DRAFT REPORT

WEKIVA RIVER HYDROLOGY AND HYDRAULIC MODELING FOR MINIMUM FLOW AND LEVEL EVALUATIONS

by

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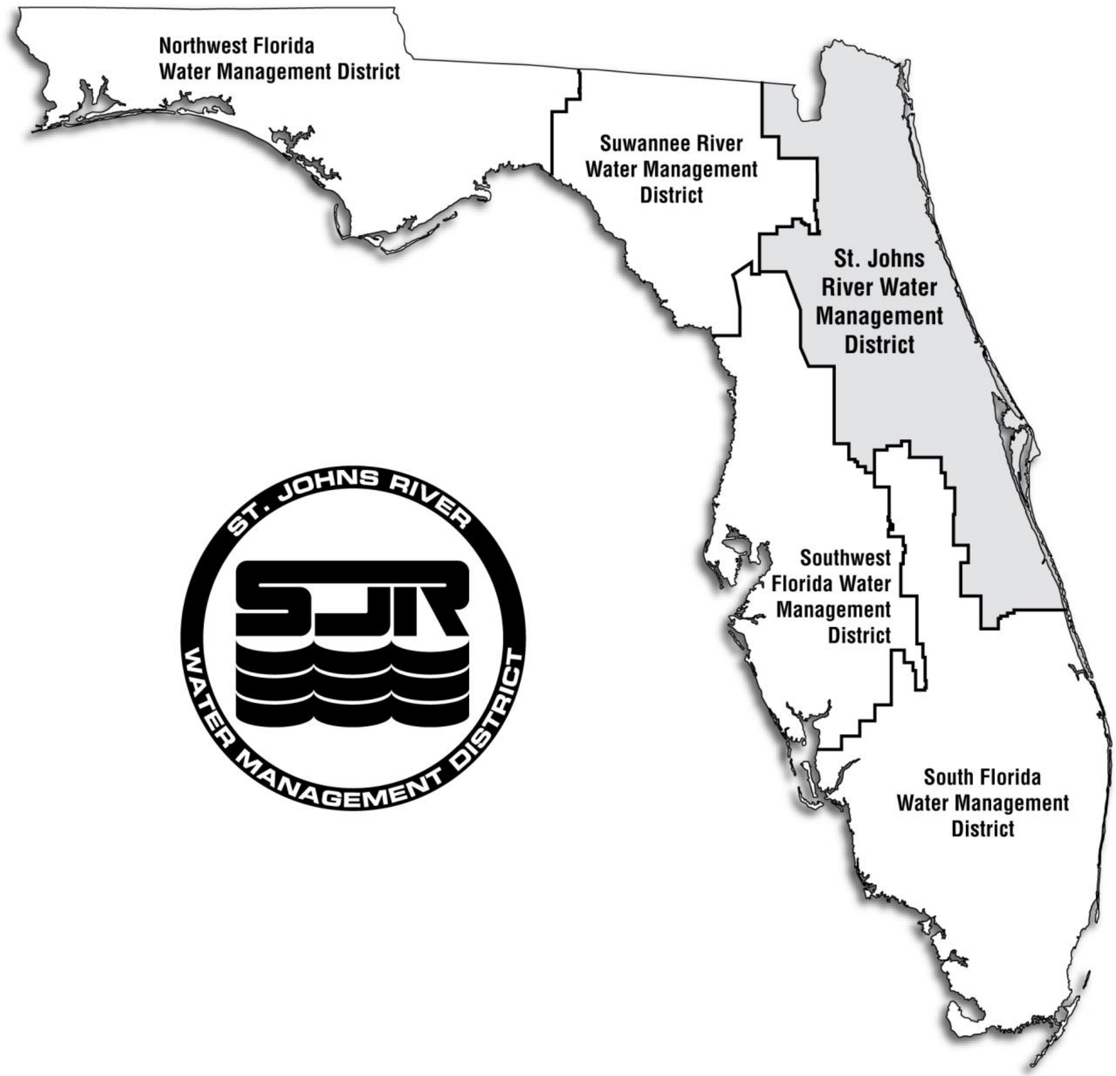
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1. INTRODUCTION

The Wekiva River watershed is a part of the Middle St. Johns River Basin, and is located in Lake, Seminole, Orange, and Marion counties (Figure 1). The Wekiva River watershed drains an area of approximately 376 square miles to the St. Johns River, and is comprised of four principal watercourses: the Wekiva River, the Little Wekiva River, Black Water Creek and Rock Springs Run. Many named springs (>30) exist in the watershed, including Wekiva Springs, Rock Springs, Seminole Springs, Sanlando Springs, and Messant Spring. Discharges from the springs contribute to a significant portion of flow in the Wekiva River.

The St. Johns River Water Management District (SJRWMD) is mandated by statute to establish minimum surface water flows and levels (MFLs) for priority water bodies (Section 373.042, *Florida Statutes* (F.S.). Four water bodies within the Wekiva River system (Wekiva River at SR 46, Little Wekiva River, Wekiwa Springs and Rock Springs) are on the SJRWMD's MFLs priority list. MFLs for the Wekiva River at SR 46 were adopted in 1992, and it is currently under reevaluation. All four systems are scheduled for adoption by 2019. The goal of the reevaluation (Wekiva River at SR 46) and determination (other systems) is to ensure that adopted MFLs are based on the most up-to-date criteria, hydrological data and models available.

The objective of this work is to develop hydrologic and hydraulic models to support the reevaluation and determination of the MFLs in the Wekiva River Watershed. The previous Hydrological Simulation Program – FORTRAN (HSPF) model that was developed to simulate the hydrology of the Wekiva River Watershed was updated. The HSPF model uses the land use, rainfall, evaporation, spring flows, and stream flow data in the watershed to perform long-term flow simulations in the Wekiva River Watershed. The existing HEC-RAS, steady state one-dimensional river hydraulics model was updated and extended to include the Little Wekiva River and Rock Springs Run, as well as Wekiva River to simulate the water surface profiles of the Wekiva River system. In addition, dynamic HEC-RAS model simulation was conducted in this study. The HEC-RAS model is used to convert the flows simulated by the HSPF into stages and to calculate the stages at other transect locations along the Wekiva River. Results from these two models will be used to determine and evaluate the MFLs.

The hydrologic and hydraulic modeling process for MFL evaluations is documented as follows. Section 2 provides descriptions of key characteristics of the Wekiva River watershed and the dataset used for surface water modeling. Sections 3 and 4 describe the development of HSPF and HEC-RAS models for hydrologic and hydraulic simulations. Section 5 summarizes the results of this study. The use of these models for MFL evaluations will be presented in a separate report.

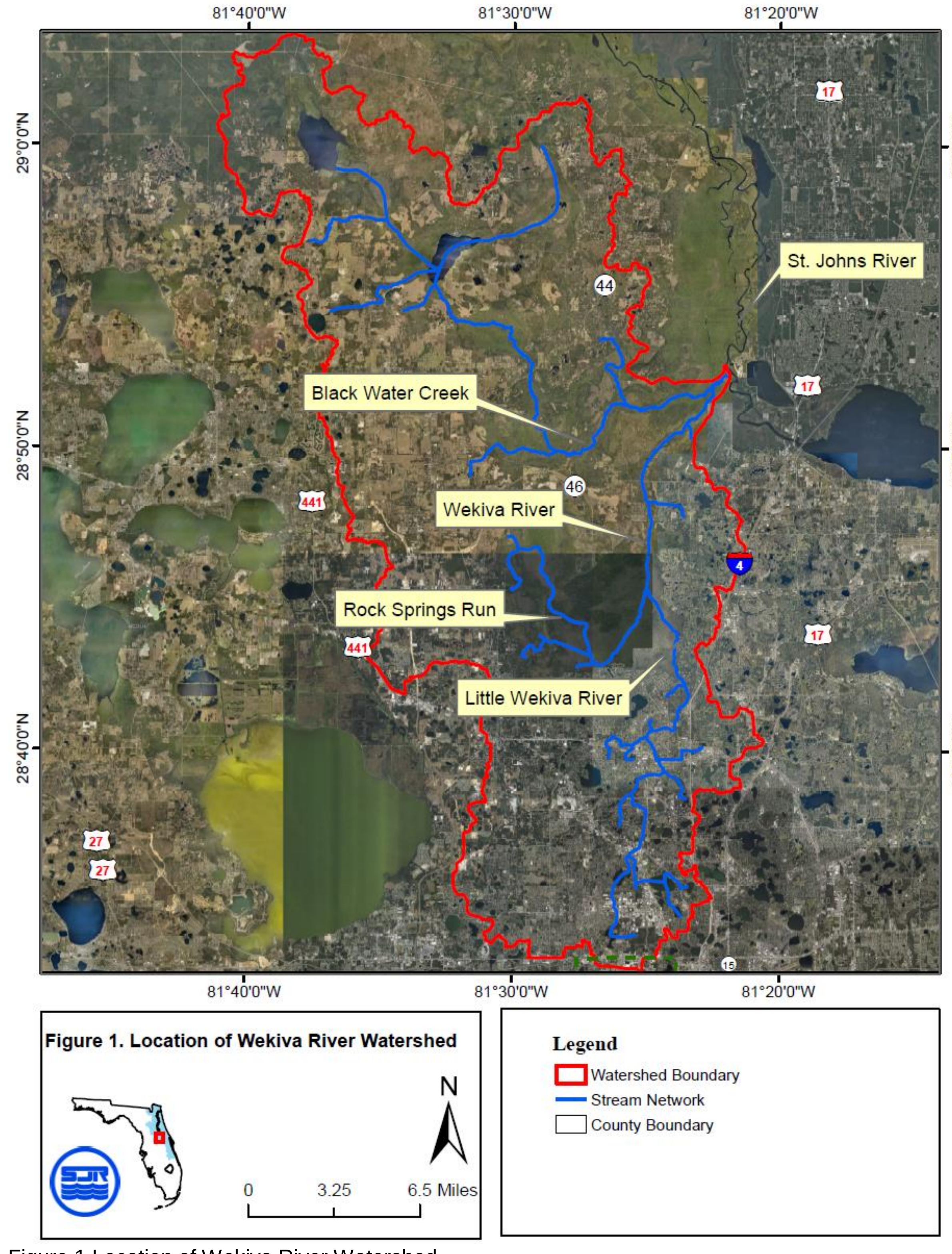


Figure 1 Location of Wekiva River Watershed

2. DATA COLLECTION AND PREPARATION

2.1 WATERSHED DELINEATION

The Wekiva River watershed was divided into 44 sub-watersheds. The watershed boundaries were defined using elevation and terrain models developed by SJRWMD. These sub-watersheds can be grouped into three major sub-basins: Black Water Creek watershed (sub-watersheds 1 – 13), Wekiva River watershed (sub-watersheds 14 – 19, 26 – 29, 39 – 43), and Little Wekiva River watershed (sub-watersheds 20 – 25, 30 – 38, 44), as shown in Figure 2. Black Water Creek and the Little Wekiva River are major tributaries to the Wekiva River.

In addition, there are three tributaries: Rock Springs Run, Sulphur Run, and Seminole Creek. Rock Springs Run drains to the Wekiva River directly. Sulphur Run and Seminole Creek drain to Black Water Creek first, and then to the Wekiva River. The drainage areas of Rock Springs Run, Sulphur Run, and Seminole Creek are sub-watersheds 14 – 17, sub-watershed 11, and sub-watersheds 9 – 10, respectively. Sub-watersheds 39 – 44 are closed drainage areas and do not contribute surface runoff to downstream areas. Outflows from these closed drainage areas recharge groundwater. The contributions from these closed sub-watersheds to the Wekiva River are assumed to occur through the nearby springs; thus, not simulated directly in the HSPF model.

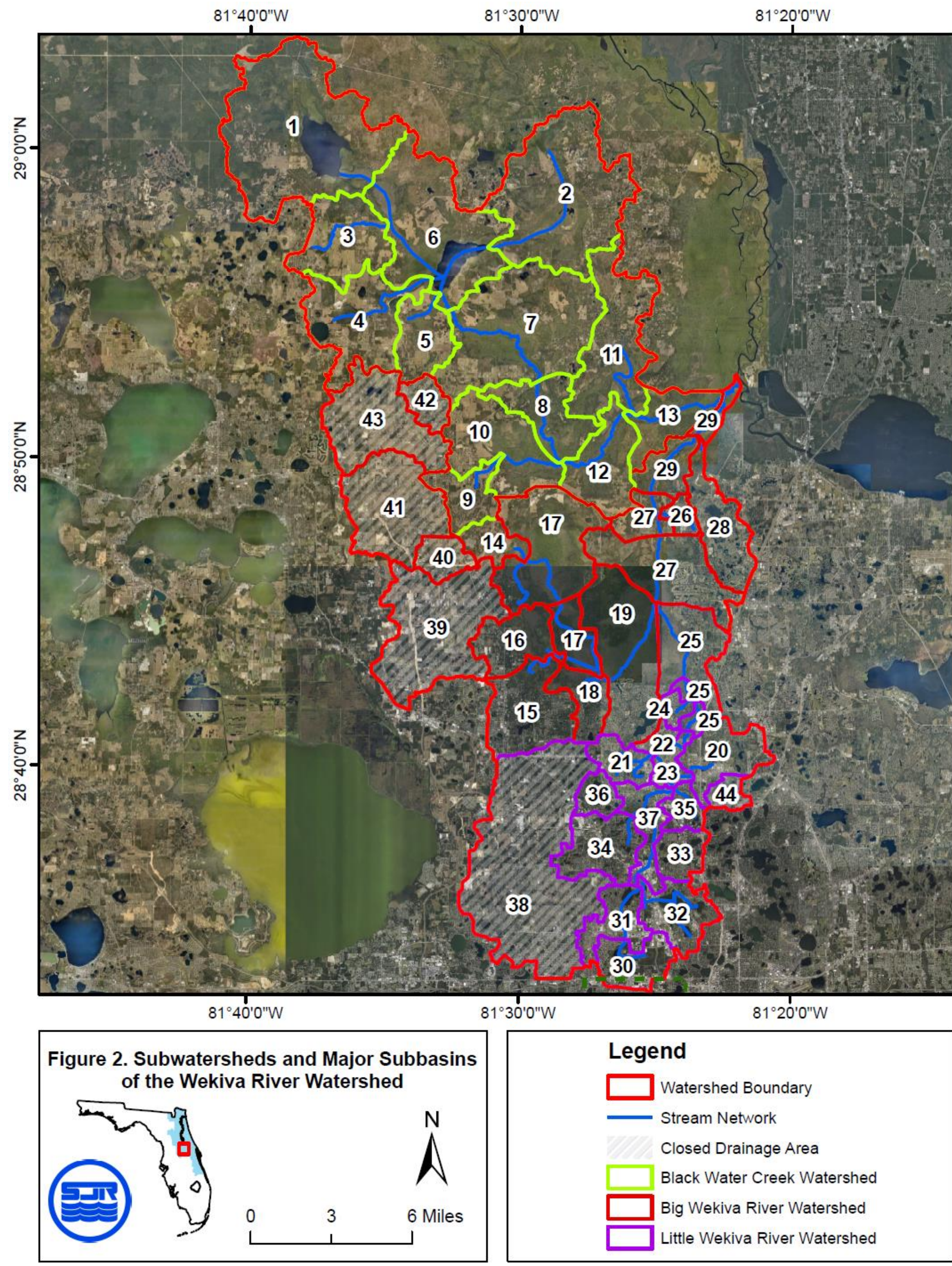


Figure 2 Sub-watersheds and major sub-basins of the Wekiva River watershed

2.2 LAND USE

The SJRWMD's 2009 land use and land cover map is used in this study. There are over 100 different land use classes within the Wekiva River watershed based on the Florida Land Use Classification Code System (FLUCCS). For modeling purposes, these land use classes are grouped into 13 major land uses, following the HSPF land use grouping method developed for the St. Johns River Water Supply Impact Study (Cera et al. 2012). Consolidation of the FLUCCS land use classes is mainly based on similarities in their hydrologic properties. Table 1 and Figure 3 show the distribution of these aggregated land uses in the Wekiva River watershed. Land use data is from 2009, as this was the most recent data available at the time of model development; 2014 data became available post model calibration. The difference between percent land use area between 2009 and 2014 is listed in Table 1.

Table 1 Distribution of the HSPF land uses in the Wekiva River watershed

Land Use	Acreage	Percent of the Study Area	Difference in percent land use area between 2009 and 2014
Low Density Residential	17,893	7.4	0.17%
Medium Density Residential	29,249	12.2	0.32%
High Density Residential	5,971	2.5	0.57%
Industrial and Commercial	13,447	5.6	0.02%
Mining	366	0.2	0.19%
Open Land	2,275	0.9	-0.72%
Pasture	20,434	8.5	-0.32%
Agriculture General	12,563	5.2	-0.15%
Agriculture Tree Crop	1,223	0.5	0.62%
Rangeland	13,670	5.7	-0.79%
Forest	58,388	24.3	-0.49%
Water	9,663	4.0	0.48%
Riparian Wetland	42,042	18.5	0.17%
Nonriparian Wetland	12,820	5.6	
Sum	**240,403**	**100**	**-**

To better represent the impact of wetlands on the drainage pattern in the Wekiva River watershed, the wetland land use category is split into two subgroups depending on whether wetlands are riparian (adjacent to streams or lakes) or non-riparian. Figure 4 shows the spatial distribution of riparian and non-riparian wetlands. The areas that drain to non-riparian wetlands are also shown in the map. The surface runoff from these areas are routed first to the non-riparian wetlands and then to the downstream streams or lakes. The baseflow from these areas are routed to the downstream streams or lakes directly.

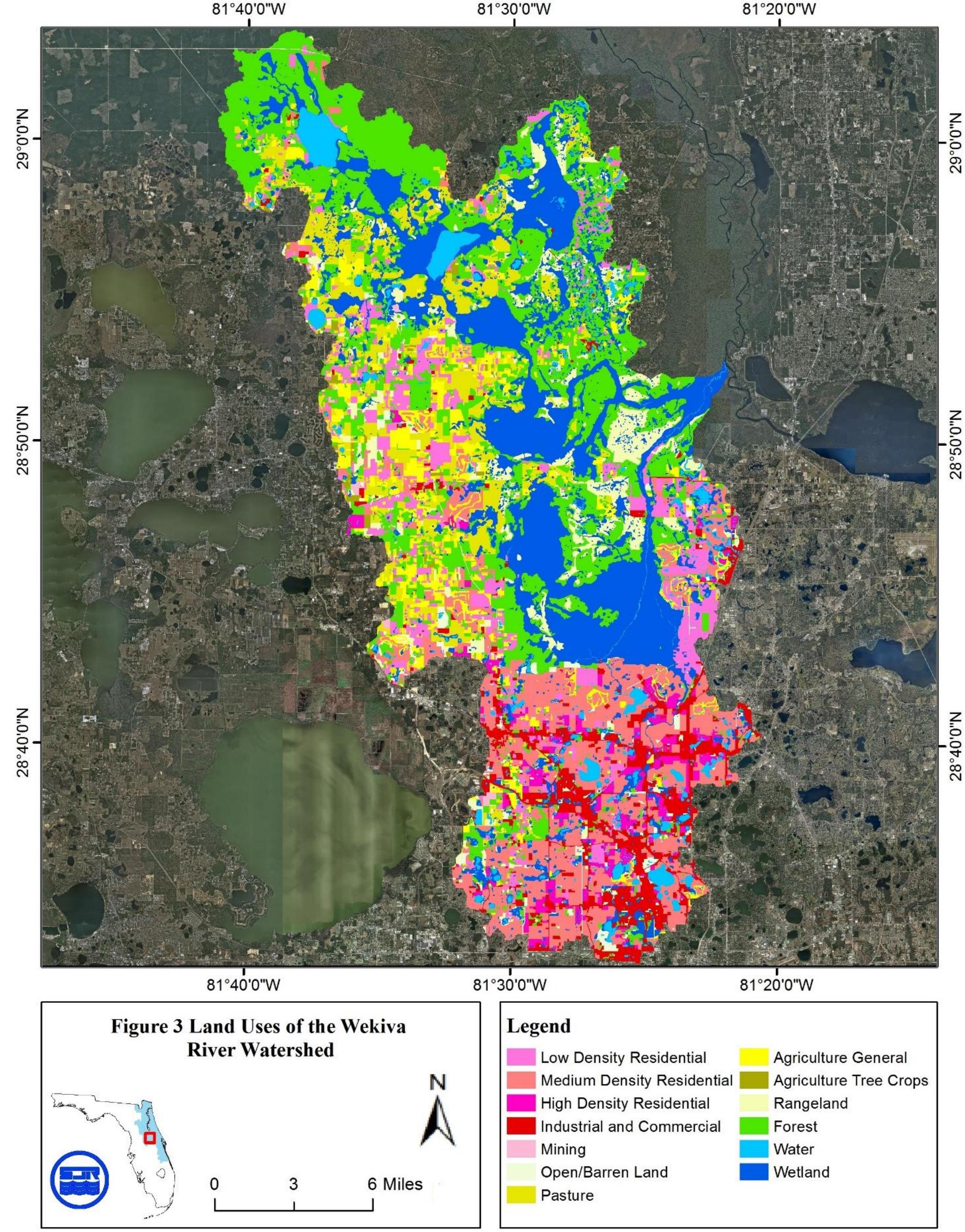


Figure 3 Land uses of the Wekiva River watershed

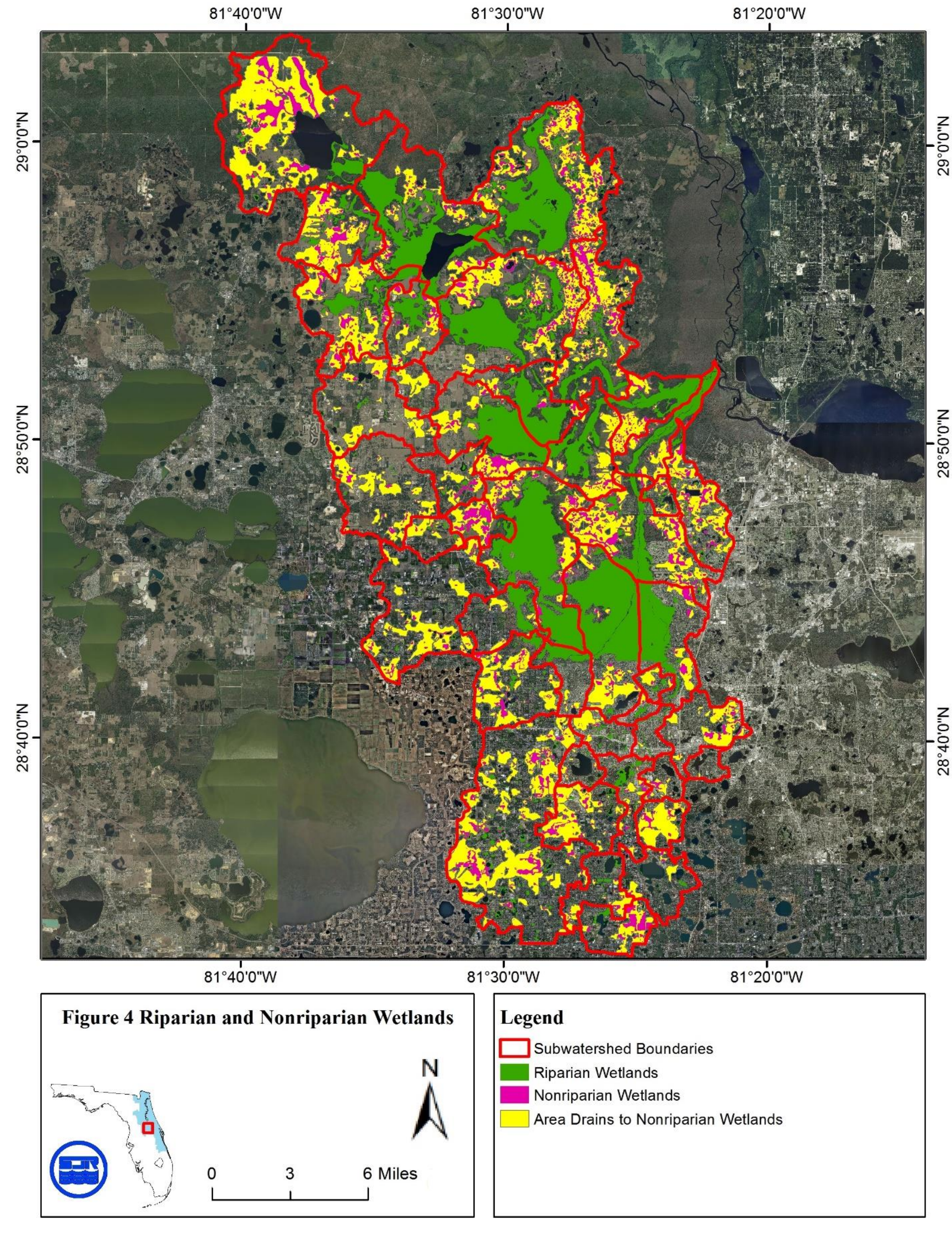


Figure 4 Riparian and non-riparian wetlands

2.3 METEOROLOGICAL DATA

Daily rainfall data for four weather stations (Figure 5 and Table 2) were downloaded from NOAA. Missing rainfall data were infilled using NEXRAD radar rainfall, available from SJRWMD. Daily rainfall totals for each station were disaggregated into an hourly time series based on an hourly NEXRAD radar rainfall time-series. NEXRAD data from several National Weather Service (NWS) radar stations is calibrated with SJRWMD rain gauge data to provide a gauge-adjusted rainfall dataset. WDMUtil, the watershed data management tool for HSPF (USEPA. 2001), was used for rainfall disaggregation.

Potential evapotranspiration (PET) estimates were developed using the Hargreaves method (Hargreaves and Samani, 1985), with a monthly correction factor scaled to the Priestly-Taylor estimated evaporation (Priestley and Taylor, 1972), to standardize long periods of recorded input data to HSPF. PET and rainfall are summarized in Table 3 and annual rainfall is presented in Figure 6.

Table 2 Distribution of weather stations

Station Name	Station ID	Latitude	Longitude	Data Source	Period of Record
Deland 1 SSE FL US	USC00082229	29.0181	-81.3106	NOAA and SJRWMD NEXRAD	DPET:1948-2017 PREC:1914-2017
Lisbon FL US	USC00085076	28.8728	-81.7844	NOAA and SJRWMD NEXRAD	DPET:1948-2017 PREC:1914-2017
Orlando International Airport	USW00012815	28.4339	-81.325	NOAA and SJRWMD NEXRAD	DPET:1948-2017 PREC:1914-2017
Sanford FL US	USC00087982	28.8147	-81.2778	NOAA and SJRWMD NEXRAD	DPET:1948-2017 PREC:1914-2017

Table 3 Summary of rainfall and potential evapotranspiration (PET) data over period from 1970 to 2016

Item	Deland	Lisbon	Orlando	Sanford
Minimum Annual Rainfall	38.48	29.28	30.38	32.83
Maximum Annual Rainfall	76.69	66.88	67.85	71.09
Average Annual Rainfall	56.67	47.99	49.69	52.04
Minimum Annual PET	54.28	53.32	56.54	55.70
Maximum Annual PET	63.79	64.06	62.42	63.37
Average Annual PET	59.35	57.65	59.12	59.21

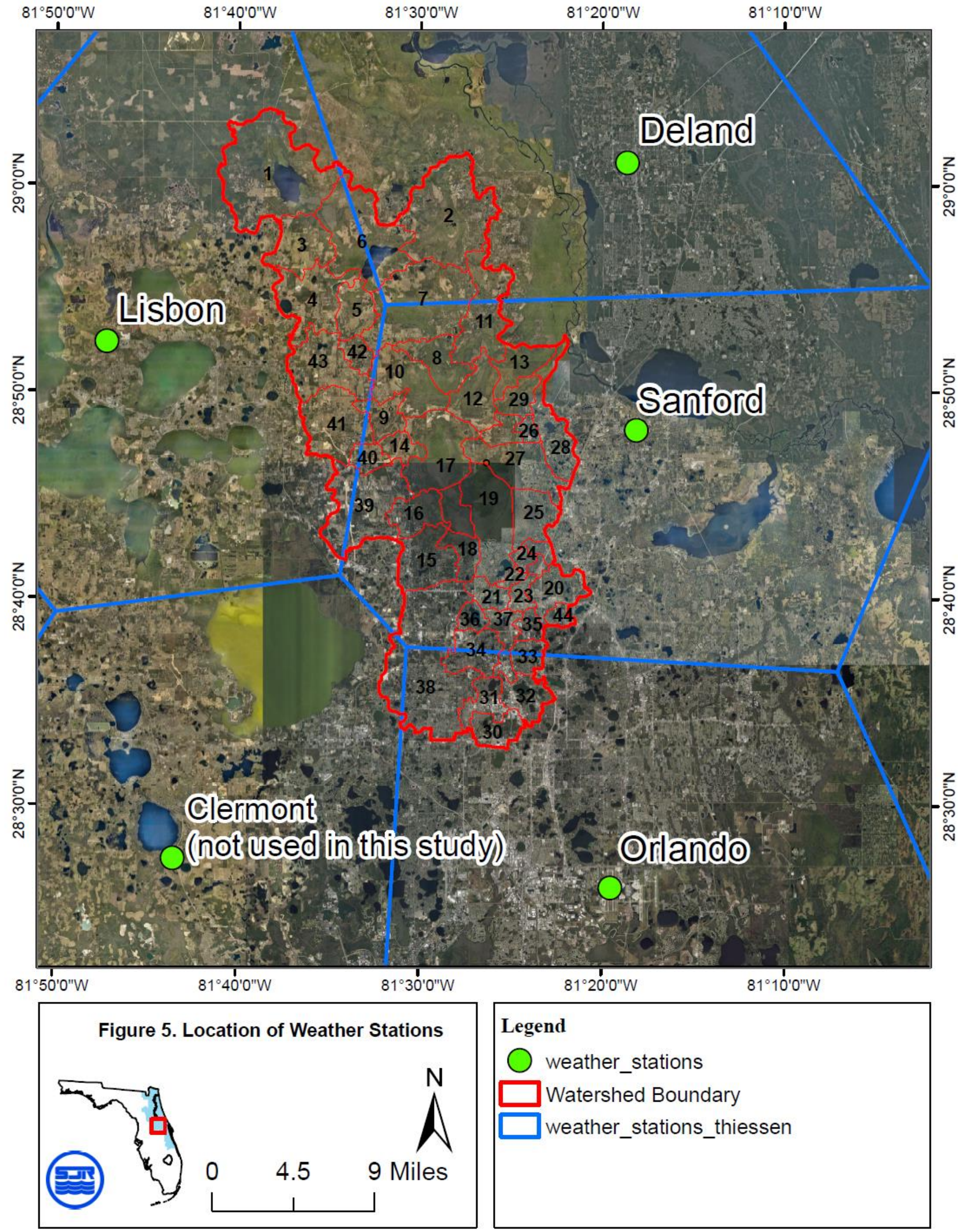


Figure 5. Location of Weather Stations

Figure 5 Map of Weather Station Locations

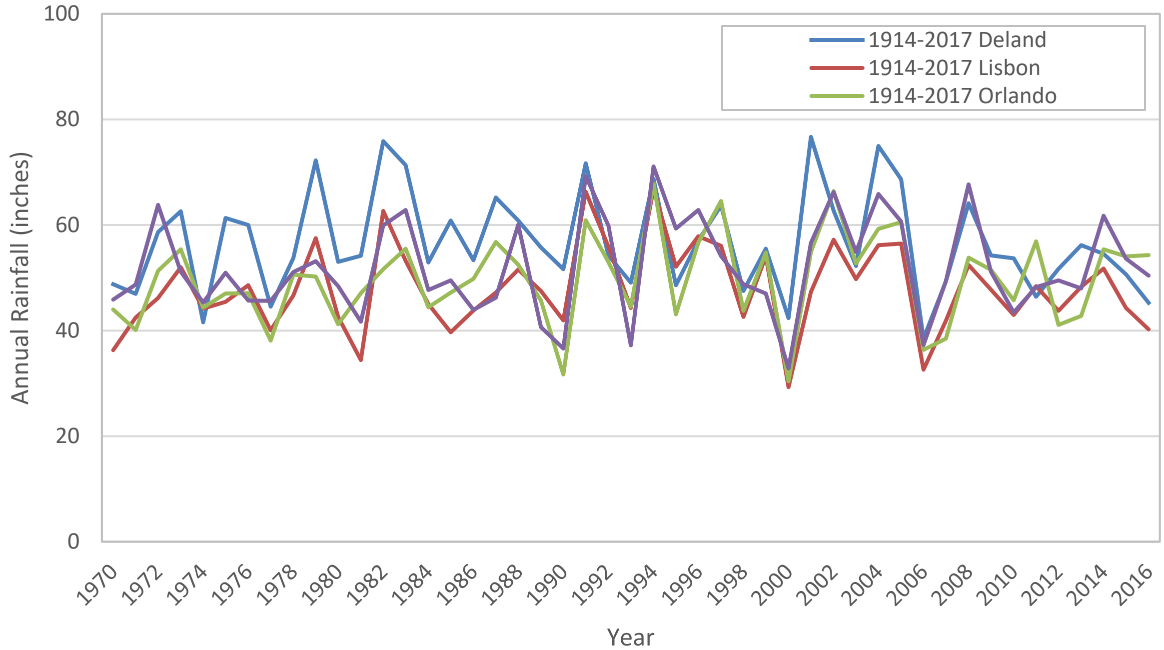


Figure 6 Annual Rainfall at Weather Station Locations (1970-2017)

2.4 STREAM GAGES

Long-term daily flow and level data from eight sites along the main stems of Black Water Creek, the Little Wekiva River, and the Wekiva River were used in the model calibration (Figure 6 and Table 4). It should be noted that all the observed flow data were not measured directly, but were calculated based on the stage measurements using a rating curve, which describes the relationship between flows and stages. The rating curves were developed based on the field measurements of flows over a range of stages. The rating curves need to be updated periodically to reflect the recent channel morphological changes and to ensure the estimated flow is accurate for a given stage. Additionally, the Wekiva River near Apopka station was disabled between 2013-2015, so this period was excluded for the model calibration.

