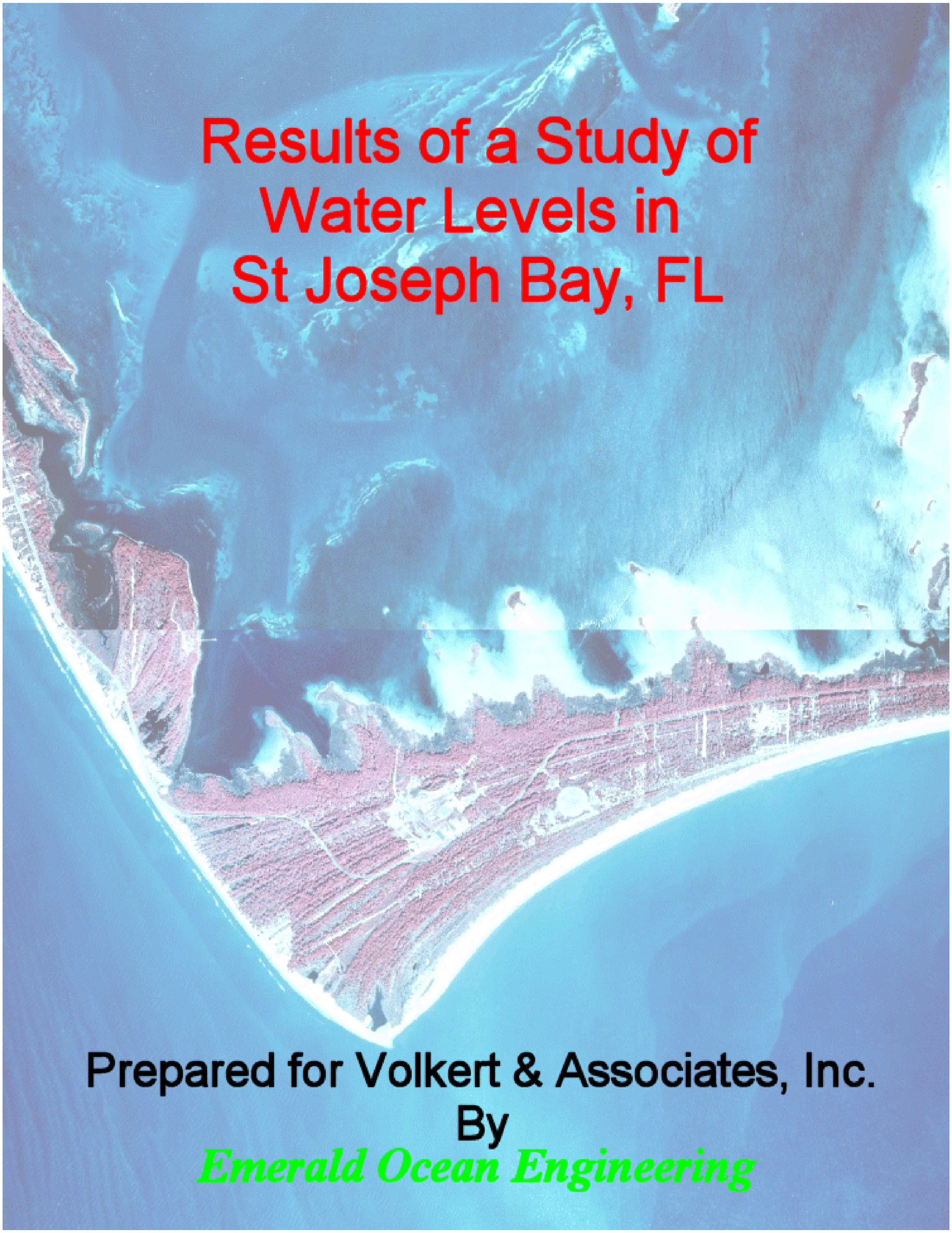

Results of a Study of Water Levels in St Joseph Bay, FL

Prepared for Volkert & Associates, Inc.
By
Emerald Ocean Engineering

Revised March 2006

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Report Number

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Executive Summary

Water level measurements were collected around St Joseph Bay, FL to support investigations into the potential impacts if a breach developed at an erosion-threatened site near Stump Hole on the St Joseph Peninsula. Instruments were placed in the Gulf of Mexico offshore of Stump Hole, in the Bay behind Stump Hole, and in the Bay near its entrance. Data were collected for four days, capturing spring tides and the passage of a strong cold front. Raw pressure data were reduced to water elevation time series relative to NGVD. Local conversions to NAVD and mean seal level (MSL) were calculated from analysis of spatial and temporal trends in MSL at regional tidal stations. Analysis of the measured water levels led to the following conclusions and recommendations.

Conclusions

Meteorological effects can exceed tidal effects on water levels inside St Joseph Bay. Long waves in the Gulf with periods on the order of 1 to 6 hours excite oscillations inside St Joseph Bay. Resonance with natural seiche modes amplify and sustain these long waves in the Bay for days.

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 produces a significant hydraulic head across Stump Hole that can generate currents stronger, and that reverse more quickly, than tidal forcing alone generates.

If breach develops, routine meteorological conditions will produce currents stronger than tidal forcing alone would generate. Depending upon duration of these currents, additional scour and expansion of the inlet beyond the tidal equilibrium dimensions could result. A tropical storm passing to the east of St Joseph Bay would be an extreme case of one of those conditions, but typical winter cold fronts are sufficient.

An inlet at Stump hole will have effects on water quality and the ecology in St Joseph Bay because water with high sediment concentrations from Apalachicola Bay discharge immediately offshore of Stump Hole. Even under tidal flow alone, these waters and their sediments will be introduced into the Bay in significant quantities.

Recommendations

Any model intended to simulate and accurately predict the hydraulics of this system on short time scales should consider meteorological and wind wave induced long waves.

Empirical rules relating equilibrium inlet cross sections to tidal prisms should be reliable for the long-term fate of the inlet, but may not be a reliable predictor of transient effects.

Investigations into the impacts of a breach at Stump Hole should include water quality modeling and the effects of increased sediment loads on the Bay.

Any protective measures to prevent or postpone a breach should address both sides of the roadway. Under storm conditions, a breach is as likely to develop from the Bay side as from the Gulf side.

I. 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 north and is sheltered from direct offshore wave energy. The mean tidal range in the Bay is about 1.5 ft.

Figure 1 – Project Area and Project Site Map

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, in light of the likely, eventual breach of the peninsula, is a bridge bypassing the resulting inlet.

Figure 2 - Stump Hole and Endangered Section of Roadway

A numerical hydrodynamic circulation model will be developed under a separate subtask of the contract and used in planning by DOT. 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 the model. This report describes the collection, analysis, validation, and implications of that data set of water level time series.

