TWA# 17TW0000471

Horse Creek
HEC-RAS Modeling and
Inundation Mapping

Final Report

Submitted to:

The Southwest Florida Water Management District

Submitted by:

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

October 30, 2018

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Introduction

Horse Creek is one of the six major tributaries to Peace River and is the longest tributary in river miles. The headwaters of the creek originate in the "Four Corners" where the counties of Hillsborough, Manatee, Polk and Hardee meet and flow southeast toward the confluence with the Peace River south of Zolfo Springs. The Horse Creek drainage area covers approximately 218 square miles which includes portions of Hardee, DeSoto, Polk Counties. The major land use is dominated by phosphate mining, range land and agricultural which shape the watershed. The watershed is relatively flat in surrounding terrain with very little elevational changes. The stream channel is relatively well defined and is comprised of mostly sand and woody debris. The banks are generally lower in elevation as compared to other tributaries of the Peace River. The majority of the land within or adjacent to Horse Creek is owned by Mosaic Company but leased out to local famers for agricultural and will be future mining sites for phosphate in the next decade.

A HEC-RAS model of Horse 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 Horse 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 Horse Creek, and the model was calibrated within the District's desired residual range 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). Horse Creek Flows in a south, southeasterly direction to its confluence with Peace River (Figure 1). A HEC-RAS model was constructed for approximately 30 miles of the creek for the study reach from State Road 64 to State Road 72 for use in the development of minimum flows and levels (MFLs). The model of the study reach was constructed using the best available data provided by the District, 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). This section describes the data collection and review and model development. Two flow gages maintained by the United States Geological Survey (USGS) were used as the upstream and downstream boundaries of the model. The USGS Horse Creek near Myakka gage (USGS 02297155) served as the upstream model boundary, while the USGS Horse Creek near Arcadia gage served as the downstream model boundary (USGS 02297310).

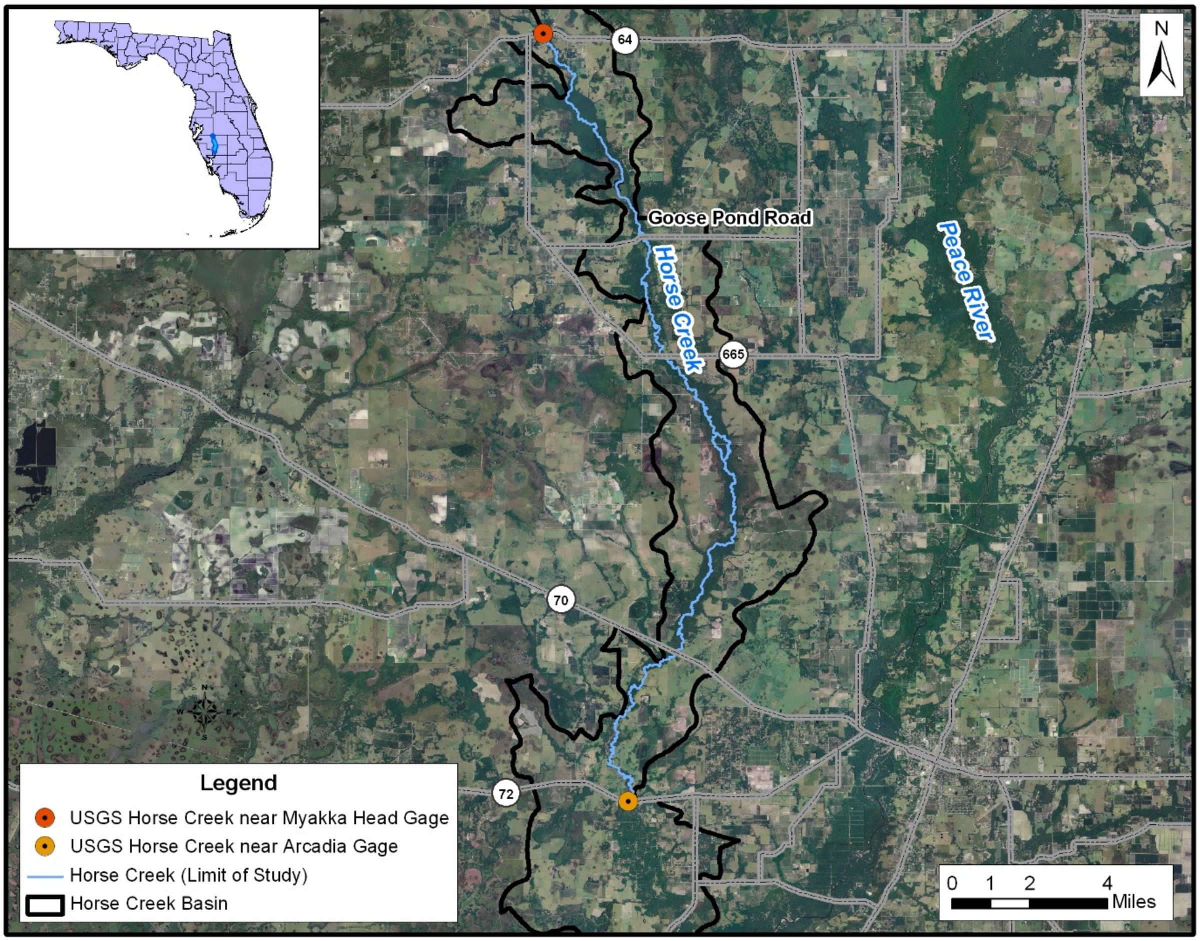

Figure 1. Location Map

Data for the initial model development was provided by the District. The District data included LiDAR (DEM) data, surveyed cross section and bridge elevations, and measured flows and stages. Additional flow data and stage data were obtained from the USGS Horse Creek near Myakka Head gage (02297155) and the USGS Horse Creek near Arcadia gage (02297310) and are considered the boundary conditions for this project.

A field survey was conducted by the District professional land surveyors to record transects at thirteen locations (Figure 2; Table 1). 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 two-thirds of a mile upstream of Goose Pond Bridge and progressed downstream to Northwest Pine Level Bridge. Two sets of data points were provided by the District for transects T2, T3, T4, and T6, while one set was provided for T1 and T5. For T2, T3, T4, and T6. 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. As an example, Figure 3 shows the data points collected for T4 at transects Horse Creek - Instream Transect 4 and Horse Creek - Transect 4 11-266. The points in these two transects were surveyed June 28, 2011 and August 9, 2011, respectively. Access to T4 and Brownville Road Bridge was limited to a short duration (July-August of 2011) as designated by the land owner, therefore the District staff and surveyors were only onsite for a single visit to obtain elevations. A summary of the survey data from upstream to downstream is provided in Table 1. The field survey data points were used to construct model cross sections, as described later in the model development section.

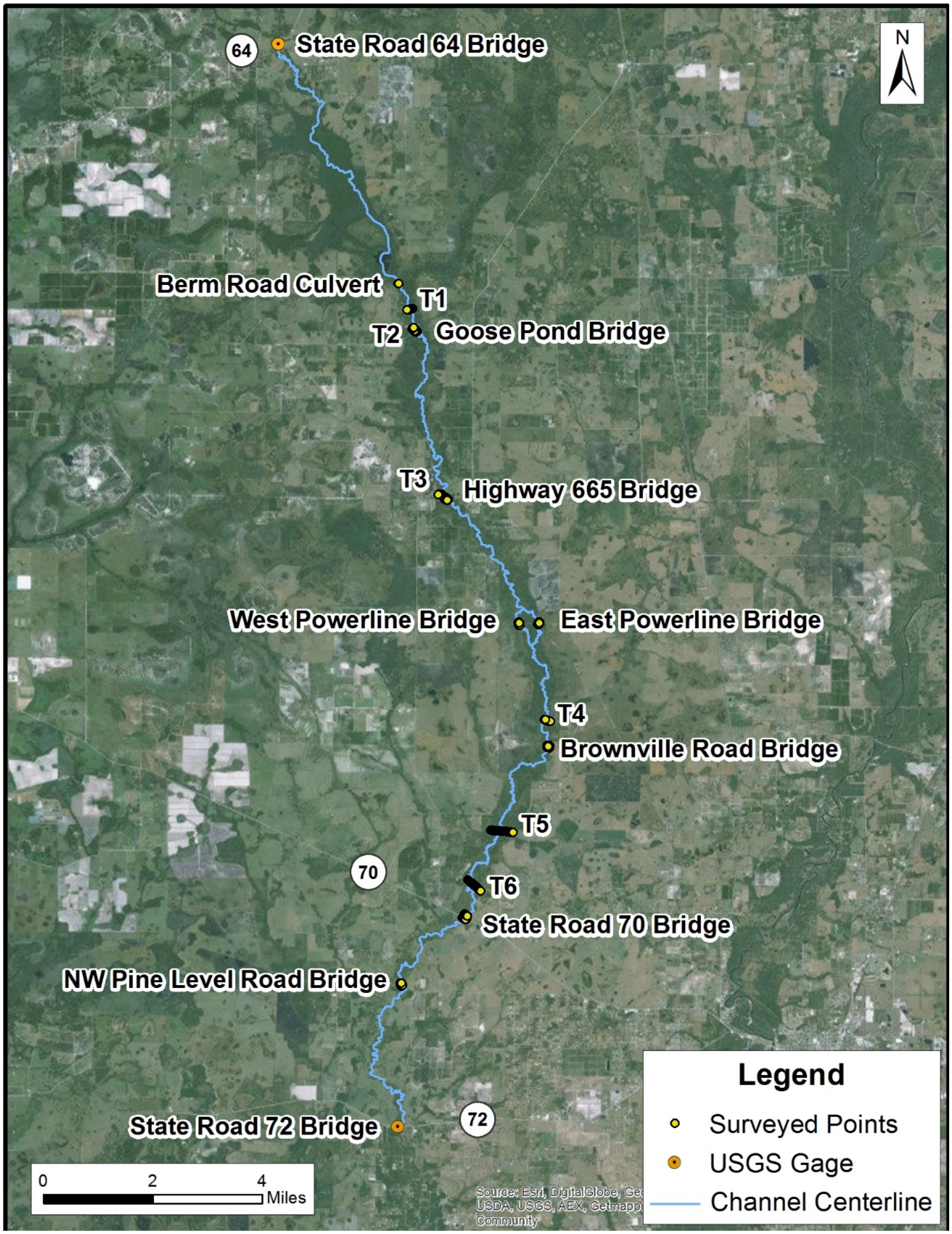

Figure 2. Horse Creek Field Survey

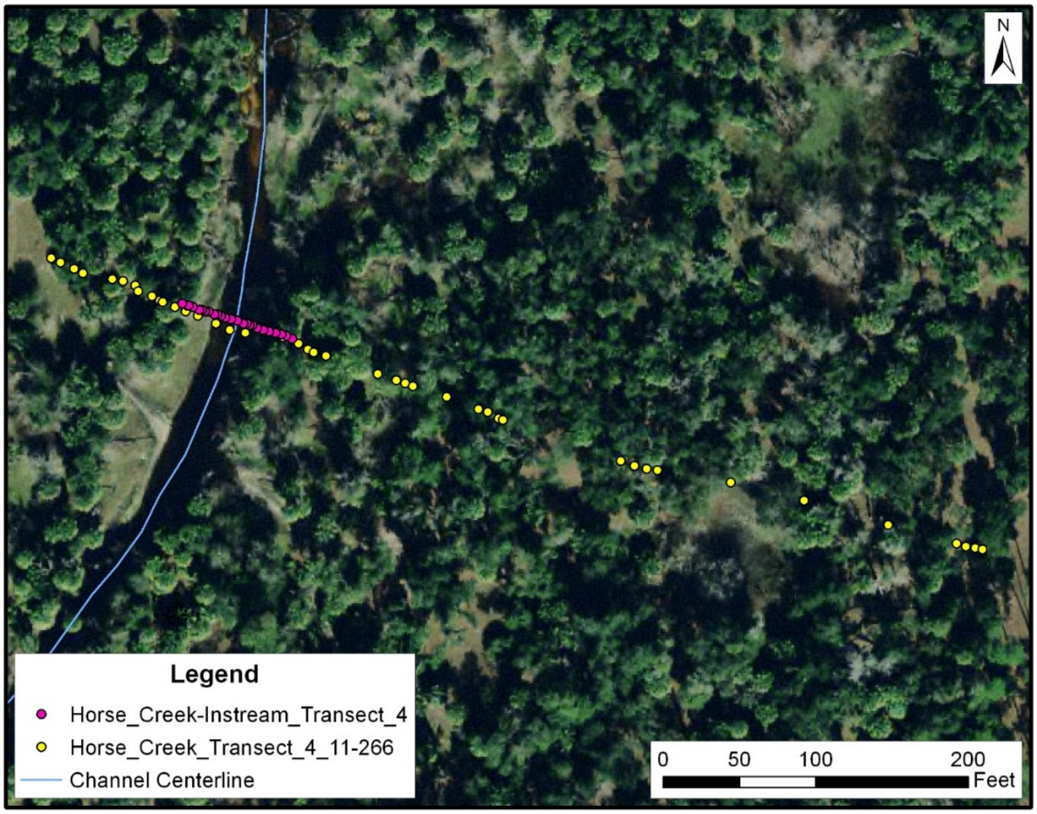

Figure 3. Surveyed Data Points for Transect #4 (T4)

Table 1. Survey Data Used to Construct Model Cross Sections

Transect Name	File Name	Date of Survey
T1	Horse Creek - Transect 1 11-317.xlsx	November 30, 2011
T2	Horse Creek - Instream Transect 2 12-088.xlsx	June 29, 2011
T2	Horse Creek - Transect 2 11-276.xlsx	July 19, 2011
Goose Pond Bridge	Horse Creek - Control 11-281 Goose Pond Road Bridge.xlsx	December 5, 2011
T3	Horse Creek - Instream Transect 3-PHAB1 12-088.xlsx	July 14, 2011
T3	Horse Creek - Transect 3-PHAB 1 11-278.xlsx	July 7, 2011
Highway 665 Bridge	Horse Creek - Control 11-281 Hwy 665 Bridge.xlsx	December 5, 2011
Powerline Bridge (W&E)	Horse Creek - Powerline Bridge 11-298.xlsx	August 11, 2011
T4	Horse Creek - Instream Transect 4 12-088.xlsx	June 28, 2011
T4	Horse Creek - Transect 4 11-266.xlsx	August 9, 2011
Brownville Road Bridge	Horse Creek - Brownville Rd. Bridge 11-302.xlsx	August 22, 2011
T5	Horse Creek - Transect 5 11-318.xlsx	December 7, 2011
T6	Horse Creek - Instream Transect 6-PHAB2 12-088.xlsx	August 18, 2011
T6	Horse Creek - Transect 6 - PHAB 2 11-319.xlsx	December 6, 2011
State Road 70 Bridge	Horse Creek - Control 11-281 State Road 70 Bridge.xlsx	December 13, 2011
NW Pine Level Rd Bridge	Horse Creek - Control 11-281 NW Pine Level St. Bridge.xlsx	November 28, 2011

Relevant DEM tiles for Hardee and DeSoto counties were selected and merged into a single DEM for use in this project. A few DEMs containing erroneous data were identified by the project team and were revised by the District; the corrected DEMs were subsequently merged into the overall DEM. The final DEM consisted of 5-foot by 5-foot cells with elevations ranging from 13 to 109 feet NAVD 88. There were a few discrepancies remaining in the final version of the DEM. For example, at the powerline bridges the District survey was approximately 1 foo0t lower than the DEM in the area around the bridges. Since it is unlikely that flows will overtop the bridges and the District believes that the survey is correct, the DEM data were used as-is for cross section elevations with no available survey data. Additionally, small areas of artificially raised terrain were visible in the DEM around the powerline poles. The cross-section elevations extracted from the DEM at these locations were lowered to be more consistent with surrounding elevations.

Additional Cross Sections

After the completion of the initial modeling effort (INTERA, 2016), the District sought a better understanding of the Horse Creek floodplain inundation, requiring extension of some cross sections in the previous Horse 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 requires creek bathymetry and floodplain topography. Bathymetric and topographic surveys were 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 shows the DEM containing Horse 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 Horse Creek model was constructed with the objective of simulating MFLs at critical cross-sections. In many segments of Horse Creek, the channel remains consistent; however, there is variation in the floodplain between the existing model cross sections. Therefore, additional cross sections are required for better assessment of flood conditions. The DEM and NWI maps were employed for identification of floodplain variation and optimizing new cross section placement. Figure 5 shows the 2016 project Horse Creek model cross section locations. Figure 6 shows the new cross section locations. Figure 7 depicts the new cross sections in addition to the existing 2016 Horse 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 updated 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.

