Evaluation of the Impacts of Storm Surge Flooding on the Hydrology and Water Quality of the Near-shore Environment and on Coastal Aquifers in Sewered and Un-sewered Communities

Final Report

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Background

The initial purpose of this investigation was to examine the effect of tropical storm system surge on the hydrology of a coastal karst aquifer springshed, and on the impacts of domestic sewage treatment processes in canal and levee coastal development areas. Lack of a significant storm event during the study period precluded that goal, however, valuable information on the dynamics of the Woodville Karst plane aquifer, and tidal effects on gravity sewer and septic tank serviced areas was obtained and outlined in this report.

This report is in two major sections. The Woodville Karst Plain hydrological investigations are in part one, on the page immediately following. The water quality impacts study follows that report beginning on page 38.

Part 1.

Woodville Karst Plain
Hydrologic Research Program

Report on Tasks Performed in 2011 & 2012
Under FDEP Contract RM100 Amendment #3

June 15, 2012

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OVERVIEW

GeoHydros, LLC was sub-contracted by the University of West Florida (UWF) in 2011 under contract# RM100 Amendment #3 with the Florida Geological Survey (FGS) to continue ongoing hydrogeologic characterization and modeling activities in the Woodville Karst Plain (WKP) of north Florida focusing on how sea-level rise and groundwater pumping impacts the coastal and near-coastal ecosystems. Analyses were to be performed using a dual-permeability numerical model of groundwater flow through the WKP to the Gulf of Mexico that is being developed by GeoHydros for the FGS. This contract primarily provided for revisions to that model intended to include: 1) a comprehensive assessment of groundwater pumping from the Floridan Aquifer System (FAS) within the groundwater basins encompassing the WKP; and 2) results of a groundwater tracer test, to be performed under this contract, intended to delineate the eastern extent of the Wakulla springshed. Additional tasks under this contract included the continued maintenance of the network of hydrologic and water level meters that are deployed in the WKP, and preparation and transfer of electronic educational materials regarding karst and groundwater flow in the WKP to the Hydrogeology Consortium.

There were four specific tasks identified in the contract. Task-A1 provided for support for FGS staff to maintain the network of Falmouth hydraulic meters, water level loggers, and water parameter probes deployed and operating in the WKP; and uploading the data to the project database. Task-A2 provided for the model revisions and scenario analyses. Task-A3 provided for the electronic document preparation and delivery. Task-A4 provided for the groundwater tracer test.

As has been the case with previous year's work, time and budget assignments on a sub-task level were shifted, with approval from the FGS Program Manager, during the course of the year in order to accommodate the unforeseen problems. Specifically, some funds and energy were shifted away from the electronic data preparation and transfer, and meter data analysis tasks, and diverted to the model revision effort. Table 1 summarizes the work performed. The remainder of this report provides a more detailed description of the work performed on Tasks A1, A2, and A4.

Table 1. Summary of work performed for each sub-task defined in the scope of work for RM100 Amendment #3.

Task	Description	Work Summary
A1	Meter Network Maintenance	All meters were downloaded regularly and uploaded to the project database. The Falmouth data and some of the water level data are available through the online project database. The storm surge piezometers were downloaded regularly, and removed after the contract period. Most of the reference elevations at all water level recorder stations have been calculated.
A2	Model Revision & Scenario Analyses	All municipal and agricultural pumping data in the model region have been compiled and formatted for model input. All available geologic data have been compiled and interpreted to identify the structural surface of the key hydrostratigraphic units. All available flow and head data have been compiled from which the calibration datasets will be derived.
A3	Electronic Data Preparation and Transfer	All materials related to the Hydrogeology Consortium have been compiled and transferred. Educational materials related to the WKP and Florida's groundwater including the Florida's Awesome Aquifer materials and WKP maps have been delivered to the Hydrogeology Consortium and the Tallahassee Community College.
A4	Groundwater Tracer Test	One tracer injection was performed at Bird Sink, which is the largest of the NE swallets. Sampling was conducted for 3 months at Horn, Newport, Rhodes, Wacissa-Big Blue, and Wakulla Springs as well as at the St. Marks River Rise. The tracer was detected at multiple locations and breakthrough curves for tracer concentration have been compiled for each station where the tracer was detected.

TASK-A1 MAINTAINING THE WKP ISTRUMENTATION NETWORK

The primary objective of this task was to maintain the instrumentation network that has been established in the WKP, which includes water level and conductivity probes installed in peizometers at Shell Point and Live Oak Island to measure the effect of storm surge on shallow groundwater levels; Falmouth hydraulic meters that have been installed at various locations within the Wakulla-Leon Sinks and Spring Creek cave systems; and conductivity, temperature and depth (CTD) recorders that have been installed in various sinkholes and swallets between the Leon/Wakulla County boundary in the north and approximately one mile south of US Highway 98.

All of the devices were regularly downloaded and serviced during the contract period by FGS staff, who then transmitted the data to GeoHydros electronically. GeoHydros has uploaded all of the data to a server that is regularly backed up. All of the data from the Falmouth meters and head data collected from locations with reference elevations surveyed and provided to GeoHydros prior to January 2012 were then uploaded to the project database and rendered accessible for download and/or graphical query through the project website: http://www.geohydros.com/FGS/Meters/Query/flash/conduits_mp_flash.php.

Head, temperature, and conductivity data from the remaining meters are stored on the server and are presented graphically in this report.

Table 2 summarizes the status of the meter network. Table 3 lists the parameters measured by each of the types of devices deployed in the WKP. Tables 4-6 summarize the data recorded during the period addressed in this study (listed by meter in Table 2) by the long-term water level and CTD meters deployed in the WKP. Table 7 summarizes the data collected by the Falmouth hydraulic meters deployed in the Wakulla-Leon sinks and Spring Creek cave systems. Tables 8-9 summarize the data recorded by the meters deployed in the piezometers for the surge study.

Figure 1 shows the approximate locations of the meters. Figures 2 and 3 provide plots comparing the estimated water level elevations at the Wakulla Boat Dock with those measured at the Lost Creek swallet, Revell sink, Punchbowl sink, Tobacco sink, Sullivan sink, and Turner sink. Figure 3 also provides a plot of water depths measured at the Wakulla K-Tunnel and Wakulla B-Tunnel wells that have not been converted to elevations. Figures 4 and 5 provide plots comparing water temperatures measured at the Wakulla Boat Dock with those measured at the Lost Creek swallet, Revell sink, Punchbowl sink, Tobacco sink, Sullivan sink, and Turner sink. Figure 5 also provides a plot of electrical conductivity measured at 30 feet and 60 feet below the water surface in Punchbowl sink. Figure 6 provides a comparison of head measured in the surge study piezometers normalized to a 1-foot record range. Figure 7 provides a comparison of water temperature and electrical conductivity measured in the Shell Point and Live Oak Island piezometers that were instrumented with CTDs. As the Falmouth data is available for online download and query, it is not presented graphically in this report.

The comparative plots reveal problems with the datasets that warrant further investigation. The depth plot for the Wakulla K-Tunnel well shows a consistently rising trend in depth after a hiatus in the record that occurred between October 2008 and May 2009. The rising trend indicates a drift in measurement that will likely render the data unusable after October 2008. The Turner and Sullivan Sink data also reveal a potential problem as the water table elevation in Sullivan sink consistently plots below Turner sink, which is unlikely given their locations where Sullivan sink is several miles up-gradient from Turner sink and both are directly connected to large conduits within the Wakulla-Leon Sinks cave system.

To date, only part of the data has been corrected for barometric pressure, the data recorded by the vented Global Water devices. The Sullivan-Turner relationships indicate that the corrections are likely needed to accurately discriminate head gradients between the two locations.

Table 2. Device type, record period for study, location, and status of meters deployed in the WKP.

Station	Map ID	Device	Record Period	Active	Lat (DD)	Lon (DD)	TOC Elev (ft)	Trans Elev (ft)
BG02	BG02	Global WL16	06/22/10 – 04/11/12	No	30.093570	-84.290250	NA	NA
GS01	GS01	Global WL16	06/17/10 – 04/11/12	No	30.064450	-84.291740	NA	NA
GS02	GS02	Insitu LT 200	06/30/10 – 04/11/12	No	30.064100	-84.291750	NA	NA
ST04	ST04	Global WL16	06/22/10 – 04/11/12	No	30.069560	-84.277800	NA	NA
ST05	ST05	Insitu LT 200	06/30/10 – 04/11/12	No	30.069370	-84.277730	NA	NA
Lost Creek-3	LC3	Insitu LT 500	01/04/10 – 04/09/12	Yes	30.167898	-84.393954	18.43	0.347
Punchbowl-3	PB3	Global WL16	05/20/10 – 04/09/12	Yes	30.127730	-84.346686	7.31	0.06
Punchbowl-30	PB30	Insitu LT 200	10/24/11 – 04/09/12	Yes	30.127730	-84.346686	NA	NA
Punchbowl-60	PB60	Insitu LT 200	10/24/11 – 04/09/12	Yes	30.127730	-84.346686	NA	NA
Revell Sink-2	RS2	Insitu LT 500	11/18/09 – 04/09/12	Yes	30.182608	-84.329105	8.11	2.24
Sullivan Sink	SUL	Insitu LT 500	11/18/09 – 04/06/12	Yes	30.309166	-84.360057	10.015	4.098
Tobacco Sink	TS	Insitu LT 500	03/18/10 – 04/09/12	Yes	30.130371	-84.318280	7.62	1.71
Turner Sink	TUR	Insitu LT 500	08/25/10 – 12/26/11	No	30.265313	-84.341356	9.289	3.029
B-Tunnel Well	BT-W	Global Logger	11/18/10 – 03/29/12	Yes	30.233763	-84.301640	NA	NA
Wakulla Boat Dock	WBD	Insitu LT 500	01/04/10 – 04/09/12	Yes	30.241944	-84.302778	10.54	2.84
K-Tunnel Well	KT-W	Global Logger	02/16/06 – 04/05/12	Yes	30.228769	-84.305493	26.21	-3.707
AD Tunnel	ADT	Falmouth	02/07/04 – 04/05/12	Yes	30.232453	-84.304724	NA	NA
AK Tunnel	AKT	Falmouth	02/07/04 – 04/05/12	Yes	30.228517	-84.304808	NA	NA
K Tunnel	KT	Falmouth	02/07/04 – 04/05/12	Yes	30.228581	-84.305230	NA	NA
B Tunnel	BT	Falmouth	11/22/03 – 04/06/12	Yes	30.233763	-84.301640	NA	NA
C Tunnel	CT	Falmouth	11/25/03 – 02/26/12	Yes	30.233320	-84.301875	NA	NA
D Tunnel	DT	Falmouth	02/07/04 – 04/05/12	Yes	30.233045	-84.304708	NA	NA
Wakulla Vent	WV	Falmouth	10/29/03 – 08/26/09	No	30.235302	-84.302792	NA	NA
Revell Sink Tunnel	RST	Falmouth	09/17/10 – 04/05/12	Yes	30.182608	-84.329105	NA	NA
Spring Creek 1	SC1	Falmouth	05/20/09 – 11/02/11	No	30.080094	-84.330014	NA	NA
Spring Creek 10	SC10	Falmouth	05/28/09 – 04/16/12	Yes	30.077744	-84.327845	NA	NA

Table 3. Parameters measured by the types of devices deployed in the WKP.

Device	Recorded Parameters
Global WL16	Water Depth (converted to level where surveyed)
Insitu LT 200	Temperature, Actual Conductivity, Specific Conductivity, Salinity, Total dissolved Solids, Resistivity, Water Depth (converted to level where surveyed)
Insitu LT 500	Water Depth (converted to level where surveyed)
Global Logger	Water Depth (converted to level where surveyed)
Falmouth	Velocity, Temperature, Conductivity

Table 4. Summary of water table elevations measured during the study period in the WKP.

		LC3	PB3	RS2	SUL	TS	TUR	WakB	WBD	WakK
Water Level Elevation (ft)	Count	74,667	63,343	57,140	67,990	64,098	42,138	NA	47,225	283,569
	Max	19.76	6.83	8.35	11.15	9.00	10.98	NA	8.63	16.56
	Min	3.29	0.75	3.94	6.66	3.37	4.15	NA	6.09	-5.26
	Average	7.48	4.76	6.41	7.90	6.92	8.19	NA	7.26	4.33
	STDEV	2.40	1.29	0.50	0.68	1.44	0.37	NA	0.41	3.99
	90%tile	8.68	6.09	7.00	8.72	8.44	8.61	NA	7.77	10.32
	75%tile	8.10	5.78	6.74	8.09	8.17	8.44	NA	7.47	6.62
	50%tile	7.45	5.26	6.47	7.78	7.50	8.26	NA	7.27	2.14
	25%tile	6.03	3.74	6.04	7.50	5.59	7.93	NA	7.04	1.67
	10%tile	5.08	2.75	5.71	7.22	4.77	7.67	NA	6.72	1.35

Table 5. Summary of water temperatures measured during the study period in the WKP.

		LC3	PB30	PB60	PB3	RS2	SUL	TS	WBD
Temperature (C)	Count	74,667	16,116	16,116	57,140	67,990	64,098	47,225	NA
	Max	31.59	22.59	20.87	26.90	26.34	28.81	21.81	NA
	Min	3.35	16.77	16.82	18.78	9.42	7.29	20.25	NA
	Average	20.45	18.70	18.61	21.17	21.95	21.10	20.89	NA
	STDEV	6.26	1.66	1.42	1.40	2.11	4.27	0.15	NA
	90%tile	27.93	21.10	20.55	23.11	24.80	26.48	21.04	NA
	75%tile	26.40	20.26	20.29	22.01	23.27	24.78	20.95	NA
	50%tile	21.06	18.25	18.29	20.71	21.49	21.59	20.90	NA
	25%tile	15.61	17.19	17.24	20.22	20.98	17.37	20.83	NA
	10%tile	11.80	16.99	17.03	19.91	20.69	15.15	20.71	NA

Table 6. Summary of conductivity-related parameters measured at Punchbowl Sink in the WKP during the study period.

		PB30	PB60		PB30	PB60		PB30	PB60
Actual Conductivity (µS)	Count	16,116	16,116	Specific Conductivity (mS)	16,116	16,116	Salinity (PSU)	16,116	16,116
	Max	1457.17	1450.43		1610.85	1602.06		0.82	0.82
	Min	334.32	339.10		354.11	368.20		0.17	0.18
	Average	486.64	497.88		554.00	566.92		0.27	0.28
	STDEV	183.49	178.75		203.94	196.67		0.10	0.10
	90%tile	701.18	702.84		768.49	775.06		0.38	0.38
	75%tile	486.05	487.39		574.15	575.05		0.28	0.28
	50%tile	452.93	455.29		532.30	534.09		0.26	0.26
	25%tile	388.90	414.19		435.87	459.94		0.21	0.22
	10%tile	337.89	376.45		363.86	413.83		0.18	0.20

Table 7. Summary of all Falmouth hydraulic data collected from within the Wakulla-Leon Sinks and Spring Creek cave systems in the WKP.

Station	Record Period	# Records	Max Flow (CFS)	Min Flow (CFS)	Max Temp (C)	Min Temp (C)	Max Cond (µS)	Min Cond (µS)
AD	02/07/04 - 04/05/12	266920	472.771	0.075	22.201	18.943	0.639	0.185
AK	02/07/04 - 04/05/12	190287	832.134	0.197	22.047	17.864	0.635	0.180
K	02/07/04 - 04/05/12	211613	384.562	0.276	22.322	15.860	0.663	0.166
B	11/22/03 - 04/06/12	285192	128.798	7.036	20.703	19.072	0.319	0.277
C	11/25/03 - 02/26/12	273962	142.583	0.569	20.659	20.361	30.327	0.282
D	02/07/04 - 04/05/12	180923	65.932	0.060	20.829	20.488	0.311	0.263
Vent	10/29/03 - 08/26/09	130804	1958.780	48.576	56.240	0.000	20.768	-0.015
Revell	09/17/10 - 04/05/12	39127	1455.350	1.071	20.835	19.393	3.182	0.257
SC-1	05/20/09 - 11/02/11	75898	1911.100	0.364	33.353	8.677	52.792	1.502
SC-10	05/28/09 - 04/16/12	92940	1128.080	0.113	33.486	8.109	56.632	0.626

Table 8. Summary of water depths and temperatures measured by the CTD probes deployed in piezometers at Shell Point and Live Oak Island for the surge study.

		BG02	GS01	GS02	ST04	ST05		GS02	ST05
Water Depth (ft)	Count	40,216	41,093	40,869	41,645	43,795	Temperature (C)	40,869	43,795
	Max	7.12	8.28	7.09	7.97	41.98		27.26	23.70
	Min	1.50	1.21	2.01	4.21	38.51		18.05	16.90
	Range	5.62	7.07	5.08	3.76	3.48		9.21	6.80
	Average	4.22	4.47	4.83	5.65	40.17		24.01	21.18
	STDEV	1.25	1.09	0.59	0.49	0.54		2.64	1.85
	90%tile	5.88	5.89	5.51	6.30	40.89		27.02	23.26
	75%tile	5.32	5.28	5.14	5.95	40.51		26.48	22.90
	50%tile	4.21	4.47	4.80	5.64	40.15		24.77	21.62
	25%tile	3.17	3.67	4.47	5.34	39.81		21.28	19.30
	10%tile	2.62	3.04	4.15	5.07	39.50		20.43	18.66

Table 9. Summary of conductivity-related parameters measured by the CTD probes deployed in piezometers at Shell Point and Live Oak Island for the surge study.

		GS02	ST05		GS02	ST05		GS02	ST05
Actual Conductivity (µS)	Count	36,652	39,569	Specific Conductivity (mS)	36,652	39,569	Salinity (PSU)	36,652	39,569
	Max	1430.91	16083.08		1530.29	16380.56		0.78	9.96
	Min	479.00	11239.92		481.35	12232.46		0.28	7.42
	Range	951.91	4843.16		1048.94	4148.10		0.50	2.54
	Average	846.83	14094.65		867.11	15047.54		0.44	9.04
	STDEV	210.95	854.88		228.82	802.29		0.11	0.45
	90%tile	1099.88	15127.12		1142.43	15918.06		0.57	9.48
	75%tile	1039.49	14789.75		1093.32	15679.00		0.55	9.36
	50%tile	817.17	13991.95		846.40	15339.32		0.44	9.19
	25%tile	656.69	13615.26		643.98	14414.51		0.34	8.84
	10%tile	595.84	12963.85		578.08	13945.40		0.31	8.30

TASK-A4 GROUNDWATER TRACER TEST

The purpose of the groundwater tracer test was to delineate eastern boundary of the Wakulla springshed by delineating the flow path(s) connecting one or more of the swallets located northeast of Tallahassee with the springs to which the rapidly recharged water at those locations discharges. These swallets include: Bird sink, Paddy sink, Copeland sink, Wood sink, Creek sink, and Lake Drain sink. Bird and Paddy sinks were estimated to be the largest of the swallets, and Bird sink is the only one of the group that has been explored by divers and found to connect to a large south-trending underwater cave system. It was explored by the Woodville Karst Plain Project prior to 2000 during which time they mapped approximately 1 mile of conduit trending south away from the sink. Because of these factors, Bird sink was the primary target for this study.

Prior to this test, the flow paths leading away from these swallets were the largest remaining karstic flow paths in the western Woodville Karst Plain that had not been traced. The pathways must be defined in the groundwater flow model that we have been developing for the Woodville Karst Plain and, in previous versions of the model, had been assumed to connect solely to the St. Marks River rise.

There are three reasonably probable spring groups to which the water from these swallets would likely flow: Wacissa, located approximately 10.6 miles southeast of Bird sink; the St. Marks River rise, located approximately 15.5 miles south-southwest of Bird sink; and Wakulla spring, located approximately 23.5 miles southwest of Bird sink. All of these locations were regularly sampled for the injected tracer during the study period. Wacissa was sampled at Big Blue spring and a point in the Wacissa River approximately 100 yards upstream from the confluence between the Big Blue outflow and the river. The St. Marks River was sampled at numerous locations including: Horn spring, Natural Bridge sink, Rhodes spring, and the River rise. Wakulla spring was sampled at the spring vent. Figure 8 shows the locations of the swallets relative to the St. Marks and Wakulla rivers.

The potential St. Marks and Wakulla flow paths are significantly longer than any pathway traced to date in the Woodville Karst Plain, where the longest traced pathway was between the City of Tallahassee’s southeast sprayfield and Wakulla spring at approximately 12 miles. That trace produced significant but low-concentration recovery curves for both uraninie and eosine, which were injected into wells and a swallet respectively. For that reason and the potential that the injected tracer would travel to Wakulla, the longest flow path, it was decided to focus on Bird sink as a solitary injection using a single large quantity slug injection.

The tracer injection was performed on February 22, 2012 under nearly ideal hydraulic conditions, a rising stage in the swallet immediately following a moderate precipitation event. The injection occurred at such a late date because we endeavored to wait for such conditions, which were rare during the previous 18 months due to dry conditions in north Florida. Bird sink was in fact dry for much of that previous time period.

Once the stage began to rise and we were confident that it would continue to rise for one or more days, 18 5-gallon pales of liquid uranine dye were released into the flowing water immediately upstream of the swallet. The liquid was 36% dye creating a slug injection of 220 lbs.

Sampling began approximately two weeks prior to the injection at all locations. The stations at Big Blue, the Wacissa River, the St. Marks River rise, and Wakulla spring were configured with automatic water samplers set to collect one sample every 12 hours. Grab samples were collected on a weekly basis at the other locations. All water samples were analyzed using a scanning spectrofluorphotometer. Tracer detections were recorded at Horn spring, Natural Bridge sink, and Rhodes spring at levels well within the visible range. The tracer was also detected at Wakulla spring, though at very small concentrations. The tracer was not detected at either of the Wacissa stations. The traced flow paths are shown on figure 8. Figure 9 provides the tracer recovery curves produced from the samples collected and analyzed at the stations where the tracer was detected. Appendix I provides the tracer concentrations derived from spectrofluorophotometric analysis.

Travel times were calculated based on the peak of the recovery curves. Table 10 provides the results, which reveal the fastest travel times recorded in the Woodville Karst Plain. Based on these results, we conclude that groundwater flow through this region of the Floridan aquifer is highly concentrated into the conduits, despite traveling under parts of the confined portion of the aquifer, where the flow velocity is driven by large head gradients created when the swallets are filled.

The estimated groundwater velocity to Wakulla Spring was approximately 5 times faster than the velocities recorded during the City of Tallahassee sprayfield test. We hypothesize that these results are more reflective of the extremely fast travel time from Bird Sink to the edge of the confining unit (proximal to the sprayfield) and that the actual travel time along the pathway from there to Wakulla is similar to that recorded in the sprayfield traces.

Table 10. Distances, travel times, and groundwater velocities recorded and calculated from the Bird Sink tracer test results.

Location	Straight-line Distance from Injection (miles)	Date of Peak Arrival	Travel Time (days)	Minimum Groundwater Velocity (ft/day)
Horn Spring	12.5	3/5/2012 10:16	11.78	5601.79
Rhodes Spring	15.2	3/6/2012 15:40	13.01	6170.24
St. Marks River Rise	15.5	3/7/2012 7:00	13.65	5997.44
Natural Bridge Sink	15.2	3/6/2012 15:25	13.00	6175.19
Wakulla Spring	23.2	4/14/2012 18:15	52.11	2350.51

The Bird Sink tracer test produced important data about groundwater flow through the upper Floridan aquifer. It revealed unequivocally that flow directions and velocities are controlled by karstic conduits even under the confining unit and well north of the transition zone between confined and unconfined conditions. In short, the trace demonstrated that swallets feed conduits that transport the water rapidly to springs. The primary pathway was to the St. Marks group of discharges, which confirmed our hypothesis and establishes the eastern boundary of the Wakulla springshed along a northeast-southwest line between the City of Tallahassee sprayfield and the upper St. Marks River.

Finally, the low-concentration detections at Wakulla spring demonstrate that water from the conduit flow paths must overflow into secondary conduits leading to competing springs. This same type of overflow was recorded during the sprayfield trace wherein low-concentration detections were recorded at McBride’s, Indian, and Sally ward springs, which presumably resulted from overflow out of the primary pathway connecting to Wakulla B-Tunnel.

TASK-A2 GROUNDWATER MODEL REVISION

The purpose of this task was to use the numerical karst groundwater flow model (GWM) that had been developed in 2010 for the WKP to evaluate the impact of sea-level rise on groundwater flow patterns in the southern part of the WKP and to specifically quantify changes in the magnitude and distribution of groundwater flow to the Gulf of Mexico. Two factors were to be considered: 1) projected 50-year sea-level rise, and 2) current and predicted future groundwater extractions in the springsheds supplying fresh water to the coastal ecosystems, which include: Wakulla, Spring Creek, St. Marks, and Wacissa springs. The model was also to be updated to account for conduit flow pathways and velocities determined through the groundwater tracing performed under Task-A4.

The 2009 model was adequately calibrated to head and spring flow data but did not include groundwater pumping. At the outset of this task, our analysis of pumping in north Florida and south Georgia revealed significantly more extractions than were anticipated. Once the pumping data was compiled and entered into the model, we found that the 2010 calibration was inadequate. Revising the model calibration required a closer scrutiny and interpretation of the geologic framework on which the groundwater model was constructed. We began that process and successfully revised our interpretations of the geology but time and budget prohibited the necessary recalibration before the planned scenario analyses could be performed.

In this report, we will therefore summarize the work that was completed: compilation of pumping data and reinterpretation of the geologic framework, and provide a list of the remaining tasks required in order to produce scenario analyses designed to evaluate the impact of sea level rise. A detailed description of the model as it was constructed in 2010 is provided by GeoHydros (2010).

PUMPING

An accurate understanding of the magnitude, location, and hydrostratigraphic source of groundwater pumping is crucial to the development of an accurate water budget and therefore a reliable numerical groundwater flow model. Previous modeling studies, including ours and Davis (1994) had not addressed pumping in a comprehensive manner. Our effort therefore began by compiling, analyzing, and sorting pumping data from Federal, State, and County resources. The data was broken out and will be described here in three categories: agricultural, municipal, and other.

Agricultural

Agricultural groundwater pumping data has been compiled and broken out by land use by collaborative efforts conducted by universities and State agencies in both Georgia and Florida. For Georgia, the most comprehensive data and accounting is available from The National Environmentally Sound Production Agriculture Laboratory (NESPAL) unit of the University of Georgia's College of Agricultural and Environmental Sciences (NESPAL, 2012[a]; NESPAL, 2012[b]). For Florida, the most comprehensive data is maintained by the Northwest Florida Water Management District (NFWMD) and the Suwannee River Water Management District (SRWMD). Both the Georgia and Florida datasets were compiled for the Floridan aquifer. For this effort, the data was processed in total (aquifer-wide) and then parsed into datasets pertaining to the GWM domain.

Table 11. Hydrostratigraphic units within the GWM domain and for which groundwater pumping data has been listed.

Hydrostratigraphic Unit	Abbrev.
Claiborne (Avon Park, Lisbon, Lake City, Tallahatta)	CA
Floridan-Claiborne	FC
Floridan (Ocala, Suwannee)	FL
Floridan-Miocene	FM
Miocene (Brunswick)	MI
Surficial	SF

In Georgia, NESPAL digitized most of the irrigated areas in Georgia into polygons, which were then assigned a centriod point that contained the critical data including: area, crop type, and extraction aquifer for each polygon. We took this file and parsed it out by extraction aquifers that are represented in the GWM domain (Table 11). We then collected data on all of the permitted groundwater extraction wells in Georgia (GA EPD, 2008) and correlated the permits to the groups of agricultural land use polygons using GIS and tolerance distances of between 300 and 800 meters. An effort was made to match the final number of extraction points to the number of permits such that the distribution of agricultural pumping in the model would correspond generally to the property owners. A final set of agricultural extraction points was then created, which represents the centroid of the grouped points and lists the total irrigated area as the sum of the areas represented by the initial land use polygon centroids contained within the group. Data describing the total agricultural pumping by County in 2005 was then compiled (Fanning and Trent, 2009) and then assigned to the extraction points according to the percentage of agricultural land represented by the point relative to the total for the County. Table 12 summarizes the distribution and magnitude of agricultural pumping in the Georgia Counties intersected by the GWM domain along with the hydrostratigraphic units from which the water is derived. The result of this process was 2,407 agricultural extraction points within the GWM domain with a total flow rate of 92.71 MGD. These numbers are less than those listed in Table 12 because the GWM domain crosses some of the counties for which the totals are presented in the table.

Table 12. Irrigated areas and total groundwater pumping for agricultural land uses in Florida and Georgia in the counties intersected by the GWM domain.

