APPENDIX B — HYDROLOGICAL ANALYSES

INTRODUCTION

In addition to extensive work conducted to understand the ecological structure and function, and most sensitive environmental values of priority waterbodies, assessing the status of minimum flows and levels (MFLs) requires substantial hydrological analysis. Several steps were involved in performing the hydrologic analysis, including:

1. Review of available data for compiling long-term datasets;
2. Historical groundwater pumping impact assessment;
3. Development of spring flow datasets representing no-pumping and current-pumping conditions; and
4. Estimating available water (freeboard or deficit).

Figure 1 shows the flowchart for the hydrologic analysis. This document describes the first three steps and associated results. Appendix C includes the description of the last step.

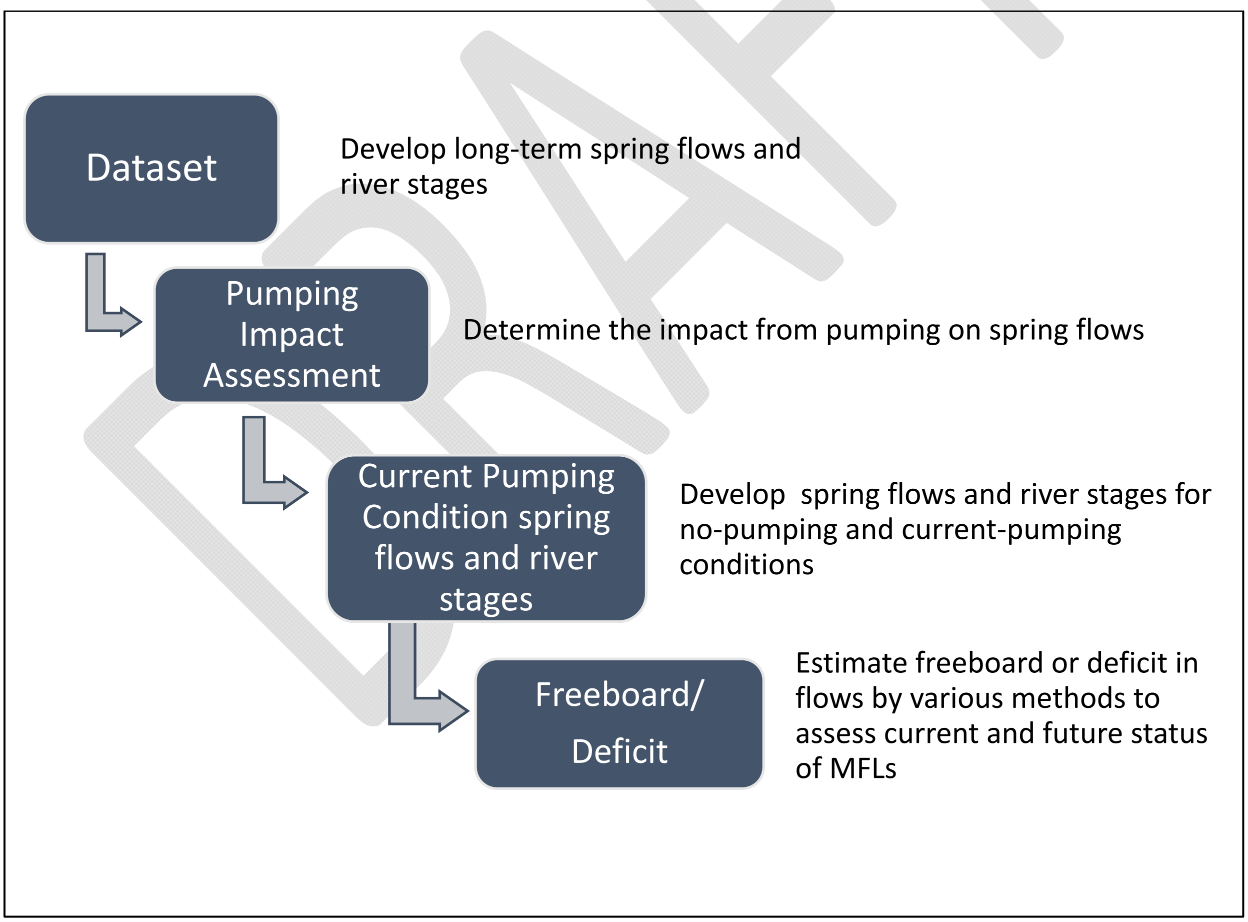

Figure 1. Flowchart for Hydrologic Analysis Process

BACKGROUND

The Wekiva River watershed is in Lake, Seminole, Orange, and Marion counties of Florida (Figure 2). The total area of the watershed is about 376 square miles. The watershed consists of four principal watercourses, the Wekiva River, the Little Wekiva River, Black Water Creek and Rock Springs Run. The Wekiva River is a major tributary of the St. Johns River.

The St. Johns River Water Management District (SJRWMD) developed a Hydrological Simulation Program – FORTRAN (HSPF) (Bicknell 2001) model and HEC-RAS (USACE 2016) model of the Wekiva River watershed (Seong and Wester 2019). The HSPF model was calibrated from 2003 to 2016, and the unsteady HEC-RAS model was calibrated between the period of 1/20/2009 to 7/20/2009.

The models were used to assess the MFLs for the Wekiva River system. When applicable, development of MFLs at SJRWMD is an event-based approach. It requires performing frequency analysis using long-term flows and levels time series data. This report also documents the development of the updated Wekiva River system models for a long-term period comprising from 1948 to 2018.

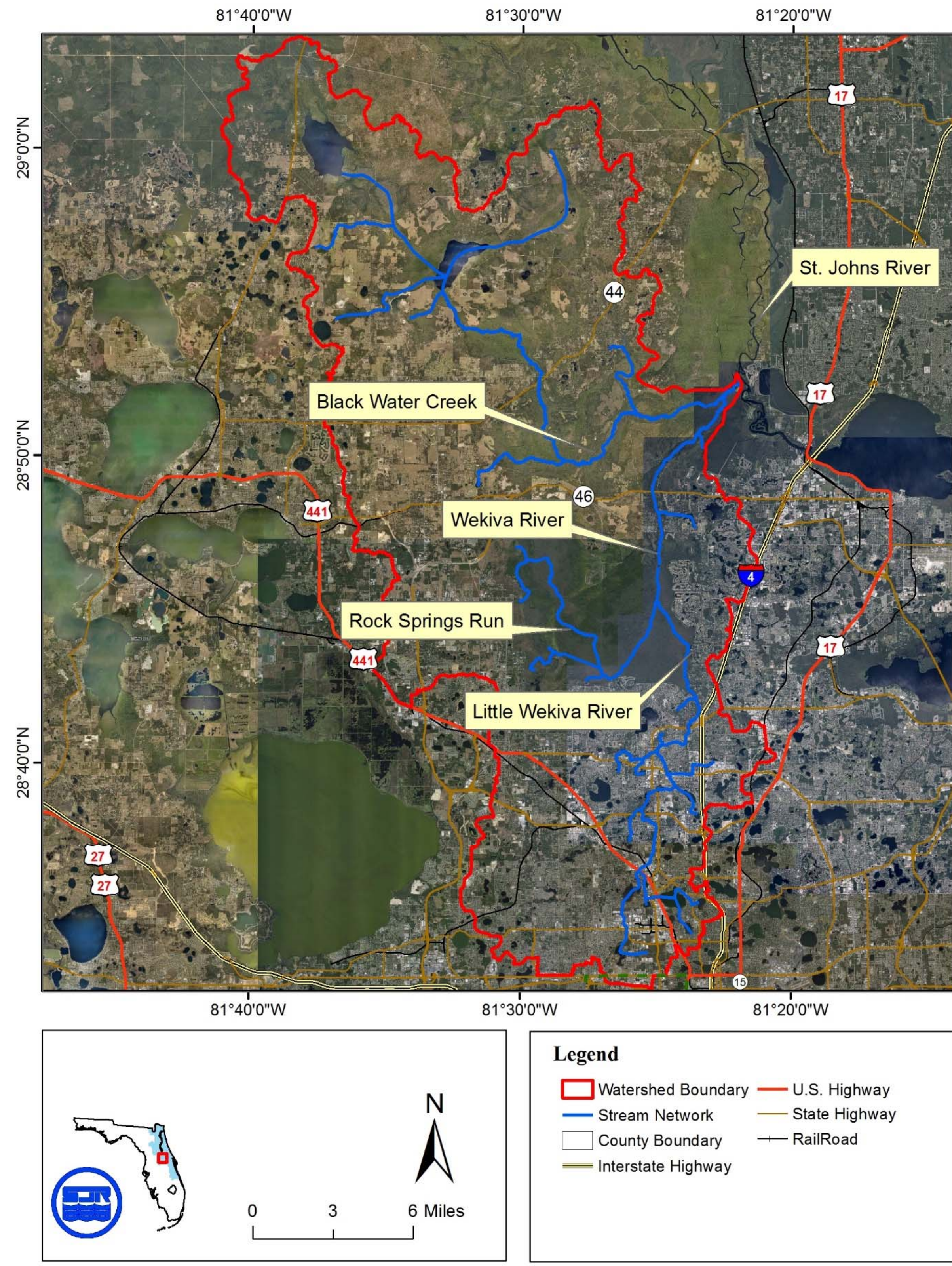

Figure 2. Wekiva River Watershed

REVIEW OF AVAILABLE DATA

Rainfall and Potential Evapotranspiration (PET)

National Oceanic and Atmospheric Administration (NOAA) daily observed data of four weather stations (Figure 3 and Table 1) were used in the HSPF model. The weather stations are at Deland, Lisbon, Orlando, and Sanford. The missing rainfall data were filled using SJRWMD NEXRAD radar rainfall. Daily rainfall totals for each station were disaggregated into an hourly time-series based on an hourly NEXRAD radar rainfall time-series using WDMUtil, the watershed data management tool for HSPF (USEPA 2001).

Potential evapotranspiration (PET) was estimated using the Hargreaves method (Hargreaves and Samani 1985). The Hargraves-Samani method was scaled with monthly correction coefficients to GOES Priestly-Taylor (Priestley and Taylor 1972) evaporation estimate (WSIS 2012). Annual rainfall and PET data are shown in Figures 4 and 5, respectively, and summarized in Table 2.

Table 1. Weather Stations

Station Name	Station ID	Latitude	Longitude	Data Source	Period of Record
Deland 1 SSE, Fla., US	USC00082229	29.0181	-81.3106	NOAA and SJRWMD NEXRAD	PET:1948-2018 PREC:1914-2018
Lisbon, Fla., US	USC00085076	28.8728	-81.7844	NOAA and SJRWMD NEXRAD	PET:1948-2018 PREC:1914-2018
Orlando International Airport, Fla., US	USW00012815	28.4339	-81.325	NOAA and SJRWMD NEXRAD	PET:1948-2018 PREC:1914-2018
Sanford, Fla., US	USC00087982	28.8147	-81.2778	NOAA and SJRWMD NEXRAD	PET:1948-2018 PREC:1914-2018

Table 2. Summary of Annual Rainfall (inches) and PET (inches) for a Period of Record 1948 to 2018

Parameter	DELAND		LISBON		ORLANDO		SANFORD	
	Rainfall	PET	Rainfall	PET	Rainfall	PET	Rainfall	PET
Mean	56.12	58.96	48.38	57.90	50.18	58.74	52.12	59.23
Median	54.55	58.96	48.26	57.98	50.93	58.67	51.15	59.10
Standard Deviation	9.56	2.16	8.15	2.62	8.12	1.55	8.87	1.78
Minimum	38.48	53.92	29.28	52.95	30.38	54.64	32.83	55.30
Maximum	76.69	63.34	67.58	63.58	68.74	61.99	74.06	62.94

