Appendix I

HEC-RAS Modeling of Rainbow River, MFL Technical Support—Freshwater Stream Final Report. Prepared by Environmental Consulting & Technology, Inc. for the Southwest Florida Water Management District, Brooksville, Florida. 2017.

ENVIRONMENTAL CONSULTING & TECHNOLOGY, INC.

SWFWMD TWA# 15TW0000033

HEC-RAS MODELING OF RAINBOW RIVER MFL TECHNICAL SUPPORT – FRESHWATER STREAM

FINAL REPORT

Submitted to:

Southwest Florida Water Management District
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Brooksville, FL 34604-6899

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January 25, 2017

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1. INTRODUCTION

1.1 BACKGROUND

Environmental Consulting & Technology, Inc. (ECT) was authorized by the Southwest Florida Water Management District (SWFWMD or the District) to conduct HEC-RAS modeling in support of establishing Minimal Flows and Levels (MFLs) for Rainbow River (the River).

1.2 PROJECT STUDY AREA

The Rainbow River is located in western Marion County, 120 kilometers (75 miles) north of Tampa and 32 kilometers (20 miles) southeast of Ocala, near the town of Dunnellon (Figure 1-1). The Rainbow River watershed is approximately 73.5 square miles or 47,000 acres. Land use is primarily urban on the western side of the River and wetland and upland forest on the eastern side (SWFWMD, 2004). The River starts at Rainbow Springs and empties into the Withlacoochee River 9.2 kilometers (5.7 miles) to the south of the headsprings. The Withlacoochee River flows westward into Lake Rousseau, past the Inglis Dam, and eventually into the Gulf of Mexico.

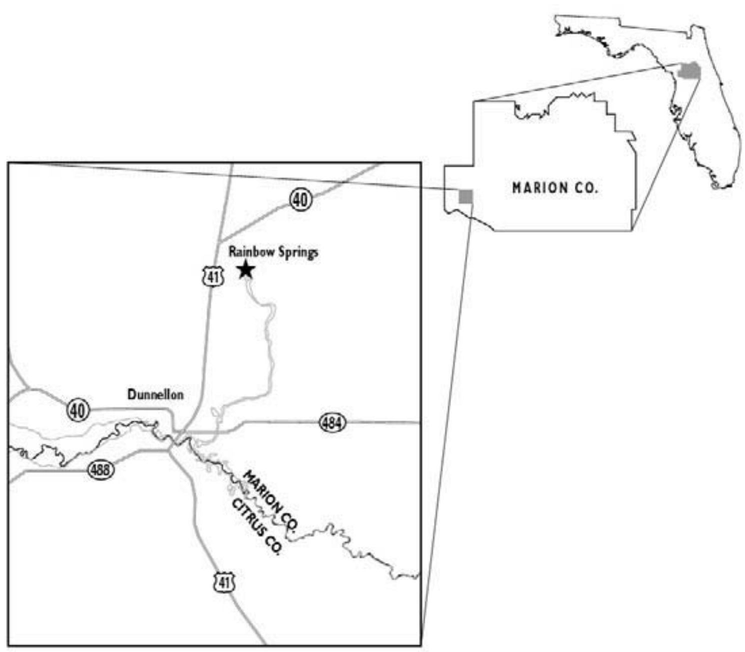

Figure 1-1. Location of the Rainbow River and Rainbow Springs

The project study area is selected at the upstream portion of the River, a river segment of approximately 5.1 river miles in length that is defined by the springhead to the north and CR 484 Bridge to the south, as graphically presented in Figure 1-2. The overall length of the River is approximately 6.0 river miles measured from the springhead to its confluence at Withlacoochee River to the south.

Of the 33 first magnitude springs in the State of Florida, Rainbow Springs, forming the headwaters of the Rainbow River, is the fourth largest in terms of discharge. The Rainbow River discharges an average of 763 cubic feet per second (CFS), or 493 million gallons of water per day (MGD) into the Withlacoochee River, just upstream of Lake Rousseau. Because of the Rainbow River's exceptional scenic beauty and its ecological significance, the river has been designated by the State, to be an Outstanding Florida Water (OFW), an Aquatic Preserve, and a SWIM priority water body (SWFWMD, 2004b).

A staff gage operated by the Florida Department of Environmental Protection (FDEP) is located just downstream of the springhead, which is the upstream end of the study area. U.S. Geological Survey (USGS) 02313098 Rainbow River near Dunnellon, Florida, a short-term stream gage, was recently installed upstream of a rocky shoal in 2013. USGS 02313100 Rainbow River at Dunnellon, Florida, a long-term stream gage that was installed at the downstream side of CR 484 Bridge, is used to define the downstream boundary conditions of the HEC-RAS model to be developed in this task.

A long-term USGS groundwater well station, named as USGS 290514082270701 Rainbow Springs Well near Dunnellon, Florida, is located on the east side of U.S. Highway 41, approximately 2.8 miles north of Dunnellon, Florida. The well records are used to determine flow of the River at CR 484 Bridge by USGS (Lambeth, D., 2010). A long-term USGS stream gage at the Withlacoochee River, identified as USGS 02313200 Withlacoochee River at Dunnellon, Florida, is located near center of span on the downstream side of bridge on U.S. Highway 41, approximately 0.6 mile downstream from the River. Severe backwater effects are concluded by comparing the stage records collected at this USGS gages and USGS gage 02313100 in the River. Locations of USGS and FDEP gage stations described above are presented in Figure 1-2.

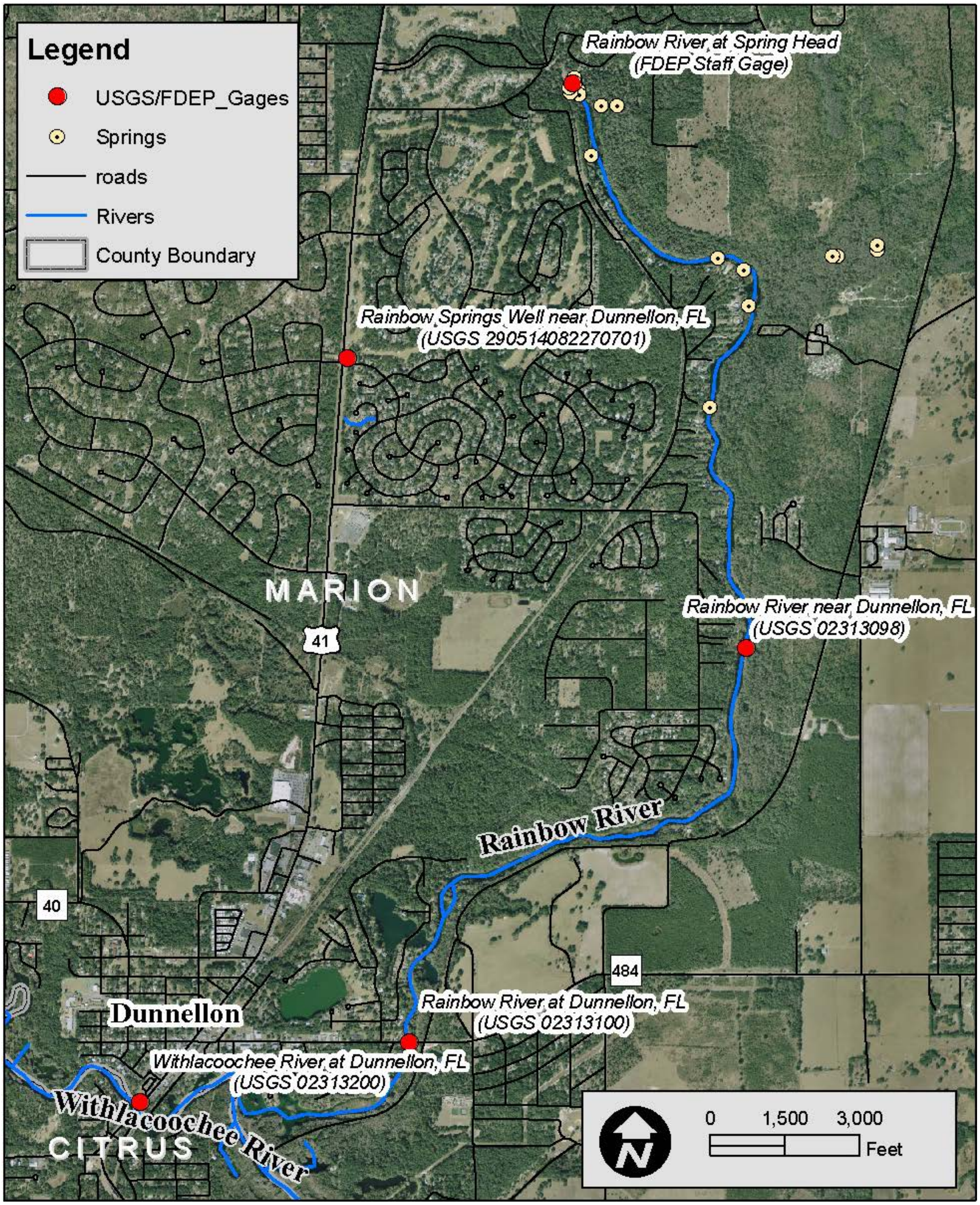

Figure 1-2. Study Area of Rainbow River HEC-RAS Modeling Project

2. HEC-RAS MODEL DEVELOPMENT

2.1 GEOMETRIC DATA DEVELOPMENT IN HEC-GEORAS

HEC-GeoRAS 4.2.92, an ArcGIS 9.2 extension for HEC-RAS, was used in developing the HEC-GeoRAS database of the River. A geometry exchange file was created by HEC-GeoRAS prior to being imported into the new HEC-RAS model.

2.1.1 RIVER CENTERLINE

The river centerline of the River, as shown in Figure 2-1, was provided by SWFWMD for the river segment within the project study area, from the spring head to CR 484 Bridge. The river centerline between CR 484 Bridge and the confluence at the Withlacoochee River was derived from the high-resolution USGS National Hydrography Dataset (NHD), which was generally developed at a scale of 1:24,000 or 1:12,000.

The river centerline was used to assign the river station (RS) values of the cross-sections, measured in river miles from the river confluence at the Withlacoochee River along the river reach, by utilizing HEC-GeoRAS in ArcGIS.

2.1.2 CROSS-SECTION CUTLINES

The primary data source used in characterizing cross-sections in the study area is the cross-section dataset provided by Dr. Xinjian Chen of SWFWMD, which includes a total of 165 cross-sections in the project study area.

The secondary data sources include: 1) the 2008 vegetation transect survey performed by SWFWMD and St. Johns River Water Management District (SJRWMD), including a total of 12 cross-sections; 2) the 2014 topographic survey of CR 484 Bridge performed by SWFWMD; and 3) the 2003 Light Detection and Ranging (LiDAR) topographic survey by SWFWMD in Marion County, as summarized in Table 2-1.

As listed in Table 2-1, a total of 196 raw cross-sections were either provided or derived from the survey data sources. Based on these raw cross-sections, a total of 179 cross-sections, with river stations ranged from 0.89 to 6.00, were digitized and stored in the HEC-GeoRAS geodatabase, as shown in Figure 2-1, which includes 164 of 165 cross-sections from 2015 Cross-Section Dataset, 12 of 14 from 2008 Vegetation Transect Survey, and 3 of 5 from 2014 Topo Survey at CR 484 Bridge.

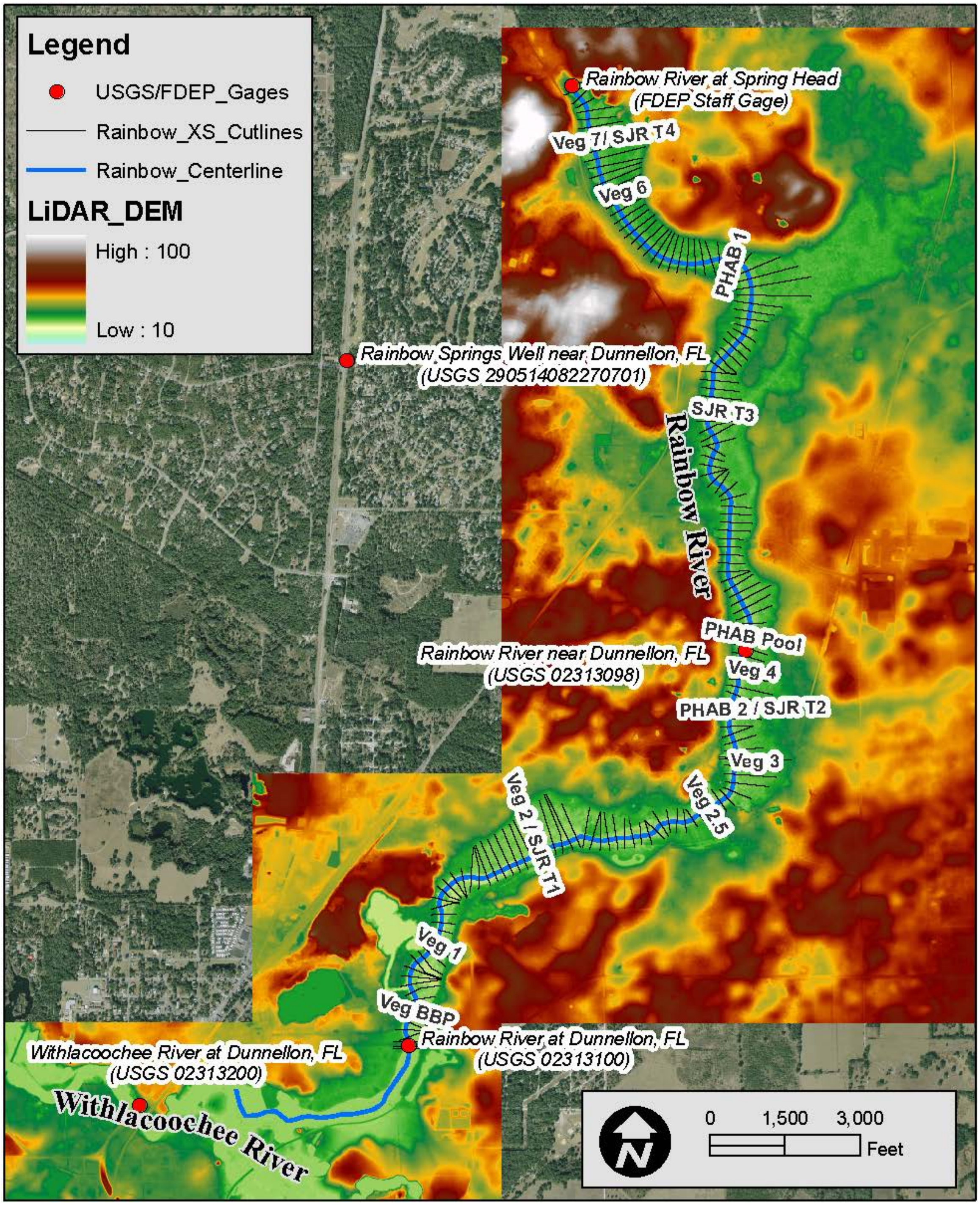

Figure 2-1. River Centerline and Cross-Section Cutlines of Rainbow River

Table 2–1. Summary of Data Sources for Cross-Section Characterization

Data Source Name	Provider	Cross-Section No.	Description
2003 LiDAR DEM	SWFWMD	-	In Marion County, Florida. Used in developing cross-section geometry data in floodplain area.
2008 Bathymetry Survey	SWFWMD/ Jones Edmunds	14	ArcGIS geodatabase point feature (X, Y, Z). Not involved in Geometric Data Development in HEC-GeoRAS as this dataset does not provide additional benefits after compared with the 2015 Cross-Section Dataset.
2008 Vegetation Transect Survey	SWFWMD/ SJRWMD	12	11 Veg Transects by SWFWMD in ESR Shapefile format. 4 Veg Transect by SJRWMD in MS Excel Table (X, Y, Z).
2014 Topo Survey	SWFWMD	5	Provided in MS Excel Table (X, Y, Z). For CR 484 bridge.
2015 Cross-Section Dataset	SWFWMD (Dr. Chen)	165	Provided in MS Excel Table (X, Y, Z). Cross-sections at a 164-foot interval A FORTRAN code was developed by Dr. Chen to calculate cross-section geometry data on the basis of 2015 bathymetry survey provided by University of South Florida (USF) and 2003 LiDAR DEM data by SWFWMD.

2.1.3 BRIDGES

Only one bridge centerline was digitized at CR 484 Bridge and stored in the HEC-GeoRAS geodatabase.

2.1.4 OPTIONAL GIS LAYERS

Optional GIS layers, including flow path and bank line polylines, were also digitized in support of developing the required cross-section geometric parameters, such as river stations, downstream reach lengths, bank stations, and others.

With the required and optional GIS layers, a HEC-GeoRAS geodatabase was developed for the River, including the station-elevation data pairs for all the 179 cross-sections.

A geometry exchange file was then generated by HEC-GeoRAS for future use in HEC-RAS. The projection coordination system of the geometric data was geo-referenced to “NAD_1983_HARN_StatePlane_Florida_West_FIPS_0902_Feet.”

2.2 GEOMETRIC DATA DEVELOPMENT IN HEC-RAS

A preliminary HEC-RAS model was developed by ECT with raw geometric data being imported from the HEC-GeoRAS geometry exchange files created in Section 2.1.4, as shown in Figure 2-2 below.

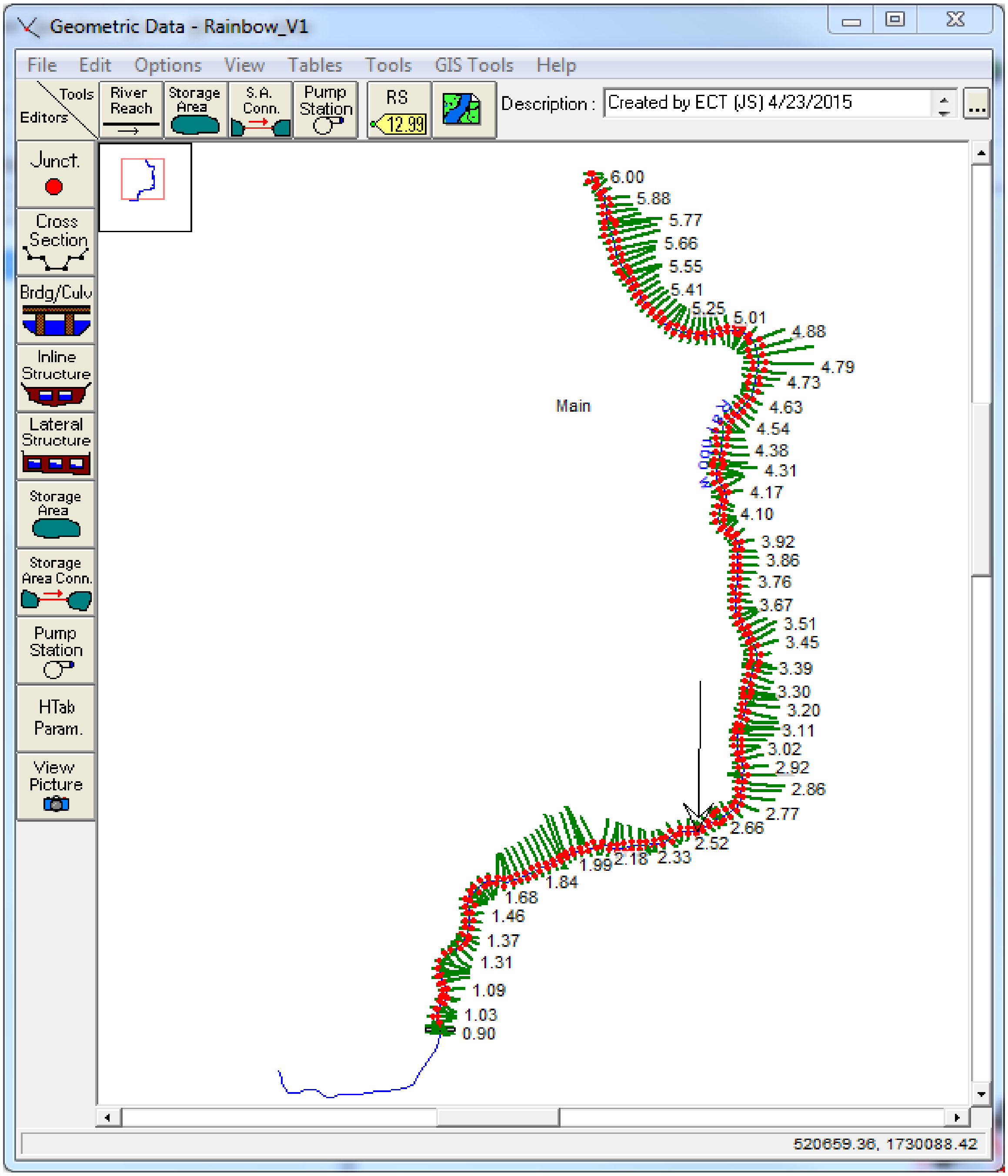

Figure 2-2. Geometric Data of the Preliminary HEC-RAS Model of Rainbow River

2.2.1 CROSS-SECTIONS

As part of the HEC-GeoRAS geometry exchange files, the station-elevation data for the 179 cross-sections was derived from the 2003 LiDAR-based DEM data. Given that the LiDAR-based DEM data is not appropriate to represent the river bathymetry in main channel, the station-elevation data derived from the survey data sources as listed in Table 2-1 was employed to substitute the main channel portion of the LiDAR-based cross-section geometric data, for example the cross-section at RS 0.92 as presented in Figure 2-3 below.

The “hybrid” cross-section geometric data was reviewed by ECT staff, with some minor adjustments of station-elevation data points and other parameters, such as bank stations and ineffective flow areas.

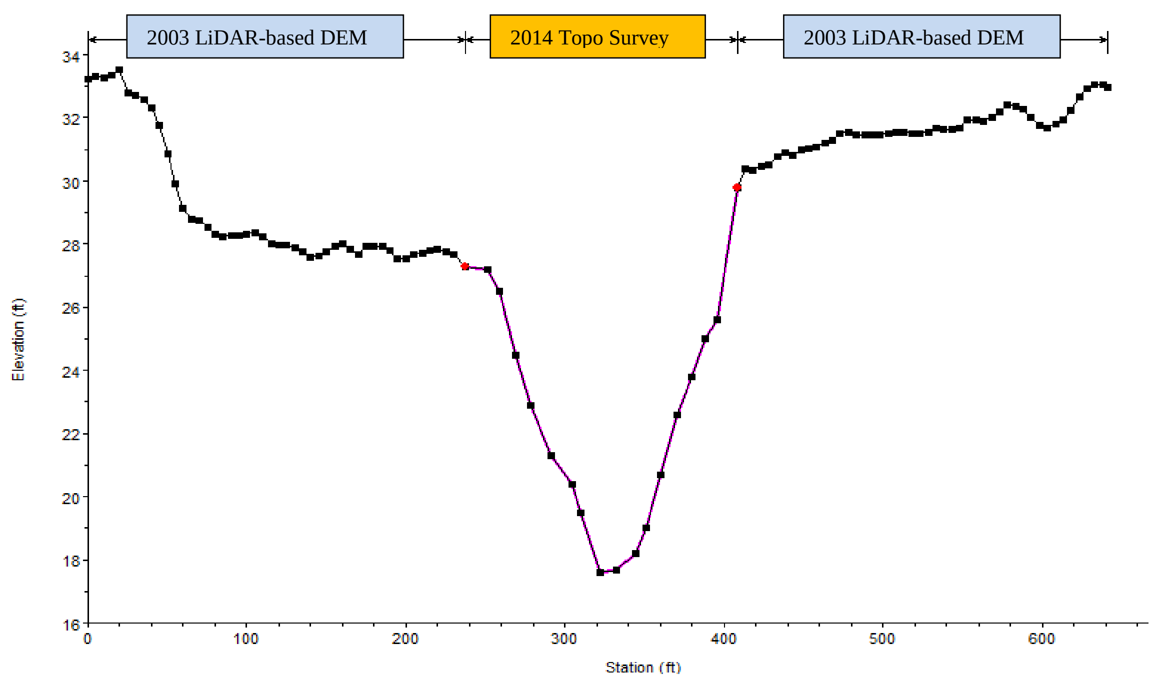

Figure 2-3. Hybrid Geometric Data of Cross-Section at RS 0.92

2.2.1.1 Manning’s N Value

Parameterization of Manning’s roughness coefficient (n) is critical to the accuracy of the simulated water surface levels in hydraulic modeling. The Manning’s n value varies depending on surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the channel, stage and discharge, seasonal changes, temperature, and suspended material and bedload.

The initial values of Manning's n were assigned with the values used in the existing HEC-RAS model developed by SWFWMD in 2008. The Manning's n values were further adjusted in the subsequent model calibration task, in which the natural conditions of the main channel and floodplain of the River were reevaluated for modification of the Manning's n values for each cross-section, with the assistance of aerial map, land use map, field observations performed under Task 2, as well as analyses of model results of calibration runs conducted under Task 5 in this project.

2.2.1.2 Contraction & Expansion Coefficients

The subcritical flow regime is used for steady state flow simulation in the HEC-RAS modeling. Within the selected study area of the River, the change in effective cross-section area is not abrupt. Therefore, the expansion and contraction coefficients of 0.1 and 0.3 were applied to most of the 179 cross-sections, except at the cross-sections near CR 484 Bridge, where expansion and contraction coefficients of 0.3 and 0.5 were assigned, respectively.

2.2.2 BRIDGES

For the only bridge (CR 484) included in the HEC-RAS model, as shown in Figure 2-4 the geometric data of roadway/deck and piers was mostly derived from the 2014 Topo Survey data and supplemented with the 2003 LiDAR-based DEM data for the roadway (Table 2-1).

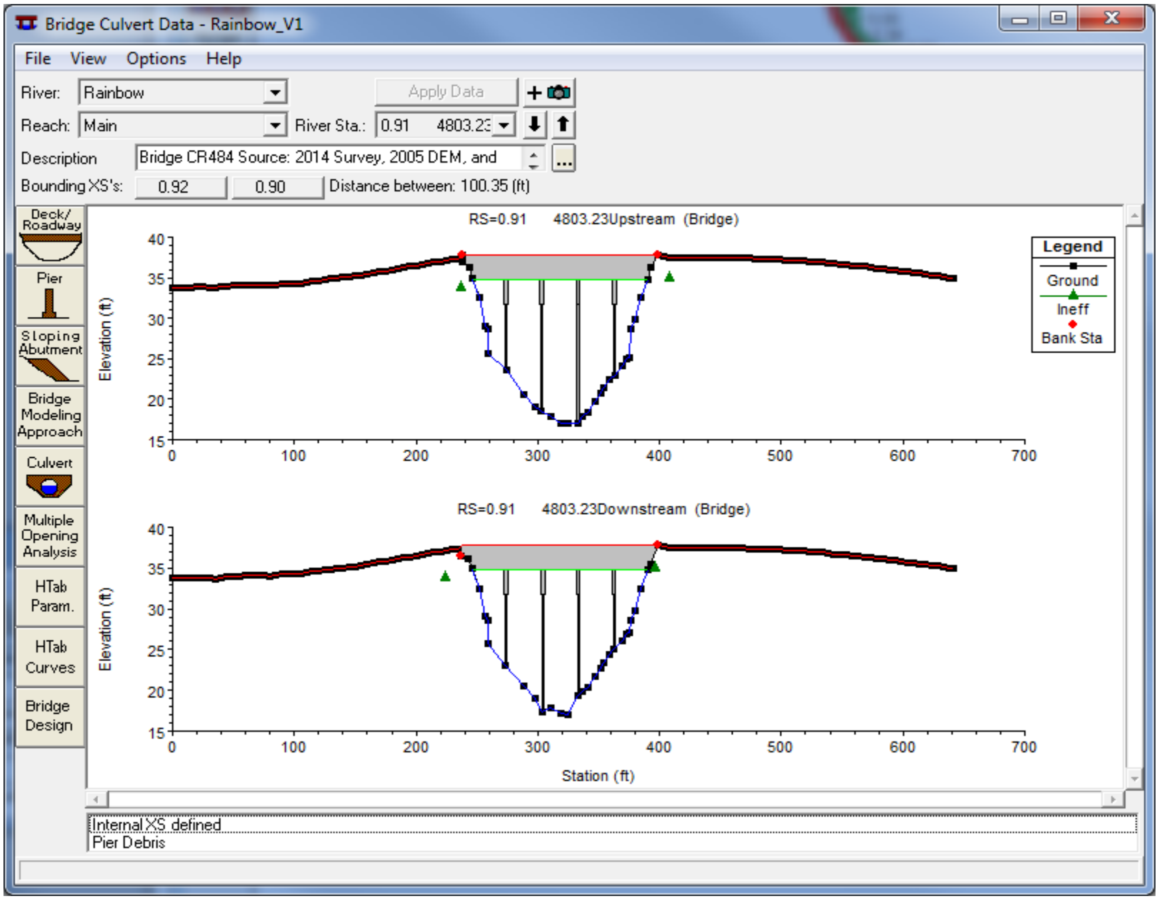

Figure 2-4. Geometric Data of CR 484 Bridge (RS 0.91)

2.3 PRELIMINARY HEC-RAS MODEL SIMULATION

2.3.1 CHANNEL FLOW PROFILES

To start a steady-state analysis in HEC-RAS, a flow profile should be composed by estimating a flow rate at the cross-sections where flow rate changes.

Along the 5.1-river-mile study area of the River, historic flow/stage measurement data was collected at four headsprings by USGS during 2004 through 2010, and at 11 of the 12 vegetation transects, and at the USGS gage at CR 484 Bridge by SWFWMD during 2005 through 2013, as graphically presented in Figure 2-5. A summary of the flow measurement data is provided in Table 2-2. The average flow percentage values at each flow measurement site were used to determine the channel flow profile along the river reach.

Upon review of the flow distribution analysis results summarized in Table 2-2, it was concluded that only selected flow measurement sites were used in developing the channel flow profile due to the following considerations:

- First of all, the SWFWMD flow measurement sites near various vegetation transect locations have a higher priority over the USGS sites at the springs.
- Veg 4 and USGS Station – not selected due to limited amount of flow records.
- Veg 2.5 and Veg below Borrow Pit (BBP) – not selected in order to maintain an incremental flow profile along the river reach.
- Rainbow No. 3 Spring – percentage of flow at CR 484 Bridge was reduced from 55% to 40% using professional judgment, which is lower than the percentage value of 41.7% estimated at upstream of Bubbling Spring (45.3% at Veg 7 minus 3.6% from Bubbling Spring), as shown in Table 2-3. The flow percentage difference between Rainbow No. 3 Spring at RS 5.94 and upstream of Bubbling Spring at RS 5.88 is calculated at 1.7%, which seems a reasonable estimate to account for any incidental groundwater inflows between these two river stations.

Per Water-Year summary for USGS Gage 02313100, the flow measurement for this gage was conducted at 0.25 mile upstream of CR 484 Bridge or RS 1.15 in the HEC-RAS model set up. It is assumed that no additional groundwater or surface water discharges to the river reach downstream of RS 1.15; and therefore, 100% of flow at CR 484 Bridge was defined at this location.

In summary, a total of 13 cross-sections or river stations have been assigned with a flow relationship between the cross-section and USGS 02313100 Rainbow River at Dunnellon, Florida, as listed in Table 2-3. Note that at RS 5.88 the percentage value of 41.7% was estimated by subtracting the discharge from Bubbling Spring (3.6%, see Table 2-2) from the value of 45.3% at Veg 7 (SJR T4).

A linear interpolation approach was used to generate the flow values at each cross-section depending on its distances to the 13 cross-sections or river stations listed in Table 2-3.