Table 4 List of stream gages

Station	ID	Source	Years	Data
Black Water Creek at SR44 (SR44)	USGS 02235200	USGS	1994-present	Water level and discharge
Black Water Creek near Debary (near Debary)	SJRWMD 30143084	SJRWMD	1990-present	Water level and discharge
			2000-present	Discharge
Little Wekiva River at SR434 (SR434)	USGS 02234990	USGS	1994-present	Water level and discharge
Little Wekiva Springs Landing Blvd (SLB)	SJRWMD 09502132	SJRWMD	1995-2009 8.2016 - present	Water level
			2002-2009	Discharge

			8.2016 - present	
Wekiva River near Apopka (near Apopka)	SJRWMD 09522138	SJRWMD	1995-2012 and 2016-present	Water level and discharge
Old Railroad Bridge at Sanford (RR)	SJRWMD 09512135	SJRWMD	1995-present	Water level and discharge
Wekiva River at SR46 (SR46)	USGS 02235000	USGS	1986-present	Water level and discharge
Lower Wekiva River at Debary (LWR)	SJRWMD 16913302	SJRWMD	2002-2018	Water Level

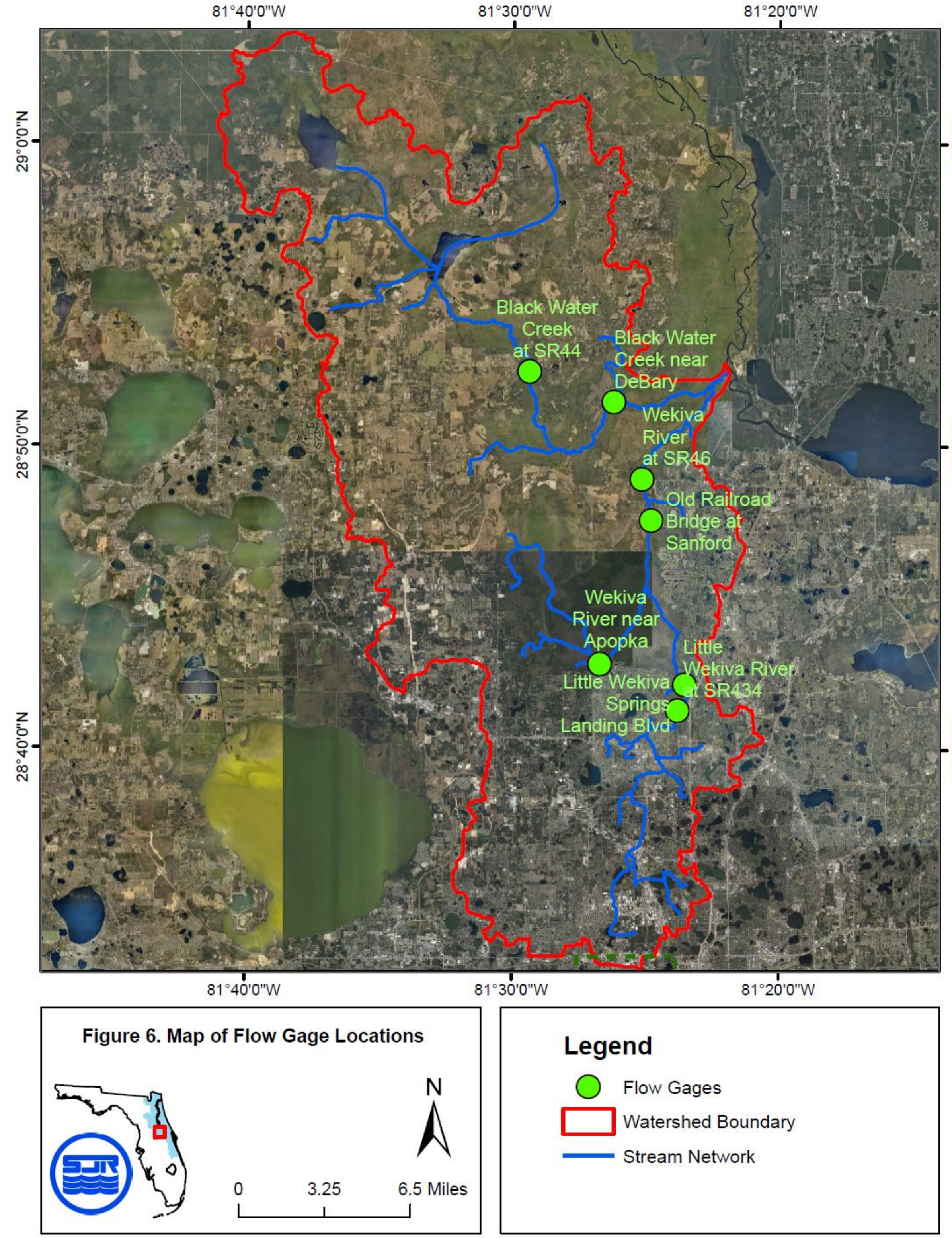


Figure 7 Map of Flow Gage locations

Many factors, such as channel modifications, sediment deposition and erosion, vegetation encroachment, and herbicide application, can change river channel morphology and habitat. These changes subsequently alter the shape and roughness of the river channel, which affects the water velocity in the channel and over the floodplain. Given the complexity and interaction of these factors, it is difficult to pinpoint the main cause for the changing stage and discharge relationship over time. However, based on SJRWMD staff observations, in the last few years (after 2008) the main cause of the changing stage/discharge relationship appears to be the significant increase in vegetation in the Wekiva River. Further, Hurricane Irma (September 2017) caused erosion/scouring of the river bottom at the gage stations leading to a dramatic decrease in in-channel water levels. The dense in-channel vegetation reduces the river flow velocity and raises the in-channel water levels (Figure 7 and 8). This is further discussed in Section 4.1.2.

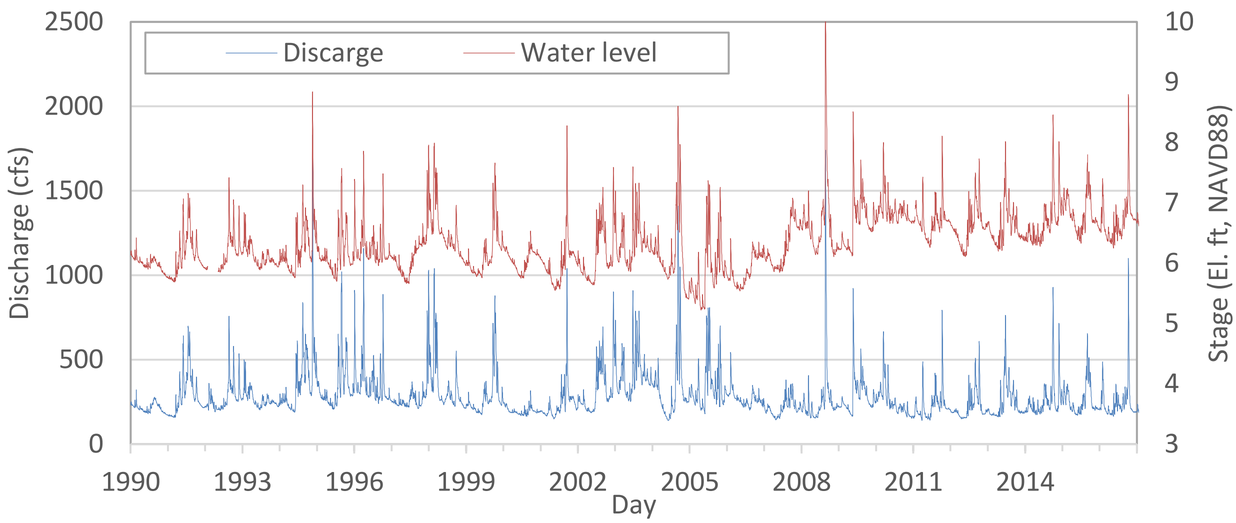


Figure 8 Flow and stage hydrographs for the Wekiva River at SR46

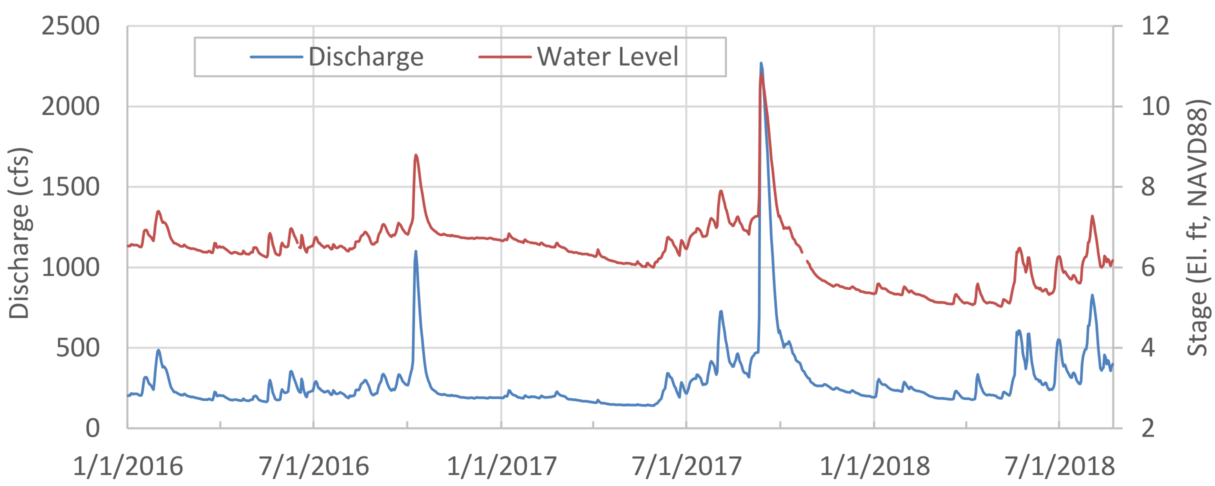


Figure 9 Flow and stage hydrographs for the Wekiva River at SR46, focusing on Hurricane Irma, September, 2017

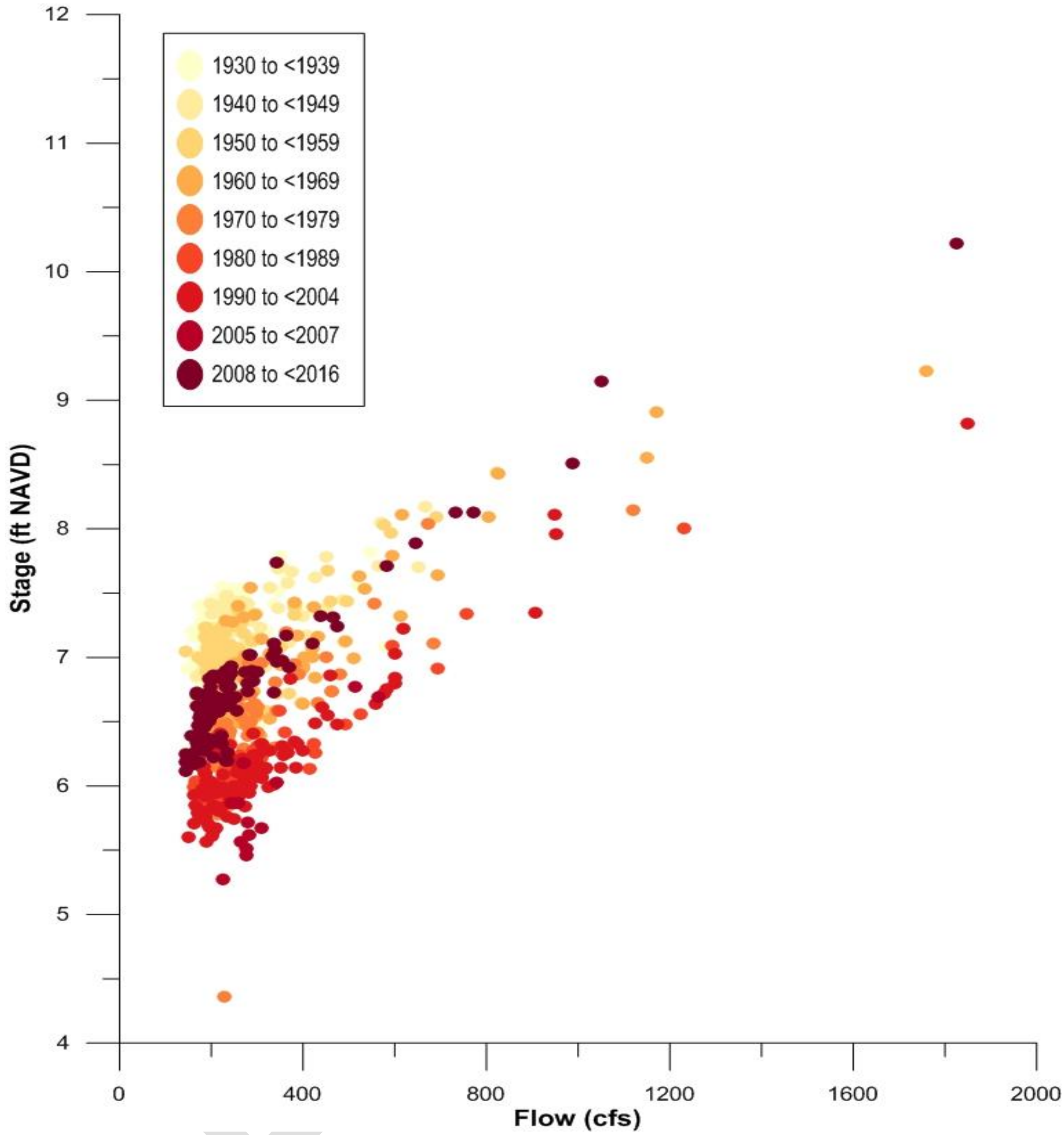


Figure 10 USGS field measurements of flows and stages for the Wekiva River at SR46

2.5 SPRINGS DISCHARGE

Springs are responsible for a substantial portion of the flow in the Wekiva River, especially in periods of low flow. For example, when river flow is less than 150 cfs, discharge from Wekiwa Springs alone could correspond to over 40% of the flow, and when all the springs are combined, this can contribute to 90% of the stream flow. The locations and magnitudes of 34 springs in the Wekiva River watershed are shown in Figure 9 and Table 5. Springs are classified by their average discharges. A first magnitude spring has a discharge of greater than 100 cfs; whereas, a fifth magnitude spring has a discharge of 0.0223 cfs to 0.223 cfs (Florida Geological Survey Bulletin No. 31). The average discharge and magnitude of each spring was evaluated between the years of 1970 through 2016. The methods used in preparing the spring discharge datasets summarized in Table 5 were described in detail in Appendix A.

Table 5 Mean flows (1970-2016) and magnitudes for the named springs with data in the Wekiva River watershed

Name	Average Discharge (cfs)	Spring Magnitude	Method/ N
Barrel Springs	0.24	4	Ratio / N=3
Blue Algae Boil Springs	0.13	5	Ratio / N=2
Boulder Springs	0.21	5	Ratio / N=3
Camp La No Che Springs	0.78	4	Ratio / N=3
Cedar Springs	0.029	5	Ratio / N=2
Droty Springs	0.59	4	Ratio / N=2
Ginger Ale Springs	0.11	5	Ratio / N=2
Green Algae Springs	0.13	5	Ratio / N=2
Helene Springs	1.22	3	SLR / Daily
Island Springs	8.49	3	SLR / N=41
Markee Springs	0.22	5	Ratio / N=3
Messant Springs	14.077	2	Ratio / N=26
Miami Springs	5.36	3	LOC / Daily
Nova Springs	7.267	3	Ratio / N=2
Palm Springs	5.519	3	LOC / Daily
Pegasus Springs	2.509	3	Ratio / N=2
Rock Springs	55.63	2	LOC / Daily
Sanlando Springs	19.98	2	LOC / Random, N=214 (1941-2019) LOC / Daily, N=5120 (2002-2018)
Shark Tooth Springs	0.17	5	Ratio / N=6
Snail Springs	0.24	4	Ratio / N=2 (2005,2008)
Starbuck Springs	12.38	2	LOC / N=210 (1944-2018) LOC / Daily (2002-2017)
Sulphur Springs	0.48	4	SLR / Observed/ N=24
Wekiwa Springs	62.28	2	LOC / N=350 (1932-2018) LOC / Daily (2002-2018)
Witherington Springs	2.8989	3	Ratio / Observed/ N=2
Palm Springs, Lake County	0.7170	4	Ratio / N= 6

Seminole Springs	36.1389	2	Ratio / N= 38
Wekiva Falls	13.1852 (1995-2007) 18.58524 (2007-2016)	2	ECFT & Ratio / N= 12

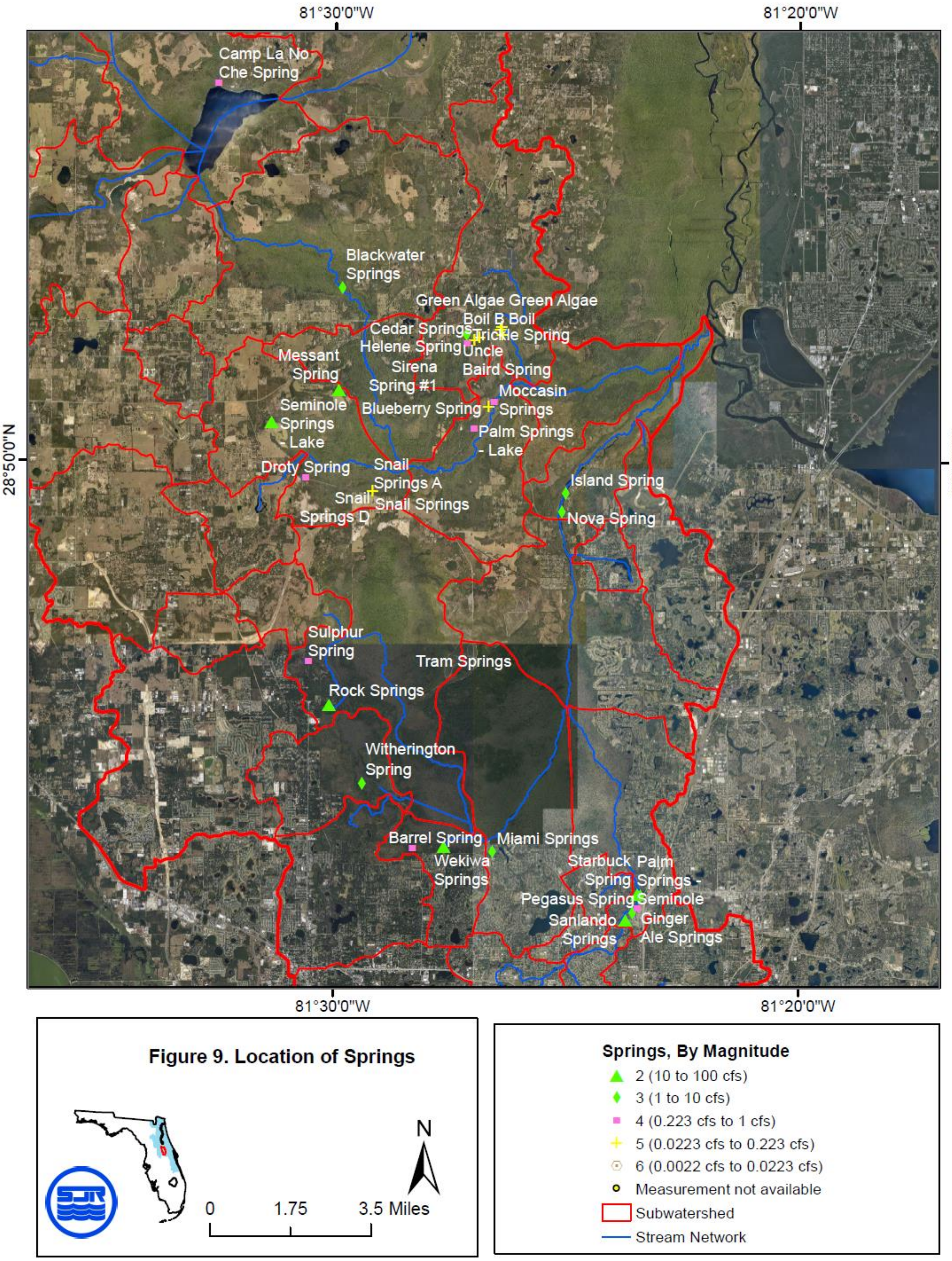


Figure 11 Locations of Springs and Floridan aquifer well

A combined approach was implemented to estimate discharges at Wekiva Falls, which showed a significant change in its amount of discharge in 2007. A well near Wekiva Fall, constructed in 2007, reduced the discharge of Wekiva Falls significantly (Internal communication with Douglas Hearn at SJRWMD, January 2018). Discharge simulation results using the East-Central Florida Transient (ECFT) Model (CFWI HAT 2014) for Wekiva Falls were used for the period of 1995-2007. The ratio method was applied to extend the timeseries to 2016. A multiplier calculated using recent Wekiva Falls discharge measurements was applied to the estimated timeseries by the ratio method from 2007 to 2016 to account for the reduction in discharge over that time-period (Figure 12 and Table 6).

Table 6 Recent Wekiva Falls Discharge Measurement

Date	Discharge (MGD)	Discharge (cfs)
1/5/2018	8.65	13.38353
1/19/2018	8.85	13.69297
2/19/2018	8.02	12.40877

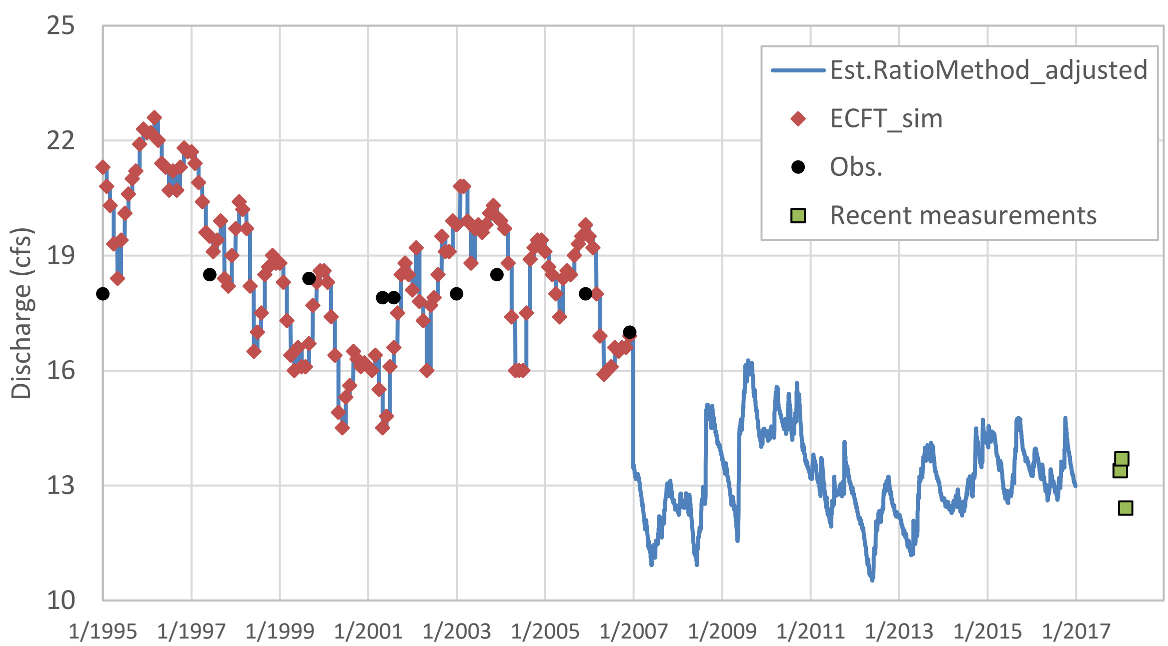


Figure 12 Adjusted Discharge at Wekiva Falls

2.6 POINT SOURCE DISCHARGE

Point source discharges, such as treated domestic wastewater and stormwater, occur throughout the Wekiva Basin. FDEP identified 60 permitted point source discharge sites in the Wekiva River watershed (FDEP 2003). Of these point sources, two wastewater treatment facilities, Altamonte Springs/Swofford wastewater treatment facility (WWTF) and Wekiva Hunt Club WWTF, discharge treated wastewater effluent directly to the Wekiva or Little Wekiva Rivers (Table 7).

The Altamonte Springs/Swofford WWTF outfall is located in Subwatershed 37, just upstream of the confluence between the Little Wekiva River and Spring Lake. The Wekiva Hunt Club WWTF discharges to Sweetwater Creek, which flows to the Wekiva River in Subwatershed 18. Table 8 shows the annual discharges from these two facilities based on the discharge monitoring reports obtained from FDEP (http://www.dep.state.fl.us/Water/wastewater/wce/edmr/index.htm).

Table 7 Point source locations

Name	FDEP ID #	Permit Volume (MGD)	Location
Altamonte Springs/ Swofford WWTF	FL0033251	12.5	950 Keller Rd, Altamonte Springs, FL 32714
Wekiva Hunt Club WWTF	FL0036251	2.9	144 Ledbury Dr, Longwood, FL 32779

Table 8 Annual effluent discharges from Altamonte Springs/Swofford WWTF and Wekiva Hunt Club WWTG

Year	Altamonte Springs/Swofford WWTF FL0033251 (MGD)	Wekiva Hunt Club WWTG FL0036251 (MGD)
2000	2.07	1.59
2001	2.07	1.59
2002	2.07	1.59
2003	4.60	3.91
2004	4.33	2.73
2005	4.39	1.84
2006	1.17	0.47
2007	0.83	0.00
2008	2.76	0.48
2009	1.07	0.79
2010	0.92	1.87
2011	0.21	1.90
2012	0.37	1.94
2013	3.17	1.56
2014	3.44	1.51
2015	3.45	1.56
2016	3.45	1.56
2017	3.45	1.56

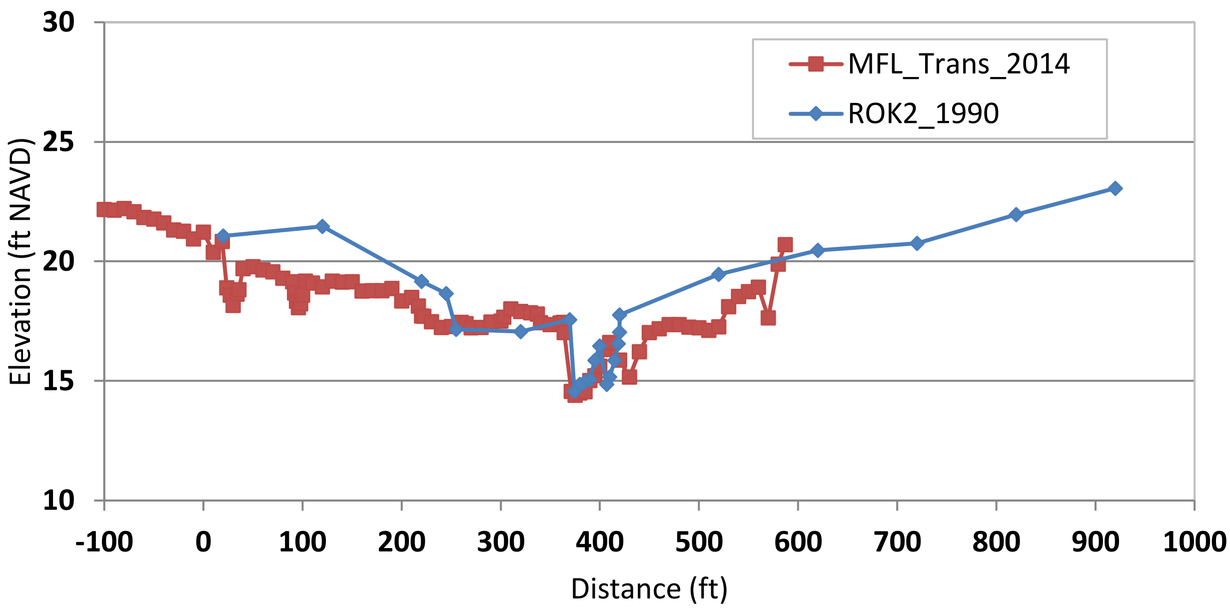
2.7 Stream Cross Section

Stream cross section data for the Wekiva River and its upstream locations were collected from various sources including 1990s survey data (A.R.Toussaint and Associates 1991; Post, Buckley, Schuh and Jernigan 1992; SJRWMD 1990), recent Wekiva River hydraulic modeling study

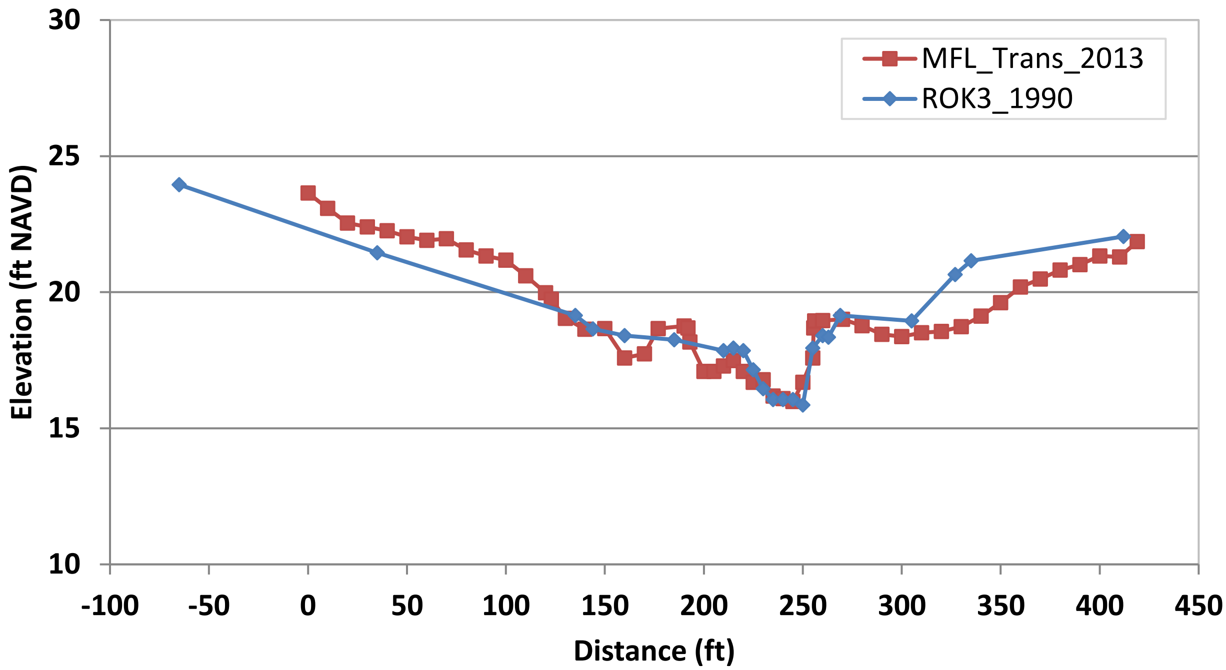
(SJRWMD 2016), and SJRWMD surveying data to support MFLs assessments. Additionally, stream locations at Rock Springs Run and the Little Wekiva River were surveyed for this project (Figure 14-16 and Table 9).

The 1990s cross section data covers the entire Wekiva River including Rock Springs Run, Wekiwa Run and Little Wekiva River. The recent Wekiva River HEC-RAS modeling study used 20 cross sections on the Wekiva River downstream of the confluence with the Little Wekiva River. The recent SJRWMD environmental transects have been surveyed to collect biological and topographic information for MFLs analysis. The identified MFL transects in the study area are asterisked in table 9. When multiple cross sections were in the same or nearby location, the most recent cross section was selected as a representative transect for developing a hydraulic model; however, the SJRWMD MFL environmental transects were all included in the hydraulic modeling. Elevations in the selected cross sections are relative to North American Vertical Datum -1988 (NAVD88).

The 1990s cross section data were relatively outdated, so a few of them were compared to recently surveyed cross sections (Figure 13). It was found that the old and new cross sections at ROK2 and ROK3 were comparable in terms of bottom elevation, stream width and bank, and general shape of cross section. This indicated that the old cross section measurements could be used for the model development.



