LARGE AMPLITUDE SEICHE IN ST. JOSEPH BAY, FL - OBSERVATIONS AND IMPLICATIONS

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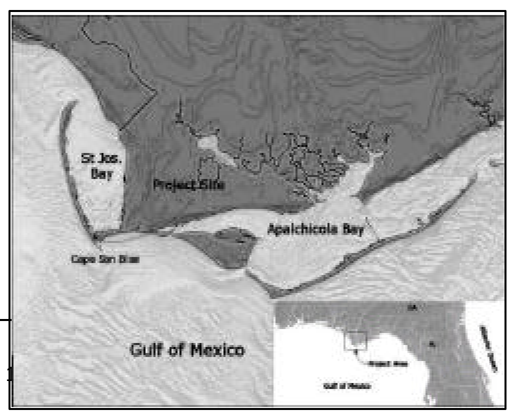
St Joseph Bay, FL is on the northern shore of the Gulf of Mexico. It is formed by St. Joseph Peninsula, a curving, rapidly - eroding sand spit with the prominent Cape San Blas located at its southern tip. A section of the peninsula at a site called Stump Hole will likely breach in the near future. The new inlet will bisect the only road available to peninsula residents and visitors to St Joseph Peninsula State Park. Tidal hydraulic data were collected to identify and quantify the hydrodynamic processes governing the bay system and to calibrate and verify a numerical hydrodynamic circulation model (ADCIRC) for predicting the long-term fate of a new inlet. 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, coincidentally, 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 were calculated from analysis of regional spatial and temporal trends in MSL. The tidal circulation model predicted that an inlet, once formed, would be stable over the long term under tidal forcing alone. However, measurements showed that sub-tidal long wave energy (associated with the passage of the cold front) occurred with periods near the resonant seiche modes of the bay. This could have significant impacts on the flow regime through any new inlet over short time scales. 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 much larger hydraulic head across Stump Hole than tidal analysis alone would predict. Potential impacts include short term scour 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 the relatively clear waters of St Joseph Bay.

BACKGROUND

St Joseph Bay, FL is located on the northern shore of the Gulf of Mexico situated between the mainland and St. Joseph Peninsula (Figure 1). The bay entrance opens to the northwest and is



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sheltered from direct offshore wave energy. The tide in St Joseph Bay is diurnal with a mean range of about 1.5 ft. Tides in the Gulf of Mexico to the **Figure 1. Map of region & study area**

east of Cape San Blas are mixed, while those west of the Cape are predominantly diurnal (FDEP 2000). 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).

Measured water level time series were needed at various sites in and **Figure 2. Aerial photo of Stump Hole** around the bay to understand the hydrodynamic processes governing the bay and to calibrate and verify a numerical hydrodynamic circulation model (ADCIRC) of the system (Chen, 2005). 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 most important tidal 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 the bay (Figure 3).

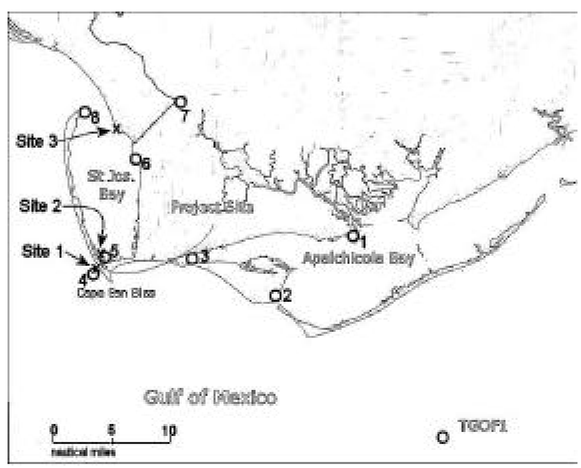


Figure 3. Gages sites (x's) & local tide/met stations (o's)

Water level time series were measured at each site using self contained water level gages with internal battery power and solid state memory. The gages were programmed to measure and record 900 2-Hz samples (7.5 min) of ambient water pressure (absolute) and temperature every 10 min, which allowed a 2-week, battery-limited deployment.

