TWA# 17TW0000470

Charlie Creek

HEC-RAS Modeling and Inundation Mapping

Final Report

Submitted to:

The Southwest Florida Water Management District

Submitted by:

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

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Introduction

Charlie Creek is one of the six major tributaries to Peace River and it has the largest volume of streamflow contributing to the Peace River flow. The headwaters of the creek originate in Winter Haven and flow continues southwest toward the Peace River just south of Zolfo Springs. The Charlie Creek watershed encompasses an area of approximately 330 square miles including portions of Hardee, Polk, Highlands, and DeSoto Counties. The major land use is dominated by agricultural with citrus and row crops which shape the watershed. The watershed is relatively flat in surrounding terrain except for the upper region. The stream channel is comprised of mostly sand in the upstream reach and transitions into gravel and large rock outcropping for the majority of the downstream reach. The instream channel is well-defined within the steep banks and its fluvial features are shaped by woody debris and the substrate.

A HEC-RAS model of Charlie Creek was developed and calibrated to support the development of the freshwater MFL. This report documents the conceptualization, calibration, validation, and predictive simulations performed with the Charlie Creek HEC-RAS model. This includes a summary of the available data for the model development, including channel geometry data and flow data. The best available data was used to develop and calibrated the HEC-RAS model for Charlie Creek, and the model was calibrated within the District's desired calibration tolerance of 0.5-feet.

Current Project Objectives

After initial model construction, it was desired to have an improved understanding of floodplain inundation, particularly for wetlands. The initial modeling effort also determined that the flow profiles could be improved through additional flow data collection to better quantify pickup along the channel. With these goals in mind, the District contracted with INTERA to:

- Incorporate additional cross sections into the model,
- Collect additional flow and stage data,
- Re-calibrate the model, and
- Perform predictive simulations, including floodplain inundation mapping.

The above additional tasks are documented in this report.

Initial Model Construction

The initial modeling effort is documented in INTERA (2016). A HEC-RAS model was constructed for approximately 16 miles of the creek for the study reach that extends between two United States Geological Survey (USGS) stream gaging stations: the Charlie Creek near Gardner gage (Gardner gage; USGS 02296500) on US 17 and the Charlie Creek near Crewsville gage (Crewsville gage; USGS 02296260) on SR 66. The District provided the available data including digital elevation model (DEM) data and surveyed vegetative cross sections and bridges within the study reach. All elevation or level work was displayed in North American Vertical Datum of 1988 (NAVD88). The Crewsville and Gardner gages served as the upstream and downstream model boundary conditions, respectively (Figure 1).

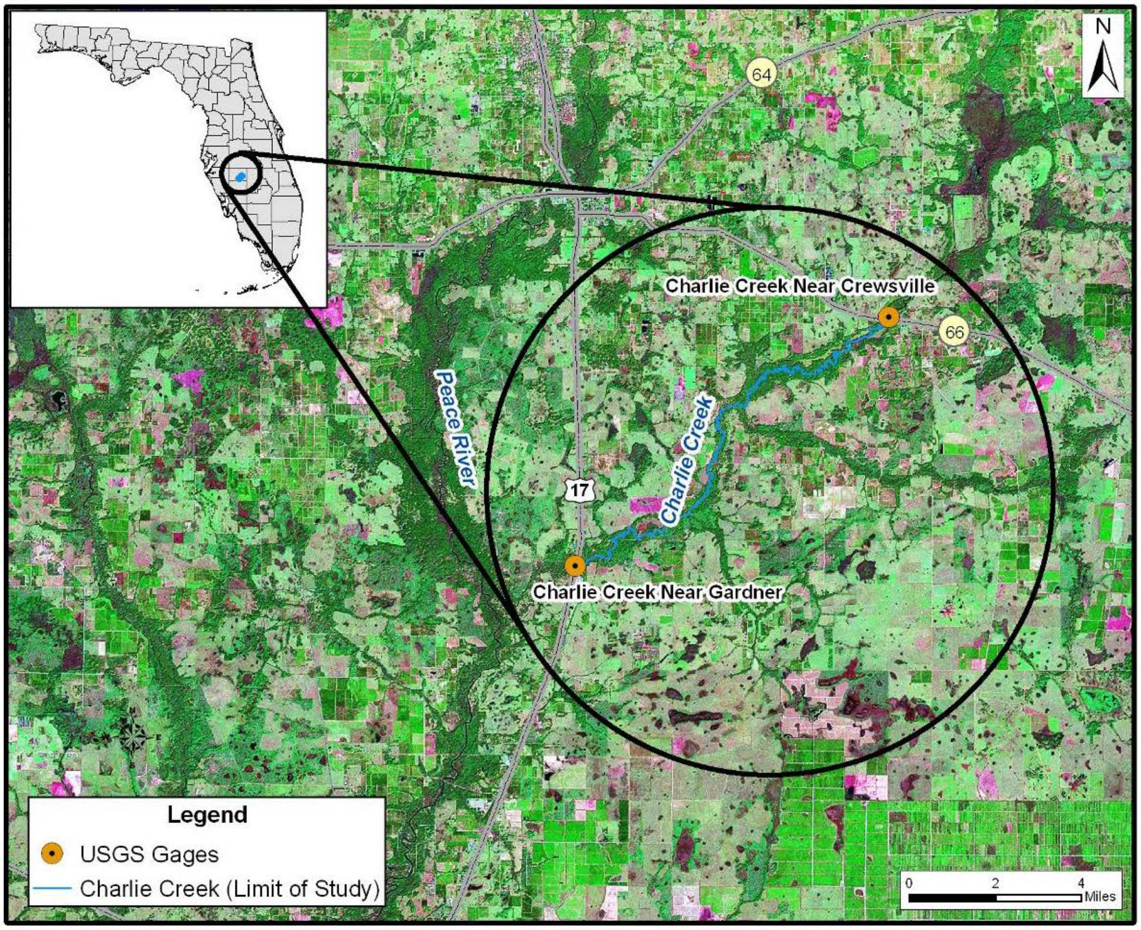

Figure 1. Charlie Creek Location Map

Data for the initial model development was primarily provided by the District. The District data included LiDAR (DEM) data, surveyed cross section and bridge elevations, and limited measured flows and stages. Additional flow data and stage data were obtained from the USGS Charlie Creek near Gardner gage (02296500) and the USGS Charlie Creek near Crewsville gage (02296260) and are considered the boundary conditions for this project.

A field survey was conducted by the District professional land surveyors and additional support by a professional land surveyor to record transects at eight locations, including seven vegetative transects and one bridge (Figure 2). Cross section data points were provided in spreadsheet format as well as in shapefile format, with one to two shapefiles per vegetative cross section. The field survey began approximately one mile downstream of the SR 66 bridge and progressed downstream to a location approximately two miles upstream of the US 17 bridge. Two sets of data points were provided by the District for transects T1, T2, T2.5, T4.5, and T5, while one set was provided for T6 and T7. For T1, T2, T2.5, T4.5, and T5, the first set of data points contained a detailed channel cross section (labeled as instream), and the second set of points provided a wider cross section that included the floodplain. A summary of the survey data is provided in Table 1. There are four bridge crossings within the limits of the study - State Road 66, County Road 634 (Sweetwater Road), an unnamed bridge, and the US

17 bridge, however, surveyed data was only available for the Sweetwater Road Bridge. The unnamed bridge was a bridge without piers in the flow path and therefore did not influence instream parameters. A cross section was placed at the unnamed bridge and LiDAR measurements reflected the bridge approach road bed elevations. The field survey data points were used to construct model cross sections, as described in INTERA (2016).

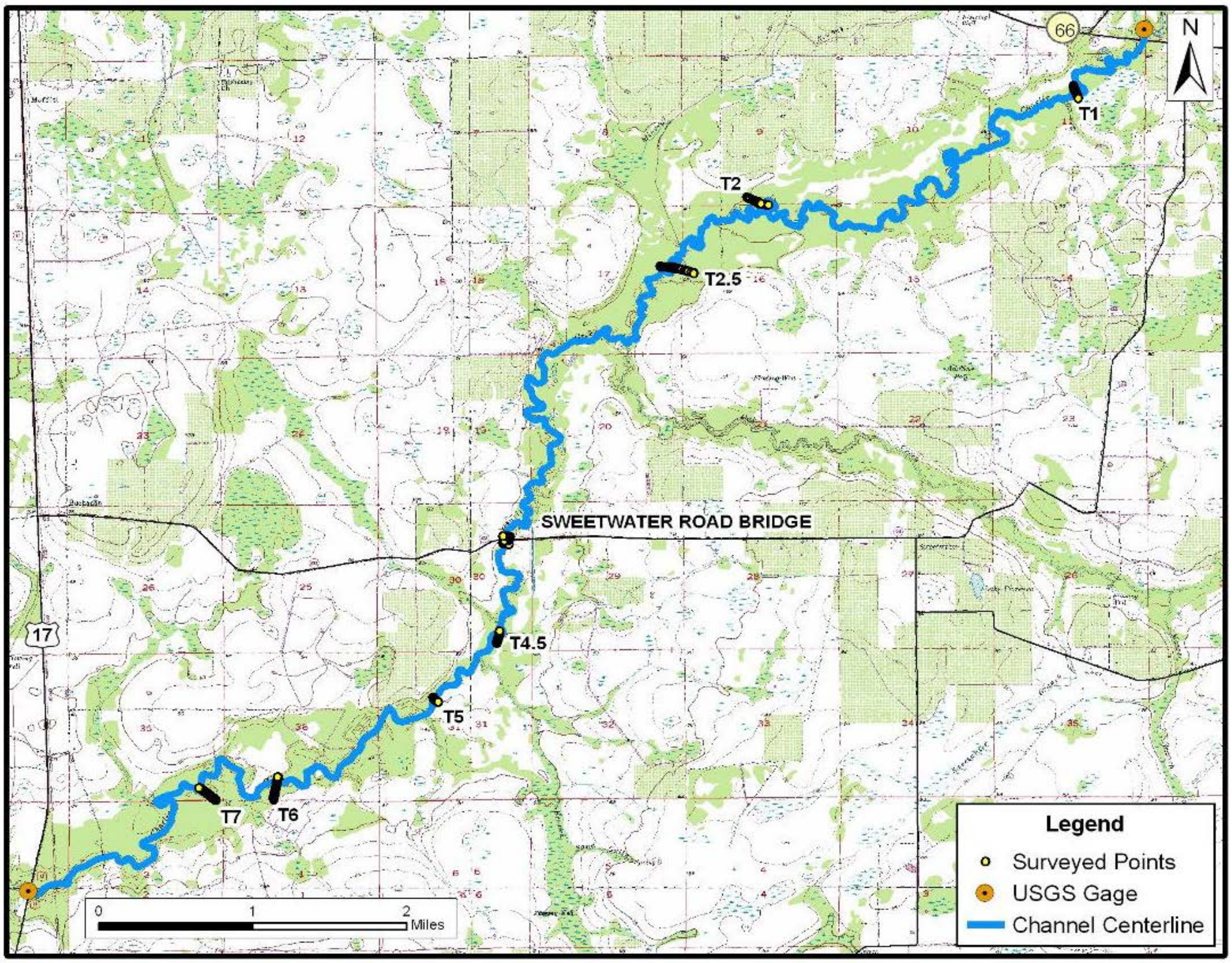

Figure 2. Charlie Creek Field Survey

Table 1. Survey Data Used to Construct Model Cross Sections

Transect Name	File Name	Date of Survey
T1	Charlie Creek Instream Transect 1-PHAB1 12-087	July 13, 2011
T1	Charlie Creek - Transect 1-PHAB 1 11-325	September 19, 2011
T2	Charlie Creek Instream Transect 2 12-087	November 2, 2011
T2	Charlie Creek - Transect 2 11-320	August 25, 2011
T2.5	Charlie Creek Instream Transect 2.5 12-087	November 3, 2011
T2.5	Charlie Creek - Transect 2.5 11-321	August 24, 2011
Sweetwater Road Bridge	Charlie Creek - Control [11-291] - Sweetwater Road Bridge	January 5, 2012
T4.5	Charlie Creek Instream Transect 4.5 12-087	September 22, 2011
T4.5	Charlie Creek - Transect 4.5 11-335	November 29, 2011
T5	Charlie Creek Instream Transect 5 12-087	September 28, 2011
T5	Charlie Creek - Transect 5 11-338	November 21, 2011
T6	Charlie Creek - Transect 6 11-342	December 14, 2011
T7	Charlie Creek - Transect 7 11-343	December 15, 2011

Digital elevation model data (5-foot by 5-foot cells) provided by the District was combined with surveyed data to develop HEC-RAS cross sections. The initial Charlie Creek model incorporated seven surveyed vegetative cross sections as well as four surveyed cross sections at the Sweetwater Road Bridge. A total of nineteen cross sections were constructed for the model. Seven cross sections correspond to the seven surveyed vegetative cross sections, two cross sections corresponded to the upstream and downstream boundaries (Figure 3), six cross sections corresponded to bridges. The remaining four cross sections were interpolated cross sections and were added for model stability. Two interpolated cross sections were added between transect T2.5 and the Sweetwater Road Bridge at River Stations 51227.9 and 48027.1. An interpolated cross section was added between transects T4.5 and T5 at River Station 27254.7, and the final interpolated cross section was added between transects T5 and T6 at River Station 27254.7. Cross section locations (including interpolated cross sections) are shown in Figure 3. To create model cross sections for HEC-RAS, the surveyed data was first filtered by removing surveyed points that were not ground elevations (e.g. eye bolt tag and hydrologic indicator nail elevations). Next, a line (referred to as a XS cut line in HEC-GeoRAS) was digitized through remaining points so that as many points as possible were included while also minimizing the distance from the line to the points. Off-center points located relatively far from the XS cut line were not included in the model cross section. One model cross section was placed at the beginning and at the end of the channel near the USGS gages (02296260 and 02296500) to define the upstream and downstream boundaries of the channel. Interpolated cross sections were constructed in HEC-RAS by interpolating between the upstream and downstream cross sections.

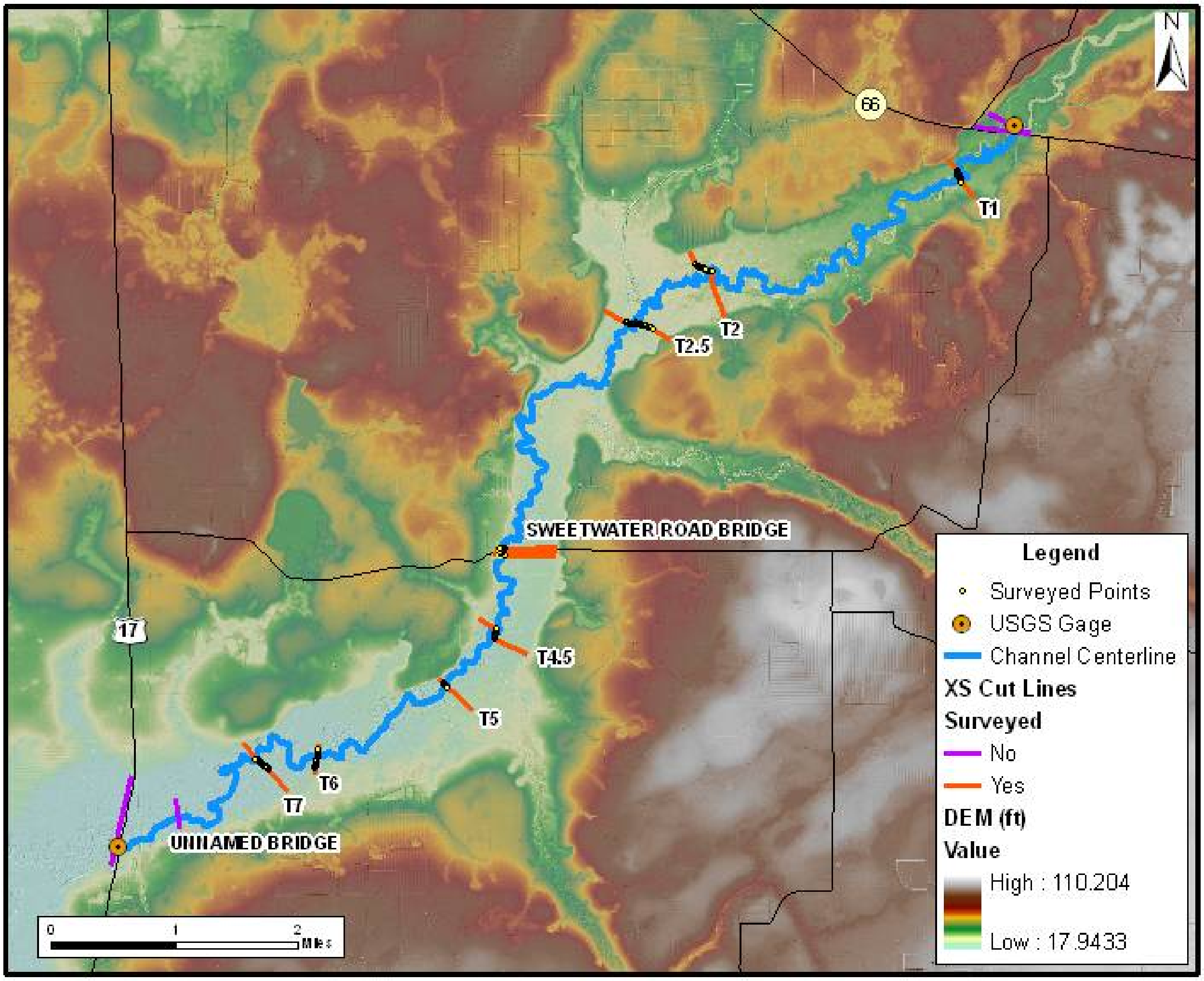

Figure 3. Cross Section Locations

Additional Cross Sections

After the completion of the initial modeling effort (INTERA, 2016), the District sought a better understanding of the Charlie Creek floodplain inundation, requiring extension of some cross sections in the previous Charlie Creek model as well as addition of new model cross sections to fully capture the floodplain of the studied reach. These modifications better captured the variability of the floodplain and wetlands throughout the modeled section and allowed for a more precise simulation of floodplain inundation area.

Data Collection and Assimilation

The addition of model cross sections required creek bathymetry and floodplain topography. Bathymetric and topographic surveys were previously collected for the 2016 project. Project budget and schedule did not accommodate the acquisition of new survey data for the current project task. Therefore, existing bathymetric survey for the channel was employed as the basis of the channel elevation data for the additional model cross sections.

The same general procedure used to develop the original model cross sections was applied to the new cross sections. Digital elevation model data (5-foot by 5-foot cells) provided by the District was combined with surveyed data to develop the new HEC-RAS cross sections. The DEM is based on aerial LiDAR data collected in 2005 for SWFWMD. Figure 4 displays the DEM containing Charlie Creek. The new cross sections were created by manually digitizing cut lines in ArcMap 10.2. The new cross sections were placed at locations where significant widening or narrowing of wetlands occurs along the main channel. Both existing and new cross section cut lines were extended beyond the boundary of the wetlands as depicted by aerial imagery, the National Wetlands Inventory (NWI) geodatabase (USFWS, 2012), and District floodplain shapefiles.

Floodplain elevation data for both the channel and the overbanks was extracted at each new/extended cross section with the HEC-GeoRAS version 10.2 tool within ArcMap version 10.2. Since surveyed elevation data for the main channel is contained in existing cross sections, the cross-section interpolation tool in HEC-RAS 4.1.0 was applied for generation of intermediate elevation data at the new cross sections. The interpolated surveyed channel data from the interpolated cross sections that were closest to the new cross sections replaced the DEM data for the main channel to create the final cross sections. The model vertical datum is the same as the DEM and survey vertical datums, which is the North American Vertical Datum of 1988 (NAVD88).

