piles) on the island as a primary strategy for protection and oil containment: the first to prevent complete overwashing during a weak tropical storm, and the second for containment on the beachface under typical conditions. At the time, a means of stemming the oil leak was unavailable, a growing slick of surface oil had begun its translation toward the north-central gulf coast, and the forecast of an active hurricane season suggested that the island's west end could potentially be covered in oil during the next overwash event.

The first protective sand barrier/pile was constructed just south of Bienville Boulevard extending from St. Stephens Street to the public park on the west end, a distance of approximately 4 km. It was completed in several days as a stopgap measure to prevent a complete overtopping event. It was not extended across roads or driveways but additional sand was placed near those gaps with the intent that should oil start to wash across the island, bulldozers could close the gaps fairly quickly. That sand barrier pile initially had a height of 2 to 3 m above grade (thus the crest elevation was typically +3.5 to +4.5 m NAVD). The width of the base of the pile was controlled mainly by the angle of repose and varied from 5 to 7 m. The contractor was instructed to not smooth the surfaces but just dump it to "make it look like the Rocky Mountains."

Guidance provided in Hallermeier and Rhoades (1988) was used to determine the amount of sand in this first (northern) sand barrier/pile. The initial volume density of the northern sand barrier afforded protection against a storm having a recurrence interval of roughly 10 years. It was subsequently expanded with placement of more sand, where there was room for expansion amongst the existing houses, to increase the level of protection to a 20-year storm event.

Construction of a second, southern, protective sand barrier/pile commenced shortly after initial construction of the northern pile was completed. The second, southern sand pile was placed on the beach at or near the highest elevation (the existing storm berm) of the subaerial beach with the goal of containing the oil on the beachface. It was originally envisioned that this small pile of sand would likely be eroded in the next high tide event. However, due to the mildness of the winds and waves, and the addition of more sand by the contractor, this southern sand barrier/pile survived along most of the island for the summer. Approximately 267,000 m^3 of sand was used in the construction of the two protective sand barriers, and placed on the island between the months of May and July 2010.

Results. Oil was contained successfully on the beachface throughout the summer and fall by the second, southern, sand barrier/pile. Regular beach patrols quickly removed tarballs and emulsifications. The summer and fall of 2010 was a relatively mild period with natural, seasonal, beach accretion south of the southern sand barrier.

It should be noted however, that neighboring beach communities that opted to forego any beach profile manipulation had a much more serious oil problem. There were a few days in the summer of 2010 when storms raised the Gulf sea level over the natural berm elevations, but not the manipulated profile on Dauphin Island, and oil was deposited across 20 to 30 meters of beach width in the neighboring beach communities. These photographs, of extensive black oil deposited on the native white beaches, were broadcast nationally and contributed to the temporary collapse of the beach tourism economy. The cleanup of these neighboring oiled beaches also included excavation and mechanical sieving of the top 1 m of beach material. Dauphin Island avoided these problems in large part because of the beach profile manipulations described here.

The elevation of the second, southern sand barrier/pile was reduced in the winter of 2010-2011 after the oil spill was contained and the threat of large surface oil slicks washing ashore was gone. The sand in that barrier, essentially a sand pile along the beach berm crest, was sifted and redistributed into a much flatter, more naturally-shaped beach berm. Figure 4 shows a comparison of photos of this feature during and one year after placement.

The first, northern sand barrier/pile remains today and the Town has decided to maintain it as a sand dune. It was planted with native sand dune species in the summer of 2010 with the goal of stabilizing the sand. The vegetation has survived (see Figures 5 – 6), and six months of weathering has resulted in a much more natural looking feature.

Figure 4. Photos taken of the frontal sand barrier on Dauphin Island (a) in May 2010 during placement, and (b) May 2011 one year after placement.

Figure 5. Photos taken of the initial, larger roadside sand barrier on Dauphin Island (a) in May 2010 during placement, and (b) May 2011 one year after placement.

Figure 6. Photos taken of the initial, larger roadside sand barrier on Dauphin Island (a) in May 2010 during placement, and (b) May 2011 one year after placement.

