Observation and Implications of Long Waves in St Joseph Bay, FL

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Abstract: A section of St Joseph Peninsula is experiencing significant erosion; if it breaches, a new inlet into St Joseph Bay will result. Water levels were measured inside, near the entrance, and outside of the Bay to understand the hydrodynamic processes governing the Bay system and to calibrate and verify a numerical hydrodynamic circulation model for predicting impacts. Long waves were observed during a frontal passage at sub-tidal frequencies with amplitudes that exceeded the mean tidal range. The phase lag of one component between the outside and the inside of the bay at the potential breach site was near 180 deg, resulting in a larger hydraulic head than tidal analysis alone would predict. Potential impacts include rapid growth of the inlet, beyond the equilibrium size, during certain meteorological events (including hurricanes), and introduction of water with much higher sediment loads, discharged from adjacent Apalachicola Bay, into St Joseph Bay.

Additional Key Words: erosion, breach, inlet, long waves, seiche, phase lag, scour suspended sediment.

Background

St Joseph Bay, FL is an embayment located on the northern shore of the Gulf of Mexico situated between the mainland and St. Joseph Peninsula, a curving sand spit with the prominent Cape San Blas located at its southern corner (Figure 1). The Bay entrance opens to the northwest and is sheltered from direct offshore wave energy. Tides in the Gulf of Mexico to the east of Cape San Blas are mixed, while those west of the Cape are predominantly diurnal (FDEP 2000). The tide in St Joseph Bay is diurnal with a mean range of about 1.5 ft.

In recent history the peninsula has experienced significant long term and episodic erosion along its western side – the highest historical shoreline erosion rate in the state (Coastal America 1996). SR 30E, is the roadway that runs along St Joseph Peninsula and provides routine access and the only evacuation route for the residents of the peninsula and visitors to the St Joseph Peninsula State Park. A segment of roadway near a site called Stump Hole is particularly threatened, and is currently protected by a rock revetment (Figure 2). One of the options being considered by the Florida Department of Transportation is to allow the breach to occur naturally and replace that section of roadway with a bridge behind the resulting inlet.

Measured water level time series at various sites in and around the Bay are needed to understand the hydrodynamic processes governing the Bay and to calibrate and verify a numerical hydrodynamic circulation model (ADCIRC) of the system. This paper describes the collection, analysis, validation, and implications of that data set of water level time series.

Data Collection

Three sites were selected to define the important hydraulic characteristics of the system: Site 1, in the Gulf, offshore of Stump Hole, Site 2, in the Bay, just north of Stump Hole, and Site 3, near the entrance to St Joseph Bay (Figure 3).

Water level time series were measured at each site using self contained water level gages with internal battery power and solid state memory (Coastal Leasing, 2005). The gages measure and record ambient water pressure (absolute) and temperature at a programmable sampling scheme. The following parameters resulted in a battery-limited operational life of about 2 weeks:

Sample Rate – 2 Hz.

Sample Length – 450 sec = 7.5 min

Sample Interval – 10 min

The gage's software saved the average of the nine hundred samples over the sample length. Thus, a data point represents the mean of the 2 Hz samples of water pressure (and temperature) over a 7.5 minute interval, and there were six data points retained every hour.

Gage mounts were fabricated from PVC pipe to avoid galvanic corrosion of the stainless steel instrument housings and minimize weight. To discourage tampering from the curious, the top of the housing was attached by cement, sealing the instrument inside. Removal of the instrument required sawing the main housing apart after recovery.

A 2-in-diameter x 5-ft-long PVC pipe piling extended from the bottom of each of the main housings (Figure 4). A removable 2-in-diameter deployment pipe could be threaded into the top of the main housing; a 2-in-diameter hose with control valve was attached to the top end of this pipe. To deploy the mount, a portable pump forced water through the removable pipe, around the annular space between the gage and the main housing, and out through the lower piling. Using the control valve to regulate the water flow, the pipe piling was jetted into the sand until the lower end of the main housing was at or below the level of the sea bed. For additional support, the main housing was attached to adjacent pilings using heavy gauge nylon cable ties. After installation, the deployment pipe was unscrewed, exposing the pressure sensor to ambient water pressure. Recovery was by reversing this process.

The goal of the deployment was to obtain a minimum of 3 days of data over a spring tidal cycle. Figure 5 shows the predicted tide at Port St Joe inside St Joseph Bay, and Figure 6 shows the measured winds at SGOFI[1], a meteorological station located on an offshore platform about 20 nm SSE of Cape San Blas, during the first two weeks of March, 2005. The deployment interval is highlighted.

A frontal passage brought moderate to strong NW winds the first few days of the month. Winds stayed between 10 and 20 knots from the NE between the 3rd and 4th, then veered more northerly on the 5th as a mild cold front passed through. Gages were deployed on the 6th. Two gages, a primary and redundant were placed at Sites 2 and 3. The redundant gage mount at Site 1 was damaged during placement, so only the primary gage was deployed. A strong cold front reached the area late on the 7th – the rapid wind shift to the north around midnight is obvious. Winds peaked at 35 kt as the front passed and remained above 20 kt for the next 24 hours. While the gages could have operated for at least another week, the brief lull that presented itself between the afternoon of the 9th and the morning of the 10th seemed an opportunity for recovery worth grabbing. Just after retrieval of the last gage, winds picked up and stayed above 12 kt nearly continuously for the next week, including the third front in two weeks

[1] A 24-hour data gap beginning 0900 on March 9 was filled with data from Apalachicola Airport

The gages' horizontal position was determined to about ±10 ft with a differential GPS receiver. Elevations were determined from an optical level on shore by reading a graduated rod placed on the top of the gage through the opening in the top of the main housing. That level was then referenced to the nearest benchmark to provide the elevation of the top of the gage relative to NGVD. Table 1, summarizes the deployment parameters at the three sites.

Data Analysis

Data Reduction

The gage's pressure transducer measures absolute ambient pressure. To convert the data to gage pressure, atmospheric pressure must be removed. Atmospheric pressure in millibars (mb) was obtained from SGOF1[2]. Measured air pressures were converted to pounds per square inch (psi) and, because the meteorological data were only recorded hourly, linearly interpolated to match the units and sampling interval of the water level gages.

Measured gage pressure is directly proportional to water depth by way of sea water density, which is a function of water temperature and salinity. Water temperature was measured by the gages - it remained between 16 and 20 °C at all sites - but salinity had to be assumed. Table 2 lists the effect of temperature and salinity (S) on density and on the conversion factor K. At constant S of 35 ppt (standard sea water), only the 4th significant digit is affected over a temperature range of 16 deg. Reduction in salinity by half has a slightly larger affect of about 2 percent. While there had been no

[2] A 24-hour data gap beginning 0900 on March 9 was filled with data from Apalachicola Airport

rain locally for the week prior to deployment, about 1 ¼ inch of rain fell at Apalachicola on the 7th. This may have reduced salinity at Site 2, but given the fact that no major rivers drain into the Bay and its significant tidal flushing, it will be assumed negligible. A conversion factor 2.25 ft/psi was used to produce the water depth time series for each gage. Water depth was converted to water surface elevation relative to NGVD by adding the measured elevation of each gage.