(a) ROK2 transects at Rock Springs Run



(b) ROK3 transects at Rock Springs Run

Figure 13 Cross section comparison in between 1990 and 2013 at ROK2 and ROK3 at Rock Springs Run

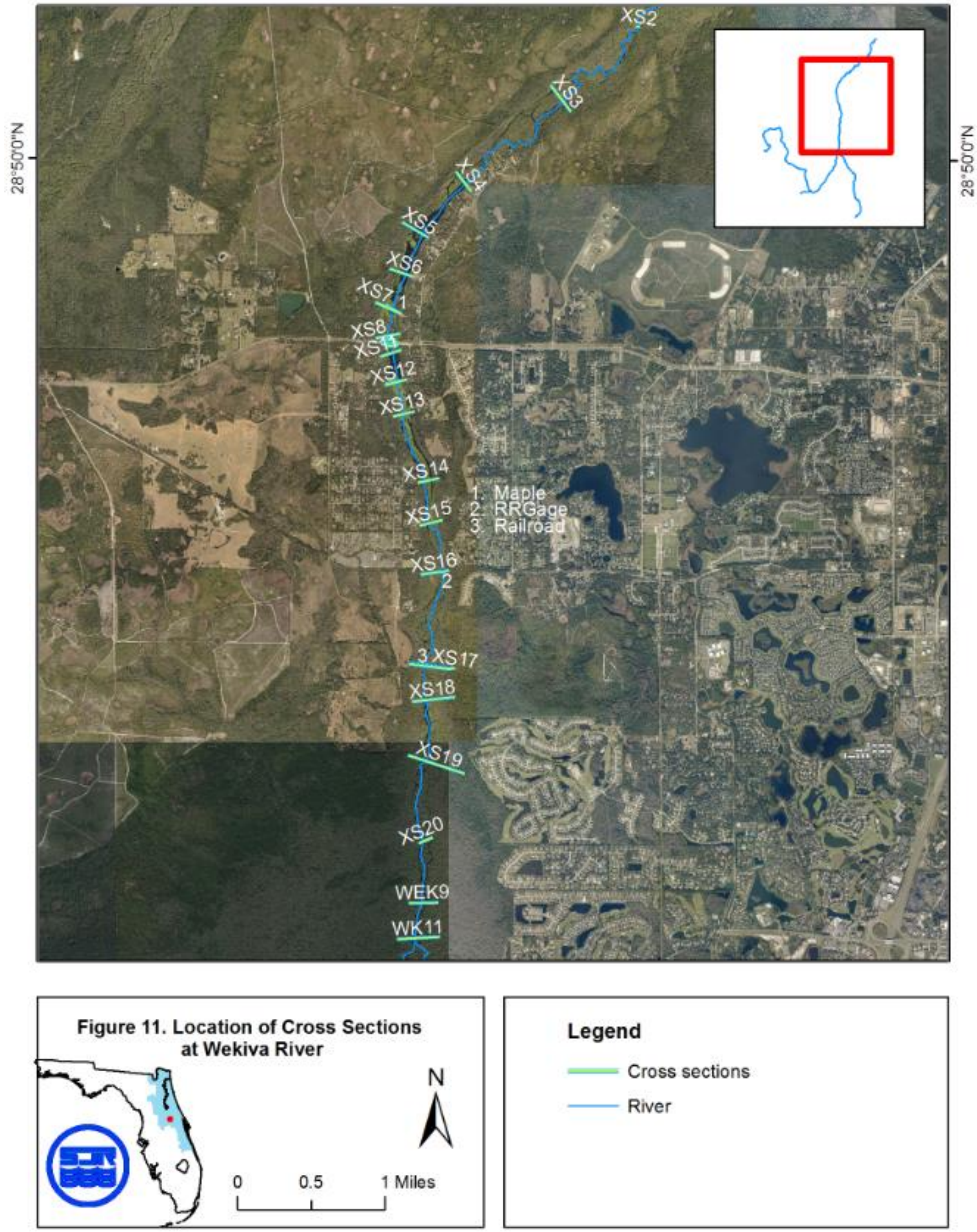


Figure 14 Location of cross sections at downstream of Wekiva River

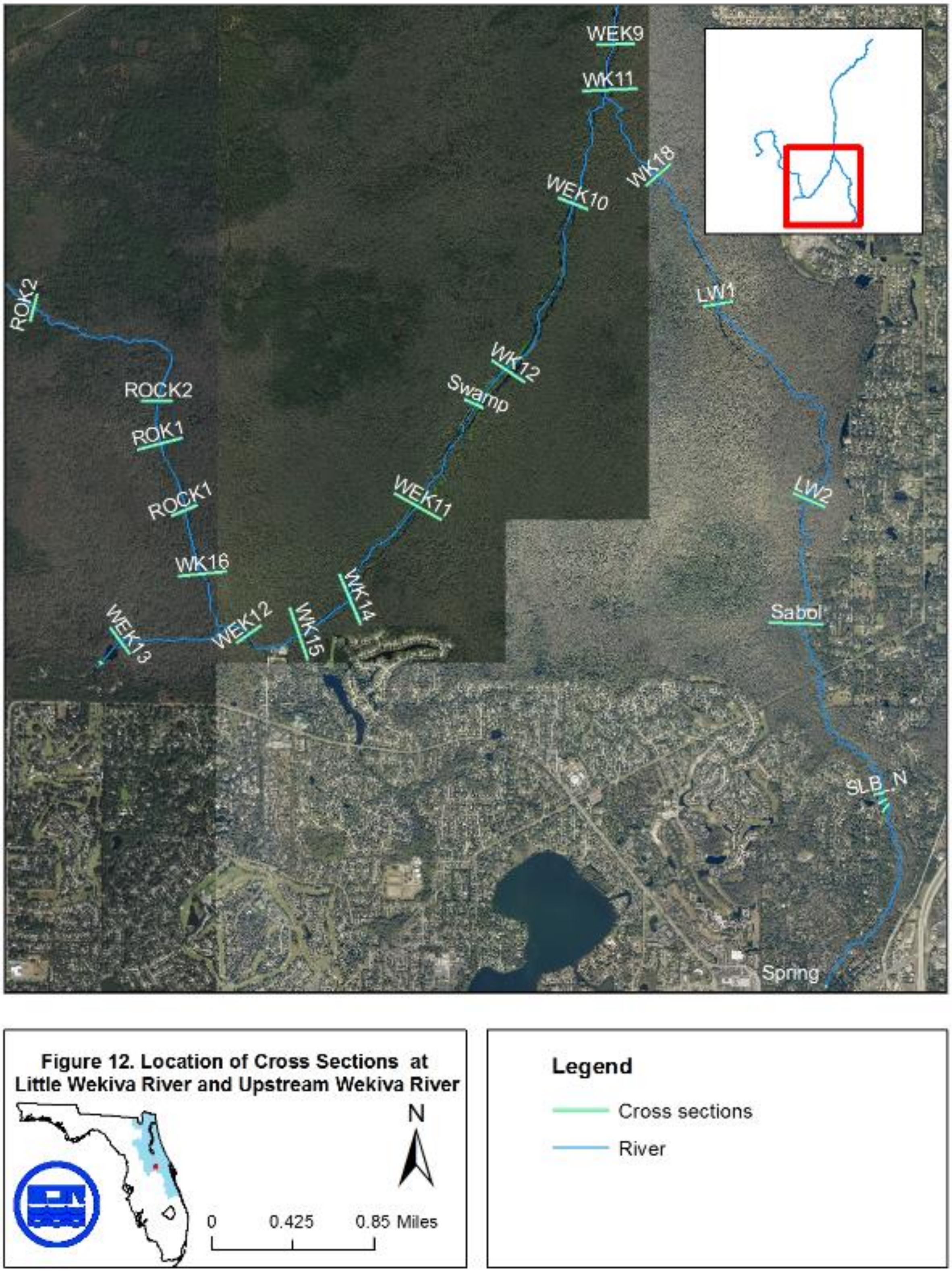


Figure 15 Location of cross sections at upstream of Wekiva River and Little Wekiva River

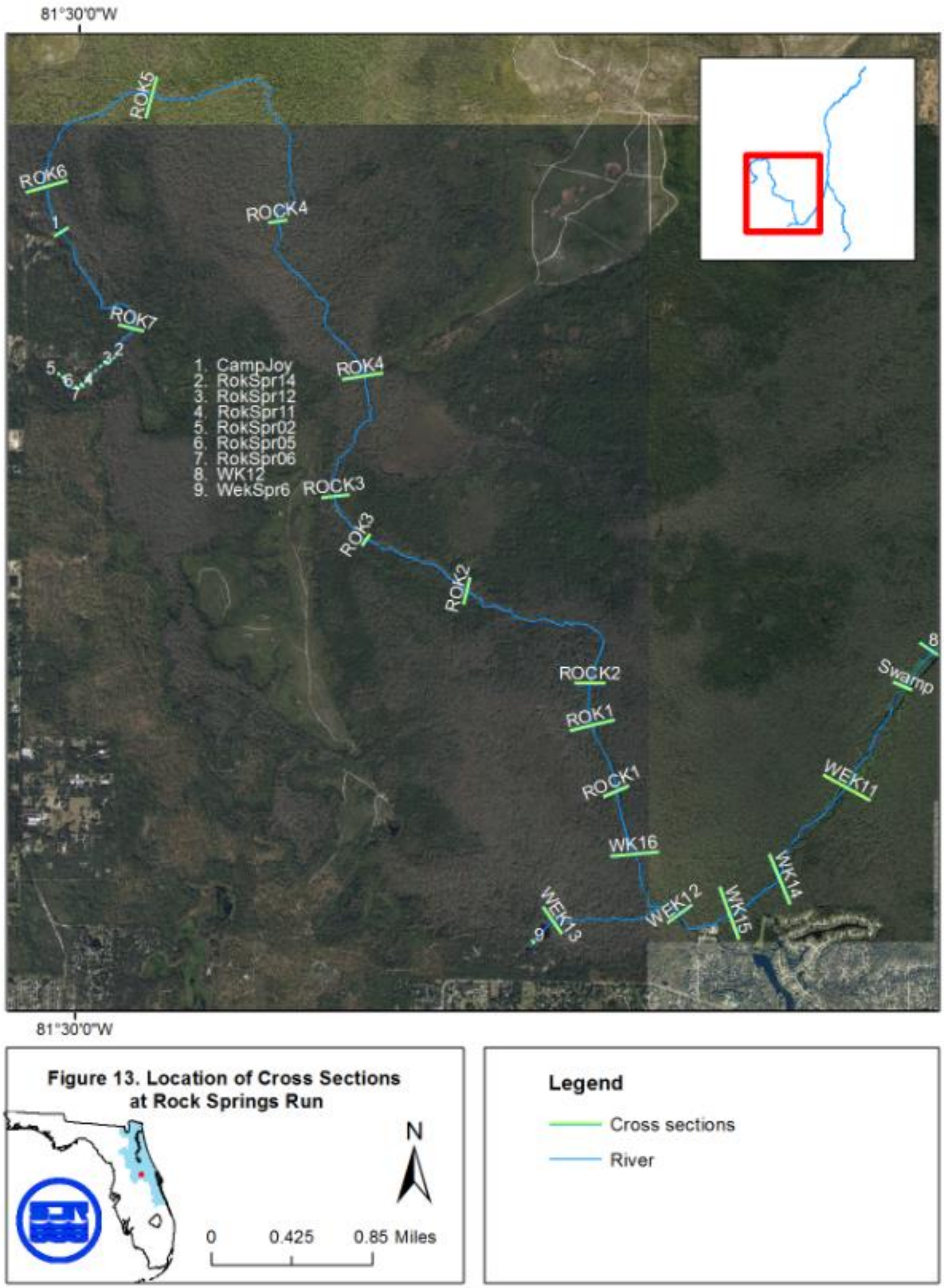


Figure 16 Location of cross sections at Rock Springs Run

Table 9 River Transect Descriptions

Transect Name	Stream	River Station (ft/100)	Data Source	Year
Lower Wekiva	Wekiva River	0.00	SJRWMD Survey	2012
XS1	Wekiva River	76.89	SJRWMD 2016	2016
XS2	Wekiva River	143.23	SJRWMD 2016	2016
XS3	Wekiva River	197.61	SJRWMD 2016	2016
XS4	Wekiva River	252.74	SJRWMD 2016	2016
XS5	Wekiva River	276.66	SJRWMD 2016	2016
XS6	Wekiva River	292.23	SJRWMD 2016	2016
Maple*	Wekiva River	305.54	SJRWMD Survey	2013
XS7	Wekiva River	305.84	SJRWMD 2016	2016
XS8	Wekiva River	315.81	SJRWMD 2016	2016
SR46F	Wekiva River	317.25	SJRWMD Survey	2013
XS9	Wekiva River	318.03	SJRWMD 2016	2016
SR46A	Wekiva River	318.19	SJRWMD Survey	2013
SR46B	Wekiva River	318.81	SJRWMD Survey	2013
XS10	Wekiva River	318.86	SJRWMD 2016	2016
SR46E	Wekiva River	319.75	SJRWMD Survey	2013
XS11	Wekiva River	322.22	SJRWMD 2016	2016
Flats*	Wekiva River	332.58	SJRWMD Survey	2013
XS12	Wekiva River	333.01	SJRWMD 2016	2016
XS13	Wekiva River	344.64	SJRWMD 2016	2016
XS14	Wekiva River	370.65	SJRWMD 2016	2016
XS15	Wekiva River	386.11	SJRWMD 2016	2016
XS16	Wekiva River	405.81	SJRWMD 2016	2016
Railroad Gage	Wekiva River	405.90	SJRWMD Survey	2013
XS17	Wekiva River	442.46	SJRWMD 2016	2016
Railroad*	Wekiva River	442.71	SJRWMD Survey	2011
XS18	Wekiva River	455.35	SJRWMD 2016	2016
XS19	Wekiva River	477.90	SJRWMD 2016	2016
XS20	Wekiva River	508.92	SJRWMD 2016	2016
WEK9	Wekiva River	531.40	Post, Buckley, Schuh and Jernigan 1992	1992
WK11	Wekiva River	544.57	A.R.Toussaint and Associates 1991	1991
WEK10	Wekiva River	579.74	Post, Buckley, Schuh and Jernigan 1992	1992
WK12	Wekiva River	632.67	A.R.Toussaint and Associates 1991	1991
Swamp*	Wekiva River	645.38	SJRWMD 2016	2016
WEK11	Wekiva River	678.62	Post, Buckley, Schuh and Jernigan 1992	1992
WK14	Wekiva River	711.81	A.R.Toussaint and Associates 1991	1991
WK15	Wekiva River	729.66	A.R.Toussaint and Associates 1991	1991
WEK12	Wekiva River	747.19	Post, Buckley, Schuh and Jernigan 1992	1992
WK17	Wekiwa Run	779.51	A.R.Toussaint and Associates 1991	1991
WEK13	Wekiwa Run	785.19	Post, Buckley, Schuh and Jernigan 1992	1992

Transect Name	Stream	River Station (ft/100)	Data Source	Year
WekivaSpr_XS6	Wekiwa Run	793.32	SJRWMD Survey	2007
WK16	Rock Springs Run	18.2	A.R.Toussaint and Associates 1991	1991
ROCK1	Rock Springs Run	36.7	SJRWMD Survey	2018
ROK1	Rock Springs Run	56.3	Post, Buckley, Schuh and Jernigan 1992	1992
ROCK2	Rock Springs Run	68.3	SJRWMD Survey	2018
ROK2*	Rock Springs Run	126.9	SJRWMD Survey	2014
ROK3*	Rock Springs Run	160.5	SJRWMD Survey	2013
ROCK3	Rock Springs Run	176.5	SJRWMD Survey	2018
ROK4	Rock Springs Run	215.8	Post, Buckley, Schuh and Jernigan 1992	1992
ROCK4	Rock Springs Run	268.8	SJRWMD Survey	2018
ROK5	Rock Springs Run	350.3	Post, Buckley, Schuh and Jernigan 1992	1992
ROK6	Rock Springs Run	396.1	Post, Buckley, Schuh and Jernigan 1993	1992
Camp Joy*	Rock Springs Run	414.5	SJRWMD Survey	2018
ROK7	Rock Springs Run	449.3	Post, Buckley, Schuh and Jernigan 1994	1992
RockSpr_XS14	Rock Springs Run	459.9	SJRWMD Survey	2007
RockSpr_XS13	Rock Springs Run	462.3	SJRWMD Survey	2007
RockSpr_XS12	Rock Springs Run	464.3	SJRWMD Survey	2007
RockSpr_XS11	Rock Springs Run	466.2	SJRWMD Survey	2007
RockSpr_XS09	Rock Springs Run	468.6	SJRWMD Survey	2007
RockSpr_XS08	Rock Springs Run	469.5	SJRWMD Survey	2007
RockSpr_XS05	Rock Springs Run	473.9	SJRWMD Survey	2007
RockSpr_XS04	Rock Springs Run	477.8	SJRWMD Survey	2007
RockSpr_XS03	Rock Springs Run	479.3	SJRWMD Survey	2007
RockSpr_XS02	Rock Springs Run	480.8	SJRWMD Survey	2007
WK18	Little Wekiva River	30.5	SJRWMD Survey	2018
LW1	Little Wekiva River	71.1	Post, Buckley, Schuh and Jernigan 1992	1992
LW2	Little Wekiva River	144.0	Post, Buckley, Schuh and Jernigan 1992	1992
Sabol point*	Little Wekiva River	182.5	SJRWMD Survey	2017
SLB_North*	Little Wekiva River	245.7	SJRWMD Survey	2017
SLB_Bridge	Little Wekiva River	248.5	SJRWMD Survey	2017
SLB_South*	Little Wekiva River	250.5	SJRWMD Survey	2017
The Springs	Little Wekiva River	312.1	SJRWMD Survey	2013

* MFL environmental transects

3. HYDROLOGIC MODEL DEVELOPMENT FOR WEKIVA RIVER WATERSHED

3.1 HSPF MODEL SETUP

An existing HSPF model for the Wekiva River Watershed (SJRWMD, 2016) was updated for this study. The watershed model simulation period was extended to the period of 2003 to 2016. The spring discharge dataset used in the previous model was updated based on measured data. The parameter set developed in the previous study (SJRWMD, 2016) was used, since the updated model performed well for the extended simulation period as well. Detailed model performance evaluation follows in the next section.

3.1.1 Model segmentation

A watershed and its stream network are characterized in HSPF by various pervious land segments (PERLND), impervious land segments (IMPLND), and reach segments (RCHRES) based on subwatershed delineation, land uses, and the ratio of perviousness and imperviousness for each land use. As described in section 2.2, the land uses in the Wekiva River watershed are grouped into 13 categories. These land uses are further divided into pervious and impervious fractions. The pervious portion of a land use in a subwatershed is represented as a PERLND, and the impervious portion of a land use in a subwatershed is represented as an IMPLND. Among 13 land uses, four urban land uses (Low density residential, medium density residential, high density residential, and industrial/commercial) are assumed to have impervious areas. The impervious percentages for these land uses are 5, 10, 35 and 50, respectively. The remaining land uses are assumed to be 100% pervious (Bicknell et al., 2001).

For modeling purposes, the stream network in a subwatershed is grouped together and represented as a RCHRES. A RCHRES could be either a free-flowing stream or a lake. A series of reach segments connects upstream subwatersheds to downstream subwatersheds. Runoff is routed through the reach segments. The geometric and hydraulic properties of a RCHRES are represented in HSPF by a piecewise-linear function table called FTABLE, which describes the relationships between stage, surface area, volume, and discharge for the reach segment (Bicknell et al., 2001). The FTABLEs are mainly derived from the modeling results of the ICPR models developed by CDM (2005) and the SJRWMD's HEC-RAS model, which will be described in the next chapter. In addition, cross section survey data, lake bathymetry, observed stage and discharge relationships are used for FTABLE development. In total, 44 reaches are represented in the Wekiva River Watershed HSPF model.

The reach segment draining a subwatershed receives the runoffs from the land segments in that subwatershed. For the area not drained by non-riparian wetlands, the runoffs are delivered to the reach segment directly. However, for the area drained by non-riparian wetlands (see Figure 4), the surface runoffs and interflows are first delivered to non-riparian wetlands, and then the outflows are delivered to the reach segment. The non-riparian wetlands are modeled by surface FTABLEs in HSPF to represent the high water table and storage effects in non-riparian wetlands. The impacts of non-riparian wetlands on baseflow runoffs are assumed to be negligible. Consequently, the baseflow originating from the non-riparian wetland drainage areas is routed to receiving reach segment directly.

3.1.2 HSPF modules

HSPF has a modular structure, in which the simulation of PERLND, IMPLND and RCHRES is handled by the PERLND module, the IMPLND module, and the RCHRES module, respectively. Each of these modules includes a variety of submodules to perform different tasks. Hydrologic simulation for PERLND and IMPLND is carried out in the PWATER submodule and the IWATER submodule. The simulated hydrologic processes for a PERLND are interception, infiltration, evapotranspiration, runoff, and deep percolation. The simulated processes for an IMPLND are similar to those for a PERLND, except there are no infiltration and subsequent subsurface processes. Hydraulic behaviors in a RCHRES are simulated in the HYDR submodule. Detailed description of these submodules can be found in Bicknell et al. (2001).

During a simulation run, the riparian wetland PERLND areas will change as the RCHRES surface expands and contracts. The HSPF Special Actions module is used to account for variable PERLND and RCHRES surface areas. Different areas for the water and wetland are used so that both the PERLND and RCHRES section in a subwatershed would not use the same area at the same time. For most subwatersheds, the average RCHRES area can be subtracted from the PERLND water and wetland area for each subwatershed. This would cause some double counting of rainfall and evaporation when water levels are high and some undercounting when water levels are low. As long as this area is small, this error is considered insignificant to the overall model. When the variable area within the RCHRES becomes large, however the error becomes significant. The Special Actions for variables PERLND and RCHRES calculate the current RCHRES area and subtract it from the total water and wetland area for the subwatershed. Then the model uses this area as a wetland PERLND in the modeled subwatershed (Bicknell et al., 2001). This action is applied to every subwatershed in this study.

3.1.3 Model calibration

Calibration of HSPF models involves iterative adjustment of model parameters so that model simulations closely match the observed flow data. To assist the calibration process, an automatic parameter estimation tool called PEST (Doherty 2004) is used. PEST uses a nonlinear optimization approach to explore the parameter space defined by the modeler and find the best parameter set for the specified objective function. The objective function typically includes multiple weighted statistical measures, such as mean, median, and percentiles, to evaluate the statistical characteristics of model simulations and observations. The modeler needs to adjust these statistical measures and their weights during calibration in order to get the best match between model simulations and observed data.

A variety of HSPF hydrologic parameters relating to watershed storage, infiltration, evaporation, and deep percolation are adjusted in the hydrologic calibration process to match the observed flows at USGS flow stations over the calibration period from 2003 to 2012. The extents of adjustment for these hydrologic parameters are defined by the HSPF Common Logic developed for the St. Johns River Water Supply Impact Study (Cera et al. 2012). This HSPF Common Logic was derived from an evaluation of the possible range of model parameters for Florida's unique hydrology, extensive SJRWMD experience, and the parameter ranges common in other parts of the world (USEPA 2000). Various statistic measures are used by PEST to minimize the differences between the predicted and observed flows in terms of mass balance, low flow recession, flow distribution, and seasonal distribution.

3.2 Model performance evaluation

In this study, the HSPF model results were evaluated with statistical measures of coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and RMSE-observations standard deviation ratio (RSR) as well as visual comparison of observed and simulated flow time series and flow duration curves. Table 10 is a guide for assessing the performance of hydrologic model.

Table 10 Hydrologic model performance guide

Statistics	Period	Very Good	Good	Satisfactory (fair)	Unsatisfactory (Poor)	Ref.
R^2*	Daily	$0.80<R^2\leq 1$	$0.70 < R^2 \leq 0.80$	$0.60 < R^2 \leq 0.70$	$R^2 \leq 0.60$	Duda et al, 2012
R^2	Monthly	$0.86<R^2 \leq 1$	$0.75 < R^2 \leq 0.86$	$0.65 < R^2 \leq 0.75$	$R^2 \leq 0.65$	Duda et al, 2012
NSE	Monthly	0.75< NSE ≤1	0.65<NSE≤ 0.75	0.50< NSE ≤0.65	NSE ≤ 0.50	Moriasi,et al, 2007
PBIAS	Monthly	PBIAS < ±10	±10≤PBIAS<±15	±15≤PBIAS<±25	PBIAS ≥ ±25	Moriasi,et al, 2007
RSR	Monthly	0 ≤ RSR ≤ 0.5	0.5 < RSR ≤ 0.6	0.6< RSR ≤ 0.7	RSR > 0.7	Moriasi,et al, 2007

* Performance criteria ranges estimated from Figure 4 in Duda et al.

R^2 describes the degree of collinearity between simulated and measured flow (Nagelkerke, 1991), ranging from 0 to 1, where N is the total number of flow data; Q_{obs} is observed flow; Q_{sim} is simulated flow; and the over bar denotes the mean for the entire evaluation time period. R^2 of 1 means a perfect linear relationship between two variables, while an R^2 of zero represents no linear relationship.

$$R^2 = \left(\frac{\sum_{i=1}^{N}(Q_{obs,i} - \bar{Q}_{obs})((Q_{sim,i} - \bar{Q}_{sim})}{\left[\sum_{i=1}^{N}(Q_{obs,i} - \bar{Q}_{obs})^2\right]^{0.5}\left[\sum_{i=1}^{N}(Q_{sim,i} - \bar{Q}_{sim})^2\right]^{0.5}}\right)^2$$

NSE is a normalized value that assesses the relative magnitude of the residual variance, ranging from minus infinity to 1 (Nash, J.E. et al., 1970). NSE values greater than zero imply that the model predictions are more accurate than the average of the observed data, and a NSE = 1 indicates the model predictions completely match observed data.

$$NSE = 1 - \frac{\sum_{i=1}^{N}(Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{N}(Q_{obs,i} - \bar{Q}_{obs})^2}$$

PBIAS represents the overall agreement between two variables. A PBIAS of zero means there is no overall bias in the simulated output of interest compared to the observed data. Positive and negative PBIAS values indicate over-estimation and under-estimation bias of the model, respectively (Gupta, H.V. et al, 1999).

$$PBIAS = \frac{\sum_{i=1}^{N}(Q_{sim,i} - Q_{obs,i}) \times 100}{\sum_{i=1}^{N}(Q_{obs,i})}$$

RSR uses the fraction of RMSE and $STDEV_{obs}$ to measure model performance. Results can vary from 0 to a large positive value. A lower RSR value indicates better model performance.

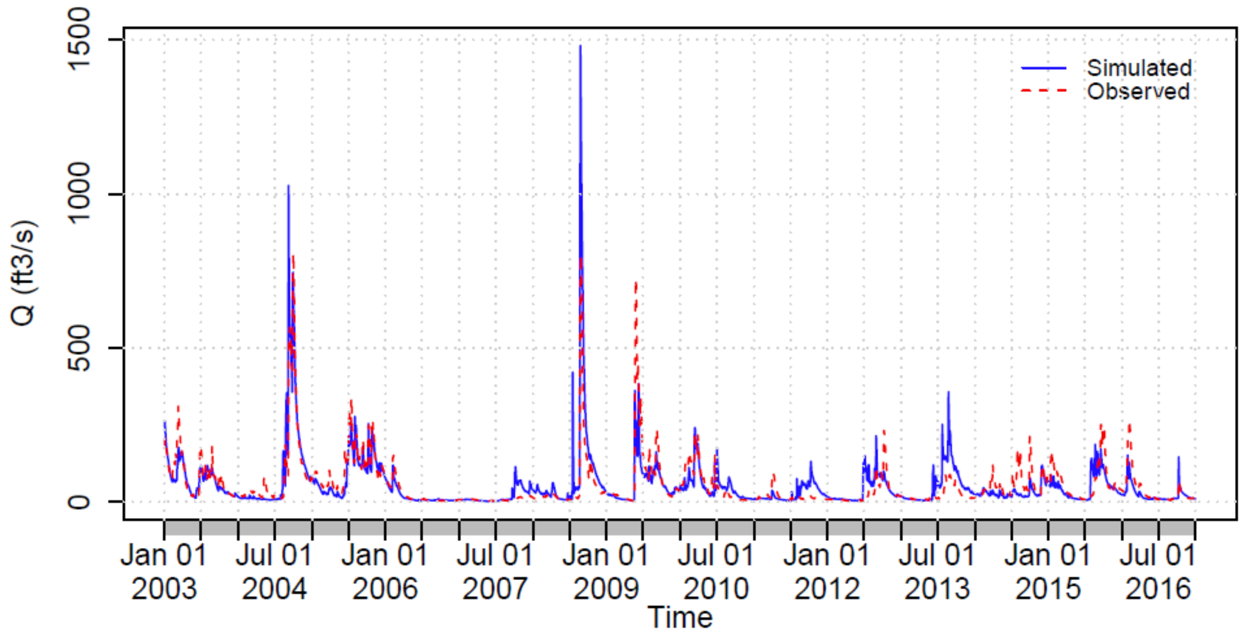
$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{N}(Q_{obs,i} - Q_{sim,i})^2}}{\sqrt{\sum_{i=1}^{N}(Q_{obs,i} - \overline{Q}_{obs})^2}}$$

Table 11 presents the statistical measures to quantify the performance of the hydrologic model at the 7 discharge stations in the Wekiva River Watershed. Three italic asterisked values indicate unsatisfactory model performance.

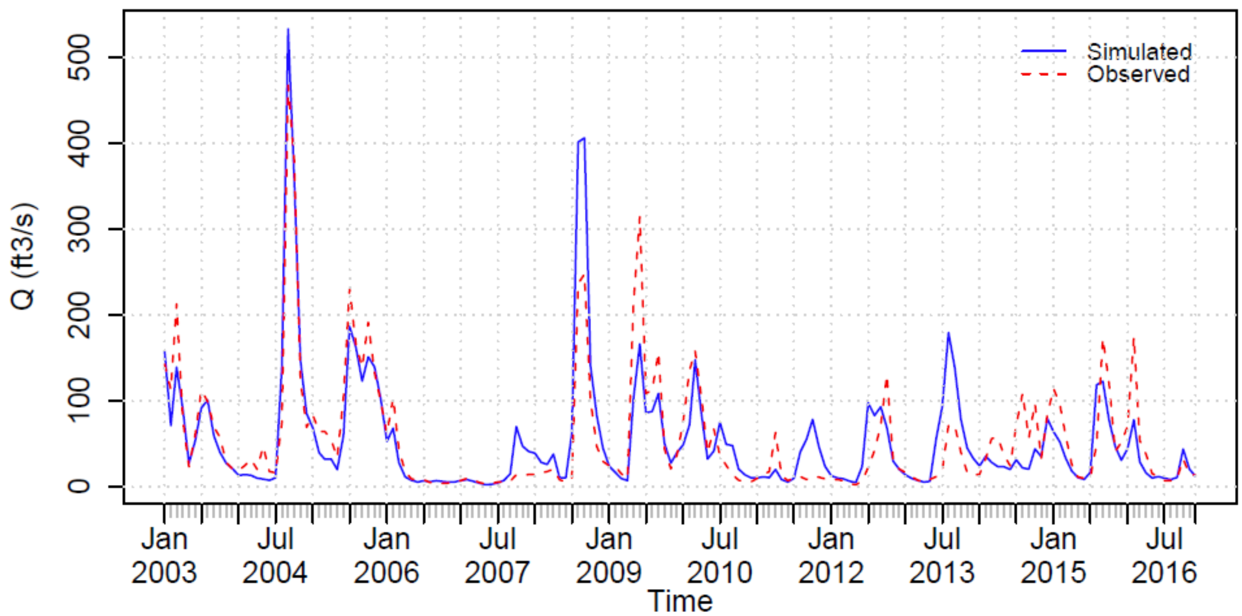
Table 11 Results of performance analysis

Statistics		Black Water Creek		Little Wekiva River		Wekiva River		
		SR44	Near Debary	SR434	SLB	Near Apopka	Old Railroad (RR)	SR46
Daily	RMSE	50.97	73.53	27.01	34.00	29.17	69.63	76.68
	R^2	0.69	0.64	0.69	0.76	0.50	0.73	0.69
	PBIAS %	-1.00	-1.10	-0.40	-6.90	0.00	4.80	-0.30
	high10%	-3.41	1.46	-4.29	-15.02	-6.91	-1.52	-3.99
	low50%	11.76	0.90	-1.26	9.99	0.53	9.28	4.28
	NSE	0.63	0.53	0.67	0.76	0.45	0.71	0.67
	RSR	0.60	0.69	0.57	0.49	0.74	0.54	0.58
Monthly	RMSE	37.24	54.50	15.14	22.50	24.62	47.27	54.36
	R^2	0.75	0.70	0.79	0.82	*0.45**	0.77	0.72
	PBIAS %	-1.30	-1.20	-0.50	-6.60	0.10	4.80	-0.30
	NSE	0.72	0.65	0.79	0.80	*0.34**	0.74	0.70
	RSR	0.53	0.59	0.46	0.44	*0.81**	0.51	0.54

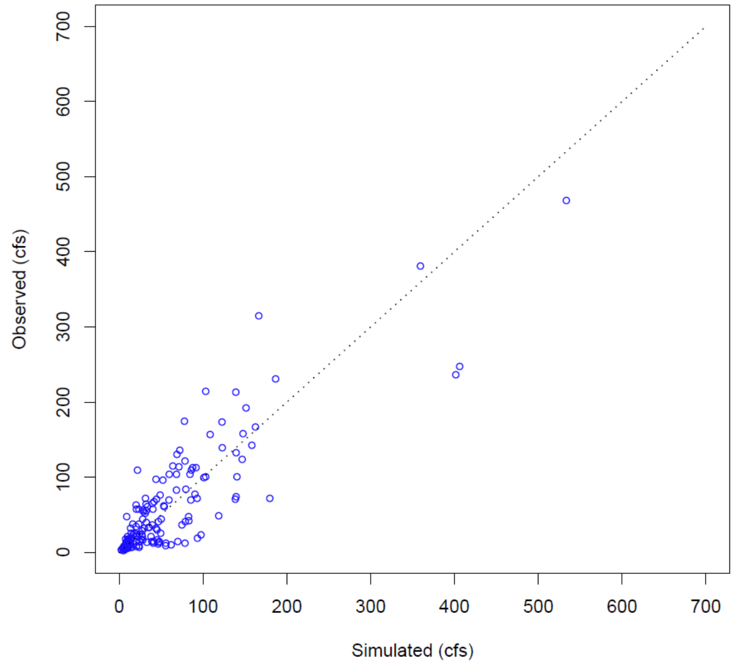
The calculated statistics indicate that the model performed well, except for the Wekiva River near Apopka site (Near Apopka). The model simulation for 6 of the sites was considered satisfactory to very good; however, the results of the simulation at the Apopka site were not satisfactory. Excluding Near Apopka, monthly NSE values were calculated in the range of 0.65 to 0.80, while monthly PBIAS ranged from -6.6% to 4.8%. The unsatisfactory results for the Near Apopka site could be because the rainfall dataset didn't capture some of the storm events in that discharge area and the site was disabled from 2012-2016, so no data is available for that time. Further, the flow at this particular station could have been highly impacted by some surrounding urban development activities that could not be accounted for temporally. Hydrographs of monthly and daily observed discharge data are overlaid with the model simulation results at each of the calibration sites. A flow duration curve for each site illustrates the probability of exceedance of daily average flow, comparing both simulated and observed data. A scatterplot of the monthly observed discharge versus the monthly simulated discharge is also provided to assess the performance of the model (Figures 17-23).