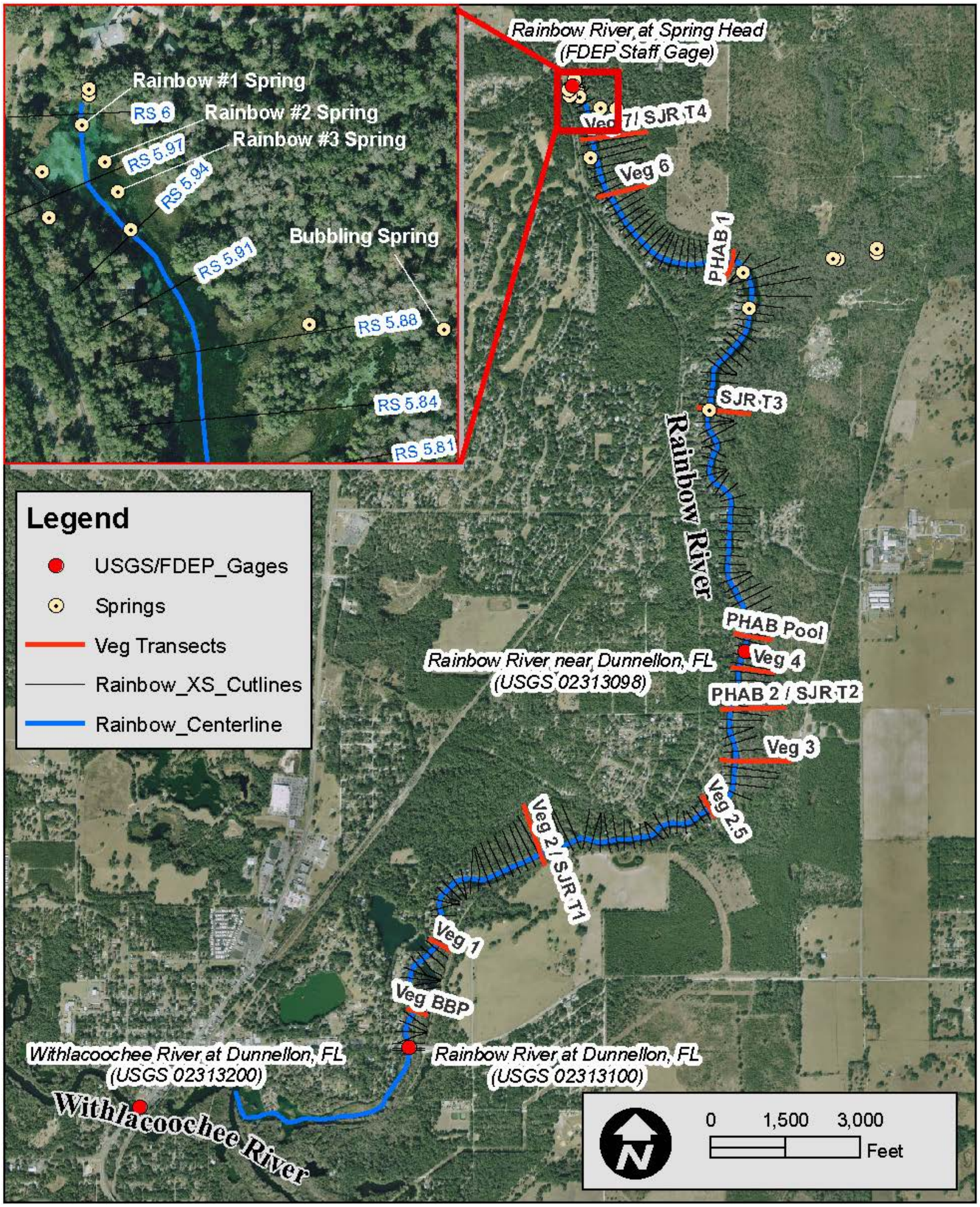

Figure 2-5. Locations of USGS/SWFWMD Flow/Stage Measurement in Rainbow River

Table 2–2. Summary of Flow Distribution Analysis Results

Site Name	RS in HEC-RAS	Selected Duration	Data Count	Avg. % of Flow @ CR 484	Involvement in Channel Flow Profile Development
Rainbow No. 1 Spring	6.00	2006-2010	16	31.2%	Selected!
Rainbow No. 2 Spring	5.97	2006-2010	16	33.3%	Selected!
Rainbow No. 3 Spring	5.94	2006-2010	16	55.0%	Selected! Use 40.0%
Bubbling Spring	5.77-5.84*	2004-2010	22**	3.6%	Selected!
Veg 7 (SJR T4)	5.77	2009-2013	11	45.3%	Selected!
Veg 6	5.55	2009-2013	6	49.7%	Selected!
PHAB 1	4.96	2009-2013***	10	58.8%	Selected!
PHAB Pool	3.37	2009-2013***	10	84.1%	Selected!
Veg 4	3.25	2009-2013	2	77.0%	Not Selected!
PHAB 2 (SJR T2)	3.09	2009-2013***	10	86.5%	Selected!
Veg 3	2.88	2009-2013	6	89.3%	Selected!
Veg 2.5	2.66	2009-2013	6	85.3%	Not Selected!
Veg 2 (SJR T1)	1.97	2009-2013	6	92.9%	Selected!
Veg 1	1.36	2009-2013	9	94.7%	Selected!
Veg Below Borrow Pit	1.05	2009-2013	7	94.6%	Not Selected!
USGS Station	0.90	2009-2010	3	84.9%	Not Selected!

* It is assumed that discharge from Bubbling Spring is evenly distributed to the River from RS 5.77 to RS 5.84.
** Two data outliers were eliminated.
*** To be consistent with other vegetation transect sites, flow records prior to 2009 at the PHAB transect sites were excluded.

Table 2–3. Summary of Channel Flow Profile

ID	Site Name	RS in HEC-RAS	% of Flow @ CR 484
1	Rainbow No. 1 Spring	6.00	31.2%
2	Rainbow No. 2 Spring	5.97	33.3%
3	Rainbow No. 3 Spring	5.94	40.0%
4	Upstream of Bubbling Spring	5.88	41.7%
5	Veg 7 (SJR T4)	5.77	45.3%
6	Veg 6	5.55	49.7%
7	PHAB 1	4.96	58.8%
8	PHAB Pool	3.37	84.1%
9	PHAB 2 (SJR T2)	3.09	86.5%
10	Veg 3	2.88	89.3%
11	Veg 2 (SJR T1)	1.97	92.9%
12	Veg 1	1.36	94.7%
13	USGS Flow Measurement Point	1.15	100%

2.3.2 DOWNSTREAM BOUNDARY CONDITIONS

Generally, the downstream boundary will be selected at a USGS gage station where a USGS stage-flow rating curve is available. However, a defined stage-flow rating curve is not available at the selected downstream boundary at USGS 02313100 Rainbow River at Dunnellon, Florida (CR 484 Bridge), mostly due to the severe backwater effects from Withlacoochee River through a short river reach, approximately 0.9 mile, between the gage at CR 484 Bridge and the river confluence.

A simple linear regression method, with one independent variable X – Flow at USGS Gage 02313100, was first employed to develop a stage-flow rating curve at USGS Gage 02313100. The flow/stage records at this USGS gage, in a period of 2005 through 2013, were utilized in the regression analysis. The resultant regression curve is plotted in Figure 2-6, with a coefficient of multiple determination (R^2) value of 0.5258.

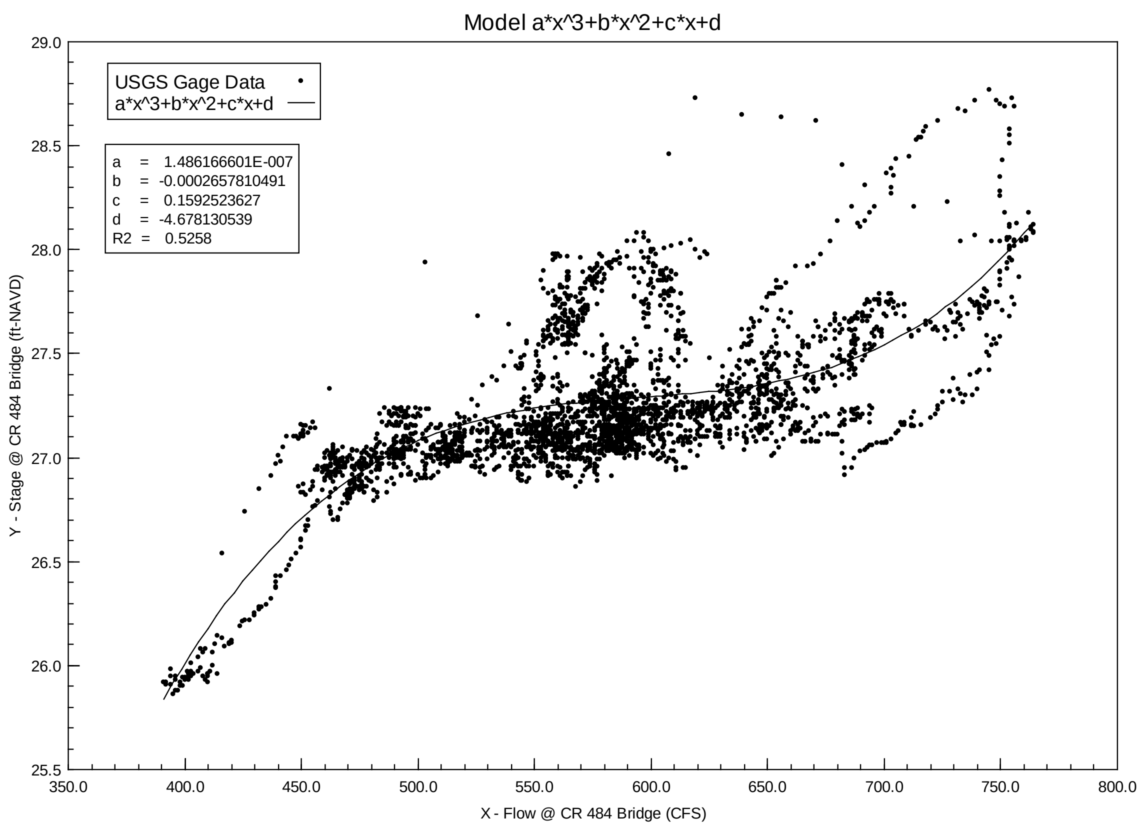

Figure 2-6. Simple Linear Regression Curve at USGS 02313100

Upon review of the historic stage/flow records at the two USGS long-term gages, USGS 02313100 Rainbow River at Dunnellon, Florida and USGS 02313200 Withlacoochee River at Dunnellon, Florida (Figure 2-1), it is deemed feasible to improve the rating curve described above by implementing multiple regression method and the historic stage/flow data at these two USGS gages.

In the multiple regression analysis, two independent variables were involved: X_1 - Flow at USGS 02313100 at CR 484 bridge; and X_2 - Stage at USGS 02313200 Withlacoochee River at Dunnellon, Florida (US 41 bridge), and the dependent variable is Y - Stage of USGS 02313100 at CR 484 Bridge. The flow/stage records in a period of 3/112005 through 9/30/2013 were utilized in the multiple regression analysis. The resultant multiple regression curve is plotted in Figure 2-7, with a significantly improved R^2 value of 0.9860.

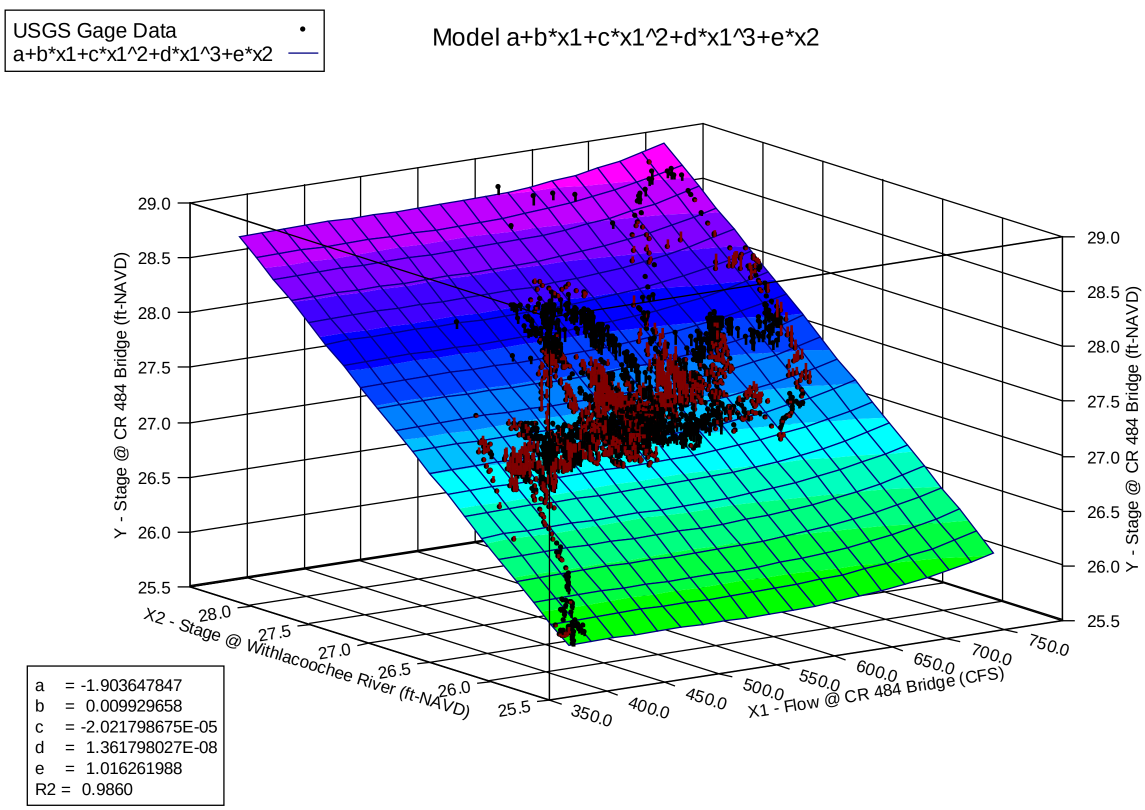

Figure 2-7. Multiple Regression Curve at USGS 02313100

To verify whether these two "independent" variables used in the multiple regression analysis are correlated with each other or not, a linear regression analysis was performed based on the stage data at USGS 02313200 and flow data at USGS 02313100. The resultant linear regression curve is plotted in Figure 2-8, with a R^2 value of 0.1159, which suggests there is a very weak correlation between the stage in Withlacoochee River and the flow in Rainbow River. Therefore, the multiple regression analysis with these two "independent" variables seems appropriate in general.

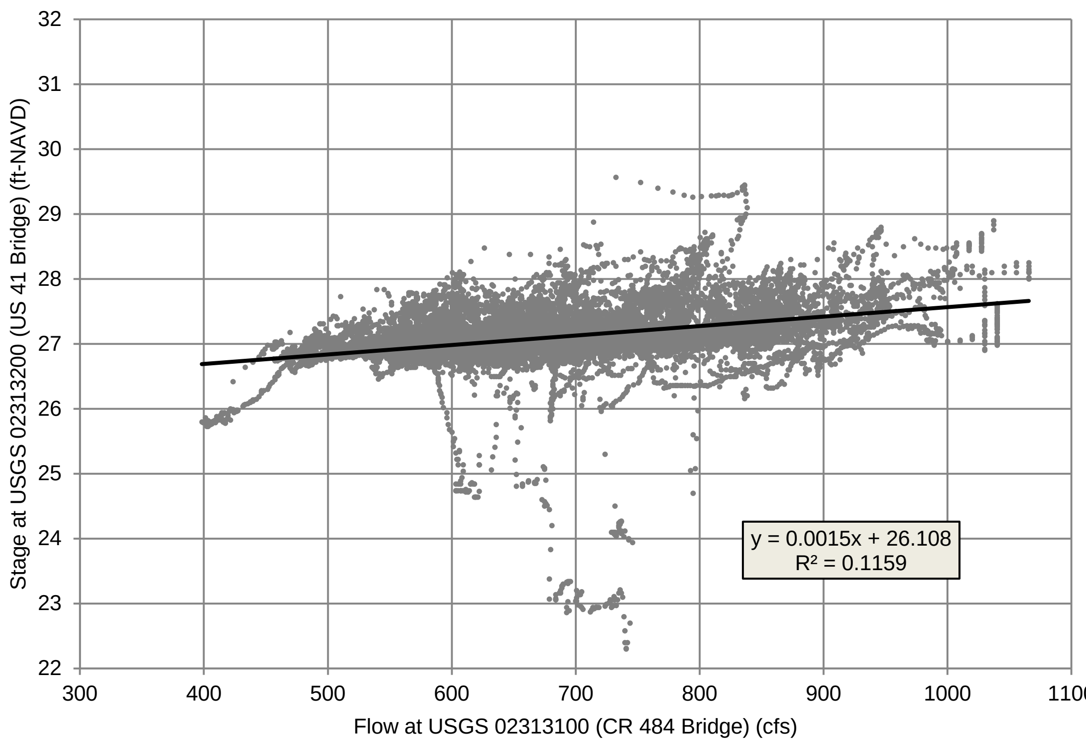

Figure 2-8. Stage at USGS 02313200 vs. Flow at USGS 02313100

In summary, at the downstream boundary of USGS Gage 02313100, the stage-flow rating curve has been significantly improved by using multiple regression method (Figure 2-7). However, for a given flow scenario to be simulated in HEC-RAS, two independent variables - flow in Rainbow River and stage in Withlacoochee River, have to be defined prior to estimating an reasonable boundary condition (stage) at CR 484 Bridge.

2.3.3 STEADY-STATE MODEL SIMULATION

To identify any potential errors or omissions in the geometric data of the preliminary HEC-RAS model of Rainbow River, a steady-state flow scenario was developed and simulated. The steady-state flow scenario assumed a 50 percentile (P50) flow condition in both Rainbow River and Withlacoochee River.

The channel flow profile and downstream boundary condition for the P50 flow scenario were first formulated using the methodology discussed in Sections 2.3.1 and 2.3.2, and stored in an Excel working spreadsheet prior to being imported into the HEC-RAS model. Computation message of the steady-state flow analysis was reviewed to fix errors or warnings in the river geometric data and flow profile data, if any.

The stage profile plot for this steady-state flow scenario is presented in Figure 2-9. The stage profile plot could be used to check the overall water elevation profile for a given flow scenario, or be zoomed in to identify the type of flow profile, e.g., M1 profile.

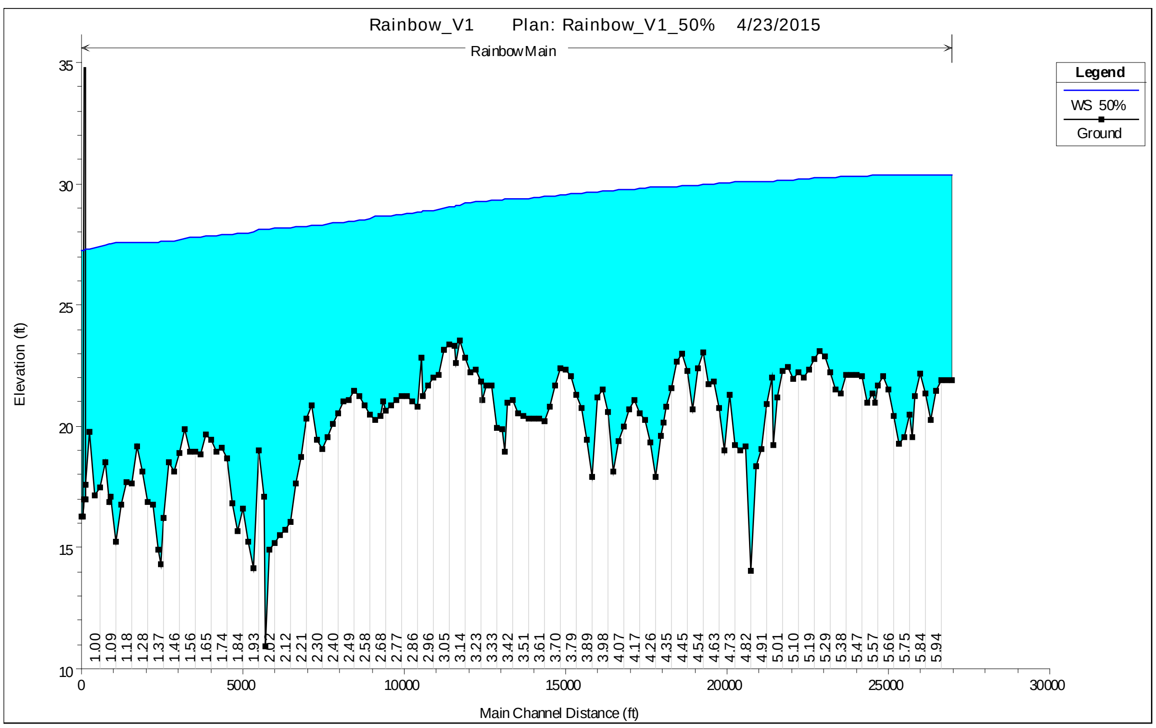

Figure 2-9. Stage Profile Plot of P50 Steady-State Flow Scenario in Rainbow River

3. HEC-RAS MODEL CALIBRATION

3.1 GAGE DATA ANALYSIS

Long-term daily flow and stage data at USGS gages is usually required to develop the dynamic flow and stage hydrographs used at boundary conditions for a dynamic HEC-RAS model analysis. Two long-term USGS gages in the Rainbow and Withlacoochee Rivers, as listed below and presented in Figure 3-1 and Table 3-1, are employed in developing the dynamic flow and stage hydrographs to be used in the dynamic HEC-RAS model.

- USGS 02313100 Rainbow River at Dunnellon, Florida at CR 484 Bridge provides long-term daily average flow and stage data at the downstream boundary of the HEC-RAS model.
- USGS 02313200 Withlacoochee River at Dunnellon, Florida at U.S. Highway 41 Bridge provides long-term daily average stage data that was used to estimate the missing stage data at USGS 02313100 in the Rainbow River (River).

Short-term stage data collected at various gage stations and vegetation transect sites facilitates comparison with the model predicted water level elevations at the same locations, for model calibration or verification purposes. Four agencies, including USGS, FDEP, SWFWMD, and SJRWMD, have conducted miscellaneous stage measurements at a total of 14 river stations or sites along the river segment as shown in Figure 3-1 and listed in Table 3-1.

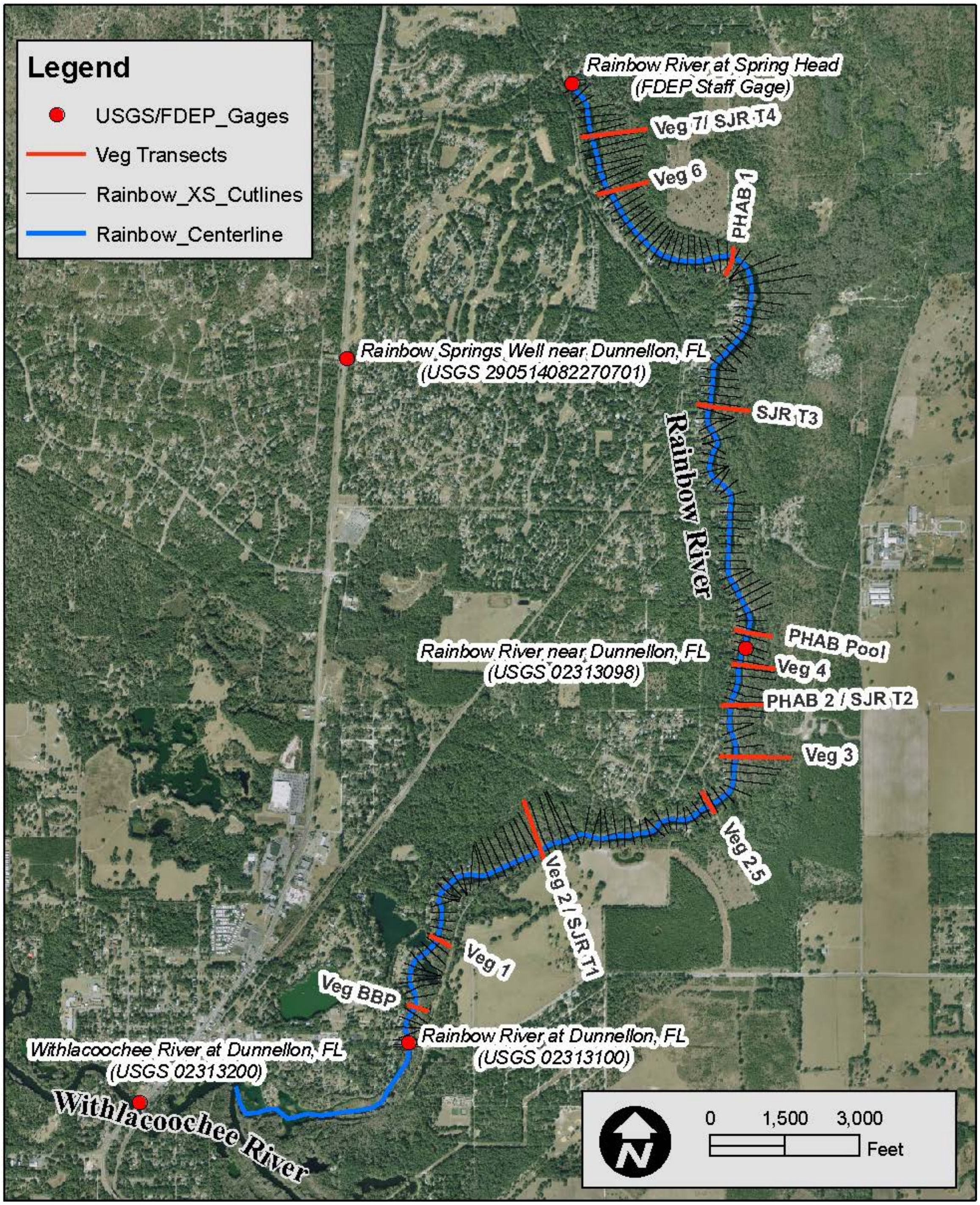

Figure 3-1. Stream Gages in Rainbow and Withlacoochee Rivers

Table 3–1. Summary of Stage Datasets in Rainbow and Withlacoochee Rivers

Station/Site Name	Station ID	Agency	RS in HEC-RAS	Start Date	End Date*	Stage Data** Count
Rainbow River at Spring Head***		FDEP	6.00	10/8/2005	1/25/2013	582
Rainbow River at Spring Head***		USGS	6.00	1/14/1965	1/31/2012	224
Veg 7****		SWFWMD	5.77	7/1/2009	3/12/2015	34
Veg 7		SWFWMD	5.77	5/22/2014	9/2/2014	2,473 (hourly)
SJR T4		SJRWMD	5.77	9/1/2009	9/26/2011	712 (daily)
Veg 6****		SWFWMD	5.55	7/1/2009	3/12/2015	21
PHAB 1****		SWFWMD	4.96	8/17/2005	3/12/2015	47
SJR T3		SJRWMD	4.31	9/1/2009	9/27/2011	757 (daily)
PHAB Pool****		SWFWMD	3.37	8/30/2005	3/12/2015	38
Rainbow River near Dunnellon	02313098	USGS	3.33	11/15/2013	3/17/2015	47,098 (15-min) 483 (daily)
Veg 4****		SWFWMD	3.25	7/1/2009	7/29/2009	3
PHAB 2****		SWFWMD	3.09	8/11/2005	3/12/2015	46
PHAB 2		SWFWMD	3.09	3/10/2014	2/9/2015	8,065 (hourly)
SJR T2		SJRWMD	3.09	9/1/2009	9/26/2011	687 (daily)
Veg 3****		SWFWMD	2.88	7/14/2009	3/12/2015	27
Veg 2.5****		SWFWMD	2.66	7/1/2009	3/12/2015	31
Veg 2****		SWFWMD	1.97	7/1/2009	3/12/2015	31
SJR T1		SJRWMD	1.97	9/2/2009	9/26/2011	706 (daily)
Veg 1****		SWFWMD	1.36	7/1/2009	3/12/2015	40
Veg 1		SWFWMD	1.36	9/24/2009	2/9/2015	3,311 (hourly)
Veg Below Borrow Pit (BBP) ****		SWFWMD	1.05	7/1/2009	3/12/2015	31
Rainbow River at Dunnellon	02313100	USGS	0.90	3/11/2005	3/17/2015	3,245 (daily)
Withlacoochee River at Dunnellon	02313200	USGS	-	2/6/1963	3/17/2015	18,896 (daily)

Notes: RS – River station is measured in river miles from the river confluence at the Withlacoochee River.

* End date of the USGS stage data was selected at the end of the simulation span (3/11/2005 -3/17/2015) of the dynamic HEC-RAS model.

** 15-min, hourly, and daily stage data was derived from the real-time data loggers installed by USGS, SWFWMD, and SJRWMD at various gage locations.

*** Stage data at the spring head was either read from staff gage by FDEP staff (Mr. Jeff Sowards) or measured by USGS staff.

**** Stage data was read from staff gage or surveyed at the same day when flow measurement was conducted at these vegetation transects.

Upon review of the short-term stage datasets listed in Table 3-1, the stage datasets collected by FDEP at the springhead (Figure 3-2) and by SJRWMD at four vegetation transect sites (Figure 3-3) provide a reasonably large amount of stage records that cover a wide range of flow conditions, and hence will serve as the primary model calibration targets in this project.

The real-time or hourly stage datasets collected by SWFWMD at three river sites (Veg 7, PHAB 2, and Veg 1) also offer a good amount of hourly stage records since 2013, as shown in Figure 3-4, and will be used as the secondary model calibration targets.

SWFWMD also provided miscellaneous stage data measured at the same time when flow measurements were taken at a total of 11 vegetation transect sites along the River. These stage datasets, with very limited amount of stage data as summarized in Table 3-1, had not been well calibrated by the District; therefore, they will be used for model verification purposes once the dynamic HEC-RAS is calibrated with the above mentioned primary and secondary targets.

USGS 02313098 Rainbow River near Dunnellon, Florida, as listed in Table 3-1 and presented in Figure 3-1, was recently installed upstream of a rocky shoal by USGS in 2013. However, review of the stage records provided at this gage suggests that the vertical datum of 27 ft-NAVD appears to be inappropriate when compared with the stage data collected at other river sites. Therefore, the stage data at this short-term USGS gage will be excluded from the subsequent model calibration and verification.