Datum Adjustment

In the following sections, the project data set will be compared to both measured and predicted time series from tidal stations established by the National Ocean Service (NOS), the federal government agency charged with measuring and predicting tides and establishing tidal datums. Table 3 shows the official tidal datums provided by the NOS at several locations around St. Joseph Bay, along with the duration of the measured record and the reference station (NOS 2005). The locations of the eight closest stations are shown on Figure 3. Each station's datums are listed (in ft) relative to MLLW at that station. Theoretically, the geodetic datums are fixed in space, so the apparent fluctuation in NGVD or NAVD should actually be the change in local MLLW from station to station. Note that even though Apalachicola is a primary station, all of the stations except White City (up the Apalachicola River) are referenced to the Pensacola primary station, either directly or indirectly through the Port St. Joe Station. Coincidentally, the Cape San Blas and Richardson Hammock tide stations were within a few hundred ft of Sites 1 and 2, respectively, but they were not operated simultaneously.

Before the 1980's, NOS only referenced selected tide station benchmarks and the measured tidal datums to NGVD as established at primary stations during the 1960-1978 tidal epoch. More recently, NOS has referenced measured local tidal datums to NAVD and MSL, using the 1983-2001 tidal epoch; NGVD is no longer utilized. Some, but not all, of the tidal datums established from measurements made in the earlier epoch have been recomputed to MSL from the later epoch and to NAVD. Since the water level data collected for this project are referenced to NGVD, comparisons to contemporaneous NOS tidal data – either measured or predicted – or to numerical models that provide output relative to MSL will require a conversion between NGVD and NAVD and/or MSL in this area. Note that only four of the stations in Table 3 (in bold) have been referenced to both geodetic datums.

Table 4 compares the statistics derived from the two epochs at the nearest station, Apalachicola (columns 2 and 3). The earlier set of statistics was calculated in 1987, and the later set was calculated in 2001. Two additional elevations that are included in both columns are the Lowest Observed (LO) and Highest Observed water levels ever recorded. Column 4 ("Delta '01 –'87") is the difference between the tidal statistics calculated in 2001 and 1987, including NAVD – NGVD in the last row. The small differences between tidal datums in column 4 are deceiving because of long term sea level rise, which affects not only MSL but MLLW, the zero for both columns.

The official rise in MSL provided by NOS for the 21 tidal stations within 150 nm of Site 1 are listed in Table 5 (Zervas, 2001). At Apalachicola, the difference in MSL between the two tidal epics is 0.14 ft. Returning to Table 4, column 5 shows the 2001 datums adjusted by that amount; column 6 shows the new differences. Note that Mean Tide Level is now exactly 0.14 ft higher. However, HO, which occurred in the overlap between the two data sets, does not precisely match.
For completeness sake, column 7 in Table 4 is the 2001 data set adjusted so that HO matches precisely. This brings LO into precise agreement as well. (Since MTL is not the same as MSL, its

rise of just 0.13 ft does not indicate an error). In any case, when rounded to two decimal places there is no change in NAVD – NGVD. The other datum adjusted in the last row of the table, MSL-NGVD, is also unaffected.

To evaluate the suitability of these adjustments at the 3 project measurement sites, the regional spatial trends were calculated. Only the five stations in bold in Table 5 include elevations for both NGVD from the earlier epoch and NAVD and MSL from the later epoch. Of those, Destin is an anomaly and won't be included. Table 6 provides MSL, NAVD – NGVD, and MSL – NGVD for the remaining four: Cedar Key, Apalachicola, Panama City, and Pensacola.
Table 7 shows the calculated linear trend of these parameters at the other three sites as their variation from Apalachicola's values, per nautical mile (nm) distance from Apalachicola.

The first four rows of Table 7 reveal two facts that make transfer of any datums to the project sites by linear interpolation problematic.

- The trend in sea level rise in not linear with longitude (column 3).
- The two geodetic datums do not remain fixed relative to each other (column 5).

The second issue is beyond the scope of this report. Insight to the first is gained by examination of Figure 7, the monthly mean sea levels and the trend line in long-term MSL rise, with the 95% confidence bands, from which the values in Table 5 were produced. It shows that MSL during any epoch is calculated from a signal with significant variance, that the rate of sea level rise at any location has fairly wide error bands, and temporal trends projected into the future are affected by the length of record.

Values of these parameters at the Project measurement sites (all three measurement sites are very near the same longitude) using linear interpolation from Apalachicola are listed in row 6 of Table 7, using the trend between Apalachicola and Panama City, and in row 7 using the trend between Apalachicola and Pensacola. While it may seem more appropriate to use the trend to the nearer station, the trend to Pensacola for MSL adjustment may be equally reliable, because: 1) the tide gage at Pensacola has been in place longer; the record for the earlier epoch spans 19 years; 2) The MSL record at Panama City begins in the mid 70's a period of higher monthly means that lowers the MSL rate of change compared to a longer record. The last row is the average of the adjustments using the two distant stations. These are the recommended values for transferring the Project water level time series data, as referenced to NGVD, to either NAVD or MSL. Note that the adjustment is only provided to one decimal place; further resolution is unjustified.

Validation

Certainly the first issue when examining the data is comparing the primary and backup gages to each other. Figure 8 overlays the reduced elevation time series and Figure 9 shows the residual between the primary and redundant backup gages at Sites 2 and 3.

Table 8 provides the arithmetic means of the individual gage elevations, the residuals between primary and redundant gages, and of the final qualified time series for each site. Both the plot and the table confirm a reasonably close agreement for the gages at Site 2. The residual is fairly random with a mean near zero (0.01 ft) and a maximum variance of approximately 0.05 ft. There is a definite trend from slightly negative, to neutral, to slightly positive over the 4 day interval. The water temperature, shown, does not show any obvious correlation, so the reason for this drift is unknown.

At Site 3, the residual has a mean of 0.13 ft. This offset is more than expected for transducer uncertainty, and indicates a probable survey error. With no other information, the only recourse would be to average the two time series, and the error, leaving an uncertainty in the qualified data at Site 3 approaching 0.1 ft. It happens that the Site 3 backup gage was the last gage to be surveyed, and a misstep in the water forced the rodman (the author) and the collapsible survey rod into the dock just prior to its measurement. Examination of the rod when this bias was discovered in the analysis (after gage removal) revealed a broken plastic retainer that allowed slippage between rod sections on the order of an inch. The most probable scenario is that the rod slipped downward with this impact, causing the backup gage to appear lower, and thus the water level higher, by the amount shown in Table 8. By removing the bias from the backup gage, the residual is forced to zero. The line labeled “S-3 Resid.–Bias” in Figure 9 is consistent with Site 2, even showing the same slow drift upward.