Model Geometry Construction

The 2016 Charlie Creek model was constructed with the objective of simulating MFLs at critical cross-sections. In many segments of Charlie Creek, the channel remains consistent; however, there is variation in the floodplain between the existing model cross sections. Therefore, additional cross sections were required for better assessment of flood conditions. The DEM and NWI maps were employed for identification of floodplain features and optimizing new cross section placement. Figure 5 shows the 2016 project Charlie Creek model cross section locations. Figure 6 shows the new cross sections in addition to the existing 2016 Charlie Creek model cross section locations. The initial model friction (Manning's n) values at the new cross sections are set to the same values as the bounding cross sections from the 2016 project. Friction values were further evaluated and modified during model calibration. Table 2 compares downstream reach length, or the distance to the next downstream cross section, for the 2016 and updated models. The reduced lengths demonstrate the improved cross section spacing. In the table, LOB refers to the flow path of the left overbank, Chan to the centerline of the main channel, and ROB to the flow path of the right overbank.

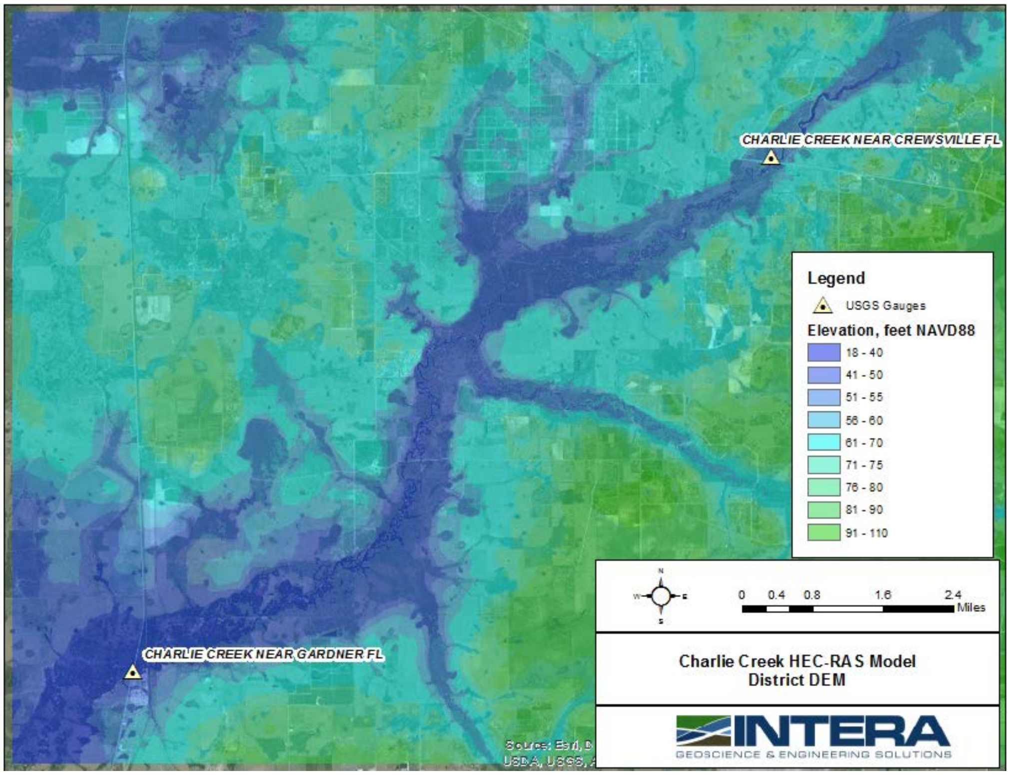

Figure 4. Digital Elevation Model for Charlie Creek

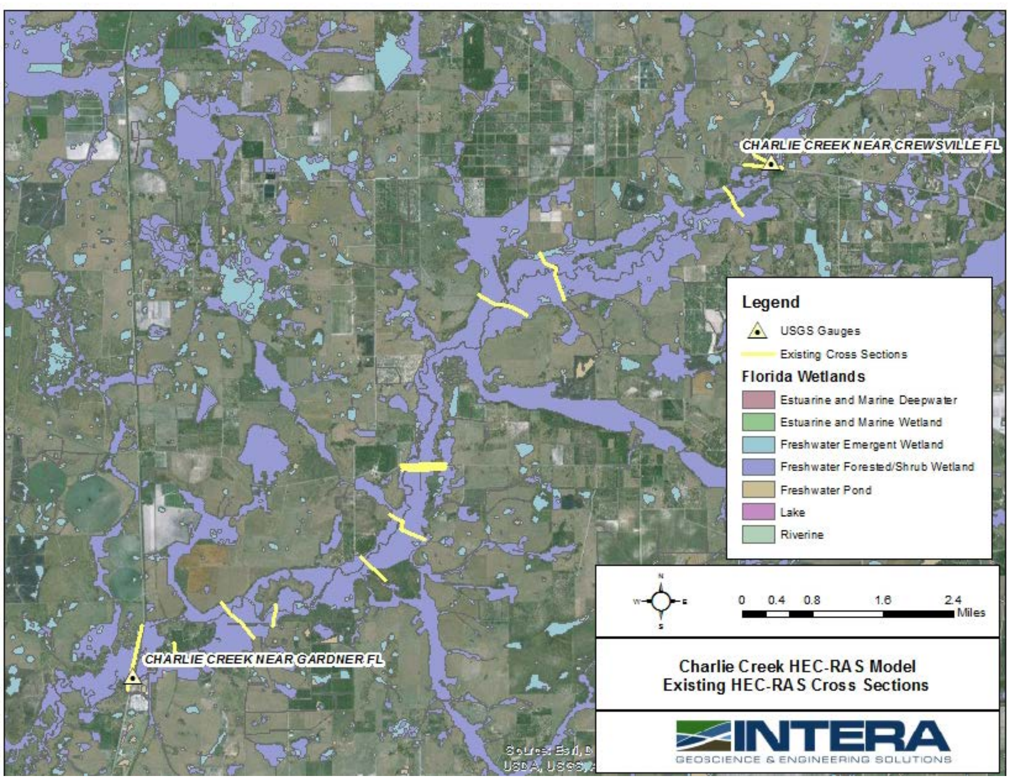

Figure 5. Charlie Creek Model Existing Cross Sections

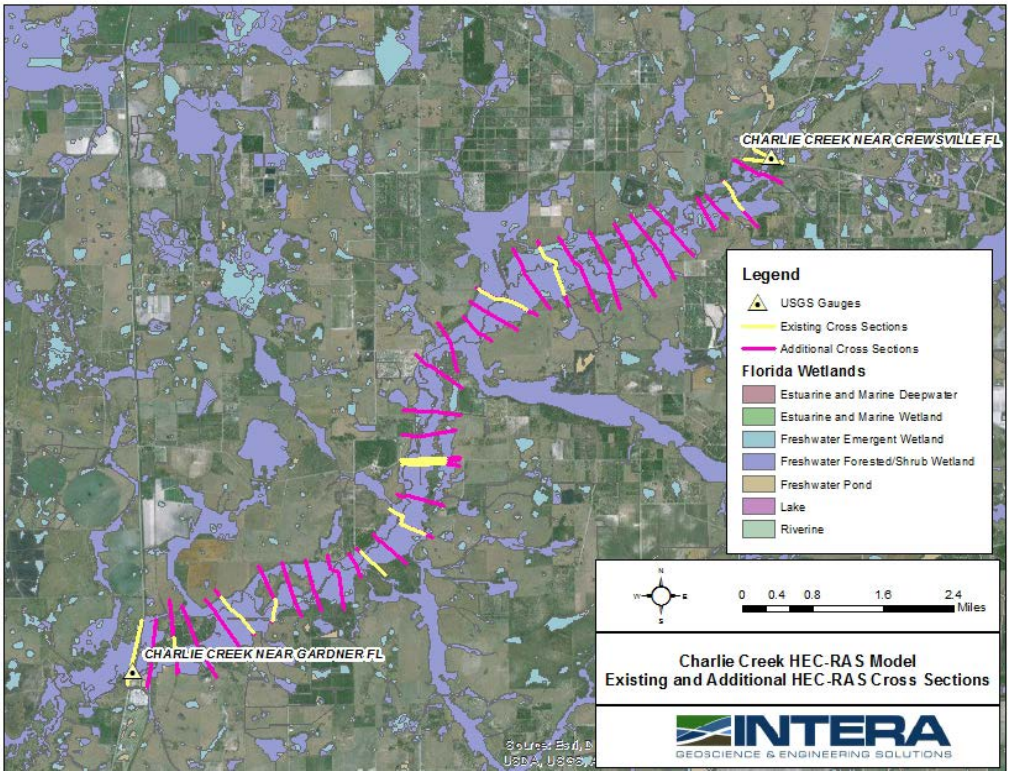

Figure 6. Charlie Creek Model Existing and Additional Cross Sections

Table 2. Downstream Reach Lengths for 2016 and New Model

Charlie Creek - Main Reach						
	2016 Model			Updated Model		
River Station	LOB	Chan	ROB	LOB	Chan	ROB
86227.02	105.83	318.05	518.22	105.83	318.05	518.22
85908.98	30	30	30	30	30	30
85879	3435.01	5103.81	2474.85	981.03	1158.48	719.06
84737.34				2471.1	3962.47	1772.91
80774.52	12236.46	22060.5	12377.44	1152.87	1559.23	1448.43
79215.03				827.78	735.62	553.48
78479.41				2137.32	3984.1	2457.07
74495.3				1439.99	3190.88	1392.78
71304.43				1606.88	3009.94	1323.57
68294.49				1911.38	2847.96	1778.27
65446.54				1538.73	3166.32	1997.23
62280.21				1621.51	3566.46	1426.6
58713.94	3306.73	6685.77	4220.48	1580.33	3160.32	1445.66
55553.44				1727.38	3526.1	2774.82
52028.14	468.6	800.2	521.37	1274.59	1700.78	934.59
51227.9	1874	3201	2085			
50326.56				1326.32	1718.94	1141.32
48607.62				2661.32	3109.8	1579.59
48027.1	8432	14747	9608			
45497.82				687.81	2478.43	2260.43
43019.39				2096.33	5196.9	3236.33
37822.48				1426.23	2083.02	1509.58
35739.47				1503.45	2459.61	1552.01
33279.96	49.14	74.76	80.16	49.14	74.76	80.16
33205.22	103.37	100.58	104.42	103.37	100.58	104.42
33148.78	Mult Open			Mult Open		
33104.64	155.23	84.63	50.73	155.23	84.63	50.73
33019.8	4031.54	4796.27	3315.64	2158.84	2969.13	2254.37
30050.57				1872.71	1830.61	1059.05
28223.52	781.97	968.82	803.84	1826.1	2410.99	1929.52
27254.7	2346	2906	2412			
25808.97				1301.78	1460.81	1288.07
24348.24	766.86	932.28	707.84	1115.15	888.35	773.36
23459.81				1313.93	1900.96	1392.73
23415.9	6135	7458	5663			

Table 2. 21558.85	**(continued)**			1620.77	1947.11	1773.47
19611.74				1333.5	1844.57	1333.85
17767.17				1518.41	1809.55	1097.14
15957.67	1826.6	4867.11	3850.06	1826.6	4867.11	3850.06
11090.54	4979.73	7856.24	4365.76	1148.31	1311.91	841.59
9778.588				2093.93	4618.23	2202.97
5313.746				1730.27	1918.77	1313.9
3403	15	15	15	15	15	15
3387.685	3281.17	3371.81	2329.41	1898.26	1909.39	1309.59
1478.012				1397.91	1477.41	1034.83
0	32	0	23.71	32	0	23.71

Additional Data Collection

Prior to data collection, property owners along the creek were contacted for site access. Sites were selected based on ease-of-access and distance from other sites. It was desirable to have data collections at various locations along Charlie Creek so that the pickup along the channel could be determined and the stage variability along the modeled section could be quantified. Additional stage data was collected at 2 locations along the creek. Flow data was collected for 3 events and 6 locations along the creek for medium and high flows and 3 locations along the creek for low flows.

Flow Measurements

Field engineers from INTERA were onsite to collect a series of flow measurements on Charlie Creek for 3 events during the data collection period. It was desirable to measure several different events that roughly represented low, medium and high flows. This would provide pickup data across the flow regime. A Sontek ADCP was used to collect flow measurements for the medium and high flow events. Because the ADCP is not accurate in shallow depths (less than 6-inches), it could not be used to measure the low flow event. INTERA personnel were trained on the use of the Sontek equipment by Water Cube, LLC., who accompanied INTERA personnel during the first flow measurement event.

Flow Measurement #1

Field engineers from INTERA and Water Cube were on site on October 18, 2017 to collect a series of flow measurements on Charlie Creek. The goal of the field work was to measure flow at 6 locations in the system. A Sontek ADCP was used to collect flow measurements. At each location, reciprocal measurements were made going back and forth across the creek. Prior to flow data collection, a bed velocity check was run with the ADCP. This file was later used in data processing. Locations for flow data collection are shown in Figure 7. As shown, data collection locations are evenly distributed along the modeled section of the creek, which is bounded by 2 United States Geological Survey (USGS) gauges. Locations were assigned identification numbers by a GPS device, as shown. Note that way point numbers (locations) are not ordered from upstream to downstream, or downstream to upstream. GPS point 14 represents the upstream boundary of the model while GPS point 18 represents the downstream model boundary.

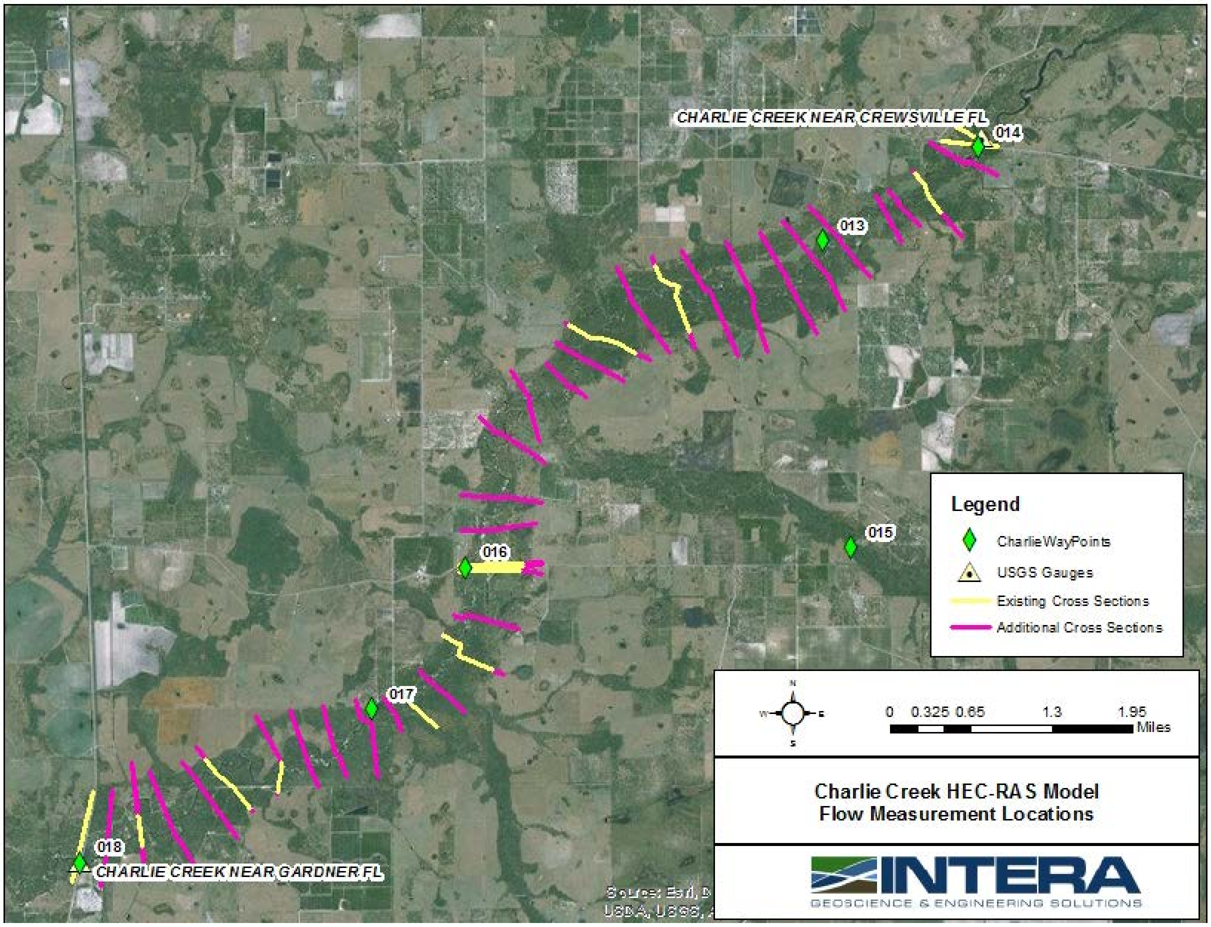

Figure 7. Flow Measurement Locations

Preliminary Flow Measurements

ADCP data from several passes at each location were recorded. The RiverSurveyor Live software was used on site to verify data quality. Preliminary flow data for each location is shown in Table 4. For each location, the average of the recorded flows was determined.

