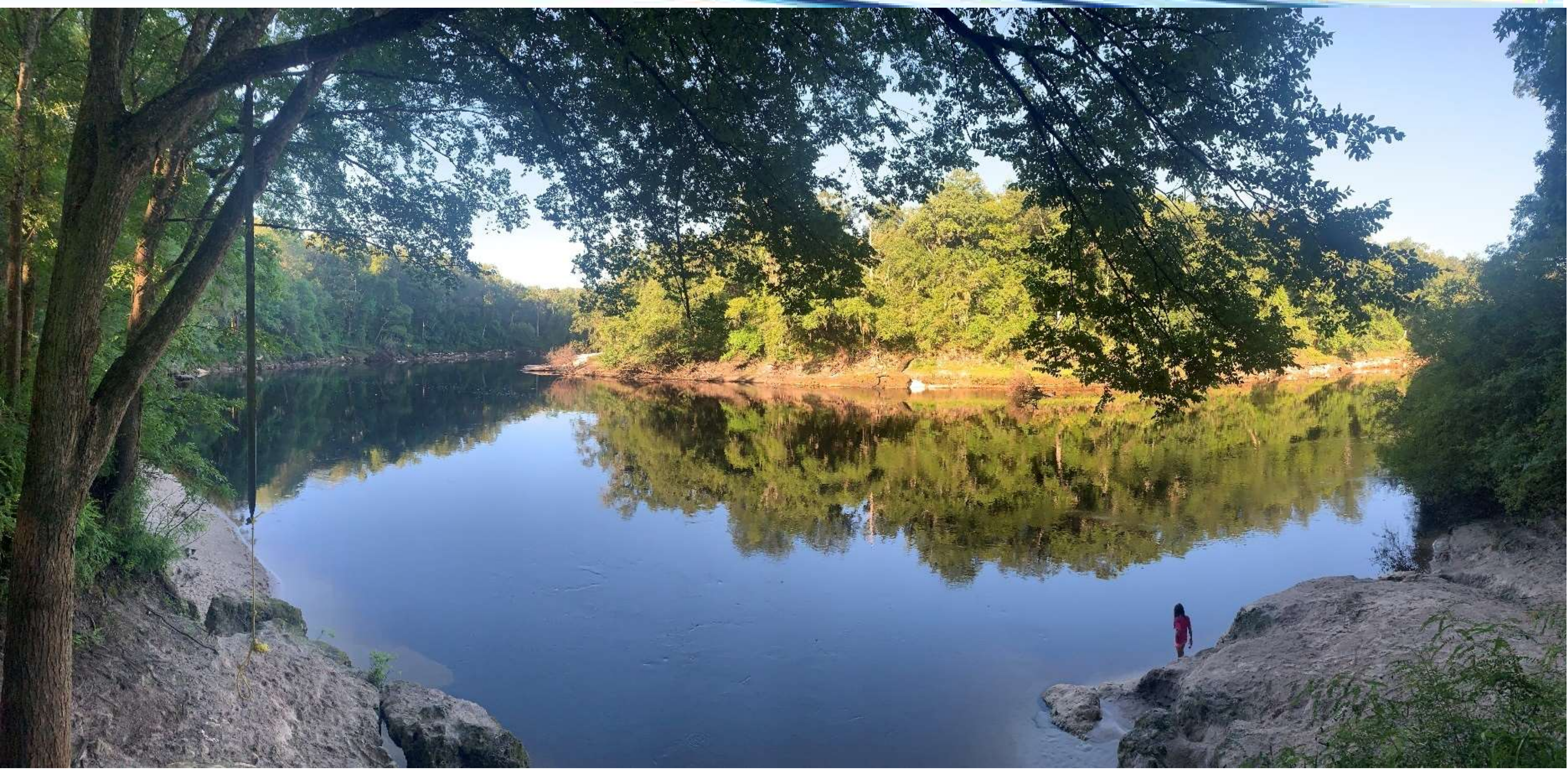

Spring Flow Extraction Results for the Anderson Springs Complex on the Suwannee River

WATERCUBE DATA COLLECTION, PROCESSING, & VISUALIZATION SERVICES

June 23rd, 2021

John Sloat, Chief Technical Officer
jsloat@watercubedata.com

June 2022 Anderson Spring Complex Flow Extraction Measurements

Background

Spring discharge from Anderson Springs and a nearby unnamed submerged spring was measured on the Suwannee River using the WaterCube (WC) flow extraction method. The WC flow extraction method has been used previously by SRWMD on other submerged spring inflows, sinks, and rises at locations along the Santa Fe and Suwannee rivers in 2017 and 2021 where traditional discharge methods were not possible due to the complex nature of the locations in the river.

In each survey, ADCPs are used to sweep a defined river reach traversing longitudinally (primarily) collecting geo-referenced, high-resolution 3D water-velocity profiles co-located with water depth. The 3D data is then screened and processed into a regular 3D grid which is used to determine flow patterns along the river reach and locations of spring inflow (or outflow) within the 3D grid. Once locations are determined, polygons are used to segment gridded data from the area of interest which is then used to compute "flow" into or out of the polygon along with a computed uncertainty.

Presently, Anderson Springs is known to have a single discharge vent located adjacent to the left downstream bank along the Suwannee River. A previous WC survey conducted in the summer of 2021 indicated the likelihood of an additional submerged inflow location along the end of the ADCP surveyed section near the middle of the river channel. Figure 1 shows a plan view of the Suwannee River showing the known Anderson Springs inflow vent location along with the possible additional submerged inflow location on the Suwannee River just downstream of the Interstate 10 bridge.

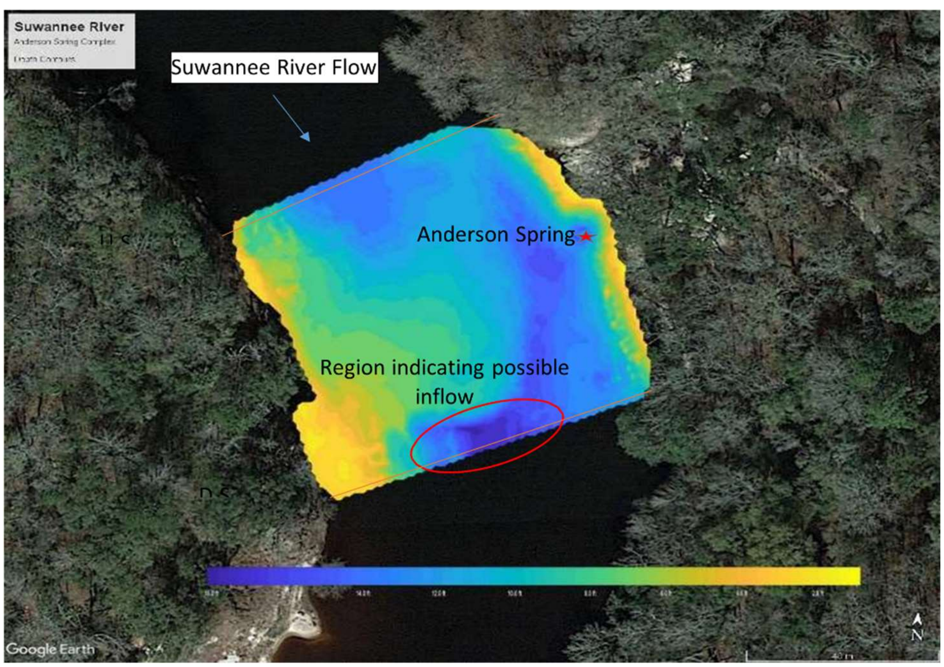

Figure 1: 2021 elevation contour map of Anderson Spring on the Suwannee River with region of additional inflow outlined.

Data Collection

Data collection was segmented into two surveys that included, 1) the collection of high-resolution swath bathymetric data coupled with 3D acoustic side-scan data and second, and 2) collection of geo-referenced 3D ADCP water-velocity profiles along the river survey reach.