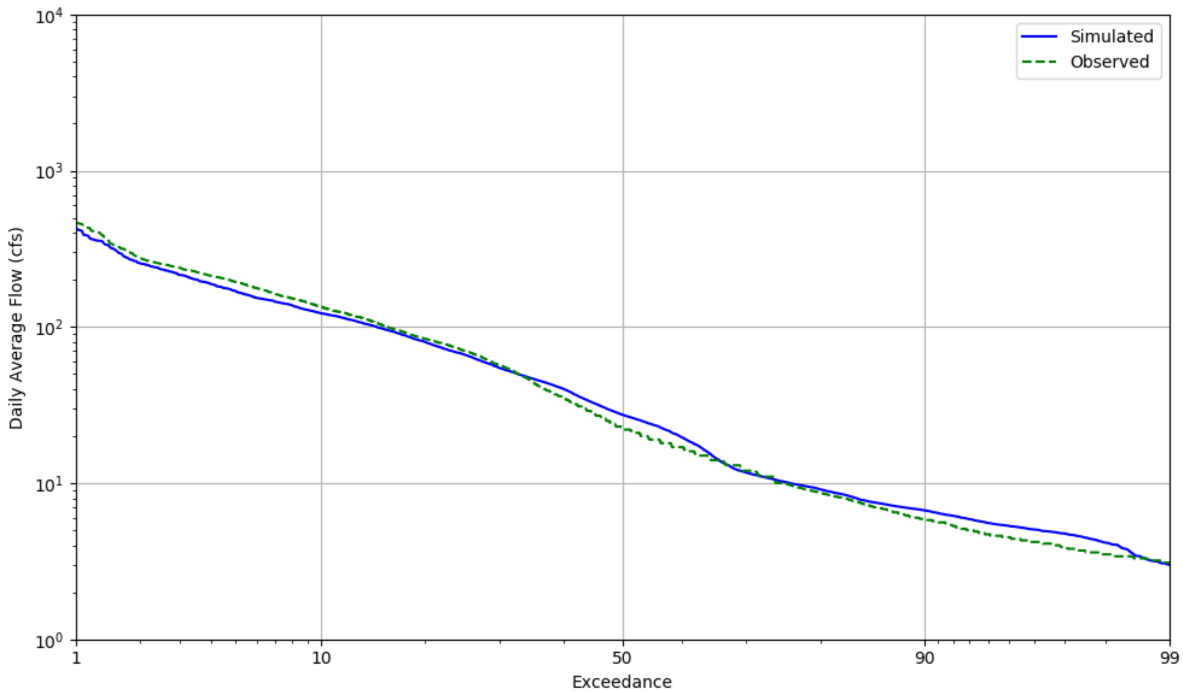
(a) Daily observed and simulated flow at SR44 gage (USGS 02235200) in Black Water Creek



(b) Monthly observed and simulated flow at SR44 gage (USGS 02235200) in Black Water Creek

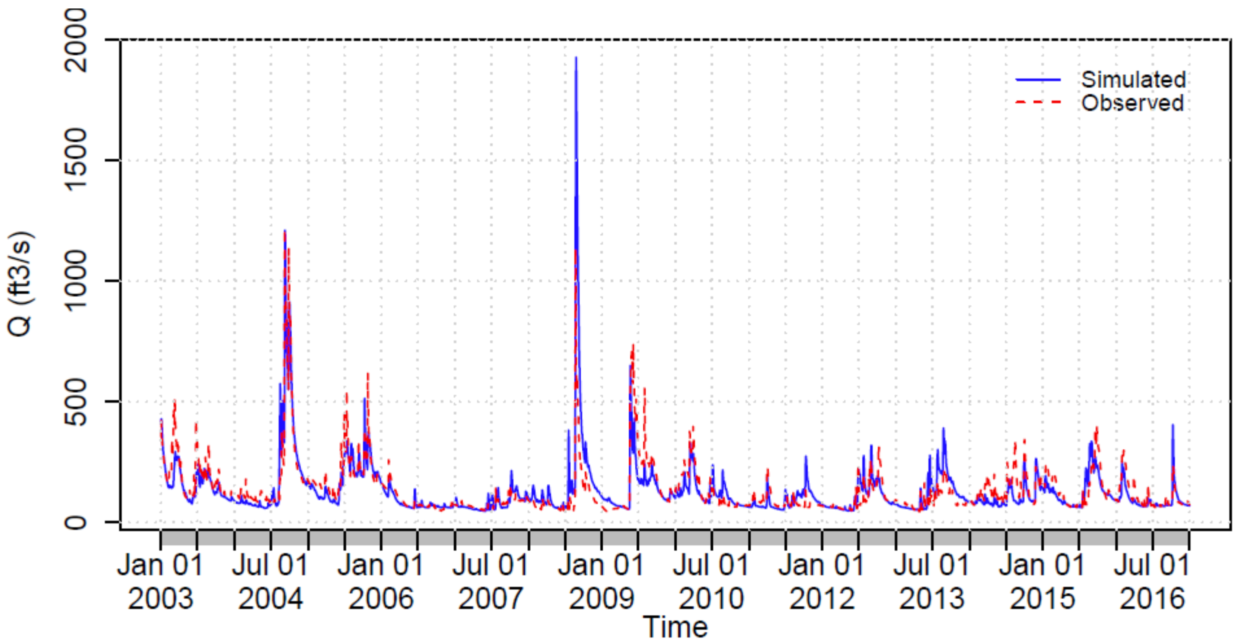


(c) Scatter plot of monthly observed and simulated flow at SR44 gage (USGS 02235200) in Black Water Creek

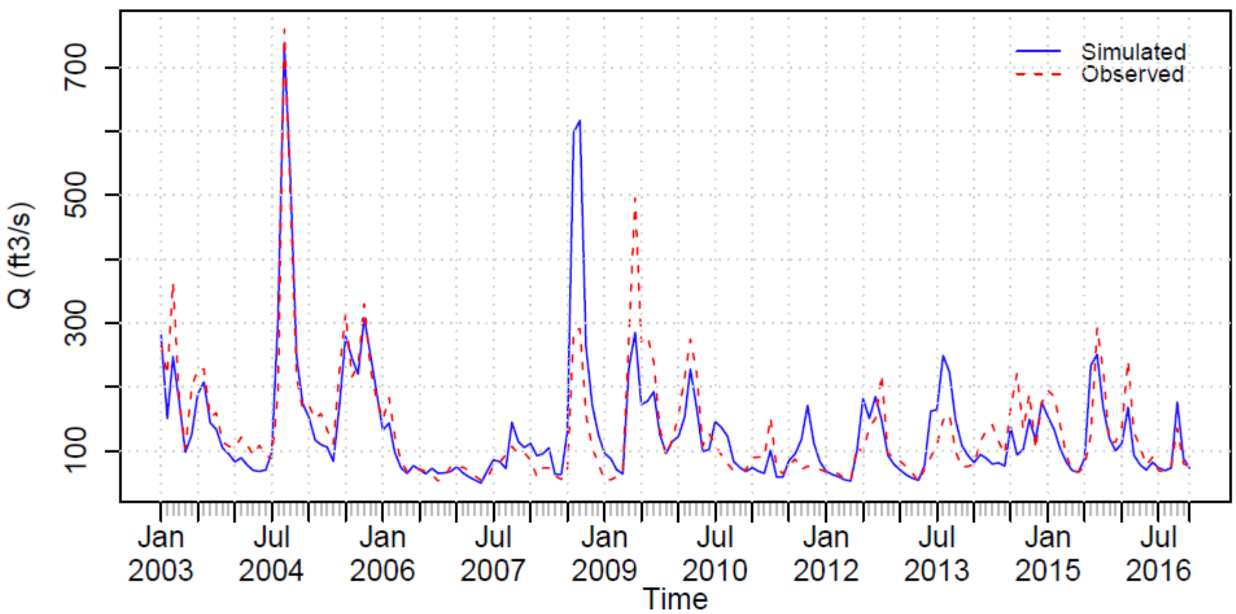


(d) Flow duration curve at SR44 gage (USGS 02235200) in Black Water Creek

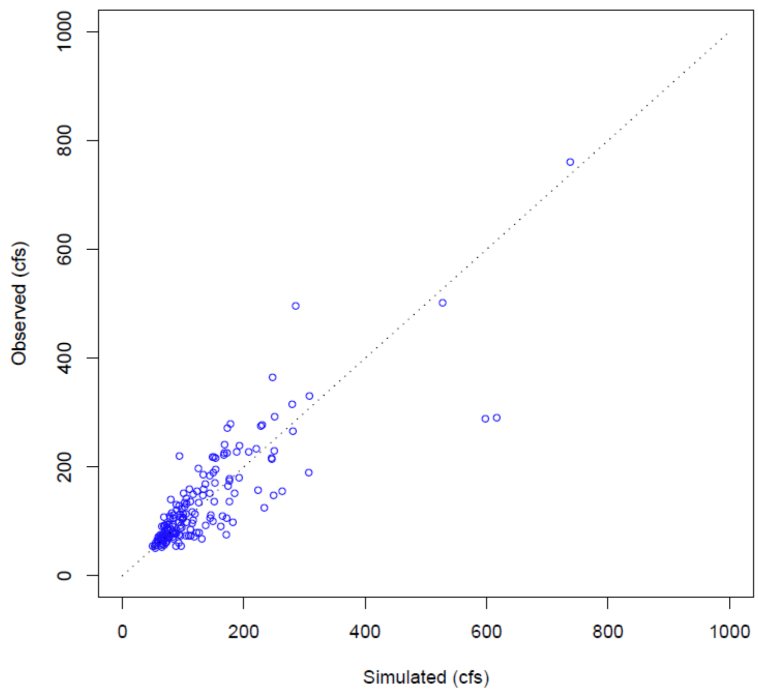
Figure 17 Visual comparison of observed and simulated discharges at SR44 gage (USGS 02235200) in Black Water Creek



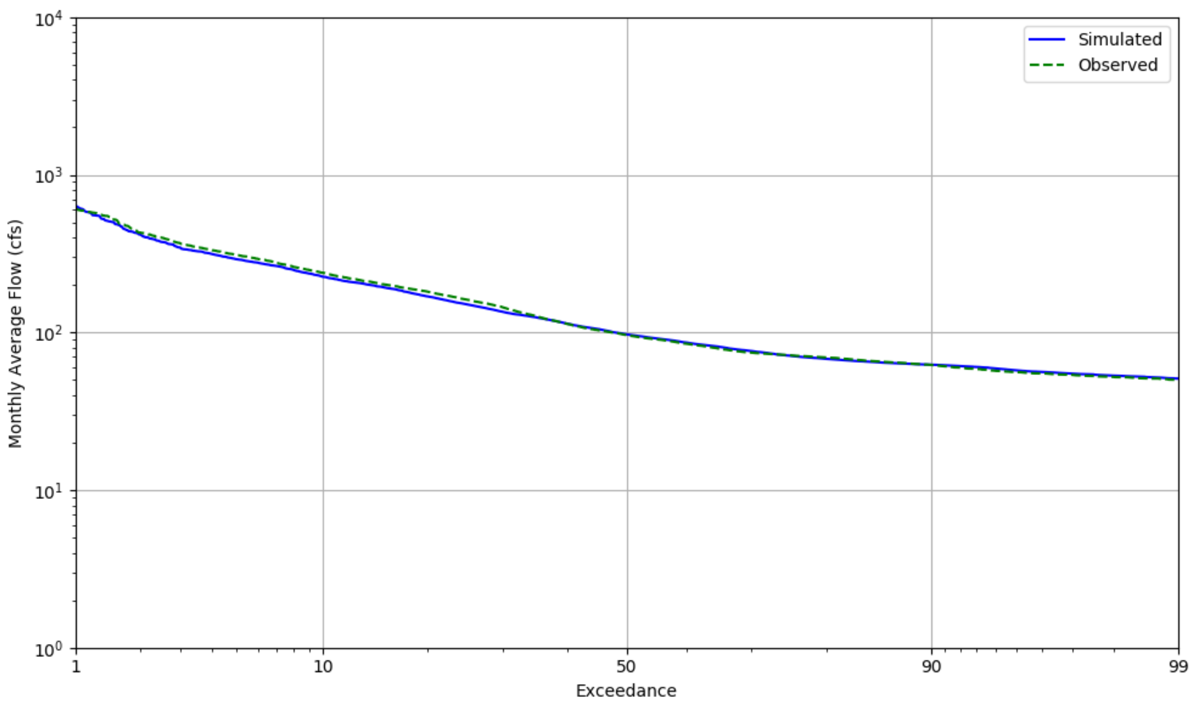
(a) Daily observed and simulated flow at Near Debary gage in Black Water Creek at Near Debary gage (SJRWMD 30143084) in Black Water Creek



(b) Monthly observed and simulated flow at Near Debary gage (SJRWMD 30143084) in Black Water Creek

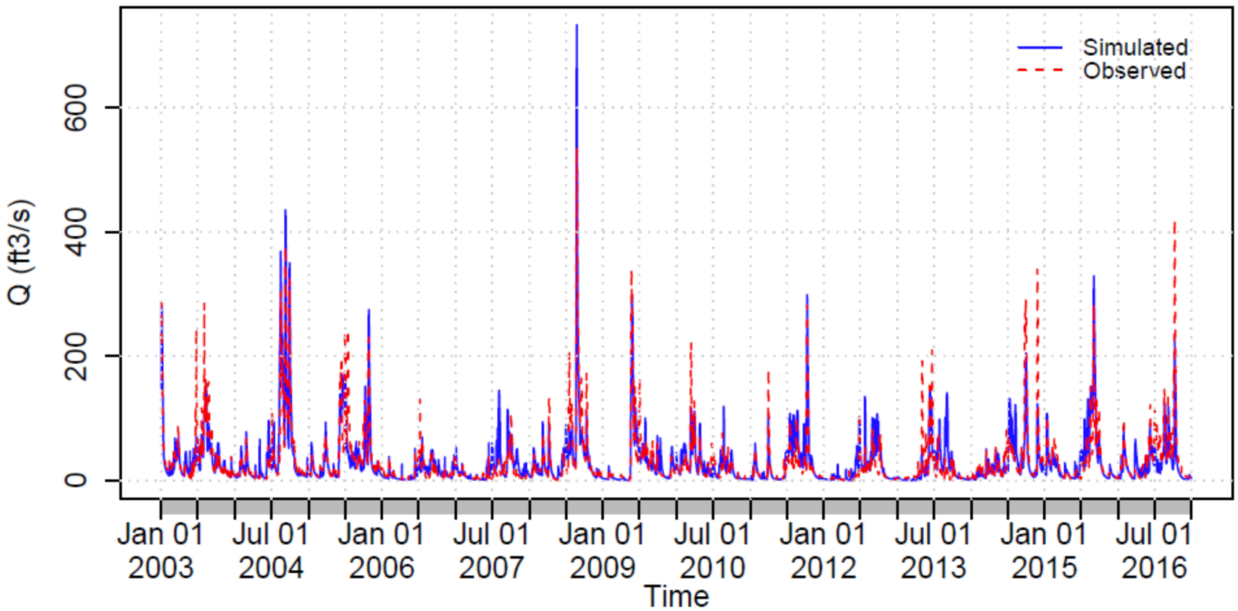


(c) Scatter plot of monthly observed and simulated flow at Near Debary gage (SJRWMD 30143084) in Black Water Creek

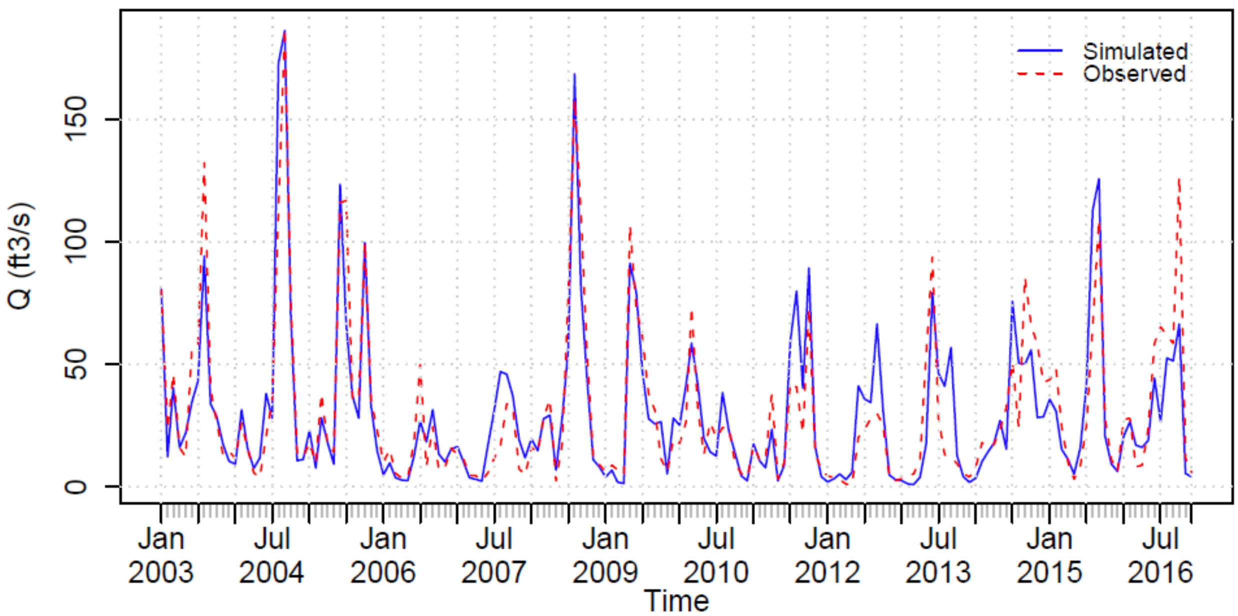


(d) Flow duration curve at Near Debary gage (SJRWMD 30143084) in Black Water Creek

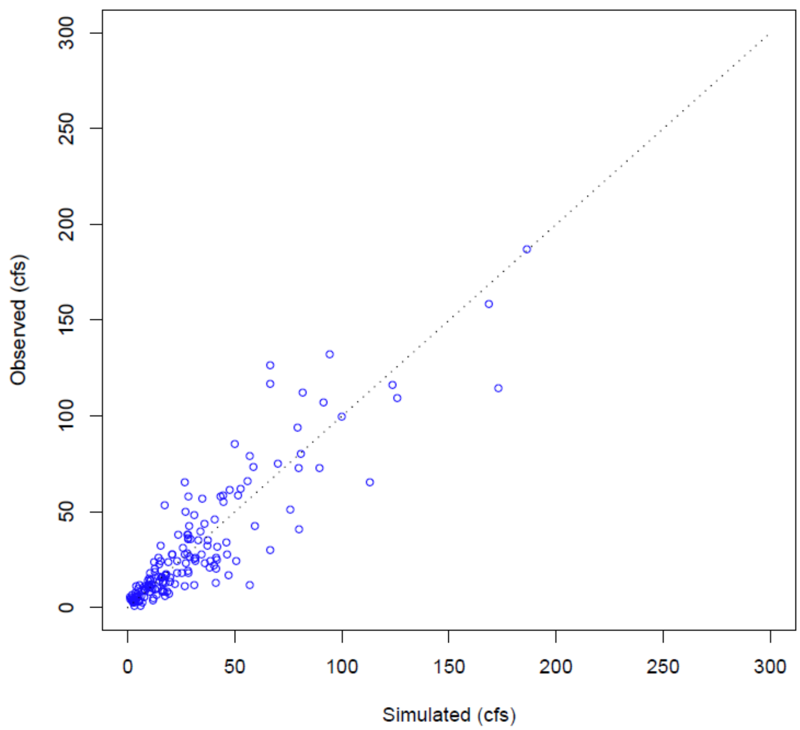
Figure 18 Visual comparison of observed and simulated discharges at Near Debary gage (SJRWMD 30143084) in Black Water Creek



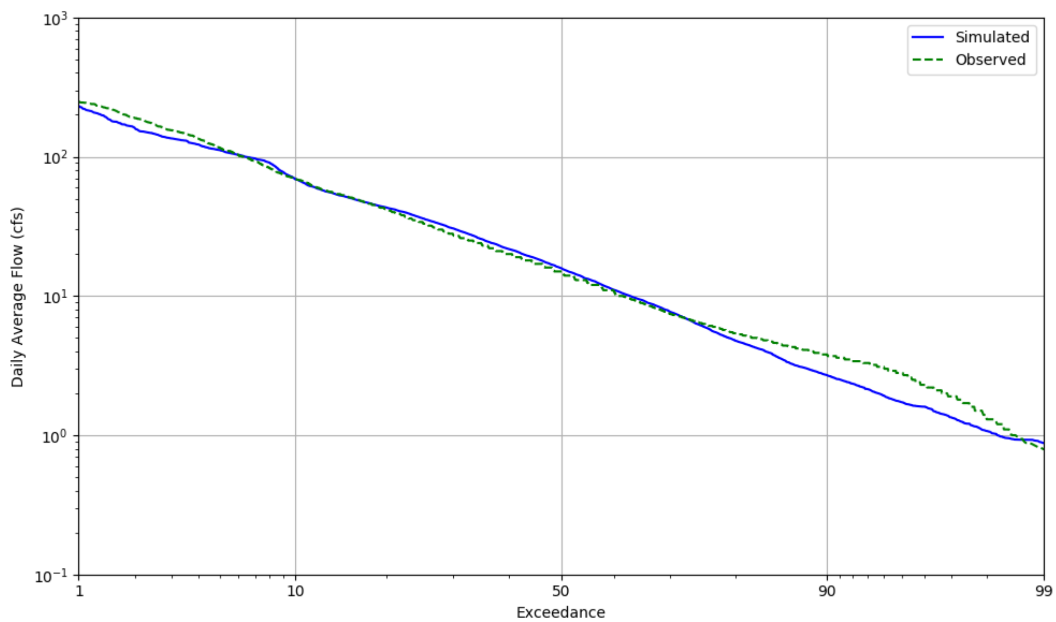
(a) Daily observed and simulated flow at SR434 gage (USGS 02234990) in Little Wekiva River



(b) Monthly observed and simulated flow at SR434 gage (USGS 02234990) in Little Wekiva River

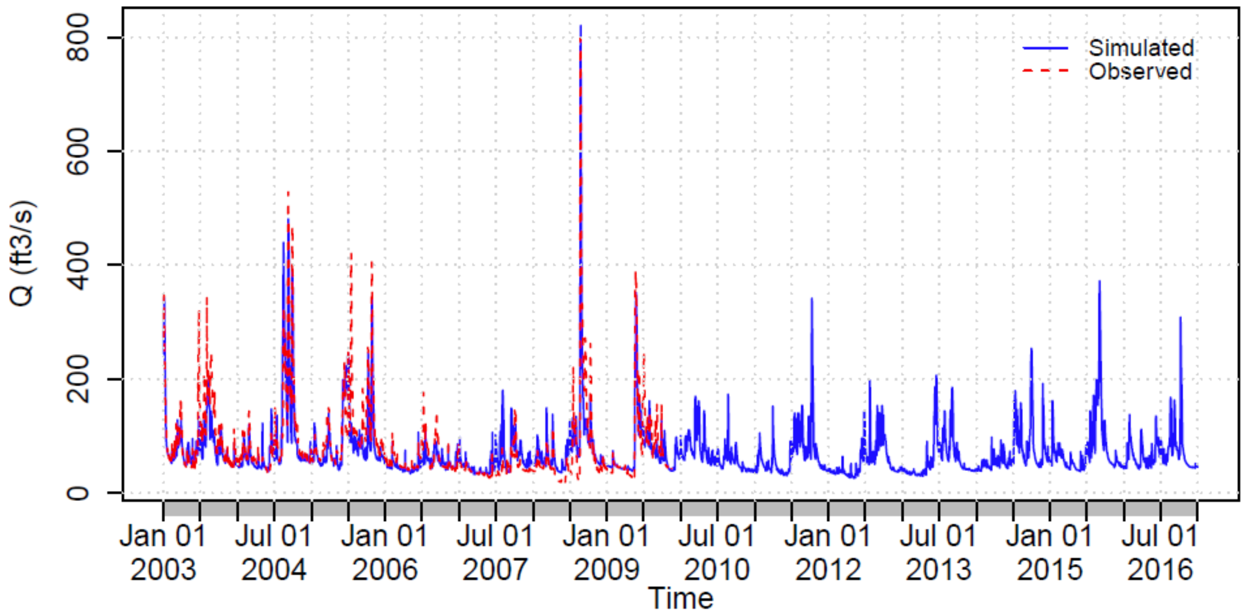


(c) Scatter plot of monthly observed and simulated flow at SR434 gage (USGS 02234990) in Little Wekiva River

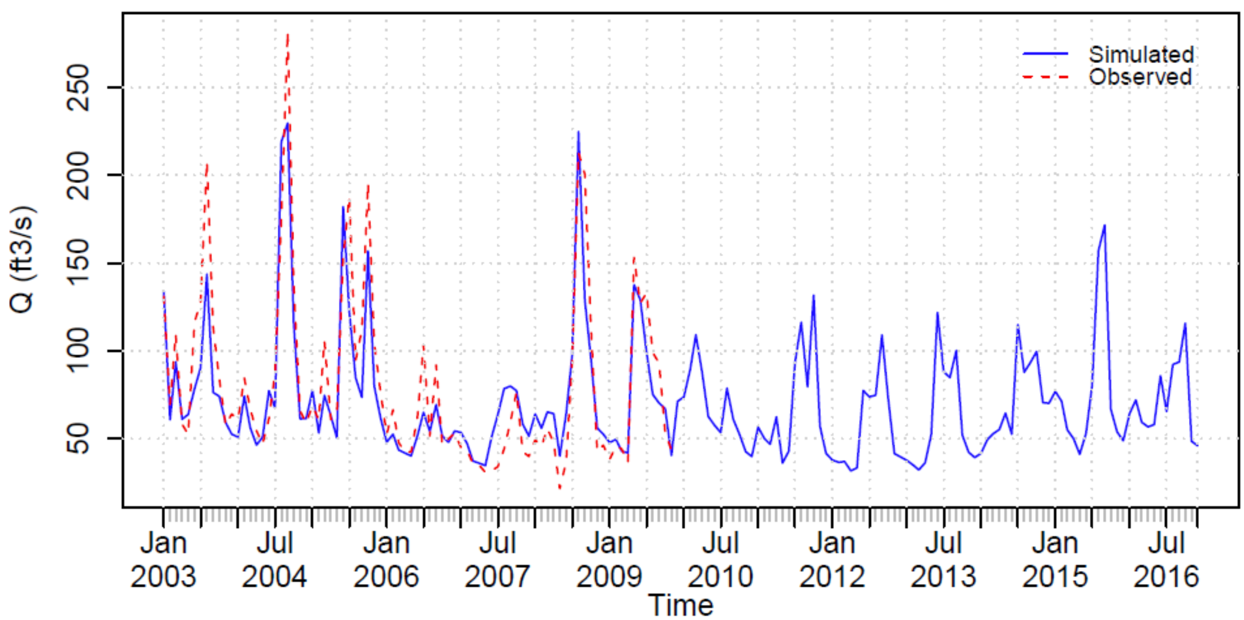


(d) Flow duration curve at SR434 gage (USGS 02234990) in Little Wekiva River

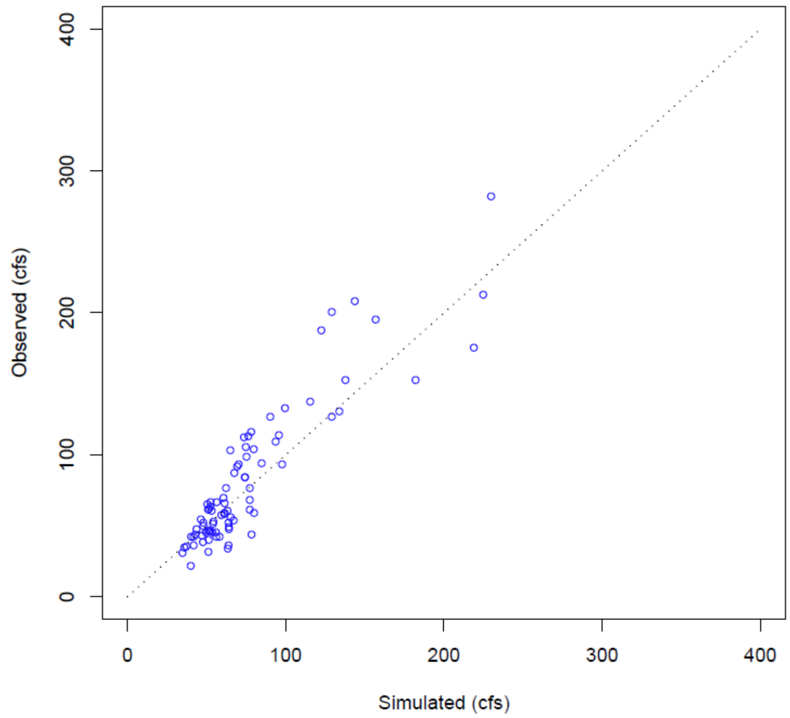
Figure 19 Visual comparison of observed and simulated discharges at SR434 gage (USGS 02234990) in Little Wekiva River



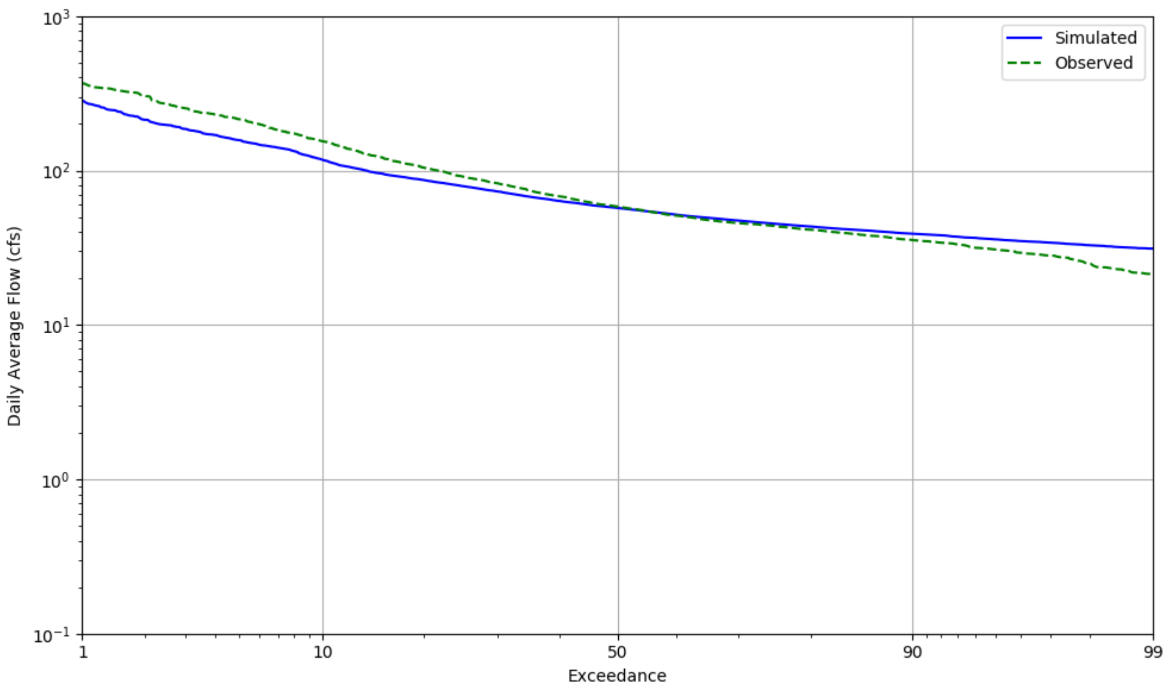
(a) Daily observed and simulated flow at SLB gage (SJRWMD 09502132) in Little Wekiva River



(b) Monthly observed and simulated flow at SLB gage (SJRWMD 09502132) in Little Wekiva River

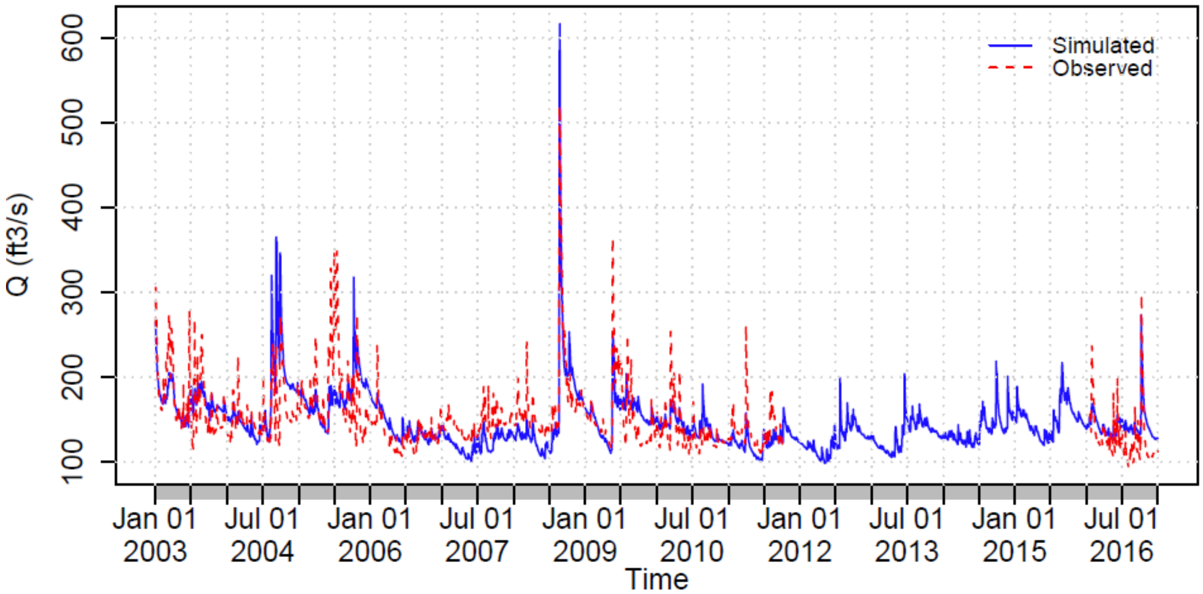


(c) Scatter plot of monthly observed and simulated flow at SLB gage (SJRWMD 09502132) in Little Wekiva River

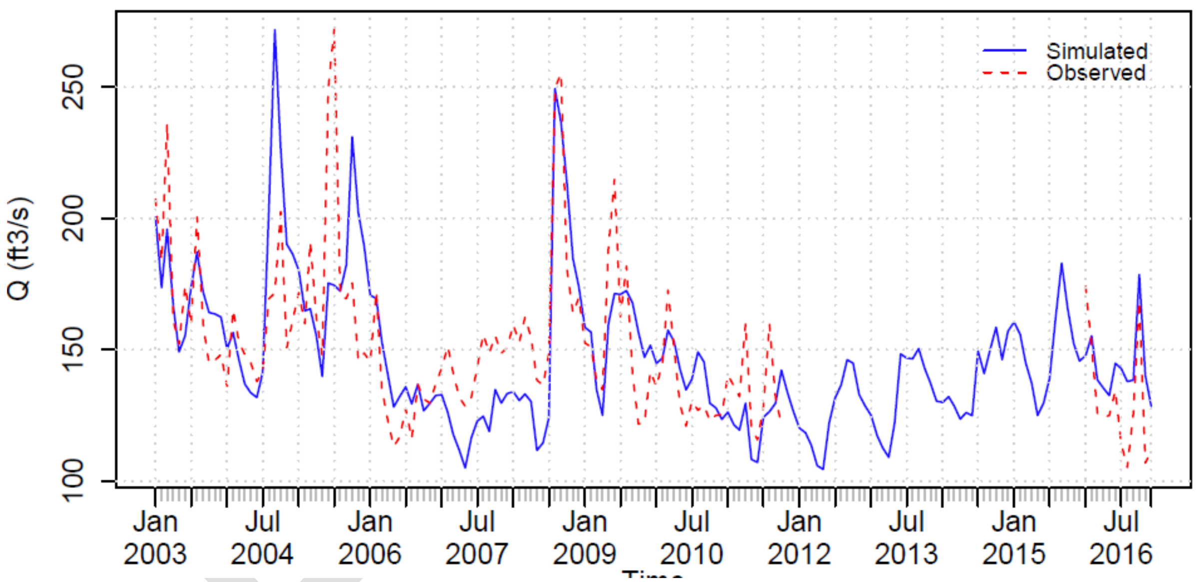


(d) Flow duration curve at SLB gage (SJRWMD 09502132) in Little Wekiva River

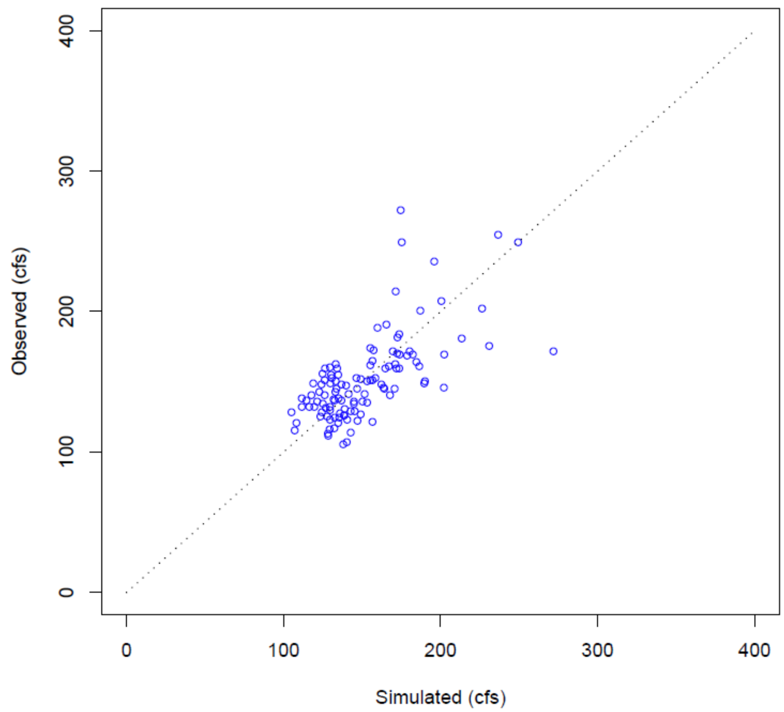
Figure 20 Visual comparison of observed and simulated discharges at SLB gage (SJRWMD 09502132) in Little Wekiva River



