DATA AND CONCEPTUALIZATION EVALUATION OF

The Alapaha River Sink Rise System

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Introduction

The Alapaha River basin begins in southern Georgia and flows south into northern Florida and is a major tributary to the Suwanee River. The river first encounters karstic environments four miles south of the Florida-Georgia border. The karstic features give way to a series of sinks and rises with interconnecting conduits, causing stretches of the river to flow underground. This section of the document reviews available literature and analyses of the Alapaha River sink-rise system (ARSRS) and model documentation to evaluate the representation of the Alapaha in other modelling efforts.

Physiography and Topography of the Alapaha

The Alapaha River begins in southern Georgia near the town of Cordele (Ceryak, 1977), and flows southward into Florida in Hamilton County, near the town of Jennings (Conover and Leach, 1975). Much of the Alapaha River basin is in southern Georgia, where it flows through what is predominantly agricultural lands just west of the Okefenokee Swamp, which are the headwaters of the Suwannee River. The southern terminus of the Alapaha River is the confluence with the Suwannee River, with the Alapaha river serving as a major tributary of the Suwannee River. The Alapaha River Basin in Hamilton County is approximately 100-square-miles, less than 10% of the roughly 1,700-square-miles of the river's total drainage basin (Ceryak, 1977).

The topography of the area is attributable to the Cody Escarpment (or Cody Scarp). The location of the escarpment approximates the ancient shoreline when sea levels were much higher. The Highlands in the northeast of the river basin are approximately 100 to 200-feet above mean sea level. The Lowlands to the southwest are between 0 to 100-feet above mean sea level. This gives way to up to 80-feet of relief. The only river that originates in the Highlands that does not go underground as it crosses this transition zone is the Suwannee River (Ceryak, 2005).

Geomorphology of the Cody Escarpment

Upchurch (2007) provides a detailed description of the geomorphology of the Cody Escarpment. The Alapaha River encounters limestone and dolostone for the first time when it crosses the Cody Scarp. The Cody Scarp is the largest topographic break in Florida and has nearly 100 feet of relief. The scarp represents the divide between the Northern Highlands physiographic region and the Gulf Coastal lowlands region to the southwest. The Lowlands are characterized by small sinkholes across a flat landscape and are the result of ancient shoreline erosion, fluvial erosion, and karst related activities. The formation of the Cody scarp is a result of marine, fluvial, and karst-related headward erosion of the Hawthorn Group sediments of the highlands and karstification of the Eocene/Oligocene limestones in the Lowlands (Upchurch 2007). Erosion from wave and ocean currents, during times of higher sea levels, stripped the clay confinement of the Hawthorn group exposing the underlying limestone. Fluvial erosion continued to erode the escarpment and expose the limestone and creating the river valleys. With the limestone exposed karst features continue to shape the landscape. The Hawthorn group in this area contains sand and clay layers and confines the underlying Floridan Aquifer. All karst escarpments are characterized by the toe of the scarp being exposed limestone dissolved by surface water and groundwater as the scarp retreated. As the limestone becomes more weathered and the scarp retreats, a series of swallets form as a result of the thinning of the Hawthorn group. These swallets capture the surface water flows across the scarp. Above the Cody Scarp, on the northern highlands, a well-developed, dendritic drainage pattern has formed. Streamflow from these drainage features is captured in these swallets and later reappears downstream at springs and resurgences.

Hydrogeology of the Alapaha River

An extensive literature review of the Alapaha River was conducted to characterize the swallets, resurgences, and underground flows. The underlying aquifer system and dye tracer analyses to establish flow connectivity were also examined in order to assess all available literature on the ARSRS.

Swallets, Resurgences, and Underground Flow

North of the State Road (SR) 150 bridge crossing of the Alapaha River, near Jennings, Florida, the Alapaha River flows year-round, as it traverses low permeability sediments. South of the crossing, flow diminishes due to the presence of swallets in the Alapaha Riverbed and at the terminus of the Dead River. These swallets funnel river water into karst conduits in the underlying weathered limestone. Due to this process, the riverbed is dry 50% of the time three river miles south of the SR 150 bridge (Upchurch 2014). The Hawthorn formation and younger sediments have been eroded in this reach and south of it, exposing limestone at the land surface below the Cody Scarp (Ceryak, 1977).

The Alapaha River contains a series of swallets in the riverbed southeast of Jennings, Florida. This is approximately four miles south of the Florida state line. During periods of low flow, noted as below 350 to 500 cubic-feet-per-second (cfs), surface water in the river is entirely captured by the swallets and enters limestone conduits. This water provides recharge to the Floridan aquifer (Upchurch, 2014). The water that enters the aquifer via the swallets at Dead River eventually discharges to the Suwannee River through two resurgences: the Alapaha Rise and Holton Creek Rise. This is about nineteen miles away from the location of the sinks. Dye tracer tests in 2016 by Greenhalgh and Fowler showed that when the flow into Dead River Swallet was measured at 311 cfs and dye was placed at Dead River Swallet, it was observed at Alapaha Rise six days after introduction and at Holton Creek nine days after introduction. In some underground drainage conduits near the Ichetucknee system, water is estimated to flow nearly one mile per day (Upchurch, 2014). When flow in the Upper Alapaha is greater than 350 to 500 cfs, the conveyance capacity of the conduits is surpassed, and overland flow in the Alapaha River is able to reach the Suwannee River (Ceryak, 1977).

Ceryak (1977) describes groundwater level fluctuations of up to 20-feet between periods of low and high flow, where high flow is defined as flow greater than 786 cfs. During low flow, Holton Creek discharges clear ground water. During high flows when the river stage exceeds the elevation of the potentiometric surface of the Floridan aquifer, water from the river is forced into the Floridan aquifer. Discharge from the Alapaha Rise and Holton Creek Rise is typically discolored by organic material during such times. During low flows, discharge from Holton Creek Rise is entirely clear and will dry up during extreme low flows.

Upchurch (2014) describes two flow regimes in the Alapaha River and the lag time between underground capture and resurgence. When flow is below 500 cfs at Jennings, the lag time of the flood peak at the Alapaha Rise is between three to six days. When flow is greater than 500 cfs at Jennings, the peak lag at the Alapaha Rise is eighteen to twenty-one days. The lags reported seem reversed as high flows should seemingly have a short lag and low flows a longer lag. Upchurch (2014), however, states that the "increased lag is a result of the increased complexity of the conduit system required to store recharged water and backwater effects caused by the Suwannee River in flld (sic). Thus, high flow into the aquifer causes the flow system to access less efficient conduits."

Underlying Aquifer System

The Alapaha River is underlain by three aquifers: a water-table aquifer, a secondary artesian aquifer, and the Floridan aquifer. Ceryak (1977) provides a description of each aquifer and the water quality characteristic of each. The water-table aquifer is characterized as post-Miocene sands. The waters from this aquifer have relatively high concentrations of chloride and sodium but low specific conductivity. The secondary artesian aquifer is within the Hawthorn formation and is capped by low permeability layers. This aquifer is also referred to as the Hawthorn Aquifer. The aquifer recharges from overlying low-permeability layers where they are sufficiently permeable to transmit water or absent. The Hawthorn group contains a high percentage of phosphate minerals. This results in waters with high concentrations of ortho-phosphate and fluoride. The Floridan aquifer is within the St. Marks formation, the Suwannee Limestone, and underlying limestone of approximately 1,500-feet thick (Ceryak 1977). This is the primary aquifer for groundwater production in the state of Florida. The Floridan aquifer is generally unconfined below the Cody Scarp, which includes the Dead River swallet and Alapaha Rise. Because the aquifer is contained within limestone formations, its waters are abundant in calcium and magnesium and have a higher alkalinity than the other aquifers. This also results in a high specific conductivity (Ceryak 1977).

Dye Tracer Analyses

Greenhalgh and Fowler (2016) present the results of a dye tracer tests in the Alapaha River. Dye was introduced into the Dead River Swallet and was observed six days later at the Alapaha Rise. Dye was observed at Holton Creek in charcoal samples nine days after introduction. Dye was also introduced to the Tiger Creek Swallet. The dye was not detected in the Alapaha or Holton Creek Rises in the first or second rounds of charcoal sampling but was detected in the third and fourth. Round three was conducted 4 to 20 days, and round four was conducted 20 to 40 days after dye introduction. They also include time series data of Fluorescein concentrations (in parts per billion) at the Alapaha Rise and Holton Creek. The samples were taken via an ISCO sampler. The Alapaha time series is from 06/21/2016 through 08/09/2016. The Holton time series is from 06/22/2016 through 08/09/2016. Data from this study should be evaluated to determine if dilution rates can be synthesized.

Hydrology of the Alapaha River

The Alapaha River displays a high flow and low flow regime (SEGS Guidebook, 2014). The external influence of the swallets and the lag effects of aquifer storage cause the river system to display hysteresis. In essence, the river stage is represented by a double value function and does not experience steady flow. As the stage rises, the discharge to the Suwannee River is expressed by one function as the bank storage is filled, and as it falls, it is expressed by another as the bank storage is drained. These stage-discharge loops reflect the internal storage processes at springs and resurgences (Upchurch, 2014). The flow duration plots show the Jasper gauge reaches zero flow when the Jennings gauge is approximately 500 cfs. At this low flow threshold 100% of the river flow is captured by the sinks. At flows greater than the low flow threshold the flow at the Jasper station is approximately 75% of the flow at Jennings which mean 25% of high flows are captured by the sinks. Data gaps in the observed data were filled with the lagged endogenous variable method.

Ceryak (1977) describes the seasonality of flow in the Alapaha. The Alapaha flows its entire length 60-percent of the time. During the remaining 40-percent, a group of sinkholes 4 miles south of the Florida state line captures the entire river flow. The water travels through solution channels in the limestone for approximately 19 miles and emerges mixed with groundwater at the Alapaha Rise and Holton Creek which discharge into the Suwannee River. Along the river corridor groundwater levels respond very quickly to changes in river stages. At flood stages the river water mixes with the groundwater and migrates as far as 5 miles from the river corridor.

Modeling of the Alapaha

The ARSRS has been included in several modeling efforts, including groundwater and surface water models. The literature associated with these models was evaluated in order to assess whether the calibration and conceptualization of the ARSRS was adequate or it could be enhanced.

Groundwater Modeling

The Alapaha River Sink Rise System is represented in the North Florida Groundwater Model (INTERA, 2014). The assignment of Alapaha River cells to layers was based on knowledge of hydrology in the area. The Alapaha River was assigned to model layer 2, the Upper Floridan aquifer, because of incision down to limestone. The tributaries were assigned to layer 1, the surficial aquifer. The surface water flux into the Alapaha River and Dead River swallets was represented as an injection well. The flux into the Alapaha River and Dead River swallets was estimated by developing a linear regression between flows at Statenville and Jasper gages. This flow was 364.5 cubic-feet-per-second (cfs). The accumulated baseflow is included in the computation of the baseflow target at the Suwannee River at Ellaville gauge. The discharge at the Alapaha Rise was also used as a spring flow target during calibration.

The Alapaha River is also represented in North Florida Southeast Georgia Groundwater Model (NFSEG; Durden et al., 2019). The Alapaha River to the streamflow gage near Jasper, Florida, is included as a tributary to the Suwannee River in the model domain. The Alapaha and Holton rises are included as springs in the model domain. Baseflow in the river was estimated through five different averaging techniques. The USGS program Groundwater Toolbox was used for three of the baseflow separation techniques. A low pass filter is used for the fourth estimation technique, and a flow duration curve for the fifth. Baseflow was estimated for 2001 and 2009. The HYSEP and PART methods were also examined but not used for final results. Very high peak flows were noted in spring of 2009, and it was noted that this will diminish the degree to which baseflow estimates would correspond to recharge rates in the contributing areas because the flow becomes much more difficult to estimate as the river becomes flooded, and the energy gradient becomes more variable.

Kuniansky et al. (2016) simulated groundwater flow in the Floridan Aquifer system over the Woodville Karst Plain near Tallahassee, Florida. They compare three models to better understand the ability to accurately simulate groundwater flow in karst areas. They compare a single continuum porous equivalent media model (SCPE) with laminar flow only, a hybrid model that consists of a SCPE couples to a one-dimensional pipe-flow network capable of simulating laminar and non-laminar flow, and a SCPE model with laminar and turbulent flow in the SCPE. They find that with adequate knowledge of the karst network, a SCEP model may be sufficient to simulate the groundwater flow. However, the ability to simulate laminar and turbulent flow is important. They note that they most important factor is having high-quality datasets and maps of the conduit networks in the domain of interest for accurate model calibration.

The modeling effort simulated the conduits with several modeling techniques including porous media as well as techniques that can represent hydraulic losses and laminar/non-laminar flow. Kuniansky et al. (2016) concludes that for seasonal or monthly average springflows, the ability to simulate laminar and non-laminar flow is not necessary. The main challenge to modeling the karst conduits is related to the uncertainties of conduit geometry including location, size, and roughness.

Davis et al. (2010) model nitrate-nitrogen (nitrate-N) loading into Wakulla Springs. They hypothesize that nitrate-N is infiltrating the Upper Floridan aquifer and flowing into Wakulla Springs, thus increasing the concentration of nitrate-N in the springs. The authors collect field data, which showed that at the high flow times at Wakulla, the Sopchoppy River was very low. This indicates that there was no surface water flow into the local sinks and would mean that the changing flow and nitrate-N concentrations in Wakulla are a results of groundwater flow in the underground tunnels moving north towards Wakulla Spring.

They model two scenarios in their study: that Wakulla Springs was not capturing any groundwater flow from underground conduits, and that Wakulla Springs was capturing groundwater flow from underground conduits. They simulate groundwater flow from 1966 through 2018. nitrate-N loading was simulated from capture of groundwater flow through karst conduits at two different stress periods in each modeling scenario. The authors used a two-layer MODFLOW groundwater model with MT3D for transport modeling. The first layer is an upper portion of the Floridan aquifer with sand overlaying limestone and rainwater recharging the aquifer. Groundwater flow in this layer is mostly vertical. Hydraulic conductivity in the first layer ranges from 10 to 10,000 feet per day. The second layer is a lower part of the aquifer, where there is higher hydraulic conductivity and groundwater velocity. Groundwater flow in the second layer is mostly horizontal, and hydraulic conductivity ranges from 10 to 5,000,000 feet per day.

Both model scenarios show an increase in nitrate-N at Wakulla Springs due to rising population, increases in onsite sewage disposal, and nitrate-N loading from flow across the model boundary. The authors note potential sources of error in the model, including parameter and model uncertainty. They conclude that groundwater velocity is the most important factor in the model for the purposed of their study.

Surface Water Modeling

Schneider et al. (2006) used a regression analysis to develop a 70-year record of surface-water flow at gages upstream and downstream of sinks in the Alapaha River. This timeseries was used to quantify the percentage of flow in the Alapaha River that enters the groundwater system. It was found that when flow is below 500 cubic-feet-per-second, all surface water flow infiltrates the aquifer. When upstream flow is above this threshold, 20-percent of the flow above the threshold also enters the aquifer. Flow into the aquifer exceeds downstream flow two-thirds of the time. Several correlations between discharge and seasonal flow patterns were tested and a good relationship was found between Alapaha Rise discharge data and the water level in a nearby shallow well. A good relationship between Alapaha Rise discharge lagged 6 days for low flow and 21 days for high flow was also found.

Additional surface water modeling of the basins surrounding the ARSRS was completed by the St. Johns Water Management District is support of the NFSEG model using HSPF (Durden et al., 2019). Model documentation for the NFSEG (Durden et al., 2019) provides a description of the HSPF modeling that is relevant to the groundwater modeling work including HSPF parameters, flow calibration, and HUC basin summaries. The surface water modelling included all the watersheds within the groundwater model domain. The HSPF surface water model was used to help constrain the recharge and groundwater ET rates used in the groundwater model. The surface water model simulated surface water balance was shown to mimic the observed metrics of streamflow, springflow, and baseflow. This surface water modeling effort represented the Alapaha River basin and specifically the Dead River Sink as well as the Alapaha Rise and Holton Creek Rise is discussed in the modeling and data collection sections.

Literature Review Summary

Extensive literature is available on the Alapaha River sink rise system. As the river flows from southern Georgia into Florida, the system becomes very complex. As the river crosses into the state, it encounters the Cody Scarp, characterized by a dissolution of limestone and dolostone. As the Alapaha River moves across the topographic break, from the Highlands to the north to the Lowlands in the south, the river enters a swallet in Dead River. The swallet in Dead River, along with other minor swallets, captures the overland flow and conveys it underground through a karst conduit system. This capture yields a unique low flow and high flow regime in the river. When flow is high, above 350 to 500 cfs, the river flows its entire length and only loses a portion of flow to the swallets. However, when flow is low, it is entirely captured by the swallets and flows exclusively underground. The water discharges into the Suwannee River through the Alapaha Rise and Holton Rise. Because of the karstic geology in the region, the Alapaha River (surface water) interacts quite dramatically with groundwater. This surface water – groundwater interaction leads to mixing with the underlying Floridan aquifer water, the most productive aquifer in Florida. At the resurgence, the flow is a combination of river water and groundwater. Understanding this relationship is the first step in developing process models that replicate the natural system.

The ARSRS has been represented in several groundwater models. River cells are associated with the Upper Floridan aquifer, because of the incision into the Cody Scarp. Surface water fluxes via injection wells have been used to represent in the swallets, and the resurgences have been used as spring flow targets in calibration. The complex nature of baseflow has also been studied in detail to ensure proper representation in modeling. A variety of estimation techniques have been used to estimate baseflow. Although the geology and aquifer systems in the Alapaha River have been described in great detail, the ARSRS has not been represented in many modeling studies in an integrated fashion. The available literature will provide a strong framework for further modeling studies.

Model Review Introduction

In addition to literature review, the surface water and groundwater models of the ARSRS were evaluated by examining the calibration and conceptualization in order to determine if enhancements to the models could be obtained through additional calibration or changes to conceptualization. This section presents a general introduction to the groundwater and surface water models and examines the calibration and conceptualization of each model in detail.

NFSEG Introduction

The NFSEG (Northern Florida Southeast Georgia) is a regional groundwater flow model which covers portion of Florida, Georgia, South Carolina, and potions of the Atlantic Ocean and the Gulf of Mexico. This covers an area of approximately 60,000 square miles. The model was developed jointly by the St. Johns River Water Management District and the Suwannee River Water Management District to assist in water resources and groundwater decision making among stakeholders. The model is intended to be applied to the evaluation of consumptive use permits, support analysis for minimum flow levels, and water supply planning.

The model is three-dimensional, steady state, and is calibrated to hydrologic conditions of 2001 and 2009. The groundwater model is an application of MODFLOW-NWT formation of MODFLOW 2005. The model is unconfined throughout. Surface water in all basins was simulated using HSPF (Hydrological Simulation Programming – FORTRAN) software. The HSPF was also used to generate the recharge input for the groundwater model.

The groundwater model contains seven (7) active layers: the surficial aquifer (if present, otherwise unconsolidated sediments), the intermediate aquifer or intermediate confining unit, the Upper Floridan aquifer, the middle confining unit (MCU) or the Upper Floridan aquifer where the MCU is absent, the Lower Floridan aquifer, the lower semi-confining unit and the Fernandina Permeable zone of the Lower Floridan aquifer, where these hydrogeologic units are present. If an aquifer is not present, it is substituted with the Upper Floridan aquifer.

NFSEG HSPF Model Review

Hydrological Simulation Program – FORTRAN (HSPF) is a comprehensive rainfall-runoff water quality model. The HSPF model developed for the NFSEG area is calibrated to observed surface water flows. Most model parameters can be specified by spatial or physical watershed data, but some parameters were determined through model calibration. The HSPF model of each basin in the NFSEG model domain was calibrated from 1992 to 2015. Relevant watersheds to the Alapaha River Sink Rise System (ARSRS) are shown in **Figure 1.** The USGS flow station used in the calibration are also shown in **Figure 1** as well as listed in **Table 1**. **Figure 2** show a general calibration workflow process. Primary calibration targets were flows at USGS gauges and estimates of actual evapotranspiration (AET).

Table 1: HUC8 Units Relevant To The Alapaha Sink Rise System.

HUC8	**Name**
03110202	Alapaha
03110201	Upper Suwannee
03110203	Withlacoochee
03110205	Lower Suwannee

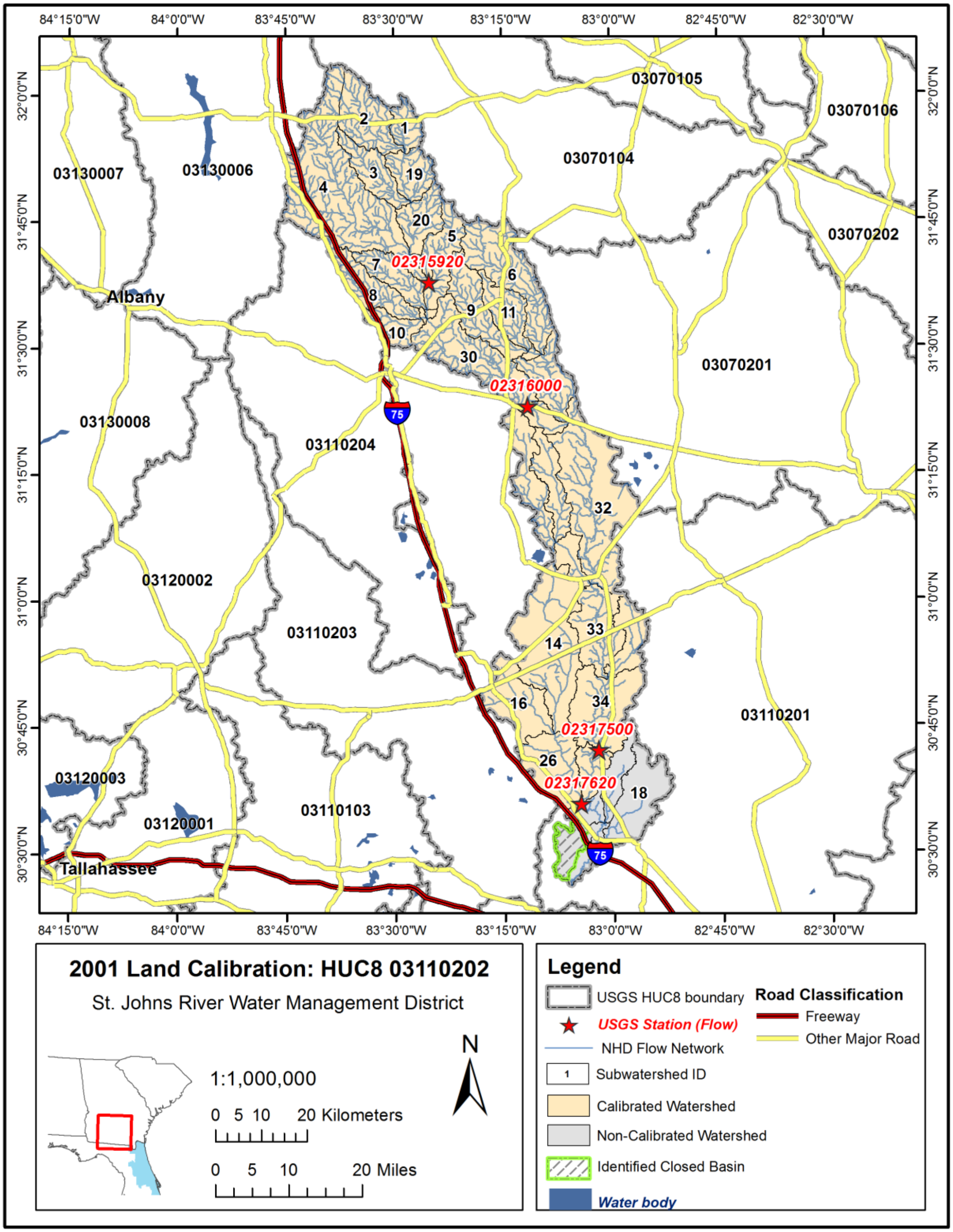

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Figure 1 Alapaha Watershed and Flow Stations Used in Calibration Effort (NFSEG 2019)

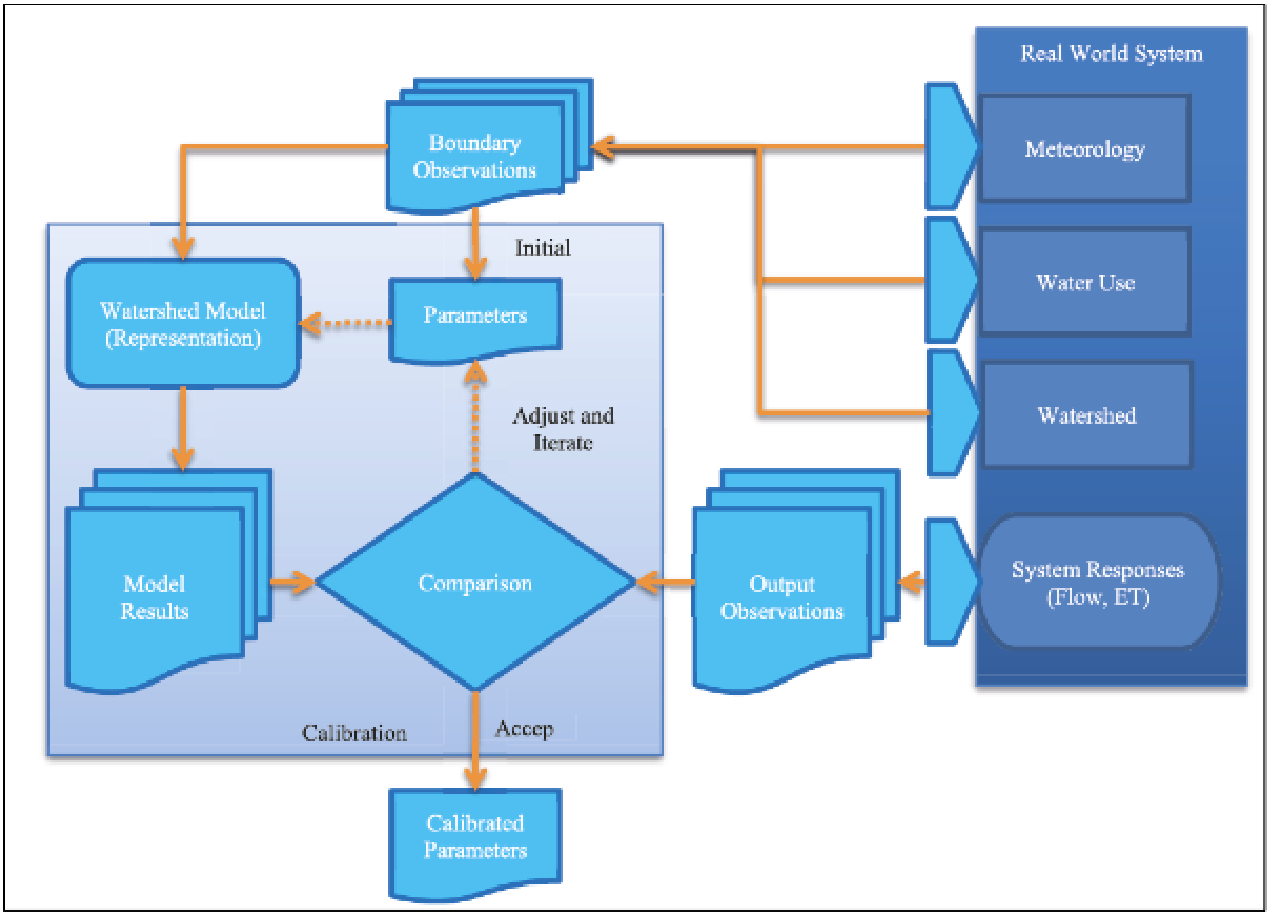

Figure 2: HSPF Model Calibration Process. Figure 9-25 in NFSEG v1.1 Report.

Noteworthy components of the HSPF conceptualization include:

- The PET and rainfall boundary conditions for 2001, 2009, and 2010 appear reasonable.
- Septic field volume was applied to Lower Zone Lateral Inflow (LZLI). It was assumed that the contribution of water from urban irrigation and septic came from groundwater.
- Various types of irrigation, including micro drip, container nurseries, low volume and micro spray were assigned to appropriate HSPF water balance terms.
- Land cover was divided into 12 consolidated landuses, which is consistent with other SJRWMD HSPF modeling efforts.
- The two primary calibration datasets were observed USGS flows and literature estimates of total evapotranspiration (ET). Several USGS gauges in the vicinity of the ARSRS were used for model calibration, including four gauges on the Alapaha River (**Table 2**).
- The calibration period for each gauge was generally within the 1992 to 2015 time period.
- Springflow was not represented as an external source (boundary condition) due to the limited availability of springflow data. As an alternative, an underground reservoir was created in the model to collect IGWI within each springshed, which was then used as a

springflow source. Springsheds were delineated using potentiometric surface maps and were not coincident with surface watersheds.

HSPF Calibration in the ARSRS Vicinity

The calibration of the HSPF model in the vicinity of the ARSRS was examined to determine the goodness-of-fit of the calibration in the area. Calibration statistics for the USGS gauges within the Alapaha HUC are shown in **Table 2**. As shown, the model generally simulated mean monthly streamflow for gauges within the basin with a low bias and a high Nash-Sutcliffe. The NFSEG appendix lists hydrographs on daily and monthly scales that show excellent agreement between observed and simulated flows. Extracted monthly data listed for the Alapaha @ Jennings calibration from the NFSEG appendix is shown in **Figure 3**. The graph shows the good agreement between observed and simulated monthly averages. The peak of the wet season is shown to be slightly underpredicted by the model (-23%). Other calibration stations in the Alapaha basin exhibited similar response. Looking at the calibrated parameters, most of the sub-basins within the Alapaha watershed used the same parameters set, although basins 12-18 as well as a few other had a marked change in the parameters indicating a significant difference in hydrologic response (see Table T-03110202-18 of the NFSEG appendix).

Table 2: Observed Flows and Simulated Mean Monthly Flows In HSPF Recharge Model, Percent Differences In Flows, and NSE for Monthly Data for HUC 03110202: Alapaha (Table 9-17 in NFSEG V1.1 Final Report.)

HSPF Model Reach	Calibration Gauge	Gauge Name	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe
27	02315920	Alapaha River at GA 125/32 Near Irwinville, GA	294	290	1	0.85
30	02316000	Alapaha River Near Alapaha, GA	450	453	-1	0.87
34	02317500	Alapaha River Near Statenville, GA	1072	1002	6	0.88
36	02317620	Alapaha River Near Jennings, FL	975	903	7	0.84

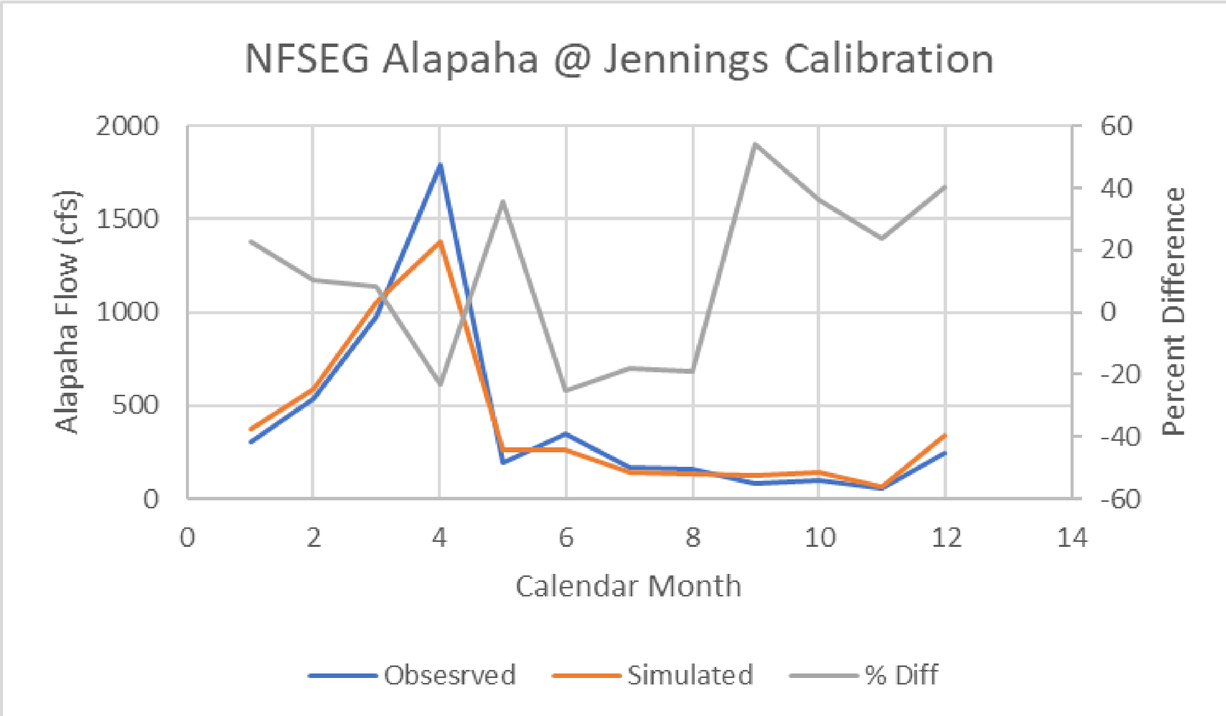

Figure 3 *Monthly Average Flow Comparison*

Similarly, the model calibration for the nearby Upper Suwannee, Withlacoochee, and Lower Suwannee HUCs were examined, shown in **Tables 3**, **4**, and **5**, respectively. Similar to the Alapaha HUC, the calibration was generally very good in these watersheds, which indicates that the model represents streamflows well.

Table 3: Observed Flows and Simulated Mean Monthly Flows In HSPF Recharge Model, Percent Differences In Flows, and NSE for Monthly Data for HUC 03110201: Upper Suwannee (Table 9-17 in NFSEG V1.1 Final Report.)

HSPF Model Reach	Calibration Gauge	Gauge Name	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe
24	02315000	Suwannee R Near Benton, FL	1201	1163	3	0.90
13	02315200	Deep Creek Near Suwannee Valley, FL	70	63	9	0.76
31	02315500	Suwannee Rive at White Springs, FL	1469	1422	3	0.90
34	02315550	Suwannee River at Suwannee Springs, FL	1982	1997	-1	0.88
0	02319500	Suwannee River at Ellaville, FL	5560	5143	8	0.88

Table 4: Observed Flows and Simulated Mean Monthly Flows In HSPF Recharge Model, Percent Differences In Flows, and NSE for Monthly Data for HUC 03110203: Withlacoochee (Table 9-17 in NFSEG V1.1 Final Report.)

HSPF Model Reach	Calibration Gauge	Gauge Name	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe
15	00231774A	NA	458	270	41	0.65
16	02317755	Withlacoochee River at US 41 Near Valdosta, GA	241	173	28	0.76
			Short period of record.			
18	02318500	Withlacoochee River at US 84, Near Quitman, GA	1237	1086	12	0.83
13	02318700	Okapilco Creek at GA 333, Near Quitman, GA	233	161	31	0.73
21	02319000	Withlacoochee River Near Pinetta, FL	1758	1546	12	0.82
22	02319300	Withlacoochee River Near Madison, FL	1457	1487	-2	0.78
23	02319394	Withlacoochee River Near Lee, FL	1982	1777	10	0.79
44	02319500	Suwannee River at Ellaville, FL	5560	5131	8	0.88

Table 5. Observed Flows and Simulated Mean Monthly Flows In HSPF Recharge Model, Percent Differences In Flows, and NSE for Monthly Data for HUC 03110205: Lower Suwannee (Table 9-17 in NFSEG V1.1 Final Report.)

HSPF Model Reach	Calibration Gauge	Gauge Name	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe
14	02319800	Suwannee River at Dowling Park, FL	4803	4832	-1	0.87
16	02320000	Suwannee River at Luraville, FL	5115	4960	3	0.86
21	02320500	Suwannee River at Branford, FL	6319	6185	2	0.82
22	02323000	Suwannee River Near Bell, FL	6930	7039	-2	0.75
26	02323500	Suwannee River Near Wilcox, FL	8157	8485	-4	0.76
29	02323592	Suwannee River AB Gopher River Near Suwannee, FL	7407	7468	-2	0.74

HSPF Application for the ARSRS Vicinity

As mentioned above, the HSPF models are well calibrated and represent the dynamic transitions between low and high seasonal flows very well. The hydrographs, seasonal flow data, and ET estimates all agree with the observed data as well as accepted relative magnitudes of the significant water balance terms. The most downstream flow station has an outstanding representation of the overall water balance. The applicability of this model for representing the Dead River Sink and the Alapaha Rise interaction are minimized due to the scale of the problems. The karst interaction all occurs below the final gage used in the calibration. The model can serve as a basis for additional effort to improve the near field karst interactions.

The NFSEG MODFLOW Model Review

The NFSEG model was calibrated to two years: 2001 and 2009. Calibration years are selected based on groundwater level steadiness, whether rainfall was near average with respect to annual totals and monthly distributions, and data availability. The model was calibrated using Parameter ESTimation (PEST). The PEST calibration uses an observation group of water levels and flow rates, and systematically adjusts the targeted calibration parameters in the model. PEST runs through many optimization iterations with predefined parameter ranges specified by the model user. PEST constructs a Jacobian matrix to estimate an improved parameter data set based on the user specified range.

Using PEST, the NFSEG model was calibrated to median observed water levels and flow rates for 2001 and 2009. Observation groups used in the calibration process include groundwater levels, spring discharge rates, baseflow rates, vertical head differences in the surficial aquifer system and Upper Floridan aquifer (Layers 1 and 3), horizontal head differences within the Upper Floridan Aquifer (Laver 2), and estimated lake leakance rates. Calibration residuals for layer 1 are shown for 2001 and 2009 in **Figures 4** and **5**, respectively. The general vicinity of the ARSRS is shown with a star in the maps. As shown, there were no layer 1 targets in the vicinity of the ARSRS.

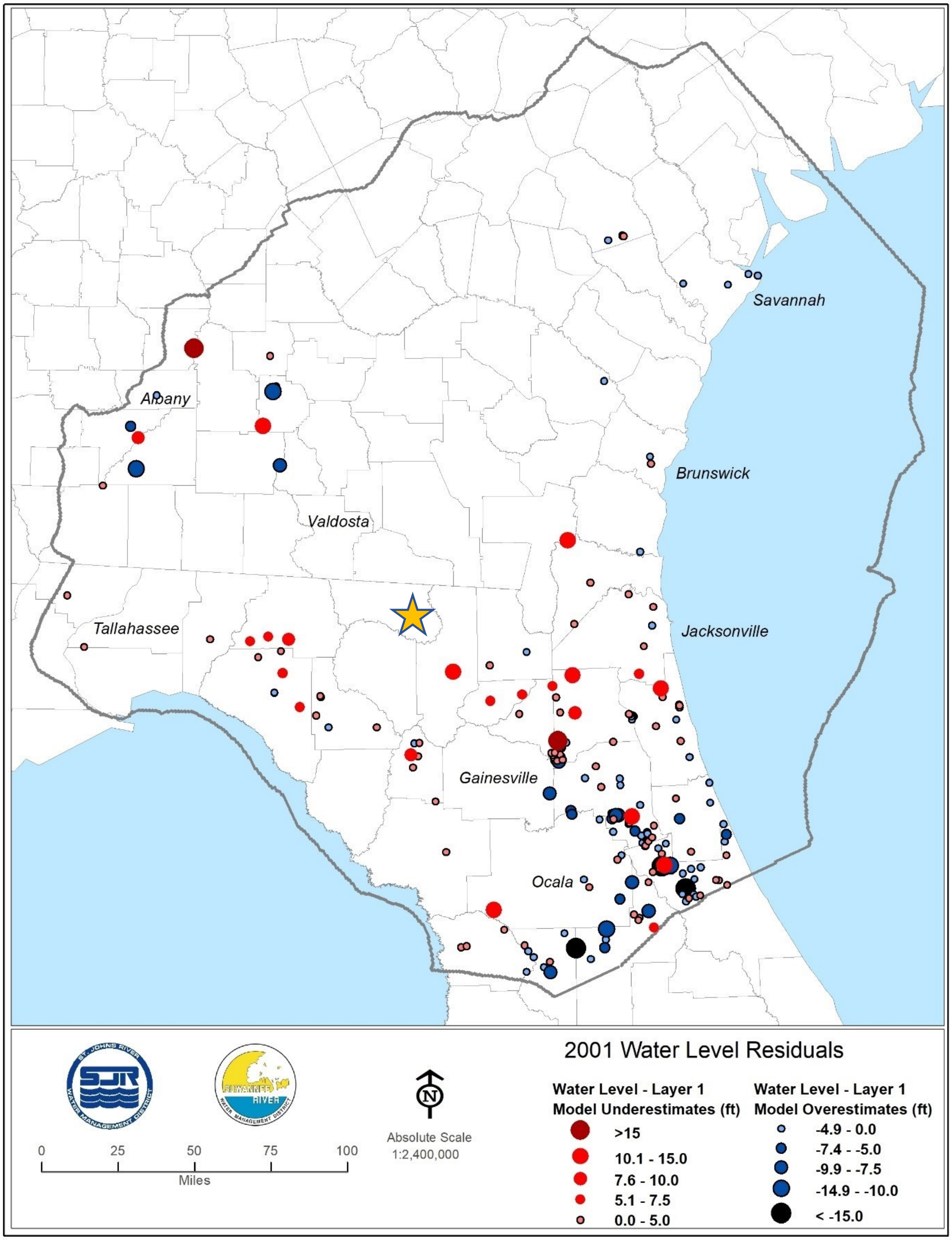

Figure 4: Hydraulic Head Residuals (feet), Model Layer 1, 2001.

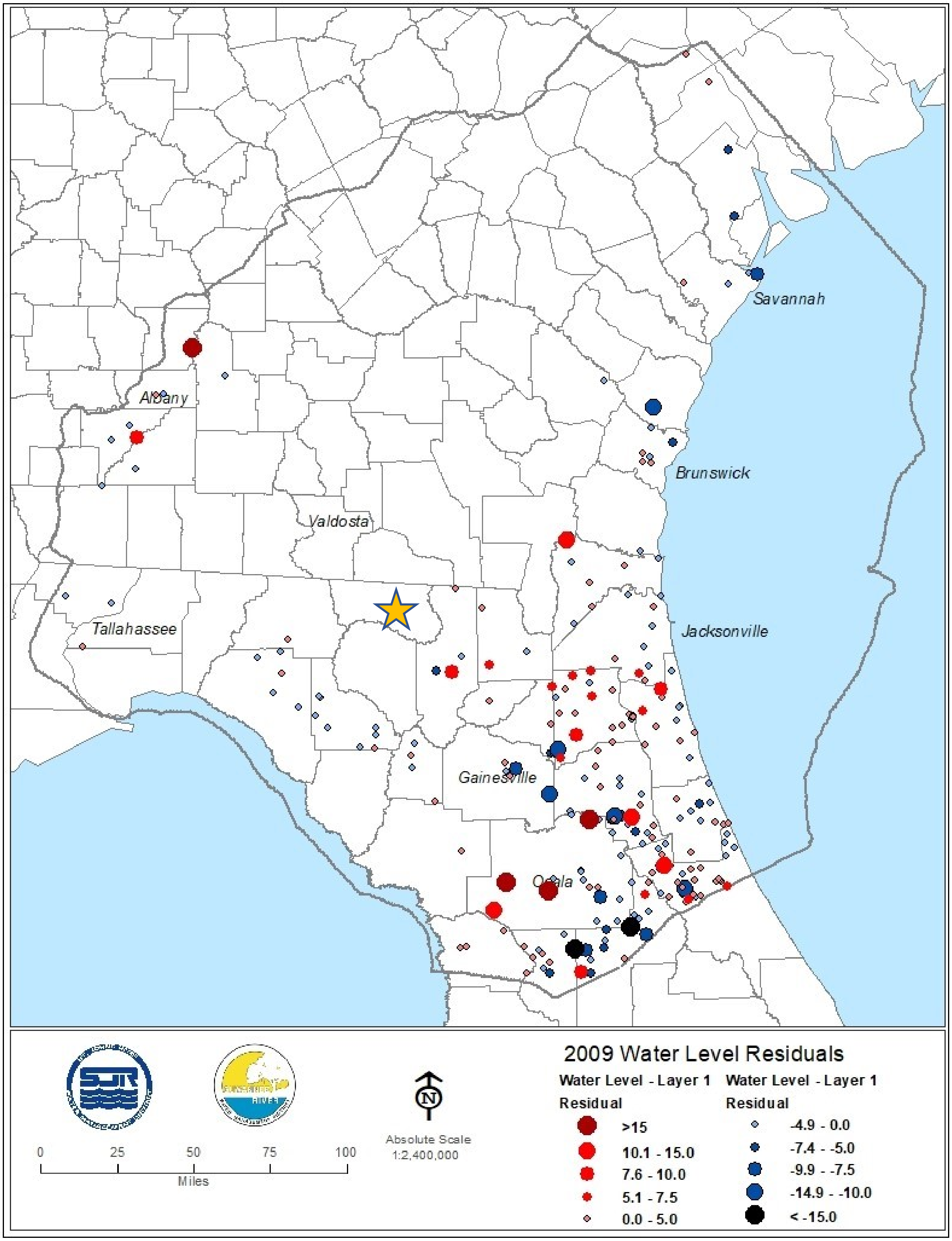

Figure 5: Hydraulic Head Residuals (feet), Model Layer 1, 2009.

NFSEG Addendum Calibration Summary Information

An addendum to the NFSEG documentation was issues due to a change in the calculation of the recharge package. The final calibrated model results (Case007h-1) were compared to the original model calibration (Case007h). Statistics for springflows within the ARSRS are shown in **Table 6**. As shown, the calibration for Alapaha Rise is excellent for 2001 and 2009, and the calibration for Holton Creek is also very good for both calibration periods.

Table 6: Comparison of Simulated and Estimated Spring Flows from Selected First-Magnitude Springs and Spring Groups, 2001 And 2009 NFSEG. Data from Tables 1 And 2 In NFSEG V1.1 Addendum.

Spring Group	**Estimated Discharge (cfs)**	**Case007h Simulated Discharge (cfs)**	**Case007h-1 Simulated Discharge (cfs)**	**Case007h-1 Minus Case007h (cfs)**	**Year**
Alapaha Rise	386	195.9	195.9	0	2001
Alapaha Rise	244	240.4	239.6	-0.7	2009
Holton Creek	71	64.0	63.5	-0.5	2001
Holton Creek	63	66.5	66.3	-0.2	2009

Baseflows in the vicinity of the ARSRS were also examined (**Table 7**). As shown, the model overestimates baseflow at Jennings and underestimates baseflow at the Suwannee River at White Springs.

Table 7: Comparison of Simulated Cumulative Baseflows for Selected USGS Gages, 2001 And 2009. Data from Tables 7 and 8 In NFSEG V1.1 Addendum.

USGS Gauge	**Gauge Name**	**Target Baseflow (cfs)**	**Case007h Simulated Baseflow (cfs)**	**Case007h-1 Simulated Baseflow (cfs)**	**Case007h-1 Minus Case007h (cfs)**	**Year**
02317620	Alapaha River Near Jennings, Fla.	223.86	464.39	464.39	0	2001
02317620	Alapaha River Near Jennings, Fla.	341.67	810.42	810.40	-0.02	2009
02315500	Suwannee River at White Springs, Fla.	153.67	85.10	85.10	0	2001
02315500	Suwannee River at White Springs, Fla.	383.55	162.73	162.70	-0.03	2009

Tables 8 and **9** represent the comparison of the simulated springflow and baseflow from the NFSEG scenarios. **Figures 6-8** show the NFSEG results in map form. The simulated 2001 residuals are shown on the map in **Figure 6**; residuals for 2009 are shown in Durden et al. (2019). The simulated 2001 baseflow residuals are shown on the map in **Figure 7**; baseflow and cumulative baseflow targets are also shown in Durden et al. (2019). The simulated residuals for the 2009 scenario are shown on the map in **Figure 8.** The example of the NFSEG results were extracted from the NFSEG V1.1 Addendum. For complete documentation please refer to the NFSEG addendum.

Table 8: Comparison of Simulated 2009 and No-Pumping Springs Discharges for Selected Springs. Table 15 in NFSEG V1.1 Addendum.

Spring	2009 Case007h Discharge (cfs)	2009 Case007h-1 Discharge (cfs)	2009 Difference (cfs)	No-Pumping Case007h Discharge (cfs)	No-Pumping Case007h-1 Discharge (cfs)	No-pumping Difference (cfs)
Alapaha Rise	240.36	239.64	-0.72	298.82	298.01	-0.81
Holton Creek	66.52	66.30	-0.23	88.47	88.20	-0.27

Table 9: Comparison of Simulated 2009 and No-Pumping Baseflows for Selected USGS Gages.

USGS Gauge	USGS Gauge Name	2009 Case007h Baseflow (cfs)	2009 Case007h-1 Baseflow (cfs)	2009 Difference (Cfs)	No- Pumping Case007h Baseflow (cfs)	No- Pumping Case007h-1 Baseflow (cfs)	No- pumping Difference (cfs)
02315500	Suwannee River at White Springs, Fla.	162.7	162.7	0	162.5	162.5	0

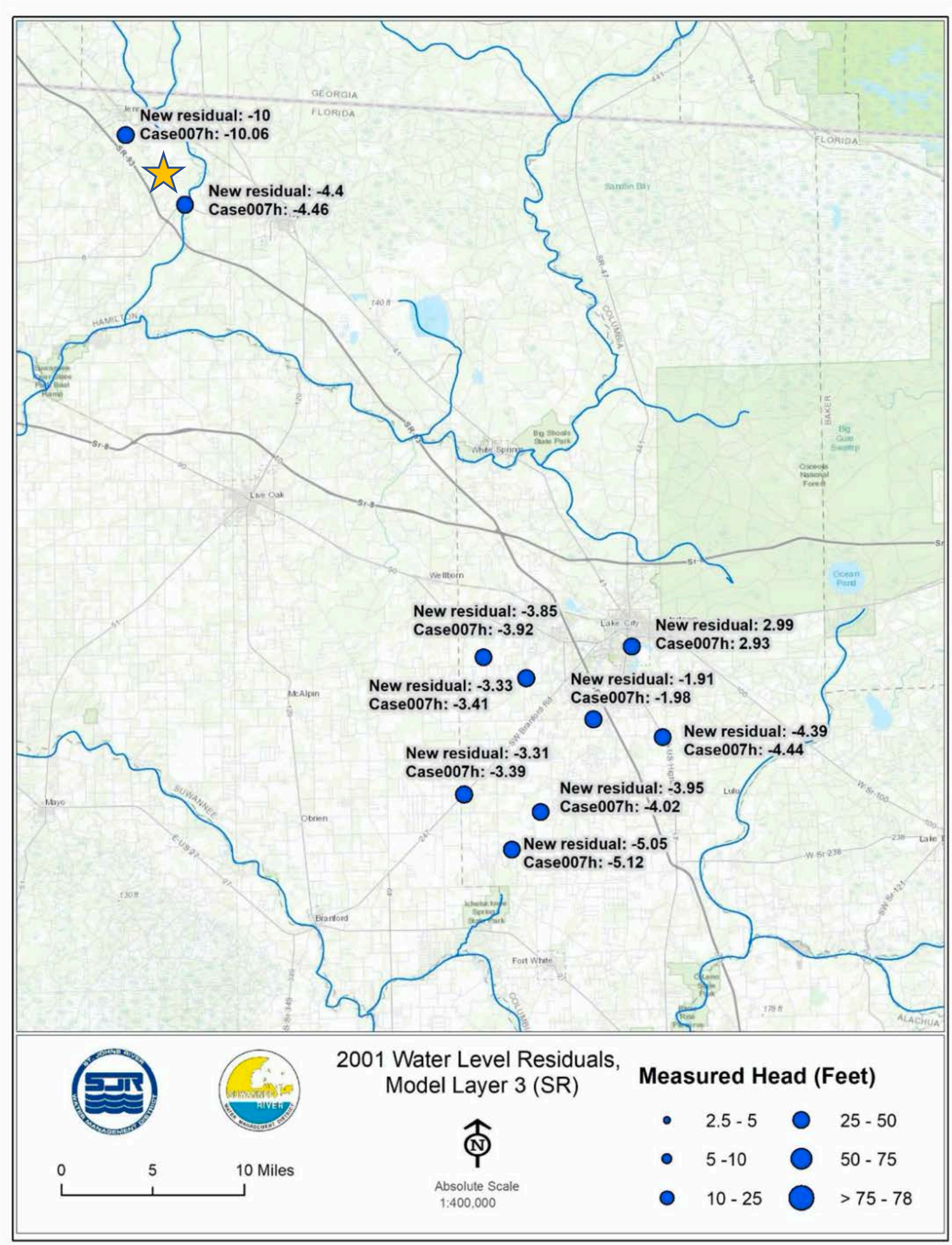

Figure 6: Comparison of Groundwater Level Residuals in Model Targets in Suwannee and Columbia County, 2001. NSFEG.v.1.1 Addendum Page 29.

Figure 7: Comparison of Cumulative Baseflow Rate Residuals for Select USGS Gauges, 2001. NSFEG.V.1.1 Addendum Page 38.

Figure 8: Comparison of Cumulative Baseflow Rate Residuals for Selected USGS Gauges, 2009. NFSEG V.1.1 Addendum Page 39.

NFSEGv1.1 Final Report Information

Range of estimated and simulated baseflows for relevant gauges are shown in **Table 10**.

Table 10: Range of Estimated Cumulative Baseflow and Simulated Baseflow. Table 5-3 in NFSEG V1.1 Final Report.

USGS Gauge	USGS Gauge Name	Estimated Average Baseflow (cfs)	Estimated Minimum Baseflow (cfs)	Estimated Maximum Baseflow (cfs)	Simulated Baseflow (cfs)
02317620	Alapaha River Near Jennings, Fla.	**-607**	**-145**	**-915**	**-447**
02315500	Suwannee River at White Springs, Fla.	**-542**	**-106**	**-863**	**26**

Model Evaluation Conclusions

The NFSEG represents a significant multidisciplinary effort to calibrate a surface water model and a groundwater model of the full extent of the Floridan Aquifer System in north Florida and southeast Georgia. This comprehensive modeling strategy incorporated the calibration of both the surface water and groundwater systems to constrain the calibration and increase the confidence in the model's predictive capabilities. This strategy eliminated the uncertainties associated with a later flow boundary condition. The surface water component is well calibrated and incorporated a robust application of available data sources. The groundwater calibration was good with good agreement to flow and head targets. The scale to which the NFSEG modeling strategy was developed does not immediately lend itself to an accurate representation of the near field karstic processes found between the Dead River Sink and the Alapaha/Holton Creek Rise but it is great starting point for a refined representation of the small-scale processes.

The NFSEG groundwater model was reviewed for accuracy in the Alapaha River Sink Rise System. The Alapaha is also represented in North Florida Southeast Georgia Groundwater Model (NFSEG; Durden et al., 2019). The Alapaha is included as a tributary to the Suwannee in the model domain. The Alapaha and Holton rises are included as river rises in the model domain. The model is calibrated to groundwater head targets. The heads in the model are influenced by transmissivity and groundwater flow, both of which influence the overall resistance in the subsurface layers in the model. These parameters can be changes in order to change heads in the model.

It was found that the Dead River sink is not included as an injection well in the model. This means that the model is only quantifying the groundwater contribution to the Alapaha Rise from the aquifer, and not including the groundwater flow contribution from surface water flow by the swallets. To account for this and match the head targets at the Alapaha and Holton Rise, transmissivity is decreased to compensate for improper groundwater flow representation in the model.

It is recommended that the Dead River sink be included as a surface water injection well in the model. This will improve the representation of groundwater flows to the Alapaha Rise, increase the accuracy of the transmissivity array, and improve the representation of groundwater heads in the model.

Data Collection Introduction

Data relevant to the Alapaha River Sink Rise System (ARSRS) were compiled by INTERA with the assistance of the Suwannee River Water Management District (SRWMD or the District). The District provided a list of area wells and gauges available for review, including a spreadsheet analysis completed by the District in 2017. This data included the Alapaha and Suwannee River flows and levels, groundwater levels in nearby Floridan aquifer system (FAS) wells, and pool elevations and discharge rates at the Alapaha Rise and Holton Creek Rise. This document provides a summary of the data collection and compilation, and a summary of the initial data analysis.

Data Collection Summary

Stream gauge, spring, and well stations were identified from GIS shapefile data and compiled in a list delineating USGS and SRWMD (or District) IDs and station types. Hydrologic data including discharge, gauge height, and level, and the associated station metadata including name, location (coordinates), and datum were downloaded if available. Data collected from the District was extracted from the SRWMD database and received through email communication (**Table 11**).

Table 11. Data Collected from the District

Station Type	USGS ID	District ID	Station Name	Discharge	Gauge Height	Stage	Level
Stream Gauge	02315550		Suwannee River at Suwannee Springs, Fl.	x	x	x	
Stream Gauge	02317620		Alapaha River near Jennings, Fl.	x	x	x	
Stream Gauge	02319394		Withlacoochee River near Lee, Fl.	x	x	x	
Stream Gauge	02315000		Suwannee River near Benton, Fl.	x	x	x	
Stream Gauge	02319300		Withlacoochee River near Madison, Fl.	x	x	x	
Stream Gauge	02315620	02315620	Holton Springs near Ft. Union, FL	x			
Stream Gauge		02315626	Alapaha Rise above SW 68th Drive near Jasper FL	x			
Spring	02319498		Suwanacoochee Spring at Ellaville, Fl.	x			
Spring		1121903	Lime Springs / Little Gem	x			
Spring		LSR010C1	Lime Sink Run	x			
Well	302957082441201	N011608001	Irene Morgan aka Camp Mallory				x
Well		N021713001	Sandlin Bay Floridan				x
Well		N011117015	Nestle FSC - 1				x
Well		N021332004	Alapaha Tower				x
Well	302959082481001	N011510003	Christie Tower aka Arky Rogers				x
Well		S011535004	Bullock Tower				x
Well		S021322008	Suwannee Co. Comm-Colliseum				x
Well		N011714002	Old Benton Tower				x
Well	302334082560201	S011420001	FL Board of Conservation				x
Well		N011316001	Carl Ivey Carter aka Adams Farm				x
Well		N011422007	Pete Deas				x
Well	303626083172001	N021002001	John Homzak				x
Well		N021125001	Santa Deas				x
Well	303158082562901	N021432001	Stafford Scaff				x
Well		S011232006	Falmouth				x
Well		S011511001	PCS Admin MD4				x
Well		S011534001	Hilward Morgan				x
Well		S021335001	Church of God				x
Well		S021516001	G E Poucher				x
Well		N011405010	Jasper Upper Floridan Aquifer H-0079				x
Well		N011610001	Bay Creek Upper Floridan				x

Station Type	USGS ID	District ID	Station Name	Discharge	Gauge Height	Stage	Level
Well		N011610002	Bay Creek Intermediate				x
Well		N011610003	Bay Creek Lower Floridan				x
Well		N021013001	Westwood West				x
Well		N021713002	Sandlin Bay Surficial				x
Well		S021430004	SRWMD Office				x
Well		N011405005	Jasper Lower Floridan H-0078				x

Data collected from the USGS was downloaded from the National Water Information System (waterdata.usgs.gov) and received through email communication (**Table 12**).

Table 12. Data Obtained from USGS

Station Type	USGS ID	District ID	Station Name	Discharge	Gauge Height	Stage	Level
Stream Gauge	02315500		Suwannee River at White Springs, Fl.	x	x	x	
Stream Gauge	02315550		Suwannee River at Suwannee Springs, Fl.	x	x	x	
Stream Gauge	02317620		Alapaha River near Jennings, Fl.	x	x	x	
Stream Gauge	02319000		Withlacoochee River near Pinetta, Fl.	x	x	x	
Stream Gauge	02319302		Madison Blue Spring near Blue Springs, Fl.	x	x	x	
Stream Gauge	02319394		Withlacoochee River near Lee, Fl.	x	x	x	
Stream Gauge	02319500		Suwannee River at Ellaville, Fl.	x	x	x	
Stream Gauge	02319520		Falmouth Spring at Falmouth, Fl.		x	x	
Stream Gauge	302556082433800		Occidental Pond South CSA Outfall near White Springs, Fl.	x	x		
Stream Gauge	302623082434200		Occidental Pond North CSA Outfall near White Springs, Fl.	x			
Stream Gauge	02315000		Suwannee River near Benton, Fl.	x	x	x	
Stream Gauge	02315200		Deep Creek Near Suwannee Valley, Fl.	x	x	x	
Stream Gauge	02317500		Alapaha River at Statenville, Ga.	x	x	x	
Stream Gauge	02319300		Withlacoochee River near Madison, Fl.	x	x	x	
Stream Gauge	02318500		Withlacoochee River at US 84, near Quitman, Ga.	x	x	x	
Spring	02319498		Suwanacoochee Spring at Ellaville, Fl.	x			
Stream Gauge	02315648		Alapaha Rise near Fort Union	x	x		
Stream Gauge	02317630		Alapaha River near Jasper	x	x		
Well	302127082475801		Hilward Morgan Well near Facil, Fl.				x
Well	301909082490985		Local No. 019-249-1				x
Well	302323082493501	S011521001	A C Hogan Well				x
Well	302835082545301	N011421001	FFS Well S of Jasper				x
Well	302642083065201	N011234001	Walter Phillips near Ft. Union				x
Well	303805083164301	19D044	19D044				x
Well	304136083095901	20D018	20D018				x
Well	304150083015802	21D028	21D028				x
Well	304447083112701	20D051	20D051				x
Well	304610083000502	21E012	21E012				x
Well	304610083000501	21E007	21E007				x

Data was imported into a Microsoft Access database for efficiency in querying, editing, and performing quality assurance and quality control steps. Data from stream and spring gauges, wells, and station metadata was organized by table (**Table 13**). A summary of flow station (**Table 14)** and well (**Table 15**) minimum, maximum, and average values as well as counts of data points are presented. Daily time series are presented for discharge (**Appendix B**), stage (**Appendix C**), and level (**Appendix D**) for stations with available data as well as average annual and monthly time series. For flow station hydrograph time series in Appendix C, gauge height is displayed when a datum is not available, and stage is displayed when a datum is available for that site.

Table 13. Description of Access Database Tables

Table Name	**Table Description**
FlowStationTimeSeries	Daily time series for discharge (cfs) and gauge height (ft) for stream and spring gauges.
NAVD88TimeSeries	Daily time series for NAVD88 stage (ft) converted from gauge height.
StageTimeSeries	Daily time series for well levels (ft).
Station	Stream gauge, spring, and well station metadata.

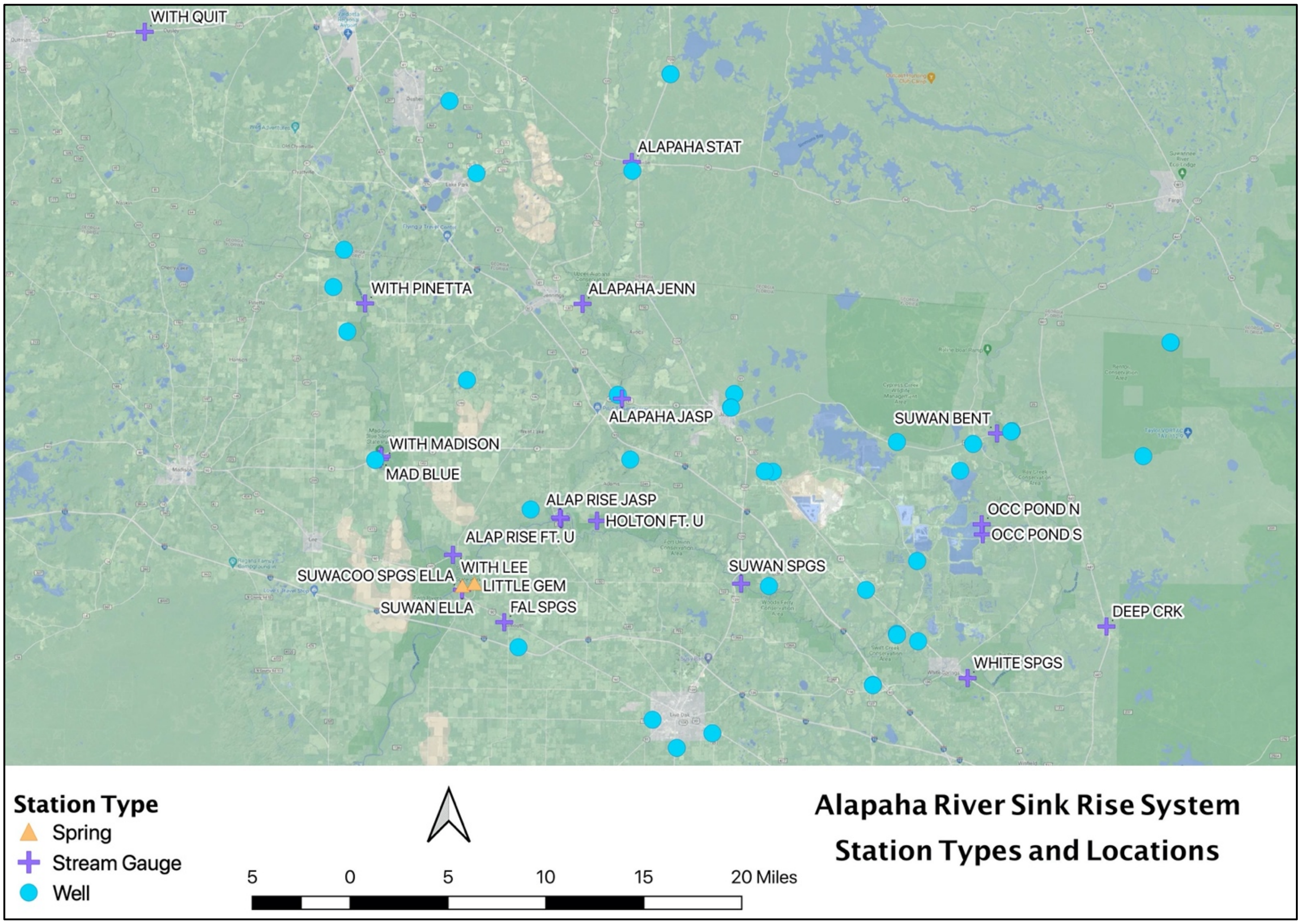

Figure 9. Location Map of Springs, Stream Gauges, and Wells in the Microsoft Access Database.