PingDSP 3DSS Side-Scan Sonar and Swath Bathymetry

Geo-referenced high-resolution “swath bathymetric data” coupled with “3D side-scan” (3DSS) images of the river section was collected using a Ping DSP “3DSS” iDx sonar to provide additional information of riverbed features that may identify a spring flow location. The clarity and resolution of the 3DSS gives the ability to quickly visualize and locate specific underwater features of interest (like spring vents, tunnels, riverbed fractures, sand wave formations, etc…) including targets within the water column (like pilings, debris, ropes, fish, etc…). In addition, the “swath width” of the sonar is wide enough such that only 1 -2 upstream/downstream transects are required to cover the entire river reach enabling the ability to cover large areas in a relatively short period of time.

The Ping DSP system consists of a “multiple array” port and starboard transducers. They are vertical and side looking sonar arrays. The PING DSP uses a unique “CAATI technology” to blend high resolution side scan and 3D bathy points for sub surface rendering. Measurements can be made about depth, height, and intensity of the return echo pulse from the sonar real time processing. The PING DSP is an “Integrated System” including a MRU in the sonar head and two GPS antennas. The kit is compact and can be deployed on a vessel of opportunity with minimal effort. Figures 2 shows the 3DSS sonar array and GPS configuration used on the SRWMD vessel for the Anderson Springs survey. This was a rudimentary setup specific to this survey, however, demonstrates the portability of the equipment.

Figure 2: Ping DSP 3DSS Sonar Array (left) and RTK GPS (left) used on SRWMD survey vessel.

Ping DSP 3DSS Real-time data was collected and processed using HYPACK/HYSWEEP/MBmax64 which allowed the field operators the ability to view the 3D data sonar imagery as it was collected as shown in Figure 3 below:

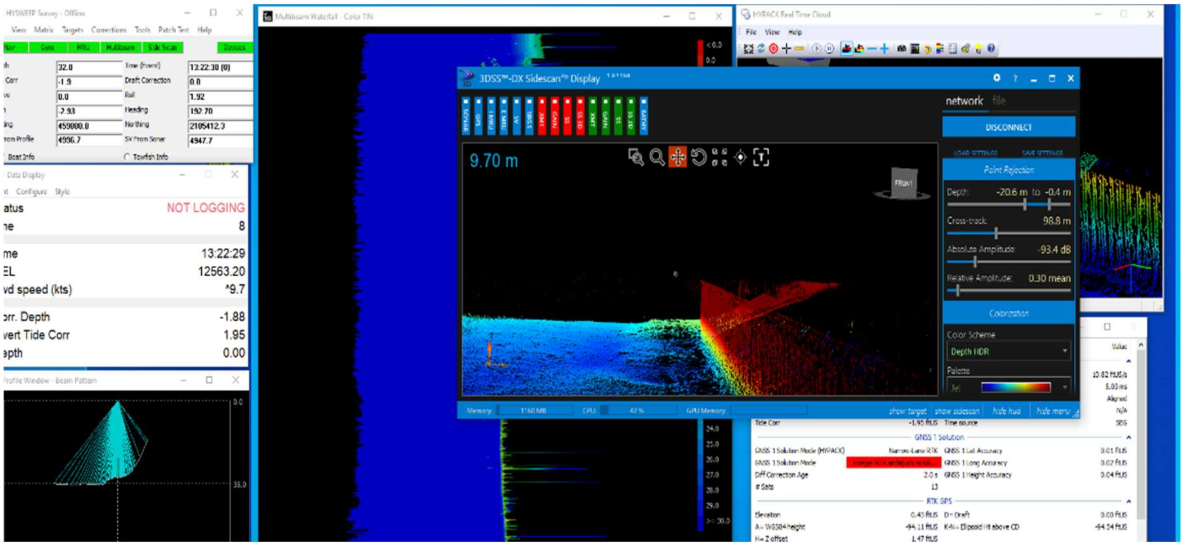

Figure 3: HYPACK/HYSWEEP/MBMax64 Data collection and processing software.

Figure 4 is a screen shot of HYPACK bathymetric processing software that shows the Ping DSP 3DSS surveyed section along the Suwannee River in relation to Anderson Springs. Data collection started just south of the I-10 bridge and finished approximately 2000’ below Anderson Springs. Red colors show relatively shallow water compared to the darker blue colors indicating deeper water.

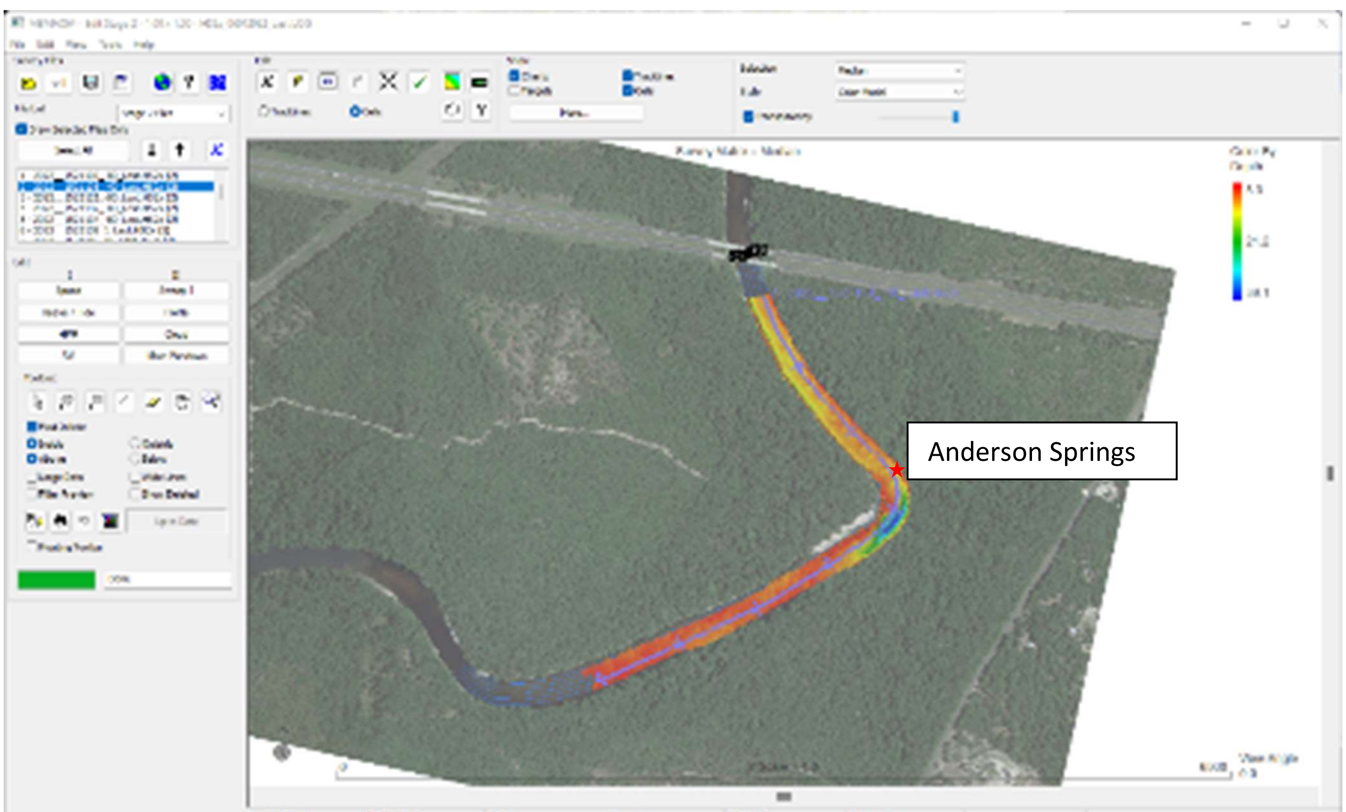

Figure 4: HYPACK bathymetric processing software showing the PingDSP 3DSS surveyed section relative to Anderson Springs.

Collection of 3D ADCP water-velocity profiles and depth data:

Geo-referenced ADCP 3D water-velocity profiles and depth data were collected continuously over a 5-hour period with multiple ADCPs along the Suwannee River upstream and downstream of the known Anderson Springs submerged vent including the region where a potential spring inflow was detected during the 2021 survey.