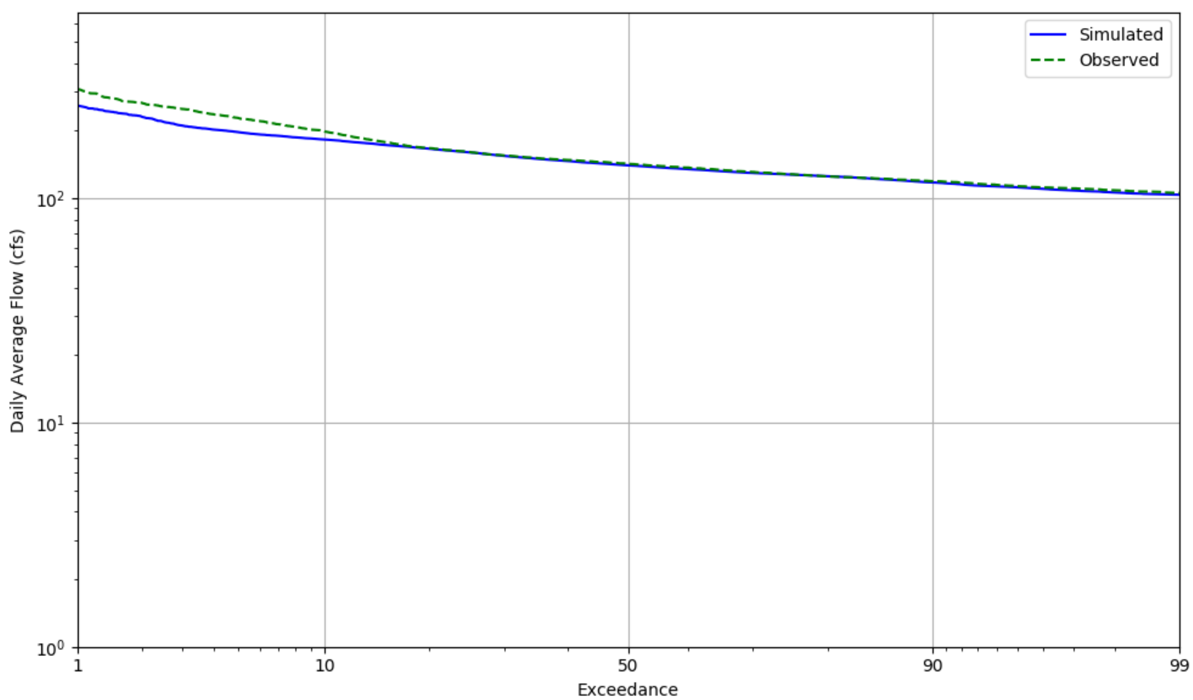
(a) Daily observed and simulated flow at Near Apopka gage (SJRWMD 09522138) in Wekiva River



(b) Monthly observed and simulated flow at Near Apopka gage (SJRWMD 09522138) in Wekiva River

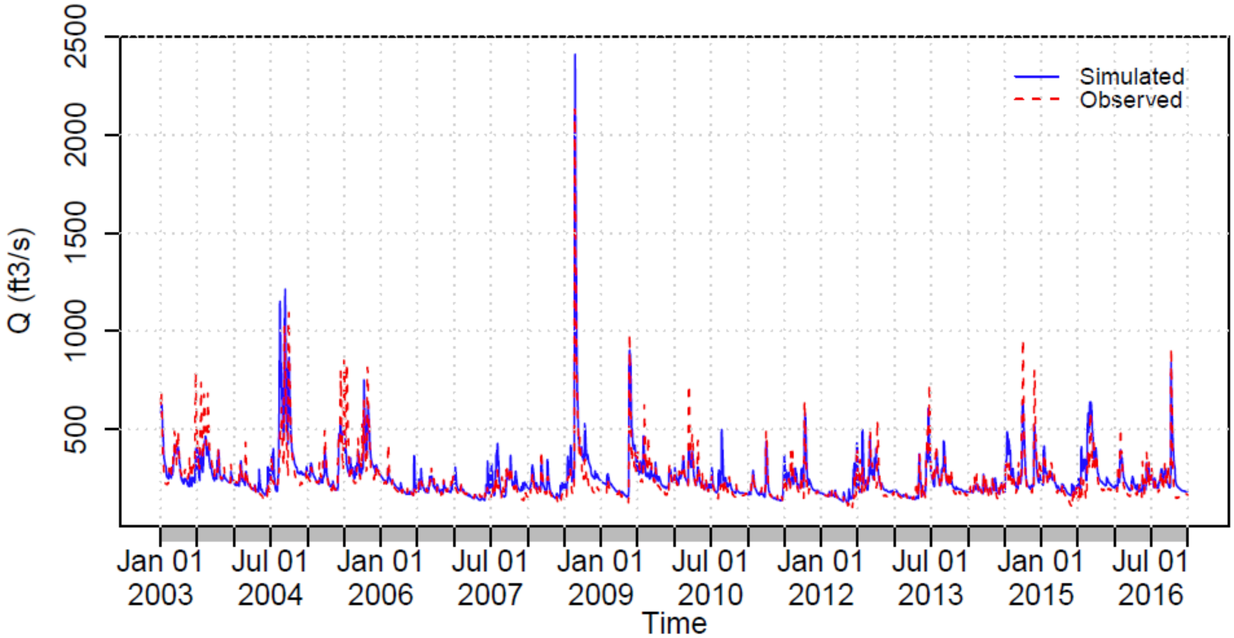


(c) Scatter plot of monthly observed and simulated flow at Near Apopka gage (SJRWMD 09522138) in Wekiva River

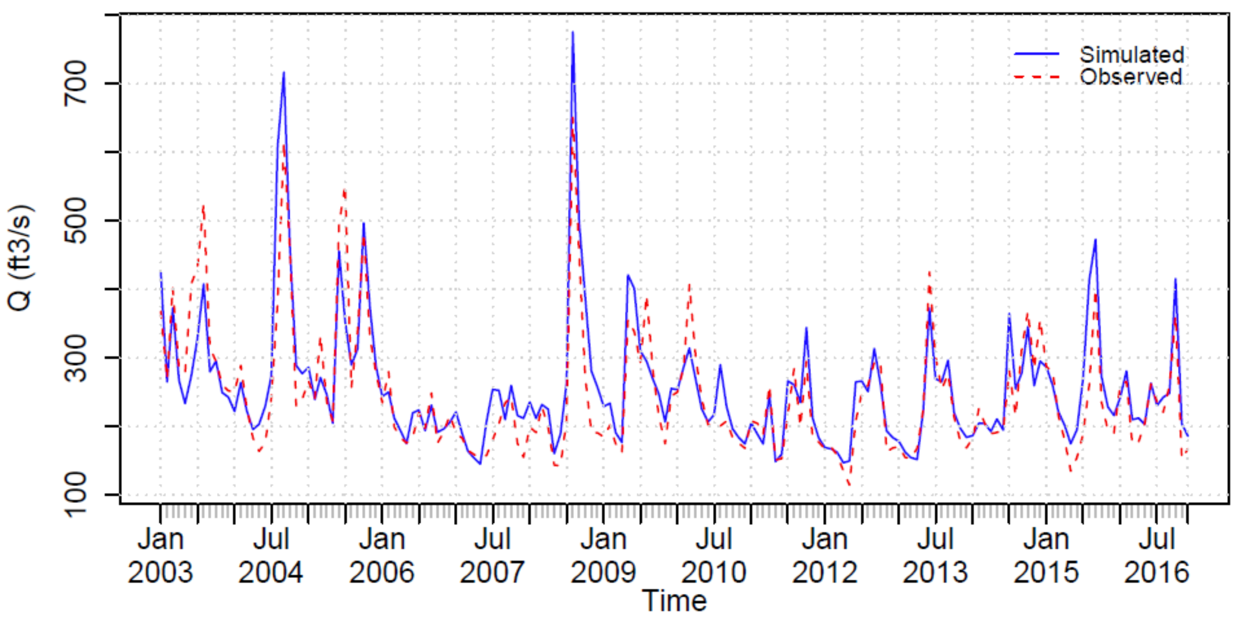


(d) Flow duration curve at Near Apopka gage (SJRWMD 09522138) in Wekiva River

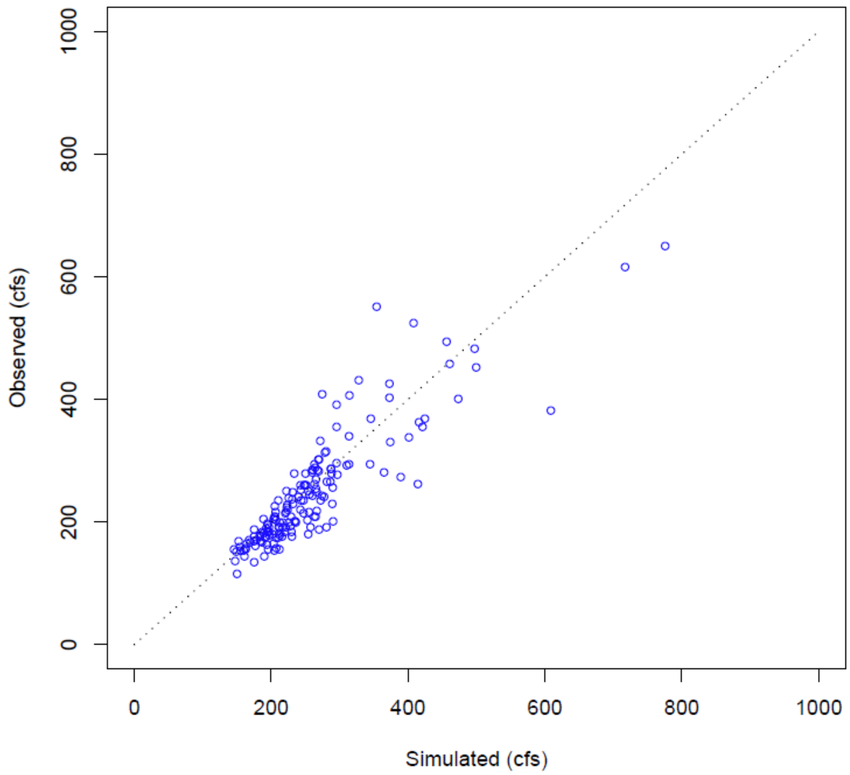
Figure 21 Visual comparison of observed and simulated discharges at Near Apopka gage (SJRWMD 09522138) in Wekiva River



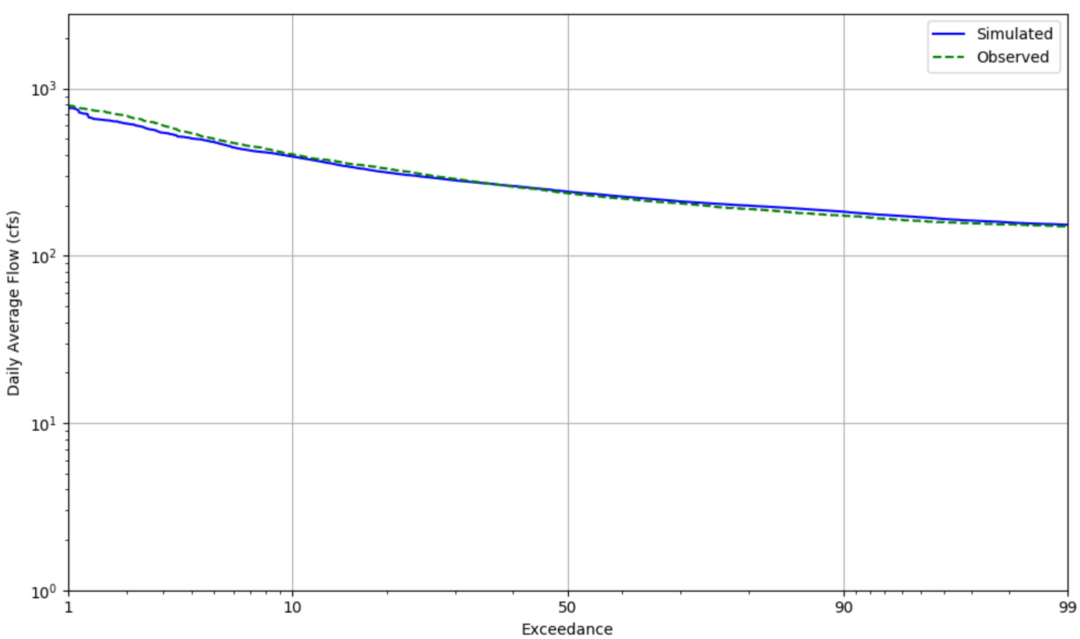
(a) Daily observed and simulated flow at Old Railroad gage (SJRWMD 09512135) in Wekiva River



(b) Monthly observed and simulated flow at Old Railroad gage (SJRWMD 09512135) in Wekiva River

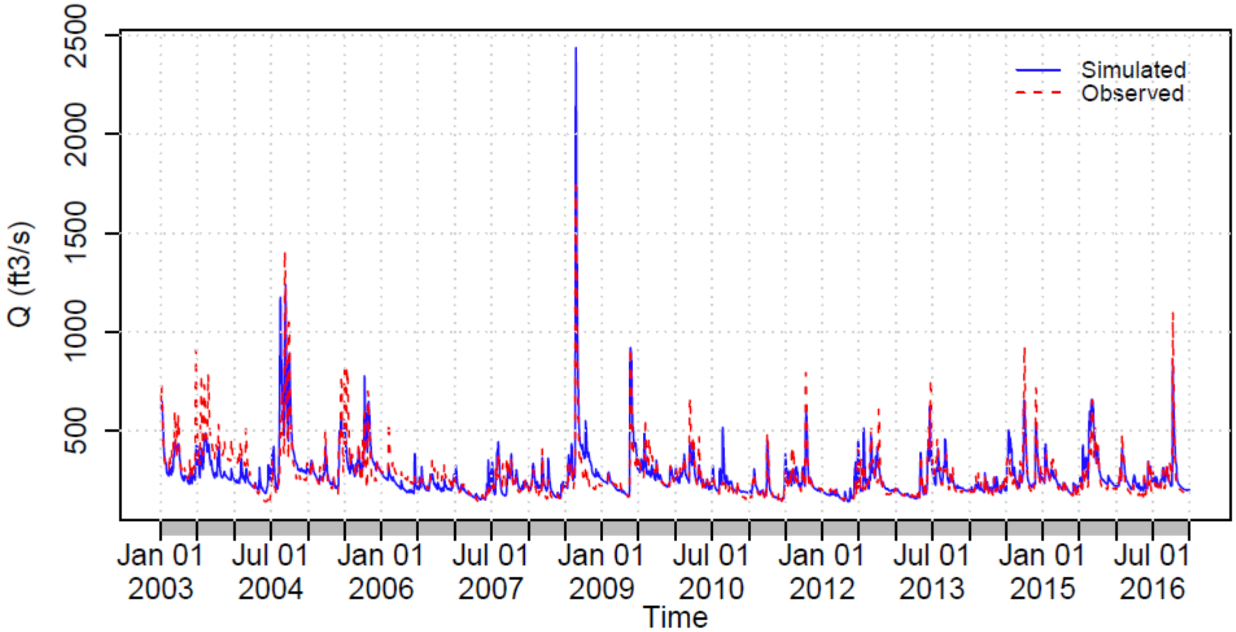


(c) Scatter plot of monthly observed and simulated flow at Old Railroad gage (SJRWMD 09512135) in Wekiva River

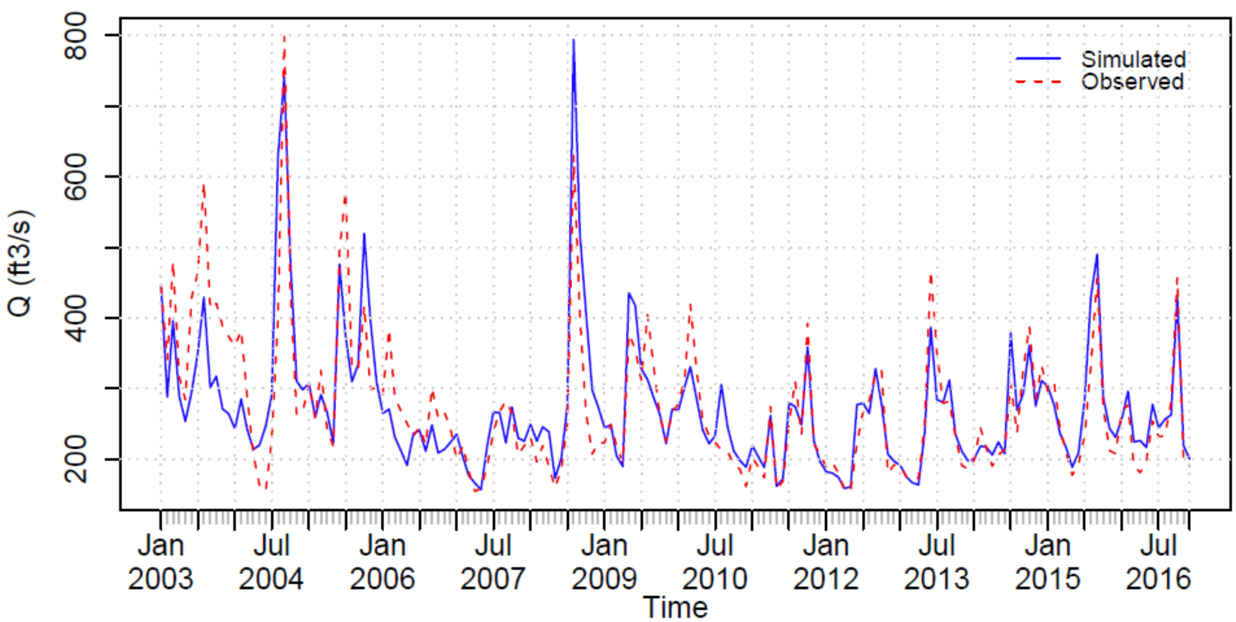


(d) Flow duration curve at Old Railroad gage (SJRWMD 09512135) in Wekiva River

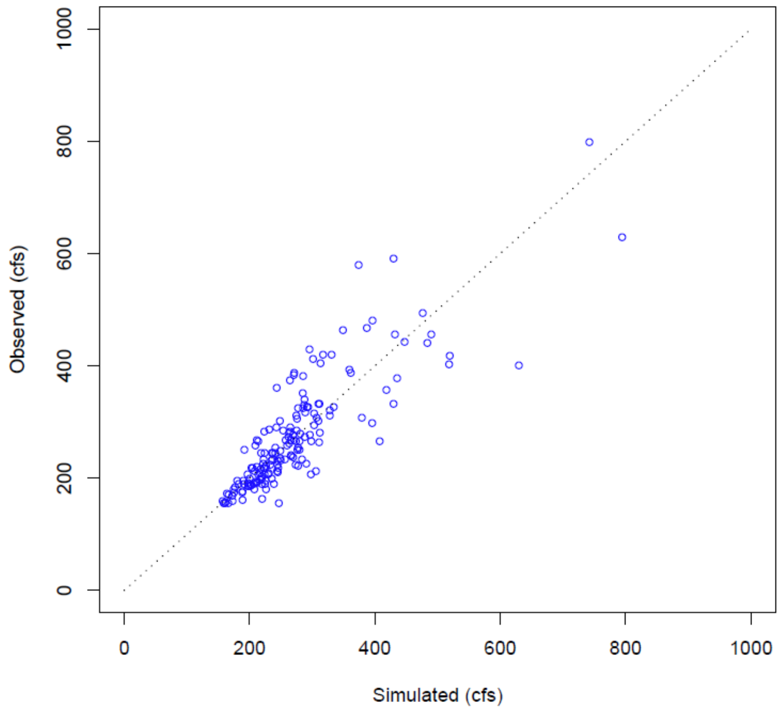
Figure 22 Visual comparison of observed and simulated discharges at Old Railroad gage (SJRWMD 09512135) in Wekiva River



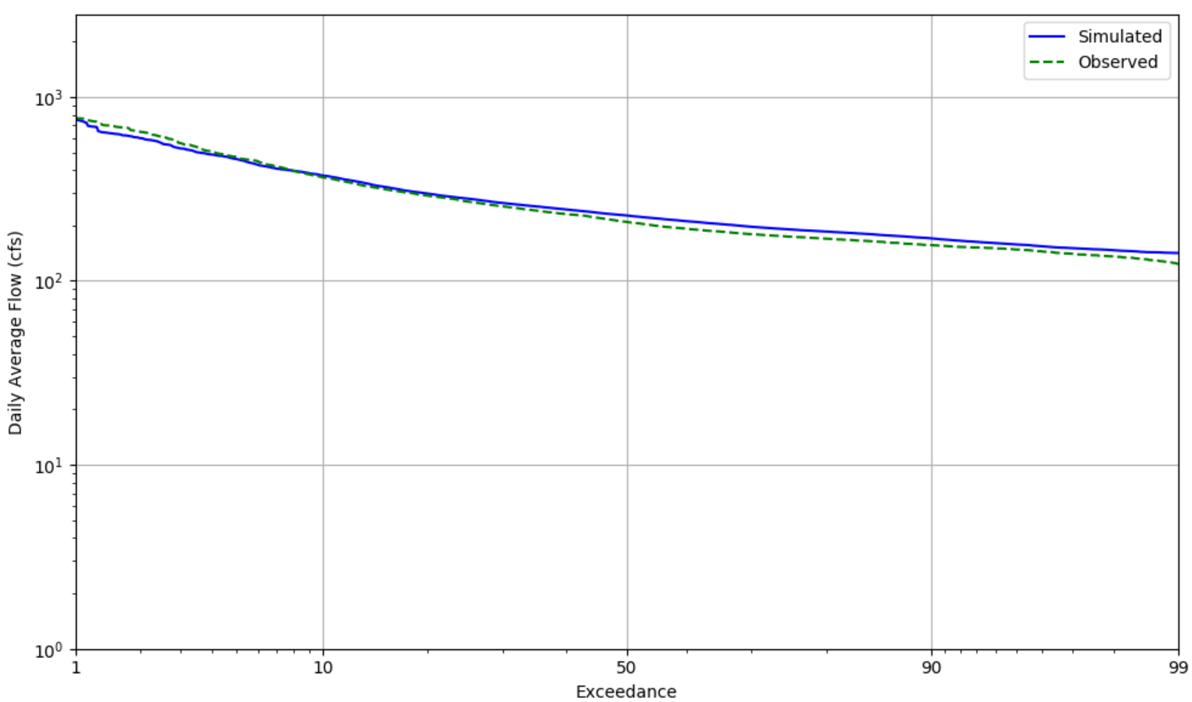
(a) Daily observed and simulated flow at SR46 (USGS 02235000) gage in Wekiva River



(b) Monthly observed and simulated flow at SR46 (USGS 02235000) gage in Wekiva River



(c) Scatter plot of monthly observed and simulated flow at SR46 (USGS 02235000) gage in Wekiva River



(d) Flow duration curve at SR46 (USGS 02235000) gage in Wekiva River

Figure 23 Visual comparison of observed and simulated discharges at SR46 (USGS 02235000) gage in Wekiva River

4. HYDRAULIC MODEL DEVELOPMENT FOR THE WEKIVA RIVER AND ASSOCIATED TRIBUTARIES

4.1 HEC-RAS MODEL DEVELOPMENT

4.1.1 Model domain

The HEC-RAS model domain includes Rock Springs Run, Wekiwa Springs Run, the segment of Little Wekiva River downstream of the SR464 bridge, and the segment of Wekiva River from its junction with Rock Springs Run to the Lower Wekiva River gage (Figure 24). In total, 72 cross sections were used to represent the study area in the model. Density of cross sections varied by streams. For example, 38 transects over 13.3 miles of the Wekiva River were used in the model, while 5.9 miles of the Little Wekiva River portion were represented with 8 cross sections. Upstream waters of the Wekiva River above the confluence with the Little Wekiva River were set up with relatively less cross section data compared to the Wekiva River downstream from the Little Wekiva River confluence. When the distance between the upstream and downstream cross sections was too large, such as XS1 and Lower Wekiva, interpolated cross sections were added to reduce model instability during the model simulation. Cross section data surveyed in 2018 were not available when the HEC-RAS model was calibrated, so were not incorporated in this model.

As discussed in Section 2.4, due to stream bed condition change, observed stages at low flow conditions in the Wekiva River were significantly increased after 2008, and the pattern was consistent through 2016. Therefore, the time domain for the HEC-RAS model simulation was selected from 2008 to 2016 instead of using the HSPF model simulation period (2003-2016).

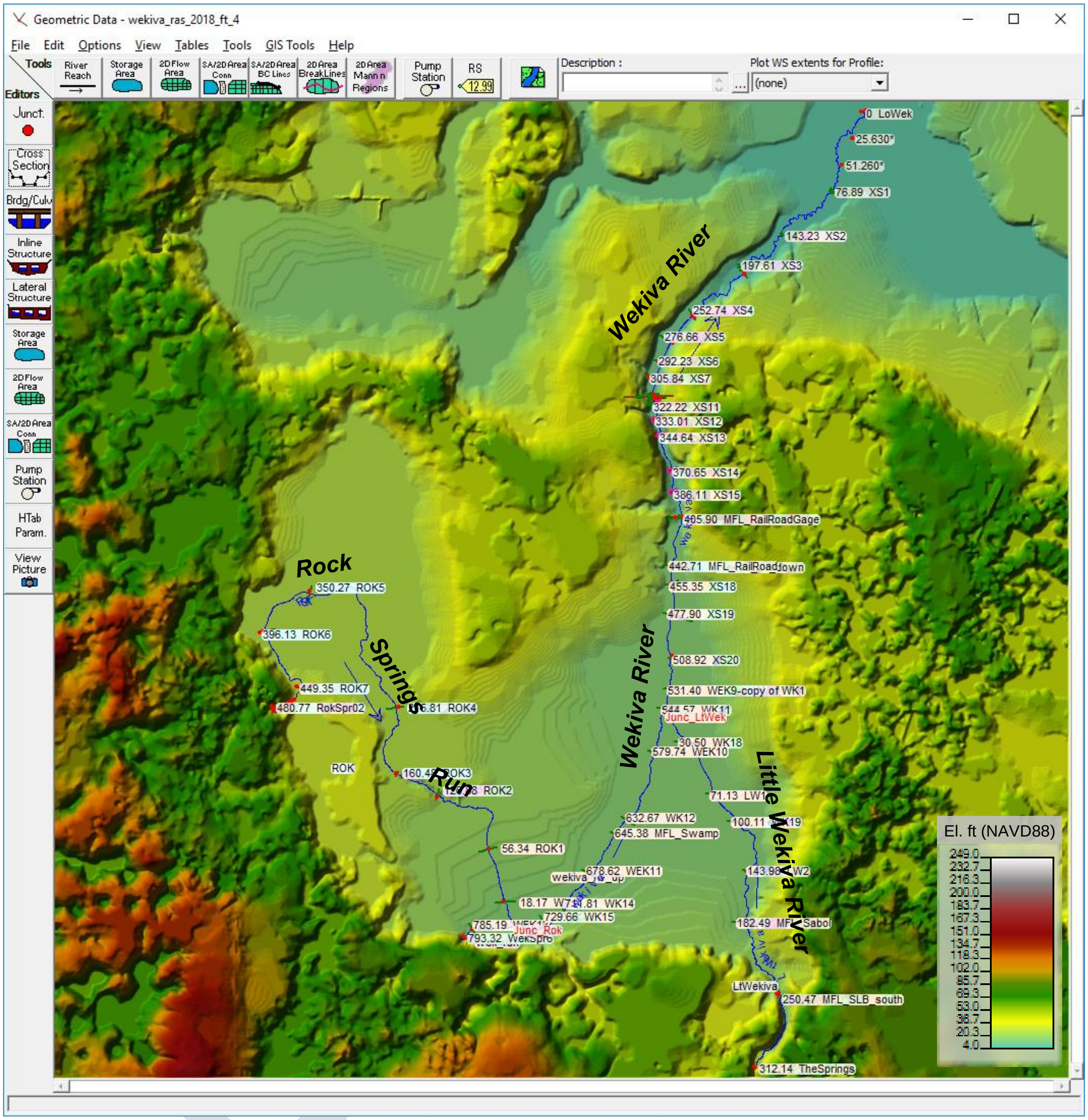


Figure 24 Geometric data view of the HEC-RAS model for Wekiva River

4.1.2 Manning's n

Floodplain and instream vegetation significantly impacts both stage and flow. Previous studies showed that in a highly vegetated channel, Manning's n is generally decreased as stream depth increases (Kadlec and Wallace, 2009 and Wu et al., 1999). Highly vegetated stream segments are often encountered in the Wekiva River and upstream segments (Figure 25-29); friction from this streambed vegetation varies by flow or water level and contributes to water level increase.

Figure 25 Vegetated stream near ROK2. The photo was taken by J. Mace on 2/27/2018. The white tape ruler line found near the bottom of the picture is for surveying the stream cross section, and is perpendicular to the stream direction.

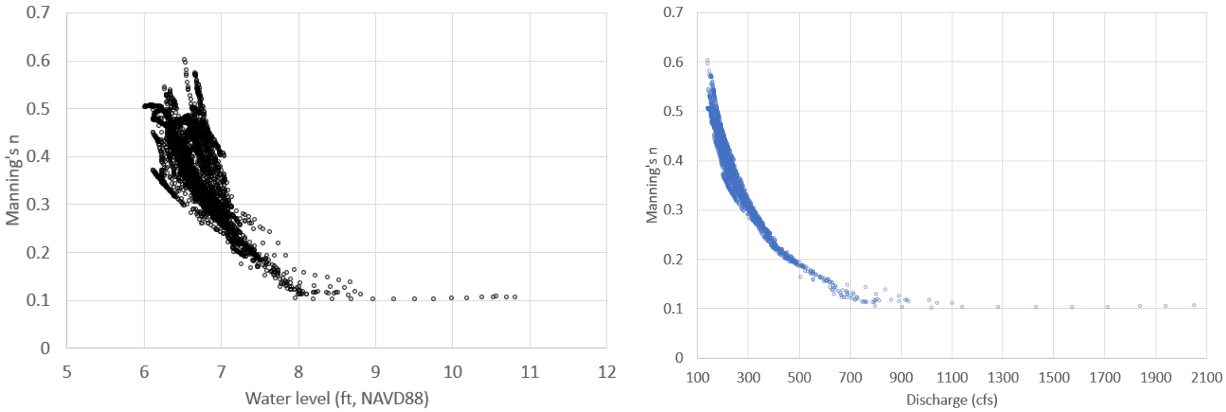
Figure 26 Vegetated stream at near ROK1. The photo was taken by Ray Doeshler on 2/27/2018.

Figure 27 Little Wekiva River at Spring Landing Blvd South. The photo was taken by J. Mace on 3/14/2017.

Figure 28 Wekiva River at the Wekiva Swamp Transect. The photo was taken by J. Mace on 4/13/2016.

Figure 29 Blackwater Creek near SR44. The photo was taken by J. Mace on 10/21/2010.

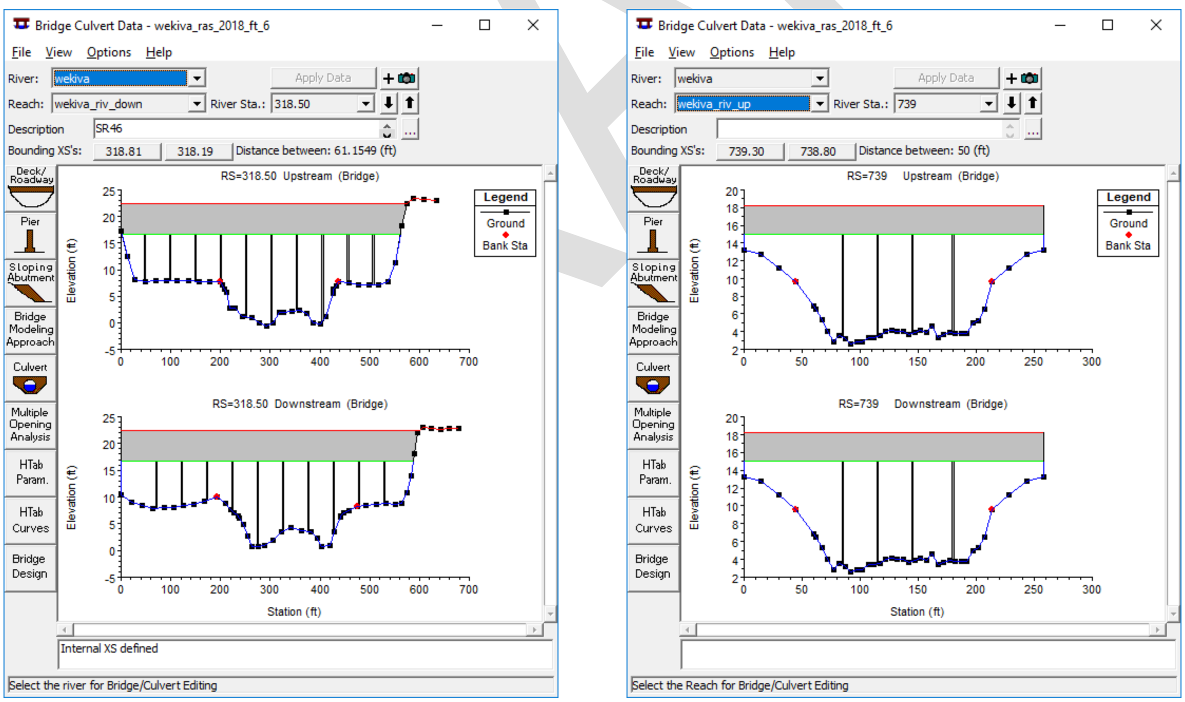
HEC-RAS model provides options for varying Manning's n by flow or depth. A preliminary analysis was conducted to calculate Manning's n at SR 46; its results showed more consistent relationship between Manning's n and flow (Figure 30). Therefore, Manning's n was varied with respect to flow in the HEC-RAS model to simulate low to high flow regimes for both steady and unsteady simulation. In the steady state simulation, the "Vertical Variation in Manning's n Values" option under cross section data editor was used to vary Manning's n, while the "flow roughness factors" option was implemented during the unsteady state simulation.



(a) Varied Manning's n by water level (b) Varied Manning's n by flow
Figure 30 Calculated Manning's n values by different water level and discharge at the SR46

4.1.3 Bridges

The Wekiva River bridges at SR46 and at the end of Miami Springs Drive were included in the HEC-RAS model (Figure 31). The geometric data of the bridge at SR46, such as pier and deck were derived from previous HEC-RAS modeling work (SJRWMD, 2016). The bridge geometry located at the end of the Miami Springs Drive, was collected from a field trip in 2018.



