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Beach Responses to Hurricane Impacts: A Case Study of Long Bay Beach, Negril, Jamaica

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ABSTRACT. Over a three year period between hurricanes Michelle (2001) and Hurricane Ivan (2004) the Long Bay Beach, Negril Jamaica, was able to largely recover to its pre hurricane Michelle position. Between hurricanes Ivan (2004) and Wilma (2005) and hurricanes Wilma and Dean (2007) however, the Beach experienced a net loss of approximately five (5) meters. Overall the data suggest that the Beach requires a minimum of 3-4 years to recover to its pre- storm position following the near passage of a category 4 storm event.

This Paper documents the erosion and recovery of Long Bay Beach, following storm events and proposes a beach recovery response time schedule which would be of interest to beach property owners and other economic users and stakeholders. Bench marks established in 2000 and beach profile data collected over a nine year period (2000-2008) provide an opportunity to study the effects of five (5) hurricanes (Mitch 1998, Michelle 2001, Ivan 2004, Wilma 2005, Dean 2007) on the level of beach erosion and to monitor post-storm recovery.

Tropical storms and hurricanes, particularly late season hurricanes as demonstrated by Hurricanes Mitch, Michelle and Wilma pose, a serious threat to beaches on the south west coast of Jamaica including the Long Bay Beach, Negril. Beach property owners and beach managers in this area must therefore prepare and implement beach adaptation strategies as a counter to the impact of these storm events.

Key words: beach, climate change, erosion, coastal vulnerability, hurricane, Jamaica, Negril.

1. INTRODUCTION

The beaches of Jamaica are perhaps the Island's single most important natural resource. They are the basis for much of the tourism industry, which is Jamaica's largest source of employment and second largest source of foreign exchange. There is a strong link between the quality of beaches and the level of tourist activity. Tourism is one of the most important economic sectors for Island states. For a number of countries, such as Antigua and Barbuda, the Bahamas, Barbados, Cyprus, Grenada, Jamaica, St. Kitts and Nevis, tourist revenue makes up more than 20 percent of the gross national product (Nurse, 2002).

Beaches also provide an important recreational resource for the local residents; protect coastal lands from wave action, especially during hurricanes; provide fish landing sites and are an aesthetically pleasing part of the environment.

In recent decades, beach loss has become a major problem and concern to Jamaica (Hendry, 1985). This is partly because in some areas, coastal infrastructure and entire communities are threatened by beach erosion. This concern has been heightened given the real or perceived increase in the numbers and intensity of tropical storms and hurricanes in the Caribbean Basin and the possible effect of climate change, in particular, sea level rise.

There is hardly any doubt that tropical storms and hurricanes have played a significant role in the historical development of Jamaica's coastline. The effects of Hurricane Gilbert (1988) on Jamaican beaches have been well documented (UNEP 1989).

Hendry (1982) made observations of the influence of Hurricane Allen in August 1980 and Tropical Storm Arlene in May 1981 on the beaches at Negril. More recently approximately 2 km of the shoreline in Negril suffered from erosion as a result of the passage of Hurricane Mitch in 1998.

Records of hurricane damage exist in the archives of the Caribbean for over five centuries. The records over the past century show a wide band of hurricane activity across the Caribbean (UN-ECLAC 2002).

Cyclones cause storm surges and with elevated sea levels, these surges are predicted to be more destructive, and even more so if cyclone intensity increases due to climate change (Barnett, 2001; Van Vuren et al., 2004). Recent studies suggest an

increase of 10–20 percent in the intensity of tropical cyclones under enhanced atmospheric carbon dioxide conditions (IPCC 2007).

Six of the Atlantic most intense hurricanes have occurred over the last ten years. Four of these (Mitch 1998, Ivan 2004, Wilma 2005, Dean 2007) have had a direct impact on Jamaica's coastline and beaches.

This Paper seeks to use bench marks established in 2000 and beach profile data collected over a nine year period to study the effects of five (5) hurricanes (Mitch 1998, Michelle 2001, Ivan 2004, Wilma 2005, Dean 2007) on the level of beach erosion and to monitor post-storm recovery at Long Bay Negril, Jamaica . The erosion and recovery of the Long Bay Beach following the storm events is documented and a beach recovery response time schedule is proposed.