The goal of the deployment was to obtain a minimum of 3 days of data over a spring tidal cycle. Figure 4a shows the predicted tide at Port St Joe inside St Joseph Bay, and Figure 4b shows the measured winds at SGOF1 (see Figure 3), a meteorological station located on an offshore platform about 20 nm SSE of Cape San Blas, during the first two weeks of March, 2005. *(A 24-hour data gap beginning 0900 on March 9 was filled with data from Apalachicola Airport.)* The deployment interval is highlighted in Figure 4a.

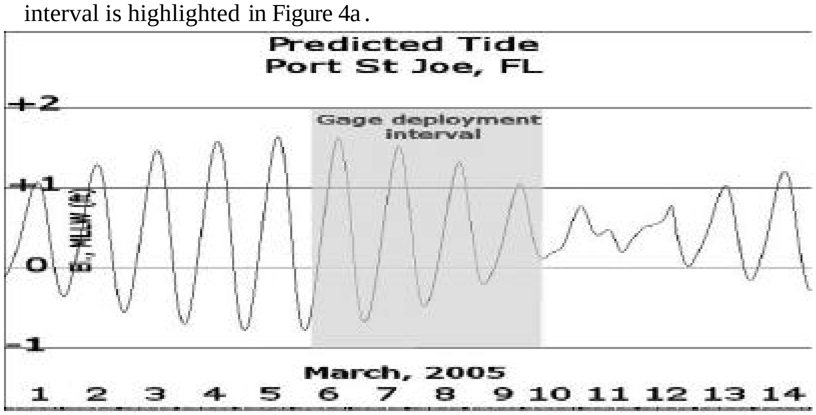
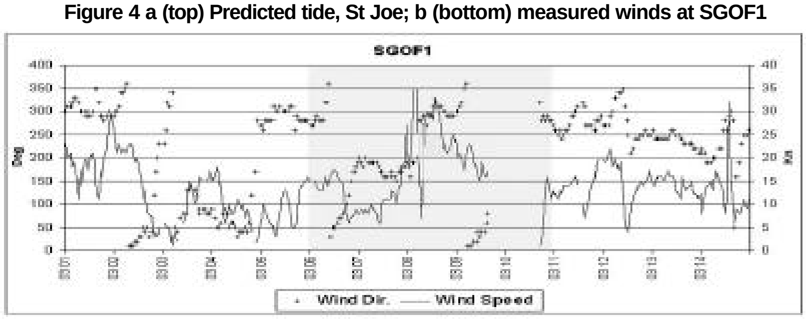


Figure 4 a (top) Predicted tide, St Joe; b (bottom) measured winds at SGOF1



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 to above 12 kt nearly continuously for the next week, including the third front in two weeks

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. 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 º C at all sites - but salinity had to be assumed at constant S of 35 ppt (standard sea water). 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 may have reduced salinity at Site 2 marginally, 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

Before the project data set could be qualified or used to validate numerical models, conversions between various vertical datums had to be identified. Before the 1980's, the National Ocean Service (NOS) only referenced selected tide station benchmarks, and their measured tidal datums as established at primary stations during the 1960-1978 tidal epoch, to NGVD. More recently, NOS has referenced 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.

Table 1 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 fluctuations in NGVD or NAVD should actually be the change in local MLLW from station to station. Note that only four of the stations (bolded) were referenced to both geodetic datums; only Pensacola has two full tidal epochs.