II. Data Collection

Site Selection

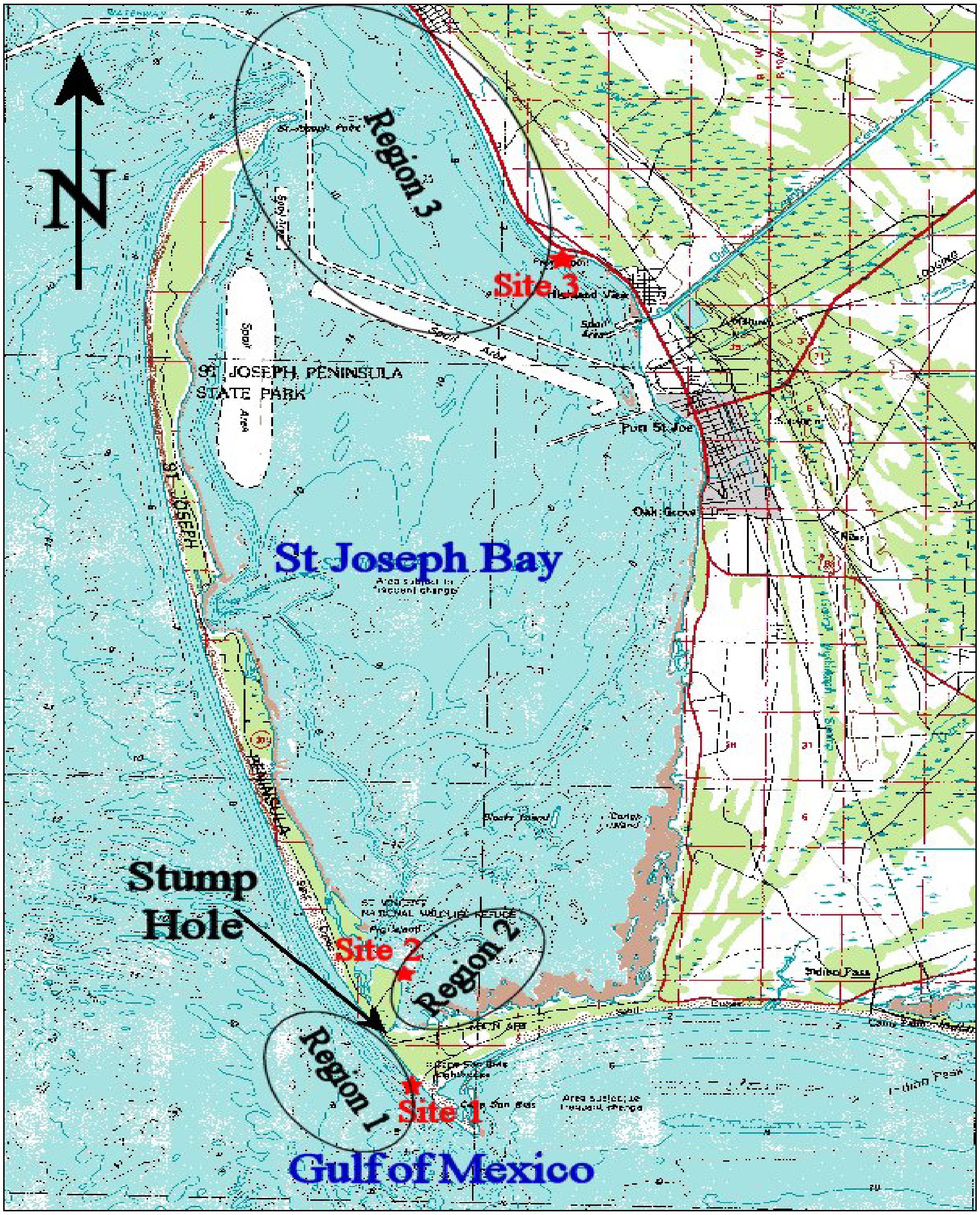

Figure 3 - Measurement Regions and Selected Gage Sites

Three measurement regions were identified in the planning phase of the study and designated in the scope of work. These were 1) in the Gulf, offshore of Stump Hole, 2) in the Bay, near Stump Hole, and 3) near the entrance to St Joseph Bay (Figure 3). After a site inspection in February, 2005, three gage deployment sites were identified:

←Figure 3A - Site 1
Stump Hole Gulf Side;

This site is just offshore of the Cape San Blas Lighthouse. There is a cluster of piles in the water about 200 ft off the remnants of the US Fish & Wildlife research station. The upland property belongs to the federal government and public access is restricted by a chain link fence and warning signs. Access is by foot along the beach or by boat.

Figure 3B - Site 2 →
Stump Hole Bay Side;

Site 2 is on a pier adjacent to a fire tower in Lighthouse Bay. The pier is inside the boundaries of the St Joseph Bay State Buffer Preserve and the upland property belongs to the state of Florida. Access is by foot along a sand pathway or boat.

← Figure 3C - Site 3
Palm Point;

This site is on a pier belonging to the private development of Palm Point. Access is by foot for residents of Palm Point or by car for the general public, or by boat.

The sites are close to shore and existing fixed structures; this provides several logistic advantages:

- Leveling – Establishing the elevation of the sensor is straightforward, economical, and reliable using traditional survey leveling methods. For reliable results using an optical station, the distance from the instrument (on shore) to the rod (set on the instrument) should be within a few hundred yards. While some movement of the rod due to wave action can be tolerated, the availability of a platform for the rodman to stand on or brace against greatly increases the ease, accuracy, and weather window of the surveying operation.

- Security – The biggest risk to these gages while deployed is accidental or deliberate interference from someone in a boat, particularly by fishing vessels. All of these sites are adjacent to structures (piers or pilings) that protect them from accidentally being run over and dispense with the need to mark them with buoys that attract the curious/malicious. An instrument bolted to a pile several feet below the water line is safe from all but deliberate theft/vandalism by someone who is willing to get wet and has the appropriate tools to remove it.

- Stability – The pilings on these structures add rigidity to the temporary instrument mounts and provide an additional measure of stability for the instruments during the deployment.

Instruments

Water levels were measured using the MacroTide self contained water level gage with internal battery power and solid state memory. The MacroTide measures and records ambient water pressure (absolute) and temperature at a programmable sampling scheme. Specifications on the gage and its sensors are listed in Appendix A.

The gage's sampling scheme is programmable to allow user optimization of data quantity, battery life and memory capacity. Variables are the sampling rate (how frequently the sensor is sampled), the sample length (how long the samples are collected before averaging to provide each pressure or temperature data point) and the sample interval (the time between collection and storage of each data point). High frequency sampling rates, long sample lengths and short sample intervals all utilize more power and memory and decrease the total period the gage can operate. The following parameters resulted in a battery-limited operational life of about 2 weeks.

Sample Rate – specified as the number of 0.01-sec clock cycles between discrete samples.
Setting = 50; effective sampling rate = one every 50 x .01 sec = 2 Hz. High frequency sampling eliminates bias from wind waves

Sample Length – specified as the number of sensor samples averaged.
Setting = 900; effective sample length = 900 x ½ sec = 450 sec = 7.5 min

Sample Interval – specified as the time between samples, in minutes.
Setting = 10 min; provides six water level measurements/hour

Thus, a data point represents the average of the high frequency samples of water pressure (and temperature) over a 7.5 minute interval, and there were six data points collected every hour.

Mounts

Mounts were fabricated from PVC pipe to avoid galvanic corrosion of the stainless steel instrument housings and minimize weight. After initialization and status verification, the gage was placed inside the gage housing.

← Figure 4A

Figure 4B →

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” x 5’ PVC pipe piling extended from the bottom of each of the main housings (Fig 5). A removable 2” x 6’ deployment pipe could be threaded into the top of the main housing; a 2” 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.

Figure 5 - Gage Mount with Fixed Pile and Deployment Pipe Attached

Deployment

The specified task in the scope of work for this study was to obtain a minimum of 3 days of data over a spring tidal cycle. The notice to proceed was received on February 15, 2005, and a "kick-off" teleconference was held on February 22. The next spring tide cycle would begin on March 1, just one week later, and extend through March 9. The following spring tide began March 14 (Figure 6a).

