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- Ice processes in the Susitna River study, Study plan Section 7.6, 2014-2015 Study Implementation Report. [Main report]
- Appendix A. Alternative visualizations of freeze-up progression and open leads.
- Appendix C. River2D open-water modeling report, Focus Area 128 (Slough 8A)

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Ice Processes in the Susitna River Study
Study Plan Section 7.6

2014-2015 Study Implementation Report

Appendix B
Technical Memorandum: River1D Model - Initial Open Water Calibration and Validation

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

HDR Alaska, Inc.

University of Alberta

October 2015

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1. INTRODUCTION

HDR, the lead for the Ice Processes in the Susitna River Study, partnered with the University of Alberta to conduct modeling of the Middle River Reach of the Susitna River for ice-covered conditions. The University of Alberta created the public domain *River1D* hydrodynamic and ice processes model and has a strong record of applying the model to a wide variety of river types and conditions including modeling the effects of hydropower operations. The University of Alberta has developed several improvements to the *River1D* platform specifically for the Susitna River modeling including the option for non-rectangular cross sections and greater ease of use when importing HEC-RAS geometry files. HDR has completed three seasons of ice processes observations and data collection which will be used to provide input to the *River1D* ice model for existing and proposed project operational scenarios. The data will assist in the validation and verification of the model results, especially as it is applied to post-project conditions.

HDR has provided a variety of geometric, hydrometric, and ice processes data to the University of Alberta for model development, calibration, and testing. This data includes USGS gauging records, HEC-RAS geometry files developed through the Instream Flow Study (Study 8.5), stage, air, and water temperatures from the Susitna Watana Data Network (Instream Flow Study), and a variety of other data either collected by HDR or by other studies. The University of Alberta provided HDR with an optimal set of input and data requirements for calibration and verification of the *River1D* model. HDR provided these data when available and for missing or unavailable/unobtainable data, developed appropriate substitutions based on engineering judgment and experience. The impacts of the assumptions made were discussed with the University of Alberta to ensure that the modeling results would not be adversely impacted. Close coordination of modeling requirements, data availability, assumptions, and output between HDR and the University of Alberta has resulted in very strong confidence in the *River1D* modeling efforts.

This report describes the development of the Middle Susitna River *River1D* model and the procedures followed to conduct open water calibration and validation. The geometric and hydrographic data used to develop the model as well as the inputs required for the model are discussed. The objectives and methods of the open water calibration and validation are explained and results of these efforts described. The next steps in the development of the ice model include the calibration and validation of the thermal modeling capabilities of River1D. Attachment 1 to this report describes the preliminary water temperature calibration efforts to date. Further validation of the thermal capabilities will be followed by simulation of ice production, transport and ice cover formation, hydraulic thickening, and thermal decay.

2. OBJECTIVES

Before the *River1D* model can be set up for ice process modelling, the model must be calibrated and validated for a number of open water events. Calibration involves determining the appropriate hydraulic roughness values required to ensure that the model accurately reproduces observed discharges and water levels over a broad range of event conditions. Validation involves testing this calibrated model on an independent set of measured events to ensure it reliably predicts discharges and water levels over the full range of expected conditions.

The Susitna River ice process modelling study reach, shown as the middle reach (blue line) in Figure 1, extends from the proposed dam site at Project River Mile (PRM) 187.2 to the town of Talkeetna (around PRM 99.9). The study reach excludes the braided portion of the river downstream of the confluences with the Chulitna and Talkeetna Rivers as the flow in braided rivers is very two-dimensional (2-D) in nature and cannot be well represented by a one-dimensional (1-D) model, such as *River1D*.

Figure 1 also shows the locations of the available **Environmental Susitna Surface** (**ESS**) and **United States Geological Survey** (**USGS**) gauging stations within, and near to, the study reach. As hydraulic routing requires water levels as input at the downstream boundary, it is optimal to locate the downstream end of the study reach at a water level gauging station. For example, in this case, either the water level station at PRM 102.1 or at PRM 98.4 could have been selected as the downstream boundary station in the model. However, since this would leave only one **USGS** station (**USGS** 15292000 Susitna River at Gold Creek) within the model study reach to compare with the model discharge results, the **University of Alberta** (**UA**) decided to extend the *River1D* model further downstream to enable a comparison at **USGS** 15292780 Susitna River near Sunshine for our own modelling assessment. However, as this gauge is within the braided portion of the river, we should not expect the agreement between the model results and this gauge's data to be perfect.

The first objective of open water calibration is to obtain a good match between the modelled and observed flows along the study reach. As *River1D* has been shown to conserve mass exactly (Hicks and Steffler 1992), this effort only requires that all of the inflows to the study reach during a given event are properly quantified, both in terms of magnitude and timing. However, this can be challenging when all of the inflows have not been measured (as was the case here). To address this data deficiency, **HDR** identified and quantified ungauged lateral inflows within the study reach and also determined the proper lag times for gauged tributaries (to account for time of travel between the tributary gauge and the confluence with the Susitna River).

The second objective of an open water calibration is to obtain a good match between the modelled and observed water levels along the study reach. This is achieved by adjusting the modelled roughness values. So as to be consistent with current standards of practice, only the channel roughness was adjusted in calibrating this 1-D open channel flow model of the study reach. The floodplain roughness values provided by **HDR**, which were set based on engineering judgment, were accepted and used. In order to produce a physically realistic 1-D model of the river, a calibration tolerance of 1 foot was employed. This value was selected by taking into account the magnitude of potential errors in measuring water levels on a river of this size and type (e.g. such as wave effects, instrument error, and survey error) as well as 2-D and 3-D effects (such as flow superelevation) which cannot be accounted for in a 1-D model. Subreaches of the river were identified based on channel geomorphology (e.g. planform pattern, channel width, slope, and roughness features) and efforts were made to ensure that calibrated channel roughness values (Manning's n_c) were consistent with these physical characteristics. Given the 1-D approximation and the spacing of the available channel geometry, values of channel roughness were rounded to the nearest 0.005.

3. AVAILABLE DATA AND INPUT FILE SETUP

This open water calibration was done using the geometry provided by **HDR** on April 11, 2014 in a *HEC-RAS* geometry file. This geometry file reflected updates to the river geometry to include overbank information for cross-sections between PRM 187.2 and PRM 80 (including overbank Manning's *n* roughness values), left and right bank stationing (at the edge of vegetation / top of bank). New cross-section data were also provided between PRM 80 and PRM 29.9. Figure 2 shows, for the study reach, (a) the width of the main channel between the bank locations and (b) the left and right overbank roughness values. The main channel widths increase dramatically at the end of the study reach (Figure 2a). This is where the river transitions to a braided channel.

Before converting the *HEC-RAS* geometry into the *River1D* file format, two modifications to the original geometry file were required. First, **HDR** had supplied the Manning's *n* values for each cross-section in a horizontal variation of n-values scheme which was changed to be specified in terms of left overbank (LOB), main channel (CH) and right overbank (ROB), as required by the *River1D HEC-RAS* geometry file converter software. Second, cross-sections were interpolated with a maximum spacing of 1056 ft. (0.2 miles) for a total of 875 (242 original cross-sections plus 633 interpolated cross-sections).

One other issue was noticed when converting the *HEC-RAS* geometry data file provided by **HDR** to the *River1D* format. Although cross-sections are named according to their PRM in the *HEC-RAS* geometry file (*HEC-RAS* River Station), it was found these cross-section names do not fully agree with the actual downstream reach lengths input for the channel in the HEC-RAS geometry file, as illustrated in Figure 3. The total length of the provided *HEC-RAS* reach calculated using the PRM's is 157.3 miles (187.2 miles – 29.9 miles) while the total length of the *HEC-RAS* reach calculated using the channel reach lengths is 150.4 miles, a difference of almost 7 miles. This is a concern since modelling results will vary with the length of the channel. However, for the project study reach, the length of the reach calculated by these two approaches is not very different: 87.3 miles and 87.2 miles (a difference of 0.1 miles), using PRM's and actual channel reach lengths, respectively. Since this difference is small, it is assumed that any differences in the modelling results from using either system to calculate the stationing along the study reach would be negligible within the study reach.

Data for five open water periods were provided by **HDR** for the calibration and verification efforts. Four events were provided for calibration and one event was provided for validation. These events are listed in Table 1. For these five events, model inflow data were provided for five locations along the river. These inflows are listed in Table 2. The locations along the study reach where these flows were to be input to the model were provided in terms of PRM location. Where these locations did not correspond to cross-sections in the model, the closest cross-section (surveyed or interpolated) was used as an input location in the model. Figure 4 shows the locations along the river where these inflows are input into the model.

Gauge data for comparison with model results were obtained from two **USGS** stations and nine **ESS** stations. The two **USGS** stations are:

- **USGS** 15292000 Susitna River at Gold Creek (PRM 140)
- **USGS** 15292780 Susitna River near Sunshine (PRM 87.8)

Water level and discharge data were available at both **USGS** stations for all five events. Table 1 shows the maximum and minimum discharges for each event at both **USGS** stations. Only water level data were available at the **ESS** stations and the availability of the data varied by event. Table 3 lists all of the **ESS** water level stations and data availability. Available data are denoted with a check mark (✓). Note that, although water level data was provided at **USGS** 15292780 (PRM 87.8) and **ESS30** (98.4), these stations are not within the study area and are therefore not included in the table.

Although the study reach encompasses the portion of the Susitna River from the proposed dam site (PRM 187.2) to the town of Talkeetna (around PRM 99.9), the model was extended down to PRM 29.9 using the available surveyed cross-section data to ensure that any backwater or drawdown effects associated with erroneous values input for the downstream boundary condition would not extend upstream into the study reach. This allowed the downstream water level boundary condition to be set to a constant value for the five events.

4. CALIBRATION

For the purposes of calibrating the modelled roughness values, the study reach was delineated into subreaches based on the channel geomorphology. The subreaches are shown in Figure 4. For context, this figure also shows the locations of the available gauging stations within and near the study reach, and the locations along the channel where the inflows were applied to the model.

Open water calibration of the model only focused on the adjustment of the main channel Manning's *n* values (n_c). Calibration of the main channel roughness was completed by adjusting roughness values within each subreach, starting at the downstream subreach and working upstream until the model water levels agreed well with the observed gauge water levels for the four calibration events. The calibrated n_c values are shown in Figure 4. Where two n_c values are reported, the model was calibrated using the first value at lower discharges and the second value at higher discharges. The lower values used at higher discharges are justified since, generally, the relative channel roughness decreases with increasing discharge. The calibrated roughness values are all within the acceptable range of values for natural streams as reported in Table 5-6 in Chow (1959).

Each calibration event was run with a time step of 1.5 minutes (0.025 hours) and implicitness of $\theta = 0.5$. For all four events, the water level at the downstream boundary was set to 45 ft. This value was determined based on the main channel inverts in the model. This value ensured a positive water depth at the downstream boundary where the channel invert is 5.1 ft but also ensured that any backwater effects did not extend to the downstream end of the study reach (PRM 99.9) where the channel invert is 322.6 ft. Model results were output at all of the gauge locations at 15 minute intervals (0.25 hours).

Figures 5 through 12 show comparisons of the modelled discharge to the data provided for the two **USGS** gauges for each of the four calibration events. Table 4 summarizes the absolute and relative errors between the modelled and observed discharges at the two **USGS** gauges for all five events.

Relative error was defined as follows:

$$\text{relative error} = \left|\frac{Q_{modelled} - Q_{observed}}{Q_{observed}}\right|$$

where $Q_{modelled}$ is the modelled discharge and $Q_{observed}$ is the observed discharge.

Overall, the agreement between the modelled and observed discharge values is very good. At both **USGS** gauges, for all four calibration events, the mean relative error is not greater than 1% and the maximum relative error does not exceed 13%.

Figures 13 through 35 show the comparisons of the modelled water levels to the observed water levels for the four calibration events. Table 5 summarizes the mean and maximum absolute error between the modelled and observed water levels. Note that water level comparisons and errors are not reported at **USGS** 15292780 (PRM 87.8) and **ESS30** (98.4) since they are not within the study reach. The mean absolute errors in the water levels are all less than or equal to the 1 foot tolerance.

To further reduce the maximum and mean absolute errors in the water level would likely require breaking the study reach down into smaller subreaches and/or using channel roughness values rounded to the nearest 0.001. Based on the approximate nature of 1-D modelling, the spacing of the available channel geometry, and the potential errors in measuring water levels on a river of this size and type, it is not deemed that this level of calibration refinement is warranted.

5. VALIDATION

Once the model channel roughness values were calibrated for the four calibration events, the Validation Event was simulated. The event was run in the same manner as the calibration events, with a time step of 1.5 minutes (0.025 hours) and implicitness of $\theta = 0.5$. The water level at the downstream boundary was set to 45 ft. Model results were output at all of the gauge locations at 15 minute intervals (0.25 hours).

Figures 36 through 37 show comparisons of the modelled discharge to the data provided for the two **USGS** gauges. Table 6 summarizes the absolute and relative errors between the modelled and observed discharges at the two **USGS** gauges. At both **USGS** gauges, the mean relative error is less than 1% and the maximum relative error does not exceed 4%. Figure 38 compares the modelled water levels to the observed water levels at **USGS** 15292000 (PRM 140). Table 6 also summarizes the mean and maximum absolute error between the modelled and observed water levels at **USGS** 15292000 (PRM 140). Both maximum and mean absolute errors are within the 1 foot tolerance at this gauge.

Although good results were achieved for this model validation, it is important to note that only one gauge within the study reach was operational at the time of this event. As a result the model has not been validated at any stations other than at **USGS** 15292000 (PRM 140). In addition, only one validation event was available to assess the model performance and this event only covers a very small range of discharges, from 17,000 to 24,200 cfs (see Table 1); therefore the model is not validated for events outside of this range.

6. SUMMARY

Prior to calibrating the *River1D* model for ice process modelling within the study reach of the Susitna River, an open water calibration was required. The *River1D* model was set-up for simulating open water events within the study reach using geometry and overbank Manning's *n* roughness values provided by **HDR**. The model was then calibrated for four open water events within the study reach using discharge and water level data. The study reach was delineated into subreaches based on the channel geomorphology. Calibration of the main channel Manning's *n* values (n_c) was completed by adjusting these roughness values within the subreaches, rounded to the nearest 0.005. For all four calibration events, the mean relative error in discharge was not greater than 1% and the maximum relative error was not greater than 13%. The mean absolute errors in the water levels were less or equal to the 1 foot specified tolerance. Given the approximate nature of 1-D modelling, the available data, and potential errors in water level measurements on a river this size and type, further refinement to the calibration is not justified.

Once the model was calibrated, it was validated for one event using discharge and water level data. For this event, the mean relative error in the discharge was less than 1% and the maximum relative error in the discharge did not exceed 4%. For the water level gauge data within the study reach, the maximum and mean absolute errors in the water levels were within the 1 foot tolerance. Since only one water level gauge was active within the study reach during this validation event, it is recommended that additional events be provided to facilitate completion of the model validation, particularly ones where more of the gauges within the study reach were operational.

7. LITERATURE CITED

Chow, V.T. 1959. Open Channel Hydraulics. McGraw-Hill Book Company, New York, New York, 680 pp.

Hicks, F.E. and Steffler, P.M. 1992. A characteristic dissipative Galerkin scheme for open-channel flow, Journal of Hydraulic Engineering, 118 (2): 337-352.

8. TABLES

Table 1. List of Calibration and Validation Events.

Event	Event Start Date	Event End Date	USGS 15292000		USGS 15292780	
			Discharge (cfs)			
			Minimum	Maximum	Minimum	Maximum
Calibration Event 1	August 17, 2012	August 22, 2012	15100	17900	34800	45600
Calibration Event 2	September 11,2012	October 5, 2012	10100	72900	28200	198000
Calibration Event 3	August 17, 2013	August 30, 2013	16100	49100	42900	96900
Calibration Event 4	October 1, 2013	October 31, 2013	6710	11400	19700	52300
Validation Event	July 26, 2013	August 4, 2013	17000	24200	51600	65500

Table 2. List of model inflows.

Input Flow Name	Input Flow Description	PRM Input Location (specified by HDR)	Actual Model PRM Input Location
Upstream Boundary	Tsusena Creek (USGS 15291700), lagged -0.5 hours (upstream inflow boundary condition)	187.2	187.2 (surveyed cross section)
Ungauged 1	Ungauged lateral inflows between PRM 187.2 and PRM 140, calculated at PRM 140, lagged -3.25 hours (lateral inflow boundary condition)	163.4	163.41 (surveyed cross section)
Ungauged 2	Ungauged lateral inflows between PRM 140 and PRM 88, calculated at PRM 88, lagged -3.5 hours (lateral inflow boundary condition)	112	112.05 (interpolated cross section)
Chulitna River	Chulitna River HDR Model Output (lateral inflow boundary condition)	102.4	102.5 (interpolated cross section)
Talkeetna River	Talkeetna River HDR Model Output (lateral inflow boundary condition)	100.3	100.3 (interpolated cross section)

Table 3. List of available ESS station water level data for the calibration and validation events.

Event	ESS Station								
	ESS70 (PRM 187.2)	ESS65 (PRM 176.5)	ESS60 (PRM 168.1)	ESS55 (PRM 152.1)	ESS50 (PRM 124.1)	ESS45 (PRM 116.6)	ESS40 (PRM 107.1)	ESS35 (PRM 102.1)	ESS30 (PRM 98.4)
Calibration Event 1	✓	✓		✓	✓	✓	✓	✓	✓
Calibration Event 2	✓			✓	✓	✓	✓	✓	✓
Calibration Event 3					✓	✓	✓		✓
Calibration Event 4					✓	✓	✓		✓
Validation Event									✓

Table 4. Errors in discharge for the calibration events: absolute and relative.

Event	USGS Station							
	USGS 15292000 Susitna River at Gold Creek (PRM 140)				USGS 15292780 Susitna River near Sunshine (PRM 87.8)			
	Absolute error (cfs)		Relative Error (%)		Absolute error (cfs)		Relative Error (%)	
	maximum	mean	maximum	mean	maximum	Mean	maximum	mean
Calibration Event 1	900	83	5.4	0.5	995	397	2.6	1.0
Calibration Event 2	6664	337	12.7	0.9	19402	720	11.3	0.8
Calibration Event 3	1442	203	6.7	0.8	4586	637	4.9	1.0
Calibration Event 4	324	71	4.6	0.8	1167	192	4.5	0.7

Table 5. Absolute errors in water level (in feet) for the calibration events.

Station Name	Calibration Event 1		Calibration Event 2		Calibration Event 3		Calibration Event 4	
	maximum	mean	maximum	mean	maximum	mean	maximum	mean
ESS70 (PRM 187.2)	0.6	0.5	1.6	0.6				
ESS65 (PRM 176.5)	0.8	0.6						
ESS55 (PRM 152.1)	0.4	0.2	2.2	0.6				
USGS 15292000 (PRM 140)	0.3	0.3	0.9	0.3	0.5	0.3	0.4	0.3
ESS50 (PRM 124.1)	0.5	0.4	1.3	0.6	0.5	0.2	1.0	0.6
ESS45 (PRM 116.1)	0.2	0.1	1.3	0.2	0.6	0.1	1.1	0.5
ESS40 (PRM 107.1)	0.3	0.1	2.0	0.9	0.7	0.4	1.7	0.6
ESS35 (PRM 102.1)	0.6	0.5	2.1	1.0				

Note: Blanks in table are for cases where there was no data to compare to the model results.

