUA TERRA Consultants. 2011. HSPF Model Framework Development for the Crow Wing, Redeye, and Long Prairie River Watersheds (Review Draft). Submitted to Minnesota Pollution Control Agency, St. Paul, MN.

AQUA TERRA Consultants. 2005. Nutrient Criteria Development with a Linked Modeling System: Methodology Development and Demonstration Case Studies for Blue Earth, Rum and Crow Wing Rivers, Minnesota. Submitted to USEPA, Office of Water, Washington, DC.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, T.H. Jobes, A.S. Donigian. HSPF Version 12.2 User's Manual. Submitted to Office of Surface Water, Water Resources Discipline, USGS, Reston, Virginia, 20192.

Kelley, D. W., & Nater, E. A. (2000). Historical sediment flux from three watersheds into Lake Pepin, Minnesota, USA. *Journal of Environmental Quality*, *29*(2), 561-568.

Krause, P., D.P. Boyle, and F. Bäse. 2005. Comparison of different efficiency criteria for hydrological model assessment. Advances in Geosciences, 5, 89-97.

Reisinger, D.L., and J.T. Love. 2012. HSPF Modeling of the Sauk River, Crow River, and South Fork Crow River. Topical Report RSI-2292. Prepared For MPCA, St. Paul, MN.

Schottler, S.P., D.R. Enhstom, D. Blumentritt. 2010. Fingerprinting Sources of Sediment in Large Agricultural River Systems. St. Croix Watershed Research Station: Science Museum of Minnesota. Prepared for MPCA, St. Paul, MN.

Schottler, S.P., J. Ulrich, P. Belmont, R. Moore, J.W. Lauer, D.R. Engstorm, and J.E. Almendinger. 2013. Twentieth century agricultural drainages creates more erosive rivers. Hydrological Processes. doi: 10.1002/hyp.9738

Stark, J.R., S.S. Armstrong, and D.R. Zwilling. 1994. Stream-aquifer Interactions in the Straight River Area, Becker and Hubbard Counties, Minnesota. United States

Tetra Tech. 2002. Minnesota River Basin Model. Model Calibration and Validation Report. Prepared for MPCA, St. Paul, MN.

Tetra Tech. 2009. Minnesota River Basin Turbidity TMDL and Lake Pepin Excessive Nutrient TMDL. Prepared for MPCA, St. Paul, MN.

USDA. 2010. Rapid Watershed Assessment - Redeye River. Available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022049.pdf Accessed on July 2010.

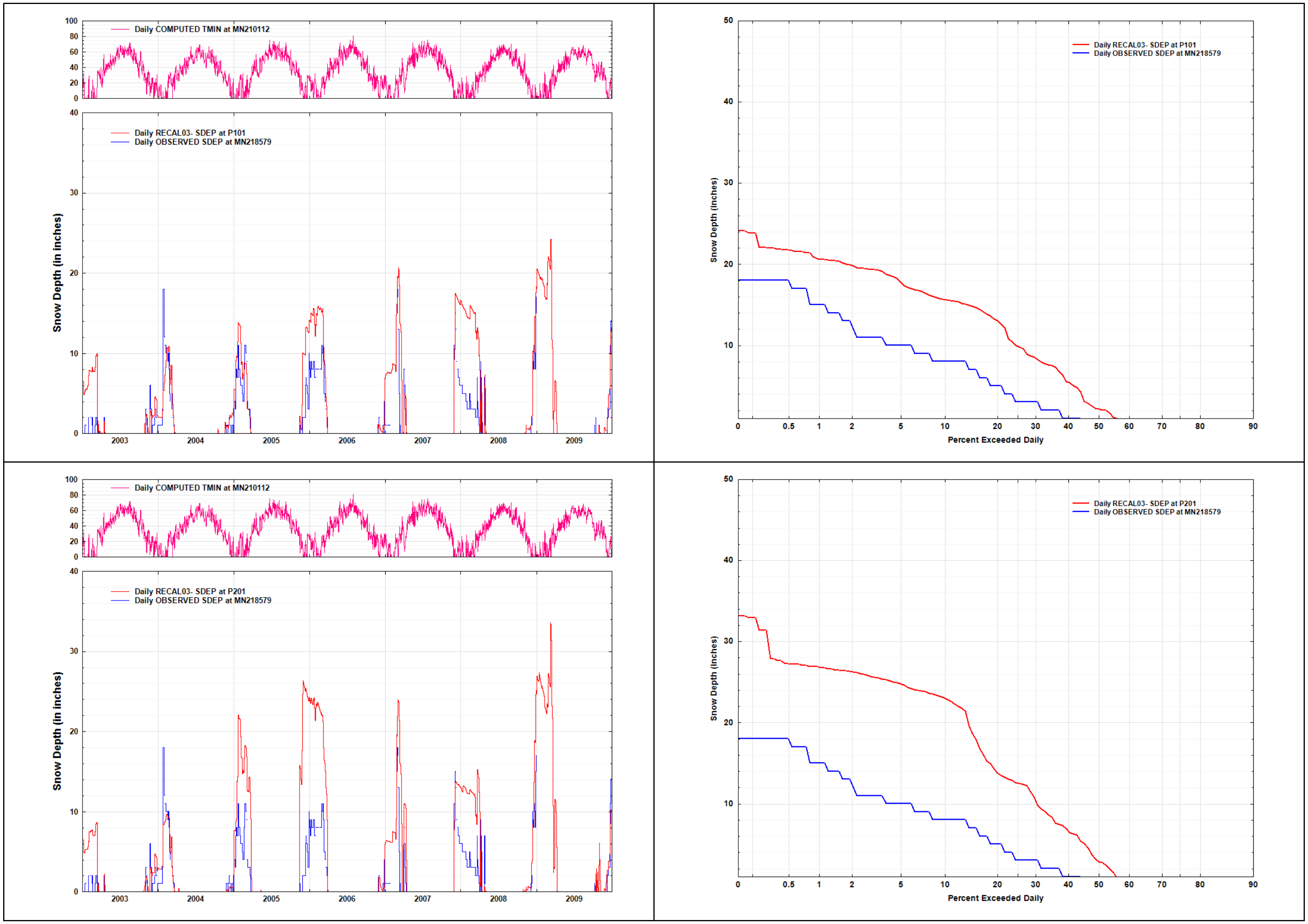
USDA. 2010a. Rapid Watershed Assessment - Long Prairie River. Available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_021797.pdf Accessed on July 2010

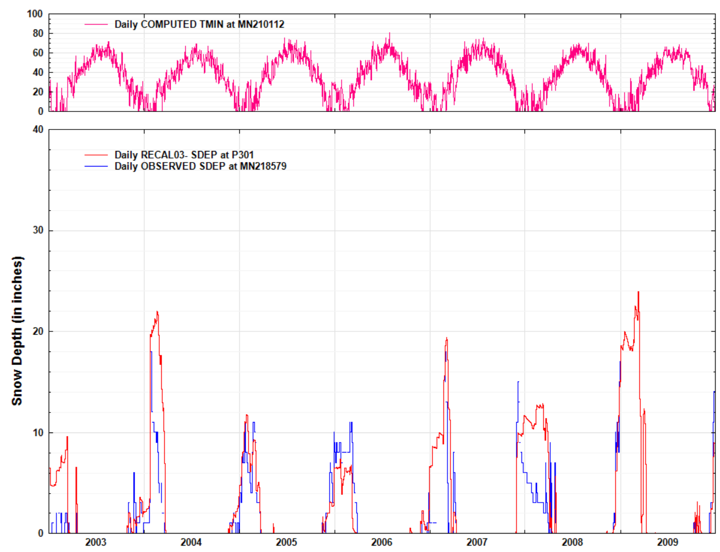
USDA. 2010b. Rapid Watershed Assessment - Long Prairie River. Available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022928.pdf Accessed on July 2010.

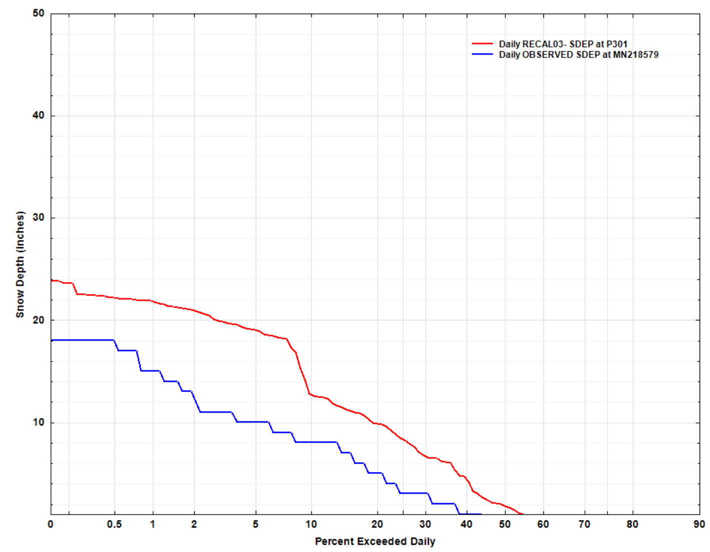
USDA. 1982. Basic Statistics 1977. National Resources Inventory. Iowa State University Statistical Laboratory. Statistical Bulletin Number 686.

APPENDIX A
SNOW DEPTH AND FREQUENCY DURATION GRAPHS FOR THE CALIBRATION PERIOD

A.1 REDEYE RIVER WATERSHED




Daily COMPUTED TMIN at MN210112
Daily RECAL03- SDEP at P301
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009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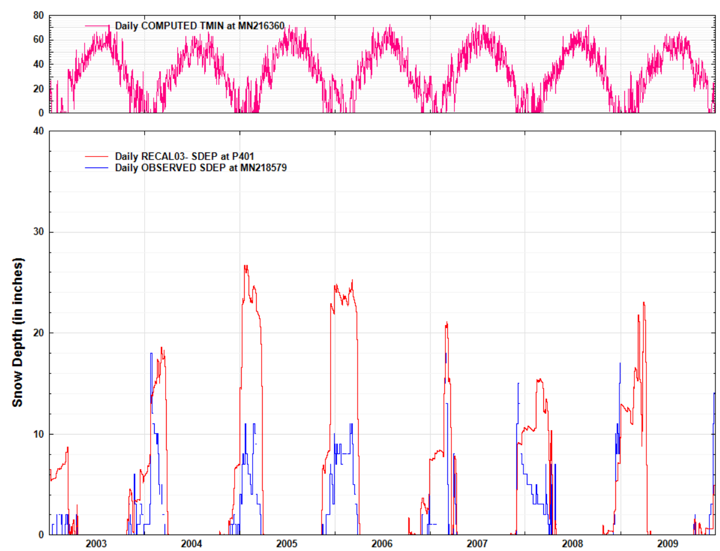
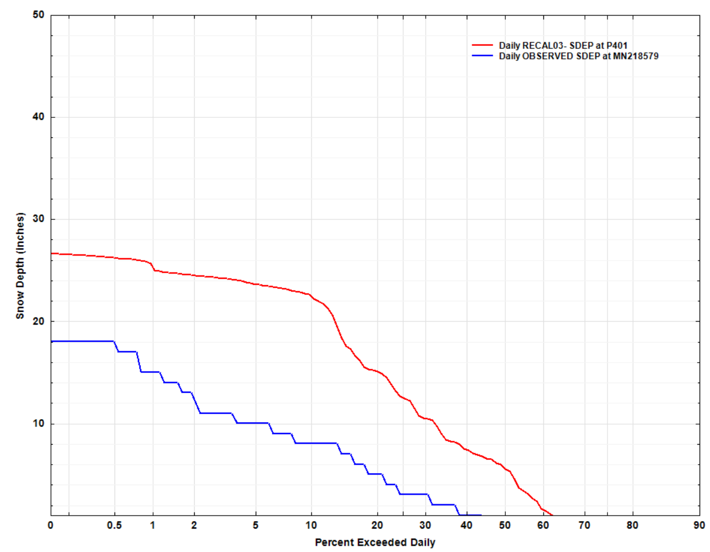
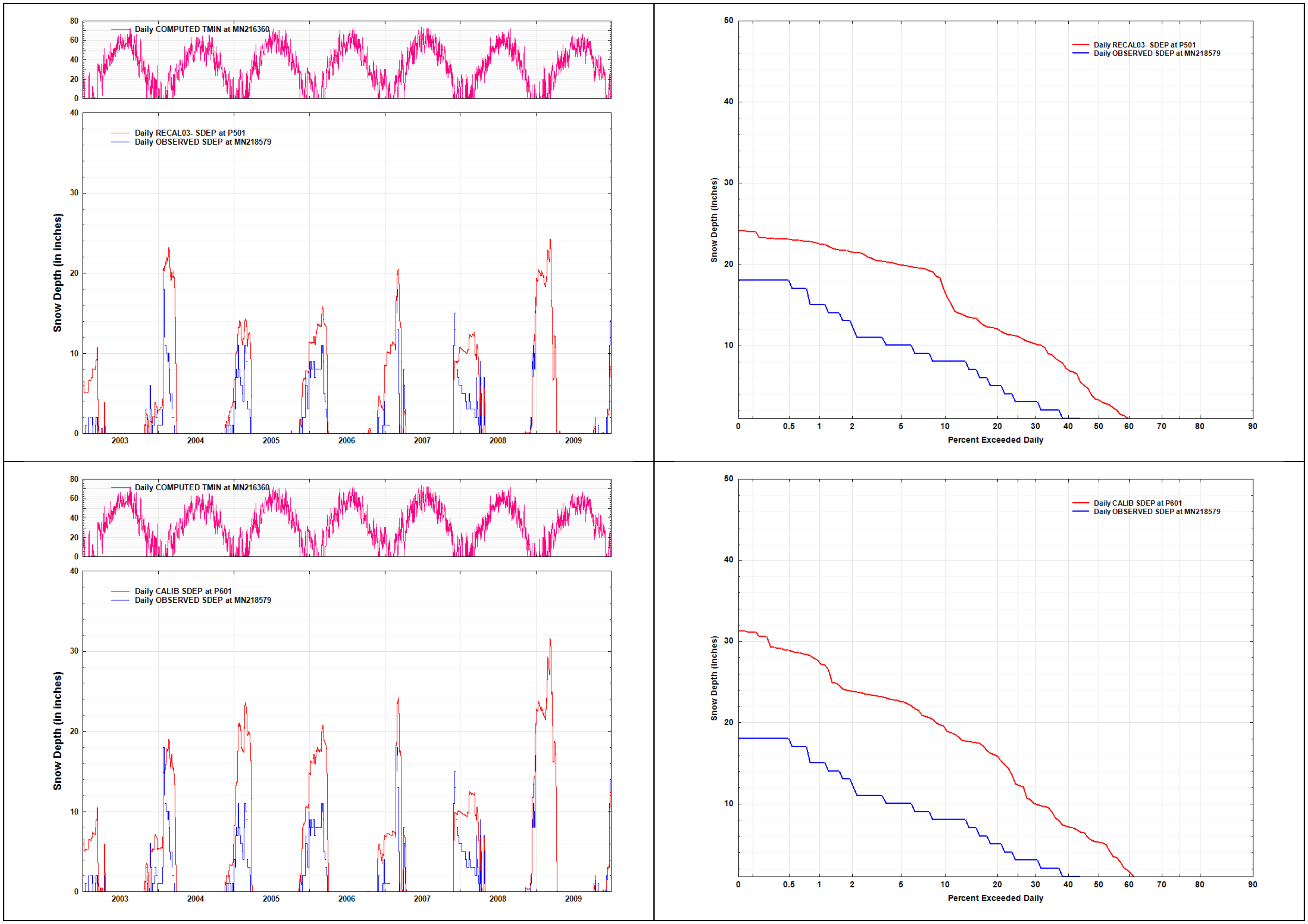
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily RECAL03- SDEP at P401
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009


Daily RECAL03- SDEP at P401
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily RECAL03- SDEP at P501
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009
Snow Depth (inches)
Percent Exceeded Daily
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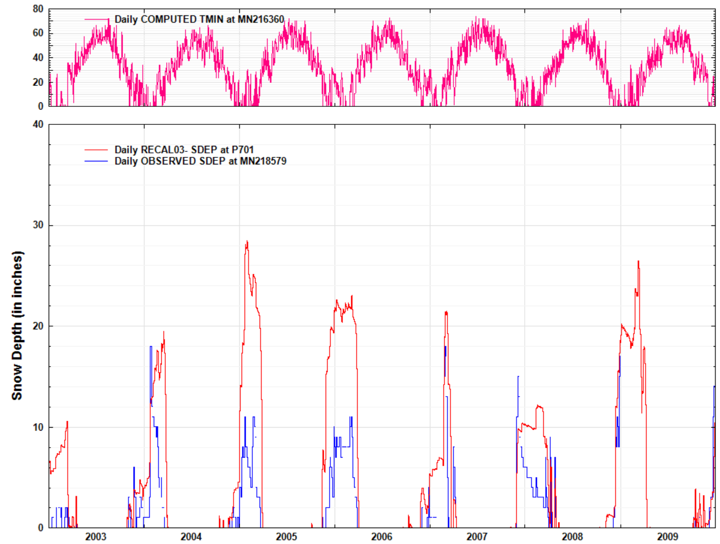
Daily CALIB SDEP at P601
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
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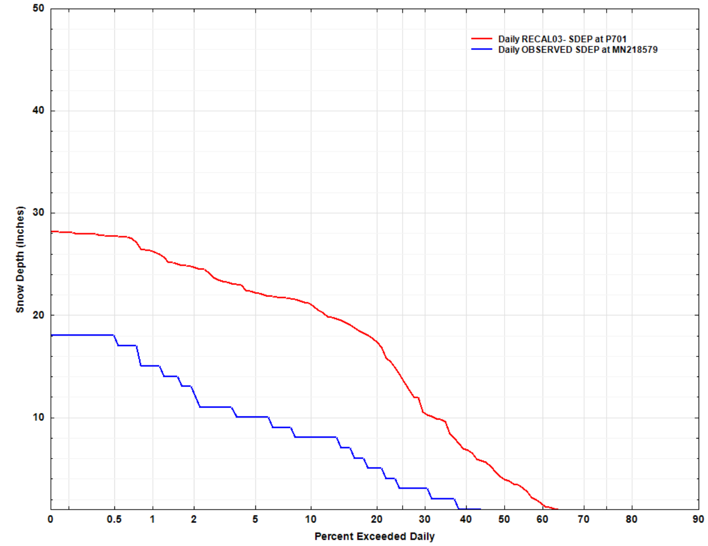
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009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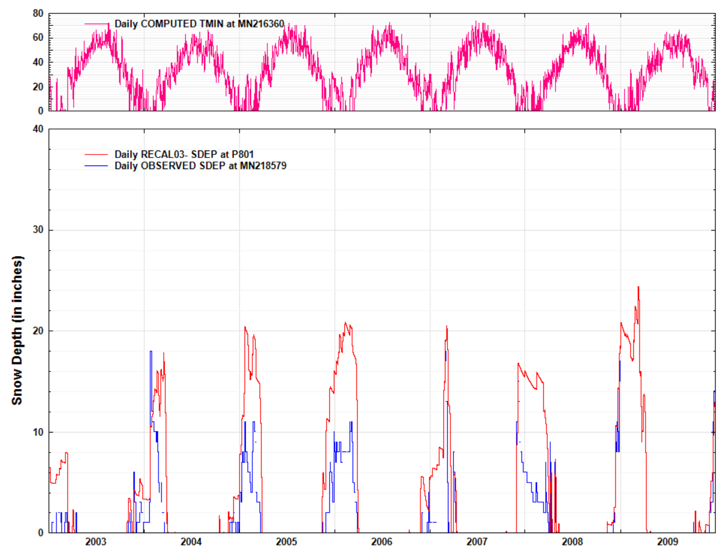
Snow Depth (inches)
Percent Exceeded Daily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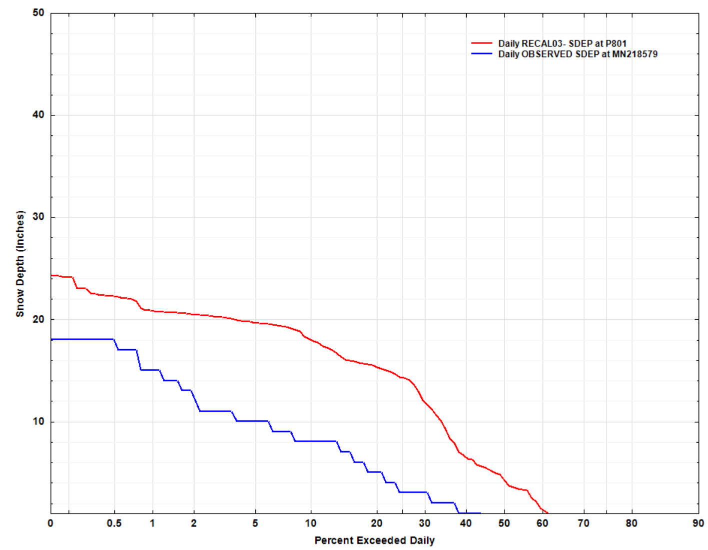
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009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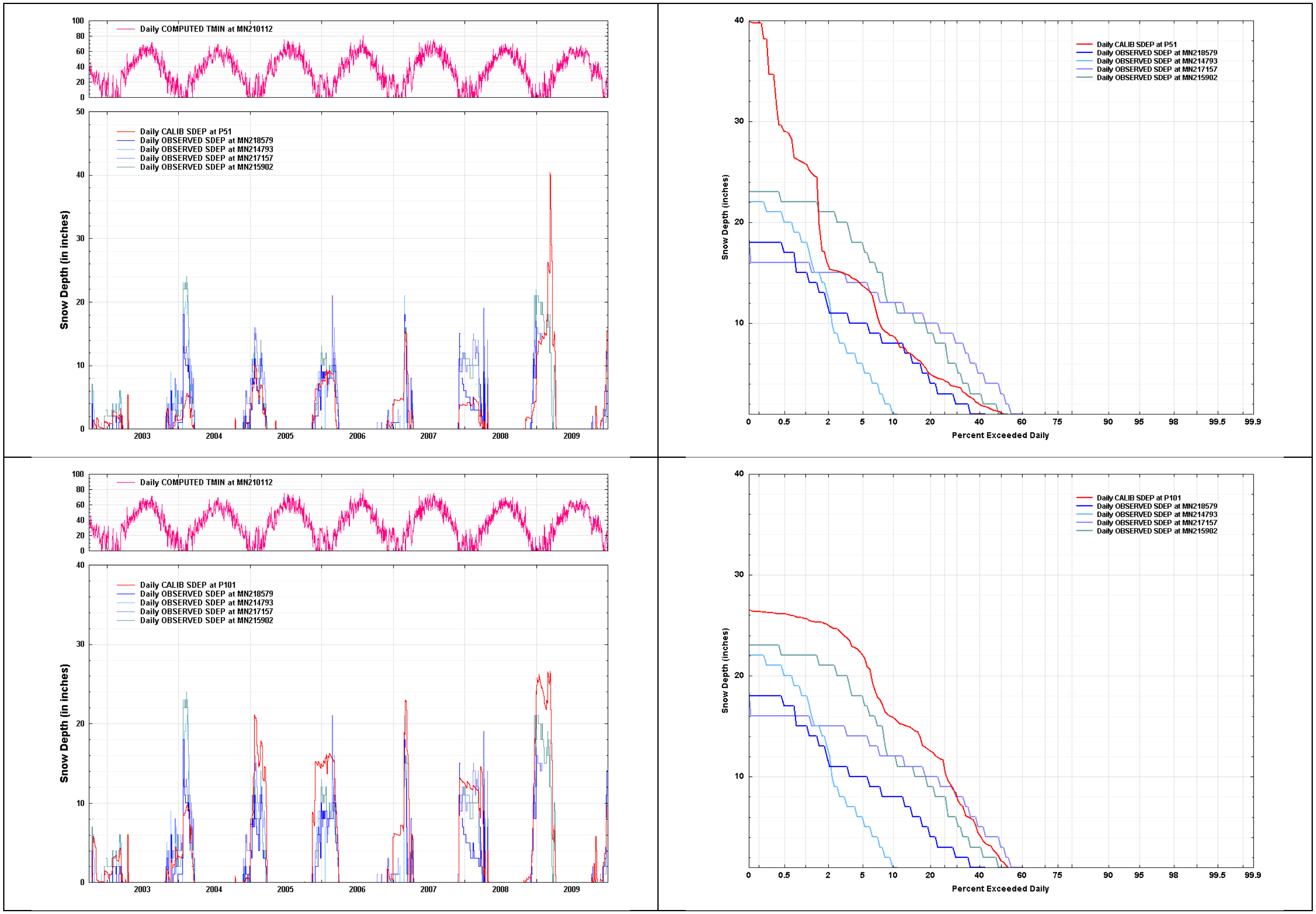
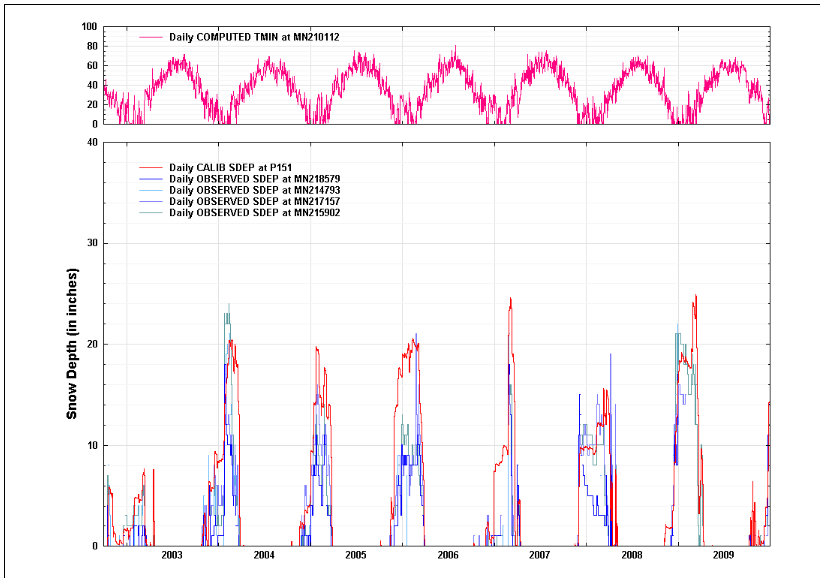
Snow Depth (inches)
Percent Exceeded Daily

A.2 LONG PRAIRIE RIVER WATERSHED

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Daily OBSERVED SDEP at MN214793
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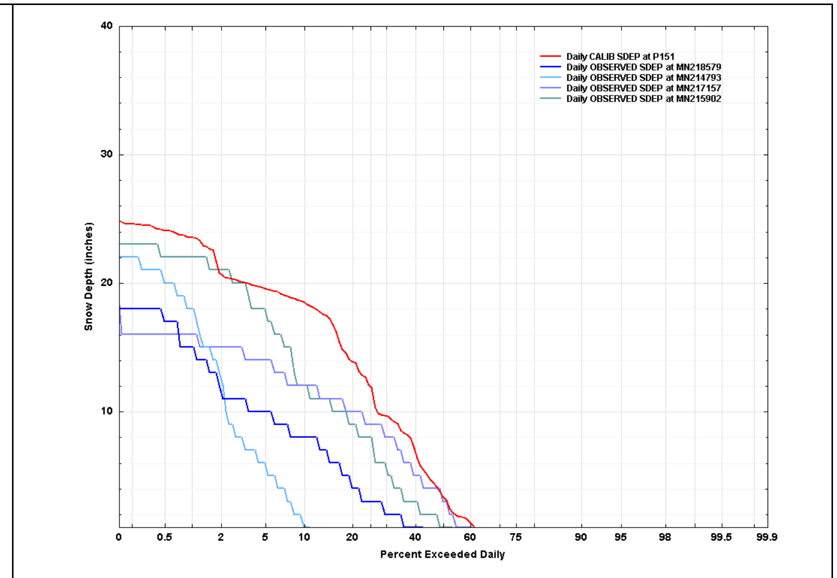
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009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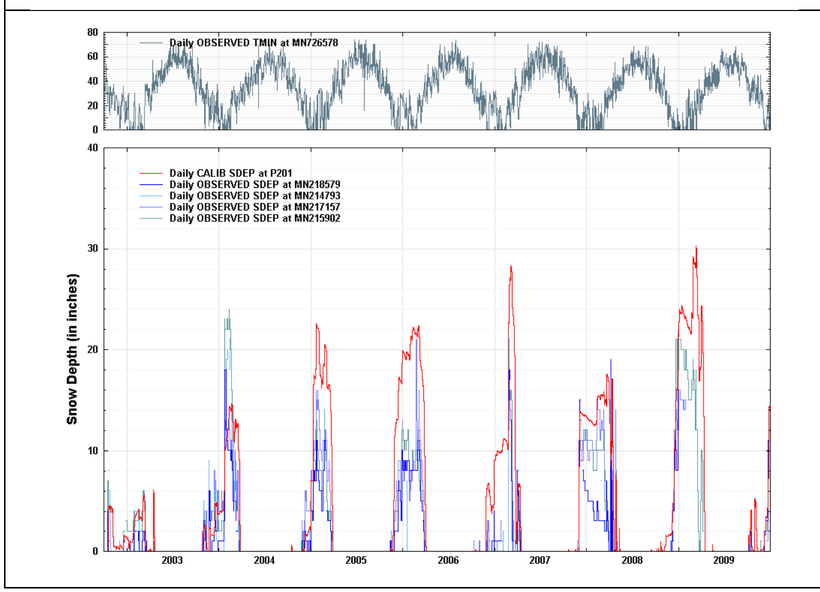
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily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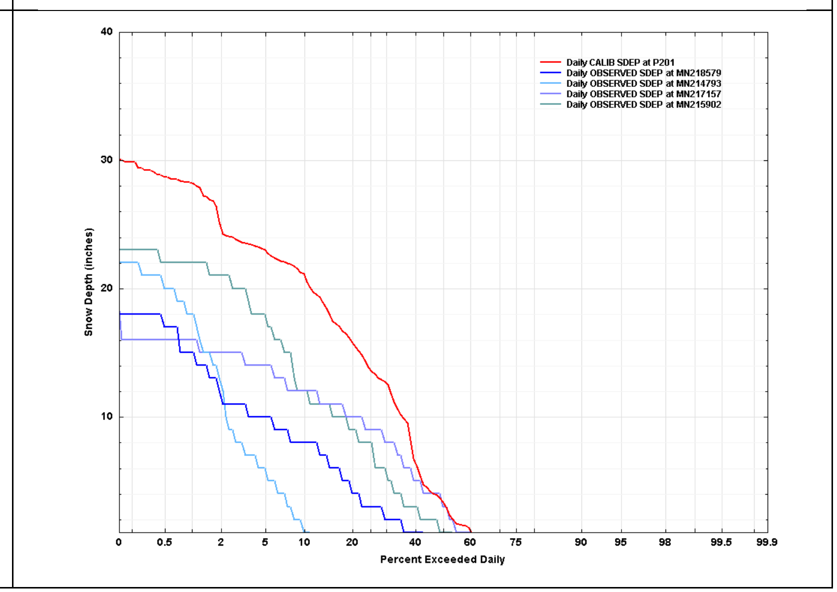
2005
2006
2007
2008
2009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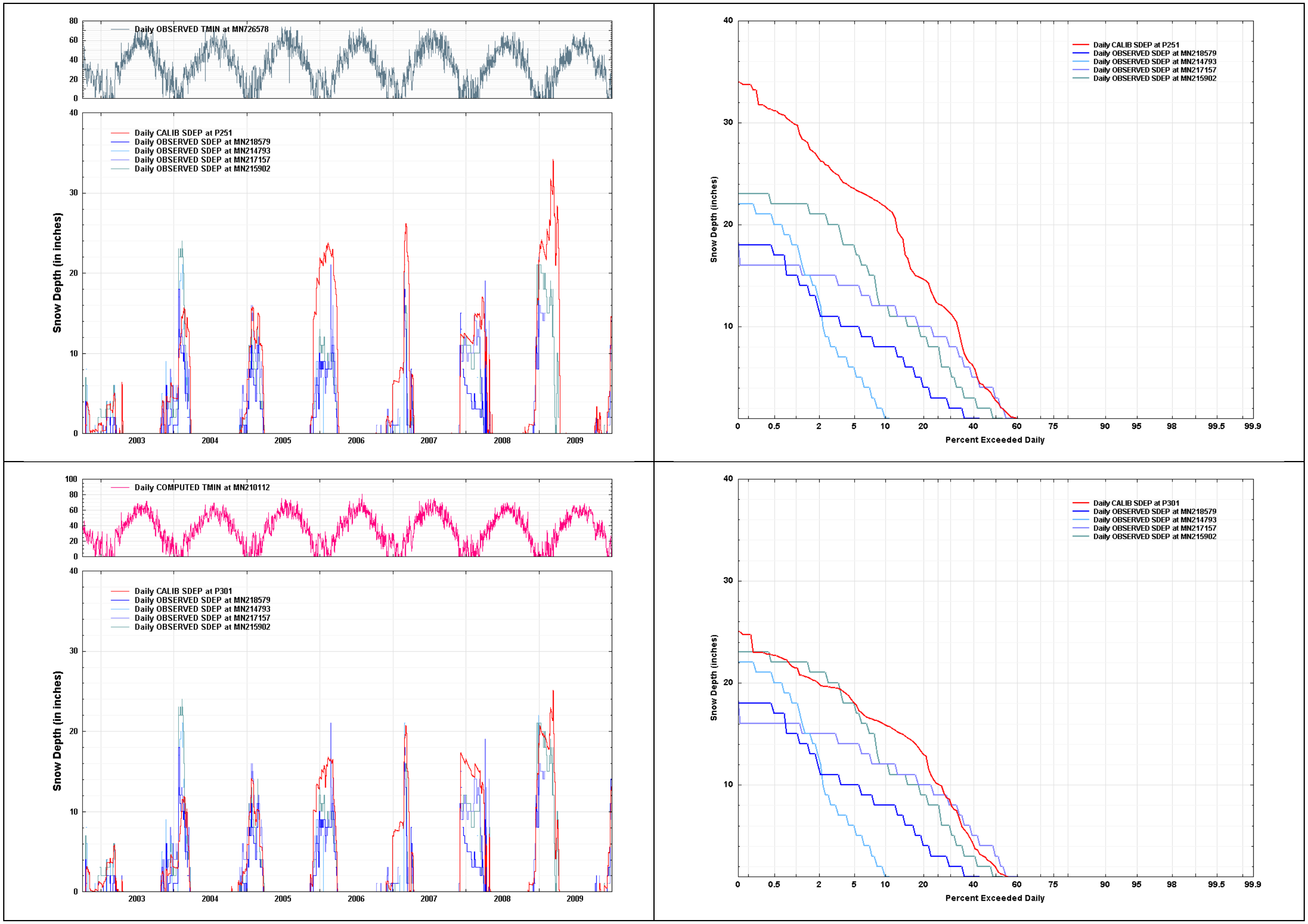
Snow Depth (inches)
Percent Exceeded Daily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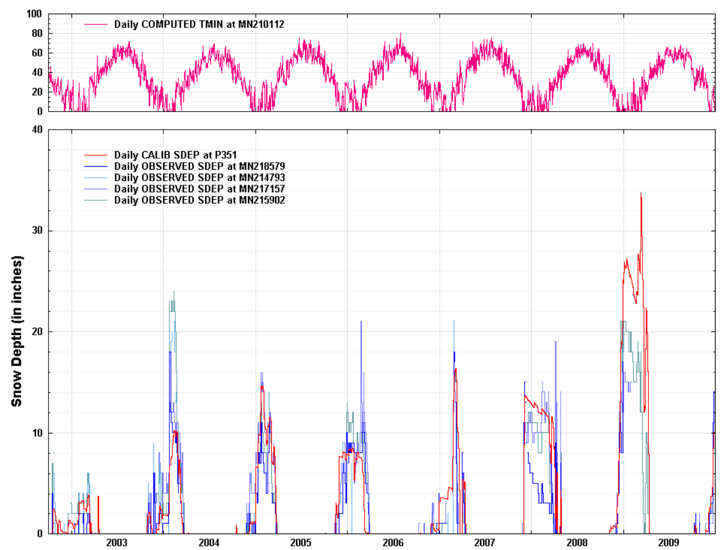
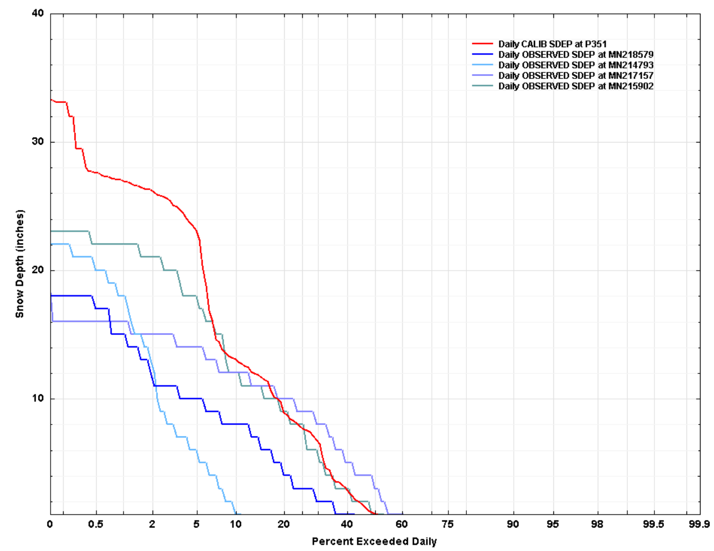
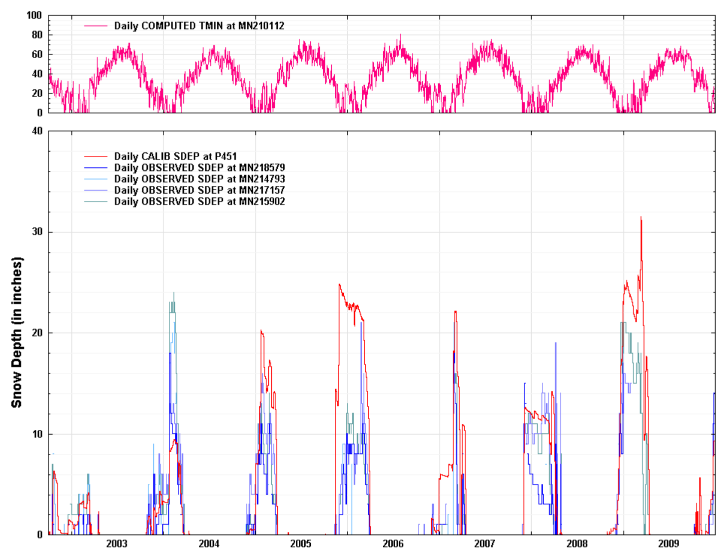
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009
Snow Depth (inches)
Percent Exceeded Daily
Daily COMPUTED TMIN at MN210112
Daily CALIB SDEP at P301
0
0.5
2
5
10
20
40
60
75
90
95
98
99.5
99.9


Daily COMPUTED TMIN at MN210112
Daily CALIB SDEP at P351
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB SDEP at P351
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily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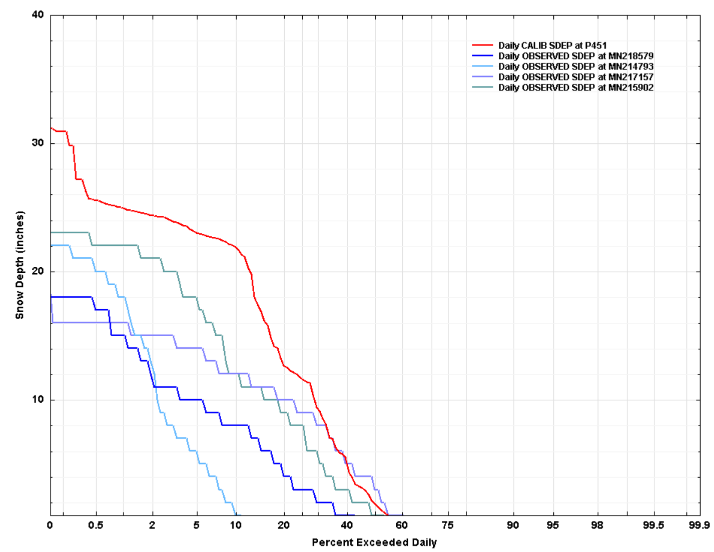
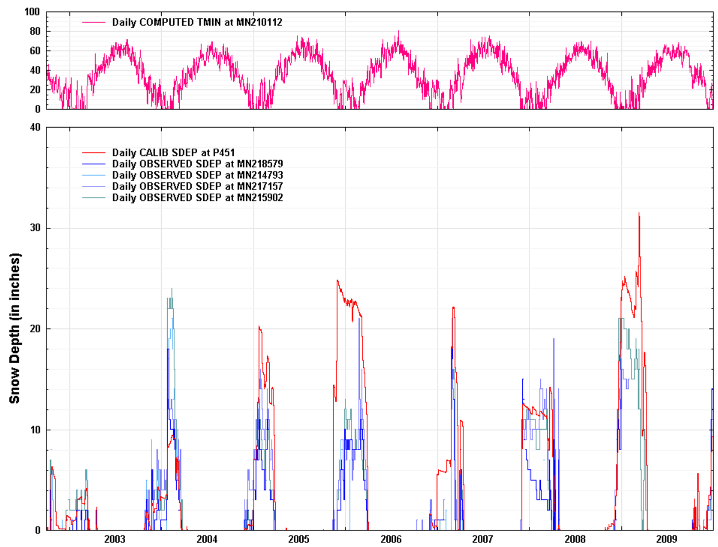
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB SDEP at P451
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily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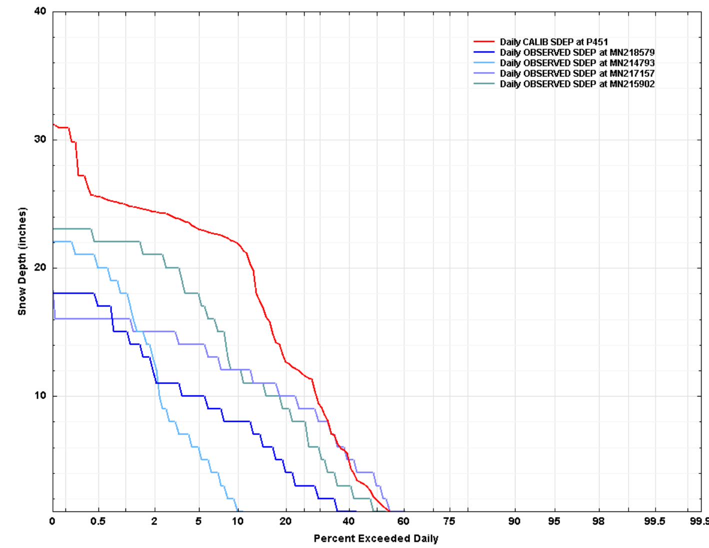
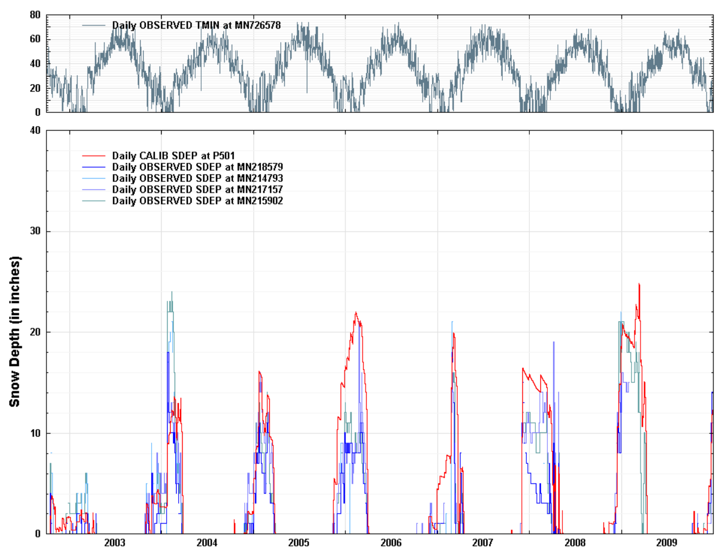
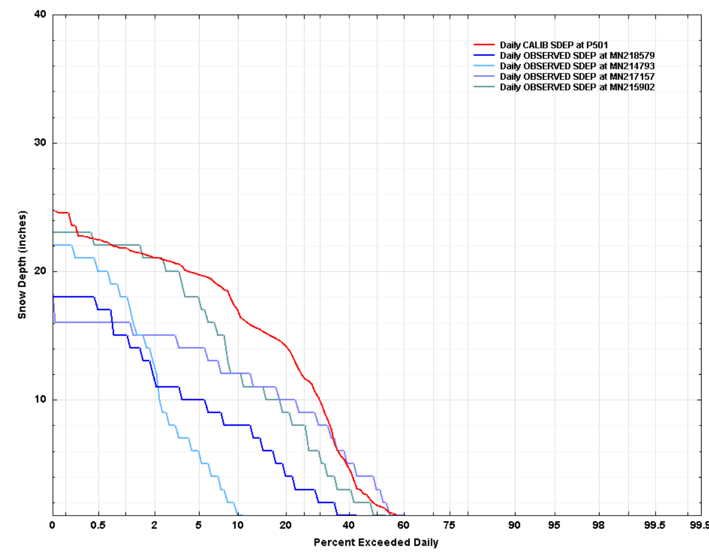
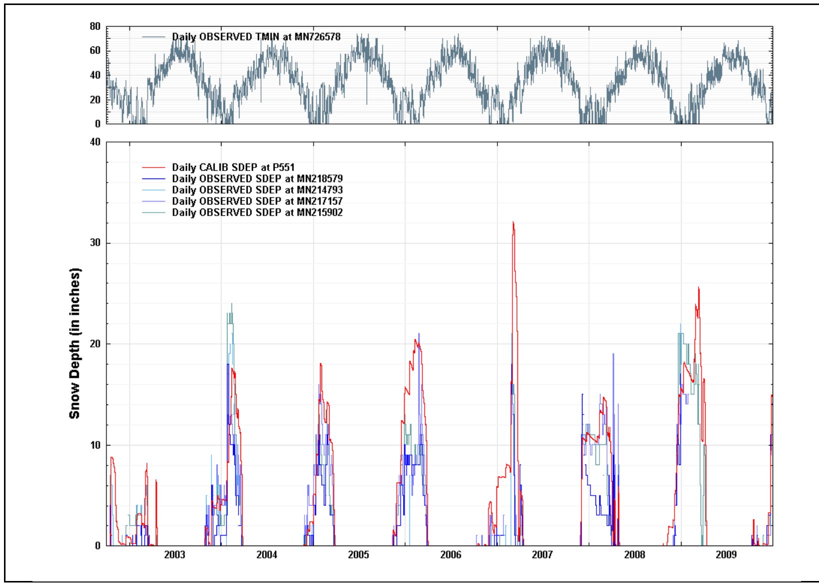
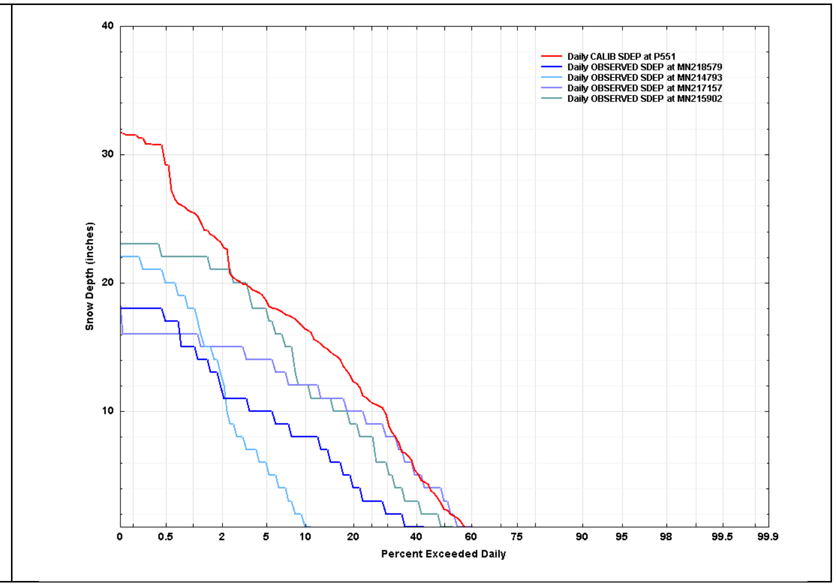
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB SDEP at P451
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily

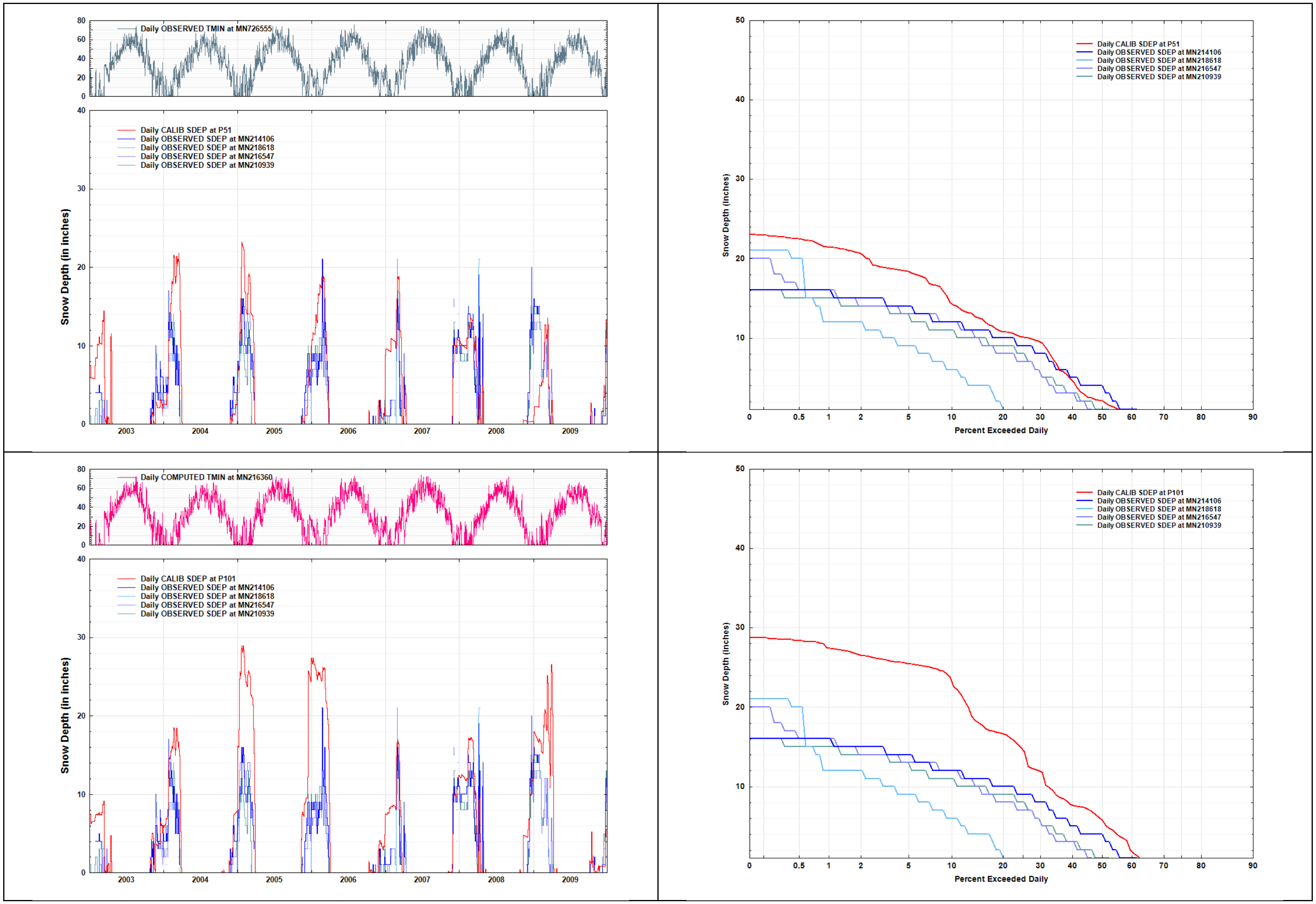

Daily OBSERVED TMIN at MN726578
Daily CALIB SDEP at P501
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

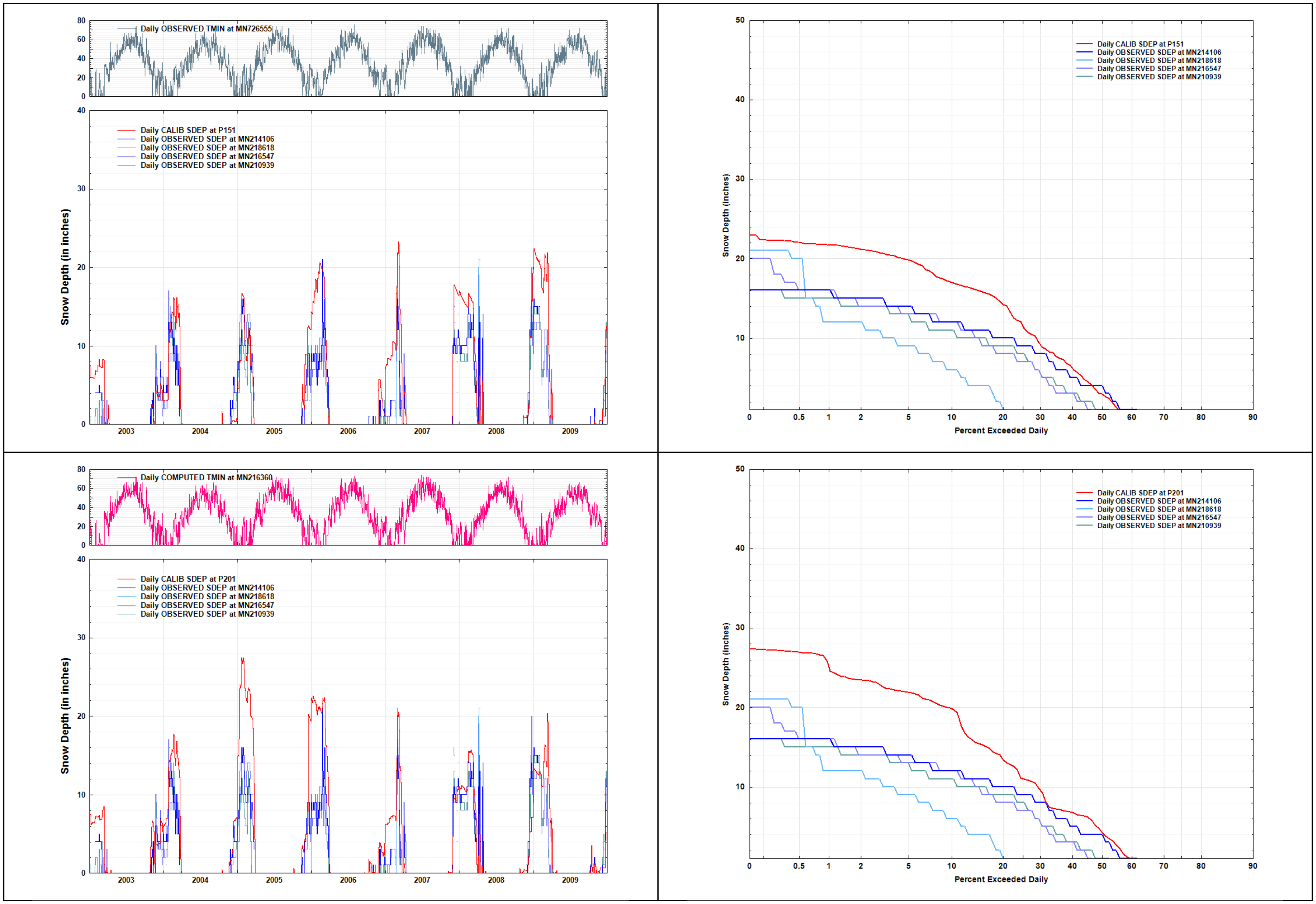

Daily CALIB SDEP at P501
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily

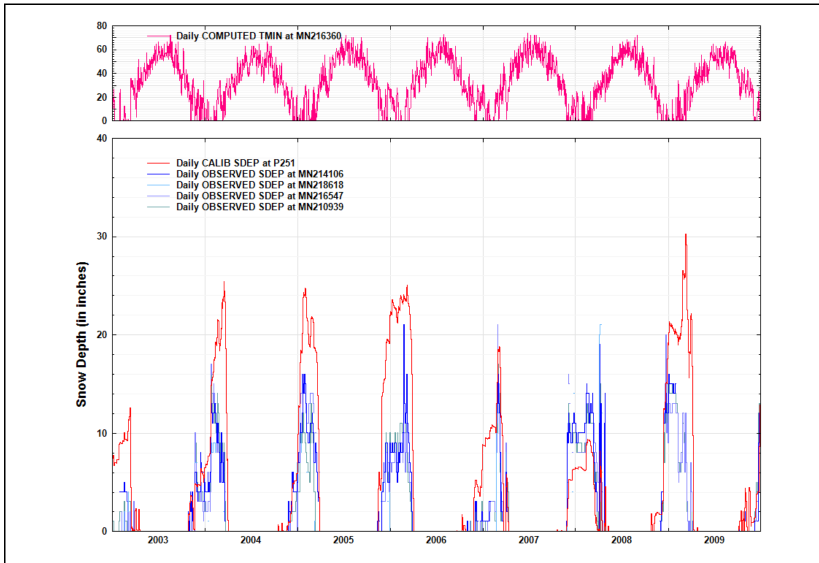

Daily OBSERVED TMIN at MN726578
Daily CALIB SDEP at P551
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

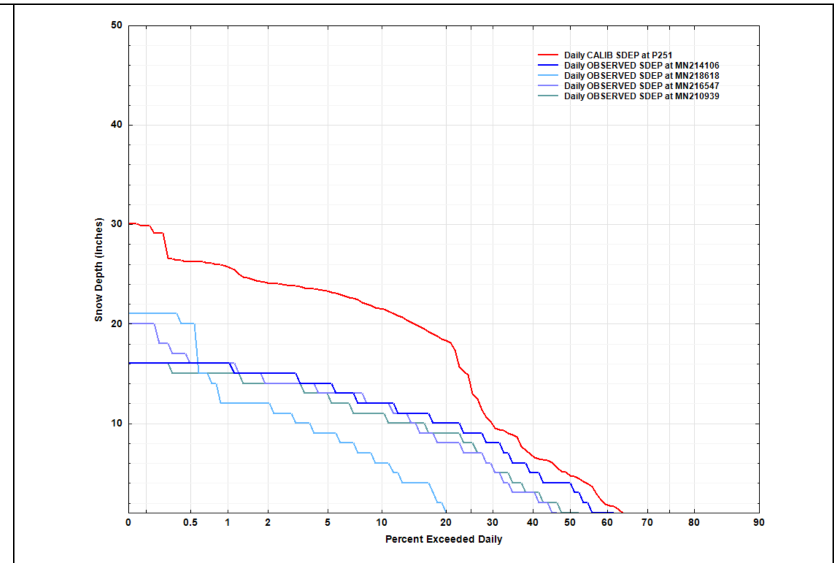

Daily CALIB SDEP at P551
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily

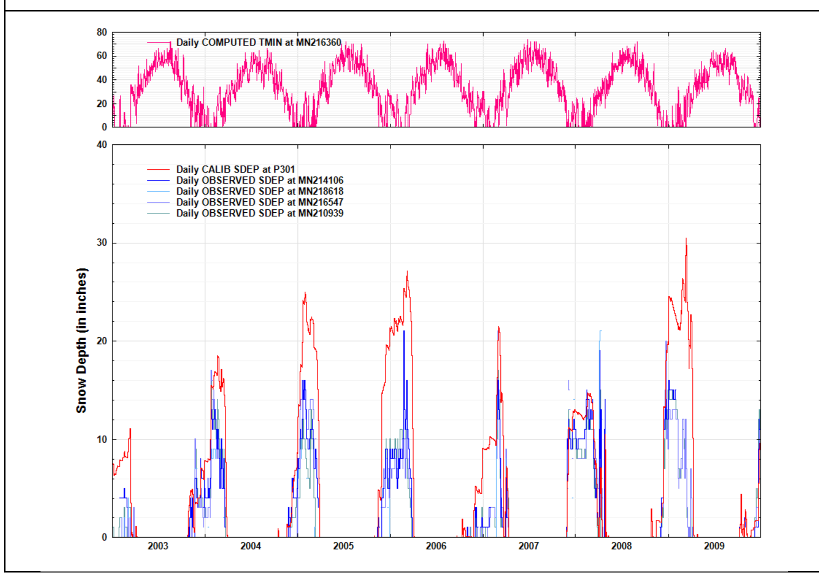
A.3 CROW WING RIVER WATERSHED

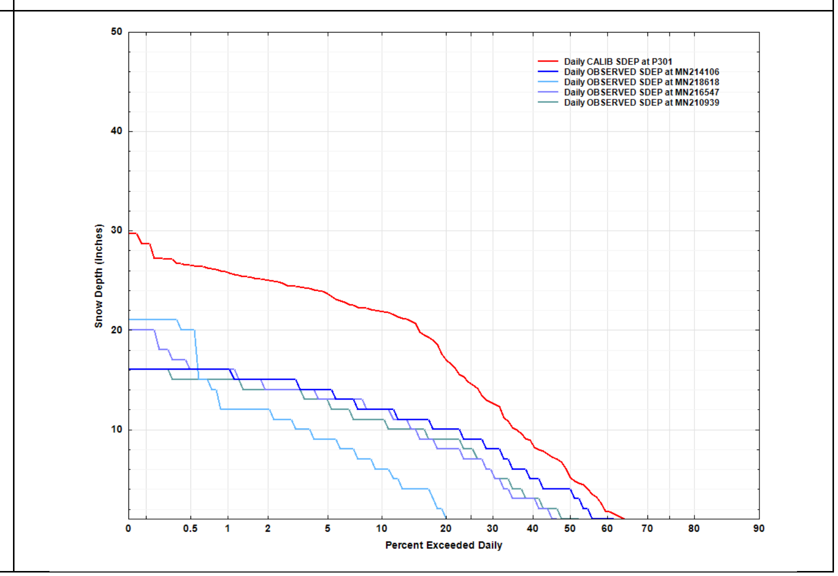


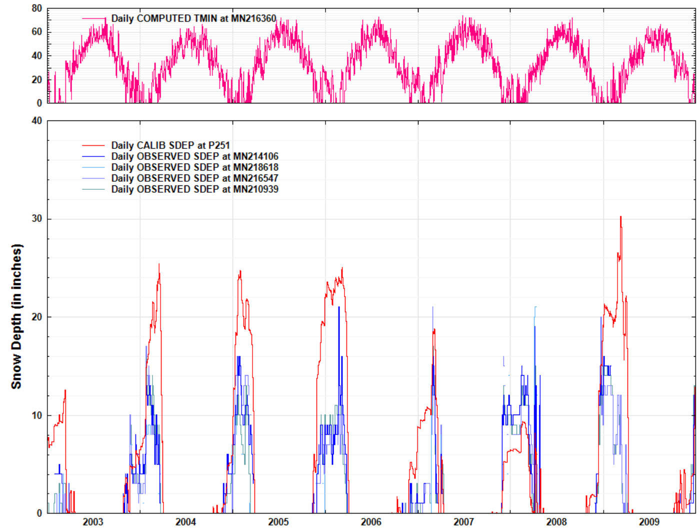

Daily OBSERVED TMIN at MN726555
Daily CALIB SDEP at P151
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009
Snow Depth (inches)
Percent Exceeded Daily
Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P201

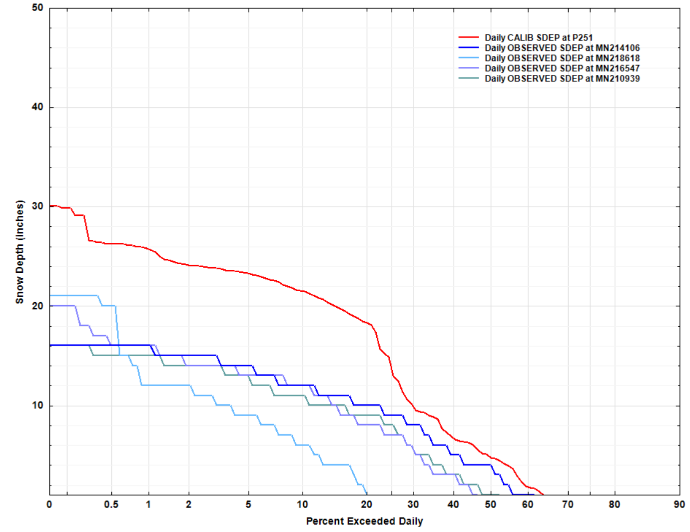

Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P251
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

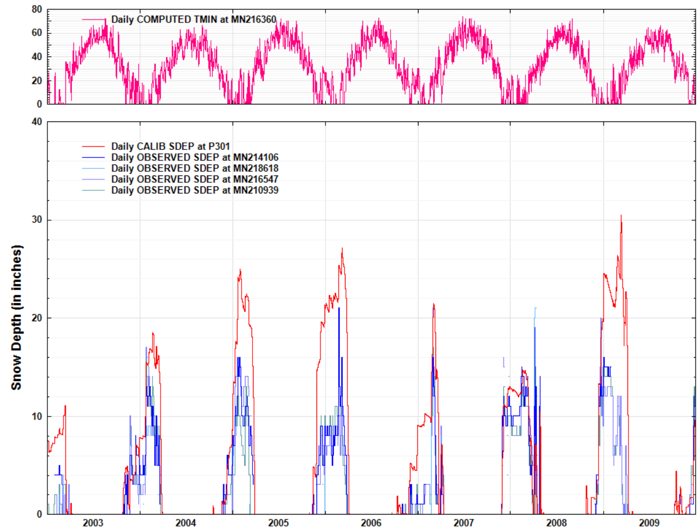

Daily CALIB SDEP at P251
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

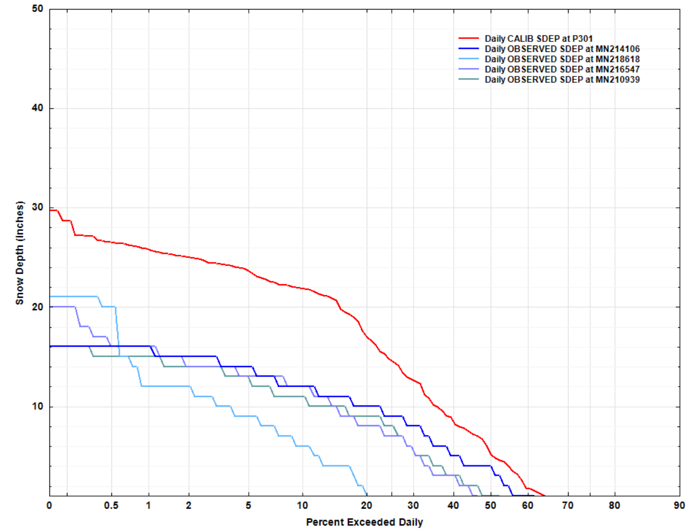

Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P301
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

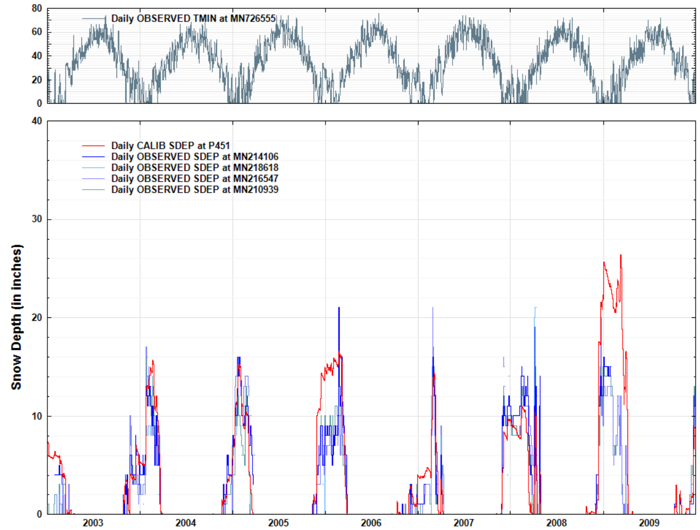

Daily CALIB SDEP at P301
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

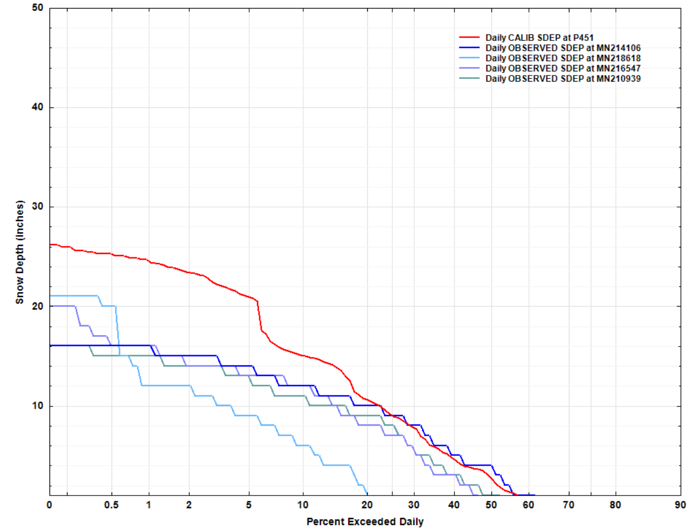

Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P251
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

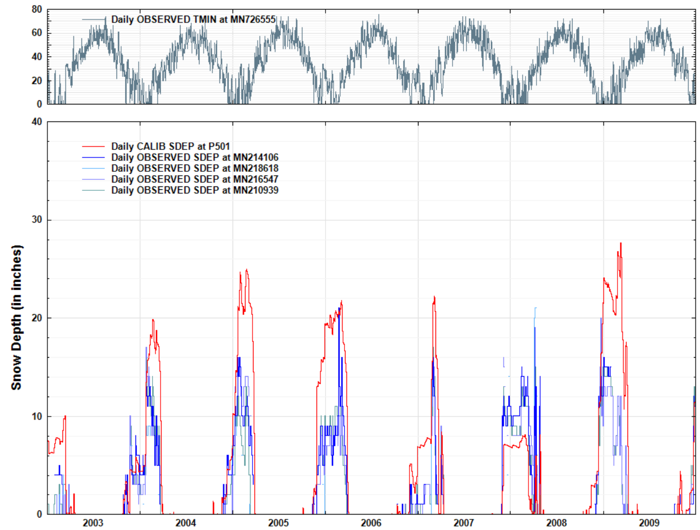

Daily CALIB SDEP at P251
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

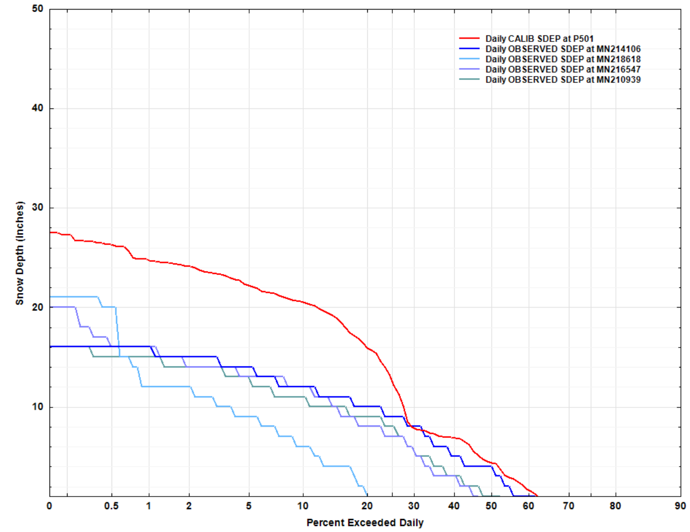

Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P301
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

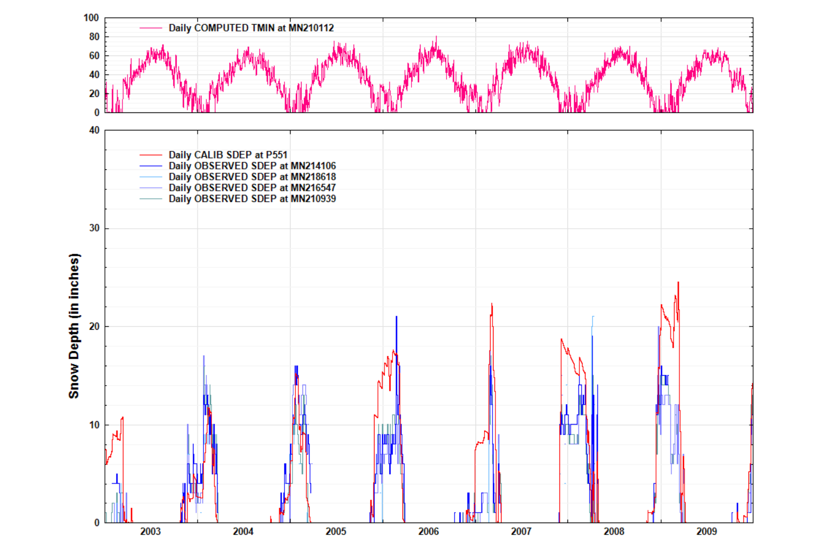

Daily CALIB SDEP at P301
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

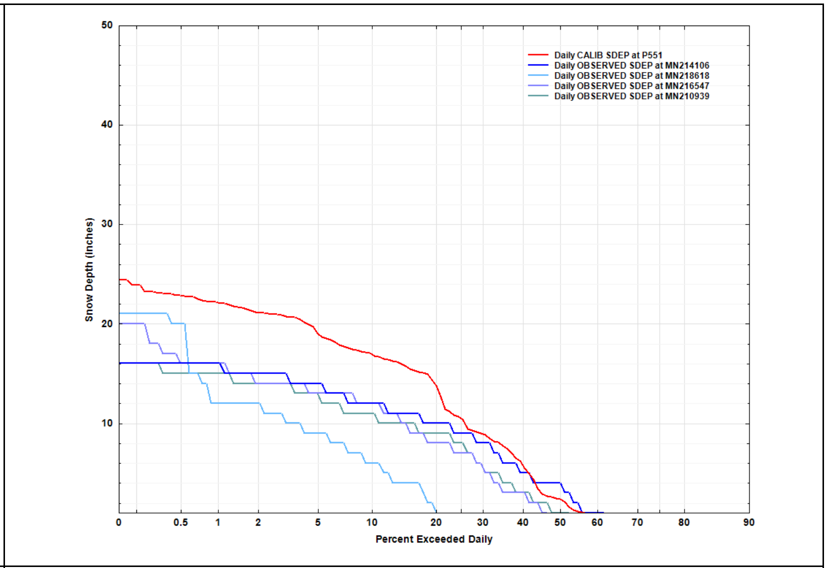

Daily OBSERVED TMIN at MN726555
Daily CALIB SDEP at P451
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

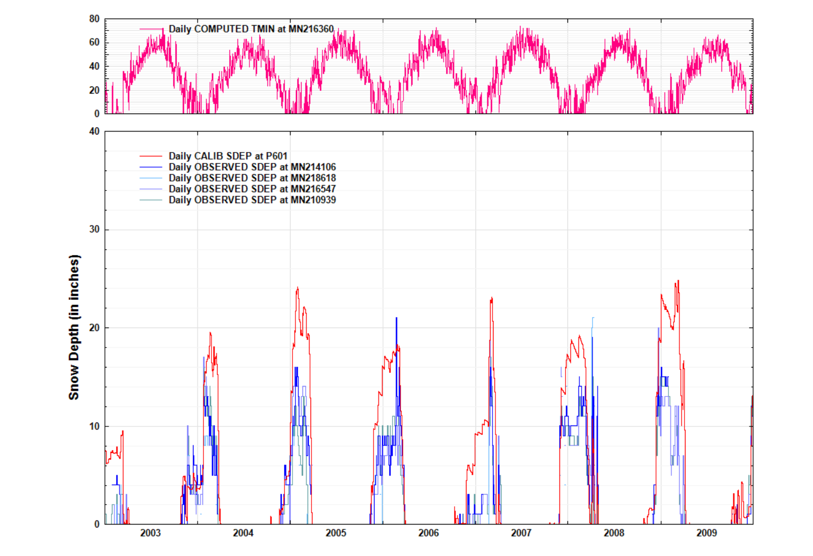

Daily CALIB SDEP at P451
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily OBSERVED TMIN at MN726555
Daily CALIB SDEP at P501
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB SDEP at P501
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN210112
Snow Depth (in inches)
Daily CALIB SDEP at P551
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
2003
2004
2005
2006
2007
2008
2009


Daily CALIB SDEP at P551
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Snow Depth (in inches)
Daily CALIB SDEP at P601
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
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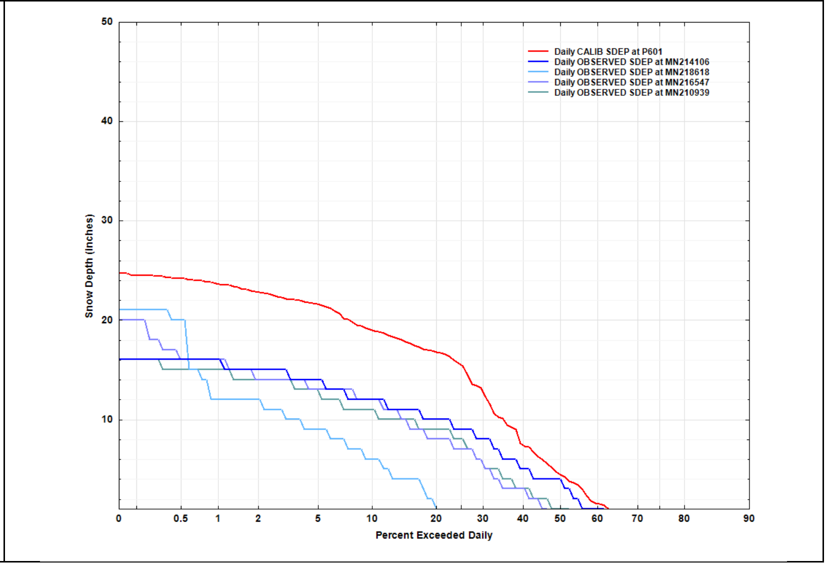
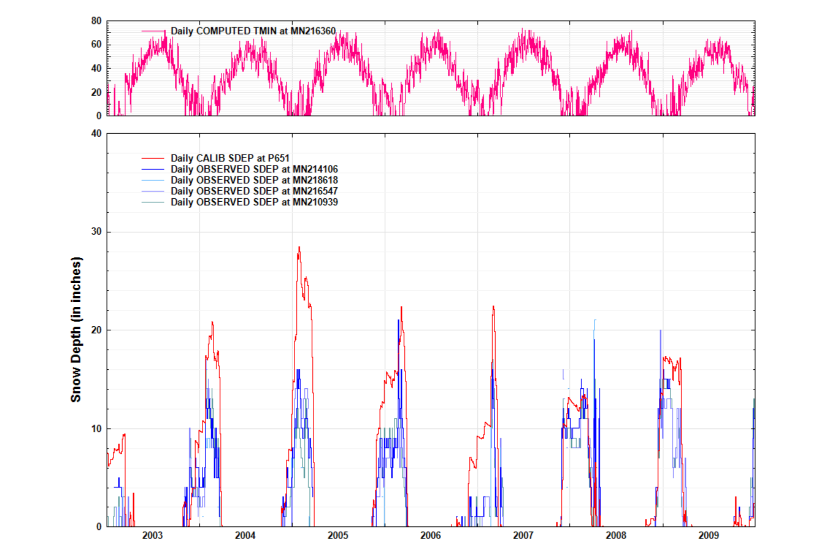
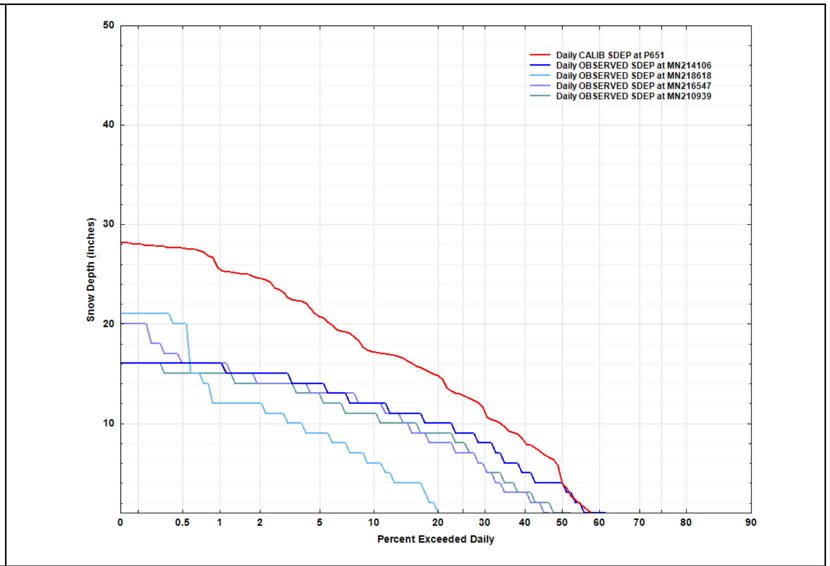
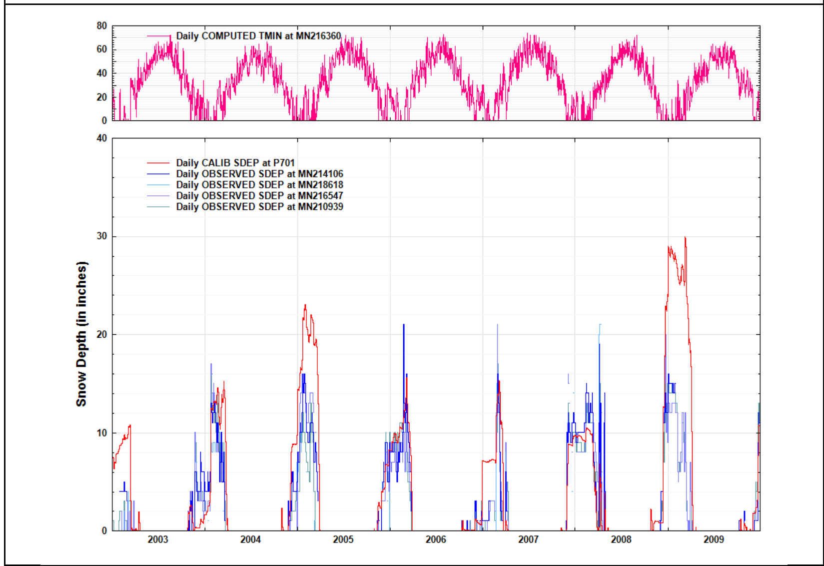
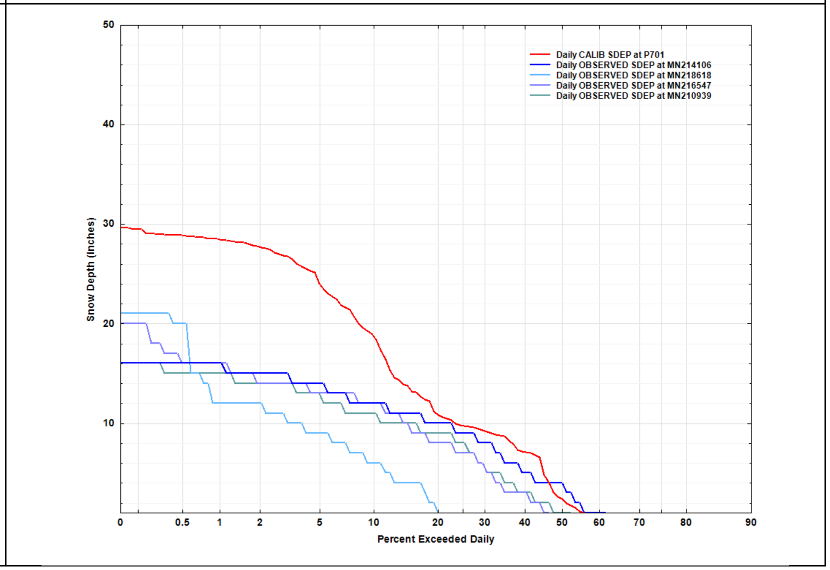
2005
2006
2007
2008
2009

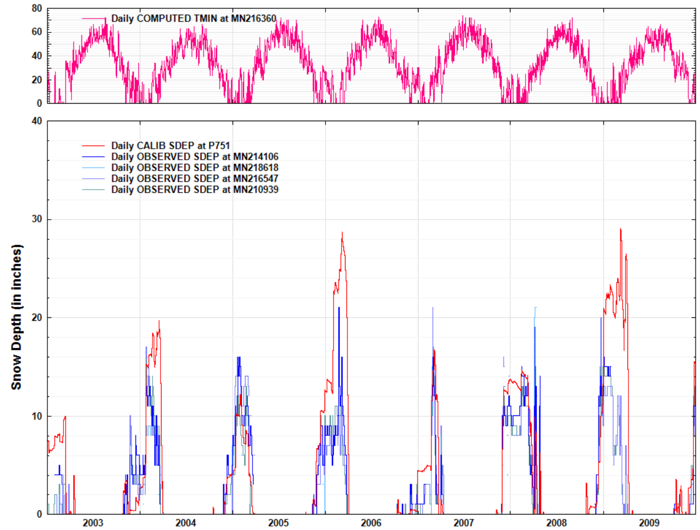

Daily CALIB SDEP at P601
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P651
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

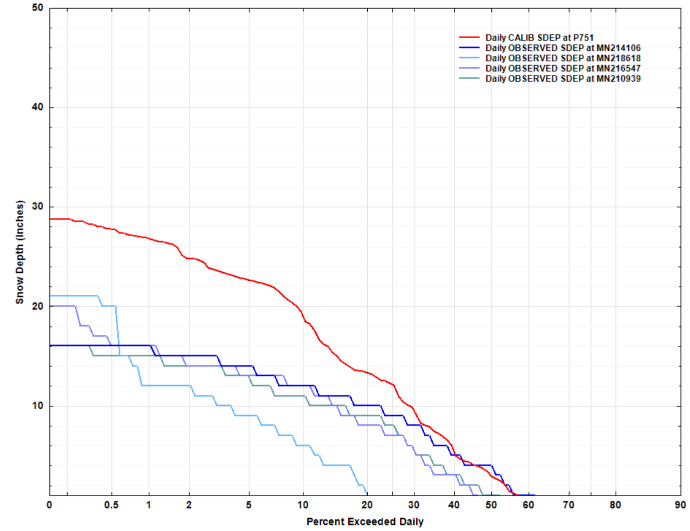

Daily CALIB SDEP at P651
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P701
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB SDEP at P701
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily



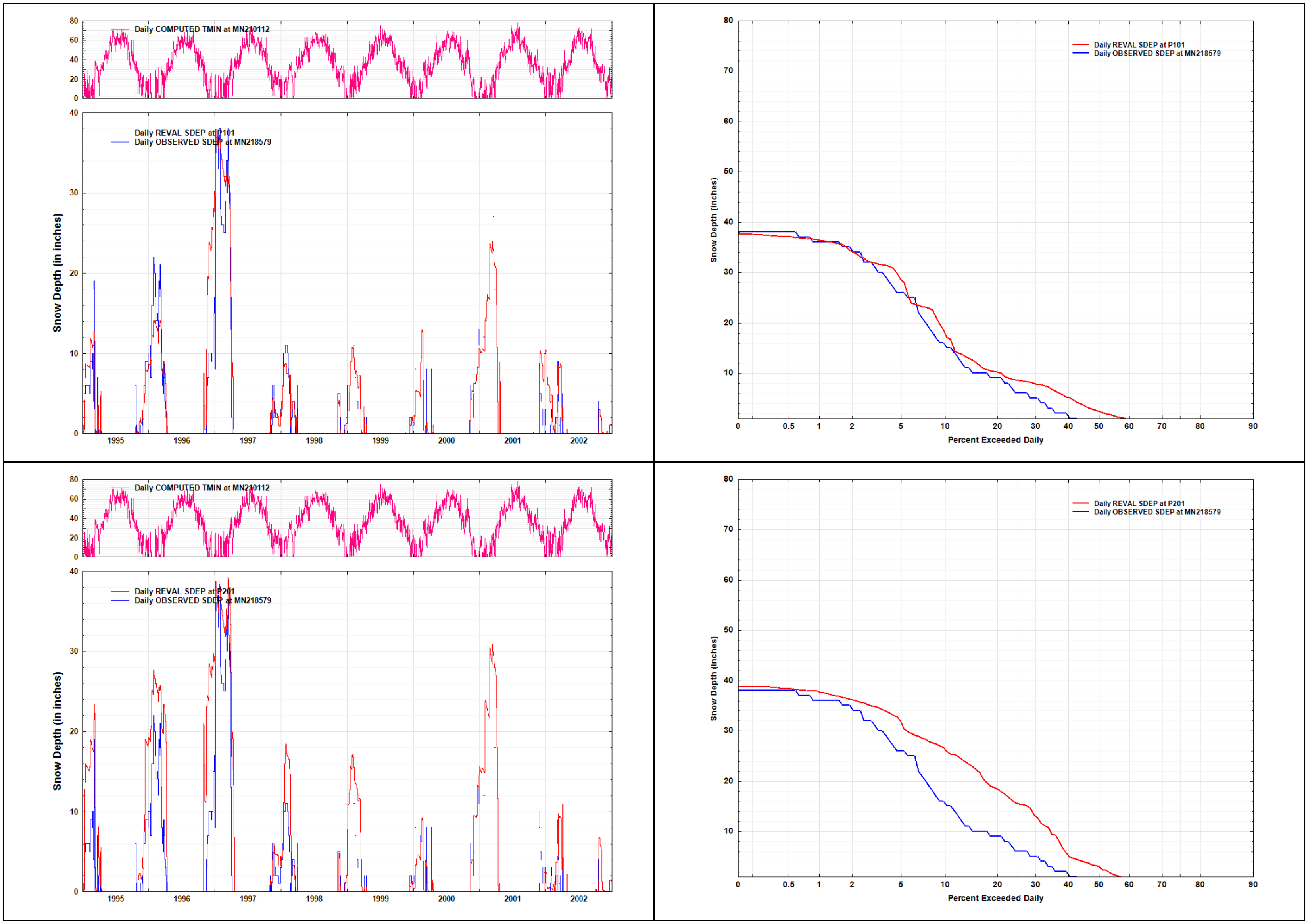
Daily COMPUTED TMIN at MN216360
Daily CALIB SDEP at P751
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
2003
2004
2005
2006
2007
2008
2009

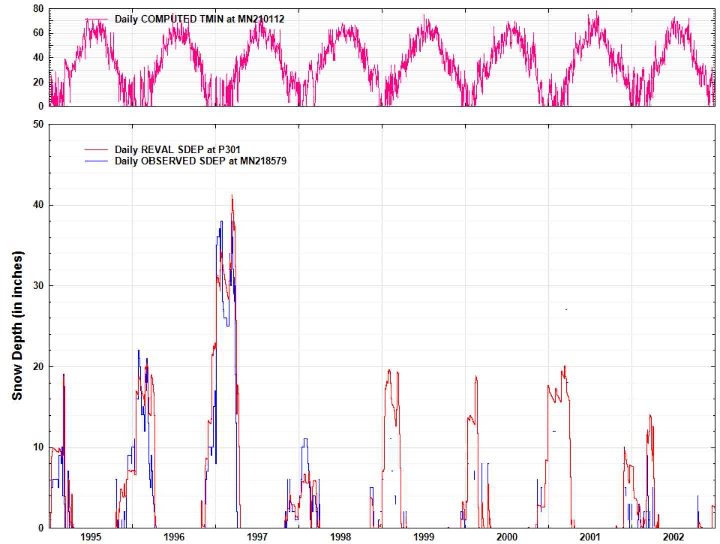


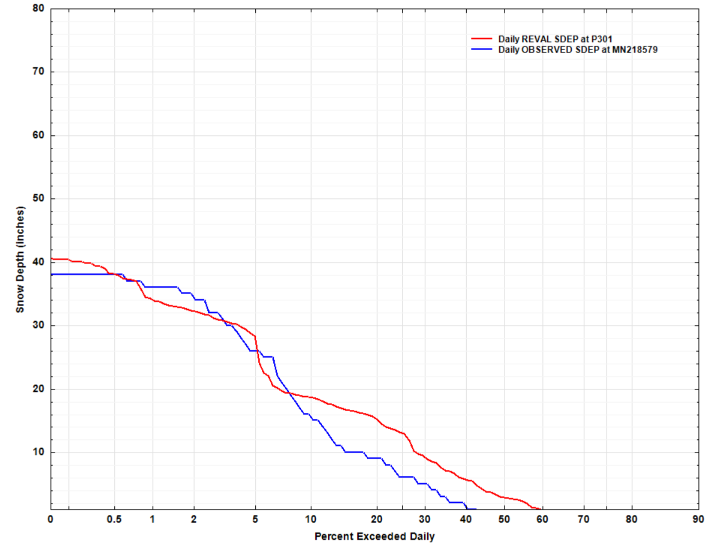
Daily CALIB SDEP at P751
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

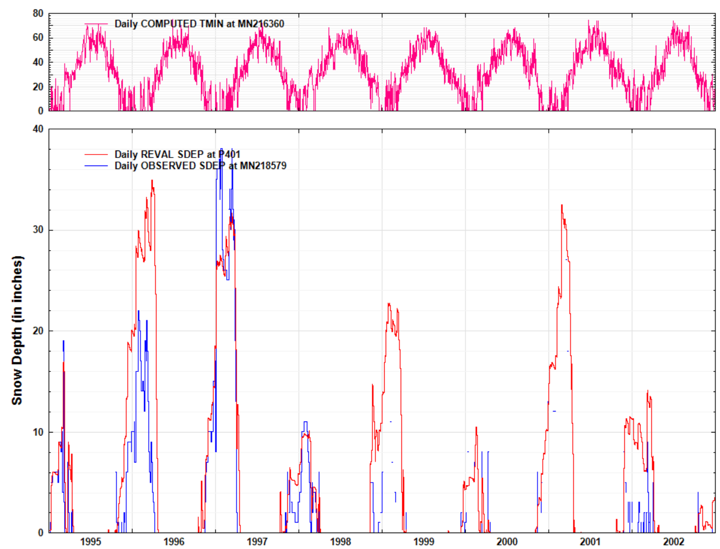
APPENDIX B
SNOW DEPTH AND FREQUENCY DURATION GRAPHS FOR THE VALIDATION PERIOD

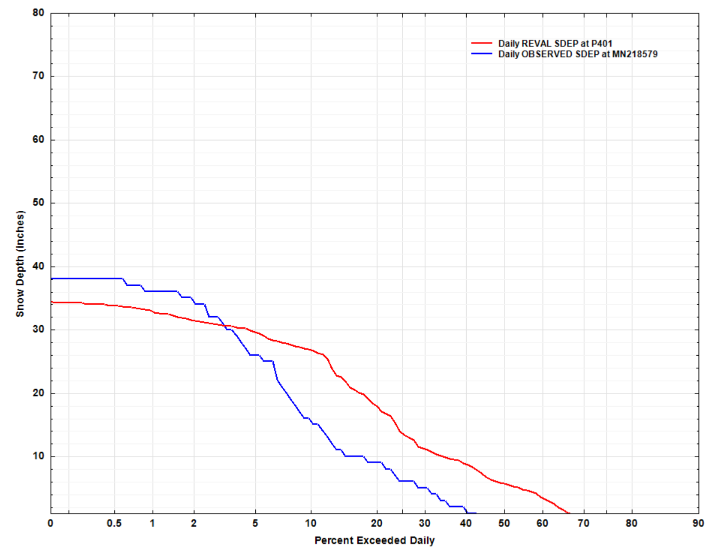
B.1 REDEYE RIVER WATERSHED

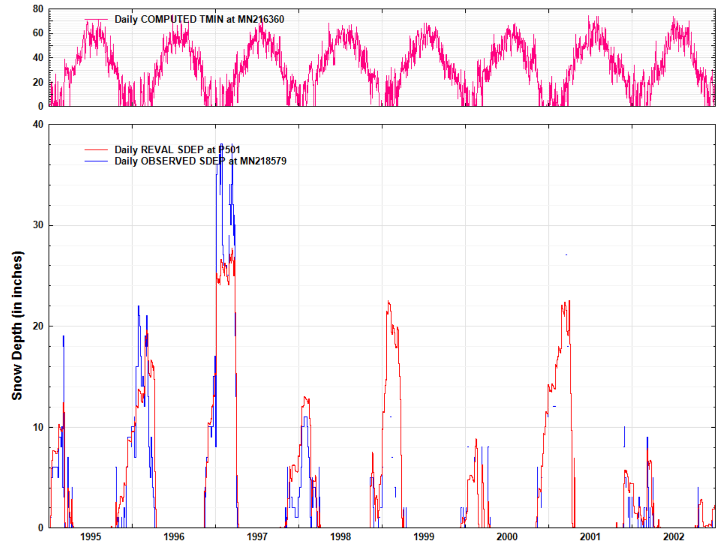


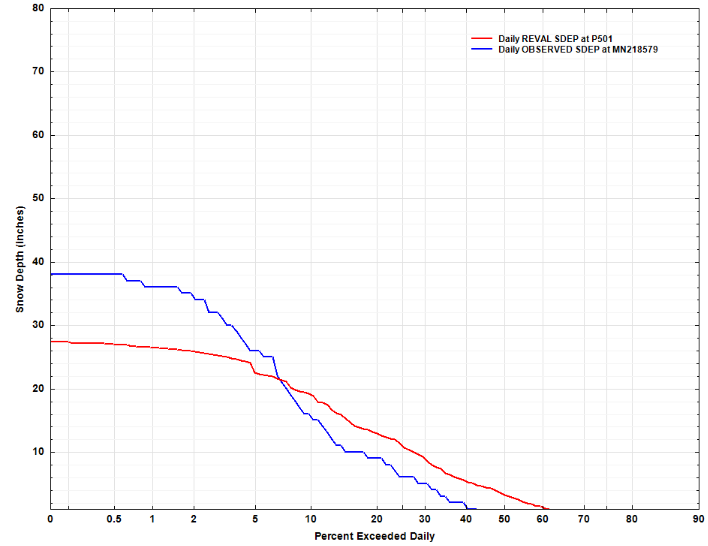

Daily COMPUTED TMIN at MN210112
Daily REVAL SDEP at P301
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002

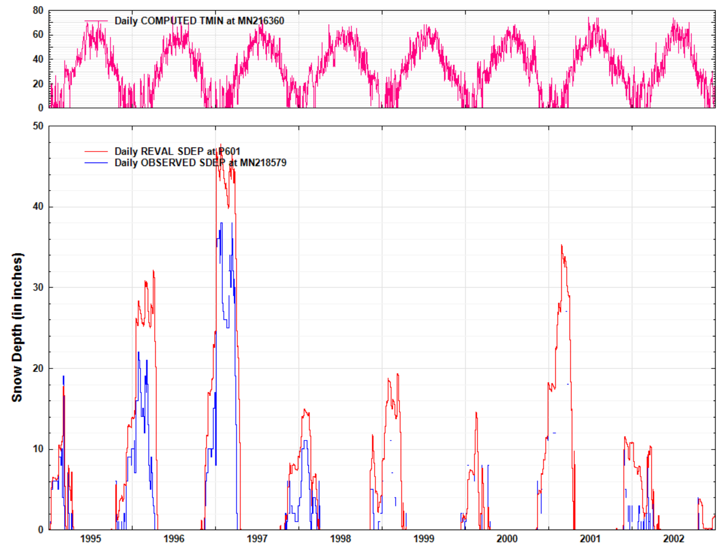

Daily REVAL SDEP at P301
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily

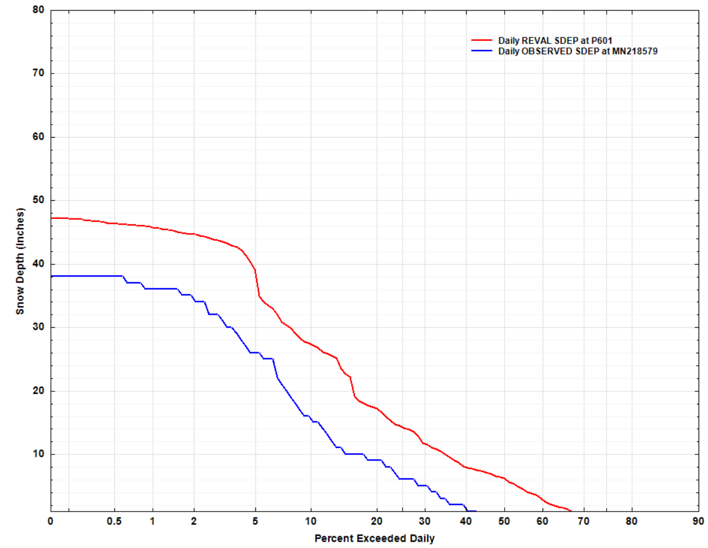

Daily COMPUTED TMIN at MN216360
Daily REVAL SDEP at P401
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002

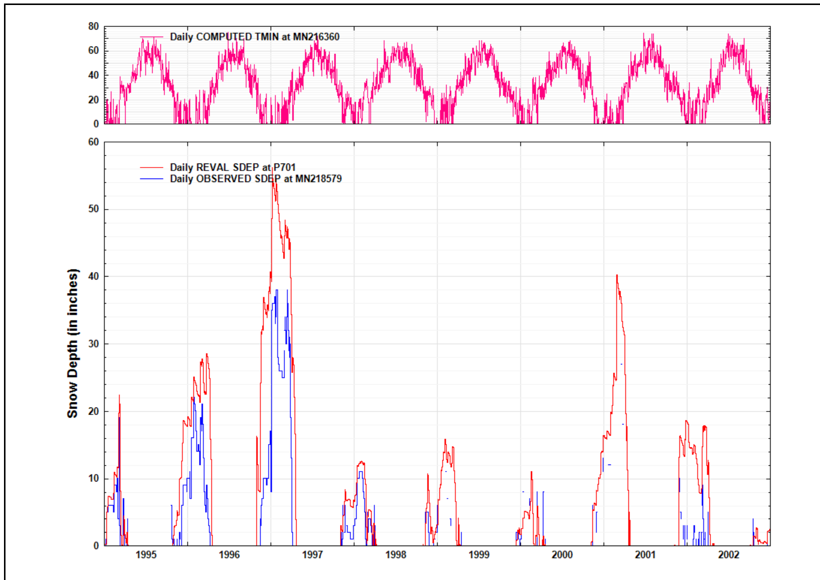

Daily REVAL SDEP at P401
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily

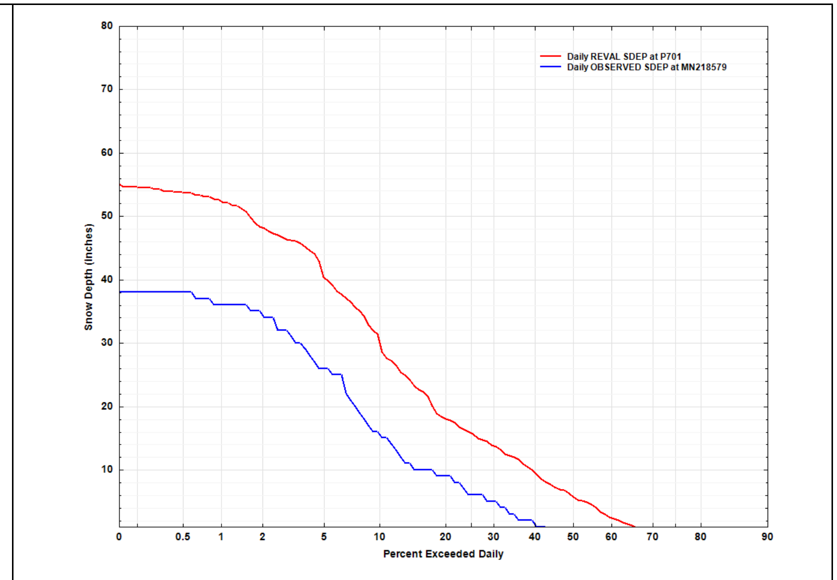

Daily COMPUTED TMIN at MN216360
Daily REVAL SDEP at P501
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002

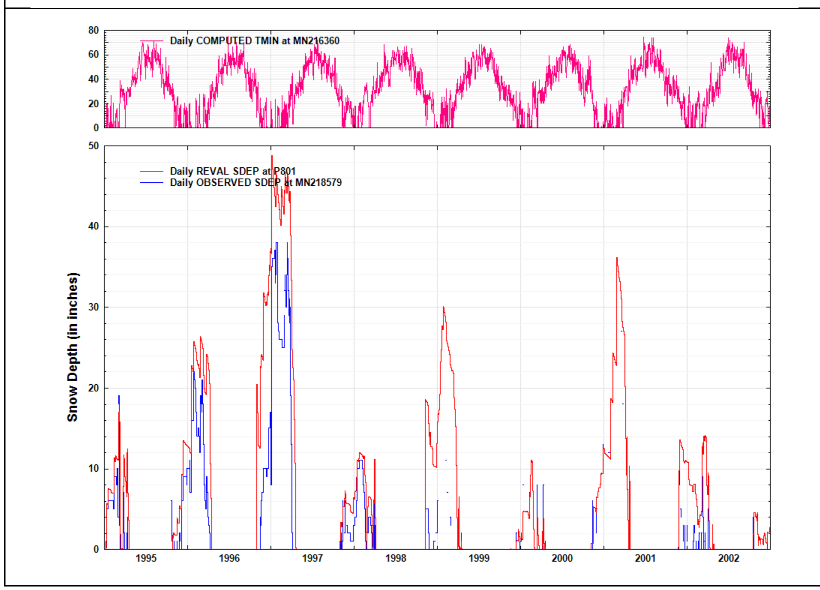

Daily REVAL SDEP at P501
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily

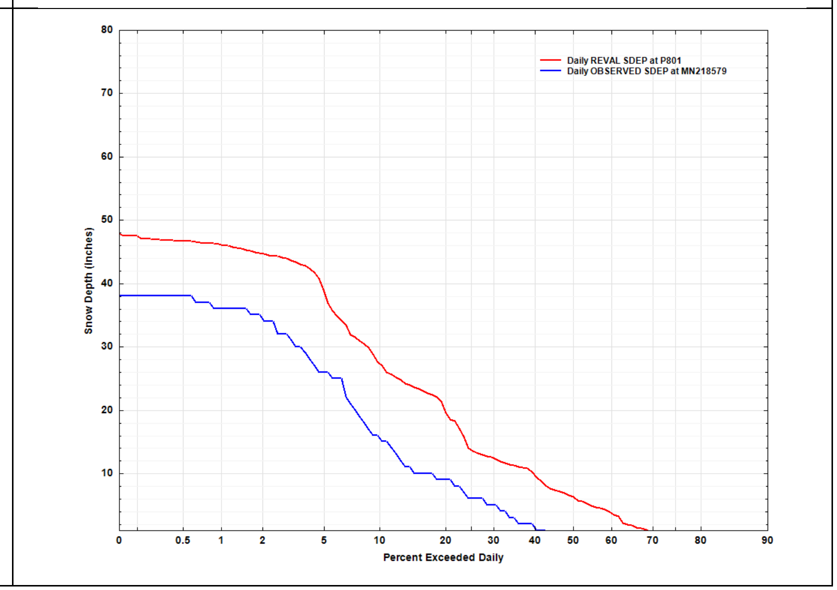

Daily COMPUTED TMIN at MN216360
Daily REVAL SDEP at P601
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002


Daily REVAL SDEP at P601
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily

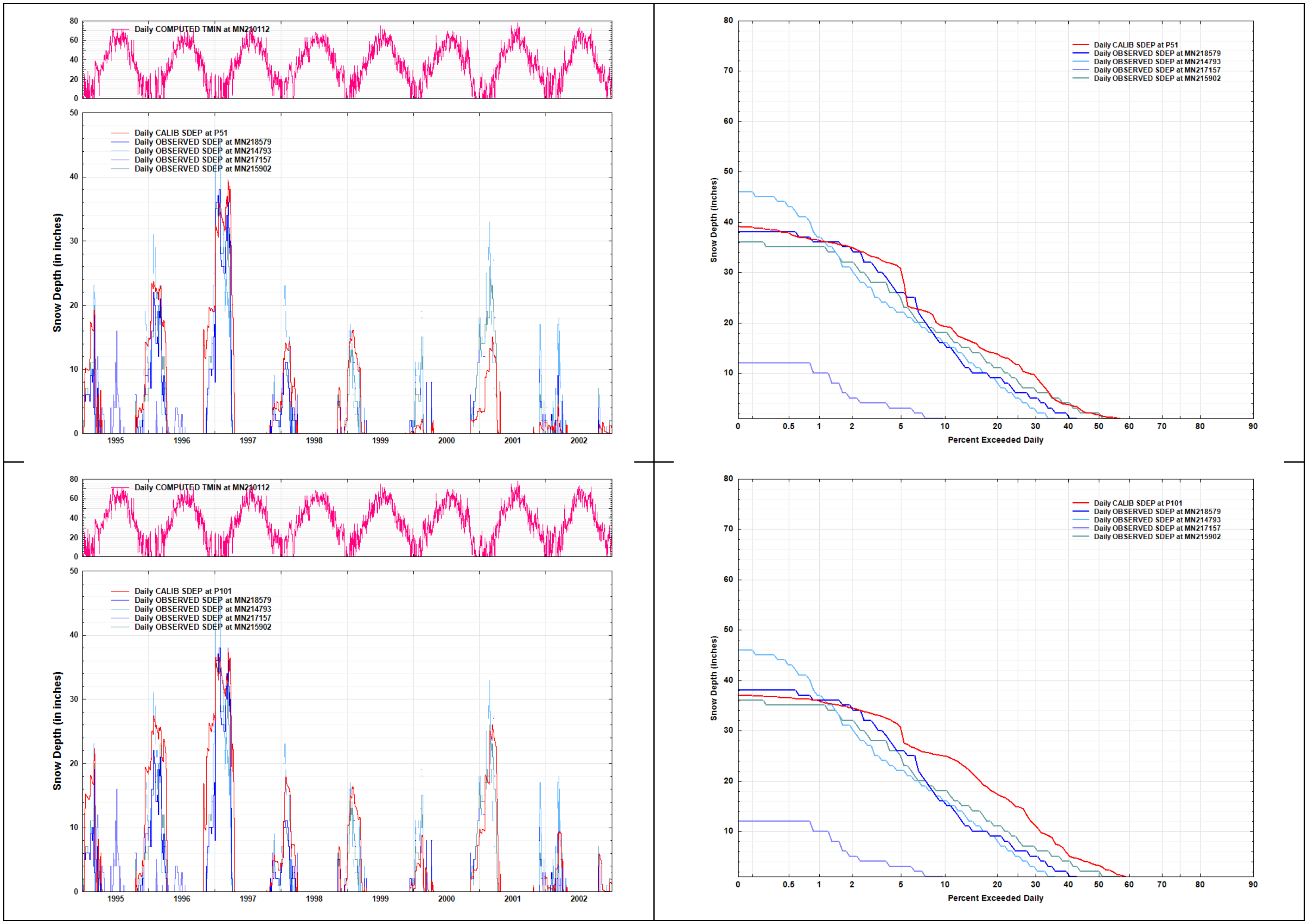

Daily COMPUTED TMIN at MN216360
Daily REVAL SDEP at P701
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)

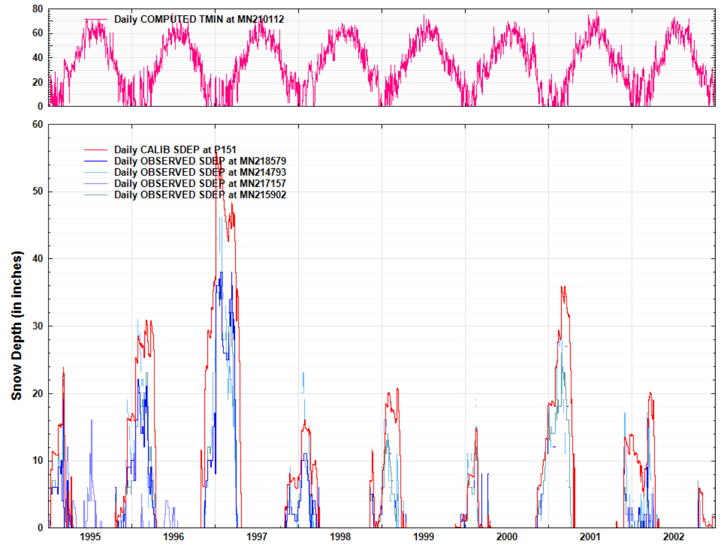

Daily REVAL SDEP at P701
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily

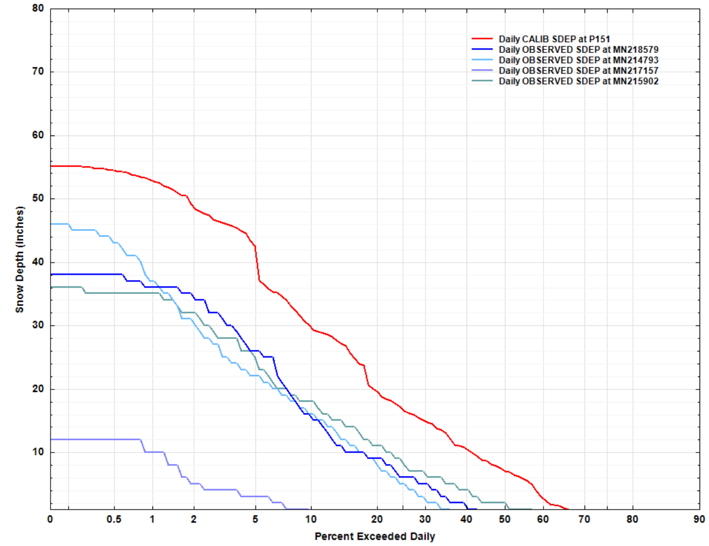

Daily COMPUTED TMIN at MN216360
Daily REVAL SDEP at P801
Daily OBSERVED SDEP at MN218579
Snow Depth (in inches)

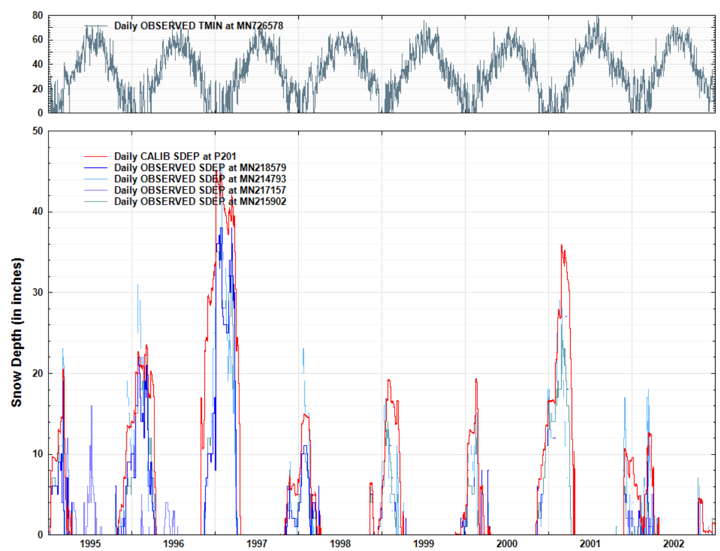

Daily REVAL SDEP at P801
Daily OBSERVED SDEP at MN218579
Snow Depth (inches)
Percent Exceeded Daily

B.2 LONG PRAIRIE RIVER WATERSHED




Daily COMPUTED TMIN at MN210112
Daily CALIB SDEP at P151
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CALIB SDEP at P151
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily


Daily OBSERVED TMIN at MN726578
Daily CALIB SDEP at P201
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
1995
1996
1997
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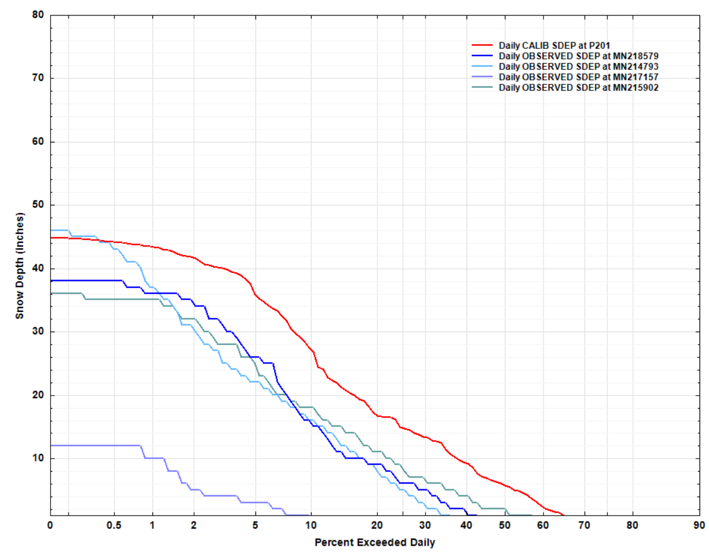
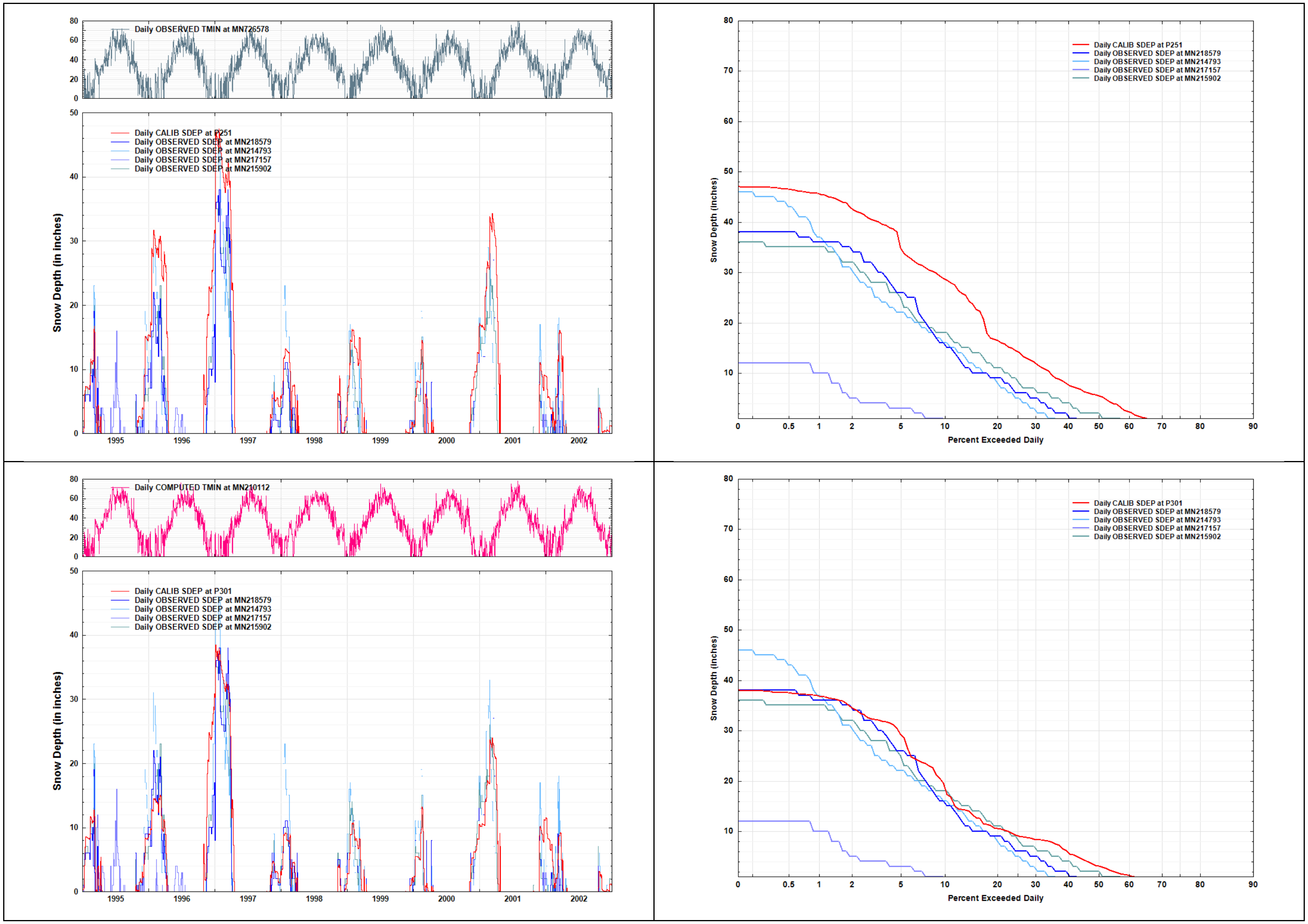
2001
2002