Figure 5 show the ADCP/GPS data collection setup used during the measurements. Figure 6 shows the ADCP track lines collected over a 5-hour period during the survey. In general, most ADCP transects were oriented along the streamline of the river. In addition, due to the complex geometry and flow of the area in proximity to Anderson Springs, additional ADCP data was collected in that area.

Figure 5: ADCP data collection setup showing motorized zodiac with ADCP w/GPS deployed on a small float.

Figure 6: ADCP data collection track lines for Anderson Springs WaterCube survey June 1st, 2022.

Ping DSP Swath Bathymetry and 3DSS Results

Data collected with the PingDSP 3DSS included geo-referenced high-resolution swath bathymetry and 2D/3D side scan sonar. These data provide the most detailed and comprehensive view of the river below the water-surface (both on the riverbed and in the water-column). The following imagery from the survey illustrates the level or detail and resolution of sonar imagery data collected along the Suwannee River during the WC Anderson Spring survey. The high-resolution bathymetry provided detailed views of the riverbed complexity and is useful to improve the bathymetry models for WC processing. The detailed imagery also helped understand the complex dynamics of the river section impacting river discharge and spring flow.

Figure 7 is an excellent representation of the level of detail that can be seen of the riverbed when using this type of technology. Sand dunes are easily identifiable in the upper section of the plot, a shallow reef type structure located on the inside of the river bend (red) adjacent to a large "scoured" section on the outside of the riverbed (blue) transitioning back to more uniform cross-section following the riverbed with longer period sand dunes.

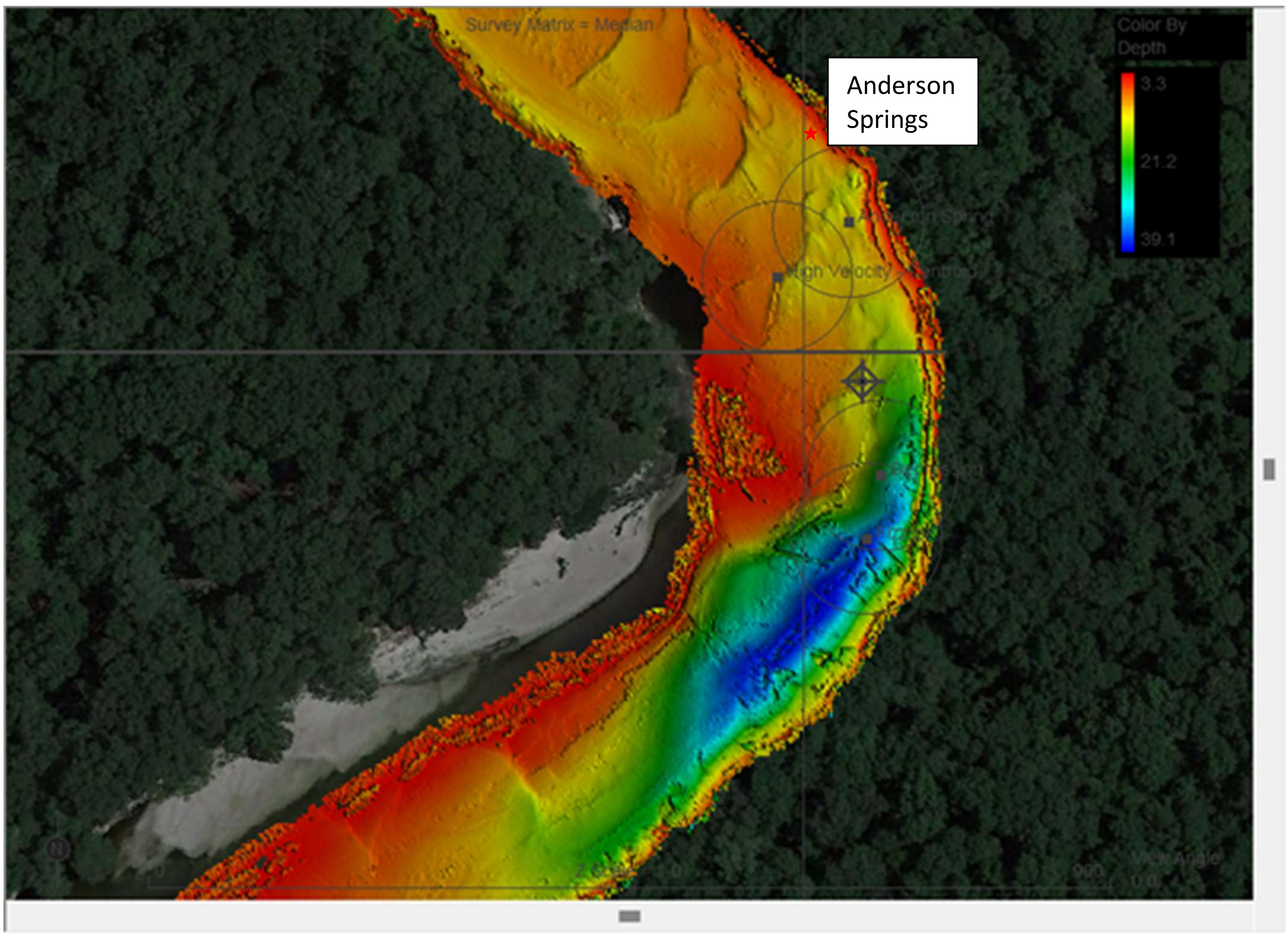

Figure 7: Ping DSP 3DSS Swath Bathymetry Plot of the Suwannee River in proximity to Anderson Springs.

Figure 8 and 9 shows a 3D side-scan imagery of the water-column within the scoured river section of the river from two different perspectives. The perspective on the left (Figure 8) is looking downstream and shows numerous fish (likely Sturgeon) schooling in the water-column in context to the 3D riverbed structure. The perspective on the right (Figure 9) is looking upstream into the scoured river section showing a detailed 3D view of the vertical wall located on the left downstream riverbank in addition to the fish schooling within the water-column itself.

Figure 8: 3D sidescan view - upstream view of scoured river section.

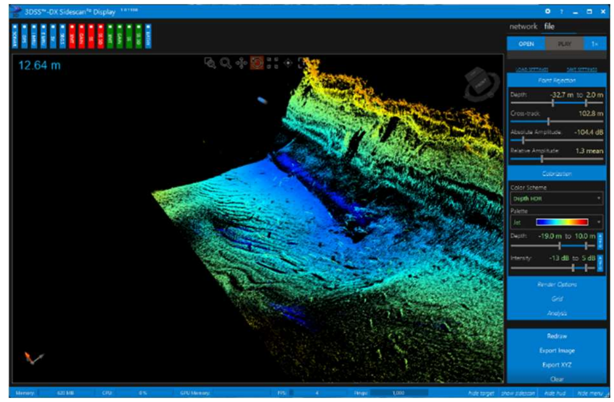

Figure 9: 3D sidescan - downstream view of scoured river section.

Figures 10 and 11 are 2D sidescan views with a reference map location the imaged area to the right. Figure 10 is the area just upstream of the scoured river section showing the large sand dunes and smaller dunes within them. Figure 11 is just past the scoured riverbed section also showing the sand dunes along with the fish located within the water column.