1.1. Setting

The Long Bay Beach in Negril is part of a lagoon, beach and morass complex situated at the western end of the island of Jamaica (Latitude 18° 16' - 18° 23' N; Longitude 78° 18' - 78° 21' W; **Figure 1**). Long Bay is a gently curving 6.4 km long beach, backed by a strip of sand with a relief of less than 2 m.

The shallow coastal shelf, has a general depth of between 5 m and 12 m below sea level, and extends offshore for distances of up to 2 km from the beaches of Long Bay. The current direction in Long Bay is predominantly along shore. And although the general direction of the currents is from north to south, there are occasions in which the flow changes.

The non-skeletal grain composition of the beach is dominated by amorphous and crystalline grains, while the skeletal grains are characterized by abundant foraminifera with smaller amounts of red algae, bivalves and *Halimeda* (Mitchell et al., 2002). Due to nutrient influx there has been a gradual replacement of *Thalassia* by fleshy algae. This coupled with the removal of sea grasses to facilitate the tourism industry is leading to smaller areas of sea grass cover. Mitchell et al. (2002) anticipates that the loss in sea grass area will lead to an overall reduction of carbonate sediment production and the increased likelihood of beach erosion.

1.2. Previous work

Hendry (1982) undertook beach profile surveys during the winter of 1980, coinciding with a time when 'northers' were noticeably frequent, generating rough seas at Negril which repeatedly eroded the beach foreshore and created longshore bars. Hendry (1982) described the Long Bay beach as being stable in relation to wave activity, being able to recover in a short period of time after an extreme weather event.

Comparative observations by Hendry (1982) suggest that shoreline change over the previous 30 year period were negligible and examination of the aerial photo series from 1941 to 1990 for Long Bay beach (Robinson et al., 2000) does not reveal any major change in the shoreline position during this period. During the 1990s however, serious concerns began to be raised regarding the stability of the beach.

Beach erosion is not a uniformly occurring phenomenon along the entire 6.4 km length of the beach at Long Bay. The study undertaken by the Robinson (2000) found that sections of the Long Bay beach were being affected to varying degrees. The northern section of the Bay appears to be undergoing more severe, long-term erosion. Other sections appear to be periodically affected by significant storm related erosion, from which the beach eventually recovers. The southernmost sections of the beach appear to be generally stable. The study indicated that the recovery time of the beach following storm event was more protracted during the last 10 years when compared to the prior 20 years.

1.3. Hurricanes

An average hurricane season in the Caribbean basin consists of some 10 tropical storms, of which six reach hurricane intensity (Rubiera, 2003). Six of the top ten most intense hurricanes (Wilma 2005, Rita 2005, Katrina 2005, Mitch 1998, Dean 2007, Ivan 2004) occurred over the last twelve years.

Of interest to Jamaica is the direction that the hurricanes take while on their path through the region. Of particular interest is the path taken by late season tropical systems that form in the central Caribbean during mid to late October through to December and move north. Jamaica's south-western beaches which are normally protected from the regularly tracking hurricanes and winter storms are now under these circumstances exposed directly to the storm surges and swell waves that these systems generate.

The data shows that from 1950-2007 approximately 79 storms systems came within 250 miles of Jamaica. Thirty or approximately 41% of these storms can be categorized as late season systems. Thirty-one systems attained hurricane status at their closest points to Jamaica. An analysis of the last 50 years show that there were at least six periods of higher than normal storm activity all of which had storm erosion implications for Long Bay Negril. These periods are; 1950-1952, 1961-1964, 1969-1971, 1079-1981, 1988-2001 and 2004-2007 (**Figure 1**).