Obstacles. A number of issues were encountered in the construction of these sand barrier/pile features that were addressed with what might be called "incremental field engineering." Siting issues, homeowner concerns, overhead utilities clearances, water and sewer infrastructure, fire hydrants, and the availability of suitable fill material all dictated an immediate design modification at one time or another. Regular communication and coordination with the US Fish and Wildlife Service was a necessity, particularly in light of premature turtle activity in the area. Routine morning patrol volunteers searched the beachface for turtle crawls and any other signs of turtle activity.

BREACH CLOSURE: KATRINA CUT

Background. Due to its relatively narrow width and low elevation, the western end of Dauphin Island has been overtopped and breached many times in the past 160 years of well-documented history. Over that same period of time, the western end of the island has actually migrated northward one entire island's width. In September 2004, Hurricane Ivan's storm surge and waves created multiple breaches through the undeveloped western portion of the island (Froede, 2006). Such breaches had historically healed through wave-driven longshore sand transport, but Hurricane Katrina in 2005 widened and stabilized the breach, growing to more than 2.5 km in width with an average depth of 2 m during the 5 years that followed (Froede, 2008). The breach was given the moniker Katrina Cut by the locals (see Figures 1 and 7).

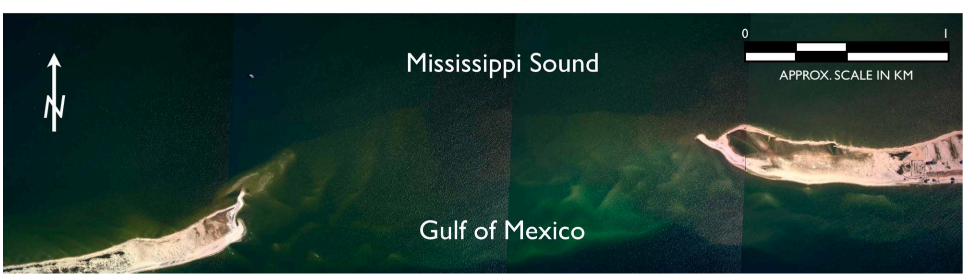

Figure 7. Tiled aerial imagery of Katrina Cut (Dauphin Island, AL) taken on May 9, 2010.

For a number of reasons, including concern over a declining oyster population in Mississippi Sound thought to be partially due to increased salinity levels as a result of Katrina Cut, many have proposed filling the breach and fusing the two ends of Dauphin Island back together. This potential project was given substantial relevance during the oil spill, as blocking the breach would relieve one point of ingress for surface oils into the sensitive habitats of Mississippi Sound and Mobile Bay.

Strategy. The strategy adopted and implemented for closing Katrina Cut was to use a combination of rock and sand fill to create a sand-tight rubble mound structure in the 2.5 km gap. The project was designed and constructed by a local engineering firm under an emergency permit issued by the U.S. Army Corps of Engineers, Mobile District. Project construction began in early July 2010, and a final inspection was completed in April 2011. Under the existing emergency permit, the structure must be removed by June 2011. A permanent permit is being sought for the project.

Results. A sketch of the structure cross-section is provided in Figure 8. The rubble mound structure was built in stages: two, parallel internal sections were built first; good quality sand fill from a nearby borrow area was then pumped in between the rock structures and sealed within a geotextile fabric; finally, a nearly 1-m-thick layer of armor stone was applied and choked at the crest with a 0.3-m-thick layer of smaller stone. Placing 60 – 90 m of rock per day, the original construction timeline called for completion in 100 days. The two internal sections were completed in early November 2010, effectively sealing the breach.