The qualified time series for Site 2 is the average of the primary and backup gages. The qualified time series for Site 3 is designated as the average of the primary gage data and the redundant gage data with the bias subtracted. The uncertainty is on the order of $\pm$ 0.05 ft.

Without two data sets to intercompare, the primary gage at Site 1 can only be compared to the predicted and measured tides in the vicinity. Figure 10 plots the measured elevations at Site 1 with the measured tides from the two closest operating tide stations: Apalachicola and Panama City Beach.

The flattened and attenuated low tide signals and the amplified high tidal peak at Apalachicola shows that Apalachicola Bay is exit dampened: the Bay fills up more readily than it drains. Because of this unequal phase lag, low water has already occurred and begun rising before the Bay fully empties. The tide station at Panama City Beach is on the open coast, and provides a much better match to the Site 1 data.

The only period between March 6 and March 10 with relatively low wind velocity is from around mid afternoon on the 6th to mid afternoon on the 7th (see Figure 6), and during that interval, the Panama City Beach and Site 1 data nearly overlay. On the 9th, winds were decreasing and coming offshore, and again these two stations are in close agreement. The extensive Cape San Blas shoals offshore of Site 1 cause that site to be much more responsive to wind, and wind wave, effects such as set down (mid day on the 6th, from offshore winds blowing all morning), set up (most of the 8th, from incident waves generated the previous evening and that morning). There is no indication of any errors in the data from the single gage at Site 1. Figure 11 plots the final qualified data from the 3 measurement sites.

Discussion

A notable aspect of the signal at all three project sites, as well as at Panama City Beach, is the prevalence of intermediate oscillations between wind wave periods (order of sec to 10's of sec) and tidal periods (order of a half to full day). These oscillations, called long waves, can be generated directly by forces of sufficient size and scale, such as meteorological features, e.g., fronts, or indirectly from non-linear interactions between incident and reflected wind waves, wind waves of different periods, or wind waves and currents. Continuation of the oscillations beyond one or two cycles indicates that the frequency of the forcing energy is near resonance with the natural frequency of oscillation, or sloshing, of one or more nearby basins. These resonant oscillations (including sub harmonics) are called seiching, and will occur in St Joseph Bay, as well as any area defined by a sudden change in depth, such as the offshore shoals, the bights to either side of the cape, even the continental shelf. Even when their amplitudes are small (on the order of inches), the horizontal water velocities associated with long waves can have significant impacts (McGehee 1991).

While long waves are usually detectable at most ocean sites, the persistence and amplitude of these harmonics at this site are fairly unusual. This weather event generated long waves inside the Bay on the order of 1 ft, comparable with tidal amplitudes, but because they have shorter periods, horizontal current velocities associated with the seiche will exceed tidal currents. However, the most significant effect of the long waves for any breach at Stump Hole is due to the geometry of the Bay.

Geometric Effects

Stump Hole is located at the very back of St Joseph Bay, and the time it takes for a long wave to travel from Cape San Blas to St Joseph Point and back down the Bay results in a phase lag between different locations. For the largest of the oscillations measured during this event, the phase lag is near 180 degrees between Sites 1 and 2. The impact is evident in the hydraulic head, as measured by the instantaneous difference in elevation at the two sites, available to drive currents through any breach connecting these sites. Figure 12 plots the Site 2 minus the Site 1 time series (solid line) along with the dominant factors affecting it: wind and tide. The wind's influence is better illustrated by separating it into southern and western components. The variance of the head is more dramatic than the water level; it cycles from + 1.8 ft to – 1.6 ft and back to nearly + 1 ft in a 6-hour period beginning 2200 on March 7 as the cold front passed through. Following the sequence of events that produced this signal will be aided with 12-hour "zoomed in" plots of that period (Figures 13a, b).

A strong south wind (causing northerly, or negative south stress) peaks around 2100, then rapidly switches to the west (negative west stress) as the front passes. The south wind causes wave and wind setup in the Gulf, and that water travels into the Bay. This flow coincides with the rising tide, as shown by the measured tide in the far field at Panama City Beach (Figure 13a). Meanwhile, the southerly wind has been blowing water northward inside the Bay, causing a set down at Site 2 around 2100. When the wind rapidly switches west, the offshore water levels rapidly fall, but the easterly stress continues to force water into the Bay through the wide, eastward facing entrance. By the time the water levels peak in the back of the Bay, levels offshore have dropped. Coincidentally, the water in the bay begins to ebb just as the tide is turning offshore. Water levels drop rapidly in the Bay and continue to fall as far as 1.5 ft lower than offshore, so the flow reverses again.

The response of the system is an oscillation that continues for the remainder of the measurement interval. The rapid switch in wind stress is, in effect, a pulse load on a vibrating system. Because the periods of the seiche are harmonics of tidal periods, the oscillations can become large. Long waves with heights on the order of 1 ft at periods near 6 hr, about half of diurnal tide periods, are evident at both Sites 2 and 3. Site 2 also has another set of waves with a similar height but with a shorter period about 1 ½ hr, or about 5400 sec. The mode 1 seiche period for a rectangular basin with the Bay's length (12 nm) and an average depth of 22 ft is 5,427 sec. The lower, shallower portion of the Bay forms another basin, roughly 4 nm square and about 2 – 3 ft deep. The first seiche mode for a basin with these dimensions is 5,456 sec, so these two long waves will reinforce each other, if in phase, or cancel if out of phase. Waves with periods between 1 and 1 ½ hr are seen at Site 1 at high tide on the 6th, so there is some offshore forcing energy – perhaps related to seiche on the shoals – that is available to excite these resonant modes inside the Bay.

Even under tidal influence alone, there is sufficient hydraulic head at Stump Hole to drive significant currents through an inlet. Figure 13b also plots the predicted tides at West Pass and Port St Joe (tide stations 3 and 6, respectively, in Figure 3) and compares the head difference for predicted tides to the measured head difference on March 7th and 8th. The general trend is similar, with sufficient head to move significant currents through an inlet during spring tides, but meteorological effects magnify the tidal only head by a factor of 2 to 3.

Potential Impacts on Adjacent Shorelines

Calculation of inlet current velocities during a storm event and short term evolution of any future inlet is well beyond the scope of this report. Qualitatively, hydraulic heads measured in this deployment will likely drive currents well above the threshold for movement of the sediments, so the inlet, once opened, should continue to grow until it reaches equilibrium. Empirical rules derived from other inlets that relate equilibrium cross sections to tidal prisms may not be applicable for the short term response of the inlet during a storm event because the hydraulic head reverses at frequencies much higher than tidal frequencies. However, the tidal/equilibrium approach is appropriate for predicting the long-term fate of the inlet, assuming the proportions of the tidal prism captured by the new and old inlets can be reasonably allocated. Chen, 2005, predicted a stable inlet with a triangular cross section of approximately 276 m^2 with a maximum depth of 3.5 m and a width of 189 m.