Table 6. Errors in discharge and water level for the Validation Event

Station Name	Errors in Discharge				Errors in Water Level	
	Absolute error (cfs)		Relative Error (%)		Absolute error (ft)	
	maximum	mean	maximum	mean	maximum	mean
USGS 15292000 Susitna River at Gold Creek (PRM 140)	700	67	3.7	0.3	0.4	0.3
USGS 15292780 Susitna River near Sunshine (PRM 87.8)	1734	508	3.1	0.9	station is not within the study reach	

9. FIGURES

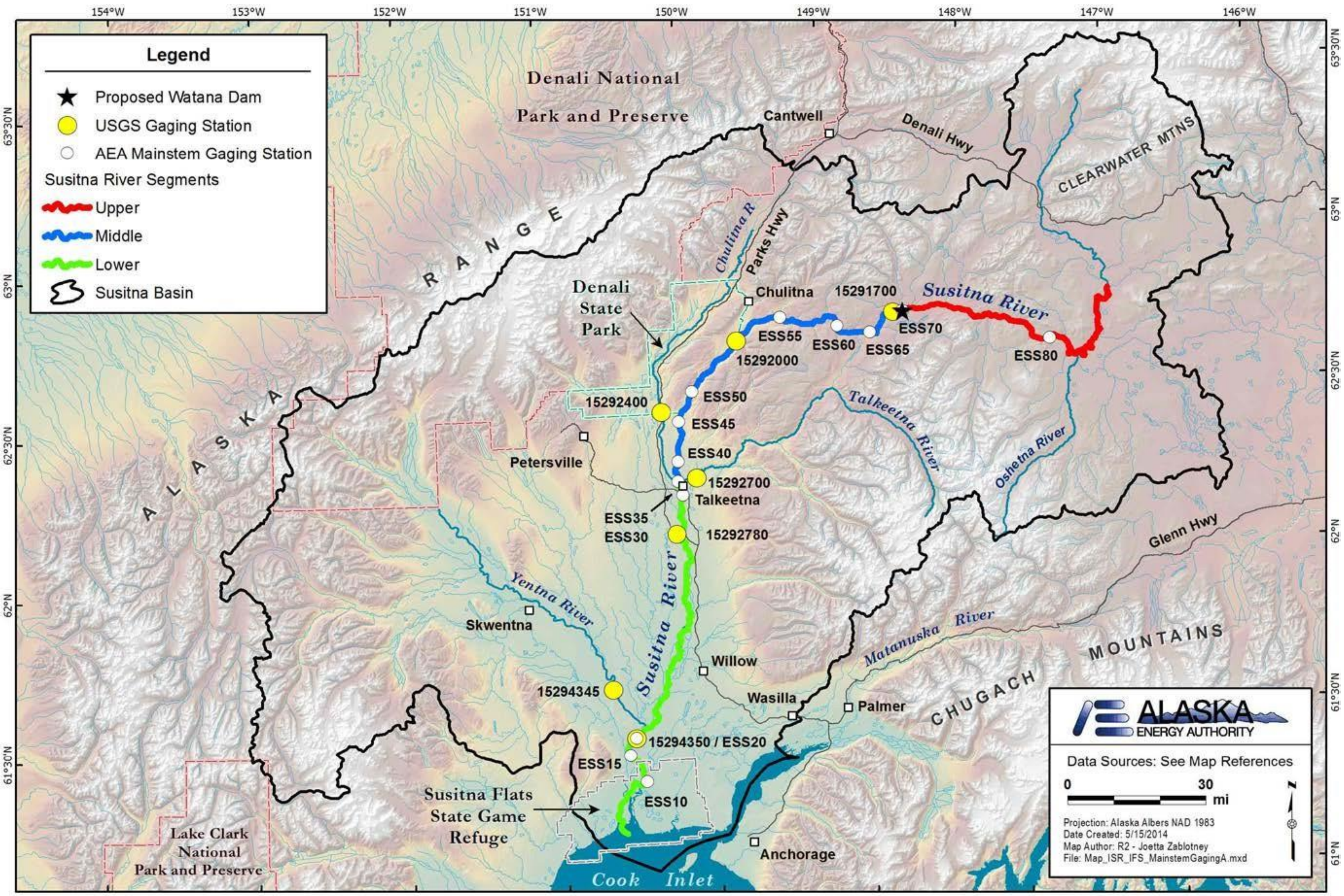

Figure 1. Location Map for the Susitna River ice process modelling study.

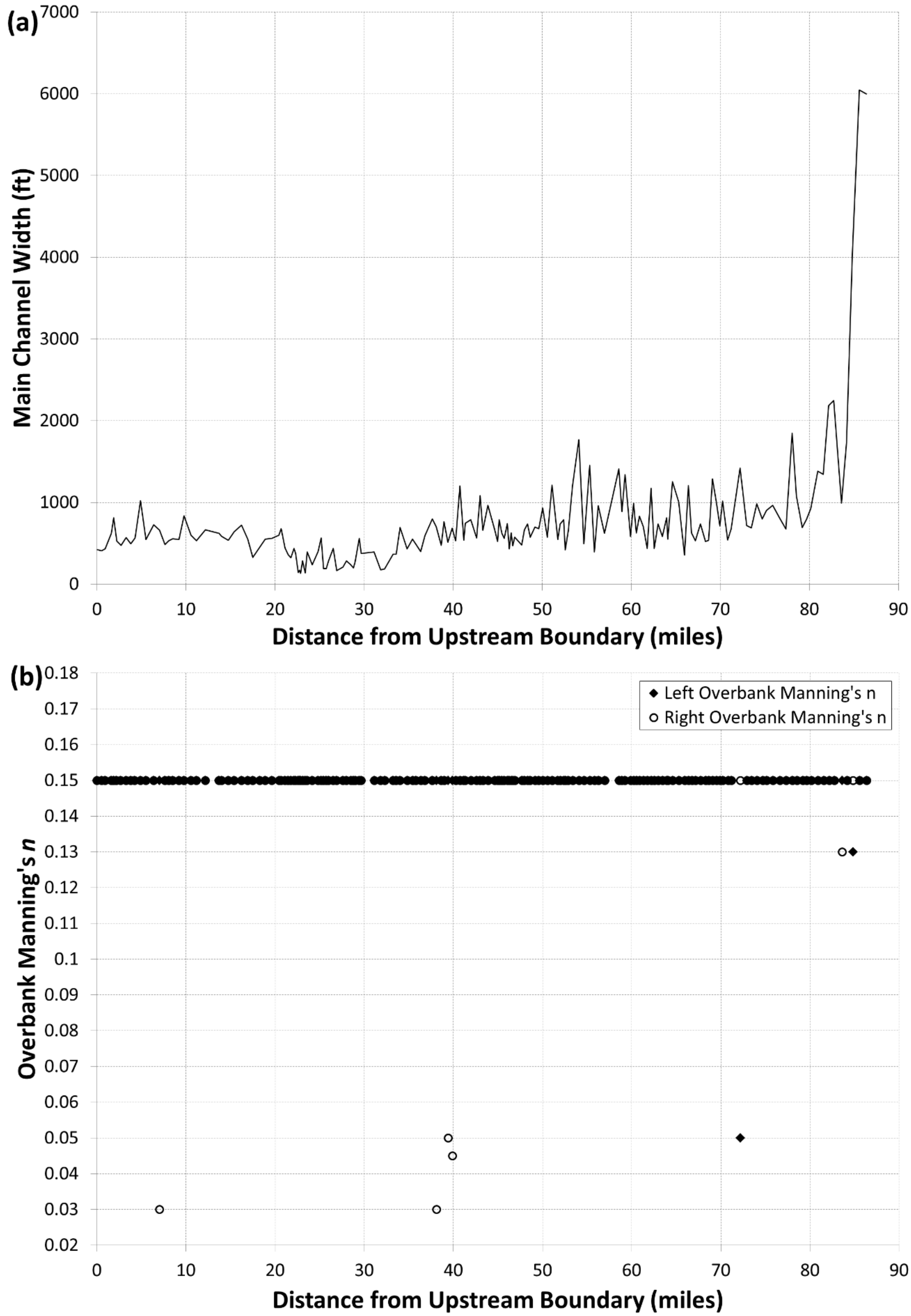

Figure 2. Overbank information for the study reach: (a) Main channel widths and (b) overbank roughness values.

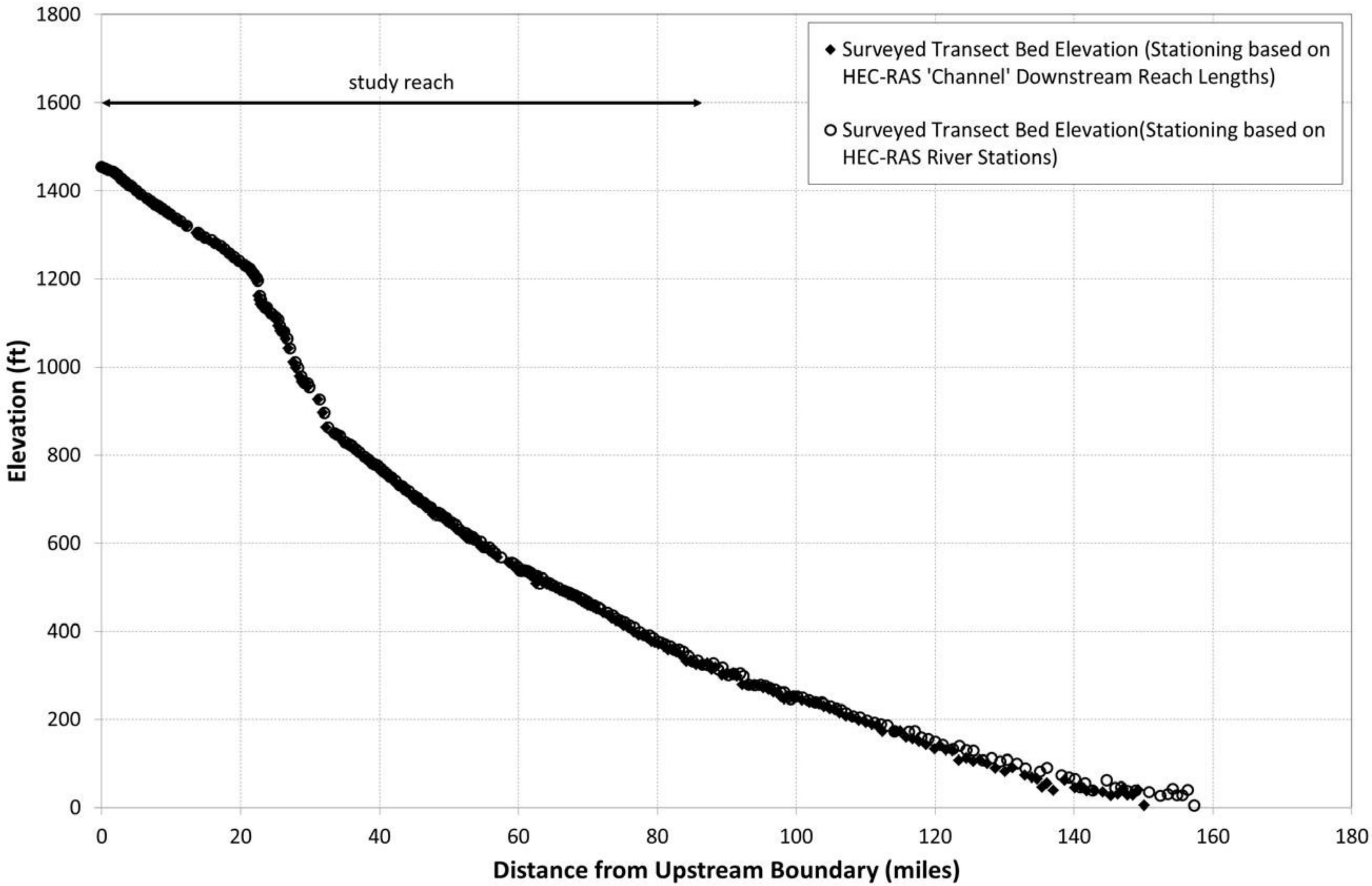

Figure 3. Comparison of Bed profile generated using HEC-RAS River Stations (based on PRM's) and using HEC-RAS Channel Downstream Reach Length between PRM 187.2 and PRM 29.9.

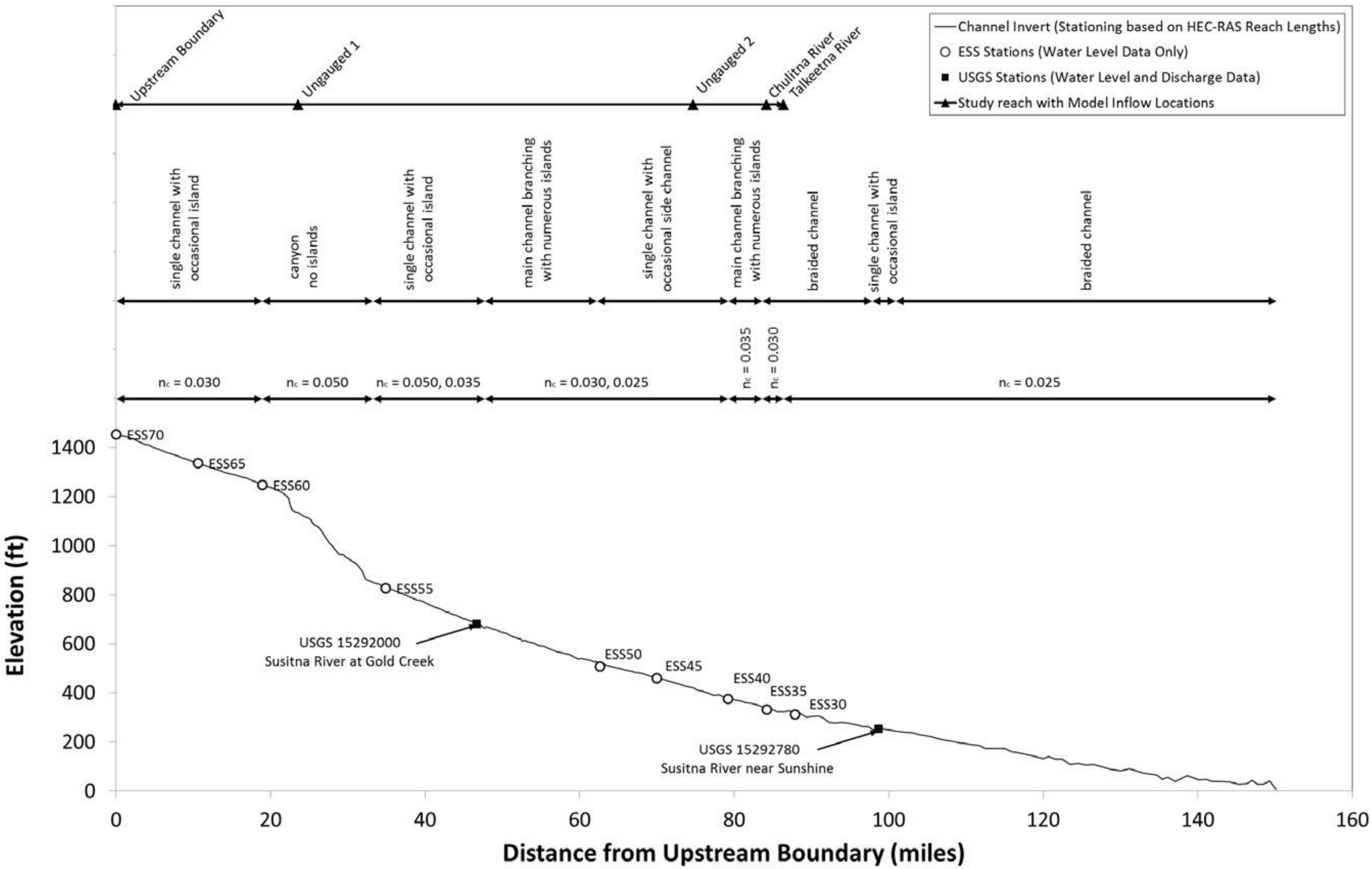

Figure 4. Channel pattern subreaches, calibrated main channel Manning's *n* values (n_c), model input flow locations and available gauge data locations between PRM 187.2 and PRM 29.9.

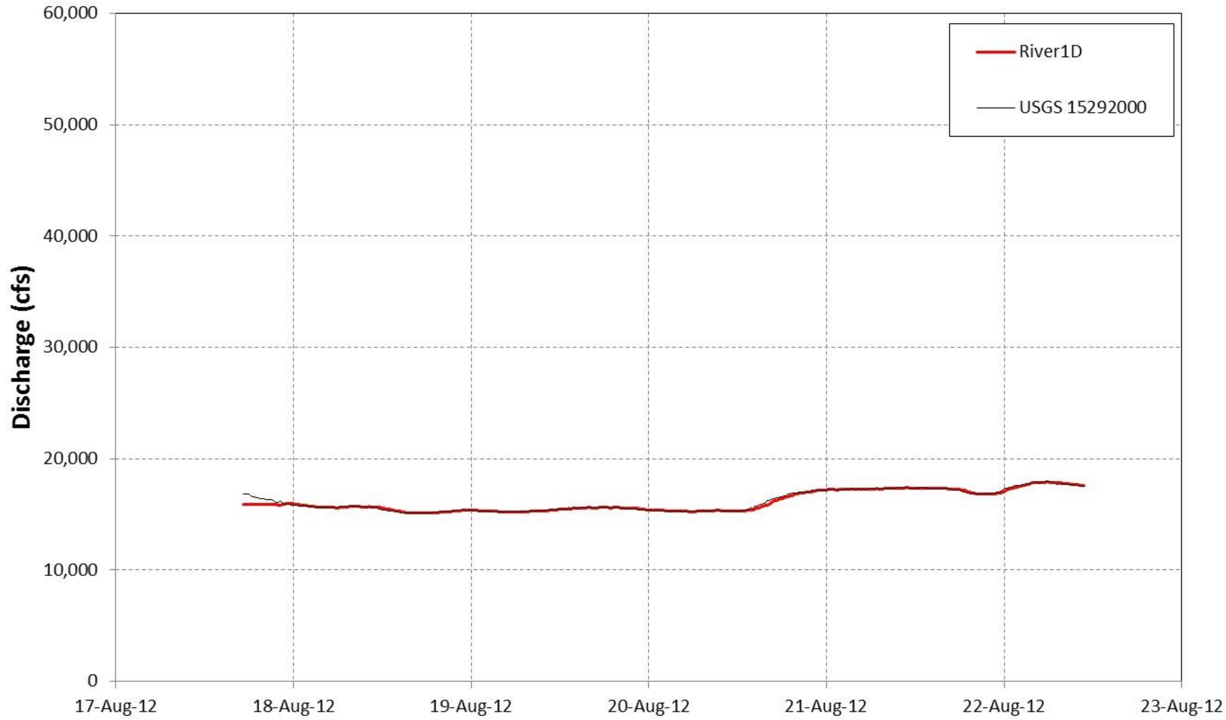

Figure 5. Modelled discharge results compared to observed data at PRM 140 for Calibration Event 1.

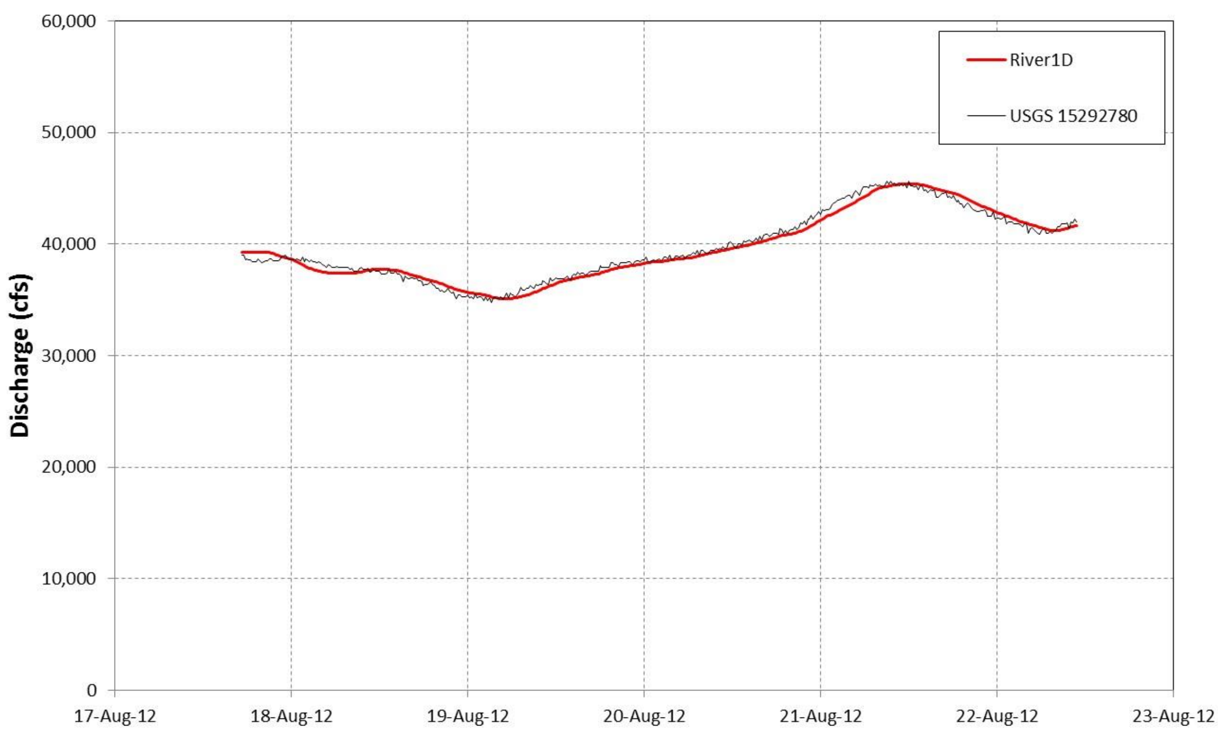

Figure 6. Modelled discharge results compared to observed data at PRM 87.8 for Calibration Event 1.

