Willowmoor Floodplain Restoration Project

Hydraulic Modeling

DRAFT Technical Memorandum

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1.0 INTRODUCTION

King County's Willowmoor Floodplain Restoration Project is a multi-objective flood control and habitat restoration project for the Sammamish River Transition Zone (TZ) and left bank floodplain area. The TZ extends from the Lake Sammamish outlet weir approximately 1,400 feet downstream through Marymoor Park. This hydraulic modeling technical memorandum is part of a body of work that will inform the Willowmoor Floodplain Restoration Preliminary Design and will serve as an appendix to the Preliminary Basis of Design Report (Figure 1). Hydraulic modeling is being used in this project to evaluate existing conditions, develop a baseline condition for alternative design, and test various alternative design configurations.

The basis for the project model is the HEC-RAS hydraulic model developed for the Sammamish River FEMA Flood Insurance Study (FIS) (NHC, 2010). This memo documents updates to the FIS model, model calibration to a range of flows and events from 2013 through 2018, and simulation of a baseline scenario representing conditions for water years 2001 through 2017.

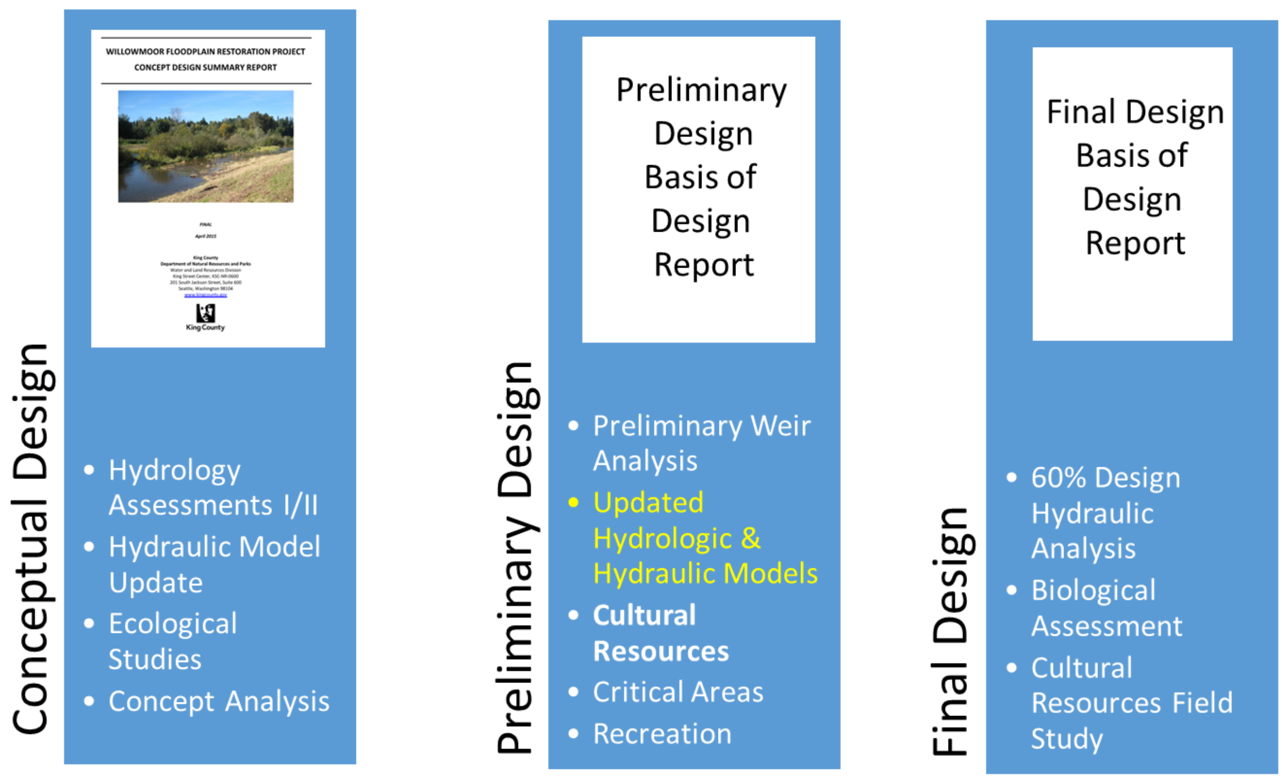


Figure 1. The hydraulic model as a component of the preliminary design.

2.0 MODEL DEVELOPMENT UPDATES

The Sammamish River Flood Insurance Study (FIS) model, a schematic of which is shown in Figure 2, was originally developed in HEC-RAS Version 4.0 (NHC, 2010). For this project, the model was updated to be compatible with the latest version of the HEC-RAS software (Version 5.0.5). The model was imported to Version 5.0.5, and results for the FIS scenarios (steady state simulations of 10-, 50-, 100-, and 500-year events and December 2001, January 2009, and March 1991 calibration events) were compared to the previous HEC-RAS Version 4.0 model. Simulated water surface elevations were within 0.03 feet of the FIS values, indicating no issues with the software update (that is, the relatively small difference in stage was attributed to changes in the software code).

Upon confirmation of consistency between software versions, channel cross-section data from Lake Sammamish downstream to Bear Creek, a distance of approximately 8,800 feet, were updated using the May 2018 bathymetric survey collected as part of this project. The weir geometry was left as is from the FIS model, as the 2018 survey data matched the weir crest elevations within 0.1 feet. The stage-volume curve used for Lake Sammamish was also reviewed and left unmodified from the FIS, as it is based on the best available information. Depending on location within the HEC-RAS model, simulated water surface elevations using the 2018 survey data were within +/- 0.1 feet of the FIS model results for the December 2001, January 2009, and March 1991 events. These are the same events for which the FIS model was calibrated.

Both the FIS model and the updated model for this project reference the North American Vertical Datum of 1988 (NAVD88), which is the current vertical standard and required by FEMA. Therefore, elevations in this document are reported in NAVD88. Elevation values can be converted to the older National Geodetic Vertical Datum of 1929 (NGVD29) by subtracting 3.57 feet in the area near the TZ (NHC, 2010).

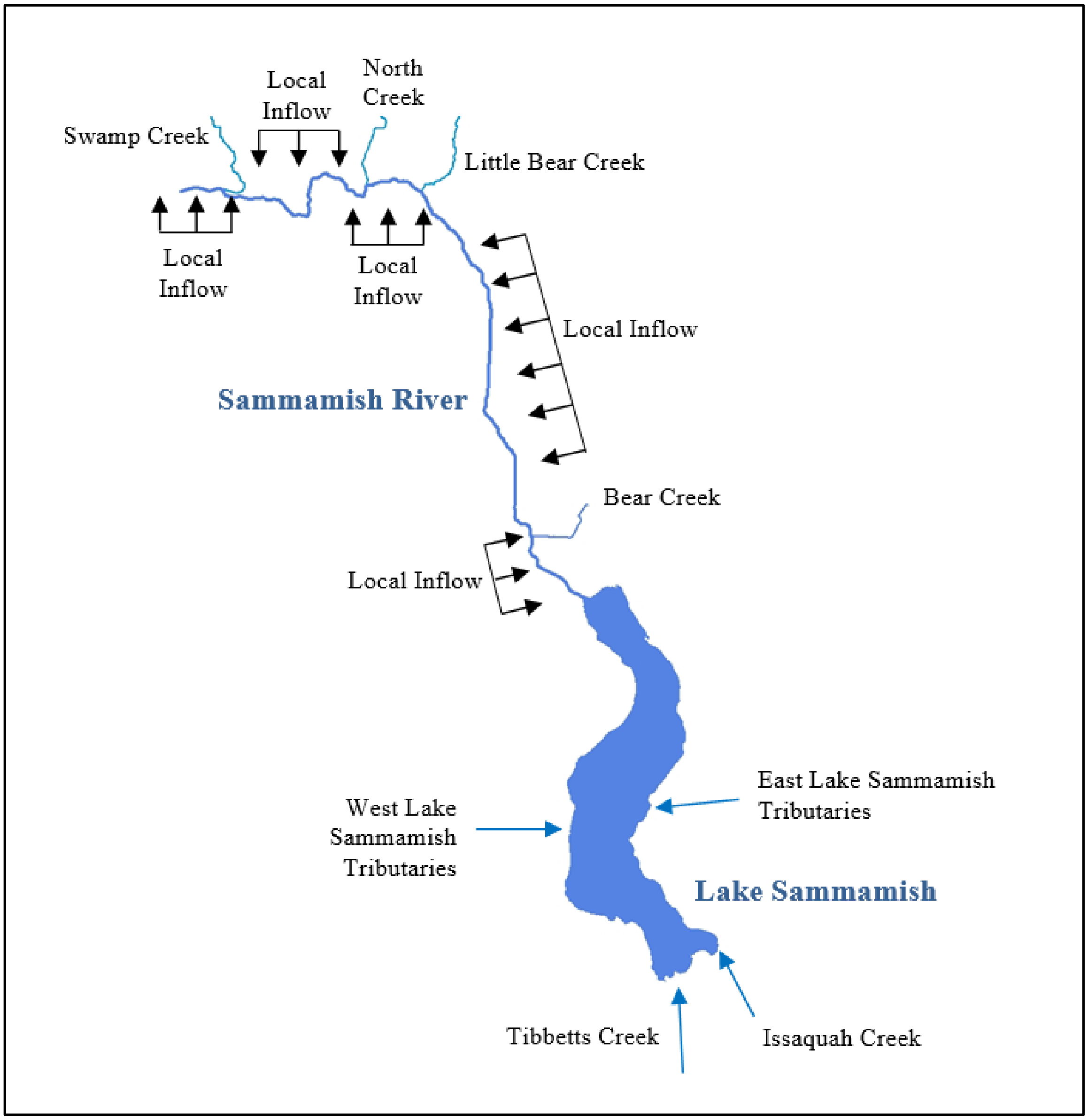


Figure 2. HEC-RAS model schematic with HSPF-model flow inputs.

3.0 MODEL CALIBRATION

The HEC-RAS model was calibrated to match observed water surface elevations at five gages from the Marymoor weir through the transition zone and downstream through the confluence with Bear Creek. In addition, King County gages at the weir, near 116th Street, and on Bear Creek were used to provide boundary condition data during some phases of calibration. Table 1 summarizes gage locations, as shown in, periods of record, and data used during the calibration simulations. Figure 3 maps the gages listed in this table.

Table 1. Gages used in the calibration.

Gage	System and River Mile	Location Description	Period of Record	How applied
51M	Sammamish 13.25	Just upstream of Sammamish Weir	7/18/2001 - Present	Flow specified at upstream boundary condition for simulations with gaged inflow and stage used for calibration for simulations with simulated HSPF inflow.
TZ1	Sammamish 13.23	Near upstream end of TZ, just downstream of Sammamish Weir	8/19/2011 - 10/30/2017	Used for calibration in the upper TZ.
TZ2	Sammamish 13.09	Near downstream end of TZ, approximately 650 feet downstream of the Sammamish Weir	8/19/2011 – 10/30/2017	Used for calibration in the lower TZ.
TZ3	Sammamish 12.34	Upstream of Bear Creek confluence, downstream of the SR 520 bridge	1/3/2011 – 10/30/2017	Used for calibration near Bear Creek confluence.
TZ4	Sammamish 12.26	Approximately 200 feet downstream of the Bear Creek confluence	4/21/2011 – 10/30/2017	Used for calibration near Bear Creek confluence.
51T	Sammamish 9.49	Near 116th St bridge (Former USGS gage #12125200)	2/1/1965 - Present	Stage used as downstream boundary condition
02A	Bear Creek 1.31	Near Union Hill Road bridge, downstream of Evans Creek Confluence	10/1/1987 - Present	Flow used for Bear Creek inflow for TZ characterization

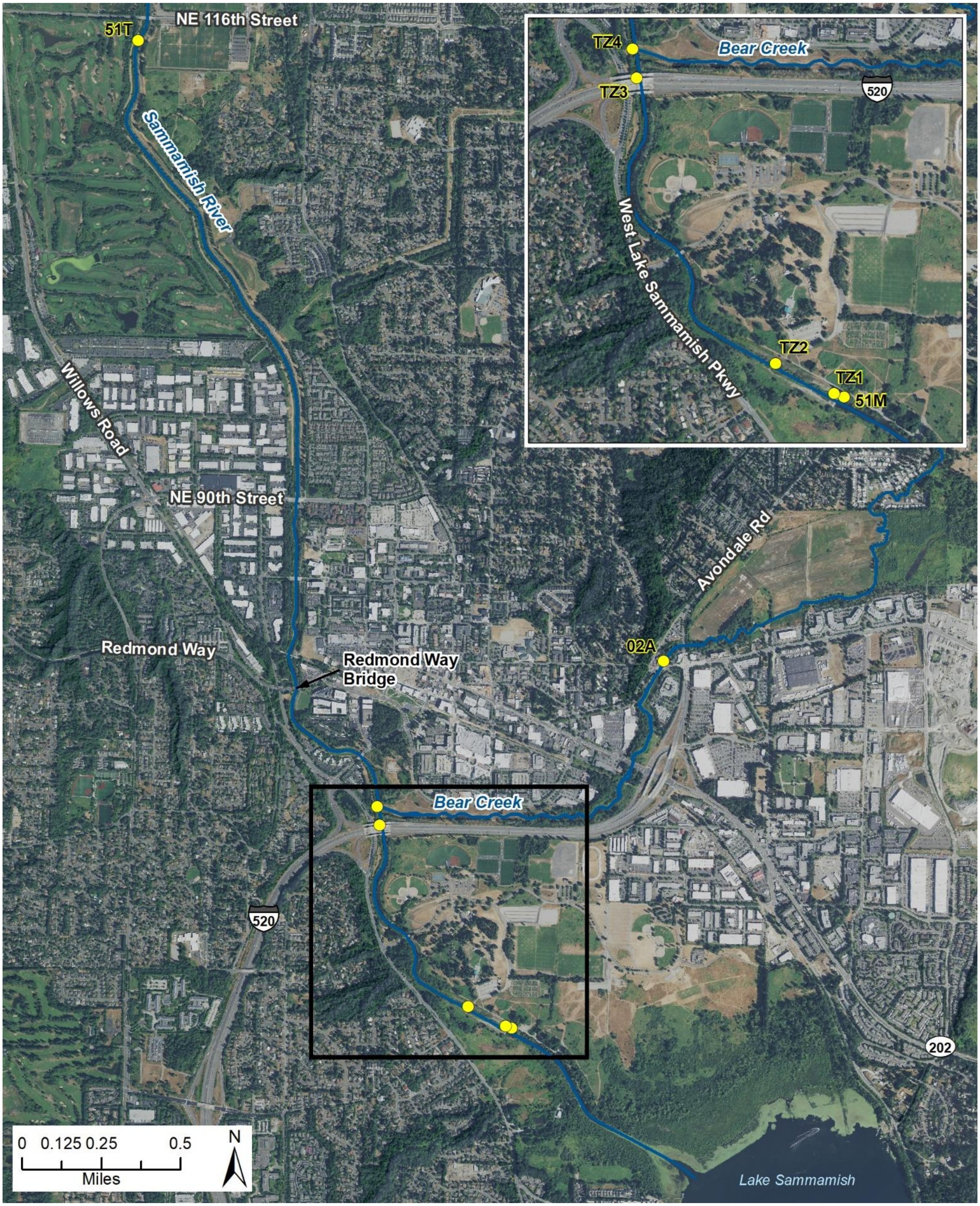


Figure 3. Location of Sammamish River gages used in the calibration.

Calibration focused primarily on matching three high peak flow periods—February/March 2014, November/December 2015, and February 2017 (Table 2)—where recorded data existed at gages 51M, and TZ1 through TZ4. Secondary consideration was given to matching simulated stage to surveyed May 2018 low flow water surface elevations and the observed stage hydrographs for water year 2014 through the end of water year 2017, a period of relatively consistent maintenance operations through the TZ. The calibration target was set to match simulated and observed peak water surface elevations to ±0.5 feet and general matching the stage hydrograph shape at the Marymoor Weir and the four observed TZ gages.

Table 2. Flow events used in calibration.

Date/year	Peak flow (cfs) at 51M	Peak flow (cfs) at 02A
May 2018	140 to 180*	32 to 76*
Feb. 2017	1,010	805
Nov./Dec. 2015	955	710
Feb./March 2014	940	505

**Range in flows recorded during low flow May 2018 survey in the TZ.*

The calibration process consisted of two steps 1) estimation of roughness parameters based on representing various vegetation conditions, first through the TZ and then from the TZ downstream to Bear Creek, to match the surveyed low flow condition and the selected three high flow events and then 2) refining the calibration of water surface elevations from the weir through Bear Creek for an approximately four-year calibration period from water year 2014 through water year 2017. The assumptions and model adjustments associated with each of these steps are discussed in Sections 3.1 and 3.2, respectively, and final calibration results are presented in Section 3.3.

3.1 Estimation of Roughness Using Truncated Model Domain

Changes to the discharge rating curve for the Marymoor weir gage (51M) over time clearly demonstrate the effect of variable vegetation and maintenance conditions through the TZ on flows and water levels. In the HEC-RAS model, these conditions are represented by the hydraulic roughness parameter, or Manning's 'n' value. To represent a full range of flow and vegetation conditions, as needed to assess the effects of the proposed restoration project, a much more complex representation of hydraulic roughness is required in this model. As an initial calibration step, the model domain was truncated to allow observed data to be applied as boundary conditions, effectively isolating the river hydraulics and eliminating the uncertainty of simulated hydrologic inputs used for full model simulations. The downstream extent of the model was cut off near the NE 116th Street bridge, where the stage record for gage 51T was applied as the downstream boundary condition. The Lake Sammamish storage area was also removed and the weir flow record (from gage 51M) was applied as the upstream boundary condition. Observed Bear Creek flow (gage 02A) was also applied as a model inflow. For this scenario, the only simulated flow inputs were for lateral inflows representing the relatively minor local (ungaged) drainage to the Sammamish River. These local inflows make up only 4 percent of the total inflow to the reach (evaluated from water year 2002 through water year 2017), whereas Lake Sammamish outflows make up approximately 81 percent and Bear Creek accounts for 15 percent of the total volume.