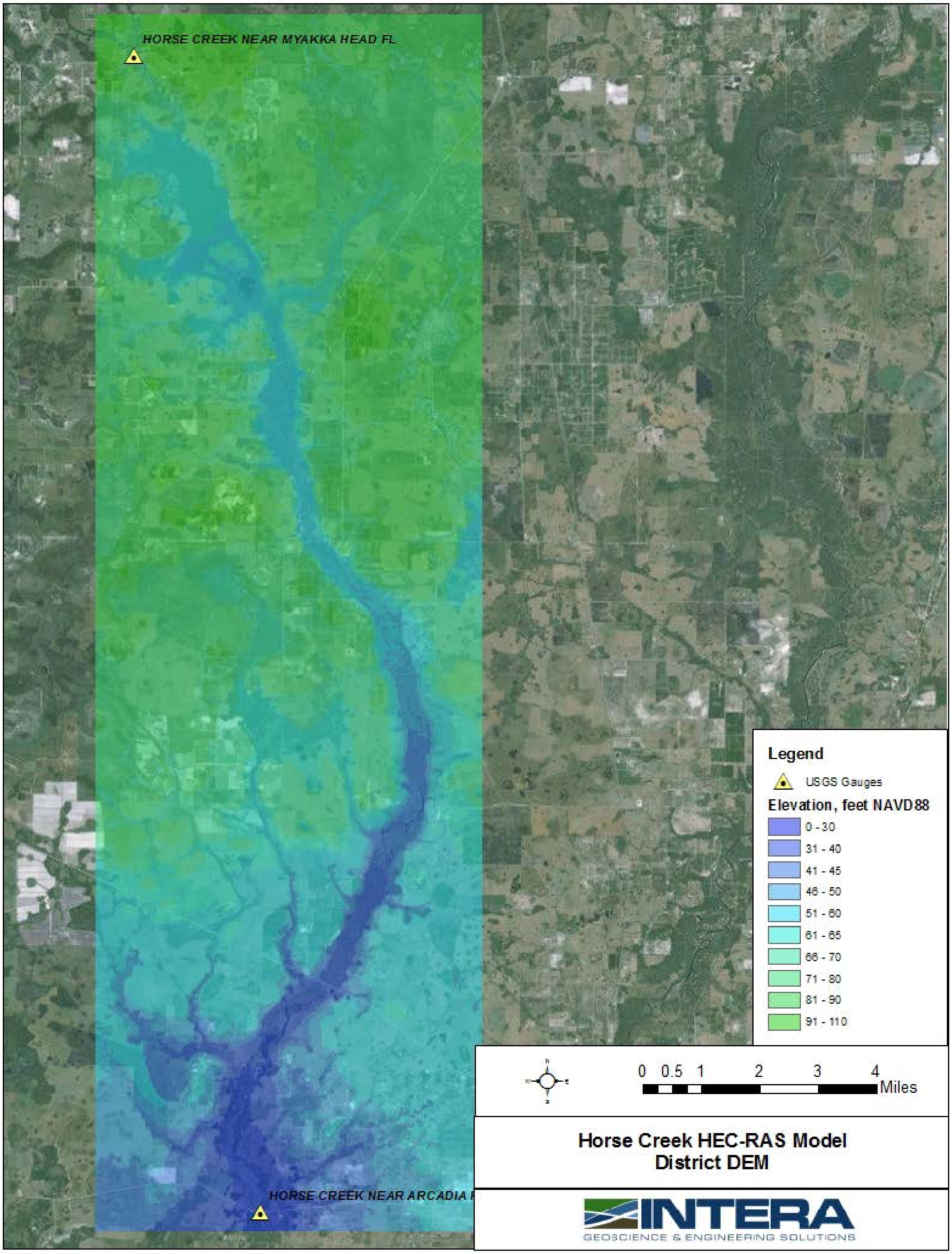

Figure 4. Digital Elevation Model for Horse Creek

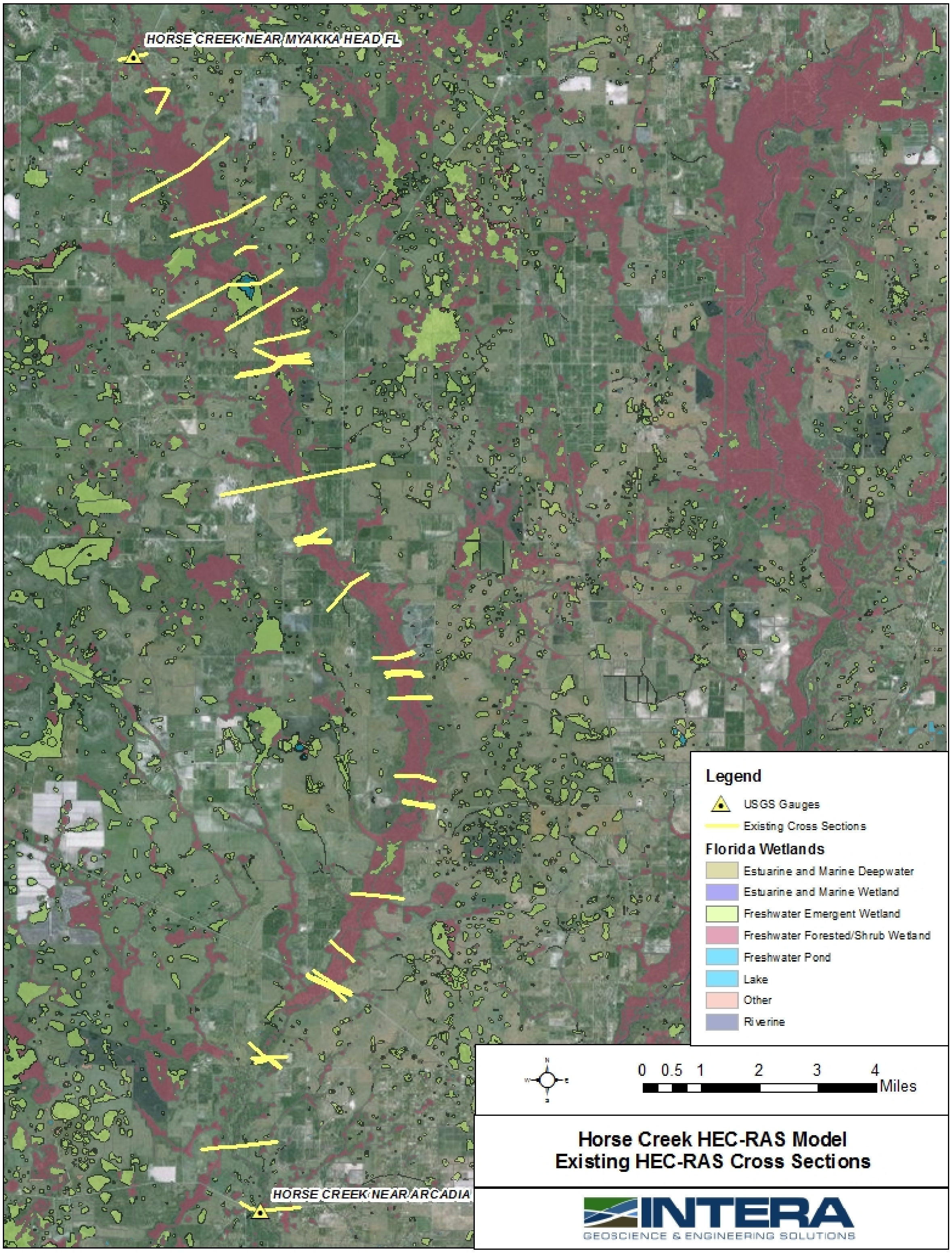

Figure 5. Horse Creek Model Existing Cross Sections

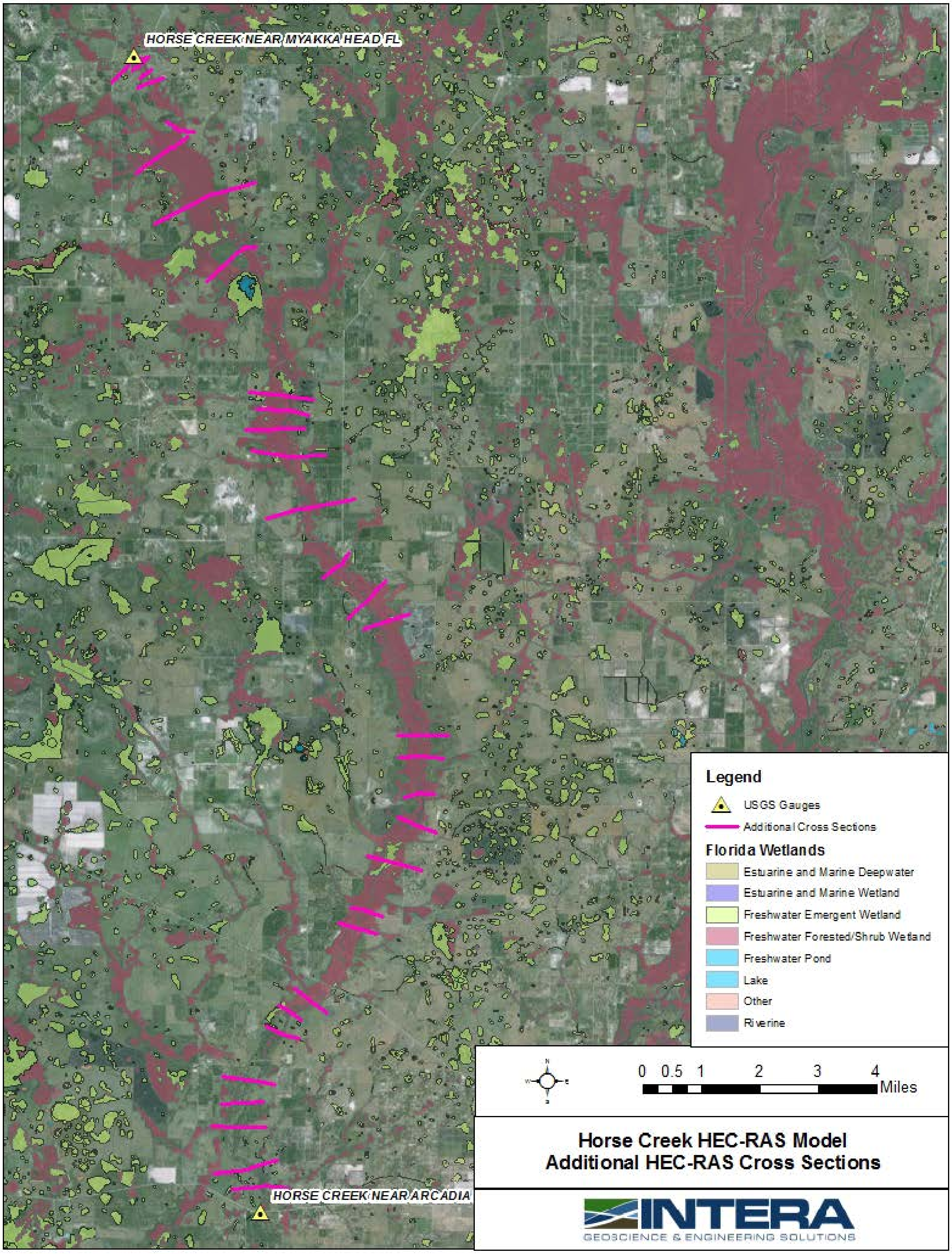

Figure 6. Horse Creek Model Additional Cross Sections

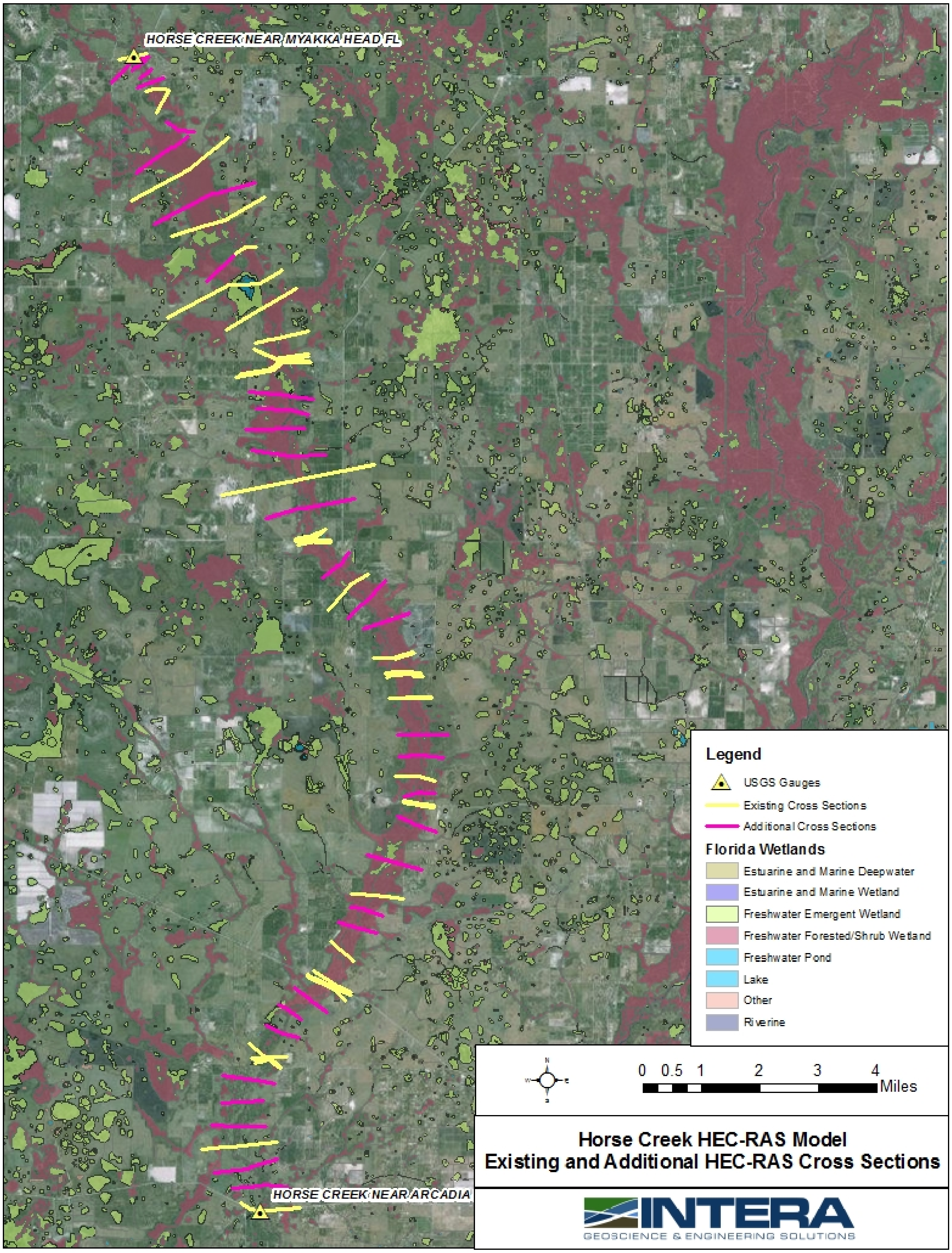

Figure 7. Horse Creek Model Existing and Additional Cross Sections

Table 2. Downstream Reach Lengths for 2016 and New Model

Horse Creek - Upper Reach						
	2016 Model			New Model		
River Station	LOB	Chan	ROB	LOB	Chan	ROB
171902.2	3918.94	5710.71	3555.4	287.16	309.16	449.38
171594				683.35	861.62	641.39
170732.4				1055.07	2097.25	1017.3
168635.1				1044.95	1168.69	792.82
167466.4				848.41	1273.98	654.52
166191.6	1365.87	2343.33	1892.97	1365.87	2343.33	1892.97
163848.3	7313.8	9056.93	8728.43	3772.4	4055.18	2150.48
159794				926.11	1895.84	4312.22
157898.1				2615.29	3105.91	2265.73
154791.4	5858.59	7738.59	5150.83	3412.21	4349.06	2924.41
150443.2				2446.39	3389.53	2226.43
147052.9	3259.47	3385.02	4344.16	3259.47	3385.02	4344.16
143668	3394.05	4183.64	1896.73	3394.05	4183.64	1896.73
139484.4	1483.08	3183.84	4907.438	1483.08	3183.84	4907.438
136300.6	19.7	152.5	355.45	19.7	152.5	355.45
136148.1	68.64	80.44	54.03	68.64	80.44	54.03
136110.7	Culvert			Culvert		
136067.7	577.14	105.39	20.77	577.14	105.39	20.77
135962.3	3578.65	2788.66	2019.49	3578.65	2788.66	2019.49
133173.7	1945.21	3067.32	1725.74	1945.21	3067.32	1725.74
130106.4	153.15	247.57	95.78	153.15	247.57	95.78
129858.8	237.087	101.475	1196.915	237.087	101.475	1196.915
129757.4	60.95	96.83	70.71	60.95	96.83	70.71
129710.5	Mult Open			Mult Open		
129660.5	56.17	64.26	94.9	56.17	64.26	94.9
129596.3	10937.39	15184.09	10486.58	3370.66	4851.02	2150.67
124745.8				1304.27	1493.73	1414.77
123252.1				1590.11	2158.97	1802.75
121093.1				2563.02	4007.9	2432.15
117085.2				2109.33	2672.47	2686.25
114412.3	5197.81	8641.33	5505.17	2804.25	4622.97	2751.08
109789.7				2393.55	4018.35	2754.08
105771.1	257.69	616.36	399.12	257.69	616.36	399.12
105154.8	600.39	131.51	23.13	600.39	131.51	23.13

Table 2.	**(continued)**					
105023.3	73.33	96.34	76.65	73.33	96.34	76.65
104974.8	Bridge			Bridge		
104926.9	83.67	62.14	201.73	83.67	62.14	201.73
104864.8	4937.06	6924.01	5515.58	2646.1	4311.82	3350.1
100553.2				2290.95	2612.19	2165.49
97940.84	8305.57	11180.71	7557.78	1975.04	3181.24	1970.97
94759.78				2822.27	3396.79	2382.04
91362.98				3508.25	4602.68	3204.76
86760.24	79.07	153.82	59864.15	79.07	153.82	59864.15
Horse Creek - East Reach						
86606.43	2149.13	3097.92	1977.85	2149.13	3097.92	1977.85
83508.5	39.59	76.3	233.44	39.59	76.3	233.44
83432.2	27.27	25.85	25.79	27.27	25.85	25.79
83420.7	Bridge			Bridge		
83406.35	240.1	148.21	59.53	240.1	148.21	59.53
83258.14	1946.11	3668.96	2428.4	1946.11	3668.96	2428.4
79589.18	140.86	135.57	70429.48	140.86	135.57	70429.48
Horse Creek - Lower Reach						
79453.61	7873.38	10064.74	7425.73	3731.68	5071.62	3707.41
74382				2033.16	2569.33	1967.77
71812.66				2108.54	2423.78	1750.55
69388.88	2479.61	3203.59	2466.24	1388.92	2085.9	1766.49
67302.98				1090.69	1117.69	699.75
66185.28	105.25	105.32	89.57	105.25	105.32	89.57
66079.96	35.38	30.6	46.76	35.38	30.6	46.76
66067.23	Bridge			Bridge		
66049.37	85.5	89.17	98.89	85.5	89.17	98.89
65960.2	9597.32	13649.53	10048.32	1897.88	2288.46	1565.32
63671.73				4302.18	6901.14	4948.63
56770.6				3397.25	4459.93	3534.38
52310.68	6445.44	9180.07	5984.46	1721.19	1939.32	1544.69
50371.35				1822.71	3182.69	1882.66
47188.67				2901.34	4058.05	2557.11
43130.62	3159.74	5606.99	3598.03	3159.74	5606.99	3598.03

Table 2. 37523.64	(continued) 177.49	287.71	308.21	177.49	287.71	308.21
37235.93	96.79	123.97	92.23	96.79	123.97	92.23
37190.67	Mult Open			Mult Open		
37111.96	150.59	117.37	90.43	150.59	117.37	90.43
36994.59	9304.51	13427.03	9165.94	2314.08	3003.86	2244.68
33990.73				2148.33	3291.36	2188.26
30699.36				1970.27	2569.84	2240.29
28129.51				2871.82	4561.98	2492.7
23567.56	240.502	107.606	695.94	240.502	107.606	695.94
23459.95	55.32	79.71	70.17	55.32	79.71	70.17
23418.97	Bridge			Bridge		
23380.24	200.46	91.27	325.74	200.46	91.27	325.74
23288.98	8143.5	12695.46	8884.42	2177.47	2898.1	2232.48
20390.86				2083.71	3148.11	2430.46
17242.74				2190.4	3255.75	2247.56
13986.99				1691.93	3393.5	1973.91
10593.51	6429.86	10563.97	6273.1	1848.34	3131.21	2437.43
7462.289				2481.4	4456.92	1750.68
3005.386				2100.12	2975.84	2085
29.54714	59.96	29.55	128.96	59.96	29.55	128.96
West Trib - West Reach						
5260.038	1464.77	1878.65	1387.33	1464.77	1878.65	1387.33
3381.384	265.43	129.8	37.96	265.43	129.8	37.96
3251.588	32.32	32.47	36.8	32.32	32.47	36.8
3232.173	Bridge			Bridge		
3219.117	185.7	184.72	248.81	185.7	184.72	248.81
3034.397	2525.78	2981.44	2252.81	2525.78	2981.44	2252.81
52.96038	9.61	52.96	55834.1	9.61	52.96	55834.1

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 Horse 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 3 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 Horse 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 17, 2017 to collect a series of flow measurements on Horse 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 8. 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.