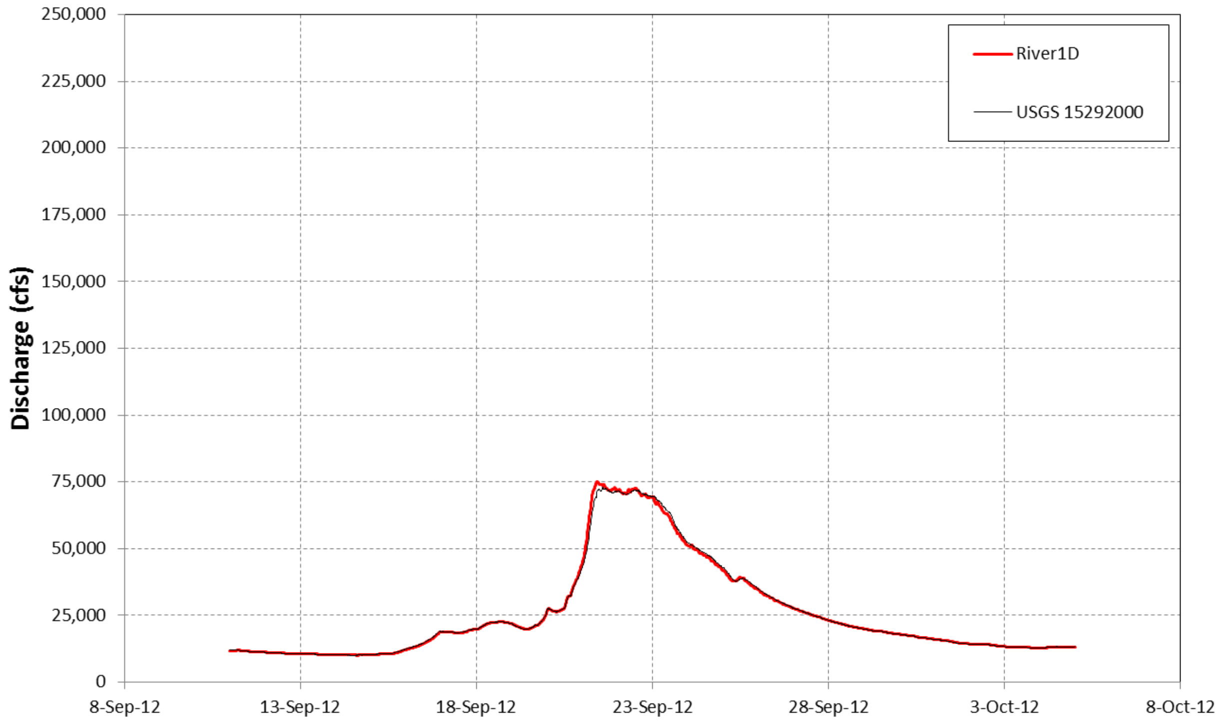

Figure 7. Modelled discharge results compared to observed data at PRM 140 for Calibration Event 2.

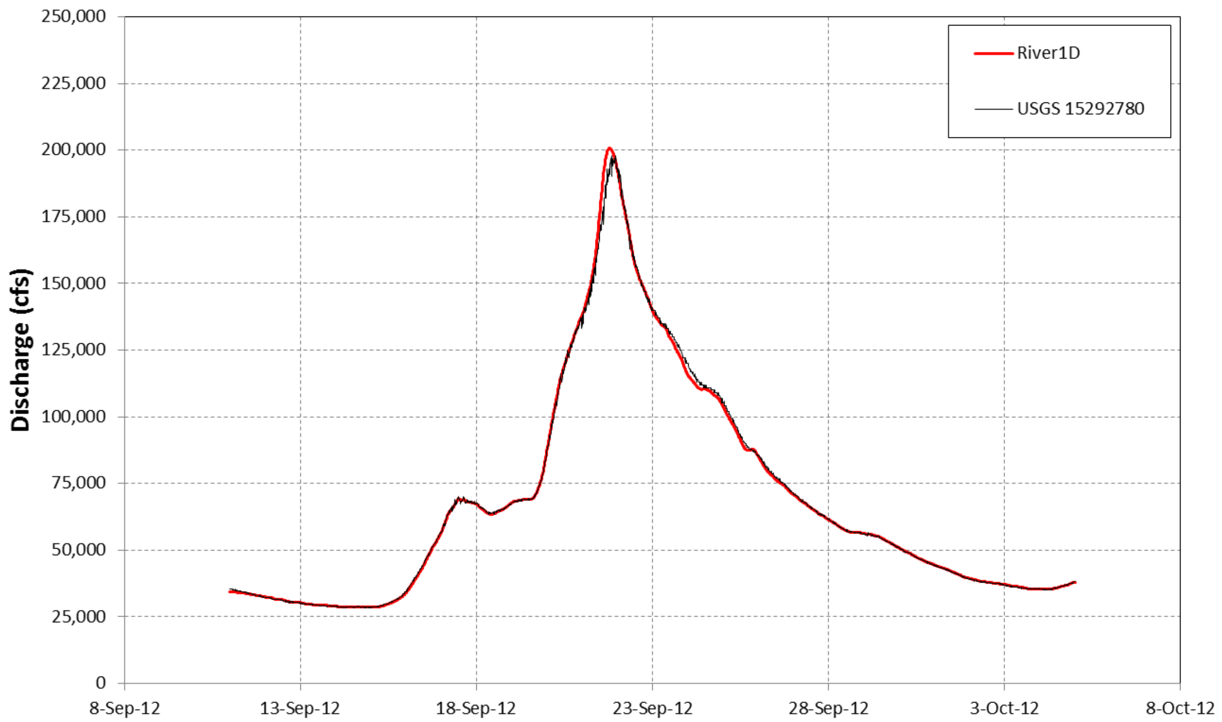

Figure 8. Modelled discharge results compared to observed data at PRM 87.8 for Calibration Event 2.

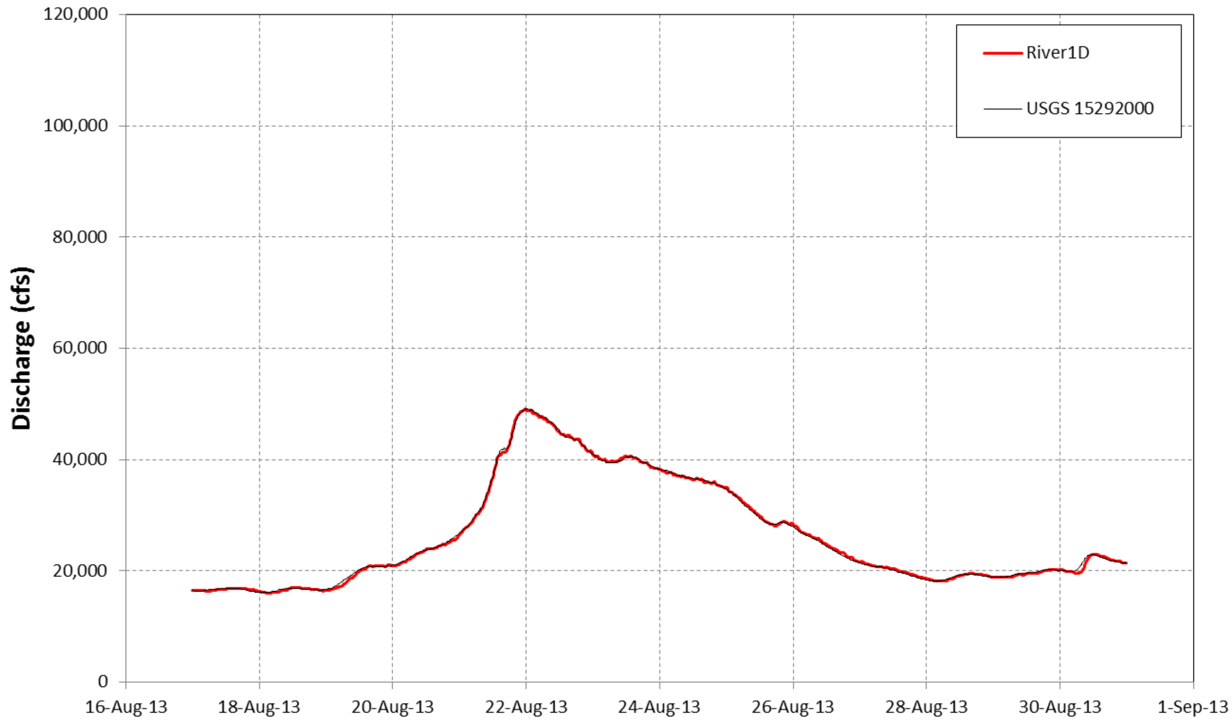

Figure 9. Modelled discharge results compared to observed data at PRM 140 for Calibration Event 3.

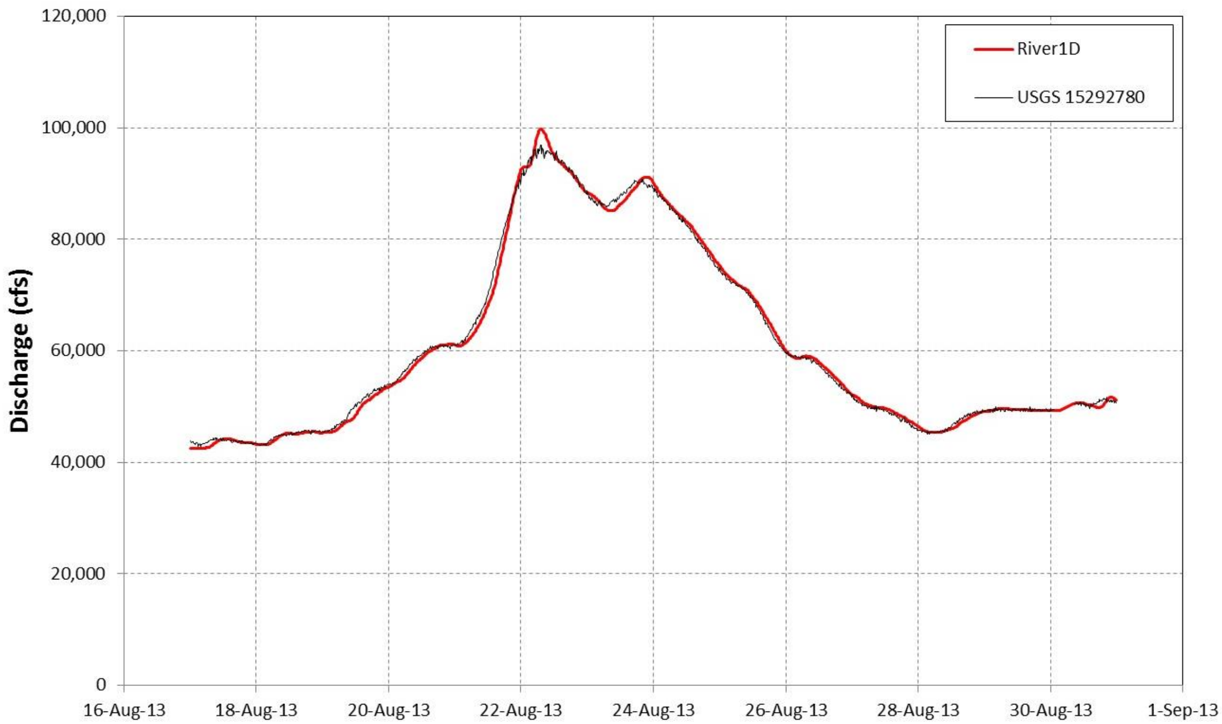

Figure 10. Modelled discharge results compared to observed data at PRM 87.8 for Calibration Event 3.

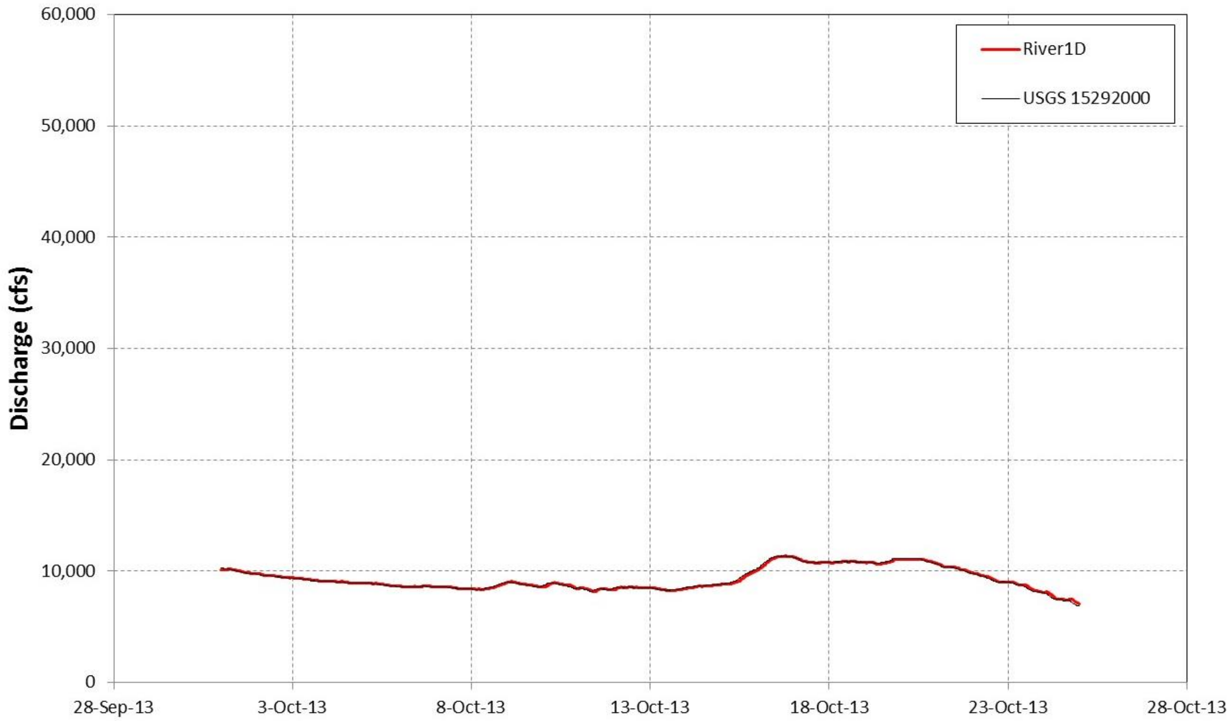

Figure 11. Modelled discharge results compared to observed data at PRM 140 for Calibration Event 4.

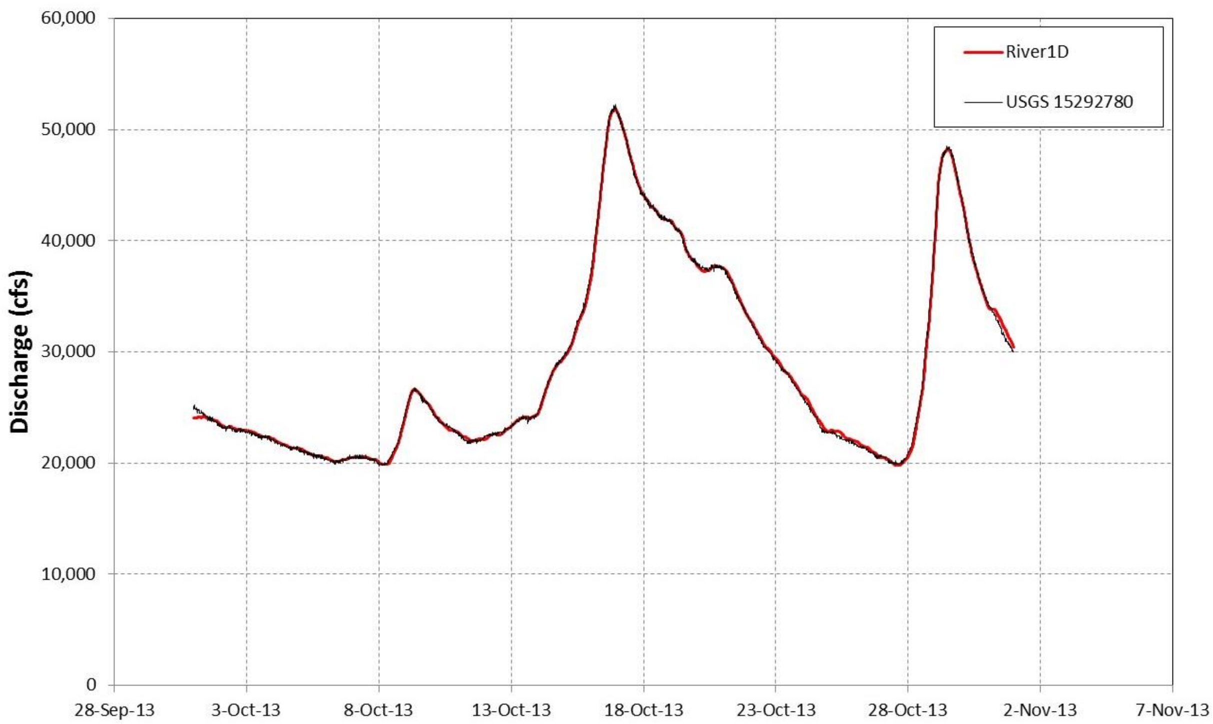

Figure 12. Modelled discharge results compared to observed data at PRM 87.8 for Calibration Event 4.

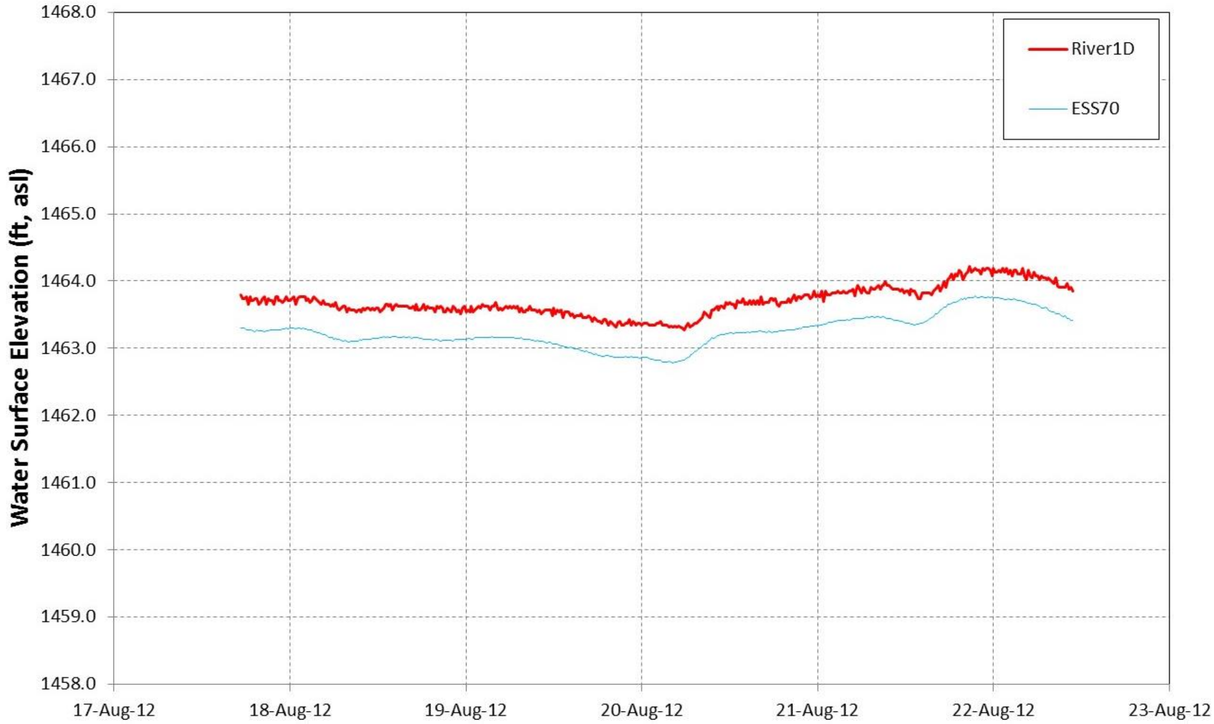

Figure 13: Modelled water levels compared to observed data at PRM 187.2 for Calibration Event 1.