Table 14. Flow Station Summary Table

Station ID	Station Name	Minimum Date	Maximum Date	Minimum Discharge (cfs)	Maximum Discharge (cfs)	Average Discharge (cfs)	Count of Discharge values	Minimum Stage NAVD88 (ft)	Maximum Stage NAVD88 (ft)	Average Stage NAVD88 (ft)	Count of Stage values
02315500	Suwannee River at White Springs, Fl.	6/1/1906	3/22/2021	2	38,000	1,703	35,303	0	85	27	34,356
02315550	Suwannee River at Suwannee Springs, Fl.	10/1/1969	3/28/2021	25	19,800	1,727	16,203	35	78	43	12,929
02317620	Alapaha River near Jennings, Fl.	7/28/1976	3/28/2021	30	25,800	1,346	11,583	3	93	42	9,788
02319000	Withlacoochee River near Pinetta, Fl.	10/1/1931	3/28/2021	57	73,600	1,689	32,670	52	88	56	32,465
02319302	Madison Blue Spring near Blue Springs, Fl.	4/12/2002	3/28/2021	-922	752	98	6,620	55	86	58	6,862
02319394	Withlacoochee River near Lee, Fl.	11/1/2000	3/28/2021	185	51,400	2,001	7,194	29	64	33	7,367
02319500	Suwannee River at Ellaville, Fl.	2/1/1927	4/12/2021	299	94,700	6,119	34,405	28	67	33	33,941
02319520	Falmouth Spring at Falmouth, Fl.	10/11/2015	3/28/2021				0	76	93	79	1,912
302556082433800	Occidental Pond South CSA Outfall near White Springs, Fl.	7/1/1996	9/30/1998	0	13	0	227				0
302623082434200	Occidental Pond North CSA Outfall near White Springs, Fl.	7/1/1996	9/29/1998	0	75	1	821				0
02315000	Suwannee River near Benton, Fl.	1/1/1932	9/15/2017	0	18,600	1,310	15,472	73	99	78	11,603

Station ID	Station Name	Minimum Date	Maximum Date	Minimum Discharge (cfs)	Maximum Discharge (cfs)	Average Discharge (cfs)	Count of Discharge values	Minimum Stage NAVD88 (ft)	Maximum Stage NAVD88 (ft)	Average Stage NAVD88 (ft)	Count of Stage values
02315200	Deep Creek near Suwannee Valley, Fl.	4/1/1976	9/29/1998	0	2,630	64	4,929	84	98	86	4,702
02317500	Alapaha River at Statenville, Ga.	1/28/1921	4/4/2021	17	32,700	1,057	32,778	77	107	81	8,484
02319300	Withlacoochee River near Madison, Fl.	7/8/1977	9/30/2018	11	55,000	1,510	5,078	40	75	43	4,964
02318500	Withlacoochee River at US 84, near Quitman, Ga.	10/1/1928	4/18/2021	6	61,000	1,194	16,676	85	118	89	9,444
02319498	Suwanacoochee Spring at Ellaville, Fl.	11/6/1931	1/26/2021	1	82	37	35				0
01121903	Lime Springs / Little Gem	4/30/1976	1/26/2021	0	51	17	26				0
LSR010C1	Lime Sink Run	5/14/1998	1/26/2021	-354	173	11	16				0
02315648	Alapaha Rise near Fort Union	11/25/1975	3/8/1985	0	1,040	448	57				0
02317630	Alapaha River near Jasper	4/6/1948	4/1/1996	4	24,600	4,436	28				0
02315620	Holton Springs near Ft. Union, FL	2/13/1976	4/27/2021	0	875	229	514				
02315626	Alapaha Rise above SW 68th Drive near Jasper FL	4/2/1976	9/30/2016	0	1290	57	1547				

Table 15. Well Summary Table

Station ID	Station Name	Minimum Date	Maximum Date	Minimum Level (ft)	Maximum Level (ft)	Average Level (ft)	Count of Level values
N011608001	Irene Morgan aka Camp Mallory	8/1/1976	6/13/2016	51	78	60	409
N021713001	Sandlin Bay Floridan	5/26/2005	4/3/2021	43	59	51	2,677
N011117015	Nestle FSC - 1	10/6/2003	4/4/2021	41	70	44	2,346
N021332004	Alapaha Tower	6/12/1989	4/4/2021	32	74	44	3,432
N011510003	Christie Tower aka Arky Rogers	8/1/1967	4/3/2021	43	110	52	2,931
S011535004	Bullock Tower	11/4/1981	4/3/2021	45	76	53	3,289
S021322008	Suwannee Co. Comm-Colliseum	3/1/1990	9/4/2013	32	51	38	77
N011714002	Old Benton Tower	7/18/1988	4/3/2021	44	61	51	2,980
S011420001	FL Board of Conservation	11/1/1976	4/3/2021	37	69	44	3,252
302127082475801	Hilward Morgan Well near Facil, Fl.	12/7/1977	4/20/1982	50	63	54	1,393
N011316001	Carl Ivey Carter aka Adams Farm	11/1/1976	4/3/2021	32	69	40	14,374
N011422007	Pete Deas	3/11/1981	4/4/2021	37	69	45	14,179
N021002001	John Homzak	11/1/1976	3/15/2021	55	84	62	461
N021125001	Santa Deas	3/10/1981	4/4/2021	40	70	46	13,610
N021432001	Stafford Scaff	11/1/1976	4/5/2021	33	68	43	14,125
S011232006	Falmouth	2/28/2000	4/4/2021	30	54	37	2,605
S011511001	PCS Admin MD4	5/8/1975	3/2/2021	44	78	52	414
S011534001	Hilward Morgan	11/4/1981	11/17/2015	44	79	53	11,880
S021335001	Church of God	11/1/1976	4/4/2021	33	55	42	13,958
S021516001	G E Poucher	1/20/1961	12/4/2017	44	80	54	500
301909082490985	Local No. 019-249-1	1/1/1961	8/17/1994	46	75	56	250
302323082493501	A C Hogan Well	10/1/1967	5/10/1990	46	65	52	39
302835082545301	FFS Well S of Jasper	10/1/1967	5/8/1990	40	58	46	32
N011405010	Jasper Upper Floridan Aquifer H-0079	6/26/2013	4/11/2021	21	56	44	2,878
N011610001	Bay Creek Upper Floridan	8/1/1976	4/10/2021	42	70	52	3,251
N011610002	Bay Creek Intermediate	6/17/2013	4/10/2021	101	111	106	2,883
N011610003	Bay Creek Lower Floridan	6/17/2013	4/10/2021	47	67	52	2,797
N021013001	Westwood West	12/8/2011	4/10/2021	55	84	60	2,762
N021713002	Sandlin Bay Surficial	5/26/2005	4/11/2021	107	116	114	2,678
S021430004	SRWMD Office	12/30/1988	4/12/2021	9	56	47	3,458
302642083065201	Walter Phillips near Ft. Union	11/15/1976	5/10/1990	29	50	34	19
303805083164301	19D044	5/21/1974	5/26/2010	57	68	61	19
304136083095901	20D018	5/21/1974	5/20/2010	59	83	73	19
304150083015802	21D028	5/25/2010	5/25/2010	51	51	51	1
304447083112701	20D051	5/26/2010	5/26/2010	77	77	77	1
304610083000502	21E012	1/25/2002	5/25/2010	55	57	56	2
304610083000501	21E007	6/10/2009	6/10/2009	51	51	51	1
N011405005	Jasper Lower Floridan H-0078	6/20/2013	4/22/2021	33	63	43	2,881

QA/QC Documentation Steps & Notes

Data that was loaded into the database for use was critically examined through an extensive quality assurance/ quality control (QA/QC) process. The following methodology was employed to QA/QC the data:

- Data was imported into the Alapaha Access database from the USGS and SRWMD data portals using station IDs extracted from GIS files and provided by the District.
- Well time series levels equal to 0 were replaced with -9999, a flag indicating no data, in the database for quality codes with missing or bad data (**Table 16**). The time series for flow stations did not have missing or bad quality codes with 0 values.
- Downloaded data from the USGS and SRWMD databases was compared to data files received from the District (HYCSV and HYEXTR files).
    - That the District and USGS data files contained overlapping dates with different discharge values for several stream gauge stations (**Table 17**). For all but one of these stations, the District data is marked ‘USGS Provisional,’ while USGS data is marked ‘Approved.’ For these stations, USGS ‘Approved’ data was included in the Access database instead of the District data.
        - Conversely, District data marked ‘USGS Provisional’ was included in the Access database when USGS data files had excluded select dates and discharge values.
    - Stream gauge station at Withlacoochee River near Madison, FL (**Table 17**) has different discharge values between the District data and USGS data, yet both are marked ‘USGS Approved.’ Additionally, the District data are missing some discharge values that are included in the USGS database. Hydrographs for the USGS and District data are plotted below (**Figure 10**), as well as the difference between the two discharge values. For this station, USGS data was included in the Access database instead of the District data.
    - At times, District files had contained USGS data on random dates when compared to USGS data files.
    - For dates with both daily discharge and measured discharge, daily discharge was entered into the Access database flow station time series. Where daily discharge was missing, measured discharge values were included in the Access database.
- Blank discharge values for USGS stream gauge at Falmouth Spring Florida were replaced with -9999 to denote missing data.
- An internal station ID number was assigned to each data set in the database for efficiency during database processing. Station IDs were numbered so that stream gauges and wells were grouped sequentially to be easily read by the Python plotting scripts as follows:
    - Stream Gauge IDs <= 18 And > 56
    - Well IDs > 18 And <= 56

- Empty gauge height values were replaced for flow station at Occidental Pond North CSA Outfall near White Springs Florida with -9999 to denote missing data.
    - Repeated for flow stations at springs.
- Replaced -9999 level missing values for wells in the stage time series table so plots with data can be read for several stations.
    - Four USGS stations contain only 1 to 2 data points but are included in database.
- Converted datum elevations in NGVD29 to NAVD88 so that all stages and water levels can displayed in a consistent datum, NAVD88, for ease of comparison.

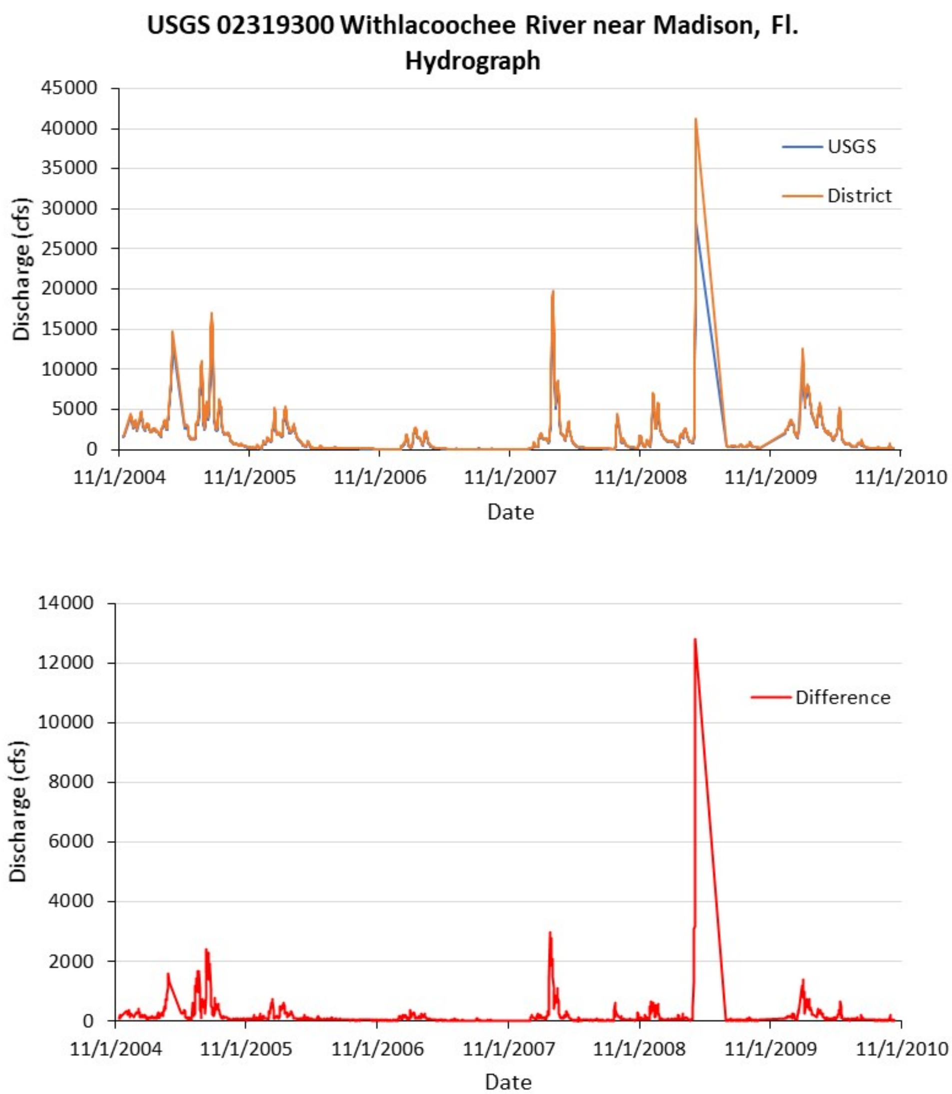

Figure 10. Hydrograph for USGS 02319300 Stream Gauge using discharge values from the USGS database and district files (top). The difference between USGS and district discharge is represented in its own hydrograph (bottom).

Table 16. Count of Well level values equal to 0 with respective quality codes in the Access database prior to update.

Station ID	Level (ft)	Station Name	Count of Level (ft)	QualCode
N021713001	0	Sandlin Bay Floridan	562	Missing Data
N011117015	0	Nestle FSC - 1	3661	Missing Data
N021332004	0	Alapaha Tower	237	Missing Data
S011535004	0	Bullock Tower	2	Erroneous data
S011535004	0	Bullock Tower	446	Missing Data
N011714002	0	Old Benton Tower	335	Missing Data
S011420001	0	FL Board of Conservation	5	Missing Data
N011316001	0	Carl Ivey Carter aka Adams Farm	704	Missing Data
N011422007	0	Pete Deas	828	Missing Data
N021125001	0	Santa Deas	13	Float tape malfunction (off wheel, mud dauber, etc.)
N021125001	0	Santa Deas	1383	Missing Data
S011232006	0	Falmouth	656	Missing Data
S011534001	0	Hilward Morgan	722	Missing Data
S021335001	0	Church of God	73	Bad Data from logger
S021335001	0	Church of God	995	Missing Data
S021516001	0	G E Poucher	1	Erroneous data
N011405010	0	Jasper Upper Floridan Aquifer H-0079	1	Missing Data
N011610001	0	Bay Creek Upper Floridan	5	Missing Data
N011610002	0	Bay Creek Intermediate	1	Missing Data
N011610003	0	Bay Creek Lower Floridan	86	Missing Data
N021013001	0	Westwood West	547	Missing Data
N021713002	0	Sandlin Bay Surficial	566	Missing Data
S021430004	0	SRWMD Office	27	Missing Data
N011405005	0	Jasper Lower Floridan H-0078	19	Missing Data

Table 17. Differences between USGS and SRWMD discharge for stations with overlapping data.

Station Name	Station ID	SRWMD Quality Code	USGS Quality Code	Count of different discharge values	Date Range	Range of USGS - SRWMD discharge differences
Alapaha River near Jennings, Fl.	02317620	USGS Provisional	USGS Approved	150	2009 - 2011	-40 - 5.3
Withlacoochee River near Lee, Fl.	02319394	USGS Provisional	USGS Approved	347	2009 - 2010	-1140 - 2
Withlacoochee River near Pinetta, Fl.	02319000	USGS Provisional	USGS Approved	499	2009 - 2011	-67 - 90
Alapaha River at Statenville, Ga.	02317500	USGS Provisional	USGS Approved	377	2009 - 2011	-10 - 91
Withlacoochee River near Madison, Fl.	02319300	USGS Approved	USGS Approved	1915	2004 - 2010	-12800 - 98
Withlacoochee River at US 84, near Quitman, Ga.	02318500	USGS Provisional	USGS Approved	427	2009 - 2011	-310 - 170

Alapaha Rise Flow Data Analysis

The collected data was analyzed for spatial and temporal relationships along the sink-rise system. Data from USGS stations at Alapaha River near Jennings (above the swallets), Alapaha River near Jasper (below the swallets), Alapaha Rise near Fort Union (at the resurgence), and the closest downstream Suwannee station were compared. **Figure 11** displays discharge at the four stations in the top panel, as well as stage at the Suwannee at Ellaville station in the bottom panel. This plot displays data for their entire periods of record.

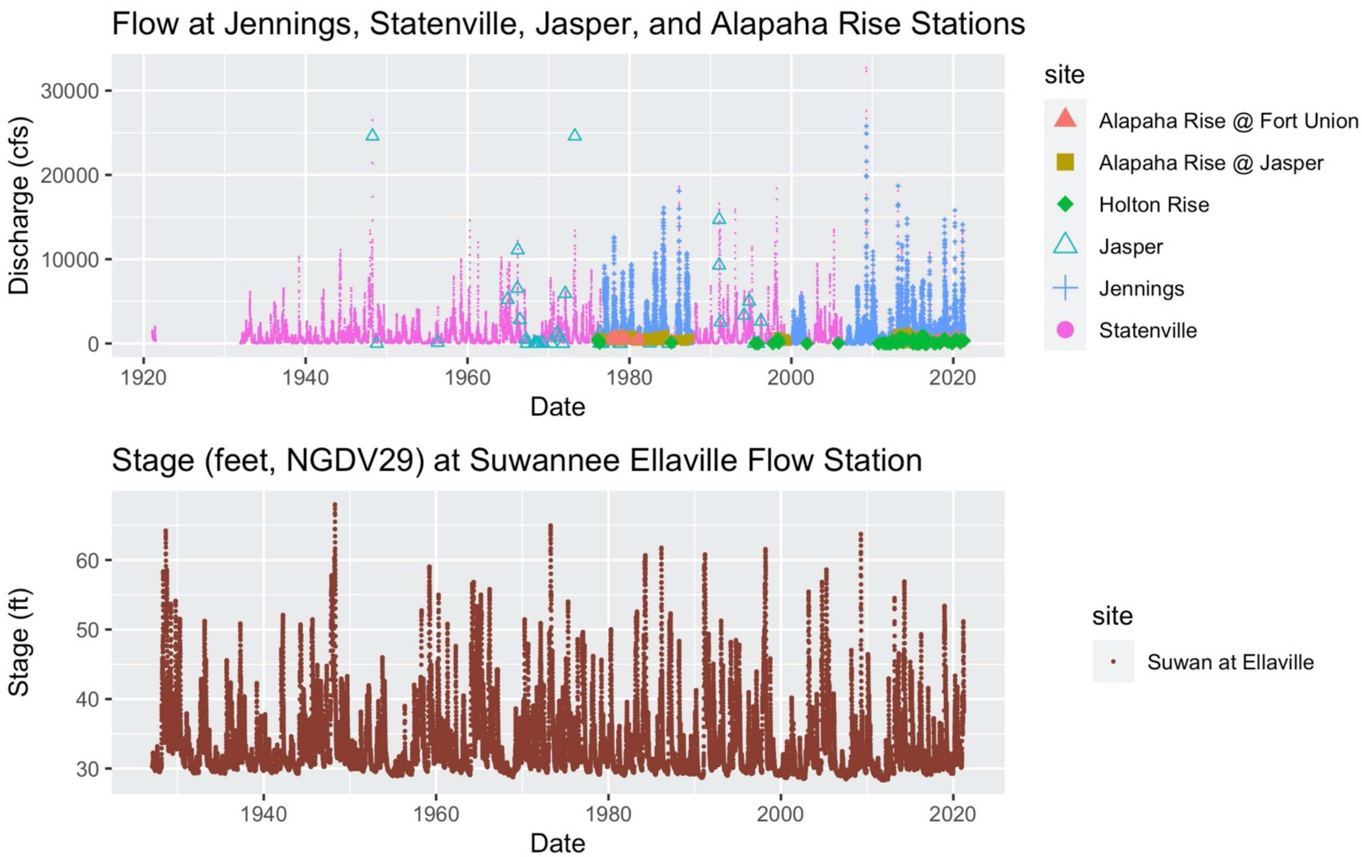

Figure 11. Discharge from Fort Union, Jasper, Jennings, and Suwannee at Ellaville Flow Stations, and Stage from Suwannee at Ellaville Flow Station, for Entire Periods of Record.

Figure 12 displays the same information, but for the period of record for which there is data for all flow stations (07/01/1975 - 09/01/1985). Additionally, the discharge data was log-transformed. This allows for closer examination of overlapping records.

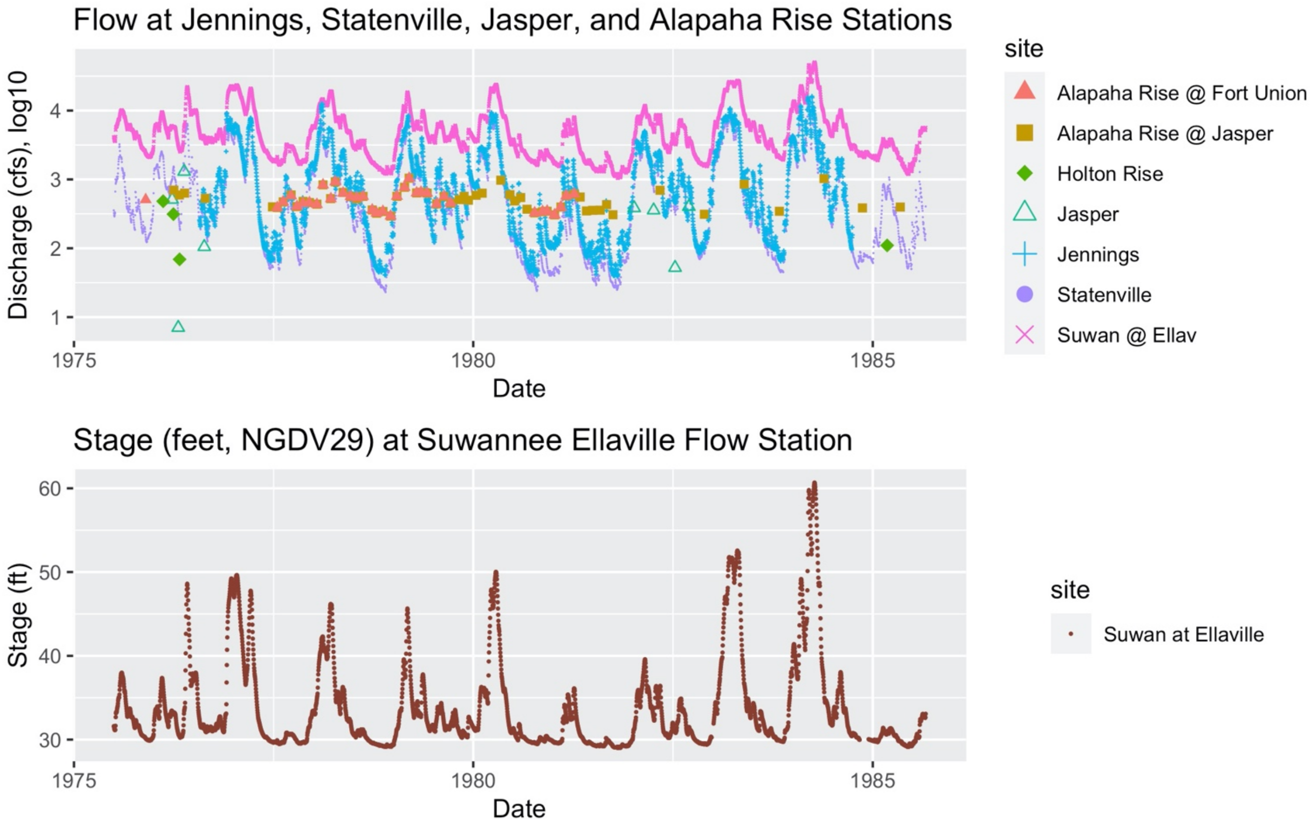

Figure 12. Discharge (log10) from Fort Union, Jasper, Jennings, and Suwannee at Ellaville Flow Stations, and Stage from Suwannee at Ellaville Flow Station, for Fort Union Period of Record (11/25/1975 - 03/08/1985).

Figure 13 summaries the available periods of records for all flow stations. “NA Recorded” indicates a date which was included in the timeseries of data that was obtained, but with no corresponding data values.

Figure 13: Data Availability for All Flow Stations.

The Statenville flow station is upstream of the Alapaha and has a complete period of record from 1932 to 2020. This station was used to build a linear model of the Jennings flow time series. This was done using the "lm" function in R. The linear model showed good fit, with a robust dataset available to develop the relationship. **Figure 14** shows the linear regression between the Statenville and Jennings flow stations, as well as the 99% confidence band. The 99% confidence band interval is hardly visible, indicating a good fit between the modeled relationship and the observations.

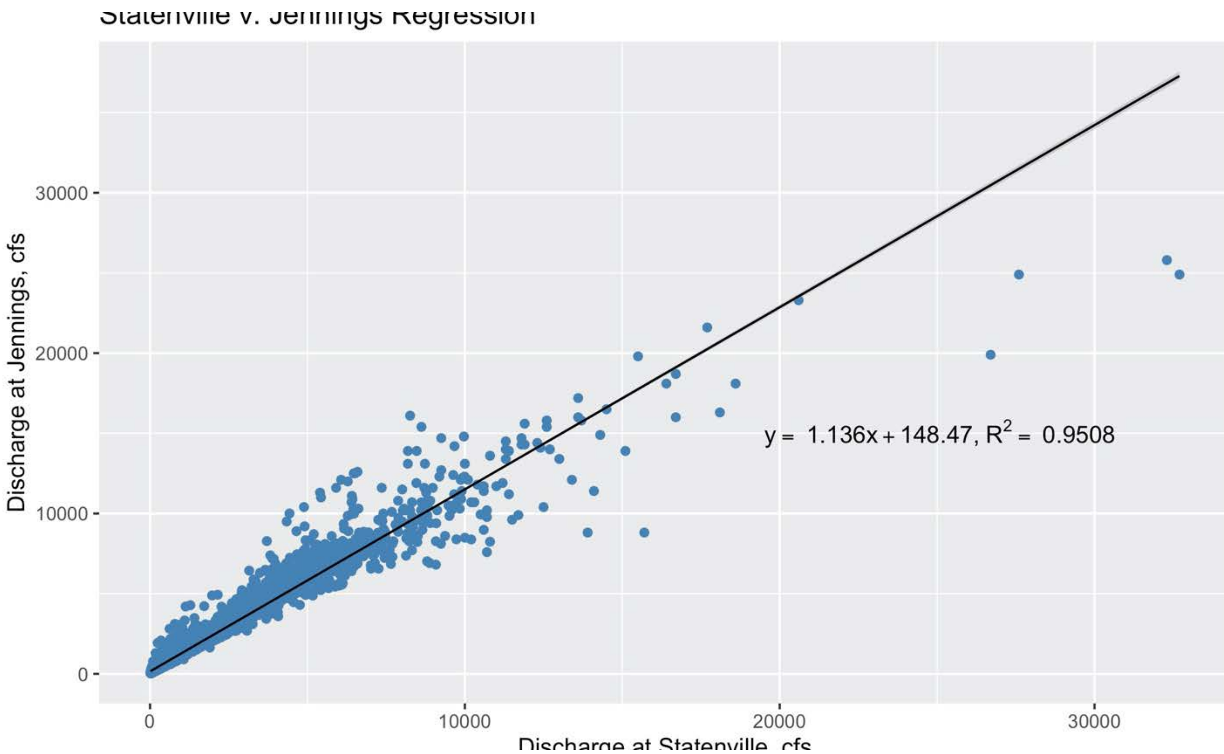

Figure 14: Linear model between the Statenville and Jennings flow stations.

The equation displayed in **Figure 14** was used to calculate flows at the Jennings flow station for the entire timeseries of the Statenville flow station, from 02/05/1921 until 04/04/2021. The predicted and observed Jennings timeseries is shown in **Figure 15**.

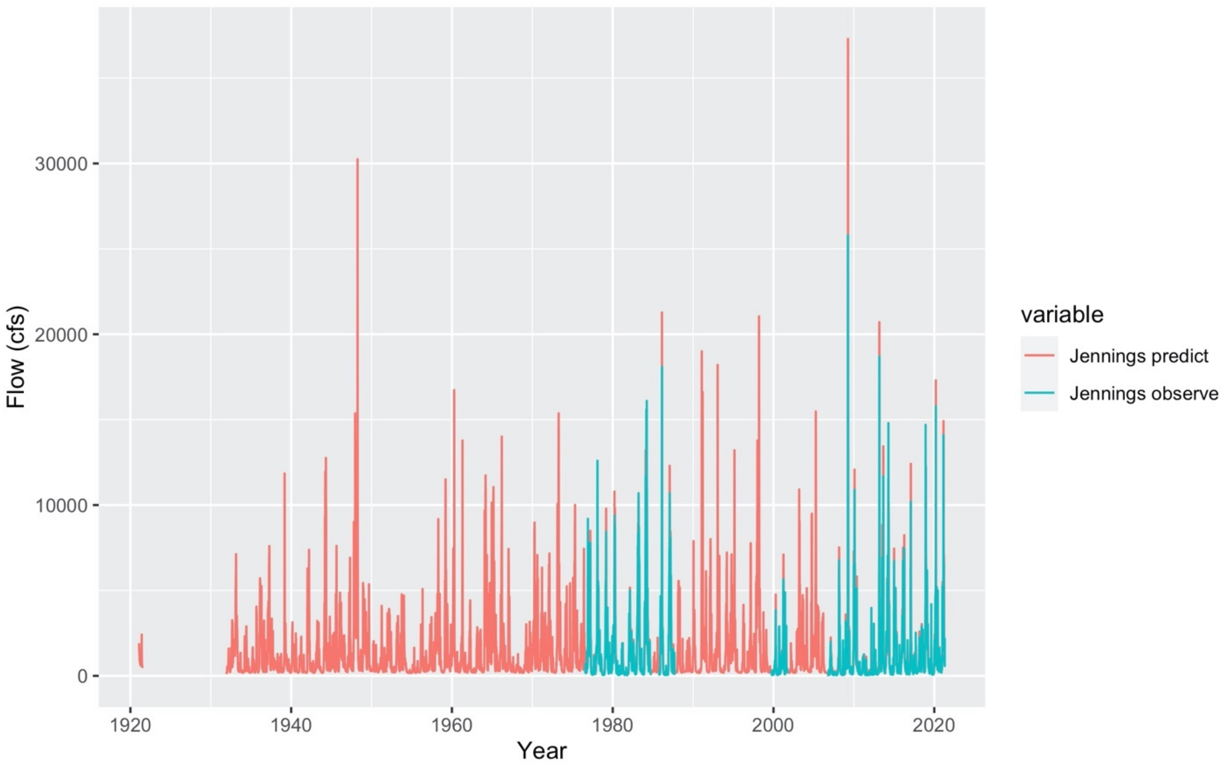

Figure 15: Predicted and Observed Flows at the Jennings Flow Station Using the Statenville-Jennings Linear Model.

Next, the predicted Jennings timeseries was used to investigate the relationship between the Jennings and Jasper flow stations. Because there were only 43 observations from the Jasper flow station, using the predicted Jennings time series is advantageous over the observed Jennings time series because it results in more overlapping dates with which to develop a linear model.

Figure 16 displays the relationship between the predicted Jennings flows and the observed Jasper flows. The regression equation is also displayed on the graph. Although the R^2 indicates a good fit, it is clear that the observations at Jasper are biased towards low flows. The slope value of 0.9 means that the model is predicting 90% of Jennings flows to be present as overland flow at the Jasper station, with only 10% being routed to the underground conduits. The model is likely predicting this because of the lack of data, particularly high flow data. As seen in the figure, the majority of datapoints are low flow points, therefore instilling a low flow bias in the model.

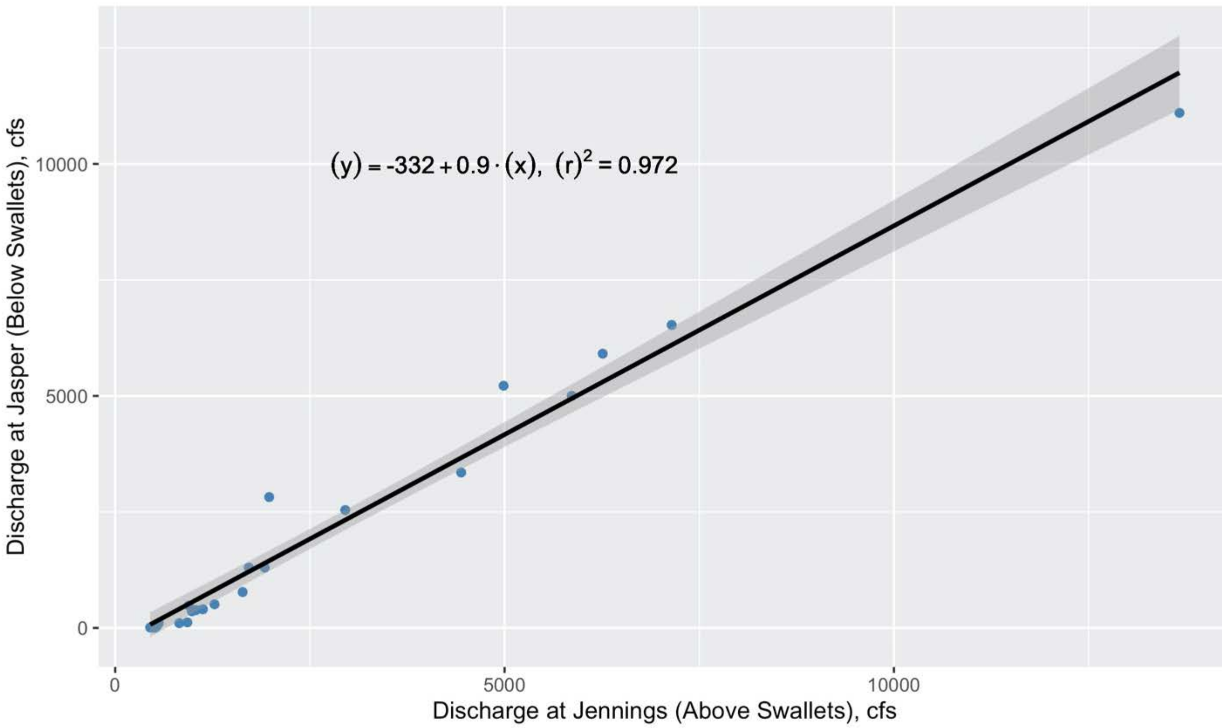

Figure 16: Regression Equations Between Modeled Jennings Flow and Observed Jasper Flows, with 95% Confidence Intervals.

Figure 17 shows the relationship between modeled discharge at the Jennings flow station above the swallets, and discharge at the Alapaha Rise near Fort Union flow station at the resurgence. This figure shows that there is a linear relationship between flow in the Alapaha above the swallets and flow at the resurgence when flow at Jennings is low. However, when flow is high, the relationship is lost. This relationship was also found in Upchurch (2014). Though there is some scatter, the relationship seen in Upchurch (2014) is generally preserved.

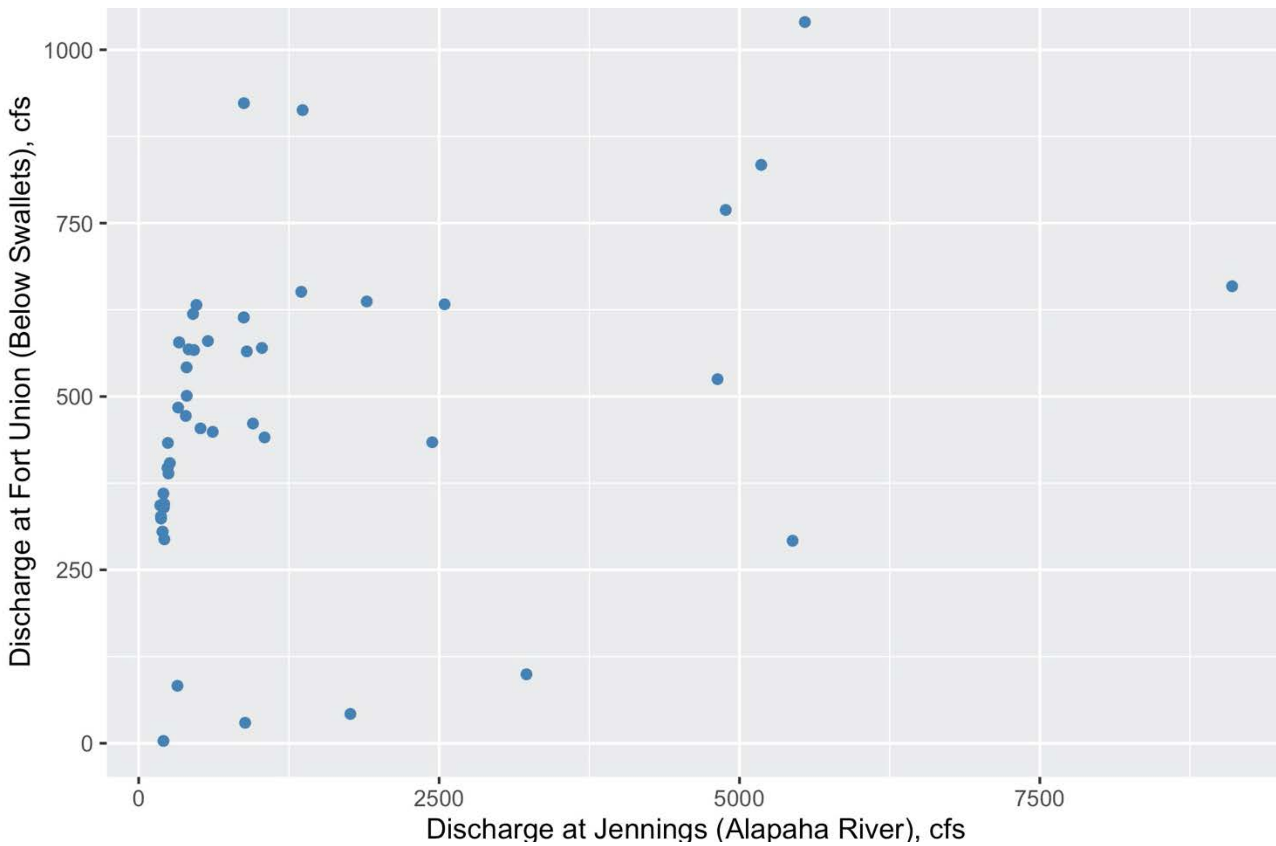

Figure 17. Modeled Discharge at Jennings Compared to Observed Discharge at Fort Union at the Resurgence.

Figure 18 displays the relationship upstream of the swallets at the Jennings station, and flow downstream of the swallets at the Jasper station. Modeled Jennings flows were used to for this analysis, in accordance with the Upchurch (2014) analysis. When flow is low in Jennings, there is no flow below the swallets. Upchurch (2014) notes that when flow at Jennings is below 300 cubic feet per second (cfs), flow at Jasper is minimal. The analysis below displays a similar trend, using observed discharge data at Jennings instead of modeled data. **Figure 18** shows the same data as **Figure 16**, but with log-log axes. All observed flows at Jennings below 300 cfs correspond to no flow at the Jasper station. There are only 23 overlapping data points when using the modeled Jennings flows, and only 8 overlapping dates of actual observed (not modeled) data. Therefore, it is difficult to conclude the flow at Jennings at which there is no overland flow at Jasper.

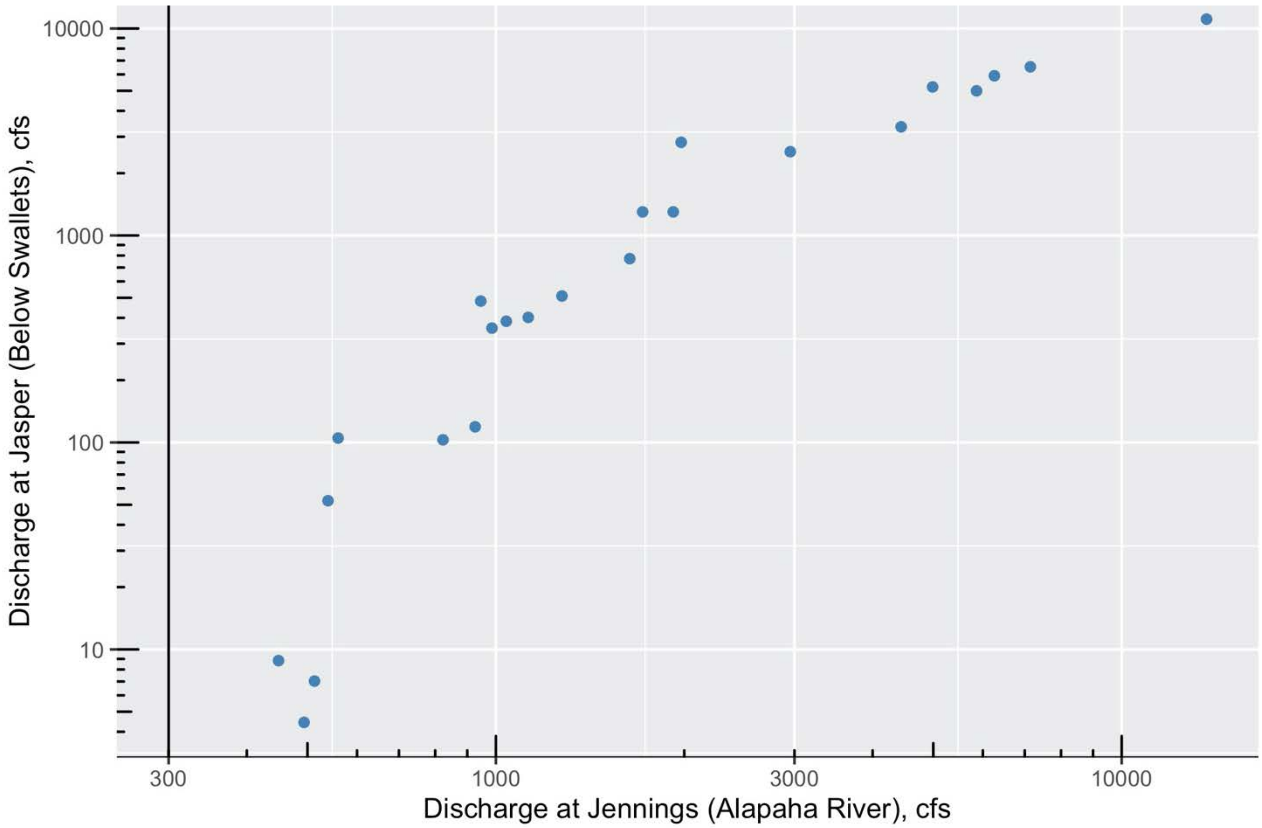

Figure 18. Modeled Discharge at Jennings Compared to Observed Discharge at Jasper Below the Swallets.

Next, the relationship between observed discharge at Jasper and observed discharge at Jennings is examined in order to determine a mathematical relationship between upstream flow and overland flow below the swallets. For this analysis, overlapping dates with no flow were removed (**Figure 19B**), resulting in 5 plotted data pairs. Additionally, the modeled discharge at Jennings and observed discharge at Jasper are used to develop a second linear regression. The linear regression displayed in Upchurch (2014) was recreated to assess the ability to obtain the same relationship using observed data instead of modeled data. **Figure 19** shows the linear regressions of observed values and modeled values at Jennings, compared to the linear regression from Upchurch (2014).

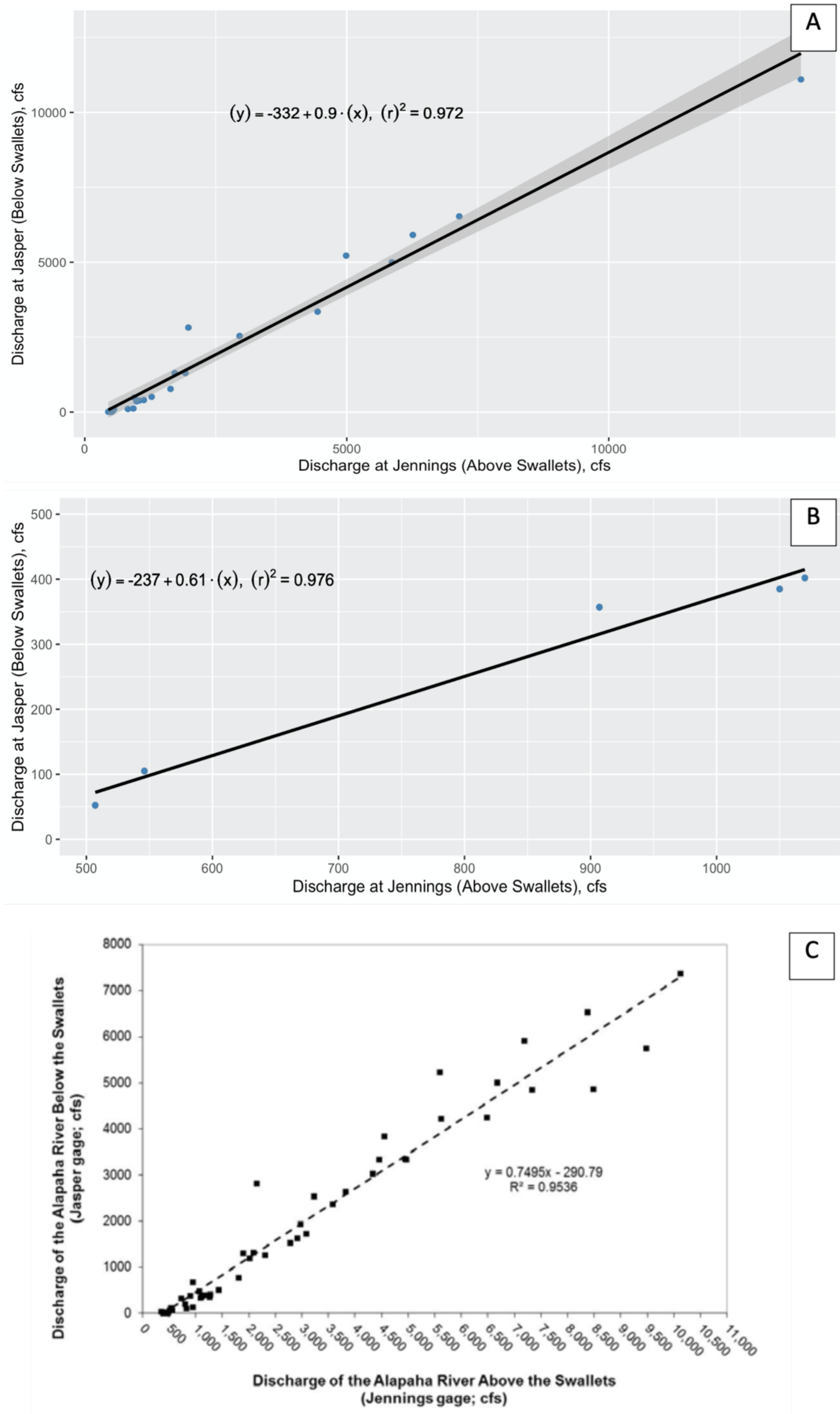

Figure 19. Comparison of INTERA Linear Regression between Modeled Jennings and Observed Jasper (Panel A), Observed Jennings and Observed Jasper (Panel B), and Upchurch Linear Regression between Jennings and Jasper (Panel C).

In **Figure 20**, the regression equations display similar slopes, within 14% of each other. Discrepancies between the equations are a result of the differences in the data used to calculate the regressions. In **Table 18**, the regression equations from the new analysis presented here is compared to the Unchurch (2014) analysis. The calculated x-intercept indicate the flow at Jennings at which there is no overland flow at Jasper. The analysis on observed Jennings values and the Upchurch (2014) analysis are within 1 cfs of each other, indicating good agreement between the two equations. However, the analysis on predicted Jennings values resulted in a nearly 20-cfs discrepancy with the Upchurch (2014) values. It is likely that this discrepancy is a result of model error. Because predicted values were used to develop the Upchurch (2014) regression and the INTERA Analysis on Predicted Values, both models contain propagated model error from the predicted Jennings values. The exact regression equation and data products used in the Upchurch (2014) analysis were not provided, therefore the analysis could not be exactly replicated. The discrepancies between the two are likely a result of differences in model construction, model inputs, and propagated model error.

Table 18. Comparison of Regression Equations and Calculated X Intercepts.

Source	Equation	X Intercept
Upchurch Analysis (2014) on Modeled and Observed Jennings Values	y= 0.7495x - 290.79	387.97
INTERA Analysis on Observed Jennings Values	y=0.61x - 237	388.52
INTERA Analysis on Modeled and Observed Jennings Values	y= 0.9x - 332	368.89

When the equations from **Table 18** are plotted together (**Figure 20**), it is apparent that at high flows the equations result in divergent estimates. The Upchurch (2014) analysis is intermediate between the INTERA analyses with either observed or modeled Jennings flows.

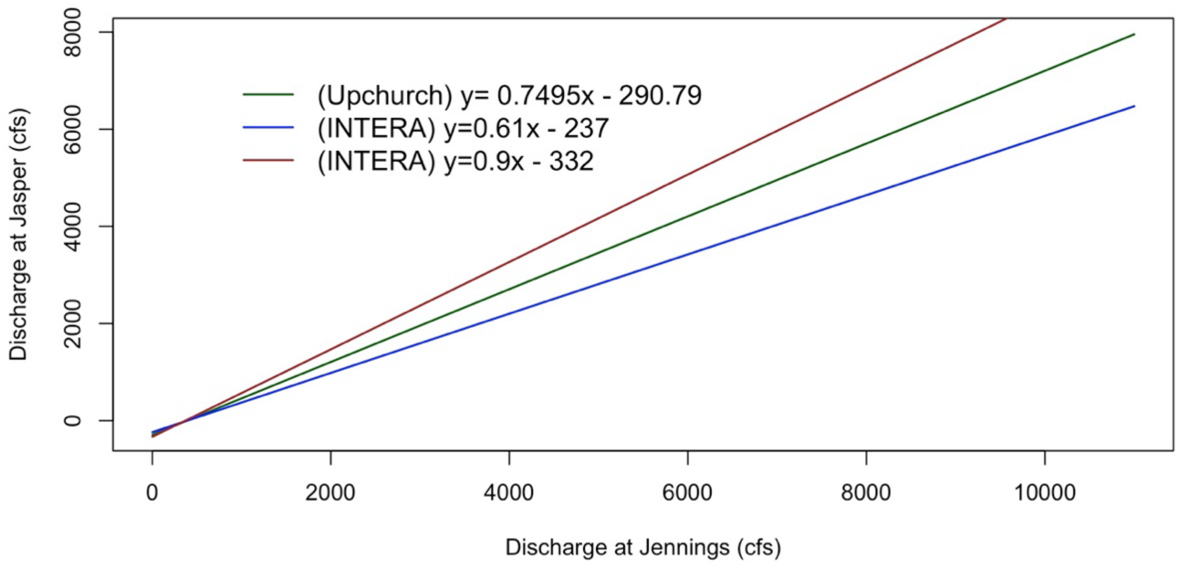

Figure 20. Comparisons of Regression Equations from 0 to 11,000 cfs.

The observed flows at Jasper were compared to the regression equations above in **Figure 20**. This highlights the relationship between the observed Jasper flows and the linear equations, and elucidates any flow regimes that are present in the system. The Upchurch model also used a hybrid of observed and modeled data from Jennings. The observed flow values at Jasper that overlap with observed or modeled flows at Jennings were compared to each regression equation, displayed in **Figure 21**.

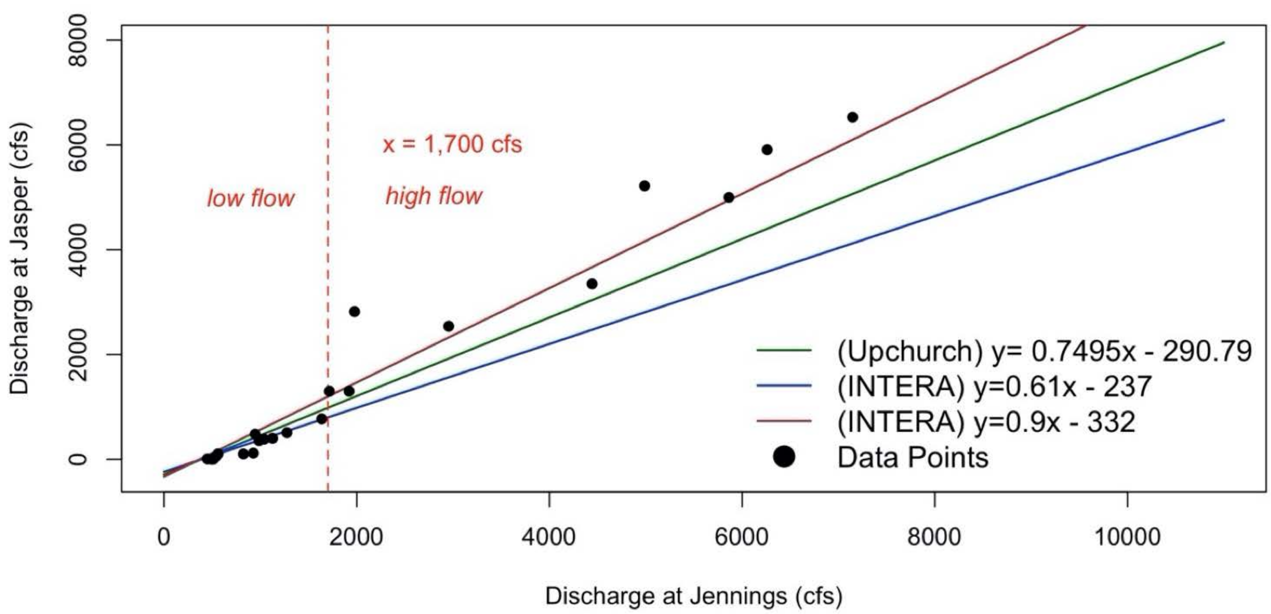

Figure 21: Jasper Observation Data Compared to Jennings-Jasper Regression Equations.

Figure 21 shows two clear flow regimes occurring between the Jennings and Jasper flow stations. When flows at Jennings are above approximately 1,700 cfs, flows from Jasper generally follow the red regression line (*y = 0.9x – 332*). When flows at Jennings are below 1,700 cfs, flows from Jasper follow the blue regression line (*y=0.61x – 237*). **Figure 22**, below, focuses on the low flow instances to highlight the change in flow regime at approximately 1,700 cfs.

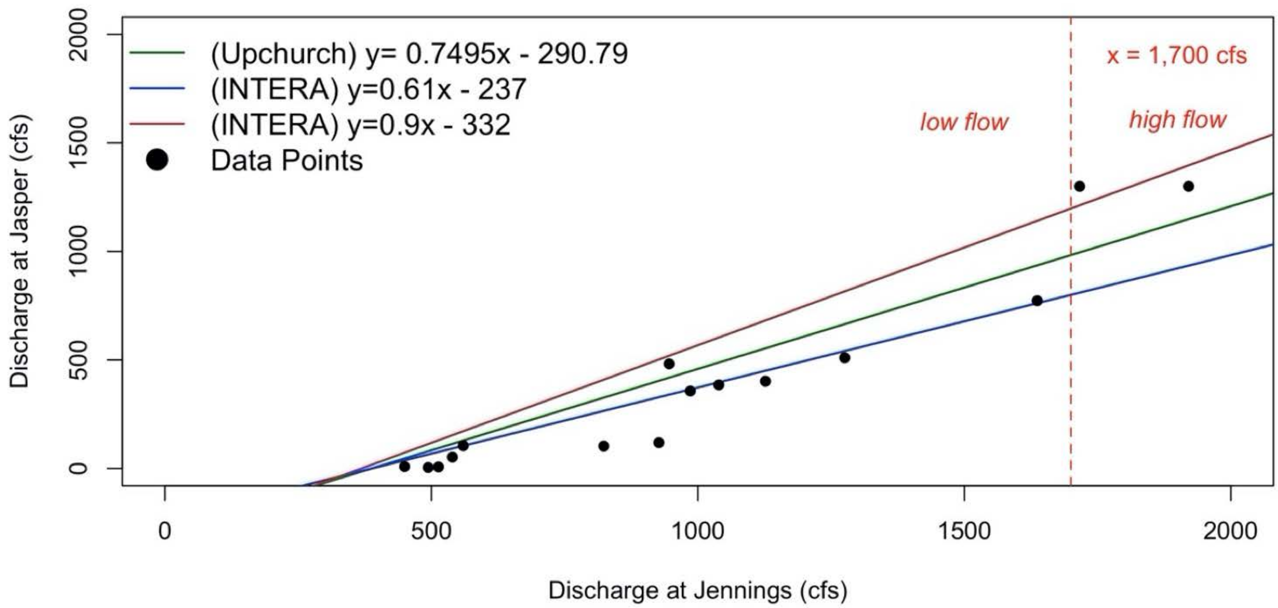

Figure 22: Jasper Observation Data Compared to Jennings-Jasper Regression Equations.

These relationships were used to reconstruct the Jasper timeseries. The gap-filled Jennings timeseries (**Figure 23)** was used to calculate the Jasper flows based on the magnitude of flow as Jennings. Three flow regimes were use, outlined in **Table 19**:

Table 19: Jennings Flow Conditions and Corresponding Jasper Equations.

Jennings Flow Conditions	Equation to Calculate Jasper Flow
< 385 cfs	0
385 – 1,700 cfs	y=0.61x – 237
>1,700 cfs	y = 0.9x – 332

Using the equations above in **Table 19**, the Jasper time series was reconstructed for the entire period of record for the Statenville stations. This allows for comparison against all available observed Alapaha Rise discharge data (**Figure 23**).

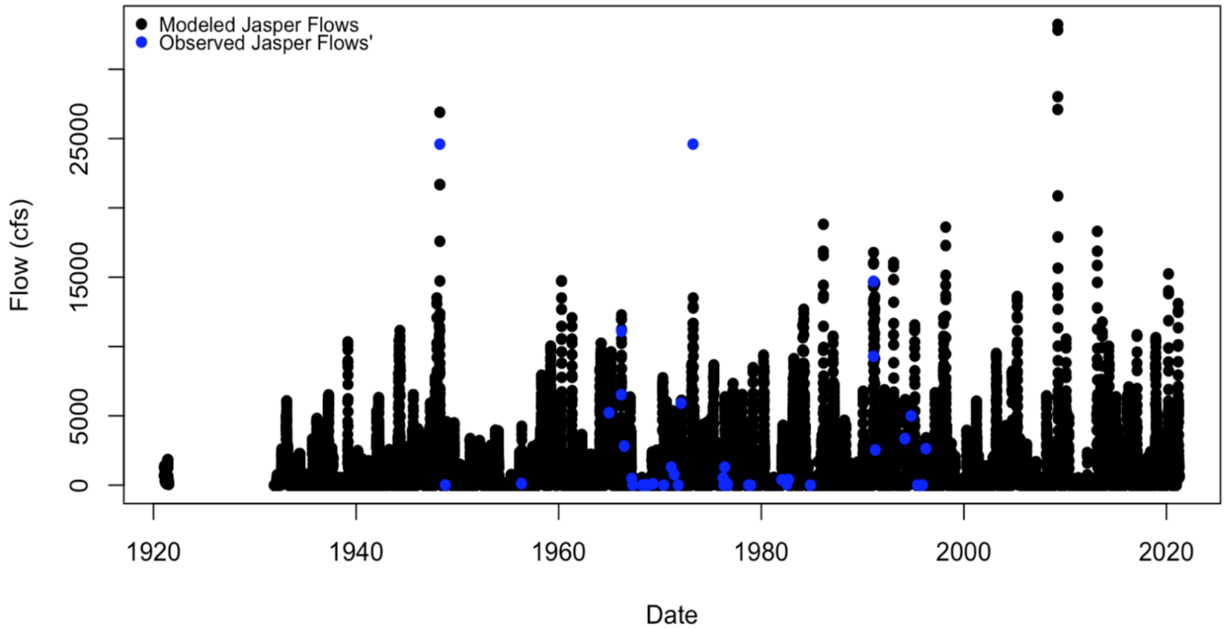

Figure 23: Reconstructed Timeseries for Jasper Flow Station.

The reconstructed Jasper time series was then used to calculate the amount of water entering the conduits at the swallets. The difference between the Jennings and Jasper timeseries was taken, effectively estimating the Dead River flow.

The 15-day rolling average was calculated for flow in the Dead River and flow at the Alapaha Rise at Jasper. This was used to dampen any noise in the data and include the effect of travel time in the conduits. **Figure 24** displays the modeled Dead River flows compared to the Alapaha Rise at Jasper.

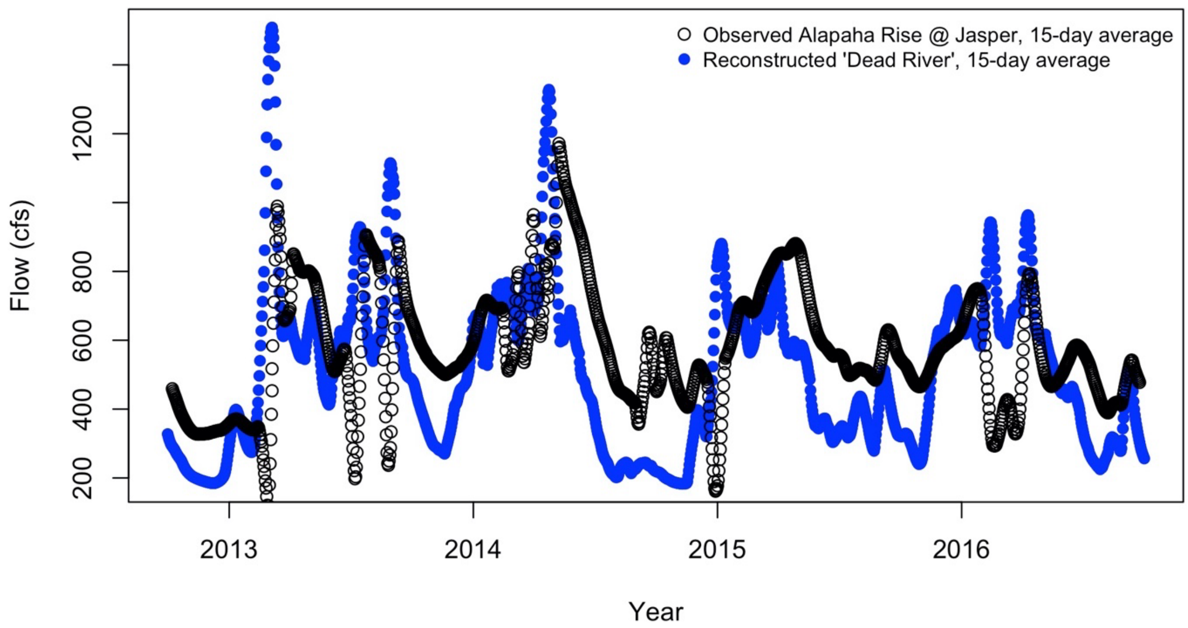

Figure 24: 15-day Average Modeled Dead River Flows and 15-day Average Observed Alapaha Rise Discharge.

The Dead River flows were calculated for the entire period of the reconstructed Jasper and Jennings flow stations. **Figure 25** displays a portion of that record, from 2010 through 2020, to display the relationship between the stations above the swallets, below the swallets, and the resurgences.

Figure 25: Reconstructed Discharge for Flow Stations Above and Below Swallets, and Reconstructed Dead River Flows. 2010 - 2020. Data Displayed in Log Scale.

Next, the modeled flows in the Alapaha Rise and Dead River were compared in a scatter plot to see if a regression could be developed. **Figure 26** displays the flow relationship between the Dead River and the Alapaha Rise.

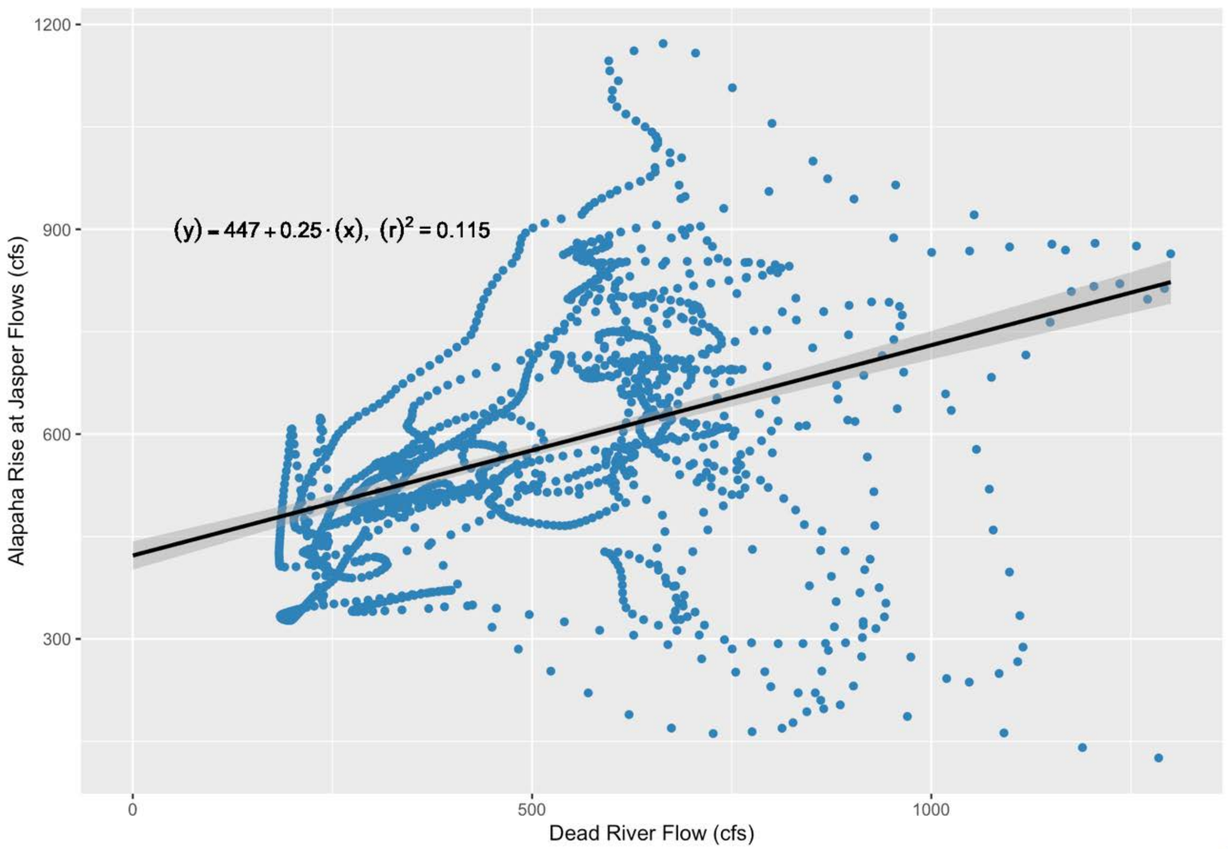

Figure 26: Relationship Between the Modeled Dead River Flows and Observed Alapaha Rise Flows Using a 15-Day Rolling Average.

Figure 26 highlights the effect of inundation from the Suwannee River. Because the springs of the Alapaha Rise are on the banks of the Suwannee, the flows are influenced by bank storage. This creates the hysteresis loops present in **Figure 26**. This indicates that there are many factors contributing to discharge rates at the Alapaha Rise. Hysteresis is seen across all flow rates, indicating that there are additional factors contributing to the discharge at any stage. The slope of the relationship indicates the factor to calculate pickup at the Rise. Extensive noise in this relationship is due to lag, bank storage, hysteresis, measurement error, and accumulated model errors etc. Despite the noise in the relationship, the loss to Holton Creek and gain in groundwater flows is visible, albeit not accurate.

Analysis Summary

Regressions were developed between the Statenville station and Jennings station, and between the Jennings station and the Jasper station. This allows the periods of record for the Jennings and Jasper flow station to modeled for the entire period of record of the Statenville station. The Dead River flow was then estimated by taking the difference between the modeled Jennings and modeled Jasper flows. Although the reconstructed Jennings and Jasper flows contain decent confidence, estimating the flows to the Dead River prove more difficult. There are no observations of flow in the swallets to compare the estimations. Additionally, flows observed at the Alapaha Rise are a result of many more factors in addition to the Dead River. Therefore, containing the portion of Alapaha Rise flows attributed to groundwater inflow from the Dead River is uncertain. The relationship between the Dead River and the Alapaha Rise displays hysteresis loops, indicated inflow from the Suwannee River and bank storage.

The analysis indicates that additional data collection at the Jasper flow station (below the swallets) and at the Alapaha Rise is needed to develop a better model between flow through into the swallets. This would allow for a better understanding of surface water behavior between the swallets and the resurgence. There are only 15 days where there is available observed data at both the Jasper flow station and Jennings flow station. There are 57 days with available observed data at both the Fort Union (Alapaha Rise) flow station and Jennings flow station. There are 0 days over overlap between the Jasper flow station and Fort Union flow station observed records. This provides incomplete information to confidently estimate surface water flow duration, magnitude, and timing within the Alapaha between the swallets and the resurgence. Additionally, it is recommended that special attention be paid to data collection at Jasper and Alapaha Rise during high flow events. In **Figure 19B**, the only available observations at Jasper that overlap with Jennings observations are during relatively low-flow events, compared to **Figure 19C,** which has flows over 8,000 cfs at Jasper. Additional data collection below the swallets and at the Alapaha Rise on high flow days would improve the ability to decipher the behavior of overland flow along the Alapaha River Sink Rise system.

Holton Rise Conductivity Data Analysis

Conductivity data from the Alapaha Rise and Holton Creek Rise were provided from the District. The data was analyzed for relationships between specific conductivity at the rises and discharge upstream at Jennings flow station.

Figure 27 and **Figure 28** display the timeseries of conductivity at the Alapaha Rise and Holton Rise, respectively.

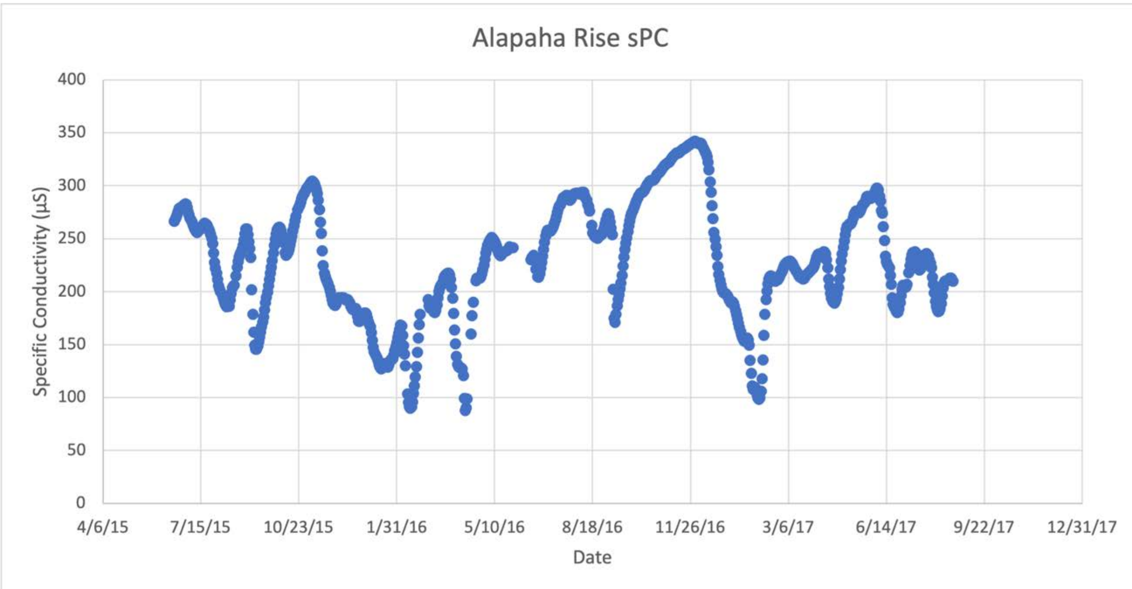

Figure 27. Timeseries of Specific Conductivity at Alapaha Rise.

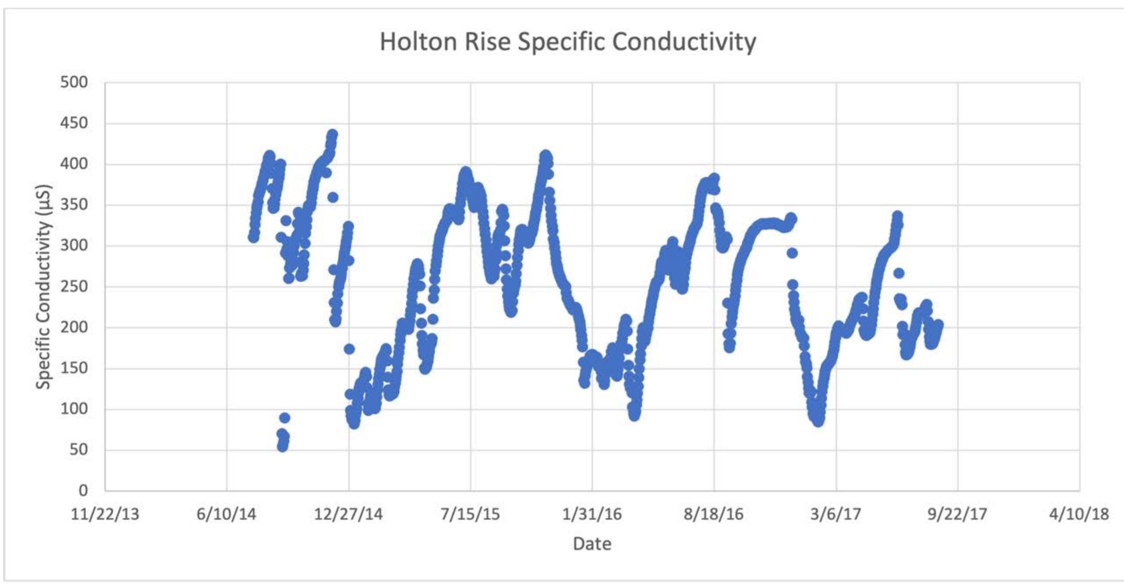

Figure 28. Timeseries of Specific Conductivity the Holton Rise.

The District provided an analysis of conductivity as a function of discharge at the Jennings flow station. Conductivity data from the Alapaha Rise were binned for three flow levels: flow at Jennings 5 days before is less than 400 cfs, between 400 and 1500 cfs, or above 1500 cfs. These categories were organized into histograms to examine their distributions. Holton Rise conductivity data were binned into the same categories, but for Jennings discharge 10 days prior. Below, the histograms for all flow conditions are displayed for Alapaha Rise and Holton Rise (**Figures 29** through **34**). The title of each histogram indicates the equation for the normal bell curve shown in red on each histogram. For example, the equation in **Figure 29** of 325*0.1*normal(x,0.2414, 0.119) indicates that the data distribution can be replicated using a normal distribution function x with a mean of 0.2414 and a standard deviation of 0.119. Distribution fitting to a normal distribution was executed within *Statistica* analysis software.