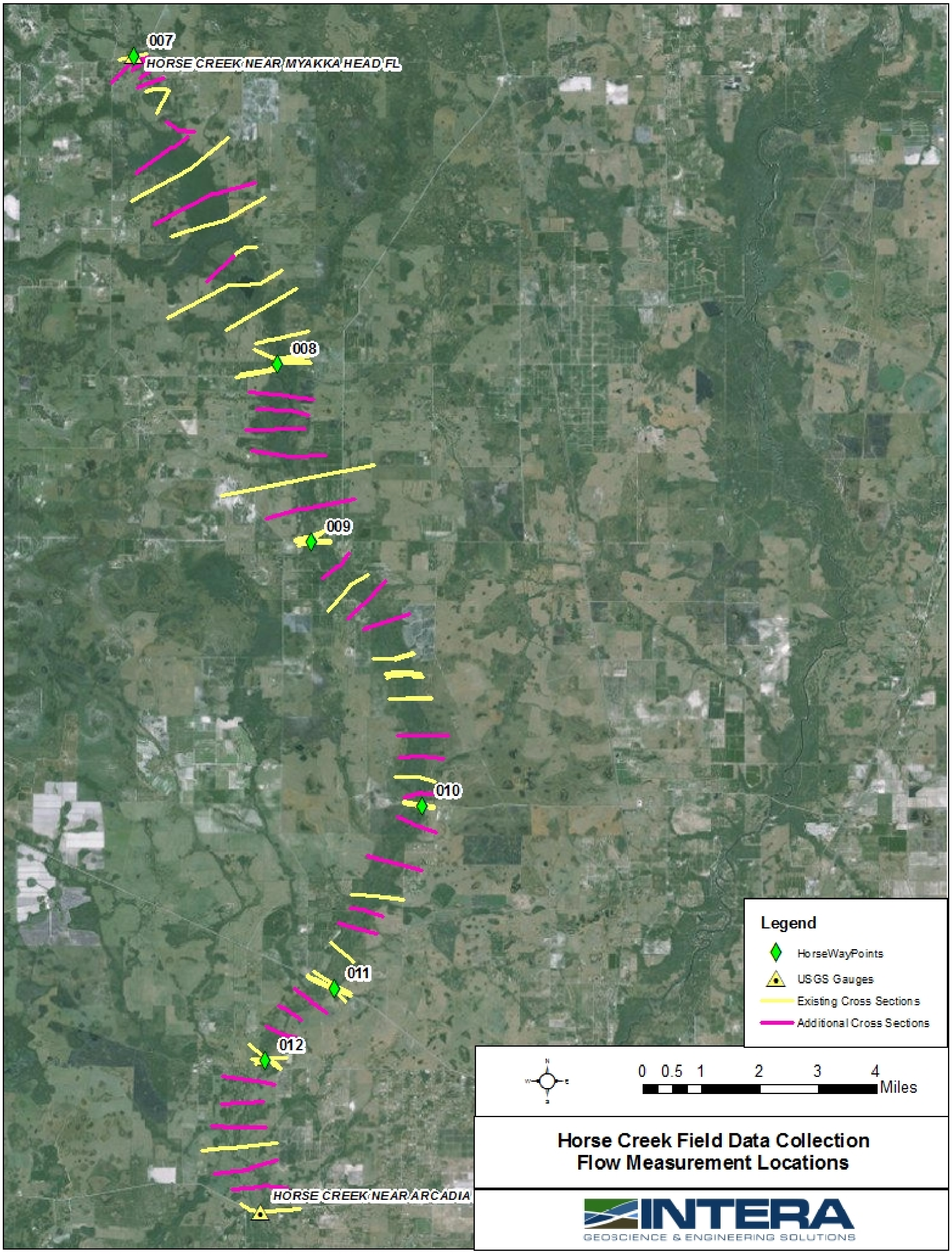

Figure 8. Flow Measurement Locations

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 3. 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
7	20171017090636.riv	10/17/2017	9:07:10 AM	0:02:01	14.65	0.762	0.127	11.569
	20171017091201.riv	10/17/2017	9:11:53 AM	0:01:19	14.57	0.763	0.193	11.379
	20171017091333.riv	10/17/2017	9:13:23 AM	0:01:48	15.24	0.669	0.15	11.21
8	20171017102425.riv	10/17/2017	10:24:14 AM	0:02:39	42.38	0.193	0.275	26.395
	20171017103237.riv	10/17/2017	10:32:20 AM	0:02:03	40.13	0.202	0.358	26.634
	20171017103450.riv	10/17/2017	10:34:30 AM	0:03:07	42.73	0.188	0.24	26.421
	20171017103823.riv	10/17/2017	10:38:00 AM	0:02:20	39.93	0.192	0.313	25.199
9	20171017113617.riv	10/17/2017	11:36:12 AM	0:04:04	58.15	0.136	0.263	30.131
	20171017114055.riv	10/17/2017	11:40:45 AM	0:03:03	51.71	0.157	0.348	28.51
	20171017114445.riv	10/17/2017	11:44:32 AM	0:03:58	60.23	0.123	0.279	27.319
	20171017114912.riv	10/17/2017	11:48:55 AM	0:02:15	53.57	0.164	0.454	30.639
	20171017115852.riv	10/17/2017	11:58:36 AM	0:03:57	55.26	0.142	0.268	28.222
	20171017120352.riv	10/17/2017	12:03:29 PM	0:02:38	49.73	0.163	0.374	29.394
10	20171017131304.riv	10/17/2017	1:12:54 PM	0:03:59	92.2	0.101	0.425	33.236
	20171017131807.riv	10/17/2017	1:17:53 PM	0:04:18	87.16	0.093	0.382	28.322
	20171017132454.riv	10/17/2017	1:24:58 PM	0:04:00	93.51	0.107	0.42	35.635
	20171017133009.riv	10/17/2017	1:29:45 PM	0:05:33	84.35	0.121	0.299	36.667
	20171017133704.riv	10/17/2017	1:36:34 PM	0:04:28	94.32	0.11	0.372	37.03
	20171017134405.riv	10/17/2017	1:43:39 PM	0:07:12	77.48	0.127	0.225	33.973
11	20171017145227.riv	10/17/2017	2:52:20 PM	0:03:01	39.89	0.346	0.23	39.452
	20171017145540.riv	10/17/2017	2:55:29 PM	0:02:58	35.15	0.418	0.242	42.31
	20171017145844.riv	10/17/2017	2:58:31 PM	0:03:02	38.17	0.347	0.244	37.663
	20171017150158.riv	10/17/2017	3:01:42 PM	0:02:59	37.74	0.368	0.252	38.565
	20171017150550.riv	10/17/2017	3:05:32 PM	0:03:07	39.42	0.367	0.225	41.972
	20171017150910.riv	10/17/2017	3:08:48 PM	0:02:57	36.21	0.401	0.239	42.837
12	20171017164044.riv	10/17/2017	4:39:59 PM	0:02:37	24.35	0.367	0.17	48.811
	20171017164328.riv	10/17/2017	4:42:40 PM	0:02:58	24.68	0.356	0.152	47.72
	20171017164651.riv	10/17/2017	4:46:01 PM	0:03:15	24.83	0.349	0.14	47.169
	20171017165017.riv	10/17/2017	4:49:24 PM	0:03:00	25.7	0.354	0.173	47.685

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 Tables 4 through 9.

Table 4. Final QA/QCed Flows, Site 007

Measurement	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/17/2017)	End Time (10/17/2017)
Average	**7.781**	5.582	1.104	1.095	305	9:07:10	9:15:10
20171017090636.riv	**7.811**	5.612	1.106	1.094	120	09:07:10 L	9:09:10
20171017091201.riv	**7.762**	5.557	1.113	1.093	78	09:11:53 R	9:13:11
20171017091333.riv	**7.770**	5.578	1.093	1.1	107	09:13:23 L	9:15:10

Table 5. Final QA/QCed Flows, Site 008

Measurement	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/17/2017)	End Time (10/17/2017)
Average	**26.801**	6.597	15.993	3.626	605	10:24:13	10:40:19
20171017102425.riv	**26.658**	6.666	15.895	3.538	158	10:24:13 L	10:26:51
20171017103237.riv	**27.267**	6.657	16.276	3.709	122	10:32:20 R	10:34:22
20171017103450.riv	**27.154**	6.681	16.244	3.618	186	10:34:30 L	10:37:36
20171017103823.riv	**26.125**	6.387	15.556	3.64	139	10:38:00 R	10:40:19

Table 6. Final QA/QCed Flows, Site 009

Measurement	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/17/2017)	End Time (10/17/2017)
Average	**27.848**	6.224	17.53	3.918	1189	11:36:12	12:06:06
20171017113617.riv	**28.544**	6.478	18.002	3.931	243	11:36:12 L	11:40:15
20171017114055.riv	**25.945**	5.671	16.287	3.794	182	11:40:45 R	11:43:47
20171017114445.riv	**27.149**	6.291	17.11	3.515	237	11:44:32 L	11:48:29
20171017114912.riv	**28.956**	6.305	18.371	4.098	134	11:48:55 R	11:51:09
20171017115852.riv	**28.292**	6.183	17.668	4.213	236	11:58:36 L	12:02:32
20171017120352.riv	**28.201**	6.414	17.741	3.957	157	12:03:29 R	12:06:06

Table 7. Final QA/QCed Flows, Site 010

<u>Measurement</u>	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/17/2017)	End Time (10/17/2017)
Average	**33.055**	6.744	22.291	3.942	1764	13:12:53	13:50:49
20171017131304.riv	**30.092**	5.408	21.766	2.832	238	13:12:53 L	13:16:51
20171017131807.riv	**29.014**	5.733	20.136	3.095	257	13:17:52 R	13:22:09
20171017132454.riv	**37.696**	8.086	23.48	6.033	239	13:24:57 L	13:28:56
20171017133009.riv	**32.935**	6.925	22.187	3.823	332	13:29:44 R	13:35:16
20171017133704.riv	**35.380**	7.553	23.817	3.902	267	13:36:33 L	13:41:00
20171017134405.riv	**33.216**	6.759	22.359	3.965	431	13:43:38 R	13:50:49

Table 8. Final QA/QCed Flows, Site 011

<u>Measurement</u>	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/17/2017)	End Time (10/17/2017)
Average	**42.722**	11.721	24.507	6.341	900	14:52:20	15:11:44
20171017145227.riv	**40.481**	11.336	23.228	5.865	180	14:52:20 L	14:55:20
20171017145540.riv	**44.610**	12.019	25.626	6.687	177	14:55:29 R	14:58:26
20171017145844.riv	**40.675**	11.225	23.417	5.86	181	14:58:31 L	15:01:32
20171017150550.riv	**43.192**	11.81	25.031	6.309	186	15:05:32 L	15:08:38
20171017150910.riv	**44.652**	12.213	25.233	6.982	176	15:08:48 R	15:11:44

Table 9. Final QA/QCed Flows, Site 012

<u>Measurement</u>	**Total Q (ft3/s)**	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (10/17/2017)	End Time (10/17/2017)
Average	**47.112**	8.386	33.404	4.706	706	16:39:59	16:52:23
20171017164044.riv	**48.381**	8.511	33.975	4.781	156	16:39:59 L	16:42:35
20171017164328.riv	**46.861**	8.371	33.327	4.581	177	16:42:40 R	16:45:37
20171017164651.riv	**46.665**	8.273	32.95	4.782	194	16:46:01 L	16:49:15
20171017165017.riv	**46.542**	8.388	33.363	4.681	179	16:49:24 R	16:52:23

Average flows for each location are shown in Figure 9. As shown, flows generally increase from upstream to downstream. Significant pickup was noted by the large flow difference between the two most upstream locations. This increase in pickup is likely due to inflows from the tributary between the measurement locations.

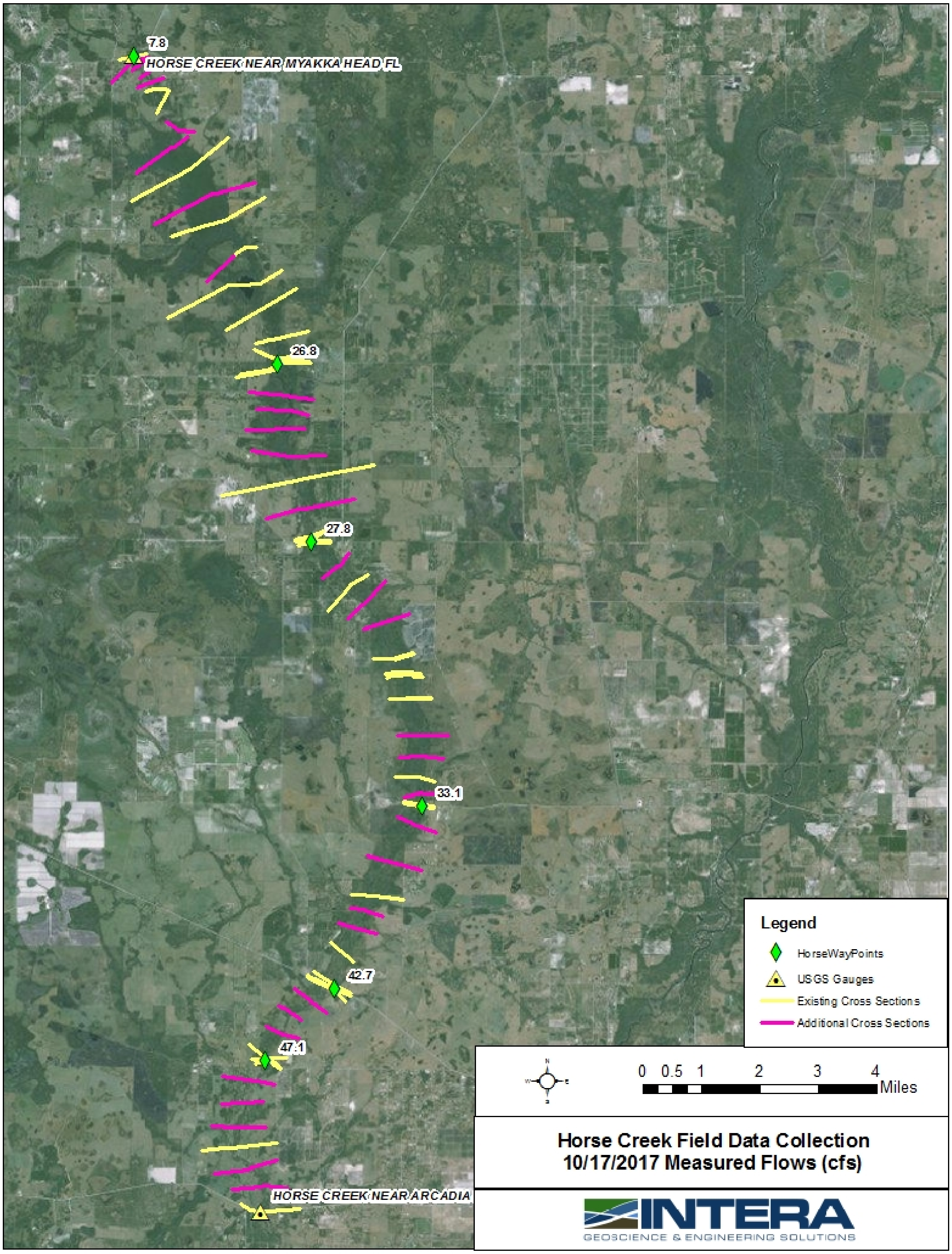

Figure 9. Horse Creek Flow Data Collection #1 Flows

Flow Measurement #2

Field engineers from INTERA were onsite on May 10, 2017 to collect a series of flow measurements on Horse Creek. The goal of the field work was to measure flow at 3 locations in the system during a low flow event. Prior to data collection, property owners along the creek were contacted for site access. Sites were selected based on access and distance from other sites. It was desirable to have data collections at various locations along Horse Creek so that the pickup along the channel could be determined.

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 10. These identification numbers are the same as previous data collection efforts.