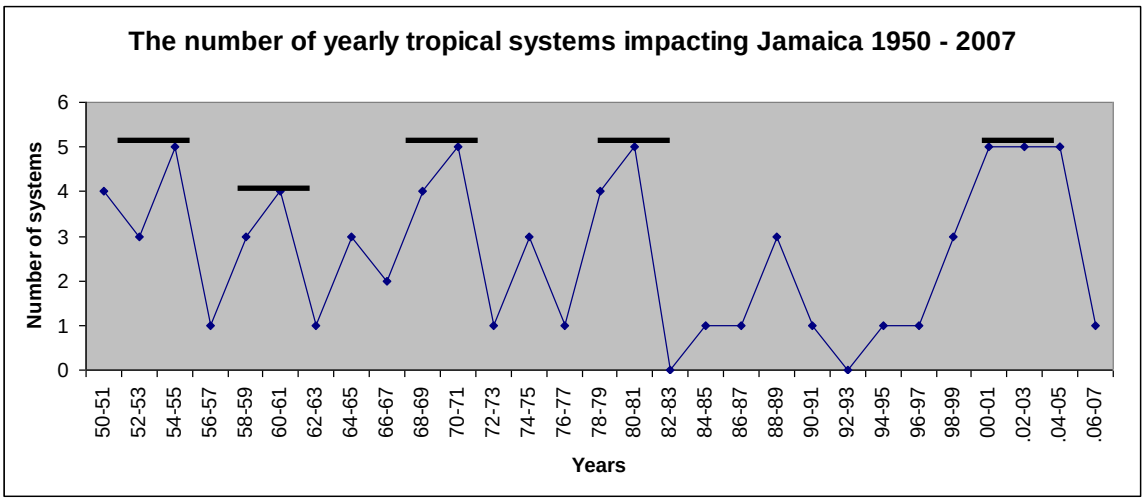

Figure 1. Periods of higher numbers of tropical systems affecting Jamaica. A significant period was the last ten (10) years.

During the period 1950 –1953, three hurricanes and two tropical storms came within 250 miles of Jamaica. Hurricane Charlie in August 1951 came across Jamaica and caused extensive flooding. Of significance is the fact that three of these systems (hurricane King 1950, Tropical Storm Item 1951 and hurricane Fox 1952) were late season systems that formed in the Central Caribbean and moved northwest of the Island exposing Negril to storm surges. It is highly probable that the Long Bay Beach experienced some level of erosion during this period.

Four hurricanes and three tropical storms impacted the Island during the period 1961 –1964. Hurricane Flora (1963) and hurricane Cleo (1964) were hurricanes that severely impacted the Island causing extensive flooding. Another of these hurricanes was hurricane Hattie (1961) which became a category 5 hurricane and caused tremendous damage to Belize. Hurricane Hattie was a late season system whose tract took it within impact distance of Negril. The path and strength of hurricane Hattie were similar to that of hurricane Mitch (1998). It is reasonable to assume that the Long Bay Beach was significantly impacted by Hattie. Two other tropical storms, tropical storm Isbell (1964) and tropical Storm #12 (1964) were late season systems and could have impacted Negril.

Nine systems developed and came within 250 miles of the Island during the period 1969-1971. Three of these were late season storms that could have had some impact on the Long Bay Beach. However at their closest points to Jamaica they were categorized as tropical depressions. Hurricane Alma (1970) probably had the greatest impact on Negril during this period. This hurricane formed in the central Caribbean and moved north and west of Negril.

Eight systems came within 250 miles of Jamaica during the period 1979-1981; there were two hurricanes, hurricane David (1979) and hurricane Allen (1980), two tropical storms, and two late season systems. One of these hurricanes, hurricane David became a category 5 hurricane and past within 150 miles to the North of the Island. There were reports of structural damages along the North Coast as a result of the passage of this hurricane. The impact of hurricane Allen on the Island's coast is documented by Hendry (1982) and Lyn (1982). Of all the systems during this period tropical storm Katrina (1981) a late season system could have had the greatest impact on the Long Bay Beach.

The years 1998-2001 were an active period for Jamaica. Five hurricanes came within impact distance of Jamaica (hurricane Mitch 1998, hurricane Georges 1998, hurricane Lenny 1999, hurricane Michelle 2001 and hurricane Iris 2001). The impact on Long Bay of hurricanes Mitch and Michelle will be examined in greater detail in this study, but it is obvious that these two late seasons hurricanes had the greatest impact on Long Bay during this period and resulted in significant beach erosion.

The years 2004-2007 have undoubtedly been the most active period for Jamaica when five hurricanes came within 250 miles of Jamaica. These include, Hurricanes Ivan 2004, Wilma 2005 and Dean 2007. Hurricane Wilma was a late season storm that formed in the central Caribbean.

This paper examines the impact of five hurricanes on the Long bay Beach. A summary of the descriptions of these hurricanes is given in **Table 1**.