Table 3. Initial Flows

Site ID Number	File	Start Date	Start Time	Duration	Distance Made Good, ft	Mean Speed, ft/s	Boat Speed, ft/s	Total Q, cfs
13	20171018083118.riv	10/18/2017	8:31:12 AM	0:03:40	88.88	1.13	0.50	440.56
	20171018084015.riv	10/18/2017	8:40:08 AM	0:05:31	92.35	1.08	0.35	427.81
	20171018084600.riv	10/18/2017	8:45:43 AM	0:04:19	94.47	1.16	0.40	459.74
	20171018085026.riv	10/18/2017	8:50:06 AM	0:04:40	91.70	1.16	0.40	451.73
	20171018085514.riv	10/18/2017	8:54:50 AM	0:04:00	97.36	1.08	0.44	453.15
	20171018085922.riv	10/18/2017	8:58:56 AM	0:04:39	94.66	1.12	0.45	429.73
	20171018090434.riv	10/18/2017	9:04:04 AM	0:06:11	85.55	1.05	0.29	373.39
	20171018091054.riv	10/18/2017	9:10:18 AM	0:06:20	83.49	1.15	0.35	426.38
14	20171018102527.riv	10/18/2017	10:27:52 AM	0:06:19	156.64	0.49	0.44	432.75
	20171018103441.riv	10/18/2017	10:34:29 AM	0:08:10	156.99	0.48	0.35	422.93
15	20171018112203.riv	10/18/2017	11:22:25 AM	0:04:50	33.17	0.96	0.22	74.00
	20171018112745.riv	10/18/2017	11:27:39 AM	0:04:25	39.55	0.48	0.19	89.09
	20171018113653.riv	10/18/2017	11:36:47 AM	0:02:20	38.61	0.59	0.32	104.57
	20171018114000.riv	10/18/2017	11:39:34 AM	0:01:55	36.97	0.56	0.34	94.61
	20171018114231.riv	10/18/2017	11:42:03 AM	0:02:13	36.99	0.56	0.30	93.60
	20171018114510.riv	10/18/2017	11:44:39 AM	0:02:07	37.95	0.57	0.33	102.94
	20171018114750.riv	10/18/2017	11:47:16 AM	0:01:49	39.02	0.56	0.38	96.20
	20171018114952.riv	10/18/2017	11:49:16 AM	0:02:10	42.63	0.56	0.34	114.26
	20171018115229.riv	10/18/2017	11:51:51 AM	0:02:06	38.78	0.63	0.34	103.01
	20171018120451.riv	10/18/2017	12:04:01 PM	0:02:33	42.39	0.48	0.30	113.04
	20171018120826.riv	10/18/2017	12:07:40 PM	0:01:45	42.09	0.51	0.42	116.76
	20171018121054.riv	10/18/2017	12:10:04 PM	0:02:28	39.51	0.44	0.30	102.35
	20171018121404.riv	10/18/2017	12:13:11 PM	0:02:20	40.13	0.44	0.31	96.51
	20171018123846.riv	10/18/2017	12:37:20 PM	0:02:07	31.89	1.00	0.32	95.71
	20171018124129.riv	10/18/2017	12:40:05 PM	0:02:00	32.00	1.04	0.30	102.21
	20171018124346.riv	10/18/2017	12:42:18 PM	0:02:23	31.44	0.98	0.26	96.10
	20171018124625.riv	10/18/2017	12:44:52 PM	0:01:56	31.37	1.02	0.32	98.07
16	20171018133756.riv	10/18/2017	1:37:50 PM	0:02:18	61.89	1.93	0.47	575.38
	20171018134045.riv	10/18/2017	1:40:36 PM	0:02:31	63.31	1.92	0.44	587.83
	20171018134341.riv	10/18/2017	1:43:34 PM	0:02:47	60.16	1.92	0.38	563.22
	20171018134644.riv	10/18/2017	1:46:29 PM	0:02:54	64.63	1.88	0.39	591.79
	20171018135019.riv	10/18/2017	1:50:05 PM	0:00:10	0.15	0.00	0.06	0.00
	20171018135056.riv	10/18/2017	1:50:38 PM	0:02:42	59.33	1.92	0.39	571.46
17	20171018145358.riv	10/18/2017	2:53:54 PM	0:02:22	63.21	1.40	0.50	611.27
	20171018145635.riv	10/18/2017	2:56:26 PM	0:02:19	62.97	1.36	0.60	557.74
	20171018150500.riv	10/18/2017	3:04:48 PM	0:03:13	77.98	1.25	0.48	577.21
	20171018150858.riv	10/18/2017	3:08:43 PM	0:02:13	69.50	1.24	0.55	579.23
	20171018151122.riv	10/18/2017	3:11:03 PM	0:00:19	11.40	0.00	0.60	0.00

Site ID Number	File	Start Date	Start Time	Duration	Distance Made Good, ft	Mean Speed, ft/s	Boat Speed, ft/s	Total Q, cfs
	20171018151303.riv	10/18/2017	3:12:44 PM	0:03:41	66.36	1.32	0.35	588.12
	20171018151706.riv	10/18/2017	3:16:45 PM	0:02:13	63.82	1.45	0.53	615.66
	20171018152158.riv	10/18/2017	3:21:33 PM	0:03:18	67.24	1.24	0.39	579.07
	20171018152531.riv	10/18/2017	3:24:57 PM	0:02:35	60.36	1.46	0.48	595.31
18	20171018162310.riv	10/18/2017	4:23:13 PM	0:04:02	85.07	1.07	0.47	616.66
	20171018162737.riv	10/18/2017	4:27:25 PM	0:04:25	89.77	0.97	0.39	562.26
	20171018163222.riv	10/18/2017	4:32:04 PM	0:03:46	88.55	1.02	0.49	595.38
	20171018163631.riv	10/18/2017	4:36:09 PM	0:04:35	91.83	1.09	0.40	649.77
	20171018165451.riv	10/18/2017	4:54:23 PM	0:03:57	67.57	1.04	0.34	573.12
	20171018165858.riv	10/18/2017	4:58:25 PM	0:03:49	71.30	1.05	0.38	594.52
	20171018170342.riv	10/18/2017	5:03:08 PM	0:03:33	73.21	1.03	0.41	583.37
	20171018170750.riv	10/18/2017	5:07:11 PM	0:03:18	68.28	1.07	0.41	589.14

Final Flow Measurements

After data were processed in RiverSurveyor Live, data were also processed in QRev, an application developed by the USGS (USGS, 2017). QRev provides improved consistency and efficiency of ADCP measurements through automated quality checks, automated data filtering, consistent processing algorithms independent of ADCP type. Because processing algorithms may be different than RiverSurveyor Live, computed discharges may be slightly different than discharges computed with RiverSurveyor Live. Discharge measurements computed with QRev are shown for each location in Table 4 through Table 9.

Table 4. Final QA/QCed Flows, Site 013

Measurement	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/18/2017)	End Time (10/18/2017)
Average	**437.307**	59.722	294.784	82.138	2352	8:31:11	9:16:36
20171018083118.riv	**442.995**	60.551	306.928	74.529	219	08:31:11 L	8:34:50
20171018084015.riv	**435.823**	57.421	297.336	80.842	330	08:40:07 L	8:45:37
20171018084600.riv	**450.597**	67.024	296.468	86.4	258	08:45:42 R	8:50:00
20171018085026.riv	**455.382**	62.376	312.113	79.984	279	08:50:05 L	8:54:44
20171018085514.riv	**418.968**	56.483	278.841	82.714	239	08:54:49 R	8:58:48
20171018085922.riv	**447.687**	59.791	301.368	86.101	278	08:58:55 L	9:03:33
20171018090434.riv	**409.417**	55.807	272.093	80.829	370	09:04:03 R	9:10:13
20171018091054.riv	**437.584**	58.326	293.128	85.701	379	09:10:17 L	9:16:36

Table 5. Final QA/QCed Flows, Site 014

Measurement	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/18/2017)	End Time (10/18/2017)
Average	**446.113**	55.081	321.576	69.127	868	10:27:52	10:42:39
20171018102527.riv	**451.584**	55.807	324.884	70.450	378	10:27:52 L	10:34:10
20171018103441.riv	**440.643**	54.355	318.267	67.804	490	10:34:29 R	10:42:39

Table 6. Final QA/QCed Flows, Site 015

Measurement	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/18/2017)	End Time (10/18/2017)
Average	**96.975**	19.489	60.484	16.364	788	12:10:03	12:46:46
20171018114000.riv	**100.096**	13.847	65.364	20.512	114	11:39:33 L	11:41:27
20171018114510.riv	**102.982**	14.443	66.548	21.666	126	11:44:38 L	11:46:44
20171018114750.riv	**99.977**	14.107	62.839	23.032	108	11:47:15 R	11:49:03
20171018115229.riv	**101.012**	14.066	65.588	21.045	125	11:51:50 R	11:53:55
20171018121054.riv	**99.591**	11.976	71.274	16.194	147	12:10:03 L	12:12:30
20171018121404.riv	**96.487**	7.633	70.133	18.636	139	12:13:10 R	12:15:29
20171018123846.riv	**94.951**	24.015	55.1	15.302	126	12:37:19 L	12:39:25
20171018124129.riv	**98.754**	24.021	56.359	16.53	119	12:40:04 R	12:42:03
20171018124346.riv	**94.862**	24.814	53.412	15.955	142	12:42:17 L	12:44:39
20171018124625.riv	**97.203**	24.478	56.627	15.568	115	12:44:51 R	12:46:46

Table 7. Final QA/QCed Flows, Site 016

Measurement	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/18/2017)	End Time (10/18/2017)
Average	**578.402**	95.123	398.578	83.056	626	13:37:50	13:49:22
20171018133756.riv	**576.385**	95.014	393.359	86.832	137	13:37:50 R	13:40:07
20171018134045.riv	**581.477**	95.349	402.922	82.148	150	13:40:36 L	13:43:06
20171018134341.riv	**570.557**	93.23	391.451	83.839	166	13:43:34 R	13:46:20
20171018134644.riv	**585.189**	96.899	406.581	79.405	173	13:46:29 L	13:49:22

Table 8. Final QA/QCed Flows, Site 017

<u>Measurement</u>	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/18/2017)	End Time (10/18/2017)
Average	**598.45**	79.128	426.141	84.443	1168	14:53:53	15:27:31
20171018145358.riv	**611.404**	81.151	441.434	87.566	141	14:53:53 L	14:56:14
20171018150500.riv	**596.196**	81.113	422.706	86.533	192	15:04:48 R	15:08:00
20171018150858.riv	**578.456**	77.864	418.785	80.318	132	15:08:43 L	15:10:55
20171018151303.riv	**600.344**	77.982	420.811	82.009	220	15:12:44 R	15:16:24
20171018151706.riv	**622.205**	80.500	435.313	86.219	132	15:16:45 L	15:18:57
20171018152158.riv	**572.861**	75.713	415.56	84.166	197	15:21:33 R	15:24:50
20171018152531.riv	**607.687**	79.571	428.38	84.287	154	15:24:57 L	15:27:31

Table 9. Final QA/QCed Flows, Site 018

<u>Measurement</u>	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/18/2017)	End Time (10/18/2017)
Average	**601.595**	55.613	457.688	87.243	1877	16:23:13	17:10:27
20171018162310.riv	**639.202**	55.665	478.596	104.433	241	16:23:13 L	16:27:14
20171018162737.riv	**567.086**	56.134	425.168	85.193	264	16:27:25 R	16:31:49
20171018163222.riv	**606.993**	50.966	453.705	102.233	225	16:32:04 L	16:35:49
20171018163631.riv	**645.504**	60.602	491.452	92.950	274	16:36:09 R	16:40:43
20171018165451.riv	**584.494**	54.642	443.66	83.760	236	16:54:22 R	16:58:18
20171018165858.riv	**587.11**	56.203	456.716	72.273	228	16:58:24 L	17:02:12
20171018170342.riv	**594.779**	54.167	456.623	83.316	212	17:03:07 R	17:06:39
20171018170750.riv	**587.59**	56.521	455.58	73.790	197	17:07:10 L	17:10:27

Average flows for each location are shown in Figure 8. As shown, flows generally increase from upstream to downstream. Measured flow on the tributary was significant, measuring approximately 97 cubic feet per second. It is noteworthy that with the exception of the tributary, pickup is somewhat small along the system when compared to the average flows.

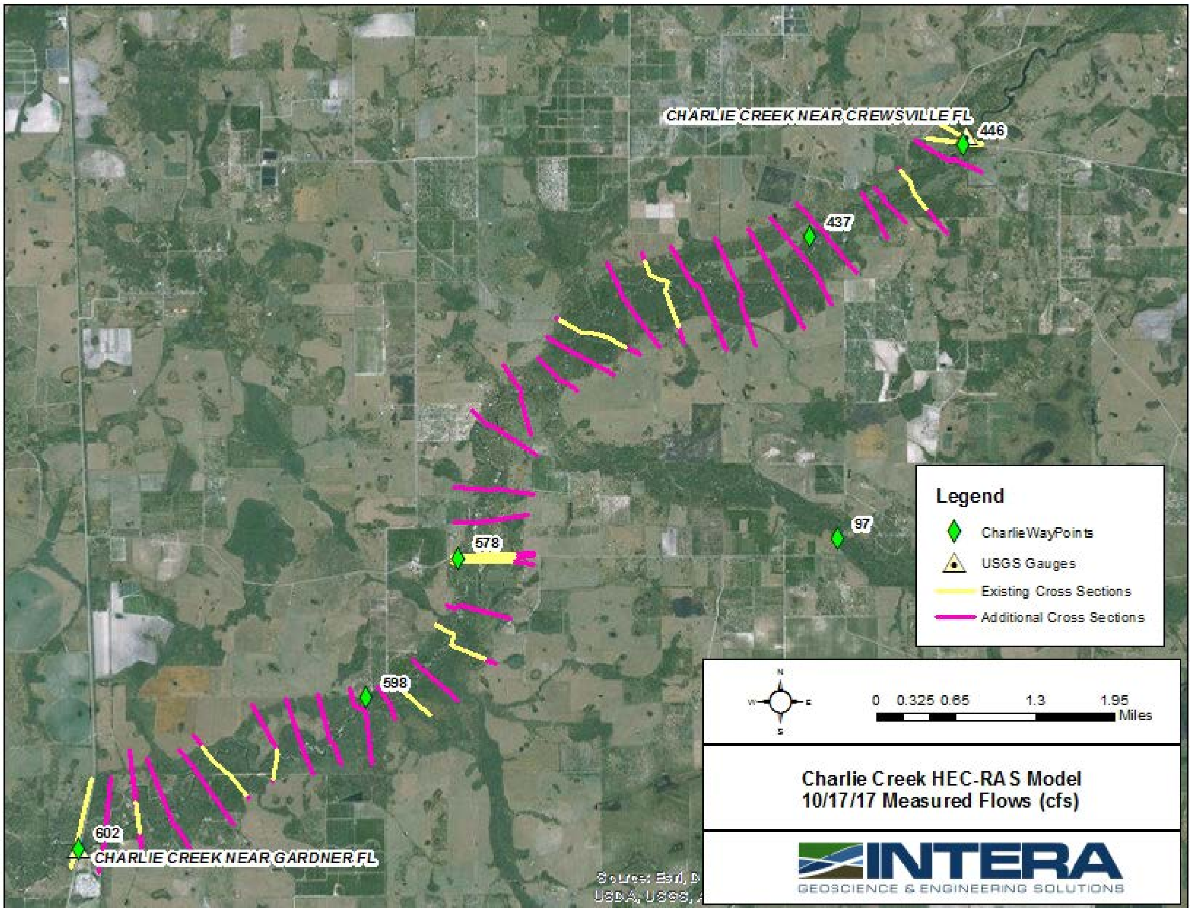

Figure 8. Charlie Creek Flow Data Collection #1 Flows

Flow Measurement #2

Field engineers from INTERA were onsite on May 10, 2017 to collect low flow measurements. The goal of the field work was to measure flow at 3 locations in the system during a low flow event. A Marsh McBirney Flow Probe 2000 electromagnetic flow meter with a top setting wading rod was used to measure water velocity. Standard USGS stream gaging techniques were used to measure flow. A tagline was placed across the creek, perpendicular to the direction of flow. The cross section was divided into sections based on the total width. Depth and velocity measurements were made at each interval. Using the velocity, depth, and width of the measured interval, the total flow for the interval was calculated. The total flow at the cross section was calculated as the summation of the flows for each interval. Because flows were low and did not increase substantially moving downstream, flows were measured at 3 locations, as opposed to 6 locations during higher flows. As shown, data collection locations are evenly distributed along the modeled section of the creek, which is bounded by 2 United States Geological Survey (USGS) gauges. Locations were assigned identification numbers by a GPS device, as shown in Figure 9. These identification numbers are the same as previous data collection efforts.

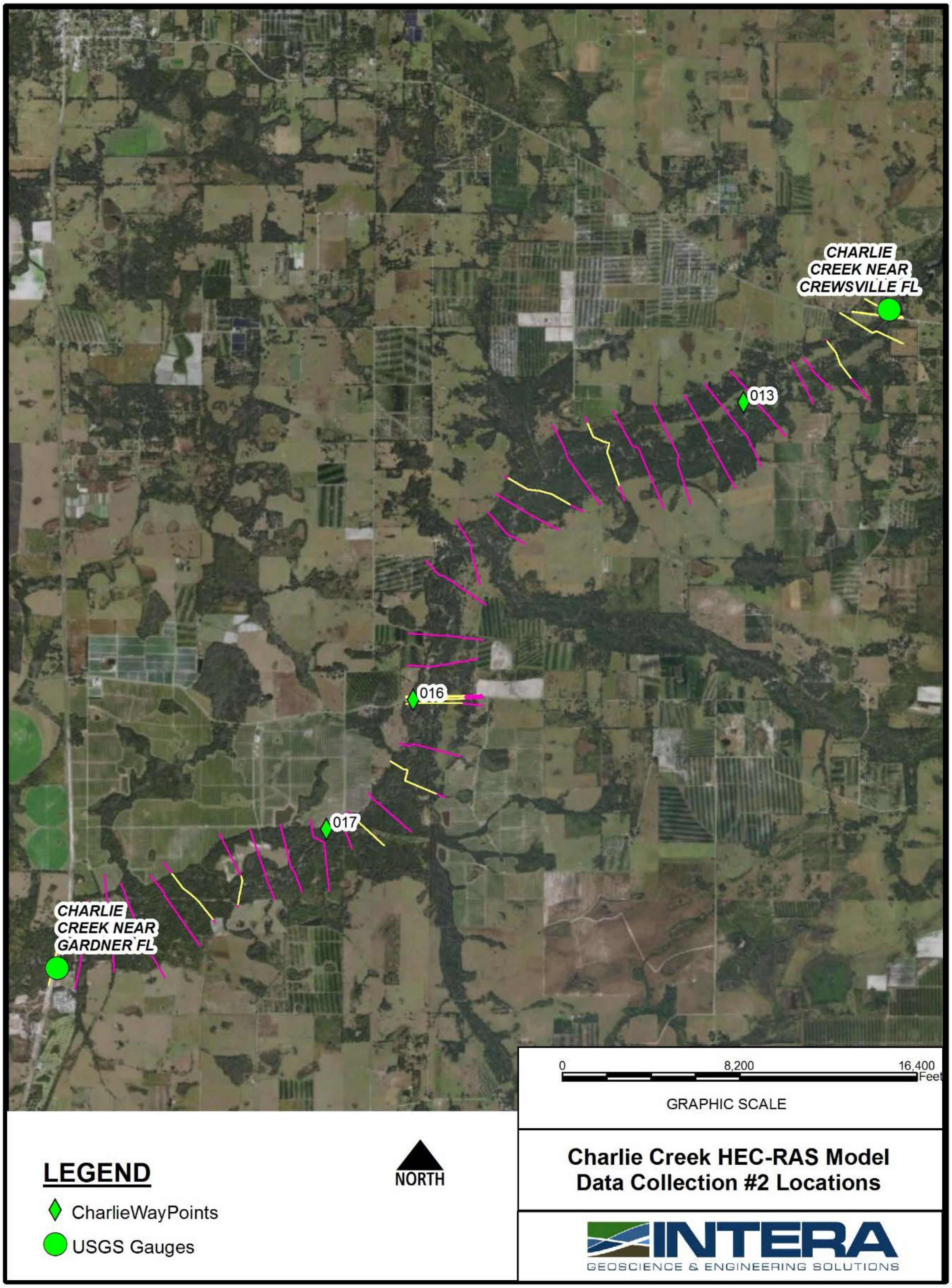

Figure 9. Flow Measurement Locations

Preliminary Velocity Data

Incremental velocity and depth measurements for each of the 3 flow measurement locations are shown in Table 10 through Table 12.

Table 10. Field Measurements, Way Point 13, 5/10/18 3:33 p.m.

Start Station, ft.	Stop Station, ft.	Width, ft.	Depth, ft.	Velocity, ft/sec	Area, ft^2	Flow, cfs
12.5	11.5	1.0	0.25	0.2	0.25	0.05
11.5	10.5	1.0	0.25	0.63	0.25	0.16
10.5	9.5	1.0	0.30	1.10	0.30	0.33
9.5	8.5	1.0	0.20	0.70	0.20	0.14
8.5	7.0	1.5	0.20	0.39	0.30	0.12
					Total Flow (cfs)	0.79

Table 11. Field Measurements, Way Point 16, 5/10/18 2:22 p.m.