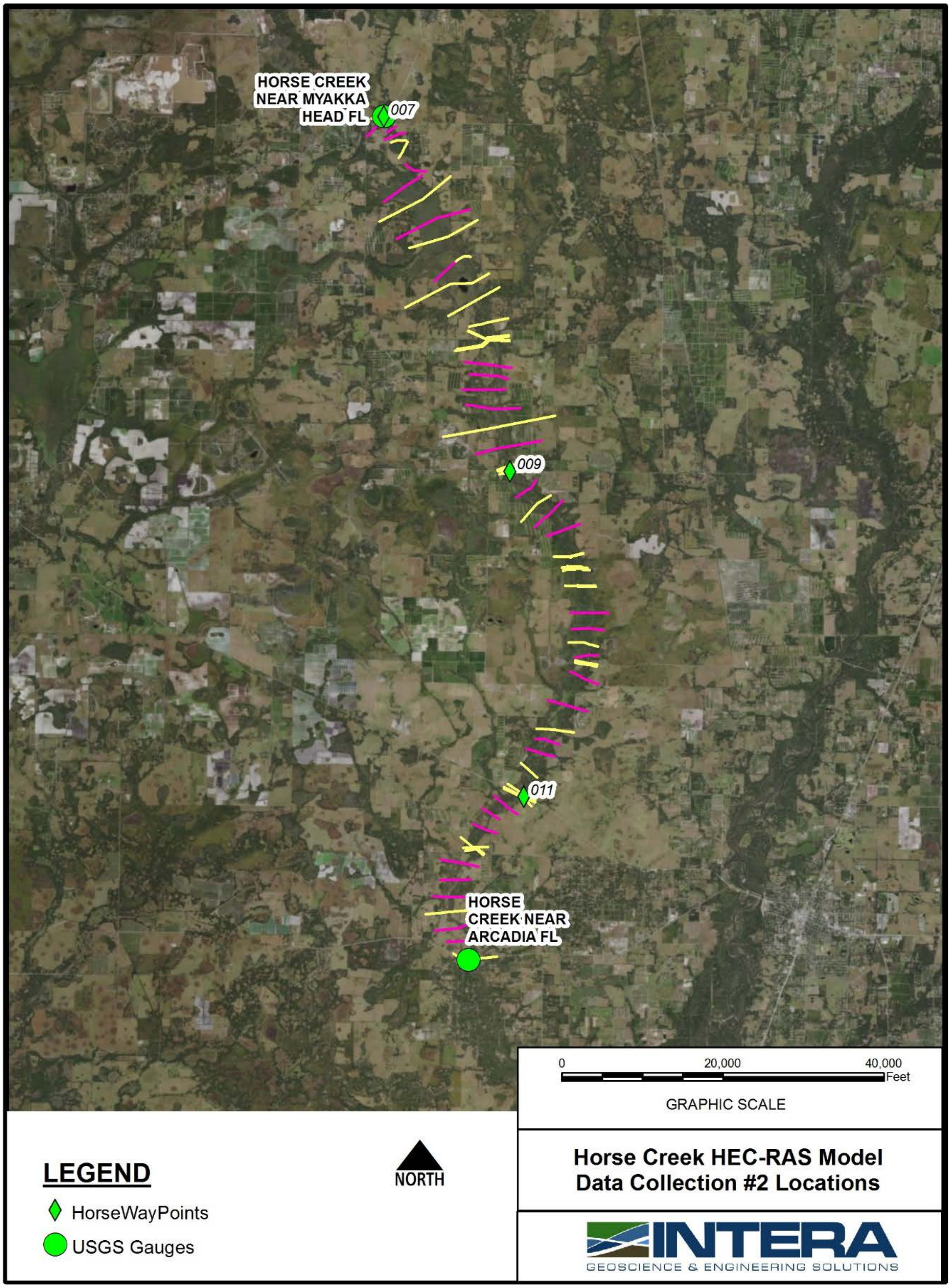

Figure 10. Flow Measurement Locations

Preliminary Velocity Data

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

Table 10. Field Measurements, Way Point 7, 5/10/18 4:26 p.m. (SR 64)

Start Station, ft.	Stop Station, ft.	Width, ft.	Depth, ft.	Velocity, ft/sec	Area, ft^2	Flow, cfs
5.0	6.0	1.0	0.20	0.04	0.20	0.0080
6.0	7.0	1.0	0.30	0.21	0.30	0.0630
7.0	8.0	1.0	0.45	0.28	0.45	0.1260
8.0	9.0	1.0	0.60	0.29	0.60	0.1740
9.0	10.0	1.0	0.65	0.29	0.65	0.1885
10.0	11.0	1.0	0.60	0.10	0.60	0.0600
11.0	12.0	1.0	0.50	0.04	0.50	0.0200
12.0	13.0	1.0	0.41	0.02	0.41	0.0082
13.0	14.0	1.0	0.30	0.01	0.30	0.0030
					Total Flow (cfs)	0.6507

Table 11. Field Measurements, Way Point 9, 5/10/18 8:35 a.m.

Start Station, ft.	Stop Station, ft.	Width, ft.	Depth, ft.	Velocity, ft/sec	Area, ft^2	Flow, cfs
7.0	10.0	3.0	0.20	0.00	0.60	0.00
10.0	12.0	2.0	0.60	0.00	1.20	0.00
12.0	14.0	2.0	0.80	0.01	1.60	0.02
14.0	16.0	2.0	1.00	0.01	2.00	0.02
16.0	18.0	2.0	0.90	0.01	1.80	0.02
18.0	20.0	2.0	1.00	0.00	2.00	0.00
20.0	22.0	2.0	0.90	0.02	1.80	0.04
22.0	24.0	2.0	0.85	0.03	1.70	0.05
24.0	26.0	2.0	0.55	0.03	1.10	0.03
26.0	28.0	2.0	0.60	0.01	1.20	0.01
28.0	30.0	2.0	0.35	0.00	0.70	0.00
					Total Flow (cfs)	0.186

Table 12. Field Measurements, Way Point 11, 5/10/18 10:05 a.m.

Start Station, ft.	Stop Station, ft.	Width, ft.	Depth, ft.	Velocity, ft/sec	Area, ft^2	Flow, cfs
18.0	16.0	2.0	0.30		0.60	0.000
16.0	15.0	1.0	0.30	0.03	0.30	0.009
15.0	14.0	1.0	0.35	0.05	0.35	0.018
14.0	13.0	1.0	0.40	0.19	0.40	0.076
13.0	12.0	1.0	0.45	0.28	0.45	0.126
12.0	11.0	1.0	0.50	0.22	0.50	0.110
11.0	10.0	1.0	0.53	0.21	0.53	0.111
10.0	9.0	1.0	0.50	0.61	0.50	0.305
9.0	8.0	1.0	0.25	0.52	0.25	0.130
8.0	7.0	1.0	0.28	0.14	0.28	0.039
7.0	6.0	1.0	0.30	0.20	0.30	0.060
6.0	5.0	1.0	0.20	0.02	0.20	0.004
					Total Flow (cfs)	0.988

Total flows for each location are shown in Figure 11. As shown, flows generally increase from upstream to downstream. The USGS flows at the upstream and downstream model boundaries (Horse Creek near Myakka Head and Horse Creek near Arcadia, respectively) are shown with the field measurements in Table 13.

Table 13. Average flow, 5/10/18

Location	Flow, cfs	Measured by
Horse Creek near Myakka Head/	1.27	USGS (Provisional)
Way Point 7	0.65	INTERA
Way Point 9	0.186	INTERA
Way Point 11	0.988	INTERA
Horse Creek near Arcadia	1.89	USGS (Provisional)

As shown above, the flows are extremely low and there is a very small amount of pickup moving from upstream to downstream. While INTERA field technicians were on-site, Vincent Budd, a technician from the USGS was also onsite. He stated that there are issues with the gauges at low flows and suggested that the USGS rating curve may not be accurate at low flows. It is noteworthy that all flows recorded by INTERA were lower than both the upstream and downstream flows calculated by the USGS. This corroborates his suggestion that the USGS flows are not accurate for low flows. INTERA technicians noted that the channel was wide at Way Point 9, leading to very small velocity measurements. These low measurements may result in a larger flow measurement error than the other locations. The overall pickup in the system of 0.62 cfs measured by the USGS will be used with the INTERA measurements to adjust the flows in the creek for model calibration.

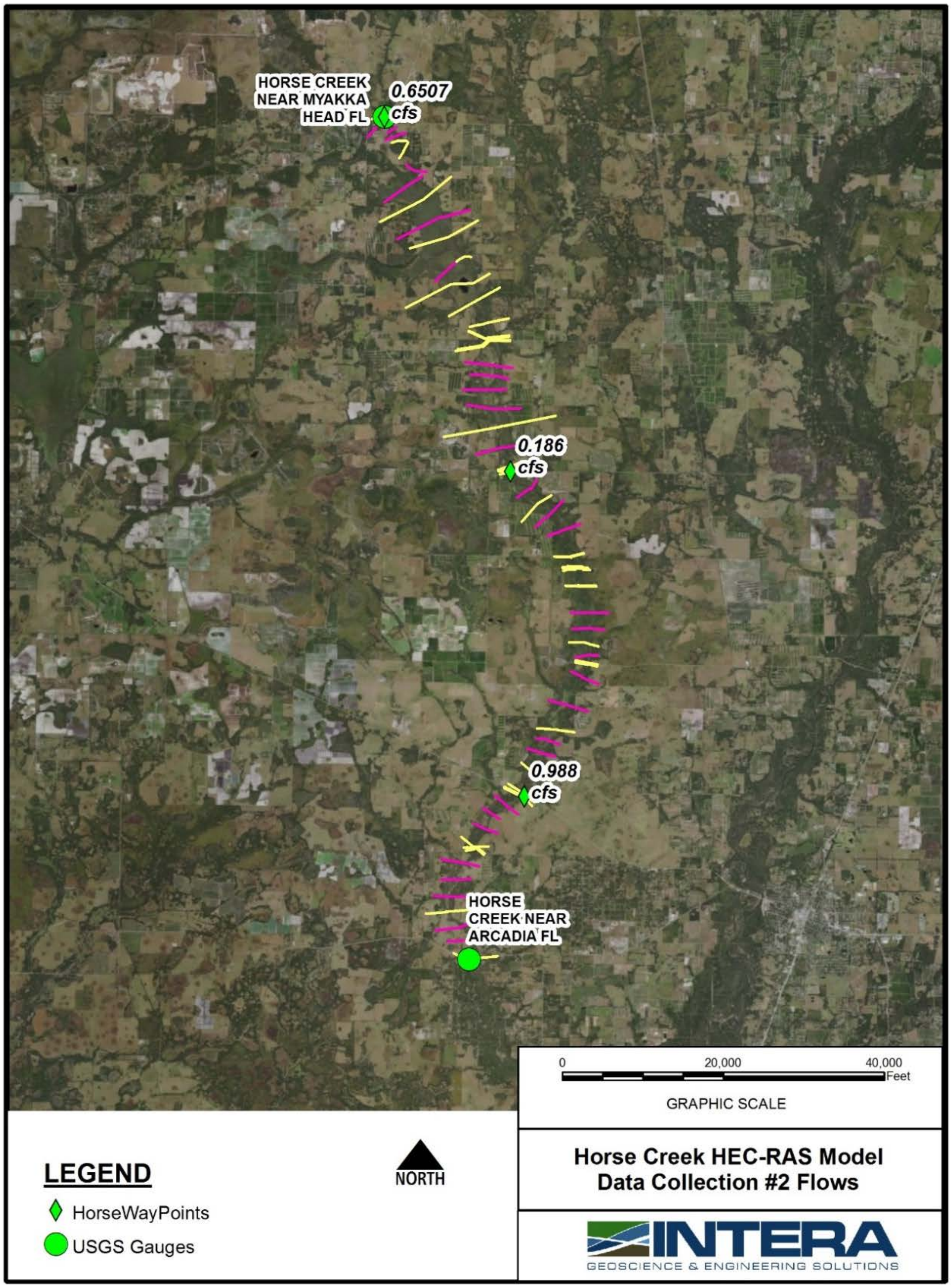

Figure 11. Horse Creek Flow Data Collection #2 Flows

Flow Measurement #3

Field engineers from INTERA and Water Cube were on site on June 10 and June 11, 2018 to collect a series of flow measurements on Horse Creek. The goal of the field work was to measure flow at 6 locations in the system. Prior to data collection, property owners along the creek were contacted for site access. Sites were selected based on access and distance from other sites. It was desirable to have data collections at various locations along Horse Creek so that the pickup along the channel could be determined.

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 12. 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.

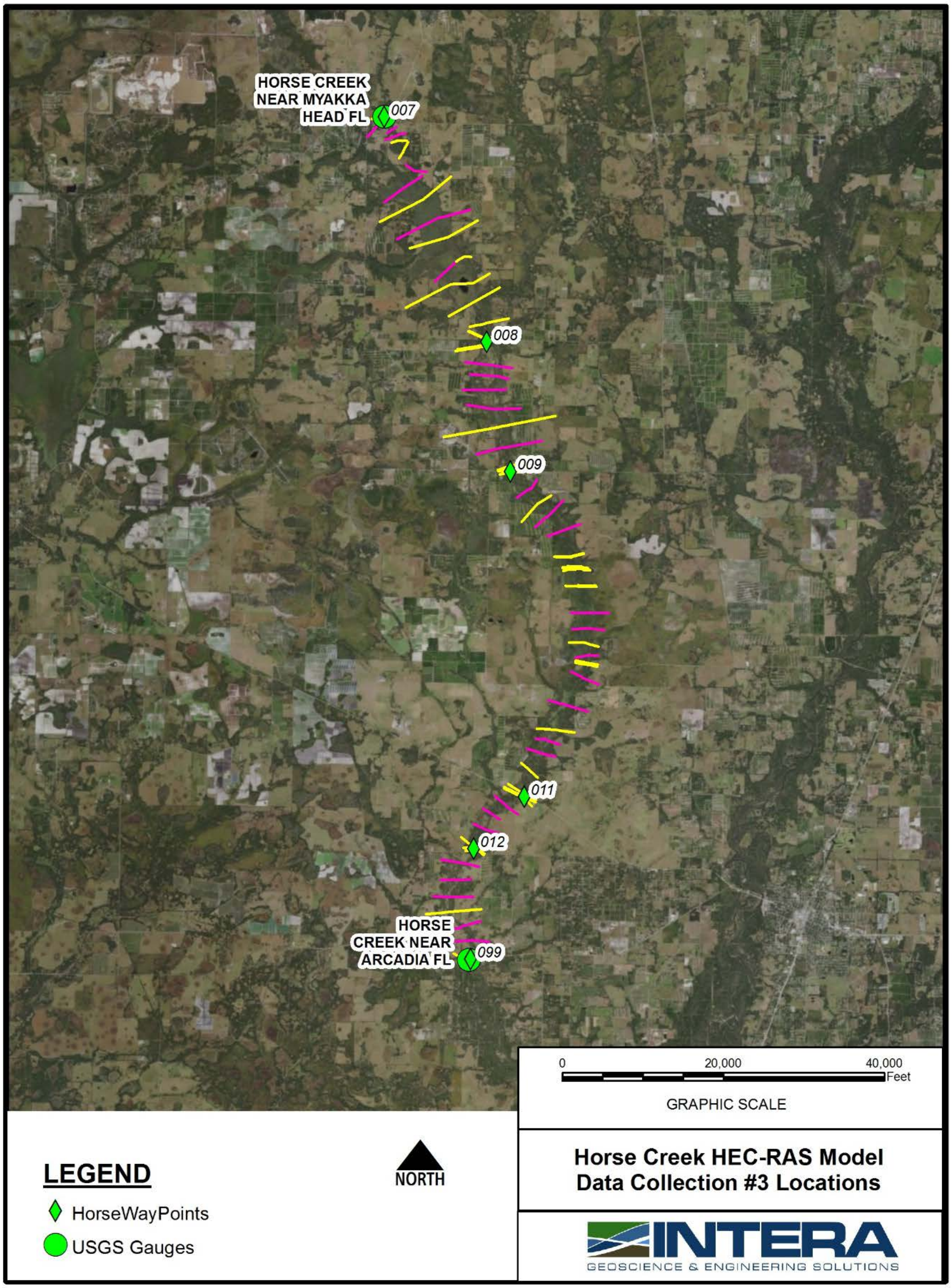

Figure 12. Flow Measurement Locations

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 14. For each location, the average of the recorded flows was determined.

Table 14. Initial Flows

Site ID Number	File	Start Date	Start Time	Duration	Distance Made Good, feet	Mean Speed, ft/s	Boat Speed, ft/s	Total Q, ft/s
7	20180610094102r.rivr	6/10/2018	9:41:01 AM	0:03:41	20.22	1.633	0.161	81.655
	20180610094451r.rivr	6/10/2018	9:44:50 AM	0:03:09	20.55	1.78	0.19	89.929
	20180610094822r.rivr	6/10/2018	9:48:20 AM	0:03:35	22.55	1.645	0.151	93.308
	20180610095222r.rivr	6/10/2018	9:52:21 AM	0:02:53	20.65	1.704	0.178	86.455
	20180610095547r.rivr	6/10/2018	9:55:45 AM	0:03:15	20.97	1.769	0.146	86.928
8	20180610104500r.rivr	6/10/2018	10:44:58 AM	0:05:27	107.95	0.416	0.357	151.649
	20180610105035r.rivr	6/10/2018	10:50:33 AM	0:04:35	105.09	0.452	0.446	163.093
	20180610105521r.rivr	6/10/2018	10:55:19 AM	0:04:09	107.37	0.45	0.455	163.959
	20180610105938r.rivr	6/10/2018	10:59:35 AM	0:04:26	106.59	0.458	0.443	162.786
9	20180610120430r.rivr	6/10/2018	12:04:27 PM	0:03:55	69.45	0.372	0.438	205.153
	20180610120834r.rivr	6/10/2018	12:08:31 PM	0:02:40	79.55	0.362	0.554	193.726
	20180610121126r.rivr	6/10/2018	12:11:22 PM	0:03:18	80.26	0.349	0.443	194.376
	20180610121503r.rivr	6/10/2018	12:14:59 PM	0:02:34	80.85	0.378	0.563	203.193
	20180610121754r.rivr	6/10/2018	12:17:49 PM	0:02:37	78.11	0.362	0.571	197.181
11	20180610150005r.rivr	6/10/2018	3:00:12 PM	0:04:29	278.17	0.433	1.111	273.146
	20180610150554r.rivr	6/10/2018	3:05:56 PM	0:06:00	303.22	0.426	0.904	288.912
	20180610151221r.rivr	6/10/2018	3:12:15 PM	0:04:10	299.63	0.448	1.275	303.863
	20180610151647r.rivr	6/10/2018	3:16:41 PM	0:05:36	299.65	0.408	0.992	277.773
12	20180610161740r.rivr	6/10/2018	4:18:02 PM	0:04:06	105.97	0.815	0.458	330.389
	20180610183343r.rivr	6/10/2018	6:33:43 PM	0:03:02	103.08	0.79	0.683	332.655
	20180610183655r.rivr	6/10/2018	6:36:55 PM	0:03:05	104.71	0.711	0.626	299.302
	20180610184007r.rivr	6/10/2018	6:40:07 PM	0:03:15	104.32	0.768	0.638	327.861
	20180610184335r.rivr	6/10/2018	6:43:34 PM	0:02:52	100.62	0.686	0.718	304.599
99	20180611121641r.rivr	6/11/2018	12:16:37 PM	0:02:43	53.76	1.553	0.412	335.831
	20180611121930r.rivr	6/11/2018	12:19:26 PM	0:02:24	53.83	1.612	0.404	340.814
	20180611122202r.rivr	6/11/2018	12:21:57 PM	0:02:36	54.44	1.51	0.419	335.61

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 Tables 15 through 20.