A rough calibration was achieved from the Marymoor Weir through the TZ, as discussed in Section 3.1.1, by defining both vertical and horizontal variations in Manning's 'n' values, similar to the FIS modeling approach (NHC, 2010), and by scaling Manning's 'n' values based on both flow and seasonality between the TZ and the 116th Street bridge, as discussed in Section 3.1.2. This was an iterative process, shifting between adjustments to the two main sections, Marymoor Weir through the TZ and TZ to Bear Creek confluence sections.

3.1.1 Marymoor Weir through TZ

The TZ roughness characterization first focused on setting Manning's 'n' values to match low flow channel water surface elevations, surveyed during May 2018 low flow conditions. Figure 4 shows the location of the low flow channel within the TZ. As the May 2018 flow was essentially contained within the low flow channel, this event was used to set the main channel Manning's 'n' value at a low elevation.

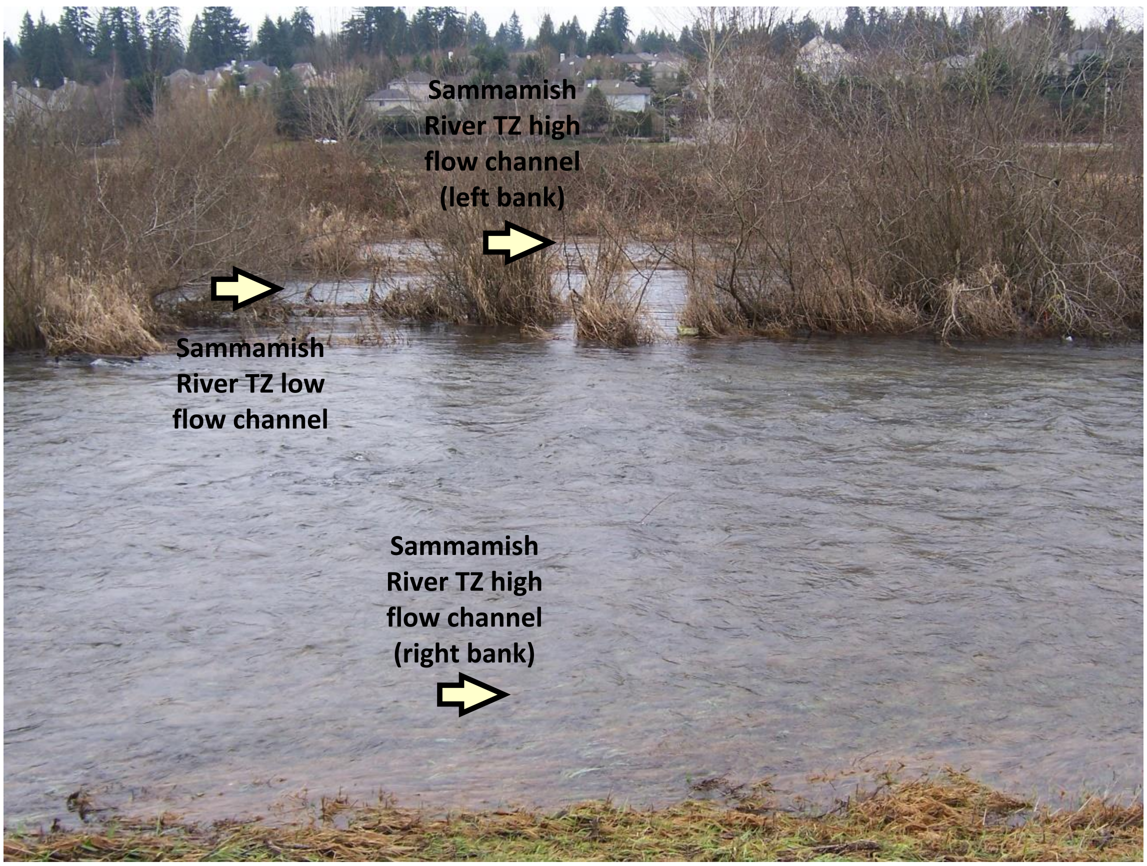
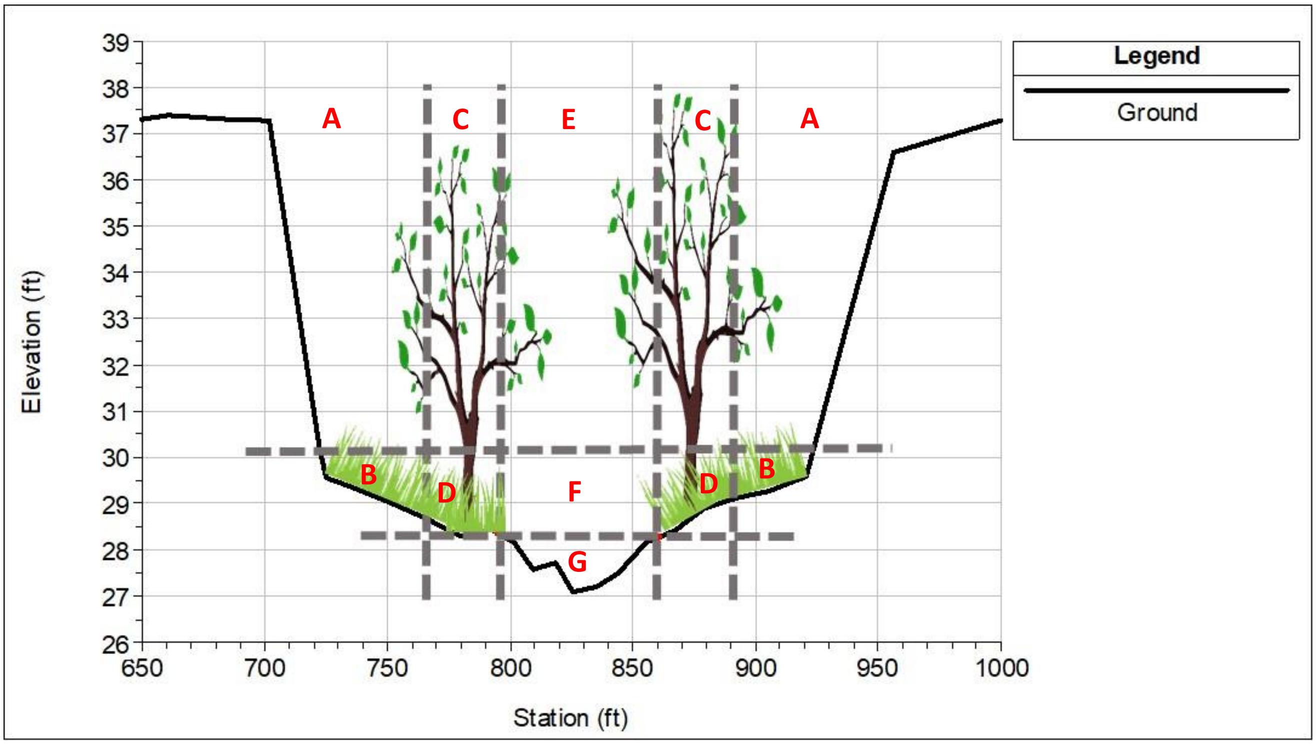


Figure 4. Looking west toward the Sammamish River TZ on January 16, 2009 (flow is approximately 600 cfs at 51M).

The February/March 2014, November/December 2015, and February 2017 events were then used to set horizontal and vertical roughness coefficient values at elevations above the low flow channel, and in both overbank high flow channels, focusing on matching stage for the range of flows at the 51M, TZ1, and TZ2 gages. Figure 5 shows a representative TZ channel, with grey dash lines showing where breaks in horizontal and vertical Manning's 'n' were varied based on channel geometry and vegetation within individual cross-sections (representative Manning's 'n' values are provided in the key). In the grass lined overbank high flow channels, there is denser vegetation near the ground surface, and therefore higher Manning's 'n' value at lower elevation compared to higher elevations. Manning's 'n' for where the willow trees are located, has a much higher 'n' than the rest of the channel due to the vegetation blocking flow. The 'n' value for the low flow channel was set to a relatively high 'n' value for depths around 1 foot, based on matching the surveyed water surface elevation where bed features have a larger effect on channel roughness, transitioning to a lower 'n' value (due to less roughness) at a higher elevation. As the simulation results began to match observed data at TZ1 and TZ2, focus shifted to the downstream reach between the TZ and Bear Creek, at gages TZ3 and TZ4.



Key:

A = High flow channel with lower 'n' value due to the lack of grasses ('n' = 0.03).

B = High flow channel with dense grasses and higher 'n' value ('n' = varied from 0.20 at bottom to 0.03 at top).

C = Very high 'n' value due to presence of willow trees ('n' = 0.12).

D = Highest 'n' value due to willow trees and dense grasses in this portion of high flow channel ('n' = varied from 0.25 at bottom to 0.12 at top).

E = Low flow channel at higher elevation with slightly higher 'n' value than in high flow channel, at same elevation, due to some overhanging willow branches ('n' = 0.04).

F = Low flow channel transitioning from lower 'n' at higher elevation to higher 'n' at lower elevation ('n' = varied from 0.12 at bottom to 0.04 at top).

G = Low flow channel where depths are shallow and bed forms have a greater affect on roughness and thus a higher 'n' value ('n' = 0.12).

Figure 5. Schematic of typical cross-section for varying TZ horizontal and vertical roughness zones.

3.1.2 Downstream of the TZ to Bear Creek

Manning's 'n' values were modified both seasonally and with flow uniformly from the TZ downstream to the 116th Street bridge. Between the TZ and Bear Creek, when using only main channel and overbank 'n' values, as was applied in the FIS, simulations underpredicted stage during both low flow conditions, especially from approximately June through December, and during peak flow conditions, as compared to recorded TZ3 and TZ4 stage data.

To adjust the model to lower flows, through consultation with King County, Manning's 'n' values were varied through the use of "seasonality factors". This is an option within HEC-RAS that enables the user to apply a factor by which roughness coefficients are multiplied and which changes by time of year. The seasonal variation was set to approximate the seasonal growth cycle of aquatic vegetation (elodea) that develops dense growth mats and "occupies most of the river channel from the weir at Marymoor Park downstream for about seven miles" (King County, 2013), extending several feet deep within the channel (Figure 6) and thus significantly increasing the channel roughness. Seasonal multipliers ranged from 1.2 to 4.0 to match recorded stage at TZ3 and TZ4. Application of the seasonal multipliers can create high 'n' values (up to 0.12) during the summer low flow months, and observed conditions tend to support such Manning's 'n' values.

Figure 6. Elodea grows in thick mats through much of the Sammamish River (King County, 2013).

To match the peak stage hydrographs, Manning's 'n' was increased linearly by a factor (referred to as the flow factor) of 1 to 1.3 for flows from 500 to 1,000 cfs. This is based on the assumption that overhanging vegetation, such as blackberries, willows, etc., does not affect lower flows but increases roughness at higher flows when the

rising water level comes into contact with the vegetation. A constant factor of 1.3 was applied to flows above 1,000 cfs. When used in combination with seasonal factors, constant flow factors are applied first and seasonal factors are applied last when computing the resultant roughness coefficients.

The flow factor was used in the calibration to increase roughness at the higher stage and flows. Since the seasonality factor, used to adjust for monthly changes in elodea density, is also applied, certain combinations of seasons and flows could produce an unrealistically large in-channel Manning's 'n' value for high flows during the summer months (for example, 0.156 for August = 0.03 *1.3 flow factor* 4.0 seasonality factor) (Table 3). However, since flows during the summer are low, this did not affect model performance. The Manning's 'n' value during the fall and winter is more reasonable because the seasonal factor during these months is lower. Table 3 shows the final main channel Manning's 'n' values used in the calibration effort. Overbank 'n' values were scaled in the same way, though their effect on the simulated water surface elevation is minimal (see Section 5.0) and ranged from 0.045 to 0.25 from the TZ down to Bear Creek. This combination of seasonal and flow factors appeared to generally replicate observed conditions to within the targeted criteria of ±0.5 feet. In consultation with King County, this was decided to be the most reasonable calibration approach for the TZ downstream to the Bear Creek confluence.

Table 3. Seasonal and flow scaling factors and resulting Manning's 'n' values downstream of the TZ.

Month	Seasonality Factor	Main Channel 'n' with Seasonal and Flow Factor	
		When flows < 500 cfs	When flows > 1,000 cfs
Jan	1.5	0.045	0.059
Feb	1.3	0.039	0.051
Mar	1.2	0.036	0.047
Apr	1.2	0.036	0.047
May	1.5	0.045	0.059
Jun	2.5	0.075	0.098*
Jul	4.0	0.120	0.156*
Aug	4.0	0.120	0.156*
Sep	4.0	0.120	0.156*
Oct	3.0	0.090	0.117*
Nov	1.5	0.045	0.059
Dec	1.5	0.045	0.059

******HEC-RAS would apply an unrealistically high 'n' value should flows get above 1,000 cfs during these months.*

3.2 Calibration Using Completed FIS Model Domain with HSPF Simulated Inflow

A consequence of fixing the flow at the upstream boundary condition to the observed record is that it limits the ability of the model to dynamically simulate the Bear Creek backwater effect, which is accounted for in the gage rating curve as a fixed function of Bear Creek flow. Thus, events where Bear Creek flows significantly exceed Sammamish River flow (on the order of hundreds of cfs) and creates a backwater effect on the Sammamish River —for example, December 2015, when Bear Creek peaked near 700 cfs corresponding with a pre-peak Sammamish River flow of near 500 cfs—did not match as well as those with lower and moderate Bear Creek flows when using gaged Sammamish River inflow. Adding the Lake Sammamish storage area with HSPF-simulated lake inflows allows the flow at the weir to be computed dynamically and better simulates the backwater effect. Incorporation of the lake and dynamic weir simulation also allows for evaluation of scenarios that affect lake inflows or lake levels compared to historic conditions.

For these runs, the model geometry was extended back up through Lake Sammamish and downstream to Lake Washington (using the model geometry from the FIS model for the added reaches), and HSPF-simulated inflows were applied to Lake Sammamish and throughout the project reach (including Bear Creek), for the water year 2014 to water year 2017 calibration period. The entire period from water year 2014 through water year 2017 was reviewed, and slight modifications to Manning's 'n' values, including the seasonality and flow factors, were made during this final calibration scenario to improve simulation results for all events. A weir coefficient of 2.5 for determining model flow over the Marymoor Weir and resulting upstream stage (when using the weir flow equation in HEC-RAS, only a non-varying weir coefficient is allowed) was chosen to best represent a range of conditions (see Section 5.0 for how upstream stage varies by changing the weir coefficient value).

3.3 Calibration Results

Plots comparing simulated and observed conditions for the final calibration using HSPF simulated inflows for the May 2018 low flow survey and three high flow calibration periods are shown in Figure 7 through Figure 22. Due to the number of figures in this section, all figures are included following the calibration discussion. The Y-axis (elevation) scales were chosen to maintain consistency between plots with similar data.

Observed water surface elevations were surveyed in addition to the channel bathymetry over a two-week period in May 2018. Simulated water surface profiles were simulated for May 10, 14, and 16, 2018, corresponding with the dates of surveyed TZ water surface elevations. Each of these simulated profiles are shown (as different color lines) in Figure 7. Flows during these days, as measured at gage 51M, were 180, 150, and 140 cfs, on May 10, 14, and 16, respectively. When comparing the surveyed water surface elevations to the same simulated day and location in the TZ, all simulated water surface values were within 0.3 feet of the observed data.

The February/March 2014, November/December 2015, and February 2017 high flow calibration results are summarized in Table 4 and displayed in Figure 8 through Figure 22, with the simulated HEC-RAS stage compared to recorded gage values. Table 4 shows that simulated peak flows at the Marymoor weir are within 10% for all three events, and peak stage values are within 0.5 feet at all four TZ gages. As seen in the figures, simulated results consistently match the timing of observed rising and falling stage. Calibration focused on matching both peaks and low flow stage for the calibration period, and for these periods simulated results typically match

observed stage elevation within half a foot or less, though occasionally deviate by one foot or more, when compared to the four TZ gages and gage 51M at the Marymoor Weir.

Table 4. Calibration results for peak water surface elevation and peak flow.

Gage	Type	Calibration Event								
		Feb/March 2014			Nov/Dec 2015			Feb 2017		
		Obs	Sim	Diff	Obs	Sim	Diff	Obs	Sim	Diff
51M	Stage (ft)	31.8	31.4	-0.4	32.1	32.1	0.0	31.7	31.6	-0.1
	Flow (cfs)	940	955	15	955	933	-22	1010	930	-80
TZ1	Stage (ft)	31.4	31.2	-0.2	31.8	32.1	0.3	31.2	31.6	0.4
TZ2	Stage (ft)	31.1	31.0	-0.1	31.6	32.0	0.4	31.1	31.5	0.4
TZ3	Stage (ft)	30.8	30.6	-0.2	31.5	31.6	0.1	31.1	31.5	0.4
TZ4	Stage (ft)	30.7	30.4	-0.3	31.4	31.5	0.1	30.8	31.3	0.5

In addition to the selected calibration events, the model is well-calibrated to water surface elevations over the full calibration period, encompassing water years 2014 through 2017. Figure 23 through Figure 32 show how the simulated results generally match the rising and falling stage of the observed data at all five calibration sites during this period (blue lines are observed data, red lines are simulated data, and the vertical range is set the to be the same in these charts). Figure 33 shows histograms of the difference between simulated and observed water levels for the full hourly data set over the calibration period. Table 5 shows the 95th, 75th, 50th, 25th and 5th percentile values for differences in simulated and observed water levels at the five gaged sites used in the calibration.