Table 1: Summary description of Hurricanes over a ten year period

Hurricane	Impacting Date	Status closest to Jamaica	Direction of movement	Main features
Mitch	25-27 October 1998	Category 4	230 miles south and North West	One of the deadliest and most powerful hurricanes on record in the Atlantic basin. Reached category 5 status.
Michelle	31 October 2001	Category 4	250 miles west and North	One of the strongest hurricanes of the 2001 Atlantic hurricane season. Reached category 4 status.
Ivan	10 September 2004	Category 4	30 miles south and west	Strongest hurricane of the 2004 Atlantic hurricane season. Reached category 5 status.
Wilma	16-18 October 2005	Tropical depression	160 miles south – north west	The most intense hurricane ever recorded in the Atlantic basin
Dean	20 August 20 2007	Category 4	50-60 miles south and west	Strongest tropical cyclone of the 2007 Atlantic hurricane season. Reached category 5 status.

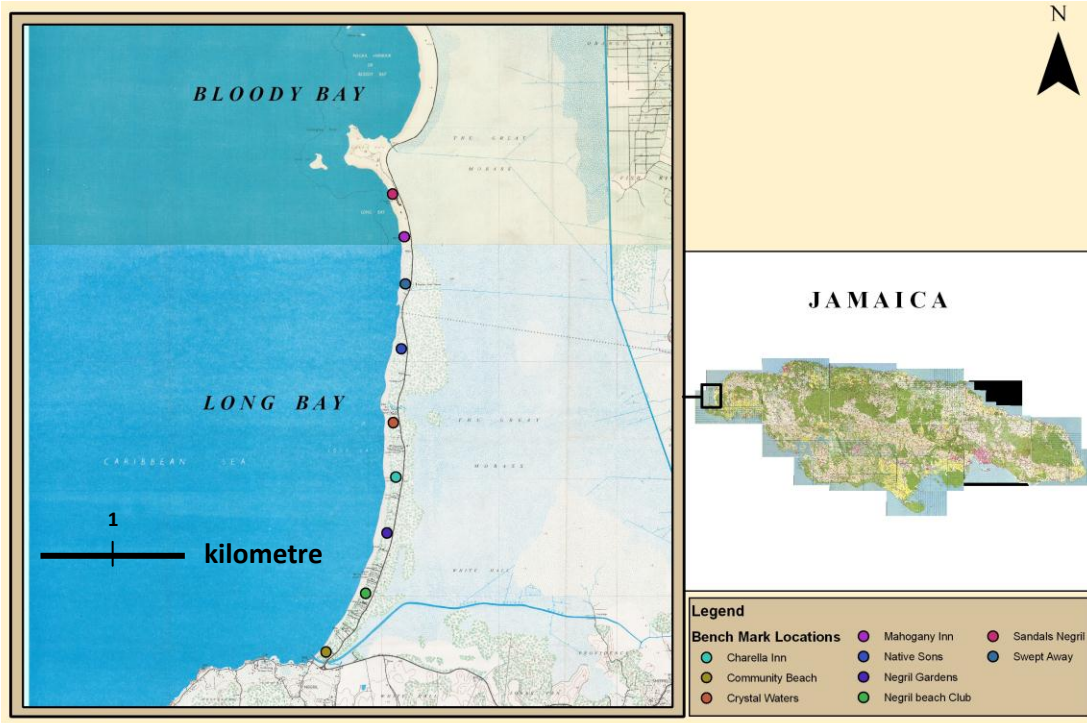

Figure 2. Map showing bench mark locations at Long Bay, Negril, Jamaica.

1.4. Beach Profiles

Beach profiles are commonly used to quantify changes in beach morphology, the assumption being that a single profile is representative of the three-dimensional (3D) morphology of a beach segment (Swales, 2002).

Beach profile data were collected at nine survey stations established at fairly regular distances along Long Bay (**Figure 2**). Beach profile data were collected over a nine year period between 2000 and 2008. Monthly data were collected over the first three years and approximately every three months thereafter.

The high water mark (HWM) is the shoreline indicator that is used to measure shoreline change. Crowell et al., (1991) and Phillips and Williams (2007) notes that the high water line (HWL) is considered the best shoreline indicator by many researchers because it is easily field-located and photo interpreted. For this study the location of the HWM prior to and after the storm events are compared.

