ECF-HANFORD-13-0028
Revision 2

COLUMBIA RIVER STAGE CORRELATION FOR THE HANFORD AREA

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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APPROVED
By Janis D. Aardal at 1:29 pm, Mar 11, 2019

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ENVIRONMENTAL CALCULATION COVER PAGE

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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Terms

amsl	above mean sea level
AWLN	automated water level network
BFGS	Broyden-Fletcher-Goldfarb-Shanno
CHPRC	CH2M HILL Plateau Remediation Company
CRAN	Comprehensive R Archive Network
HEIS	Hanford Environmental Information System
MND	McNary Dam
NWIS	National Water Information System
OU	operable unit
PRD	Priest Rapids Dam
USGS	United States Geological Survey

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1 Purpose

This document describes a method for estimating the stage of the Columbia River at locations along the Hanford Reach. Specifically, stage estimation is accomplished by developing a relationship between, or model of, the stage of the Columbia River at the 100-B, 100-K, 100-N, 100-D, 100-H, 100-F, and 300 Areas (herein collectively called the Hanford Area River Gauges) and river stage measurements reported by the U.S. Geological Survey (USGS). The relevant USGS river gauge (Station 12472800) is located upstream from the Hanford Area River Gauges and below Priest Rapids Dam (PRD). The model is based upon historical river stage measurements collected at the Hanford Area River Gauges using data collected by the USGS below PRD. Figure 1 shows PRD, the USGS river gauge and Hanford Area River Gauge locations.

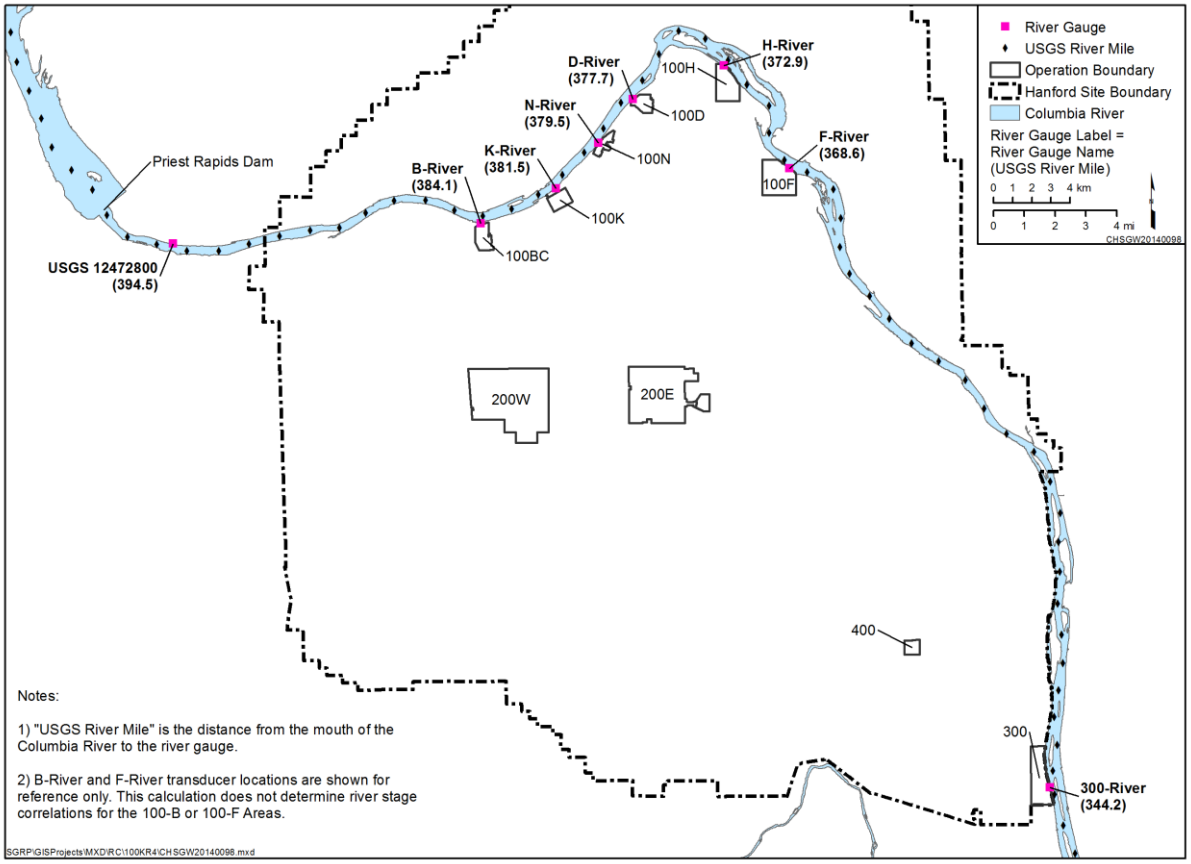

Figure 1. USGS Station 12472800 and Hanford Area River Gauge Locations

Determining the relationship between the USGS reported river stage measurements and Hanford Area River Gauge measurements is useful for the following purposes:

- A predictive model can be used to decide whether out-of-service river stage pressure transducers need to be replaced.
- When direct measurements are not available for the Hanford Area River Gauges, the model can be used to estimate river stage at these areas to fill in data gaps.
- At times and places, the USGS data driven predictive model can be used in lieu of direct measurements in determining river stage at intermediate locations where river stage is not measured.

2 Background

The Hanford Reach of the Columbia River extends from PRD to the City of Richland, Washington. Although the Hanford Reach is essentially the last free-flowing section of the river, the river stage along this reach is affected by the storage and release of water at dams. PRD is a water storage and hydroelectric generating facility located upstream of the Hanford Site. The McNary Dam (MND), another hydroelectric facility located downstream of the Hanford Site, impounds water that forms Lake Wallula, which extends upstream of MND to the lower extents of the Hanford Reach.

River stage along the Hanford Reach fluctuates (a) daily (and indeed, more frequently) with the release of water from PRD in response to electric power demands and (b) seasonally in response to the annual snowmelt and upstream drainage, which generally occurs in spring and early summer. The magnitude of diurnal stage transients ranges from less than one meter to as much as three or more meters. Seasonal transients with overall magnitude of more than five meters have been measured. These seasonal and diurnal fluctuations in river stage affect groundwater elevations along the Hanford Site shoreline where the river forms a flow boundary to groundwater.

For most of the year, the river functions as a discharge boundary (i.e., groundwater discharges to the river), with groundwater elevations within the shallow unconfined aquifer consistently higher than the river stage. During the peak of the annual high river stage, the daily average river stage is higher than the elevation of groundwater in the near-river environment for periods of days to weeks. During this time, groundwater flow directions near the river may reverse; river water can, under these conditions, locally enter the aquifer and a condition known as bank storage may occur, in which river water displaces or mixes with groundwater near the river shore. As the river stage remains high during the spring and summer, the inland groundwater level elevation increases to seek equilibrium with the river elevation and riverward flow of groundwater is ultimately restored. As the river stage declines after the passing of peak stage, a period of increased groundwater gradient toward the river is induced until groundwater elevations once again stabilize to something approximating an average of the daily fluctuations of the river.

Understanding the river stage variations, as well as quantifying the river stage at selected locations and times along the Hanford Reach, provides a definition of the groundwater discharge boundary elevation that can be used to derive and interpret groundwater levels and hydraulic gradients close to the shoreline, and to define the boundary condition for use when modeling or mapping groundwater elevations. Protection of the Columbia River from discharge of contaminated groundwater is a concern of the Department of Energy at the Site. Understanding of river stage conditions at each of the groundwater operable (OU) units along the Hanford Reach is important to interpretation of groundwater flow and continued successful operation of groundwater remedies.

3 Methodology

This section discusses the data and methods used to complete the calculations presented in this document.

3.1 Data Acquisition and Data Processing

This section discusses the acquisition and processing of data prior to undertaking calculations.

3.1.1 Data Acquisition

This section discusses the acquisition of data used in this analysis.

3.1.1.1 Priest Rapids Dam River Stage Data

River stage data reported at both 15-minute and daily intervals at USGS Station 12472800 (herein called the PRD gauge) are available on the USGS National Water Information System (NWIS). The data were downloaded using the statistical programming language R and the dataRetrieval package, which is available from the Comprehensive R Archive Network (CRAN) (see Section 5 for information on applicable software). The dataRetrieval package was developed by the USGS to aid in accessing NWIS data.

The 15-minute river stage dataset was downloaded from the following link: https://nwis.waterservices.usgs.gov/nwis/iv/?format=rdb&startDT=2007-1-1&endDT=2018-07-20&sites=12472800&parameterCd=00065. The downloaded dataset contains data on the agency collecting the data, USGS site number, measurement date and time, time zone, gauge height in feet (ft) and data qualification (Table 1).

Table 1. USGS River Stage Data for Preist Rapids Dam – 15-Minute

Field	Definition
agency_cd	Collection Agency
site_no	USGS Site Number
datetime	Measurement Date and Time
tz_cd	Time Zone
X151852_0065	Gauge Height (ft)
X151852_0065_cd	Data Qualifier
tz_cd_reported	Original Time Zone of Measurement

USGS = United States Geological Survey

The daily river stage dataset was downloaded from the following link: https://waterdata.usgs.gov/wa/nwis/dv?cb_00065=on&format=rdb&site_no=12472800&referred_module=sw&period=&begin_date=1992-1-1&end_date=2018-07-20. The downloaded dataset contains data on the agency collecting the data, USGS site number, measurement date, gauge height in ft and data qualification (Table 2).

Table 2. USGS River Stage Data for Preist Rapids Dam – Daily

Field	Definition
agency_cd	Collection Agency
site_no	USGS Site Number
datetime	Measurement Date
X149897_00065_00003	Gauge Height (ft)
X149897_00065_00003_cd	Data Qualifier

USGS = United States Geological Survey

3.1.1.2 Hanford River Gauge Stage Data and Groundwater Level Data

Transducer data of historical river stage data for the 100-B, 100-K, 100-N, 100-D, 100-H, 100-F, and 300 Area river gauges and nearby wells were downloaded from the automated water level network (AWLN), which is maintained by CH2M HILL Plateau Remediation Company (CHPRC) and exported into a Microsoft Access® database (named AWLN_07112018.accdb). The data for this analysis were downloaded from the AWLN database on July 11, 2018. The AWLN database contains one table (dbo_v_AWLN_ProcessedData), which contains the gauge name, measurement date, and gauge height. The tables in the AWLN_07112018 database pertaining to transducer water level measurements are dbo_v_AWLN_ProcessedData (Table 3).

Table 3. AWLN Database Fields for Transducer Water Level Measurements

Field Extracted*	Definition
HEIS2_ADM_HYDRAULIC_HEAD_MV	
Well_Name	Location Identification
procDate	Measurement Date and Time
procWaterElevation	Water-Level Elevation (m)

*Field codes are defined in HNF-38155, *HEIS Sample, Result, and Sampling Site Data Dictionary*.

AWLN = automated water level network

Manual water-level measurements for nearby wells were downloaded from the Hanford Environmental Information System (HEIS) database and exported into a Microsoft Access database (named HEIS_07112018.accdb). The data for this analysis were downloaded from the HEIS database on July 11, 2018. The table in the HEIS_07112018 database pertaining to manual water level measurements is titled HEIS_ADM_HYDRAULIC_HEAD_MV (Table 4).

Table 4. HEIS Database Fields for Manual Water Level Measurements

Field Extracted*	Definition
HEIS2_ADM_HYDRAULIC_HEAD_MV	
WELL_NAME	Location Identification
HYD_DATE_TIME_PST	Measurement Date
HYD_HEAD_METERS_NAVD88	Water-Level Elevation (m)
REVIEW_QUALIFIER	Measurement Qualifier

*Field codes are defined in HNF-38155, *HEIS Sample, Result, and Sampling Site Data Dictionary*.

HEIS = Hanford Environmental Information System

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Transducer data were obtained directly from CHPRC for the 300-Area river gauge from 2/6/2013 through 12/31/2017[1]. The data were obtained in several comma-separated value (CSV) files and consist of water-level measurements obtained on a 15-minute interval.

3.1.2 Conversion of River Gauge Height to Elevation

The PRD gauge reports river gauge height in feet (ft). The data were converted to river stage elevation in meters (m) prior to evaluation of the convolution method:

$$RS = 0.3048(GH + g) \qquad \textbf{(Equation 1)}$$

where:

RS = river stage elevation (meters above mean sea-level (m amsl))

GH = gauge height (ft)

g = elevation of the river gauge (393.49 ft amsl)

3.1.3 Daylight Savings Time

The dataRetrieval package automatically converts measurement date and time into the Coordinated Universal Time (UTC) zone. Water-level data from the AWLN and HEIS databases were reported in the America/Los Angeles time zone (Pacific Standard Time (PST) or Pacific Daylight Time (PDT), as applicable) and were converted to UTC for this analysis.

3.1.4 Linear Interpolation

Linear interpolation was used to fill in gaps in the 15-minute and daily river stage datasets from the USGS gauging station at PRD.

3.1.5 Daily Averaging

A daily average was calculated for the Hanford Area river gauges for use in the daily river stage convolution (see Section 3.3). No daily averaging was conducted for the 15-minute river stage convolution (see Section 3.3).

3.2 River Stage Convolution Calculations

Changes in river stage at locations downstream from PRD gauge can be approximated through a diffusive wave model (Miller, 1984, *Basic Concepts of Kinematic-Wave Models*). Ogata and Banks, 1961, *A Solution of the Differential Equation of Longitudinal Dispersion in Porous Media*, presents an analytical solution to the advection-dispersion equation for conservative solutes (Runkel, 1996, "Solution of the Advection-Dispersion Equation: Continuous Load of Finite Duration"), which is parametrically equivalent to the river stage. Following is the Ogata-Banks solution:

$$C(x,t) = \frac{1}{2}C_0\left[erfc\left(\frac{x - vt}{2\sqrt{Dt}}\right) + \mathrm{e}^{\left(\frac{vx}{D}\right)} \times erfc\left(\frac{x + vt}{2\sqrt{Dt}}\right)\right] \qquad \textbf{(Equation 2)}$$

where:

C_0 = initial concentration

[1] Transducer data were received via email correspondence with Virginia Rohay (CHPRC) on 4/27/2016, 6/1/2016, 2/8/2017, 2/28/2017, 5/8/2017, and 2/22/2018.

erfc = the complementary error function

x = distance from source

v = groundwater velocity

D = dispersion coefficient

t = time

Using the diffusive wave model to approximate river stage, the source concentration employed in the Ogata-Banks (1961) solution for transport of solutes is replaced by the incremental or step-change in stage at the upstream river boundary at the PRD gauge. The equivalent wave diffusion solution becomes the following:

$$\Delta S_c = \frac{1}{2}\Delta S_m \left[erfc\left(\frac{x - ct}{2\sqrt{Dt}}\right) + \mathrm{e}^{\left(\frac{cx}{D}\right)} \times erfc\left(\frac{x + ct}{2\sqrt{Dt}}\right)\right] \quad \textbf{(Equation 3)}$$

where:

delta S_c = model calculated river stage at location *x* and time *t*

delta S_m = the measured incremental change in river stage at the upstream boundary or, in this case, the PRD gauge

c = wave celerity

The final model calculated river stage (S_f) is then adjusted to account for the time-averaged elevation difference (x_0) and for differences in channel geometry (*A*) between the PRD gauge and the Hanford Area River Gauge for the period of analysis:

$$S_f = x_0 + (\Delta S_c A) \quad \textbf{(Equation 4)}$$

For each application of this method, the following parameters need to be estimated:

- *D* (dispersion coefficient)
- *c* (wave celerity)
- x_0 (time-averaged elevation difference)
- *A* (differences in channel geometry)

For the calculations presented herein, parameters were estimated using a modification of the Broyden-Fletcher-Goldfarb-Shanno quasi-Newton method optimization process, which is readily available in the R programing platform, and optimized based on minimizing the sum of squared residuals between measured and estimated river stage. The cumulative effect of incremental changes in river stage at the upstream boundary (PRD gauge) is calculated by applying the principle of convolution to the incremental changes. Based upon several testing phases of this approach, the convolution integral was calculated for 80 time steps for the 15-minute dataset (19.75 hours)and 10 timesteps for the daily dataset (10 days) which was sufficient to result in a cumulative unit response that was very close to 1.0. In other words, the effect of an incremental change in river stage at the upstream boundary is fully manifested at a downstream location within about 20 hours (15-minute dataset) or within 10 days (daily dataset).

An advantage of the wave diffusion model approach over linear regression-based approaches is that the parameters of the model are physically based; thus, some assurance is provided of the use of the model for either data gap infilling for predictive purposes, by the physical plausibility of the underlying parameters. Purely statistical methods, such as linear regression, essentially align and scale the input data with the gauge data without providing physically based parameters that can be verified or used to provide estimates at alternative locations. As a result, the wave-diffusion model approach can predict changes in the stage of a wave of water as it passes downstream from the PRD gauge through the Hanford Reach in a physically based manner that reproduces the migration, spreading, and damping of the wave as it propagates.

3.3 River Stage Convolution

This section discusses the process of the river stage convolution method.

3.3.1 Initial Evaluation

River stage elevations at the Hanford Area River Gauges were modeled individually for two different datasets: (1) 15-minute PRD data (available PRD data from 10/1/2007 through 7/20/2018), and; (2) daily PRD data (available PRD from 3/26/1992 through 7/20/2018). Each river gauge was evaluated for outliers (inconsistent data) and to determine if changing conditions (e.g., changes in discharge from the PRD, adjustments to the river gauge transducers, gauge not maintained over long periods of time) impacted the relationship between the PRD gauge and the river gauge.

3.3.2 Data Removals

The data were evaluated for systematic offsets (i.e., changes in the baseline measurements) and suspect data. Systematic offsets were identified by comparing hydrographs of the measured Hanford Area river gauge and groundwater elevation in nearby wells. An example of systematic offsets is presented in Figure 2. In 2012 and the early part of 2013 (January through mid-July), the measured river stage at the H-River Gauge was similar to the measured groundwater-level elevation at well 699-99-41 (located 67 m from the Columbia River). The gauge was not maintained from 10/4/2013 through 12/5/2015. After the gauge was re-establishing in late 2015, the measured river stage was systematically lower than the measured groundwater elevation in well 699-99-41. The gauge was offline again from 12/3/2016 through 6/21/2017. When the gauge was re-established in late 2017, the measured river stage was again systematically lower than the measured groundwater elevation in well 699-99-41. Data that demonstrated systematic offsets were removed from the convolution analysis (Table 5).