To improve the chances of data recovery two gages and mounts, a primary and a redundant back up, were planed for each site. Instruments were acquired and tested and six mounts were fabricated in the 10 days following the kick off meeting; the next move was up to the weather. Figure 6b shows the measured winds during the first two weeks of March, 2205 at SGOFI[1], a meteorological station located on an offshore platform about 20 nm SSE of Cape San Blas (See Figure 7 and Appendix B).

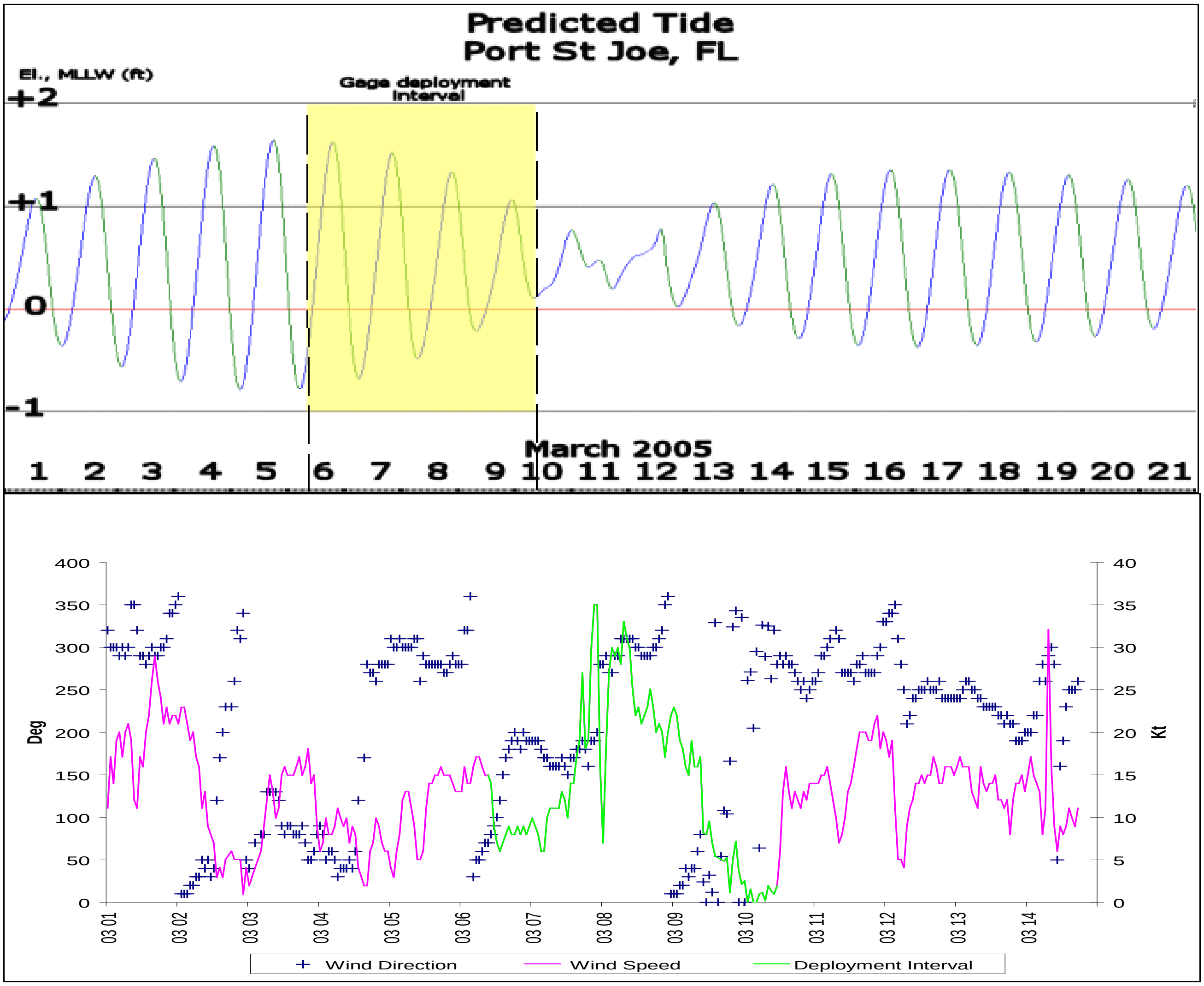

Figure 6a (top) – Predicted tides at Apalachicola, March 2005; Figure 6b (bottom) – Local Winds, March 1–14.

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

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 at Sites 3 and 1 in the lee of windward shores in the morning of the 6th, but the sharp (and unforecast) easterly veer in late morning kicked up steep seas at Site 1 midway through the operation. The mount for the backup gage was damaged during installation, so only the primary gage was deployed at Site 1. (Primary and backup gages were installed at both Sites 2 and 3.) Site 2 was instrumented in the afternoon of the 6th, when the peninsula sheltered it from the southerly winds.

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 operate 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. By taking advantage of this narrow window, it was possible to provide preliminary analyzed data by early April.

All five gages were surveyed on the morning of the March 7 when light southerly winds prevailed. The gages' horizontal position was determined to an accuracy on the order of 10 ft with a differential GPS receiver. Elevations were determined by optical level. A graduated rod was placed on the top of the gage (through the opening in the mount used to attach the removable deployment pipe) and read by an instrument person onshore. The 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; additional details are in Appendix C, Deployment Notes.

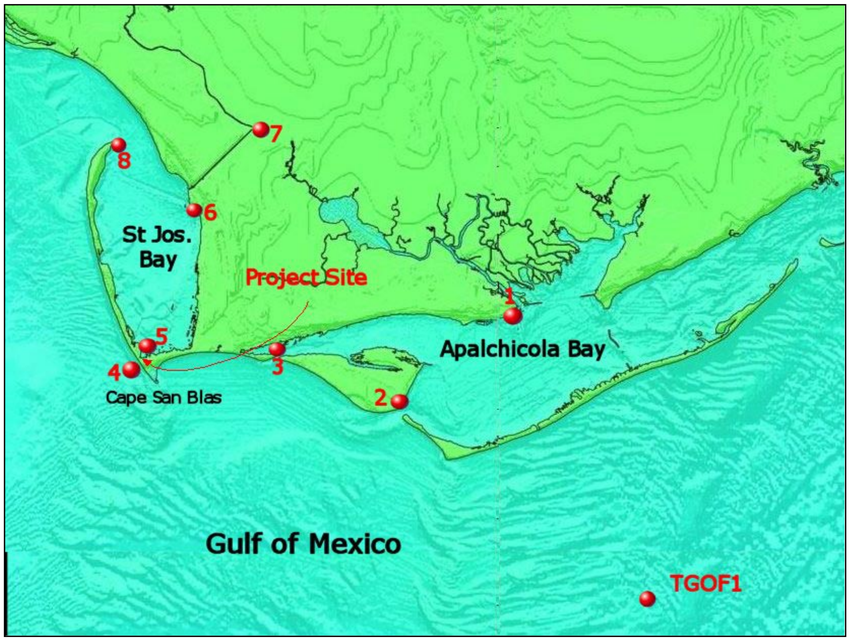

Figure 7 - Local Tidal and Meteorological Stations

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

III. 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]. Because the meteorological data was only recorded hourly, air pressures were converted to pounds per square inch (psi) and 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 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 rain locally for the week prior to deployment, about 1 ¼ inch of rain fell at Apalachicola on the 7th. This would 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.