Table 5. 95th through 5th percentile values of simulated minus observed stage for the five calibration sites for water year 2014 through water year 2017.

Date/year	51M	TZ1	TZ2	TZ3	TZ4
95th Percentile	0.1	0.2	0.6	0.7	0.7
75th Percentile	0.0	0.0	0.0	0.1	0.1
50th Percentile	-0.1	-0.1	-0.1	-0.2	-0.2
25th Percentile	-0.1	-0.1	-0.2	-0.6	-0.6
5th Percentile	-0.2	-0.3	-0.6	-1.3	-1.3

The calibration results show a good match between observed and simulated conditions in the project area, including the Marymoor Weir (51M) and the upstream and downstream ends of the TZ (TZ1 and TZ2, respectively), with nearly all values being with a few tenths of feet at both 51M and TZ1, and within 0.6 feet for TZ2, for water years 2014 through 2017. There is greater variation downstream of the project area, as evaluated at TZ3 and TZ4, compared to upstream through the project area. At low flows, simulated water levels at 51M, TZ1 and TZ2 show a relatively good match to observed, whereas at TZ3 and TZ4, the model generally underpredicts observed stage for water years 2014 through 2017.

Much of the variation at TZ3 and TZ4 is due to data prior to January 1, 2015 (seen in Figure 29 and Figure 31). Though this was not investigated further, by removing these data from the analysis that the range of differences is reduced, with nearly all simulated values falling within a foot of observed data, and there is also less of a bias to underpredict stage as seen with the 50th percentiles shifting to -0.1 feet from -0.2 feet at both gages TZ3 and TZ4 (Table 6 and Figure 34). Results upstream at 51M, TZ1, and TZ2 for the same abbreviated period remain essentially unchanged. During storm events, the difference at TZ3 and TZ4 may also be due in part to the influence of simulated Bear Creek inflows. The HSPF model, used to produce input to the hydraulic model, tends to produce spikier flow hydrographs than observed during large events (NHC, 2018), leading to simulated higher and shorter-duration stage peaks. This is seen in the stage hydrograph plots with higher peak simulated stage at several time periods, which leads to higher stage at TZ3 and TZ4.

Table 6. 95th through 5th percentile values of simulated minus observed stage for the five calibration sites for January 1, 2015 through water year 2017.

Date/year	51M	TZ1	TZ2	TZ3	TZ4
95th Percentile	0.1	0.2	0.6	0.8	0.8
75th Percentile	0.0	0.0	0.0	0.2	0.3
50th Percentile	-0.1	-0.1	-0.2	-0.1	-0.1
25th Percentile	-0.1	-0.2	-0.2	-0.4	-0.3
5th Percentile	-0.2	-0.3	-0.5	-0.9	-0.9

The model developed in this effort is better calibrated than previous models over a greater range of flows and seasonal conditions and hence provides a more accurate depiction of existing hydraulic conditions under the current TZ maintenance regime. Thus, it will be a credible tool for predicting the performance of alternative weir and channel configurations during the alternatives analysis phase. Based on the simulated peak flows for the three selected events, the HEC-RAS model matches Marymoor peak flows within 10% at the Marymoor weir. At the weir and through the TZ (as evaluated at gages TZ1 and TZ2 at the upstream and downstream end of the TZ, respectively) peak stage is within 0.5 feet. In addition, nearly all simulated hourly values are within 0.6 feet of observed stage over the four-year calibration period at gages 51M, TZ1 and TZ2. From the TZ downstream to Bear Creek, the HEC-RAS simulation also generally follows the trend of the observed hydrographs at TZ3 and TZ4. At TZ3 and TZ4, like the upstream TZ section, the simulated peak stage matched observed within 0.5 feet; however, when evaluating over the full calibration period, the simulated stage has a wider deviation from observed. Much of this difference is attributed to differences leading up to approximately December 2014, after which the simulation ability to match observed improves significantly such that differences between the model results and observed data are nearly all within 1 foot as measured at gages TZ3 and TZ4.

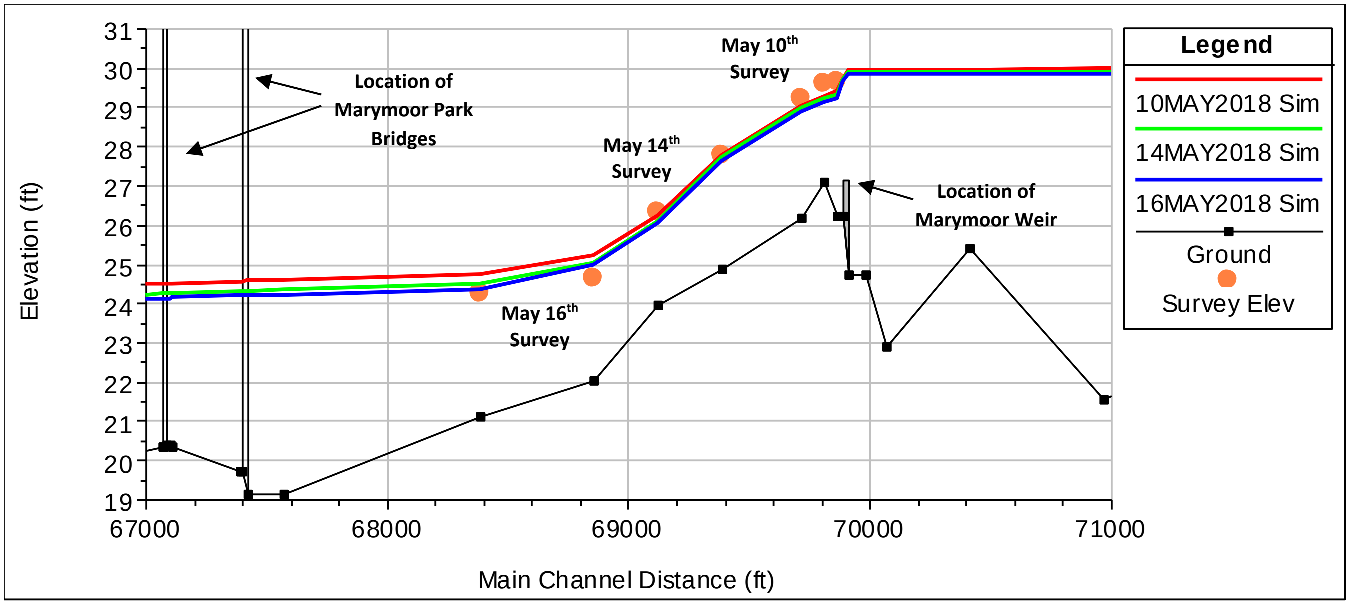


Figure 7. Comparison of simulated water surface profiles to surveyed water surface elevations during May 10th, 14th, and 16th, 2018 with flows of 180, 150, and 140 cfs, respectively, at 51M.

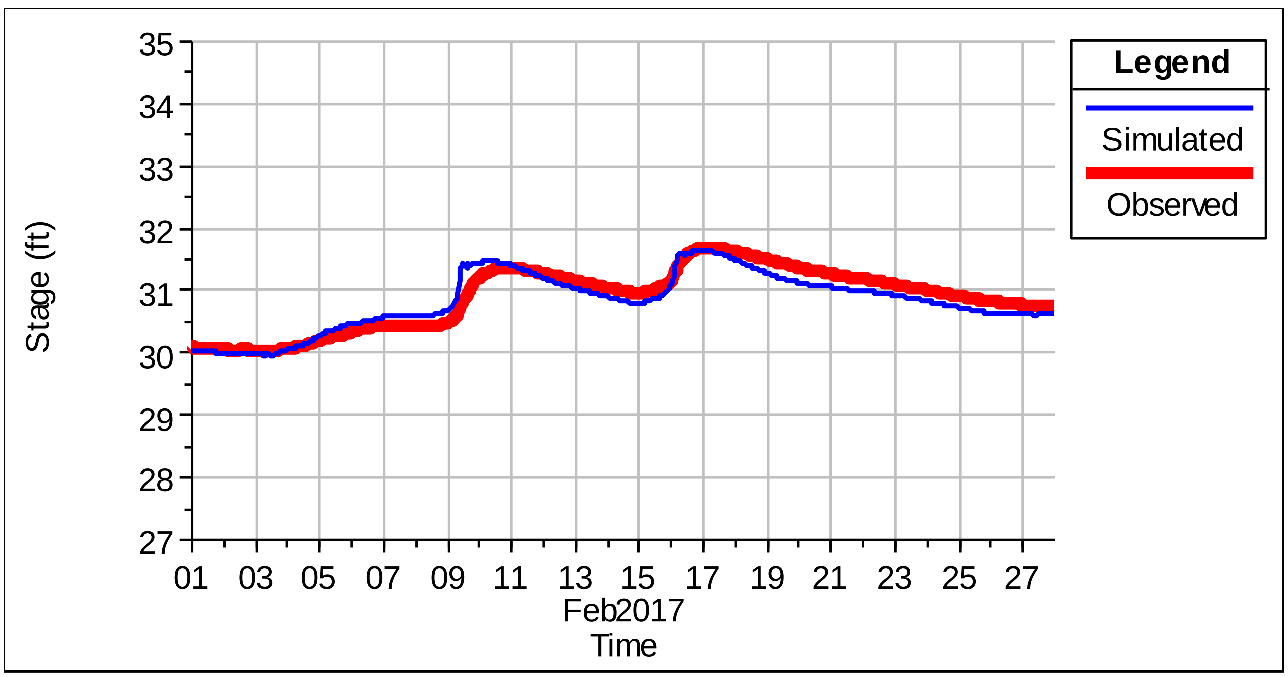


Figure 8. Comparison at Sammamish Weir (gage 51M) of February 2017 observed to simulated stage (NAVD88).

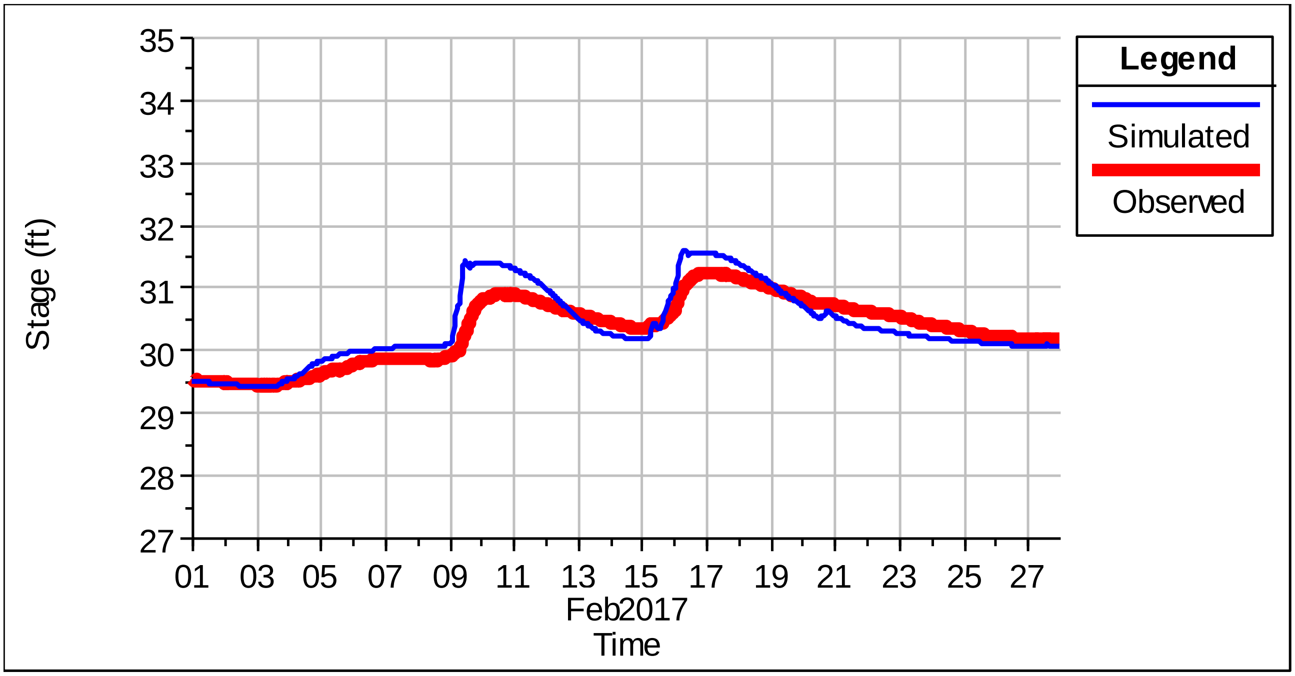


Figure 9. Comparison at King County gage TZ1 of February 2017 observed to simulated stage (NAVD88).

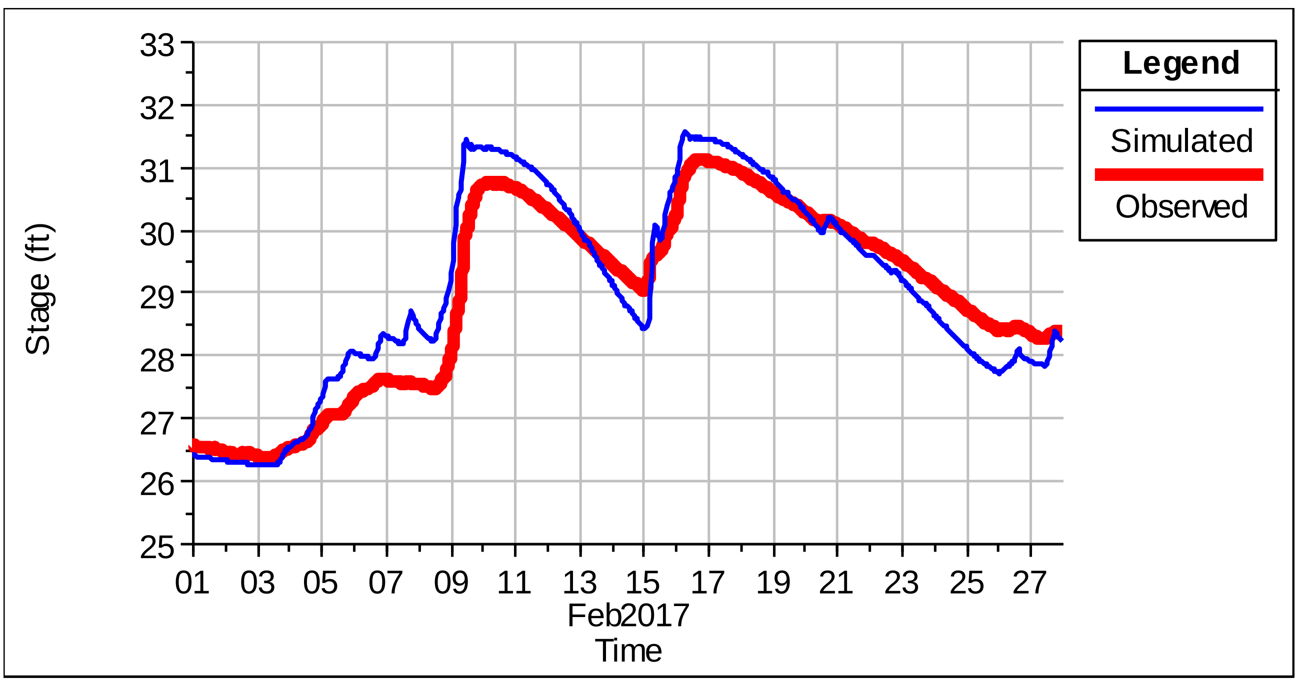


Figure 10. Comparison at King County gage TZ2 of February 2017 observed to simulated stage (NAVD88).

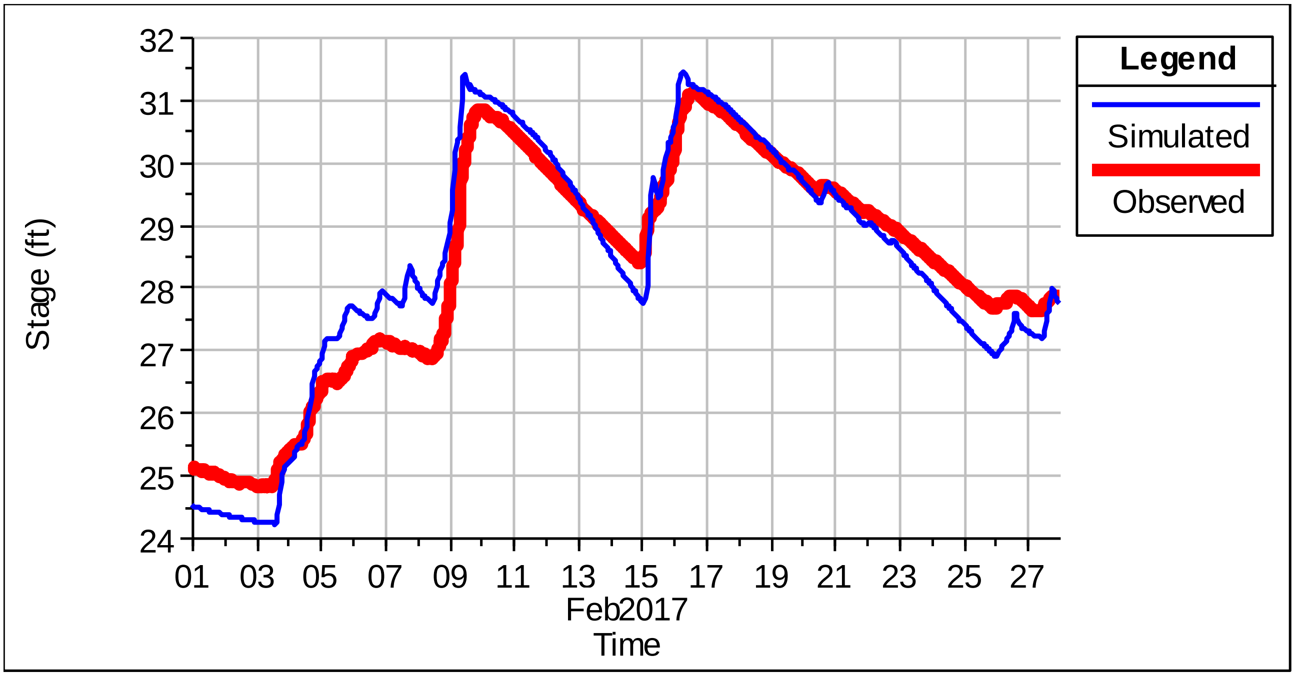


Figure 11. Comparison at King County gage TZ3 of February 2017 observed to simulated stage (NAVD88).