Start Station, ft.	Stop Station, ft.	Width, ft.	Depth, ft.	Velocity, ft/sec	Area, ft^2	Flow, cfs
19.0	17.0	2.0	0.20	0.06	0.40	0.02
17.0	15.0	2.0	0.20	0.21	0.40	0.08
15.0	13.0	2.0	0.30	0.36	0.60	0.22
13.0	11.0	2.0	0.40	0.46	0.8.0	0.37
11.0	9.0	2.0	0.45	0.51	0.9.0	0.46
9.0	7.0	2.0	0.55	0.51	1.10	0.56
7.0	5.0	2.0	0.65	0.42	1.30	0.55
5.0	3.0	2.0	0.35	0.31	0.70	0.22
					Total Flow (cfs)	2.48

Table 12. Field Measurements, Way Point 17, 5/10/18 1:51 p.m. (20-20 Groves)

Start Station, ft.	Stop Station, ft.	Width, ft.	Depth, ft.	Velocity, ft/sec	Area, ft^2	Flow, cfs
7.0	9.0	2.0	0.25	0.01	0.50	0.01
9.0	11.0	2.0	1.00	0.05	2.00	0.10
11.0	13.0	2.0	1.50	0.11	3.00	0.33
13.0	15.0	2.0	2.70	0.11	5.40	0.59
15.0	17.0	2.0	2.95	0.11	5.90	0.65
17.0	19.0	2.0	2.95	0.12	5.90	0.71
19.0	21.0	2.0	2.00	0.07	4.00	0.28
21.0	23.0	2.0	1.00	0.04	2.00	0.08
23.0	24.0	1.0	0.20	0.01	0.20	0.00
					Total Flow (cfs)	2.75

Total flows for each location are shown in Figure 10. As shown, flows generally increase from upstream to downstream. The USGS flows at the upstream and downstream model boundaries (Charlie Creek near Crewsville and Charlie Creek near Gardner, respectively) are shown with the field measurements in Table 13.

Table 13. Average flow, 5/10/18

Location	Flow, cfs	Measured by
Charlie Creek near Crewsville	0.69	USGS (Provisional)
Way Point 13	0.79	INTERA
Way Point 16	2.48	INTERA
Way Point 17	2.75	INTERA
Charlie Creek near Gardner	7.28	USGS (Provisional)

As shown above, there is a large amount of pickup between the last flow measurement location and the downstream boundary. It has been suggested that the USGS rating curve may not be accurate at low flows. Thus, this large amount of pickup could either be attributed to error in the USGS rating curve at low flows, flow measurement error, or actual pickup in the creek.

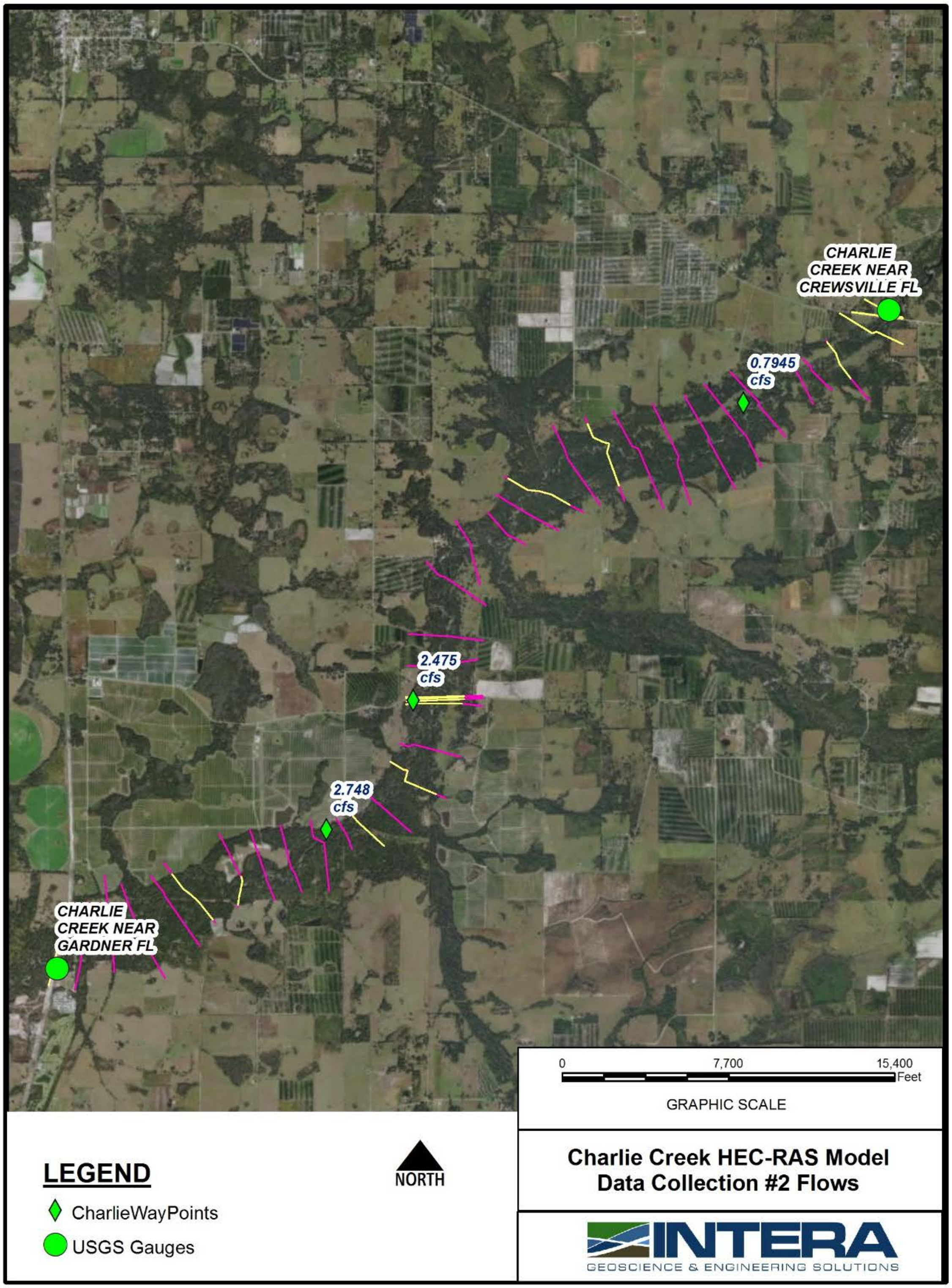

Figure 10. Charlie Creek Flow Data Collection #2 Flows

Flow Measurement #3

Field engineers from INTERA were on site on June 11, 2018 to collect a series of flow measurements on Charlie Creek. The goal of the field work was to measure flow at 6 locations in the system. A Sontek ADCP was used to collect flow measurements at the same locations as Flow Measurement #1 (Figure 7). At each location, reciprocal measurements were made going back and forth across the creek. Prior to flow data collection, a bed velocity check was run with the ADCP. This file was later used in data processing.

Preliminary Flow Measurements

ADCP data from several passes at each location were recorded. The RiverSurveyor Live software was used on site to verify data quality. Preliminary flow data for each location is shown in Table 14. For each location, the average of the recorded flows was determined.

Table 14. Initial Flows

Way Point Number	File	Start Date	Start Time	Duration	Distance Made Good, feet	Mean Speed, feet/sec	Boat Speed, feet/sec	Total Q, cfs
13	20180611152841r.rivr	6/11/2018	3:28:36 PM	0:03:16	102.56	1.15	0.62	598.52
	20180611153203r.rivr	6/11/2018	3:31:57 PM	0:03:04	100.32	1.14	0.64	576.88
	20180611153510r.rivr	6/11/2018	3:35:04 PM	0:03:25	103.06	1.16	0.58	602.49
14	20180611103555r.rivr	6/11/2018	10:35:52 AM	0:03:43	147.62	0.55	0.71	555.47
	20180611103943r.rivr	6/11/2018	10:39:39 AM	0:03:46	151.43	0.61	0.75	612.86
	20180611104332r.rivr	6/11/2018	10:43:28 AM	0:04:07	147.76	0.55	0.67	551.20
	20180611104750r.rivr	6/11/2018	10:47:45 AM	0:03:36	148.73	0.57	0.79	585.09
	20180611105149r.rivr	6/11/2018	10:51:45 AM	0:03:47	143.52	0.58	0.80	578.51
15	20180611094906r.rivr	6/11/2018	9:49:04 AM	0:03:56	46.15	0.76	0.27	160.54
	20180611095331r.rivr	6/11/2018	9:53:44 AM	0:02:24	46.36	0.75	0.38	158.28
	20180611095620r.rivr	6/11/2018	9:56:18 AM	0:03:00	47.12	0.83	0.33	177.68
	20180611100152r.rivr	6/11/2018	10:01:49 AM	0:02:28	46.54	0.77	0.35	166.64
16	20180611084925r.rivr	6/11/2018	8:49:25 AM	0:03:53	133.53	1.18	0.68	927.21
	20180611085325r.rivr	6/11/2018	8:53:25 AM	0:04:15	131.19	1.13	0.79	836.23
	20180611085758r.rivr	6/11/2018	8:57:57 AM	0:03:55	136.35	1.13	0.78	861.96
	20180611090156r.rivr	6/11/2018	9:01:55 AM	0:03:11	130.88	1.22	0.76	912.10
	20180611090513r.rivr	6/11/2018	9:05:12 AM	0:03:29	125.74	1.10	0.76	799.32
	20180611090857r.rivr	6/11/2018	9:08:56 AM	0:03:04	132.84	1.12	0.81	876.02
	20180611091236r.rivr	6/11/2018	9:12:35 AM	0:03:24	131.09	1.19	0.78	882.90
17	20180611142704r.rivr	6/11/2018	2:27:00 PM	0:03:07	113.49	1.52	0.77	994.35
	20180611143408r.rivr	6/11/2018	2:34:03 PM	0:02:52	112.97	1.41	0.73	946.51
	20180611143708r.rivr	6/11/2018	2:37:02 PM	0:03:04	118.18	1.39	0.81	950.40
18	20180611074103r.rivr	6/11/2018	7:41:04 AM	0:03:18	69.05	1.24	0.58	927.54
	20180611074433r.rivr	6/11/2018	7:45:07 AM	0:02:47	74.24	1.22	0.56	964.44
	20180611074824r.rivr	6/11/2018	7:48:24 AM	0:02:33	74.54	1.29	0.73	989.88
	20180611075111r.rivr	6/11/2018	7:51:11 AM	0:02:33	78.17	1.28	0.62	1036.87
	20180611075407r.rivr	6/11/2018	7:54:07 AM	0:03:08	83.25	1.18	0.59	984.06
	20180611075719r.rivr	6/11/2018	7:57:19 AM	0:02:54	79.88	1.20	0.63	916.78

Final Flow Measurements

After data were processed in RiverSurveyor Live, data were also processed in QRev, an application developed by the USGS (USGS, 2017). QRev provides improved consistency and efficiency of ADCP measurements through automated quality checks, automated data filtering, consistent processing algorithms independent of ADCP type. Because processing algorithms may be different than RiverSurveyor Live, computed discharges may be slightly different than discharges computed with RiverSurveyor Live. Discharge measurements computed with QRev are shown for each location in Table 15 through Table 20.

Table 15. Final QA/QCed Flows, Site 013

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/11/2018)	End Time (06/11/2018)
Average	**573.64**	91.50	391.13	91.05	582	3:28:35 PM	3:38:27 PM
1	**560.17**	84.07	388.16	87.93	195	15:28:35 L	3:31:50 PM
2	**562.65**	94.51	374.46	93.94	183	15:31:56 R	3:34:59 PM
3	**598.08**	95.91	410.78	91.27	204	15:35:03 L	3:38:27 PM

Table 16. Final QA/QCed Flows, Site 014

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/11/2018)	End Time (06/11/2018)
Average	**549.42**	70.27	411.31	70.17	1134	10:35:52	10:55:31
1	**555.95**	72.50	408.05	75.59	222	10:35:52 L	10:39:34
2	**552.15**	75.57	405.13	71.78	225	10:39:39 R	10:43:24
3	**549.83**	71.07	412.28	66.67	246	10:43:28 L	10:47:34
4	**553.55**	67.47	414.45	68.01	215	10:47:45 R	10:51:20
5	**535.64**	64.74	416.67	68.77	226	10:51:45 L	10:55:31

Table 17. Final QA/QCed Flows, Site 015

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/11/2018)	End Time (06/11/2018)
Average	**164.53**	31.64	102.53	29.01	791	9:49:04	10:04:16
1	**158.03**	31.45	98.72	28.08	235	09:49:04 L	9:52:59
2	**162.72**	31.45	98.06	30.22	143	09:53:44 R	9:56:07
3	**174.73**	34.63	104.87	31.42	179	09:56:18 L	9:59:17
4	**162.64**	29.99	102.48	27.61	147	10:01:49 L	10:04:16

Table 18. Final QA/QCed Flows, Site 016

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/11/2018)	End Time (06/11/2018)
Average	**816.38**	146.37	579.49	91.02	1504	8:49:24 AM	9:15:57 AM
1	**849.57**	127.16	641.73	82.11	232	08:49:24 L	8:53:16 AM
2	**809.48**	154.89	549.12	106.14	254	08:53:24 R	8:57:38 AM
3	**857.50**	160.66	580.84	116.18	234	08:57:56 L	9:01:50 AM
4	**823.68**	162.96	574.70	87.44	190	09:01:54 R	9:05:04 AM
5	**740.75**	118.19	558.73	63.90	208	09:05:11 L	9:08:39 AM
6	**800.75**	150.19	564.65	85.70	183	09:08:55 R	9:11:58 AM
7	**832.91**	150.55	586.65	95.69	203	09:12:34 L	9:15:57 AM

Table 19. Final QA/QCed Flows, Site 017

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/11/2018)	End Time (06/11/2018)
Average	**966.25**	137.23	642.65	177.79	540	2:26 PM	2:40 PM
1	**997.42**	135.28	666.23	187.99	186	14:26:59 L	2:30 PM
2	**947.26**	149.46	604.34	183.52	171	14:34:02 R	2:36 PM
3	**954.08**	126.93	657.39	161.86	183	14:37:01 L	2:40 PM

Table 20. Final QA/QCed Flows, Site 018

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/11/2018)	End Time (06/11/2018)
Average	**966.71**	106.00	637.24	207.21	1027	7:41 AM	8:00:11 AM
1	**930.84**	103.90	621.93	192.24	197	07:41:03 R	7:44:20 AM
2	**949.22**	99.54	649.27	172.31	166	07:45:06 L	7:47:52 AM
3	**961.22**	102.03	621.47	229.11	152	07:48:23 R	7:50:55 AM
4	**1046.69**	117.54	723.66	190.05	152	07:51:10 L	7:53:42 AM
5	**987.04**	111.39	585.41	277.55	187	07:54:06 R	7:57:13 AM
6	**925.26**	101.56	621.69	182.01	173	07:57:18 L	8:00:11 AM

Average flows for each location are shown in Figure 11. As shown, flows generally increase from upstream to downstream. Measured flow on Oak Creek (Way Point 15) was significant, measuring approximately 164 cubic feet per second. It is noteworthy that with the exception of the Oak Creek tributary and the tributary to the south, pickup along the system is fairly low. This is consistent with other flow measurements along Charlie Creek. Pickup in the lower portion of the system, between Way Point 17 and the downstream boundary condition, is also low.

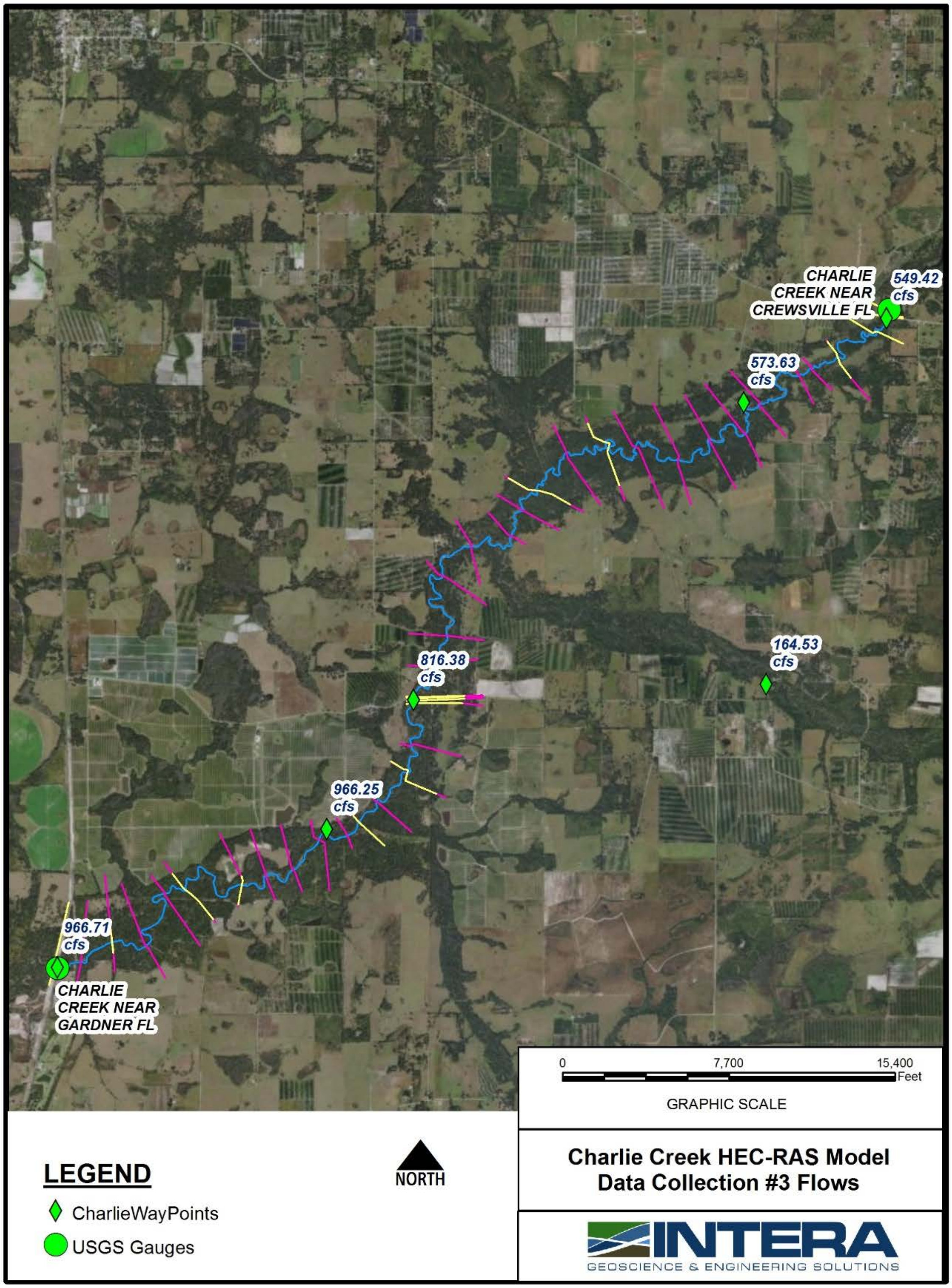

Figure 11. Average Flows at Selected Locations, High Flow

Summary of All Measurements

A total of three sets of flow measurements were recorded by INTERA. The low flow event was measured at 3 locations along Charlie Creek, while the medium and high flow events were measured at 6 locations along Charlie Creek. The three sets of flow measurements are summarized in Table 21.

Table 21. Summary of All Flow Measurements

Way Point	5/10/2018 Flow, cfs	10/18/2017 Flow, cfs	6/11/2018 Flow, cfs
14 (USGS Charlie Creek near Crewsville gauge)	Not measured	446	549
13	0.7945	437	574
15 (Oak Creek)	Not measured	97	164
16	2.475	578	816
17	2.748	598	966
18 (Charlie Creek near Gardner gauge)	Not measured	602	967

As shown above, pickup was relatively low in the upper portion of the channel for all flow events. Flows shown above will be incorporated into the Charlie Creek HEC-RAS model. Once incorporated, the model calibration will be evaluated. The results of the flow data collection will provide an excellent data set for model calibration.

