RESPEC
WATER & NATURAL RESOURCES

June 20, 2013

Dr. Charles Regan
Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155

Dear Dr. Regan:

RE: Hydrology Calibration of Mississippi River Headwaters (07010101), Leech Lake River (07010102), and Pine River (07010105) Watersheds HSPF Models

The initial hydrology calibration portion of the Mississippi River Headwaters (07010101), Leech Lake River (07010102), and Pine River (07010105) Watershed models were completed. Please review the following results at your convenience.

Calibration is a critical process in developing parameters for an **HSPF** hydrologic model application and is required for parameters that cannot be reasonably estimated by the watershed characteristics. Calibrating an **HSPF** model application is a cyclical process of making parameter changes, running the model and producing graphical and statistical comparisons of simulated and observed values, and interpreting the results. Observed data for hydrologic calibration involve continuous stream flow and lake-level data collected at available gaging stations from reputable sources. Calibration is typically evaluated with visual and statistical performance criteria and model performance validation that is separate from the calibration effort.

CALIBRATION DATA

The continuous observed stream flow data required for calibration and validation are available at five gages within the Mississippi River Headwaters Watershed. One gage within the Leech Lake River Watershed and two gages within the Pine River Watershed are shown in Figure 1 and the data are summarized in Table 1. All of these gages are located on mainstem reaches or below lakes that intersect a mainstem reach. Observed flow data downstream of Lake Bemidji (Reach 400) and Lake Winnibigoshish (Reach 520) in the Mississippi River Headwaters Watershed, Leech Lake (Reach 160) in the Leech Lake River Watershed, and Cross Lake (Reach 280) in the Pine River Watershed were used as inputs to each respective watershed model. At these locations, observed outflow data were used to represent reservoir outflows. Continuous flow data at Reaches 210, 340, and 640 in the Mississippi River Headwaters Watershed and Reach 330 in the Pine River Watershed were used as calibration points. Flow data were downloaded from the Minnesota Cooperative Stream Gaging Program website (*www.dnr.state.mn.us/waters/csg/index.html*) and from the U.S. Army Corps of Engineers, St. Paul District Water Control Center website (*http://www.mvp-wc.usace.army.mil/*). Five of the calibration sites have discharge data for the entire modeling period, while others have data only for a subset of those years (Table 1).

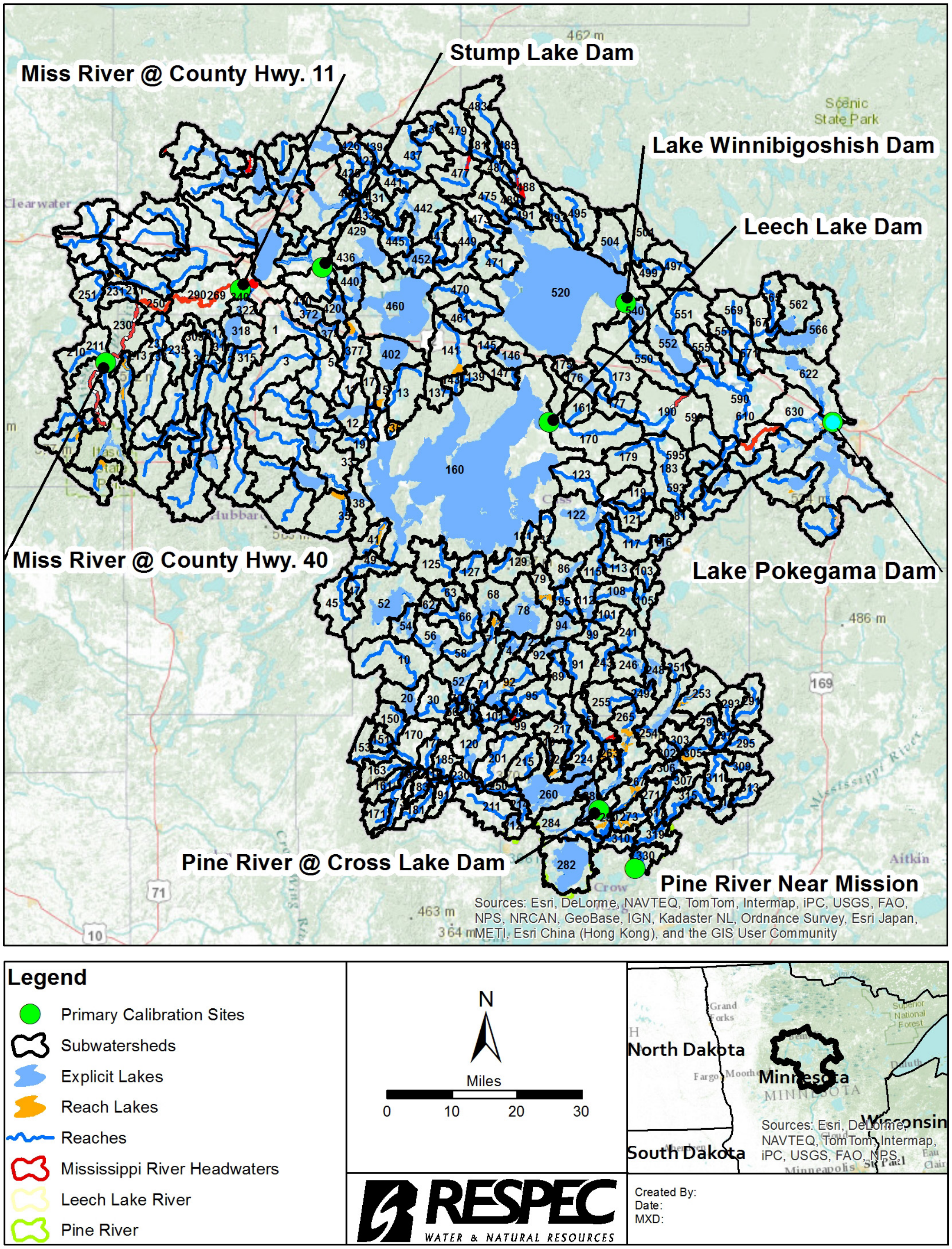


Figure 1. Flow Calibration Gages Within the Mississippi Headwaters, Leech Lake, and Pine River Watersheds.

Table 1. Discharge Calibration Gages Within the Mississippi River Headwaters, Leech Lake, and Pine River Watersheds

Watershed	Gage	Gage Description	HSPF Reach I.D.	Drainage Area (mi^2)	Data Availability	Sample Count
Mississippi River Headwaters	7115001	Stump Lake Near Bemidji	400	615	1995–2009	3,875
Mississippi River Headwaters	23232323	Lake Pokegama Army Corps of Engineers Dam	640	1,921	1995–2009	5,479
Mississippi River Headwaters	11014700	Lake Winnibigoshish Army Corps of Engineers Dam	520	1,471	1995–2009	5,479
Mississippi River Headwaters	7052001	Mississippi River at County Highway 40	210	86	2001–2009	1,907
Mississippi River Headwaters	7062001	Mississippi River at County Highway 11	340	555	2006–2009	597
Leech Lake River	8022001	Leech Lake Army Corps of Engineers Dam	160	859	1995–2009	5,479
Pine River	11051001	Pine River Near Mission	330	781	2008–2009	545
Pine River	18031200	Pine River at Army Corps of Engineers Dam on Cross Lake	280	583	1995–2009	5,479

Calibration typically is performed over a minimum 5-year period with a range of hydrologic conditions (from wet to dry) and then validated over a separate period of time (i.e., a split-sample validation). Separate User Control Inputs (UCIs) were created to represent land cover changes [Love, 2011]; one UCI represents 1995 through 2003 using National Land Cover Database (NLCD) 2001 land cover data, and the other UCI represents 2004 through 2009 using NLCD 2006 land cover data. The primary calibration period is from 2004 to 2009 (based on NLCD 2006 land cover data), and the validation period is from 1996 to 2003 (based on NLCD 2001 land cover data). The initial year (1995) was simulated to allow the model to adjust to existing conditions. Calibrating the model application using multiple gages that represent the variability of the watershed while maintaining consistent parameters throughout the watershed is, in itself, a form of validation.

STANDARD HYDROLOGIC CALIBRATION

The standard hydrologic calibration is an iterative process that is intended to match simulated flow to observed flow by methodically adjusting model parameters. Water-quality simulations depend highly on the hydrology process. Therefore, the water-quality calibration cannot begin until the hydrology calibration is considered acceptable. The standard HSPF hydrologic calibration is divided into four sequential phases of adjusting appropriate parameters to improve the performance of their respective components of watershed hydrology simulation. These four phases are described below in order of application.

- **Establish an annual water balance.** This phase consists of comparing the total annual simulated and observed flow (in inches) and is governed by the input (rainfall and evaporation), the listed parameters (lower zone nominal storage [LZSN], lower zone evapotranspiration parameter [LZETP], deep groundwater recharge losses [DEEPFR], and infiltration index [INFILT] and the factor applied to pan evaporation to calculate potential evapotranspiration (ET).
- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to determine if runoff needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters vegetal interception (CEPSC), upper zone storage (UZSN), and LZETP. LZETP will vary greatly by land cover, especially during summer months, because of ET differences. Adjustments to variable groundwater recession (KVARY) and baseflow ET index (BASETP) as well as snow accumulation and melt parameters are also used.
- **Adjust low-flow/high-flow distribution.** This phase compares high- and low-flow volumes using flow percentile statistics and flow duration curves. This component is generally affected by adjusting parameters such as INFILT, groundwater recession (AGWRC), and BASETP.
- **Adjust storm flow/hydrograph shape.** The storm flow, which is largely composed of surface runoff and interflow, is compared using daily and hourly hydrographs. Adjustments are made to the UZSN, interflow parameter (INTFW), and interflow recession (IRC). INFILT can also be adjusted slightly.

Monthly variations in the CEPSC and LZETP parameters will initially be applied to all pervious land categories (PERLND). Monthly variations in UZSN, NSUR (Manning's *n* for the overland flow plane), INTFW, and IRC parameters will be applied as necessary for improving the model performance.

By iteratively adjusting the specific calibration parameter values within accepted ranges, the simulation results will be improved until an acceptable comparison of simulated results and measured data is achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and the **HSPF** hydrologic calibration expert system (**HSPEXP**) [Lumb et al., 1994].

Land cover and soil properties were the basis for estimating initial hydrologic parameters; these properties typically represent most of the variability in the hydrologic responses of a watershed. RESPEC's previous work in northern Minnesota model applications includes the Big and Little Fork Watersheds. The land cover characteristics and climatic conditions present in the Big and Little Fork calibrations provided a starting point for estimating some of the initial hydrologic parameters in the these watersheds. The land cover characteristics primarily affect water losses from evaporation or transpiration by vegetation. The movement of water through the system is also affected by vegetation and associated characteristics. Soil properties primarily affect infiltration, interflow, and soil storage parameters. **HSPF** model categories were developed based on the aggregation of the existing land cover and hydrologic soil group classifications into representative hydrologic areas.

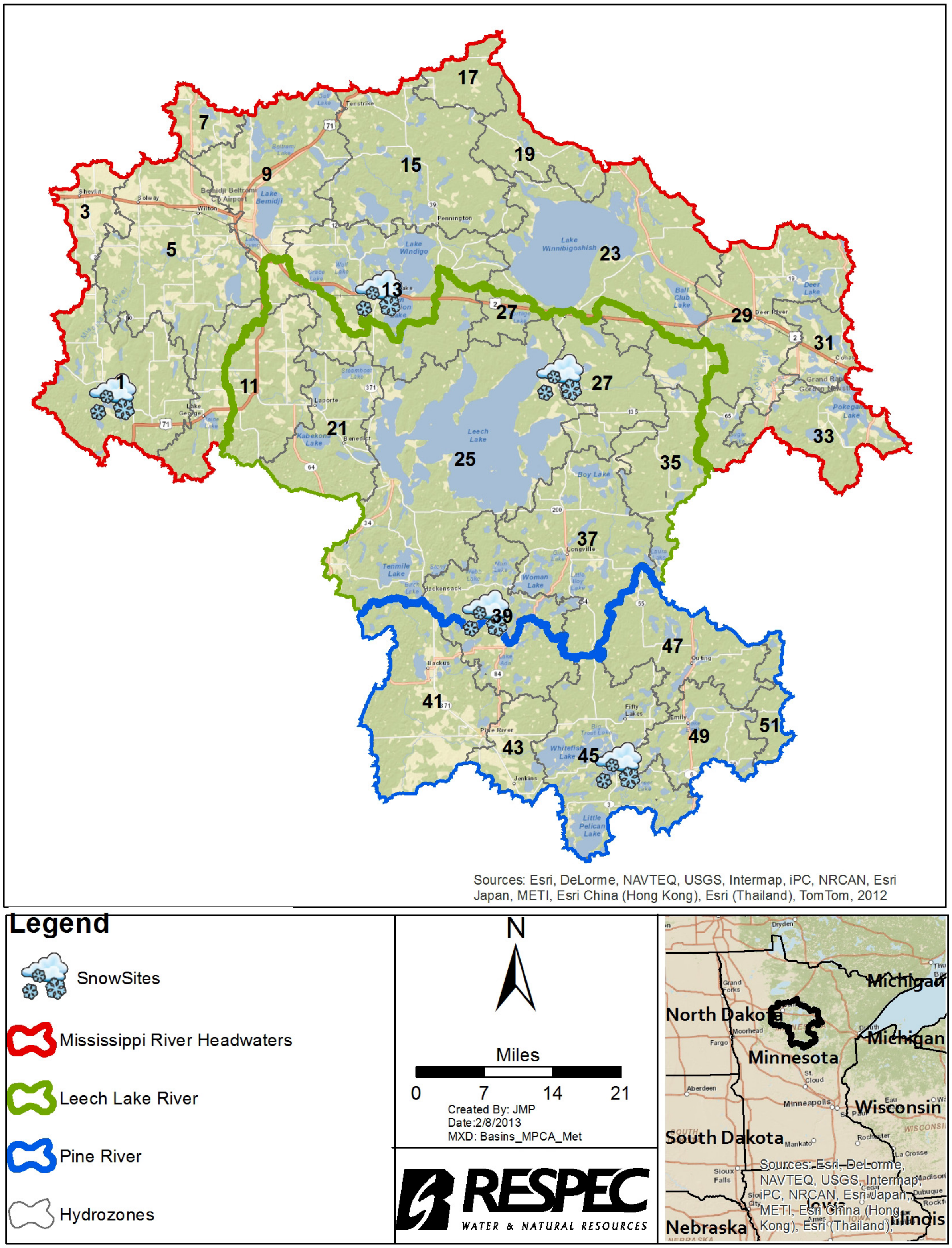
Initial parameter estimates and their relative variances between land segment categories are crucial to maintaining appropriate representation of the hydrologic components. Engineering judgment is used to adjust parameters congruently within land segment categories during calibration because of their diversity and spatial distribution within the watershed. It is difficult to isolate each discrete category during calibration to justify deviations from initial estimated intraparameter variations within land segments because of the detailed classification of land segments and spatial availability of observed data.

INITIAL SNOW ACCUMULATION AND MELT CALIBRATION

Snow accumulation and melt is a significant element of hydrology in Minnesota; thus, snow simulation is an integral part of the hydrology calibration (especially during the winter and spring). The snow calibration is generally completed early in the calibration process along with the seasonal phase of the standard calibration procedure. Snow is simulated in **HSPF** with meteorological time-series data (air temperature, solar radiation, wind, and dew point temperature) with a suite of adjustable parameters. Initial values for TSNOW (the wet bulb air temperature below which precipitation occurs as snow under saturated conditions), CCFACT (the factor to adjust the rate of heat transfer from the atmosphere to the snowpack because of condensation and convection), MGMELT (the maximum rate of snowmelt by ground heat), SNOEVP (the factor to adjust evaporation/sublimation from the snowpack), and MWATER (the maximum rate of snowmelt by ground heat) were attained from previous **HSPF** applications in Minnesota and adjusted as necessary. The initial snow parameter calibration was supported by comparing observed and simulated snowfall and snow depth data to verify a reasonable representation of snow accumulation and melt processes. A more detailed calibration of snow parameters was based more heavily on comparisons of observed and simulated flow data during the standard hydrologic calibration process. Observed snowfall and depth data were downloaded from the High Plains Regional Climate Center Climate Information for Management and Operational Decisions (CLIMOD) website (*http://climod.unl.edu/*) for the five locations in and near the Mississippi River Headwaters Watershed shown in Figure 2. Calibration figures, such as the plot illustrated in Figure 3, were constructed to compare the observed snowfall to the simulated snowfall and the observed snow depth to the simulated snow levels. Air temperature is included on the snowfall figure to help estimate parameters, such as TSNOW, and to verify the accuracy of the snowfall data.