	County	Total Irrigated Acres	2005 Ag Pumping (mgd)	# Extraction Points in Group	# Extraction Permits	Grouping Tolerance (m)	Count by Aquifer					
							CA	FC	FL	FM	MI	SF
GEORGIA	Baker	39,722.2	30.75	373	370	300	5	5	362	1	0	0
	Brooks	21,478.0	2.34	172	178	500	0	0	162	10	0	0
	Colquitt	26,552.6	9.72	231	238	600	0	0	199	28	2	2
	Cook	13,095.5	5.11	160	153	400	0	0	106	54	0	0
	Crisp	22,008.2	15.02	204	193	500	70	9	115	10	0	0
	Decatur	68,114.8	34.95	601	561	300	0	1	586	10	2	2
	Dougherty	357.7	9.50	168	174	0	4	1	162	1	0	0
	Grady	9,975.3	2.82	122	114	400	0	4	98	15	5	0
	Lee	45,900.3	3.06	312	335	400	149	24	139	0	0	0
	Lowndes	6,142.6	8.02	95	95	300	0	0	75	15	5	0
	Mitchell	78,563.8	28.88	718	670	300	0	1	690	25	2	0
	Thomas	11,646.6	7.83	141	131	300	0	0	139	2	0	0
	Tift	16,886.7	11.33	260	275	400	0	0	121	128	11	0
	Turner	17,229.0	6.09	203	195	400	5	0	129	69	0	0
	Worth	36,467.3	7.46	328	335	500	10	5	203	110	0	0
	State Total	*414,140.6*	*182.88*	*4088*	*4017*	-	*243*	*50*	*3286*	*478*	*27*	*4*
FLORIDA	Franklin	31,617.3	0.09	451	NA	400	0	0	451	0	0	0
	Gadsden	3.4	3.89	1	NA	400	0	0	1	0	0	0
	Jefferson	34,716.4	11.09	362	NA	400	0	0	362	0	0	0
	Leon	1,505.3	1.35	45	NA	400	0	0	45	0	0	0
	Liberty	40,123.0	0.14	573	NA	400	0	0	573	0	0	0
	Madison	131,556.1	11.08	1218	NA	400	0	0	1218	0	0	0
	Taylor	51,939.7	1.12	409	NA	400	0	0	409	0	0	0
	Wakulla	6,160.4	0.27	96	NA	400	0	0	96	0	0	0
	State Total	*297,621.6*	*29.03*	*3155*	*0*	-	*0*	*0*	*3155*	*0*	*0*	*0*
Model Total		711,762.2	*211.91*	*7243*	*4017*	-	*243*	*50*	*6441*	*478*	*27*	*4*

The methodology for Florida was slightly different because the water management districts have not developed detailed spatial polygons for groundwater extractions nor have they attributed the pumping to a specific hydrostratigraphic unit. Instead, we derived the spatial location of pumping from the land use polygons published and made available by the water management districts and assumed that all pumping is from the upper Floridan aquifer.

All agriculturally-related land use polygons were first parsed from the total land use GIS coverages and further parsed into datasets representing croplands, tree crops, nurseries & vineyards, and livestock. Polygons representing pasture land and fallow crop land were not used in the pumping assignments. Each of the datasets were then grouped spatially using a 400 meter tolerance, which was found to be the most common distance used in the Georgia calculations. Total agricultural groundwater pumping by county in 2005 was then compiled from Marella (2009) and assigned to the extraction points following the same methodology as used for the Georgia data. The Florida agricultural pumping distributions are also summarized in Table 12. The result of this process was 1,289 agricultural extraction points within the GWM domain with a total flow rate of 20.59 MGD. Again, these numbers are less than those listed in Table 12 because the GWM domain crosses some of the counties for which the totals are presented in the table.

Figure 10 shows the final distribution of extraction points that will be assigned in the GWM to represent agricultural pumping where the points are colored by the hydrostratigraphic unit from which the water is withdrawn. The complete listing of the grouped extraction points and corresponding pumping magnitudes represented by Figure 10 is provided in Appendices II & III.

Municipal

Municipal groundwater pumping data was considerably easier to compile. Data for Georgia was largely derived from Fanning and Trent (2009). Data for Florida was largely derived from Maralla (2009). In both cases, the data was broken out by use categories including: public supply, domestic & commercial, industrial & mining, and thermo-electric, and by county. For Florida, individual public supply data was also provided by the NFWMD (2003) in the form of future projections. Pumping values used were those compiled for 2005. When needed, additional data was derived from borehole logs containing owner information and from various USGS databases.

Table 13. Summary of municipal groundwater extractions by county intersected by the GWM domain.

	County	# Suppliers	GW Withdrawal (MGD)	GW Withdrawal (gpm)
GEORGIA	Baker	1	0.11	76.39
	Brooks	3	0.86	597.22
	Colquitt	7	3.58	2,488.89
	Cook	4	2.02	1,402.78
	Crisp	3	2.02	1,402.78
	Decatur	4	2.80	1,944.44
	Dougherty	2	13.35	9,270.83
	Grady	2	1.78	1,236.11
	Lee	2	1.45	1,006.94
	Lowndes	6	9.69	6,729.17
	Mitchell	5	3.86	2,680.56
	Thomas	8	5.36	3,722.22
	Tift	3	4.91	3,409.72
	Turner	3	0.86	597.22
	Worth	5	1.27	881.94
	State Total	*58*	*53.92*	*37,447.22*
FLORIDA	Franklin	6	2.07	1,437.50
	Gadsden	6	4.40	3,055.56
	Jefferson	1	0.69	479.17
	Leon	11	39.10	27,152.78
	Liberty	2	0.41	284.72
	Madison	0	0.00	0.00
	Taylor	0	0.00	0.00
	Wakulla	4	2.03	1,409.72
	State Total	*30*	*48.70*	*33,819.44*
Model Total		*88*	*102.62*	*71,266.67*

Table 13 provides a summary of the 2005 municipal groundwater pumping by county. Figure 11 shows the location of all non-agricultural groundwater pumping within and surrounding the GWM domain. Appendix IV provides a list of all individual municipal groundwater extractors compiled from the individual State datasets.

Other

The magnitude of all permitted groundwater pumping within the GWM domain has been compiled from the sources described above. The locations of the extractions, however, have not been completely delineated. Locations for domestic self-suppliers, commercial, industrial, and mining extraction points have yet to be defined. The plan is to use tax parcel county GIS coverages to locate these extraction points. Division of domestic extraction will be based on population information included with the permit data for the respective suppliers.

GEOLOGY

The 2010 model was largely based on a delineation of the Suwannee and Ocala limestones as continuous units throughout all of Georgia with the Gulf Trough represented as a dip in elevations of these units. As pumping in Georgia was not represented in the 2010 model, simulated conduits were extended into the regions connecting to or coming close to the lowest head wells. This practice was in keeping with the assumption that, unless explained by data, significant permeability variations in the upper Floridan aquifer are due to conduit development rather than matrix heterogeneity.

Once we added Georgia pumping, we found that we didn't need the conduit extensions to get the lower observed heads and that we couldn't keep the high observed heads to the northwest of the Trough with the assumed conduit network plus pumping. We therefore turned to a more in-depth analysis of the Georgia geology to solve the head problem.

We collected over 2,000 additional bore log descriptions in Georgia and Florida from Herrick (1961), McFadden and others (1986), and the FGS-LithProg database. All of the new Georgia logs were in paper format and had to be digitized manually. Throughout most of the model region with the exception of the Gulf Trough area, the new bore log data was consistent with the data used to construct the 2010 model framework. Inconsistencies in the Gulf Trough area were mostly identified by comparing newly acquired lithology logs with the initial data which consisted predominantly of geologic picks categorized by age (Early Eocene, Middle Eocene, Late Eocene, etc.). The process was time-consuming but the result was a new dataset representing a consistent interpretation of the geology underlying and adjacent to the Gulf Trough region.

The most significant correlation we were able to make was to delineate upper and lower Late Eocene units, where the upper unit consists of purely Ocala limestone that is discontinuous in the Gulf Trough and Apalachicola Embayment region; and where the lower unit consists of lower permeability mixed carbonate and clastic rocks that exist only within the Gulf Trough and Embayment region. A similar correlation was made delineating upper and lower Oligocene units, where the upper unit is composed of purely Suwannee limestone and the lower unit is made up of dense and clastic-rich Marianna limestone. Like the Late Eocene units, the higher permeability upper unit is discontinuous in the Gulf Trough and the lower unit only exists in the Trough and in the Embayment.

These correlations are consistent with discontinuous low permeability regions around the Trough and Embayment regions within the Late Eocene picks defined by Miller (1988). By looking at many more bore logs in those regions, we were able to connect Miller’s discrete low permeability zones throughout the Trough and Embayment regions.

A second line of correlation was made through water chemistry analysis. We saw that the deeper Late Eocene pumping wells which also had the lowest head measurements (assumed to be due to low permeability) had elevated levels of sulfate. From looking at lithology logs from the same wells in which Miller defined the low permeability zones, we found that they all contained gypsum in the lower Late Eocene unit. We therefore used the presence of gypsum and other shallow water deposits such as glauconite to identify and delineate the lower Late Eocene unit. Using this method, we were also able to extend the delineation of the Lake City fraction of the lower Early Eocene unit into Georgia because nearly all of the Florida Lake City picks from the FGS-LithProg database contained gypsum and or glauconite but at much greater depths than the Late Eocene picks.

A third line of correlation was based on an observation that the lower Late Eocene unit contains many more sand and clay lenses than the Ocala unit, which reduce permeability.

Table 14 shows the hydrostratigraphic sequence and relative permeability of the units that will be defined in the revised version of the GWM. A complete tabulation of the interpreted and correlated hydrostratigraphic picks is provided as Appendix V. Figure 12 shows the locations of all bore logs used to delineate the hydrostratigraphic units that will form the framework for the revised GWM. Figures 13-19 provide maps showing the approximate extent of each of the aquifer units to be represented in the revised GWM (Table 14).

At the conclusion of these delineations, nearly 3,300 well logs had been analyzed and correlated on the basis of lithologic descriptions and water chemistry. We now feel very confident that the high heads northwest of the Trough and the low heads southeast of the Trough can be accurately simulated with the addition of FAS pumping and the new geologic delineations and that this accomplishment will be achieved using highly defensible geologic structure in the model.

Table 14. Hydrostratigraphic sequence and relative permeability of units that will be represented in the revised GWM.

GWM LAYER	AGE	HIGH PERM	LOW PERM	NOTE
1	Post Miocene	Undif. sand & clay		Continuous, vertical K will define where Hawthorn present
	Miocene	Altamaha	Hawthorne	
2	Miocene	Chattahoochee / Tampa / St. Marks		Discontinuous, all Miocene limestones where present
3	Upper Oligocene	Suwannee		Discontinuous, all Suwannee where present
4	Lower Oligocene		Marianna / Undif.	Discontinuous, all Marianna where present
5	Upper Late Eocene	Ocala	Cooper Marl	Discontinuous, all Ocala where present
6	Lower Late Eocene	Wilson	Undif. / Barnwell	Discontinuous, horizontal K will define Wilson / Undifferentiated division
7	Upper Middle Eocene	Avon Park	Lisbon	Continuous, horizontal K will define Avon Park / Lisbon division
8	Lower Middle Eocene	Lake City	Tallahatta	Continuous, horizontal K will define Lake City / Tallahatta division
9	Early Eocene	Oldsmar	HTGB	Continuous, horizontal K will define Oldsmar / HTGB division
-	Paleocene	Cedar Key	Cedar Key	Top of the layer is bottom slice of model

SUMMARY

The fundamental result of the work performed for this contract has been a realization of the significance of groundwater extractions in Georgia to the water budget in north Florida. Prior to this study, there has been a tacit assumption that pumping in Florida represents the largest anthropomorphic impact to the springs and coastal freshwater discharge. After the data was compiled however, it clearly reveals that agricultural and municipal pumping in Georgia is of much larger magnitude than all groundwater pumping in north Florida in the model area. It is clear therefore that these data must be included in any modeling analysis designed to predict the impacts of pumping or sea-level rise on spring flows. In essence Georgia pumping has and is impacting the boundaries of the springsheds. It reduces upland storage which in turn reduces heads and flows particularly in times of drought. Management actions that focus exclusively on Florida will therefore not likely be effectual.

We've also learned that in order to calibrate to both heads and spring flows, it is critical to develop an accurate conceptualization of the hydrostratigraphic structure including both conduit patterns and geologic heterogeneity. Arbitrary delineations of permeability designed to match heads are not likely to result in accurate or defensible delineations of springshed boundaries or travel-times.

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FIGURES

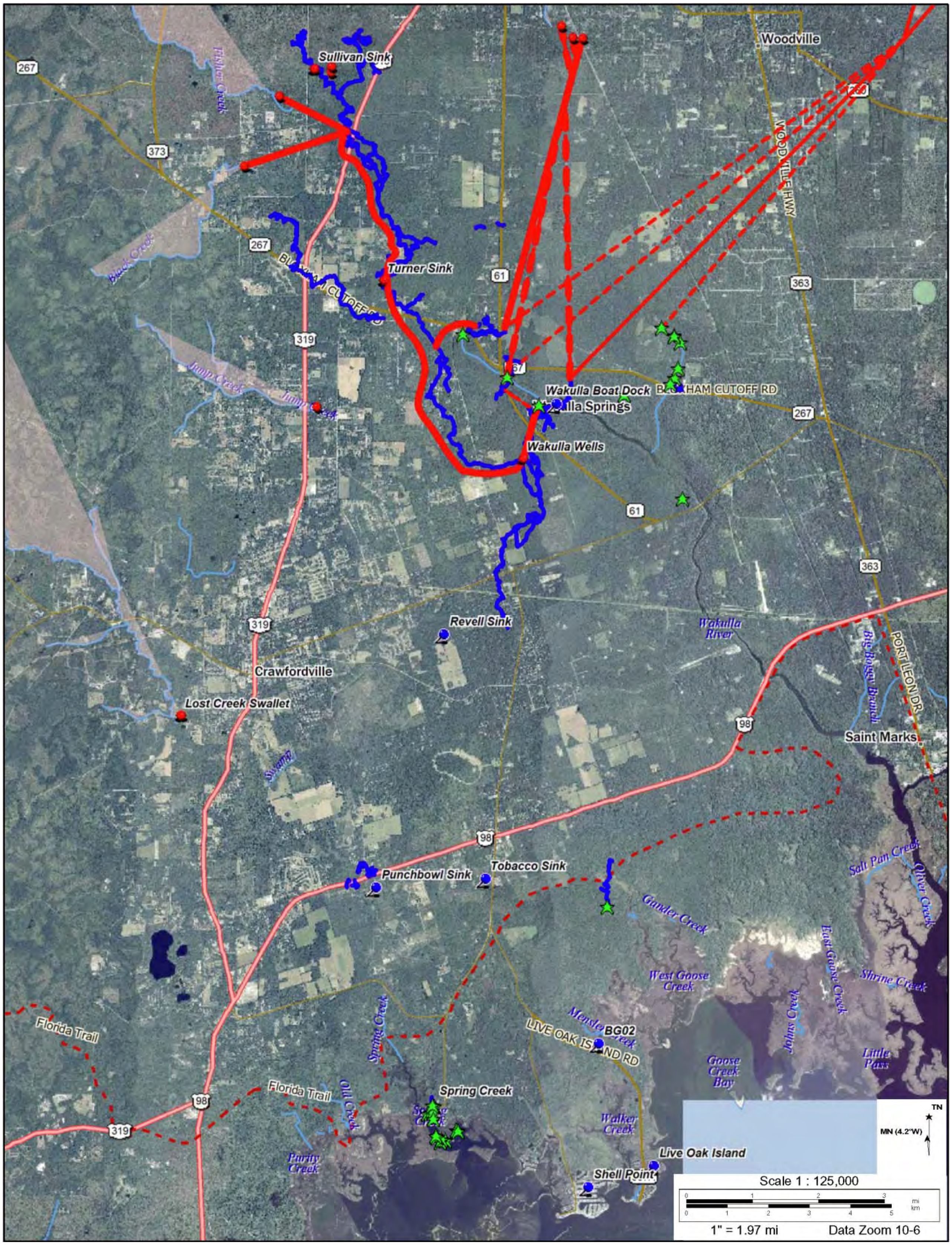
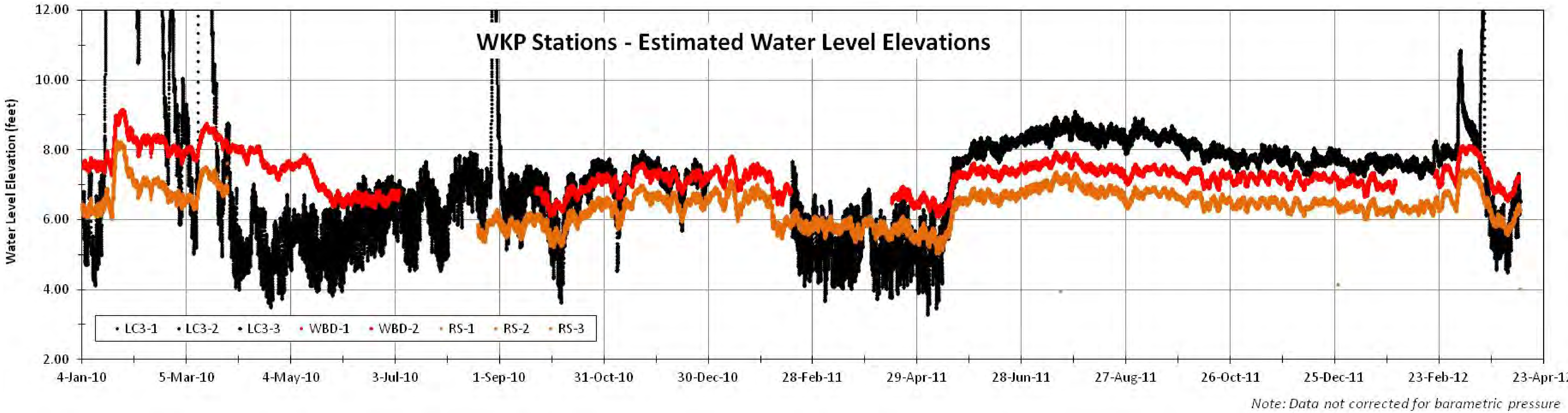


Figure 1. Map showing the approximate locations of the meters deployed for the WKP characterization and surge studies.



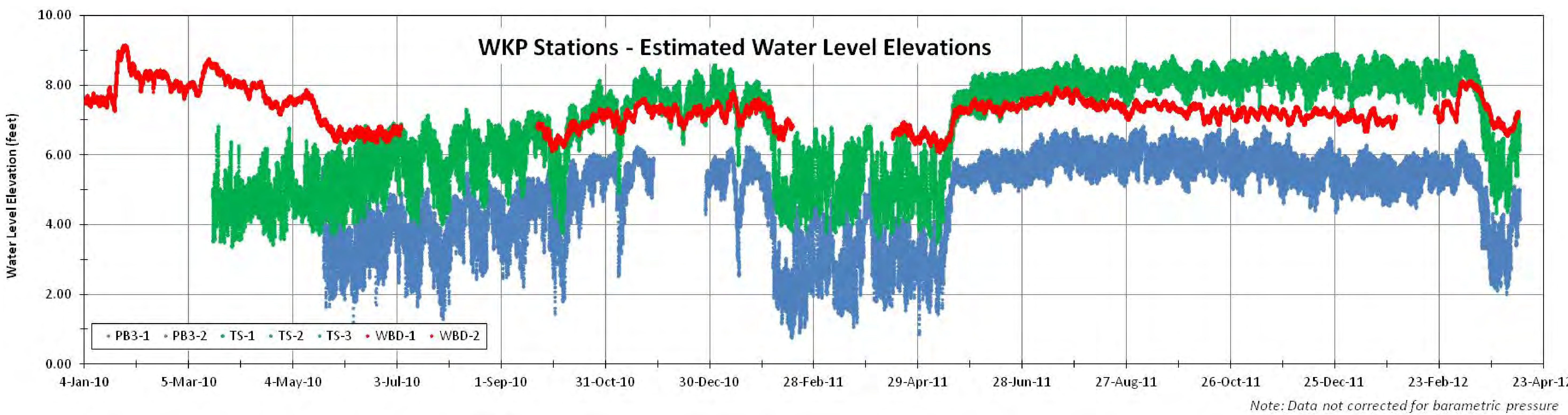
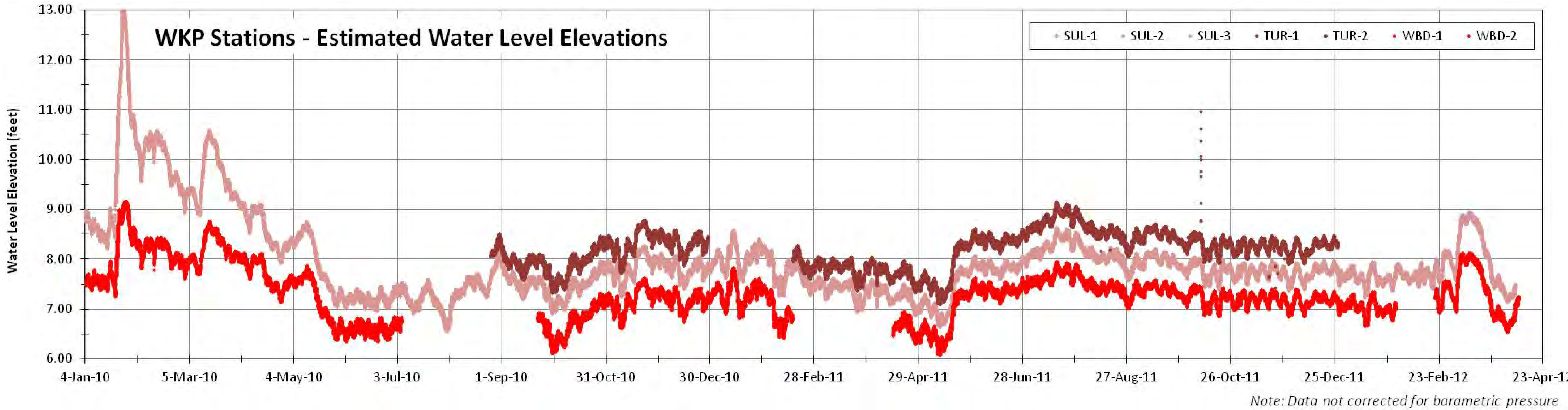


Figure 2. Estimated water level elevations measured at the Wakulla Boat Dock, Lost Creek swallet, and Revell Sink (top), and the Wakulla Boat Dock, Punchbowl Sink, and Tobacco Sink (bottom) between January 2010 and April 2012. Note that the data has not been corrected for barometric pressure.



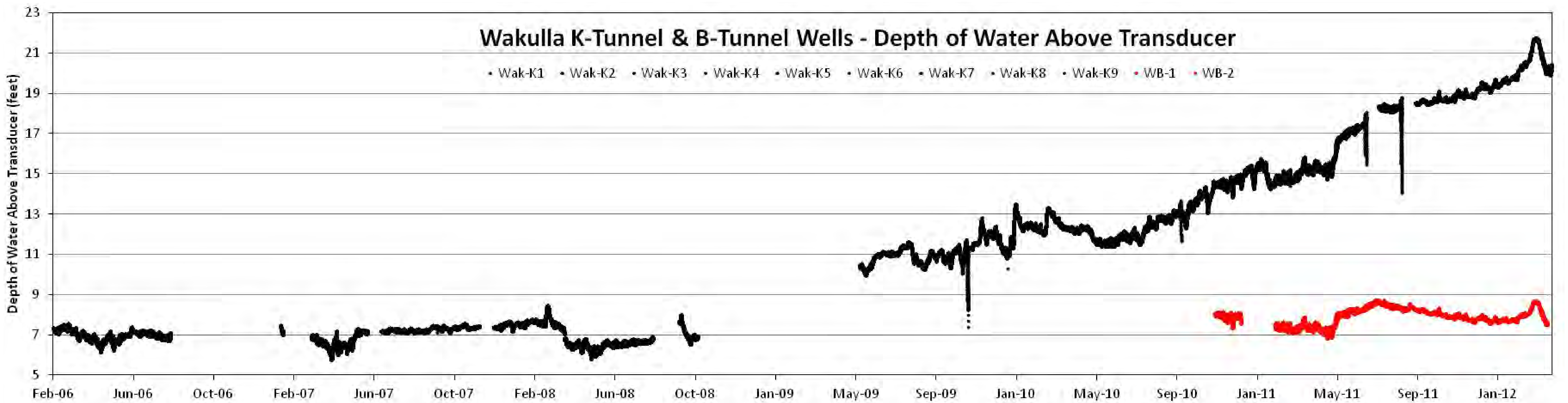


Figure 3. Estimated water level elevations measured at the Wakulla Boat Dock, Turner Sink, and Sullivan Sink between January 2010 and April 2012 (top), and the recorded depth of water above the transducers at Wakulla K-Tunnel and B-Tunnel between February 2006 and April 2012 (bottom). Note that the water level elevation data has not been corrected for barometric pressure. Note also that the water level elevation at Turner Sink consistently plots higher than the water level elevation in Sullivan, which indicates a probable problem with the elevation conversions (surveyed elevations or depth of transducer placement).Finally, note the consistent upward trend in the depth of water above the K-Tunnel transducer after a hiatus in recording between October 2008 and May 2009, which indicates that the meter is not working properly.

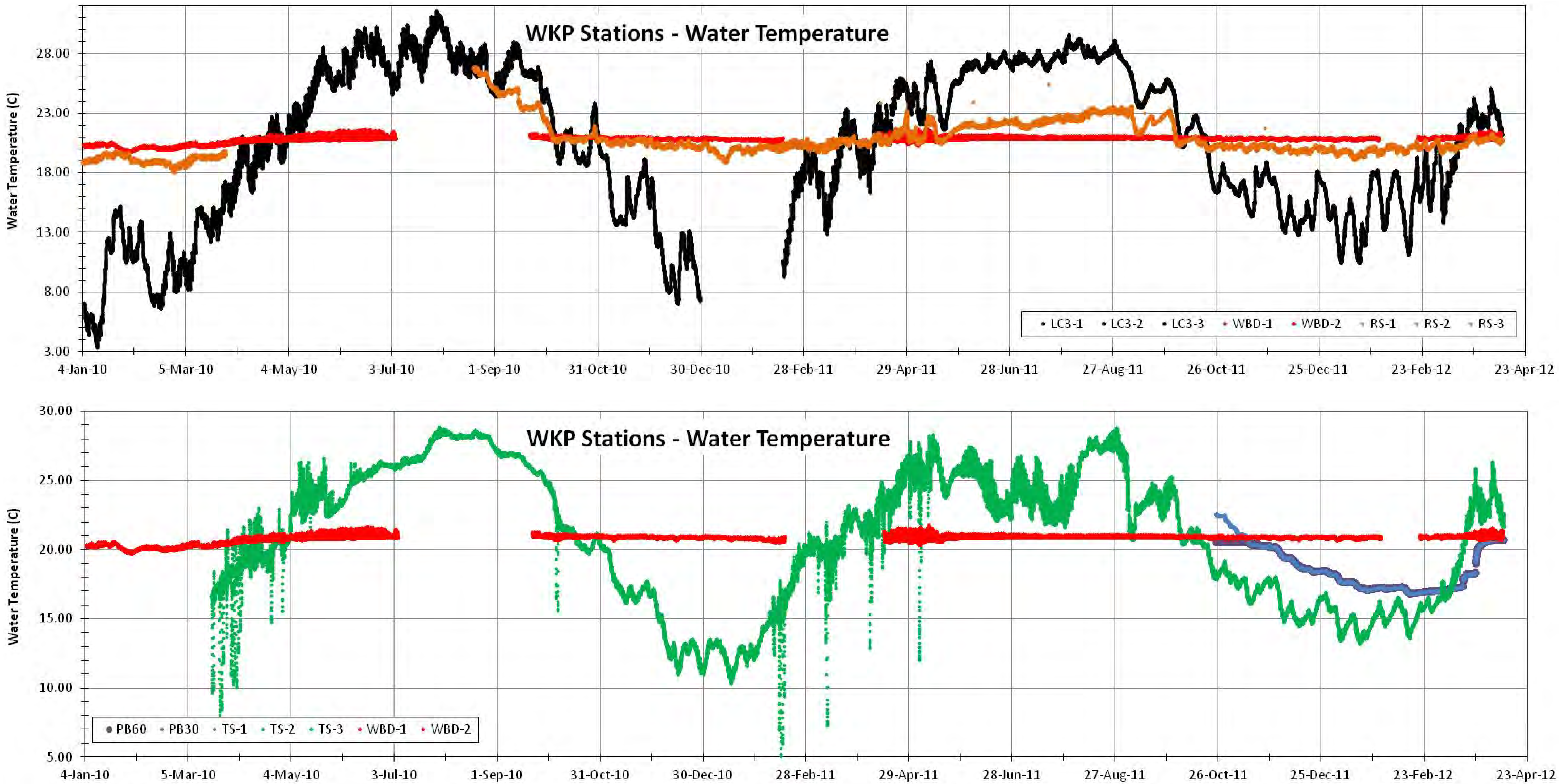
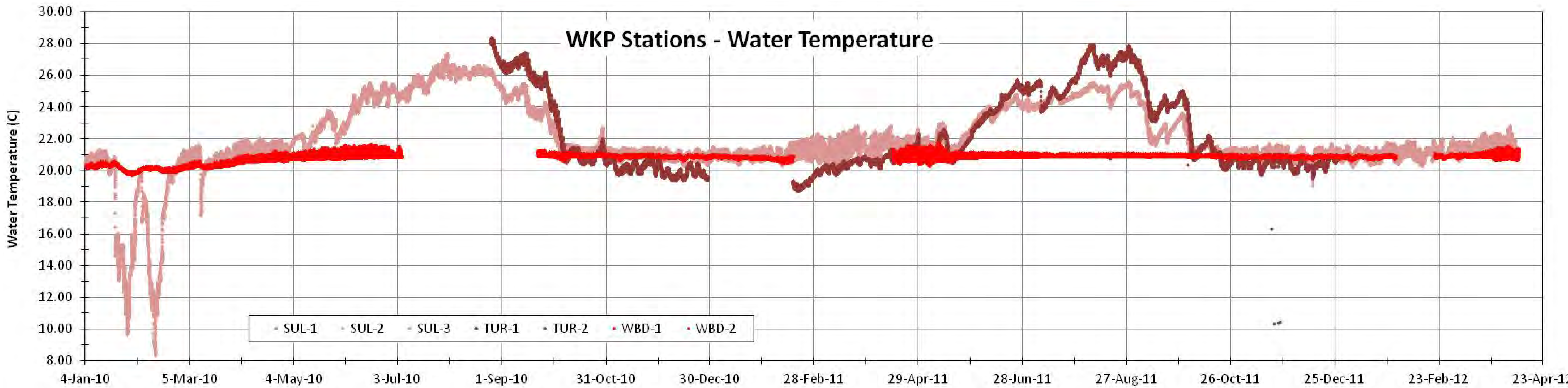


Figure 4. Water temperatures recorded at the Wakulla Boat Dock, Lost Creek swallet, and Revell Sink (top) and the Wakulla Boat Dock, Tobacco Sink and Punchbowl Sink (bottom) between January 2010 and April 2012.