Table 1. Tidal and Geodetic Datums of Regional Tidal Stations

Station; Epoch	*Map #*	*Length (yr) Recorded*	*MLLW*	*MLW*	*NGVD*	*NAVD*	MSL	*MTL*	*MHW*	*MHHW*
Apalachicola 1960-1978	1	7 1/79-12/85	0	0.41	0.35			0.97	1.52	1.66
Apalachicola 1983-2001	1	19 1/83-12/01	0	0.40		0.76	.91	0.95	1.51	1.61
West Pass 1960-1978	2	0.2 9.83-3/84	0	0.23				0.81	1.38	1.49
Indian Pass 1960-1978	3	0.2 9/83-3/84	0	0.25				0.79	1.33	1.39
Cape S Blas 1960-1978	4	0.6 3/78-978	0	0.00				0.68	1.37	1.39
Cape S Blas 1983-2001	4	0.3 10/77-1/78	0	0.09		0.76	0.74	0.74	1.38	1.44
R Hammock 1960-1978	5	.25 1/81-3/81	0	0.17				0.82	1.46	1.74
R Hammock 1983-2001	5	.25 1/81-3/81	0	0.15		0.46	0.83		1.43	1.71
Port St Joe 1960-1978	6	1 1/76-12/76	0	0.22				0.79	1.37	1.67
Port St Joe 1983-2001	6	1 1/76-12/76	0	0.20		0.82	0.82	0.78	1.35	1.65
White City 1960-1978	7	0.5 12/77-5/78	0	0.09	-0.31			0.52	0.95	1.03
White City 1983-2001	7	0.5 12/77-5/78	0	0.10	-	0.02	0.53	0.50	0.91	0.97
St Joe Point 1960-1978	8	0.1 1/76	0	0.10				0.68	1.26	1.56
St Joe Point 1983-2001	8	0.1 1/76	0	0.09		0.78	0.76	0.67	1.25	1.55
Pan. City 1960-1978	NA	9 '74 – '84	0	0.05	0.21			0.67	1.29	1.37
Pan. City 1983-2001	NA	18 1/83-12/01	0	0.05		0.56	0.67	0.67	1.30	1.34
Pensacola 1960-1978	NA	19 '61-'79	0	0.04	0.26			0.64	1.23	1.27
Pensacola 1960-1978	NA	19 1/83-12/01	0	0.03		0.32	0.62	0.66	1.23	1.26

Statistics were calculated for the two epochs at the nearest station, Apalachicola, and additional reference points in the record, such as Lowest

Observed and Highest Observed water levels ever recorded were used to investigate long term sea level rise, which affects not only MSL but MLLW . To evaluate the suitability of the resulting temporal adjustments at the 3 project measurement sites, the regional spatial trends were calculated as a function of distance from the project site. Table 2 summarizes the calculated linear trend of these parameters at three distant sites as their variation from Apalachicola's values, per nautical mile (nm) distance from Apalachicola.

The first four rows of Table 2 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 aren't fixed relative to each other (column 5).

Values of the correlations and trends at the Project measurement sites (all three measurement sites are very near the same longitude) using linear interpolation from Apalachicola are listed next. Row 6 uses the trend between Apalachicola and Panama City and row 7 uses 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.

Table 2. Linear spatial trends of datums & datum differences for regional tidal stations and the project site.

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: Average	0.1		0.5		0.7	

Additional quality assurance tests were conducted on the data, including comparisons between the primary and redundant gages and both primary and redundant gages with adjacent tide gages, to verify that the data reduction, datum adjustments, and surveying errors were all within acceptable limits. Final uncertainty of the measured time series is on the order of $\pm$ 0.05 ft. Figure 5 plots the final qualified data from the 3 measurement sites.