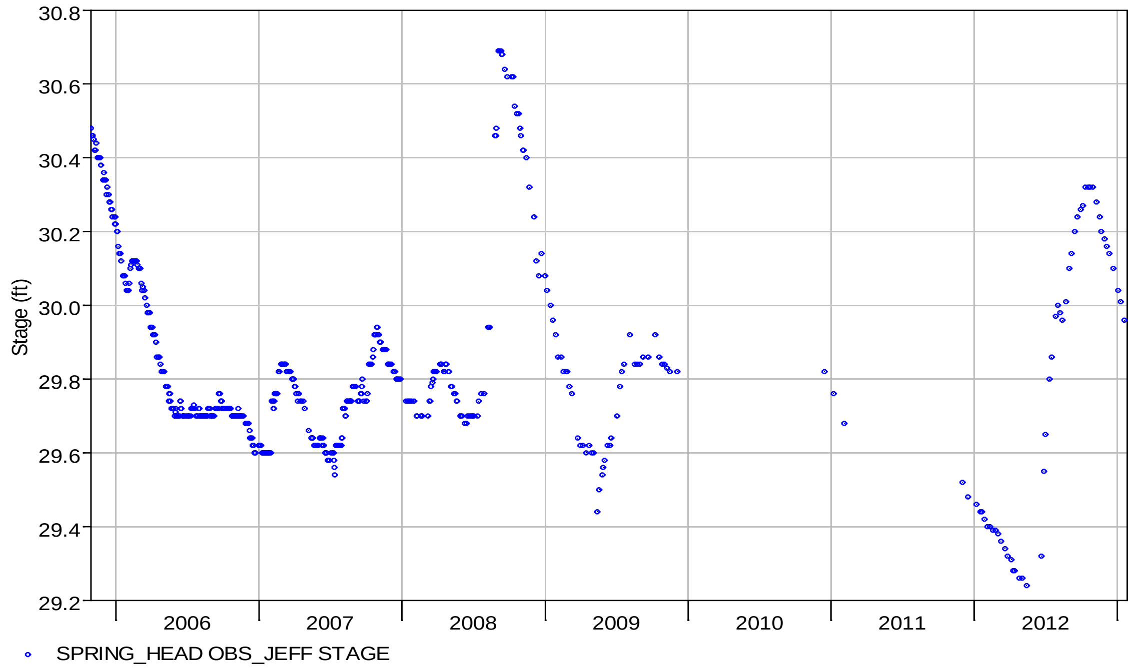

Figure 3-2. Stage Data at Spring Head by FDEP

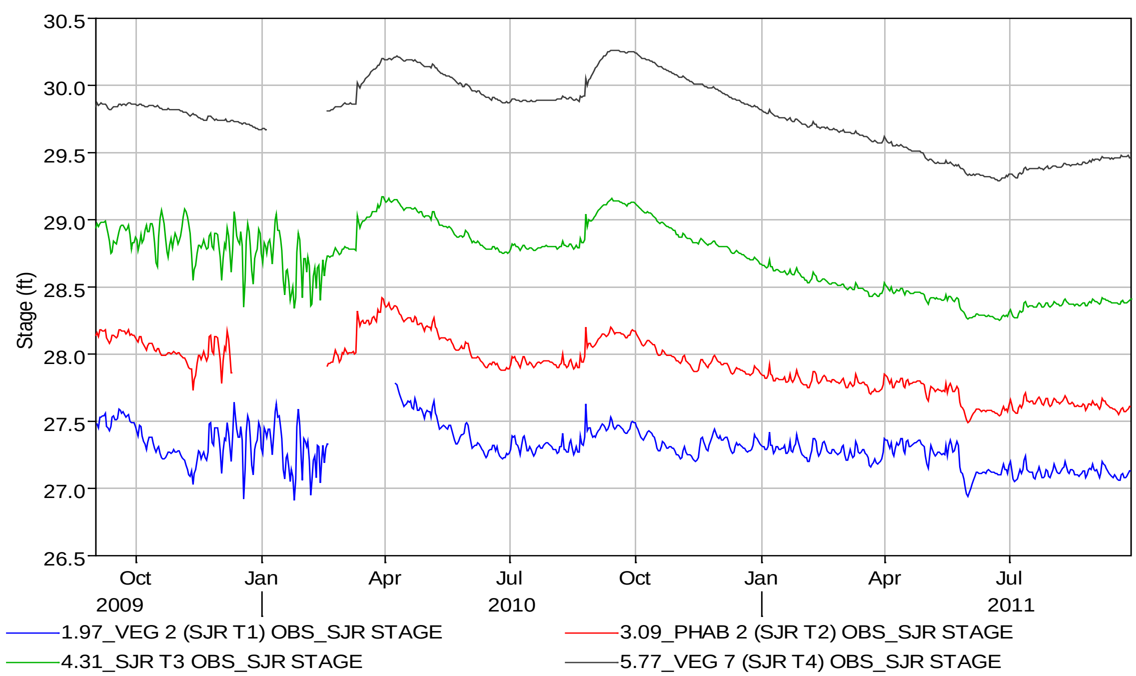

Figure 3-3. Daily Stage Data at SJRWMD Vegetation Transects

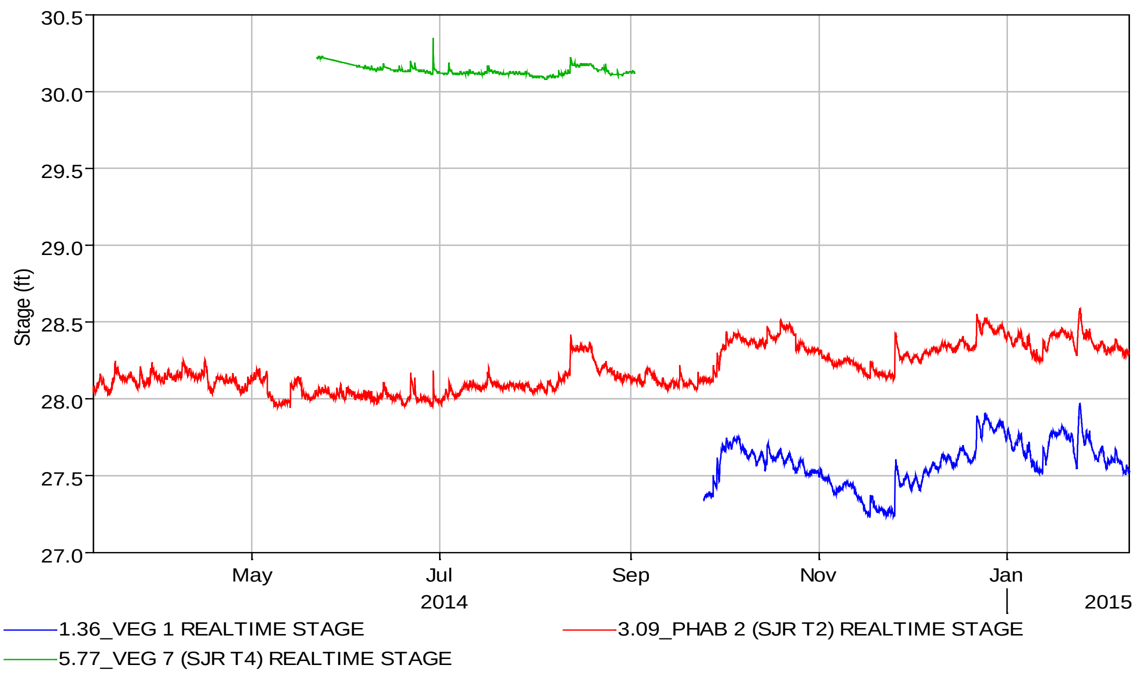

Figure 3-4. Hourly Stage Data at SWFWMD Vegetation Transects

3.2 DYNAMIC FLOW DATA – BOUNDARY CONDITIONS

3.2.1 FLOW HYDROGRAPH BOUNDARY CONDITIONS

A flow hydrograph boundary condition is required to be defined at the upstream end of the study area. However, there is no long-term flow data available at the spring head, the upstream end of the River at RS 6.00.

Based on the channel flow profile analysis results presented in Table 2-3 of Section 2.3.1, 31.2% of the flow at USGS 02313100 Rainbow River at Dunnellon, Florida was used to represent the flow hydrograph boundary conditions at the spring head. The resultant flow hydrograph at RS 6.00 is plotted in Figure 3-5.

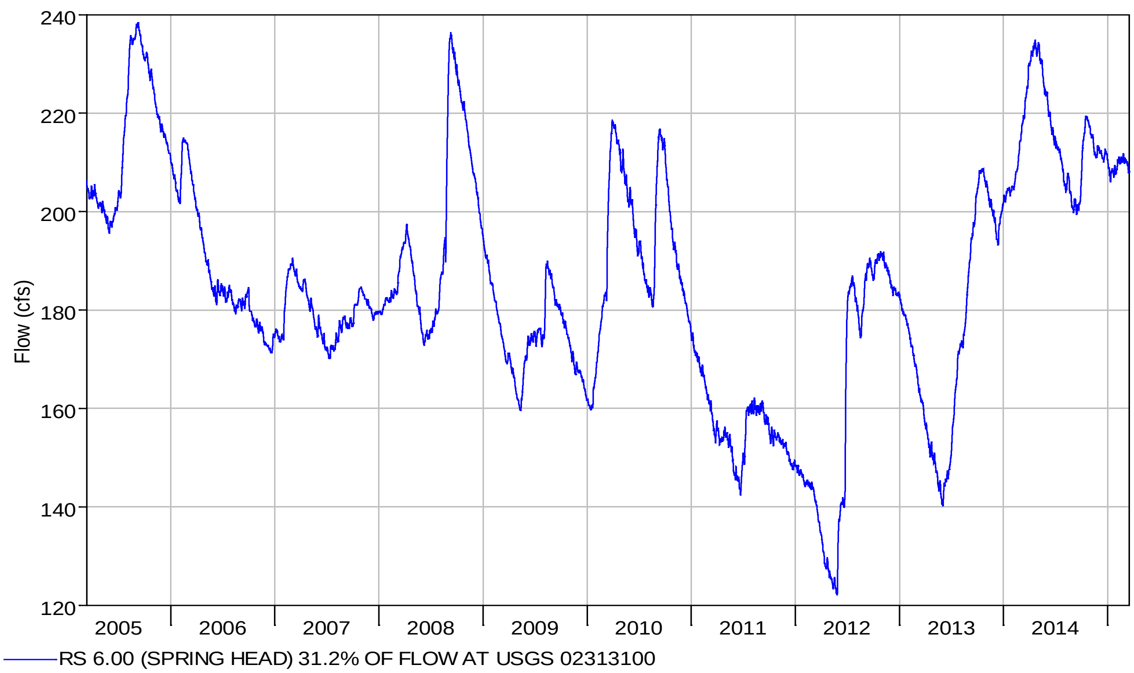

Figure 3-5. Flow Hydrograph at RS 6.00 (Spring Head)

3.2.2 STAGE HYDROGRAPH BOUNDARY CONDITIONS

A stage hydrograph boundary condition is defined at RS 0.89, the downstream end of the River located downstream of CR 484 Bridge. The cross-section at RS 0.89 was intentionally added to the river geometric data, as HEC-RAS requires at least two cross-sections downstream of a structure to run dynamic flow analysis. The stage records of USGS 02313100 Rainbow River at Dunnellon, Florida at CR 484 Bridge (RS 0.90) are used to define the stage hydrograph boundary conditions at RS 0.89, by assuming there is no noticeable head loss between the gage location and downstream boundary node.

Stage records at this gage are missing for entire Water Year (WY) of 2014. Data filling was performed by using the multiple regression curve previously developed in this project (Section 2.3.2). The flow data provided at this gage and the stage data at USGS 02313200 Withlacoochee River at Dunnellon, Florida are the two independent variables used in the multiple regression analysis.

The stage hydrograph at RS 0.89, consisting of the stage records obtained from USGS and the values estimated using the multiple regression analysis for WY 2014, is plotted in Figure 3-6.

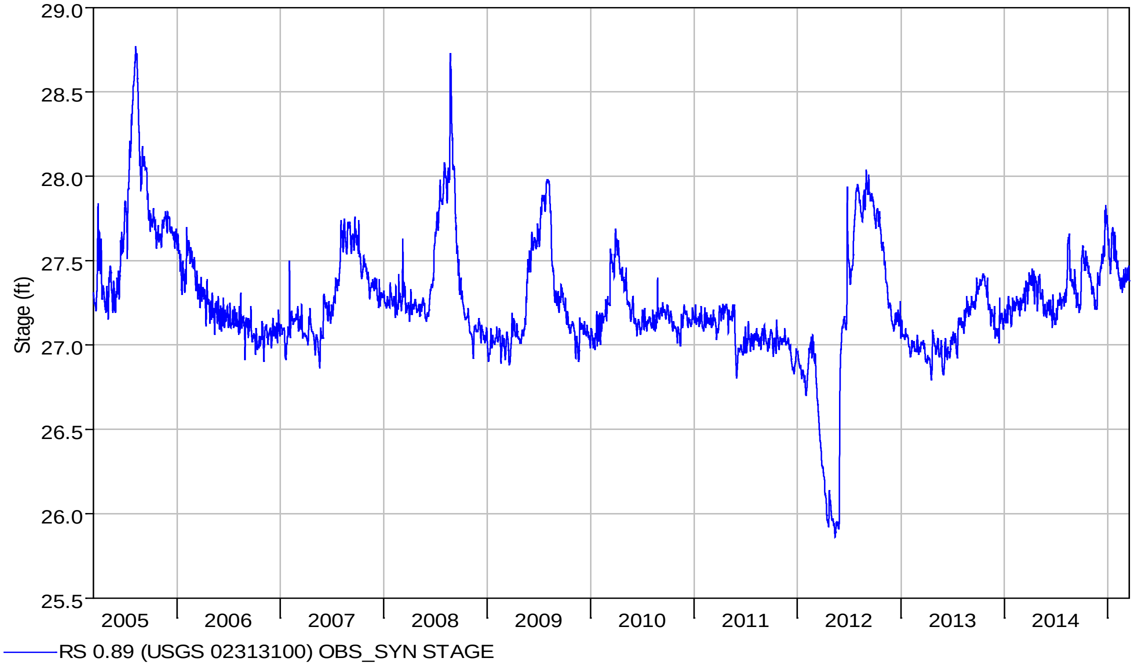

Figure 3-6. Stage Hydrograph at RS 0.89 (CR 484 Bridge)

3.2.3 LATERAL INFLOW HYDROGRAPH BOUNDARY CONDITIONS

The lateral inflow hydrograph is used as an internal boundary condition in HEC-RAS to represent inflow, e.g., surface water inflow from a tributary or groundwater inflow from a spring, at a specified point or cross-section along the river reach. In the dynamic HEC-RAS model of Rainbow River, two lateral inflow hydrograph boundary conditions were defined at RS 5.97 and RS 5.94 to represent the groundwater inflow from Rainbow No. 2 Spring and Rainbow No. 3 Spring, respectively, as listed in Table 3-2.

The uniform lateral inflow hydrograph is used as an internal boundary condition in HEC-RAS to represent uniformly distributed inflow along the river reach between two specified cross-section locations. The uniform lateral inflow hydrograph is very useful when the inflow could not be assigned to a specified point along the river reach, e.g., multiple small springs or surface water runoff along a river reach. A total of 10 uniform lateral inflow hydrograph boundary conditions were defined in the dynamic HEC-RAS model, between RS 5.91 and RS 1.15 to represent the groundwater and surface water inflows along the River, as listed in Table 3-2.

The percentage values of listed in Table 3-2 were derived from the channel flow profile analysis results presented in Table 2-3 of Section 2.3.1. The total flow percentage values for the lateral/uniform lateral inflow hydrographs is 68.8% of flow at CR 484, as plotted in Figure 3-7. The remaining 31.2% of flow at CR 484 has been assigned to the spring head at RS 6.00, modeled as a flow hydrograph boundary condition in Section 3.2.1.

Note that it is not practical to develop time-variant percentage values at each river site in long-term dynamic flow analysis, mostly due to the very limited flow measurement data in the study area (Table 2-2).

Table 3–2 Summary of Lateral/Uniform Lateral Inflow Hydrograph Boundary Conditions

ID	RS in HEC-RAS	% of Flow @ CR 484	Boundary Condition Type	Comments
1	5.97	2.10%	Lateral Inflow	Rainbow No. 2 Spring and others
2	5.94	6.70%	Lateral Inflow	Rainbow No. 3 Spring and others
3	5.91 - 5.88	1.70%	Uniform Lateral Inflow	Waterfall Spring and others
4	5.88 - 5.77	3.60%	Uniform Lateral Inflow	Bubbling Spring
5	5.77 - 5.55	4.40%	Uniform Lateral Inflow	Between Veg 7 (SJR T4) and Veg 6
6	5.55 - 4.96	9.10%	Uniform Lateral Inflow	Between Veg 6 and PHAB 1
7	4.96 - 3.37	25.30%	Uniform Lateral Inflow	Between PHAB 1 and PHAB Pool
8	3.37 - 3.09	2.40%	Uniform Lateral Inflow	Between PHAB Pool and PHAB 2 (SJR T2)
9	3.09 - 2.88	2.80%	Uniform Lateral Inflow	Between PHAB 2 (SJR T2) and Veg 3
10	2.88 - 1.97	3.60%	Uniform Lateral Inflow	Between Veg 3 and Veg 2 (SJR T1)
11	1.97 - 1.36	1.80%	Uniform Lateral Inflow	Between Veg 2 (SJR T1) and Veg 1
12	1.36 - 1.15	5.30%	Uniform Lateral Inflow	USGS Flow Measurement Point
Total:		**68.8 %**		

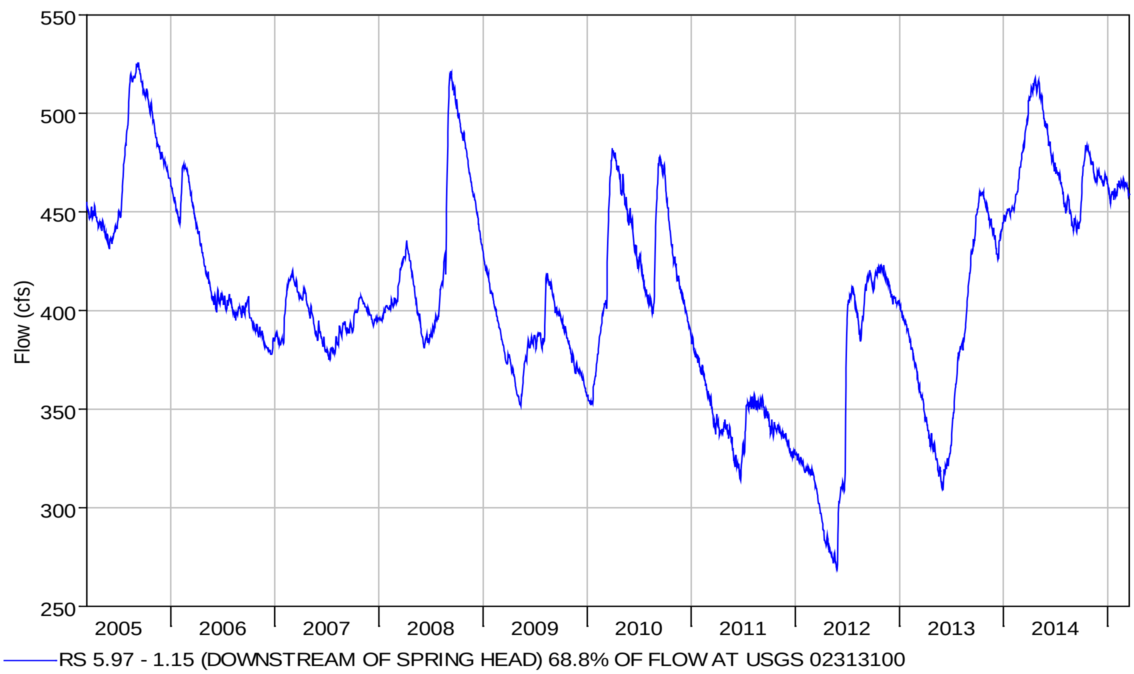

Figure 3-7. Accumulated Lateral/Uniform Lateral Inflow Hydrographs from RS 5.97 to 1.15 (Downstream of Spring Head)

3.3 DYNAMIC HEC-RAS MODEL SIMULATION AND CALIBRATION

3.3.1 MODEL SIMULATION

A total of 10 years from 3/11/2005 to 3/17/2015 are selected as a simulation span for unsteady flow analysis of the Rainbow River. As discussed in the previous section, all required boundary conditions have been developed and stored in several DSS database files to be used for the unsteady flow analysis in HEC-RAS.

The boundary conditions and initial conditions are defined in the "Unsteady Flow Analysis Editor" in HEC-RAS.

3.3.2 MODEL STABILIZATION

During low flow conditions, the unsteady flow simulation is expected to fail at certain hydraulic critical points of the River, where subcritical flow changes to supercritical flow within a very short distance (i.e., rocky shoal near RS 3.10). To improve model stability of the dynamic HEC-RAS model at the hydraulic critical points, Manning's n values were adjusted in order to increase critical water depth and reduce Froude number. Adding interpolated cross-sections and/or reducing computation interval were also considered, if the instability still exists. Upon a few iterations of model coefficient adjustments, the dynamic HEC-RAS model was stabilized to be able to simulate all flow conditions experienced within the 10-year simulation span.

3.3.3 MODEL CALIBRATION

3.3.3.1 Model Calibration Targets

Based on evaluation of the available stage data collected at various stream gages and river sites, as listed in Table 3-1, a total of eight stage datasets, including one at FDEP staff gage, four at SJRWMD vegetation transect sites and three at SWFWMD vegetation transect sites, were selected as the calibration targets for the dynamic HEC-RAS model, as listed in Table 3-3.

Table 3–3. Summary of Calibration Targets for Model Calibration

ID	Station/Site Name	Agency	RS in HEC-RAS	Start Date	End Date	Stage Data Count
1	**Rainbow River / at Spring Head**	FDEP	6.00	10/8/2005	1/25/2013	582
2	**SJR T4**	SJRWMD	5.77	2/17/2010*	9/26/2011	587 (daily)
3	**SJR T3**	SJRWMD	4.31	2/17/2010*	9/27/2011	588 (daily)
4	**SJR T2**	SJRWMD	3.09	2/17/2010*	9/26/2011	587 (daily)
5	**SJR T1**	SJRWMD	1.97	4/8/2010*	9/26/2011	537 (daily)
6	**Veg 7**	SWFWMD	5.77	5/22/2014	9/2/2014	2,473 (hourly)
7	**PHAB 2**	SWFWMD	3.09	3/10/2014	2/9/2015	8,065 (hourly)
8	**Veg 1**	SWFWMD	1.36	9/24/2009	2/9/2015	3,311 (hourly)

Note: Sites 1 through 5 serve as the primary calibration targets and Sites 6 through 8 serve as the secondary calibration targets.
* Stage data prior to 2/17/2010 was discarded due to its poor data quality, see Figure 3-3.

3.3.3.2 Adjustment of Manning's n Coefficient

Manning's n coefficient is the first and also the most important parameter to be adjusted in HEC-RAS model calibration. Based on field observations on river bottom roughness and vegetation growth conditions, using one single Manning's n coefficient might not be adequate to represent the real roughness of the river under different flow conditions. Roughness generally decreased with increases flow and depth. This is especially true for the river segment upstream of the rocky shoal near RS 3.10, where the aquatic plant overgrowth could dramatically increase river bottom roughness with reduced flow and depth.

Therefore, to improve the model calibration results, roughness coefficients were automatically adjusted in HEC-RAS with changes in flow, using a set of flow roughness factors at each cross-section. Table 3-4 provides a set of flow roughness factors in corresponding to the flow at CR 484 Bridge (RS 0.89). Between the flows listed in this table, HEC-RAS will use linear interpolation to obtain a roughness factor (Brunner, 2010b). The flow roughness factors in the cross-sections from RS 3.11 to RS 6.00 could be developed by varying flow rates based on the flow profile analysis results listed in Table 2-3 of Section 2.3.1. Note that no flow roughness factors were used in the cross-sections downstream of the rocky shoal (RS 3.11) due to less vegetation overgrowth observed in this river segment.

In summary, flow roughness factors provide the modeler a more effective and flexible tool to meet the calibration targets under different flow conditions.

Table 3–4. Summary of Flow Roughness Factors in Cross-Sections (RS 3.11 - 6.00)

ID	Flow at CR 484 (CFS)	Roughness Factor
1	350	1.25
2	400	1.2
3	450	1.1
4	500	1.0
5	550	1.0
6	600	1.0
7	800	1.0
8	1000	1.0

3.3.3.3 Model Calibration Results

The model calibration results are summarized in Table 3-5. Plots of the model calibration results are graphically presented in Figures 3-8 through 3-39, including:

- Plots of simulated and observed stage hydrographs;
- Plots of stage residuals (simulated stage minus observed stage);
- Scatter plots comparing simulated and observed stages against a 45-degree (1:1) line; and
- Scatter plots comparing stage residuals and observed stages.

Table 3–5. Summary of Model Calibration Results

ID	Station/Site Name	RS in HEC-RAS	% Stage Residuals within 0.1 ft	% Stage Residuals within 0.15 ft	% Stage Residuals within 0.2 ft	% Stage Residuals within 0.25 ft	% Stage Residuals within 0.5 ft
1	**Rainbow River at Spring Head**	6.00	44.67%	76.46%	95.88%	**98.11%**	100%
2	**SJR T4**	5.77	62.69%	92.33%	99.83%	**100%**	100%
3	**SJR T3**	4.31	86.40%	99.83%	100%	**100%**	100%
4	**SJR T2**	3.09	99.66%	99.66%	100%	**100%**	100%
5	**SJR T1**	1.97	98.70%	100%	100%	**100%**	100%
6	**Veg 7**	5.77	75.73%	100%	100%	**100%**	100%
7	**PHAB 2**	3.09	64.29%	80.06%	94.94%	**97.62%**	100%
8	**Veg 1**	1.36	98.55%	99.28%	99.28%	**100%**	100%

For the secondary calibration target sites of Veg 7, PHAB 2, and Veg 1, the hourly stage data was first converted to daily average stage data prior to being used in the statistical analysis, as plotted in Figures 3-28 through 3-39. This data interval conversion was primarily used to smooth the raw hourly stage hydrograph. In addition, the resultant daily average stage data is consistent with the daily average data used in the HEC-RAS model, including the stage hydrograph at the downstream boundary and flow/lateral inflow hydrographs.

As observed in the plots of the model calibration results, the dynamic HEC-RAS model is able to capture the hydrologic response to all flow conditions with stage residuals being less than 0.5 foot. Also as summarized in Table 3-5, over 97% of the stage residuals fall within a range of ±0.25 foot, and majority of the stage residuals fall within ±0.1 foot at seven of the eight river sites.

In summary, the model calibration performed at the selected river sites is considered reasonable and adequate.

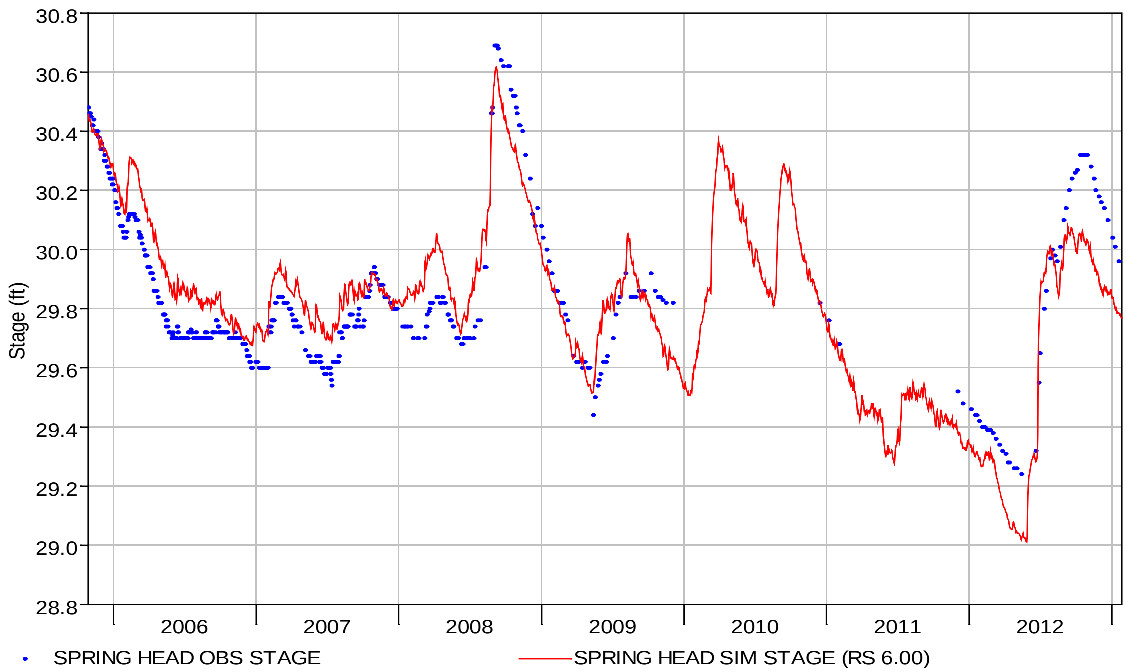

Figure 3-8. Simulated and Observed Stage Hydrographs at Spring Head (RS 6.00)

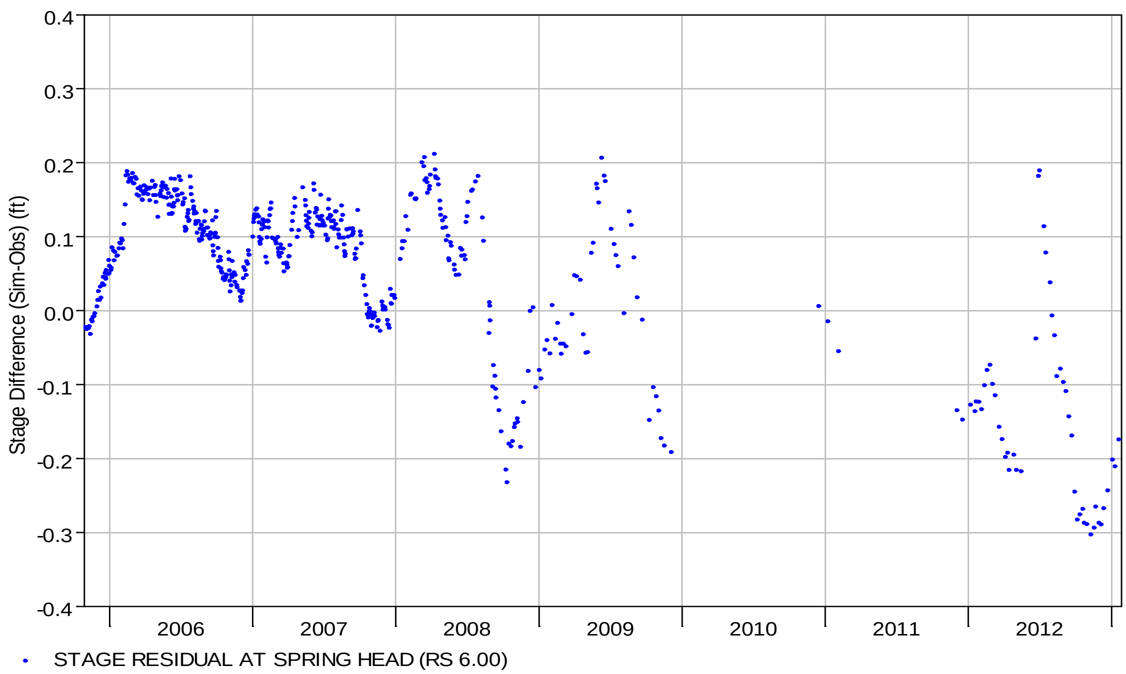

Figure 3-9. Stage Residuals at Spring Head (RS 6.00)

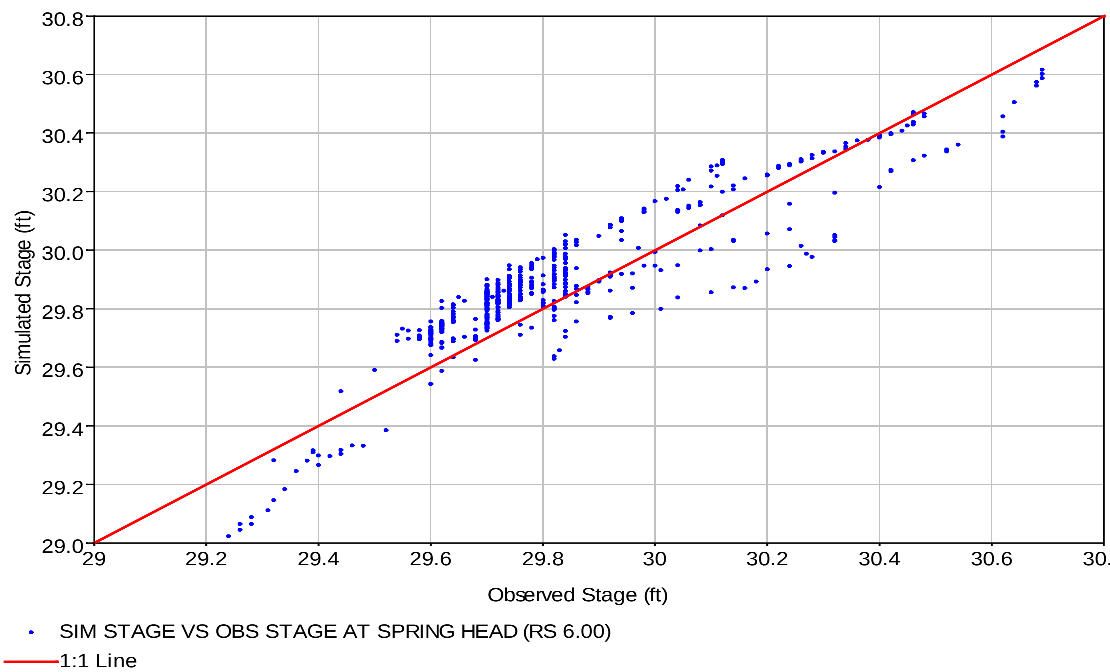

Figure 3-10. Scatter Plot Comparing Simulated and Observed Stages at Spring Head (RS 6.00)