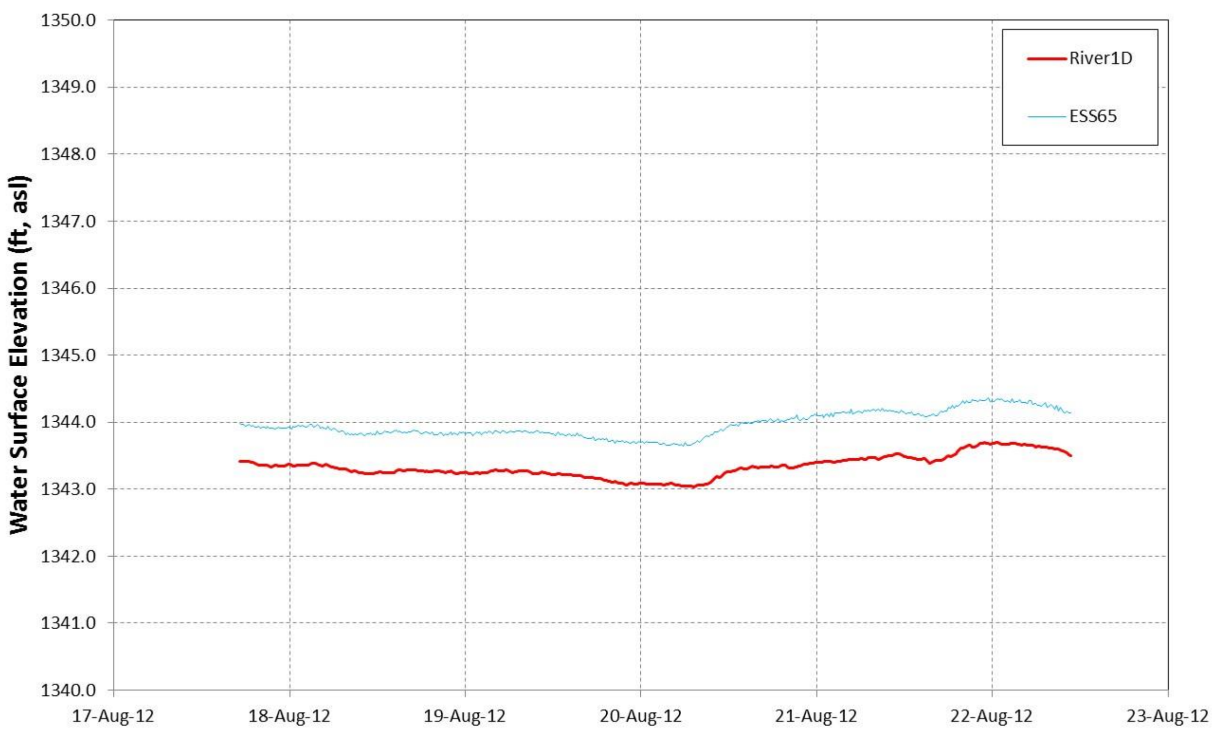

Figure 14: Modelled water levels compared to observed data at PRM 176.5 for Calibration Event 1.

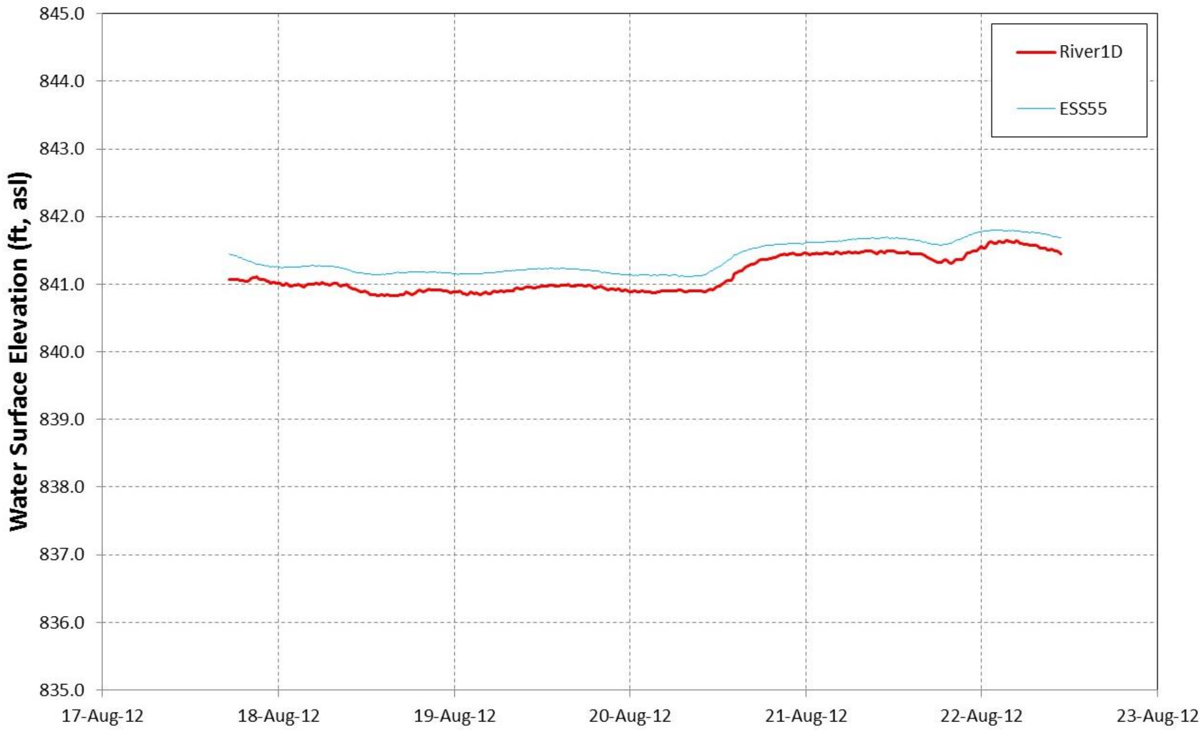

Figure 15: Modelled water levels compared to observed data at PRM 152.1 for Calibration Event 1.

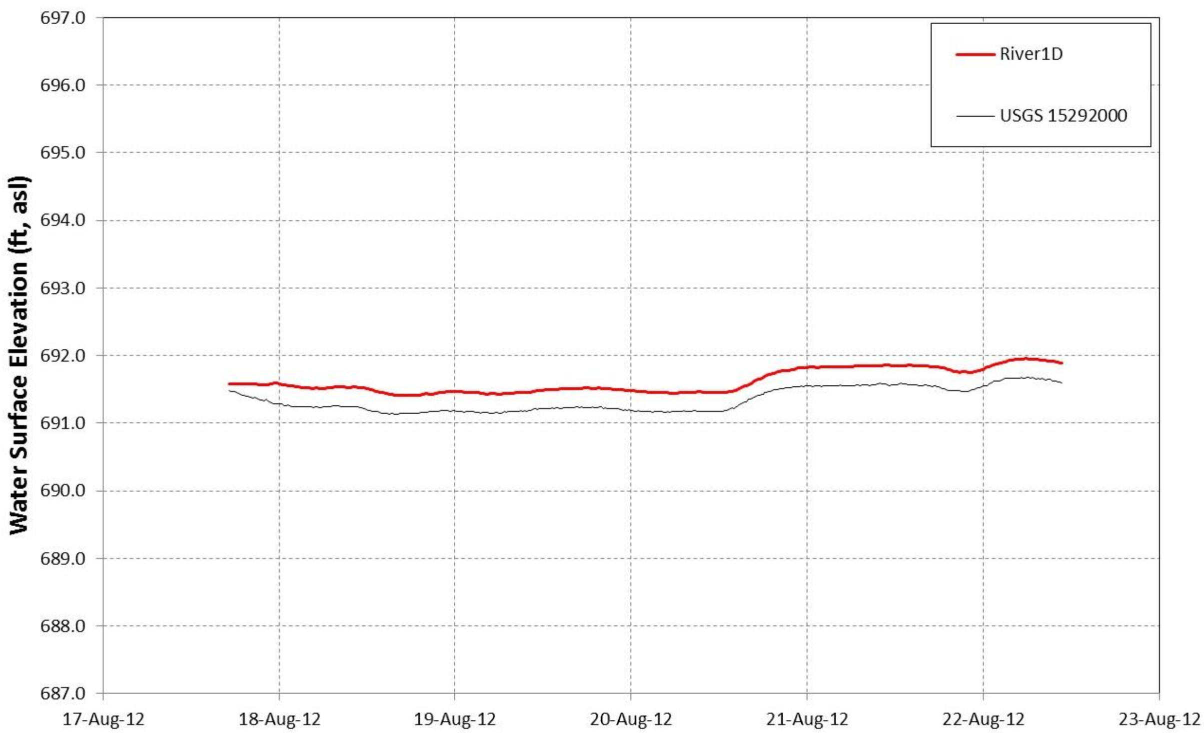

Figure 16: Modelled water levels compared to observed data at PRM 140 for Calibration Event 1.

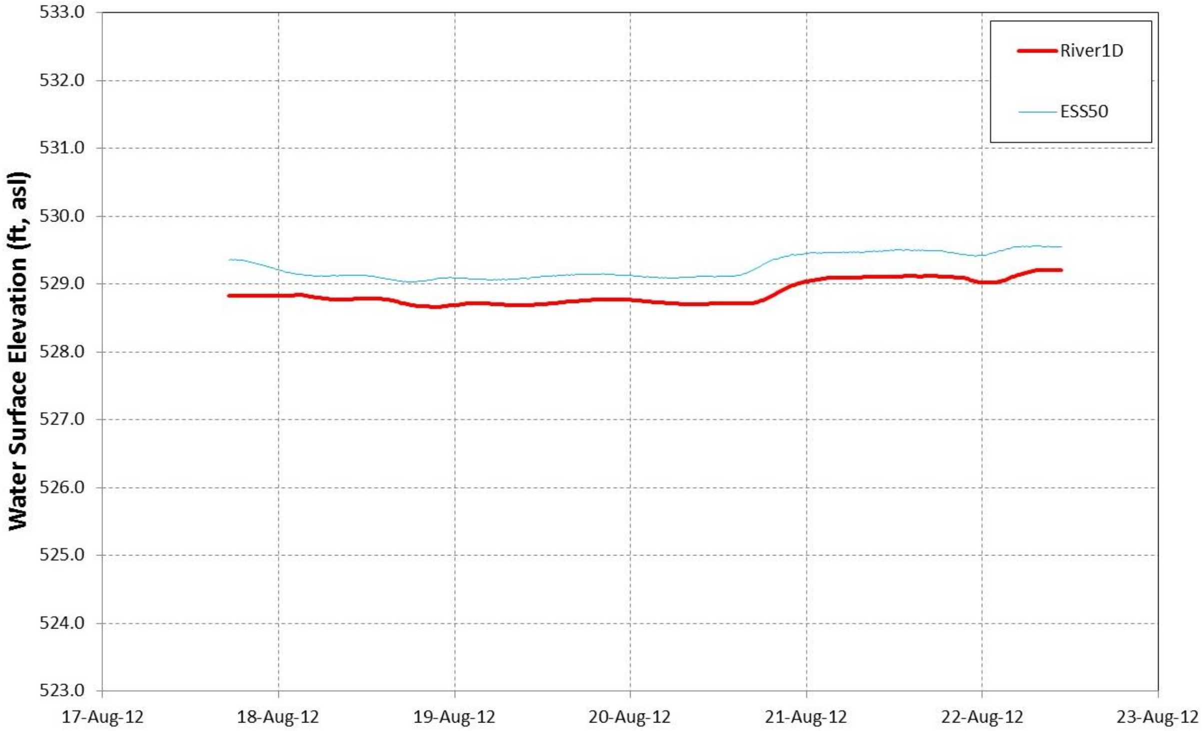

Figure 17: Modelled water levels compared to observed data at PRM 124.1 for Calibration Event 1.

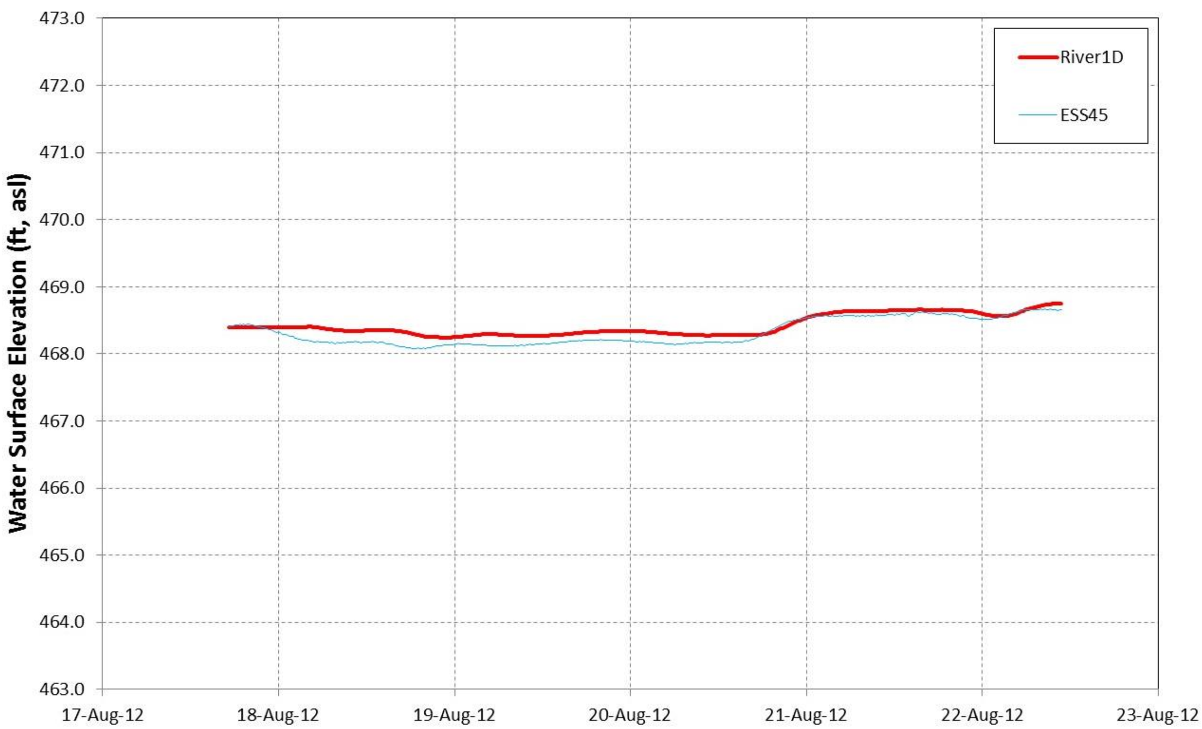

Figure 18: Modelled water levels compared to observed data at PRM 116.6 for Calibration Event 1.

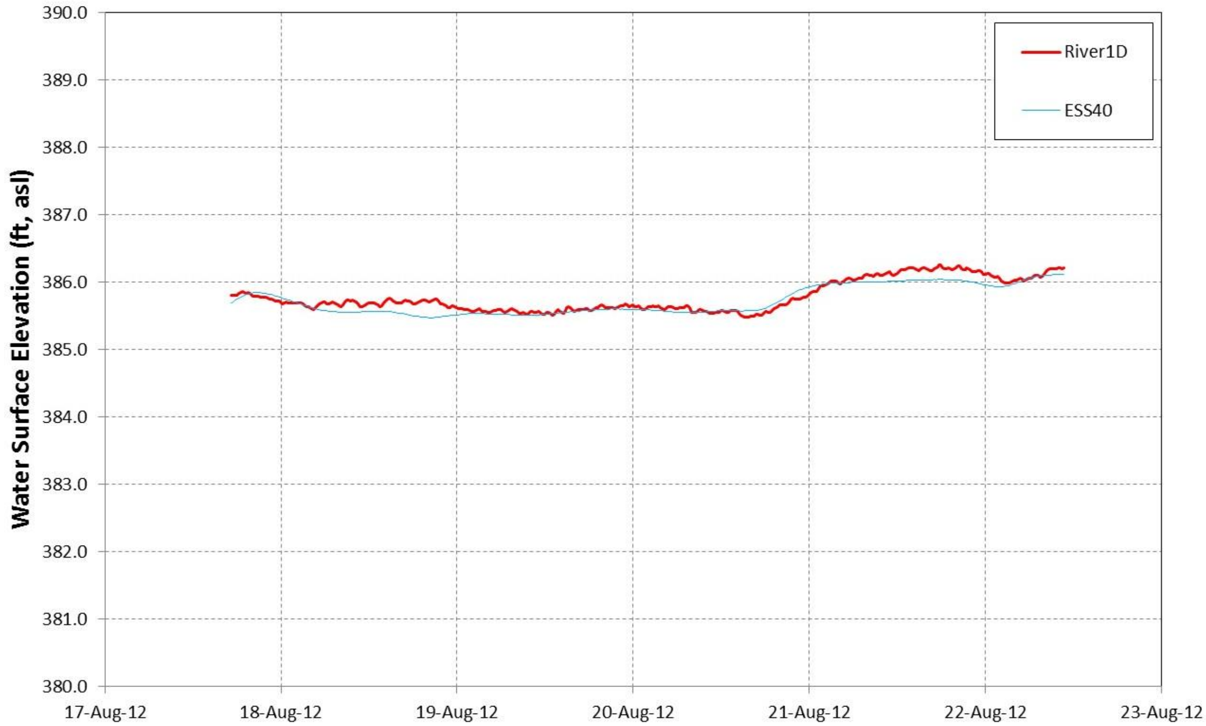

Figure 19: Modelled water levels compared to observed data at PRM 107.1 for Calibration Event 1.

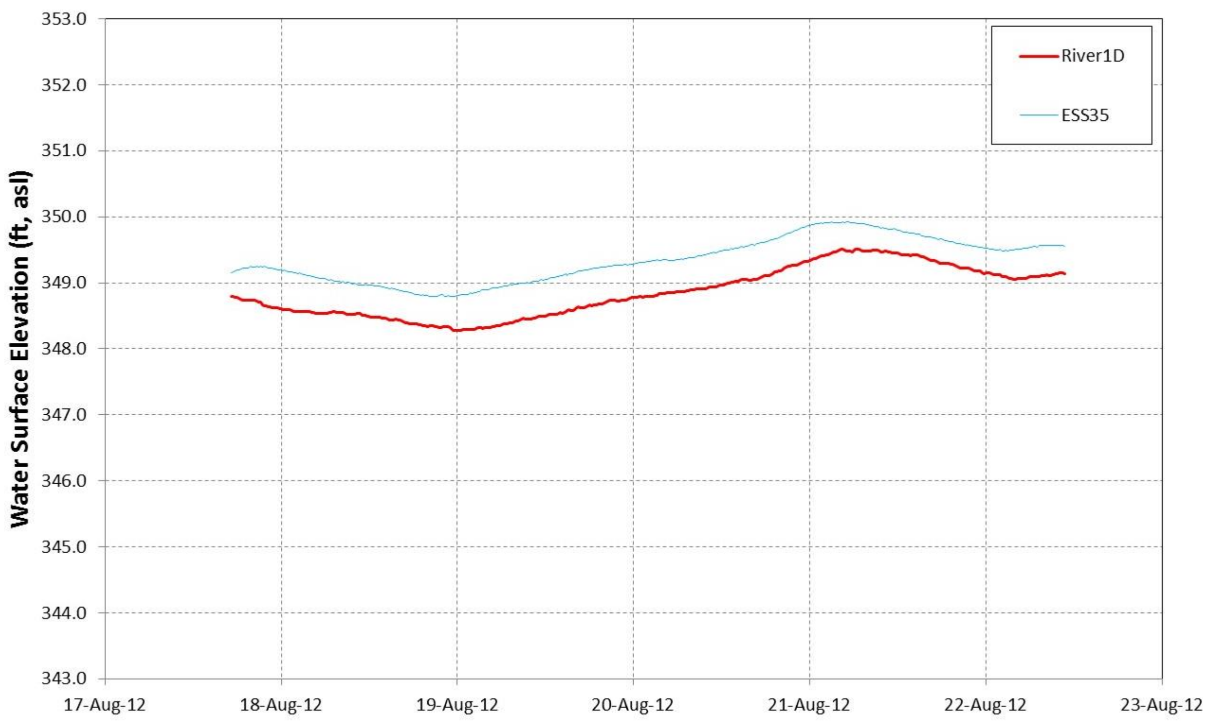

Figure 20: Modelled water levels compared to observed data at PRM 102.1 for Calibration Event 1.