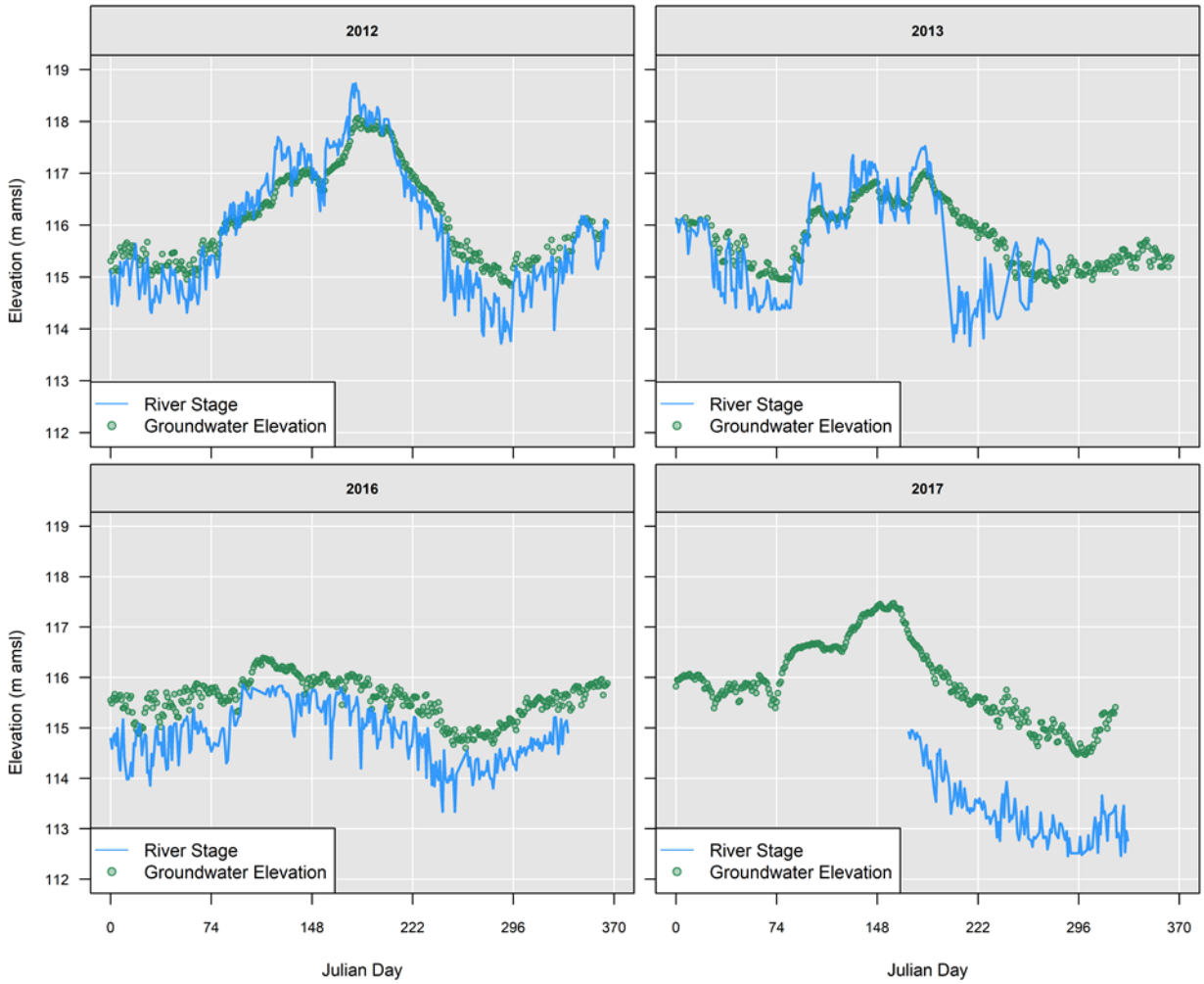

Figure 2. Example of Systematic Offsets in River Stage Measurements at the H-River Gauge

Suspect data were identified by evaluating the correlation between measured and modeled river stage (Figure 3). When the modeled river stage was abnormally high or abnormally low, the data were flagged as suspect and removed from the convolution analysis (Table 5).

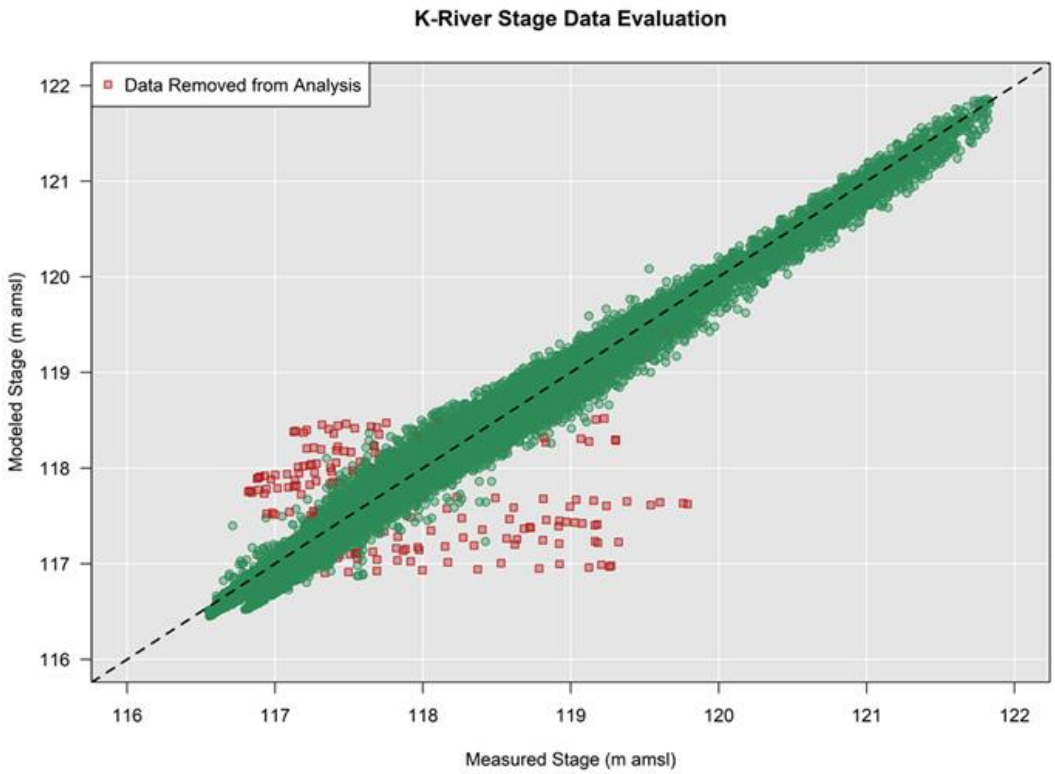

Figure 3. Example of Visual Inspection for Outliers at K-River Gauge

Data identified as either systematic offsets or suspect data presented in Table 5.

Table 5. Systematic Offsets and Suspect Data

Gauge	Data Removed from Analysis
B-River Gauge	8/21/2009 – 8/28/2009 1/31/2014 – 2/1/2014 2/5/2014 – 2/6/2014
K-River Gauge	8/21/2009 – 8/28/2009
N-River Gauge	8/21/2009 – 8/28/2009
D-River Gauge	8/21/2009 – 8/28/2009 10/5/2010 – 4/10/2011 6/20/2017 – 6/27/2017
H-River Gauge	8/21/2009 – 8/28/2009 7/16/2013 – 12/31/2013 12/1/2015 – 12/31/2017
F-River Gauge	1/1/2008 – 1/31/2008
300 Area Gauge	8/21/2009 – 8/28/2009

3.3.3 Evaluation of Changes in Stage Relationship

The relationship between the PRD gauge and the Hanford river gauges can be effected for variety of reasons, including changes in discharge from the PRD, adjustments to the river gauge transducers and gauges that are not maintained over long periods of time. When changes in the stage relationship occur, using one set of optimized parameters is inappropriate for modeling river stage.

Changes in the stage relationship were identified as offsets in the initial modeled relationship between the PRD gauge and the Hanford river gauge (Figure 4).

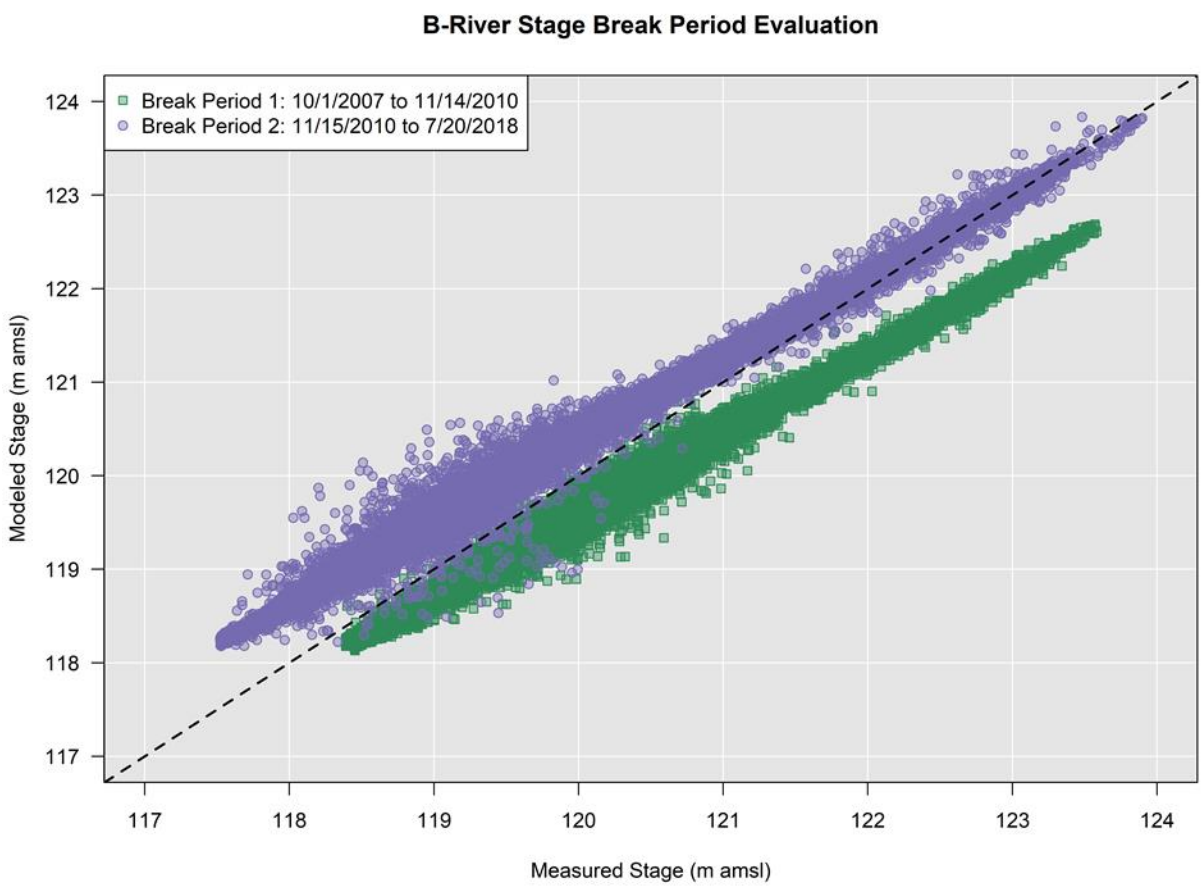

Figure 4. Example of Changes in the Relationship Between the PRD Gauge and the Hanford River Gauges

Instead of adjusting the measured data of the second break period to match the first break period (as discussed in ECF-HANFORD-13-0028, REV. 1), the river gauge was broken into distinct time periods and the convolution was performed independently on each time period. The time periods, or break periods, identified for each Hanford river gauge (other than the 300 Area gauge) are presented in Table 6.

Table 6. River Gauge Break Periods

Gauge	Time Period of AWLN Measurements	Break Periods	Rational for Different Break Periods
B-River Gauge	10/1/2007 – 7/31/2014	Break Period 1: 10/1/2007 – 11/14/2010 Break Period 2: 11/15/2010 – 7/31/2014	Discharge from PRD changed in duration and magnitude
K-River Gauge	3/25/2008 – 2/7/2011	3/25/2008 – 2/7/2011	No observed changes
N-River Gauge	10/1/2007 – 9/1/2010	Break Period 1: 10/1/2007 – 2/11/2008 Break Period 2: 2/12/2008 – 5/27/2009 Break Period 3: 5/28/2009 – 9/1/2010	Discharge from PRD changed in duration and magnitude and observed change in relationship between PRD and river gauge
D-River Gauge	10/1/2007 – 11/28/2017	Break Period 1: 10/1/2007 – 4/10/2011 Break Period 2: 4/11/2011 – 12/31/2011 Break Period 3: 1/1/2012 – 11/28/2017	Gauge not maintained over long periods of time
H-River Gauge	10/1/2007 – 11/29/2017	Break Period 1: 10/1/2007 – 12/31/2009 Break Period 2: 1/1/2010 – 12/31/2013	Discharge from PRD changed in duration and magnitude and gauge not maintained over long periods of time
F-River Gauge	10/1/2007 – 11/28/2017	Break Period 1: 10/1/2007 – 12/31/2007 Break Period 2: 1/1/2008 – 12/31/2009 Break Period 3: 1/1/2010 – 11/28/2017	Gauge not maintained over long periods of time

AWLN = automated water level network
PRD = Priest Rapids Dam

4 Assumptions

It was assumed that the PRD data obtained from the USGS were reliable and representative of the population of data for this location. This assumption underlines all steps in the methodology described in this document. Assumptions that underlie the derivation and application of the Ogata-Banks (1961) solution are also implied when using this method for the purposes detailed herein.

5 Software Applications

Calculations were performed using the public domain computing platform R (version 3.1.3 [published March 9, 2015]). The R platform provides data manipulation, calculation, and graphical display capabilities to support data analysis (Venables et al., 2015, *An Introduction to R Notes on R: A Programming Environment for Data Analysis and Graphics*). The platform is freely available to the public and can be compiled and run on a variety of media. The base installation of R contains statistical and plotting functions. Many more functions are available for download through the CRAN. The R routines described previously were independently checked and verified by detailed review as part of the preparation of this calculation. Development of software quality assurance documentation for this set of routines under CHPRC's controlled software management procedure would permit this process to be handled through software acceptance testing, rather than by detailed review and verification of each application of these R routines. Accordingly, preparation of software quality assurance documentation is recommended to support efficient future applications of these R routines.

Several R packages used for this analysis were downloaded from CRAN and are listed in Table 7.

Table 7. R Packages Used for River Convolution

R Package	Package Description	Version
dataRetrieval	Retrieval Functions for USGS and EPA Hydrologic and Water Quality Data	2.5.5
data.table	Enhanced data processing	1.9.4
zoo	S3 Infrastructure for Regular and Irregular Time Series (Z's ordered observations)	1.7-11

EPA = United States Environmental Protection Agency
USGS = United States Geological Survey

In addition to the CRAN packages listed in Table 7, several functions specific to the calculations performed in this document were incorporated into a user-defined R package called "sspariverconvolve."

The calculations were performed with the following series of R scripts:

- 01_Ogata-Banks_15min_Initial.R
- 02_Calculated River Stage_15min_Initial.R
- 03_Ogata-Banks_15min_Final.R
- 04_ Calculated River Stage_15min_Final.R
- 05_ Ogata-Banks_Daily_Initial.R
- 06_ Calculated River Stage_Daily_Initial.R
- 07_ Ogata-Banks_Daily_Final.R

- 08_ Calculated River Stage_Daily_Final.R

6 Calculation

The following input files were used in the implementation of this analysis:

- *qryAWLNAWLN.txt*: Transducer data from the AWLN database
- *OgataBanks.csv*: Hanford Area River Gauges
- *Manual Data Removals.csv*: Data flagged as outliers (see Table 5)
- *Breaks.csv*: List of break periods (see Table 6)

The calculations were performed with a series of R scripts (listed in Chapter 5 of this document). The first set of scripts (*01_Ogata-Banks_15min_Initial.R* and *05_ Ogata-Banks_Daily_Initial.R*) optimized the convolution parameters using all of the available data. The second set of scripts (*02_Calculated River Stage_15min_Initial.R* and *06_ Calculated River Stage_Daily_Initial.R*) calculated the river stage at each Hanford Area river gauge based on the initial convolution results. The third set of scripts (*03_Ogata-Banks_15min_Final.R* and *07_ Ogata-Banks_Daily_Final.R*) removed data with systematic offsets or suspect data and subset the remaining data by break period prior to optimizing the convolution parameters for each break period. The final set of scripts (*04_ Calculated River Stage_15min_Final.R* and *08_ Calculated River Stage_Daily_Final.R*) calculated the river stage at each Hanford Area river gauge based on the final convolution results.

7 Results

Outputs of the calculations are provided in Tables 8 and 9 and Figures 5 through 32.

7.1 Optimized Parameter Estimates

Sections 7.1 and 7.2 contain the results of river elevation modeling performed for each of the Hanford Area River Gauges using the diffusive wave approximation. The following optimized parameters of the model, using the entirety of the historical data (with the systematic data adjustments detailed earlier), are presented in Table 8 (15-minute convolution) and Table 9 (daily convolution):

- Downstream distance: the distance of the Hanford Area River Gauge from the upstream input (i.e., the USGS gauge below PRD)
- Dispersion coefficient (D): a factor associated with the attenuation of a wave as it progresses down the river (see Equations 2 and 3)
- Velocity: the average wave celerity (c) associated with that section of the river between the PRD gauge and the location of interest (see Equation 3)
- Time-averaged elevation difference (x_0) (see Equation 4)
- Differences in channel geometry (A) (see Equation 4)

Table 8. Optimized Model Parameters for Entire Measured Gauge Dataset – 15-Minute Dataset

Gauge	Time Period	Optimized Parameters				
		Distance Downstream (mi)	Dispersion Coefficient (mi^2/hr)	Celerity (mi/hr)	Scale	Offset
B-River Gauge	Break Period 1: 10/1/2007 – 11/14/2010	9.15	86.0	6.57	0.862	118.5
	Break Period 2: 11/15/2010 – 7/31/2014	9.15	70.8	6.35	0.861	117.5
K-River Gauge	3/25/2008 – 2/7/2011	12.0	45.7	6.22	0.887	116.6
N-River Gauge	Break Period 1: 10/1/2007 – 2/11/2008	15.8	27.3	7.28	0.792	116.1
	Break Period 2: 2/12/2008 – 5/27/2009	13.5	43.5	5.95	0.847	116.5
	Break Period 3: 5/28/2009 – 9/1/2010	13.5	54.4	5.49	0.729	116.3
D-River Gauge	Break Period 1: 10/1/2007 – 4/10/2011	15.3	42.8	6.68	0.679	116.2
	Break Period 2: 4/11/2011 – 12/31/2011	15.3	63.2	6.79	0.686	116.2
	Break Period 3: 1/1/2012 – 11/28/2017	15.3	53.5	7.56	0.675	115.6
H-River Gauge	Break Period 1: 10/1/2007 – 12/31/2009	19.1	31.3	6.11	0.74	113.8
	Break Period 2: 1/1/2010 – 12/31/2013	19.4	30.7	6.24	0.737	113.6
F-River Gauge	Break Period 1: 10/1/2007 – 12/31/2007	24.4	28.2	6.55	0.749	112.0
	Break Period 2: 1/1/2008 – 12/31/2009	22.5	29.1	6.39	0.779	111.3
	Break Period 3: 1/1/2010 – 11/28/2017	28.9	26.4	6.34	0.836	111.9
300 Area Gauge	10/1/2007 – 6/30/2017	50.643.	43.25.1	5.14	0.5310.	104.1

Table 9. Optimized Model Parameters for Entire Measured Gauge Dataset – Daily Dataset

Gauge	Time Period	Optimized Parameters				
		Distance Downstream (mi)	Dispersion Coefficient (mi^2/hr)	Celerity (mi/hr)	PRD Scale	Offset
B-River Gauge	Break Period 1: 10/1/2007 – 11/14/2010	8.65	86.0	6.57	0.820	120.2
	Break Period 2: 11/15/2010 – 7/31/2014	9.65	70.8	6.35	0.840	119.3
K-River Gauge	3/25/2008 – 2/7/2011	9.65	45.7	6.22	0.850	118.4
N-River Gauge	Break Period 1: 10/1/2007 – 2/11/2008	15.8	27.3	7.28	0.797	118
	Break Period 2: 2/12/2008 – 5/27/2009	14.0	43.5	5.93	0.782	118.3
	Break Period 3: 5/28/2009 – 9/1/2010	13.0	54.4	5.50	0.628	117.9
D-River Gauge	Break Period 1: 10/1/2007 – 4/10/2011	14.8	42.8	6.69	0.637	117.6
	Break Period 2: 4/11/2011 – 12/31/2011	15.8	63.3	4.17	0.680	117.6
	Break Period 3: 1/1/2012 – 11/28/2017	15.8	53.5	7.54	0.646	117.0
H-River Gauge	Break Period 1: 10/1/2007 – 12/31/2009	18.6	31.1	8.84	0.689	115.3
	Break Period 2: 1/1/2010 – 12/31/2013	18.9	30.7	6.25	0.731	115.1
F-River Gauge	Break Period 1: 10/1/2007 – 12/31/2007	23.9	28.1	6.57	0.747	112.9
	Break Period 2: 1/1/2008 – 12/31/2009	22.0	29.1	6.40	0.761	112.9
	Break Period 3: 1/1/2010 – 11/28/2017	29.4	26.4	6.32	0.822	113.6
300 Area Gauge	10/1/2007 – 6/30/2017	50.3	814	126	0.510	105.2

PRD = Priest Rapids Dam

The distances downstream presented in Tables 8 and 9 were obtained from parameter optimization (calibration). The differences calibrated downstream distances are within 1 mile of the mapped downstream distance for each gauge location. Discrepancies between these distances may be caused by a difference in the bed slope or other factors between the PRD gauge and the Hanford gauge locations.