Daily CALIB SDEP at P201
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily


Daily OBSERVED TMIN at MN726578
Daily CALIB SDEP at P251
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
Snow Depth (inches)
Percent Exceeded Daily
Daily COMPUTED TMIN at MN210112
Daily CALIB SDEP at P301
1995
1996
1997
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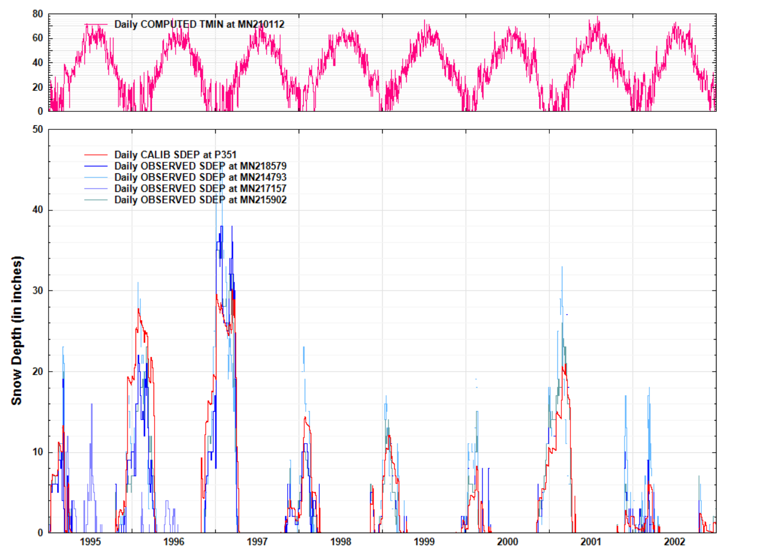
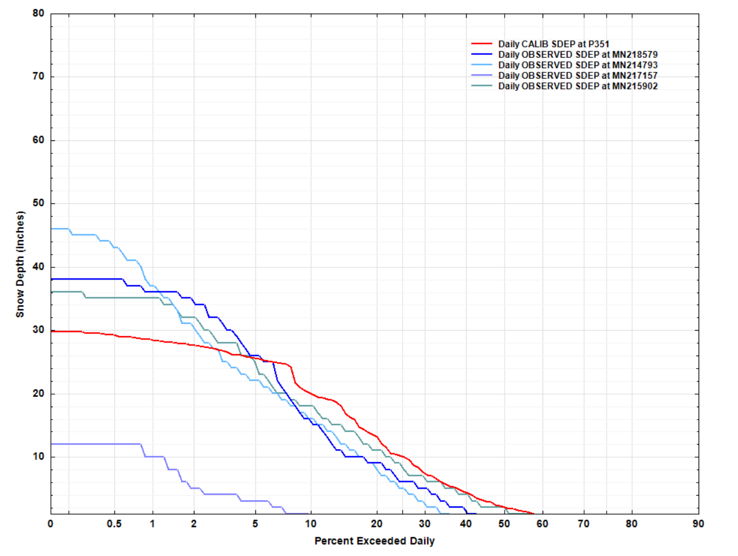
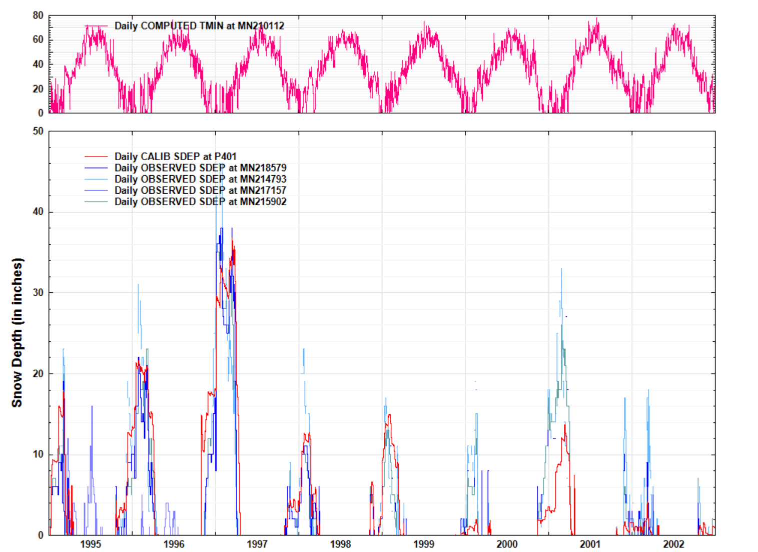
1999
2000
2001
2002


Daily COMPUTED TMIN at MN210112
Daily CALIB SDEP at P351
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CALIB SDEP at P351
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN210112
Daily CALIB SDEP at P401
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
1995
1996
1997
1998
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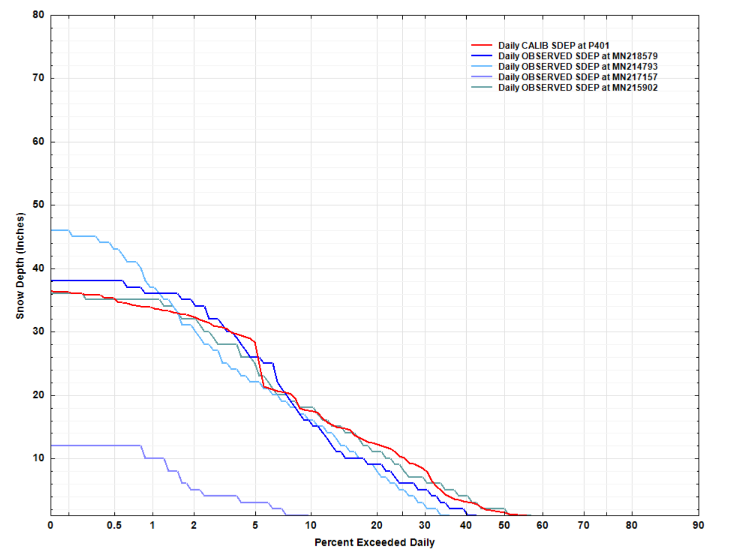
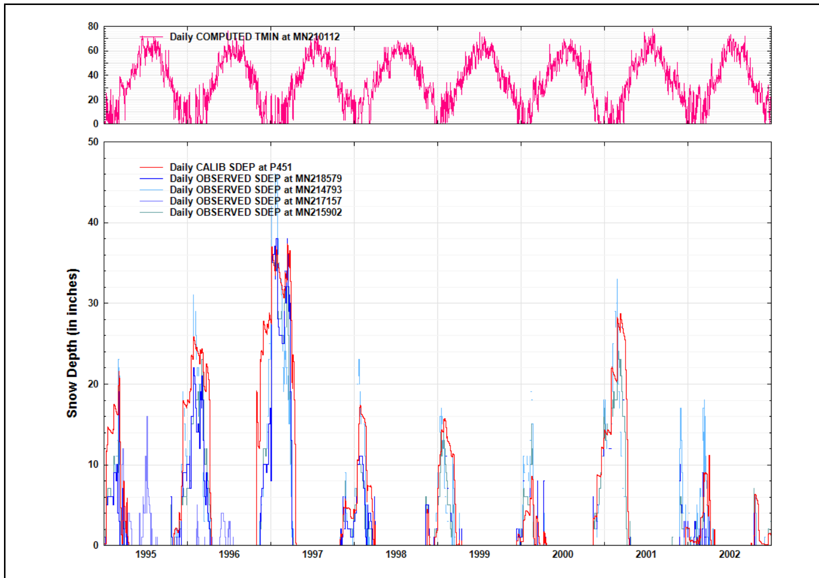
2001
2002


Daily CALIB SDEP at P401
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN210112
Daily CALIB SDEP at P451
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
1995
1996
1997
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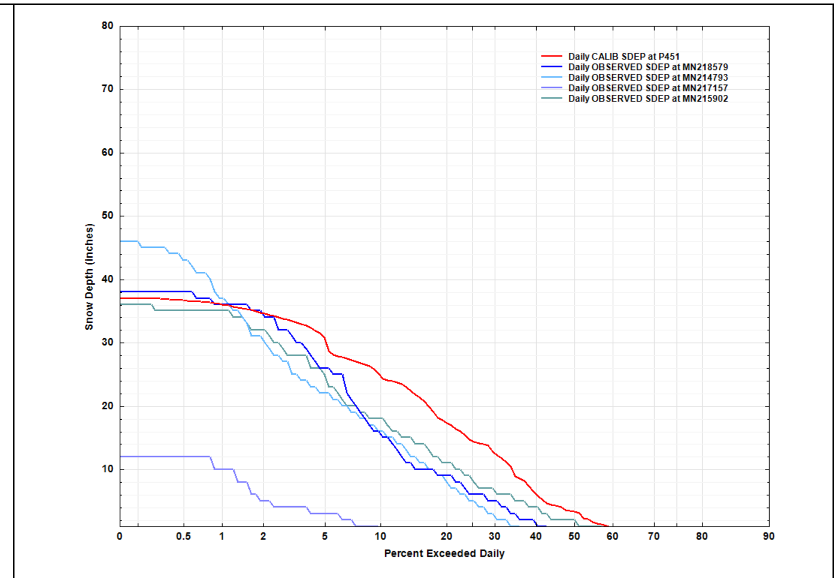
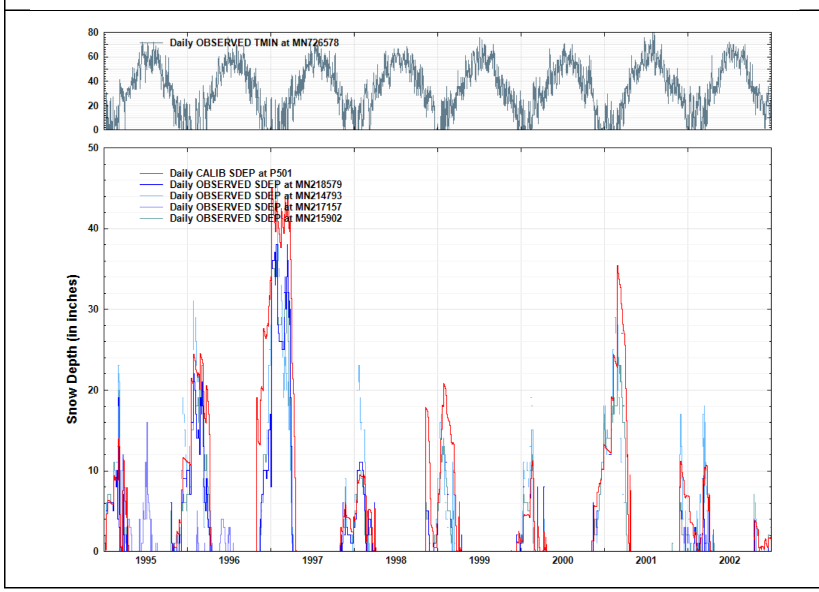
2002


Daily CALIB SDEP at P451
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily


Daily OBSERVED TMIN at MN726578
Daily CALIB SDEP at P501
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
1995
1996
1997
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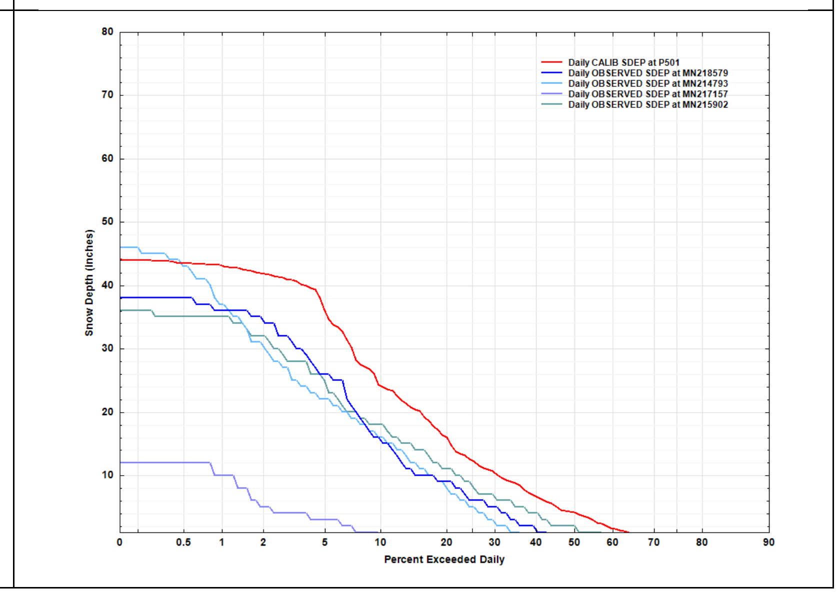
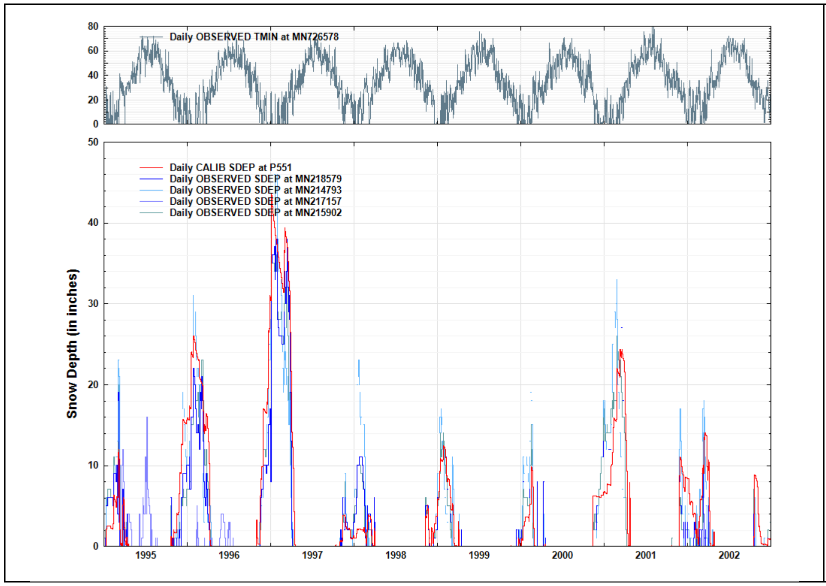
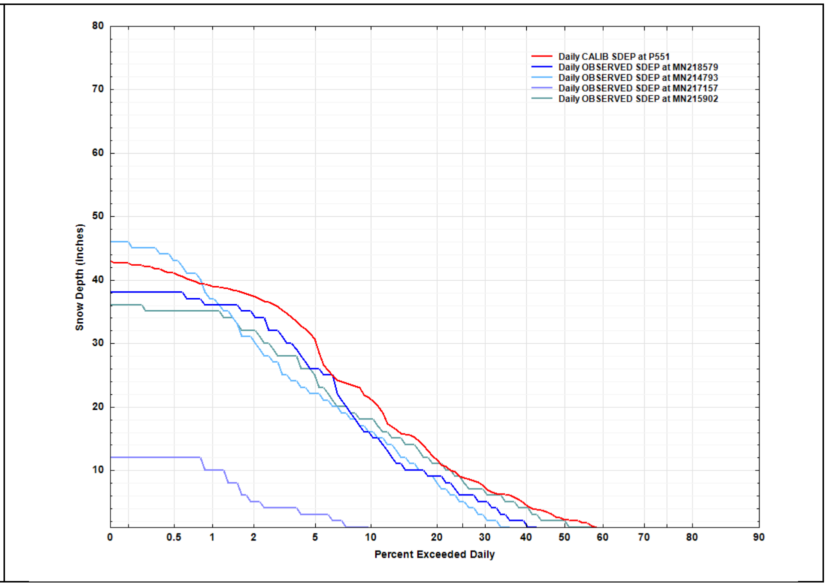
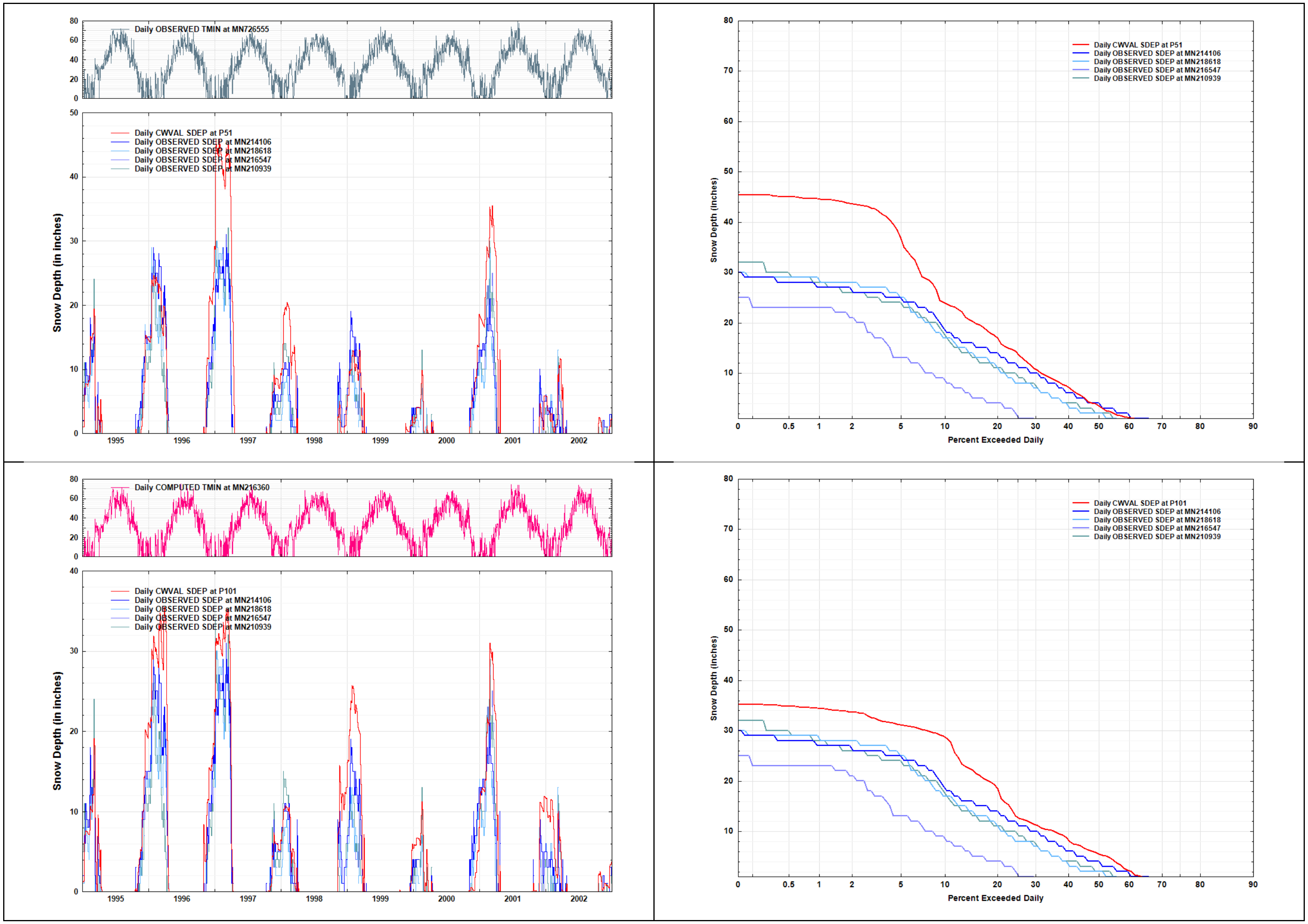
2002

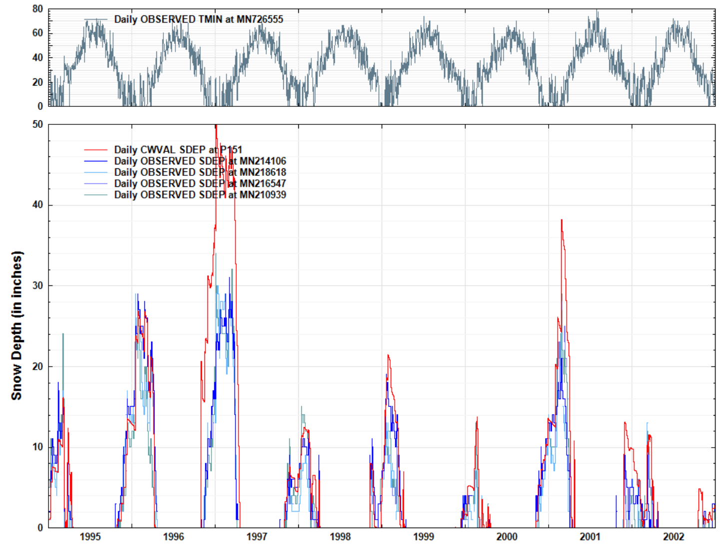

Daily CALIB SDEP at P501
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily

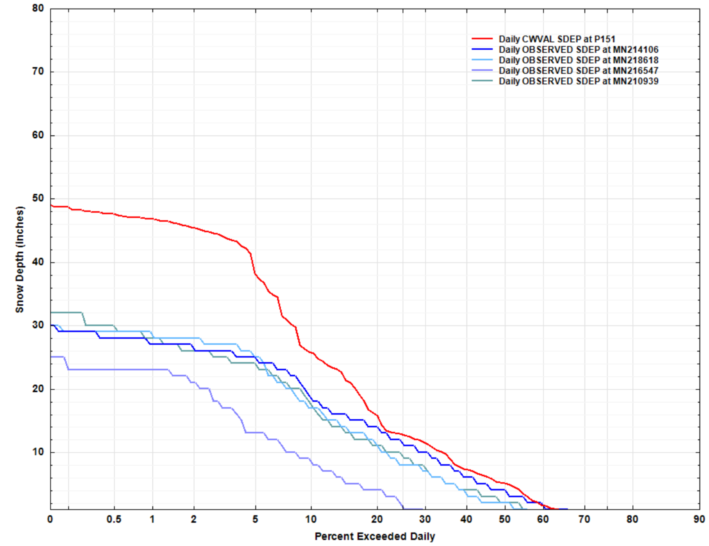

Daily OBSERVED TMIN at MN726578
Daily CALIB SDEP at P551
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002

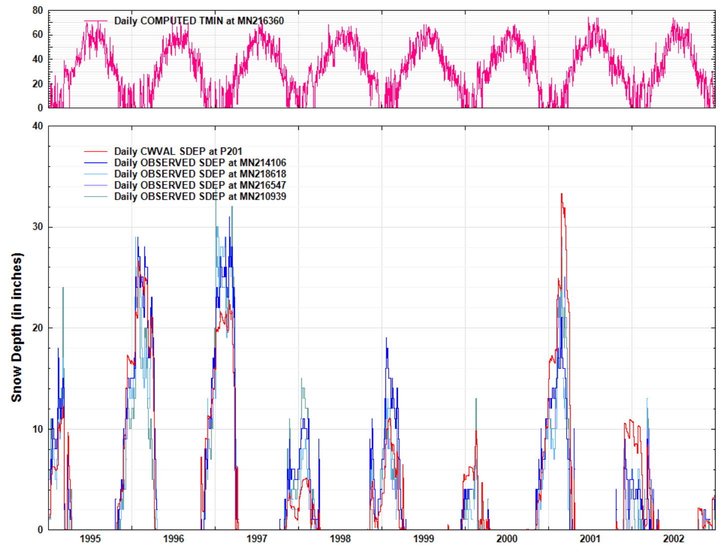

Daily CALIB SDEP at P551
Daily OBSERVED SDEP at MN218579
Daily OBSERVED SDEP at MN214793
Daily OBSERVED SDEP at MN217157
Daily OBSERVED SDEP at MN215902
Snow Depth (inches)
Percent Exceeded Daily

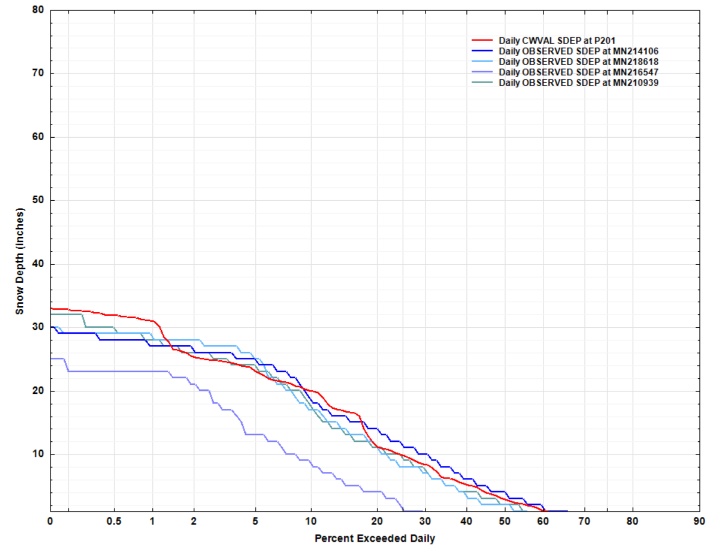
B.3 CROW WING RIVER WATERSHED

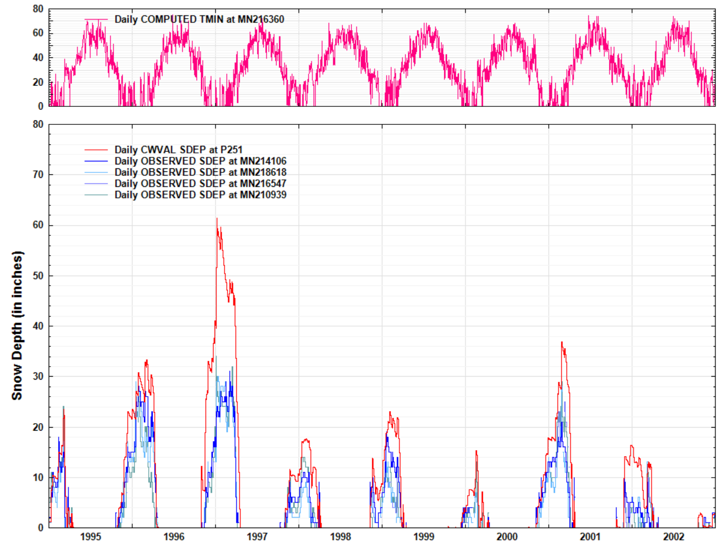



Daily OBSERVED TMIN at MN726555
Daily CWVAL SDEP at P151
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL SDEP at P151
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P201
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL SDEP at P201
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P251
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
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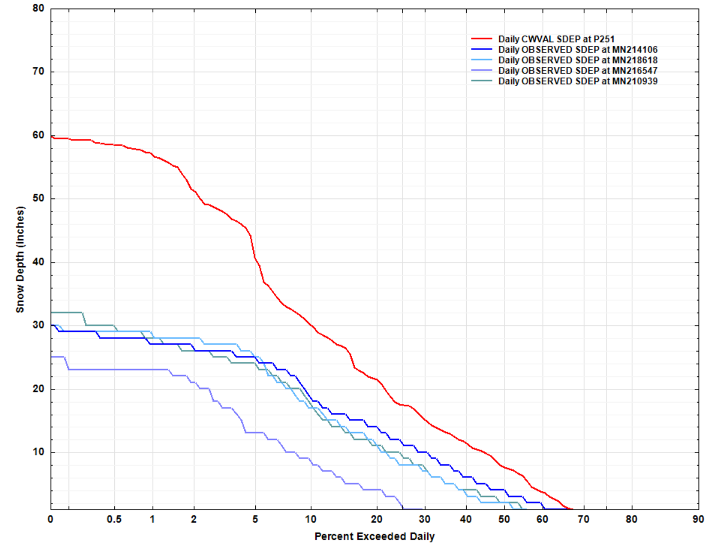
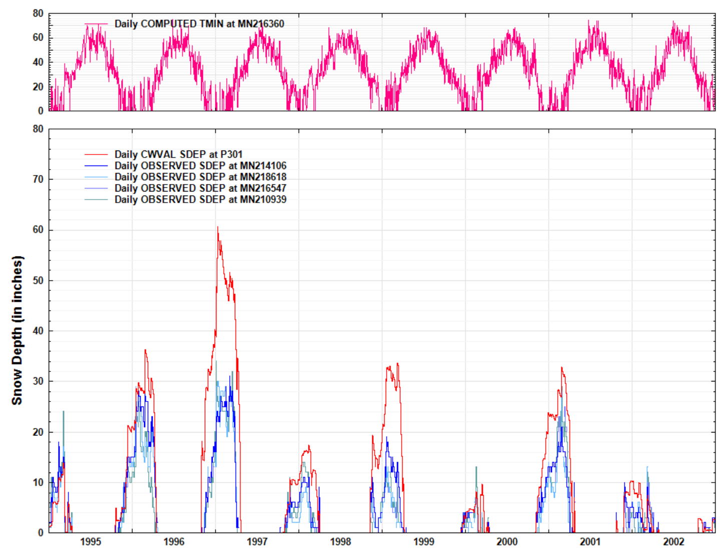
1999
2000
2001
2002


Daily CWVAL SDEP at P251
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P301
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
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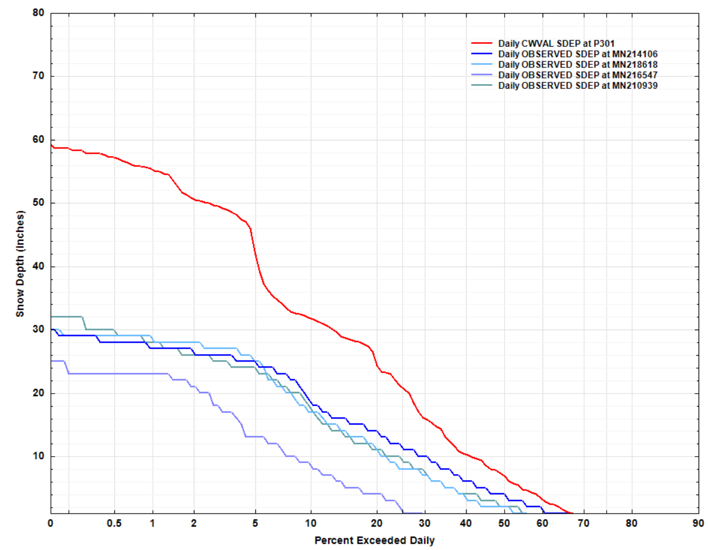
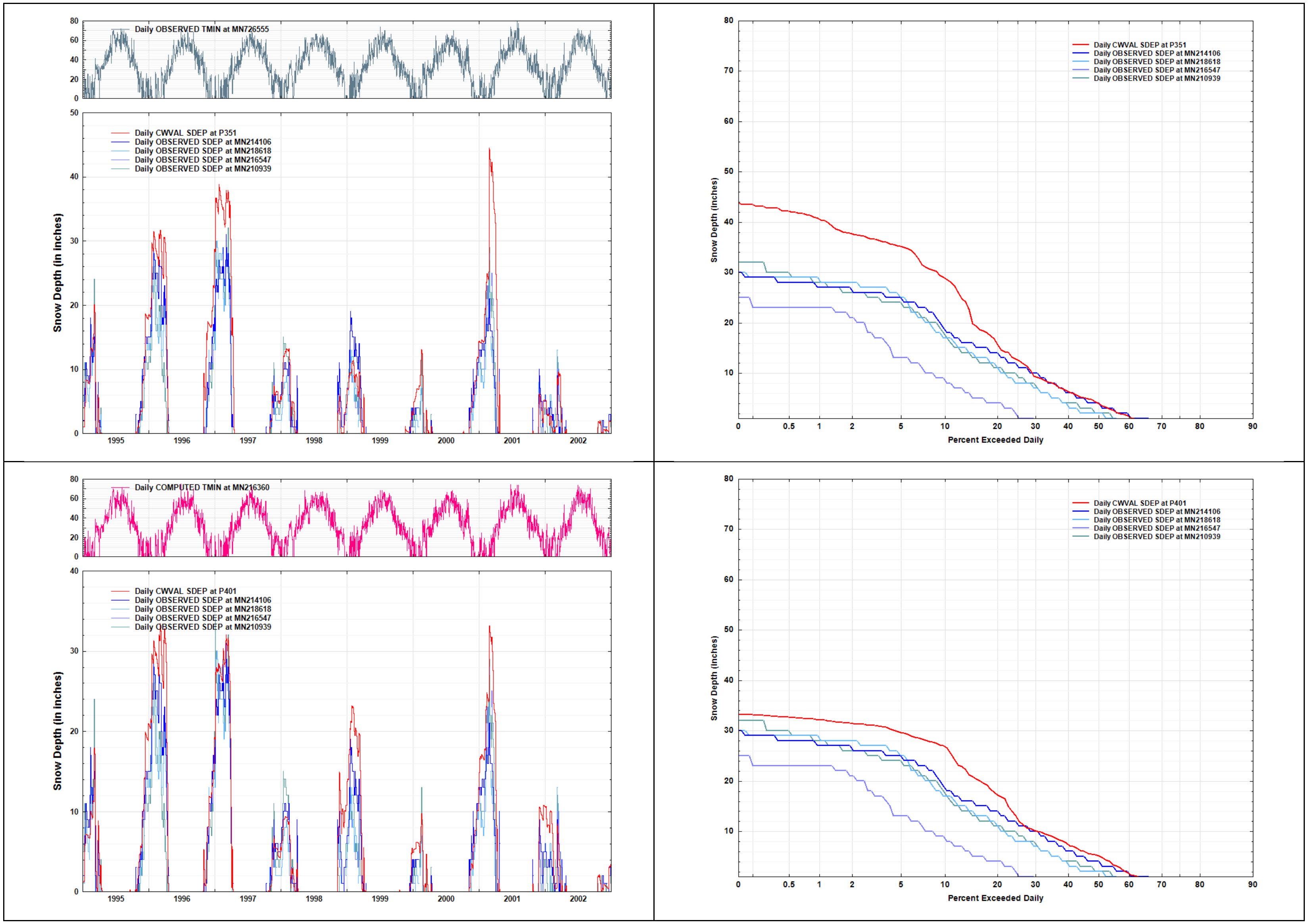
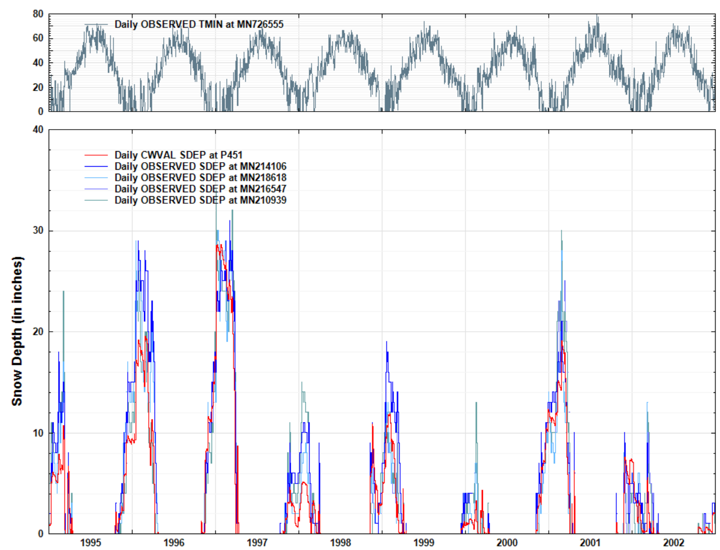
2002


Daily CWVAL SDEP at P301
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily OBSERVED TMIN at MN726555
Daily CWVAL SDEP at P351
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995 1996 1997 1998 1999 2000 2001 2002
Snow Depth (inches)
Percent Exceeded Daily
Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P401
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
Snow Depth (inches)
Percent Exceeded Daily


Daily OBSERVED TMIN at MN726555
Daily CWVAL SDEP at P451
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
1998
1999
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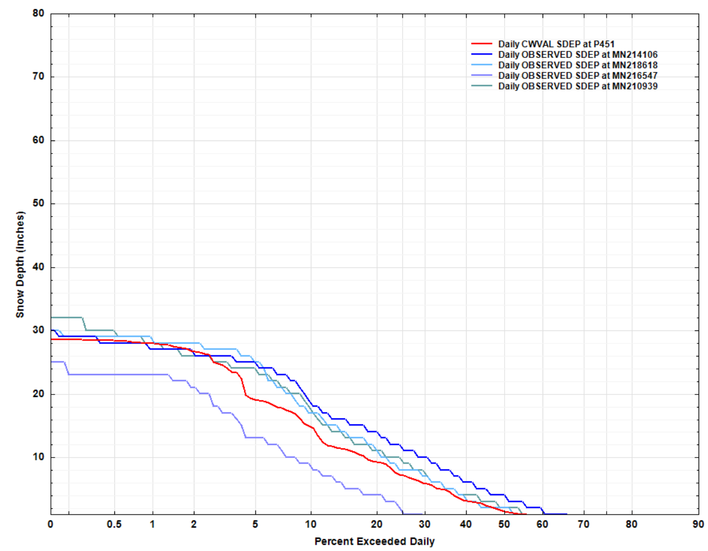
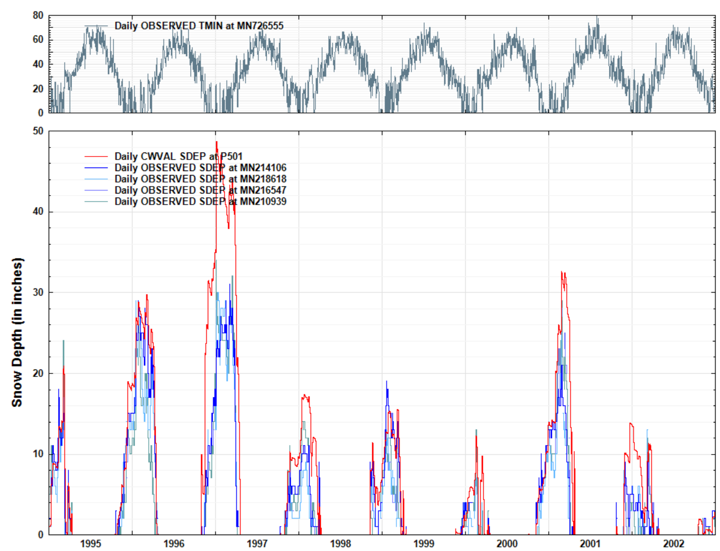
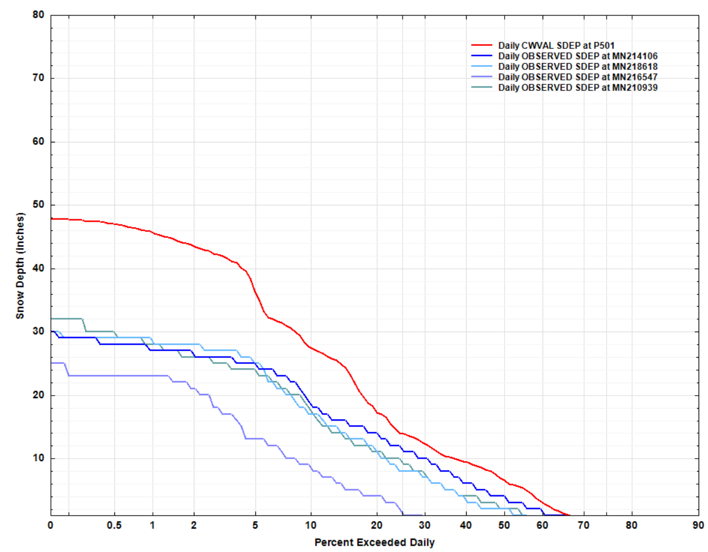
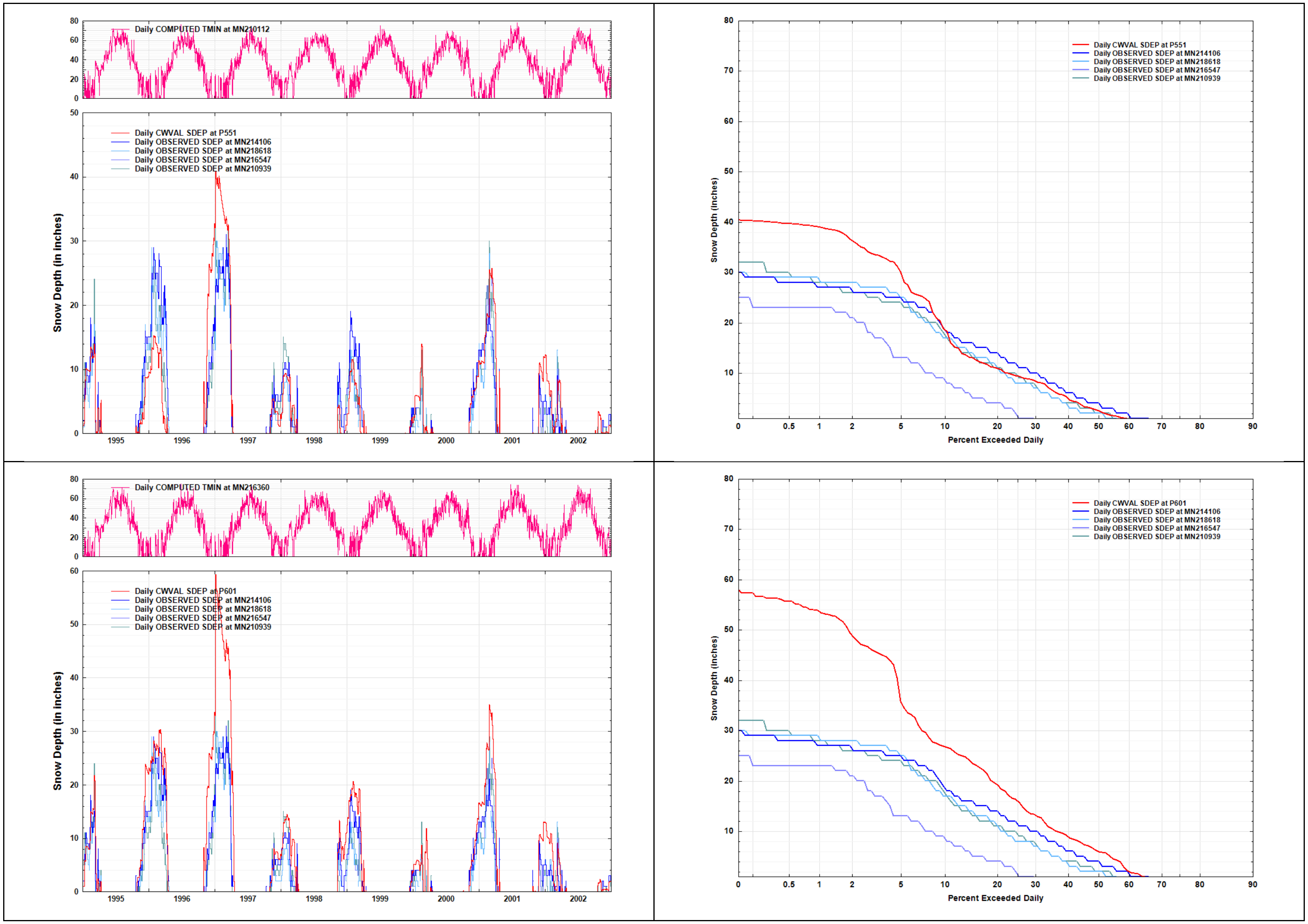
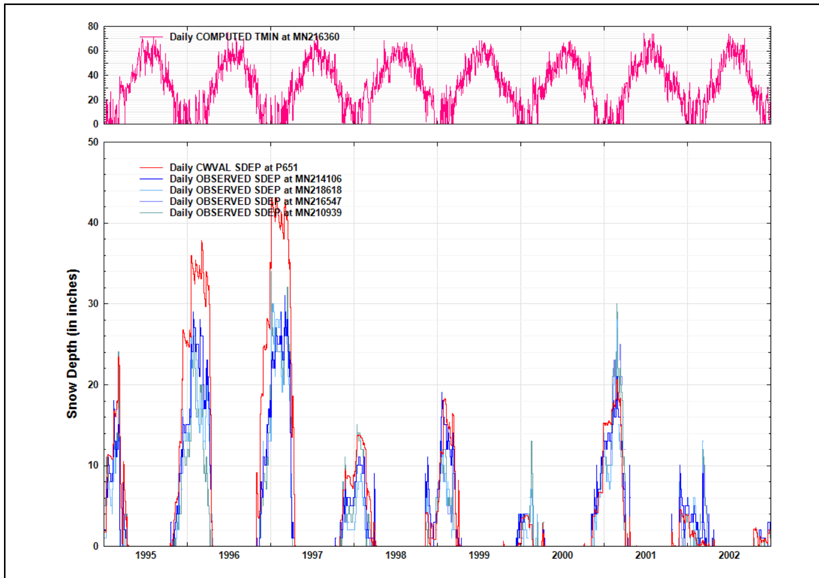
2001
2002

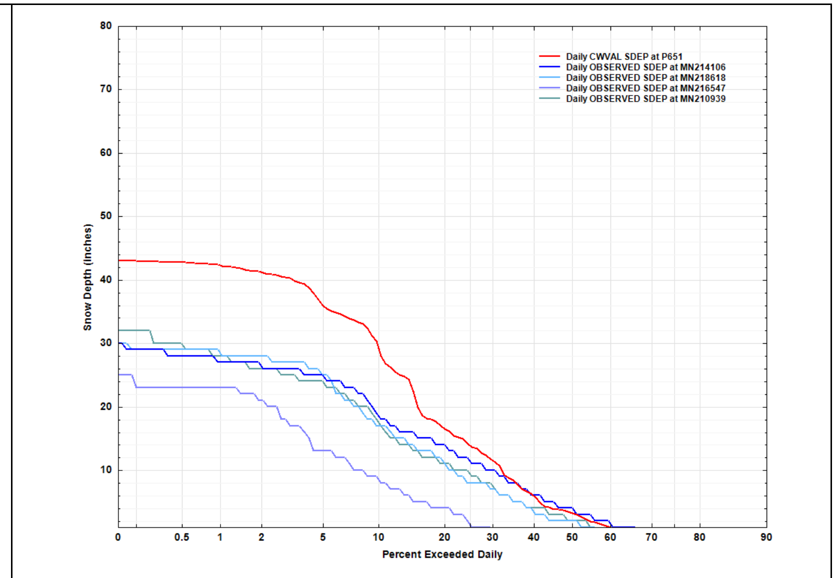

Daily CWVAL SDEP at P451
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

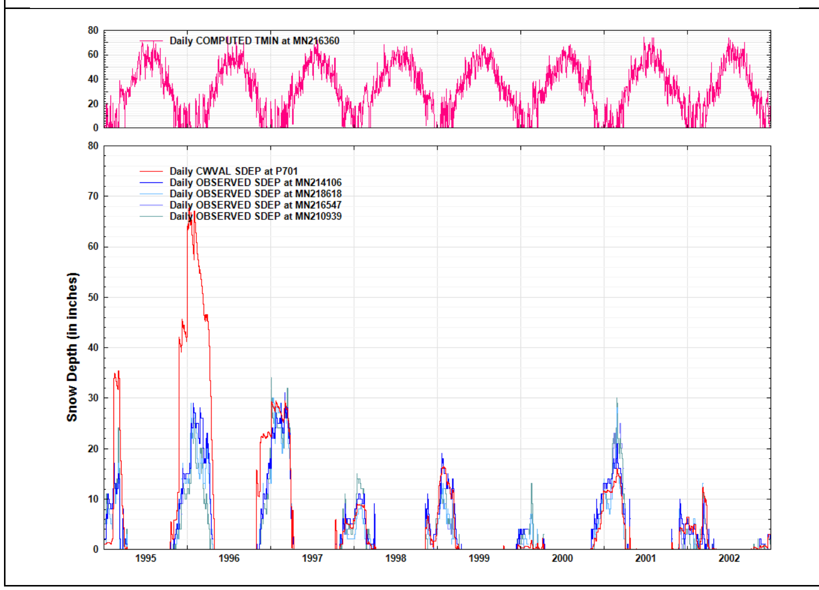

Daily OBSERVED TMIN at MN726555
Daily CWVAL SDEP at P501
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002

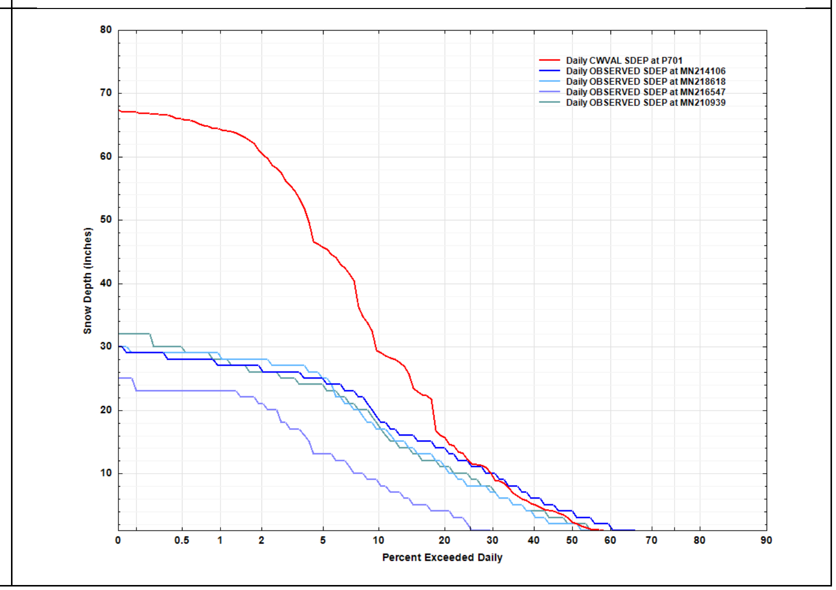

Daily CWVAL SDEP at P501
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

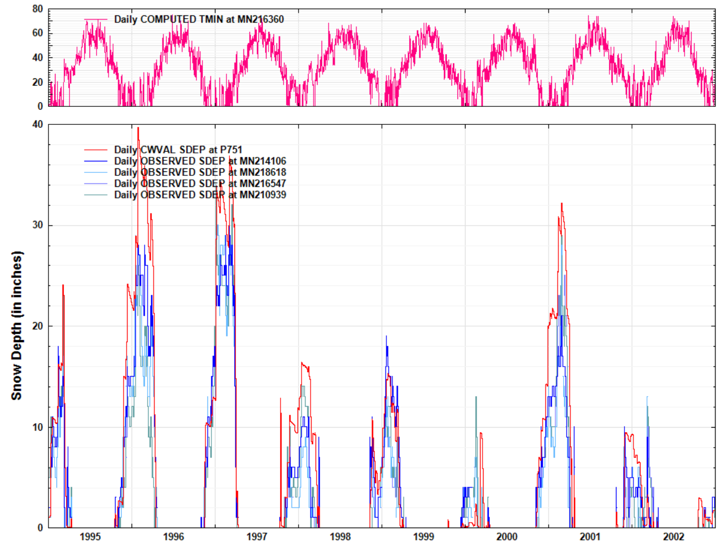

Daily COMPUTED TMIN at MN210112
Daily CWVAL SDEP at P551
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002
Snow Depth (inches)
Percent Exceeded Daily
Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P601
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
Snow Depth (inches)
Percent Exceeded Daily

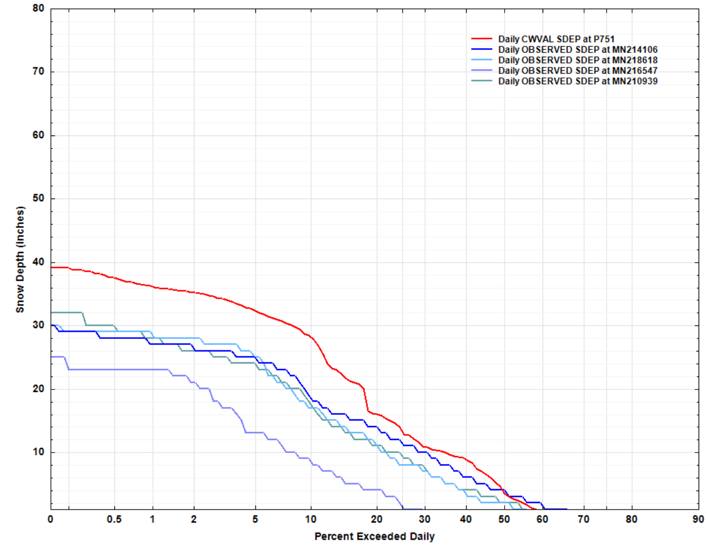

Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P651
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in Inches)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL SDEP at P651
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily


Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P701
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in Inches)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL SDEP at P701
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

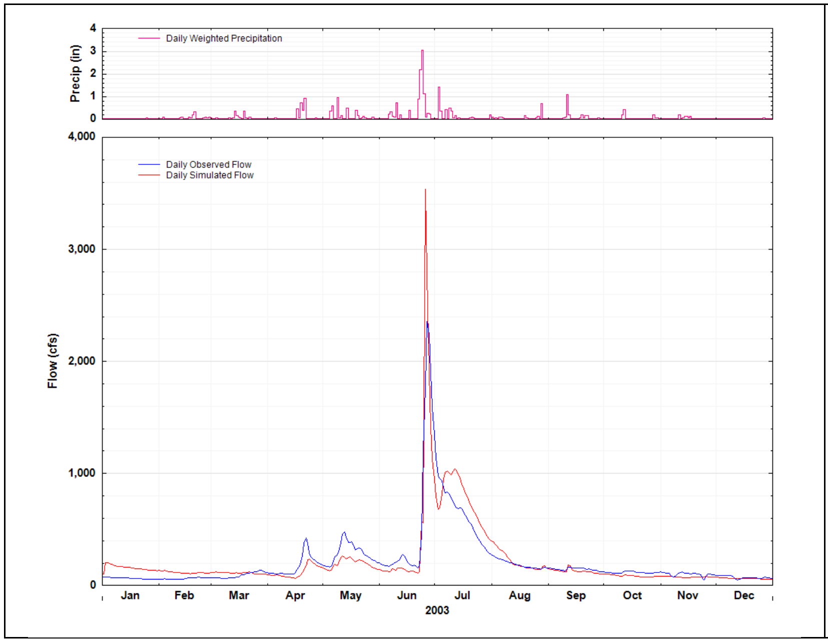

Daily COMPUTED TMIN at MN216360
Daily CWVAL SDEP at P751
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (in inches)
1995
1996
1997
1998
1999
2000
2001
2002

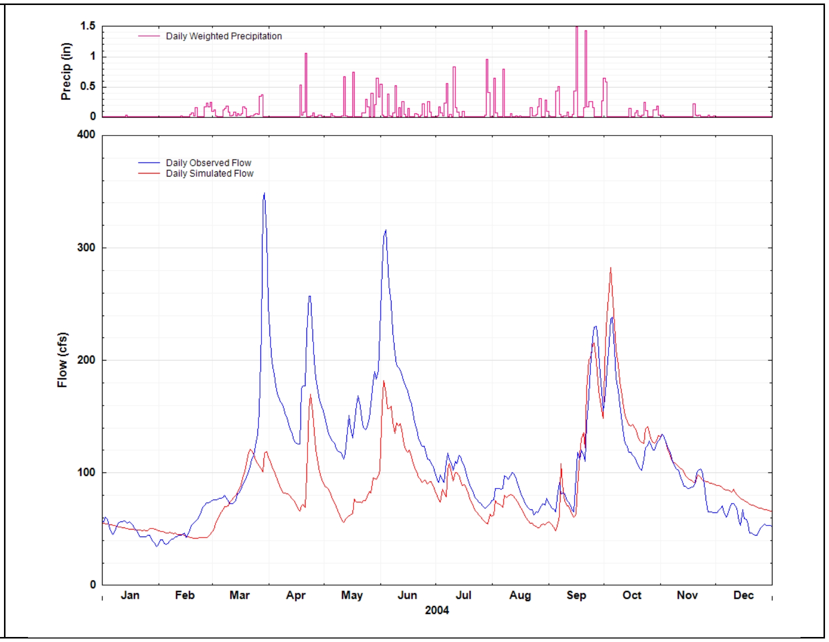

Daily CWVAL SDEP at P751
Daily OBSERVED SDEP at MN214106
Daily OBSERVED SDEP at MN218618
Daily OBSERVED SDEP at MN216547
Daily OBSERVED SDEP at MN210939
Snow Depth (inches)
Percent Exceeded Daily

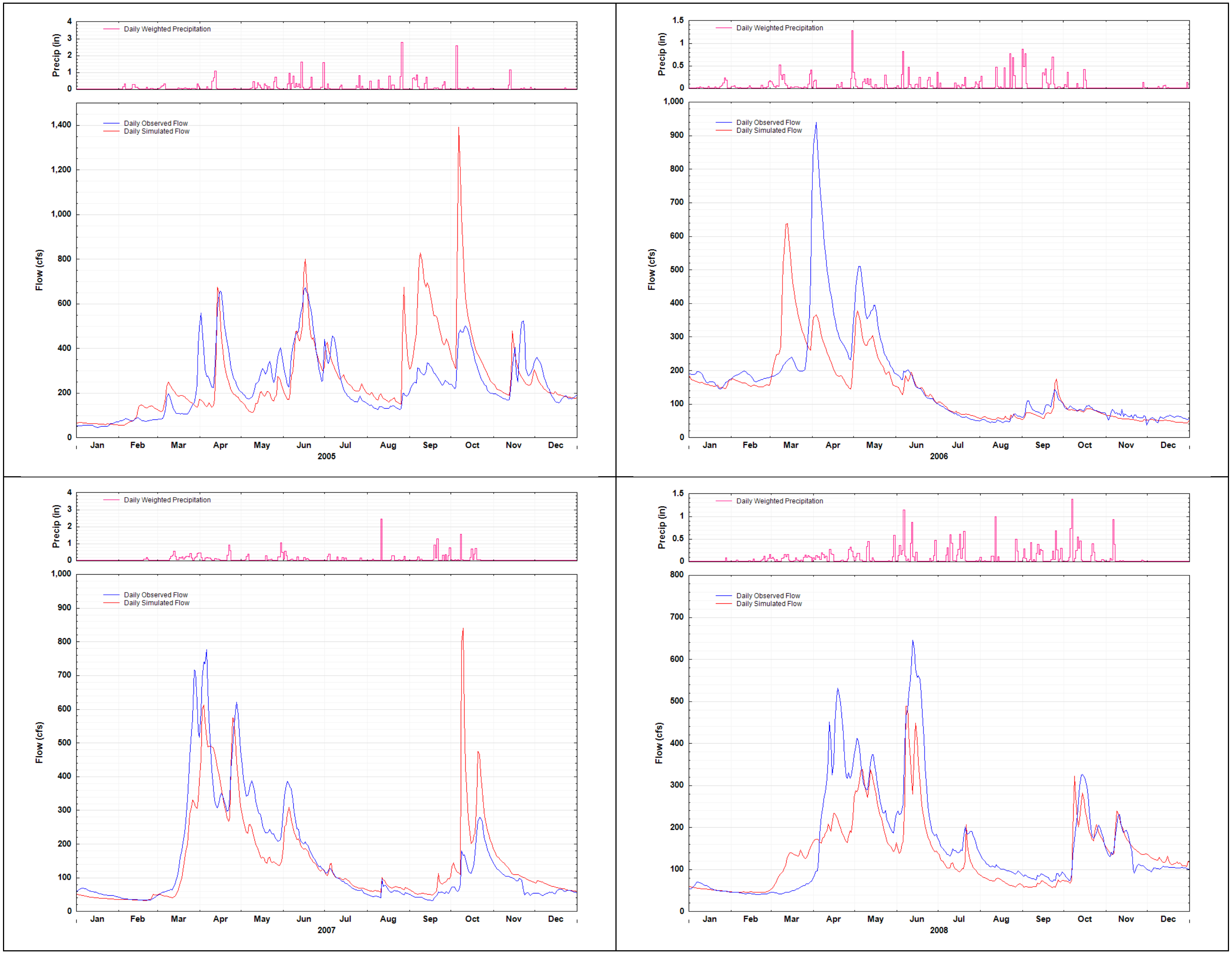
APPENDIX C
YEARLY HYDROGRAPHS FOR THE CALIBRATION PERIOD

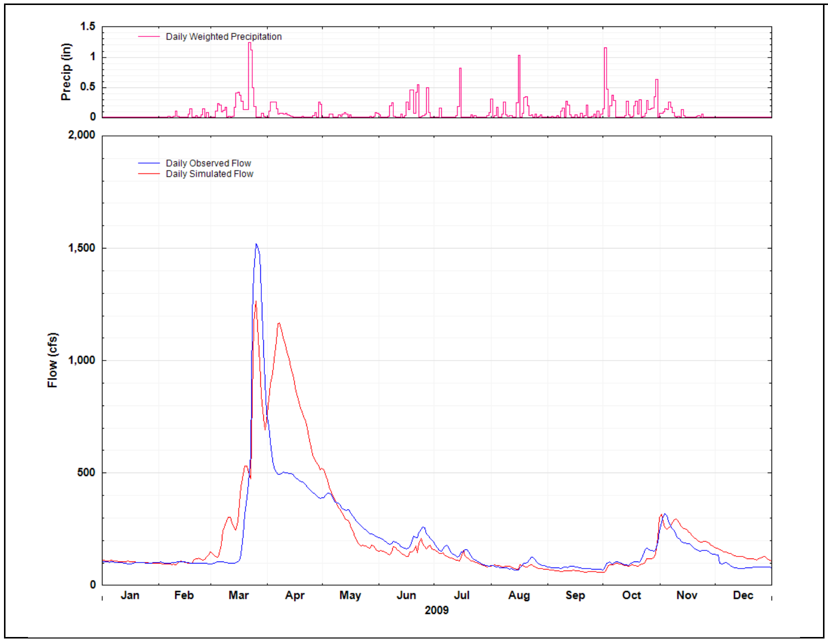
C.1 LONG PRAIRIE RIVER WATERSHED

C.1.1 USGS gage 05245100



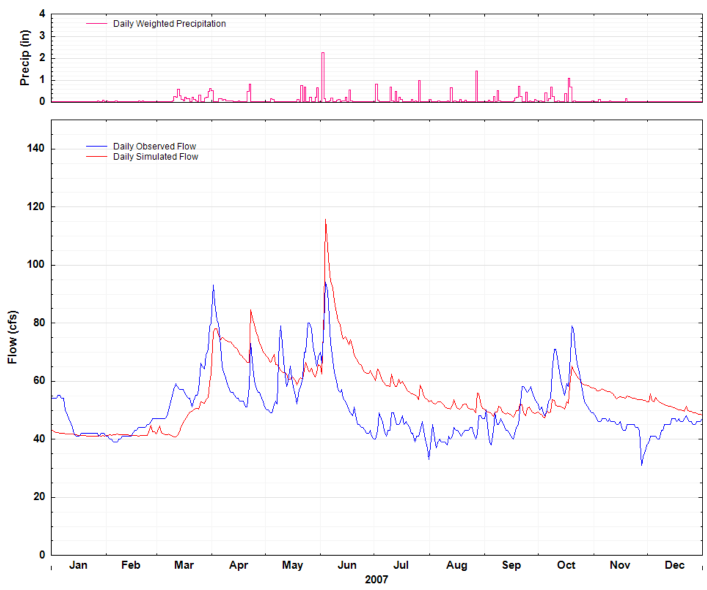


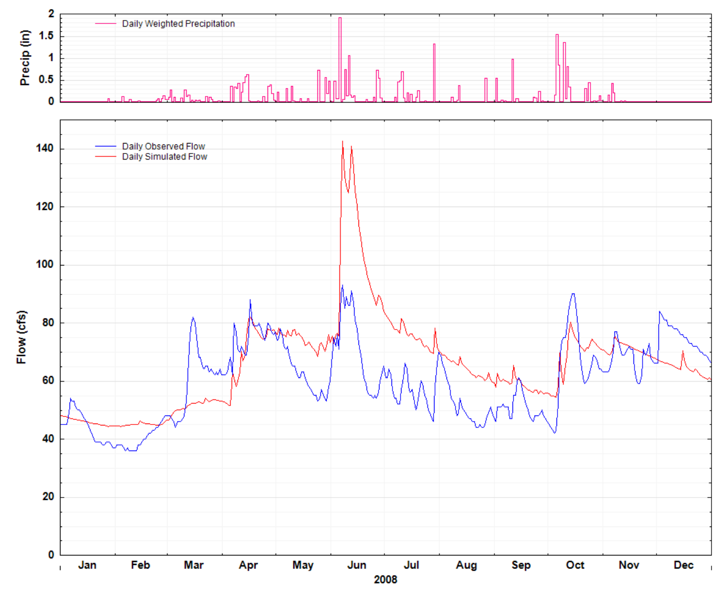

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2005
2006
2007
2008

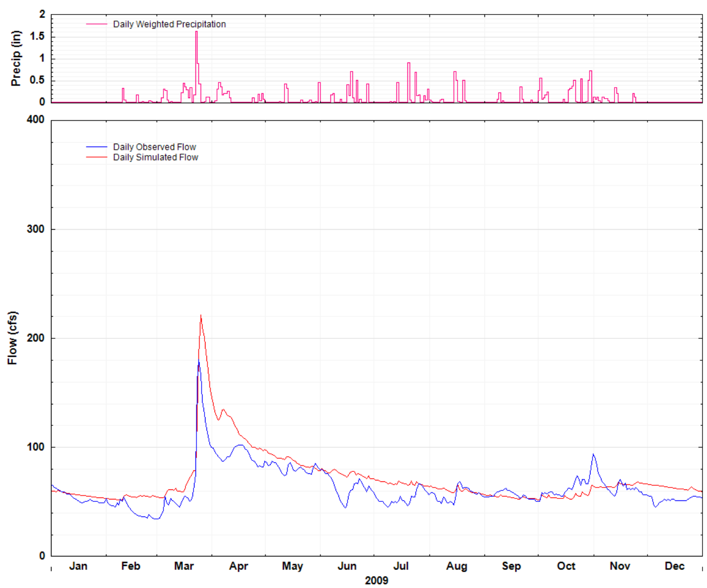

Daily Weighted Precipitation
Precip (in)
1.5
1
0.5
0
2,000
1,500
1,000
500
0
Flow (cfs)
Daily Observed Flow
Daily Simulated Flow
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2009

C.2 CROW WING RIVER WATERSHED

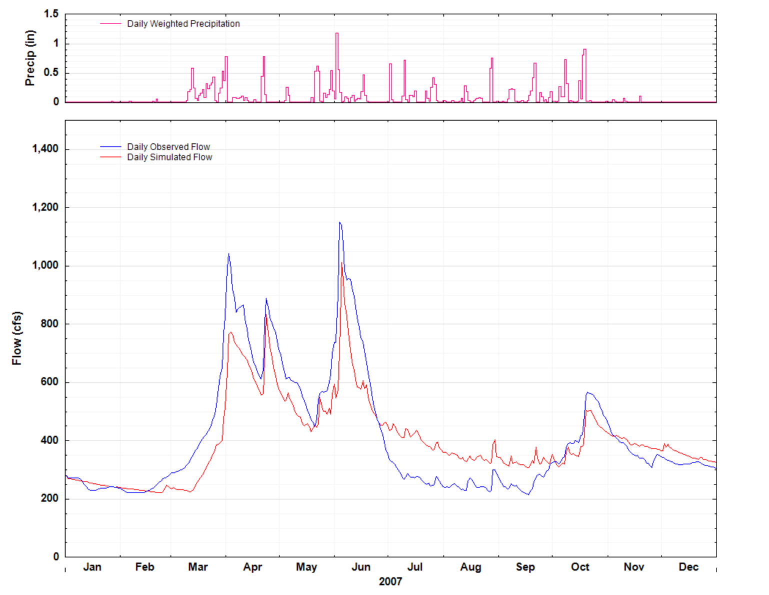
C.2.1 USGS gage 05243725

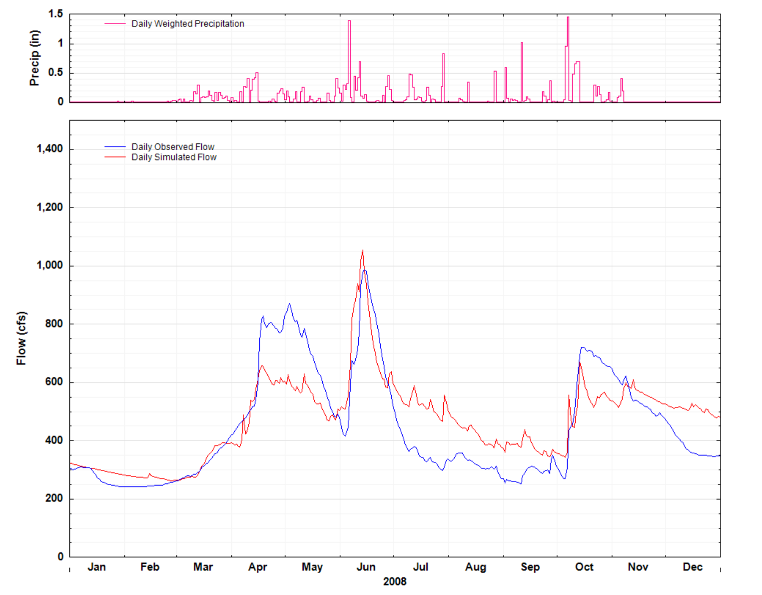

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2007

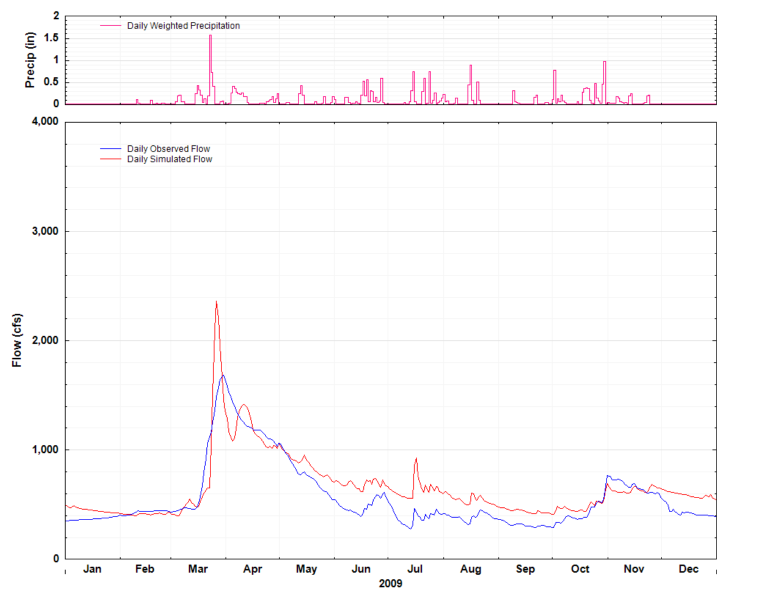

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2008


Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2009

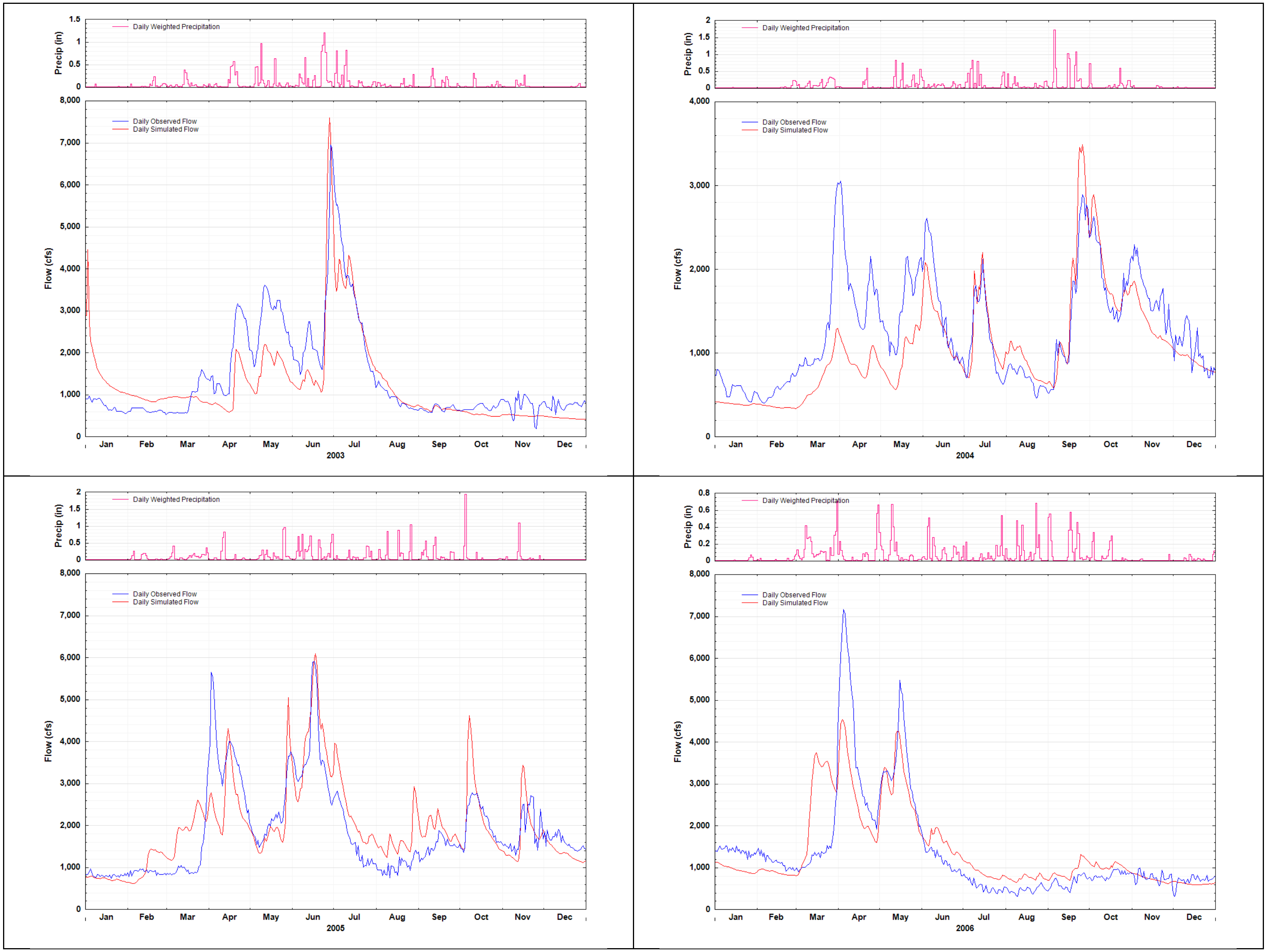
C.2.2 USGS gage 05244000

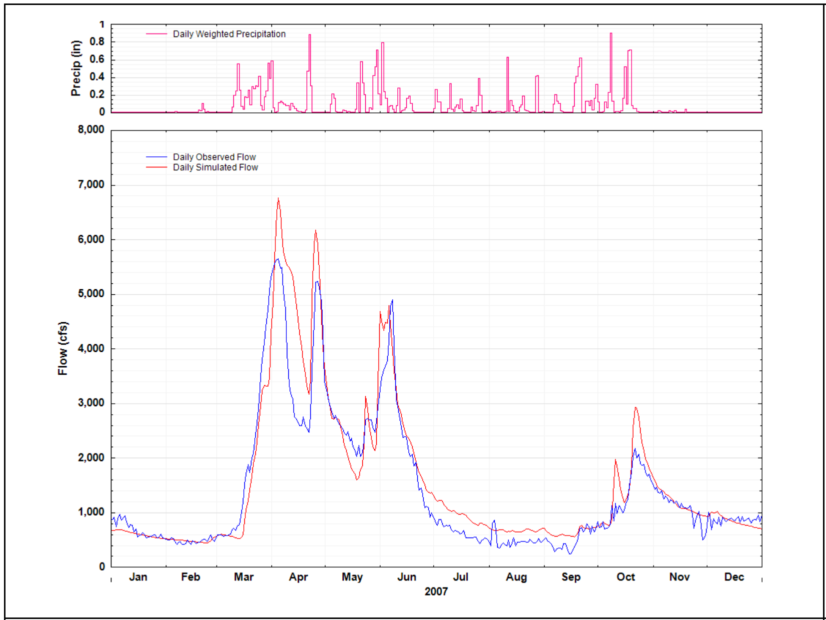

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2007

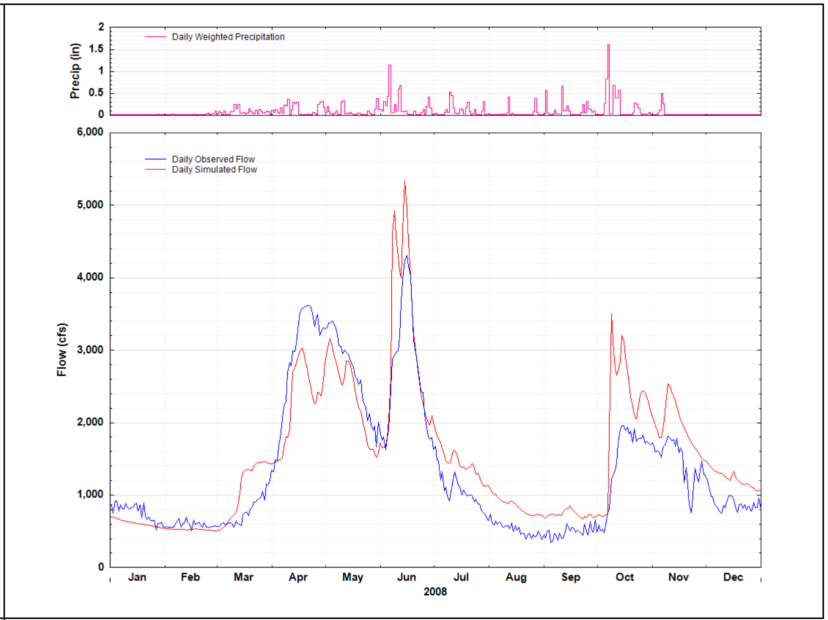

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2008

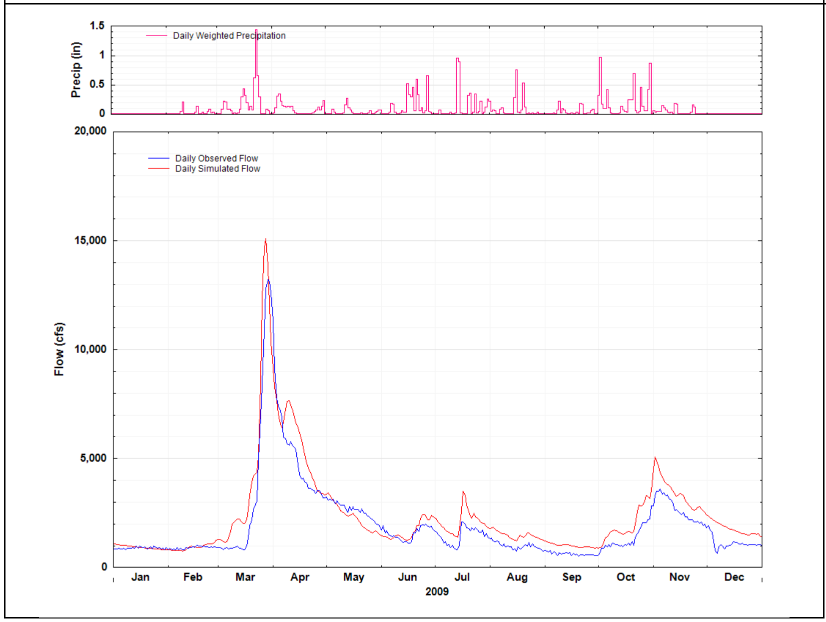

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2009

C.2.3 USGS gage 05247500




Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2007

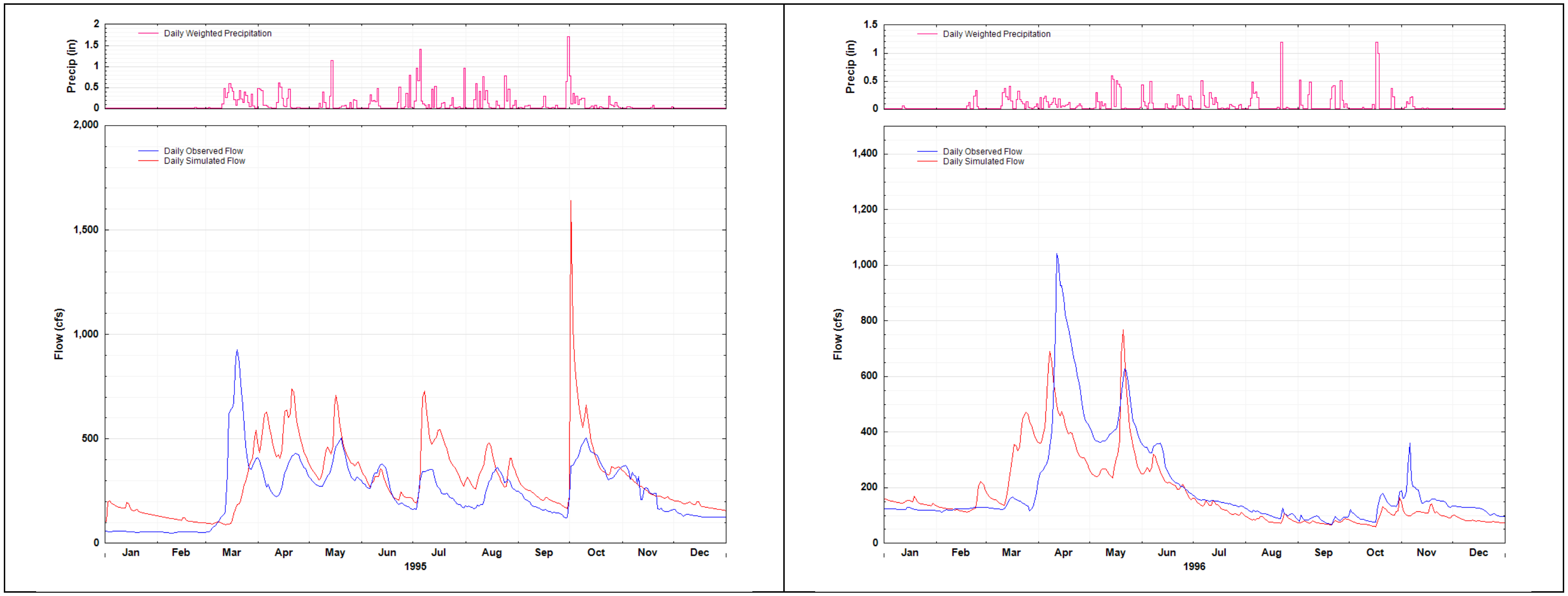

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2008

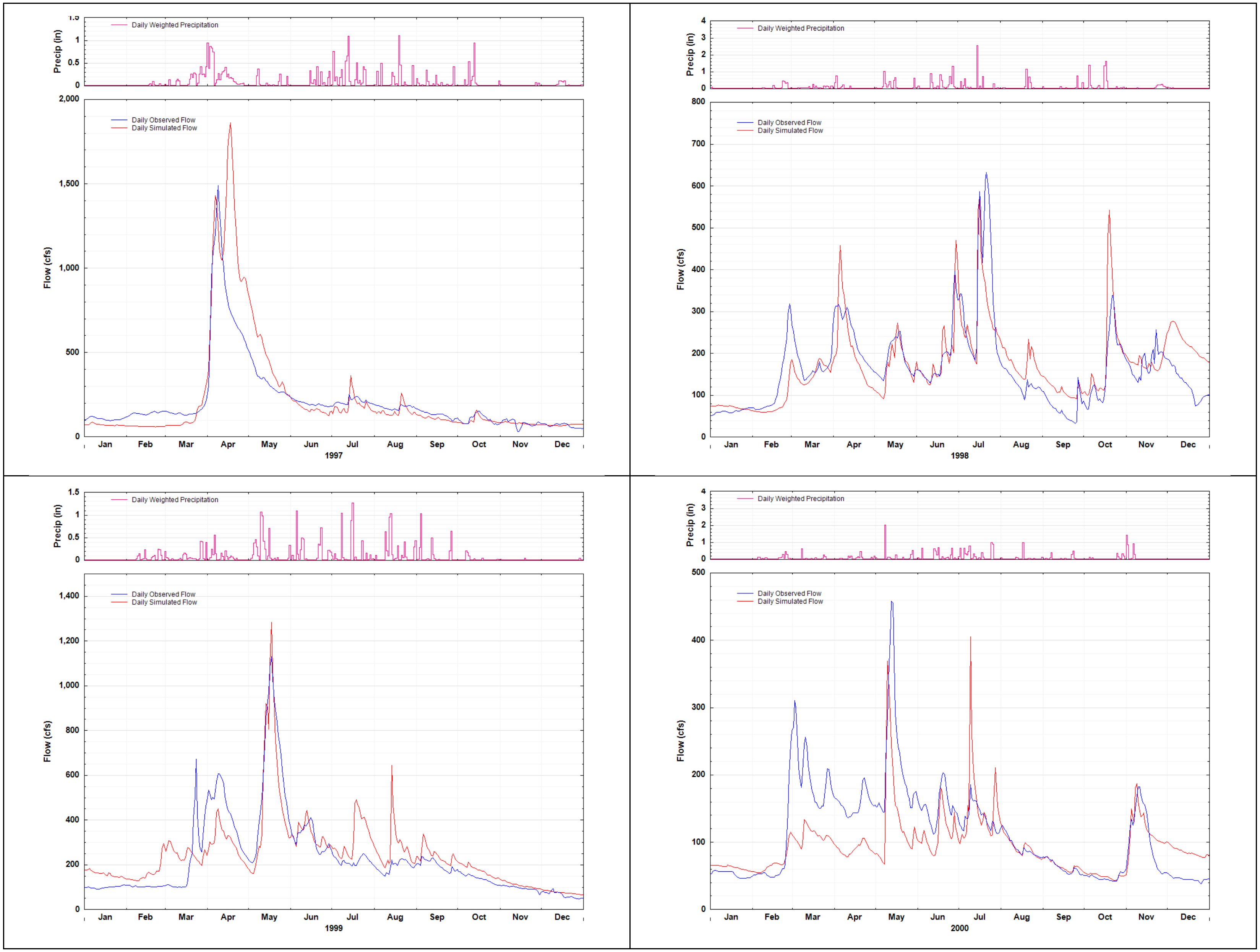

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2009

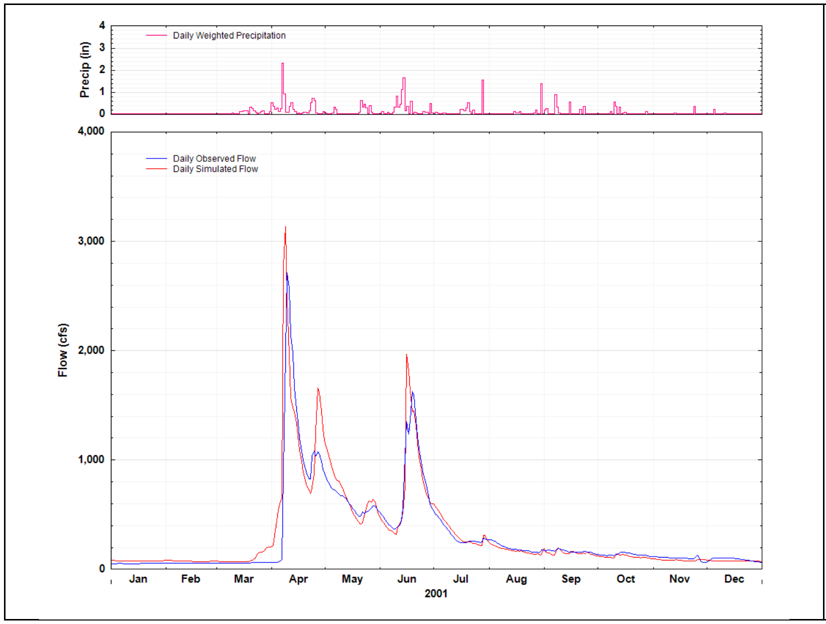
APPENDIX D
YEARLY HYDROGRAPHS FOR THE VALIDATION PERIOD

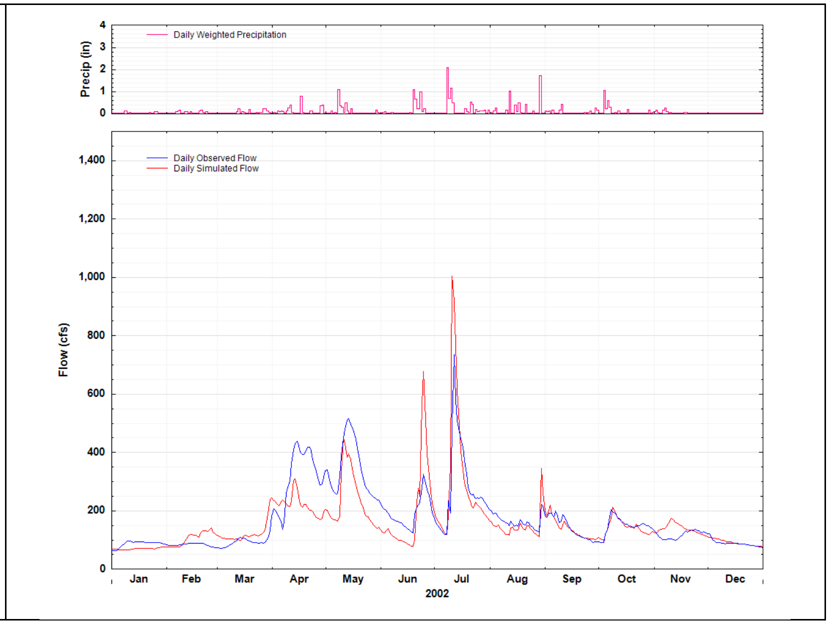
D.1 LONG PRAIRIE RIVER WATERSHED

D.1.1 USGS gage 05245100



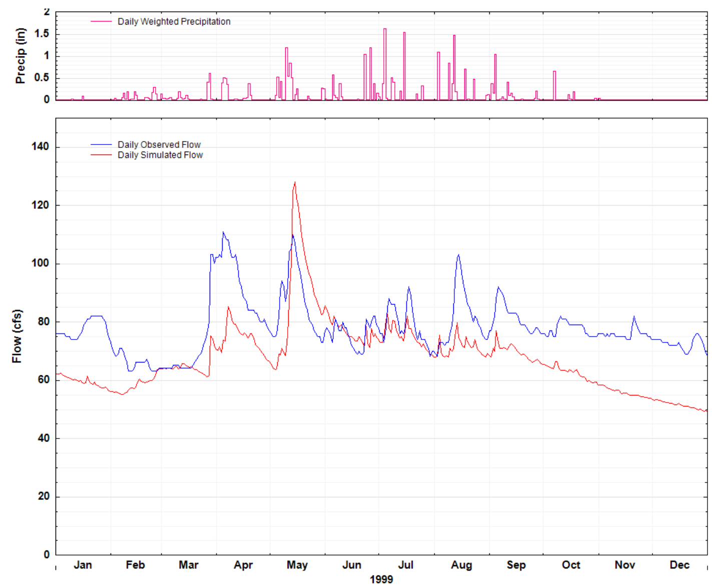

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1997
1998
1999
2000

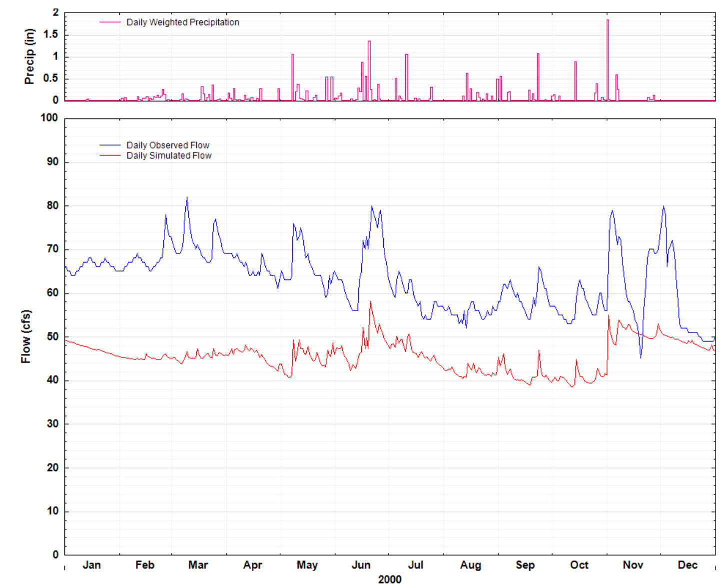

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2001

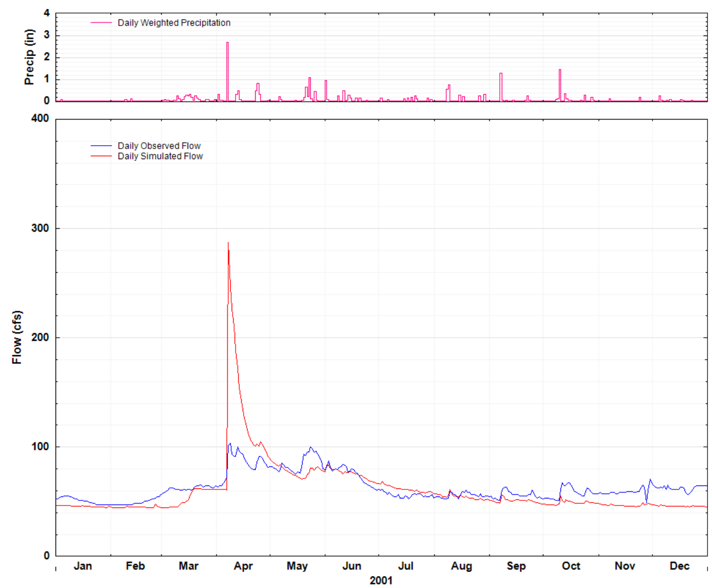

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2002

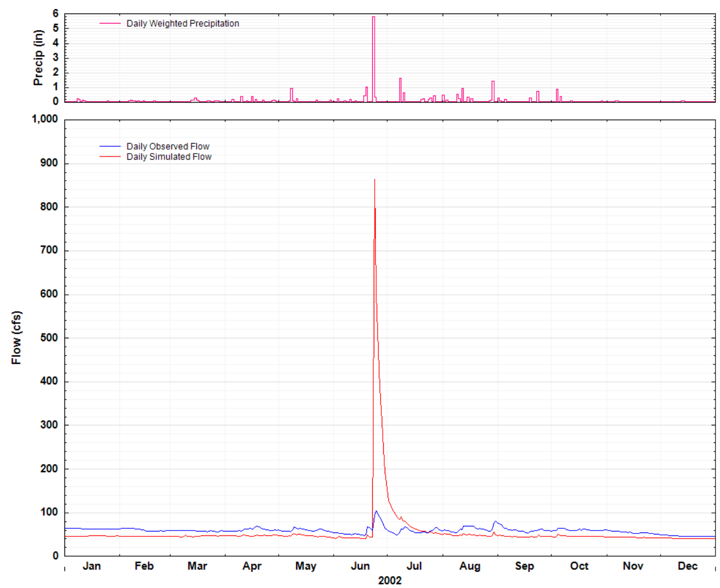
D.2 CROW WING RIVER WATERSHED

D.2.1 USGS gage 05243725

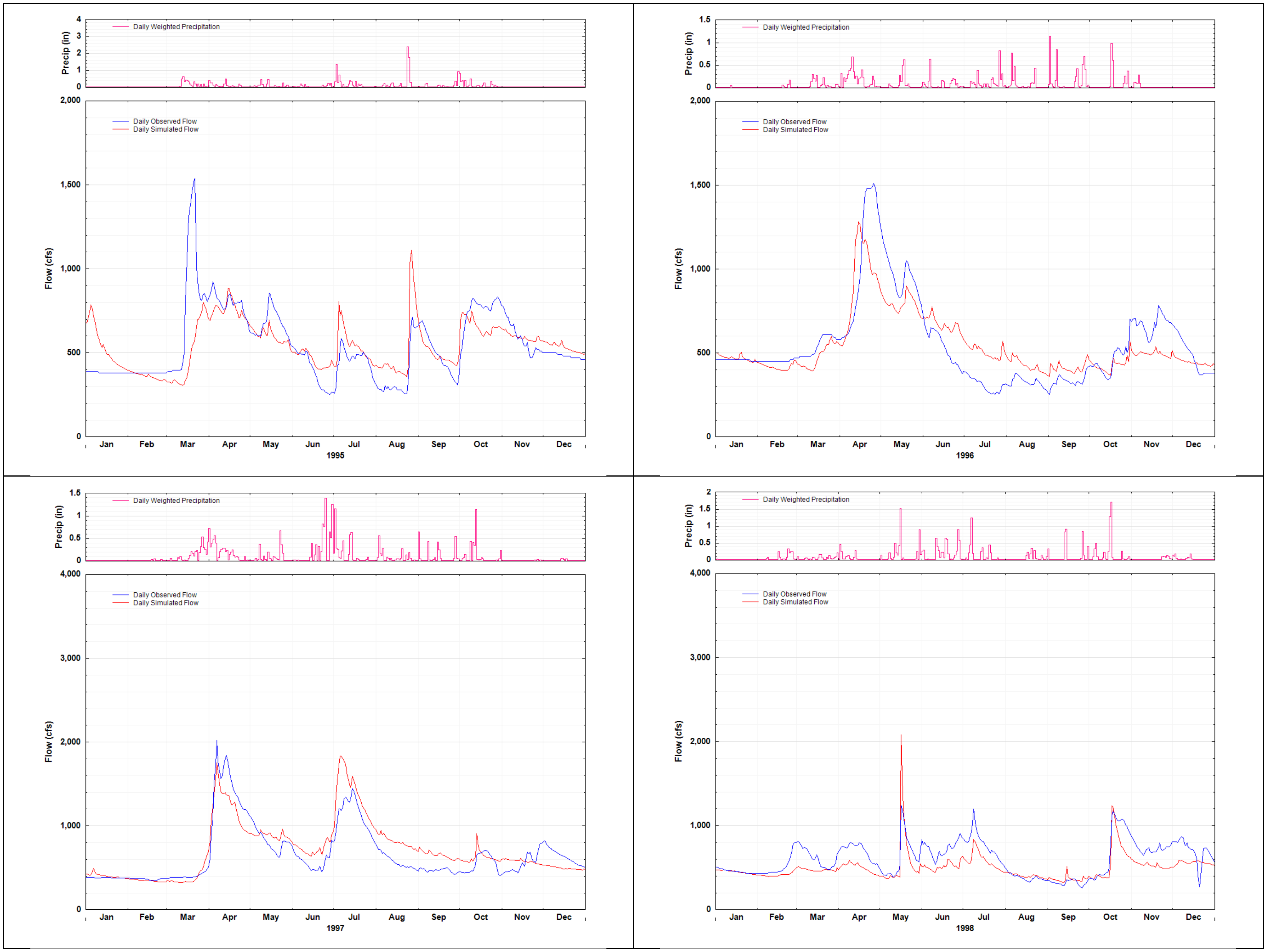

Precip (in)
Daily Weighted Precipitation
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1999

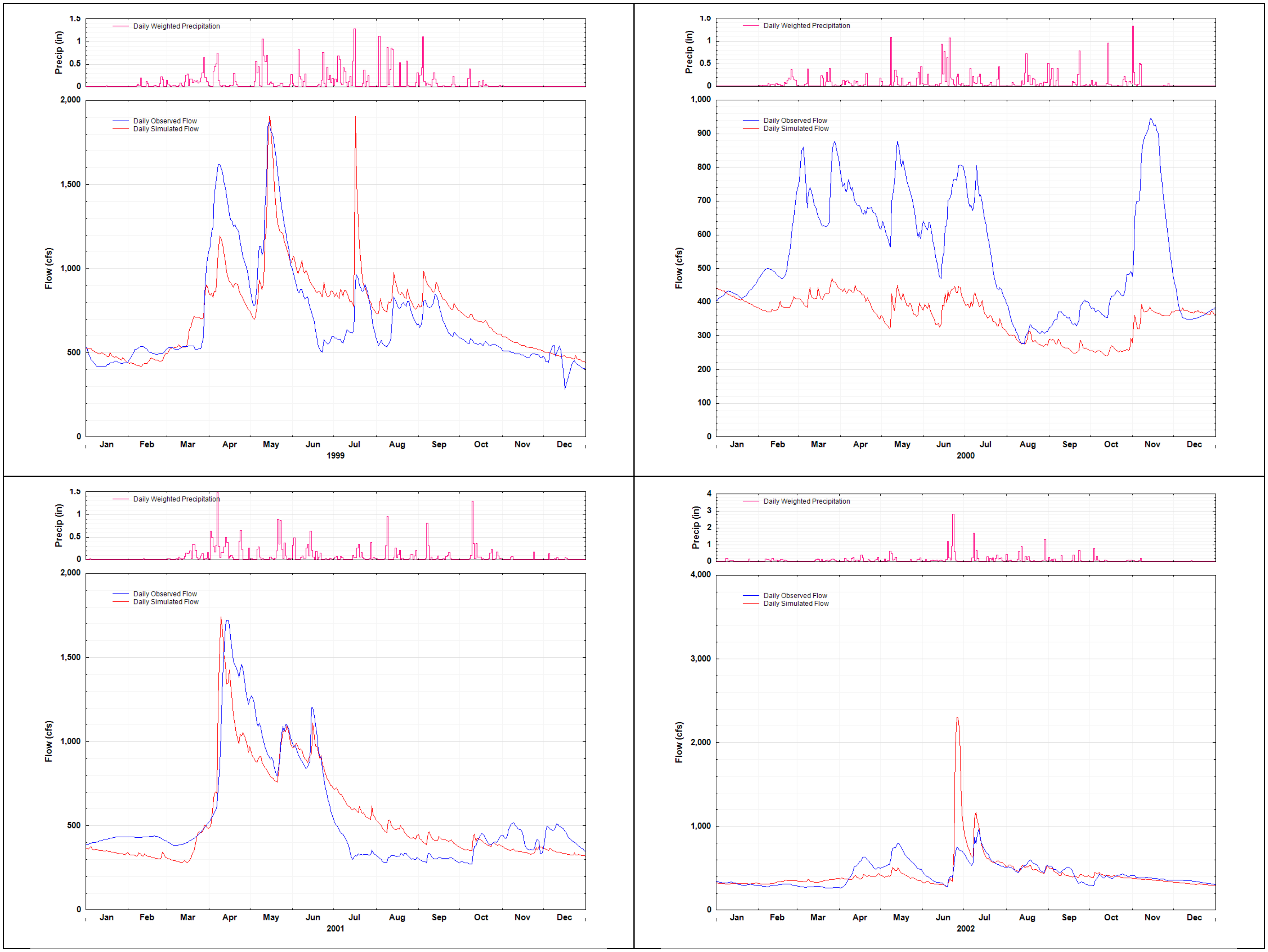

Precip (in)
Daily Weighted Precipitation
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2000


Precip (in)
Daily Weighted Precipitation
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2001

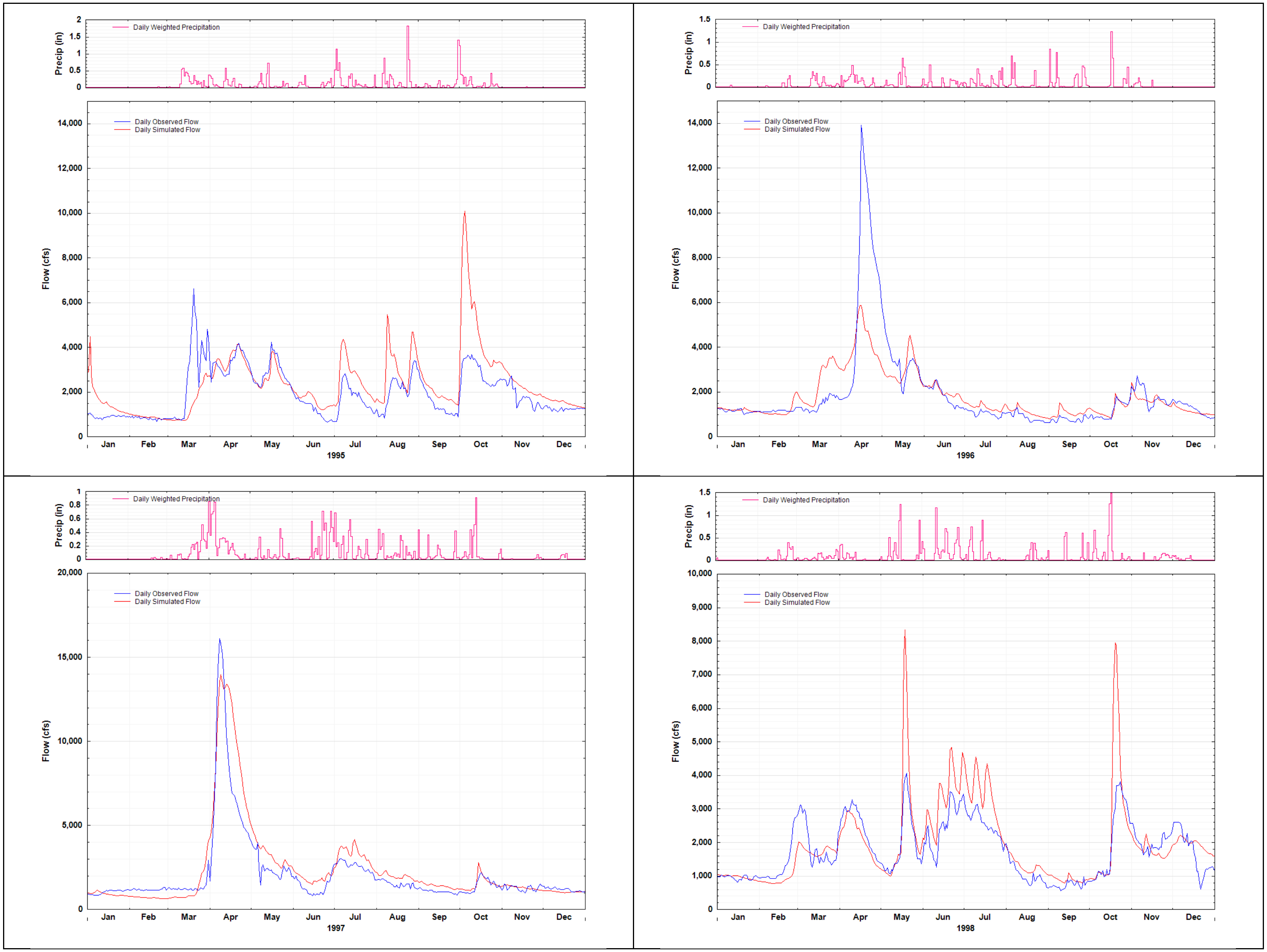

Precip (in)
Daily Weighted Precipitation
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2002

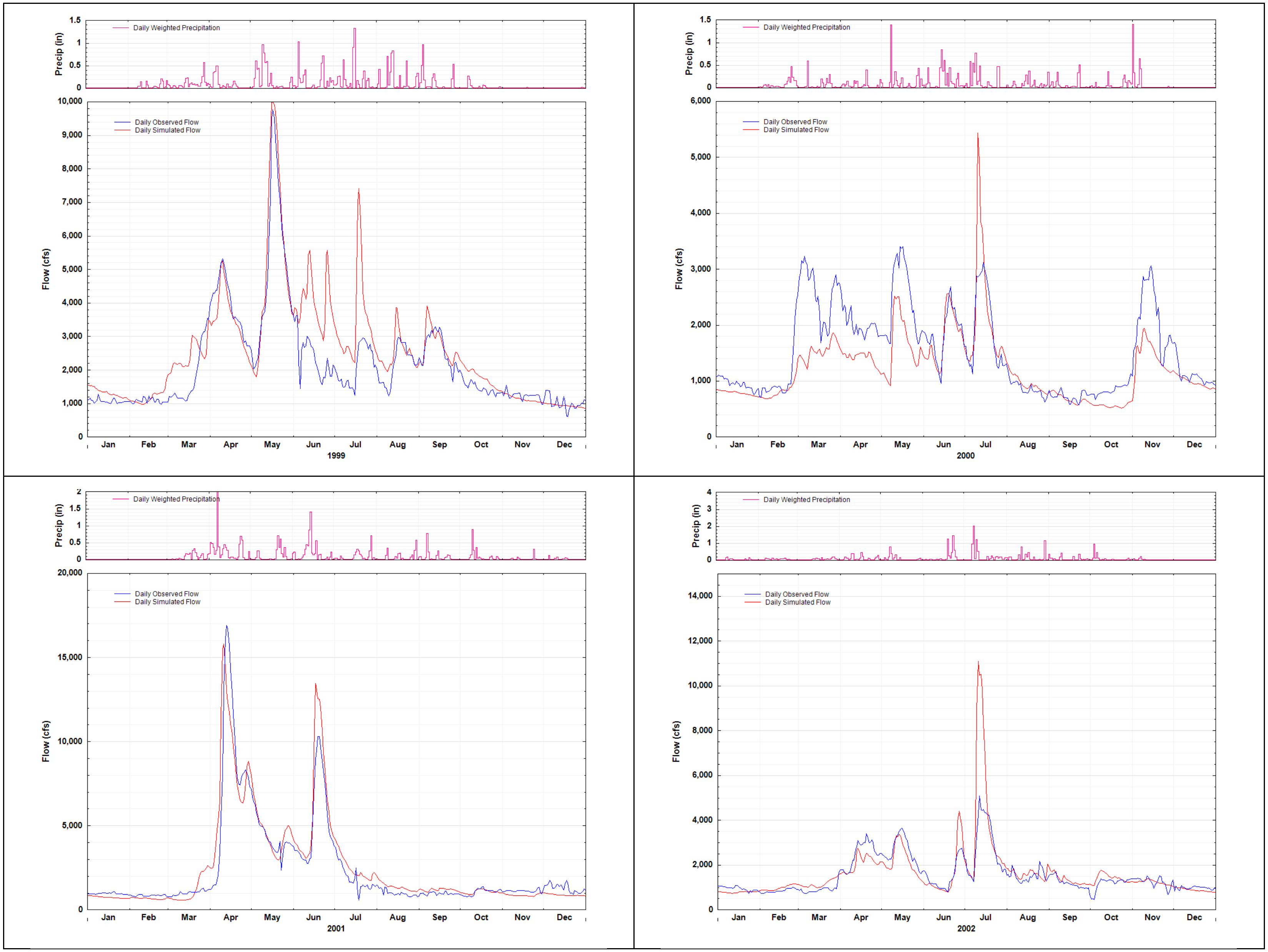
D.2.2 USGS gage 05244000




Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1999
2000
2001
2002

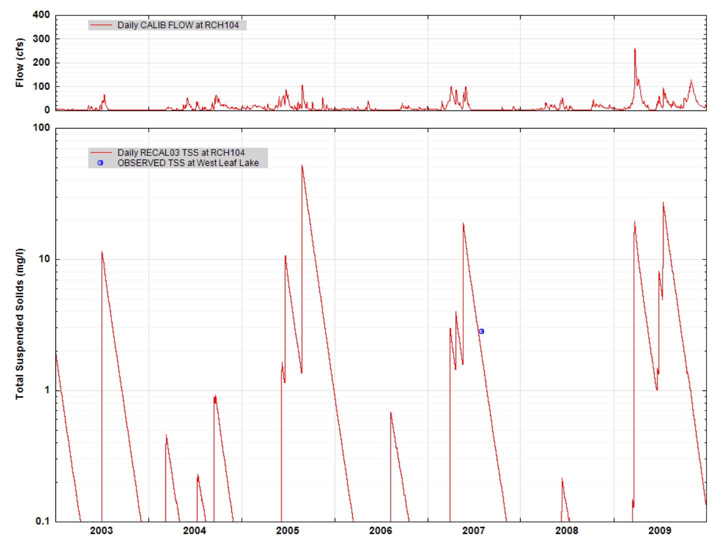
D.2.3 USGS gage 05247500

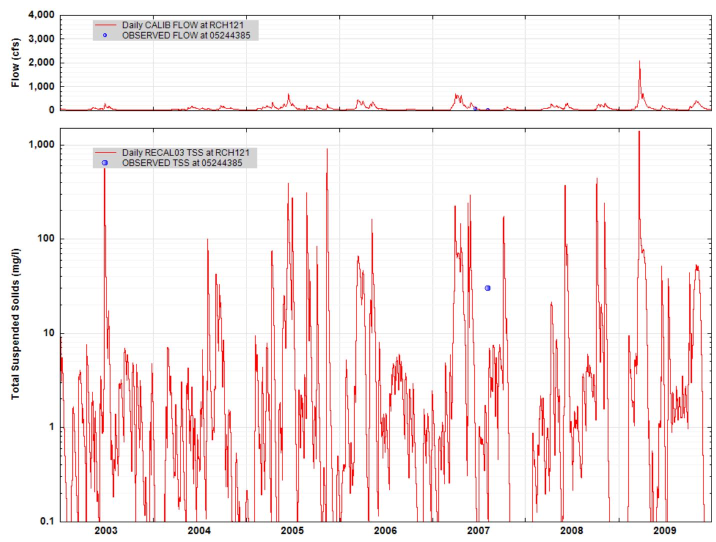


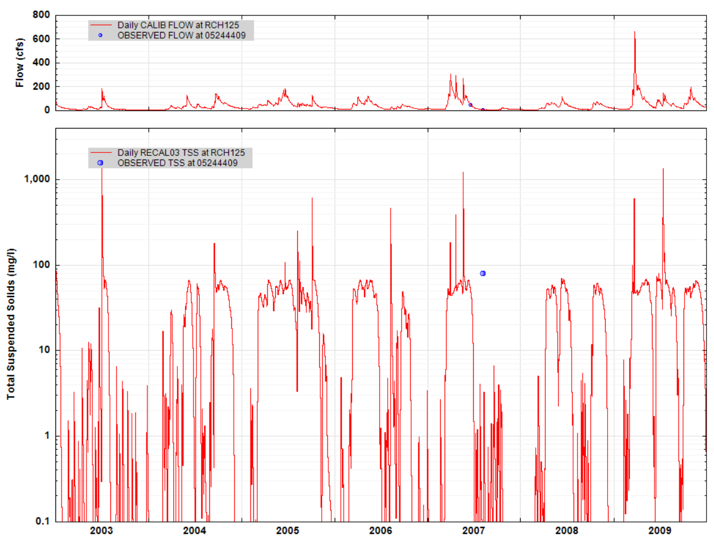

Daily Weighted Precipitation
Precip (in)
Daily Observed Flow
Daily Simulated Flow
Flow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1999
2000
2001
2002