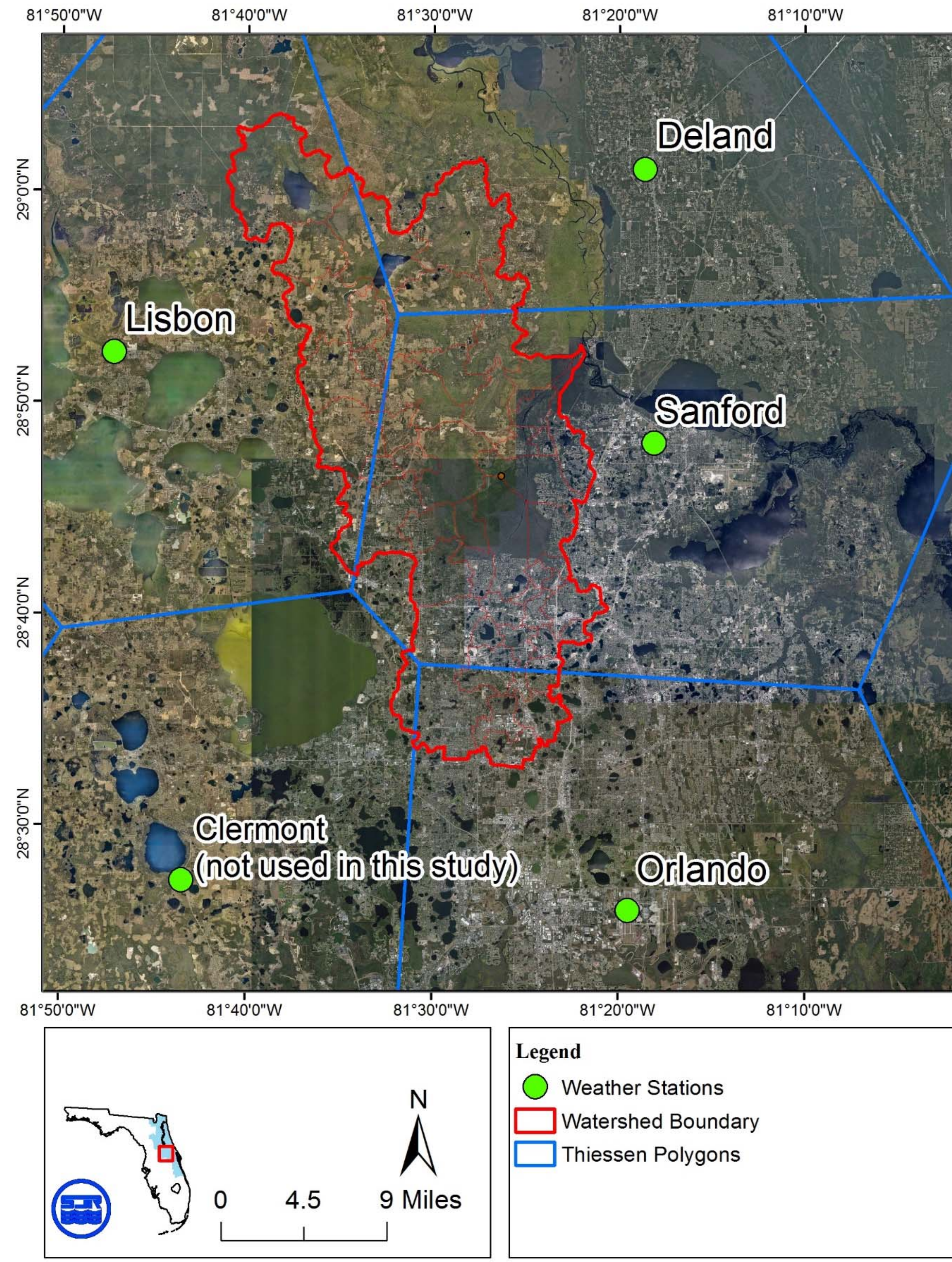

Figure 3. Weather Stations and Thiessen Polygons

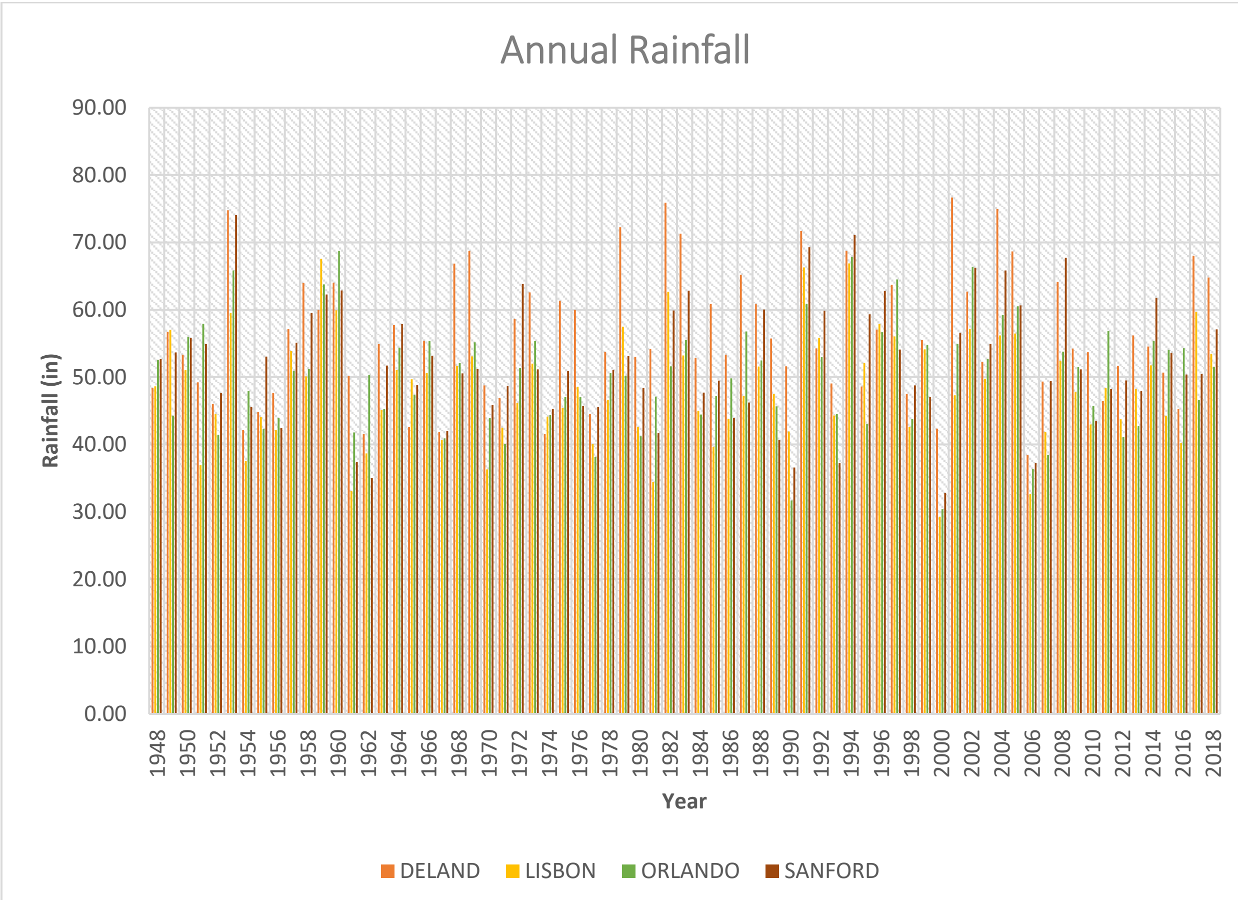

Figure 4. Annual Rainfall

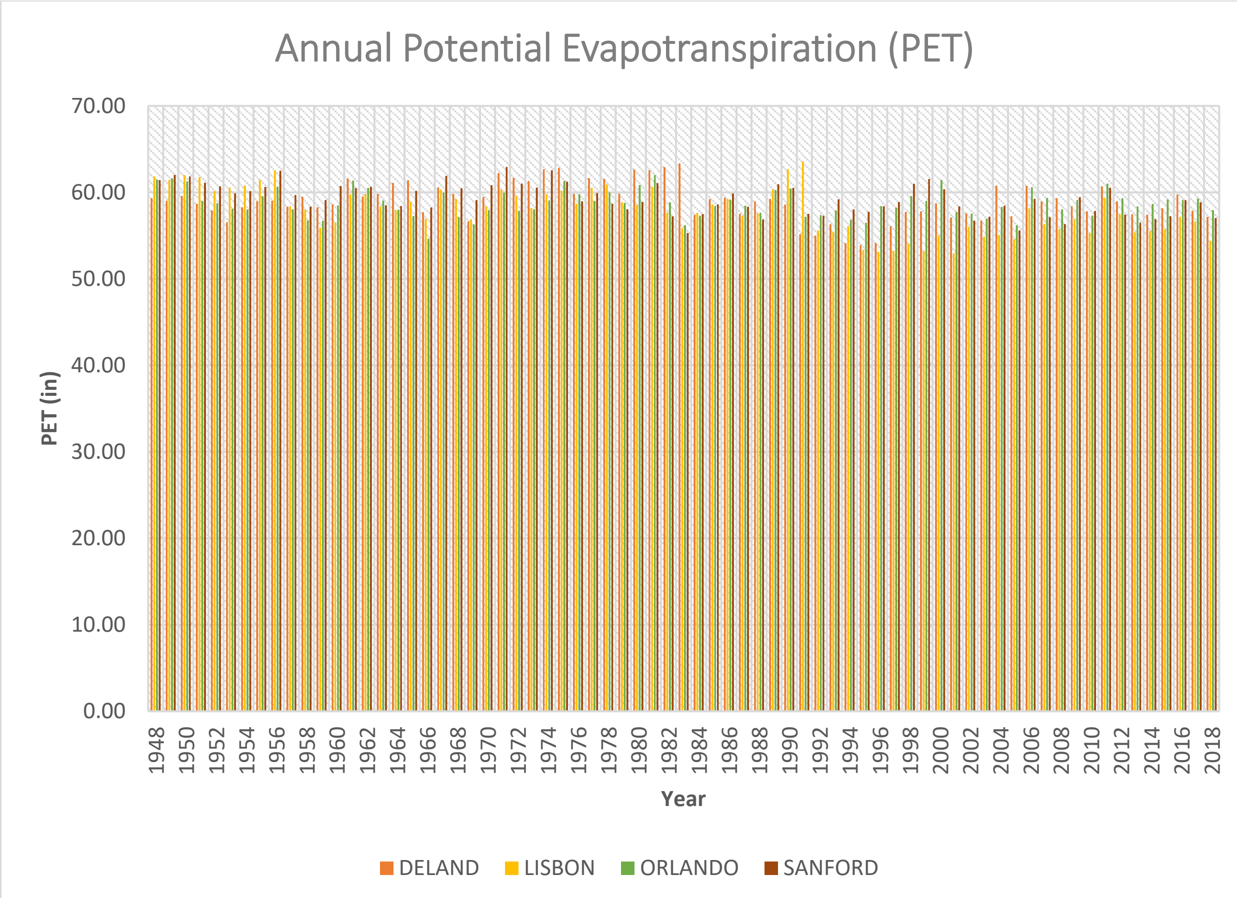

Figure 5. Annual Potential Evapotranspiration (PET)

Flows and River Stages

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 models. Figure 6 shows the stations in the basin. Figures 7 to 14 show the observed data at the eight gages. Summary of available data are presented in Table 3. Flow and stage summary statistics are presented in Table 4 and Table 5, respectively.

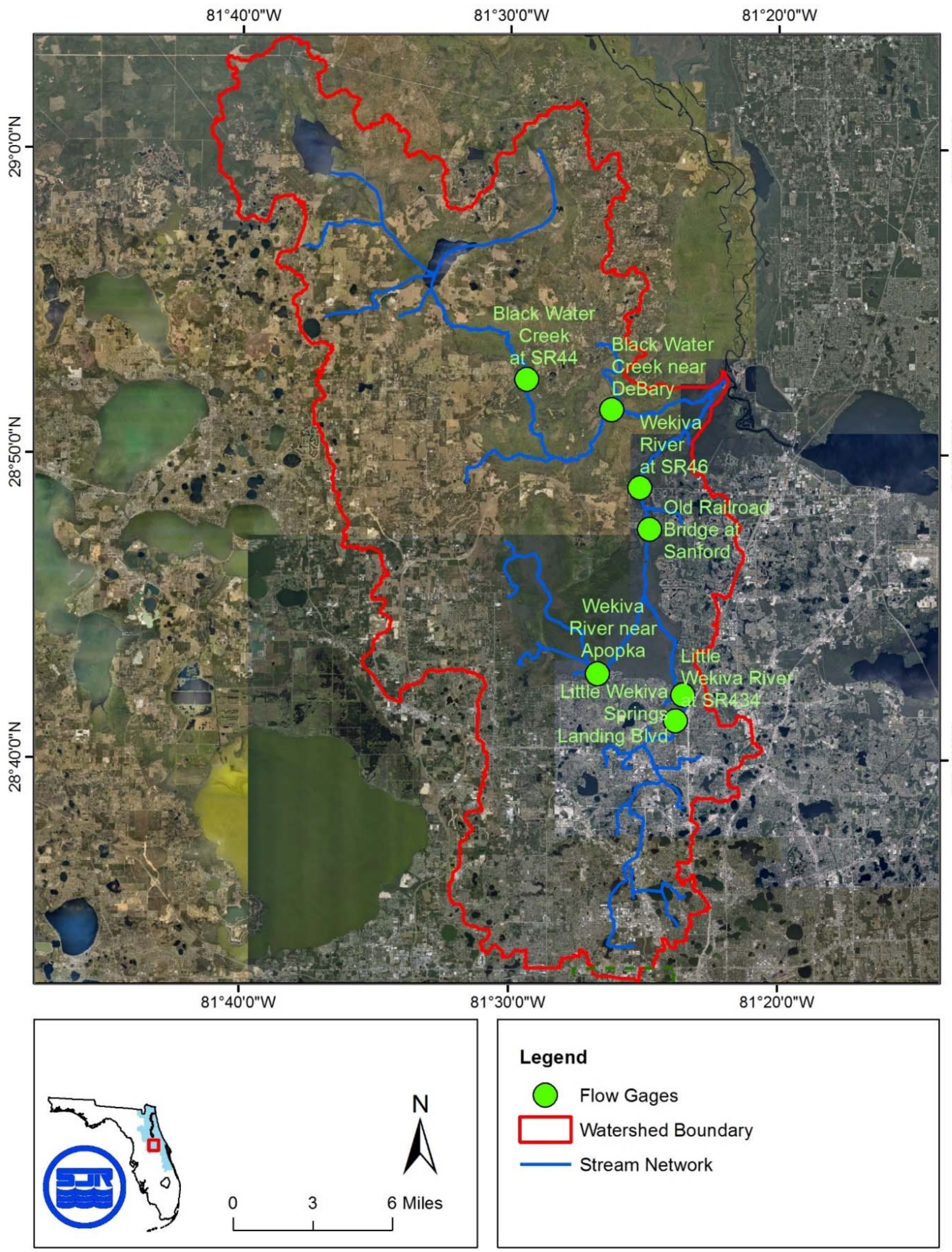

Figure 6. Observed Stations in Wekiva River Basin

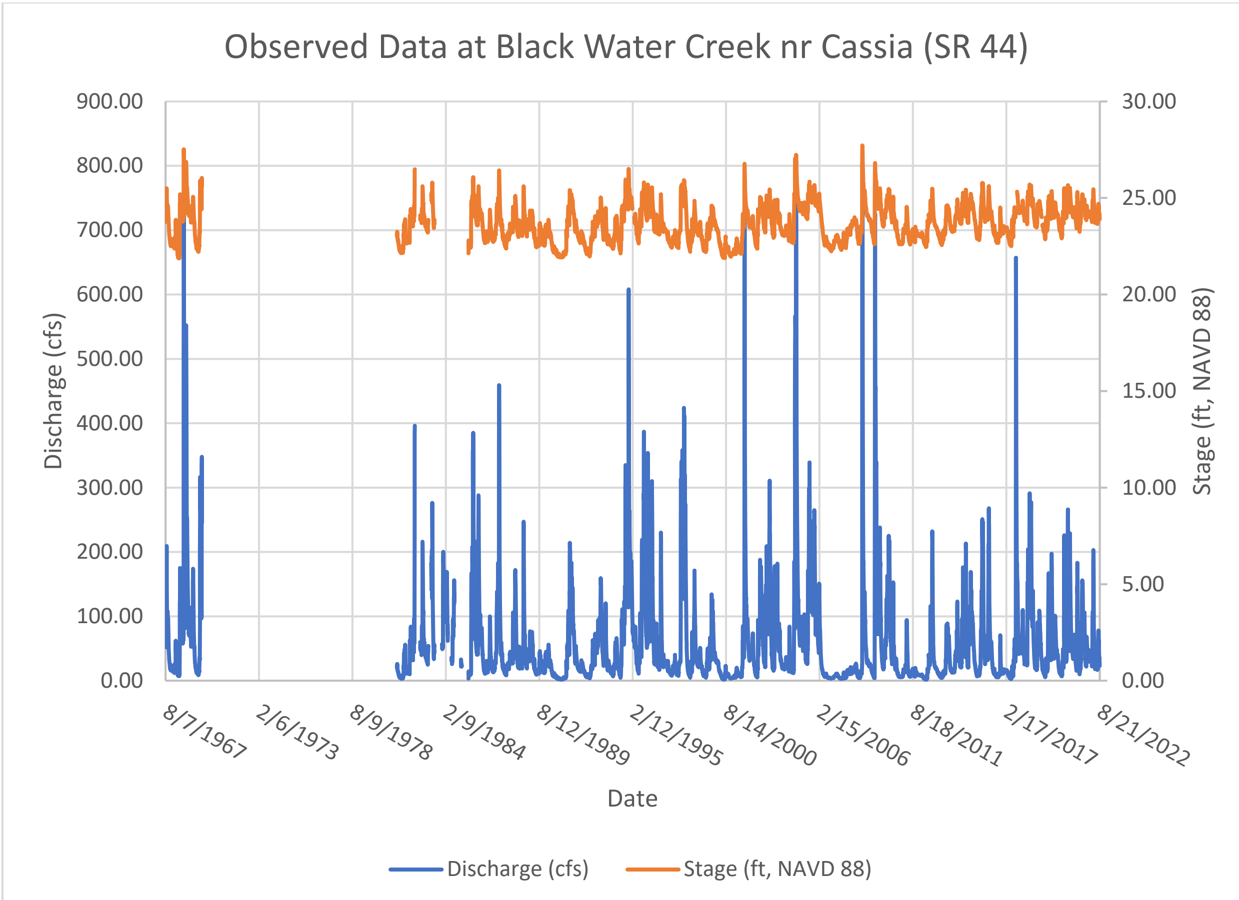

Figure 7. Black Water Creek Observed Data at SR 44 (USGS 02235200).

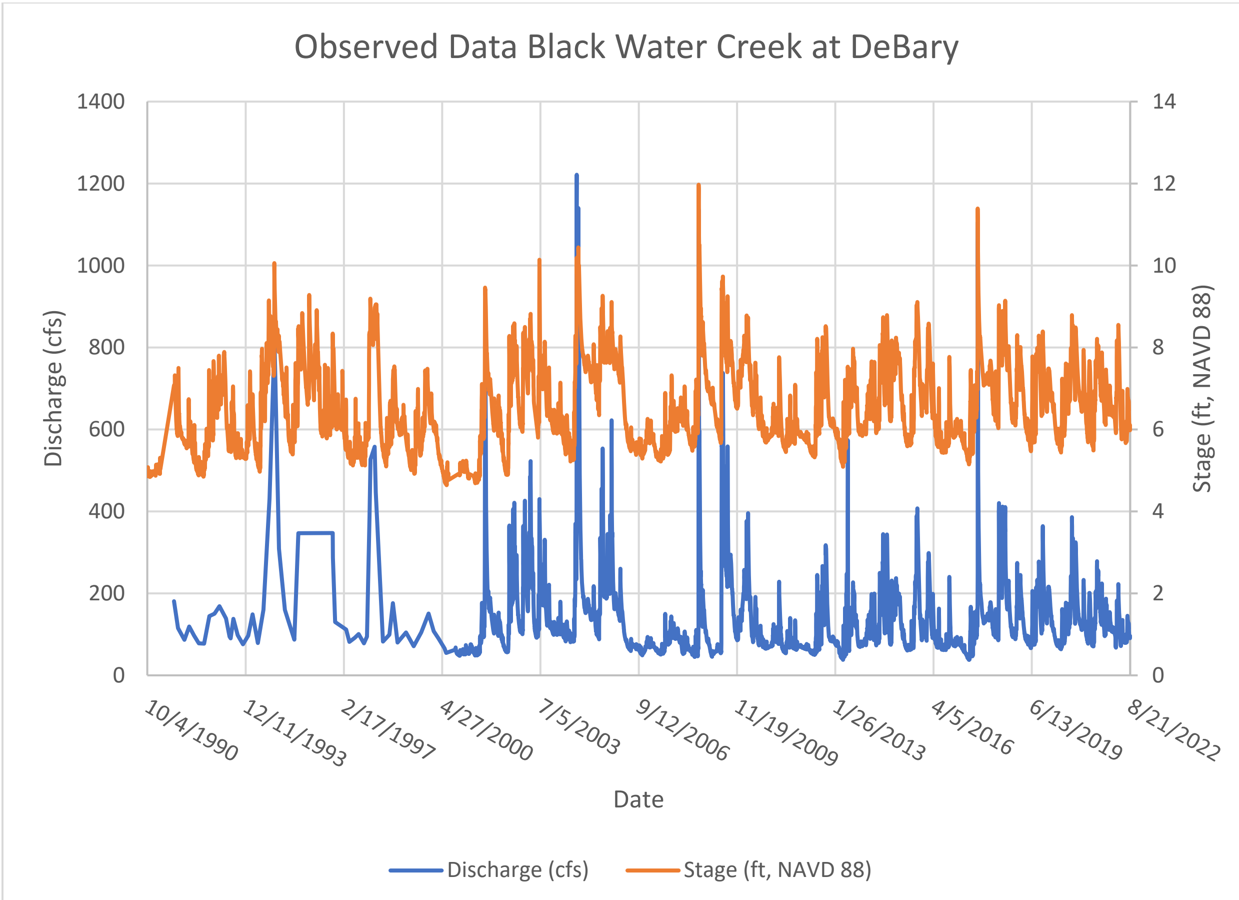

Figure 8. Black Water Creek Observed Data at DeBary (SJRWMD 30143084).

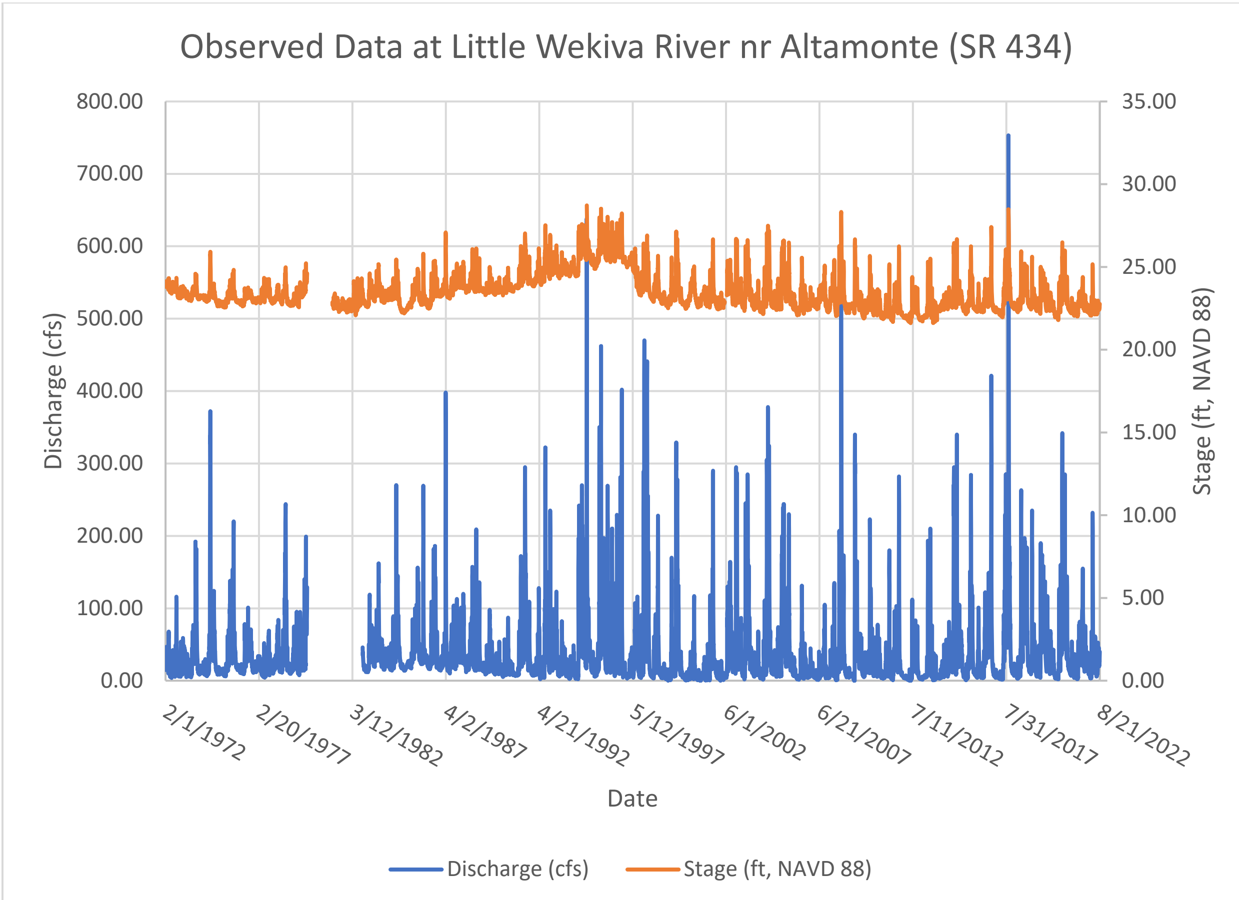

Figure 9. Little Wekiva River Observed Data at SR 434 (USGS 02234990).

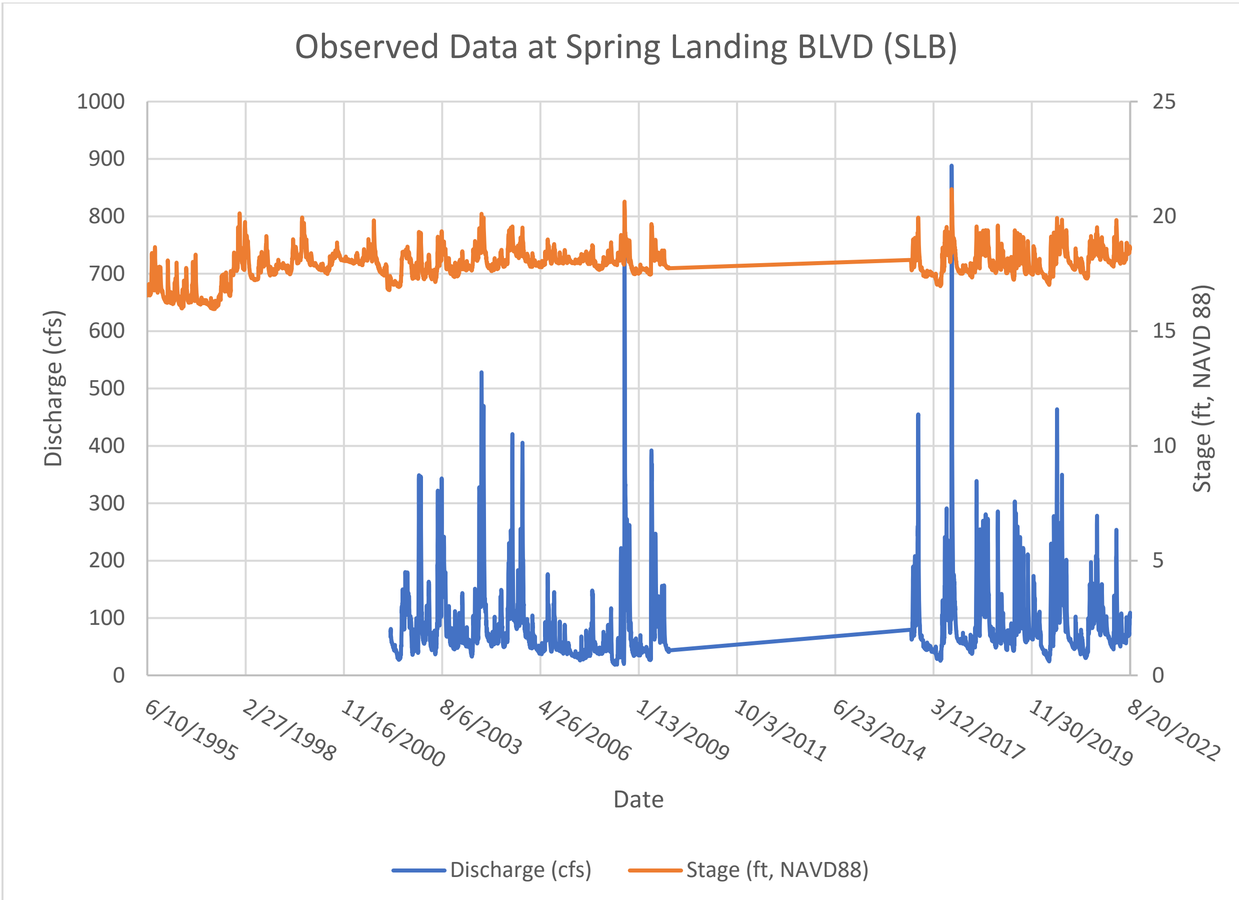

Figure 10. Little Wekiva River at Spring Landing Boulevard Observed Data (SJRWMD 09502132).

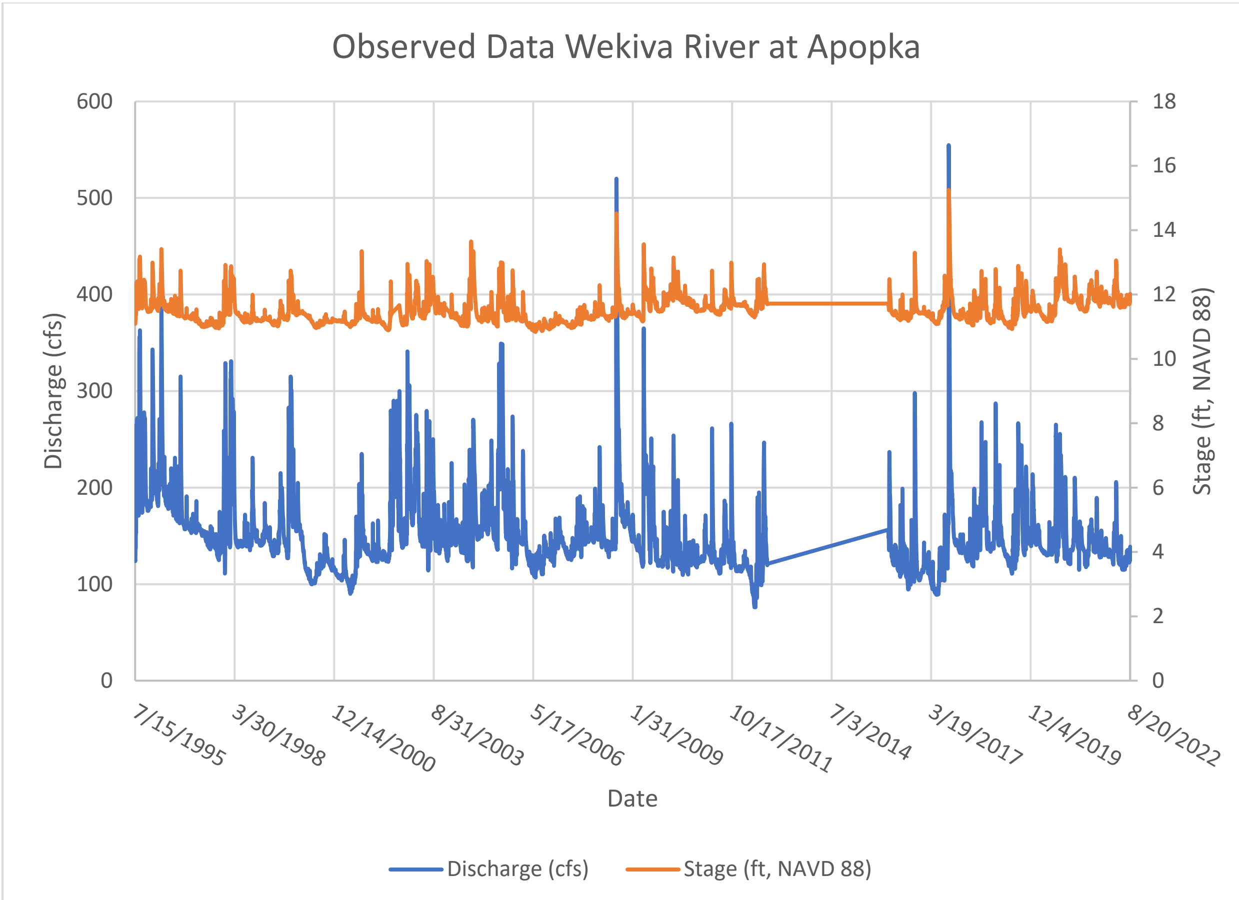

Figure 11. Wekiva River Observed Data at Apopka (SJRWMD 09522138).

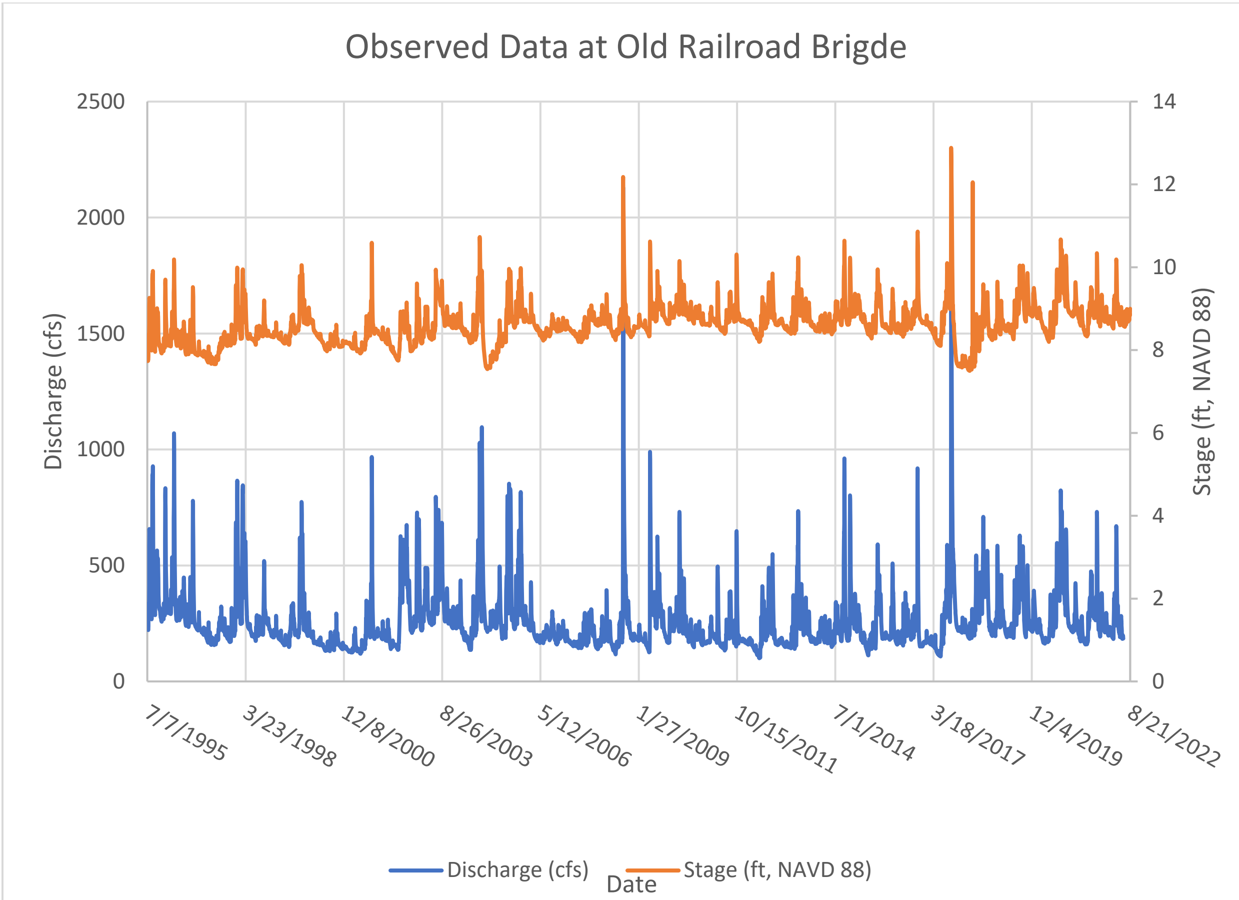

Figure 12. Wekiva River at Old Railroad Bridge Observed Data (SJRWMD 09512135).

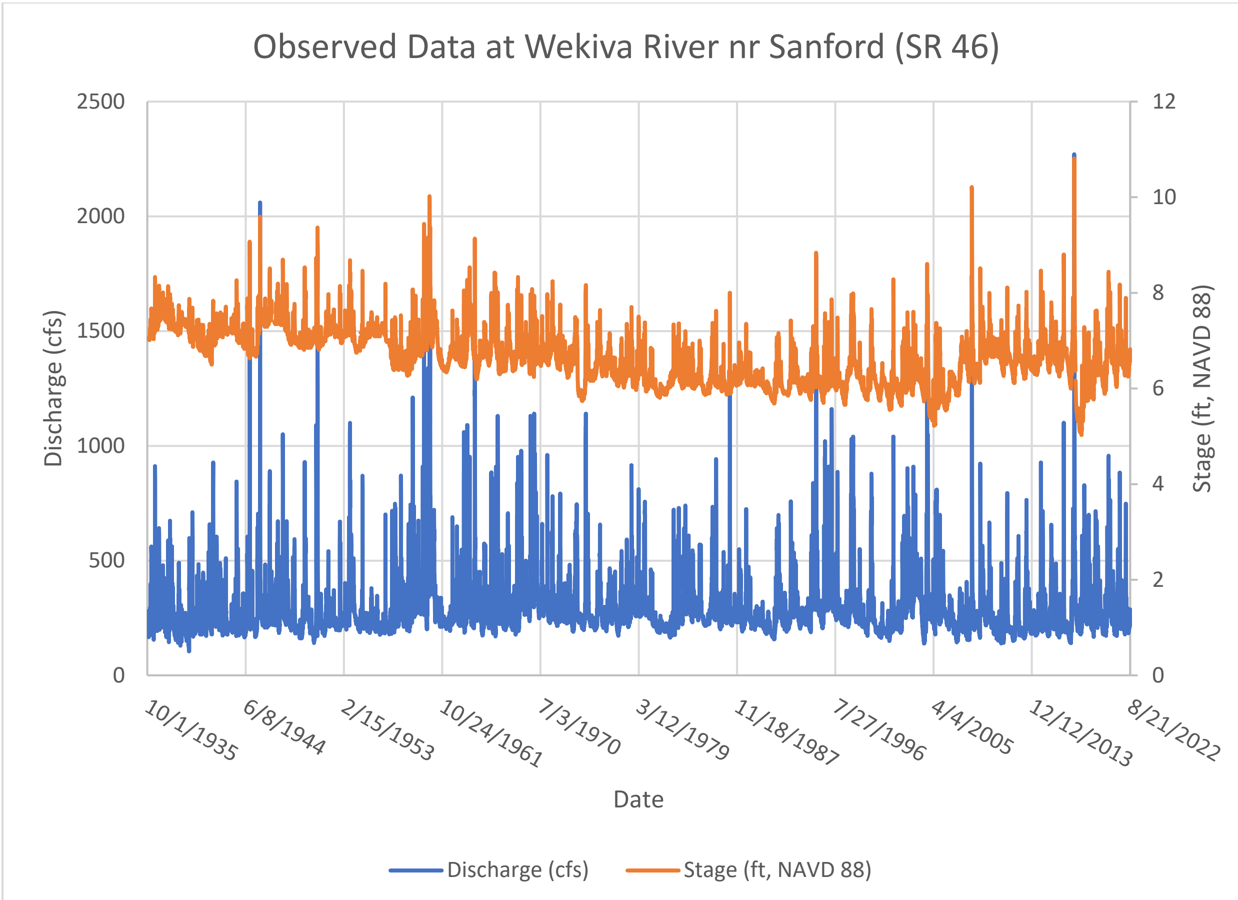

Figure 13. Wekiva River Observed Data at SR 46 (USGS 02235000).

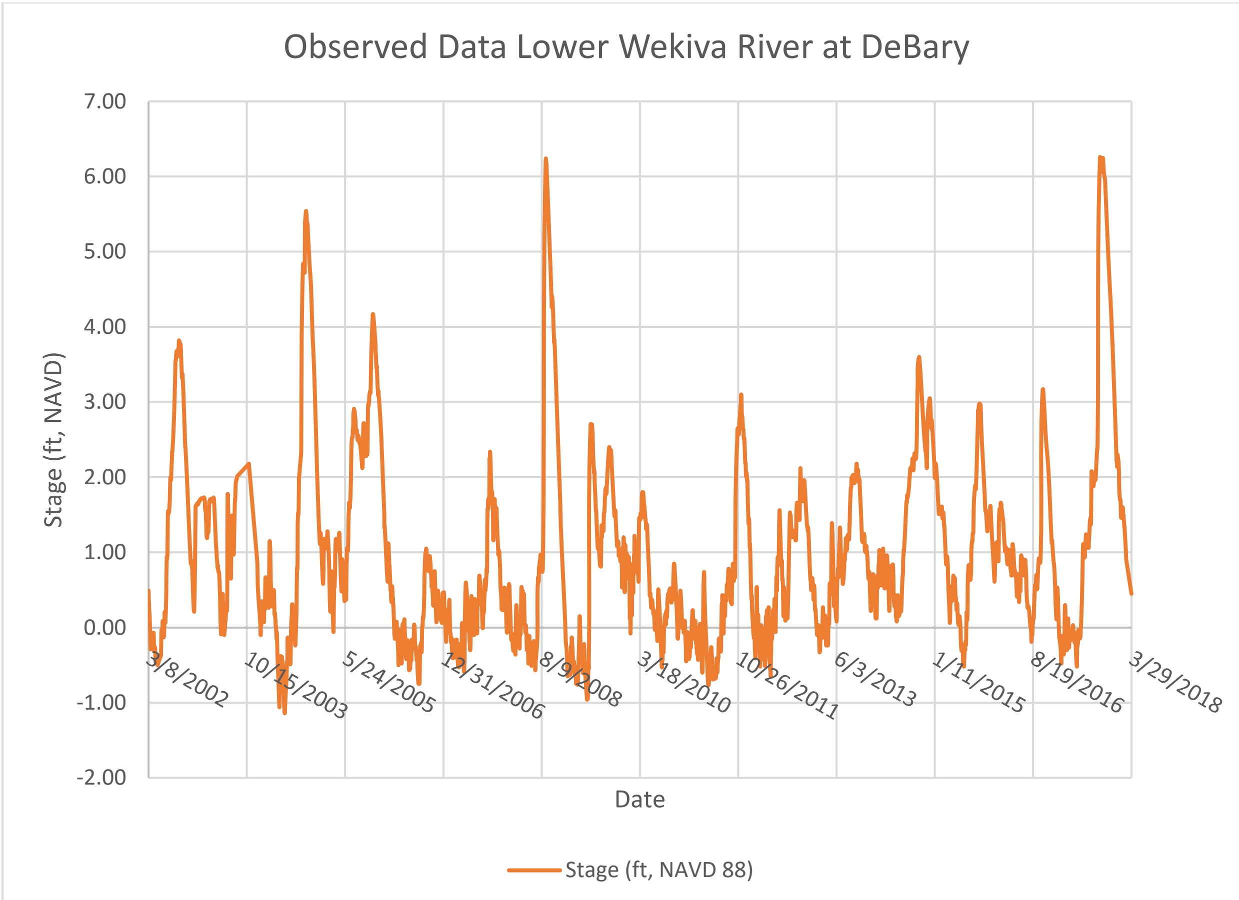

Figure 14. Lower Wekiva River Observed Data at DeBary (SJRWMD 16913302).

Table 3. Stream Gages and Summary of available Data.

Station	ID	Source	Years	Data
Black Water Creek at SR 44	USGS 02235200	USGS	1994-present	Water level and discharge
Black Water Creek near Debary	SJRWMD 30143084	SJRWMD	1990-present	Water level and some discharge
			2000-present	Discharge
Little Wekiva River at SR 434	USGS 02234990	USGS	1994-present	Water level and discharge
Little Wekiva at Springs Landing Blvd (SLB)	SJRWMD 09502132	SJRWMD	1995-2009 8/2016 - present	Water level
			2002-2009 8/2016 - present	Discharge
Wekiva River near Apopka	SJRWMD 09522138	SJRWMD	1995-2012 and 2016-present	Water level and discharge
Old Railroad Bridge at Sanford	SJRWMD 09512135	SJRWMD	1995-present	Water level and discharge
Wekiva River at SR 46	USGS 02235000	USGS	1936-present	Water level and discharge
Lower Wekiva River at Debary	SJRWMD 16913302	SJRWMD	2002-2018	Water Level

Table 4.Discharge (cfs) Summary Statistics of Observed Data.

Station	Period of Record	Statistical Parameter						
		Mean	Median	Standard Deviation	Range	Minimum	Maximum	Count
USGS 02235200	8/7/1967-8/21/2022	57.62	30.60	76.85	806.31	1.69	808.00	15,215.00
SJRWMD 30143084	8/15/1991-8/21/2022	135.09	105.08	99.29	1,183.57	37.90	1,221.47	7,993.00
USGS 02234990	2/1/1972-8/21/2022	34.56	19.00	47.17	752.87	0.13	753.00	17,368.00
SJRWMD 09502132	3/1/2002-8/20/2022	86.11	64.52	67.63	869.71	18.60	888.31	5,034.00
SJRWMD 09522138	7/15/1995-8/20/2022	151.29	141.00	41.11	478.70	76.07	554.77	8,495.00
SJRWMD 09512135	7/7/1995-6/13/2022	257.33	219.00	133.49	2,029.80	100.20	2,130.00	9,767.00
USGS 02235000	10/1/1935-8/21/2022	286.27	249.00	132.48	2,165.00	105.00	2,270.00	31,737.00

Table 5. Stage (ft, NAVD 88) Summary Statistics of Observed Data.

Station	Period of Record	Statistical Parameter						
		Mean	Median	Standard Deviation	Range	Minimum	Maximum	Count
USGS 02235200	8/7/1967-8/21/2022	23.65	23.57	0.93	5.85	21.87	27.72	14,863.00
SJRWMD 30143084	10/4/1990-8/21/2022	6.50	6.28	1.01	7.33	4.64	11.97	11,098.00
USGS 02234990	2/1/1972-8/21/2022	23.42	23.18	1.08	7.11	21.61	28.72	17,761.00
SJRWMD 09502132	6/10/1995-8/20/2022	17.88	17.92	0.69	5.22	15.96	21.18	7,398.00
SJRWMD 09522138	7/15/1995-8/20/2022	11.52	11.41	0.44	4.41	10.84	15.25	8,332.00
SJRWMD 09512135	7/8/1995-8/21/2022	8.61	8.59	0.48	5.38	7.50	12.88	9,619.00
USGS 02235000	11/6/1935-8/21/2022	6.61	6.58	0.56	5.78	5.03	10.81	31,146.00
SJRWMD 16913302	3/8/2002-3/19/2018	1.02	0.74	1.30	7.40	-1.14	6.26	5,676.00

Springs

Springs contribute a major portion of the flows to the Wekiva River. Twenty-six springs and Wekiva Falls Resort in the Wekiva River watershed were incorporated into Wekiva River basin model. The model requires long-term springs flow data for MFLs development. The methodology used to gap fill and extend the springs time series are detailed in Seong and Wester (2019) report. Figure 15 shows the springs and their locations in the Wekiva River watershed. Table 6 summarized the observed springs discharges in the basin.

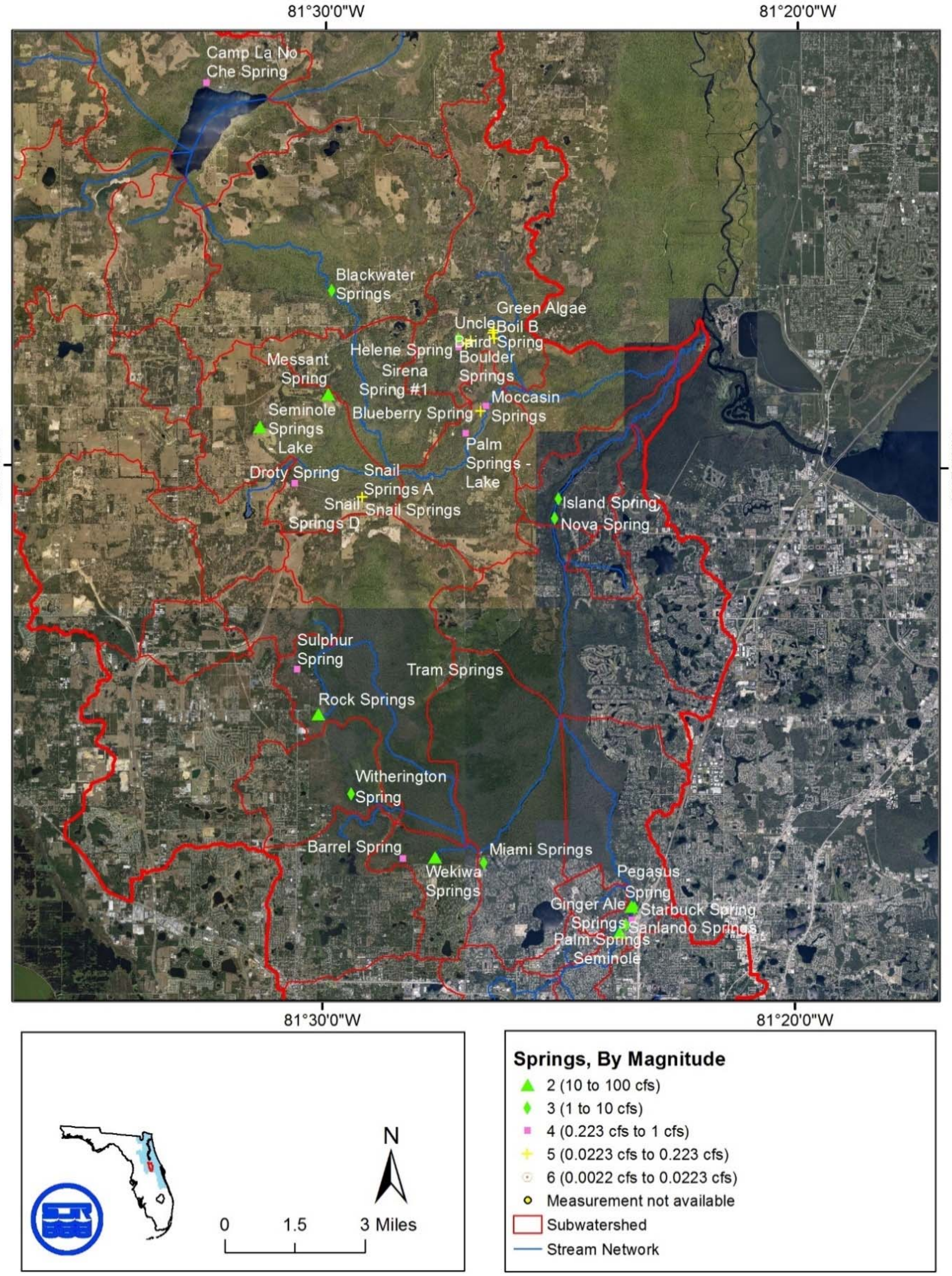

Figure 15. Locations of Wekiva River Basin Springs.

Table 6. Summary of Springs Discharge in Wekiva River Basin.

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	1,229	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	5,247	2.71	5.25	7.83
Nova Springs	3/14/2005	1	8.52	8.52	8.52
Palm Springs	1941-2018	5,250	2.75	5.4	12.2
Pegasus Springs	3/16/2005	1	2.8	2.8	2.8
Rock Springs	1931-2018	6,084	37	54.9	83.2
Sanlando Springs	1941-2018	5,371	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	4,953	6.06	12.11	22.79
Sulphur Spring	1995-2017	22	0.19	0.49	0.95
Wekiwa Springs	1932-2018	5,492	48.59	61.49	91.7
Witherington Springs	1972-1995	2	2.2	2.95	3.7

Point Source Discharges

Two wastewater treatment facilities, Altamonte Springs/Swofford wastewater treatment facility (WWTF) and Wekiva Hunt Club WWTF, are permitted by the Florida Department of Environmental Protection (FDEP) through the National Pollutant Discharge Elimination System (NPDES) to discharge into the Wekiva River. The Altamonte Springs/Swofford WWTF discharges 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. Table 7 presents the point source locations.

Table 7. Point Sources in Wekiva River Basin

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

Cross Sections

Stream cross sections were obtained from various sources as indicated in Table 8. Figure 16 shows the Wekiva River cross sections. The cross sections were updated by lengthening to include the entire flood plain (Intera 2022).

Table 8. Wekiva River Cross Sections

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

Transect Name	Stream	River Station (ft/100)	Data Source	Year
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
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

Transect Name	Stream	River Station (ft/100)	Data Source	Year
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

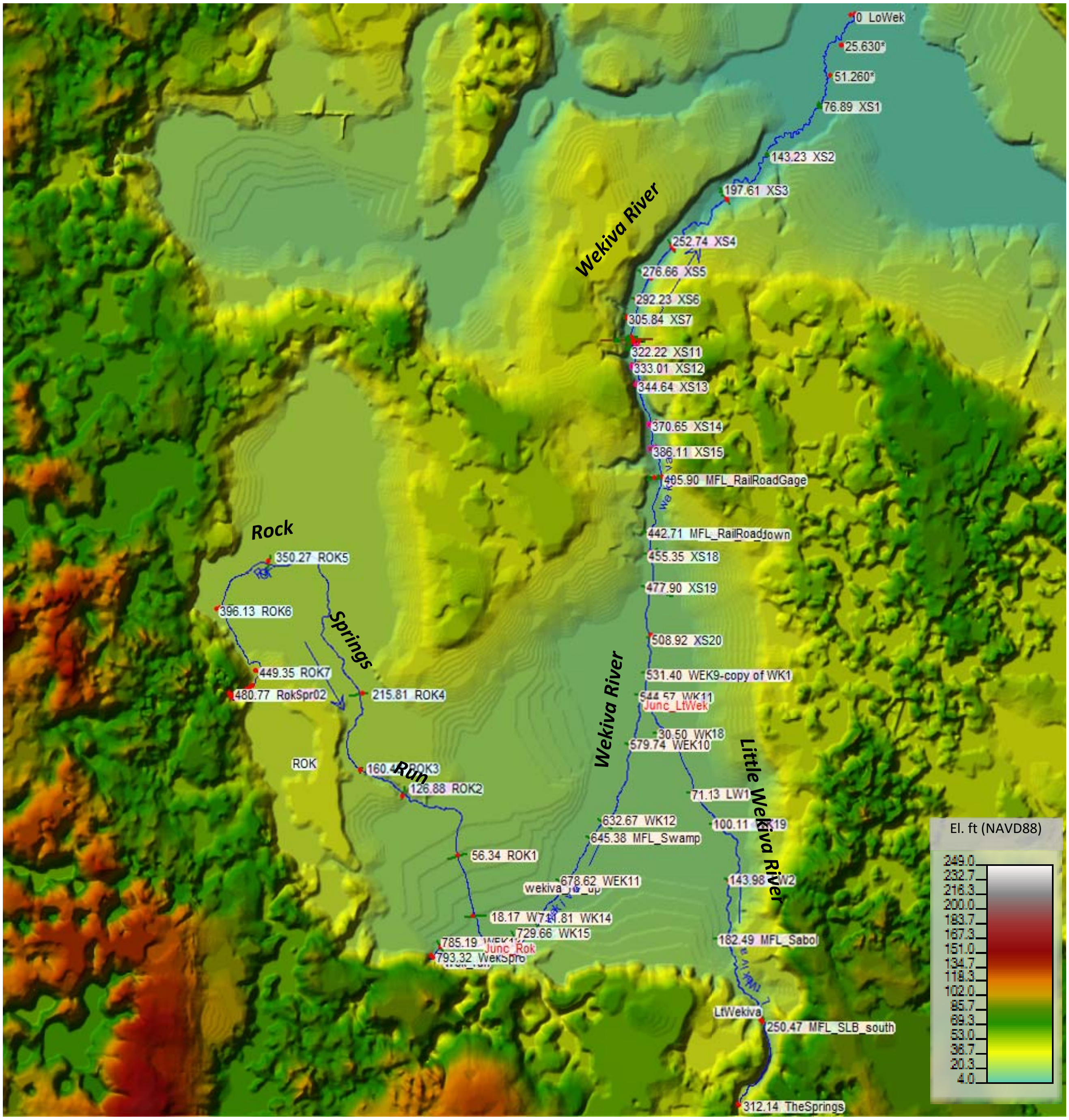

Figure 16. Wekiva River Cross Sections.

WEKIVA RIVER BASIN LONG-TERM MODEL SIMULATIONS

MFLs development requires long-term simulation analysis to capture the effect of short- and long-term climatic changes. The original HSPF and HEC-RAS models of the Wekiva River basin (Seong and Wester 2019) were extended to a period from 1/1/1948 to 12/31/2018. Various long-term model scenarios were simulated. Two different models, HSPF and HEC-RAS, were used sequentially to model the Wekiva River basin. The HSPF model comprises the Rock Springs Run, Little Wekiva River, Wekiwa Springs Run, Black Water Creek, and the Wekiva River watersheds. The HEC-RAS model domain includes Rock Springs Run, Wekiwa Springs Run, Little Wekiva River, and the Wekiva River from its junction with Rock Springs Run to the Lower Wekiva River gage.

Historical Long-Term Simulation Scenario

All hourly input data were extended to cover the period from 1/1/1948 to 12/31/2018. The original parameters of the HSPF models were kept unchanged. Because of the extension of cross sections to include the flood plain, the HEC-RAS model was recalibrated slightly by changing the Manning n values. Simulated historical stages at selected gages are shown in Figures 17 to 21. Table 9 presents summary of descriptive statistics of the gages.

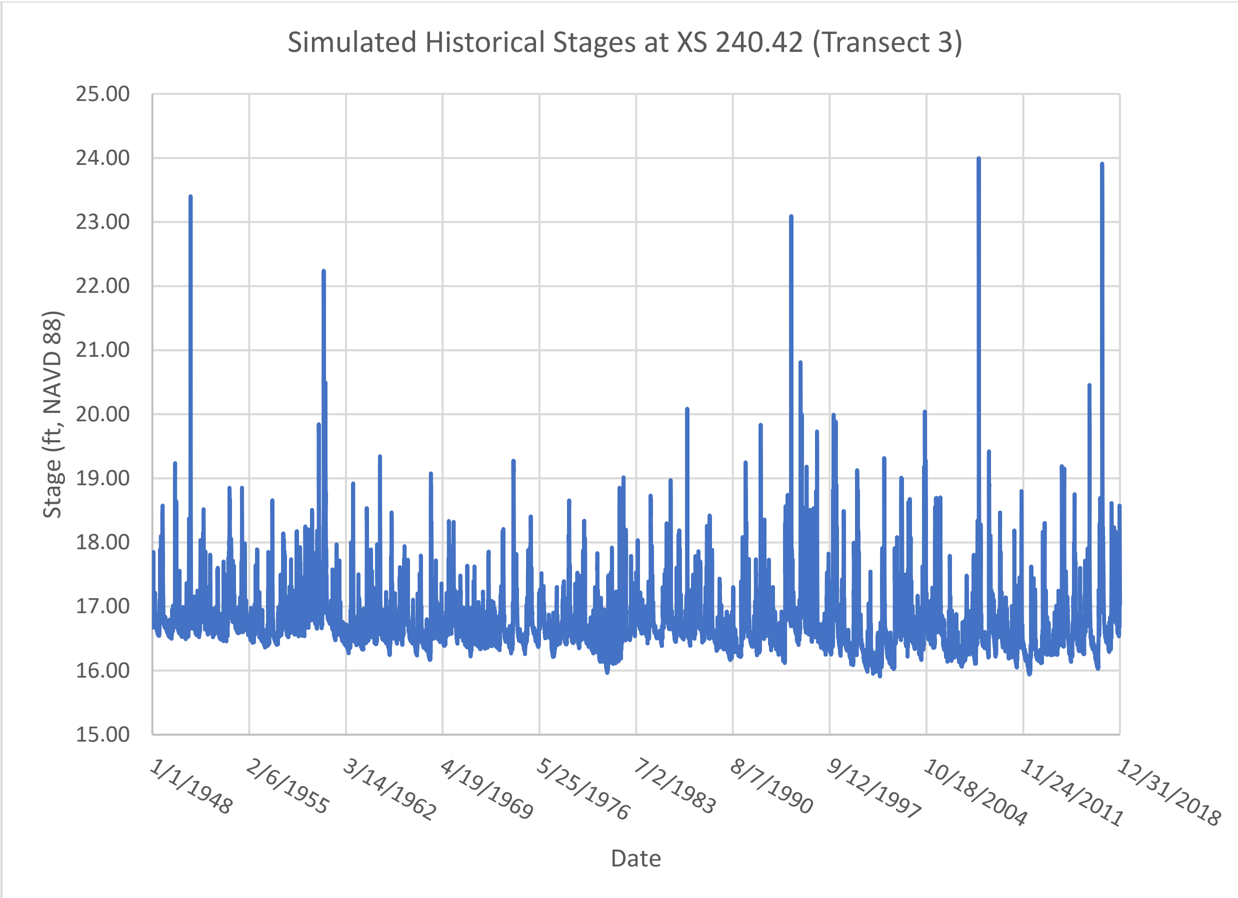

Figure 17. Simulated Historical Stages at Transect 3.

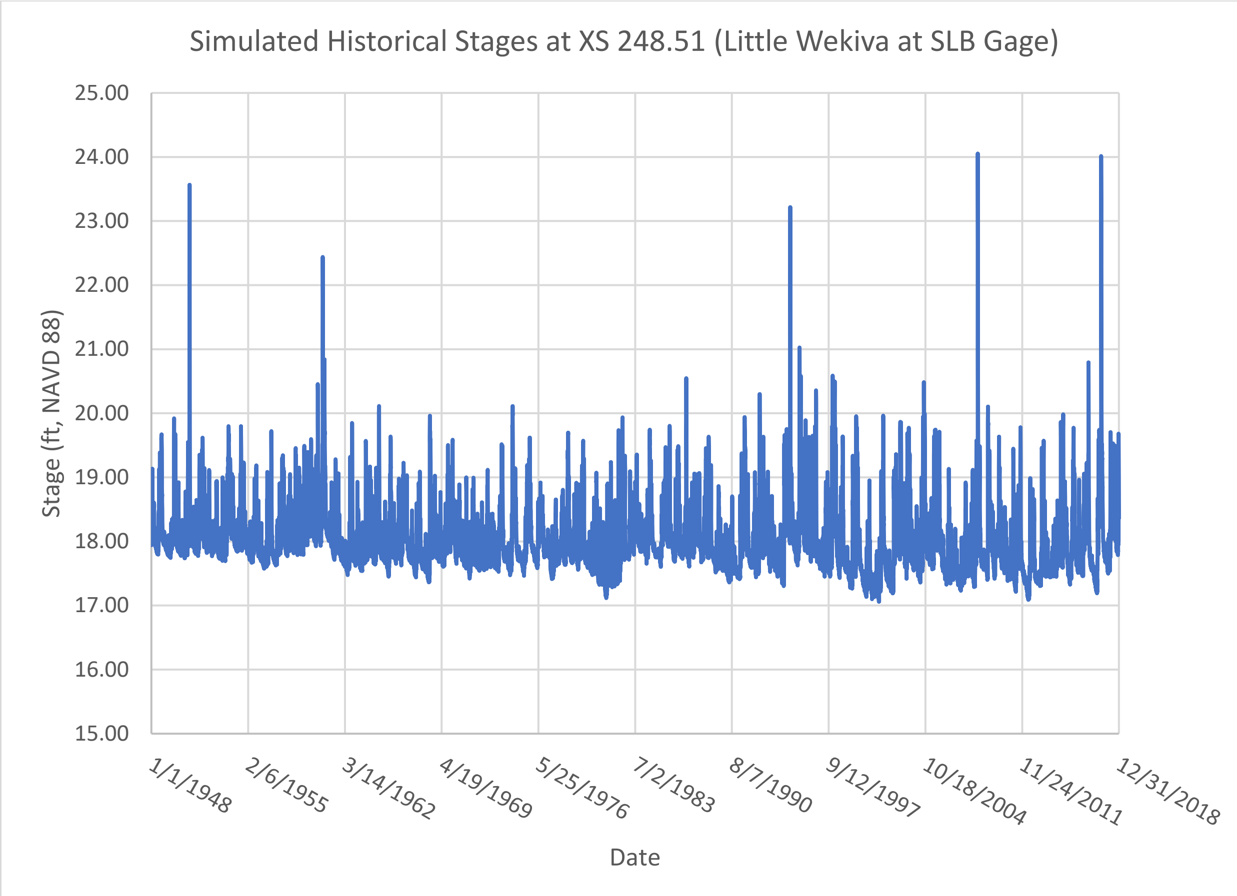

Figure 18. Simulated Historical Stages at Little Wekiva River at SLB

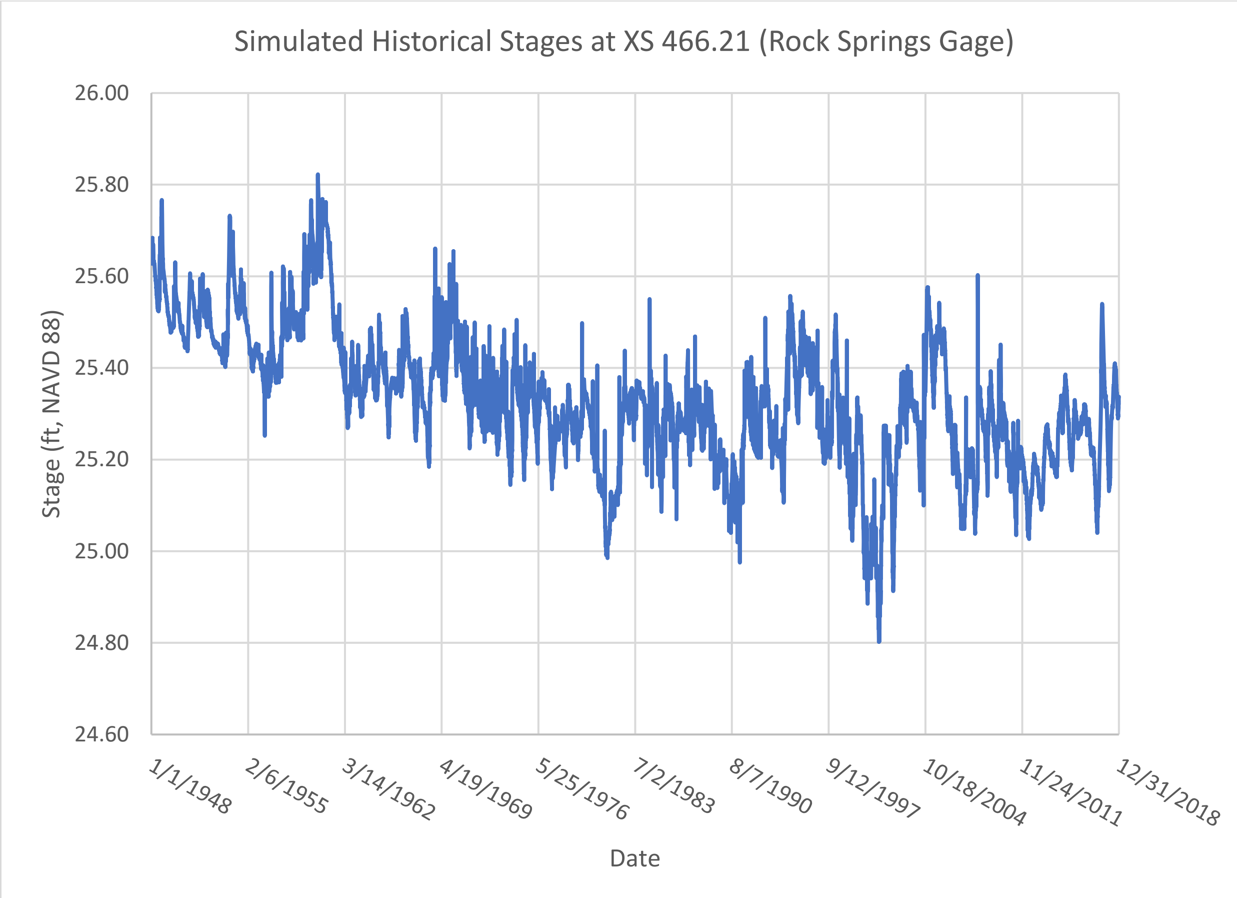

Figure 19. Simulated Historical Stages at Rock Springs.

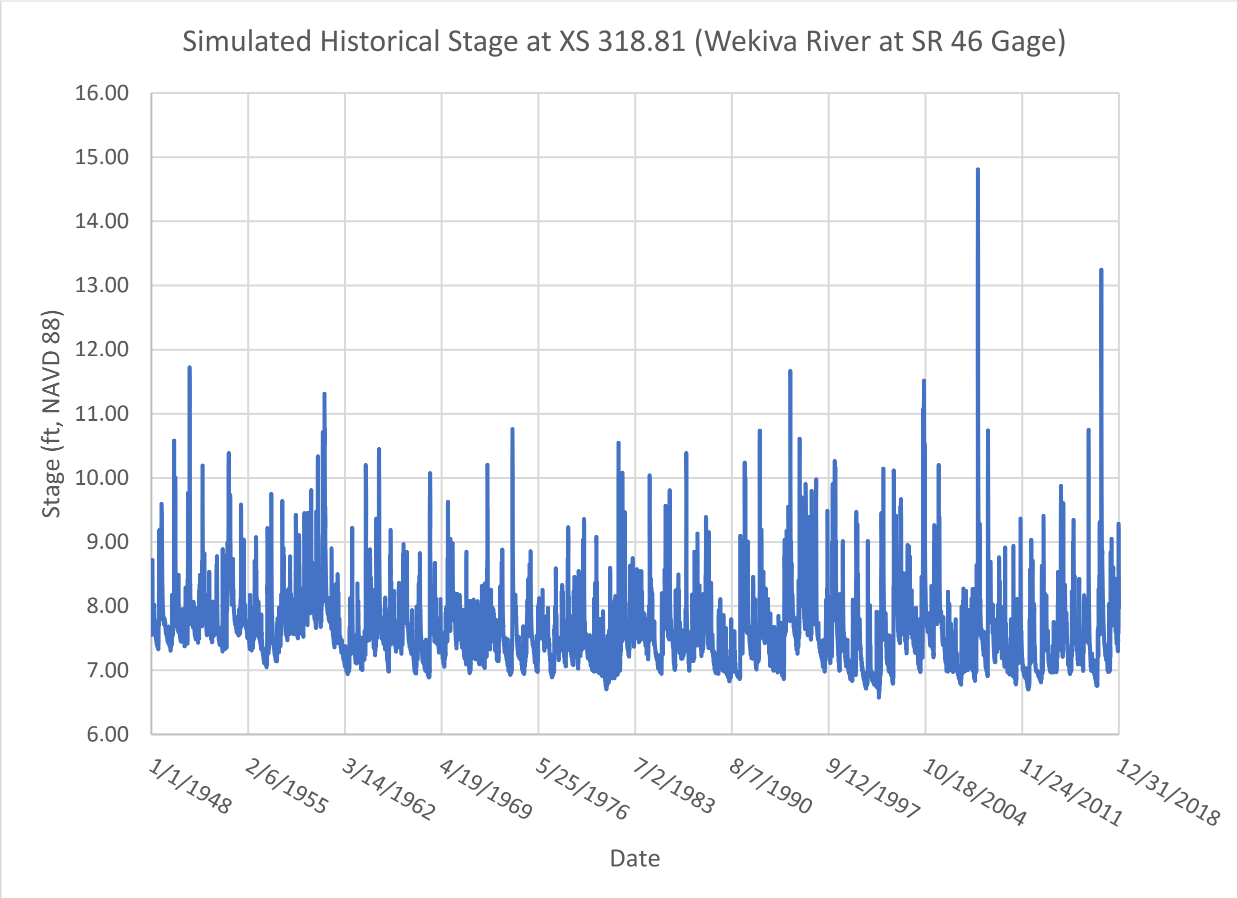

Figure 20. Simulated Historical Stages at Wekiva River at SR 46.

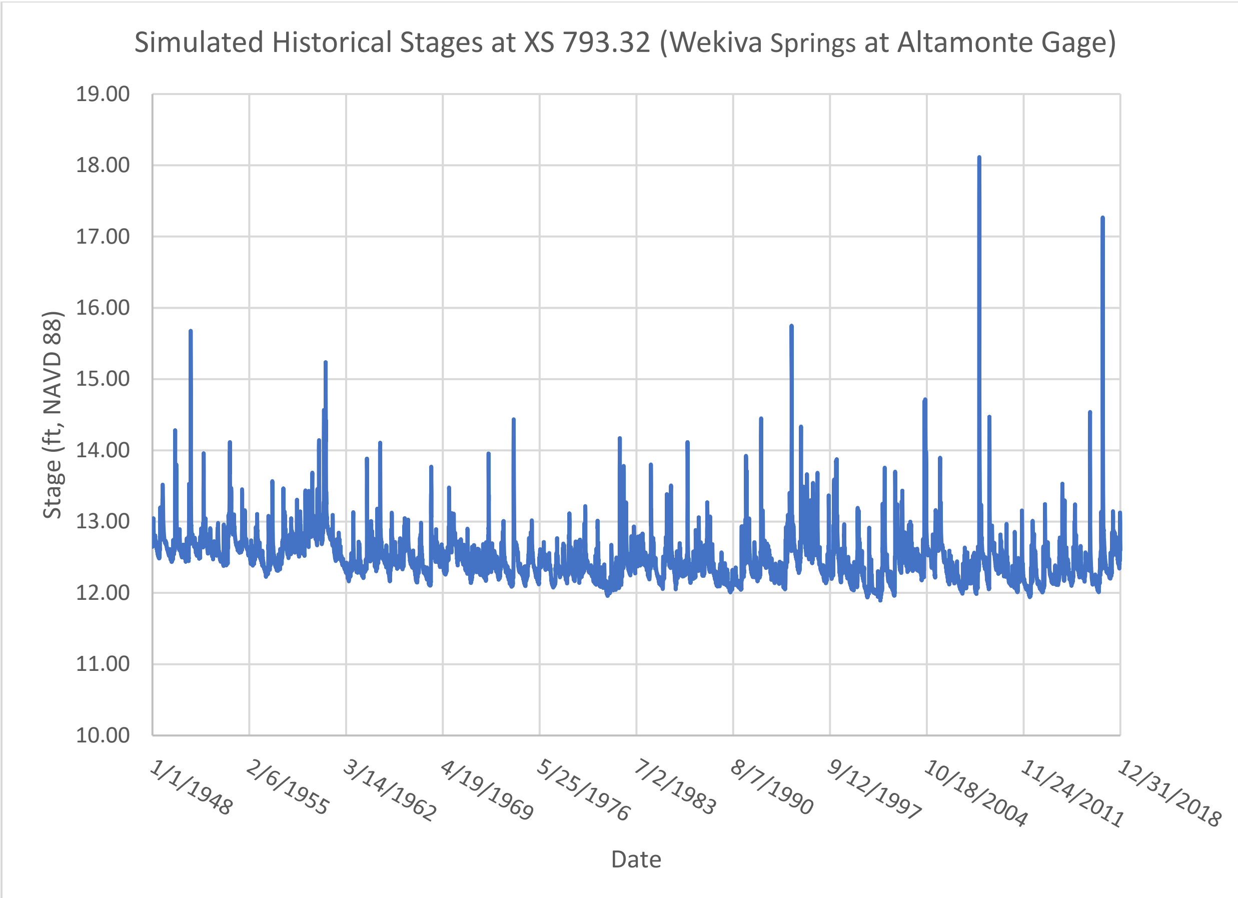

Figure 21. Simulated Historical Stages at Wekiva Springs.

Table 9. Summary Descriptive Statistics of Simulated Historical Stages (ft, NAVD 88).

Descriptive Statistical Parameter	XS 240.42 (Transect 3)	XS 248.51 (Little Wekiva at SLB Gage)	XS 466.21 (Rock Springs Gage)	XS 318.81 (Wekiva River at SR 46 Gage)	XS 793.32 (Wekiva Springs at Altamonte Gage)
Mean	16.69	17.95	25.22	6.71	12.03
Median	16.58	17.84	25.21	6.59	11.99
Standard Deviation	0.45	0.48	0.14	0.56	0.26
Minimum	15.92	17.07	24.70	5.90	11.57
Maximum	22.31	22.49	25.70	12.96	16.77

DEVELOPMENT OF NO-PUMPING AND CURRENT-PUMPING WEKIVA RIVER LEVELS

The objective of the MFLs status assessment is to determine whether the Wekiva River minimum levels are being achieved under the current pumping condition. Because of our limited understanding of possible future climatic conditions and significant uncertainties in predicting future levels using global circulation model forecasts, historical levels are considered the best available data and are adjusted for groundwater pumping impact to assess the current status of minimum levels.

An important part of assessing MFLs at springs is the simulation of long-term flows under no pumping and current pumping conditions. These flows are then used to perform freeboard and deficit analyses to assess current and future MFL status. To develop no pumping and current pumping condition spring flows required for surface water models, the impact from pumping on these systems must first be determined using information extracted from a groundwater flow model. This process involves performing a pumping impact analysis using simulated flows at spring locations under different simulated pumping conditions. Using this information, a pumping-flow reduction relationship is developed for each spring, which is used to estimate impact from historical groundwater pumping data that are used to develop the no-pumping condition spring flows. The estimated impact from the average 2014 to 2018 pumping is used to develop the current pumping spring flows. The process is illustrated in Figure 22.

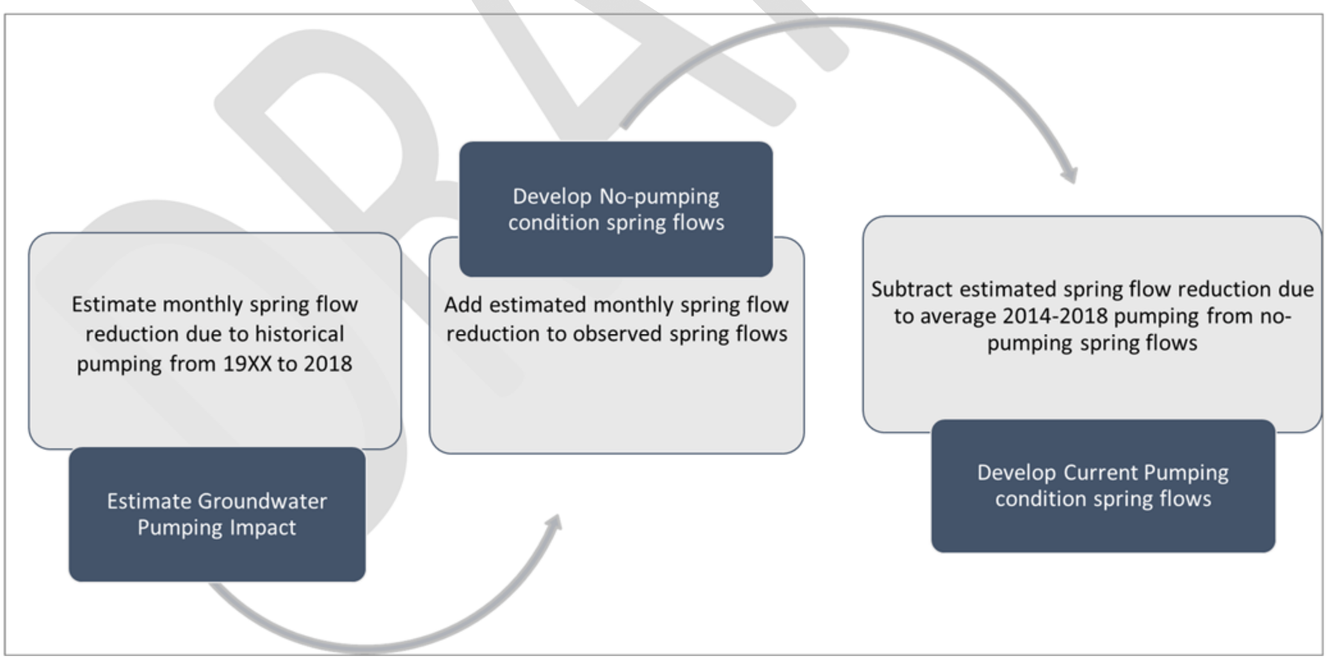

Figure 22. Flow Chart Illustrating the Groundwater Flow Model Pumping Impact Analysis.

GROUNDWATER PUMPING IMPACT ASSESSMENT

GROUNDWATER USE

Groundwater pumping within the Wekiva River springshed (Figure 23) would have direct impact on springs in the Wekiva MFL system because springshed defines the primary groundwater contributing area for spring flows. Therefore, to estimate the impact on groundwater levels from pumping, monthly groundwater use data was compiled or estimated at all stations within the springshed boundary from 1930 to 2018 (Figure 24). It should be noted that the groundwater pumping within the springshed was only used as a proxy to understand the variation of regional groundwater pumping from 1930 to 2018. The impact of groundwater pumping on spring flow was assessed based on all groundwater pumping within the groundwater model domain.

The groundwater pumping data was estimated from 1930 through 2018 using the data available from different sources. The pumping data from 1995 to 2014 was from the Central Florida Water Initiative (CFWI) regional water supply plan which was a collective effort between water management districts and stakeholders. Data for 2015 to 2018 was from the SJRWMD historical water use database with actual monthly use and station-level details. The data from 1965 to 1995 were based on the United States Geological Service (USGS) published county-level water use (available every five years starting in 1965) and the annual SJRWMD county-level Annual Water Use Survey (AWUS), starting in 1978. Using these two sources, the water use data was aggregated to the county for every five years and some years in between from 1965. Any missing years for each county were estimated using an exponential growth assumption to create a complete aggregate table. If the USGS and AWUS estimates do not match, the published AWUS data were used. To estimate annual groundwater use by county for the period before 1965, per capita groundwater use was estimated for each county. Multiplying the 1965 per capita water use by the historic county-level population from U.S. Census, the annual groundwater uses by county were estimated for the period before 1965. The U.S. Census data was reported in 10-year intervals. An exponential growth was assumed to estimate the annual population between 10-year intervals. The 1995 proportion of county water use captured in the springshed domain was multiplied to the county aggregate from 1948 to 1994 to estimate the water use within the springshed. To disaggregate the annual data to monthly groundwater use, the average monthly proportions by county, estimated from the monthly SJRWMD database from 2004 to 2014, were applied to the annual data.

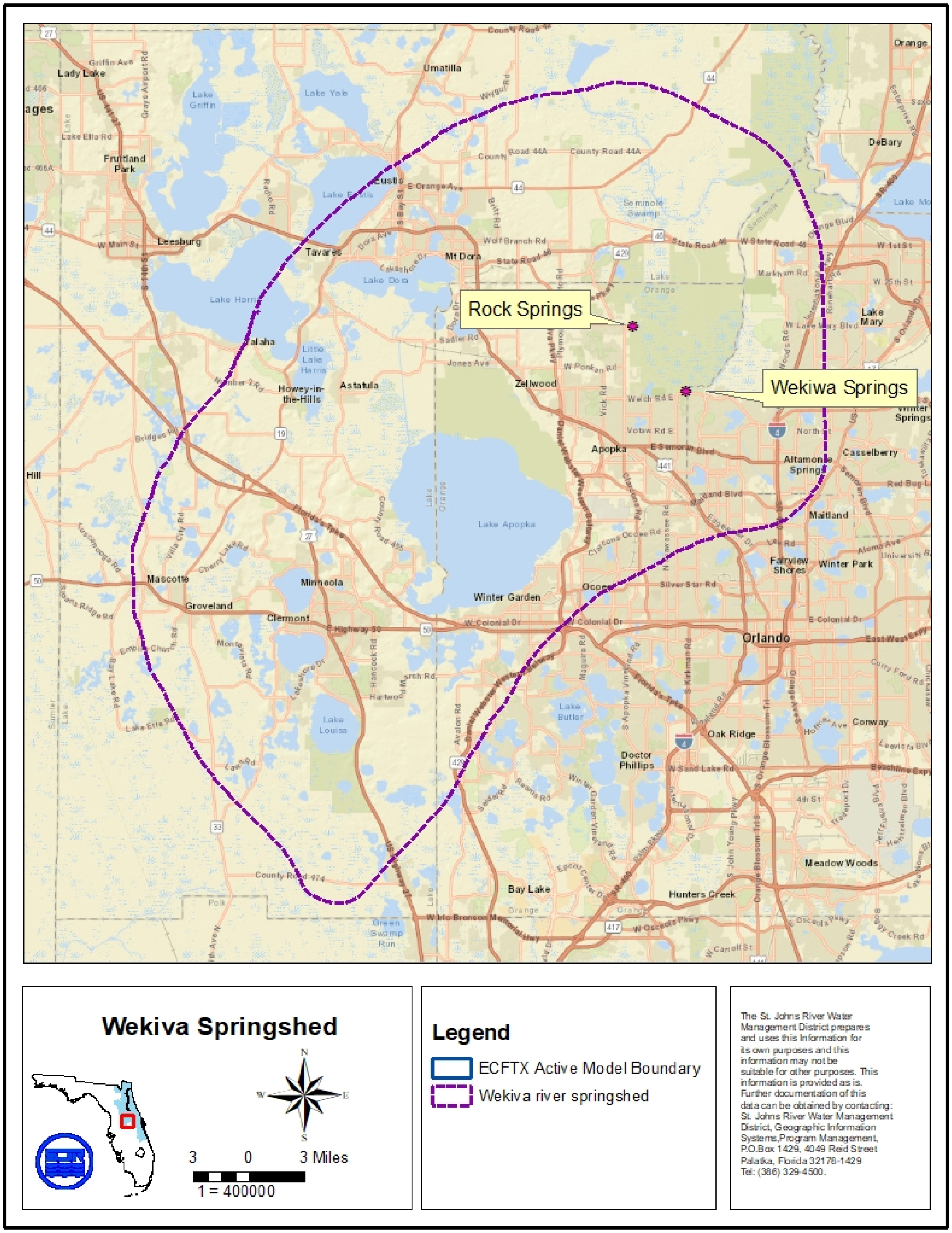

Figure 23. Wekiva River Springshed.

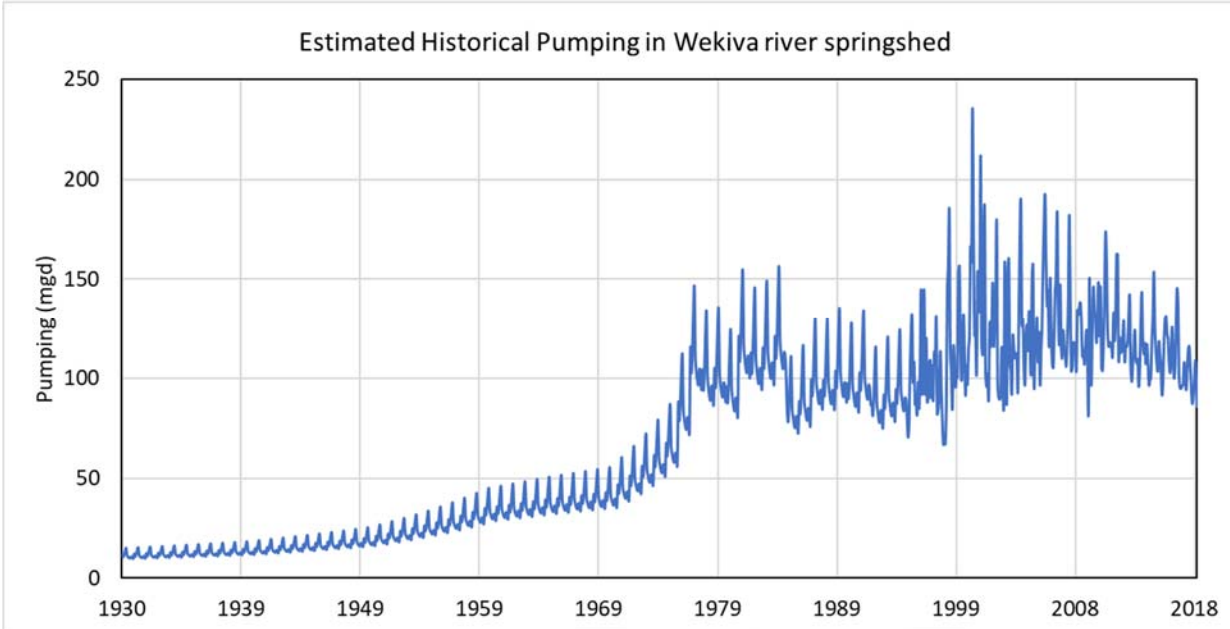

Figure 24. Monthly Estimated Historical Groundwater Pumping in Wekiva River Springshed from 1930 to 2018.

GROUNDWATER MODELING

The East-Central Florida Transient Expanded (ECFTX) groundwater flow model was developed by the Central Florida Water Initiative (CFWI) to support regional water supply planning and understand groundwater resource limitations for sustainable water supplies while protecting natural systems (CFWI HAT 2020). The ECFTX model was recalibrated in 2022, referred to as ECFTX v2.0, to improve simulation of groundwater levels and flows within the Wekiva river basin (Gordu et al. 2022). ECFTX v2.0 was used for this pumping impact analysis. The ECFTX v2.0 consists of an initial stress period representing steady state conditions for the year 2003, followed by 132 monthly transient stress periods representing the years 2004 through 2014. The ECFTX v2.0 model domain and CFWI planning areas are shown in Figure 25.

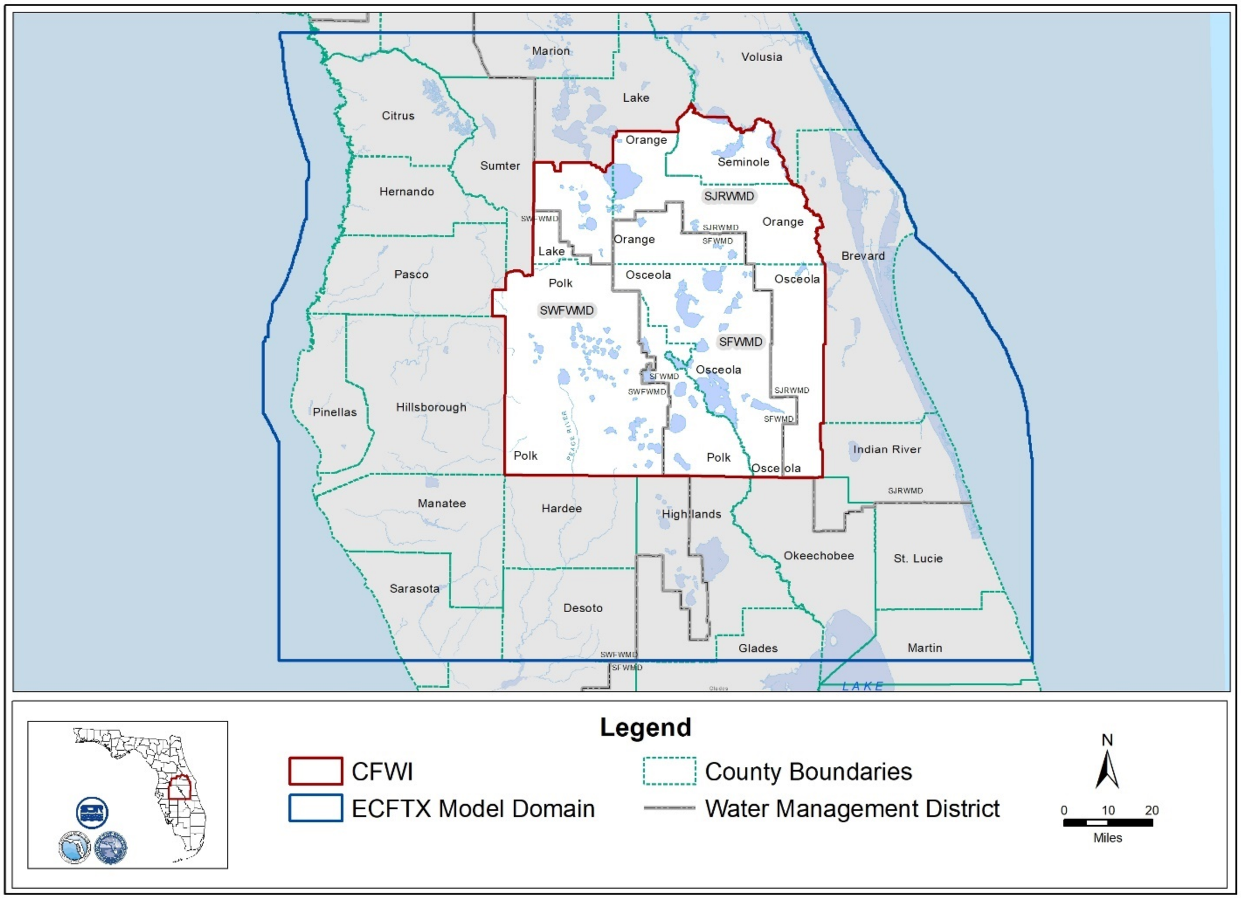

Figure 25. ECFTX v2.0 Model Domain Boundary (blue) and CFWI Planning Area (red).