Differences in calibration parameters among break periods at a single gauge likely reflect changes in the positioning of the transducer or bed form with time.

The following statistics comparing the model and measured data are presented in Table 10:

- Number of available measured data values for each gauge.
- Sum Square Difference (the sum of the squared difference between individual model results and measured data values).
- The standard deviation here represents the residual standard deviation; it is a measure of the variation of the residuals. A smaller standard deviation indicates that the model results correspond better overall to the measured data.

Table 10. Optimized Model Statistics

Gauge	Statistics				
	Dataset	Data Point Count*	R-squared	Sum Square Difference	Standard Deviation (m)
B-River Gauge	15-Minute	46,471	0.991	703.8	0.056
	Daily	3,723	0.925	14560	233
K-River Gauge	15-Minute	24,755	0.986	433.2	0.032
	Daily	1,042	0.917	89.87	0.138
N-River Gauge	15-Minute	22,061	0.954	986.6	0.070
	Daily	2,405	0.867	2810	401
D-River Gauge	15-Minute	52,529	0.984	723.9	0.033
	Daily	3,911	0.912	231.6	0.108
H-River Gauge	15-Minute	59,686	0.984	1026	0.031
	Daily	3,493	0.935	13500	255
F-River Gauge	15-Minute	13,629	0.997	83.11	0.020
	Daily	1,969	0.881	262.0	2.31
300-River Gauge	15-Minute	86,008	0.880	4815	0.069
	Daily	4,804	0.529	1176	0.537

*The number of measured river gauge data used in the convolution, excluding outliers.

7.2 River Stage Convolution Results

The measured data were plotted along with the final model calculated river stage in time series plots. Additional one-to-one scatter plots of measured versus model calculated river stage are presented. Plots are also shown for a very short data period (about 30 days) providing a visual indication of the ability of the convolution method using the Ogata-Banks (1961) model approach to mimic the shape of the wave as it propagates past each Hanford groundwater OU location.