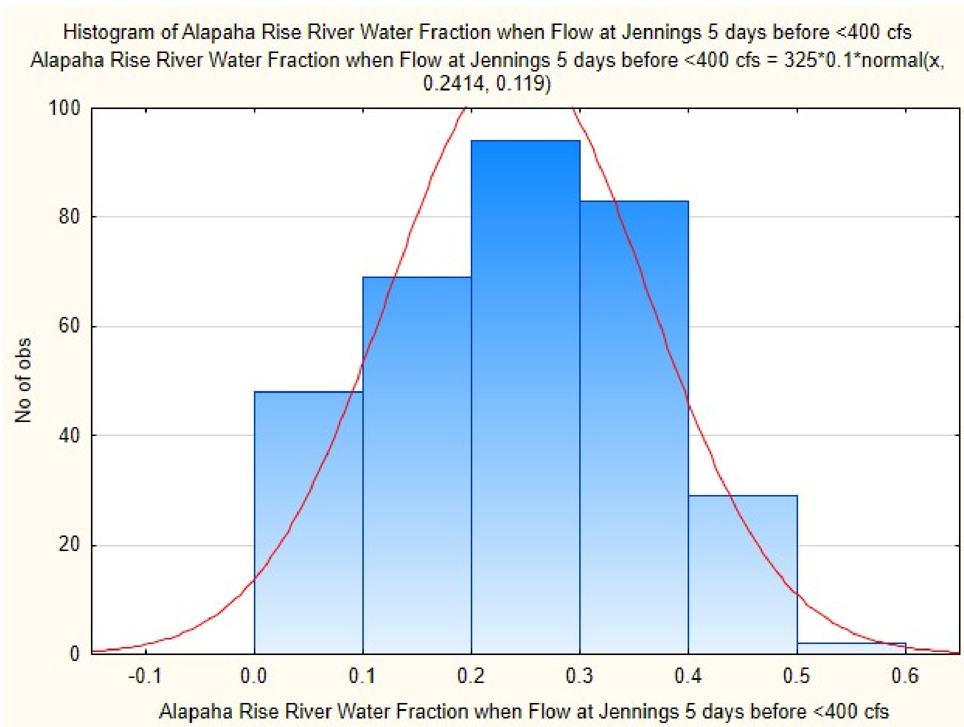

Figure 29. Histogram of River Water Fraction at Alapaha Rise when Flow at Jennings 5 days before is <400 cfs.

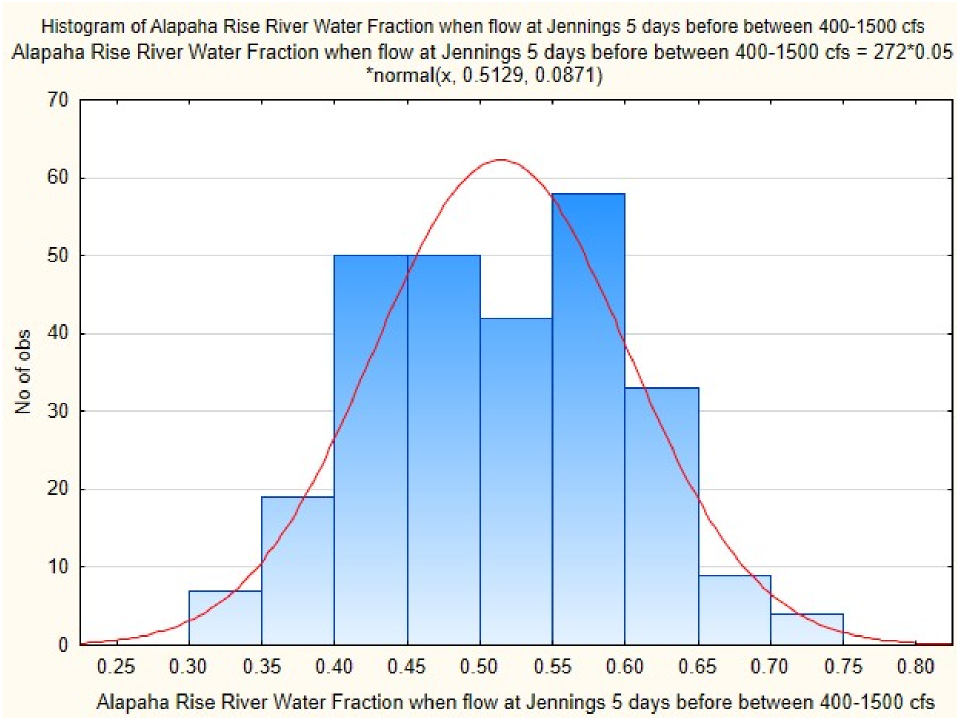

Figure 30. Histogram of River Water Fraction at Alapaha Rise when Flow at Jennings 5 days before is between 400 and 1,500 cfs.

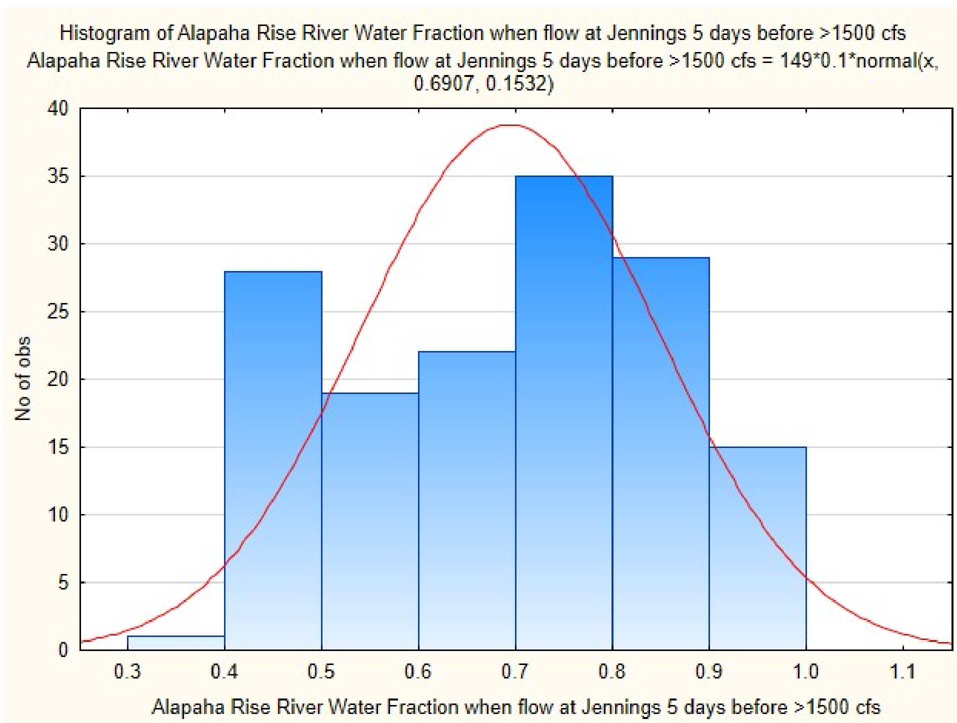

Figure 31. Histogram of River Water Fraction at Alapaha Rise when Flow at Jennings 5 days before is >1,500 cfs.

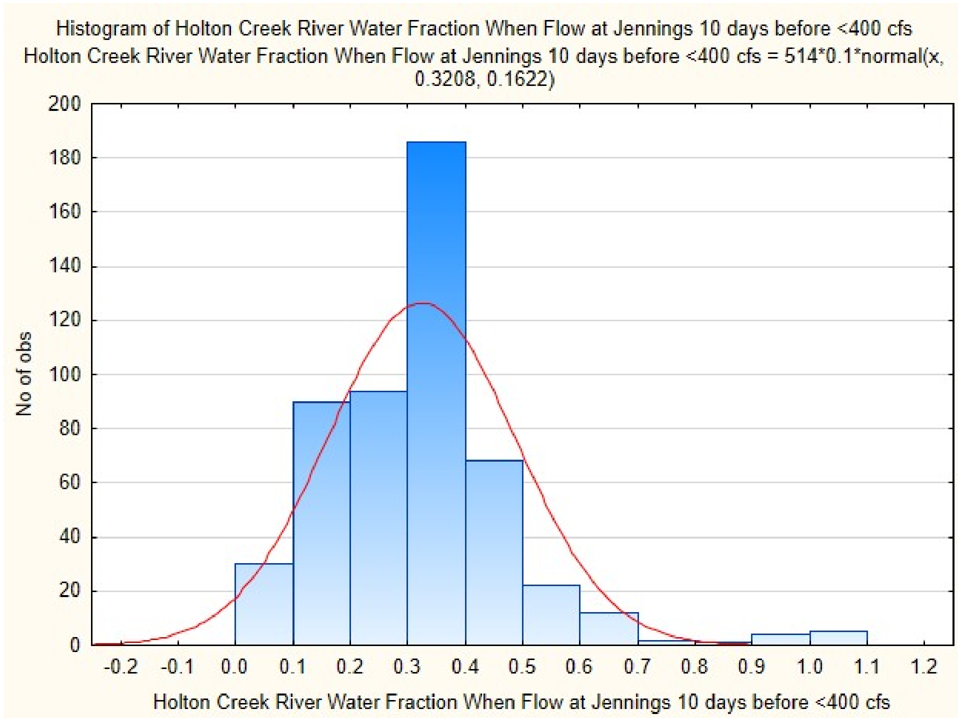

Figure 32. Histogram of River Water Fraction at Holton Rise when Flow at Jennings 5 days before is <400 cfs.

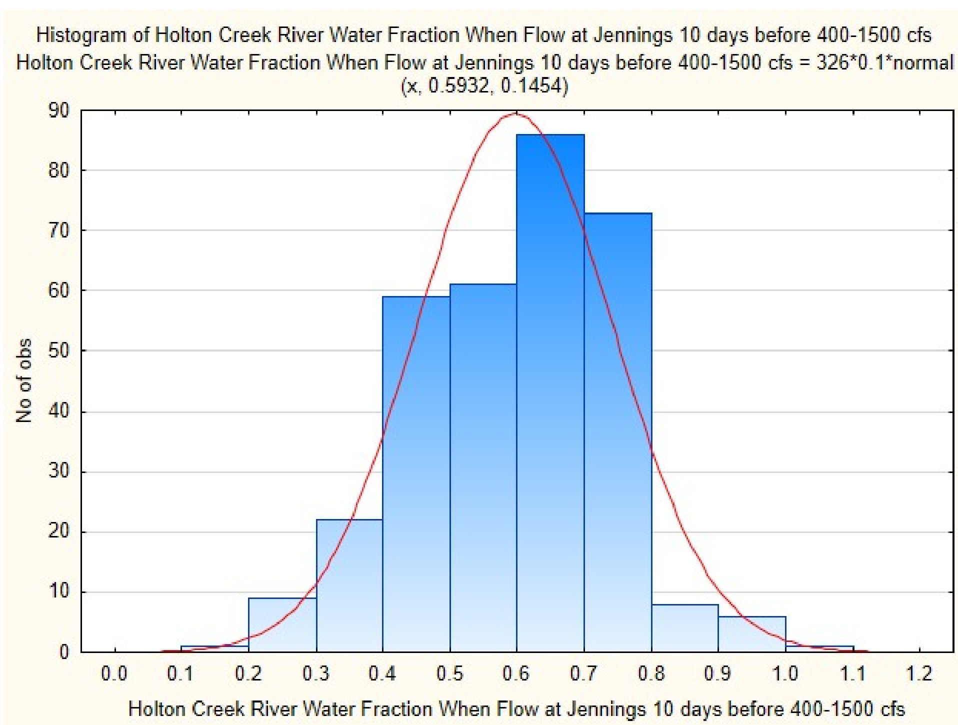

Figure 33. Histogram of River Water Fraction at Holton Rise when Flow at Jennings 5 days before is between 400 and 1,500 cfs.

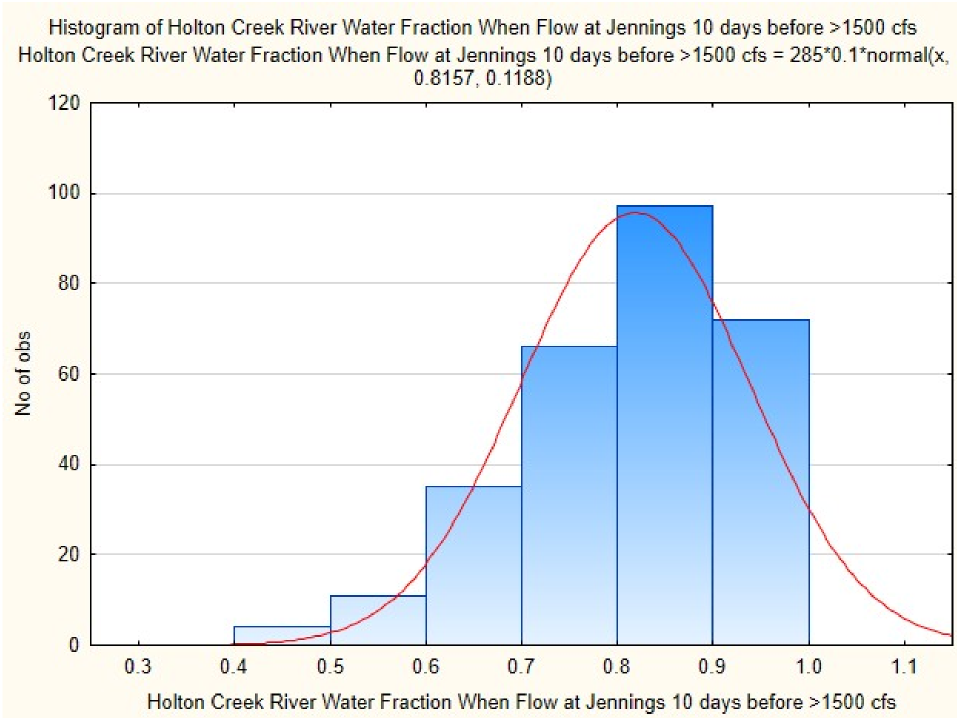

Figure 34. Histogram of River Water Fraction at Holton Rise when Flow at Jennings 5 days before is >1,500 cfs.

Table 20 summarizes the mean surface water fraction at Holton Rise and Alapaha Rise for each Jennings flow condition 5 days prior for the Alapaha Rise, and 10 days prior for the Holton Rise.

Table 20. Mean River Water Fractions at Alapaha Rise and Holton Rise based on Jennings Flow Conditions.

Flow Condition	Holton Rise River Water Fraction	Alapaha Rise River Water Fraction
< 400 cfs	0.3208	0.2414
400 – 1500 cfs	0.5931	0.5129
> 1500 cfs	0.8157	0.6907

The District provided an analysis of the conductivity at both rises in relation to a baseline surface water conductivity and a baseline groundwater conductivity. The District reported the river water endmember conductivity value as 79 microsiemens (or µS), and the groundwater endmember as 342µS. This information allows estimation of the fraction of water at the Alapaha Rise and Holton Rise that is attributed to surface water flow. **Figures 36** and **35** show that as discharge at Jennings increases, the amount of surface water present in the flow at the rise increases. As discharge decreases, the fraction of surface water present at the rise also decreases and groundwater attributes to the majority of water present at the rises. This is congruent with the understanding of overland flow and groundwater flow behavior through the Alapaha River Sink Rise System.

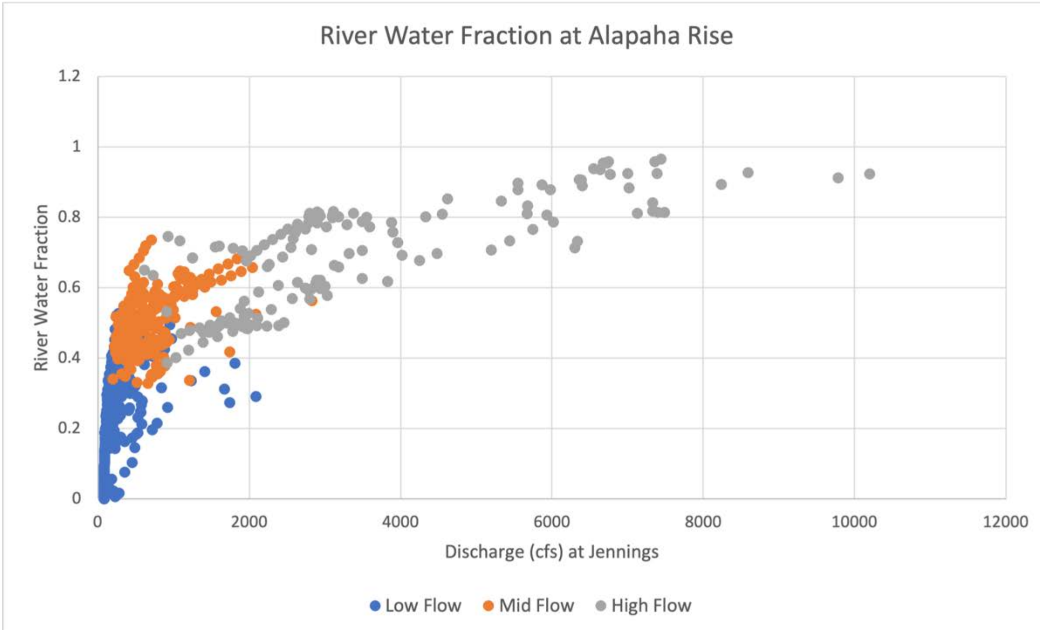

Figure 35. Relationship Between River Water Fraction at Alapaha Rise and Discharge at Jennings.

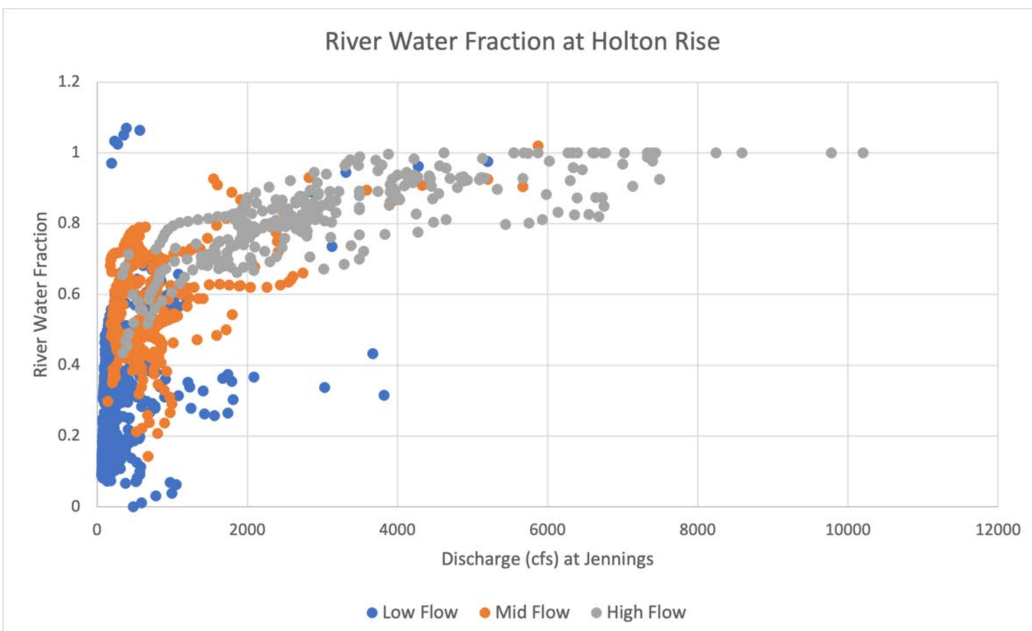

Figure 36. Relationship Between River Water Fraction at Holton Rise and Discharge at Jennings.

The figures above show a clear relationship between the discharge at Jennings and the conductivity at both the Alapaha Rise and Holton Rise. As the discharge at Jennings increases, the fraction of river water which is attributed to surface water also increases. At Holton Rise, there are several points classified as low flow based on the discharge at Jennings that are mapping with high flow values or are above a River Water Fraction of 1. It is possible that these points are influenced by high flow in the Suwannee River (bank storage), and that high flows in the Suwannee are inundating the Holton Rise, resulting in a conductivity value closer to the surface water endmember.

The relationships presented in **Table 20** were used to reconstruct Dead River flows. The fraction of water flowing from the swallets into the Alapaha Rise and Holton Rise was calculated using the River Water Fractions presented in **Table 20**. The River Water Fractions for each rise is based on the mean of the river water fraction distributions presented above in **Figures 29 – 34**. The Jennings flow was multiplied by one minus the mean River Water Fraction for each flow condition for each spring (**Table 20**). The Jennings flow data was lagged by 10 days for the Holton Creek calculations, and the Jennings flow was lagged by 5 days for the Alapaha Rise at Jasper calculations. **Figures 37** and **38** present the modeled swallet-derived contribution to each spring.

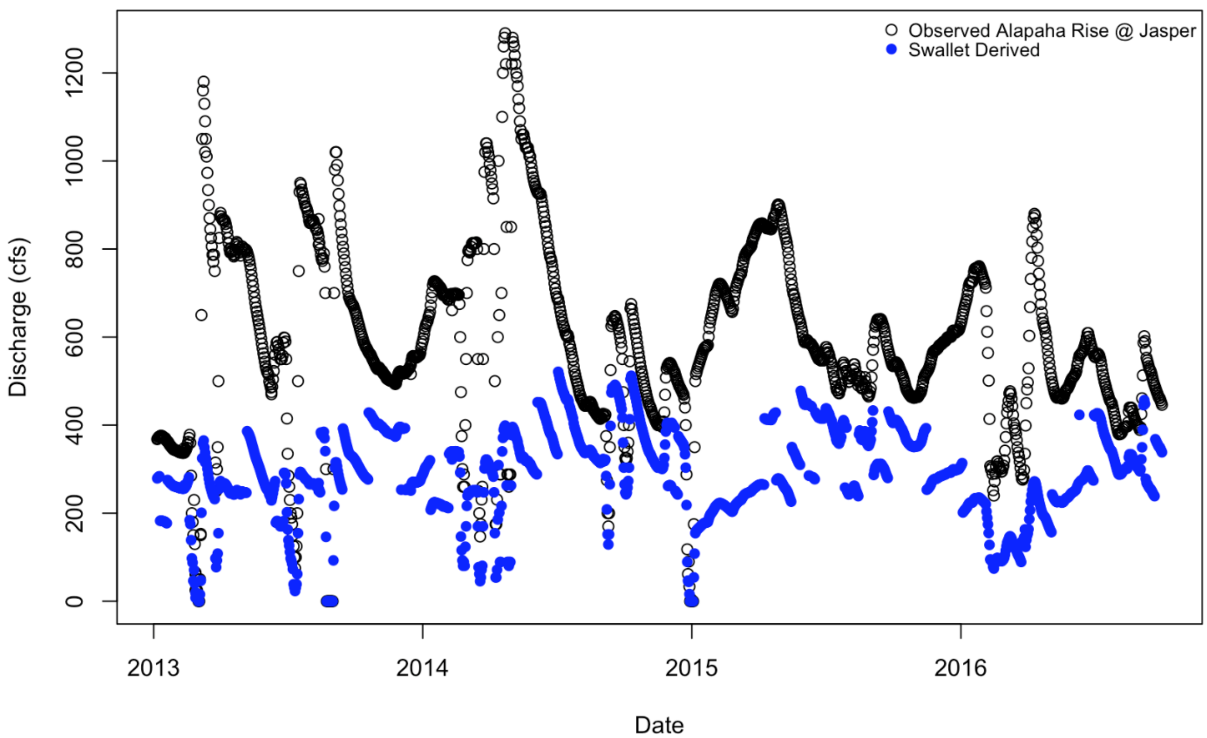

Figure 37: Swallet-derived Flow Contribution to the Alapaha Rise at Jasper.

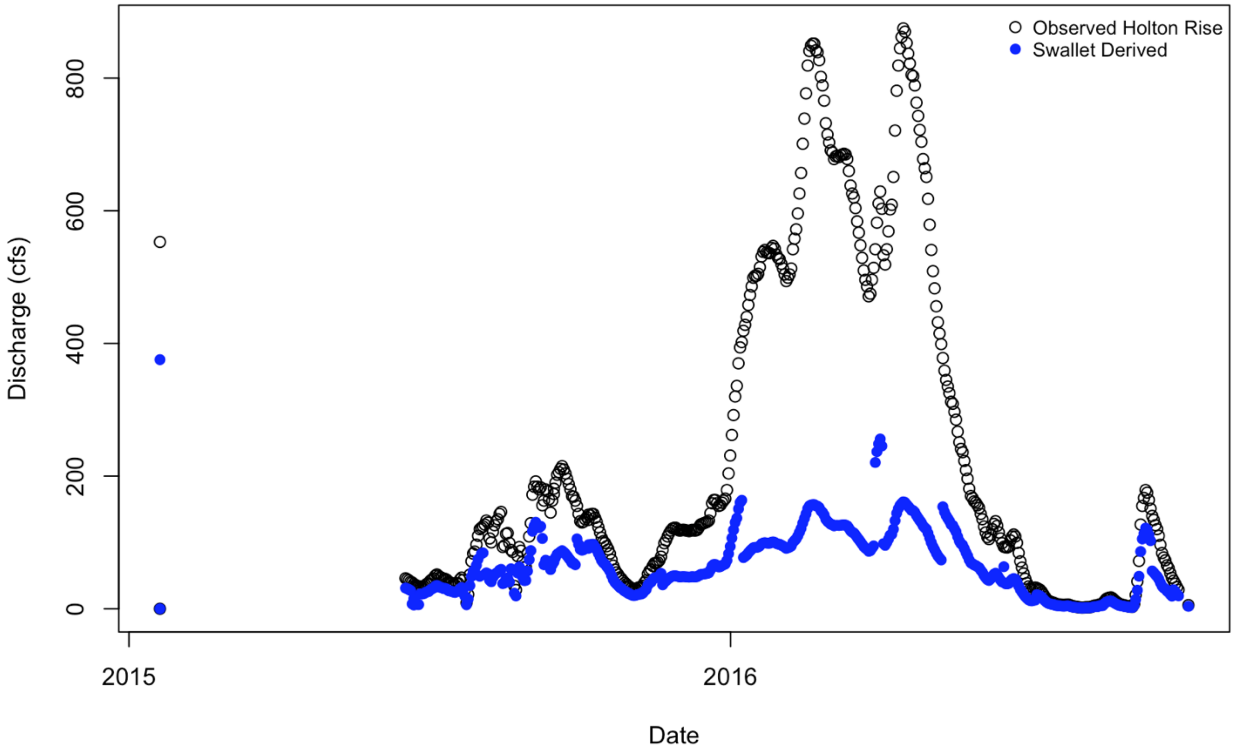

Figure 38: Swallet-derived Flow Contribution to the Alapaha Rise at Jasper

The specific conductivity data and analysis provides a method for estimating the groundwater flow contribution to the springs. The linear relationships between swallet contribution and flow at the rises for each flow condition show a nearly perfect fit (**Figures 39 and 40**). This is because the flow contribution from the swallets is modeled using as a percentage of the total water present in the springs. This method does not completely isolate the effects of inflow from the Dead River, but does allow the estimation of overall swallet inflow to the springs.

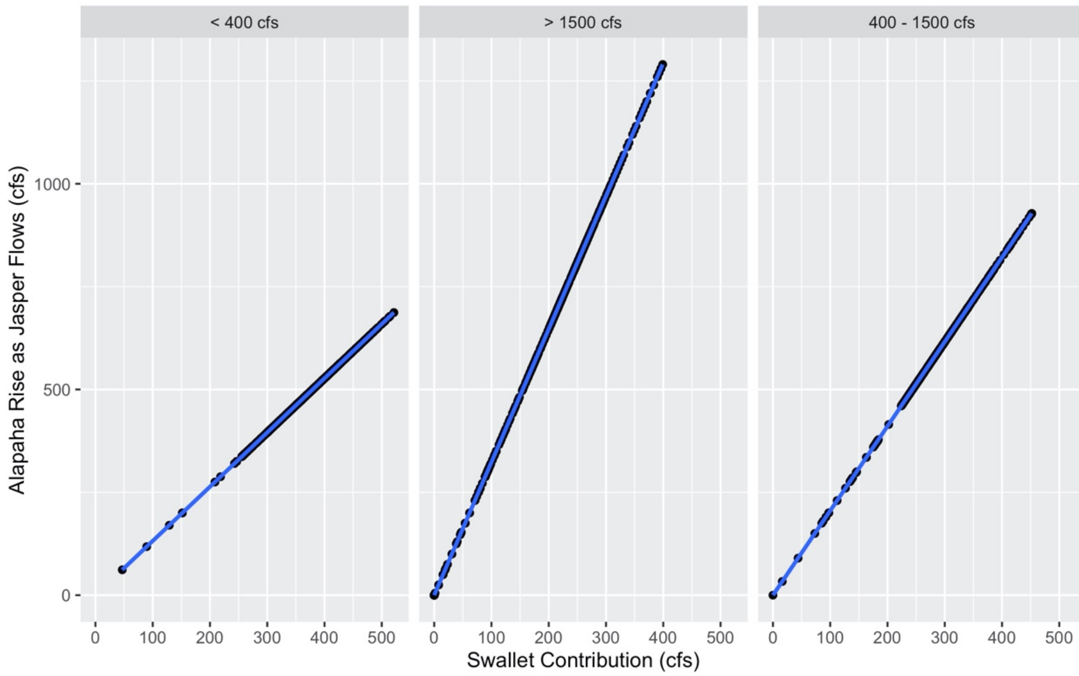

Figure 39: Flow at the Alapaha Rise at Jasper versus Calculated Inflow from the Swallets, Partitioned by Flow Condition.

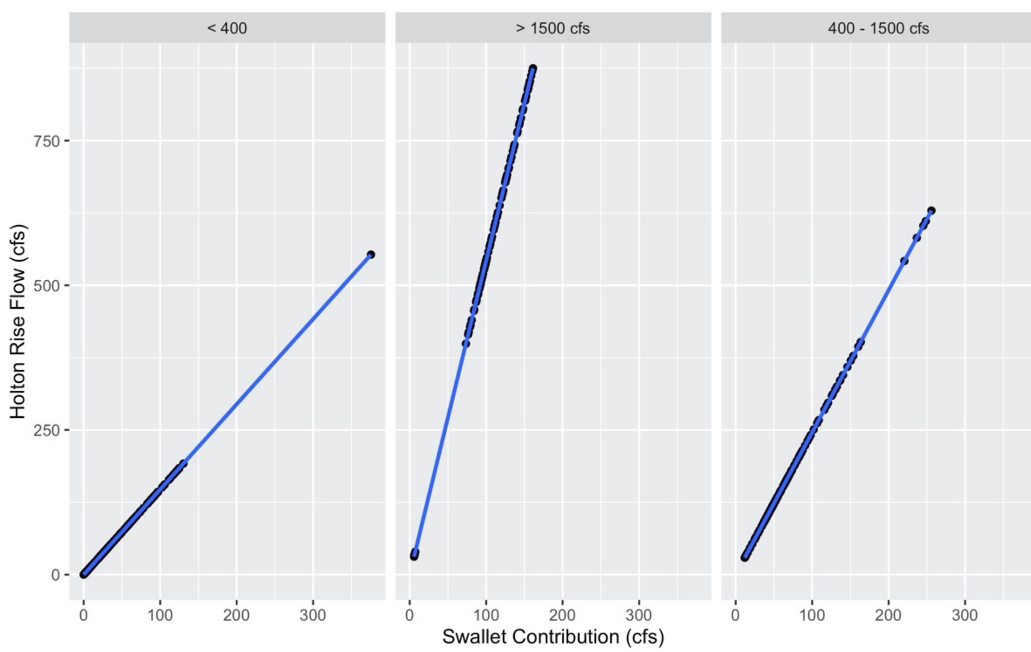

Figure 40: Flow at the Holton Creek Rise versus Calculated Inflow from the Swallets, Partitioned by Flow Condition.

Holton Creek Rise Rating Curve

HSW (2019) developed a rating curve for Holton Creek Rise, using data from well N011316001 (Carl Ivey Carter aka Adams Farm, SRWMD) as the explanatory variable. The equation is $Q = 43.17(GW - 35.08)^{1.040}$, where GW is the explanatory variable water level at well N011316001. The root-mean-squared-error (RMSE) of the model was 63.2 cubic feet per second. The model fit is shown in **Figure 41**. During data collection efforts, it was noted that data is available at this groundwater well from November 1, 1976 through April 3, 2021, with a total of 14,374 measurements which range from 32-feet to 69-feet NAVD88. It should be noted that the rating curve developed for Holton Creek rise is lacking high groundwater level observations above 50-feet NGVD29.

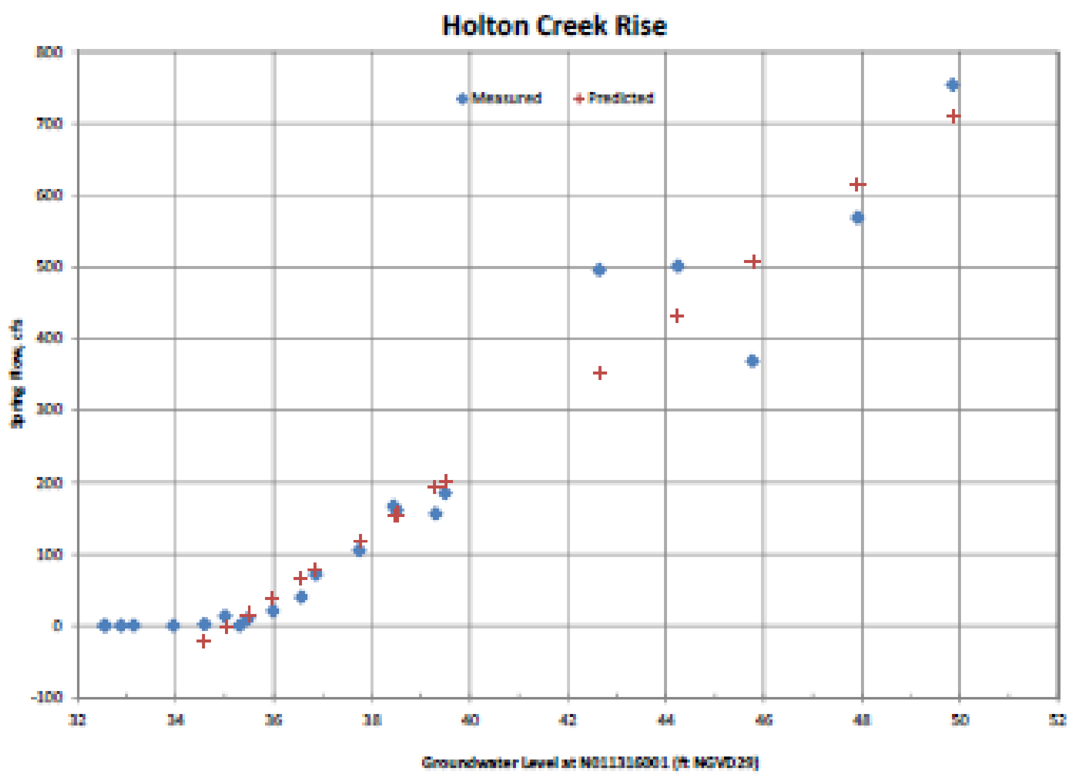

Figure 41: Holton Creek Rise Rating Curve Based on Nearby Groundwater Level (from page 110 of HSW [2019])

Data Collection Recommendations

Additional data collection would be helpful to further understand the Dead River flows and the understand resurgence at Alapaha Rise. A summary of each potential additional data collection effort is described in **Table 11**, with additional procedural details shown following the table for several of the recommendations.

Table 21. Additional Data Collection Recommendations for the ARSRS

Data Collection Recommendation	Level-of-Effort	Priority
Measure continuous stage at a surveyed transect upstream of **Dead River** (the Jennings station could be used if the head loss to Dead River is low), take synoptic flow measurements of **Dead River**	Medium; transect survey is required but monitoring of the pressure transducer will be low effort	High: this would yield an estimate of approximate flow into the swallet and help establish lag times between the sinks and the rises
Dye tracer study at **Dead River Sink**, **Alapaha Rise** and **Holton Creek Rise** (medium to high flows)	High; flows would be continuously monitored to identify events for measurements, measurements would be daily (or continuously with loggers) at several locations for several weeks for each event.	Medium to high; lag times and surface water contribution amounts can be determined from this analysis
Additional simultaneous synoptic measurements at **Alapaha Rise**, **Holton Creek Rise** and **Dead River** (medium to high flows)	Low; equipment needs are low (ADCP only, no boat); ideally flows should be measured for at least several days in a row at all locations to establish lag times	High; lag times could be established for various flow regimes.
Additional flow data collection at **Alapaha River near Jennings**	Low; flow data could be collected via a pressure transducer to measure stage and several flow measurements to develop a rating curve	Low; there is a good relationship between Jennings and Statenville flows, making additional flow measurement a low priority
Additional flow data collection at **Alapaha River at Jasper**	Low; flow data could be collected via a pressure transducer to measure stage and several flow measurements to develop a rating curve	Low; there is a good statistical relationship between Jasper and Jennings flows, making additional flow measurement a low priority

Dye Tracer Study

A dye tracer study would be helpful to determine the relative flow contribution and more importantly timing of Dead River flow and groundwater flows at Alapaha Rise and Holton Creek Rise. Previous studies have not examined dye concentrations, but rather the absence or presence of dye at a resurgence. Although the previous tracer study is helpful for determining the lag between the sink and resurgence (only for the beginning of the presence of the dye and not the centroid of the dye curve), a dye tracer study using a fluorometer would help determine the relative contribution of flow between the groundwater and surface water systems and the lag between the centroids of inflow and discharge. In general, the procedure for the dye tracer study is as follows:

- Monitor flows at Jennings and have personnel on standby for a medium to high flow event.
- When an event is observed, inject rhodamine dye at Dead River in accordance with ASTM D5613 (2014) or another appropriate methodology.
- Monitor rhodamine concentration at Alapaha Rise and Holton Creek Rise using grab samples (an ISCO sampler) and a fluorometer at least daily (or more frequently, if possible) or continuously with a YSI sonde and rhodamine sensor until concentrations diminish at both locations. This will yield a curve a concentration versus time for each location and allow for the determination of lag time between Dead River sink and Alapaha Rise and Holton Creek Rise.
- The total mass of dye introduced at the sink can be compared to the mass collected at the rises (area under the concentration curve).

Synoptic Measurements at Alapaha Rise, Holton Creek Rise, and Dead River

Synoptic simultaneous flow measurements at Alapaha Rise, Holton Creek Rise, and Dead River are another alternative to a dye tracer study that would require a smaller level of effort but also yield important results about relative flow amounts and lag times. In general, the procedure for synoptic flow measurements is as follows:

- Monitor flow at Jennings and have personnel on standby for a medium to high flow event.
- When an event is observed, record daily (or sub-daily) flow observations at Dead River, Alapaha Rise, and Holton Creek Rise.
- Continue to take measurements for several days to several weeks after the peak flow is observed at each location to determine the lag time between Dead River sink and the two resurgences.

Note that the procedure above refers to synoptic measurements. If an ADCP was permanently installed, adjustments to the flow would still be needed since the in situ ADCP only measures flow at one plane and is therefore known as an index velocity.

Continuous Flow Measurements at Stations-of-Interest

Although there are many swallets that receive flow from the Alapaha, the Dead River receives a predominant amount of flow. The placement of a continuous stage recorder just upstream of Dead River sink will allow for the development of a rating curve for Dead River sink. Several synoptic flow measurements at the stage recorder location will also be required to develop the rating curve. An alternate to stream rating (in the event of tailwater conditions) an in situ ADCP equipment can be installed to develop a flow time series by recording an index velocity and the water depth. The ADCP equipment is slightly more expensive but does not rely on a stationary rating curve.

Summary of Recommendations

Surface water, spring, and groundwater data within the Alapaha River Sink Rise System (ARSRS) were collected from the District and the USGS. The data was compiled into a Microsoft Access Database for ease of editing and increased efficiency for retrieval and analysis. The discharge data above and below the swallets and at the Alapaha Rise were analyzed to better understand the surface water behavior using the available observations. It is found that there is a linear relationship between surface water flow below the swallets and flow above the swallets, consistent with finding in Upchurch (2014). Additionally, and low flow and high flow models were found to better reconstruct Jasper flows under varying flow regimes upstream at Jennings. The reconstructed periods-of-record were used to estimate the amount of water entering the conduits. Although there is a relationship between Jennings and Jasper flows, there is insufficient data to conclusively draw a mathematical relationship between conduit flow and flow present at the resurgences.

Specific conductivity at the Alapaha Rise and Holton Rise data was provided by the District. The data was analyzed for river water fraction relationships to decipher the amount of surface water present at both rises based on upstream flow conditions at Jennings flow station, as well as groundwater and surface water endmember conductivities. The specific conductivity data was binned into categories based on flow conditions at Jennings. It was found that as discharge at Jennings increases, the fraction of surface water at each rise also increases. When flow is low at Jennings, the fraction of surface water decreases and water at the rises is mostly groundwater. This is consistent with available knowledge of overland flow behavior along the ARSRS. The river water fractions were used to estimate the portion of groundwater present in the resurgences. This does not decipher the amount of groundwater inflow attributed to the Dead River, but does allow a percentage estimate of groundwater in the resurgence.

The NFSEG groundwater model was reviewed to provide recommendations for improvement to the ARSRS representation. It is recommended that the Dead River sink be included as an injection point in the model. This will improve the representation of groundwater flow field and head loss from the sink to the Alapaha Rise, increase the accuracy of the transmissivity array, and improve the representation of groundwater heads in the model.

It is recommended that additional data be collected at the Jasper flow station (below the swallets) and at the Alapaha Rise and Holton Creek Rise. This data is needed to develop a better mathematical relationship between flow at Jennings and flow below the swallets using observation data. This would allow for a better understanding of surface water behavior between the swallets and the resurgence. Additionally, it is recommended that special attention be paid to data collection at Jasper and the Alapaha Rise during high flow events. It is also recommended that a more thorough statistical analysis be performed to understand the relationship between Jennings flow and overland flow at Jasper. Additional data collection and a more thorough statistical analysis would aid in developing a hydrogeologic model of the system, and better capture the complex the behavior of overland flow and conduit flow along the Alapaha River Sink Rise system.

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The Southeastern Geological Society, (2014). *Karst Hydrogeology of the Upper Suwannee River Basin, Alapaha River Area Hamilton County, Florida*. Southeastern Geological Society Guidebook Number 63.

Upchurch, S. B. (2007). *An Introduction to the Cody Escarpment, North-Central Florida*. Prepared for the Suwannee River Water Management District by Sam B. Upchurch, SDII Global Corporation.

Upchurch, SB. (2014). *Hydrogeology of the swallet and resurgence system in the Alapaha River, Hamilton County, Florida. Lawn A (comp.), Karst hydrogeology of the upper Suwannee River basin, Alapaha River area, Hamilton County, Florida.* Tallahassee, Southeastern Geol Soc Field Trip Guidebook, 63, p. 30-45.

Appendix A. Annotated Bibliography

Ceryak, R., 1977, "Hydrogeology of a river basin in karst terrain, Alapaha River, Hamilton County, Florida, Suwannee River Water Management District Information Circular 5, Suwannee River Water Management District.

This study describes the geologic and hydrogeologic setting of the Alapaha River Basin. The author describes the two profiles of the Alapaha River which is a result of the lithology and subsurface structure of the area. In the northern stretch of the river, the river flows all year as it traverses low permeability sediments. To the south, below the stream sinks, flow is intermittent because of karst formation in the Floridan aquifer, which forms the riverbed in this reach of the river. The Hawthorn formation and younger sediments have been eroded, exposing limestone at the land surface.

The author then describes the three aquifers within the study: a water table or perched aquifer, a secondary artesian aquifer, and Floridan aquifer (Figure 4). The secondary and Floridan aquifers are confined by low permeability layers. Each aquifer has a distinct water type, but there are zones of mixing. The Floridan is most productive aquifer in the area.

The authors then describe the stratigraphy between aquifers in detail.

Next, a factor analysis of water quality data to trace groundwater in the southern section of the Alapaha River was described. The authors used 105 water quality samples to characterize the area. They found that each aquifer has a unique water quality, described in Figure 6:

- Factor 1: Perched aquifer (Cl, Na, Low Specific Conductivity)
- Factor 2: Secondary Artesian Aquifer (ortho-phosphate, Fluoride)
- Factor 3: Floridan Aquifer (High Specific Conductivity, Alkalinity, Ca, Mg, Sulfate)

The authors then describe the seasonality of flow in the Alapaha River. They state that the Alapaha River flows its entire length 60% of the time. During the remaining 40%, a group of sinkholes 4 miles south of the FL state line captures the entire river flow. The water travels through solution channels in the limestone for approximately 19 miles and emerges mixed with groundwater at two resurgences (Alapaha Rise and Holton Creek) and flows into the Suwannee River.

The report states that the groundwater level fluctuates up to 20 feet between periods of low and high flow. They define high flow as greater than 786 cfs. During low flow, Holton Creek discharges clear ground water.

Figure 12 shows the zone of mixing between river water and the Floridan aquifer (along the Alapaha, Suwannee, and Withlacoochee rivers).

Ceryak, R., et al. 2005. Significance of the Cody Scarp on the hydrogeology of the Suwannee River Water Management District. In R. Copeland (Compiler), Geomorphic Influence of Scarps in the Suwannee Basin, Southeastern Geological Society Field Trip Guidebook 44, p. 37.

*The document of interest is within a larger field trip guidebook compiled by R. Copeland of the Southeastern Geological Society.

This document briefly discusses the topography of the Cody scarp, and how it is the most significant topographic break in Florida. Elevations in the Highlands (North and East) are between 100 and 200 feet above MSL. The Lowlands (South and West) are between 0 and 100 feet above MSL. Relief along the scarp can be up to 80 feet. The author then notes that the only river that originates in the Highlands that does not go underground as it crosses this transition zone is the Suwannee River.

He then discusses the nature of the Floridan aquifer within the Highlands. In the Highlands, the aquifer is confined and artesian. Additional confined, artesian, carbonate intermediate aquifers lie above the Floridan within the Hawthorn formation. There is the surficial aquifer at the land surface, which drains down the scarp into the lowlands.

He then notes that in the lowlands the Floridan is unconfined and the only aquifer present. The Suwannee and Santa Fe Rivers incise the aquifer, and surface water features are coincident with the water table.

Conover, C.S., and S.D. Leach, 1975. River basin and hydrologic unit map of Florida. Florida Geological Survey, Map Series 72, 1 sheet.

This is a map of the river basins and hydrologic units of Florida, from the Florida Department of Natural Resources. This map was published in 1975. The Alapaha River Basin is hydrologic unit 09J2, and is located in the green shaded area (subregion 11, Suwannee and Aucilla Rivers), labeled 0202 (accounting unit 02, cataloging unit 02). This is along the north-central (slightly east) border of Florida. This unit is not labeled as Alapaha on the map, but it is on the table in the center of the map.

Davis, J. H., Katz, B. G., & Griffin, D. W. (2010). Nitrate-N movement in groundwater from the land application of treated municipal wastewater and other sources in the Wakulla Springs Springshed, Leon and Wakulla counties, Florida, 1966–2018. US Geol Surv Sci Invest Rep, 5099, 90.

This study examines nitrate (N) loading from the Southwest Farm into Wakulla Springs. They hypothesis that N may be moving through the Upper Floridan aquifer to Wakulla springs and increasing the concentration of N in the springs. They note that the discharge from Wakulla can change rapidly even with no rainfall, and that this is probably due to Wakulla sometimes capturing groundwater that has been going to the Spring Creek Springs Group. They simulate N loading in 2007 and 2018 under the two scenarios with varying amounts and sources of N per year (07 or 18) and per simulation.

The authors measure N concentrations in groundwater at 4 known underground tunnels (karst conduits) that are connected to Wakulla Springs. They say that the N concentration at Wakulla is the results of mixing of waters from the four tunnels. The authors then say that during periods of high flow at the spring, N levels in the spring are closest to those at tunnel A which supports the groundwater divide postulated by Kincaid (1999). The divide can shift and push more water from the A tunnel region north towards Wakulla. At the high flow times at Wakulla, the Sopchoppy River was very low, indicating that there was no surface water flow into the local sinks. This would mean that the changing flow and N concentrations in Wakulla are a results of groundwater flow in the underground tunnels moving north towards Wakulla Spring.

The simulated scenarios are: 1.) assumed that Wakulla Springs was not capturing Spring Creek Springs Group flow, SWF sprayfield becomes operational. Almost all flow in A/R-tunnel is -- going to Spring Creek Springs Group; 2.) assumed that Wakulla Spring was capturing Spring Creek Springs Group flow, almost all flow in A/R-tunnel diverted to Wakulla Springs. The nitrate-N distribution and water levels from Scenario 1 at time 1/1/2007 was the starting distribution for Scenario 2.

Groundwater flow modeling and fate and transport modeling were conducted to determine the effect of each N source on Wakulla Springs. MODFLOW was used for GW flow modeling, MT3D was used for F-T modeling. The MODFLOW model simulates two layers. The first layer is an upper portion of the Floridan aquifer with K ranging from 10 to 10,000 ft/day. The second layer is a lower part of the Upper Floridan Aquifer System with higher hydraulic conductivity especially in areas representing conduits. In layer 2 the K ranges from 10 to 5,000,000 ft/day. All rivers were represented with drain cell boundary condition. Drains can only represent gaining river therefore cannot represent sinks or losing systems. Lateral boundary conditions were defined using a regional GW model which was recalibrated for this effort (the recalibration effort was not documented). The sub-regional model is transient with most stress periods representing one calendar. Some calendar years with significant boundary condition changes were divided into two stress periods. Conduits were represented with high horizontal conductivity pathways (only in layer 2). The Wakulla Springs cave system has been extensively mapped but the location, extent, and magnitude of many smaller solution conduits are uncertain.

Durden, Douglas, Fatih Gordu, Douglas Hearn, Tim Cera, Tim Desmarais, Lanie Meridth, Adam Angel, Christopher Leahy, and Joanna Oseguera (St. Johns River Water Management District) and Trey Grubbs (Suwannee River Water Management District), 2019, "North Florida Southeast Georgia Groundwater Model (NFSEG v1.1),"

This document outlines the development of the Northeast Florida-Southeast Georgia model. The model was designed by the SJRWMD and SRWMD, and stakeholders as a tool to evaluate inter-district, inter-state, and individual groundwater pumping effects. This document is 513 pages long.

The Alapaha river and/or rise were mentioned on 5 pages, found through a keyword search. The first section that the Alapaha is mentioned in is the Rivers section. It is mentioned as an important tributary to the Suwannee, and that is baseflow is derived from the surficial aquifer system. They discuss the low-flow regime of the river, and the hydrography of the river. They also mention that the Floridan aquifer is unconfined around the Dead River and Alapaha Rise.

The second section that mentions the Alapaha is in the Spring Flows section. The authors note that the Alapaha River Rise is included as a major river rise in the model domain, along with the Holton Creek Rise, and several other rises.

The next section that mentions the Alapaha is the Cumulative Baseflow estimates paragraph. They say that cumulative baseflows are defined as the total of all baseflows above a given USGS gauge location in a stream. They average the baseflows by averaging the results of four different hydrograph separation techniques, and a fifth approach utilizing a flow duration curve. They used the USGS program Groundwater Toolbox for three of the separation techniques. A low pass filter for the fourth, and a FDC for the fifth. They estimated baseflow for 2001 and 2009. They also look at estimated from HYSEP methods and the PART method but did not use the final results.

The Alapaha is also mentioned in the Quality of Baseflow Matches section. They discuss how extremely high flow events will lower the accuracy of flow and baseflow estimates. Particularly, they mention that peak flows in the Alapaha and Withlacoochee were among the highest recorded in the spring of 2009. They state that this will diminish the degree to which baseflow estimates would correspond to recharge rates in the contributing areas. This is because the flow becomes much more difficult to estimate as the river becomes flooded and the energy gradient becomes more variable.

Table 5-3 lists the range of estimated cumulative and simulated baseflow for all gages in the model and lists the Alapaha River Near Jennings Fla, USGS Gauge 02317620.

The development and calibration of the HSPF model is described in Chapter 9: pages 433 (9-1) through 488 (9-72).

Greenhalgh, Tom and Karlee Fowler, 2016, "Alapaha Swallets Dye Trace Project," the Florida Department of Environmental Protection--Florida Geological Survey.

Appendix IV pg 17-21, Alapaha rise dye trace timeseries

The report outlines the methodology used to conduct a dye tracer test at two locations along the Alapaha. Dye was introduced into the Dead River Swallet and was observed six days later at the Alapaha Rise. Dye was observed in charcoal samples nine days after introduction at Holton Creek. Figure 4 shows the results of the Dead River tracer test.

Dye was also introduced to the Tiger Creek Swallet. The dye was not detected in the Alapaha or Holton Creek Rises in the first or second rounds of charcoal sampling but was detected in the third and fourth. Round three was conducted 4 to 20 days, and round four was conducted 20 to 40 days after dye introduction.

Figure 1 shows a good map of the tracer test locations. It shows the location of dye injection and sampling locations, as well as the distances between the injection sites and sampling sites.

Appendix IV contains the timeseries data from the Alapaha Rise and Holton Creek Rise ISCO sampler. This shows the spike and decline in dye ppb.

Appendix IV contains timeseries data of Fluorescein concentration (ppb) at the Alapaha Rise and Holton Creek. The samples were taken via an ISCO sampler. The Alapaha timeseries is from 06/21/2016 through 08/09/2016. The Holton timeseries is from 06/22/2016 through 08/09/2016.

INTERA Geosciences and Engineering, 2014, "Updates and Re-Calibration of the North Florida Groundwater Model," for the Suwannee River Water Management District.

This document discusses the Alapaha River Sink in the section "Representation of the Siphons and Swallets"

Table 7 lists the Siphons and Swallets modeled in the NFM, with the Alapaha Sink listed. The INTERA Model Well Rate is 365.5 cfs.

The document states that the assignment of river cells to layers was based on knowledge of hydrology in the area. The Apalaha was assigned to model layer 2 (the Upper Floridan aquifer) because of incision. The tributaries were assigned to layer 1 (surficial).

The report discusses the representation of the Alapaha sink and how it was represented in the model. The surface water flux into the sink was represented as an injection well. The accumulated baseflow is included in the computation of the baseflow target at the Suwannee River @Ellaville gauge. The discharge at the Alapaha rise was also used as a springflow target during calibration. The surface water flux into the Alapaha sink was estimated by developing a linear regression between flows at Statenville and Jasper gages. This flow was 364.5 cfs (1995). Values for the simulated spring flow, target spring flow, and residual are listed in Appendix A .

Kuniansky, E. L. (2016). Simulating groundwater flow in karst aquifers with distributed parameter models—comparison of porous-equivalent media and hybrid flow approaches (No. 2016-5116). US Geological Survey.

This document compares a porous-equivalent media model with and without turbulence (MODFLOW-Conduit Flow Process mode 2, and basic MODFLOW), and a hybrid model (MODFLOW-Conduit Flow Process mode 1) of the Woodville Karst Plain near Tallahassee, Florida.

Representation of karst features was tested through three modeling approaches: 1.) porous-equivalent media model, no high K cells at conduits; 2.) porous-equivalent media model, high K cells at conduits' 3.) Hybrid model with 1D pipes linked to porous equivalent media model.

A hybrid model (HM) is the coupling of an SCPE (single continuum porous equivalent) model with a discrete one-dimensional conduit or pipe network model.

From the document, they describe the three models:

"(1) SCPE with laminar flow only (Davis and others, 2010), (2) HM that consists of a single continuum coupled to a one-dimensional pipe-flow network capable of simulating laminar and non-laminar flow, an application of MODFLOW- CFP mode 1 (Shoemaker and others, 2008; Gallegos, 2011; Gallegos and others, 2013; Kuniansky, 2014), and (3) SCPE model in approach 1, but with laminar and turbulent flow in the SCPE, an application of the CFP mode 2 (Shoemaker and others, 2008; Kuniansky and others, 2008; Davis and others, 2010; Kuniansky and others, 2011; Reimann and others, 2012; Kuniansky, 2014)."

All models have two-layer discretization. Top layer is the confined upper 200 ft of the Upper Floridan aquifer, and layer 2 is the lower part of the Upper Floridan aquifer. Layer 2 contains the submerged conduits in the SCPE model, and flow in this layer can be non-laminar. The modeling effort simulated the conduits with several modeling techniques including porous media as well as techniques that can represent hydraulic losses and laminar/non-laminar flow. The conclusions stated for seasonal or monthly average springflows the ability to simulate laminar and non-laminar flow is not necessary. The main challenge to modelling the karst conduits is related to the uncertainties of conduit geometry including location, size, and roughness.

Schneider, J.C., Upchurch, S.B., and Champion, K.M., 2006. Stream/Aquifer Interactions in a Karstic River Basin, Alapaha River, Florida. Geological Society of American Abstracts with Programs, Vol. 38, No. 3, p.83.

The authors used a regression analysis to develop a 70-year record of surface-water flow at gages upstream and downstream of sinks in the Alapaha river. They used this timeseries to quantify the percentage of flow in the Alapaha that enters the groundwater system. They find that when flow is below ~500 cfs, all surface water flow enters the aquifer via Dead River Swallet. When upstream flow is greater than ~500 cfs, they find that 20% of the flow above the 500 cfs threshold also enters the aquifer. They also find that flow into the aquifer exceeds downstream flow 2/3 of the time. The authors test several correlations between discharge and seasonal flow patterns and find a good relationship between Alapaha Rise (AR) discharge data and the water level in a nearby shallow well. They also find a good relationship between AR discharge lagged 6 and 21 days behind the upstream discharge for low and high flow data (lagged 6 days for low flow and 21 days for high flow).

The Southeastern Geological Society, 2014, Southeastern Geological Society Guidebook Number 63, “Karst Hydrogeology of the Upper Suwannee River Basin, Alapaha River Area Hamilton County, Florida.”

This is a field trip guidebook. The first few pages describe their schedule of stops. Then there is a series of ariel images and topographic maps of the areas of interest. Then there is a compilation of papers discussing the Alapaha River system and Cody escarpment.

The first section of the guidebook is **Upchurch, S. B. (2007)** which is summarized already in this bibliography.

The next paper is Hydrogeology of the **Swallet and Resurgence System in the Alapaha River**, by Sam Upchurch. This paper summarizes the results of a modeling study of the Alapaha Rise in order to better understand the nature of its underground flow. First the author discusses the hydrogeography of the Alapaha River, and states that it first encounters karst when it reaches the Cody escarpment. Then a series of swallets capture the entire flow during low flow season. Overland flow only reaches the Suwannee during high flow, which he describes at 350 to 500 cfs. He then states that the Alapaha enters the Floridan Aquifer at Dead River, and that the swallets in the riverbed discharge to the Suwannee through two resurgences: the Alapaha Rise, and Holton Creek Rise. He describes Holton Rise as an overflow route for when there is too much water to discharge through the Alapaha Rise.

Then there is a section on the Topography and physiography of the area. Figure 14 shows a potentiometric surface map of the Floridan aquifer at the Alapaha. The author states that recharge to the Floridan aquifer is directly related to its confinement, and that the highest recharge rates occur where the Floridan is unconfined or at or near the land surface; Floridan recharge may also be high in areas with karst features, sinkholes or swallets, within the Alapaha River near Dead River. He notes that underground flow velocities may be as high as 1 mile per day.

Next, he discusses the lag time between underground capture and resurgence.

- When $Q < 500$ cfs at Jennings, the lag time of the flood peak at the Alapaha Rise is 3 - 6 days (Figure 23) and
- When $Q > 500$ cfs at Jennings, the peak lag at the Alapaha Rise is 18 - 21 days (Figure 24).

Then he discusses the relationship of resurgence discharge to river stage by displaying hysteresis loops. There is also a flow duration curve for the Alapaha River above and below the swallets. Table 1 compares the modeled discharge above and below the swallets on the Alapaha and shows the calculated loss to the swallet system in Dead River. This provides a decent picture of the hydrodynamics of the river during periods of high and low flow.

The next document in this compilation is excerpts from a USF Master's thesis on the sedimentology of one river meander in the Alapaha river, titled **Sedimentology of a Low Sinuosity Meander within the Alapaha River**. He shows a series of slides on the depositional environments, velocity versus depth plots, facies diagrams, and lots of photographs of the meander. One take away that may be relevant is that his data indicates that flow in the Alapaha exceeds the volume that flows into the ground at Dead River 45% of the time.

Upchurch, S. B. (2007). An Introduction to the Cody Escarpment, North-Central Florida. ***Prepared for the Suwannee River Water Management District by Sam B. Upchurch, SDII Global Corporation*****.**

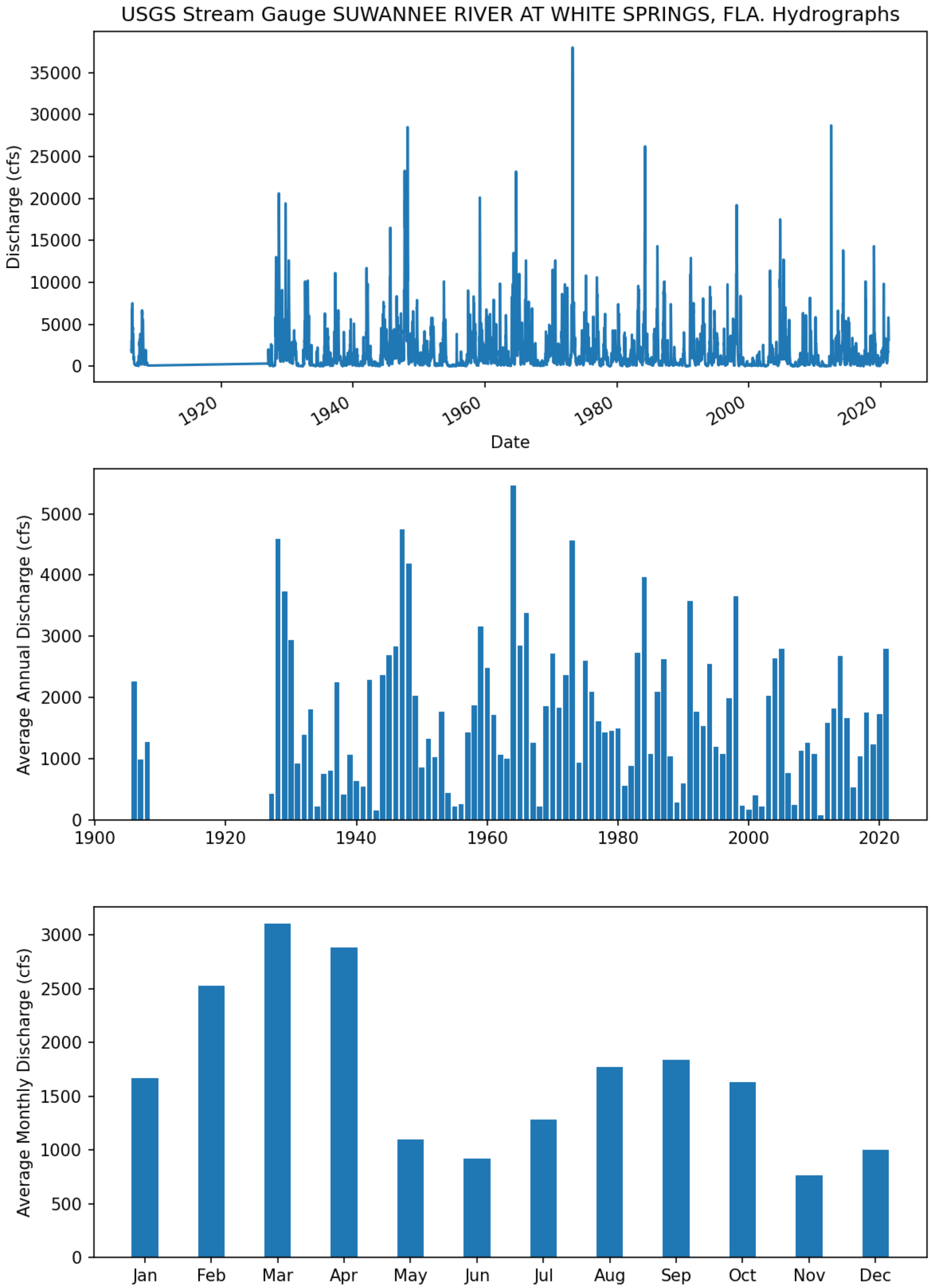
Though this paper does not directly mention the Alapaha, it does provide a brief geologic history of the Cody escarpment and the geomorphologic processes that form a karst escarpment. It also shows the geography of the Cody scarp with respect to the topography of Northern Florida. The authors discuss the processes of karst scarp retreat, and how this forms swallets, traces, sinks, and other geologic features in the landscape. Table 1 summarizes the properties of the Cody scarp in each geomorphic area, including the Upper Floridan Aquifer. Figure 5 shows the location of closed depressions in a 144mi^2 area near Lake City, Florida. Figure 6 summarizes the geologic process of each geomorphic domain. The authors then discuss the effect of the scarp on the groundwater quality in the area.

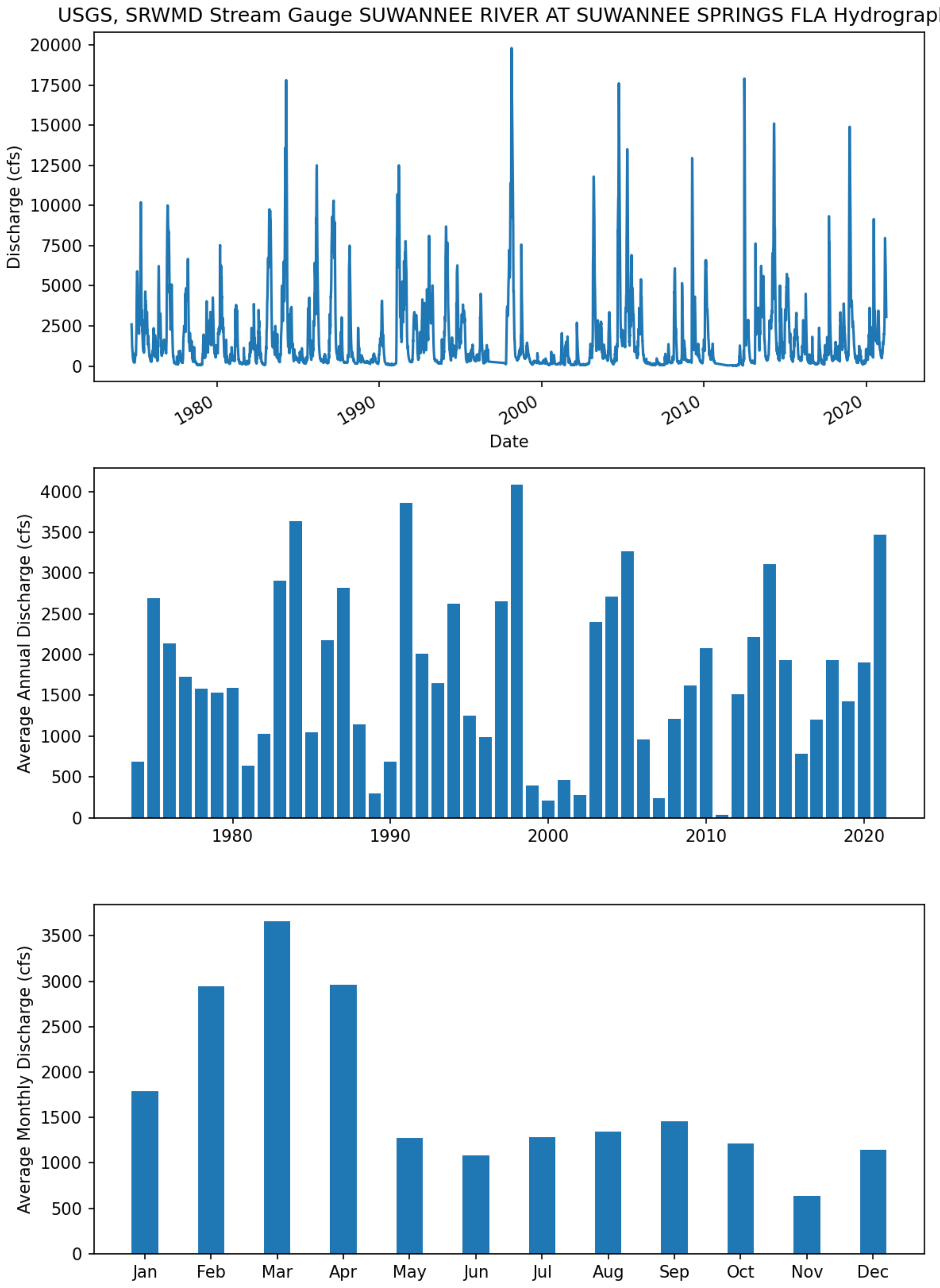
Near the end of the document, the authors discuss the behavior of streams at the Cody scarp. They say that streams that cross the scarp are usually associated with swallets and siphons, and that water captured usually emerge from the aquifer as spring. They note that all streams that cross the scarp go underground, except the Suwannee River.