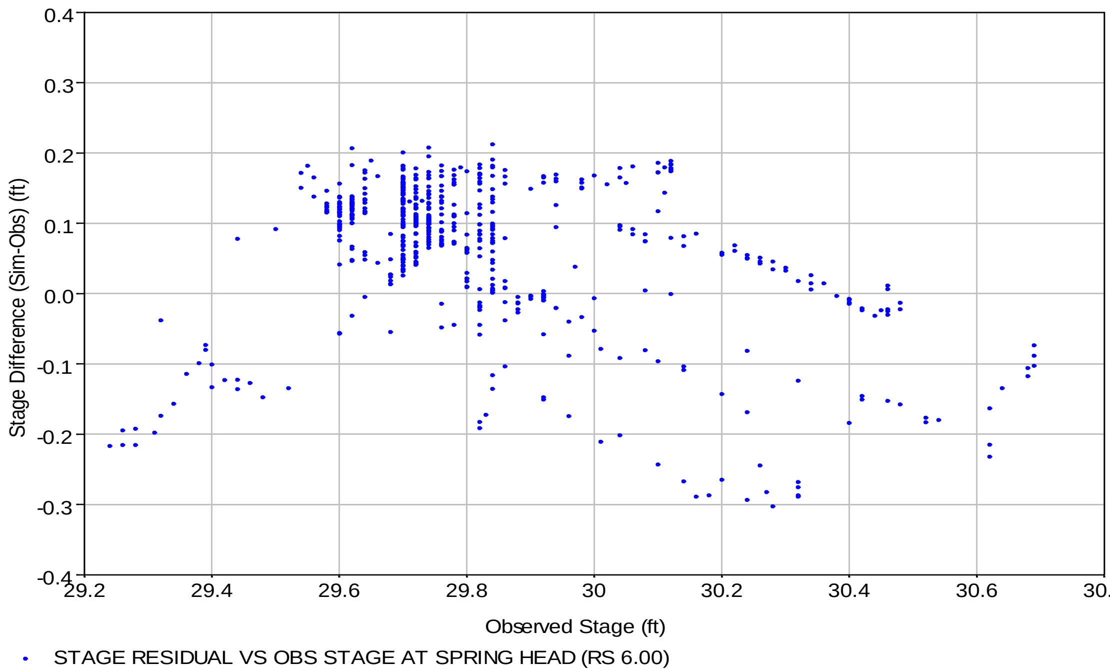

Figure 3-11. **Scatter Plot Comparing Stage Residuals and Observed Stages at Spring Head (RS 6.00)**

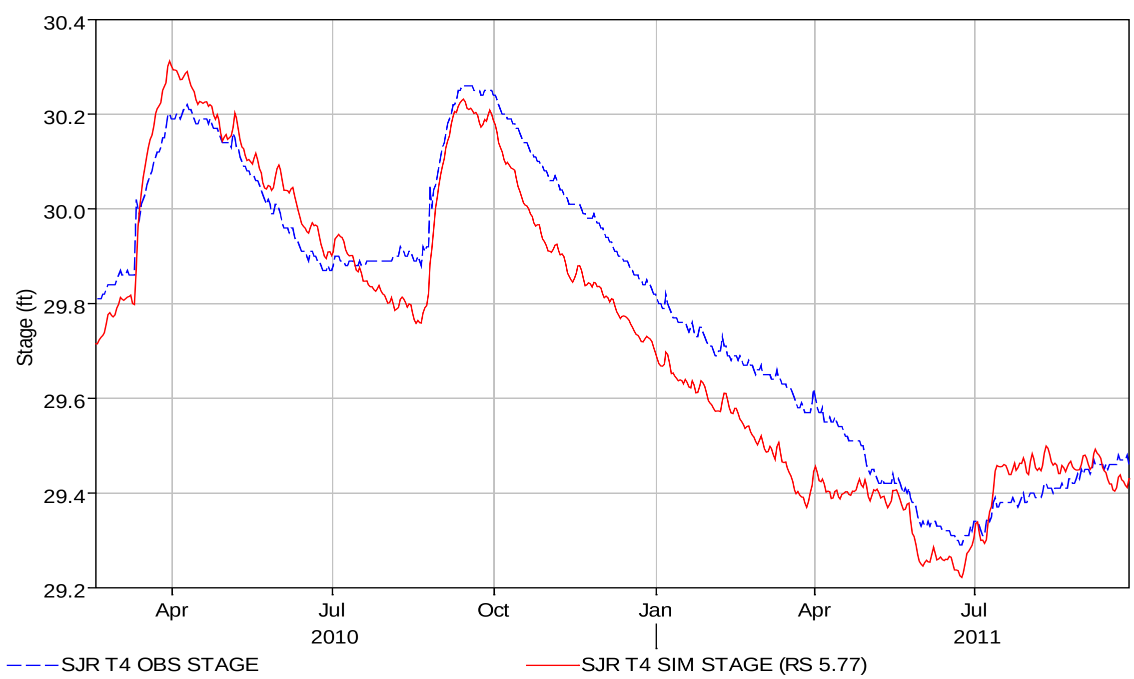

Figure 3-12. **Simulated and Observed Stage Hydrographs at SJR T4 (RS 5.77)**

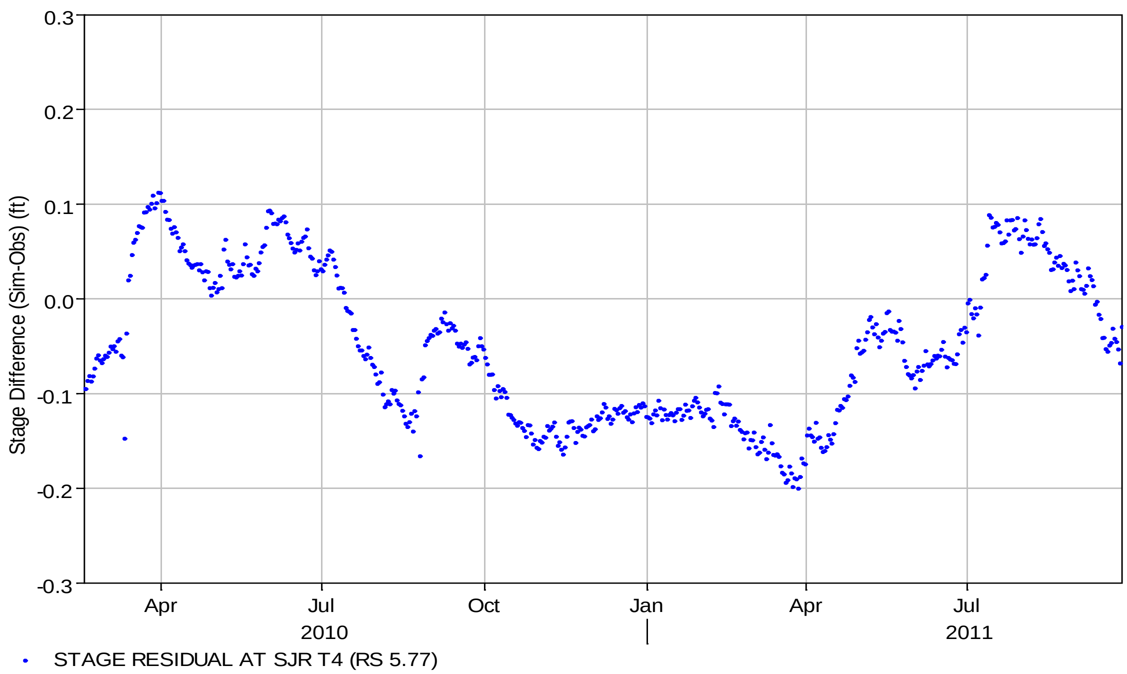

Figure 3-13. Stage Residuals at SJR T4 (RS 5.77)

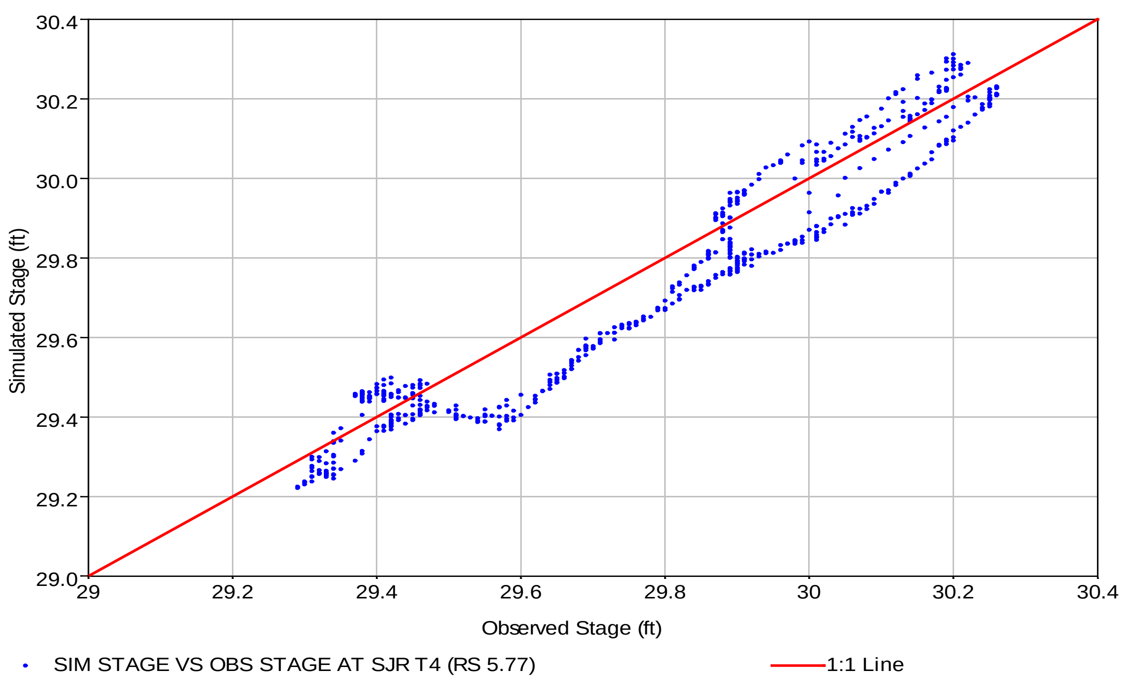

Figure 3-14. Scatter Plot Comparing Simulated and Observed Stages at SJR T4 (RS 5.77)

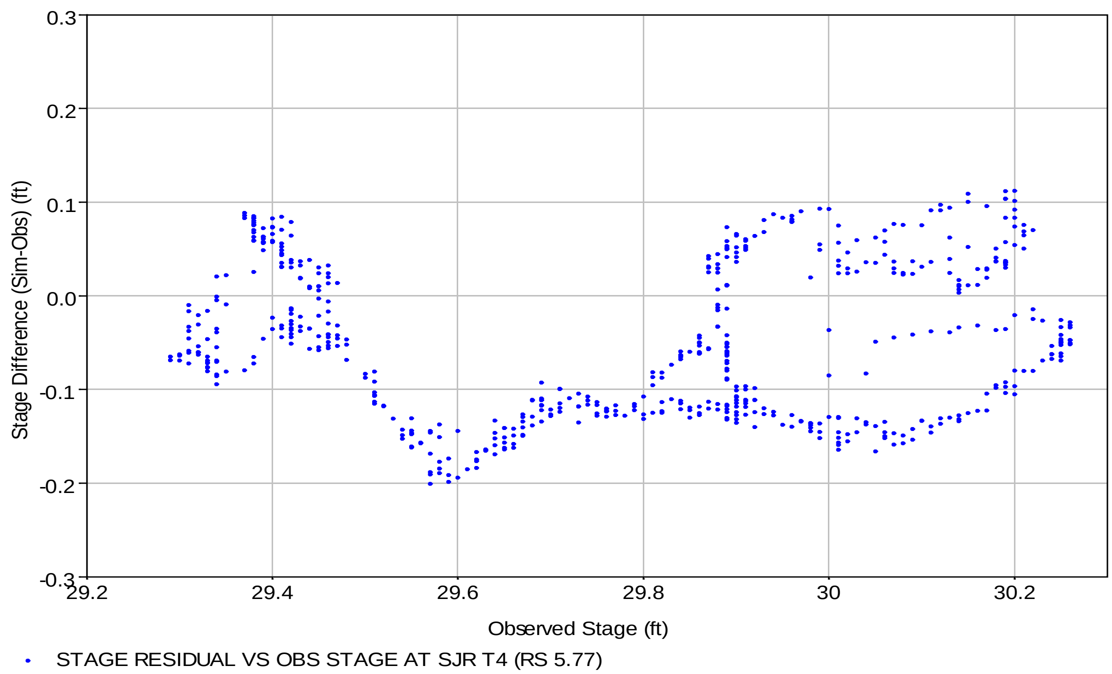

Figure 3-15. Scatter Plot Comparing Stage Residuals and Observed Stages at SJR T4 (RS 5.77)

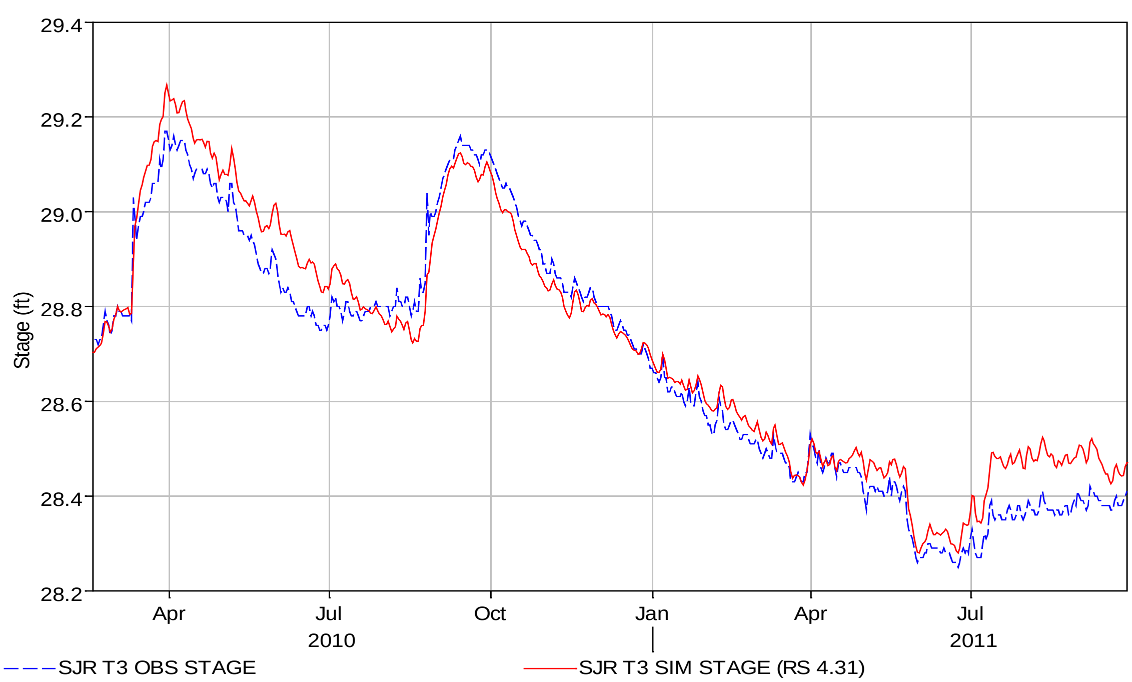

Figure 3-16. Simulated and Observed Stage Hydrographs at SJR T3 (RS 4.31)

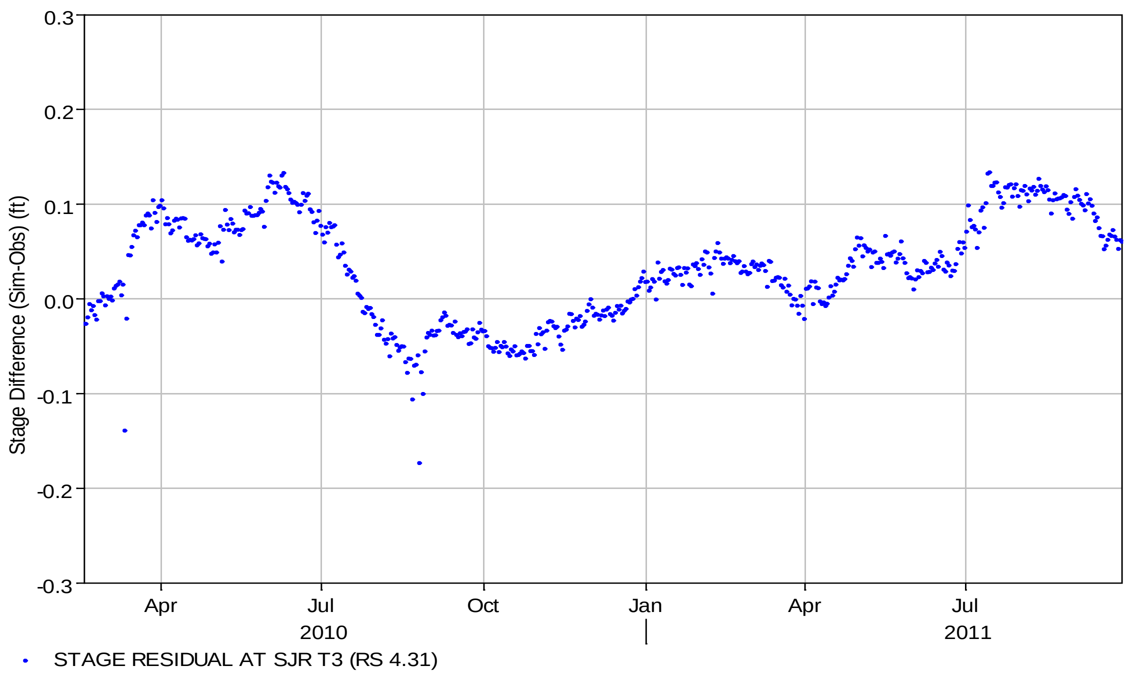

Figure 3-17. Stage Residuals at SJR T3 (RS 4.31)

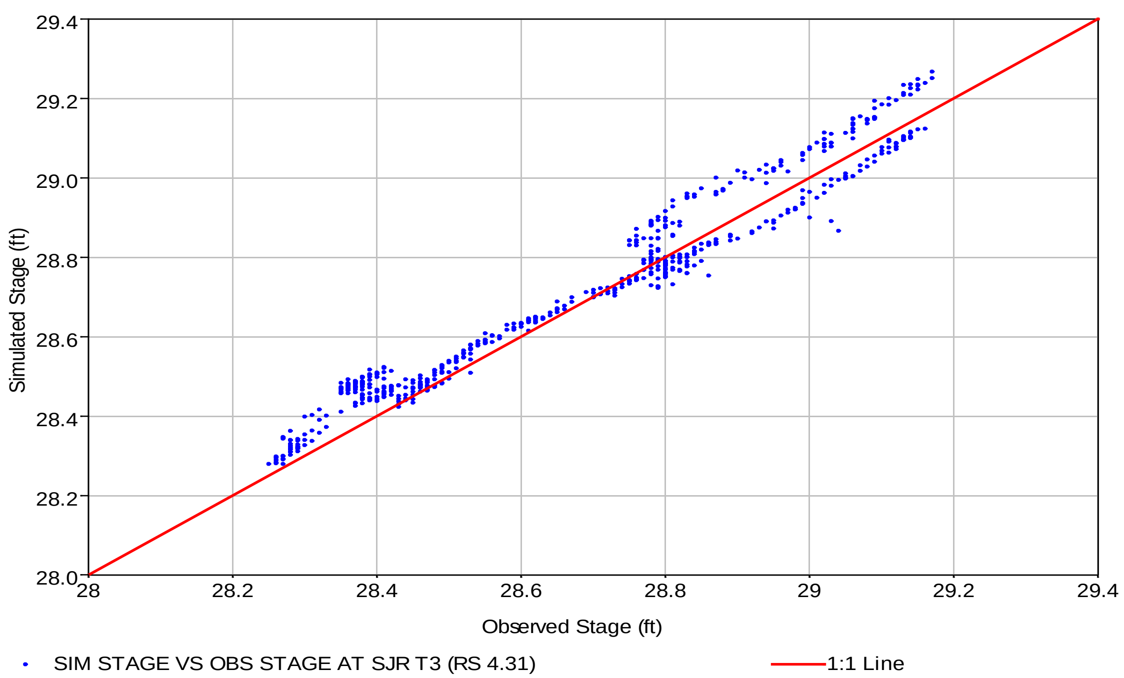

Figure 3-18. Scatter Plot Comparing Simulated and Observed Stages at SJR T3 (RS 4.31)

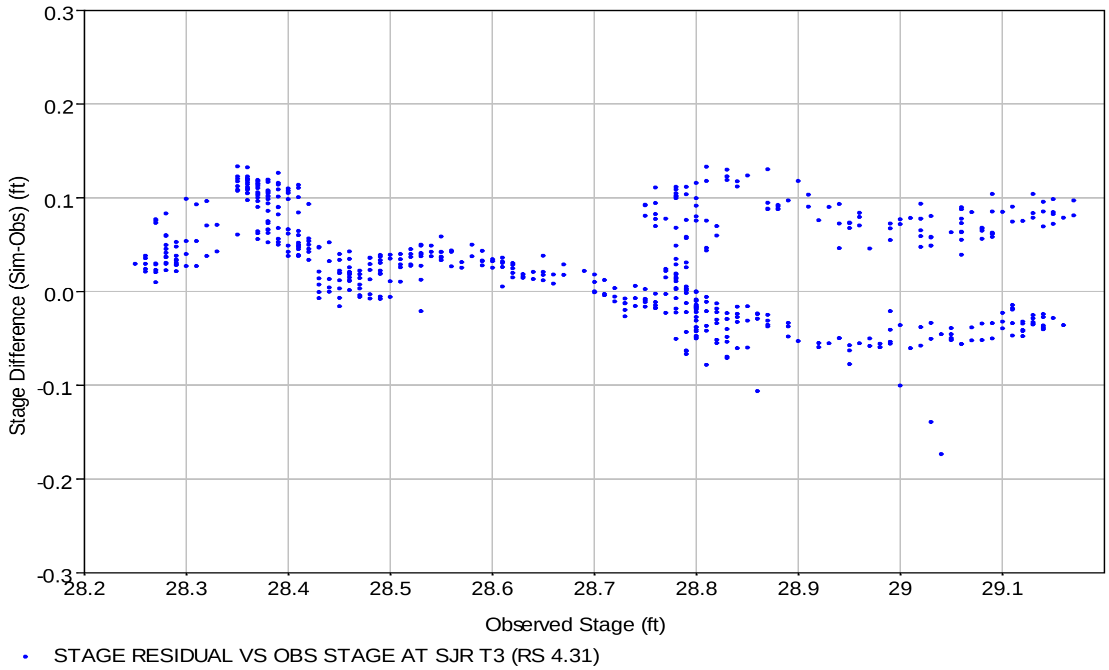

Figure 3-19. Scatter Plot Comparing Stage Residuals and Observed Stages at SJR T3 (RS 4.31)

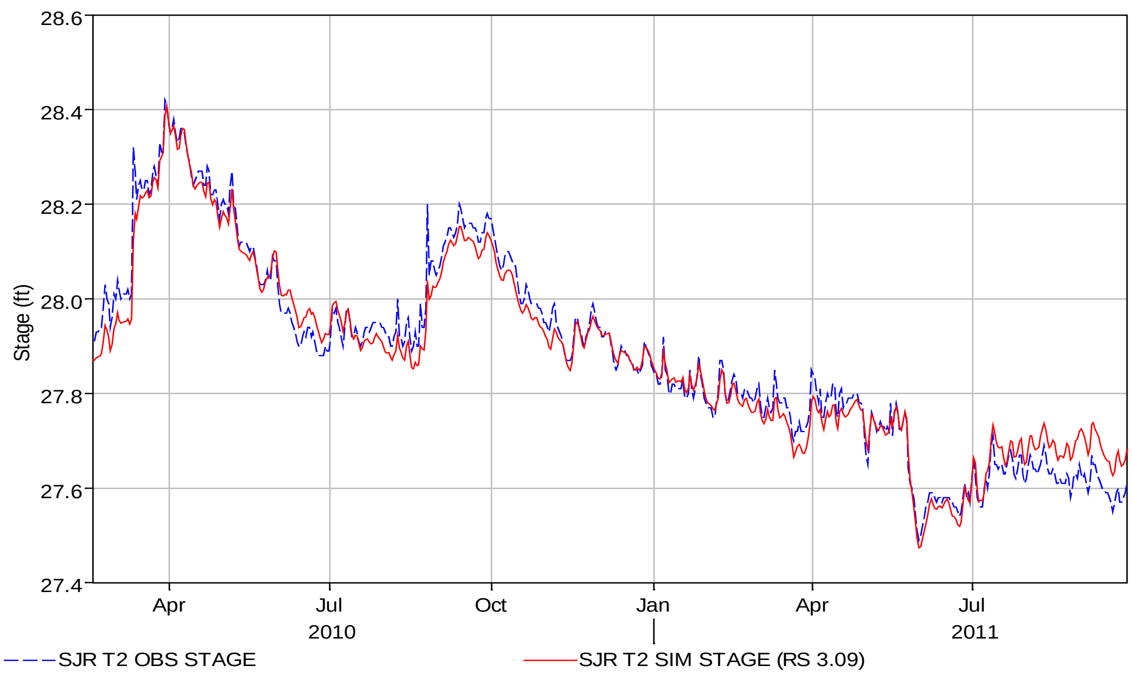

Figure 3-20. Simulated and Observed Stage Hydrographs at SJR T2 (RS 3.09)

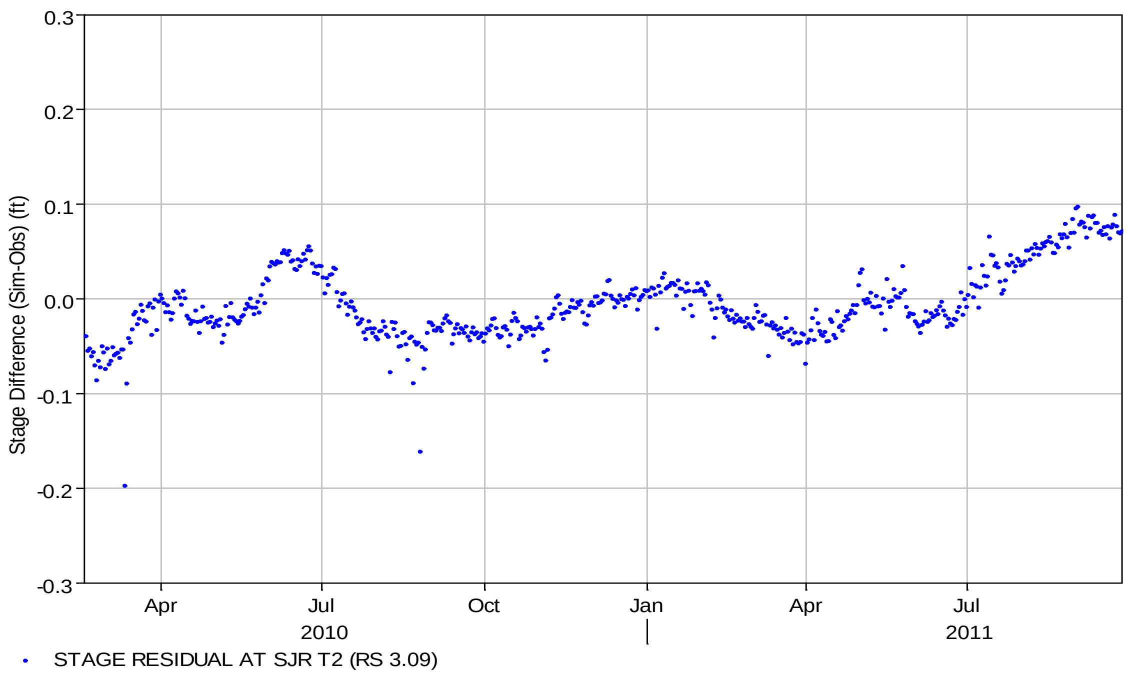

Figure 3-21. Stage Residuals at SJR T2 (RS 3.09)

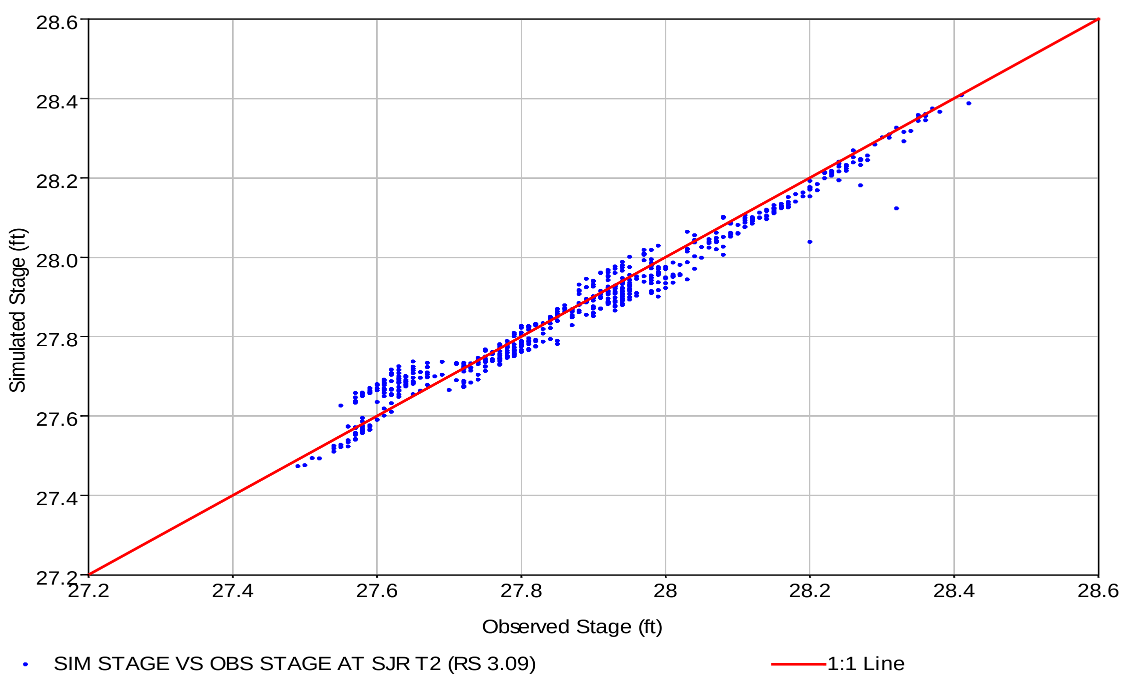

Figure 3-22. Scatter Plot Comparing Simulated and Observed Stages at SJR T2 (RS 3.09)