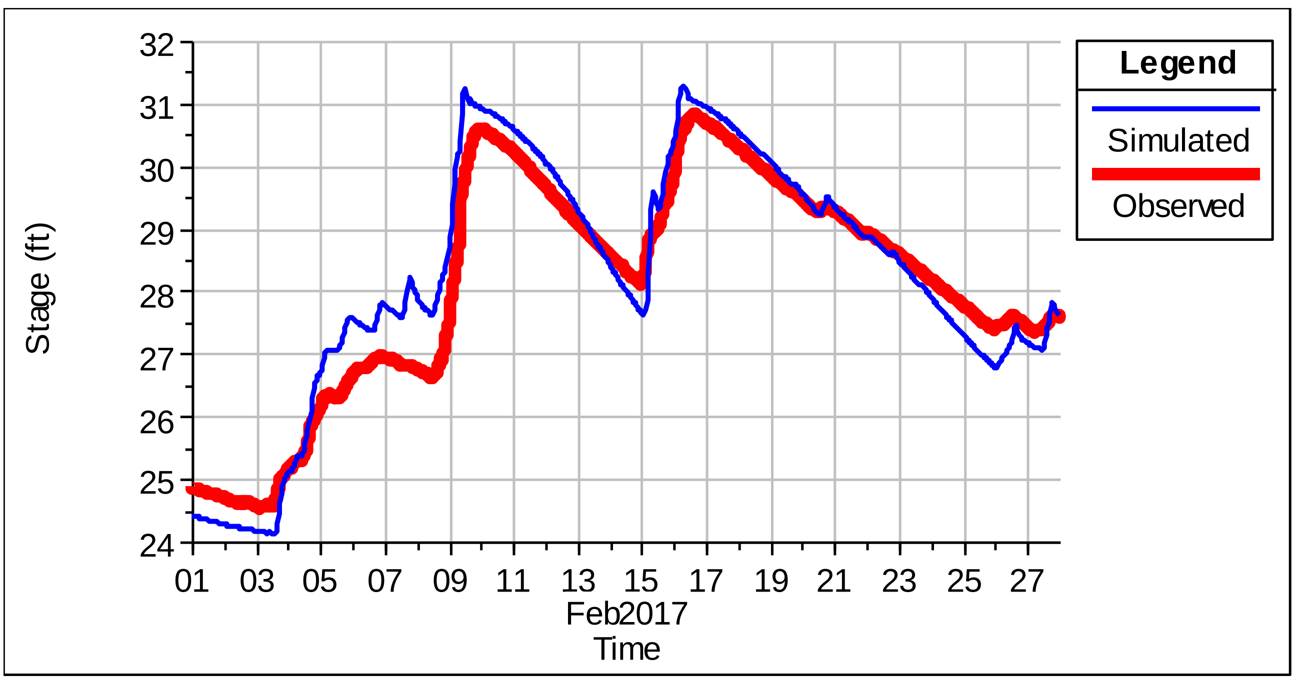


Figure 12. Comparison at King County gage TZ4 of February 2017 observed to simulated stage (NAVD88).

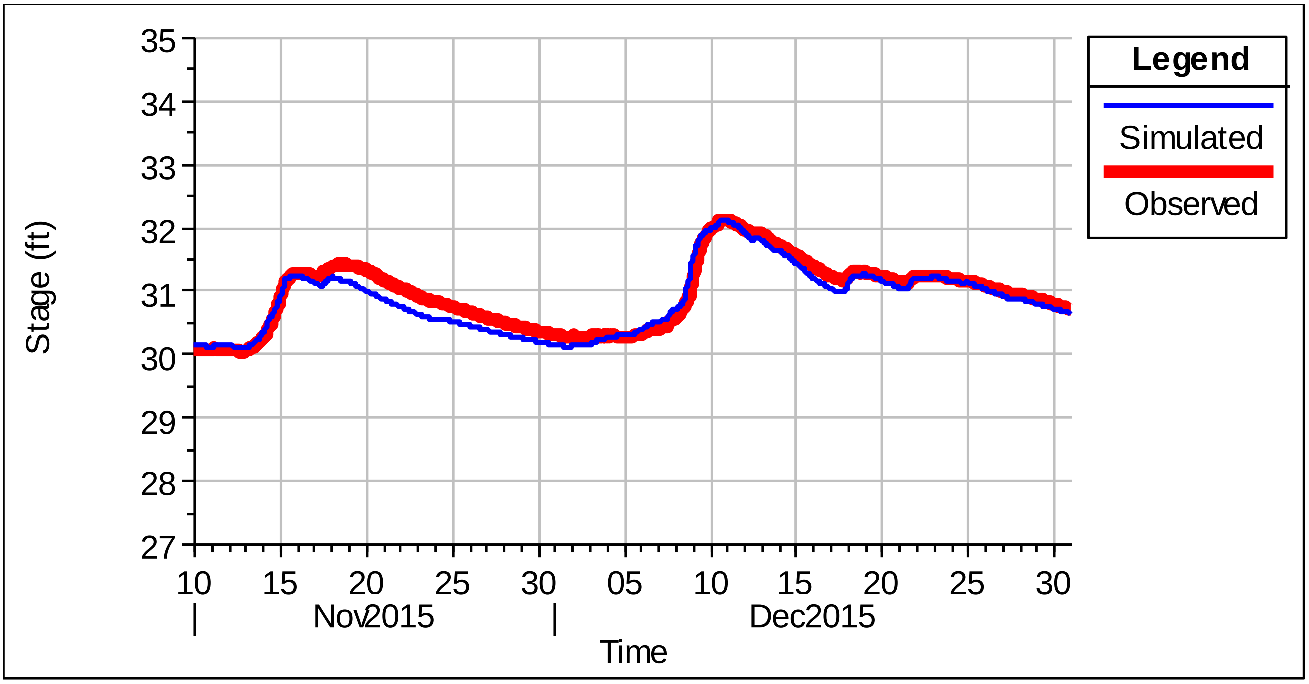


Figure 13. Comparison at Sammamish Weir (gage 51M) of Nov/Dec 2015 observed to simulated stage (NAVD88).

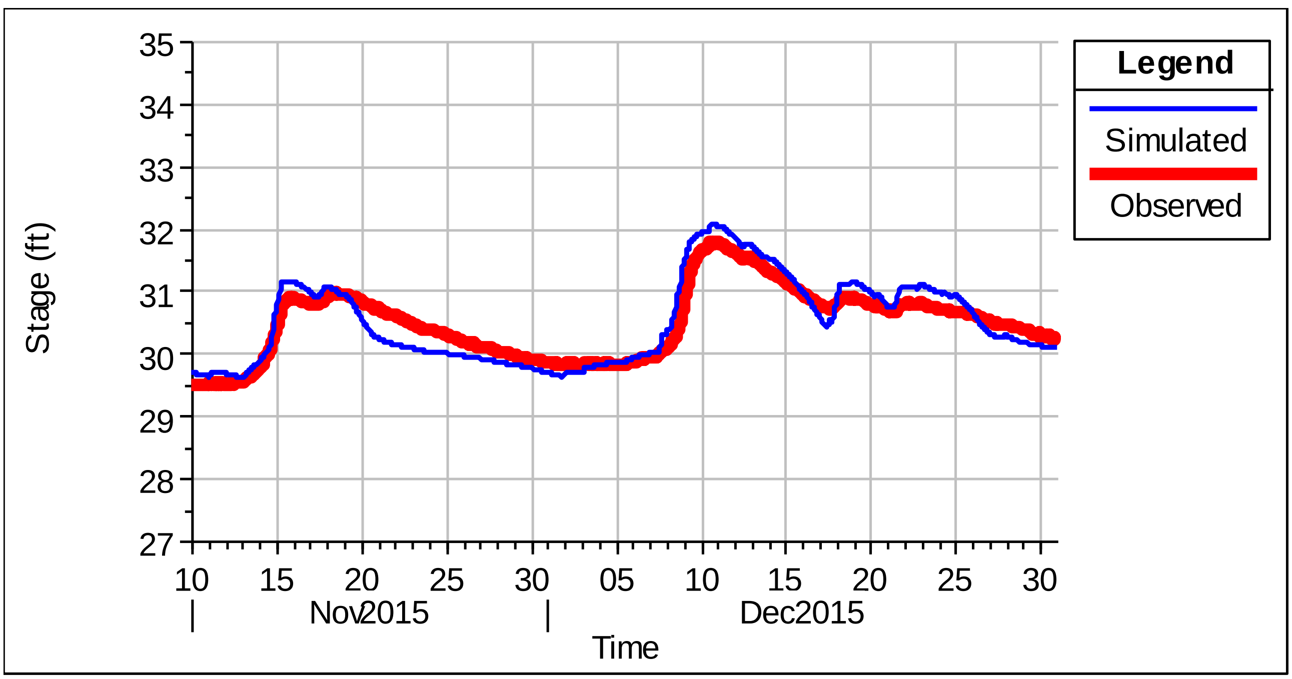


Figure 14. Comparison at King County gage TZ1 of Nov/Dec 2015 observed to simulated stage (NAVD88).

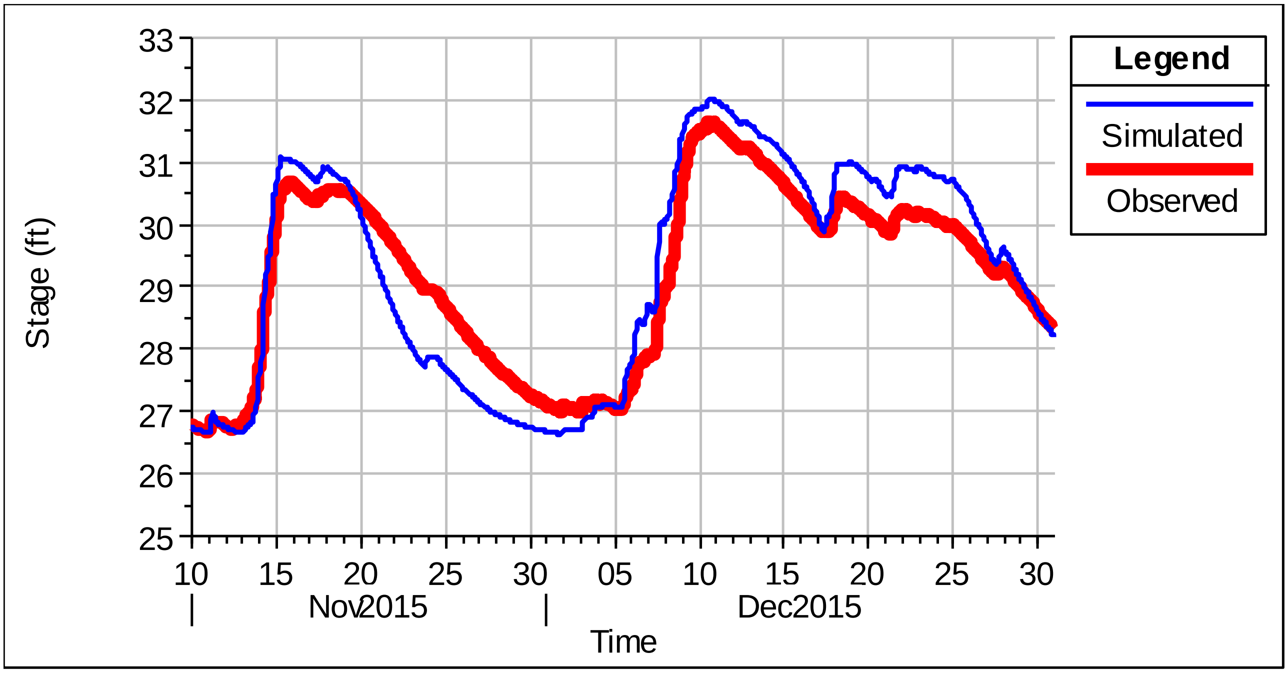


Figure 15. Comparison at King County gage TZ2 of Nov/Dec 2015 observed to simulated stage (NAVD88).

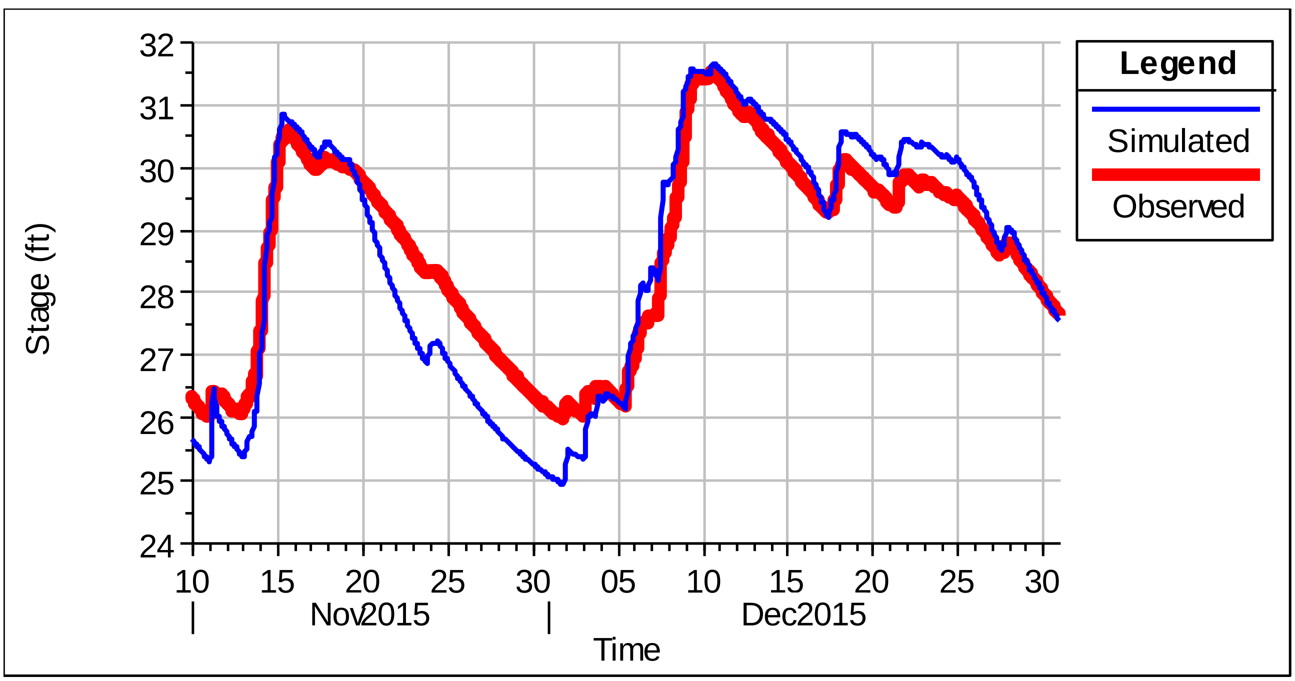


Figure 16. Comparison at King County gage TZ3 of Nov/Dec 2015 observed to simulated stage (NAVD88).