Table 15. Final QA/QCed Flows, Site 007

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/10/2018)	End Time (06/10/2018)
Average	**91.28**	32.94	39.13	14.12	988	9:41:01	9:58:59
1	**84.68**	30.14	35.72	13.57	220	09:41:01 L	9:44:41
2	**97.13**	35.26	42.16	14.61	188	09:44:50 R	9:47:58
3	**97.69**	35.61	41.78	14.49	214	09:48:20 L	9:51:54
4	**90.86**	32.69	39.38	13.92	172	09:52:21 R	9:55:13
5	**86.02**	31.00	36.60	14.02	194	09:55:45 L	9:58:59

Table 16. Final QA/QCed Flows, Site 008

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/10/2018)	End Time (06/10/2018)
Average	**157.14**	32.34	100.51	23.36	1113	10:44:58	11:04:00
1	**152.08**	30.97	95.94	24.13	326	10:44:58 L	10:50:24
2	**157.77**	32.63	102.45	21.82	274	10:50:33 R	10:55:07
3	**161.95**	33.38	102.91	24.76	248	10:55:19 L	10:59:27
4	**156.78**	32.40	100.73	22.73	265	10:59:35 R	11:04:00

Table 17. Final QA/QCed Flows, Site 009

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/10/2018)	End Time (06/10/2018)
Average	**193.06**	23.17	146.80	23.20	899	12:04:27	12:20:25
1	**200.92**	26.03	149.32	25.50	234	12:04:27 L	12:08:21
2	**186.54**	21.26	143.22	21.69	159	12:08:31 R	12:11:10
3	**190.89**	24.02	145.24	22.30	197	12:11:22 L	12:14:39
4	**194.92**	21.14	150.48	23.23	153	12:14:59 R	12:17:32
5	**192.03**	23.40	145.72	23.29	156	12:17:49 L	12:20:25

Table 18. Final QA/QCed Flows, Site 011

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/10/2018)	End Time (06/10/2018)
Average	**284.70**	74.19	157.42	53.25	1211	15:00:12	15:22:16
1	**302.08**	87.71	151.05	62.89	268	15:00:12 R	15:04:40
2	**279.73**	69.64	165.15	45.41	359	15:05:56 L	15:11:55
3	**276.80**	71.51	150.72	54.72	249	15:12:15 R	15:16:24
4	**280.19**	67.91	162.77	49.97	335	15:16:41 L	15:22:16

Table 19. Final QA/QCed Flows, Site 012

Measurement Number	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Duration (s)	Start Time (06/10/2018)	End Time (06/10/2018)
Average	**307.83**	44.73	232.44	34.16	975	4:18 PM	6:46 PM
1	**323.24**	48.19	240.26	37.15	245	16:18:01 R	4:22 PM
2	**318.46**	46.69	237.32	37.87	181	18:33:43 R	6:36 PM
3	**297.47**	44.38	225.32	31.43	184	18:36:55 L	6:39 PM
4	**321.24**	52.97	238.19	34.18	194	18:40:07 R	6:43 PM
5	**278.74**	31.42	221.09	30.17	171	18:43:34 L	6:46 PM

Table 20. Final QA/QCed Flows, Site 099

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	**328.58**	74.19	209.98	41.39	460	12:16:36	12:24:31
1	**329.68**	74.69	212.06	39.79	162	12:16:36 L	12:19:18
2	**329.12**	74.07	208.16	44.35	143	12:19:25 R	12:21:48
3	**326.93**	73.82	209.73	40.02	155	12:21:56 L	12:24:31

Average flows for each location are shown in Figure 13. As shown, flows increase from upstream to downstream. Pickup along the channel appears fairly consistent given the distance between measurement locations.

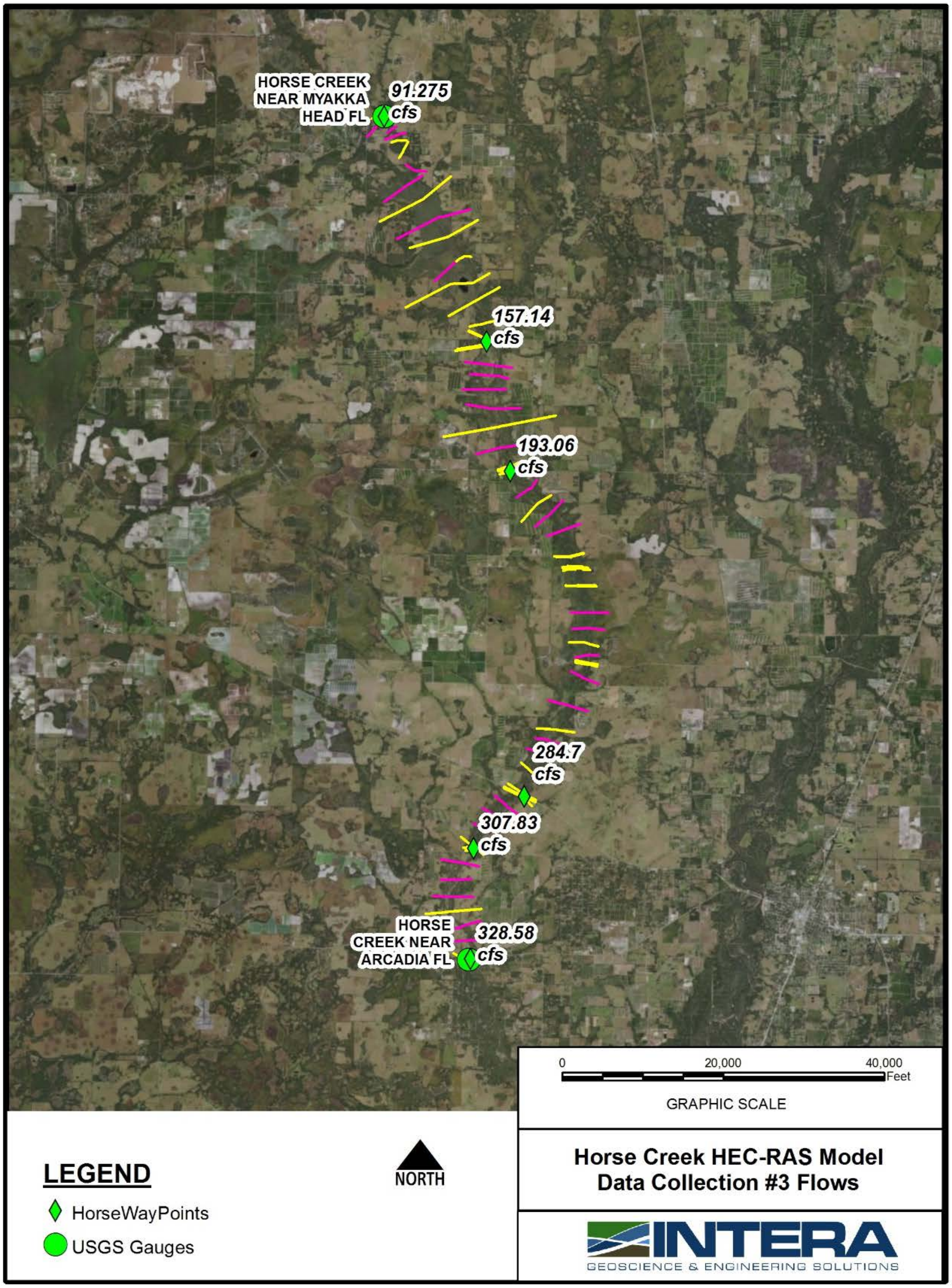

Figure 13. Average Flows at Selected Locations, High Flow Measurement

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 Horse Creek, while the medium and high flow events were measured at 6 locations along Horse 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
007/ Horse Creek near Myakka Head	0.65	8	91
008	Not measured	27	157
009	0.186	28	193
010	Not measured	33	Not measured
011	0.988	43	285
012	Not measured	47	308
099/ Horse Creek near Arcadia	Not measured	Not measured	329

All flows shown above were measured by INTERA. Additional flow measurements from the USGS are available at the USGS gauges at the upstream and downstream model boundaries. As shown above, pickup was fairly consistent along the creek. The above dataset will be incorporated into the HEC-RAS model as additional flow profiles. 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 and flow calibration data that was available for model calibration, it was decided to collect additional stage data at 3 locations along the modeled section to refine the model calibration. Additional stage data was collected at 3 locations along Horse Creek: Goose Pond Road, County Road 665, and State Road 70 (Figure 14).

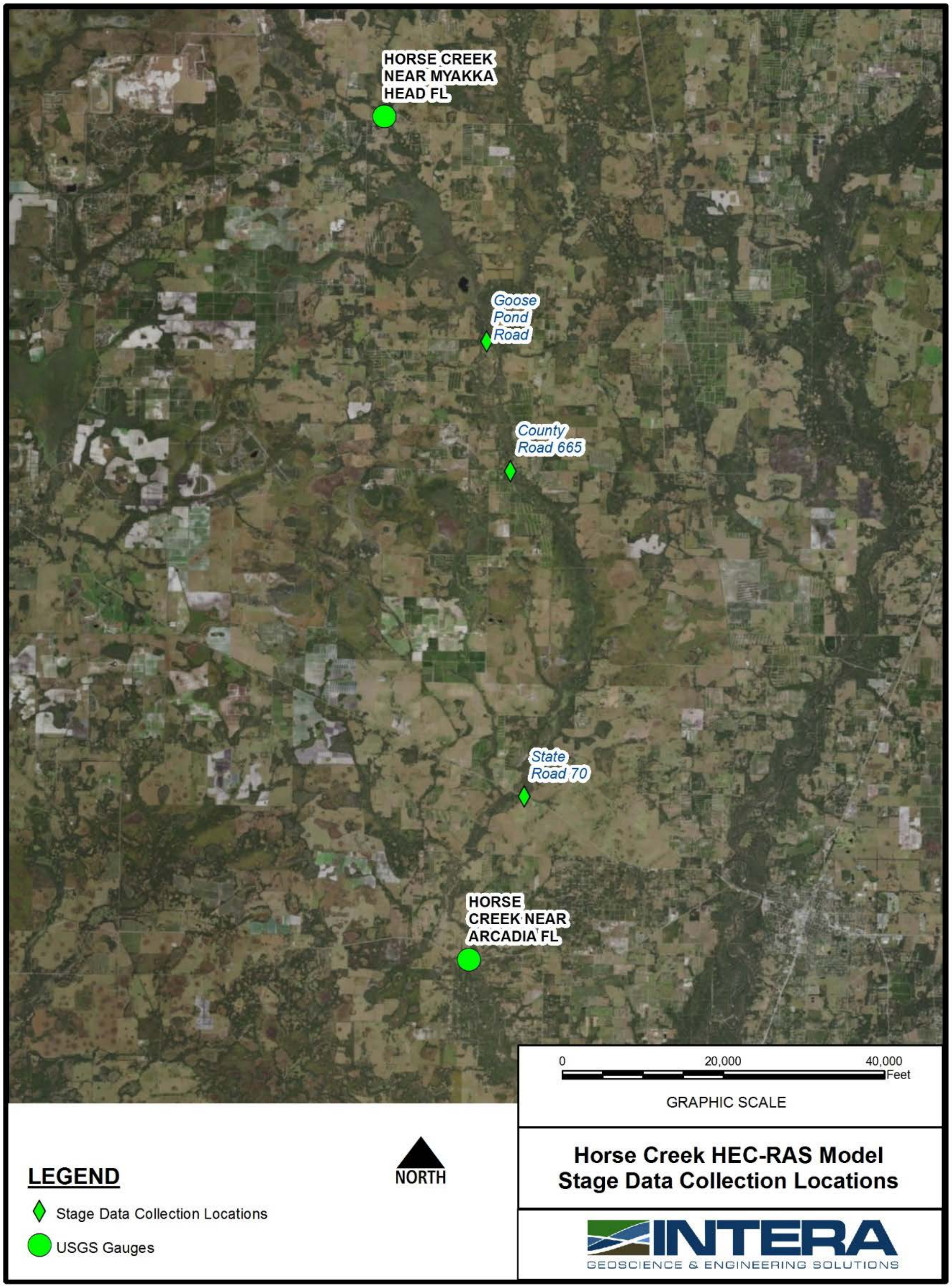

Figure 14. Stage Data Collection Locations

Three HOBO Water U20L-04 Water Level Loggers (with a range of 0 to 13 feet) were installed on Horse Creek to measure the water level (recorded in pounds per square inch of absolute pressure, psia) and temperature at Goose Pond Road, County Road 665, State Road 70, and barometric pressure in the area. These locations were selected due to ease of site access and because they would provide model constraint throughout the modeled section of Horse Creek. 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. Raw measurements from the four loggers are shown in Figure 15 through Figure 18. Barometric pressure was used to correct the water level records to produce a relative pressure records. 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 Goose Pond Road, County Road 665, and State Road 70 were surveyed by DeGrove Surveyors on August 3, 2018. The surveyed water surface elevations of 57.83-feet above NAVD88 at Goose Pond Road, 54.26-feet above NAVD88 at County Road 665, and 35.20-feet above NAVD88 at State Road 70 on August 3, 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 three locations. 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.