7.2.1 100-B Model Results

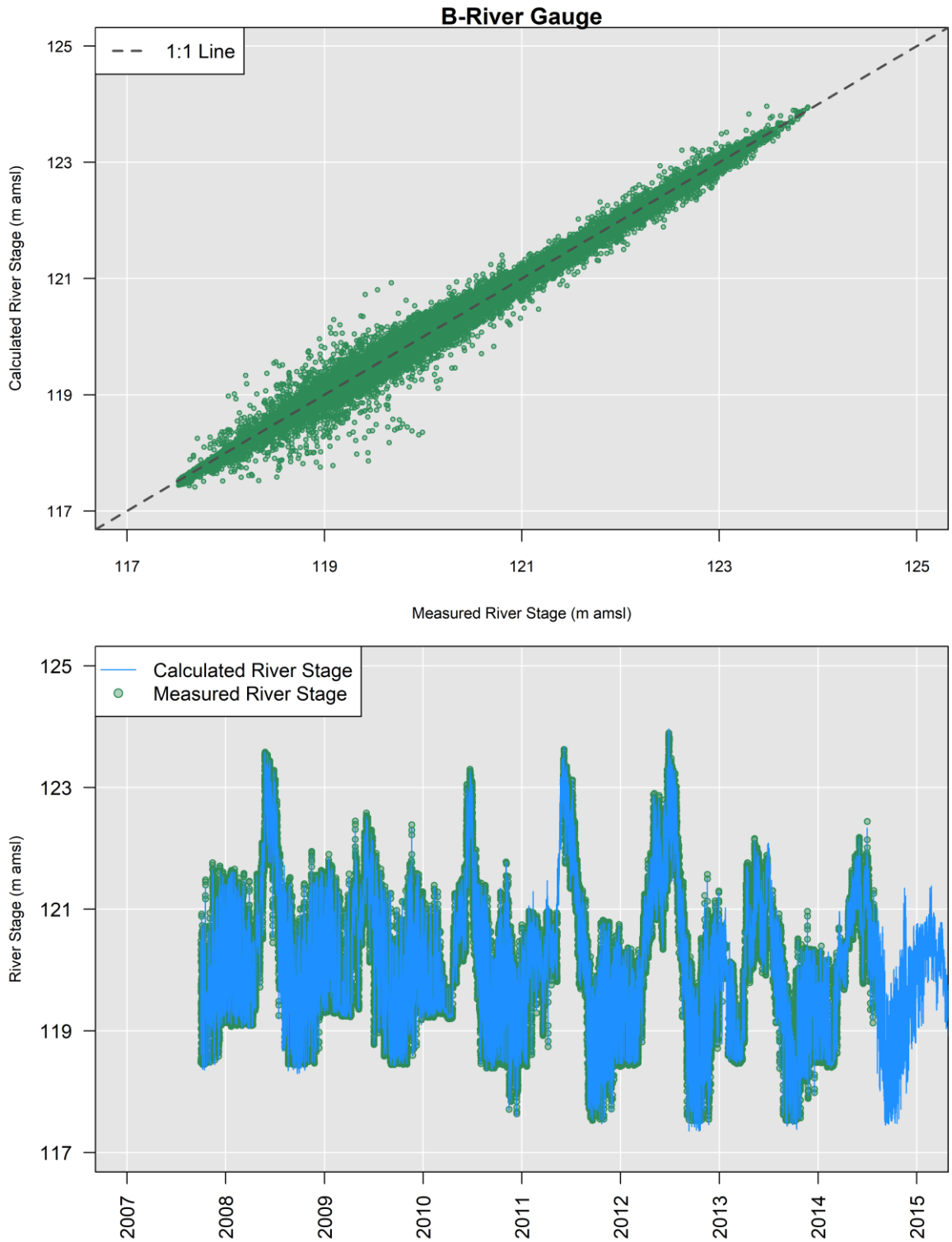

Figure 5. B-River Gauge Convolution Based on 15-Minute Dataset

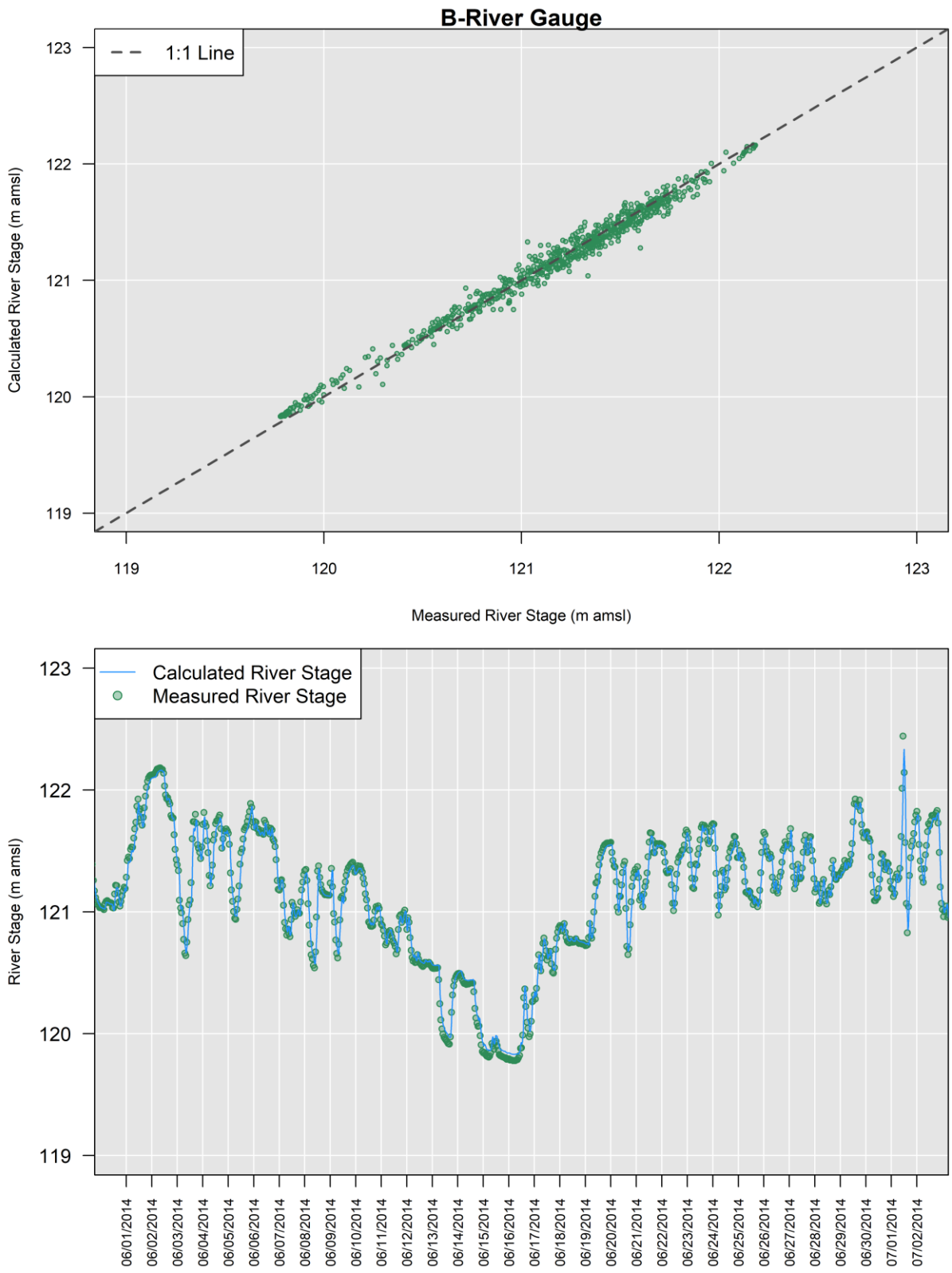

Figure 6. B-River Gauge Convolution for 30-Days Based on 15-Minute Dataset

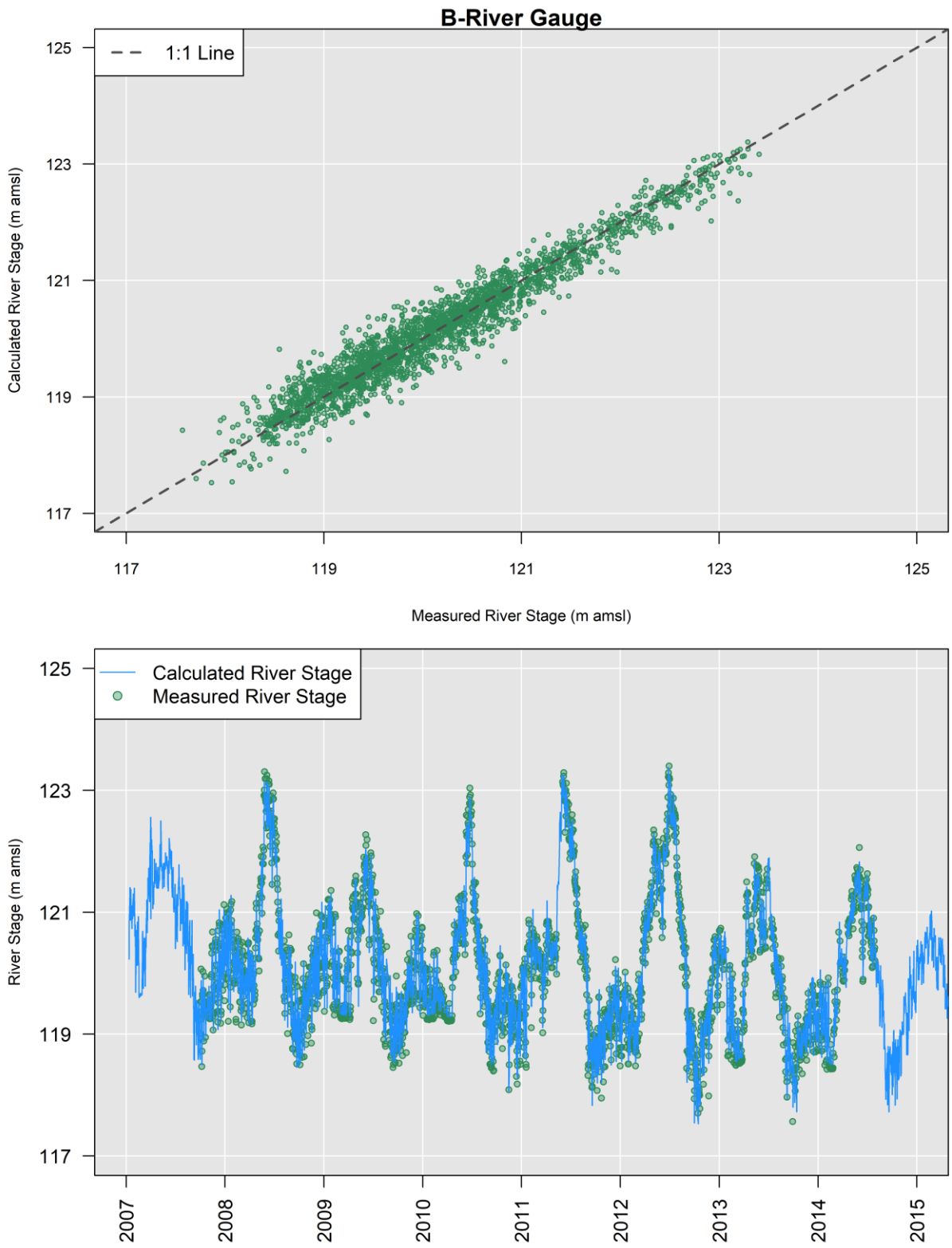

Figure 7. B-River Gauge Convolution Based on Daily Dataset

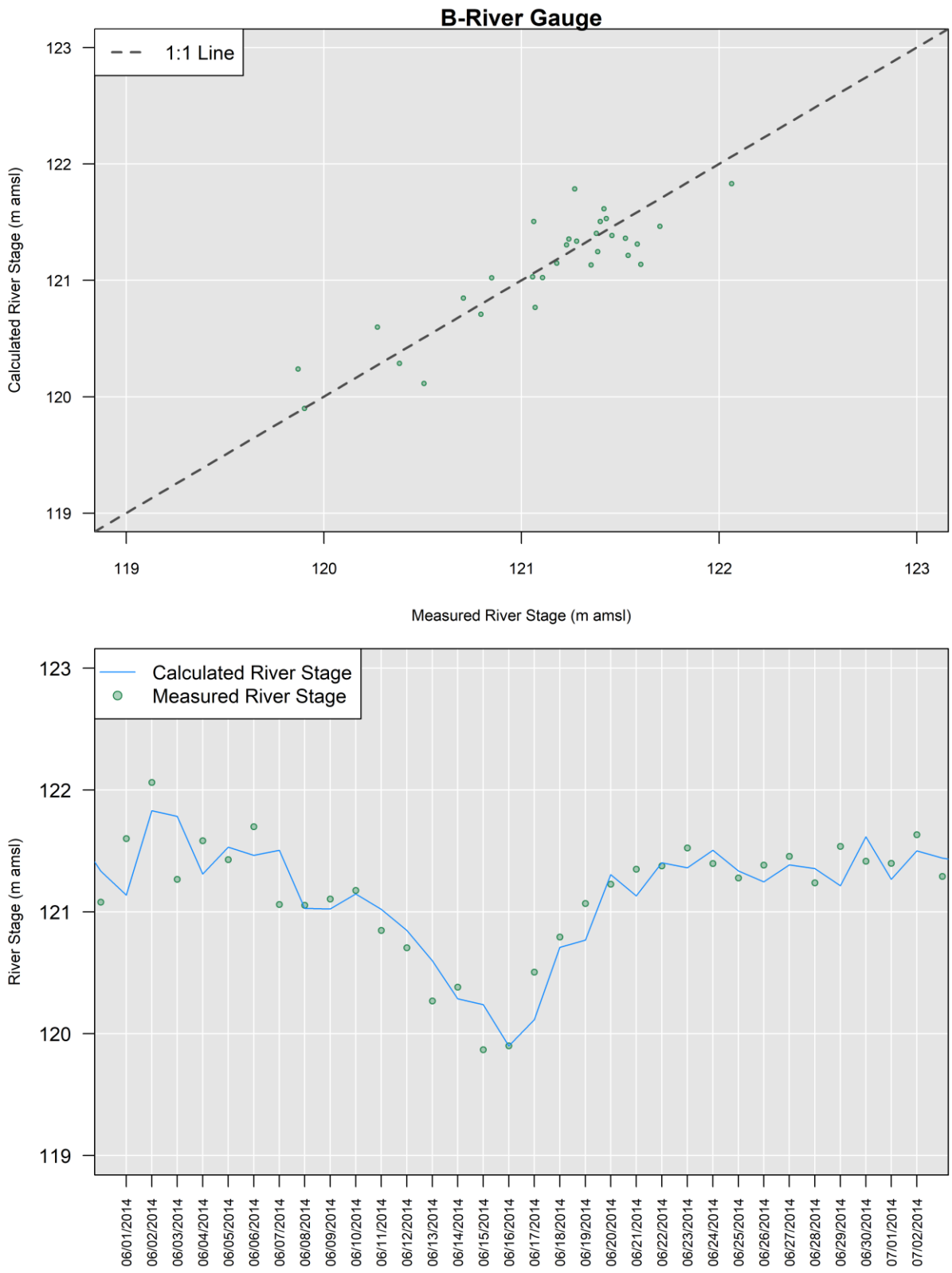

Figure 8. B-River Gauge Convolution for 30-Days Based on Daily Dataset

7.2.2 100-K Model Results

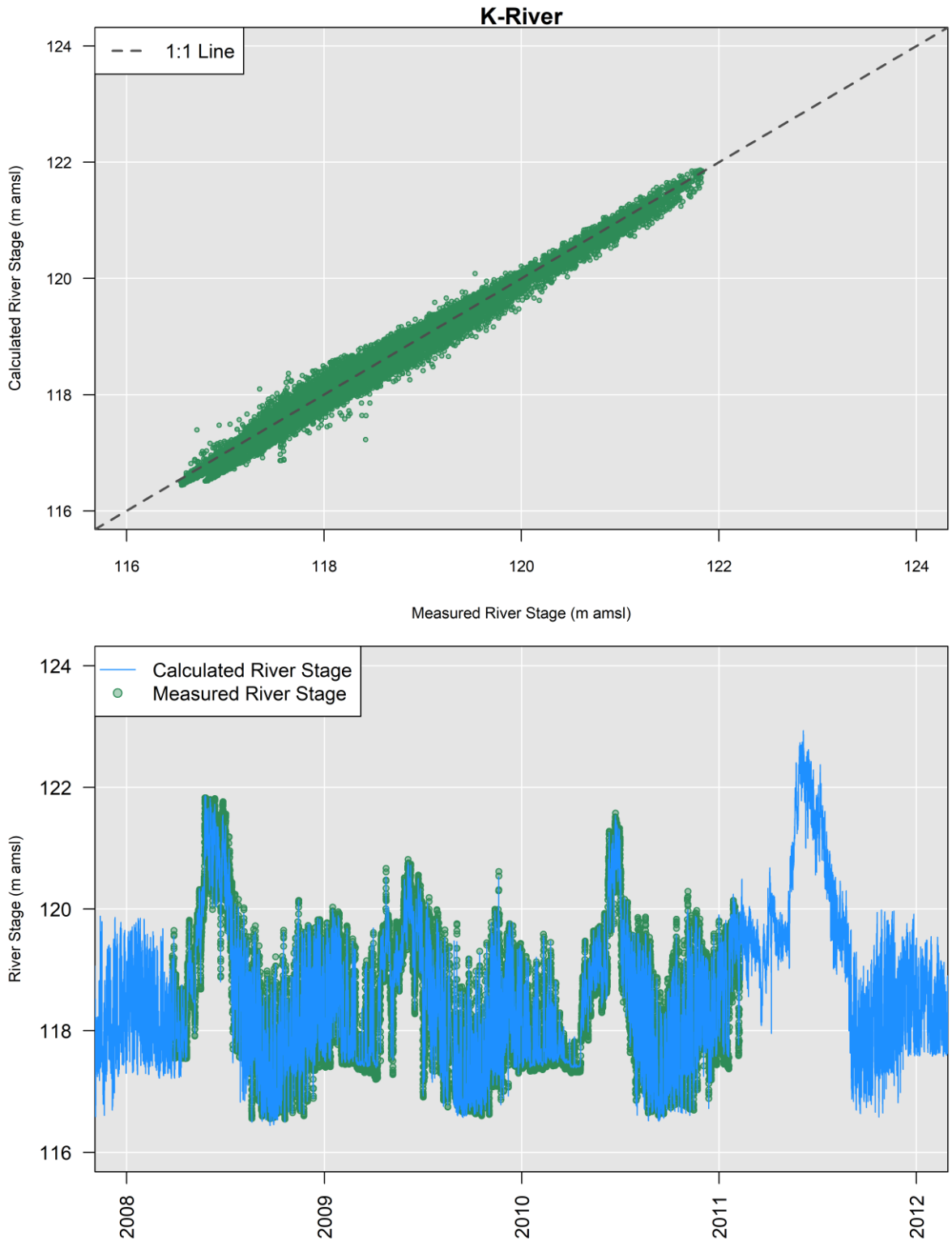

Figure 9. K-River Gauge Convolution Based on 15-Minute Dataset

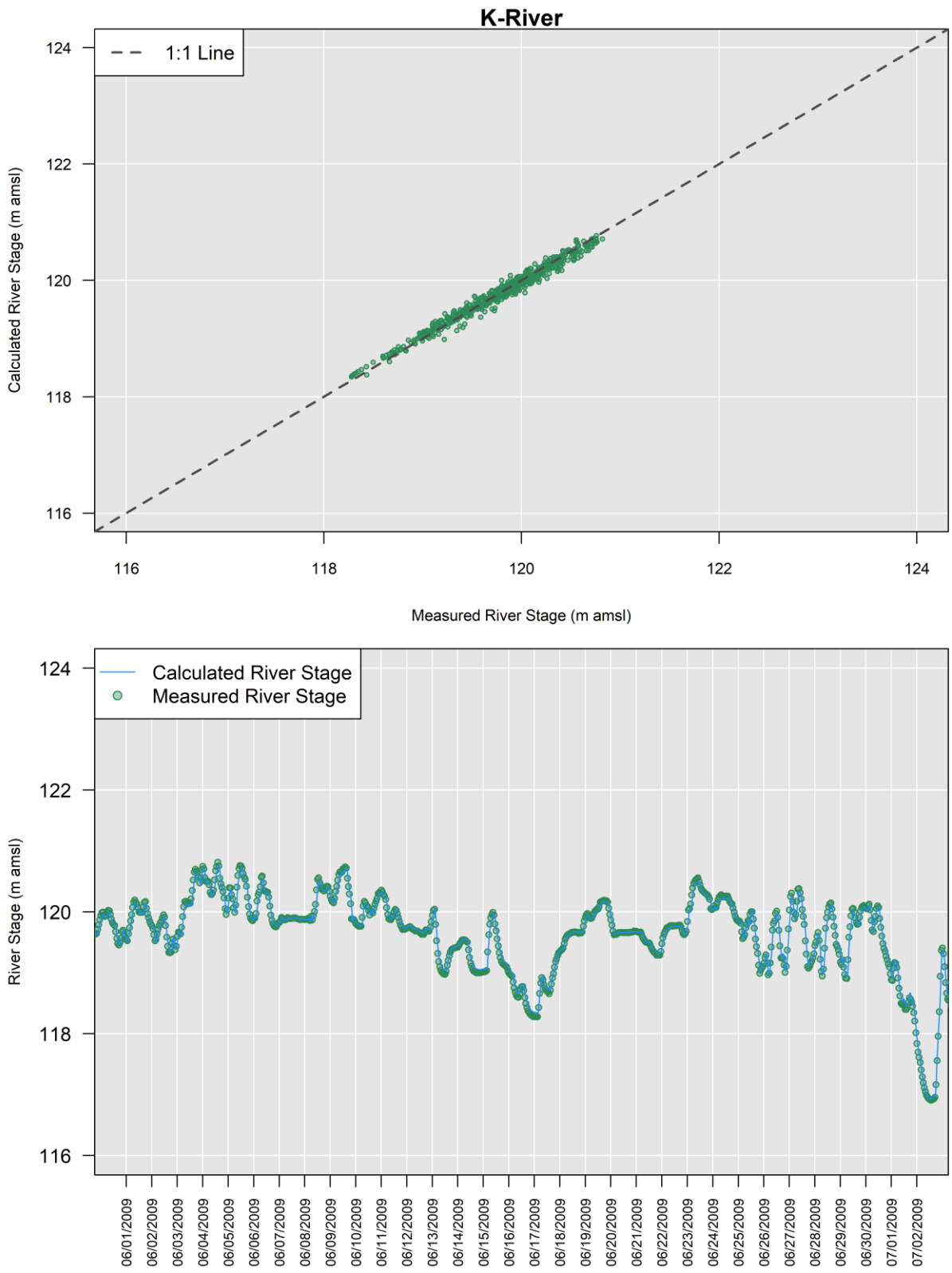

Figure 10. K-River Gauge Convolution for 30-Days Based on 15-Minute Dataset

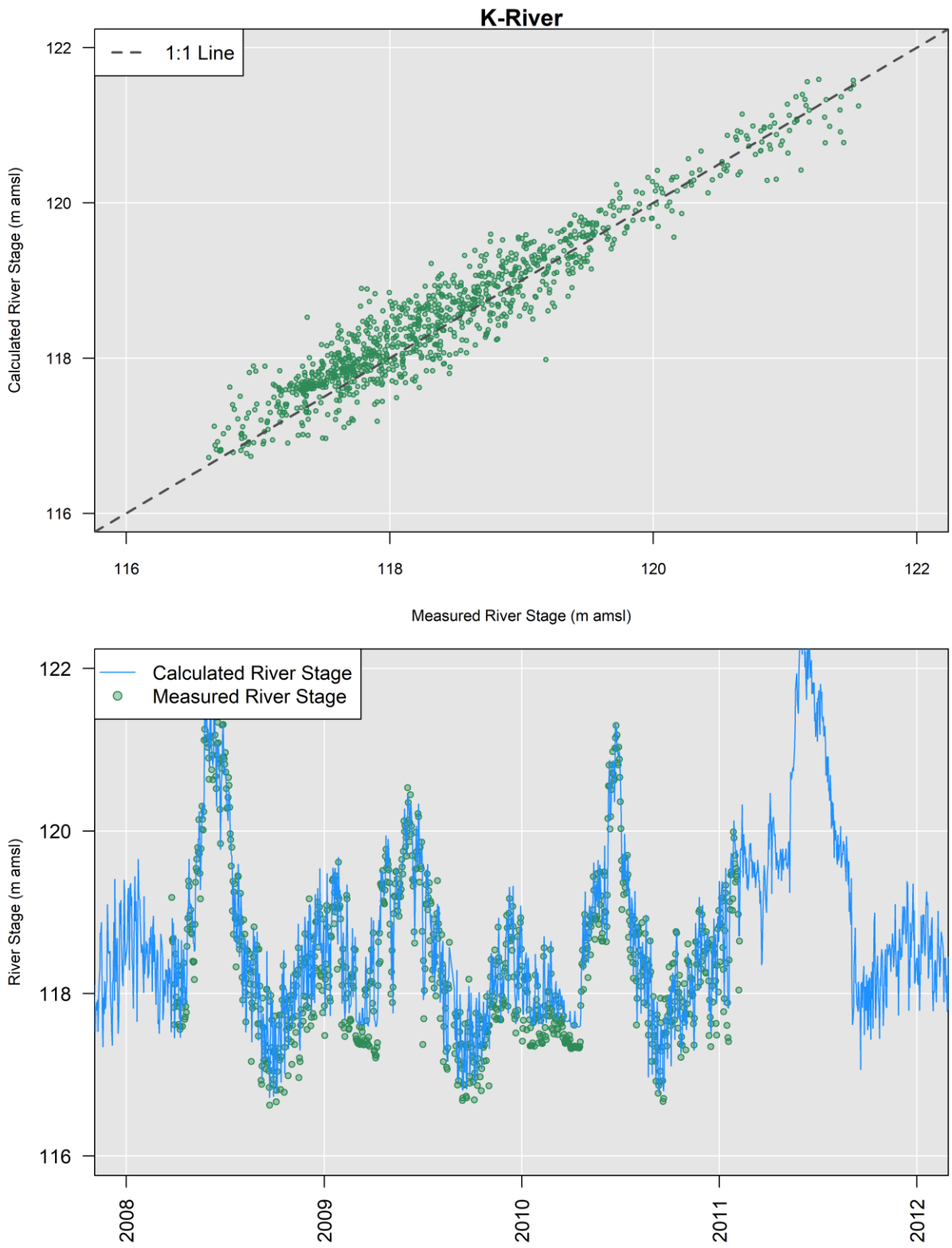

Figure 11. K-River Gauge Convolution Based on Daily Dataset

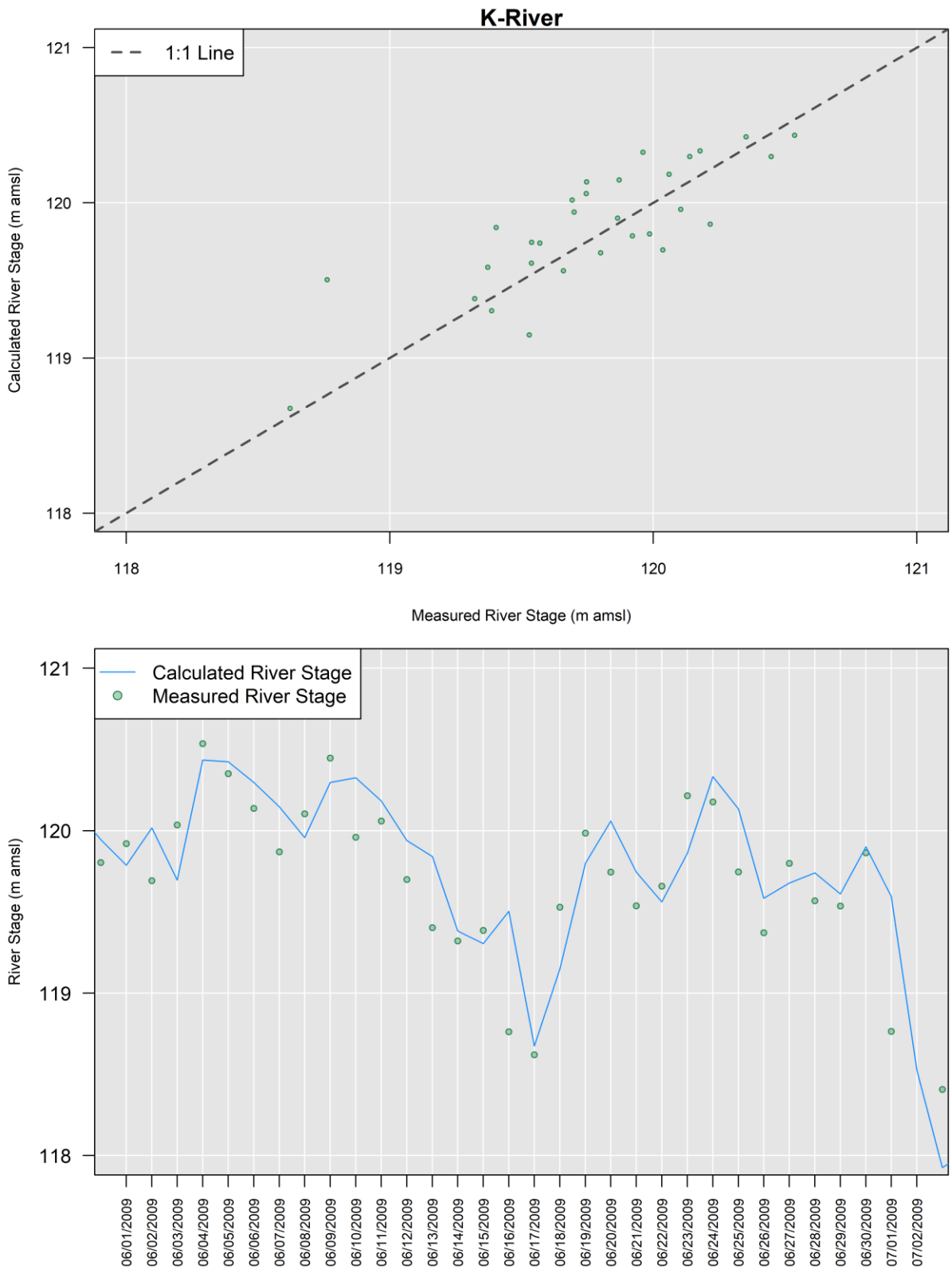

Figure 12. K-River Gauge Convolution for 30-days Based on Daily Dataset

7.2.3 100-N Model Results

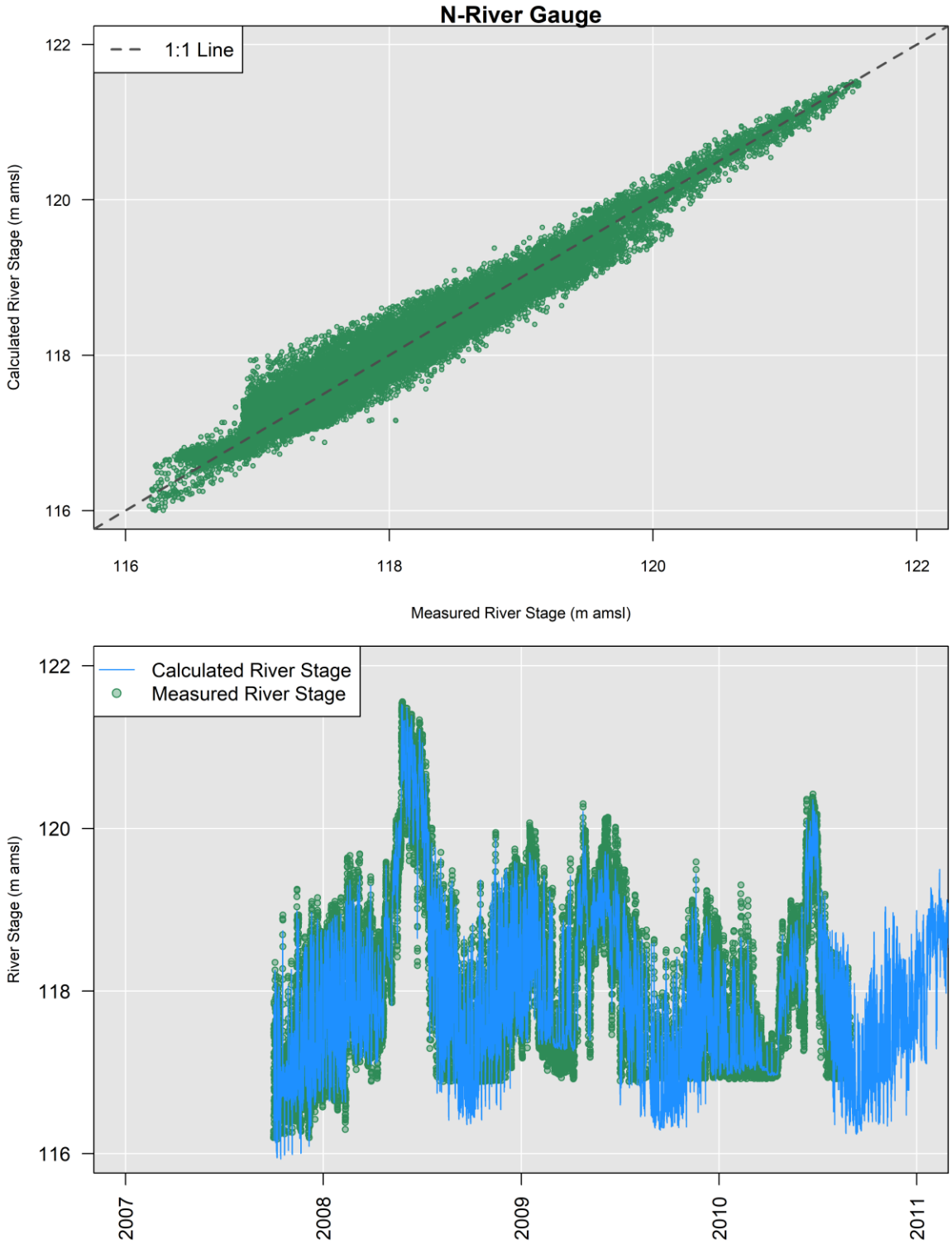

Figure 13. N-River Gauge Convolution Based on 15-Minute Dataset

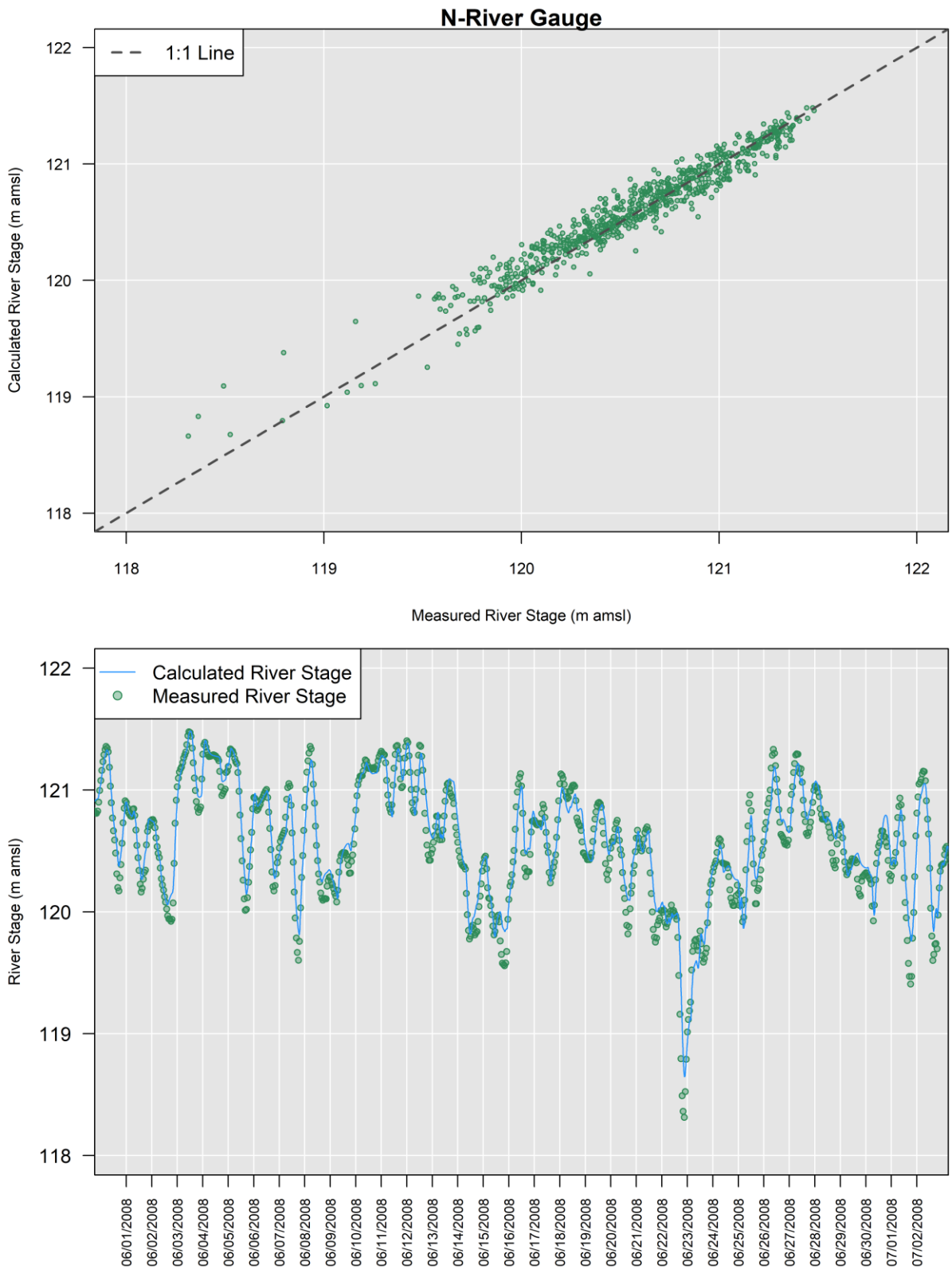

Figure 14. N-River Gauge Convolution for 30-Days Based on 15-Minute Dataset

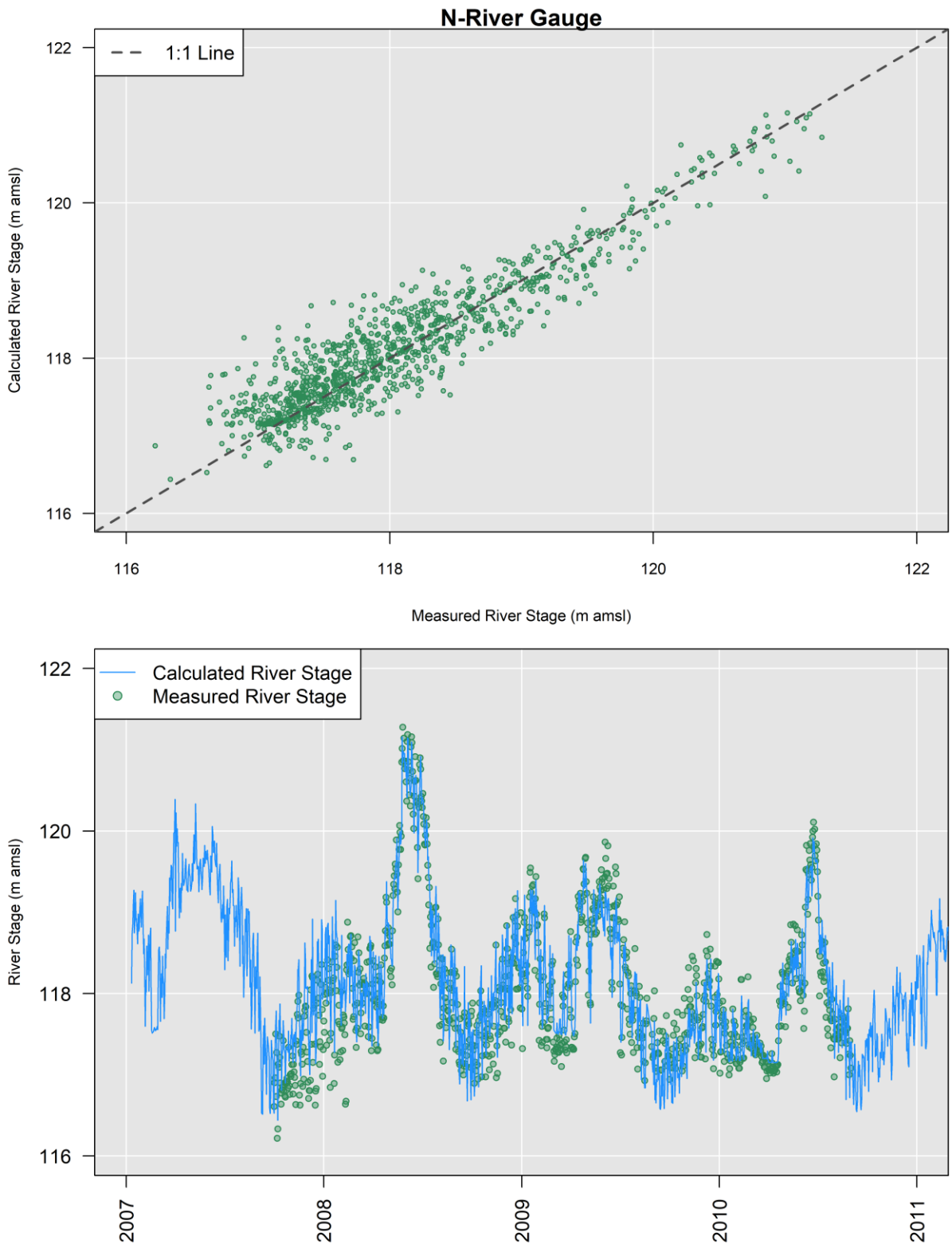