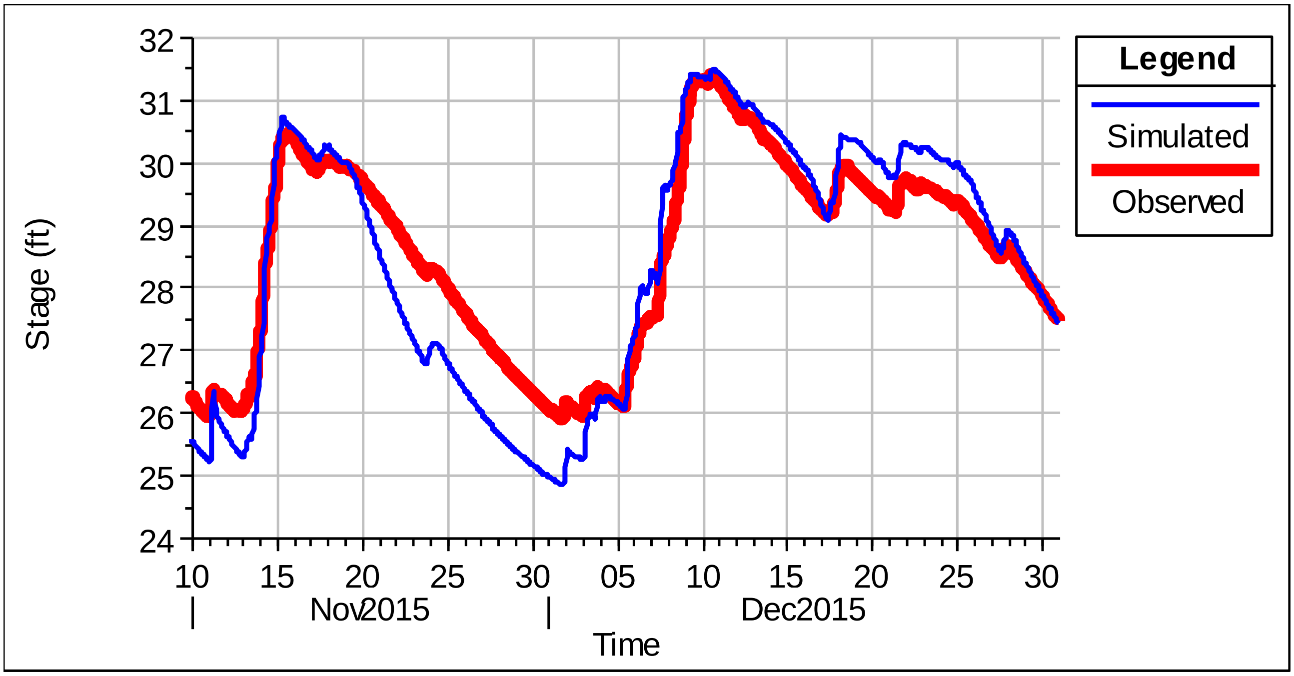


Figure 17. Comparison at King County gage TZ4 of Nov/Dec 2015 observed to simulated stage (NAVD88).

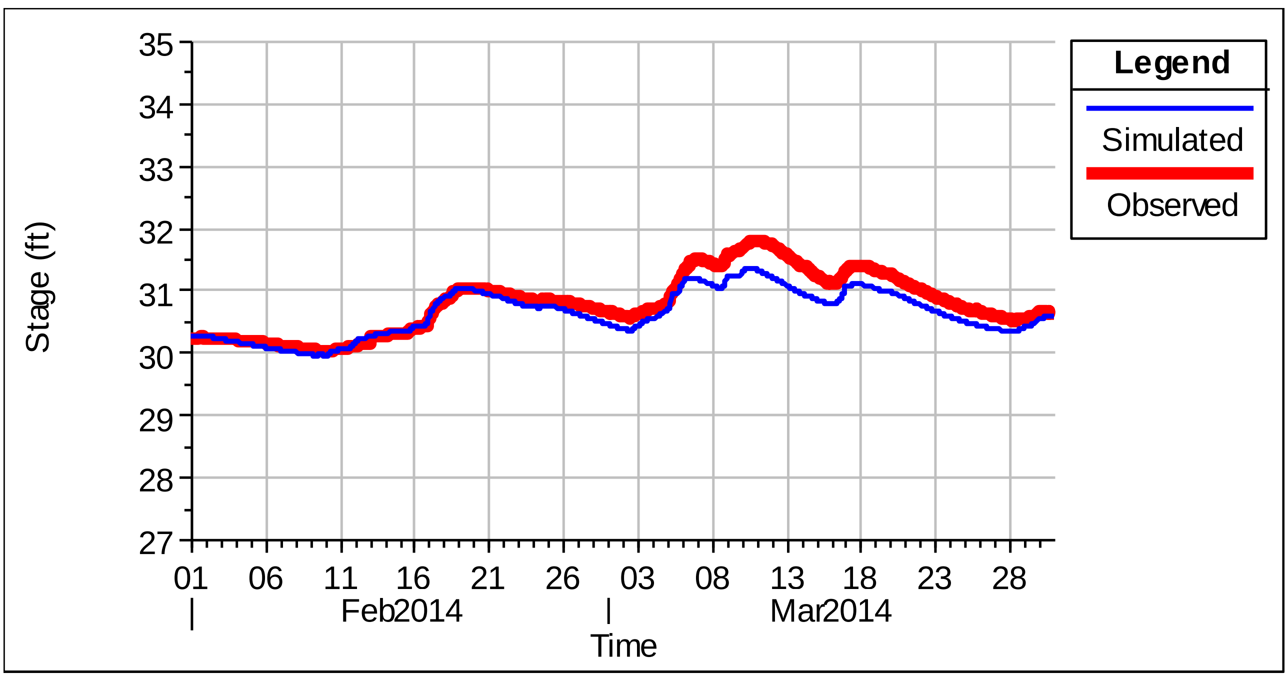


Figure 18. Comparison at Sammamish Weir (gage 51M) of February/March 2014 observed to simulated stage (NAVD88).

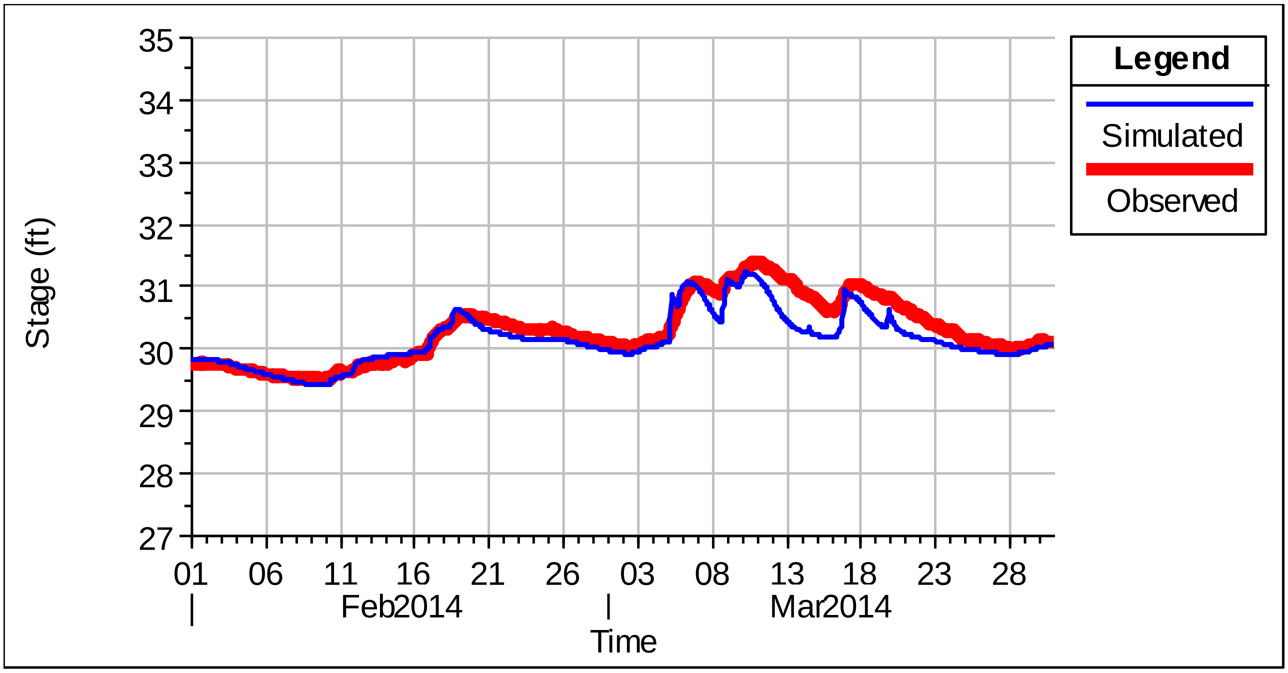


Figure 19. Comparison at King County gage TZ1 of February/March 2014 observed to simulated stage (NAVD88).

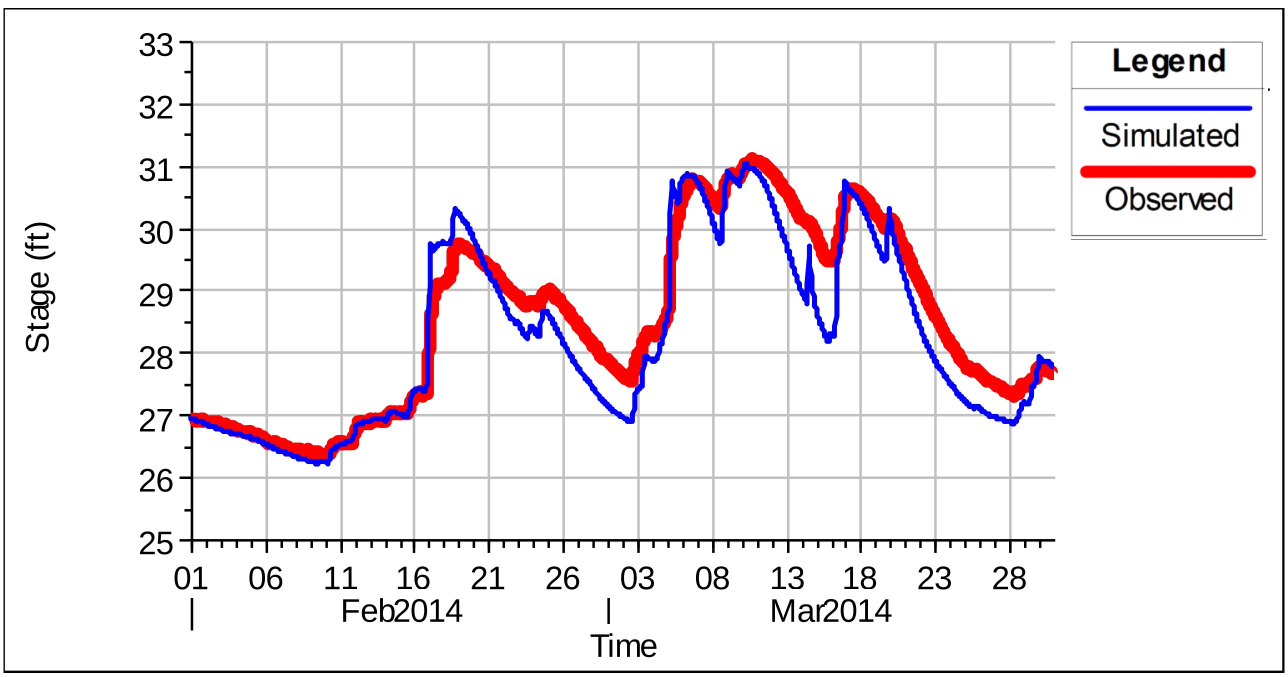


Figure 20. Comparison at King County gage TZ2 of February/March 2014 observed to simulated stage (NAVD88).

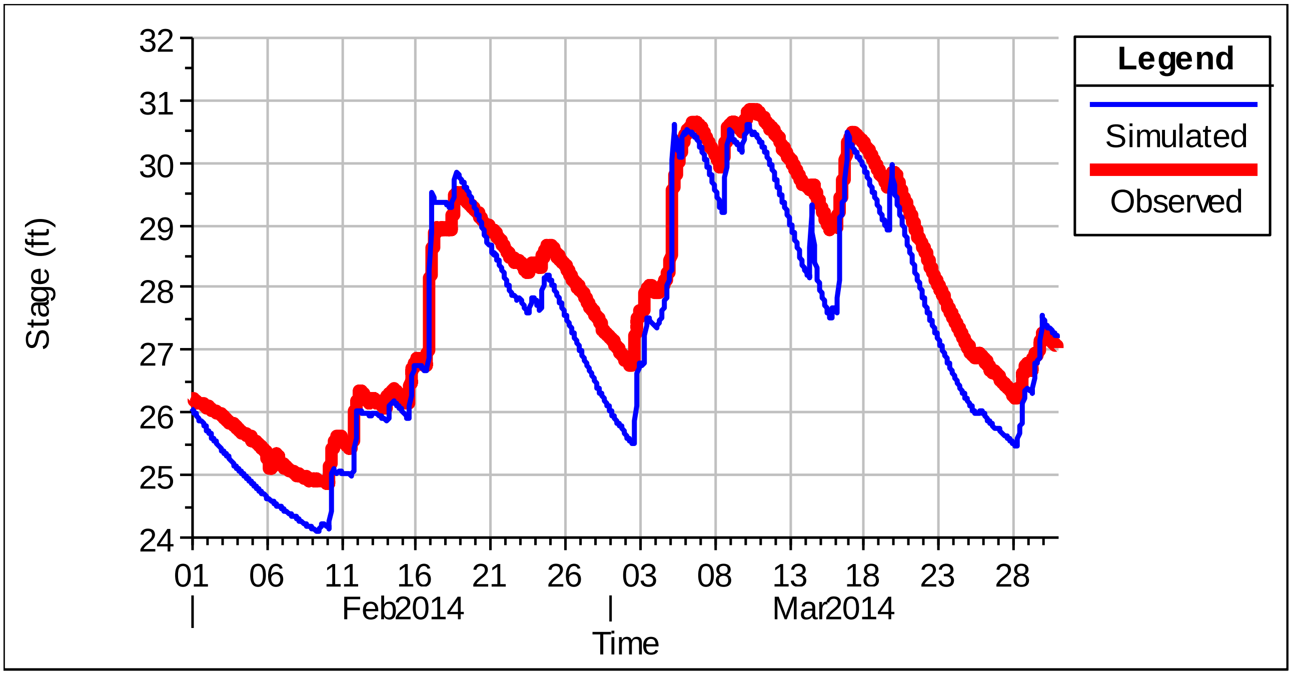


Figure 21. Comparison at King County gage TZ3 of February/March 2014 observed to simulated stage (NAVD88).

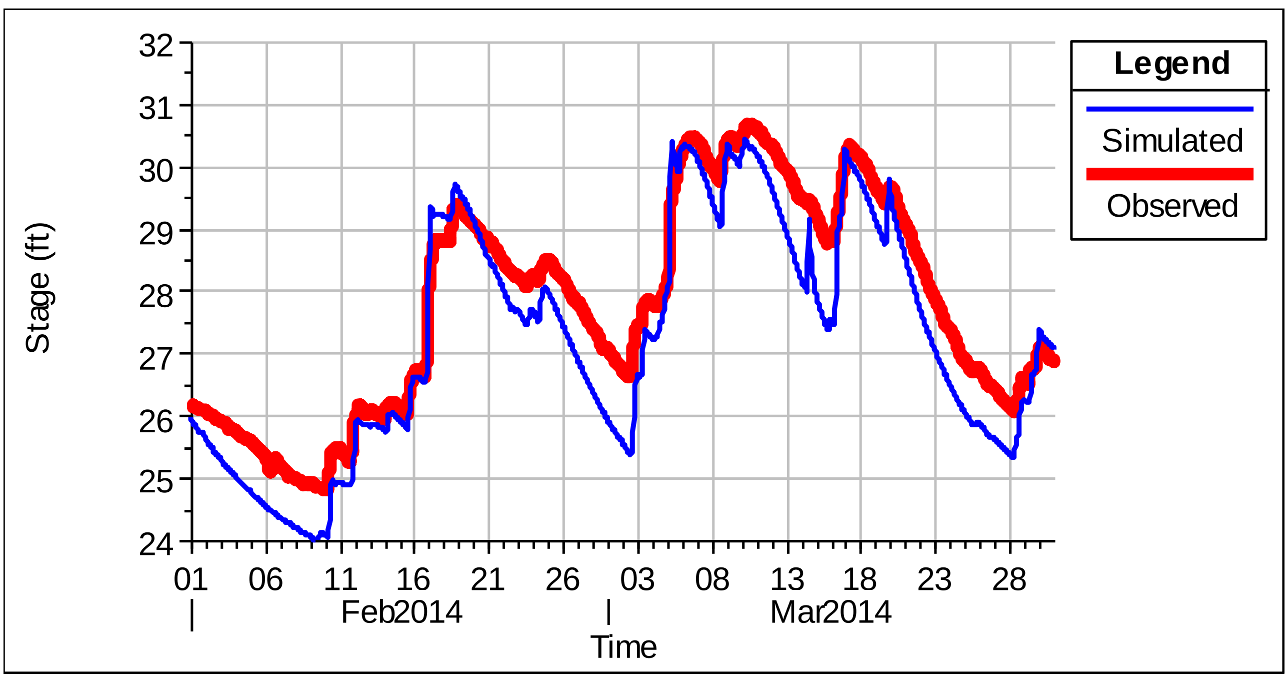


Figure 22. Comparison at King County gage TZ4 of February/March 2014 observed to simulated stage (NAVD88).