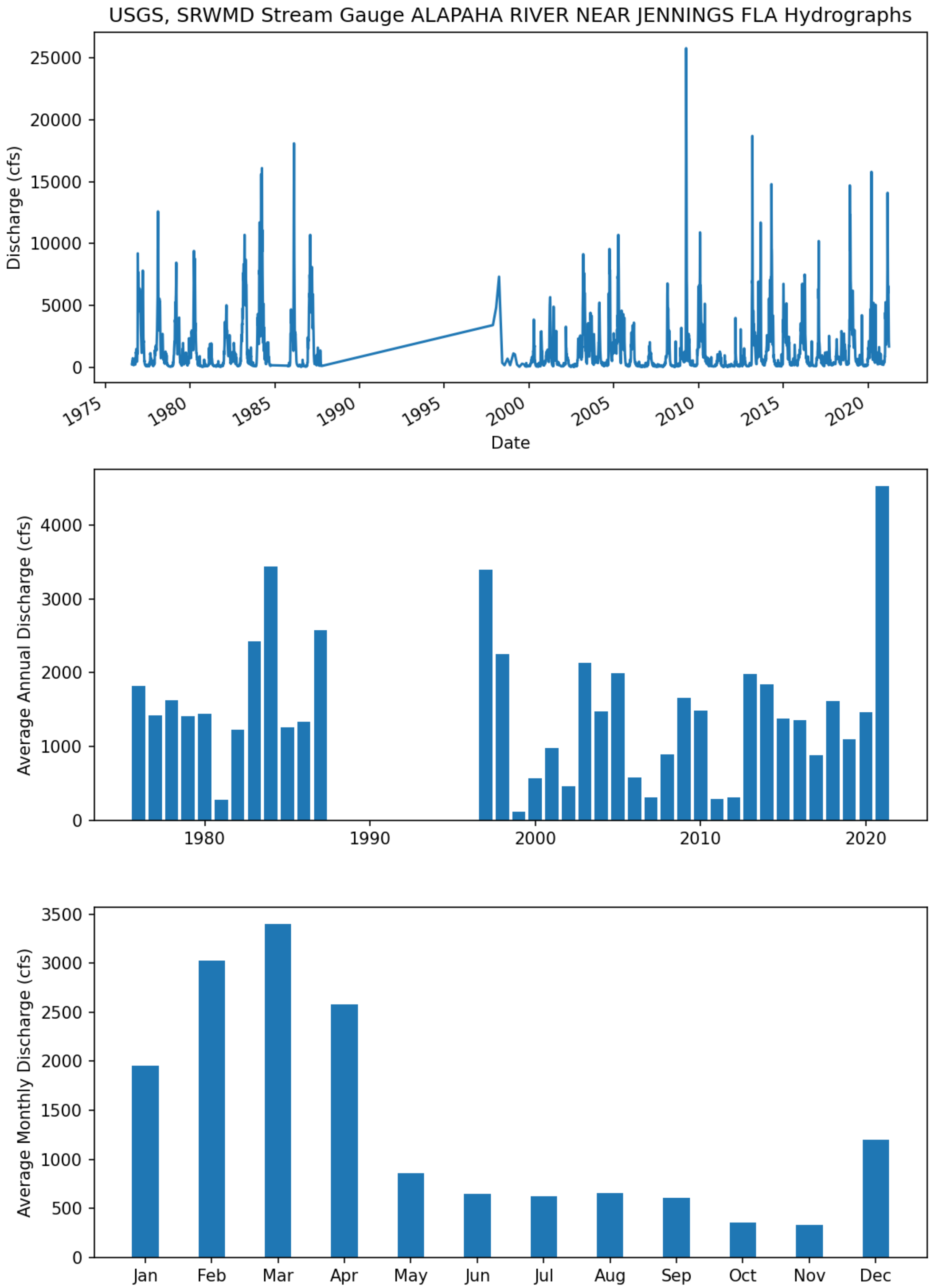
Upchurch, SB. (2014). Hydrogeology of the swallet and resurgence system in the Alapaha River, Hamilton County, Florida. Lawn A (comp.), Karst hydrogeology of the upper Suwannee River basin, Alapaha River area, Hamilton County, Florida. Tallahassee,

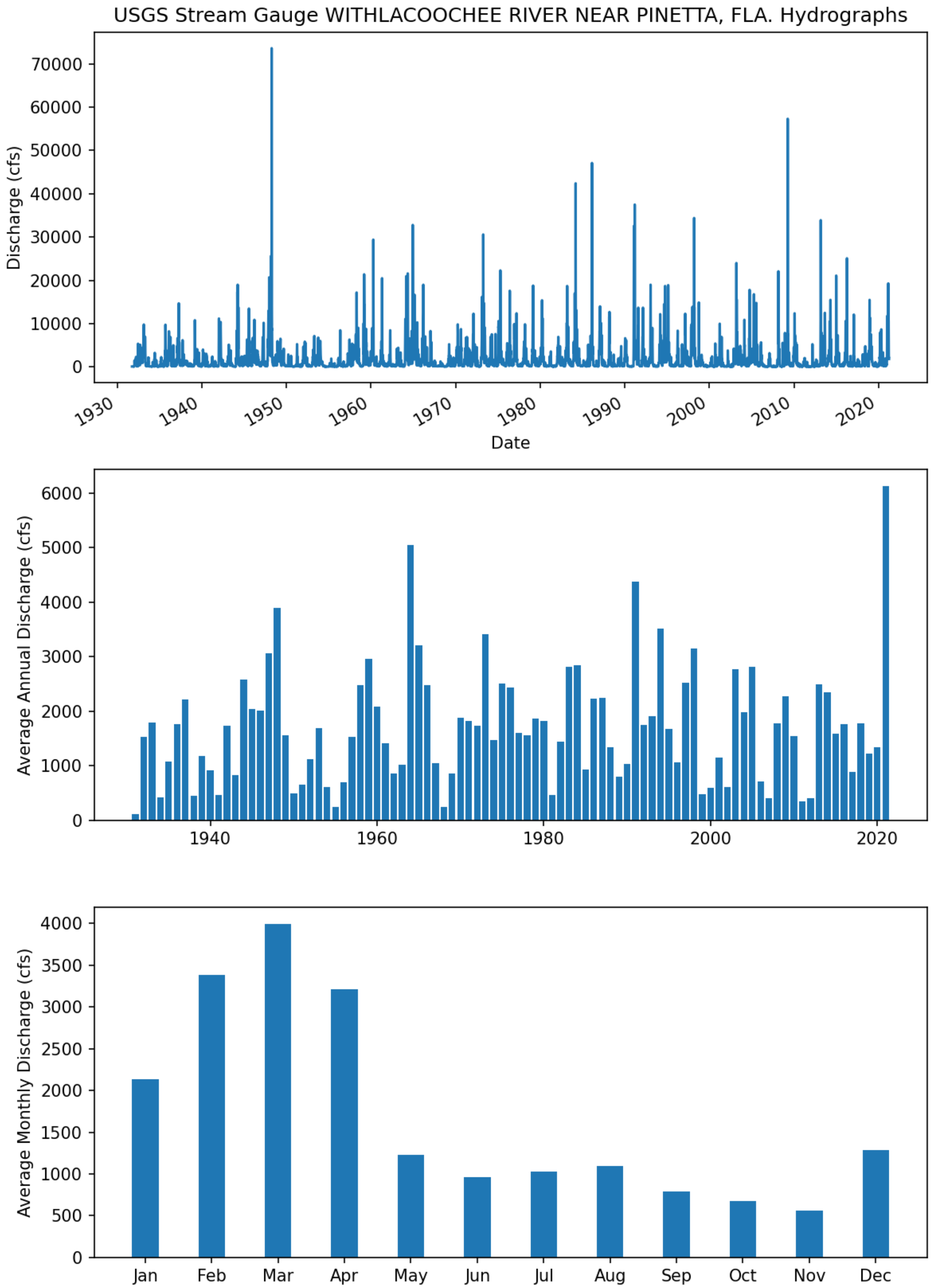
This report documents the geologic setting of the Alapaha River Basin. It describes the basin hydrology as well as the karst features in the Alapaha River. The development of swallets results from the thinning of the Hawthorn by erosion from the river. The Dead River is labeled as a “Blind Valley”. The Alapaha River reached the Suwannee only during high flows exceeding 350 to 500 cfs or about 50% of the time. The low flows are completely captured by the Dead River Swallet and resurges at 2 locations Alapaha Rise and Holton Creek. The Alapaha Rise is usually discolored showing it captures the inflow from Dead River Sink. At low flow, Holton Creek flows clear with mostly Floridan Aquifer is the source with little to no inflow from Dead River Sink. Discharge and stage data were modeled with the lagged endogenous variable method. The lag times between at low flow periods was estimated at 3-6 days while at high flows (>500cfs) the lag was 18-21 days. Significant hysteresis was observed a the Alapaha Rise. Storage in the aquifer was described as a cause for the lag and hysteresis loops in the hydrograph. The Alapaha Rise may serve as an estavelle.

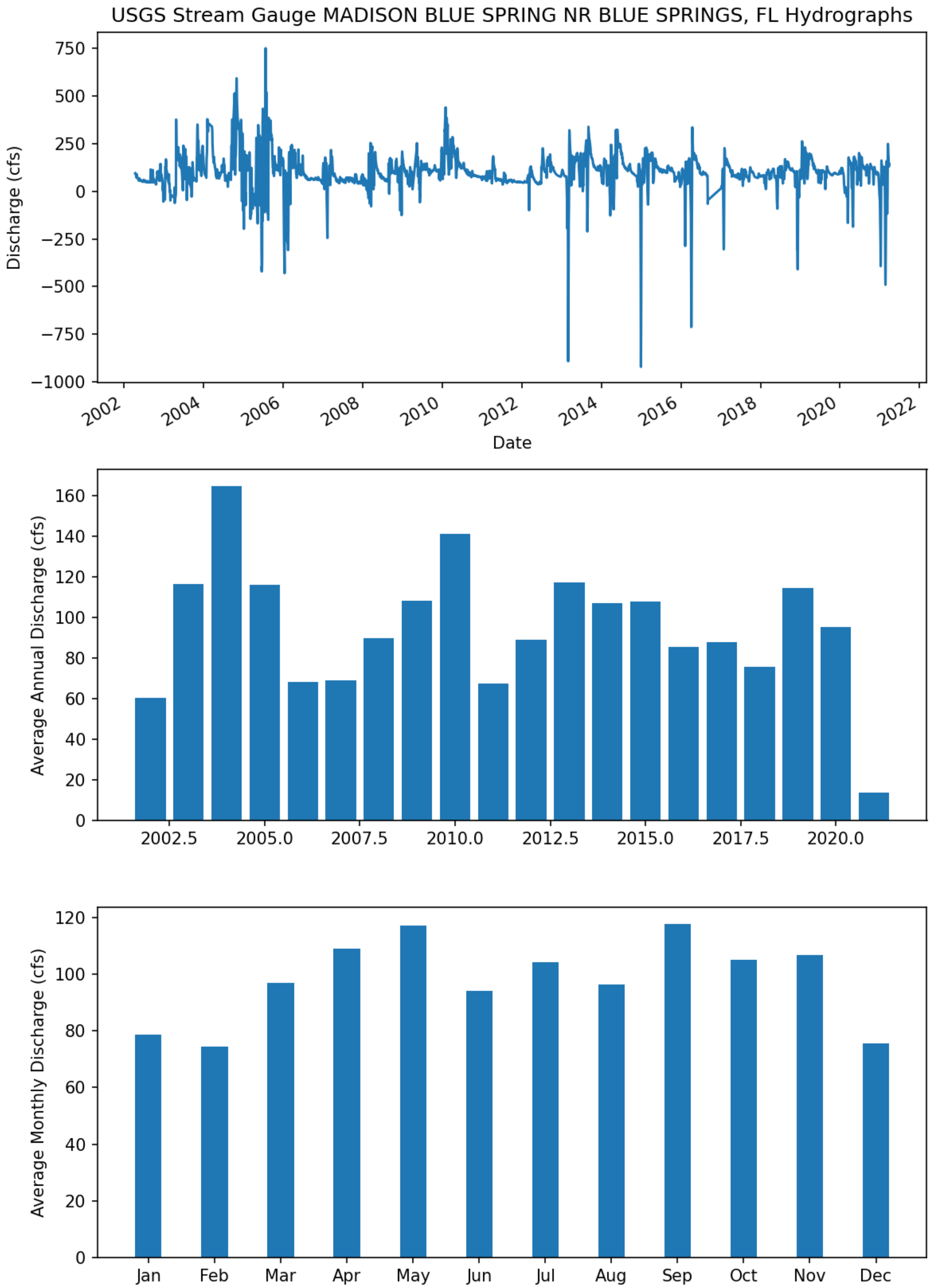
Appendix B: Discharge Time Series for Flow Stations

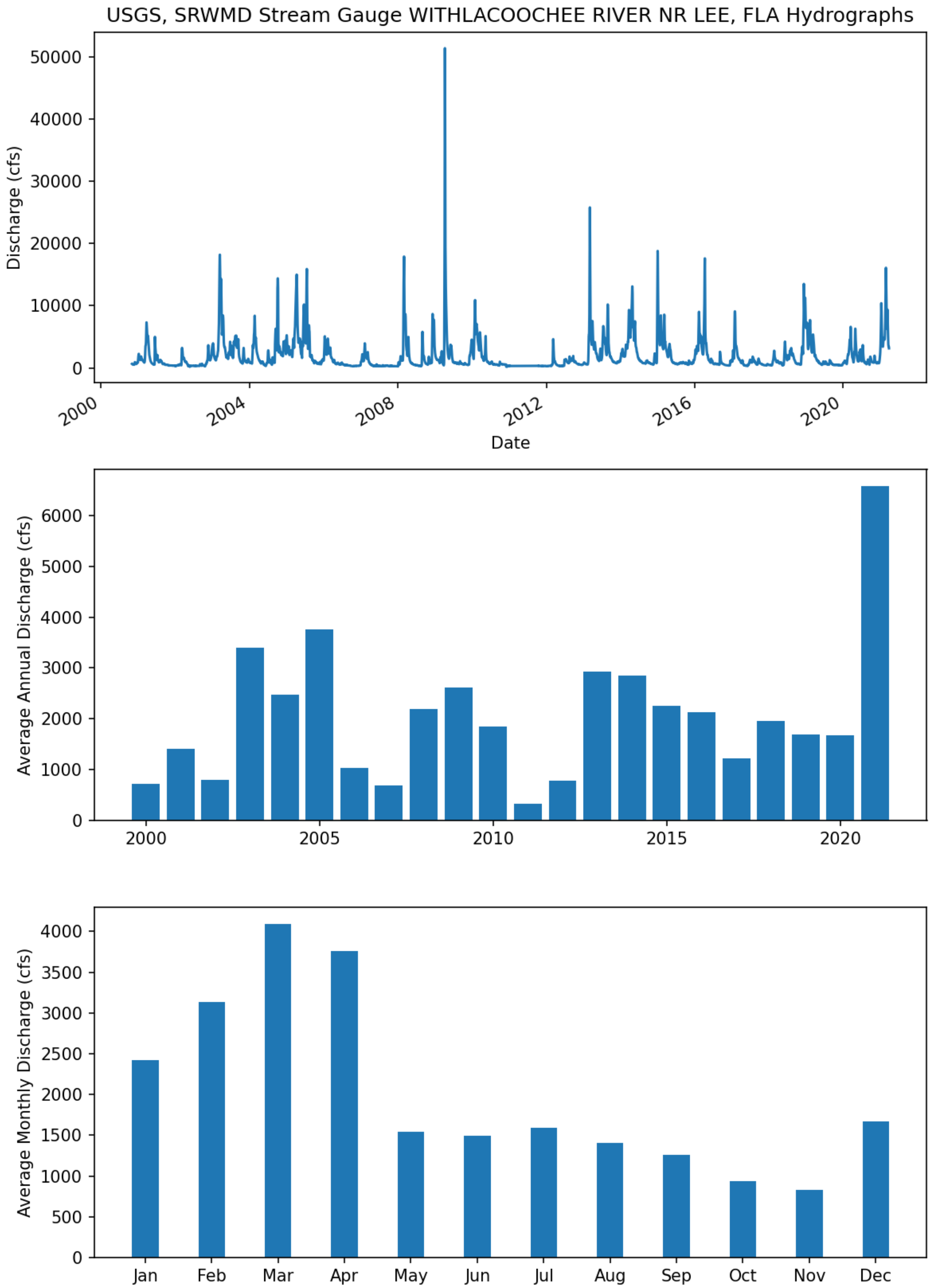

USGS Stream Gauge SUWANNEE RIVER AT WHITE SPRINGS, FLA. Hydrographs
Discharge (cfs)
0
5000
10000
15000
20000
25000
30000
35000
1920
1940
1960
1980
2000
2020
Date
Average Annual Discharge (cfs)
0
1000
2000
3000
4000
5000
1900
1920
1940
1960
1980
2000
2020
Average Monthly Discharge (cfs)
0
500
1000
1500
2000
2500
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

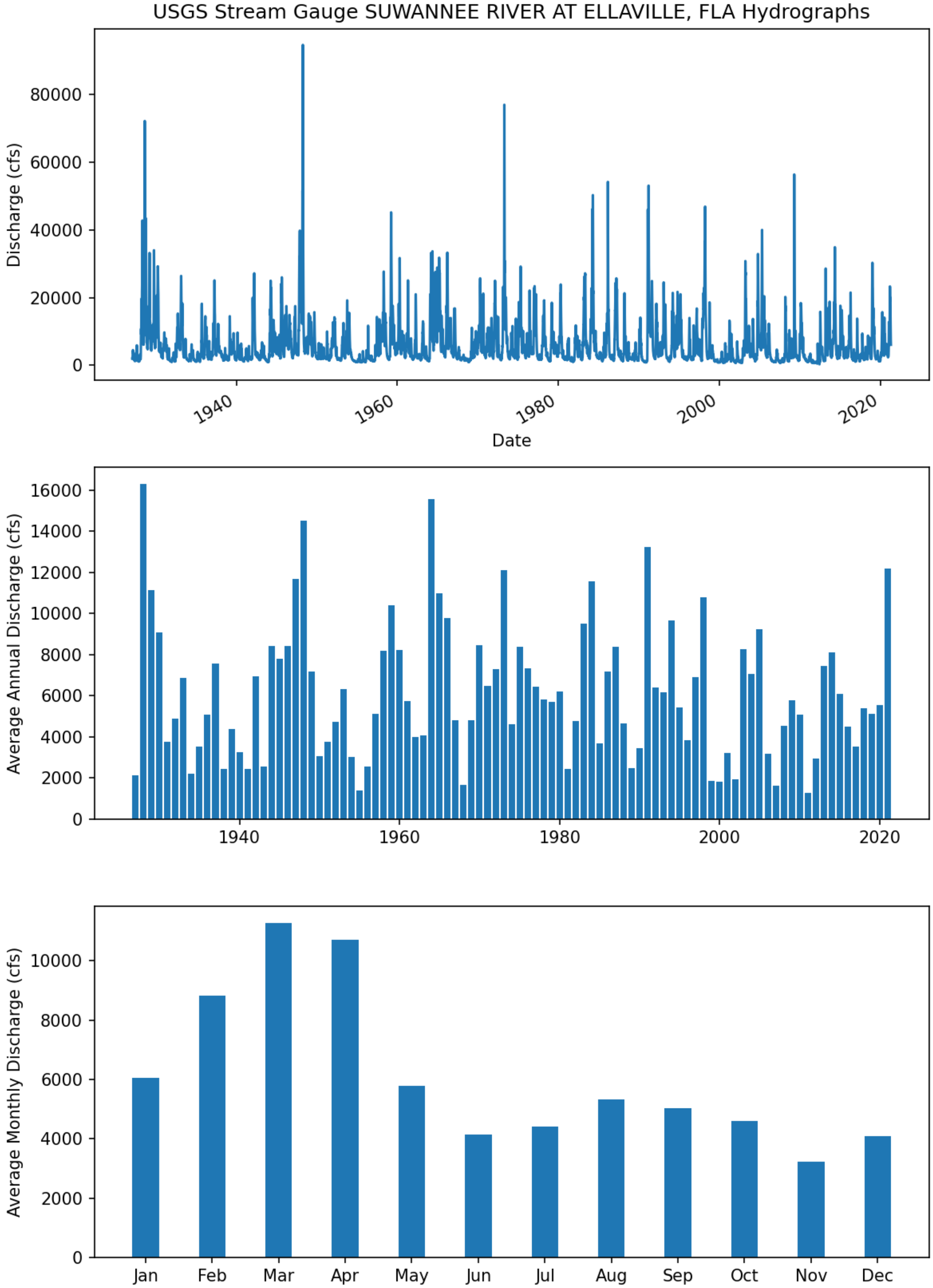

USGS, SRWMD Stream Gauge SUWANNEE RIVER AT SUWANNEE SPRINGS FLA Hydrograpl
Discharge (cfs)
20000
17500
15000
12500
10000
7500
5000
2500
0
1980
1990
2000
2010
2020
Date
Average Annual Discharge (cfs)
4000
3500
3000
2500
2000
1500
1000
500
0
1980
1990
2000
2010
2020
Average Monthly Discharge (cfs)
3500
3000
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

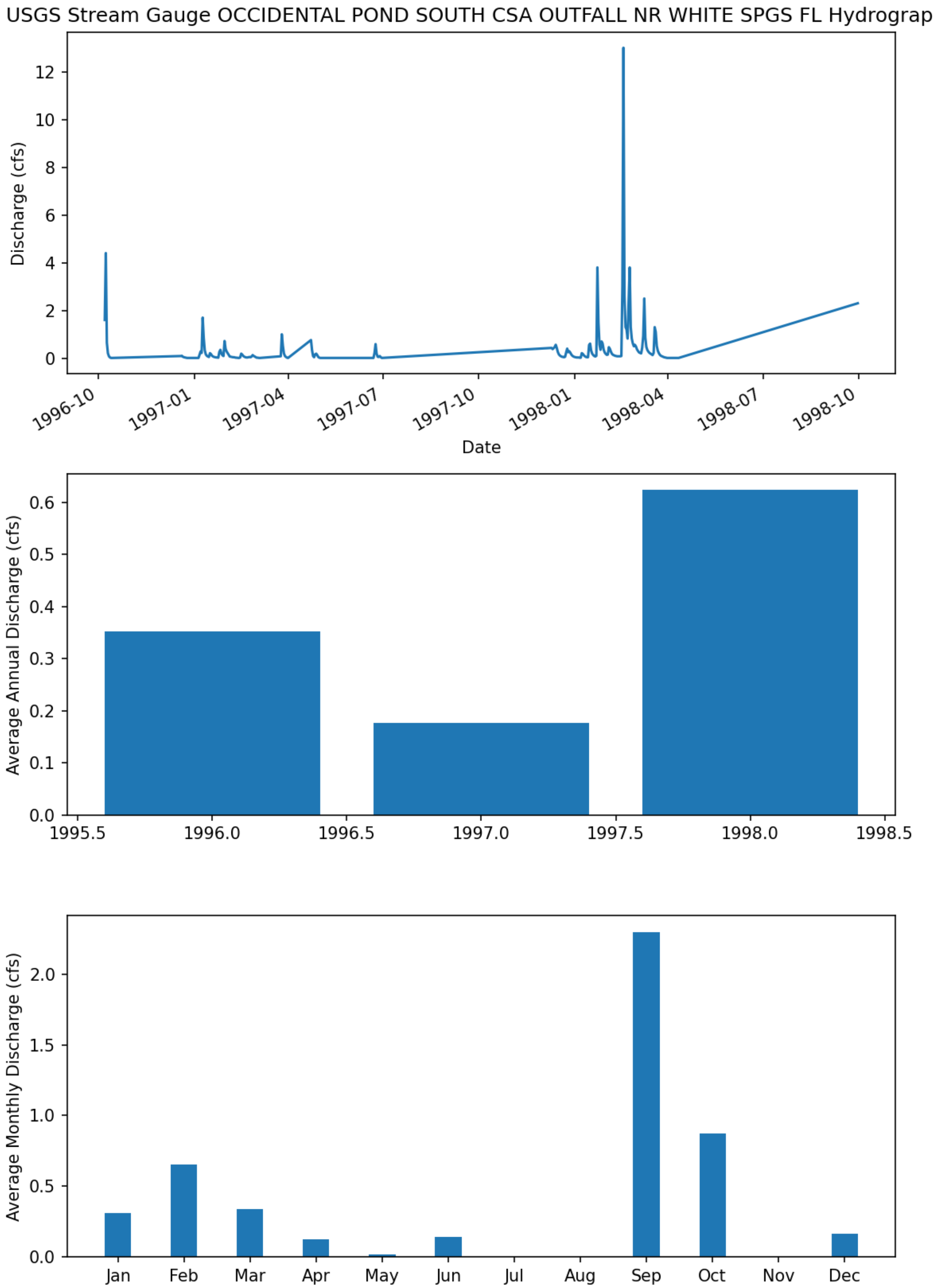

USGS, SRWMD Stream Gauge ALAPAHA RIVER NEAR JENNINGS FLA Hydrographs
Discharge (cfs)
25000
20000
15000
10000
5000
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date
Average Annual Discharge (cfs)
4000
3000
2000
1000
0
1980
1990
2000
2010
2020
Average Monthly Discharge (cfs)
3500
3000
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


USGS Stream Gauge WITHLACOOCHEE RIVER NEAR PINETTA, FLA. Hydrographs
Discharge (cfs)
0
10000
20000
30000
40000
50000
60000
70000
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Date
Average Annual Discharge (cfs)
0
1000
2000
3000
4000
5000
6000
1940
1960
1980
2000
2020
Average Monthly Discharge (cfs)
0
500
1000
1500
2000
2500
3000
3500
4000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

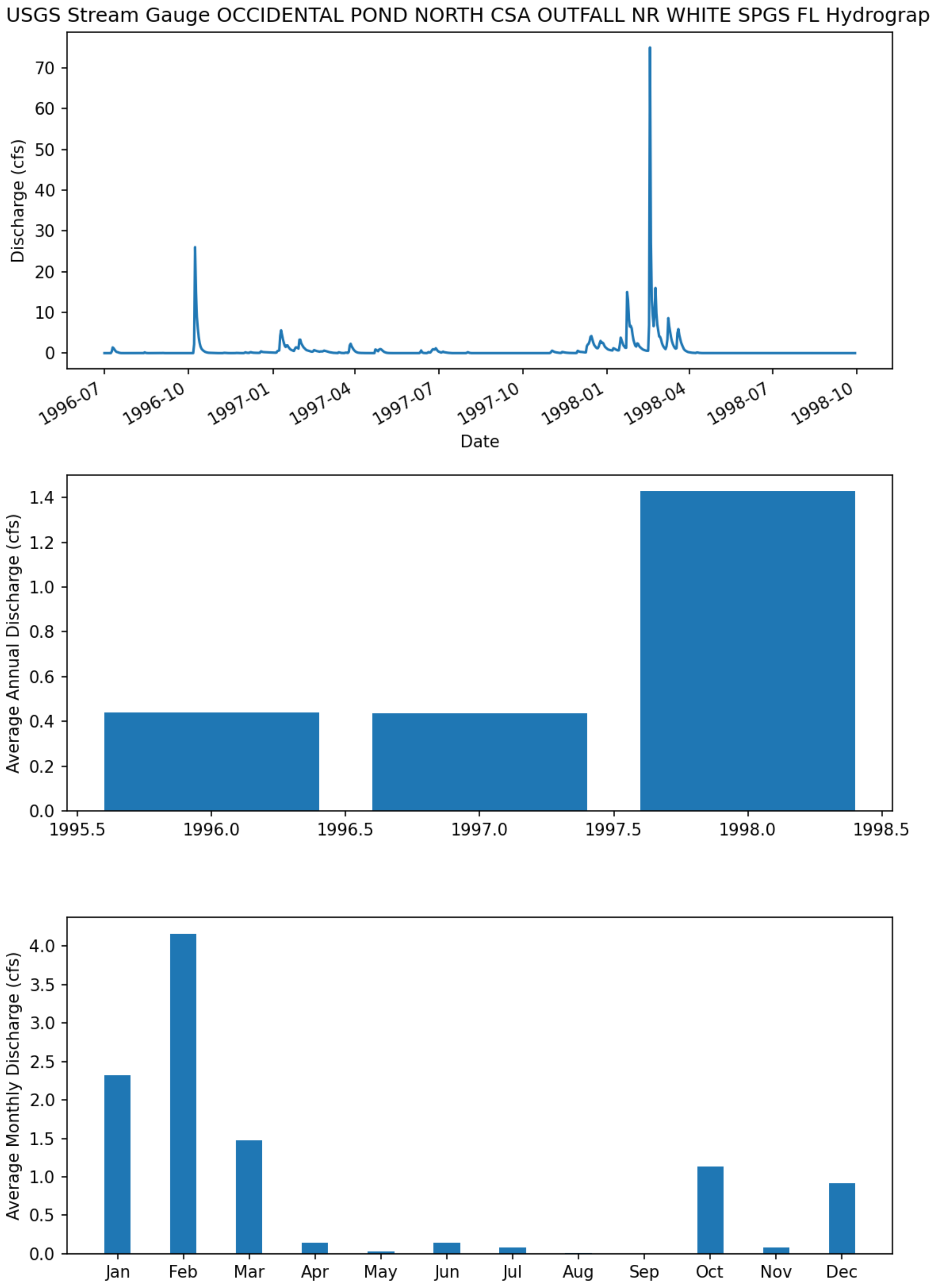

USGS Stream Gauge MADISON BLUE SPRING NR BLUE SPRINGS, FL Hydrographs
Discharge (cfs)
Date
Average Annual Discharge (cfs)
Average Monthly Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

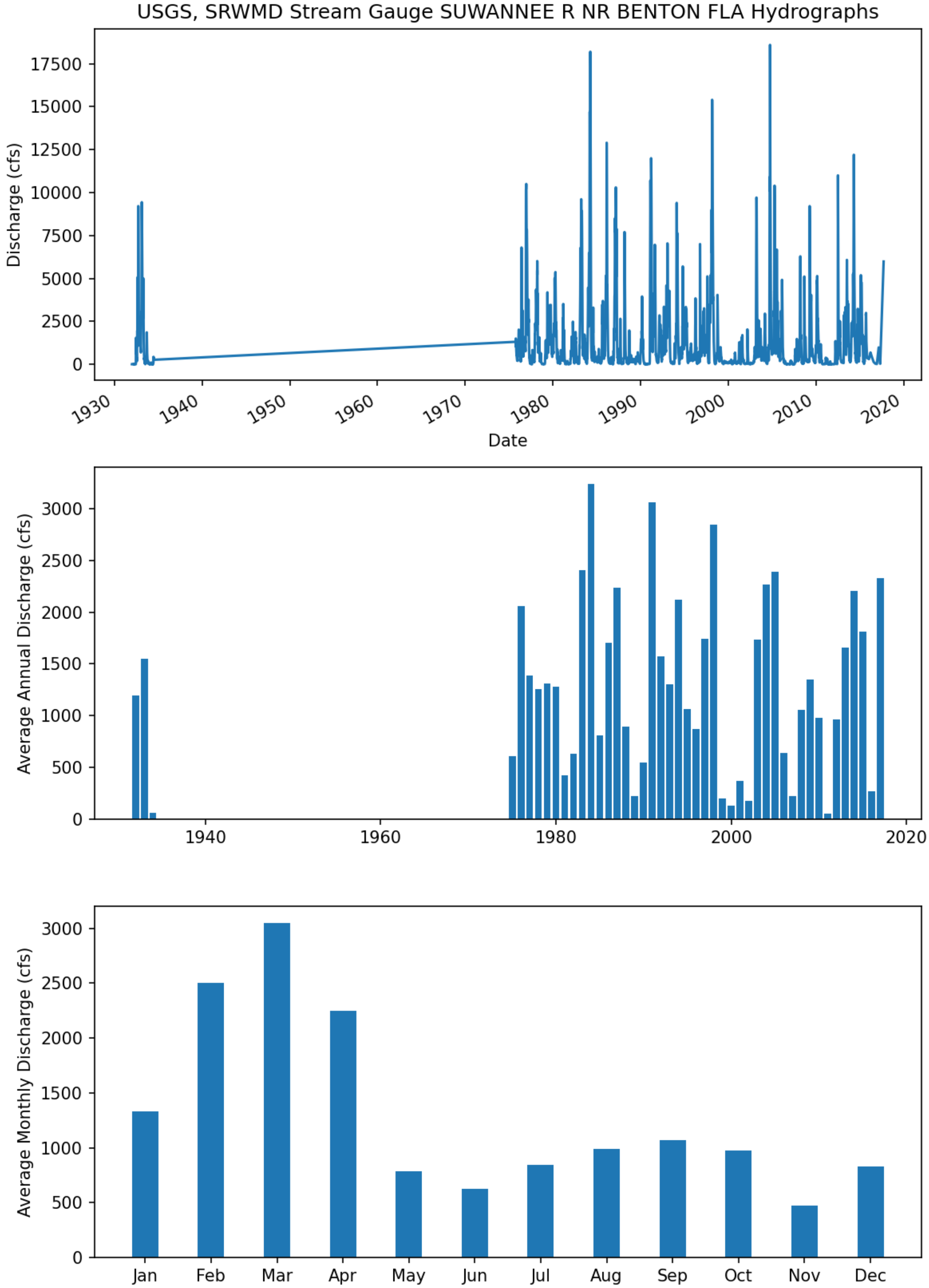

USGS, SRWMD Stream Gauge WITHLACOOCHEE RIVER NR LEE, FLA Hydrographs
Discharge (cfs)
50000
40000
30000
20000
10000
0
2000
2004
2008
2012
2016
2020
Date
Average Annual Discharge (cfs)
6000
5000
4000
3000
2000
1000
0
2000
2005
2010
2015
2020
Average Monthly Discharge (cfs)
4000
3500
3000
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


USGS Stream Gauge SUWANNEE RIVER AT ELLAVILLE, FLA Hydrographs
Discharge (cfs)
0
20000
40000
60000
80000
1940
1960
1980
2000
2020
Date
Average Annual Discharge (cfs)
0
2000
4000
6000
8000
10000
12000
14000
16000
1940
1960
1980
2000
2020
Average Monthly Discharge (cfs)
0
2000
4000
6000
8000
10000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

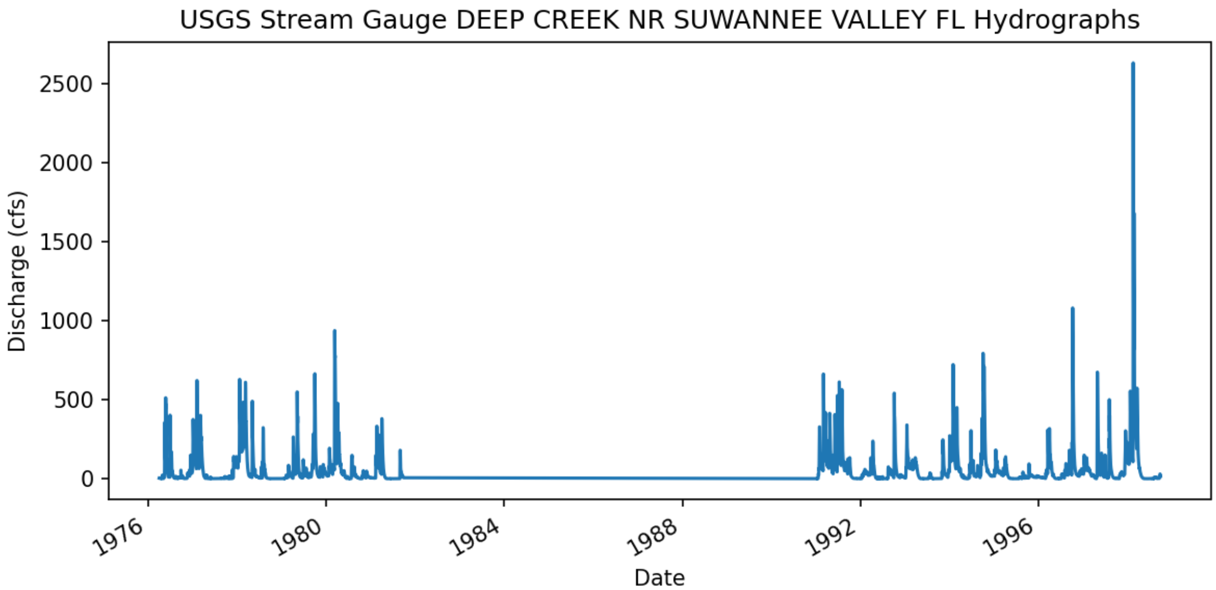


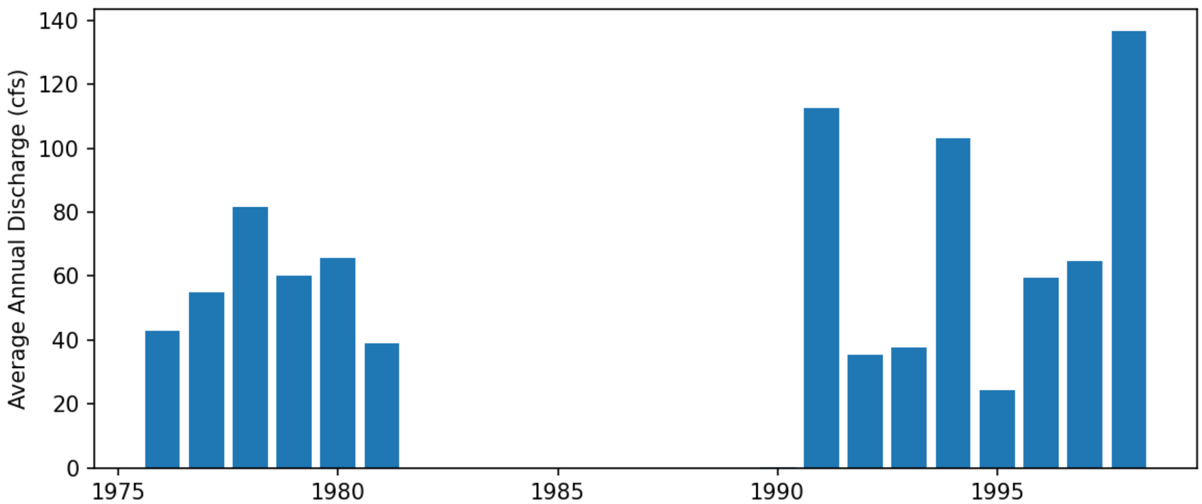
USGS Stream Gauge OCCIDENTAL POND SOUTH CSA OUTFALL NR WHITE SPGS FL Hydrograp
Discharge (cfs)
0
2
4
6
8
10
12
1996-10
1997-01
1997-04
1997-07
1997-10
1998-01
1998-04
1998-07
1998-10
Date
Average Annual Discharge (cfs)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1995.5
1996.0
1996.5
1997.0
1997.5
1998.0
1998.5
Average Monthly Discharge (cfs)
0.0
0.5
1.0
1.5
2.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

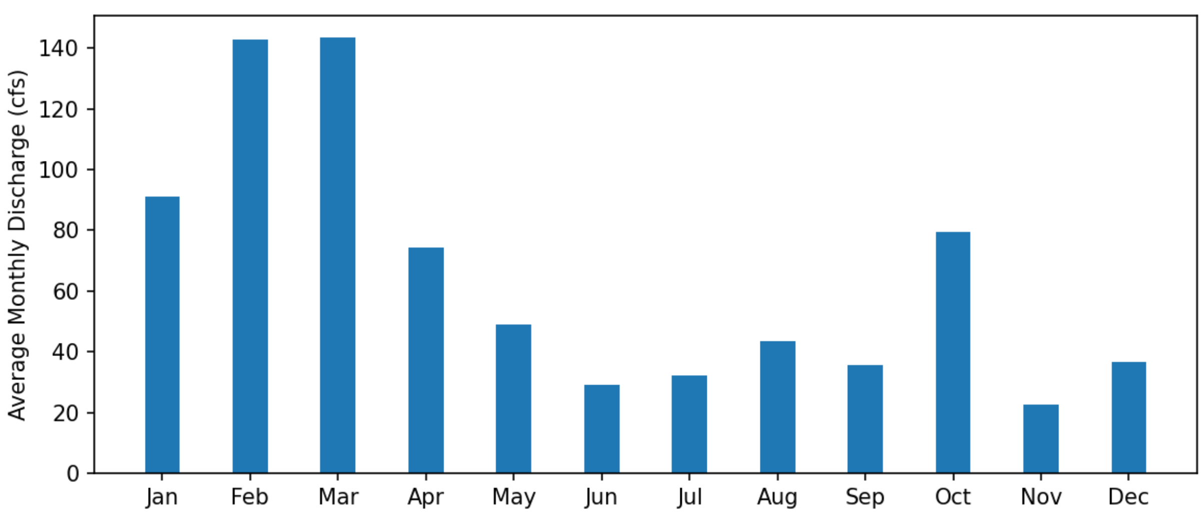

USGS Stream Gauge OCCIDENTAL POND NORTH CSA OUTFALL NR WHITE SPGS FL Hydrograp
Discharge (cfs)
0
10
20
30
40
50
60
70
1996-07
1996-10
1997-01
1997-04
1997-07
1997-10
1998-01
1998-04
1998-07
1998-10
Date
Average Annual Discharge (cfs)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1995.5
1996.0
1996.5
1997.0
1997.5
1998.0
1998.5
Average Monthly Discharge (cfs)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

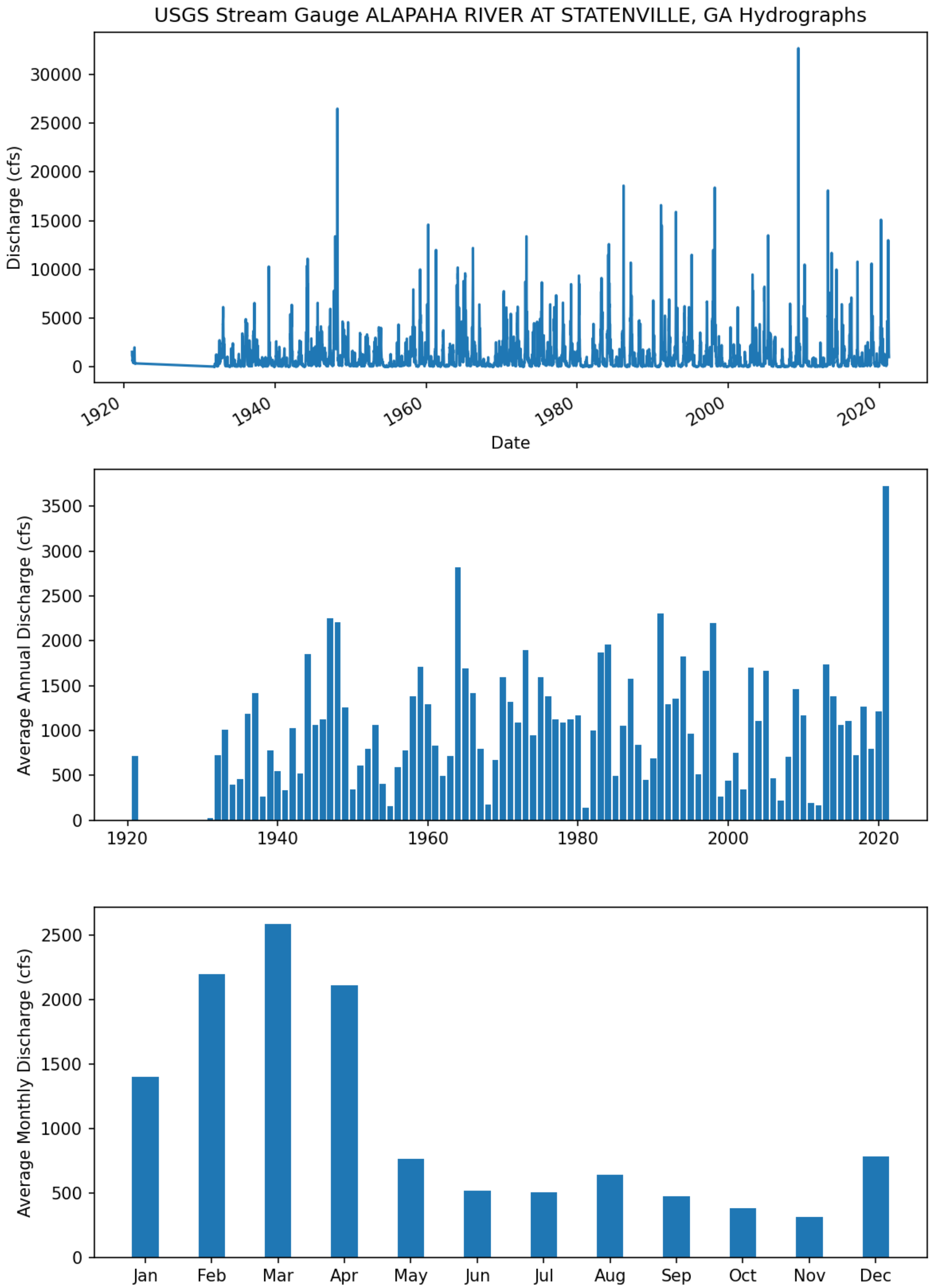


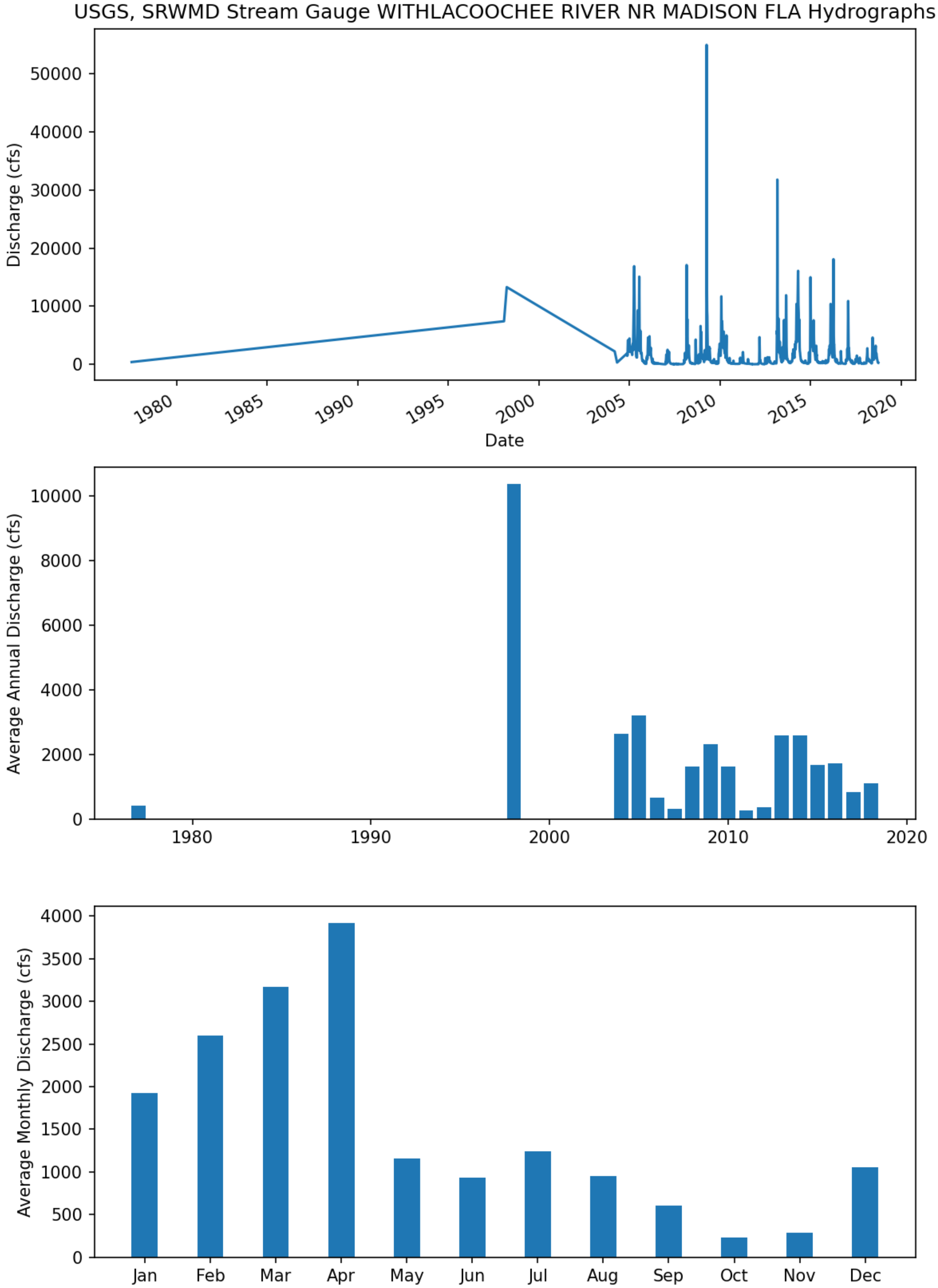
USGS, SRWMD Stream Gauge SUWANNEE R NR BENTON FLA Hydrographs
Discharge (cfs)
Date
Average Annual Discharge (cfs)
Average Monthly Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

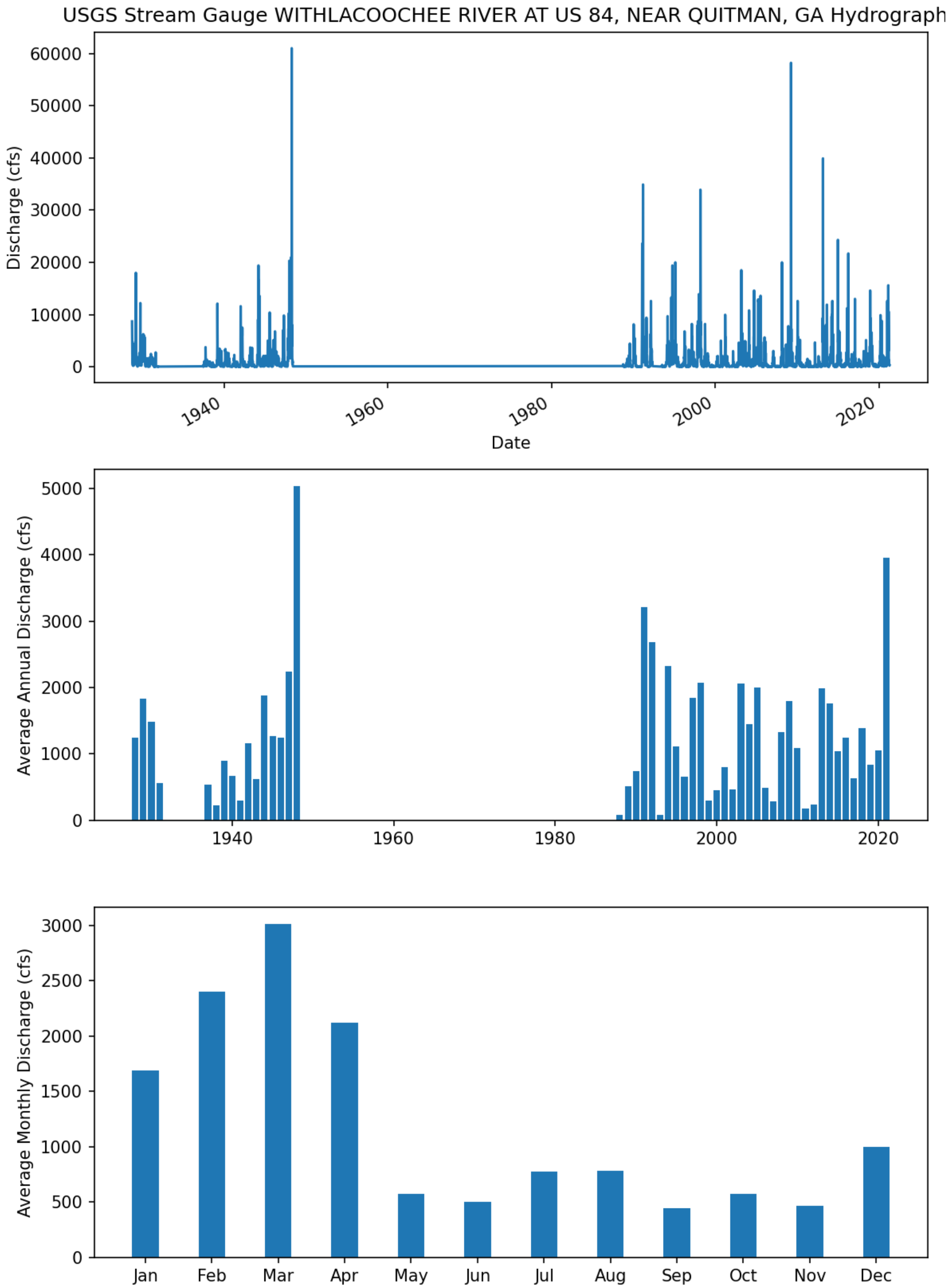

USGS Stream Gauge DEEP CREEK NR SUWANNEE VALLEY FL Hydrographs
Discharge (cfs)
2500
2000
1500
1000
500
0
1976
1980
1984
1988
1992
1996
Date

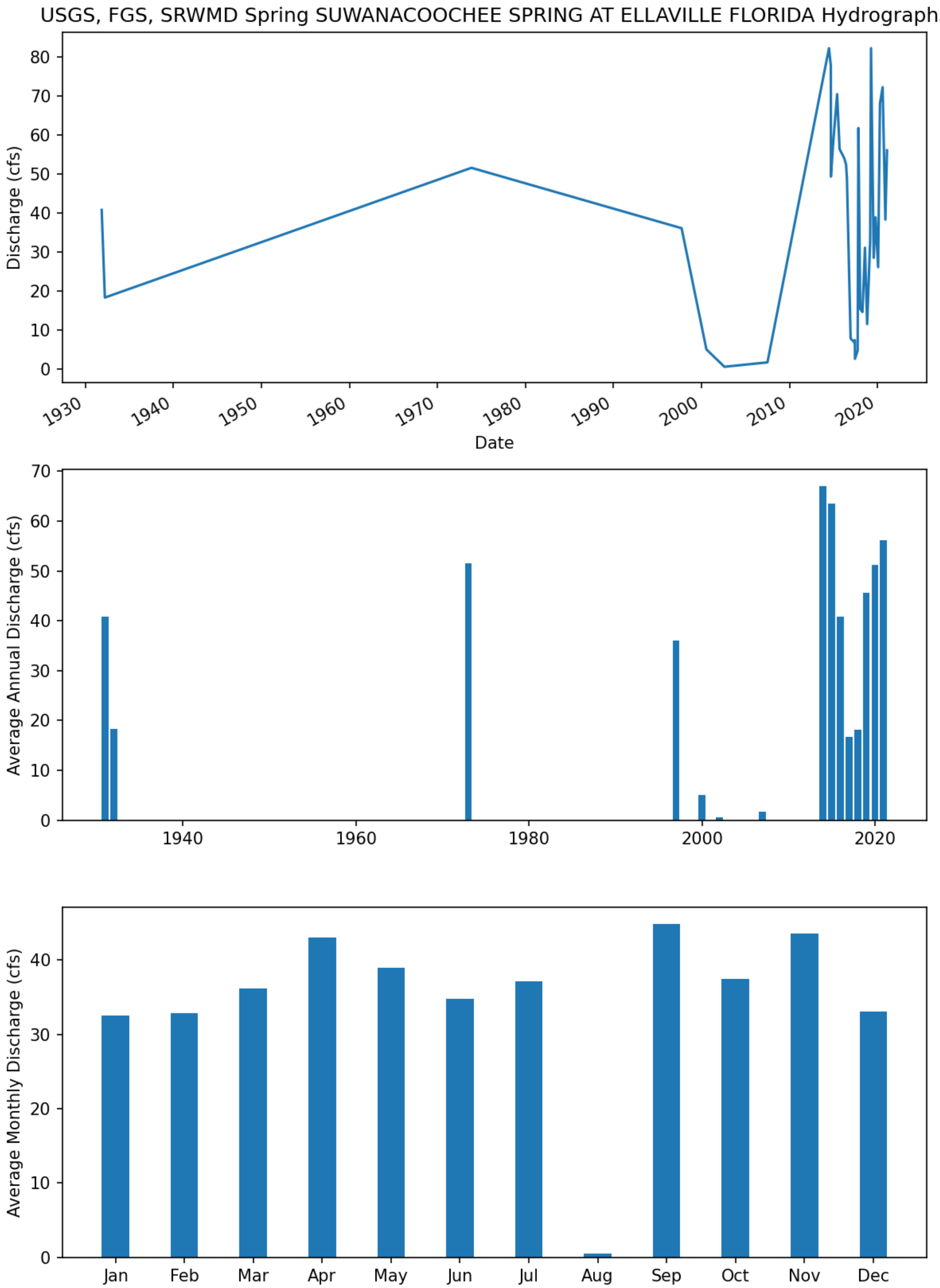

Average Annual Discharge (cfs)
140
120
100
80
60
40
20
0
1975
1980
1985
1990
1995

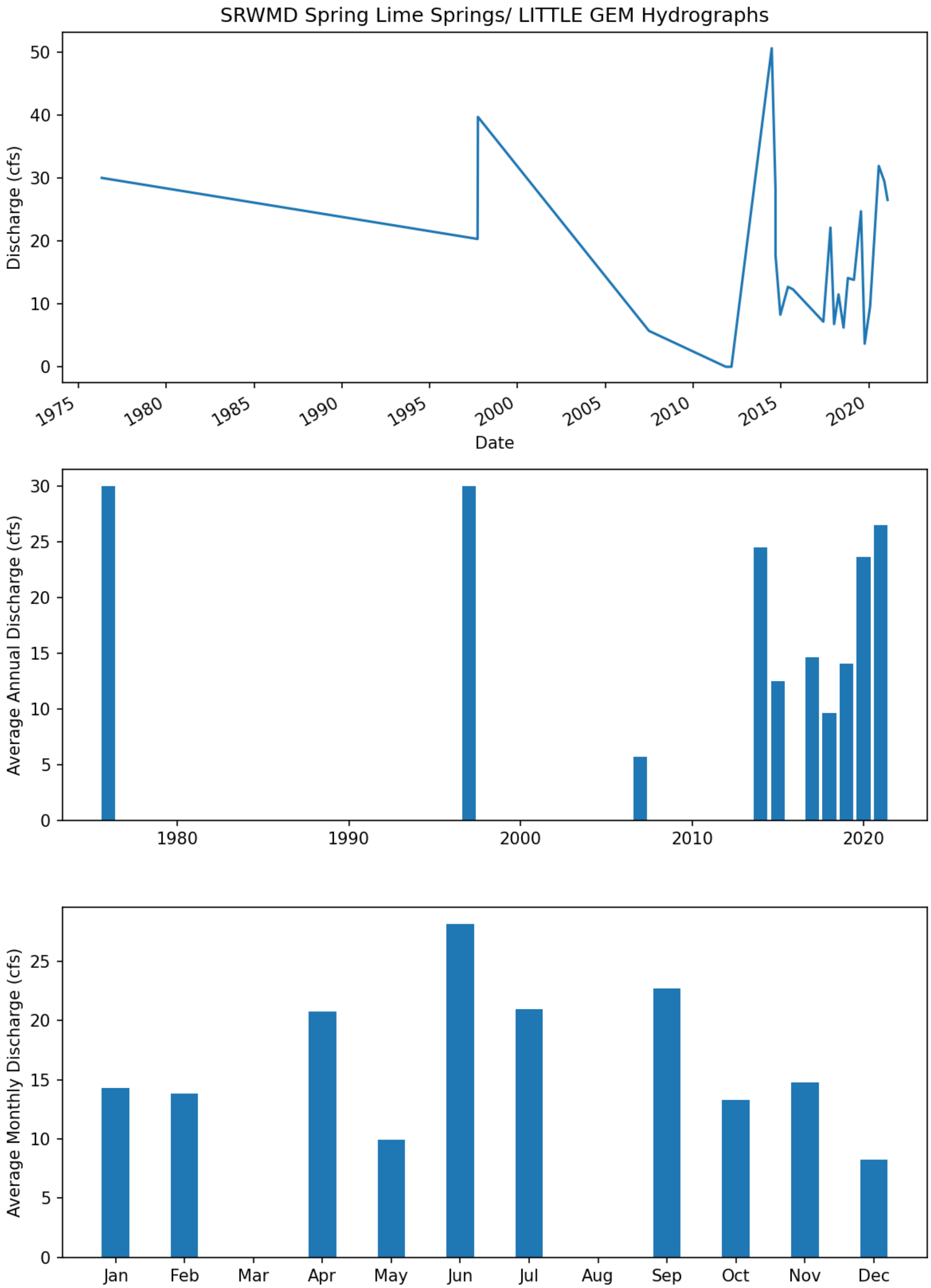

Average Monthly Discharge (cfs)
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


USGS Stream Gauge ALAPAHA RIVER AT STATENVILLE, GA Hydrographs
Discharge (cfs)
30000
25000
20000
15000
10000
5000
0
1920
1940
1960
1980
2000
2020
Date
Average Annual Discharge (cfs)
3500
3000
2500
2000
1500
1000
500
0
1920
1940
1960
1980
2000
2020
Average Monthly Discharge (cfs)
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

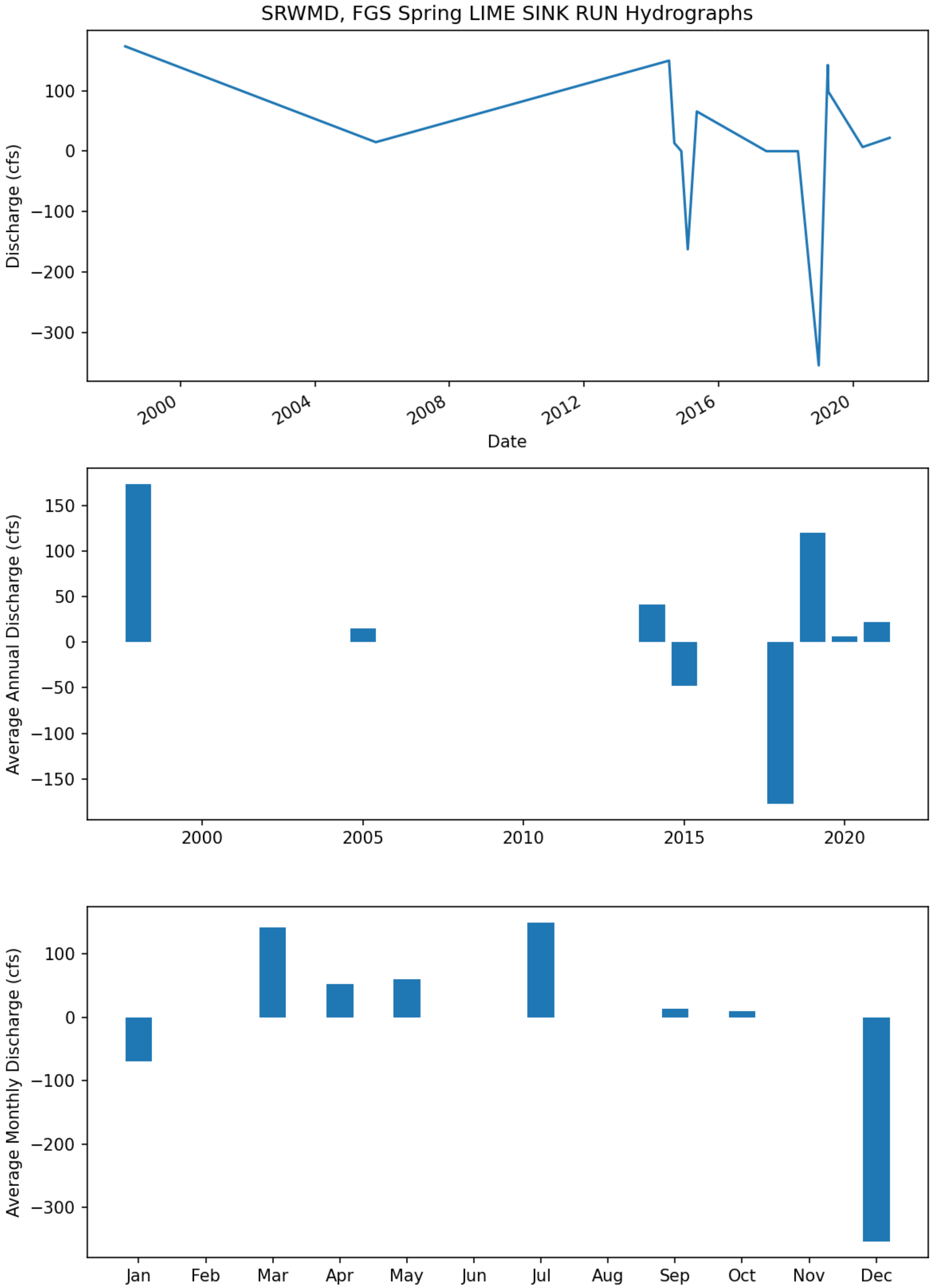

USGS, SRWMD Stream Gauge WITHLACOOCHEE RIVER NR MADISON FLA Hydrographs
Discharge (cfs)
Date
Average Annual Discharge (cfs)
Average Monthly Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

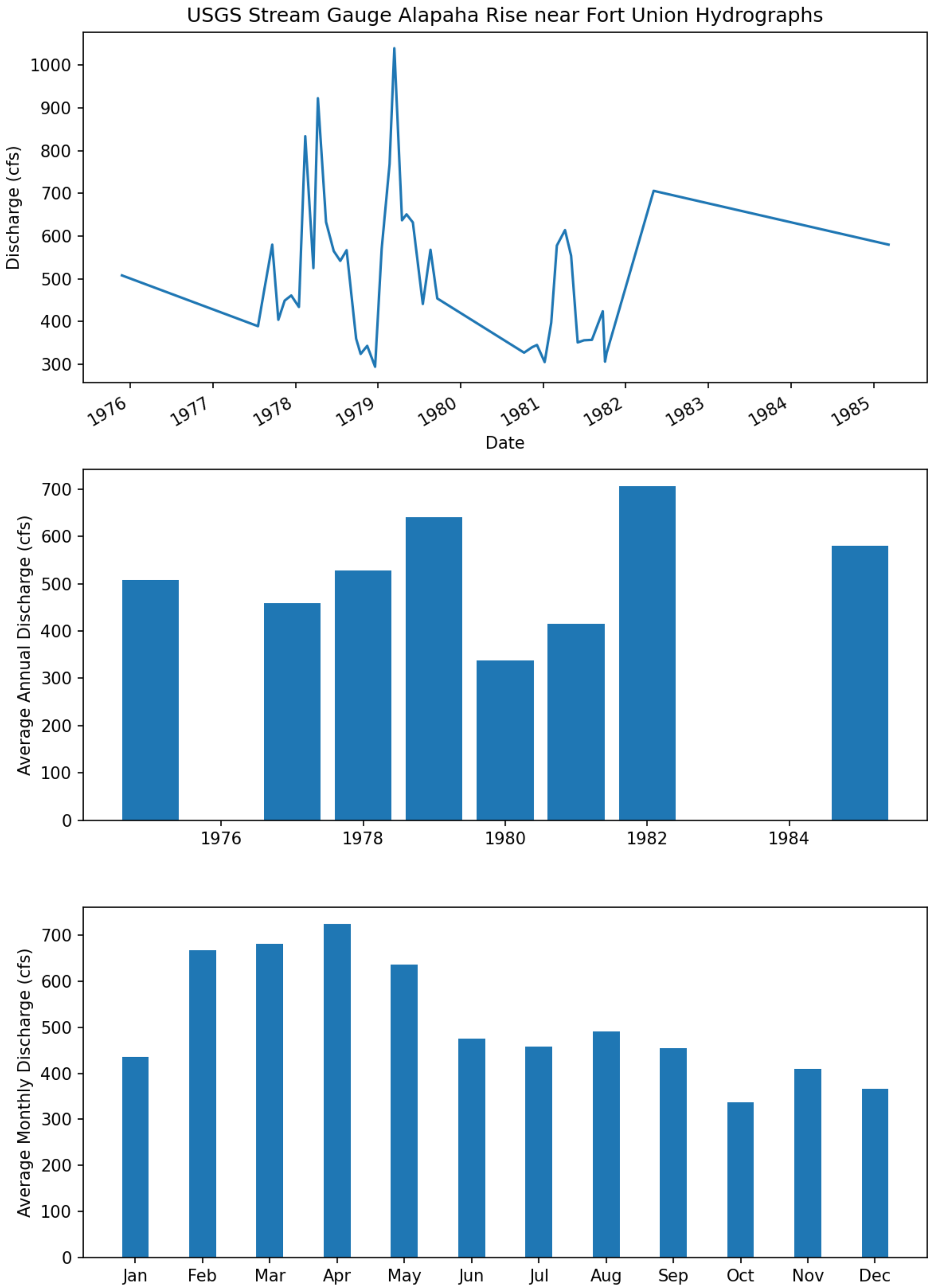

USGS Stream Gauge WITHLACOOCHEE RIVER AT US 84, NEAR QUITMAN, GA Hydrograph
Discharge (cfs)
0
10000
20000
30000
40000
50000
60000
1940
1960
1980
2000
2020
Date
Average Annual Discharge (cfs)
0
1000
2000
3000
4000
5000
1940
1960
1980
2000
2020
Average Monthly Discharge (cfs)
0
500
1000
1500
2000
2500
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

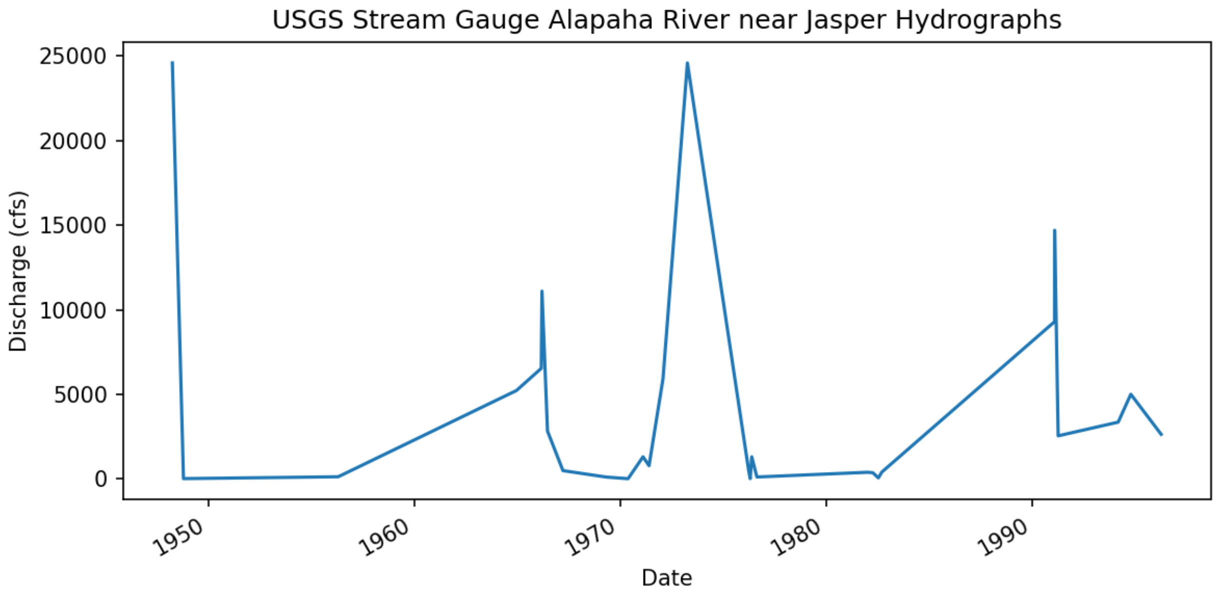

USGS, FGS, SRWMD Spring SUWANACOOCHEE SPRING AT ELLAVILLE FLORIDA Hydrographs
Discharge (cfs)
Date
Average Annual Discharge (cfs)
Average Monthly Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