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

T (° C)	S (ppt)	ρ (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

Datum Adjustment

All dynamic water levels are measured by a sensor that detects the distance to the water surface (e.g., a float, a surface piercing staff, a pressure or acoustic transducer, a laser or microwave ranging device, etc.). The measurement can be taken either downward from a point above the water – usually a fixed platform, but airplanes and satellites are also used) or upward from a point below the surface. No additional information is needed if only the relative variation in water level is required, such as for measurements of wave *heights* or tidal range. If two or more vertical measurements are to be compared, though, the *elevations* of the fixed points relative to a common datum are needed.

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

Typical datums used to establish vertical elevations in the marine environment are: Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Seal Level, (MSL), Mean Tide Level (MTL), Mean Low Water (MLW), Mean Lower Low Water (MLLW). All of these are local datums derived from statistical analysis of tidal measurements at that location, and all vary both spatially and temporally. In order to be considered a primary station, the time series must extend over a specific 19-year cycle that includes all of the principal harmonics of tidal fluctuations called a tidal epoch. The two most recent tidal epochs cover 1960-1978 and 1983-2001. Secondary stations are operated for much shorter periods, and phase and amplitude differences from another nearby station with longer records are calculated. These differences are used to predict times and heights of the high and low tides at these secondary sites, relative to the longer-term station, after the secondary gage is removed.

For many engineering applications, the local datums can be considered identical over a limited region, such as within St Joseph Bay, but they can not be assumed identical over tens of miles or between different bodies of water. The National Geodetic Vertical Datum (NGVD) was an attempt to provide a “fixed earth” datum, useable over continental scales that was adopted as a standard geodetic reference for heights. Numerous adjustments have been made since NGVD was originally established in 1929. Later, the North American Vertical Datum (NAVD 88) was calculated through simultaneous, least squares, minimum-constraint adjustment of Canadian-Mexican-United States leveling observations.

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. The times of the measured record and the reference station are also provided. The locations of the eight closest stations are shown on Figure 7. 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 are referenced to the Pensacola primary station, either directly or indirectly through the Port St. Joe Station. 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 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 provides output relative to MSL will require a conversion between the NGVD and NAVD and MSL in this area. Note that only four of the stations in Table 3 (in bold) have been referenced to both geodetic datums.

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 Pensacola; 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 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 this column are deceiving because of long term sea level rise, which affects not only MSL but MLLW, the zero for both columns.

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	

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, columns 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.

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**

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 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 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.

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	

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 8, 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.

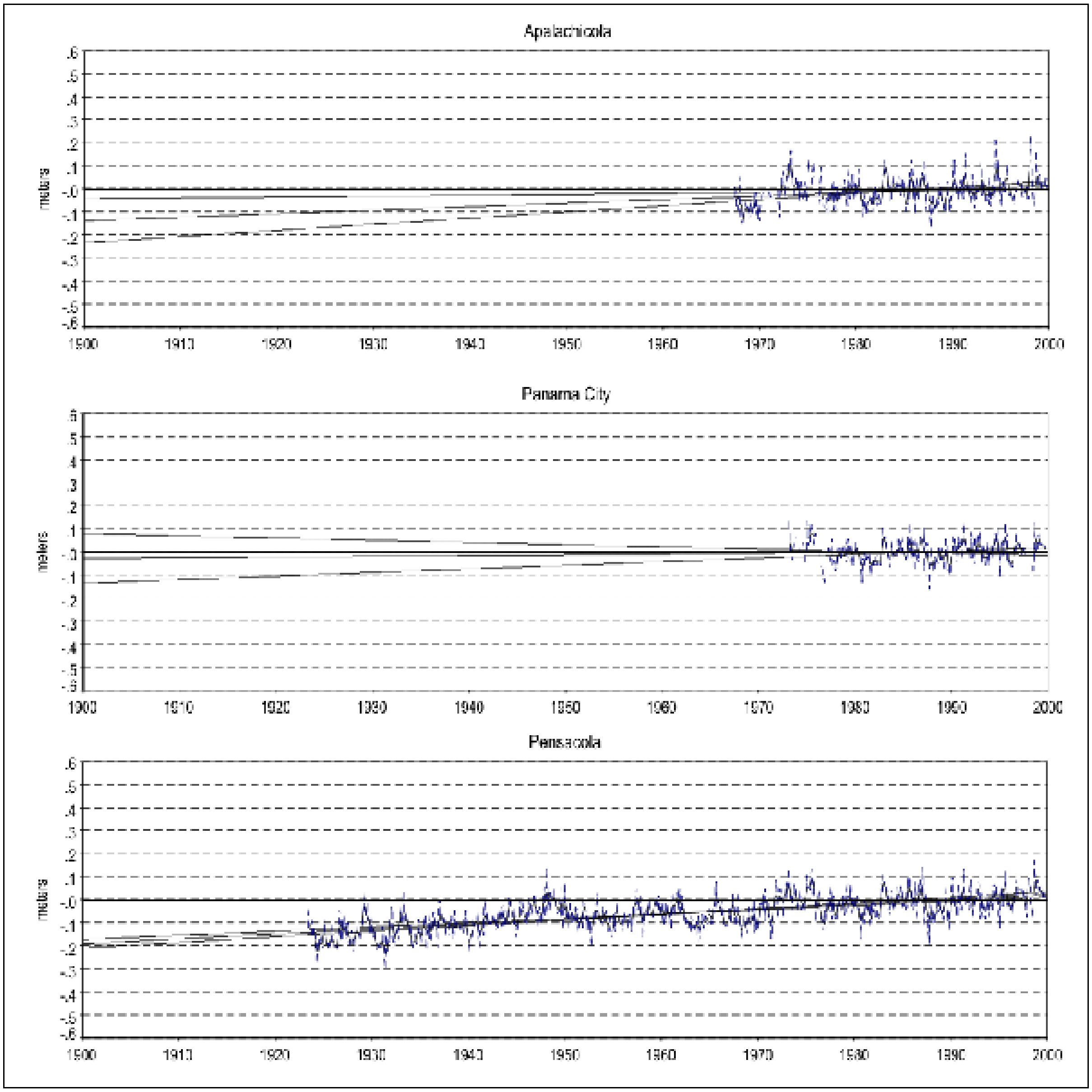

Figure 8 - Monthly Mean Seal Level Rise at Regional Tidal Stations

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 9 overlays the reduced elevation time series and Figure 10 shows the residual between the primary and redundant backup gages at Sites 2 and 3.