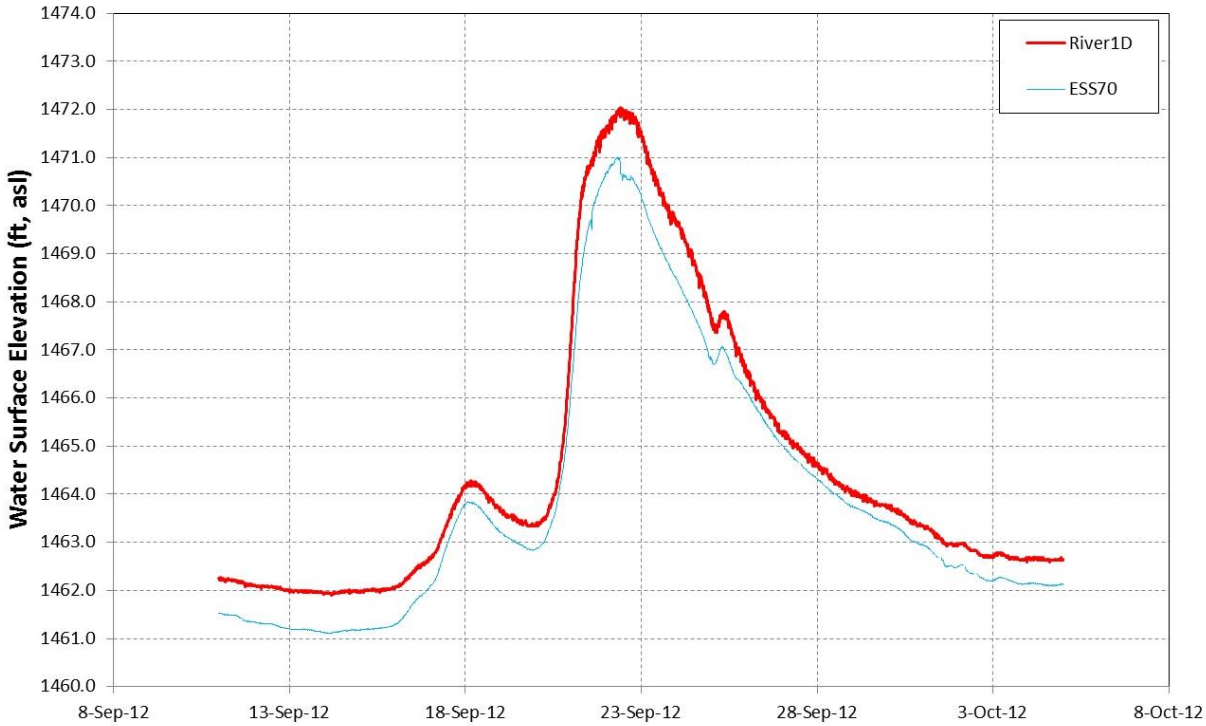

Figure 21: Modelled water levels compared to observed data at PRM 187.2 for Calibration Event 2.

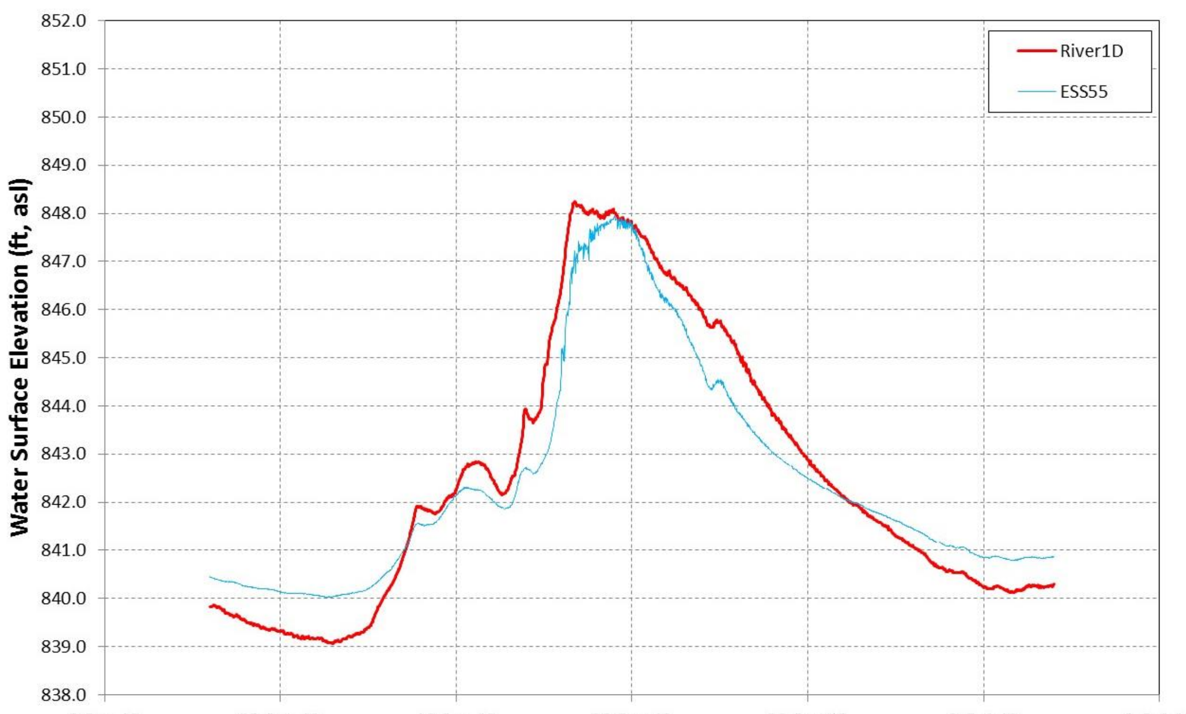

Figure 22: Modelled water levels compared to observed data at PRM 152.1 for Calibration Event 2.

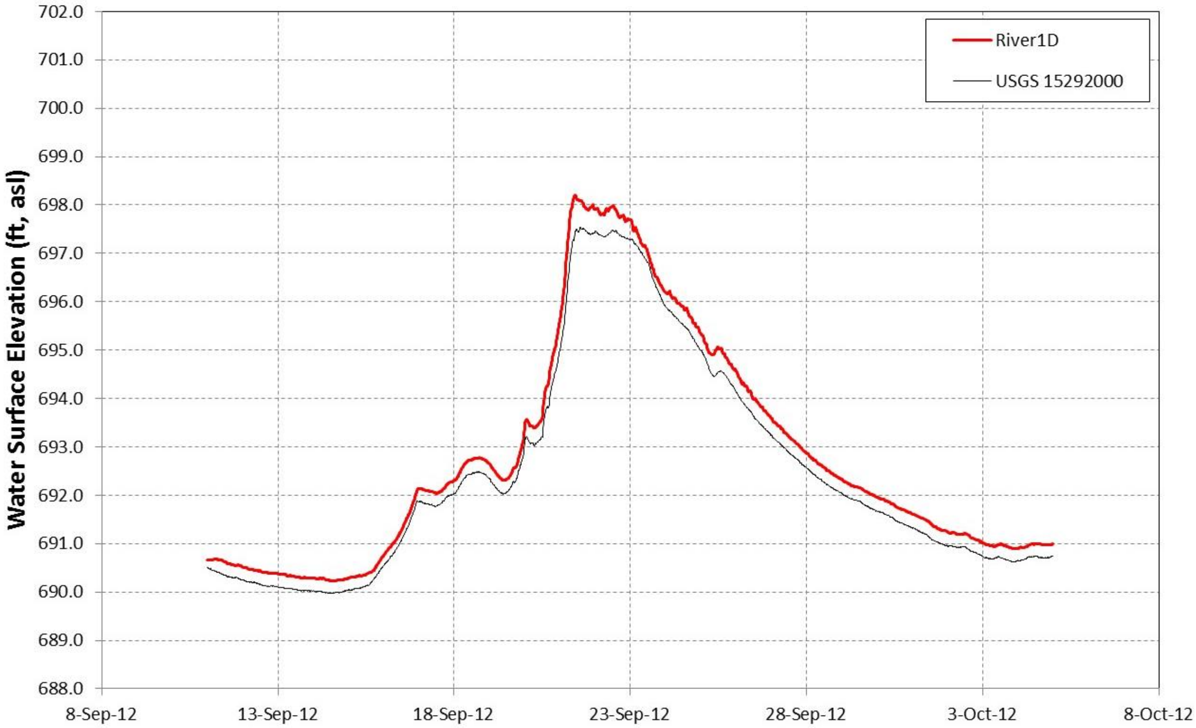

Figure 23: Modelled water levels compared to observed data at PRM 140 for Calibration Event 2.

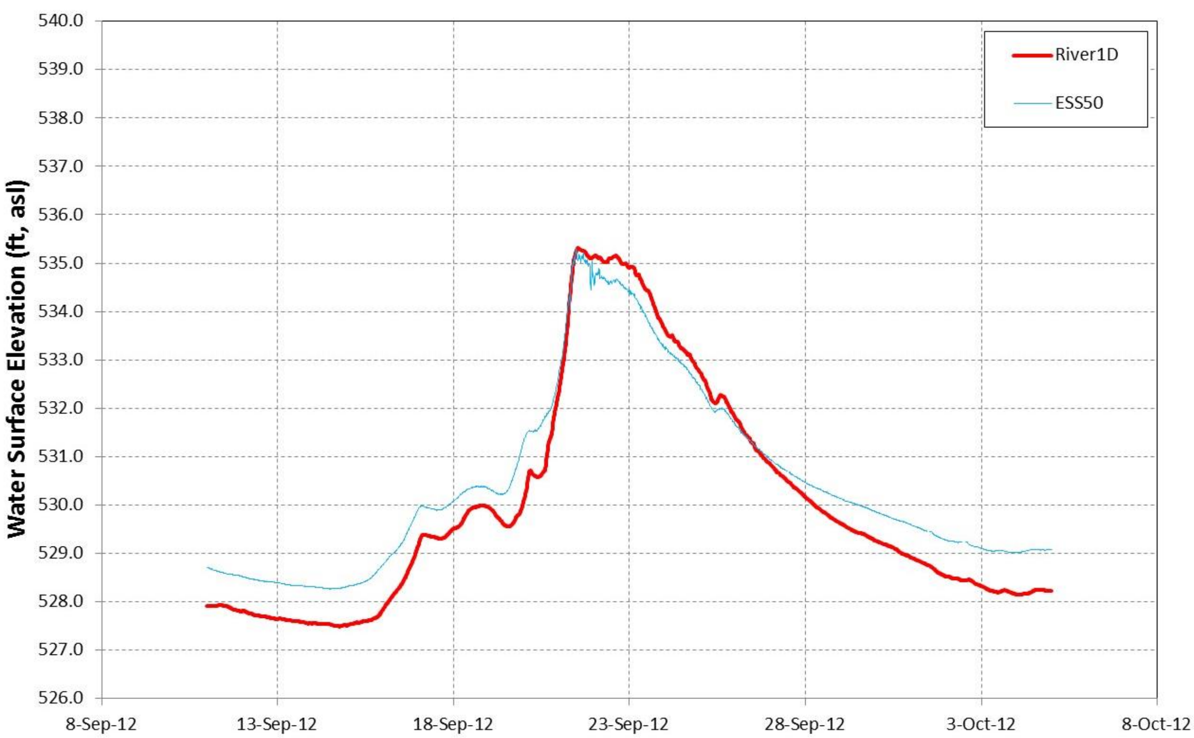

Figure 24: Modelled water levels compared to observed data at PRM 124.1 for Calibration Event 2.

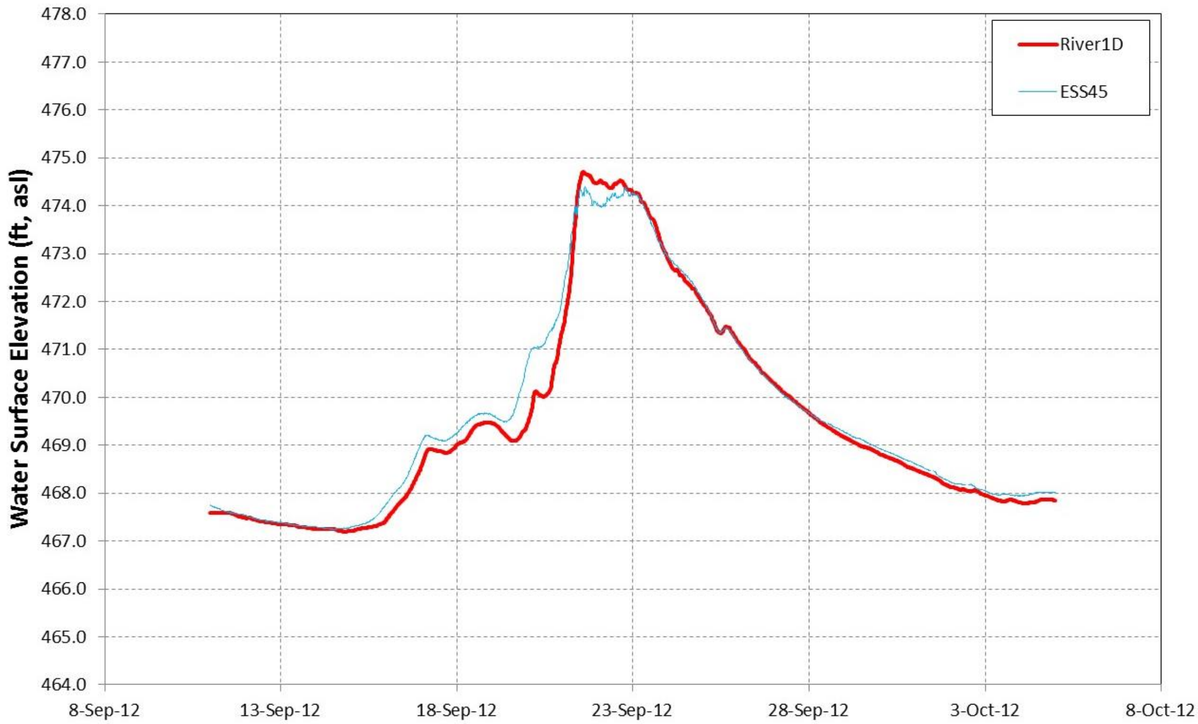

Figure 25: Modelled water levels compared to observed data at PRM 116.6 for Calibration Event 2.

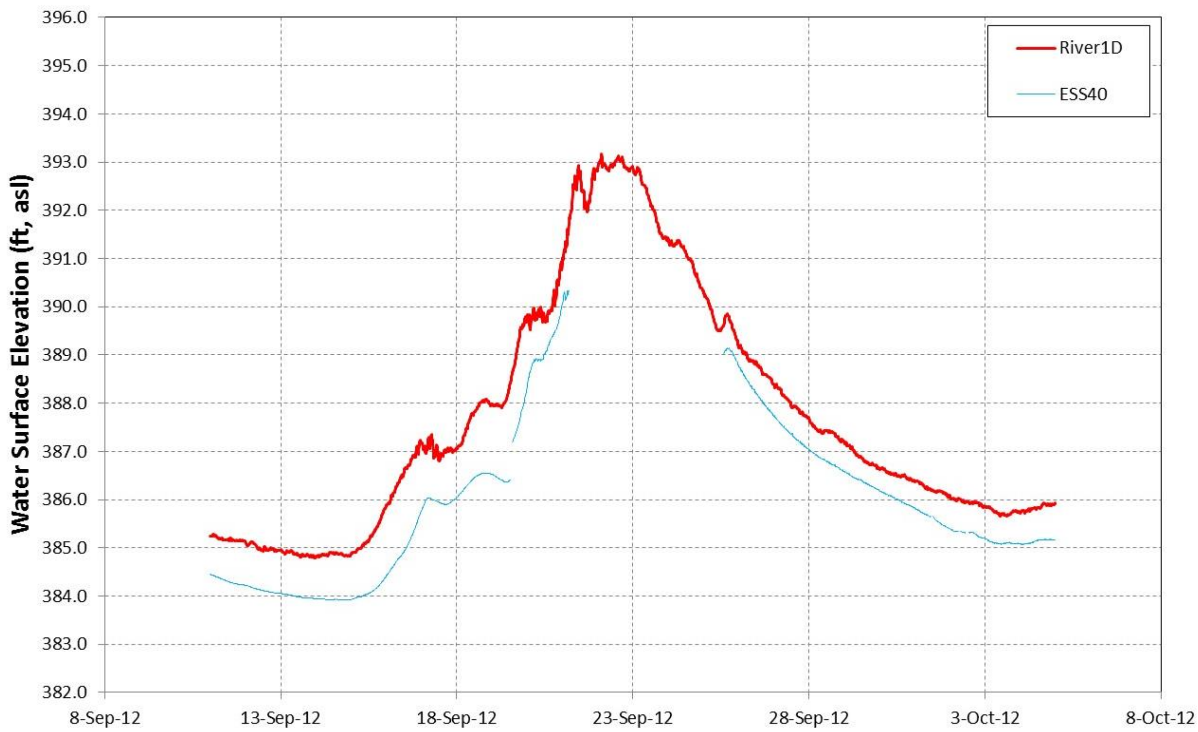

Figure 26: Modelled water levels compared to observed data at PRM 107.1 for Calibration Event 2.

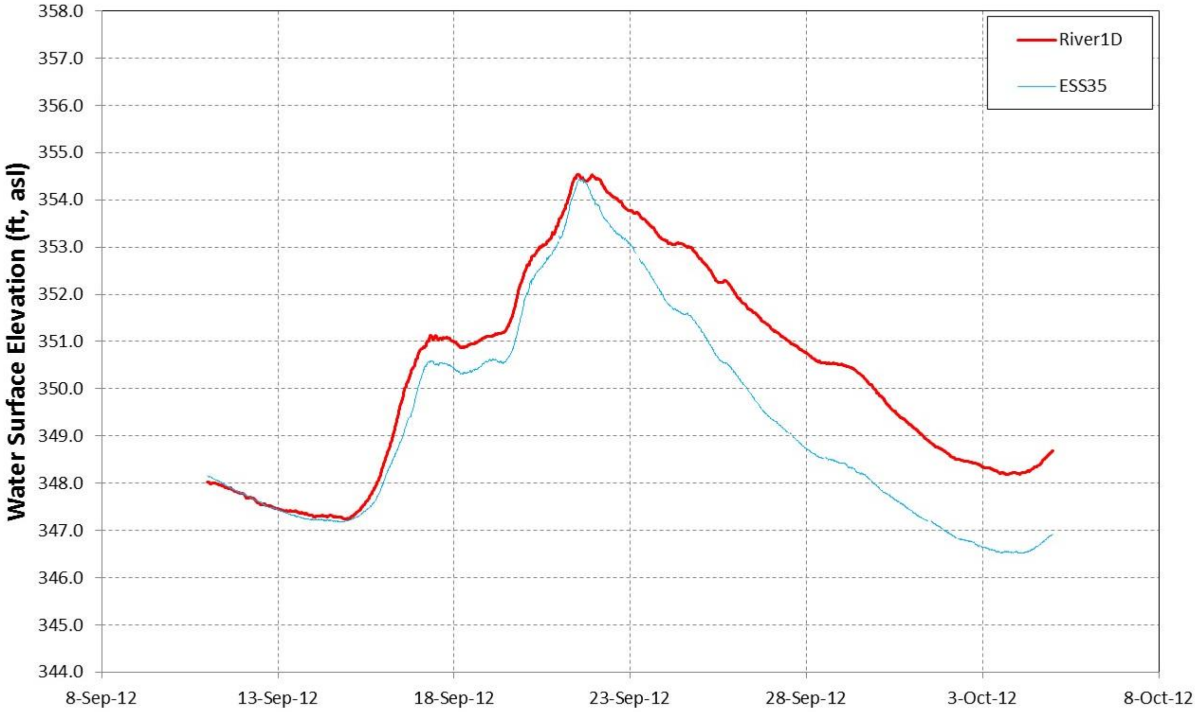

Figure 27: Modelled water levels compared to observed data at PRM 102.1 for Calibration Event 2.