HYDRAULIC CALIBRATION

Because of the high number of lakes in these watersheds, lake level is considered an important factor for the hydrology calibration. Lake-level data were available for 57 percent of the lakes that were modeled and were used for comparing simulated lake levels. A summary of the available lake-level data is provided in Table 2. The initial lake-level calibration, which was completed as an early portion of the hydrology calibration, involved adjusting the reference outlet elevations to accurately represent lake volumes before outflow occurs. Lake geometry



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2012

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Figure 2. Meteorological Stations With Snow Data Used for Calibration.

parameters and outlet depths and outflow calculations were adjusted to modify the F-tables in congruence with the storm flow phase of the standard calibration. The overall goal was to adequately represent lake volumes and outflows. Figure 4 illustrates an example of the calibration figures constructed for comparing the observed lake-level data and the simulated lake-level data. The difference between the observed and simulated axes represents the differences between the lake bottom reference elevations from the lake level and bathymetry data. Storm hydrographs were also used to calibrate lake F-tables to represent flow attenuation throughout the watershed. In cases where multiple lakes are represented as one F-table, simulated lake levels cannot be effectively compared to observed lake levels because the combined F-table represents cumulative volume and surface area with absolute depths. Outlet levels can be adjusted but lake level variations will be less variable because of greater storage volumes associated with the same depths. These combined F-tables were evaluated by comparing patterns in the lake-level data instead of actual lake-level values. Lake-level plots from the Mississippi River Headwaters Watershed are included in Appendix A. The Leech Lake River and the Pine River Watersheds lake-level plots are included in Appendix B and Appendix C, respectively.

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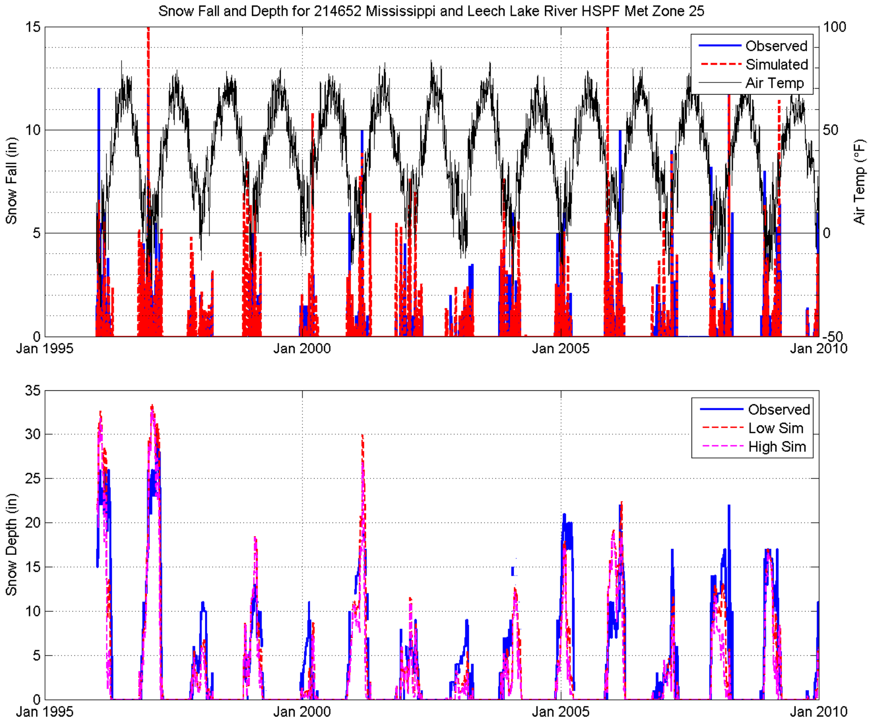

Figure 3. Examples of Snowfall (Top) and Snow Depth (Bottom) Calibration Figures.

Table 2. Lake Level Calibration Gages Within the Mississippi River Headwaters, Leech Lake, and Pine River Watersheds

Watershed	Lake	Lake I.D.	Reach I.D.	Sample Count
Mississippi River Headwaters	Bemidj	4013000	360	1,573
Mississippi River Headwaters	Grace	29007100	372	378
Mississippi River Headwaters	Stump	4013001	400	1309
Mississippi River Headwaters	Wolf	4007900	420	436
Mississippi River Headwaters	Three Island	4013400	422	164
Mississippi River Headwaters	Big	4004900	436	282
Mississippi River Headwaters	Andrusia	4003800	440	243
Mississippi River Headwaters	Pimushe	4003200	442	263
Mississippi River Headwaters	Kitchi	4000700	452	59
Mississippi River Headwaters	Cass	4003000	460	2,894
Mississippi River Headwaters	Dixon	31092100	488	358
Mississippi River Headwaters	Winnibigoshish	11014700	520	5,462
Mississippi River Headwaters	Pokegama	31053200	640	8,453
Leech Lake River	Garfield	29006100	8	117
Leech Lake River	Kabekona	29007500	32	333
Leech Lake River	Blackwater	11027400	74	324
Leech Lake River	Woman	11020100	78	681
Leech Lake River	Lower Trelipe	11012900	108	400
Leech Lake River	Leech	11020300	160	5,423
Pine River	Pine Mountain	11041100	20	169
Pine River	Norway	11030700	120	233
Pine River	Washburn	11005900	248	260
Pine River	Cross Lake	18031200	280	5,480
Pine River	Pelican	18030800	282	208
Pine River	Ossawinnamakee	18035200	284	365
Pine River	Ruth	18021200	302	243
Pine River	Emily	18020300	306	257
Pine River	Ross	18016500	314	430
Pine River	Pine Mountain	11041100	20	169
Pine River	Big Portage	11030800	52	15
Pine River	Hattie	11023200	80	15

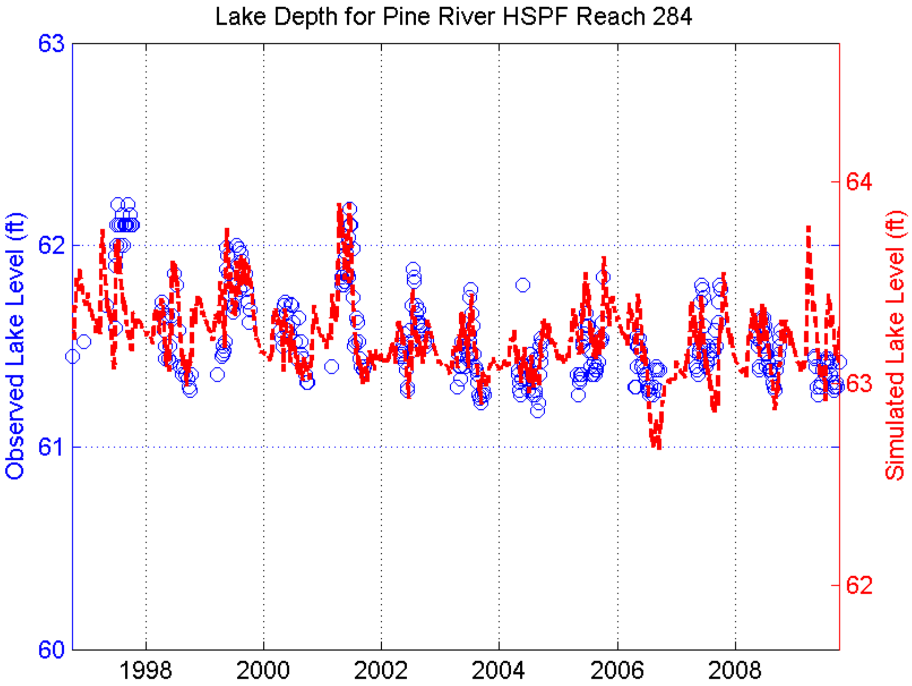

Figure 4. Lake-Level Calibration.

ARMY CORPS OF ENGINEERS LARGE RESERVOIR OUTFLOW

Six large reservoirs are located in the Mississippi River Headwaters, Leech Lake River, and Pine River Watersheds. The U.S. Army Corps of Engineers (USACE) is responsible for controlling water levels on four of them: Leech Lake, Lake Winnibigoshish, Lake Pokegama, and Cross Lake. The other two reservoirs are operated by Otter Tail Power (Lake Bemidji) and the U.S. Forest Service (Knutson Dam on Cass Lake). The USACE maintains outflow gages at Leech Lake, Lake Winnibigoshish, Lake Pokegama, and Cross Lake while Otter Tail Power maintains a flow gage on Lake Bemidj. Recorded outflow measurements at these sites are computed based on the hydraulic head (difference between the elevation of water above the dam and the elevation of the water below the dam) and the number of gates that are open at any given time. A sliding rating table based on the number of gates open, hydraulic head, and design of the dam is used to compute the discharge leaving the dam. The large size of the reservoirs (Leech Lake: 112,000 acres, Lake Winnibigoshish: 58,544 acres) allows for the accumulation of large volumes of water at the face of the dam from wind and wave action [Johnson, 2013]. Water accumulation on the windward side of the lake occasionally results in an inaccurate reading of the true lake level [Kleinert, 2013]. Therefore, during these periods of time, the computed release of water may be higher than the expected precipitation records. Despite these inaccuracies, the observed flow time series at these reservoirs were used as input to the model because these data reflect the USACE management strategy and the operating rules for each reservoir. The operating rules for each reservoir are designed to maintain a summer pool through July 15 and then fall at a rate of approximately 2 inches per month to allow for flood storage in the following spring. This management style provides maximum recreational and wildlife benefit which allows flood storage to protect downstream municipalities during the spring.

WEIGHT-OF-EVIDENCE APPROACH

Model performance was evaluated using a weight-of-evidence approach described in Donigian [2002]. This type of approach uses both visual and statistical methods to best define the performance of the model. The approach was integrated into the hydrologic calibration to continuously evaluate the model results to efficiently improve calibration performance until no apparent improvement was observed from further parameter adjustment. This process was performed at each flow gage by adjusting parameters for land segments upstream. Moreover, greater weight was applied to the performance of the model at gages where there is a larger contributing area and a longer period of record. An attempt was made to maintain comparable parameter values and intraparameter variations for each land segment category throughout the watershed. The specific model-data comparisons of simulated and observed values for the calibration period and their associated phase of the standard hydrologic calibration are grouped below.

- **Establish an annual water balance**
  - Total runoff volume errors for calibration/validation period
  - Annual runoff volume errors
- **Make seasonal adjustments**
  - Monthly runoff volume errors
  - Monthly model fit statistics
  - Summer/winter runoff volume errors
  - Summer/winter storm volume errors
- **Adjust low-flow/high-flow distribution**
  - Highest 5 percent, 10 percent, and 25 percent flow volume errors
  - Lowest 5 percent, 10 percent, 15 percent, 25 percent, and 50 percent flow volume errors
  - Flow frequency (flow duration) curves
- **Adjust storm flow/hydrograph shape**
  - Daily/hourly flow time-series graphs to evaluate hydrograph shape
  - Daily model fit statistics
  - Average storm peak flow errors
  - Summer/winter storm volume errors.

Common model fit statistics used for evaluating hydrologic model applications include correlation coefficient (r), coefficient of determination (r^2), coefficient of model-fit efficiency (mfe), mean error, mean absolute error, and mean square error. Statistical methods may provide definitive answers, but they are still subject to the modeler's best judgment for overall model performance.

Annual and monthly average runoff plots were used to visually compare runoff volumes over the contributing area. The annual and monthly average values represent a volume of water as a depth in inches distributed over the entire contributing area to normalize the runoff using the drainage area. Monthly plots help to verify the model's ability to capture the variability in the runoff among the watersheds and also verify that the snowfall and snowmelt processes are simulated accurately. Average yearly plots help to verify that the annual water balances are reasonable and allow trends to be considered. Flow frequency curves, or flow duration curves, were used to characterize the flow conditions under which flows are occurring. The flow duration curve presents measured flow and simulated flow versus the corresponding percent of time the flow is exceeded. Thus the flow duration curves provide a way to evaluate model performance for various flow conditions (e.g., storm events or baseflow) and determine which parameters to adjust to better fit the data. Daily flow, time-series plots allow analyzing individual storm events, the snow accumulation and snowmelt processes, and baseflow trends. Examples of daily flow time-series plots, monthly plots, annual plots, and flow duration curves used for the calibration/validation process are illustrated in Figures 5 through 8, respectively.

In addition to the comparisons above, the water balance components of watershed hydrology were reviewed. Reviewing the water balance involves summarizing outflows from each individual land cover and soil group classification for the following hydrologic components:

- **Precipitation**
- **Total runoff (sum of following components)**
  - Overland flow
  - Interflow
  - Baseflow
- **Potential evapotranspiration**
- **Total actual ET (sum of following components)**
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET
- **Deep groundwater recharge/losses**

Although the observed values are not available for each of the water balance components listed above, the average annual values must be consistent with the expected values for the region, as impacted by the individual land cover and soil group categories.

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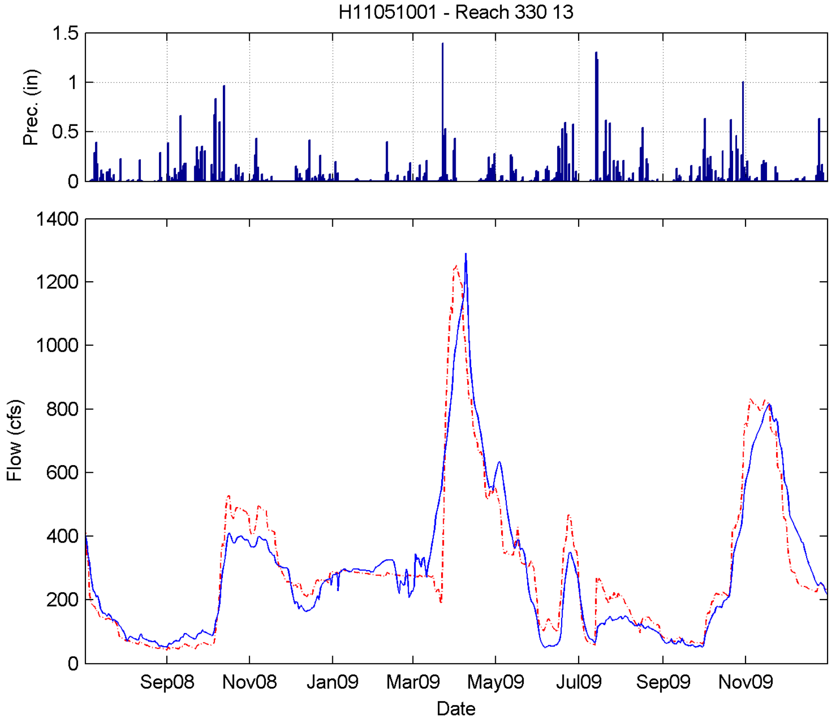

Figure 5. Daily Flow Time-Series Plot Example.

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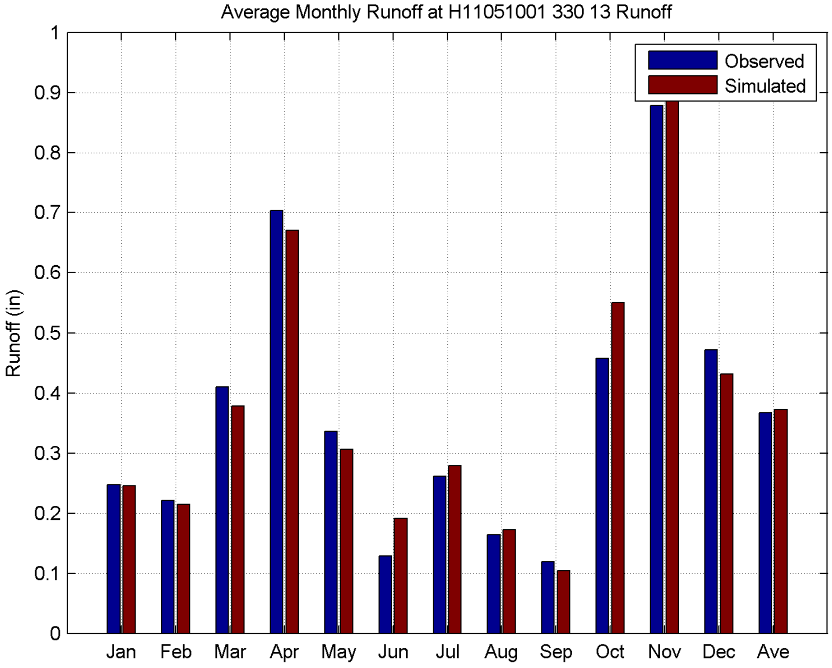

Figure 6. Average Monthly Runoff Plot Example.