If the event triggering long wave seiching lasts sufficiently long, the short term dimensions of the inlet could exceed these predicted long-term equilibrium dimensions. Triggering conditions, which will continue to occur even after the initial breach develops, include strong cold fronts and tropical storms. A hurricane passing nearby to the east of the Bay will produce a similar, and much more severe, rapid reversal from southerly to northerly winds, and can be expected to produce even larger seiche response than observed in this study. Thus, the threat of short term inlet growth beyond the equilibrium size will remain indefinitely into the future.

Impacts on the Bay

An inlet at Stump Hole is likely to have significant influences on the water quality in the bay. Sediments to the east of Cape San Blas have higher silt contents than the sands that prevail to the west, and waters in Apalachicola Bay carry a much higher suspended sediment load than the waters of St Joseph Bay. Figure 14 is a satellite image from April 1994. The sediment plume from Apalachicola Bay extends up the Peninsula beyond Stump Hole, but is dissipated before it reaches St Joseph Point and the Bay entrance. The waters of St Joseph Bay come from the Gulf of Mexico and are noticeably clearer. The water that enters the bay through a breach at Stump Hole will contain an increased suspended sediment load under similar conditions.

Conclusions

Meteorological effects strongly influence, and at times dominate, water levels inside and outside St Joseph Bay. The meteorological effects can produce incident long waves with periods on the order of hours in the Gulf offshore of Stump Hole and at Panama City Beach.

Incident long waves excite resonant seiche modes inside St Joseph Bay that amplify and sustain them. The geometry of the bay causes the seiche at the back of the Bay near Stump Hole to be nearly 180 deg out of phase with the incident long wave in the Gulf offshore of Sump Hole.

The combination of the amplification and phase shifting of the long waves can produce a significant hydraulic head across Stump Hole that produces currents several times faster, and that reverses several times more quickly, than tidal forcing alone generates.

If a breach develops at stump hole, tidal currents alone will likely be sufficient to maintain it. Under routine meteorological events, the inlet will, for the short term, experience additional horizontal and vertical scour over that due to tidal forcing alone. A tropical storm or hurricane passing near and to the east of St Joseph Bay would be one of those conditions.

An inlet at Stump hole will have a significant effect on water quality inside St Joseph Bay because water with high suspended sediment concentrations from Apalachicola Bay discharge into the region immediately offshore of Stump Hole. This water will be captured on flood flows through any new inlet and injected into the Bay.

Acknowledgements

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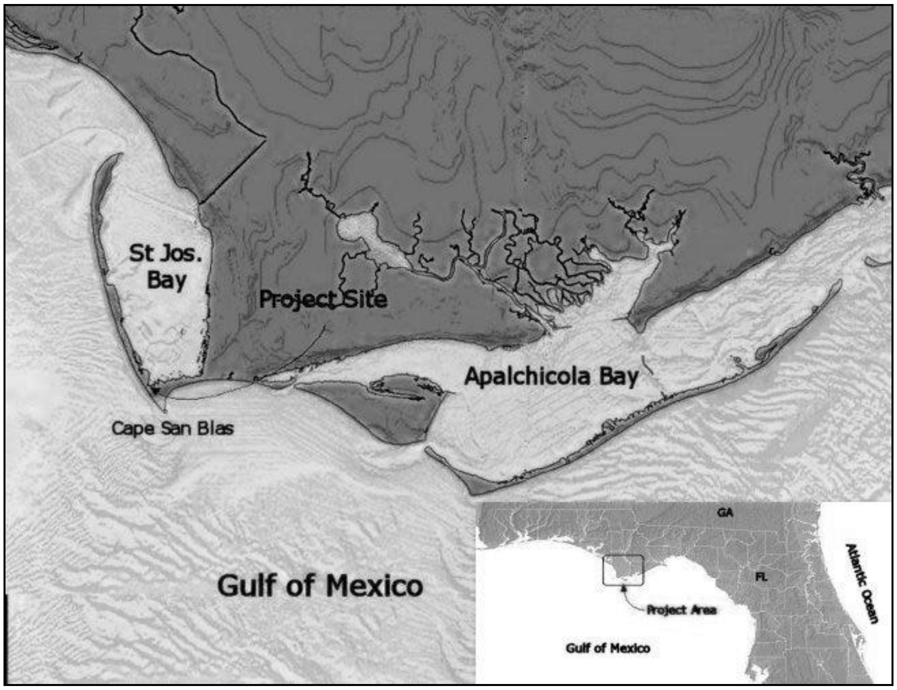

Figure 1 – Map of region and project study area.

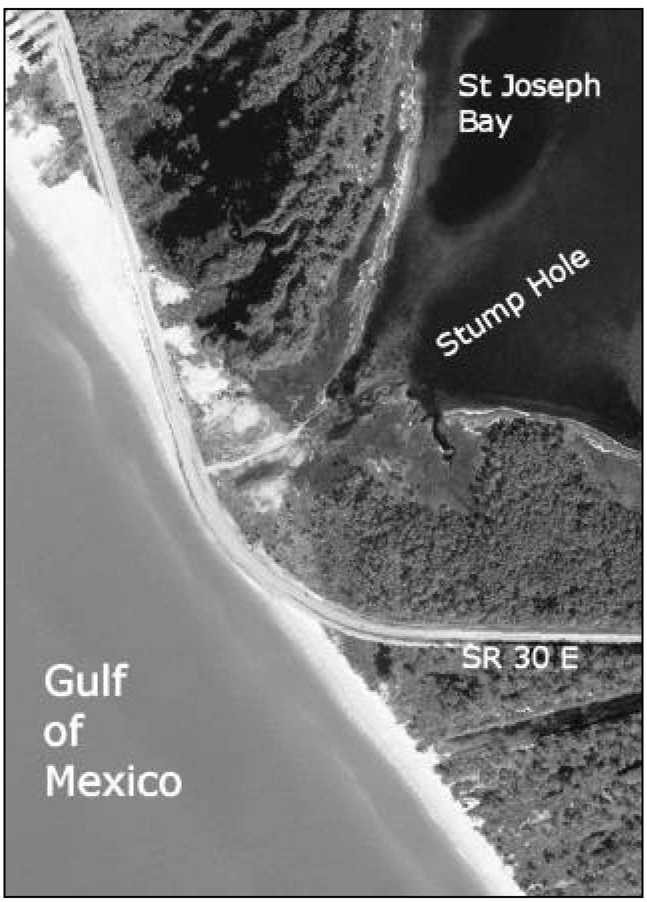

Figure 2 – Aerial photo of Stump Hole and endangered section of roadway.