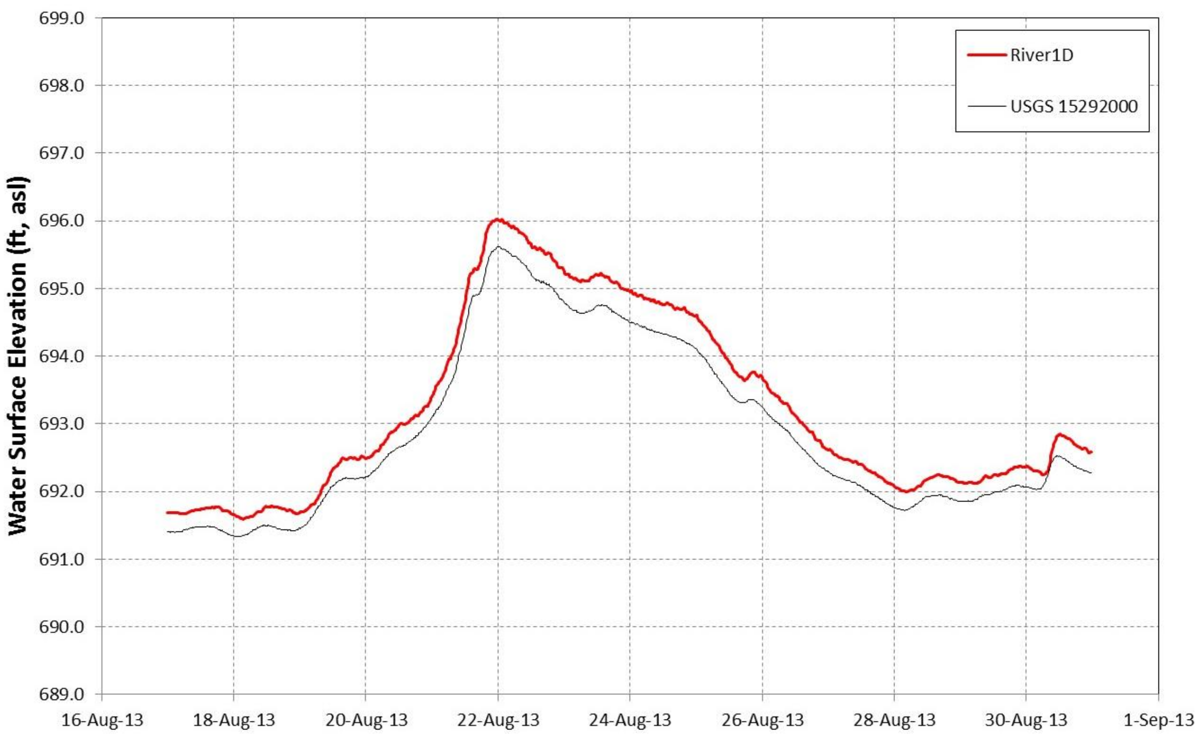

Figure 28: Modelled water levels compared to observed data at PRM 140 for Calibration Event 3.

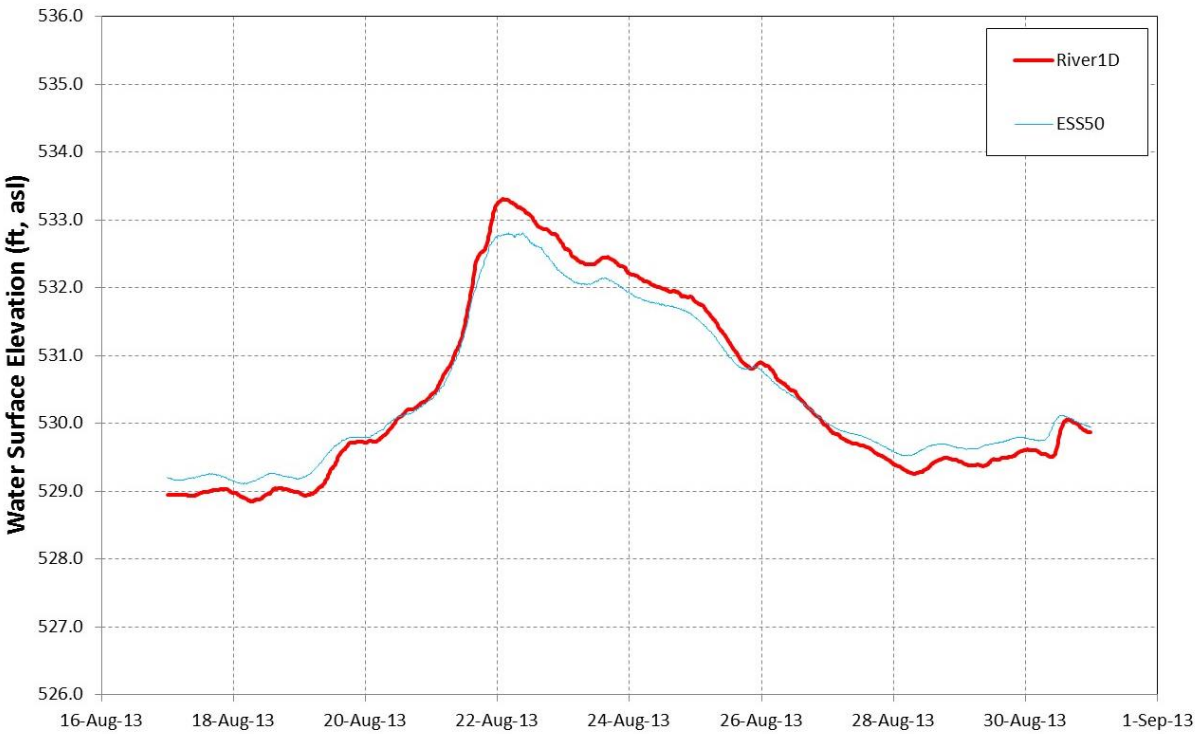

Figure 29: Modelled water levels compared to observed data at PRM 124.1 for Calibration Event 3.

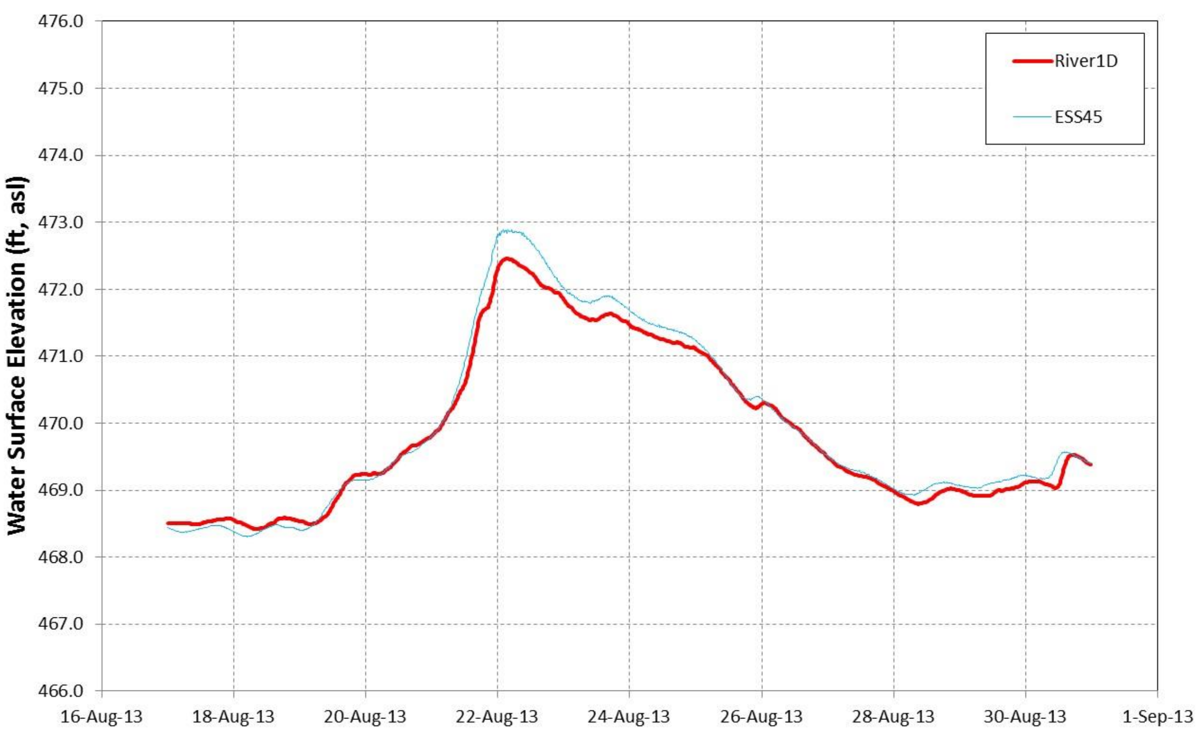

Figure 30: Modelled water levels compared to observed data at PRM 116.6 for Calibration Event 3.

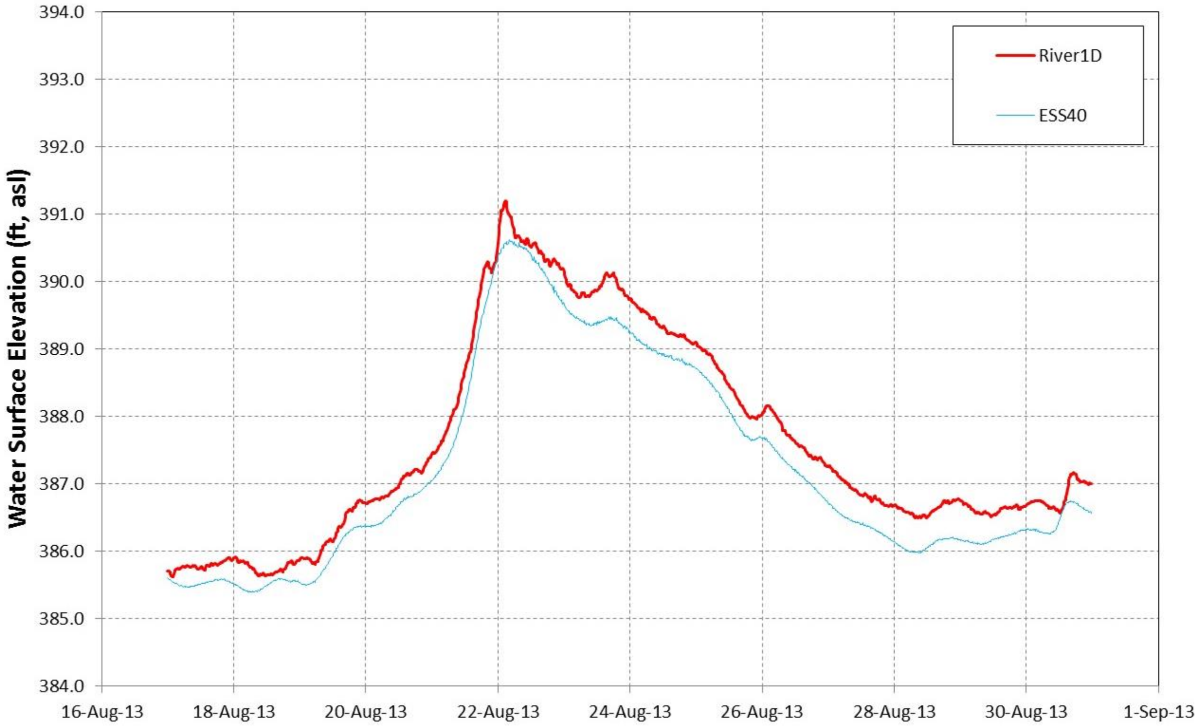

Figure 31: Modelled water levels compared to observed data at PRM 107.1 for Calibration Event 3.

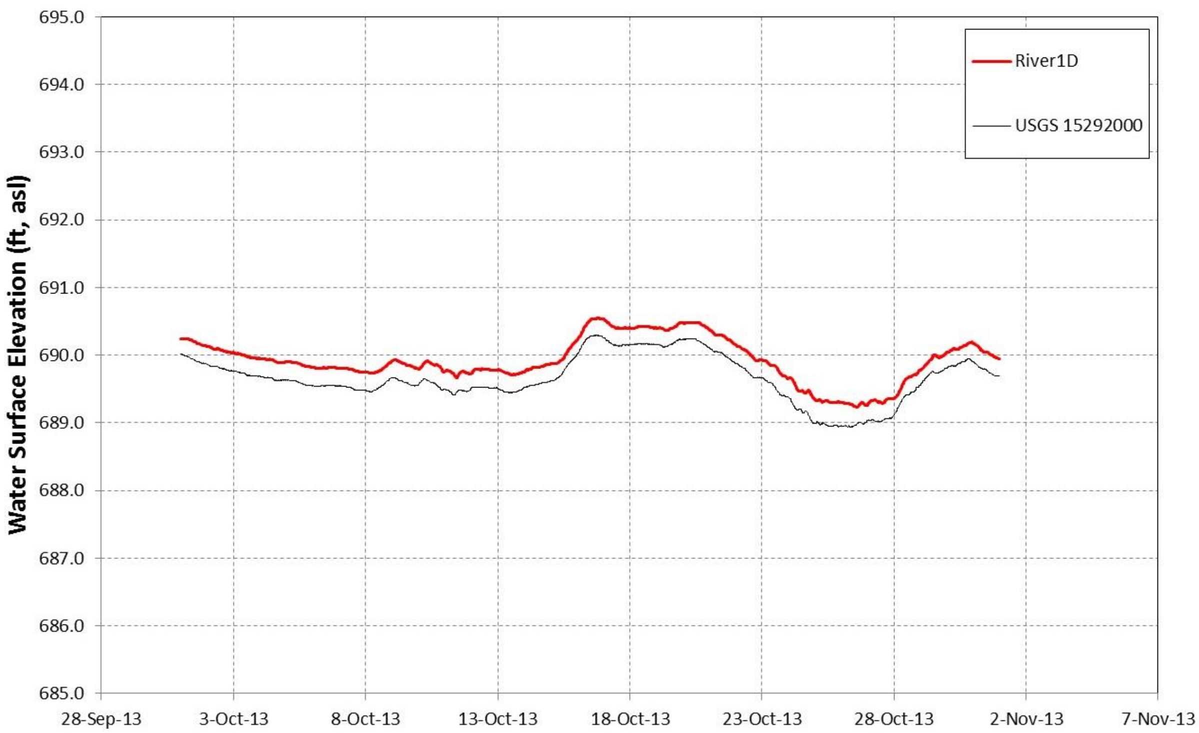

Figure 32: Modelled water levels compared to observed data at PRM 140 for Calibration Event 4.

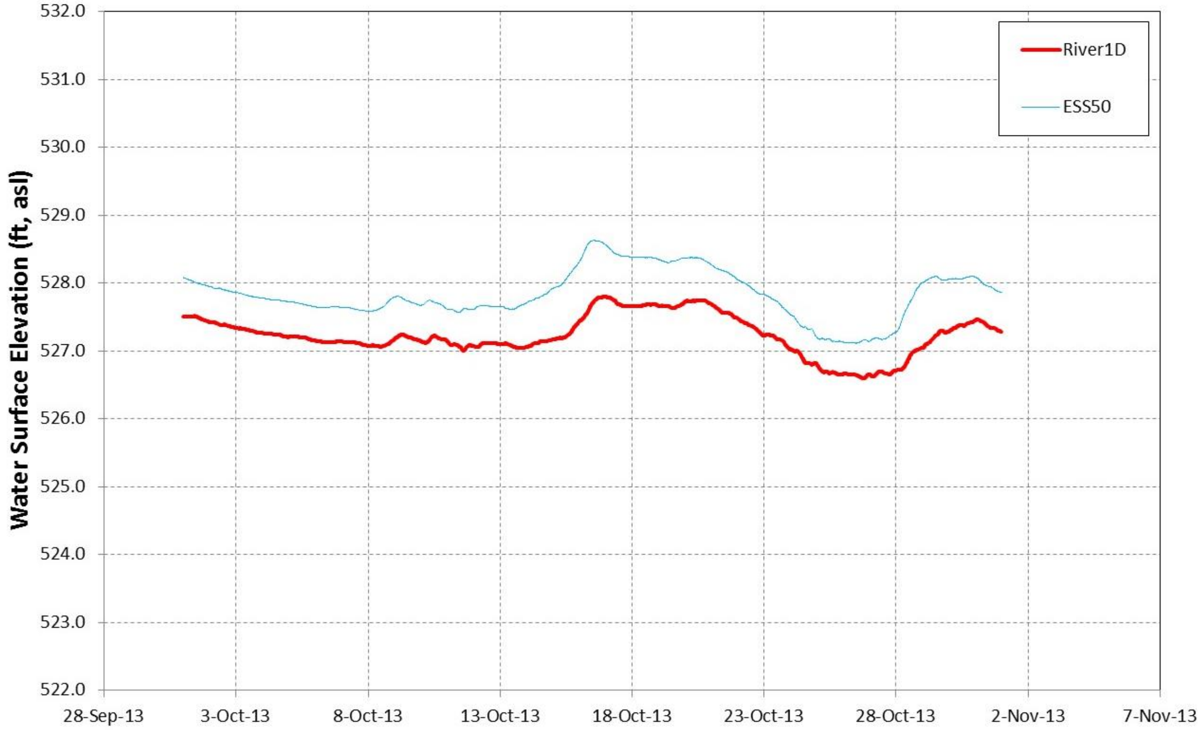

Figure 33: Modelled water levels compared to observed data at PRM 124.1 for Calibration Event 4.

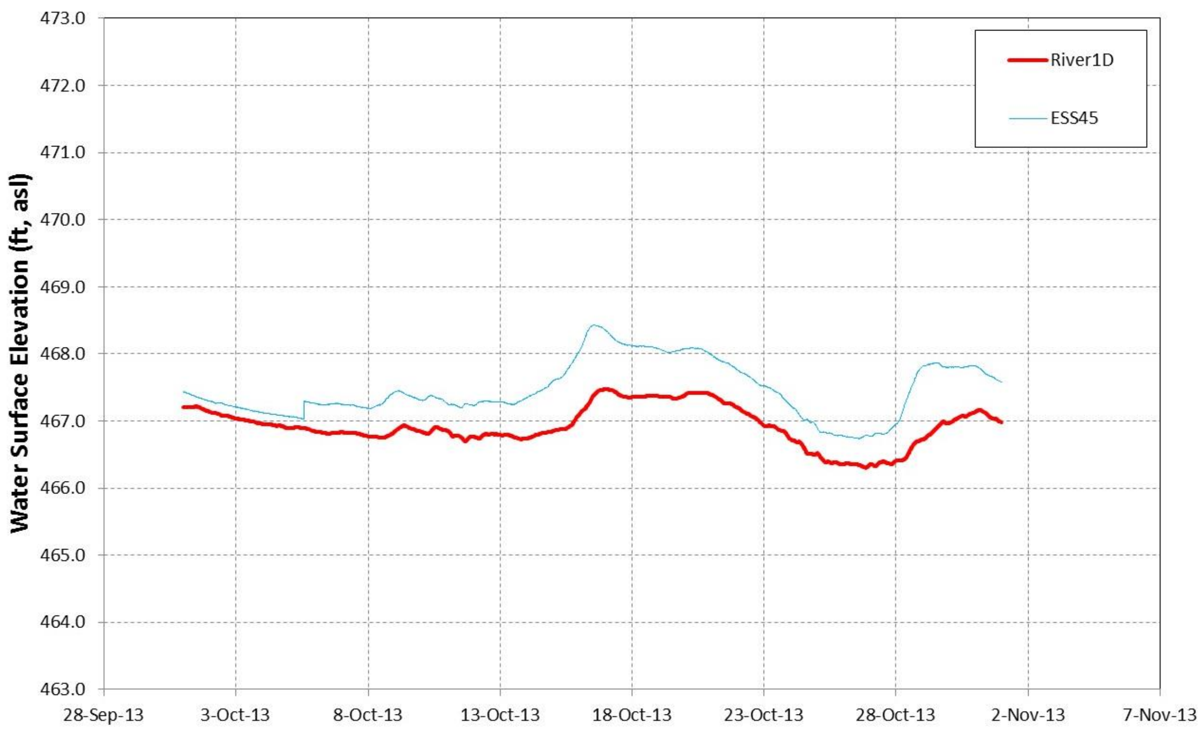

Figure 34: Modelled water levels compared to observed data at PRM 116.6 for Calibration Event 4.