Figure 15. N-River Gauge Convolution Based on Daily Dataset

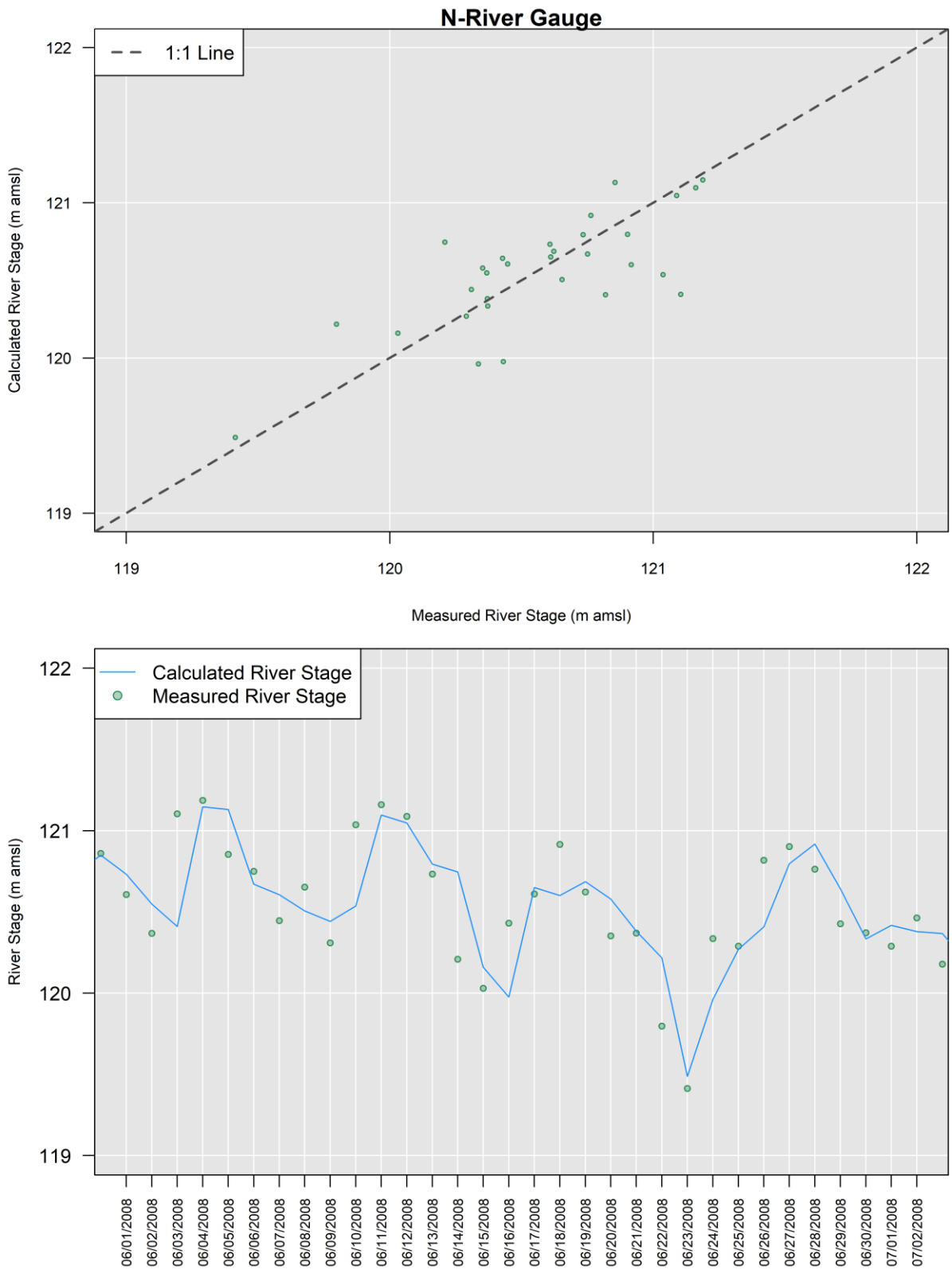

Figure 16. N-River Gauge Convolution for 30-Days Based on Daily Dataset

7.2.4 100-D Model Results

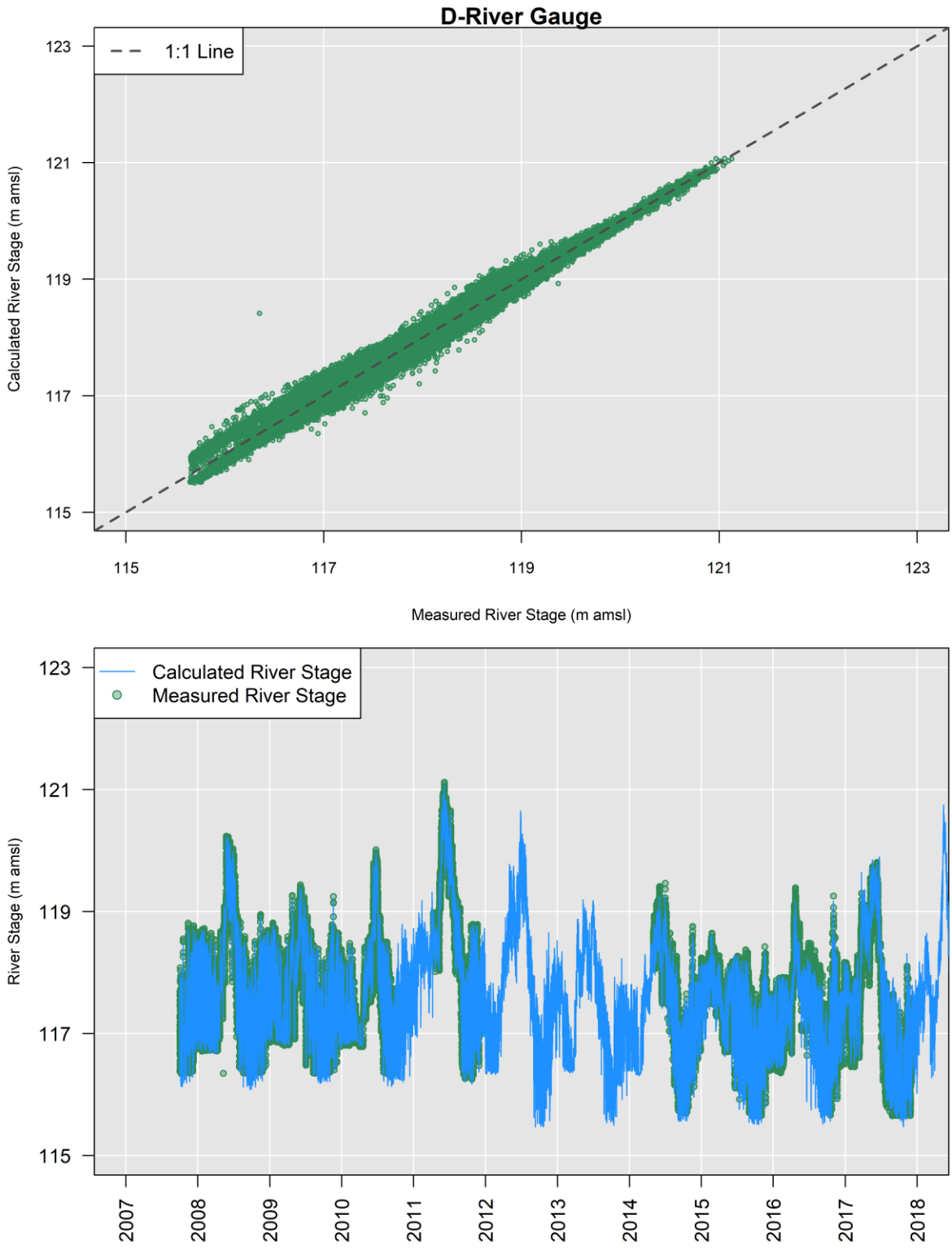

Figure 17. D-River Gauge Convolution Based on 15-Minute Dataset

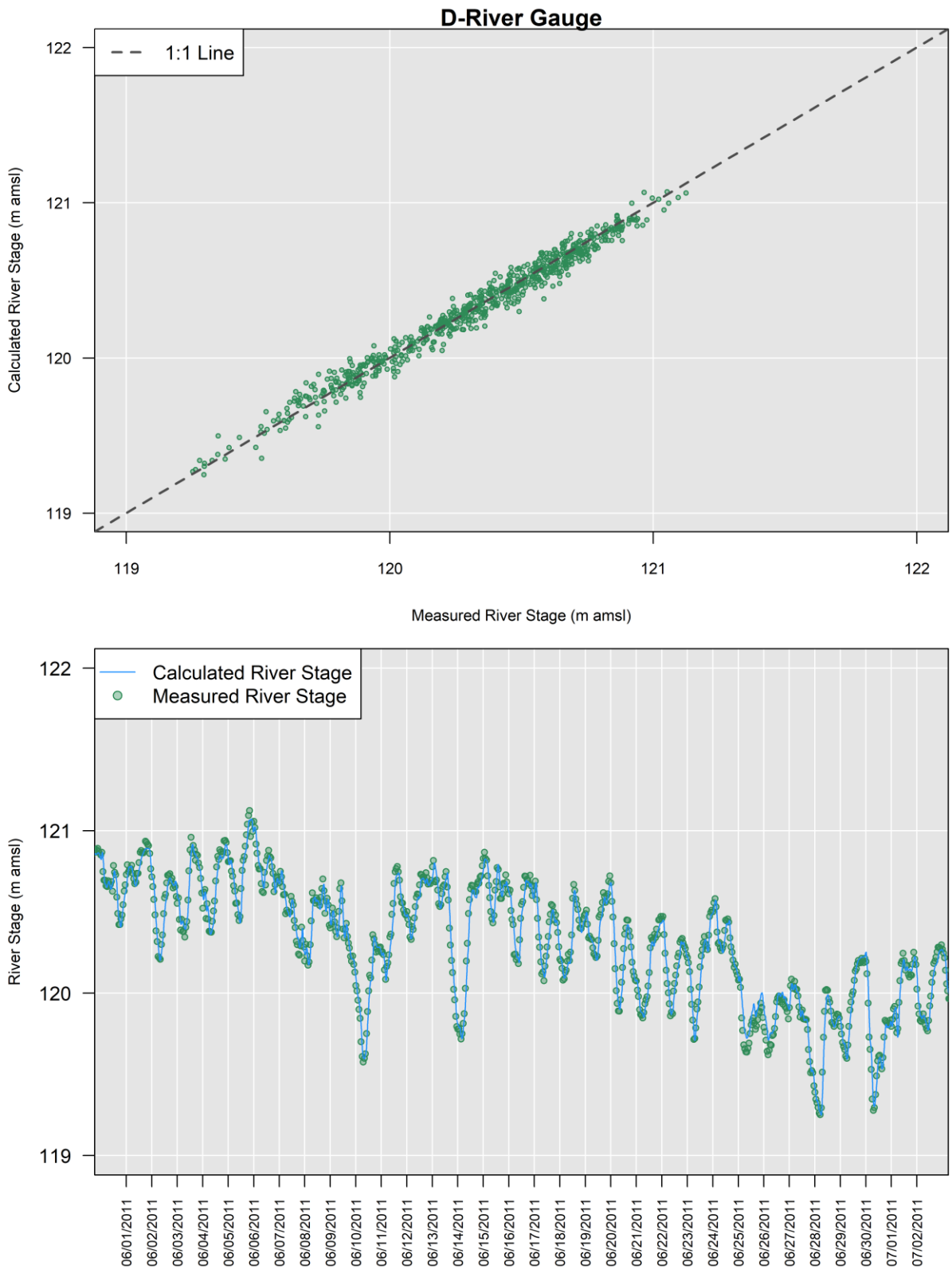

Figure 18. D-River Gauge Convolution for 30-Days Based on 15-Minute Dataset

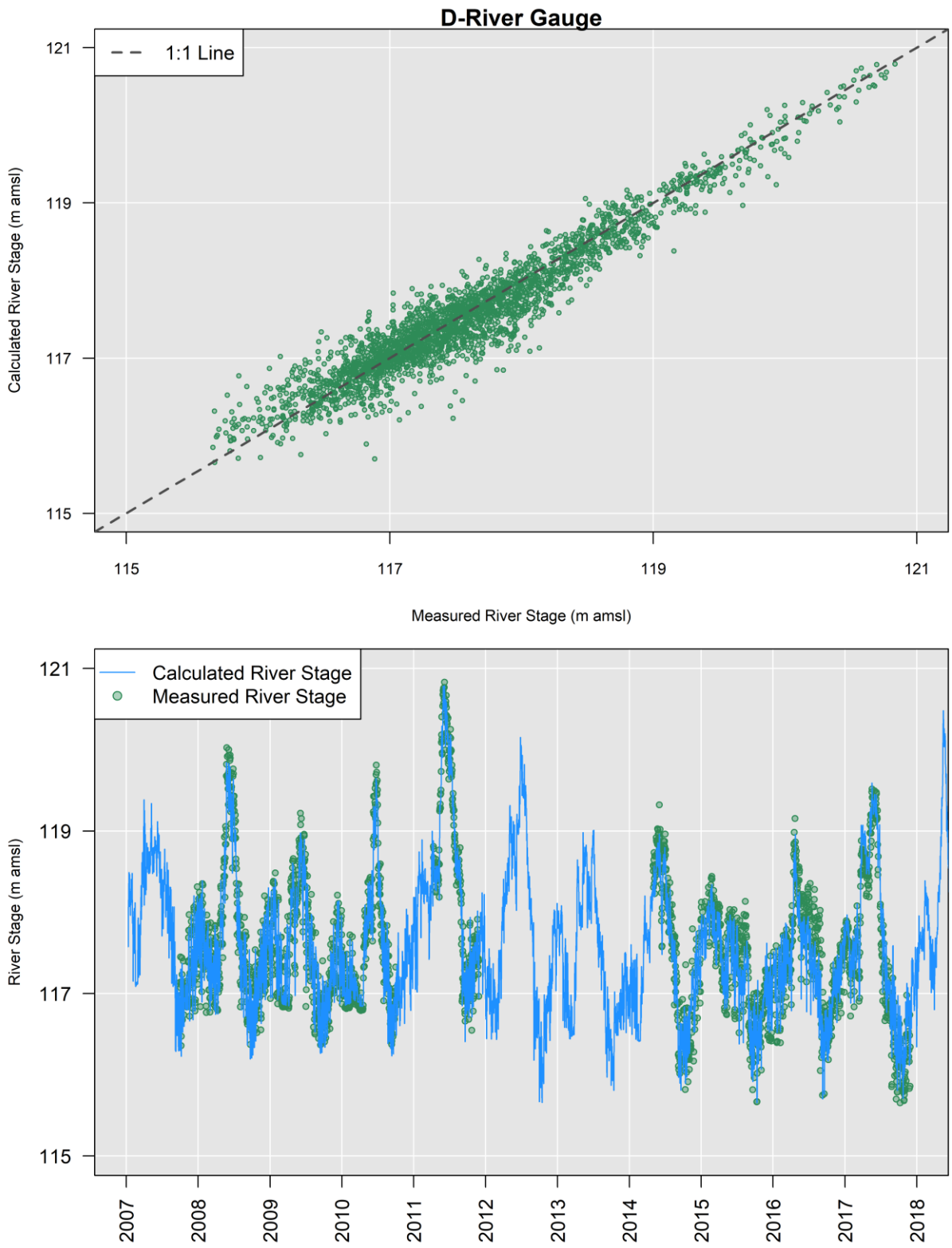

Figure 19. D-River Gauge Convolution Based on Daily Dataset

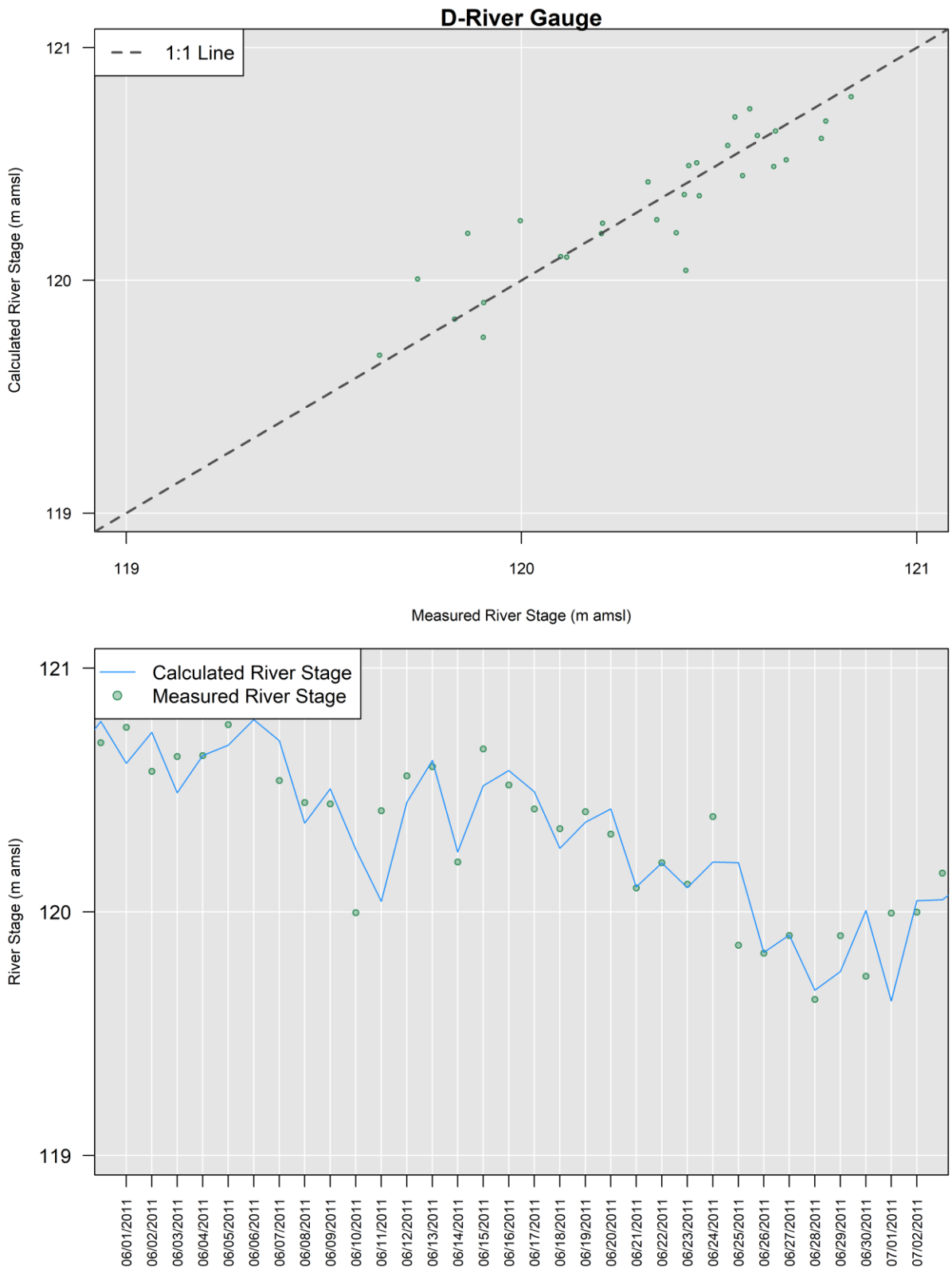

Figure 20. D-River Gauge Convolution for 30-Days Based on Daily Dataset

7.2.5 100-H Model Results

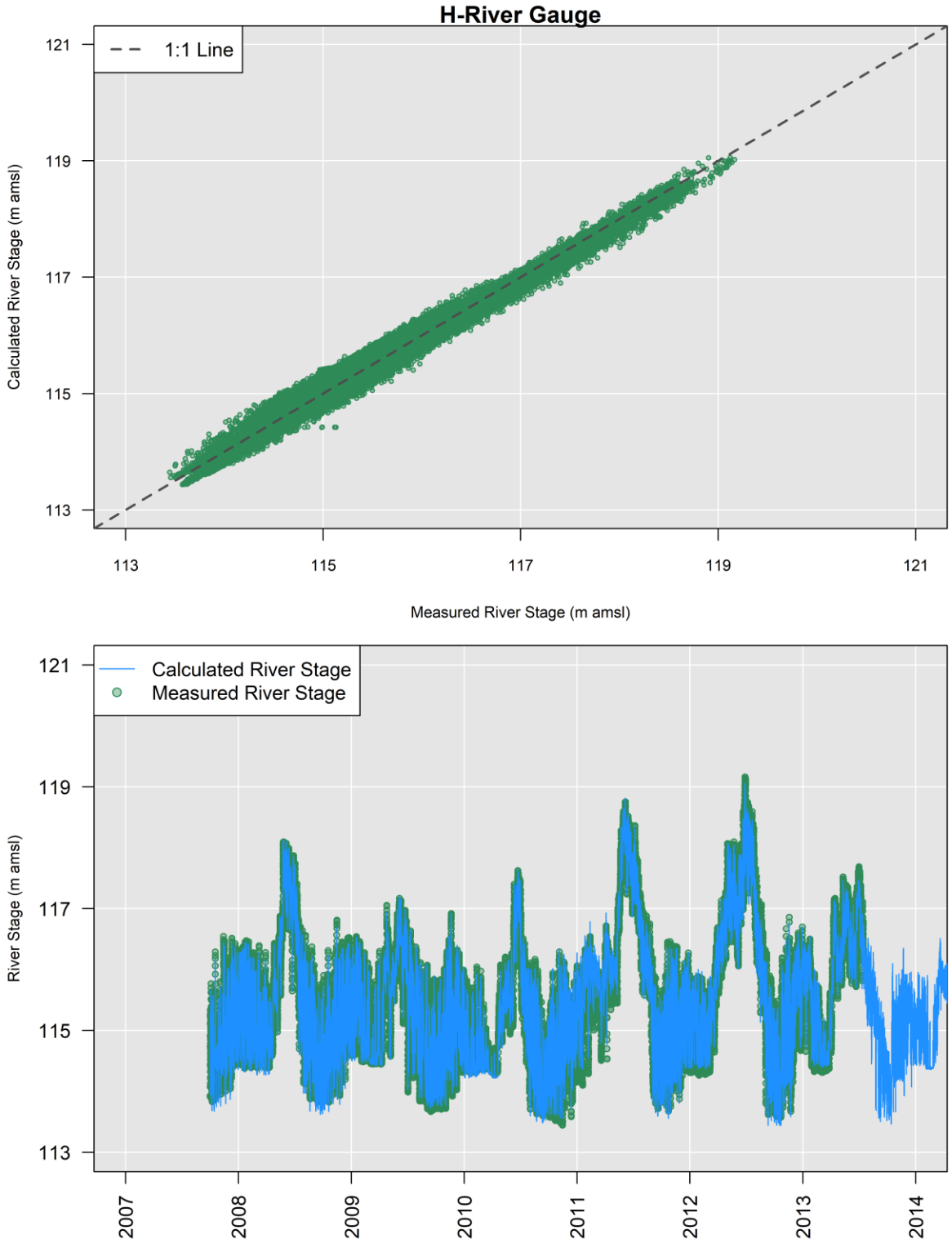

Figure 21. H-River Gauge Convolution Based on 15-Minute Dataset

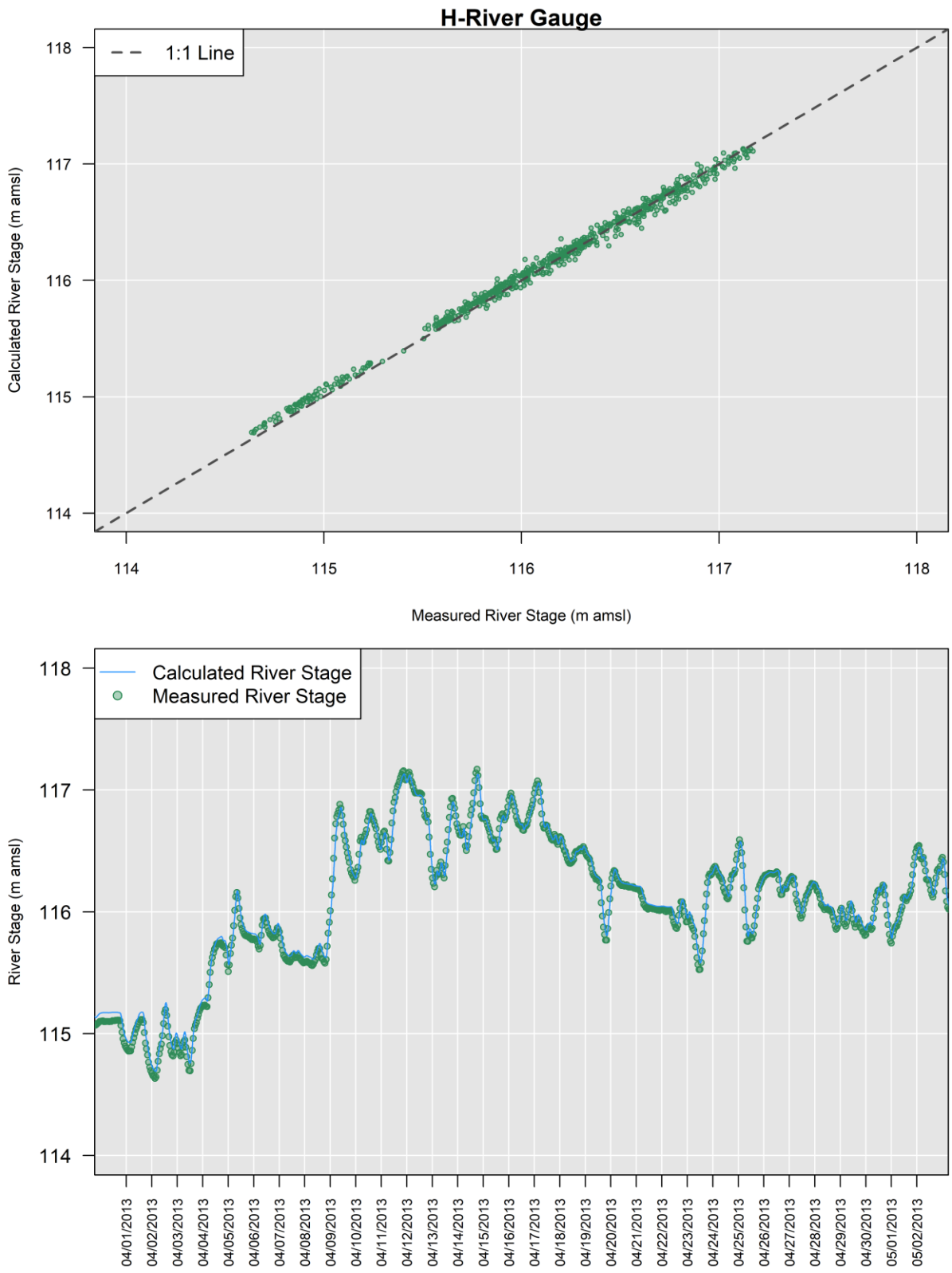

Figure 22. H-River Gauge Convolution for 30-Days Based on 15-Minute Dataset

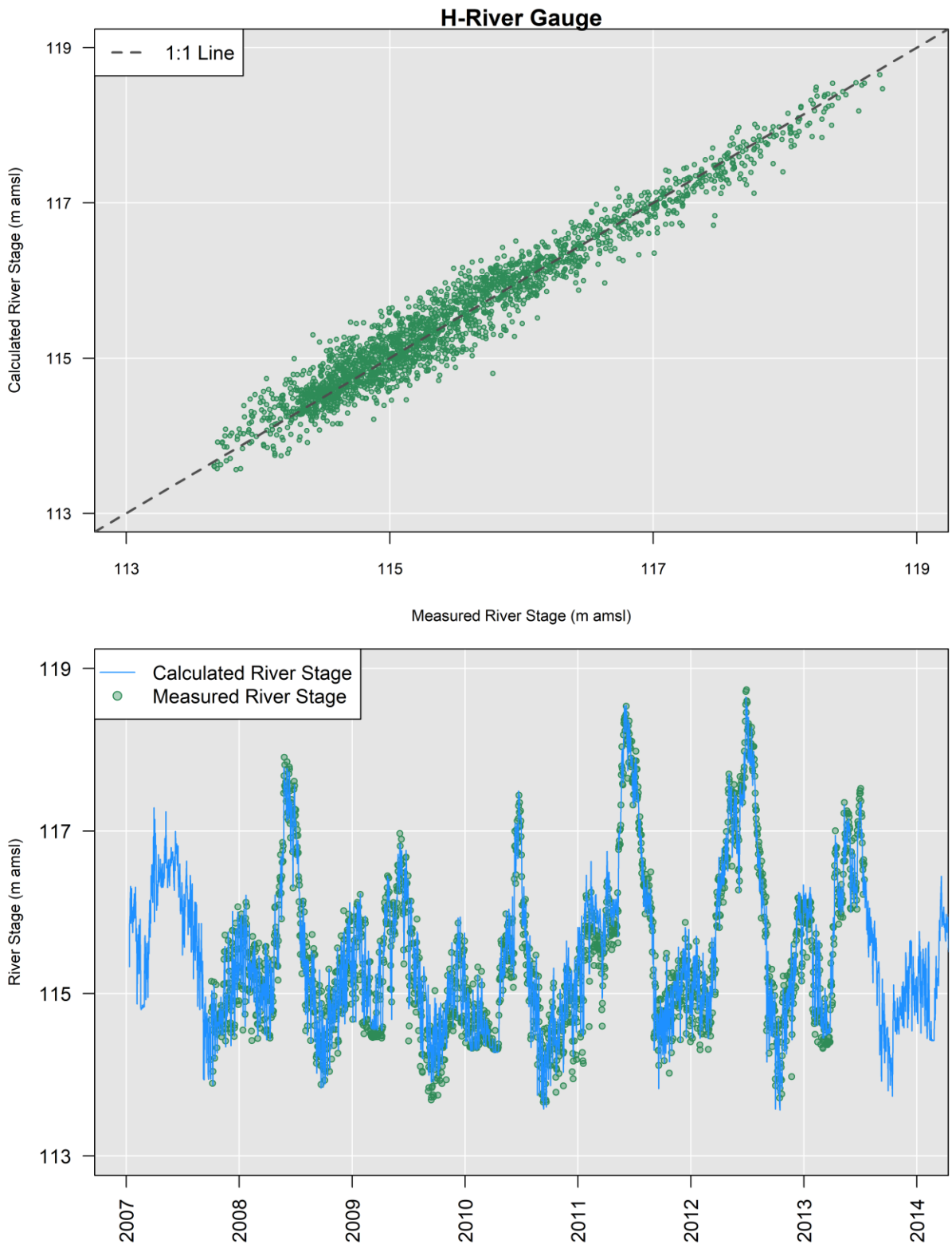

Figure 23. H-River Gauge Convolution Based on Daily Dataset

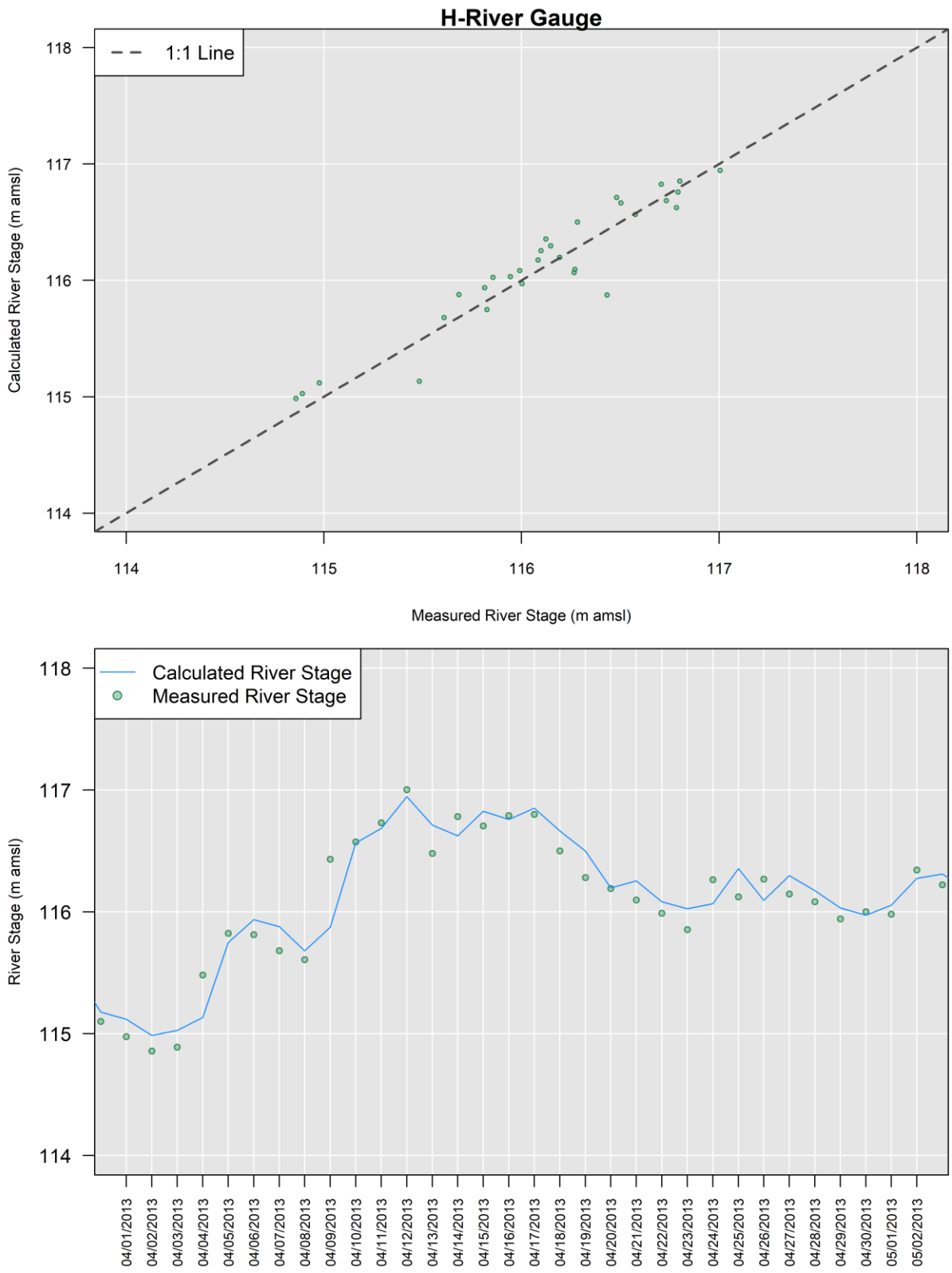

Figure 24. H-River Gauge Convolution for 30-Days Based on Daily Dataset

7.2.6 100-F Model Results

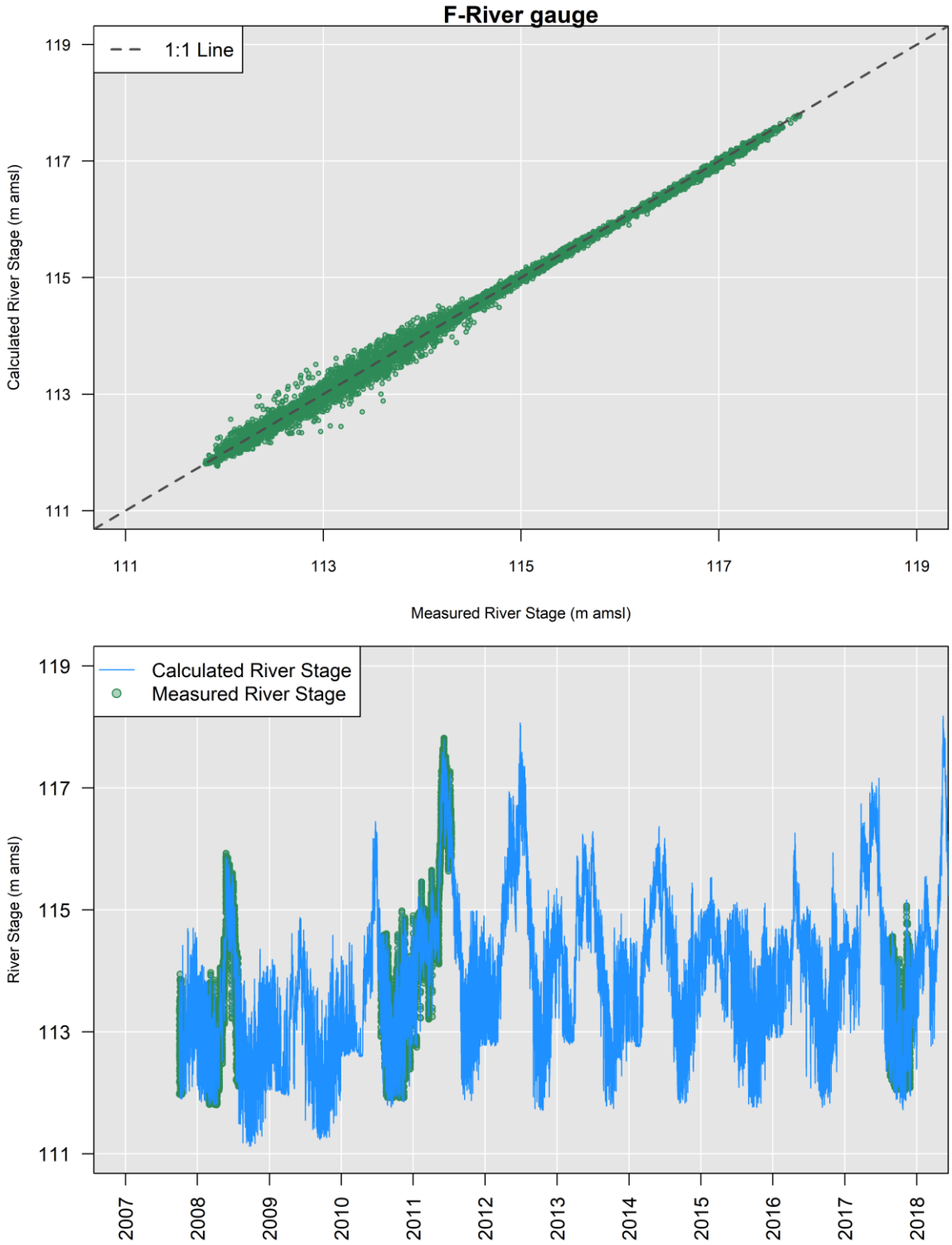

Figure 25. F-River Gauge Convolution Based on 15-Minute Dataset