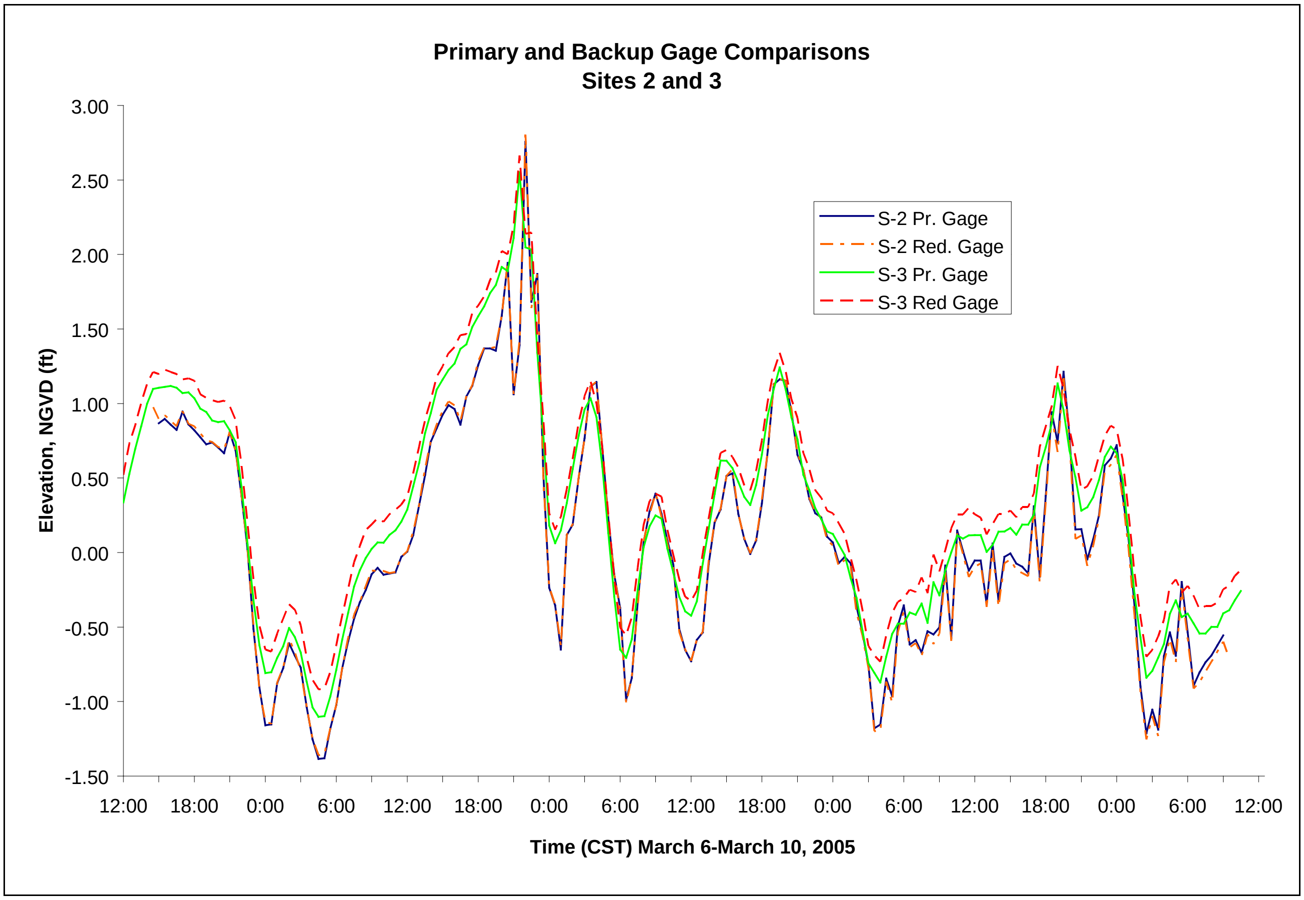

Figure 9 - Primary and Redundant Time Series, Sites 2 and 3

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.

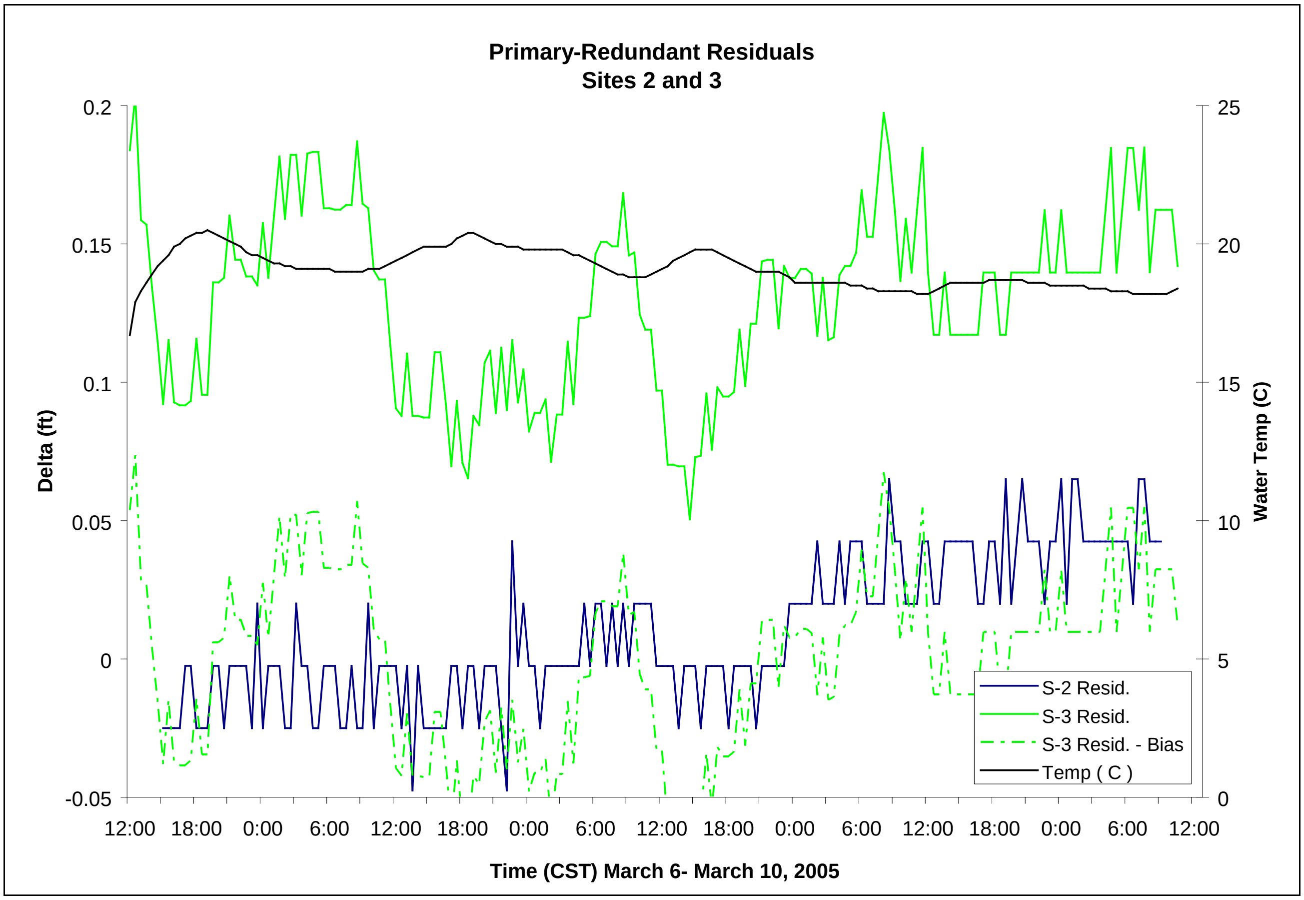

Figure 10 - Residuals at Sites 2 and 3

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

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 1- 2 in. 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 10 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 ± 0.05 ft.

Without two data sets to intercompare, the primary gage at Site 1 can only be compared to the predicted and measured ties in the vicinity. Figure 11 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.