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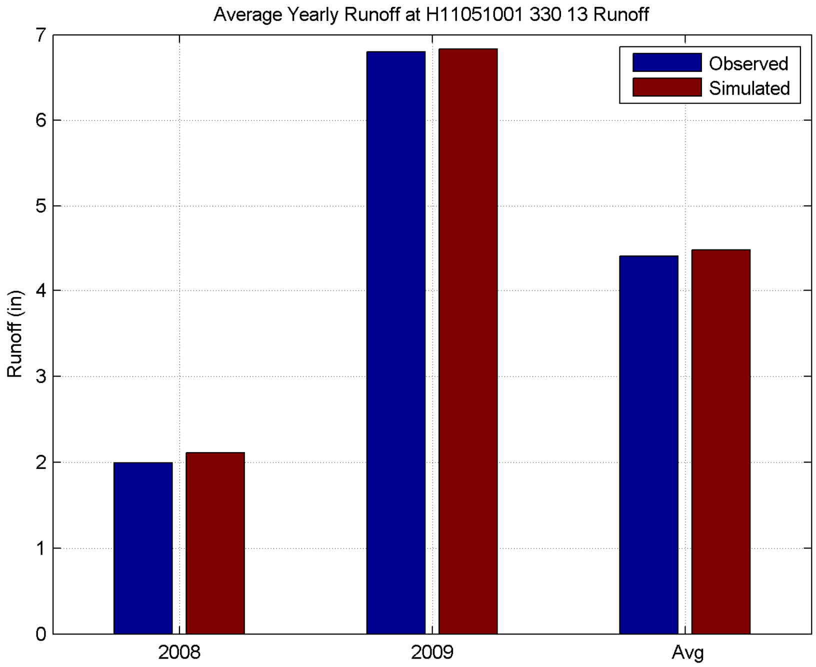

Figure 7. Average Yearly Runoff Plot Example.

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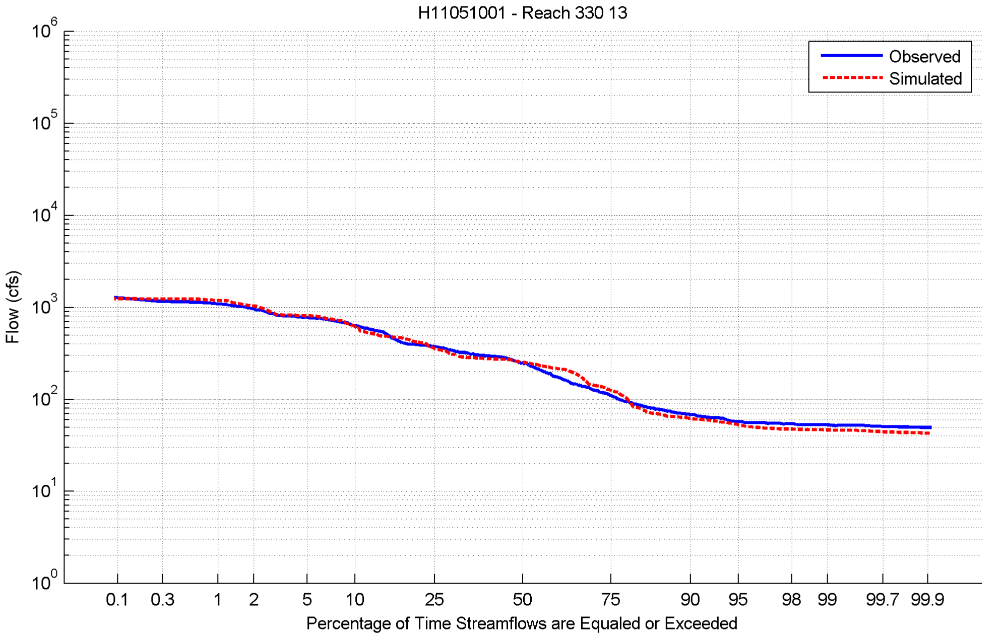

Figure 8. Flow Duration Curve Example.

The calibration parameters were adjusted to improve the performance of the model until the preferred performance criteria were met or no apparent improvement was observed from the parameter refinement. The graphical plots were visually evaluated to objectively assess the model performance while the statistics were compared to objective criteria. The percent error statistics were evaluated with the hydrology criteria in Table 3. The correlation coefficient (*r*) and coefficient of determination (r^2) were compared with the criteria in Figure 9 to evaluate the performance of the daily and monthly flows. These measures allow the user to assess the quality of the overall model application performance in descriptive terms to determine if the model application should be accepted or rejected. The developed performance criteria are explained in detail in Donigian [2002]. Once the specifications document is developed, RESPEC will evaluate the reasonableness of criteria and work to achieve the agreed-upon criteria.

Table 3. General Calibration/Validation Targets or Tolerances for HSPF Applications

	Difference Between Simulated and Recorded Values (%)		
	Fair	**Good**	**Very Good**
Hydrology/Flow	15–25	10–15	<10

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

Source: Donigian [2000].

RSI-1953-12-011

Figure 9. General Calibration/Validation *r* and r^2 Targets for HSPF Applications.

INITIAL CALIBRATION RESULTS

The initial calibration was performed using the primary mainstem stream gages for the Mississippi River Headwaters and Pine River Watershed model applications. The single flow gage in the Leech Lake Watershed is located on Leech Lake (Reach 160). As previously mentioned, the observed flow data at Reach 160 were used as model input; therefore, only lake level calibrations were performed in this watershed. Secondary gages on tributaries were not found in any of the three watersheds; the focus of this hydrology calibration was on mainstem gages. The initial calibration results for all mainstem gages rate good or very good with respect to the calibration and validation targets in Figure 9. Tables 4 and 5 show the results for the model applications. The weighted overall statistic represents a drainage area weighted average. Table 6 summarizes the weighted water balance components at the outlets of each watershed model applications. The initial calibration figures for primary gages in the Mississippi Headwaters Watershed, the Leech Lake River Watershed, and the Pine River Watershed are located in Appendices A, B, and C, respectively.

Table 4. Summary Statistics for Primary Calibration Gages in the Mississippi River Headwaters Watershed

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% Δ	*r*	r^2	MFE	*r*	r^2	MFE	Volume	Peak
H7052001	210	4.18	4.09	2.15	0.90	0.82	0.78	0.87	0.76	0.69	–5.01	–11.95
H7062001	340	1.47	1.48	0.57	0.94	0.88	0.88	0.86	0.74	0.72	–0.39	–0.72
H8022001	640	7.09	6.96	–1.77	0.93	0.86	0.85	0.87	0.76	0.76	2.63	–1.06
Weighted Overall		5.77	5.68	–1.56	0.93	0.86	0.85	0.87	0.75	0.75	1.72	–1.35

Table 5. Summary Statistics for Primary Calibration Gage in the Pine River Watershed

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% Δ	*r*	r^2	MFE	*r*	r^2	MFE	Volume	Peak
H11051001	330	4.40	4.47	6.81	0.98	0.96	0.96	0.94	0.88	0.88	2.03	–0.10

Table 6. Summary of Water Balance Components

Water Balance Component	Water Balance Component Description	Mississippi River Headwaters, Leech Lake River, and Pine River Watersheds Percent of Water Supply
SURO	Surface outflow	1%
IFWO	Interflow outflow	6%
AGWO	Active groundwater outflow	18%
IGWI	Inflow to inactive groundwater	0%
CEPE	Evaporation from interception storage	22%
UZET	Evapotranspiration from upper zone	17%
LZET	Evapotranspiration from lower zone	11%
AGWET	Evapotranspiration from active groundwater storage	21%
BASET	Evapotranspiration from active groundwater outflow (baseflow)	1%

Some land use differences exist within the three watersheds that require parameter modifications. For example, the Mississippi River Headwaters Watershed contains a greater percentage of coniferous forests, while the Leech Lake River and Pine River Watersheds have a higher percentage of deciduous forests. Lakes represent a larger percentage of the Mississippi

River Headwaters and Leech Lake River Watersheds, and the lakes are generally larger in these watersheds as compared to the Pine River Watershed. However, these three watersheds share many of the same land use characteristics, such as the percentage of wetlands that represent approximately one-fourth of all land area in all three watersheds. Additionally, all three watersheds are located in the northern lakes and forests ecoregion so some parameters remained consistent in all three watersheds.

REFERENCES

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

Johnson, B., 2013. Personal communication from J. Pallardy, RESPEC, Roseville, MN, and B. Johnson, U.S. Army Corps of Engineers, St. Paul, MN, June 6.

Kleinert, J., 2013. Personal communication from J. Pallardy, RESPEC, Roseville, MN, and J. Kleinert, U.S. Army Corps, St Paul, MN, June 6.

Love, J. T., 2011. *Pervious (PERLND) and Impervious Land (IMPLND) Category Development*, Revision 1, RSI(RCO)-1953/4-11/5, from J. T. Love, RESPEC, Rapid City, SD, to C. Reagan, Minnesota Pollution Control Agency, St. Paul, MN, April 7.

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

Thank you for reviewing the methods regarding the calibration and validation of the Mississippi River Headwaters, Leech Lake River, and Pine River Watershed **HSPF** model applications. Please contact me with any questions or concerns.

Sincerely,

Seth J. Kenner
Staff Engineer

SJK:llf

cc: Project Central File 2046 — Category A

APPENDIX A

INITIAL CALIBRATION RESULTS AT PRIMARY GAGES FOR THE MISSISSIPPI RIVER HEADWATERS WATERSHED MODEL

RSI-2046-13-011

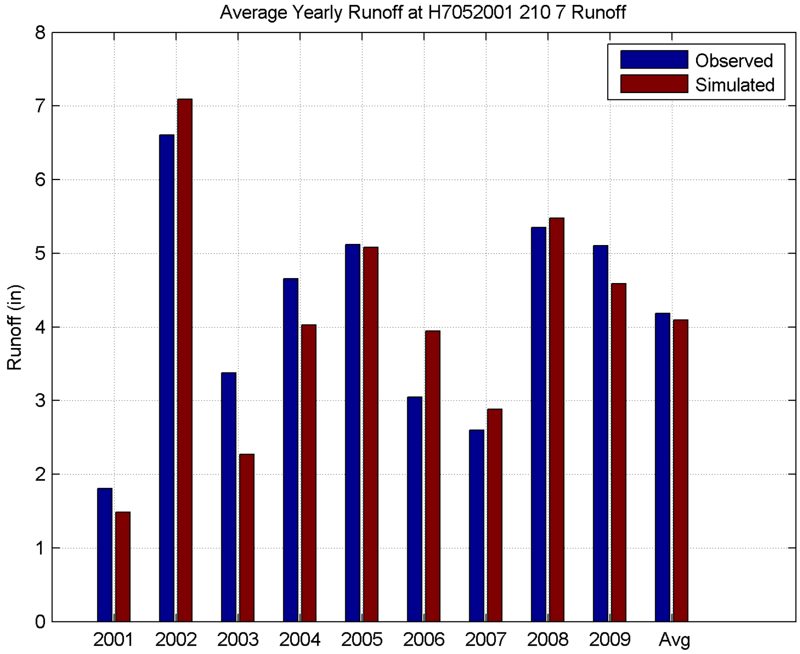

Figure A-1. Average Yearly Runoff at Reach 210.

RSI-2046-13-012

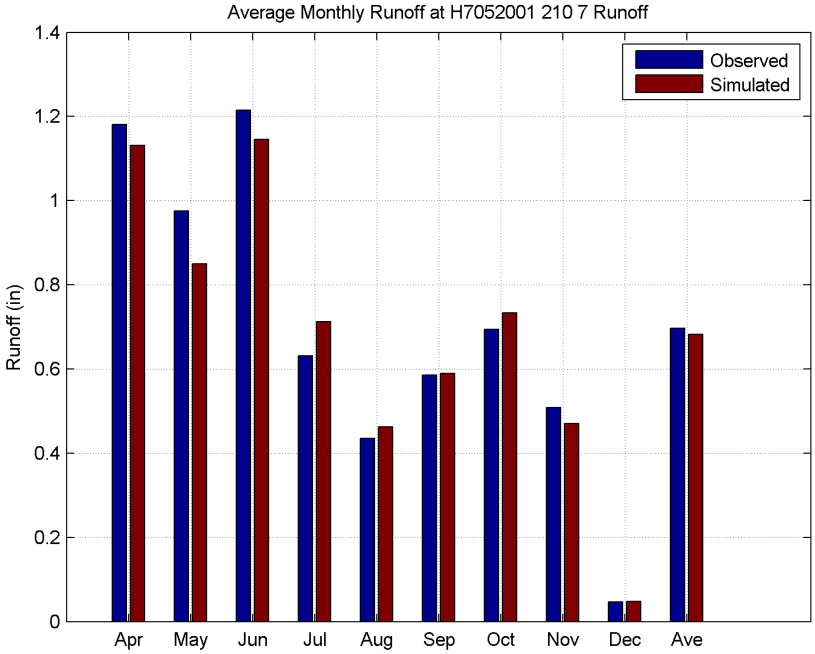

Figure A-2. Average Monthly Runoff at Reach 210.

RSI-2046-13-013

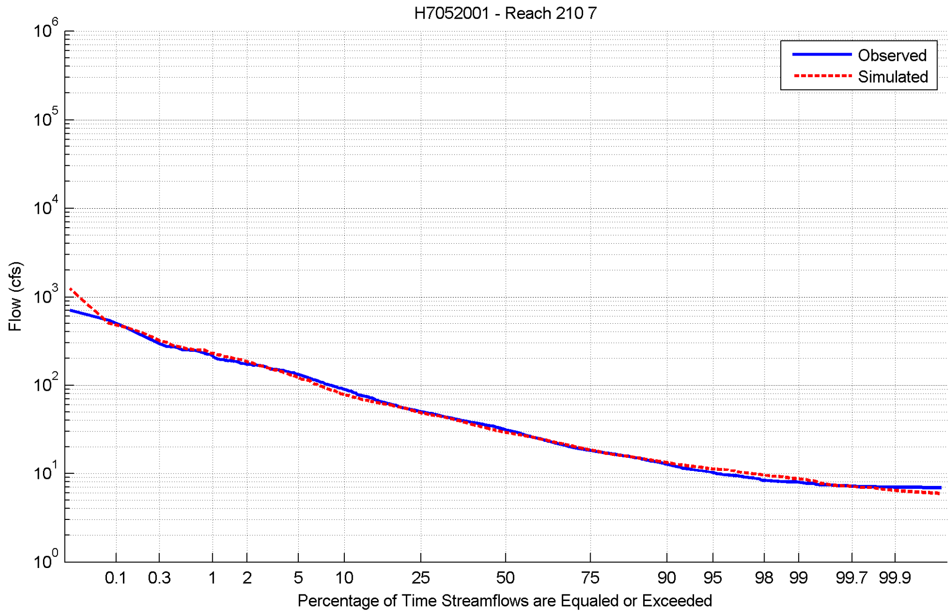

Figure A-3. Flow Duration Plot for Reach 210.

RSI-2046-13-014

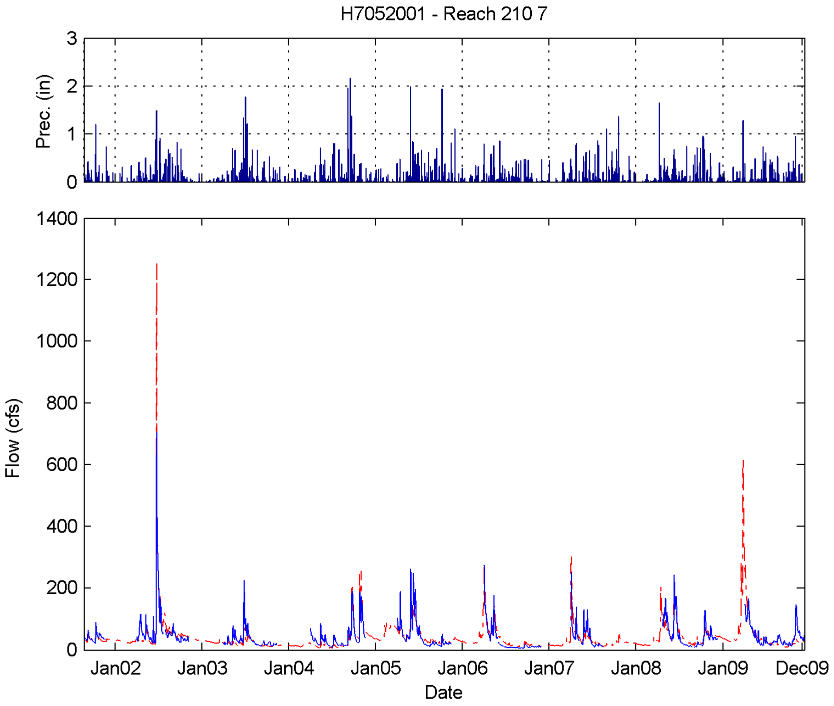

Figure A-4. Daily Hydrographs for Reach 210.

RSI-2046-13-015

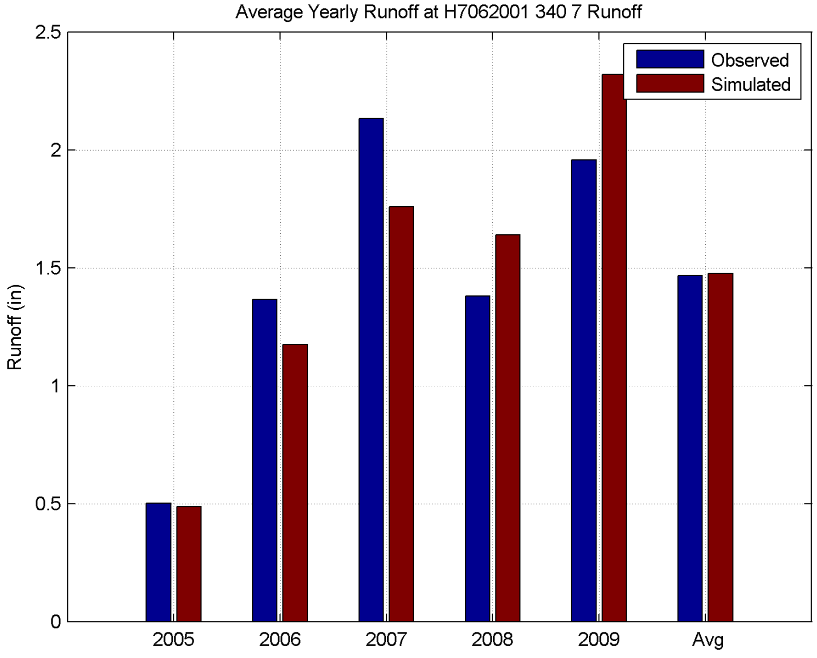

Figure A-5. Average Yearly Runoff at Reach 340.