The crest of the structure is approximately +2.4 m NAVD. The armor stone is specified as an ALDOT Class 5 riprap, which has a median weight of 454 kg (1000 lbs). Assuming some nominal values and considering the 2:1 structure side slopes, the median weight of the armor stone should accommodate wave heights up to 1.5 m according to Hudson's equation (USACE, 1984). The structure base is 26 m wide in some locations and rests on a Tensar BX 1200 geogrid. A total of nearly 215,000 metric tons of rock were used to build this structure. Other structure quantities include: 54,000 m^2 of geogrid; 47,000 m^2 of geotextile fabric; 100,000 metric tons of armor stone; 20,000 m^3 of sand fill; 108,000 metric tons of stone for the two internal structures; and 7,000 metric tons of #57 stone to choke the structure crest. A Type III floating turbidity barrier was used throughout the project.

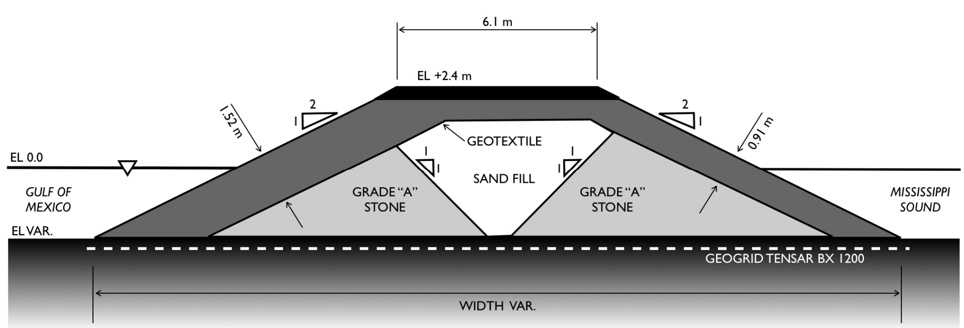

Figure 8. General cross-section sketch of the rubble mound structure constructed to close Katrina Cut.

TIDAL INLET CLOSURE: LITTLE LAGOON PASS

Background. Little Lagoon is a 9 km^2 estuary separated from the Gulf of Mexico by the beaches of Gulf Shores (see Figure 1). The estuary has a large freshwater input from a nearby freshwater lake and serves as an aquatic nursery for octopus, squid, speckled trout and flounder. Little Lagoon has a very small tidal connection to the Gulf of Mexico that is maintained through regular dredging to ensure adequate flushing and provide a navigable waterway for those living on the lagoon. The tidal connection, called Little Lagoon Pass, is stabilized by a combination of steel sheetpile and reinforced concrete seawall. The width of the pass as it cuts across the beach is only about 15 m.

Strategy. Although the tidal connection of Little Lagoon is highly restricted, officials in the City of Gulf Shores were concerned about the potential environmental impacts and the difficulty of cleaning large amounts of oil from within the estuary. City officials elected to plug the tidal pass with sand rather than battle what may have been a continuous tending of ocean boom on the gulf side of the pass. The pass was initially plugged in early May using over 4500 m^3 of sand fill, as shown in Figure 9.

Figure 9. Aerial photo of the sand barrier in Little Lagoon Pass. The estuary is in the foreground while the Gulf of Mexico is in the background. The road visible is West Beach Boulevard, AL 182. Photo courtesy: Mark Acreman, City of Gulf Shores.

Results. City officials were very pleased with their decision to plug the pass. The estuary did not receive any reports of visible oiling with the barrier in place. Indeed, the barrier was installed prior to Baldwin County beaches receiving their first major oiling. As seen in Figure 9, some boom was deployed on the gulf side of the sand barrier to train oil to an extraction location. The final restoration of Little Lagoon Pass was initiated in February 2011.

Obstacles. Precipitation, the seasonal groundwater table, and inflows from a nearby freshwater lake primarily control water levels in Little Lagoon owing to the small 0.4 m tide range in the area. As a result, the sand barrier was mechanically breached in August 2010 to relieve an accumulation of water due to precipitation that increased lagoon waterlevels by about 0.5 m above their normal levels. An earlier breaching was conducted during an ebb tide in July 2010 to allow flushing of the estuary. A secondary diversion channel was excavated through the subaerial beach in an “S” shape to control the exchange of estuary and gulf water during these mechanical breaches.

CONTAINMENT BOOM

Background. Perdido Pass, located in Orange Beach, Alabama, provides a tidal connection and navigable waterway between the Gulf of Mexico, Perdido Bay, Wolf Bay, and the Gulf Intracoastal Waterway (see Figure 1). The pass itself is stabilized with rubble mound jetties and reinforced concrete seawalls. A fixed bridge carries Perdido Beach Boulevard (AL 182) over the pass to Escambia County, Florida immediately to the east. It is not uncommon to have boat traffic numbering in the thousands in this pass on a single day during tourist and sportfishing seasons. The pass itself is a dynamic place: tidal currents in the pass routinely exceed 4 m/s (8 kt).

On June 9, 2010, a concentrated slick of surface oil entered Perdido Pass on a flood tide, subsequently soiling shoreline as much as 5 km away from the pass. Hundreds of meters of existing boom deployed to waterways north of the pass were oil-laden. Two days later, waters near Perdido Pass were closed to all recreational and commercial boat traffic not involved with oil response operations.

Strategy. An early idea for preventing another widespread oiling of the bays was to plug Perdido Pass with a large volume of rock and sand fill. For a number of reasons, navigation included, this plan was never implemented. Similarly, any complete closure of the pass would create a significant hardship for recreational and commercial boaters in the area, as well as reduce the flushing capacity of the tidal inlet. And due to the strong tidally induced flows through the pass (> 4 m/s), the deployment of standard ocean boom was not possible owing to its practical limitation of about 0.4 m/s (0.7 kt).

A local engineering firm was contracted to design, build, and install a boom system that would train surface oils to extraction locations while allowing for safe navigation through the pass. The plan called for nearly 1000 m of 1 m diameter steel dredge pipe to be filled with polystyrene foam to aid in flotation, and to be anchored with chains affixed to a number of 1 m diameter steel pipes driven into the seabed. A photo of the boom during construction is provided in Figure 10. The system also included a steel curtain and dampers affixed to the bottom of the floating pipe to capture and train oil entrained in the upper portion of the water column to extraction points.

Figure 10. Photo of the polystyrene foam-filled 1 m dredge pipe used as oil training boom in Perdido Pass, Alabama. The Gulf of Mexico is in the background and the image is shot looking toward the west-southwest. Orange ocean boom can be seen in the distance below the horizon. Photo courtesy: Phillip West, City of Orange Beach.

Results. Construction of the novel boom system began in mid-June 2010 and was completed in the first weeks of July 2010. The system sustained some minor damage from increased wave heights during Hurricane Alex prior to completion (H_s ~ 2 m, T_p ~ 10 s in 25 m of water south of Orange Beach). The boom system was disassembled on July 23, 2010 as a precaution ahead of a strengthening Tropical Storm Bonnie in the Gulf of Mexico. Days later, the Macondo well was capped, and the infrequent presence of oil near the pass did not justify replacement of the system. The total project cost was about \$5.3 million USD, where \$4.8 million USD was used for construction, and the remaining for removal and disassembly. By comparison, the unit cost of ocean boom during the height of the oil spill crisis was approximately \$330/m.

Obstacles. Although the complete system was only in place for a few weeks during the oil spill, officials with the City of Orange Beach stated that the system performed as designed. The boom could be seen training oil to the extraction points on the flood tide, and even captured some surface oils that had been communicated through the coastal waterways on the ebbing tide. Its premature disassembly in light of tropical storm activity may point to a possible future improvement of the system: to be able to flood and sink the boom during rough weather as opposed to complete disassembly. One idea was to use pressurized tubes as opposed to the foam-filled steel dredge pipe.

CONCLUSIONS

The 2010 oil spill in the Gulf of Mexico had a tremendous impact on the coastal resources and economies of Texas, Louisiana, Mississippi, Alabama, and Florida. In the state of Alabama, 100% of the beaches were impacted by oil in some form during the one-year period May 2010 – May 2011. A number of strategies were implemented to eliminate, capture, skim, train, and contain surface oils in order to mitigate damage to shorelines, salt marshes, and other coastal habitat. Even within the state of Alabama, some novel approaches were considered and taken to minimize the impacts of oil, particularly on its 100 km of sandy beaches. While the beaches of Baldwin County endured a rather lengthy cleaning process that included tilling of the uppermost 1 m of sand across the subaerial beach, Dauphin Island chose to erect two shore-parallel protective sand barriers to contain oil on the beachface. A small tidal inlet was effectively plugged with sand to prevent the oiling of a sensitive estuary; a novel boom system was designed and implemented to withstand the strong 4 m/s current in a dynamic tidal inlet; and a barrier island breach was sealed with a 2.5-km-long sand-tight rubble mound structure. In most cases, sound coastal engineering principles were applied in the design and implementation of oil spill response projects, but a number of lessons were learned that highlight areas for improvement. The identification of an oil spill as an ever-present coastal hazard for much of the shoreline of the Gulf of Mexico should serve to stimulate continued discussion within the coastal engineering community on how best to respond to such a disaster in the future.

ACKNOWLEDGEMENTS

The authors would like to recognize and thank Phillip West, Coastal Resource Manager for the City of Orange Beach, and Mark Acreman, Public Works Director for the City of Gulf Shores, for contributing to this article.

REFERENCES

Froede, C. R. Jr. (2006). “The impact that Hurricane Ivan (September 16, 2004) made across Dauphin Island, Alabama.” *Journal of Coastal Research*, 22(3), 561 – 573.

Froede, C. R. Jr. (2008). “Changes to Dauphin Island, Alabama, brought about by Hurricane Katrina (August 29, 2005).” Journal of Coastal Research, 24(3), 110 – 117.

Hallermeier, R. J., and P. E. Rhodes. (1988) “Generic Treatment of Dune Erosion for 100-Year Event,” Proceedings, Twenty-First International Conference on Coastal Engineering, ASCE, pp. 1121-1197.

U.S. Army Corps of Engineers (1984). *Shore Protection Manual, 4th Ed.* Waterways Experiment Station, Vicksburg, MS.

Sea Level Rise Impact Assessment and Mitigation Alternatives Development for Balboa Island and Little Balboa Island, City of Newport Beach, California

Ying Poon[1], Brett Sanders[2], Randy Mason [3], and Robert Stein[4]
[1]Everest International Consultants, Inc., 444 West Ocean Blvd, Suite 1104, Long Beach, CA 90802, USA; Ying.Poon@EverestConsultants.com;
[2]Civil and Environmental Engineering, University of California, Irvine, Irvine, CA 92697
[3]URS Corporation, 5772 Bolsa Avenue, Suite 100, Huntington Beach, CA 92649
[4]City of Newport Beach, 3300 Newport Boulevard, Newport Beach, CA 92663

Abstract: *The City of Newport Beach (City), a highly developed, densely populated coastal city in southern California is periodically subject to flooding from coincident high tides and waves. To prepare for sea level rise and potential flood damages, the City initiated a study to assess the potential flood impact to Balboa Island and Little Balboa Island. A recently developed 2D flood simulation model is utilized to investigate the effect of high tides occurring with increased sea levels. Additionally, a simple wave overtopping model is proposed to account for the effect of wind waves and ocean swells. The results of the flood model simulations were used to help the City to formulate flood inundation mitigation alternatives.*

Keywords: *Coastal flooding, Inundation modeling, Flood mapping, Urban flooding, Wave overtopping, Sea level rise*

1. Introduction

The City of Newport Beach (City) has been dealing with localized flooding for several decades due to lower-than-optimum seawall and land mass heights in various locations around Newport Harbor. Flooding of streets and walkways has occurred on Balboa Peninsula, Balboa Island and other localized areas as a consequence of high tides and waves. The challenge of flood control is compounded by City storm drain lines that empty by gravity into the Bay and therefore do not provide flood relief when the bay water level is high. To a lesser extent, distress in the form of concrete cracks and construction joints allows water to breach the protection of these walls and contribute to localize flooding.

Figure 1. Site Location