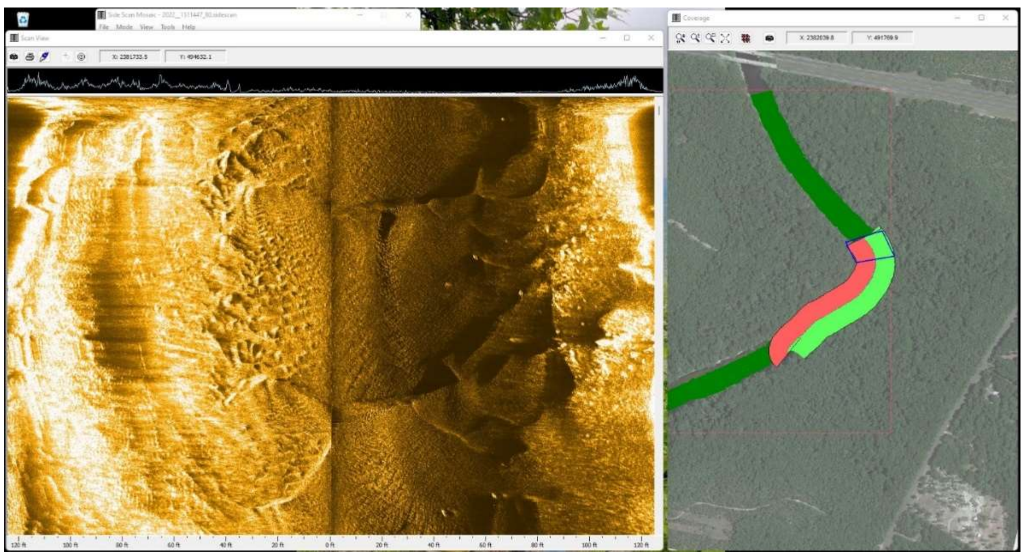

Figure 10: 2D sidescan view just upstream of scoured riverbed section.

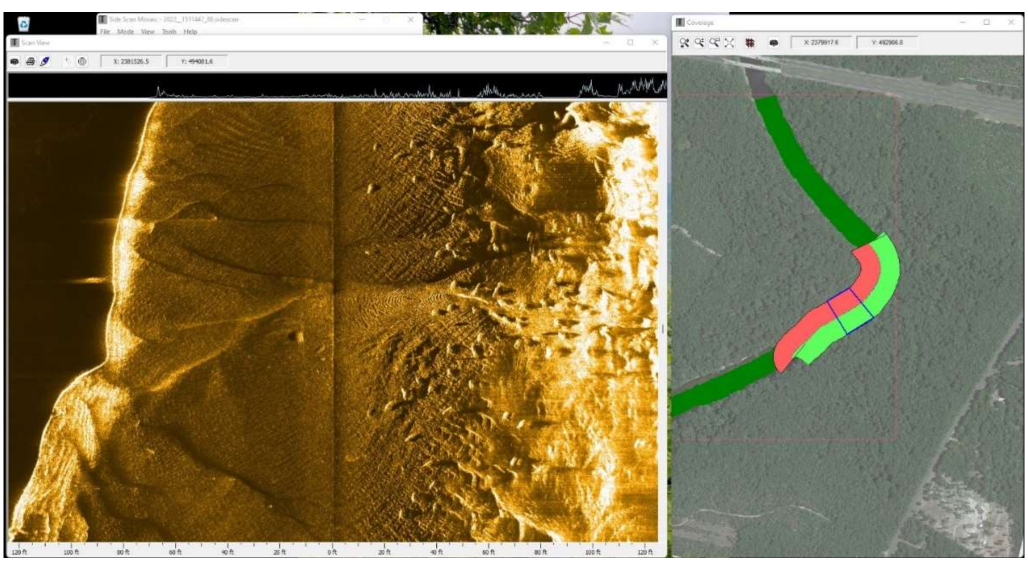

Figure 11: 2D sidescan view just downstream of scoured riverbed section.

WaterCube Processing – Generating 3D Water-Velocity and Depth Grids

ADCP data collected during the survey were used to create a geo-referenced 3D grid of depth and velocity throughout the entire surveyed section. These grids were then used to extract flows from Anderson Springs and the unnamed spring. Similar to the PingDSP 3DSS imagery, WaterCube processing plots below indicate a very complex riverbed and channel resulting in highly dynamic and complex water-velocities throughout the surveyed section.

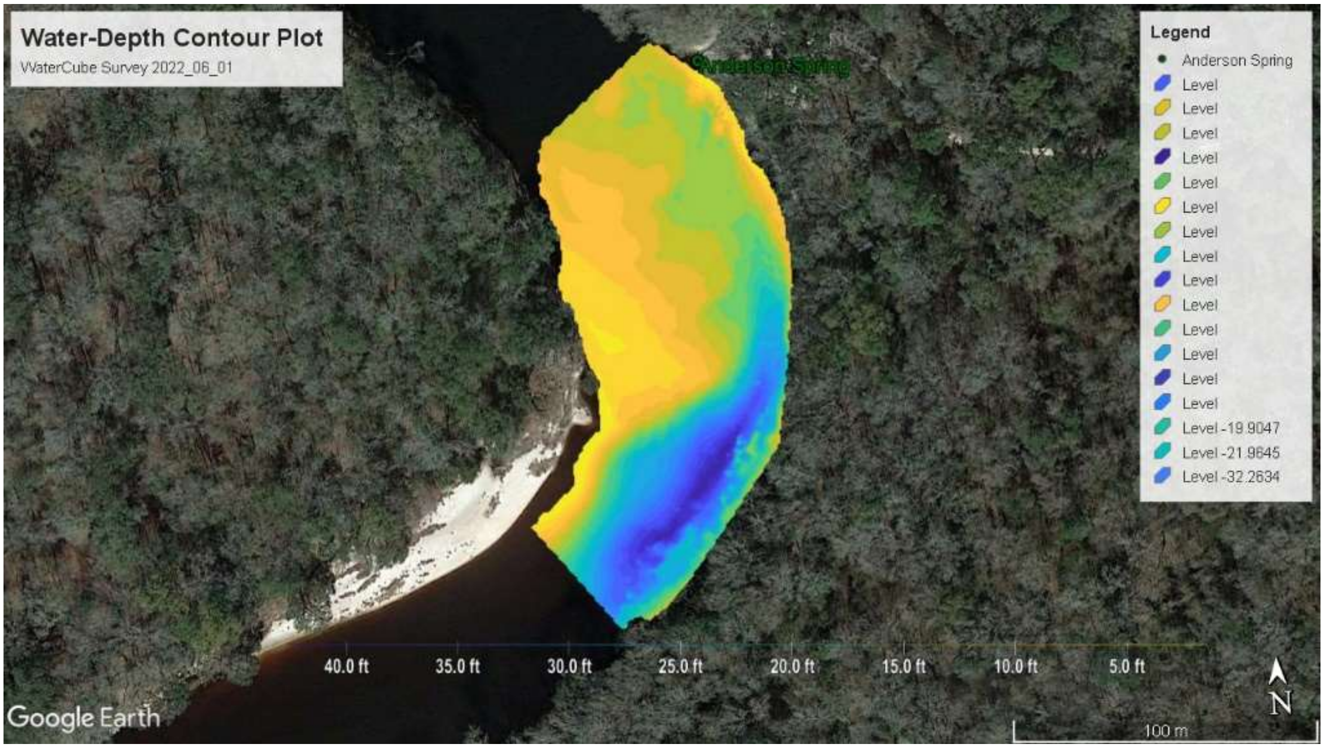

Figure 12: Water-Depth Contour Plot from ADCP data processed by WaterCube.

The water-depth contour plot (Figure 12) shows darker blue areas indicating a steep drop-off (ledge) into a large scour hole along the left back towards the downstream survey section.