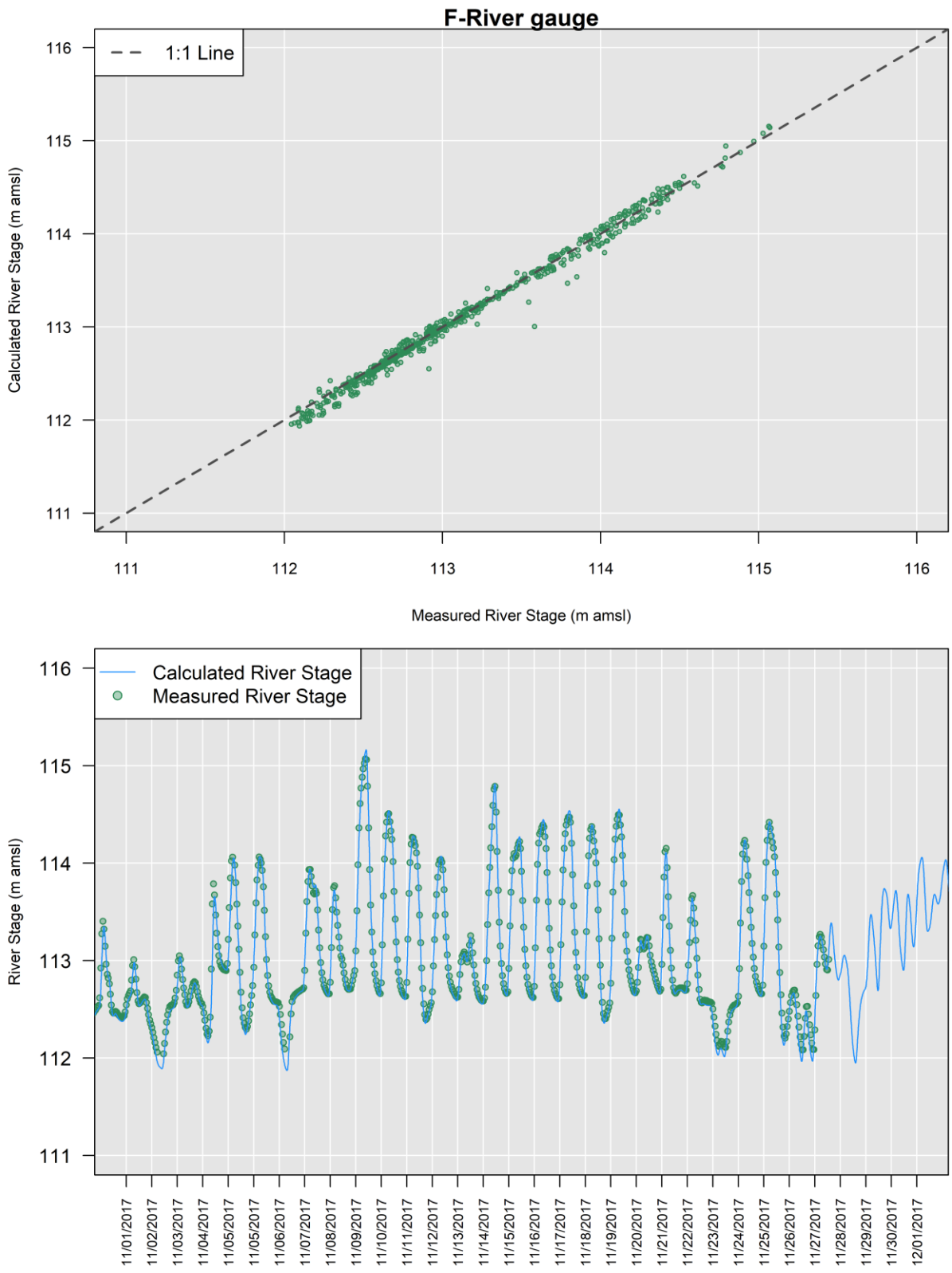

Figure 26. F-River Gauge Convolution for 30-Days Based on 15-Minute Dataset

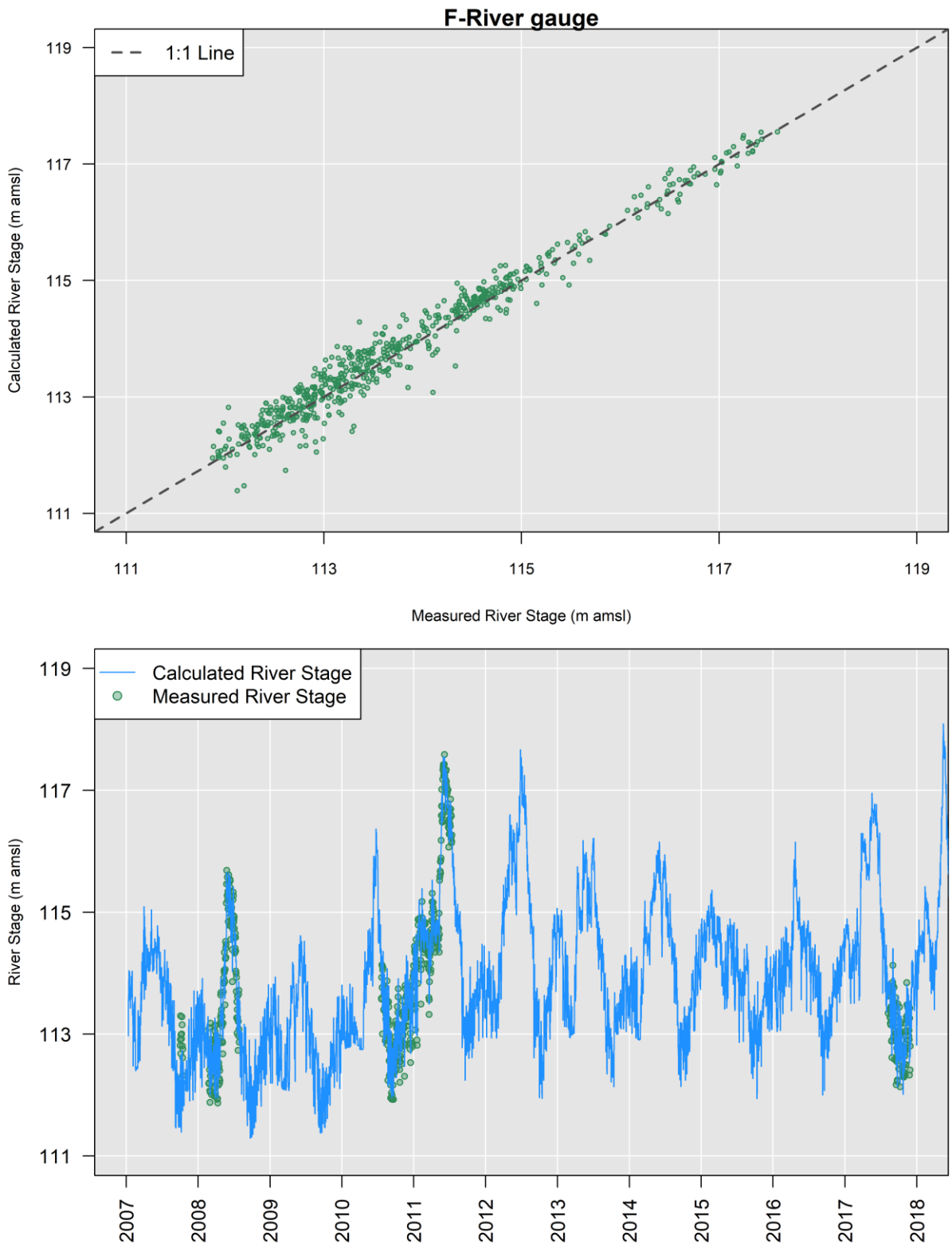

Figure 27. F-River Gauge Convolution Based on Daily Dataset

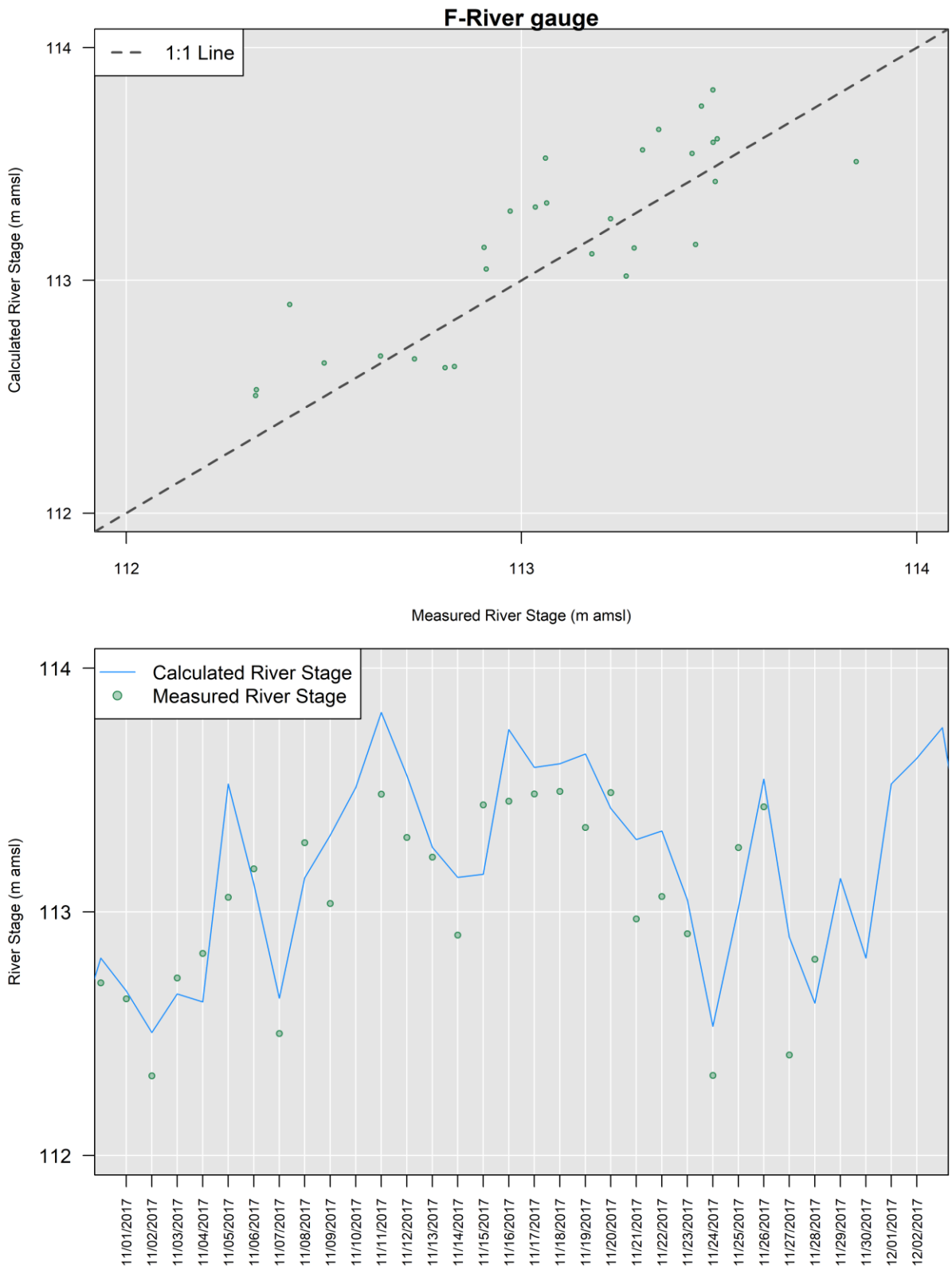

Figure 28. F-River Gauge Convolution for 30-days Based on Daily Dataset

7.2.7 300 Area Model Results

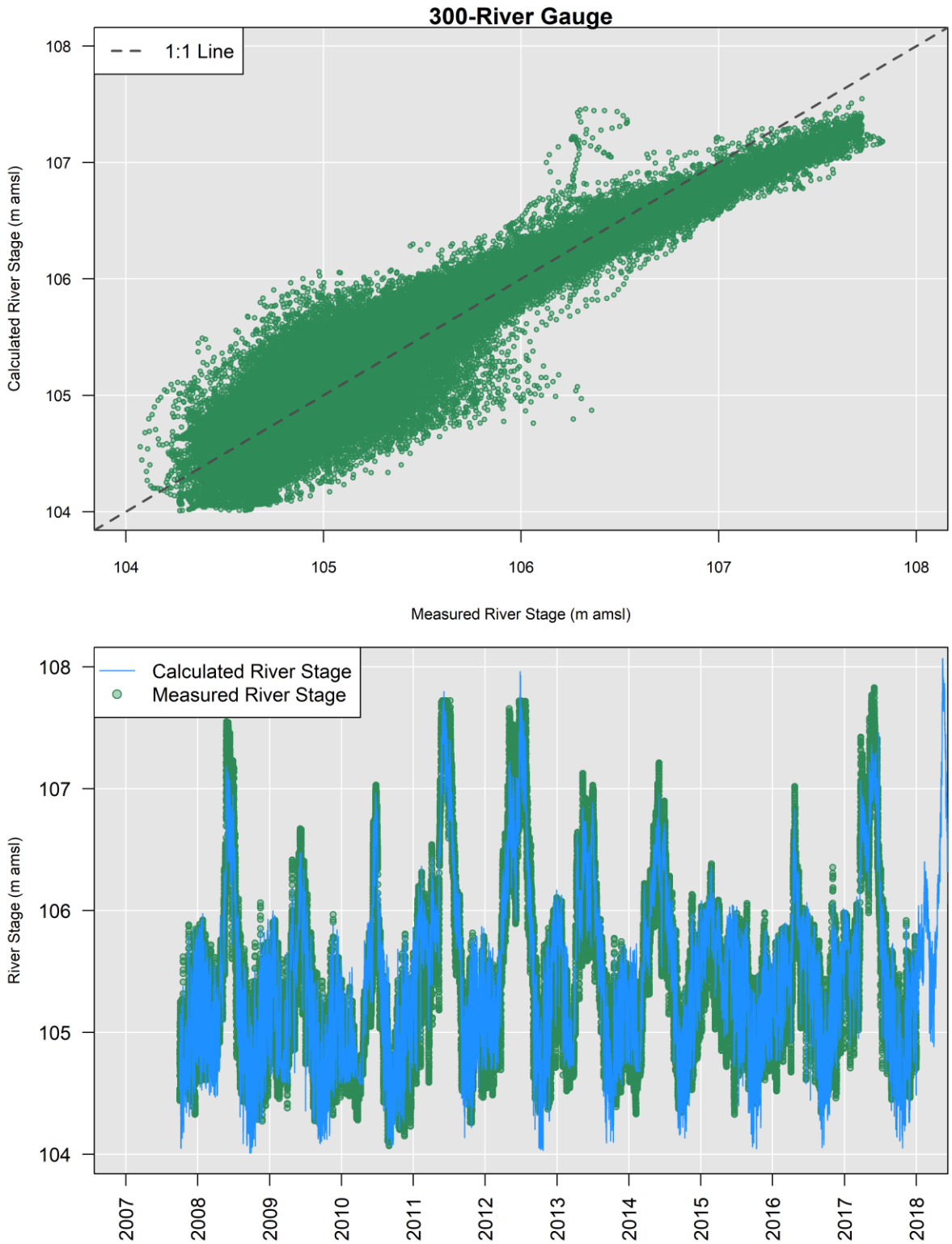

Figure 29. 300-River Gauge Convolution Based on 15-Minute Dataset

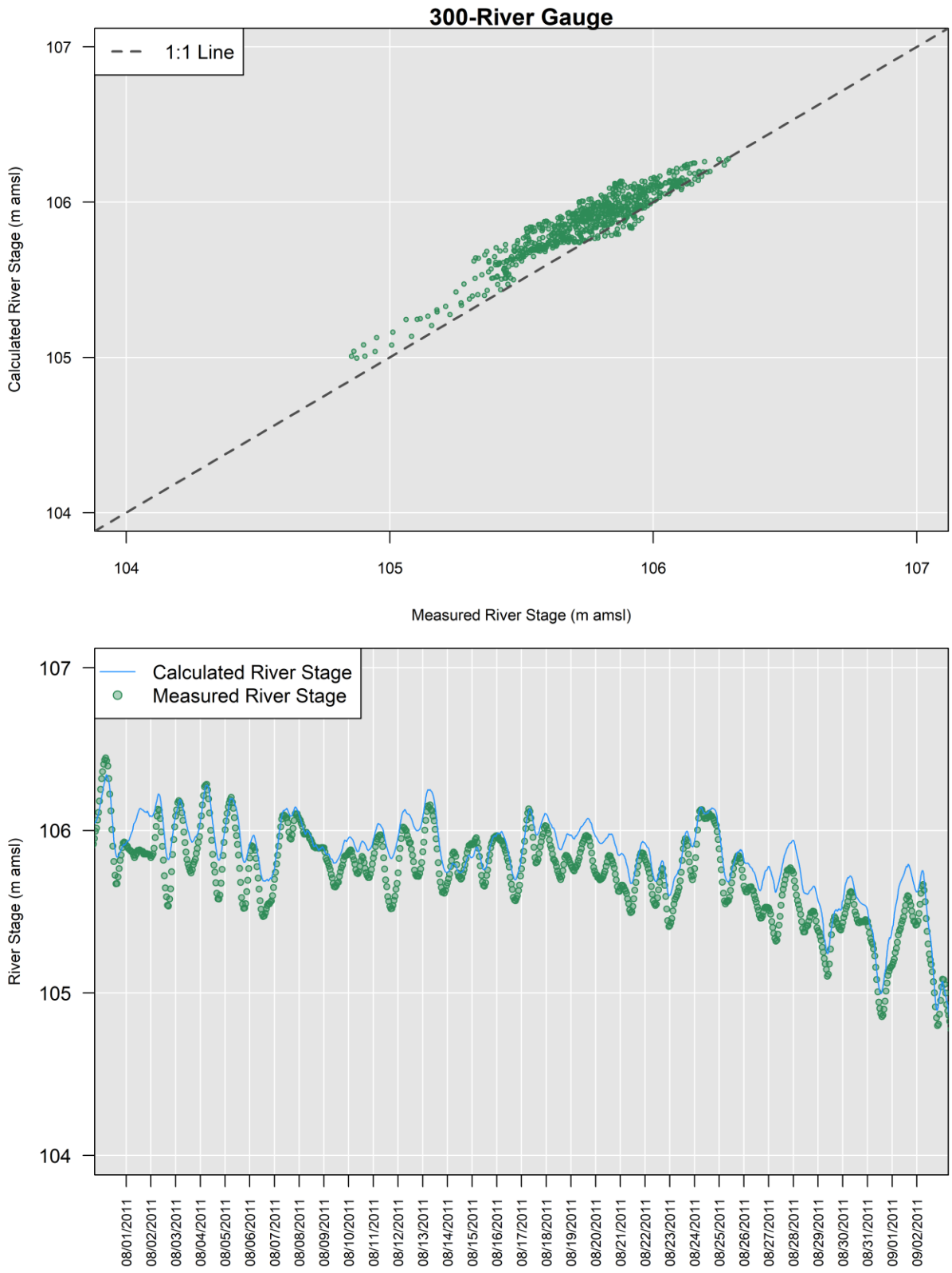

Figure 30. 300-River Gauge Convolution for 30-Days Based on 15-Minute Dataset

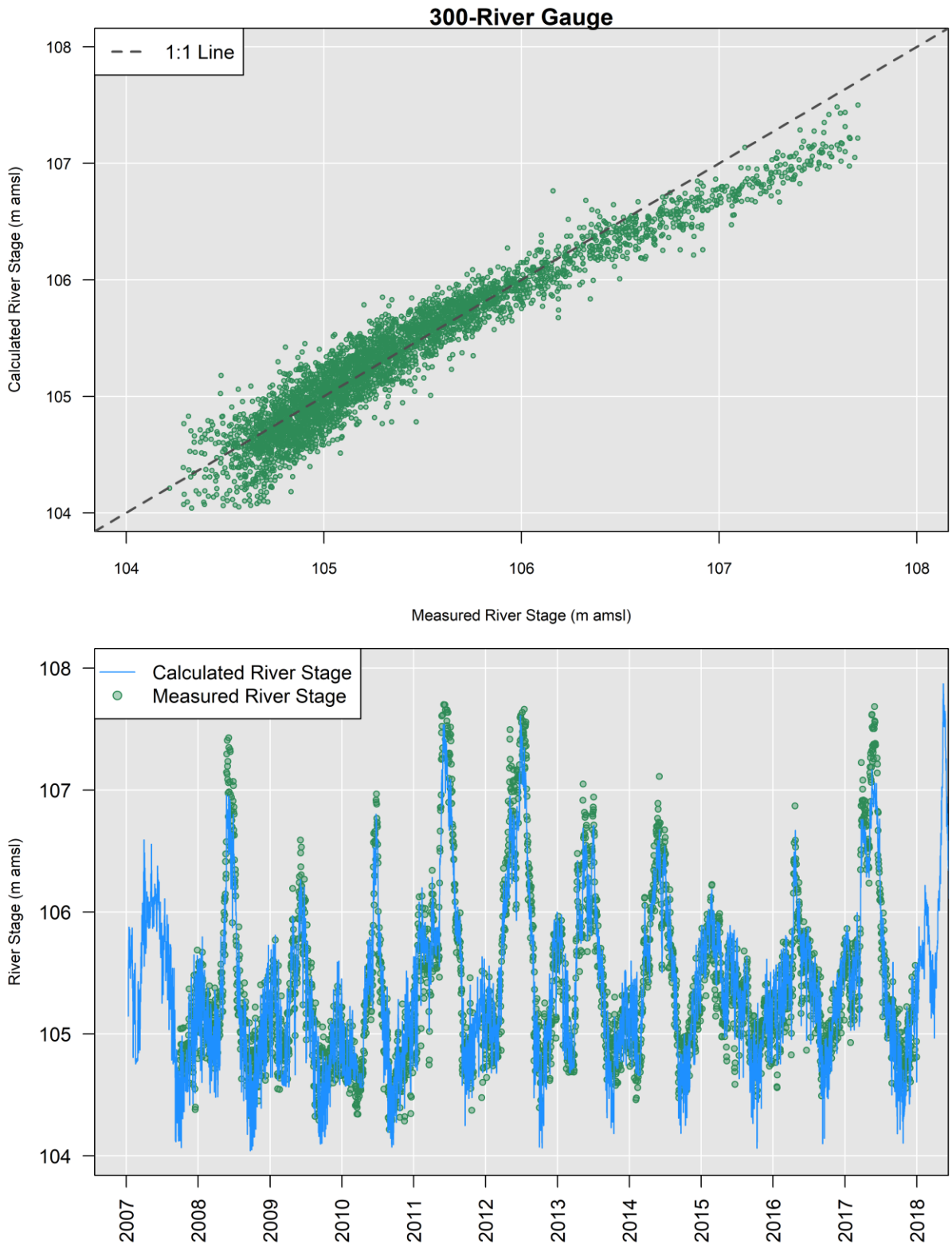

Figure 31. 300-River Gauge Convolution Based on Daily Dataset

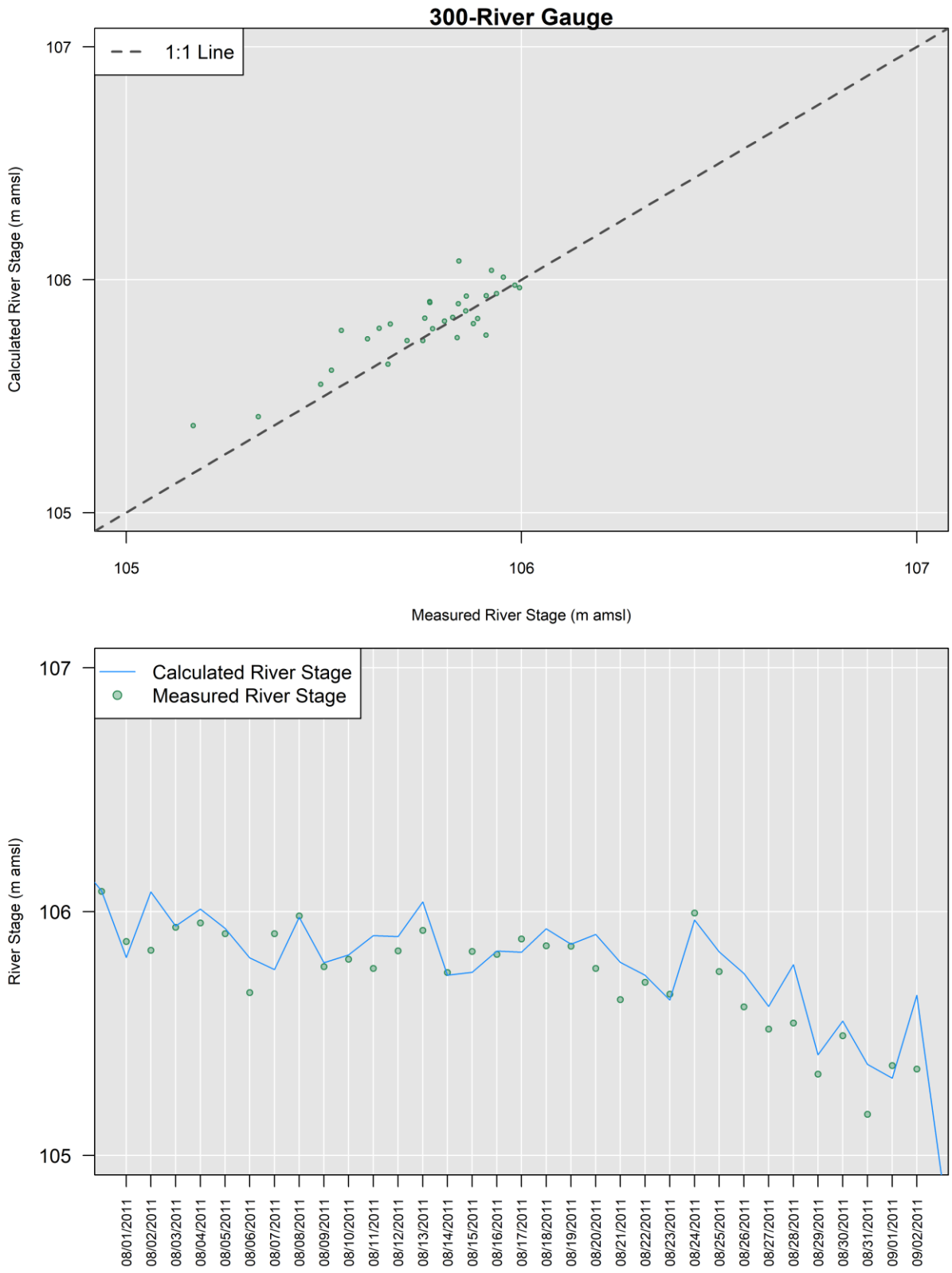

Figure 32. 300-River Gauge Convolution for 30-Days Based on Daily Dataset

8 Conclusions & Recommendations

The river gauge model was successful in closely approximating measured historical river stage elevations at the Hanford Reach gauge locations. This indicates that, for most purposes, the modeled data can be used in lieu of, or as a supplement to, transducer records monitored at these locations. In particular, models for the gauge locations at 100-B, 100-N, 100-K, 100-D, 100-H, and 100-F exhibit near perfect