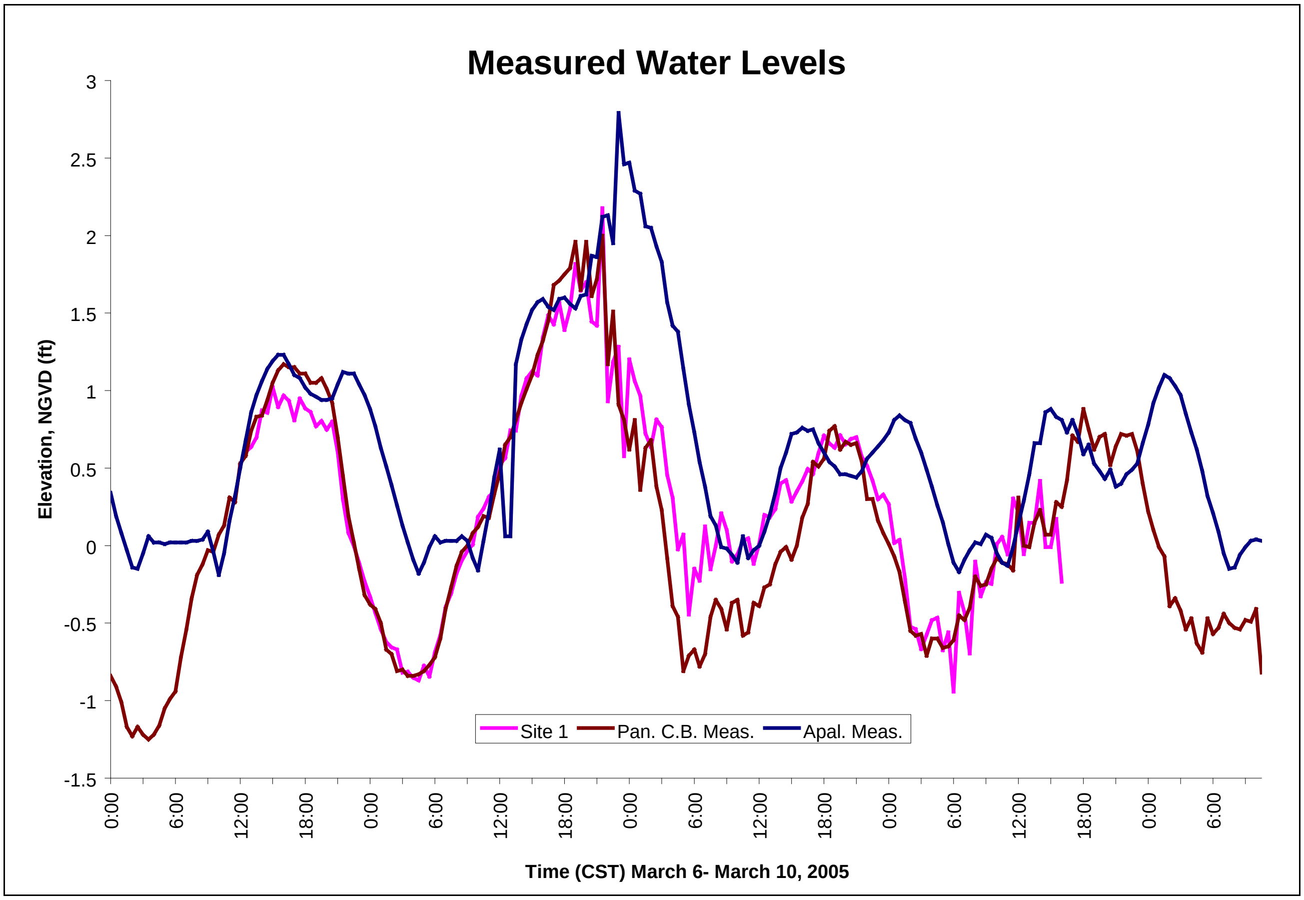

Figure 11 – Site 1 Time Series and Measured Tides at Panama City Beach and Apalachicola

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 12 plots the final qualified data from the 3 measurement sites.

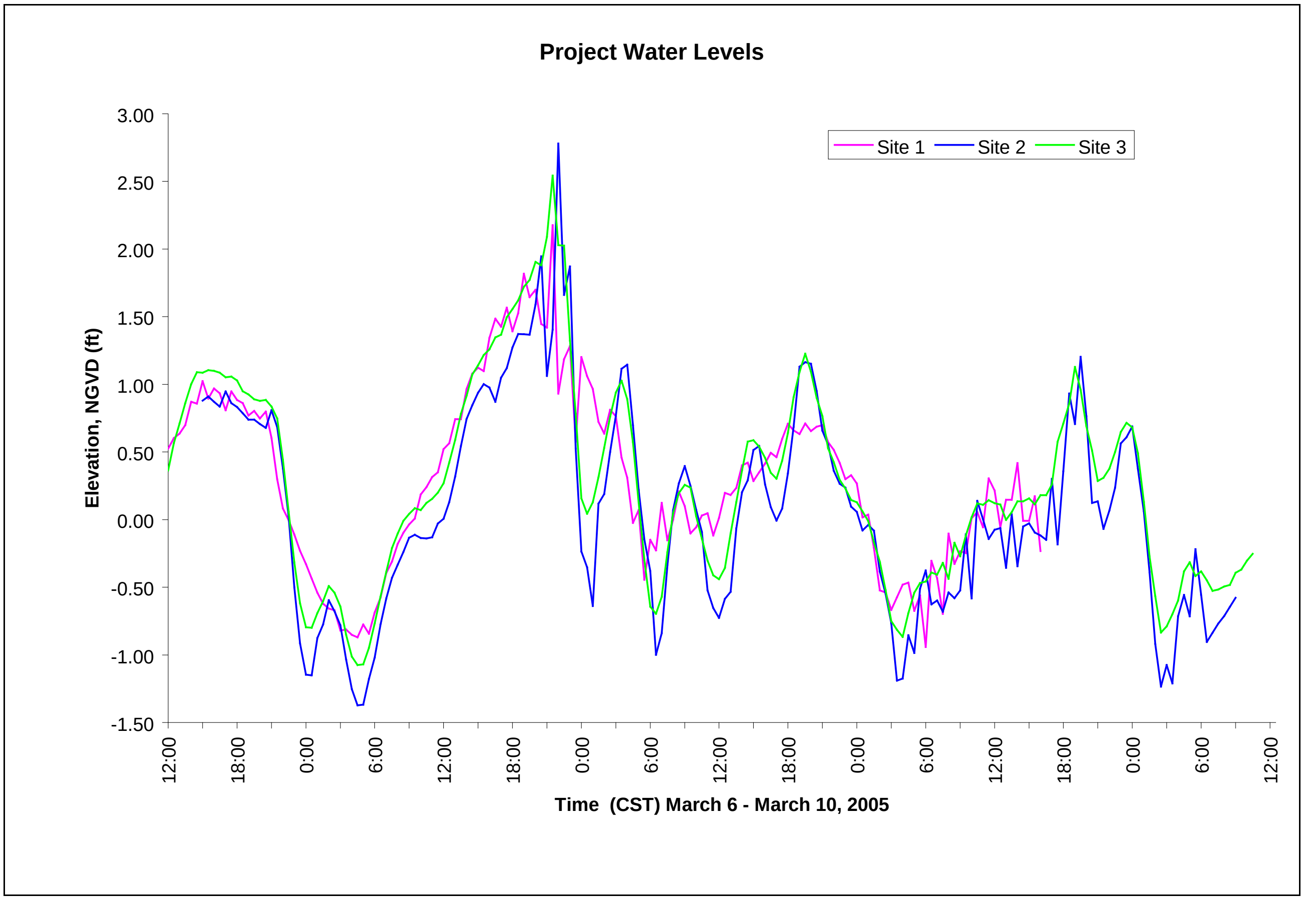

Figure 12 - Qualified Water Level Time Series at Sites 1, 2, & 3

IV. Discussion

The most noticeable 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 sec) and tidal periods (order of ½ 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), 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 ft, comparable with tidal amplitudes, but because they have shorter periods, 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 13 plots the Site 2 minus the Site 1 time series (black 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 14a, 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 (brown line, figure 14a). 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.