APPENDIX E
OBSERVED AND SIMULATED WATER TSS GRAPHS FOR THE CALIBRATION PERIOD

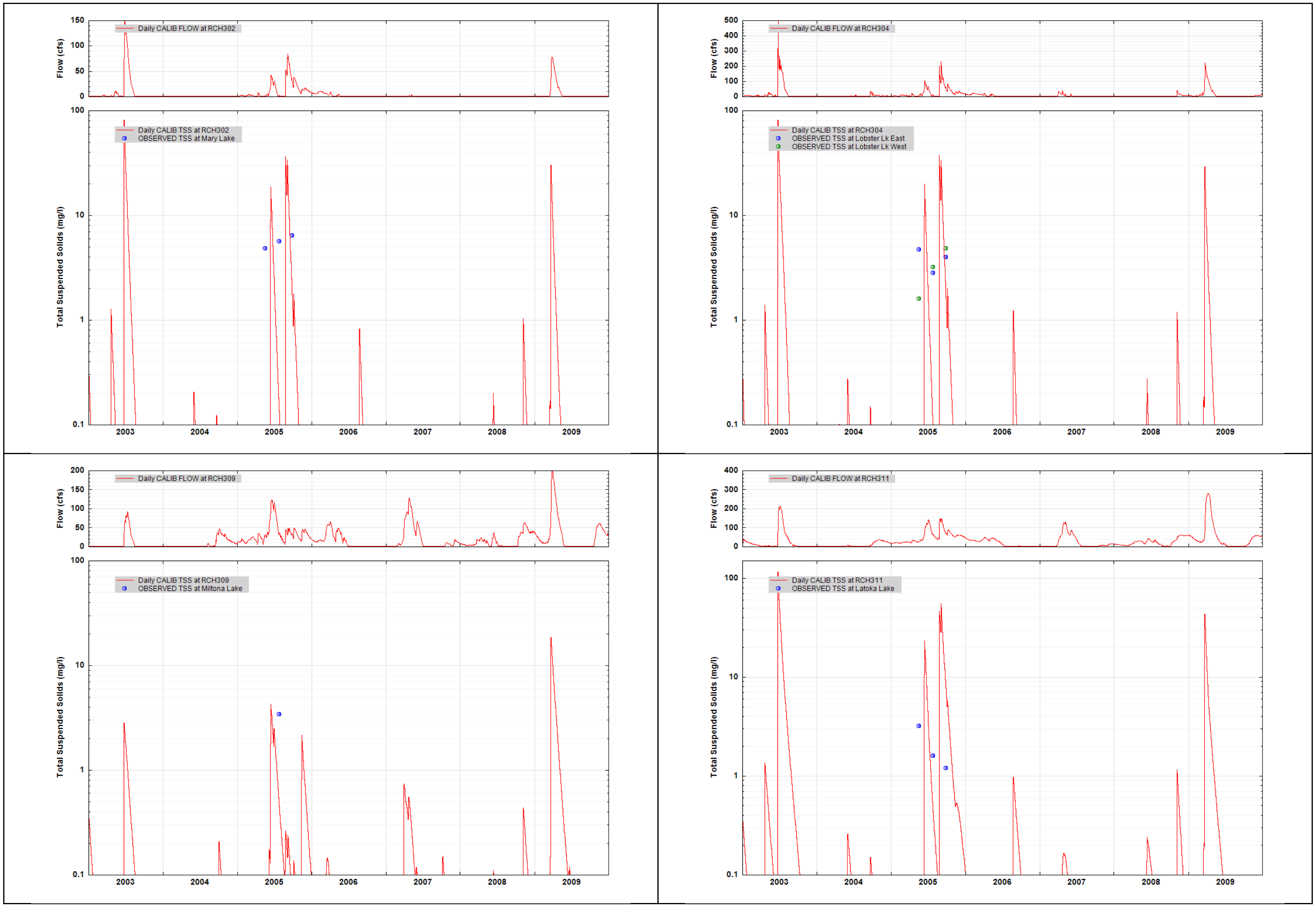
E.1 REDEYE RIVER WATERSHED

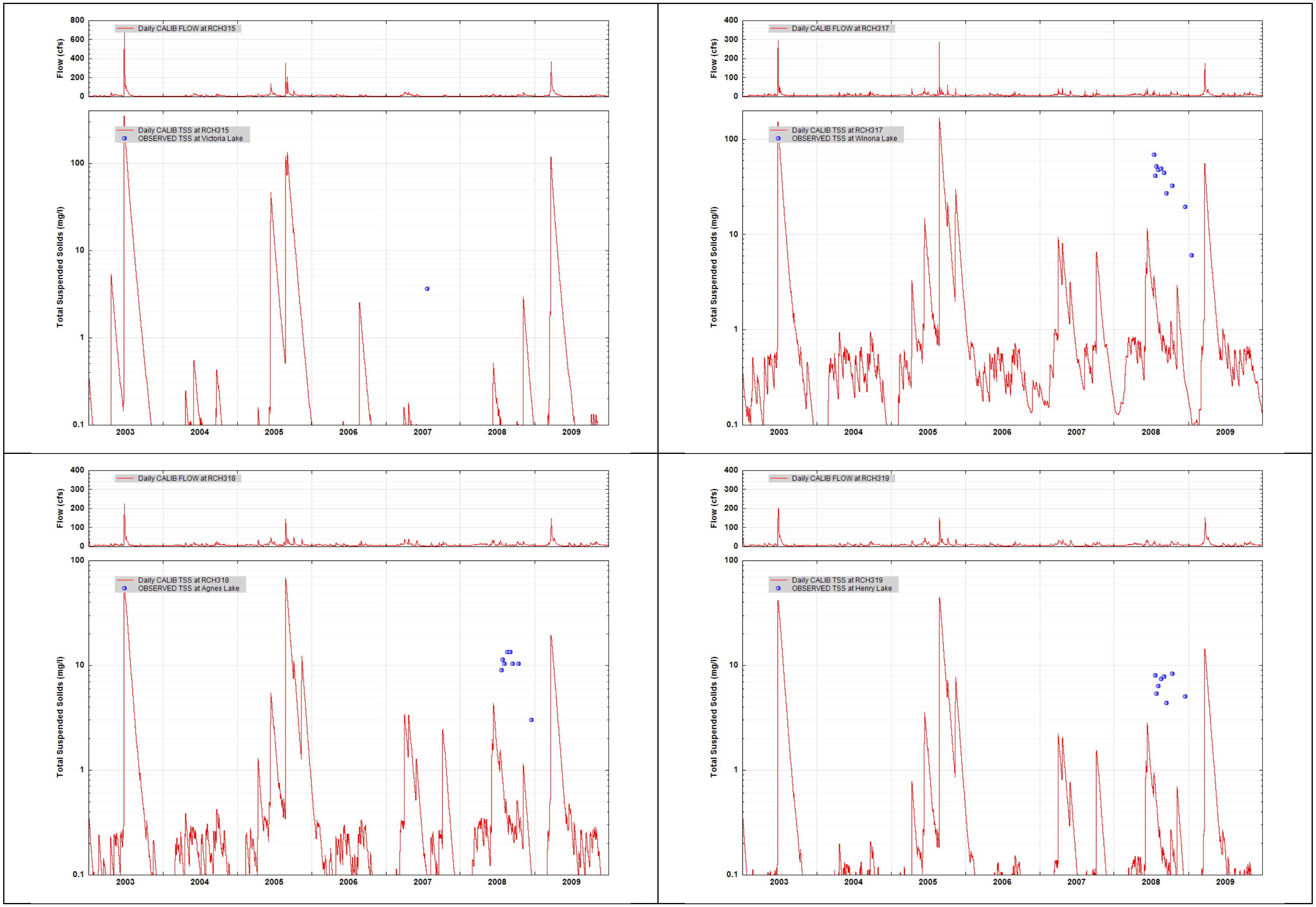


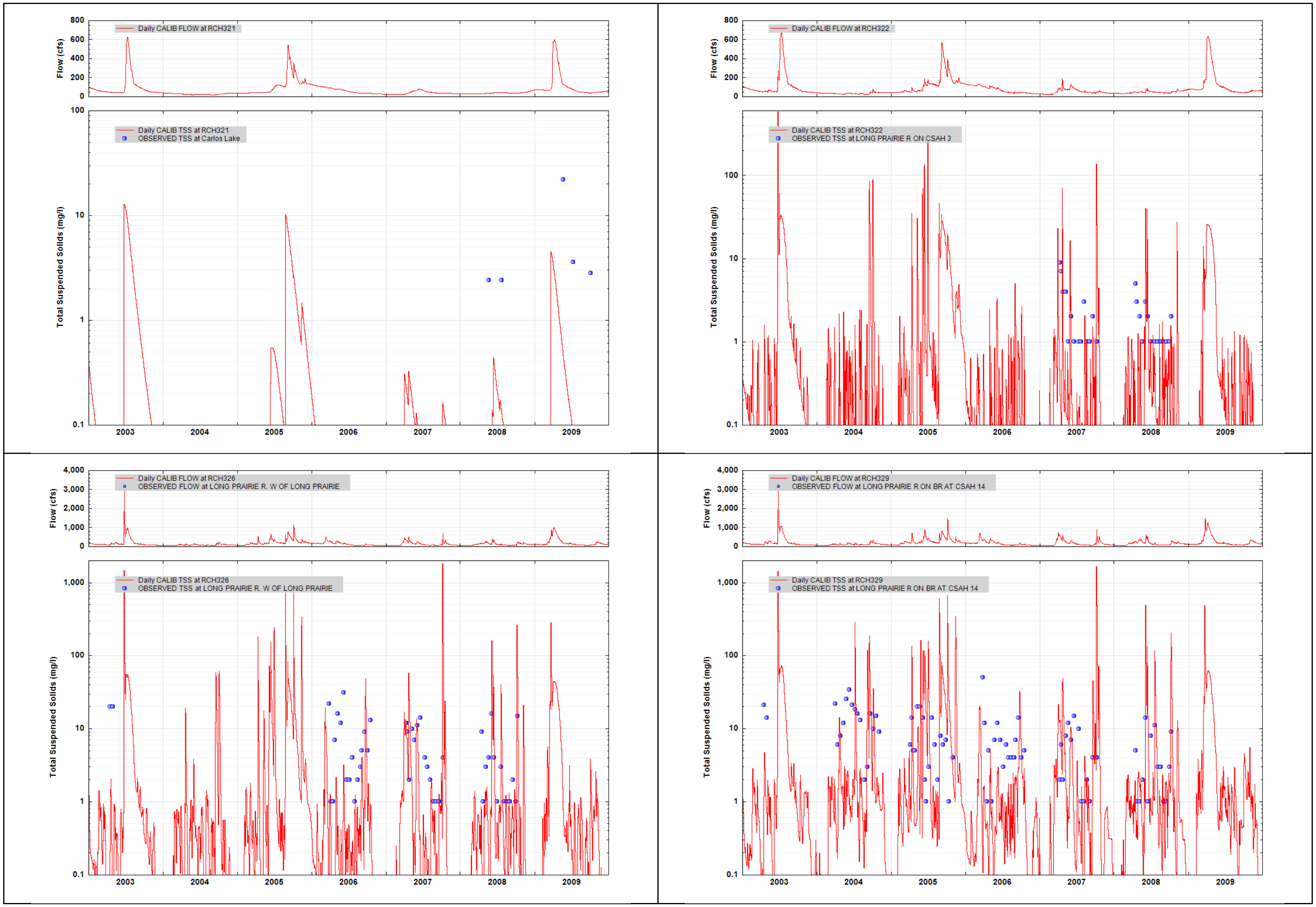


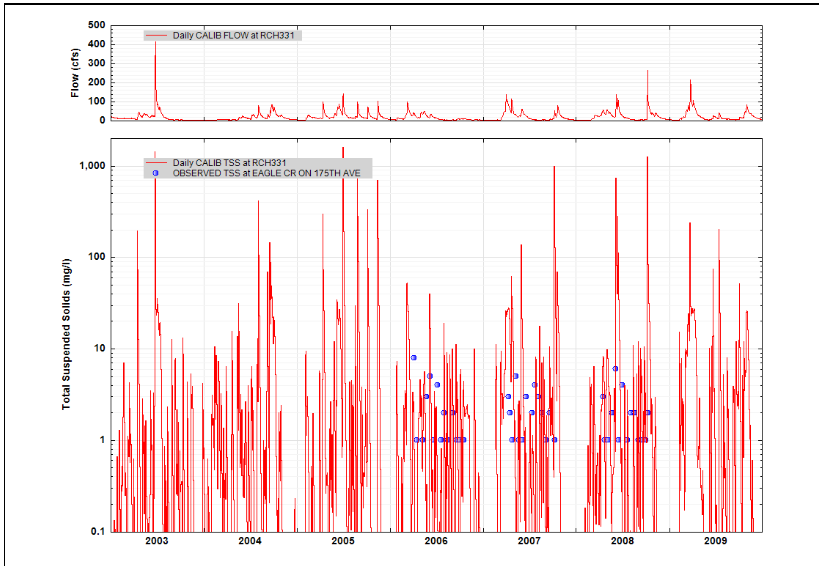


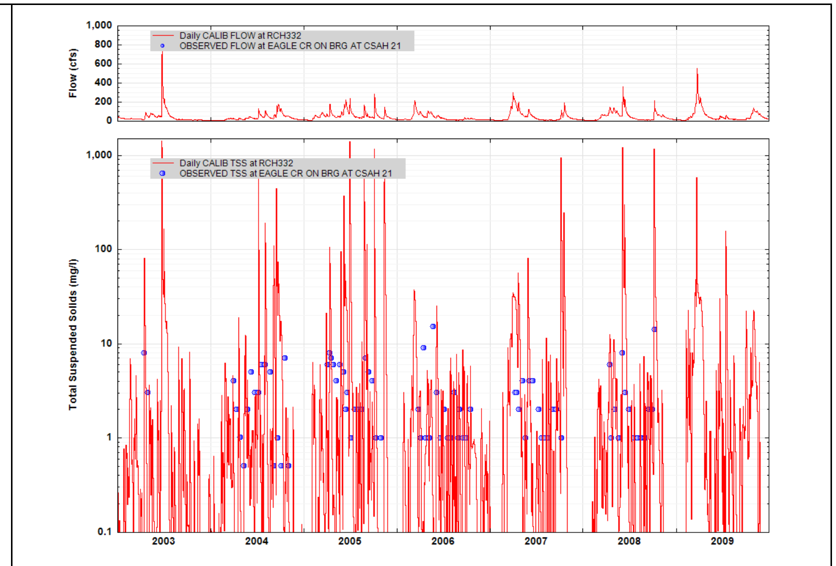
E.2 LONG PRAIRIE RIVER WATERSHED

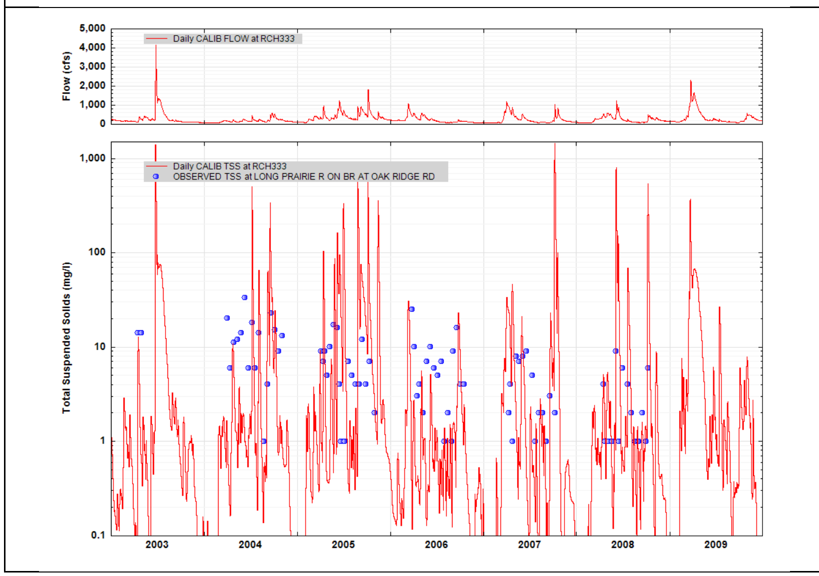


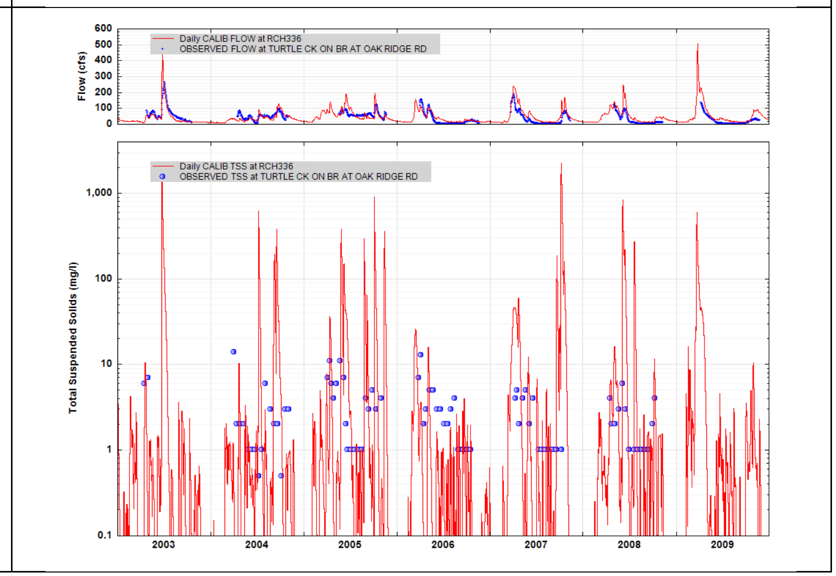

Daily CALIB FLOW at RCH315
Flow (cfs)
Daily CALIB TSS at RCH315
OBSERVED TSS at Victoria Lake
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH317
Daily CALIB TSS at RCH317
OBSERVED TSS at Winona Lake
Daily CALIB FLOW at RCH318
Daily CALIB TSS at RCH318
OBSERVED TSS at Agnes Lake
Daily CALIB FLOW at RCH319
Daily CALIB TSS at RCH319
OBSERVED TSS at Henry Lake
2003
2004
2005
2006
2007
2008
2009

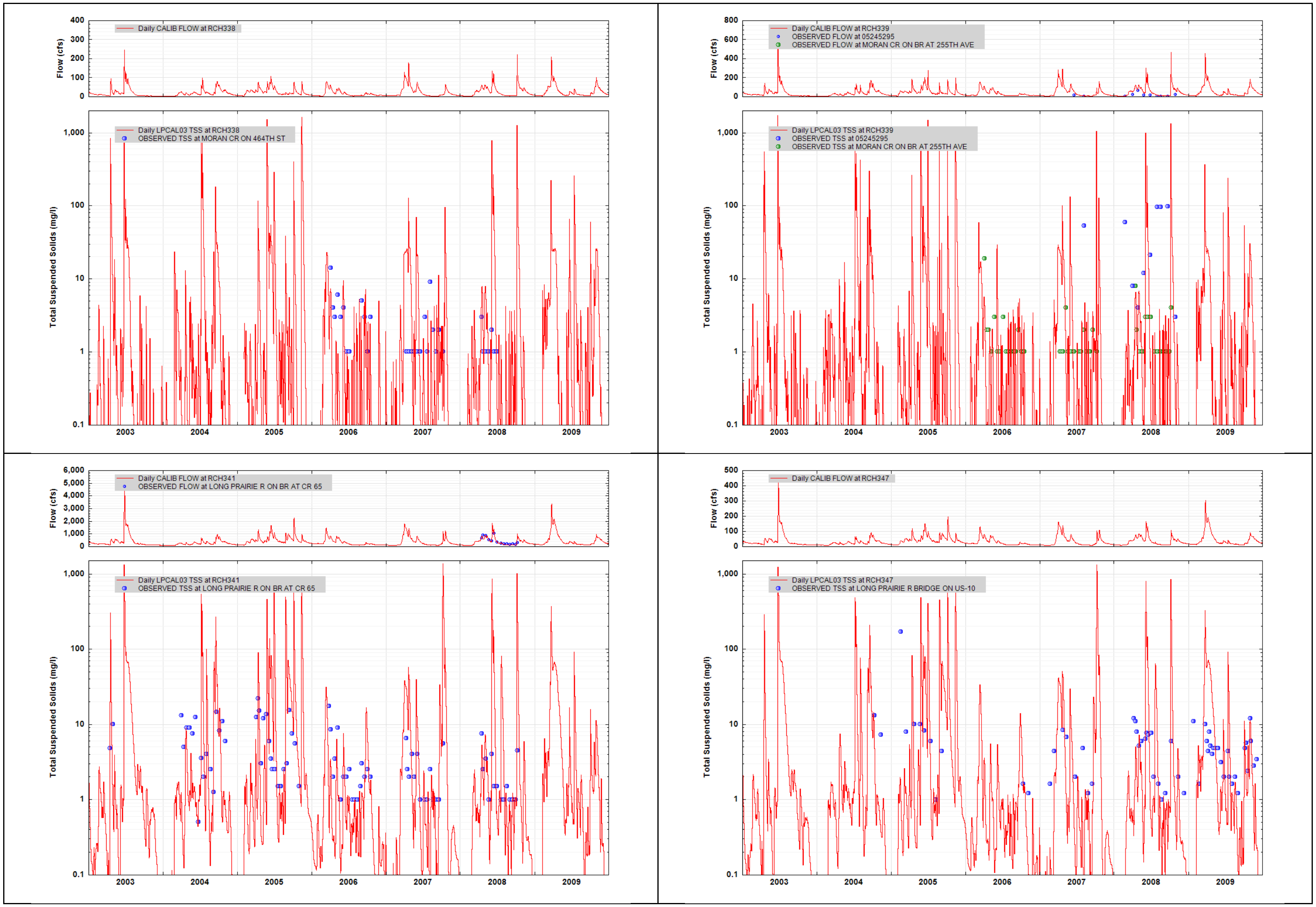

Daily CALIB FLOW at RCH321
Flow (cfs)
Daily CALIB TSS at RCH321
OBSERVED TSS at Carlos Lake
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH322
Daily CALIB TSS at RCH322
OBSERVED TSS at LONG PRAIRIE R ON CSAH 3
Daily CALIB FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily CALIB TSS at RCH326
OBSERVED TSS at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily CALIB FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
Daily CALIB TSS at RCH329
OBSERVED TSS at LONG PRAIRIE R ON BR AT CSAH 14
2003
2004
2005
2006
2007
2008
2009

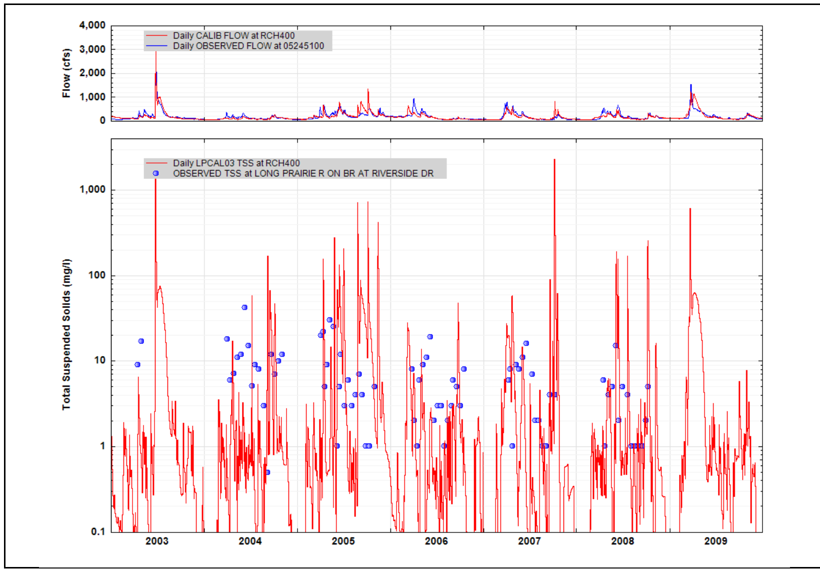

Daily CALIB FLOW at RCH331
Flow (cfs)
Daily CALIB TSS at RCH331
OBSERVED TSS at EAGLE CR ON 175TH AVE
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
Daily CALIB TSS at RCH332
OBSERVED TSS at EAGLE CR ON BRG AT CSAH 21
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

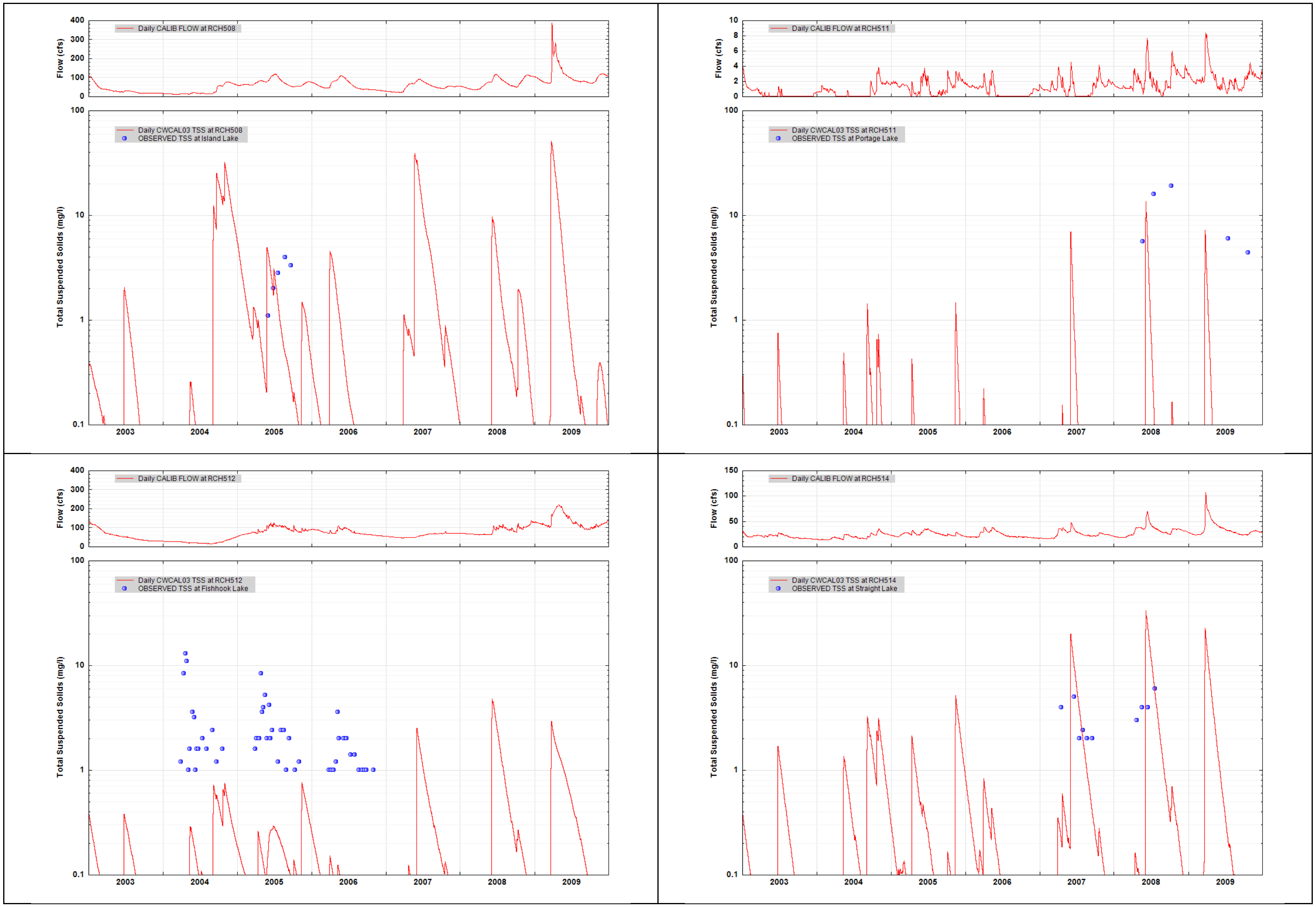

Daily CALIB FLOW at RCH333
Flow (cfs)
Daily CALIB TSS at RCH333
OBSERVED TSS at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

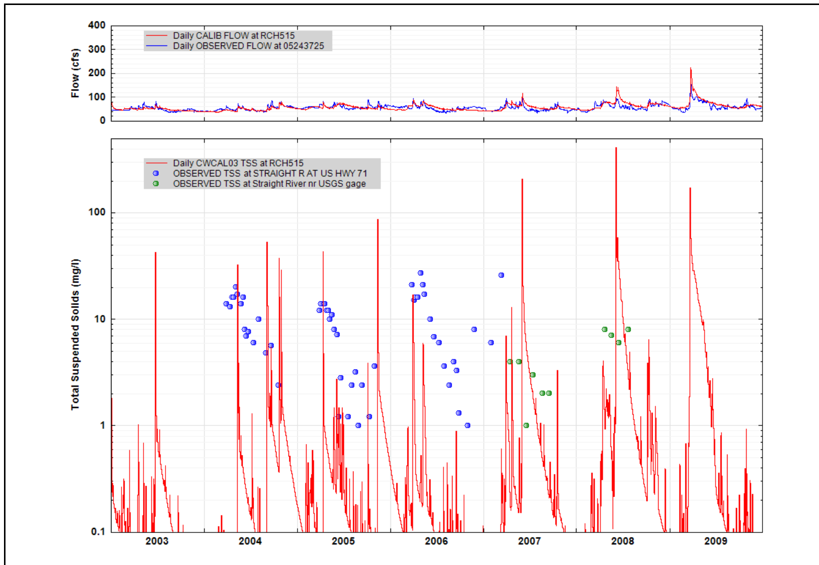

Daily CALIB FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Daily CALIB TSS at RCH336
OBSERVED TSS at TURTLE CK ON BR AT OAK RIDGE RD
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

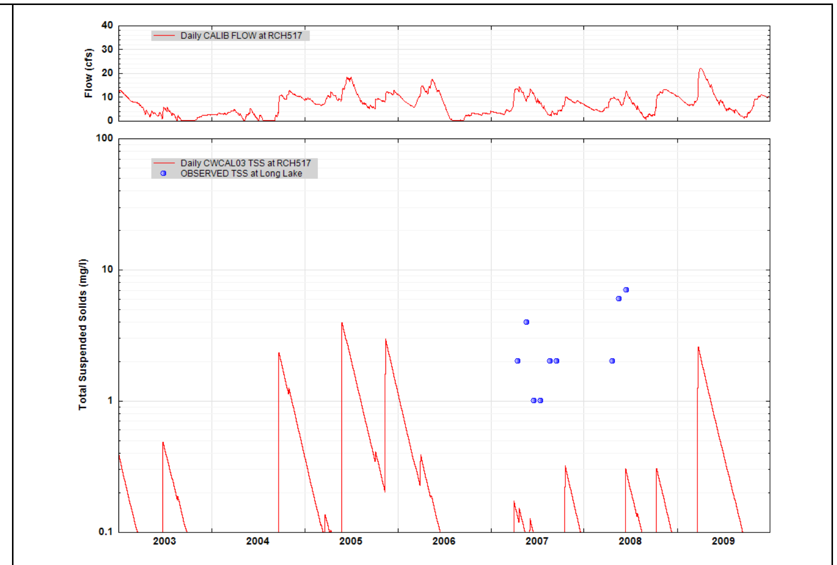

Daily CALIB FLOW at RCH338
Flow (cfs)
Daily LPCAL03 TSS at RCH338
OBSERVED TSS at MORAN CR ON 464TH ST
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 TSS at RCH339
OBSERVED TSS at 05245295
OBSERVED TSS at MORAN CR ON BR AT 255TH AVE
Daily CALIB FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 TSS at RCH341
OBSERVED TSS at LONG PRAIRIE R ON BR AT CR 65
Daily CALIB FLOW at RCH347
Daily LPCAL03 TSS at RCH347
OBSERVED TSS at LONG PRAIRIE R BRIDGE ON US-10
2003
2004
2005
2006
2007
2008
2009

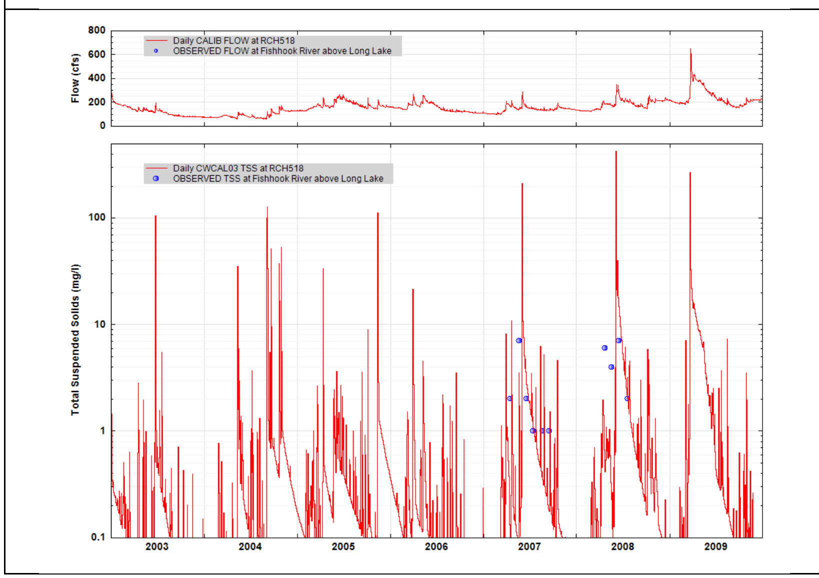

4,000
3,000
2,000
1,000
0
Flow (cfs)
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Daily LPCAL03 TSS at RCH400
OBSERVED TSS at LONG PRAIRIE R ON BR AT RIVERSIDE DR
1,000
100
10
1
0.1
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

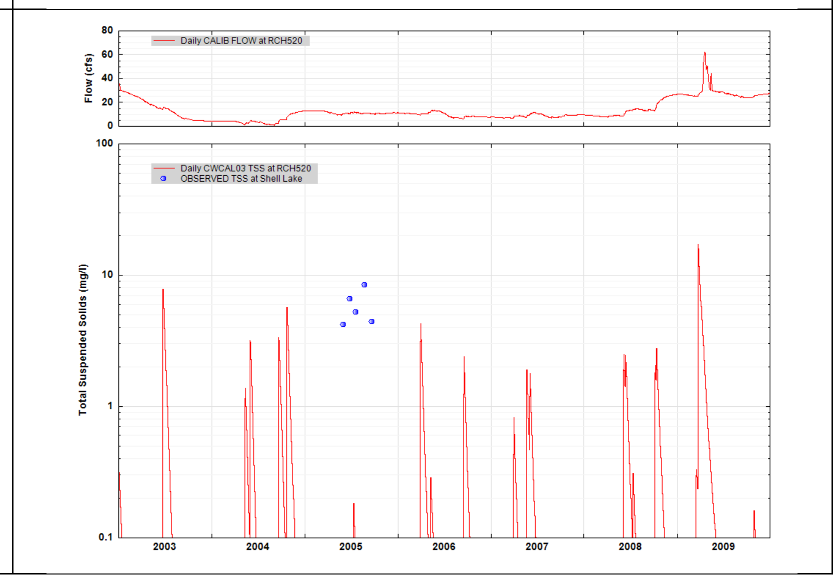
E.3 CROW WING RIVER WATERSHED

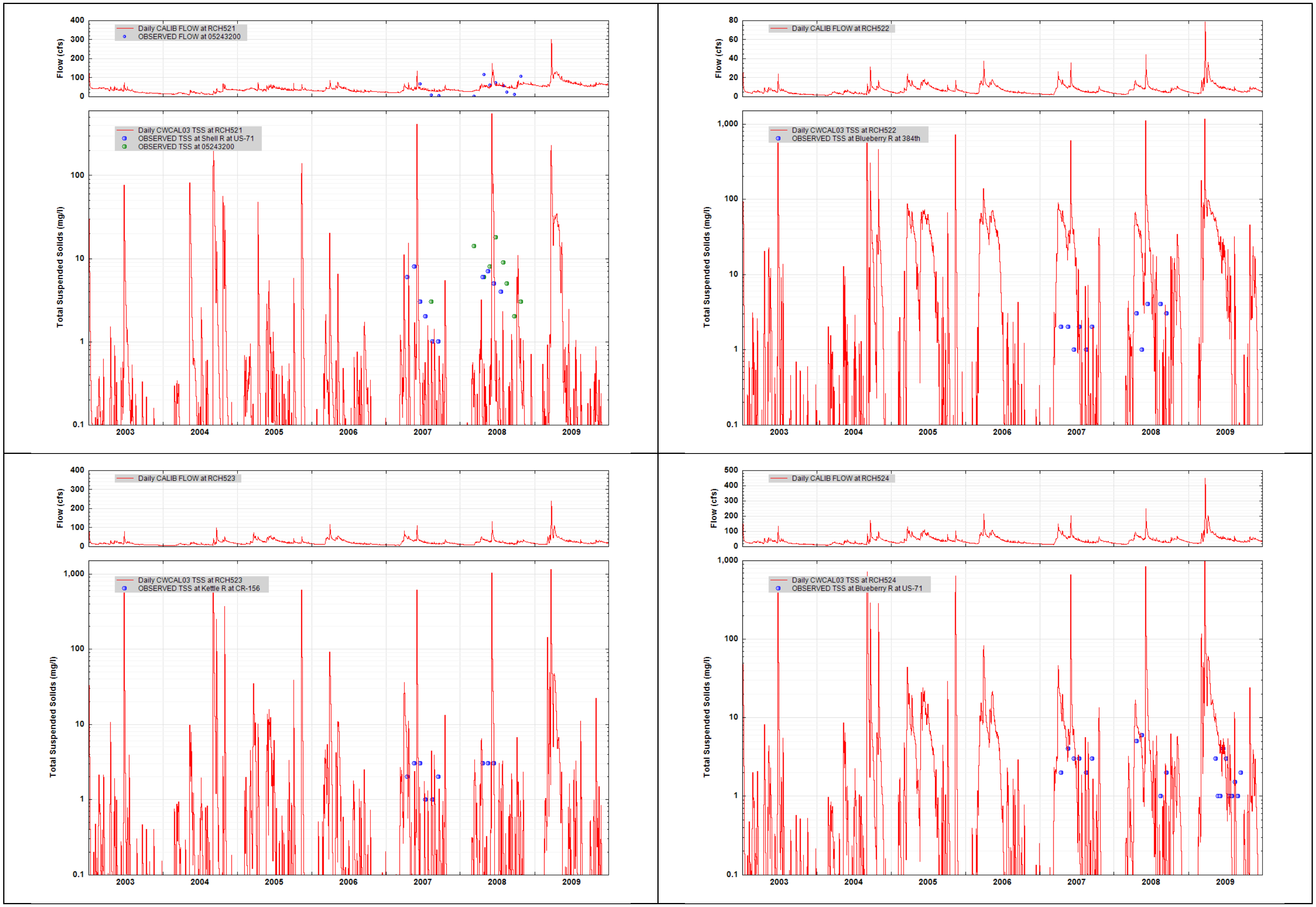


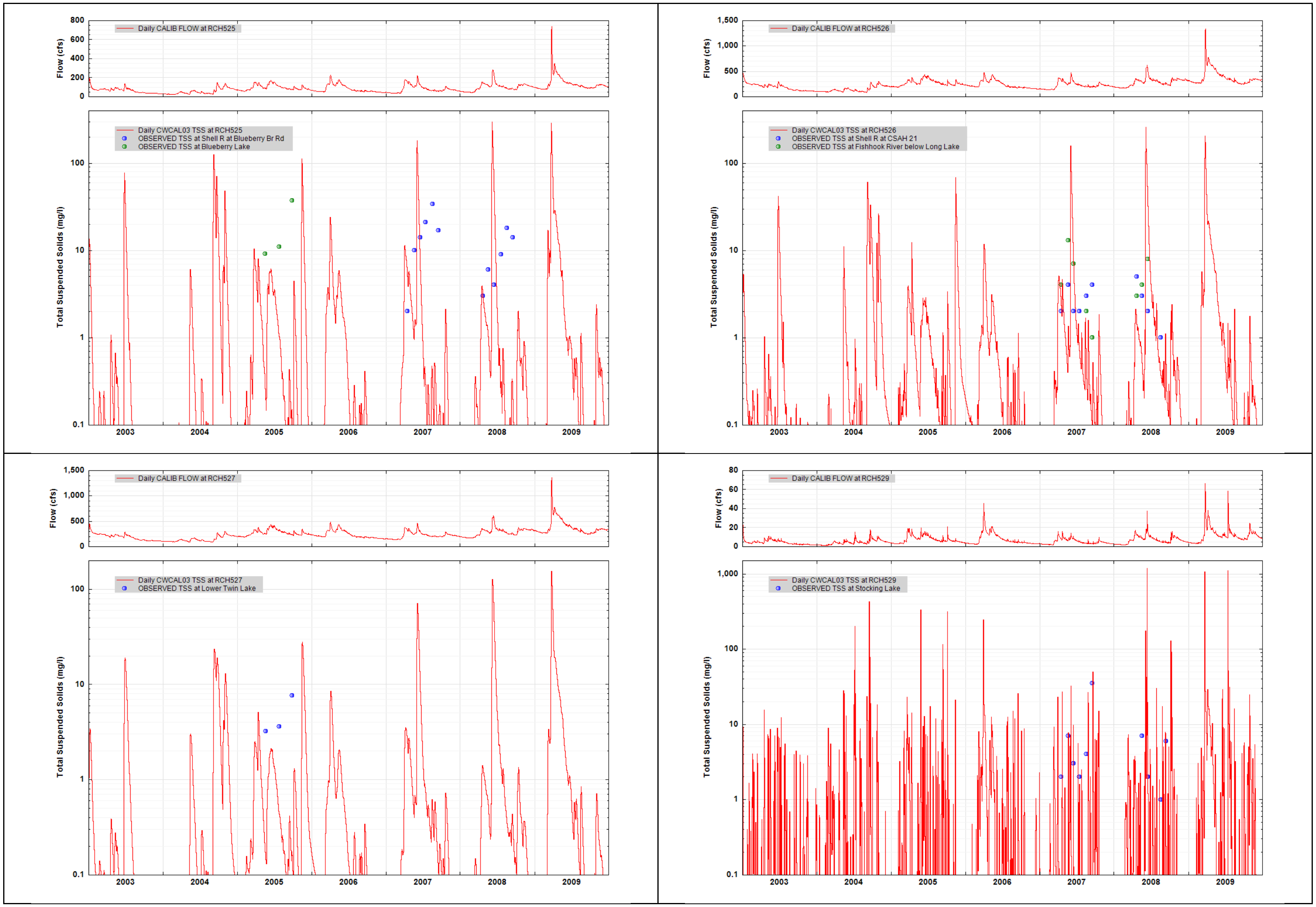

Daily CALIB FLOW at RCH515
Daily OBSERVED FLOW at 05243725
Flow (cfs)
Daily CWCAL03 TSS at RCH515
OBSERVED TSS at STRAIGHT R AT US HWY 71
OBSERVED TSS at Straight River nr USGS gage
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

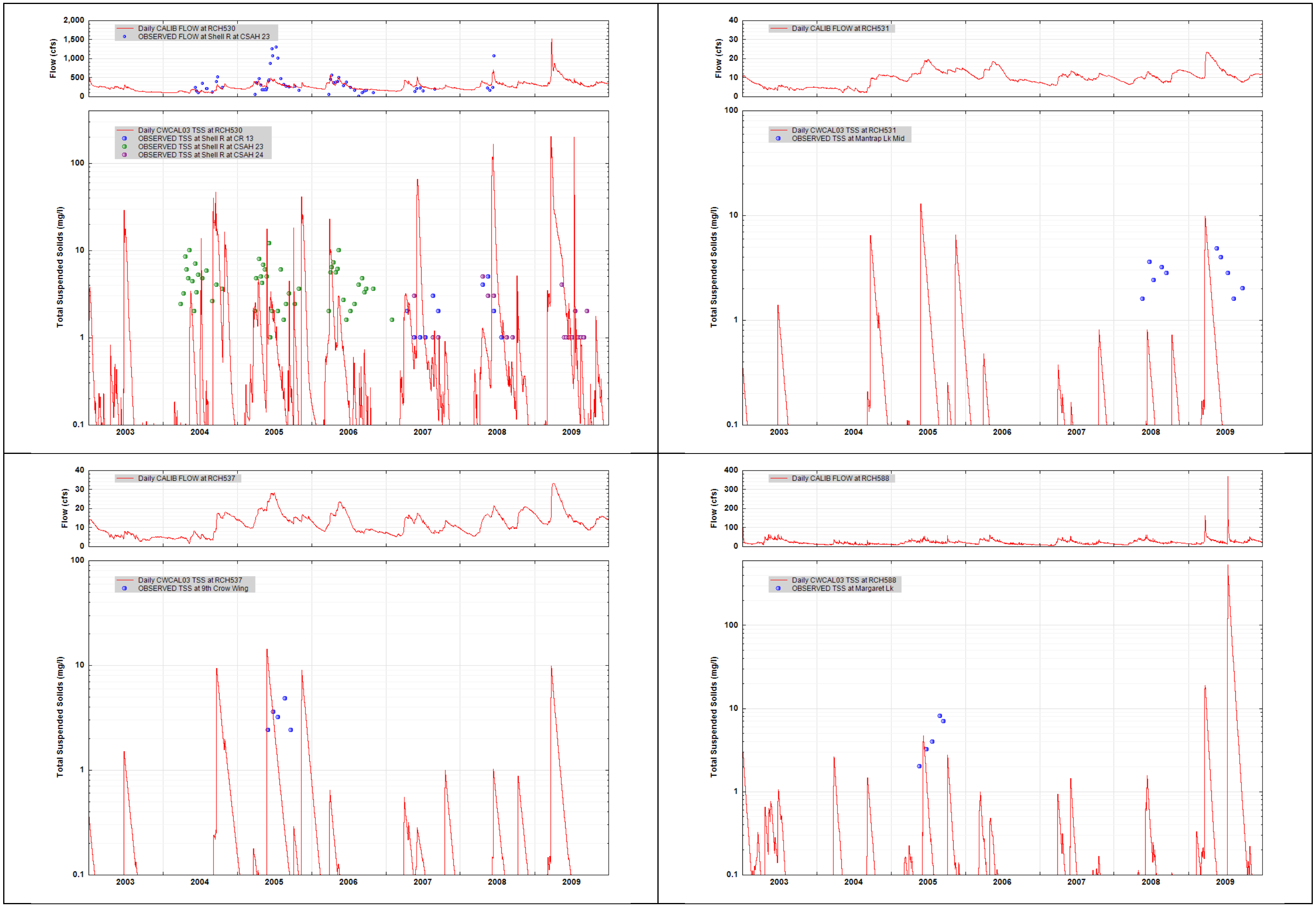

Daily CALIB FLOW at RCH517
Flow (cfs)
Daily CWCAL03 TSS at RCH517
OBSERVED TSS at Long Lake
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH518
OBSERVED FLOW at Fishhook River above Long Lake
Flow (cfs)
Daily CWCAL03 TSS at RCH518
OBSERVED TSS at Fishhook River above Long Lake
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

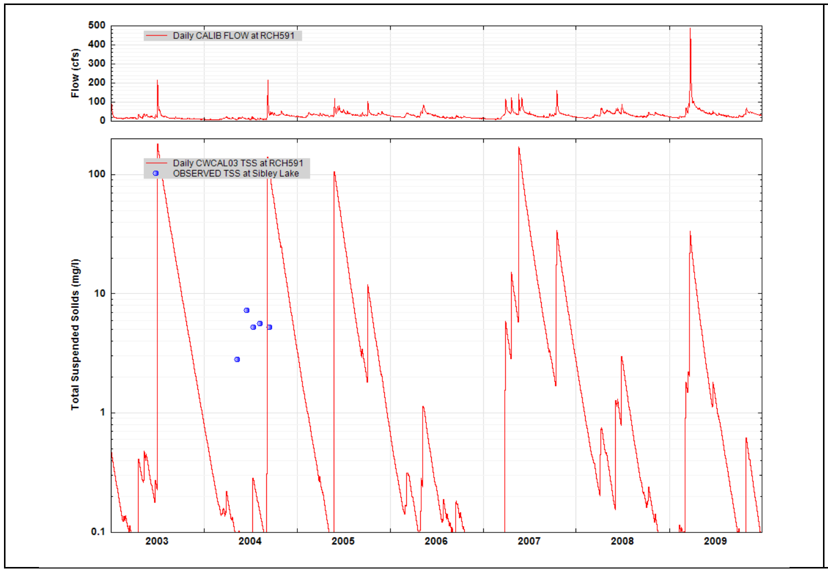

Daily CALIB FLOW at RCH520
Flow (cfs)
Daily CWCAL03 TSS at RCH520
OBSERVED TSS at Shell Lake
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH521
OBSERVED FLOW at 05243200
Flow (cfs)
Daily CWCAL03 TSS at RCH521
OBSERVED TSS at Shell R at US-71
OBSERVED TSS at 05243200
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH522
Flow (cfs)
Daily CWCAL03 TSS at RCH522
OBSERVED TSS at Blueberry R at 384th
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH523
Flow (cfs)
Daily CWCAL03 TSS at RCH523
OBSERVED TSS at Kettle R at CR-156
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH524
Flow (cfs)
Daily CWCAL03 TSS at RCH524
OBSERVED TSS at Blueberry R at US-71
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

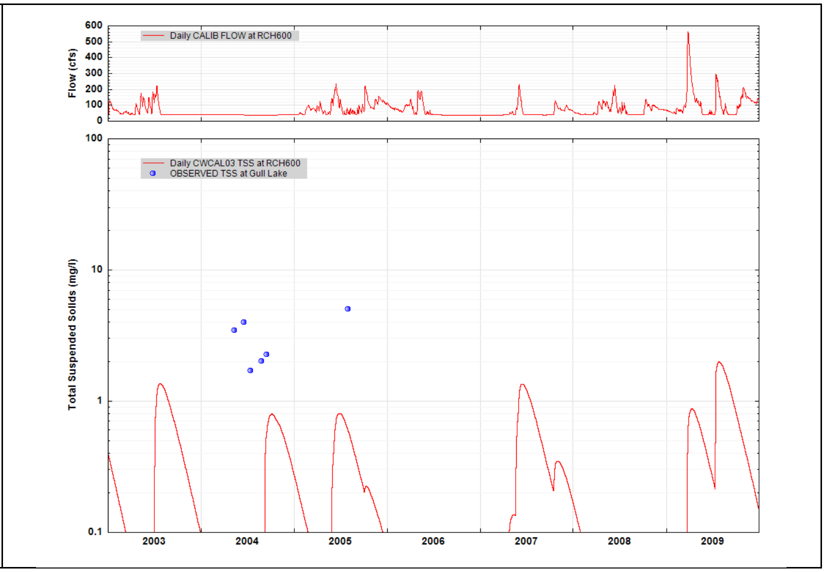

Daily CALIB FLOW at RCH525
Flow (cfs)
Daily CWCAL03 TSS at RCH525
OBSERVED TSS at Shell R at Blueberry Br Rd
OBSERVED TSS at Blueberry Lake
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH526
Daily CWCAL03 TSS at RCH526
OBSERVED TSS at Shell R at CSAH 21
OBSERVED TSS at Fishhook River below Long Lake
Daily CALIB FLOW at RCH527
Daily CWCAL03 TSS at RCH527
OBSERVED TSS at Lower Twin Lake
Daily CALIB FLOW at RCH529
Daily CWCAL03 TSS at RCH529
OBSERVED TSS at Stocking Lake
2003 2004 2005 2006 2007 2008 2009



Daily CALIB FLOW at RCH530
OBSERVED FLOW at Shell R at CSAH 23
Flow (cfs)
Daily CWCAL03 TSS at RCH530
OBSERVED TSS at Shell R at CR 13
OBSERVED TSS at Shell R at CSAH 23
OBSERVED TSS at Shell R at CSAH 24
Total Suspended Solids (mg/l)
Daily CALIB FLOW at RCH531
Daily CWCAL03 TSS at RCH531
OBSERVED TSS at Mantrap Lk Mid
Daily CALIB FLOW at RCH537
Daily CWCAL03 TSS at RCH537
OBSERVED TSS at 9th Crow Wing
Daily CALIB FLOW at RCH588
Daily CWCAL03 TSS at RCH588
OBSERVED TSS at Margaret Lk
2003
2004
2005
2006
2007
2008
2009



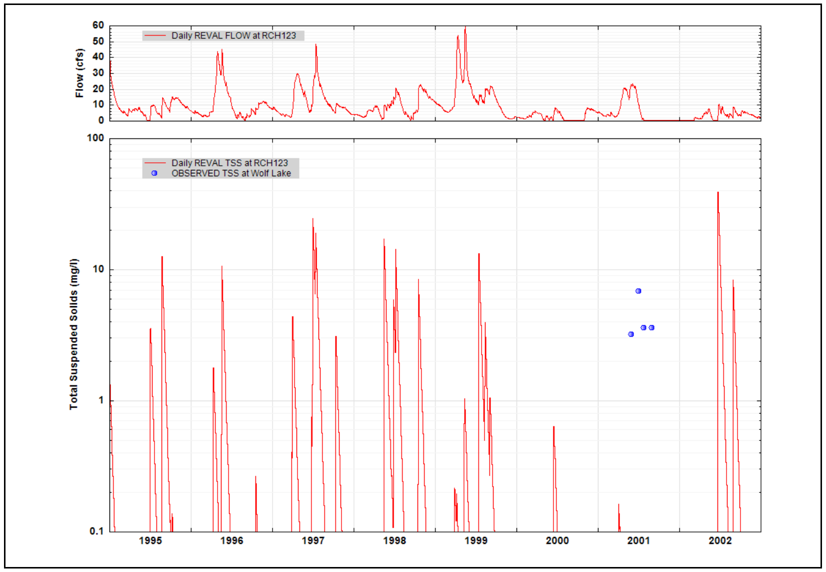
Daily CALIB FLOW at RCH591
Flow (cfs)
Daily CWCAL03 TSS at RCH591
OBSERVED TSS at Sibley Lake
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009



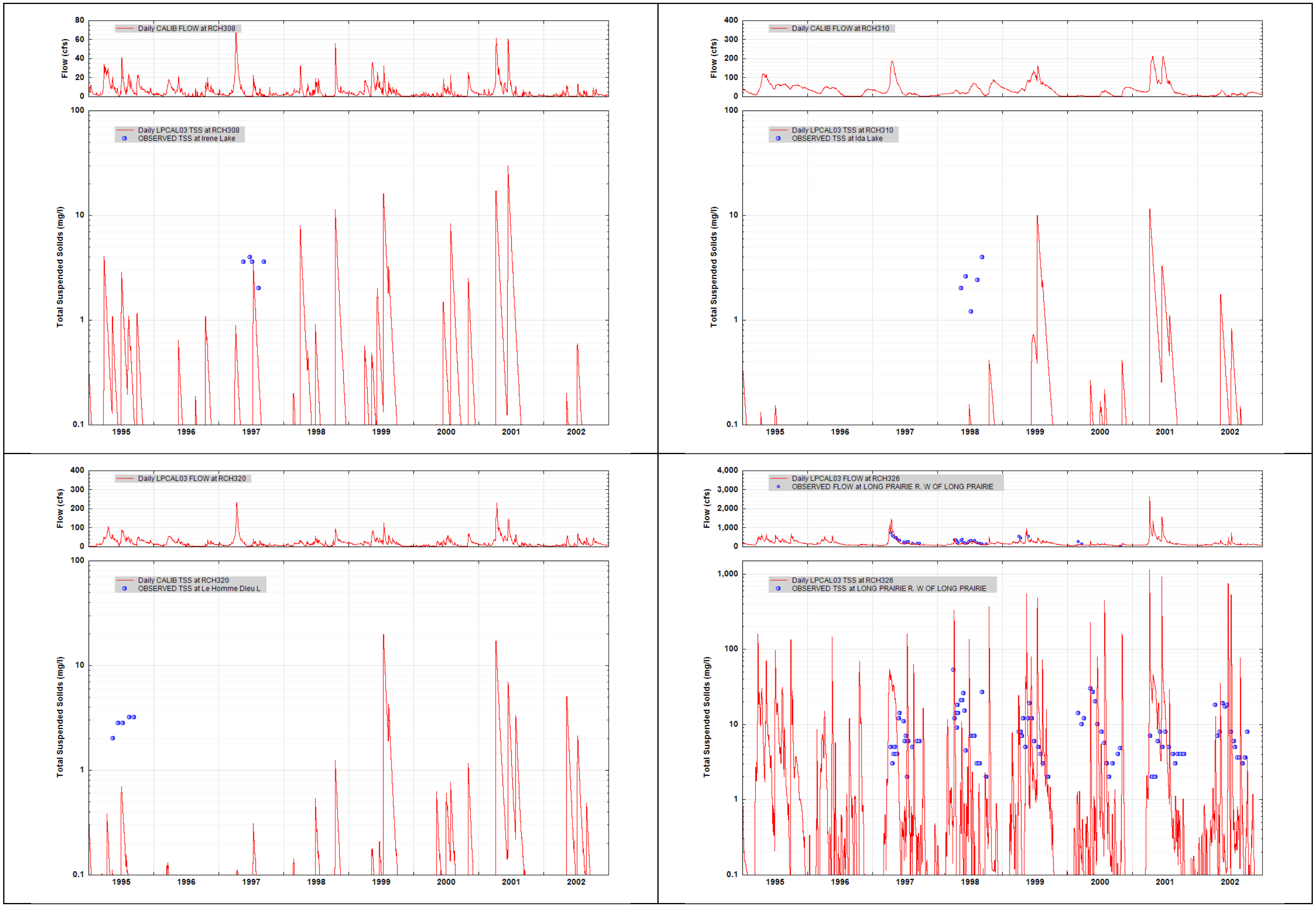
Daily CALIB FLOW at RCH600
Flow (cfs)
Daily CWCAL03 TSS at RCH600
OBSERVED TSS at Gull Lake
Total Suspended Solids (mg/l)
2003
2004
2005
2006
2007
2008
2009

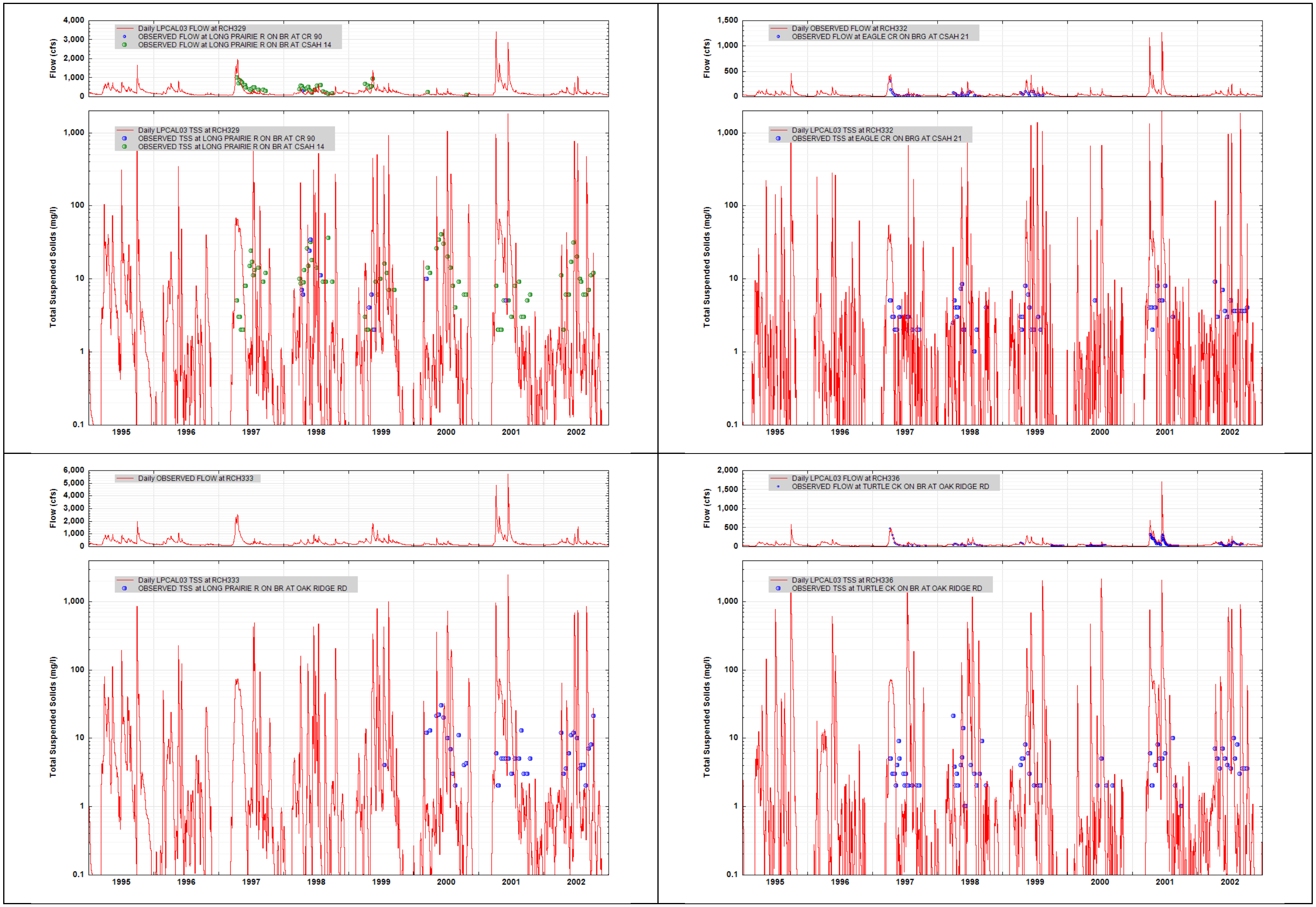
APPENDIX F
OBSERVED AND SIMULATED WATER TSS GRAPHS FOR THE VALIDATION PERIOD

F.1 REDEYE RIVER WATERSHED

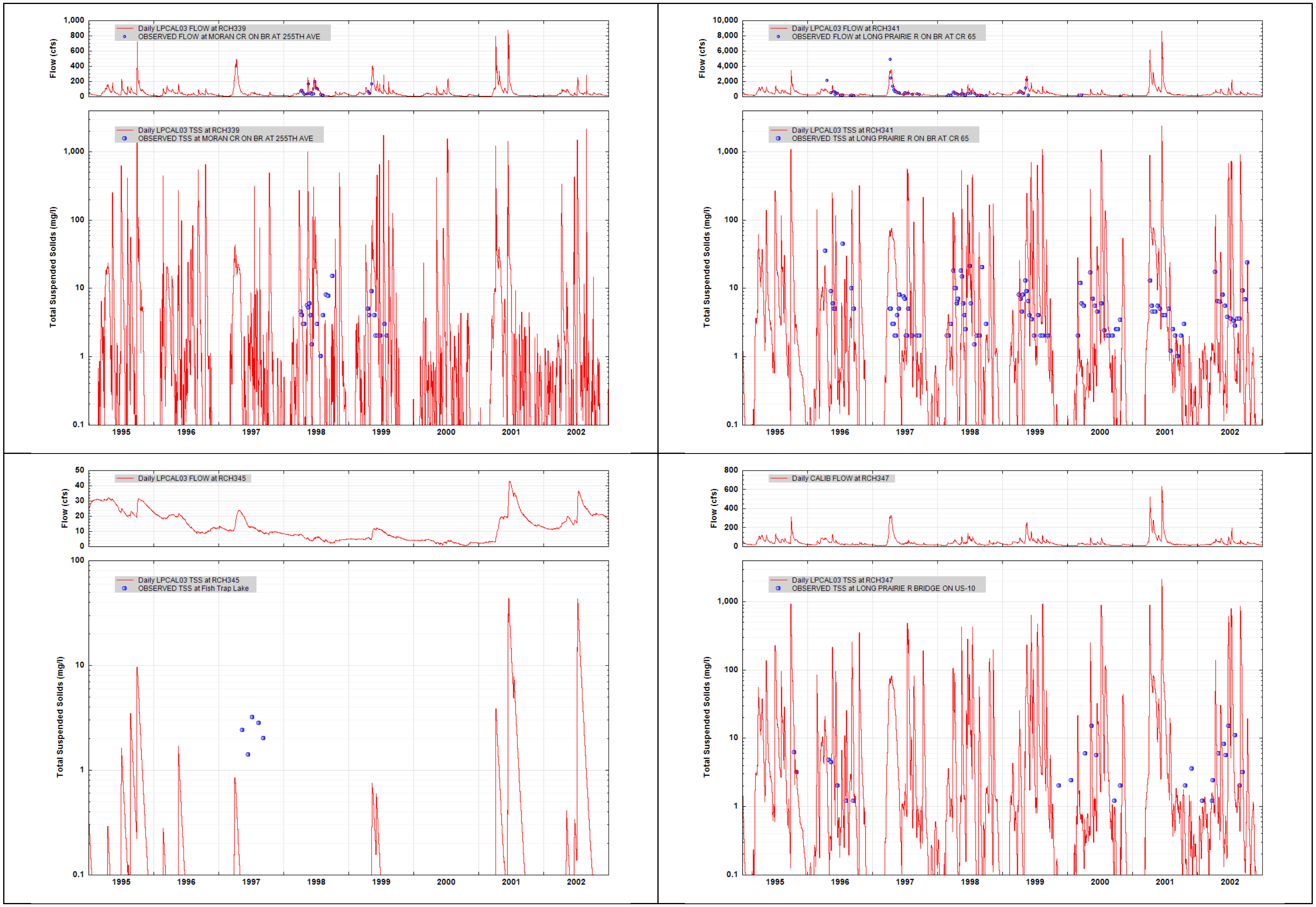


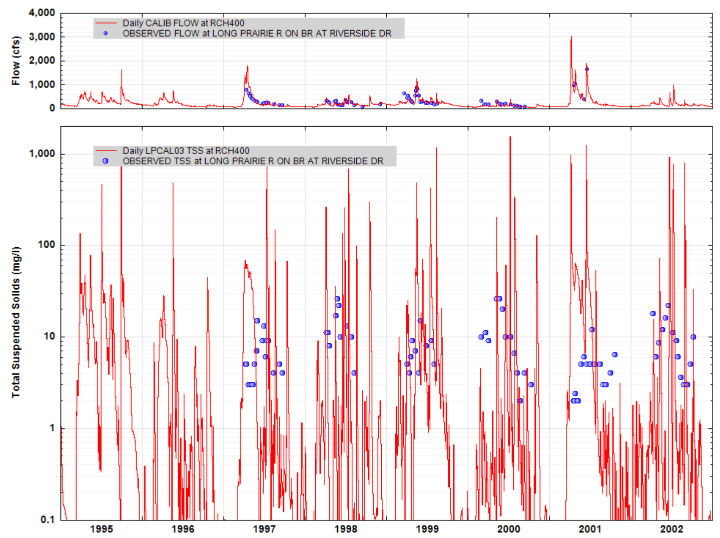
F.2 LONG PRAIRIE RIVER WATERSHED



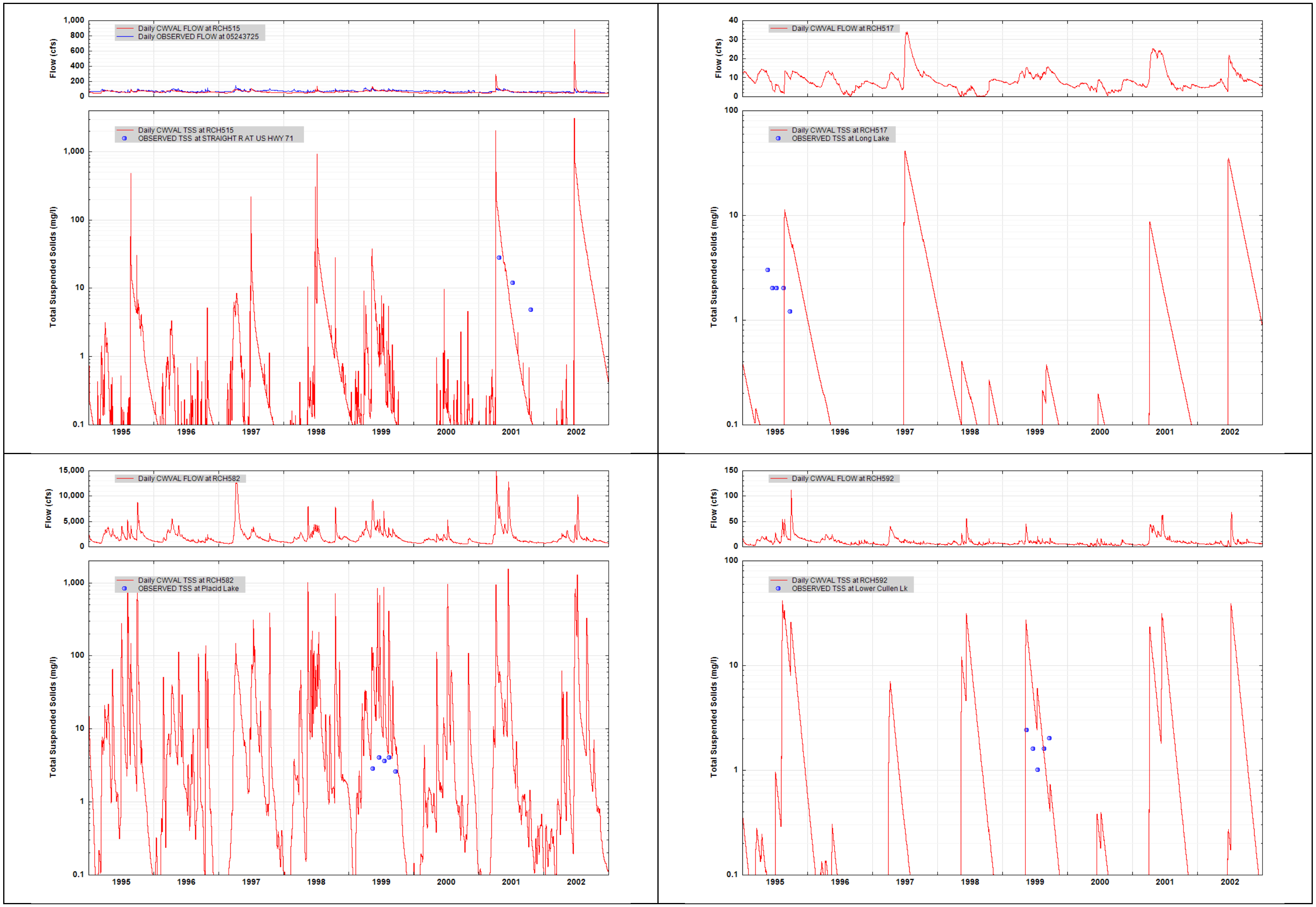


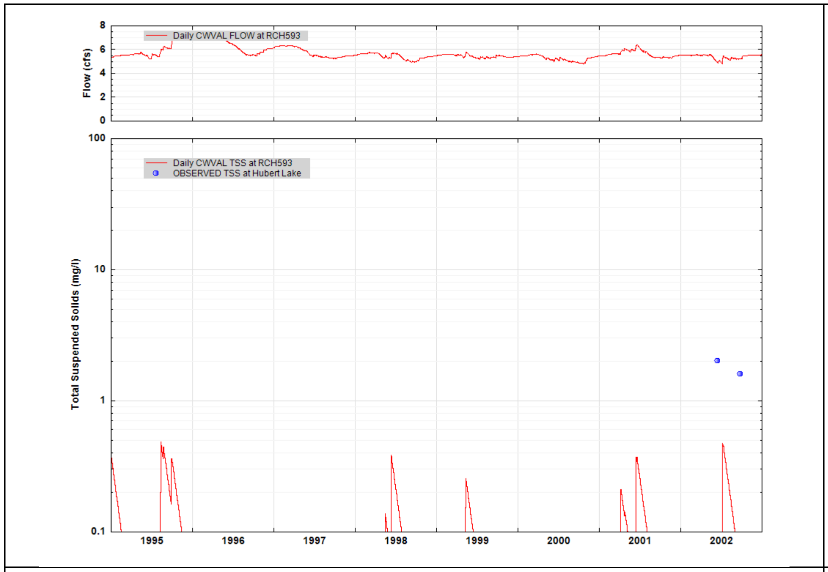
Flow (cfs)
Daily LPCAL03 FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 90
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
Total Suspended Solids (mg/l)
Daily LPCAL03 TSS at RCH329
OBSERVED TSS at LONG PRAIRIE R ON BR AT CR 90
OBSERVED TSS at LONG PRAIRIE R ON BR AT CSAH 14
Flow (cfs)
Daily OBSERVED FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Total Suspended Solids (mg/l)
Daily LPCAL03 TSS at RCH332
OBSERVED TSS at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
Daily OBSERVED FLOW at RCH333
Total Suspended Solids (mg/l)
Daily LPCAL03 TSS at RCH333
OBSERVED TSS at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Flow (cfs)
Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Total Suspended Solids (mg/l)
Daily LPCAL03 TSS at RCH336
OBSERVED TSS at TURTLE CK ON BR AT OAK RIDGE RD
1995
1996
1997
1998
1999
2000
2001
2002

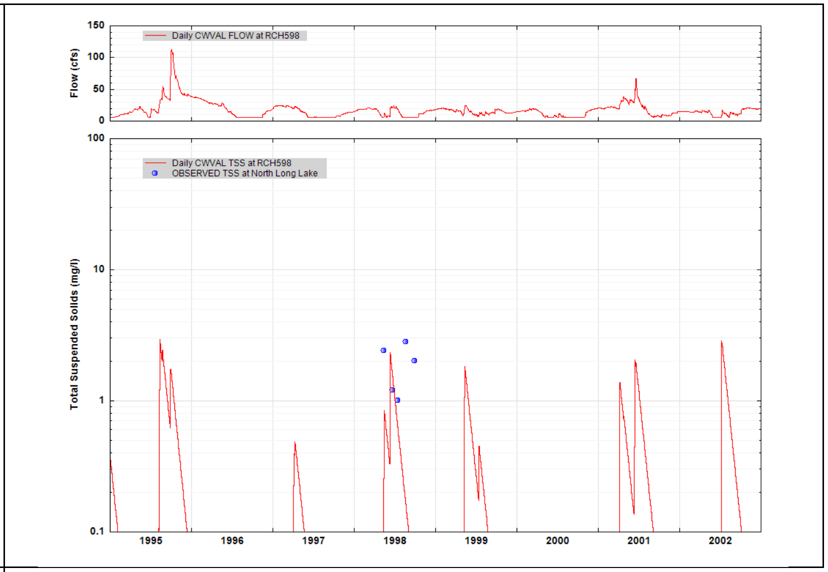

Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Flow (cfs)
Daily LPCAL03 TSS at RCH339
OBSERVED TSS at MORAN CR ON BR AT 255TH AVE
Total Suspended Solids (mg/l)
Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 TSS at RCH341
OBSERVED TSS at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 FLOW at RCH345
Daily LPCAL03 TSS at RCH345
OBSERVED TSS at Fish Trap Lake
Daily CALIB FLOW at RCH347
Daily LPCAL03 TSS at RCH347
OBSERVED TSS at LONG PRAIRIE R BRIDGE ON US-10
1995
1996
1997
1998
1999
2000
2001
2002

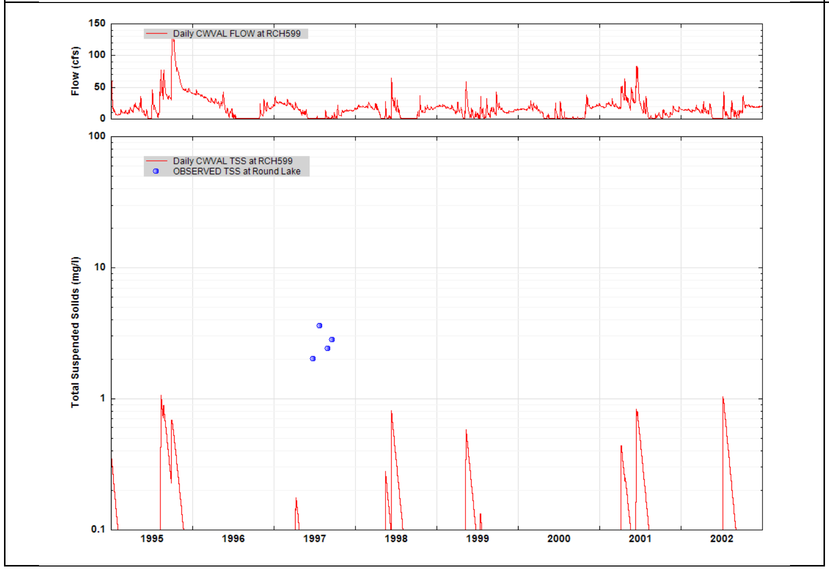

4,000
3,000
2,000
1,000
0
Flow (cfs)
Daily CALIB FLOW at RCH400
OBSERVED FLOW at LONG PRAIRIE R ON BR AT RIVERSIDE DR
1,000
100
10
1
0.1
Total Suspended Solids (mg/l)
Daily LPCAL03 TSS at RCH400
OBSERVED TSS at LONG PRAIRIE R ON BR AT RIVERSIDE DR
1995
1996
1997
1998
1999
2000
2001
2002

F.3 CROW WING RIVER WATERSHED



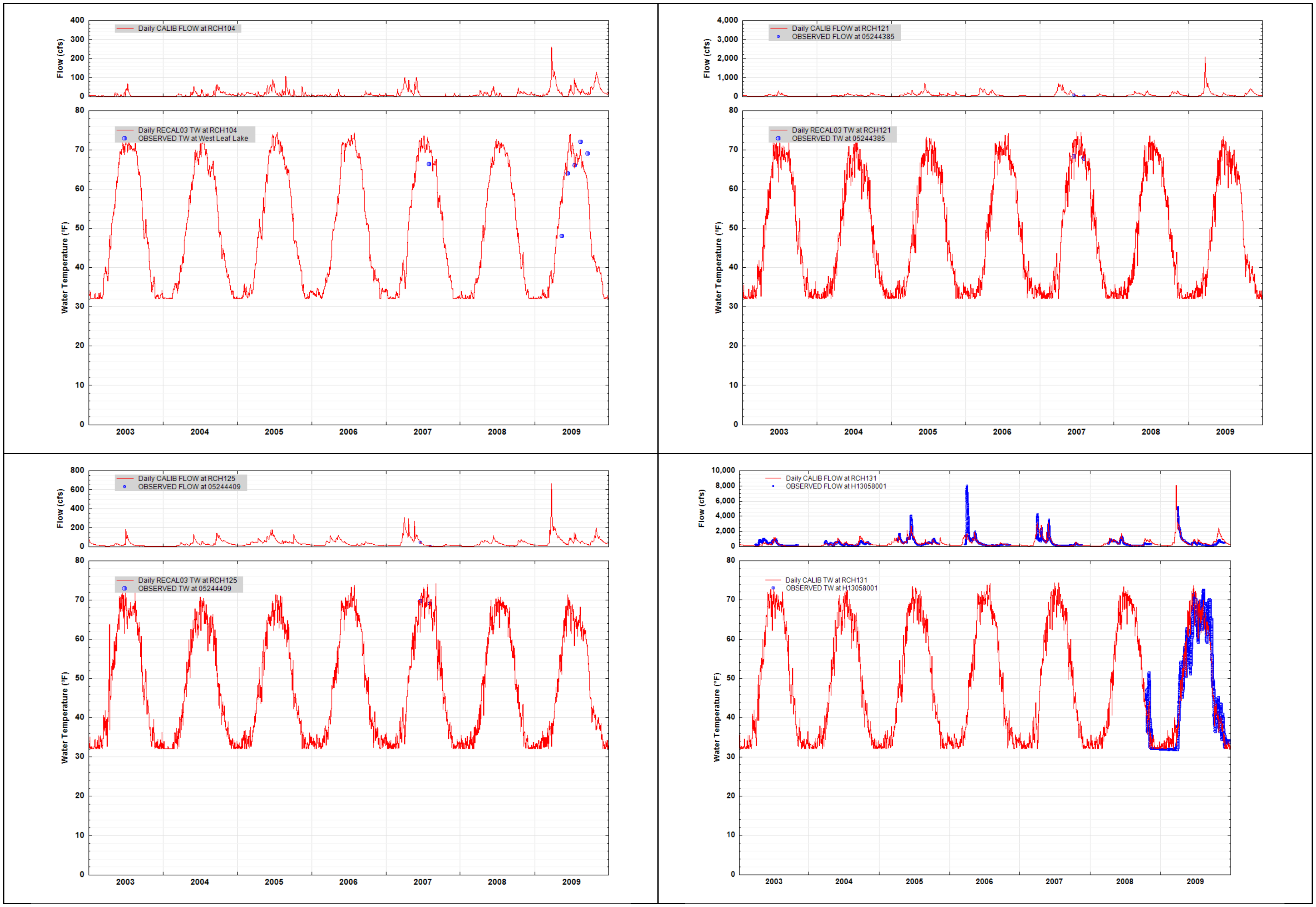

Daily CWVAL FLOW at RCH593
Flow (cfs)
Daily CWVAL TSS at RCH593
OBSERVED TSS at Hubert Lake
Total Suspended Solids (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL FLOW at RCH598
Flow (cfs)
Daily CWVAL TSS at RCH598
OBSERVED TSS at North Long Lake
Total Suspended Solids (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002

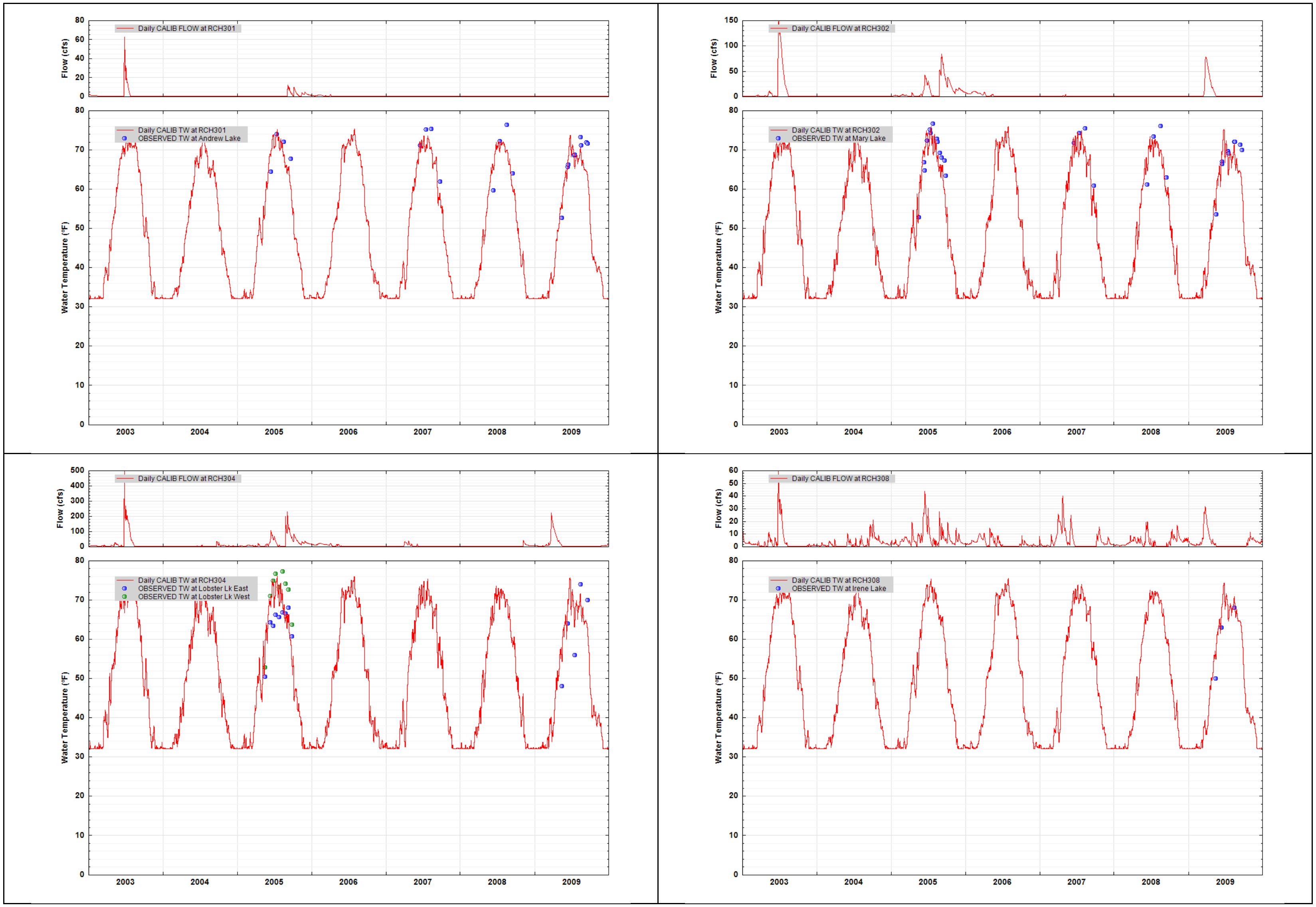

Daily CWVAL FLOW at RCH599
Flow (cfs)
Daily CWVAL TSS at RCH599
OBSERVED TSS at Round Lake
Total Suspended Solids (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002

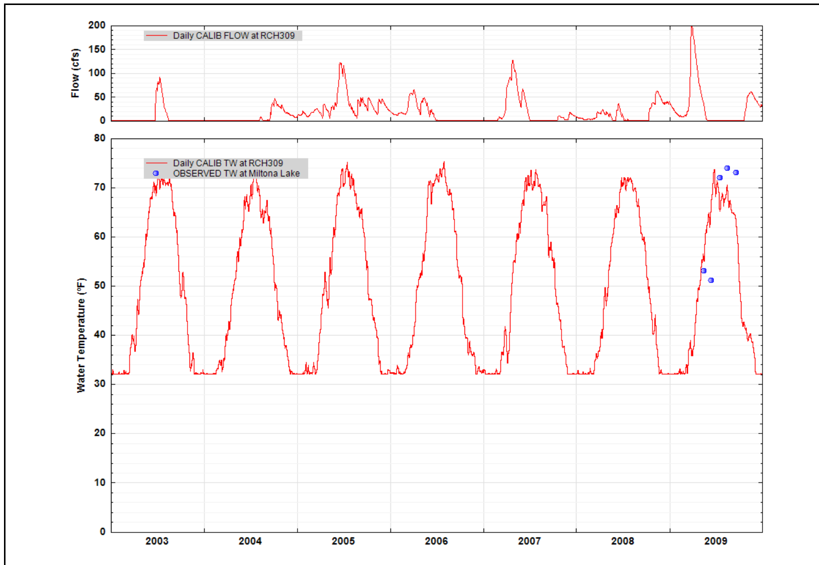
APPENDIX G
OBSERVED AND SIMULATED WATER TEMPERATURE FOR THE CALIBRATION PERIOD

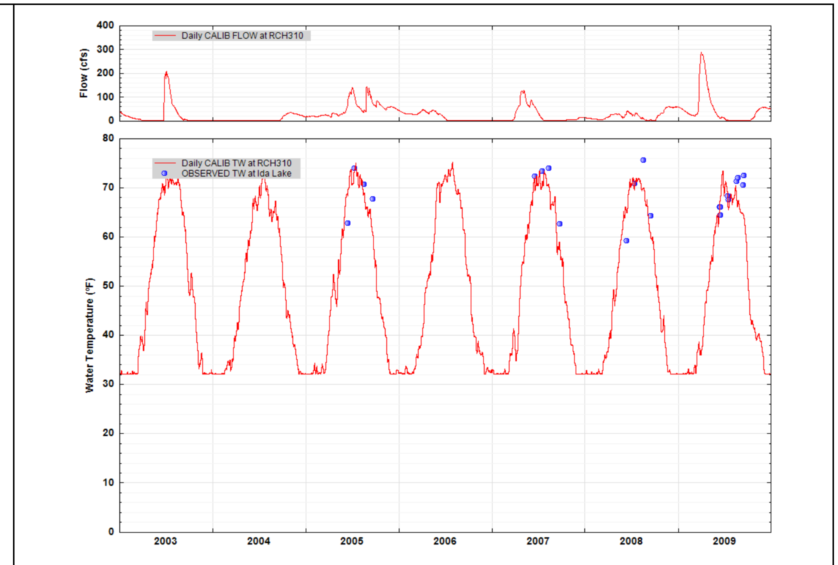
G.1 REDEYE RIVER WATERSHED

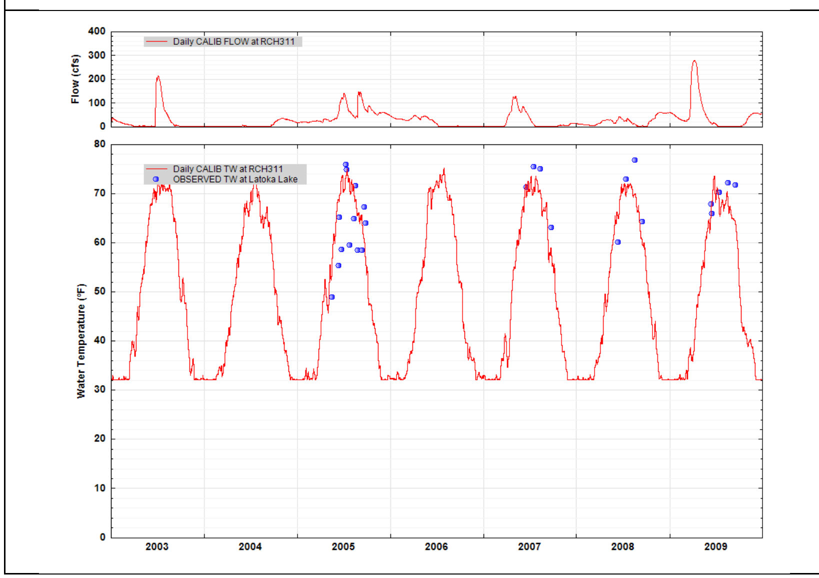


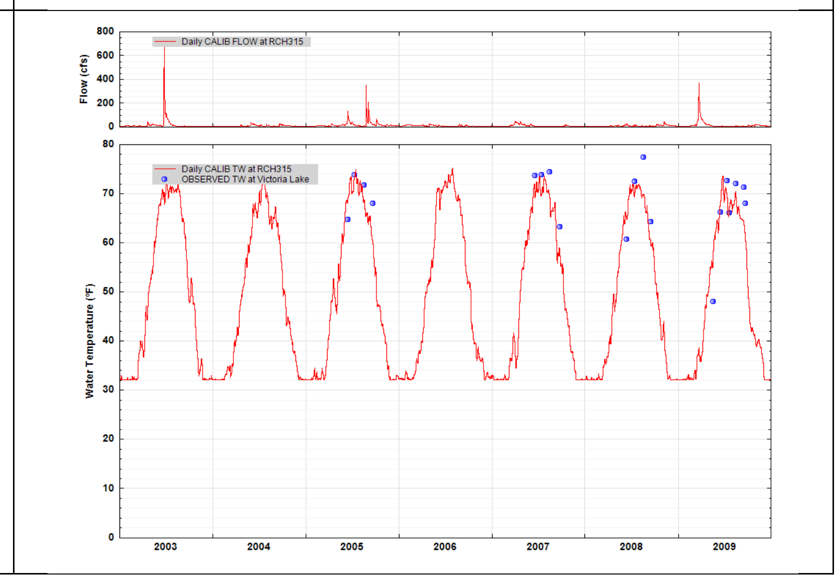
G.2 LONG PRAIRIE RIVER WATERSHED

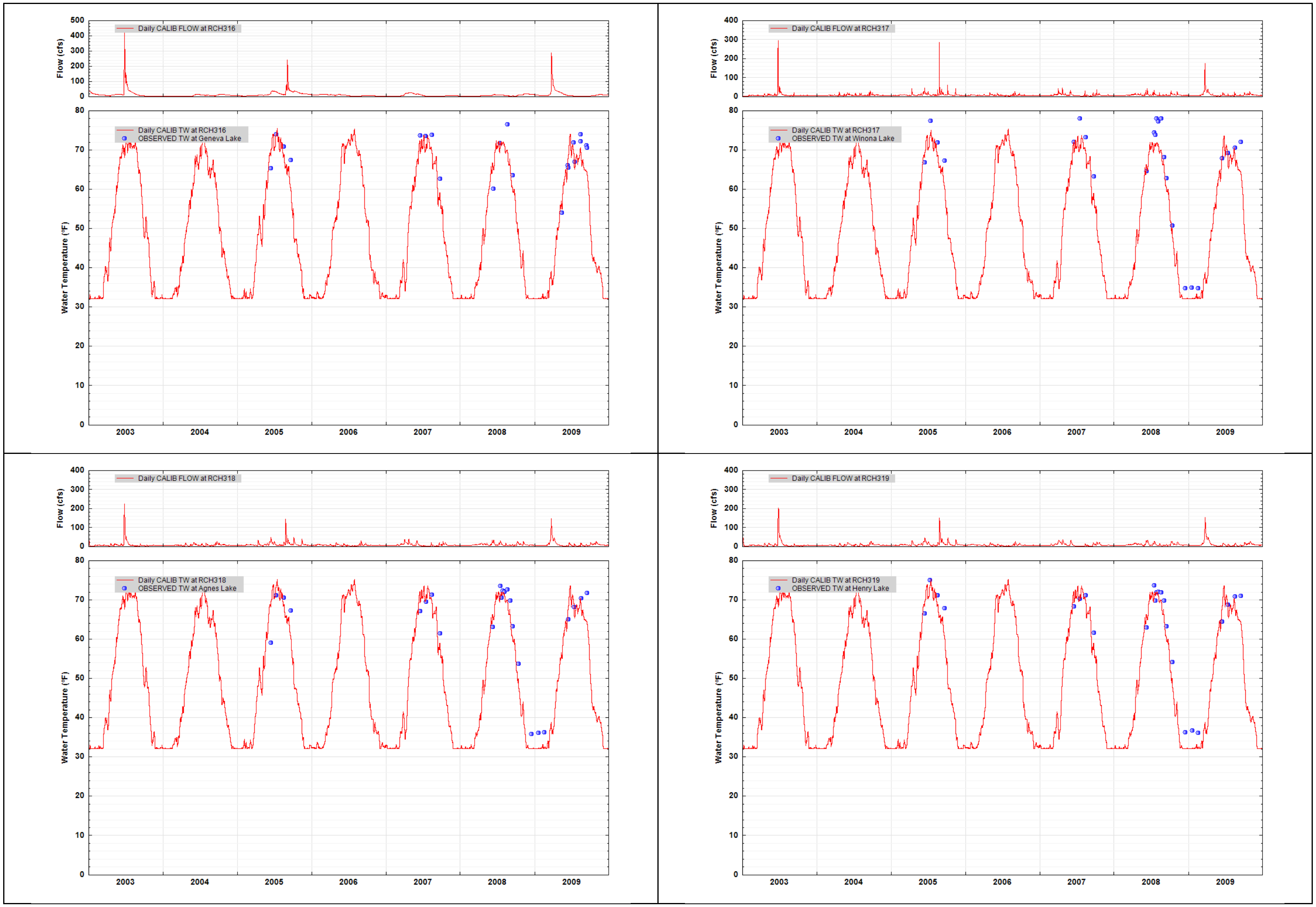


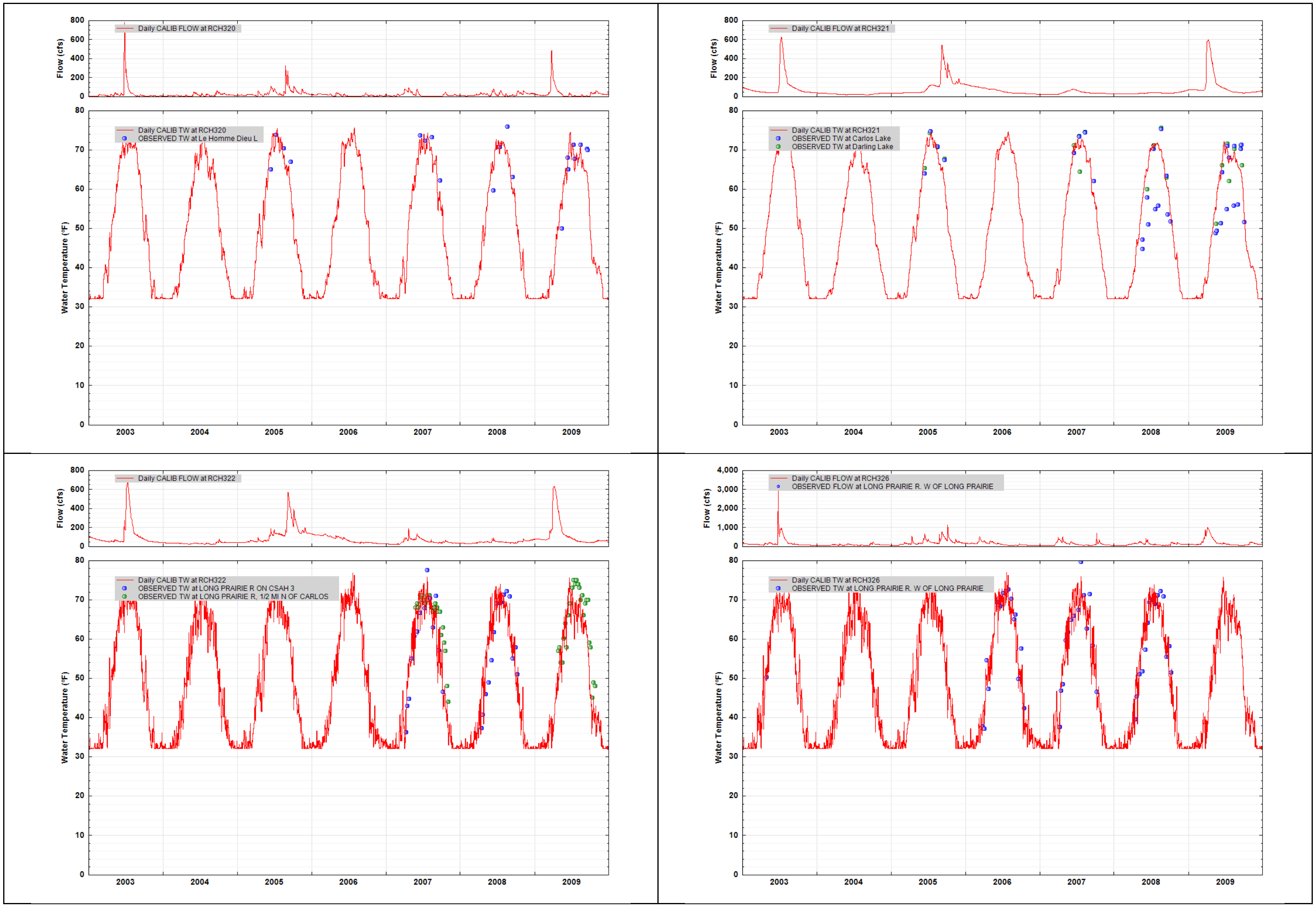

Daily CALIB FLOW at RCH309
Flow (cfs)
Daily CALIB TW at RCH309
OBSERVED TW at Miltona Lake
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

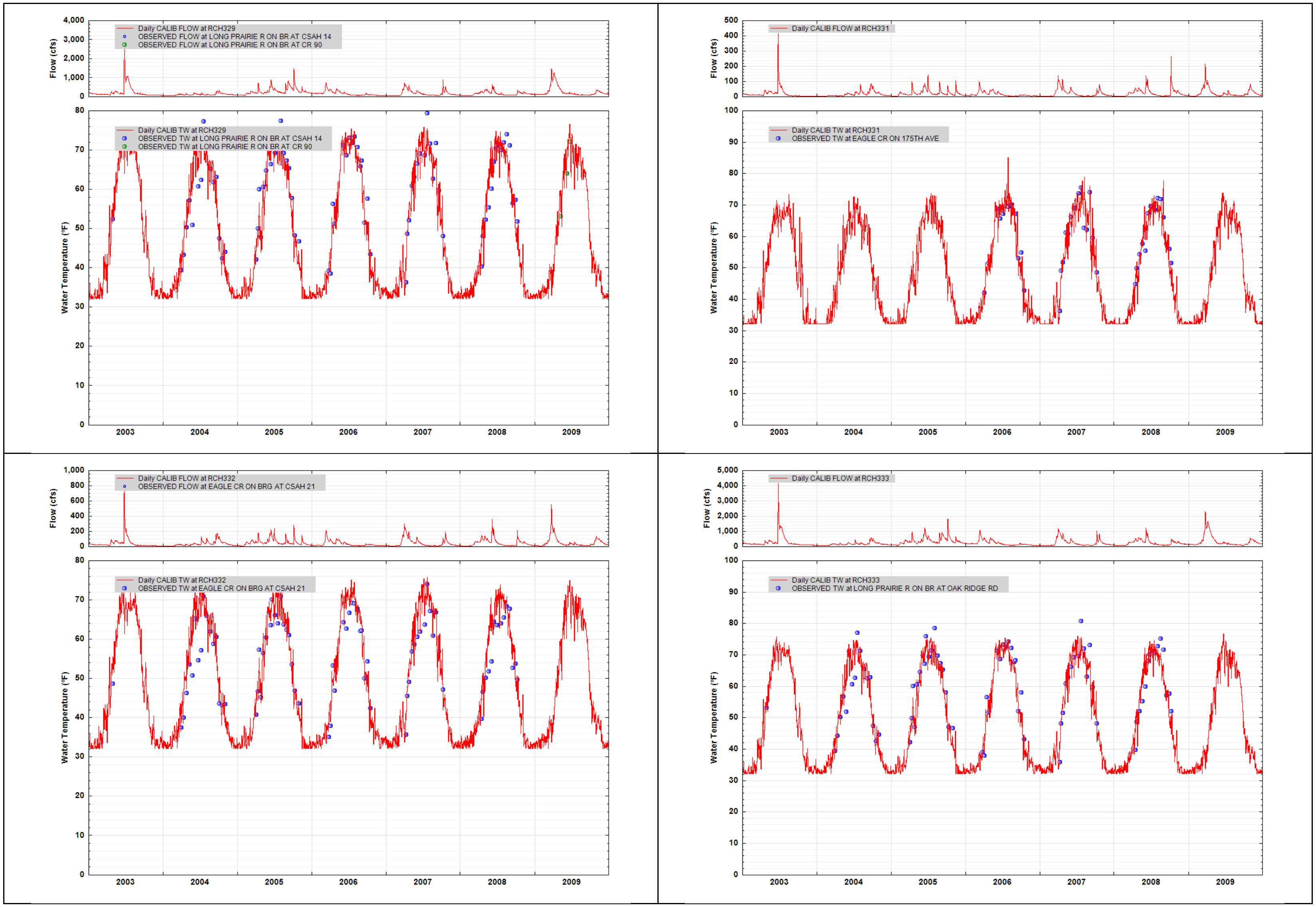

Daily CALIB FLOW at RCH310
Flow (cfs)
Daily CALIB TW at RCH310
OBSERVED TW at Ida Lake
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

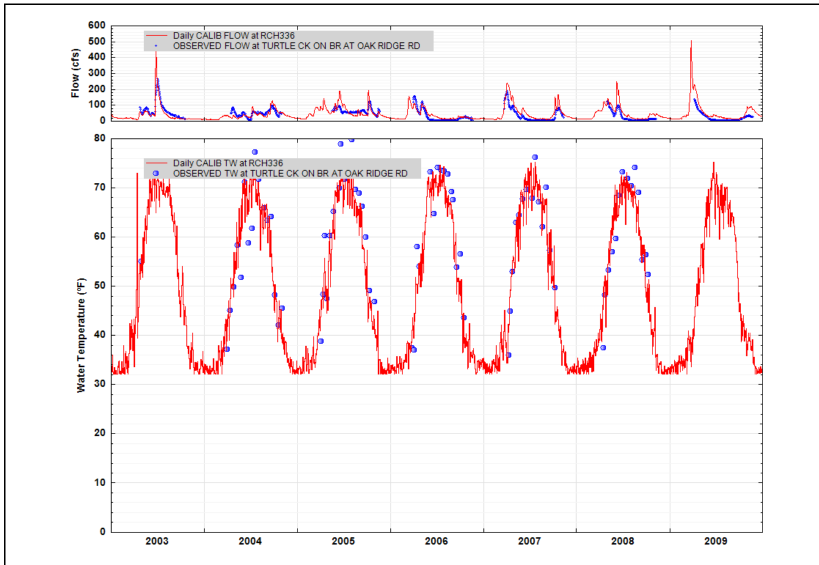

Daily CALIB FLOW at RCH311
Flow (cfs)
Daily CALIB TW at RCH311
OBSERVED TW at Latoka Lake
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

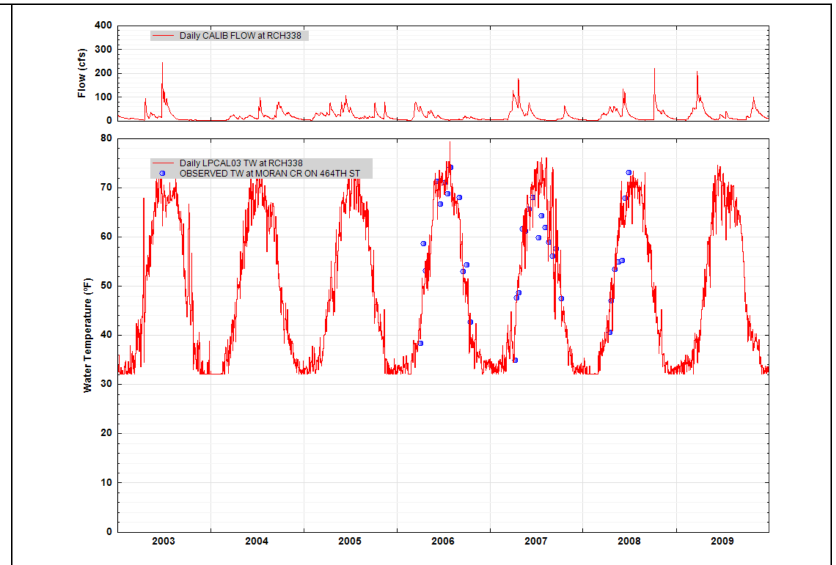

Daily CALIB FLOW at RCH315
Flow (cfs)
Daily CALIB TW at RCH315
OBSERVED TW at Victoria Lake
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

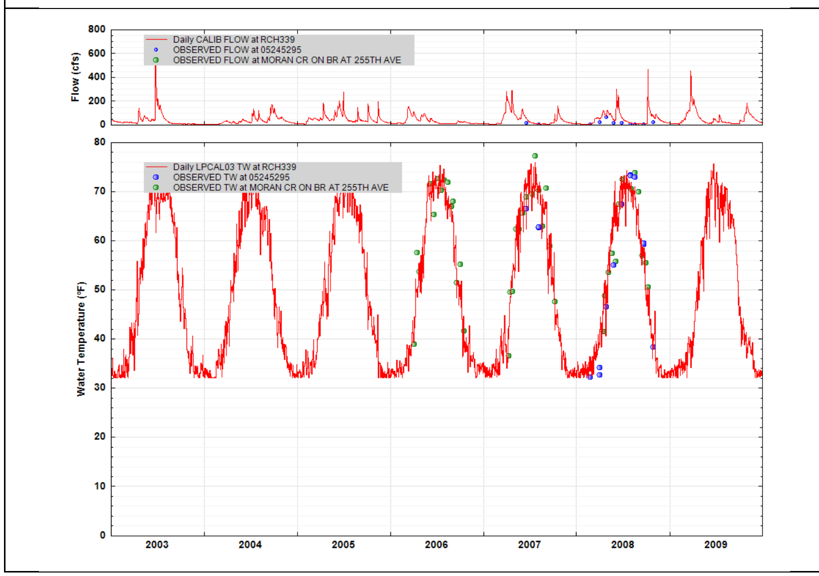

Daily CALIB FLOW at RCH316
Flow (cfs)
Daily CALIB TW at RCH316
OBSERVED TW at Geneva Lake
Water Temperature (°F)
Daily CALIB FLOW at RCH317
Daily CALIB TW at RCH317
OBSERVED TW at Winona Lake
Daily CALIB FLOW at RCH318
Daily CALIB TW at RCH318
OBSERVED TW at Agnes Lake
Daily CALIB FLOW at RCH319
Daily CALIB TW at RCH319
OBSERVED TW at Henry Lake
2003
2004
2005
2006
2007
2008
2009

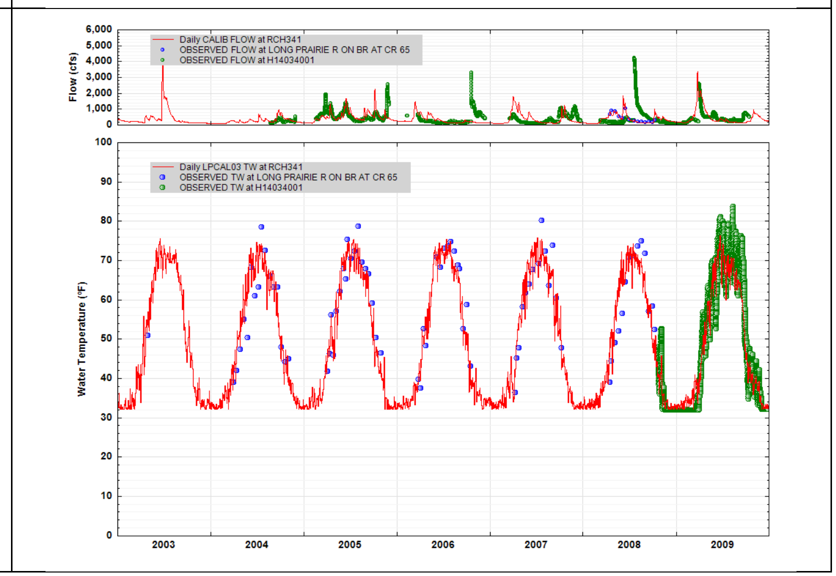

Daily CALIB FLOW at RCH320
Daily CALIB TW at RCH320
OBSERVED TW at Le Homme Dieu L
Daily CALIB FLOW at RCH321
Daily CALIB TW at RCH321
OBSERVED TW at Carlos Lake
OBSERVED TW at Darling Lake
Daily CALIB FLOW at RCH322
Daily CALIB TW at RCH322
OBSERVED TW at LONG PRAIRIE R ON CSAH 3
OBSERVED TW at LONG PRAIRIE R, 1/2 MI N OF CARLOS
Daily CALIB FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily CALIB TW at RCH326
OBSERVED TW at LONG PRAIRIE R. W OF LONG PRAIRIE
Flow (cfs)
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

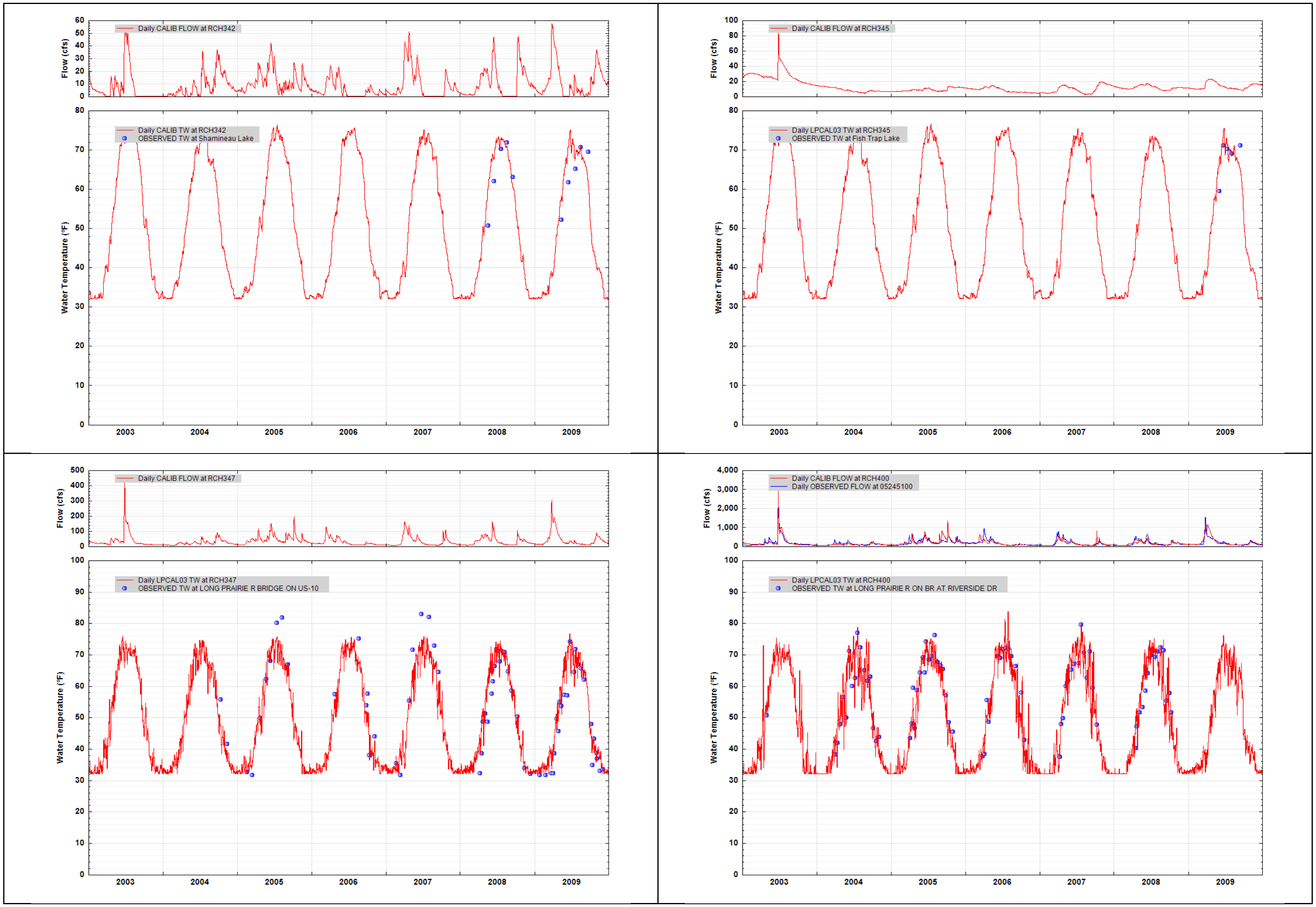

Daily CALIB FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 90
Flow (cfs)
Daily CALIB TW at RCH329
OBSERVED TW at LONG PRAIRIE R ON BR AT CSAH 14
OBSERVED TW at LONG PRAIRIE R ON BR AT CR 90
Water Temperature (°F)
Daily CALIB FLOW at RCH331
Daily CALIB TW at RCH331
OBSERVED TW at EAGLE CR ON 175TH AVE
Daily CALIB FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Daily CALIB TW at RCH332
OBSERVED TW at EAGLE CR ON BRG AT CSAH 21
Daily CALIB FLOW at RCH333
Daily CALIB TW at RCH333
OBSERVED TW at LONG PRAIRIE R ON BR AT OAK RIDGE RD
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Daily CALIB TW at RCH336
OBSERVED TW at TURTLE CK ON BR AT OAK RIDGE RD
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

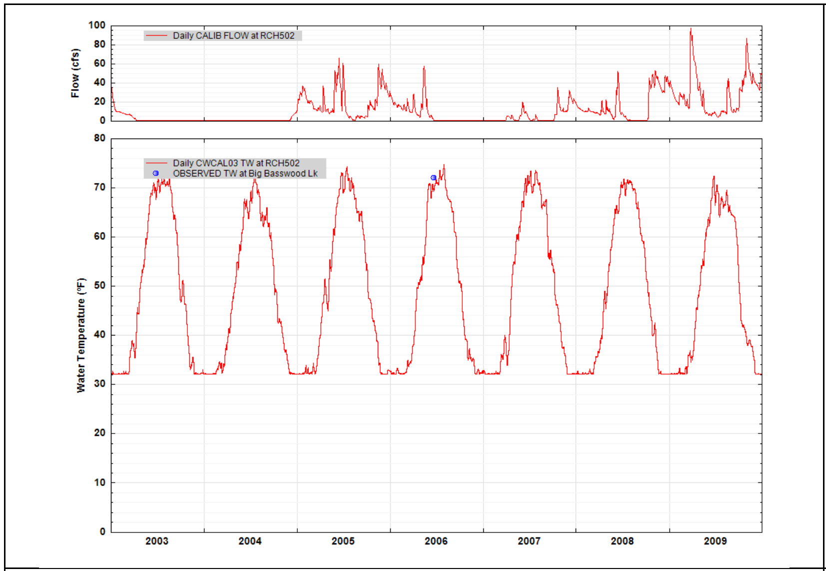

Daily CALIB FLOW at RCH338
Flow (cfs)
Daily LPCAL03 TW at RCH338
OBSERVED TW at MORAN CR ON 464TH ST
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

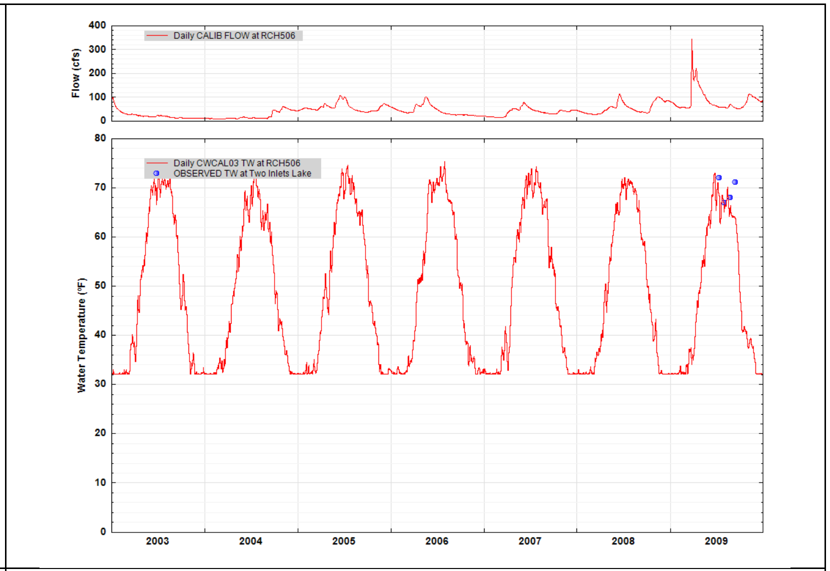

Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Flow (cfs)
Daily LPCAL03 TW at RCH339
OBSERVED TW at 05245295
OBSERVED TW at MORAN CR ON BR AT 255TH AVE
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

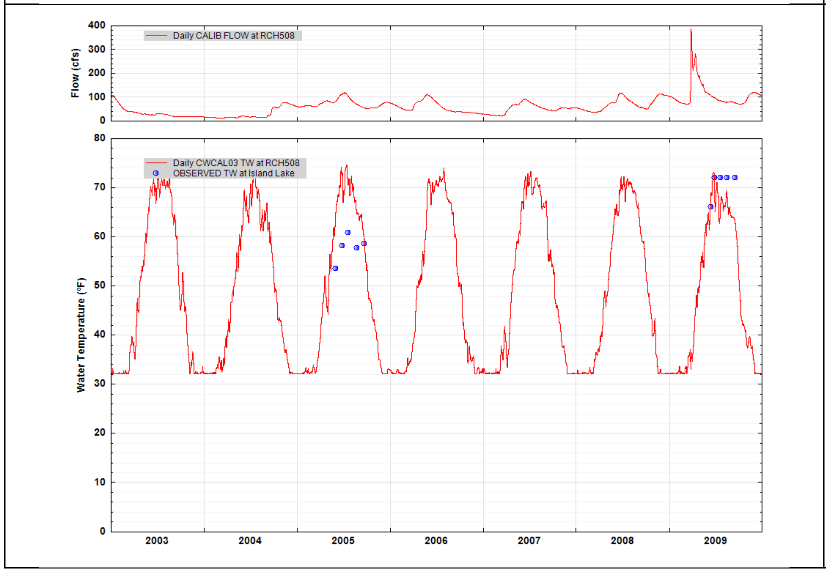

Daily CALIB FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
OBSERVED FLOW at H14034001
Flow (cfs)
Daily LPCAL03 TW at RCH341
OBSERVED TW at LONG PRAIRIE R ON BR AT CR 65
OBSERVED TW at H14034001
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

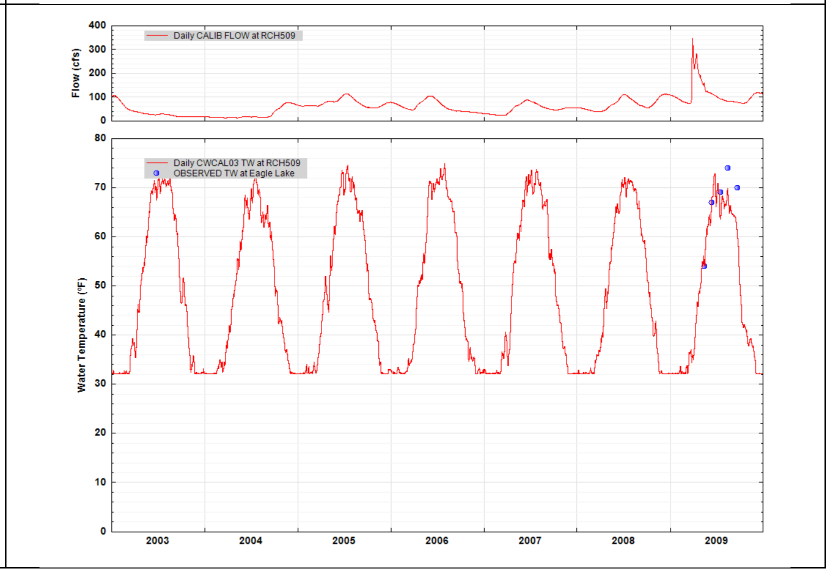

Daily CALIB FLOW at RCH342
Flow (cfs)
Daily CALIB TW at RCH342
OBSERVED TW at Shamineau Lake
Water Temperature (°F)
Daily CALIB FLOW at RCH345
Daily LPCAL03 TW at RCH345
OBSERVED TW at Fish Trap Lake
Daily CALIB FLOW at RCH347
Daily LPCAL03 TW at RCH347
OBSERVED TW at LONG PRAIRIE R BRIDGE ON US-10
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Daily LPCAL03 TW at RCH400
OBSERVED TW at LONG PRAIRIE R ON BR AT RIVERSIDE DR
2003
2004
2005
2006
2007
2008
2009