RSI-2046-13-016

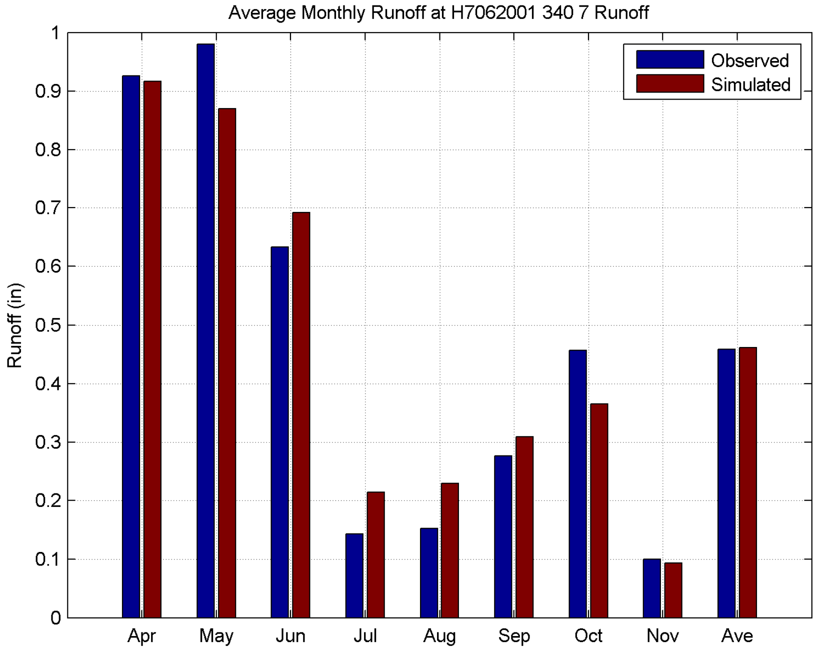

Figure A-6. Average Monthly Runoff at Reach 340.

RSI-2046-13-017

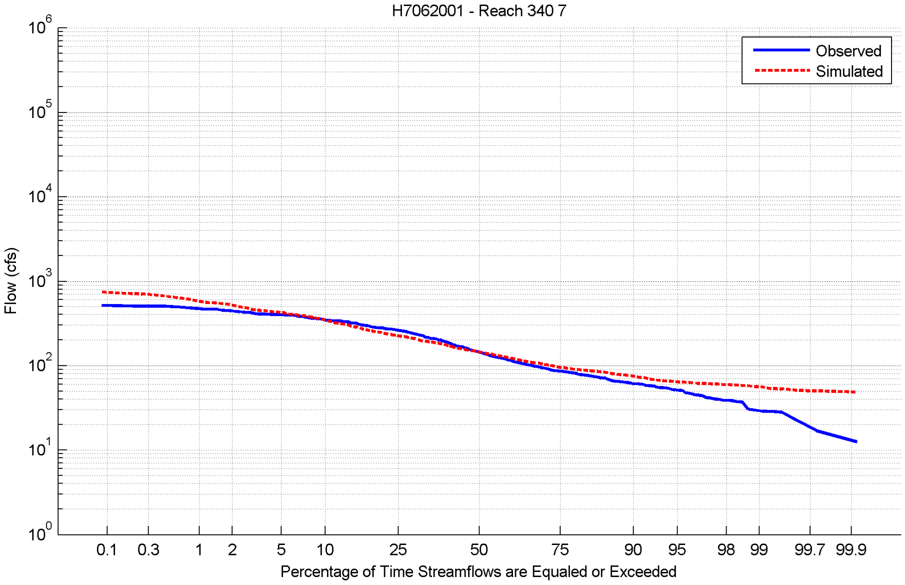

Figure A-7. Flow Duration Plot for Reach 340.

RSI-2046-13-018

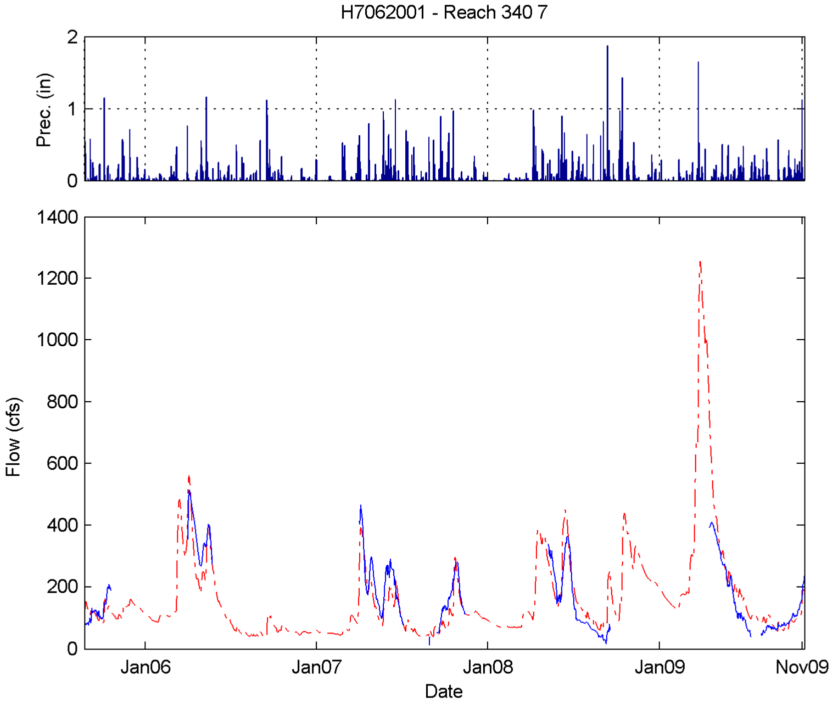

Figure A-8. Daily Hydrographs for Reach 340.

RSI-2046-13-019

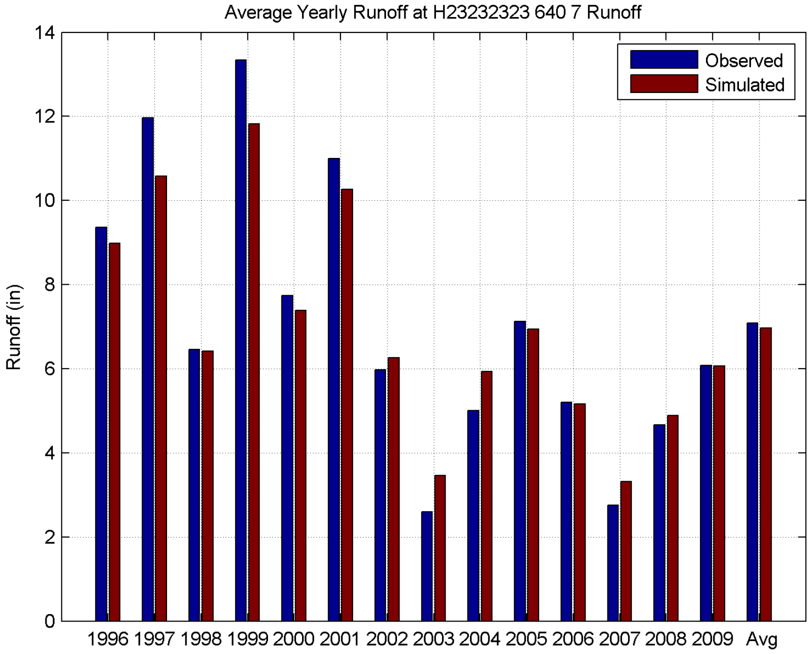

Figure A-9. Average Yearly Runoff at Reach 640.

RSI-2046-13-020

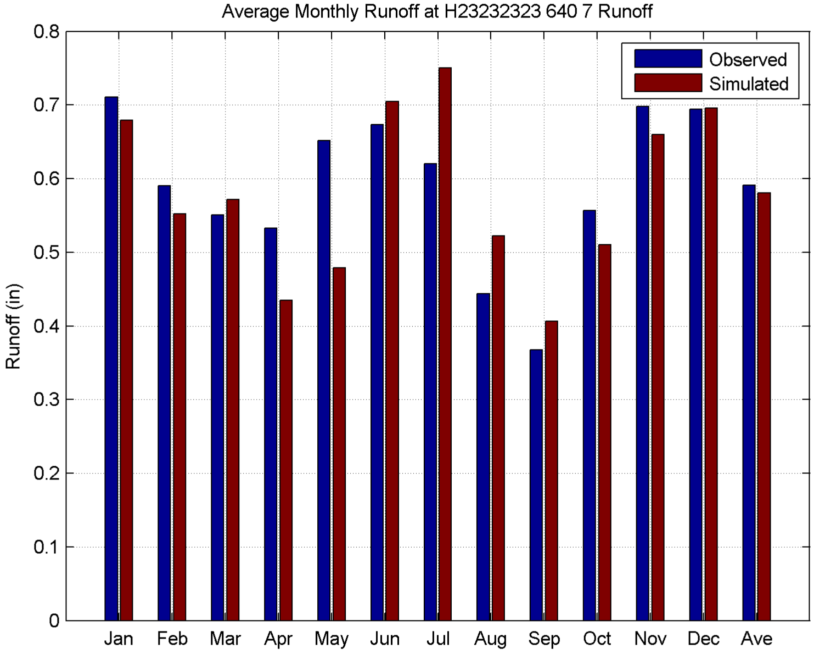

Figure A-10. Average Monthly Runoff at Reach 640.

RSI-2046-13-021

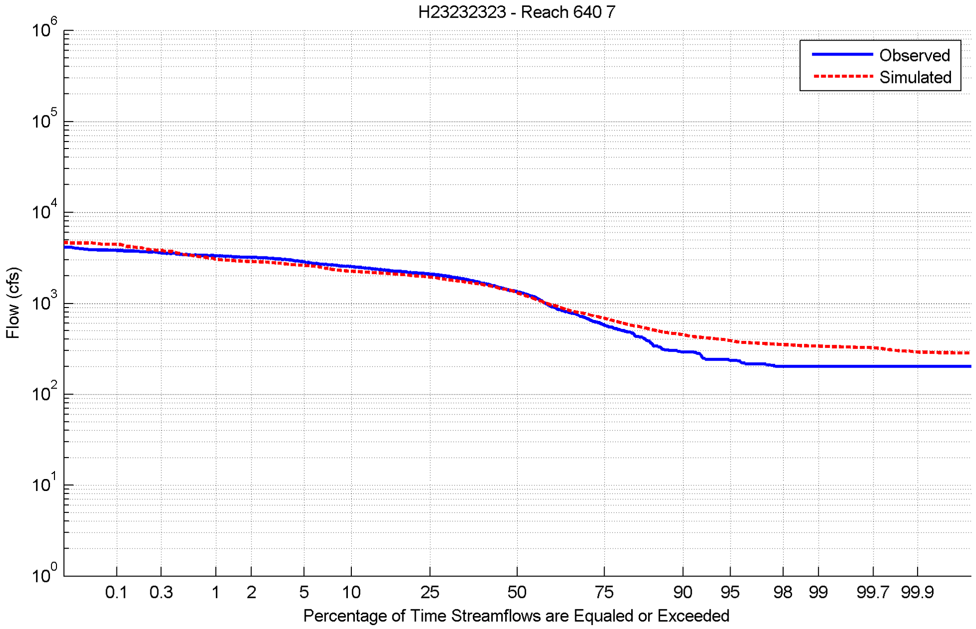

Figure A-11. Flow Duration Plot for Reach 640.

RSI-2046-13-022

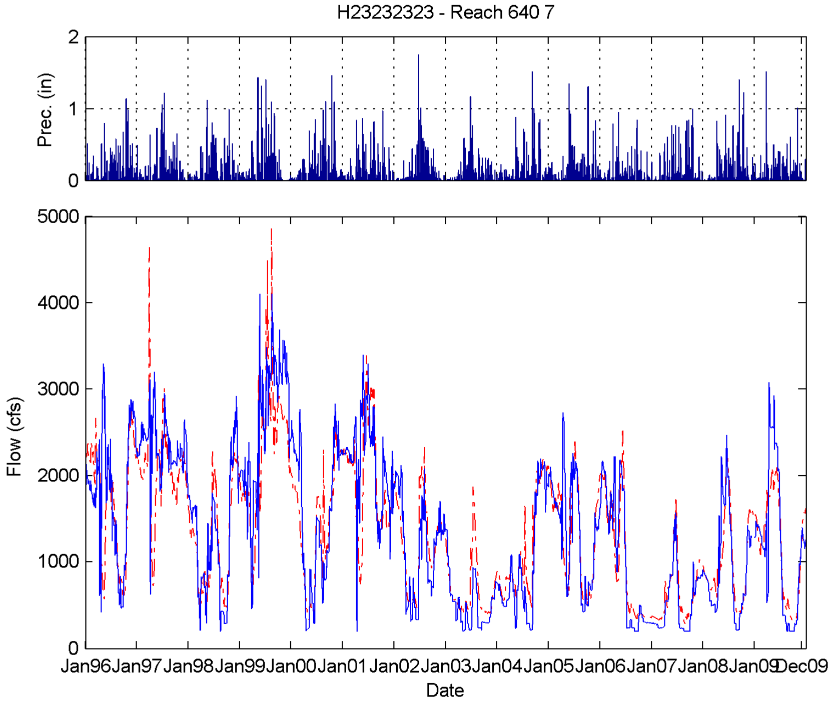

Figure A-12. Daily Hydrographs for Reach 640.

RSI-2046-13-023

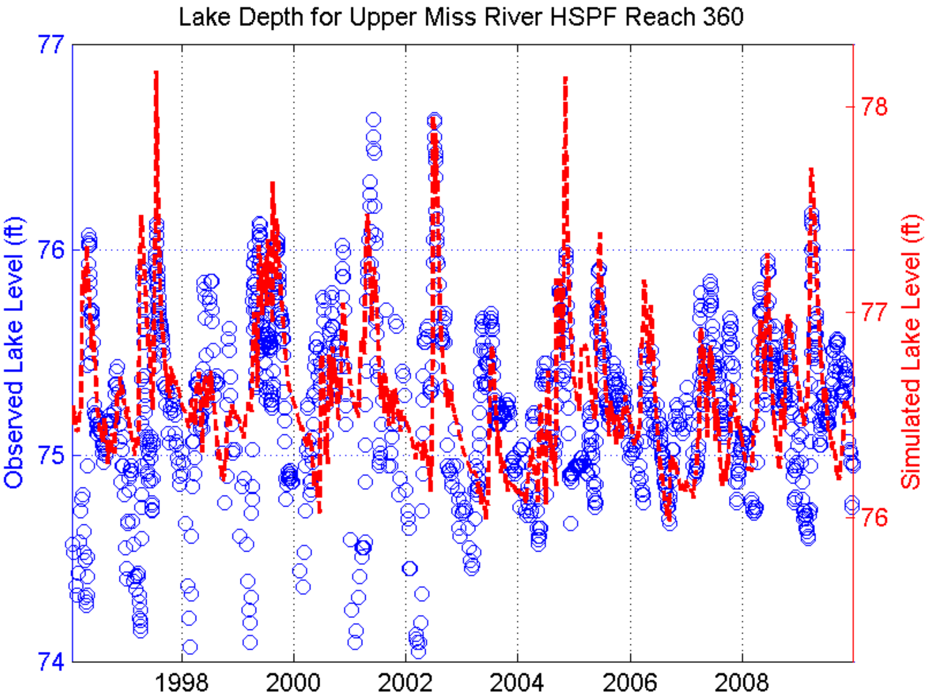

Figure A-13. Lake Bemidji Level Time Series.