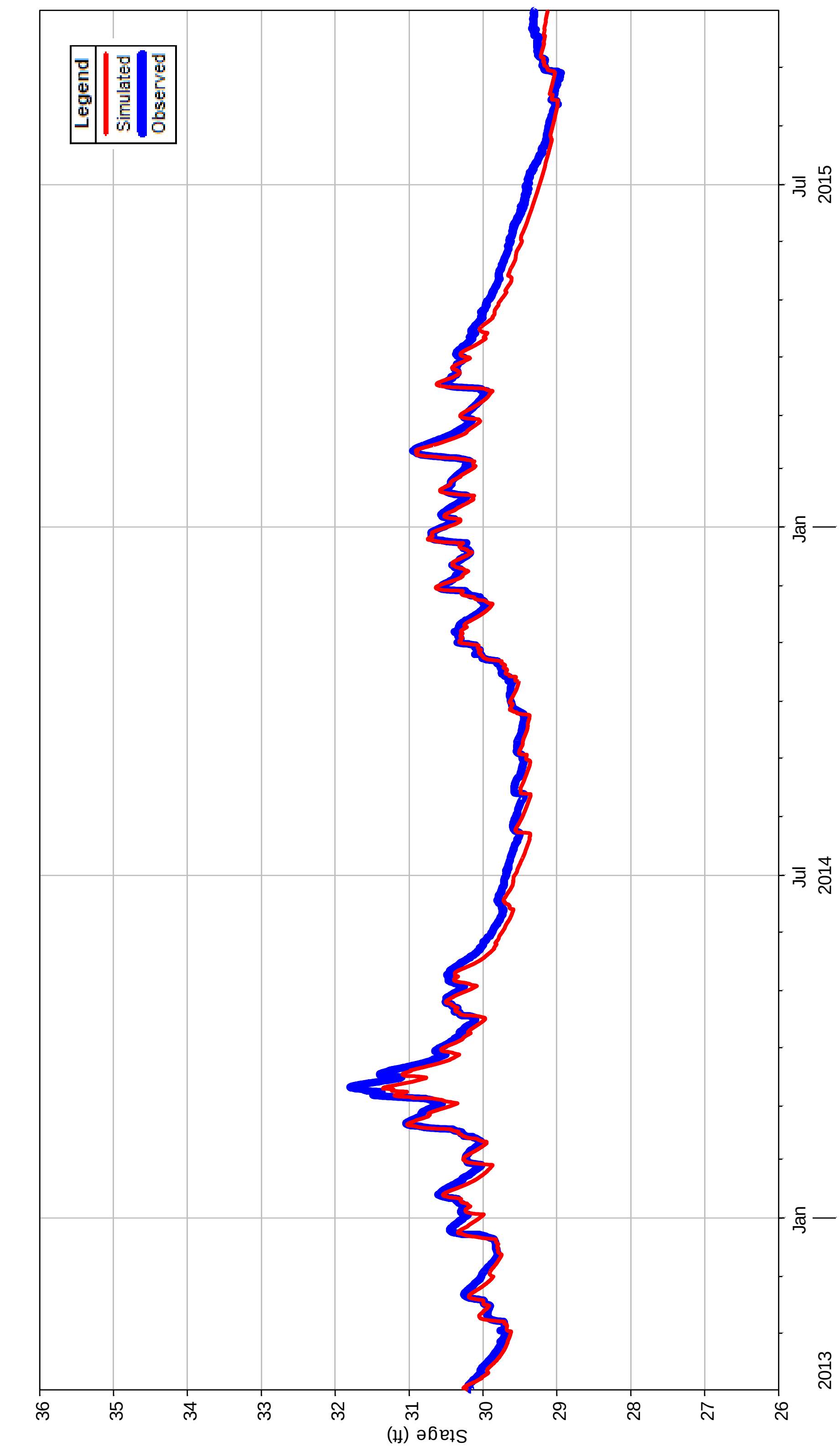


Figure 23. Comparison at King County gage 51M of water year 2014 and 2015 observed to simulated stage (NAVD88).

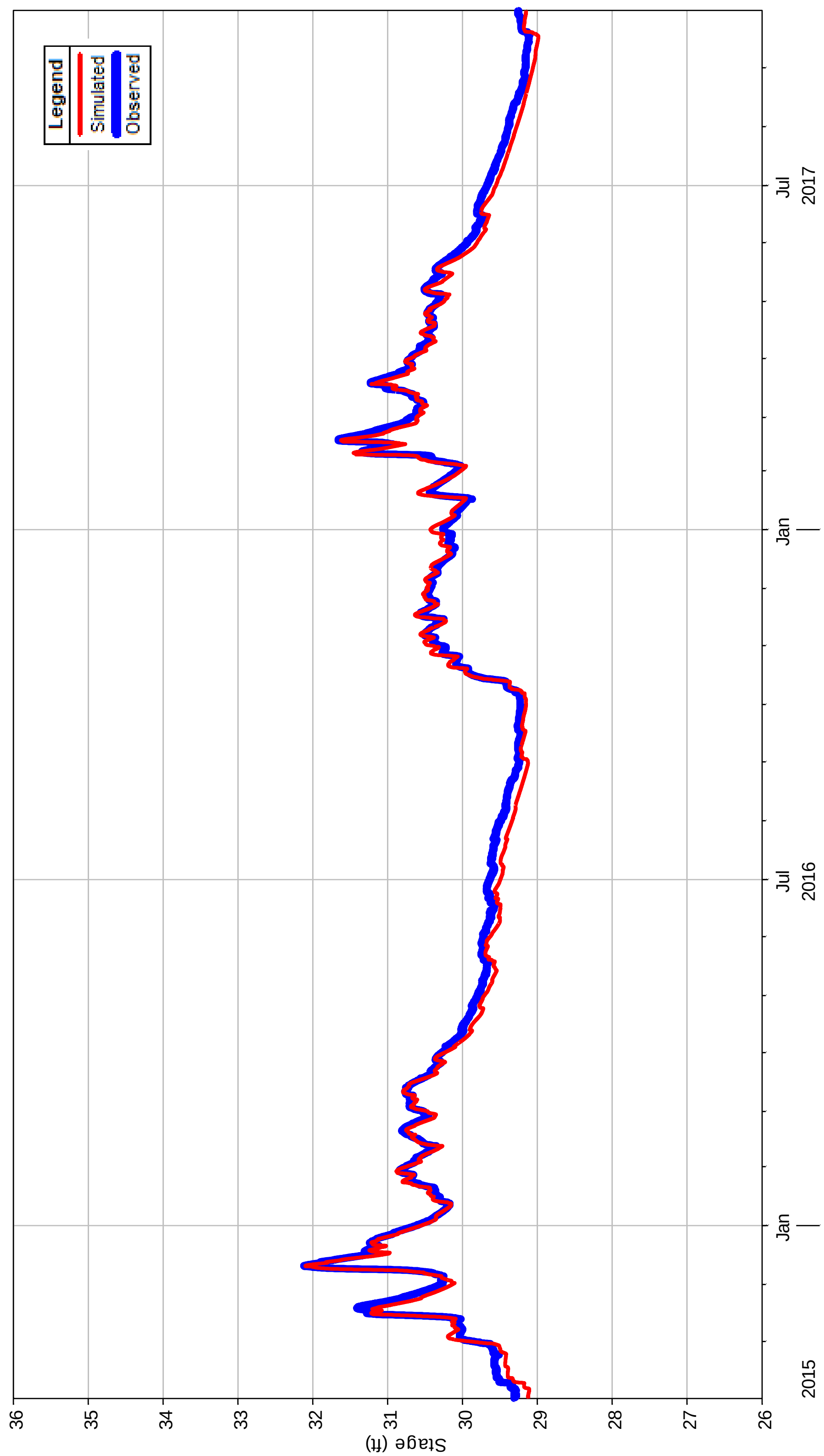


Figure 24. Comparison at King County gage 51M of water year 2016 and 2017 observed to simulated stage (NAVD88).

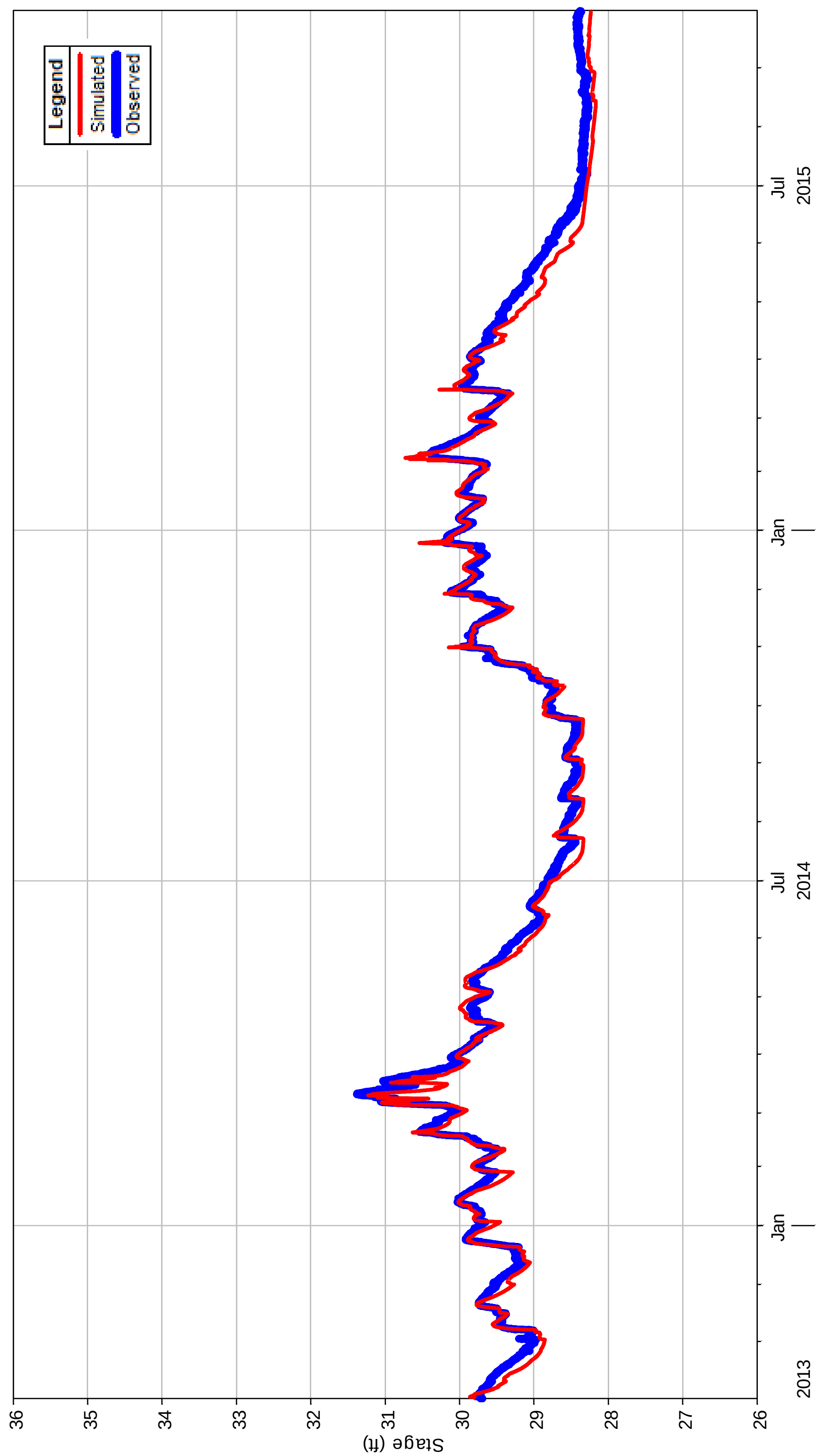


Figure 25. Comparison at King County gage TZ1 of water year 2014 and 2015 observed to simulated stage (NAVD88).

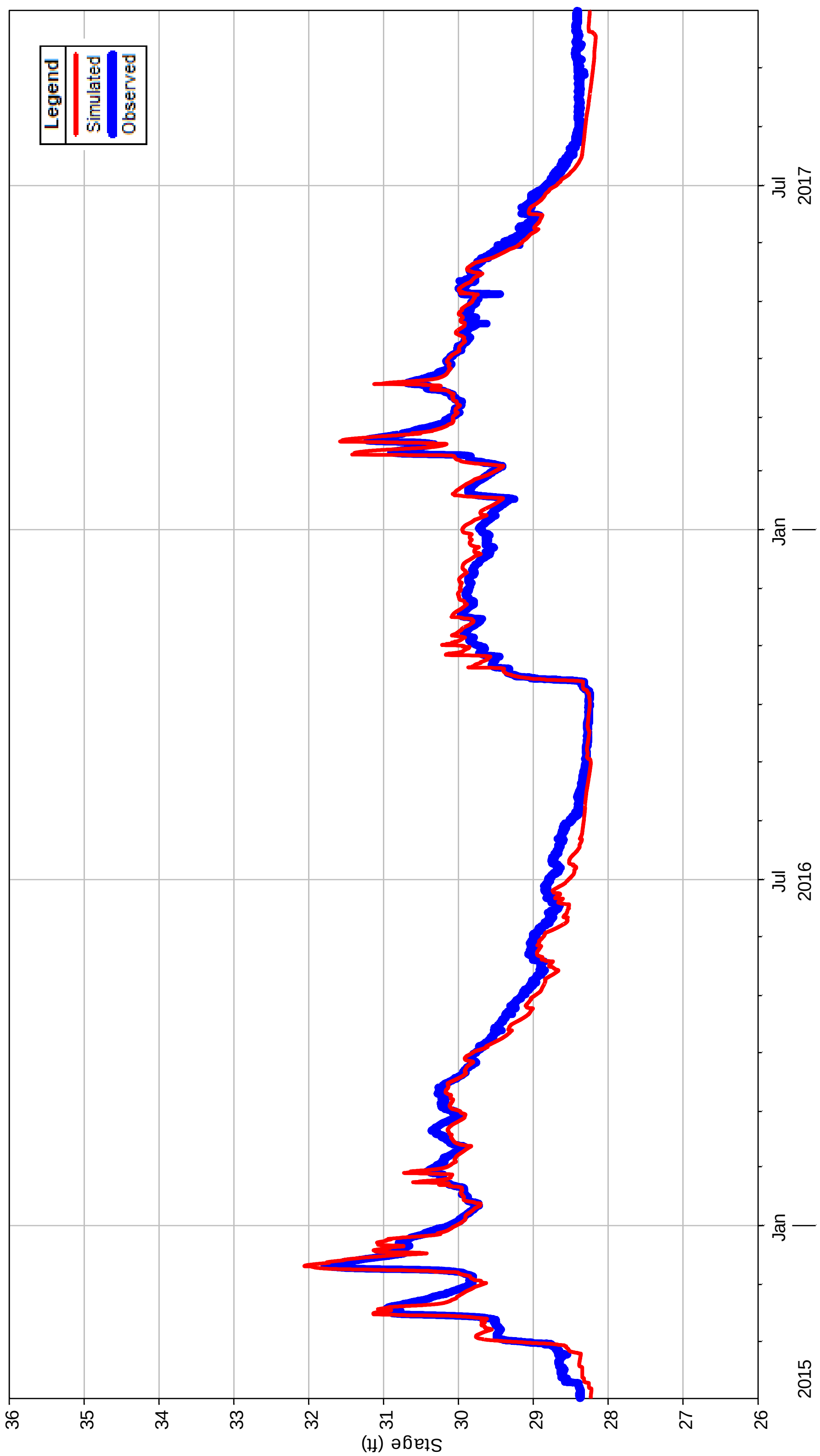


Figure 26. Comparison at King County gage TZ1 of water year 2016 and 2017 observed to simulated stage (NAVD88).

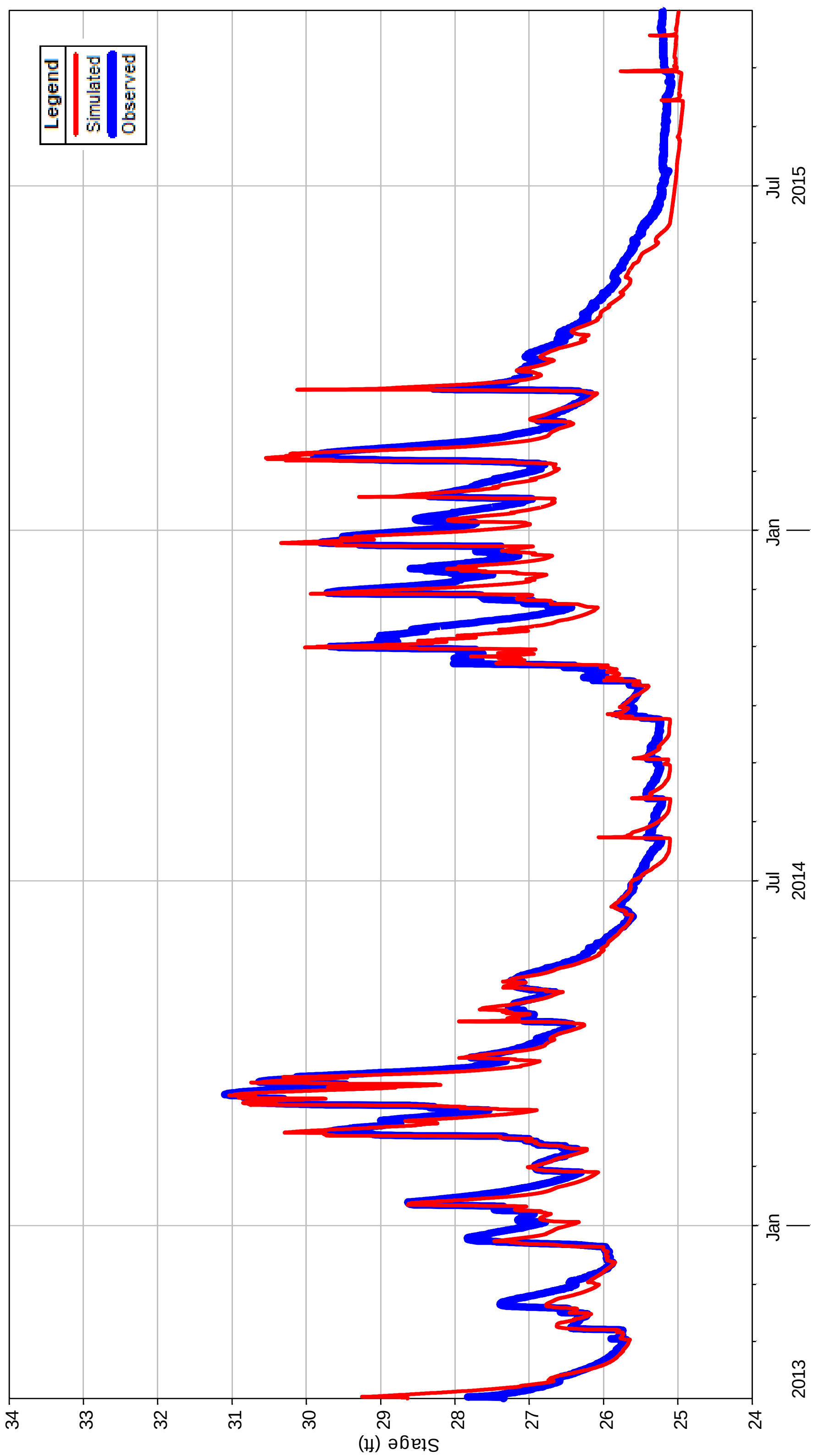


Figure 27. Comparison at King County gage TZ2 of water year 2014 and 2015 observed to simulated stage (NAVD88).