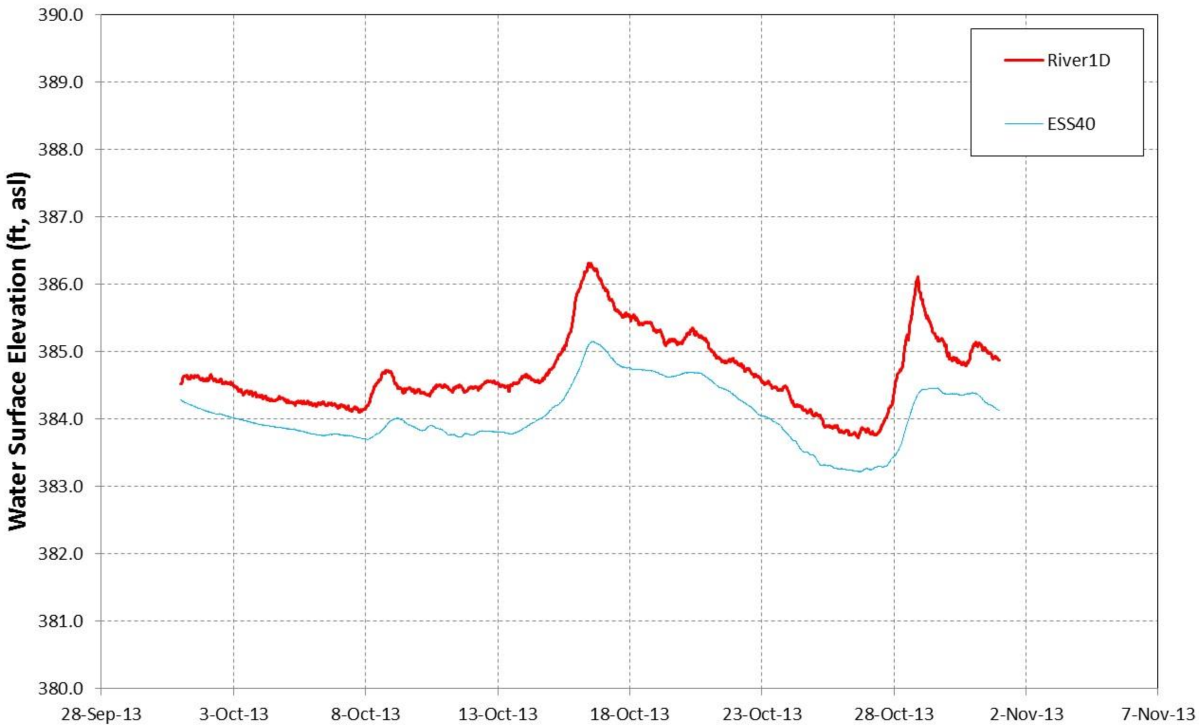

Figure 35: Modelled water levels compared to observed data at PRM 107.1 for Calibration Event 4.

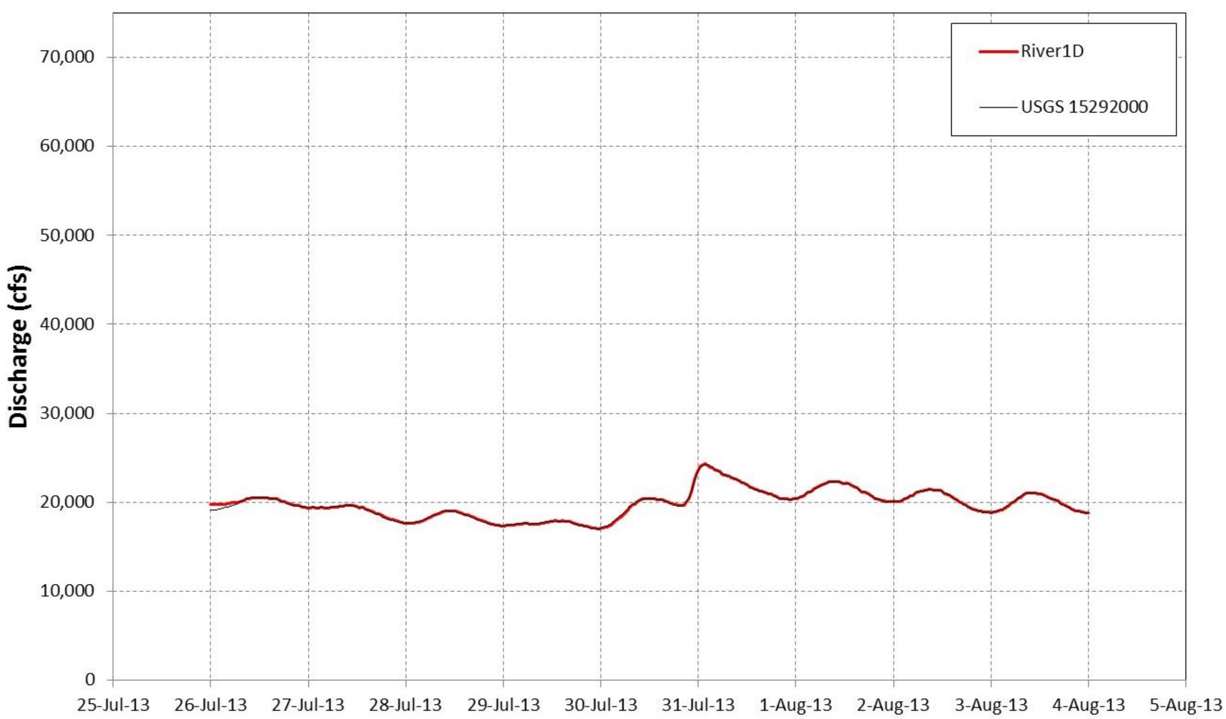

Figure 36. Modelled discharge results compared to observed data at PRM 140 for Validation Event.

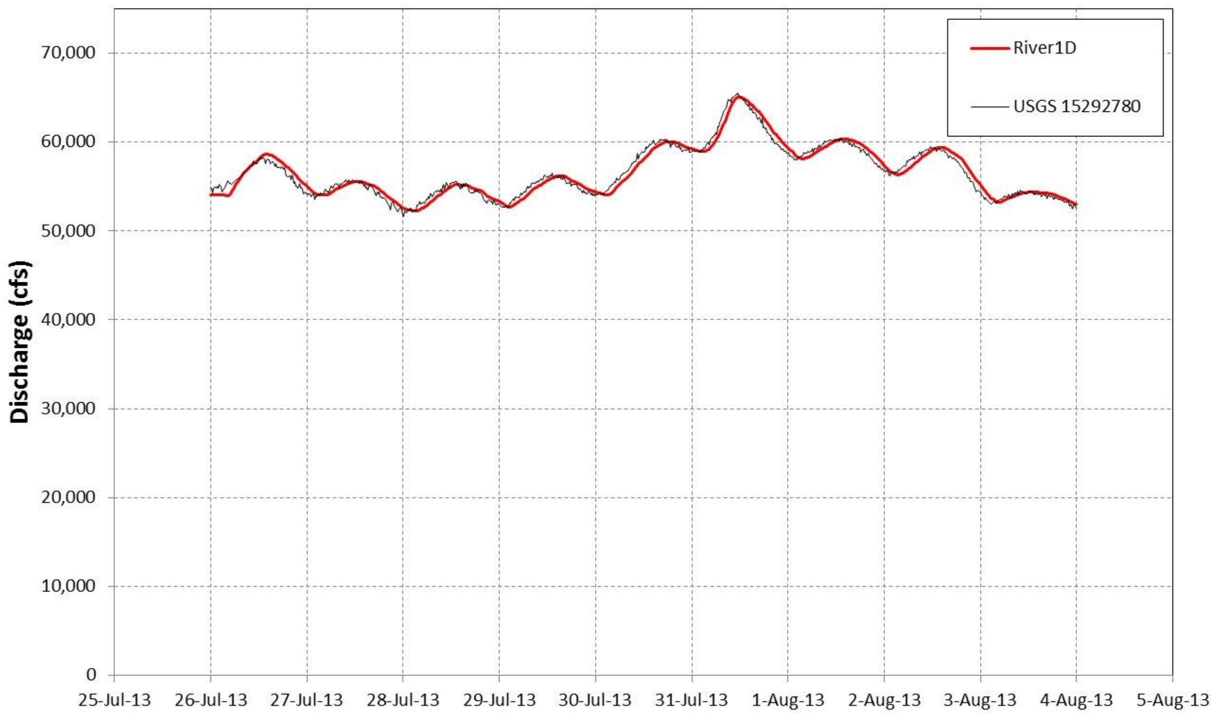

Figure 37. Modelled discharge results compared to observed data at PRM 87.8 for Validation Event.

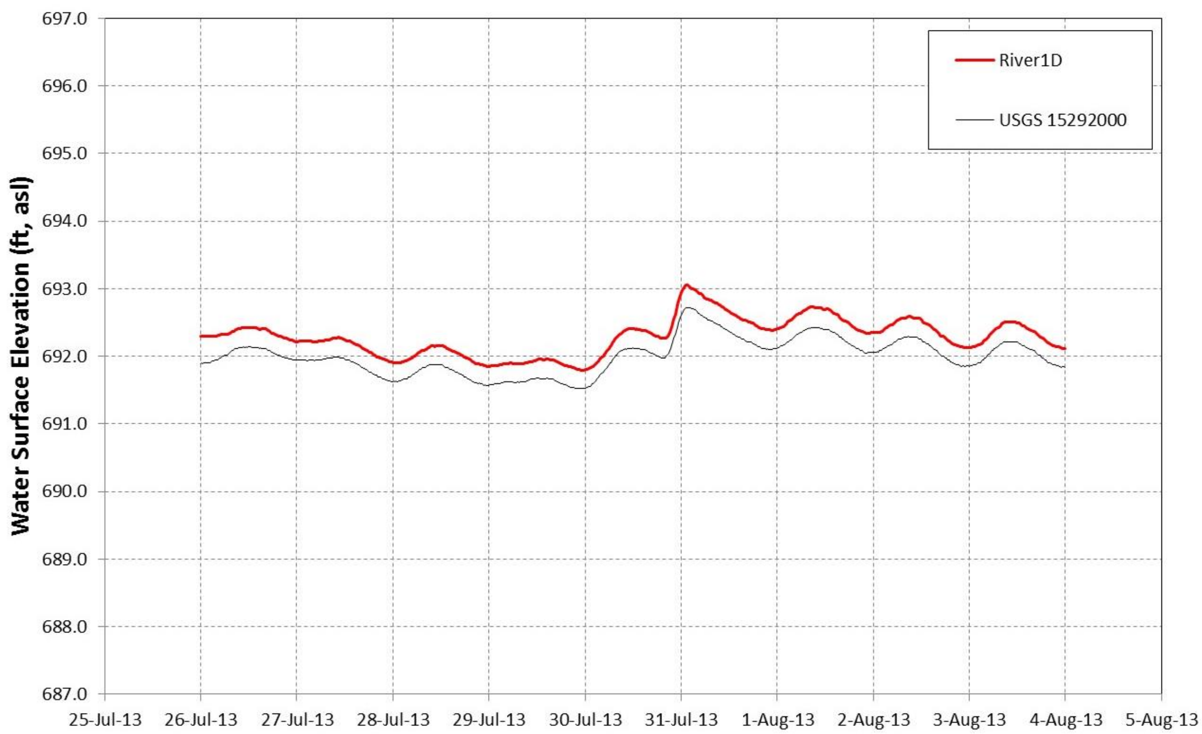

Figure 38: Modelled water levels compared to observed data at PRM 140 for Validation Event.

Attachment 1 – Preliminary Water Temperature Calibration Results

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Preliminary Water Temperature Calibration Results

The *River1D* model is currently being calibrated for simulating the instream water temperature. All results are preliminary and are subject to change.

Calibration of the water temperature is being conducted using the version of the model that was calibrated for the open water events as presented in University of Alberta Open Water Model Calibration and Validation Report (October 3rd, 2014).

The results presented are for the simulation of the water temperature in the study reach for the month of September 2012. The simulation is based on the following inputs.

There are five inflow boundaries in the model. **HDR Alaska Inc.** (**HDR**) provided inflow discharge and water temperature for these five inflow locations for the period of September 1st, 2012 to Jun 30th, 2013 at 1 hour intervals. These locations are listed in Table 1. Locations are provided in terms of **Project River Miles** (**PRM**).

The model has one outflow boundary, located at PRM 29.9. For this preliminary water temperature simulation, the water level at the downstream boundary was set to 45 ft (the level used in the simulation of all open water calibration and validation events (University of Alberta Open Water Model Calibration and Validation Report (October 3rd, 2014)).

To simulate water temperature, air temperature and net incoming solar radiation are required as input boundary conditions at every node within the domain. Air temperature data and net solar radiation data were provided by **HDR** for the period of September 1st, 2012 to Jun 30th, 2013 at 1 hour intervals.

Air temperature data were provided at nine **Environmental Susitna Surface** (**ESS**) stations along the model domain. The air temperature data were applied to the nodes within the domain based on the ESS station that is closest to the node along the river. The ESS stations and their range of application (in terms of PRM) are listed in Table 2.

HDR provided net incoming solar radiation data at two **Environmental Susitna Monitoring** (**ESM**) stations: ESM1 and ESM3. However, upon further analysis of the data and potential orographic effects at station ESM3, HDR has indicated that only the data for ESM1 should be used for modelling purposes. For this preliminary simulation, it was assumed that the data at this station are applicable to all nodes within the domain.

Table 1. List of model inflows.

Input Flow Name	Input Flow Description	Provided PRM Input Location1	Actual Model PRM Input Location	Input Water Temperature Description
Upstream Boundary	Tsusena Creek (USGS 15291700), lagged -0.5 hours (upstream inflow boundary condition)	187.2	187.2 (surveyed cross-section)	Data from ESS70 (PRM 187.16)
Ungauged 1	Ungauged lateral inflows between PRM 187.2 and PRM 140, calculated at PRM 140, lagged -3.25 hours (lateral inflow boundary condition)	163.4	163.41 (surveyed cross-section)	Water Temperature assumed to be equal to ESS60 (PRM 168.13)
Ungauged 2	Ungauged lateral inflows between PRM 140 and PRM 88, calculated at PRM 88, lagged -3.5 hours (lateral inflow boundary condition)	112	112.05 (interpolated cross-section)	Water Temperature assumed to be equal to ESS45 (PRM 116.62)
Chulitna River	Chulitna River HDR Model Output (lateral inflow boundary condition)	102.5	102.5 (interpolated cross-section)	Water Temperature assumed to be equal to ESS35 (PRM 102.1)
Talkeetna River	Talkeetna River HDR Model Output (lateral inflow boundary condition)	100.3	100.3 (interpolated cross-section)	Water Temperature assumed to be equal to ESS35 (PRM 102.1)

[1] These locations were provided in the MSExcel files entitled 2012_2013_Model_Inflows.xlsx provided by **HDR** on September 15, 2015.

Table 2. List of air temperature stations.

Station Name	Applicable Range (PRM)	
	Upstream	Downstream
ESS70 (PRM 187.2)	187.2	181.9
ESS65 (PRM 176.5)	181.75	172.3
ESS60 (PRM 168.1)	172.07	160.26
ESS55 (PRM 152.1)	160.06	138.10
ESS50 (PRM 124.1)	137.93	120.43
ESS45 (PRM 116.1)	120.30	111.90
ESS40 (PRM 107.1)	111.67	104.70
ESS35 (PRM 102.1)	104.55	100.3
ESS30 (PRM 98.4)	100.1	29.9

To simulate the water temperature in the model for the period of September 1st, 2012 to September 30th, 2012, the model was run with a time step of 1.5 minutes (0.025 hours) and an implicitness of θ = 0.5.The water-air heat exchange parameter was set to 15 $W/m^2/°C$ for this preliminary simulation.

A preliminary comparison of the modelled and observed water temperature are provided at eight locations (seven ESS stations and one USGS station) within the model domain in Figures 1 through 8 for the period of September 1st, 2012 to September 30th, 2012.

Overall the agreement between the modelled and observed water temperature values is quite good at all stations except in the first half of September at ESS 65, 60, and 55 (Figures 1 through 3). We believe that the modelled water temperatures do not agree with the observed temperatures at these stations because the water temperatures for the ungauged tributaries are not particularly realistic. Specifically the input data provided assumed that the ungauged flows had water temperatures equal to those of the main stem of the river. We suspect that at the beginning of September, the tributaries were cooler than the Susitna River and the reason that the modelled temperature agreed better with the observed temperatures later in the month, is because the main stem discharge was much higher in the latter part of the month (and thus the error in the tributary water temperatures was not as noticeable). In addition, the ungauged tributaries are input at two discrete locations along the river, rather than being input as distributed flows. The ungauged flows above Gold Creek are input at PRM 163.4 which is downstream of ESS 65 (PRM 176.5) and ES 60 (PRM 168.1). Therefore, even with the correct water temperature for the ungauged flows above Gold Creek, the results at ESS 65 and 60 would not improve. This discrete approach seemed to work well for modelling the open water hydrodynamics but may not be as appropriate for modelling the water temperature if it is necessary to accurately capture the water temperature at all stations.

It is important to note that the model's capability to accurately simulate water temperatures will need to be validated for other scenarios.

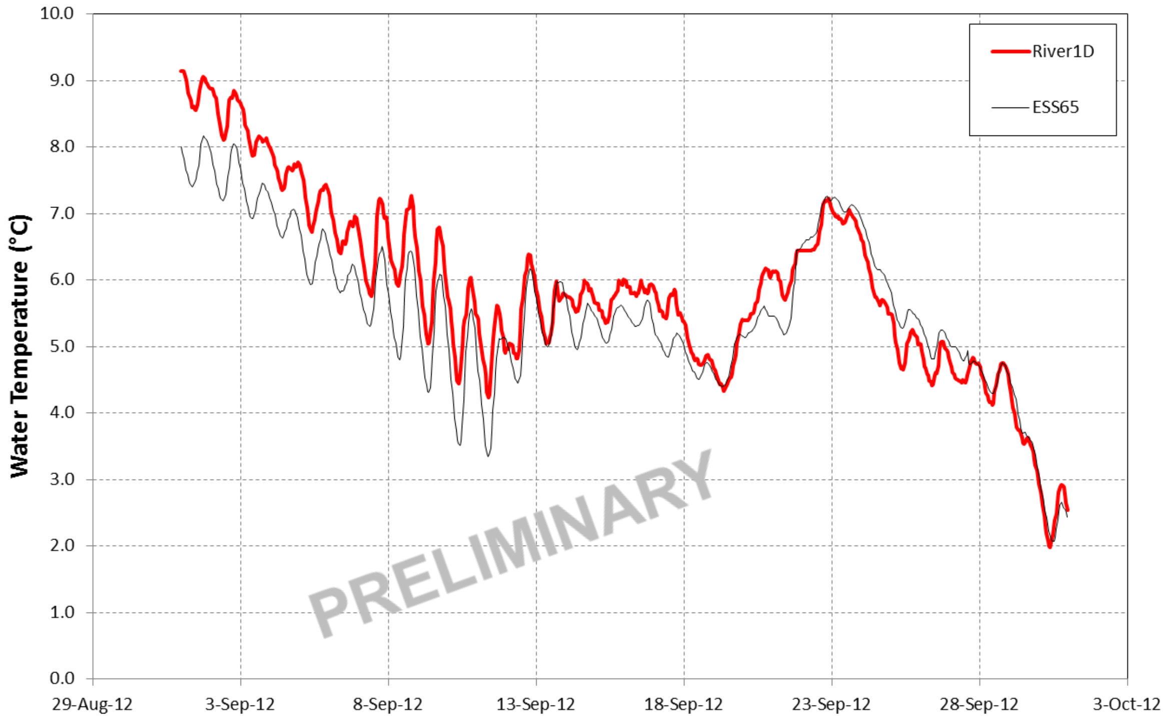

Figure 1. Modelled water temperature results compared to observed data at PRM 176.5.