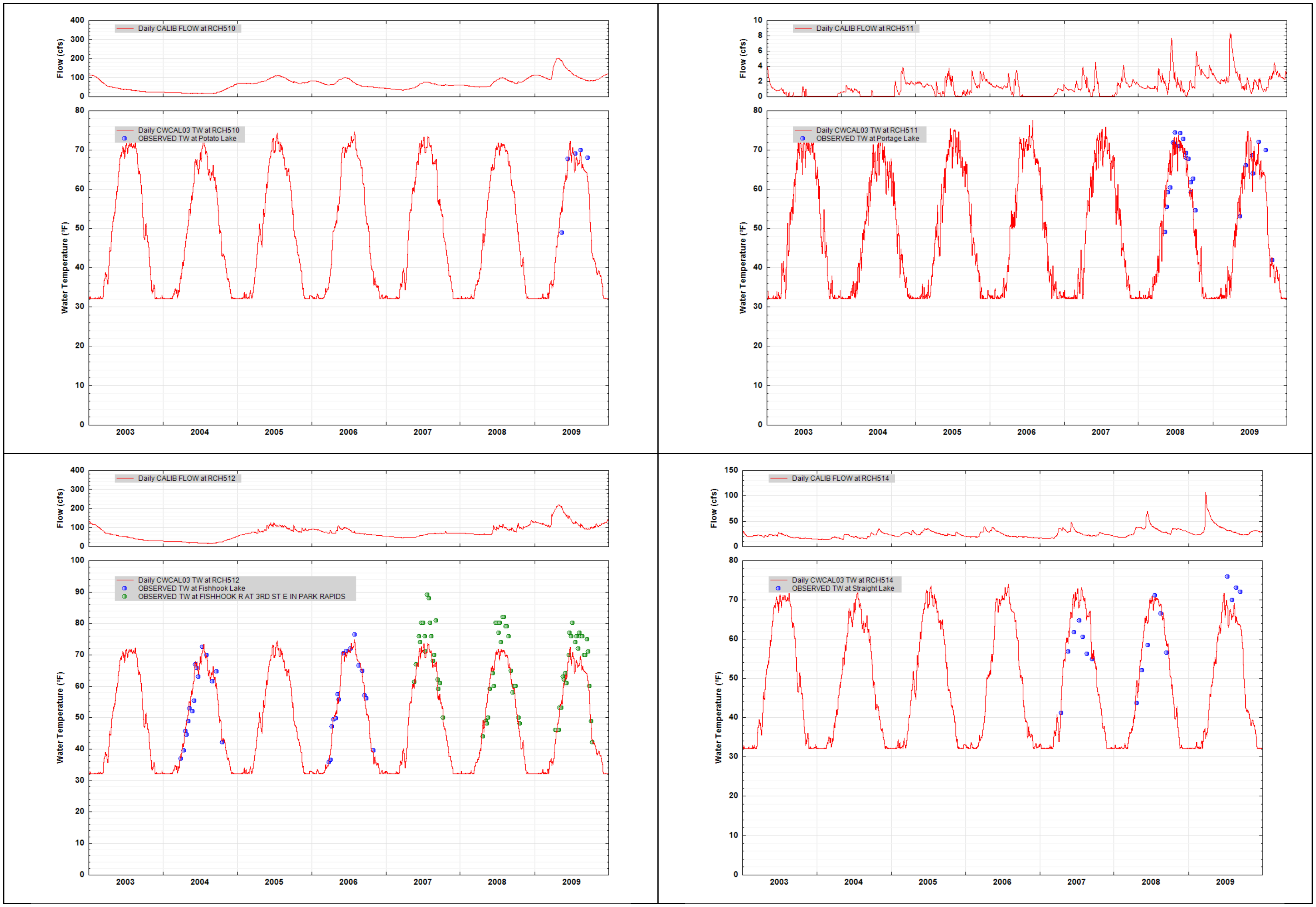
G.3 CROW WING RIVER WATERSHED

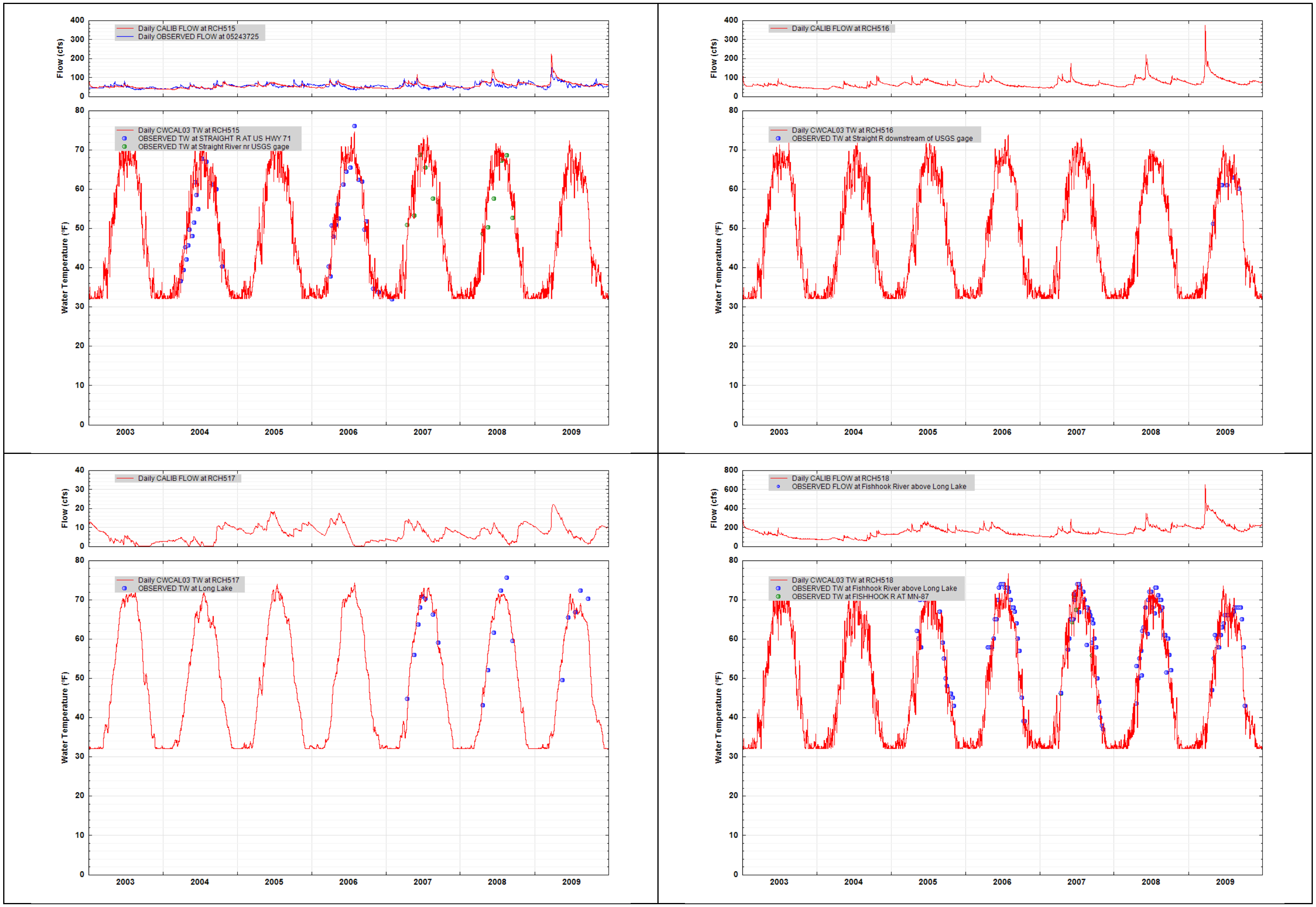


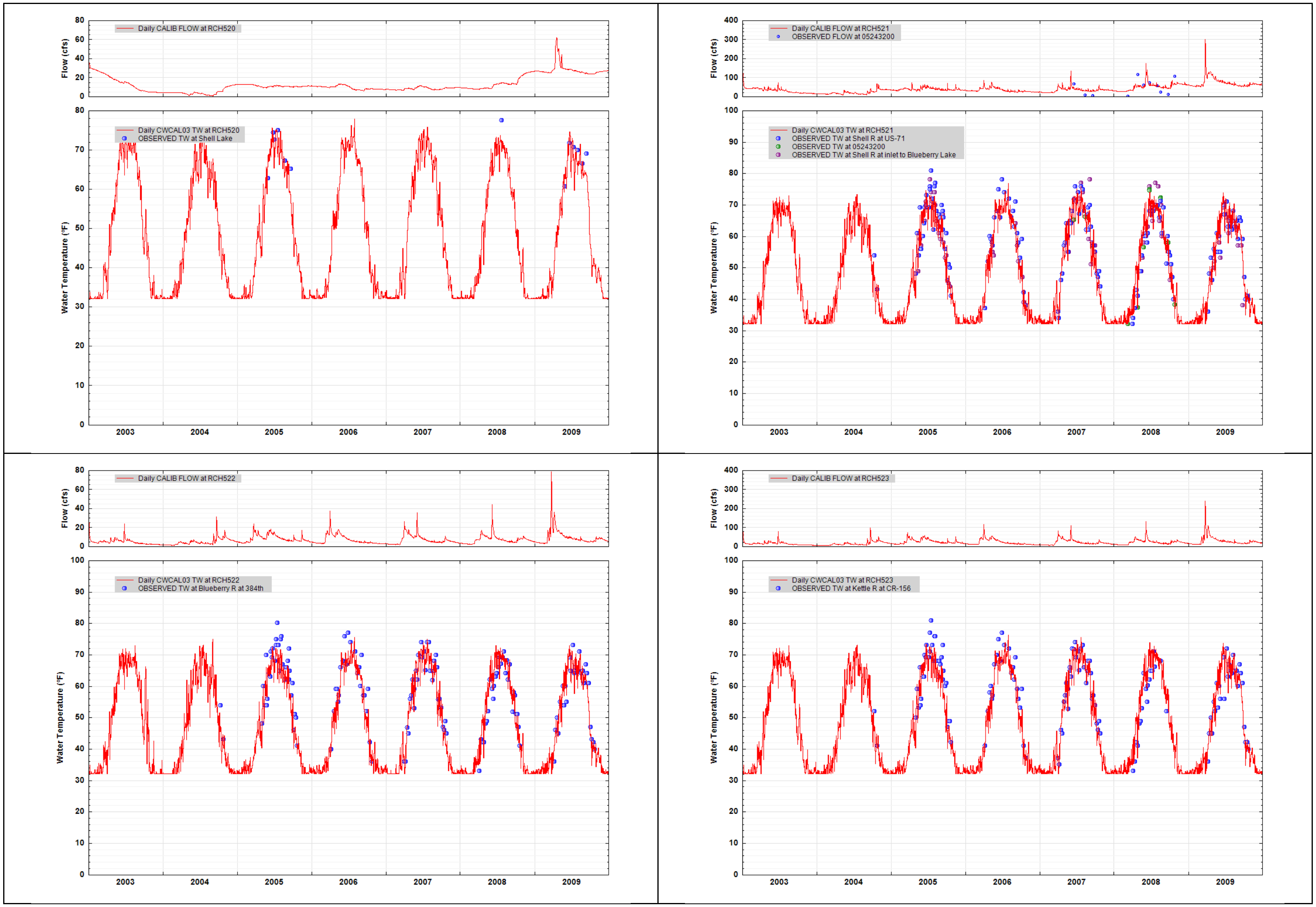


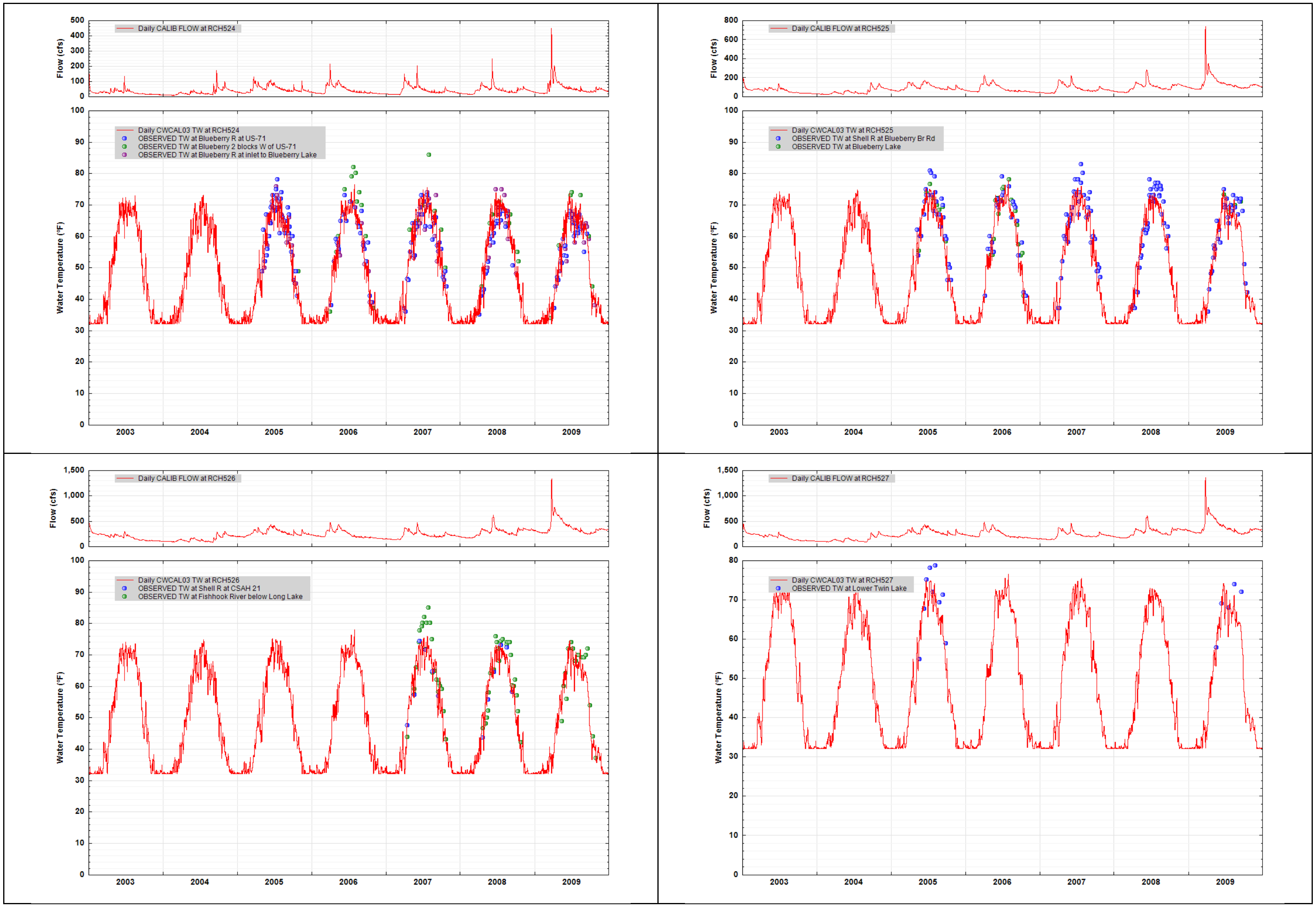




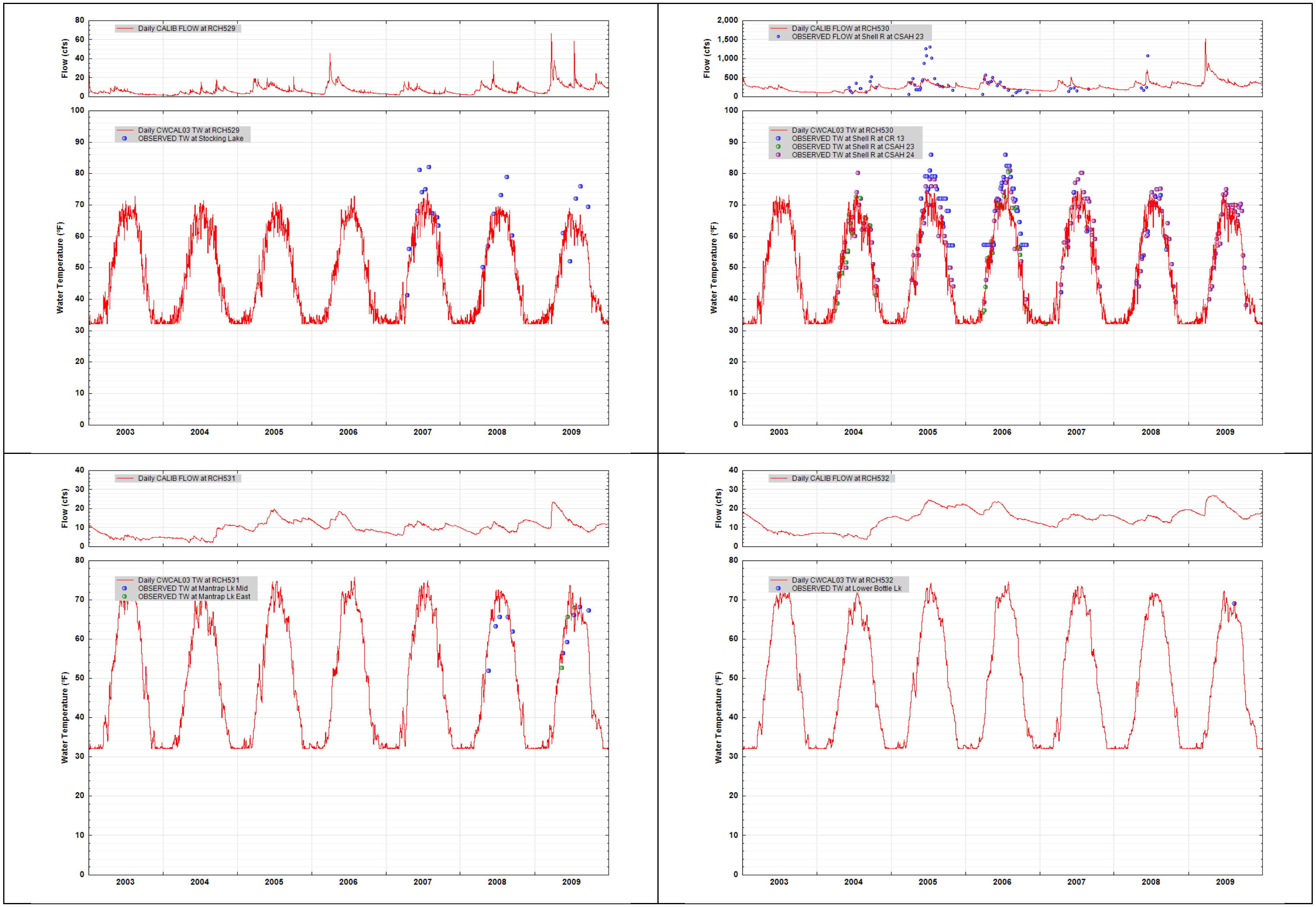

Daily CALIB FLOW at RCH510
Daily CWCAL03 TW at RCH510
OBSERVED TW at Potato Lake
Daily CALIB FLOW at RCH511
Daily CWCAL03 TW at RCH511
OBSERVED TW at Portage Lake
Daily CALIB FLOW at RCH512
Daily CWCAL03 TW at RCH512
OBSERVED TW at Fishhook Lake
OBSERVED TW at FISHHOOK R AT 3RD ST E IN PARK RAPIDS
Daily CALIB FLOW at RCH514
Daily CWCAL03 TW at RCH514
OBSERVED TW at Straight Lake
Flow (cfs)
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

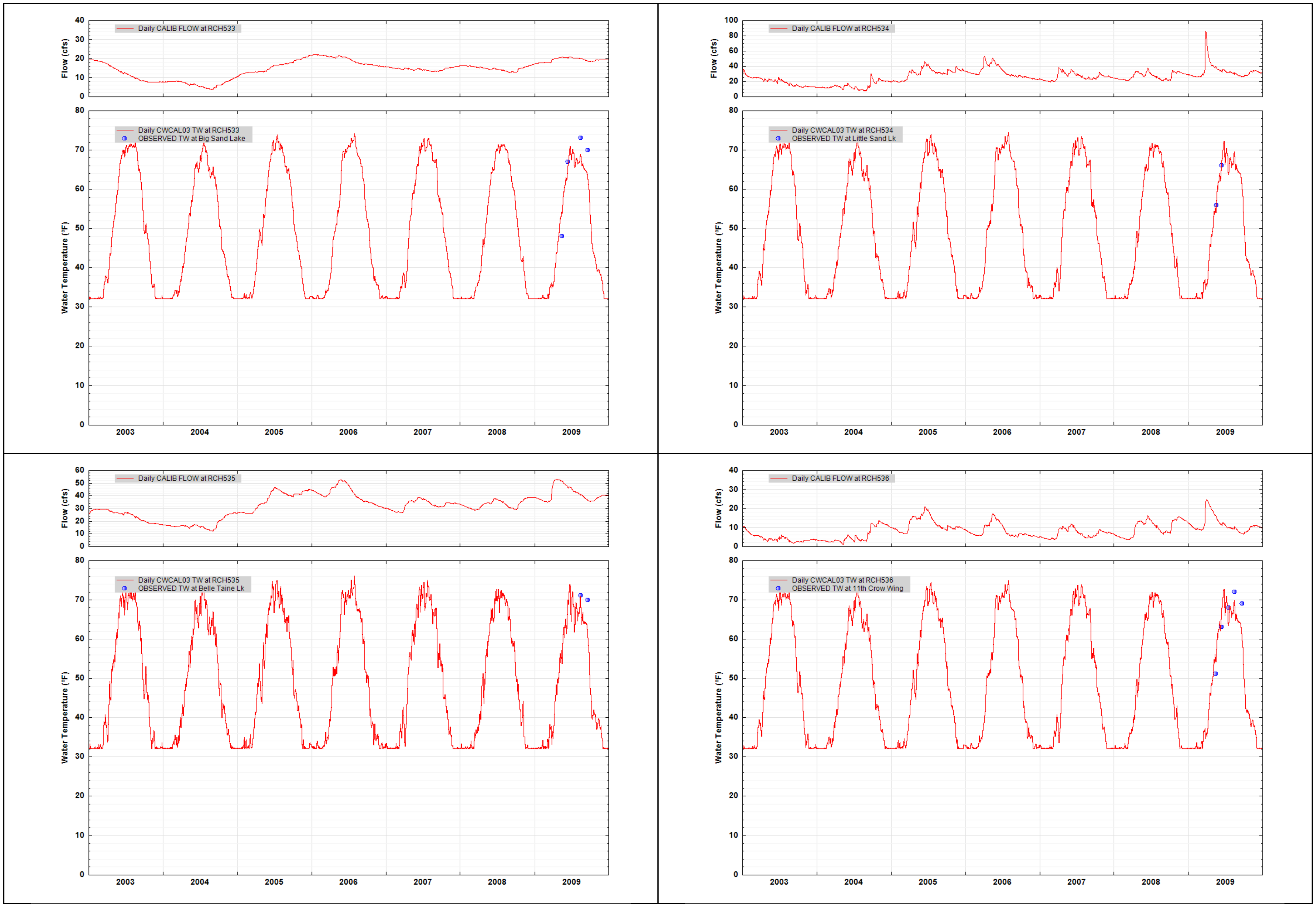

Daily CALIB FLOW at RCH515
Daily OBSERVED FLOW at 05243725
Flow (cfs)
Daily CWCAL03 TW at RCH515
OBSERVED TW at STRAIGHT R AT US HWY 71
OBSERVED TW at Straight River nr USGS gage
Water Temperature (°F)
Daily CALIB FLOW at RCH516
Daily CWCAL03 TW at RCH516
OBSERVED TW at Straight R downstream of USGS gage
Daily CALIB FLOW at RCH517
Daily CWCAL03 TW at RCH517
OBSERVED TW at Long Lake
Daily CALIB FLOW at RCH518
OBSERVED FLOW at Fishhook River above Long Lake
Daily CWCAL03 TW at RCH518
OBSERVED TW at Fishhook River above Long Lake
OBSERVED TW at FISHHOOK R AT MN-87
2003
2004
2005
2006
2007
2008
2009

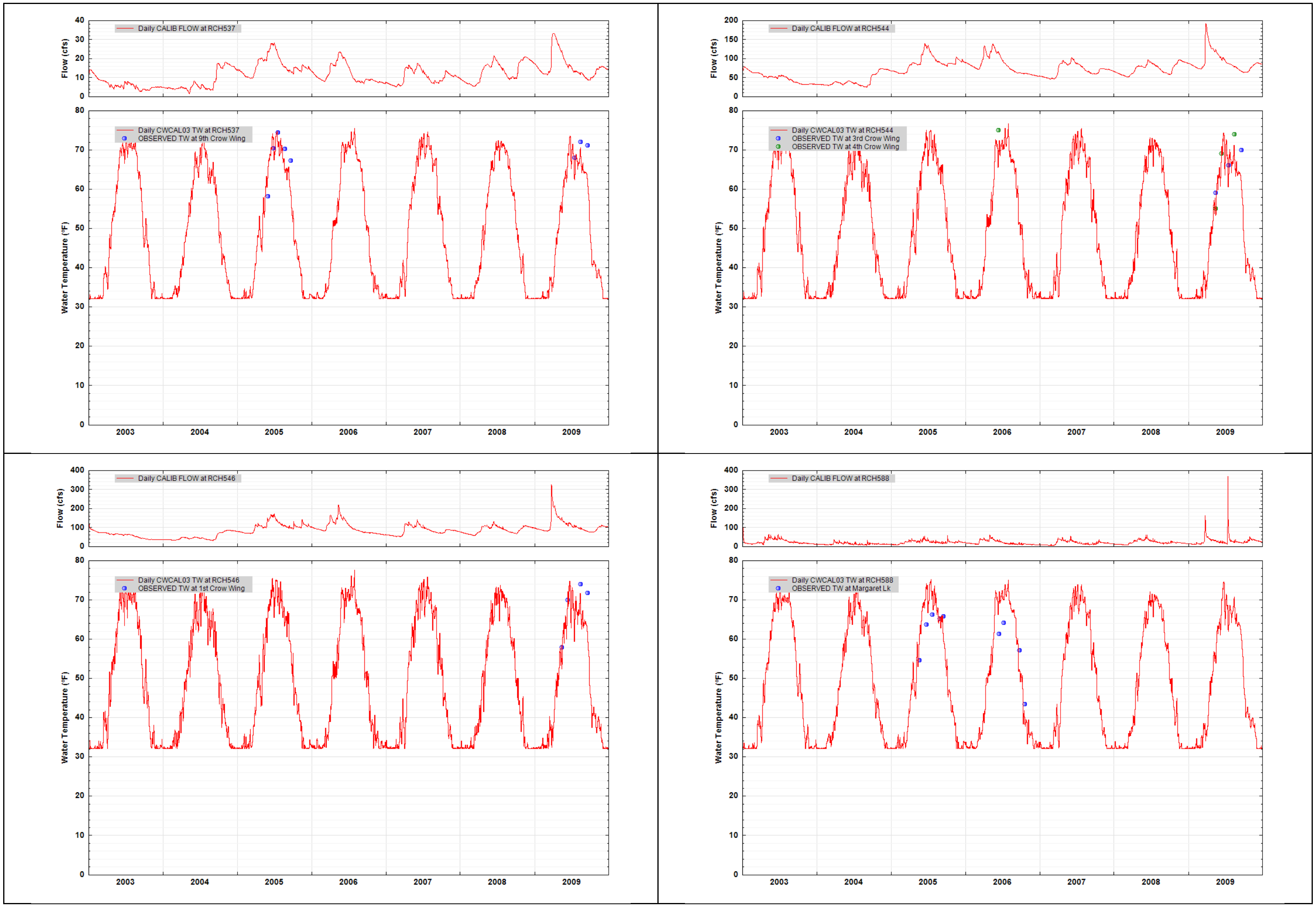

Daily CALIB FLOW at RCH520
Flow (cfs)
Daily CWCAL03 TW at RCH520
OBSERVED TW at Shell Lake
Water Temperature (°F)
Daily CALIB FLOW at RCH521
OBSERVED FLOW at 05243200
Daily CWCAL03 TW at RCH521
OBSERVED TW at Shell R at US-71
OBSERVED TW at 05243200
OBSERVED TW at Shell R at inlet to Blueberry Lake
Daily CALIB FLOW at RCH522
Daily CWCAL03 TW at RCH522
OBSERVED TW at Blueberry R at 384th
Daily CALIB FLOW at RCH523
Daily CWCAL03 TW at RCH523
OBSERVED TW at Kettle R at CR-156
2003
2004
2005
2006
2007
2008
2009

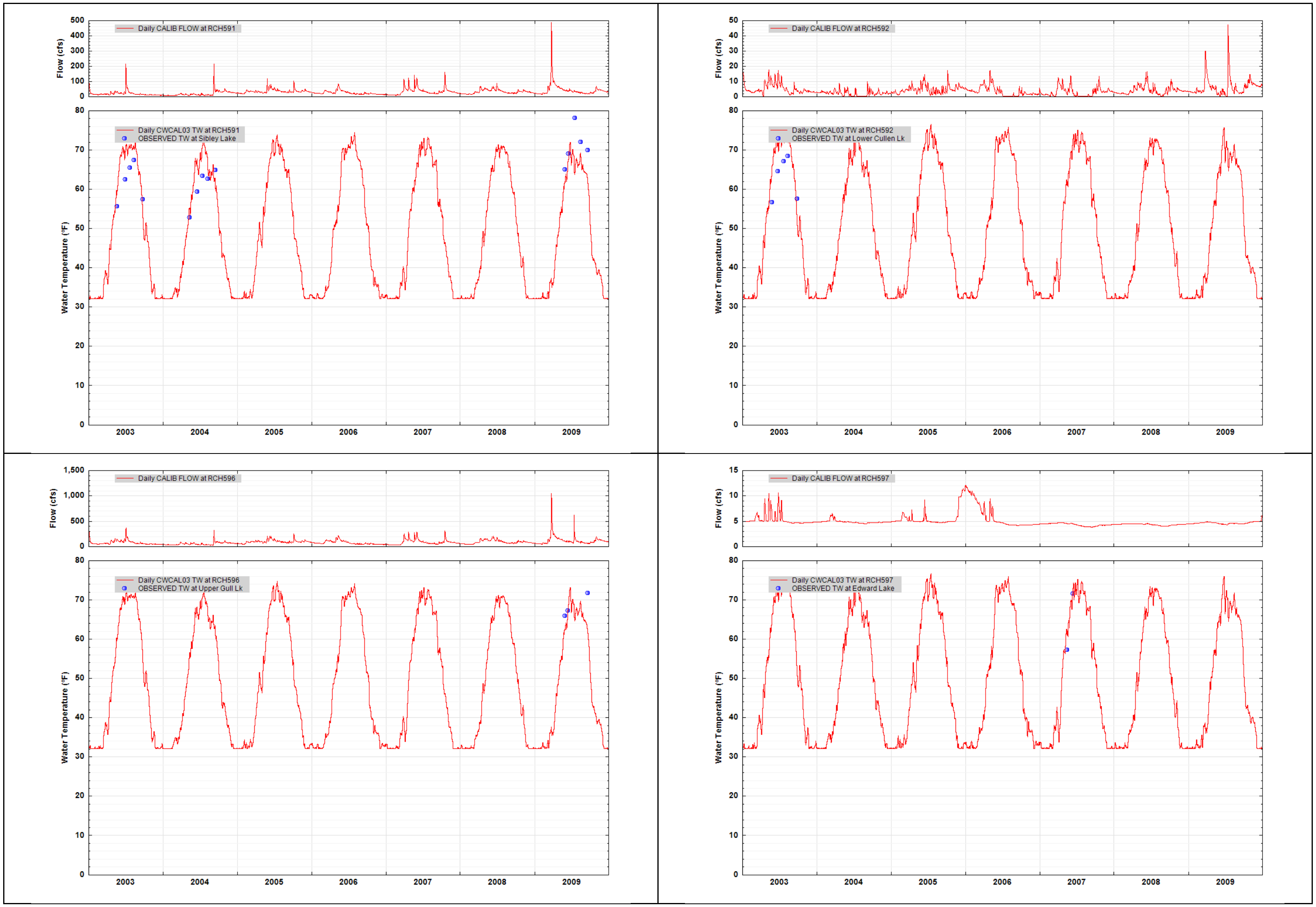


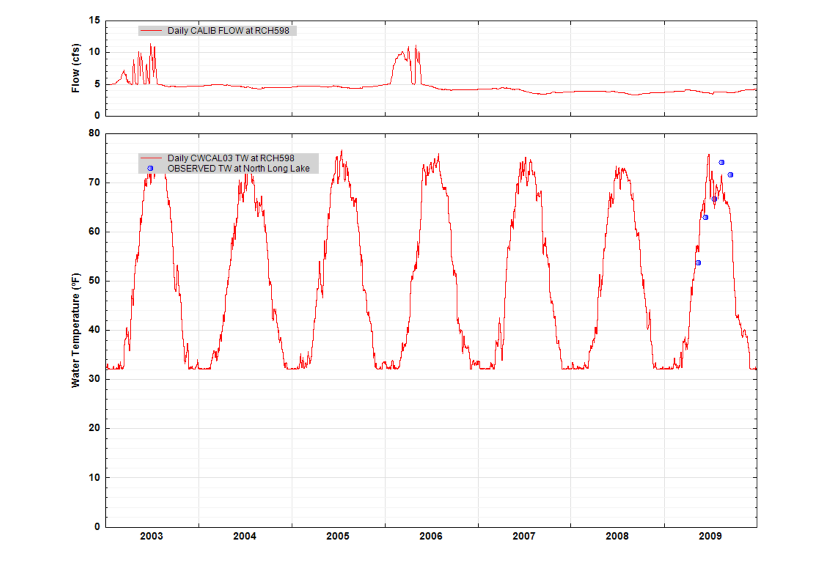
Daily CALIB FLOW at RCH524
Flow (cfs)
Daily CWCAL03 TW at RCH524
OBSERVED TW at Blueberry R at US-71
OBSERVED TW at Blueberry 2 blocks W of US-71
OBSERVED TW at Blueberry R at inlet to Blueberry Lake
Water Temperature (°F)
Daily CALIB FLOW at RCH525
Daily CWCAL03 TW at RCH525
OBSERVED TW at Shell R at Blueberry Br Rd
OBSERVED TW at Blueberry Lake
Daily CALIB FLOW at RCH526
Daily CWCAL03 TW at RCH526
OBSERVED TW at Shell R at CSAH 21
OBSERVED TW at Fishhook River below Long Lake
Daily CALIB FLOW at RCH527
Daily CWCAL03 TW at RCH527
OBSERVED TW at Lower Twin Lake
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH529
Flow (cfs)
Daily CWCAL03 TW at RCH529
OBSERVED TW at Stocking Lake
Water Temperature (°F)
Daily CALIB FLOW at RCH530
OBSERVED FLOW at Shell R at CSAH 23
Daily CWCAL03 TW at RCH530
OBSERVED TW at Shell R at CR 13
OBSERVED TW at Shell R at CSAH 23
OBSERVED TW at Shell R at CSAH 24
Daily CALIB FLOW at RCH531
Daily CWCAL03 TW at RCH531
OBSERVED TW at Mantrap Lk Mid
OBSERVED TW at Mantrap Lk East
Daily CALIB FLOW at RCH532
Daily CWCAL03 TW at RCH532
OBSERVED TW at Lower Bottle Lk
2003
2004
2005
2006
2007
2008
2009

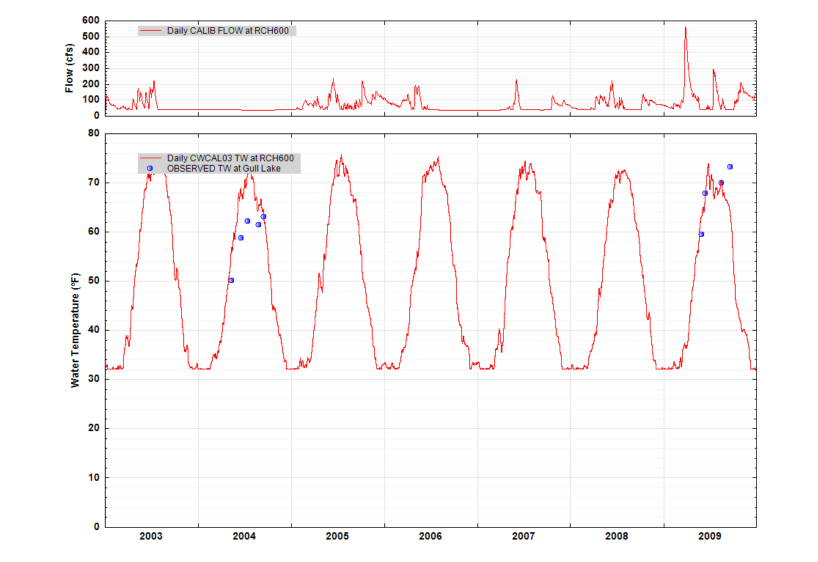

Daily CALIB FLOW at RCH533
Flow (cfs)
Daily CWCAL03 TW at RCH533
OBSERVED TW at Big Sand Lake
Water Temperature (°F)
Daily CALIB FLOW at RCH534
Daily CWCAL03 TW at RCH534
OBSERVED TW at Little Sand Lk
Daily CALIB FLOW at RCH535
Daily CWCAL03 TW at RCH535
OBSERVED TW at Belle Taine Lk
Daily CALIB FLOW at RCH536
Daily CWCAL03 TW at RCH536
OBSERVED TW at 11th Crow Wing
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH537
Daily CWCAL03 TW at RCH537
OBSERVED TW at 9th Crow Wing
Daily CALIB FLOW at RCH544
Daily CWCAL03 TW at RCH544
OBSERVED TW at 3rd Crow Wing
OBSERVED TW at 4th Crow Wing
Daily CALIB FLOW at RCH546
Daily CWCAL03 TW at RCH546
OBSERVED TW at 1st Crow Wing
Daily CALIB FLOW at RCH588
Daily CWCAL03 TW at RCH588
OBSERVED TW at Margaret Lk
Flow (cfs)
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH591
Daily CWCAL03 TW at RCH591
OBSERVED TW at Sibley Lake
Daily CALIB FLOW at RCH592
Daily CWCAL03 TW at RCH592
OBSERVED TW at Lower Cullen Lk
Daily CALIB FLOW at RCH596
Daily CWCAL03 TW at RCH596
OBSERVED TW at Upper Gull Lk
Daily CALIB FLOW at RCH597
Daily CWCAL03 TW at RCH597
OBSERVED TW at Edward Lake
Flow (cfs)
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009



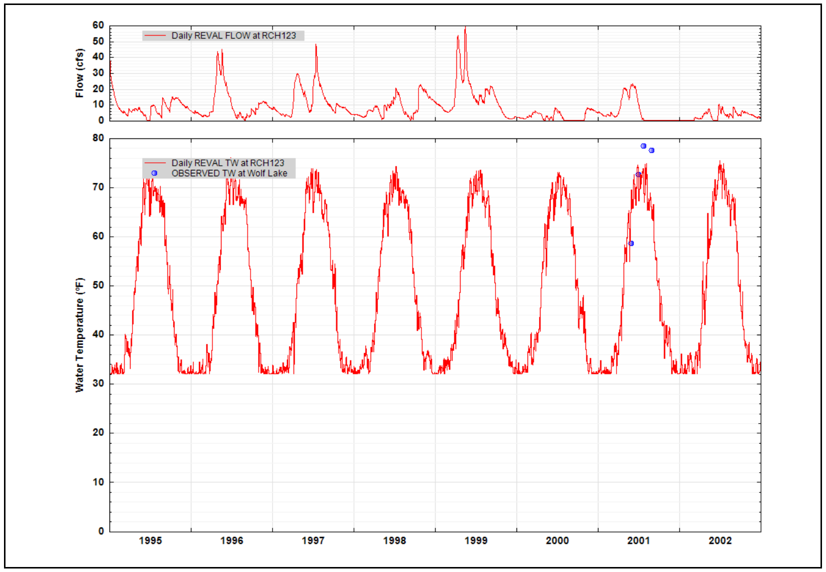
Daily CALIB FLOW at RCH598
Flow (cfs)
Daily CWCAL03 TW at RCH598
OBSERVED TW at North Long Lake
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009



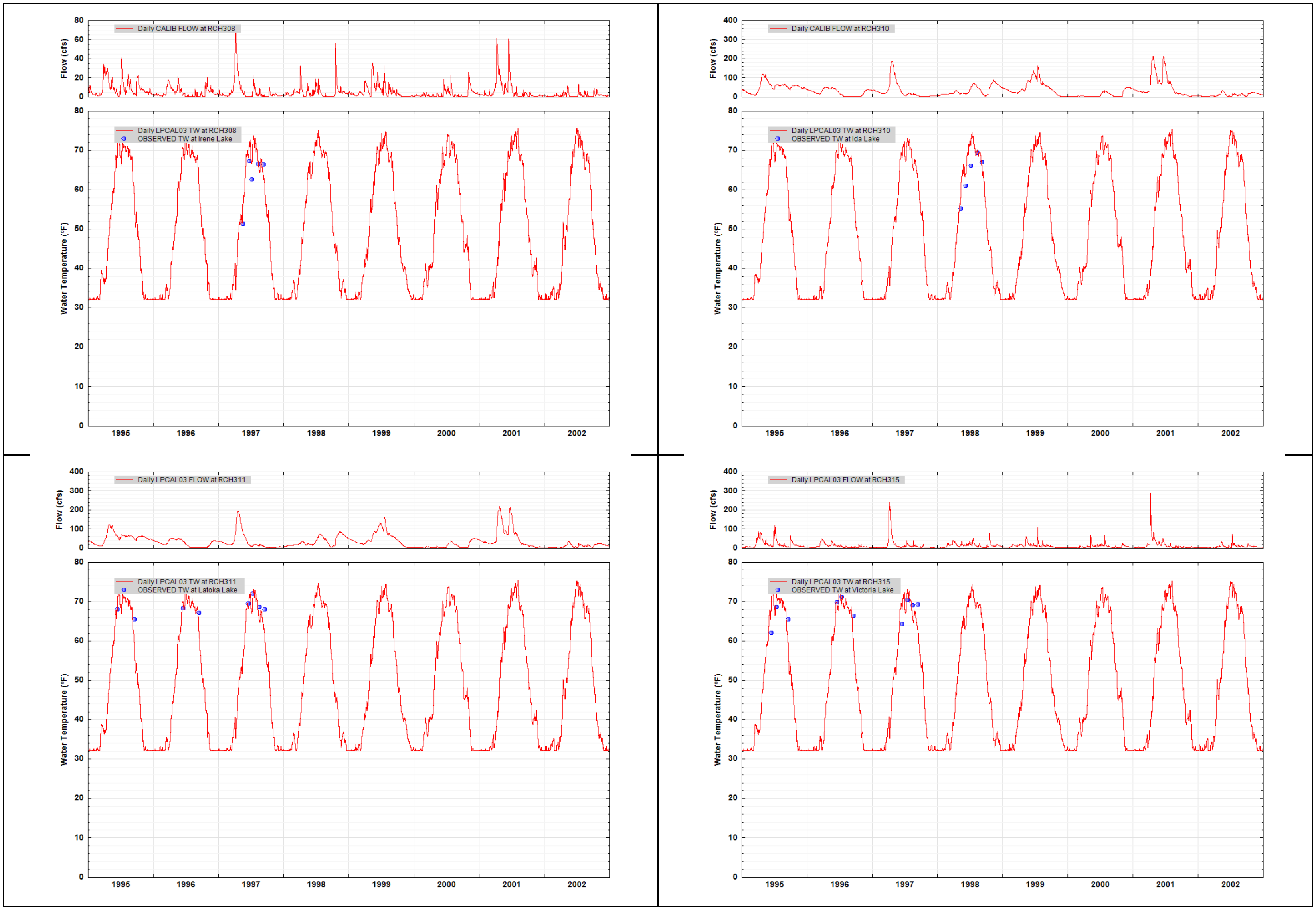
Daily CALIB FLOW at RCH600
Flow (cfs)
Daily CWCAL03 TW at RCH600
OBSERVED TW at Gull Lake
Water Temperature (°F)
2003
2004
2005
2006
2007
2008
2009

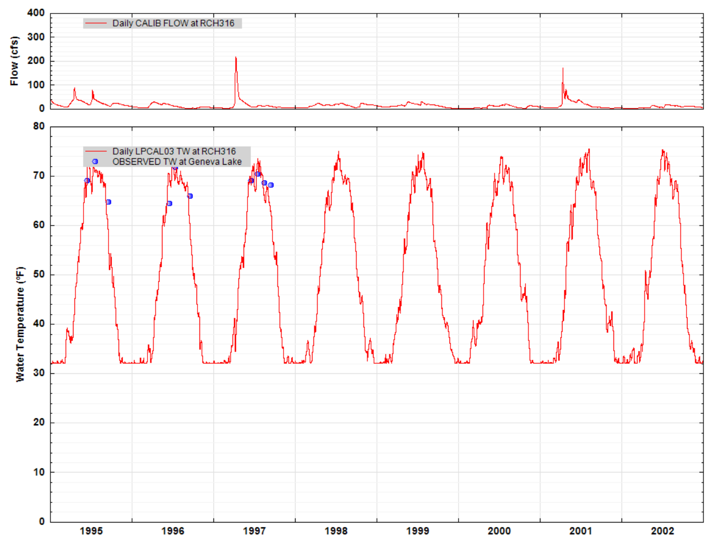
APPENDIX H
OBSERVED AND SIMULATED WATER TEMPERATURE FOR THE VALIDATION PERIOD

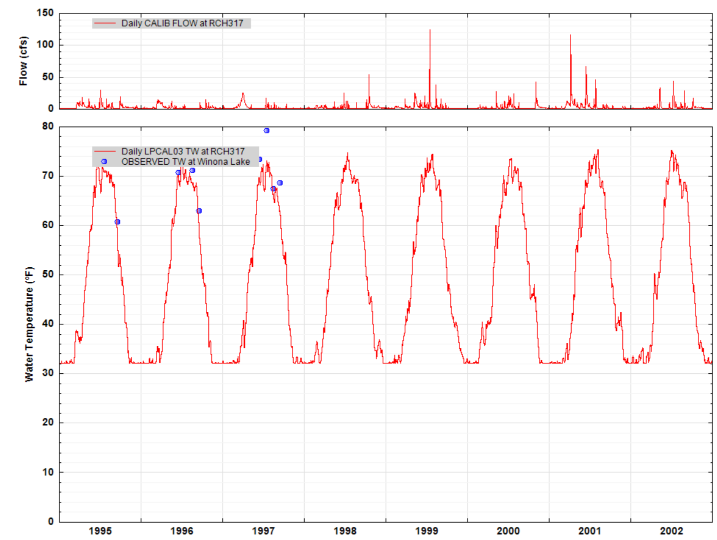
H.1 REDEYE RIVER WATERSHED

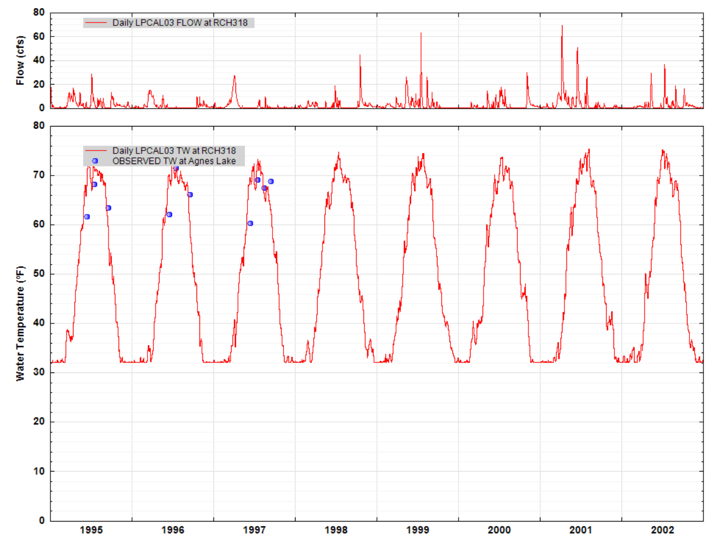


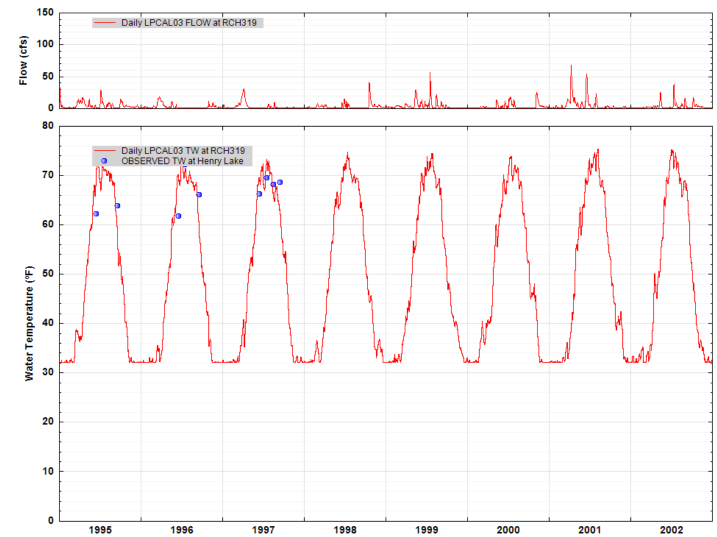
H.2 LONG PRAIRIE RIVER WATERSHED

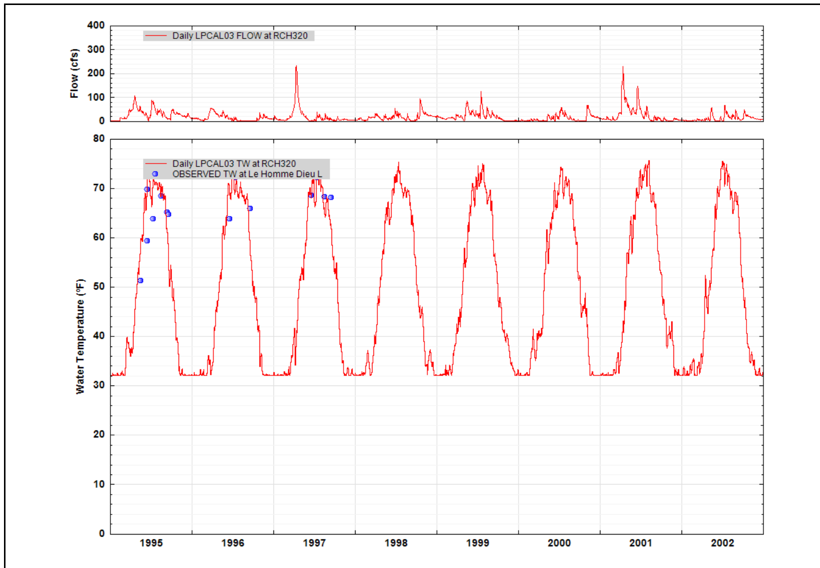


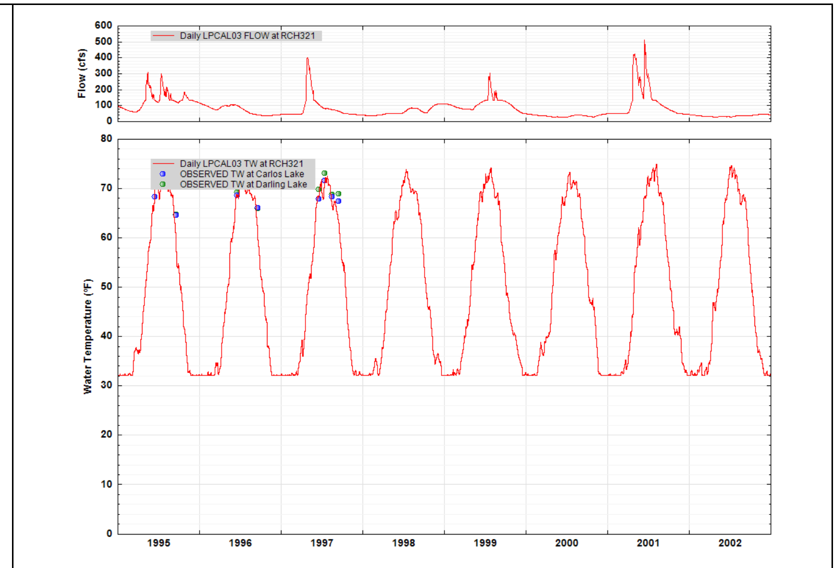

Daily CALIB FLOW at RCH316
Flow (cfs)
Daily LPCAL03 TW at RCH316
OBSERVED TW at Geneva Lake
Water Temperature (°F)
1995 1996 1997 1998 1999 2000 2001 2002

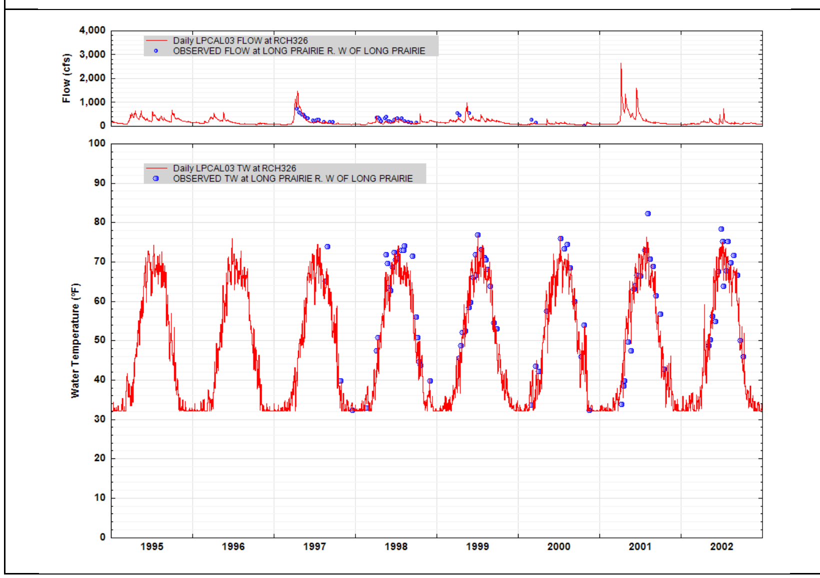

Daily CALIB FLOW at RCH317
Flow (cfs)
Daily LPCAL03 TW at RCH317
OBSERVED TW at Winona Lake
Water Temperature (°F)
1995 1996 1997 1998 1999 2000 2001 2002

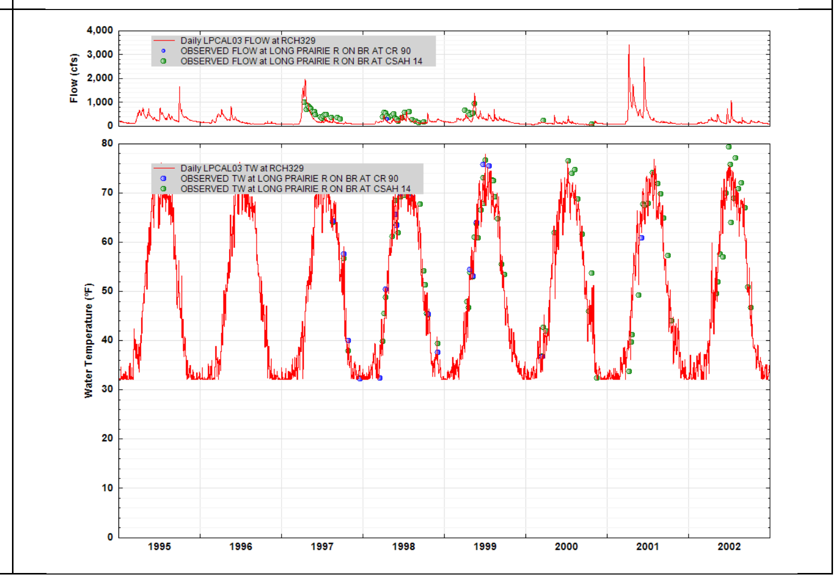

Daily LPCAL03 FLOW at RCH318
Flow (cfs)
Daily LPCAL03 TW at RCH318
OBSERVED TW at Agnes Lake
Water Temperature (°F)
1995 1996 1997 1998 1999 2000 2001 2002

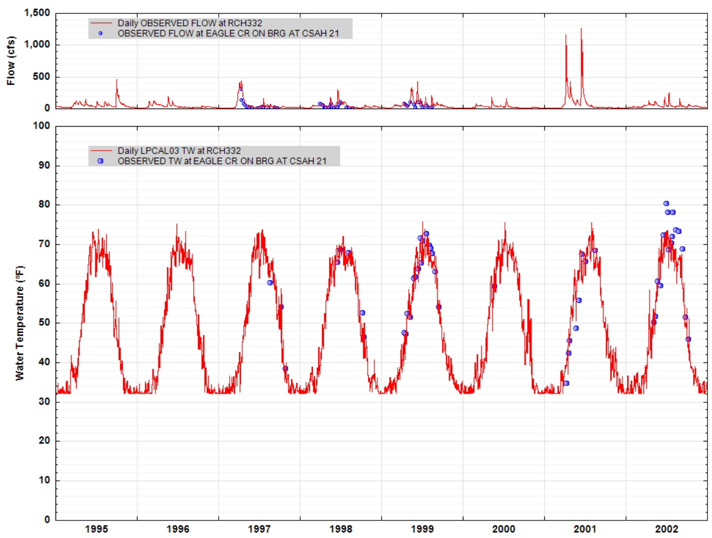

Daily LPCAL03 FLOW at RCH319
Flow (cfs)
Daily LPCAL03 TW at RCH319
OBSERVED TW at Henry Lake
Water Temperature (°F)
1995 1996 1997 1998 1999 2000 2001 2002

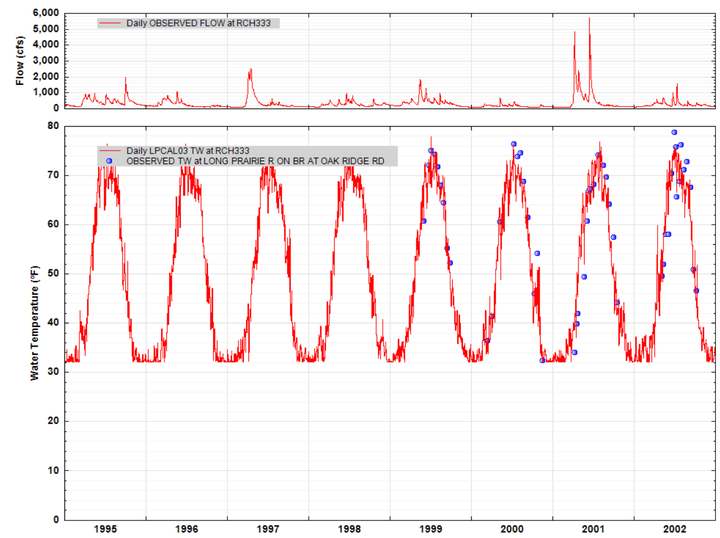

Daily LPCAL03 FLOW at RCH320
Flow (cfs)
Daily LPCAL03 TW at RCH320
OBSERVED TW at Le Homme Dieu L
Water Temperature (°F)
1995
1996
1997
1998
1999
2000
2001
2002

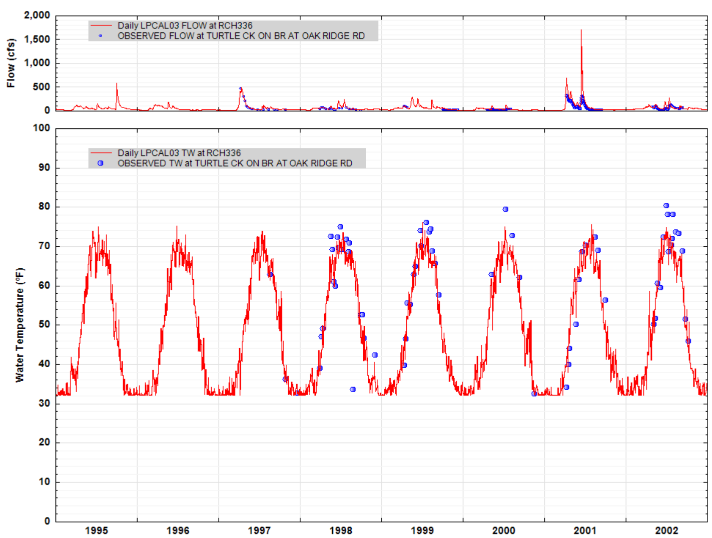

Daily LPCAL03 FLOW at RCH321
Flow (cfs)
Daily LPCAL03 TW at RCH321
OBSERVED TW at Carlos Lake
OBSERVED TW at Darling Lake
Water Temperature (°F)
1995
1996
1997
1998
1999
2000
2001
2002

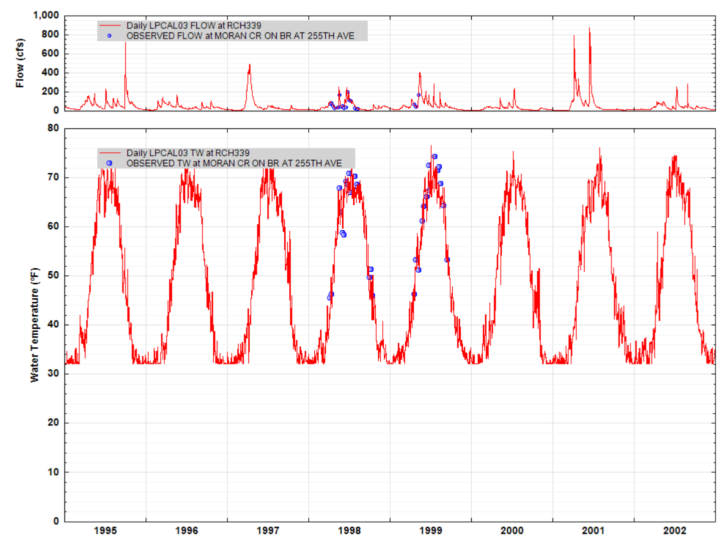

Daily LPCAL03 FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Flow (cfs)
Daily LPCAL03 TW at RCH326
OBSERVED TW at LONG PRAIRIE R. W OF LONG PRAIRIE
Water Temperature (°F)
1995
1996
1997
1998
1999
2000
2001
2002

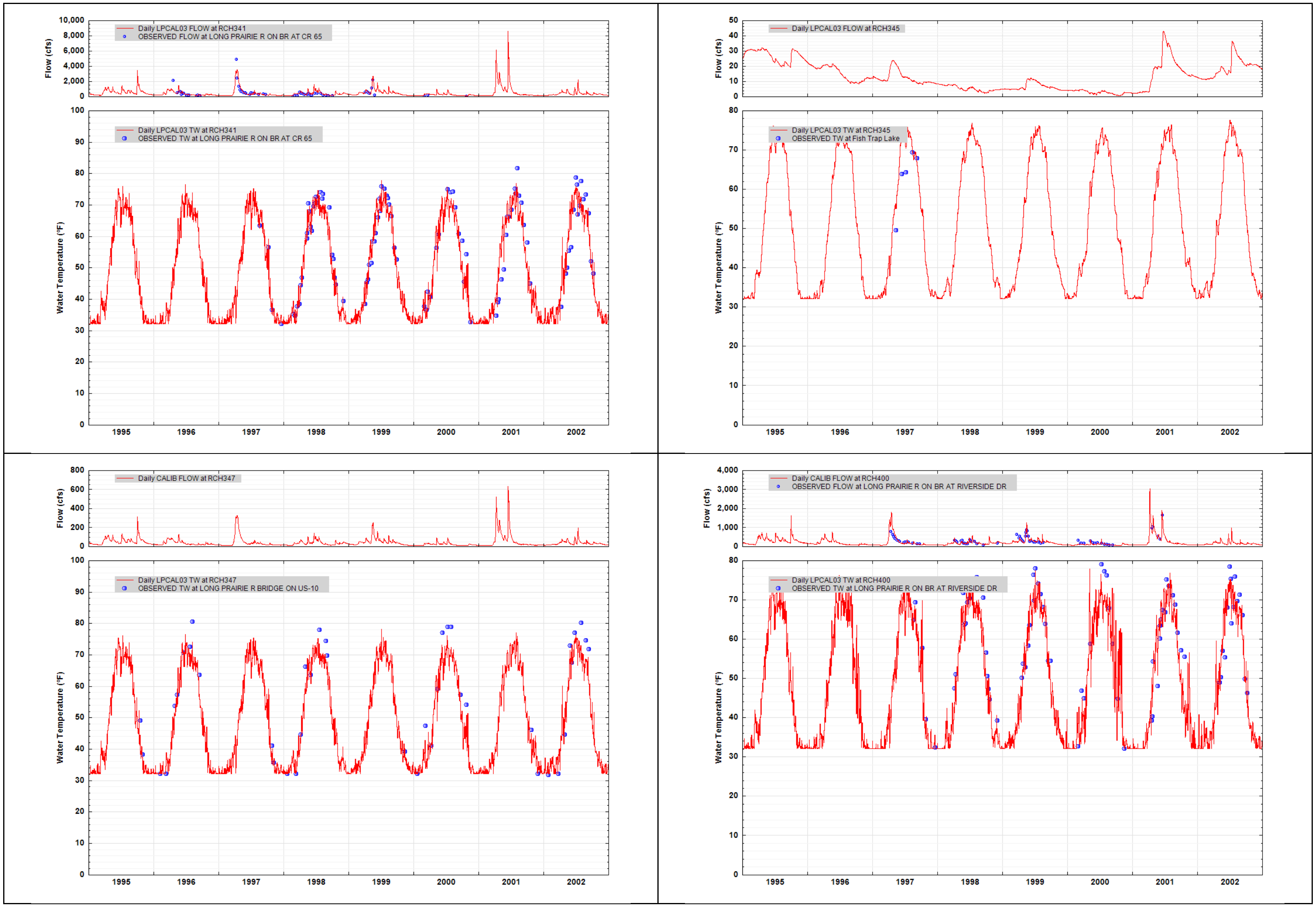

Daily LPCAL03 FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 90
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
Flow (cfs)
Daily LPCAL03 TW at RCH329
OBSERVED TW at LONG PRAIRIE R ON BR AT CR 90
OBSERVED TW at LONG PRAIRIE R ON BR AT CSAH 14
Water Temperature (°F)
1995
1996
1997
1998
1999
2000
2001
2002


Daily OBSERVED FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Daily LPCAL03 TW at RCH332
OBSERVED TW at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
Water Temperature (°F)

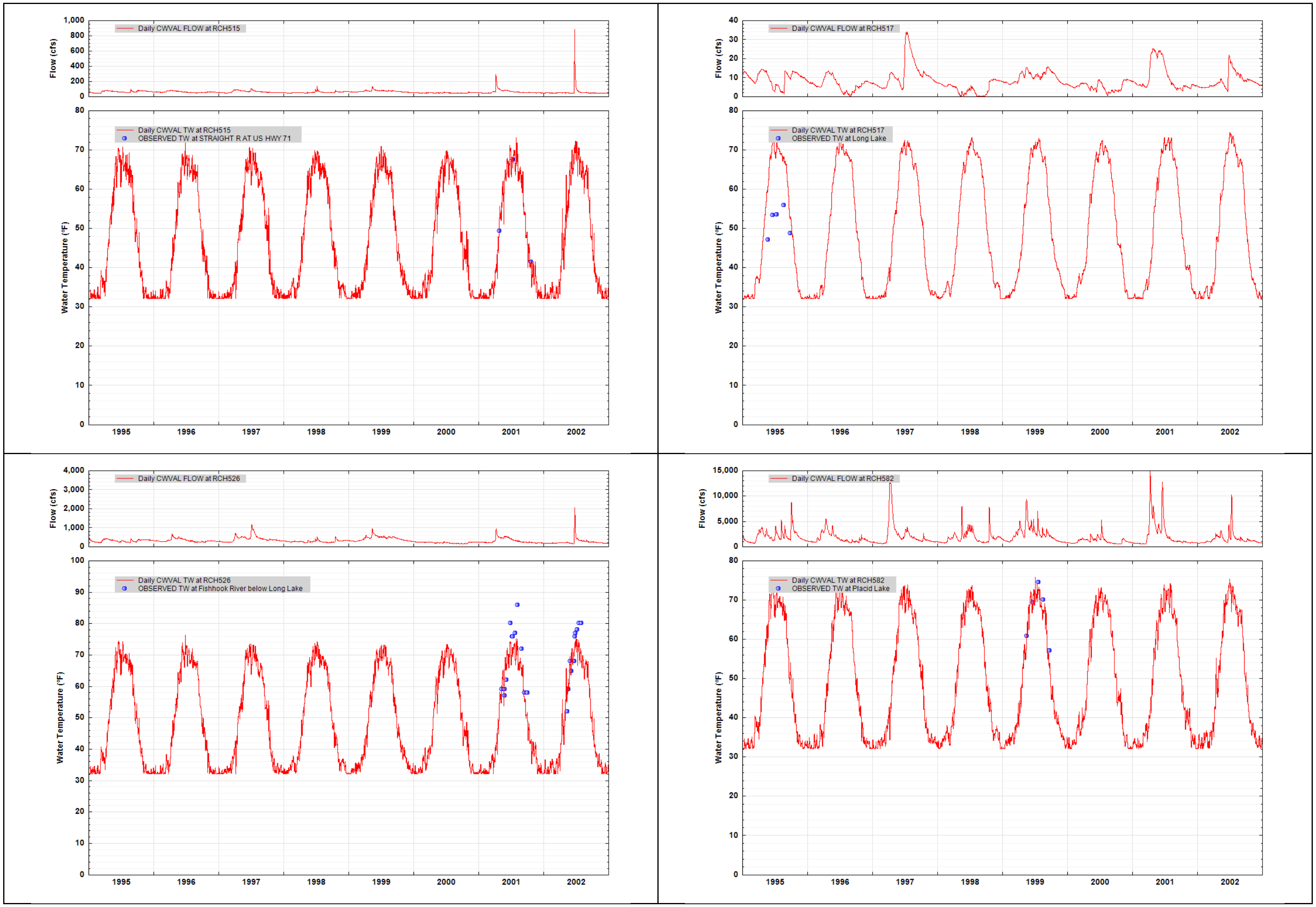

Daily OBSERVED FLOW at RCH333
Daily LPCAL03 TW at RCH333
OBSERVED TW at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Flow (cfs)
Water Temperature (°F)

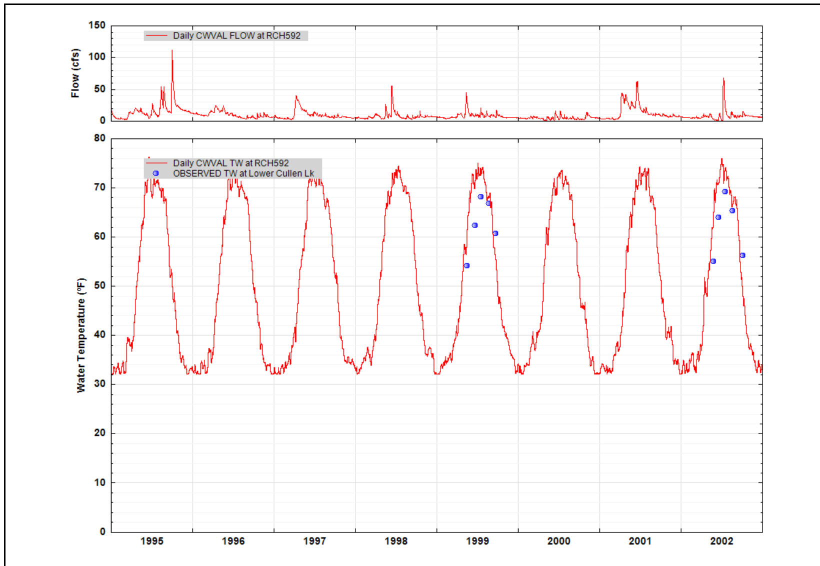

Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Daily LPCAL03 TW at RCH336
OBSERVED TW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Water Temperature (°F)

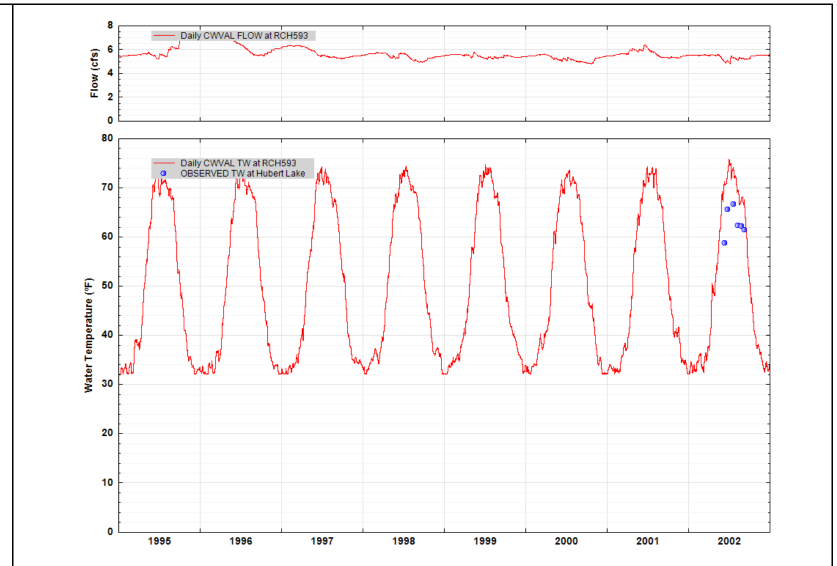

Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 TW at RCH339
OBSERVED TW at MORAN CR ON BR AT 255TH AVE
Flow (cfs)
Water Temperature (°F)

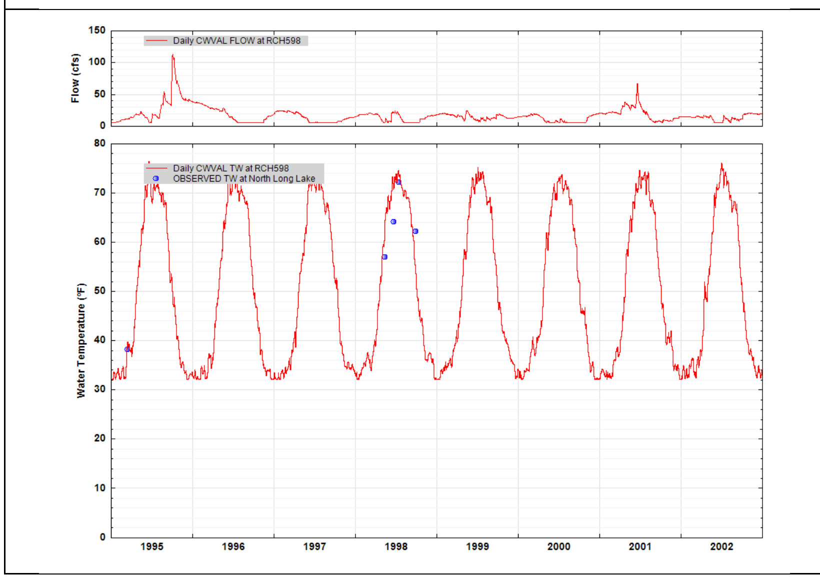

Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 TW at RCH341
OBSERVED TW at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 FLOW at RCH345
Daily LPCAL03 TW at RCH345
OBSERVED TW at Fish Trap Lake
Daily CALIB FLOW at RCH347
Daily LPCAL03 TW at RCH347
OBSERVED TW at LONG PRAIRIE R BRIDGE ON US-10
Daily CALIB FLOW at RCH400
OBSERVED FLOW at LONG PRAIRIE R ON BR AT RIVERSIDE DR
Daily LPCAL03 TW at RCH400
OBSERVED TW at LONG PRAIRIE R ON BR AT RIVERSIDE DR
Flow (cfs)
Water Temperature (°F)
1995
1996
1997
1998
1999
2000
2001
2002

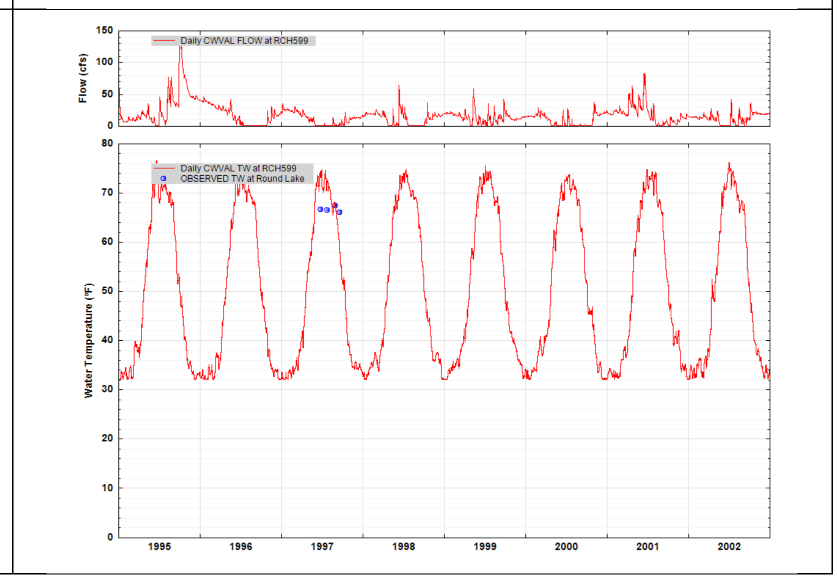
H.3 CROW WING RIVER WATERSHED




Daily CWVAL FLOW at RCH592
Flow (cfs)
Daily CWVAL TW at RCH592
OBSERVED TW at Lower Cullen Lk
Water Temperature (°F)

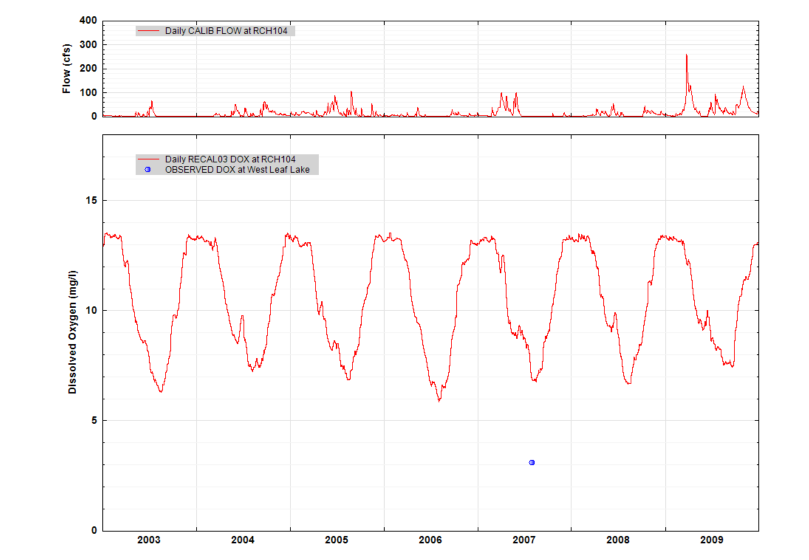

Daily CWVAL FLOW at RCH593
Flow (cfs)
Daily CWVAL TW at RCH593
OBSERVED TW at Hubert Lake
Water Temperature (°F)

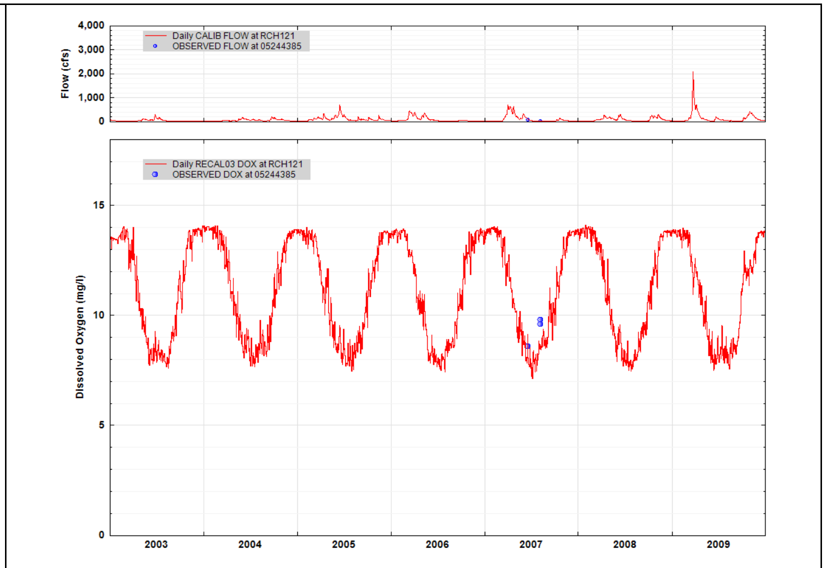

Daily CWVAL FLOW at RCH598
Flow (cfs)
Daily CWVAL TW at RCH598
OBSERVED TW at North Long Lake
Water Temperature (°F)

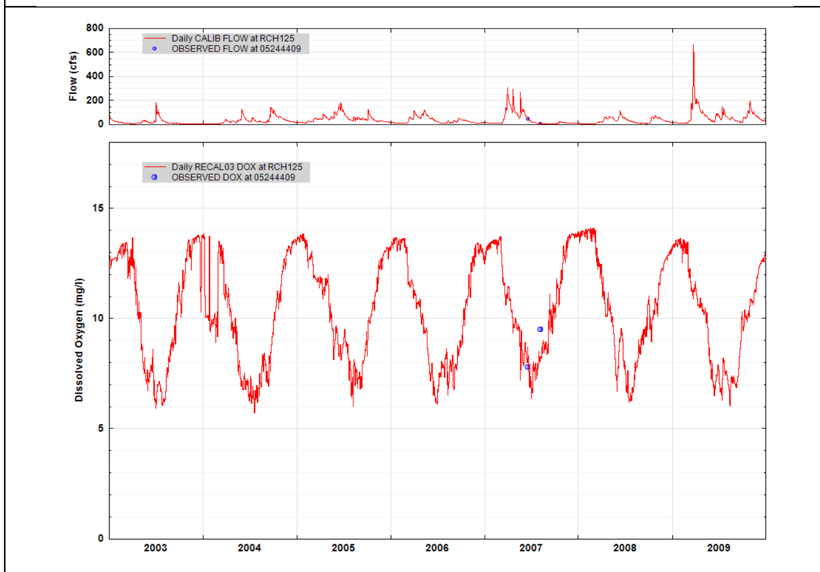

Daily CWVAL FLOW at RCH599
Flow (cfs)
Daily CWVAL TW at RCH599
OBSERVED TW at Round Lake
Water Temperature (°F)

APPENDIX I
OBSERVED AND SIMULATED DISSOLVED OXYGEN FOR THE CALIBRATION PERIOD

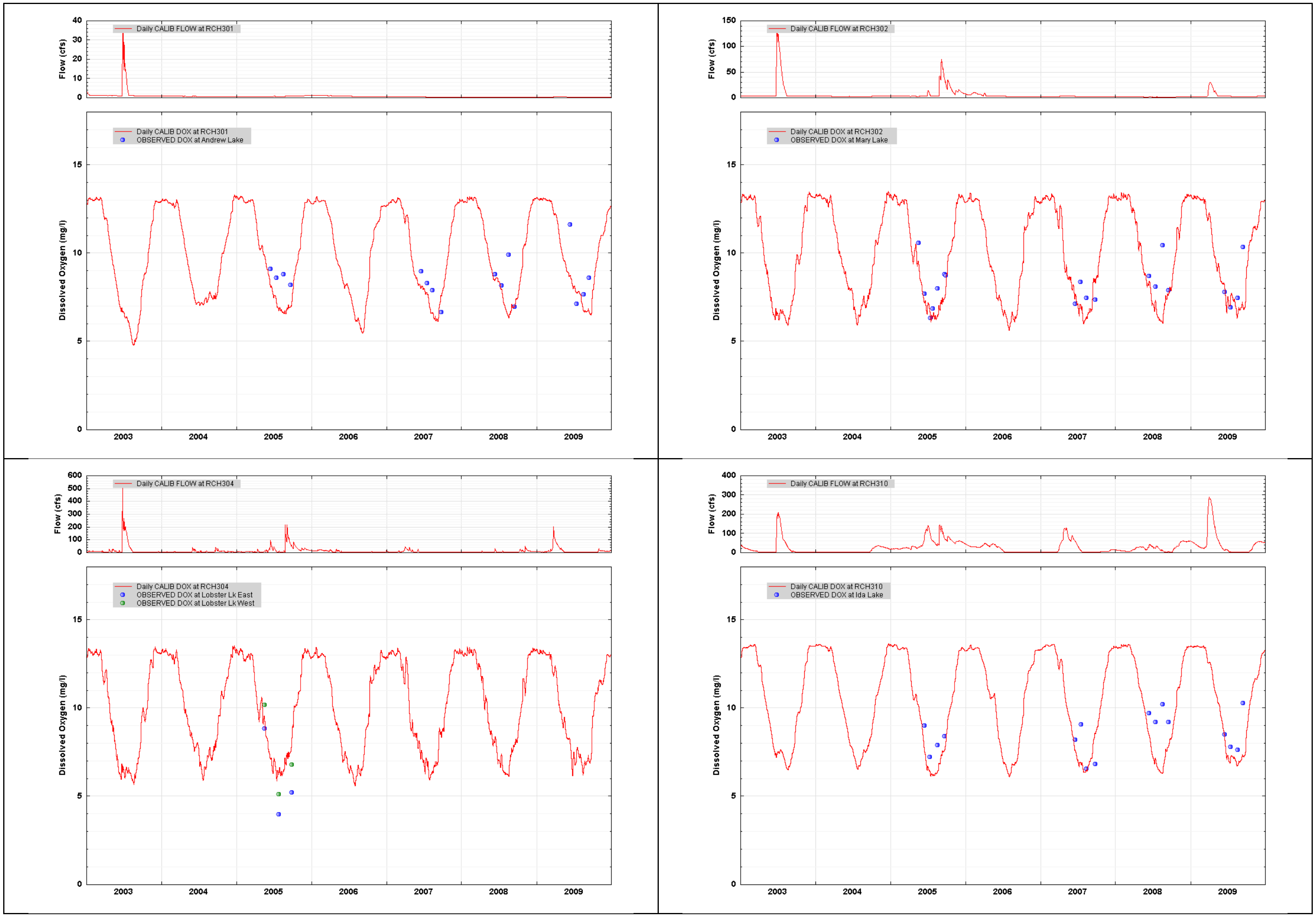
I.1 REDEYE RIVER WATERSHED

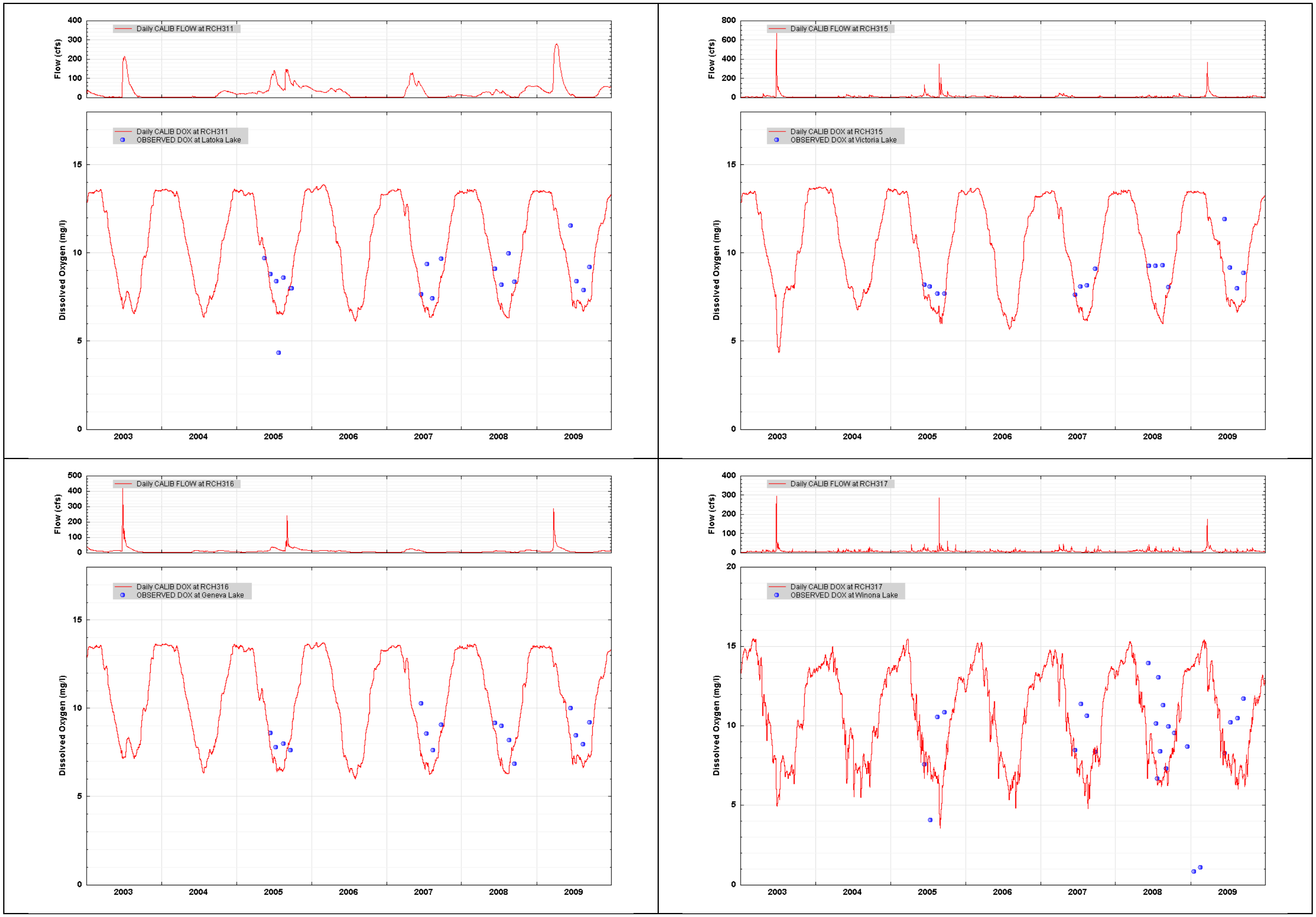


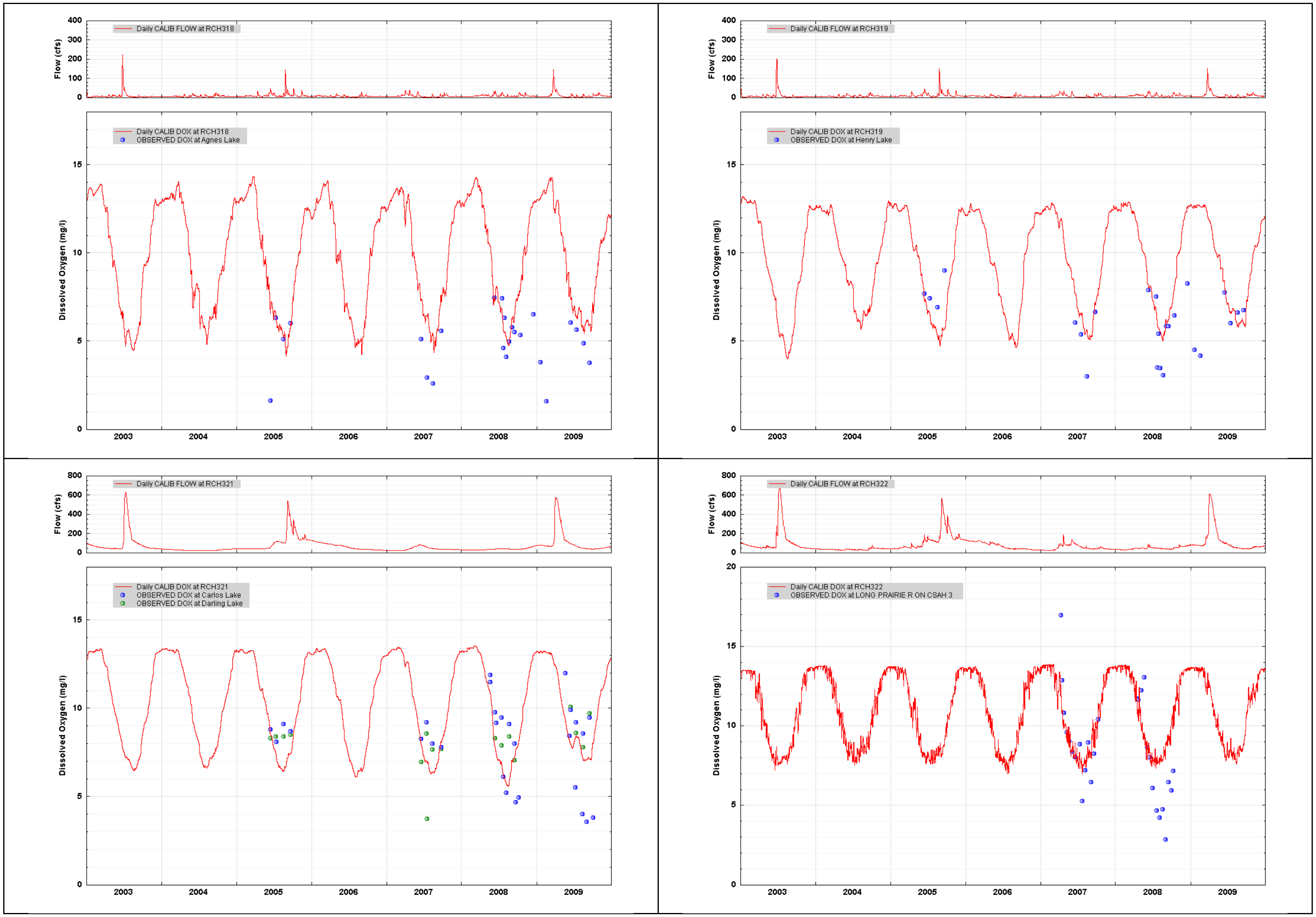


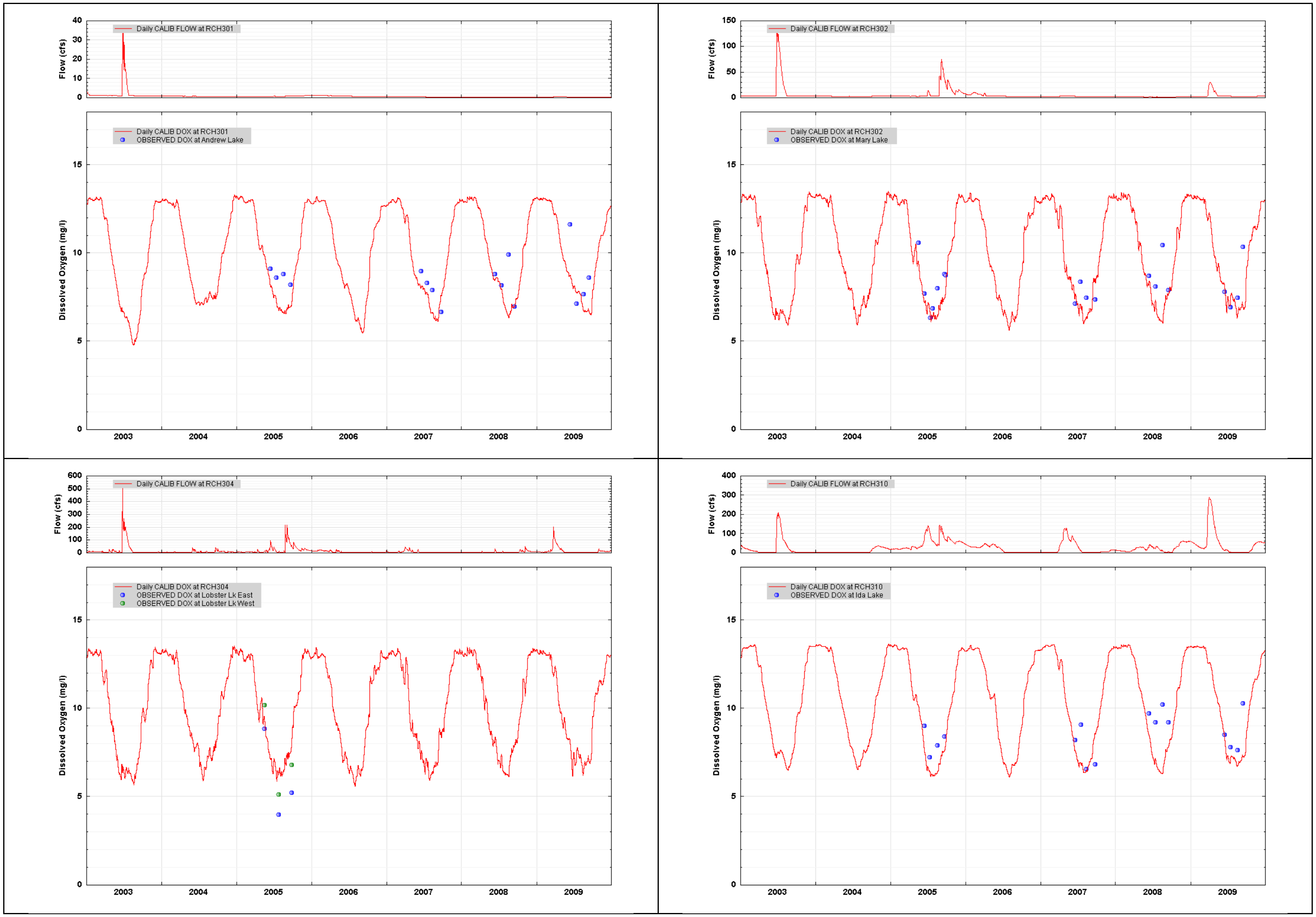


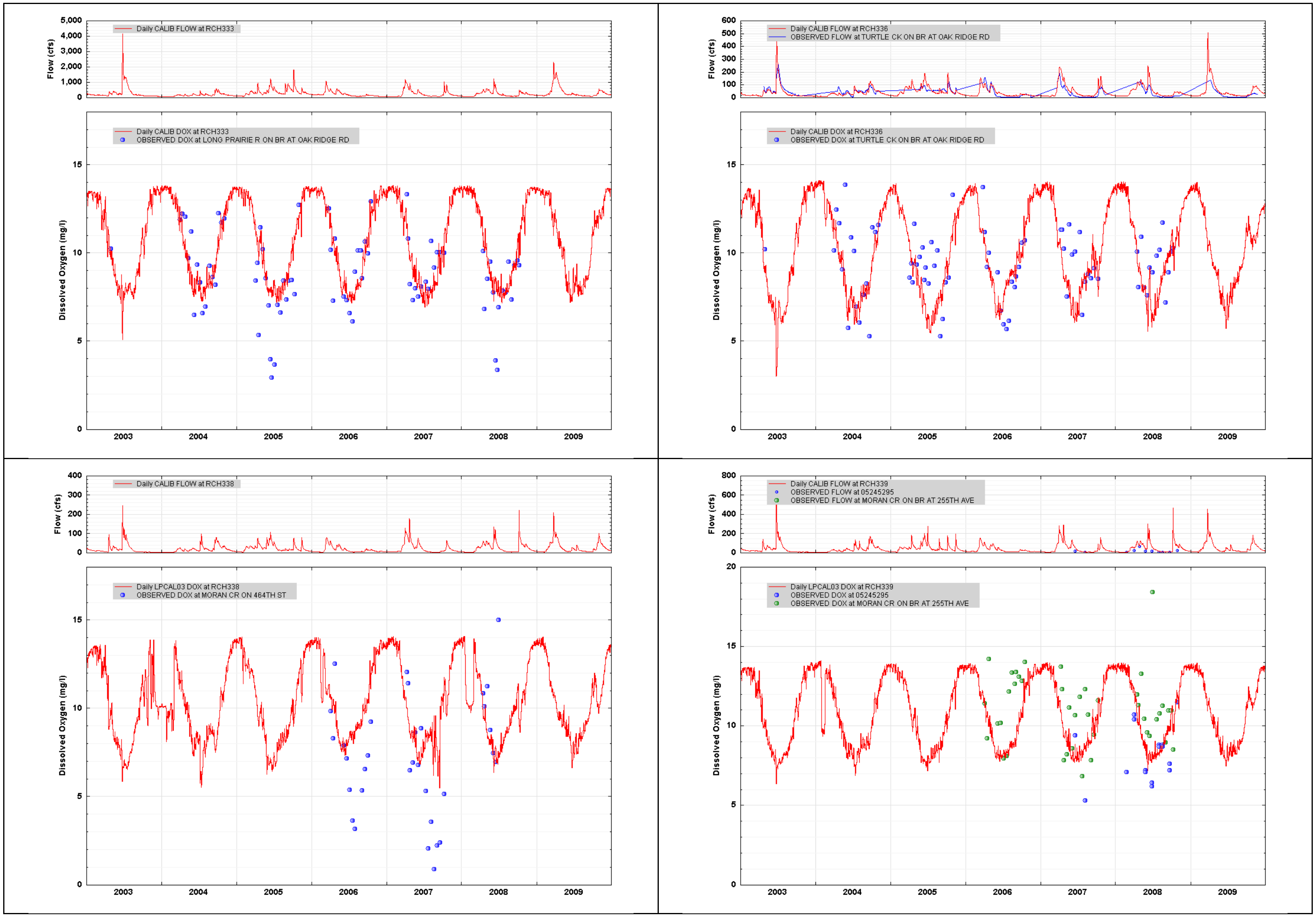
I.2 LONG PRAIRIE RIVER WATERSHED

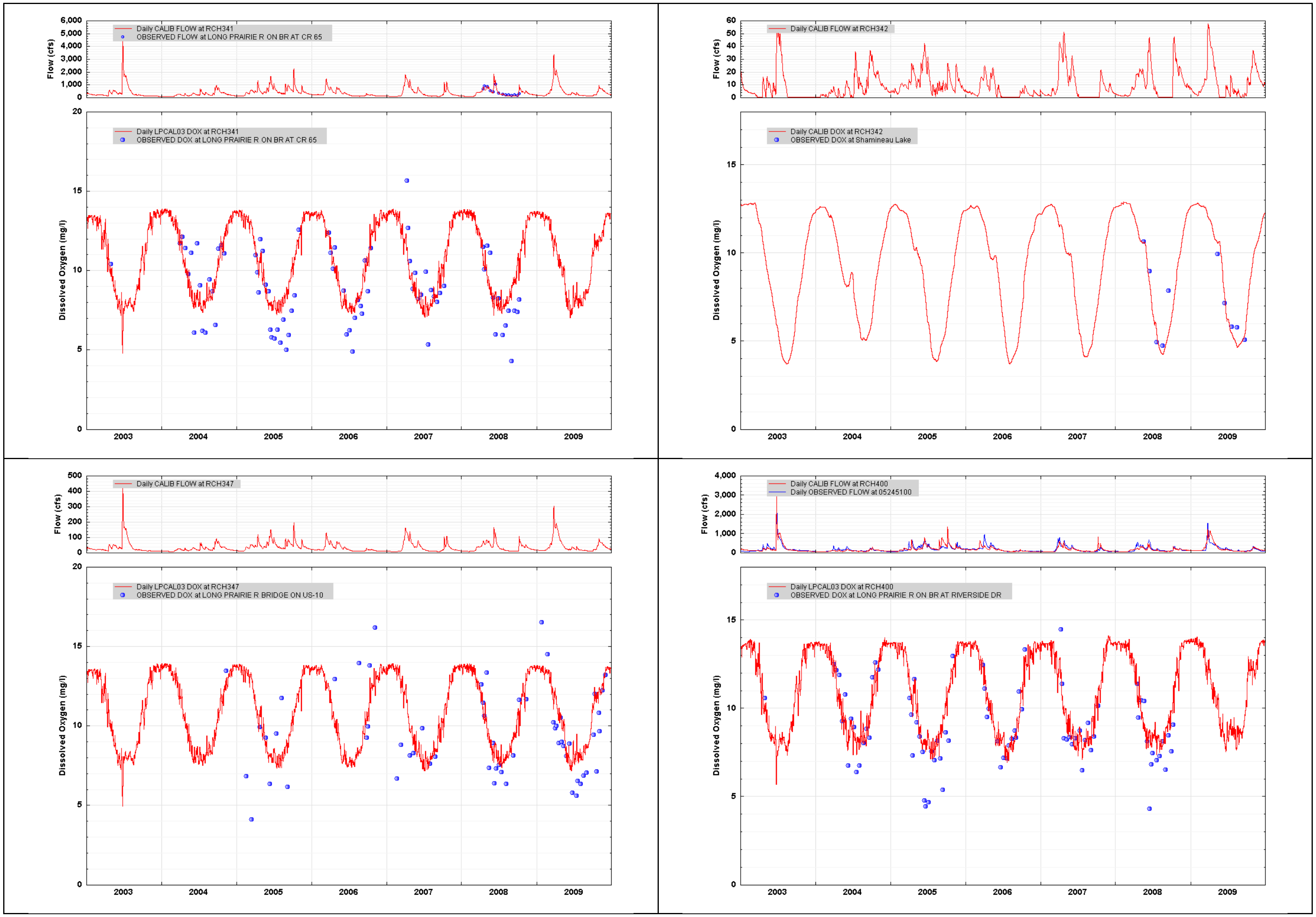



Daily CALIB FLOW at RCH311
Flow (cfs)
Daily CALIB DOX at RCH311
OBSERVED DOX at Latoka Lake
Dissolved Oxygen (mg/l)
Daily CALIB FLOW at RCH315
Daily CALIB DOX at RCH315
OBSERVED DOX at Victoria Lake
Daily CALIB FLOW at RCH316
Daily CALIB DOX at RCH316
OBSERVED DOX at Geneva Lake
Daily CALIB FLOW at RCH317
Daily CALIB DOX at RCH317
OBSERVED DOX at Winona Lake
2003
2004
2005
2006
2007
2008
2009

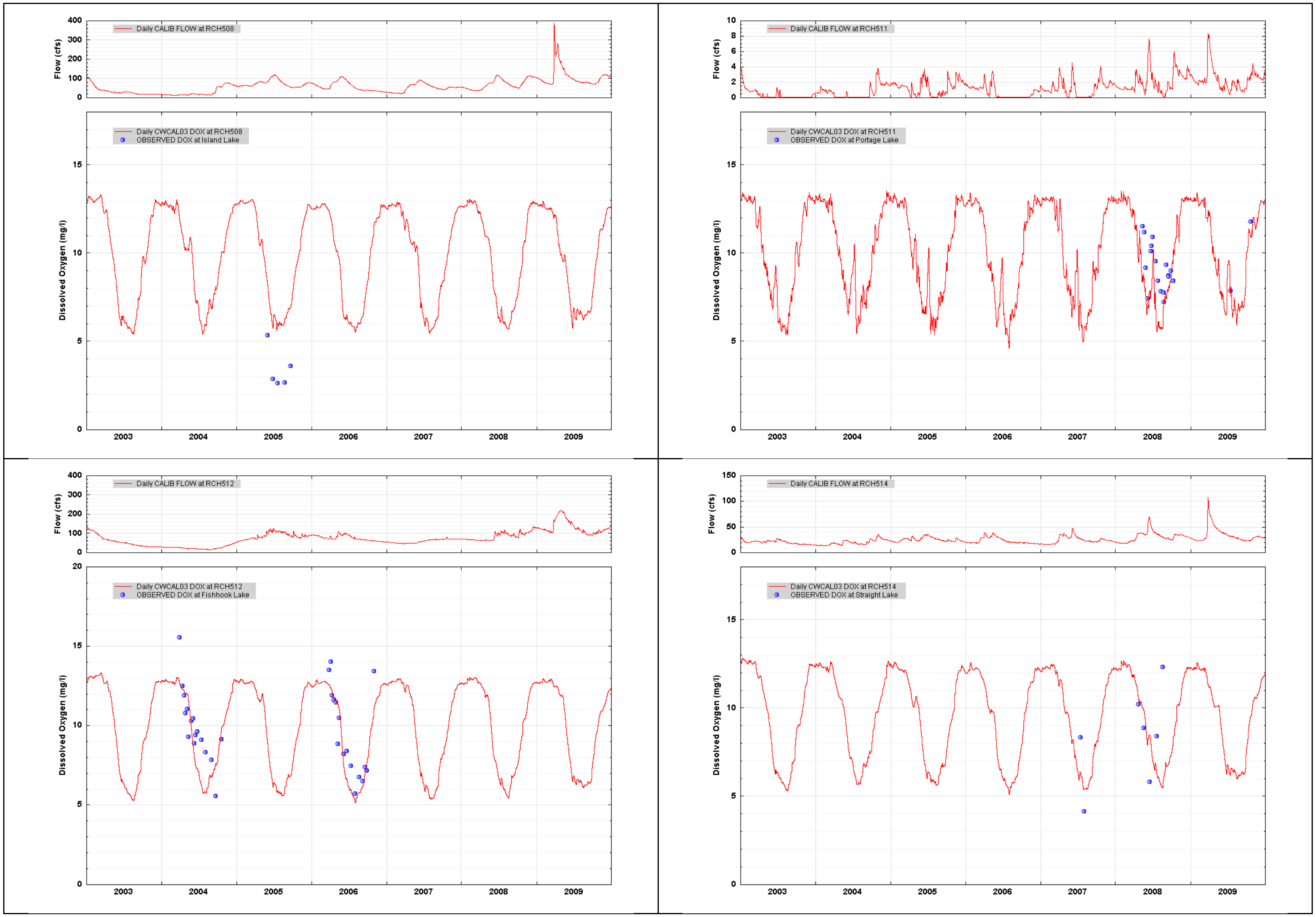

Daily CALIB FLOW at RCH318
Flow (cfs)
Daily CALIB DOX at RCH318
OBSERVED DOX at Agnes Lake
Dissolved Oxygen (mg/l)
2003 2004 2005 2006 2007 2008 2009
Daily CALIB FLOW at RCH319
Daily CALIB DOX at RCH319
OBSERVED DOX at Henry Lake
Daily CALIB FLOW at RCH321
Daily CALIB DOX at RCH321
OBSERVED DOX at Carlos Lake
OBSERVED DOX at Darling Lake
Daily CALIB FLOW at RCH322
Daily CALIB DOX at RCH322
OBSERVED DOX at LONG PRAIRIE R ON CSAH 3

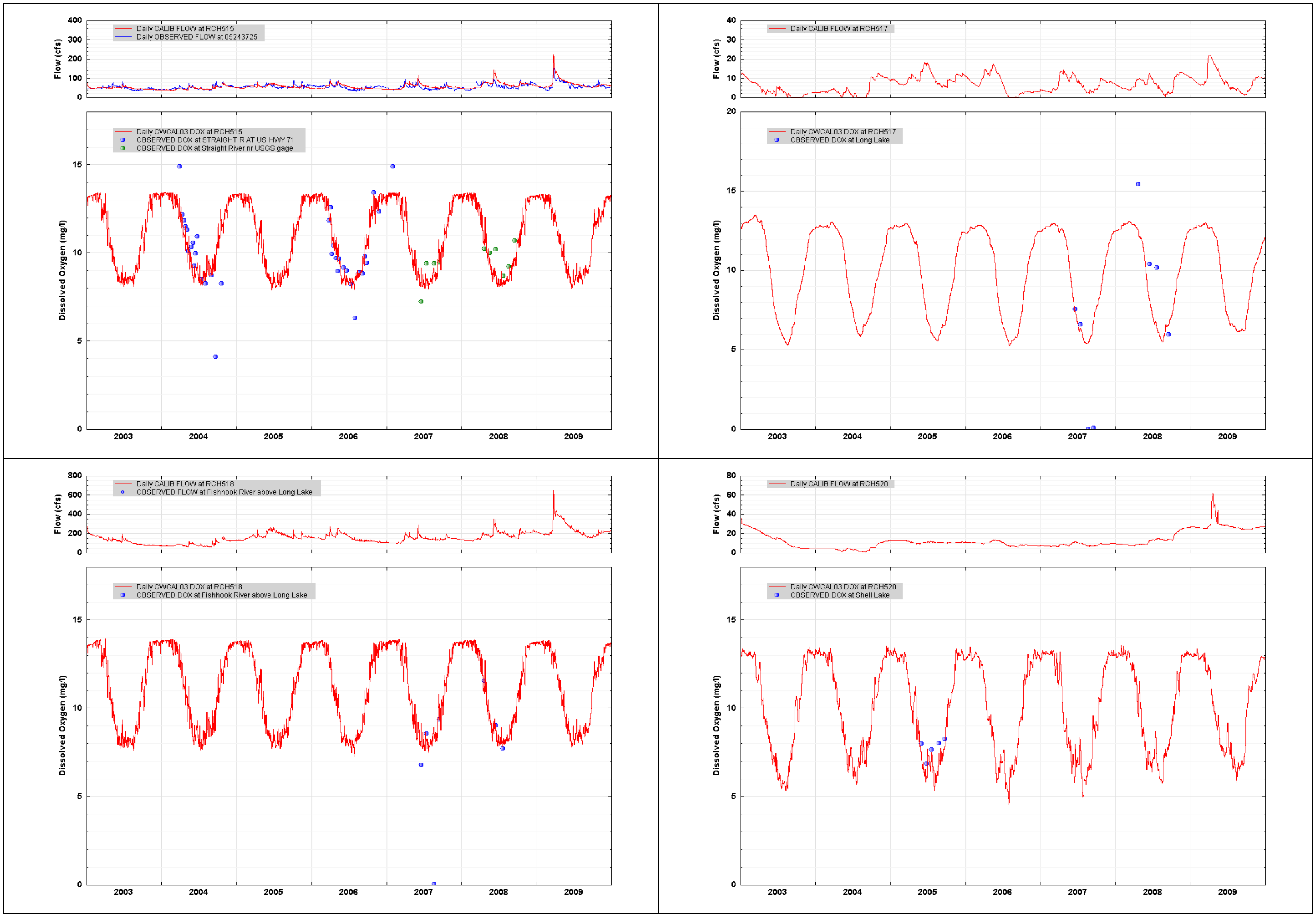

Daily CALIB FLOW at RCH301
Flow (cfs)
Daily CALIB DOX at RCH301
OBSERVED DOX at Andrew Lake
Dissolved Oxygen (mg/l)
Daily CALIB FLOW at RCH302
Daily CALIB DOX at RCH302
OBSERVED DOX at Mary Lake
Daily CALIB FLOW at RCH304
Daily CALIB DOX at RCH304
OBSERVED DOX at Lobster Lk East
OBSERVED DOX at Lobster Lk West
Daily CALIB FLOW at RCH310
Daily CALIB DOX at RCH310
OBSERVED DOX at Ida Lake
2003
2004
2005
2006
2007
2008
2009

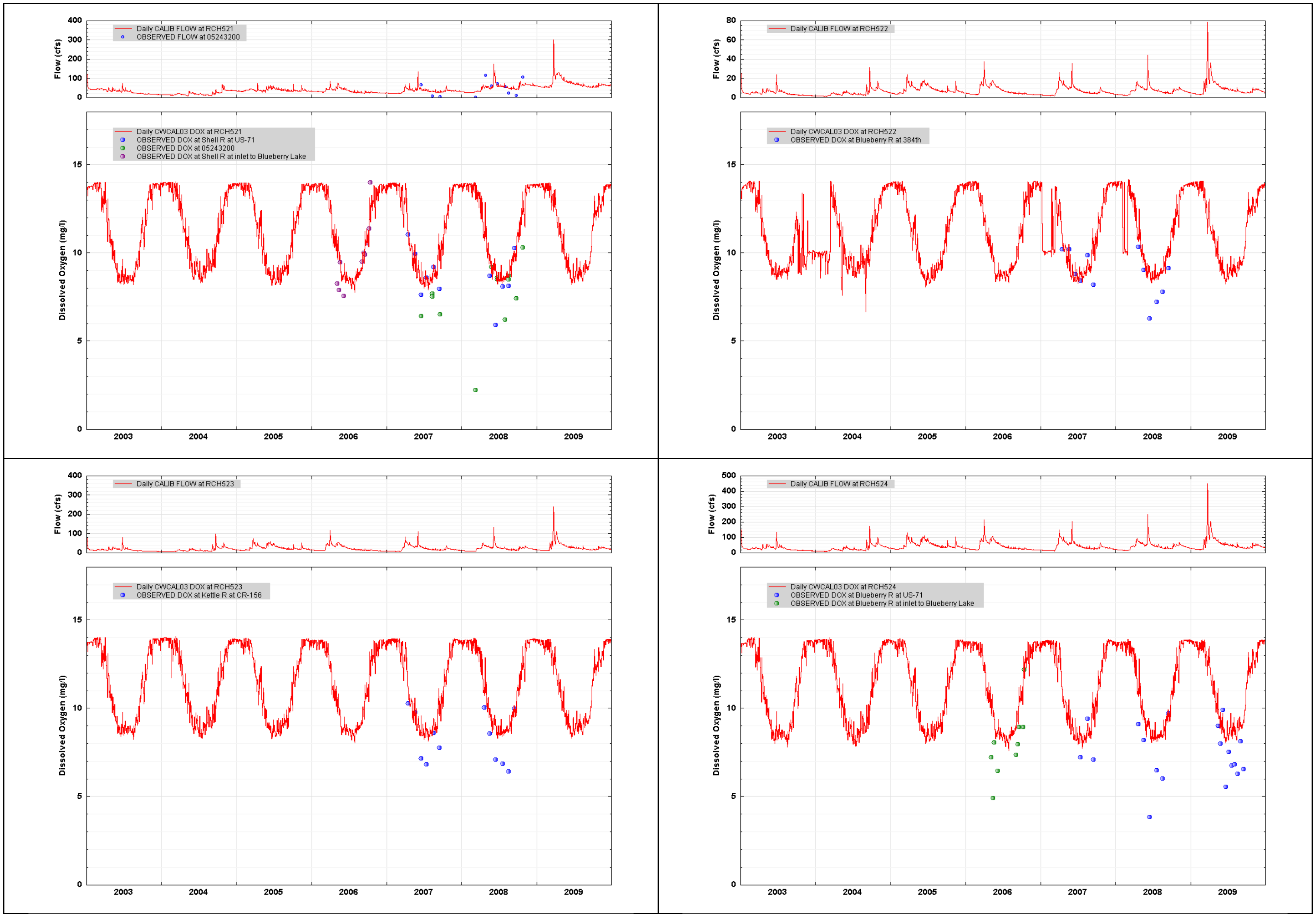

Flow (cfs)
Daily CALIB FLOW at RCH333
Dissolved Oxygen (mg/l)
Daily CALIB DOX at RCH333
OBSERVED DOX at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Daily CALIB FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Daily CALIB DOX at RCH336
OBSERVED DOX at TURTLE CK ON BR AT OAK RIDGE RD
Daily CALIB FLOW at RCH338
Daily LPCAL03 DOX at RCH338
OBSERVED DOX at MORAN CR ON 464TH ST
Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 DOX at RCH339
OBSERVED DOX at 05245295
OBSERVED DOX at MORAN CR ON BR AT 255TH AVE
2003
2004
2005
2006
2007
2008
2009

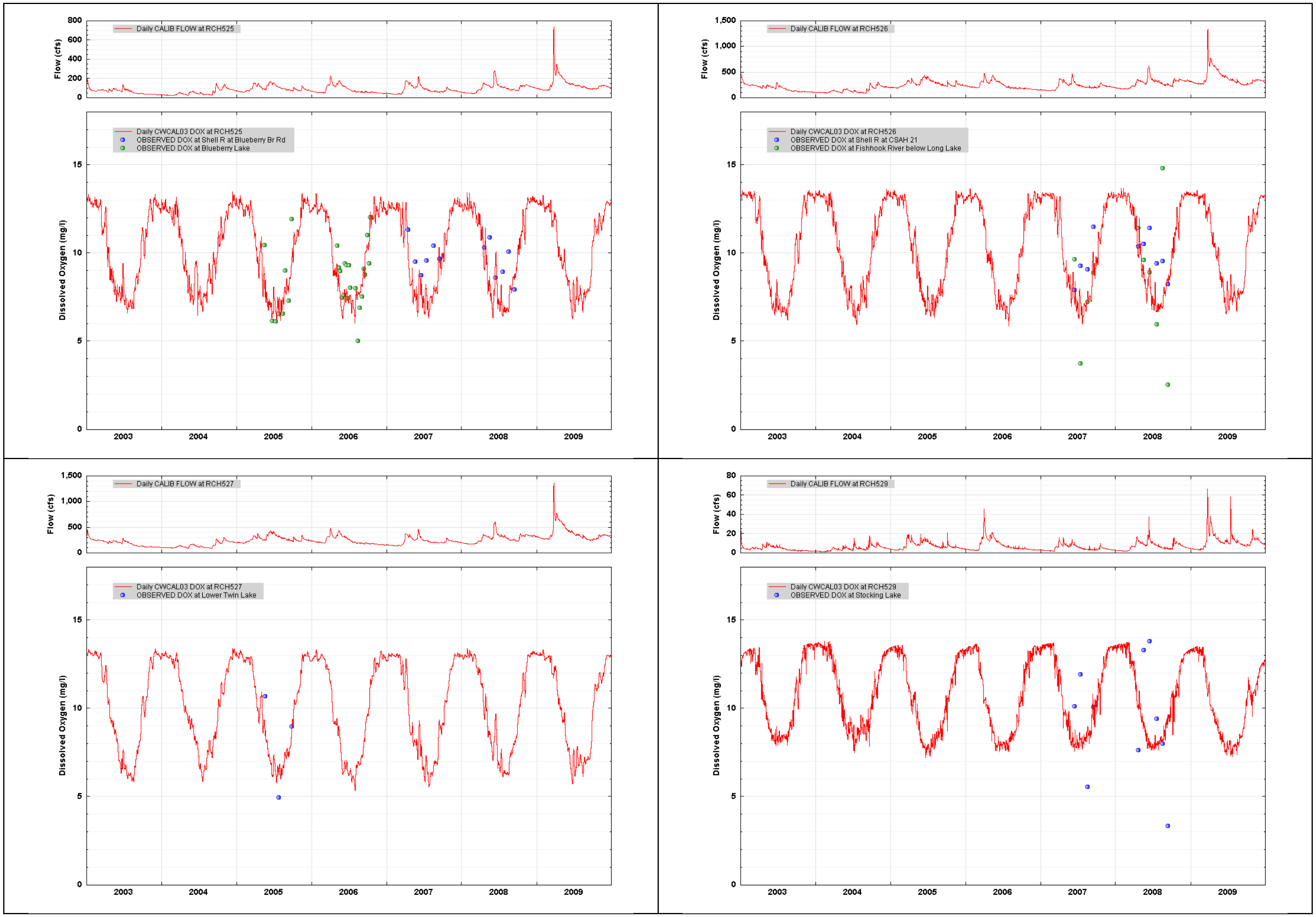

Daily CALIB FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Flow (cfs)
Daily LPCAL03 DOX at RCH341
OBSERVED DOX at LONG PRAIRIE R ON BR AT CR 65
Dissolved Oxygen (mg/l)
Daily CALIB FLOW at RCH342
Daily CALIB DOX at RCH342
OBSERVED DOX at Shamineau Lake
Daily CALIB FLOW at RCH347
Daily LPCAL03 DOX at RCH347
OBSERVED DOX at LONG PRAIRIE R BRIDGE ON US-10
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Daily LPCAL03 DOX at RCH400
OBSERVED DOX at LONG PRAIRIE R ON BR AT RIVERSIDE DR
2003
2004
2005
2006
2007
2008
2009