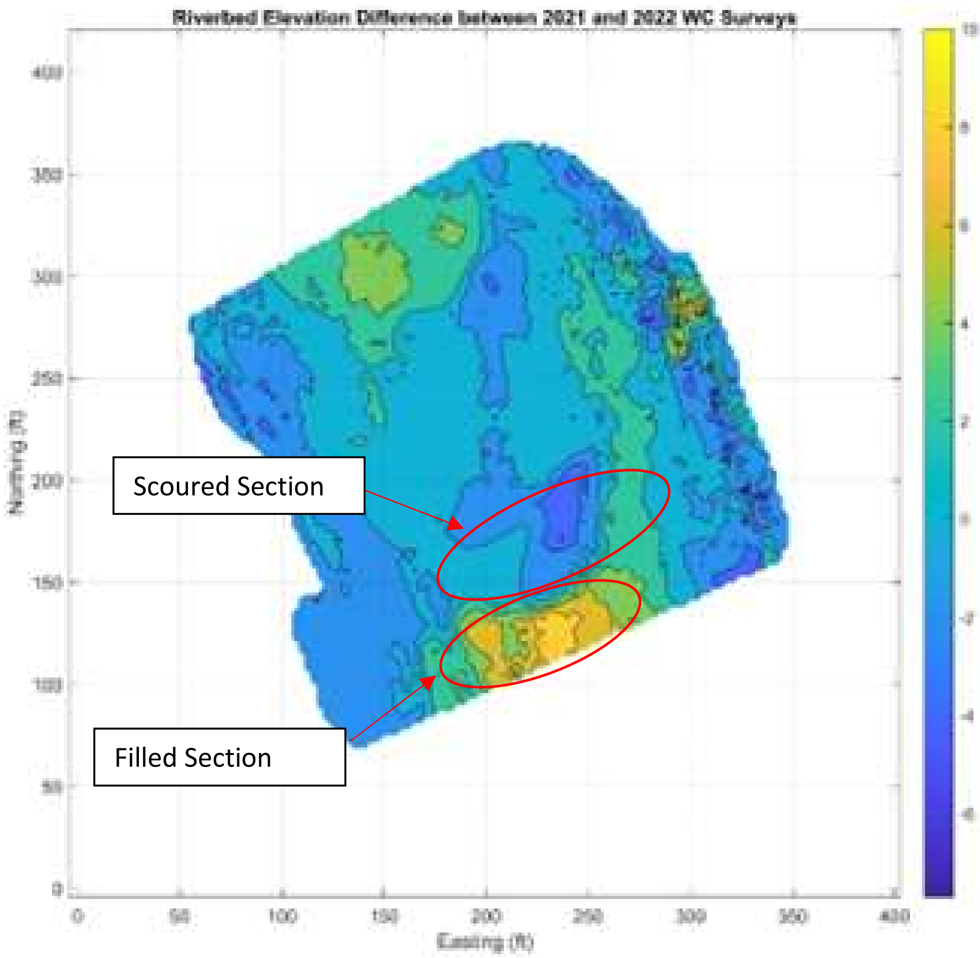

Figure 13: Depth Contour "Difference" plot between 2021 and 2022 WC surveys,

Figure 13 above shows the depth "difference" between the 2021 and 2022 WC surveys show the riverbed changes during the timespan. Most notable is the large scour and fill section towards the lower part of the plotted section. Further inspection of the much higher resolution PingDSP bathymetry and side-scan sonar survey clearly show large sand dunes upstream, downstream, and throughout the WC surveyed. The scour and fill section shown in figure 8 is likely due to the sand dunes migrating down the Suwannee River which add to the dynamic and complex nature of this river section.

Figure 14 shows high-resolution bathymetry contours from data collected with the Ping DSP 3DSS and processed in HYPACK. The figure clearly shows the large scour hole as well as multiple sand dunes on the riverbed.

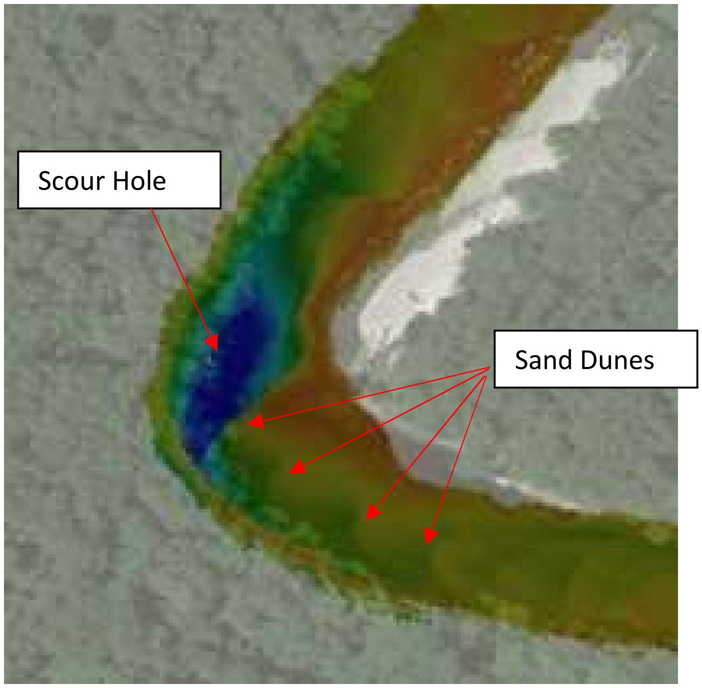

Figure 14: PingDSP Bathymetry plot of the WC surveyed section showing multiple sand dunes and large scour hole.

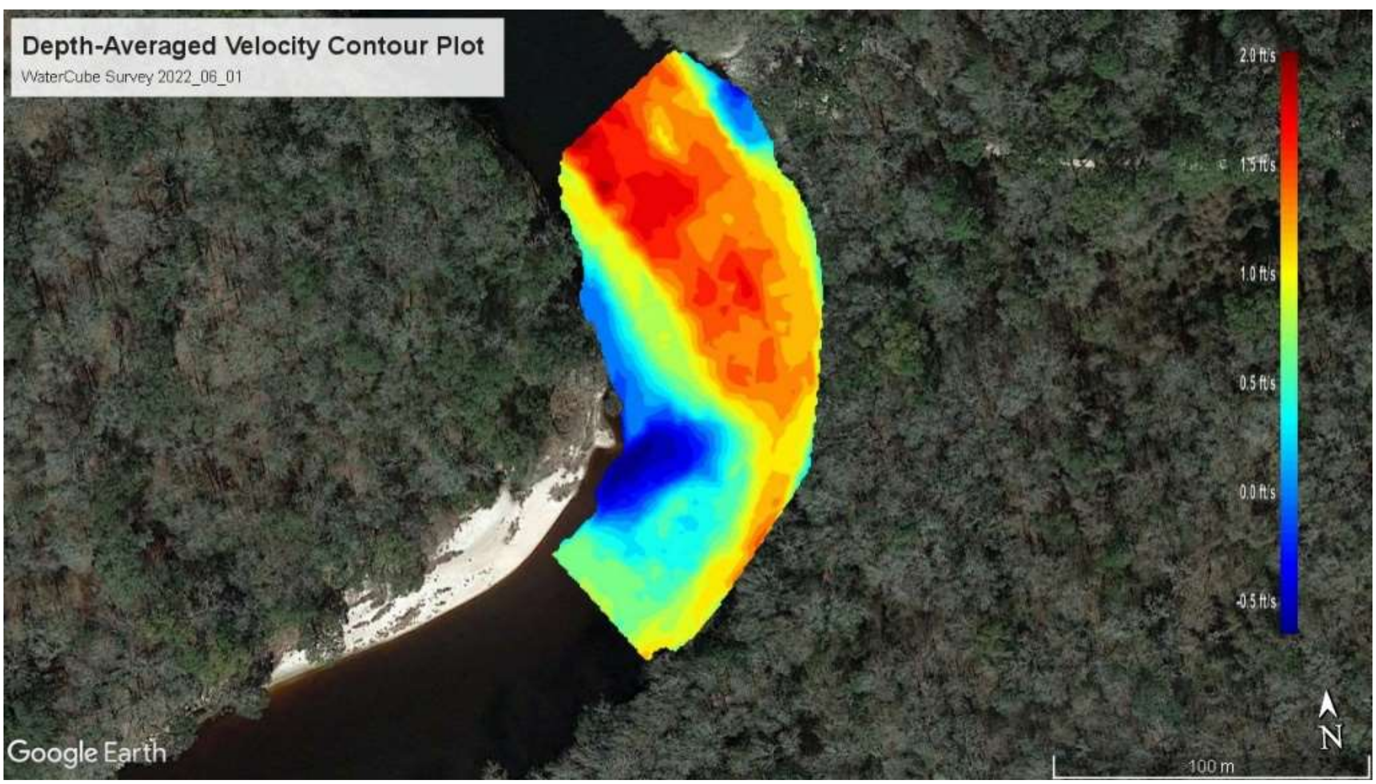

Figure 15: Depth-Averaged Water Velocity Contour.