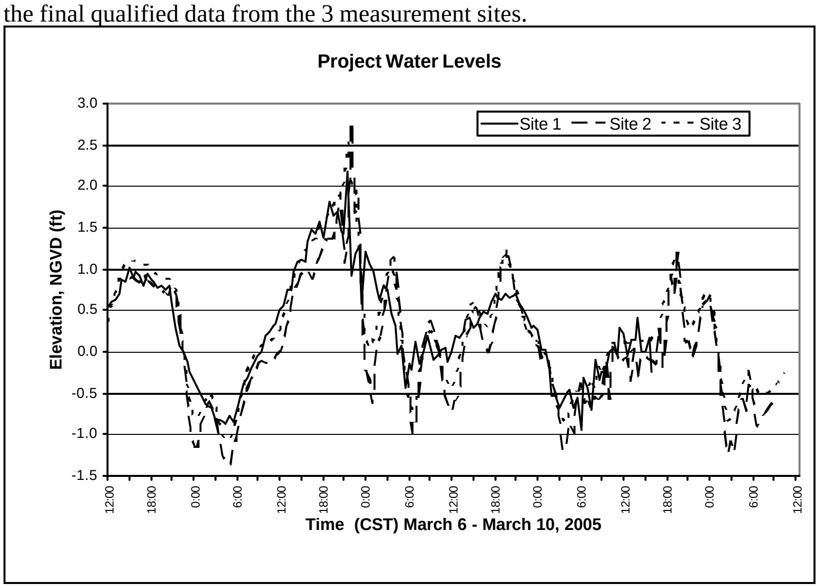


Figure 5. Plot of the qualified water level time series at Sites 1,2, & 3

DISCUSSION

A notable aspect of the signal at all three project sites, as well as at Panama City Beach, is the prevalence of large 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 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. The horizontal velocities associated with even low amplitude 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. 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 at different locations. For the largest 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 at Stump Hole. Figure 6 plots the Site 2 minus the Site 1 time series (solid line) along with the dominant factors affecting it: wind and tide.

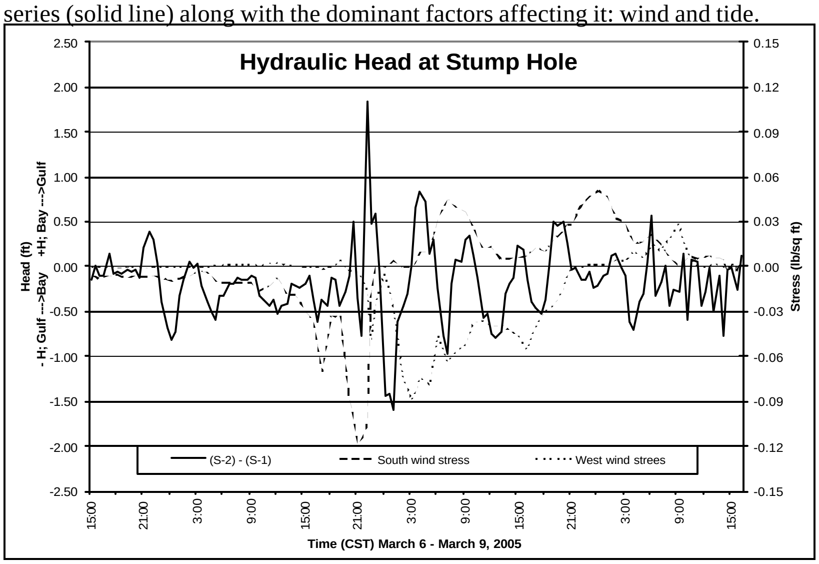


Figure 6 – Plot of the measured hydraulic head at Stump Hole with wind stress components during deployment.

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 "zoomed in" plots of that period (Figures 7a, b).

A strong south wind (causing northerly, or negative south stress) peaks around 2100, and 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 7a). Meanwhile,