RSI-2046-13-024

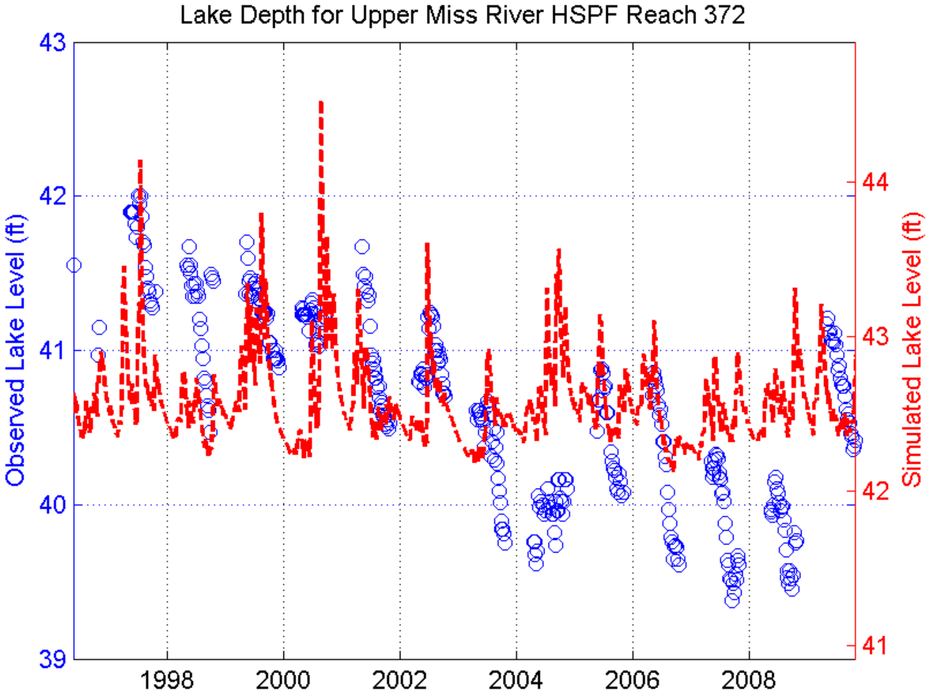

Figure A-14. Grace Lake Level Time Series.

RSI-2046-13-025

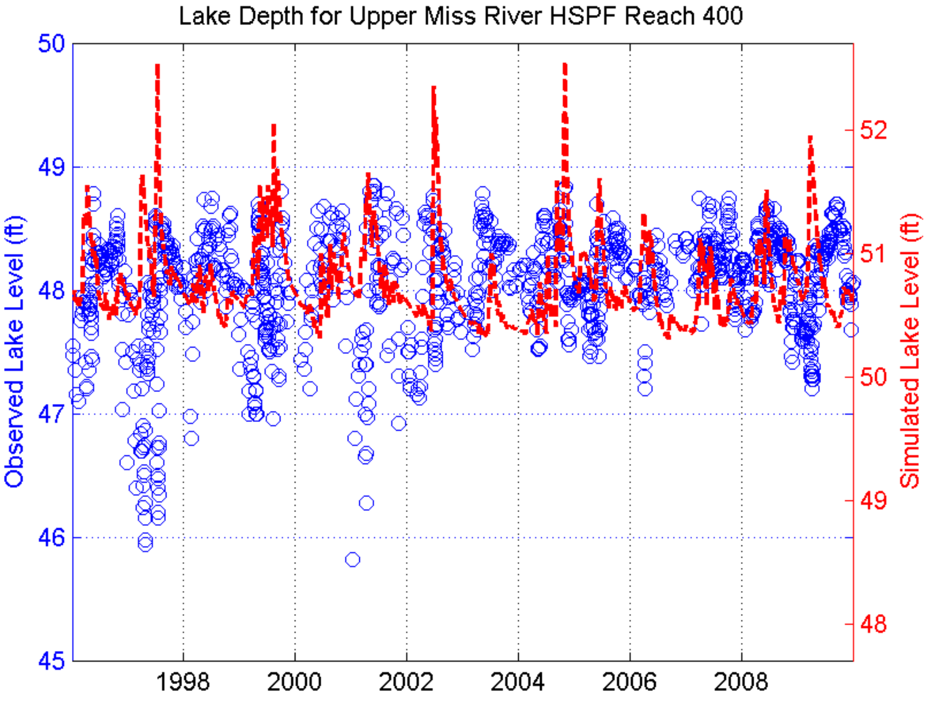

Figure A-15. Stump Lake Level Time Series.

RSI-2046-13-026

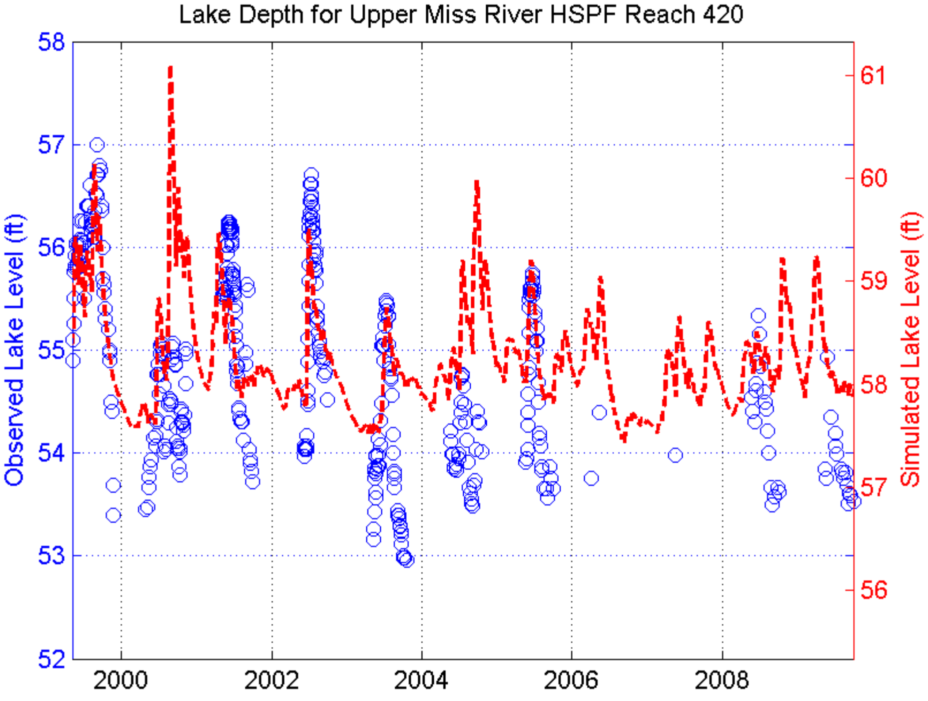

Figure A-16. Wolf Lake Level Time Series.

RSI-2046-13-027

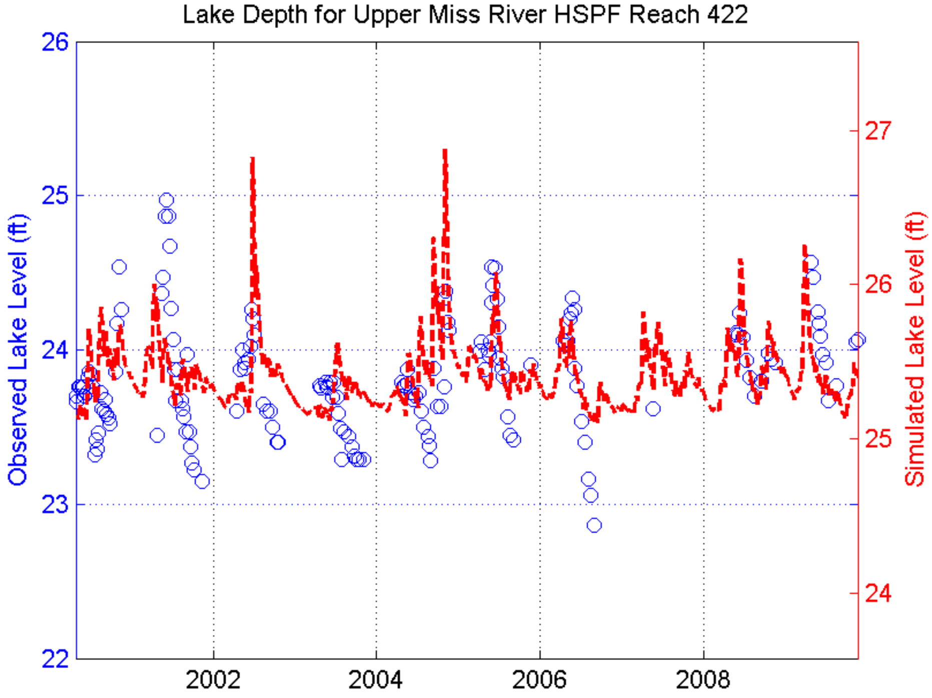

Figure A-17. Three Island Lake Level Time Series.

RSI-2046-13-028

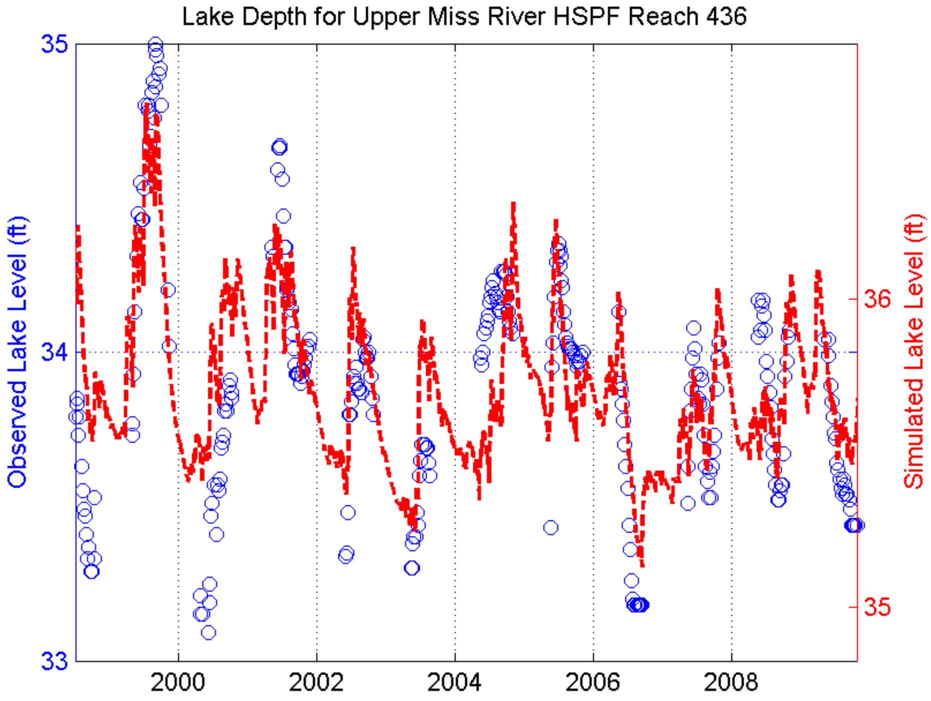

Figure A-18. Big Lake Level Time Series.

RSI-2046-13-029

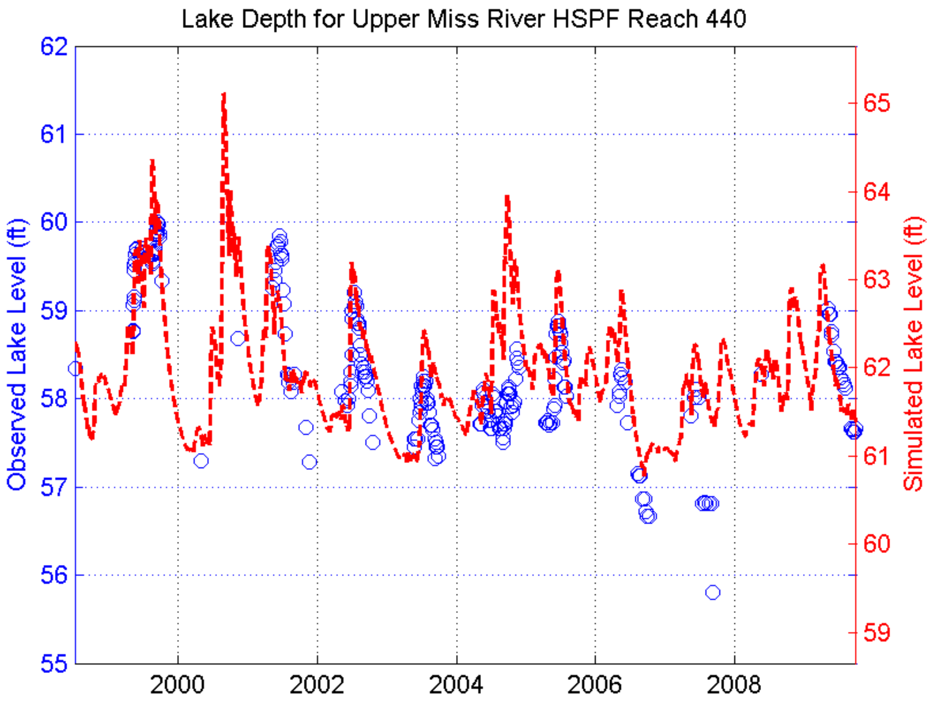

Figure A-19. Andrusia Lake Level Time Series.

RSI-2046-13-030

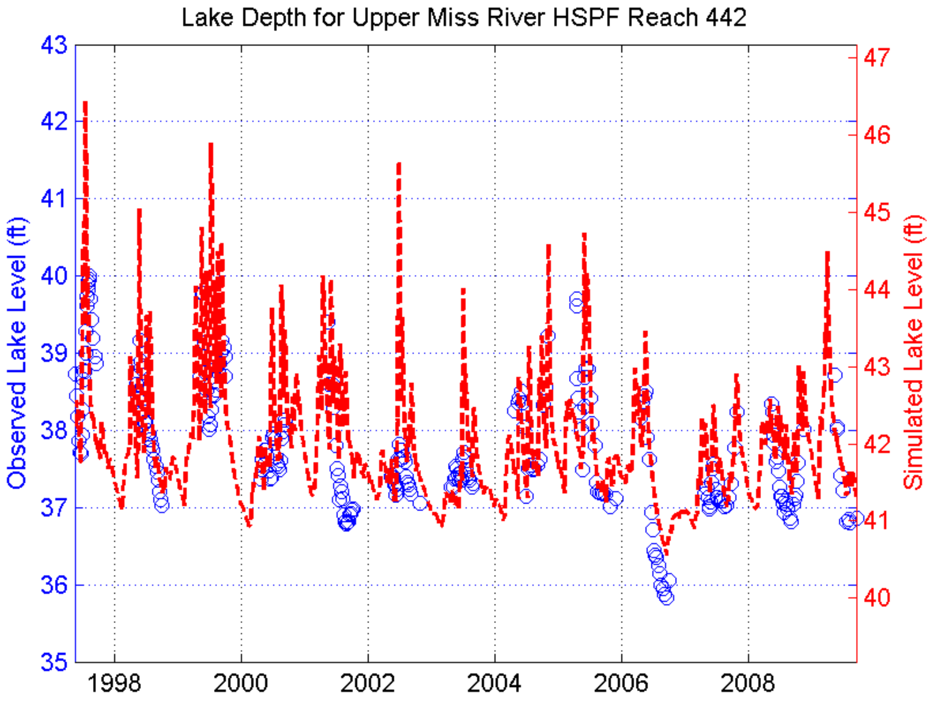

Figure A-20. Pimushe Lake Level Time Series.

RSI-2046-13-031

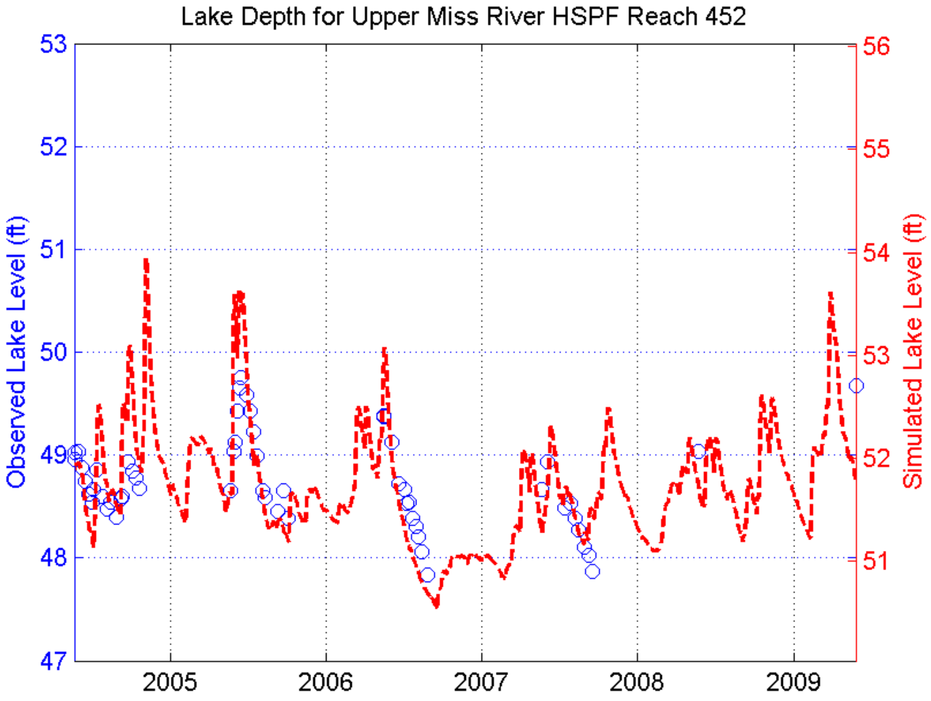

Figure A-21. Kitchi Lake Level Time Series.