Stage Measurements

Based on the lack of stage calibration data that was available for model calibration, it was decided to collect additional stage data at 2 locations along the modeled section to refine the model calibration. Additional stage data was collected at 2 locations along Charlie Creek: the Platt residence and Sweetwater Bridge (Figure 12).

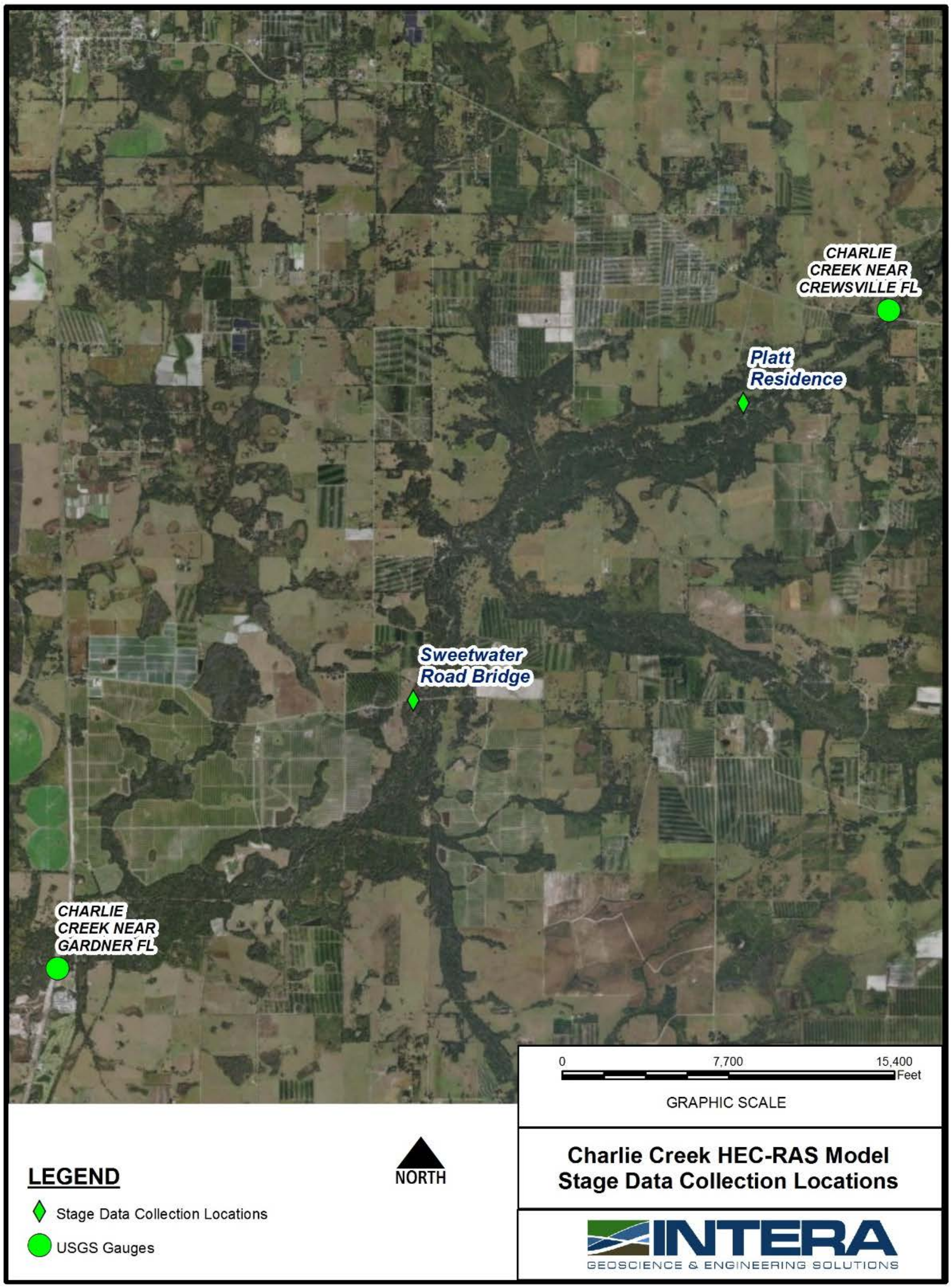

Figure 12. Stage Data Collection Locations

Two HOBO Water U20L-04 Water Level Loggers (with a range of 0 to 13 feet) were installed on Charlie Creek to measure the water level (recorded in pounds per square inch of absolute pressure, psia) and temperature at the Platt Residence and Sweetwater Bridge and barometric pressure in the area. These locations were selected due to ease of site access and because they would provide model constraint in the upper and lower modeled sections. All logger measurements were recorded in pounds per square inch of absolute pressure (psia) making the measurement of barometric pressure necessary in order to account for changes in barometric pressure with time. A third logger was deployed on the system to collect barometric pressure. Raw measurements from the two loggers are shown in Figure 13 and Figure 14. Barometric pressure was used to correct the water level records to produce a relative pressure records (Figure 15). Using the unit weight of water and unit conversions, the relative pressure records were converted to relative stage records. In order to convert from a pressure to a river stage, the following steps were employed.

1. The relative pressure head in the cross section was calculated as:

$$p_{relative\ channel} = p_{channel} - p_{barometric} \qquad (1)$$

   Where $p_{relative\ channel}$ = the relative pressure in the channel due to stage, psi
   $p_{channel}$ = the recorded pressure in the channel logger, psi
   $p_{barometric}$ = the recorded pressure in the barometric logger, psi

2. The pressure head was converted to the height of the water above the logger (in feet), according to:

$$h_{water} = p_{relative\ channel} * \frac{144in^2}{ft^2} * \frac{ft^3}{62.4\ pounds} \qquad (2)$$

3. Water surface elevations at the Platt Residence and Sweetwater Road Bridge were surveyed by DeGrove Surveyors on August 2, 2018. The surveyed water surface elevations of 50.94-feet above NAVD88 at the Platt Residence, and 41.23-feet above NAVD88 at Sweetwater Road on August 2, 2018 were used to adjust the water height time series by comparison the recorded water depth by the logger on that day at each location, resulting in a final water surface elevation time series for the Platt Residence and Sweetwater Road Bridge. Each height time series was converted to a NAVD88 stage time series by applying a datum shift based on the calculated logger elevation for each location.

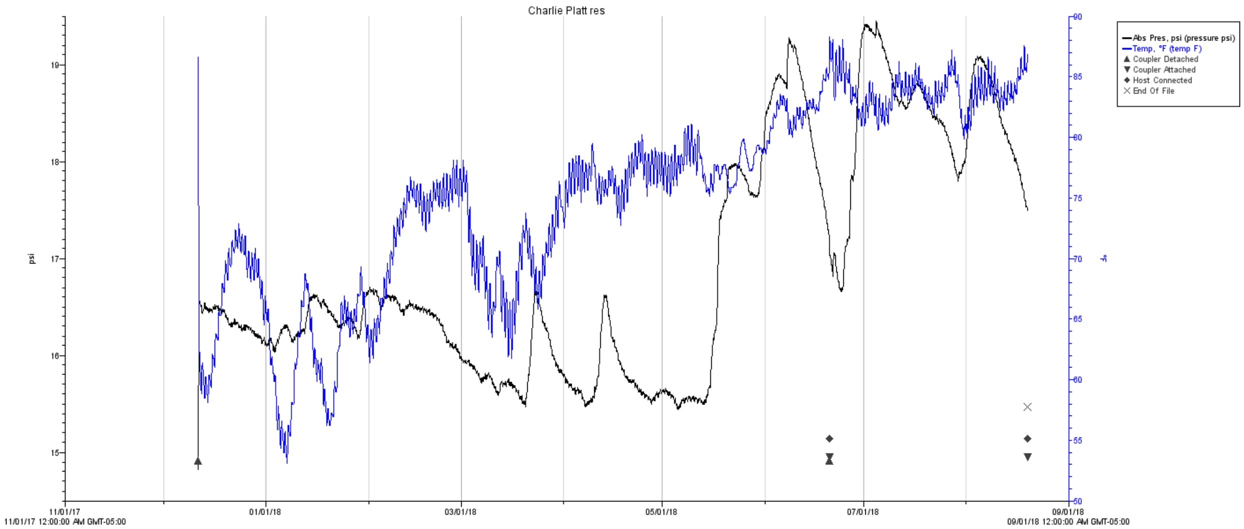

Figure 13. Water Level (psi) and Temperature (ºF) at the Platt Residence

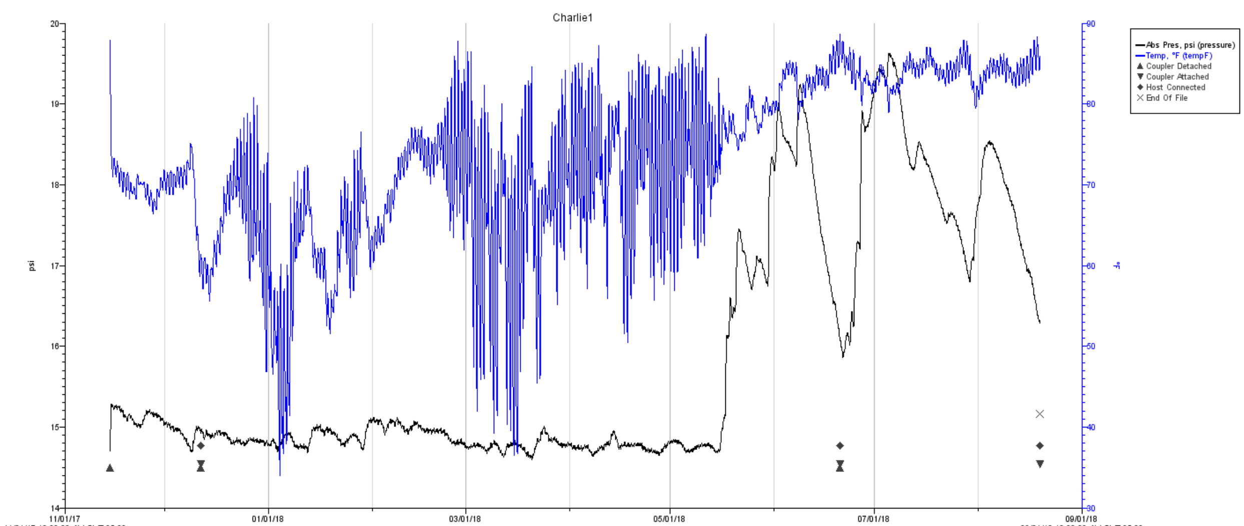

Figure 14. Water Level (psi) and Temperature (ºF) at Sweetwater Bridge

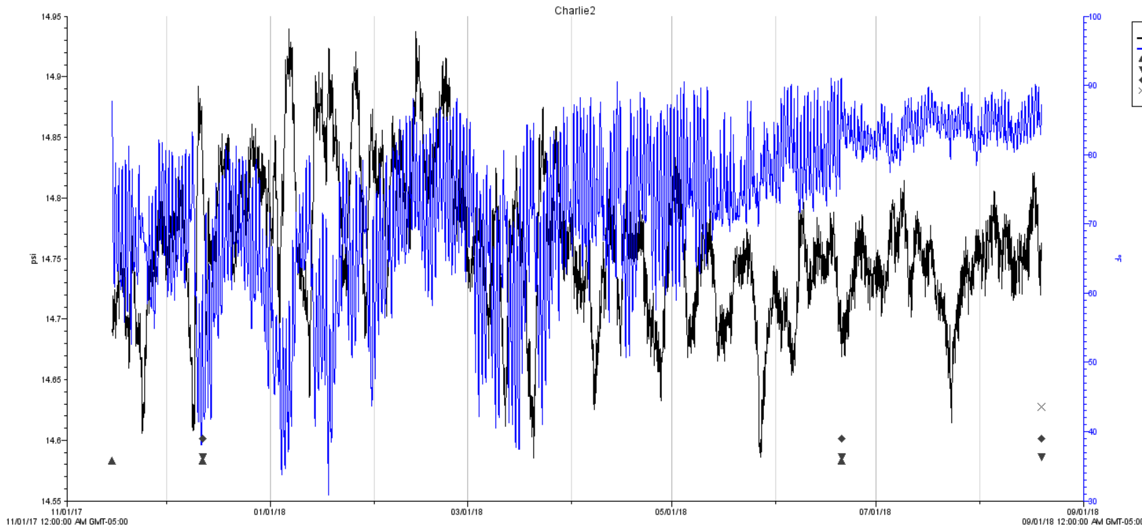

Figure 15. Barometric Pressure (psi) and Temperature (ºF)

Water surface elevations at the stage data collection locations are compared to the upstream and downstream model boundary stages in Table 22 and Figure 16. The results were examined in conjunction with the USGS stage measurements at Crewsville and Gardner, with good agreement in the shape of the stage records (Figure 16). Data collection extended from December 11, 2017 through August 19, 2018. As shown, the Platt Residence experience a stage range of almost 10-feet during the data collection period and the stage range at Sweetwater Road was over 14-feet.

Table 22. Stage Measurements, August 2, 2018

Location	Water Surface Elevation, feet above NAVD88
USGS Charlie Creek near Crewsville	52.67
Platt Residence	50.94
Sweetwater Road Bridge	41.23
USGS Charlie Creek near Gardner	32.70

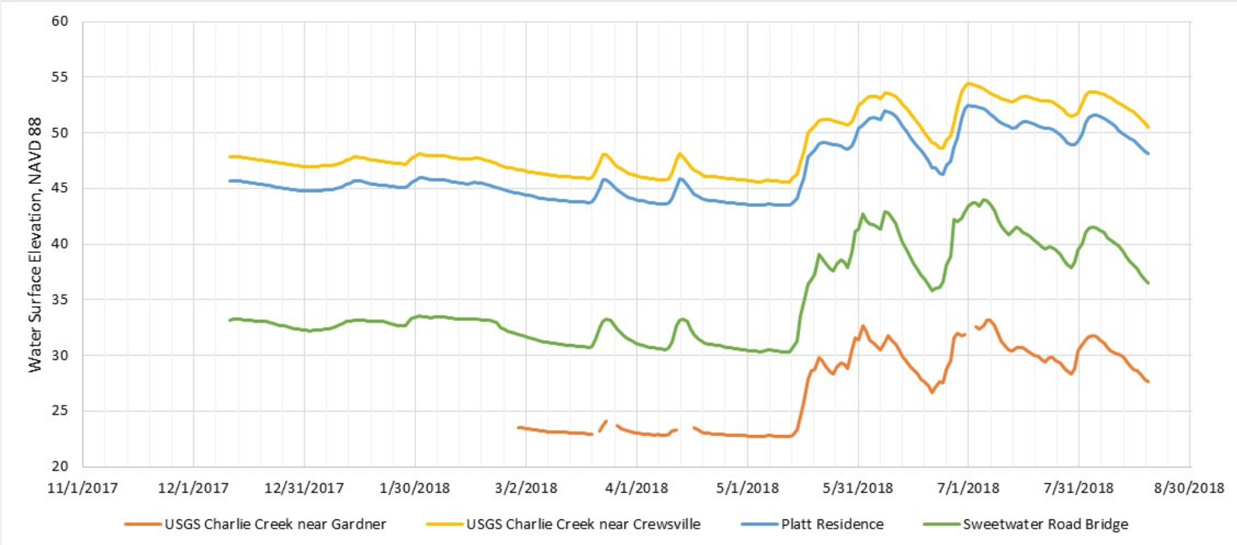

Figure 16. Stage Comparison, USGS Gages, Platt Residence, and Sweetwater Road Bridge

Calibration

Several flow profiles were developed for model calibration. Using multiple flow profiles for calibration was important in order to ensure that the model accurately simulated a range of flow regimes. Profiles were developed using the additional stage data collected from December 11, 2017 through August 19, 2018, as well as the stages and flows measured by the USGS at the Charlie Creek near Crewsville gauge and the Charlie Creek near Gardner gauge. Flow profiles represented average conditions for several days of a given flow at the downstream boundary to minimize the amount of hysteresis present in the observed data (Table 23).

Table 23. Calibration Profiles: Observed Flows and Stages

	Flows, cfs		*Stage, feet NAVD88*			
Profile Name	**USGS Gardner**	**USGS Crewsville**	**Crewsville**	**Platt Residence**	**Sweetwater Road**	**Gardner**
PF1	34.52	24.68	47.02	44.86	32.37	23.55
PF2	64.36	50.04	47.90	45.73	33.49	24.54
PF3	246.00	88.03	48.79	46.54	35.53	26.55
PF4	377.20	128.74	49.53	47.36	36.65	27.74
PF5	750.40	503.40	52.79	50.42	40.52	30.45
PF6	1218.00	686.60	53.44	51.25	42.57	32.05

Flow profiles were developed for each profile based on pickup factors determined from field flow measurements and summarized in previous technical memorandums. Flow profiles for each profile are shown in Table 24 for reference purposes. As shown, the model calibration flows range from 34.52 cubic feet per second (cfs) to 1218 cfs at the downstream model boundary. Note that flow change locations do not correspond to the locations of vegetative transects but rather are based on the additional data collection locations. This ensures that the model represents actual flow conditions as accurately as possible. In general, flows at River Station 86227.02 correspond to the flows at the USGS Charlie Creek near Crewsville gauge. In some cases (PF1 and PF5) slight adjustments were made to the flow at River Station 86227.02 to account for hysteresis, storage in the system, and potential flow measurement error. The adjusted flow better represents the average flow at the upstream boundary for a given average downstream flow and results in a smooth flow transition from upstream to downstream.

Table 24. Calibration Flow Profiles. All flows in cfs

River Station	Way Point	PF1	PF2	PF3	PF4	PF5	PF6
86227.02	14	22.58	50.04	88.03	128.74	567.72	686.60
74495.30	13	22.75	50.42	88.71	129.72	572.06	802.66
62280.21	N/A	23.25	51.54	91.37	132.60	584.75	826.74
48607.62	N/A	23.45	51.98	94.92	133.74	589.76	858.85
45497.82	15	23.50	52.00	187.74	287.87	690.37	1120.56
33205.22	16	23.50	52.00	195.00	302.00	742.00	1205.00
23459.81	17	34.38	64.10	245.02	375.69	747.40	1213.13
0.00	18	34.52	64.36	246.00	377.20	750.40	1218.00

The flow profiles shown in Table 24 were incorporated into the updated model, which includes all new and extended cross sections. The initial simulation results of the revised model showed that the model performance was slightly exceeding the 6-inch error tolerance desired for the calibrated model, making further calibration necessary. Refinement of the model calibration was performed by calibrating a composite Manning's n value (Newbury, 2008). A composite Manning's n value is helpful when Manning's equation is applied to a channel where numerous approximations are made in order to simplify modeling flow. In the case of Charlie Creek, significant factors not accounted for in the HEC-RAS model include the high degree of tortuosity of the creek and the significant number of wire fences that span across the creek in numerous locations. These fences, although only strands of wire, cause significant debris to build up and result in obstruction of flow. Therefore, the composite n approach was implemented according to the following equation (Newbury, 2008):

$$n = m(n_b + n_1 + n_2 + n_3 + n_4) \tag{2}$$

Where n = composite n

m = tortuosity factor (ranges from 1.15 for mild meandering to 1.3 for fully meandering)

n_b = base Manning's n value; based on Chow (1959)

n_1 = addition for bed irregularities (0.001 for channels with mildly slumping banks to 0.02 for channels with irregular bedrock

n_2 = addition for changes in channel cross section (0.015 for tortuous channels)

n_3 = addition for obstructions (from 0.005 to 0.05 for channels that are 50% obstructed)

n_4 = addition for vegetation (from 0.002 for low grasses to 0.1 for channels with small trees)

Prior to applying Equation (2), the sinuosity index of the modeled section of Charlie Creek was calculated in order to determine whether or not Charlie Creek was classified as a fully meandering stream. The sinuosity index was calculated as the total length of the creek along the river centerline divided by the Euclidean distance between the upstream and downstream model boundaries. The sinuosity index was therefore calculated as:

$$SI = \frac{curvilinear\ length}{Euclidean\ distance} = \frac{86227\ feet}{49050\ feet} = 1.76$$

The calculated sinuosity index of 1.76 classifies Charlie Creek as fully meandering. This was incorporated into the composite Manning's n values for the model calibration. The model was calibrated by adjusting the composite n values in the main channel and the left and right overbanks. The resulting calibrated stages for the USGS Charlie Creek near Crewsville gauge, the Platt Residence, and Sweetwater Bridge are shown in Table 27. The model was calibrated by adjusting composite Manning's n values for each cross section, with care not to perform point calibration at individual cross sections. A summary of final calibrated Manning's n values is shown in Table 25 for the channel and Table 26 for the floodplain.