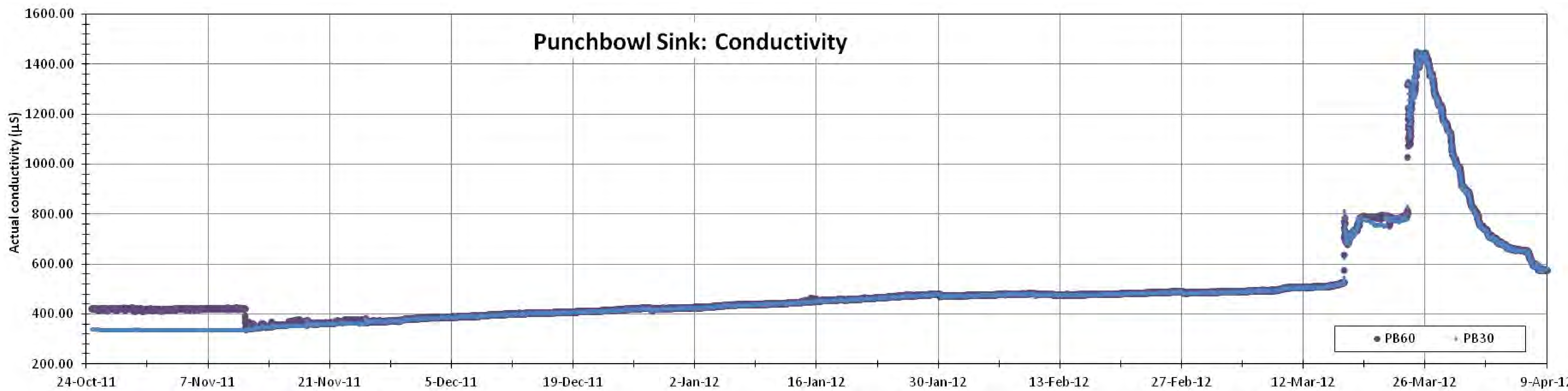


Figure 5. Water temperatures recorded at the Wakulla Boat Dock, Turner Sink, and Sullivan Sink between January 2010 and April 2012 (top), and actual conductivity recorded by the two CTDs deployed at 30 feet and 600 feet in Punchbowl Sink between October 2011 and April 2012 (bottom).

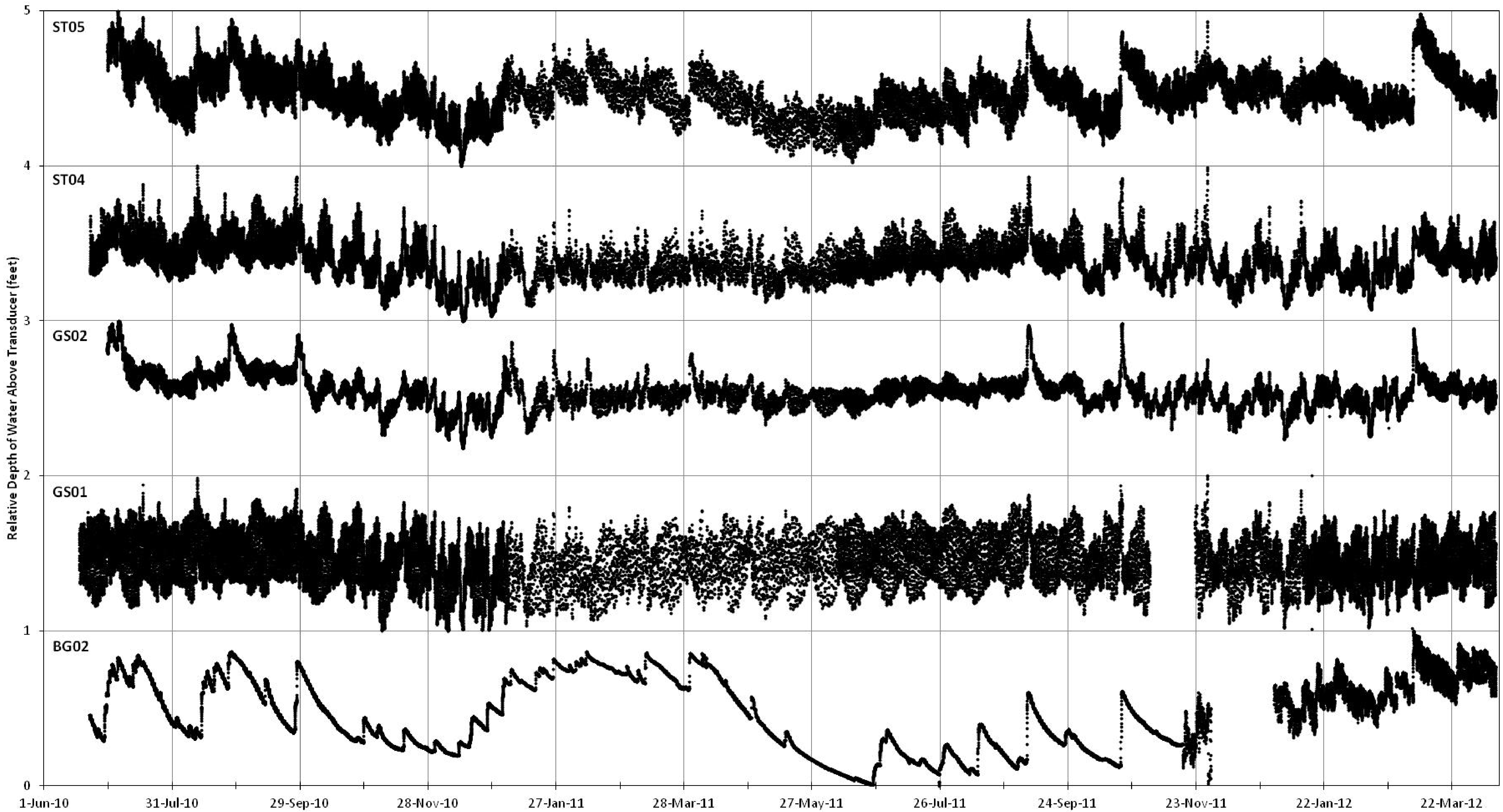


Figure 6. Relative change in water level in the piezometers installed at Shell Point and Live Oak Island for the surge study.

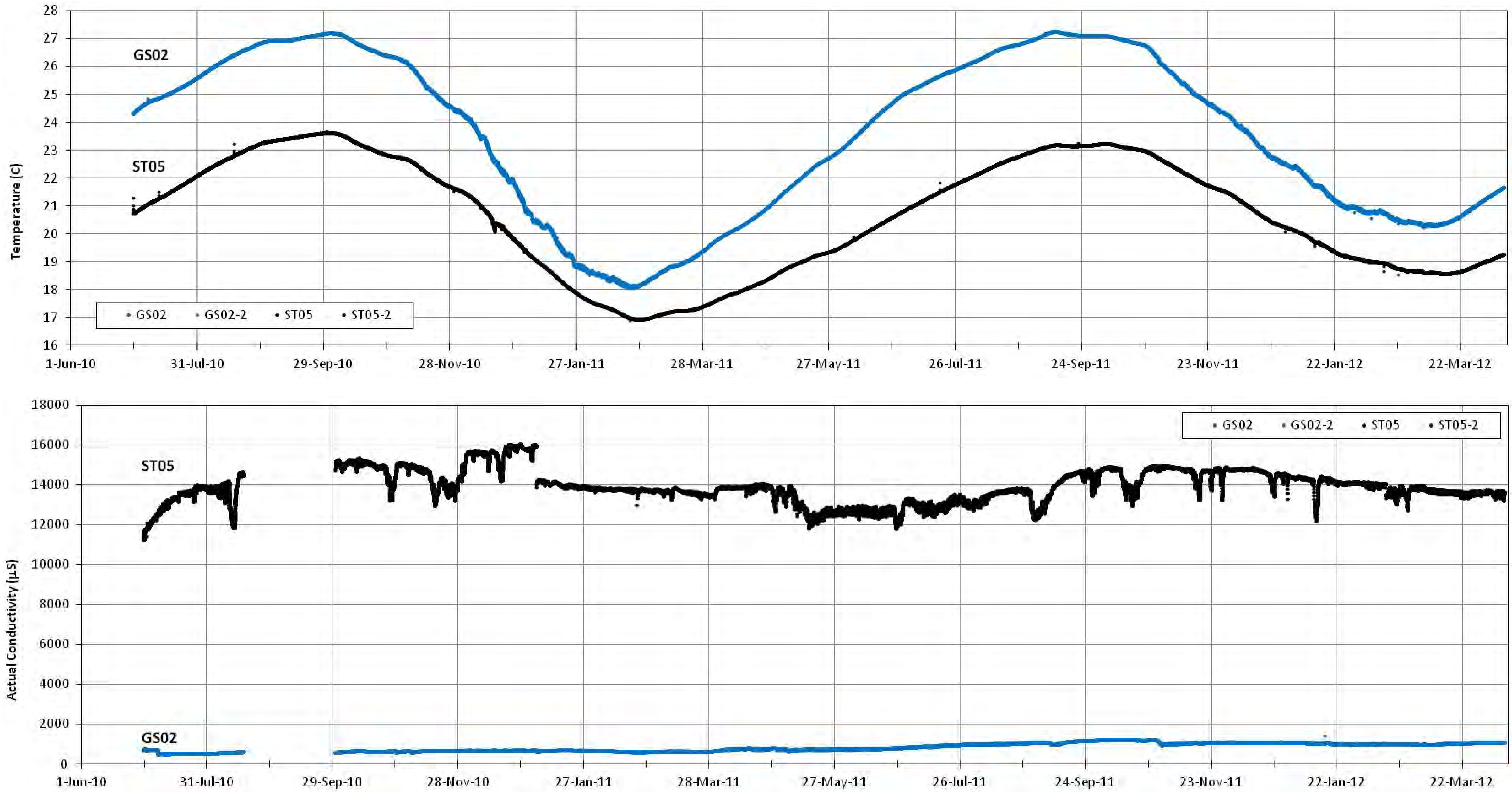


Figure 7. Shallow groundwater temperature (top) and conductivity (bottom) measured in the piezometers installed at Shell Point and Live Oak Island for the surge study.

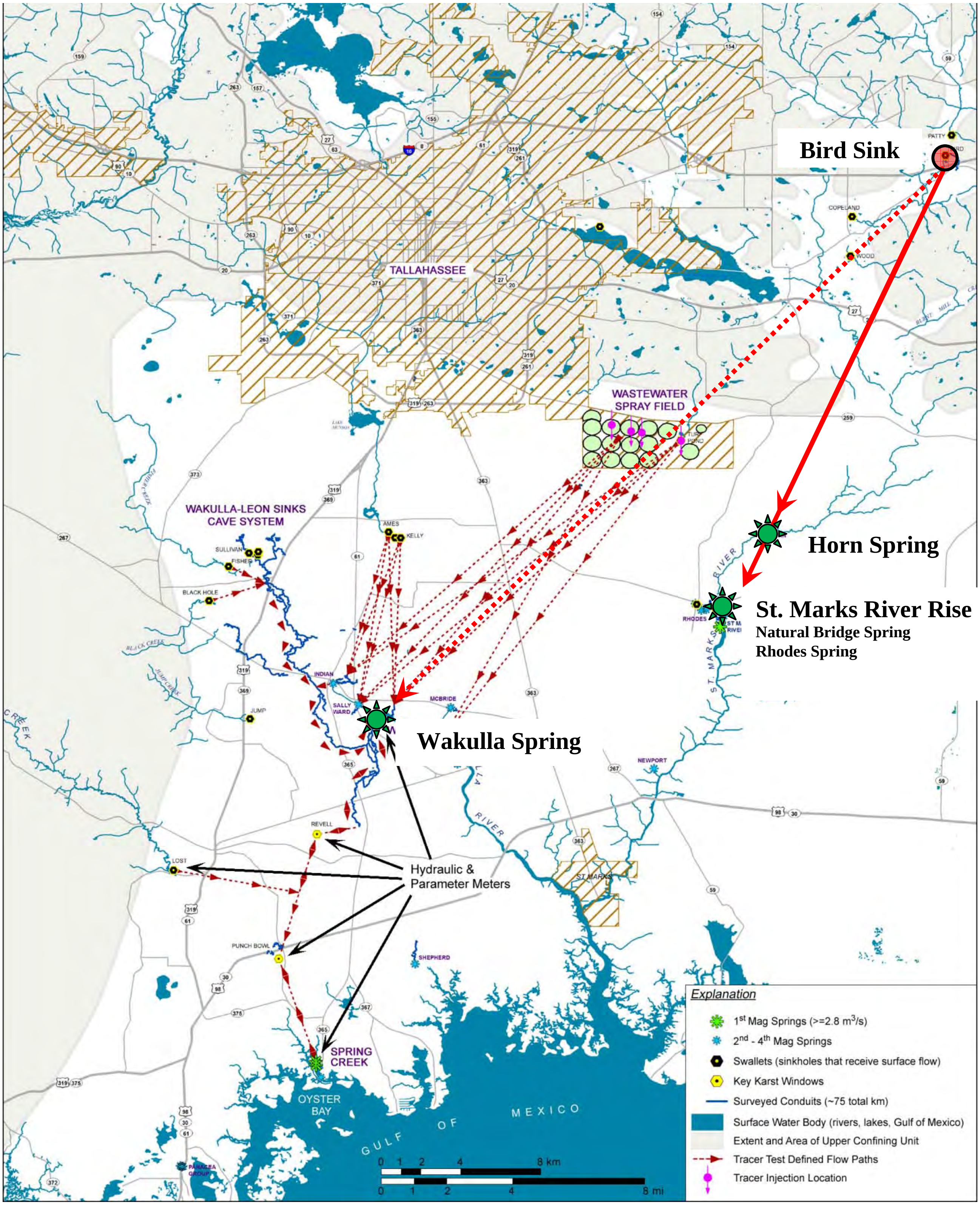


Figure 8. Map of the western Woodville Karst Plain showing the location of the Bird Sink groundwater tracer test injection (large red dot) and the sampled springs where the tracer was recovered (Horn spring, St. Marks River Rise, Natural Bridge spring, Rhodes spring, and Wakulla spring) relative to a projected straight-line flow path.

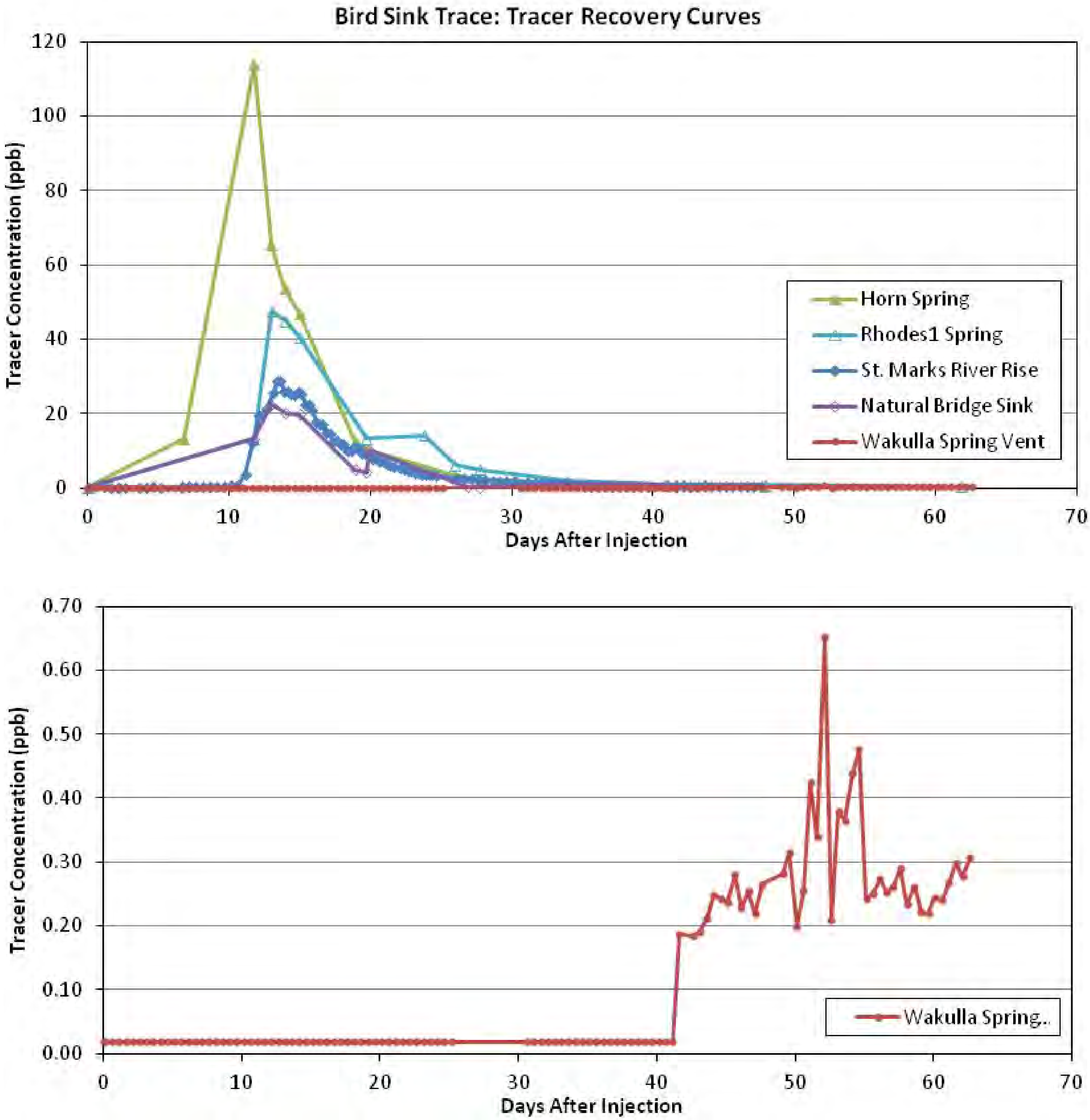


Figure 9. Tracer recovery curves from the monitored stations where dye was detected during the Bird Sink groundwater tracer test. Top plot shows all curves. Bottom plot shows an expanded view of the recovery curve produced from samples collected at the Wakulla spring vent.

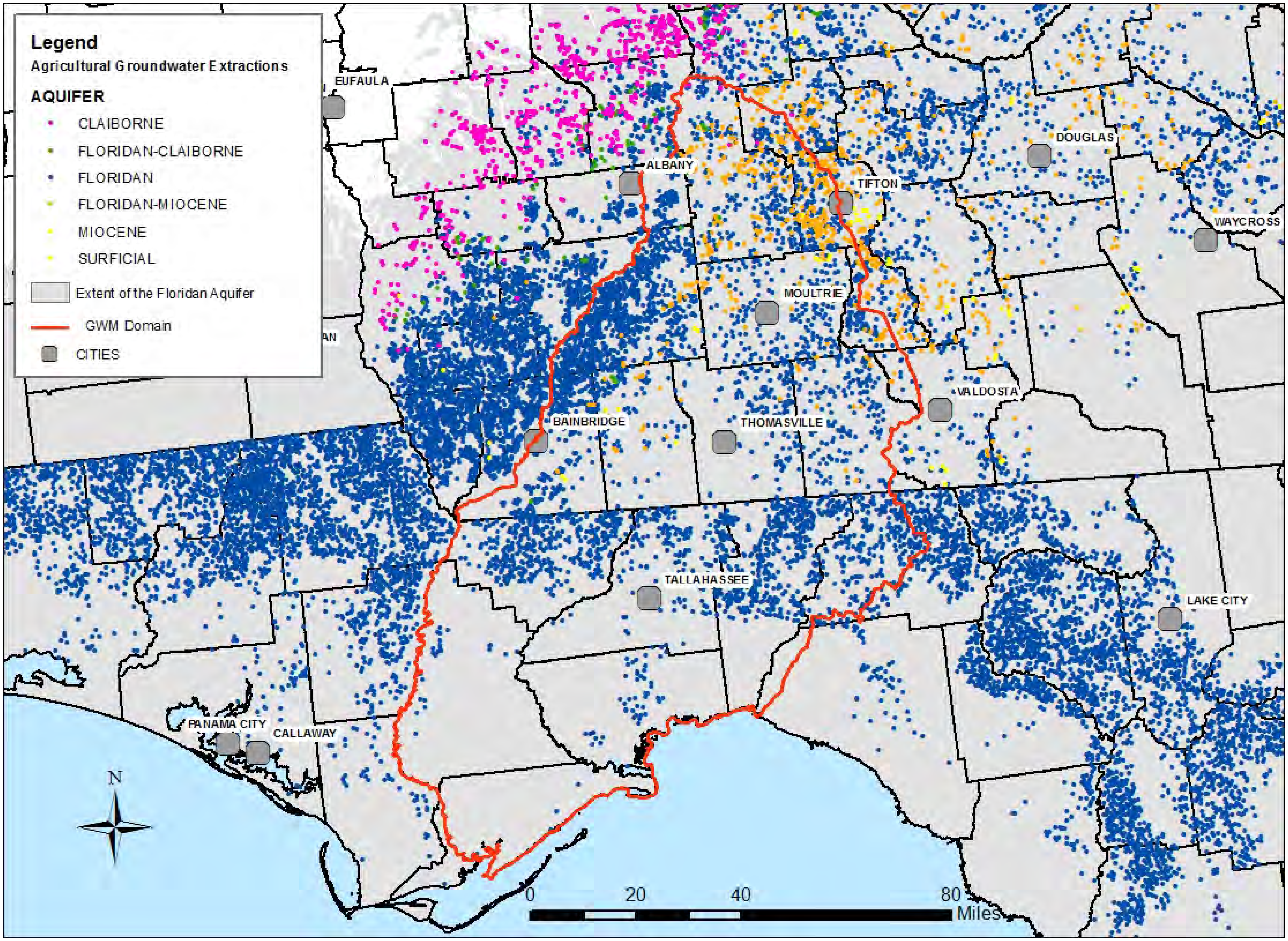


Figure 10. Consolidated locations of agricultural pumping in Georgia and Florida that will be assigned in the GWM such that the total agricultural groundwater pumping equals the percentage of total pumping in the county associated with the area represented by the point.

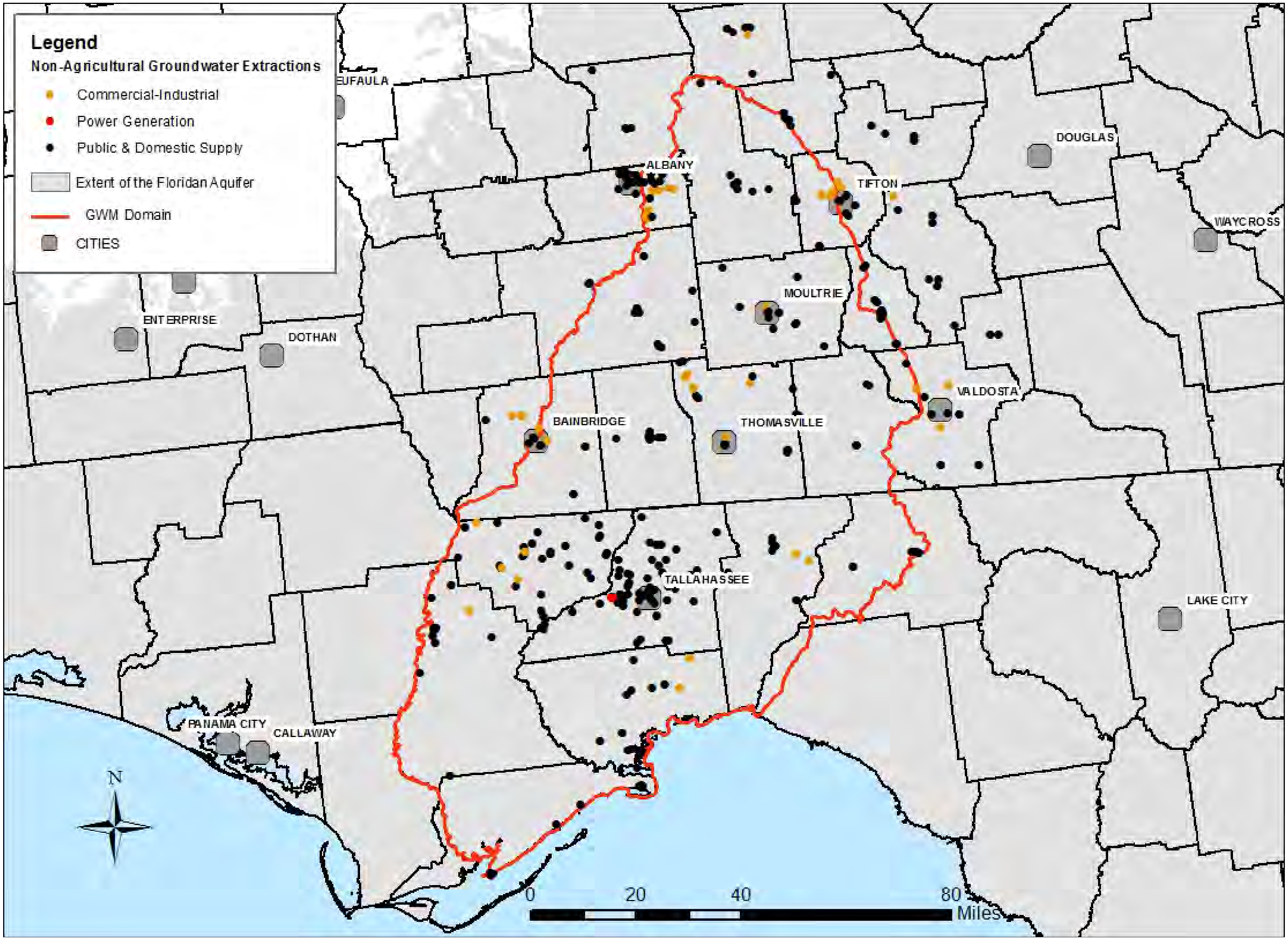


Figure 11. Locations of non-agricultural groundwater pumping in and surrounding the GWM domain.

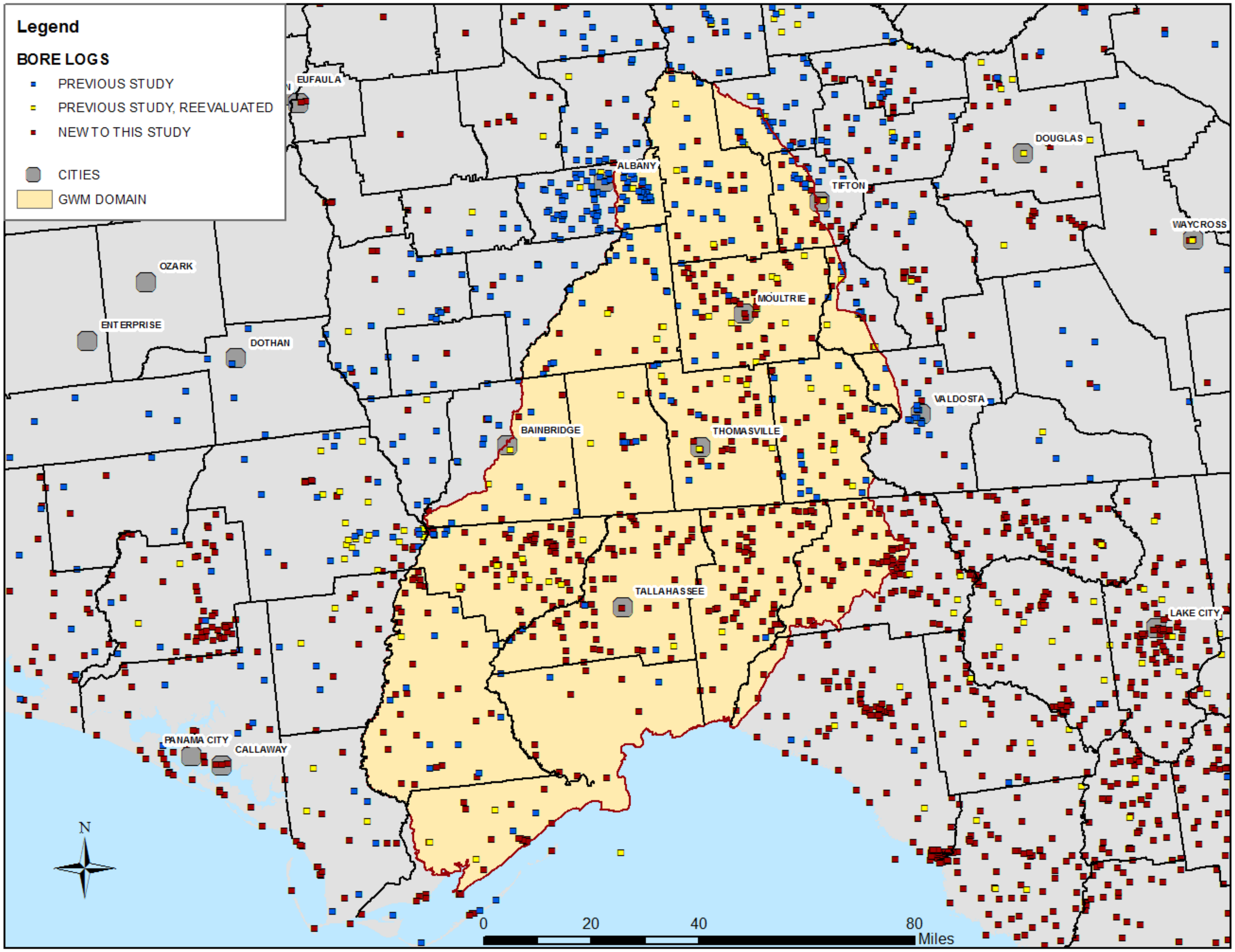


Figure 12. Map sowing the locations of all borehole logs that were compiled and analyzed as part of this study and from which the hydrostratigraphic delineations that will be used in the revised GWM were derived.