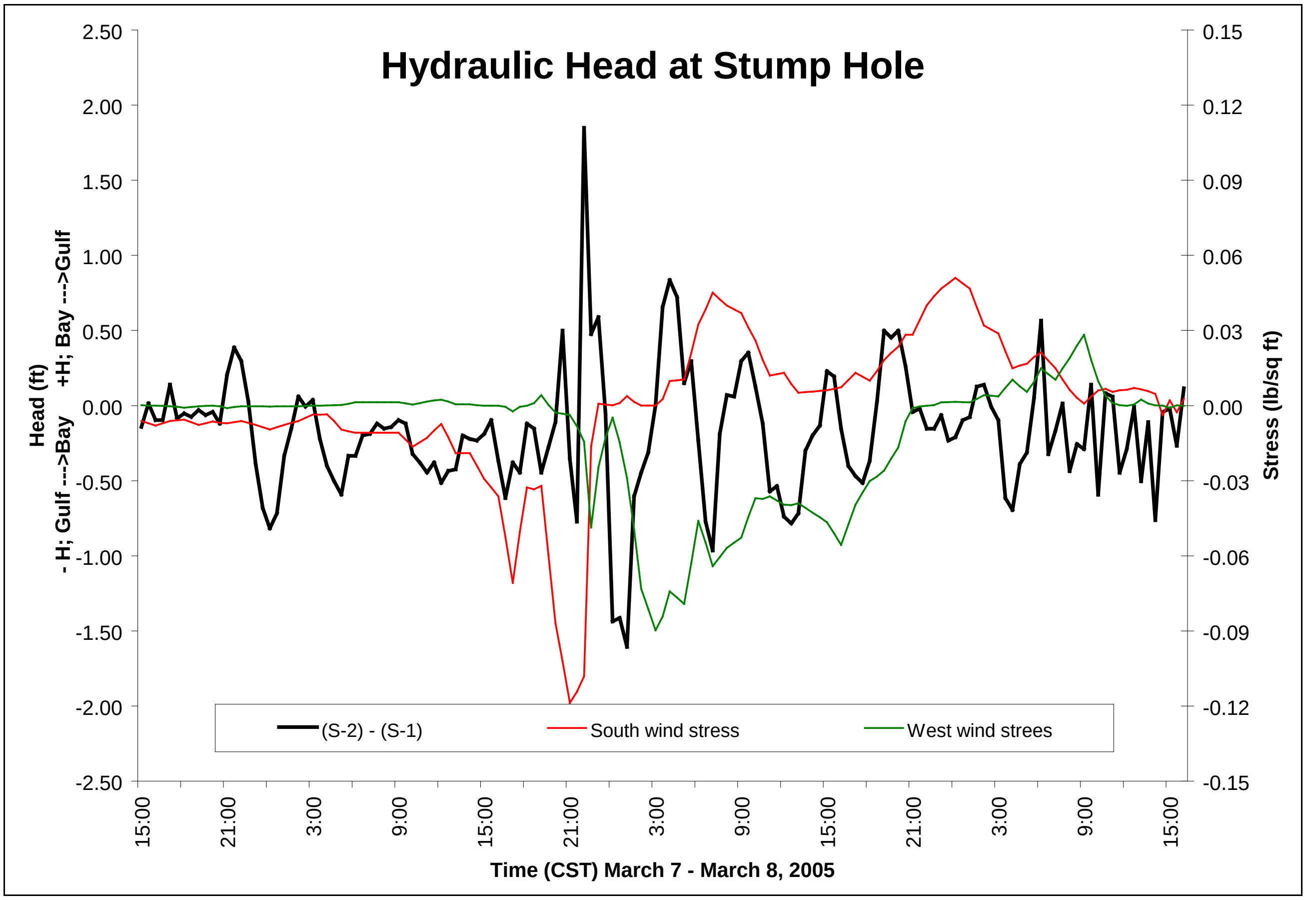

Figure 13 - Hydraulic Head at Stump Hole and Wind Stress During Deployment

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 vibratory 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 seich mode for a basin with these dimensions is 5,456 sec, so these two long waves will reinforce each other. 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 non-trivial currents through an inlet. Figure 14b also plots the predicted tides at West Pass and Port St Joe (sites 3 and 6, respectively, in Figure 7) 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.