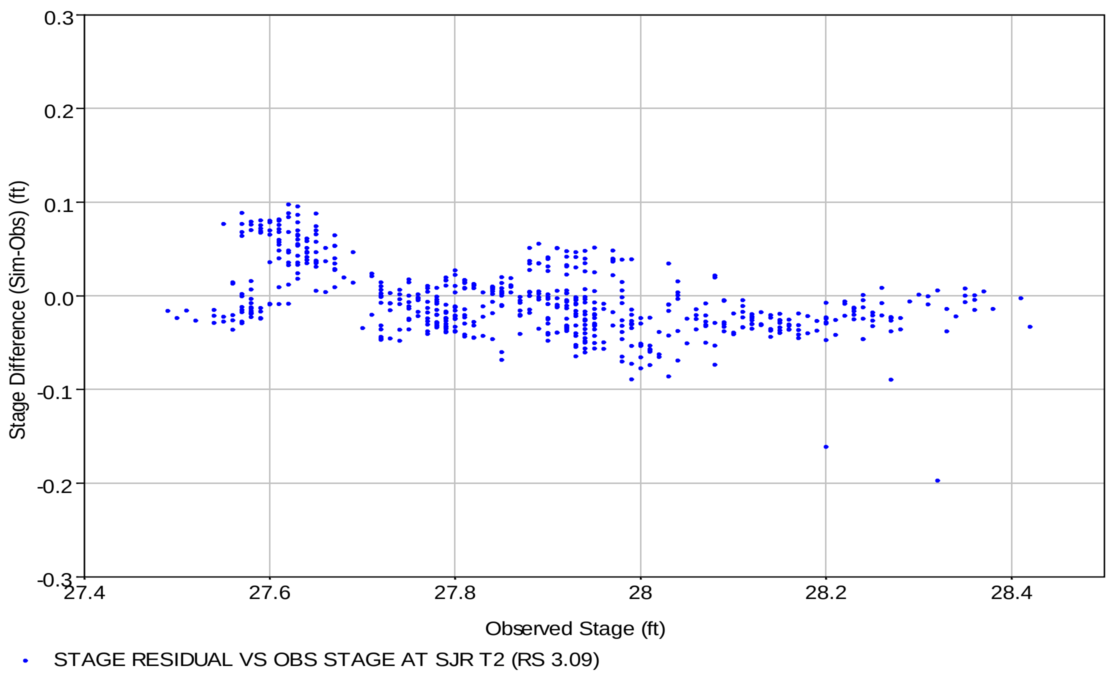

Figure 3-23. Scatter Plot Comparing Stage Residuals and Observed Stages at SJR T2 (RS 3.09)

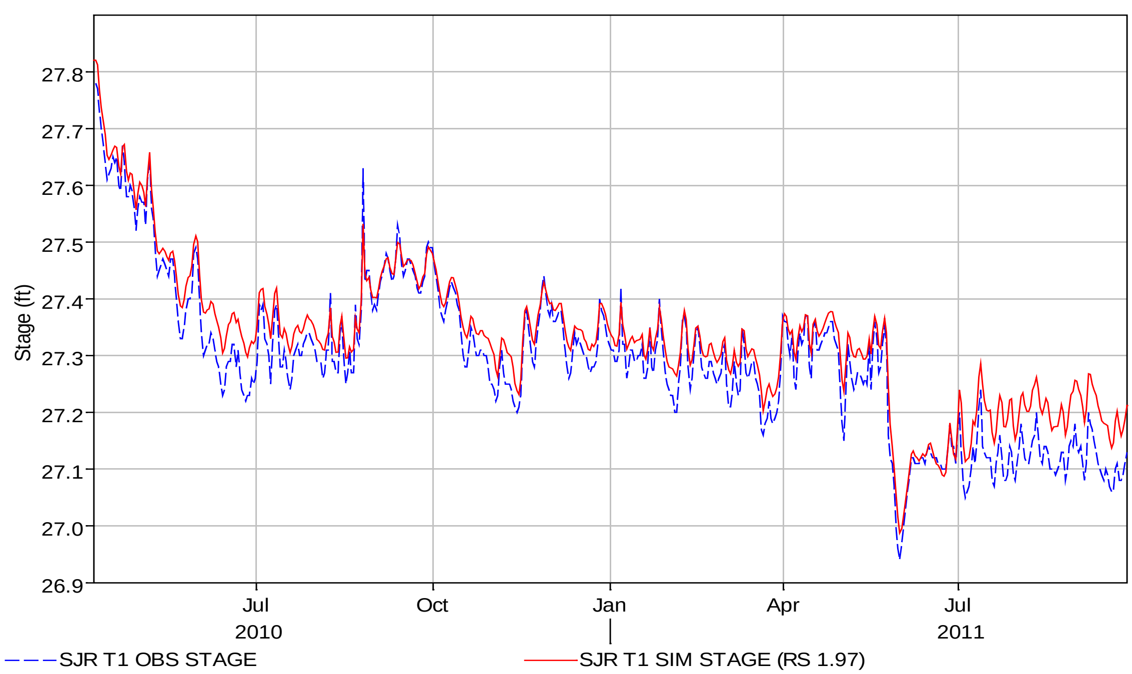

Figure 3-24. Simulated and Observed Stage Hydrographs at SJR T1 (RS 1.97)

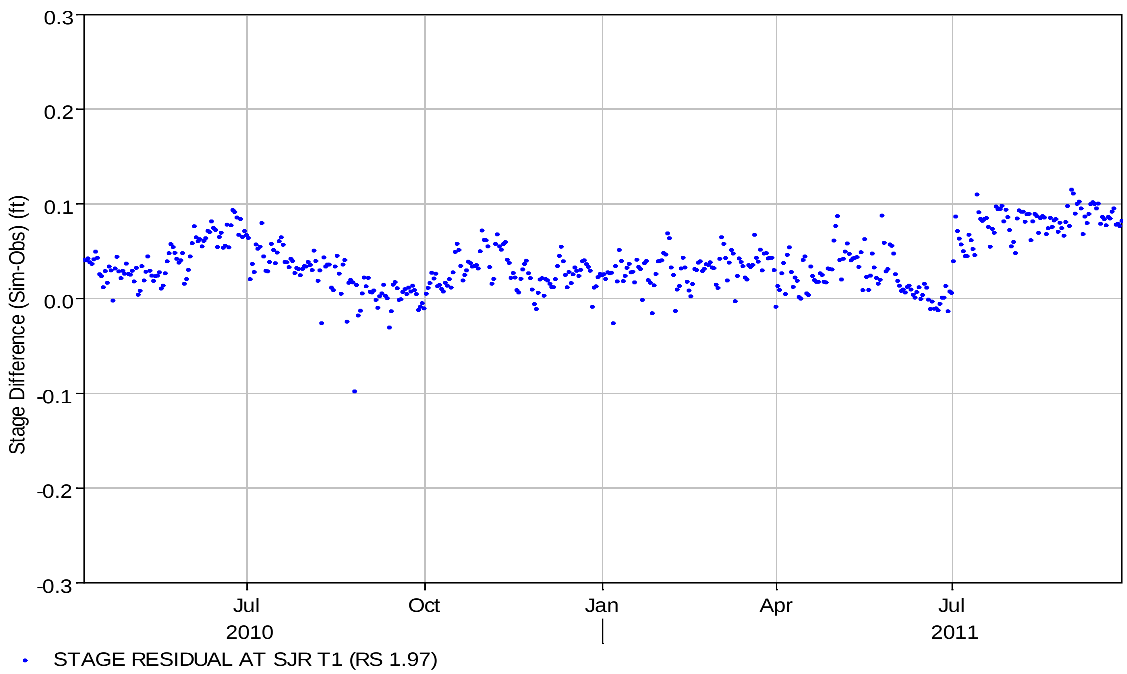

Figure 3-25. Stage Residuals at SJR T1 (RS 1.97)

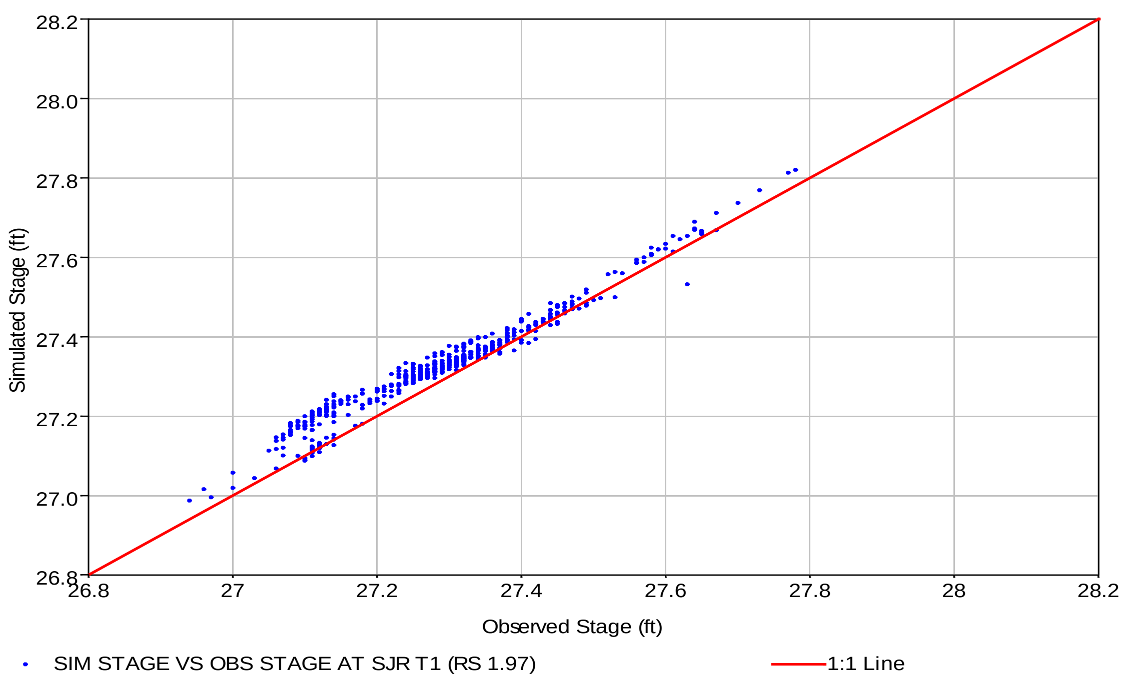

Figure 3-26. Scatter Plot Comparing Simulated and Observed Stages at SJR T1 (RS 1.97)

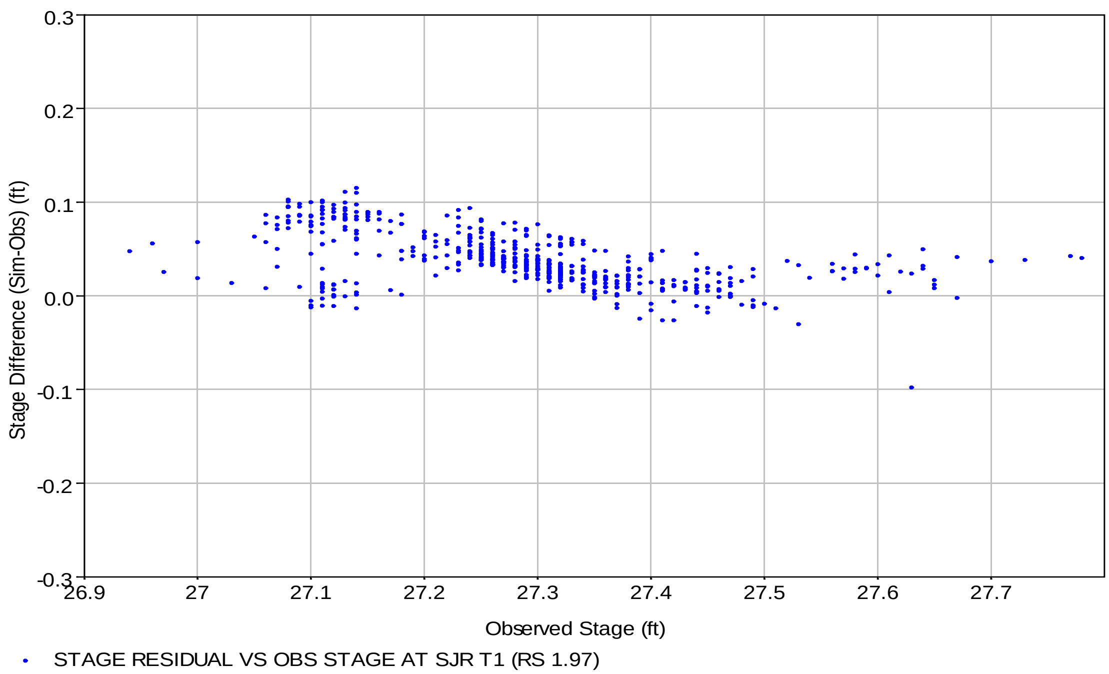

Figure 3-27. Scatter Plot Comparing Stage Residuals and Observed Stages at SJR T1 (RS 1.97)

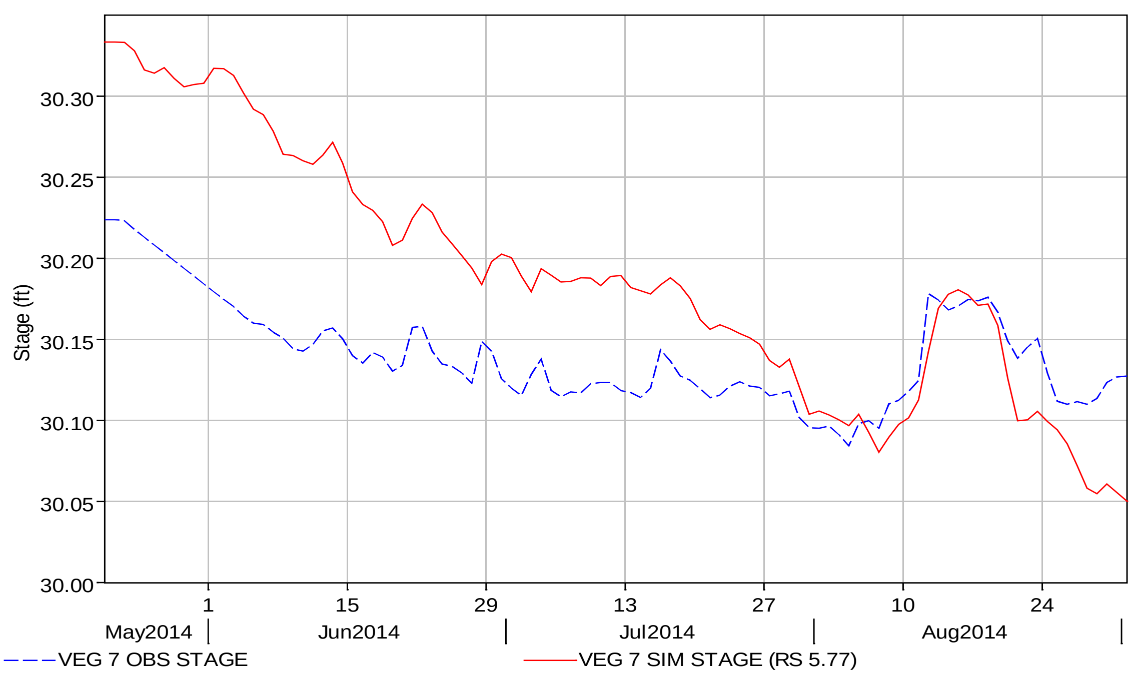

Figure 3-28. Simulated and Observed Stage Hydrographs at Veg 7 (RS 5.77)

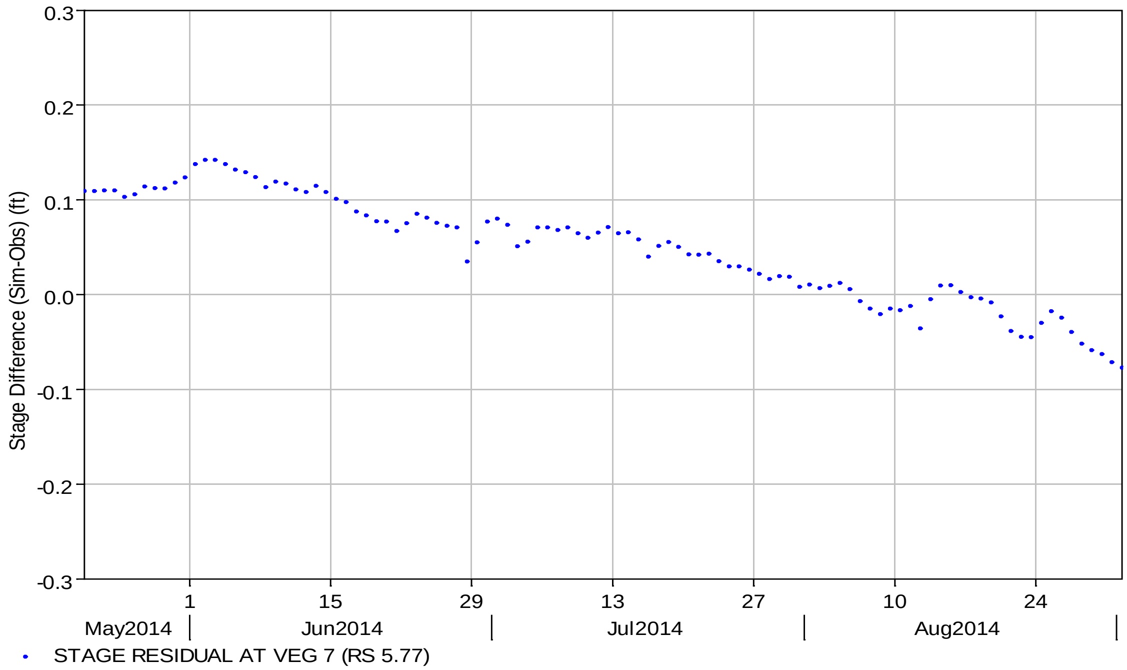

Figure 3-29. Stage Residuals at Veg 7 (RS 5.77)

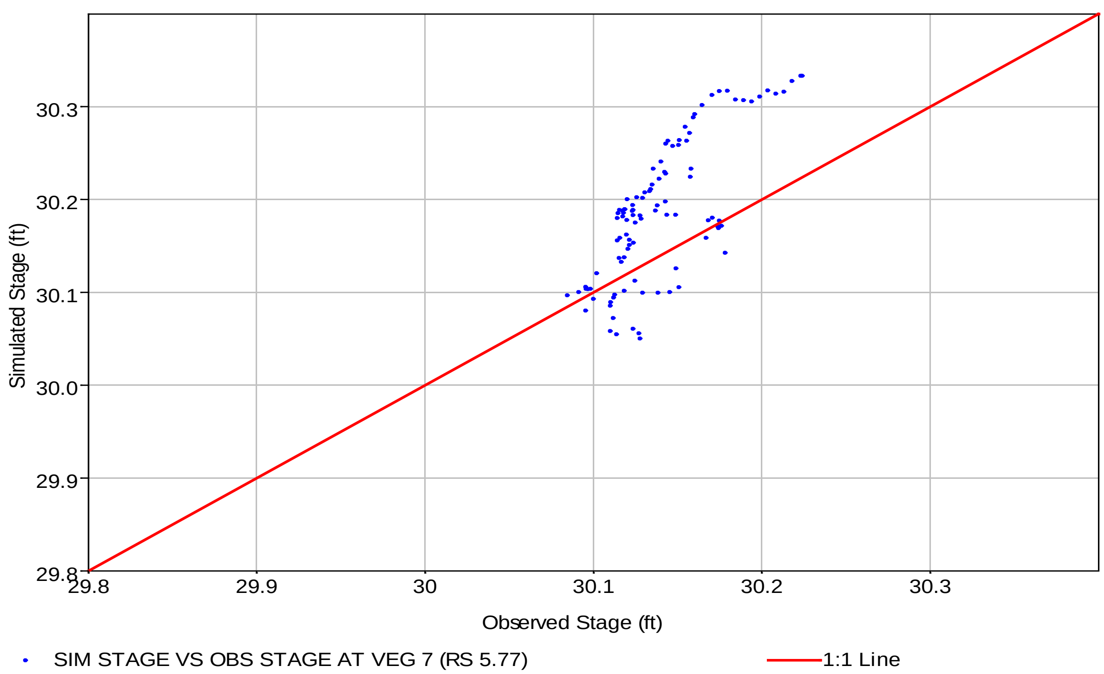

Figure 3-30. Scatter Plot Comparing Simulated and Observed Stages at Veg 7 (RS 5.77)

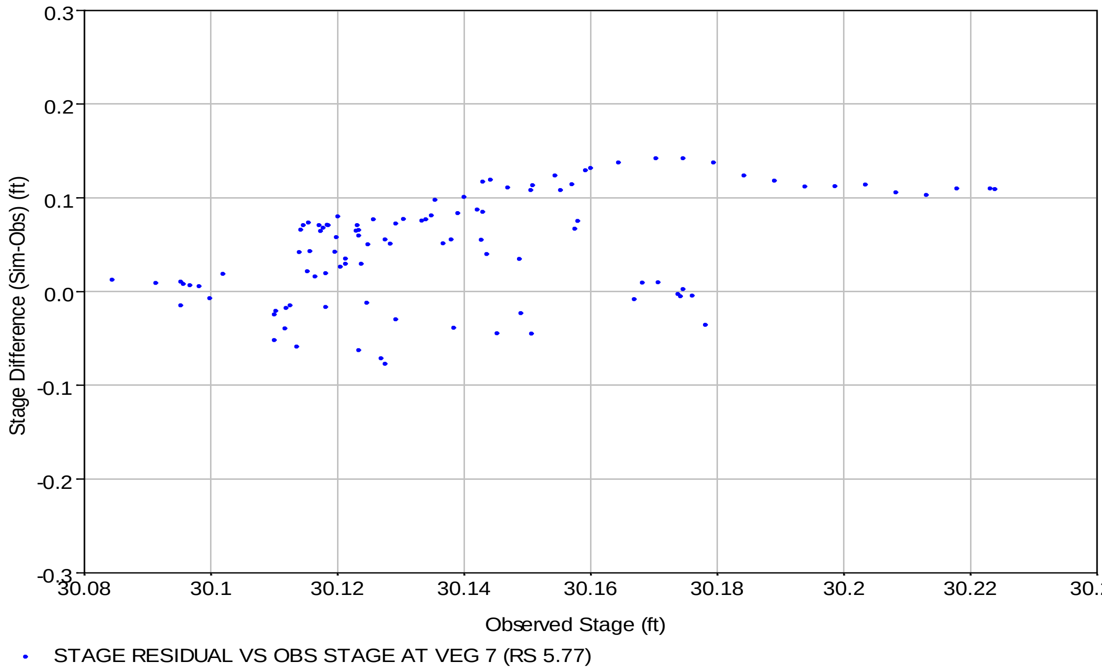

Figure 3-31. Scatter Plot Comparing Stage Residuals and Observed Stages at Veg 7 (RS 5.77)

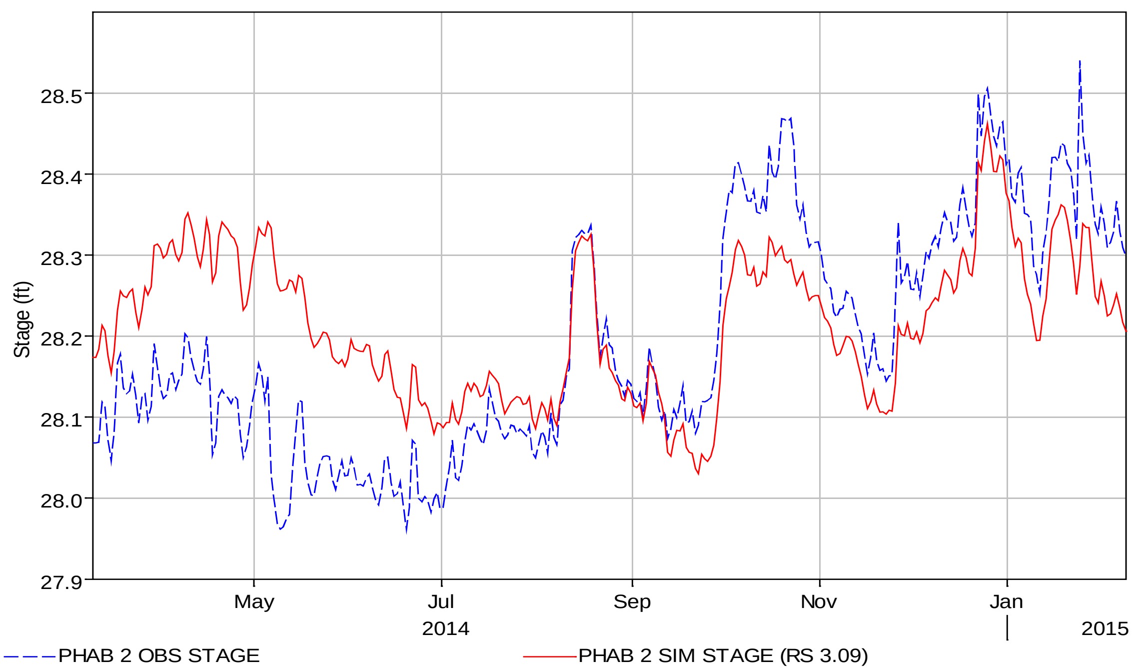

Figure 3-32. Simulated and Observed Stage Hydrographs at PHAB 2 (RS 3.09)

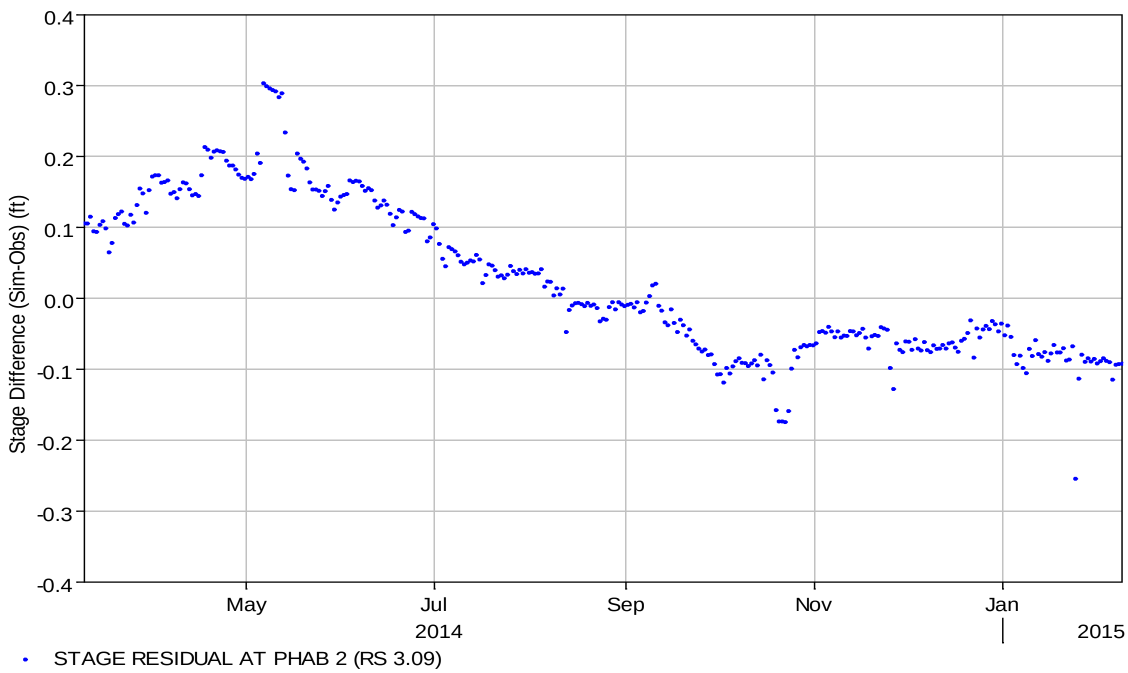

Figure 3-33. Stage Residuals at PHAB 2 (RS 3.09)

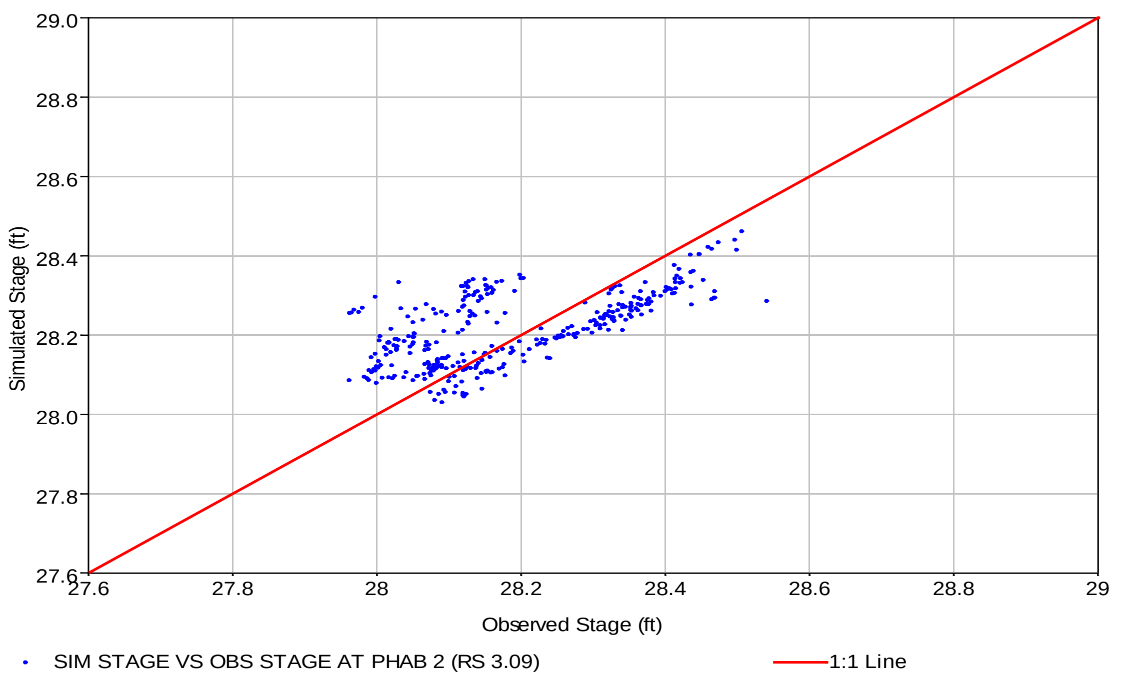

Figure 3-34. Scatter Plot Comparing Simulated and Observed Stages at PHAB 2 (RS 3.09)