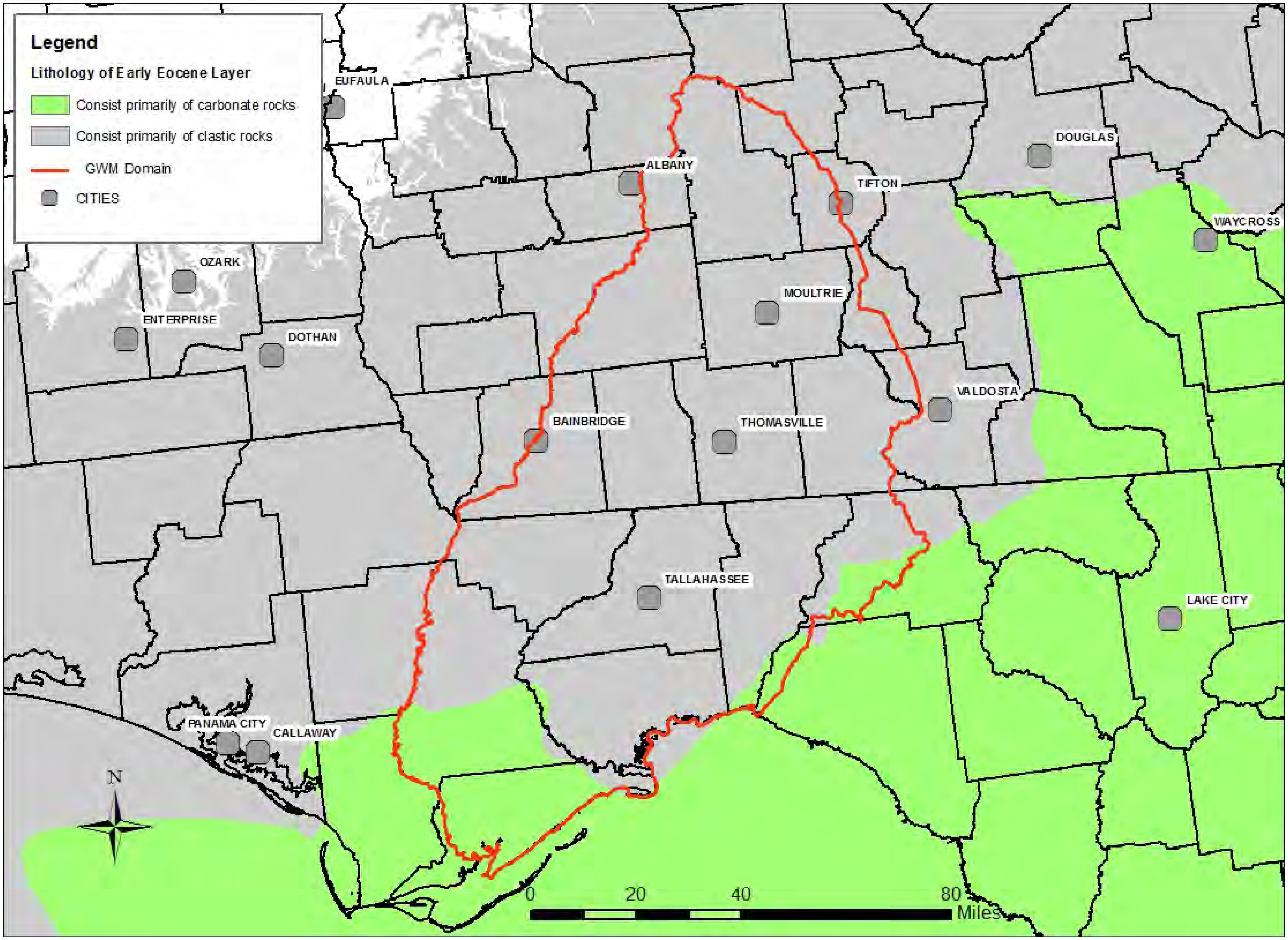


Figure 13. Delineation of lithology within the early Eocene layer that will be incorporated in the revised GWM.

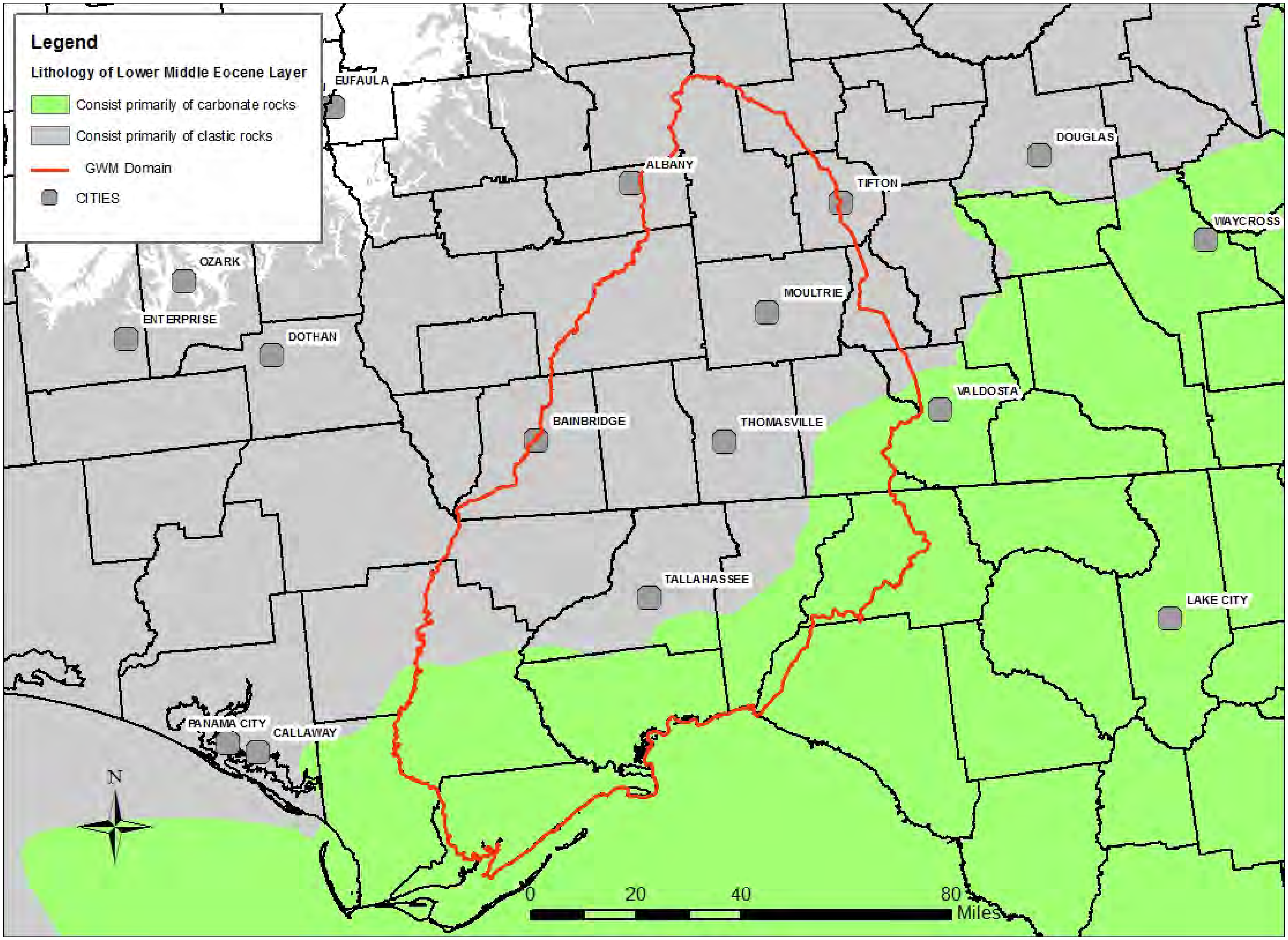


Figure 14. Delineation of lithology within the lower middle Eocene layer that will be incorporated in the revised GWM.

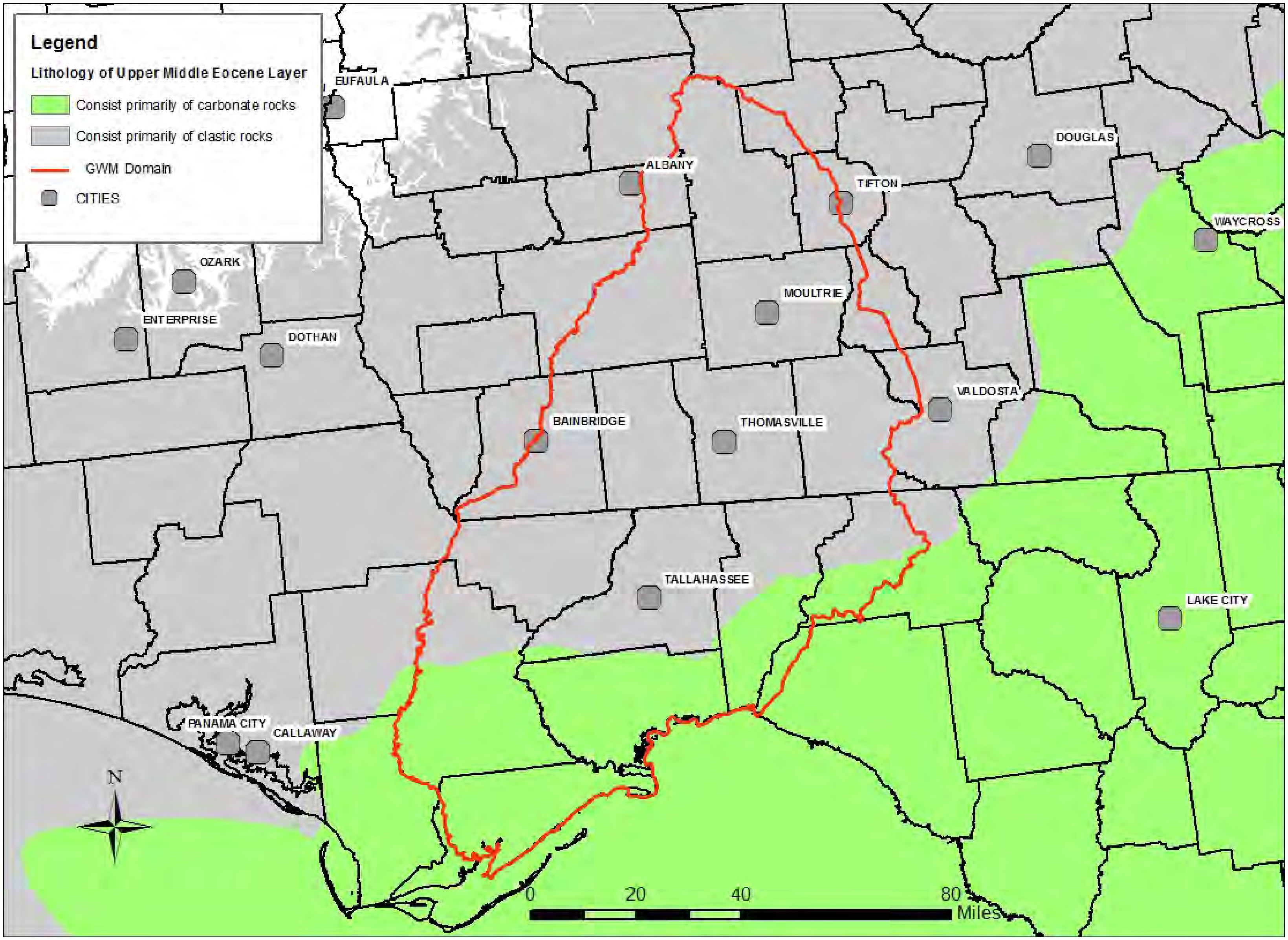


Figure 15. Delineation of lithology within the upper middle Eocene layer that will be incorporated in the revised GWM.

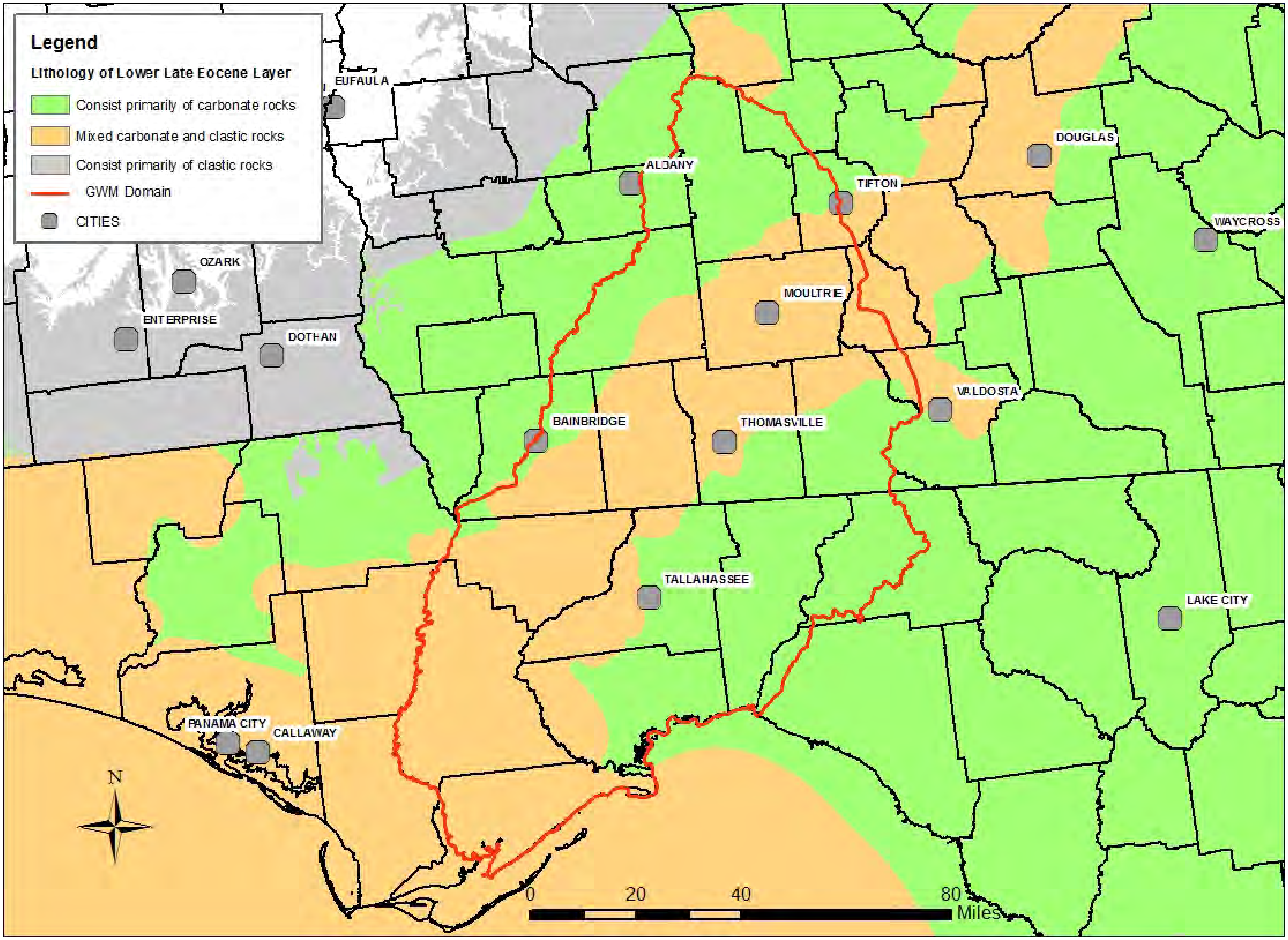


Figure 16. Delineation of lithology within the lower late Eocene layer that will be incorporated in the revised GWM.

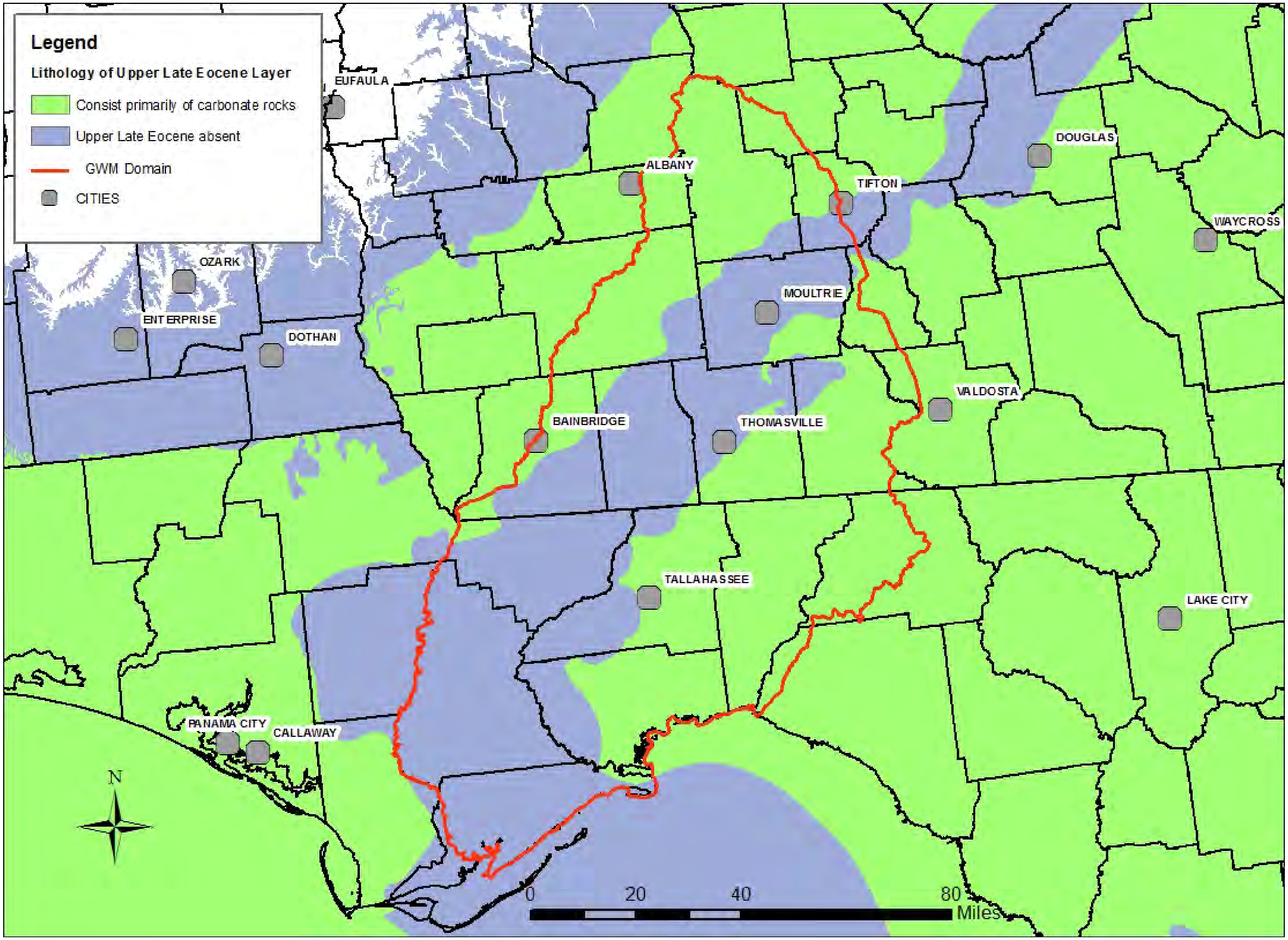


Figure 17. Delineation of lithology within the upper late Eocene layer that will be incorporated in the revised GWM.

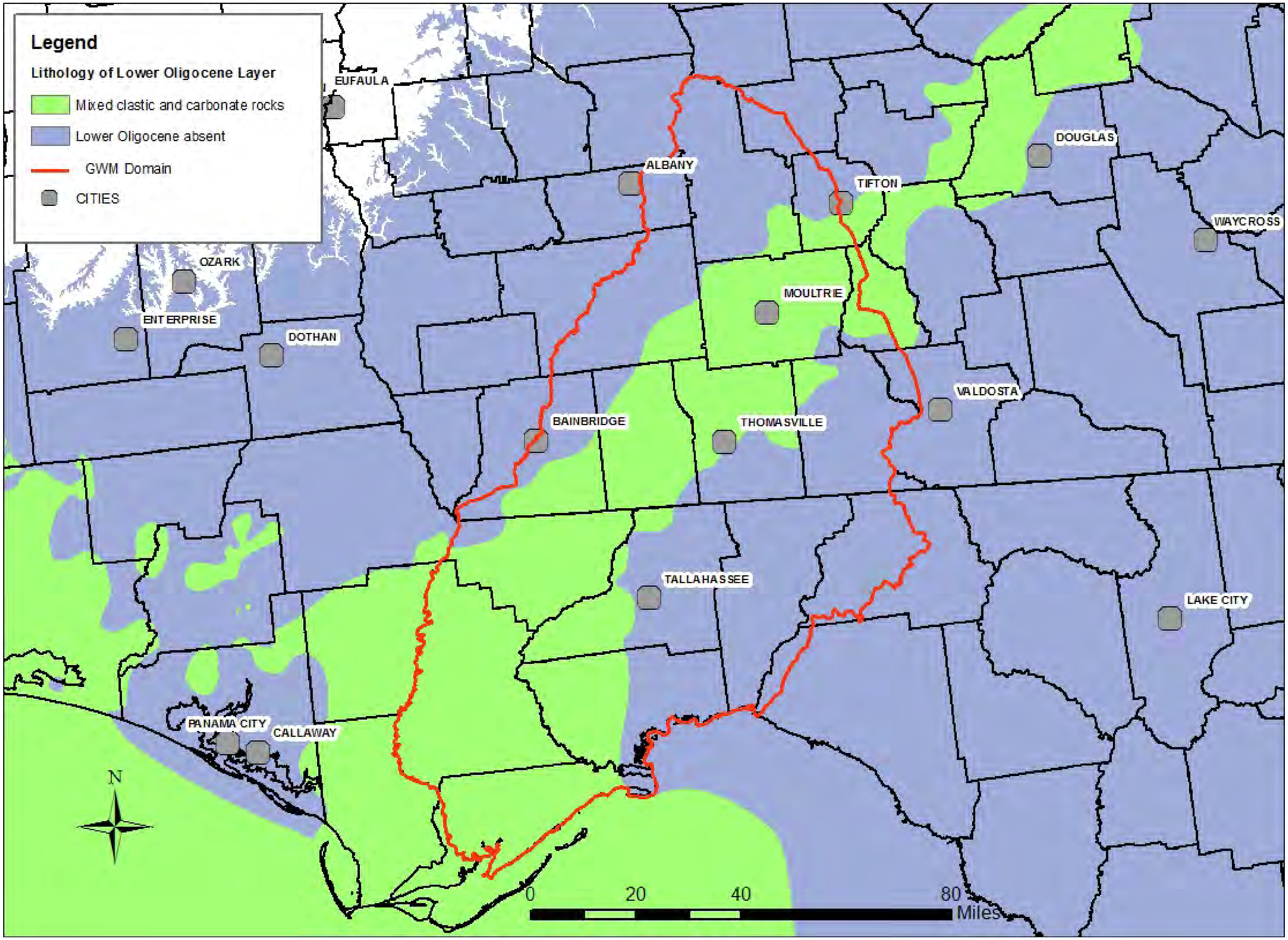


Figure 18. Delineation of lithology within the lower Oligocene layer that will be incorporated in the revised GWM.

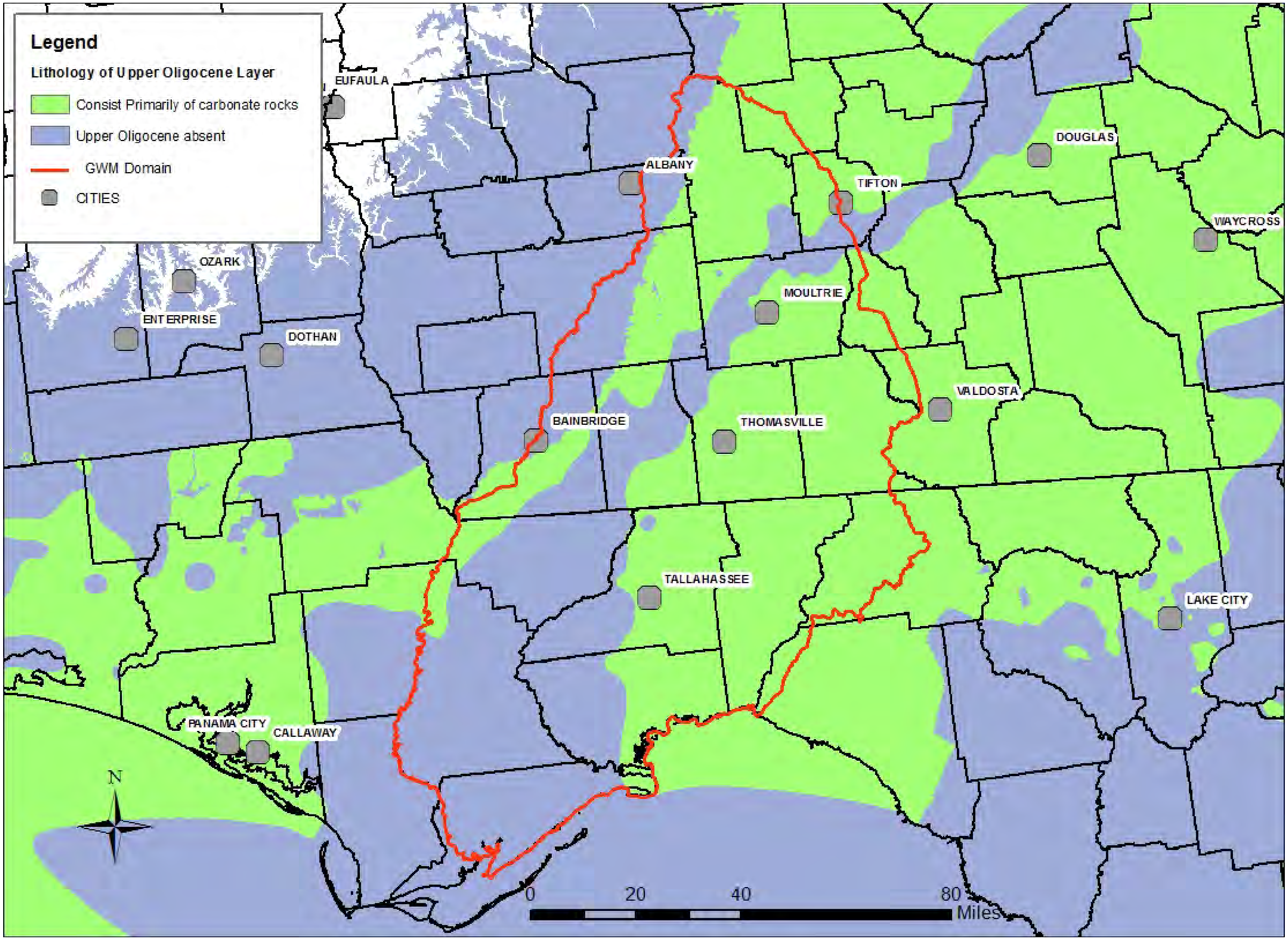


Figure 19. Delineation of lithology within the upper Oligocene layer that will be incorporated in the revised GWM.