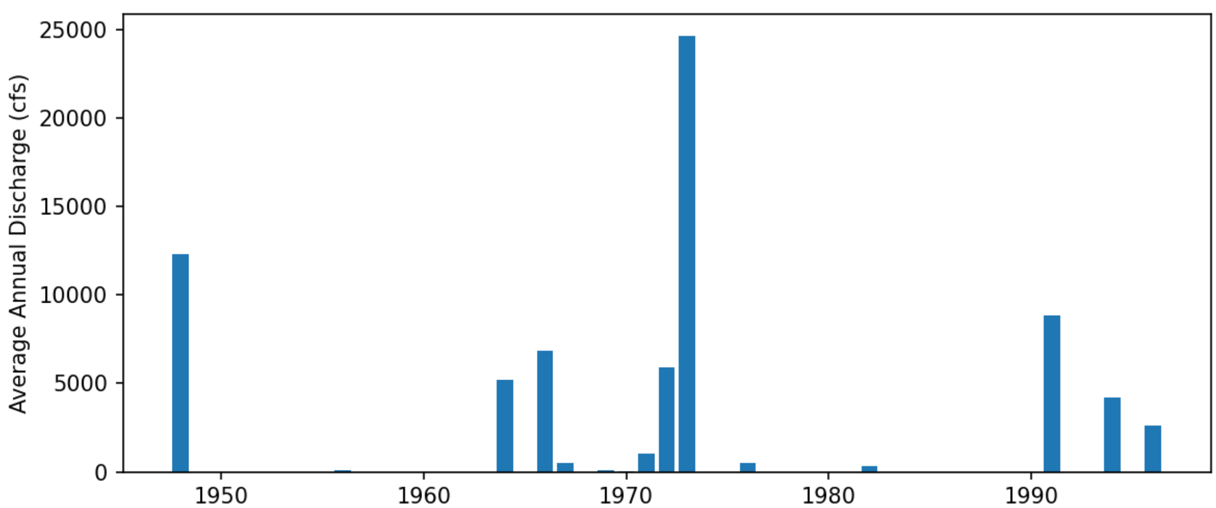


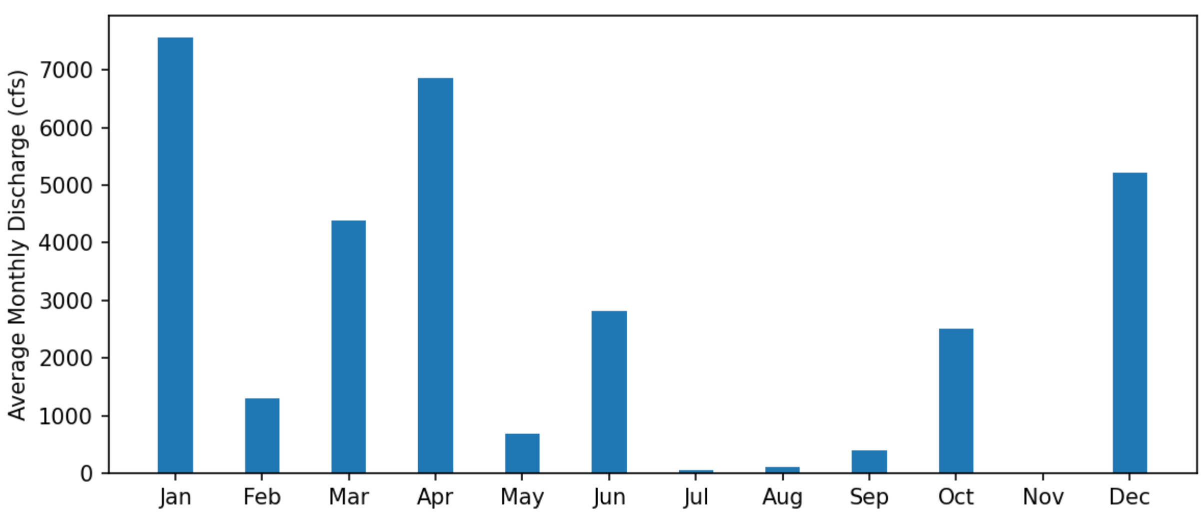
SRWMD Spring Lime Springs/ LITTLE GEM Hydrographs
Discharge (cfs)
Date
Average Annual Discharge (cfs)
Average Monthly Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

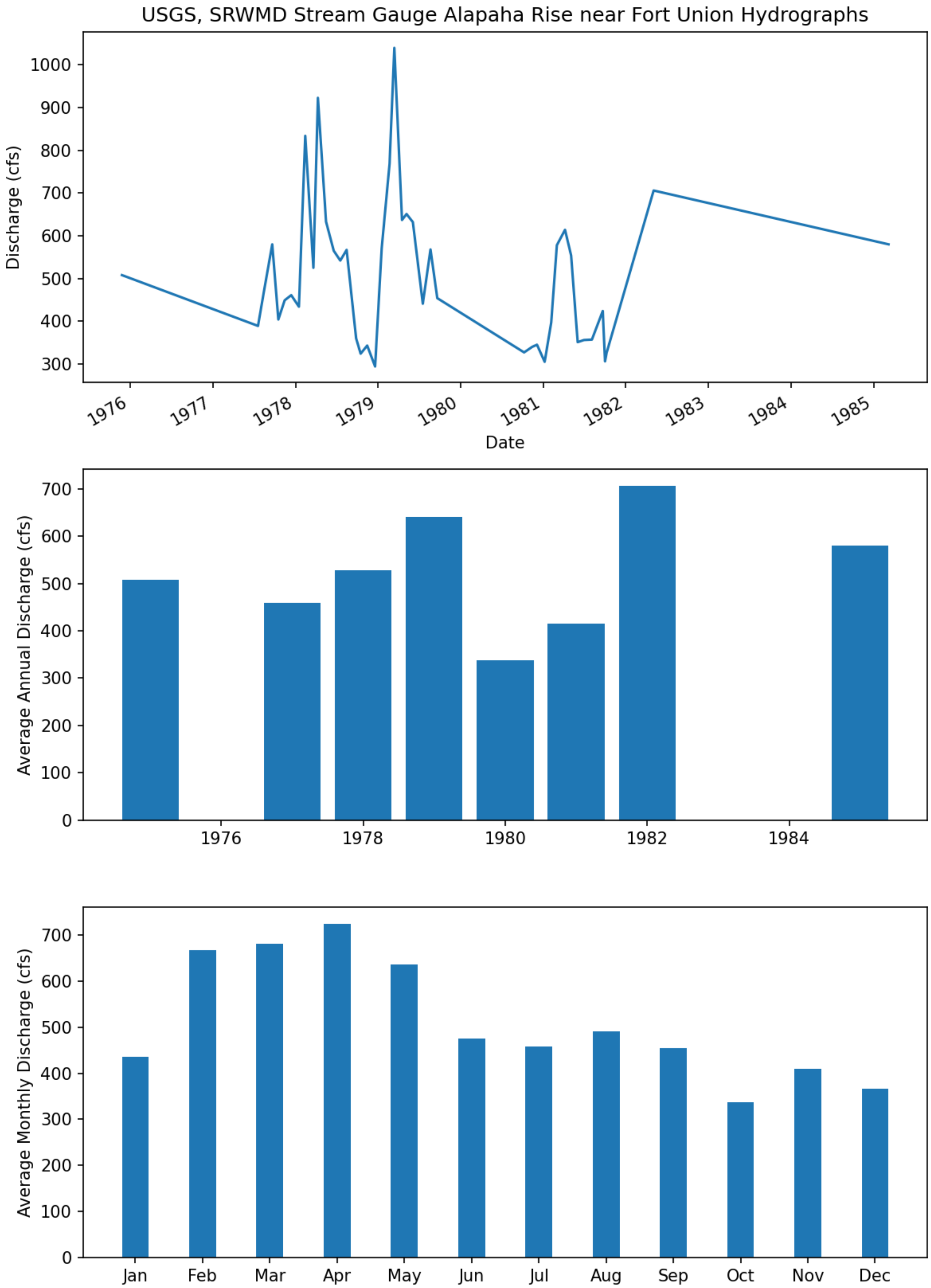

SRWMD, FGS Spring LIME SINK RUN Hydrographs
Discharge (cfs)
100
0
−100
−200
−300
2000
2004
2008
2012
2016
2020
Date
Average Annual Discharge (cfs)
150
100
50
0
−50
−100
−150
2000
2005
2010
2015
2020
Average Monthly Discharge (cfs)
100
0
−100
−200
−300
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

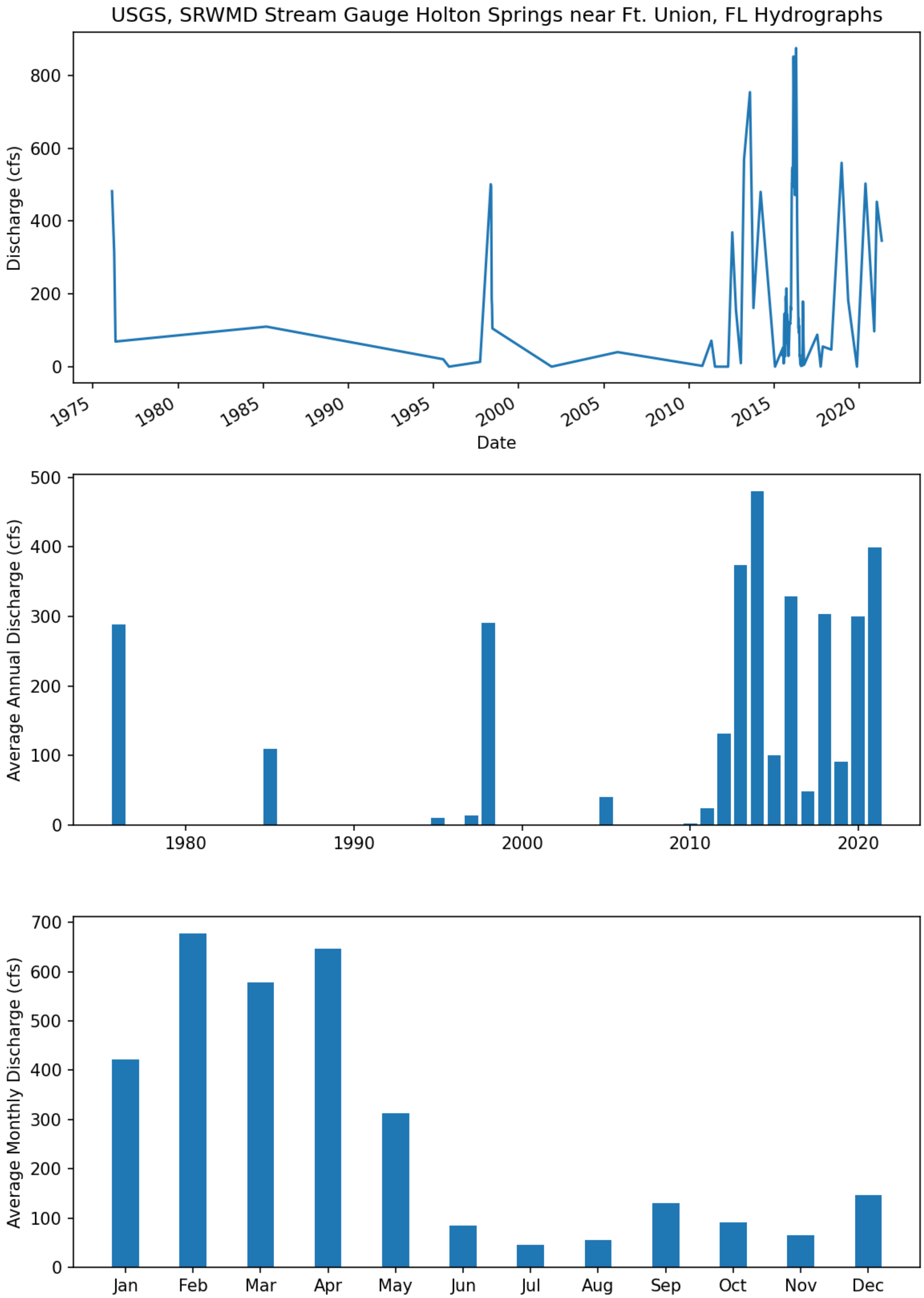

USGS Stream Gauge Alapaha Rise near Fort Union Hydrographs
Discharge (cfs)
1000
900
800
700
600
500
400
300
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
Date
Average Annual Discharge (cfs)
700
600
500
400
300
200
100
0
1976
1978
1980
1982
1984
Average Monthly Discharge (cfs)
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

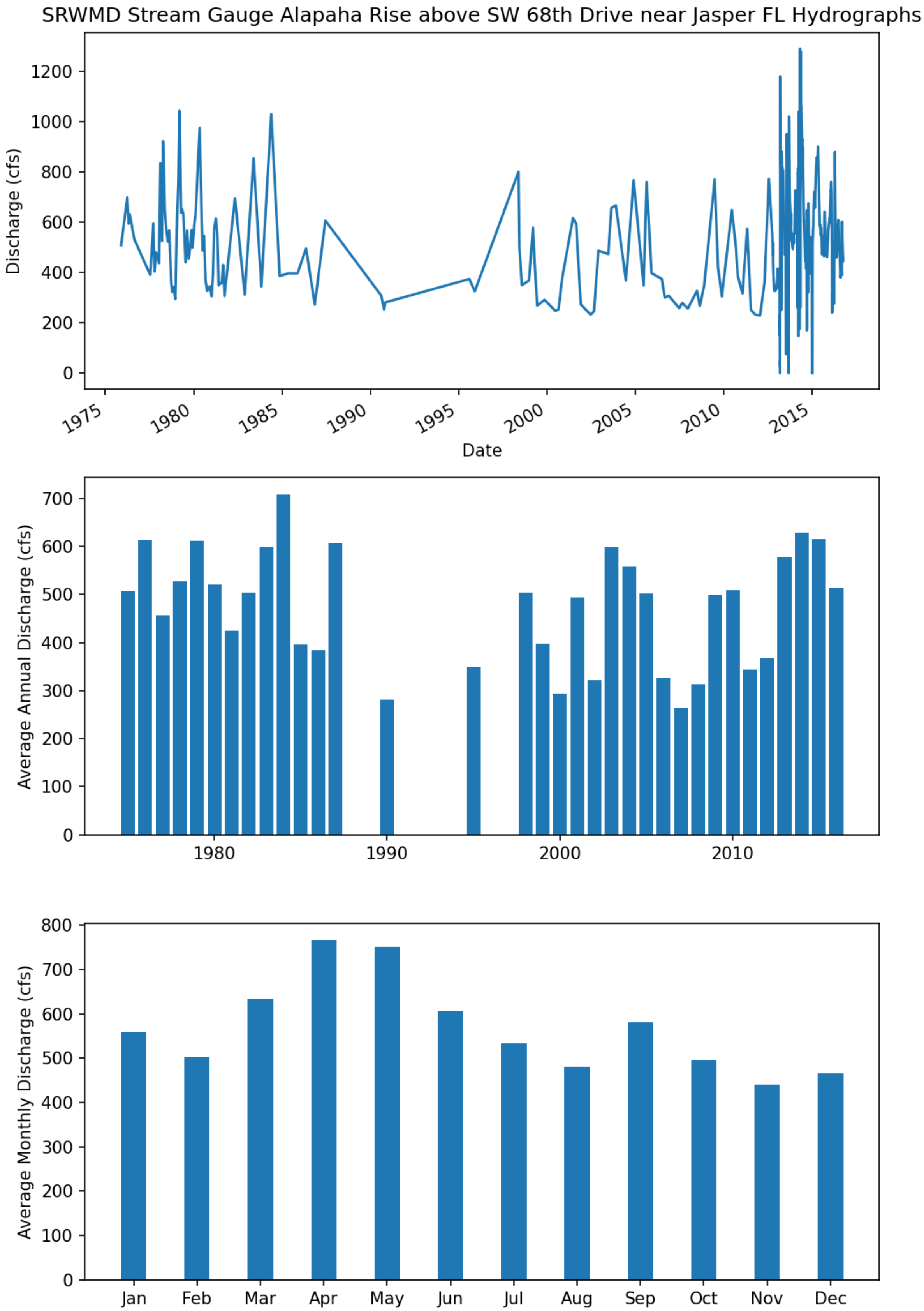

USGS Stream Gauge Alapaha River near Jasper Hydrographs
Discharge (cfs)
25000
20000
15000
10000
5000
0
1950
1960
1970
1980
1990
Date


Average Annual Discharge (cfs)
25000
20000
15000
10000
5000
0
1950
1960
1970
1980
1990

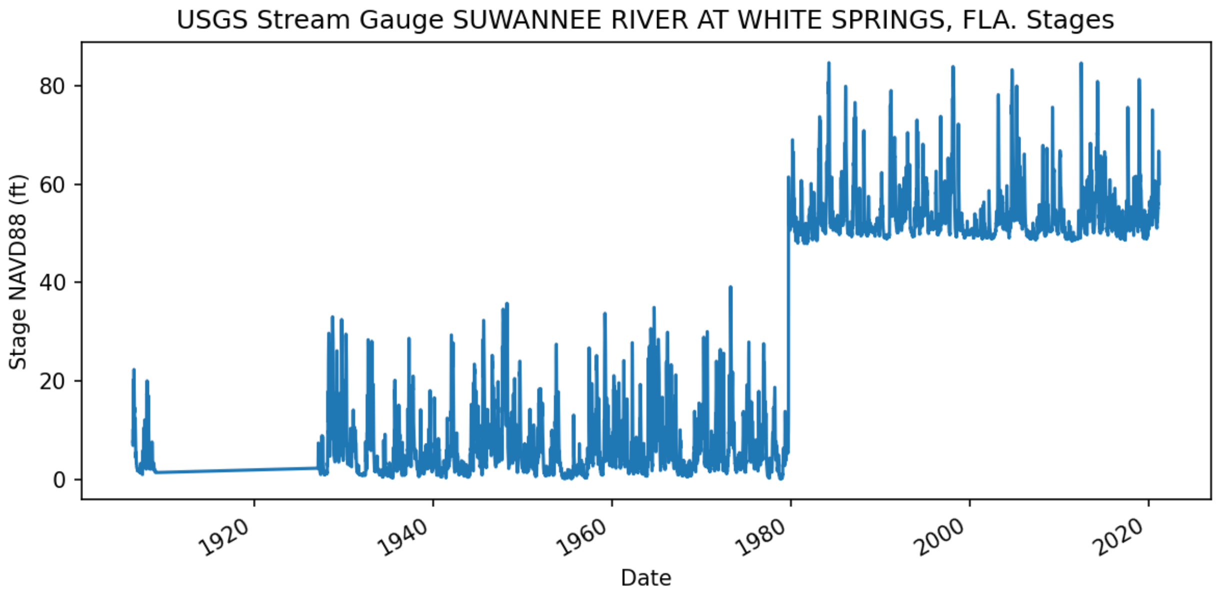

Average Monthly Discharge (cfs)
7000
6000
5000
4000
3000
2000
1000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

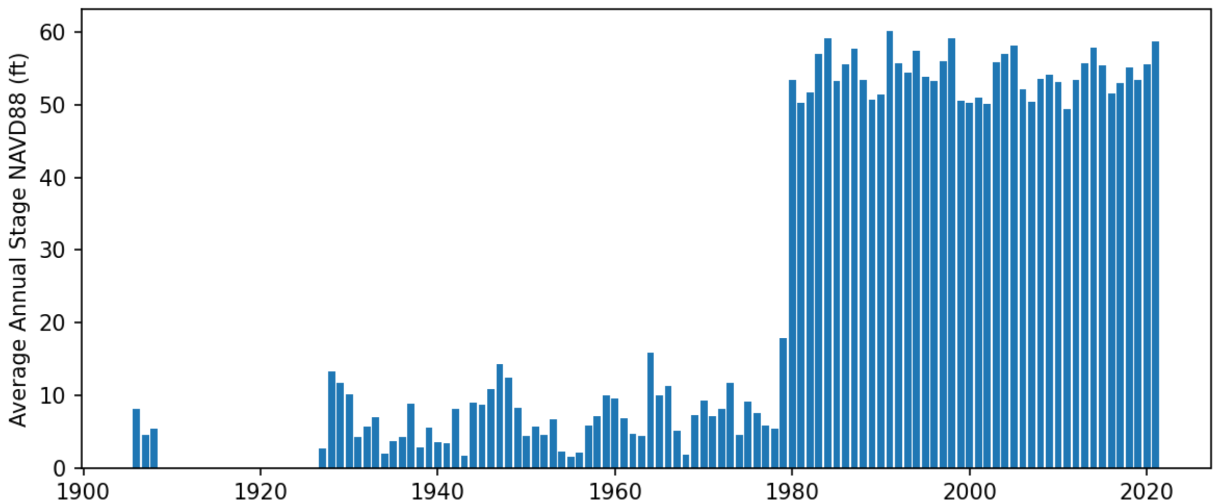

USGS, SRWMD Stream Gauge Alapaha Rise near Fort Union Hydrographs
Discharge (cfs)
1000
900
800
700
600
500
400
300
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
Date
Average Annual Discharge (cfs)
700
600
500
400
300
200
100
0
1976
1978
1980
1982
1984
Average Monthly Discharge (cfs)
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

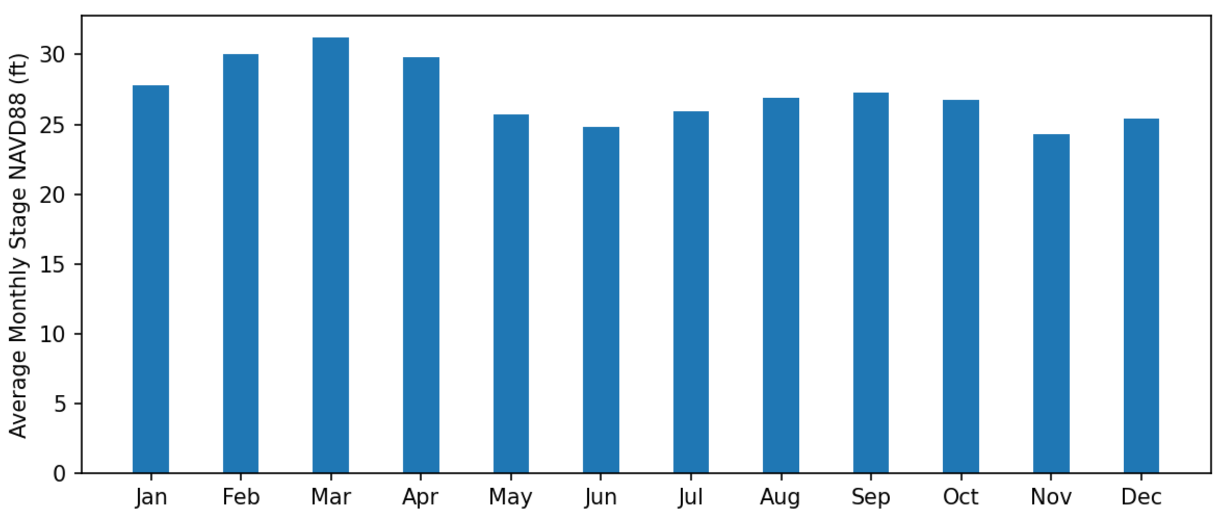

USGS, SRWMD Stream Gauge Holton Springs near Ft. Union, FL Hydrographs
Discharge (cfs)
0
200
400
600
800
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date
Average Annual Discharge (cfs)
0
100
200
300
400
500
1980
1990
2000
2010
2020
Average Monthly Discharge (cfs)
0
100
200
300
400
500
600
700
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

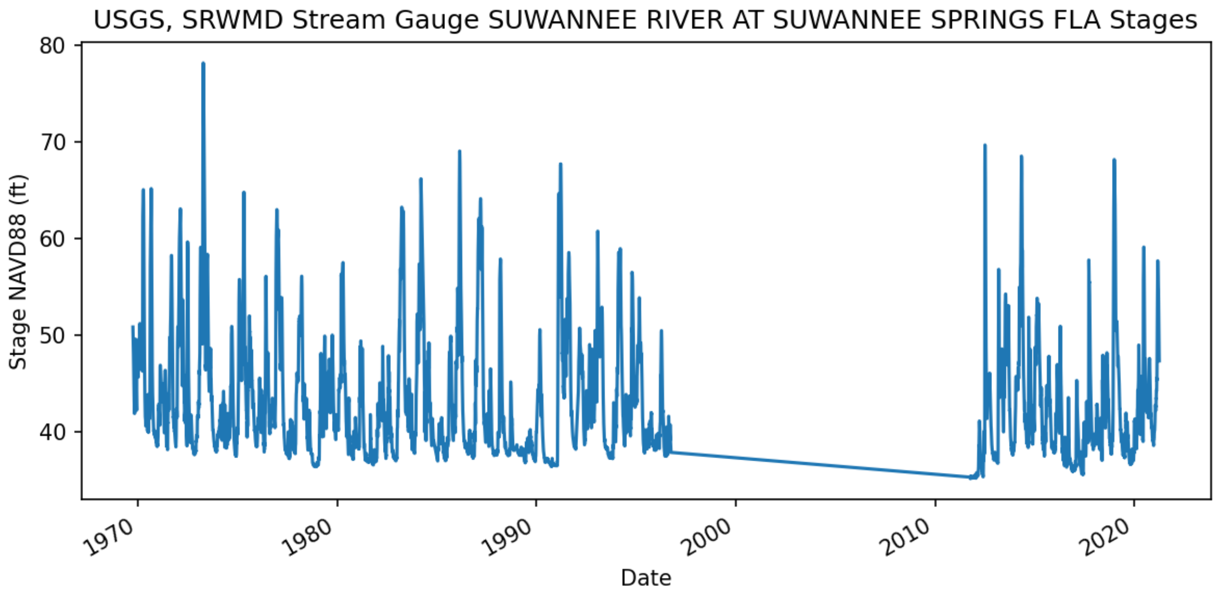

SRWMD Stream Gauge Alapaha Rise above SW 68th Drive near Jasper FL Hydrographs
Discharge (cfs)
0
200
400
600
800
1000
1200
1975
1980
1985
1990
1995
2000
2005
2010
2015
Date
Average Annual Discharge (cfs)
0
100
200
300
400
500
600
700
1980
1990
2000
2010
Average Monthly Discharge (cfs)
0
100
200
300
400
500
600
700
800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

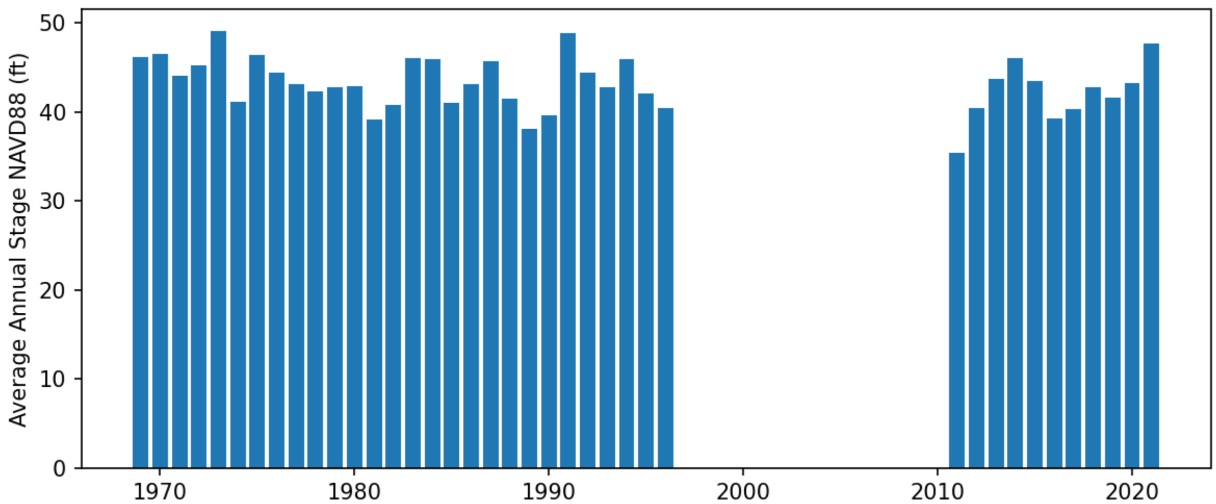
Appendix C: Stage Time Series for Flow Stations with Stage Data

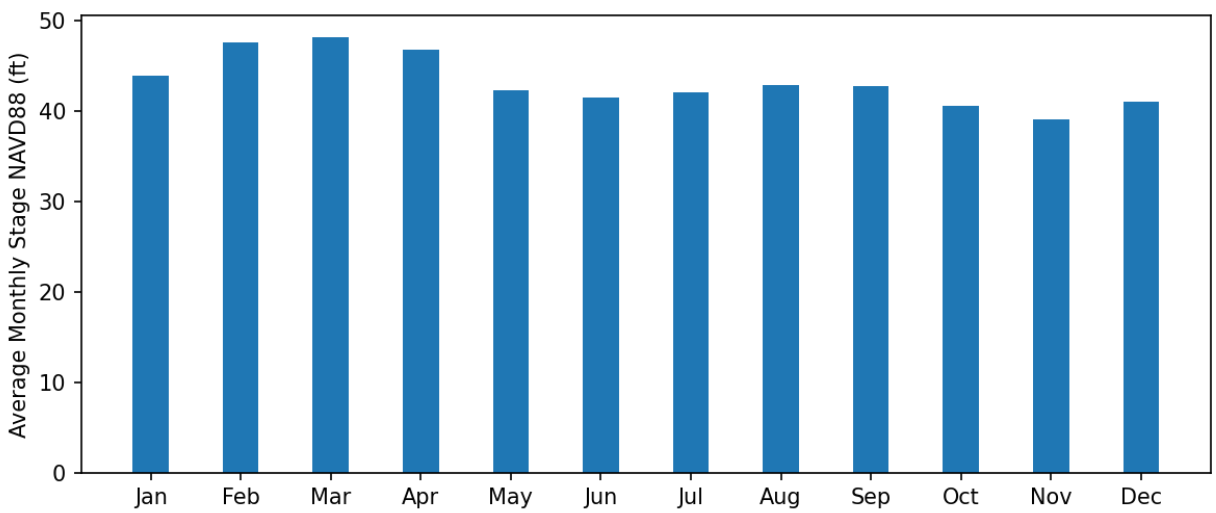

USGS Stream Gauge SUWANNEE RIVER AT WHITE SPRINGS, FLA. Stages
Stage NAVD88 (ft)
0
20
40
60
80
1920
1940
1960
1980
2000
2020
Date

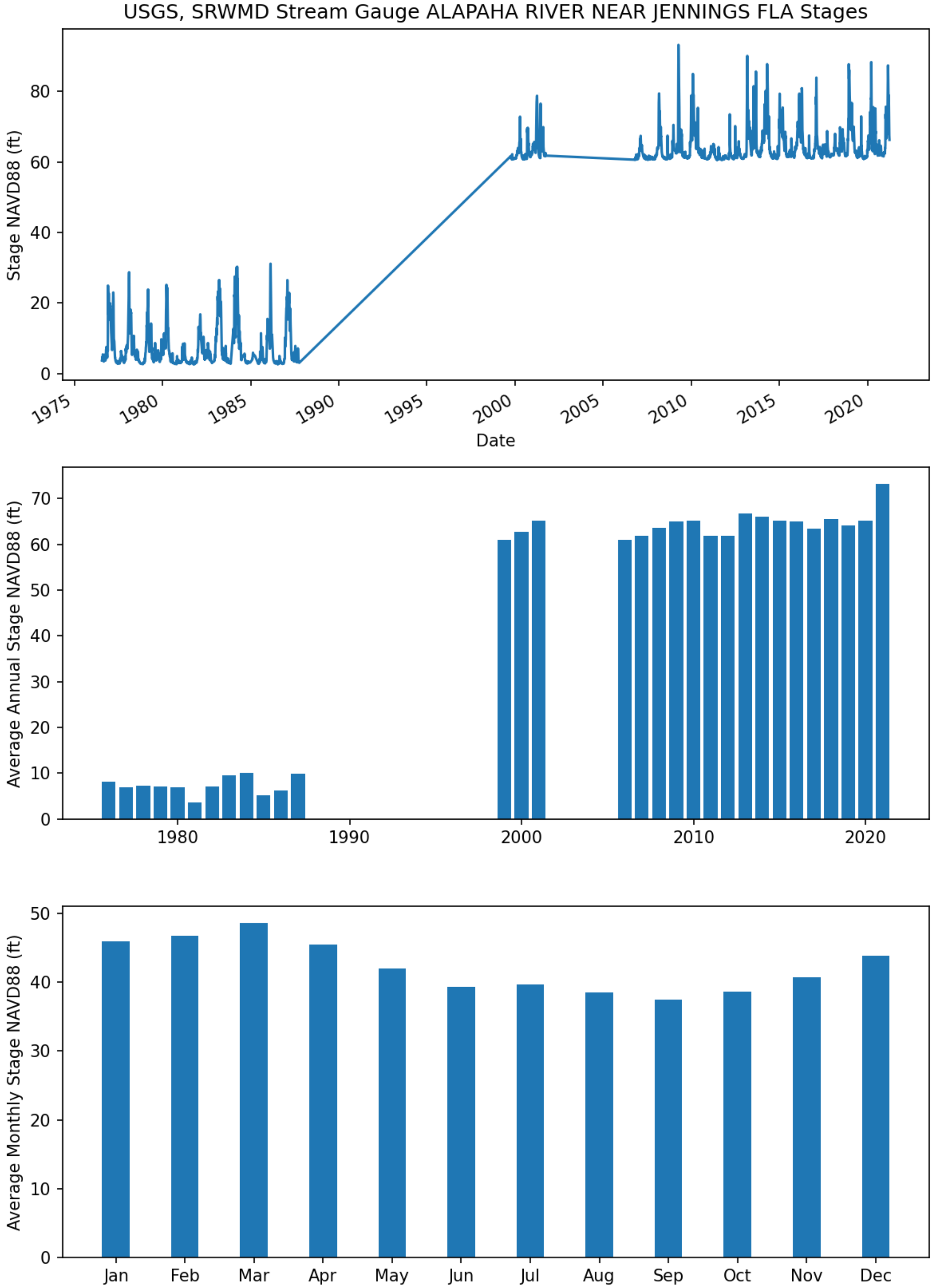

Average Annual Stage NAVD88 (ft)
0
10
20
30
40
50
60
1900
1920
1940
1960
1980
2000
2020

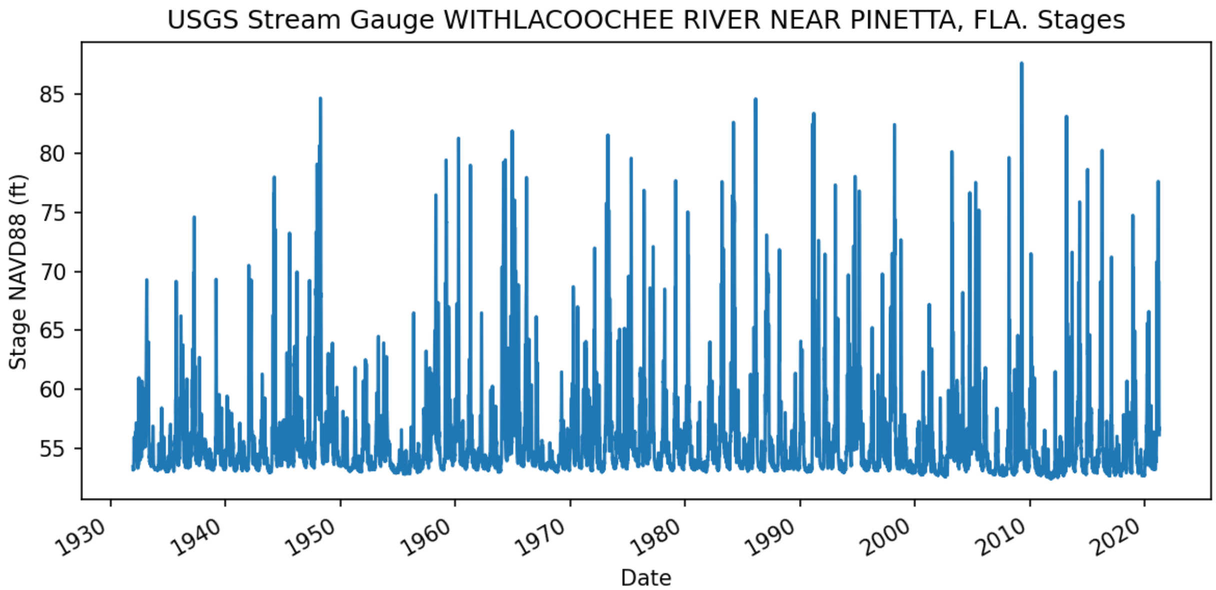

Average Monthly Stage NAVD88 (ft)
0
5
10
15
20
25
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

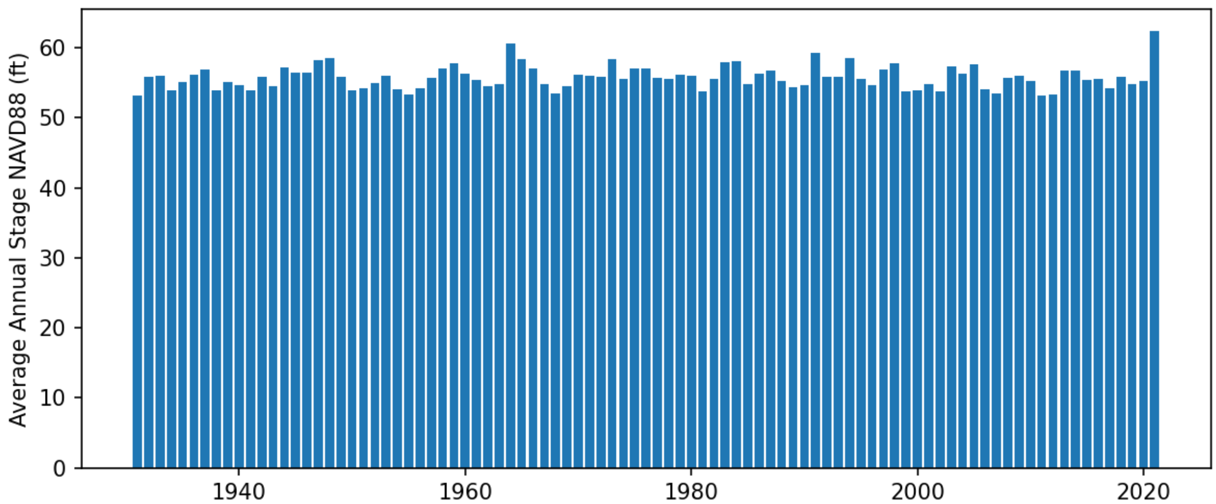

USGS, SRWMD Stream Gauge SUWANNEE RIVER AT SUWANNEE SPRINGS FLA Stages
Stage NAVD88 (ft)
80
70
60
50
40
1970
1980
1990
2000
2010
2020
Date

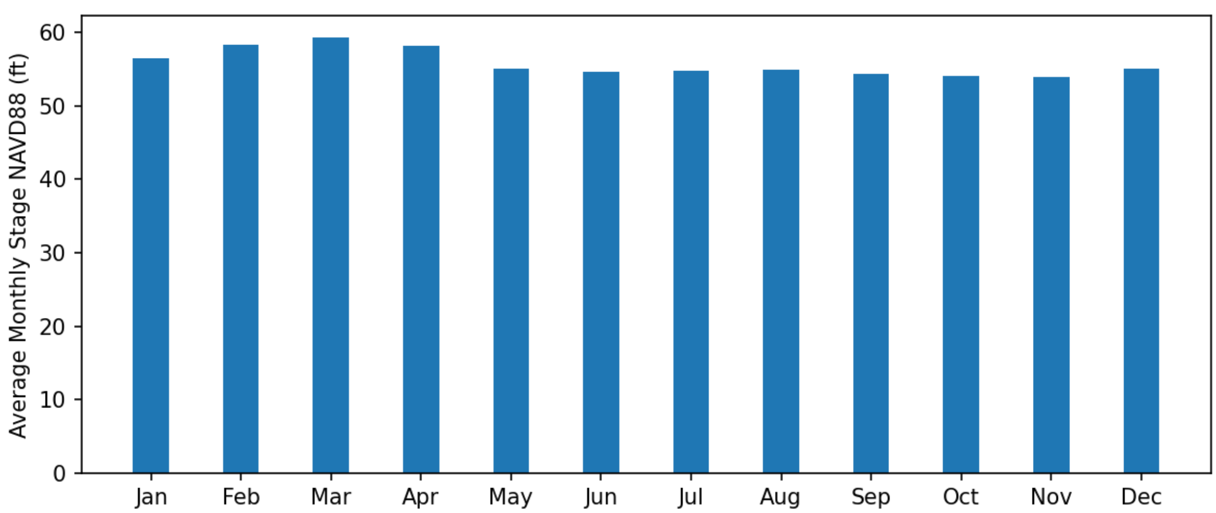

Average Annual Stage NAVD88 (ft)
50
40
30
20
10
0
1970
1980
1990
2000
2010
2020

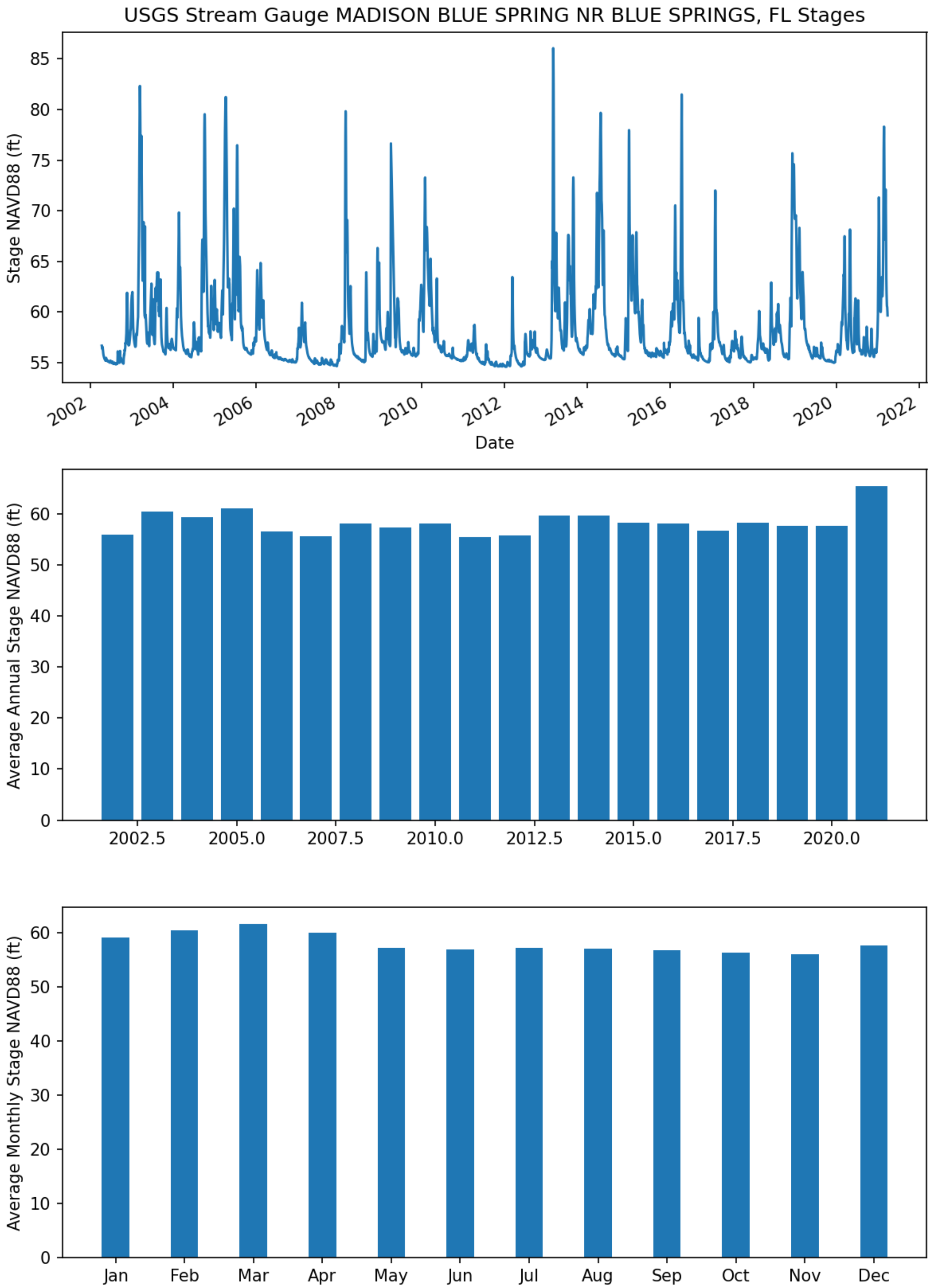

Average Monthly Stage NAVD88 (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

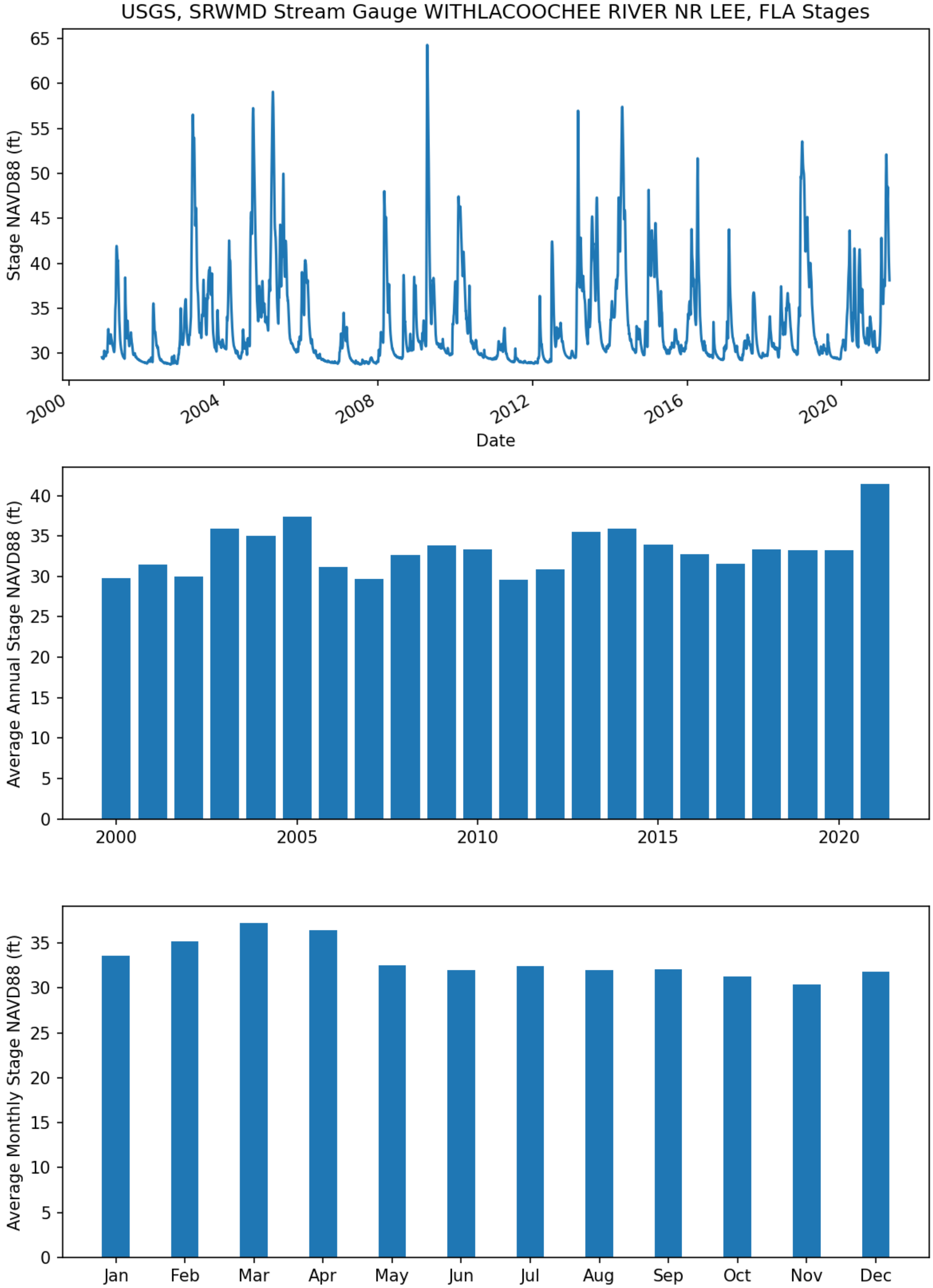

USGS, SRWMD Stream Gauge ALAPAHA RIVER NEAR JENNINGS FLA Stages
Stage NAVD88 (ft)
0
20
40
60
80
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date
Average Annual Stage NAVD88 (ft)
0
10
20
30
40
50
60
70
1980
1990
2000
2010
2020
Average Monthly Stage NAVD88 (ft)
0
10
20
30
40
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

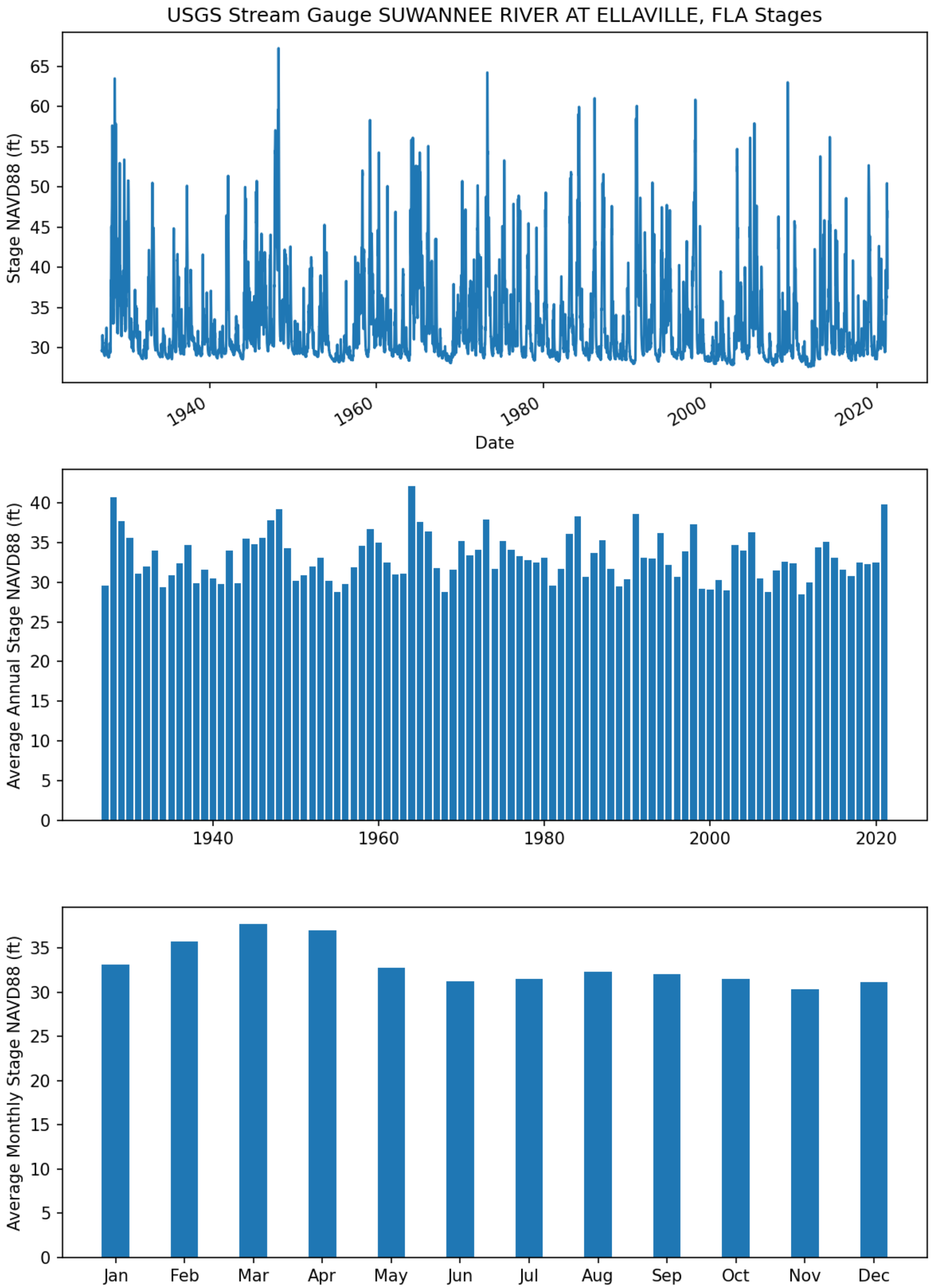

USGS Stream Gauge WITHLACOOCHEE RIVER NEAR PINETTA, FLA. Stages
Stage NAVD88 (ft)
55
60
65
70
75
80
85
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Date

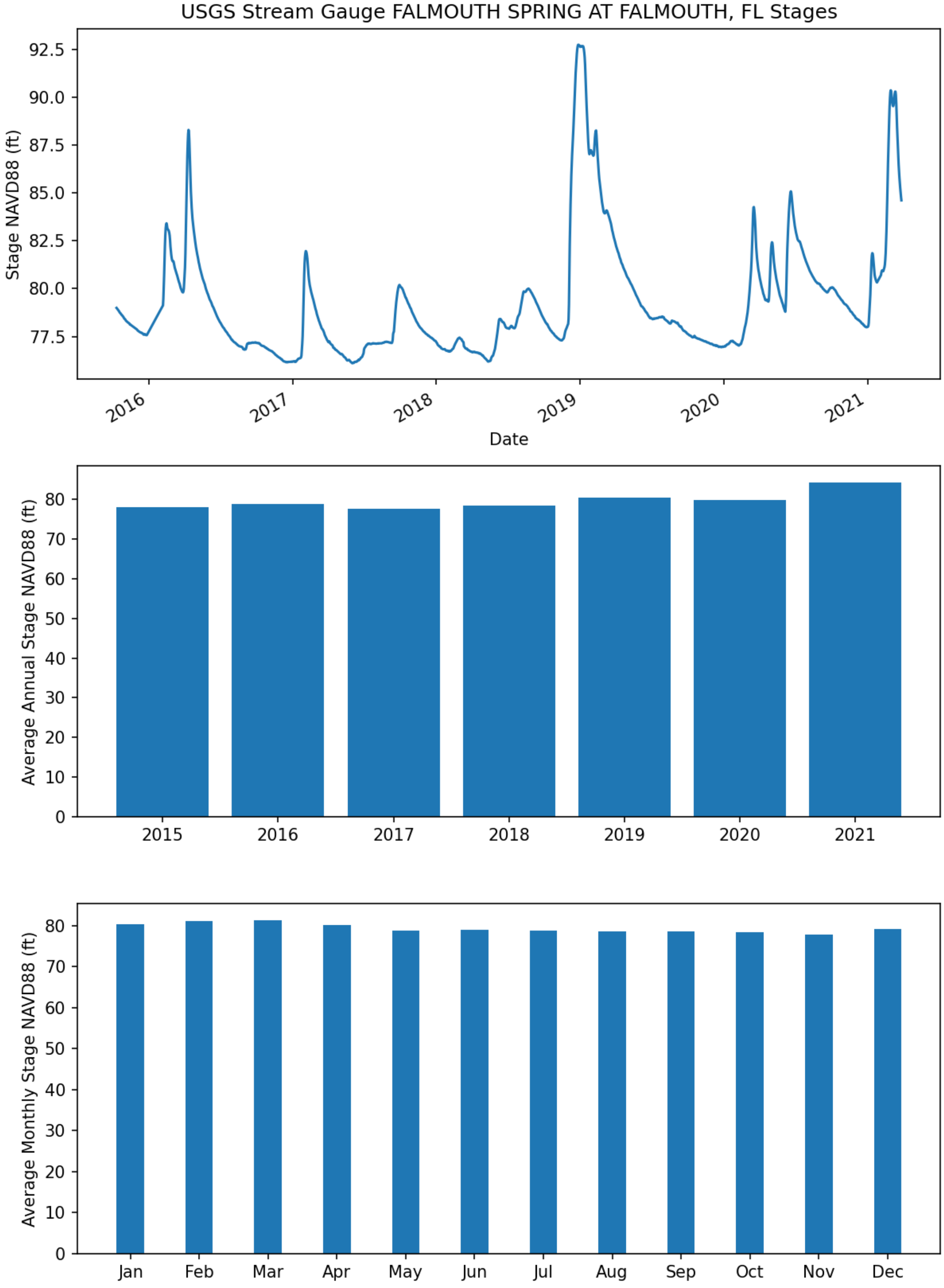

Average Annual Stage NAVD88 (ft)
0
10
20
30
40
50
60
1940
1960
1980
2000
2020

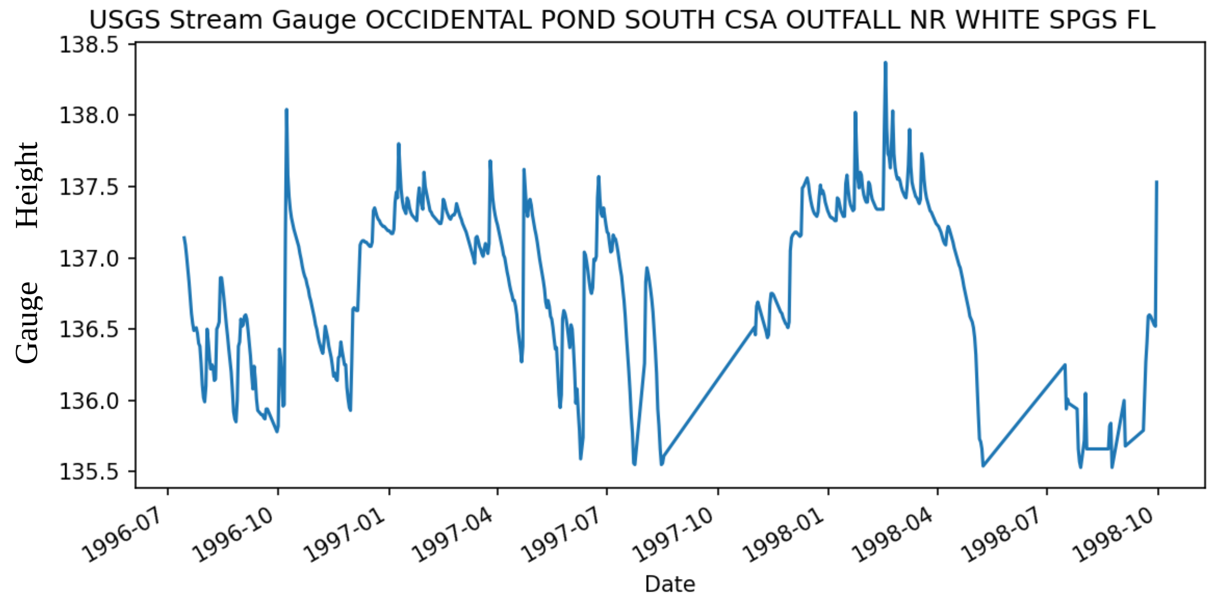

Average Monthly Stage NAVD88 (ft)
0
10
20
30
40
50
60
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

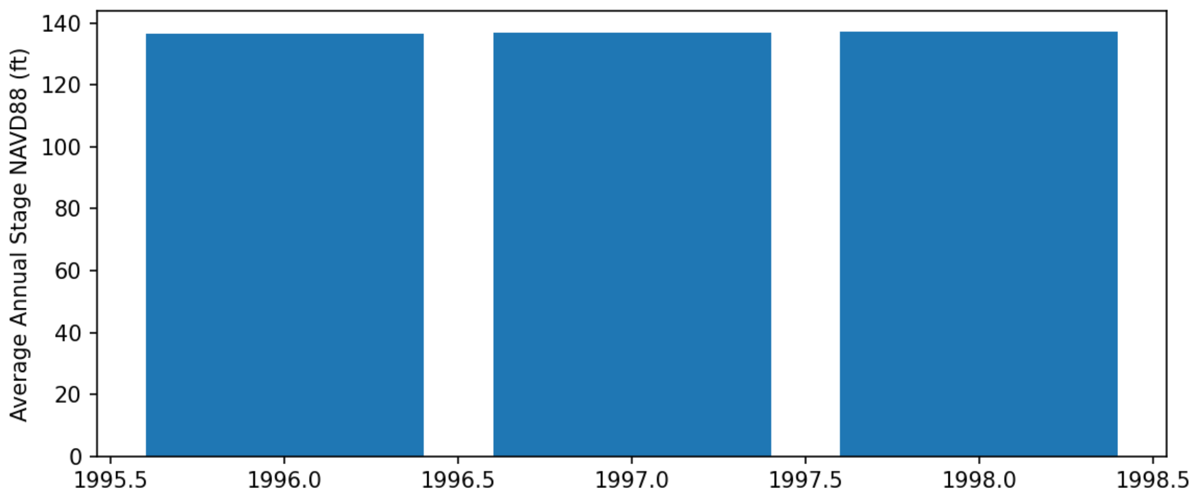

USGS Stream Gauge MADISON BLUE SPRING NR BLUE SPRINGS, FL Stages
Stage NAVD88 (ft)
85
80
75
70
65
60
55
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Date
Average Annual Stage NAVD88 (ft)
60
50
40
30
20
10
0
2002.5
2005.0
2007.5
2010.0
2012.5
2015.0
2017.5
2020.0
Average Monthly Stage NAVD88 (ft)
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

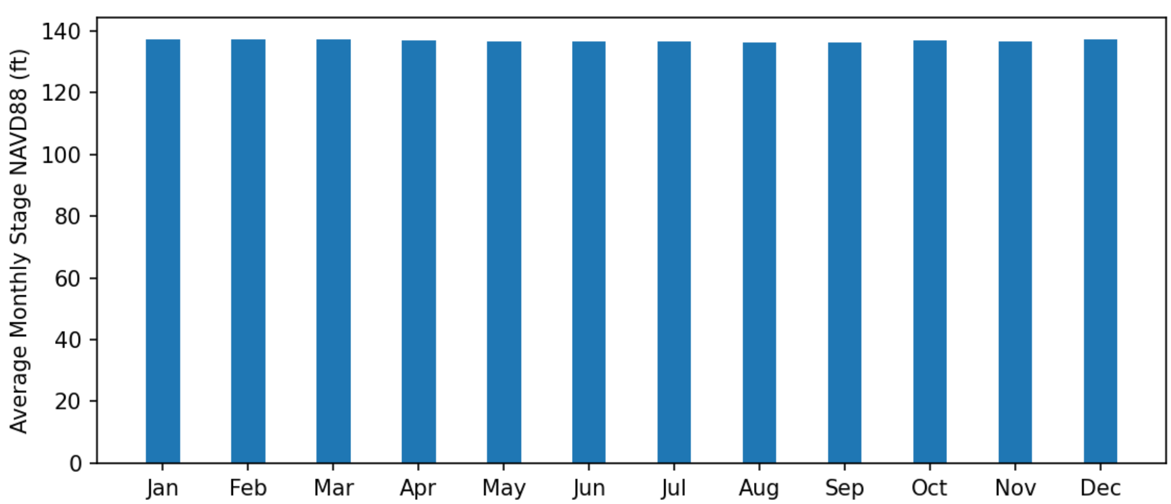

USGS, SRWMD Stream Gauge WITHLACOOCHEE RIVER NR LEE, FLA Stages
Stage NAVD88 (ft)
Date
Average Annual Stage NAVD88 (ft)
Average Monthly Stage NAVD88 (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

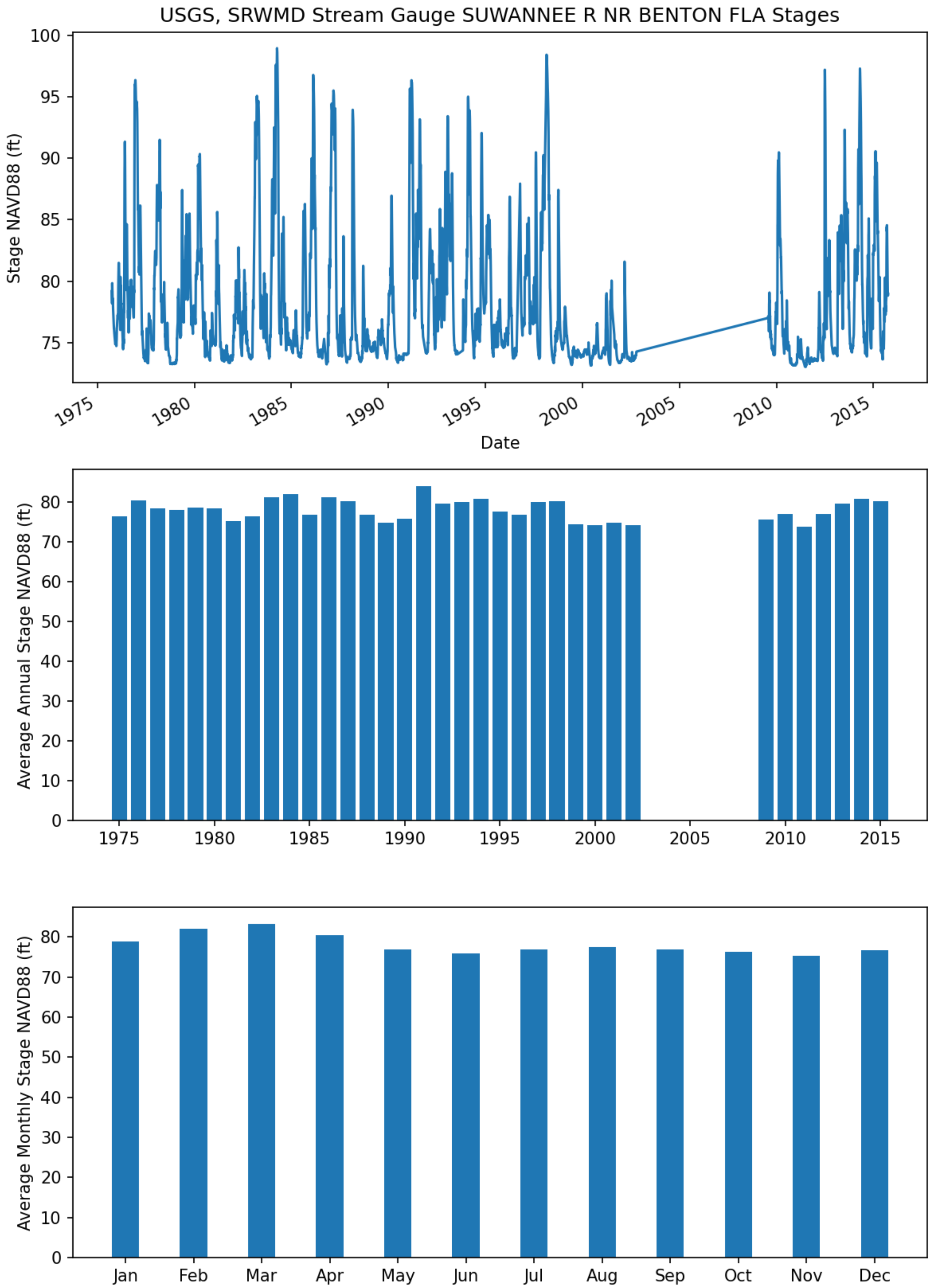

USGS Stream Gauge SUWANNEE RIVER AT ELLAVILLE, FLA Stages
Stage NAVD88 (ft)
65
60
55
50
45
40
35
30
1940
1960
1980
2000
2020
Date
Average Annual Stage NAVD88 (ft)
40
35
30
25
20
15
10
5
0
1940
1960
1980
2000
2020
Average Monthly Stage NAVD88 (ft)
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

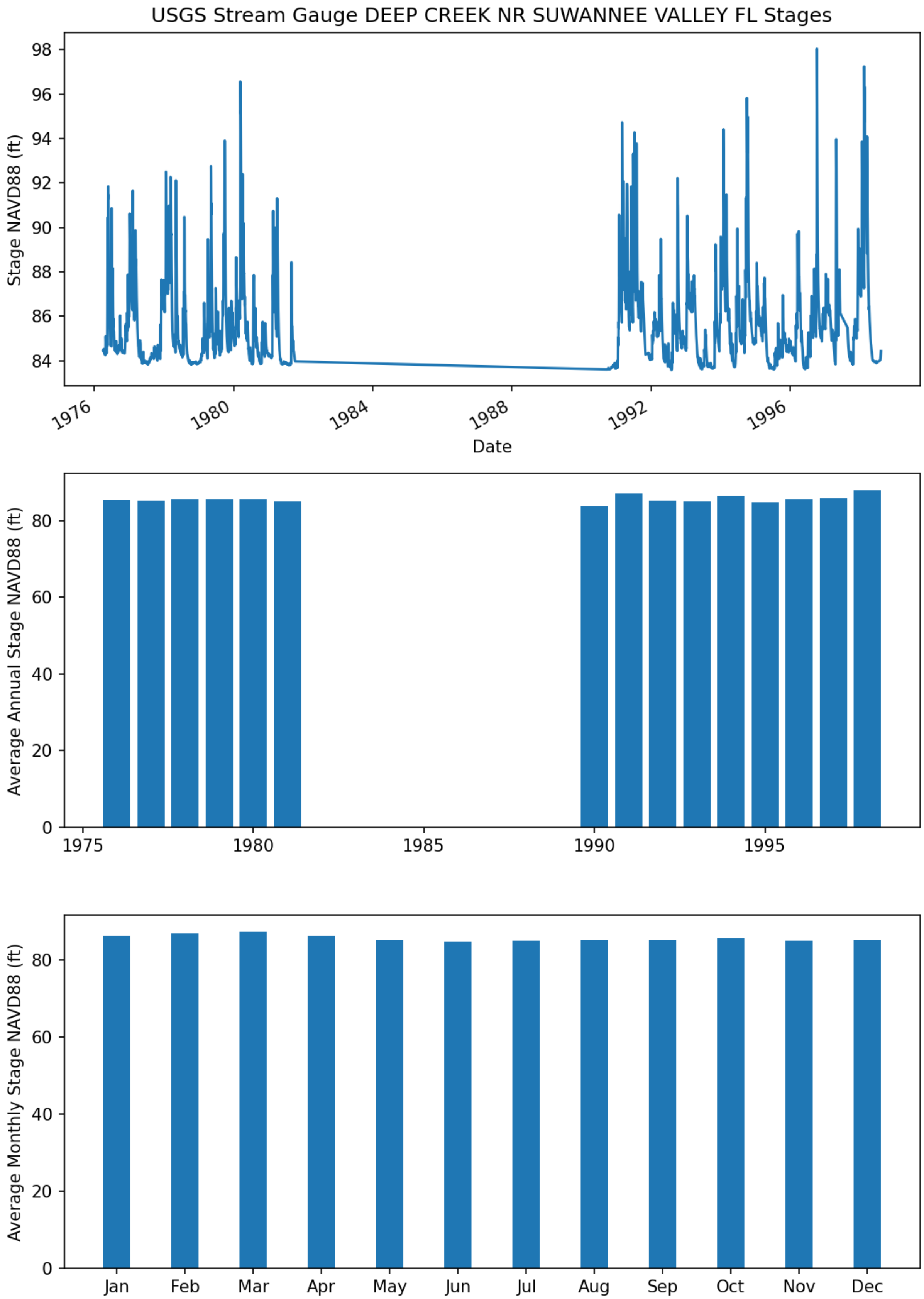

USGS Stream Gauge FALMOUTH SPRING AT FALMOUTH, FL Stages
Stage NAVD88 (ft)
92.5
90.0
87.5
85.0
82.5
80.0
77.5
2016
2017
2018
2019
2020
2021
Date
Average Annual Stage NAVD88 (ft)
2015
2016
2017
2018
2019
2020
2021
Average Monthly Stage NAVD88 (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