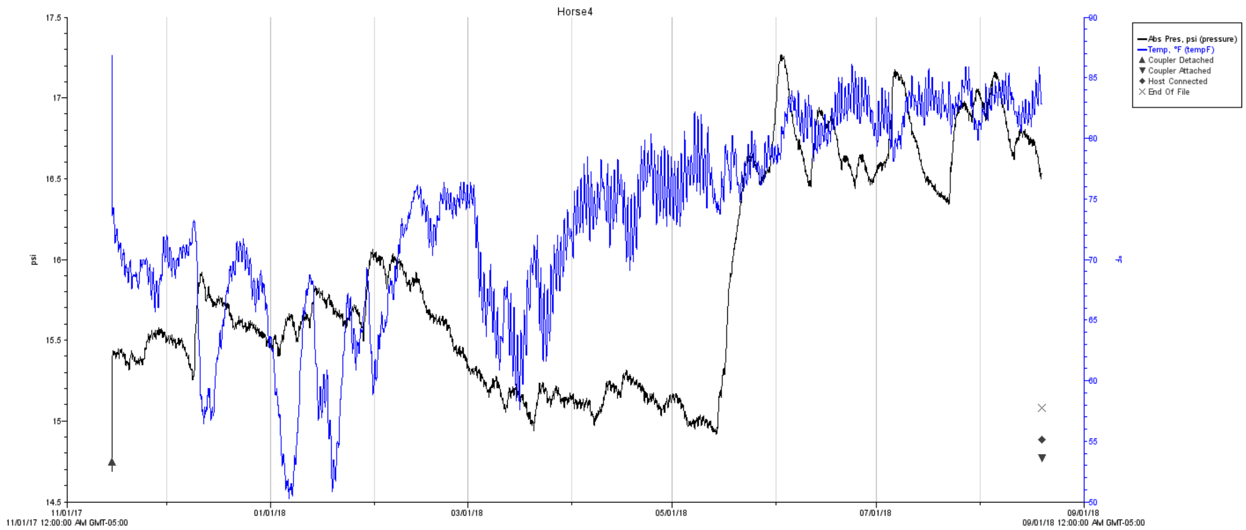

Figure 15. Water Level (psi) and Temperature (ºF) at Goose Pond Road Bridge

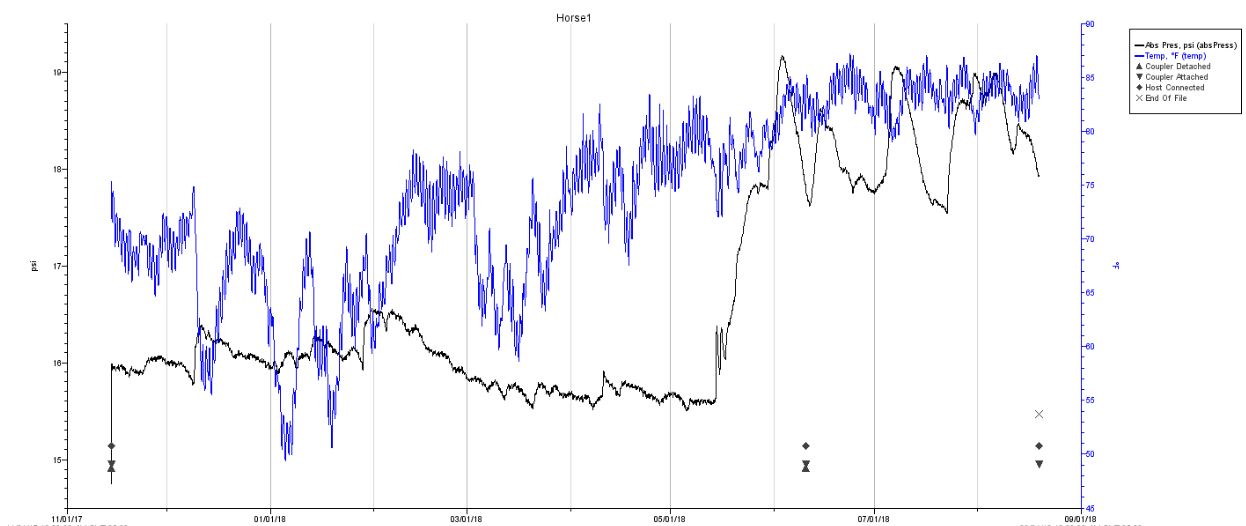

Figure 16. Water Level (psi) and Temperature (ºF) at County Road 665

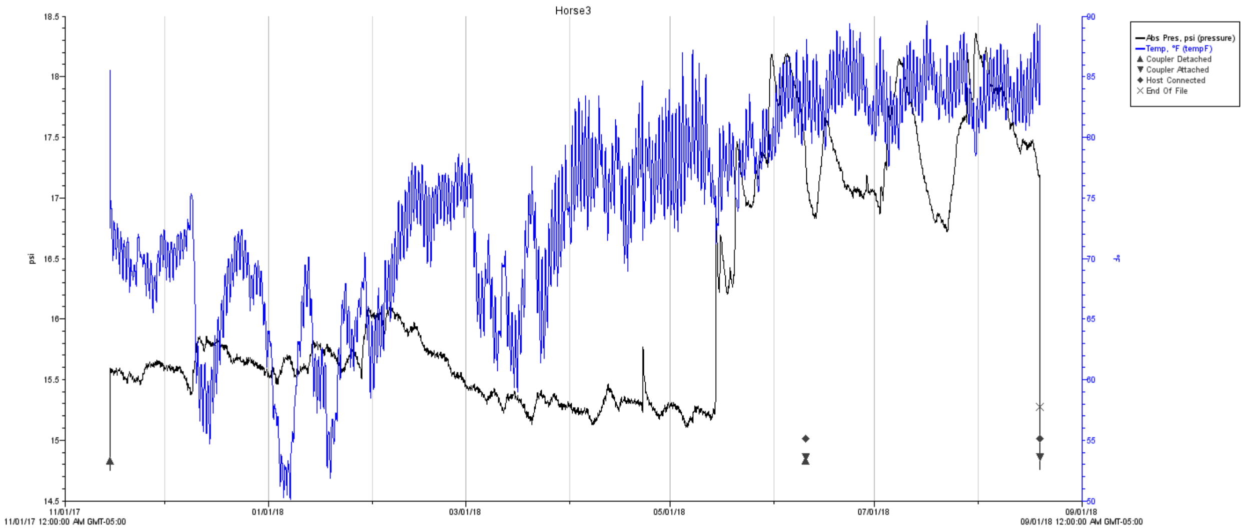

Figure 17. Water Level (psi) and Temperature (ºF) at State Road 70

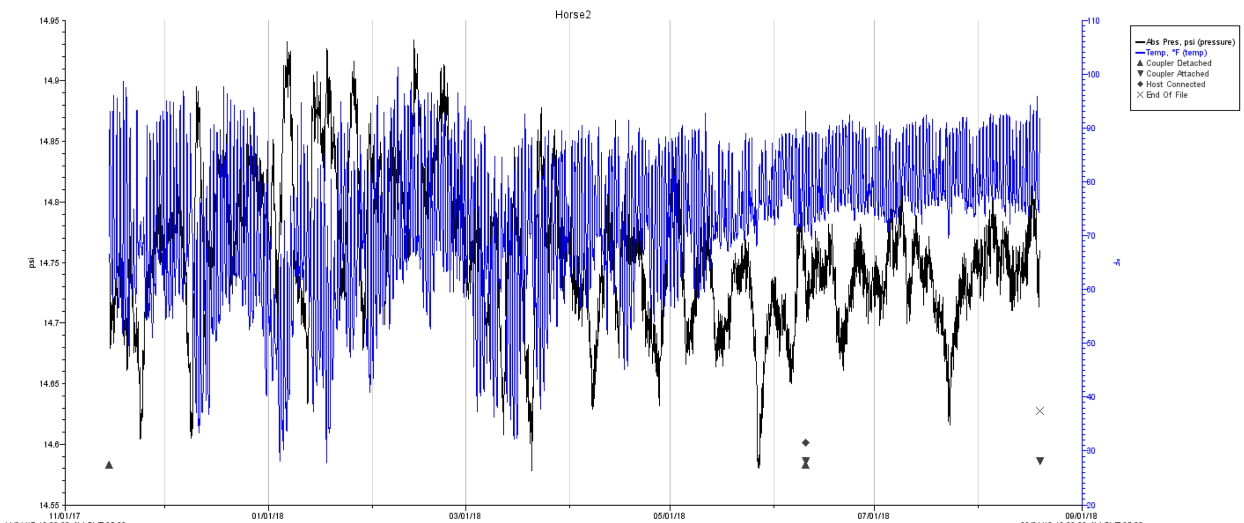

Figure 18. Barometric Pressure (psi) and Temperature (ºF)

Water surface elevations at the stage data collection locations are compared to the upstream and downstream model boundary stages in Table 22 and Figure 19. The results were examined in conjunction with the USGS stage measurements near Myakka and Arcadia, with good agreement in the shape of the stage records (Figure 19). Data collection extended from November 14, 2017 through August 19, 2018. As shown, on the day of stage measurements, there was over 52-feet of drop in stage over the entire modeled section.

Table 22. Stage Measurements, August 3, 2018

Location	Water Surface Elevation, feet above NAVD88
USGS Horse Creek near Myakka	74.34
Goose Pond Road Bridge	57.83
County Road 665	54.26
State Road 70	35.20
USGS Horse Creek near Arcadia	22.11

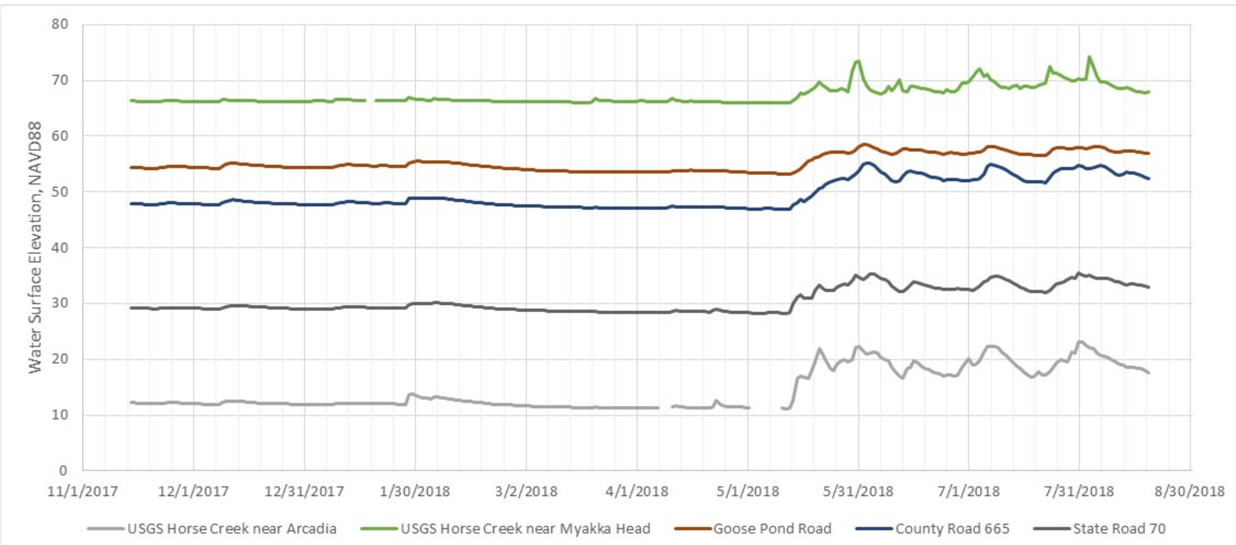

Figure 19. Stage Comparison, USGS Gauges, Goose Pond Road, County Road 665, and State Road 70

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 November 14, 2017 through August 19, 2018, as well as the stages and flows measured by the USGS at the Horse Creek near Myakka Head gauge and the Horse Creek near Arcadia gauge (Table 23).

Table 23. Calibration Profiles: Observed Flows and Stages

Profile Name	Flow, cfs		Stage, feet NAVD 88				
	USGS Arcadia	USGS Myakka	Myakka	Goose Pond	County Road 665	State Road 70	Arcadia
PF1	265.00	78.90	68.23	56.17	52.80	32.12	16.66
PF2	306.00	110.00	68.61	56.68	52.15	32.40	17.25
PF3	445.00	68.70	68.21	57.31	53.32	32.98	18.47
PF4	667.00	99.30	68.67	57.56	54.01	34.39	20.76
PF5	871.00	184.00	70.74	58.16	54.58	34.45	21.16

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. The flow profiles were incorporated into the updated model, which includes all new and extended cross sections. Flow change locations do not correspond to vegetative cross section locations. In general, flows the most upstream cross section correspond to the flows at the USGS Horse Creek near Myakka gauge. In some cases, slight adjustments were made to the flow at River Station 171902.2 to account for hysteresis, storage in the system, and potential flow measurement error in order to maintain continuity between flow profiles. 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	Reach	RS	PF1	PF2	PF3	PF4	PF5
HorseCr	UpperReach	171902.2	58.30	67.32	68.70	99.00	191.62
HorseCr	UpperReach	150443.2	95.40	110.16	160.20	240.12	313.56
HorseCr	UpperReach	129660.5	135.15	156.06	226.95	340.17	444.21
HorseCr	UpperReach	104926.9	151.05	174.42	253.65	380.19	496.47
HorseCr	East	86606.43	82.15	94.86	137.95	206.77	270.01
HorseCr	LowerReach	79453.61	166.95	192.78	280.35	420.21	548.73
HorseCr	LowerReach	66049.37	174.90	201.96	293.70	440.22	574.86
HorseCr	LowerReach	37235.93	227.90	263.16	382.70	573.62	749.06
HorseCr	LowerReach	23380.24	249.10	287.64	418.30	626.98	818.74
HorseCr	LowerReach	29.54714	265.00	306.00	445.00	667.00	871.00
WestTrib	West	5260.038	82.15	94.86	137.95	206.77	270.01

The initial simulation results of the revised model showed that the model performance slightly exceeded the 6-inch residual 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 Horse 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):

$$n = m(n_b + n_1 + n_2 + n_3 + n_4) \qquad (2)$$

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 Horse Creek was calculated in order to determine whether or not Horse 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:

$$SI = \frac{curvilinear\ length}{Euclidean\ distance} = \frac{171873\ feet}{105205\ feet} = 1.63$$

The calculated sinuosity index of 1.63 classifies Horse 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 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. The resulting calibrated stages for the USGS Horse Creek near Myakka gauge, Goose Pond Road Bridge, County Road 665, and State Road 70 are shown in Table 27.

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

Reach	River Station From	River Station to	n	n_1	n_2	n_3	n_4	m	Composite Channel n
Upper	171902.2	157898.1	0.04	0.001	0.015	0.01	0.001	1.1	0.0737
	154791.4	136148.1	0.04	0.001	0.015	0.01	0.001	1.3	0.0871
	136067.7	86760.24	0.04	0.001	0.015	0.02	0.001	1.5	0.1155
East	86606.43	79589.18	0.04	0.001	0.015	0.02	0.001	1.5	0.1155
Lower	79453.61	66079.96	0.04	0.001	0.015	0.02	0.001	1.5	0.1155
	66049.37	43130.62	0.04	0.001	0.015	0.01	0.001	1.5	0.1005
	37523.64	29.54714	0.04	0.001	0.015	0.02	0.020	1.5	0.1455

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

Reach	River Station From	River Station to	n	n_1	n_2	n_3	n_4	m	Composite Floodplain n
Upper	171902.2	123252.1	0.073	0.001	0.015	0.02	0.17	1.3	0.3627
	121093.1	117085.2	0.073	0.001	0.015	0.005	0.15	1.3	0.3172
	114412.3	109789.7	0.073	0.001	0.015	0.005	0.12	1.3	0.2782
	105771.1	86760.24	0.073	0.001	0.015	0.005	0.05	1.3	0.1872
East	86606.43	79589.18	0.073	0.001	0.015	0.005	0.05	1.3	0.1872
Lower	79453.61	29.54714	0.073	0.001	0.015	0.005	0.05	1.3	0.1872

As shown, all model residuals (defined as the simulated stage minus the observed stage) are within 0.5-feet. The model shows good performance over all flow regimes. Note that for bridge cross sections, the simulated model stage is taken as the average of the 4 bridge cross section stages for a given flow profile. The stage at Myakka is compared to the stage at the upstream model boundary condition (RS 171902.2).

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

Profile Name	Myakka			Goose Pond Road			County Road 665			State Road 70		
	Obs.	**Sim.**	**Residual**	**Obs.**	**Sim.**	**Residual**	**Obs.**	**Sim.**	**Residual**	**Obs.**	**Sim.**	**Residual**
PF1	68.23	68.06	-0.16	56.17	56.26	0.09	52.80	52.31	-0.49	32.12	32.17	0.04
PF2	68.61	68.24	-0.37	56.68	56.55	-0.14	52.15	52.60	0.45	32.40	32.37	-0.03
PF3	68.21	68.27	0.06	57.31	57.26	-0.05	53.32	53.39	0.07	32.98	33.01	0.03
PF4	68.67	68.84	0.18	57.56	57.95	0.39	54.01	54.26	0.25	34.39	33.92	-0.47
PF5	70.74	70.34	-0.39	58.16	58.40	0.24	54.58	54.81	0.23	34.45	34.54	0.09
Avg.	**68.89**	**68.75**	**-0.14**	**57.18**	**57.28**	**0.11**	**53.37**	**53.47**	**0.10**	**33.27**	**33.20**	**-0.07**

Validation

In order to verify the model calibration and performance, the validation data set from previous modeling efforts for Horse 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 3 (T3). Since current modeling efforts did not utilize observed stage data at T3, 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

River	Reach	RS	PF 1	PF 2	PF 3	PF 4	PF 5	PF 6	PF 7	PF 8
HorseCr	UpperReach	171902.20	8.00	12.00	12.00	13.00	31.68	83.00	93.00	105.00
HorseCr	UpperReach	150443.20	17.28	26.28	35.64	40.68	51.84	103.32	154.44	228.96
HorseCr	UpperReach	129660.50	24.48	37.23	50.49	57.63	73.44	146.37	218.79	324.36
HorseCr	UpperReach	104926.90	27.36	41.61	56.43	64.41	82.08	163.59	244.53	362.52
HorseCr	East	86606.43	14.88	22.63	30.69	35.03	44.64	88.97	132.99	197.16
HorseCr	LowerReach	79453.61	30.24	45.99	62.37	71.19	90.72	180.81	270.27	400.68
HorseCr	LowerReach	66049.37	31.68	48.18	65.34	74.58	95.04	189.42	283.14	419.76
HorseCr	LowerReach	37235.93	41.28	62.78	85.14	97.18	123.84	246.82	368.94	546.96
HorseCr	LowerReach	23380.24	45.12	68.62	93.06	106.22	135.36	269.78	403.26	597.84
HorseCr	LowerReach	29.55	48.00	73.00	99.00	113.00	144.00	287.00	429.00	636.00
WestTrib	West	5260.04	14.88	22.63	30.69	35.03	44.64	88.97	132.99	197.16

Results of the model validation are shown in Table 29. The maximum residual at the upstream boundary (the Myakka gauge) was 0.31-feet. This represents an improvement from the previous model validation (INTERA 2016), which showed a maximum residual of 0.92 feet for the same validation flows. Similarly, the maximum residual at T3 decreased from 0.9 in the original 2016 calibration to 0.52 for the updated calibration.

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

Profile Name	**USGS Myakka**			**Transect T3**		
	Observed	*Simulated*	*Residual*	*Observed*	*Simulated*	*Residual*
PF1	66.32	66.57	0.25	48.77	48.79	0.02
PF2	66.51	66.77	0.26	49.47	49.68	0.21
PF3	66.65	66.77	0.12	49.99	50.31	0.32
PF4	66.71	66.82	0.11	50.05	50.57	0.52
PF5	67.21	67.44	0.23	50.69	51.11	0.42
PF6	68.24	68.55	0.31	52.77	52.50	-0.27
PF7	68.46	68.73	0.27	53.82	53.34	-0.48
PF8	68.71	68.95	0.24	54.46	54.20	-0.26
Average	**67.35**	**67.58**	**0.22**	**51.25**	**51.31**	**0.06**

Predictive Simulations

The flow at the upstream and downstream boundaries, i.e. the gauge locations, of the model was needed for the HEC RAS flow profiles for predictive simulations. The long-term record for the U.S Geological Survey (USGS) gauge Horse Creek near Arcadia was provided by the District and contained seasonally corrected flows from PRMS modeling. The observed USGS record was used to develop a rating curve for the Horse Creek near Arcadia gauge so that the Arcadia stage could be calculated based on the corrected Arcadia flows. Refer to the report *Horse Creek HEC-RAS Steady State Model Development* (INTERA, 2016) for additional information.