(a) Wekiva River at SR46 (b) Wekiva River at Miami Springs Drive
Figure 31 Geometric data for bridges at SR46 and Miami Springs Drive

4.2 STEADY STATE SIMULATION AND CALIBRATION

4.2.1 Boundary conditions for steady state simulation

Observed water level data at the Lower Wekiva gage (located 0.9 miles from the Wekiva River mouth) were used as a downstream boundary condition, while discharge data at Rock Springs, Wekiwa Springs and the Little Wekiva River at SR 434 gaging stations were applied to upstream boundary conditions (Figure 32).

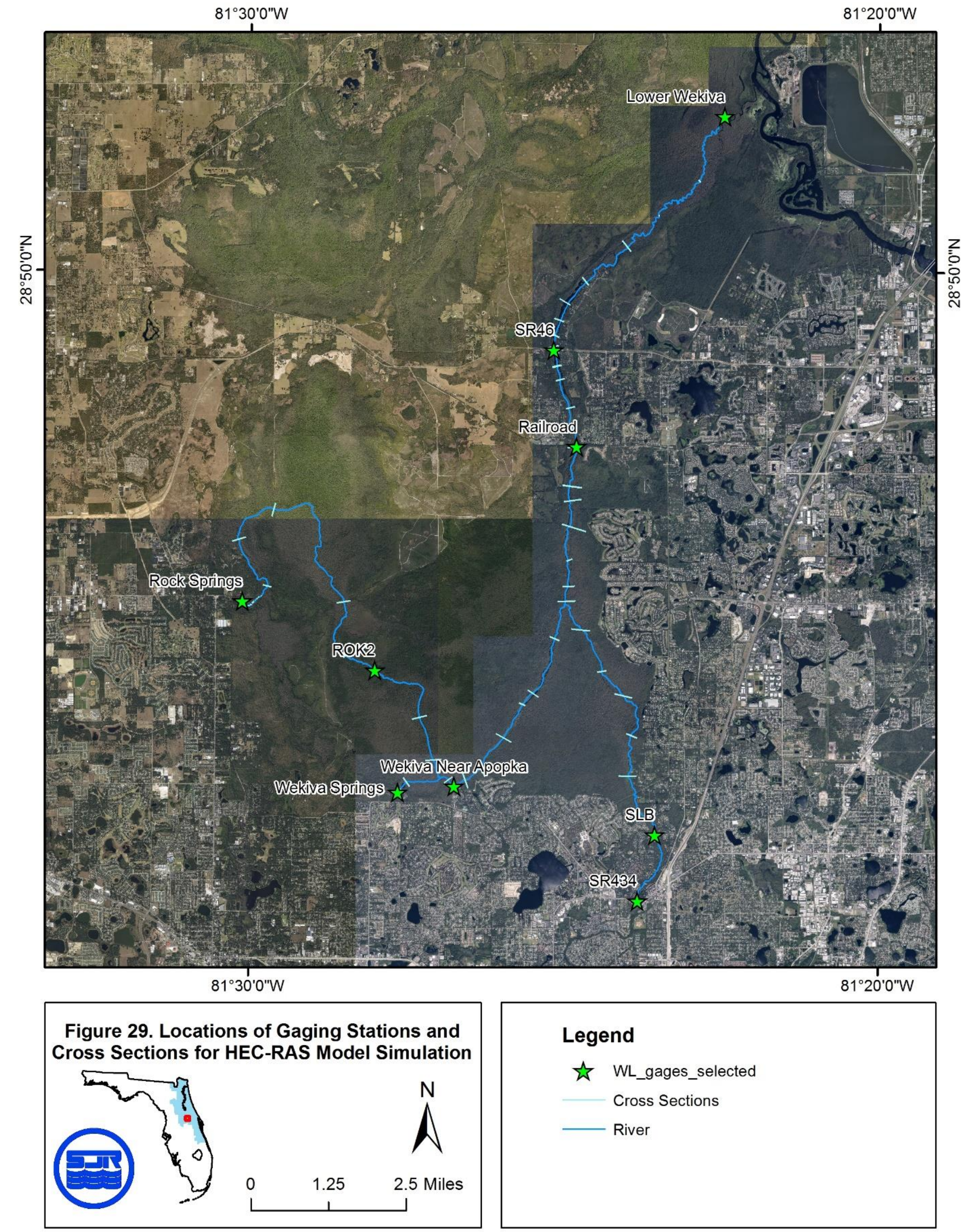


Figure 32 Locations of gaging stations and cross sections for the HEC-RAS model simulation

4.2.2 Channel flow profiles

For the steady state simulation in HEC-RAS modeling, channel flow profile inputs are required to ensure that the model is applicable at the given flow regime. Channel flow profiles were formulated with daily flow data between 2008 and 2016. Efforts have been made to select days that capture low to high flow conditions in Wekiva River. Thirteen flow profiles were selected based on flow exceedance analysis at SR46 (Figure 33), and consisted of 3 low flow (<10%), 2 medium flow and 8 high flow (>90%) conditions (Table 12).

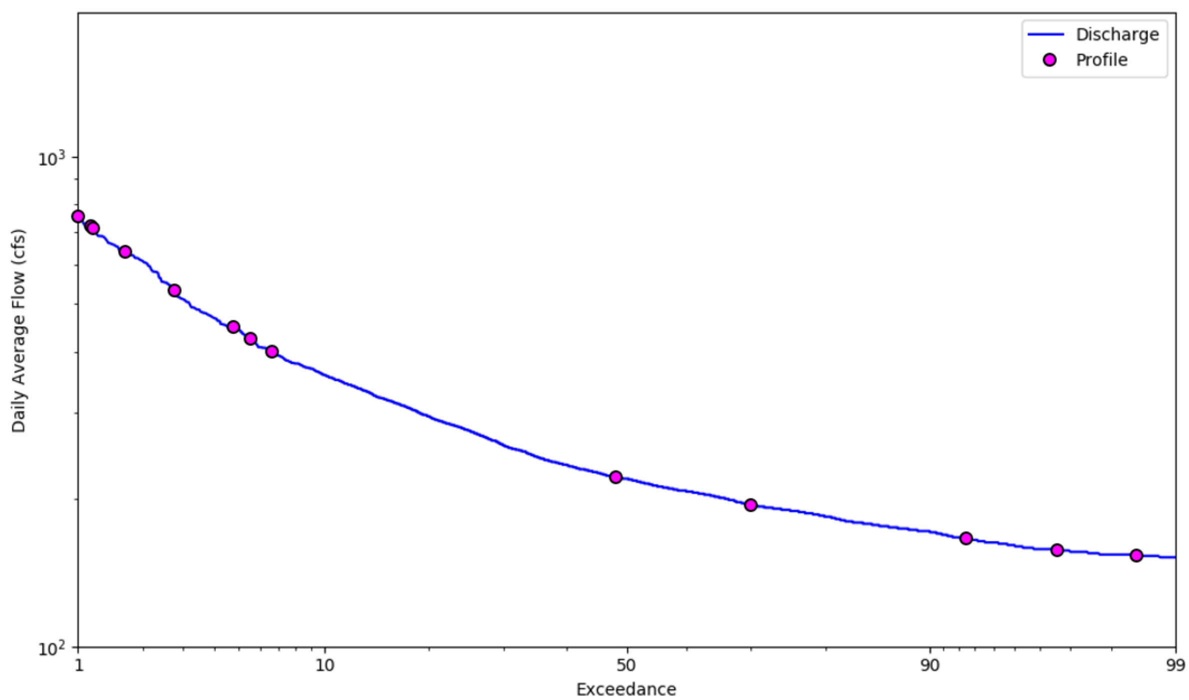


Figure 33 Flow exceedance for the Wekiva River at SR46 and selected discharge profile

Table 12 Selected flow profile for steady state simulation for Wekiva River

Profile	Date	Flow at SR46	% flow at SR46
PF1	4/17/2012	150	0.6
PF2	5/14/2012	155	2.3
PF3	4/9/2013	164	6.5
PF4	5/14/2013	196	31.0
PF5	2/15/2016	225	54.0
PF6	8/27/2012	407	93.7
PF7	9/9/2015	467	95.9
PF8	12/4/2014	479	96.3
PF9	9/30/2014	665	98.6
PF10	10/1/2014	797	99.2

PF11	5/22/2009	922	99.6
PF12	10/2/2014	927	99.6
PF13	8/23/2008	1740	100.0

Along the model domain, 17 flow-change locations were selected based on tributaries and contributing drainage areas, as defined in the HSPF model (Figure 34). Table 13 shows the prepared discharge profiles at the given flow change locations. Discharge data included in the model was obtained from the gages of the Little Wekiva River at SR434, Rock Springs, Wekiwa Springs and the Wekiva River at SR46. When observed data were not available at flow-change locations, HSPF modeling results were used with adjustment factors. These factors were derived from the relationship with downstream observed flows to estimate the channel flow profiles at the given flow-change location.

Table 13 Flow profiles for steady state simulation

Stream	XS	RS	PF 1	PF 2	PF 3	PF 4	PF 5	PF 6	PF 7	PF 8	PF 9	PF 10	PF 11	PF 12	PF 13
Little Wekiva	SR434	312.14	0.9	0.4	5.3	14.1	20.5	44.8	80.3	64.8	279.0	295.0	340.0	269.0	536.0
	SLB	245.69	29.1	29.5	36.0	47.5	57.3	99.9	113.6	112.3	320.2	345.1	382.7	327.3	576.7
	Sabol	182.49	29.3	29.7	36.2	47.9	58.1	118.5	114.8	113.8	326.6	354.8	398.6	333.1	640.0
	WK18	30.50	29.1	30.1	34.7	51.6	62.7	140.1	216.3	140.0	319.5	384.4	433.2	448.6	1020.7
Rock Springs Run	Rock Springs	480.77	46.8	46.0	48.1	48.8	56.1	50.6	56.8	58.2	59.0	59.1	56.8	59.1	72.3
	ROK5	350.27	46.8	46.0	48.1	49.1	58.2	53.9	60.4	61.2	66.4	65.4	69.4	65.1	118.0
	ROK4	215.81	48.1	47.1	50.0	50.9	67.0	60.9	71.5	68.9	72.9	73.4	79.5	72.5	244.8
	WK16	18.17	52.6	54.5	56.2	58.7	72.6	118.3	84.4	119.1	135.4	162.7	173.0	184.5	421.9
Wekiwa Run	WekSpr6	793.32	50.5	50.2	52.2	54.4	63.3	59.5	65.1	55.0	58.9	60.0	57.3	59.4	58.0
Wekiva River	WEK12	747.19	103.6	105.1	108.9	113.8	137.9	187.4	152.0	176.3	196.3	227.8	237.3	246.1	529.1
	WEK10	579.74	109.2	114.1	116.3	120.9	136.5	260.4	196.5	274.2	254.1	311.5	348.6	363.4	546.8
	WK11	544.57	138.3	144.2	151.0	172.5	199.2	400.5	412.8	414.2	573.7	695.8	781.8	812.0	1567.5
	XS19	477.90	134.5	139.0	148.0	180.4	210.9	381.7	451.0	456.6	644.0	771.6	900.7	897.7	1713.0
	XS15	386.11	149.5	153.5	163.4	196.4	226.5	398.6	469.1	473.9	662.3	789.8	919.3	915.9	1732.9
	XS12	333.01	150.0	155.0	164.0	196.0	225.0	407.0	467.0	479.0	665.0	797.0	922.0	927.0	1740.0
	XS2	143.23	164.1	169.5	178.6	235.9	259.2	395.5	520.6	552.9	662.2	837.0	896.8	992.4	1896.4
	Black Water Creek	25.63	192.3	196.8	213.1	291.6	336.5	496.7	799.6	674.1	976.3	1149.2	1327.2	1309.7	3142.0

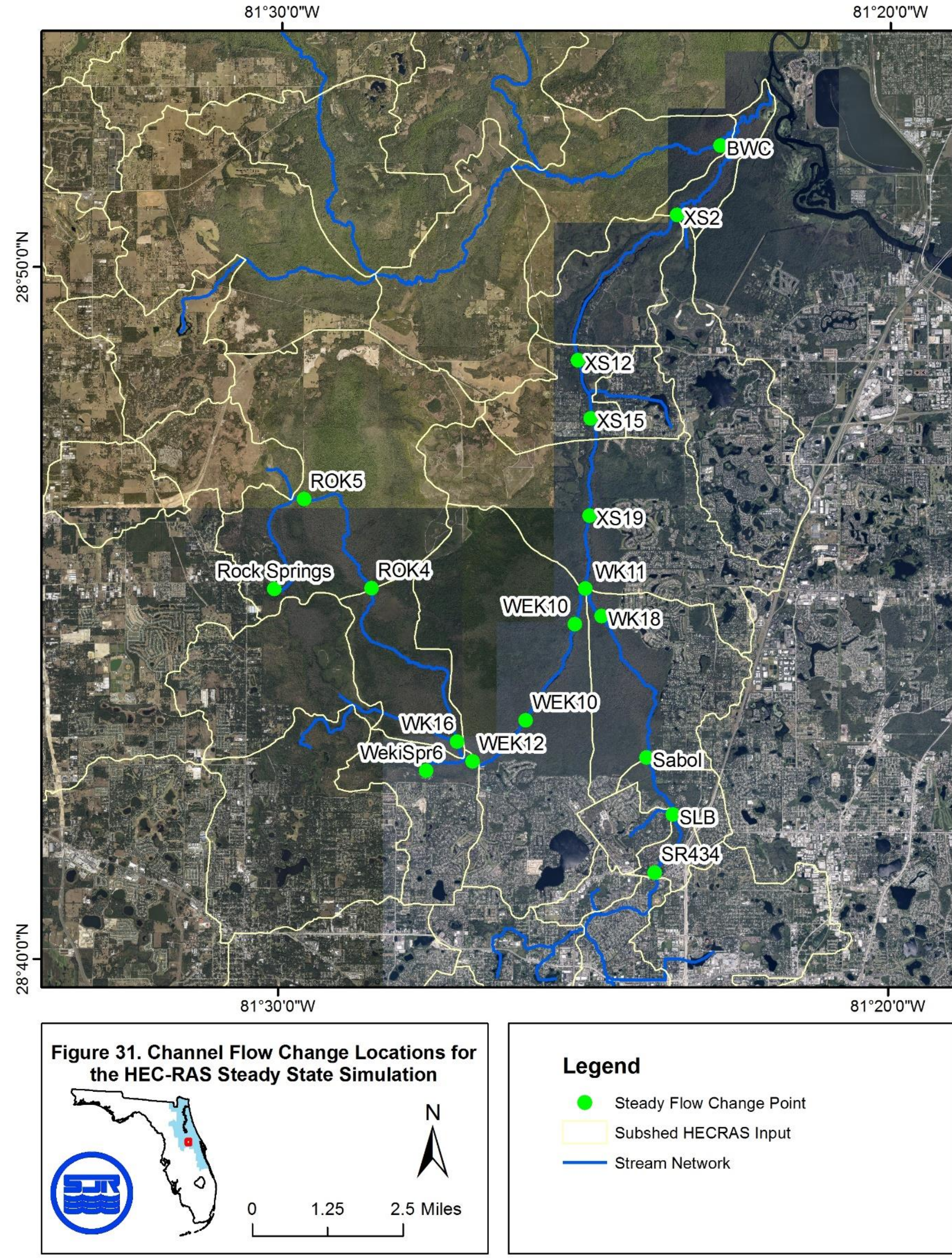


Figure 34 Channel flow change locations for the HEC-RAS steady state simulation

4.2.3 Steady state simulation results

The HEC-RAS model was calibrated by adjusting the Manning's n value to minimize surface water level differences between the observations and simulations at the eight water level gaging stations. The criterion for the calibration was 0.5 ft in discrepancy between the simulated and observed stages. Most of simulated profiles at the eight gages were within the criterion with a few exceptions at the Little Wekiva River at SR434 and Wekiwa Run stations, and showed a great correlation with observed stages (Figures 35-36). The most downstream gage, Wekiva River at SR46, showed the least difference ranging from -0.26 to 0.01 ft, while a couple of unsatisfactory simulation results were found at the most upstream gages in the model domain, such as the Little Wekiva River at SR434 and Wekiwa Springs. The discrepancy of more than 0.5 ft at the gages (3 asterisked values in Table 14) could be originated from the extrapolated rating curve for high and low flow conditions.

Table 14 Comparison of observed and simulated water level profiles in the Wekiva River Basin

Stream	Station	Profile (ft, NAVD)	PF1	PF2	PF3	PF4	PF5	PF6	PF7	PF8	PF9	PF10	PF11	PF12	PF13
Little Wekiva	SR434	Obs.	21.72	21.68	21.97	22.33	22.71	23.04	23.86	23.60	26.31	26.45	26.67	26.22	28.32
		Sim.	21.95	21.88	22.11	22.27	22.36	22.68	24.07	23.54	26.15	26.23	26.58	26.01	27.67
		Diff.	0.23	0.20	0.14	-0.06	-0.35	-0.36	0.21	-0.06	-0.16	-0.22	-0.09	-0.21	***-0.65****
	SLB	Obs.	-	-	-	-	-	-	-	-	-	-	19.66	-	20.64
		Sim.	16.70	16.71	16.88	17.16	17.37	18.20	18.39	18.37	19.54	19.62	19.75	19.54	20.33
		Diff.	-	-	-	-	-	-	-	-	-	-	0.09	-	-0.31
Rock Springs Run	Rock Springs	Obs.	24.81	24.77	24.80	24.82	25.00	25.00	24.92	24.93	25.07	25.09	25.23	25.09	25.95
		Sim.	25.12	25.11	25.14	25.15	25.26	25.18	25.27	25.29	25.30	25.30	25.27	25.30	25.48
		Diff.	0.31	0.34	0.34	0.33	0.26	0.18	0.35	0.36	0.23	0.21	0.04	0.21	-0.47
	ROK2	Obs.	-	-	-	-	17.47	-	-	17.68	17.83	18.01	-	18.19	-
		Sim.	17.56	17.54	17.61	17.63	17.77	17.88	17.91	17.89	17.97	17.98	18.04	17.97	18.84
		Diff.	-	-	-	-	0.30	-	-	0.21	0.14	-0.03	-	-0.22	-
Wekiwa Run	Wekiwa Springs	Obs.	11.90	11.87	12.04	12.07	12.10	12.40	12.34	12.81	12.61	12.72	13.50	12.83	14.52
		Sim.	11.34	11.39	11.46	11.58	11.85	12.52	12.30	12.48	12.73	12.99	13.13	13.18	14.51
		Diff.	***-0.56****	-0.48	***-0.58****	-0.49	-0.25	0.12	-0.04	-0.33	0.12	0.27	-0.37	0.35	-0.01
Wekiva River	Near Apopka	Obs.	11.41	11.35	-	-	11.51	12.62	-	-	-	-	13.43	-	14.52
		Sim.	11.29	11.33	11.40	11.52	11.80	12.48	12.27	12.45	12.70	12.96	13.10	13.15	14.47
		Diff.	-0.12	-0.02	-	-	0.29	-0.14	-	-	-	-	-0.33	--	-0.05
	Railroad	Obs.	8.38	8.27	8.41	8.53	8.59	9.33	9.45	9.58	10.10	10.44	10.62	10.64	12.18
		Sim.	8.31	8.34	8.38	8.47	8.61	9.30	9.49	9.51	9.95	10.27	10.57	10.57	12.25
		Diff.	-0.07	0.07	-0.03	-0.06	0.02	-0.03	0.04	-0.07	-0.15	-0.17	-0.05	-0.07	0.07
	SR46	Obs.	6.20	6.12	6.24	6.34	6.60	7.23	7.41	7.49	7.91	8.19	8.51	8.46	10.21
		Sim.	6.03	6.05	6.09	6.24	6.41	7.14	7.44	7.50	7.89	8.16	8.42	8.47	9.95
		Diff.	-0.17	-0.07	-0.15	-0.10	-0.19	-0.09	0.03	0.01	-0.02	-0.03	-0.09	0.01	-0.26

* |Values| > 0.5 ft

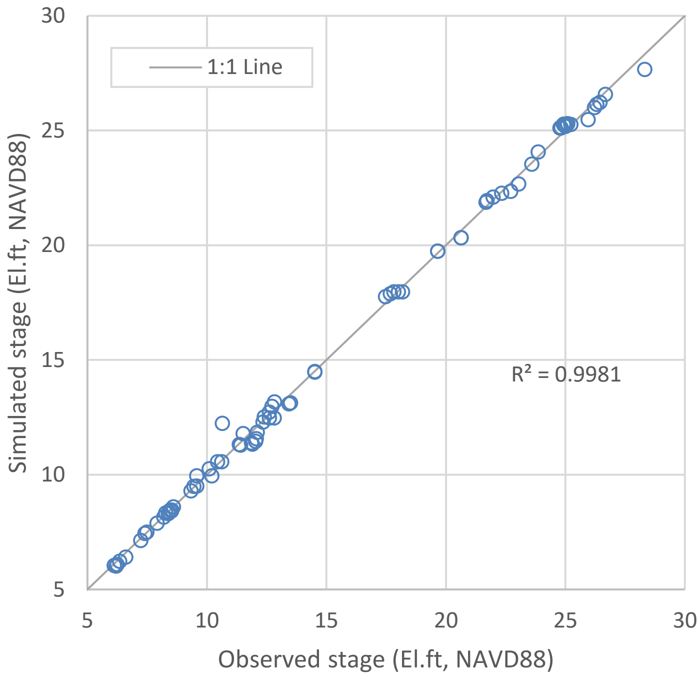
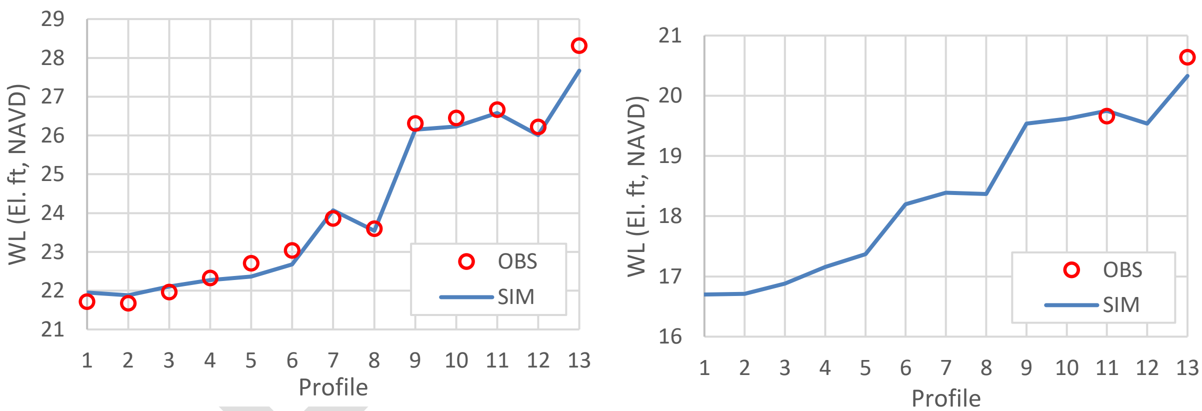


Figure 35 Scatter plot of simulated and observed stages in the steady state simulation for all gages



(a)Lt Wekiva River at SR434 (b) Lt Wekiva River at SLB

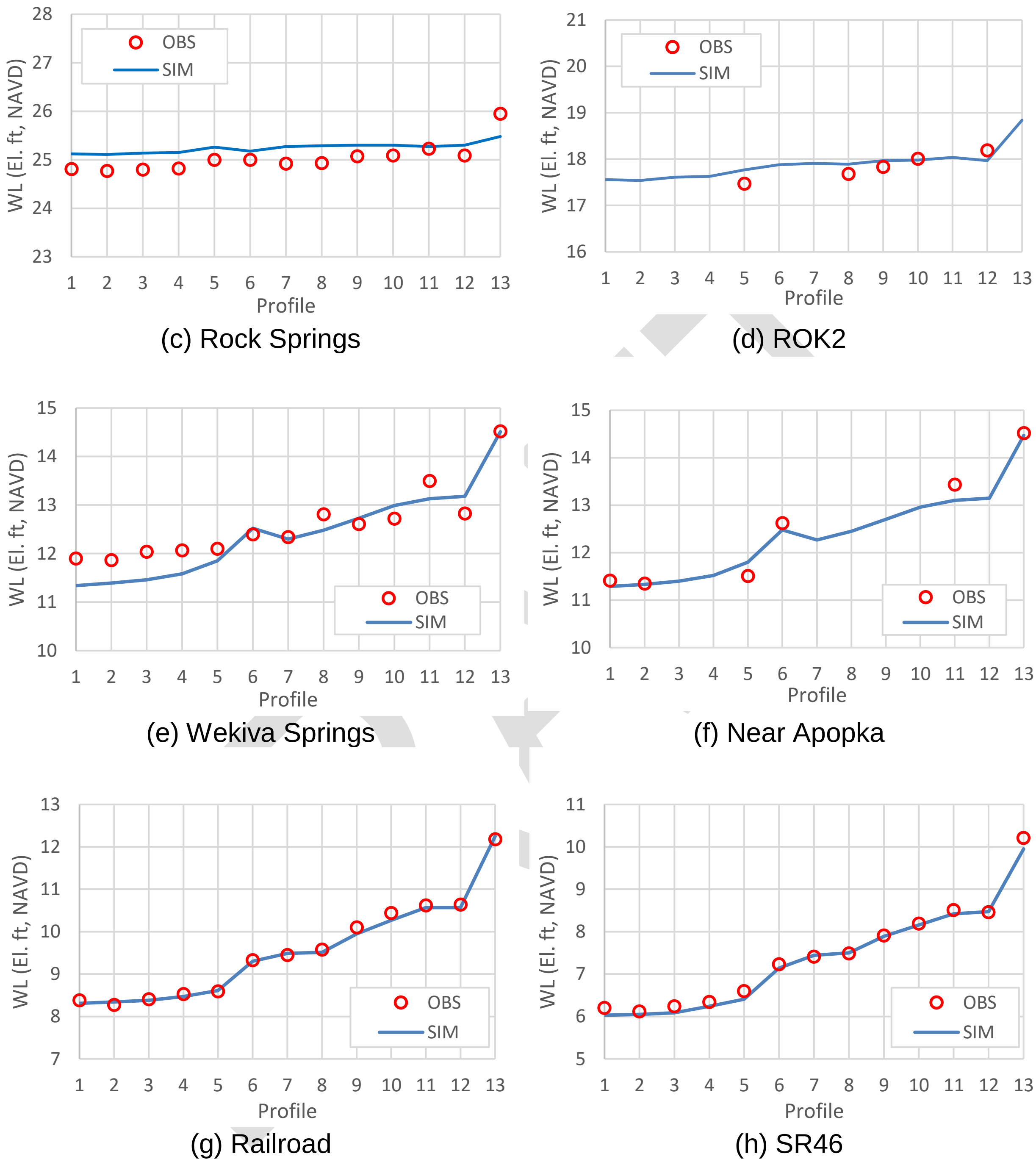


Figure 36 Comparison of observed and simulated water levels at the gages for steady state simulation

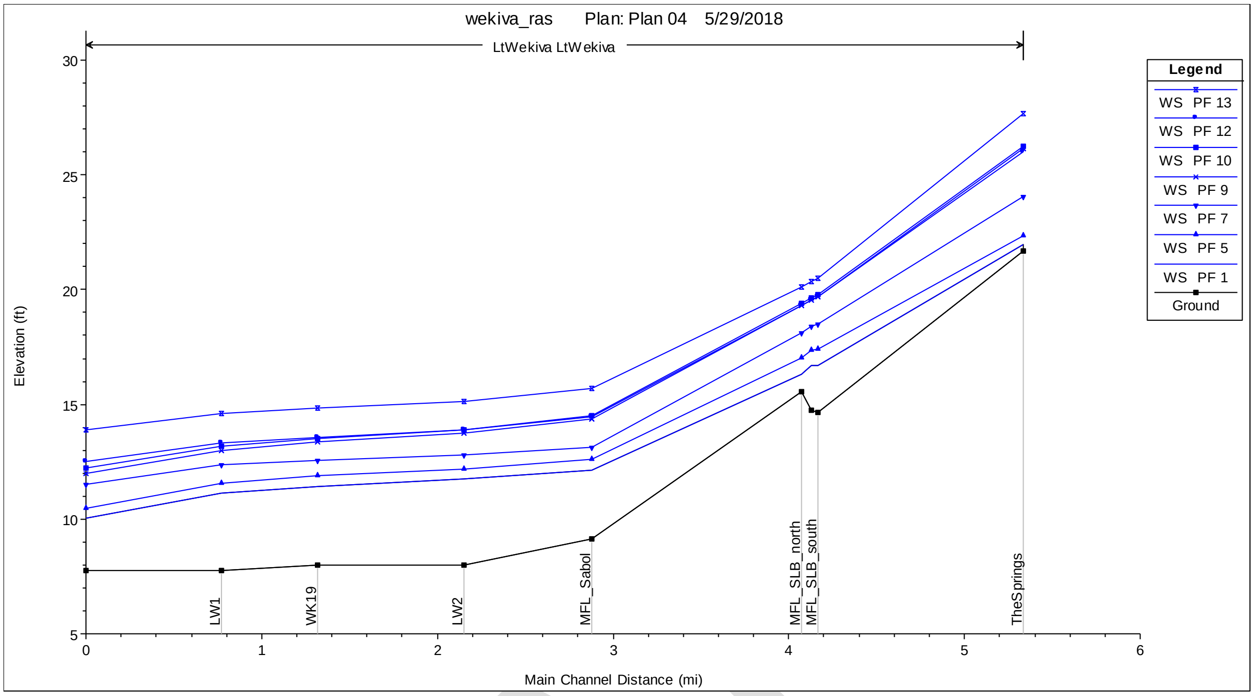


Figure 37 Simulated water surface profiles along Little Wekiva River

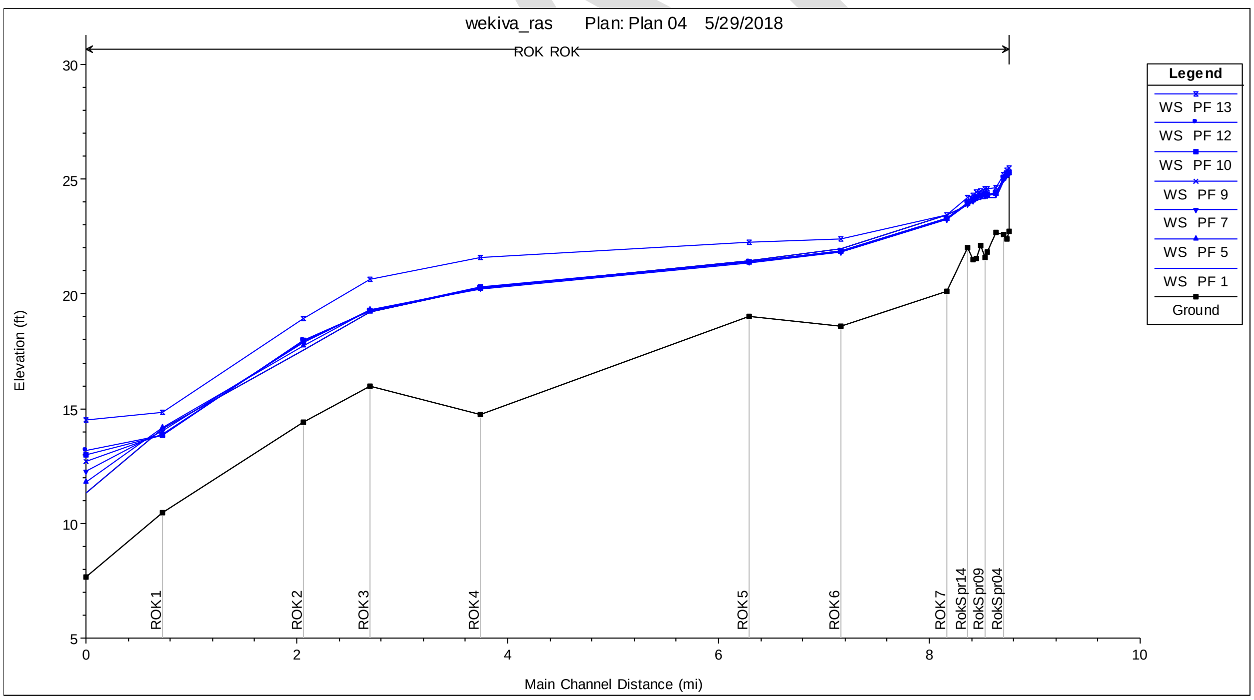


Figure 38 Simulated water surface profiles along Rock Springs Run

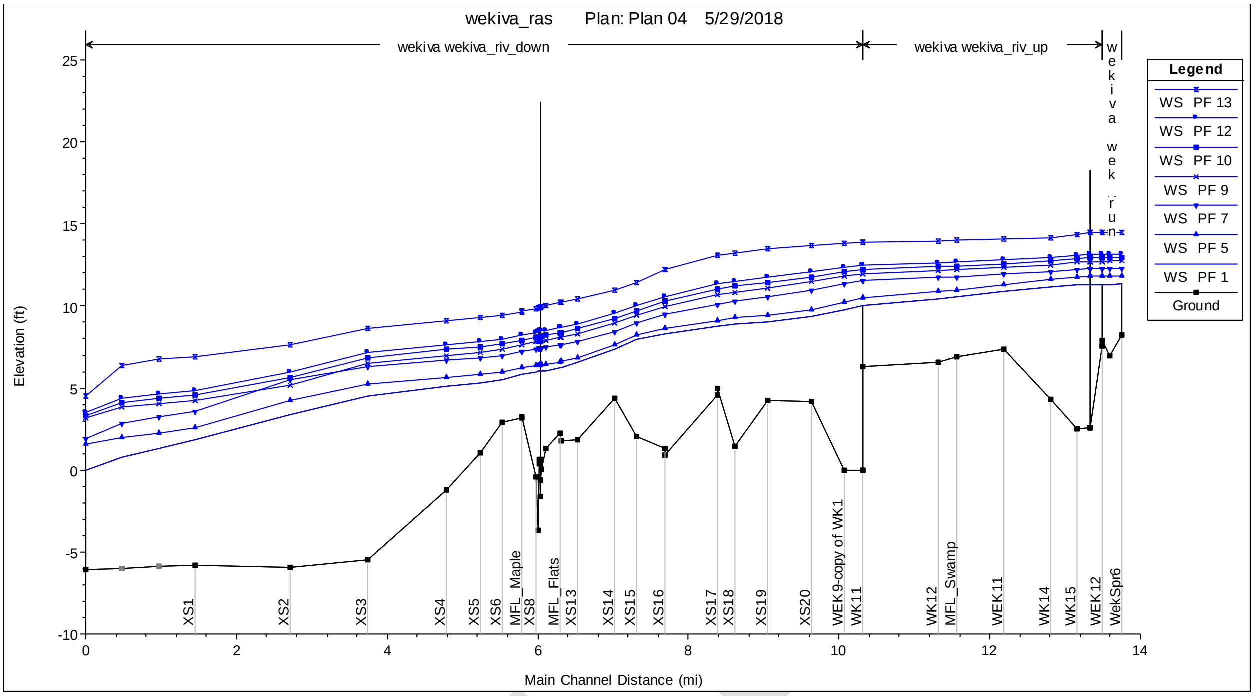


Figure 39 Simulated water surface profiles along Wekiwa Run and the Wekiva River

Manning's n values for stream segments close to the headwater and/or relatively high slope, such as upper portions of Rock Springs Run and Little Wekiva River, were calibrated to 0.04-0.055. The n values for the main stream segments with extensive stream bed vegetation ranged from 0.1-0.2 and varied by flow.