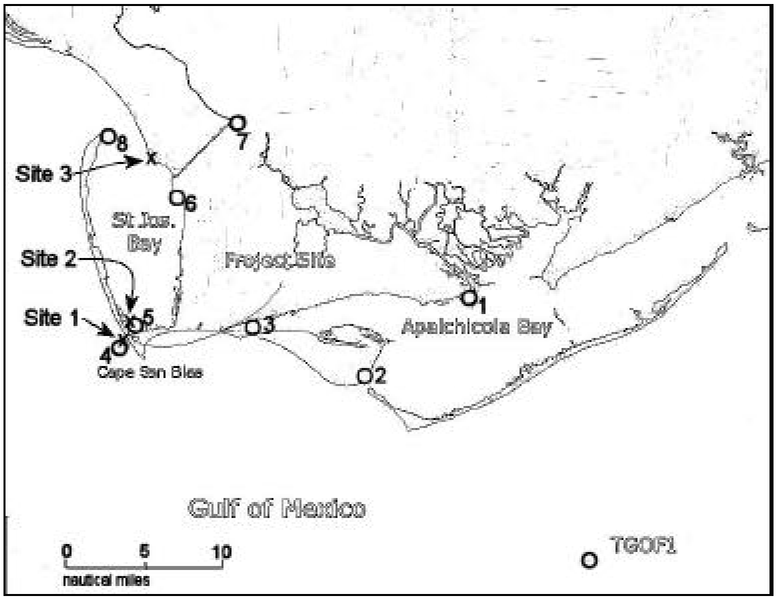

Figure 3 – Map showing project gage sites (x's) and area tide and met stations (o's).

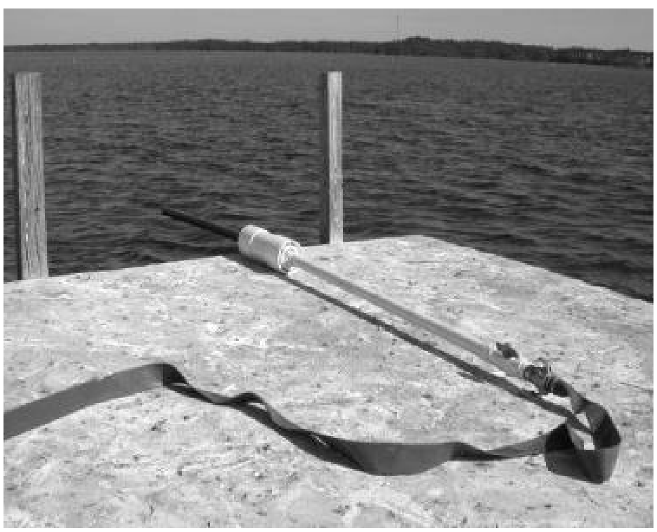

Figure 4 – Gage mount with fixed pile and deployment pipe ready for installation.

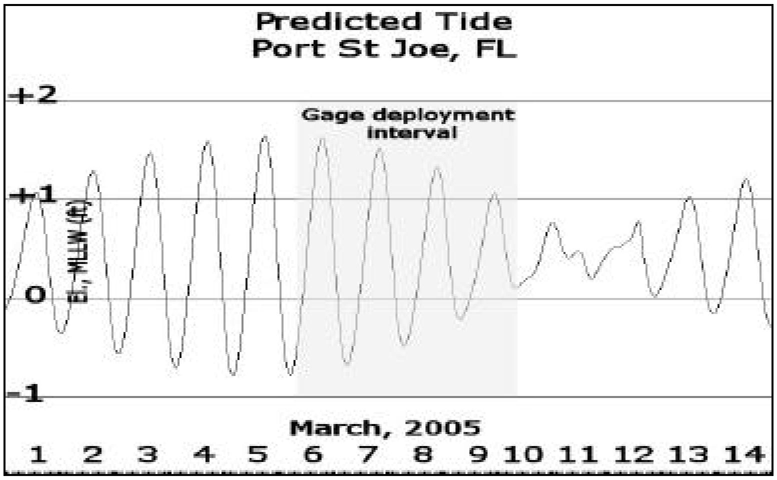

Figure 5 – Predicted Tides at Port St. Joe, March 1- 14, 2005.

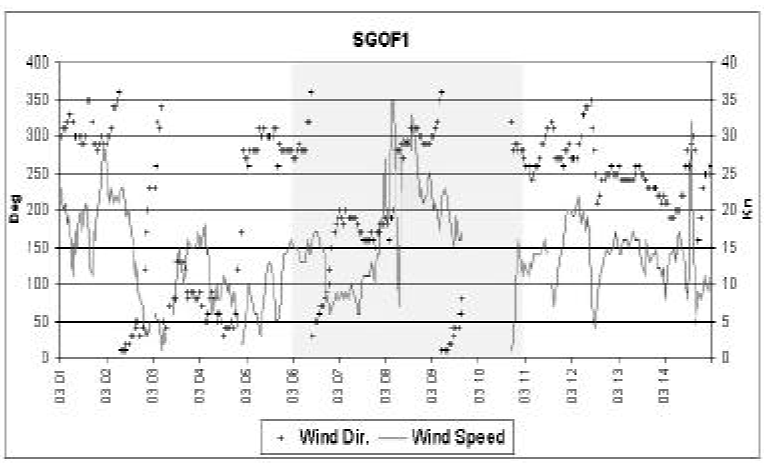

Figure 6 – Plot of the measured winds in the area, March 1–14, 2005.

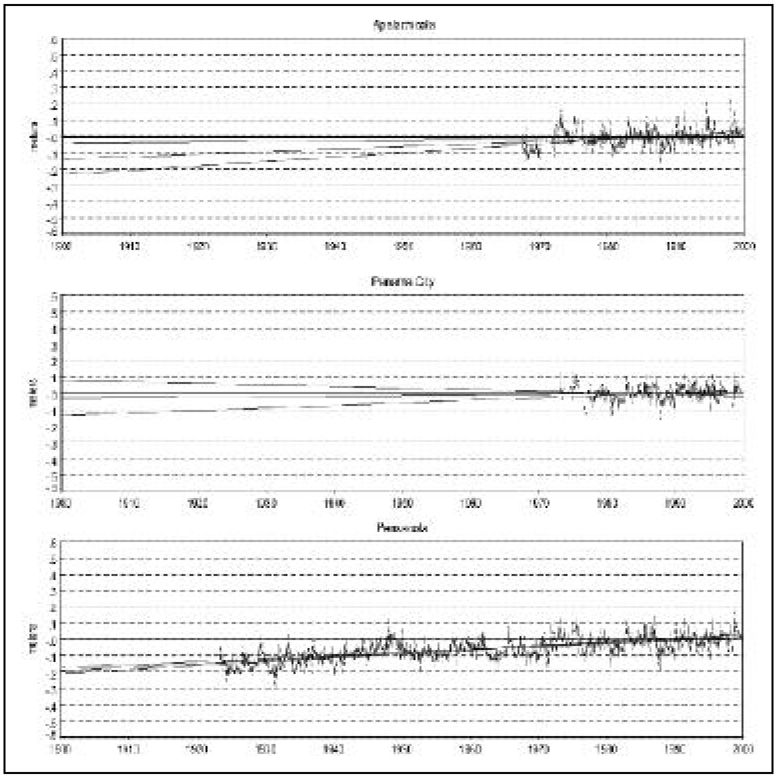

Figure 7 – Plot of monthly Mean Seal Level rise from 1900 to 2000 at three regional tidal stations.

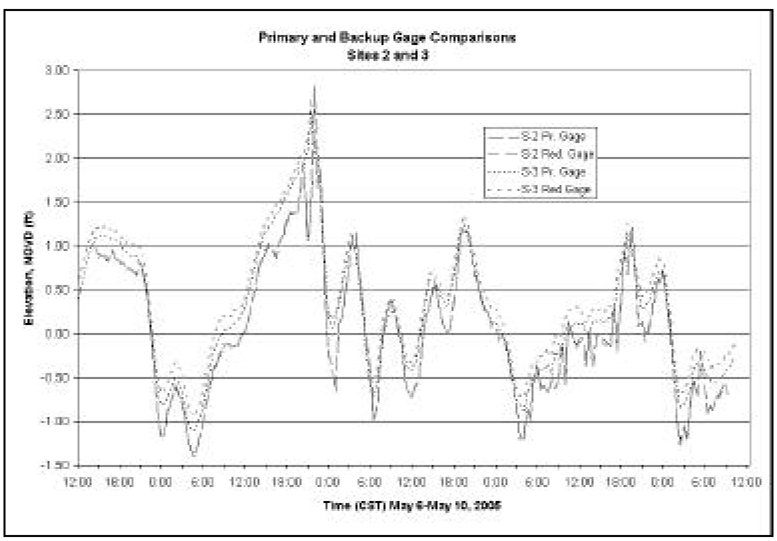

Figure 8 – Plot of primary (pr.) and redundant (red.) water surface time series at Sites 2 and 3.

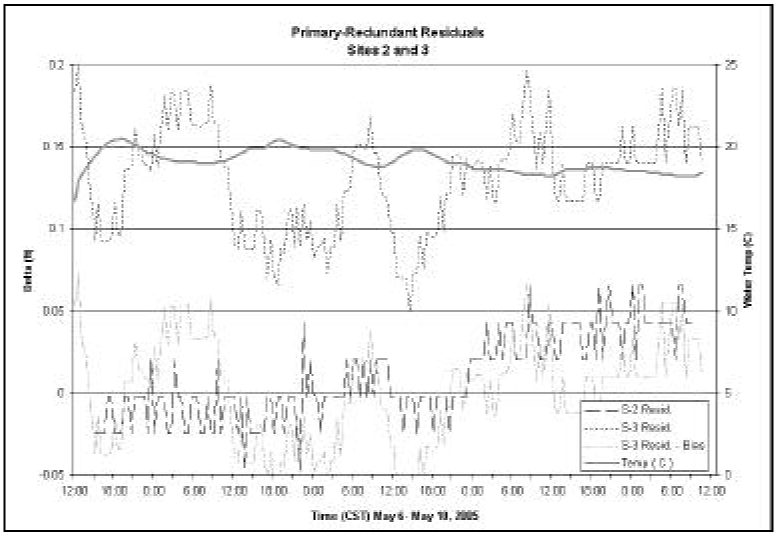

Figure 9 – Plot of the residuals and measured temperature at Sites 2 and 3.

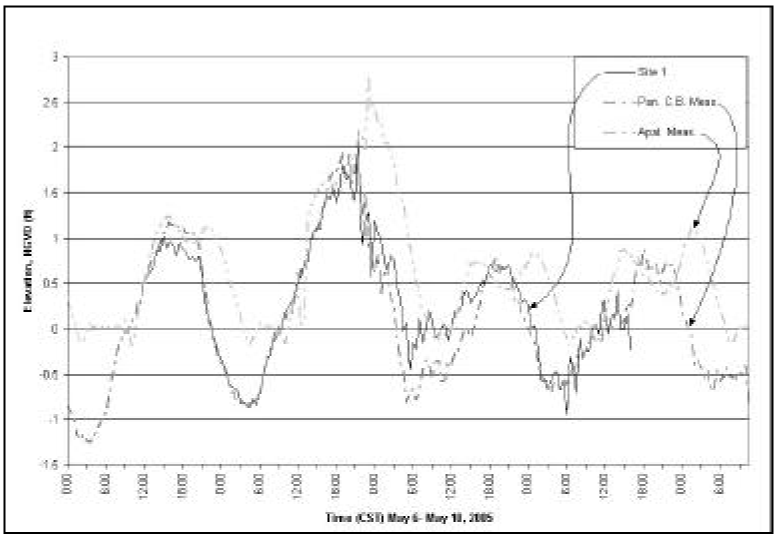

Figure 10 – Comparison of the water surface at Site 1 with measured tides at Panama City Beach and Apalachicola, FL

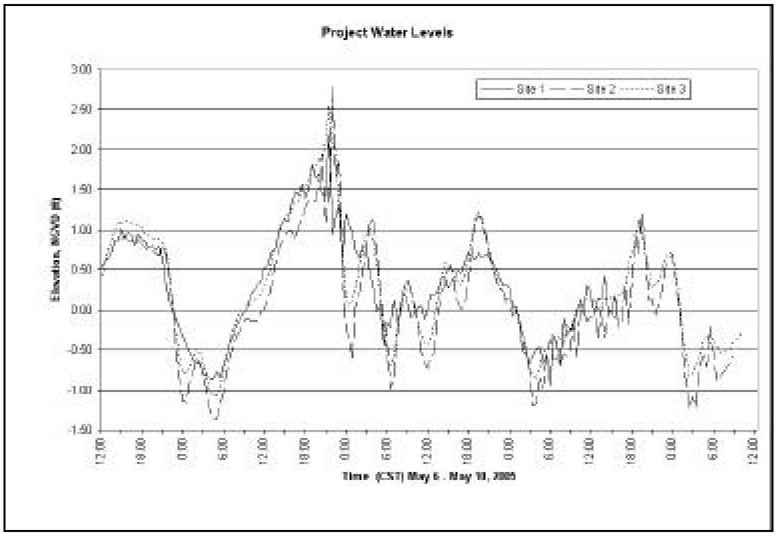

Figure 11 – Plot of the qualified water level time series at Sites 1, 2, & 3

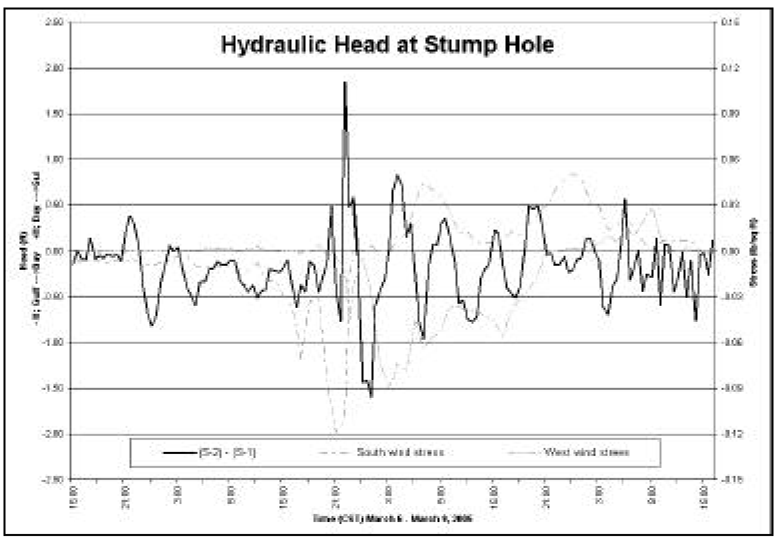

Figure 12 – Plot of the measured hydraulic head at Stump Hole with wind stress components during deployment.

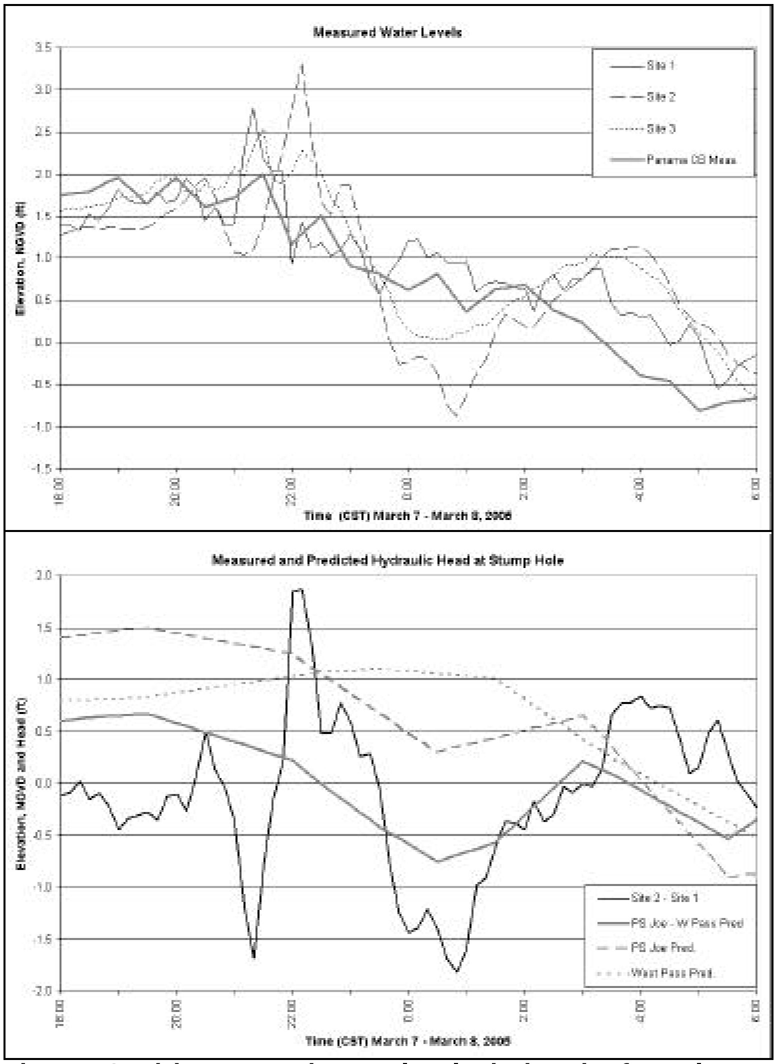

Figure 13 – (a) Measured water levels during the frontal passage; (b) the measured and predicted hydraulic head during the frontal passage.

Figure 14 - Satellite image showing discharge of sediment-laden water from Apalachicola Bay into the Gulf of Mexico directly offshore of Stump Hole.

Potential Cover Photo?

Table 1 – Gage Deployment Sites

Site	Lat - N (deg min)	Long - W (deg min)	Water Depth (ft, MLLW)	Deployed (date time CST)	Recovered (date time CST)
1	29º 40.158	85º 21.436	5	03/06/05 1030	03/09/05 1600
2	29º 41.221	85º 21.668	6	03/06/05 1430	03/10/05 0930
3	29º 50.788	85º 20.039	3	03/06/05 0900	03/10/05 1100

Table 2 - Density (?) and Conversion Constant, K for selected Temperatures and Salinities

T (º C)	S (ppt)	? (lb/cf)	K (ft/psi)
4	35	64.1338	2.2453
8	35	64.1019	2.2464
12	35	64.0592	2.2479
16	35	64.0067	2.2498
20	35	63.9452	2.2519
16	35	64.0067	2.2498
16	25	63.5278	2.2667
16	15	63.0506	2.2839
16	0	62.3890	2.3081

Table 3 - Tidal and Geodetic Datums of Regional Tidal Stations

Station Control Station; Epoch	*Map Index #*	*Lat Long*	*Length (yr) Recorded*	*MLLW*	*MLW*	*NGVD*	*NAVD*	MSL	*MTL*	*MHW*	*MHHW*
Apalachicola Primary: 1960-1978	1	29 43.6 84 58.9	7 1/79-12/85	0	0.41	**0.35**			0.97	1.52	1.66
Apalachicola Primary; 1983-2001	1	29 43.6 84 58.9	19 1/83-12/01	0	0.40		**0.76**	.91	0.95	1.51	1.61
West Pass Pens acola; 1960-1978	2	29 38.0 85 05.8	0.2 9.83-3/84	0	0.23				0.81	1.38	1.49
Indian Pass Pensacola; 1960-1978	3	29 40.8 85 13.0	0.2 9/83-3/84	0	0.25				0.79	1.33	1.39
Cape San Blas Pensacola; 1960-1978	4	29 40.1 85 21.6	0.6 3/78-978	0	0.00				0.68	1.37	1.39
Cape San Blas Pensacola; 1983-2001	4	29 40.1 85 21.6	0.3 10/77-1/78	0	0.09		0.76	0.74	0.74	1.38	1.44
Richardson Hammock Port St. Joe; 1960-1978	5	29 41.4 85 21.8	.25 1/81-3/81	0	0.17				0.82	1.46	1.74
Richardson Hammock Port St. Joe; 1983-2001	5	29 41.4 85 21.8	.25 1/81-3/81	0	0.15		0.46	0.83		1.43	1.71
Port St Joe Pensacola; 1960-1978	6	29 48.9 85 18.8	1 1/76-12/76	0	0.22				0.79	1.37	1.67
Port St Joe Pensacola; 1983-2001	6	29 48.9 85 18.8	1 1/76-12/76	0	0.20		0.82	0.82	0.78	1.35	1.65
White City ICW Apalachicola; 1960-1978	7	29 52.8 85 13.4	0.5 12/77-5/78	0	0.09	**-0.31**			0.52	0.95	1.03
White City ICW Apalachicola; 1983-2001	7	29 52.8 85 13.4	0.5 12/77-5/78	0	0.10	-	**0.02**	0 .53	0.50	0.91	0.97
St Joe Point Port St Joe; 1960-1978	8	29 52.4 85 23.4	0.1 1/76	0	0.10				0.68	1.26	1.56
St Joe Point Port St Joe; 1983-2001	8	29 52.4 85 23.4	0.1 1/76	0	0.09		0.78	0.76	0.67	1.25	1.55
Panama City, St An. Bay Pensacola; 1960-1978	NA	30 09.1 85 40.0	9 '74 – '84	0	0.05	**0.21**			0.67	1.29	1.37
Panama City, St An. Bay Primary; 1983-2001	NA	30 09.1 85 40.0	18 1/83-12/01	0	0.05		**0.56**	0.67	0.67	1.30	1.34
Pensacola Primary; 1960-1978	NA	30 24.2 87 12.8	19 '61-'79	0	0.04	**0.26**			0.64	1.23	1.27
Pensacola Primary; 1960-1978	NA	30 24.2 87 12.8	19 1/83-12/01	0	0.03		**0.32**	0.62	0.66	1.23	1.26