Figure 15 shows depth-averaged water velocity contours processed by WaterCube. Figure 15 shows significantly higher velocities (red) oriented almost directly into the left riverbank because of a sharp, almost 90-degree bend, in the river.

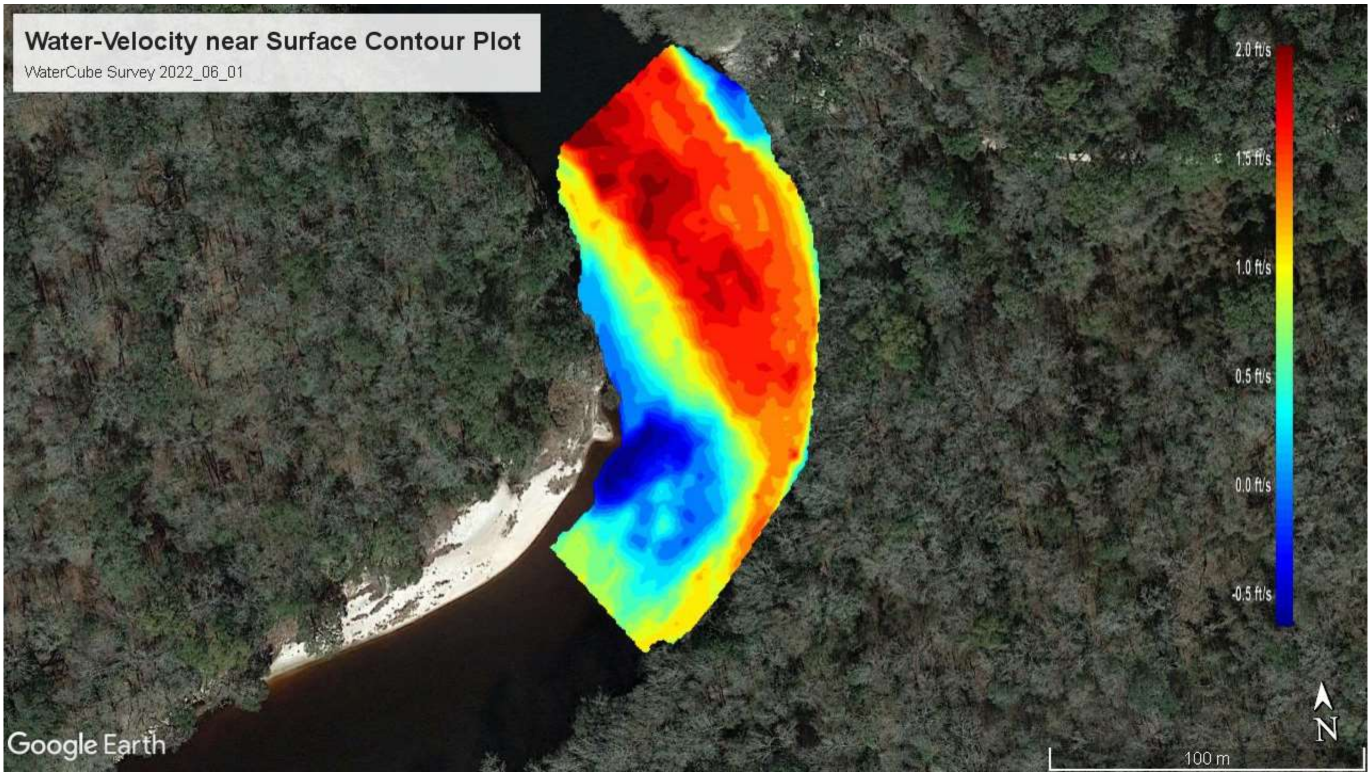

Figure 16: Water-Velocity near Surface Contour.

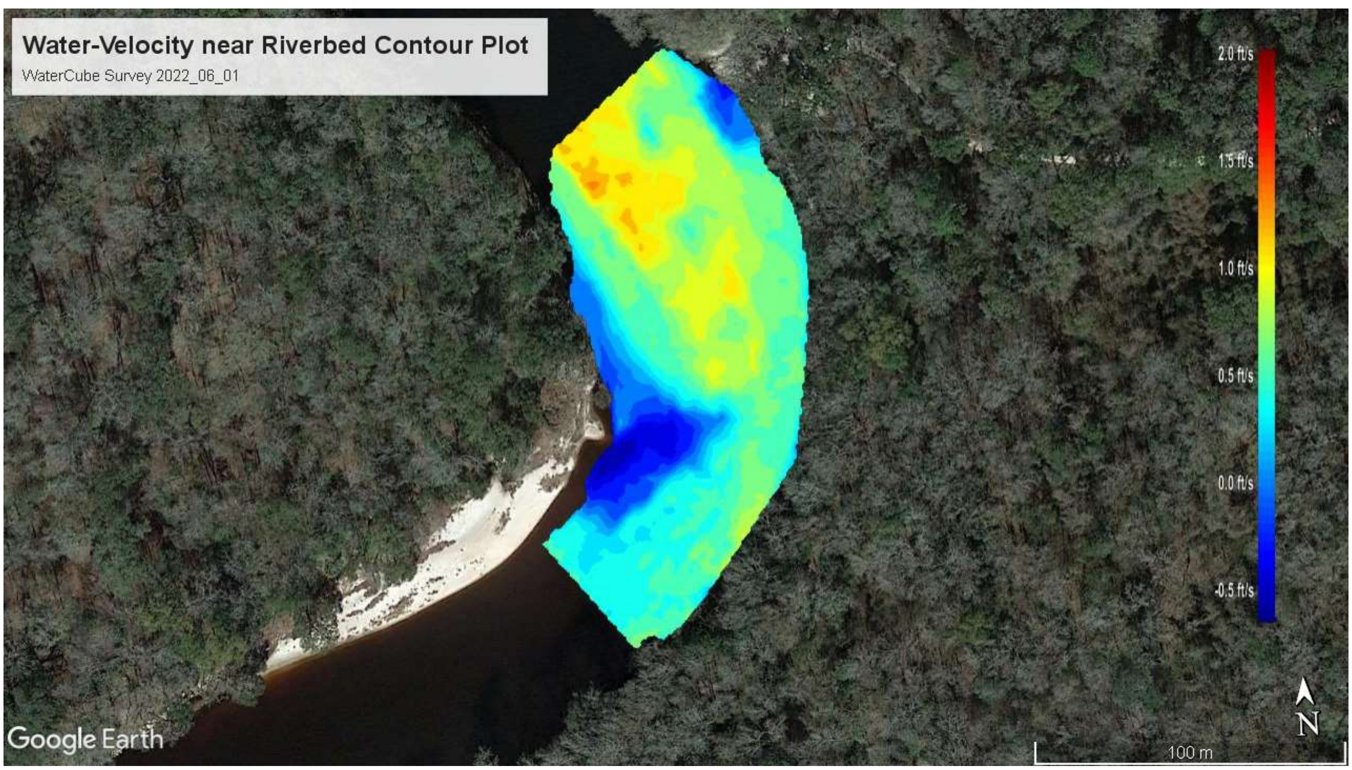

Figure 17: Water-Velocity near Riverbed Contour.

Water-velocity contour plots in Figures 16 and 17 show the water velocity at the water-surface and at the riverbed with higher velocities at the water-surface and lower velocities at the riverbed throughout the surveyed section.

Figure 18: Depth-Averaged Water-Velocity Vectors

Depth-Averaged water-velocity vectors are plotted in Figure 18 showing uniform flow as velocities approach the river bend and transitioning on the right bank into a large are of circulation a large area of circulation (eddy) caused by the sharp 90-degree bend in the river.