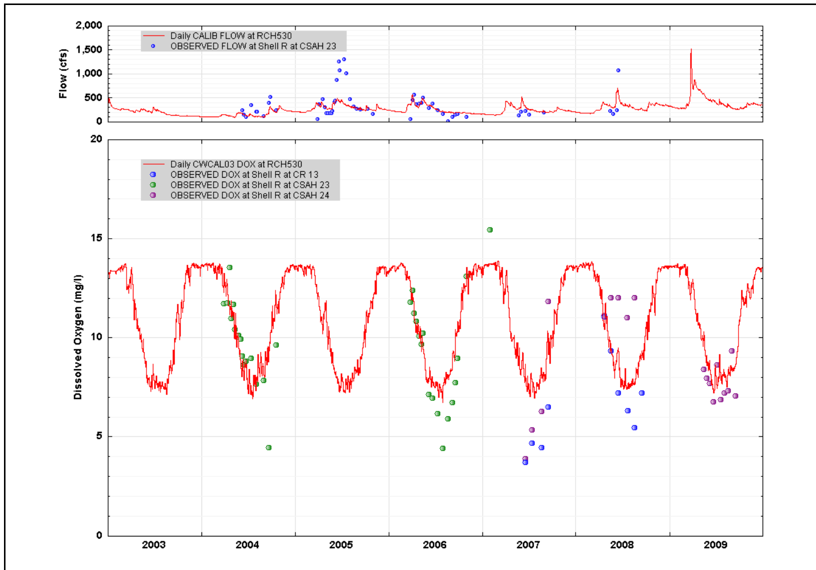
I.3 CROW WING RIVER WATERSHED

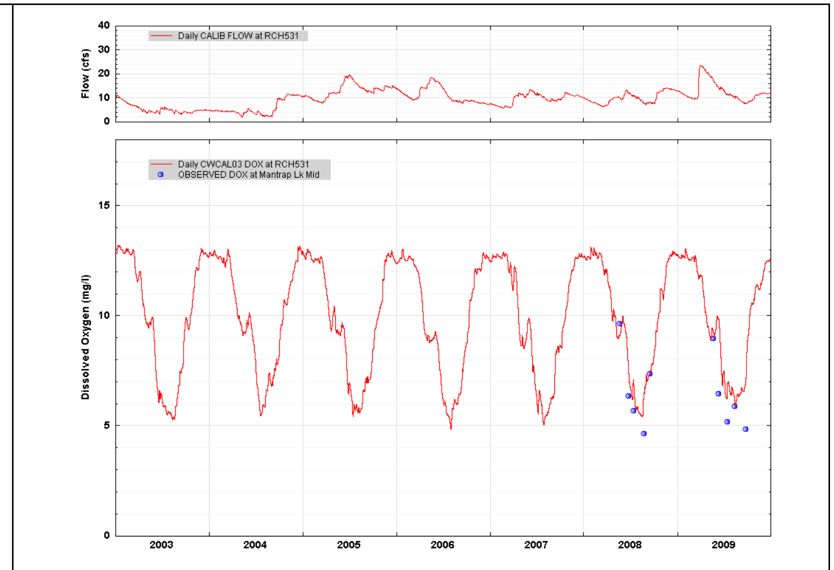


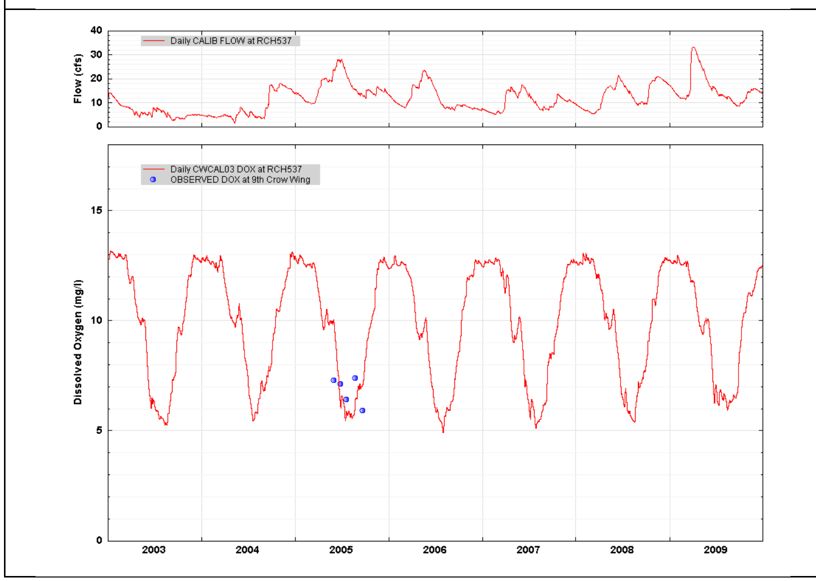

Daily CALIB FLOW at RCH515
Daily OBSERVED FLOW at 05243725
Flow (cfs)
Daily CWCAL03 DOX at RCH515
OBSERVED DOX at STRAIGHT R AT US HWY 71
OBSERVED DOX at Straight River nr USGS gage
Dissolved Oxygen (mg/l)
Daily CALIB FLOW at RCH517
Daily CWCAL03 DOX at RCH517
OBSERVED DOX at Long Lake
Daily CALIB FLOW at RCH518
OBSERVED FLOW at Fishhook River above Long Lake
Daily CWCAL03 DOX at RCH518
OBSERVED DOX at Fishhook River above Long Lake
Daily CALIB FLOW at RCH520
Daily CWCAL03 DOX at RCH520
OBSERVED DOX at Shell Lake
2003
2004
2005
2006
2007
2008
2009

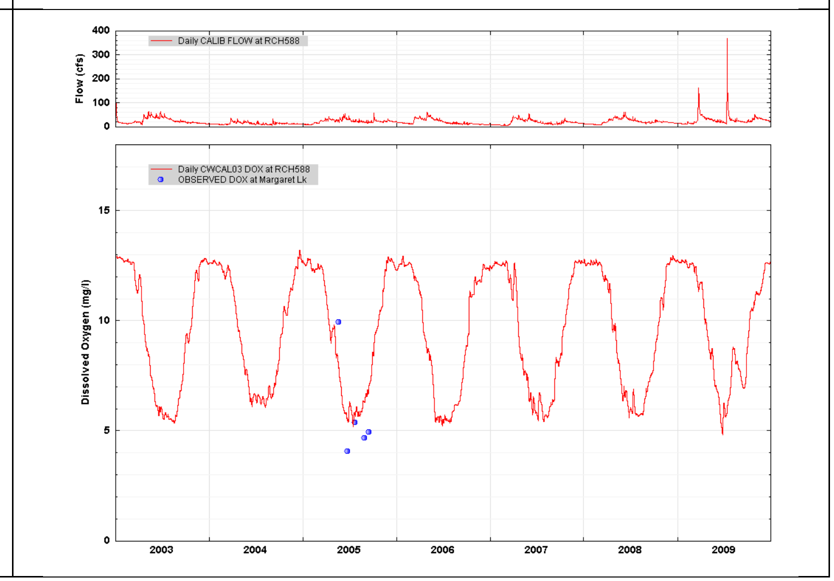

Daily CALIB FLOW at RCH521
OBSERVED FLOW at 05243200
Flow (cfs)
Daily CWCAL03 DOX at RCH521
OBSERVED DOX at Shell R at US-71
OBSERVED DOX at 05243200
OBSERVED DOX at Shell R at inlet to Blueberry Lake
Dissolved Oxygen (mg/l)
Daily CALIB FLOW at RCH522
Daily CWCAL03 DOX at RCH522
OBSERVED DOX at Blueberry R at 384th
Daily CALIB FLOW at RCH523
Daily CWCAL03 DOX at RCH523
OBSERVED DOX at Kettle R at CR-156
Daily CALIB FLOW at RCH524
Daily CWCAL03 DOX at RCH524
OBSERVED DOX at Blueberry R at US-71
OBSERVED DOX at Blueberry R at inlet to Blueberry Lake
2003
2004
2005
2006
2007
2008
2009

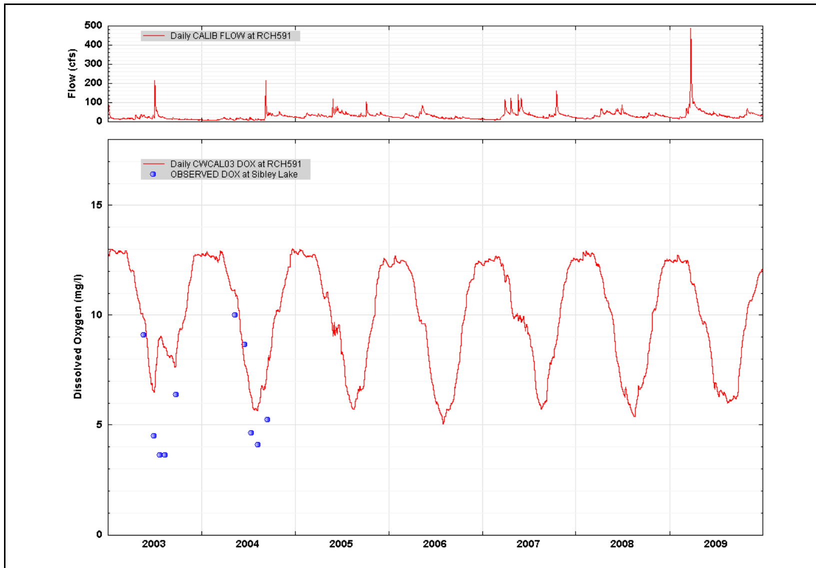

Daily CALIB FLOW at RCH525
Flow (cfs)
Daily CWCAL03 DOX at RCH525
OBSERVED DOX at Shell R at Blueberry Br Rd
OBSERVED DOX at Blueberry Lake
Dissolved Oxygen (mg/l)
Daily CALIB FLOW at RCH526
Daily CWCAL03 DOX at RCH526
OBSERVED DOX at Shell R at CSAH 21
OBSERVED DOX at Fishhook River below Long Lake
Daily CALIB FLOW at RCH527
Daily CWCAL03 DOX at RCH527
OBSERVED DOX at Lower Twin Lake
Daily CALIB FLOW at RCH529
Daily CWCAL03 DOX at RCH529
OBSERVED DOX at Stocking Lake
2003
2004
2005
2006
2007
2008
2009

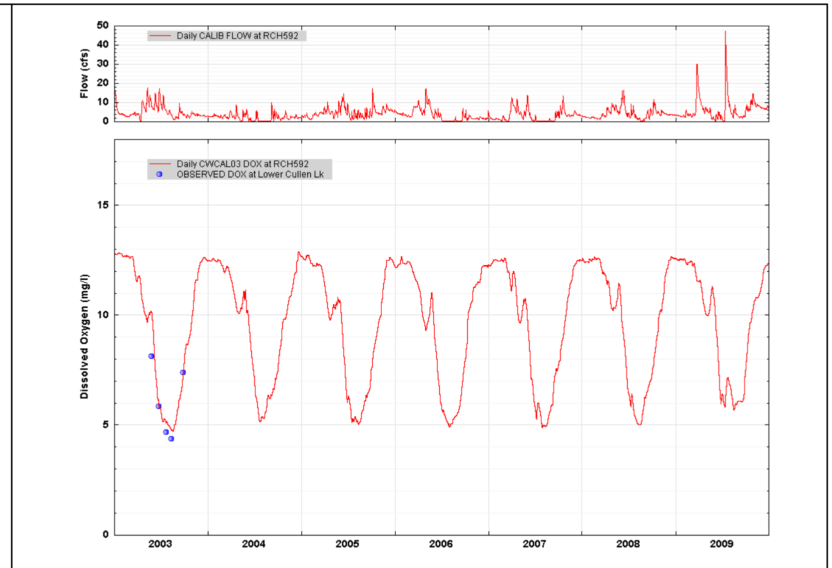

Daily CALIB FLOW at RCH530
OBSERVED FLOW at Shell R at CSAH 23
Flow (cfs)
Daily CWCAL03 DOX at RCH530
OBSERVED DOX at Shell R at CR 13
OBSERVED DOX at Shell R at CSAH 23
OBSERVED DOX at Shell R at CSAH 24
Dissolved Oxygen (mg/l)
2003 2004 2005 2006 2007 2008 2009

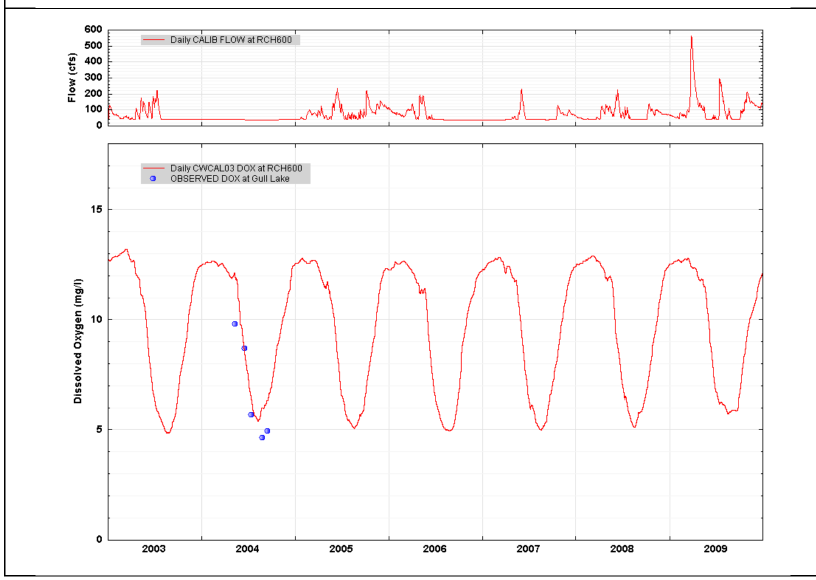

Daily CALIB FLOW at RCH531
Flow (cfs)
Daily CWCAL03 DOX at RCH531
OBSERVED DOX at Mantrap Lk Mid
Dissolved Oxygen (mg/l)
2003 2004 2005 2006 2007 2008 2009


Daily CALIB FLOW at RCH537
Flow (cfs)
Daily CWCAL03 DOX at RCH537
OBSERVED DOX at 9th Crow Wing
Dissolved Oxygen (mg/l)
2003 2004 2005 2006 2007 2008 2009


Daily CALIB FLOW at RCH588
Flow (cfs)
Daily CWCAL03 DOX at RCH588
OBSERVED DOX at Margaret Lk
Dissolved Oxygen (mg/l)
2003 2004 2005 2006 2007 2008 2009

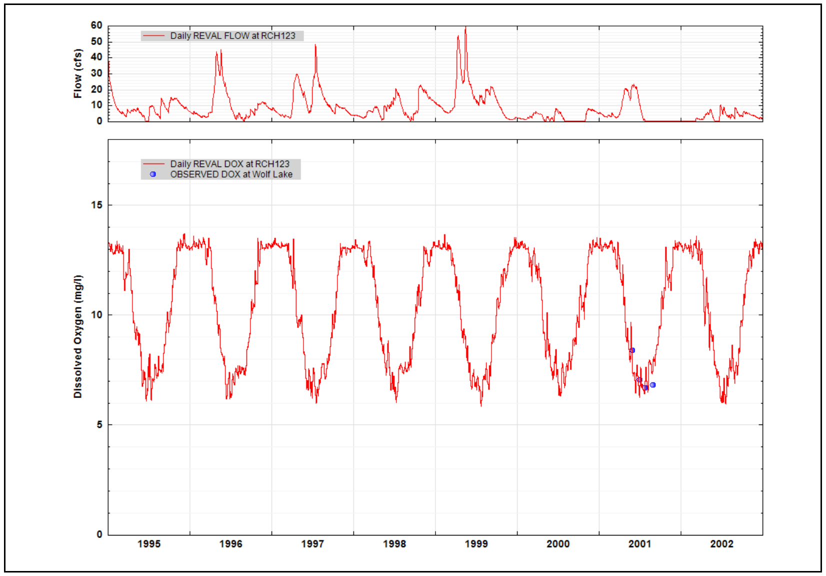

Daily CALIB FLOW at RCH591
Flow (cfs)
500
400
300
200
100
0
Daily CWCAL03 DOX at RCH591
OBSERVED DOX at Sibley Lake
Dissolved Oxygen (mg/l)
15
10
5
0
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH592
Flow (cfs)
50
40
30
20
10
0
Daily CWCAL03 DOX at RCH592
OBSERVED DOX at Lower Cullen Lk
Dissolved Oxygen (mg/l)
15
10
5
0
2003
2004
2005
2006
2007
2008
2009

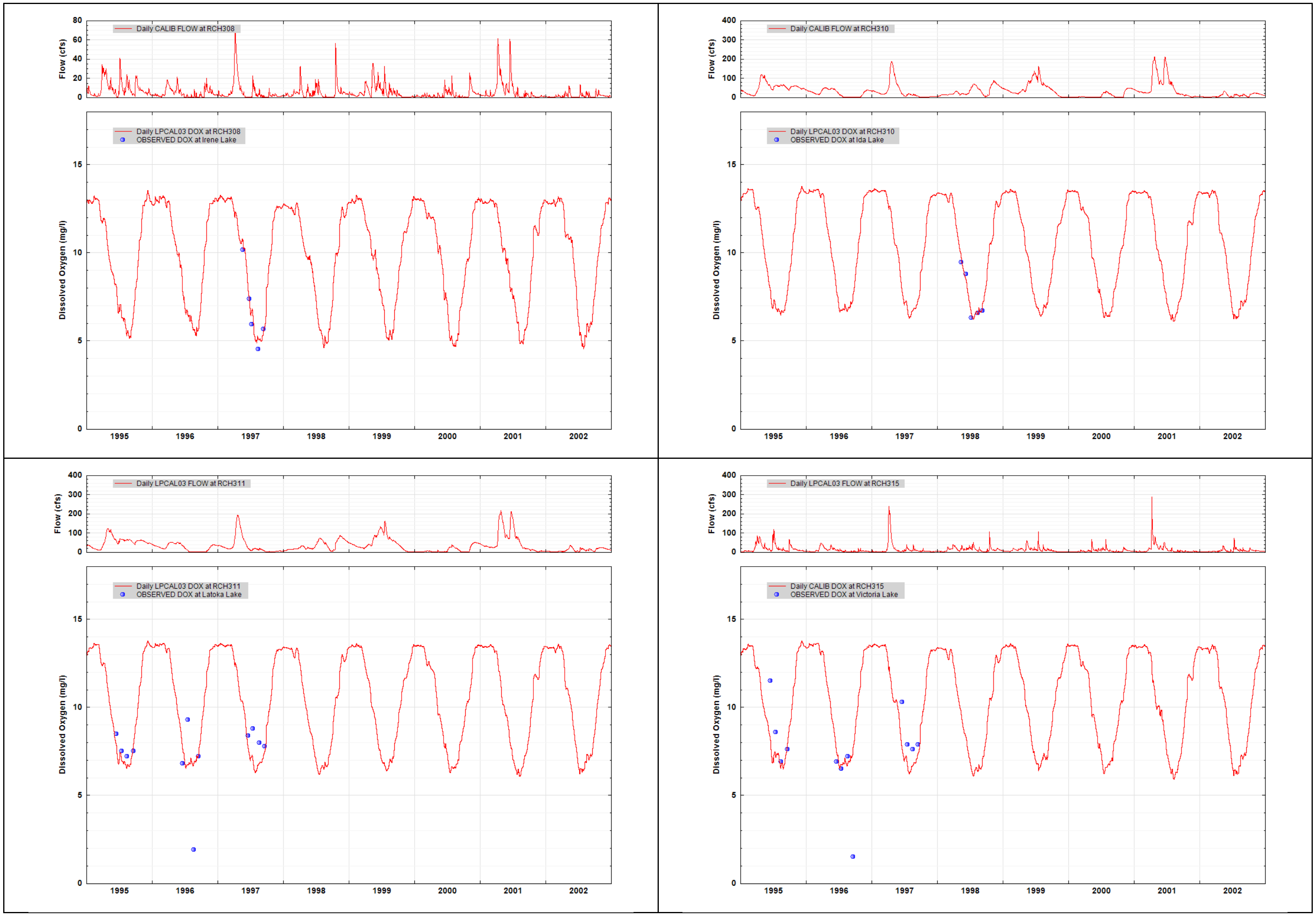

Daily CALIB FLOW at RCH600
Flow (cfs)
600
500
400
300
200
100
0
Daily CWCAL03 DOX at RCH600
OBSERVED DOX at Gull Lake
Dissolved Oxygen (mg/l)
15
10
5
0
2003
2004
2005
2006
2007
2008
2009

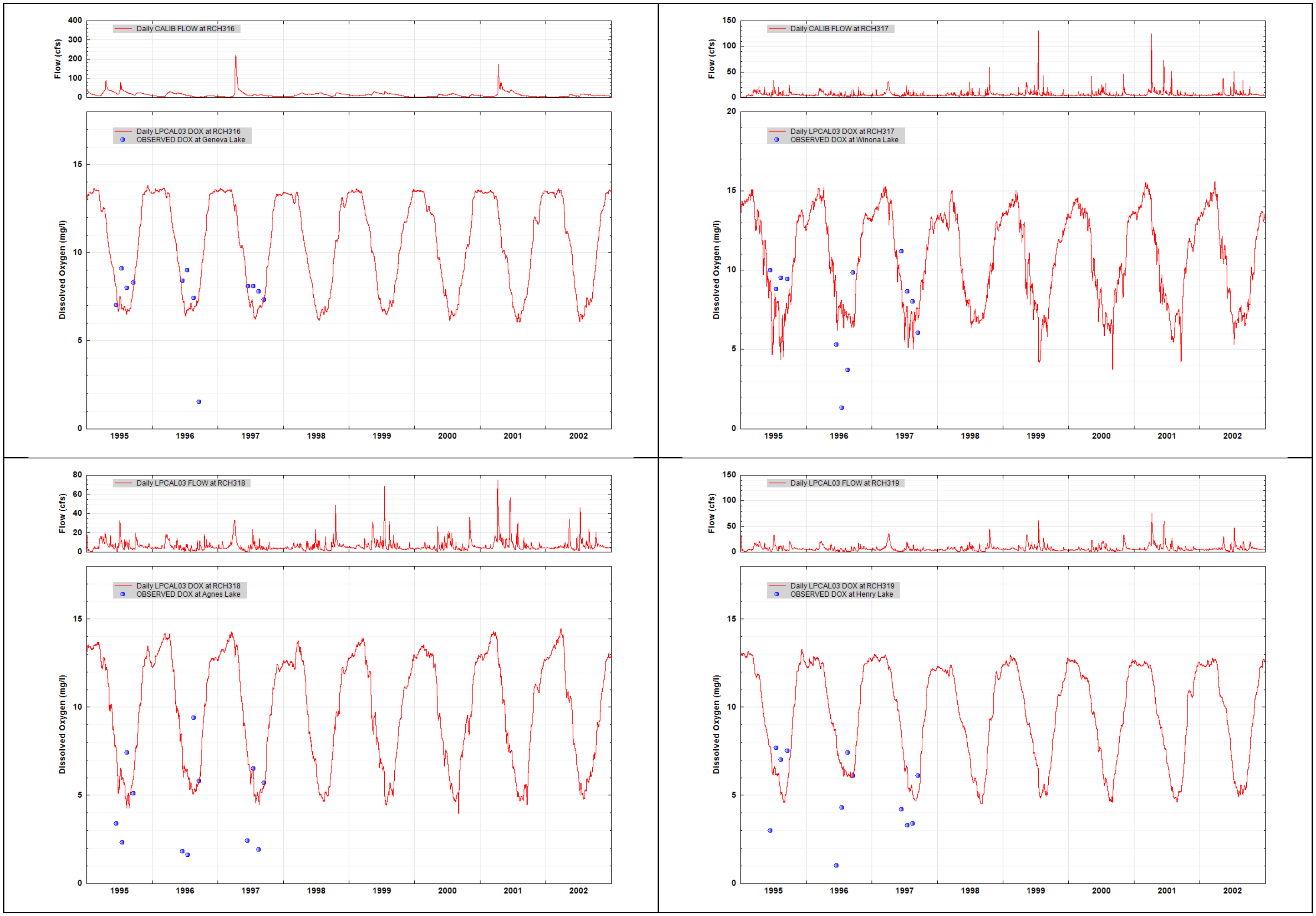
APPENDIX J
OBSERVED AND SIMULATED DISSOLVED OXYGEN FOR THE VALIDATION PERIOD

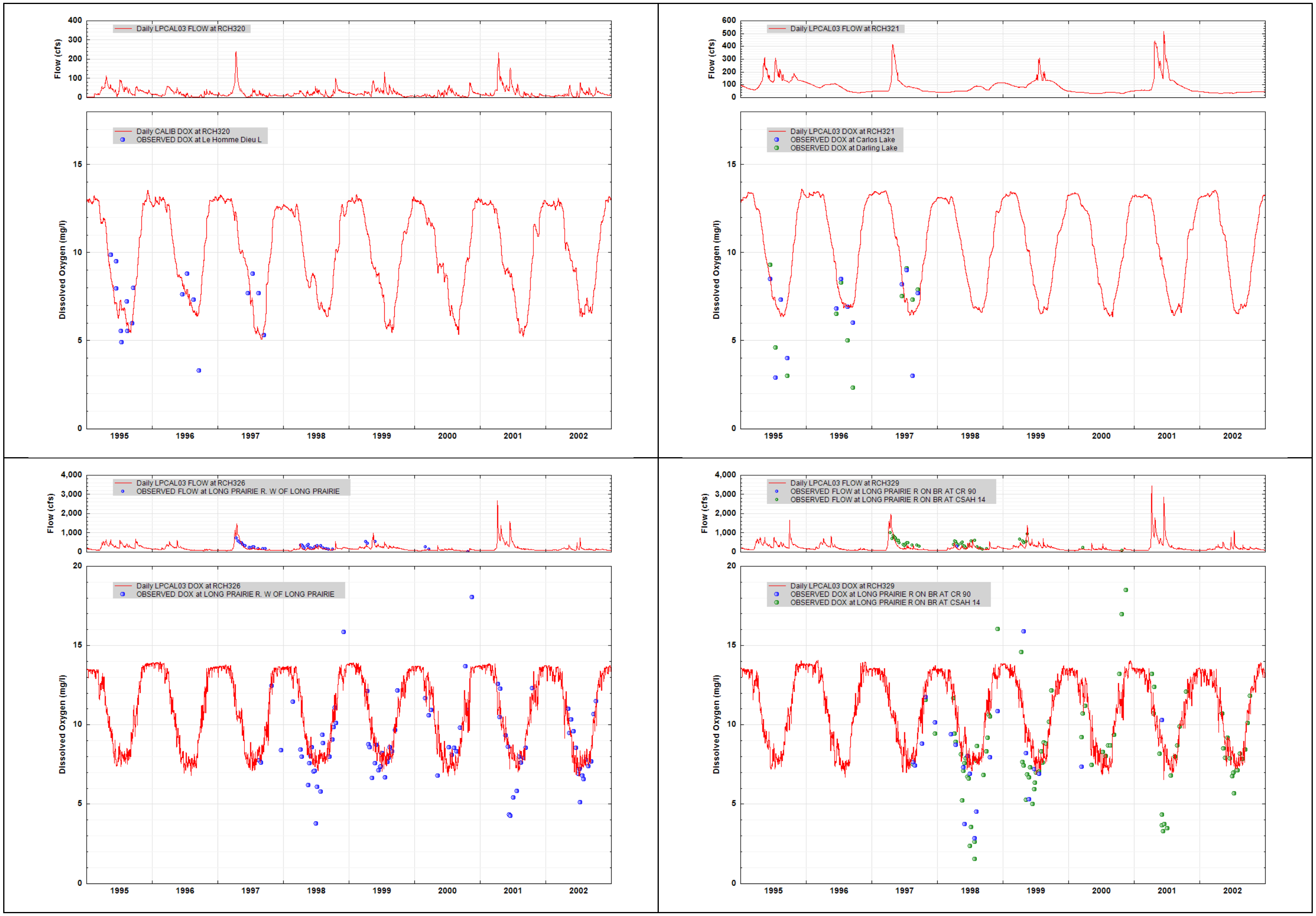
J.1 REDEYE RIVER WATERSHED

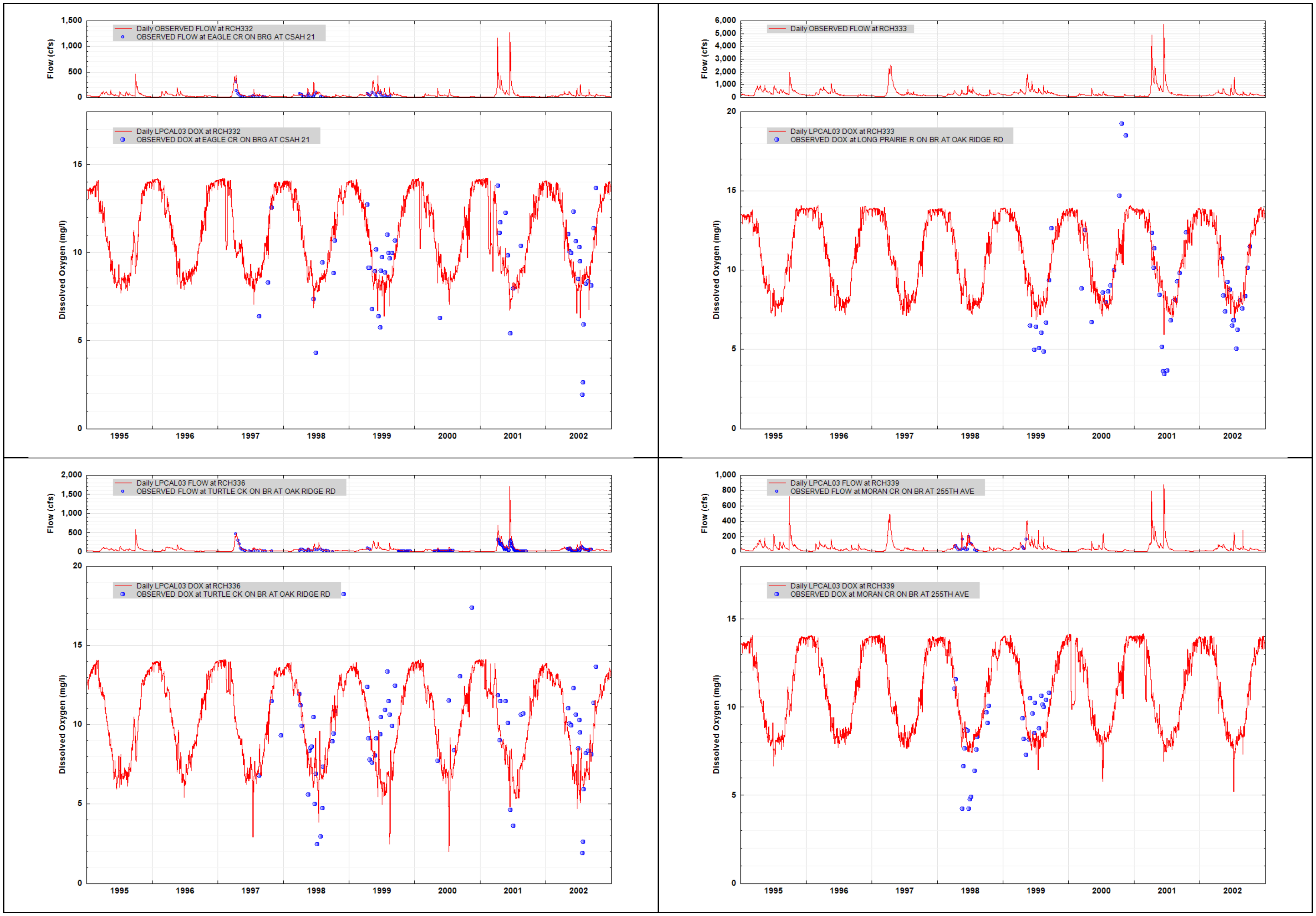


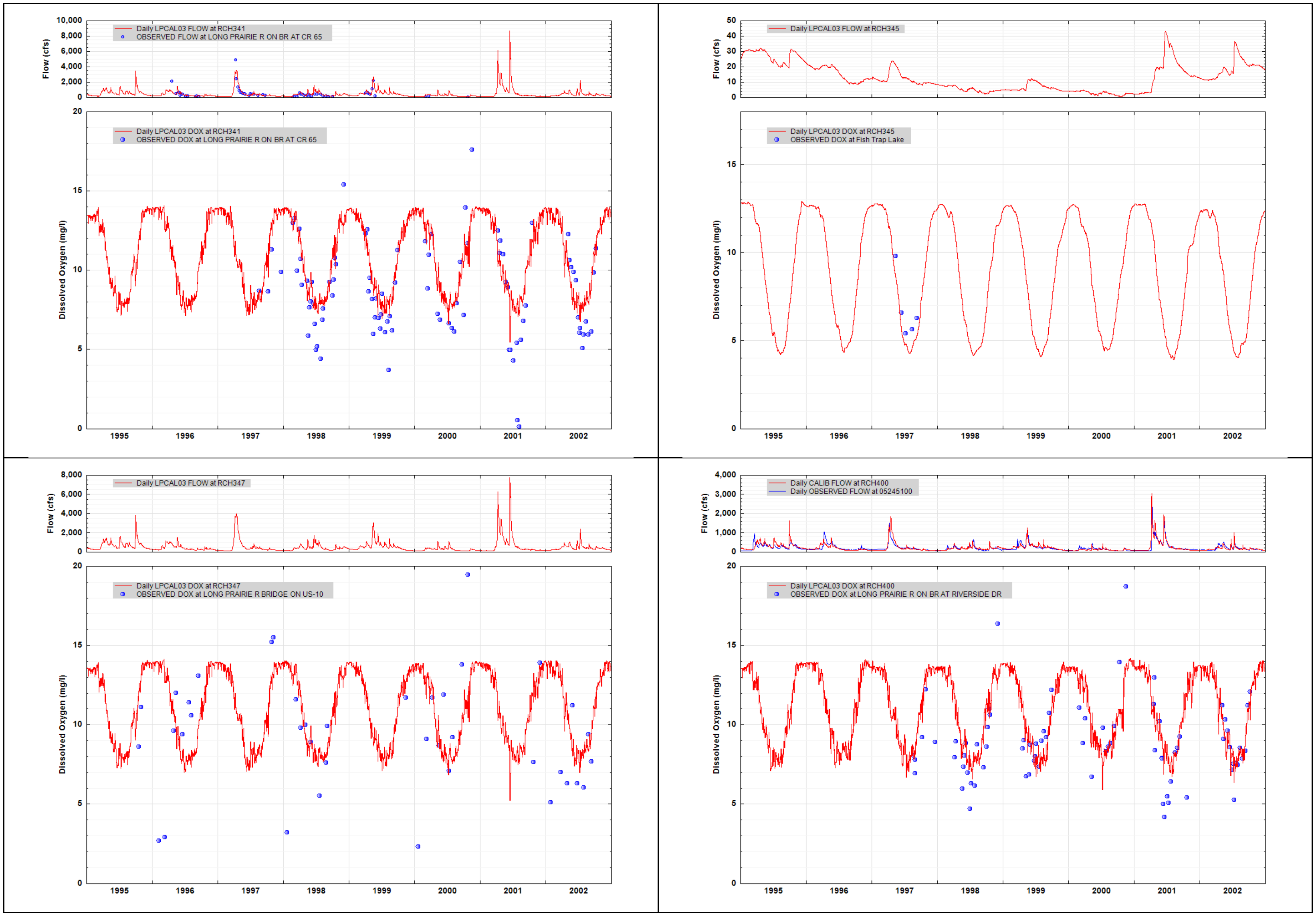
J.2 LONG PRAIRIE RIVER WATERSHED



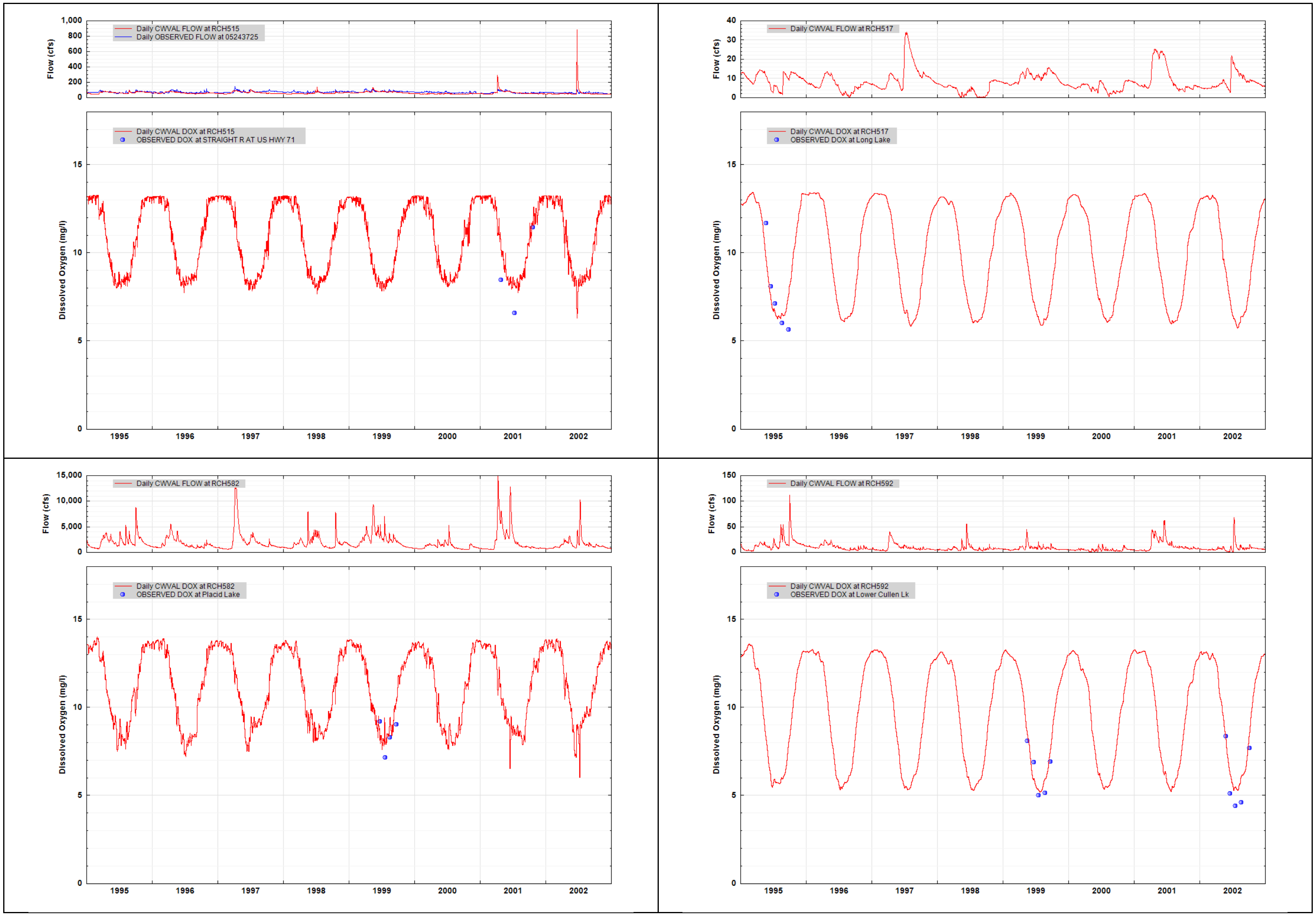

Daily CALIB FLOW at RCH316
Flow (cfs)
Daily LPCAL03 DOX at RCH316
OBSERVED DOX at Geneva Lake
Dissolved Oxygen (mg/l)
Daily CALIB FLOW at RCH317
Daily LPCAL03 DOX at RCH317
OBSERVED DOX at Winona Lake
Daily LPCAL03 FLOW at RCH318
Daily LPCAL03 DOX at RCH318
OBSERVED DOX at Agnes Lake
Daily LPCAL03 FLOW at RCH319
Daily LPCAL03 DOX at RCH319
OBSERVED DOX at Henry Lake
1995
1996
1997
1998
1999
2000
2001
2002

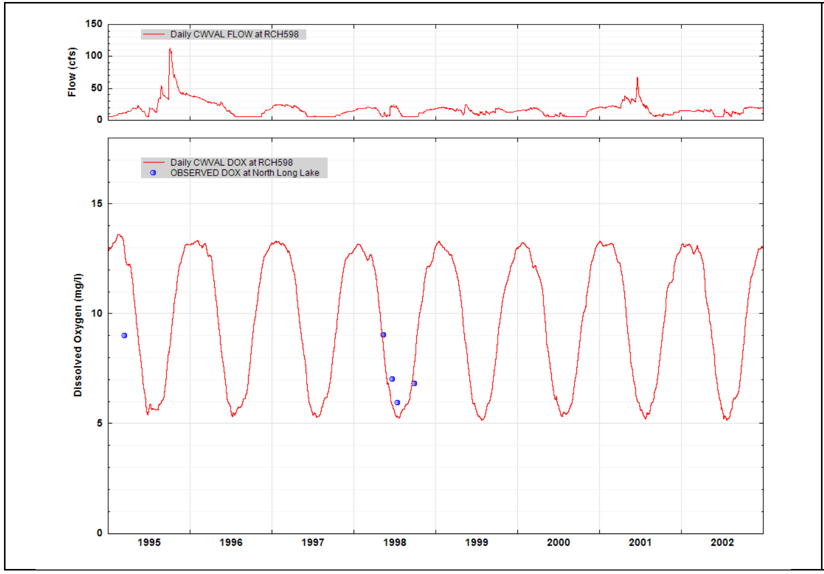

Daily LPCAL03 FLOW at RCH320
Flow (cfs)
Daily CALIB DOX at RCH320
OBSERVED DOX at Le Homme Dieu L
Dissolved Oxygen (mg/l)
Daily LPCAL03 FLOW at RCH321
Daily LPCAL03 DOX at RCH321
OBSERVED DOX at Carlos Lake
OBSERVED DOX at Darling Lake
Daily LPCAL03 FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily LPCAL03 DOX at RCH326
OBSERVED DOX at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily LPCAL03 FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 90
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
Daily LPCAL03 DOX at RCH329
OBSERVED DOX at LONG PRAIRIE R ON BR AT CR 90
OBSERVED DOX at LONG PRAIRIE R ON BR AT CSAH 14
1995
1996
1997
1998
1999
2000
2001
2002

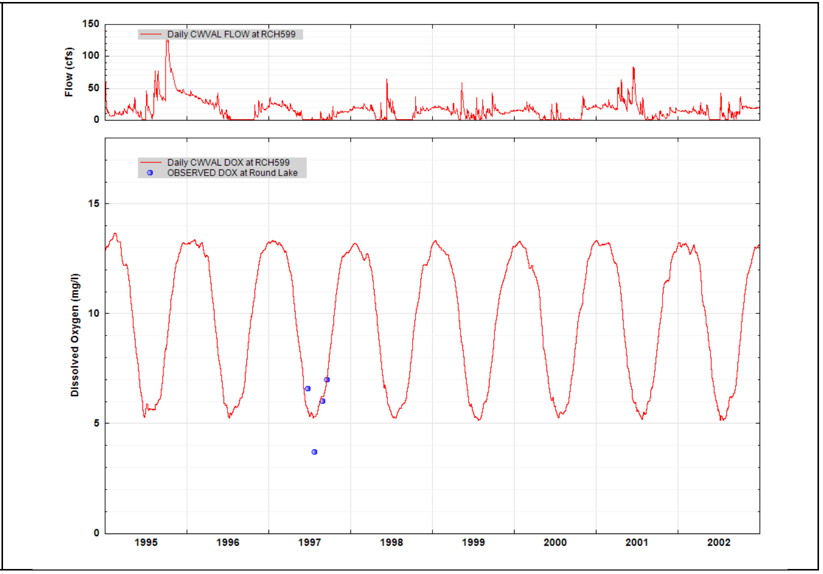

Daily OBSERVED FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
1,500
1,000
500
0
Daily LPCAL03 DOX at RCH332
OBSERVED DOX at EAGLE CR ON BRG AT CSAH 21
Dissolved Oxygen (mg/l)
15
10
5
0
1995
1996
1997
1998
1999
2000
2001
2002
Daily OBSERVED FLOW at RCH333
Flow (cfs)
6,000
5,000
4,000
3,000
2,000
1,000
0
Daily LPCAL03 DOX at RCH333
OBSERVED DOX at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Dissolved Oxygen (mg/l)
20
15
10
5
0
1995
1996
1997
1998
1999
2000
2001
2002
Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
2,000
1,500
1,000
500
0
Daily LPCAL03 DOX at RCH336
OBSERVED DOX at TURTLE CK ON BR AT OAK RIDGE RD
Dissolved Oxygen (mg/l)
20
15
10
5
0
1995
1996
1997
1998
1999
2000
2001
2002
Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Flow (cfs)
1,000
800
600
400
200
0
Daily LPCAL03 DOX at RCH339
OBSERVED DOX at MORAN CR ON BR AT 255TH AVE
Dissolved Oxygen (mg/l)
15
10
5
0
1995
1996
1997
1998
1999
2000
2001
2002


Flow (cfs)
Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Dissolved Oxygen (mg/l)
Daily LPCAL03 DOX at RCH341
OBSERVED DOX at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 FLOW at RCH345
Daily LPCAL03 DOX at RCH345
OBSERVED DOX at Fish Trap Lake
Daily LPCAL03 FLOW at RCH347
Daily LPCAL03 DOX at RCH347
OBSERVED DOX at LONG PRAIRIE R BRIDGE ON US-10
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Daily LPCAL03 DOX at RCH400
OBSERVED DOX at LONG PRAIRIE R ON BR AT RIVERSIDE DR
1995
1996
1997
1998
1999
2000
2001
2002

J.3 CROW WING RIVER WATERSHED



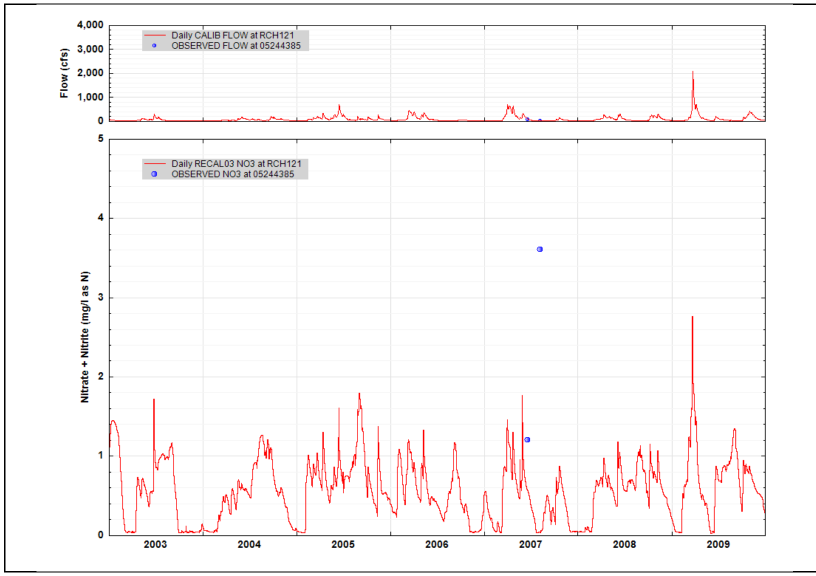

Daily CWVAL FLOW at RCH598
Flow (cfs)
Daily CWVAL DOX at RCH598
OBSERVED DOX at North Long Lake
Dissolved Oxygen (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002

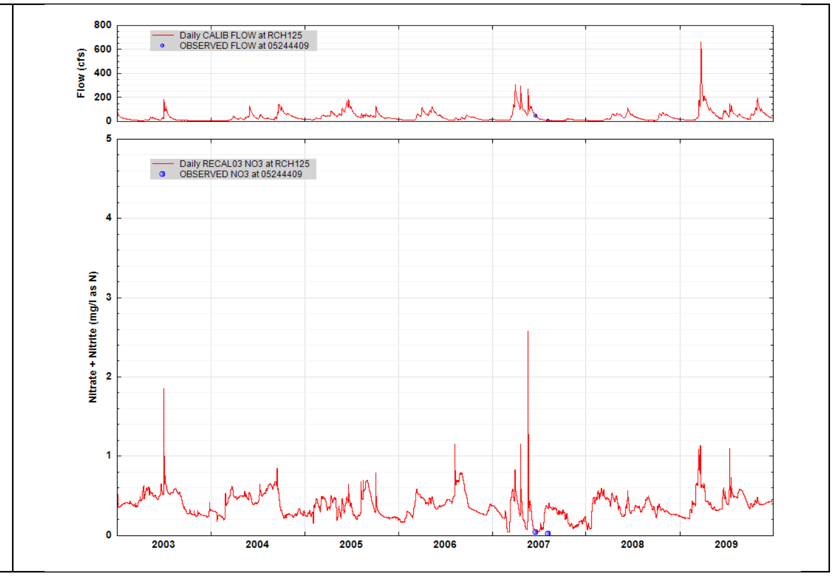

Daily CWVAL FLOW at RCH599
Flow (cfs)
Daily CWVAL DOX at RCH599
OBSERVED DOX at Round Lake
Dissolved Oxygen (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002

APPENDIX K
OBSERVED AND SIMULATED NITROGEN CONSTITUENTS FOR THE CALIBRATION PERIOD

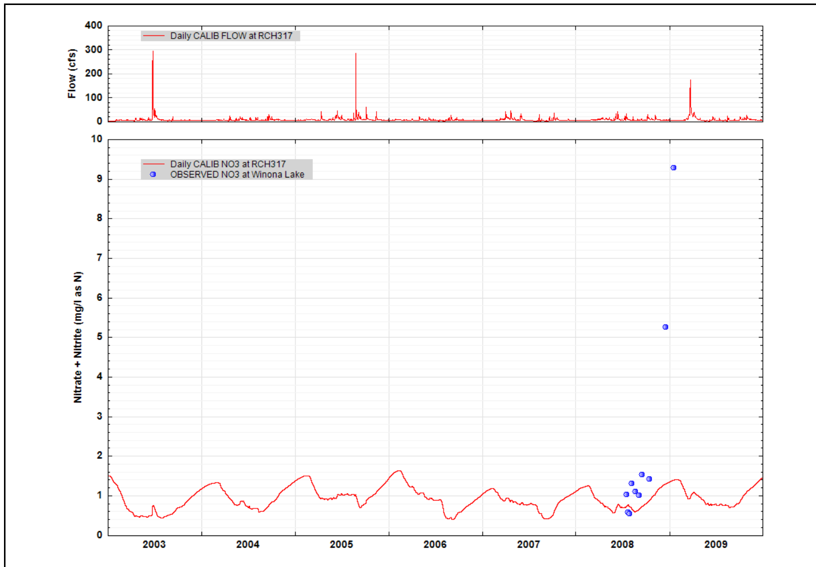
K.1 NITRATE

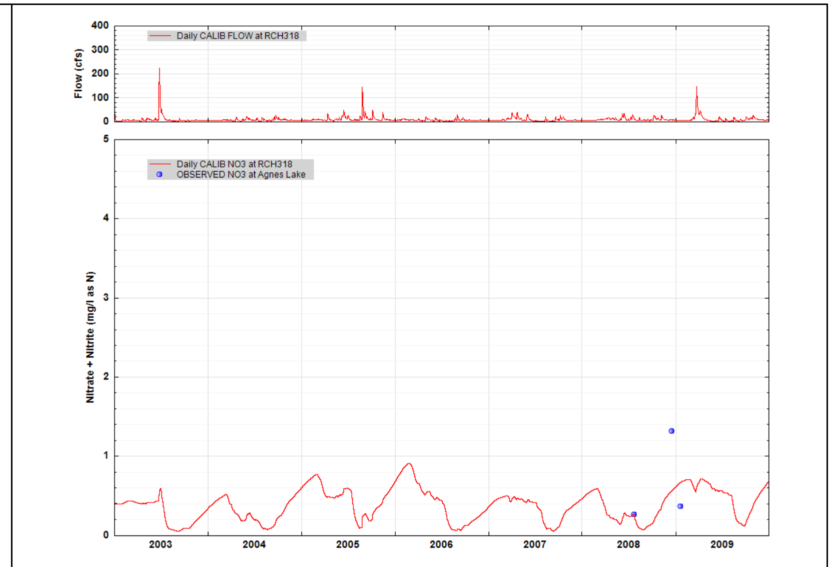
K.1.1 Redeye River Watershed

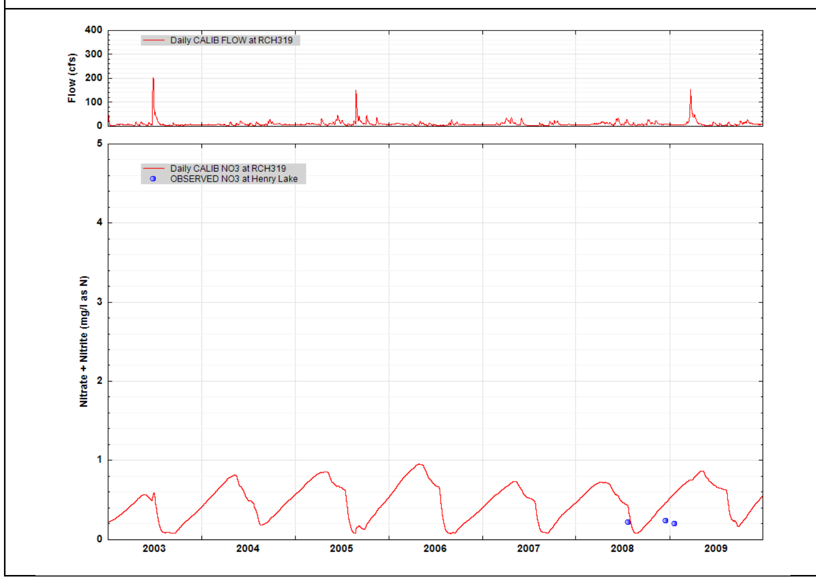


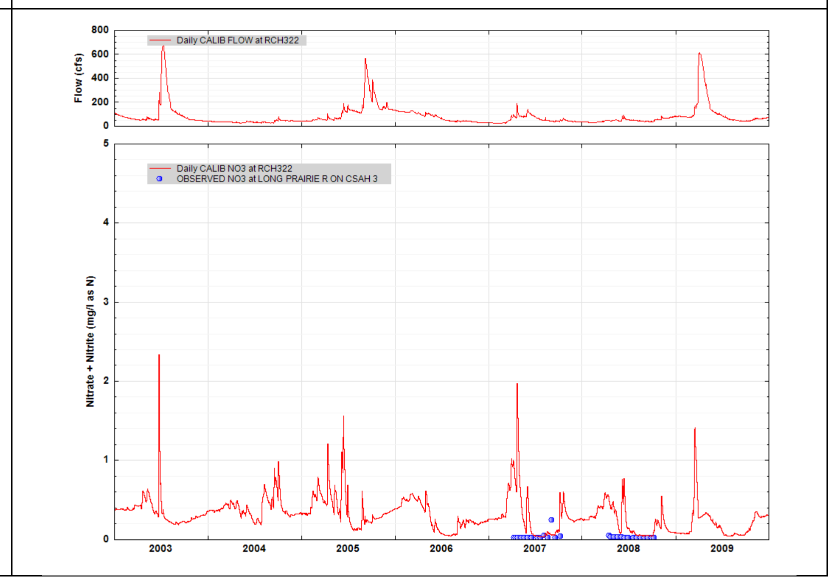


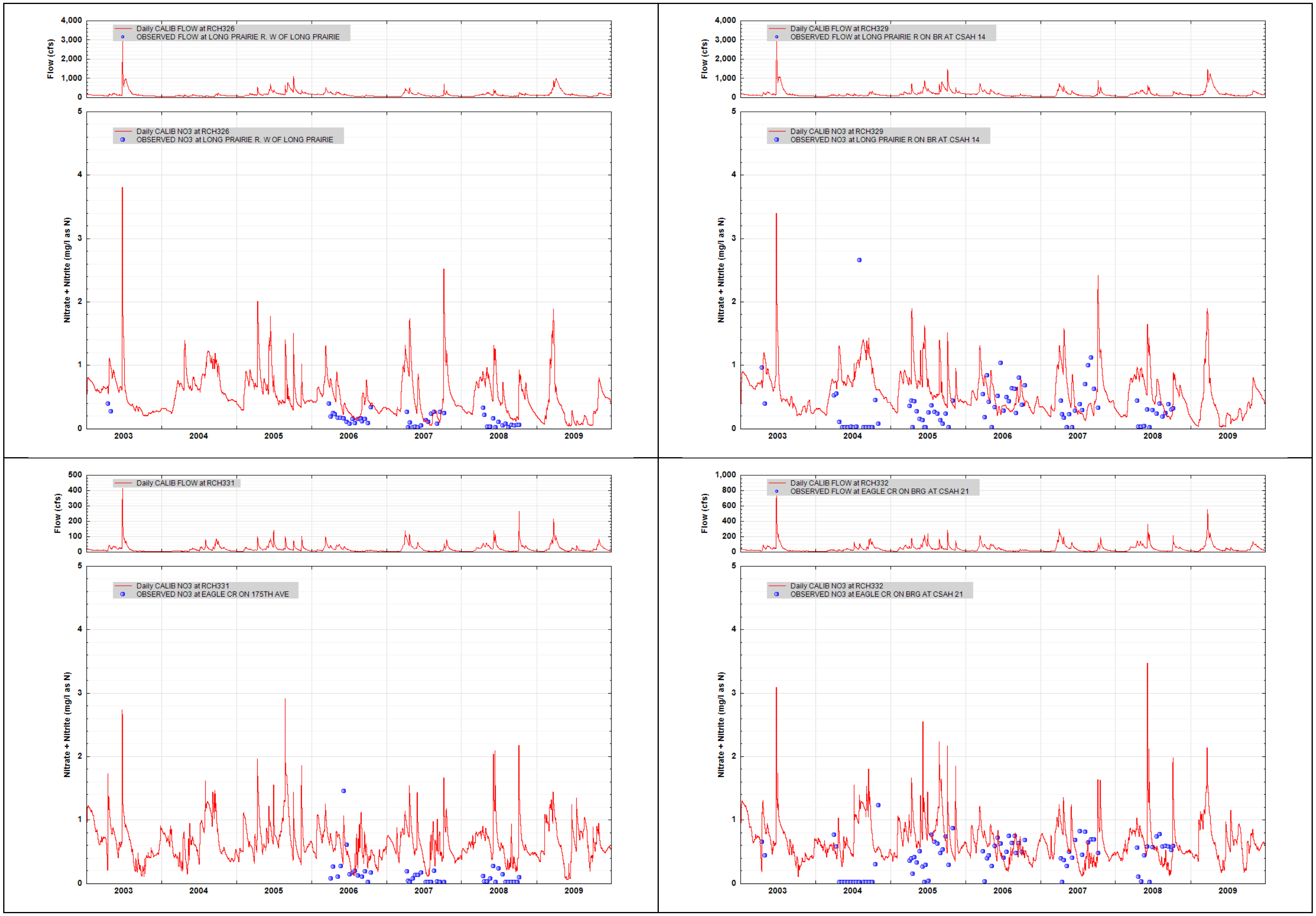
K.1.2 Long Prairie River Watershed

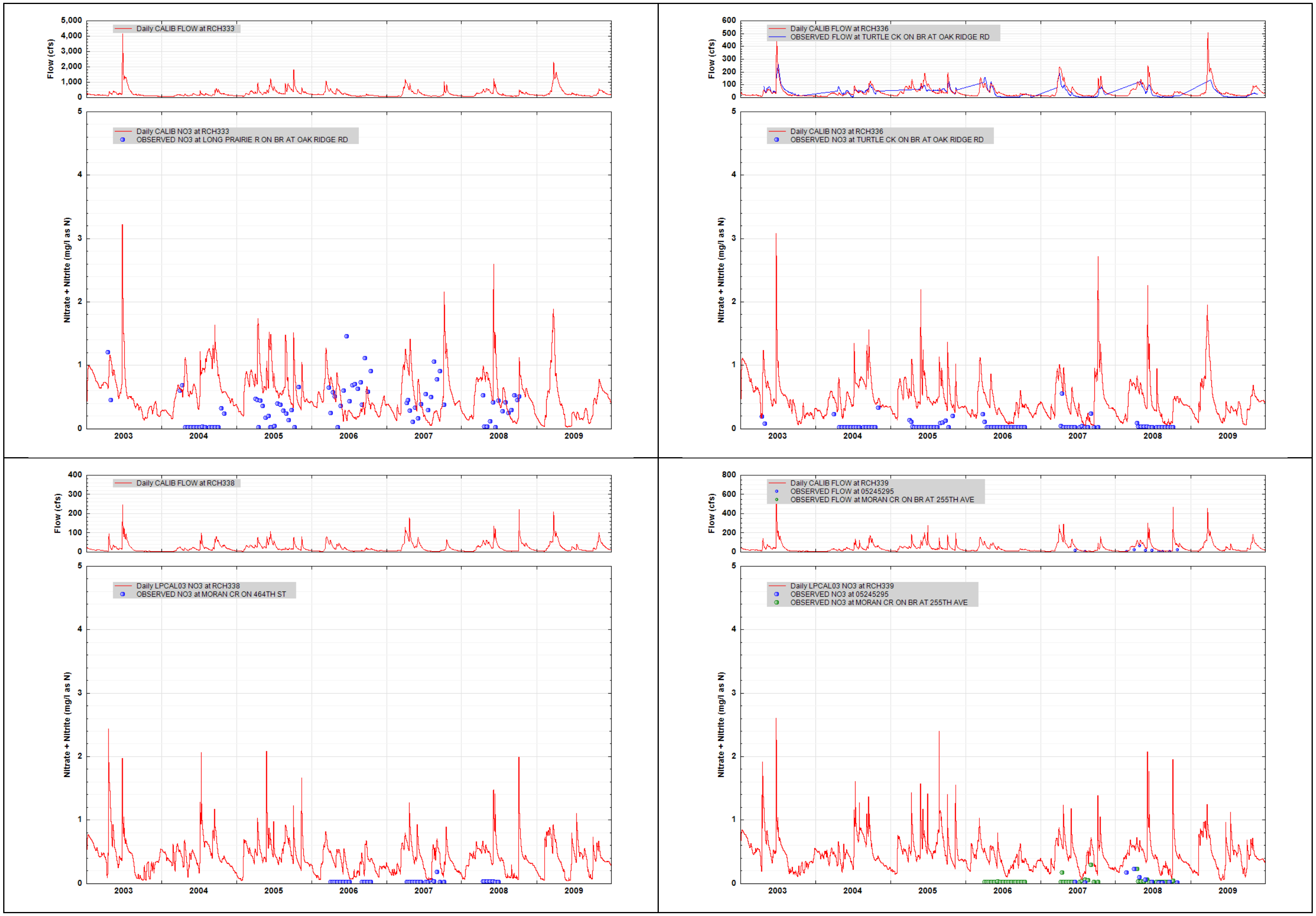




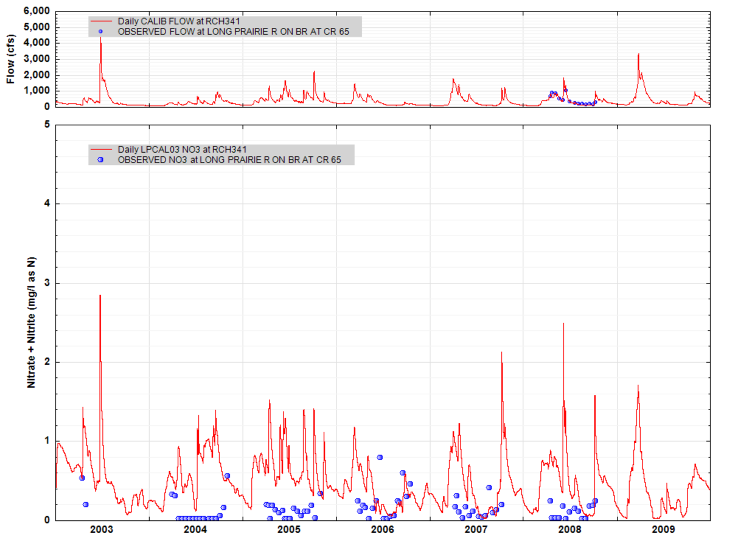


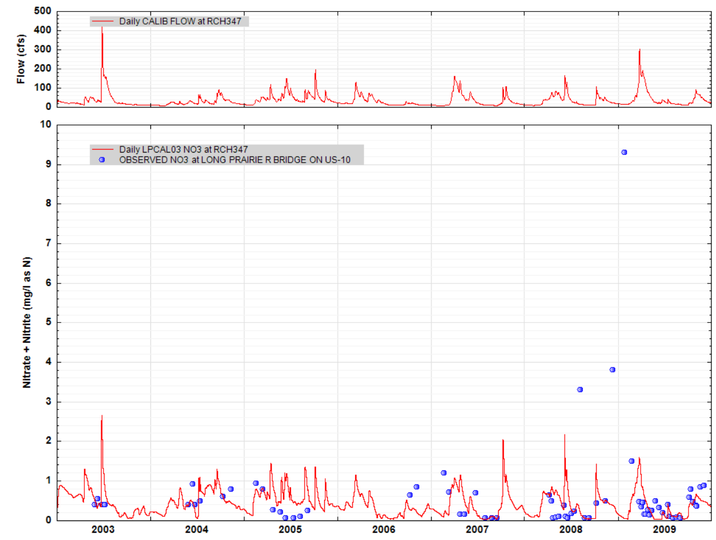


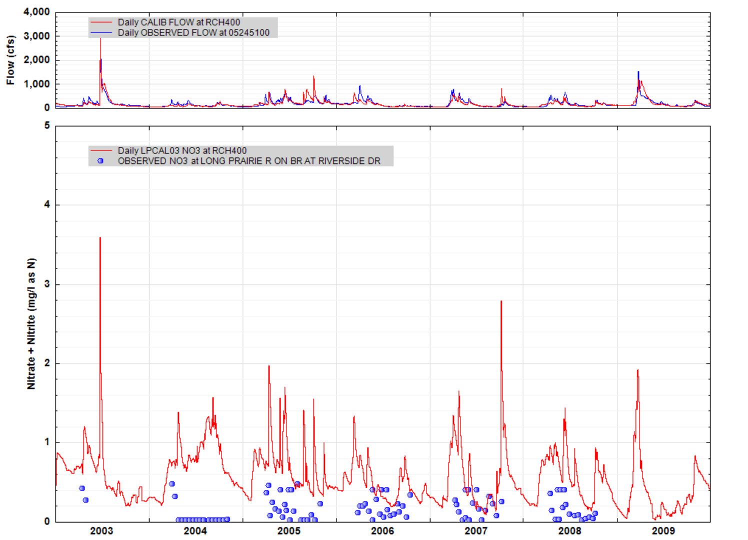

Daily CALIB FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily CALIB NO3 at RCH326
OBSERVED NO3 at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily CALIB FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
Daily CALIB NO3 at RCH329
OBSERVED NO3 at LONG PRAIRIE R ON BR AT CSAH 14
Daily CALIB FLOW at RCH331
Daily CALIB NO3 at RCH331
OBSERVED NO3 at EAGLE CR ON 175TH AVE
Daily CALIB FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Daily CALIB NO3 at RCH332
OBSERVED NO3 at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
Nitrate + Nitrite (mg/l as N)
2003
2004
2005
2006
2007
2008
2009



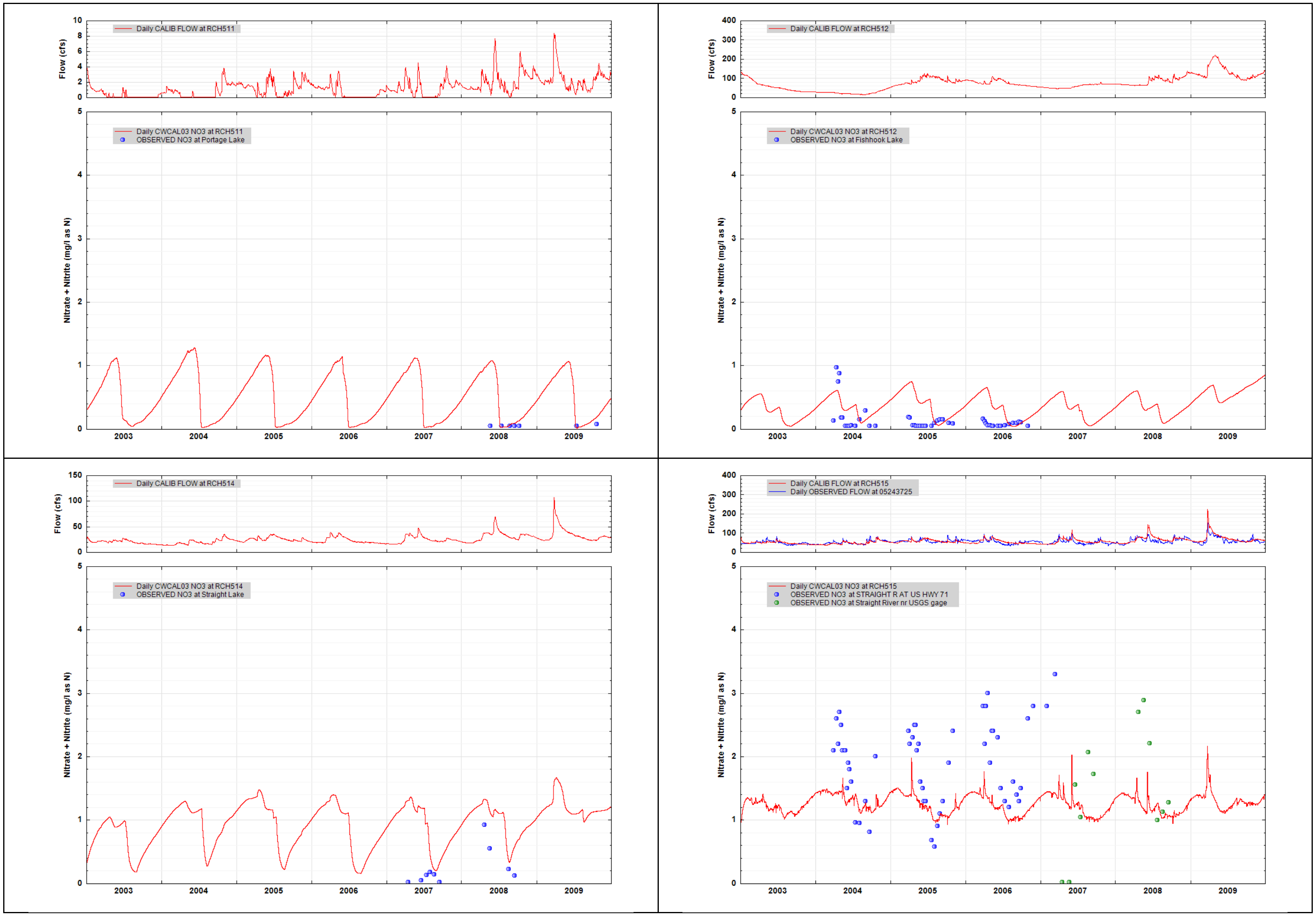
Flow (cfs)
Daily CALIB FLOW at RCH333
Nitrate + Nitrite (mg/l as N)
Daily CALIB NO3 at RCH333
OBSERVED NO3 at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Flow (cfs)
Daily CALIB FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Nitrate + Nitrite (mg/l as N)
Daily CALIB NO3 at RCH336
OBSERVED NO3 at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Daily CALIB FLOW at RCH338
Nitrate + Nitrite (mg/l as N)
Daily LPCAL03 NO3 at RCH338
OBSERVED NO3 at MORAN CR ON 464TH ST
Flow (cfs)
Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Nitrate + Nitrite (mg/l as N)
Daily LPCAL03 NO3 at RCH339
OBSERVED NO3 at 05245295
OBSERVED NO3 at MORAN CR ON BR AT 255TH AVE
2003
2004
2005
2006
2007
2008
2009

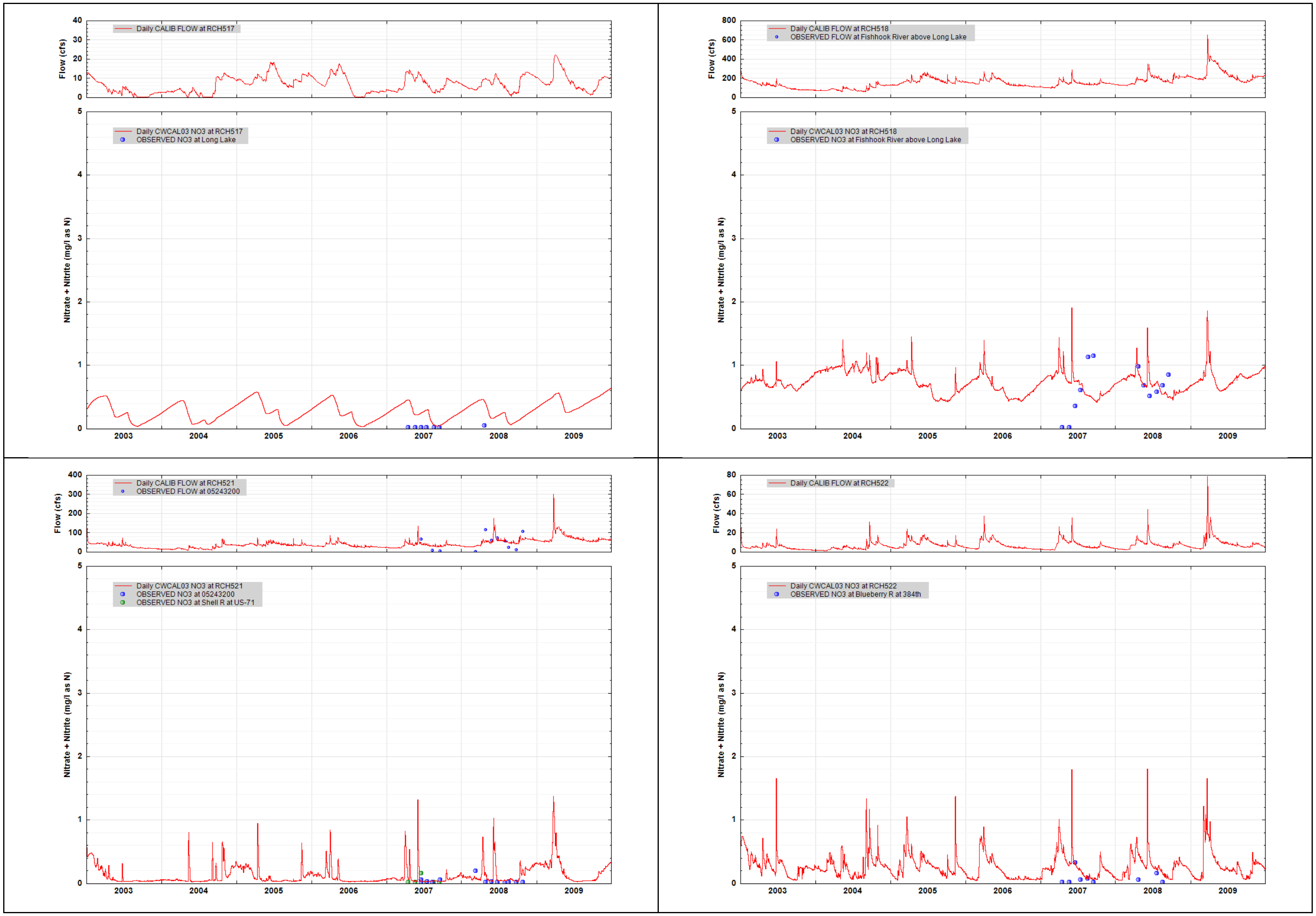

Daily CALIB FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Flow (cfs)
Daily LPCAL03 NO3 at RCH341
OBSERVED NO3 at LONG PRAIRIE R ON BR AT CR 65
Nitrate + Nitrite (mg/l as N)
2003
2004
2005
2006
2007
2008
2009

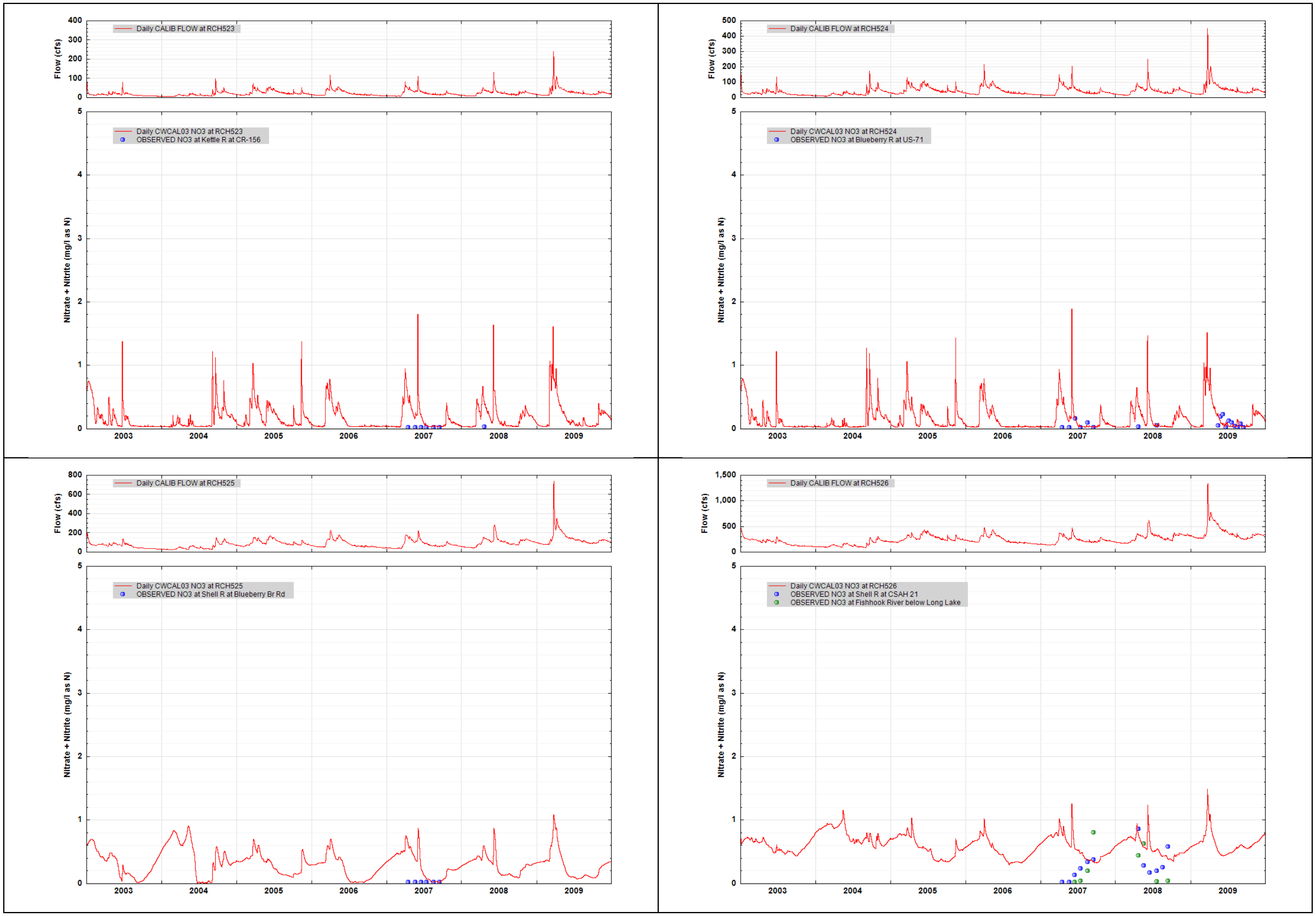

Daily CALIB FLOW at RCH347
Flow (cfs)
Daily LPCAL03 NO3 at RCH347
OBSERVED NO3 at LONG PRAIRIE R BRIDGE ON US-10
Nitrate + Nitrite (mg/l as N)
2003
2004
2005
2006
2007
2008
2009

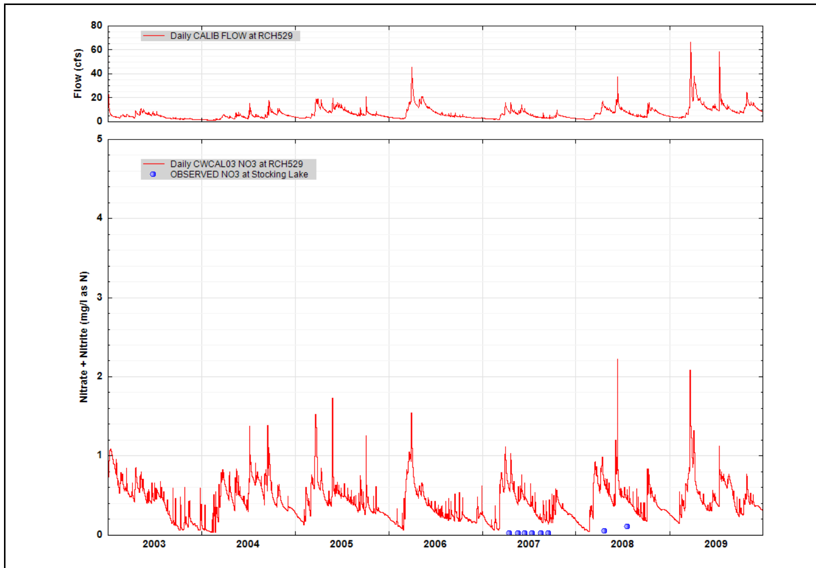

Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Flow (cfs)
Daily LPCAL03 NO3 at RCH400
OBSERVED NO3 at LONG PRAIRIE R ON BR AT RIVERSIDE DR
Nitrate + Nitrite (mg/l as N)
2003
2004
2005
2006
2007
2008
2009

K.1.3 Crow Wing River Watershed

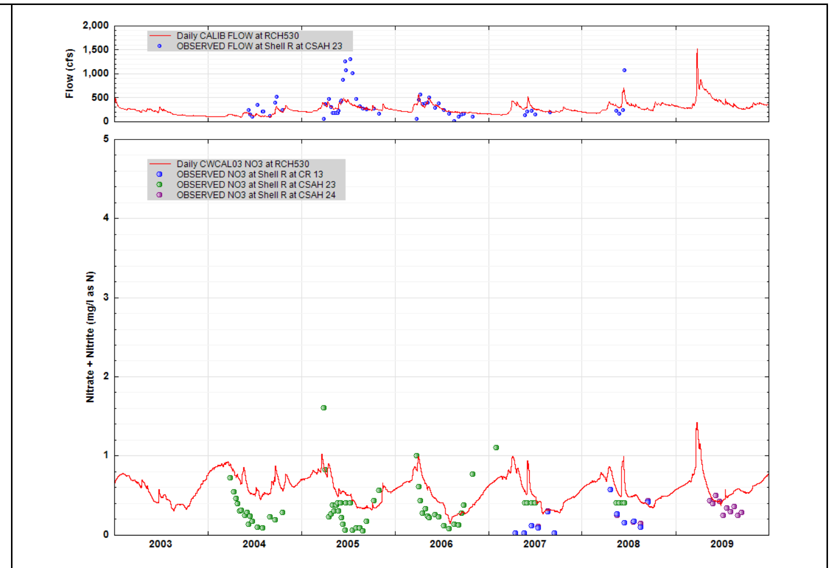



Daily CALIB FLOW at RCH517
Flow (cfs)
Daily CWCAL03 NO3 at RCH517
OBSERVED NO3 at Long Lake
Nitrate + Nitrite (mg/l as N)
Daily CALIB FLOW at RCH518
OBSERVED FLOW at Fishhook River above Long Lake
Daily CWCAL03 NO3 at RCH518
OBSERVED NO3 at Fishhook River above Long Lake
Daily CALIB FLOW at RCH521
OBSERVED FLOW at 05243200
Daily CWCAL03 NO3 at RCH521
OBSERVED NO3 at 05243200
OBSERVED NO3 at Shell R at US-71
Daily CALIB FLOW at RCH522
Daily CWCAL03 NO3 at RCH522
OBSERVED NO3 at Blueberry R at 384th
2003
2004
2005
2006
2007
2008
2009

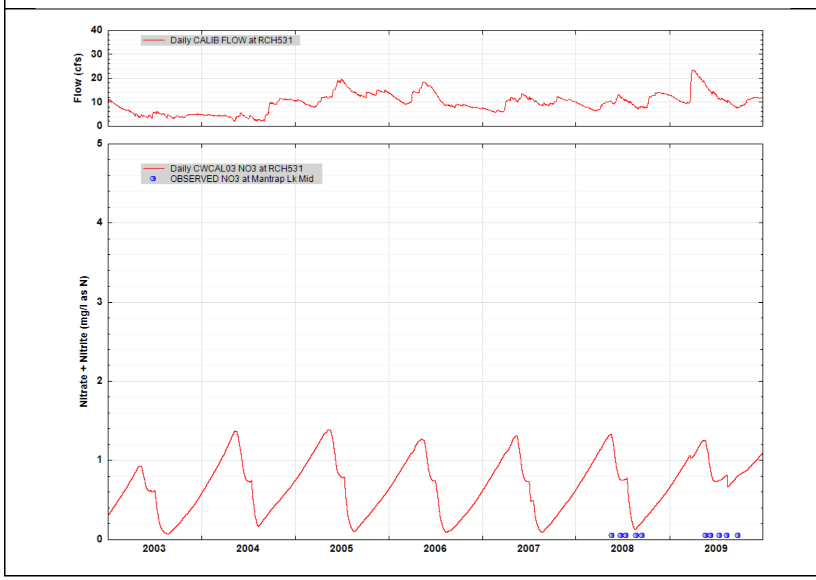

Daily CALIB FLOW at RCH523
Flow (cfs)
Daily CWCAL03 NO3 at RCH523
OBSERVED NO3 at Kettle R at CR-156
Nitrate + Nitrite (mg/l as N)
Daily CALIB FLOW at RCH524
Daily CWCAL03 NO3 at RCH524
OBSERVED NO3 at Blueberry R at US-71
Daily CALIB FLOW at RCH525
Daily CWCAL03 NO3 at RCH525
OBSERVED NO3 at Shell R at Blueberry Br Rd
Daily CALIB FLOW at RCH526
Daily CWCAL03 NO3 at RCH526
OBSERVED NO3 at Shell R at CSAH 21
OBSERVED NO3 at Fishhook River below Long Lake
2003
2004
2005
2006
2007
2008
2009



Daily CALIB FLOW at RCH529
Flow (cfs)
Daily CWCAL03 NO3 at RCH529
OBSERVED NO3 at Stocking Lake
Nitrate + Nitrite (mg/l as N)
2003
2004
2005
2006
2007
2008
2009



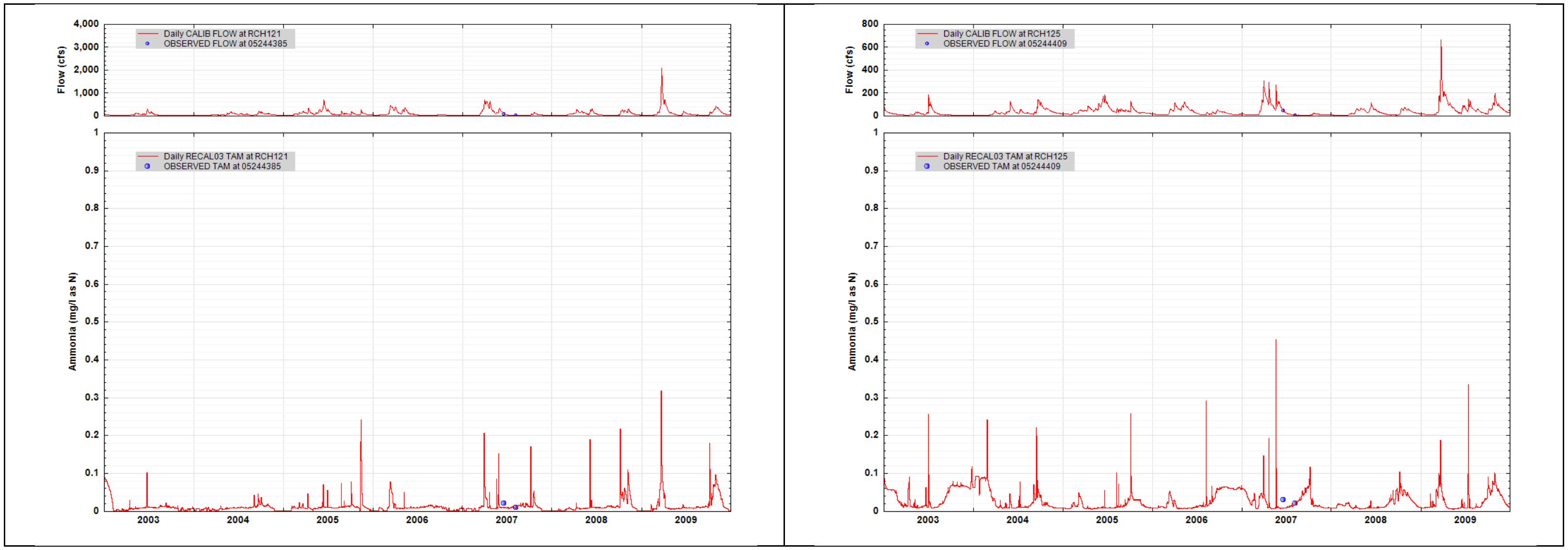
Daily CALIB FLOW at RCH530
OBSERVED FLOW at Shell R at CSAH 23
Flow (cfs)
Daily CWCAL03 NO3 at RCH530
OBSERVED NO3 at Shell R at CR 13
OBSERVED NO3 at Shell R at CSAH 23
OBSERVED NO3 at Shell R at CSAH 24
Nitrate + Nitrite (mg/l as N)
2003
2004
2005
2006
2007
2008
2009



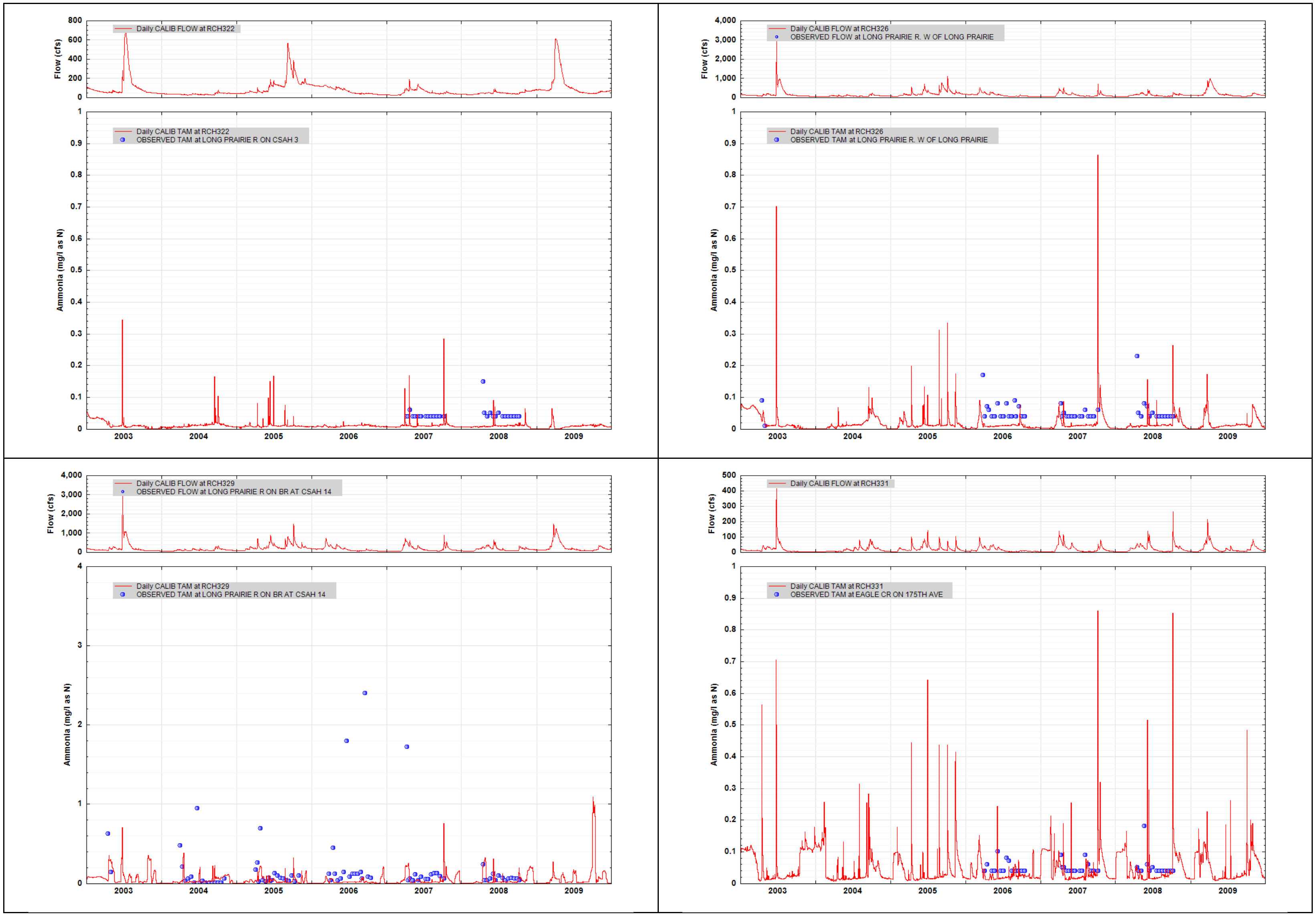
Daily CALIB FLOW at RCH531
Flow (cfs)
Daily CWCAL03 NO3 at RCH531
OBSERVED NO3 at Mantrap Lk Mid
Nitrate + Nitrite (mg/l as N)
2003
2004
2005
2006
2007
2008
2009

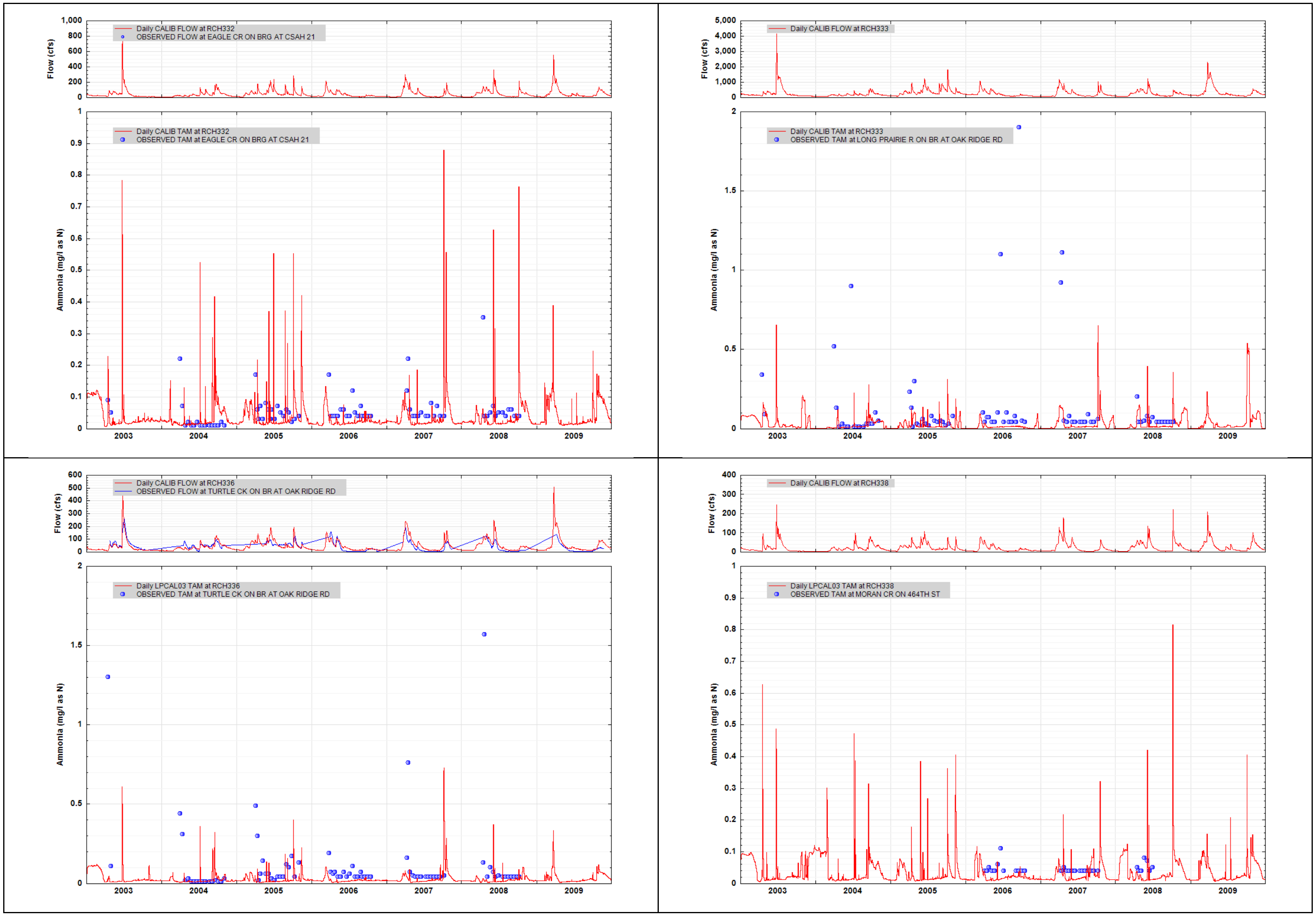
K.2 AMMONIA

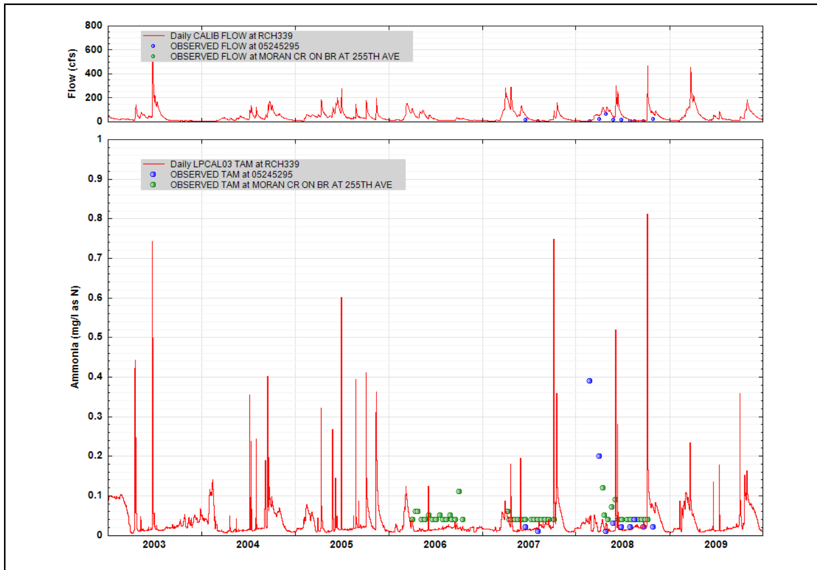
K.2.1 Redeye River Watershed

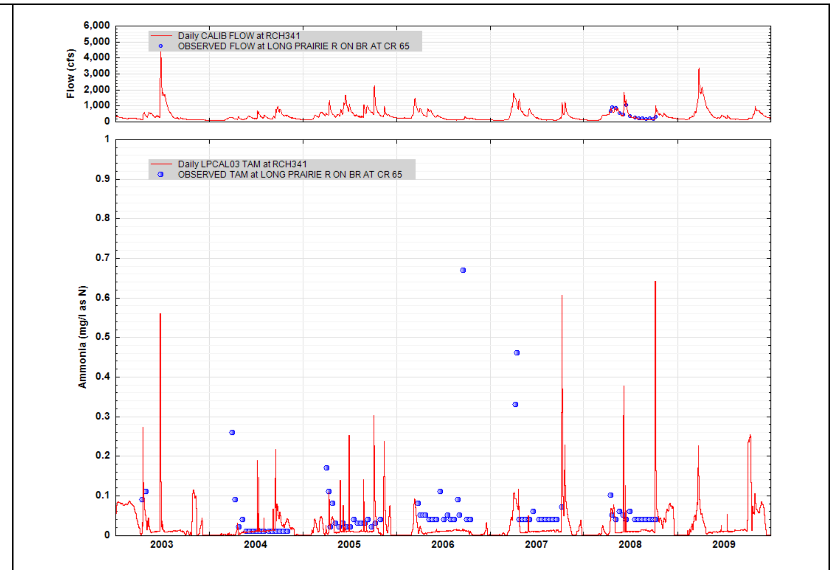


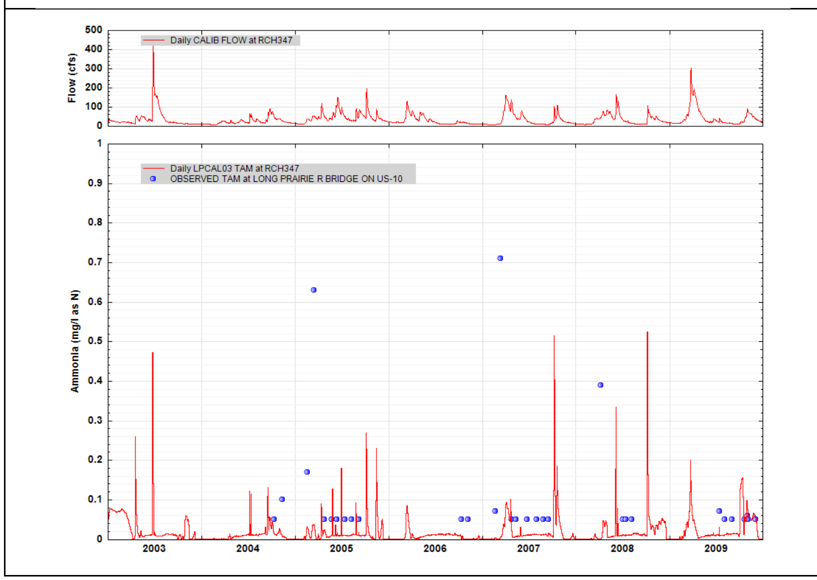
K.2.2 Long Prairie River Watershed

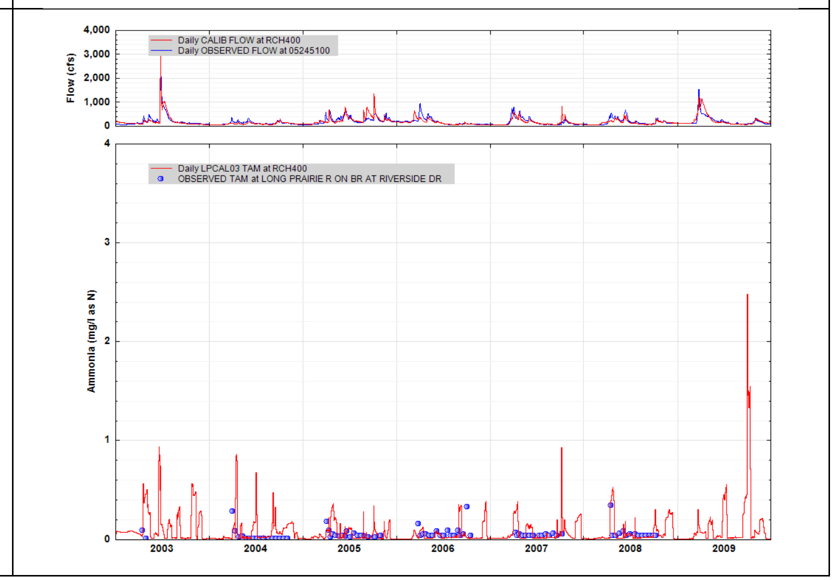



Daily CALIB FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
Daily CALIB TAM at RCH332
OBSERVED TAM at EAGLE CR ON BRG AT CSAH 21
Ammonia (mg/l as N)
Daily CALIB FLOW at RCH333
Flow (cfs)
Daily CALIB TAM at RCH333
OBSERVED TAM at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Ammonia (mg/l as N)
Daily CALIB FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Daily LPCAL03 TAM at RCH336
OBSERVED TAM at TURTLE CK ON BR AT OAK RIDGE RD
Ammonia (mg/l as N)
Daily CALIB FLOW at RCH338
Flow (cfs)
Daily LPCAL03 TAM at RCH338
OBSERVED TAM at MORAN CR ON 464TH ST
Ammonia (mg/l as N)
2003
2004
2005
2006
2007
2008
2009

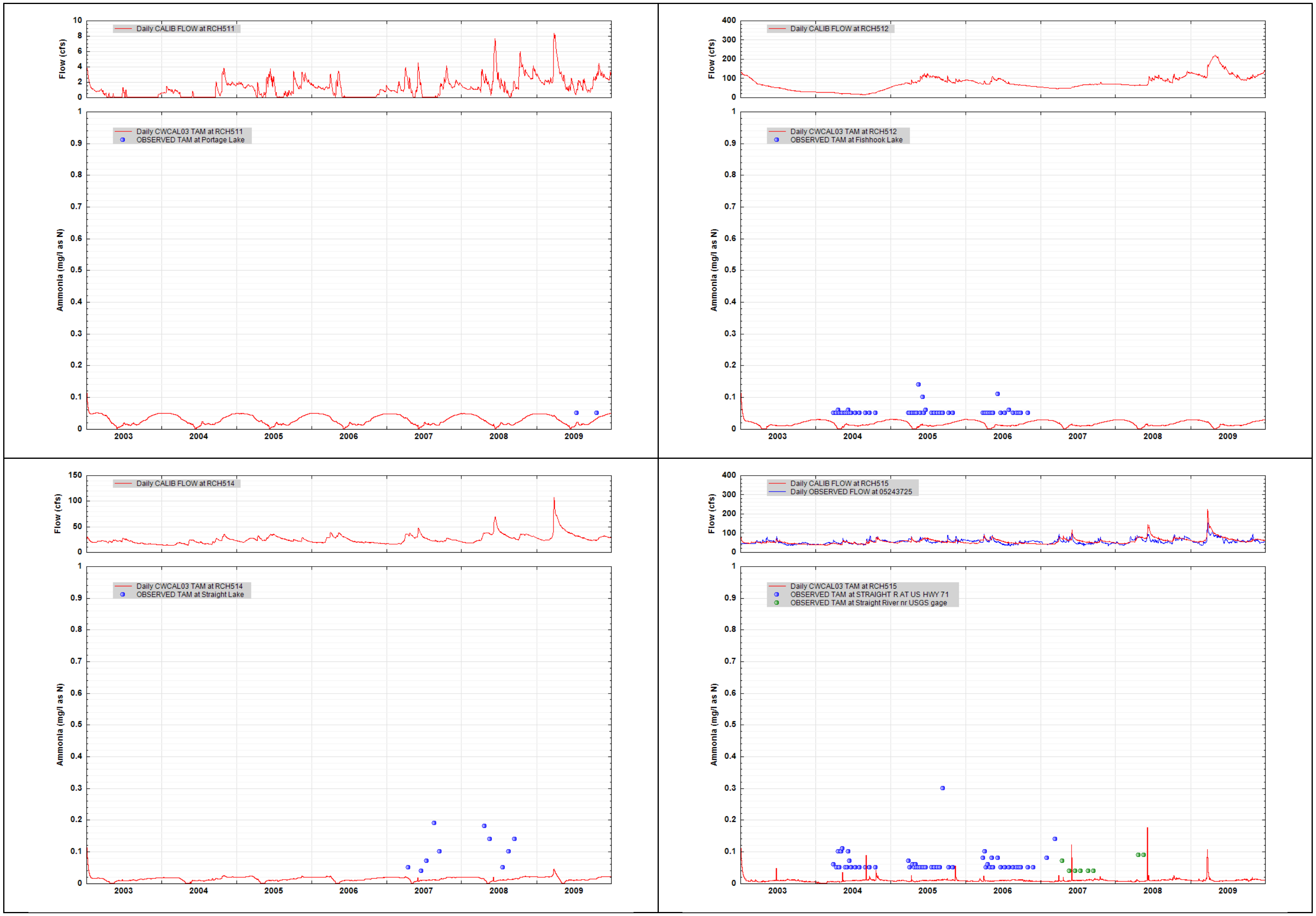

Flow (cfs)
Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH339
OBSERVED TAM at 05245295
OBSERVED TAM at MORAN CR ON BR AT 255TH AVE
2003
2004
2005
2006
2007
2008
2009


Flow (cfs)
Daily CALIB FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH341
OBSERVED TAM at LONG PRAIRIE R ON BR AT CR 65
2003
2004
2005
2006
2007
2008
2009

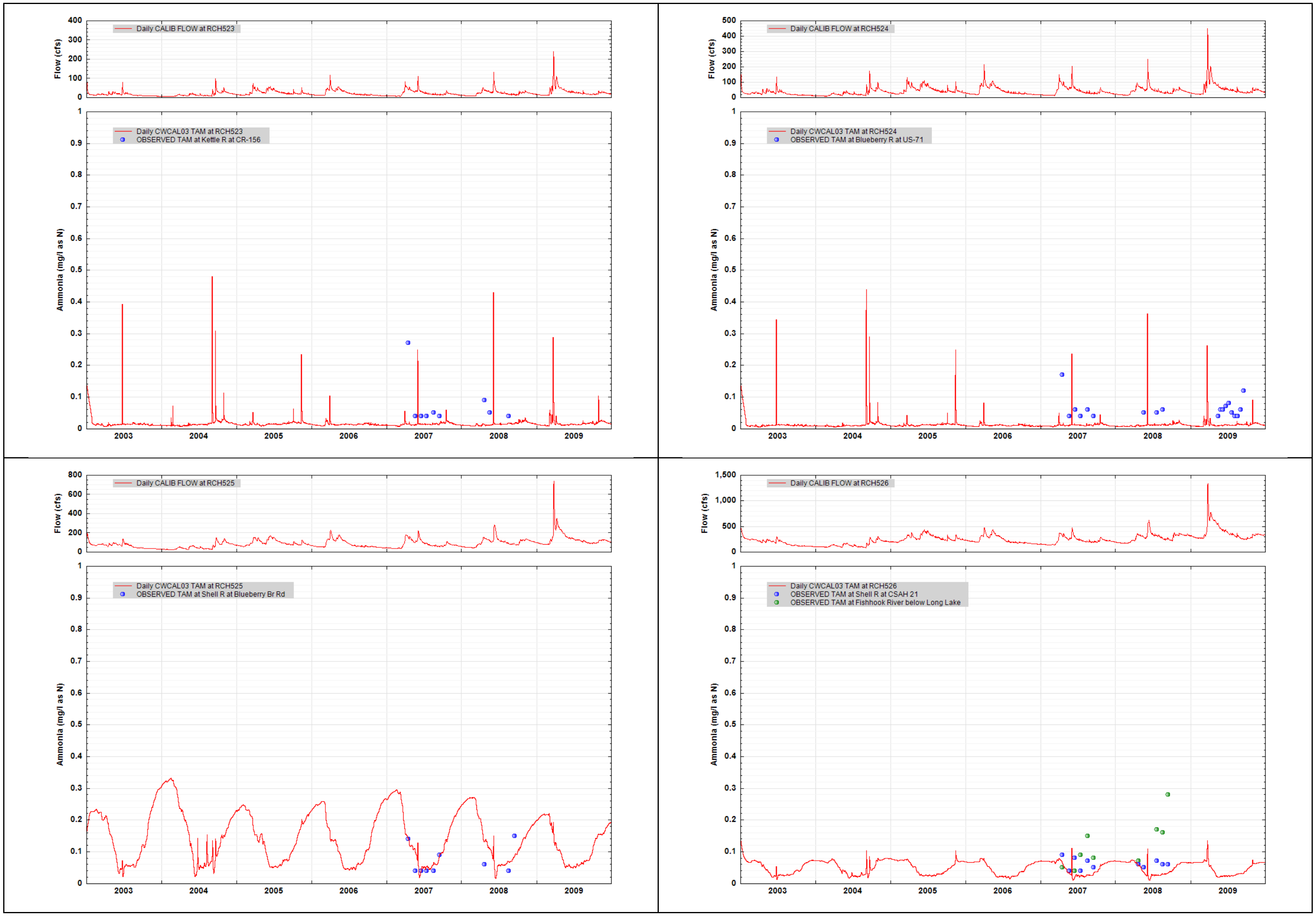

Flow (cfs)
Daily CALIB FLOW at RCH347
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH347
OBSERVED TAM at LONG PRAIRIE R BRIDGE ON US-10
2003
2004
2005
2006
2007
2008
2009


Flow (cfs)
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH400
OBSERVED TAM at LONG PRAIRIE R ON BR AT RIVERSIDE DR
2003
2004
2005
2006
2007
2008
2009

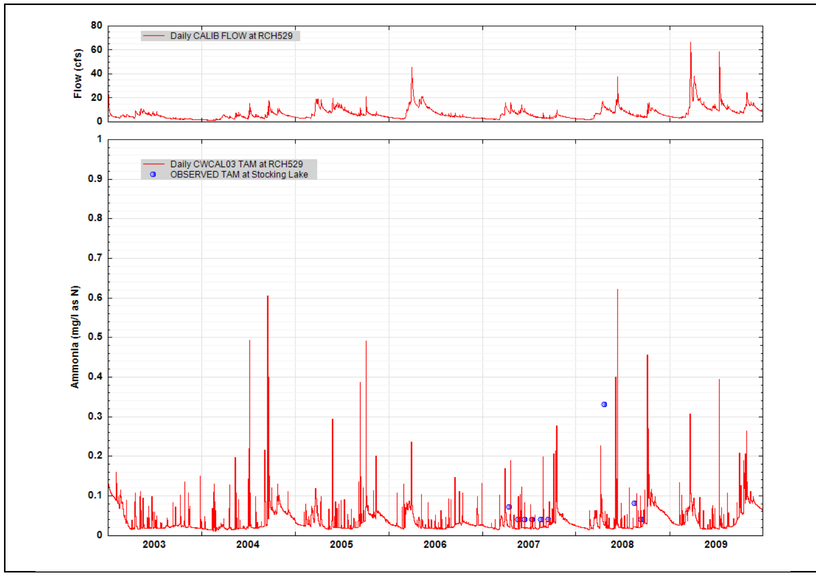
K.2.3 Crow Wing River Watershed

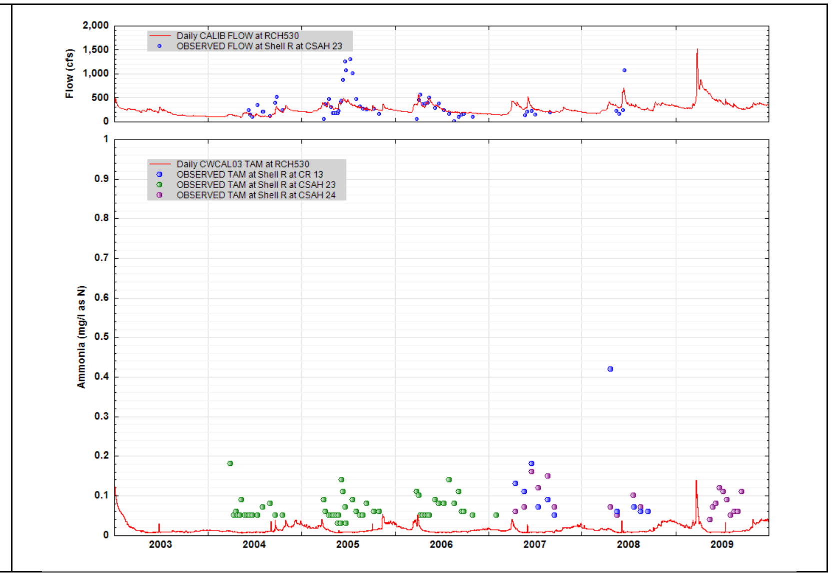



Daily CALIB FLOW at RCH517
Flow (cfs)
Daily CWCAL03 TAM at RCH517
OBSERVED TAM at Long Lake
Ammonia (mg/l as N)
Daily CALIB FLOW at RCH518
OBSERVED FLOW at Fishhook River above Long Lake
Daily CWCAL03 TAM at RCH518
OBSERVED TAM at Fishhook River above Long Lake
Daily CALIB FLOW at RCH521
OBSERVED FLOW at 05243200
Daily CWCAL03 TAM at RCH521
OBSERVED TAM at Shell R at US-71
OBSERVED TAM at 05243200
Daily CALIB FLOW at RCH522
Daily CWCAL03 TAM at RCH522
OBSERVED TAM at Blueberry R at 384th
2003
2004
2005
2006
2007
2008
2009

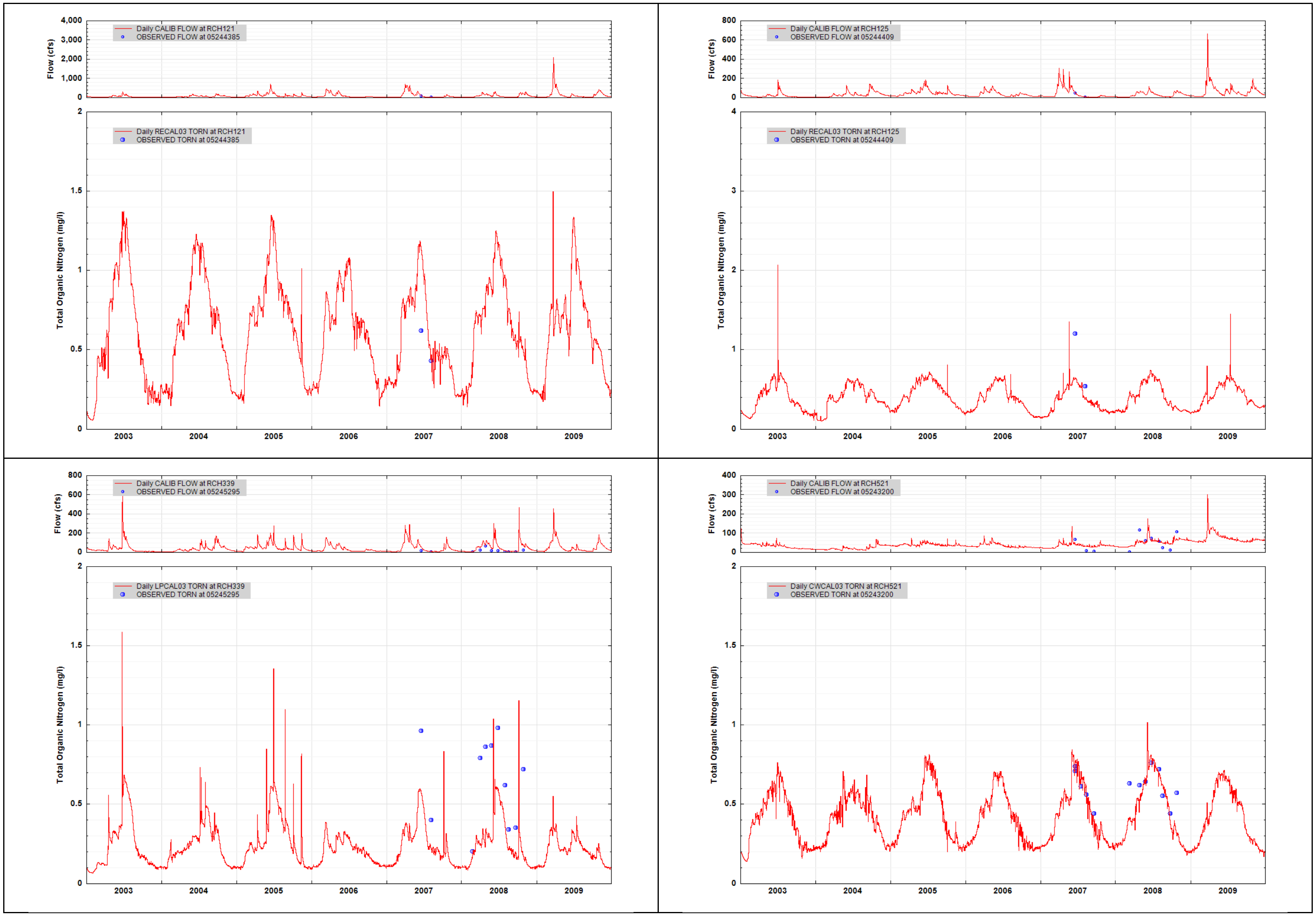


Daily CALIB FLOW at RCH523
Flow (cfs)
Daily CWCAL03 TAM at RCH523
OBSERVED TAM at Kettle R at CR-156
Ammonia (mg/l as N)
Daily CALIB FLOW at RCH524
Daily CWCAL03 TAM at RCH524
OBSERVED TAM at Blueberry R at US-71
Daily CALIB FLOW at RCH525
Daily CWCAL03 TAM at RCH525
OBSERVED TAM at Shell R at Blueberry Br Rd
Daily CALIB FLOW at RCH526
Daily CWCAL03 TAM at RCH526
OBSERVED TAM at Shell R at CSAH 21
OBSERVED TAM at Fishhook River below Long Lake
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH529
Flow (cfs)
Daily CWCAL03 TAM at RCH529
OBSERVED TAM at Stocking Lake
Ammonia (mg/l as N)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH530
OBSERVED FLOW at Shell R at CSAH 23
Flow (cfs)
Daily CWCAL03 TAM at RCH530
OBSERVED TAM at Shell R at CR 13
OBSERVED TAM at Shell R at CSAH 23
OBSERVED TAM at Shell R at CSAH 24
Ammonia (mg/l as N)
2003
2004
2005
2006
2007
2008
2009