Table 15 Calibrated Manning's n values in the HEC-RAS model

Streams	River Station	Floodplain	Stream	Etc.
Little Wekiva River	312.14-182.49	0.15	0.043, 0.055	Constant
	143.98-30.45	0.22	0.1-0.2	Varied
Rock Springs Run	480.77-449.35	0.15	0.04	Constant
	396.13-18.07	0.18	0.1-0.2	Varied
Wekiwa Run and Wekiva River	793.32-711.81	0.22	0.17, 0.2	Constant
	678.61-0	0.22	0.1-0.2	Varied

4.3 UNSTEADY STATE SIMULATION

4.3.1 Boundary condition for unsteady state simulation

Unlike the steady state simulation, unsteady state simulation requires time-series datasets to replicate stream dynamics at every time step during a simulation period. Hourly water levels gaged at the Lower Wekiva station were used as a downstream boundary condition. Daily discharge data at Rock Springs, Wekiwa Springs and the Little Wekiva River at SR434 stations were used as upstream boundary conditions. Lateral inflows from the drainage area adjacent to stream reaches were used as internal boundary conditions in the HEC-RAS model, and a total of

15 lateral flow time-series was estimated using the HSPF model results and contributing areal ratio to each lateral flow (Table 16).

Table 16 Summary of boundary conditions for unsteady simulation in the HEC-RAS model

Streams	River Station	Boundary Condition Type	Description
Little Wekiva River	312.14	Upstream boundary condition	SR434
	250.47	Lateral inflow hydrograph	Little Wekiva Springs* + Sub25×0.15
	182.49	Lateral inflow hydrograph	Sub25×0.11 + Sub24
	143.98-30.5	Uniform lateral inflow	Sub25×0.74
Rock Springs Run	480.77	Upstream boundary condition	Rock Springs
	350.27-56.34	Uniform lateral inflow	Sub17**
	350.27	Lateral inflow hydrograph	Sub14
	18.17	Lateral inflow hydrograph	Sub16
Wekiwa Run and Wekiva River	793.32	Upstream boundary condition	Wekiva Springs
	747.19	Lateral inflow hydrograph	Sub18
	711.81-579.74	Uniform lateral inflow	Sub19
	508.92-370.65	Uniform lateral inflow	Sub27×0.786
	386.11	Lateral inflow hydrograph	Wekiva Fall
	370.65	Lateral inflow hydrograph	Sub26
	344.64-322.22	Uniform lateral inflow	Sub27×0.214
	276.66-25.630	Uniform lateral inflow	Sub29
	143.23	Lateral inflow hydrograph	Sub28
	25.63	Lateral inflow hydrograph	Black Water Creek
	0	Downstream boundary condition	Lower Wekiva

*Consists of Ginger Ale Springs, Palm Springs, Pegasus Spring, Sanlando Springs and Starbuck Spring
**Refers calculated runoffs at the sub-watershed in the HSPF model

4.3.2 Model Simulation

A short representative simulation period that captures low to high flow events is used to check a model's validity under dynamic conditions. This will alleviate model instability and performance issues. The 6-month period between 1/20/2009 to 7/20/2009 was chosen for the unsteady state simulation. Flow distribution analysis showed that the selected simulation period covers flow exceedance between 0.43% to 93.28% during the period of 2008 to 2016 (Figure 40).

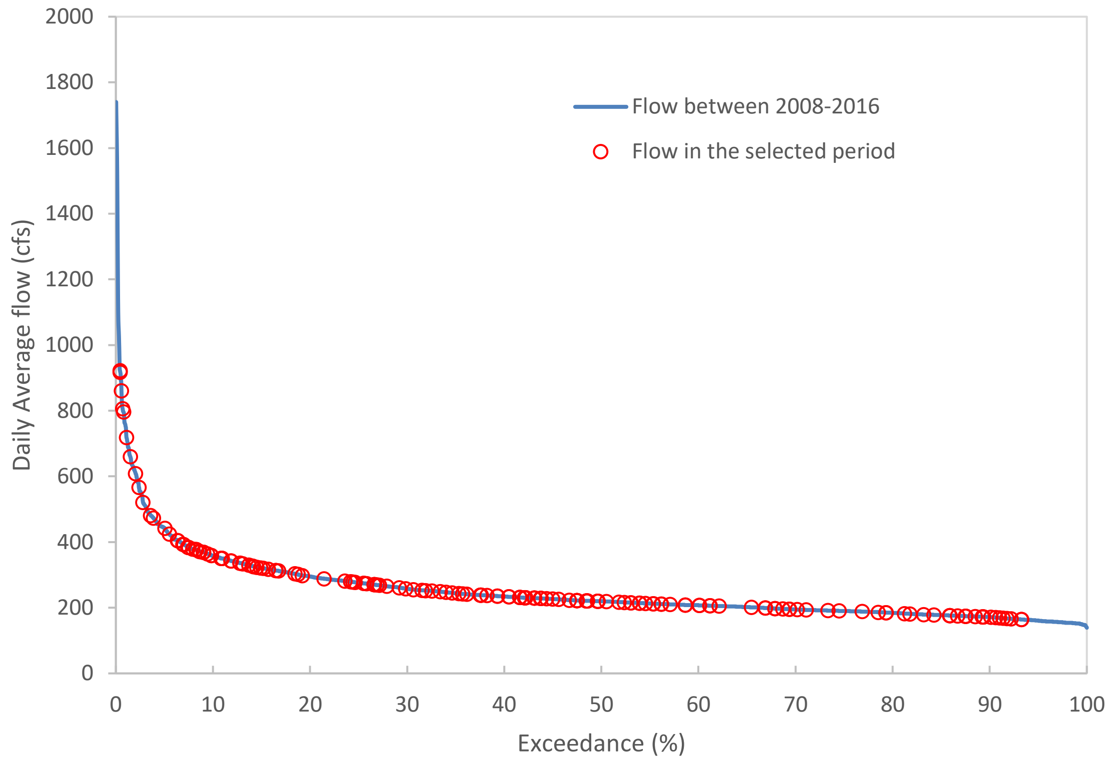


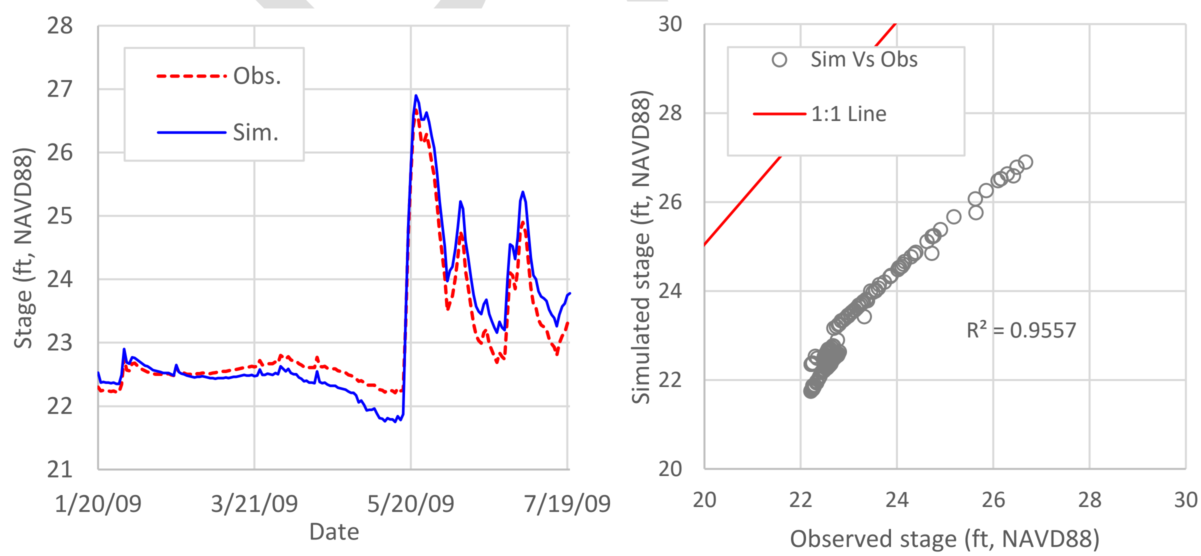
Figure 40 Flow distribution for the Wekiva River at SR46 for the selected unsteady state simulation period (1/20/2009 – 7/20/2009) in between 2008 to 2016

4.3.3 Unsteady state simulation results

The Manning's n values used in the steady state simulation, which varied by flow, were used in the unsteady state simulation. Simulated and observed water stages were compared at each water level station (Figures 41 – 47 and Table 17). Stage data at ROK2 station were unavailable during the unsteady simulation period. Discrepancy in average stages ranged from 0.03 (at SLB) to 0.42 ft (at Near Apopka). Overall, the unsteady state model showed to be a good match in low, medium and high flow conditions, except for the Wekiva River Near Apopka station. Differences between simulated and observed at the peak stages were -0.09 to 0.23 ft (at Wekiwa Springs), while the discrepancies in the lowest water levels spanned from -0.46 (Little Wekiva River at SR434) to 0.47 (Wekiva River near Apopka). At Near Apopka site, the simulation results generally underestimated low and high stages; whereas, the simulated peak stage was close to observed data. The underestimation might have originated from (1) rating curve extrapolation at high and low flow conditions and (2) a lack of stormwater discharge data for contributing drainage areas. Potential errors in lateral flow inputs from the HSPF simulation could have also contributed to the error. In addition, dramatic in-stream vegetation change or any anthropogenic conditions during the unsteady state simulation period could have caused the discrepancy, since Manning's n values were calibrated based on water level profiles from the period of 2008 to 2016.

Table 17 Observed and simulated average, maximum and minimum water levels in the Wekiva River Basin during the unsteady state simulation

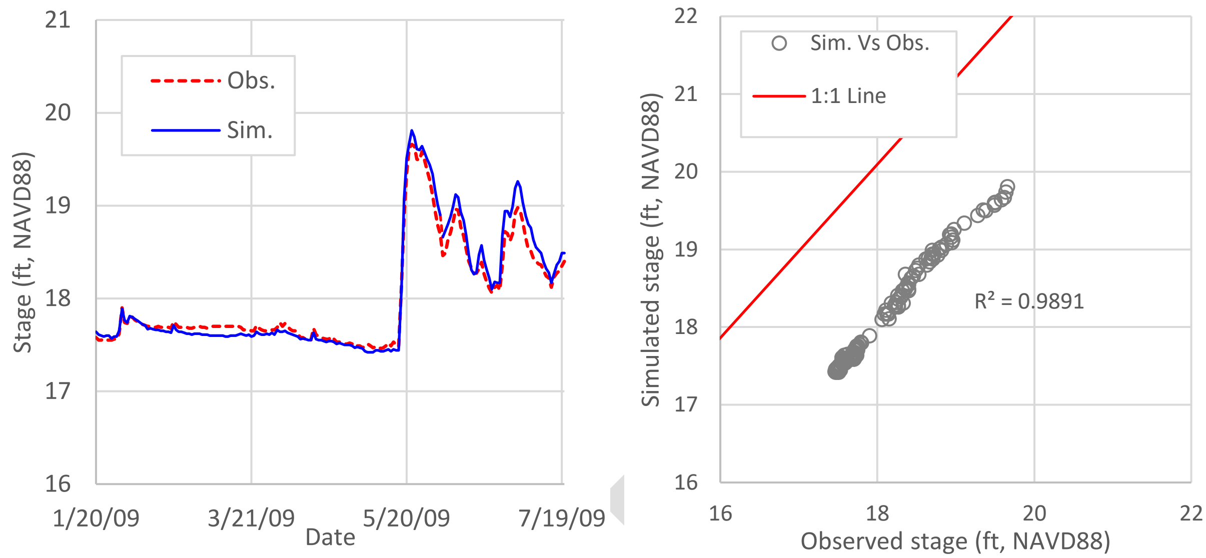
Stream	Station	Statistics (ft, NAVD)	Mean	Max	Min	R^2	RMSE	PBIAS	RSR
Little Wekiva River	SR434	Obs.	23.04	26.67	22.21	0.96	0.32	0.27	0.32
		Sim.	23.11	26.90	21.75				
		Diff.	0.07	0.23	-0.46				
	SLB	Obs.	17.99	19.66	17.46	0.99	0.11	0.14	0.19
		Sim.	18.02	19.81	17.42				
		Diff.	0.03	0.15	-0.04				
Rock Springs Run	Rock Springs	Obs.	25.16	25.35	24.97	0.92	0.14	0.53	1.53
		Sim.	25.29	25.37	25.19				
		Diff.	0.13	0.02	0.22				
Wekiwa Run	Wekiwa Springs	Obs.	12.16	13.65	11.80	0.90	0.26	1.99	0.80
		Sim.	12.40	13.56	12.03				
		Diff.	0.24	-0.09	0.23				
Wekiva River	Near Apopka	Obs.	11.63	13.56	11.16	0.90	0.45	3.57	0.96
		Sim.	12.05	13.47	11.63				
		Diff.	0.42	-0.09	0.47				
	Railroad	Obs.	8.76	10.62	8.33	0.94	0.25	2.59	0.62
		Sim.	8.99	10.60	8.58				
		Diff.	0.23	-0.02	0.25				
	SR46	Obs.	6.54	8.51	6.12	0.96	0.20	2.32	0.43
		Sim.	6.69	8.64	6.18				
		Diff.	0.15	0.13	0.06				



(a) Stage time-series comparison

(b) Scatter plot between Sim. and Obs.

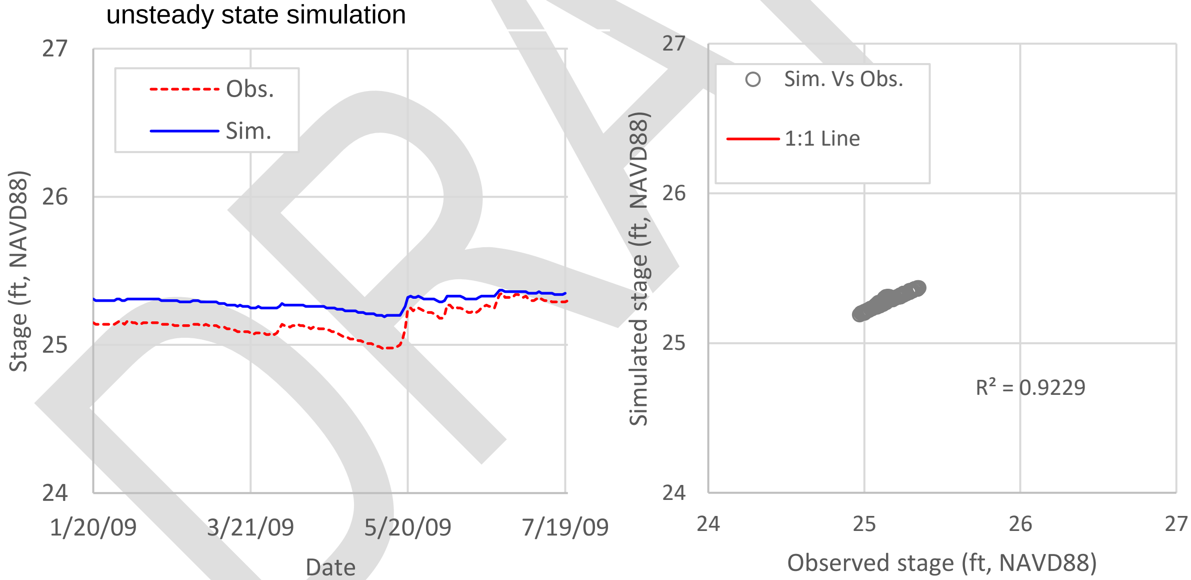
Figure 41 Comparison of observed and simulated water levels Little Wekiva River at SR434 station during unsteady state simulation



(a) Stage time-series comparison

(b) Scatter plot between Sim. and Obs.

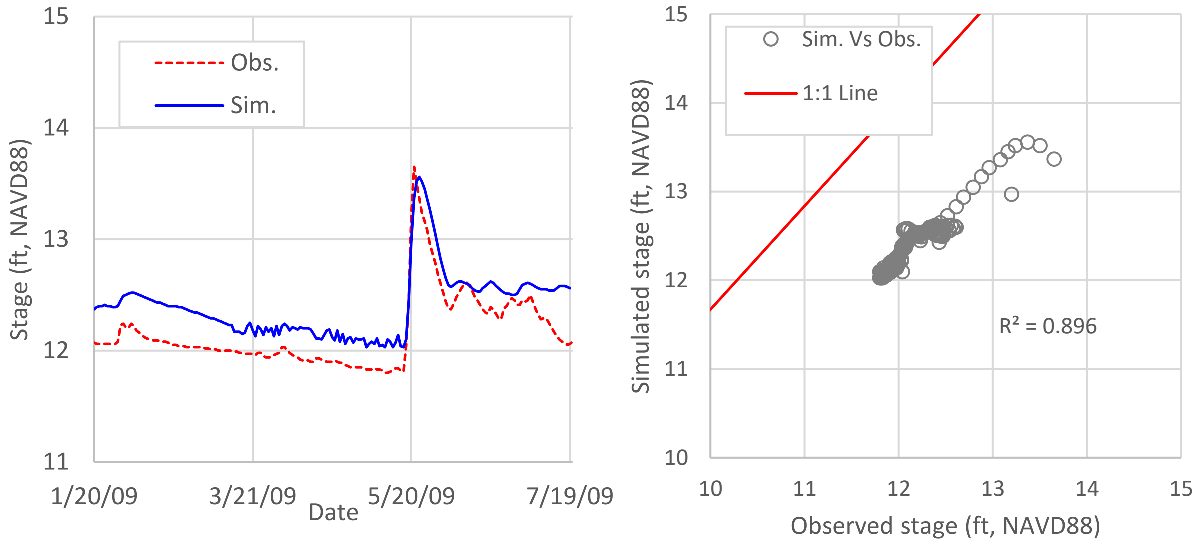
Figure 42 Comparison of observed and simulated water levels Little Wekiva River at SLB station during unsteady state simulation



(a) Stage time-series comparison

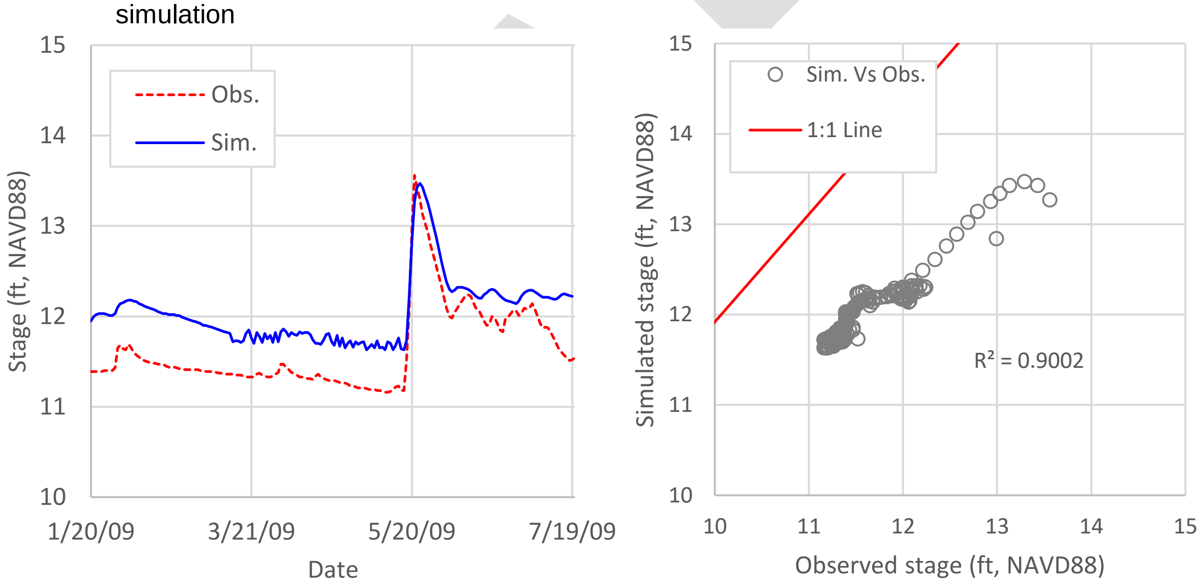
(b) Scatter plot between Sim. and Obs.

Figure 43 Comparison of observed and simulated water levels at Rock Springs during unsteady state simulation



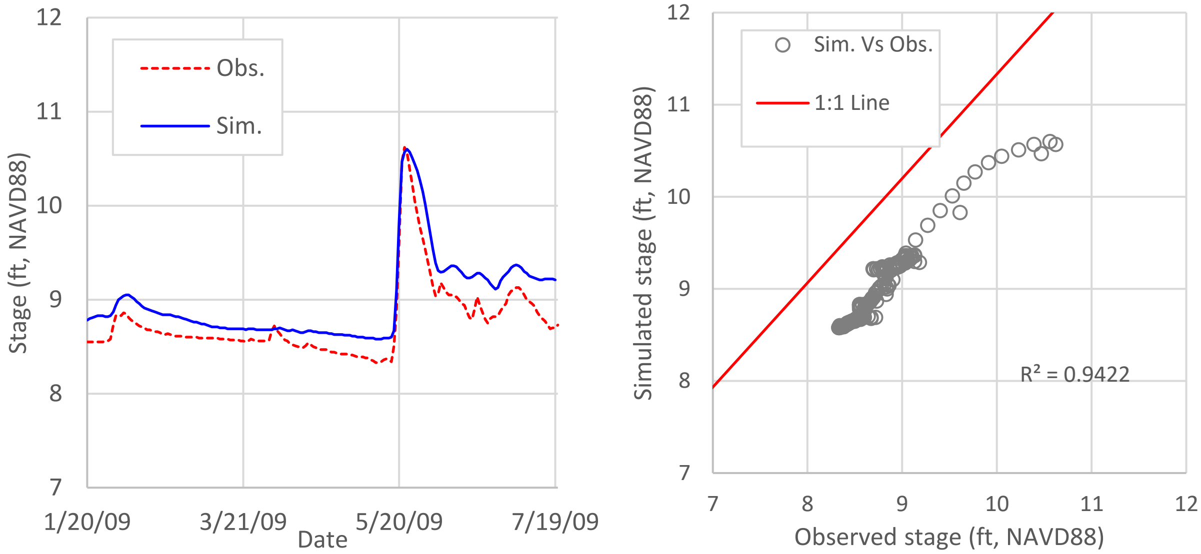
(a) Stage time-series comparison (b) Scatter plot between Sim. and Obs.

Figure 44 Comparison of observed and simulated water levels at Wekiwa Springs during unsteady state simulation



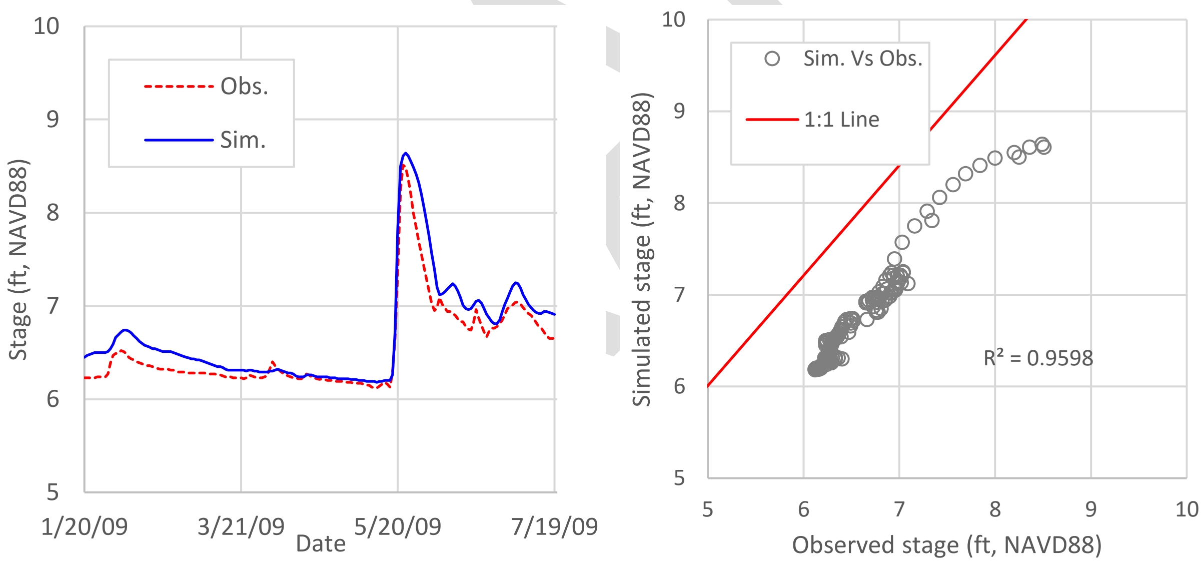
(a) Stage time-series comparison (b) Scatter plot between Sim. and Obs.

Figure 45 Comparison of observed and simulated water levels at Wekiva River near Apopka station during unsteady state simulation



(a) Stage time-series comparison (b) Scatter plot between Sim. and Obs.

Figure 46 Comparison of observed and simulated water levels Wekiva River at Railroad gage during unsteady state simulation



(a) Stage time-series comparison (b) Scatter plot between Sim. and Obs.

Figure 47 Comparison of observed and simulated water levels for the Wekiva River at SR46 during unsteady state simulation

5. SUMMARY

The St. Johns River Water Management District (SJRWMD) is to establish minimum surface water flows and levels (MFLs) for priority water bodies (Section 373.042, *Florida Statutes* (F.S.). Four water bodies within the Wekiva River system (Wekiva River at SR 46, Little Wekiva River, Wekiwa Springs and Rock Springs) are on the SJRWMD's MFLs priority list. MFLs for the Wekiva River at SR 46 were adopted in 1992 (Hupalo et al 1994), and it is currently under reevaluation. All four systems are scheduled for adoption by 2019.

The SJRWMD is mandated by statute to establish MFLs for priority water bodies (Section 373.042, F.S.) Four water bodies within the Wekiva River system (Wekiva River at SR 46, Little Wekiva River, Wekiwa Springs and Rock Springs) are on the SJRWMD's MFLs priority list, scheduled for adoption by 2019. The goal of the reevaluation of Wekiva River at SR 46, and determination of the other systems is to ensure that adopted MFLs are based on the most up-to-date criteria, hydrological data and models available. In this study, hydrologic and hydraulic models for the Wekiva River system were developed based on existing models, to support the development and reevaluation of Wekiva Basin MFLs. The HSPF model simulates the hydrology of the Wekiva River watershed; the HEC-RAS model simulates stream hydraulics in the Little Wekiva River, Rock Springs Run and Wekiva River.

The HSPF model performance was evaluated at 7 stream flow gages for the period of 2003 to 2016. Overall, the results showed good agreement between the simulated and observed flows in terms of the water mass balance, high and low flows, and seasonal flow distribution, which ensured that the model would be applicable for the Wekiva River watershed.

The HEC-RAS model was calibrated under the steady state condition with 13 flow profiles, which were selected from a range of flow conditions between the years of 2008 to 2016. The simulated water surface elevations differed from the observed data by -0.26 to +0.01 ft for the Wekiva River at SR46. The calibrated model was tested under unsteady state simulation for six months in 2009 and showed a general agreement between the observed and simulated water levels in terms of low, medium and peak stages. Average flow error for the Wekiva River at SR46 was calculated to be 0.15 ft, while discrepancies in the lowest and peak flow were 0.13 ft and 0.06 ft, respectively.

Overall, the model results indicated that the models were adequate to represent the hydrologic and hydraulic processes in the Wekiva River watershed. Therefore, the calibrated HSPF and HEC-RAS models can provide useful information for assessing the MFLs for the Wekiva River systems.

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APPENDIX A – DEVELOPMENT OF WEKIVA BASIN SPRINGS FLOWS DATA FOR HSPF MODEL

A major portion of Wekiva River flows comes from springs in the basin. Figure A-1 shows the location of springs in the Wekiva river basin. The springs vary in term of magnitude and available observed data. Table A-1 summarizes the available spring flow data in the basin. The Wekiva river basin HSPF model requires long-term springs flow data for model calibration and MFL simulations.

The gap-filling and extension of springs flow data are based on the available observed data for the springs. The available data were processed in three steps as follows:

STEP 1: SPRINGS WITH A RELATIVELY LONG PERIOD OF RECORD DATA

Some of the springs in the Wekiva river basin, mainly large springs such as Miami, Palm, Rock, Sanlando, Starbuck, and Wekiva, have a long-term observed data (Table A-1). The flows of these springs were correlated with the Upper Floridan Aquifer (UFA) levels in the region. For these springs, the extension of flow data was based on the water levels of the USGS UFA monitoring well at Orlo Vista (OR-0047 Well). OR-0047 Well is the closest UFA well with the long-term observed groundwater level data. The location of OR-0047 Well is shown in Figure A-1.

The spring flows were related to water levels of OR-0047 Well using the Line of Organic Correlation (LOC) method, also known as Maintenance of Variance Extension. LOC minimizes the errors in both X and Y directions and preserves the characteristics of the probability distribution of the data including the variance and probabilities of flooding and drying events (Helsel and Hirsch, 2002). It is widely used to gap-filling and extending of water levels and flows. LOC function in R software package was used. The LOC regression equations between OR-0047 and spring flows and their coefficient of determinations (r^2) are shown in Table A-2. Figures A-2 through A-7 show the LOC regression plots. Figures A-8 and A-9 show the estimated flows of the largest springs in the basin, Wekiva and Rock springs, respectively.

STEP 2: SPRINGS WITH SHORT PERIOD OF RECORD

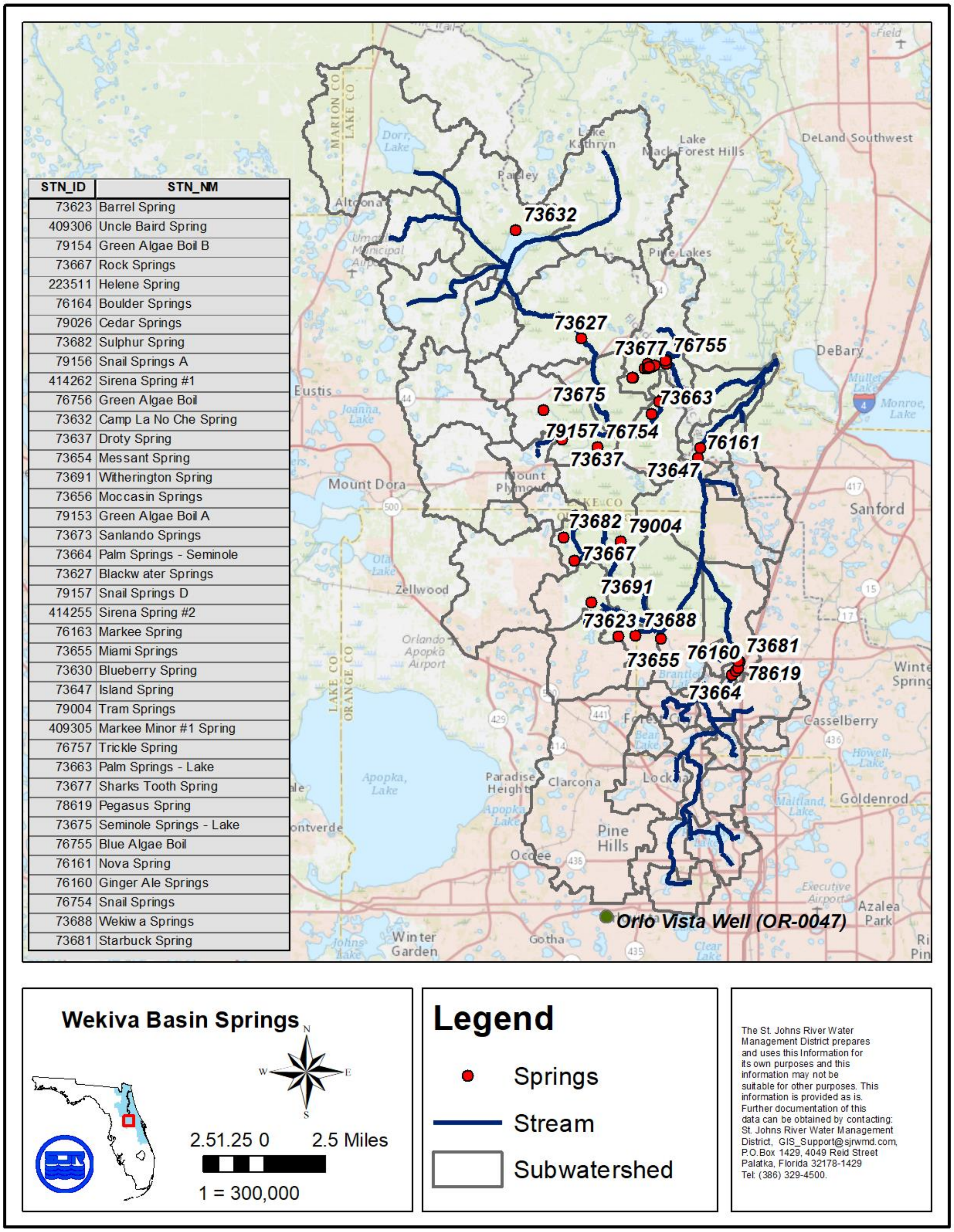
Helen, island, and Sulphur springs have relatively short-term observed data. They are also low magnitude springs (less than 10 cfs). The flow data of these springs were filled in and extended using a simple linear regression (SLR) with nearby larger magnitude springs in the basin. Rock Springs flow data was used to extend the period of record for both Island Springs and Sulphur Springs. Wekiva Springs flow data was used for the extension of the period of record of Helen Springs. Table A-3 presents the linear regression equations and their coefficient of determinations (r^2). Figures A-10 through A-12 present the SLR graphs.

STEP 3: ALL REMAINING SPRINGS

The remaining springs in the basin are characterized by very low flow and have very few observation data. The flows of these springs were estimated using the ratio of mean flows of observation data with the corresponding mean flows of nearby springs. Table A-4 presents these springs with the related nearby springs.