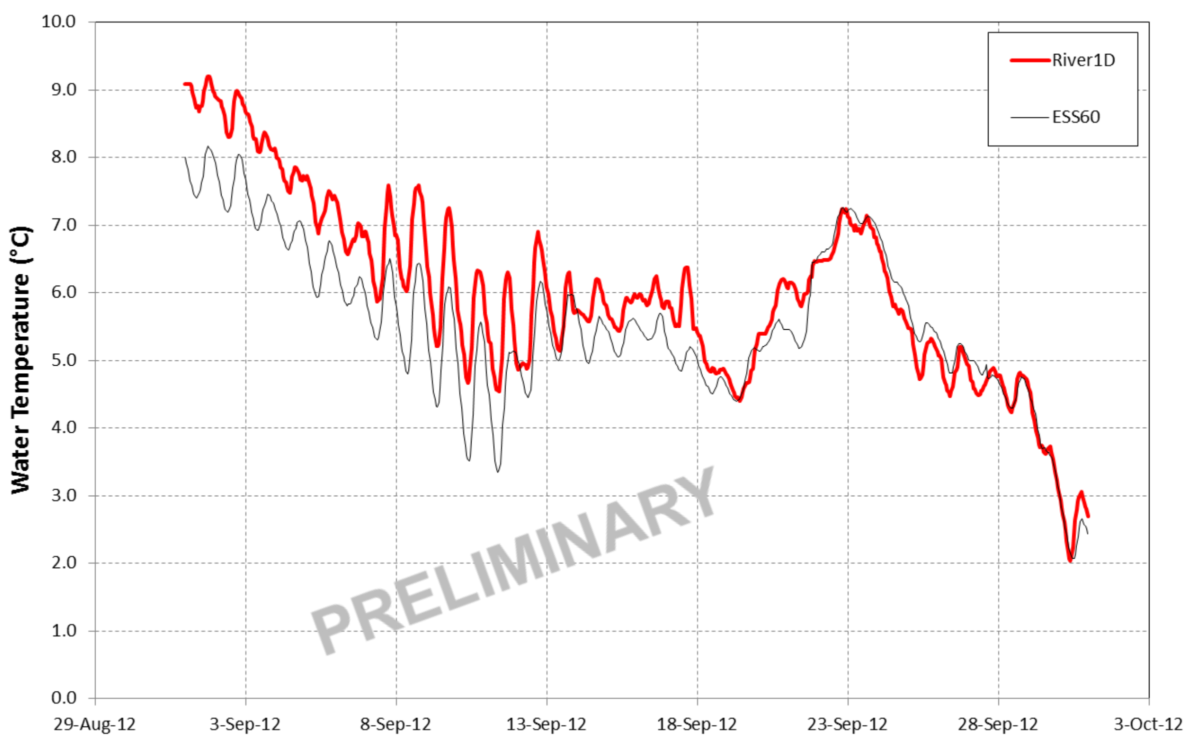

Figure 2. Modelled water temperature results compared to observed data at PRM 168.1.

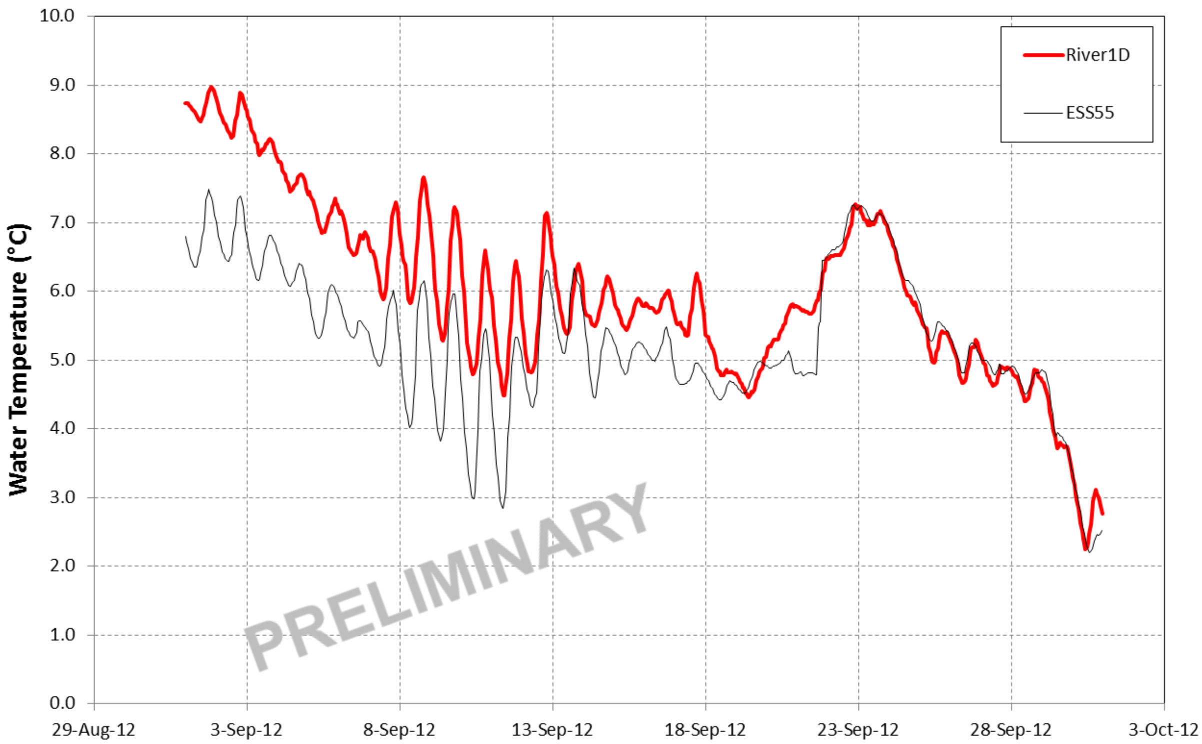

Figure 3. Modelled water temperature results compared to observed data at PRM 152.1.

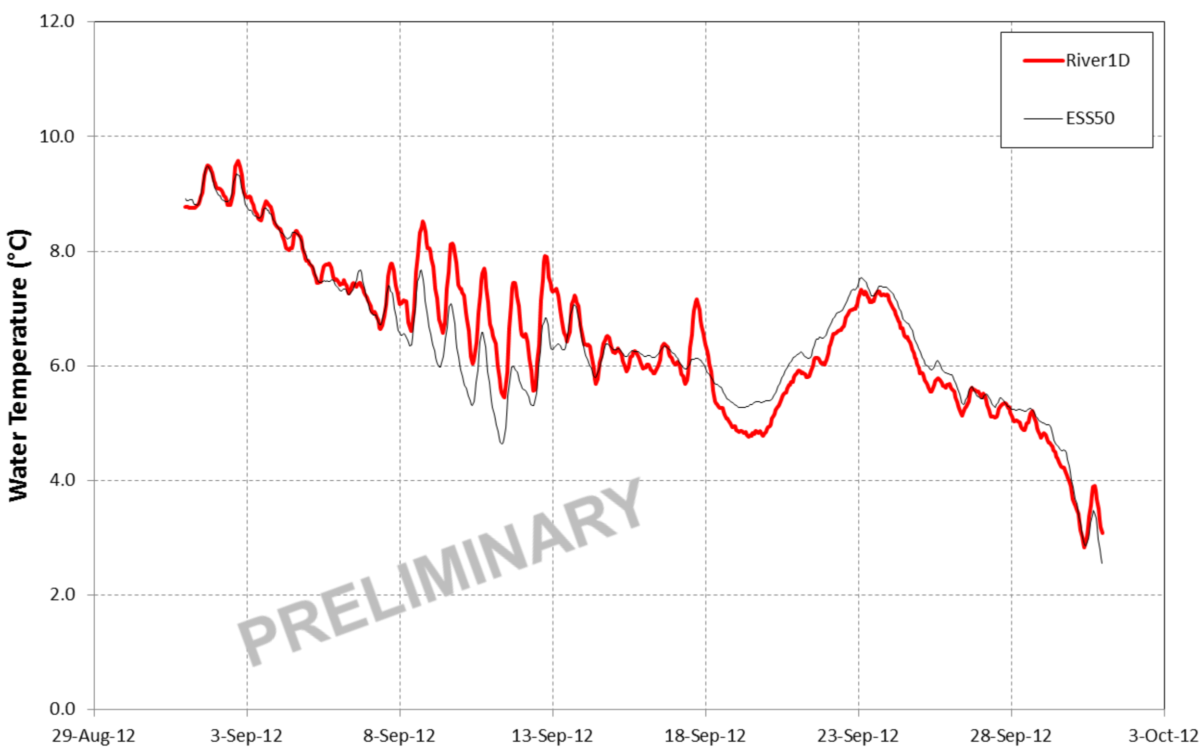

Figure 4. Modelled water temperature results compared to observed data at PRM 124.1.

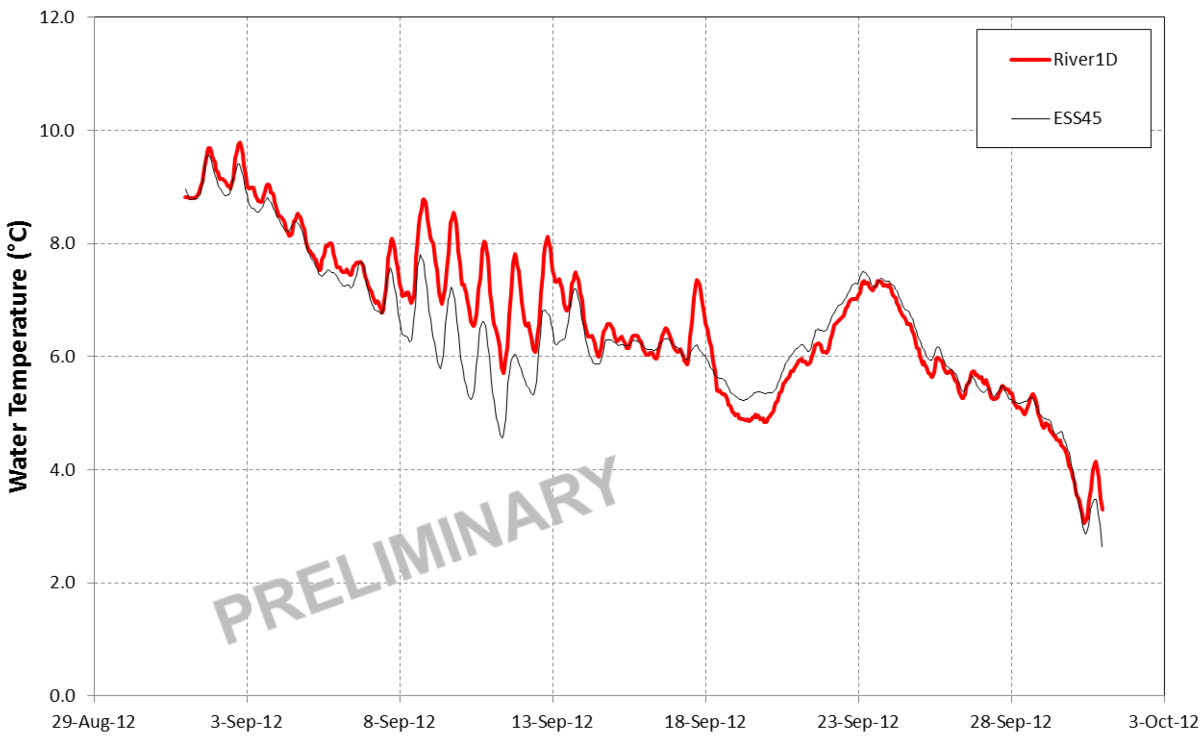

Figure 5. Modelled water temperature results compared to observed data at PRM 116.6.

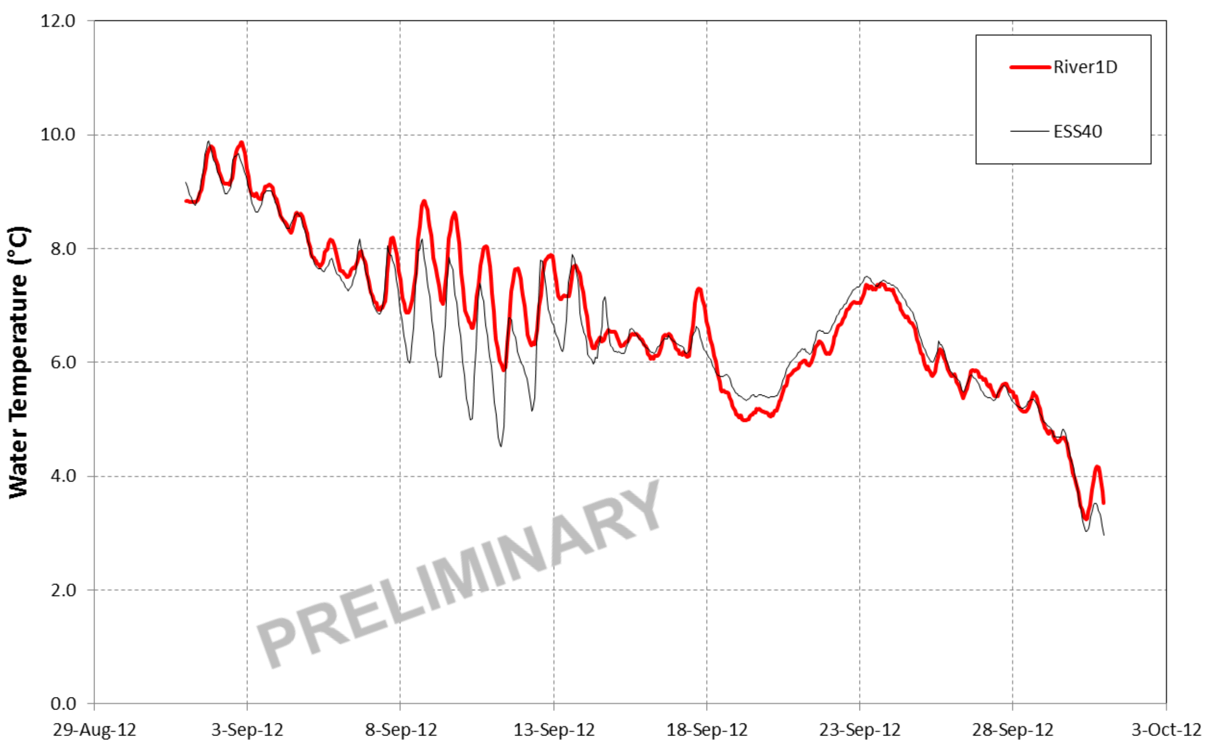

Figure 6. Modelled water temperature results compared to observed data at PRM 107.1

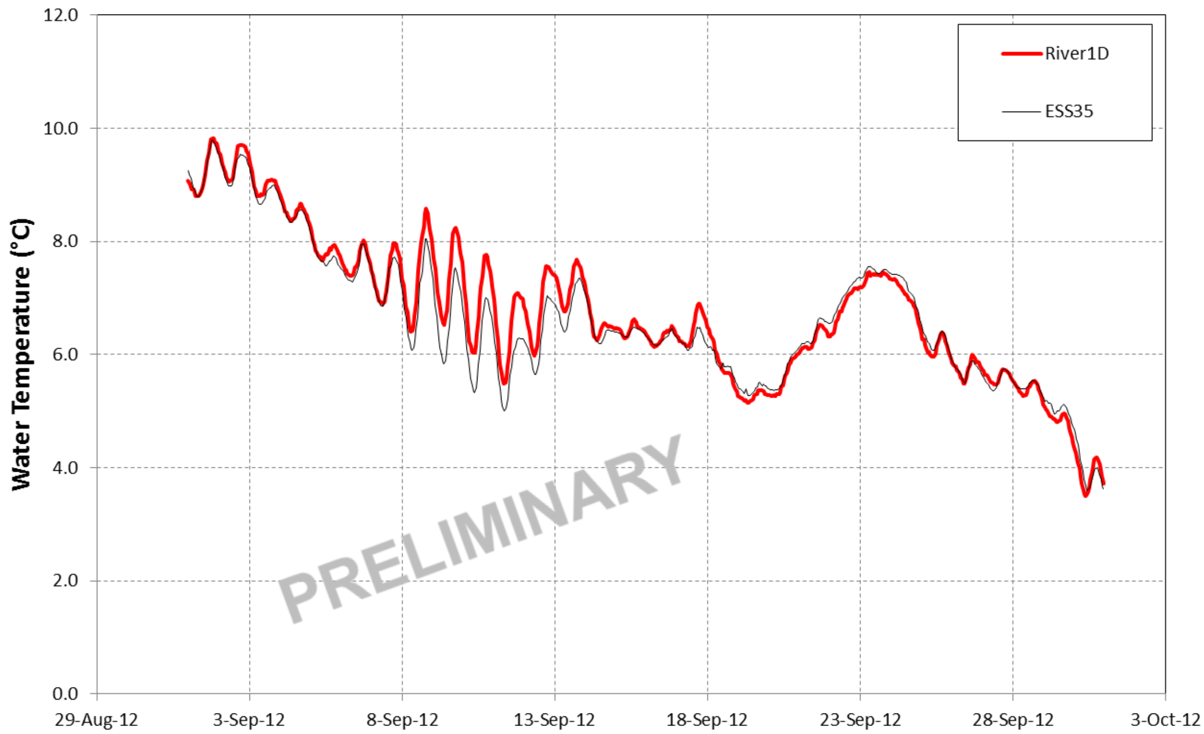

Figure 7. Modelled water temperature results compared to observed data at PRM 102.1.

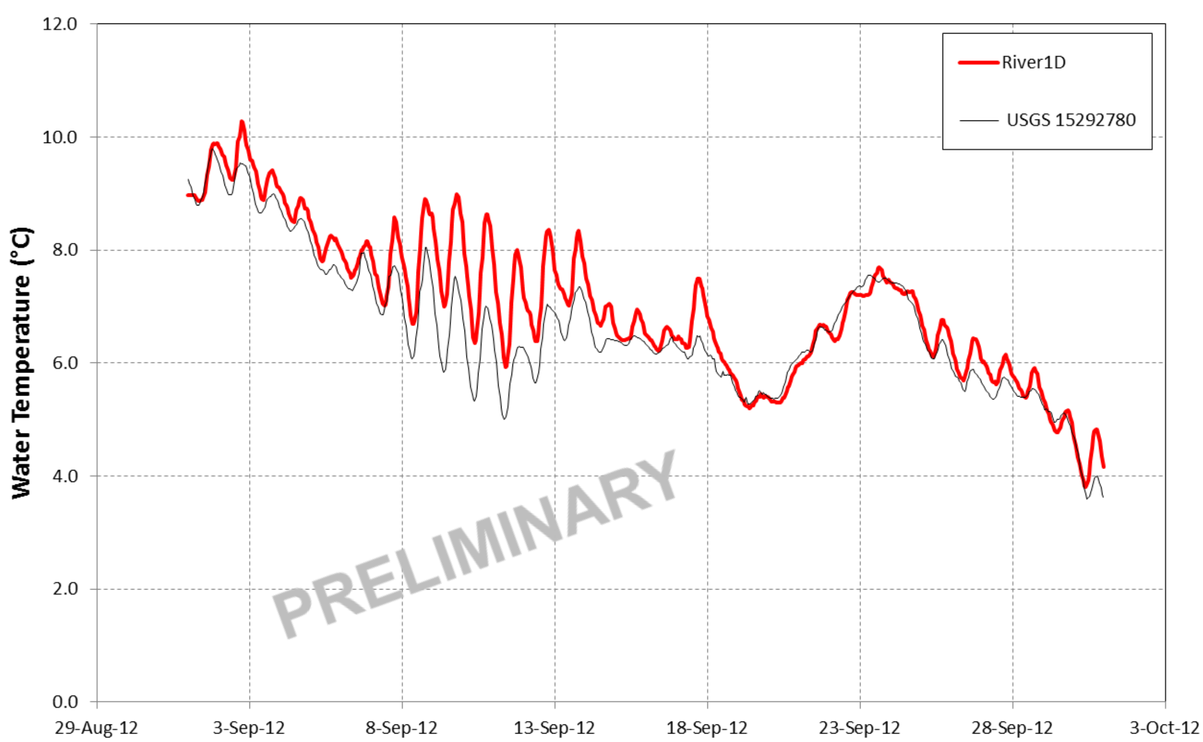

Figure 8. Modelled water temperature results compared to observed data at PRM 87.8.