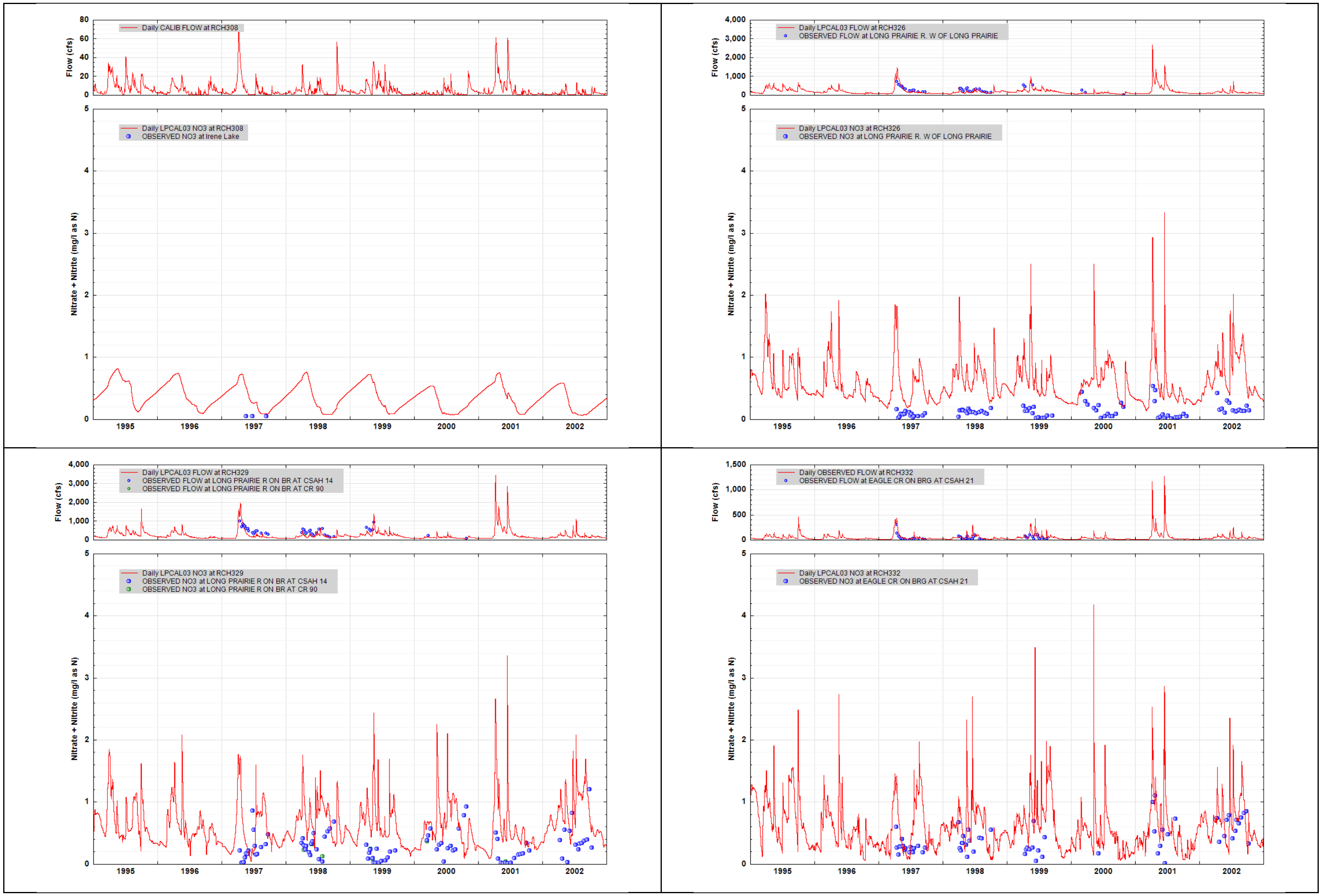
K.3 TOTAL ORGANIC NITROGEN

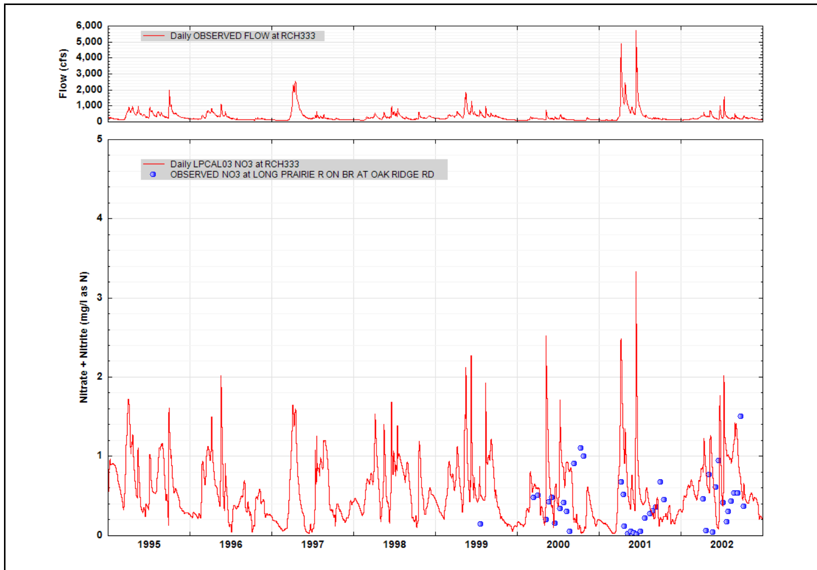


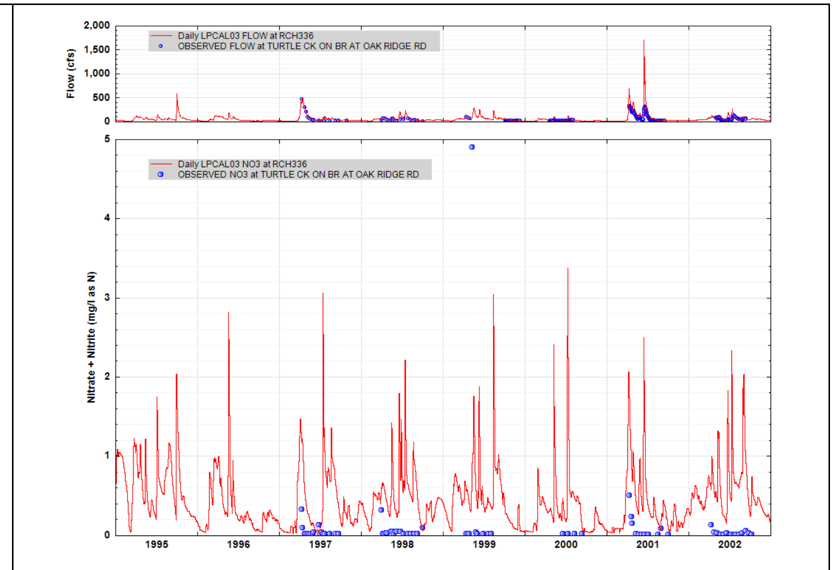
APPENDIX L
OBSERVED AND SIMULATED NITROGEN CONSTITUENTS FOR THE VALIDATION PERIOD

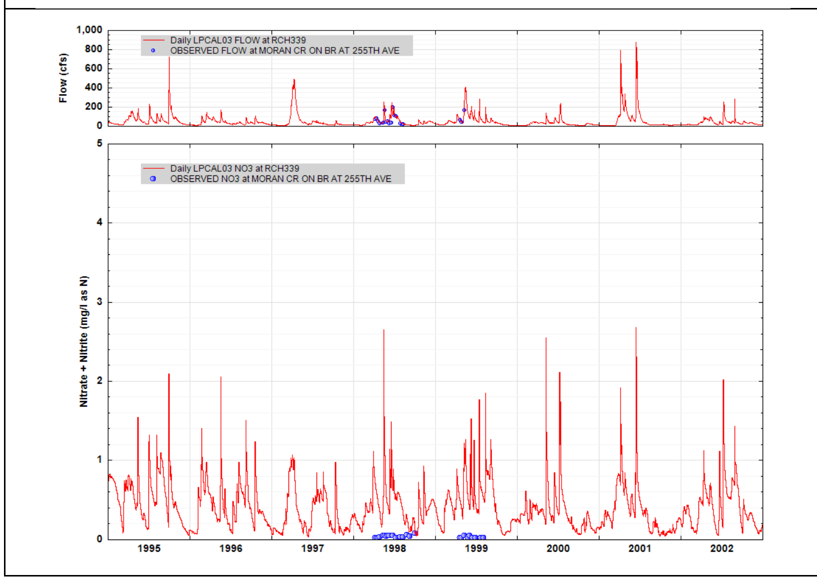
L.1 NITRATE

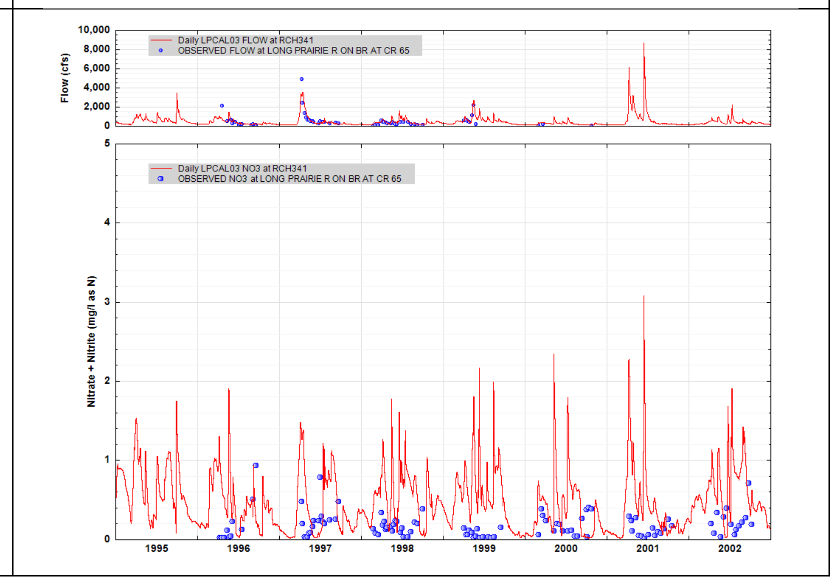
L.1.1 Long Prairie River Watershed

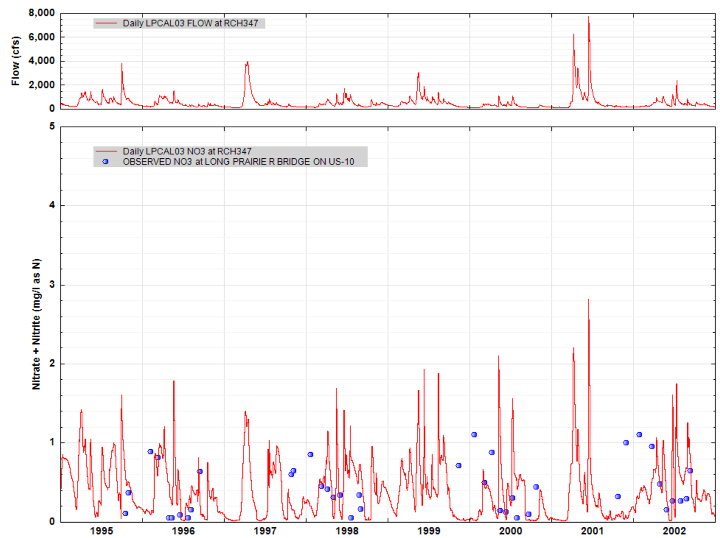



Daily OBSERVED FLOW at RCH333
Flow (cfs)
Daily LPCAL03 NO3 at RCH333
OBSERVED NO3 at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Nitrate + Nitrite (mg/l as N)
1995 1996 1997 1998 1999 2000 2001 2002

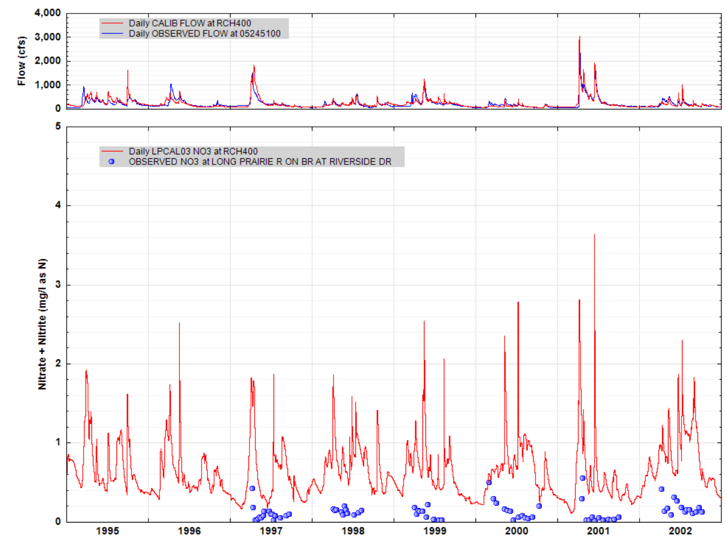

Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Daily LPCAL03 NO3 at RCH336
OBSERVED NO3 at TURTLE CK ON BR AT OAK RIDGE RD
Nitrate + Nitrite (mg/l as N)
1995 1996 1997 1998 1999 2000 2001 2002


Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Flow (cfs)
Daily LPCAL03 NO3 at RCH339
OBSERVED NO3 at MORAN CR ON BR AT 255TH AVE
Nitrate + Nitrite (mg/l as N)
1995 1996 1997 1998 1999 2000 2001 2002


Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Flow (cfs)
Daily LPCAL03 NO3 at RCH341
OBSERVED NO3 at LONG PRAIRIE R ON BR AT CR 65
Nitrate + Nitrite (mg/l as N)
1995 1996 1997 1998 1999 2000 2001 2002

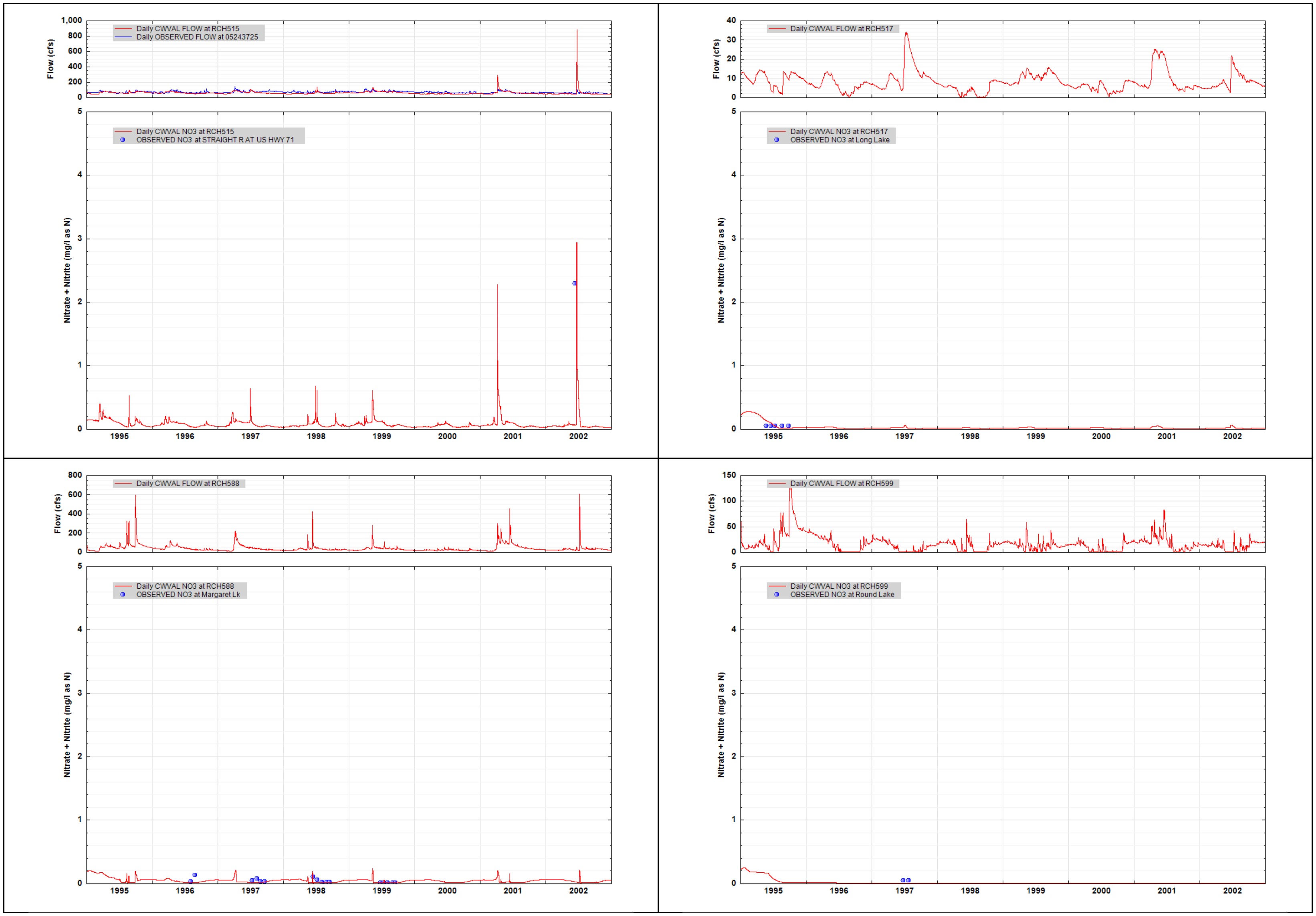


8,000
6,000
4,000
2,000
0
Flow (cfs)
Daily LPCAL03 FLOW at RCH347
5
4
3
2
1
0
Nitrate + Nitrite (mg/l as N)
Daily LPCAL03 NO3 at RCH347
OBSERVED NO3 at LONG PRAIRIE R BRIDGE ON US-10
1995
1996
1997
1998
1999
2000
2001
2002



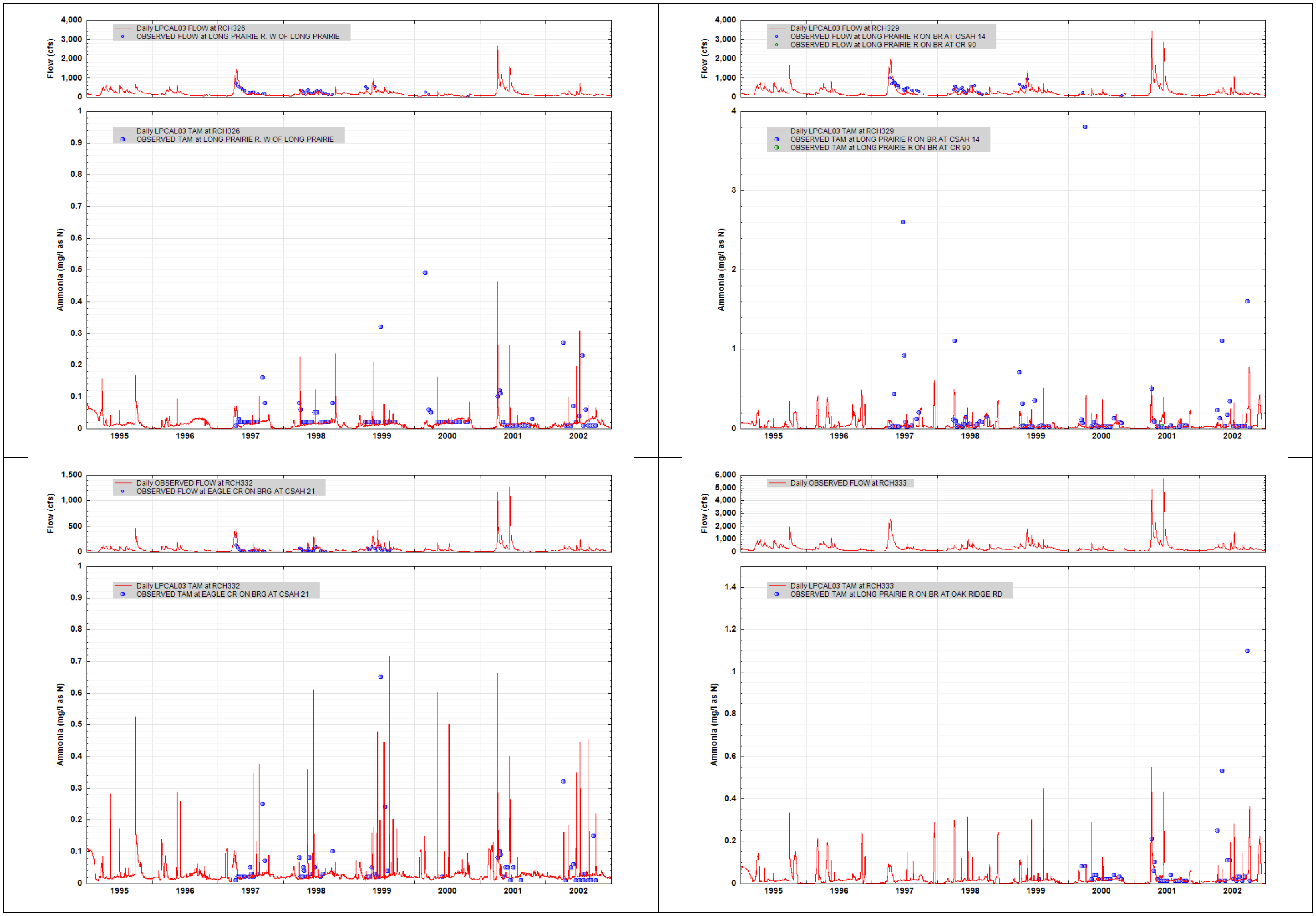
4,000
3,000
2,000
1,000
0
Flow (cfs)
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
5
4
3
2
1
0
Nitrate + Nitrite (mg/l as N)
Daily LPCAL03 NO3 at RCH400
OBSERVED NO3 at LONG PRAIRIE R ON BR AT RIVERSIDE DR
1995
1996
1997
1998
1999
2000
2001
2002

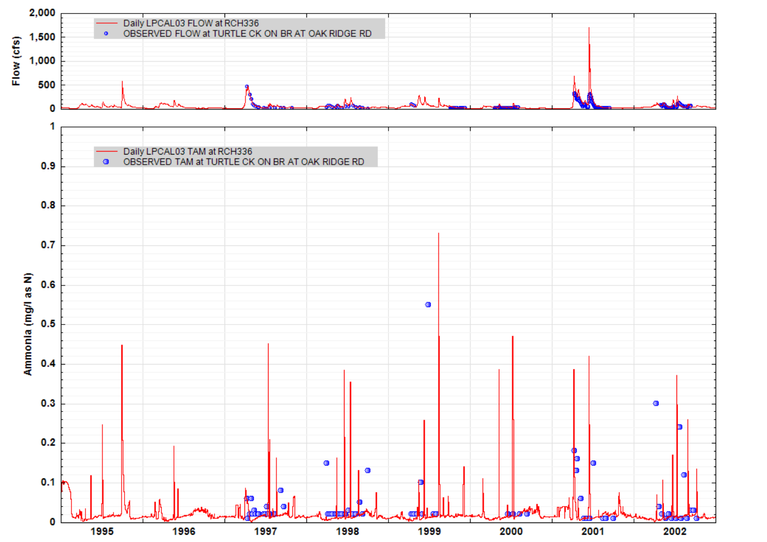
L.1.2 Crow Wing River Watershed



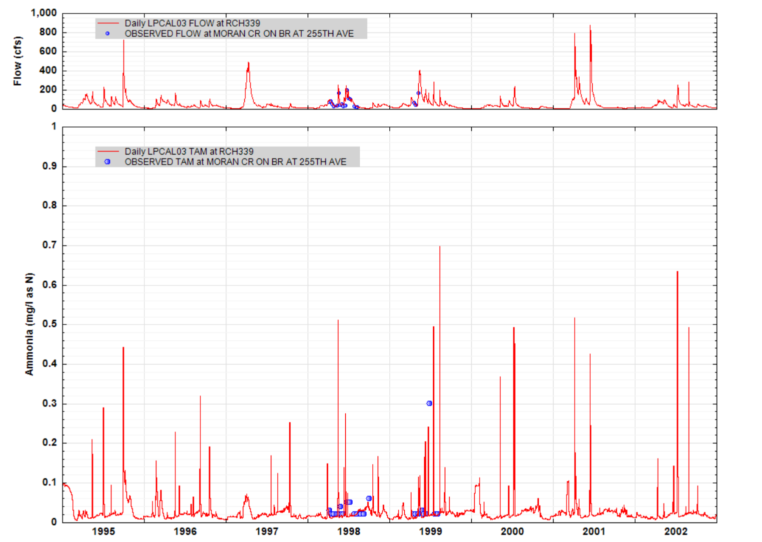
L.2 AMMONIA

L.2.1 Long Prairie River Watershed

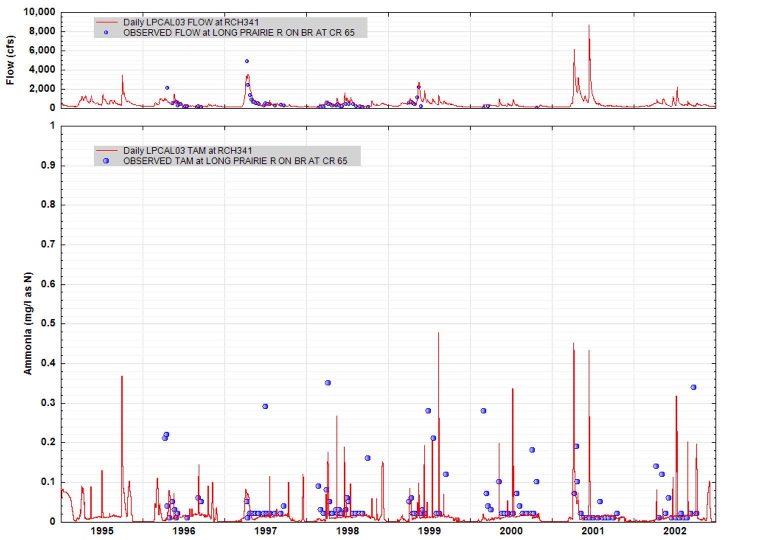




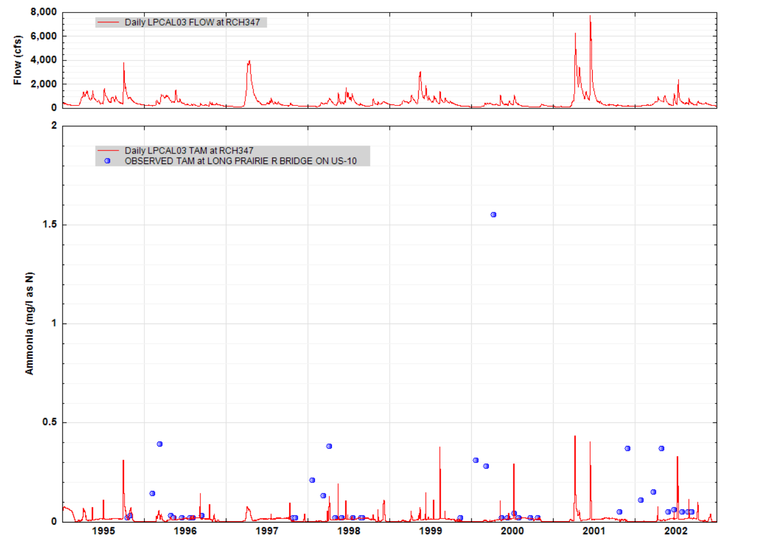
Flow (cfs)
Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH336
OBSERVED TAM at TURTLE CK ON BR AT OAK RIDGE RD
1995 1996 1997 1998 1999 2000 2001 2002



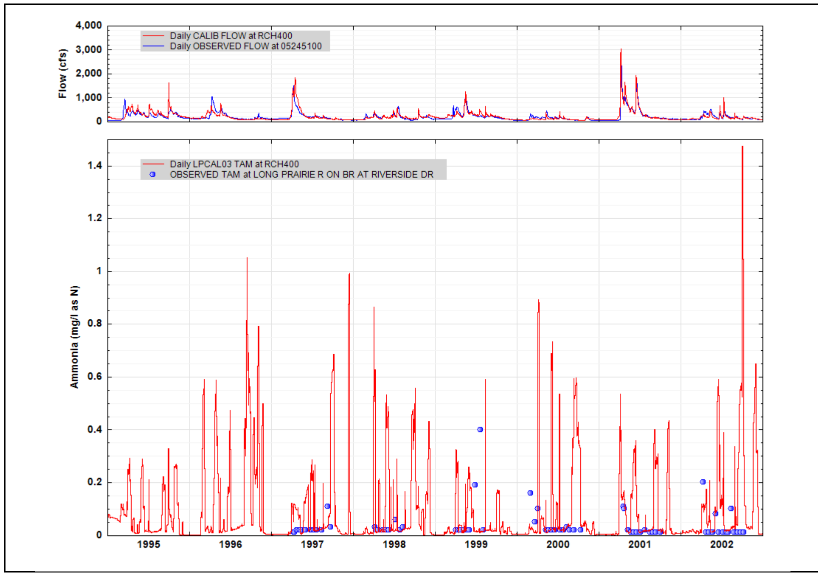
Flow (cfs)
Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH339
OBSERVED TAM at MORAN CR ON BR AT 255TH AVE
1995 1996 1997 1998 1999 2000 2001 2002



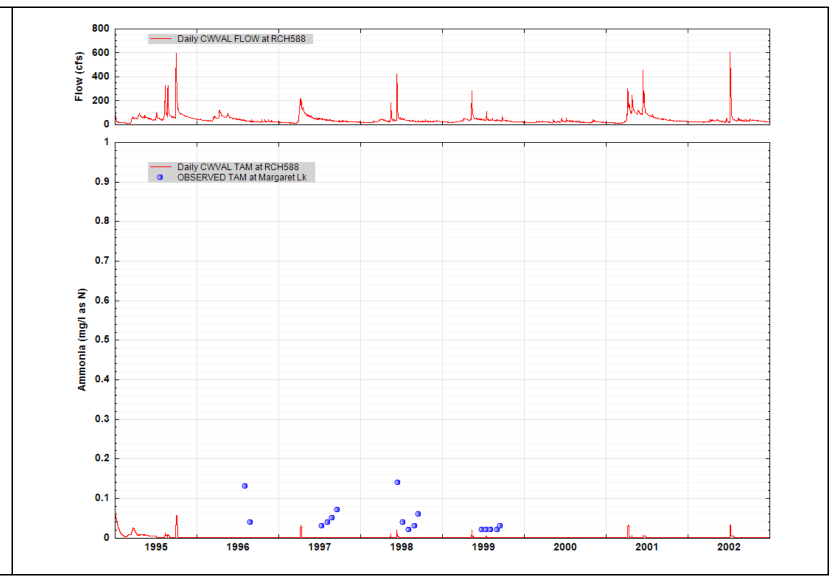
Flow (cfs)
Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH341
OBSERVED TAM at LONG PRAIRIE R ON BR AT CR 65
1995 1996 1997 1998 1999 2000 2001 2002



Flow (cfs)
Daily LPCAL03 FLOW at RCH347
Ammonia (mg/l as N)
Daily LPCAL03 TAM at RCH347
OBSERVED TAM at LONG PRAIRIE R BRIDGE ON US-10
1995 1996 1997 1998 1999 2000 2001 2002



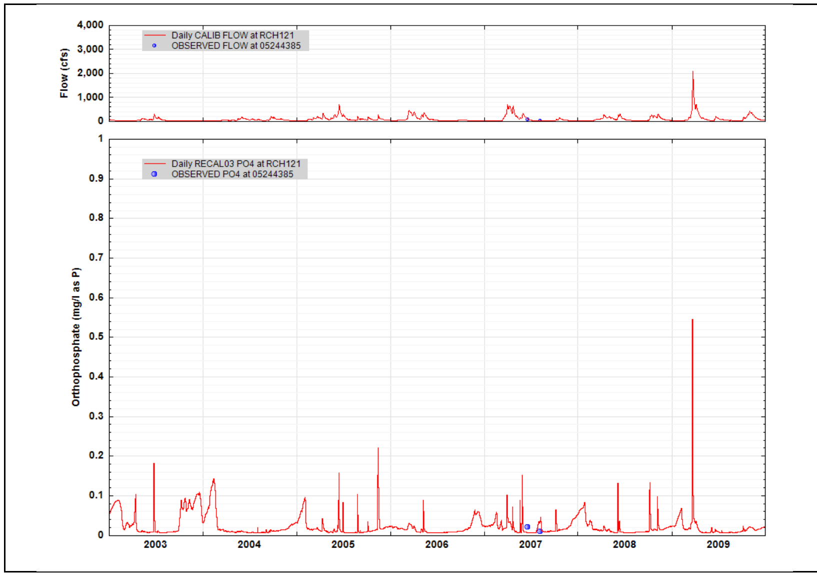
L.2.2 Crow Wing River Watershed

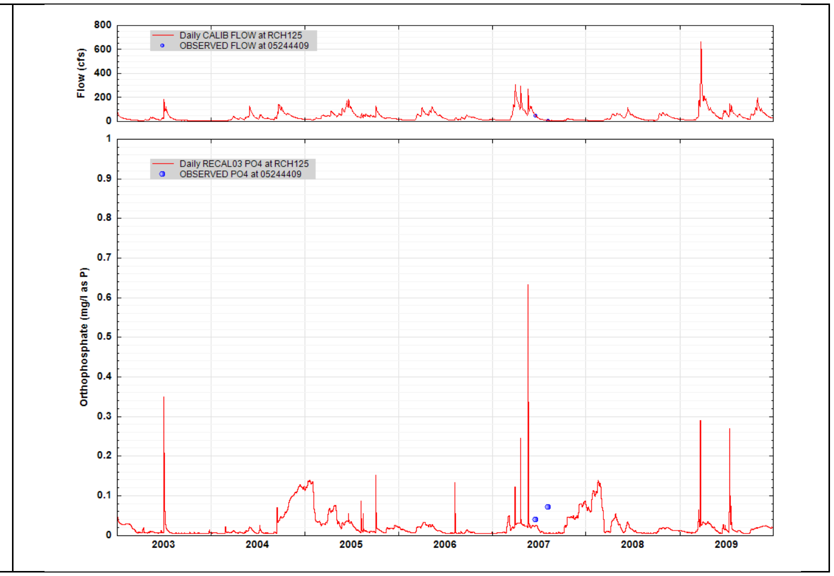


APPENDIX M
OBSERVED AND SIMULATED PHOSPHORUS CONSTITUENTS FOR THE CALIBRATION PERIOD

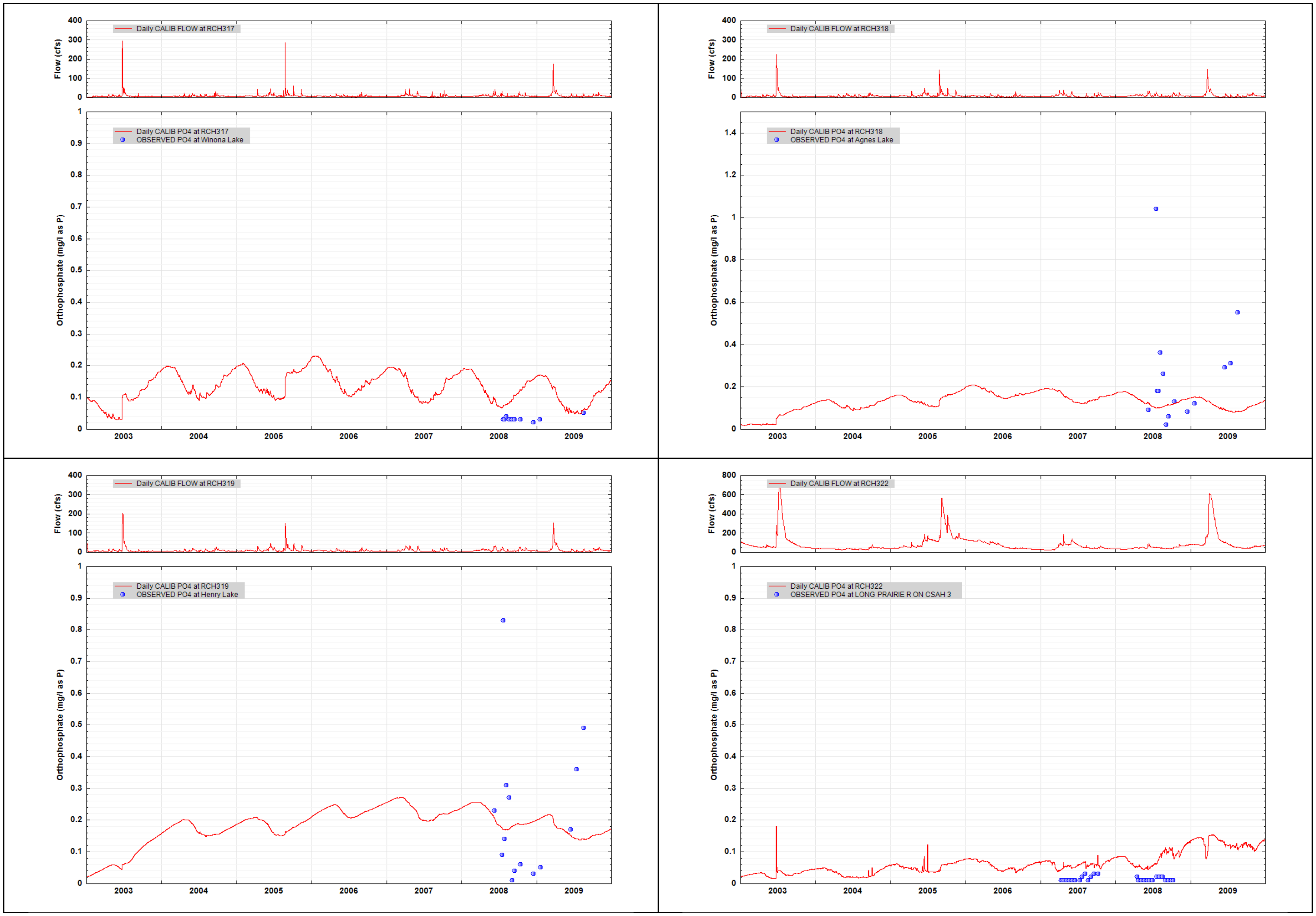
M.1 ORTHOPHOSPHATE

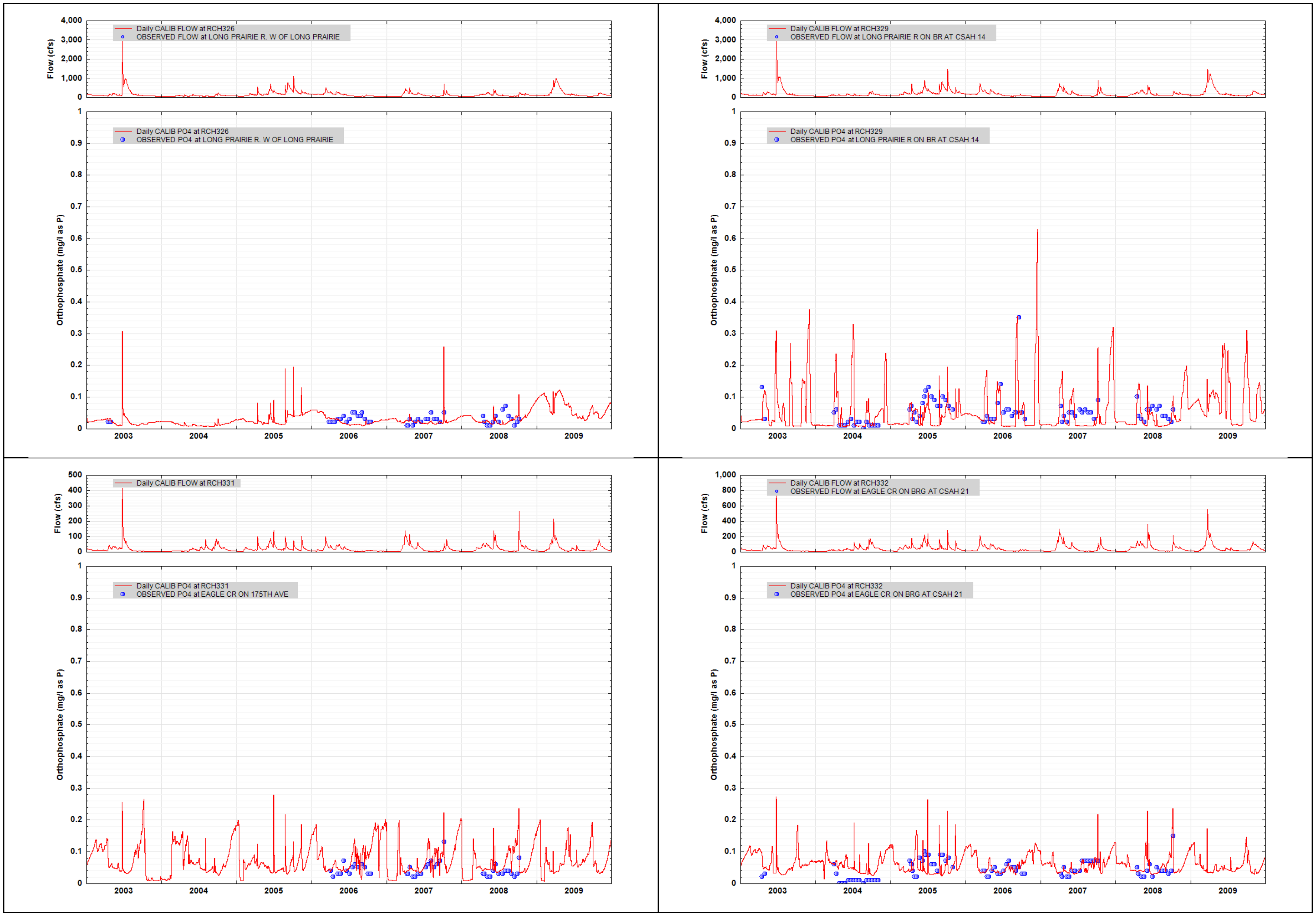
M.1.1 Redeye River Watershed



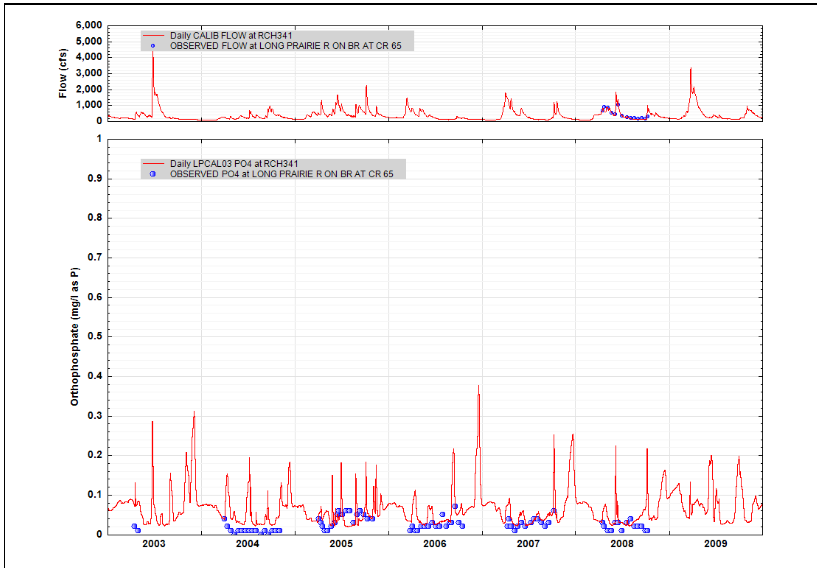


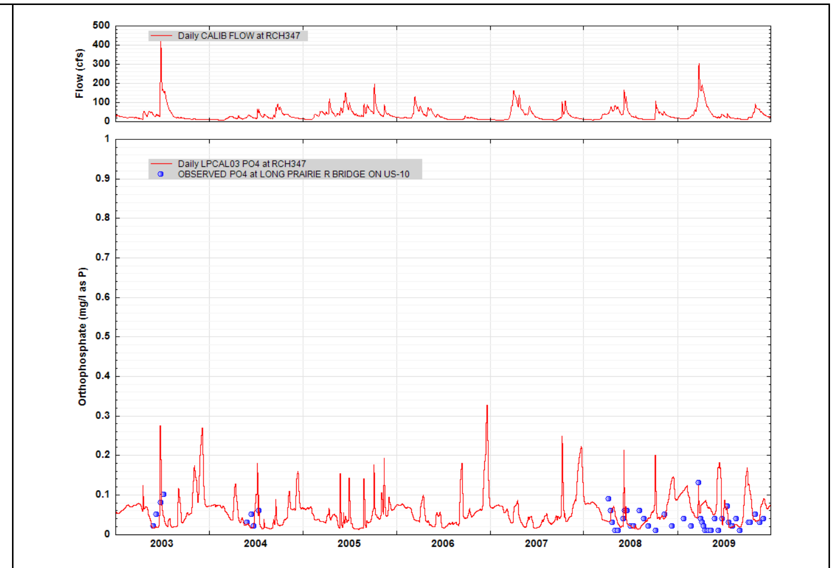
M.1.2 Long Prairie River Watershed

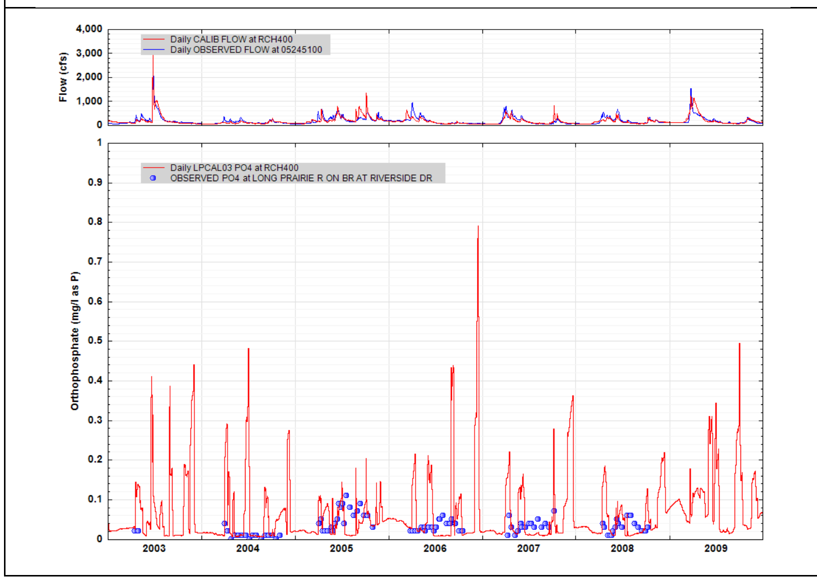



Daily CALIB FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Flow (cfs)
Daily CALIB PO4 at RCH326
OBSERVED PO4 at LONG PRAIRIE R. W OF LONG PRAIRIE
Orthophosphate (mg/l as P)
Daily CALIB FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
Daily CALIB PO4 at RCH329
OBSERVED PO4 at LONG PRAIRIE R ON BR AT CSAH 14
Daily CALIB FLOW at RCH331
Daily CALIB PO4 at RCH331
OBSERVED PO4 at EAGLE CR ON 175TH AVE
Daily CALIB FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Daily CALIB PO4 at RCH332
OBSERVED PO4 at EAGLE CR ON BRG AT CSAH 21
2003
2004
2005
2006
2007
2008
2009

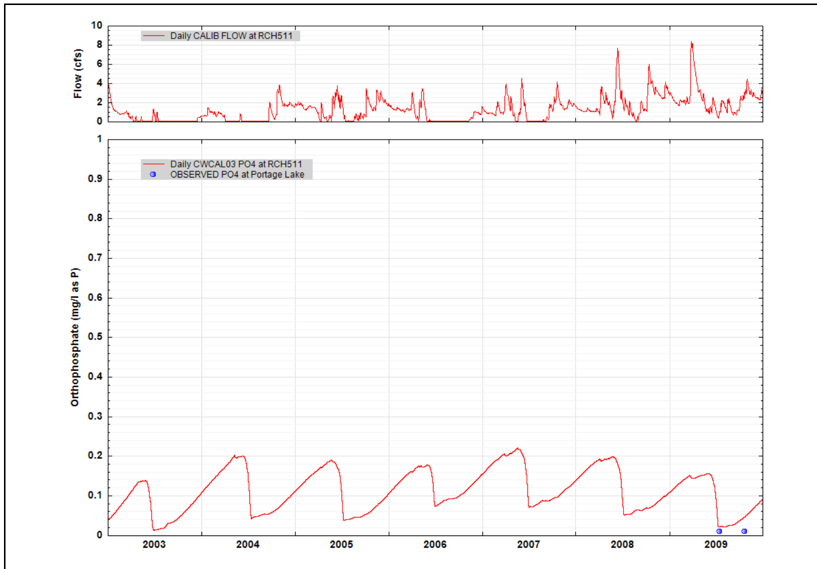

Daily CALIB FLOW at RCH333
Flow (cfs)
Daily CALIB PO4 at RCH333
OBSERVED PO4 at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Orthophosphate (mg/l as P)
Daily CALIB FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Daily LPCAL03 PO4 at RCH336
OBSERVED PO4 at TURTLE CK ON BR AT OAK RIDGE RD
Daily CALIB FLOW at RCH338
Daily LPCAL03 PO4 at RCH338
OBSERVED PO4 at MORAN CR ON 464TH ST
Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 PO4 at RCH339
OBSERVED PO4 at 05245295
OBSERVED PO4 at MORAN CR ON BR AT 255TH AVE
2003
2004
2005
2006
2007
2008
2009

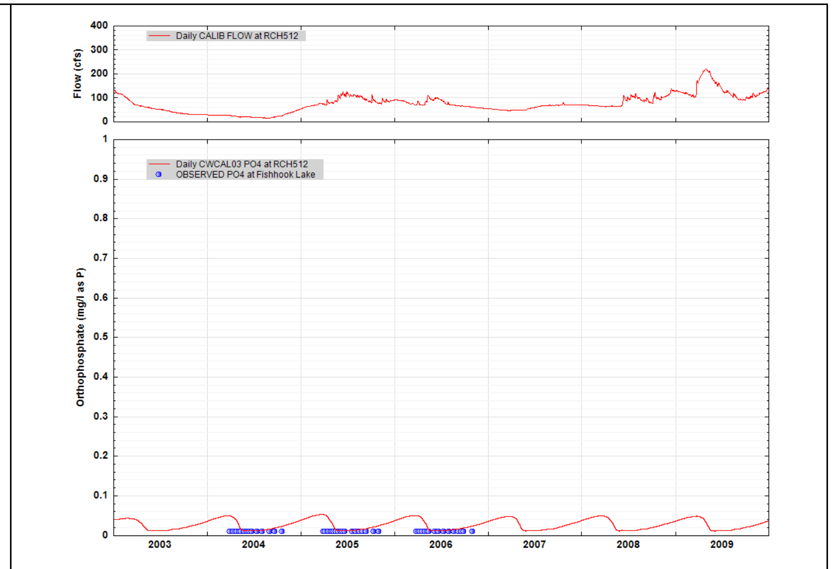

Daily CALIB FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Flow (cfs)
Daily LPCAL03 PO4 at RCH341
OBSERVED PO4 at LONG PRAIRIE R ON BR AT CR 65
Orthophosphate (mg/l as P)
2003
2004
2005
2006
2007
2008
2009

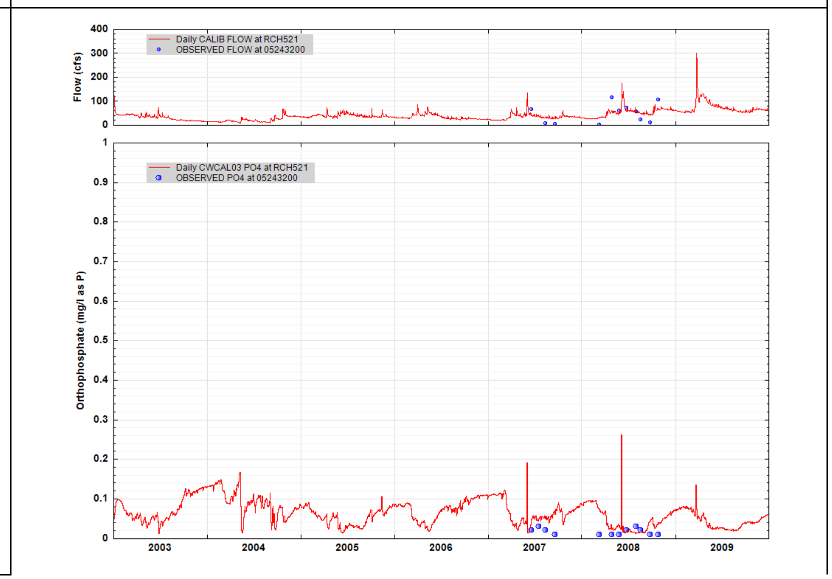

Daily CALIB FLOW at RCH347
Flow (cfs)
Daily LPCAL03 PO4 at RCH347
OBSERVED PO4 at LONG PRAIRIE R BRIDGE ON US-10
Orthophosphate (mg/l as P)
2003
2004
2005
2006
2007
2008
2009

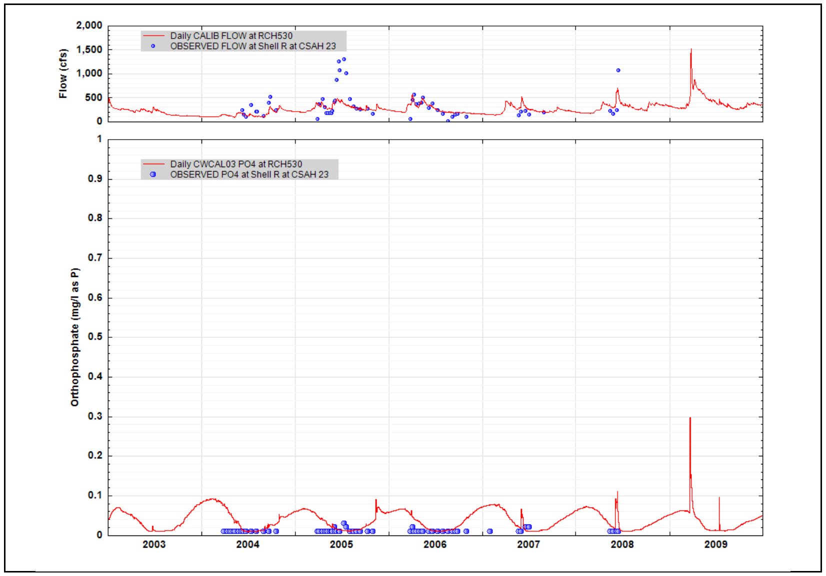

Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Flow (cfs)
Daily LPCAL03 PO4 at RCH400
OBSERVED PO4 at LONG PRAIRIE R ON BR AT RIVERSIDE DR
Orthophosphate (mg/l as P)
2003
2004
2005
2006
2007
2008
2009

M.1.3 Crow Wing River Watershed



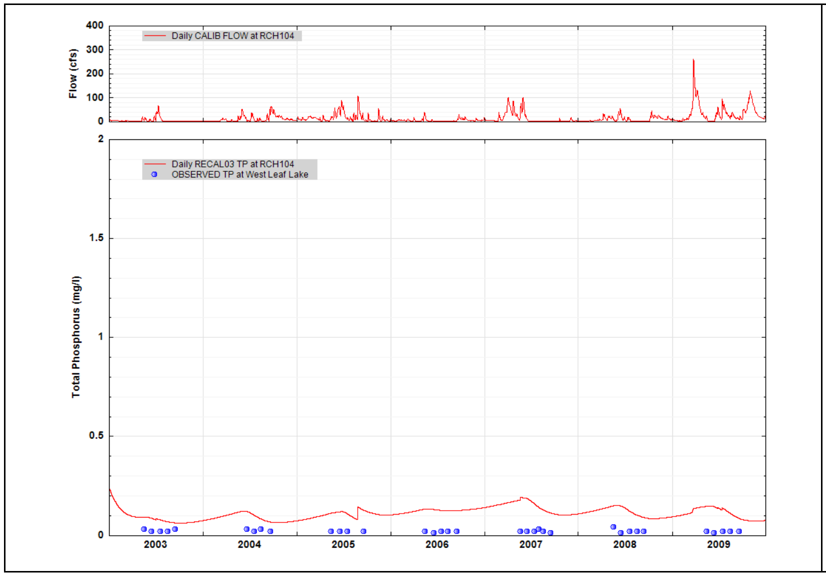


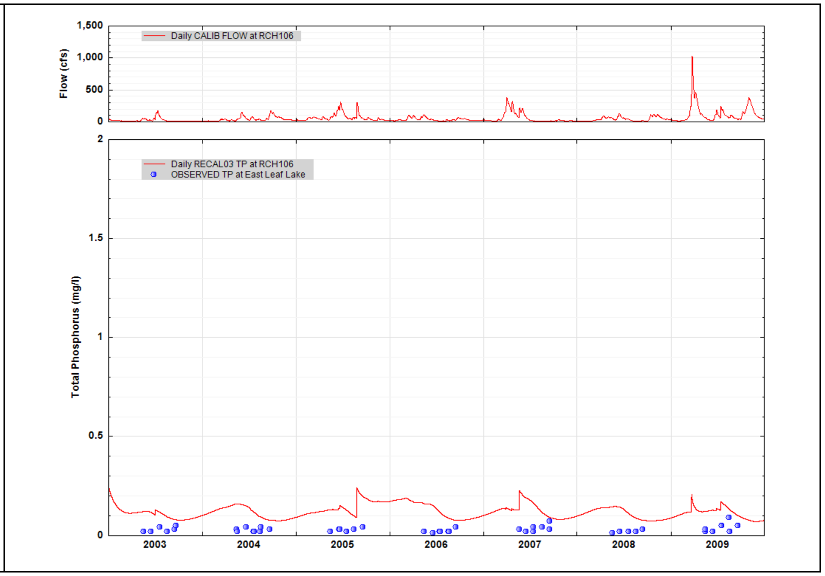


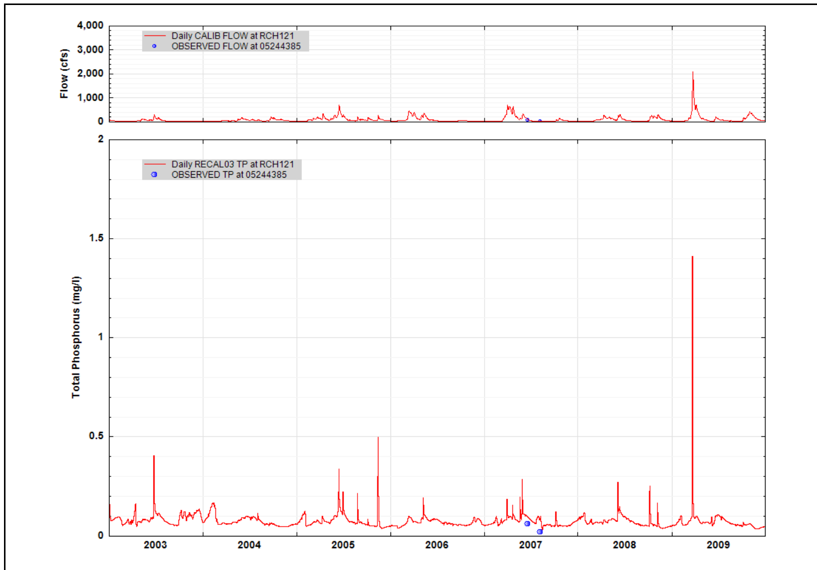


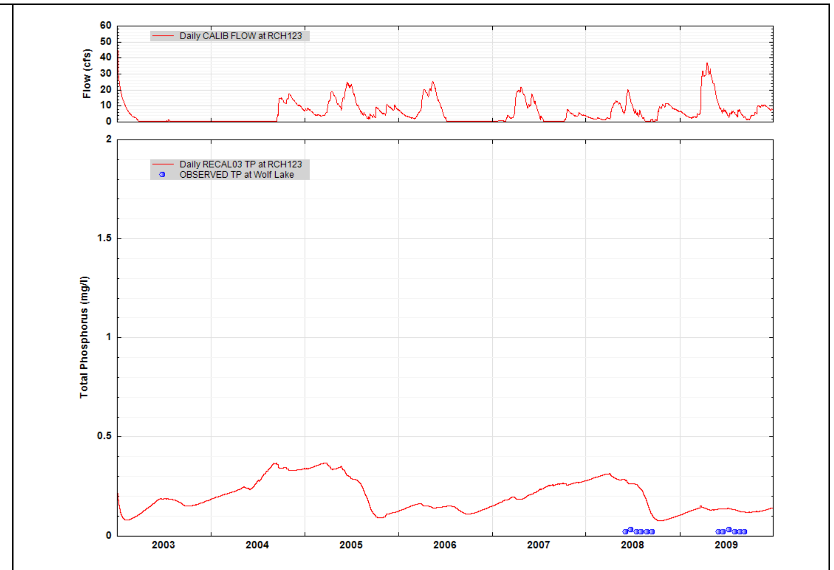
M.2 TOTAL PHOSPHORUS

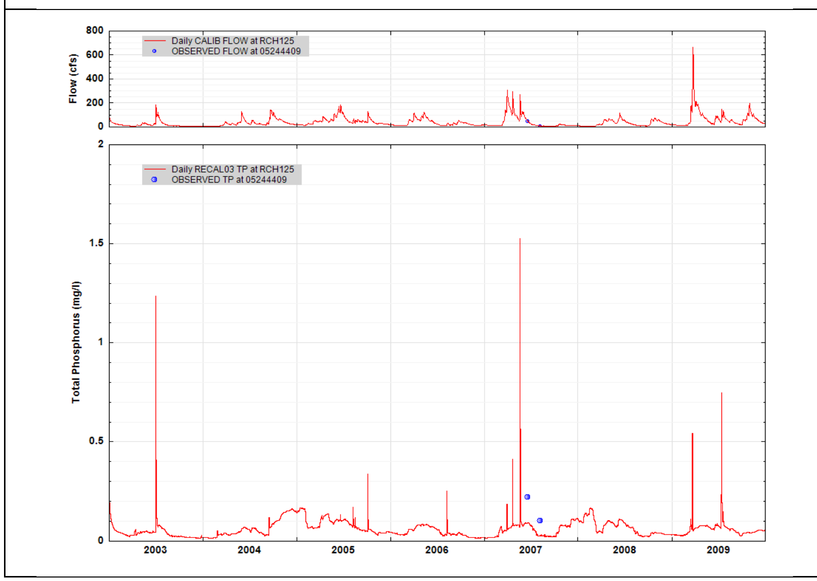
M.2.1 Redeye River Watershed



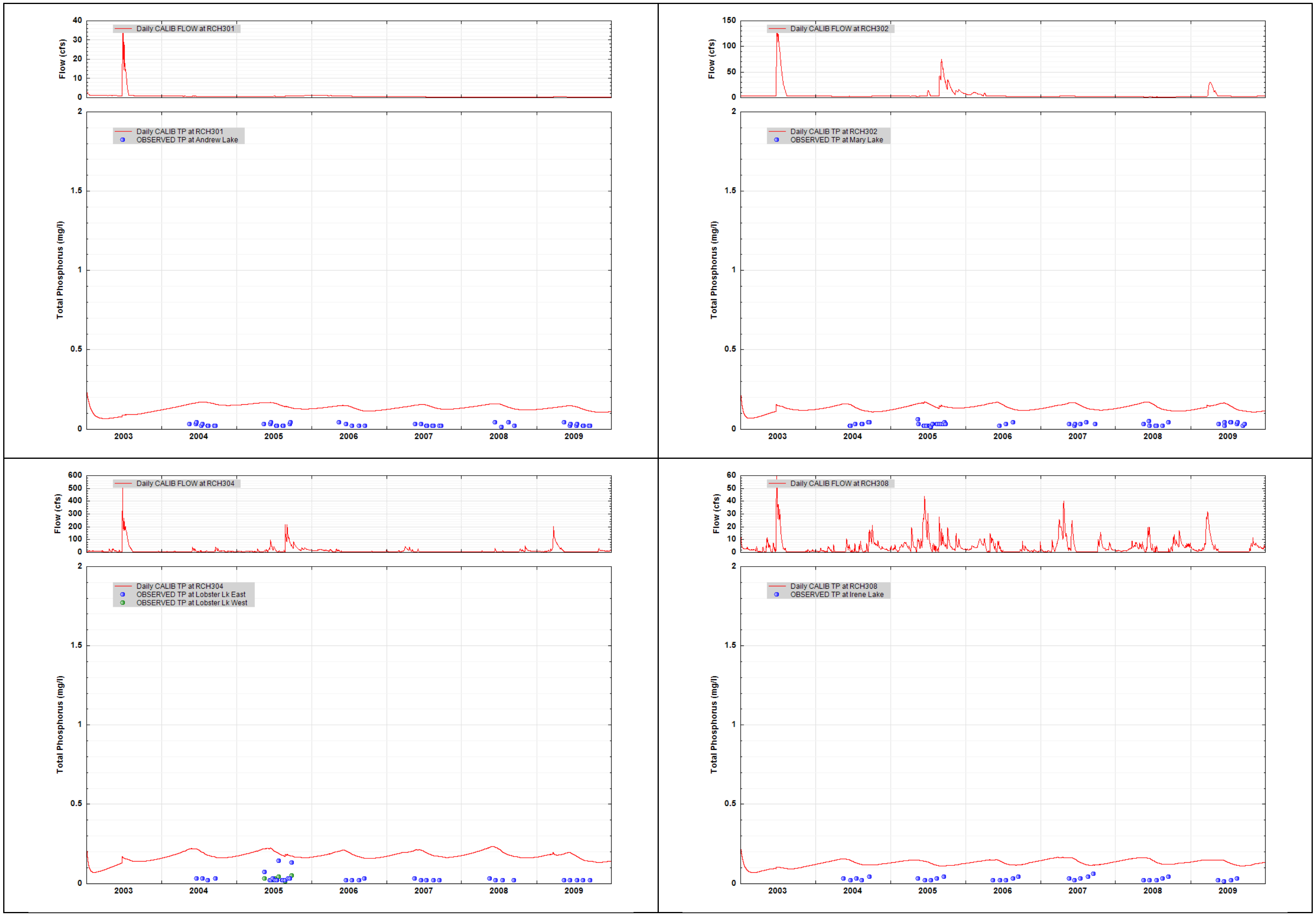


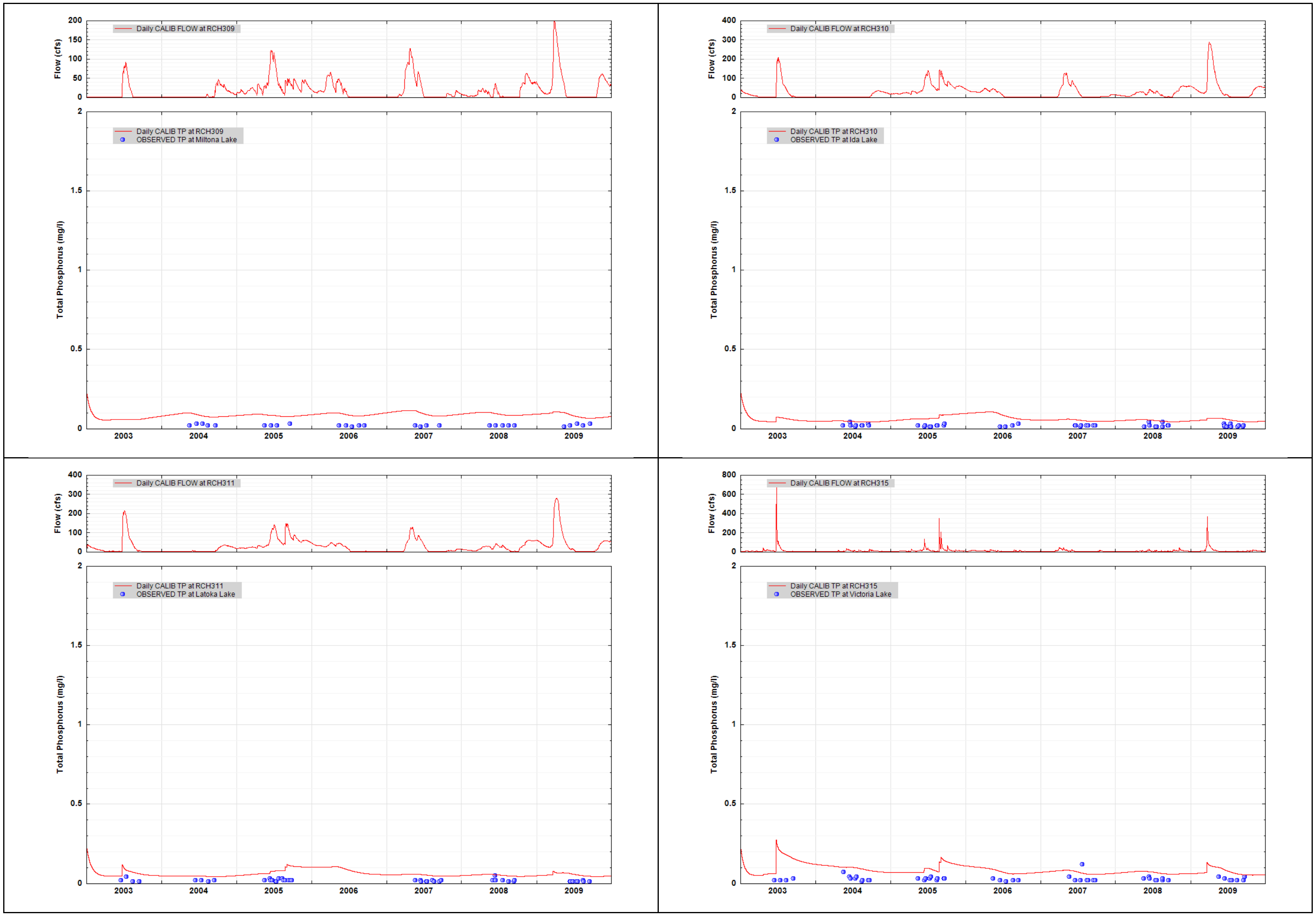

Flow (cfs)
Daily CALIB FLOW at RCH121
OBSERVED FLOW at 05244385
Total Phosphorus (mg/l)
Daily RECAL03 TP at RCH121
OBSERVED TP at 05244385
2003
2004
2005
2006
2007
2008
2009

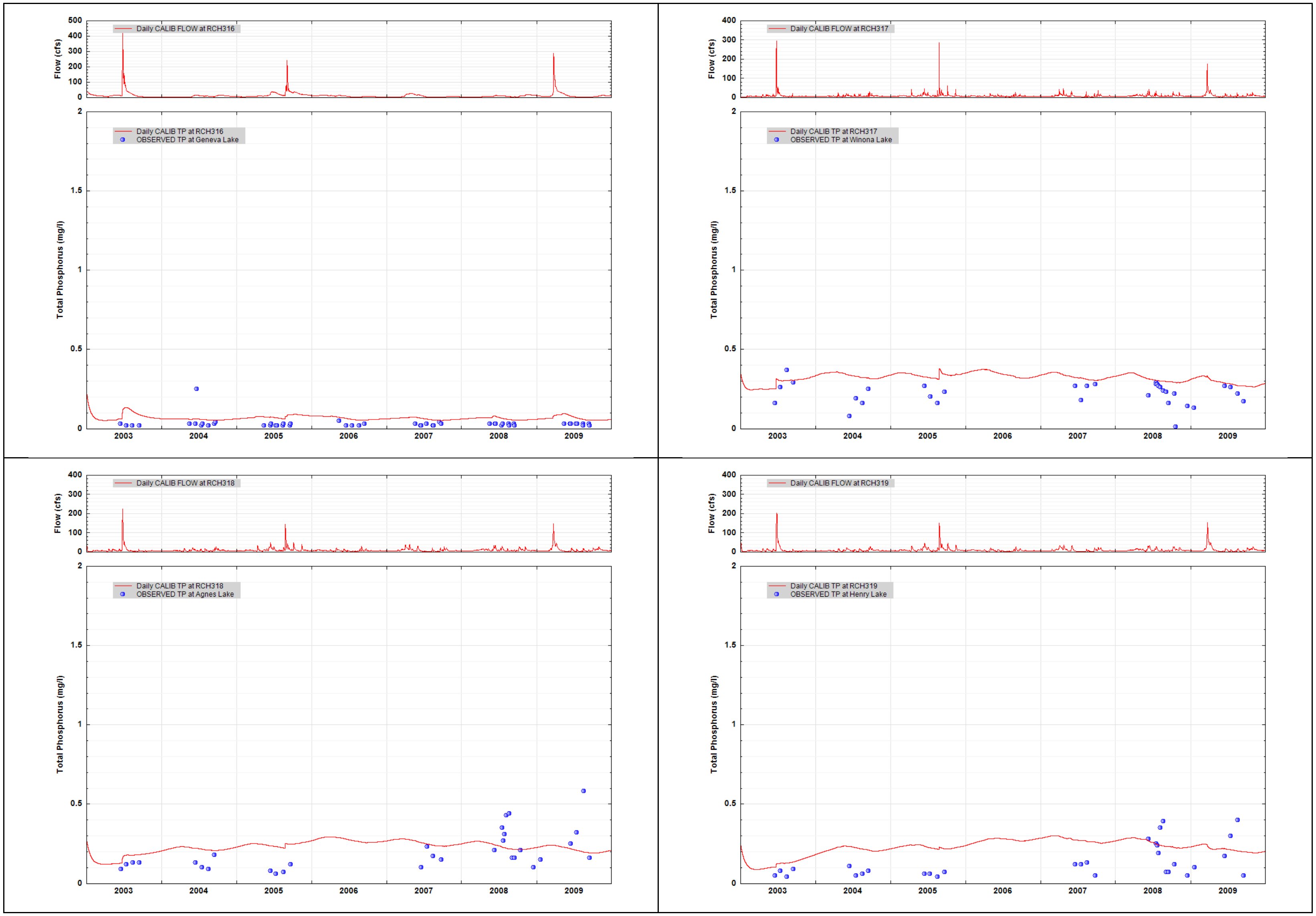

Flow (cfs)
Daily CALIB FLOW at RCH123
Total Phosphorus (mg/l)
Daily RECAL03 TP at RCH123
OBSERVED TP at Wolf Lake
2003
2004
2005
2006
2007
2008
2009


Flow (cfs)
Daily CALIB FLOW at RCH125
OBSERVED FLOW at 05244409
Total Phosphorus (mg/l)
Daily RECAL03 TP at RCH125
OBSERVED TP at 05244409
2003
2004
2005
2006
2007
2008
2009

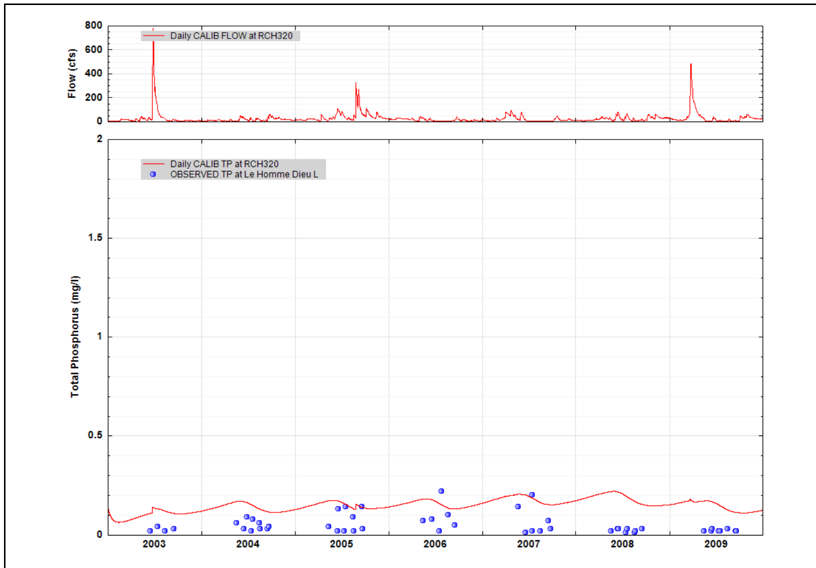
M.2.2 Long Prairie River Watershed

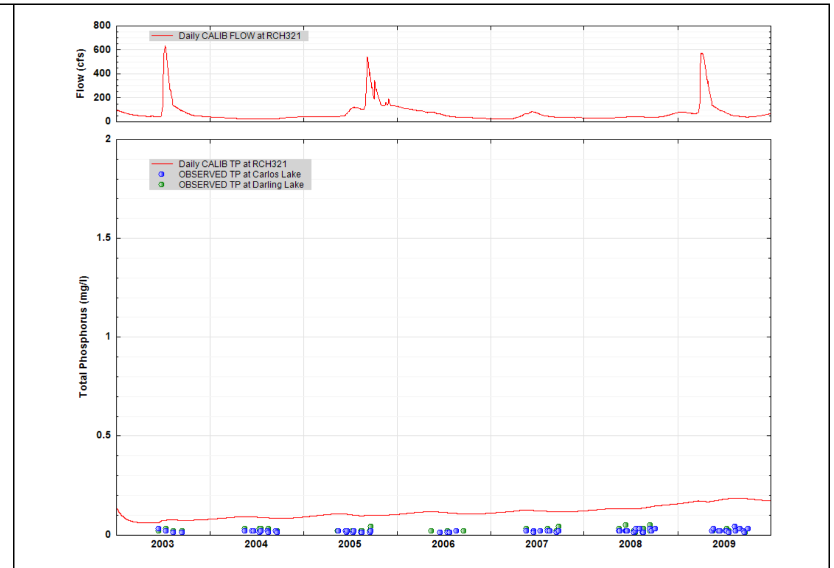


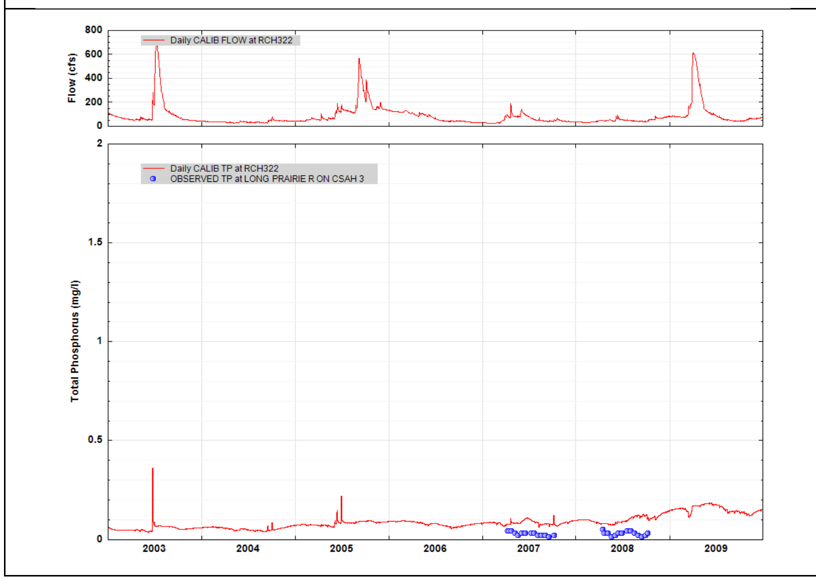

Daily CALIB FLOW at RCH309
Flow (cfs)
Daily CALIB TP at RCH309
OBSERVED TP at Miltona Lake
Total Phosphorus (mg/l)
Daily CALIB FLOW at RCH310
Daily CALIB TP at RCH310
OBSERVED TP at Ida Lake
Daily CALIB FLOW at RCH311
Daily CALIB TP at RCH311
OBSERVED TP at Latoka Lake
Daily CALIB FLOW at RCH315
Daily CALIB TP at RCH315
OBSERVED TP at Victoria Lake
2003
2004
2005
2006
2007
2008
2009

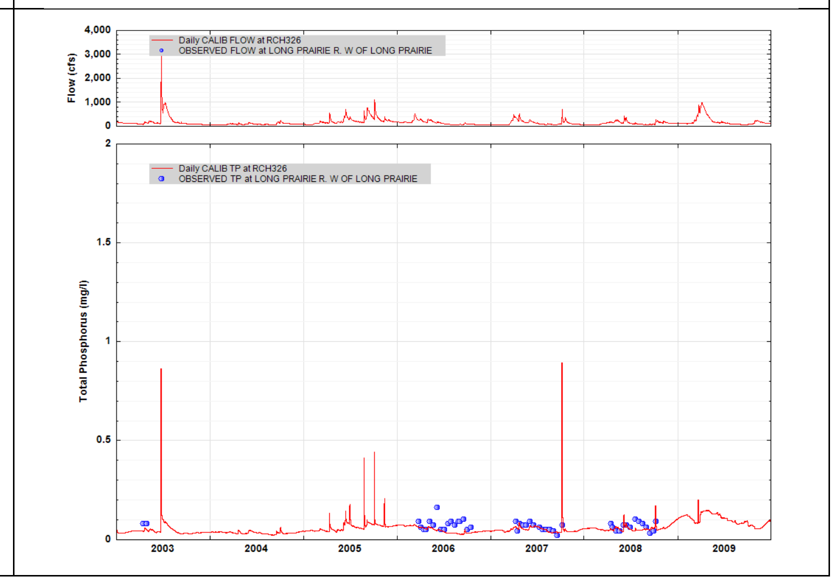


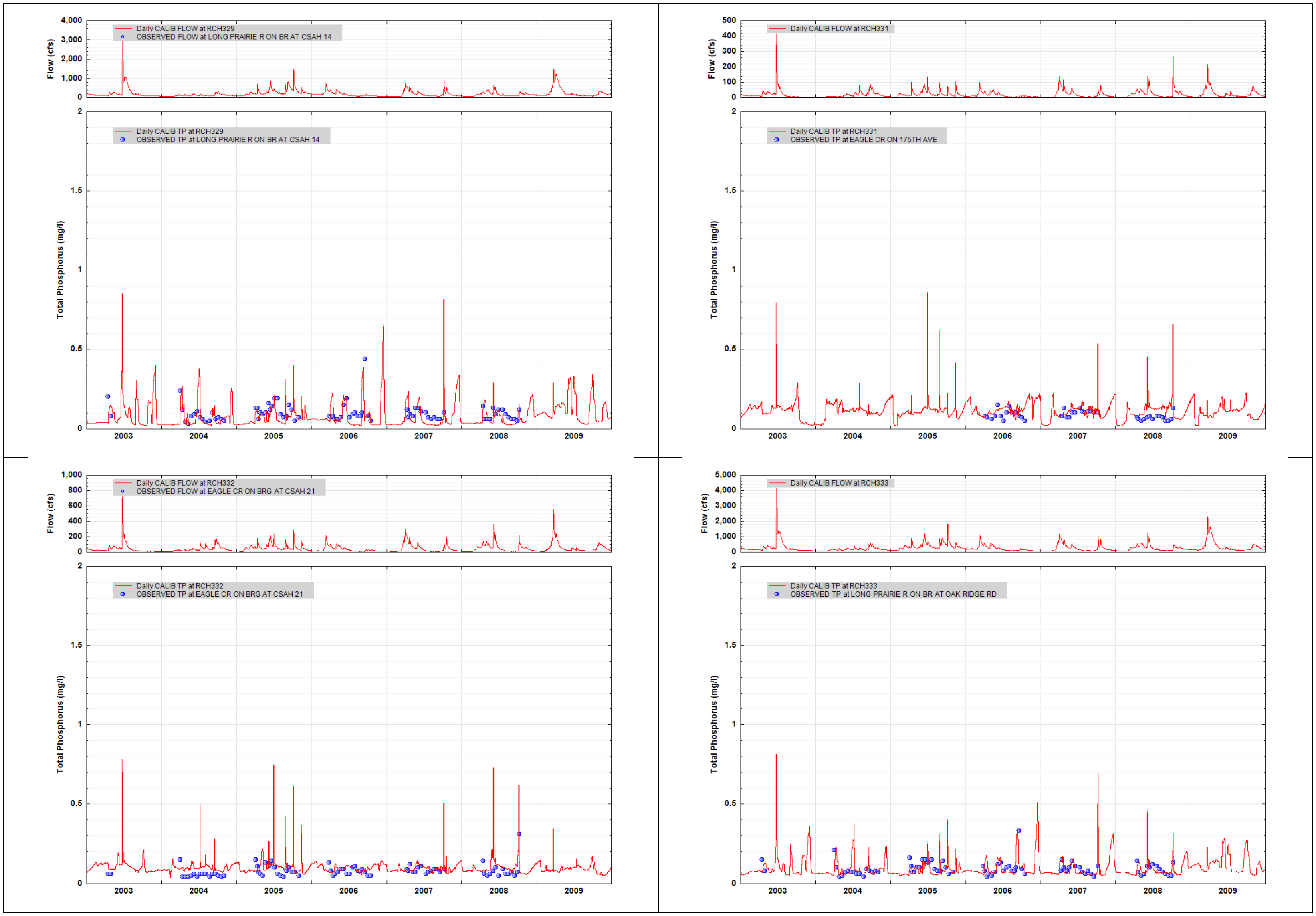
Daily CALIB FLOW at RCH316
Flow (cfs)
Daily CALIB TP at RCH316
OBSERVED TP at Geneva Lake
Total Phosphorus (mg/l)
Daily CALIB FLOW at RCH317
Daily CALIB TP at RCH317
OBSERVED TP at Winona Lake
Daily CALIB FLOW at RCH318
Daily CALIB TP at RCH318
OBSERVED TP at Agnes Lake
Daily CALIB FLOW at RCH319
Daily CALIB TP at RCH319
OBSERVED TP at Henry Lake
2003
2004
2005
2006
2007
2008
2009

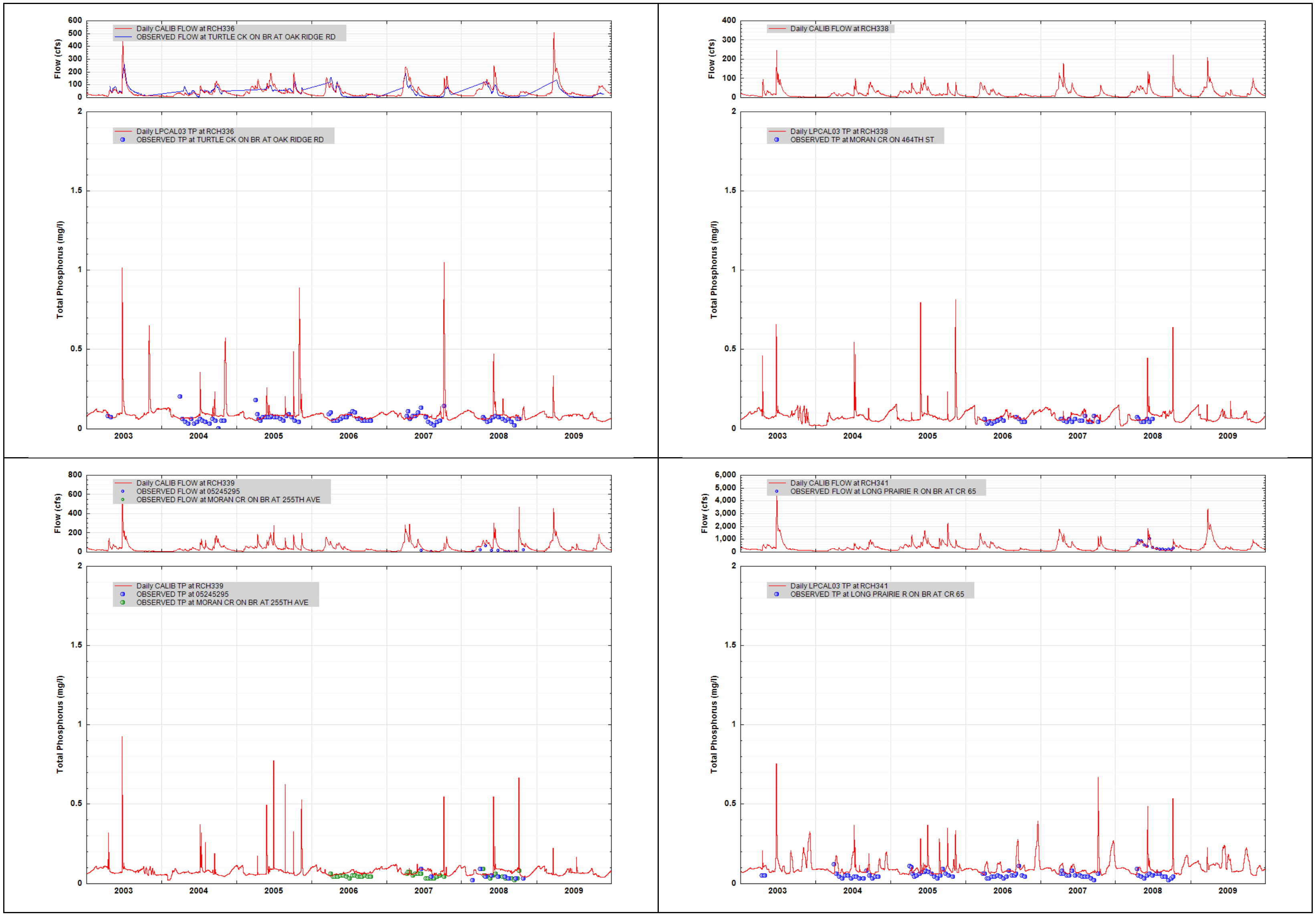

Daily CALIB FLOW at RCH320
Flow (cfs)
Daily CALIB TP at RCH320
OBSERVED TP at Le Homme Dieu L
Total Phosphorus (mg/l)
2003 2004 2005 2006 2007 2008 2009

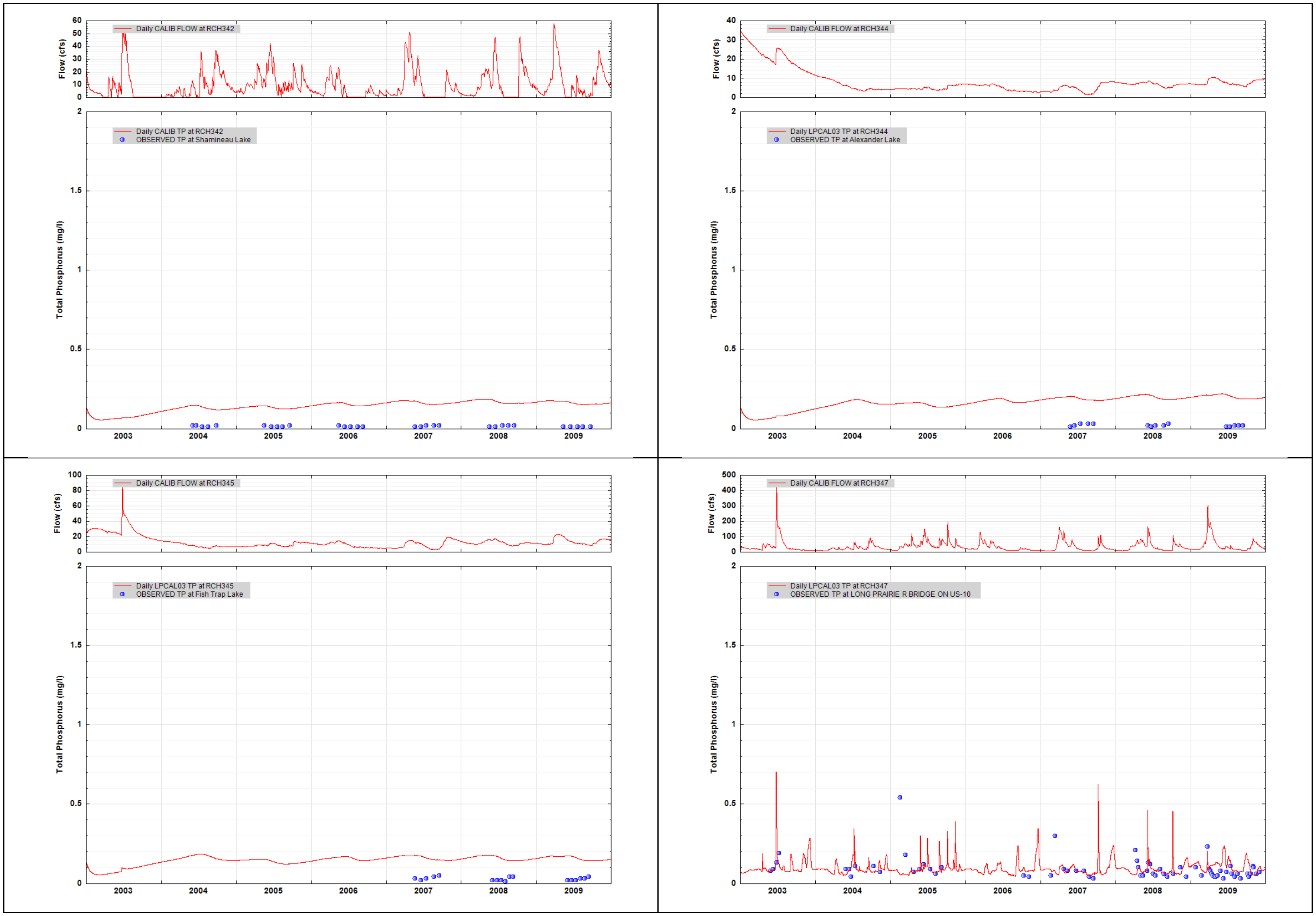

Daily CALIB FLOW at RCH321
Flow (cfs)
Daily CALIB TP at RCH321
OBSERVED TP at Carlos Lake
OBSERVED TP at Darling Lake
Total Phosphorus (mg/l)
2003 2004 2005 2006 2007 2008 2009

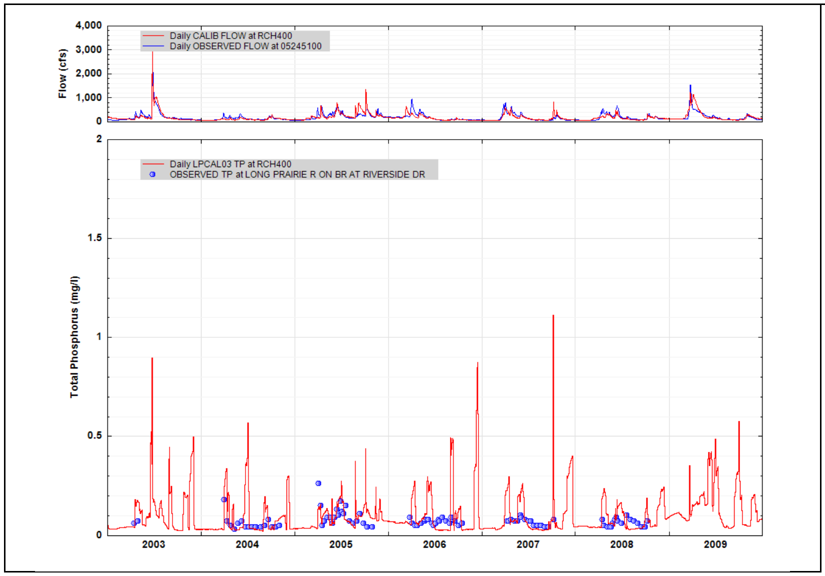

Daily CALIB FLOW at RCH322
Flow (cfs)
Daily CALIB TP at RCH322
OBSERVED TP at LONG PRAIRIE R ON CSAH 3
Total Phosphorus (mg/l)
2003 2004 2005 2006 2007 2008 2009


Daily CALIB FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Flow (cfs)
Daily CALIB TP at RCH326
OBSERVED TP at LONG PRAIRIE R. W OF LONG PRAIRIE
Total Phosphorus (mg/l)
2003 2004 2005 2006 2007 2008 2009

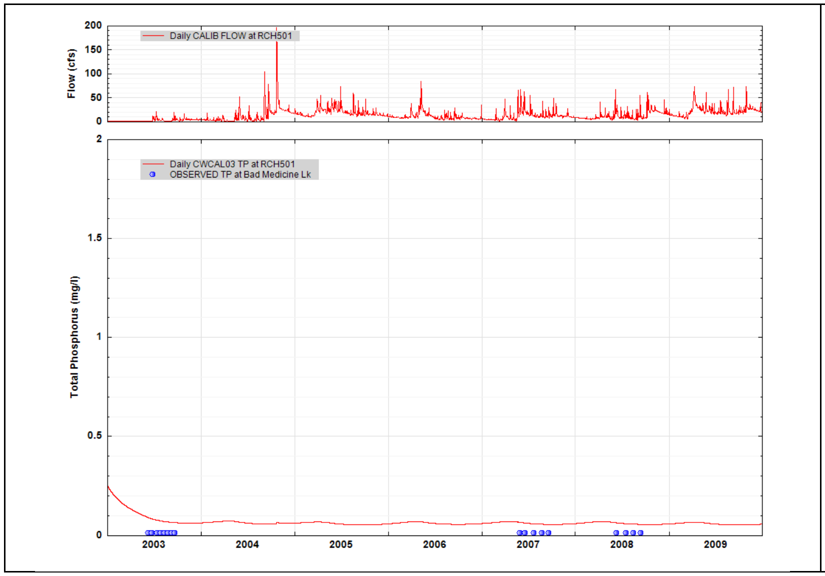

Daily CALIB FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
Flow (cfs)
Daily CALIB TP at RCH329
OBSERVED TP at LONG PRAIRIE R ON BR AT CSAH 14
Total Phosphorus (mg/l)
Daily CALIB FLOW at RCH331
Daily CALIB TP at RCH331
OBSERVED TP at EAGLE CR ON 175TH AVE
Daily CALIB FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Daily CALIB TP at RCH332
OBSERVED TP at EAGLE CR ON BRG AT CSAH 21
Daily CALIB FLOW at RCH333
Daily CALIB TP at RCH333
OBSERVED TP at LONG PRAIRIE R ON BR AT OAK RIDGE RD
2003
2004
2005
2006
2007
2008
2009

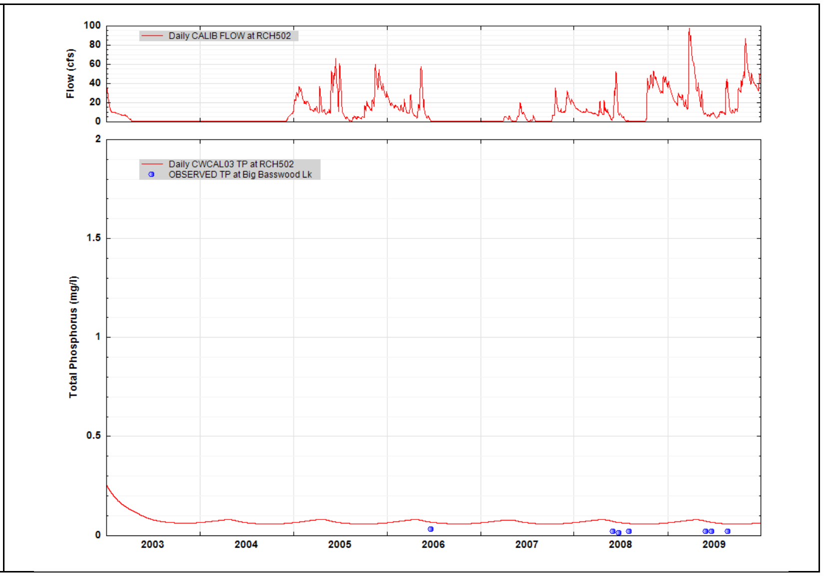

Daily CALIB FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Daily LPCAL03 TP at RCH336
OBSERVED TP at TURTLE CK ON BR AT OAK RIDGE RD
Total Phosphorus (mg/l)
Daily CALIB FLOW at RCH338
Daily LPCAL03 TP at RCH338
OBSERVED TP at MORAN CR ON 464TH ST
Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily CALIB TP at RCH339
OBSERVED TP at 05245295
OBSERVED TP at MORAN CR ON BR AT 255TH AVE
Daily CALIB FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 TP at RCH341
OBSERVED TP at LONG PRAIRIE R ON BR AT CR 65
2003
2004
2005
2006
2007
2008
2009

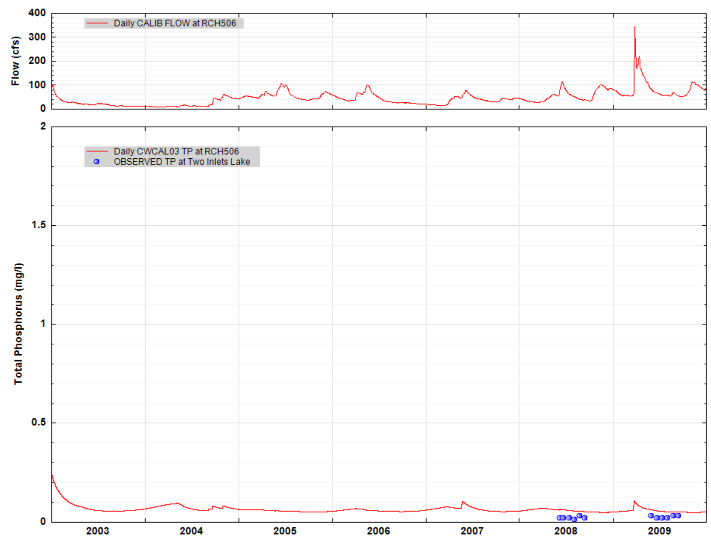

Daily CALIB FLOW at RCH342
Daily CALIB TP at RCH342
OBSERVED TP at Shamineau Lake
Daily CALIB FLOW at RCH344
Daily LPCAL03 TP at RCH344
OBSERVED TP at Alexander Lake
Daily CALIB FLOW at RCH345
Daily LPCAL03 TP at RCH345
OBSERVED TP at Fish Trap Lake
Daily CALIB FLOW at RCH347
Daily LPCAL03 TP at RCH347
OBSERVED TP at LONG PRAIRIE R BRIDGE ON US-10
Flow (cfs)
Total Phosphorus (mg/l)
2003
2004
2005
2006
2007
2008
2009

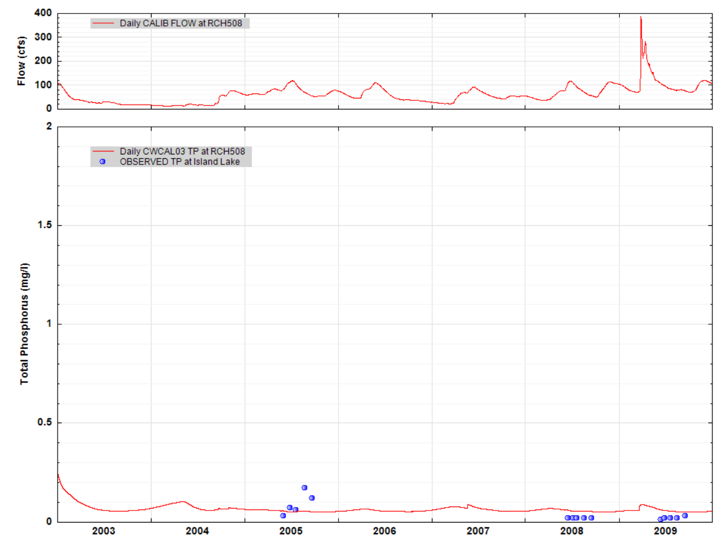


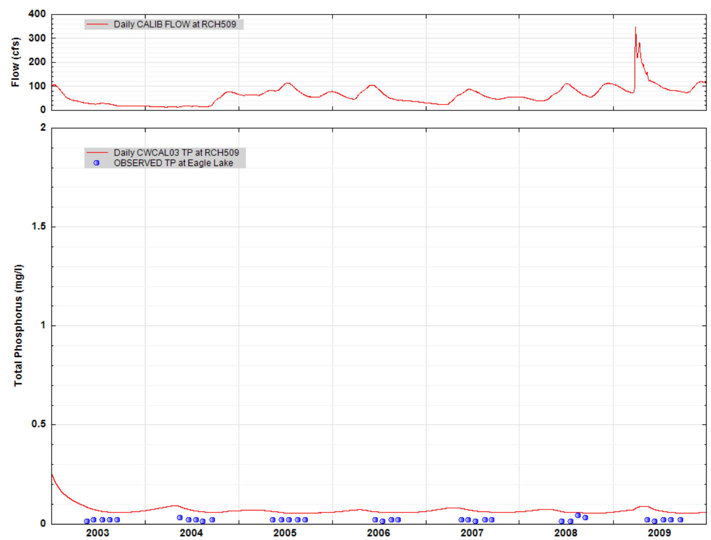
M.2.3 Crow Wing River Watershed

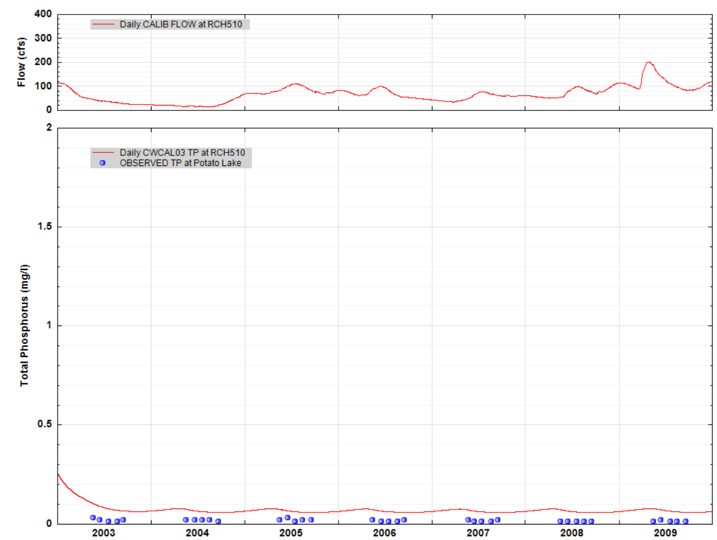


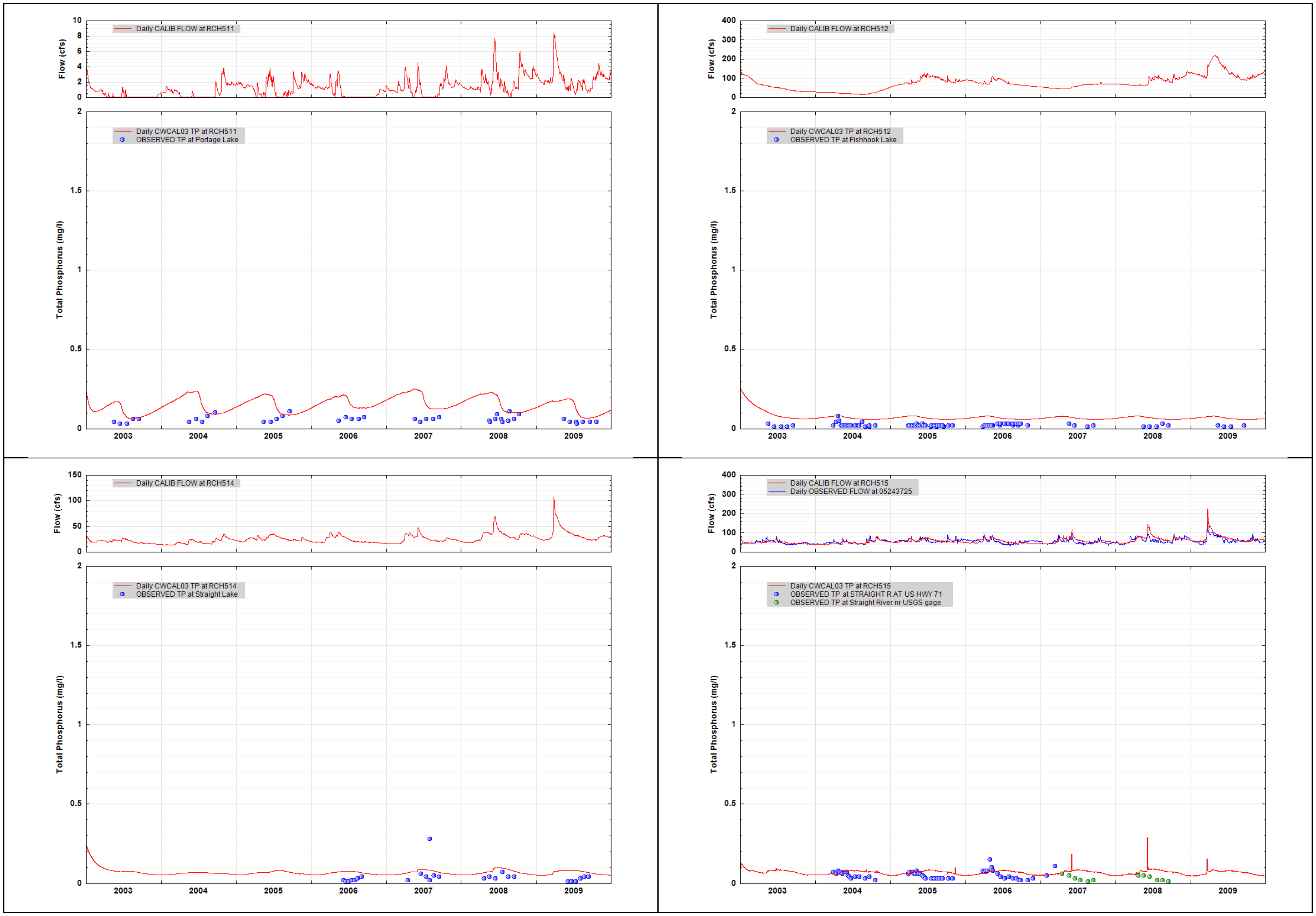


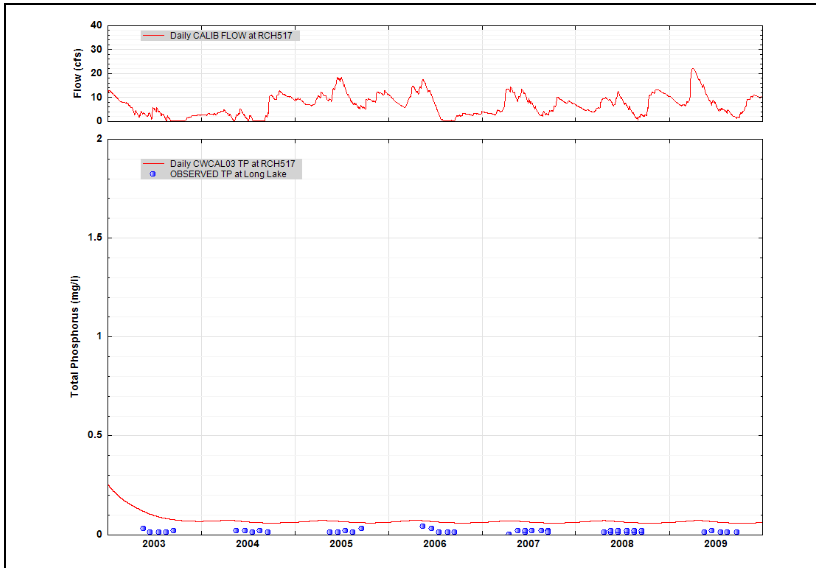

Flow (cfs)
Daily CALIB FLOW at RCH506
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH506
OBSERVED TP at Two Inlets Lake
2003 2004 2005 2006 2007 2008 2009

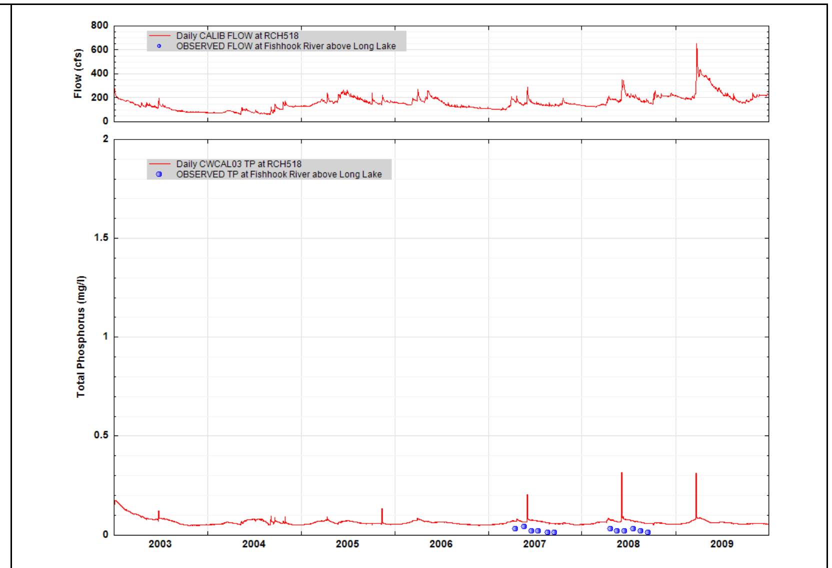

Flow (cfs)
Daily CALIB FLOW at RCH508
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH508
OBSERVED TP at Island Lake
2003 2004 2005 2006 2007 2008 2009

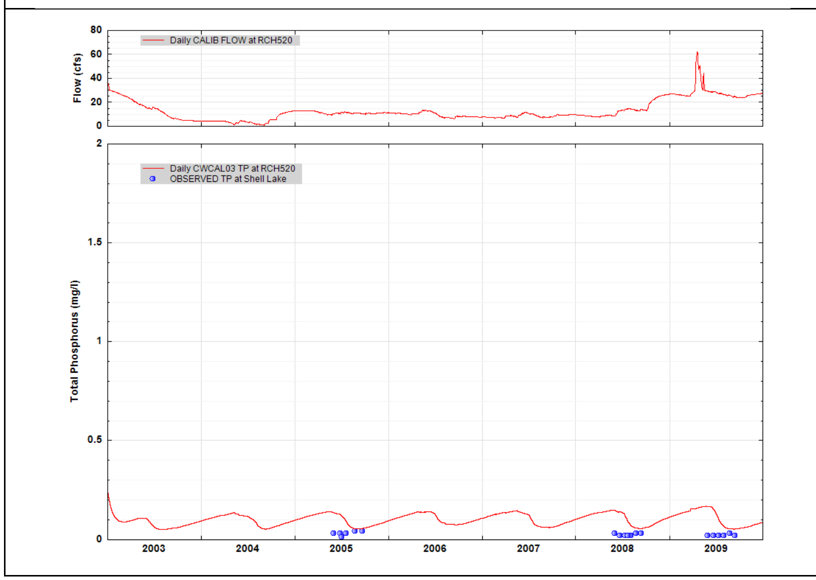

Flow (cfs)
Daily CALIB FLOW at RCH509
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH509
OBSERVED TP at Eagle Lake
2003 2004 2005 2006 2007 2008 2009

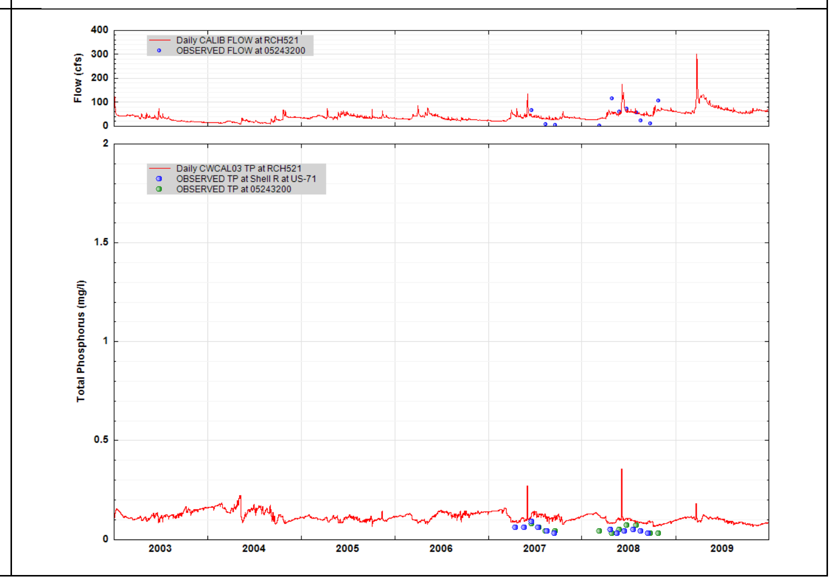

Flow (cfs)
Daily CALIB FLOW at RCH510
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH510
OBSERVED TP at Potato Lake
2003 2004 2005 2006 2007 2008 2009

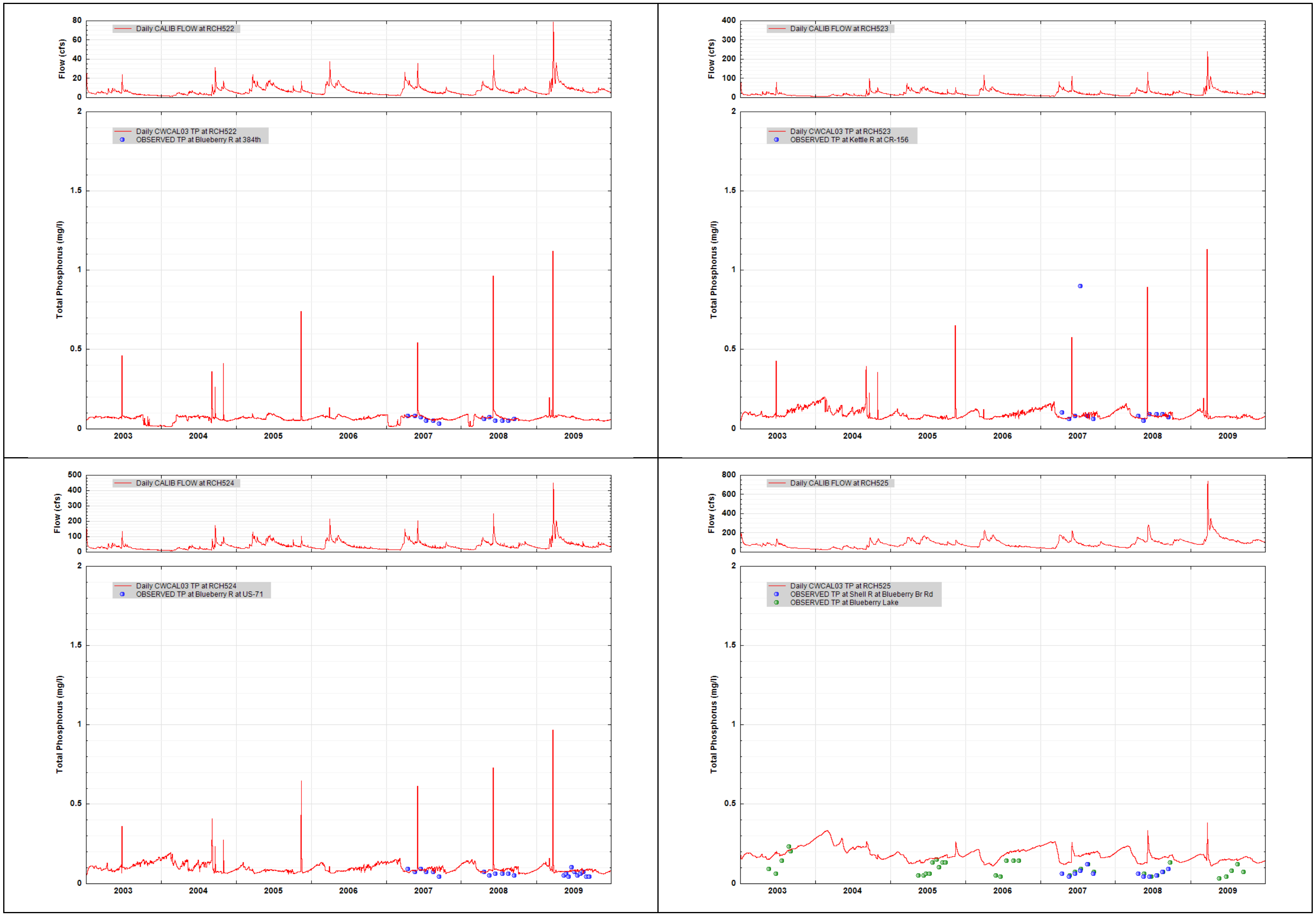

Daily CALIB FLOW at RCH511
Daily CWCAL03 TP at RCH511
OBSERVED TP at Portage Lake
Daily CALIB FLOW at RCH512
Daily CWCAL03 TP at RCH512
OBSERVED TP at Fishhook Lake
Daily CALIB FLOW at RCH514
Daily CWCAL03 TP at RCH514
OBSERVED TP at Straight Lake
Daily CALIB FLOW at RCH515
Daily OBSERVED FLOW at 05243725
Daily CWCAL03 TP at RCH515
OBSERVED TP at STRAIGHT R AT US HWY 71
OBSERVED TP at Straight River nr USGS gage
Flow (cfs)
Total Phosphorus (mg/l)
2003
2004
2005
2006
2007
2008
2009