APPENDICES

APPENDIX I
BIRD SINK GROUNDWATER TRACER TEST – TRACER RECOVERY DATA

APPENDIX II
AGRICULTURAL GROUNDWATER PUMPING DATA COMPILED FOR GEORGIA

Projection: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version / GCS_North_American_1983
GCS_North_American_1983
Datum: D_North_American_1983

False_Easting: 0.000000
False_Northing: 0.000000
Central_Meridian: -96.000000
Standard_Parallel_1: 29.500000
Standard_Parallel_2: 45.500000
Latitude_Of_Origin: 23.000000
Linear Unit: Meter

APPENDIX III
AGRICULTURAL GROUNDWATER PUMPING DATA COMPILED FOR FLORIDA

Projection: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version / GCS_North_American_1983
GCS_North_American_1983
Datum: D_North_American_1983

False_Easting: 0.000000
False_Northing: 0.000000
Central_Meridian: -96.000000
Standard_Parallel_1: 29.500000
Standard_Parallel_2: 45.500000
Latitude_Of_Origin: 23.000000
Linear Unit: Meter

APPENDIX IV
MUNICIPAL GROUNDWATER PUMPING DATA COMPILED FOR FLORIDA AND GEORGIA

Projection: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version / GCS_North_American_1983
GCS_North_American_1983
Datum: D_North_American_1983

False_Easting: 0.000000
False_Northing: 0.000000
Central_Meridian: -96.000000
Standard_Parallel_1: 29.500000
Standard_Parallel_2: 45.500000
Latitude_Of_Origin: 23.000000
Linear Unit: Meter

APPENDIX V
HYDROSTRATIGRAPHIC PICKS DERIVED FROM A COMPILATION AND INTERPRETATION OF FLORIDA AND GEORGIA BOREHOLE LOGS

Data Sources Referenced in Appendix V

Source	Citation	Description
1	Herrick, 1961	Compilation of well logs with both geologic picks and lithologic description
2	McFadden et al, 1986	Compilation and interprtation of well logs in Georgia. Some logs have both geologic picks and lithologic description, some have only geologic picks
3	FGS, 2012	FGS database of well logs throughout Florida. Most logs have both geologic picks and lithologic description, some have only one of the two.
4	Torak and Painter, 2006	Contains a table of well info (location, GSE, depth) and top and bottom FAS elevation picks used in their invetigation.
5	Torak and Painter, 2010	Contains a table of well info (location, GSE, depth) and geologic picks use in their investigation.
6	Miller, 1986	Compilation of well logs throughout Florida, Georgia, and Alabama. Logs have been interpreted into both geologic pick (grouped by age) and hydrogeologic picks (aquifer or low-perm unit). No Lithologic descriptions.

Projection: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version / GCS_North_American_1983
GCS_North_American_1983
Datum: D_North_American_1983

False_Easting: 0.000000
False_Northing: 0.000000
Central_Meridian: -96.000000
Standard_Parallel_1: 29.500000
Standard_Parallel_2: 45.500000
Latitude_Of_Origin: 23.000000
Linear Unit: Meter

Part 2.

Impacts of Storm Surge Flooding on the Water Quality in Sewered and Un-sewered Communities.

Richard A. Snyder, Ph.D., Professor and Director,
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Background
Septic tanks have long been implicated in chronic contamination of coastal waters where minimum drain field setbacks to ground and surface water exist, especially in sandy soils. However, gravity sewer, though more controlled in normal conditions, is subject to chronic pipe leakage and catastrophic failure with flooding events. Fertilizer on lawns and gardens and pet waste also contribute to the sum of coastal development contamination of ground and surface waters.

The scope of this portion of the project was redesigned after waiting for a tropical event over two years without an occurrence. While no one is complaining about this situation, we repurposed the sampling design to examine the effect of tidal pumping on ground water and any associated effects on contamination for surface and ground waters in coastal canal and levee systems served by septic tanks and gravity sewer. Sampling was conducted for a minimum of 5 spring-Neap tidal cycles in the winter-spring of 2012 when yearly tidal amplitudes are greatest.

The study area was the Shell Point and Oak Island canal and levee coastal developments located south of Tallahassee, FL (Figures 1-2). Wells were dug and piezometers installed in upgradient background areas (Figure 1) and in a series of transects across levees (Figures 1-2). Locations of the wells and associated surface water stations are listed in Table 1. Characteristics of the wells are listed in Tables 1-2.

Field Procedures.

Sampling personnel wore gloves rinsed with 70% ethanol between samples. An impeller pump with polypropylene tubing was used to pump wells to dryness and allow recharge prior to sampling for analysis. Analytical samples were obtained by peristaltic pumps and silicone tubing fitted with a lead weight on a monofilament lead so that samples were taken ~15 cm from the bottom of wells. Between samples, tubing exterior was wiped and rinsed with 70% ethanol and allowed to air dry. Tubing interior was cleaned by pumping an aliquot of ethanol through the tubing.

Three void volumes of sample water were allowed to pass through the silicone tubing before samples were taken. *Enterococcus* samples were collected in certified pre-sterilized 100 ml containers. Dissolved nutrient samples (40 ml) were obtained by filtering sample water through pre-combusted (1 hour at 500° C) 24 mm Whatman GF/F filters with 60 cc syringes fitted with a stainless steel Swinnex. Total nutrient samples (125 ml) were collected directly into sample bottles containing H_2SO_4 for preservation. A hand held multimeter (YSI Instruments) was used to measure temperature, salinity and dissolved oxygen in the sampled waters.

All samples were placed immediately on ice for transport to the Wetlands Research Lab (WRL) at the University of West Florida (UWF), NELAC certified for fecal microbiology and nutrient analyses.

Lab Procedures

Upon receipt, *Enterococcus* samples were processed immediately to accommodate prescribed hold time. Nutrient samples were frozen until analysis. Standard methods used are listed in Table 3. Nitrate analysis did not pass QA/QC due to suspected sulfide and or chloride interference and those data are not included in this report.

Data were organized in MS Excel Spreadsheets and normalized by log-transformation for statistical analysis with JMP software (SAS, Inc.). JMP and Kaleidagraph (Synergy Software) were used for graphic presentation.

Data on physical parameters of ground and surface water were obtained by: level loggers in wells, data sondes (temperature, salinity, depth/pressure, dissolved oxygen), a tide prediction model (http://tbone.biol.sc.edu/tide/; 30.06, -84.29), and precipitation records (http://www.cocorahs.org/, FL-WK-2, St. Marks 8.2 SW, 30.0657, -84.2857).

Figure 1. The Shell Point and Live Oak Island region showing locations of sampling sites including background wells north of the study area.

Figure 2. The canals at Shell Point serviced by central gravity sewer lines (upper left). All sites were sampled in May and June of 2010. The westernmost transect (left) was also the focus of sampling in the spring of 2012 to identify any effects of tidal pumping, from spring-neap tidal cycling, on mobilization of fecal contamination and nutrients. The Oak Island Road area serviced by septic tanks (right), including the canal at Bayou Road (north) and the sampling well locations on Live Oak Island (south). All sites were sampled in May and June of 2010. The westernmost transect on the Bayou Road levee and the sites on Oak Island were also the focus of sampling in the spring of 2012 to identify any effects of tidal pumping, from spring-neap tidal cycling, on mobilization of fecal contamination and nutrients. Surface water sampling locations are indicated in the lower left chart.

Table 1. Location of sampling stations. GS = Gravity Sewered. ST = Septic Tank. SW = Surface Water. BG = upgradient Background wells.

Well Identification	GPS Coordinates	Length of Well w/out Cap (ft)	Depth of Well at Ground Surface (aprox. in ft)	Depth to H2O	Depth of H2O Below Ground Surface (ft)	Pump On	Pump Off	Depth to H2O after pump (ft)	Recover time (min)	Depth (ft) to H2O after Recovery time	Volume produced (ft^3/min)
GS01	N30.06445 W084.29174	14	11.8	8.73	-6.53	13:47	13:54	14	10	10.23	0.0086
GS02	N30.06410 W084.29175	14	10.6	8.49	-5.09	14:08	14:28	11.85	10	8.97	0.0065
GS03	N30.06370 W084.29172	14	10	8.03	-4.03	14:48	15:03	9.7	10	8.85	0.0019
GS04	N30.06471 W084.28742	14	12	7.16	-5.16	12:48	13:01	14	10	10.19	0.0087
GS05	N30.06452 W084.28737	14	12	6.38	-4.38	12:16	12:30	14	10	10.74	0.0074
GS06	N30.06425 W084.2875	14	12	6.28	-4.28	11:43	12:00	14	10	9.05	0.0113
GS07	N30.06405 W084.28728	14	11.4	7.78	-5.18	11:17	11:26	14	10	12.18	0.0041
GS08	N30.06396 W084.28728	14	8.8	6.07	-0.87	10:50	11:00	14	10	12.68	0.0030
GS09	N30.06476 W084.28646	14	12	8.08	-6.08	13:29	13:35	14	10	12.57	0.0033
ST01	N30.06926 W084.27914	14	11	6.18	-3.18	11:35	11:54	14	10	7.22	0.0154
ST02	N30.0606913 W084.27908	14	11	8.12	-5.12	12:13	12:21	14	10	9.57	0.0101
ST03	N30.06893 W084.27901	14	10.9	8.33	-5.23	12:35	12:43	14	10	8.76	0.0119
ST04	N30.06956 W084.27780	14	10.5	7.9	-4.4	14:04	14:22	11.78	5		
ST05	N30.06937 W084.27773	14	10.2	7.04	-3.24	13:33	13:47	14	10	8.52	0.0125
ST06	N30.0692 W084.27773	14	10.8	7.9	-4.7	13:02	13:19	9.76	7	8.07	0.0055
ST07	N30.06415 W084.27399	14	10	8.44	-4.44	14:21	14:29	14	10	9.98	0.0091
ST08	N30.06398 W084.27402	14	11	8.22	-5.22	14:49	15:04	14	10	9.15	0.0110
ST09	N30.06339 W084.27362	14	11.8	8.37	-6.17	15:25	15:36	14	10	9.76	0.0096
BG01	N30.08244 W084.27693	14	10	6.53	-2.53	14:43	15:00	7.27	5	6.71	0.0025
BG02	N30.0935 W084.2902	14	7.8	8.58	-2.38	15:22	15:38	10.31	5	8.92	0.0063
BG03	N30.0832 W084.3065	15	9		6						0.0000

Table 2. Peizometer installation site characteristics.

Well Identification	Location on Property	Observations while digging; soil, moisture, lithology.
GS01	Few feet off SeaWall	Typical fill dirt, hit H2O around 7' from gournd surface
GS02	SW corner of lot, just off Royster	Topsoil up to 28", then 6" thick unconsolidated clay, 32-42" sandy gravelly, 42" black sulfide highly organic layer of medium/fine grain sand, 80" highly moist black hummocky, past 84" wet more med/fine sands gray in color.
GS03	SE corner, just off Sea Wall	Loamy sand upto 40", @ 50" hit dark moist med/fine grain soil, @ 60" black med/fine soil VERY moist, Dug past 10' more of same gray black mud infilling wht well
GS04	NE corner, just off Sea Wall	Same as GS06
GS05	Middle of lot, east side, under bushes	Same as GS06
GS06	East side of lot, at stair case	Notes poor, topsoil first foot or so, followed by high clay mix with fine sands gray in color, some gravelly LS unconsolidated, HIGH moisture content of clay/sand/gravel LS mix around 6 feet below surface, dug up to aprox 12 foot
GS07	East side of lot in flower bed in back	Up to 2' top soil, 2-4' shelly and unconsolidated LS and gravelly, @ 5.5' hit clay peat layer, 6.5 hit wet sand, past 7' wet sand/silt/clay slurry, around 10' hit thick clay layer, dug slightly past clay and set well.
GS08	SE corner of lot, on natural beach, few feet south of Sea Wall	Beach sand at first, transition to dark gray mix of clay, silt sand, notes re dig are weak, believe we hit gravelly LS around 9 feet
GS09	SW corner, just W of property line, 18 feet N of mailbox	Dark top soil first foot, 1 to 6 foot gray clay/fine sand and gravelly LS mix, @ 6'cut through clay/sand/gravelly mix, 7-9' peat/brown grasses, 9-10 feet wet sand/gray clay mix, @ 10' wet sand gray in color w some clay mix, dug through same up to 14', back up and set well 12' deep
ST01	NW corner of eastern lot, few feet off sea wall. Western lot reported to have 150 plus tires all along sea wall	0-2' brown sand, med grain w/ ss pebbles, 2-4' darker gray med grain sand, 4-8' gray wet sand w/ some black humic content, 8' plus more of the same, with some higher clay/silt content
ST02	Mid way eastern lot along boundary of W and E lot, 10 feet east of electrical pole by fence	0-1' dark brown topsoil/med grained, 2-3' hit moist soild, 4' hit thin layer of grass like that in marsh w/ grayish med grain sand below, @ 5.5' hit distinctive lighter gray med grained sand with higher moisture content, @ 7.5' hit almost slurry of distinctive dark brown sand, more of same through 10', had major trouble with casing past 10', around 11' hit Rock(LS) that could not cut, stopped here around 11' below surface and set well
ST03	SW corner of eastern lot, right at boundary between the two lots, 3 feet s of road and 5 feet n of marsh	0-3' sandy gray fine to med grained sand with some top soil, @ 4' darker coarser and high moisture of same, @6' slurry of dark med grained sand, @ 7' darker brown slurry , dug up to 11 feet through same
ST04	NW corner of lot, few feet off sea wall	Notes poor, trouble free dig, recall soil principally being med grained gray sand mix with some finer clay silts 0-3 feet, darker and higher moisture med grained sand up to around 6 feet, moisture continued to increase, became slurry of med grained gray sand/silt mix, more of same to about 11 feet.
ST05	On west side of lot, midway near hammock to the	Gray sand 0-2', darker black moist med grained sand up to 4', after 5' higher moisture

	west	continent of same, @ 7' hit dark brown med grained sand with organics, around 10' hit hard rock like grinding subsurface could not cut, set well here around 10' below surface.
ST06	S side of lot around SW corner across the road in a shore bend that redirected the marsh canal. On south side of road a few feet,	Sand 0-2', past 2' gray sand mixed with dry brown sand mix, hit high moisture at 4' and black sand, after 5 foot dark brown highly saturated sand, around6' hit saturation/h2o, continued to around 10 almost 11feet and set well
ST07	West side of lot, between septic mounds 25 feet south of Sawgrass Road.	Fill dirt all way to +/- 10', combo of brownish med grain sand and some lighter gray colored finer grained sand, hit some clayey granulated LS at 10 or 11feet.
ST08	West side of lot along boundary of neighbor, well is 10 feet or so N of seawall	0-3 med grained gray sand, @ 3 ft white layer of partially consolidated moist fine LS clay, @ 5 ft hit brown peaty organic layer, @ 6 ft highly moist black med grained sand, h2o around 5-6ft, @ 9 ' hit light gray saturated med grained sand, @ 10' from surface set well
ST09	East side of Sawgrass a few feet off road at NW corner of septic mound	Orange clay/sand combo up to 3', after 3' hit moist dark gray medium black coarse sand, @ 5 ft hit highly moist dark gray med grained sand, more us same up to 12 ft where set well
BG01	East of Live Oak Isle Road, on edge of pines and marshy/estuary sand bar area. Was previously w of road near borrow pit, but moved per DeHan, low flow/not natural	Black topsoil and sand first couple feet, hit noticeable moisture just past 1 feet, 2 foot plus black med grain sand and muck with high moisture, around 7 feet hit higher moisture, lighter gray to brown med grain sand/clay mix, dug up to around 10 through more of same., set well 10ft from surface
BG02	30 m inside road 217 gate off Live Oak Isl rd. Well is 20 feet east of road just past wash out with sunken concrete culvert.	0-3 feet black dark top soil, found high moisture at 2 feet, hit gray med grained saturated soil/sand/clay mix around 5', at 6' getting lighter in color and more clayish sand, @ 7 ft hit white clay gravelly layer filled with granules of LS, could not dig much past this, set well around 8ft at ground surface.
BG03	Across street from pump station on Cut Off road. Well is NW corner of road and refuge property south of Cut Off Road, just west of gate and open cut of pipe line.	Dark black topsoil 0-3', hit saturated slightly brownish soil around 3 ft, @ 4' hit very moist beige fine grained sand, dug up to 9' and set well. This well has 5 foot screen section, overall length of well is longer than others.

Table 3. Water sample analysis conducted by the WRL at UWF.

Analyte	Unit	US EPA Method
Enterococcus	CFU/100ml	1600
Dissolved Ammonia-N	mg N/L	350.1
Dissolved Phosphorus	mg P/L	365.1
Dissolved Nitrate/Nitrite	mg N/L	353.2
Total Kjeldahl Nitrogen	mg N/L	351.2
Phosphorus (Total)	mg P/L	365.4

Results

During the 2012 spring-neap tidal cycle sampling the only significant rainfall was 2.7 inches on 4 March 2012 (Figure 3). The subsequent sampling did not show any significant rain effect on ground or surface water contamination. Tidal amplitudes for the sampling period are shown in Figure 4, as the absolute tidal height and as the amplitude change. Sampling events to isolate any spring-neap tidal differences were timed toward the end of high or low amplitude periods. Spring tide periods experienced as much as 4 ft of elevation change, while spring tide periods saw as little as 1 ft of elevation change between tides (Figure 4).

Water levels at three wells are shown in Figure 5 for the period January 2011 through May 2012. The background well #2 (BG02) showed the largest longterm changes in the water table with little short-term amplitude change. The well next to a seawall in the gravity sewered area (GS01) showed the greatest short-term amplitude changes but little longer term differences. A well in the center of the gravity sewered levee (GS02) showed small short term amplitude changes and little long-term changes in water table. Similarly, a well in the center of the septic tank serviced levee (ST04) ha little long-term and short-term variation in water level. Thus, water table conditions I the levees were apparently buffered by sealevel relative to the background wells, but also buffered from tidal changes by distance from seawalls. This effect is seen more dramatically in an overlay of the amplitude changes for the surface water tidal prediction, the GS01 and ST04 wells next to the seawalls, and the GS02 and ST05 wells in the center of the levees of sewer-serviced and septic tank service areas respectively for the period January 2012 through March 2012 (Figure 6). The diminishing amplitude effect is apparent but a tidal effect is still seen, even in the center of the levee, though more dramatically for the gravity sewer serviced area.

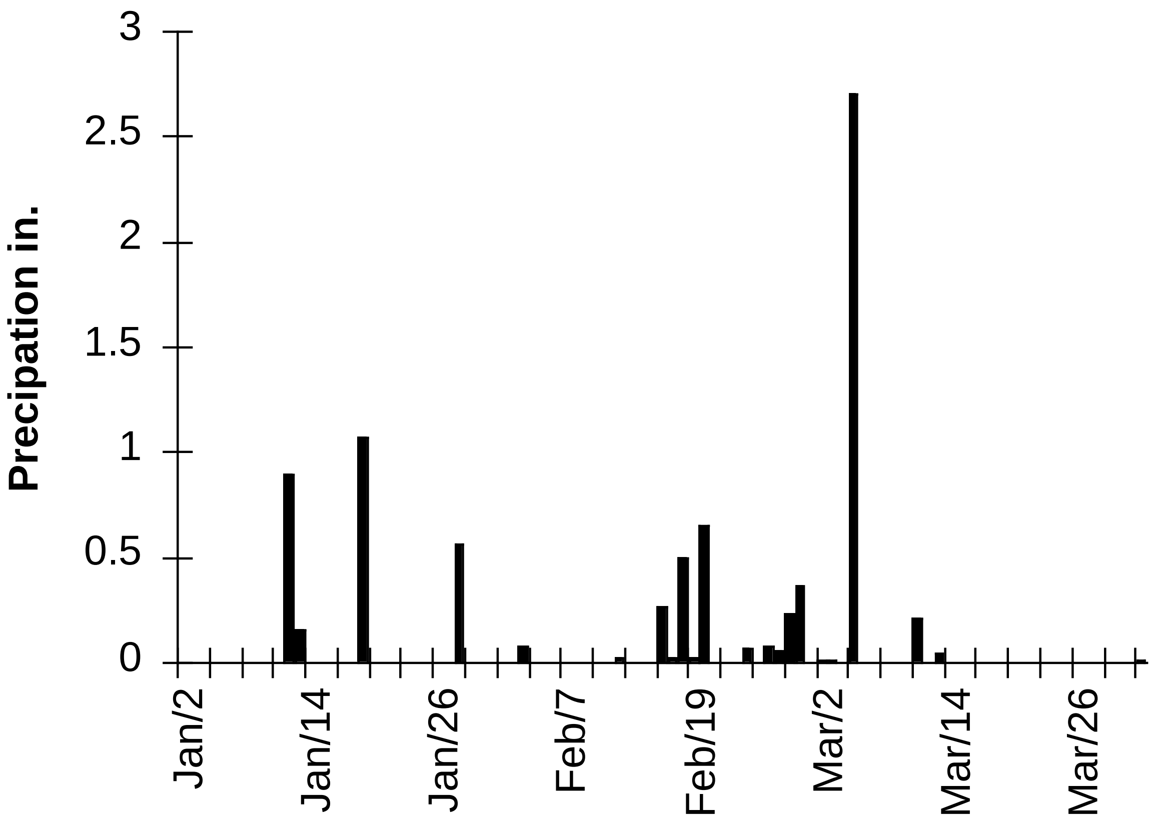
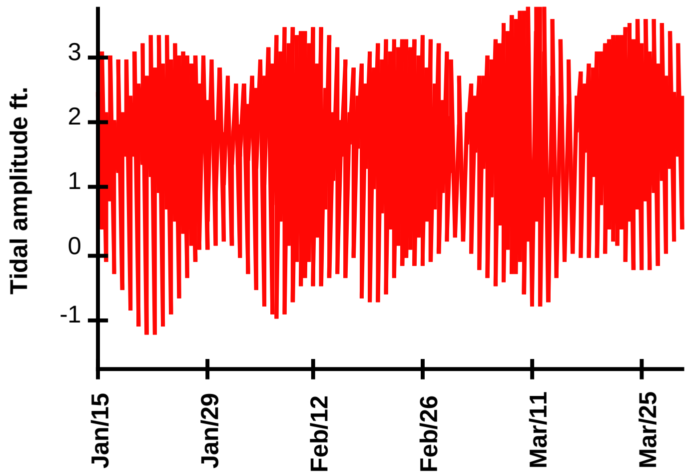


Figure 3. Precipitation records for St Mark's (30.0657, -84.2857) for the Spring of 2012.



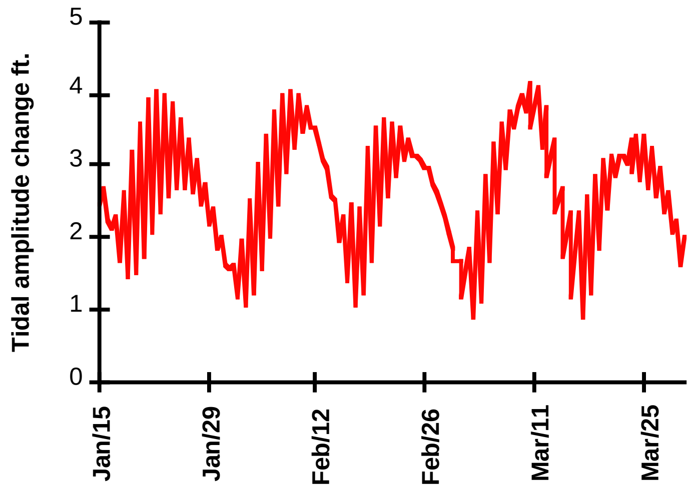


Figure 4. Tide height for Shell Point (top) and the change in amplitude (bottom) extracted from these data for the Spring of 2012. Spring tides experienced a maximum tide change of ~4 ft. Neap tides experienced a tidal change of ~1 ft.

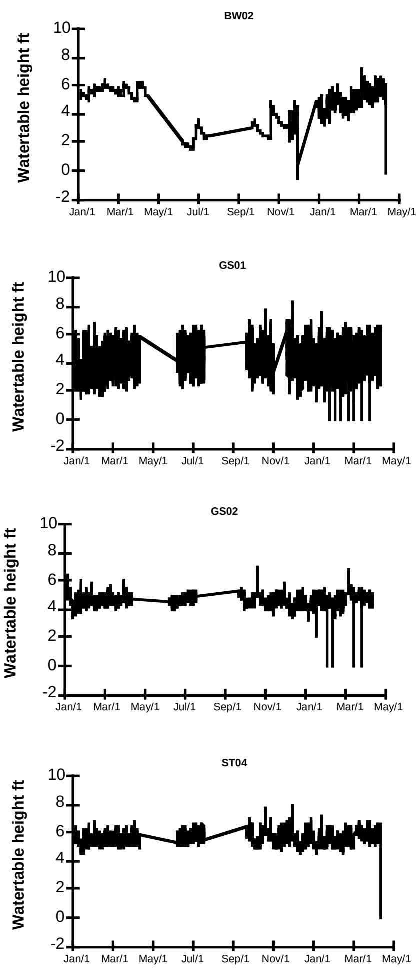
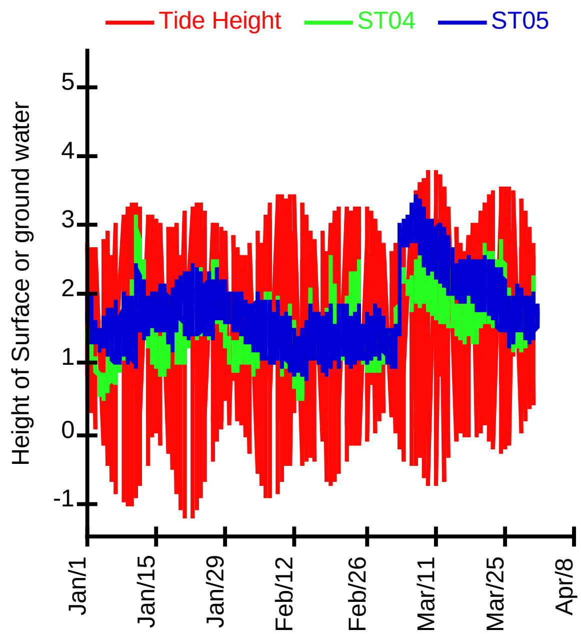


Figure 5. Water table fluctuations at a background well (BW02), a Shell point well next to a seawall (GS01), a Shell point well in the center of the levee (GS02), and in a well at Oak Island next to a seawall (ST04) for the period January 2011 to May 2012.



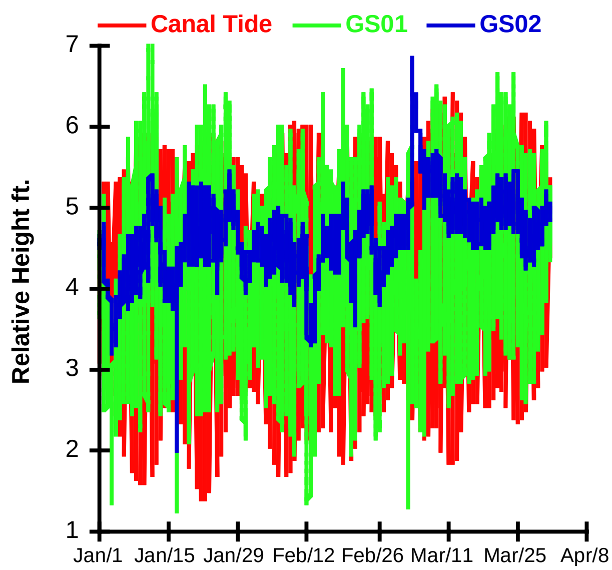


Figure 6. Tidal affects on groundwater in Shell Point (top) and Oak Island (bottom) levees. Red data is the predicted tide as shown in Figure 4 Green data is the water level in wells adjacent to seawalls on the canals. Blue data is the water level in the center of the levees. Both show attenuation with distance from the canal, but Shell Point levee ground water was affected to a greater degree than at Oak Island.

Water level, salinity, temperature, for wells in the center of the levees (GS02, ST05; Figure 7) show similar responses for water level changes, a more buffered temperature response in the septic tank serviced area, and salt water intrusion in the septic tank serviced area. It is suspected that irrigation in the gravity sewer serviced area may contribute to these differences. Adjacent dockside sondes in canals (BW for septic area, DH for gravity sewer area; Figure 8) for the first 3 months of 2012 show a fairly consistent high salinity trend for the area. Water parameters for the stations sampled for spring-neap tidal effects from Jan 2012 to April 2012 were also obtained by handheld meter (YSI multimeter) at the time of sampling (Figure 9). Surface and ground water at all three areas followed similar trends, with some buffering of temperature in the gorund water relative to adjacent surface waters (Figure 9, top row). Salinity trends show salt water intrusion along the seawalls at the GS site and the ST1 site. Dissolved oxygen (DO) trends are similar across sites, with lower DO as expected in ground waters. Sulfide odors indicating reducing conditions were common in well sampling.