Table A-1. Wekiva Basin Springs Flow Observed Period of Record

Wekiva Basin Springs	Period of Record	Number of Data	Discharge (cfs)		
			Minimum	Mean	Maximum
Barrel Springs	1995-1997	3	0.18	0.25	0.31
Blue Algae Boil	3/15/2005	1	0.14	0.14	0.14
Boulder Springs	2003-2008	3	0.06	0.23	0.32
Camp La No Che Springs	1954-1972	2	0.66	0.88	1.1
Cedar Springs	3/14/2005	1	0.03	0.03	0.03
Droty Spring	2005-2008	2	0.59	0.66	0.72
Ginger Ale Springs	2005	2	0.11	0.15	0.18
Green Algae Boil	3/15/2005	1	0.14	0.14	0.14
Helene Springs	2007-2012	1229	0.88	1.18	1.49
Island Springs	1982-2011	41	5.39	8.28	10.19
Markee Springs	2003-2008	3	0.22	0.25	0.28
Messant Springs	1972-1995	26	10.8	14.24	18
Miami Springs	1945-2018	5247	2.71	5.25	7.83
Nova Springs	3/14/2005	1	8.52	8.52	8.52
Palm Springs	1941-2018	5250	2.75	5.4	12.2
Pegasus Springs	3/16/2005	1	2.8	2.8	2.8
Rock Springs	1931-2018	6084	37	54.9	83.2
Sanlando Springs	1941-2018	5371	8.12	19.62	40.41
Sharks Tooth Springs	1997-2008	6	0.1	0.18	0.28
Snail Springs	2005-2008	2	0.09	0.26	0.42
Starbuck Springs	1944-2018	4953	6.06	12.11	22.79
Sulphur Spring	1995-2017	22	0.19	0.49	0.95
Wekiwa Springs	1932-2018	5492	48.59	61.49	91.7
Witherington Springs	1972-1995	2	2.2	2.95	3.7



STN_ID	STN_NM
73623	Barrel Spring
409306	Uncle Baird Spring
79154	Green Algae Boil B
73667	Rock Springs
223511	Helene Spring
76164	Boulder Springs
79026	Cedar Springs
73682	Sulphur Spring
79156	Snail Springs A
414262	Sirena Spring #1
76756	Green Algae Boil
73632	Camp La No Che Spring
73637	Droty Spring
73654	Messant Spring
73691	Witherington Spring
73656	Moccasin Springs
79153	Green Algae Boil A
73673	Sanlando Springs
73664	Palm Springs - Seminole
73627	Blackw ater Springs
79157	Snail Springs D
414255	Sirena Spring #2
76163	Markee Spring
73655	Miami Springs
73630	Blueberry Spring
73647	Island Spring
79004	Tram Springs
409305	Markee Minor #1 Spring
76757	Trickle Spring
73663	Palm Springs - Lake
73677	Sharks Tooth Spring
78619	Pegasus Spring
73675	Seminole Springs - Lake
76755	Blue Algae Boil
76161	Nova Spring
76160	Ginger Ale Springs
76754	Snail Springs
73688	Wekiw a Springs
73681	Starbuck Spring

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Figure A-1. Wekiva River Basin Springs

Table A-2. LOC regression equations between Well OR-0047 and Wekiva Basin springs

Name	LOC Equation	Coefficient of Determination (r^2)
Miami Springs	0.2031986 X - 6.324284	0.58
Palm Springs	0.1977196 X - 5.86095	0.27
Rock Springs	1.396982 X - 24.72688	0.79
Sanlando Springs	1.00511 X - 37.70097	0.67
Starbuck Springs	0.4566421 X - 13.88756	0.12
Wekiva Springs	1.416882 X - 19.22191	0.63

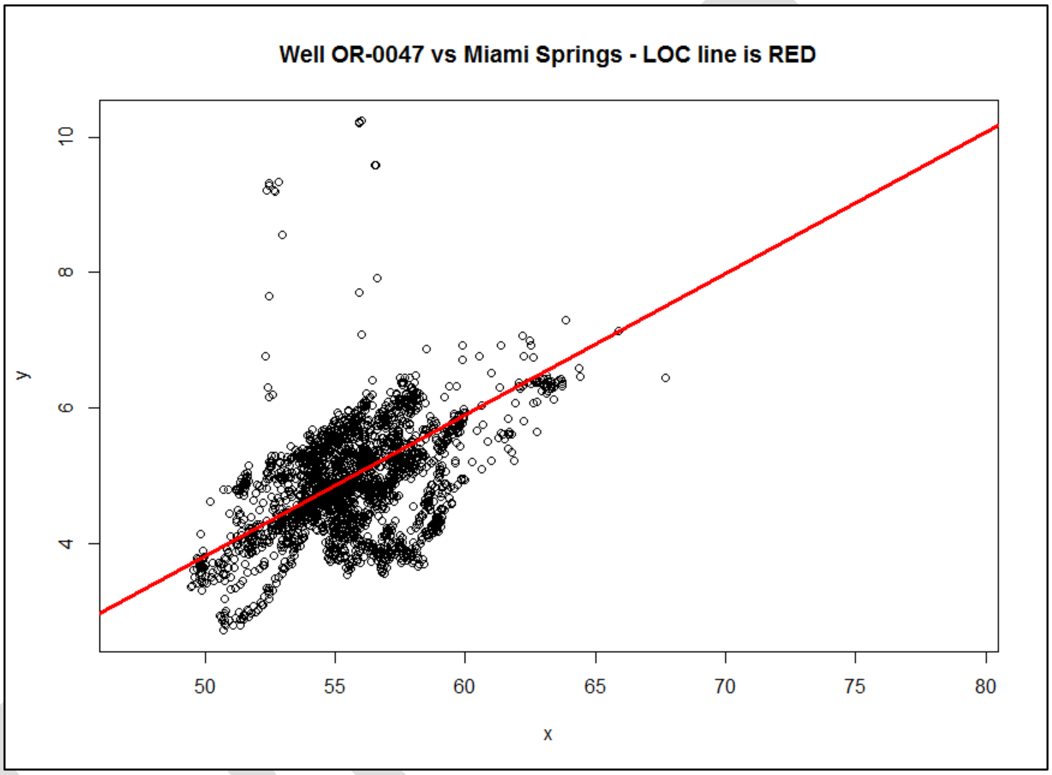

Figure A-2. Well OR-0047 levels (x-axis) and Miami Springs flows (y-axis) LOC relationship.

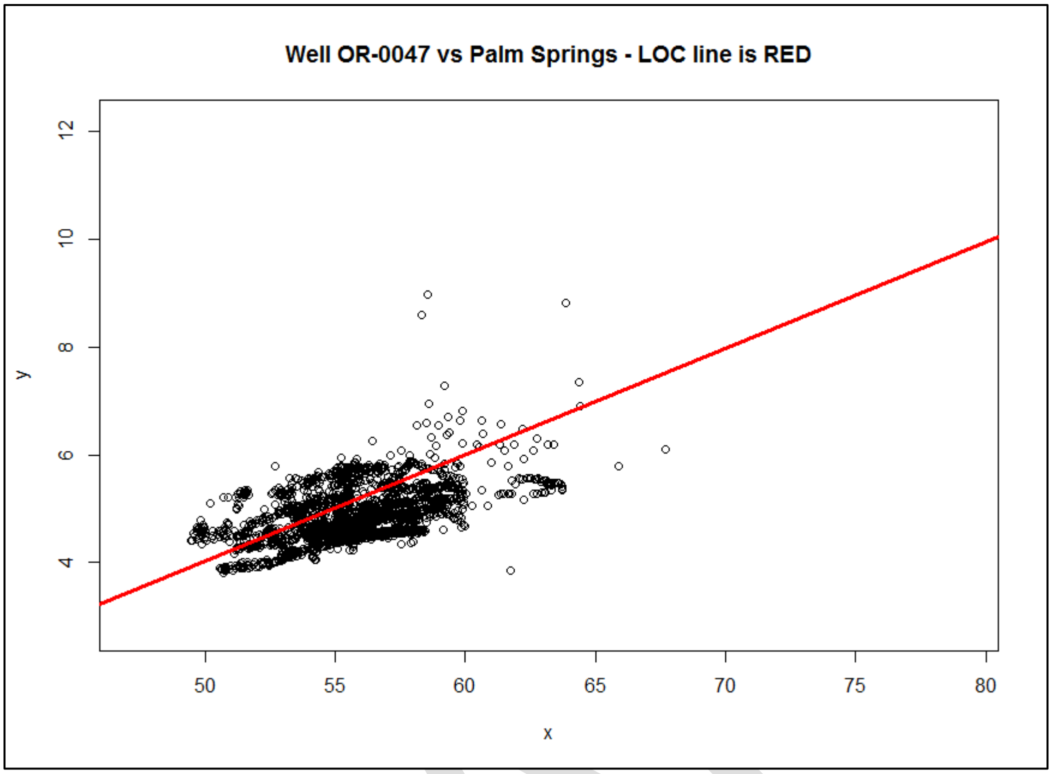

Figure A-3. Well OR-0047 levels (x-axis) and Palm Springs flows (y-axis) LOC relationship.

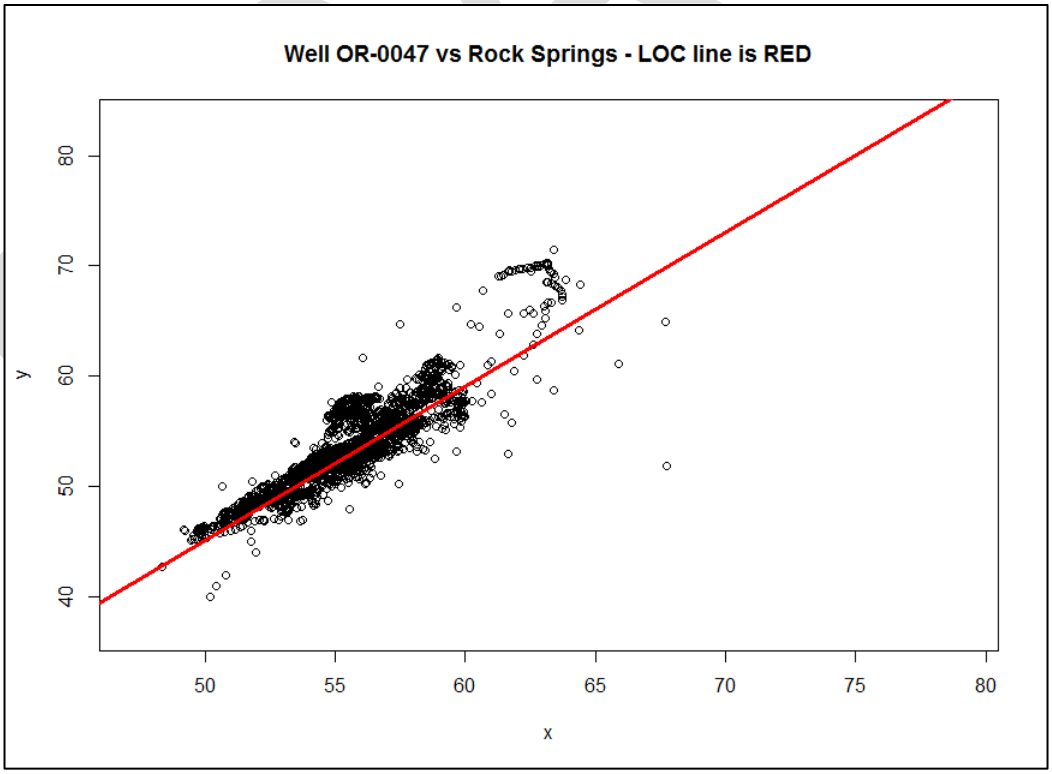

Figure A-4. Well OR-0047 levels (x-axis) and Rock Springs flows (y-axis) LOC relationship.

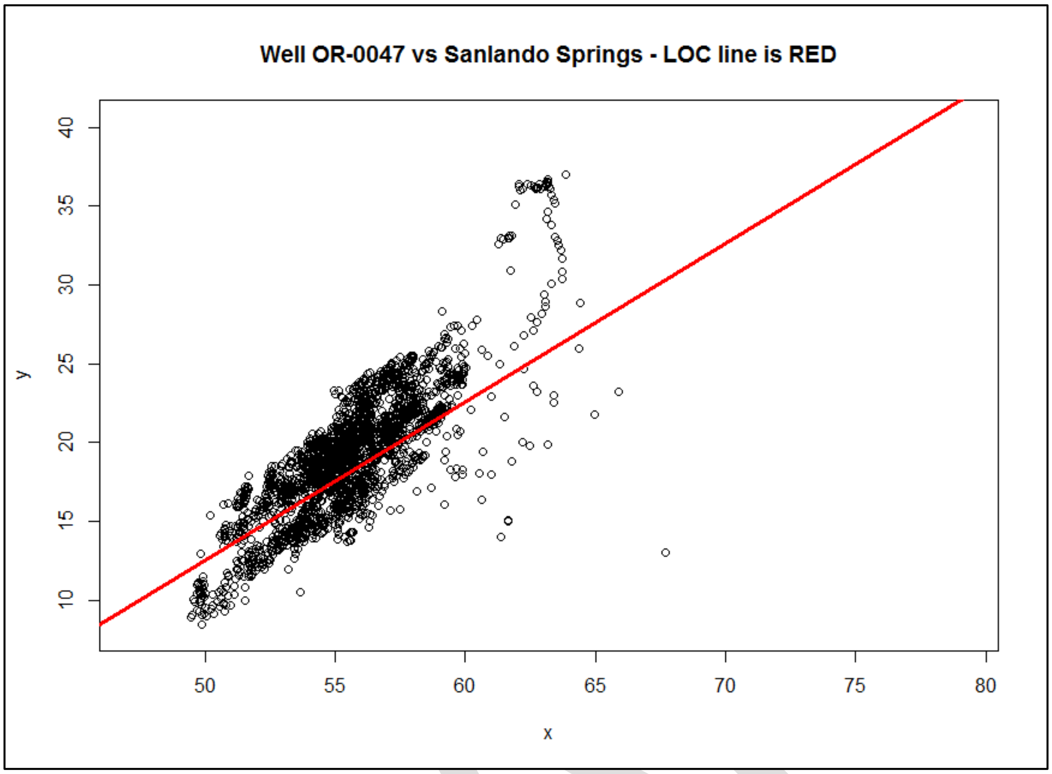

Figure A-5. Well OR-0047 levels (x-axis) and Sanlando Springs flows (y-axis) LOC relationship.

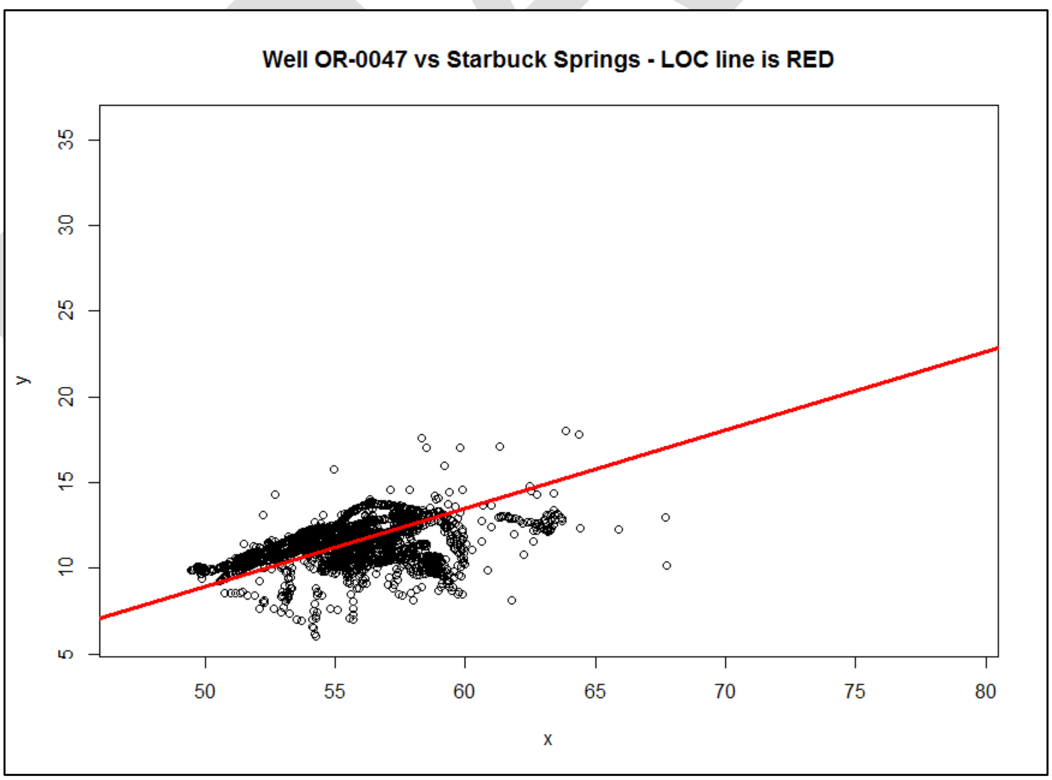

Figure A-6. Well OR-0047 levels (x-axis) and Starbuck Springs flows (y-axis) LOC relationship.

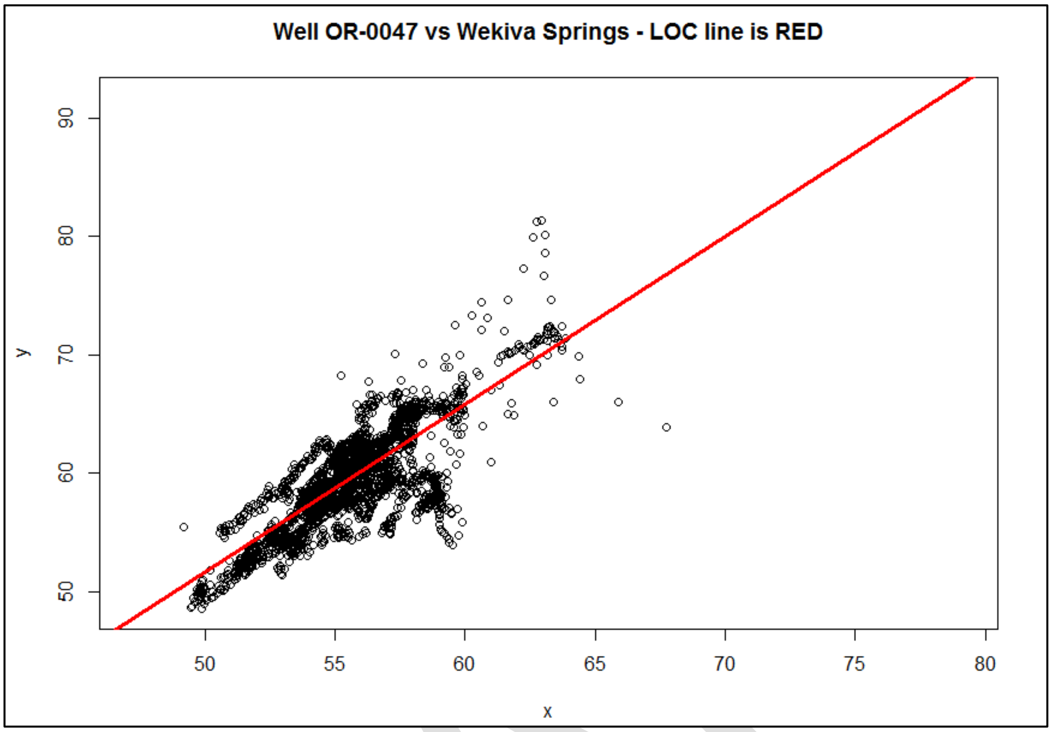

Figure A-7. Well OR-0047 levels (x-axis) and Wekiva Springs flows (y-axis) LOC relationship.

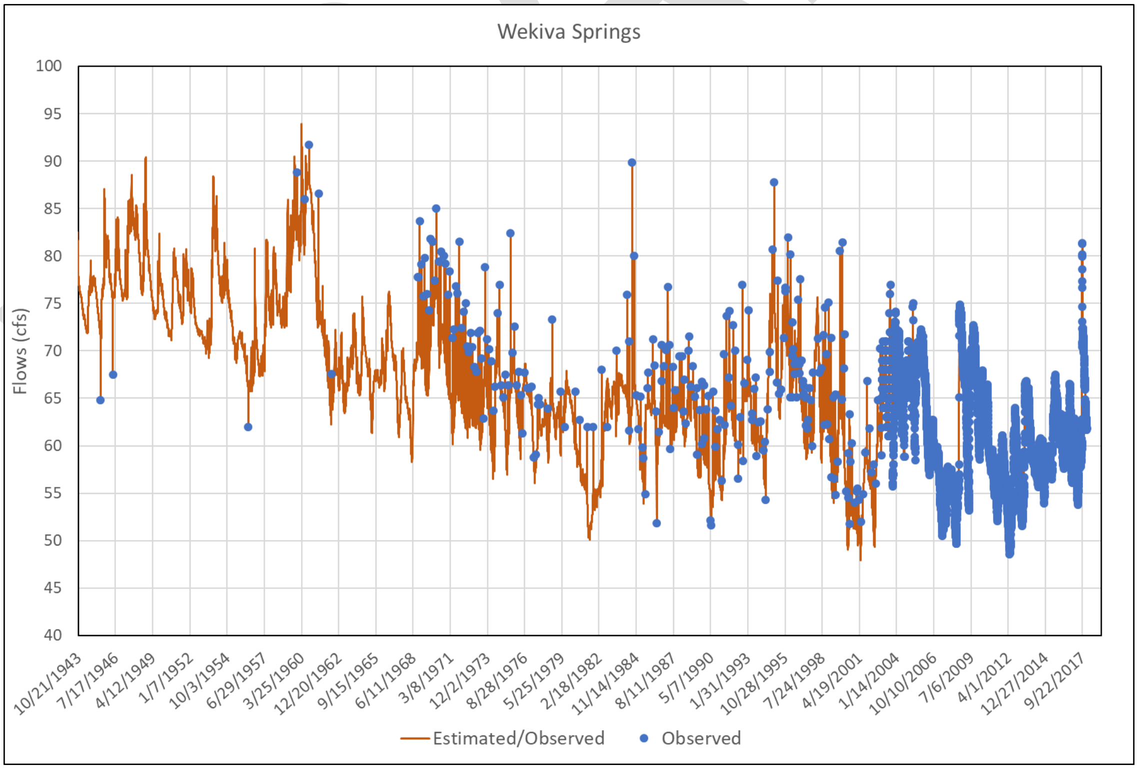

Figure A-8. Estimated and Observed Wekiva Spring flows

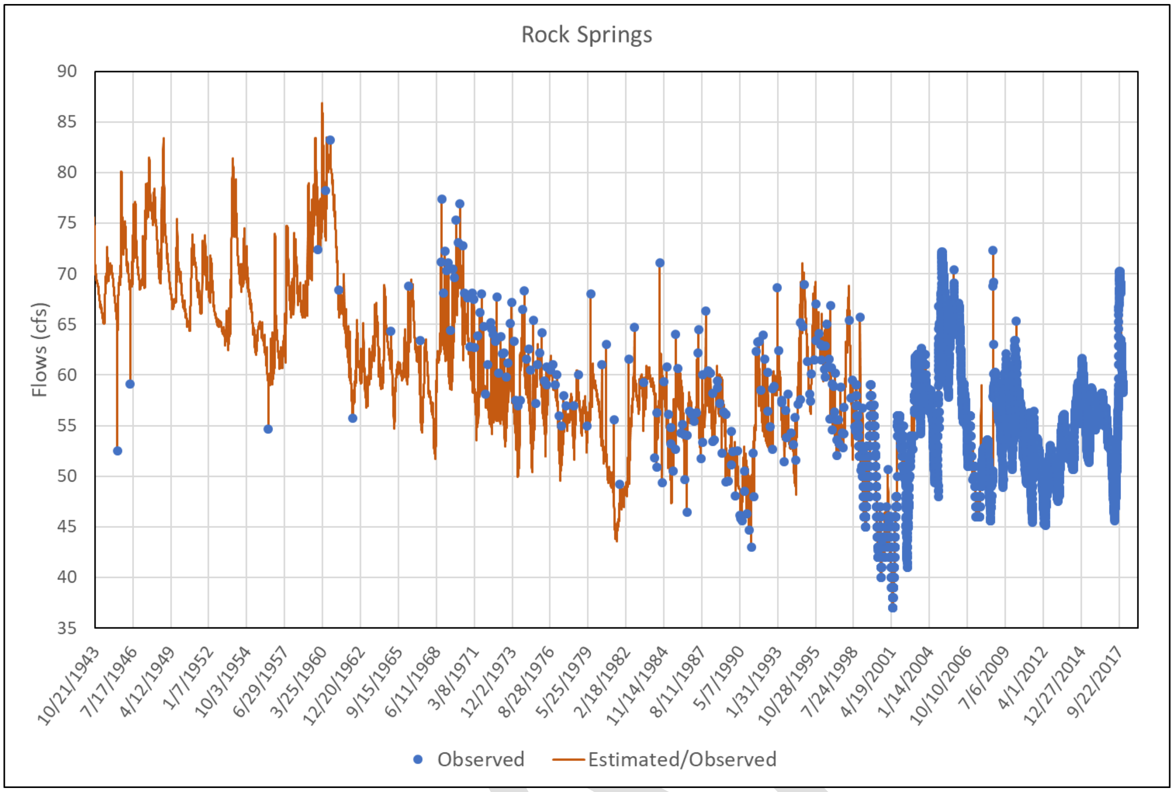

Figure A-9. Estimated and Observed Rock Spring flows

Table 3. Simple linear regression equations (SLR) of springs

Name	SLR Equation	Coefficient of Determination (r^2)
Helen Springs	0.0257 X - 0.3798	0.83
Island Springs	0.1358 X + 0.9316	0.52
Sulphur Springs	0.0244 X - 0.88	0.40

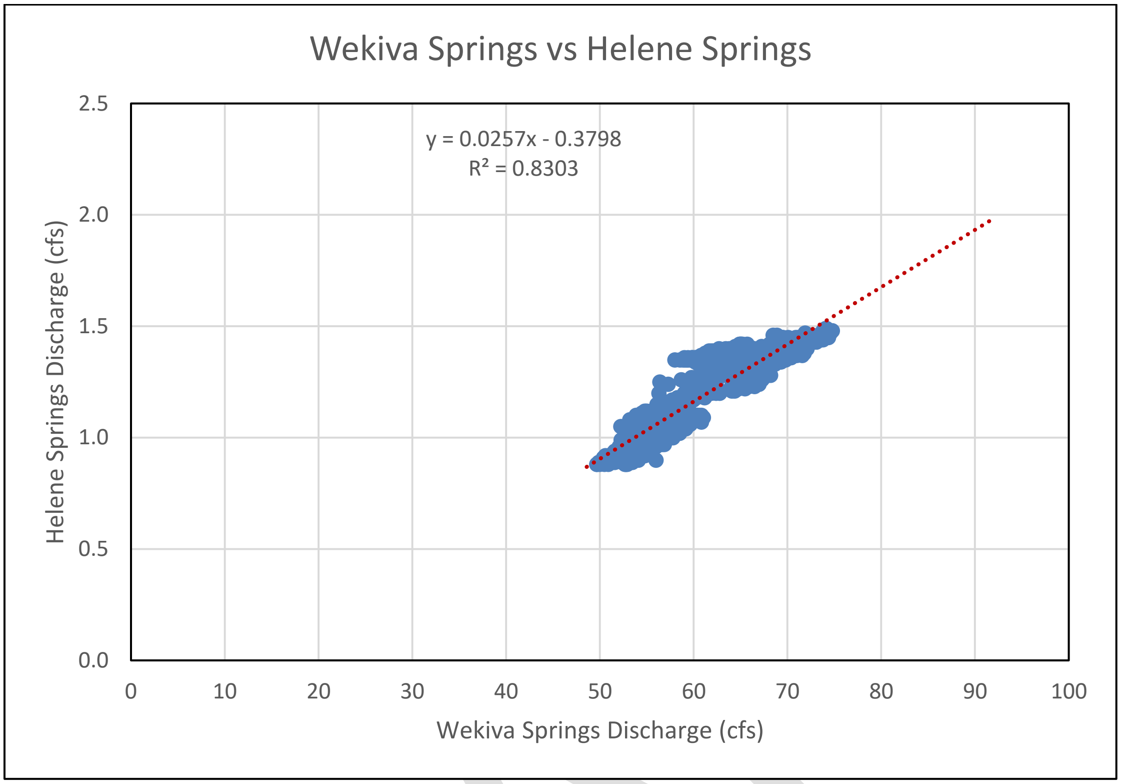

Figure A-10. SLR relationship between Wekiva Springs and Helen Springs.

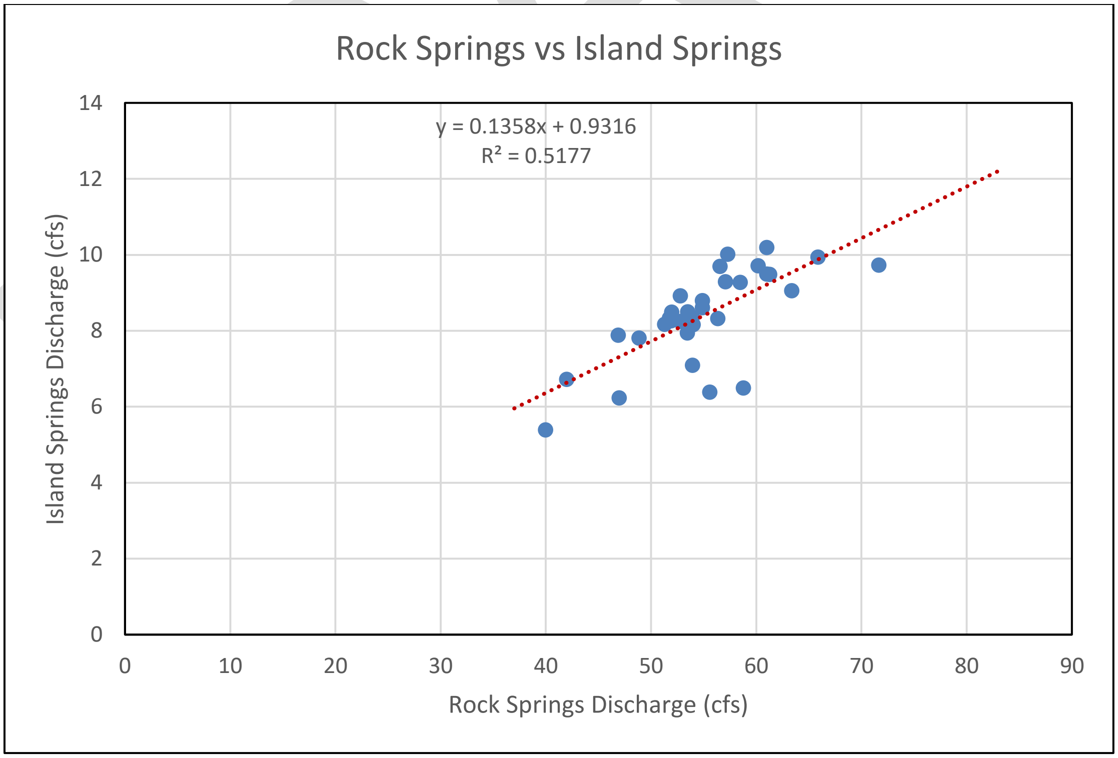

Figure A-11. SLR relationship between Rock Springs and Island Springs.

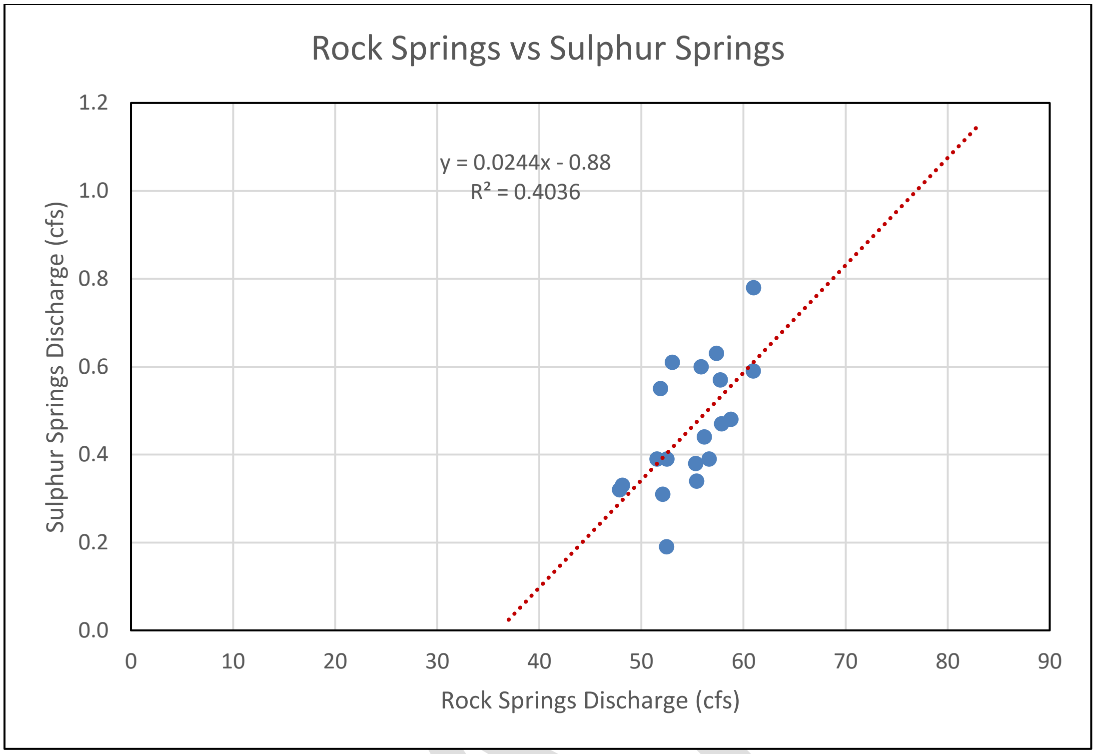

Figure A-12. SLR relationship between Rock Springs and Sulphur Springs.

Table 4. Springs with their mean ratio counterparts.

Name	Spring Magnitude	Ratio with Springs
Barrel Springs	5	Wekiva Springs
Blue Algae Boil	5	Helen Springs
Boulder Springs	5	Helen Springs
Camp La No Che Springs	4	Messant Springs
Cedar Springs	5	Helen Springs
Droty Spring	4	Rock Springs
Ginger Ale Springs	4	Palm Springs
Green Algae Boil	5	Helen Springs
Markee Springs	4	Helen Springs
Messant Springs	2	Rock Springs
Nova Springs	3	Island Springs
Pegasus Springs	3	Starbuck Springs
Sharks Tooth Springs	5	Helen Springs
Snail Springs	5	Rock Springs
Witherington Springs	3	Rock Springs

REFERENCE

Helsel, D.R. and R. M. Hirsch, 2002. **Statistical Methods in Water Resources** *Techniques of Water Resources Investigations, Book 4, chapter A3.* U.S. Geological Survey. 522 pages