RSI-2046-13-032

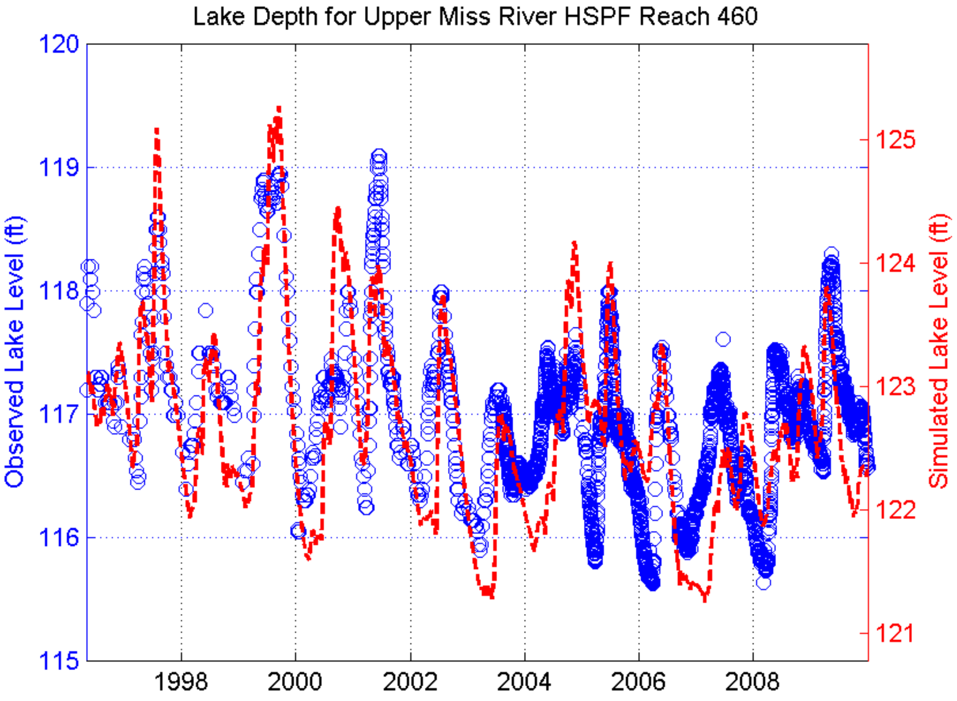

Figure A-22. Cass Lake Level Time Series.

RSI-2046-13-033

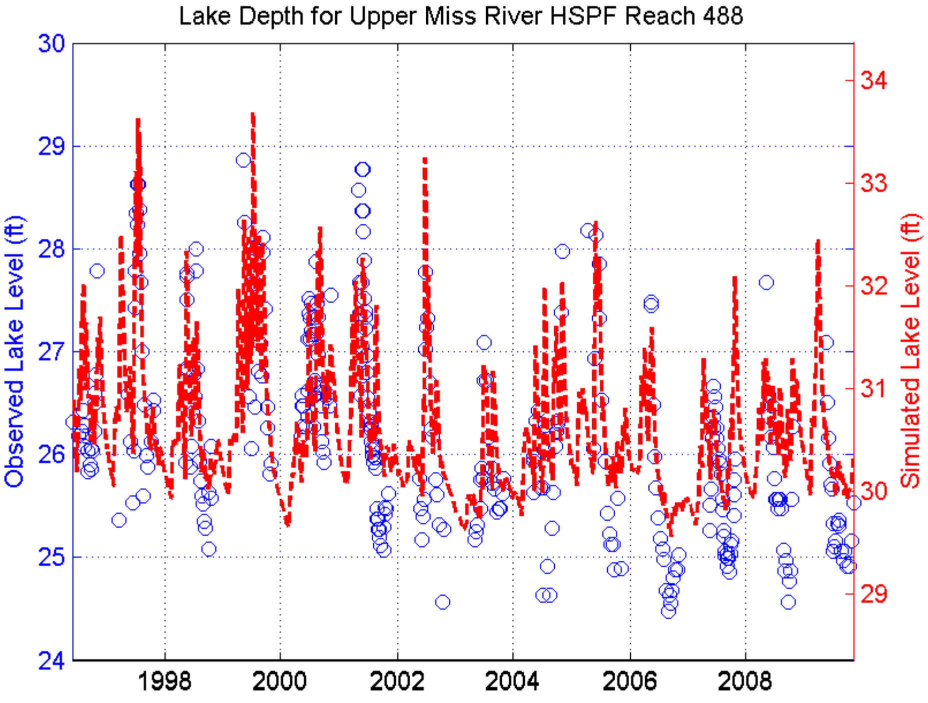

Figure A-23. Dixon Lake Level Time Series.

RSI-2046-13-034

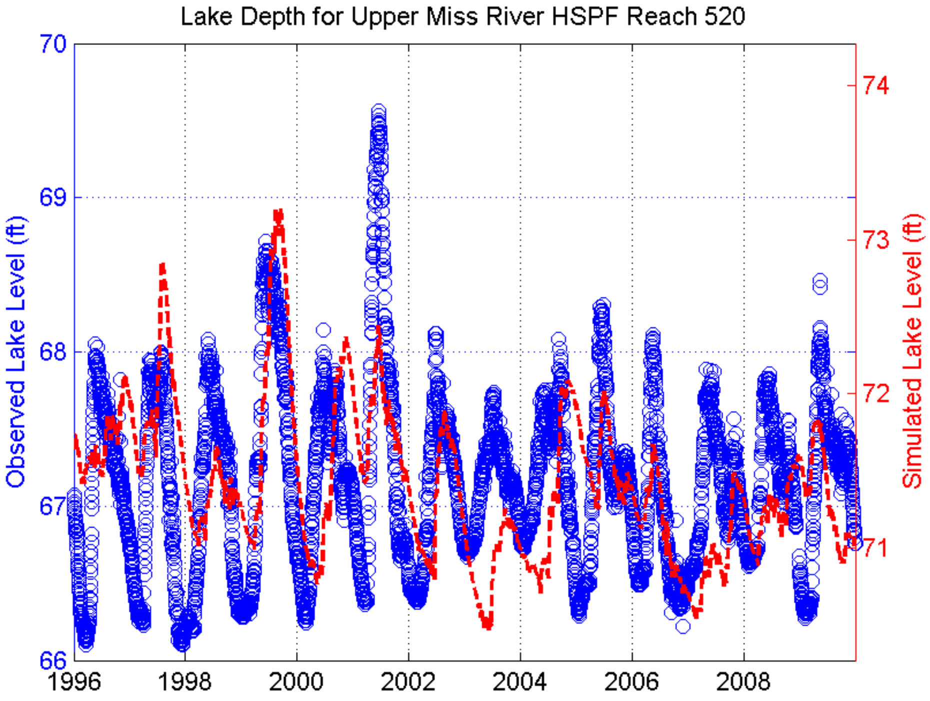

Figure A-24. Lake Winnibigoshish Level Time Series.

RSI-2046-13-035

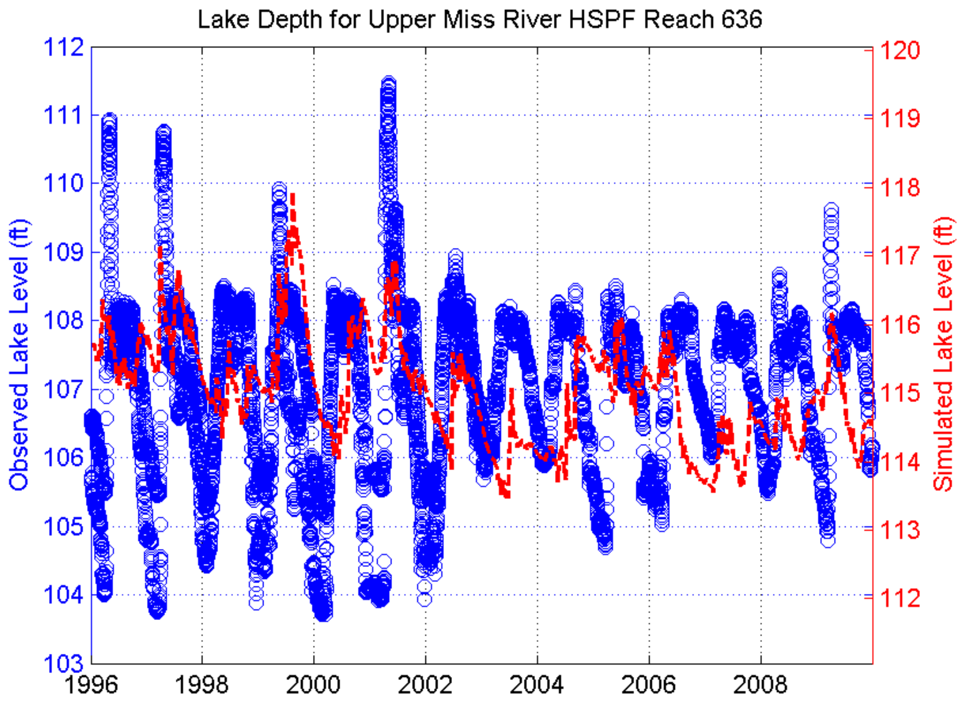

Figure A-25. Lake Pokegama Level Time Series.

APPENDIX B

INITIAL CALIBRATION RESULTS AT PRIMARY GAGES FOR THE LEECH LAKE RIVER WATERSHED MODEL

RSI-2046-13-036

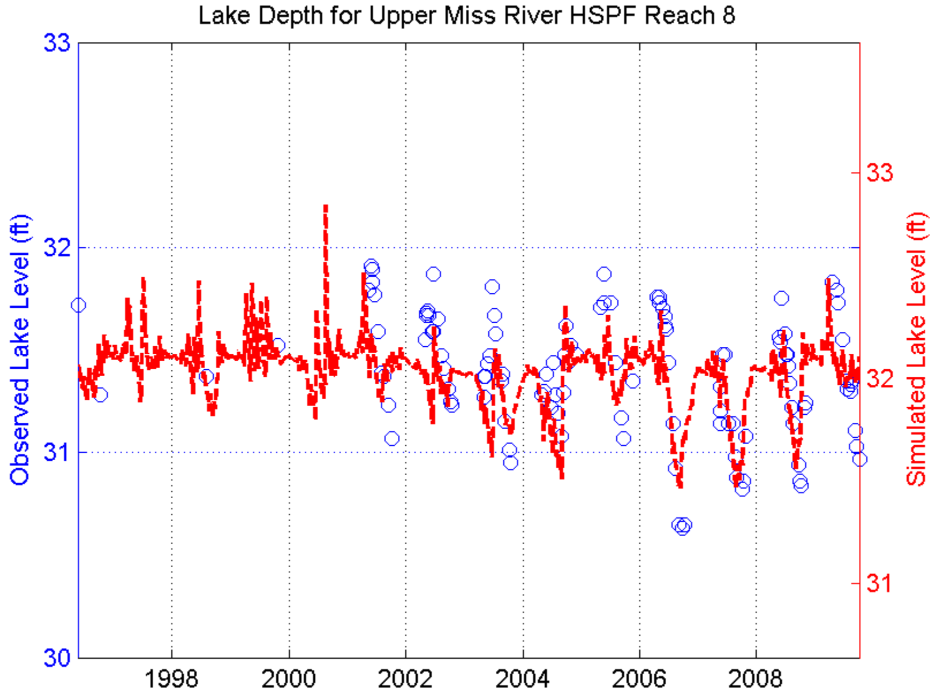

Figure B-1. Garfield Lake Level Time Series.

RSI-2046-13-037

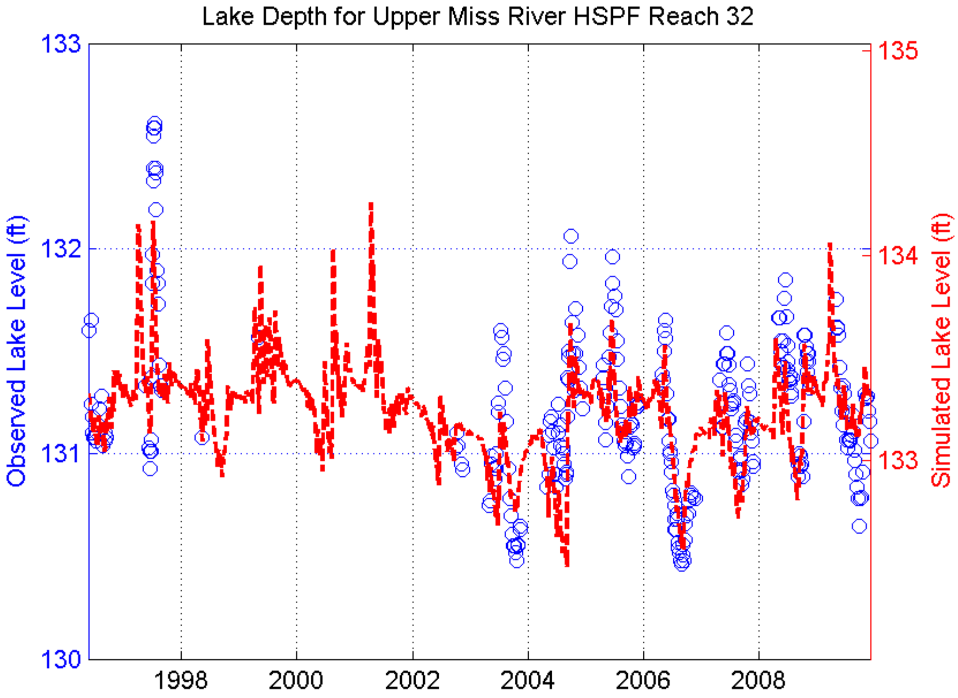

Figure B-2. Kabekona Lake Level Time Series.

RSI-2046-13-038

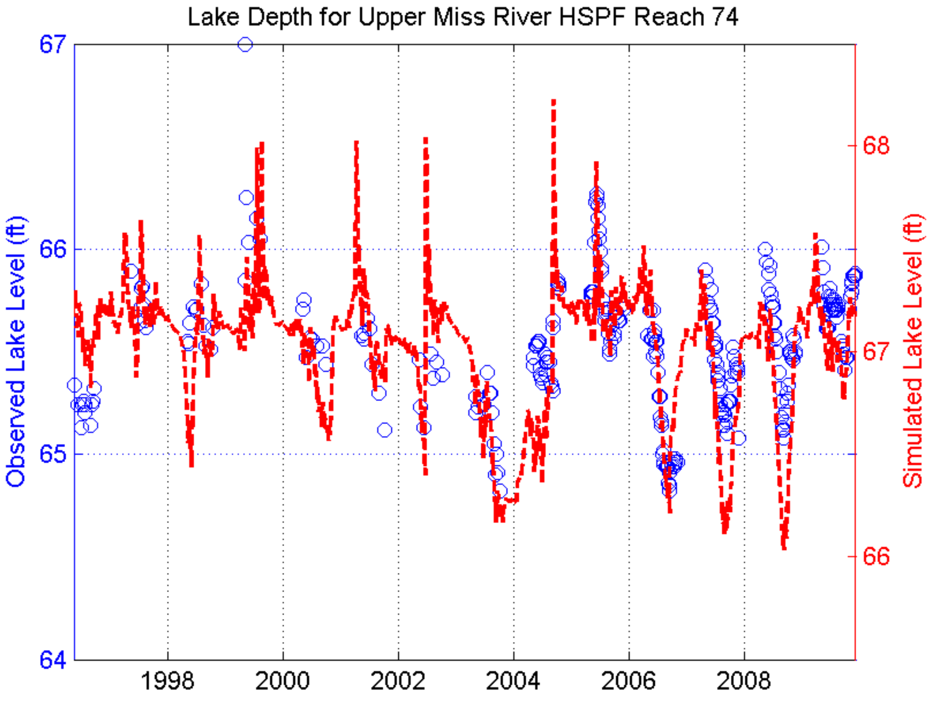

Figure B-3. Blackwater Lake Level Time Series.