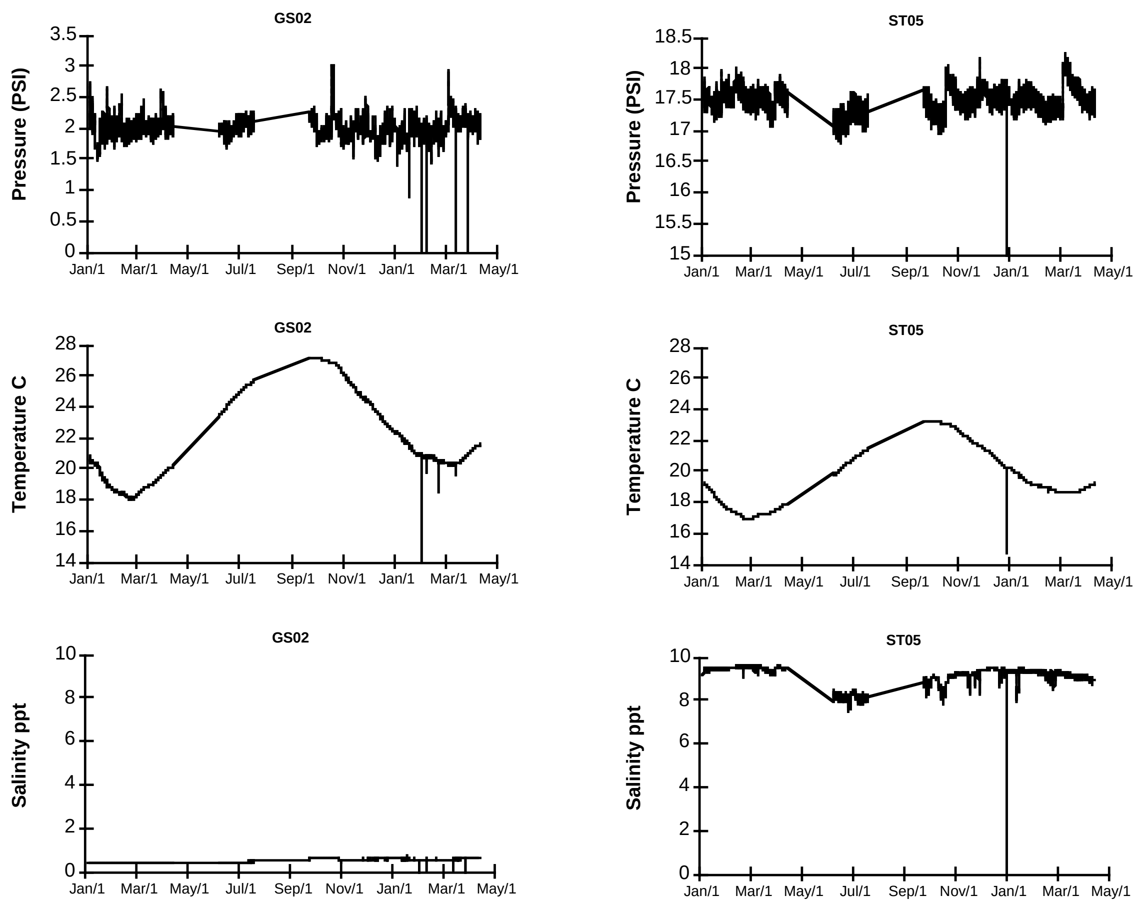


Figure 7. Relative groundwater height, temperature, and salinity at a well in the center of a levee in the Shell Point sewered area (GS02; left column) and in the center of a levee in the Oak Island area using septic tanks (ST05, right column) for the period January 2011 to May 2012. Saltwater intrusion was more apparent in the Oak Island well.

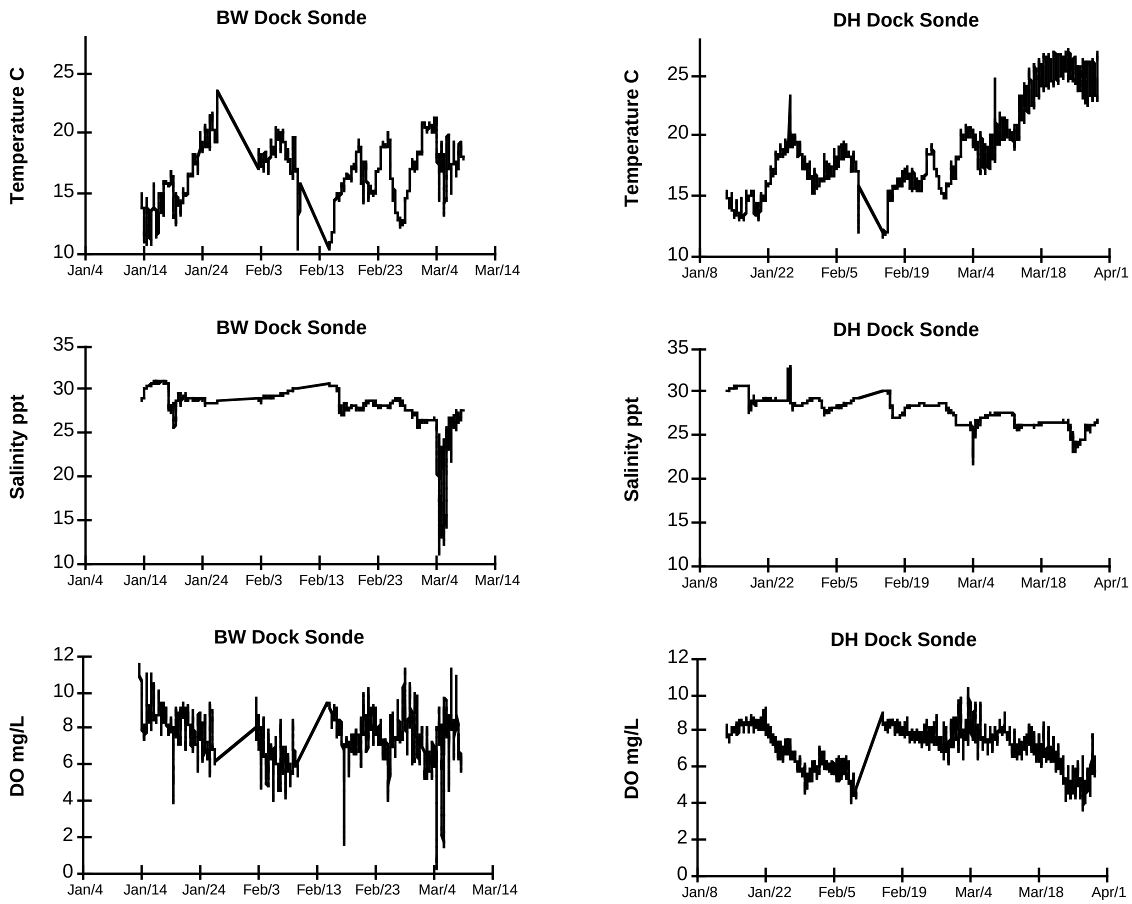


Figure 8. Temperature, Salinity, and dissolved oxygen characteristics of surface water in a canal at Oak Island (SW4, left column) and in a canal at Shell Point (SW11, right column) for the period January 2012 to April 2012

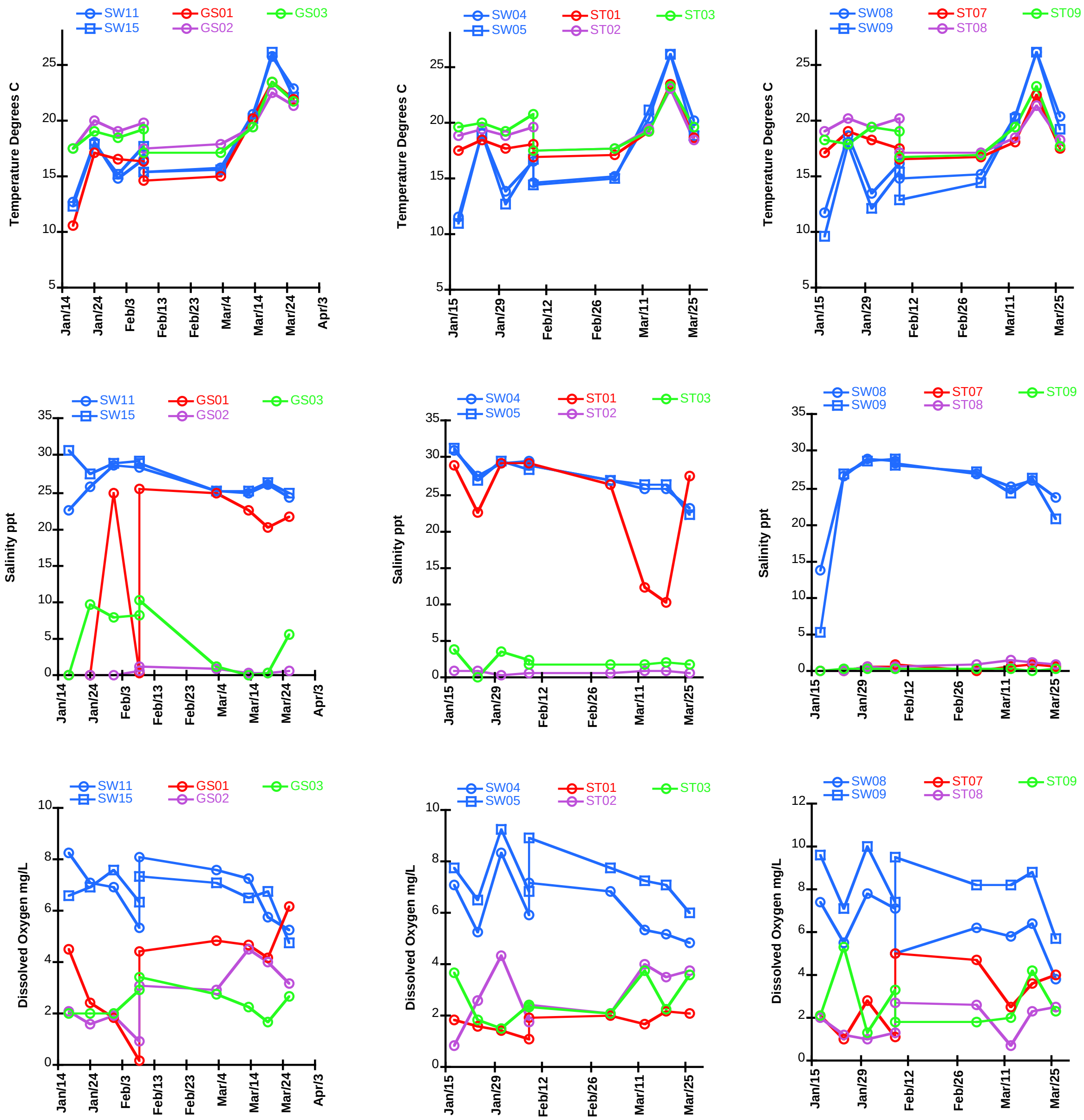


Figure 9. Water quality parameters measured at the time of sampling by handheld multimeter for the three transects of levee wells and associated surface waters for the January 2012 to April 2012 time period. GS = Gravity sewer area, ST= septic tank areas, ST1-3 = septic tank area ST1, ST7-9 = septic tank area ST2.

Summary data for *Enterococcus* fecal indicator bacteria separated by spring and neap tidal periods is presented in Table 4 and Figures 10-11. Overall there was little difference between neap and spring tide phases, though all wells had more than twice the incidence of fecal indicators exceeding the one sample time threshold value of 105 Bacteria/100 ml (Table 4). Broken down between gravity sewer area wells (GS) and septic tank area wells (ST) did show a higher frequency of excedences for neap tide periods in GS wells, but no effect on excedences for ST wells, which had a higher frequency of excedences and geomeans than the GS wells regardless of tidal phase (Table 4).

Figures 10-11 display the spatial differences in *Enterococcus* counts as those below and above the benchmark three month geomean value of 35 *Enterococcus*/100 ml. The septic tank area with mound systems on Oak Island had excedences regardless of tidal phase. Surface water showed contamination during the spring tide sampling periods for Bayou Road canal and levee, and for the sampling well in the center of the canal and levee for the sewer service area.

Table 4. Summary frequency data for *Enterococcus* analyses.

	% observations exceeding 105 counts /100 ml		**Geomeans**	**Maximum recorded**	**Geomeans**	**Maximum recorded**
	Neap Tides	**Spring Tides**	**Neap Tides**		**Spring Tides**	
All Wells	26%	20%	16	5720	21	1620
All Surface Water	12%	7%	17	1010	15	310
GS Wells	20%	13%	10	1150	8	870
ST Wells	34%	35%	22	5720	33	1620
GS1	25%	0%	18	1150	3	10
GS2	0%	33%	11	54	56	870
GS3	0%	0%	5	20	8	34
ST1	40%	33%	31	5720	83	730
ST2	20%	0%	7	188	11	78
ST3	40%	40%	29	202	19	168
ST7	40%	50%	114	880	287	1620
ST8	50%	50%	78	1090	77	410
ST9	0%	17%	5	33	18	163
Surface Water GS	0%	5%	10	40	7	310
Surface Water ST	18%	7%	20	1010	31	125

Figure 10. *Enterococcus* levels below and above the regulatory threshold of 35 geomean cells/100 ml in surface and ground water samples for Neap tide sampling periods.

Figure 11. *Enterococcus* levels below and above the regulatory threshold of 35 geomean cells/100 ml in surface and ground water samples for Spring tide sampling periods.

By ANOVA and multiple range test of log transformed data, no significant effect of tidal phase was found for Ammonium, Total P, TKN, or Enterococcus despite the frequency data tabulated in Table 4, likely due to the high variance nature of the data, and the chronic contamination of the septic tank area groundwater at particular wells. Tidal hydraulic pumping effects on groundwater were not substantiated to increase contamination of ground or surface water in these canal and levee systems. Without significant differences by tidal phase, the data were then pooled for analysis by station type for ANOVA (Figures 12-15 and Table 5).

Ammonium and Total nitrogen by digest (TKN) were highly correlated and had the same significant differences between station types (Figures 12, 13; Table 5). The highest values were found in the groundwater samples from wells in the gravity sewered area, the septic tank area, and the background area, with no significant differences between them. Surface waters regardless of location, were all significantly lower in nitrogen content than ground waters.

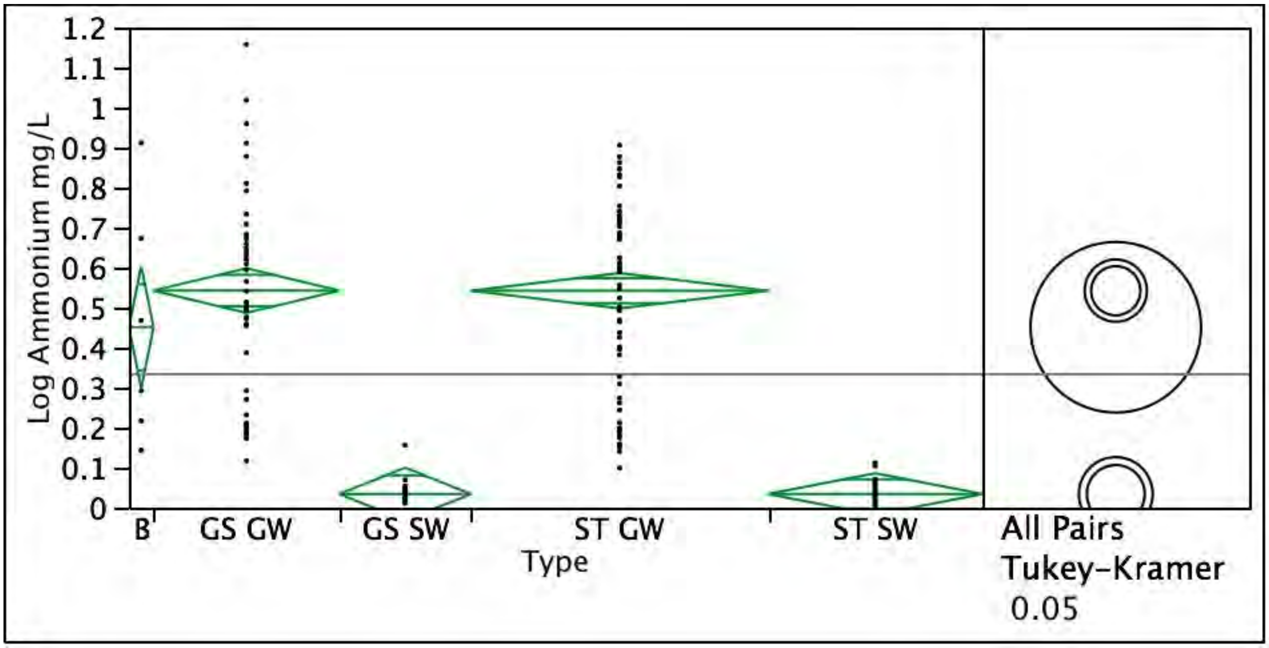


Figure 12. Oneway Analysis of Log Ammonium mg/L by type of station: B= Background wells, GS GW = Shell Point ground water wells, GS SW= Shell Point surface water, ST GW= Oak Island ground water wells, STSW= Oak Island surface water.

Oneway Analysis of Log TKN mg/L By Type

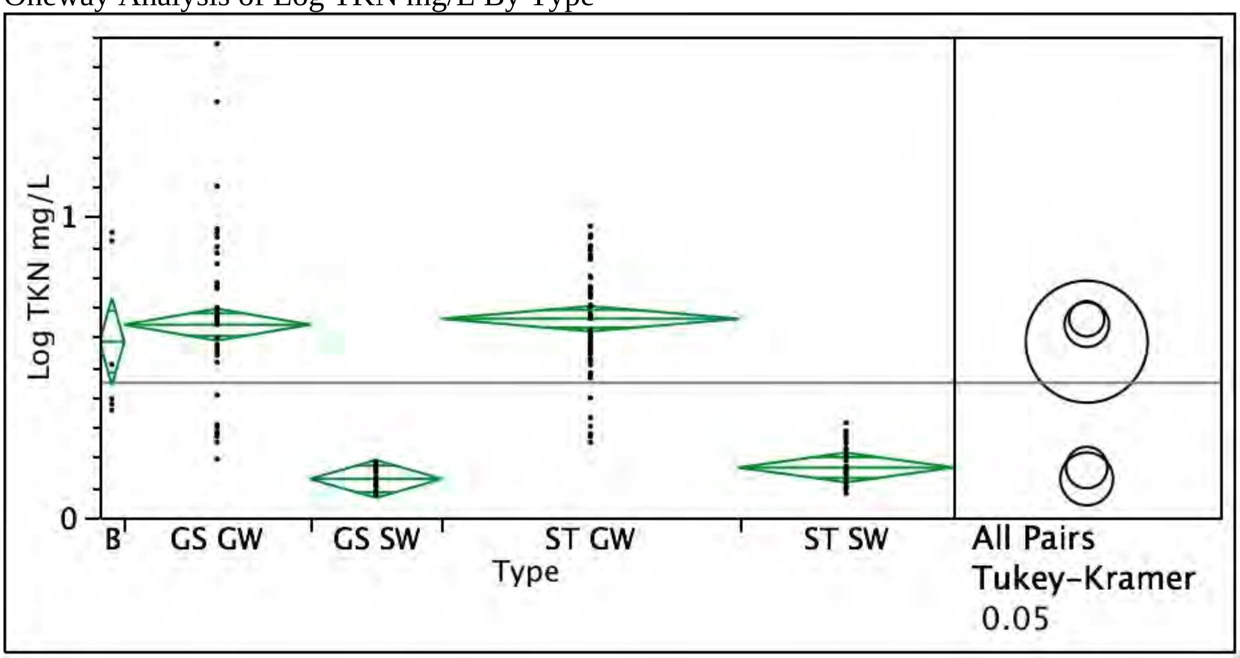


Figure 13. Oneway Analysis of Log TKN mg/L by type of station: B= Background wells, GS GW = Shell Point ground water wells, GS SW= Shell Point surface water, ST GW= Oak Island ground water wells, STSW= Oak Island surface water.

Total Phophorous by digest (TP; Figure 14; Table 5) was lowest in surface waters to the point of being undetectable in some samples (minimum detection limits were substituted for all undetected analytes), with no difference between surface water areas. Phosphorous concentrations in the background well groundwaters were not significantly different from surface waters or from the groundwater in the gravity sewered area, though the groundwater in the gravity sewered area had significantly higher phosphorous content than the surface waters. Phosphorous content of groundwaters in the septic tank area was significantly higher than all others.

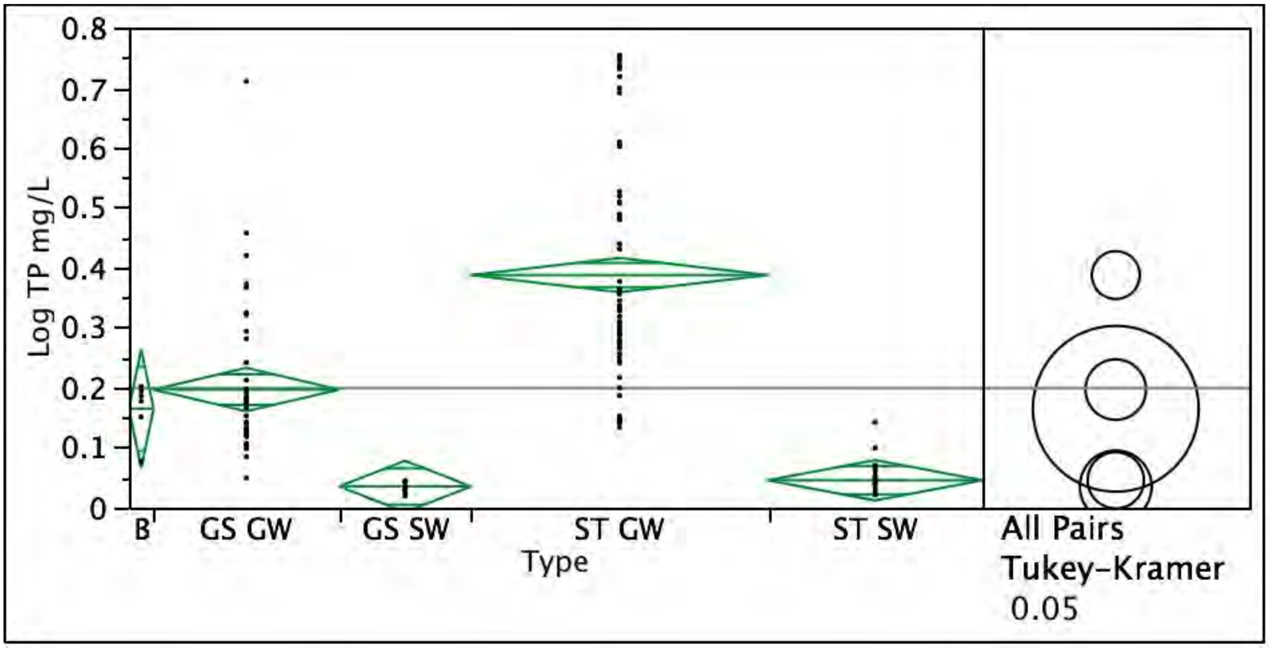


Figure 14. Oneway Analysis of Log TP mg/L by type of station: B= Background wells, GS GW = Shell Point ground water wells, GS SW= Shell Point surface water, ST GW= Oak Island ground water wells, STSW= Oak Island surface water.

Log *Enterococcus* counts in groundwater from septic tank serviced areas was significantly higher than any other station type with a geomean of 35 *Enterococcus*/100ml (Figure 15; Table 5). Septic tank area surface water *Enterococcus* counts were not significantly different than gravity sewer area groundwater, and these two sample types were significantly higher than the gravity sewer area surface water and background area groundwater. No significant differences were found between background area groundwater, gravity sewer area groundwater, and gravity sewer area surface water. Thus, overall, the septic tank service areas had significantly higher contamination from fecal indicator bacteria in both surface and ground water.

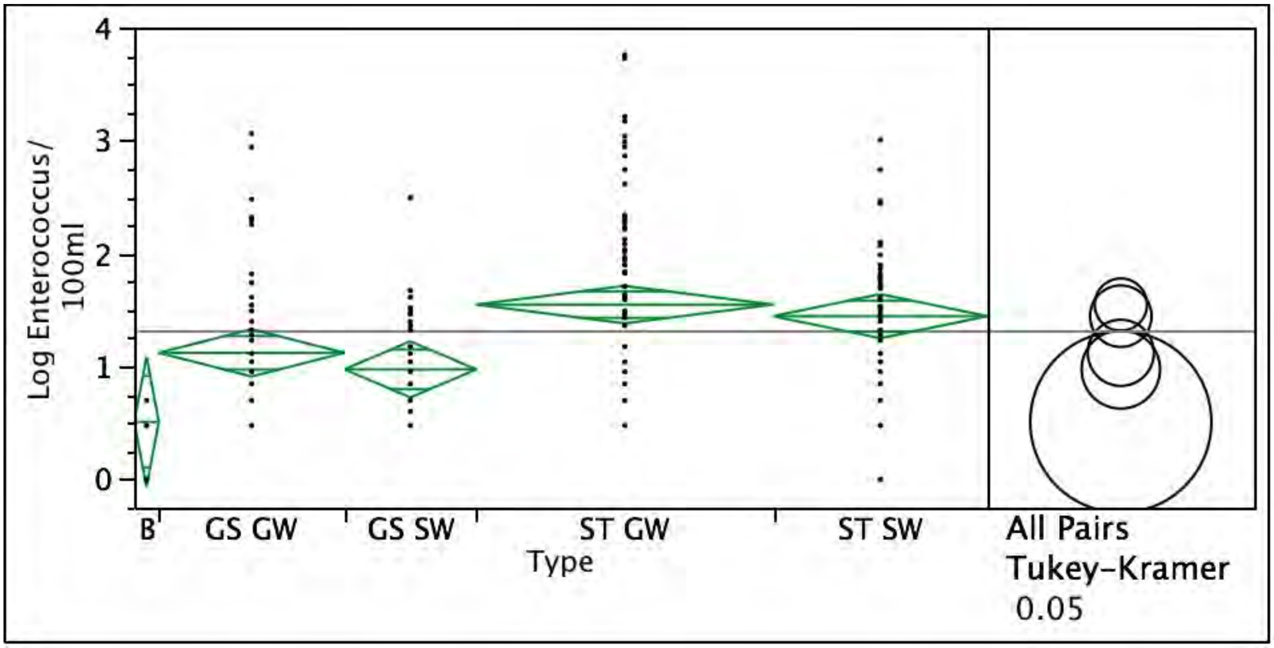


Figure 15. Oneway Analysis of Log *Enterococcus*/100ml by type of station: B= Background wells, GS GW = Shell Point ground water wells, GS SW= Shell Point surface water, ST GW= Oak Island ground water wells, STSW= Oak Island surface water.

Table 5. Mean values and significant differences for all data by type of station. Levels not connected by same letter are significantly different ($p \leq 0.05$).

Anova by Type	NH4	means mg/L	TKN	means mg/L	TP	means mg/L	Entero	means #/100 ml
Background wells	A	2.82	A	3.843	B C	1.46	C	3
Gravity sewered Groundwater	A	3.49	A	4.378	B	1.57	B, C	13
Gravity sewered Surface water	B	1.08	B	1.343	C	1.08	C	9
Septic tank groundwater	A	3.48	A	4.581	A	2.44	A	35
Septic tank surface water	B	1.08	B	1.465	C	1.11	B	28

Using multidimensional discriminant analysis with the log transformed data for all parameters measured (Figure 16), the surface water areas cluster together (left) separate from the background and sewer service area groundwaters, which cluster together (lower right). The septic tank serviced groundwater (upper right) is more similar to the other groundwater samples but is distinctly separate from background and sewer service area groundwaters along a dimension influenced by higher enterococcus and higher total phosphorous in agreement with the ANOVA analysis of these parameters separately, despite a wide scatter in the results.

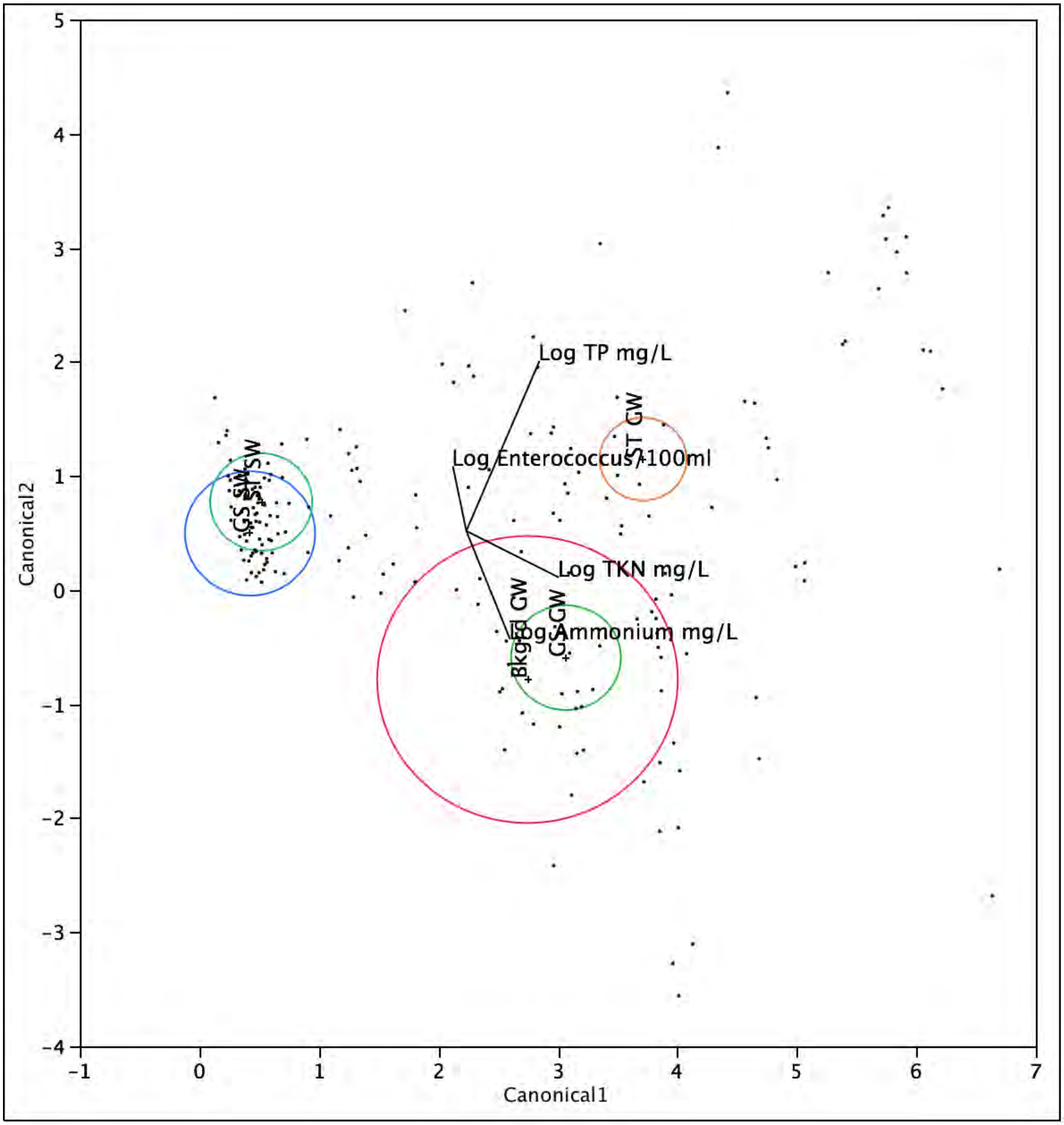


Figure 16. Discriminant analysis of sampling areas as influenced by total phosphate, TKN, dissolved ammonium and *Enterococcus* concentrations (all Log transformed). GS SW = gravity sewer area surface water, ST SW = septic tank area surface water, Bkgd GW = background area groundwater, GS GW = gravity sewer area groundwater, ST GW = septic tank area groundwater, The results show the overall characterization of the areas by the water quality parameters measured.

To resolve any differences between stations within and between sites, ANOVA was performed on the dataset using stations as a class variable (Figures 17-20; Table 6). For all nutrient analyses, surface water stations had significantly lower concentrations than any of the groundwater sample sites. Well number 8 in the septic tank service area (ST8) had the highest values for Ammonium, TKN, and TP, and shared this grouping with ST2 for nitrogen species.

For dissolved ammonium (Figure 17, Table 6), septic tank area well 1 (ST1) and gravity sewer area well 1 (GS1) were not significantly different and had the lowest ammonium levels of all ground water wells. GS1 was not significantly different than the background wells 1-3 (BW) or septic tank area well 9 (ST9) with the next lowest values. Wells 8 and 2 in the septic tank area (ST8, ST2) were not significantly different from each other and had the highest values of any wells. All other wells fell between these high and low groupings.

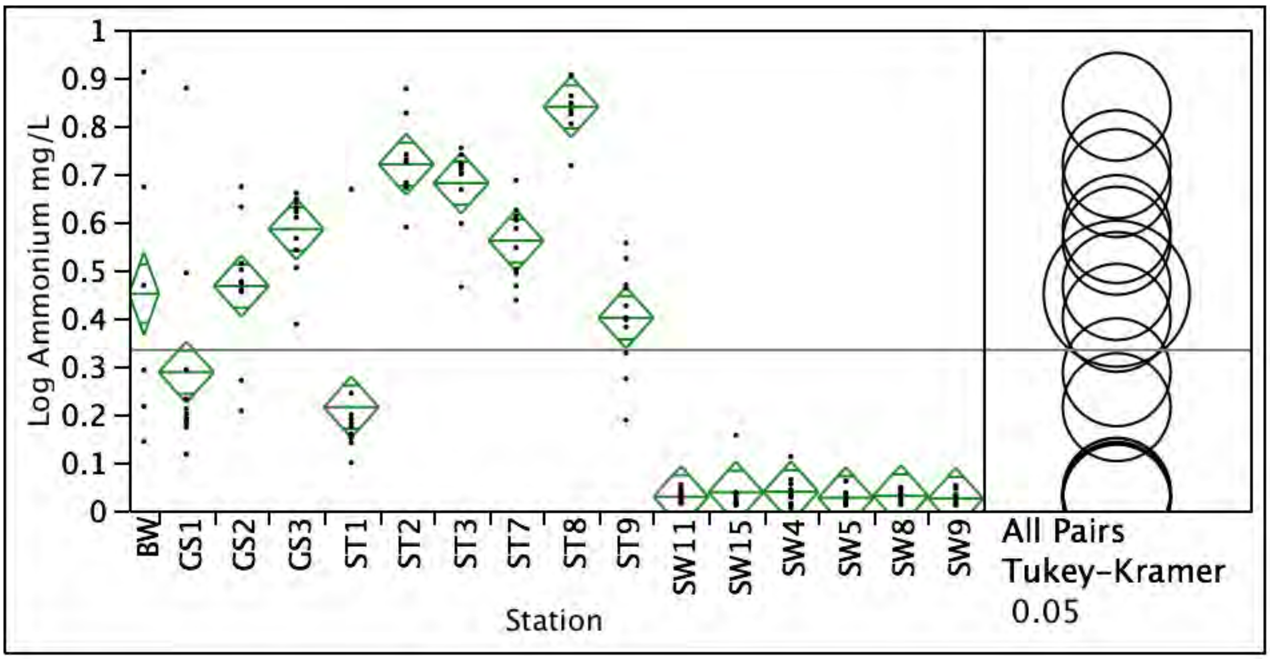


Figure 17. Oneway Analysis of Log Ammonium mg/L by station. Station identifications follow the list in Table 1.

As with the general area analysis, TKN and Ammonium show similar patterns in this station-specific analysis (Figure 18; Table 6). Well 8 in the septic tank area (ST8) had the highest levels, and with ST2 formed the highest concentration group. In the lowest group of groundwater stations were the background wells, GS1, GS2, ST1, and ST9.

Total Phosphorous (TP) was not as tightly correlated with other nutrients as was found for ammonium and TKN, but some similarities existed (Figure 19; Table 6). ST8 well yielded a stand alone highest set of samples for TP. The three highest groups for TP included only wells from the septic tank service area. ST1 well was in the lowest group above surface waters with background wells and gravity sewer area wells GS2, and GS3.

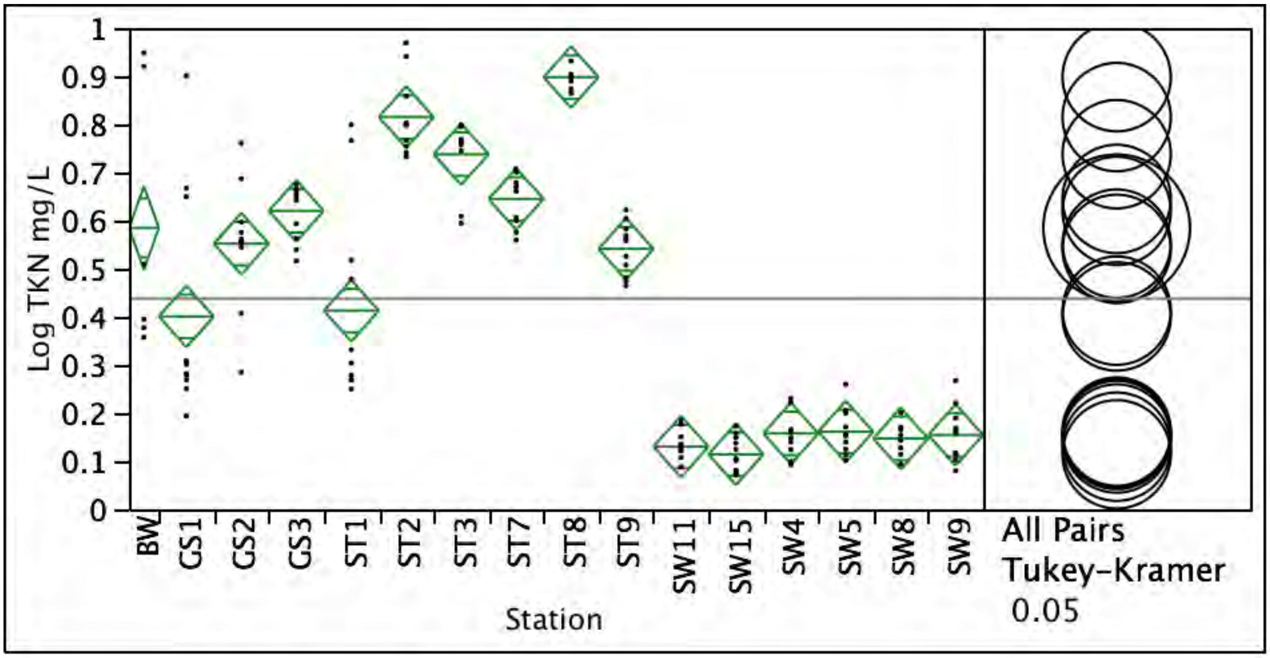


Figure 18. Oneway Analysis of Log TKN mg/L by station. Station identifications follow the list in Table 1.

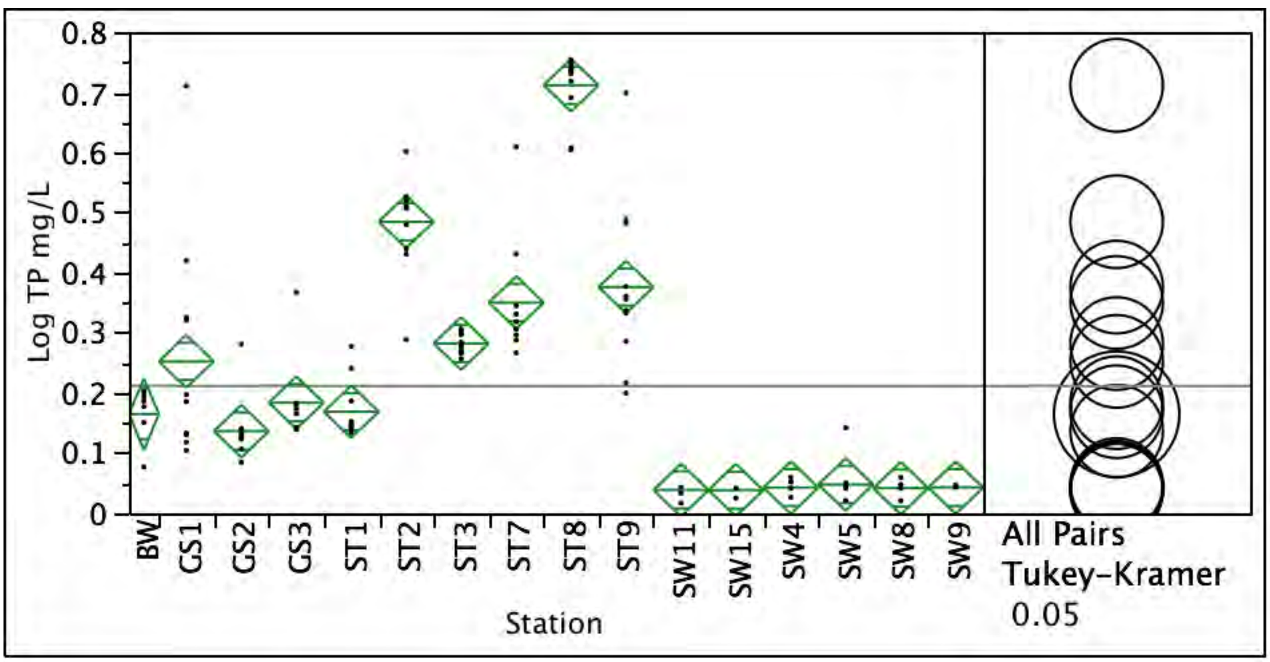


Figure 19. Oneway Analysis of Log TP mg/L by station. Station identifications follow the list in Table 1.

Enterococcus fecal indicator data were more variable than the nutrient data, with some very high values in some instances (Table 5; Figure 20, Table 6). The background wells were in the lowest grouping with a mean value of 3.22. Others in the lowest grouping were GS1, GS2, GS3, ST2, ST3, ST9, ST11, and all of the surface water stations. The highest mean value of stations in this lowest group was 35.37 for SW5 located in the septic tank area. ST7 had the highest mean value (153.44), in a group that included, in decreasing order, the following stations at or above a geomean value of 35 *Enterococcus*/100ml: ST8 (153), ST1 (54), SW8 (41), SW5 (35).

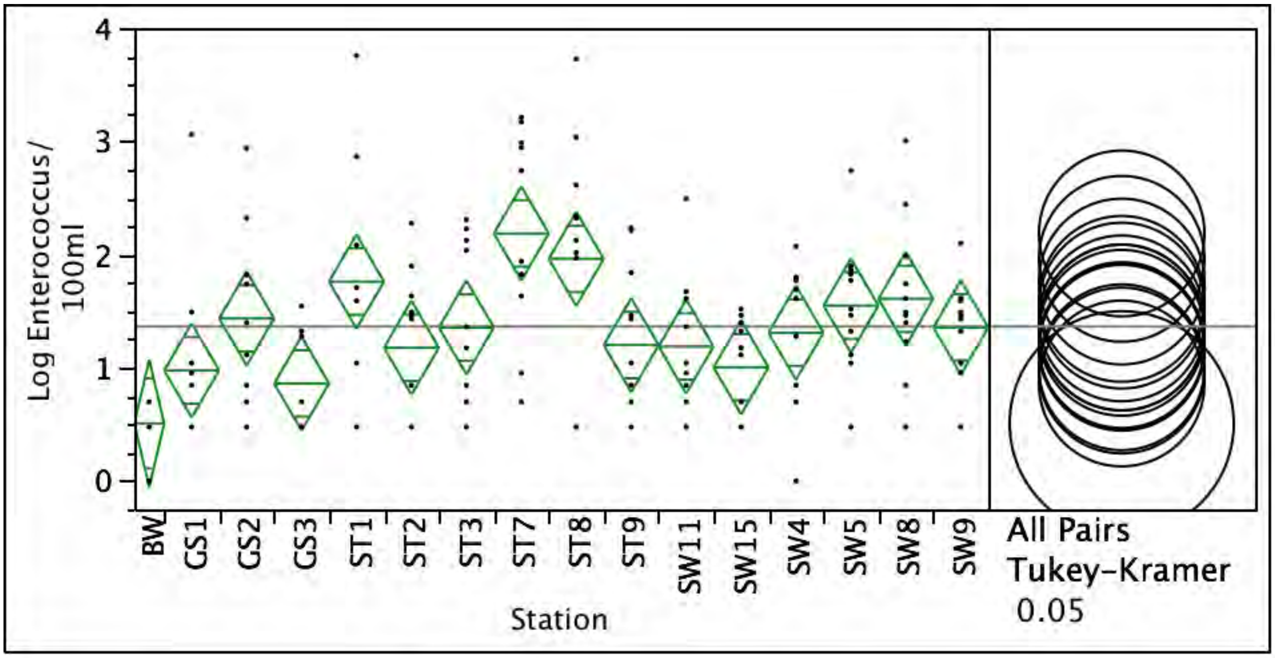


Figure 20. Oneway Analysis of Log *Enterococcus*/100ml by station. Station identifications follow the list in Table 1.

Table 6. ANOVA and Tukey's multiple range test analysis of water quality parameters by station. Levels not connected by same letter are significantly different.

Anova by Station	NH4	means mg/L	TKN	means mg/L	TP	means mg/L	Entero	#/100 ml
BW	D, E, F	2.82	C, D, E	3.84	E, F, G, H	1.46	D	3.22
GS1	F, G	1.94	E	2.52	D, E, F	1.79	B, C, D	9.46
GS2	D, E	2.93	D, E	3.56	G, H	1.37	A, B, C, D	27.27
GS3	B, C, D	3.85	C, D	4.17	E, F, G	1.53	C, D	7.26
ST1	G	1.64	E	2.59	F, G	1.47	A, B, C	57.70
ST2	A, B	5.25	A, B	6.53	B	3.05	A, B, C, D	15.03
ST3	B, C	4.79	B, C	5.47	C, D, E	1.91	A, B, C, D	22.66
ST7	C, D	3.64	C, D	4.41	C, D	2.24	A	153.44
ST8	A	6.91	A	7.91	A	5.15	A, B	91.56
ST9	E, F	2.51	D, E	3.48	B, C	2.38	A, B, C, D	15.84
SW11	H	1.07	F	1.35	H	1.09	A, B, C, D	15.41
SW15	H	1.09	F	1.30	H	1.09	B, C, D	10.09
SW4	H	1.09	F	1.44	H	1.10	A, B, C, D	20.37
SW5	H	1.06	F	1.45	H	1.12	A, B, C, D	35.37
SW8	H	1.07	F	1.40	H	1.10	A, B, C, D	40.58
SW9	H	1.06	F	1.43	H	1.10	A, B, C, D	22.70

Discriminant analysis by station including all data is shown in Figure 21. Background well 3 stands out alone lower right, the other two background wells are the similar sized circles centered in the middle to upper left in the diagram. Surface water stations tightly cluster together to the left. The rest of the well stations cluster around the middle of the diagram, with the exception of ST2 and ST8 set off to the right, indicating significantly different loadings in those wells, also reflected in the ANOVA. The only septic tank area well trending towards the surface water cluster is ST1, all other ST wells are found to the right of the GS wells in the center of the diagram.

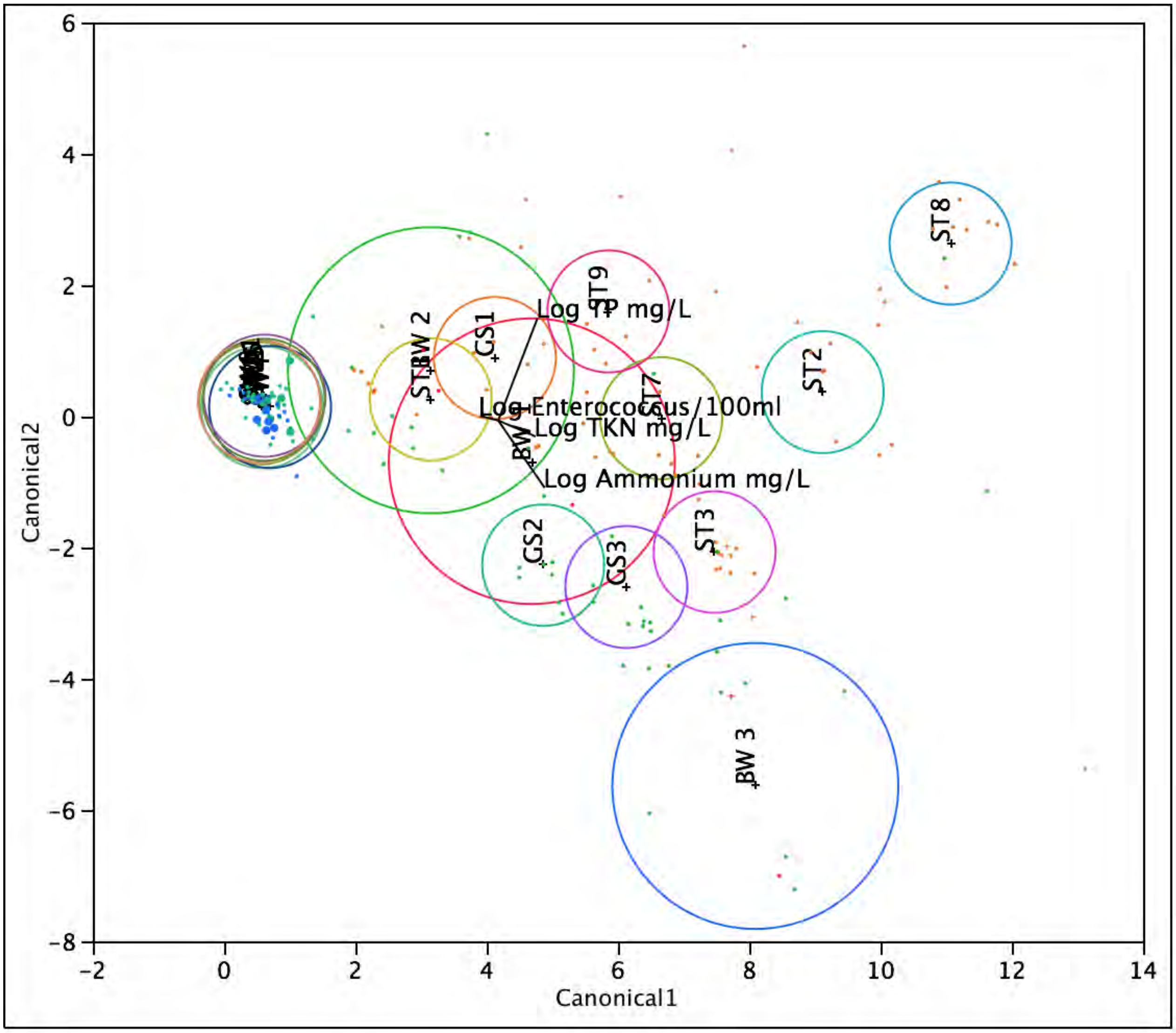


Figure 21. Discriminant analysis of sampling atations as influenced by total phosphate, TKN, dissolved ammonium and *Enterococcus* concentrations (all Log transformed). Labels are as in Table 1. The surface water stations are superimposed on each other in the tight cluster of circles to the left.

Conclusions:

No overall significant effect of tidal phase on contamination of ground water or surface water was found, despite a difference of 4ft tide amplitude for spring tides compared to 1 ft amplitude change for neap tides. Water level loggers in wells adjacent to seawalls along the canals and in in the center of the levees showed the tidal effects attenuated with distance but still affected the groundwater levels within the levees. Overall, the canal and levee systems served by septic tanks had greater contamination as elevated nutrients and fecal indicator bacteria than those in the gravity sewered area.

Appendix

Analytical report

Wetlands Research Laboratory
University of West Florida
11000 University Pkwy
Pensacola, FL 32514

State of Florida Certification # E71969
Phone: (850) 857-6096
Fax: (850) 474-3130

Laboratory Report for:
Client CEDB
Project Storm Surge
Address University of West Florida

Laboratory Report by Collection Date from 1/16/2012 to 1/16/2012

Lab ID #	Bottle	Field ID	Sampling Date	Sampling Time	Receipt Date	Receipt Time	Sample Matrix	Sampler	Analyte	Result	Unit	Data Qualifier(s)	Dilution Factor	CALC MDL	LOQ	Analysis Date	Analysis Time	Method
12-34571	A	SWN	1/16/12	7:40	1/16/12	13:39	Surface Water	JM	Ammonia-N (FIA)	56.210	ug N/L	IY	2	50.000	100.000	01/23/12	14:56	350.1
12-34572	A	GS 1	1/16/12	8:00	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	627.400	ug N/L	Y	3	75.000	150.000	01/23/12	14:56	350.1
12-34573	A	GS 2	1/16/12	8:15	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	2167.000	ug N/L	Y	4	100.000	200.000	01/23/12	14:56	350.1
12-34574	A	GS 3	1/16/12	8:30	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	3569.000	ug N/L	Y	7	175.000	350.000	01/23/12	14:56	350.1
12-34575	A	SWS-South	1/16/12	8:35	1/16/12	13:39	Surface Water	JM	Ammonia-N (FIA)	41.320	ug N/L	IY	1	25.000	50.000	01/23/12	14:56	350.1
12-34576	A	ST07	1/16/12	9:10	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	3214.000	ug N/L	Y	11	275.000	550.000	01/23/12	14:56	350.1
12-34577	A	SWS2-Sawgrass	1/16/12	9:20	1/16/12	13:39	Surface Water	JM	Ammonia-N (FIA)	36.540	ug N/L	IY	1	25.000	50.000	01/23/12	14:56	350.1
12-34578	A	ST08	1/16/12	9:25	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	7054.000	ug N/L	Y	50	1250.000	2500.000	01/23/12	14:56	350.1
12-34579	A	SWE	1/16/12	9:34	1/16/12	13:39	Surface Water	JM	Ammonia-N (FIA)	25.000	ug N/L	UY	1	25.000	50.000	01/23/12	14:56	350.1
12-34580	A	ST09	1/16/12	9:40	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	1901.000	ug N/L	Y	20	500.000	1000.000	01/23/12	14:56	350.1
12-34581	A	ST03	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	4674.000	ug N/L	Y	10	250.000	500.000	01/23/12	14:56	350.1
12-34582	A	ST03 Dup	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	4762.000	ug N/L	Y	10	250.000	500.000	01/23/12	14:56	350.1
12-34583	A	SW03 South	1/16/12	9:55	1/16/12	13:39	Surface Water	JM	Ammonia-N (FIA)	25.000	ug N/L	UY	1	25.000	50.000	01/23/12	14:56	350.1
12-34584	A	SW03 North	1/16/12	10:18	1/16/12	13:39	Surface Water	JM	Ammonia-N (FIA)	53.390	ug N/L	Y	1	25.000	50.000	01/23/12	14:56	350.1
12-34585	A	ST02	1/16/12	10:20	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	5704.000	ug N/L	Y	25	625.000	1250.000	01/23/12	14:56	350.1
12-34586	A	ST01	1/16/12	10:30	1/16/12	13:39	Ground Water	JM	Ammonia-N (FIA)	581.500	ug N/L	Y	4	100.000	200.000	01/23/12	14:56	350.1
12-34587	A	Field Blank	1/16/12	13:39	1/16/12	13:39	DI H2O	JM	Ammonia-N (FIA)	41.380	ug N/L	IYJ3	1	25.000	50.000	01/23/12	14:56	350.1
12-34571	C	SWN	1/16/12	7:40	1/16/12	13:39	Surface Water	JM	Enterococcus	2.000	CFU/ 100ml	B	2	2.000	2.000	01/16/12	14:23	1600
12-34572	C	GS 1	1/16/12	8:00	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	14:26	1600
12-34573	C	GS 2	1/16/12	8:15	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	14:29	1600
12-34574	C	GS 3	1/16/12	8:30	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	14:32	1600
12-34575	C	SWS-South	1/16/12	8:35	1/16/12	13:39	Surface Water	JM	Enterococcus	2.000	CFU/ 100ml	B	2	2.000	2.000	01/16/12	14:35	1600
12-34576	C	ST07	1/16/12	9:10	1/16/12	13:39	Ground Water	JM	Enterococcus	4.000	CFU/ 100ml	B	2	2.000	2.000	01/16/12	14:41	1600
12-34577	C	SWS2-Sawgrass	1/16/12	9:20	1/16/12	13:39	Surface Water	JM	Enterococcus	10.000	CFU/ 100ml	B	2	2.000	2.000	01/16/12	14:44	1600

12-34578	C	ST08	1/16/12	9:25	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	14:47	1600
12-34579	C	SWE	1/16/12	9:34	1/16/12	13:39	Surface Water	JM	Enterococcus	18.000	CFU/ 100ml	B	2	2.000	2.000	01/16/12	14:50	1600
12-34580	C	ST09	1/16/12	9:40	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	14:56	1600
12-34581	C	ST03	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	14:59	1600
12-34582	C	ST03 Dup	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	15:02	1600
12-34583	C	SW03 South	1/16/12	9:55	1/16/12	13:39	Surface Water	JM	Enterococcus	4.000	CFU/ 100ml	B	2	2.000	2.000	01/16/12	15:05	1600
12-34584	C	SW03 North	1/16/12	10:18	1/16/12	13:39	Surface Water	JM	Enterococcus	6.000	CFU/ 100ml	B	2	2.000	2.000	01/16/12	15:08	1600
12-34585	C	ST02	1/16/12	10:20	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	15:14	1600
12-34586	C	ST01	1/16/12	10:30	1/16/12	13:39	Ground Water	JM	Enterococcus	2.000	CFU/ 100ml	U	2	2.000	2.000	01/16/12	15:17	1600
12-34587	C	Field Blank	1/16/12	13:39	1/16/12	13:39	DI H2O	JM	Enterococcus	1.000	CFU/ 100ml	U	1	1.000	1.000	01/16/12	15:20	1600
12-34571	A	SWN	1/16/12	7:40	1/16/12	13:39	Surface Water	JM	Nitrate/Nitrite, Total	39.060	ug N/L	Y	1	4.000	12.000	01/21/12	17:38	353.2
12-34572	A	GS 1	1/16/12	8:00	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	14.740	ug N/L	Y	1	4.000	12.000	01/21/12	17:38	353.2
12-34573	A	GS 2	1/16/12	8:15	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	4.000	ug N/L	UY	1	4.000	12.000	01/21/12	17:38	353.2
12-34574	A	GS 3	1/16/12	8:30	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	5.407	ug N/L	IY	1	4.000	12.000	01/21/12	17:38	353.2
12-34575	A	SWS-South	1/16/12	8:35	1/16/12	13:39	Surface Water	JM	Nitrate/Nitrite, Total	17.930	ug N/L	Y	1	4.000	12.000	01/21/12	17:38	353.2
12-34576	A	ST07	1/16/12	9:10	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	14.640	ug N/L	Y	1	4.000	12.000	01/21/12	17:38	353.2
12-34577	A	SWS2-Sawgrass	1/16/12	9:20	1/16/12	13:39	Surface Water	JM	Nitrate/Nitrite, Total	6.214	ug N/L	IY	1	4.000	12.000	01/21/12	17:38	353.2
12-34578	A	ST08	1/16/12	9:25	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	4.000	ug N/L	UY	1	4.000	12.000	01/21/12	17:38	353.2
12-34579	A	SWE	1/16/12	9:34	1/16/12	13:39	Surface Water	JM	Nitrate/Nitrite, Total	15.820	ug N/L	Y	1	4.000	12.000	01/21/12	17:38	353.2
12-34580	A	ST09	1/16/12	9:40	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	4.000	ug N/L	UY	1	4.000	12.000	01/21/12	17:38	353.2
12-34581	A	ST03	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	4.000	ug N/L	UY	1	4.000	12.000	01/21/12	17:38	353.2
12-34582	A	ST03 Dup	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	5.459	ug N/L	IY	1	4.000	12.000	01/21/12	17:38	353.2
12-34583	A	SW03 South	1/16/12	9:55	1/16/12	13:39	Surface Water	JM	Nitrate/Nitrite, Total	9.920	ug N/L	IY	1	4.000	12.000	01/21/12	17:38	353.2
12-34584	A	SW03 North	1/16/12	10:18	1/16/12	13:39	Surface Water	JM	Nitrate/Nitrite, Total	12.000	ug N/L	Y	1	4.000	12.000	01/21/12	17:38	353.2
12-34585	A	ST02	1/16/12	10:20	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	4.000	ug N/L	UY	1	4.000	12.000	01/21/12	17:38	353.2
12-34586	A	ST01	1/16/12	10:30	1/16/12	13:39	Ground Water	JM	Nitrate/Nitrite, Total	4.000	ug N/L	UY	1	4.000	12.000	01/21/12	17:38	353.2
12-34587	A	Field Blank	1/16/12	13:39	1/16/12	13:39	DI H2O	JM	Nitrate/Nitrite, Total	4.000	ug N/L	UY	1	4.000	12.000	01/21/12	17:38	353.2
12-34571	A	SWN	1/16/12	7:40	1/16/12	13:39	Surface Water	JM	Phosphorus (FIA)	11.140	ug P/L	Y	1	5.000	10.000	01/23/12	11:15	365.1
12-34572	A	GS 1	1/16/12	8:00	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	235.600	ug P/L	Y	3	15.000	30.000	01/23/12	11:15	365.1
12-34573	A	GS 2	1/16/12	8:15	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	231.100	ug P/L	Y	4	20.000	40.000	01/23/12	11:15	365.1
12-34574	A	GS 3	1/16/12	8:30	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	428.300	ug P/L	Y	7	35.000	70.000	01/23/12	11:15	365.1
12-34575	A	SWS-South	1/16/12	8:35	1/16/12	13:39	Surface Water	JM	Phosphorus (FIA)	10.400	ug P/L	Y	1	5.000	10.000	01/23/12	11:15	365.1
12-	A	ST07	1/16/12	9:10	1/16/12	13:39	Ground	JM	Phosphorus (FIA)	801.100	ug	Y	11	55.000	110.000	01/23/12	11:15	365.1