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 30. USGS Horse Creek near Arcadia percentile flows and water surface elevation from 5/1/1950 to 8/27/2014 (as corrected and provided by the District)

Percentile	Horse Creek near Arcadia Flow (based on PRIMs model),* cfs	Horse Creek near Arcadia Water Surface Elevation, feet above NAVD88*
5	0.9	10.91
10	2.7	11.15
20	6	11.36
30	12	11.60
40	21	11.94
50	38	12.47
60	65	13.11
70	117	14.03
80	265	16.66
90	468	17.40
95	759.6	18.97
99	1787	22.99

* From Table 15 of *Horse Creek HEC-RAS Steady State Model Development* (INTERA, 2016)

Table 31. Flow profiles for predictive simulations

Reach	River Station	PER5	PER10	PER20	PER30	PER40	PER50	PER60	PER70	PER80	PER90	PER95	PER99
UpperReach	171902.2	0.20	0.59	1.3	2.6	4.6	8.4	14.3	25.7	58.3	103.0	167.2	393.1
UpperReach	150443.2	0.32	1.0	2.2	4.3	7.6	13.7	23.4	42.1	95.4	168.5	273.6	643.3
UpperReach	129660.5	0.46	1.4	3.1	6.1	10.7	19.4	33.2	59.7	135.2	238.7	387.6	911.4
UpperReach	104926.9	0.51	1.5	3.4	6.8	12.0	21.7	37.1	66.7	151.0	266.8	433.2	1019
East	86606.43	0.28	0.84	1.9	3.7	6.5	11.8	20.2	36.3	82.2	145.1	235.6	554.0
LowerReach	79453.61	0.57	1.7	3.8	7.6	13.2	23.9	41.0	73.7	167.0	294.8	478.8	1126
LowerReach	66049.37	0.59	1.8	4.0	7.9	13.9	25.1	42.9	77.2	174.9	308.9	501.6	1179
LowerReach	37235.93	0.77	2.3	5.2	10.3	18.1	32.7	55.9	100.6	227.9	402.5	653.6	1537
LowerReach	23380.24	0.85	2.5	5.6	11.3	19.7	35.7	61.1	110.0	249.1	439.9	714.4	1680
LowerReach	24.54714	0.90	2.7	6.0	12.0	21.0	38.0	65.0	117.0	265.0	468.0	759.6	1787
West	5260.080	0.28	0.84	1.9	3.7	6.5	11.8	20.2	36.3	82.2	145.1	235.6	554.0

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

Percentile	T1 (RS 133173.7)	T2 (RS 130106.4)	T3 (RS 105771.1)	T4 (RS 69388.88)	T5 (RS 52310.68)	T6 (RS 43130.62)
PER5	52.17	51.64	45.90	37.72	34.00	28.56
PER10	52.25	51.76	46.01	38.00	34.32	28.66
PER20	52.32	51.92	46.12	38.31	34.68	29.22
PER30	52.51	52.31	46.72	38.59	35.00	30.01
PER40	53.06	52.74	47.36	38.66	35.38	30.62
PER50	53.71	53.33	48.25	38.66	35.95	31.42
PER60	54.37	53.98	49.42	38.96	36.60	32.28
PER70	55.21	54.81	50.65	39.68	37.35	33.45
PER80	56.34	55.95	51.96	40.83	38.01	34.75
PER90	57.84	57.39	53.53	42.54	38.64	35.87
PER95	58.78	58.23	54.58	43.54	39.08	36.49
PER99	60.56	59.94	56.26	45.07	40.17	37.70

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 20 through Figure 23. The area of the inundation polygons for each percentile flow is provided in Table 33 . The corresponding USGS Horse Creek near Arcadia flow and water surface elevations are also provided. Comparison of the inundation area at the transect level is shown in Figure 24 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 Horse Creek near Arcadia percentile flows and HEC-RAS predictive simulation area of inundation

Percentile	Flow (based on PRIMs model), cfs	Water Surface Elevation, feet above NAVD88*	Inundation Area, acres
5	0.9	10.91	2.5
10	2.7	11.15	15.8
20	6	11.36	25.4
30	12	11.60	34.8
40	21	11.94	43.4
50	38	12.47	102
60	65	13.11	188
70	117	14.03	291
80	222	15.40	698
90	468	17.40	2148
95	760	18.97	3098
99	1787	22.99	5000