RSI-2046-13-039

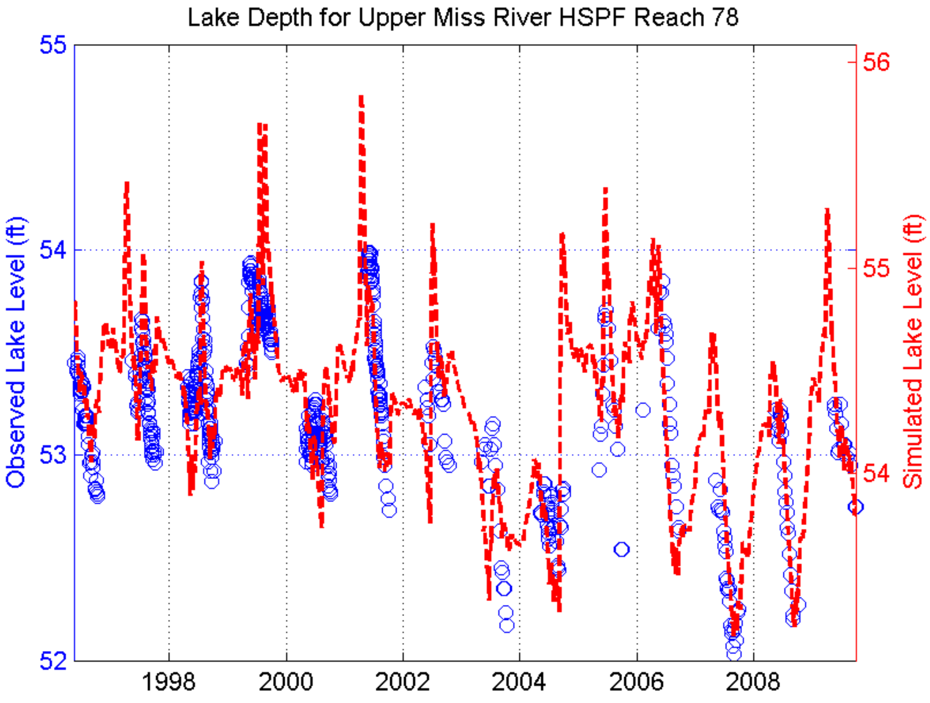

Figure B-4. Woman Lake Level Time Series.

RSI-2046-13-040

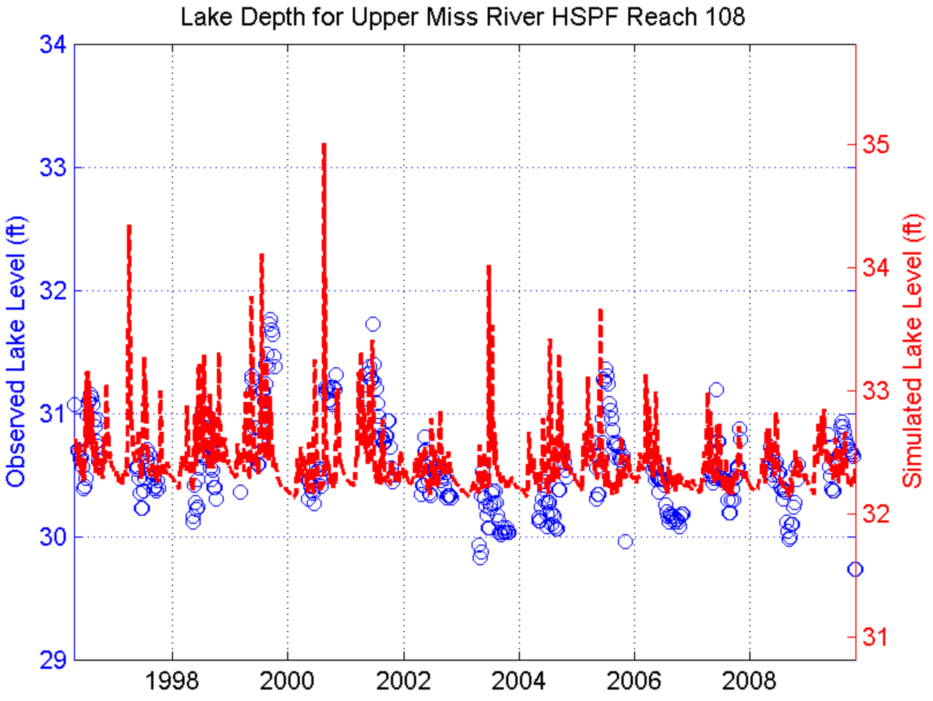

Figure B-5. Lower Trelipe Lake Level Time Series.

RSI-2046-13-041

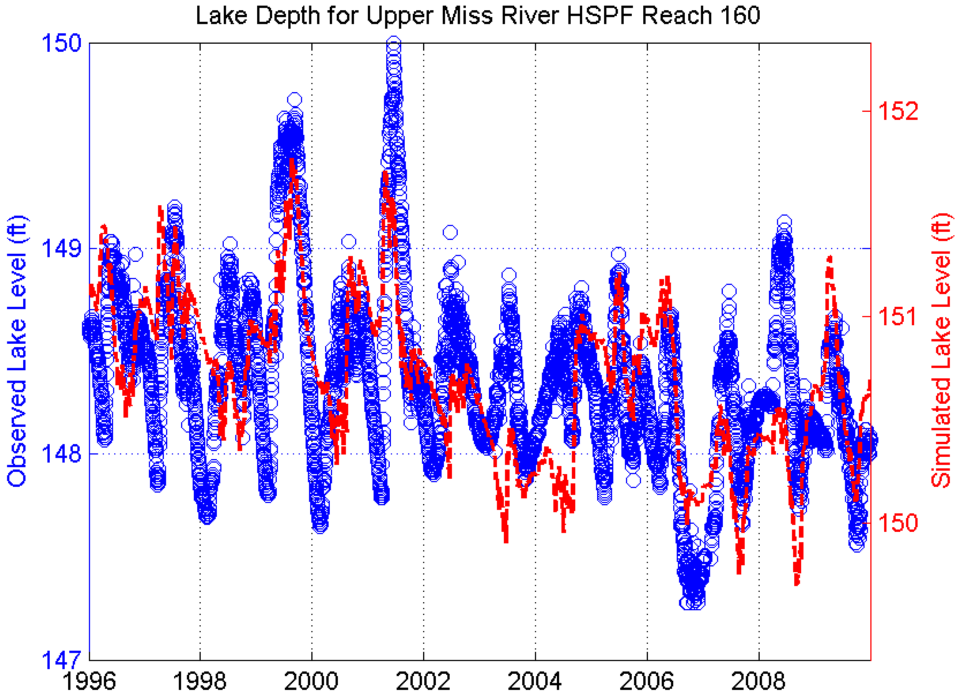

Figure B-6. Leech Lake Level Time Series.

APPENDIX C

INITIAL CALIBRATION RESULTS AT PRIMARY GAGES FOR THE PINE RIVER WATERSHED MODEL

RSI-2046-13-042

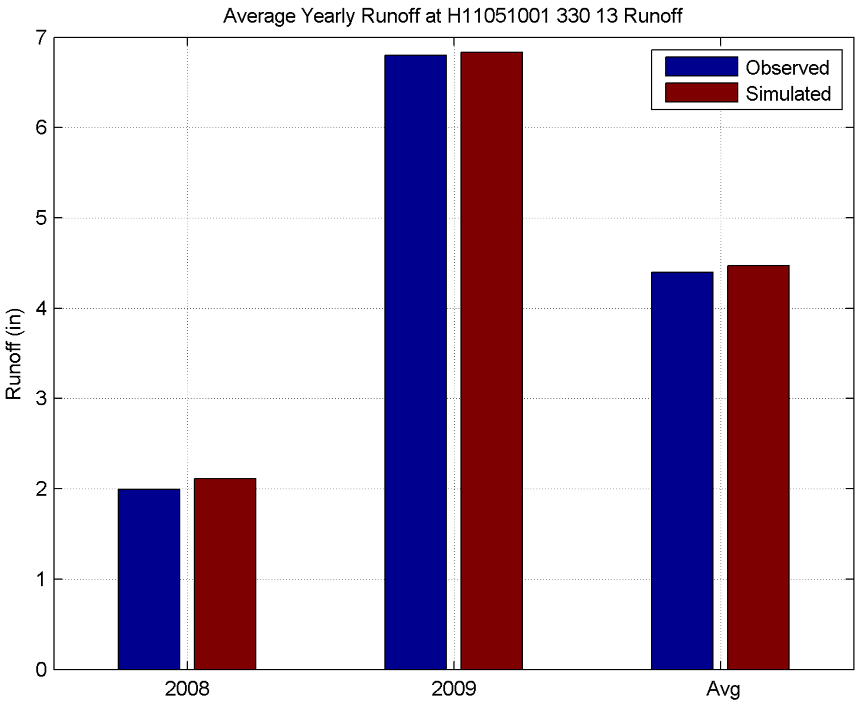

Figure C-1. Average Yearly Runoff at Reach 330.

RSI-2046-13-043

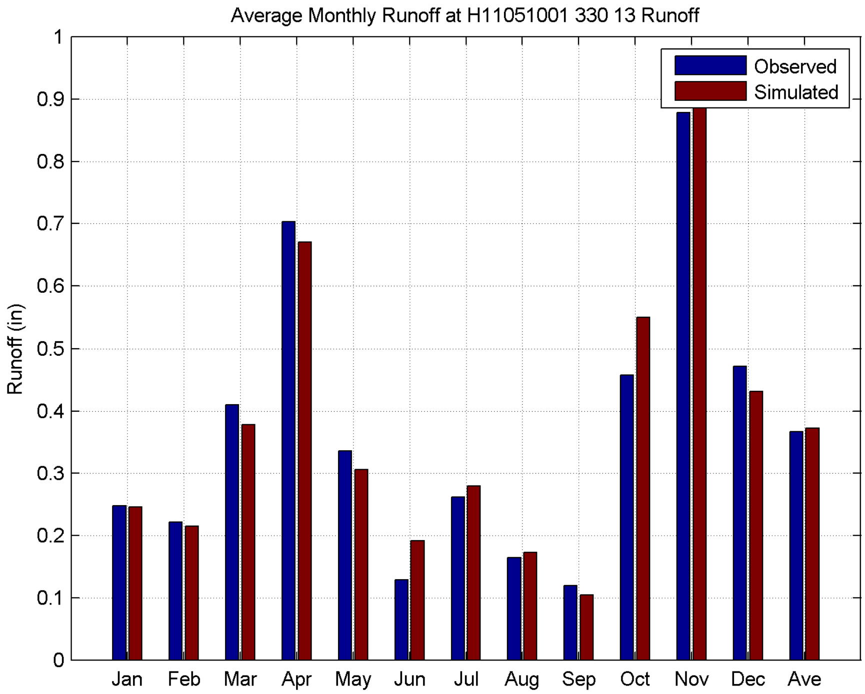

Figure C-2. Average Monthly Runoff at Reach 330.

RSI-2046-13-044

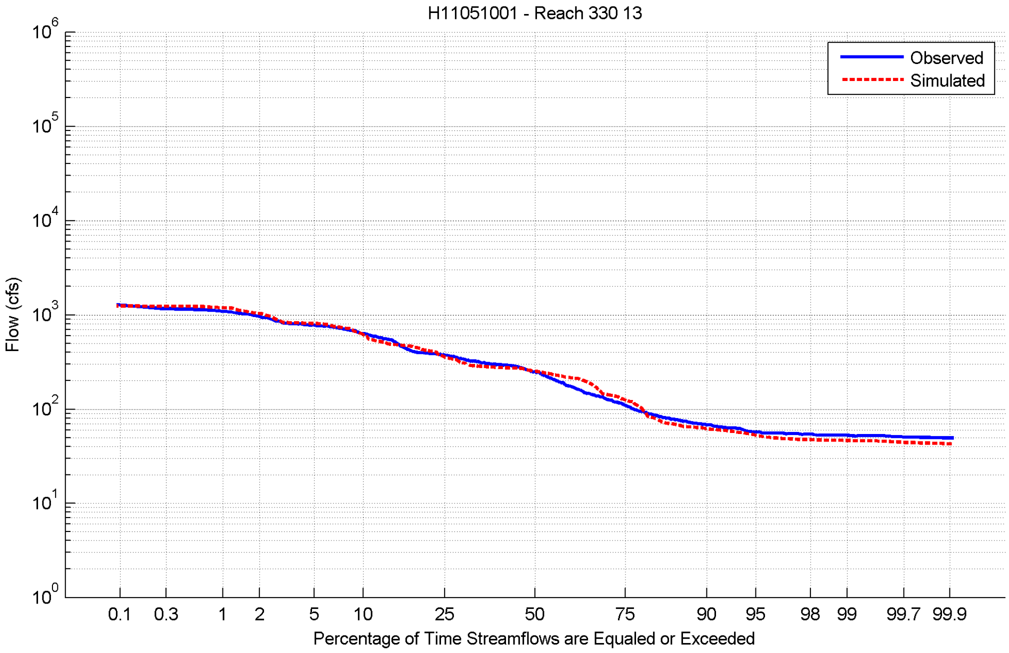

Figure C-3. Flow Duration Plot for Reach 330.

RSI-2046-13-045

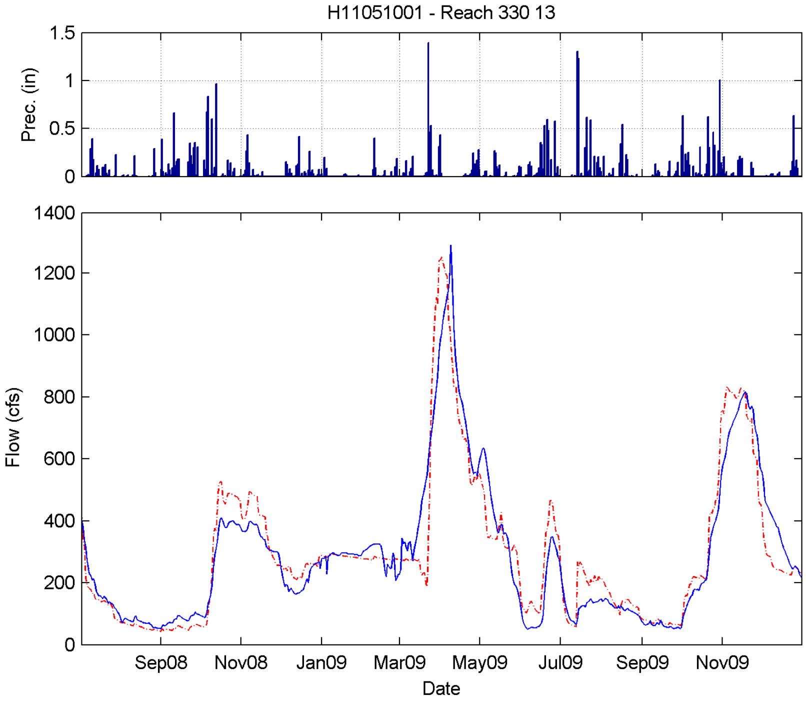

Figure C-4. Daily Hydrographs for Reach 330.

RSI-2046-13-046

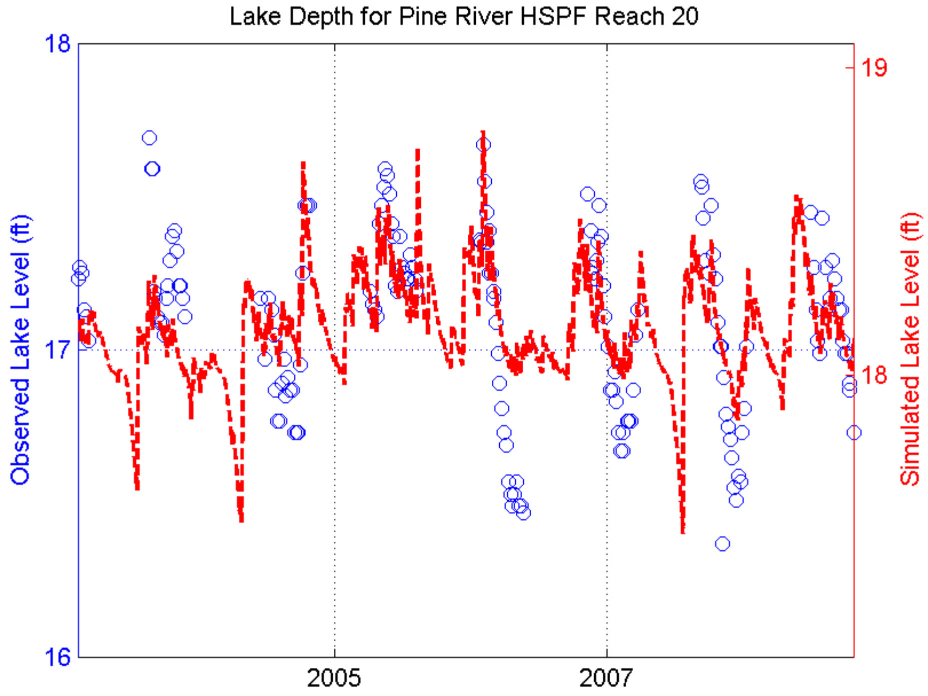

Figure C-5. Pine Mountain Lake Level Time Series.

RSI-2046-13-047

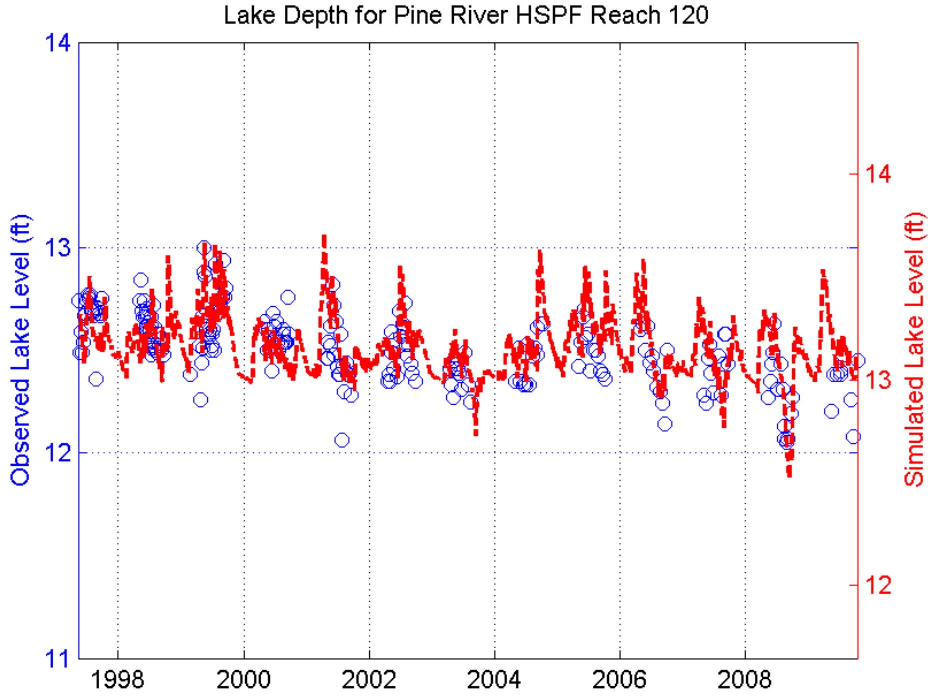

Figure C-6. Norway Lake Level Time Series.

RSI-2046-13-048

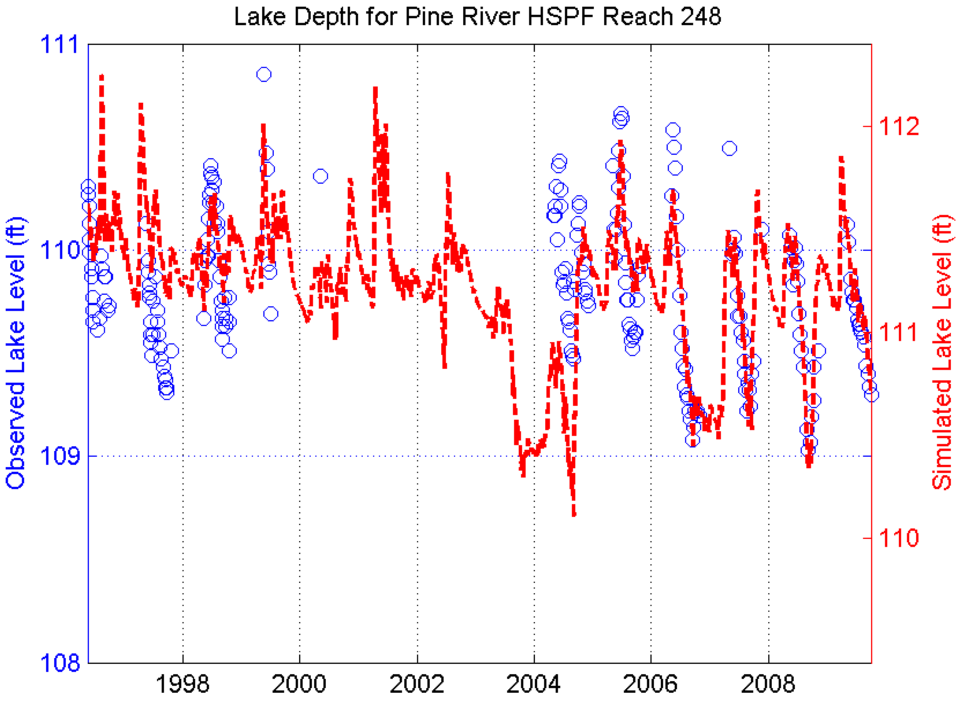

Figure C-7. Washburn Lake Level Time Series.

RSI-2046-13-049

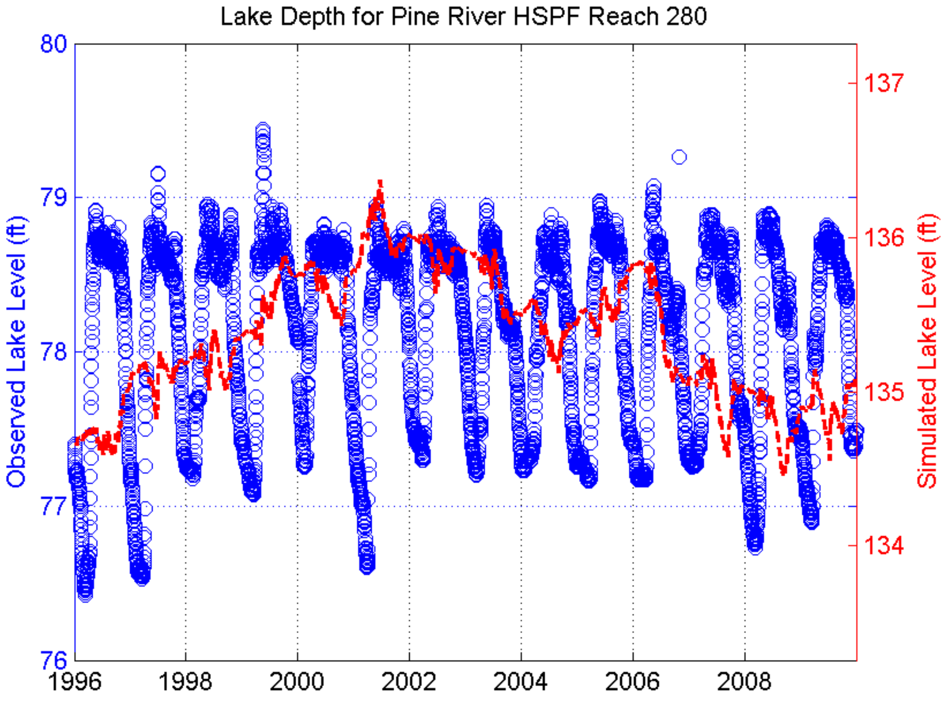

Figure C-8. Cross Lake Level Time Series.

RSI-2046-13-050

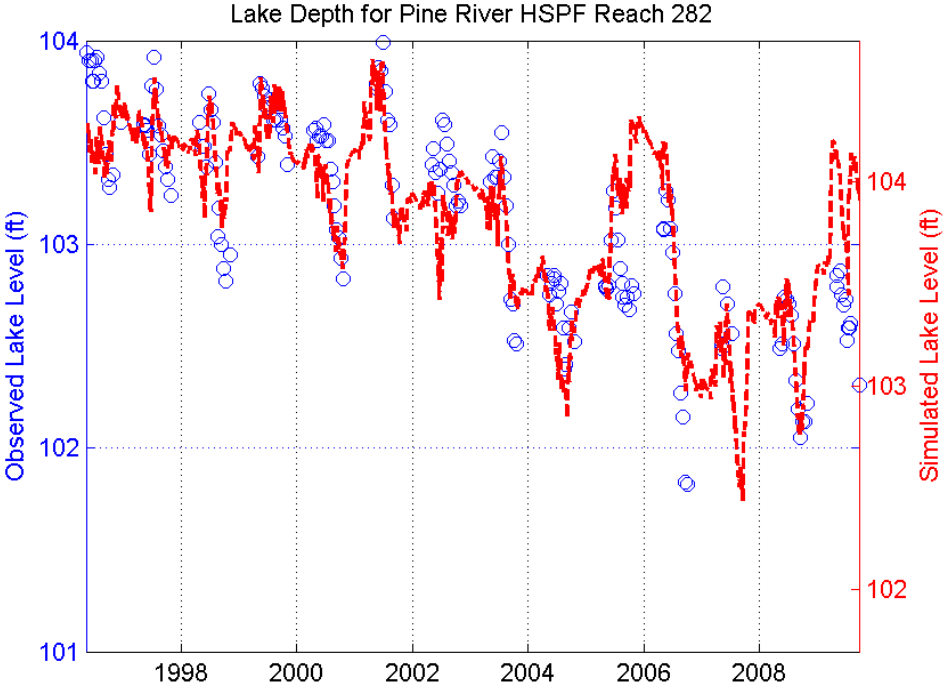

Figure C-9. Pelican Lake Level Time Series.

RSI-2046-13-051

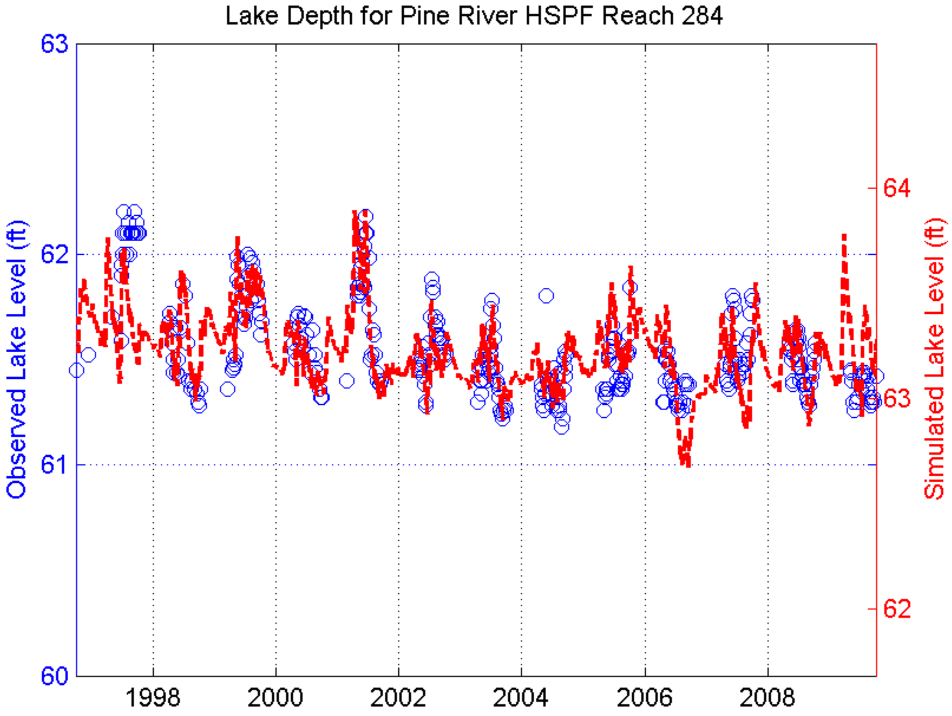

Figure C-10. Ossawinnamakee Lake Level Time Series.

RSI-2046-13-052

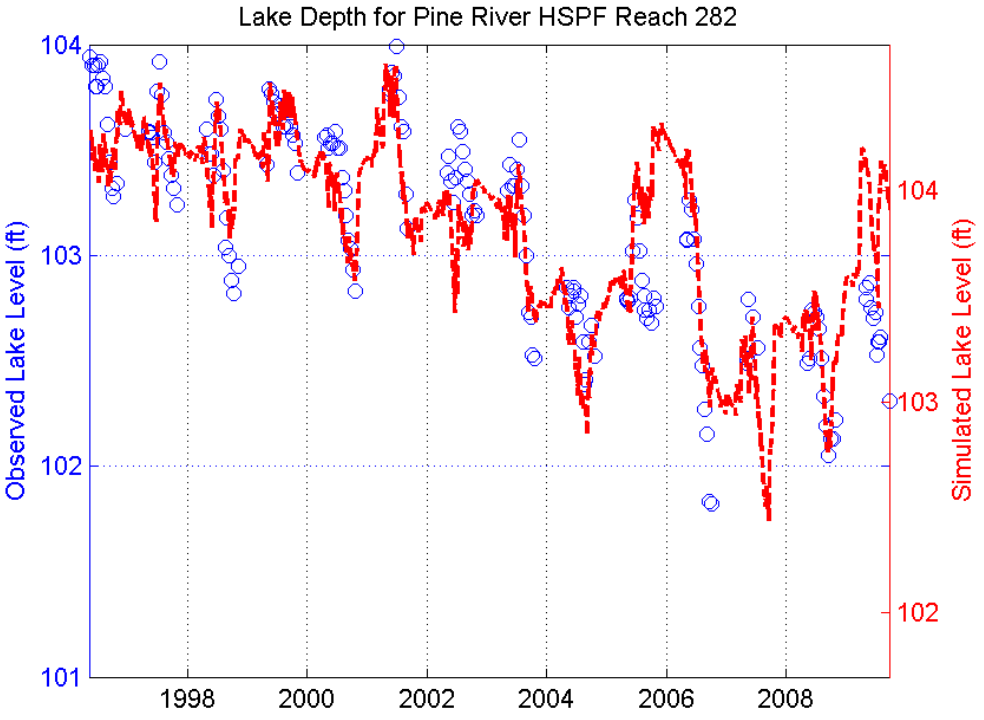

Figure C-11. George Lake Level Time Series.

RSI-2046-13-053

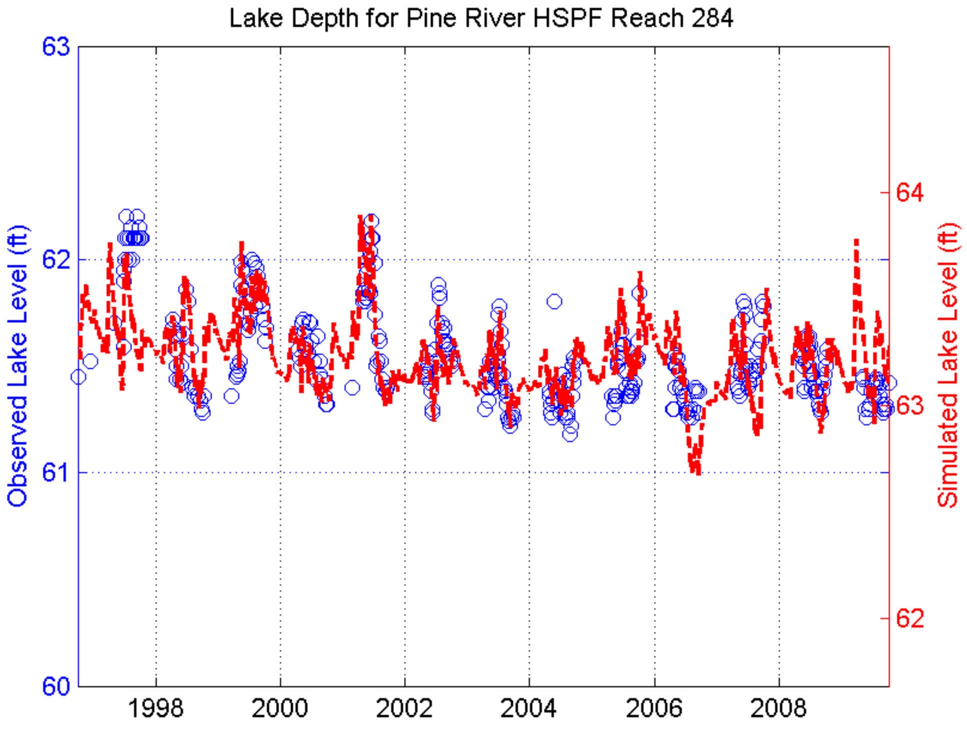

Figure C-12. Emily Lake Level Time Series.

RSI-2046-13-054

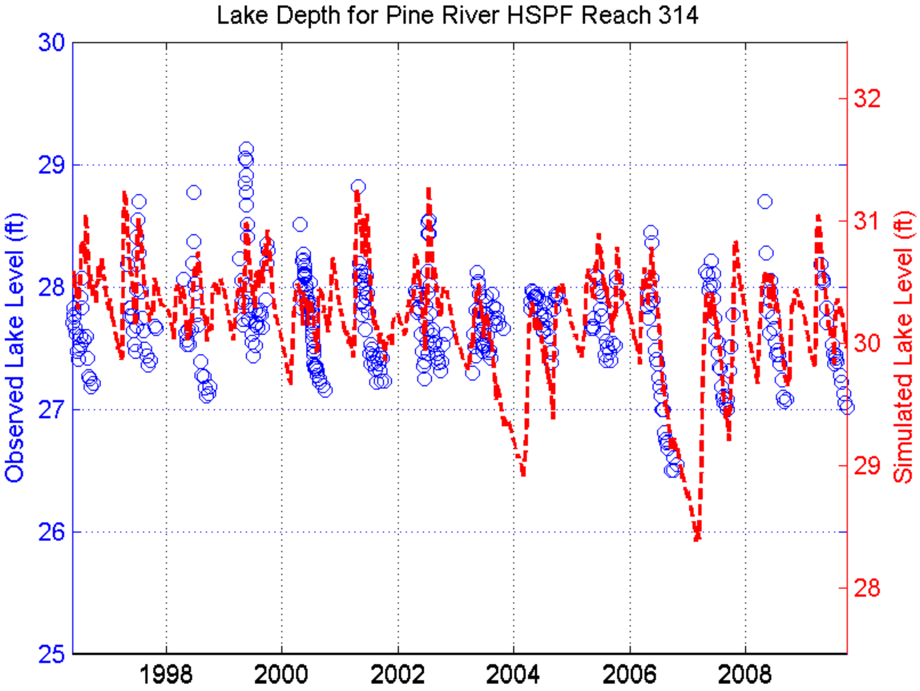

Figure C-13. Ross Lake Level Time Series.