Table 4 – Temporal Variations in Datums at Apalachicola

Tidal Epoch	'60-'78	'83-'01	Delta '01 –'78	2001 datums, adj. for MSL rise	Delta '01 –'87	20001 datums adj. to common HO	Delta '01 –'87
HO, 11/21/85	7.45	7.303	-0.15	7.44	0.01	7.45	0.00
MHHW	1.66	1.614	-0.05	1.75	0.11	1.76	0.10
MHW	1.52	1.512	-0.01	1.65	0.15	1.66	0.14
MTL	0.97	0.955	-0.02	1.10	0.14	1.10	0.13
MSL		0.909		1.05		1.06	
NAVD		0.761		0.90		0.91	
MLW	0.41	0.401	-0.01	0.54	0.15	0.55	0.14
NGVD	0.35						
MLLW	0.00	0.00	0.00	0.14	0.16	0.15	0.15
LO, 01/18/81	-1.69	-1.837	-0.15	-1.70	0.01	-1.69	0.00
NAVD - NGVD		0.41		0.56		0.56	
MSL - NGVD		0.56		0.71		0.71	

Table 5 – Spatial Variation in Mean Sea Level Rise at Regional Tidal Stations

Tidal Station	Delta MSL, 2001-1978	Distance to Apalachicola (nm)	Distance to Site 1 (nm)
8727520 CEDAR KEY, GULF OF MEXICO	**0.14**	**150**	**170**
8727695 STEINHATCHEE	0.14		
8728229 SHELL POINT, WALKER CREEK	0.14		
8728360 TURKEY POINT	0.05		
8728690 APALACHICOLA, APALACHICOLA RIVER	**0.14**	**0**	**20**
8728711 APALACHICOLA RIVER	0.1		
8728912 PORT ST. JOE	0.15		
8729015 ALLANTON, EAST BAY	0.14		
8729017 FARMDALE, EAST BAY, ST. ANDREW BAY	0.13		
8729045 LAIRD BAYOU, EAST BAY	0.13		
8729102 LYNN HAVEN, NORTH BAY	0.12		
8729108 PANAMA CITY, ST. ANDREW BAY	**0.13**	**55**	**35**
8729136 NEW ENTRANCE CHANNEL, ST. ANDREW BAY	0.13		
8729152 ALLIGATOR BAYOU, PANAMA CITY	0.13		
8729197 WEST BAY CREEK WEST BAY	-0.28		
8729210 PANAMA CITY BEACH, GULF OF MEXICO	0.1		
8729511 DESTIN, EAST PASS	**3.4**	**90**	**70**
8729538 GARNIER BAYOU, SHALIMAR	0.22		
8729678 NAVARRE BEACH	0.13		
8729747 SHIELD POINT, BLACKWATER RIVER	0.86		
8729840 PENSACOLA, PENSACOLA BAY	**0.15**	**120**	**100**

Table 6 - Temporal Variation in Datums at Regional Tidal Stations

Station	Cedar Key	Cedar Key	Apalachicola	Panama City	Panama City	Pensacola	Pensacola
Tidal Epoch	'60-'78	'83-'01 adj. for MSL rise	'83-'01 adj. for MSL rise	'60-'78	'83-'01 adj. for MSL rise	'60-78	'83-'01 adj. for MSL rise
MHHW	3.76	3.94	1.75	1.37	1.47	1.27	1.41
MHW	3.41	3.60	1.65	1.29	1.43	1.23	1.38
MTL	2.02	2.19	1.10	0.67	.80	0.64	0.78
MSL		2.18	1.05		0.80		0.77
NAVD	2.39	2.39	0.90		0.69		0.47
NGVD	1.71		0.54	0.21		0.26	
MLW	0.63	0.77		0.05	0.59	0.04	0.18
MLLW	0	0.14	0.14	0.00	0.13	0	0.15
LO	-4.10	-4.06	-1.70				
MSL Rise		0.14	0.14		0.13		0.15
MSL-NAVD		-.21	0.15		0.11		.30
NAVD-NGVD		0.68	0.56		0.48		0.21
MSL–NGVD		0.47	0.71		0.59		0.51

Table 7 - Linear Spatial Trends of Datums and Datum Differences for Regional Tidal Stations

Station	MSL rise '78 to '01 (ft)	MSL rise linear trend (ft/nm)	NAVD–NGVD (ft)	NAVD-NGVD linear trend (ft/nm)	MSL-NGVD (ft)	MSL-NGVD linear trend (ft/nm)
Cedar Key	0.14	0.0000	0.68	0.0008	-0.21	-0.0061
Apalachicola	0.14	NA	0.56		0.71	NA
Panama City	0.13	-0.0002	0.48	-0.0015	0.59	-0.0022
Pensacola	0.15	0.0001	0.21	-0.0029	0.51	-0.0017
Project Sites, Interpol. via Pan. City trend	0.136		0.531		0.667	
Project Sites,Interpol. via Pens. trend	0.142		0.502		0.677	
Project Sites: Recommended	0.1		0.5		0.7	

Table 8 – Means of Primary, Backup, and Qualified Time Series at Sites 2 and 3

Time Series	S-2 Pr.	S-2 Red.	S-2 Resid.	S-2 Qual.	S-3 Pr.	S-3 Red.	S-3 Resid.	S-3 Red. -Bias	S-3 Qual.
Means	0.068	0.058	0.010	0.063	0.257	0.387	0.130	0.257	0.257