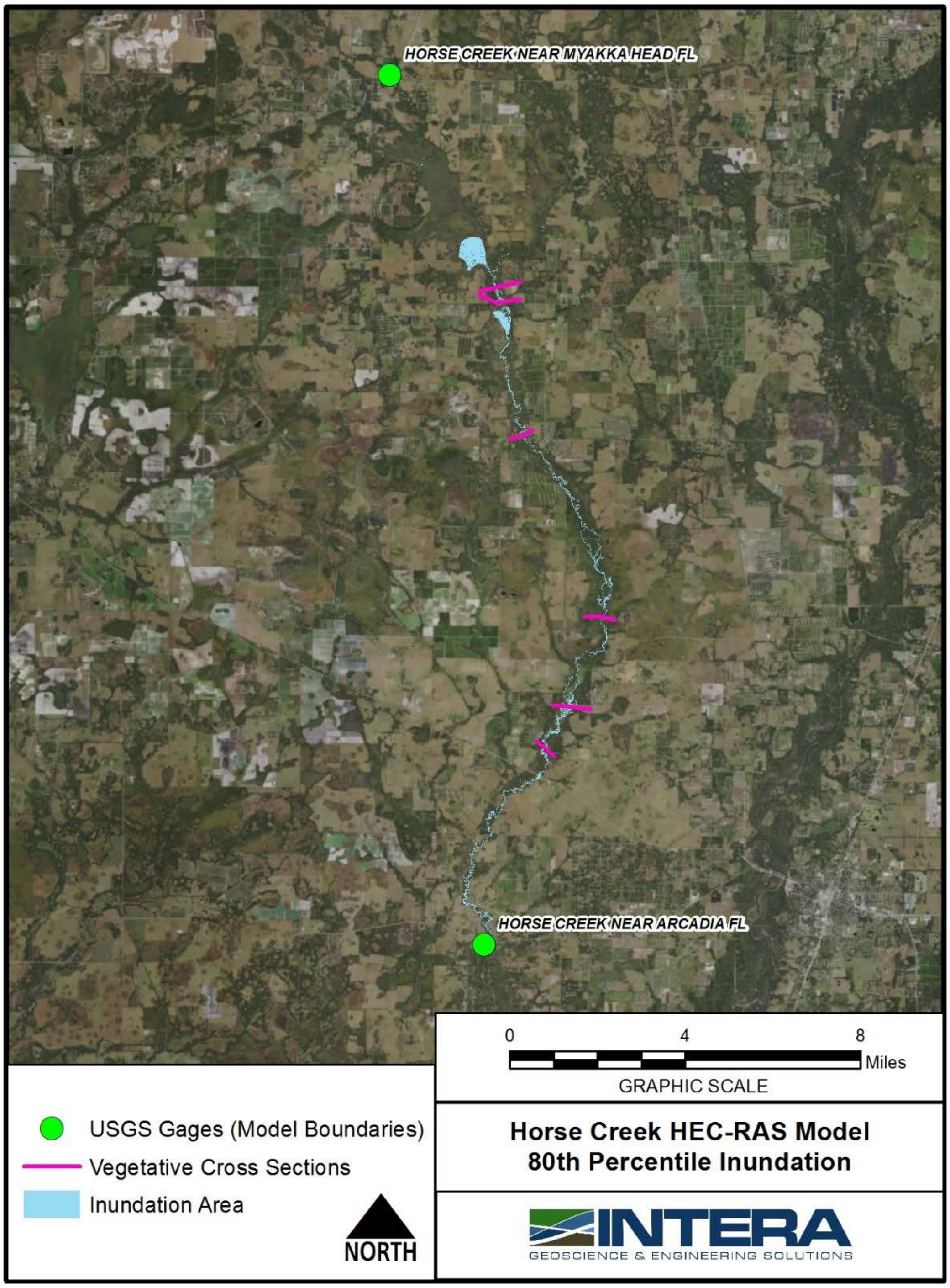

Figure 20. Inundation area for 80th percentile flow

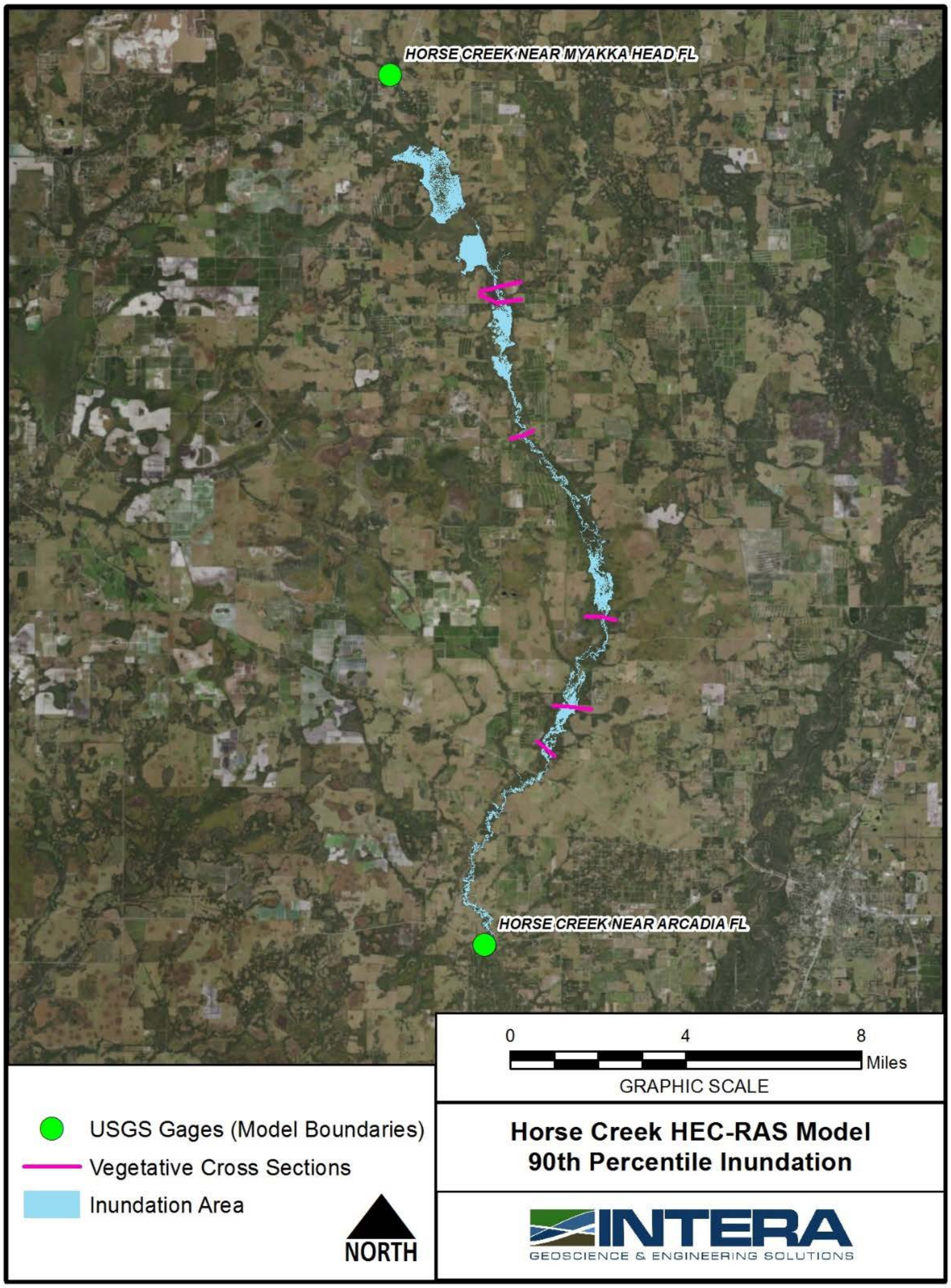

Figure 21. Inundation area for 90th percentile flow

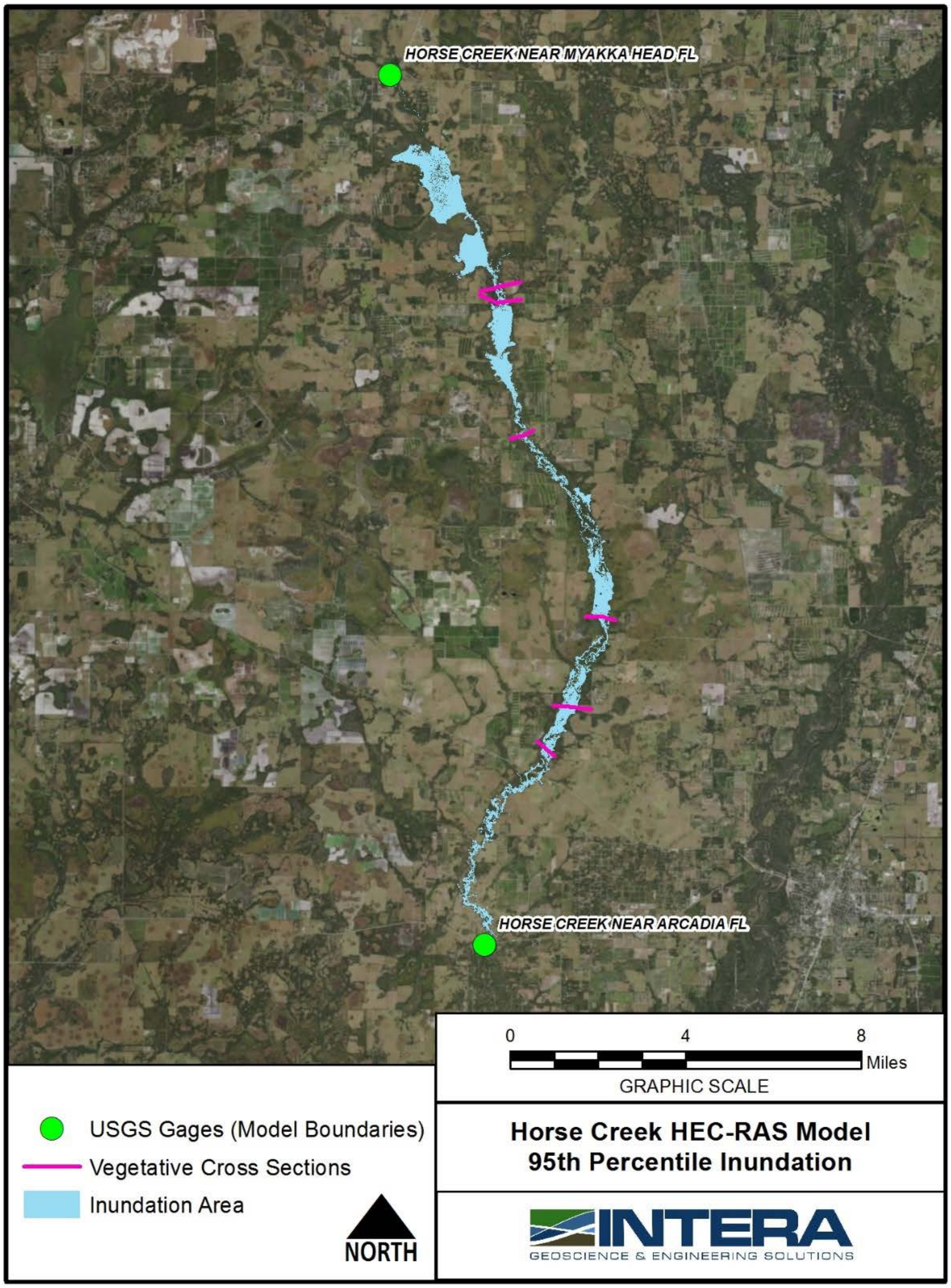

Figure 22. Inundation area for 95th percentile flow

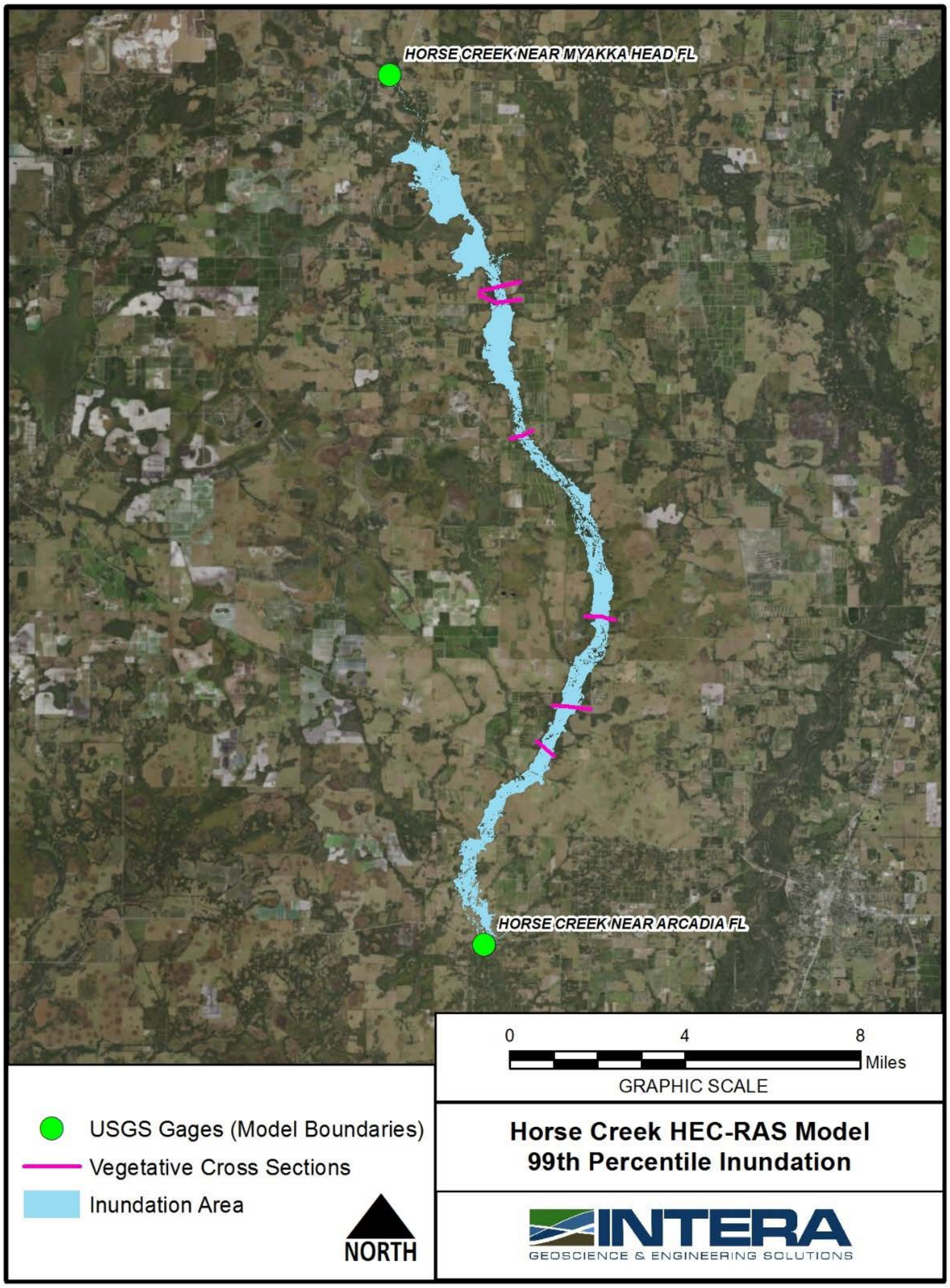

Figure 23. Inundation area for 99th percentile flow

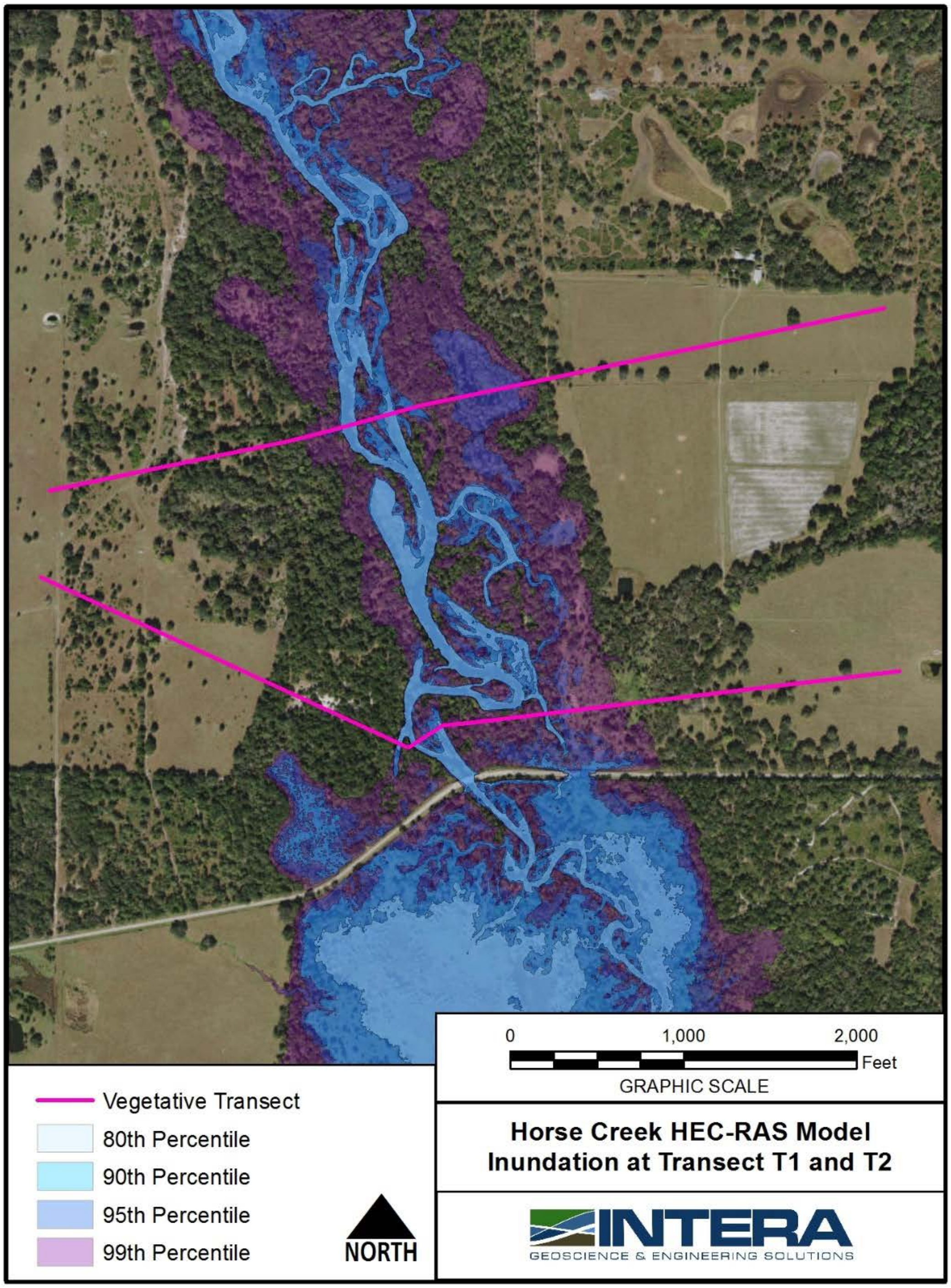

Figure 24. Inundation Comparison: T1 and T2

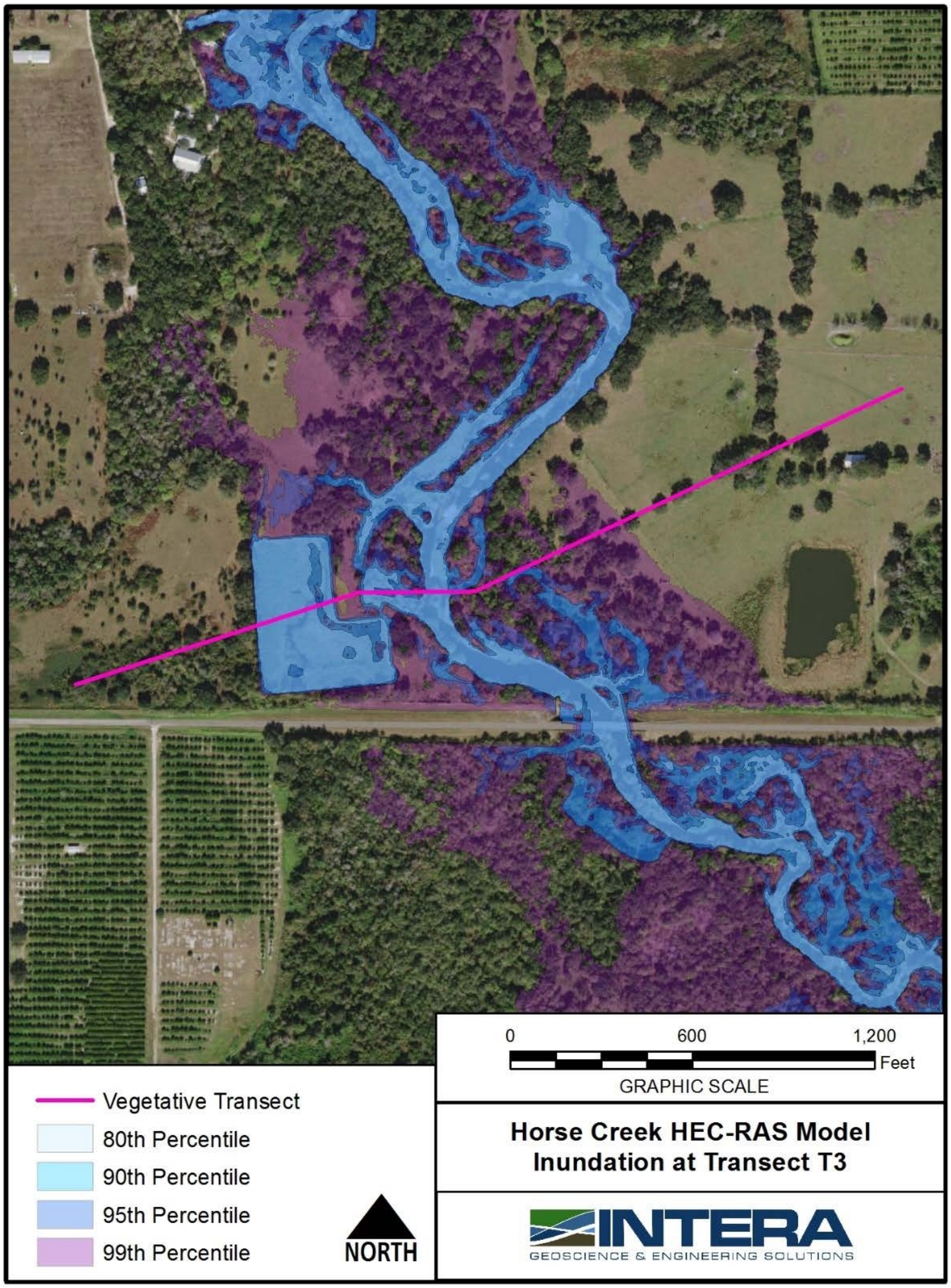

Figure 25. Inundation Comparison: T3

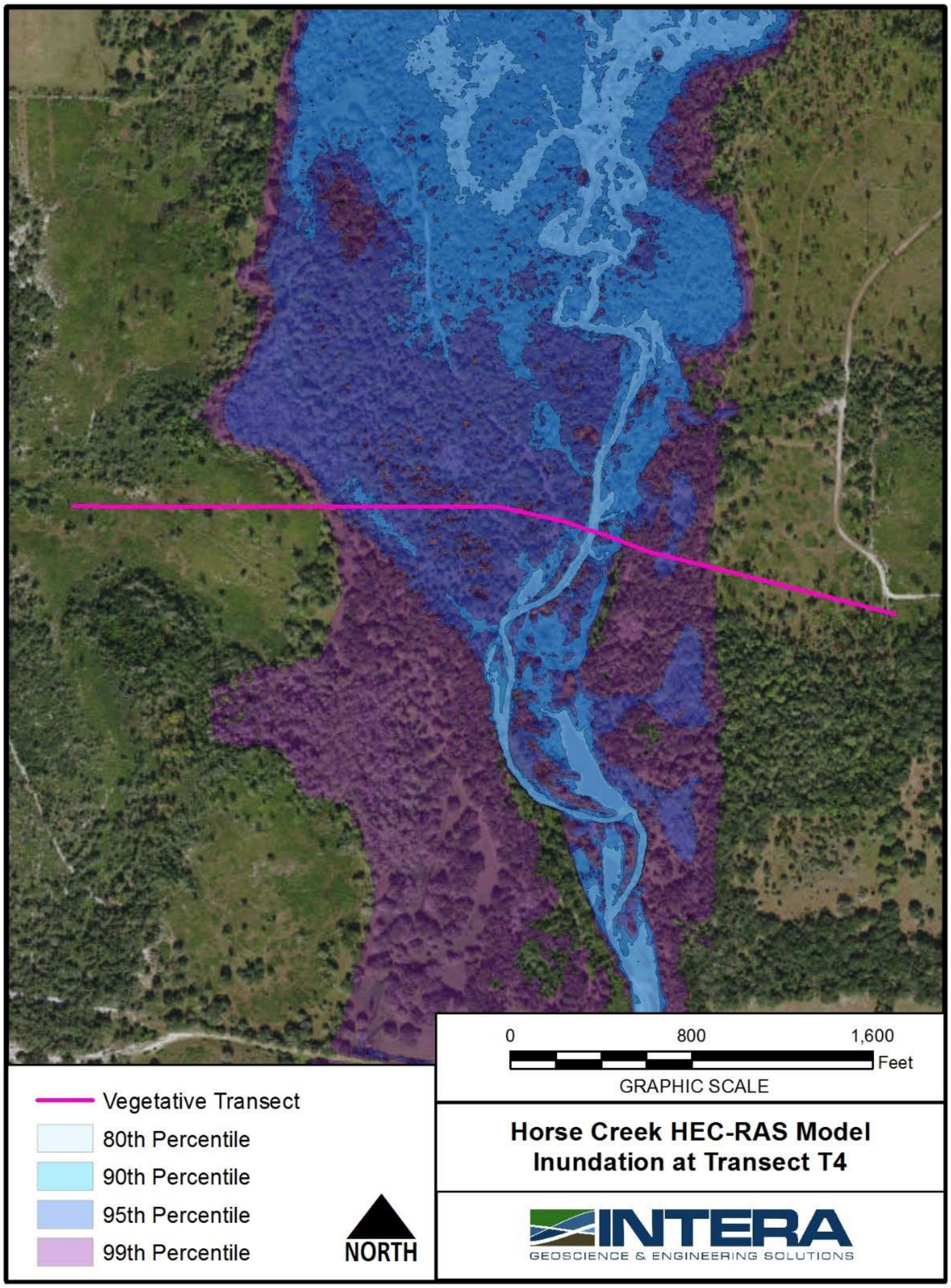

Figure 26. Inundation Comparison: T4

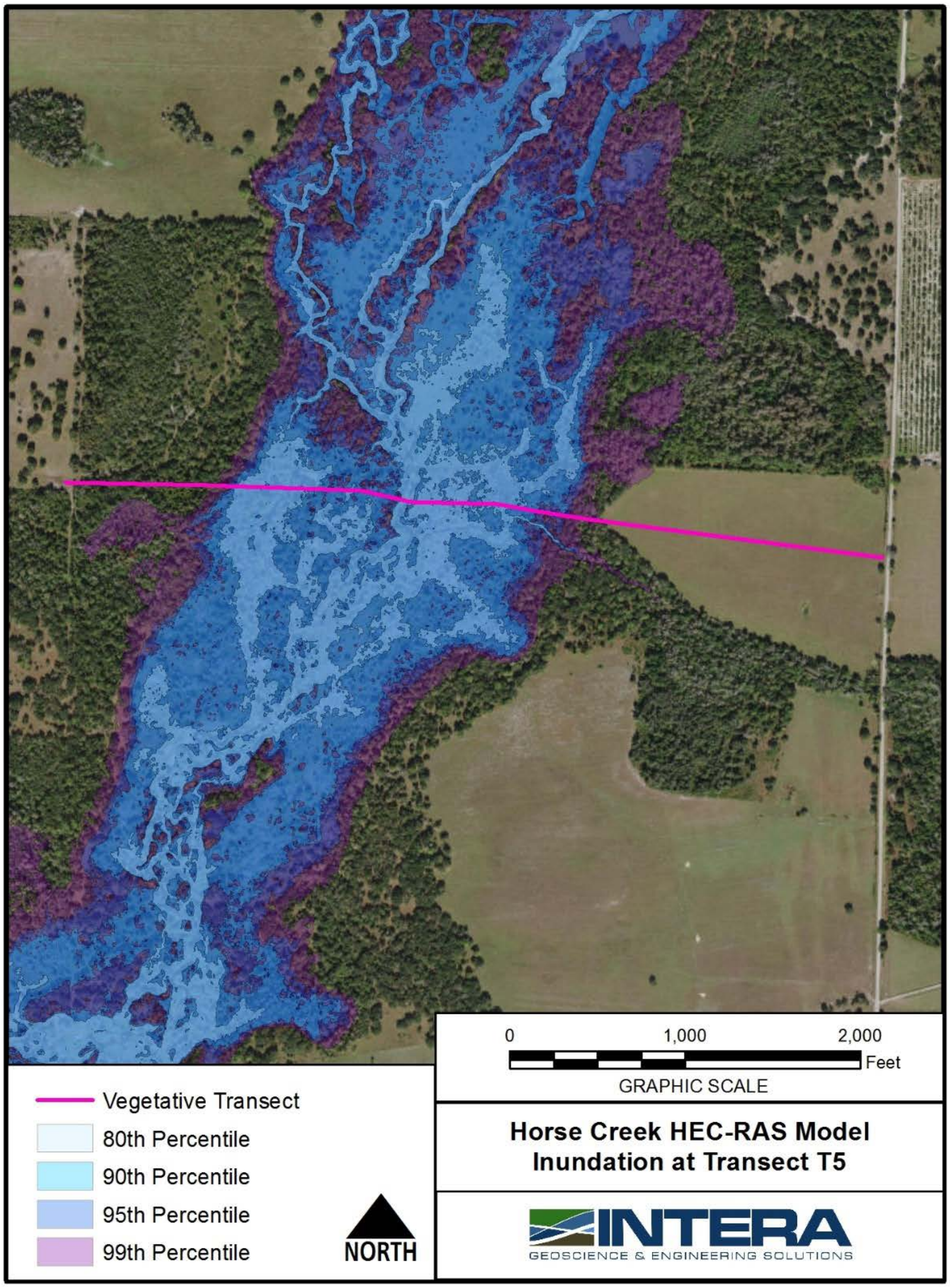

Figure 27. Inundation Comparison: T5

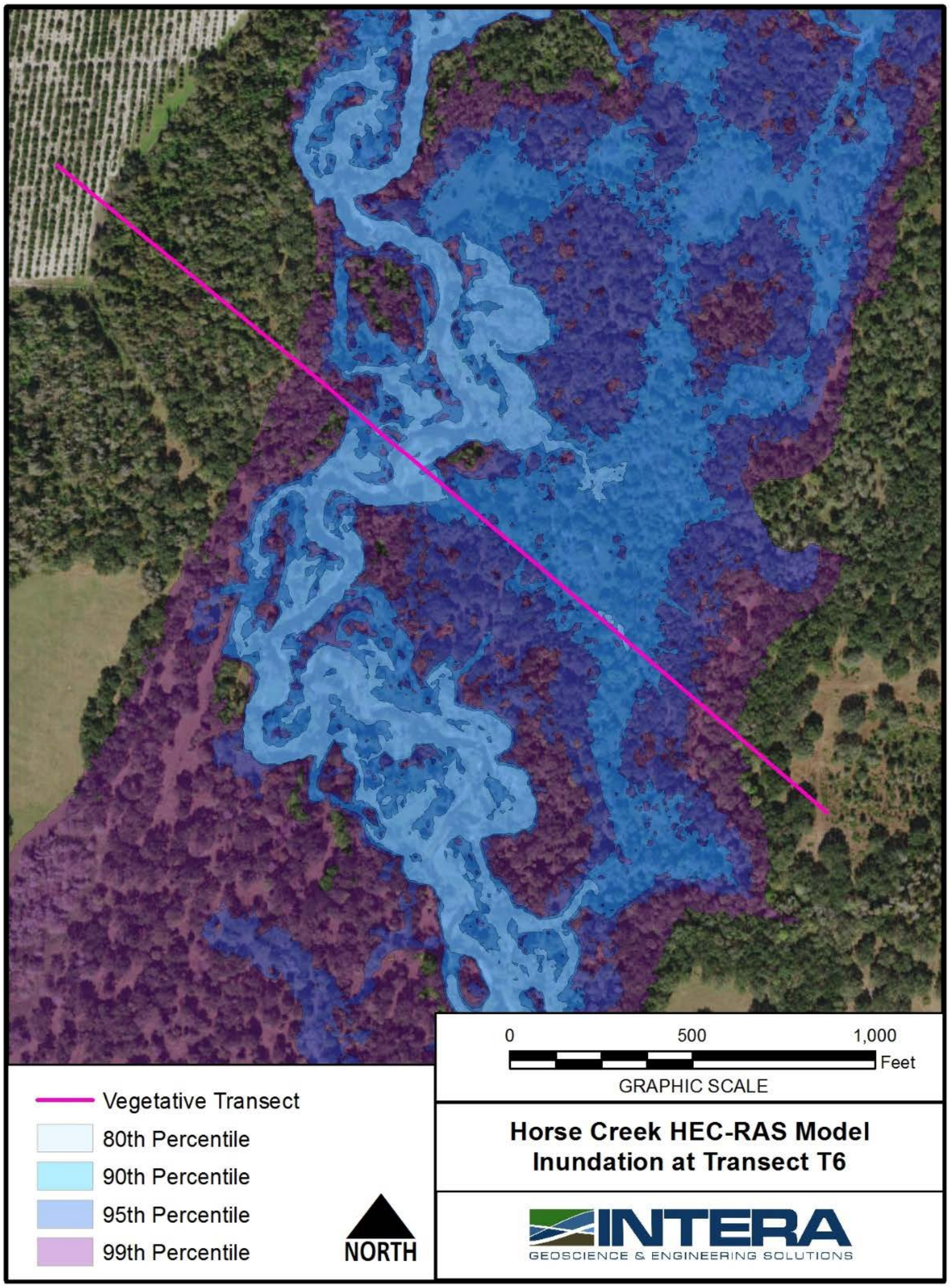

Figure 28. Inundation Comparison: T6

Conclusions

The HEC-RAS model representing Horse Creek was enhanced with additional model cross sections that adequately encompassed floodplain wetlands and re-calibrated with data obtained from additional data collection efforts. The resulting model outperforms the original model during both the calibration and verification simulations. Additional data collection greatly improved the understanding of the pickup in the Horse Creek system and improved the overall model calibration. 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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