fits to the measured data. Given the identified issues with the reliability of historical gauge data compared to USGS PRD data, as long as PRD data remain available on a continuous (demand) basis, modeled river stage should provide a reliable estimate and may be preferable to the effort required in maintaining operational gauges at these locations. Post-2007, the river convolution based on the 15-minute dataset should be used. Prior to 2007, when 15-minute river stage data for the PRD are not readily available, the river convolution based on the daily dataset is used.

The model for the 300 Area did not perform as well as at the other gauge locations due to complications arising from Lake Wallula as created by backwater from McNary Dam. As a result, the 300 Area would be a relatively high priority for the installation and long-term maintenance of a river gauge transducer until a convolution model can be developed that incorporates the effects of both the PRD and backwater from the McNary Damon river stage in the downstream regions of the Hanford Reach.

Application of the method described herein to predict river stage should be undertaken in the context of data needs. Predictions that are required over long time periods should be based upon parameters derived from calibration of the model to the most complete, quality controlled, historical data period possible. However, predictions that are required over shorter time periods might be made using parameters that are derived from calibration of the model to a shorter, controlled training period if that training period encompasses the necessary range of river stages.

Two further analyses are recommended:

1. Establish the relationship between parameter values and distance from PRD, incorporating the physical parameters as constraints for estimation of all gauge data simultaneously, which could enable a model framework based upon the diffusive wave propagation to predict the stage at any location along the Columbia River as it passes by the Hanford Site and, therefore, provide highly accurate river stage estimates for use in groundwater elevation mapping and modeling purposes.

2. Improve the model for prediction at the 300 Area gauge location in the event that difficulty is encountered maintaining the gauge transducer at that location in future, which would improve confidence in data gap infilling during times of poor or absent data.

9 References

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