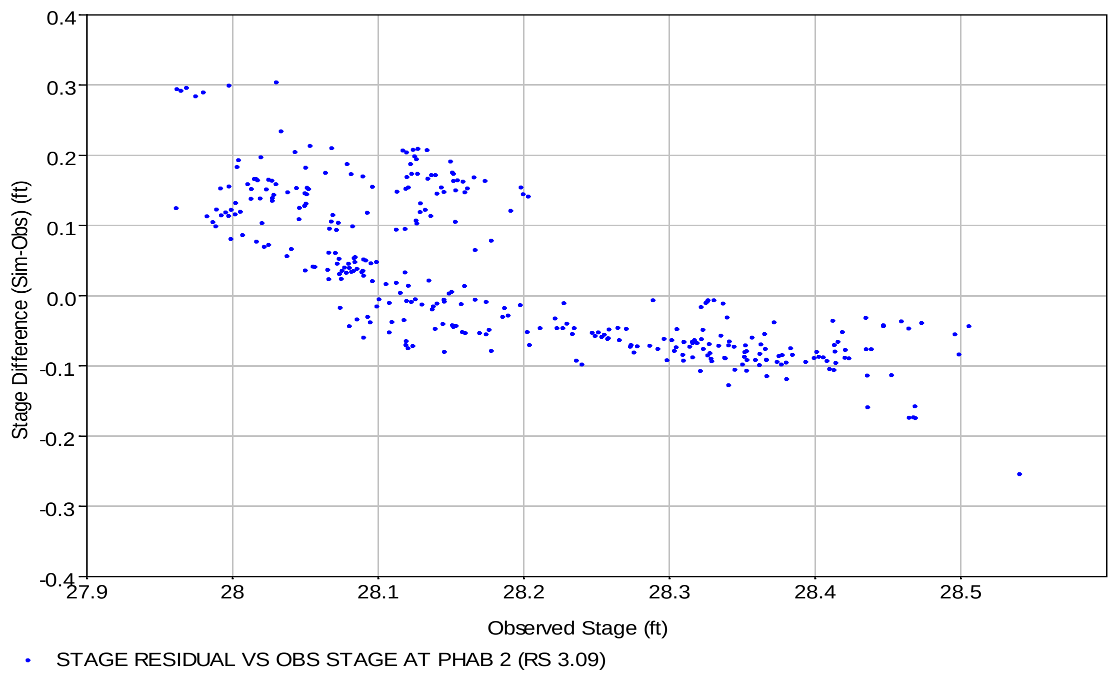

Figure 3-35. Scatter Plot Comparing Stage Residuals and Observed Stages at PHAB 2 (RS 3.09)

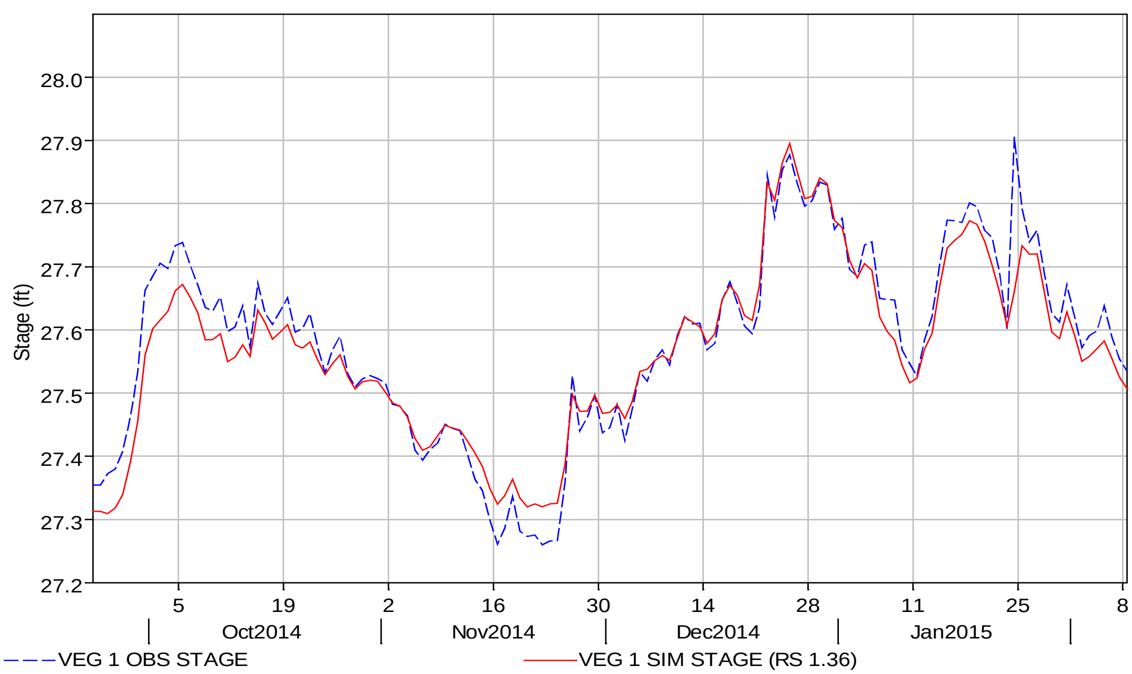

Figure 3-36. Simulated and Observed Stage Hydrographs at Veg 1 (RS 1.36)

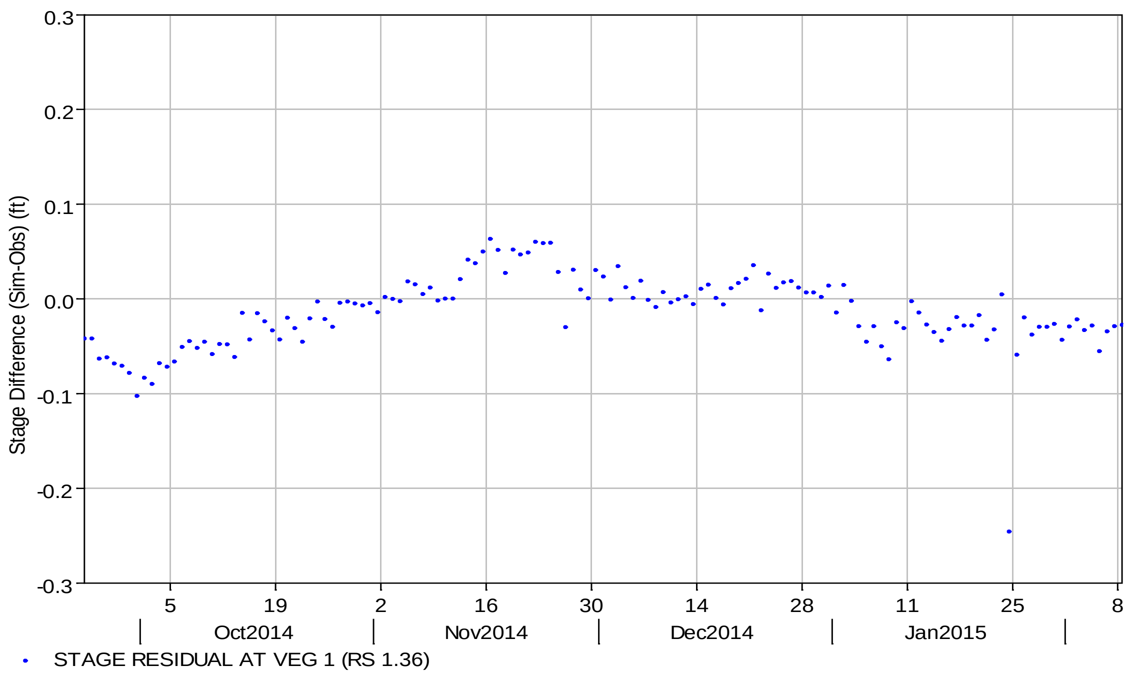

Figure 3-37. **Stage Residuals at Veg 1 (RS 1.36)**

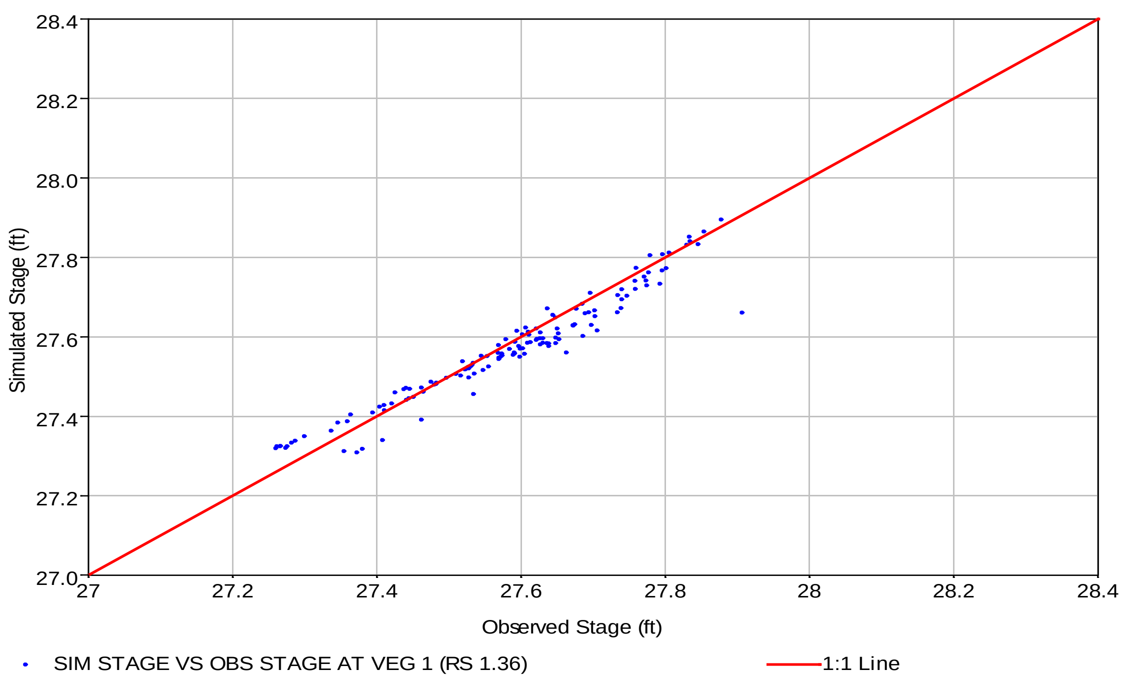

Figure 3-38. **Scatter Plot Comparing Simulated and Observed Stages at Veg 1 (RS 1.36)**

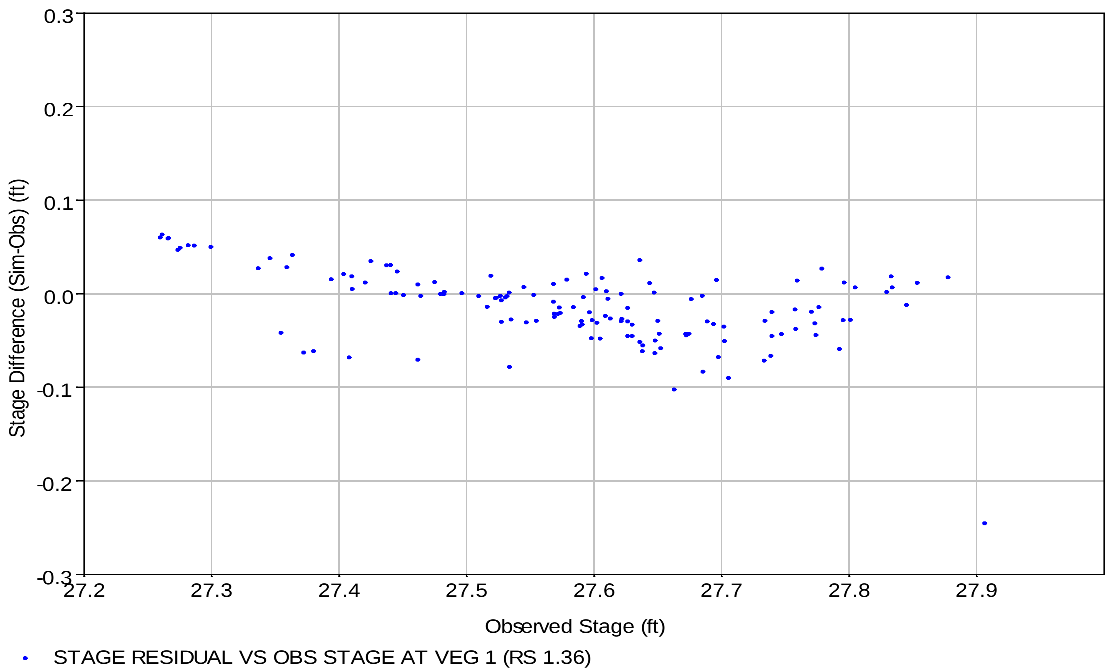

Figure 3-39. Scatter Plot Comparing Stage Residuals and Observed Stages at Veg 1 (RS 1.36)

3.3.4 MODEL VERIFICATION

In addition to the model calibration performed using the long-term daily or real-time stage data, miscellaneous stage data collected by USGS at the spring head and by SWFWMD at a total of 11 vegetation transect sites was used to verify if the dynamic HEC-RAS model is also able to predict reasonable water surface elevations at these selected river sites. The stage datasets used in the model verification process are summarized in Table 3-6.

The model verification results are graphically presented in Figures 3-40 through 3-43, including plots of simulated stage hydrographs and observed stage data at the selected river sites.

Review of the model verification results suggests most of the stage residuals fall within a range of ±0.5 foot, except in the cases when accuracy of the measured stages is highly questionable, e.g., the stage data collected in 2011 and the data in 2005 through 2007 at

PHAB 1, PHAB Pool, and PHAB 2. A thorough quality control of the observed stage data could eliminate these data errors and improve the model verification results.

Table 3–6. Summary of Stage Datasets Used in Model Verification

Station/Site Name	Agency	RS in HEC-RAS	Start Date	End Date	Stage Data Count
Rainbow River at Spring Head	USGS	6.00	3/21/2005	1/31/2012	39
Veg 7	SWFWMD	5.77	7/1/2009	3/12/2015	34
Veg 6	SWFWMD	5.55	7/1/2009	3/12/2015	21
PHAB 1	SWFWMD	4.96	8/17/2005	3/12/2015	47
PHAB Pool	SWFWMD	3.37	8/30/2005	3/12/2015	38
Veg 4	SWFWMD	3.25	7/1/2009	7/29/2009	3
PHAB 2	SWFWMD	3.09	8/11/2005	3/12/2015	46
Veg 3	SWFWMD	2.88	7/14/2009	3/12/2015	27
Veg 2.5	SWFWMD	2.66	7/1/2009	3/12/2015	31
Veg 2	SWFWMD	1.97	7/1/2009	3/12/2015	31
Veg 1	SWFWMD	1.36	7/1/2009	3/12/2015	40
Veg BBP	SWFWMD	1.05	7/1/2009	3/12/2015	31

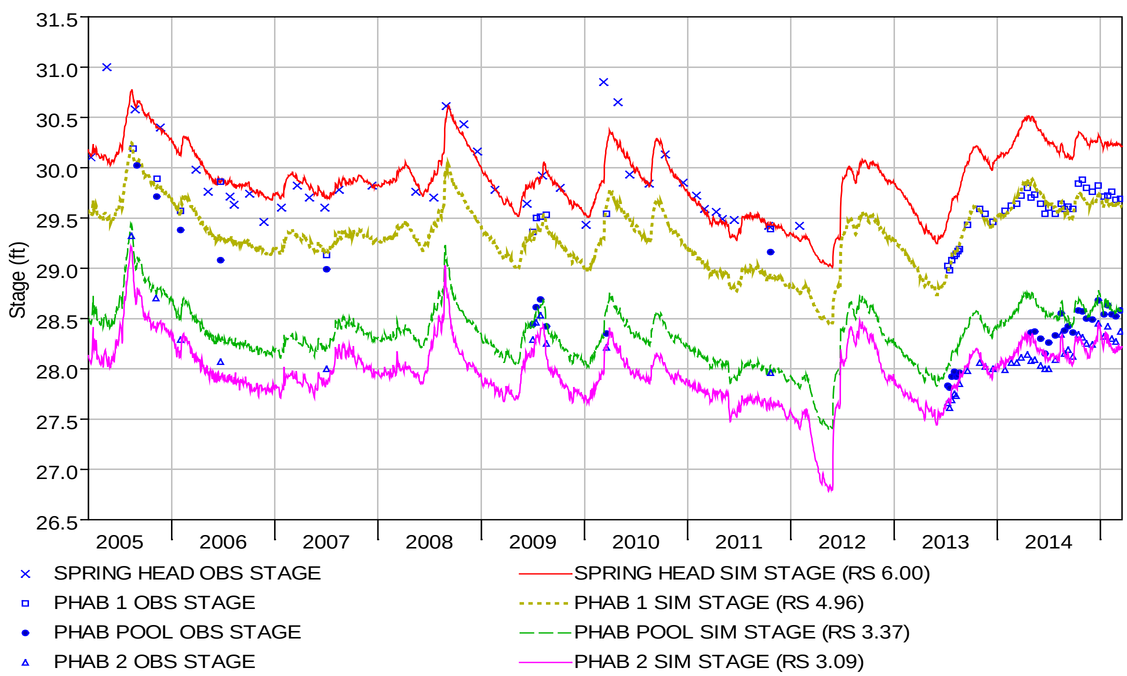

Figure 3-40. Simulated Stage Hydrographs and Observed Stage Data at Spring Head, PHAB 1, PHAB Pool & PHAB 2

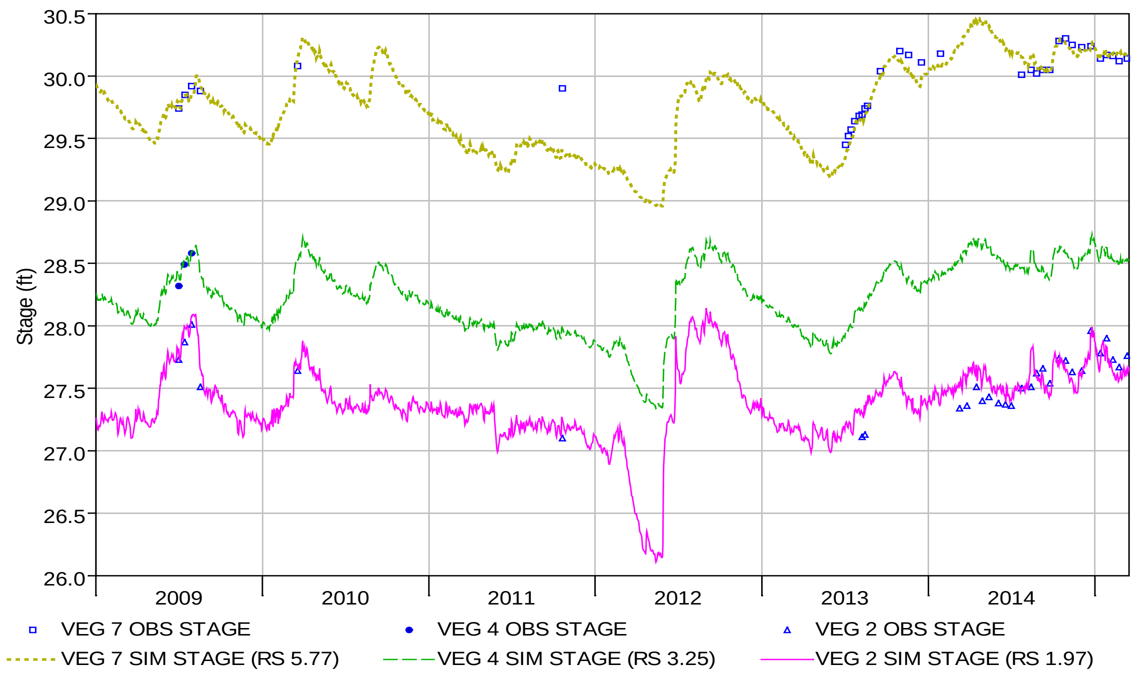

Figure 3-41. **Simulated Stage Hydrographs and Observed Stage Data at Veg 7, Veg 4 & Veg 2**

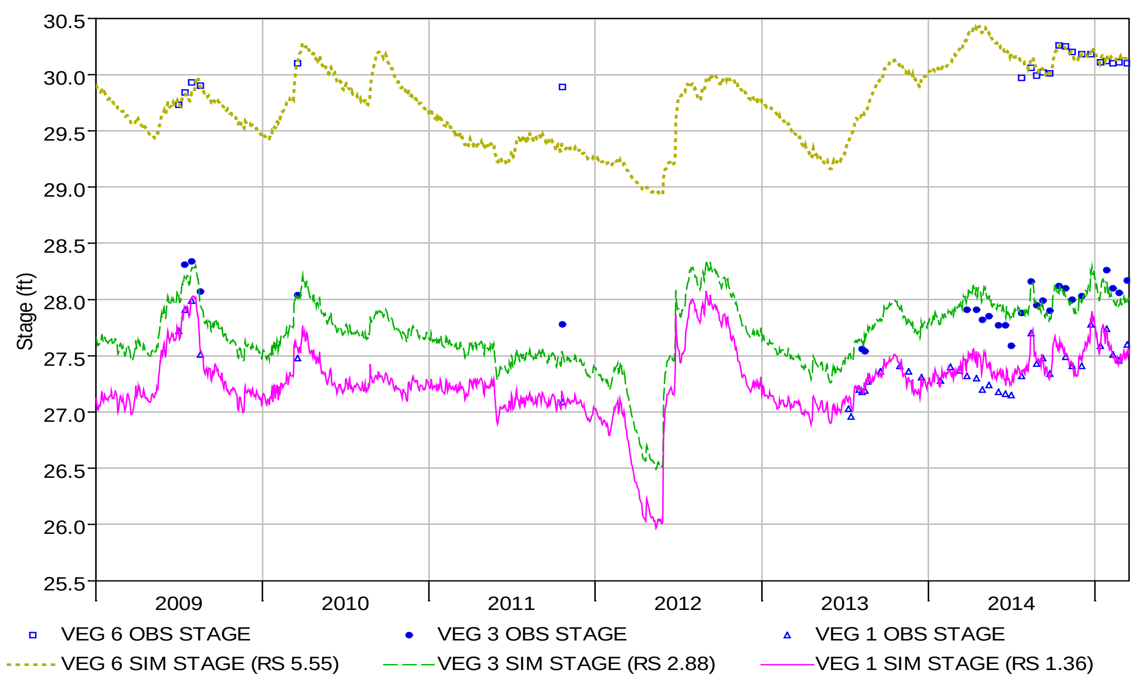

Figure 3-42. **Simulated Stage Hydrographs and Observed Stage Data at Veg 6, Veg 3 & Veg 1**

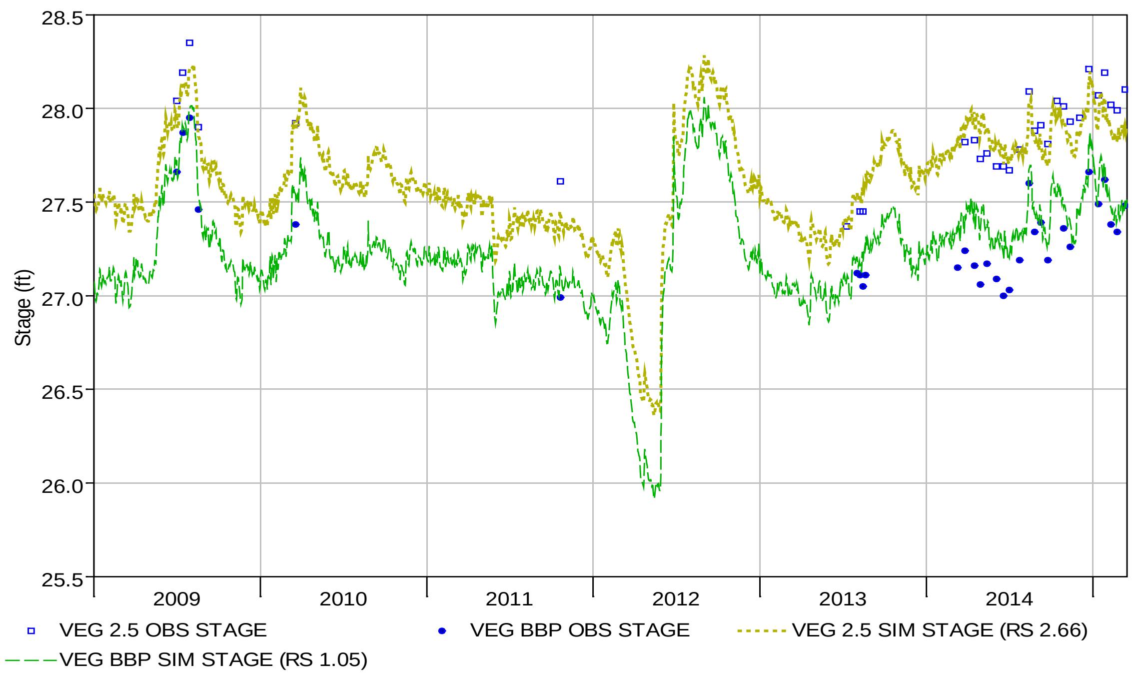

Figure 3-43. Simulated Stage Hydrographs and Observed Stage Data at Veg 2.5 & Veg BBP

3.4 SUMMARY OF DYNAMIC HEC-RAS MODEL CALIBRATION

In summary, a dynamic HEC-RAS model of Rainbow River has been developed and used for dynamic flow analysis of a time period of 10 years from 3/11/2005 to 3/17/2015. The stage data collected at various river sites were employed in the model calibration and verification.

Upon review of the preliminary model calibration and verification results, it was concluded that the model calibration task is accomplished and the HEC-RAS model could be employed in the subsequent modeling of a series of District-provided MFLs flow scenarios.

4. MFL SCENARIO SIMULATIONS

4.1 STEADY-STATE MODEL PARAMETERIZATION

4.1.1 USGS STREAM-GAUGING STATIONS

Long-term daily gage data at USGS gages is usually required to develop the flow data and downstream boundary conditions for steady-state flow analysis in HEC-RAS. Two long-term USGS gages in Rainbow and Withlacoochee Rivers, as listed below and presented in Figure 3-1, were employed in developing the steady-state HEC-RAS model for simulation of a variety of MFL scenarios provided by the District.

- USGS 02313100 Rainbow River at Dunnellon, Florida at CR 484 Bridge, provides long-term daily average flow data from 1/1/1965 to 9/30/2014 at the downstream boundary of the HEC-RAS model; and
- USGS 02313200 Withlacoochee River at Dunnellon, Florida at U.S. Highway 41 Bridge provides long-term daily average stage data from 2/6/1963 to 9/30/2014 that was used to estimate the stage data at the downstream boundary of the HEC-RAS model.

The flow and stage data, as provided and approved by USGS and SWFWMD at these two gages, was used as the base dataset in characterizing steady-state flow scenarios and channel flow profile data along the River within the study area.

4.1.2 STEADY-STATE FLOW SCENARIOS

An initial set of 15 flow scenarios, ranging from 1 percent to 99 percent exceedance time, was formulated through flow-duration analysis of the baseline flow data at USGS 02313100 Rainbow River at Dunnellon, Florida at CR 484 Bridge, which was developed by SWFWMD by applying flow impact factors to the USGS-gaged flow data for the time period from 1/1/1965 to 12/31/2010.

Based on the model results of the SWFWMD Northern District Model (NDM), Version 4, the daily flow impact factors, in percentage of flow change in relative to the baseline conditions, were estimated by the District at three different dates, as listed in Table 4-1 below, representing the baseline conditions in 1965 and the post-development conditions in 1995 and 2010. A linear interpolation approach was used to generate the daily flow impact factor for each day in between 1/1/1965 and 12/31/2010.

The resultant baseline flow data and flow-duration curve are graphically presented in Figures 4-1 and 4-2. The 15 flow scenarios, as summarized in Table 4-2, cover a wide range of flow conditions, from extreme low, average, to high flow.

Table 4–1. Summary of Flow Impact Factors at USGS 02313100

ID	Date	Daily Flow Impact Factor in Percent of Flow Change
1	1/1/1965	0.0
2	12/31/1995	1.1
3	12/31/2010	1.7

Data Source: SWFWMD, 2015.

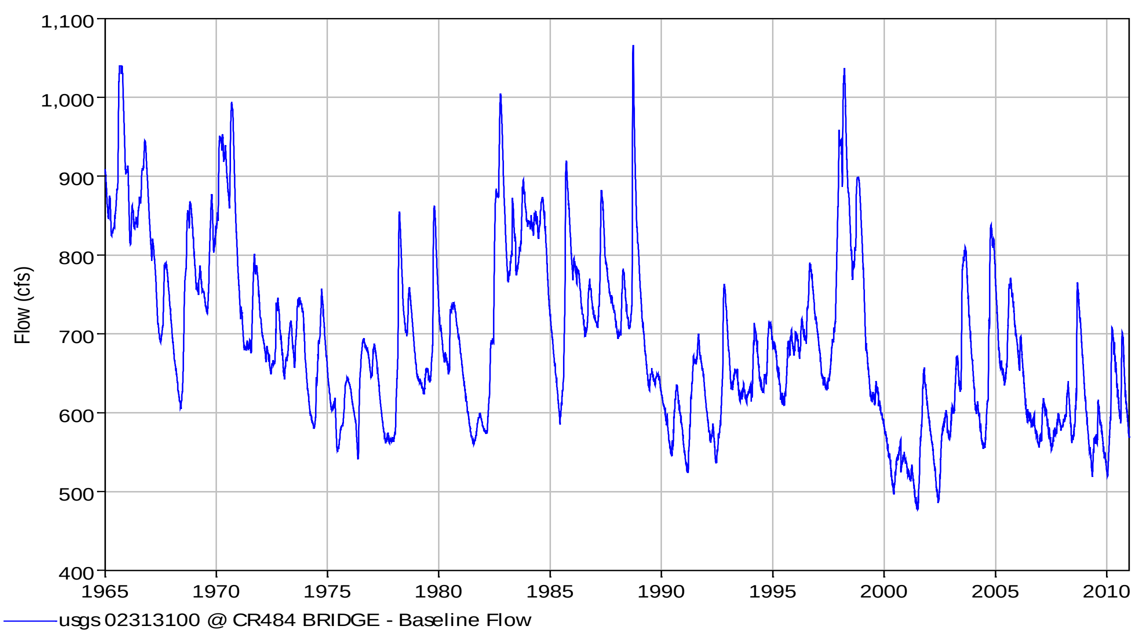

Figure 4-1. Baseline Flow Data at USGS 02313100

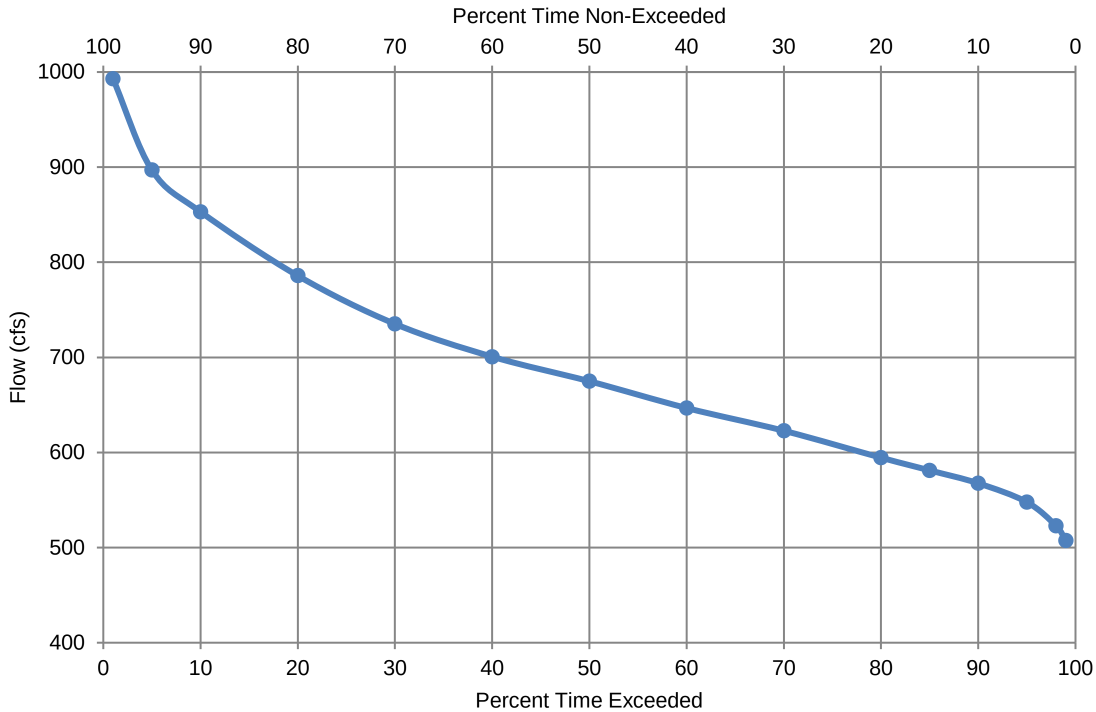

Figure 4-2. Flow-Duration Curve of Baseline Flow Data at USGS 02313100

Table 4–2. Summary of Selected Steady-State Flow Scenarios at USGS 02313100

Profile ID	Percent Time Indicated Flow is not Exceeded	Baseline Flow at USGS 02313100 (cfs)
F1	1%	507.41
F2	2%	522.81
F3	5%	547.79
F4	10%	567.61
F5	15%	581.18
F6	20%	594.54
F7	30%	622.84
F8	40%	646.74
F9	50%	674.90
F10	60%	700.71
F11	70%	735.18
F12	80%	785.85
F13	90%	853.04
F14	95%	896.94
F15	99%	993.00

4.1.3 CHANNEL FLOW PROFILES

A channel flow profile analysis has been previously developed at the study river reach, as documented in Section 2.3.1. Utilizing the methodology and results of the channel flow profile analysis, flow rates for all given steady-state flow scenarios were estimated for each of the cross-sections in the HEC-RAS model.