Table 25. Charlie Creek Reach; Channel Manning's n Components

River Station From	River Station to	n	n_1	n_2	n_3	n_4	m	Composite Channel n
86227.02	58713.94	0.029	0.001	0.01	0.005	0.001	1.3	0.06
58713.94	0	0.017	0.001	0.005	0.001	0.001	1.3	0.033

Table 26. Charlie Creek Reach; Floodplain Manning's n Components

River Station From	River Station to	n	n_1	n_2	n_3	n_4	m	Composite Floodplain n
86227.02	33279.96	0.081	0.02	0.015	0.05	0.1	1.3	0.35
33279.96	0	0.090	0.02	0.015	0.06	0.1	1.4	0.40

Model performance at the calibration locations in shown in Table 27. Because the Crewsville gauge is located downstream of the bridge, the stage comparison for Crewsville is made at RS 85879. The stage comparison for the Platt residence is made at RS 74495.3. For Sweetwater Road Bridge, the simulated model stage is taken as the average of the 4 bridge cross section stages for a given flow profile. As shown, all model residuals (defined as the simulated stage minus the observed stage) are 0.5-feet or less. The model shows good performance over all flow regimes.

Table 27. Model Calibration Results. All stages in feet NAVD88

Profile Name	Crewsville			Platt Residence			Sweetwater Road Bridge		
	Observed	Simulated	Residual	Observed	Simulated	Residual	Observed	Simulated	Residual
PF1	47.02	47.52	0.50	44.86	44.55	-0.31	32.37	32.72	0.35
PF2	47.90	48.10	0.20	45.73	45.43	-0.30	33.49	33.38	-0.11
PF3	48.79	48.64	-0.15	46.54	46.27	-0.27	35.53	35.86	0.34
PF4	49.53	49.13	-0.40	47.36	46.96	-0.40	36.65	36.80	0.14
PF5	52.79	52.51	-0.28	50.42	50.70	0.28	40.52	40.03	-0.49
PF6	53.44	53.12	-0.32	51.25	51.59	0.34	42.57	42.11	-0.45
Avg.	**49.91**	**49.84**	**-0.08**	**47.69**	**47.58**	**-0.11**	**36.85**	**36.82**	**-0.04**

Validation

In order to verify the model calibration and performance, the validation data set from previous modeling efforts for Charlie Creek was used for model simulation (INTERA, 2016). This was advantageous because it provided a data set that was unseen by the re-calibrated model and observed data was located at transect 2.5 (T2.5). Since current modeling efforts did not utilize observed stage data at T2.5, this provided a validation at a location along the creek that was not used for the current model calibration. Validation flow profiles were developed using the USGS gauges as the upstream and downstream flows. Flow change locations were developed using the improved pickup factors and pickup locations derived from recent flow data collection. Flow profiles are shown in Table 28 for reference purposes.

Table 28. Validation Flow Profiles. All flows in cfs

RS	Way Point	PF1	PF2	PF3	PF4	PF5	PF6	PF7	PF8
86227.02	14	32.00	58.00	61.00	136.00	201.00	279.00	431.00	712.00
74495.30	13	47.20	62.90	79.90	128.40	198.50	314.40	497.10	720.50
62280.21	N/A	48.60	64.80	82.30	132.20	204.40	323.80	512.10	742.10
48607.62	N/A	50.50	67.30	85.50	137.40	212.40	336.40	531.90	770.90
45497.82	15	67.00	89.30	113.50	182.30	281.80	446.40	705.90	1023.00
33205.22	16	69.10	92.20	117.10	188.20	290.90	460.80	728.60	1056.00
23459.81	17	71.70	95.70	121.60	195.30	301.90	478.30	756.30	1096.10
0.00	18	72.00	96.00	122.00	196.00	303.00	480.00	759.00	1100.00

Results of the model validation are shown in Table 29. The maximum residual at the upstream boundary (the Crewsville gauge) was 0.52-feet. This represents an improvement from the previous model validation, which showed a residual of 0.62-feet at the Crewsville gauge for the PF1 validation profile. Similarly, the error range at T2.5 improved slightly from a range of -0.51 to 0.35 in the original model validation to -0.42 to 0.38 in the current validation.

Table 29. Model Validation Results. All stages in feet NAVD88

Profile Name	Crewsville			Transect T2.5		
	Observed	Simulated	Residual	Observed	Simulated	Residual
PF1	47.22	47.74	0.52	38.45	38.83	0.38
PF2	47.83	48.23	0.40	39.01	39.13	0.12
PF3	48.09	48.28	0.19	39.10	39.44	0.34
PF4	49.41	49.20	-0.21	40.38	40.22	-0.16
PF5	50.30	49.93	-0.37	41.52	41.17	-0.35
PF6	51.26	50.80	-0.46	42.89	42.47	-0.42
PF7	52.25	51.94	-0.31	44.29	44.01	-0.28
PF8	53.58	53.08	-0.50	45.43	45.55	0.12
Average	49.99	49.90	-0.09	41.38	41.35	-0.03

Predictive Simulations

Updated flow and stage data were obtained from the U.S. Geological Survey (USGS) for the Charlie Creek near Gardner gage. The period of record for each dataset is as follows: Gardner flow 5/1/1950 through 8/26/2018; Gardner stage 10/1/1973 through 8/26/2018; Crewsville flow 4/16/2004 through 8/26/2018. The period of record of the Charlie Creek near Gardner flow record was used to develop long-term percentiles for predictive simulations (Table 30). Several percentile flows at the Charlie Creek near Gardner gage did not have corresponding measurements for Charlie Creek near Crewsville flow and/or Charlie Creek near Gardner stage due to differences in the periods of record. When this was the case, gap-filling was employed to fill data gaps. A statistical model was employed in order to fill data gaps in the Charlie Creek near Crewsville flow when needed (Figure 17).

Table 30. USGS Charlie Creek near Gardner gage percentile flows and water surface elevation (Note: Shaded cells were gap-filled)

Percentile	Charlie Creek near Gardner flow, cfs	Charlie Creek near Crewsville flow, cfs	Charlie Creek near Gardner Elevation, NAVD88
0.05	3.20	0.10	21.55
0.10	5.50	1.20	22.38
0.20	11.00	2.37	22.57
0.30	19.10	3.13	22.89
0.40	34.30	10.60	23.35
0.50	60.70	49.90	23.78
0.60	108.00	54.04	24.66
0.70	196.00	100.92	25.61
0.80	364.00	190.41	26.93
0.90	748.00	394.97	29.60
0.95	1220.00	646.40	31.49
0.99	2460.00	855.00	35.16

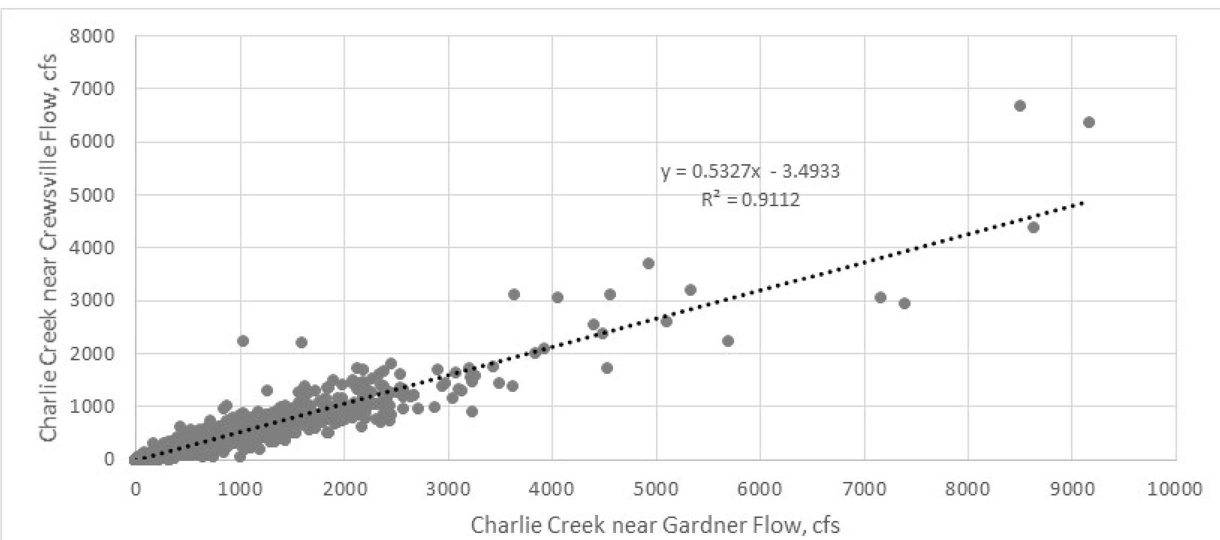

Figure 17. Statistical Model for Gap-Filling: Charlie Creek near Crewsville Flow

Due to hysteresis and attenuation, the Charlie Creek near Gardner stage can historically be different for the same flow when comparing 2 events. This would cause inconsistencies in the flow profiles and result in cases where a higher percentile flow could have a lower stage than a lower percentile flow. In these cases, the stage values were averaged for all identical observed flows at the Charlie Creek near Gardner gage since only a single stage value can be associated with one flow value in the model. Note that percentile simulations are not intended to represent actual historical events, but rather represent events that correspond to historical percentiles at the downstream boundary condition. Other boundary conditions may not necessarily correspond to field conditions on the historical day, but rather represent an average condition that the system experiences over the entire flow history.

After boundary conditions were calculated, flow profiles were calculated for the predictive simulations using the percentile flows at the downstream boundary (Table 30), and the pickup factors presented in Table 3 of INTERA (2018). Flow profiles as input into HEC-RAS are shown in Table 31. The resulting water surface elevations for each vegetative transect for each percentile flow are shown in Table 32.

Table 31. Flow Profiles for Predictive Simulations

River Station	PER5	PER10	PER20	PER30	PER40	PER50	PER60	PER70	PER80	PER90	PER95	PER99
86227.02	0.1	1.2	2.4	3.1	10.6	26.2	54.0	100.9	190.4	395.0	646.4	855.0
74495.3	2.1	3.6	7.2	12.5	22.5	39.8	70.7	128.4	238.4	489.9	799.1	1611.3
62280.21	2.2	3.7	7.4	12.9	23.1	41.0	72.9	132.2	245.6	504.6	823.1	1659.6
48607.62	2.2	3.9	7.7	13.4	24.0	42.5	75.7	137.4	255.1	524.2	855.0	1724.1
45497.82	3.0	5.1	10.2	17.8	31.9	56.5	100.4	182.3	338.5	695.6	1134.6	2287.8
33205.22	3.1	5.3	10.6	18.3	32.9	58.3	103.7	188.2	349.4	718.1	1171.2	2361.6
23459.81	3.2	5.5	11.0	19.0	34.2	60.5	107.6	195.3	362.7	745.3	1215.7	2451.2
0	3.2	5.5	11.0	19.1	34.3	60.7	108.0	196.0	364.0	748.0	1220.0	2460.0

Table 32. Percentile Stages at Vegetative Transects (feet above NAVD88)

Percentile	T1 RS 80774.52	T2 RS 58713.94	T2.5 RS 52028.14	T4.5 RS 28223.52	T5 RS 24348.24	T6 RS 15957.67	T7 RS 11090.54
PER5	44.95	38.05	37.05	29.65	28.3	26.03	24.98
PER10	45.29	38.3	37.21	29.85	28.52	26.09	25.21
PER20	45.43	38.74	37.55	30.18	28.92	26.48	25.6
PER30	45.5	39.13	37.86	30.54	29.3	26.87	26
PER40	46.01	39.6	38.23	31.02	29.81	27.42	26.54
PER50	46.7	40.19	38.67	31.62	30.43	28.1	27.23
PER60	47.4	40.93	39.27	32.33	31.18	29.02	28.12
PER70	48.31	41.98	40.22	33.32	32.22	30.35	29.26
PER80	49.65	43.41	41.65	34.71	33.66	31.89	30.82
PER90	51.52	45.58	43.97	37.22	36.13	34.51	33.5
PER95	52.75	47.27	45.91	39.07	37.99	36.53	35.59
PER99	53.94	49.23	48.14	42.24	41.13	39.72	38.99

Inundation Mapping

The results from the predictive simulations were used to generate inundation maps in HEC-RAS 4.1.0 with the RAS Mapper tool. The following steps were employed to develop inundation maps for each flow profile:

1. Twelve flow profiles were set up in HEC-RAS 4.1.0 to simulate steady flow for the 5th, 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th, 95th, and 99th percentile flows.
2. The RAS Mapper tool in HEC-RAS 4.1.0 was used to generate the floodplain maps. To use the tool, the river and cross section layers were selected from the model geometry data.
3. The 5 ft x 5 ft DEM was converted to a floating-point file (.flt) using the Raster to Float tool in ArcMap 10.1. The floating-point file was selected to generate terrain for the RAS Mapper.
4. In the RAS Mapper floodplain mapping dialog, the Water Surface Elevation variable was selected to generate the flood layers for all flow profiles. Other options were velocity, shear stress, and stream power.
5. The RAS Mapper tool automatically generates a depth grid and a floodplain polygon (floodmap.shp) for each flow profile. The area of each polygon was calculated in ArcMap 10.1. Inundation was defined as contact between the water surface elevation and the terrain. If a different inundation is desired (i.e. greater than 0.1-feet inundation), the depth grid can be filtered to determine a new floodplain inundation area.

The mapped results for the 80th through 99th percentile flows (when inundation was significant) appear in Figure 18 through Figure 21. The area of the inundation polygons for each percentile flow is provided in Table 33. The corresponding USGS Charlie Creek near Gardner flow and water surface elevations are also provided. Comparison of the inundation area at the transect level is shown in Figure 22 through Figure 28. For all cases, the inundation polygon did not exceed the cross-section length, thus verifying that the model cross sections were of adequate width. Several percentile flows show short circuiting of the main channel. This was also observed during field work at higher flows, and thus agrees with anecdotal information.

Table 33. USGS Charlie Creek near Gardner gage percentile flows, water surface elevation and HEC-RAS predictive simulation area of inundation

Percentile	Flow, cfs	Water Surface Elevation, feet above NAVD88	Inundation Area, acres
5	3.2	21.6	1.0
10	5.5	22.4	1.9
20	11.0	22.6	3.0
30	19.1	22.9	3.4
40	34.3	23.4	6.5
50	60.7	23.8	14.7
60	108.0	24.7	47.6
70	196.0	25.6	109.0
80	364.0	26.9	167.0
90	748.0	29.6	392.0
95	1220.0	31.5	979.0
99	2460.0	35.16	2018