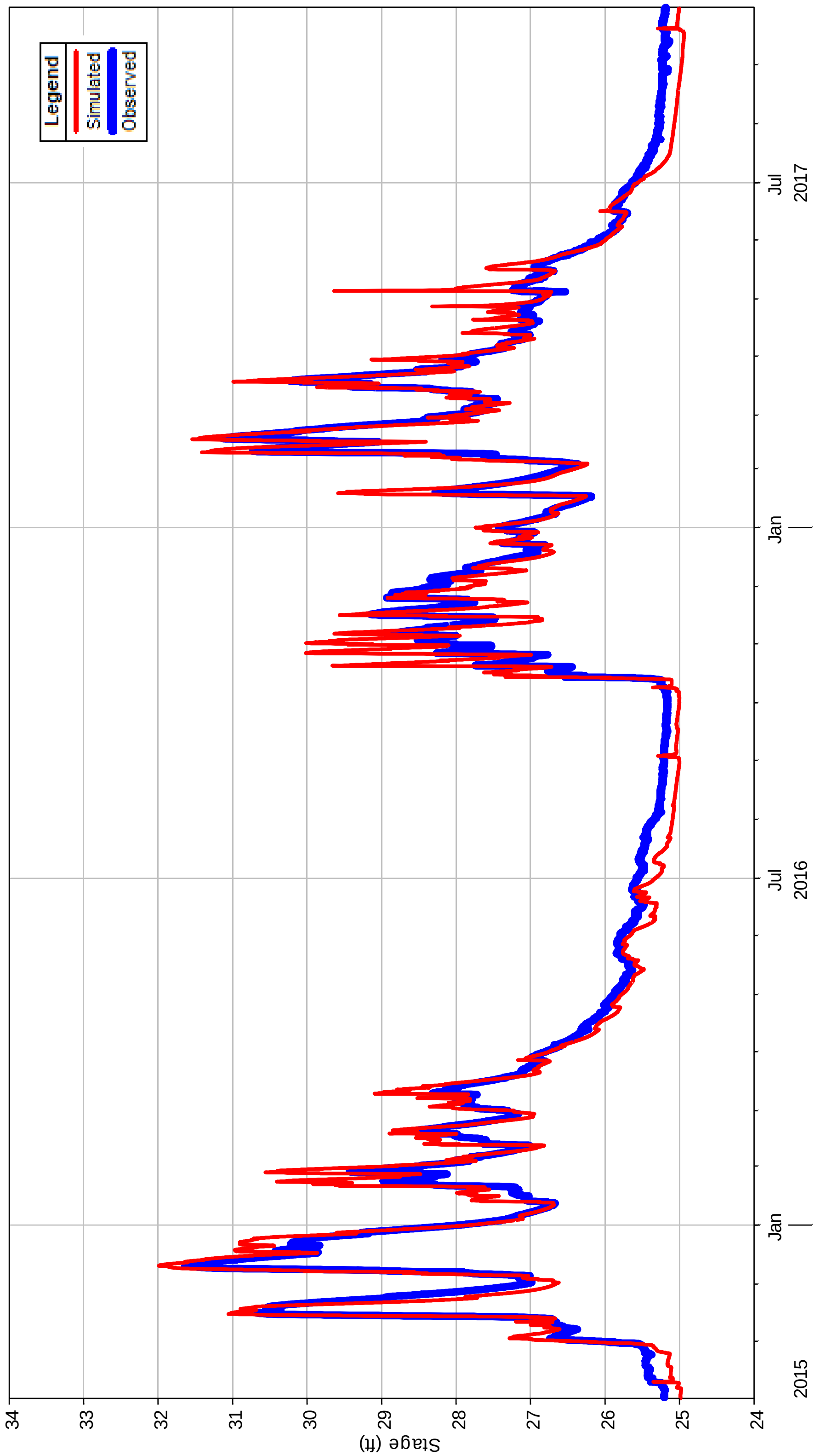


Figure 28. Comparison at King County gage TZ2 of water year 2016 and 2017 observed to simulated stage (NAVD88).

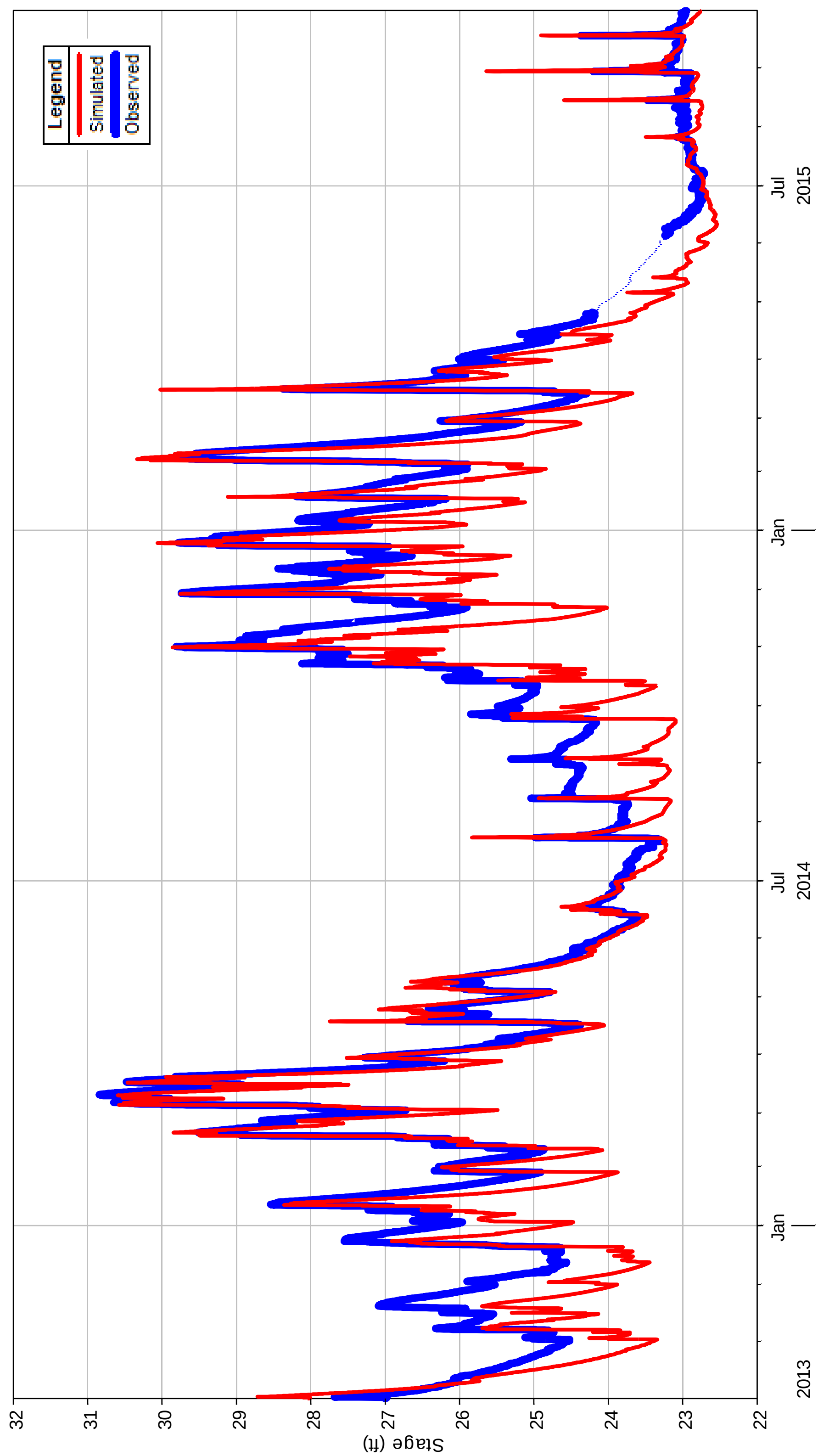


Figure 29. Comparison at King County gage TZ3 of water year 2014 and 2015 observed to simulated stage (NAVD88).

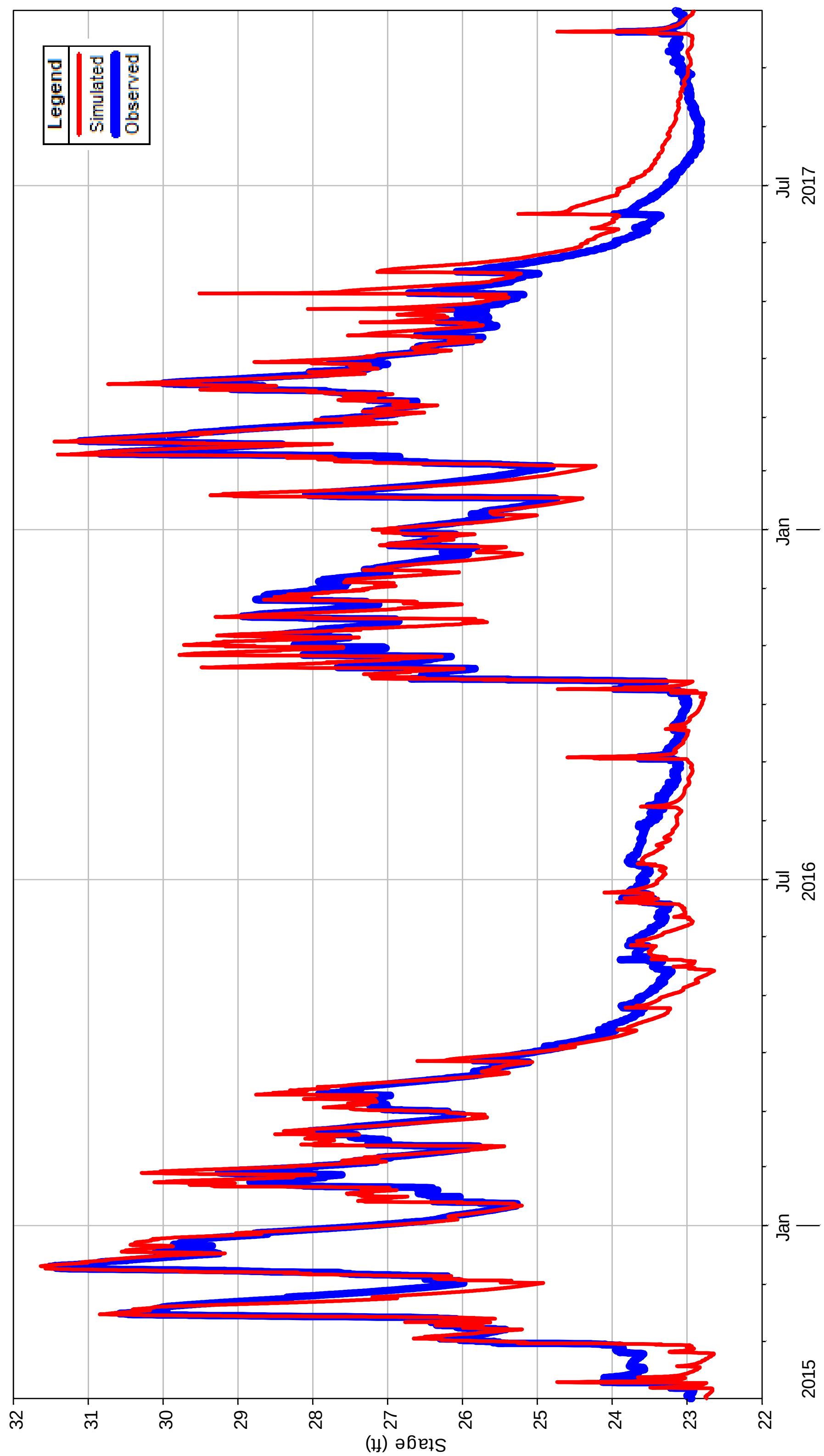


Figure 30. Comparison at King County gage TZ3 of water year 2016 and 2017 observed to simulated stage (NAVD88).

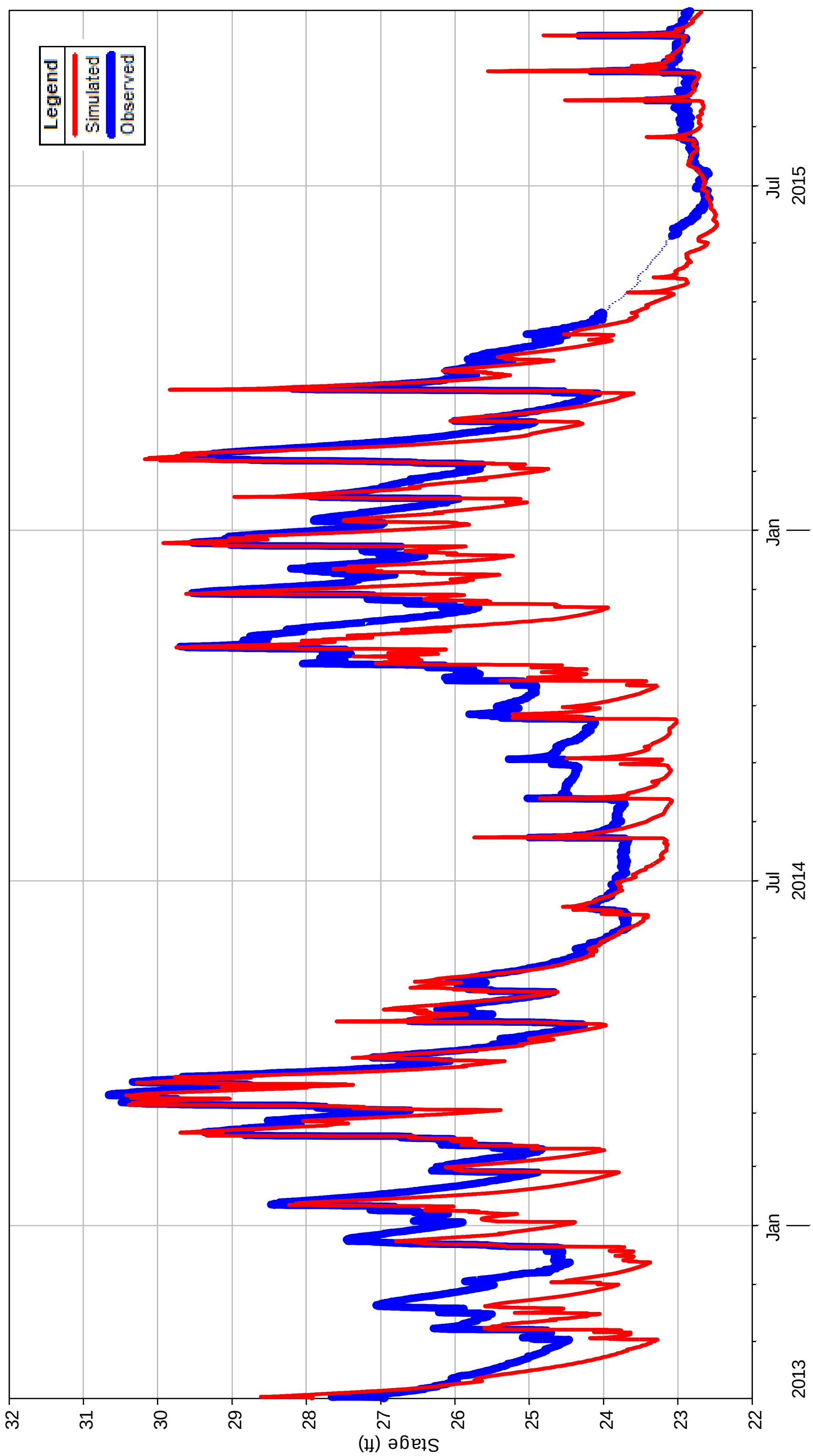


Figure 31. Comparison at King County gage TZ4 of water year 2014 and 2015 observed to simulated stage (NAVD88).