USGS Stream Gauge OCCIDENTAL POND SOUTH CSA OUTFALL NR WHITE SPGS FL
Gauge Height
138.5
138.0
137.5
137.0
136.5
136.0
135.5
1996-07
1996-10
1997-01
1997-04
1997-07
1997-10
1998-01
1998-04
1998-07
1998-10
Date

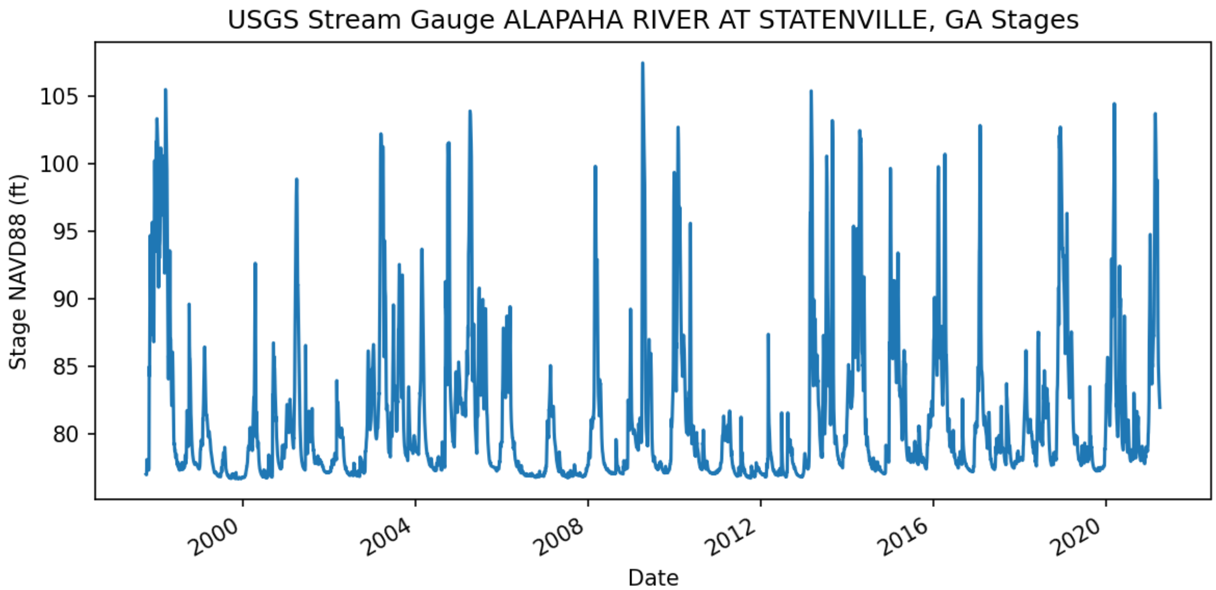

Average Annual Stage NAVD88 (ft)
140
120
100
80
60
40
20
0
1995.5
1996.0
1996.5
1997.0
1997.5
1998.0
1998.5


Average Monthly Stage NAVD88 (ft)
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

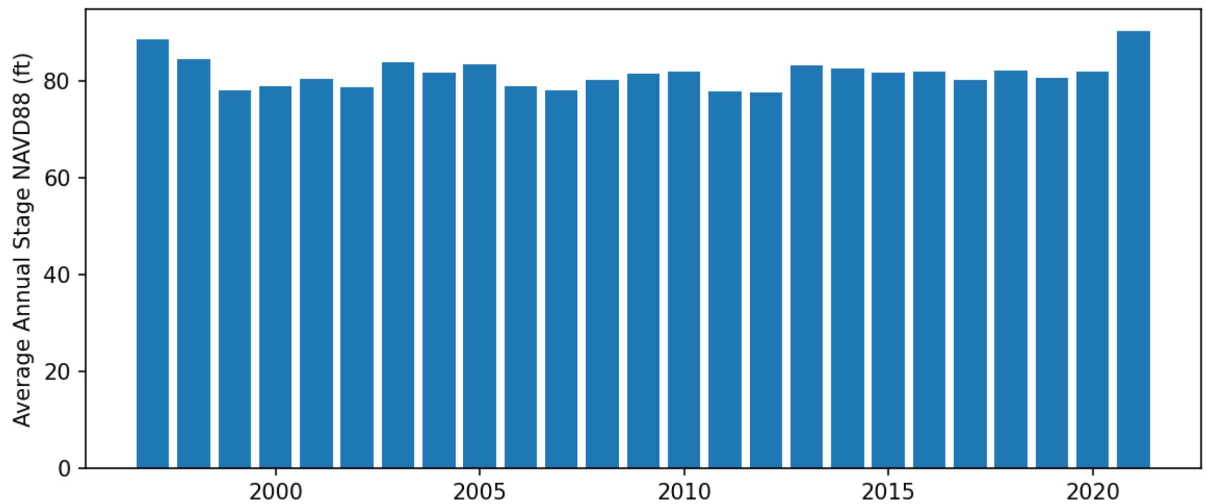

USGS, SRWMD Stream Gauge SUWANNEE R NR BENTON FLA Stages
Stage NAVD88 (ft)
Date
Average Annual Stage NAVD88 (ft)
Average Monthly Stage NAVD88 (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



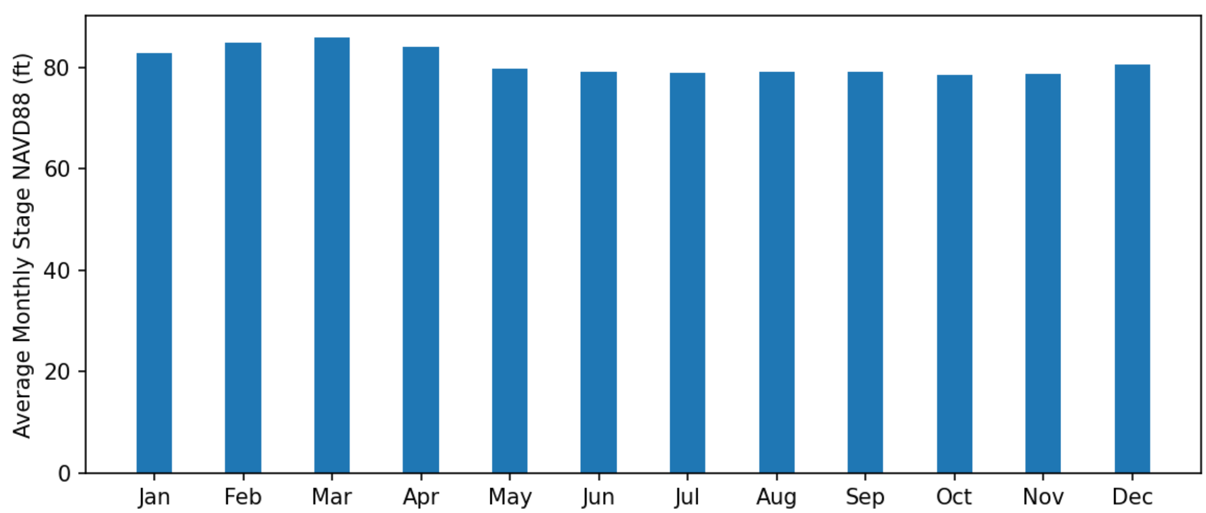
USGS Stream Gauge DEEP CREEK NR SUWANNEE VALLEY FL Stages
Stage NAVD88 (ft)
98
96
94
92
90
88
86
84
1976
1980
1984
1988
1992
1996
Date
Average Annual Stage NAVD88 (ft)
0
20
40
60
80
1975
1980
1985
1990
1995
Average Monthly Stage NAVD88 (ft)
0
20
40
60
80
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



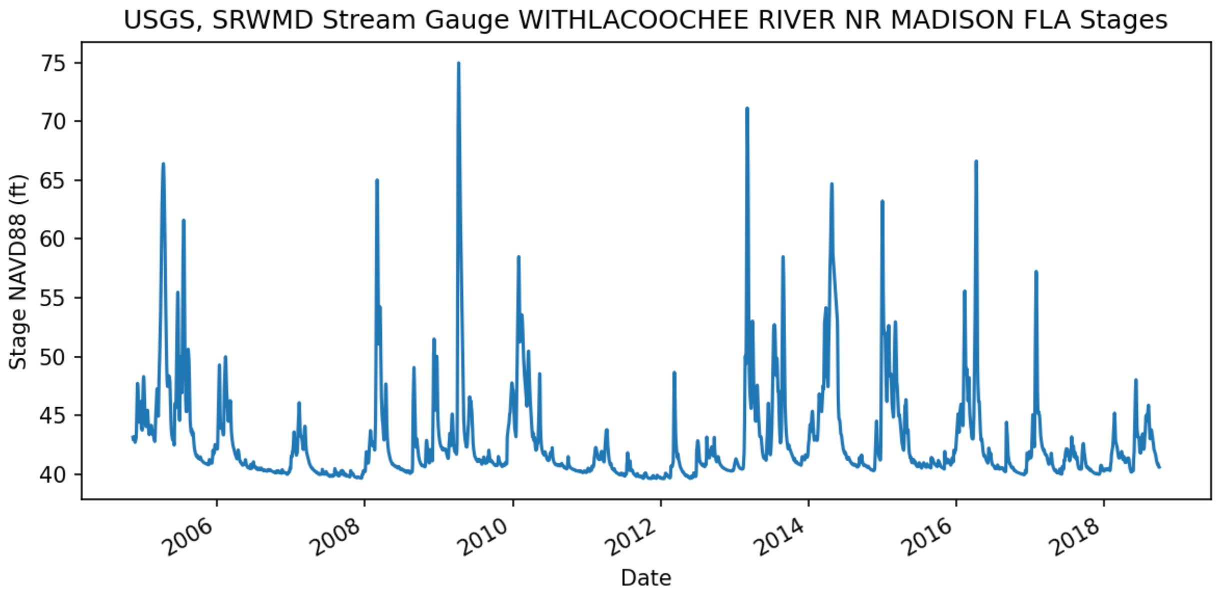
USGS Stream Gauge ALAPAHA RIVER AT STATENVILLE, GA Stages
Stage NAVD88 (ft)
105
100
95
90
85
80
2000
2004
2008
2012
2016
2020
Date

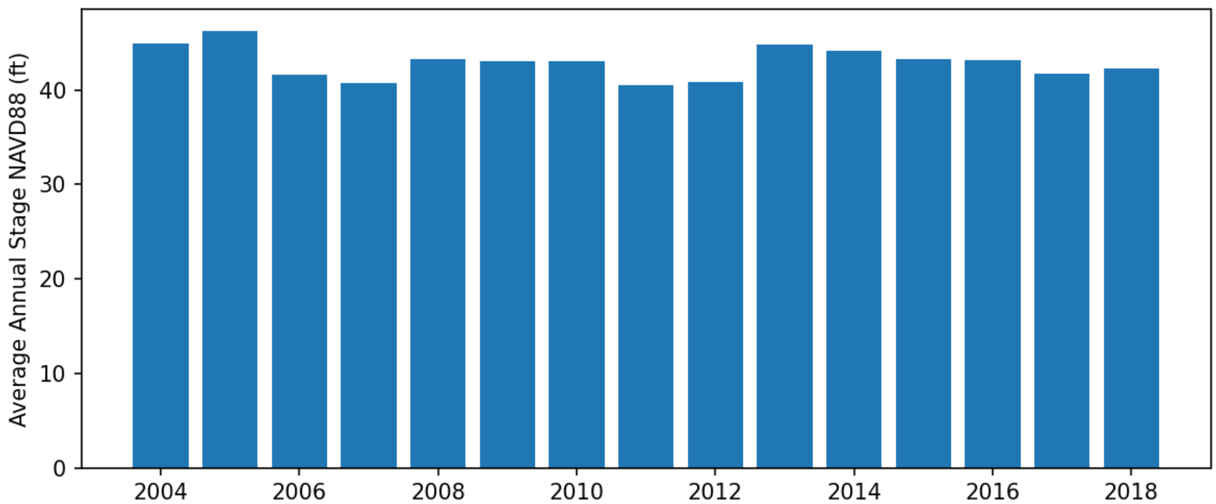


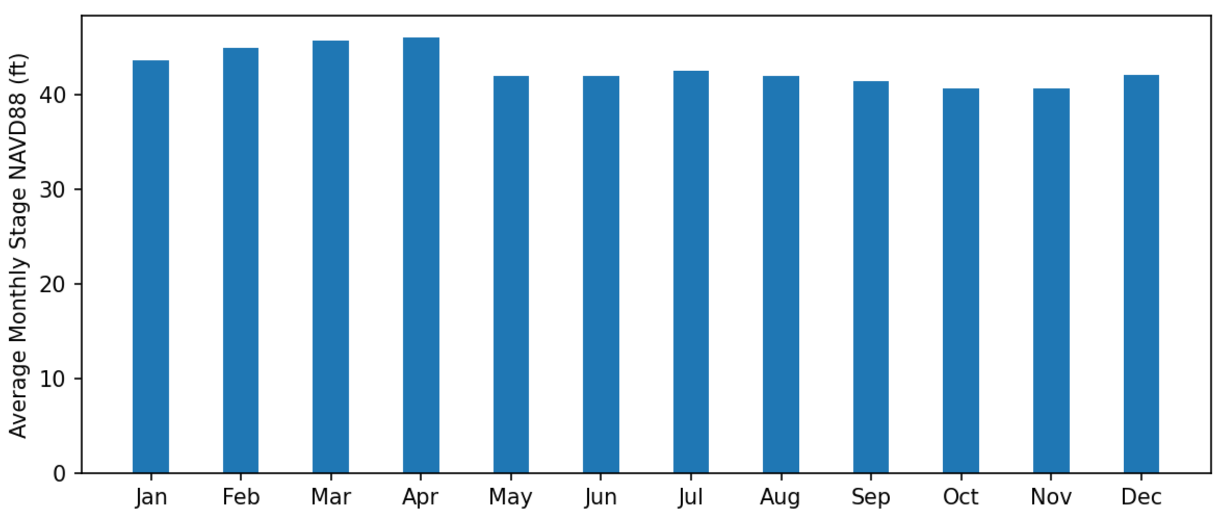
Average Annual Stage NAVD88 (ft)
0
20
40
60
80
2000
2005
2010
2015
2020

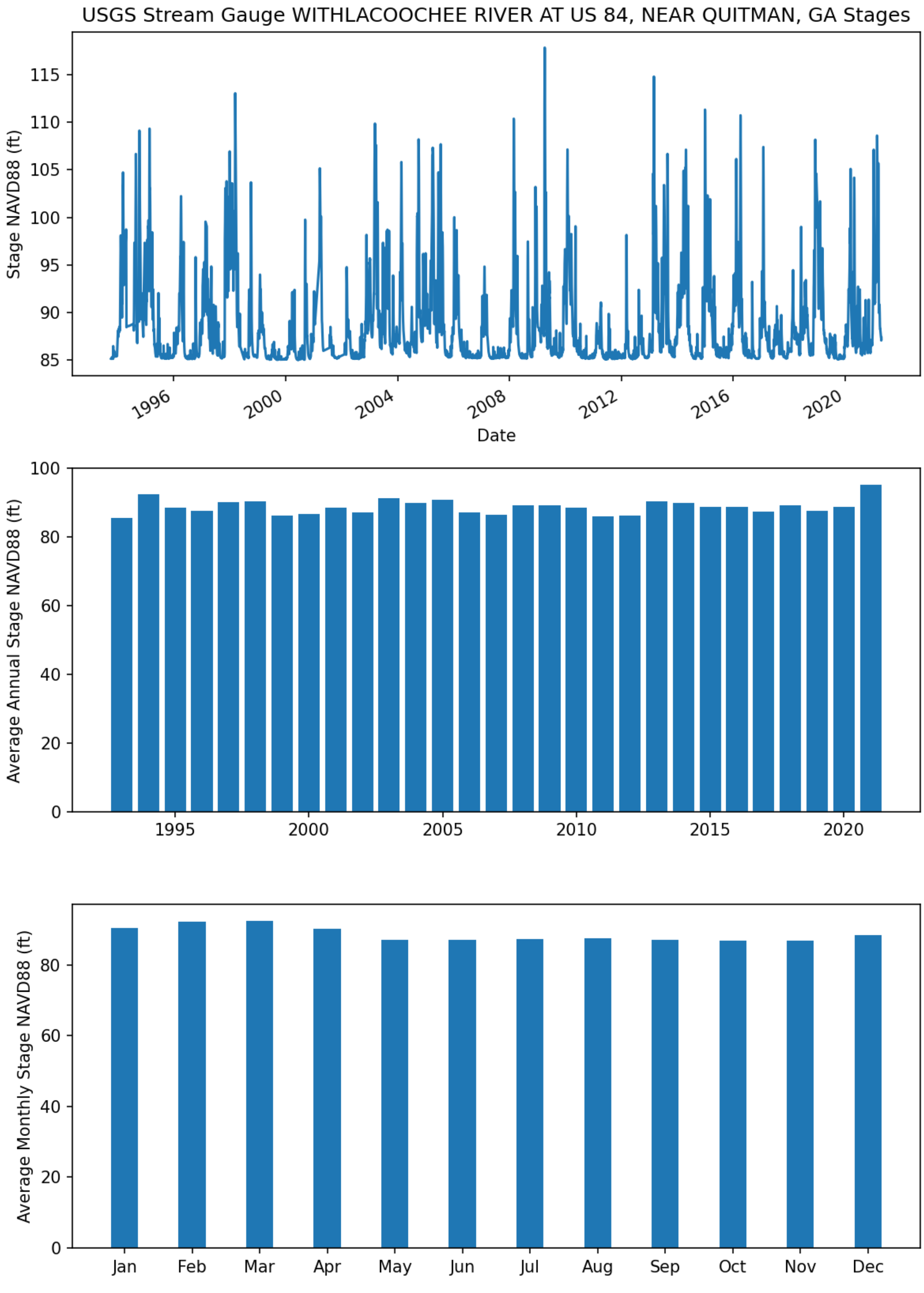


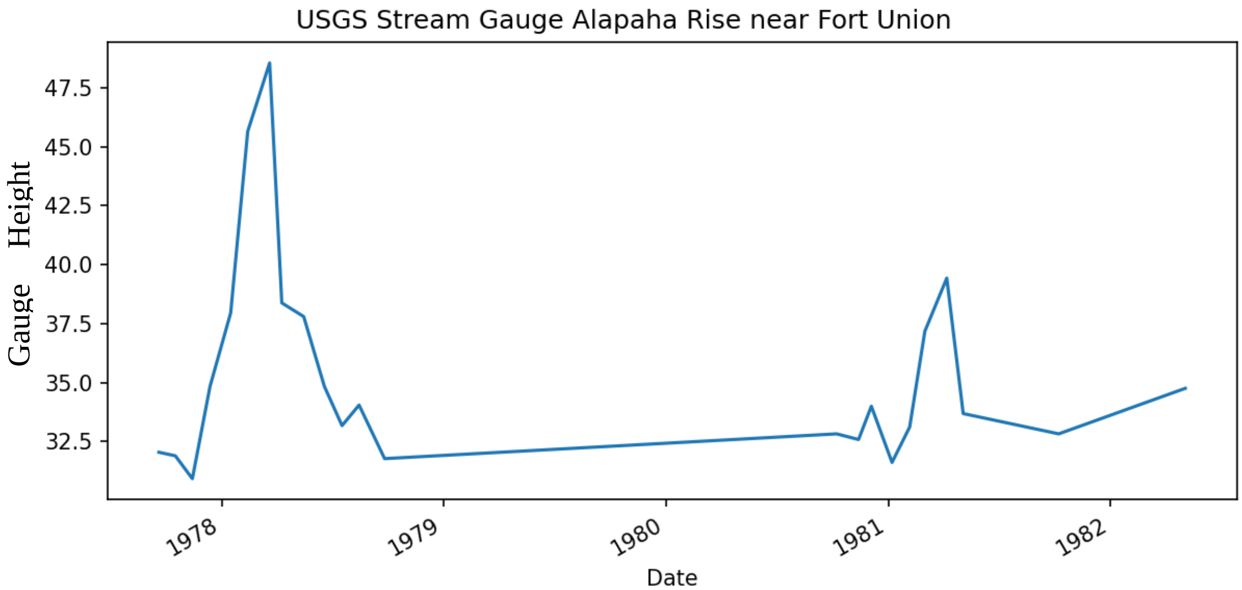
Average Monthly Stage NAVD88 (ft)
0
20
40
60
80
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

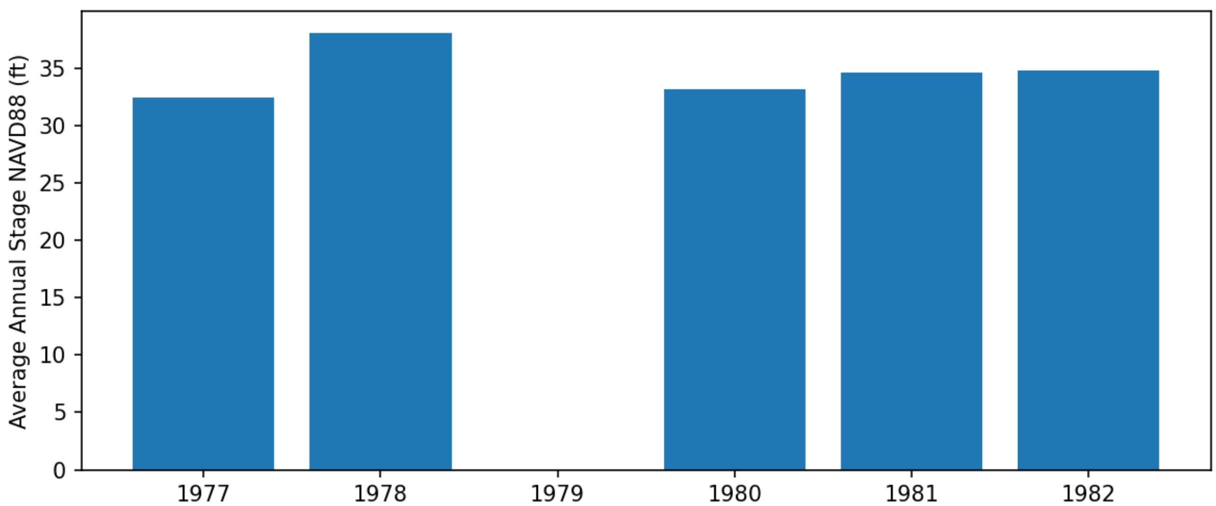

USGS, SRWMD Stream Gauge WITHLACOOCHEE RIVER NR MADISON FLA Stages
Stage NAVD88 (ft)
75
70
65
60
55
50
45
40
2006
2008
2010
2012
2014
2016
2018
Date

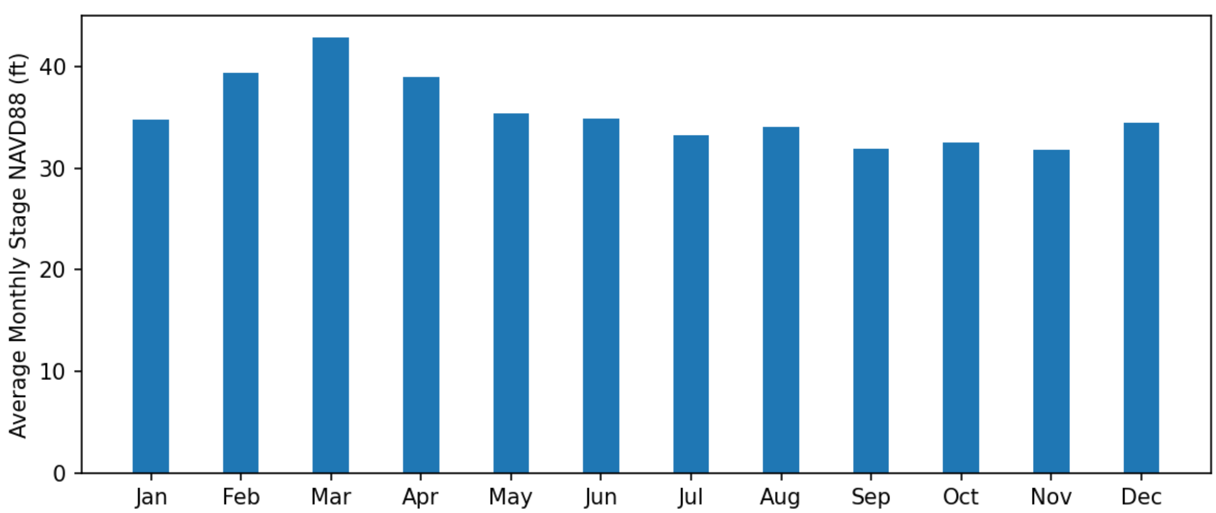

Average Annual Stage NAVD88 (ft)
0
10
20
30
40
2004
2006
2008
2010
2012
2014
2016
2018

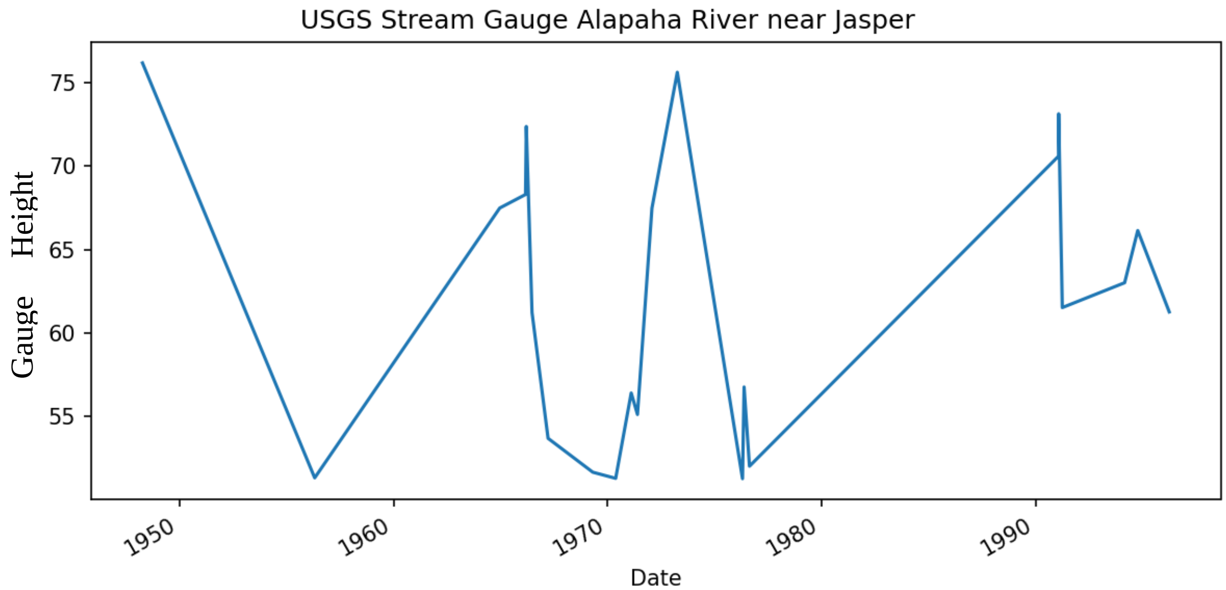

Average Monthly Stage NAVD88 (ft)
0
10
20
30
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

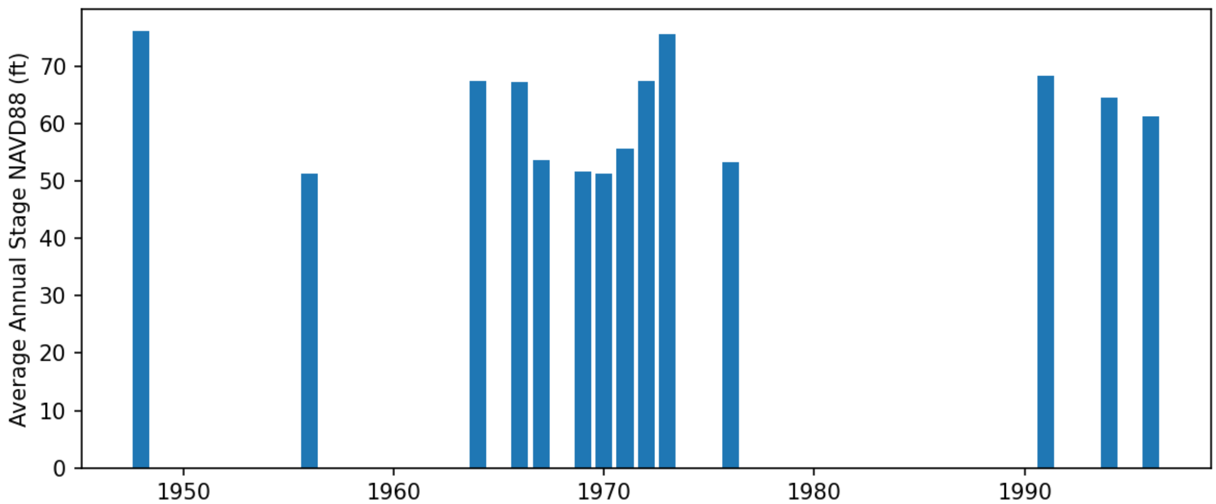

USGS Stream Gauge WITHLACOOCHEE RIVER AT US 84, NEAR QUITMAN, GA Stages
Stage NAVD88 (ft)
85
90
95
100
105
110
115
1996
2000
2004
2008
2012
2016
2020
Date
Average Annual Stage NAVD88 (ft)
0
20
40
60
80
100
1995
2000
2005
2010
2015
2020
Average Monthly Stage NAVD88 (ft)
0
20
40
60
80
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

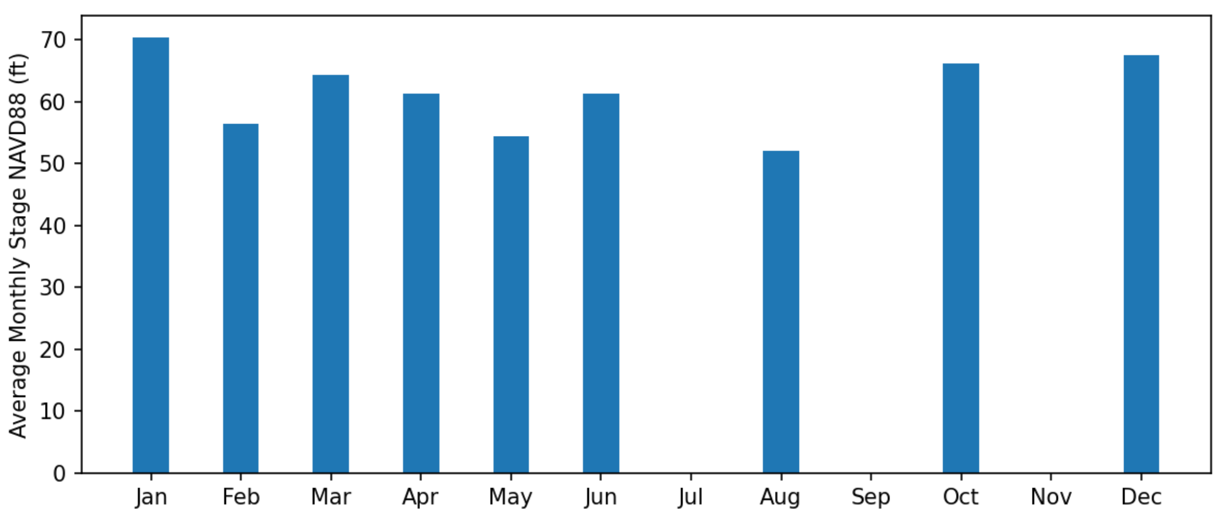

USGS Stream Gauge Alapaha Rise near Fort Union
Gauge Height
47.5
45.0
42.5
40.0
37.5
35.0
32.5
1978
1979
1980
1981
1982
Date


Average Annual Stage NAVD88 (ft)
35
30
25
20
15
10
5
0
1977
1978
1979
1980
1981
1982

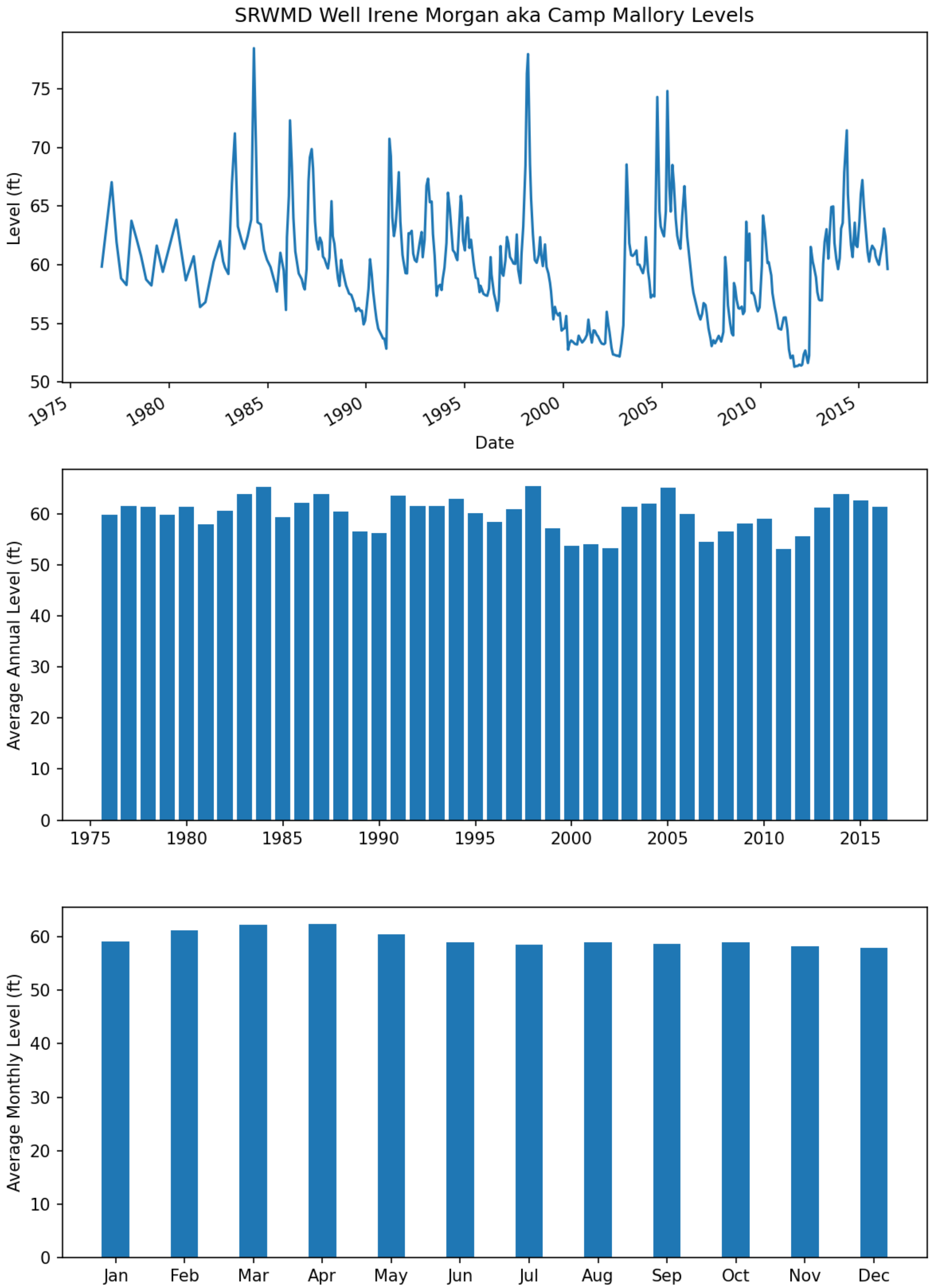

Average Monthly Stage NAVD88 (ft)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


USGS Stream Gauge Alapaha River near Jasper
Gauge Height
75
70
65
60
55
1950
1960
1970
1980
1990
Date

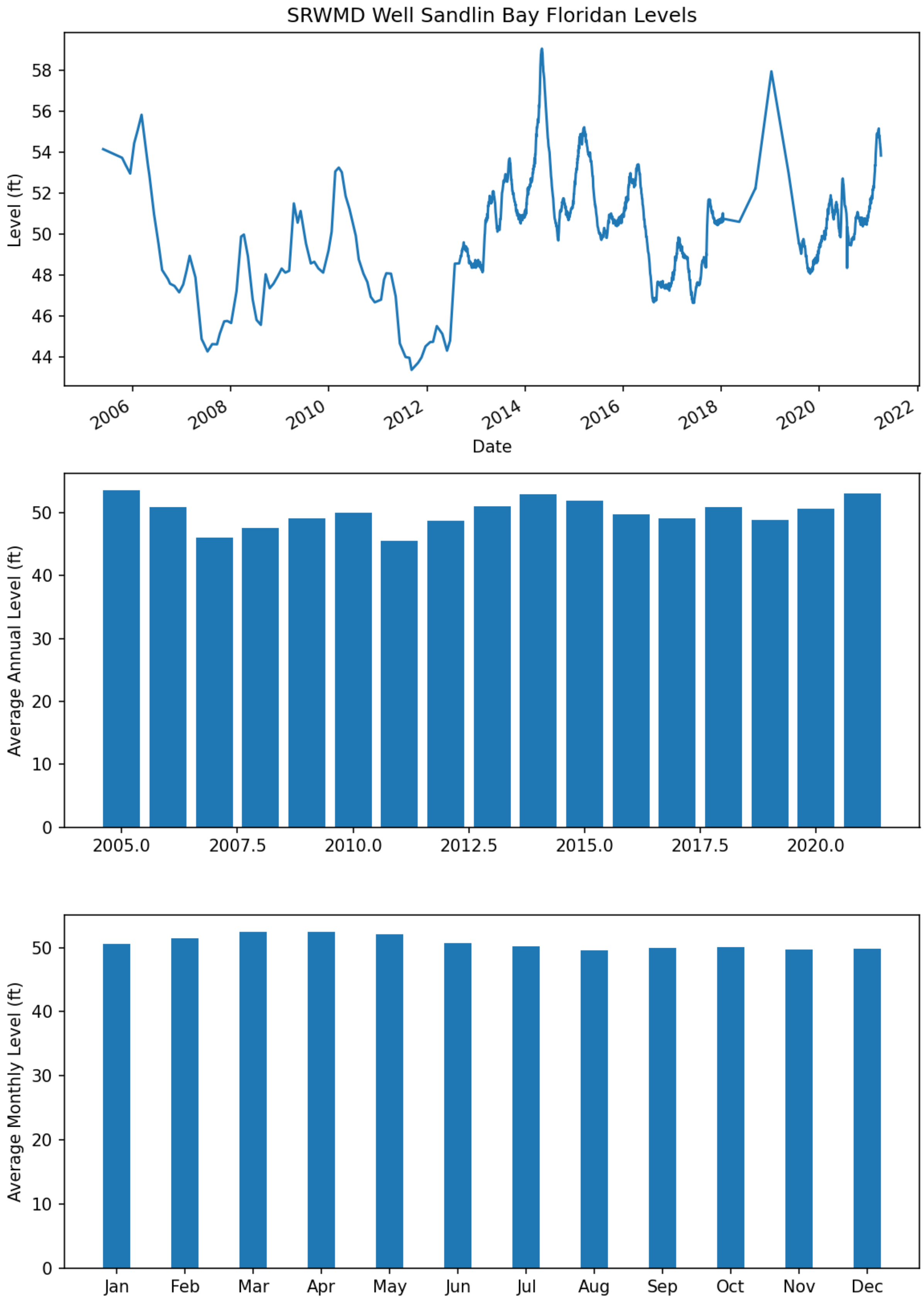

Average Annual Stage NAVD88 (ft)
0
10
20
30
40
50
60
70
1950
1960
1970
1980
1990

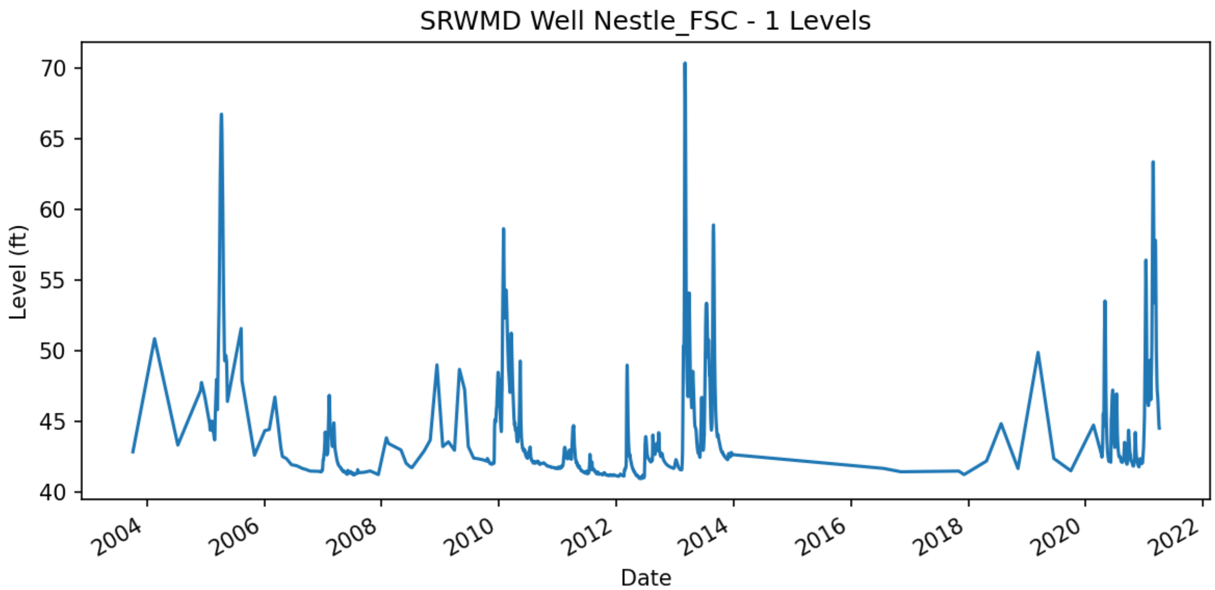

Average Monthly Stage NAVD88 (ft)
0
10
20
30
40
50
60
70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

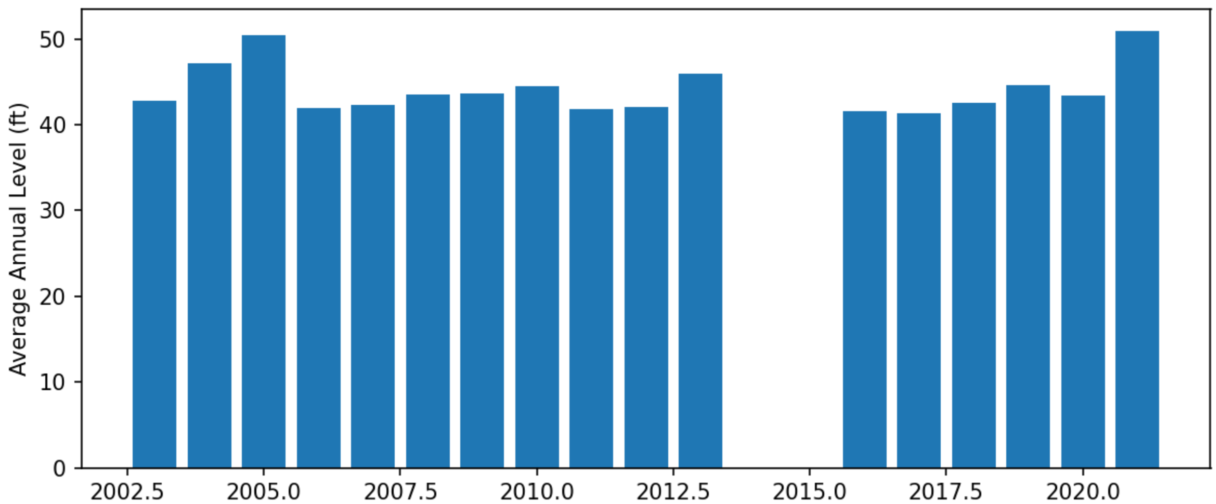
Appendix D: Well Water Level Time Series for Well Stations

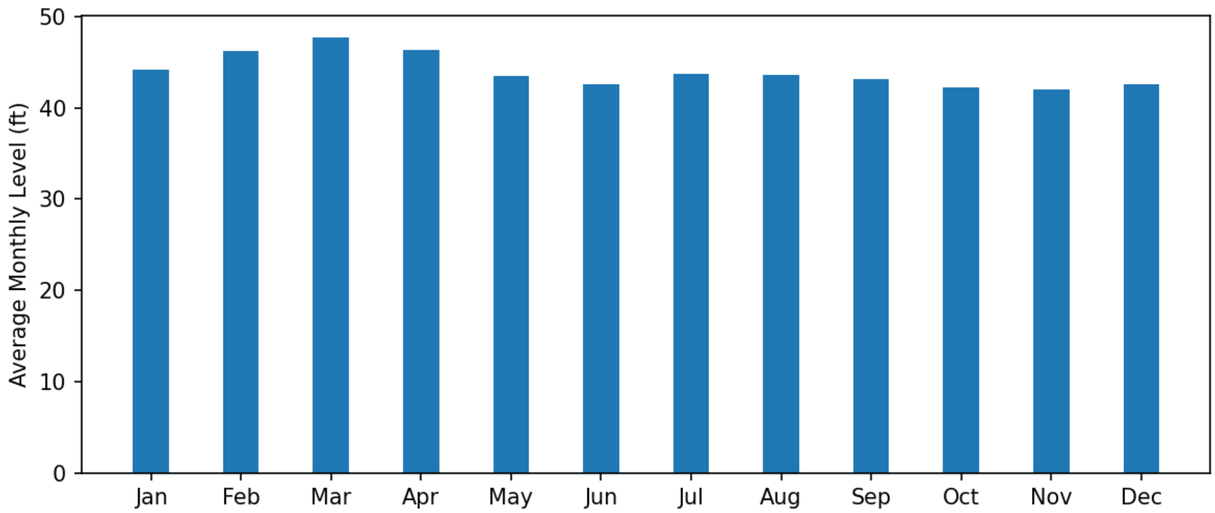


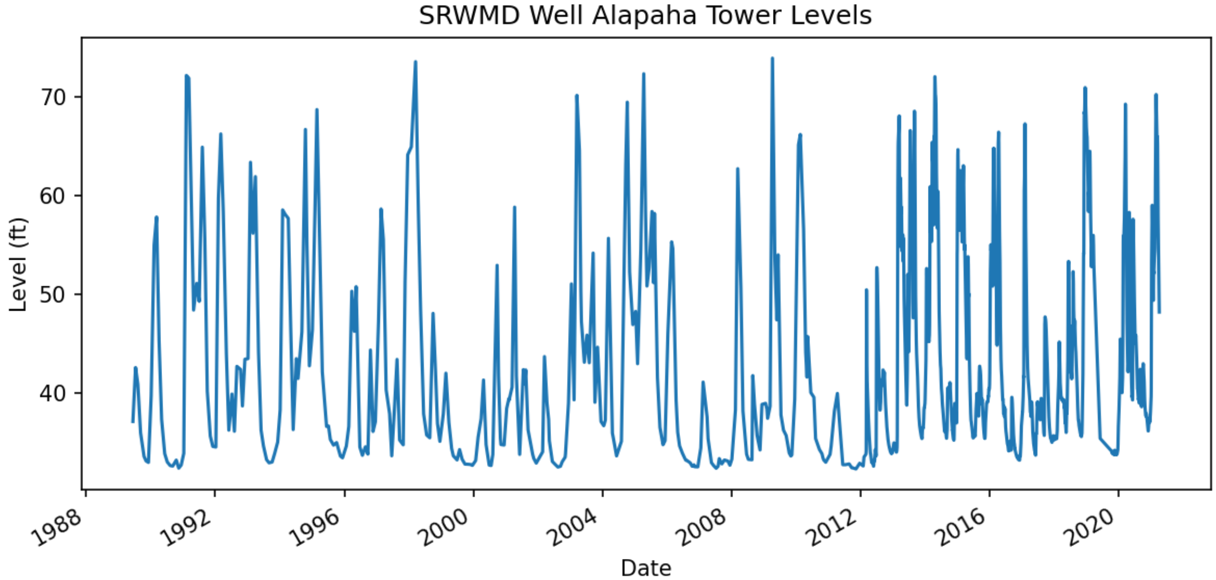
SRWMD Well Irene Morgan aka Camp Mallory Levels
Level (ft)
Date
Average Annual Level (ft)
Average Monthly Level (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SRWMD Well Sandlin Bay Floridan Levels
Level (ft)
58
56
54
52
50
48
46
44
2006
2008
2010
2012
2014
2016
2018
2020
2022
Date
Average Annual Level (ft)
50
40
30
20
10
0
2005.0
2007.5
2010.0
2012.5
2015.0
2017.5
2020.0
Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

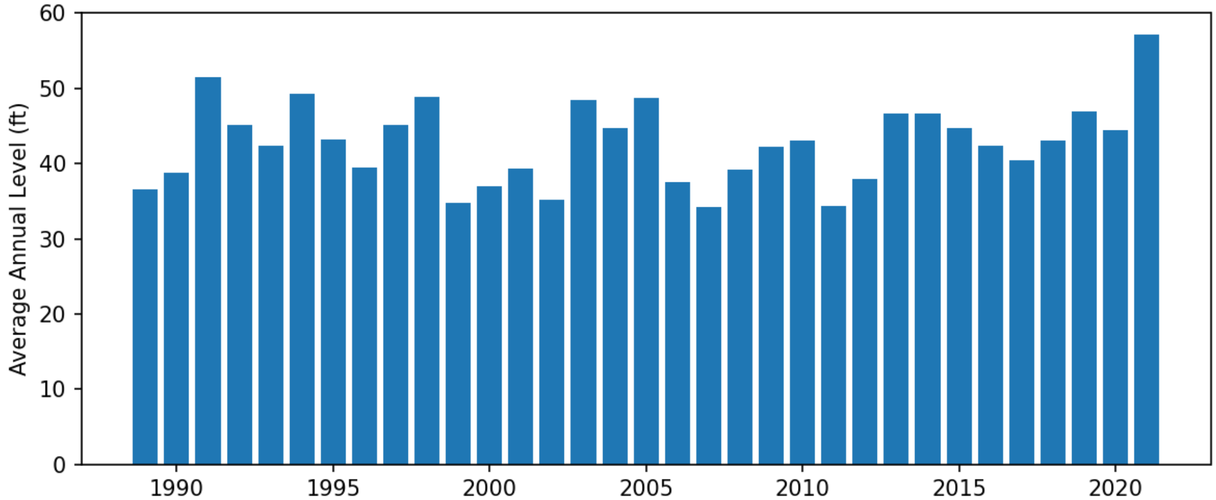

SRWMD Well Nestle_FSC - 1 Levels
Level (ft)
70
65
60
55
50
45
40
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Date


Average Annual Level (ft)
50
40
30
20
10
0
2002.5
2005.0
2007.5
2010.0
2012.5
2015.0
2017.5
2020.0

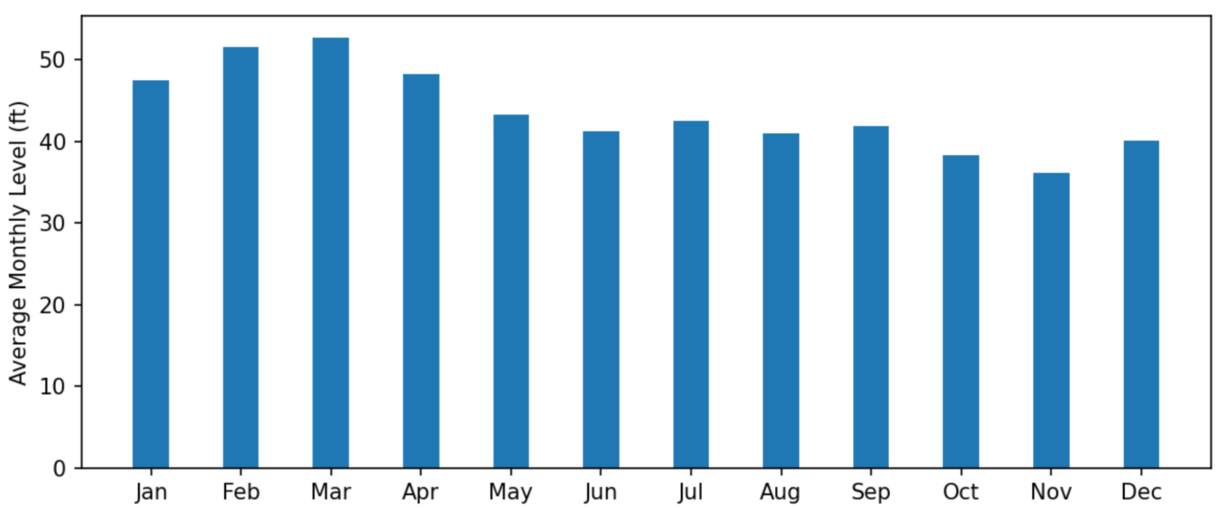

Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



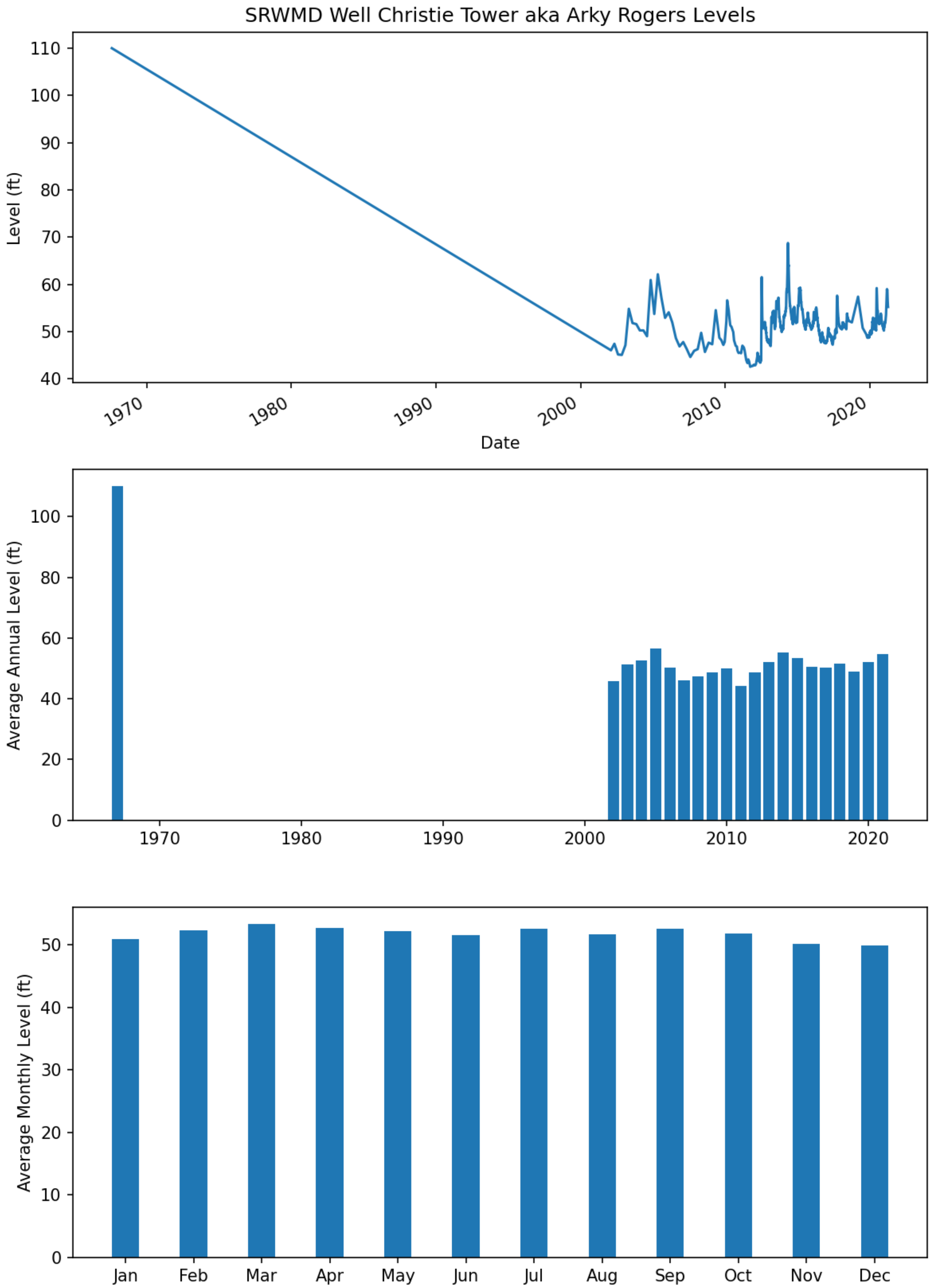
SRWMD Well Alapaha Tower Levels
Level (ft)
70
60
50
40
1988
1992
1996
2000
2004
2008
2012
2016
2020
Date



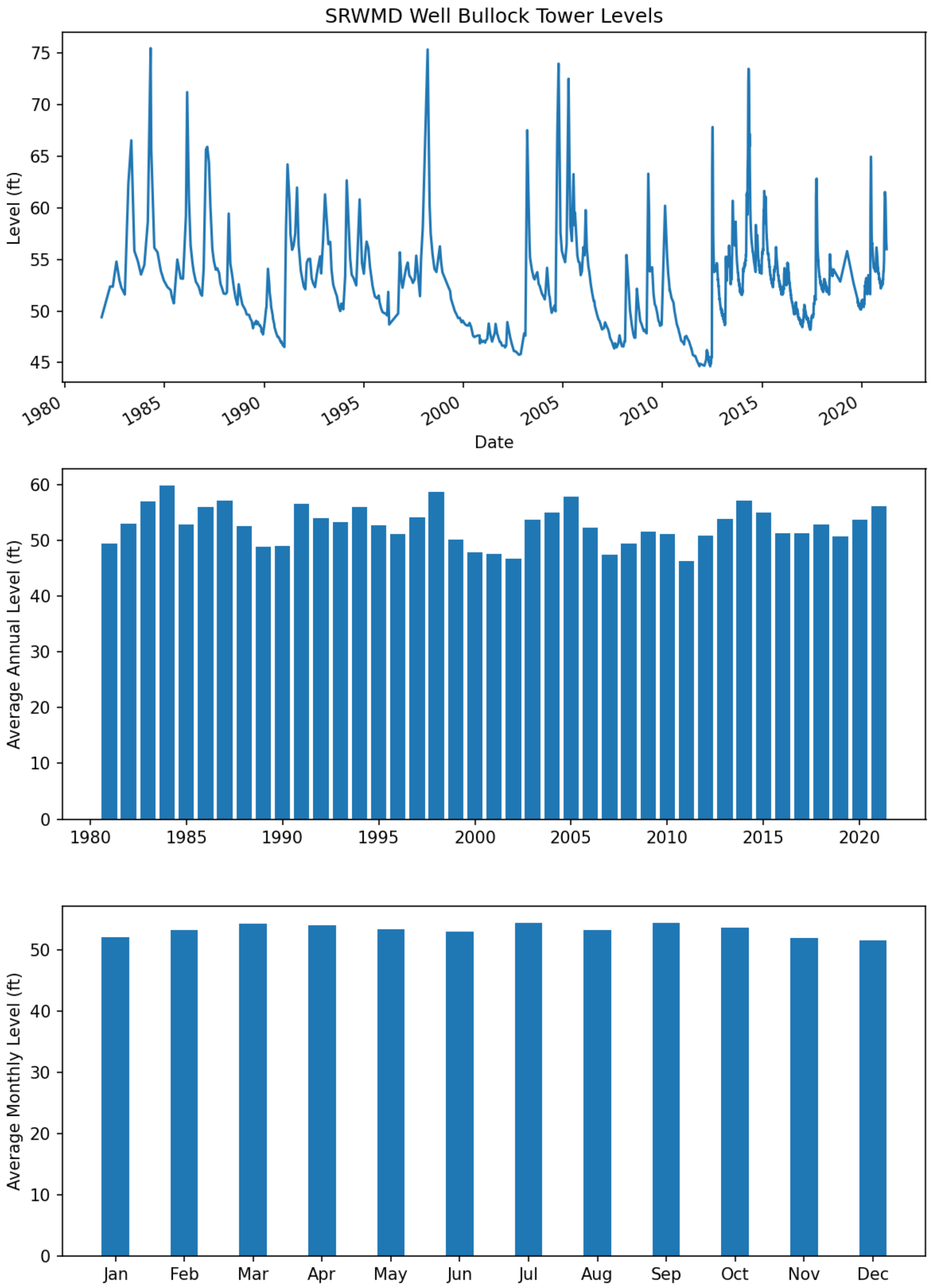
Average Annual Level (ft)
60
50
40
30
20
10
0
1990
1995
2000
2005
2010
2015
2020

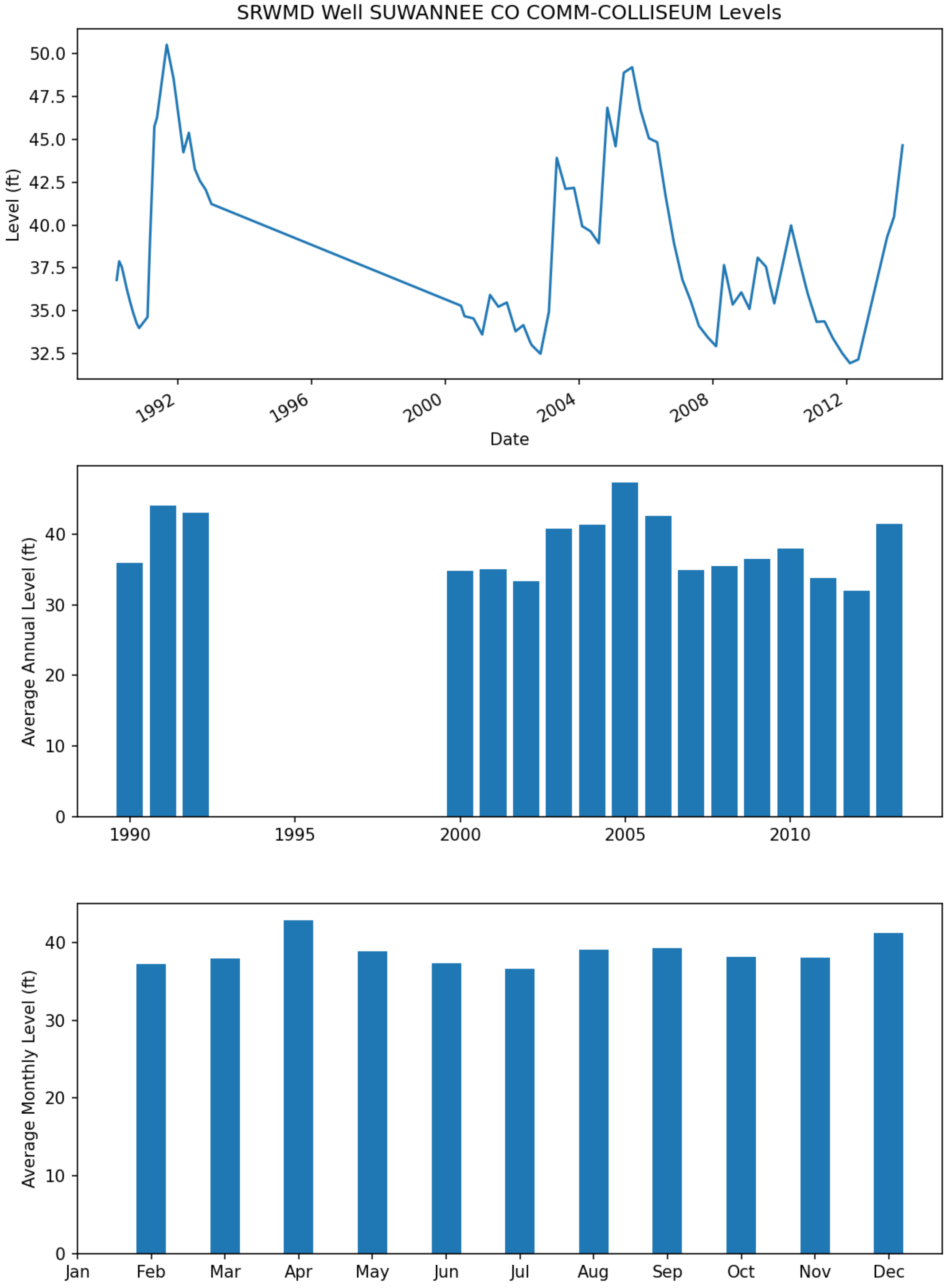


Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

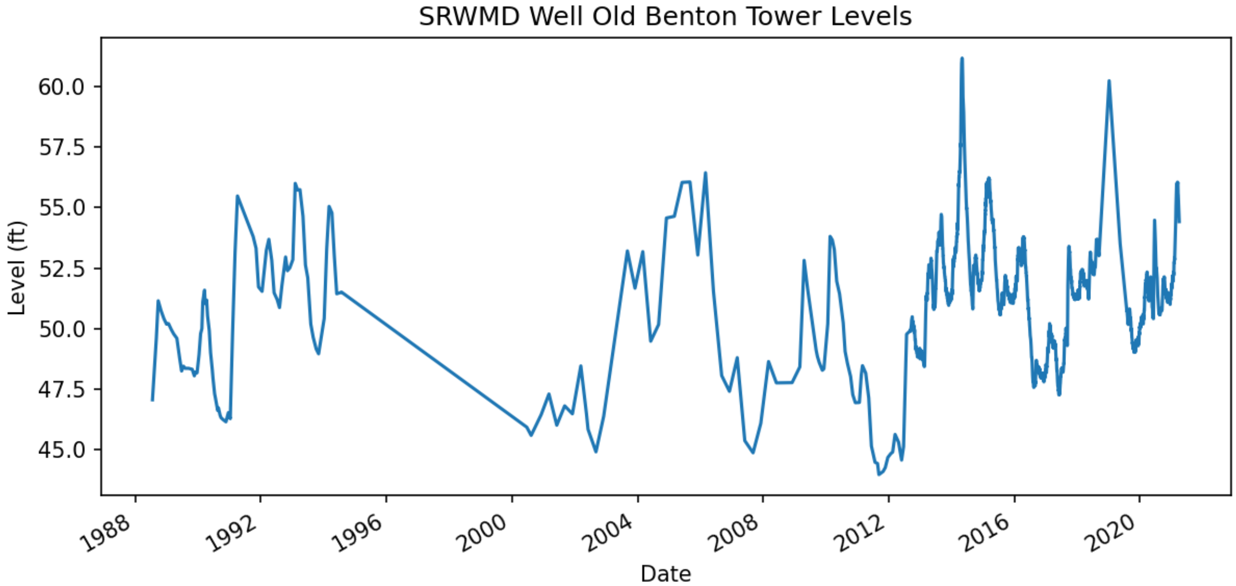


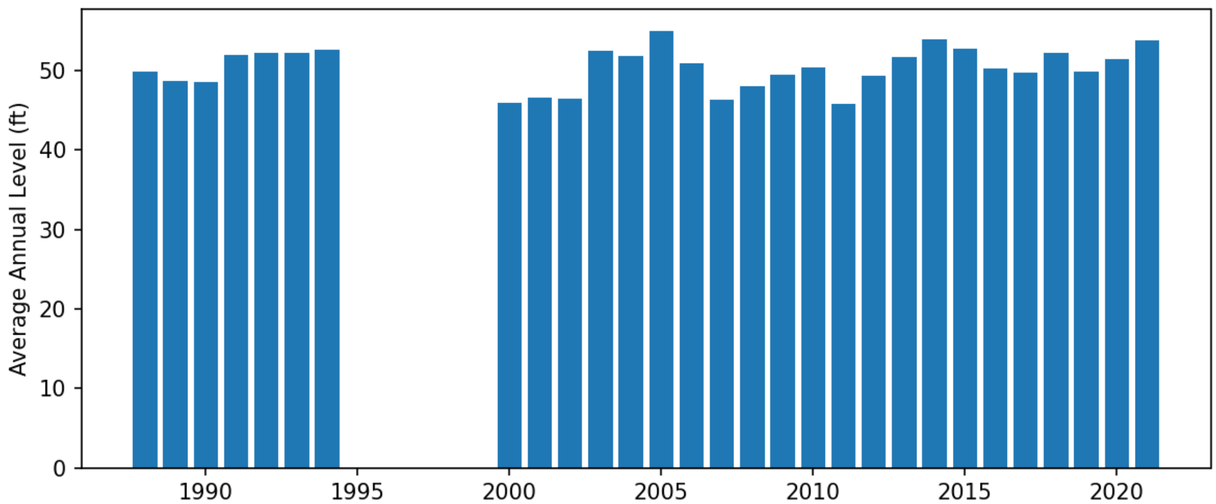
SRWMD Well Christie Tower aka Arky Rogers Levels
Level (ft)
110
100
90
80
70
60
50
40
1970
1980
1990
2000
2010
2020
Date
Average Annual Level (ft)
100
80
60
40
20
0
1970
1980
1990
2000
2010
2020
Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

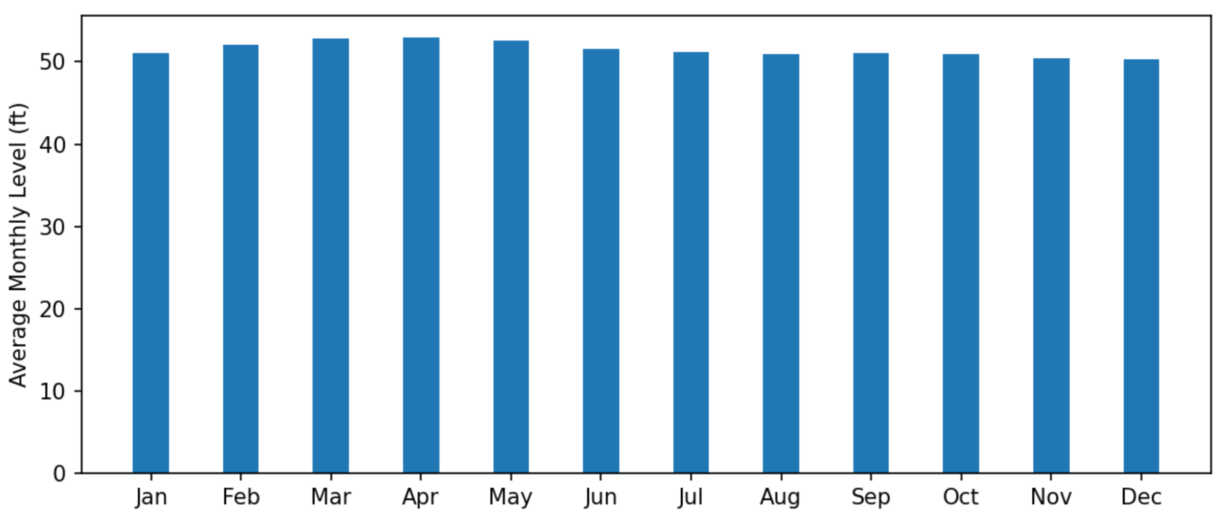

SRWMD Well Bullock Tower Levels
Level (ft)
Date
Average Annual Level (ft)
Average Monthly Level (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