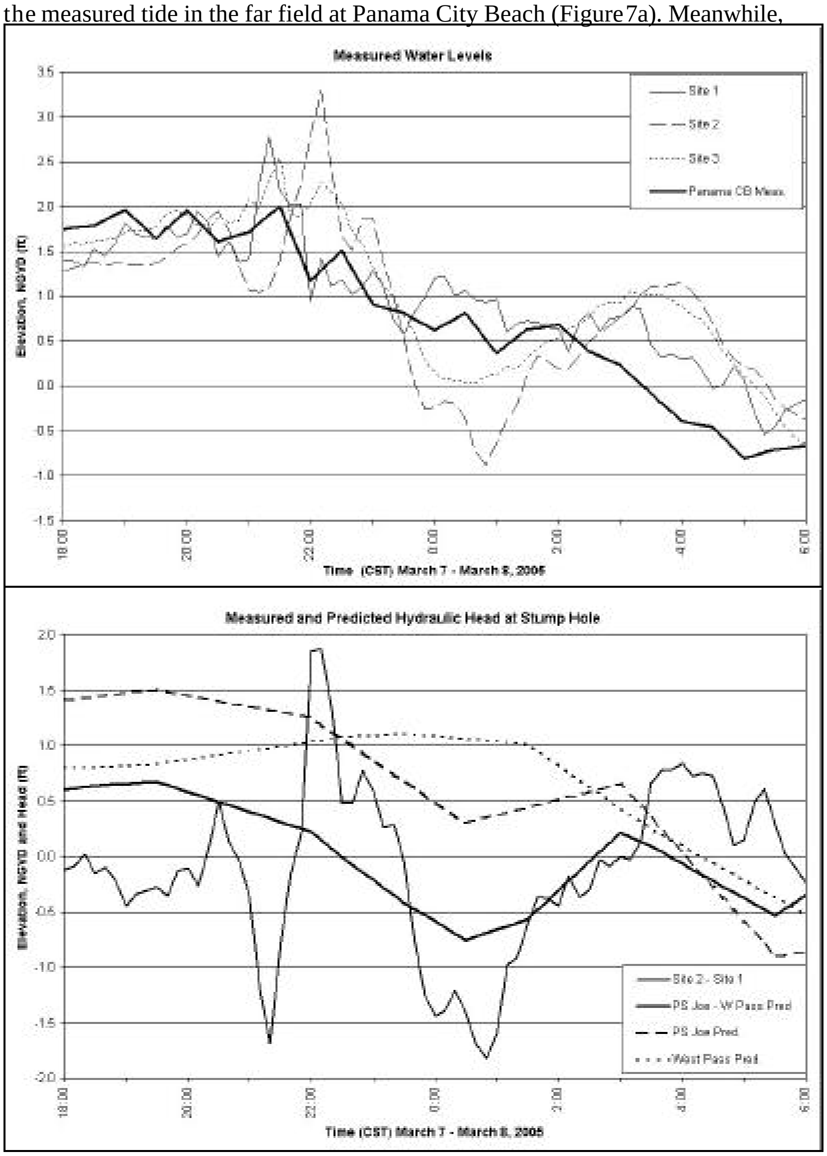


Figure 7 - (a) Measured water levels during the frontal passage; (b) the measured and predicted hydraulic head during the frontal passage.

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 7b 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

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 long term, hydraulically 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 under tidal forcing. 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 8 is a satellite image from April 1994. The sediment-laden plume from

Figure 8. Satellite image showing discharge of sediment-laden water from Apalachicola Bay into the Gulf of Mexico directly offshore of Stump Hole.

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. The existing grass beds on the bottom of the bay depend upon adequate sunlight, and a significant increase in turbidity could threaten those grass beds - and the local fisheries that depend on their productivity.

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, increasing turbidity in the bay.

ACKNOWLEDGEMENTS

The study reported in this paper was conducted for the Florida Department of Transportation under subcontract to Volkert & Associates, Inc, of Mobile AL Feedback from Dr. Scott Douglas with the University of South Alabama was gratefully accepted. The author also wishes to recognize the knowledgeable watermen in the area who provided logistic support and keen insights into the natural processes of St Joseph Bay.

REFERENCES

Chen, Q. Jim, "Hydrodynamic Modeling of St. Joseph Bay and Breach Stability Analysis at Stump Hole, FL," Final Report Prepared for Volkert & Associates, Mobile, AL, June, 2005.

Coastal America, 1996, "Coastal Restoration and Protection," Coastal America Technology Transfer Report - January 1996, http://www.coastalamerica.gov

Florida Department of Environmental Protection, Bureau of Survey and Mapping, 2000, "Type of Tide," revised 12/14/2000, http://data.labins.org/2003/SurveyData/WaterBoundary/MHW/documents/2typeoftide.pdf

McGehee, D., 2006, "Results of a Study of Water Levels in St Joseph Bay, FL," Revised Final Report Prepared for Volkert & Associates, Mobile, AL, March, 2006

McGehee, D. 1991. "Measured Response of Moored Ship to Long Period Waves at Los Angeles and Long Beach Harbors," *Bulletin of the Permanent International Association of Navigation Congresses,* Brussels, Belgium, Winter 1991.

McGehee, D. 1991. "Effects of Reflective Walls in Harbors - A Case Study," CETN III-44, US Army Engineer Waterways Experiment Station, Vicksburg, MS, Sept. 1991.

National Ocean Service, 2005, Center for Operational Oceanographic Products and Services (various web pages), http://co-ops.nos.noaa.gov/

Zervas, Chris, 2001, "Sea Level Variations Of The United States 1854-1999" NOAA Technical Report NOS CO-OPS 36, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, July, 2001, http:// www.co-ops.nos.noaa.gov/publications/techrpt36doc.pdf

KEYWORDS – ICCE 2006

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Abstract number 1999

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