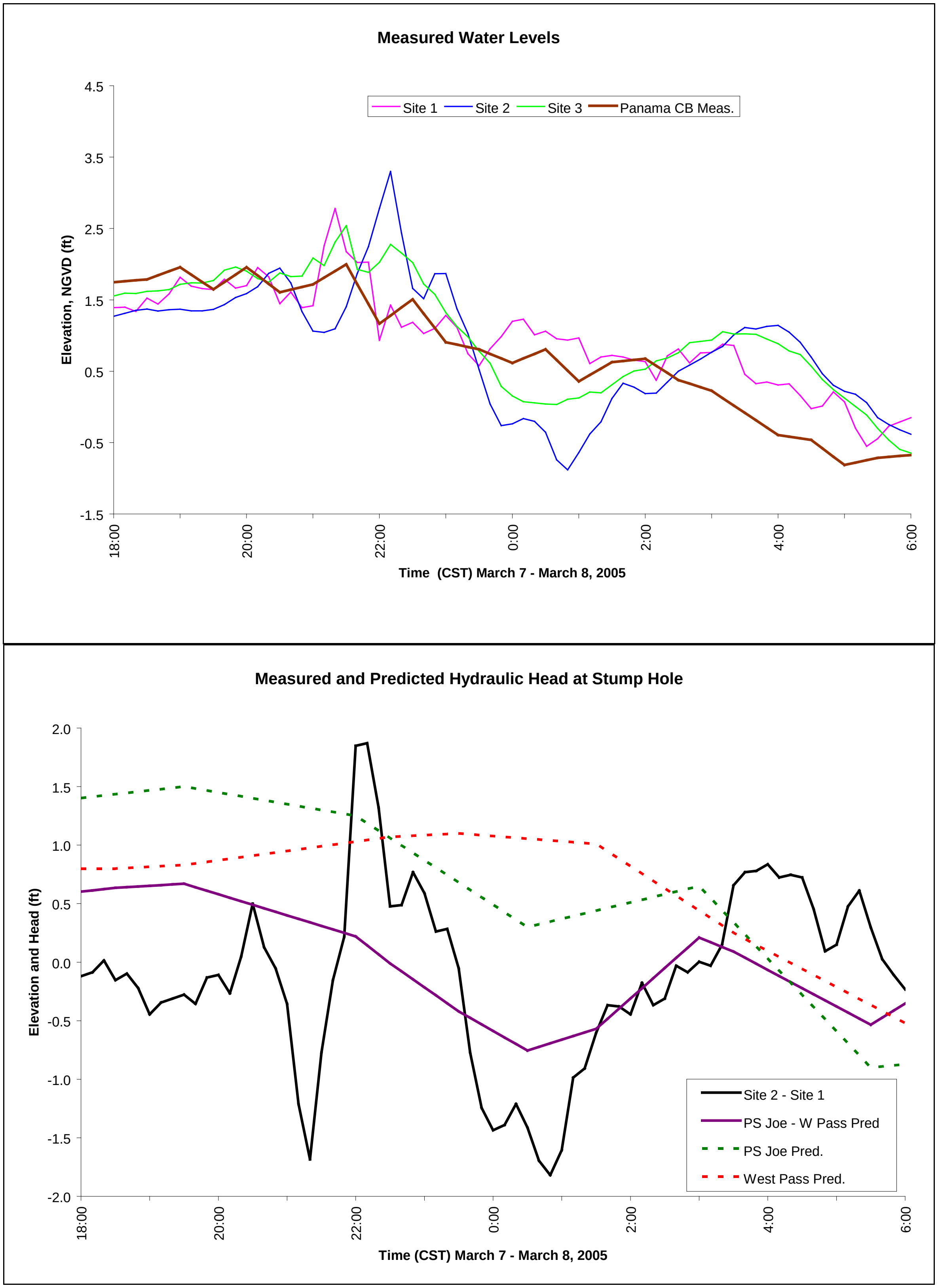

Figure 14a (top) - Measured Water Levels During Frontal Passage
Figure 14b (bottom) - Measured and Predicted Hydraulic Head During frontal Passage

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 15 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 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.

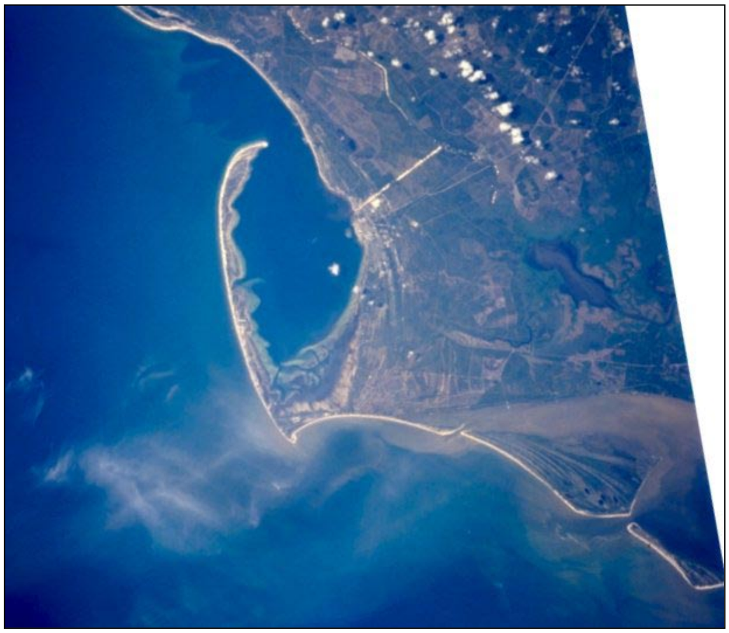

Figure 15 - Satellite Image Showing Discharge of Sediment-laden Water from Apalachicola Bay into the Gulf Offshore of Stump Hole

V. Summary

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.

Recommendations

Any model intended to simulate and accurately predict the hydraulics of this system on short time scales should consider meteorological and wind wave induced long waves.

Empirical rules relating equilibrium inlet cross sections to tidal prisms should be reliable for the long-term fate of the inlet, but may not be a reliable predictor of transient effects.

Investigations into the impacts of a breach at Stump Hole should include water quality modeling and the effects of increased sediment loads on the Bay.

Any protective measures to prevent or postpone a breach should address both sides of the roadway. Under storm conditions, a breach is as likely to develop from the Bay side as from the Gulf side.

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Appendix A

Water Level Gage Specifications

Description: Coastal's MacroTide and MacroTide+ record pressure levels in aquatic environments for tidal measurements using either an ICS Strain Gauge Pressure Sensor or a high-precision Paroscientific Digiquartz Sensor.

Capacity: 200K standard
Optional (Compact Flash Cards): 8MB, 16MB, etc.

Housing: **Diameter** – 5.5 in.
Length – 14 in. (including handle)
Weight – 15 lbs. in air
Material – Stainless steel and UHMW plastic housing
MacroTide+ length is 15.5 in., weight is 17 lbs. in air

Power: User replaceable standard alkaline D cells

Interface: *Wizard* IBM PC compatible software
ASCII data files in engineering units

User controlled sampling parameters and sensor functions

Clock: Solid state real time, accuracy one minute per year

Standard: **Pressure, Standard** – ICS Strain Gauge
Temperature, Internal – YSI Thermister

Coastal MacroTide
(exterior-above, interior-below)

Function	Sensor (*optional)	Range	Accuracy	Resolution	Units
Pressure, Standard	IC Sensors Strain Gauge, piezoresistive	30, 50, 100, 250	0.1%	12 bit	psia
Temperature	Internal YSI Thermister	-5° to 35°	0.1°	.02 typ	°C

Appendix B

Fixed Observation Stations

Station SGOF1 - Tyndall AFB Tower C (N4), FL

Owned and maintained by NOAA's National Data Buoy Center
C-MAN station
MARS payload
29.41 N 84.86 W (29°24'24" N 84°51'48" W)

Site elevation: 0.0 m above mean sea level
Air temp height: 35.1 m above site elevation
Anemometer height: 35.1 m above site elevation
Barometer elevation: 19.8 m above mean sea level

Parameters Measured

- Wind Direction (WDIR)
- Wind Speed (WSPD)
- Wind Gust (GST)
- Atmospheric Pressure (PRES)
- Pressure Tendency (PTDY)
- Air Temperature (ATMP)
- Water Temperature (WTMP)
- Dew Point (DEWP)

Appendix C

Gage Deployment Notes

Site 1
Northeastern pile of pile cluster, ~ 50 yards offshore
29º 40.158 N
85º 21.407 W; [150 ft at {cos 30 (6000)} ft/min = 0.0289 min long] ➔ 85º 21.436 W
Water depth ~ -5 ft MLLW
Deployed ~ 1030 (all times CST) March 6 2005
Gage No. 10215: Elevation, top of handle -3.70 ft NGVD 29.
Recovered Gage No. 10215 ~ 1610 March 9 2005

Site 2
Southeastern corner Fire Tower Pier, ~ 300 ft offshore
29º 41.221 N
85º 21.668 W
Water Depth ~ - 6 ft MLLW
Deployed ~ 1430 March 6 2005
Gage No. 10411 on South side: Elevation, top of handle = 3.84 – 9.00 = -5.16 ft, NGVD)
Gage No. ~ 10657 on North side; Elevation= 4.27 – 9.00 = -4.73 ft, NGVD)
Recovered both gages ~ 0930 March 10 2005

Site 3
Inside of T at outer end of pier of Wind Mark Pier # 3 (southernmost of 3), ~ 200 ft offshore
29º 50.788 N
85º 20.039 W
Water Depth ~ - 3 ft MLLW
Deployed ~ 0900 March 6 2005
Gage No. 10212 on South side: Elevation, top of handle -2.02 NGVD 29
Gage No. 10222 on North side: Elevation -1.97 NGVD
Recovered both gages ~ 1100 March 10 2005

Distance from top of handle to top of pressure case (zero pressure point for the transducer, according to manufacturer) is 2 11/16" = 0.22396 ft, or 0.22 ft.

To correct measured data

Water Level elevation (NGVD) = Depth (gage) + {gage elev. (NGVD) – 0.22}
Note: Gage elev. is always a neg. no.