34576							Water				P/L							
12-34577	A	SWS2-Sawgrass	1/16/12	9:20	1/16/12	13:39	Surface Water	JM	Phosphorus (FIA)	10.230	ug P/L	YJ2	1	5.000	10.000	01/23/12	11:15	365.1
12-34578	A	ST08	1/16/12	9:25	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	4181.000	ug P/L	Y	50	250.000	500.000	01/23/12	11:15	365.1
12-34579	A	SWE	1/16/12	9:34	1/16/12	13:39	Surface Water	JM	Phosphorus (FIA)	10.670	ug P/L	Y	1	5.000	10.000	01/23/12	11:15	365.1
12-34580	A	ST09	1/16/12	9:40	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	1604.000	ug P/L	Y	20	100.000	200.000	01/23/12	11:15	365.1
12-34581	A	ST03	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	808.800	ug P/L	Y	10	50.000	100.000	01/23/12	11:15	365.1
12-34582	A	ST03 Dup	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	933.300	ug P/L	Y	10	50.000	100.000	01/23/12	11:15	365.1
12-34583	A	SW03 South	1/16/12	9:55	1/16/12	13:39	Surface Water	JM	Phosphorus (FIA)	9.268	ug P/L	IY	1	5.000	10.000	01/23/12	11:15	365.1
12-34584	A	SW03 North	1/16/12	10:18	1/16/12	13:39	Surface Water	JM	Phosphorus (FIA)	12.400	ug P/L	Y	1	5.000	10.000	01/23/12	11:15	365.1
12-34585	A	ST02	1/16/12	10:20	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	1765.000	ug P/L	Y	25	125.000	250.000	01/23/12	11:15	365.1
12-34586	A	ST01	1/16/12	10:30	1/16/12	13:39	Ground Water	JM	Phosphorus (FIA)	358.000	ug P/L	Y	4	20.000	40.000	01/23/12	11:15	365.1
12-34587	A	Field Blank	1/16/12	13:39	1/16/12	13:39	DI H2O	JM	Phosphorus (FIA)	7.949	ug P/L	IYJ3	1	5.000	10.000	01/23/12	11:15	365.1
12-34571	B	SWN	1/16/12	7:40	1/16/12	13:39	Surface Water	JM	Total Kjeldahl Nitrogen (FIA)	0.432	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34572	B	GS 1	1/16/12	8:00	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	1.035	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34573	B	GS 2	1/16/12	8:15	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	2.643	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34574	B	GS 3	1/16/12	8:30	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	3.443	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34575	B	SWS-South	1/16/12	8:35	1/16/12	13:39	Surface Water	JM	Total Kjeldahl Nitrogen (FIA)	0.342	mg N/L	I	1	0.100	0.500	01/24/12	13:47	351.2
12-34576	B	ST07	1/16/12	9:10	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	3.679	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34577	B	SWS2-Sawgrass	1/16/12	9:20	1/16/12	13:39	Surface Water	JM	Total Kjeldahl Nitrogen (FIA)	0.444	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34578	B	ST08	1/16/12	9:25	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	7.520	mg N/L		2	0.200	1.000	01/24/12	13:47	351.2
12-34579	B	SWE	1/16/12	9:34	1/16/12	13:39	Surface Water	JM	Total Kjeldahl Nitrogen (FIA)	0.670	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34580	B	ST09	1/16/12	9:40	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	2.029	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34581	B	ST03	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	4.850	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34582	B	ST03 Dup	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	4.925	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34583	B	SW03 South	1/16/12	9:55	1/16/12	13:39	Surface Water	JM	Total Kjeldahl Nitrogen (FIA)	0.409	mg N/L	I	1	0.100	0.500	01/24/12	13:47	351.2
12-34584	B	SW03 North	1/16/12	10:18	1/16/12	13:39	Surface Water	JM	Total Kjeldahl Nitrogen (FIA)	0.501	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34585	B	ST02	1/16/12	10:20	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	6.220	mg N/L		2	0.200	1.000	01/24/12	13:47	351.2
12-34586	B	ST01	1/16/12	10:30	1/16/12	13:39	Ground Water	JM	Total Kjeldahl Nitrogen (FIA)	1.145	mg N/L		1	0.100	0.500	01/24/12	13:47	351.2
12-34587	B	Field Blank	1/16/12	13:39	1/16/12	13:39	DI H2O	JM	Total Kjeldahl Nitrogen (FIA)	0.167	mg N/L	IJ2J3	1	0.100	0.500	01/24/12	13:47	351.2
12-34571	B	SWN	1/16/12	7:40	1/16/12	13:39	Surface Water	JM	Total Phosphorus (FIA)	0.100	mg P/L	U	1	0.100	0.500	01/24/12	13:47	365.4
12-34572	B	GS 1	1/16/12	8:00	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	0.351	mg P/L	I	1	0.100	0.500	01/24/12	13:47	365.4
12-34573	B	GS 2	1/16/12	8:15	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	0.279	mg P/L	I	1	0.100	0.500	01/24/12	13:47	365.4
12-34574	B	GS 3	1/16/12	8:30	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	0.379	mg P/L	I	1	0.100	0.500	01/24/12	13:47	365.4

12- 34575	B	SWS-South	1/16/12	8:35	1/16/12	13:39	Surface Water	JM	Total Phosphorus (FIA)	0.100	mg P/L	U	1	0.100	0.500	01/24/12	13:47	365.4
12- 34576	B	ST07	1/16/12	9:10	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	1.021	mg P/L		1	0.100	0.500	01/24/12	13:47	365.4
12- 34577	B	SWS2- Sawgrass	1/16/12	9:20	1/16/12	13:39	Surface Water	JM	Total Phosphorus (FIA)	0.100	mg P/L	U	1	0.100	0.500	01/24/12	13:47	365.4
12- 34578	B	ST08	1/16/12	9:25	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	4.424	mg P/L		1	0.100	0.500	01/24/12	13:47	365.4
12- 34579	B	SWE	1/16/12	9:34	1/16/12	13:39	Surface Water	JM	Total Phosphorus (FIA)	0.100	mg P/L	U	1	0.100	0.500	01/24/12	13:47	365.4
12- 34580	B	ST09	1/16/12	9:40	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	1.382	mg P/L	J2	1	0.100	0.500	01/24/12	13:47	365.4
12- 34581	B	ST03	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	0.808	mg P/L		1	0.100	0.500	01/24/12	13:47	365.4
12- 34582	B	ST03 Dup	1/16/12	10:10	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	0.811	mg P/L		1	0.100	0.500	01/24/12	13:47	365.4
12- 34583	B	SW03 South	1/16/12	9:55	1/16/12	13:39	Surface Water	JM	Total Phosphorus (FIA)	0.100	mg P/L	U	1	0.100	0.500	01/24/12	13:47	365.4
12- 34584	B	SW03 North	1/16/12	10:18	1/16/12	13:39	Surface Water	JM	Total Phosphorus (FIA)	0.100	mg P/L	U	1	0.100	0.500	01/24/12	13:47	365.4
12- 34585	B	ST02	1/16/12	10:20	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	2.019	mg P/L		1	0.100	0.500	01/24/12	13:47	365.4
12- 34586	B	ST01	1/16/12	10:30	1/16/12	13:39	Ground Water	JM	Total Phosphorus (FIA)	0.383	mg P/L	I	1	0.100	0.500	01/24/12	13:47	365.4
12- 34587	B	Field Blank	1/16/12	13:39	1/16/12	13:39	DI H2O	JM	Total Phosphorus (FIA)	0.100	mg P/L	UJ2	1	0.100	0.500	01/24/12	13:47	365.4

See attachment A for Data Qualifier Codes: Symbols and Meaning

Report #: C275-01162012A   Report Date: 2/6/12

Report Approved by Jeremy Bosso, Lab Manager: 2/6/12

These results relate only to these samples as submitted to the laboratory.

The results reported herein meet the requirements of the NELAC standards as adopted by the reference into chapter 64E-1, Florida Administrative Code.

Analyses performed without NELAP accreditation would be flagged with a "J6" data qualifier.

Times are reported in Central Time

Data Reported on a wet-weight basis

Subcontract information: not applicable

For questions or concerns regarding this report, please contact the Laboratory Manager, Jeremy Bosso at (850) 857-6096

Field Blank (sample 12- 34587) recovered Ammonia, Phosphorus, and Total Kjeldahl Nitrogen at levels below the practical quantitation level (Limit of Quantitation, LOQ), but above the Method Detection Level (MDL), hence "J3" qualifier.

Bottle "A" was preserved per client's instructions (filtered within 15 minutes and *frozen, and no* H_2SO_4 *was added*).

This bottle was also used to analyze for Ammonia (EPA 350.1), Total Nitrate-Nitrite (EPA 353.2) and Orthohosphorus, listed above as "Phosphorus" (EPA 365.1), for samples 11- 34571 to 11- 34587.

According to FS 1000 (Table FS1000-4), the preservation protocol for Ammonia and Total Nitrate-Nitrite is to "Cool to ≤6ºC[9], H_2SO_4 to pH<2." The samples were not preserved with H_2SO_4 and were frozen.

Table FS1000-4, footnote 9 states: "Aqueous samples must be preserved at ≤6 °C, *and should not be frozen...*"

Therefore the data associated with bottle "A" for Ammonia and Total Nitrate-Nitrite was qualified with a "Y" qualifier.

Hold-times listed in FDEP's FS 1000 for Ammonia and Total Nitrate-Nitrite (28 days) only apply to samples preserved according to the protocols listed in FS 1000.

Hold-times have not been assessed for Ammonia and Total Nitrate-Nitrite for the preservation method used in samples 11- 34571 to 11- 34587, Bottle A (filtered within 15 minutes and frozen).

According to FS 1000 (Table FS1000-4), the preservation protocol for Orthophosphorus (listed above as Phosphorus) is to filter within 15 minutes of collection and cool to ≤6ºC[9],

Table FS1000-4, footnote 9 states: "Aqueous samples must be preserved at ≤6 °C, *and should not be frozen...*"

Therefore the data associated with bottle "A" for Orthophosphorus was qualified with a "Y" qualifer.

Hold-time listed in FDEP's FS 1000 for Orthophosphorus (48 hours) only applies to samples preserved according to the protocols listed in FS 1000.

Hold-time has not been assessed for Orthophosphorus for the preservation method used in samples 11- 34571 to 11- 34587, Bottle A (filtered within 15 minutes and *frozen*).

Attachment A: Data Qualifier Codes: Symbol and meaning

A - Value reported is the arithmetic mean (average) of two or more determinations.
B - Based on colony counts outside the method specified range.
C - See case narrative (comments)
D - Measurement was made in the field using approved analytical methods. Used except where code specifies a field measurement (e.g., "Field pH").
H - Value based on field kit determination; results may not be accurate. Field screening test not recognized by FDEP as equivalent to laboratory methods.
I - The reported value is ≥ the Limit of Detection, but less than the Practical Quantitation Limit (Limit of Quantitation), and has less certainty
J1 - Value is qualified by failed analytical quality control check standard (i.e. CCV, IPC, QCS, LCS)
J2 - Value is qualified by failed sample matrix quality control sample (i.e. duplicate, matrix spike)
J3 - Analyte detected in blank *other than the method blank* (i.e. Field Blank) at or above the Limit of Detection *and* > 1/10th the concentration in the sample.
J4 - Value is qualified due to improper laboratory practice.
J5 - Value is qualified due to improper field procedure.
J6 - Analysis was performed without NELAC accreditation.
K - Off-scale low. Actual value is less than the value given.
L - Off-scale high. Actual value is known to be greater than the value given.
M - Presence of material is verified but not quantified; the actual value is less than the value given. The reported value Limit of Quantitation.
N - Presumptive evidence of presence of material (i.e. identified based on mass spectral library search; presence not confirmed by alternative procedures).
O - Sample taken but analysis lost, invalidated, or not performed.
Q - Sample held beyond method-specified holding time.
U - Compound was analyzed for but not detected.
V - Analyte detected in method blank ≥ Limit of Detection *and* > 1/10th the concentration in the sample.
Verified - This sample result was verified.
Y - The laboratory analysis was from a sample preserved by an alternative, non-standard preservation procedure. The data may not be accurate.
Z - Colonies on plate too numerous to count. Result = (>60 CFU/lowest volume used x 100 mL).
? - Data are rejected and should not be used.

Rainfall and Predicted tide heights

Station	FL-WK-1	FL-WK-2		
	St. Marks 9.2 W	St. Marks 8.2 SW		Shell Pt.
	30.183393	30.0657		30.06
	-84.360234	-84.2857		-84.29
Date	FL-WK-1 Precip	FL-WK-2 Precip in inches	Date Time EDT	Tide height ft
			1/1/12 1:44	0.48
			1/1/12 7:42	1.97
			1/1/12 13:09	0.88
1/1/12	0	0	1/1/12 19:37	2.72
			1/2/12 2:59	0.34
1/2/12	0	0	1/2/12 9:18	1.87
			1/2/12 14:02	1.15
			1/2/12 20:31	2.68
			1/3/12 4:14	0.12
1/3/12	0	0	1/3/12 10:47	1.96
			1/3/12 15:08	1.35
			1/3/12 21:34	2.69
			1/4/12 5:19	-0.15
1/4/12	0	0	1/4/12 11:53	2.15
			1/4/12 16:19	1.43
			1/4/12 22:35	2.76
1/5/12	0	0	1/5/12 6:12	-0.42
			1/5/12 12:42	2.35
			1/5/12 17:23	1.41
			1/5/12 23:28	2.87
1/6/12	0	0	1/6/12 6:57	-0.65
			1/6/12 13:25	2.54
			1/6/12 18:17	1.34
			1/7/12 0:13	2.99
1/7/12	0	0	1/7/12 7:37	-0.83
			1/7/12 14:02	2.69
			1/7/12 19:03	1.23
			1/8/12 0:54	3.12
1/8/12	0	0	1/8/12 8:14	-0.96
			1/8/12 14:38	2.81
			1/8/12 19:46	1.09
			1/9/12 1:34	3.23
1/9/12	0	0	1/9/12 8:48	-1.02
			1/9/12 15:11	2.92
			1/9/12 20:27	0.92
			1/10/12 2:14	3.3
1/10/12	0	0	1/10/12 9:20	-1.02
			1/10/12 15:43	3
			1/10/12 21:08	0.72
			1/11/12 2:55	3.32
1/11/12	0.89	0	1/11/12 9:52	-0.92
			1/11/12 16:14	3.06
			1/11/12 21:51	0.51
			1/12/12 3:40	3.26
1/12/12	0.16	0	1/12/12 10:24	-0.73

			1/12/12 16:45	3.11
			1/12/12 22:37	0.31
			1/13/12 4:28	3.08
1/13/12	0	0	1/13/12 10:57	-0.43
			1/13/12 17:16	3.13
			1/13/12 23:27	0.14
1/14/12	0	0	1/14/12 5:21	2.8
			1/14/12 11:33	-0.04
			1/14/12 17:51	3.12
			1/15/12 0:25	0.01
1/15/12	0	0	1/15/12 6:27	2.45
			1/15/12 12:14	0.4
			1/15/12 18:30	3.08
			1/16/12 1:35	-0.11
1/16/12	0	0	1/16/12 7:51	2.13
			1/16/12 13:02	0.86
			1/16/12 19:17	3.01
			1/17/12 2:58	-0.27
1/17/12	0	0	1/17/12 9:37	2.02
			1/17/12 14:03	1.25
			1/17/12 20:20	2.95
			1/18/12 4:22	-0.51
1/18/12	1.07	1.09	1/18/12 11:13	2.14
			1/18/12 15:23	1.5
			1/18/12 21:39	2.95
1/19/12	0	0	1/19/12 5:36	-0.81
			1/19/12 12:23	2.36
			1/19/12 16:49	1.54
			1/19/12 22:57	3.04
1/20/12	0	0	1/20/12 6:36	-1.05
			1/20/12 13:14	2.56
			1/20/12 18:04	1.42
			1/21/12 0:02	3.17
1/21/12	0	0	1/21/12 7:27	-1.19
			1/21/12 13:56	2.71
			1/21/12 19:02	1.21
			1/22/12 0:57	3.27
1/22/12	0	0	1/22/12 8:11	-1.2
			1/22/12 14:33	2.82
			1/22/12 19:51	0.96
			1/23/12 1:44	3.31
1/23/12	0	0	1/23/12 8:49	-1.1
			1/23/12 15:05	2.89
			1/23/12 20:34	0.73
			1/24/12 2:27	3.28
1/24/12	0	0	1/24/12 9:23	-0.9
			1/24/12 15:35	2.95
			1/24/12 21:14	0.51
			1/25/12 3:07	3.19
1/25/12	0	0	1/25/12 9:53	-0.65
			1/25/12 16:02	2.98
			1/25/12 21:53	0.33
			1/26/12 3:46	3.04
1/26/12	0	0	1/26/12 10:19	-0.36

			1/26/12 16:28	3.01
			1/26/12 22:32	0.19
			1/27/12 4:25	2.84
1/27/12	0.56	0.68	1/27/12 10:42	-0.07
			1/27/12 16:52	3.01
			1/27/12 23:12	0.12
1/28/12	0	0	1/28/12 5:06	2.59
			1/28/12 11:06	0.22
			1/28/12 17:18	2.98
			1/28/12 23:56	0.12
1/29/12	0	0	1/29/12 5:52	2.31
			1/29/12 11:33	0.51
			1/29/12 17:45	2.92
			1/30/12 0:49	0.16
1/30/12	0	0	1/30/12 6:51	2.03
			1/30/12 12:05	0.81
			1/30/12 18:18	2.81
			1/31/12 1:55	0.2
1/31/12	0	0	1/31/12 8:12	1.81
			1/31/12 12:48	1.11
			1/31/12 19:02	2.69
			2/1/12 3:18	0.16
2/1/12	0	0	2/1/12 9:56	1.79
			2/1/12 13:51	1.37
			2/1/12 20:08	2.57
2/2/12	0.08	0.13	2/2/12 4:40	-0.01
			2/2/12 11:22	1.97
			2/2/12 15:19	1.51
			2/2/12 21:39	2.56
			2/3/12 5:44	-0.27
2/3/12	0		2/3/12 12:19	2.23
			2/3/12 16:49	1.48
2/4/12	0		2/3/12 22:58	2.7
			2/4/12 6:34	-0.53
			2/4/12 13:02	2.48
			2/4/12 17:58	1.31
			2/4/12 23:57	2.9
2/5/12	0		2/5/12 7:15	-0.74
			2/5/12 13:38	2.7
			2/5/12 18:51	1.08
2/6/12	0		2/6/12 0:45	3.11
			2/6/12 7:51	-0.88
			2/6/12 14:11	2.89
			2/6/12 19:35	0.8
2/7/12	0		2/7/12 1:29	3.29
			2/7/12 8:25	-0.92
			2/7/12 14:42	3.05
			2/7/12 20:17	0.5
2/8/12	0		2/8/12 2:13	3.41
			2/8/12 8:57	-0.86
			2/8/12 15:11	3.19
			2/8/12 20:58	0.19
2/9/12	0		2/9/12 2:56	3.44
			2/9/12 9:28	-0.69

		2/9/12 15:39	3.3
		2/9/12 21:40	-0.1
2/10/12	0	2/10/12 3:41	3.37
		2/10/12 9:59	-0.43
		2/10/12 16:08	3.38
		2/10/12 22:24	-0.32
2/11/12	0.02	2/11/12 4:29	3.18
		2/11/12 10:31	-0.08
		2/11/12 16:37	3.42
		2/11/12 23:12	-0.44
2/12/12	0	2/12/12 5:21	2.87
		2/12/12 11:04	0.31
		2/12/12 17:08	3.4
		2/13/12 0:06	-0.44
2/13/12	0	2/13/12 6:21	2.5
		2/13/12 11:40	0.74
		2/13/12 17:44	3.3
2/14/12	0	2/14/12 1:13	-0.36
		2/14/12 7:40	2.15
		2/14/12 12:22	1.15
		2/14/12 18:28	3.13
2/15/12	0.26	2/15/12 2:36	-0.3
		2/15/12 9:26	1.99
		2/15/12 13:21	1.5
		2/15/12 19:33	2.91
2/16/12	0.02	2/16/12 4:08	-0.35
		2/16/12 11:08	2.12
		2/16/12 14:56	1.71
		2/16/12 21:19	2.78
2/17/12	0.5	2/17/12 5:27	-0.052
		2/17/12 12:14	2.36
		2/17/12 16:50	1.63
		2/17/12 23:00	2.87
2/18/12	0.02	2/18/12 6:26	-0.67
		2/18/12 12:58	2.59
		2/18/12 18:10	1.34
2/19/12	0.65	2/19/12 0:09	3.04
		2/19/12 7:13	-0.73
		2/19/12 13:34	2.79
		2/19/12 19:04	1
2/20/12	0	2/20/12 1:01	3.18
		2/20/12 7:53	-0.69
		2/20/12 14:05	2.94
		2/20/12 19:47	0.67
2/21/12	0	2/21/12 1:45	3.25
		2/21/12 8:27	-0.55
		2/21/12 14:33	3.06
		2/21/12 20:25	0.38
2/22/12	0	2/22/12 2:24	3.26
		2/22/12 8:55	-0.36
		2/22/12 14:58	3.14
		2/22/12 21:00	0.15
2/23/12	0.07	2/23/12 3:00	3.21
		2/23/12 9:20	-0.13

		2/23/12 15:21	3.21
		2/23/12 21:34	-0.02
2/24/12	0	2/24/12 3:35	3.12
		2/24/12 9:42	0.09
		2/24/12 15:43	3.25
		2/24/12 22:07	-0.12
2/25/12	0.08	2/25/12 4:10	2.98
		2/25/12 10:03	0.3
		2/25/12 16:05	3.27
		2/25/12 22:41	-0.14
2/26/12	0.06	2/26/12 4:47	2.8
		2/26/12 10:26	0.51
		2/26/12 16:27	3.25
		2/26/12 23:19	-0.08
2/27/12	0.23	2/27/12 5:27	2.57
		2/27/12 10:52	0.73
		2/27/12 16:53	3.19
2/28/12	0.36	2/28/12 0:02	0.04
		2/28/12 6:16	2.31
		2/28/12 11:23	0.98
		2/28/12 17:22	3.07
2/29/12	0	2/29/12 0:58	0.2
		2/29/12 7:24	2.07
		2/29/12 12:03	1.25
		2/29/12 18:01	2.91
3/1/12	0.01	3/1/12 2:16	0.3
		3/1/12 9:01	1.97
		3/1/12 13:03	1.51
		3/1/12 18:58	2.71
3/2/12	0.01	3/2/12 3:48	0.25
		3/2/12 10:39	2.11
		3/2/12 14:37	1.67
		3/2/12 20:40	2.59
3/3/12	0	3/3/12 5:03	0.05
		3/3/12 11:43	2.38
		3/3/12 16:24	1.59
		3/3/12 22:30	2.71
3/4/12	2.7	3/4/12 5:58	-0.18
		3/4/12 12:26	2.67
		3/4/12 17:40	1.3
		3/4/12 23:40	2.97
3/5/12	0	3/5/12 6:41	-0.35
		3/5/12 13:01	2.94
		3/5/12 18:34	0.91
3/6/12	0	3/6/12 0:34	3.24
		3/6/12 7:19	-0.44
		3/6/12 13:33	3.17
		3/6/12 19:19	0.49
3/7/12	0	3/7/12 1:22	3.47
		3/7/12 7:54	-0.41
		3/7/12 14:03	3.36
		3/7/12 20:02	0.08
3/8/12	0	3/8/12 2:08	3.62
		3/8/12 8:28	-0.28

		3/8/12 14:32	3.53
		3/8/12 20:44	-0.3
3/9/12	0	3/9/12 2:54	3.66
		3/9/12 9:00	-0.06
		3/9/12 15:01	3.67
		3/9/12 21:26	-0.59
3/10/12	0.21	3/10/12 3:40	3.57
		3/10/12 9:32	0.22
		3/10/12 15:30	3.76
		3/10/12 22:10	-0.75
3/11/12	0	3/11/12 5:27	3.36
		3/11/12 11:04	0.54
		3/11/12 17:01	3.79
		3/11/12 23:58	-0.75
3/12/12	0.05	3/12/12 6:18	3.05
		3/12/12 11:38	0.87
		3/12/12 17:34	3.72
3/13/12	0	3/13/12 0:51	-0.69
		3/13/12 7:16	2.69
		3/13/12 12:14	1.2
		3/13/12 18:10	3.54
3/14/12	0	3/14/12 1:55	-0.34
		3/14/12 8:30	2.37
		3/14/12 12:58	1.51
		3/14/12 18:55	3.26
3/15/12	0	3/15/12 3:16	-0.1
		3/15/12 10:09	2.23
		3/15/12 14:04	1.77
		3/15/12 20:05	2.93
3/16/12	0	3/16/12 4:46	0.01
		3/16/12 11:44	2.35
		3/16/12 15:59	1.86
		3/16/12 22:19	2.73
3/17/12	0	3/17/12 6:04	-0.01
		3/17/12 12:44	2.59
		3/17/12 18:00	1.6
3/18/12	0	3/18/12 0:05	2.84
		3/18/12 7:02	-0.05
		3/18/12 13:25	2.83
		3/18/12 19:09	1.19
3/19/12	0	3/19/12 1:10	3.03
		3/19/12 7:48	-0.03
		3/19/12 13:58	3.04
		3/19/12 19:56	0.78
		3/20/12 1:59	3.18
3/20/12	0	3/20/12 8:24	0.06
		3/20/12 14:27	3.21
		3/20/12 20:34	0.42
3/21/12	0	3/21/12 2:39	3.28
		3/21/12 8:55	0.21
		3/21/12 14:53	3.33
		3/21/12 21:09	0.15
3/22/12	0	3/22/12 3:15	3.31
		3/22/12 9:21	0.38

		3/22/12 15:17	3.42
		3/22/12 21:41	-0.06
3/23/12	0	3/23/12 3:49	3.3
		3/23/12 9:44	0.55
		3/23/12 15:39	3.48
		3/23/12 22:13	-0.18
3/24/12	0	3/24/12 4:22	3.25
		3/24/12 10:06	0.71
		3/24/12 16:00	3.52
		3/24/12 22:44	-0.23
3/25/12	0	3/25/12 4:56	3.17
		3/25/12 10:28	0.84
		3/25/12 16:22	3.54
		3/25/12 23:15	-0.21
3/26/12	0	3/26/12 5:31	3.04
		3/26/12 10:52	0.97
		3/26/12 16:45	3.53
		3/26/12 23:49	-0.12
3/27/12	0	3/27/12 6:09	2.87
		3/27/12 11:20	1.12
		3/27/12 17:12	3.47
3/28/12	0	3/28/12 0:29	0.03
		3/28/12 6:55	2.66
		3/28/12 11:54	1.3
		3/28/12 17:43	3.36
3/29/12	0	3/29/12 1:17	0.21
		3/29/12 7:54	2.46
		3/29/12 12:37	1.52
		3/29/12 18:23	3.17
3/30/12	0	3/30/12 2:23	0.38
		3/30/12 9:15	2.37
		3/30/12 13:40	1.73
		3/30/12 19:19	2.93
		3/31/12 3:46	0.45
3/31/12	0.01	3/31/12 10:45	2.56
		3/31/12 15:16	1.81
		3/31/12 20:59	2.74