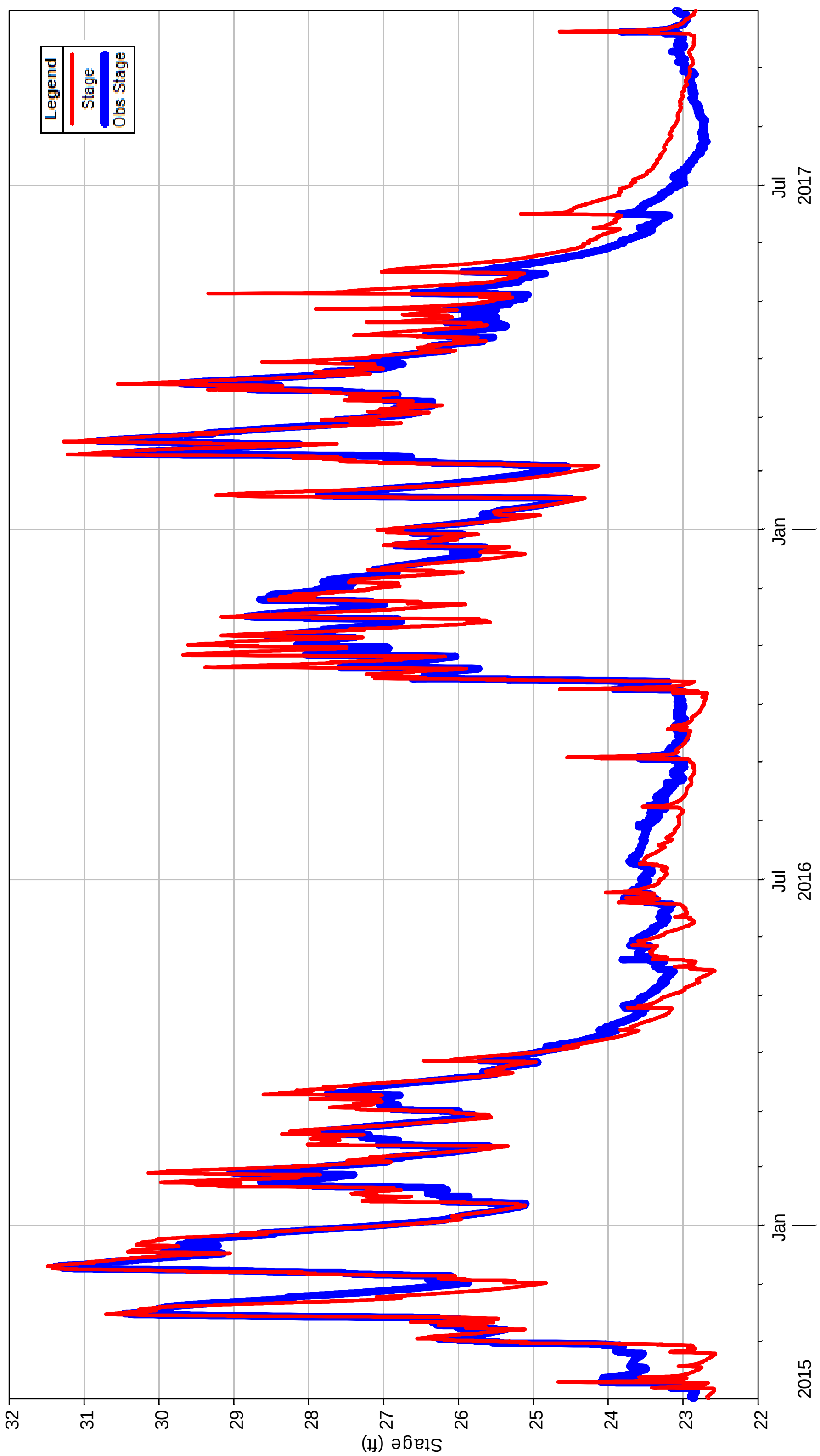


Figure 32. Comparison at King County gage TZ4 of water year 2016 and 2017 observed to simulated stage (NAVD88).

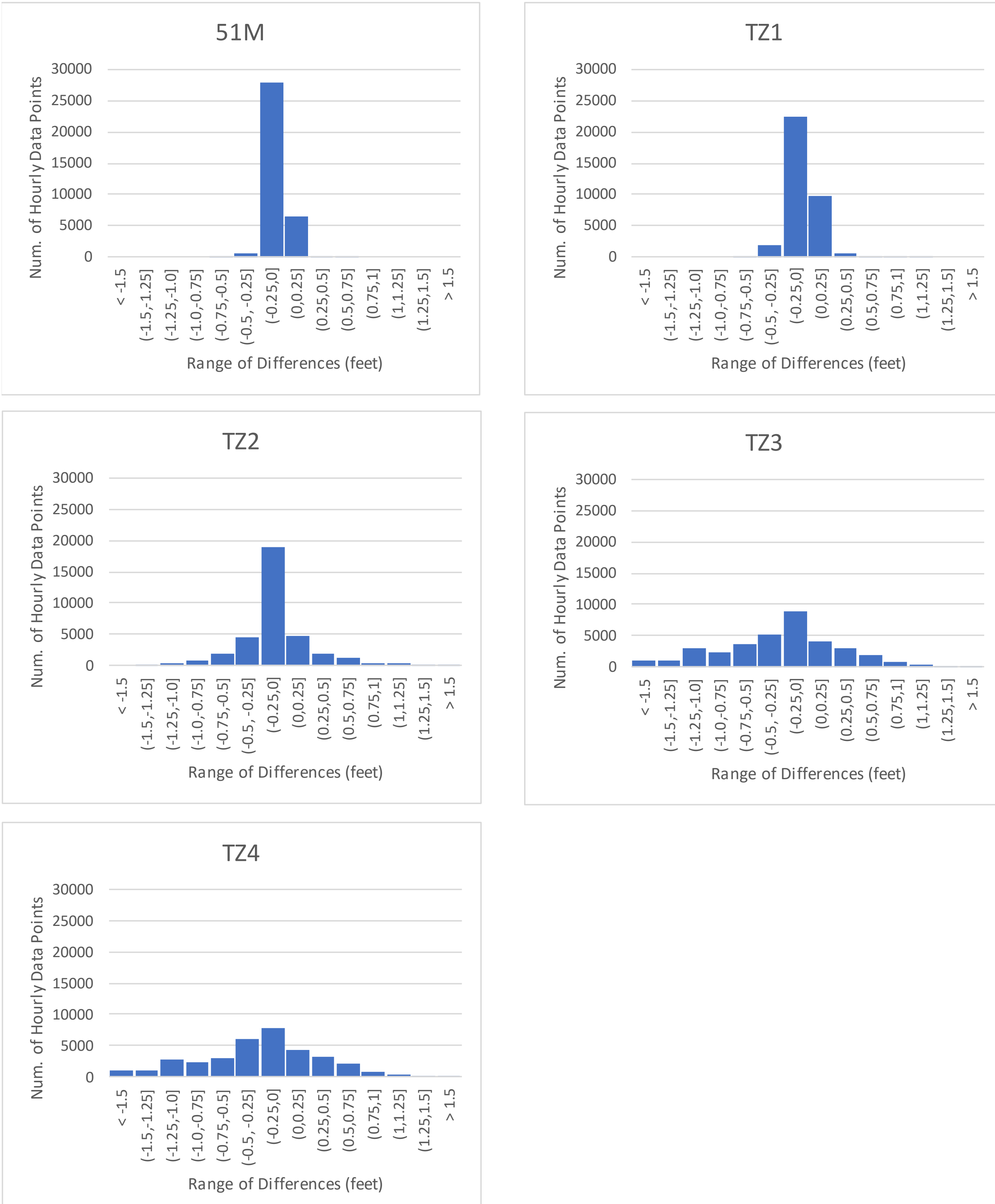


Figure 33. Histograms of Difference between Hourly Simulated and Observed Stage at King County Gage Sites for Water Year 2014 through Water Year 2017.

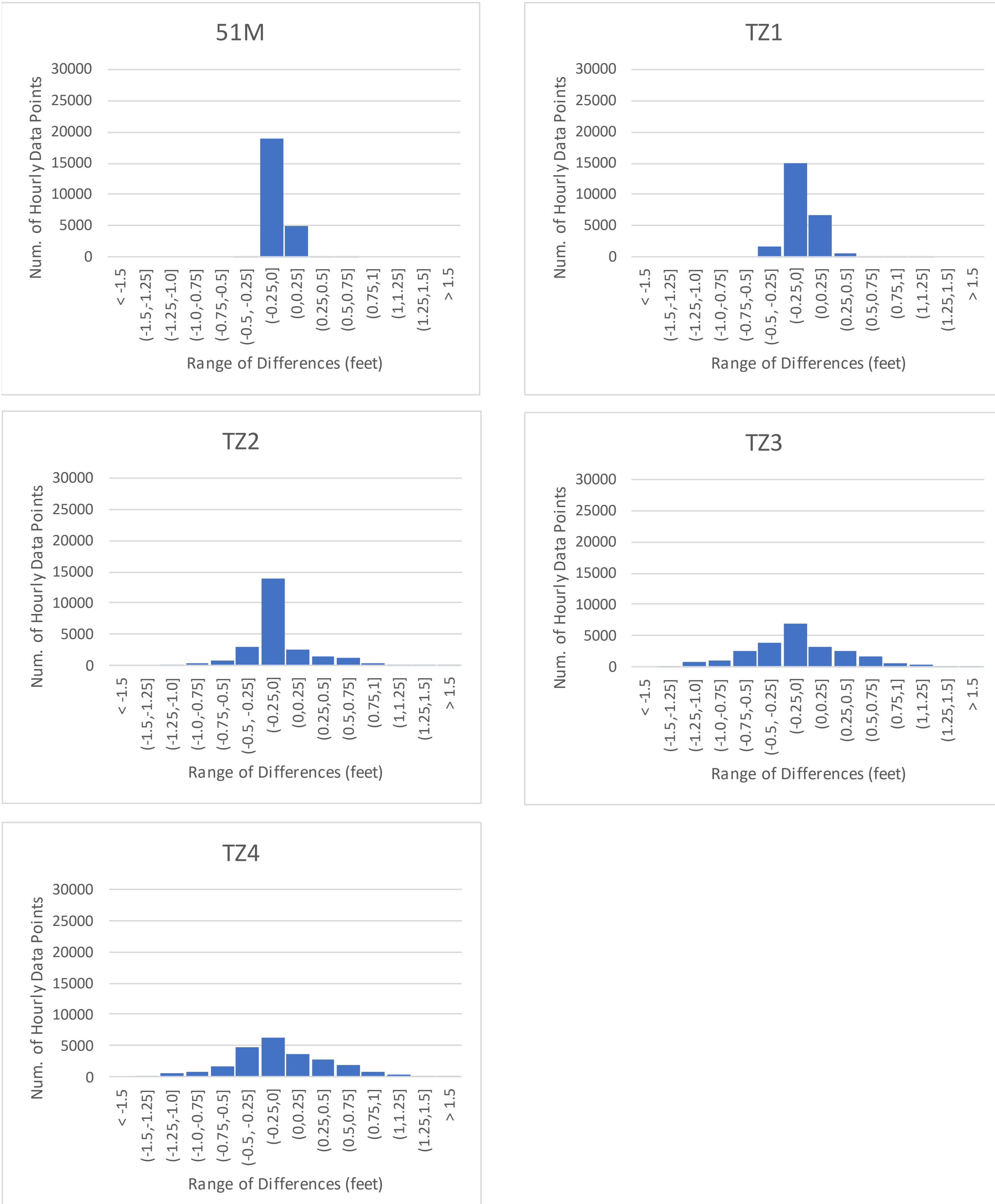


Figure 34. Histograms of Difference between Hourly Simulated and Observed Stage at King County Gage Sites for January 1, 2015 through Water Year 2017.

4.0 COMPARISON TO PRIOR MODELING

After calibration, the updated model water surface elevation results were compared to the FEMA FIS model for steady state FEMA flood flows. This comparison was performed in advance of project required No Rise regulations. With fundamental differences in the models' domain and computational algorithm (steady state versus unsteady), along with the previously discussed updates to bathymetry and calibration to a different vegetation maintenance regime, a close adherence between models is not expected. Since the updated unsteady-state calibrated model uses Manning's 'n' multipliers for flow and seasonal variation in the channel roughness, a feature not available in the steady state HEC-RAS routines, the Manning's 'n' values in the FIS model were manually changed (assuming a seasonal factor of 1.5, representative of high flow months, and a flow factor based on the actual flow). The comparison was performed using a model configuration that fixed the water surface elevation at the Bear Creek confluence to match the FIS model. Between Bear Creek and Lake Sammamish, the project model water surface profiles match to within +/- 0.4 feet of the FIS model for the 10-, 50-, 100-, and 500-year events. The discrepancy is primarily caused by differences in Manning's 'n' and the weir coefficient, as well as modifications to the channel bathymetry.

5.0 SENSITIVITY TO VARYING MODEL PARAMETERS

As part of the calibration effort, sensitivity of simulated results to various model parameters was tested as shown in Table 7. Of the evaluated scenarios, the seasonal variation and flow scaling of 'n' values affected results the most at higher stages (Figure 35) and the weir coefficient at lower stages. Changing other parameters resulted in water surface elevation differences typically on the order of tenths of feet.

Table 7. Model parameters modified to test model sensitivity.

Model Parameter Modified	Base Condition Value(s) Used	Sensitivity Value(s) Used	Typical Model Response (Simulated WSEL) to Parameter Variation
Manning's 'n' seasonal variation	See Table 3 in report text for monthly values used	Set factor of 1 for all months	Approximately 0.5 feet lower than base
Manning's 'n' flow scaling	Scaling factors of 1 to 1.3, from 500 cfs to 1,000 cfs, and 1.3 above 1,000 cfs	Set to factor of 1 for all flows	Approximately 0.3 feet lower than base
Weir coefficient	2.5	Tested both 2.0 and 3.0	±0.15 feet
Vertical Manning's 'n' variation throughout TZ low flow main channel	0.12 in the low flow section transitioning to 0.04 in upper section	Tested both 'n' = 0.04 and 0.12 for entire vertical section	±0.1 feet
Manning's 'n' for upper portion of willow overbank area throughout TZ	0.25 at grade transitioning to 0.12 in upper section	Tested both 'n' = 0.08 and 0.25 for upper section	±0.01 feet
Vertical Manning's 'n' for mowed area throughout TZ	0.20 at grade transitioning to 0.03 in upper section	Tested both 'n' = 0.03 and 'n' = 0.05 for entire vertical section	±0.02 feet
Overbank 'n' values from the TZ downstream to Bear Creek confluence (compared to a base condition of 'n' = 0.08)	0.08	Tested both 'n' = 0.03 and 0.12	±0.02 feet

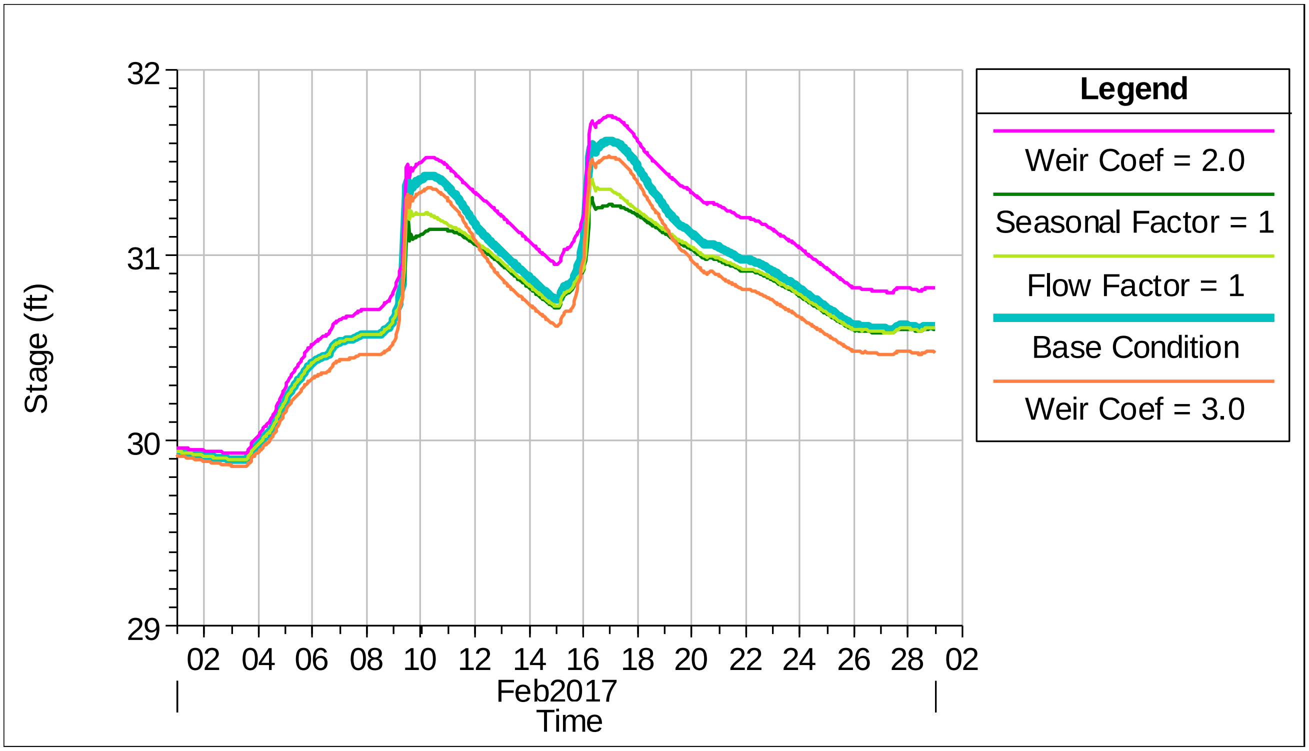


Figure 35. Hydrographs at the Sammamish Weir (51M) comparing stage for some of the parameters tested during the sensitivity analysis.

6.0 LIMITATIONS

The HEC-RAS model has been updated with 2018 geometry and calibrated to new water year 2014 through water year 2017 observed data at the Marymoor Weir 51M gage and four TZ gages for the "maintained" TZ condition. This effort included complex adjustments to the Manning's 'n' value based on horizontal and vertical variation, and both seasonal and flow scaling. As the calibration was for existing "maintained" TZ condition, model parameters would need to be changed to accurately simulate other TZ vegetation conditions. Model calibration focused on matching results from Bear Creek upstream to Lake Sammamish, where observed gage data were available, so there is additional uncertainty in application of the model beyond these extents.

7.0 REFERENCES

King County, Integrated Aquatic Vegetation Management Plan Sammamish River, King County Department of Natural Resources and Parks, Water and Land Resources Division, Noxious Weed Control Program, June 2013.

Northwest Hydraulic Consultants, Floodplain Mapping Study for the Sammamish River, February 2010.

Northwest Hydraulic Consultants, Willowmoor Floodplain Restoration Project Hydrologic Modeling Draft Technical Memorandum, October 2018.

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Principal

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