WaterCube Flow Extraction Processing Results

Flow Extraction Overview

The 3D WaterCube processed grid was used to compute flow for each grid cell within the grid. WC processing tools then scanned the grid computing flux into and out of each grid and then "grouping" grid cells together to identify areas where significant flux occurs. Once these areas within the grid boundary were determined, discharge at each "flux" location was computed first by creating a "seed" polygon around the perimeter of each area (from the riverbed to the water-surface based on the depth contour grid) and subdividing it into approximately 100 regular-spaced subsections each with a depth, width, and depth-averaged velocity. A maximum and minimum polygon perimeter was then set based on the "seed" polygon. Extraction flow magnitude with the standard deviation is computed as the average of 200 bootstrap iterations using randomly generated polygons using approximately 25% of the water-velocity data.

This is the identical method used for "Flow Extraction" for the 2017 and 2021 WaterCube surveys on the Santa Fe River (Devils complex) and the 2021 Anderson Springs survey on the Suwannee River.

Upstream and Downstream River Discharge Measurement Results

Standard USGS-style ADCP discharge measurements were collected by SRWMD personnel upstream and downstream of each site near the beginning and end of the surveyed areas. These discharge measurements were used to understand the flow magnitude of the Suwannee Rivers as well as provide an approximation of the increase in flow due to the inflow of Anderson Springs along with any other submerged spring in the section.

The following are USGS measured flows at upstream/downstream USGS gauging stations and corresponding SRWMD discharge results using USGS discharge processing tool "QREV" during the WaterCube flow extraction survey:

Upstream Ellaville USGS Station	2910 cfs (Provisional)	*N/A*
Upstream Section QREV Discharge	2851 cfs	117 cfs SDev
Downstream Section QREV Discharge	2951 cfs	233 cfs SDev
SRWMD QRev Discharge "Difference"	+100 cfs	*N/A*
Downstream Dowling Park USGS Station	3000 cfs (Provisional)	*N/A*

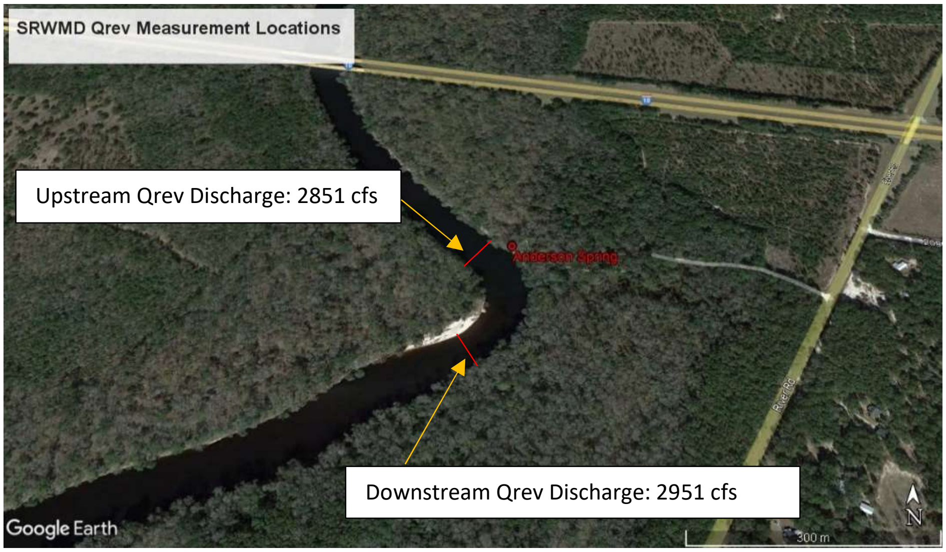

Figure 19: Upstream and Downstream Qrev Discharge showing 100 cfs difference.

The SRWMD discharge measurements agree well with USGS provisional discharge data reported upstream at Ellaville and downstream at Dowling Park. Results from the upstream and downstream SRWMD QREV results indicate an approximate flow increase of 100 cfs through the WC surveyed section with a standard deviation of 117 and 233 cfs, respectively.

Figures 20 and 21 are Qrev results for the SRWMD upstream and downstream discharge measurements.

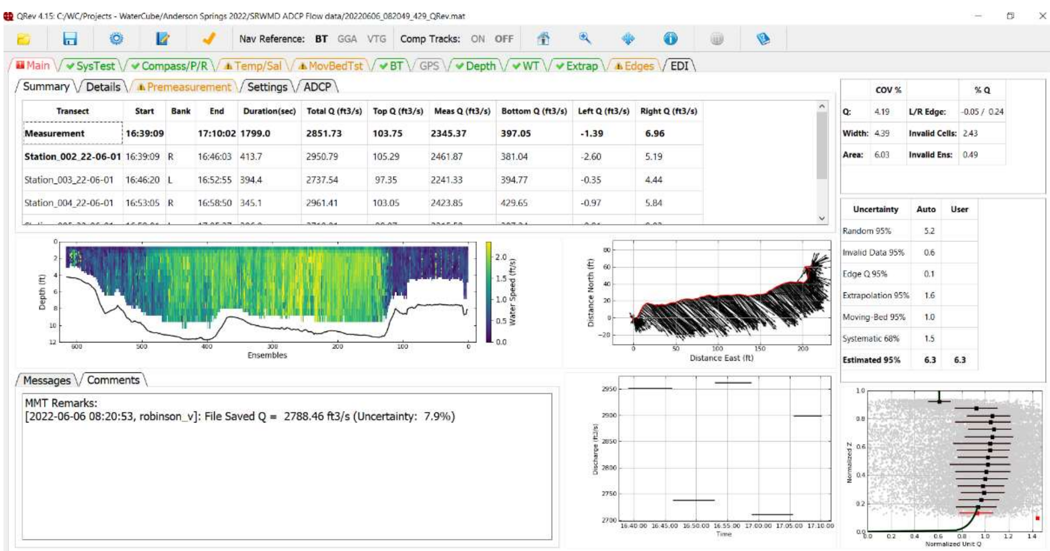

Figure 20: Upstream QRev discharge results for the 2022 WaterCube Extraction Survey

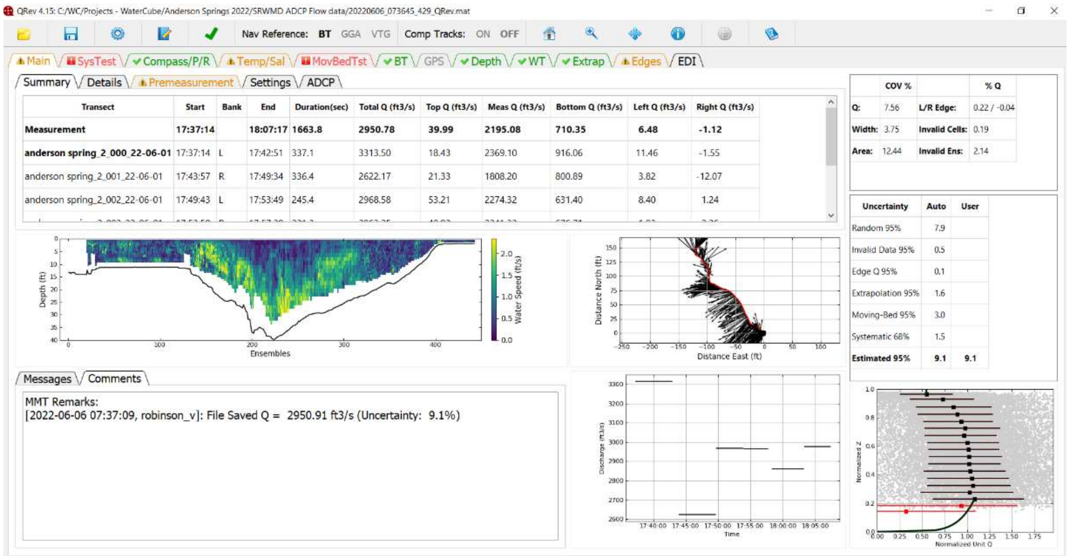

Figure 21: Downstream QRev discharge results for the 2022 WaterCube Extraction Survey

WaterCube Flow Extraction Locations

WC processing tools Identified a potential submerged spring flow in proximity to the unknown inflow approximate area identified in the 2021 WC survey. The new location in 2022 (shown in Figure 22) is approximately 50 ft north of the location identified in 2021. This new location is better defined due to having complete data coverage and coincides with a 0.8-ft scour between 2021 and 2022.