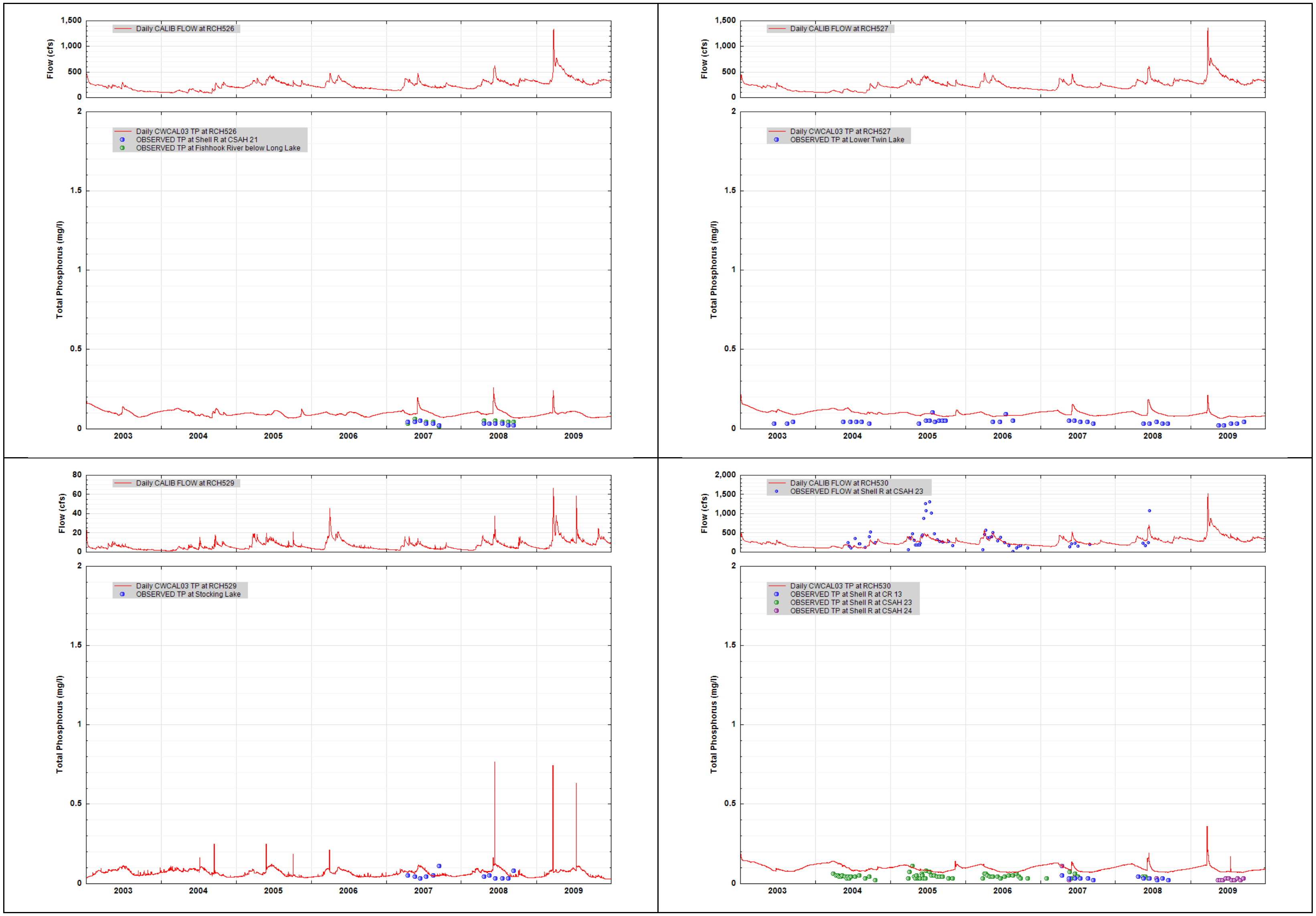

Flow (cfs)
Daily CALIB FLOW at RCH517
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH517
OBSERVED TP at Long Lake
2003
2004
2005
2006
2007
2008
2009

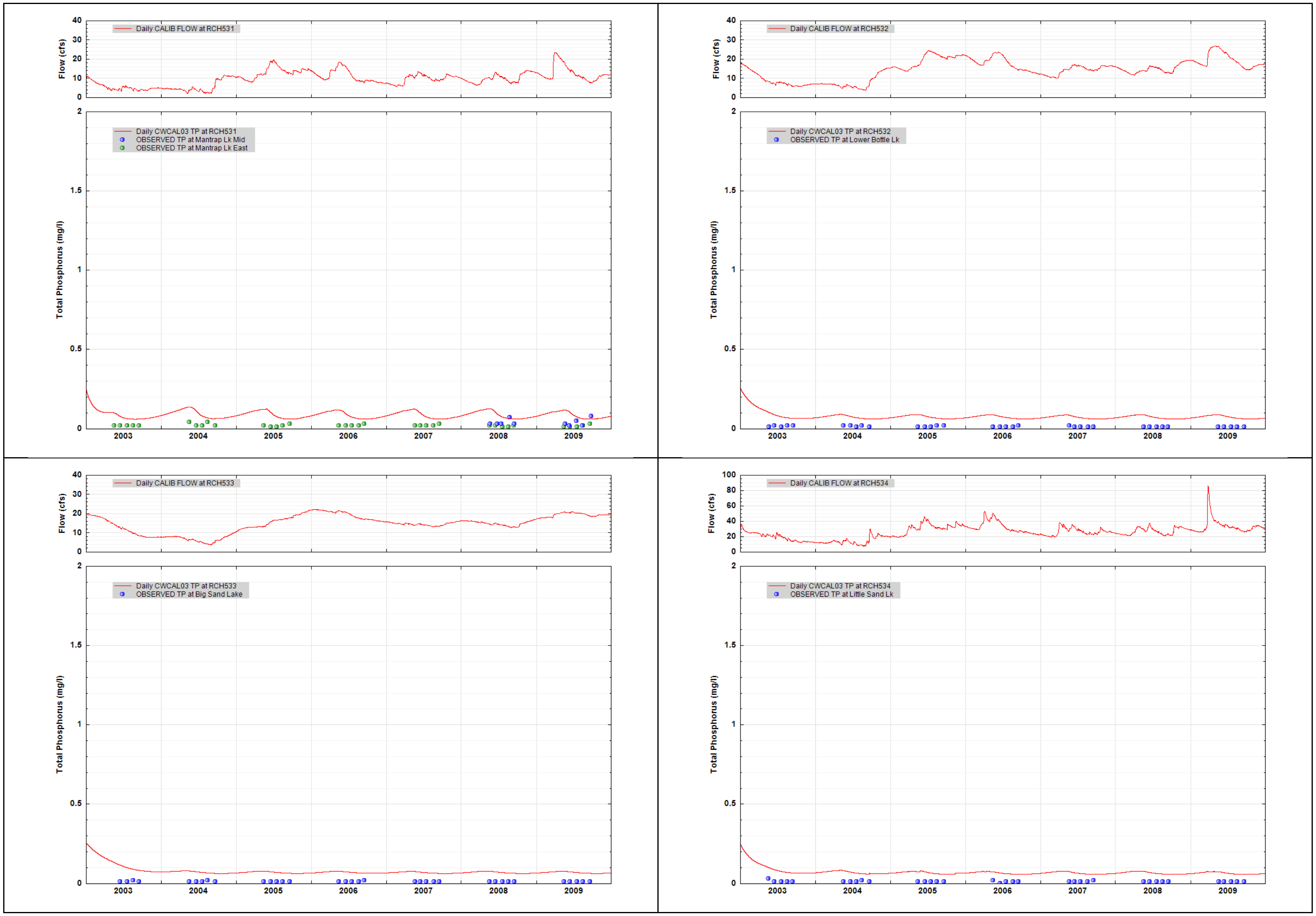

Flow (cfs)
Daily CALIB FLOW at RCH518
OBSERVED FLOW at Fishhook River above Long Lake
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH518
OBSERVED TP at Fishhook River above Long Lake
2003
2004
2005
2006
2007
2008
2009

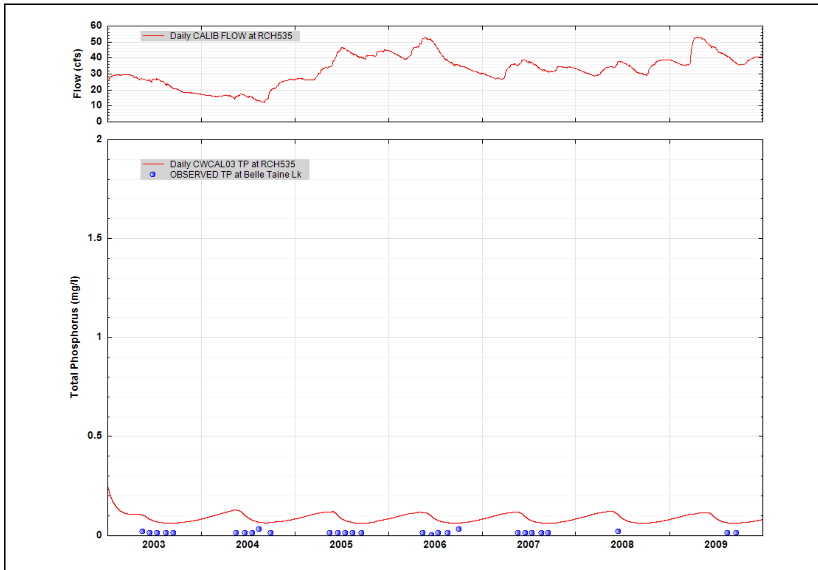

Flow (cfs)
Daily CALIB FLOW at RCH520
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH520
OBSERVED TP at Shell Lake
2003
2004
2005
2006
2007
2008
2009

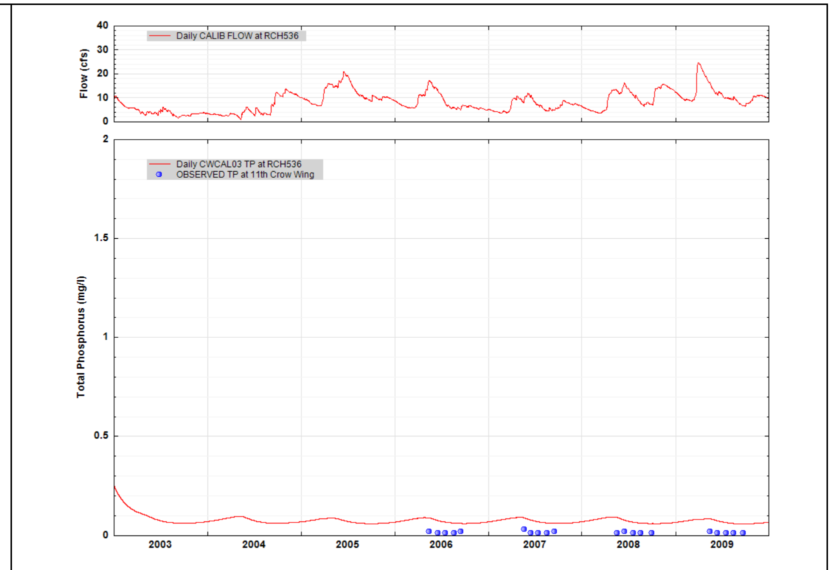

Flow (cfs)
Daily CALIB FLOW at RCH521
OBSERVED FLOW at 05243200
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH521
OBSERVED TP at Shell R at US-71
OBSERVED TP at 05243200
2003
2004
2005
2006
2007
2008
2009

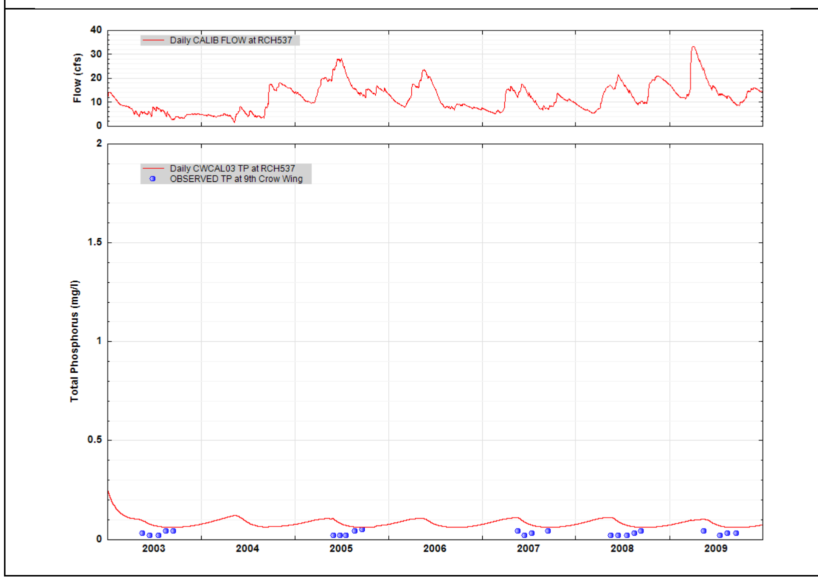

Daily CALIB FLOW at RCH522
Daily CWCAL03 TP at RCH522
OBSERVED TP at Blueberry R at 384th
Daily CALIB FLOW at RCH523
Daily CWCAL03 TP at RCH523
OBSERVED TP at Kettle R at CR-156
Daily CALIB FLOW at RCH524
Daily CWCAL03 TP at RCH524
OBSERVED TP at Blueberry R at US-71
Daily CALIB FLOW at RCH525
Daily CWCAL03 TP at RCH525
OBSERVED TP at Shell R at Blueberry Br Rd
OBSERVED TP at Blueberry Lake
Flow (cfs)
Total Phosphorus (mg/l)
2003
2004
2005
2006
2007
2008
2009

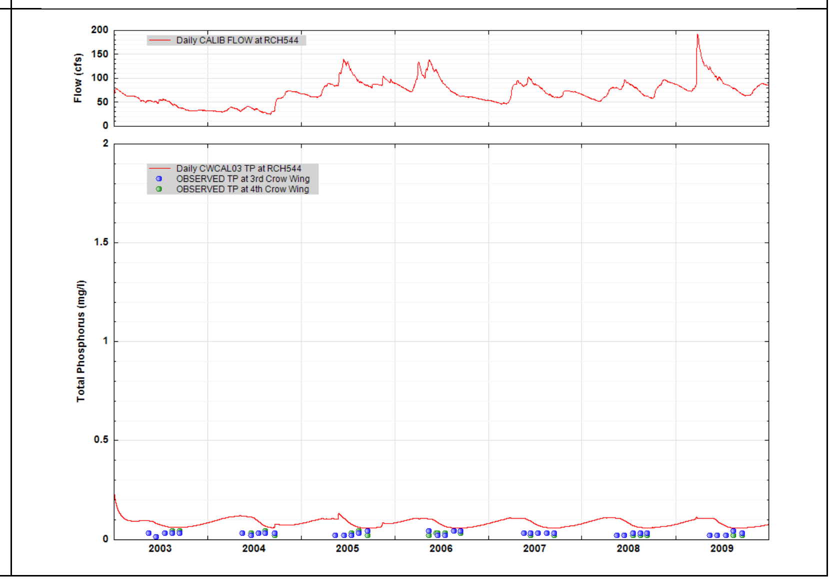

Daily CALIB FLOW at RCH526
Flow (cfs)
Daily CWCAL03 TP at RCH526
OBSERVED TP at Shell R at CSAH 21
OBSERVED TP at Fishhook River below Long Lake
Total Phosphorus (mg/l)
Daily CALIB FLOW at RCH527
Daily CWCAL03 TP at RCH527
OBSERVED TP at Lower Twin Lake
Daily CALIB FLOW at RCH529
Daily CWCAL03 TP at RCH529
OBSERVED TP at Stocking Lake
Daily CALIB FLOW at RCH530
OBSERVED FLOW at Shell R at CSAH 23
Daily CWCAL03 TP at RCH530
OBSERVED TP at Shell R at CR 13
OBSERVED TP at Shell R at CSAH 23
OBSERVED TP at Shell R at CSAH 24
2003
2004
2005
2006
2007
2008
2009

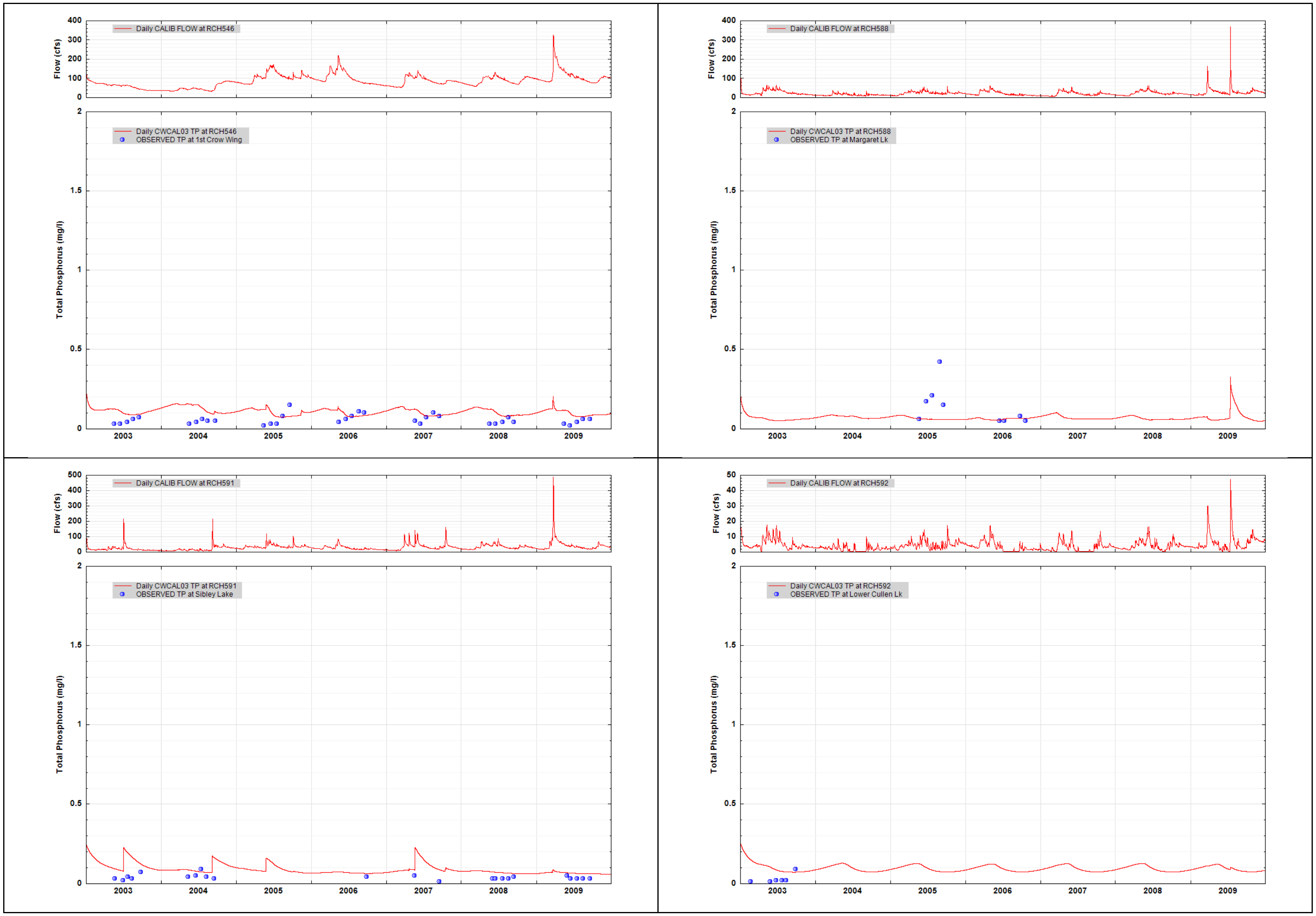

Daily CALIB FLOW at RCH531
Flow (cfs)
Daily CWCAL03 TP at RCH531
OBSERVED TP at Mantrap Lk Mid
OBSERVED TP at Mantrap Lk East
Total Phosphorus (mg/l)
Daily CALIB FLOW at RCH532
Daily CWCAL03 TP at RCH532
OBSERVED TP at Lower Bottle Lk
Daily CALIB FLOW at RCH533
Daily CWCAL03 TP at RCH533
OBSERVED TP at Big Sand Lake
Daily CALIB FLOW at RCH534
Daily CWCAL03 TP at RCH534
OBSERVED TP at Little Sand Lk
2003 2004 2005 2006 2007 2008 2009

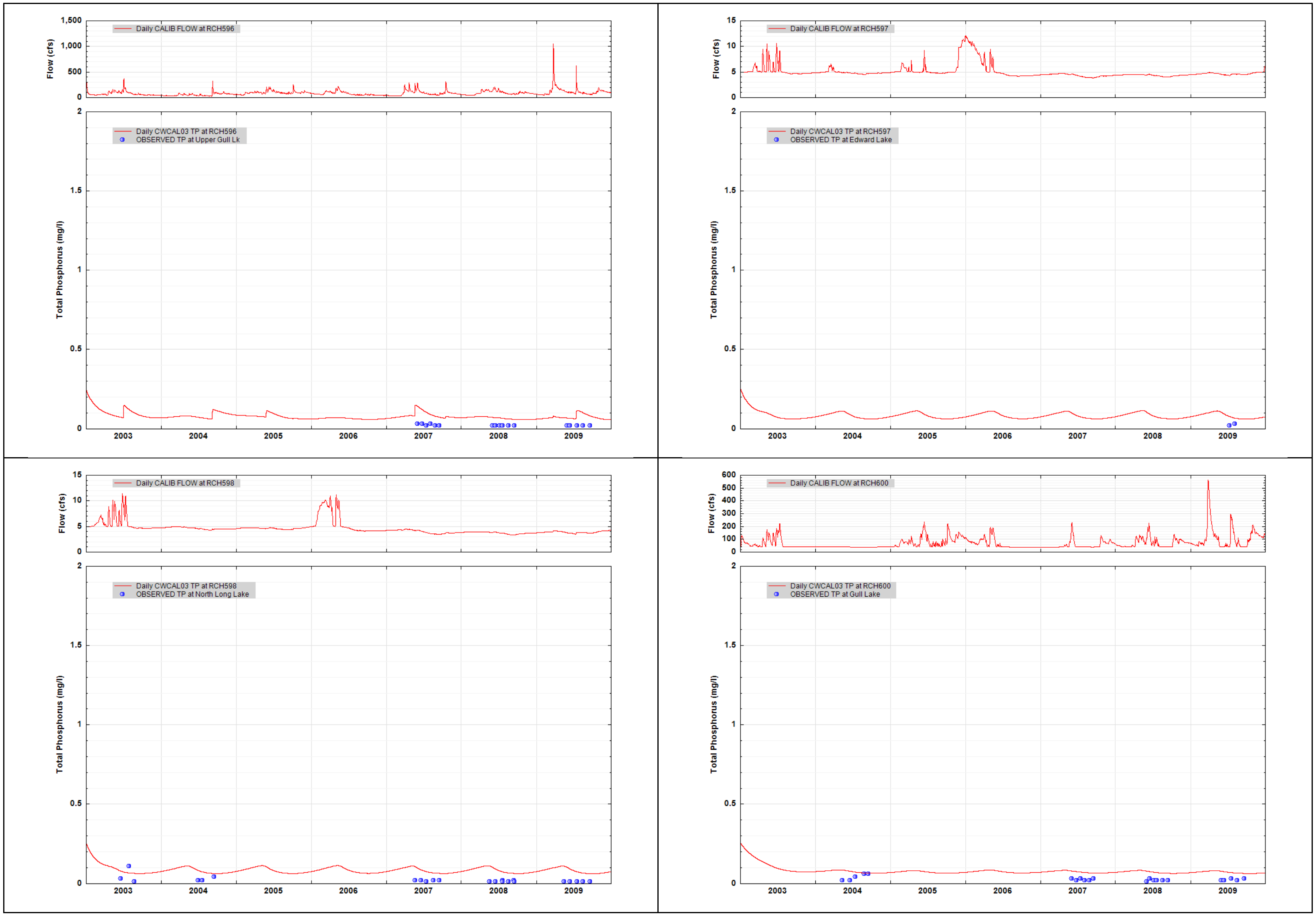

Flow (cfs)
Daily CALIB FLOW at RCH535
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH535
OBSERVED TP at Belle Taine Lk


Flow (cfs)
Daily CALIB FLOW at RCH536
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH536
OBSERVED TP at 11th Crow Wing


Flow (cfs)
Daily CALIB FLOW at RCH537
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH537
OBSERVED TP at 9th Crow Wing


Flow (cfs)
Daily CALIB FLOW at RCH544
Total Phosphorus (mg/l)
Daily CWCAL03 TP at RCH544
OBSERVED TP at 3rd Crow Wing
OBSERVED TP at 4th Crow Wing

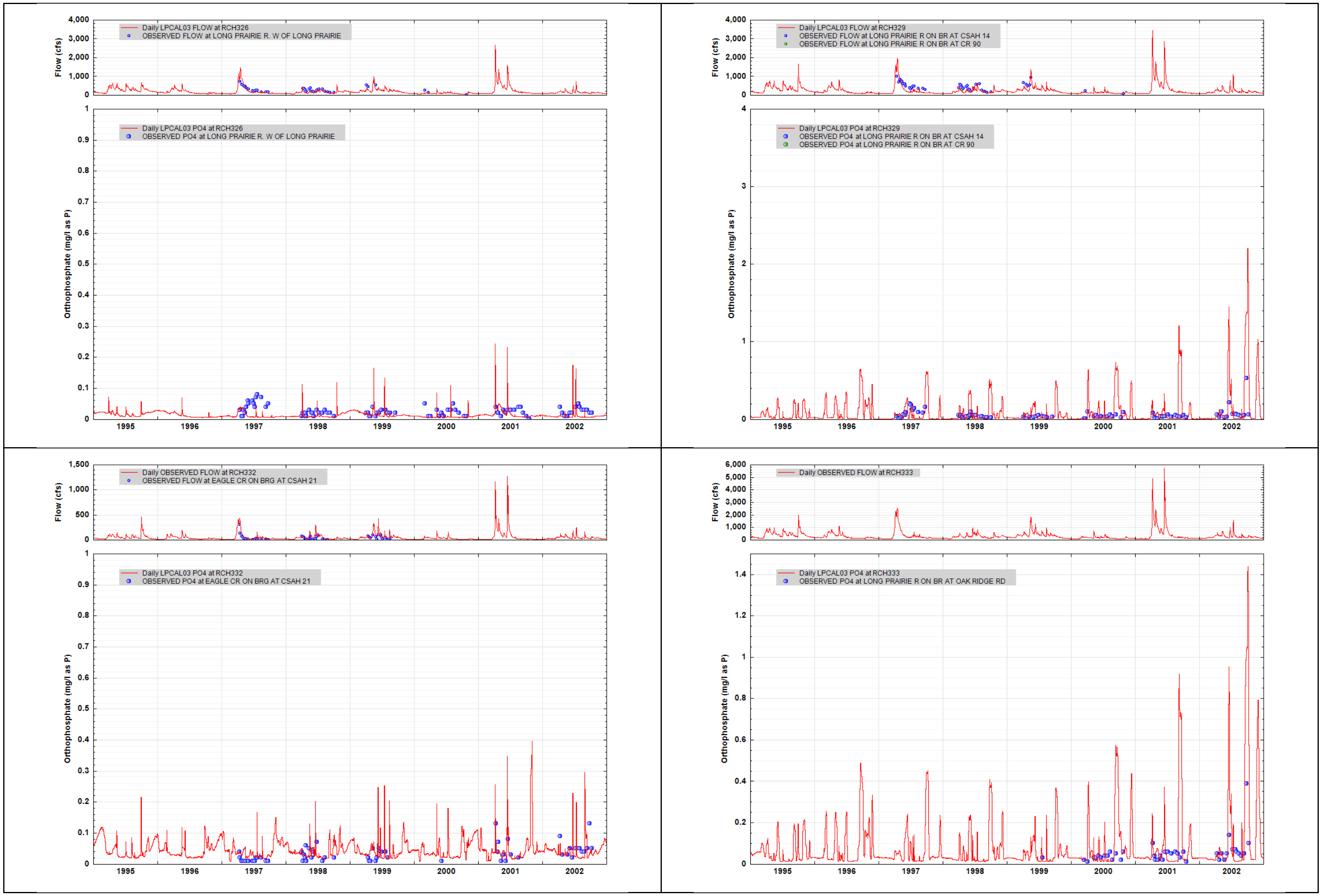

Daily CALIB FLOW at RCH546
Daily CWCAL03 TP at RCH546
OBSERVED TP at 1st Crow Wing
Daily CALIB FLOW at RCH588
Daily CWCAL03 TP at RCH588
OBSERVED TP at Margaret Lk
Daily CALIB FLOW at RCH591
Daily CWCAL03 TP at RCH591
OBSERVED TP at Sibley Lake
Daily CALIB FLOW at RCH592
Daily CWCAL03 TP at RCH592
OBSERVED TP at Lower Cullen Lk
Flow (cfs)
Total Phosphorus (mg/l)
2003
2004
2005
2006
2007
2008
2009

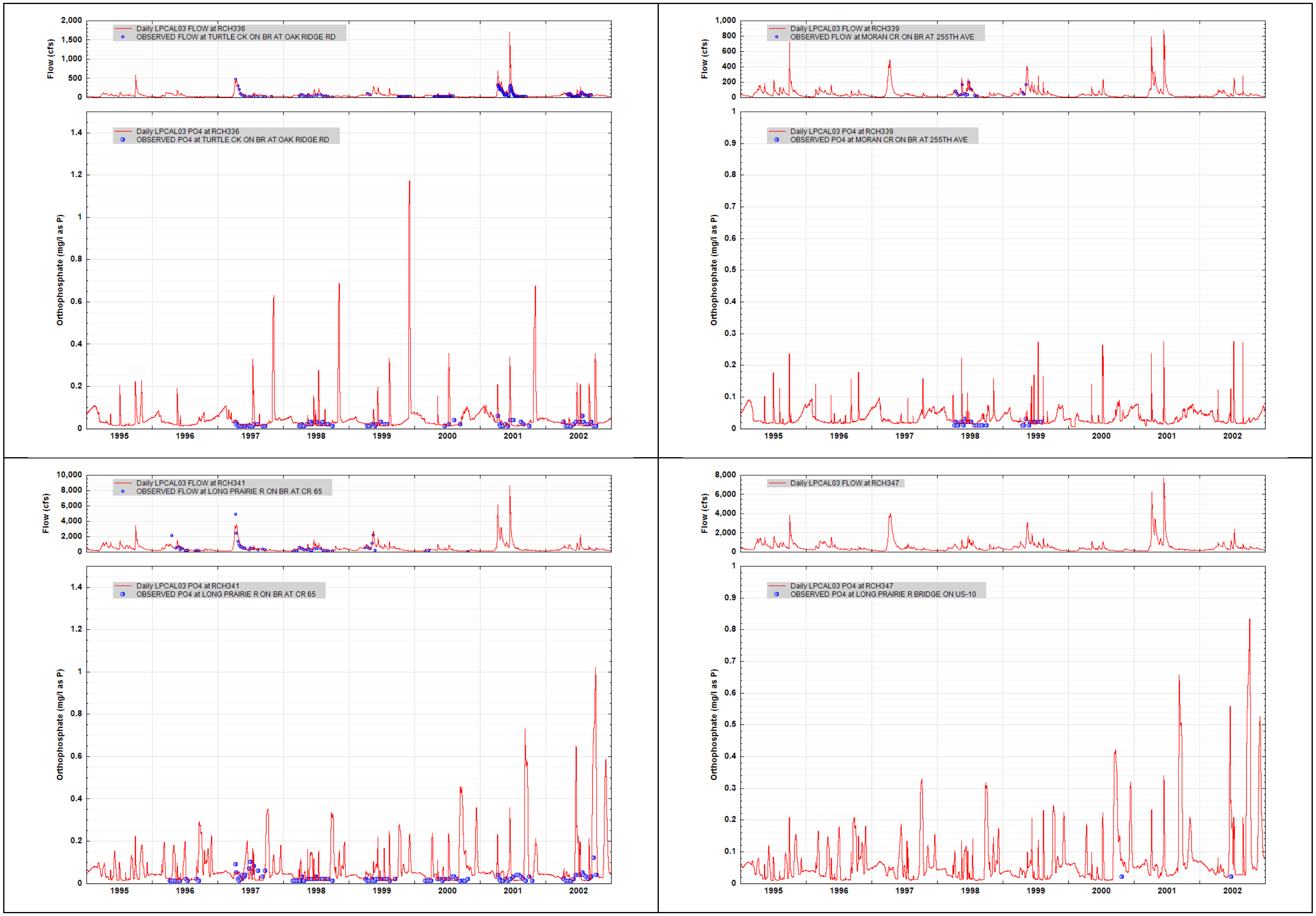

Daily CALIB FLOW at RCH596
Daily CWCAL03 TP at RCH596
OBSERVED TP at Upper Gull Lk
Daily CALIB FLOW at RCH597
Daily CWCAL03 TP at RCH597
OBSERVED TP at Edward Lake
Daily CALIB FLOW at RCH598
Daily CWCAL03 TP at RCH598
OBSERVED TP at North Long Lake
Daily CALIB FLOW at RCH600
Daily CWCAL03 TP at RCH600
OBSERVED TP at Gull Lake
Flow (cfs)
Total Phosphorus (mg/l)
2003
2004
2005
2006
2007
2008
2009

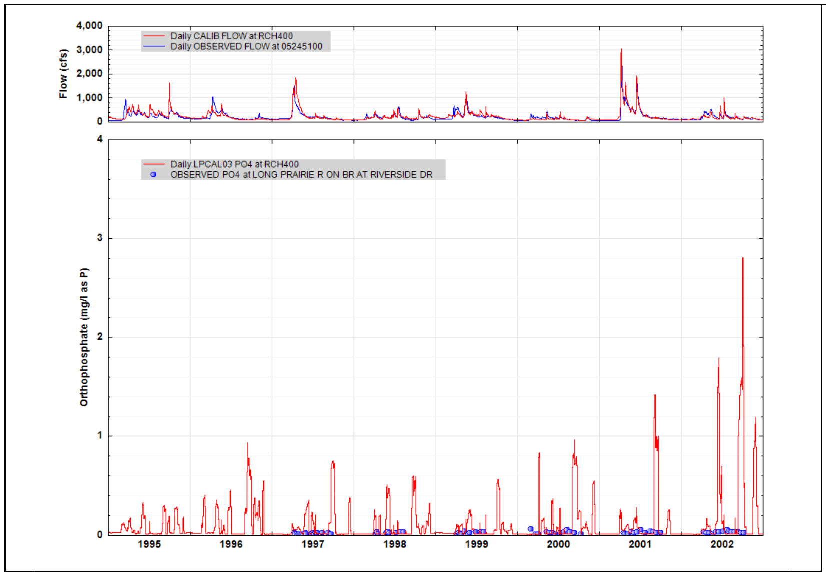
APPENDIX N
OBSERVED AND SIMULATED PHOSPHORUS CONSTITUENTS FOR THE VALIDATION PERIOD

N.1 ORTHOPHOSPHATE

N.1.1 Long Prairie River Watershed

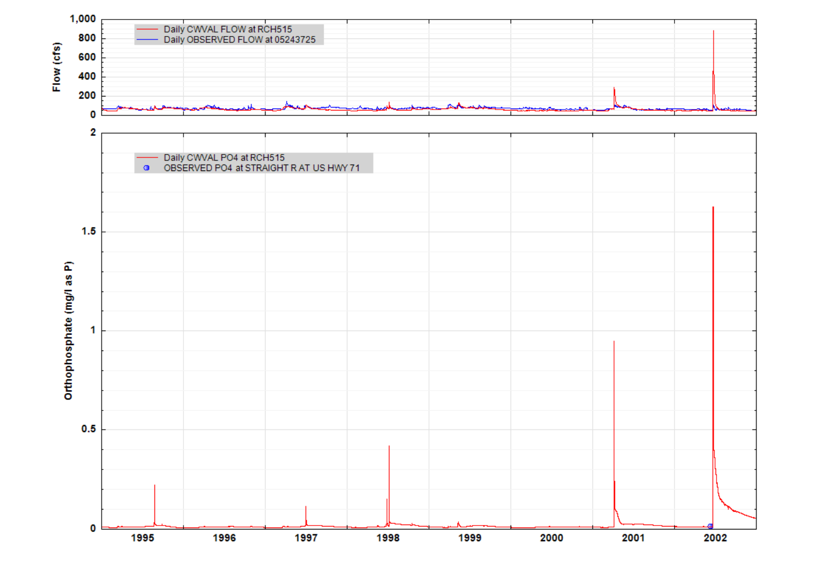


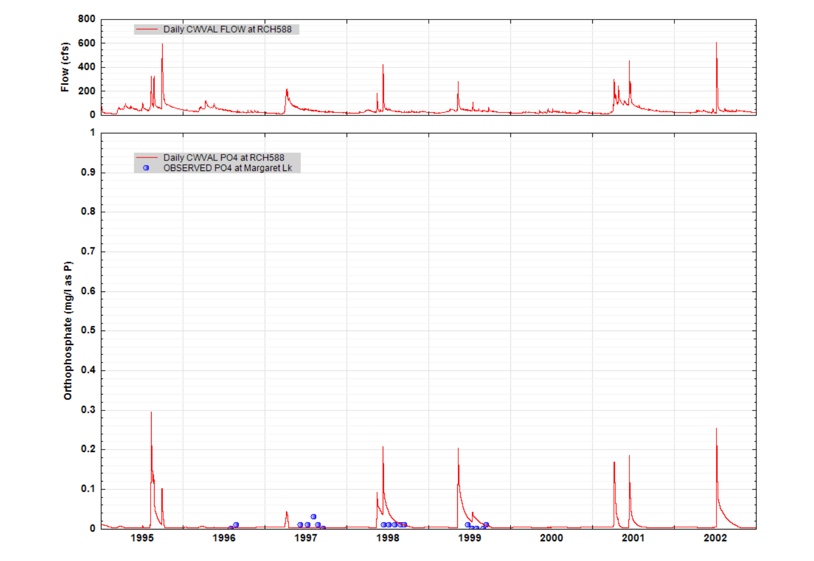

Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Flow (cfs)
Daily LPCAL03 PO4 at RCH336
OBSERVED PO4 at TURTLE CK ON BR AT OAK RIDGE RD
Orthophosphate (mg/l as P)
Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 PO4 at RCH339
OBSERVED PO4 at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 PO4 at RCH341
OBSERVED PO4 at LONG PRAIRIE R ON BR AT CR 65
Daily LPCAL03 FLOW at RCH347
Daily LPCAL03 PO4 at RCH347
OBSERVED PO4 at LONG PRAIRIE R BRIDGE ON US-10
1995
1996
1997
1998
1999
2000
2001
2002

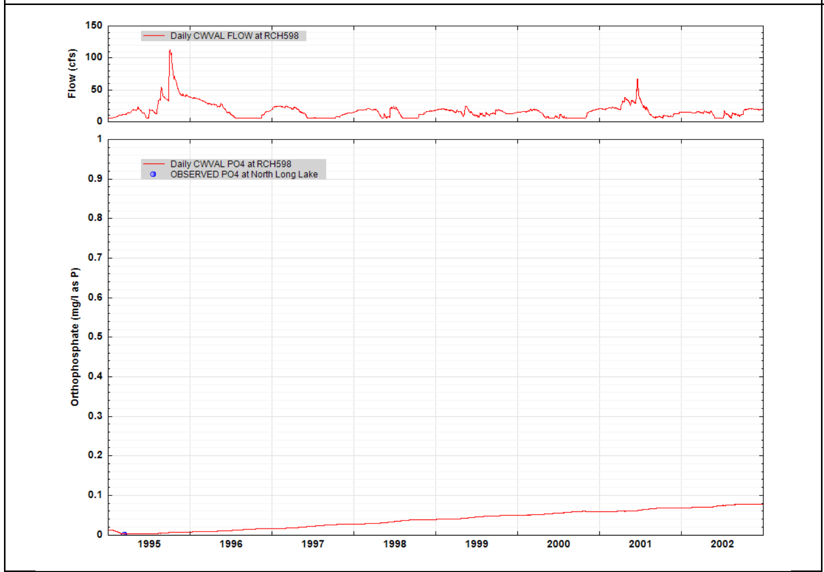


Flow (cfs)
4,000
3,000
2,000
1,000
0
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Orthophosphate (mg/l as P)
4
3
2
1
0
Daily LPCAL03 PO4 at RCH400
OBSERVED PO4 at LONG PRAIRIE R ON BR AT RIVERSIDE DR
1995
1996
1997
1998
1999
2000
2001
2002

N.1.2 Crow Wing River Watershed

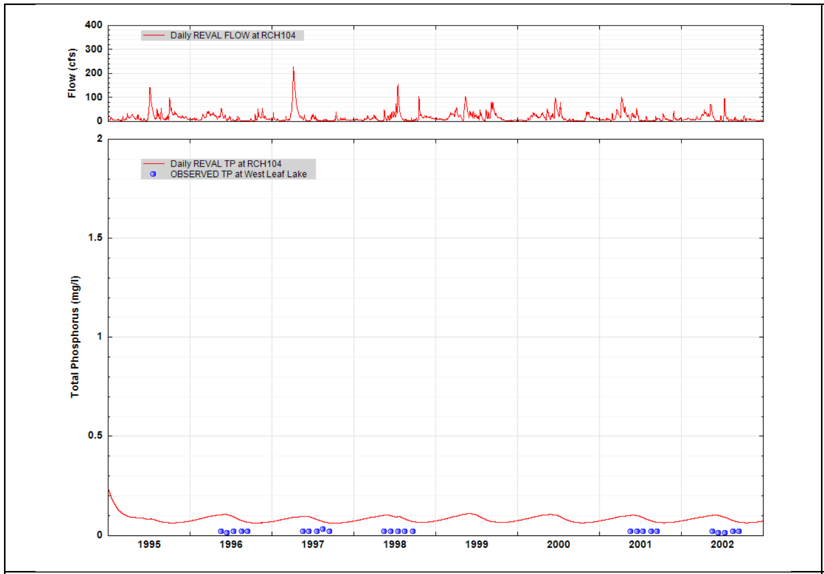


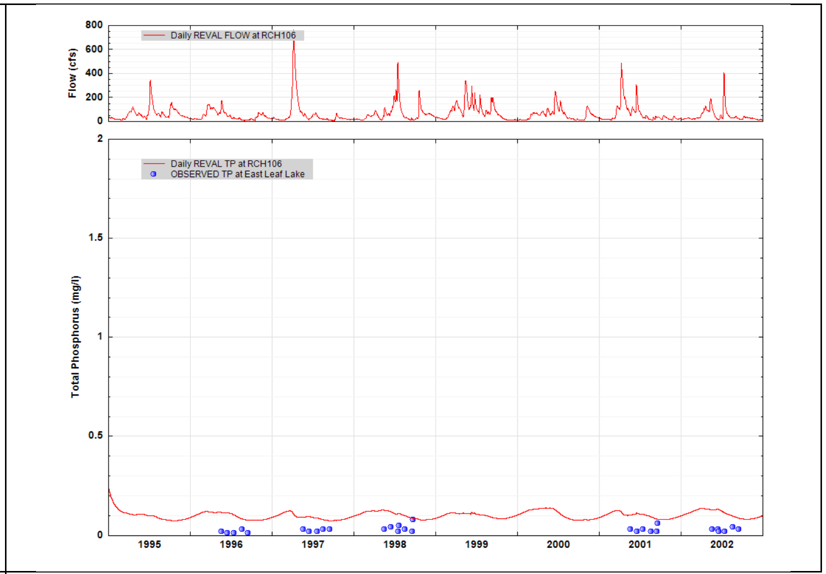


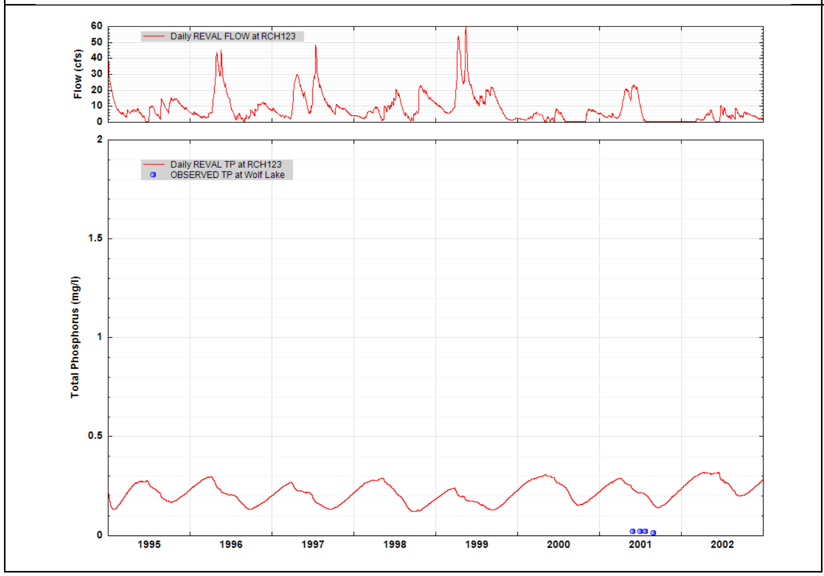


N.2 TOTAL PHOSPHORUS

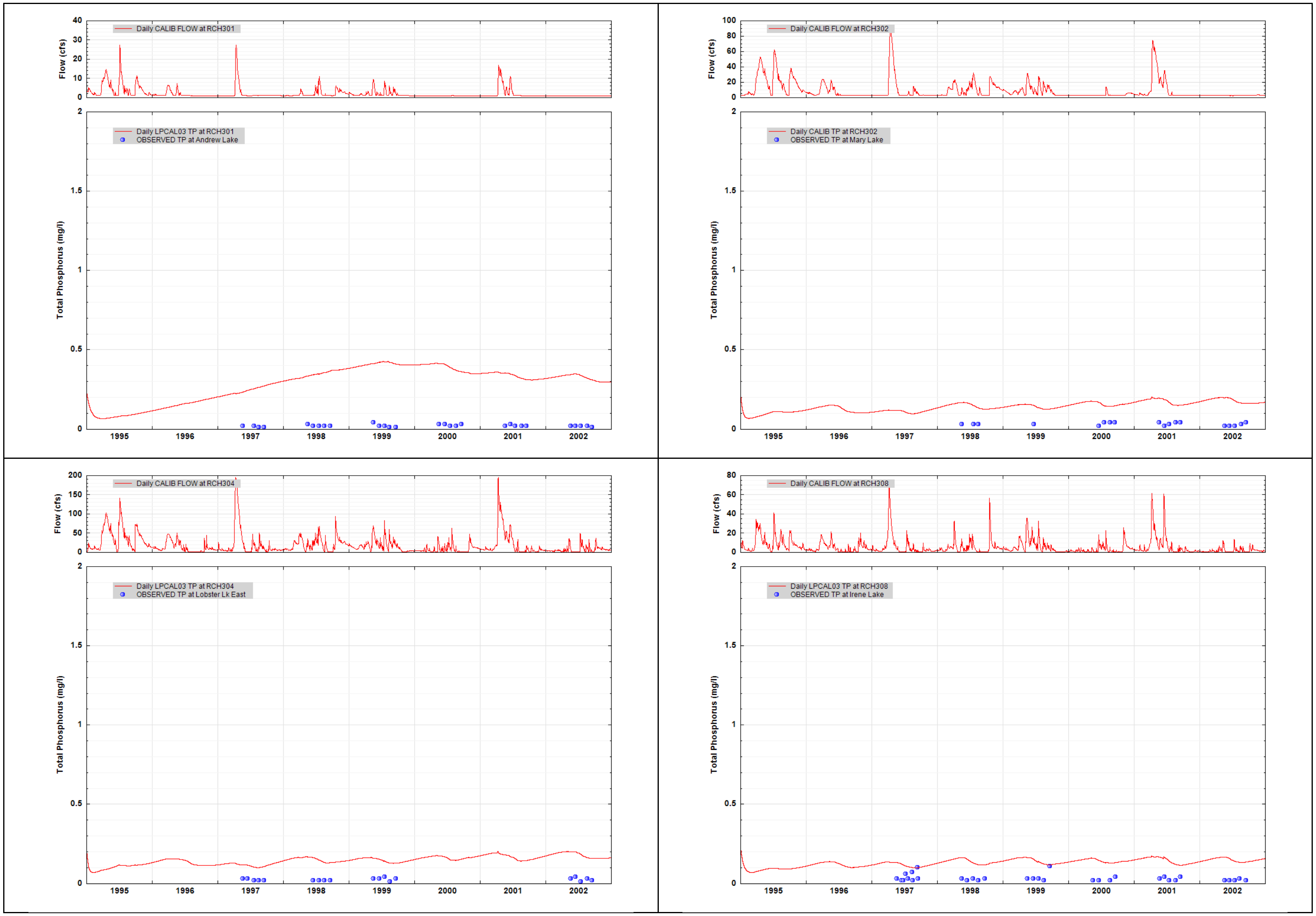
N.2.1 Redeye River Watershed

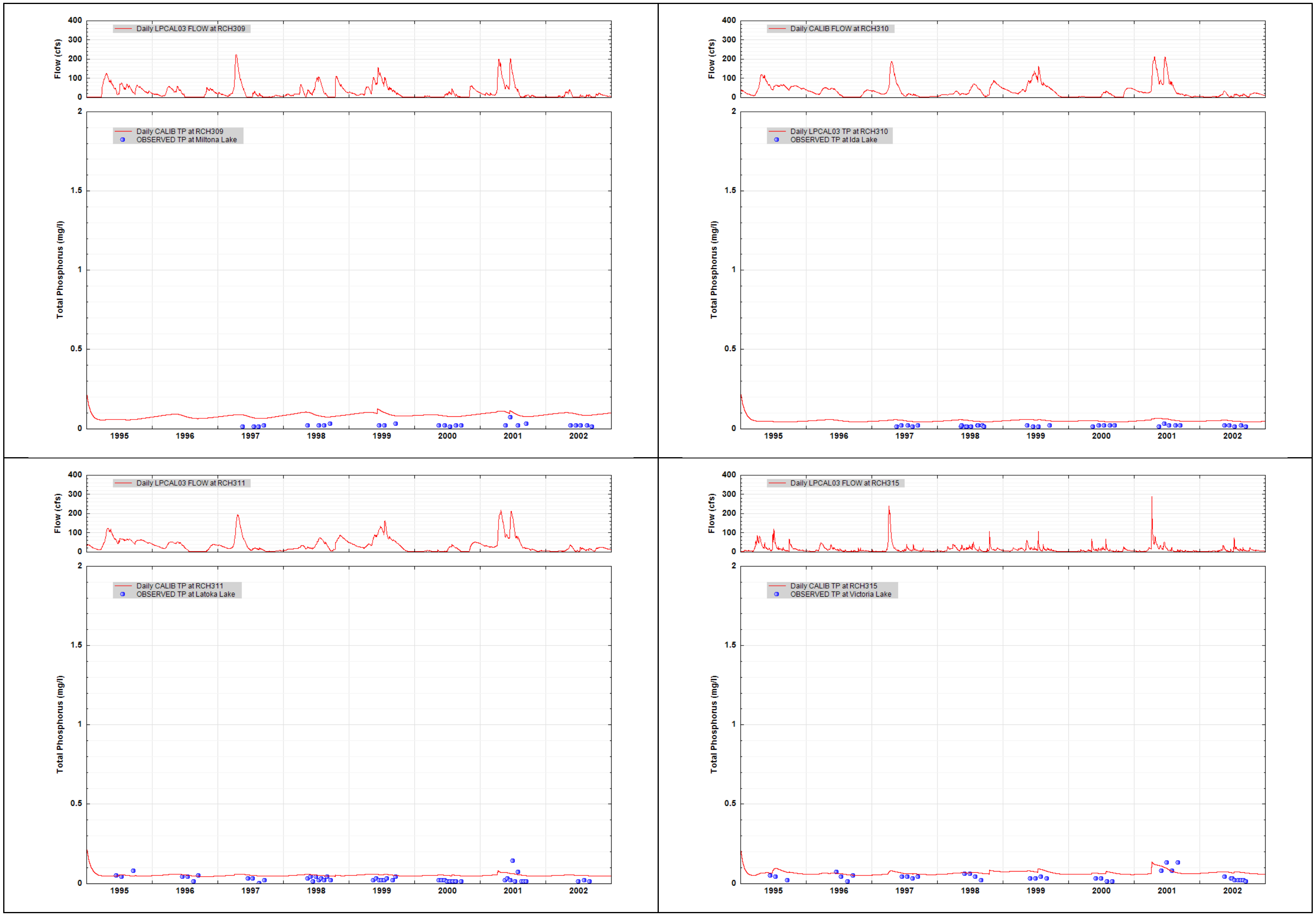




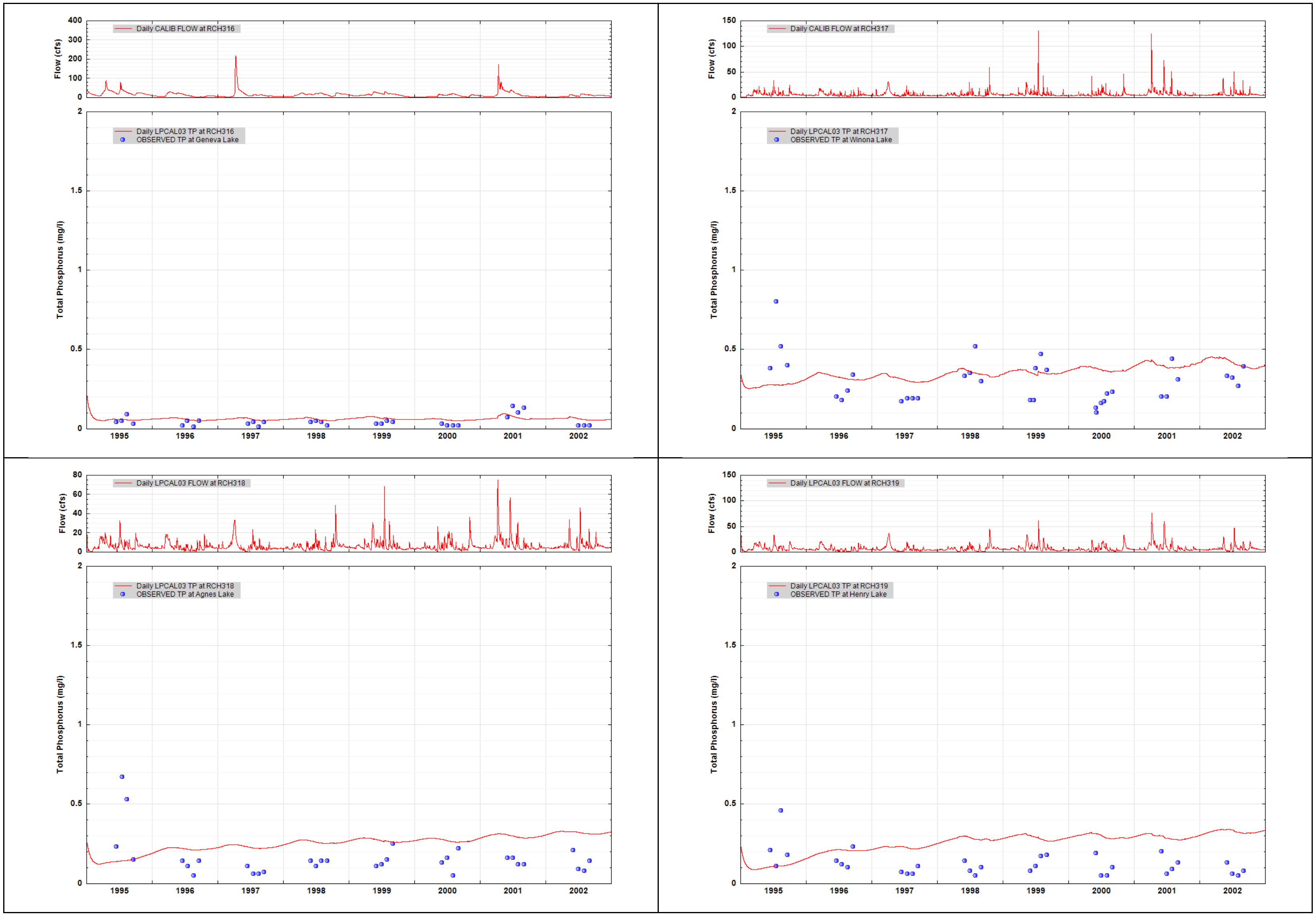


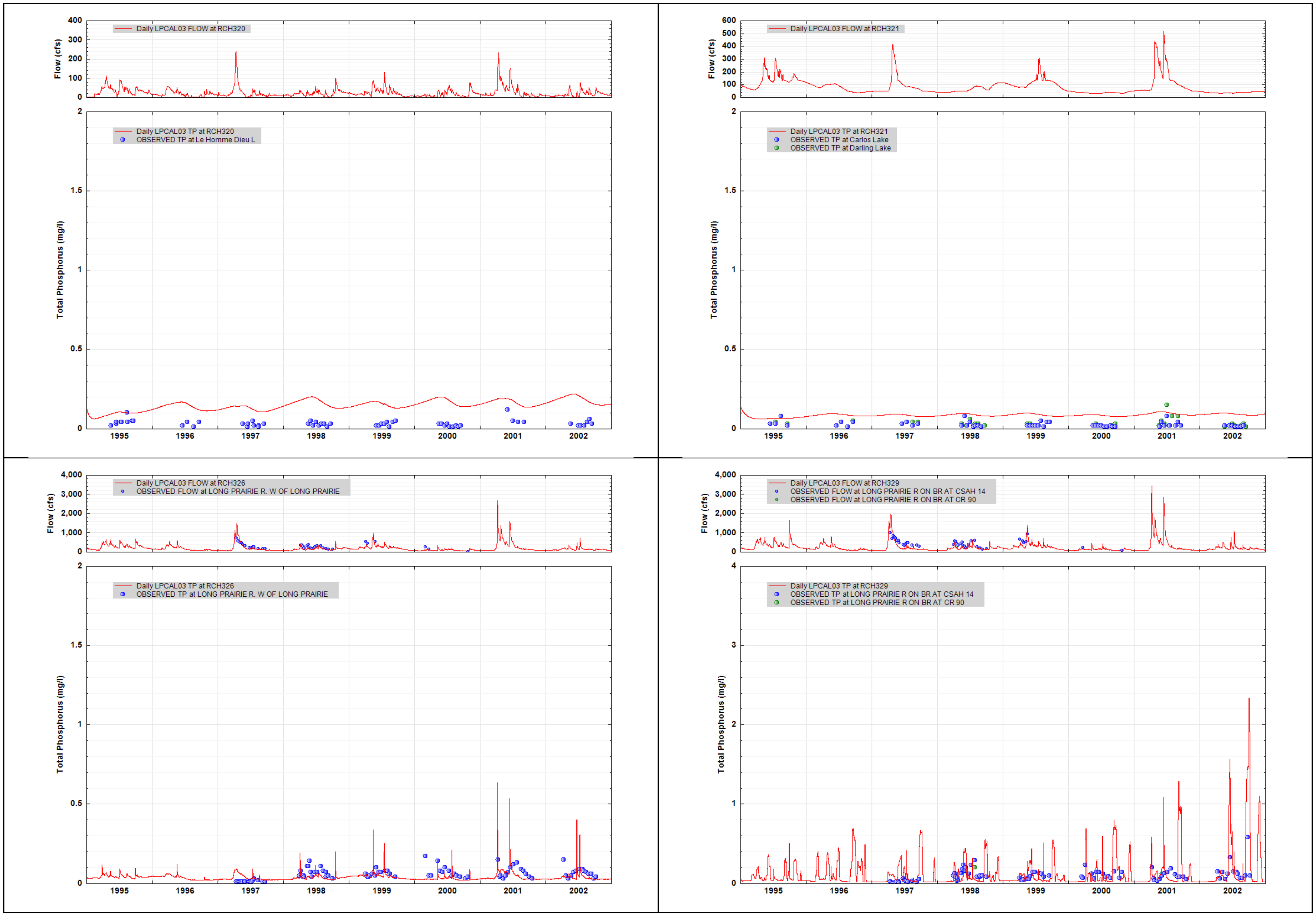
N.2.2 Long Prairie River Watershed

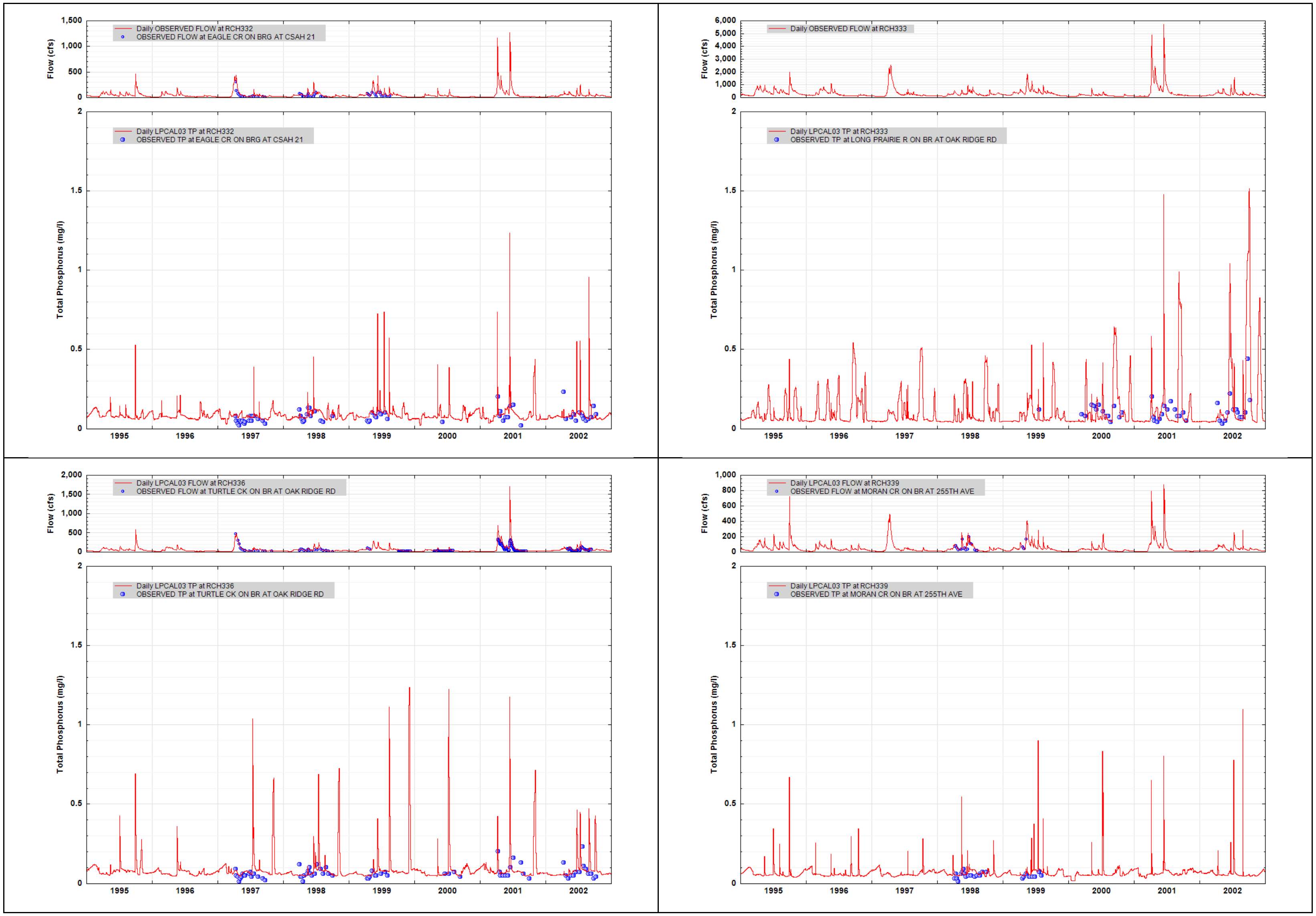


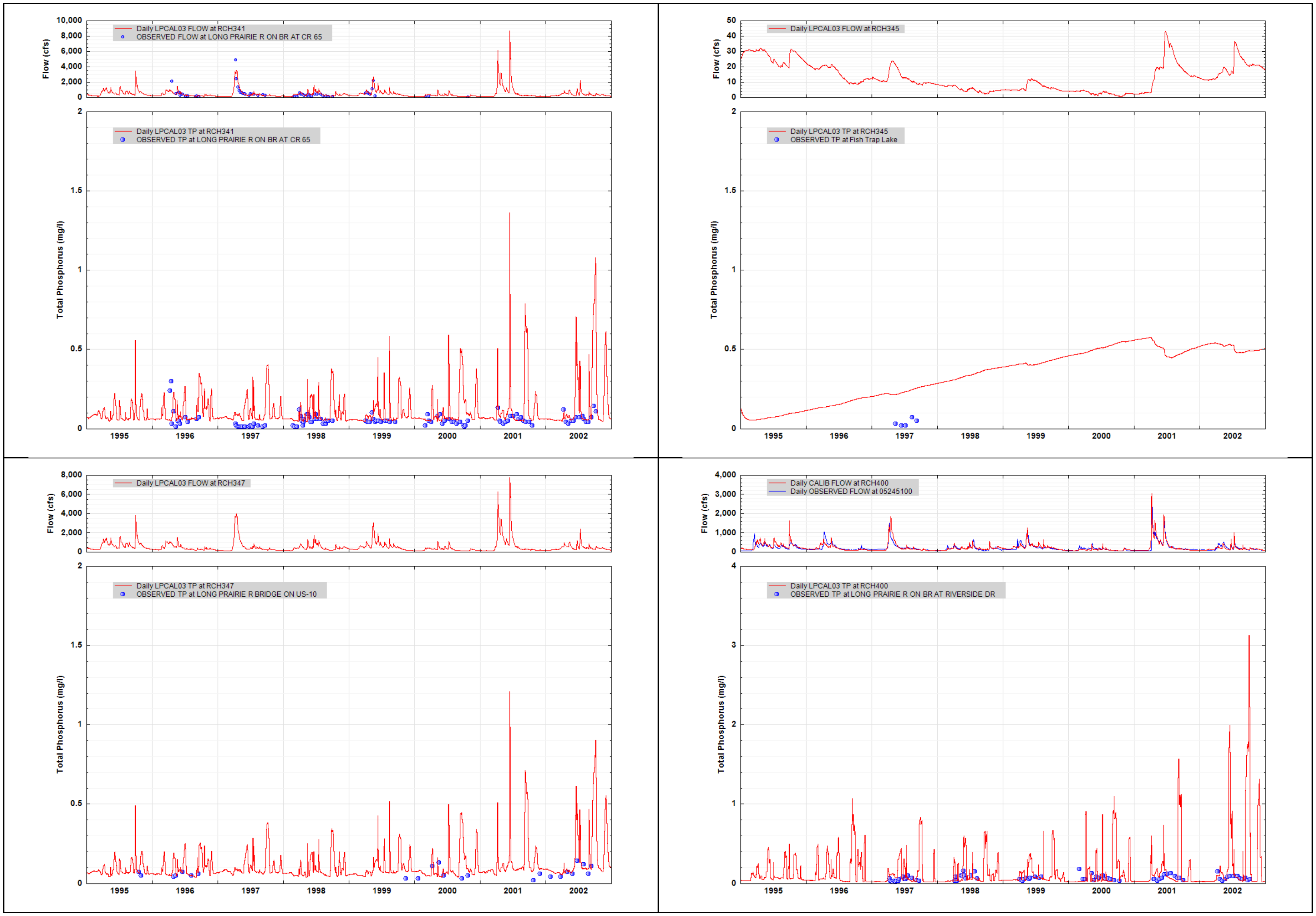


Daily LPCAL03 FLOW at RCH309
Daily CALIB TP at RCH309
OBSERVED TP at Miltona Lake
Daily CALIB FLOW at RCH310
Daily LPCAL03 TP at RCH310
OBSERVED TP at Ida Lake
Daily LPCAL03 FLOW at RCH311
Daily CALIB TP at RCH311
OBSERVED TP at Latoka Lake
Daily LPCAL03 FLOW at RCH315
Daily CALIB TP at RCH315
OBSERVED TP at Victoria Lake
Flow (cfs)
Total Phosphorus (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002

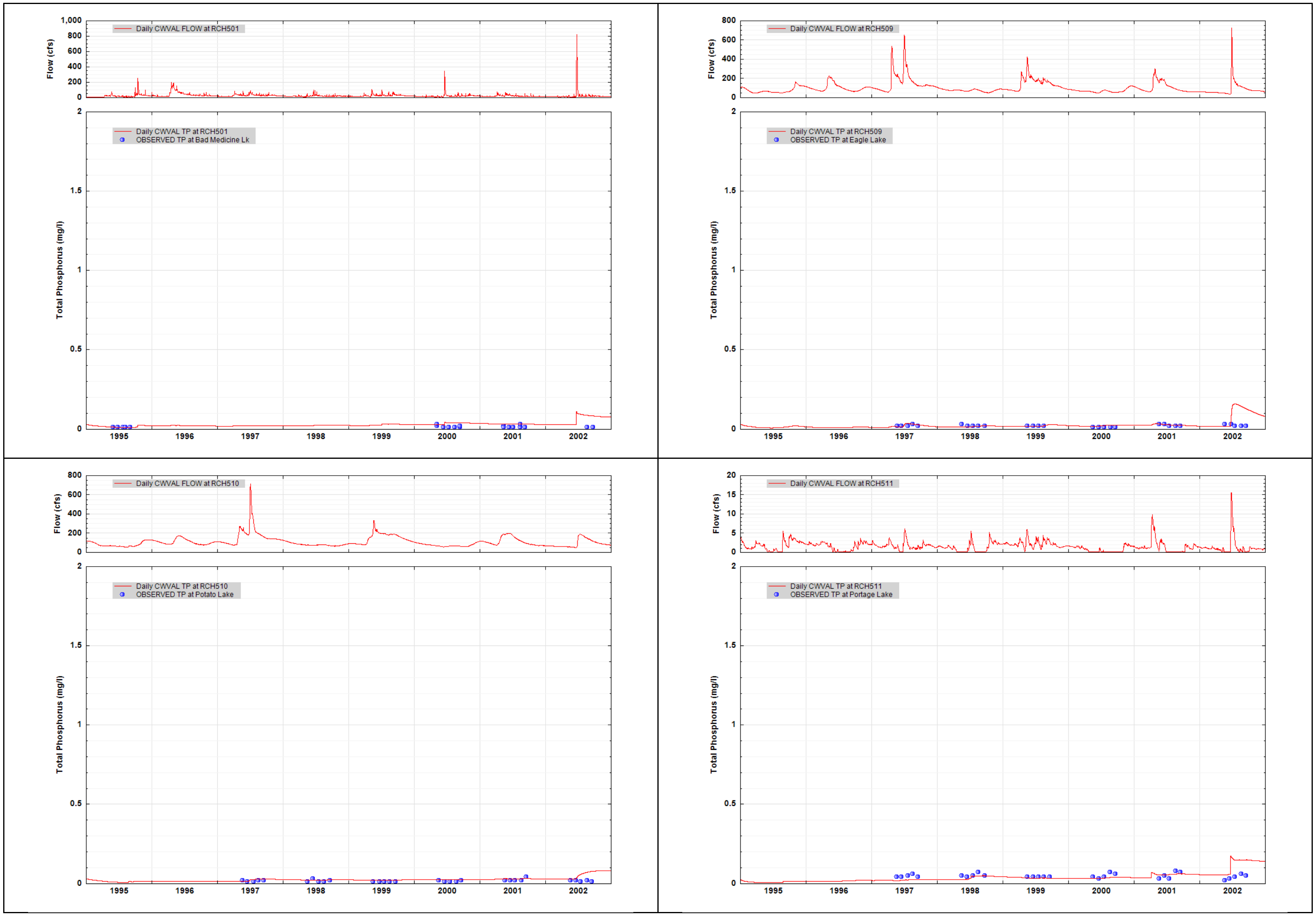

Daily CALIB FLOW at RCH316
Flow (cfs)
Daily LPCAL03 TP at RCH316
OBSERVED TP at Geneva Lake
Total Phosphorus (mg/l)
Daily CALIB FLOW at RCH317
Daily LPCAL03 TP at RCH317
OBSERVED TP at Winona Lake
Daily LPCAL03 FLOW at RCH318
Daily LPCAL03 TP at RCH318
OBSERVED TP at Agnes Lake
Daily LPCAL03 FLOW at RCH319
Daily LPCAL03 TP at RCH319
OBSERVED TP at Henry Lake
1995
1996
1997
1998
1999
2000
2001
2002

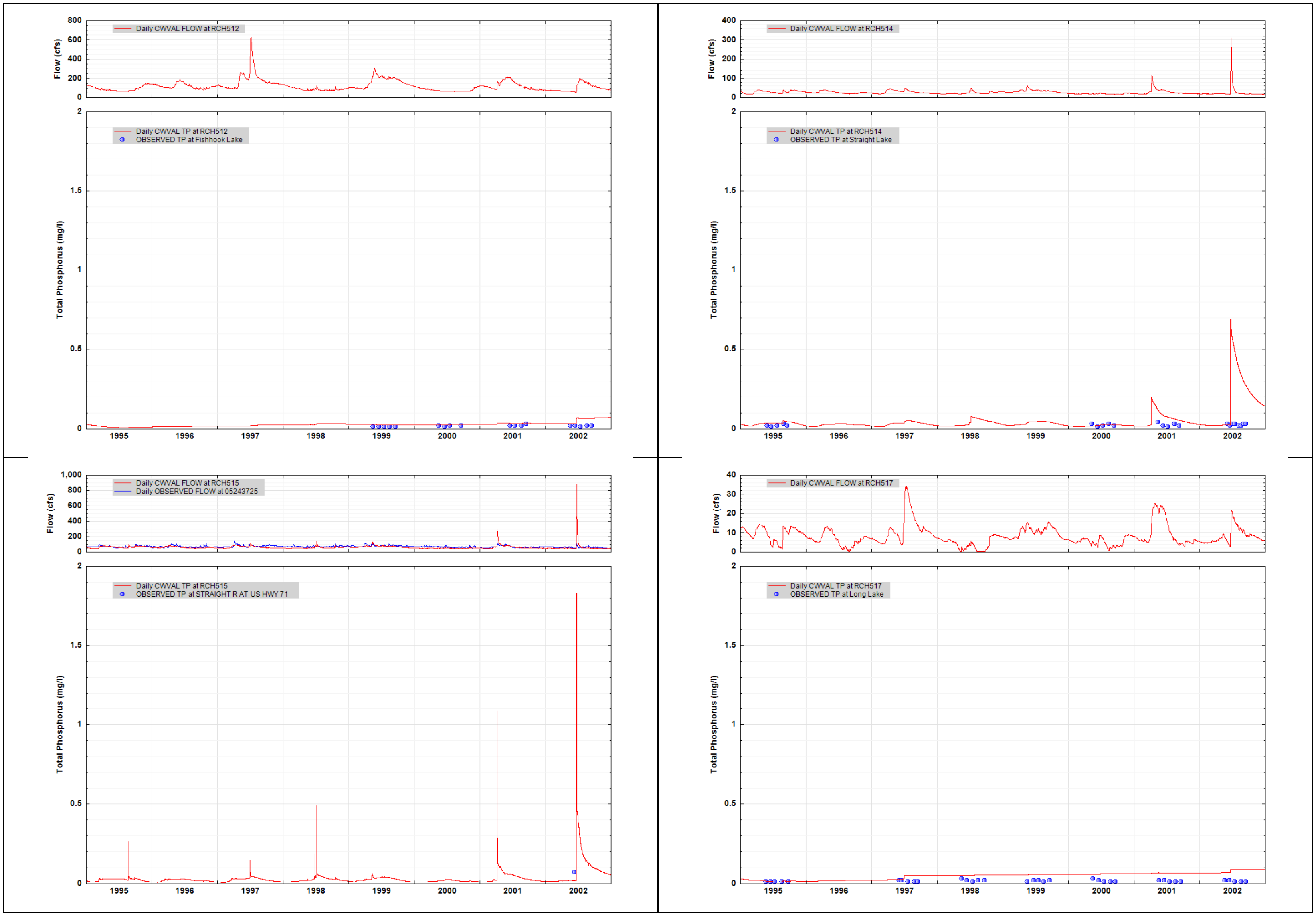

Daily LPCAL03 FLOW at RCH320
Flow (cfs)
Daily LPCAL03 TP at RCH320
OBSERVED TP at Le Homme Dieu L
Total Phosphorus (mg/l)
Daily LPCAL03 FLOW at RCH321
Daily LPCAL03 TP at RCH321
OBSERVED TP at Carlos Lake
OBSERVED TP at Darling Lake
Daily LPCAL03 FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily LPCAL03 TP at RCH326
OBSERVED TP at LONG PRAIRIE R. W OF LONG PRAIRIE
Daily LPCAL03 FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 90
Daily LPCAL03 TP at RCH329
OBSERVED TP at LONG PRAIRIE R ON BR AT CSAH 14
OBSERVED TP at LONG PRAIRIE R ON BR AT CR 90
1995
1996
1997
1998
1999
2000
2001
2002

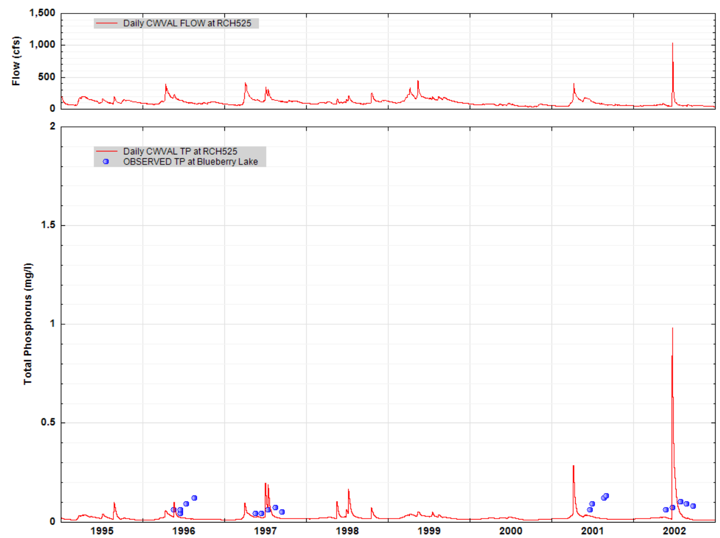

Daily OBSERVED FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
Daily LPCAL03 TP at RCH332
OBSERVED TP at EAGLE CR ON BRG AT CSAH 21
Total Phosphorus (mg/l)
Daily OBSERVED FLOW at RCH333
Daily LPCAL03 TP at RCH333
OBSERVED TP at LONG PRAIRIE R ON BR AT OAK RIDGE RD
Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Daily LPCAL03 TP at RCH336
OBSERVED TP at TURTLE CK ON BR AT OAK RIDGE RD
Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 TP at RCH339
OBSERVED TP at MORAN CR ON BR AT 255TH AVE
1995
1996
1997
1998
1999
2000
2001
2002

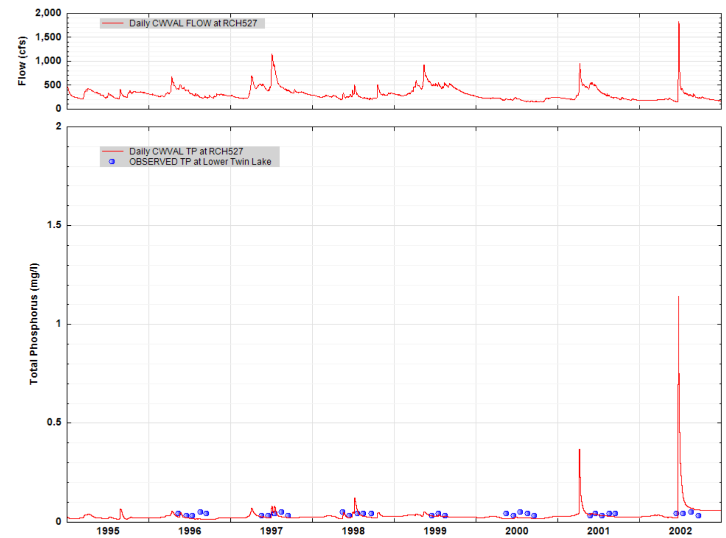

Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Flow (cfs)
Daily LPCAL03 TP at RCH341
OBSERVED TP at LONG PRAIRIE R ON BR AT CR 65
Total Phosphorus (mg/l)
Daily LPCAL03 FLOW at RCH345
Daily LPCAL03 TP at RCH345
OBSERVED TP at Fish Trap Lake
Daily LPCAL03 FLOW at RCH347
Daily LPCAL03 TP at RCH347
OBSERVED TP at LONG PRAIRIE R BRIDGE ON US-10
Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Daily LPCAL03 TP at RCH400
OBSERVED TP at LONG PRAIRIE R ON BR AT RIVERSIDE DR
1995
1996
1997
1998
1999
2000
2001
2002

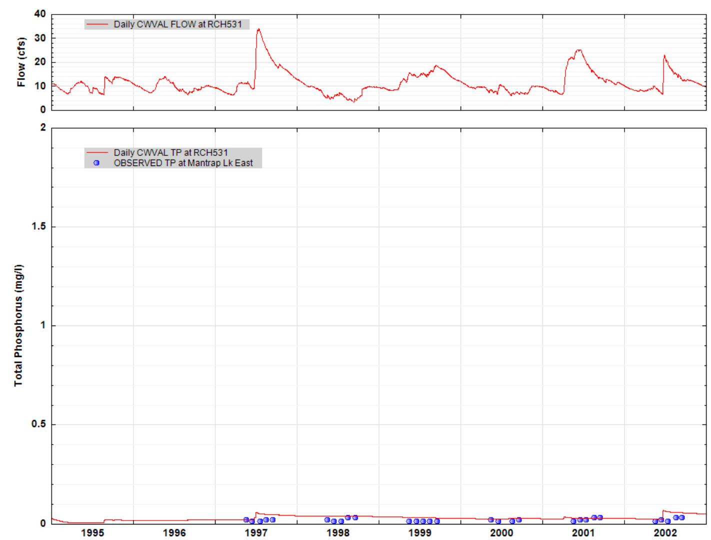
N.2.3 Crow Wing River Watershed

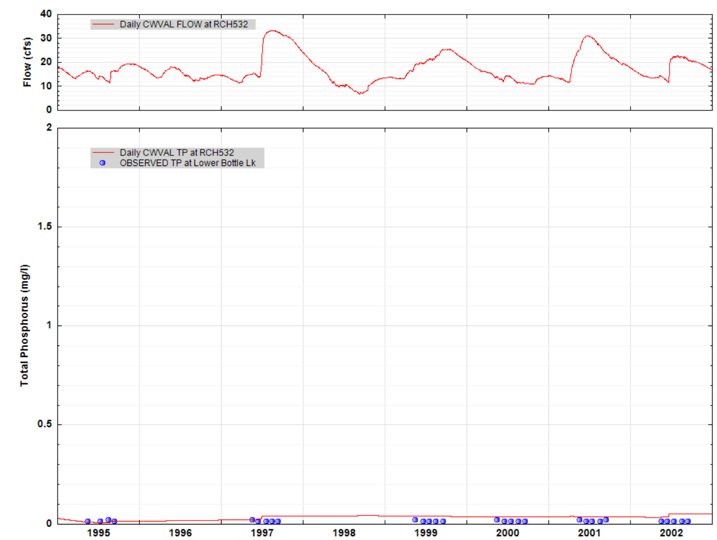


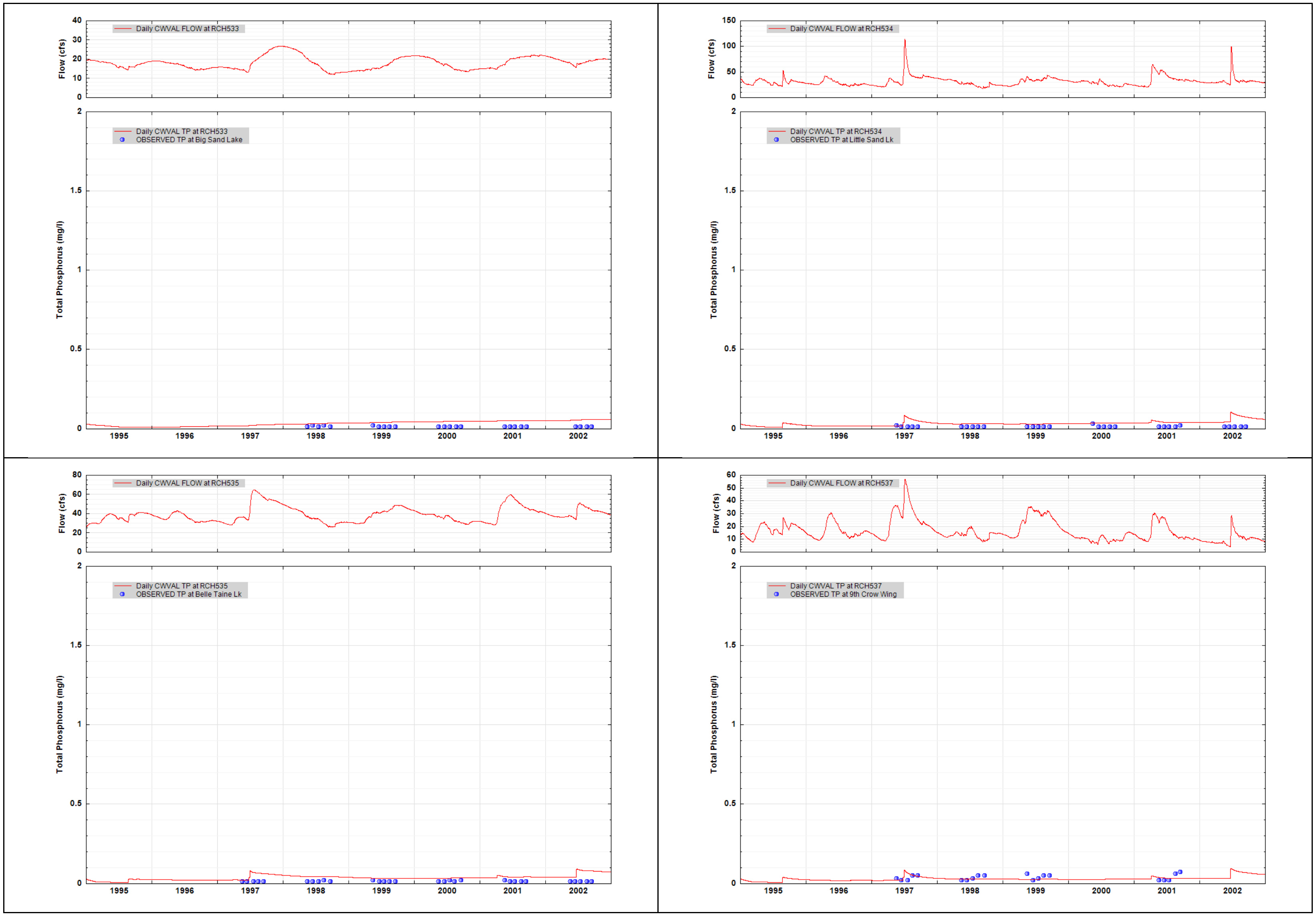

Daily CWVAL FLOW at RCH512
Flow (cfs)
Daily CWVAL TP at RCH512
OBSERVED TP at Fishhook Lake
Total Phosphorus (mg/l)
Daily CWVAL FLOW at RCH514
Daily CWVAL TP at RCH514
OBSERVED TP at Straight Lake
Daily CWVAL FLOW at RCH515
Daily OBSERVED FLOW at 05243725
Daily CWVAL TP at RCH515
OBSERVED TP at STRAIGHT R AT US HWY 71
Daily CWVAL FLOW at RCH517
Daily CWVAL TP at RCH517
OBSERVED TP at Long Lake
1995 1996 1997 1998 1999 2000 2001 2002

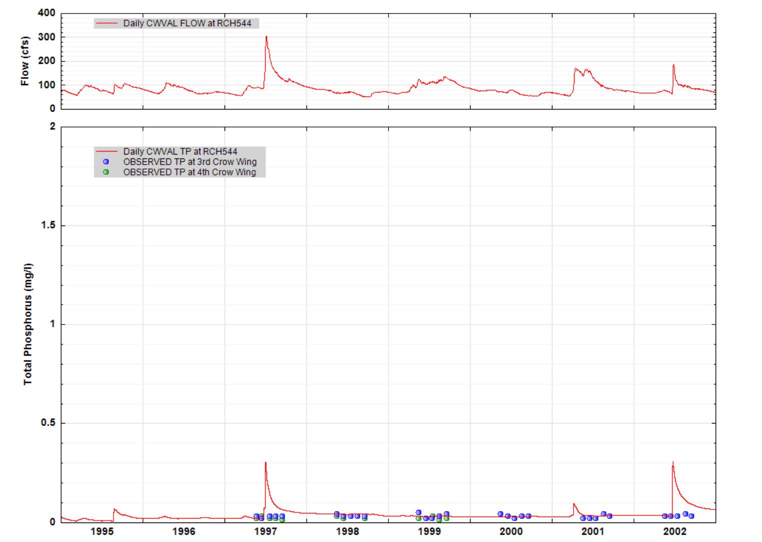

Flow (cfs)
Daily CWVAL FLOW at RCH525
Total Phosphorus (mg/l)
Daily CWVAL TP at RCH525
OBSERVED TP at Blueberry Lake
1995
1996
1997
1998
1999
2000
2001
2002


Flow (cfs)
Daily CWVAL FLOW at RCH527
Total Phosphorus (mg/l)
Daily CWVAL TP at RCH527
OBSERVED TP at Lower Twin Lake
1995
1996
1997
1998
1999
2000
2001
2002

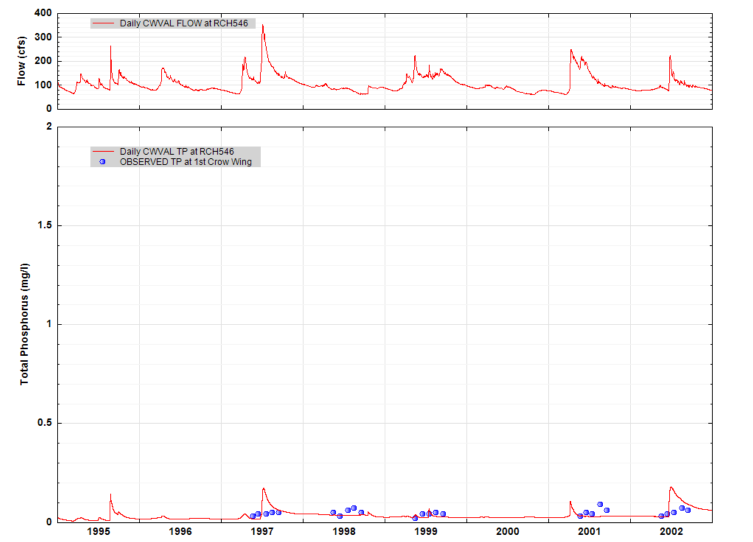

Flow (cfs)
Daily CWVAL FLOW at RCH531
Total Phosphorus (mg/l)
Daily CWVAL TP at RCH531
OBSERVED TP at Mantrap Lk East
1995
1996
1997
1998
1999
2000
2001
2002


Flow (cfs)
Daily CWVAL FLOW at RCH532
Total Phosphorus (mg/l)
Daily CWVAL TP at RCH532
OBSERVED TP at Lower Bottle Lk
1995
1996
1997
1998
1999
2000
2001
2002

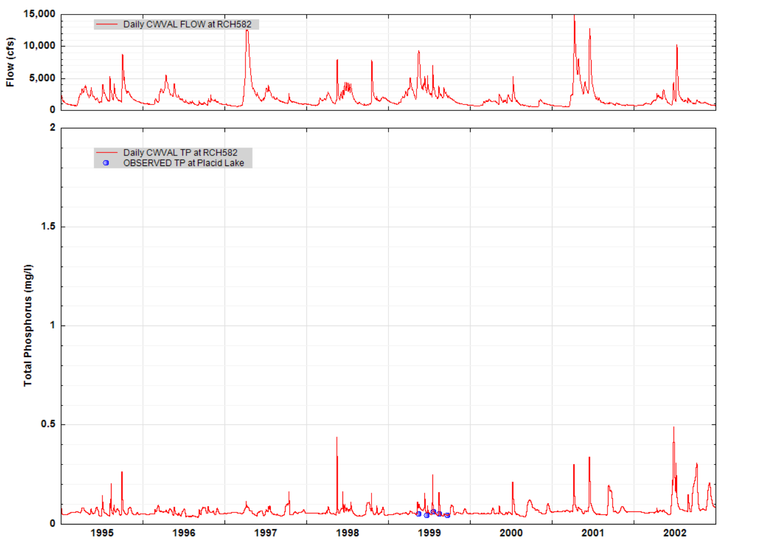

Daily CWVAL FLOW at RCH533
Flow (cfs)
Daily CWVAL TP at RCH533
OBSERVED TP at Big Sand Lake
Total Phosphorus (mg/l)
Daily CWVAL FLOW at RCH534
Flow (cfs)
Daily CWVAL TP at RCH534
OBSERVED TP at Little Sand Lk
Total Phosphorus (mg/l)
Daily CWVAL FLOW at RCH535
Flow (cfs)
Daily CWVAL TP at RCH535
OBSERVED TP at Belle Taine Lk
Total Phosphorus (mg/l)
Daily CWVAL FLOW at RCH537
Flow (cfs)
Daily CWVAL TP at RCH537
OBSERVED TP at 9th Crow Wing
Total Phosphorus (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002



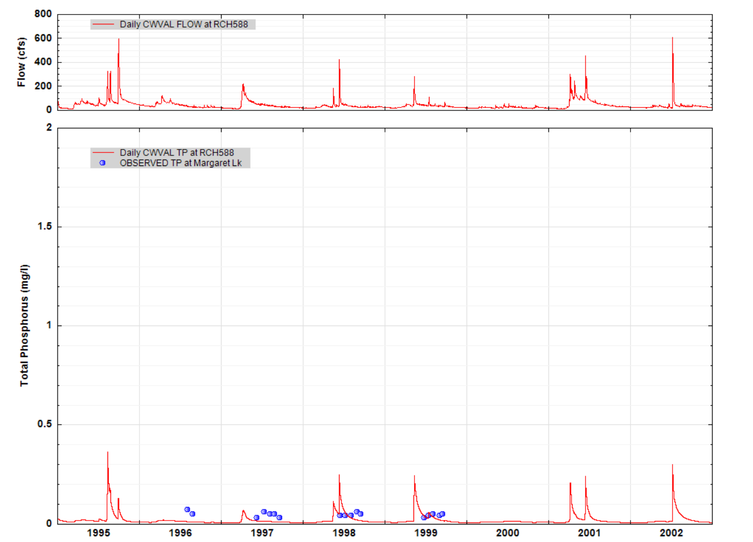
Daily CWVAL FLOW at RCH544
Flow (cfs)
Daily CWVAL TP at RCH544
OBSERVED TP at 3rd Crow Wing
OBSERVED TP at 4th Crow Wing
Total Phosphorus (mg/l)



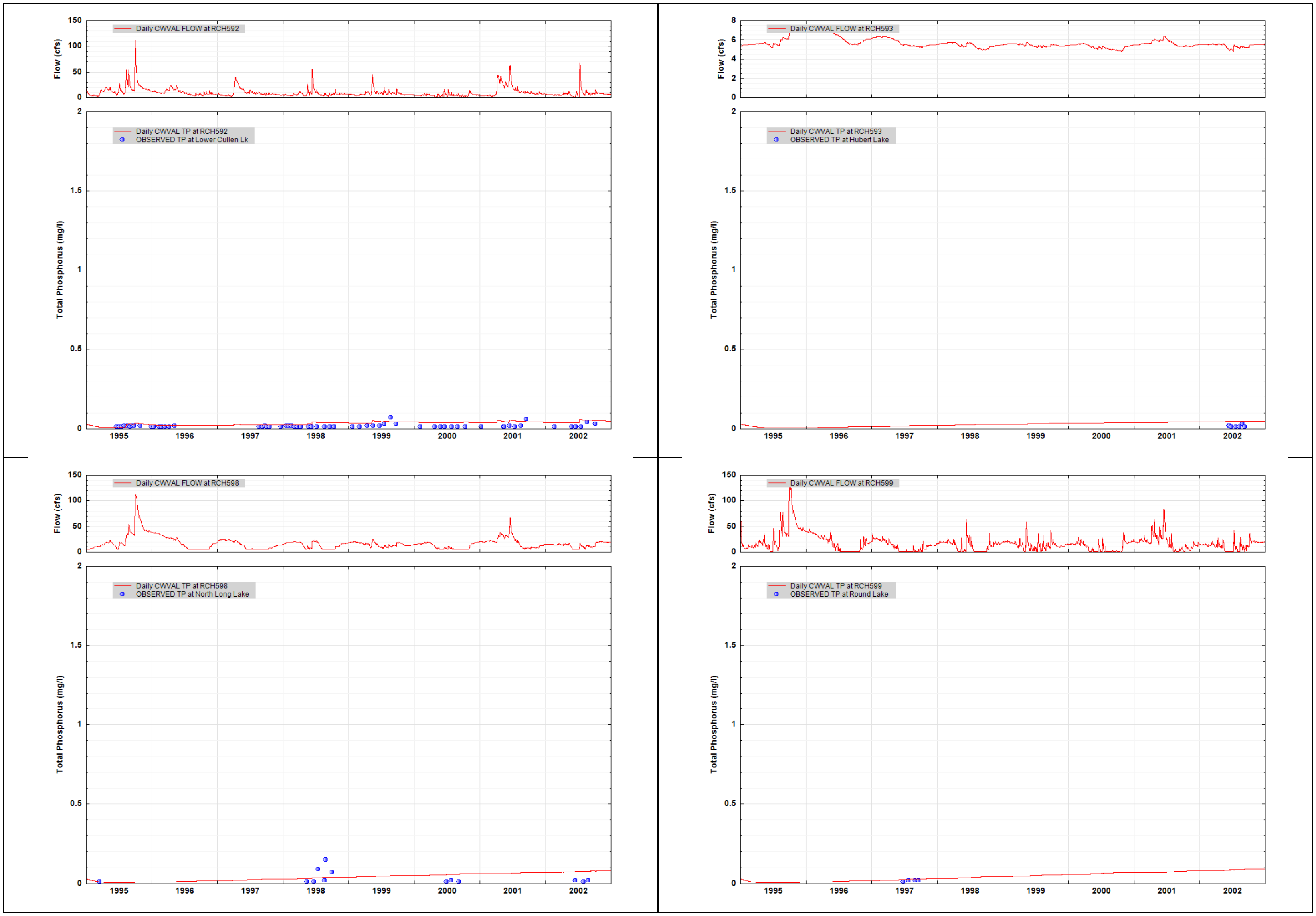
Daily CWVAL FLOW at RCH546
Flow (cfs)
Daily CWVAL TP at RCH546
OBSERVED TP at 1st Crow Wing
Total Phosphorus (mg/l)



Daily CWVAL FLOW at RCH582
Flow (cfs)
Daily CWVAL TP at RCH582
OBSERVED TP at Placid Lake
Total Phosphorus (mg/l)

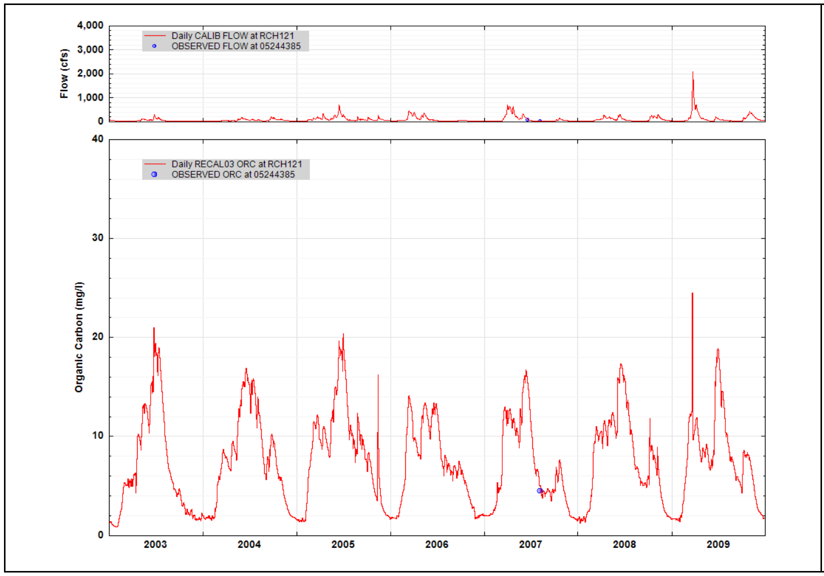


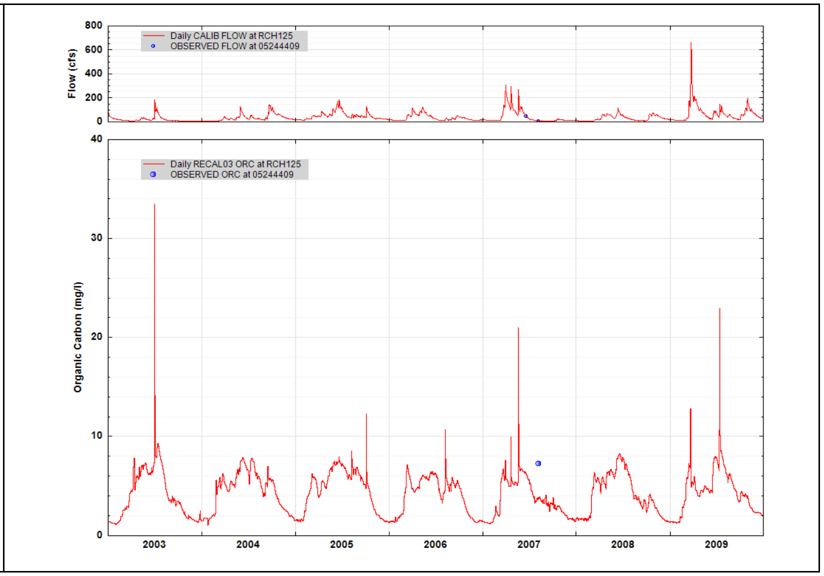
Daily CWVAL FLOW at RCH588
Flow (cfs)
Daily CWVAL TP at RCH588
OBSERVED TP at Margaret Lk
Total Phosphorus (mg/l)


Daily CWVAL FLOW at RCH592
Flow (cfs)
Daily CWVAL TP at RCH592
OBSERVED TP at Lower Cullen Lk
Total Phosphorus (mg/l)
Daily CWVAL FLOW at RCH593
Daily CWVAL TP at RCH593
OBSERVED TP at Hubert Lake
Daily CWVAL FLOW at RCH598
Daily CWVAL TP at RCH598
OBSERVED TP at North Long Lake
Daily CWVAL FLOW at RCH599
Daily CWVAL TP at RCH599
OBSERVED TP at Round Lake
1995
1996
1997
1998
1999
2000
2001
2002

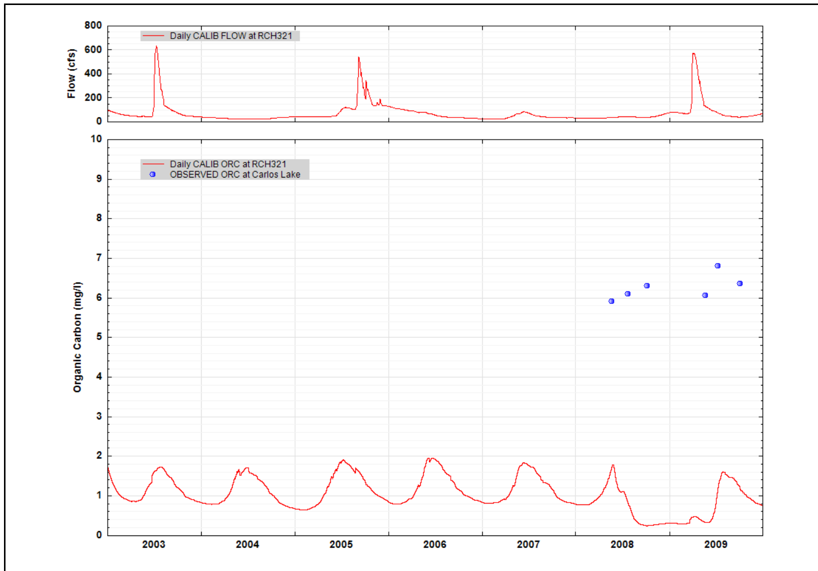
APPENDIX O
OBSERVED AND SIMULATED ORGANIC CARBON FOR THE CALIBRATION PERIOD

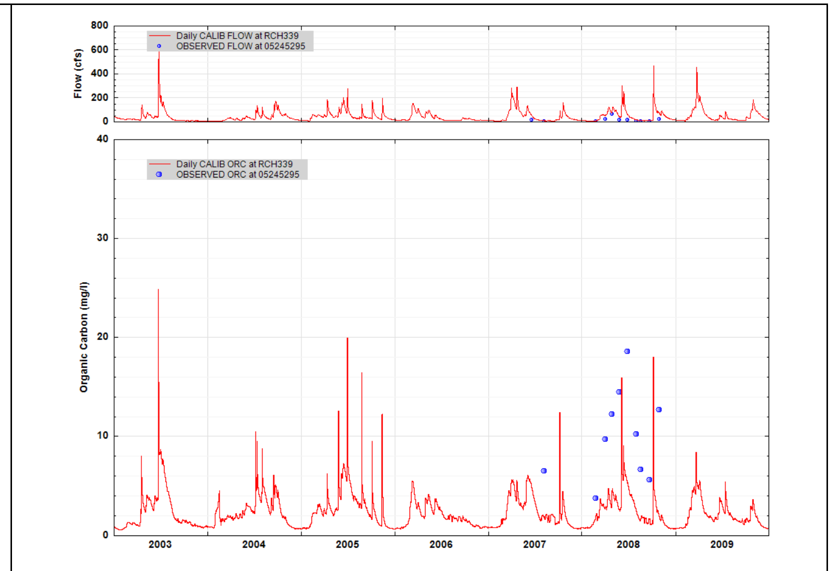
O.1 REDEYE RIVER WATERSHED

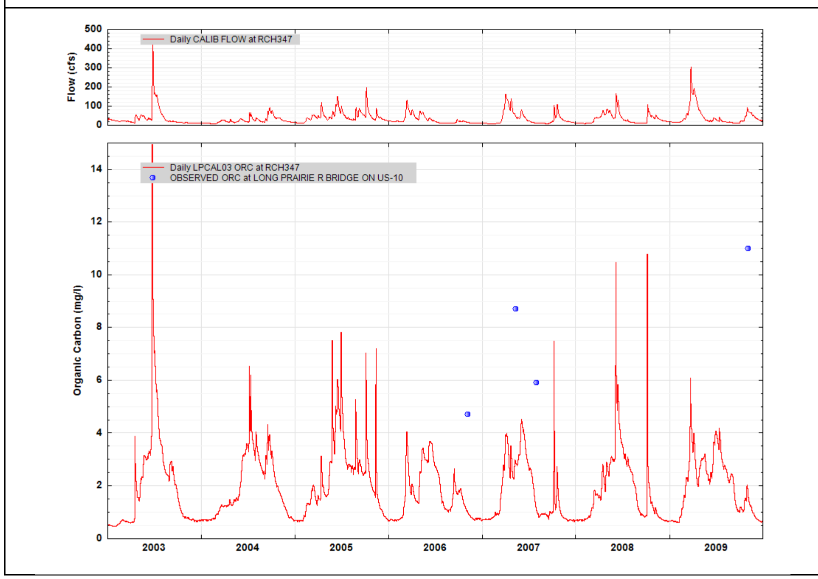




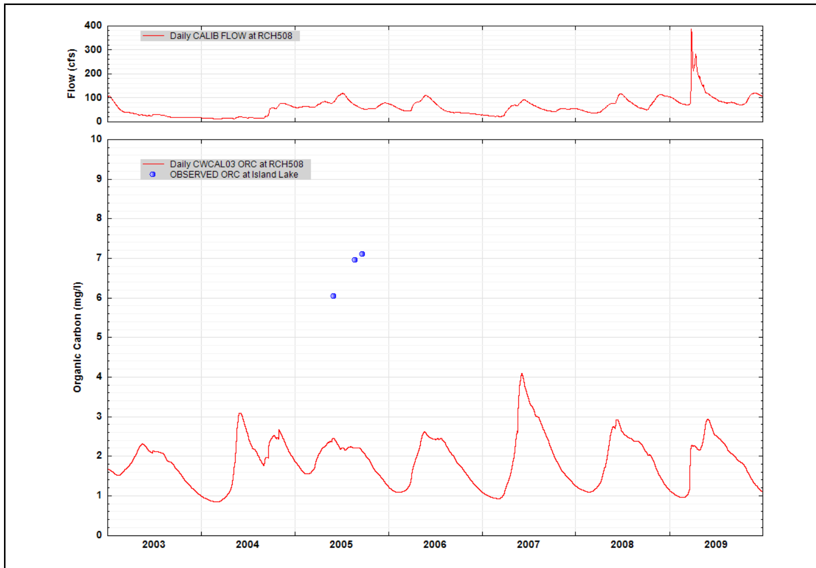
O.2 LONG PRAIRIE RIVER WATERSHED

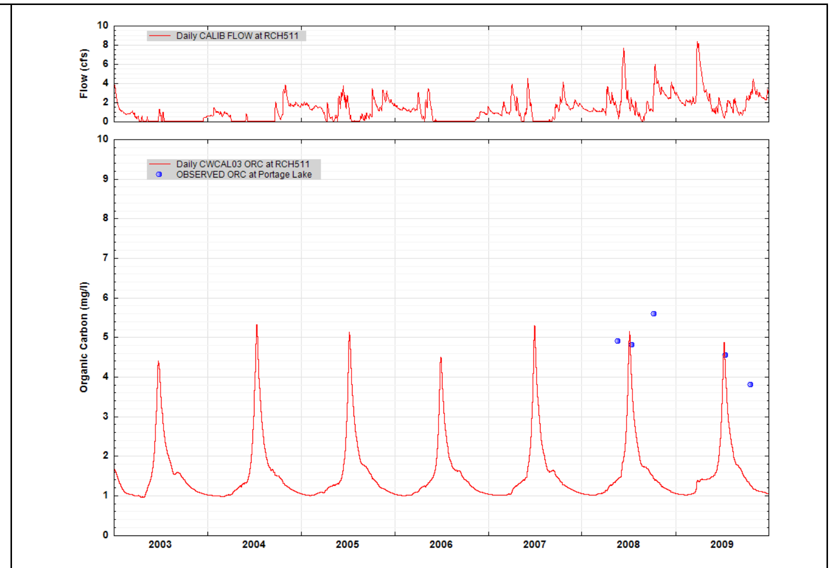


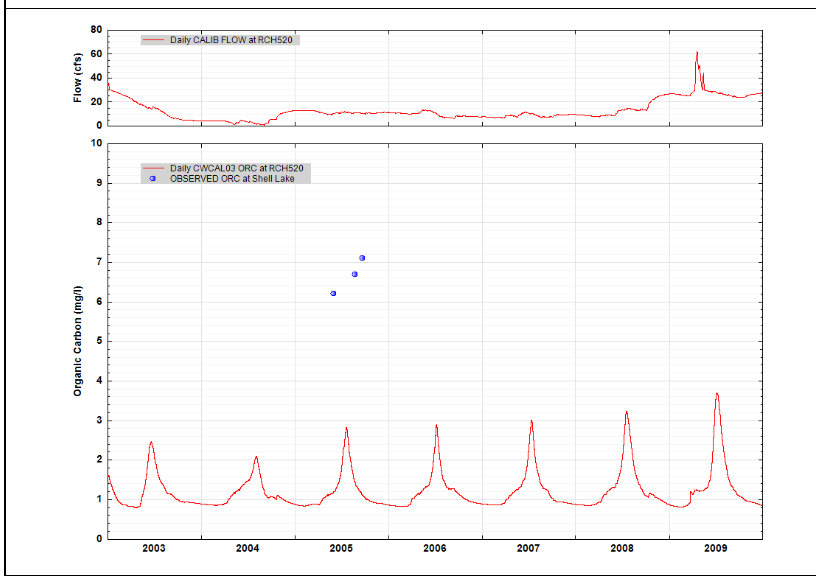


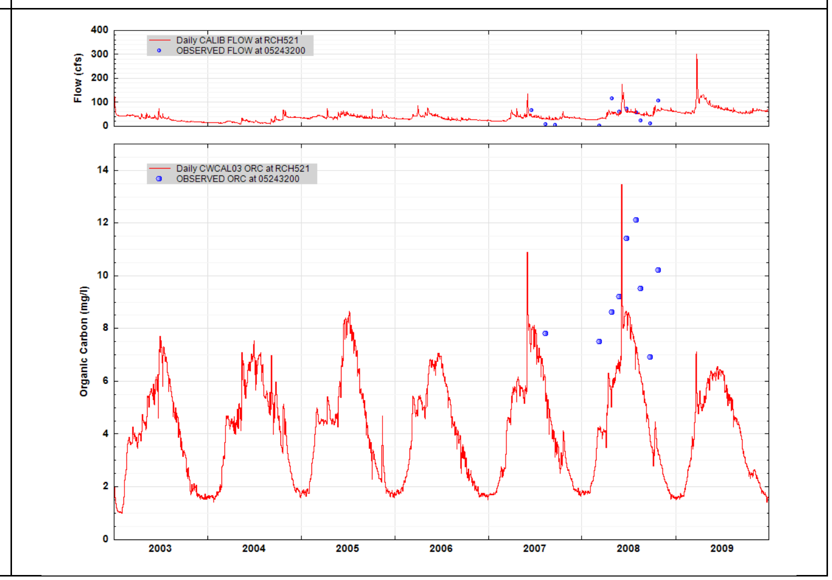


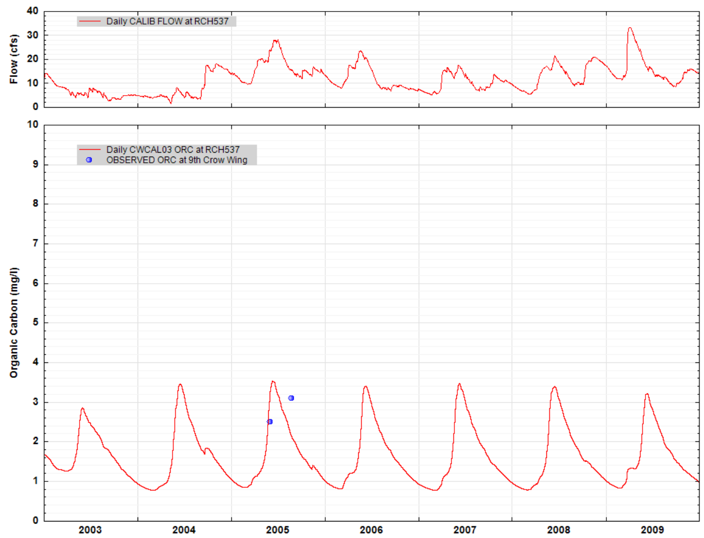
O.3 CROW WING RIVER WATERSHED





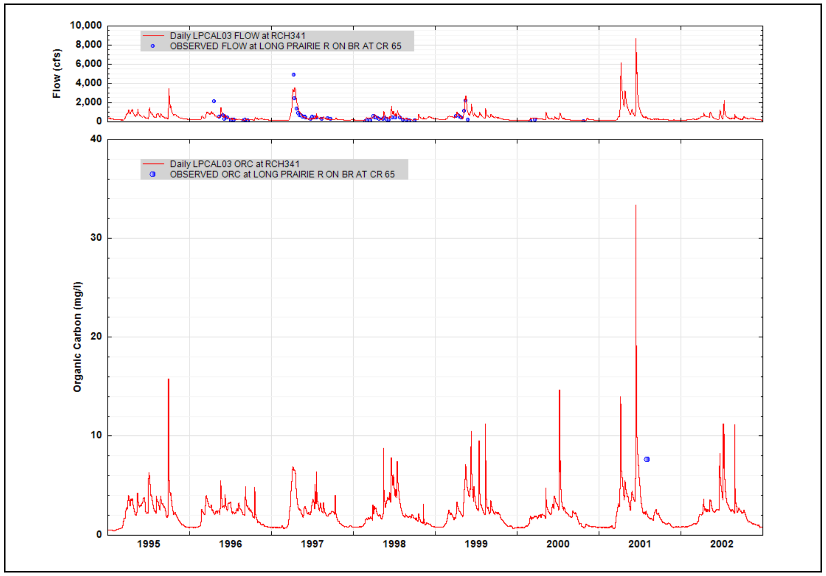





Daily CALIB FLOW at RCH537
Flow (cfs)
Daily CWCAL03 ORC at RCH537
OBSERVED ORC at 9th Crow Wing
Organic Carbon (mg/l)
2003
2004
2005
2006
2007
2008
2009

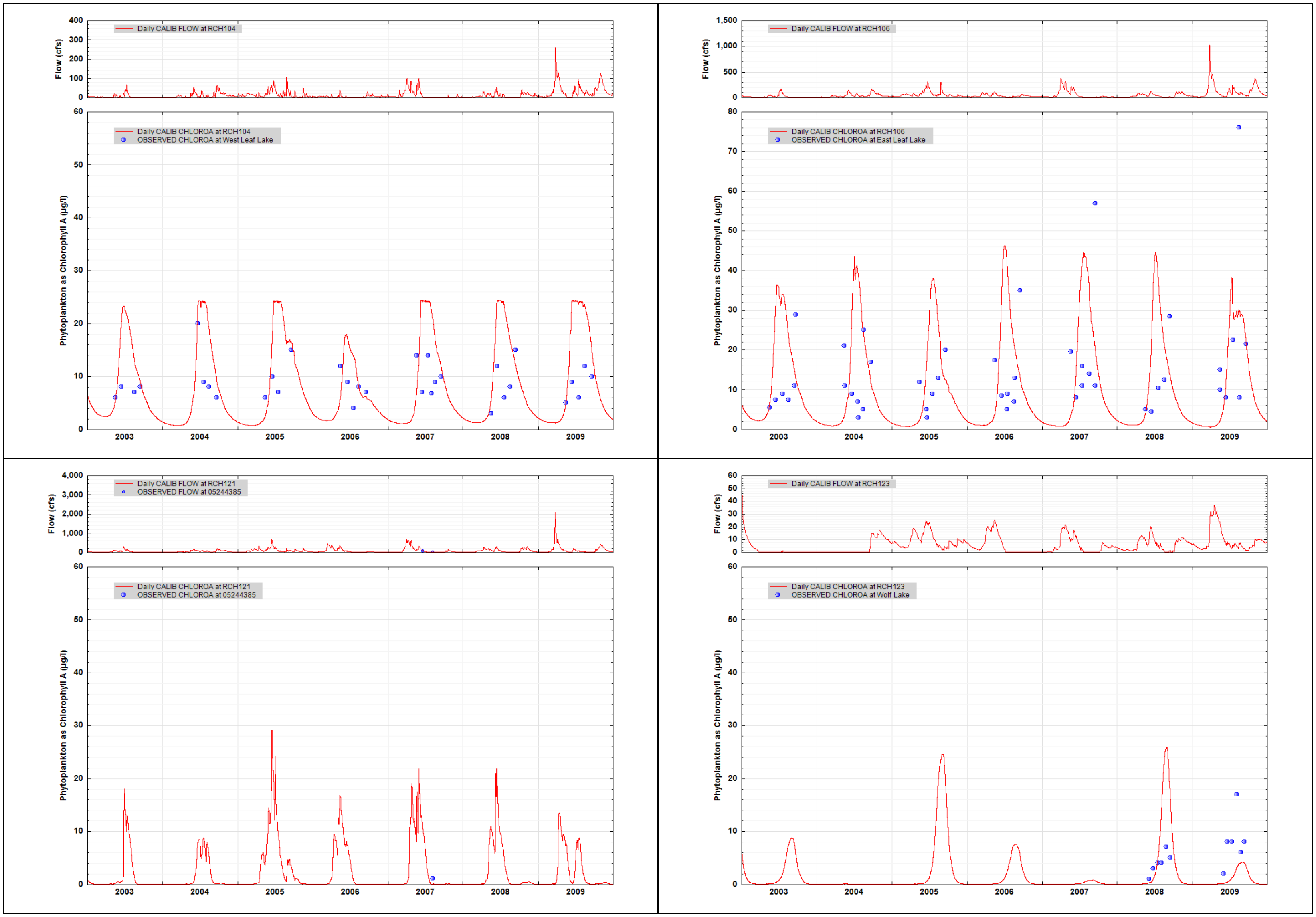
APPENDIX P
OBSERVED AND SIMULATED ORGANIC CARBON FOR THE VALIDATION PERIOD

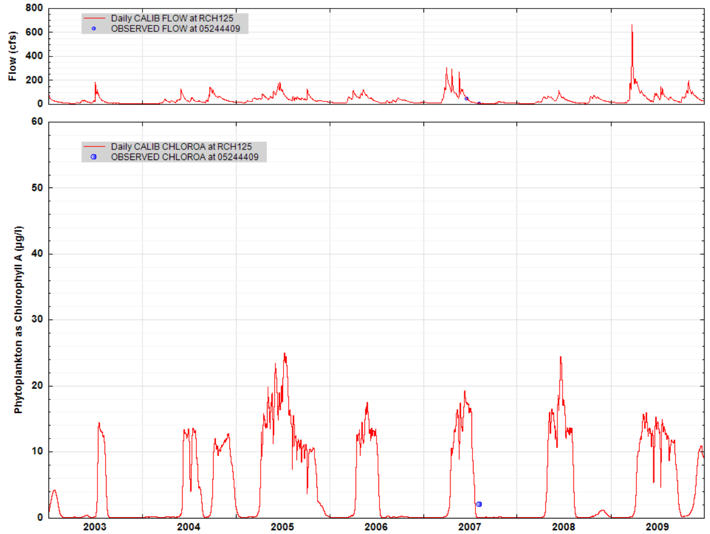
P.1 LONG PRAIRIE RIVER WATERSHED



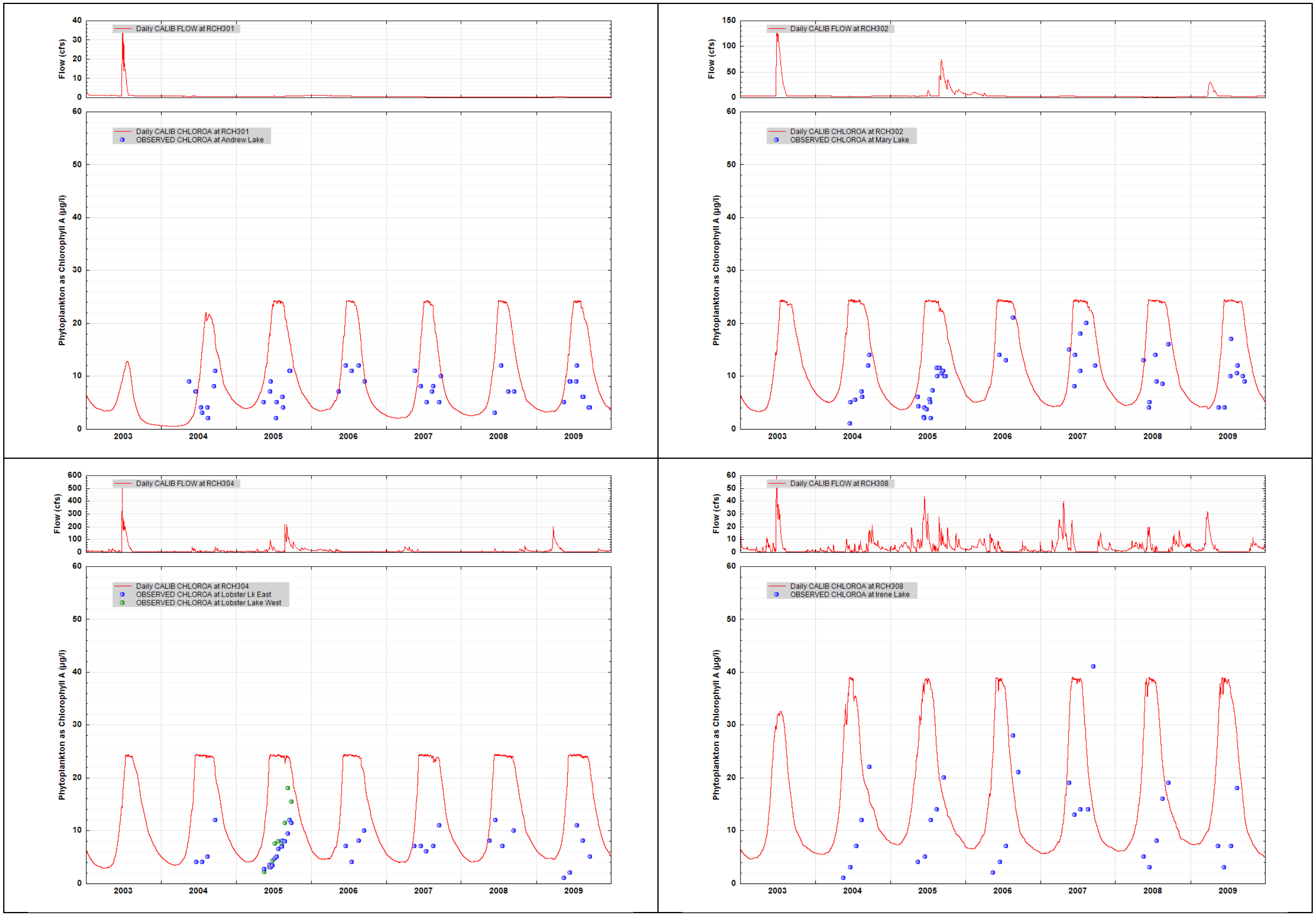
APPENDIX Q
OBSERVED AND SIMULATED CHLOROPHYLL A FOR THE CALIBRATION PERIOD

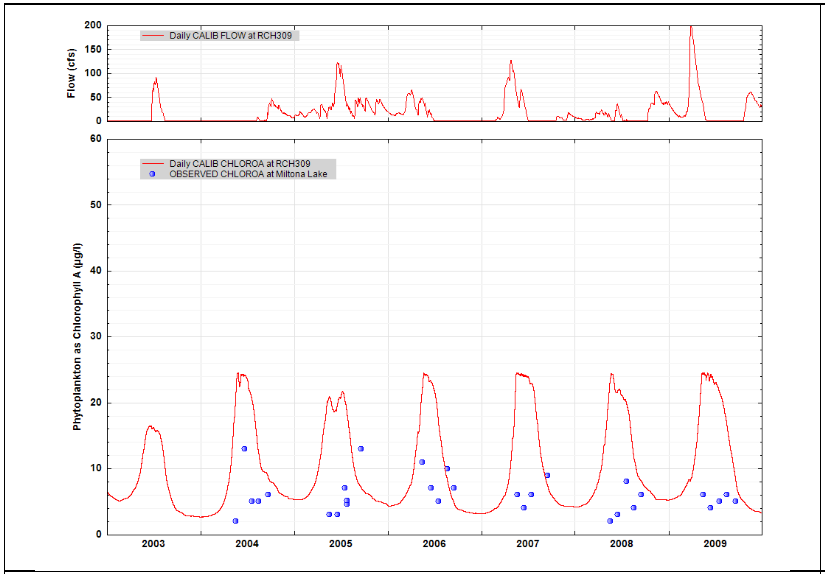
Q.1 REDEYE RIVER WATERSHED

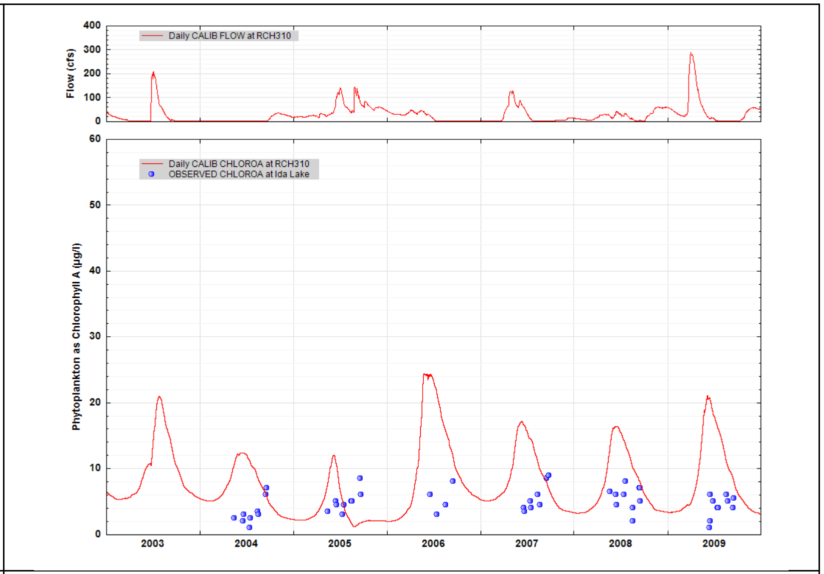


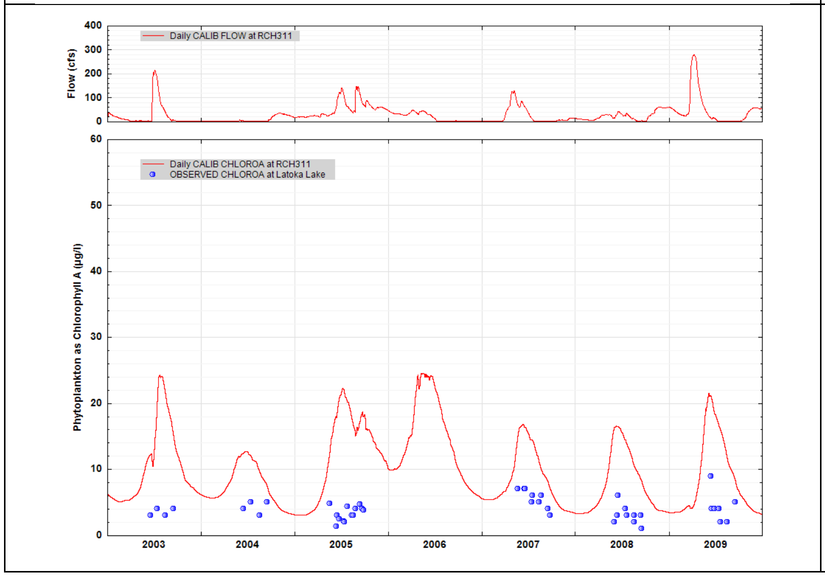

800
600
400
200
0
Flow (cfs)
Daily CALIB FLOW at RCH125
OBSERVED FLOW at 05244409
60
50
40
30
20
10
0
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB CHLOROA at RCH125
OBSERVED CHLOROA at 05244409
2003
2004
2005
2006
2007
2008
2009

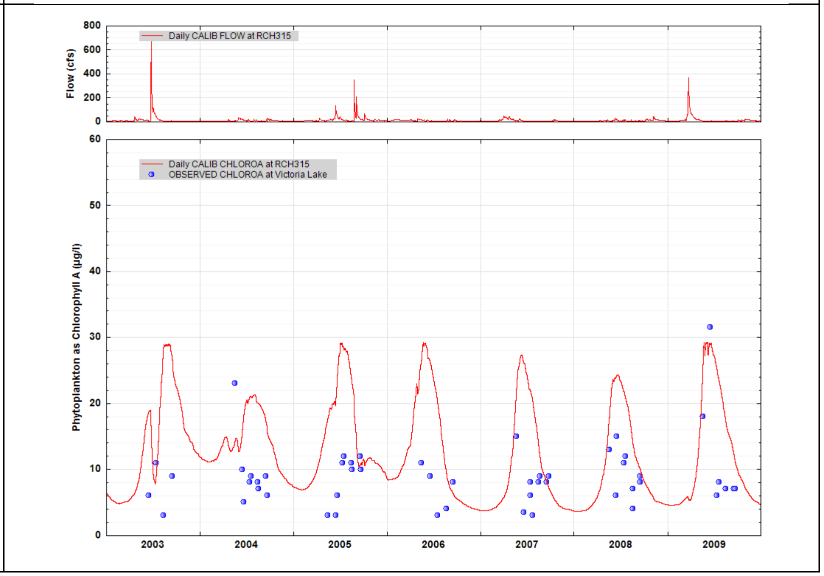
Q.2 LONG PRAIRIE RIVER WATERSHED

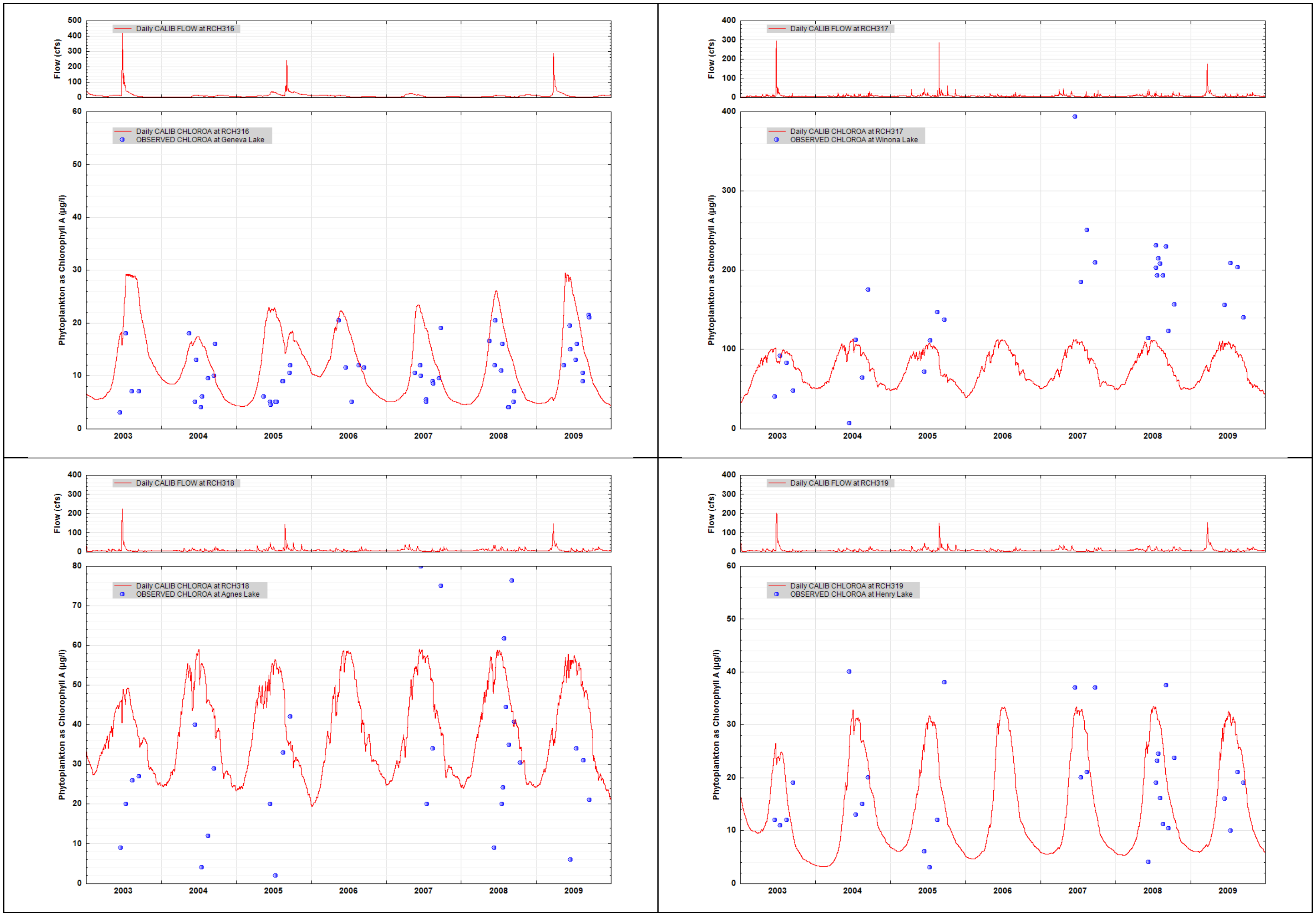


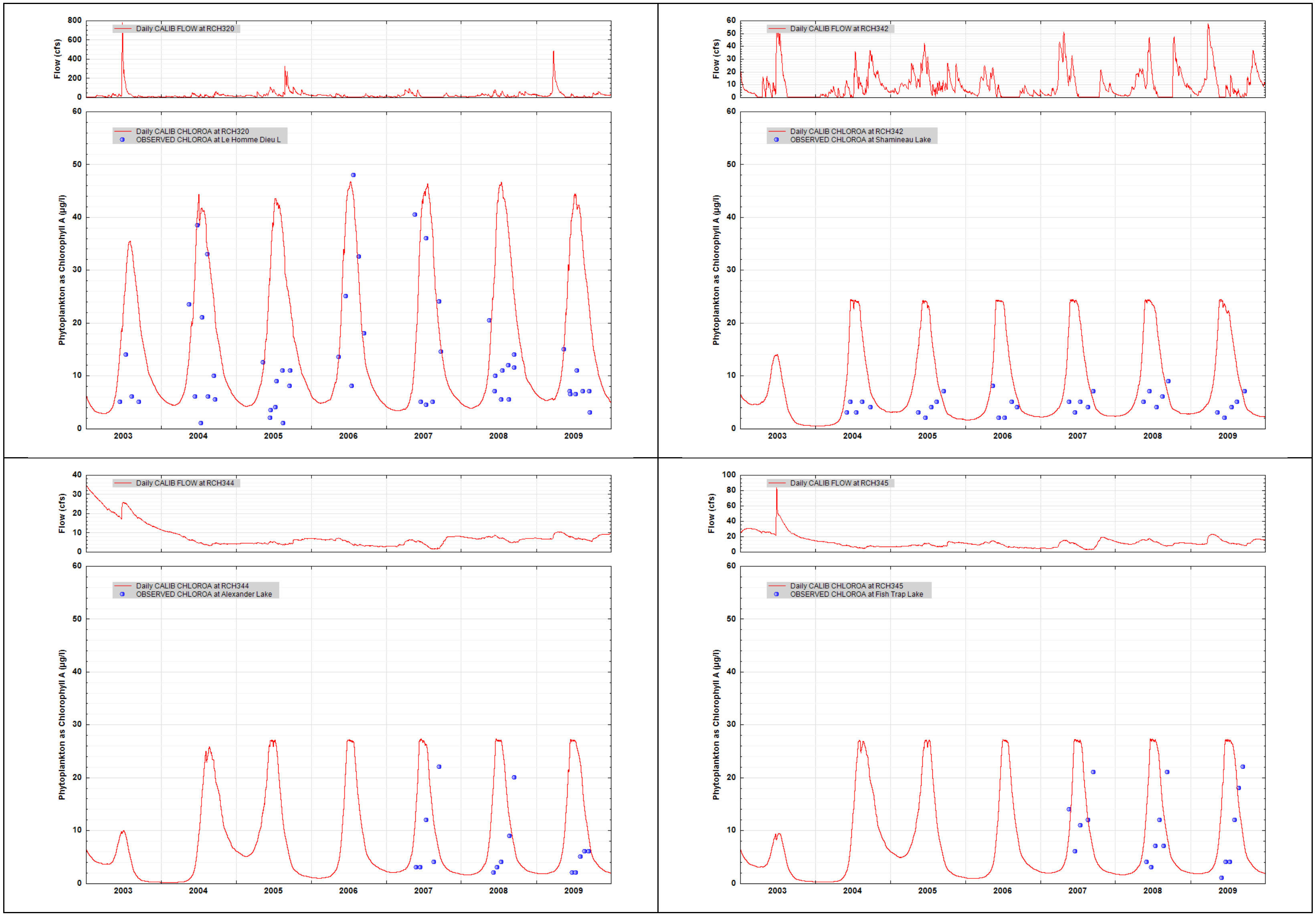

Daily CALIB FLOW at RCH309
Flow (cfs)
Daily CALIB CHLOROA at RCH309
OBSERVED CHLOROA at Miltona Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

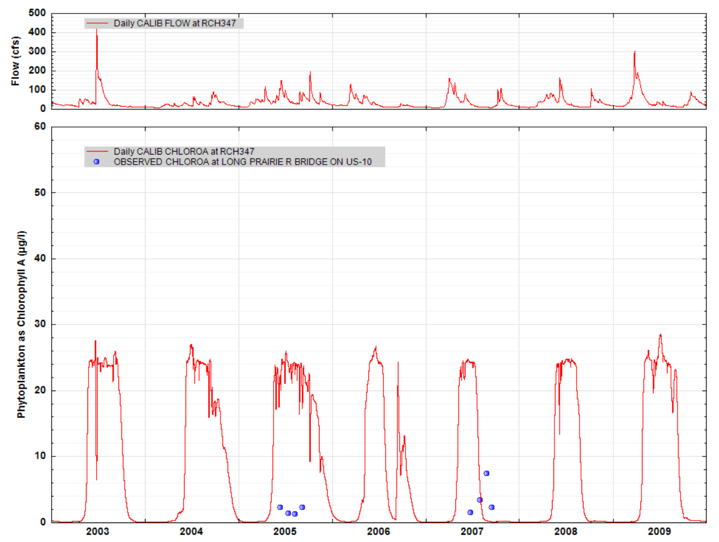

Daily CALIB FLOW at RCH310
Flow (cfs)
Daily CALIB CHLOROA at RCH310
OBSERVED CHLOROA at Ida Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

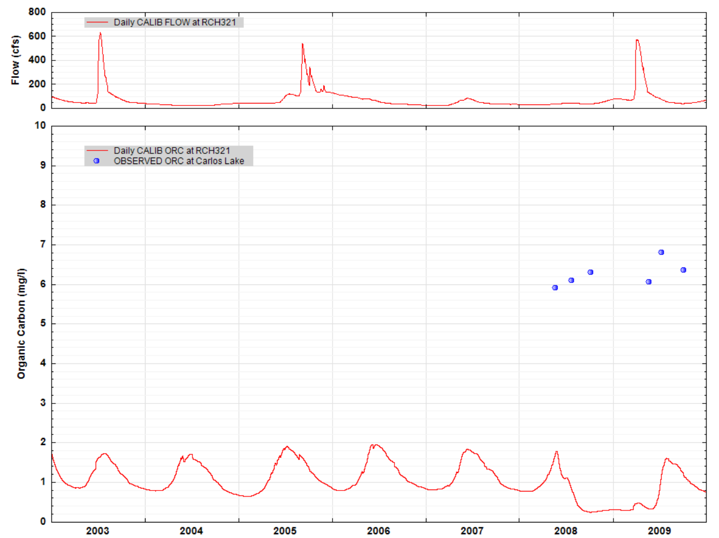

Daily CALIB FLOW at RCH311
Flow (cfs)
Daily CALIB CHLOROA at RCH311
OBSERVED CHLOROA at Latoka Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

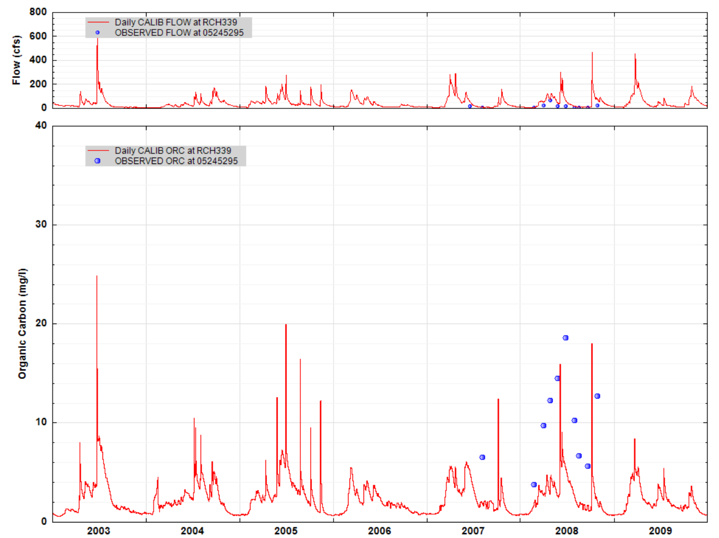

Daily CALIB FLOW at RCH315
Flow (cfs)
Daily CALIB CHLOROA at RCH315
OBSERVED CHLOROA at Victoria Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

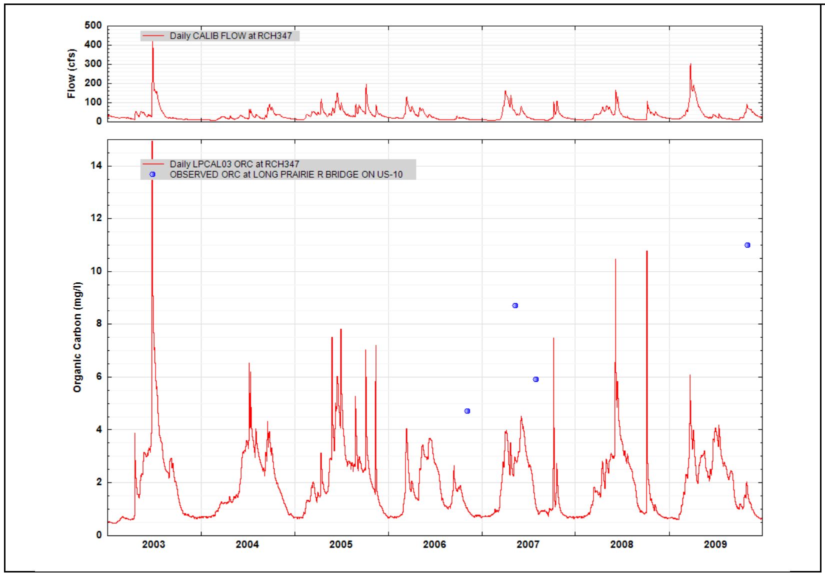

Daily CALIB FLOW at RCH316
Flow (cfs)
Daily CALIB CHLOROA at RCH316
OBSERVED CHLOROA at Geneva Lake
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB FLOW at RCH317
Daily CALIB CHLOROA at RCH317
OBSERVED CHLOROA at Winona Lake
Daily CALIB FLOW at RCH318
Daily CALIB CHLOROA at RCH318
OBSERVED CHLOROA at Agnes Lake
Daily CALIB FLOW at RCH319
Daily CALIB CHLOROA at RCH319
OBSERVED CHLOROA at Henry Lake
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH320
Flow (cfs)
Daily CALIB CHLOROA at RCH320
OBSERVED CHLOROA at Le Homme Dieu L
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB FLOW at RCH342
Daily CALIB CHLOROA at RCH342
OBSERVED CHLOROA at Shamineau Lake
Daily CALIB FLOW at RCH344
Daily CALIB CHLOROA at RCH344
OBSERVED CHLOROA at Alexander Lake
Daily CALIB FLOW at RCH345
Daily CALIB CHLOROA at RCH345
OBSERVED CHLOROA at Fish Trap Lake
2003
2004
2005
2006
2007
2008
2009

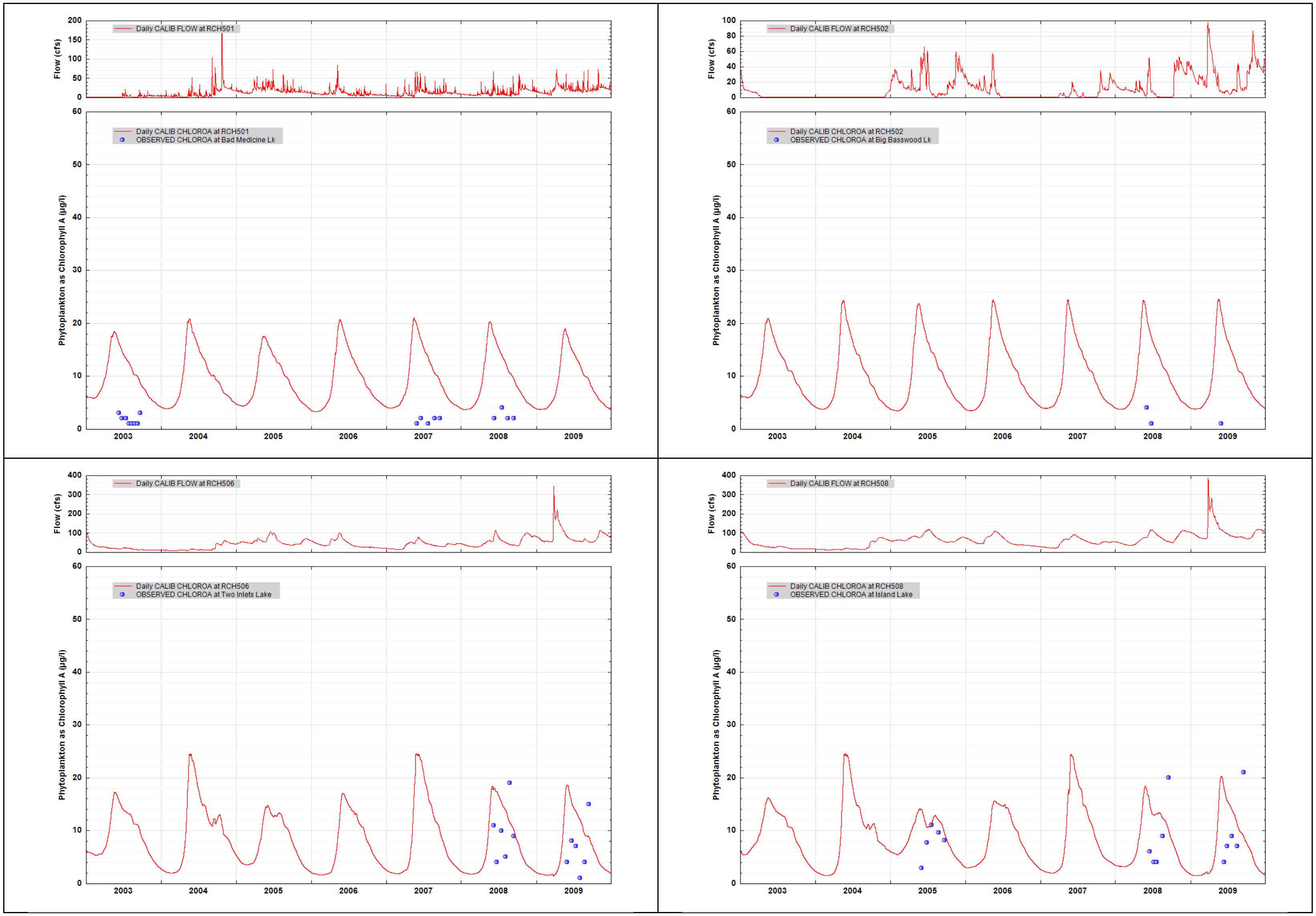

Daily CALIB FLOW at RCH347
Flow (cfs)
Daily CALIB CHLOROA at RCH347
OBSERVED CHLOROA at LONG PRAIRIE R BRIDGE ON US-10
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

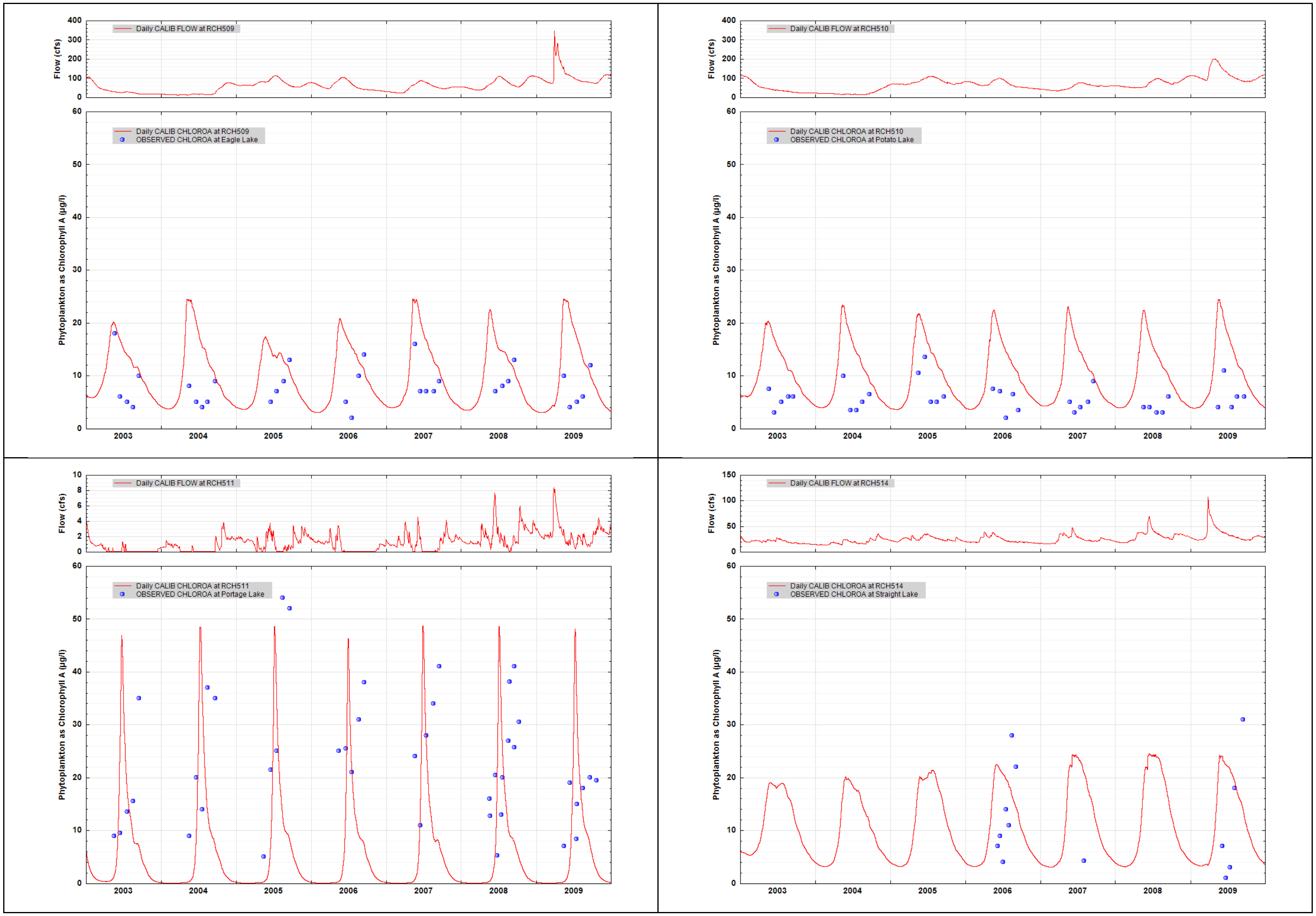

Daily CALIB FLOW at RCH321
Flow (cfs)
Daily CALIB ORC at RCH321
OBSERVED ORC at Carlos Lake
Organic Carbon (mg/l)
2003
2004
2005
2006
2007
2008
2009

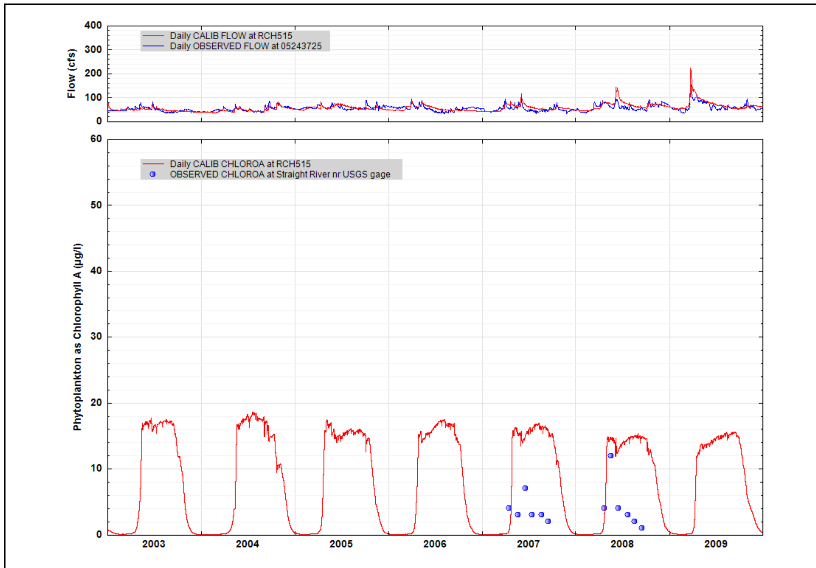

Daily CALIB FLOW at RCH339
OBSERVED FLOW at 05245295
Flow (cfs)
Daily CALIB ORC at RCH339
OBSERVED ORC at 05245295
Organic Carbon (mg/l)
2003
2004
2005
2006
2007
2008
2009

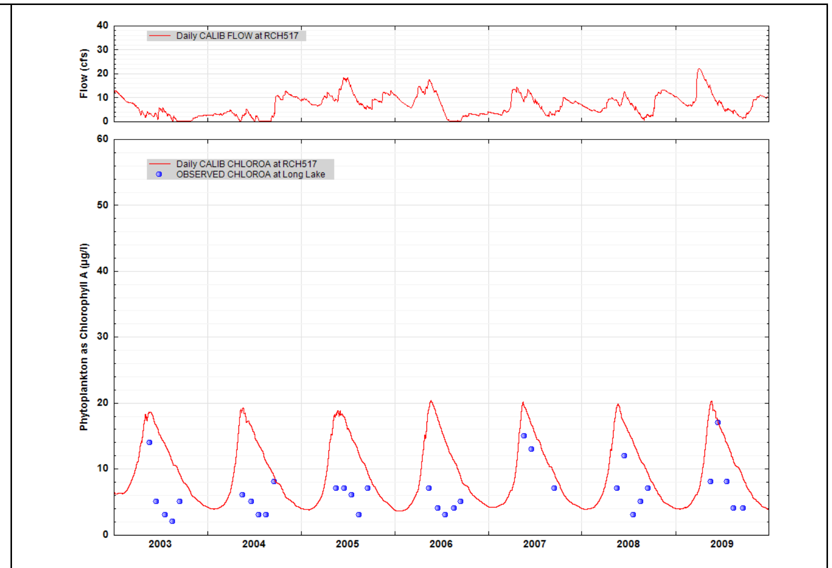

Daily CALIB FLOW at RCH347
Flow (cfs)
Daily LPCAL03 ORC at RCH347
OBSERVED ORC at LONG PRAIRIE R BRIDGE ON US-10
Organic Carbon (mg/l)
2003
2004
2005
2006
2007
2008
2009

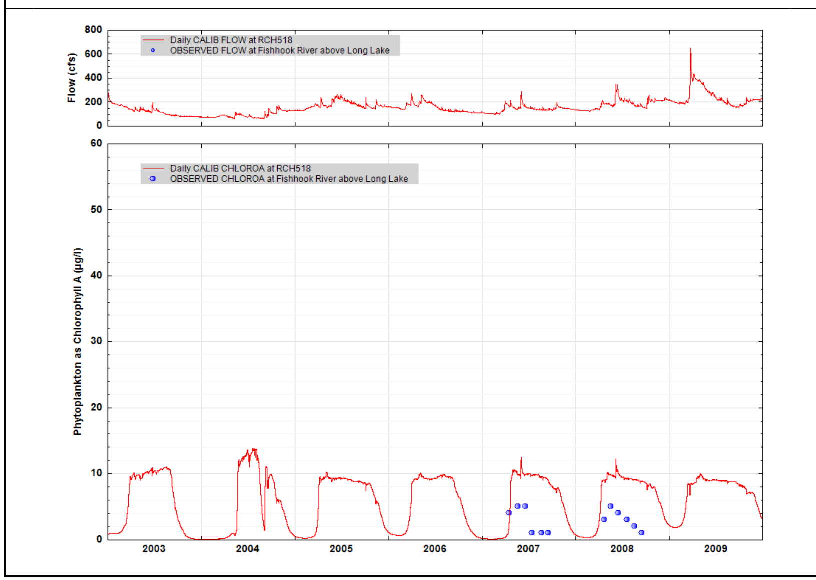
Q.3 CROW WING RIVER WATERSHED

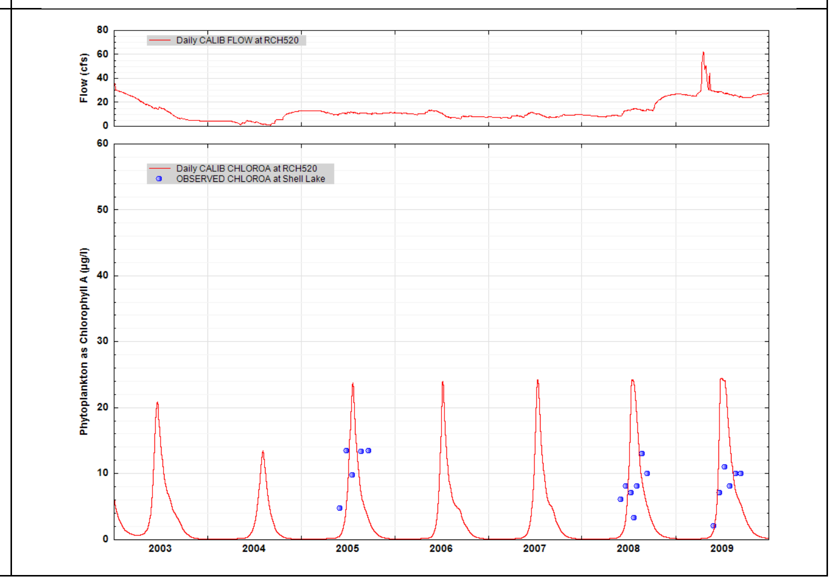


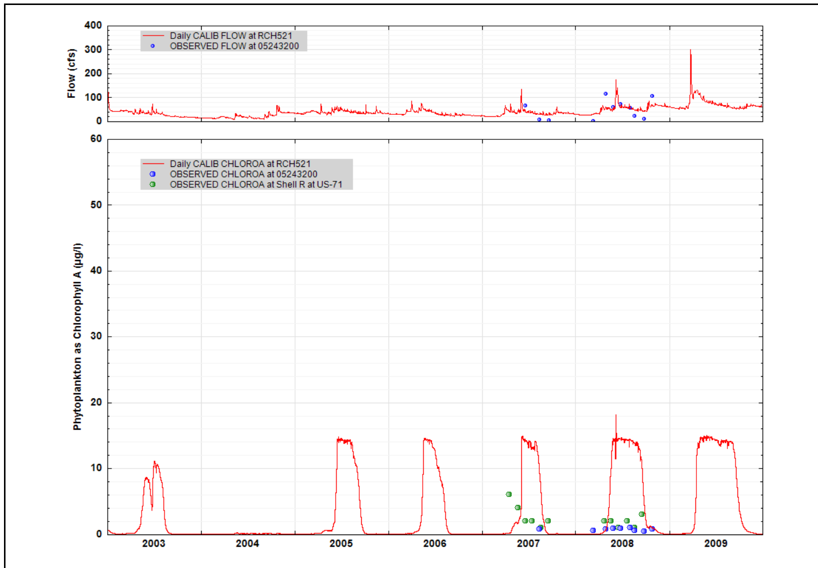

Daily CALIB FLOW at RCH509
Flow (cfs)
Daily CALIB CHLOROA at RCH509
OBSERVED CHLOROA at Eagle Lake
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB FLOW at RCH510
Daily CALIB CHLOROA at RCH510
OBSERVED CHLOROA at Potato Lake
Daily CALIB FLOW at RCH511
Daily CALIB CHLOROA at RCH511
OBSERVED CHLOROA at Portage Lake
Daily CALIB FLOW at RCH514
Daily CALIB CHLOROA at RCH514
OBSERVED CHLOROA at Straight Lake
2003
2004
2005
2006
2007
2008
2009

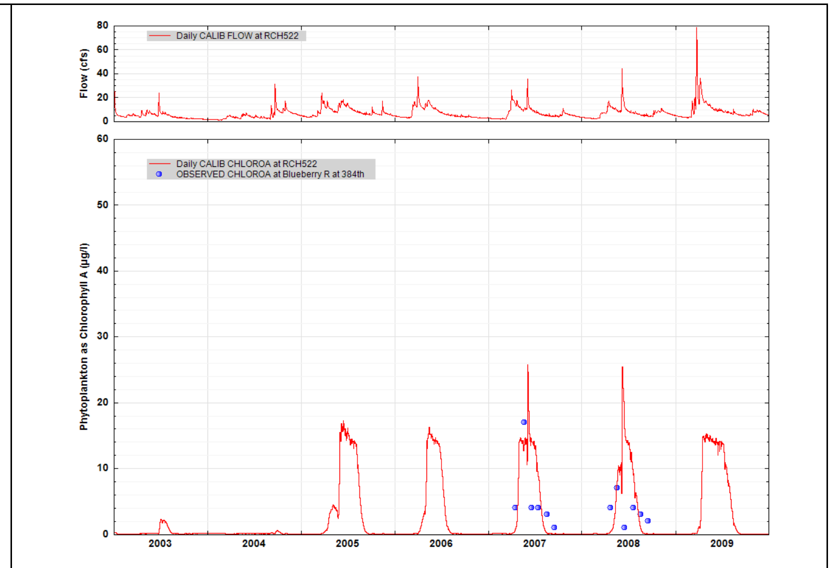

Daily CALIB FLOW at RCH515
Daily OBSERVED FLOW at 05243725
Flow (cfs)
Daily CALIB CHLOROA at RCH515
OBSERVED CHLOROA at Straight River nr USGS gage
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

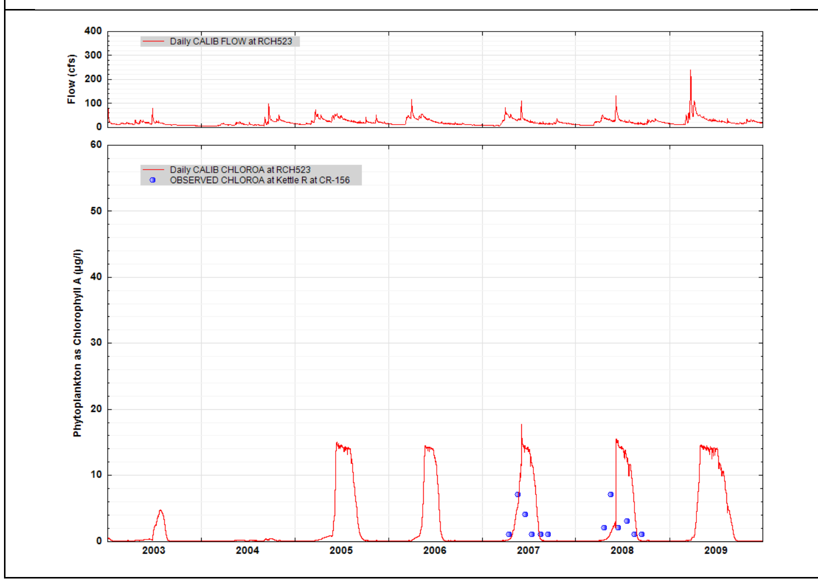

Daily CALIB FLOW at RCH517
Flow (cfs)
Daily CALIB CHLOROA at RCH517
OBSERVED CHLOROA at Long Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

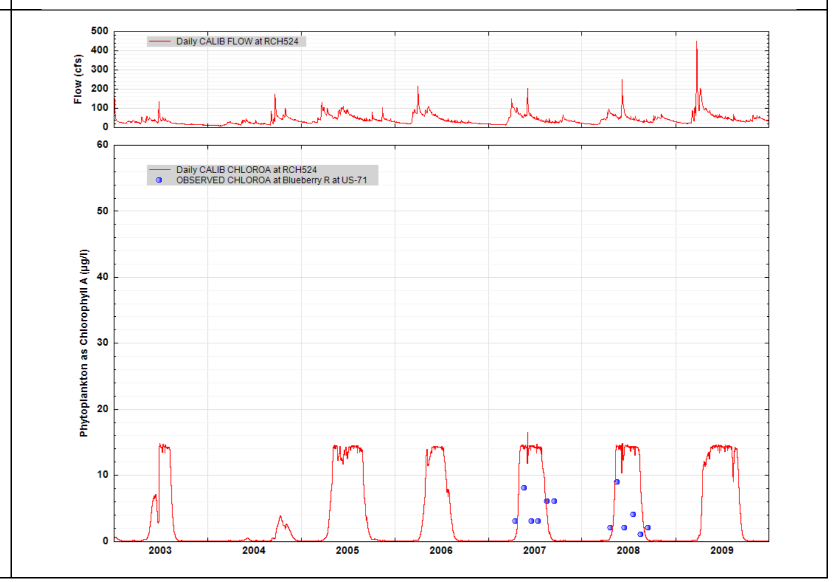

Daily CALIB FLOW at RCH518
OBSERVED FLOW at Fishhook River above Long Lake
Flow (cfs)
Daily CALIB CHLOROA at RCH518
OBSERVED CHLOROA at Fishhook River above Long Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

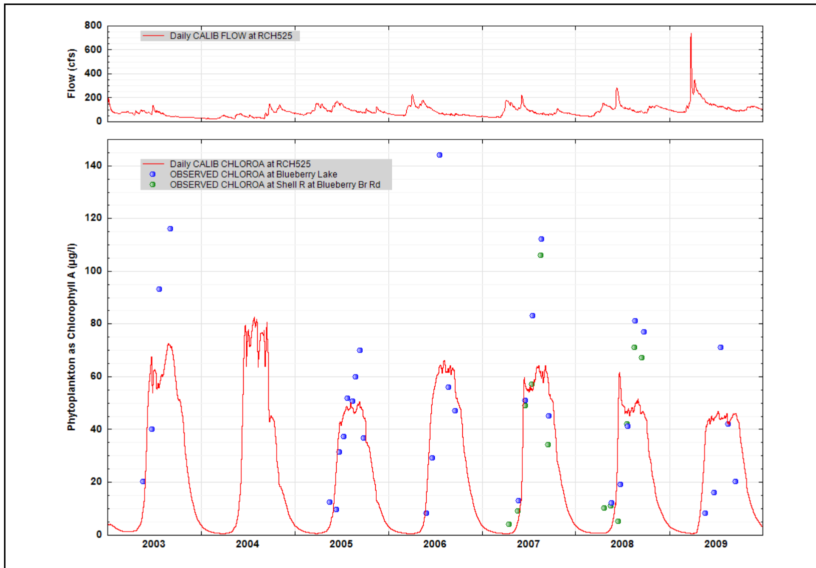

Daily CALIB FLOW at RCH520
Flow (cfs)
Daily CALIB CHLOROA at RCH520
OBSERVED CHLOROA at Shell Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

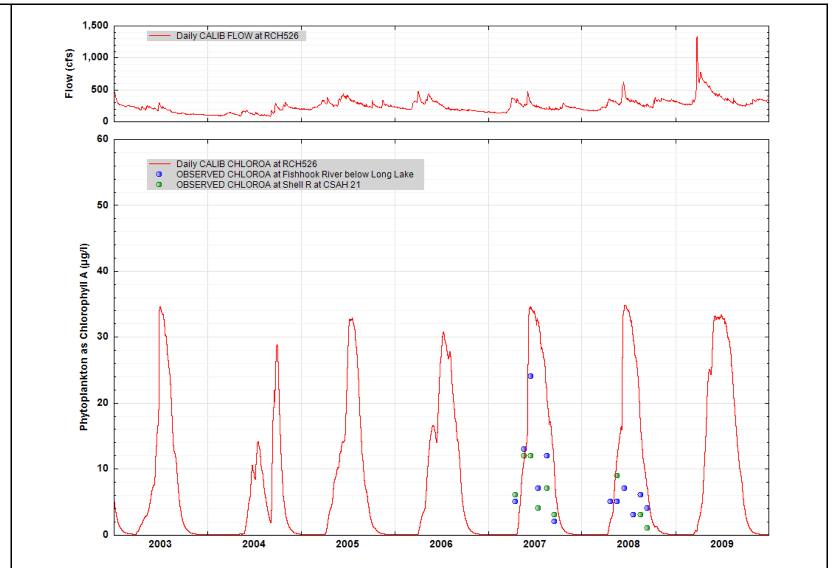

Daily CALIB FLOW at RCH521
OBSERVED FLOW at 05243200
Flow (cfs)
Daily CALIB CHLOROA at RCH521
OBSERVED CHLOROA at 05243200
OBSERVED CHLOROA at Shell R at US-71
Phytoplankton as Chlorophyll A (µg/l)
2003 2004 2005 2006 2007 2008 2009

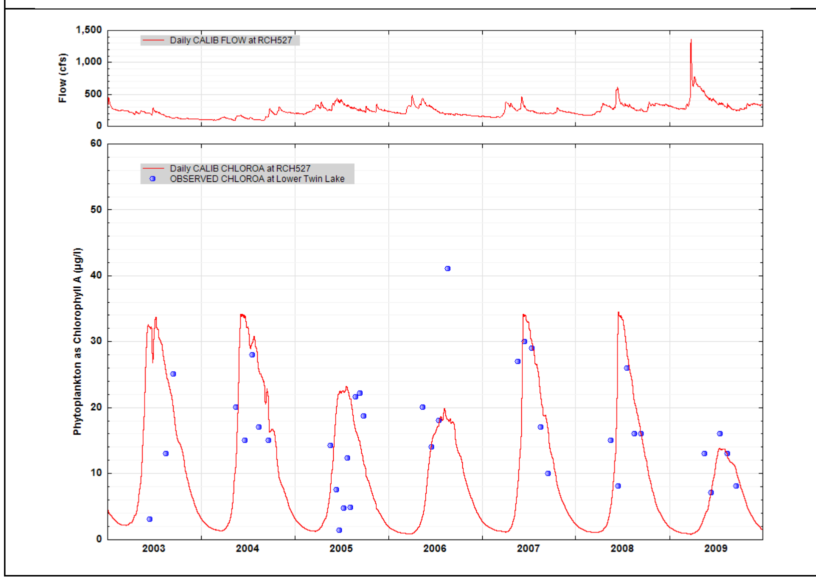

Daily CALIB FLOW at RCH522
Flow (cfs)
Daily CALIB CHLOROA at RCH522
OBSERVED CHLOROA at Blueberry R at 384th
Phytoplankton as Chlorophyll A (µg/l)
2003 2004 2005 2006 2007 2008 2009

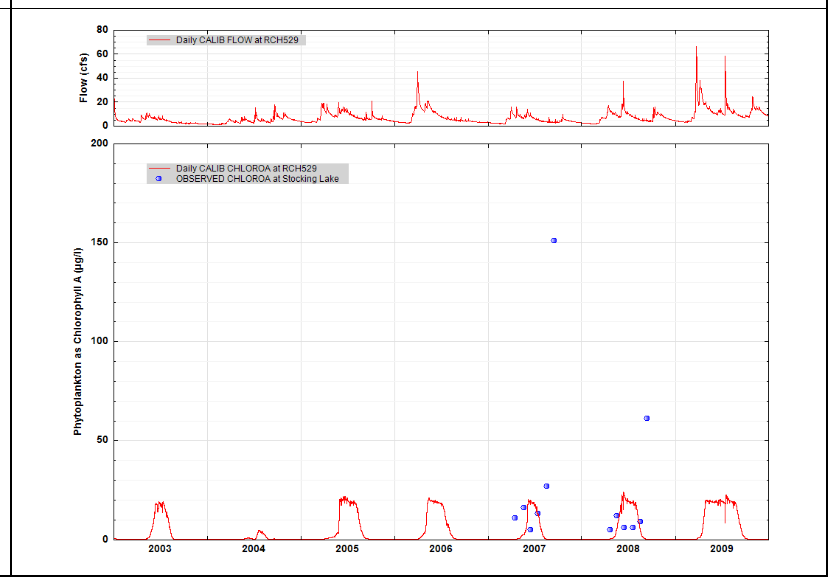

Daily CALIB FLOW at RCH523
Flow (cfs)
Daily CALIB CHLOROA at RCH523
OBSERVED CHLOROA at Kettle R at CR-156
Phytoplankton as Chlorophyll A (µg/l)
2003 2004 2005 2006 2007 2008 2009

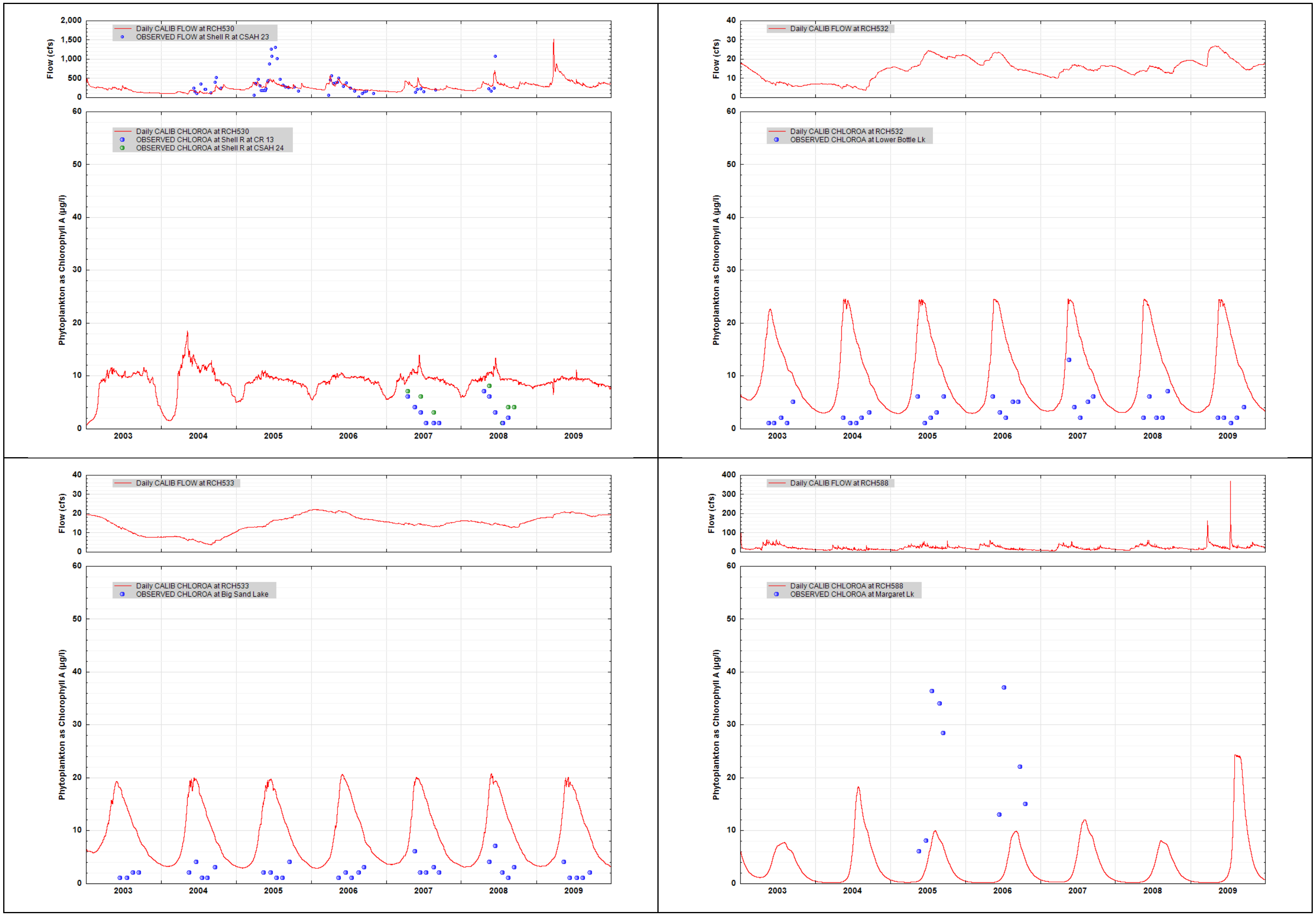

Daily CALIB FLOW at RCH524
Flow (cfs)
Daily CALIB CHLOROA at RCH524
OBSERVED CHLOROA at Blueberry R at US-71
Phytoplankton as Chlorophyll A (µg/l)
2003 2004 2005 2006 2007 2008 2009

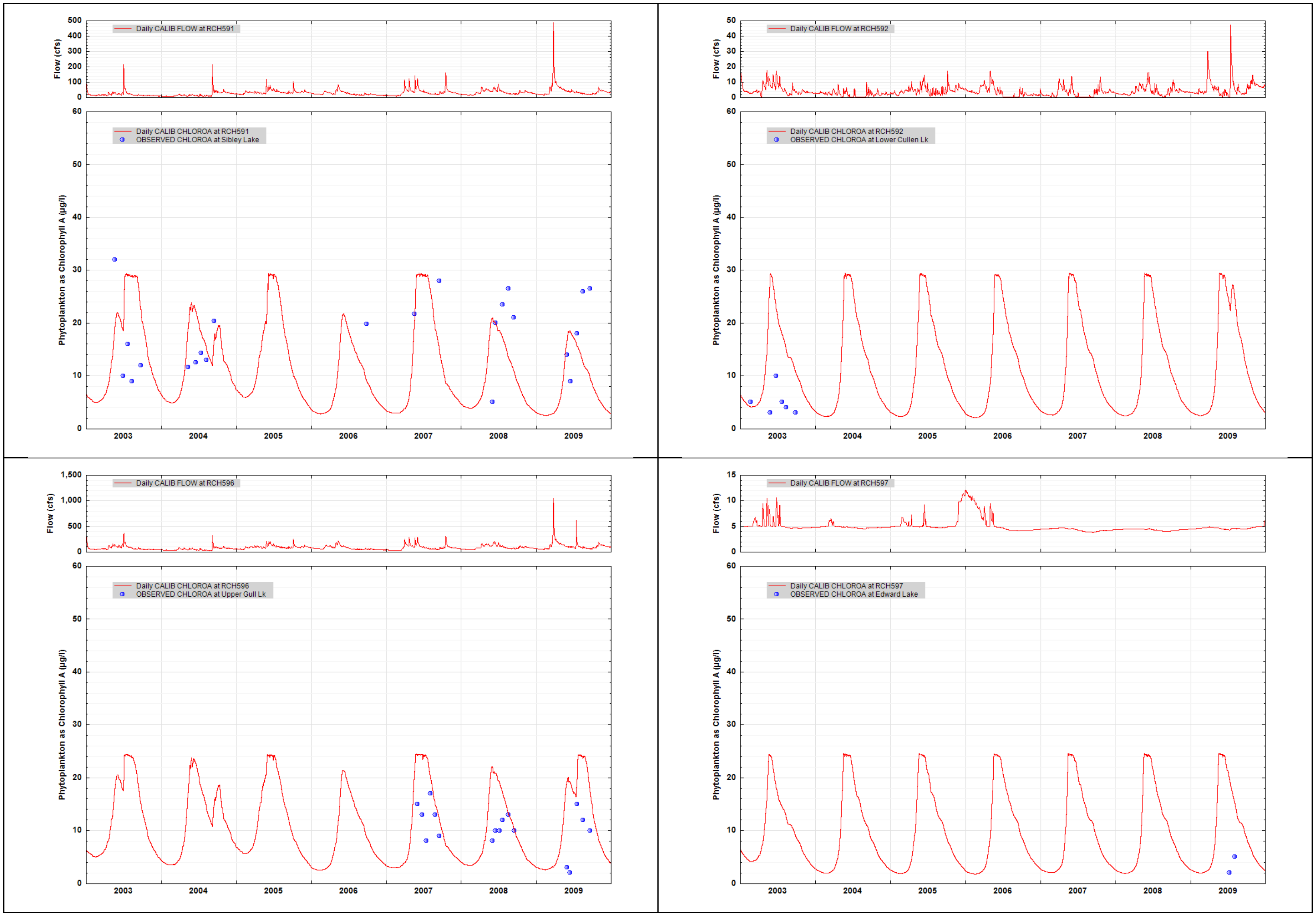

Daily CALIB FLOW at RCH525
Flow (cfs)
Daily CALIB CHLOROA at RCH525
OBSERVED CHLOROA at Blueberry Lake
OBSERVED CHLOROA at Shell R at Blueberry Br Rd
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

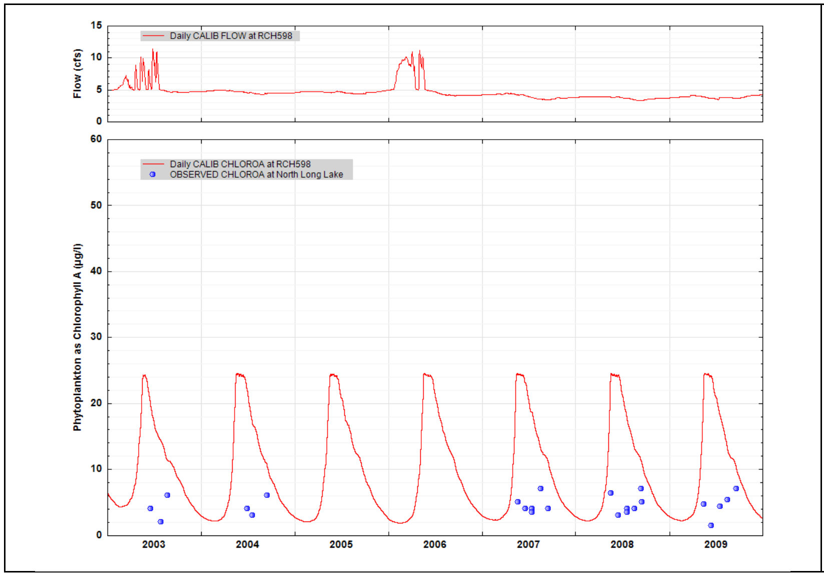

Daily CALIB FLOW at RCH526
Flow (cfs)
Daily CALIB CHLOROA at RCH526
OBSERVED CHLOROA at Fishhook River below Long Lake
OBSERVED CHLOROA at Shell R at CSAH 21
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH527
Flow (cfs)
Daily CALIB CHLOROA at RCH527
OBSERVED CHLOROA at Lower Twin Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

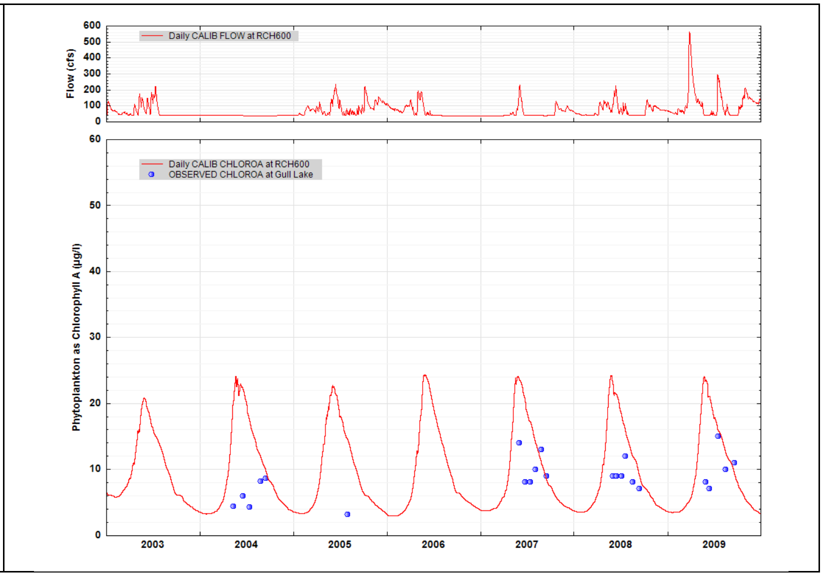

Daily CALIB FLOW at RCH529
Flow (cfs)
Daily CALIB CHLOROA at RCH529
OBSERVED CHLOROA at Stocking Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH530
OBSERVED FLOW at Shell R at CSAH 23
Flow (cfs)
Daily CALIB CHLOROA at RCH530
OBSERVED CHLOROA at Shell R at CR 13
OBSERVED CHLOROA at Shell R at CSAH 24
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB FLOW at RCH532
Daily CALIB CHLOROA at RCH532
OBSERVED CHLOROA at Lower Bottle Lk
Daily CALIB FLOW at RCH533
Daily CALIB CHLOROA at RCH533
OBSERVED CHLOROA at Big Sand Lake
Daily CALIB FLOW at RCH588
Daily CALIB CHLOROA at RCH588
OBSERVED CHLOROA at Margaret Lk
2003
2004
2005
2006
2007
2008
2009


Daily CALIB FLOW at RCH591
Flow (cfs)
Daily CALIB CHLOROA at RCH591
OBSERVED CHLOROA at Sibley Lake
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB FLOW at RCH592
Daily CALIB CHLOROA at RCH592
OBSERVED CHLOROA at Lower Cullen Lk
Daily CALIB FLOW at RCH596
Daily CALIB CHLOROA at RCH596
OBSERVED CHLOROA at Upper Gull Lk
Daily CALIB FLOW at RCH597
Daily CALIB CHLOROA at RCH597
OBSERVED CHLOROA at Edward Lake
2003
2004
2005
2006
2007
2008
2009



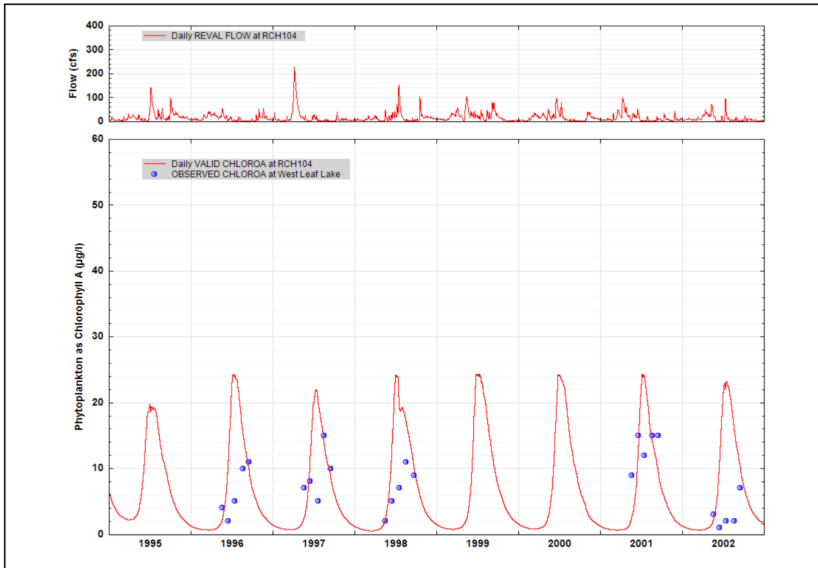
Daily CALIB FLOW at RCH598
Flow (cfs)
Daily CALIB CHLOROA at RCH598
OBSERVED CHLOROA at North Long Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

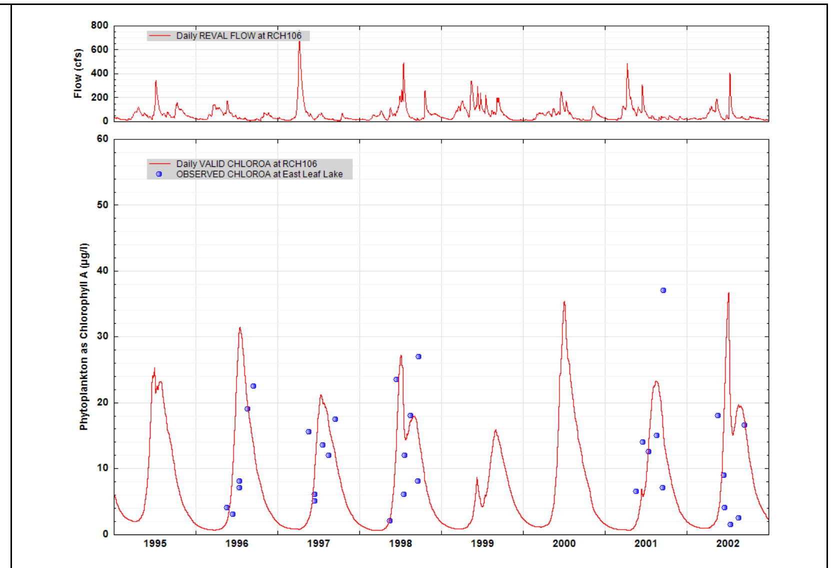


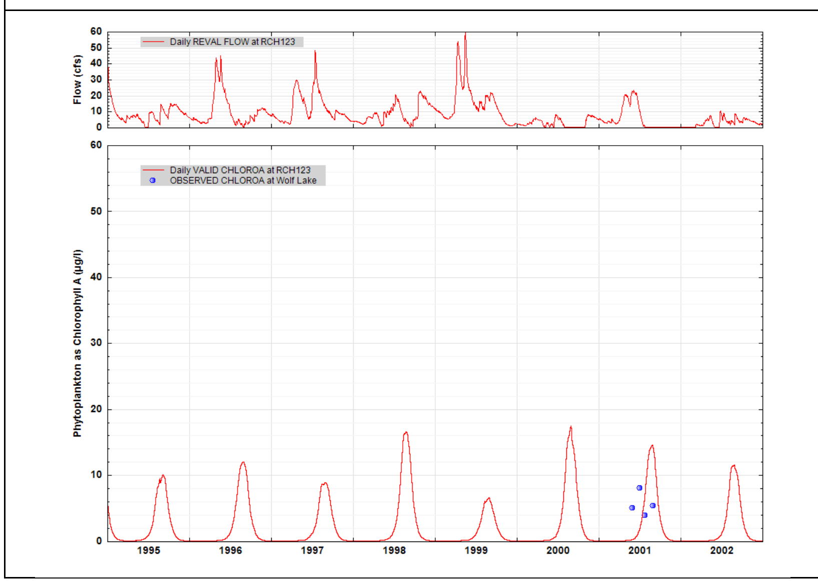
Daily CALIB FLOW at RCH600
Flow (cfs)
Daily CALIB CHLOROA at RCH600
OBSERVED CHLOROA at Gull Lake
Phytoplankton as Chlorophyll A (µg/l)
2003
2004
2005
2006
2007
2008
2009

APPENDIX R
OBSERVED AND SIMULATED CHLOROPHYLL A FOR THE VALIDATION PERIOD

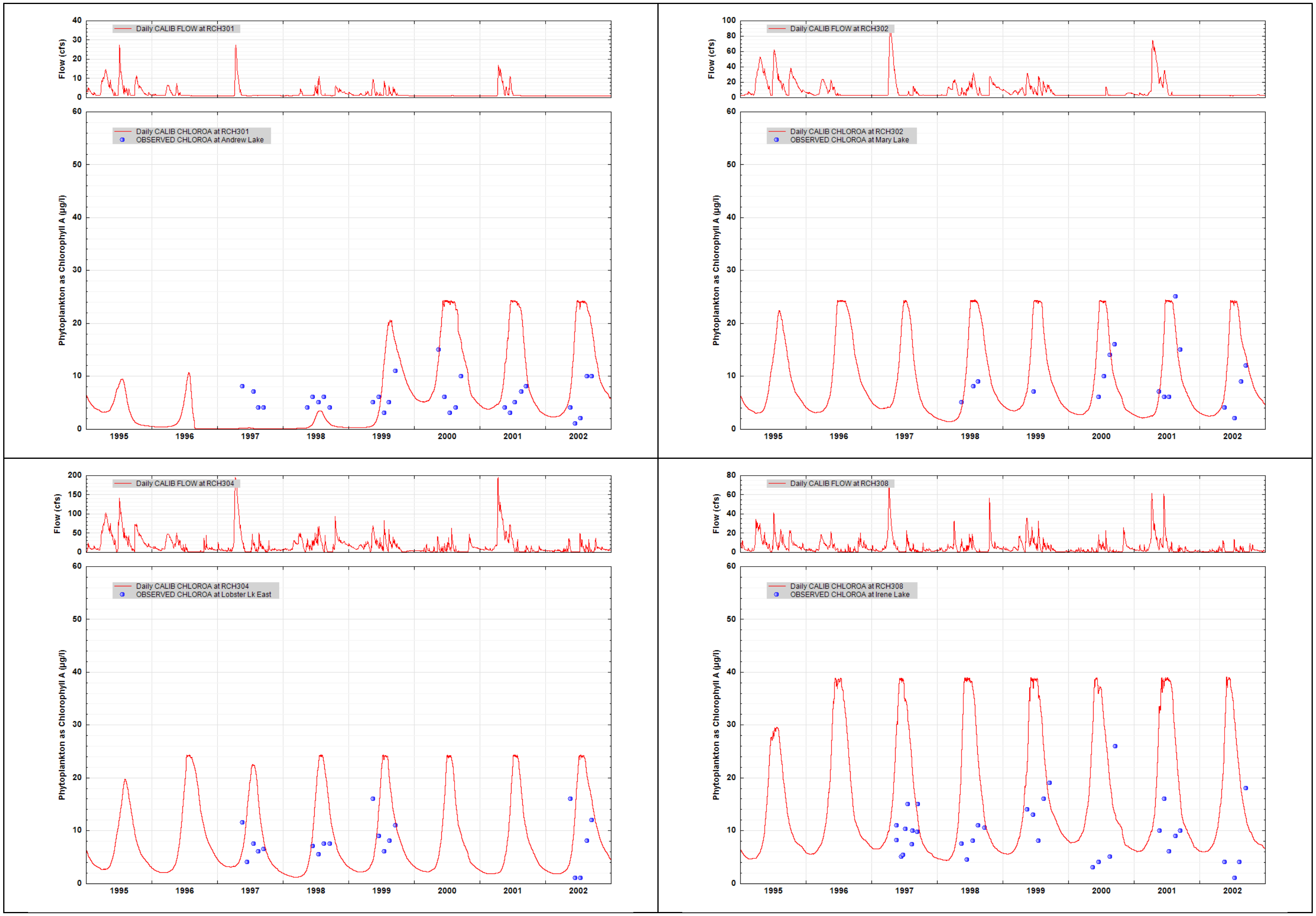
R.1 REDEYE RIVER WATERSHED

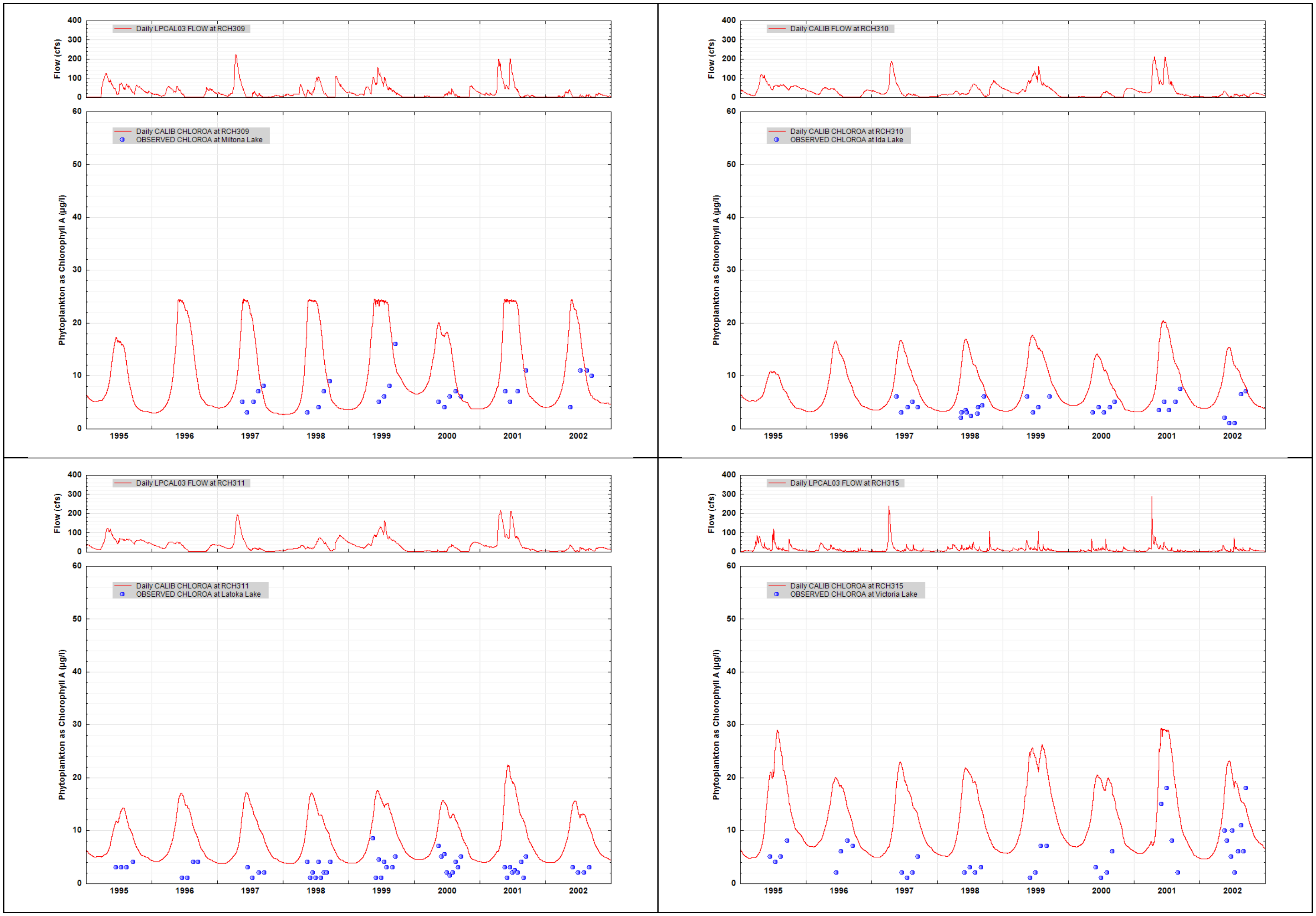


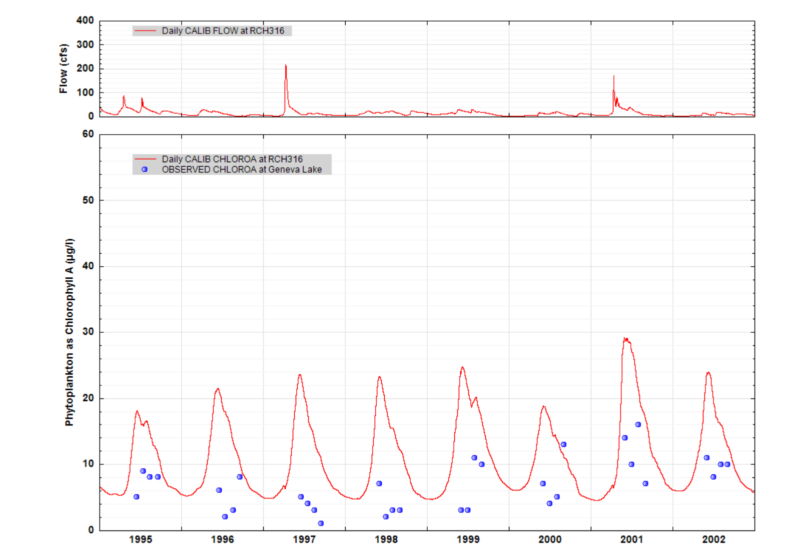


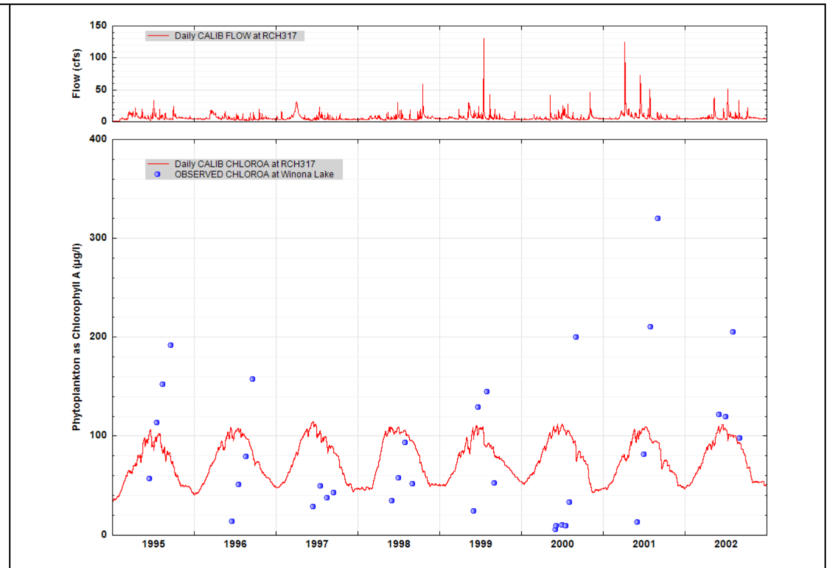


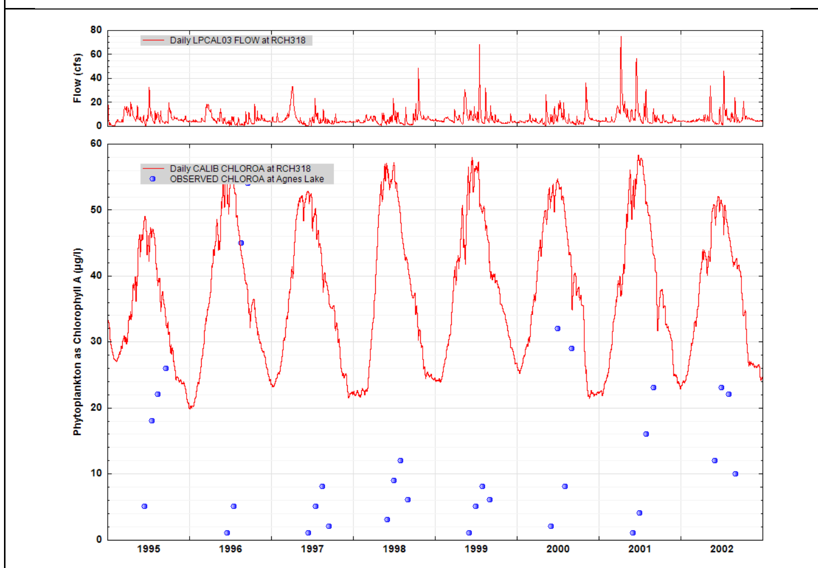
R.2 LONG PRAIRIE RIVER WATERSHED

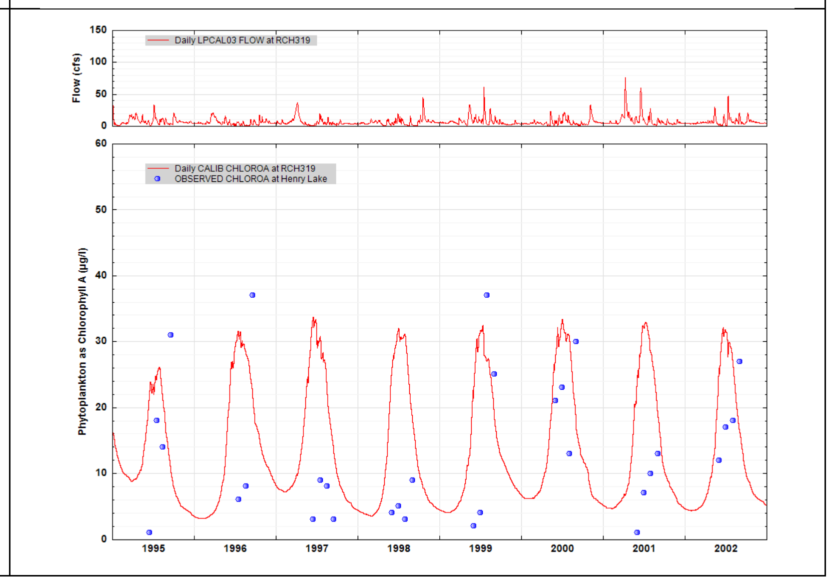


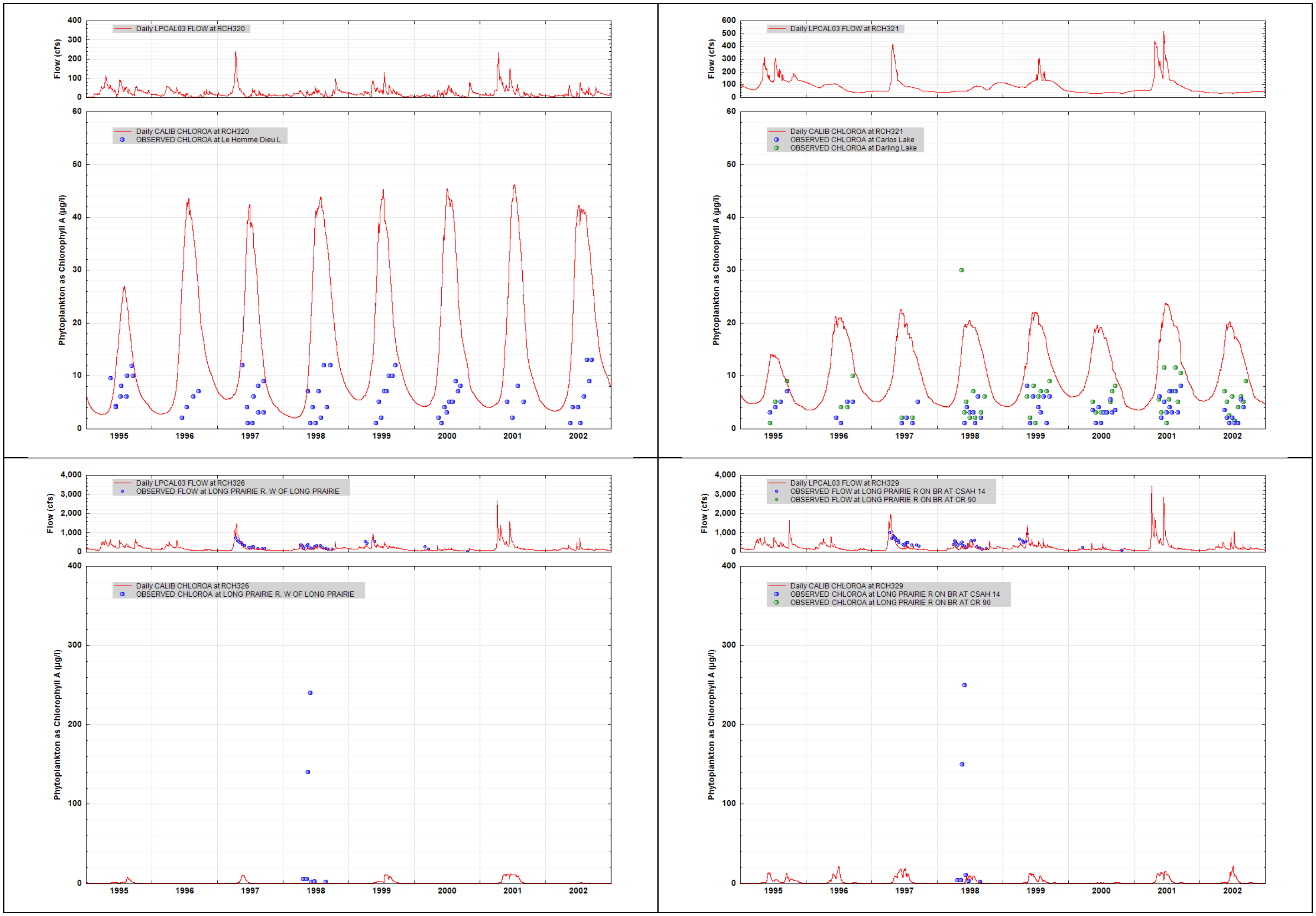

Daily LPCAL03 FLOW at RCH309
Flow (cfs)
Daily CALIB CHLOROA at RCH309
OBSERVED CHLOROA at Miltona Lake
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB FLOW at RCH310
Daily CALIB CHLOROA at RCH310
OBSERVED CHLOROA at Ida Lake
Daily LPCAL03 FLOW at RCH311
Daily CALIB CHLOROA at RCH311
OBSERVED CHLOROA at Latoka Lake
Daily LPCAL03 FLOW at RCH315
Daily CALIB CHLOROA at RCH315
OBSERVED CHLOROA at Victoria Lake
1995 1996 1997 1998 1999 2000 2001 2002

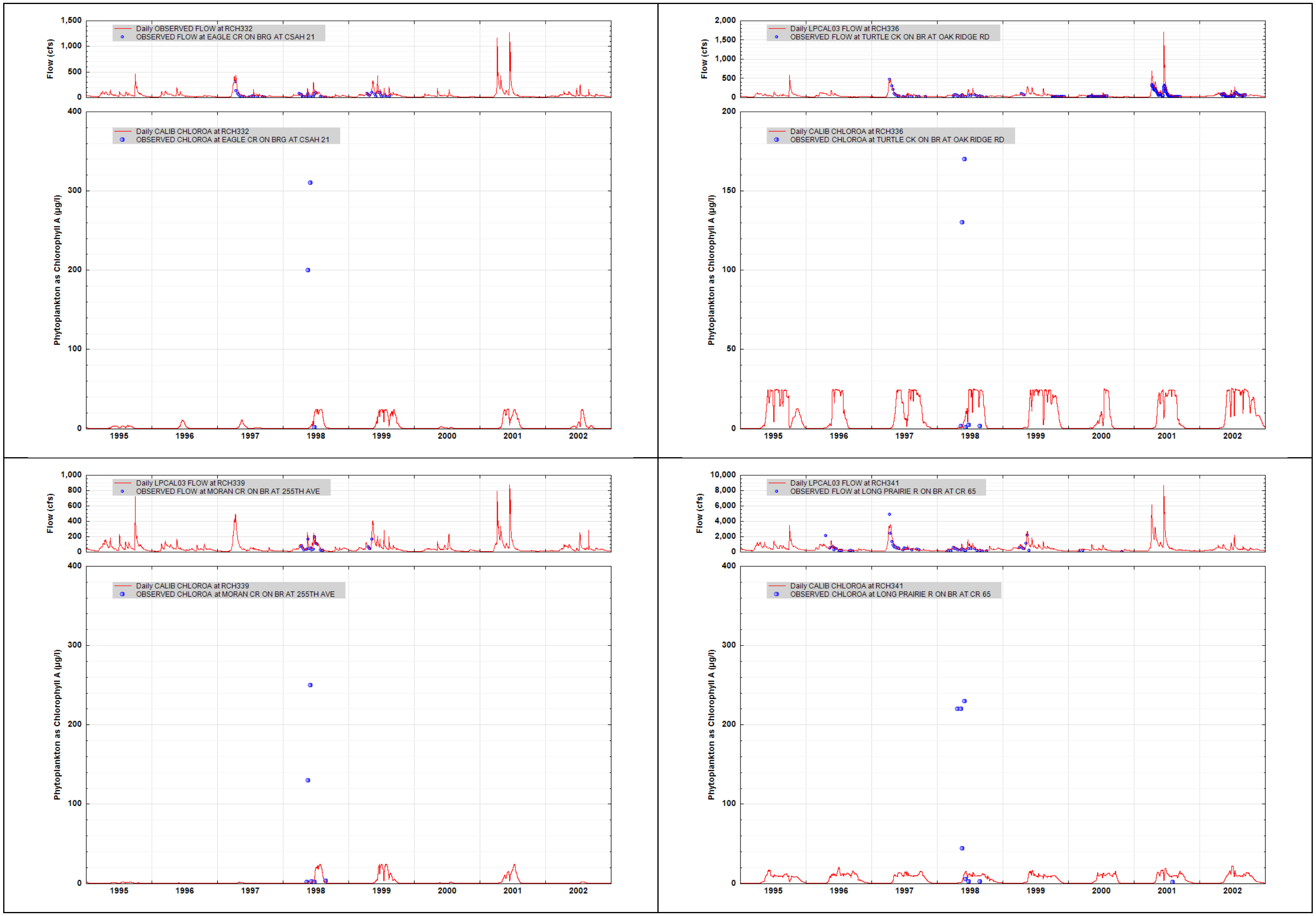

Daily CALIB FLOW at RCH316
Flow (cfs)
Daily CALIB CHLOROA at RCH316
OBSERVED CHLOROA at Geneva Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002

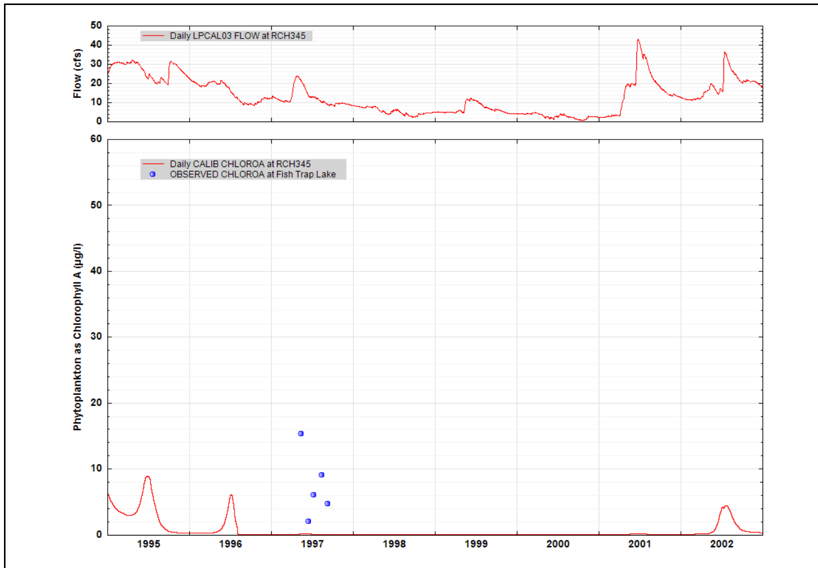

Daily CALIB FLOW at RCH317
Flow (cfs)
Daily CALIB CHLOROA at RCH317
OBSERVED CHLOROA at Winona Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002

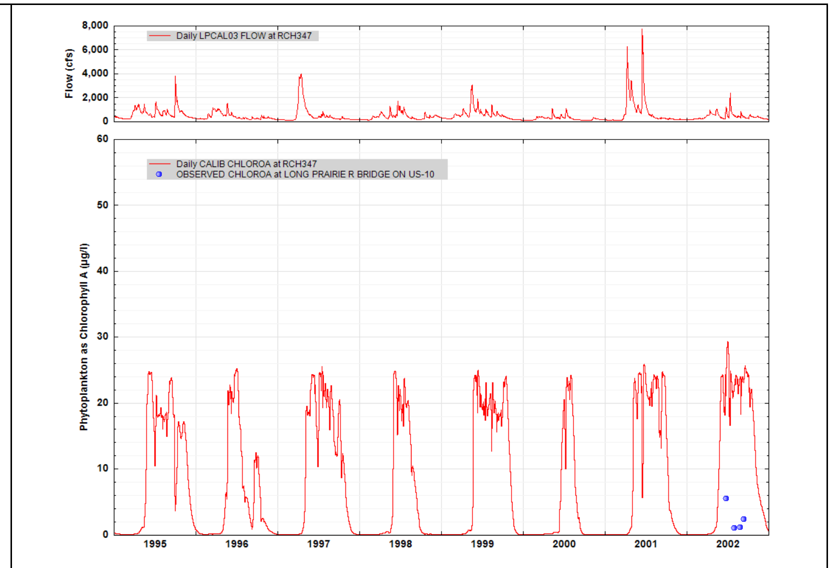

Daily LPCAL03 FLOW at RCH318
Flow (cfs)
Daily CALIB CHLOROA at RCH318
OBSERVED CHLOROA at Agnes Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002

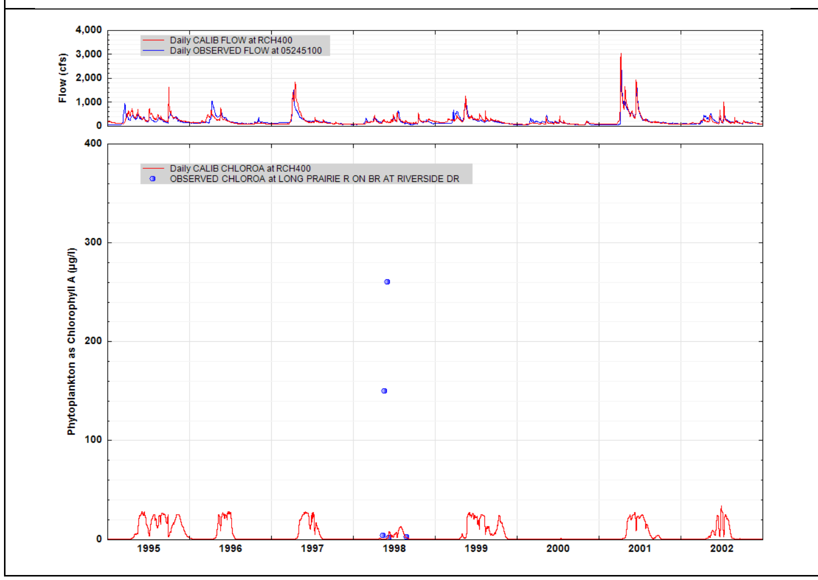

Daily LPCAL03 FLOW at RCH319
Flow (cfs)
Daily CALIB CHLOROA at RCH319
OBSERVED CHLOROA at Henry Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002


Flow (cfs)
Daily LPCAL03 FLOW at RCH320
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB CHLOROA at RCH320
OBSERVED CHLOROA at Le Homme Dieu L
Flow (cfs)
Daily LPCAL03 FLOW at RCH321
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB CHLOROA at RCH321
OBSERVED CHLOROA at Carlos Lake
OBSERVED CHLOROA at Darling Lake
Flow (cfs)
Daily LPCAL03 FLOW at RCH326
OBSERVED FLOW at LONG PRAIRIE R. W OF LONG PRAIRIE
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB CHLOROA at RCH326
OBSERVED CHLOROA at LONG PRAIRIE R. W OF LONG PRAIRIE
Flow (cfs)
Daily LPCAL03 FLOW at RCH329
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CSAH 14
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 90
Phytoplankton as Chlorophyll A (µg/l)
Daily CALIB CHLOROA at RCH329
OBSERVED CHLOROA at LONG PRAIRIE R ON BR AT CSAH 14
OBSERVED CHLOROA at LONG PRAIRIE R ON BR AT CR 90
1995
1996
1997
1998
1999
2000
2001
2002

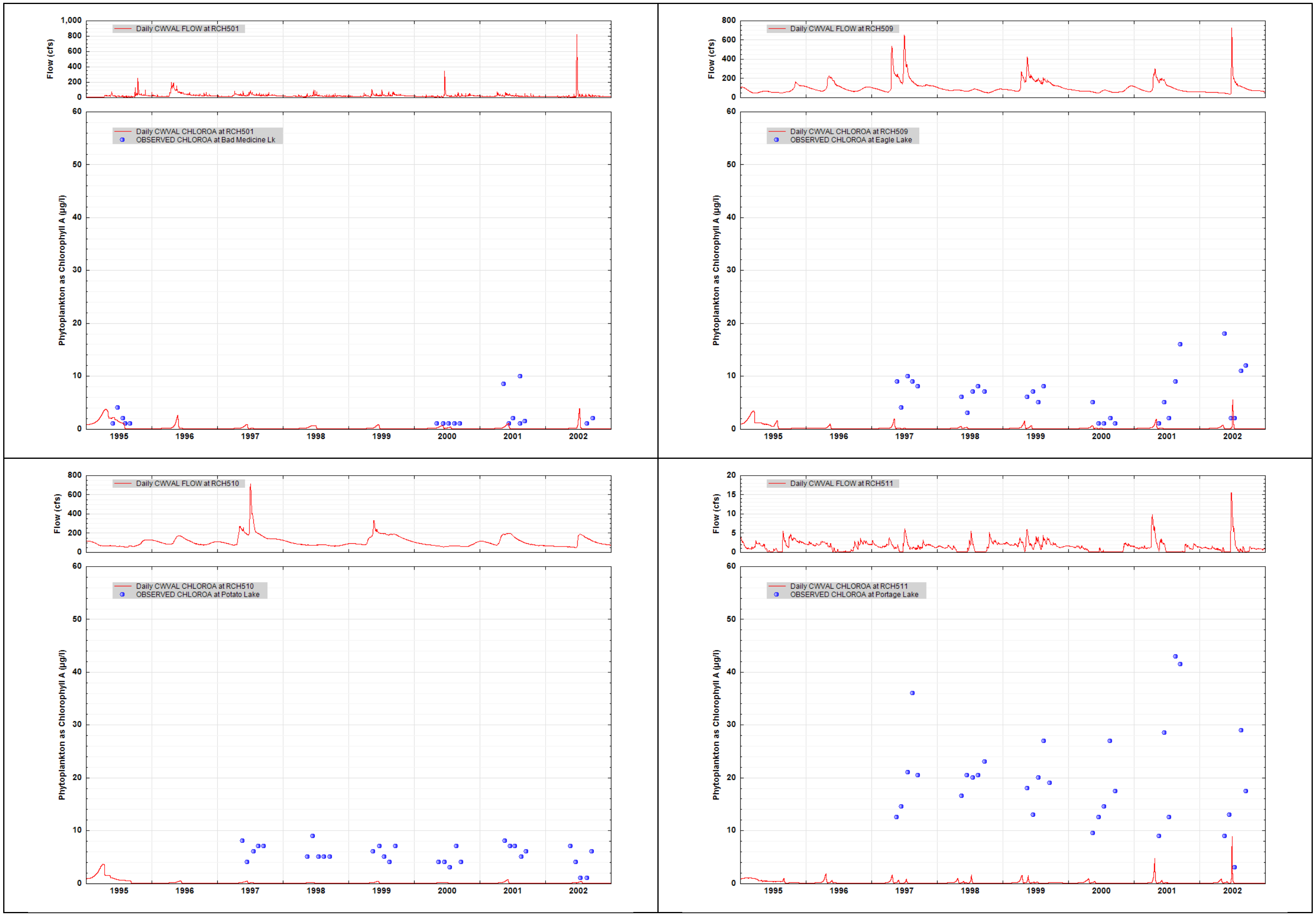

Daily OBSERVED FLOW at RCH332
OBSERVED FLOW at EAGLE CR ON BRG AT CSAH 21
Flow (cfs)
Daily CALIB CHLOROA at RCH332
OBSERVED CHLOROA at EAGLE CR ON BRG AT CSAH 21
Phytoplankton as Chlorophyll A (µg/l)
Daily LPCAL03 FLOW at RCH336
OBSERVED FLOW at TURTLE CK ON BR AT OAK RIDGE RD
Daily CALIB CHLOROA at RCH336
OBSERVED CHLOROA at TURTLE CK ON BR AT OAK RIDGE RD
Daily LPCAL03 FLOW at RCH339
OBSERVED FLOW at MORAN CR ON BR AT 255TH AVE
Daily CALIB CHLOROA at RCH339
OBSERVED CHLOROA at MORAN CR ON BR AT 255TH AVE
Daily LPCAL03 FLOW at RCH341
OBSERVED FLOW at LONG PRAIRIE R ON BR AT CR 65
Daily CALIB CHLOROA at RCH341
OBSERVED CHLOROA at LONG PRAIRIE R ON BR AT CR 65
1995
1996
1997
1998
1999
2000
2001
2002

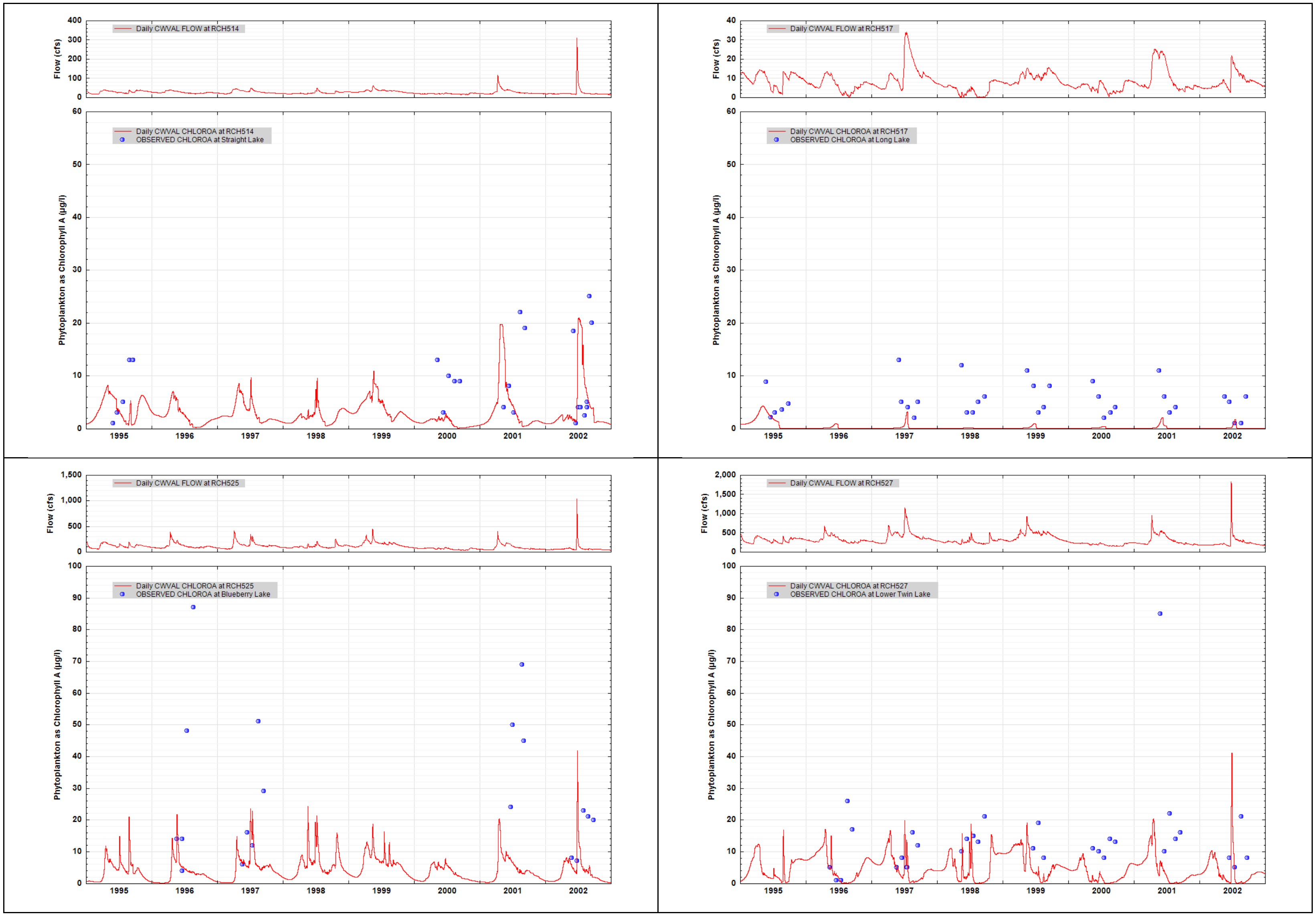

Daily LPCAL03 FLOW at RCH345
Flow (cfs)
Daily CALIB CHLOROA at RCH345
OBSERVED CHLOROA at Fish Trap Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002

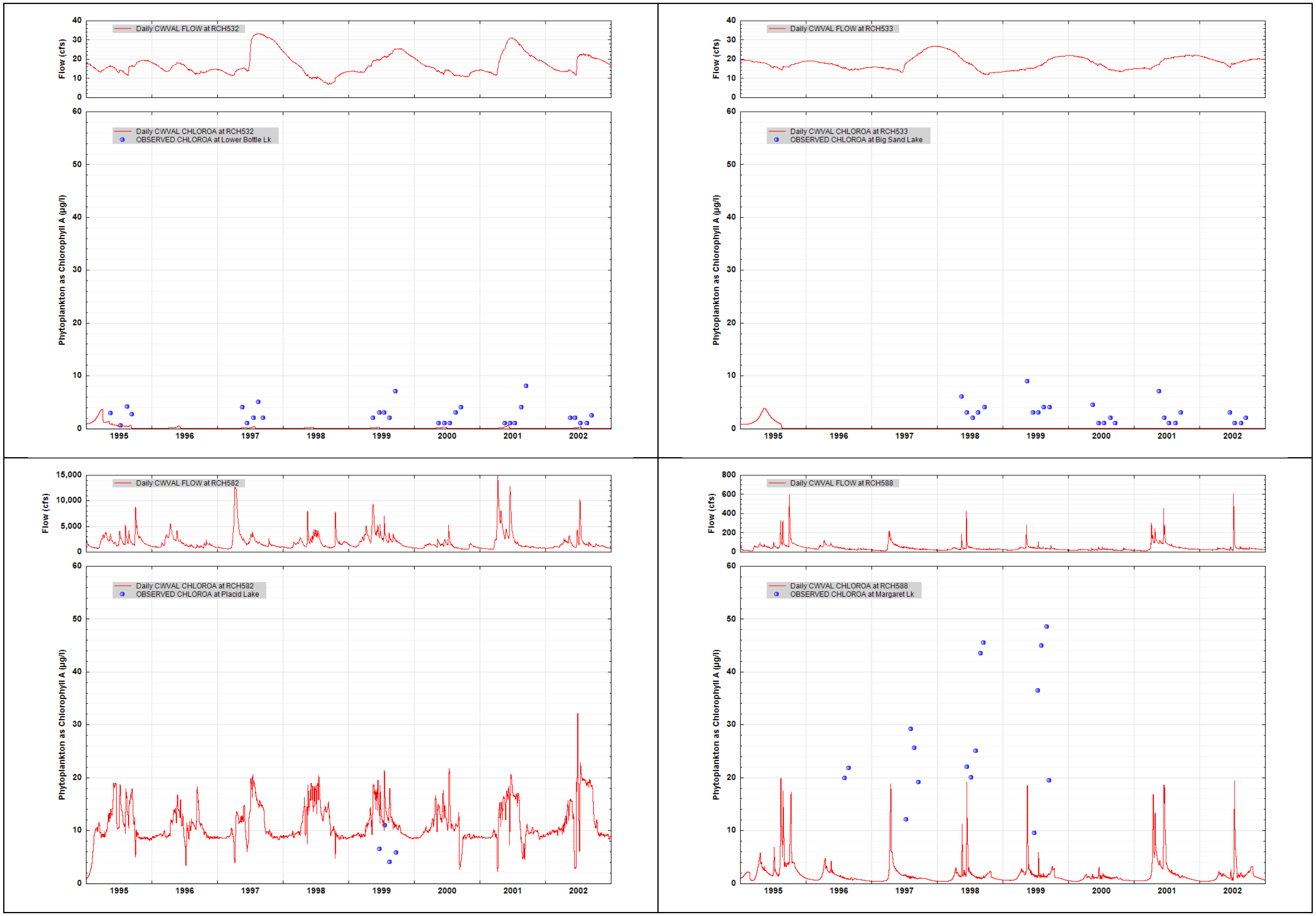

Daily LPCAL03 FLOW at RCH347
Flow (cfs)
Daily CALIB CHLOROA at RCH347
OBSERVED CHLOROA at LONG PRAIRIE R BRIDGE ON US-10
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002

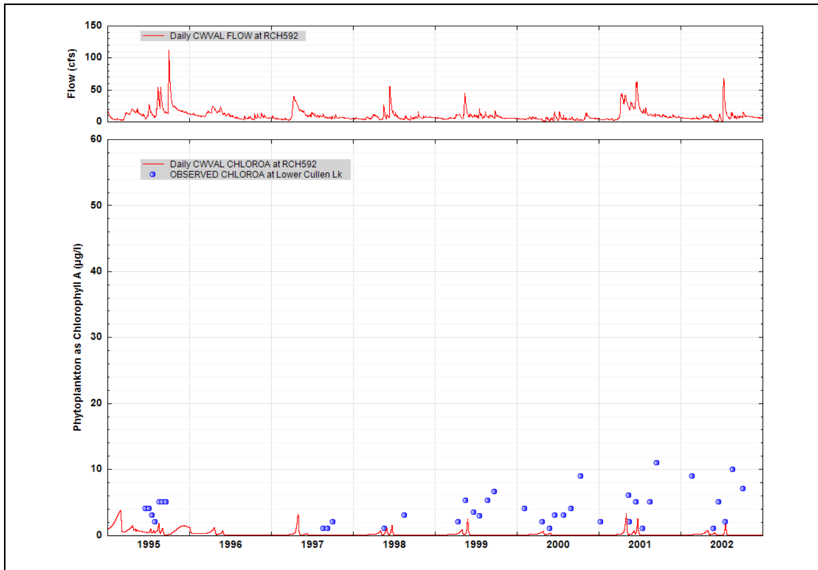

Daily CALIB FLOW at RCH400
Daily OBSERVED FLOW at 05245100
Flow (cfs)
Daily CALIB CHLOROA at RCH400
OBSERVED CHLOROA at LONG PRAIRIE R ON BR AT RIVERSIDE DR
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002

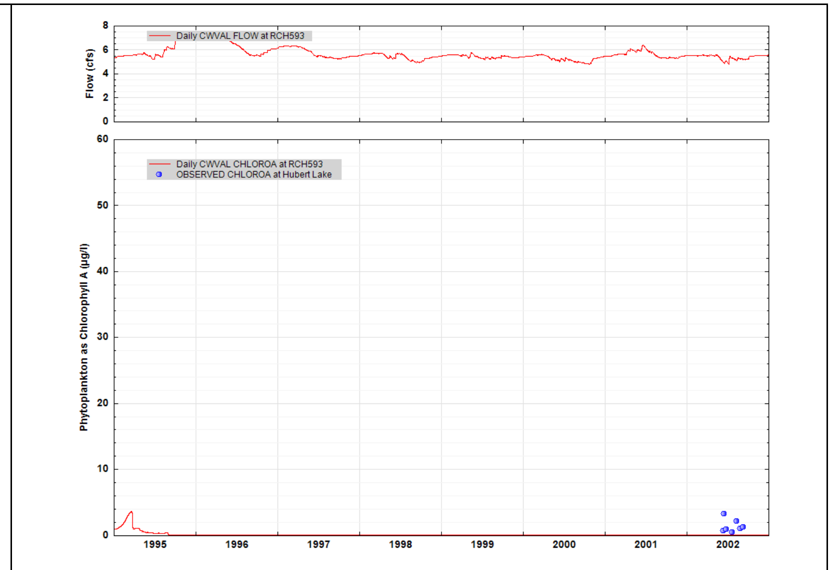
R.3 CROW WING RIVER WATERSHED

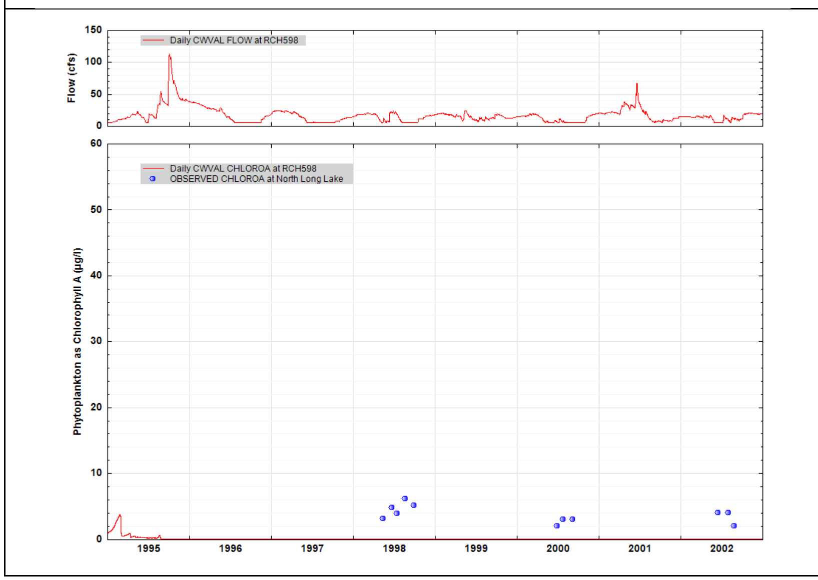


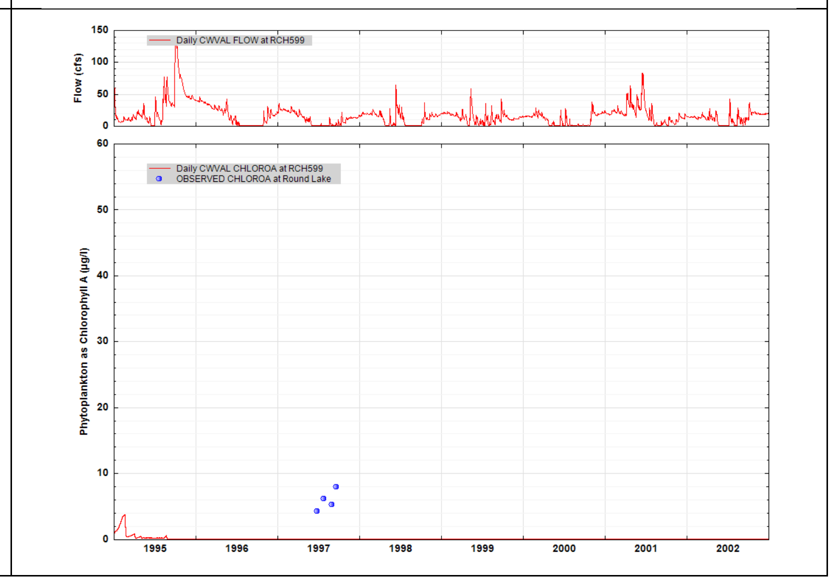

Daily CWVAL FLOW at RCH514
Flow (cfs)
Daily CWVAL CHLOROA at RCH514
OBSERVED CHLOROA at Straight Lake
Phytoplankton as Chlorophyll A (µg/l)
Daily CWVAL FLOW at RCH517
Daily CWVAL CHLOROA at RCH517
OBSERVED CHLOROA at Long Lake
Daily CWVAL FLOW at RCH525
Daily CWVAL CHLOROA at RCH525
OBSERVED CHLOROA at Blueberry Lake
Daily CWVAL FLOW at RCH527
Daily CWVAL CHLOROA at RCH527
OBSERVED CHLOROA at Lower Twin Lake
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL FLOW at RCH532
Flow (cfs)
Daily CWVAL CHLOROA at RCH532
OBSERVED CHLOROA at Lower Bottle Lk
Phytoplankton as Chlorophyll A (µg/l)
Daily CWVAL FLOW at RCH533
Daily CWVAL CHLOROA at RCH533
OBSERVED CHLOROA at Big Sand Lake
Daily CWVAL FLOW at RCH582
Daily CWVAL CHLOROA at RCH582
OBSERVED CHLOROA at Placid Lake
Daily CWVAL FLOW at RCH588
Daily CWVAL CHLOROA at RCH588
OBSERVED CHLOROA at Margaret Lk
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL FLOW at RCH592
Flow (cfs)
Daily CWVAL CHLOROA at RCH592
OBSERVED CHLOROA at Lower Cullen Lk
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL FLOW at RCH593
Flow (cfs)
Daily CWVAL CHLOROA at RCH593
OBSERVED CHLOROA at Hubert Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL FLOW at RCH598
Flow (cfs)
Daily CWVAL CHLOROA at RCH598
OBSERVED CHLOROA at North Long Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002


Daily CWVAL FLOW at RCH599
Flow (cfs)
Daily CWVAL CHLOROA at RCH599
OBSERVED CHLOROA at Round Lake
Phytoplankton as Chlorophyll A (µg/l)
1995
1996
1997
1998
1999
2000
2001
2002