4.1.4 DOWNSTREAM BOUNDARY CONDITIONS

As described in Section 2.3.3, the downstream boundary conditions at USGS 02313100 Rainbow River at Dunnellon, Florida have been defined to run a steady-state flow analysis for the preliminary HEC-RAS model. The methodology used in developing the downstream boundary conditions was described in Section 2.3.2. For a given MFL scenario to be simulated in HEC-RAS, two independent variables - Flow in Rainbow River and Stage in Withlacoochee River, have to be defined prior to estimating a stage boundary condition at CR 484 Bridge using the multiple regression method (Figure 2-7).

Similar to the flow-duration analysis performed for the baseline flow data at USGS 02313100 at CR 484 Bridge, a stage-duration analysis was conducted for the stage data at USGS 02313200 at US 41 Bridge, for a period from 1/1/1965 through 12/31/2010 (Figure 4-3). The resultant stage-duration curve is plotted in Figure 4-4 and a total of 15 steady-state stage scenarios were formulated as listed in Table 4-3.

By applying the multiple regression curve (Figure 2-7), a matrix of downstream boundary conditions, including a total of 225 stage values, were estimated at USGS 02313100 at CR 484 Bridge, as summarized in Table 4-4.

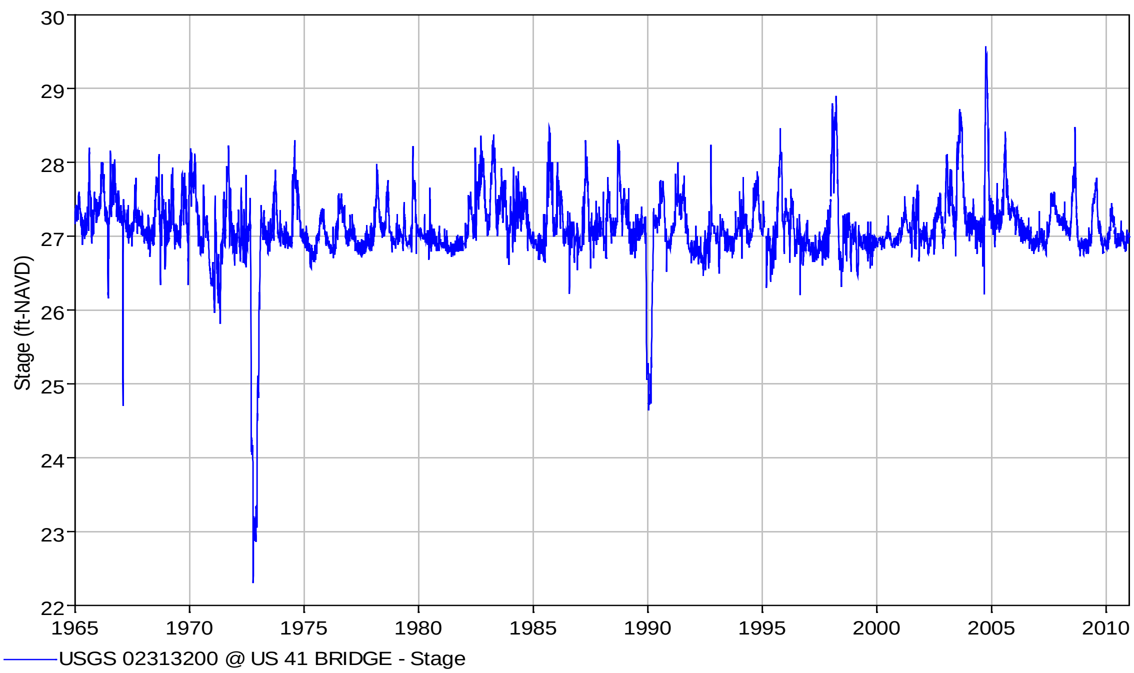

Figure 4-3. Historic Stage Data at USGS 02313200

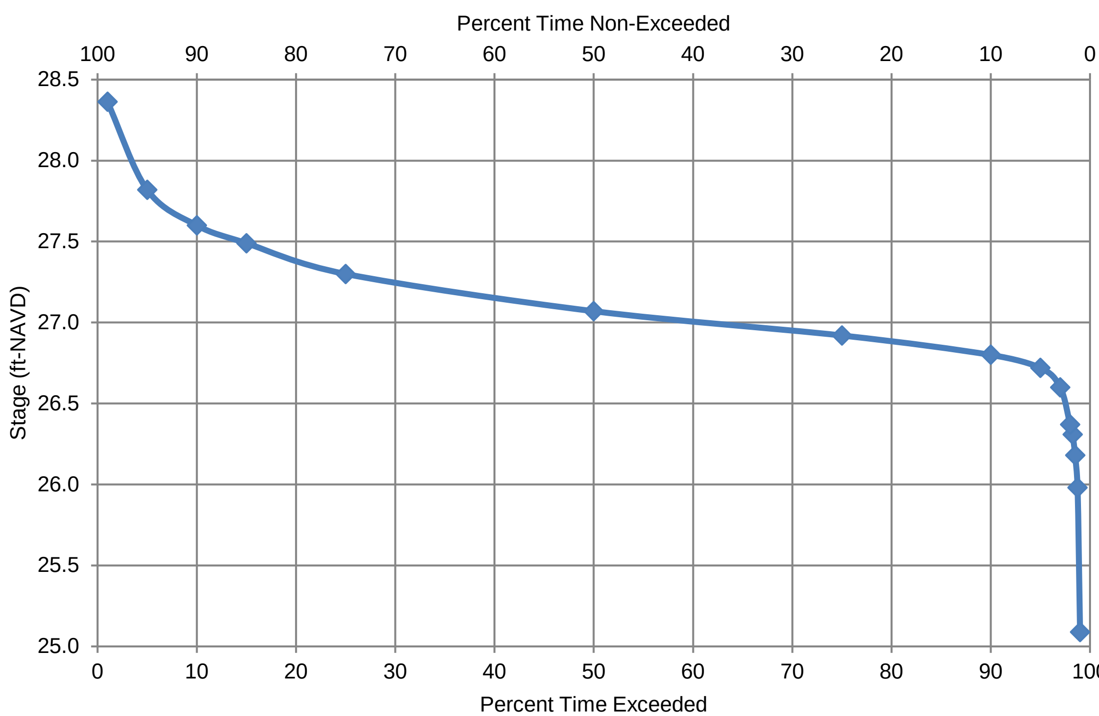

Figure 4-4. Stage-Duration Curve at USGS 02313200

Table 4–3. Summary of Selected Steady-State Stage Scenarios at USGS 02313200

Profile ID	Percent Time Indicated Stage is not Exceeded	Stage at USGS 02313200 (ft-NAVD)
S1	1%	25.09
S2	1.25%	25.98
S3	1.5%	26.18
S4	1.75%	26.31
S5	2%	26.37
S6	3%	26.60
S7	5%	26.72
S8	10%	26.80
S9	25%	26.92
S10	50%	27.07
S11	75%	27.30
S12	85%	27.49
S13	90%	27.60
S14	95%	27.82
S15	99%	28.36

Table 4–4. Summary of Downstream Boundary Conditions – Stages at USGS 02313100 Using Multiple Regression Curve

ID	Percent Time Indicated Flow is not Exceeded	Flow at USGS 02313100 (cfs)	Downstream Boundary Conditions – Stage at USGS 02313100 (ft-NAVD) With Selected Steady-State Stage Scenarios at USGS 02313200, Stage in ft-NAVD														
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**
			1%	**1.25%**	**1.5%**	**1.75%**	**2%**	**3%**	**5%**	**10%**	**25%**	**50%**	**75%**	**85%**	**90%**	**95%**	**99%**
			25.09	**25.98**	**26.18**	**26.31**	**26.37**	**26.60**	**26.72**	**26.80**	**26.92**	**27.07**	**27.30**	**27.49**	**27.60**	**27.82**	**28.36**
F1	**1%**	**507.41**	25.20	26.11	26.31	26.44	26.51	26.74	26.86	26.94	27.07	27.22	27.45	27.65	27.76	27.98	28.53
F2	**2%**	**522.81**	25.20	26.11	26.31	26.44	26.51	26.74	26.86	26.94	27.07	27.22	27.45	27.64	27.76	27.98	28.53
F3	**5%**	**547.79**	25.20	26.11	26.31	26.44	26.51	26.74	26.86	26.94	27.07	27.22	27.45	27.64	27.76	27.98	28.53
F4	**10%**	**567.61**	25.20	26.11	26.31	26.45	26.51	26.74	26.86	26.94	27.07	27.22	27.45	27.65	27.76	27.98	28.53
F5	**15%**	**581.18**	25.21	26.11	26.32	26.45	26.51	26.74	26.87	26.95	27.07	27.22	27.46	27.65	27.76	27.98	28.54
F6	**20%**	**594.54**	25.21	26.12	26.32	26.45	26.51	26.75	26.87	26.95	27.07	27.23	27.46	27.65	27.76	27.99	28.54
F7	**30%**	**622.84**	25.22	26.13	26.33	26.46	26.53	26.76	26.88	26.96	27.09	27.24	27.47	27.67	27.78	28.00	28.55
F8	**40%**	**646.74**	25.24	26.15	26.35	26.48	26.54	26.78	26.90	26.98	27.10	27.26	27.49	27.68	27.79	28.02	28.57
F9	**50%**	**674.90**	25.27	26.18	26.38	26.51	26.57	26.81	26.93	27.01	27.13	27.29	27.52	27.71	27.82	28.05	28.60
F10	**60%**	**700.71**	25.31	26.21	26.42	26.55	26.61	26.85	26.97	27.05	27.17	27.32	27.56	27.75	27.86	28.08	28.64
F11	**70%**	**735.18**	25.38	26.28	26.49	26.62	26.68	26.91	27.03	27.12	27.24	27.39	27.62	27.82	27.93	28.15	28.70
F12	**80%**	**785.85**	25.52	26.43	26.63	26.76	26.82	27.06	27.18	27.26	27.38	27.53	27.77	27.96	28.07	28.30	28.85
F13	**90%**	**853.04**	25.80	26.71	26.91	27.04	27.11	27.34	27.46	27.54	27.67	27.82	28.05	28.24	28.36	28.58	29.13
F14	**95%**	**896.94**	26.06	26.97	27.17	27.30	27.36	27.60	27.72	27.80	27.92	28.07	28.31	28.50	28.61	28.84	29.39
F15	**99%**	**993.00**	26.85	27.76	27.96	28.09	28.15	28.39	28.51	28.59	28.71	28.86	29.10	29.29	29.40	29.63	30.18

4.2 STEADY-STATE MODEL SIMULATION

4.2.1 MODEL SIMULATION

The channel flow profiles and downstream boundary conditions for the 225 steady-state scenarios were developed and stored in an Excel spreadsheet prior to being imported into the HEC-RAS model.

4.2.2 SIMULATION RESULTS

A good collection of post-processing tools are available in HEC-RAS to review model output data in both tabular and graphic views, including stage profile plot, cross-section plot, profile output table, x-y-z perspective plot, etc. Using these post-processing tools, the hydraulic characteristics of the cross-sections (e.g., water surface elevation, average depth, top surface width, wetted perimeter, and shear stress), could be reviewed in HEC-RAS. The model output data could also be exported to GIS files and/or customized reports. The followings are three commonly used post-processing tools for model output review:

Stage Profile Plot

The stage profile plot could be used to check the overall water elevation profile shape for a given steady-state scenario and be zoomed in to identify the type of flow profile (e.g., M1 profile), within a small river segment. An example stage profile plot is presented in Figure 4-5, illustrating a total of 15 steady-state flow scenarios (F1 through F15) in Rainbow River at a 50 percentile (P50) stage scenario (S10) in Withlacoochee River. For comparison purposes, Figure 4-6 illustrates the stage profile plot for a total of 15 steady-state stage scenarios (S1 through S15) in Withlacoochee River at a P50 flow scenario (F9) in Rainbow River.

Cross-Section Plot

The cross-section plot is another useful tool to check water depth and flow (velocity) distribution within the main channel or floodplain of a cross-section for a given scenario. A cross-section is allowed to be divided into up to 45 subsections and the output data of each subsection can be presented in both tabular and graphic formats in HEC-RAS.

A sample cross-section plot is presented in Figure 4-7, at one of the SWFWMD river site Veg 1 or RS 1.36. The main channel at this cross-section was evenly subdivided into 43 subsections and the flow distribution in the main channel is symbolized in graduated colors based on the flow velocity magnitude calculated in each subsection.

Profile Output Table

An example profile output table is presented in Figure 4-8, showing one of the standard tables for model output data review. The model output data summarized in the profile output tables, including water surface elevation and total flow, could be exported to an Excel spreadsheet for additional data processing, analysis, and presentation.

Figures 4-9 and 4-10 illustrate the stage-flow rating curves developed at the SWFWMD river sites Veg 1 and PHAB 1, respectively, based on the model output data of the 225 steady-state scenarios. Similar stage-flow rating curves could be developed for other cross-sections in the HEC-RAS model, and be used to assess which is the predominant variable in determining the water surface elevations at a specific cross-section or river site, between the flow in Rainbow River and the stage in Withlacoochee River.

For example at the river site Veg 1 at RS 1.36 (Figure 3-1), review of the resultant stage-flow rating curves in Figure 4-9 suggests the stage in Withlacoochee River is the major factor controlling the water surface elevations at this site.

The stage-flow rating curves for the river site PHAB 1 at RS 4.96 (Figure 3-1), as plotted in Figure 4-10, indicate much less backwater effects at this location compared to the downstream river site Veg 1 at RS 1.36. The flow from Rainbow River appears to be the predominant factor controlling the surface water elevations at this location.

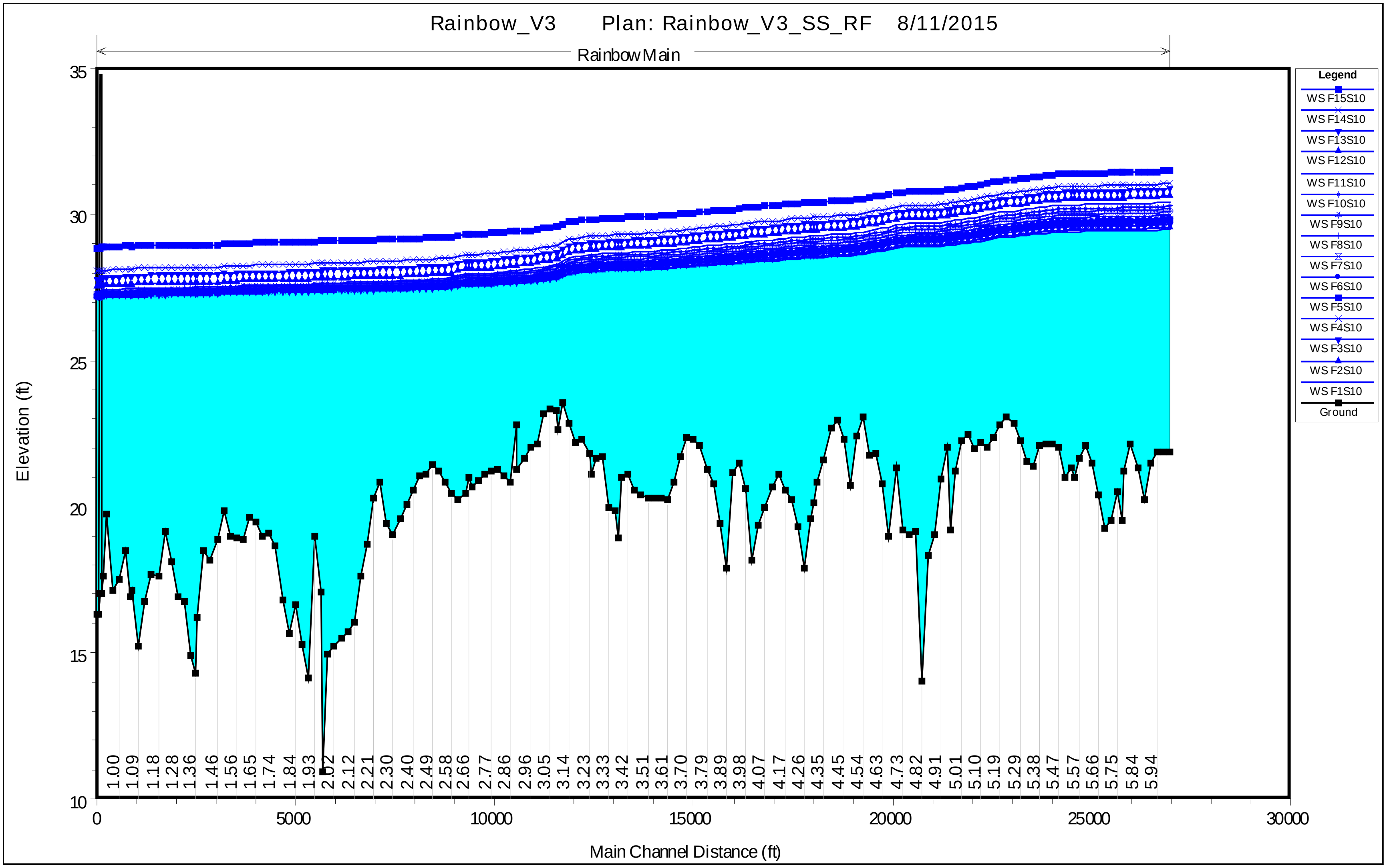

Figure 4-5. Stage Profile Plot of 15 Flow Scenarios in Rainbow River with P50 Stage Scenario (S10) in Withlacoochee River

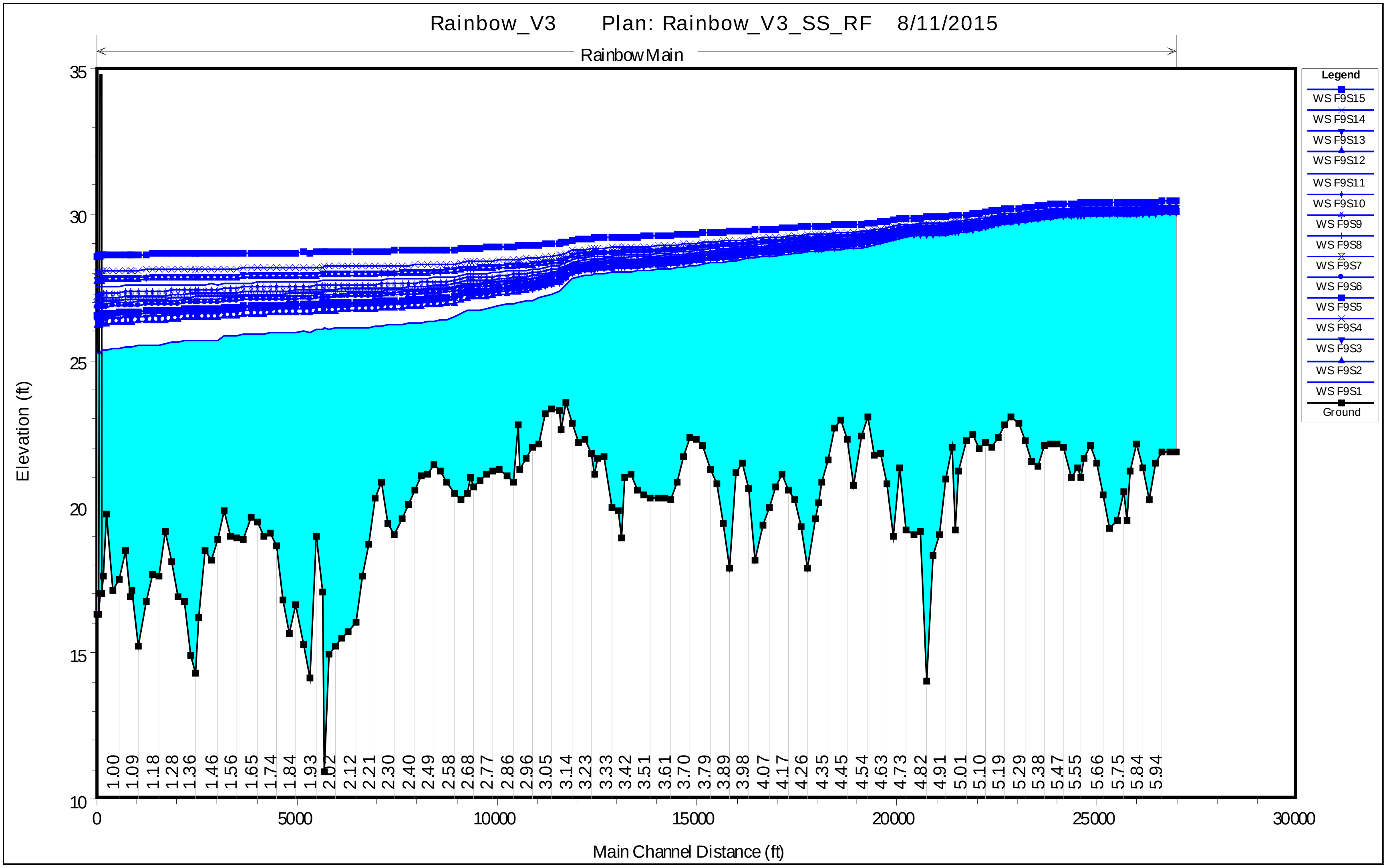

Figure 4-6. Stage Profile Plot of 15 Stage Scenarios in Withlacoochee River with P50 Flow Scenario (F9) in Rainbow River

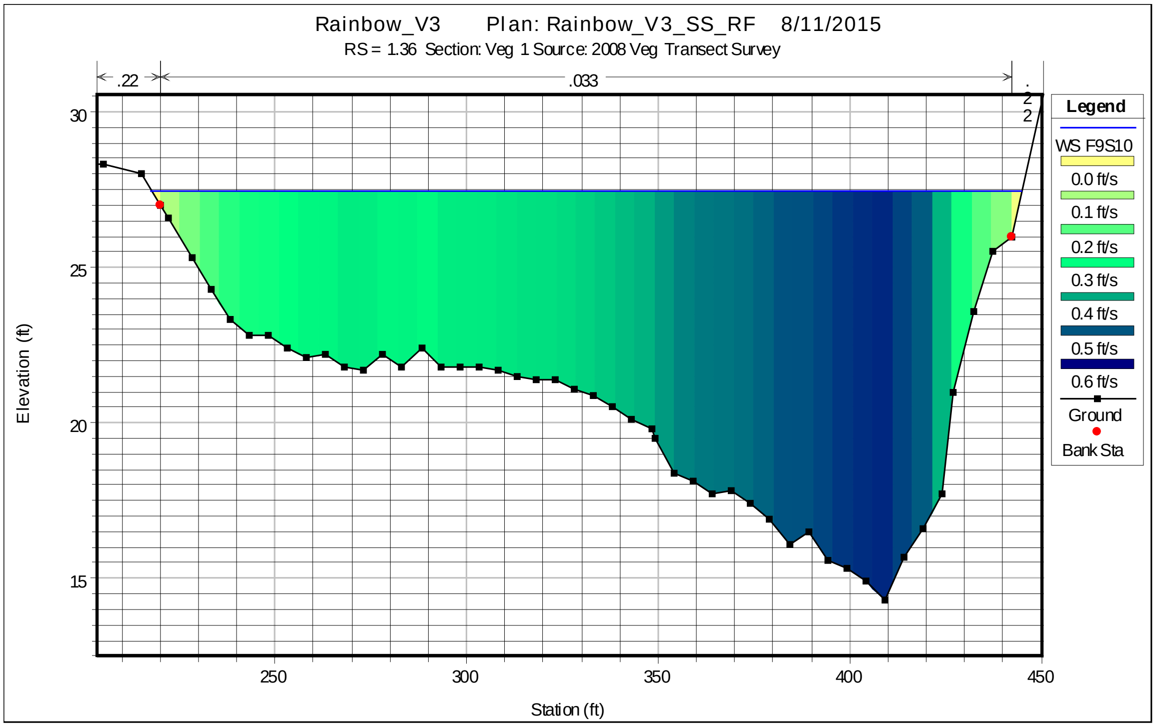

Figure 4-7. Cross-Section Plot at Veg 1 (RS 1.36) for P50 Flow Scenario (F9) in Rainbow River and P50 Stage Scenario (S10) in Withlacoochee River

Profile Output Table - Standard Table 1

File Options Std. Tables Locations Help

HEC-RAS Plan: V3_SS_RF River: Rainbow Reach: Main — Reload Data

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	6.00 31679.9	F1S1	158.31	21.88	29.27		29.27	0.000083	0.34	471.86	107.15	0.03
Main	6.00 31679.9	F2S1	163.12	21.88	29.35		29.35	0.000080	0.34	480.26	110.48	0.03
Main	6.00 31679.9	F3S1	170.91	21.88	29.47		29.48	0.000079	0.35	494.42	117.32	0.03
Main	6.00 31679.9	F4S1	177.09	21.88	29.57		29.57	0.000080	0.36	506.30	132.43	0.03
Main	6.00 31679.9	F5S1	181.33	21.88	29.63		29.64	0.000081	0.36	514.96	137.98	0.03
Main	6.00 31679.9	F6S1	185.50	21.88	29.70		29.70	0.000081	0.37	523.68	142.86	0.03
Main	6.00 31679.9	F7S1	194.33	21.88	29.82		29.83	0.000083	0.37	542.80	159.68	0.03
Main	6.00 31679.9	F8S1	201.78	21.88	29.93		29.93	0.000084	0.38	559.82	169.45	0.03
Main	6.00 31679.9	F9S1	210.57	21.88	30.05		30.05	0.000085	0.39	581.88	206.66	0.03
Main	6.00 31679.9	F10S1	218.62	21.88	30.15		30.15	0.000086	0.40	604.63	222.36	0.03
Main	6.00 31679.9	F11S1	229.38	21.88	30.29		30.29	0.000087	0.40	636.22	237.00	0.03
Main	6.00 31679.9	F12S1	245.18	21.88	30.49		30.49	0.000089	0.42	685.68	261.60	0.03
Main	6.00 31679.9	F13S1	266.15	21.88	30.74		30.74	0.000090	0.43	752.58	271.28	0.03
Main	6.00 31679.9	F14S1	279.85	21.88	30.90		30.90	0.000090	0.44	797.04	282.12	0.03
Main	6.00 31679.9	F15S1	309.82	21.88	31.25		31.25	0.000091	0.45	904.02	324.31	0.03
Main	6.00 31679.9	F1S2	158.31	21.88	29.32		29.33	0.000081	0.33	477.45	109.28	0.03
Main	6.00 31679.9	F2S2	163.12	21.88	29.40		29.40	0.000078	0.34	485.99	112.97	0.03
Main	6.00 31679.9	F3S2	170.91	21.88	29.52		29.52	0.000077	0.35	500.22	125.34	0.03
Main	6.00 31679.9	F4S2	177.09	21.88	29.62		29.62	0.000078	0.35	512.50	136.60	0.03
Main	6.00 31679.9	F5S2	181.33	21.88	29.68		29.68	0.000079	0.36	521.30	141.64	0.03
Main	6.00 31679.9	F6S2	185.50	21.88	29.74		29.74	0.000079	0.36	530.17	146.54	0.03
Main	6.00 31679.9	F7S2	194.33	21.88	29.87		29.87	0.000081	0.37	549.37	164.77	0.03

Figure 4-8. Profile Output Table for Steady-State HEC-RAS Model Output Review

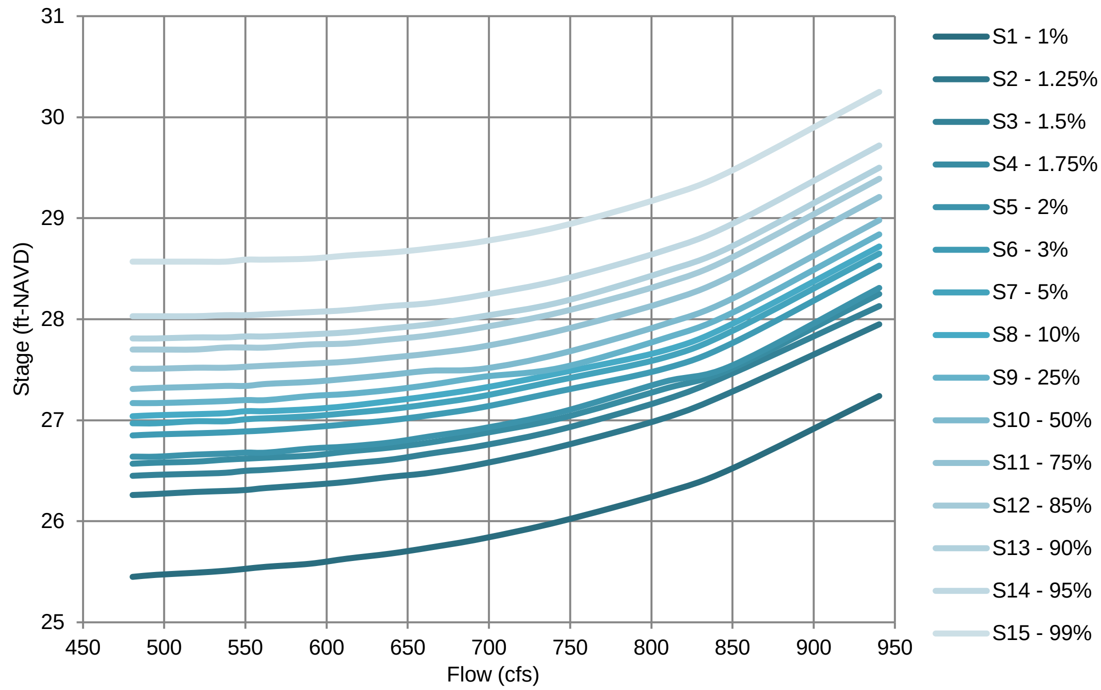

Figure 4-9. Stage-Flow Rating Curves at Veg 1 (RS 1.36)

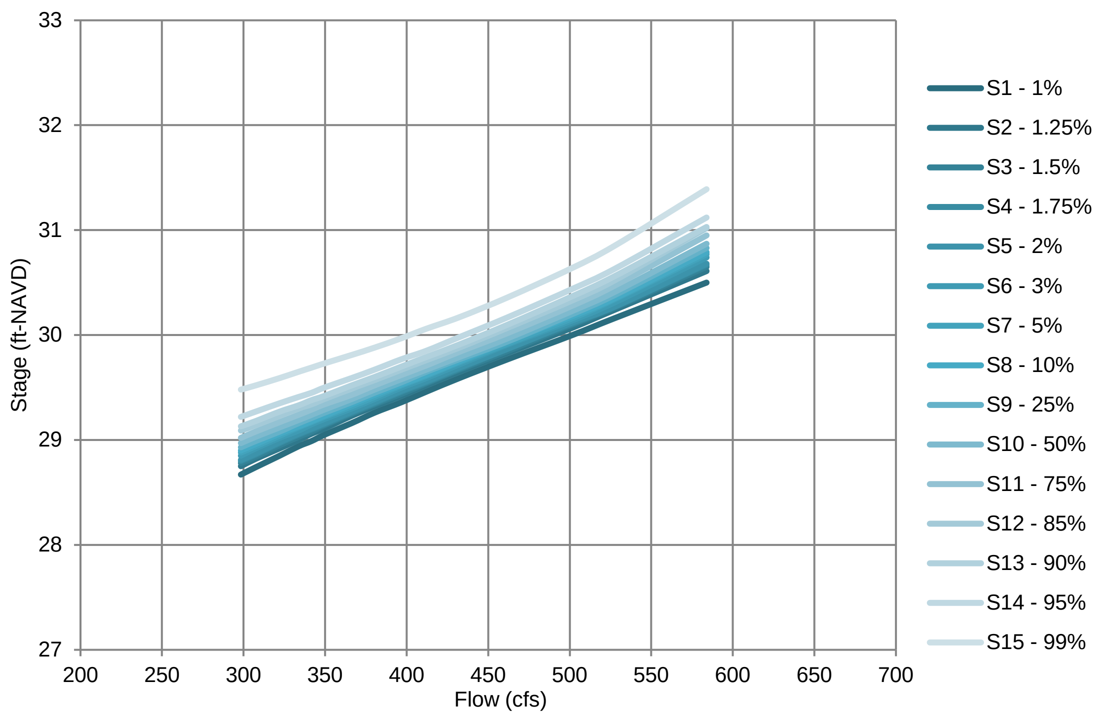

Figure 4-10. Stage-Flow Rating Curves at PHAB 1 (RS 4.96)

4.3 STEADY-STATE MODEL VERIFICATION

4.3.1 MODEL VERIFICATION TARGETS

To further verify the calibrated HEC-RAS model, a new target stage-flow rating curve at the spring head (RS 6.00) was generated by using the multiple regression analysis. Similar to the multiple regression analysis performed at the downstream boundary, two independent variables were used: X_1 - Flow at USGS 02313100 Rainbow River at CR 484 Bridge; and X_2 - Stage at USGS 02313200 Withlacoochee River at Dunnellon, Florida at US 41 Bridge, and the dependent variable is Y – Stage at the spring head. The dataset used in the regression analysis consists of a total of 581 stage data collected by FDEP staff at the spring head from 10/28/2005 to 1/25/2013, in conjunction with the flow and stage data provided at the two USGS gages at the same date.