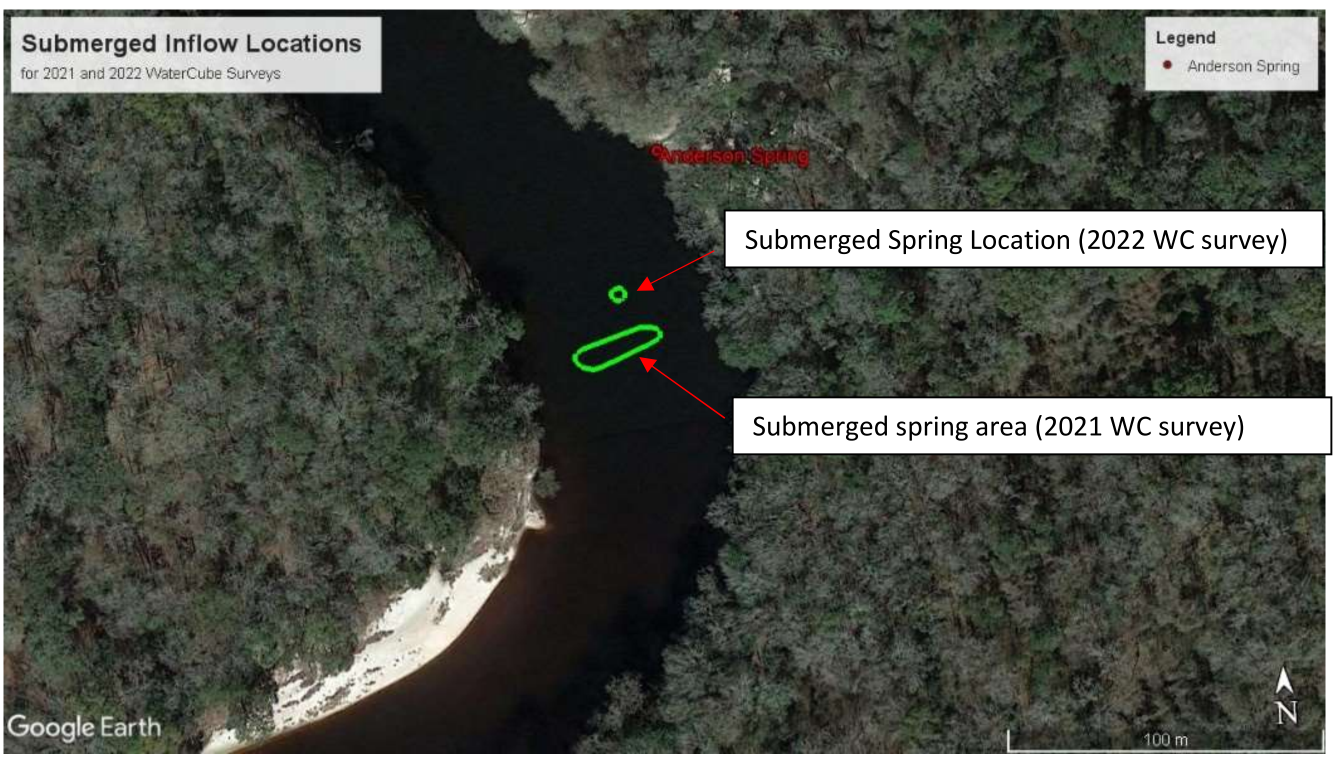

Figure 22: 2021 and 2022 Flow extraction locations for unknown spring along the Suwannee River

Also noted, the location identified as a potential spring in 2021 indicated both scour and deposition between the 2021 and 2022 surveys with 1 ft of scour in some sections and other downstream sections, particularly near downstream boundary, showing up to 6.5 ft of deposition between 2021 and 2022. The presence of sand dunes in the measurement section migrating downstream likely indicates that the actual submerged location of inflow may vary depending on the scour/fill dynamics of the river.

Summary: WaterCube Flow Extraction Results for Anderson Springs and the Unknown Spring:

The following table summarizes and compares flow results from the 2022 WC flow extraction survey and USGS QRev computed results. There was a 5.4 cfs flow difference between the combined WC processed results for Anderson Springs and the unknown spring of 105.4 cfs and the SRWMD QRev computed upstream/downstream flow differences of 100 cfs. These comparative results indicate a very strong likelihood of an additional submerged spring flow location as previously identified in the 2021 WC survey.

Anderson Spring Flow	45.1 cfs	8.3 cfs SDev
Unknown Spring Flow	60.3 cfs	4.6 cfs SDev
Total WC combined Inflow	105.4 cfs	
Total QREV computed Inflow	100 cfs	
Difference between WC combined spring flow processing (Anderson + unknown spring) and Qrev computed flow difference.	5.4 cfs	

Anderson Spring Qrev and WaterCube Statistical Comparisons

Although the Qrev discharge data are relatively noisy due to the difficult measurement locations, 100 CFS is the expected flow difference based on these measurements and based on these measurements, there is 65% probability that there is more flow downstream than upstream and a 50% probability that the flow difference is 100 cfs or more.

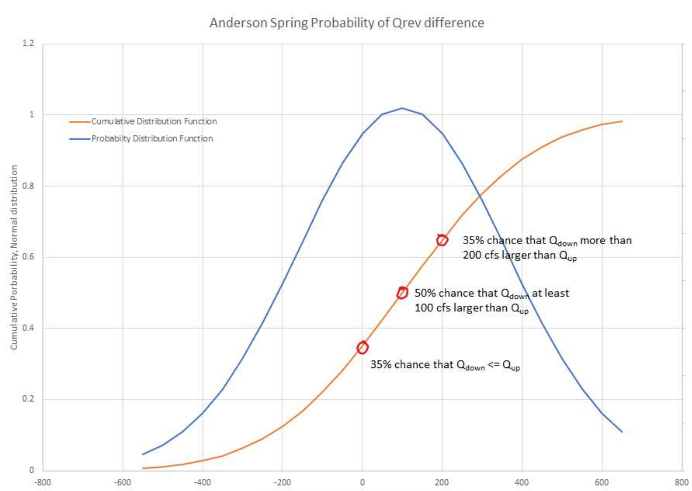

Figure 23: Anderson Spring Probability of Qrev flow difference.

More importantly, figure 24 is comparing the probability distribution functions (PDF) of the Qrev flow difference to the WaterCube extracted spring flows. The QREV PDF shows a 50% chance the spring flow is between -70 cfs and 275 CFS. WaterCube extraction calculations show that there is a 90% chance that flow from the two springs is between 99 and 112 cfs.

This figure is a good illustration to the benefit of extracting flows near the spring source to significantly increase the statistical confidence in the spring flow measurements.

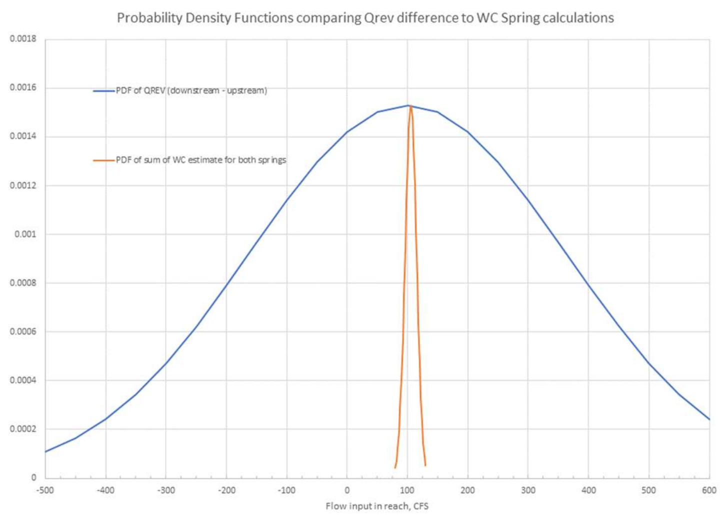

Figure 24: Probability Distribution Function comparing Qrev fow difference to WaterCube extracted spring flow.