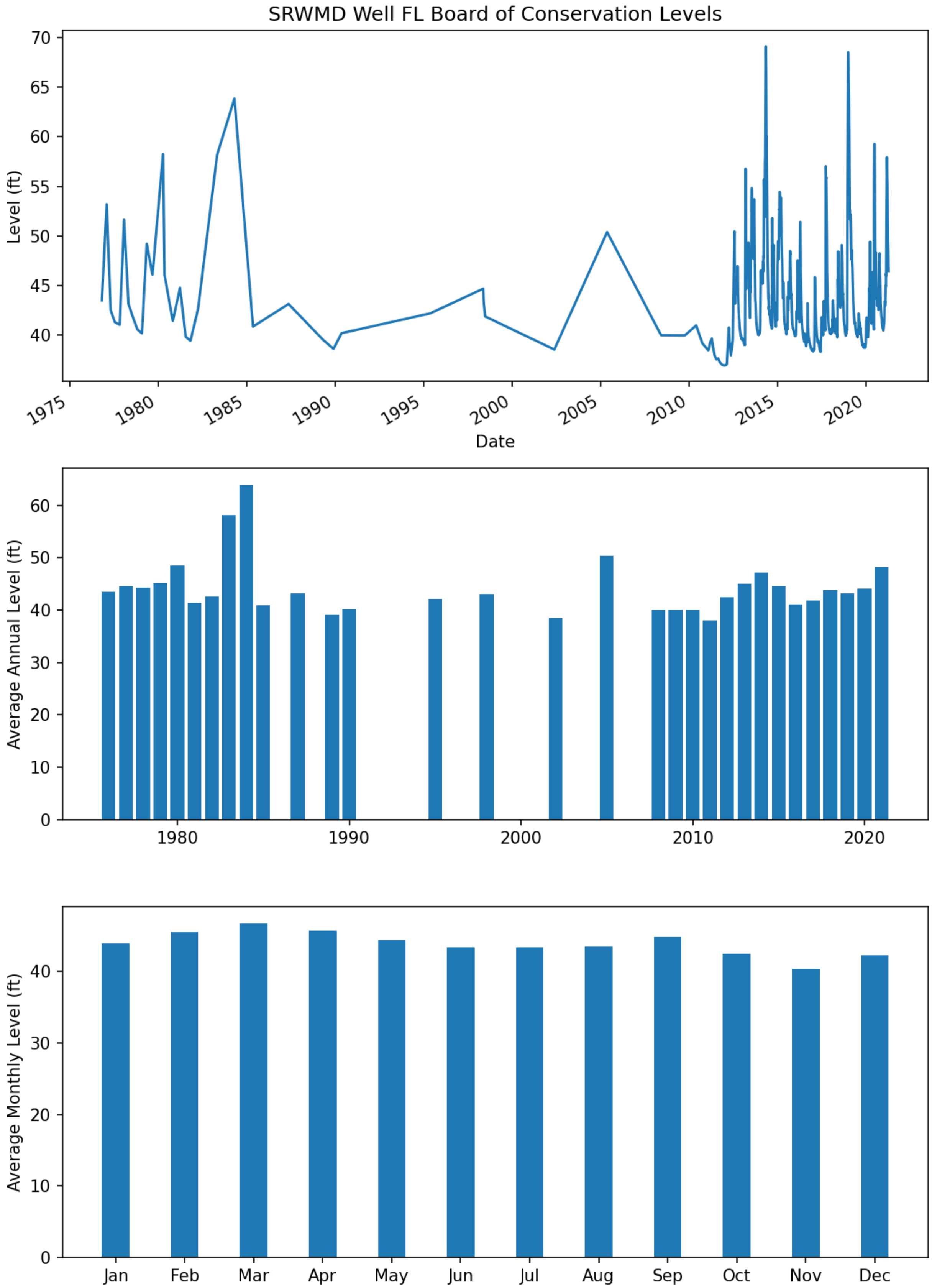


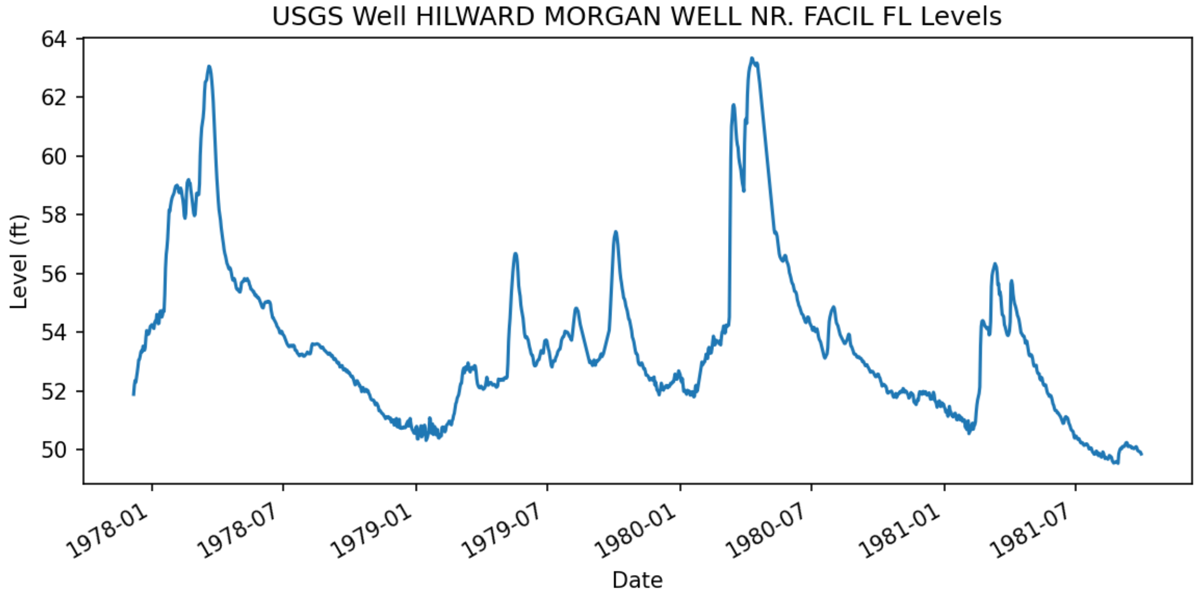
SRWMD Well SUWANNEE CO COMM-COLLISEUM Levels
Level (ft)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
1992
1996
2000
2004
2008
2012
Date
Average Annual Level (ft)
0
10
20
30
40
1990
1995
2000
2005
2010
Average Monthly Level (ft)
0
10
20
30
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

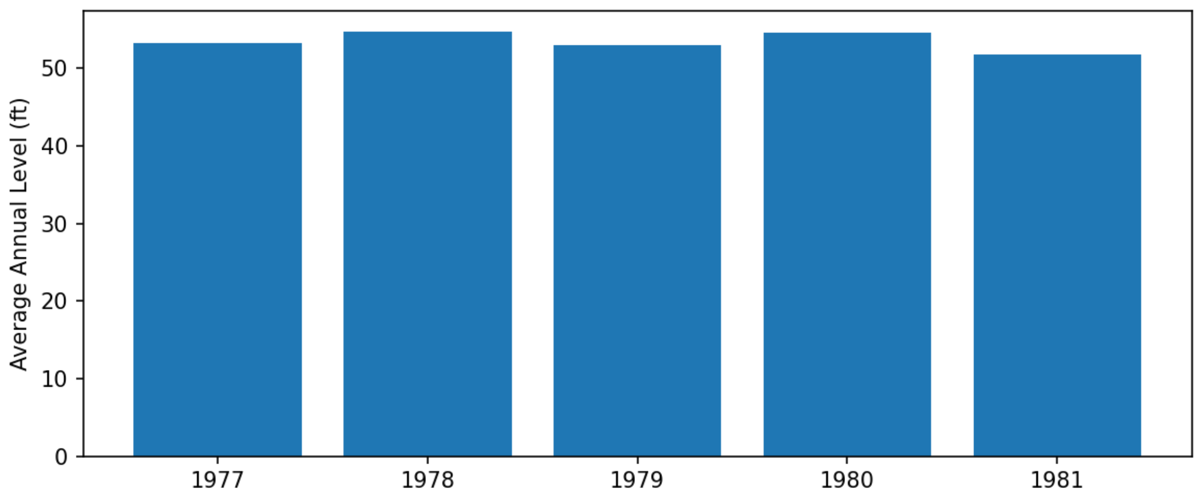

SRWMD Well Old Benton Tower Levels
Level (ft)
60.0
57.5
55.0
52.5
50.0
47.5
45.0
1988
1992
1996
2000
2004
2008
2012
2016
2020
Date

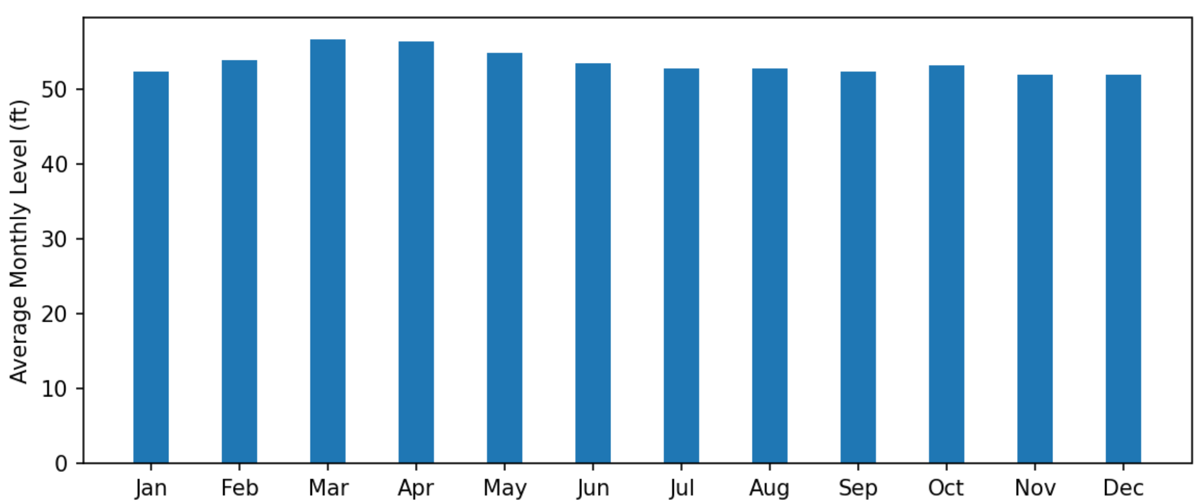

Average Annual Level (ft)
0
10
20
30
40
50
1990
1995
2000
2005
2010
2015
2020

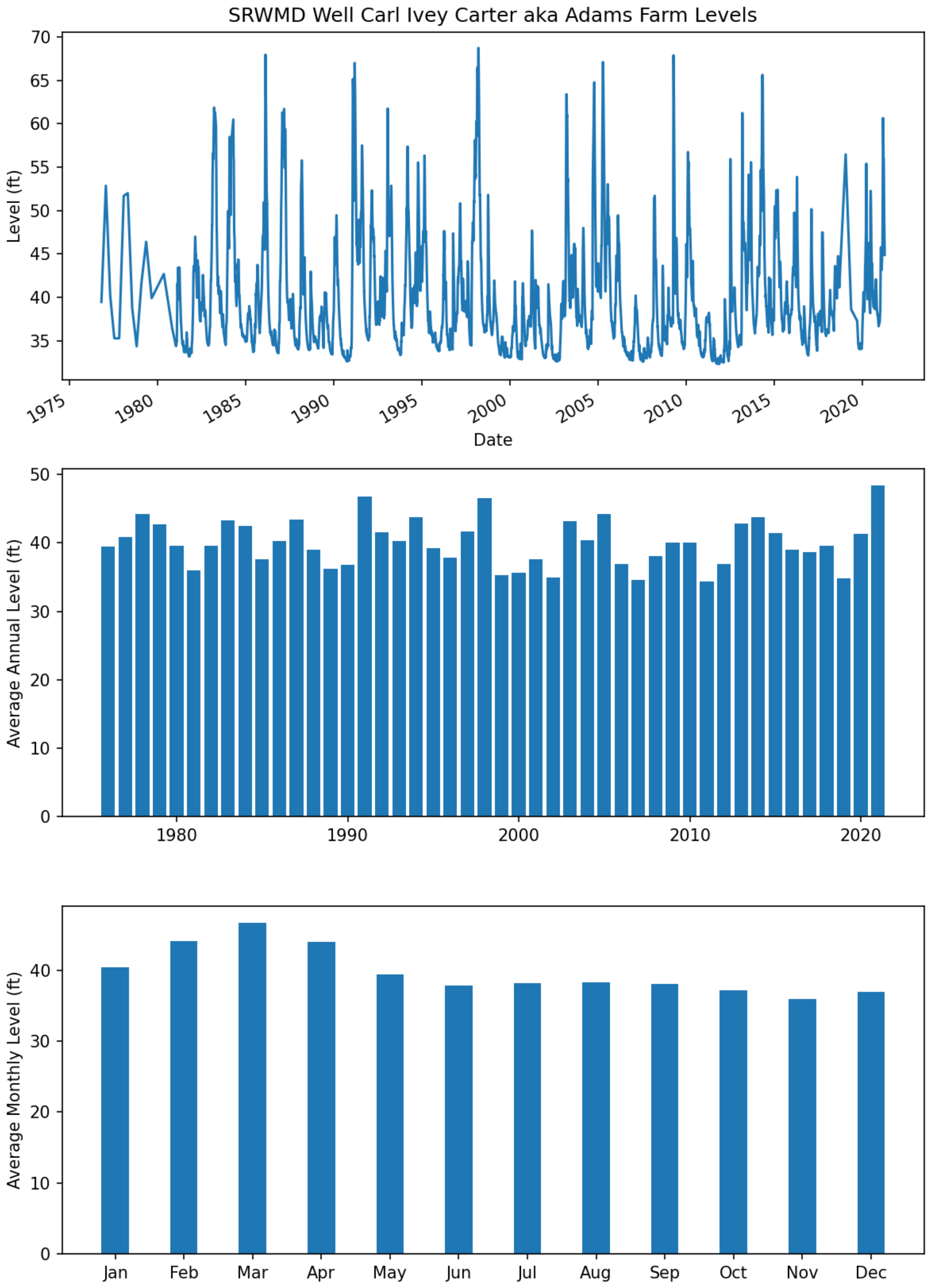

Average Monthly Level (ft)
0
10
20
30
40
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

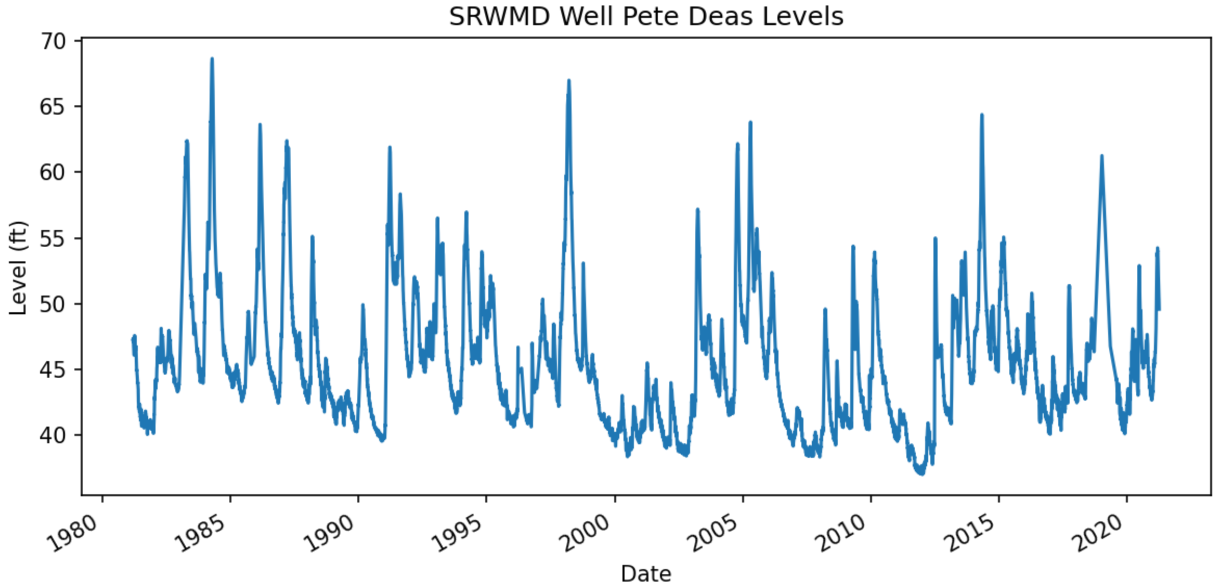

SRWMD Well FL Board of Conservation Levels
Level (ft)
Date
Average Annual Level (ft)
Average Monthly Level (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

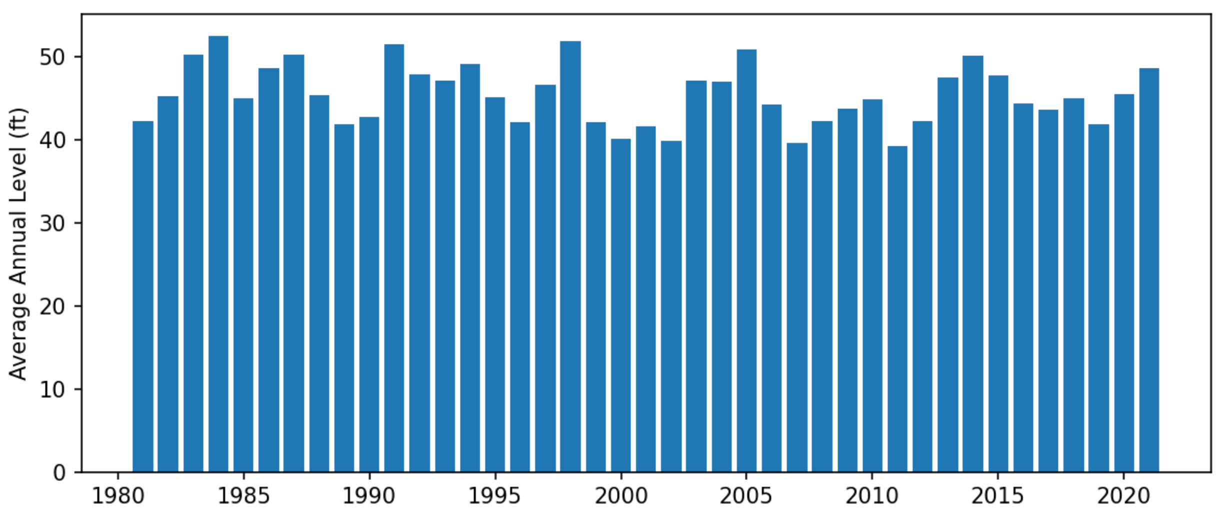

USGS Well HILWARD MORGAN WELL NR. FACIL FL Levels
Level (ft)
64
62
60
58
56
54
52
50
1978-01
1978-07
1979-01
1979-07
1980-01
1980-07
1981-01
1981-07
Date

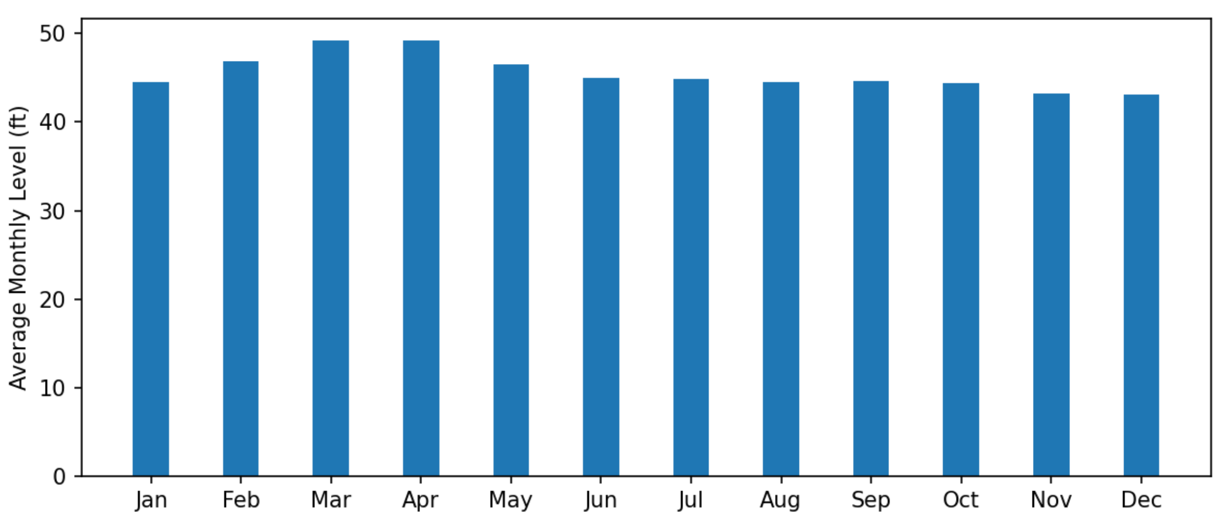

Average Annual Level (ft)
50
40
30
20
10
0
1977
1978
1979
1980
1981

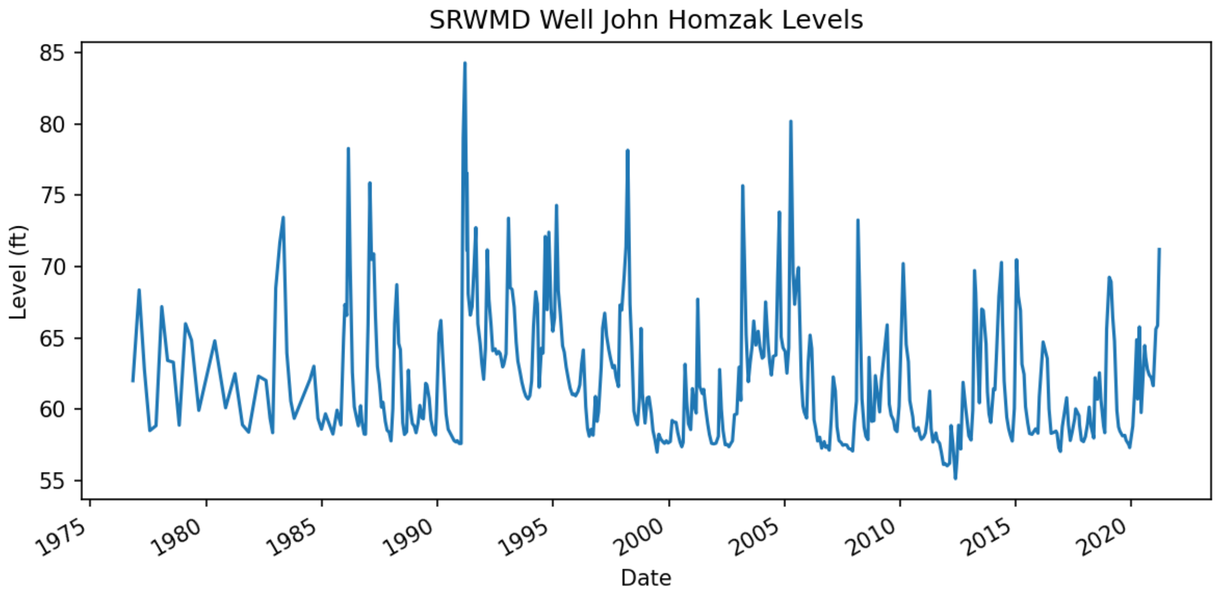

Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

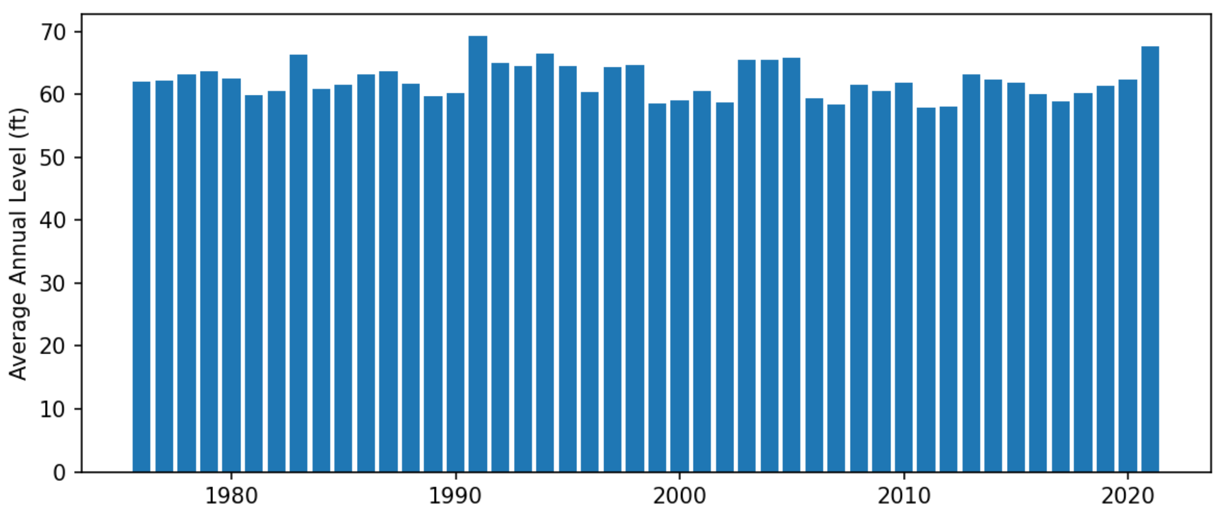

SRWMD Well Carl Ivey Carter aka Adams Farm Levels
Level (ft)
Date
Average Annual Level (ft)
Average Monthly Level (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

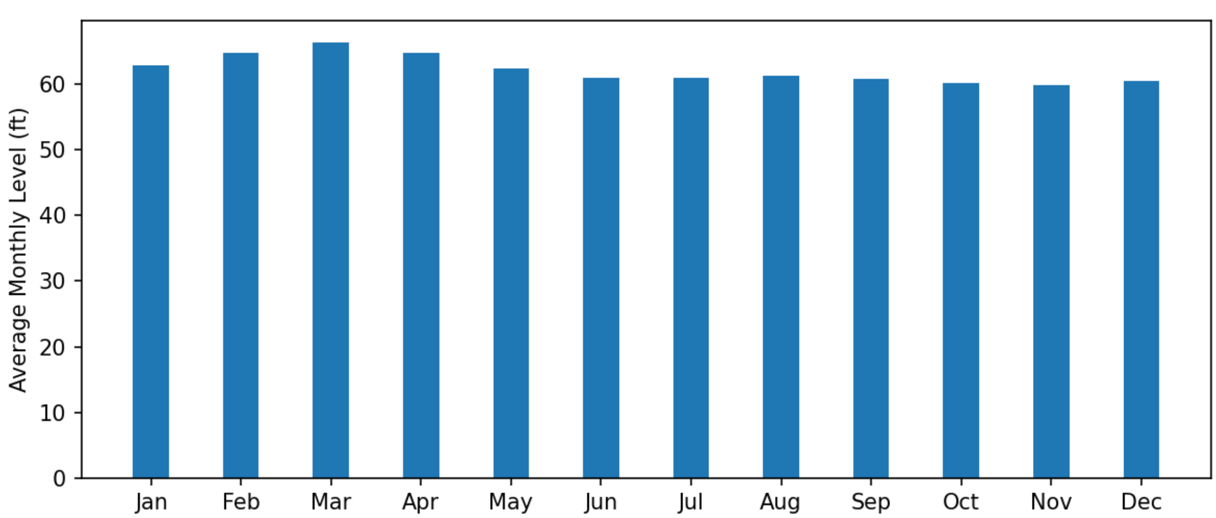

SRWMD Well Pete Deas Levels
Level (ft)
70
65
60
55
50
45
40
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date

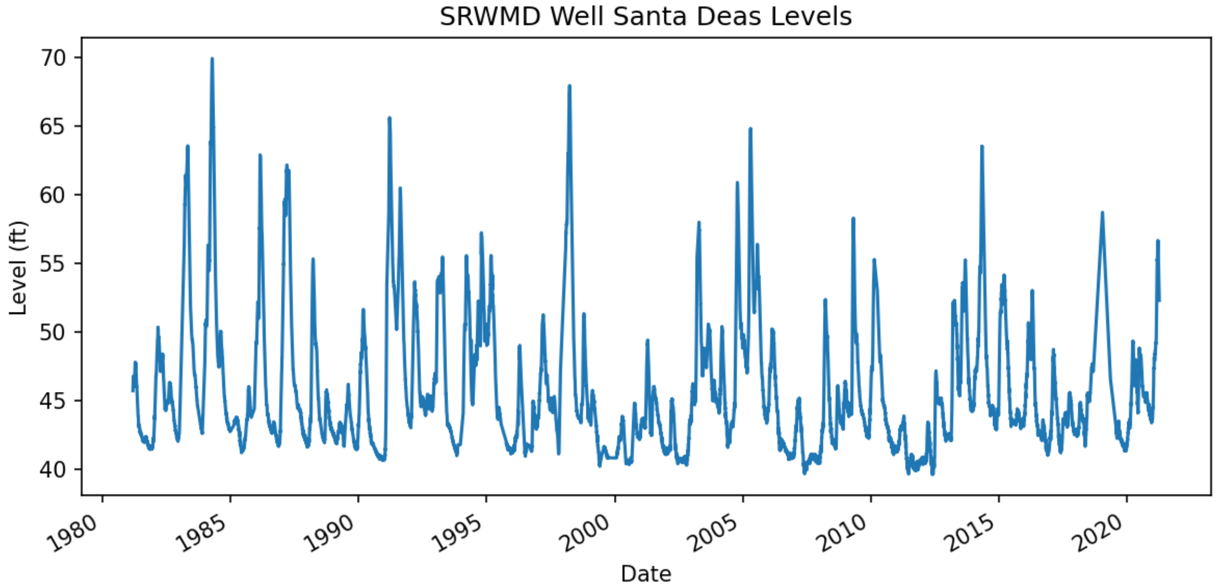

Average Annual Level (ft)
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
2020

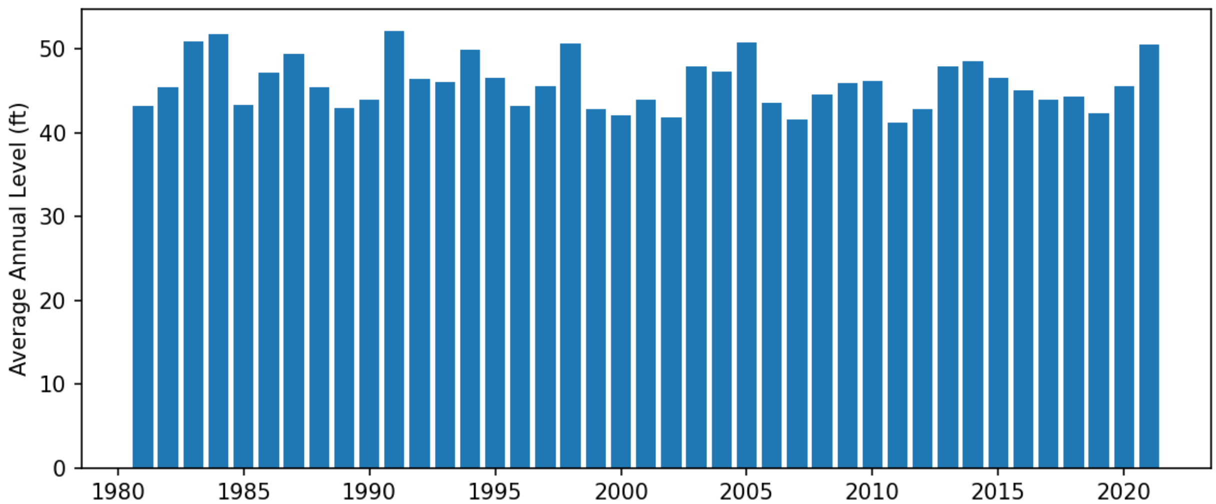

Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

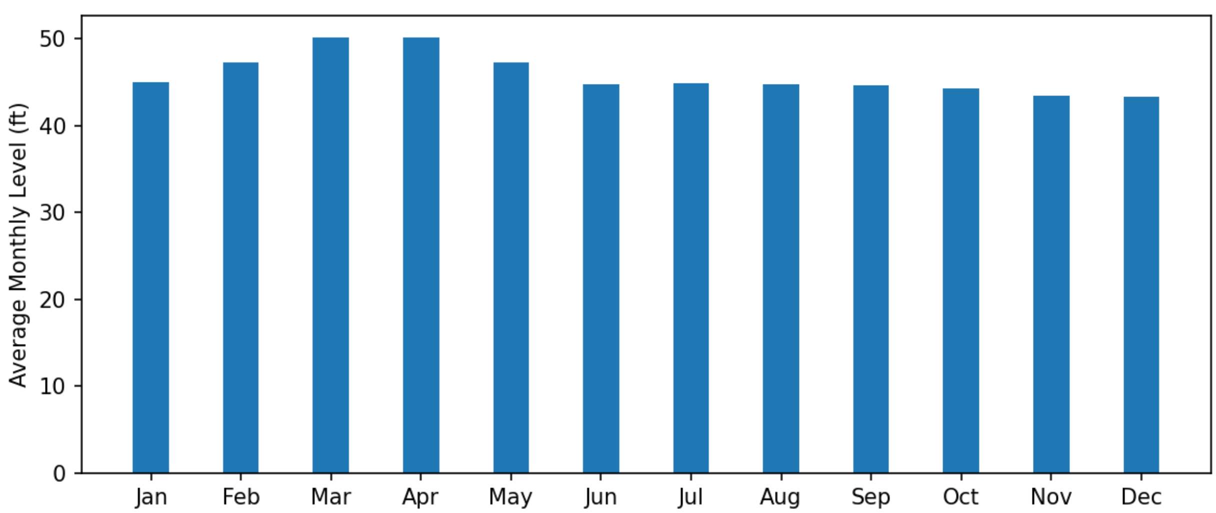

SRWMD Well John Homzak Levels
Level (ft)
Date
85
80
75
70
65
60
55
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

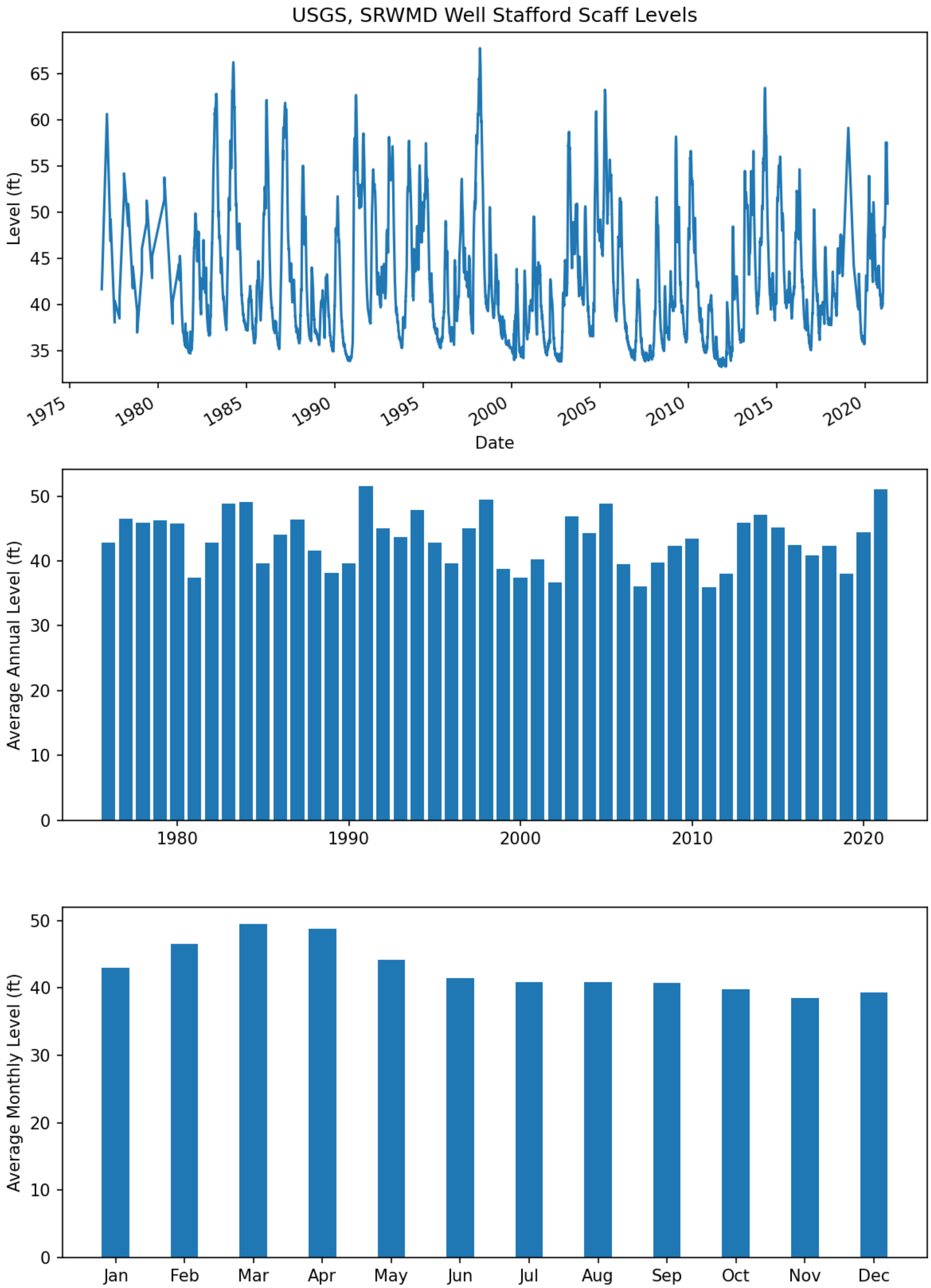

Average Annual Level (ft)
70
60
50
40
30
20
10
0
1980
1990
2000
2010
2020

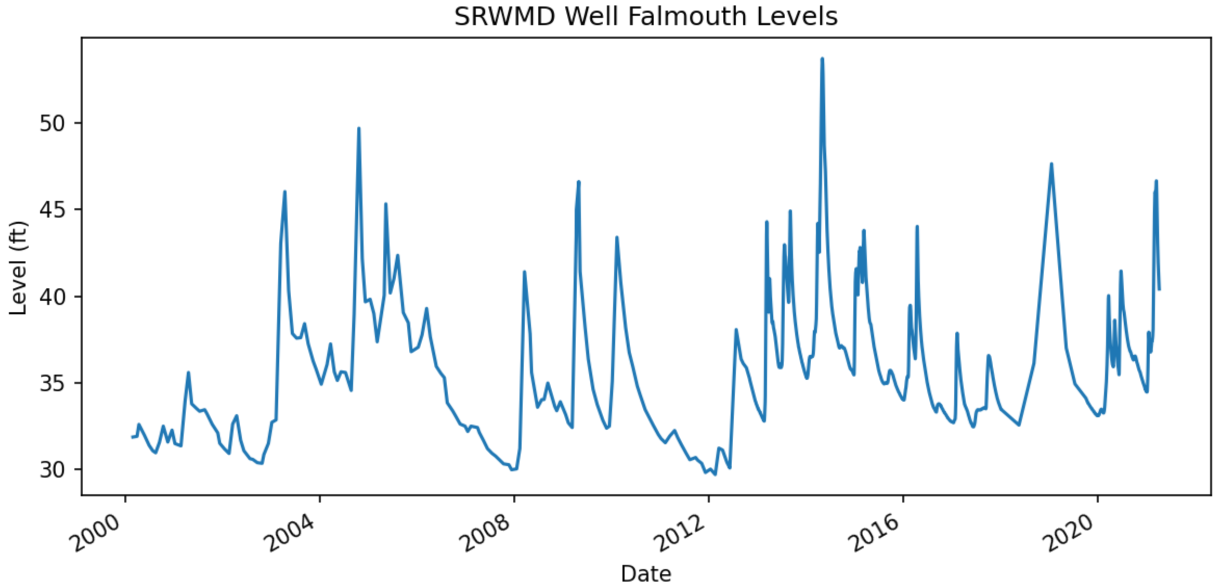

Average Monthly Level (ft)
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SRWMD Well Santa Deas Levels
Level (ft)
Date
70
65
60
55
50
45
40
1980
1985
1990
1995
2000
2005
2010
2015
2020

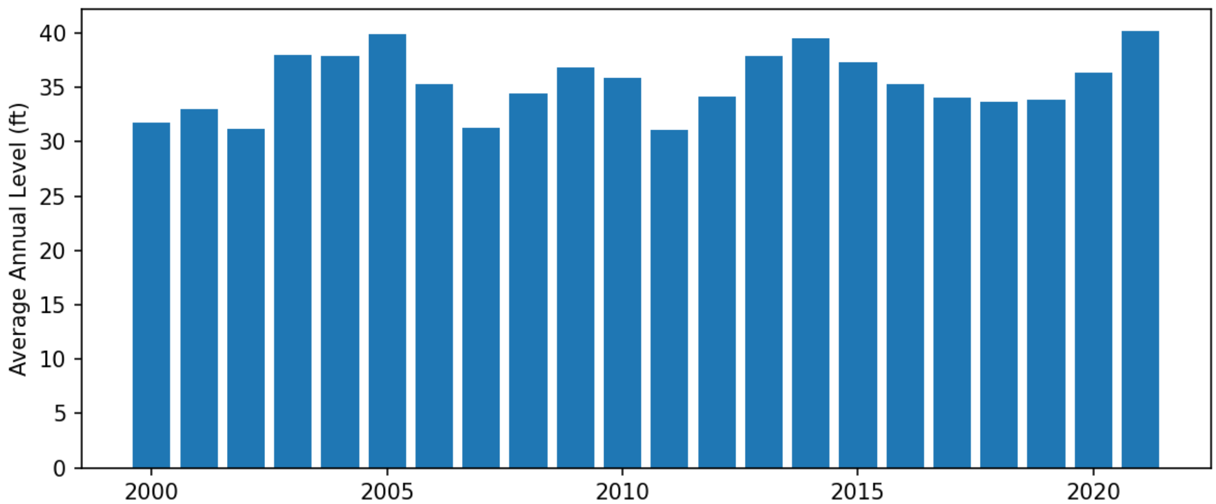

Average Annual Level (ft)
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
2020


Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

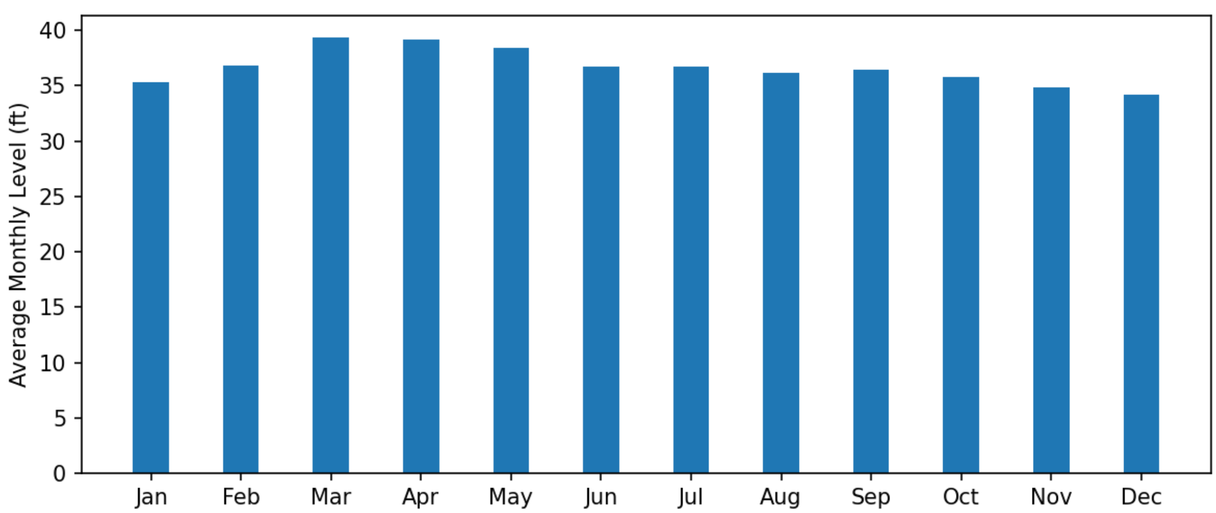

USGS, SRWMD Well Stafford Scaff Levels
Level (ft)
Date
Average Annual Level (ft)
Average Monthly Level (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



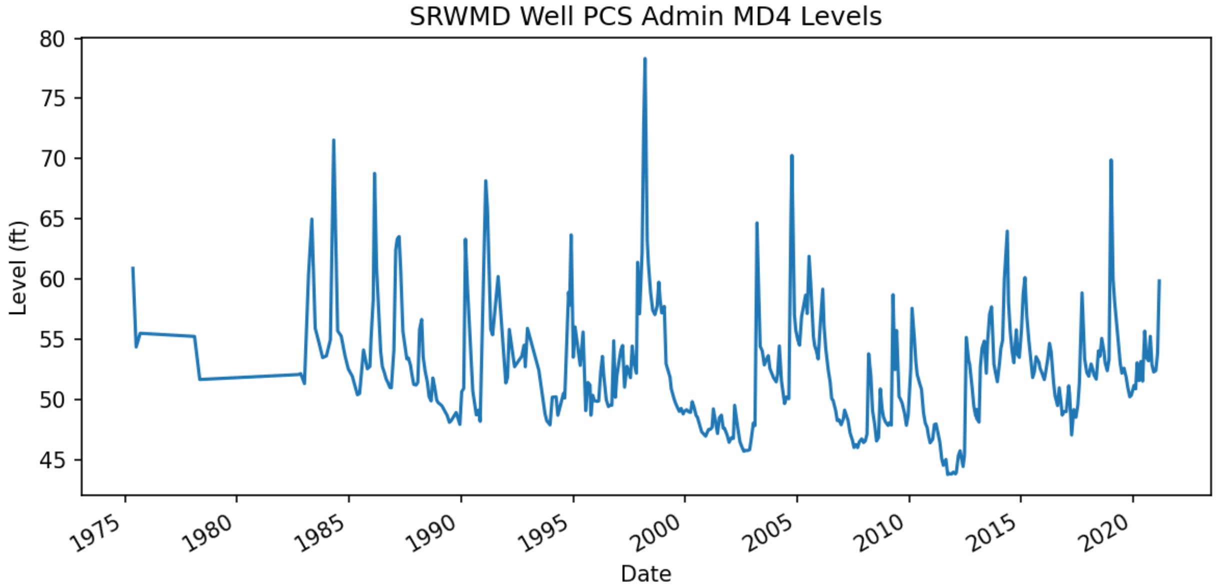
SRWMD Well Falmouth Levels
Level (ft)
Date
50
45
40
35
30
2000
2004
2008
2012
2016
2020

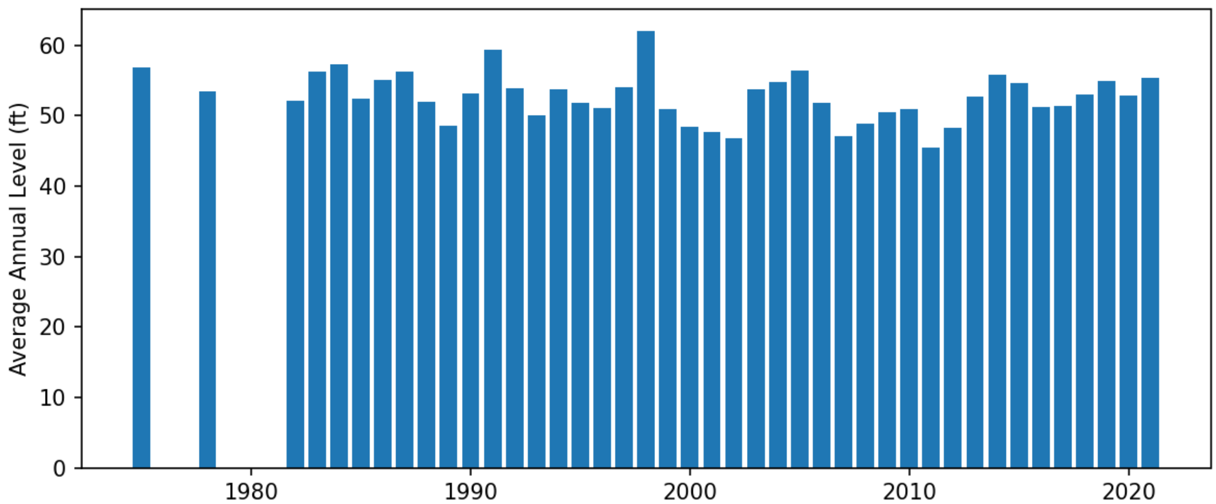


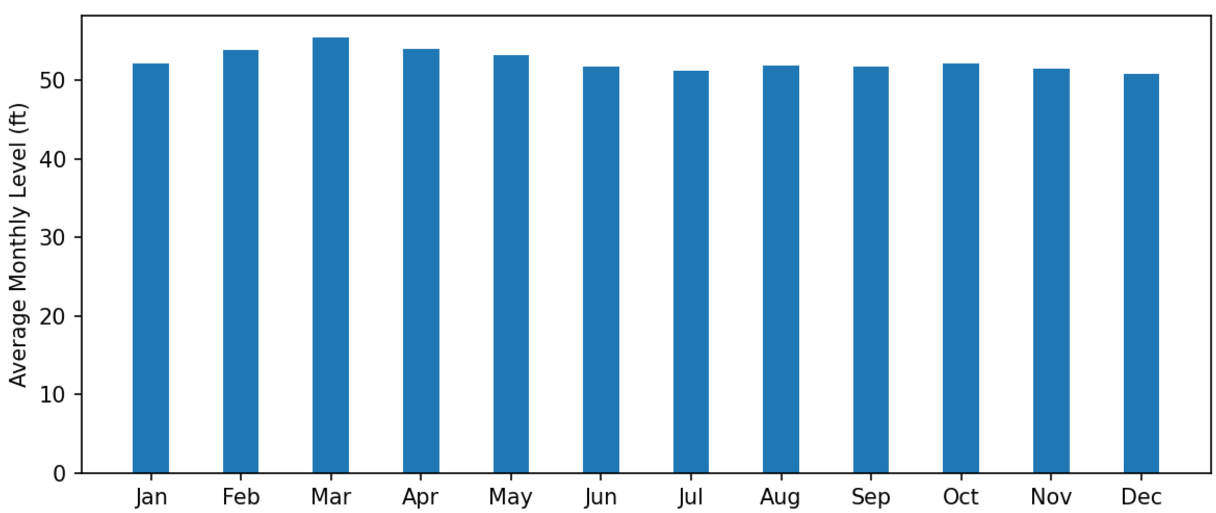
Average Annual Level (ft)
0
5
10
15
20
25
30
35
40
2000
2005
2010
2015
2020

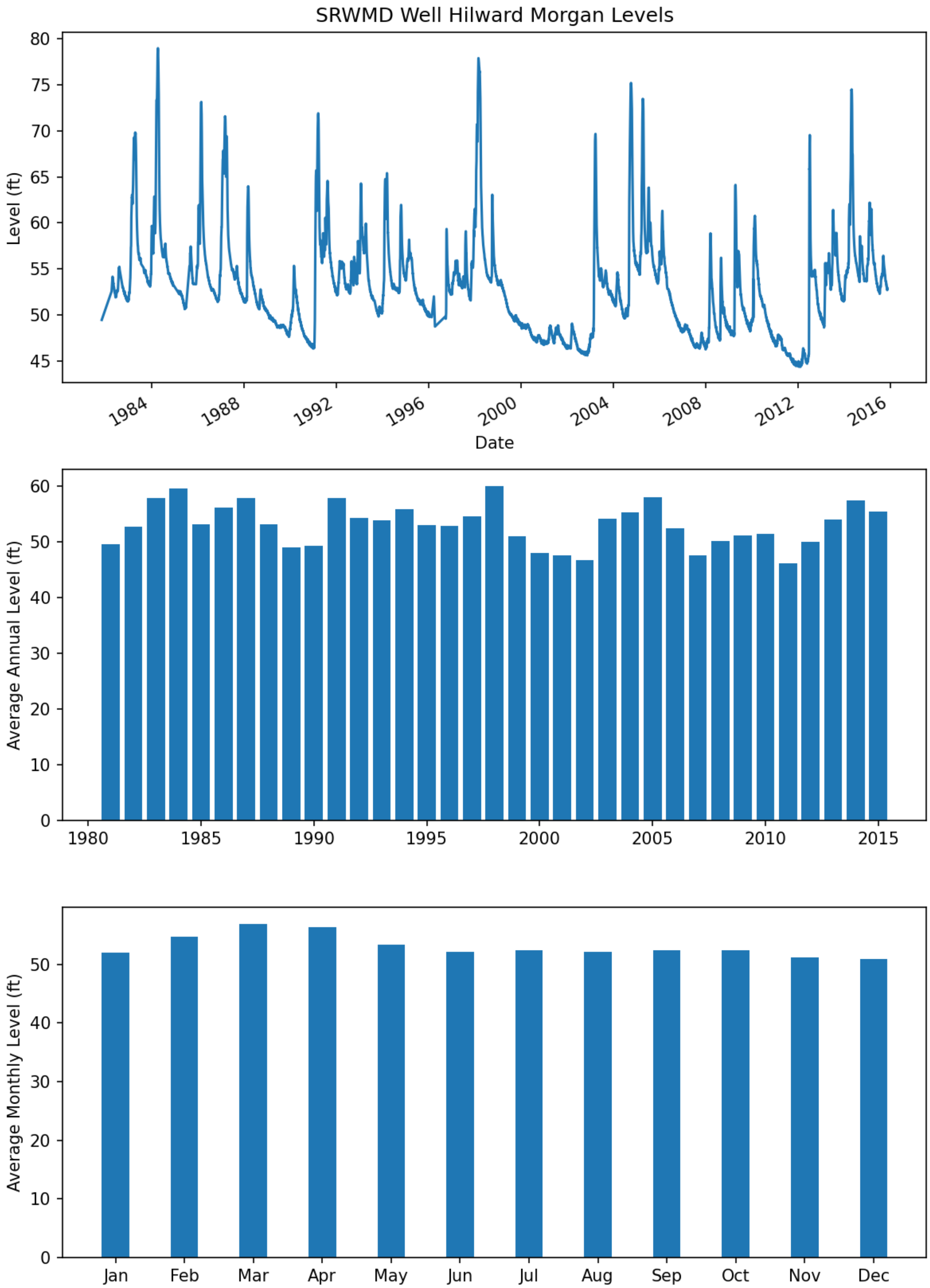


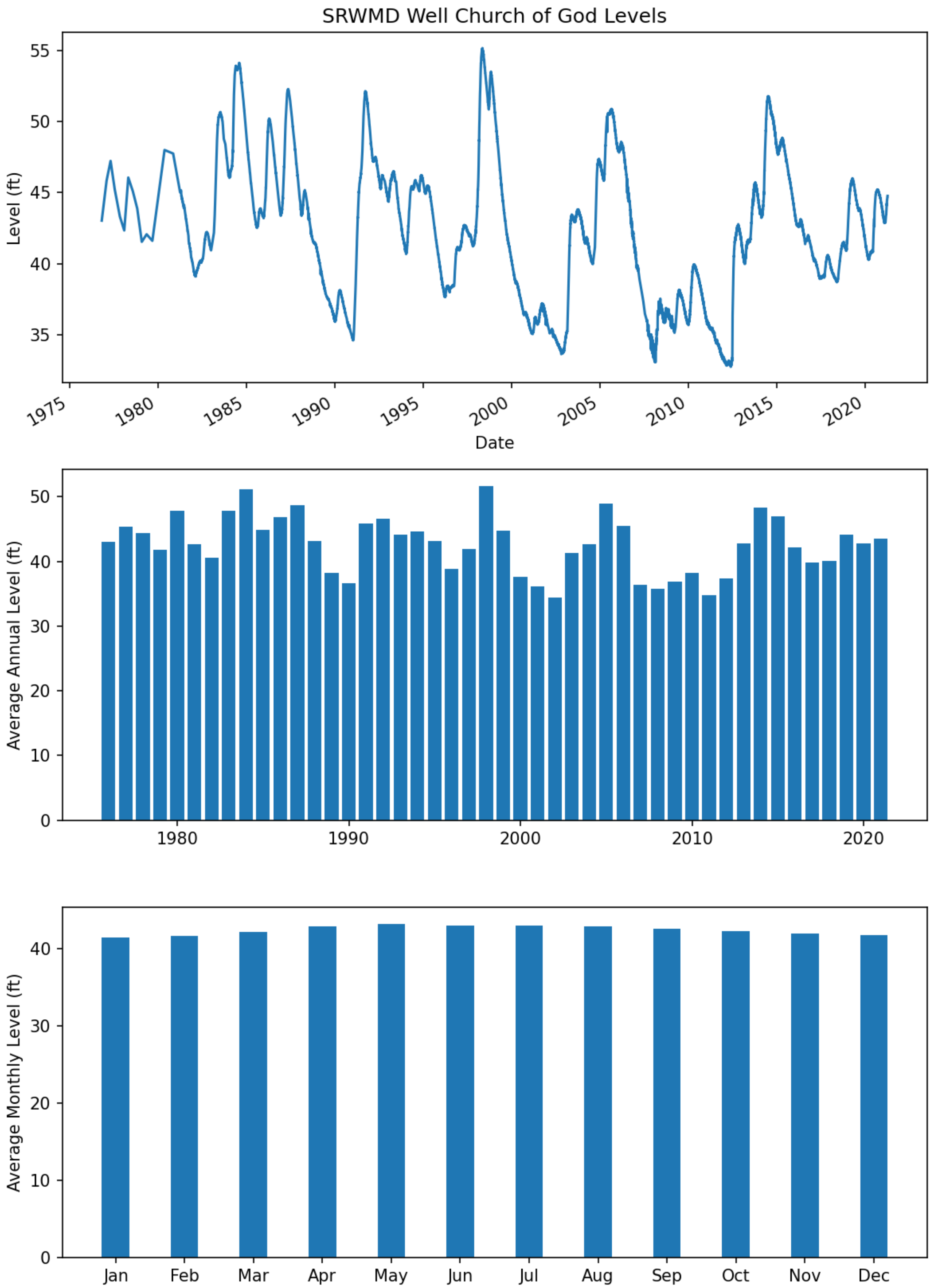
Average Monthly Level (ft)
0
5
10
15
20
25
30
35
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

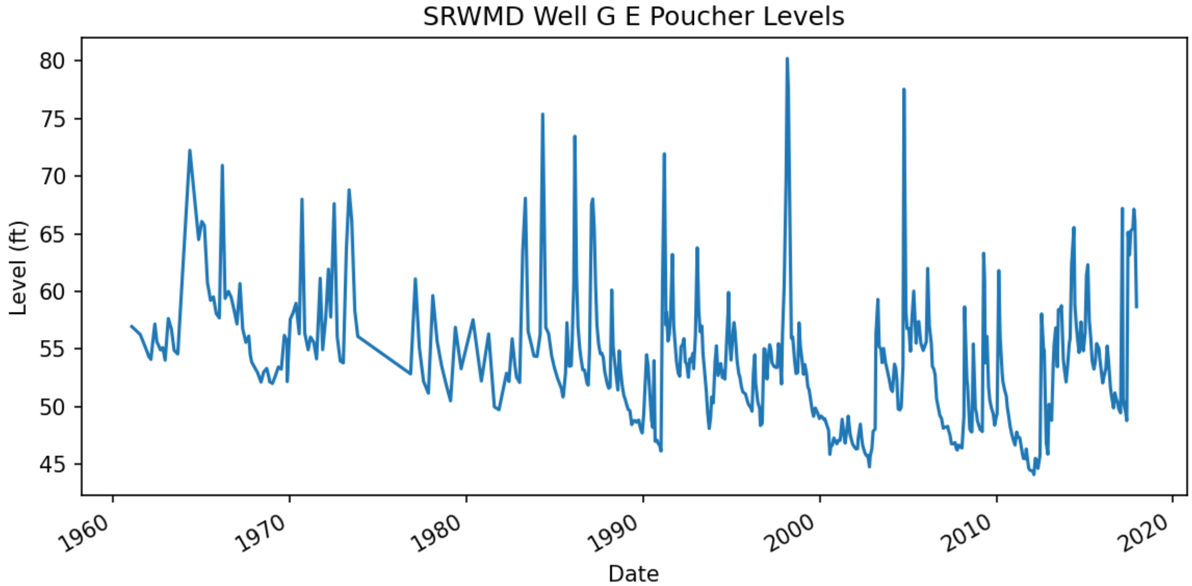

SRWMD Well PCS Admin MD4 Levels
Level (ft)
80
75
70
65
60
55
50
45
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date

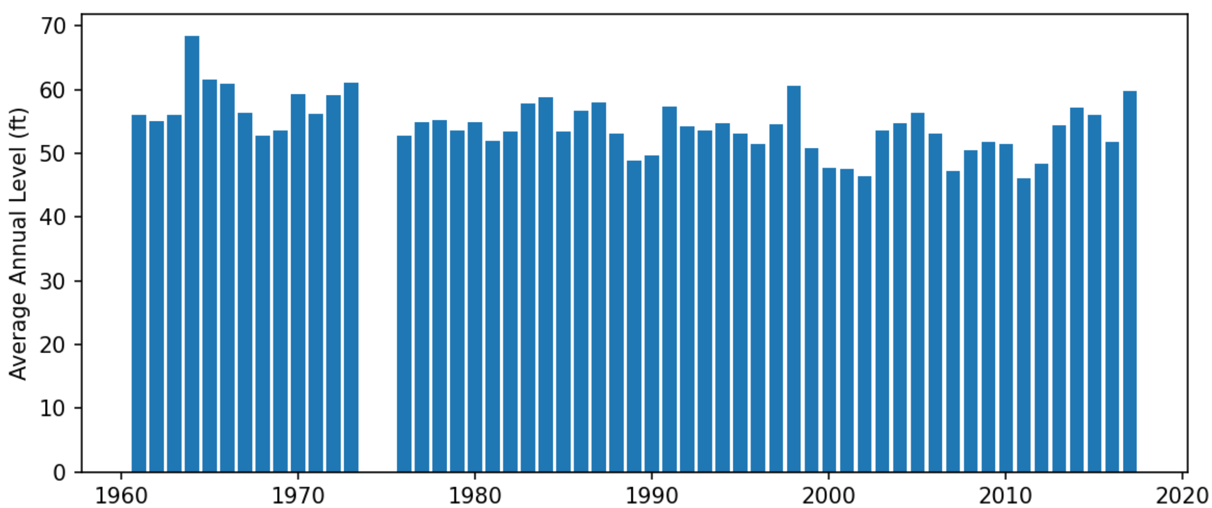

Average Annual Level (ft)
60
50
40
30
20
10
0
1980
1990
2000
2010
2020

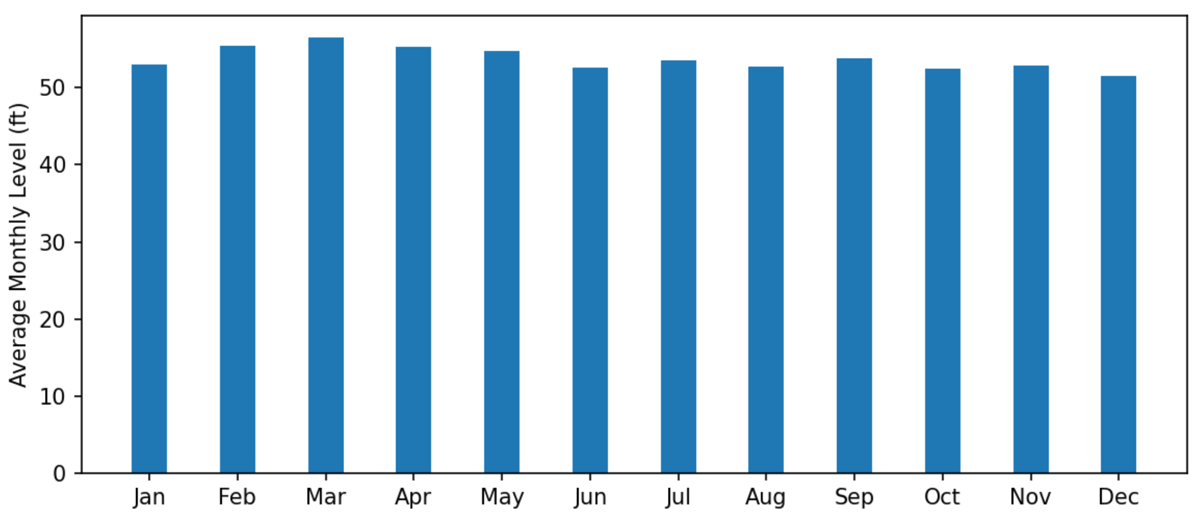

Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

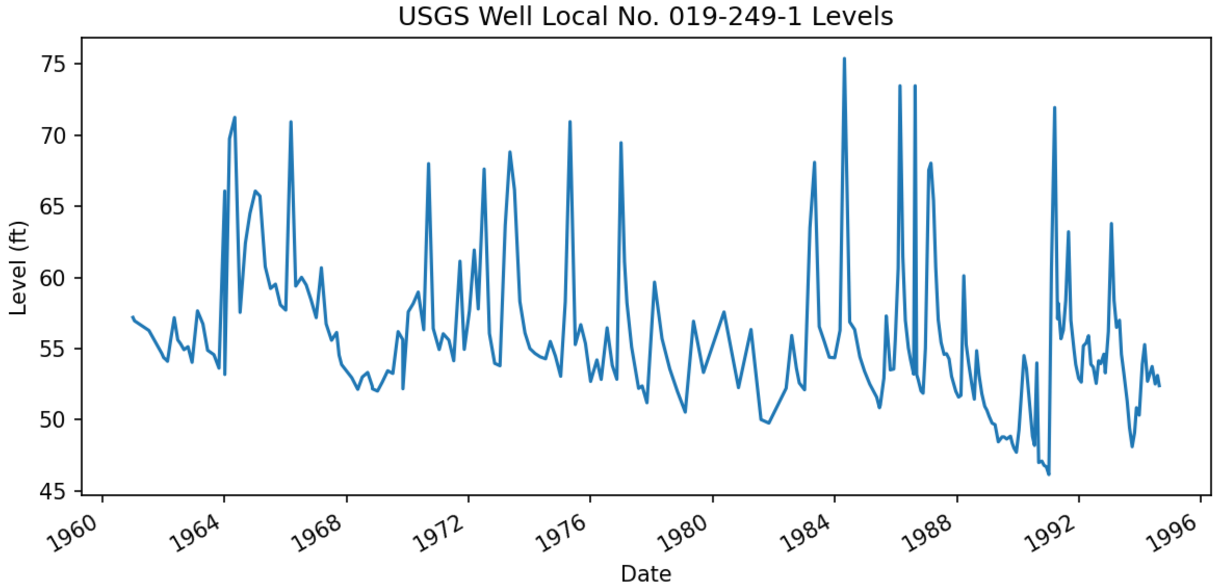

SRWMD Well Hilward Morgan Levels
Level (ft)
80
75
70
65
60
55
50
45
1984
1988
1992
1996
2000
2004
2008
2012
2016
Date
Average Annual Level (ft)
60
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

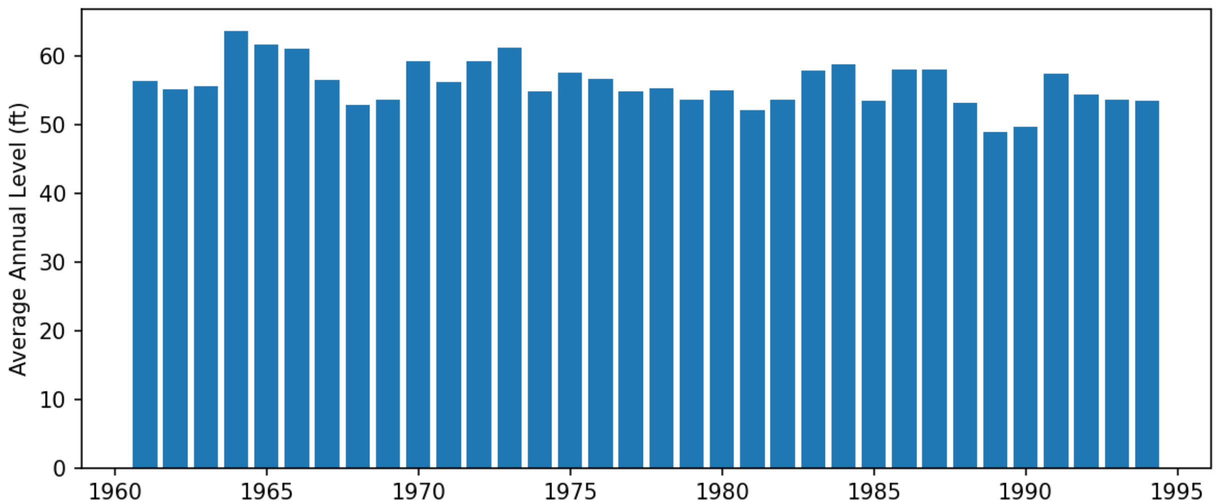

SRWMD Well Church of God Levels
Level (ft)
55
50
45
40
35
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date
Average Annual Level (ft)
50
40
30
20
10
0
1980
1990
2000
2010
2020
Average Monthly Level (ft)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

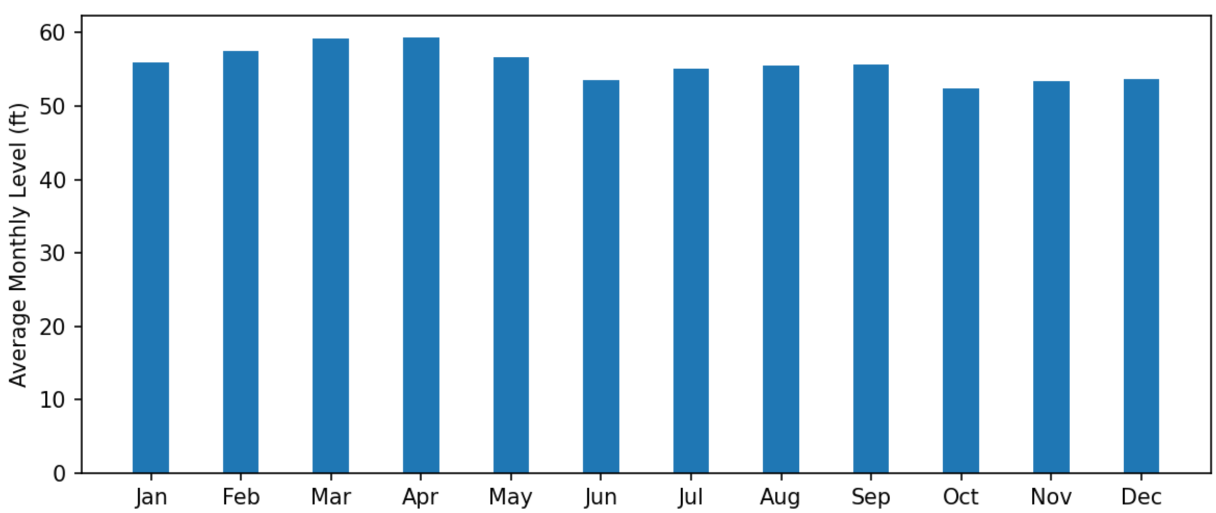

SRWMD Well G E Poucher Levels
Level (ft)
Date
45
50
55
60
65
70
75
80
1960
1970
1980
1990
2000
2010
2020