HISTORICAL IMPACT ON SPRING FLOWS

Figure 26 shows the location of 27 springs simulated in the ECFTX v2.0 model and located within the Wekiva River springshed. An estimate of daily springflow reduction at each spring within the Wekiva River springshed resulting from regional pumping for the period of 1948 to 2018 is needed to develop the no-pumping condition springflow. Since the ECFTX v2.0 model was not designed to simulate monthly conditions over this long-term period, a methodology was developed using available ECFTX v2.0 model data to estimate the impact of regional pumping on springflow outside of the model simulation period. This methodology included the development of a relationship between groundwater pumping and springflow reduction at each spring within the springshed using the ECFTX v2.0. To develop this relationship, and capture a wide range of pumping conditions, the following model simulations were used:

- Pumping reduced by 50%
- Pumping reduced by 25%
- Calibration period condition
- Pumps off

For each simulation, the simulated spring flow at each spring was extracted from the ECFTX v2.0 model for each transient monthly stress period (2004 through 2014). Subsequently, the total pumping impact, or reduction in spring flow at each spring from a no pumping condition, was calculated for each pumping scenario by subtracting the scenario simulated flow from the pumps off simulated flow. For example, the impact for the calibration pumping condition was calculated by subtracting the simulated calibrated model flow from the simulated pumps off flow for each transient stress period at each spring. This calculation was repeated for the 50% and 25% pumping reduction scenarios. This resulted in 132 simulated impact values for each pumping scenario, corresponding to each month in the transient simulation. Groundwater pumping information was also extracted from the ECFTX v2.0 model for the calibration, 25% reduced pumping and 50% reduced pumping scenarios. For each scenario, the total pumping in model layers 3 through 11 (Upper UFA to LFA) was extracted from the springshed area shown in Figure 23 and summarized for each transient monthly stress period in the model. Groundwater pumping within the springshed was considered as a proxy to develop the relationship and capture the variation of regional pumping over time.

The simulated springflow impact and pumping data for each scenario and transient stress period were combined into a single table, yielding a total of 396 pumping-impact paired data values to use to fit a relationship between impact and groundwater pumping. A simple linear regression was fit to the dataset, where modelled impact was a response variable and groundwater pumping was a predictor variable, at each spring location within the Wekiva springshed. Two low-flow springs located within the springshed boundary, Palm Spring in Lake County and Snail Spring Complex, had a simulated discharge of zero during the ECFTX v2.0 model simulation period (2003 to 2014). As a result of the simulated zero discharge and low observed spring flow of < 1 cfs, it was determined that linear regression was not a suitable method to estimate impact at these springs. Therefore, the springflow impact from groundwater pumping at these springs was assumed to be 0. Camp La Noche spring is located just outside of the springshed boundary shown in Figure 26, however, model data show a strong linear relationship exists between spring flow reduction and pumping within the springshed at that spring (coefficient of determination (R^2) = 0.90). Due to the high correlation between pumping and flow reduction, no-pumping and current-pumping flows were still estimated for this spring.

Table 10 summarizes the linear regression coefficients and R^2 at each spring. All springs resulted in an R^2 of ~0.9 or greater, except for Markee Spring ($R^2 \sim 0.7$). The flow at Markee Spring is low (~0.2 cfs) and would not affect the results significantly, thus it was determined that the $R^2 \sim 0.7$ was acceptable for this analysis. Figures 27 and 28 show the linear regression for two important MFL springs in the Wekiva River system; Rock and Wekiwa springs. A strong linear relationship existed between springflow reduction and pumping at Rock Springs ($R^2 = 0.96$) and Wekiwa Springs ($R^2 = 0.95$). The linear regression equations included in Appendix A were used to calculate a monthly historical springflow impact from long-term (1930 to 2018) estimated monthly pumping data within the springshed boundary. The monthly estimated historical impact due to pumping was disaggregated to a daily time series extending from 1930 to 2018 using linear interpolation. The daily estimated historical impacts from pumping for the period of 1930 to 2018 at Rock and Wekiwa springs are shown in Figure 29.

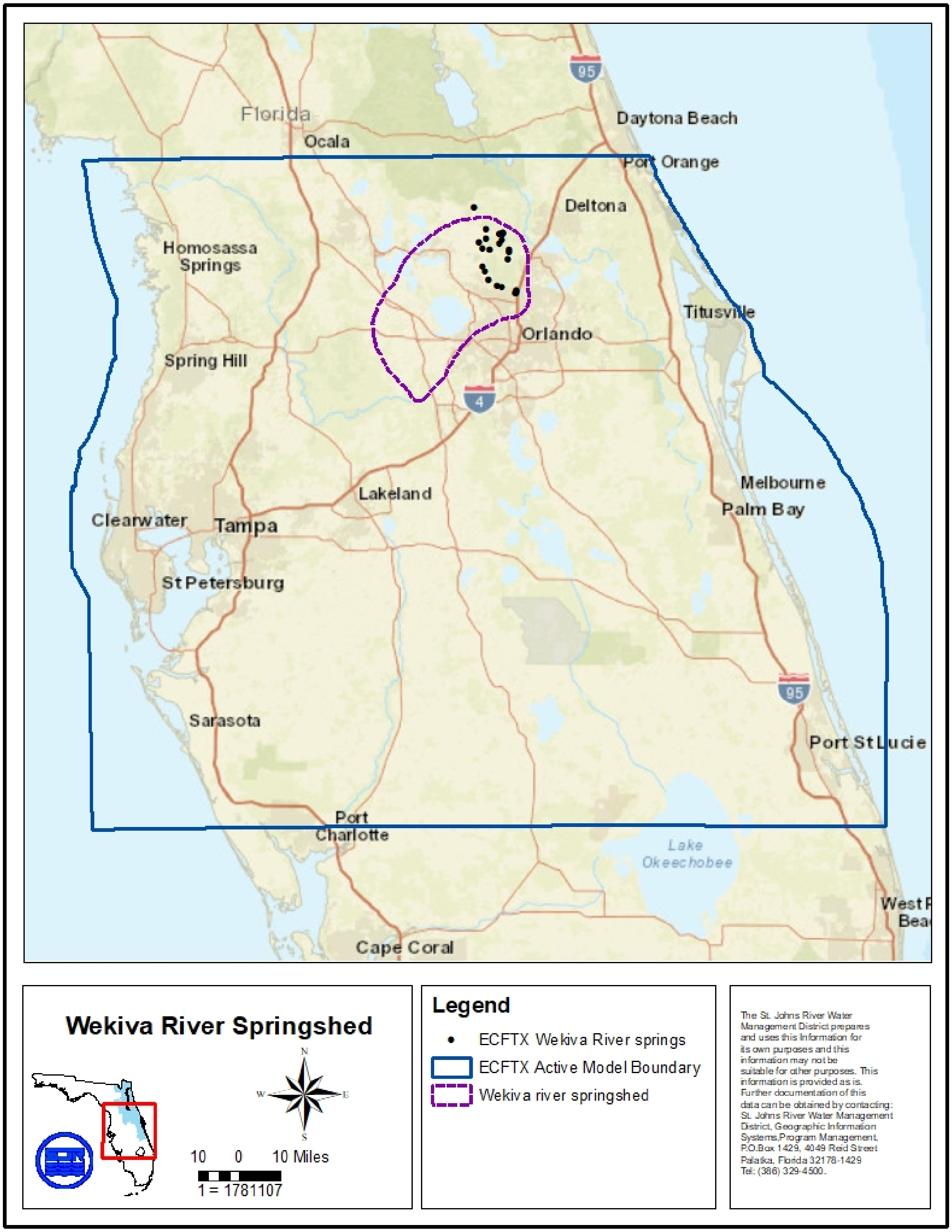

Figure 26. Wekiva River Springshed and ECFTX v2.0 Wekiva River Springs Locations.

Table 10. Regression Coefficients and R^2 at Wekiva River Springs.

Name	Slope	Intercept	R^2
Markee Spring	1.02E-04	2.07E-03	0.66
Moccasin Spring	4.90E-07	7.19E-06	0.86
Shark Tooth Spring	2.38E-04	3.21E-03	0.90
Camp La Noche Spring	5.28E-04	5.48E-03	0.90
Sulphur Spring	1.13E-03	1.40E-02	0.90
Boulder Spring	2.17E-04	2.55E-03	0.92
Blue Algae Boil Spring	1.60E-04	1.85E-03	0.92
Green Algae Spring	1.60E-04	1.85E-03	0.92
Helene Spring	7.35E-04	8.38E-03	0.93
Island Spring	3.43E-03	3.84E-02	0.93
Nova Spring	5.03E-03	5.13E-02	0.94
Droty Spring	3.59E-04	2.30E-03	0.95
Seminole Spring	2.47E-02	1.46E-01	0.95
Messant Spring	1.20E-02	7.73E-02	0.95
Wekiwa Spring	3.84E-02	2.19E-01	0.95
Wekiva Falls	1.13E-02	9.01E-02	0.96
Palm Spring (Seminole)	8.79E-03	7.32E-02	0.96
Miami Spring	6.10E-03	4.81E-02	0.96
Ginger Ale Spring	4.49E-04	3.82E-03	0.96
Sanlando Spring	3.98E-02	3.25E-01	0.96
Pegasus Spring	4.11E-03	3.32E-02	0.96
Starbuck Spring	1.79E-02	1.44E-01	0.96
Blackwater Spring	8.92E-06	6.39E-05	0.96
Rock Spring	8.98E-02	7.68E-01	0.96
Witherington Spring	3.68E-03	3.32E-02	0.96

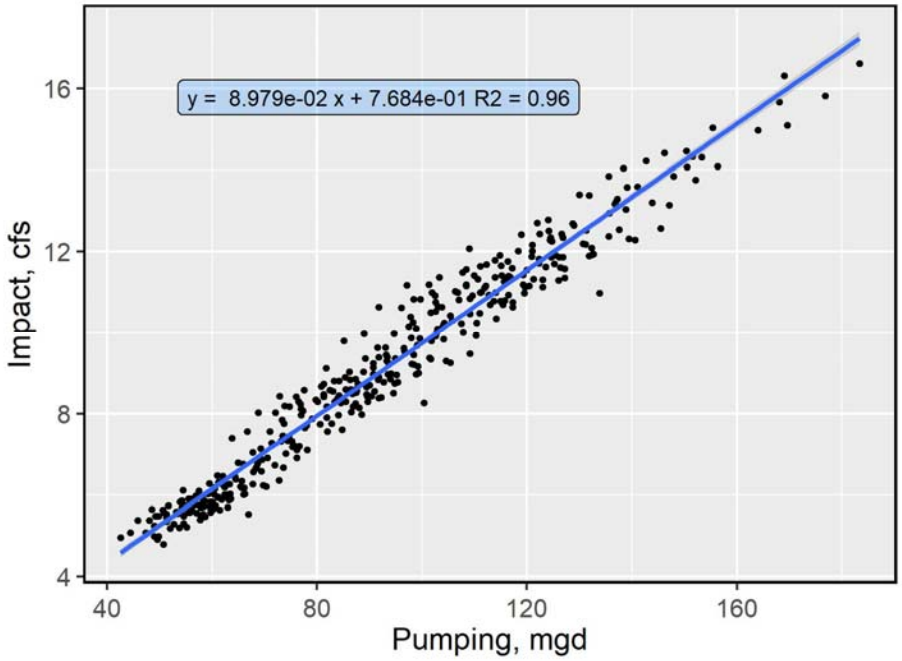

Figure 27. Linear Regression between Rock Springs Flow Impact (cfs) and Pumping (mgd) withing the Wekiva River Springshed..

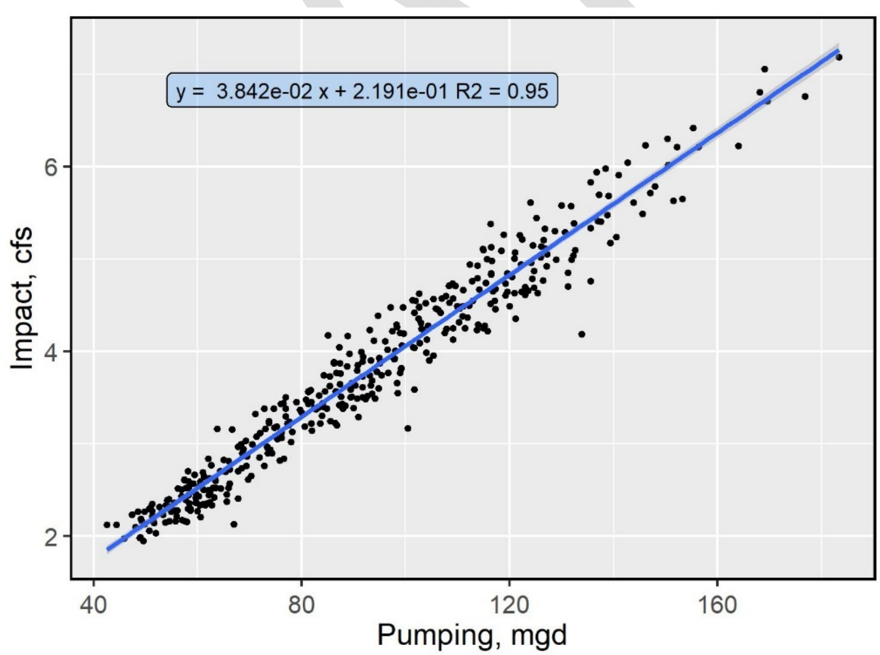

Figure 28. Linear Regression between Wekiwa Springs Flow Impact (cfs) and Pumping (mgd) within the Wekiva River Springshed.

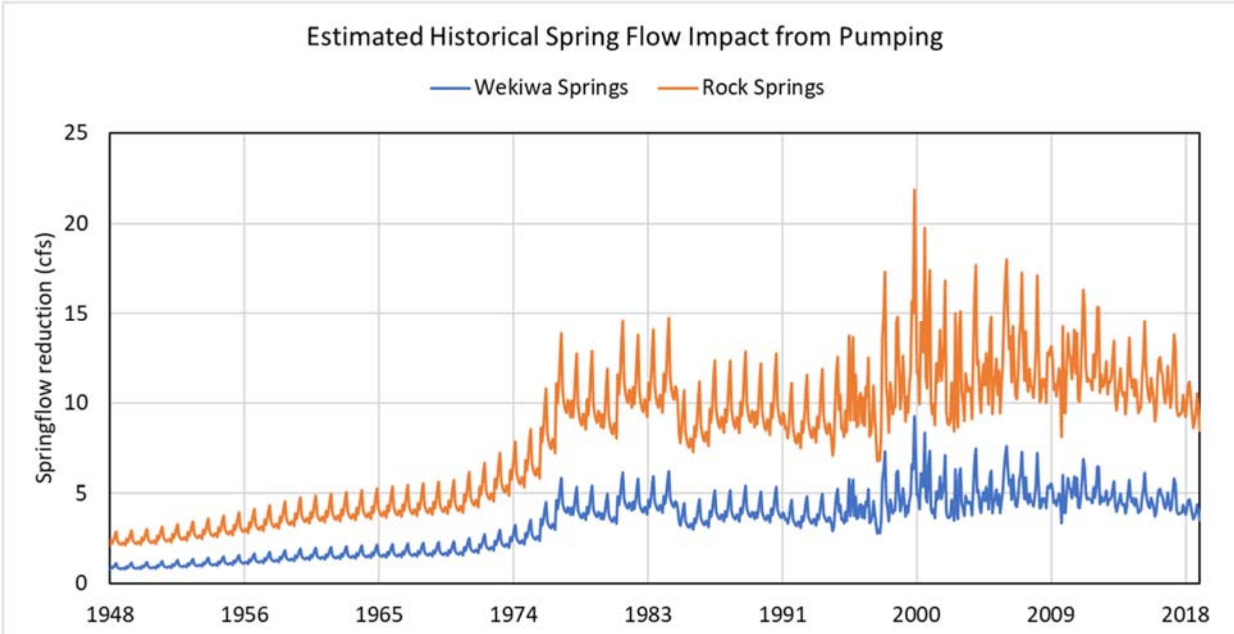

Figure 29. Estimated Daily Impact at Rock and Wekiwa Springs from Pumping within the Wekiva River Springshed from 1948 to 2018.

NO-PUMPING CONDITION SPRING FLOWS

The daily estimated impacts from pumping at each spring location were directly added to the daily observed/estimated spring flows available from 1948 to 2018 to create the no-pumping condition spring flows.

CURRENT-PUMPING CONDITION SPRING FLOWS

To generate the current pumping condition groundwater levels, the average 2003 to 2014 steady-state version of the ECFTX v2.0 model (referred to as ECFSSX v2.0) was used. The impact from average pumping from 2014 to 2018 was calculated by subtracting the steady-state simulated spring flow under average 2014 to 2018 pumping rates and return flows in the model from the steady-state simulated flow with no pumping or return flows in the model at each spring location. Table 11 includes the simulated impact from average 2014 to 2018 pumping in the model at each spring. The current pumping impact was then subtracted from the no pumping condition spring flows to generate the current pumping condition spring flows for the long-term period of 1948 to 2018. Figures 30 and 31 show the daily historical, no-pumping and current-pumping condition flows at Rock and Wekiwa springs, respectively.

Table 11. Spring Flow Impact from average 2014 to 2018 Pumping in the Model.

Spring Name	Impact from average 2014 to 2018 pumping (cfs)
Palm Springs (Lake)	0
Snail Springs Complex	0
Moccasin Springs	6.30E-05
Blackwater Springs	1.07E-03
Markee Spring	1.38E-02
Blue Algae Boil Spring	2.01E-02
Green Algae Boil Spring	2.01E-02
Boulder Springs	2.74E-02
Sharks Tooth Spring	3.06E-02
Droty Spring	4.24E-02
Ginger Ale Spring	5.64E-02
Camp Le No Che Spring	6.43E-02
Helene Spring	9.25E-02
Sulfur Spring (Orange)	1.49E-01
Island Spring	4.32E-01
Witherington Spring	4.57E-01
Pegasus Spring	5.13E-01
Nova Spring	6.28E-01
Miami Spring	7.74E-01
Palm Springs (Seminole)	1.10
Wekiva Falls	1.39
Messant Spring	1.43
Starbuck Spring	2.23
Seminole Spring (Lake)	2.92
Wekiwa Springs (Orange)	4.54
Sanlando Springs	4.98
Rock Springs (Orange)	11.10

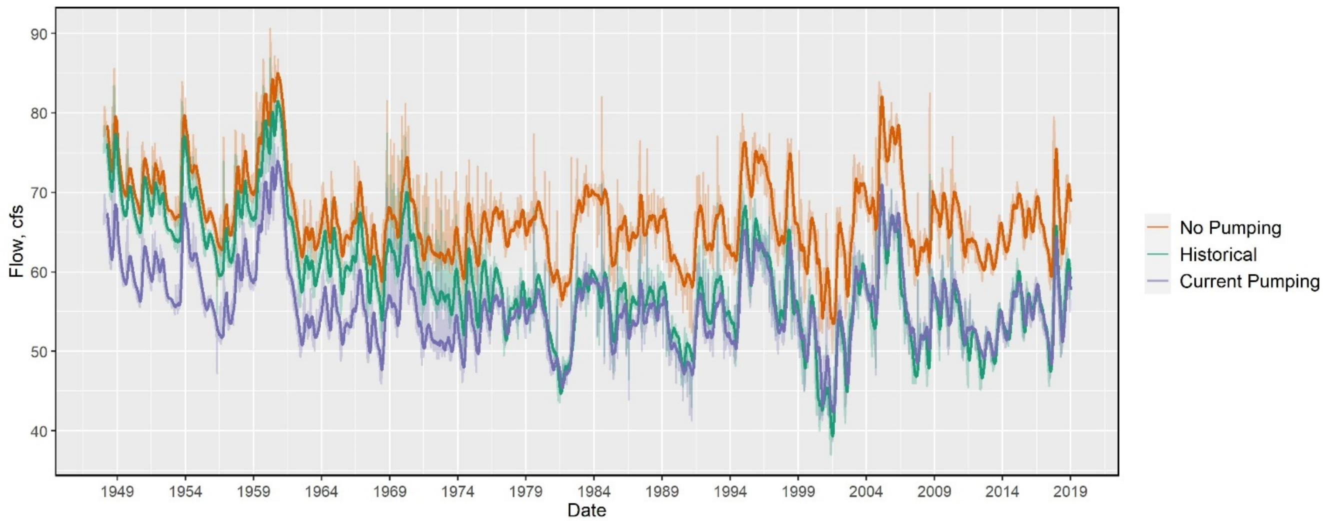

Figure 30. Historical, Current Pumping and No-pumping Condition Spring Flows at Rock Springs. A 90-day Rolling Average in Plotted over Daily Flow.

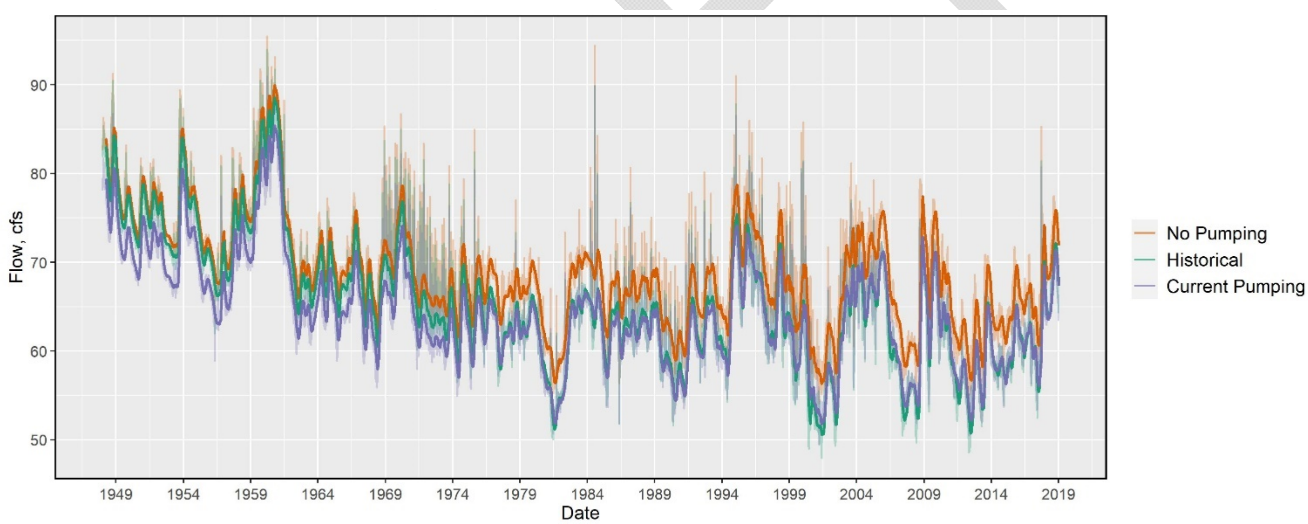

Figure 31. Historical, Current Pumping and No-pumping Condition Spring Flows at Wekiwa Springs. A 90-day Rolling Average is Plotted over Daily Flow.

Wekiva River Level Datasets for MFL Analysis

The no-pumping and current-pumping condition spring flows were inputted into the HSPF model to simulate no-pumping and current pumping condition of river flows. The simulated HSPF no-pumping and current pumping river flow are used as boundary conditions input to the unsteady state HEC-RAS Wekiva River model to simulate no-pumping and current-pumping river flows and levels. For Wekiwa and Rock springs and Wekiva River at SR46 gages, the simulated no-pumping and current-pumping river levels were adjusted for the periods when observed levels are available. The differences between the simulated no-pumping and the historical simulated river levels were added to the historical observed levels to obtain final no-pumping river level time series. Similarly, the differences between the simulated no-pumping and the simulated current-pumping river levels were subtracted from the final no-pumping levels to obtain final current-pumping river level time series. Figures 32 to 34 show both no-pumping and current-pumping conditions levels at selected gages of Wekiva River. Table 12 presents the descriptive statistics of historical, no-pumping, and current-pumping condition river levels.

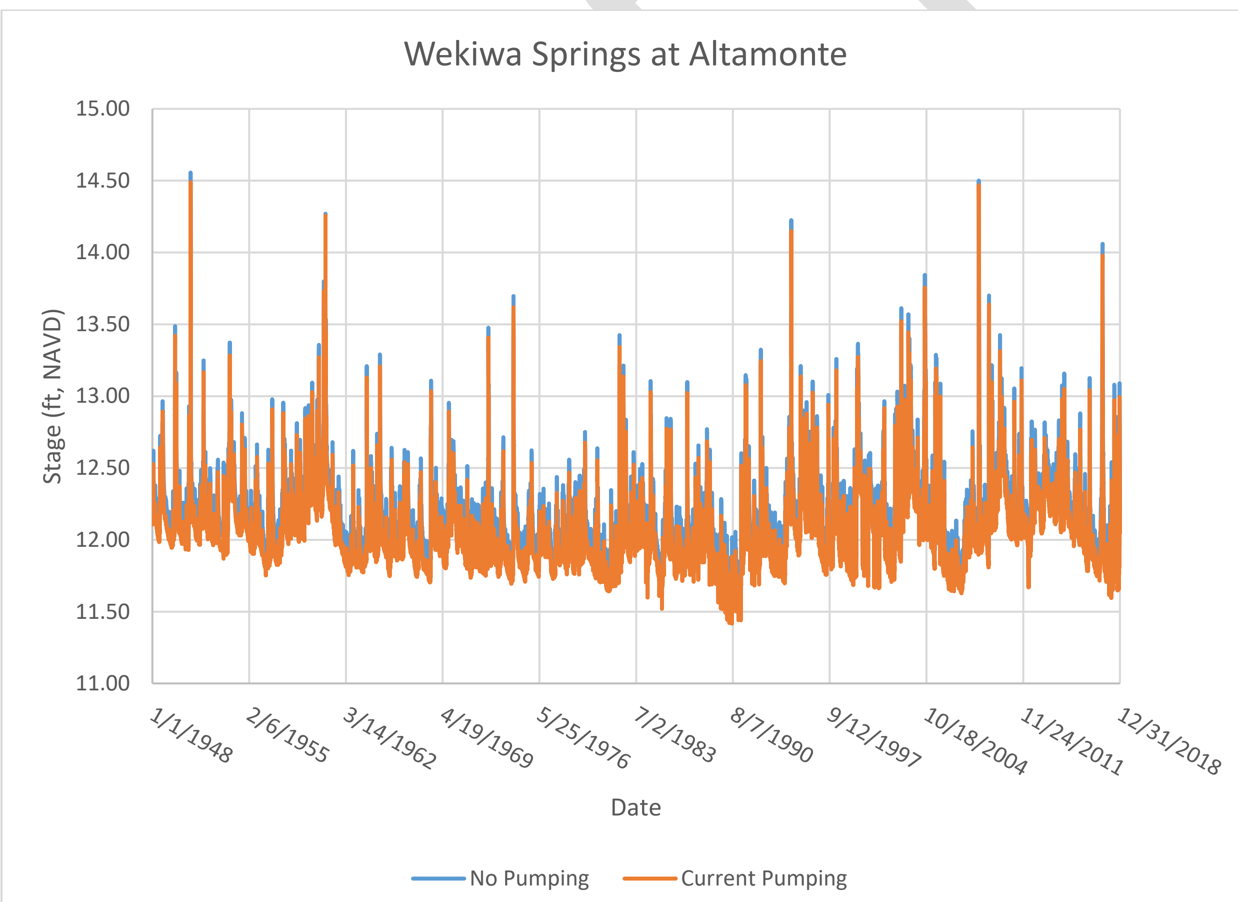

Figure 32. Simulated No Pumping and Current Pumping Stages at Wekiwa Springs.

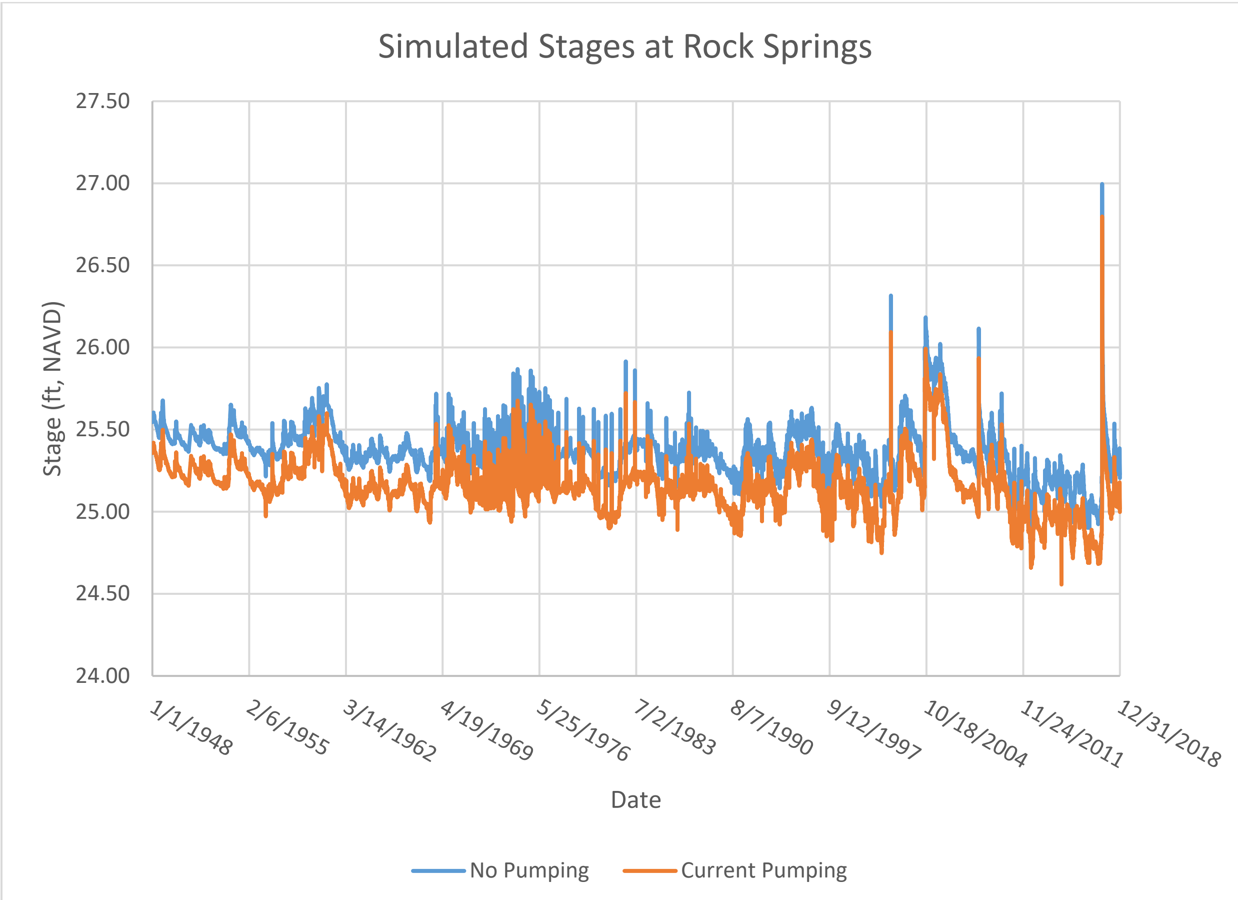

Figure 33. Simulated No Pumping and Current Pumping Stages at Rock Springs.

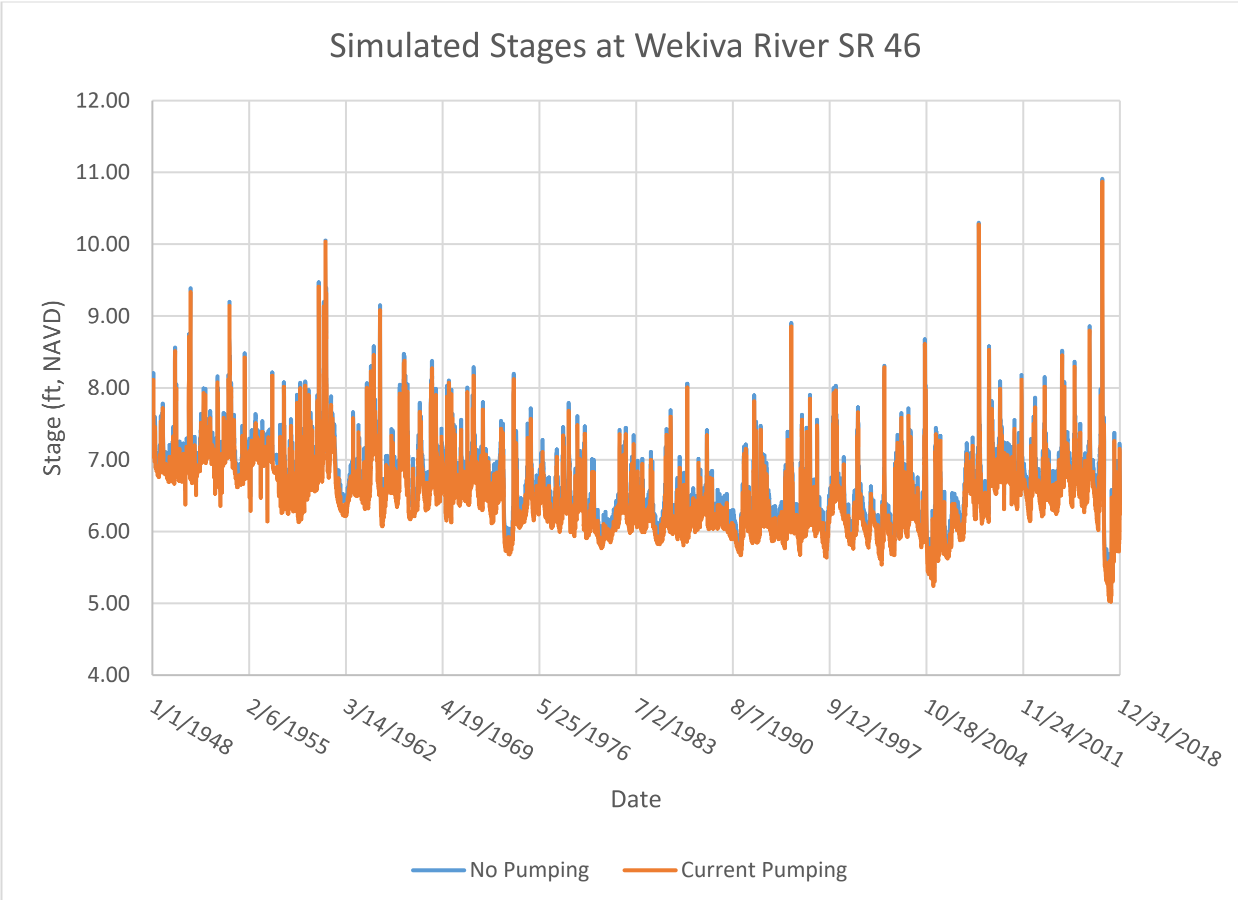

Figure 34. Simulated No Pumping and Current Pumping Stages at Wekiva River SR 46.

Table 12. Summary Descriptive Statistics of No Pumping, Historical, and Current Pumping Simulated Stages (ft, NAVD).

Gage Location	Model Scenario	Descriptive Statistics Parameter				
		Mean	Median	Standard Deviation	Minimum	Maximum
Wekiva Springs at Altamonte	No Pumping	12.17	12.13	0.26	11.49	14.56
	Historical	12.08	12.04	0.27	11.42	14.59
	Current Pumping	12.05	12.00	0.26	11.42	14.49
Rock Springs	No Pumping	25.36	25.35	0.15	24.76	27.00
	Historical	25.21	25.21	0.19	24.56	26.83
	Current Pumping	25.15	25.14	0.16	24.56	26.80
Wekiva River at SR 46	No Pumping	6.63	6.58	0.49	5.18	10.91
	Historical	6.52	6.47	0.52	5.03	10.81
	Current Pumping	6.47	6.41	0.50	5.02	10.87

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