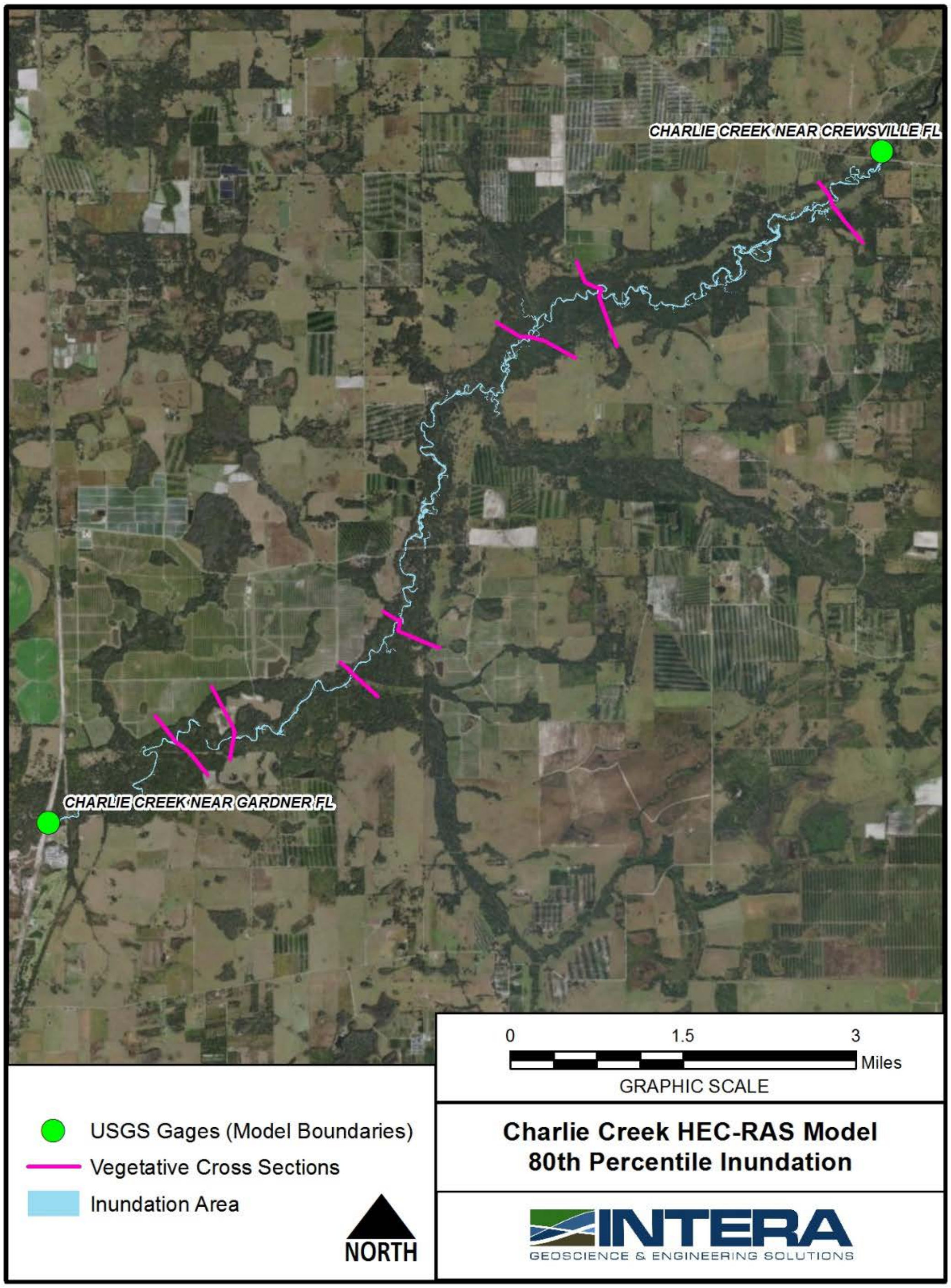

Figure 18. Inundation area for 80th percentile flow

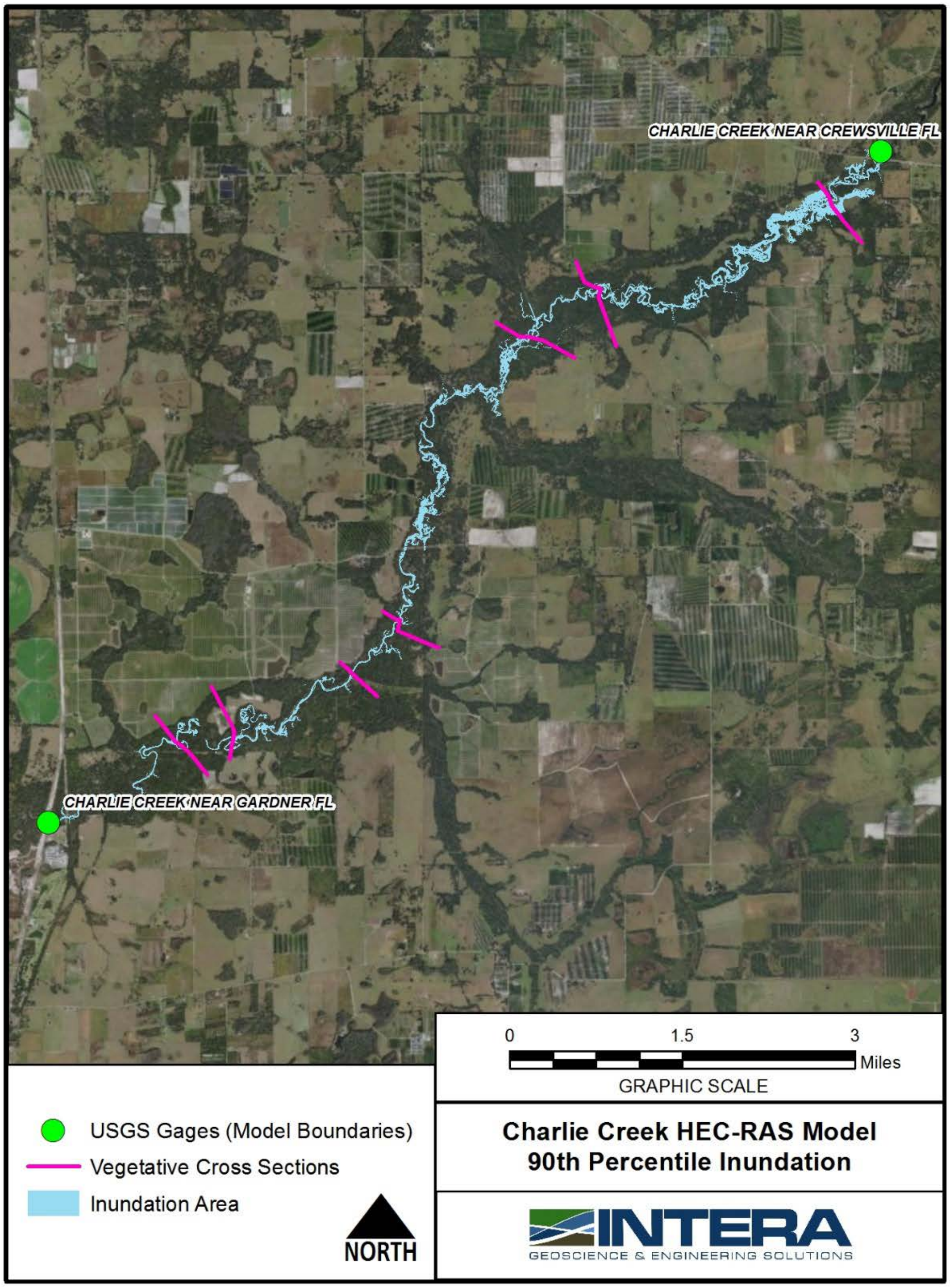

Figure 19. Inundation area for 90th percentile flow

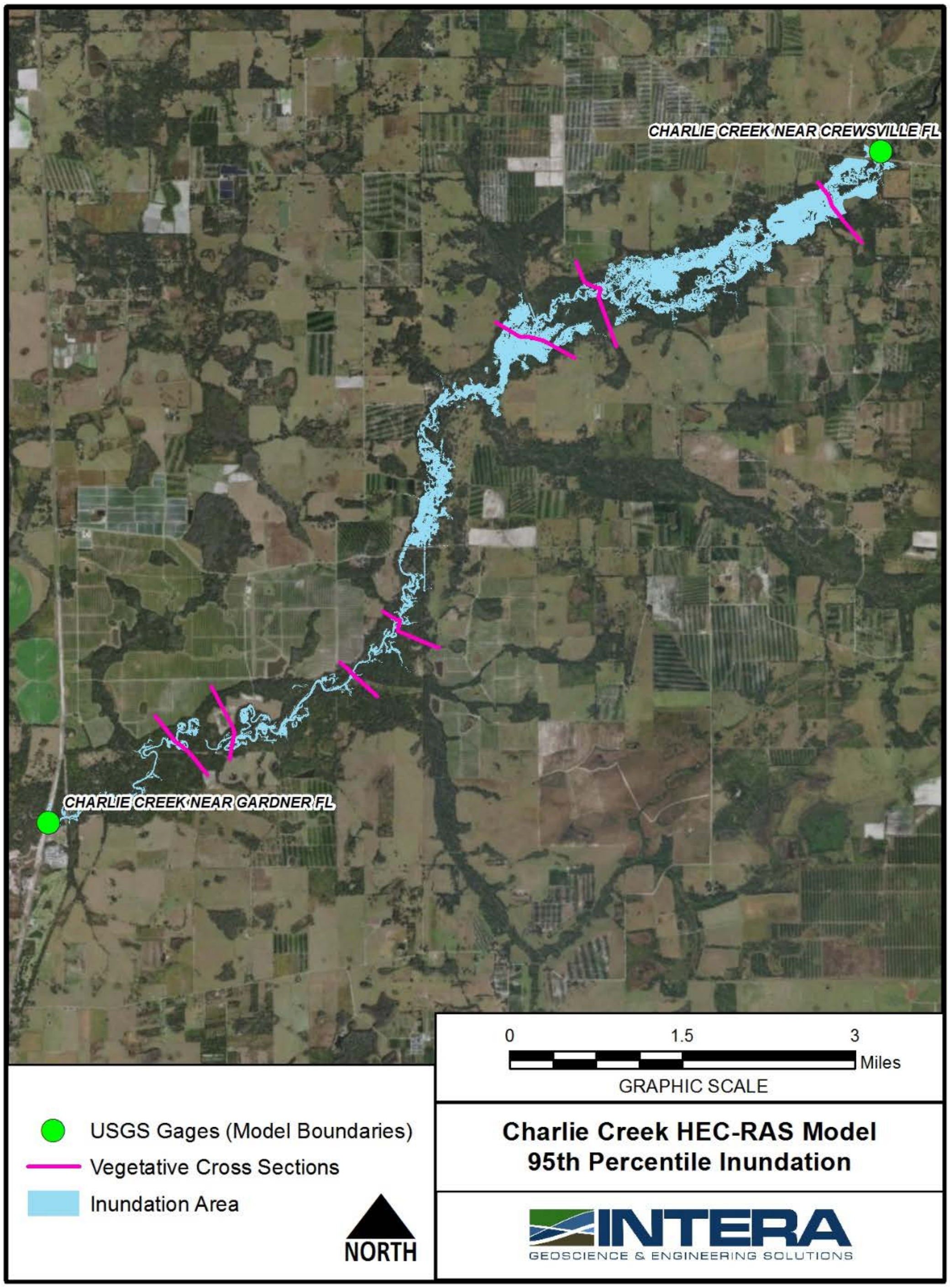

Figure 20. Inundation area for 95th percentile flow

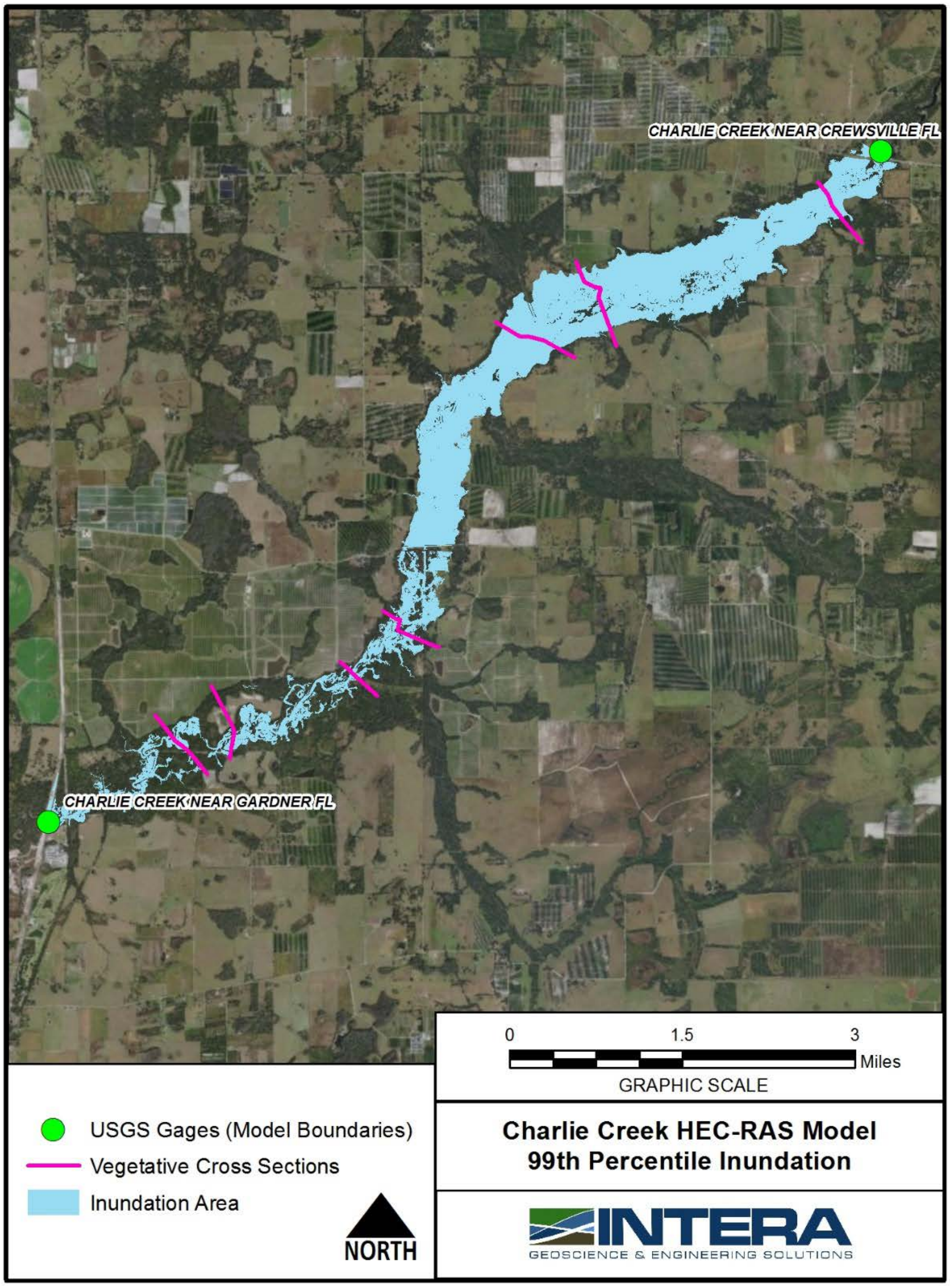

Figure 21. Inundation area for 99th percentile flow

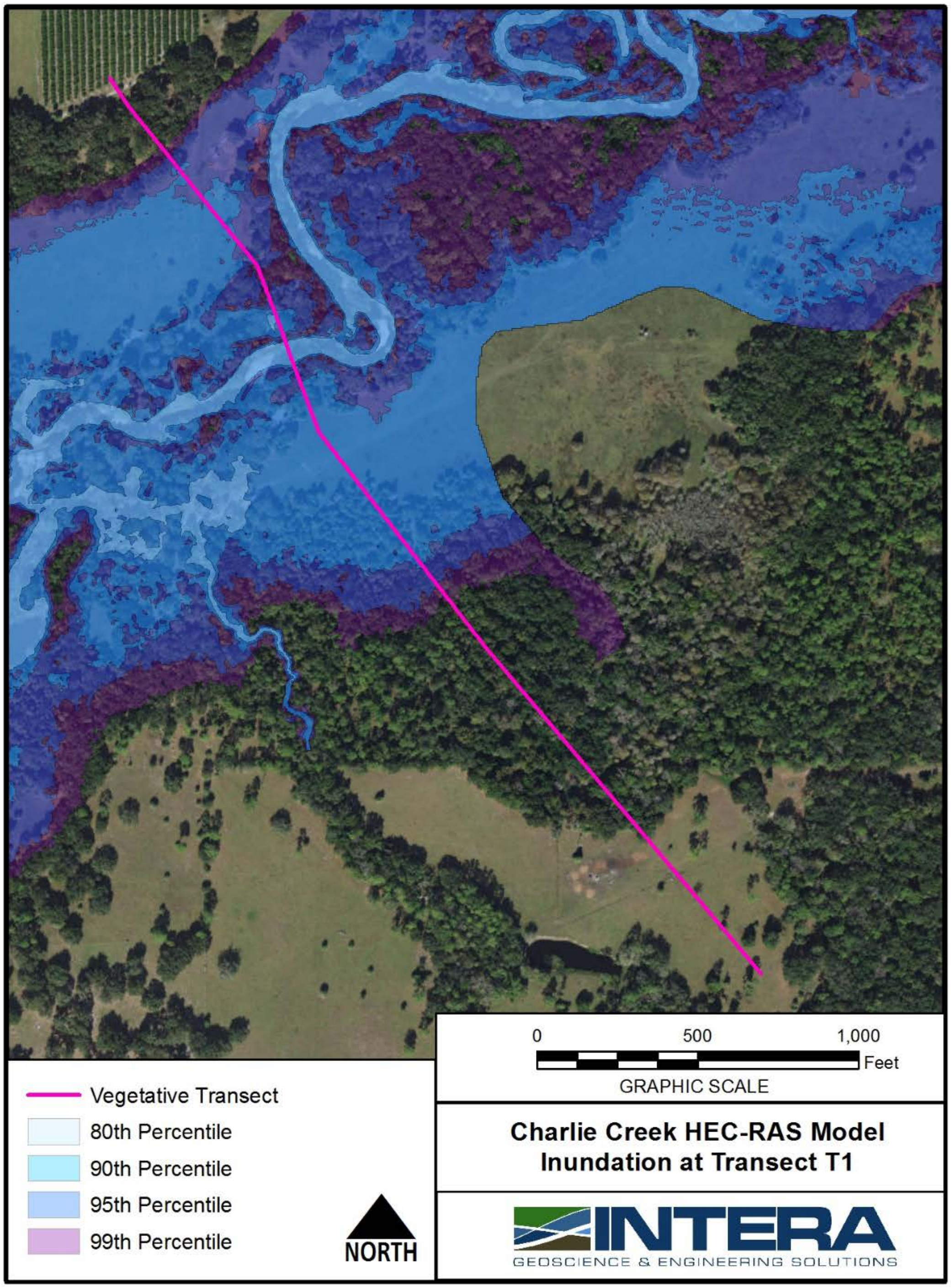

Figure 22. Inundation Comparison: T1

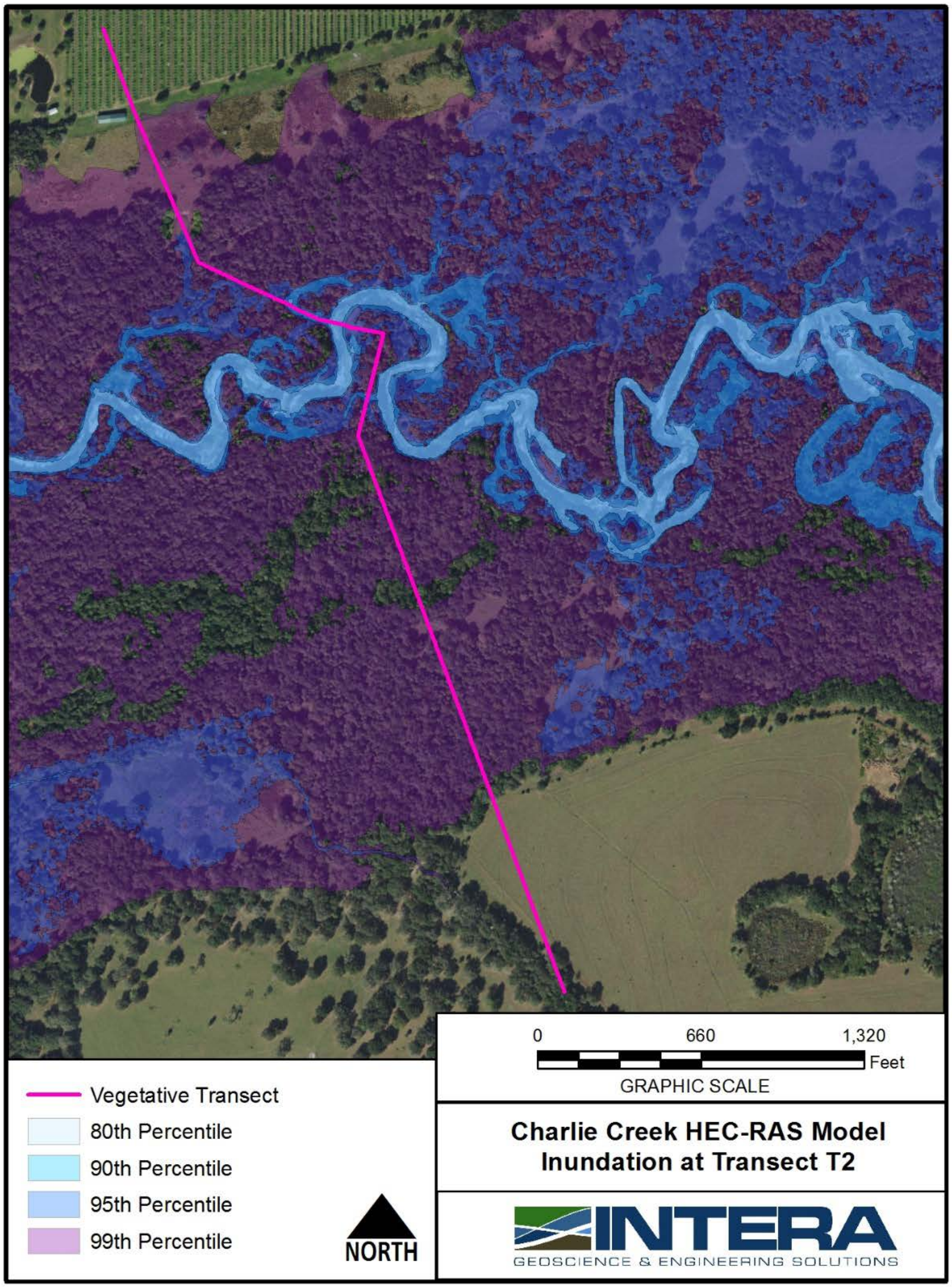

Figure 23. Inundation Comparison: T2

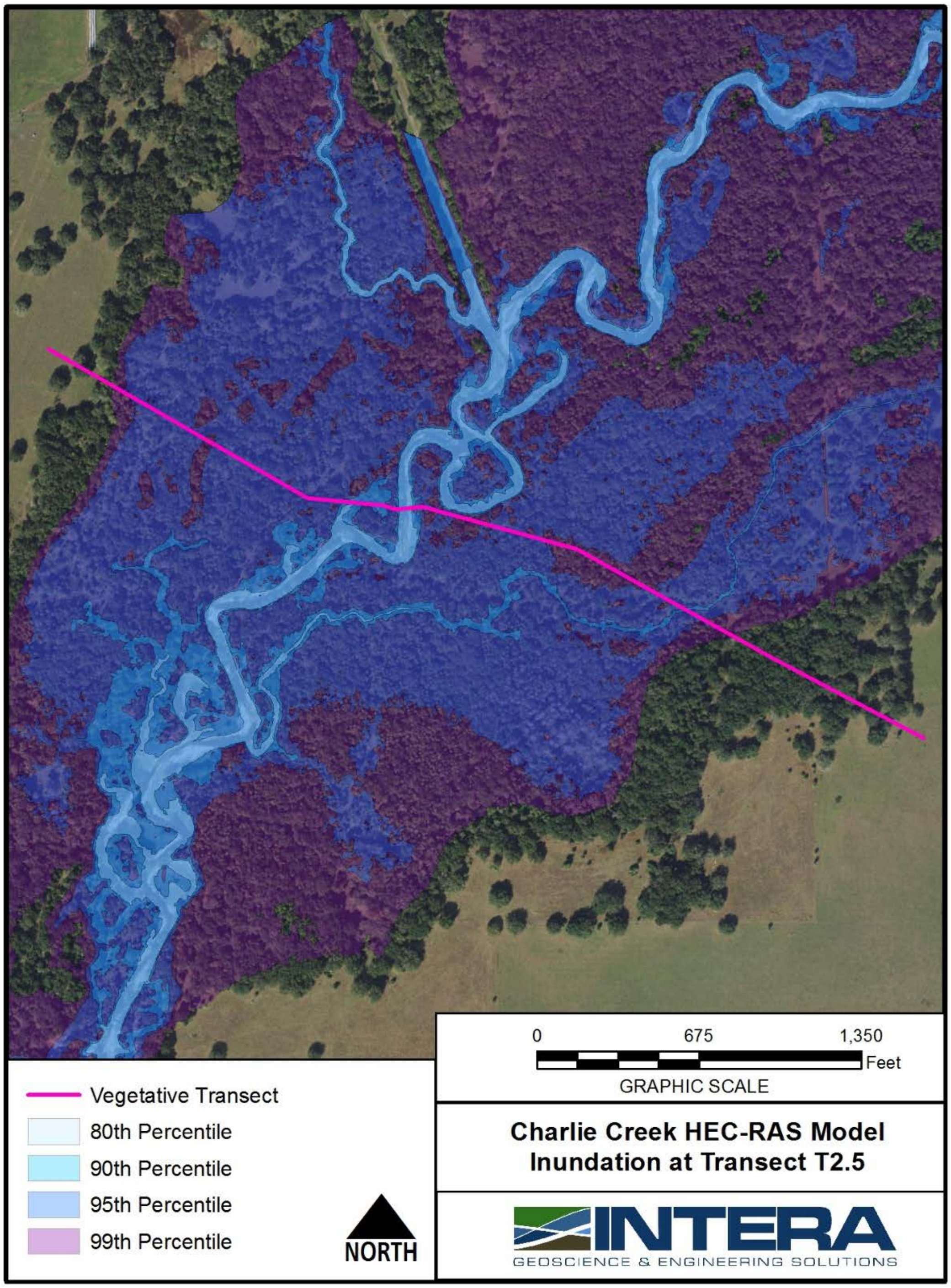

Figure 24. Inundation Comparison: T2.5

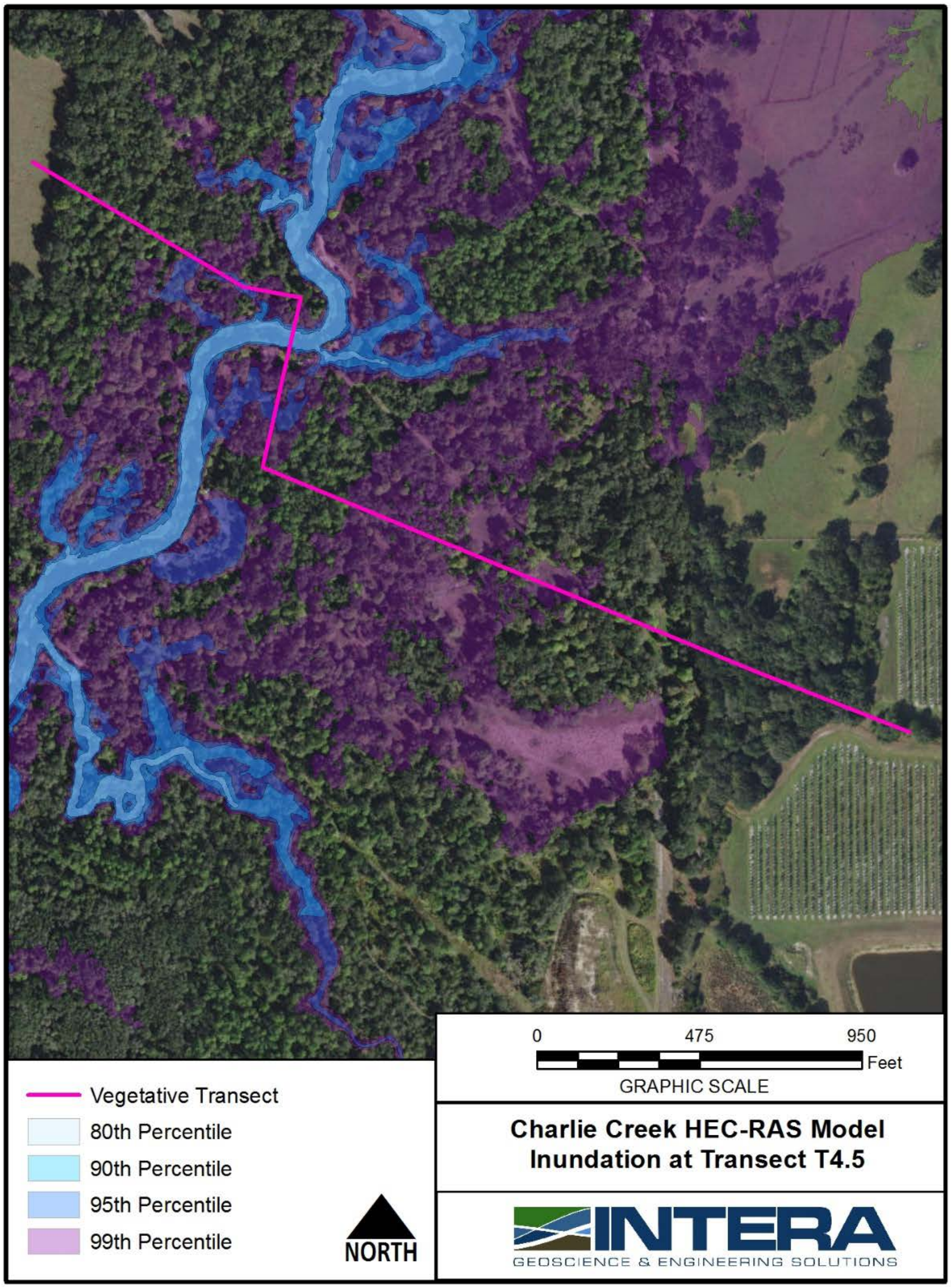

Figure 25. Inundation Comparison: T4.5

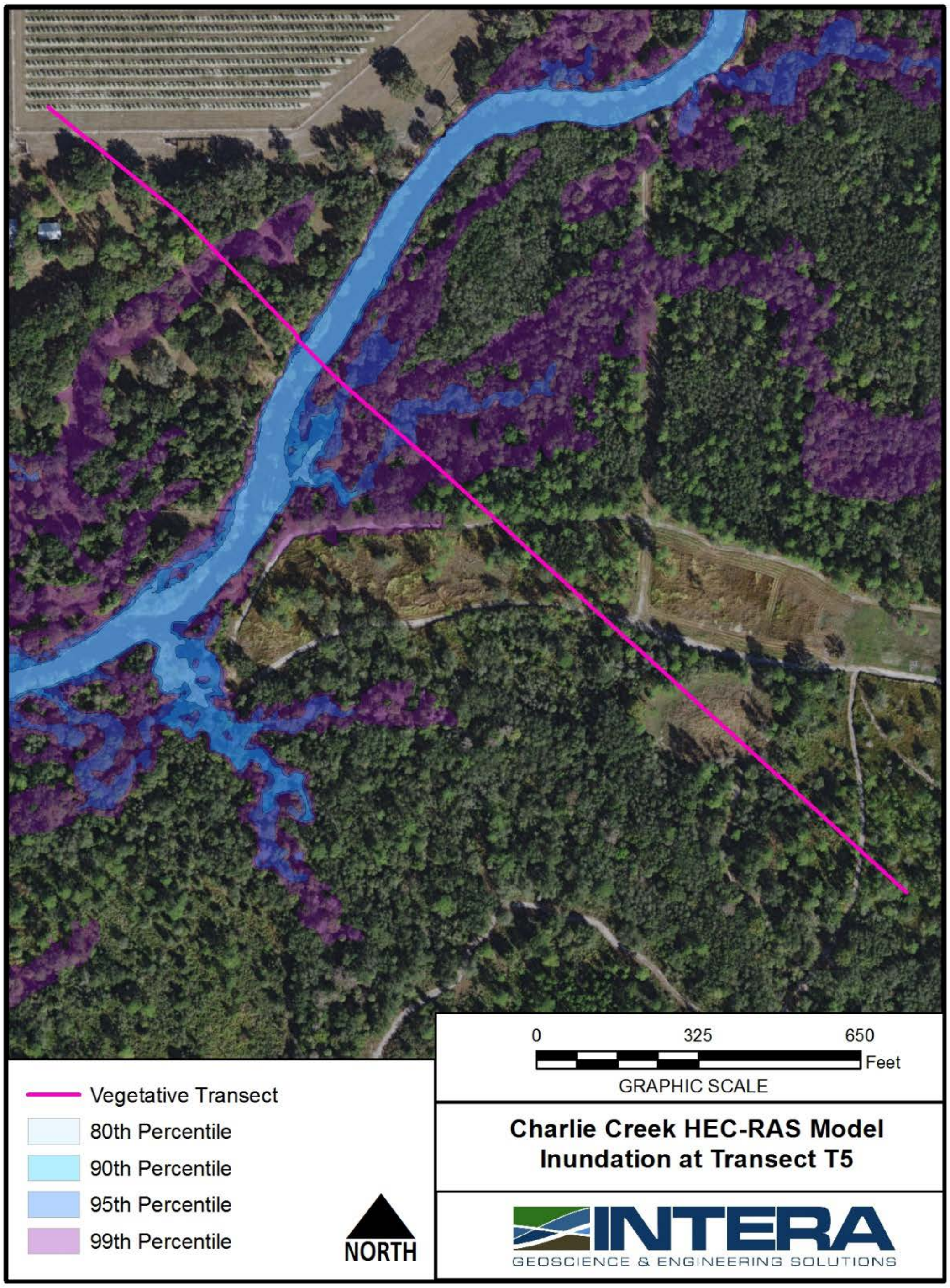

Figure 26. Inundation Comparison: T5

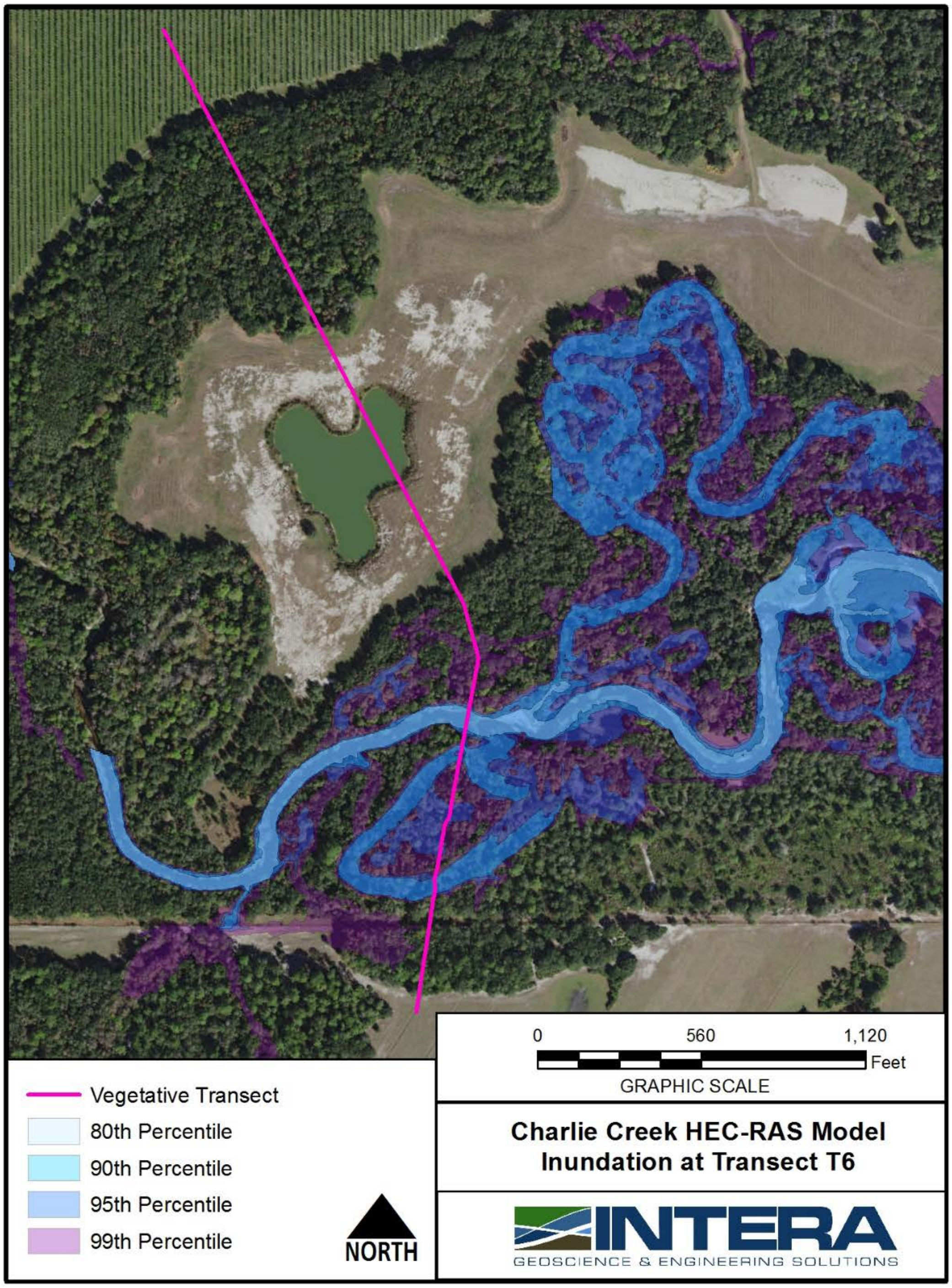

Figure 27. Inundation Comparison: T6

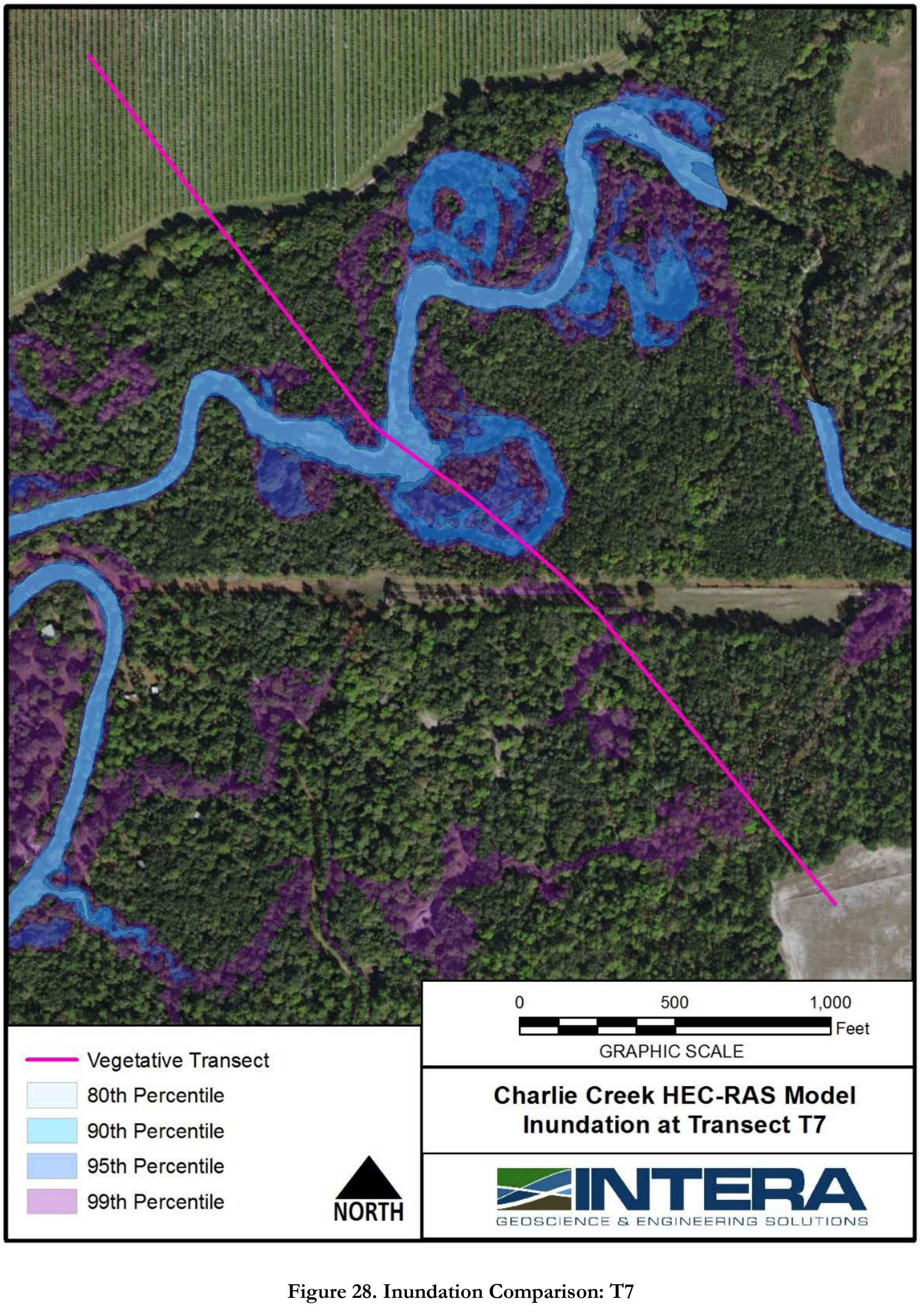

Figure 28. Inundation Comparison: T7

Conclusions

The HEC-RAS model representing Charlie Creek was enhanced with additional model cross sections that more accurately define the spatial extent of floodplain wetlands. The model was re-calibrated with data obtained from the additional stage and flow data collected. The resulting model outperforms the original model during both the calibration and verification simulations and meets the District's desired 6-inch calibration residual tolerance. Floodplain inundation mapping was performed in order to determine the extent of wetland inundation for the various ranked percentile flows. The results of this hydraulic modeling effort will be used by the District to define impacts on select Water Resource Values to define the MFL. The additional effort documented in this report can be applied by the District to evaluate the effects of consumptive use on the inundated riparian wetland areas.

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