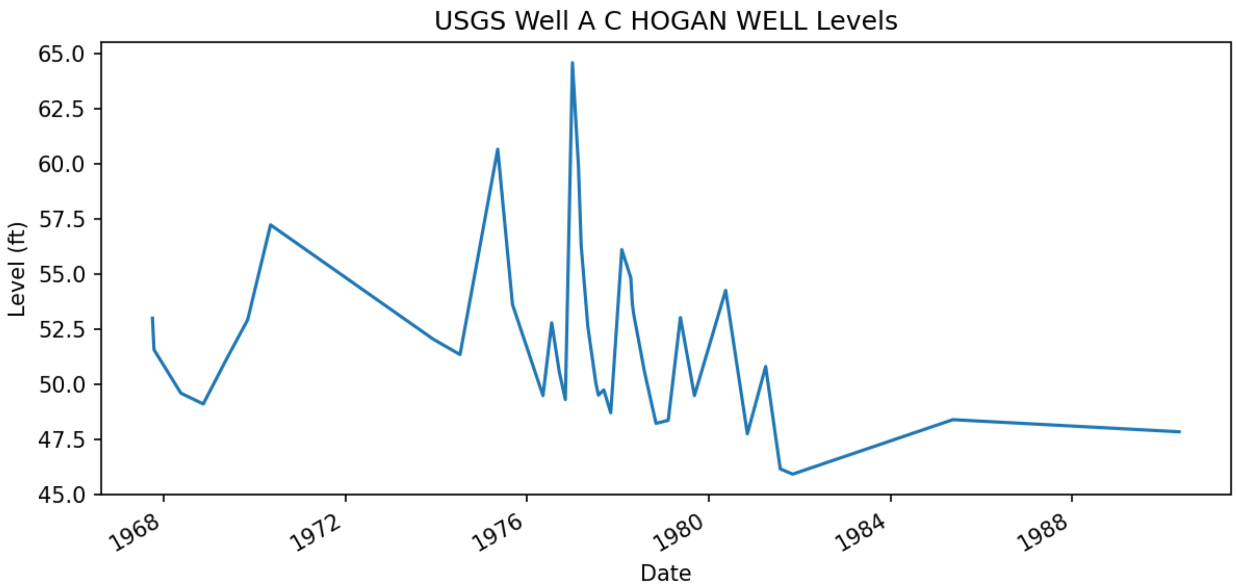

Average Annual Level (ft)
0
10
20
30
40
50
60
70
1960
1970
1980
1990
2000
2010
2020

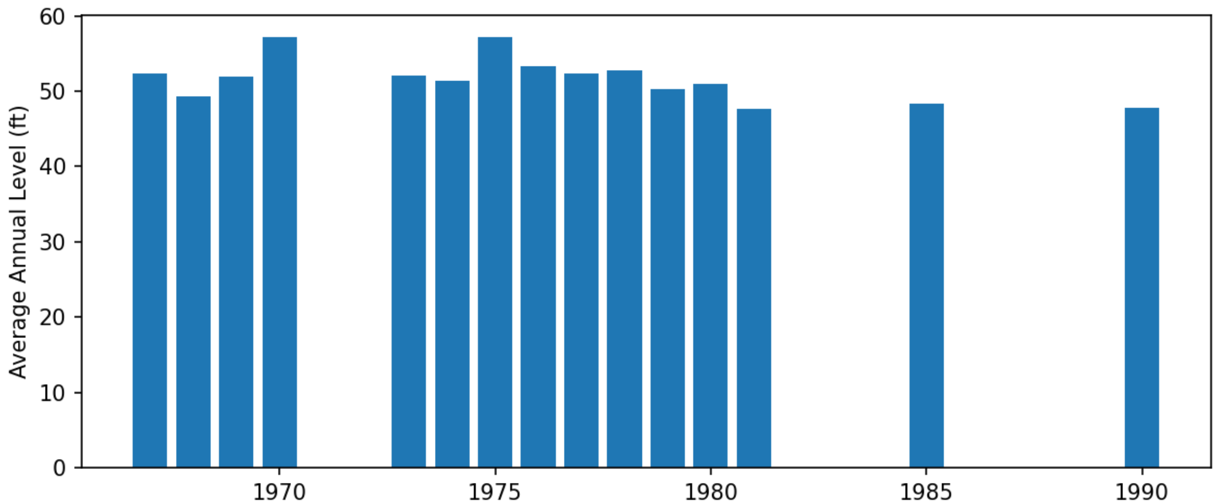

Average Monthly Level (ft)
0
10
20
30
40
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

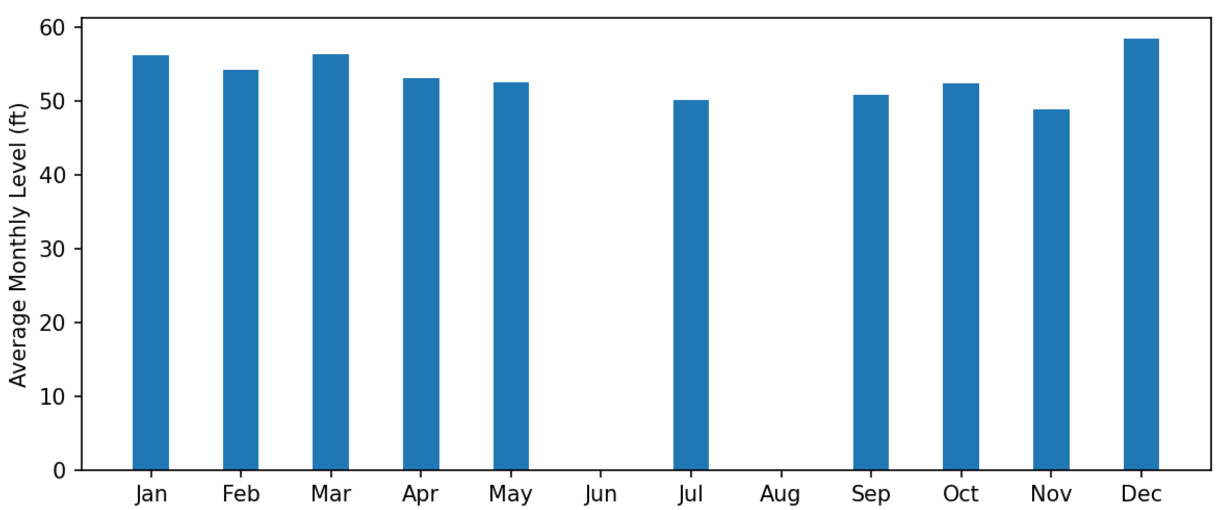

USGS Well Local No. 019-249-1 Levels
Level (ft)
75
70
65
60
55
50
45
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
Date

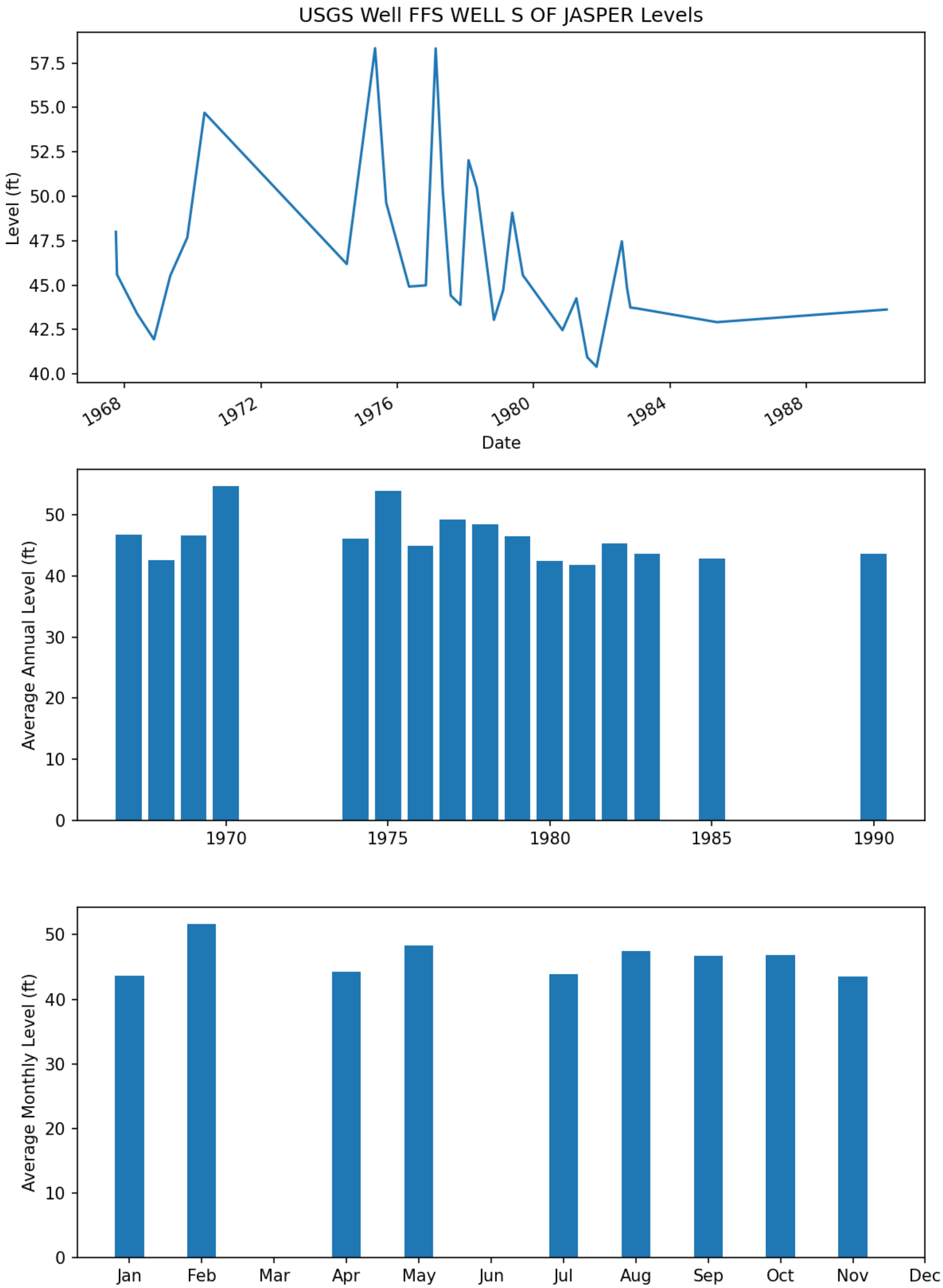

Average Annual Level (ft)
60
50
40
30
20
10
0
1960
1965
1970
1975
1980
1985
1990
1995

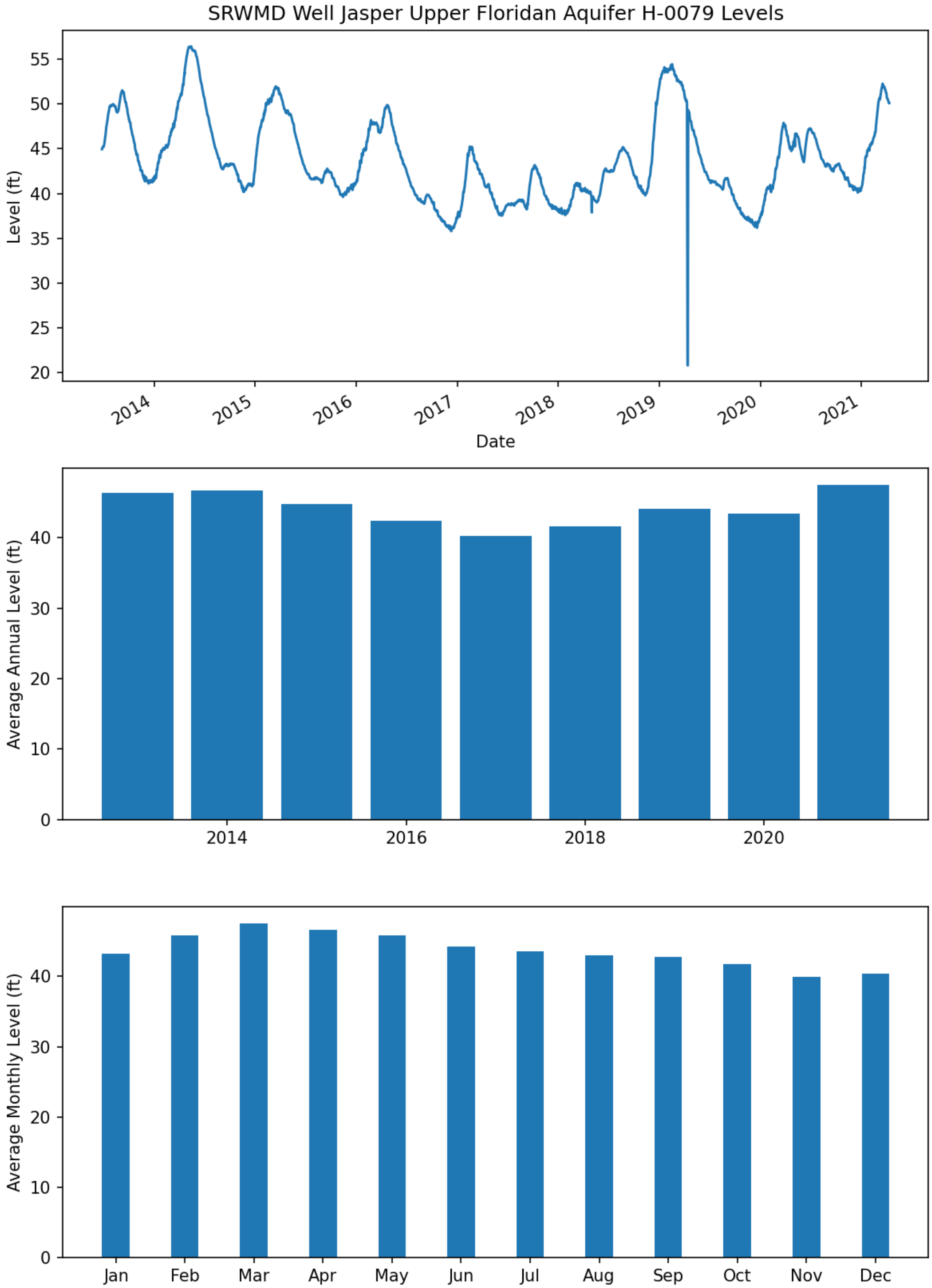

Average Monthly Level (ft)
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

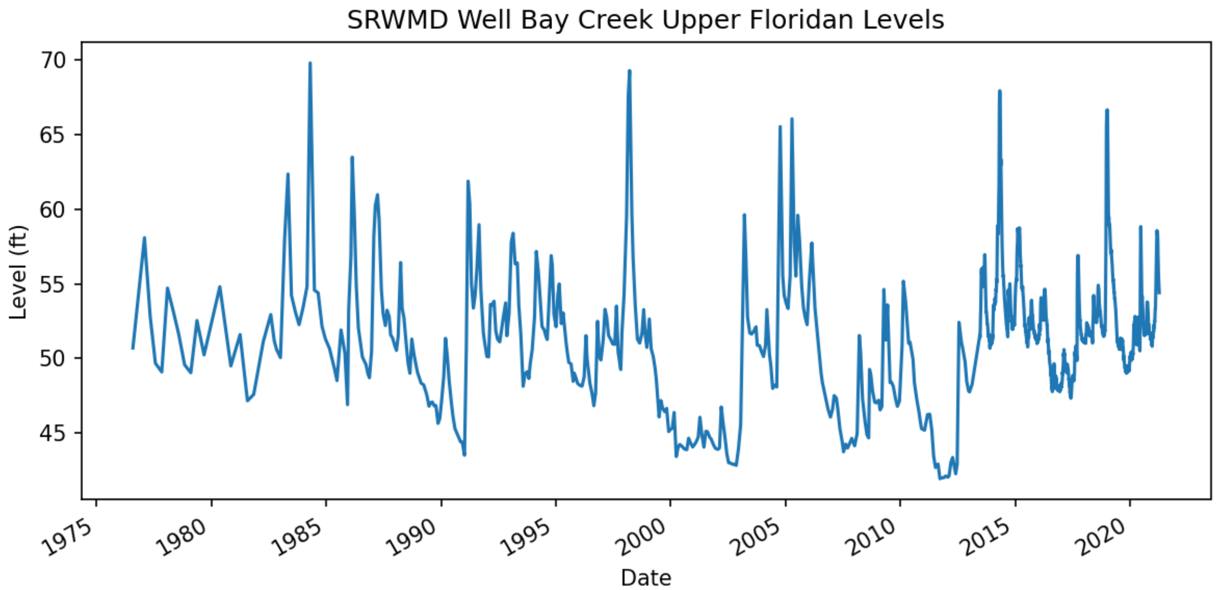

USGS Well A C HOGAN WELL Levels
Level (ft)
65.0
62.5
60.0
57.5
55.0
52.5
50.0
47.5
45.0
1968
1972
1976
1980
1984
1988
Date

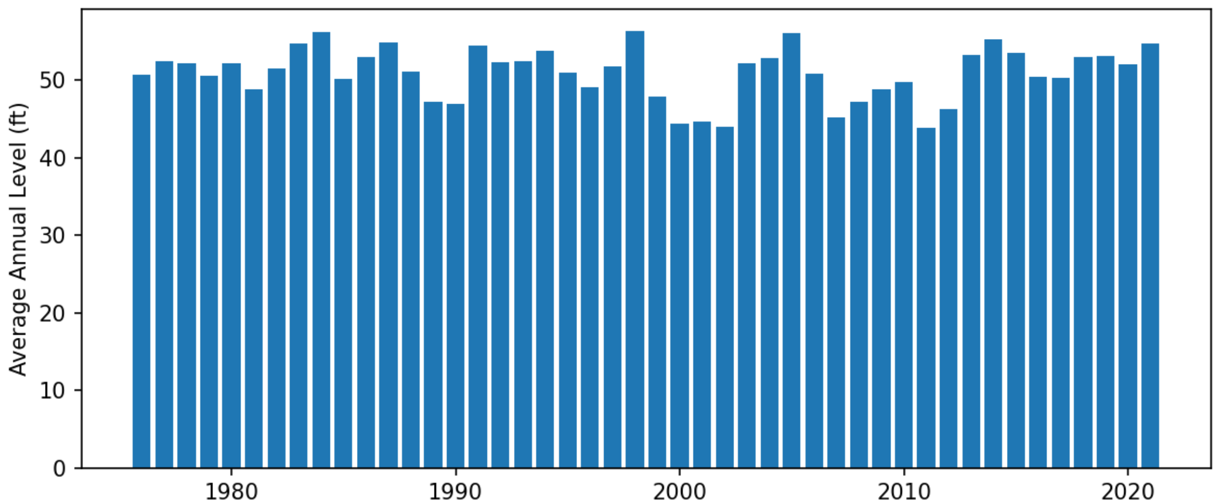

Average Annual Level (ft)
60
50
40
30
20
10
0
1970
1975
1980
1985
1990

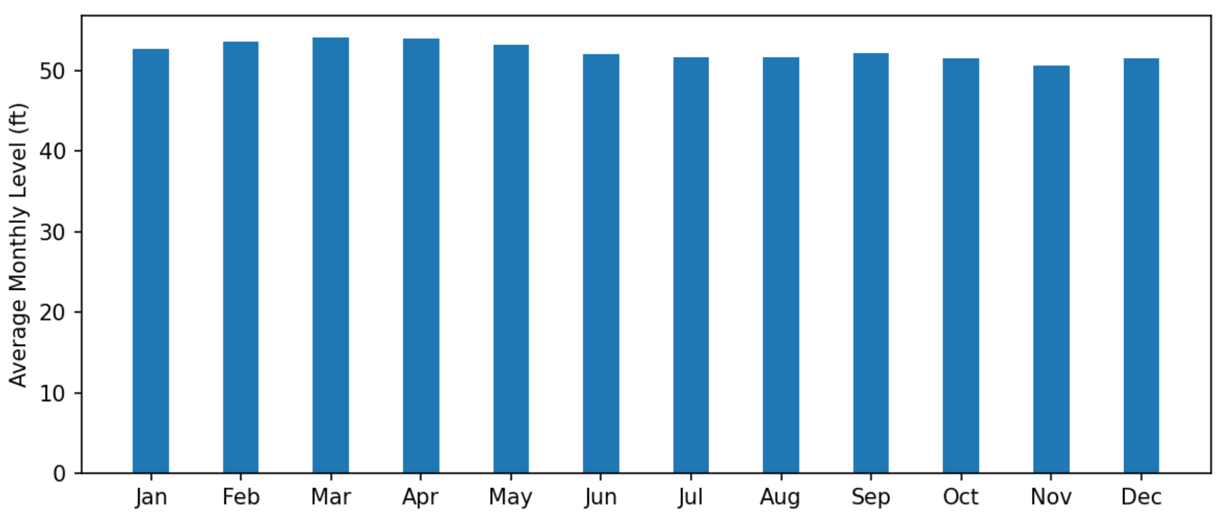

Average Monthly Level (ft)
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

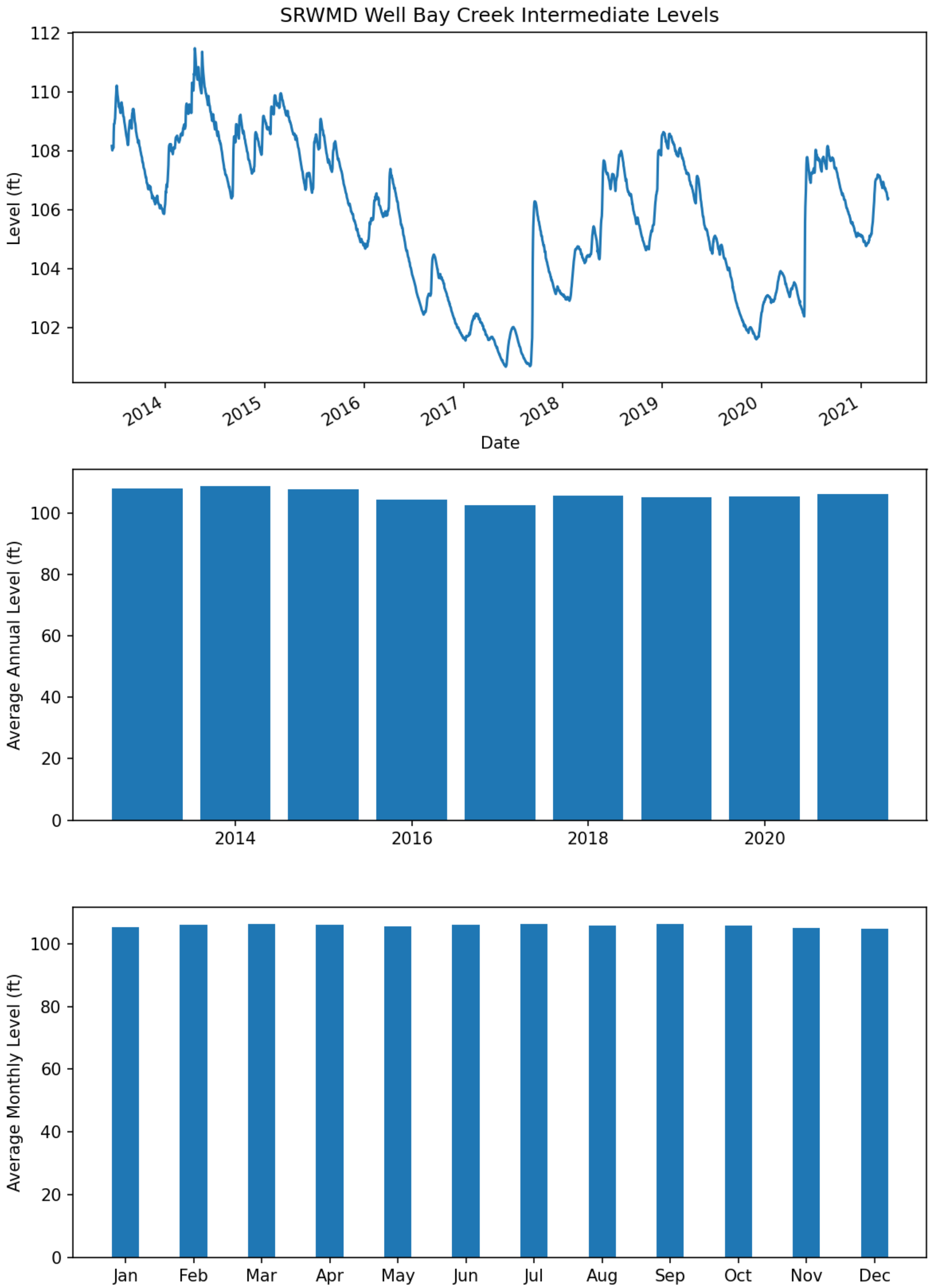

USGS Well FFS WELL S OF JASPER Levels
Level (ft)
57.5
55.0
52.5
50.0
47.5
45.0
42.5
40.0
1968
1972
1976
1980
1984
1988
Date
Average Annual Level (ft)
50
40
30
20
10
0
1970
1975
1980
1985
1990
Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

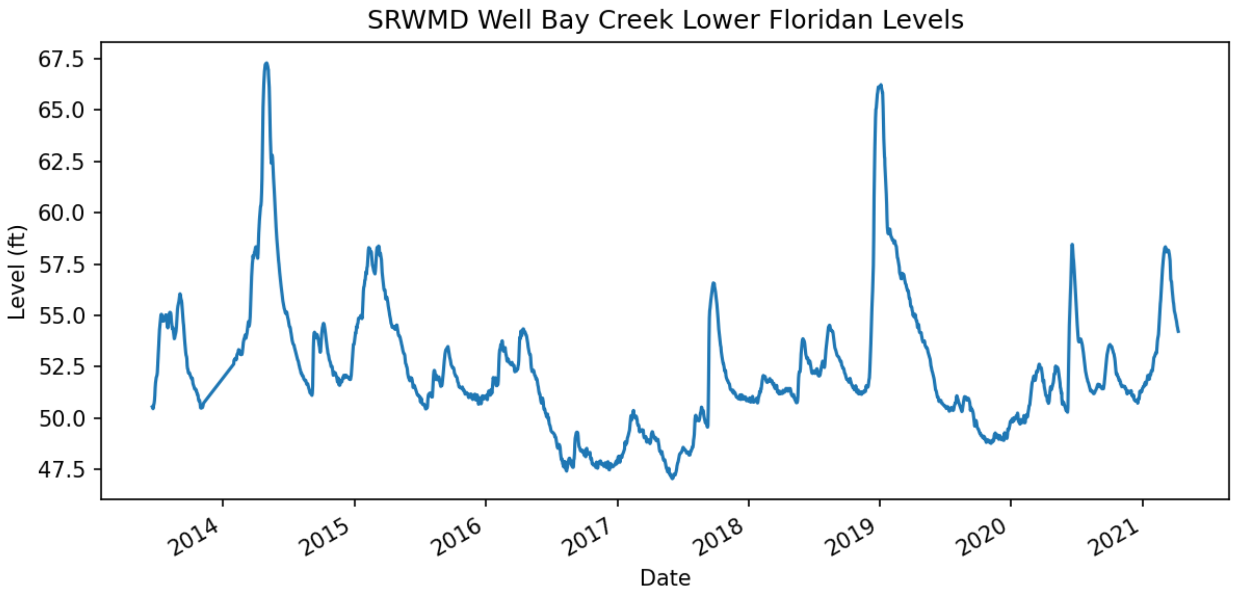

SRWMD Well Jasper Upper Floridan Aquifer H-0079 Levels
Level (ft)
55
50
45
40
35
30
25
20
2014
2015
2016
2017
2018
2019
2020
2021
Date
Average Annual Level (ft)
40
30
20
10
0
2014
2016
2018
2020
Average Monthly Level (ft)
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

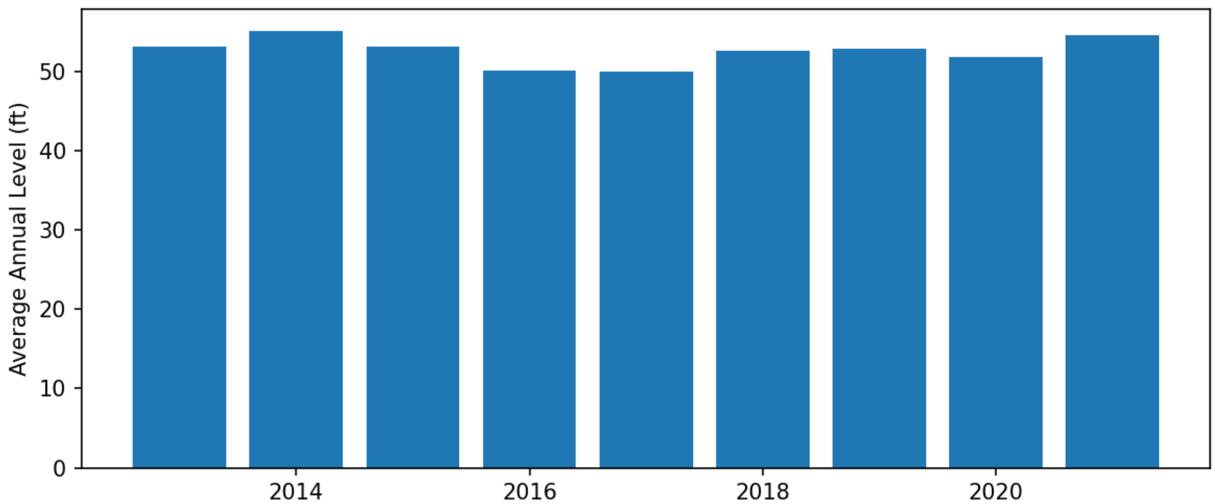

SRWMD Well Bay Creek Upper Floridan Levels
Level (ft)
70
65
60
55
50
45
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date

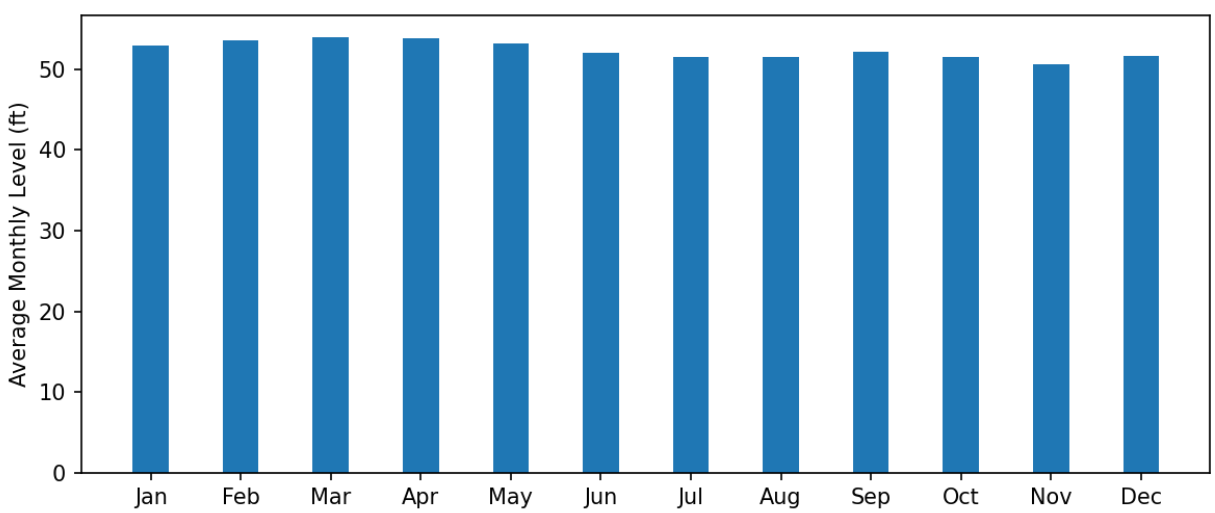

Average Annual Level (ft)
0
10
20
30
40
50
1980
1990
2000
2010
2020

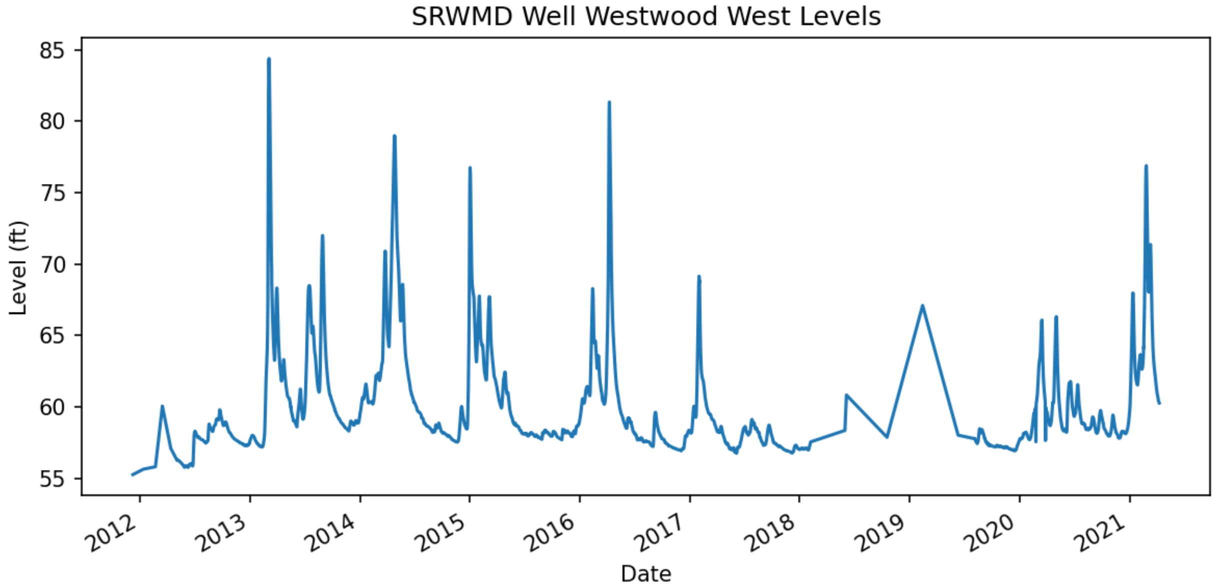

Average Monthly Level (ft)
0
10
20
30
40
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

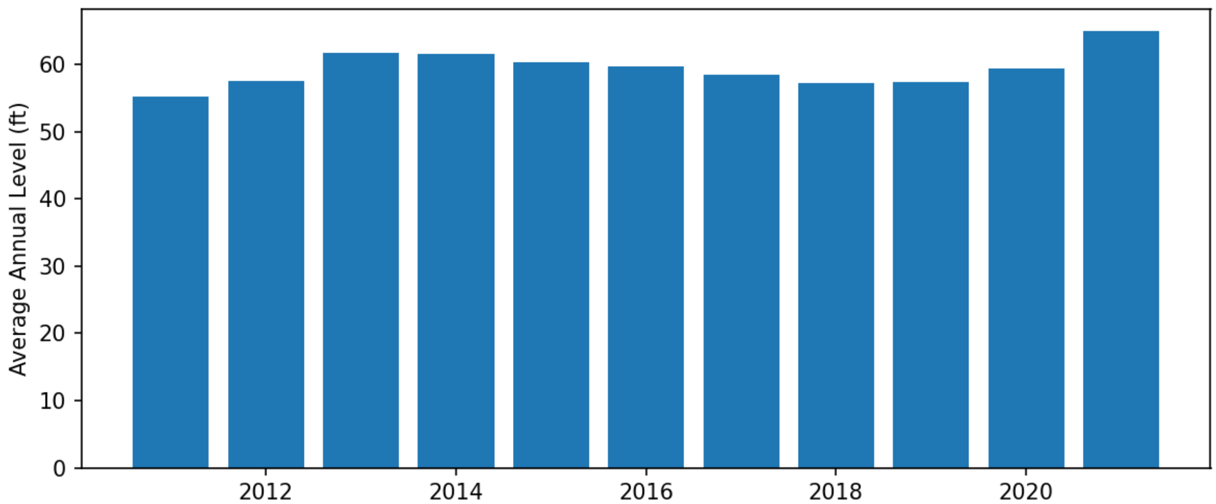

SRWMD Well Bay Creek Intermediate Levels
Level (ft)
112
110
108
106
104
102
2014
2015
2016
2017
2018
2019
2020
2021
Date
Average Annual Level (ft)
0
20
40
60
80
100
2014
2016
2018
2020
Average Monthly Level (ft)
0
20
40
60
80
100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

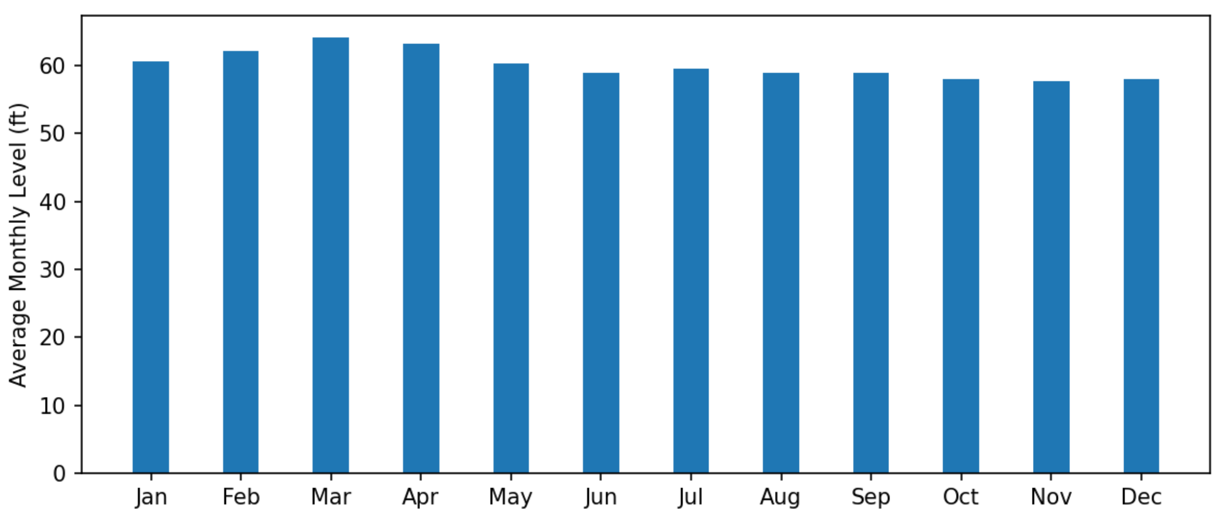

SRWMD Well Bay Creek Lower Floridan Levels
Level (ft)
Date

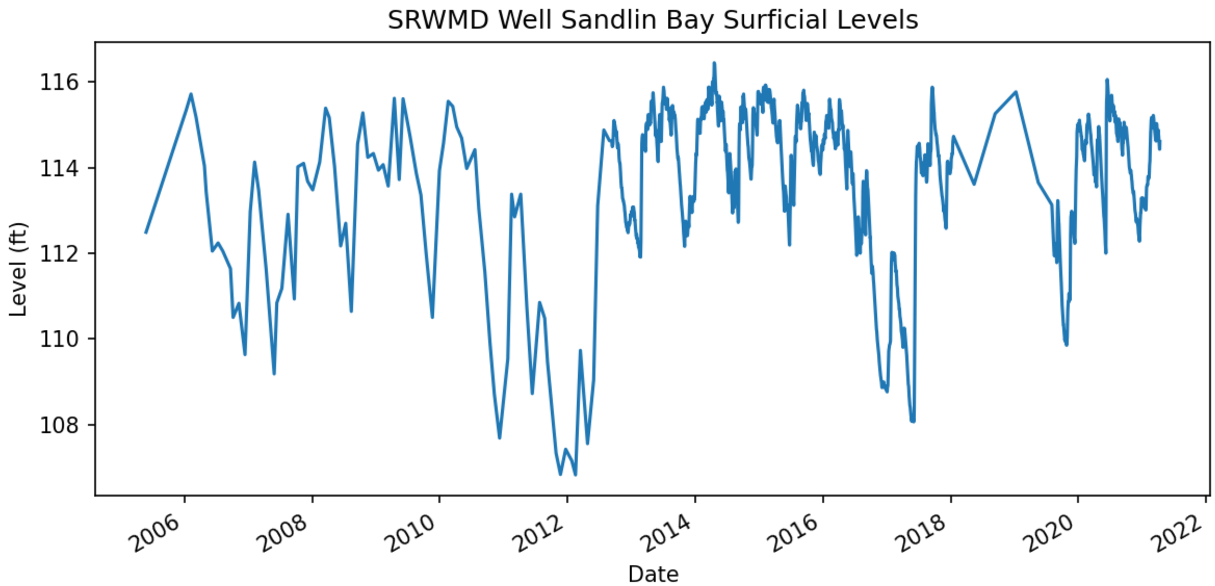

Average Annual Level (ft)

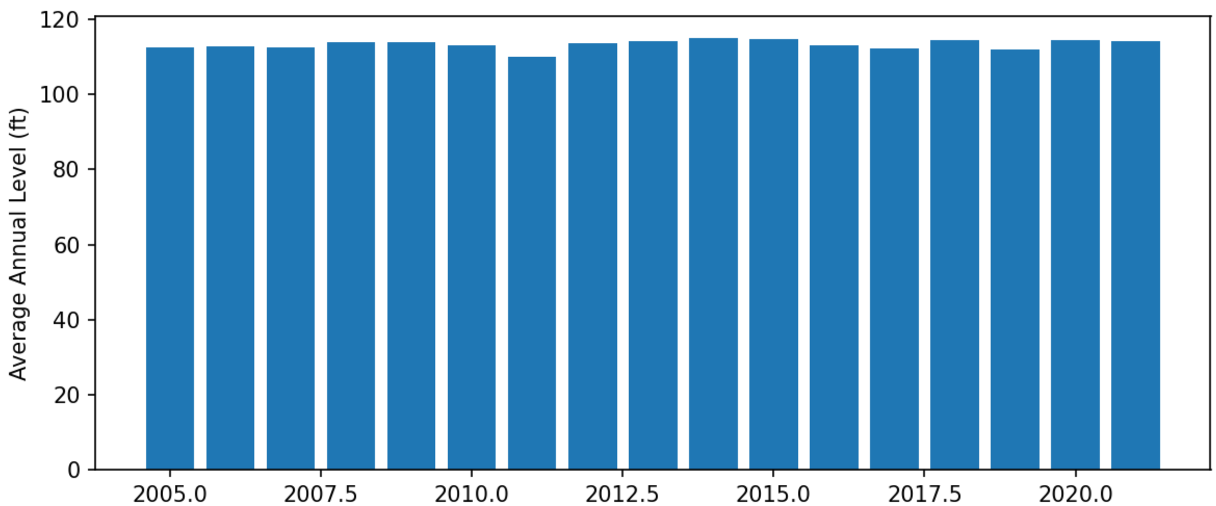

Average Monthly Level (ft)

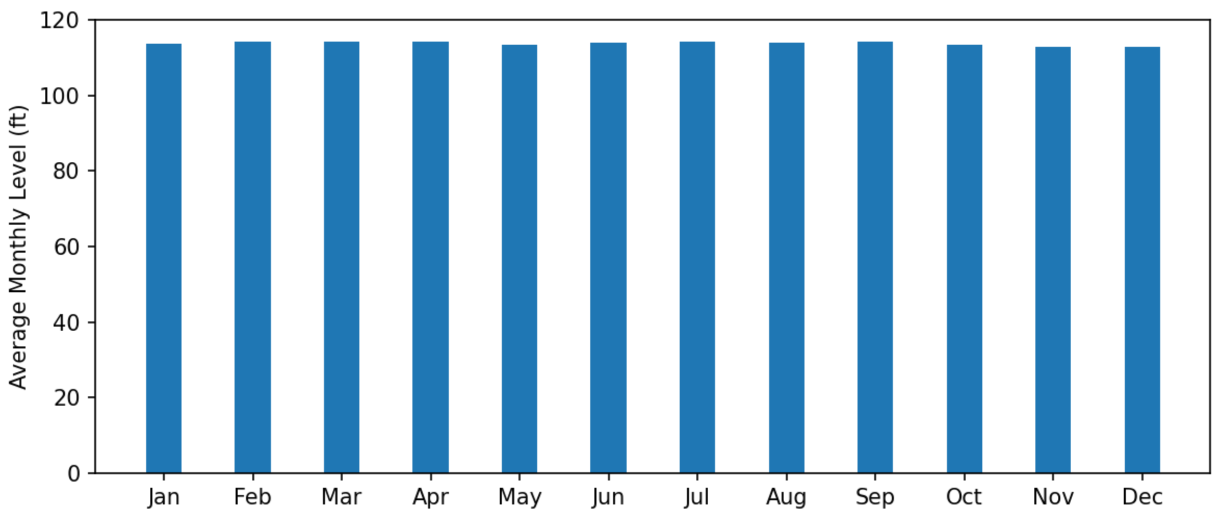

SRWMD Well Westwood West Levels
Level (ft)
85
80
75
70
65
60
55
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Date

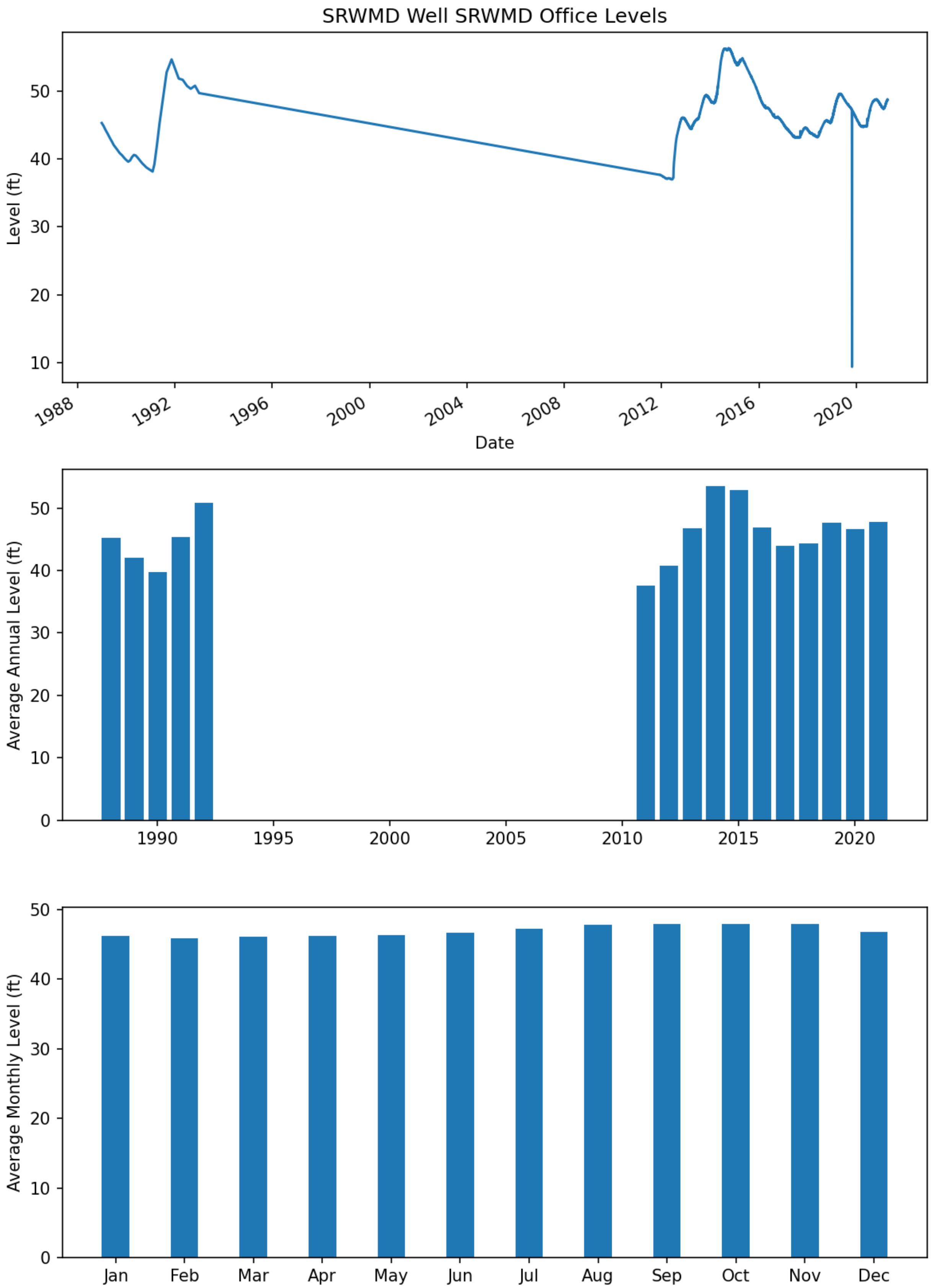

Average Annual Level (ft)
60
50
40
30
20
10
0
2012
2014
2016
2018
2020

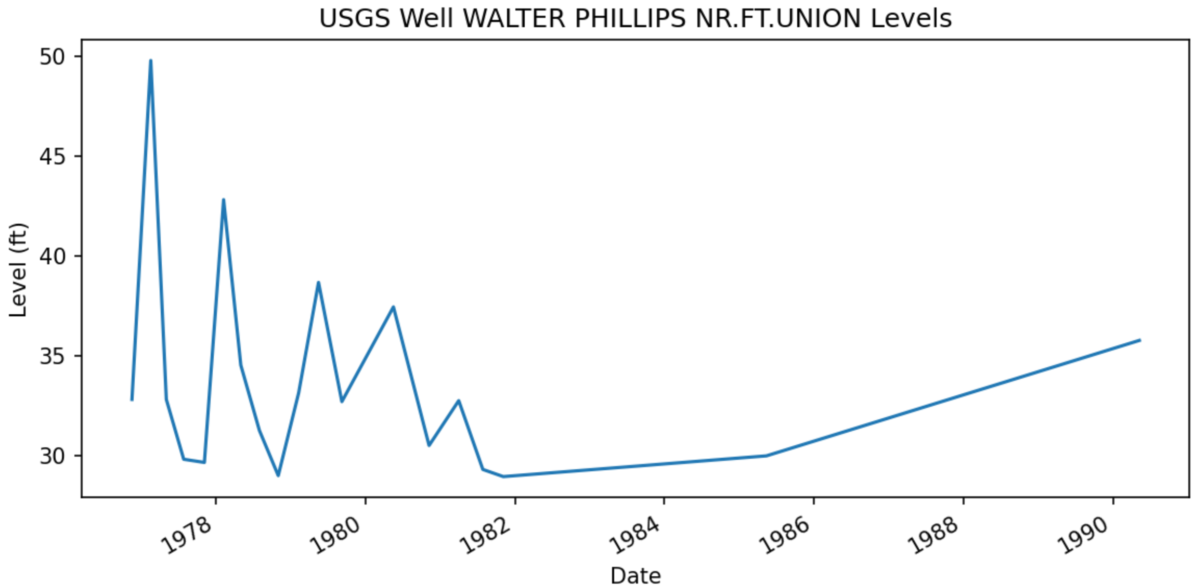

Average Monthly Level (ft)
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SRWMD Well Sandlin Bay Surficial Levels
Level (ft)
116
114
112
110
108
2006
2008
2010
2012
2014
2016
2018
2020
2022
Date

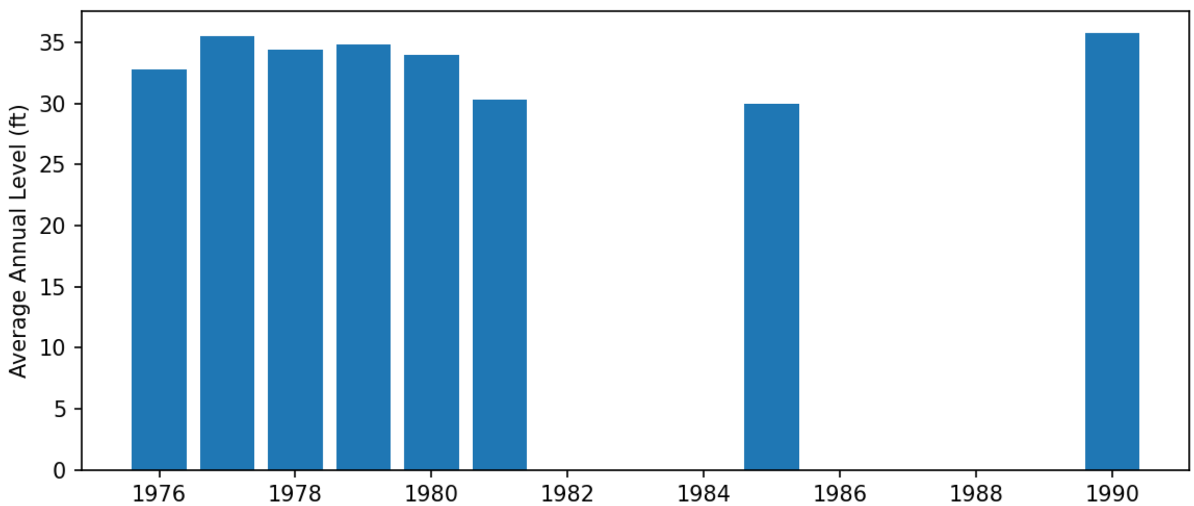

Average Annual Level (ft)
120
100
80
60
40
20
0
2005.0
2007.5
2010.0
2012.5
2015.0
2017.5
2020.0


Average Monthly Level (ft)
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

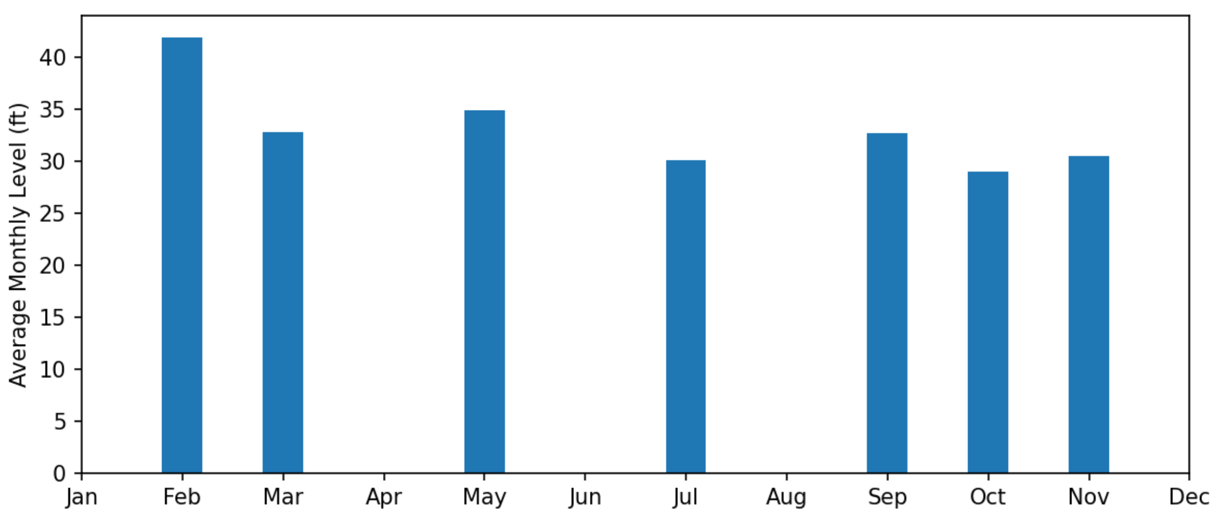

SRWMD Well SRWMD Office Levels
Level (ft)
Date
Average Annual Level (ft)
Average Monthly Level (ft)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



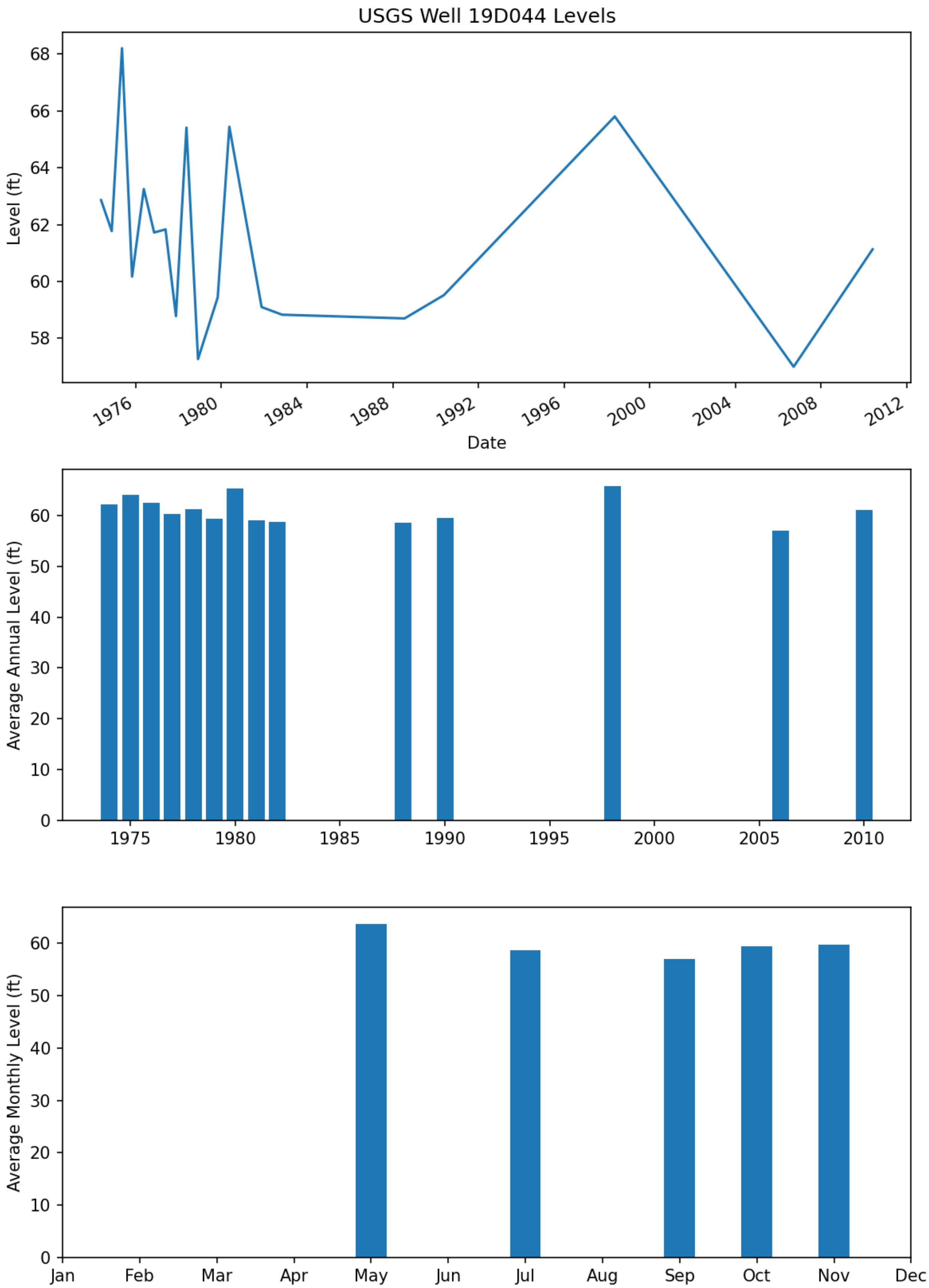
USGS Well WALTER PHILLIPS NR.FT.UNION Levels
Level (ft)
50
45
40
35
30
1978
1980
1982
1984
1986
1988
1990
Date

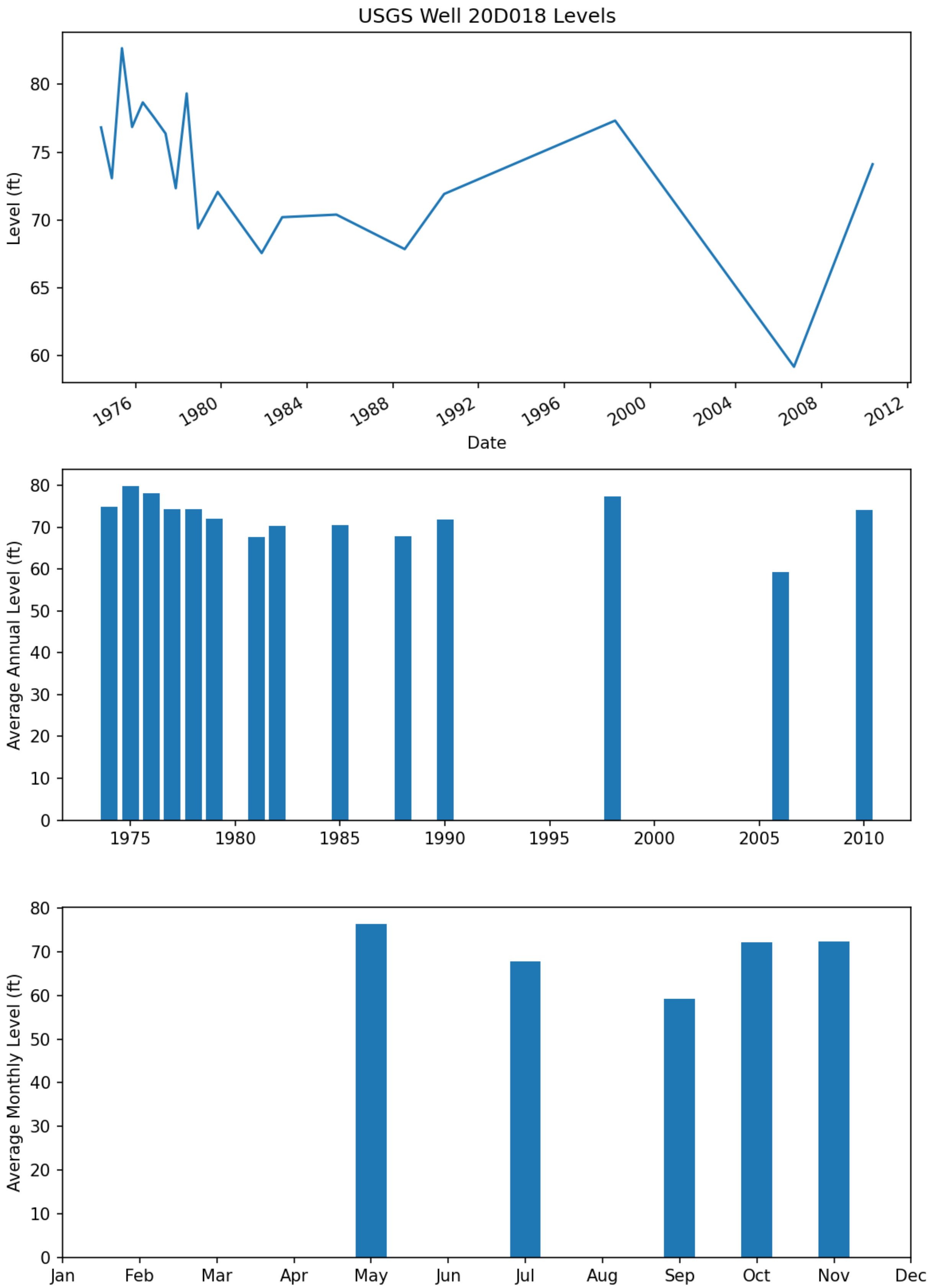


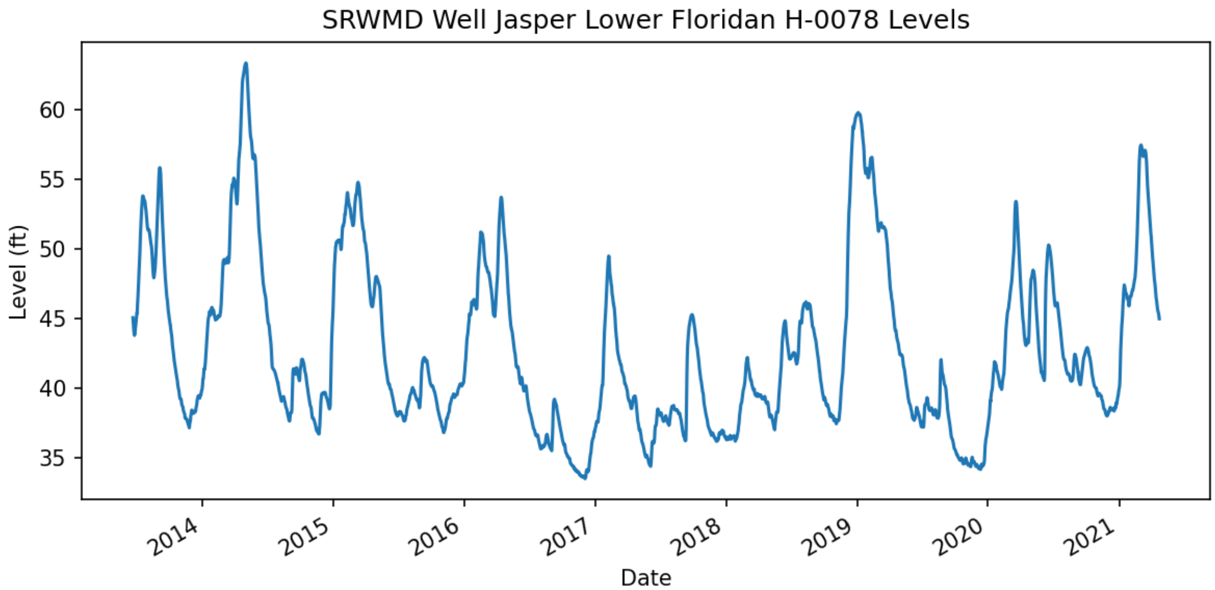
Average Annual Level (ft)
35
30
25
20
15
10
5
0
1976
1978
1980
1982
1984
1986
1988
1990

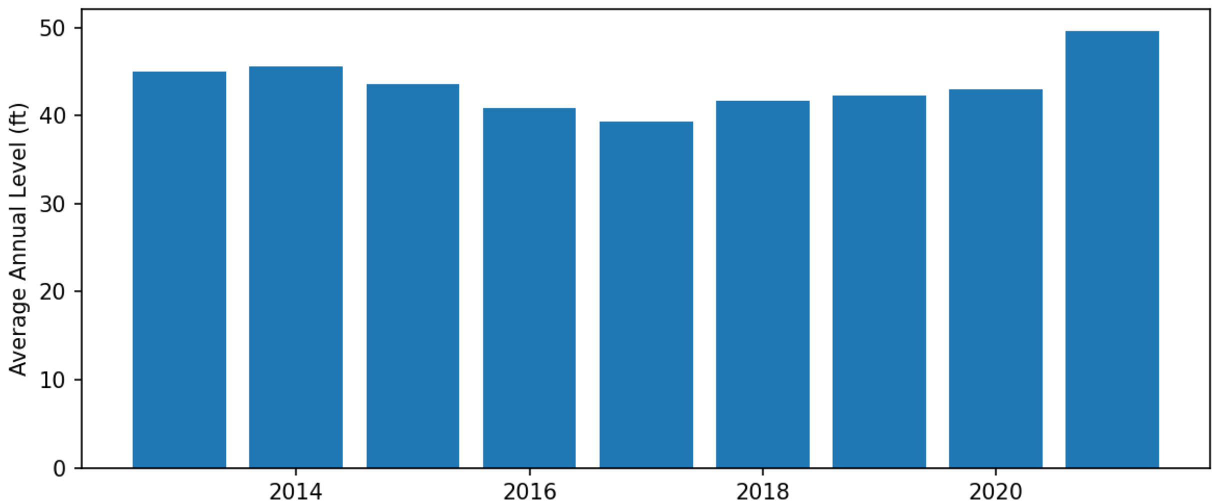


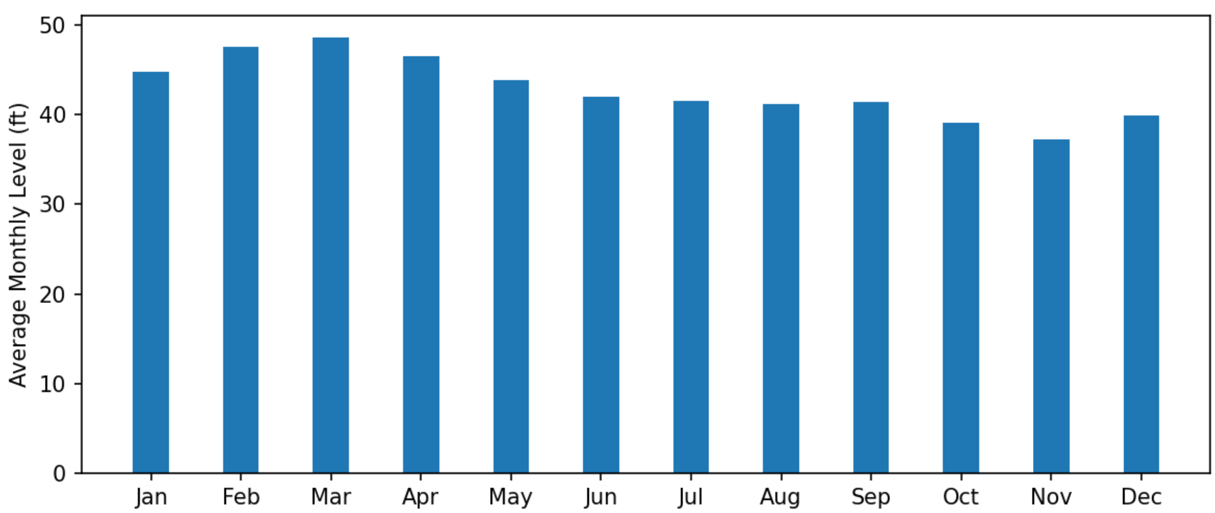
Average Monthly Level (ft)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


USGS Well 19D044 Levels
Level (ft)
68
66
64
62
60
58
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
Date
Average Annual Level (ft)
0
10
20
30
40
50
60
1975
1980
1985
1990
1995
2000
2005
2010
Average Monthly Level (ft)
0
10
20
30
40
50
60
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


USGS Well 20D018 Levels
Level (ft)
80
75
70
65
60
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
Date
Average Annual Level (ft)
80
70
60
50
40
30
20
10
0
1975
1980
1985
1990
1995
2000
2005
2010
Average Monthly Level (ft)
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SRWMD Well Jasper Lower Floridan H-0078 Levels
Level (ft)
60
55
50
45
40
35
2014
2015
2016
2017
2018
2019
2020
2021
Date


Average Annual Level (ft)
50
40
30
20
10
0
2014
2016
2018
2020


Average Monthly Level (ft)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec