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ASSESSMENT OF THE HURRICANE FRANCES STORM SURGE ON SAN SALVADOR

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ABSTRACT

On September 2, 2004, Hurricane Frances made landfall on San Salvador, Bahamas. Frances was classified as a Saffir-Simpson Category 4 hurricane with maximum sustained wind speeds of 233 kilometers per hour (146 mph). As the storm and its accompanying tidal surge struck the island's eastern shores, ocean-born debris that accumulated on the beaches was displaced into the protective dunes creating a strand line marking the approximate maximum elevation and inundation of the surge. The debris strand line, which remained relatively undisturbed and intact, was surveyed at East Beach, Holiday Tracks, and Sandy Hook during summer, 2005.

The survey results show an average storm surge height of 5.30 meters (17.38 feet), 6.05 meters (19.85 feet), and 3.03 meters (9.93 feet) for East Beach, Holiday Tracks, and Sandy Hook, respectively. Although the dune systems were successful in preventing serious storm surge inundation, the frontal dunes were overrun or breached at two of the three study sites. The shoreline area of Sandy Hook is particularly vulnerable to storm surge inundation. Future residential construction projects within the zone of inundation should consider this hazard.

INTRODUCTION

San Salvador lies in the path of hurricanes generated within tropical regions of the Atlantic. Since 1871, forty-seven hurricanes and tropical storms have either hit or passed within sixty miles of San Salvador (Neely, 2006). In the late 1990's, San Salvador sustained significant damage from Hurricane Lily (October 19, 1996) and Hurricane Floyd (September 13, 1999).

Hurricane Frances made a direct hit on the eastern shore of San Salvador at approximately 3PM EDT on September 2, 2004. Frances had a Saffir-Simpson Hurricane Scale Category 4 ranking with a maximum sustained wind speed of 233 kilometers per hour (146 mph) (Parnell et al., 2004). The storm approached San Salvador from the south east (Figure 1) producing a tidal surge that affected the entire eastern shore of the island.

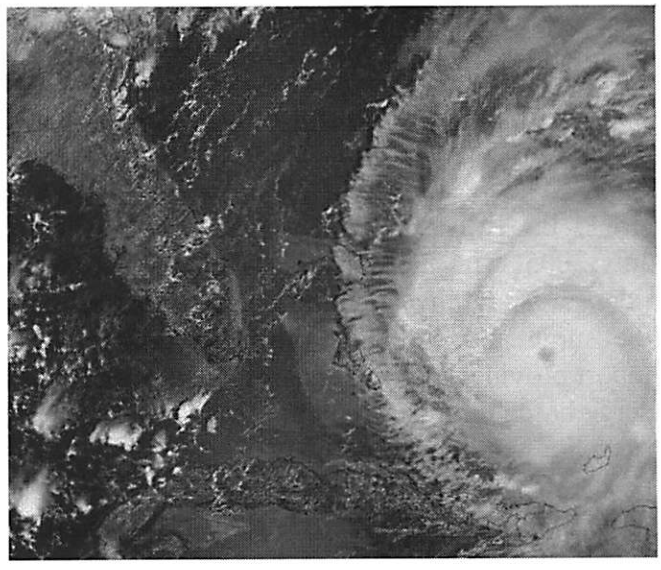

Figure 1. Satellite image of Hurricane Frances and the Bahamas archipelago (Gumley, 2004)

Reconnaissance work conducted in March, 2005 found a well-preserved strand line of shoreline debris materials within the dunes along most of the eastern shoreline (Figure 2). Vince Voegeli, Director of the Gerace Research Center, confirmed that the strand line was created by the Hurricane Frances storm surge. Typical strand line debris included tangled lines and nets, driftwood,

buoys, and a wide variety of plastic and glass materials. The position and relative elevation of the strand-line suggested possible relationships between storm surge height and shoreline physical features such as primary dune crest elevation, shelf width, reef and barrier island development, and proximity to southern the end of the island.

Figure 2. Debris strand line deposit at Holiday Tracks; arrows point to storm surge debris.

The position and elevation of the debris strand line was surveyed in late June and early July 2005, with the objective of documenting the tidal surge and investigating relationships between the surge and shoreline physical features. This report provides a physical assessment of the storm surge based on measurements along three separate shoreline segments.

METHODS AND SITE CHARACTERIZATION

The debris strand line position and elevation measurements constitute an approximate record of the storm surge. The measurements are a composite record of the surge and no distinctions between the storm-generated and tide-generated components are made. Certain lightweight and spherical-shaped debris objects such as plastic fragments, floats, bottles and light bulbs are easily moved by post hurricane wind events. The strand line measurements utilized heavier items like lines, fishing nets, driftwood, and partially buried materials that are only likely to be moved by subsequent storm surges and human scavenging. Following Hurricane Frances and the completion of strand line measurements on July 5, 2005 only one storm, Hurricane Jeanine, passed within five hundred nautical miles of San Salvador. Jeanine was a Saffir-Simpson Category 1 storm (National Hurricane Center 2009). The storm did not have any noticeable storm surge impact on San Salvador (Voegeli, 2005).

Three separate segments of the eastern shoreline at East Beach, Holiday Tracks, and Sandy Hook, were selected for measurement of the storm surge strand line (Figure 3). The selection criteria included: (1) position along the shoreline and accessibility; (2) preservation of the strand line; (3) shoreline orientation; and, (4) presence and/or absence of protective barrier reefs and islands. Strand line location and elevation measurements were made using a Topcon GTS 210 total station and standard surveying methods. In the absence of elevation benchmark references, actual elevations were calculated from the measurements using tide-line survey points corrected to published tide values (NOAA, 2004) for the period of the survey. Shoreline physical features were measured and characterized using Google Earth imagery (Google, 2009), the San Salvador topographic map (Bahamas 1972), field observations, and GPS measurements.

East Beach is located near the northern end of the island. The shoreline azimuth is 350 degrees. The shelf has an average width of 1595 meters (5233 feet). Observations of the shelf at low spring tide show abundant patch reef development over its entire width. No barrier islands are present at East Beach. The frontal primary dunes have crest elevations of approximately three meters (10 feet).

Holiday Tracks is centrally located along the island's east shore near the northern end of Pigeon Creek. The shoreline azimuth is 016 degrees. The shelf is similar to East Beach as it is relatively narrow, having an average width of 1039 meters (3408 feet) with abundant patch reefs and no barrier islands. The primary dunes are the highest on the island, ranging from approximately six meters (20 feet) immediately north of the "thumb" to more than twelve meters (40 feet) at

its southern end where modern dunes are partially superimposed on much larger lithified Pleistocene dunes.

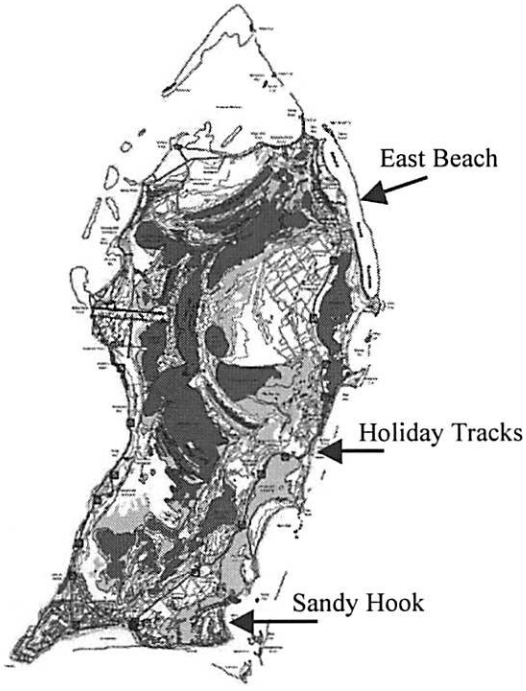

Figure 3. San Salvador map showing project study areas (after Davis and Robinson, 1999).

Sandy Hook is located at the southern end of the island and is bound by Pigeon Creek delta to the north and Snow Bay to the south. The shoreline is slightly concave with its chord having an azimuth of 352 degrees. The shelf is comparatively wide, averaging 1800 meters (5910 feet). The eroded remnants of Pleistocene dunes form a discontinuous system of barrier islands along the shelf edge. The shoreline is aggradational in nature with series of multiple dunes (as many as twenty-seven) oriented sub-parallel to the shoreline and extending inland approximately 1097 meters (3600 feet). The frontal dunes are approximately three meters (10 feet) in height.

RESULTS

East Beach

A total of twenty-six measurements along a 968 meter (3176 foot) continuous section of debris strand line at East Beach were made. The tide-corrected elevation values ranged between 4.61 meters (15.12 feet) and 6.60 meters (21.65 feet) with an average value of 5.30 meters (17.38 feet). These results differ significantly from assessment work conducted September 8-11, 2004 by Parnell and others (Parnell et al., 2004), who estimated an average storm surge height of 3.11 meters (10.20 feet). The approximate location of the strand line with selected survey elevation values is shown in Figure 4.

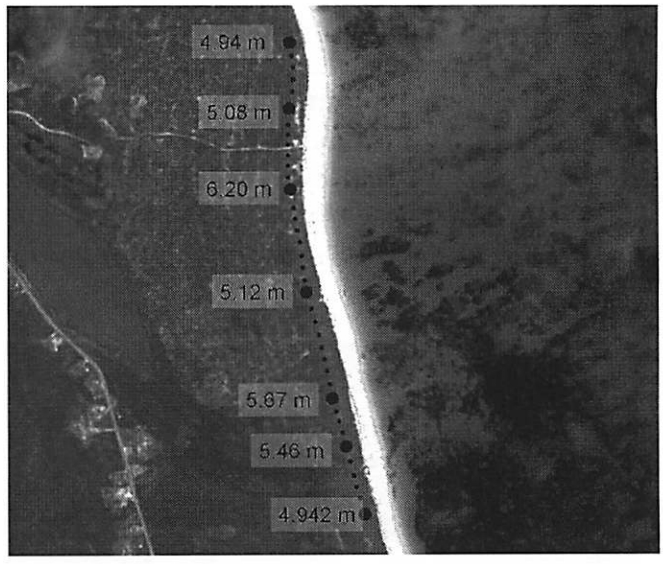

Figure 4. Aerial image of East Beach showing the approximate position of the debris strand line and selected elevation values (Image ©2010 Digital Globe and © 2009 Google).

The modern dunes at East Beach can be characterized as a series of sub-parallel dunes that successively increase in elevation in the inland direction. The frontal dune crests are approximately three meters (10 feet) above MSL (mean sea level). The inland dunes are positioned approximately 180 meters (590 feet) inland from the mean tide line and crest between 6.10 meters (20 feet) and 12.20 meters (40 feet) elevation. The storm surge breached the frontal dunes and created a debris strand line on the flank of the secondary dune line.

The breaching of frontal dunes by storm generated surges has apparently occurred in the past. Brill et al. (1993), documented "wash over lobes" produced by the breaching of the primary dunes during an October 1991 storm event. Anal-

Analysis of Google Earth pre-Hurricane Frances aerial imagery (May 10, 2003) shows what appear to be numerous breach scars of the frontal dunes.

Holiday Tracks

The debris strand line at Holiday Tracks was well established and well preserved. The thumb provided an optimum survey station location from which an approximate 1039 meter (3408 foot) long continuous survey of thirty-three debris strand line measurements was made. The tide-corrected elevation values ranged between 4.32 meters (14.17 feet) and 6.206 meters (20.37 feet) with an average value of 6.05 meters (19.85 feet). The approximate location of the strand line with selected survey elevation values is shown in Figure 5.

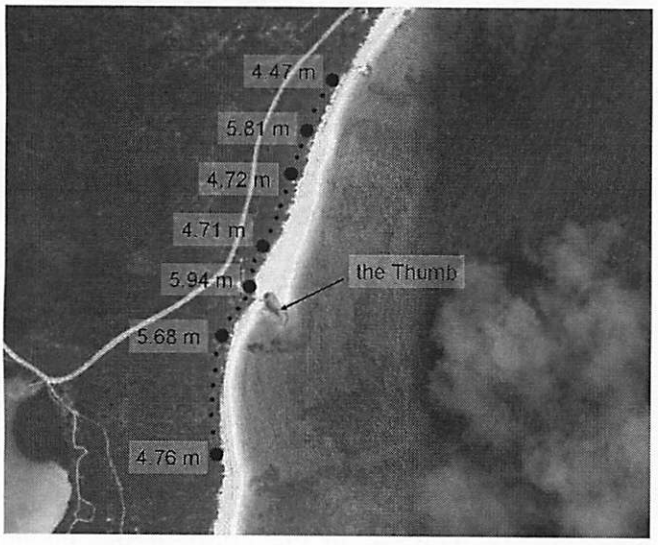

Figure 5. Aerial image of Holiday Tracks showing the approximate position of the debris strand line and selected elevation values (Image ©2010 Digital Globe and © 2009 Google).

The highest measured strand line elevations were located directly behind the "thumb" limestone promontory and continued southward within the dunes for an approximate distance of 165 meters (541 feet). This was the likely result of wave refraction around the thumb structure. A noticeable scar produced by Hurricane Frances is the complete erosion of the sand ridge that connected the thumb to the primary dune.

The dunes along the surveyed portion of Holiday Tracks were not over washed or breached by the storm surge. The dunes are greater than six meters (20 feet) at the northern end of the survey and gradually increase elevation to the south. Immediately north of the strand line survey, near Fortune Hill Settlement, there was evidence of considerable over wash across Queen's Highway and into the adjacent ponds (Voegeli, 2005). The dunes at this location are three meters (10 feet) or less in elevation.

Sandy Hook

The debris strand line at Sandy Hook was situated between the second and third dunes inland from the shoreline. Twenty-two measurements were made along a 1083 meters (3553 feet) long segment of the strand line. The tide-corrected elevation values ranged between 2.53 meters (8.31 feet) and 3.39 meters (11.11 feet) with an average value of 3.03 meters (9.93 feet). The approximate location of the strand line with selected survey elevation values is shown in Figure 6.

Figure 6. Aerial image of Sandy Hook showing the approximate position of the debris strand line and selected elevation values (Image ©2010 Digital Globe and © 2009 Google).

Sandy Hook is distinctly different from East Beach and Holiday Tracks. The shoreline is made of a series of aggrading dunes of which the frontal and successive landward dunes are three meters (10 feet) or less in elevation. The marine shelf at Sandy Hook is comparatively wide and is fringed by a number of barrier islands and shelf edge reefs. In addition, Sandy Hook is situated at the southern end of the island where storm surge energy can be physically dispersed to the west. All of these factors may contribute to or be related to the comparatively low storm surge elevation as observed in the debris strand line measurements.

Despite the relatively low storm surge, Sandy Hook is the most vulnerable of the areas surveyed in regards to potential property loss from storm-generated surges. Past and current residential construction is exclusively within the zone of inundation. If structures are to be built within this zone, they should be placed on pilings built an appropriate height above grade and in accordance with established construction standards.

CONCLUSIONS AND FURTHER WORK

The debris strand line produced by Hurricane Frances provided a record of the storm surge elevation and degree of inundation. Primary dunes effectively buffered the storm surge, however; the surge over ran and breached frontal dunes at East Beach and Sandy Hook. Potential relationships between the documented storm surge and shoreline physical features such as shelf width, reef and barrier island development, and geographic orientation is the focus of on-going research.

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