The resultant multiple regression curve is plotted in Figure 4-11, with a R^2 value of 0.8143. A total of 225 target stage values at the spring head were calculated, as summarized in Table 4-6.

For comparison purposes, a simple linear regression analysis was performed by using the flow at CR 484 Bridge as the independent variable, and the resultant simple linear regression curve is plotted in Figure 4-12, with a R^2 value of 0.8074. Using the simple linear regression curve, another set of 15 target stage values at the spring head were estimated for the given 15 flow scenarios defined at USGS 02313100 at CR 484 Bridge, as summarized in Table 4-5.

4.3.2 MODEL VERIFICATION RESULTS

The simulated stage values at the spring head are listed in Table 4-7. The stage residuals between the simulated stage values and the verification targets ranges from -0.07 to 0.30 foot, as shown in Figure 4-13.

One can still assume that the stage in Withlacoochee River will have no impact to the stage at the spring head, as the backwater effects might be gradually damped and totally dissipated along the 6-mile river reach. To test this assumption, the target stage values estimated by the simple linear stage-flow rating curve (Table 4-5 and Figure 4-12) were used to substitute the verification targets listed in Table 4-6. As presented in Figure 4-14, the stage residuals range from -0.30 to 0.41 foot, which almost doubles the range when using the multiple regression curve (Figure 4-13). Obviously, the simple linear regression curve based on the assumption of zero backwater effects is not as successful as the multiple regression curve in terms of model verification results. Therefore, the stage at the spring head appears to be influenced by the stage in Withlacoochee River, to a certain extent, while significant influence of backwater effect was observed in the lower portion of the River.

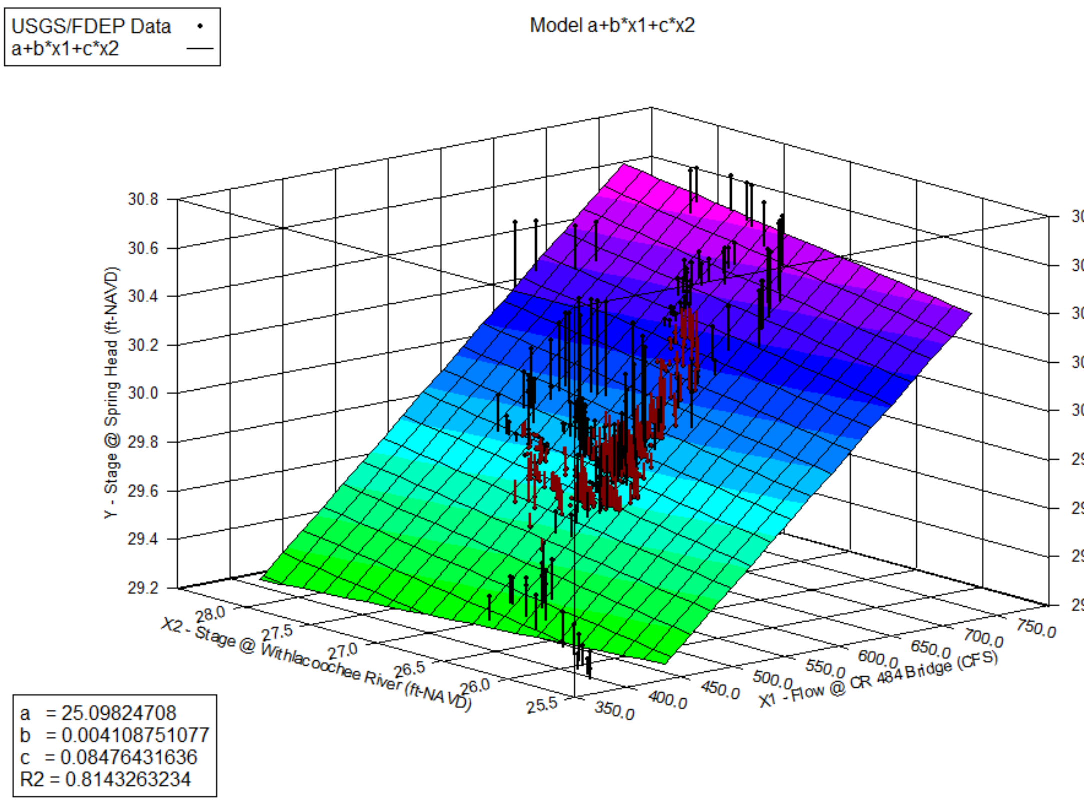

Figure 4-11. Multiple Regression Curve at Spring Head (RS 6.00)

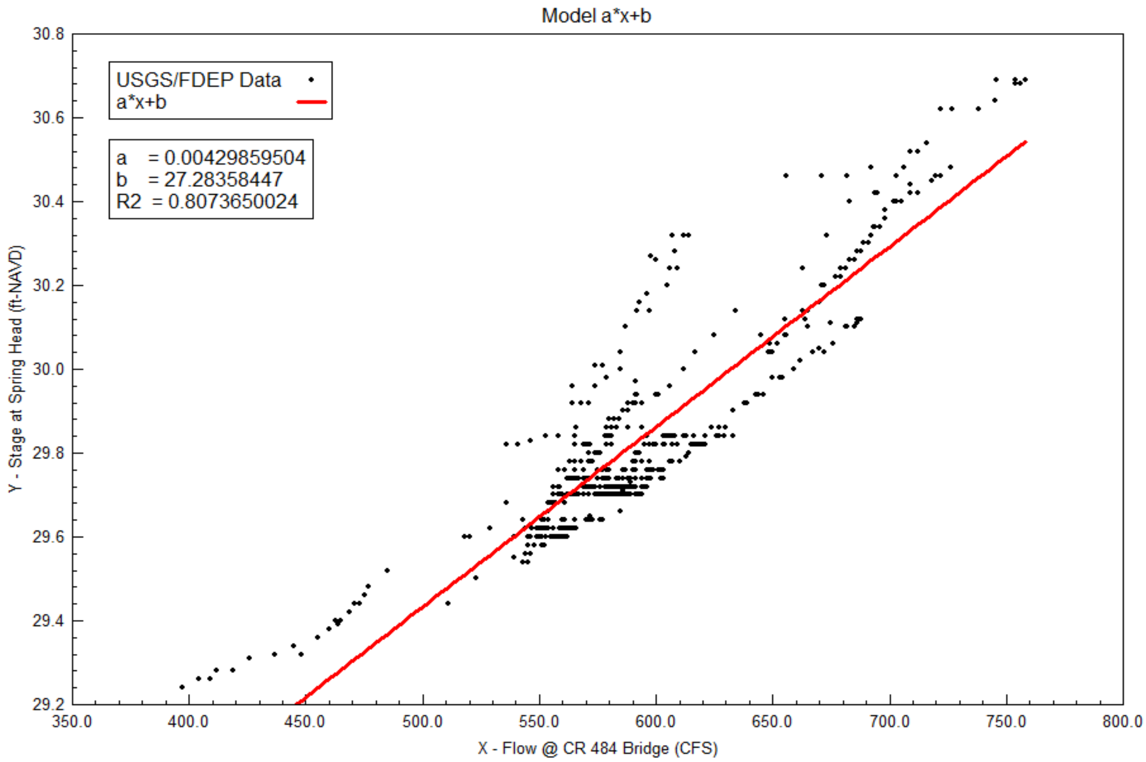

Figure 4-12. Simple Linear Regression Curve at Spring Head (RS 6.00)

Table 4–5. Summary of Model Verification Targets - Simple Linear Regression Curve

ID	Percent Time Indicated Flow is not Exceeded	Baseline Flow at USGS 02313100 (cfs)	Model Verification Targets Stage at Spring Head (ft-NAVD)
F1	1%	507.41	29.46
F2	2%	522.81	29.53
F3	5%	547.79	29.64
F4	10%	567.61	29.72
F5	15%	581.18	29.78
F6	20%	594.54	29.84
F7	30%	622.84	29.96
F8	40%	646.74	30.06
F9	50%	674.90	30.18
F10	60%	700.71	30.30
F11	70%	735.18	30.44
F12	80%	785.85	30.66
F13	90%	853.04	30.95
F14	95%	896.94	31.14
F15	99%	993.00	31.55

4.4 SUMMARY OF MFL SCENARIO SIMULATIONS

In summary, a steady-state HEC-RAS model of Rainbow River was developed on the basis of the dynamic HEC-RAS model previously developed and calibrated in Section 3. Steady-state flow analysis was conducted for each of the 225 steady-state or MFL scenarios that represent the combinations of the 15 flow scenarios in Rainbow River and the 15 stage scenarios in Withlacoochee River.

Review of the model simulation and verification results suggests that the MFL Scenario Simulations task is successfully accomplished and the steady-state HEC-RAS model could be utilized in the subsequent ecological analysis and ultimately MFLs establishment in Rainbow River by the District.

Table 4–6. Summary of Model Verification Targets - Multiple Regression Curve

ID	Percent Time Indicated Flow is not Exceeded	Baseline Flow at USGS 02313100 (cfs)	Model Verification Targets - Stage at Spring Head (ft-NAVD) With Selected Steady-State Stage Scenarios at USGS 02313200, Stage in ft-NAVD														
			S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
			1%	1.25%	1.5%	1.75%	2%	3%	5%	10%	25%	50%	75%	85%	90%	95%	99%
			25.09	25.98	26.18	26.31	26.37	26.60	26.72	26.80	26.92	27.07	27.30	27.49	27.60	27.82	28.36
F1	**1%**	**507.41**	29.31	29.39	29.40	29.41	29.42	29.44	29.45	29.45	29.46	29.48	29.50	29.51	29.52	29.54	29.59
F2	**2%**	**522.81**	29.37	29.45	29.47	29.48	29.48	29.50	29.51	29.52	29.53	29.54	29.56	29.58	29.59	29.60	29.65
F3	**5%**	**547.79**	29.48	29.55	29.57	29.58	29.58	29.60	29.61	29.62	29.63	29.64	29.66	29.68	29.69	29.71	29.75
F4	**10%**	**567.61**	29.56	29.63	29.65	29.66	29.67	29.69	29.70	29.70	29.71	29.72	29.74	29.76	29.77	29.79	29.83
F5	**15%**	**581.18**	29.61	29.69	29.71	29.72	29.72	29.74	29.75	29.76	29.77	29.78	29.80	29.82	29.83	29.84	29.89
F6	**20%**	**594.54**	29.67	29.74	29.76	29.77	29.78	29.80	29.81	29.81	29.82	29.84	29.86	29.87	29.88	29.90	29.95
F7	**30%**	**622.84**	29.78	29.86	29.88	29.89	29.89	29.91	29.92	29.93	29.94	29.95	29.97	29.99	30.00	30.02	30.06
F8	**40%**	**646.74**	29.88	29.96	29.97	29.99	29.99	30.01	30.02	30.03	30.04	30.05	30.07	30.09	30.10	30.11	30.16
F9	**50%**	**674.90**	30.00	30.07	30.09	30.10	30.11	30.13	30.14	30.14	30.15	30.17	30.19	30.20	30.21	30.23	30.28
F10	**60%**	**700.71**	30.10	30.18	30.20	30.21	30.21	30.23	30.24	30.25	30.26	30.27	30.29	30.31	30.32	30.34	30.38
F11	**70%**	**735.18**	30.25	30.32	30.34	30.35	30.35	30.37	30.38	30.39	30.40	30.41	30.43	30.45	30.46	30.48	30.52
F12	**80%**	**785.85**	30.45	30.53	30.55	30.56	30.56	30.58	30.59	30.60	30.61	30.62	30.64	30.66	30.67	30.69	30.73
F13	**90%**	**853.04**	30.73	30.81	30.82	30.83	30.84	30.86	30.87	30.87	30.89	30.90	30.92	30.93	30.94	30.96	31.01
F14	**95%**	**896.94**	30.91	30.99	31.00	31.01	31.02	31.04	31.05	31.06	31.07	31.08	31.10	31.11	31.12	31.14	31.19
F15	**99%**	**993.00**	31.30	31.38	31.40	31.41	31.41	31.43	31.44	31.45	31.46	31.47	31.49	31.51	31.52	31.54	31.58

Table 4–7. Summary of Model Simulation Results – Stage at Spring Head (RS 6.00)

ID	Percent Time Indicated Flow is not Exceeded	Baseline Flow at USGS 02313100 (cfs)	Model Simulation Results - Stage at Spring Head (ft-NAVD) With Selected Steady-State Stage Scenarios at USGS 02313200, Stage in ft-NAVD														
			S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
			1%	1.25%	1.5%	1.75%	2%	3%	5%	10%	25%	50%	75%	85%	90%	95%	99%
			25.09	25.98	26.18	26.31	26.37	26.60	26.72	26.80	26.92	27.07	27.30	27.49	27.60	27.82	28.36
F1	1%	507.41	29.27	29.32	29.34	29.36	29.37	29.4	29.42	29.43	29.45	29.48	29.53	29.57	29.6	29.67	29.87
F2	2%	522.81	29.35	29.4	29.42	29.43	29.44	29.47	29.49	29.5	29.52	29.55	29.59	29.64	29.67	29.73	29.93
F3	5%	547.79	29.47	29.52	29.54	29.55	29.56	29.59	29.61	29.62	29.64	29.66	29.7	29.74	29.77	29.83	30.02
F4	10%	567.61	29.57	29.62	29.63	29.65	29.65	29.68	29.69	29.71	29.72	29.75	29.78	29.82	29.85	29.91	30.09
F5	15%	581.18	29.63	29.68	29.7	29.71	29.71	29.74	29.76	29.77	29.78	29.81	29.84	29.88	29.9	29.96	30.14
F6	20%	594.54	29.7	29.74	29.76	29.77	29.77	29.8	29.81	29.82	29.84	29.86	29.89	29.93	29.96	30.01	30.18
F7	30%	622.84	29.82	29.87	29.88	29.89	29.9	29.92	29.93	29.94	29.96	29.98	30.01	30.05	30.07	30.12	30.28
F8	40%	646.74	29.93	29.97	29.98	29.99	30	30.02	30.03	30.04	30.06	30.08	30.11	30.14	30.16	30.21	30.37
F9	50%	674.90	30.05	30.08	30.1	30.11	30.11	30.13	30.15	30.16	30.17	30.19	30.22	30.25	30.27	30.32	30.47
F10	60%	700.71	30.15	30.19	30.2	30.21	30.22	30.24	30.25	30.26	30.27	30.29	30.32	30.35	30.37	30.42	30.57
F11	70%	735.18	30.29	30.33	30.34	30.35	30.36	30.38	30.39	30.4	30.41	30.42	30.46	30.49	30.51	30.56	30.7
F12	80%	785.85	30.49	30.53	30.54	30.55	30.55	30.58	30.59	30.6	30.6	30.62	30.66	30.69	30.71	30.76	30.9
F13	90%	853.04	30.74	30.78	30.8	30.81	30.81	30.83	30.84	30.85	30.87	30.89	30.92	30.96	30.98	31.03	31.18
F14	95%	896.94	30.9	30.95	30.96	30.97	30.97	31	31.02	31.03	31.04	31.07	31.11	31.15	31.17	31.22	31.38
F15	99%	993.00	31.25	31.32	31.34	31.36	31.37	31.41	31.43	31.44	31.47	31.5	31.56	31.61	31.61	31.67	31.88

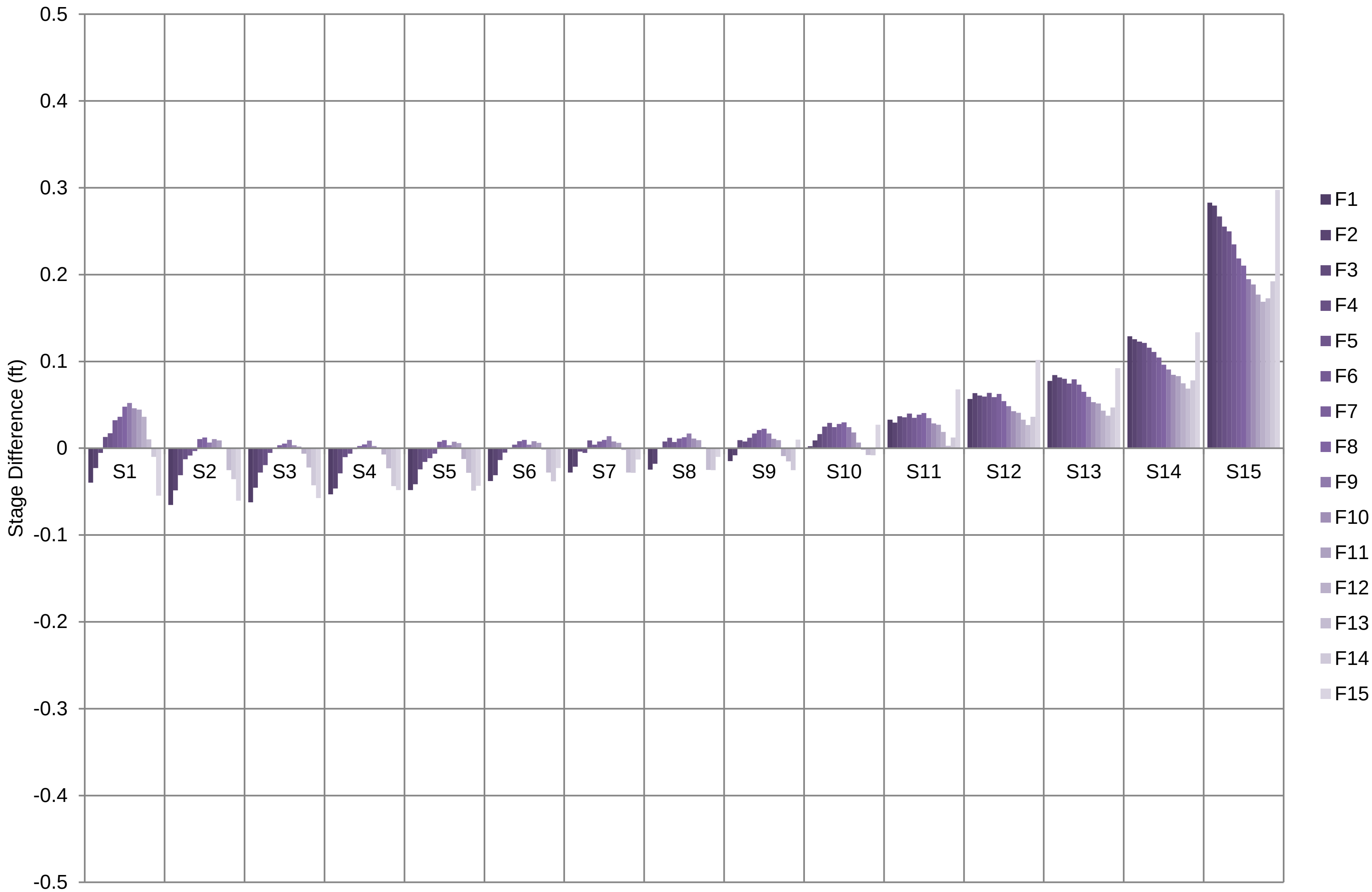

Figure 4-13. Stage Residuals at Spring Head (RS 6.00) Using Multiple Regression Curve

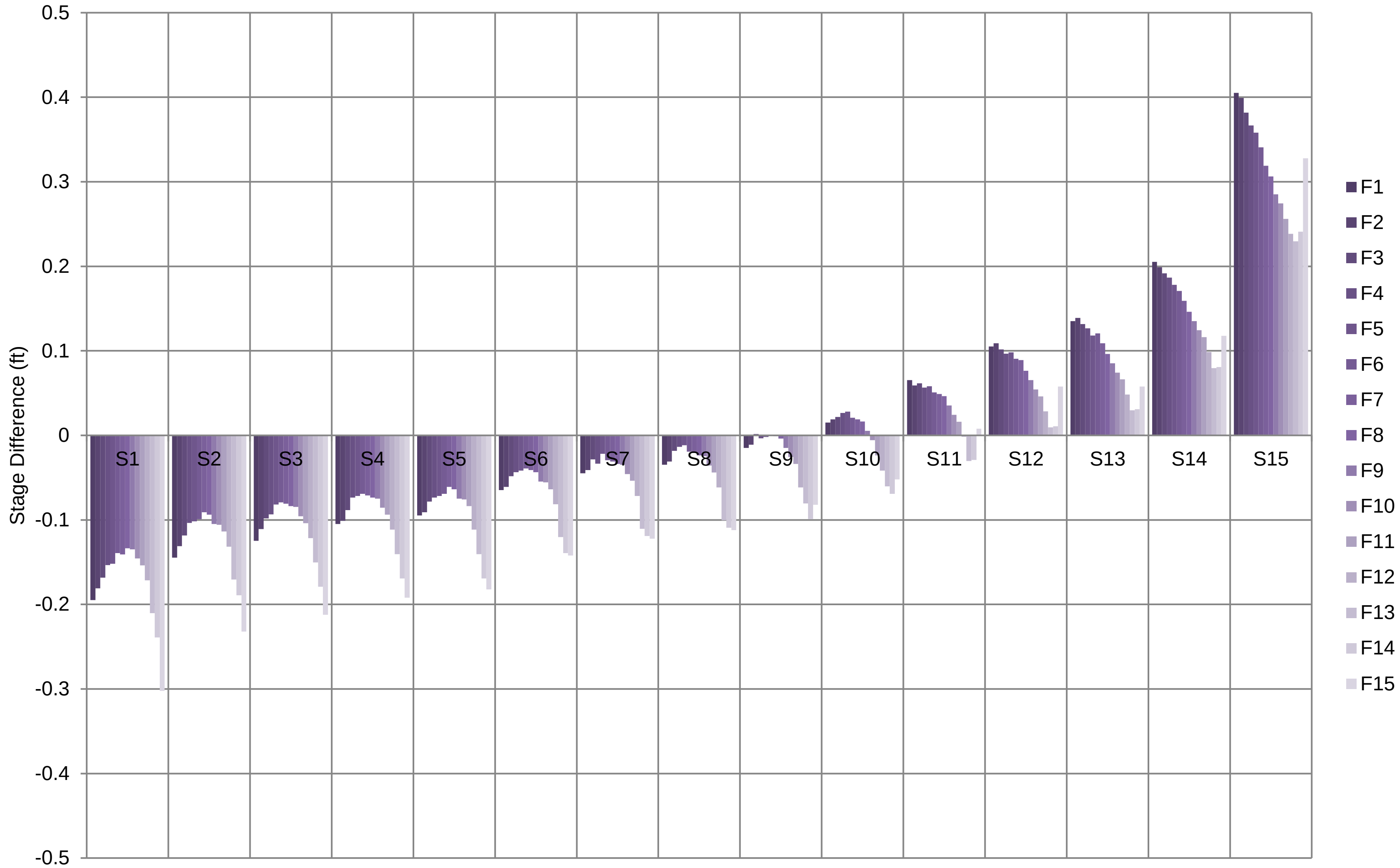

Figure 4-14. Stage Residuals at Spring Head (RS 6.00) Using Simple Linear Regression Curve

5. CONCLUSIONS AND RECOMMENDATIONS

HEC-RAS 4.1.0, HEC-GeoRAS 4.2.92, ArcGIS 9.2, and other software were selected in developing the Rainbow River HEC-RAS model. A total of 179 cross-sections and one bridge were modeled along the 5.1-river-mile study area.

A long-term dynamic HEC-RAS model was developed and used in dynamic flow analysis for a time period of 10 years from 3/11/2005 to 3/17/2015. The long-term and short-term stage data collected at various river sites was employed in the model calibration and verification. Detailed model calibrations were performed and the model calibration results indicated that over 97% of the stage residuals between the simulated water elevations and the calibration targets fall within ±0.25 foot.

A steady-state HEC-RAS model was developed and used in simulation of a total of 225 MFL scenarios that represent the combinations of the 15 flow scenarios in Rainbow River and the 15 stage scenarios in Withlacoochee River, as recommended by the District. The baseline flow data provided by the District was used in defining the 15 flow scenarios in Rainbow River. Model verification was conducted to match the verification targets, which were generated by multiple regression analysis at the spring head. The residuals between the simulated stage values and the verification targets ranges from -0.07 to 0.30 foot.

In summary, the HEC-RAS model has been well calibrated/verified in long-term dynamic flow analysis and further verified in steady-state flow analysis. Upon successful simulation of a series of steady-state MFL scenarios, the HEC-RAS model can be used for the subsequent ecologic analysis and ultimately the MFLs establishment in Rainbow River by the District.

The precision and accuracy in this current HEC-RAS modeling effort, as summarized above, is controlled by:

1. Limited flow measurements at various springs and other river sites (vegetation transects by SWFWMD/SJRWMD) were employed in development of the channel flow profiles;
2. Short-term stage measurements at various river sites were not well verified by professional surveyor;
3. Limited bathymetric survey data in the vicinity of the rocky shoal near RS 3.10;
4. It was very challenging to model the excessive vegetation overgrowth conditions observed in the river bed, most likely due to the prolonged low flow conditions (e.g., WYs 2011 & 2012). Manning's n values used were not adjusted to reflect the vegetation conditions in the river bed due to deficits in vegetation survey data;
5. The excessive vegetation overgrowth will increase water levels in the River, which may result in reduction of the groundwater discharge to the River (damming effect). The potential groundwater inflow reduction was not considered in the HEC-RAS modeling;
6. In the dynamic flow analysis, gravity wave propagation along the river reach was not considered, i.e., time-variant percentage values were not used in the development of the flow boundary conditions in the HEC-RAS model; and
7. Simple linear regression curves developed by USGS were used to estimate the flow in Rainbow River at CR 484 Bridge, based on the well levels measured at a nearby groundwater site. The uncertainty of flow measurements and regression curve development may lead to unfavorable model calibration results at some time periods.

Thus, the precision and accuracy could be improved significantly by recalibrating the HEC-RAS model when the following additional data becomes available.

1. Bathymetric survey data in the vicinity of the rocky shoal near RS 3.10;
2. Continuous stage data at five river sites (Veg 1, PHAB 2, SJR T3, Veg 7, and the spring head) for at least five years;
3. Monthly flow measurement at the existing river sites listed in Table 2-2, for at least five years;
4. Annual vegetation survey data for at least five years; and

5. Continuous groundwater level data for at least five years, at a new permanent groundwater well station to be installed just upstream or north of the spring head.

Nevertheless, a two-dimensional (2-D) model, such as HEC-RAS 5.0 (it has not been officially released by U.S. Army Corps of Engineers [USACE] at the time of writing this report), could be considered by the District in future modeling updates. The 2-D model could be used to predict water levels across a given cross-section and flow exchange between the main channel and floodplain areas, in order to refine the MFLs establishment in Rainbow River.

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APPENDIX A

REFERENCES ON HYDRAULIC PARAMETERS

Table 3-1 Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. **Main Channels**			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy. deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150
2. **Flood Plains**			
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200
3. **Mountain Streams, no vegetation in channel, banks usually steep, with trees and brush on banks submerged**			
a. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070

Table 3-1 (Continued) Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
B. *Lined or Built-Up Channels*			
1. **Concrete**			
a. Trowel finish	0.011	0.013	0.015
b. Float Finish	0.013	0.015	0.016
c. Finished, with gravel bottom	0.015	0.017	0.020
d. Unfinished	0.014	0.017	0.020
e. Gunite, good section	0.016	0.019	0.023
f. Gunite, wavy section	0.018	0.022	0.025
g. On good excavated rock	0.017	0.020	
h. On irregular excavated rock	0.022	0.027	
2. **Concrete bottom float finished with sides of:**			
a. Dressed stone in mortar	0.015	0.017	0.020
b. Random stone in mortar	0.017	0.020	0.024
c. Cement rubble masonry, plastered	0.016	0.020	0.024
d. Cement rubble masonry	0.020	0.025	0.030
e. Dry rubble on riprap	0.020	0.030	0.035
3. **Gravel bottom with sides of:**			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036
4. **Brick**			
a. Glazed	0.011	0.013	0.015
b. In cement mortar	0.012	0.015	0.018
5. **Metal**			
a. Smooth steel surfaces	0.011	0.012	0.014
b. Corrugated metal	0.021	0.025	0.030
6. **Asphalt**			
a. Smooth	0.013	0.013	
b. Rough	0.016	0.016	
7. **Vegetal lining**	0.030		0.500

Table 3-1 (Continued) Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
C. *Excavated or Dredged Channels*			
1. **Earth, straight and uniform**			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
2. **Earth, winding and sluggish**			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble side	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
3. **Dragline-excavated or dredged**			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
4. **Rock cuts**			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
5. **Channels not maintained, weeds and brush**			
a. Clean bottom, brush on sides	0.040	0.050	0.080
b. Same as above, highest stage of flow	0.045	0.070	0.110
c. Dense weeds, high as flow depth	0.050	0.080	0.120
d. Dense brush, high stage	0.080	0.100	0.140

Table 3-3

Subcritical Flow Contraction and Expansion Coefficients

	Contraction	Expansion
No transition loss computed	0.0	0.0
Gradual transitions	0.1	0.3
Typical Bridge sections	0.3	0.5
Abrupt transitions	0.6	0.8

Data Source: USACE (Brunner, G. W., 2010)

APPENDIX B

HEC-RAS MODEL INPUT & OUTPUT DATA

(Located on CD)