2. RESULTS

2.1. Erosion levels

Following the passage of hurricane Michelle (October 2001) the beach experienced erosion

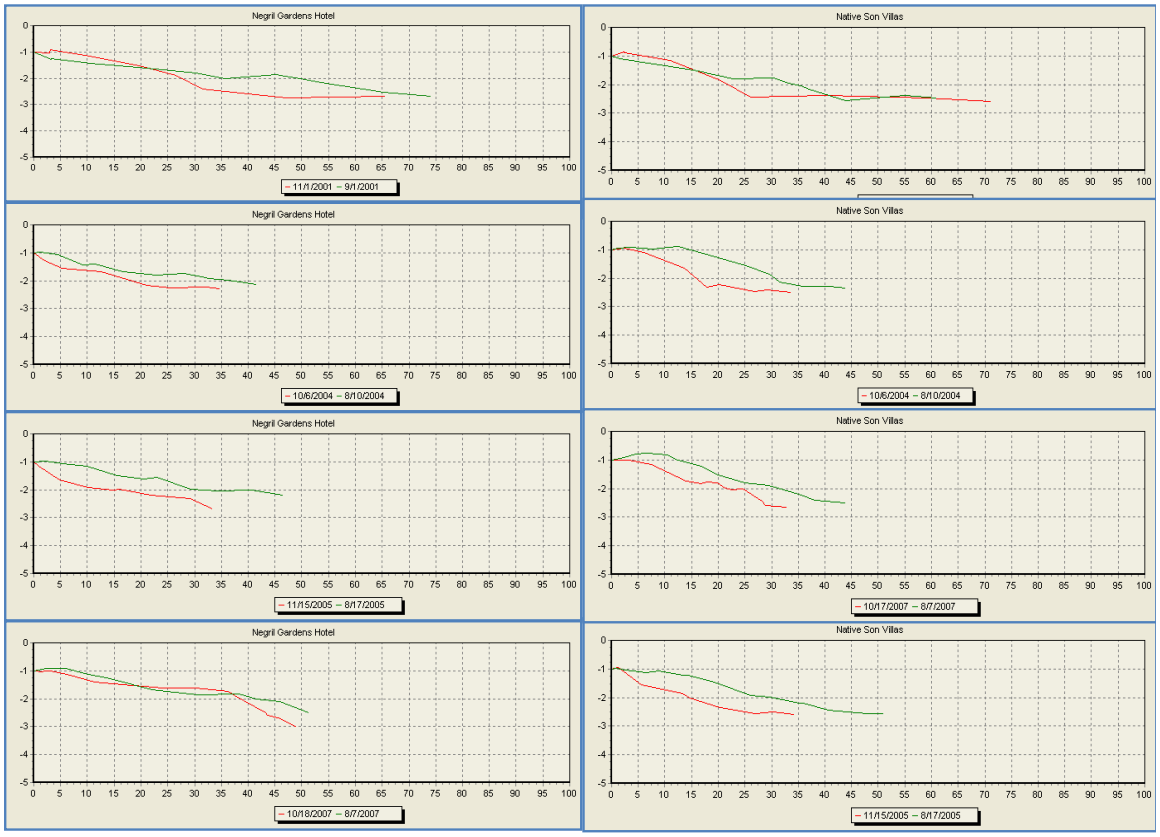

Figure 3. Pre- and post-hurricane beach profiles (Michelle 2001, Ivan 2004, Wilma 2005, Dean 2007) at bench mark locations at Negril Gardens Hotel (left) and Native Sons Villas right). Green lines are pre hurricane and red lines are post hurricane. [Larger version available at the *Caribbean Journal of Earth Science* website.]

averaging between 11 meters in the North to 16 meters in the South of the Bay. The area in the vicinity of the Swept Away Hotel was the most severely impacted, recording approximately 35 m of beach loss. Another area that experienced significantly higher than average erosion was the area between the Negril Gardens and Negril Beach Club Hotels where erosion levels ranged between 20-25 m. The area between the Sandals Hotel and Mahogany Inn experienced lower levels of erosion. In fact, the area in the vicinity of the Mahogany Inn experienced some level of accretion after the event. **Figure 3** shows pre and post hurricane beach profiles at bench mark locations at Negril Gardens Hotel and Native Sons Villas.

Hurricane Ivan (September 2004) resulted in average erosion of 16 m. The beach in the vicinity of Negril Beach, Negril Gardens, Crystal Waters, Swept Away and Sandals hotels experienced erosion above the average level of erosion – 23 m in the case of the Negril Beach Hotel Site. The least impacted area was the Mahogany Inn site where beach erosion measured 5 m.

Erosion levels resulting from Hurricane Wilma (October 2005) averaged 19 meters across the Bay. Only the site at Crystal Waters Hotel showed a significantly lower level of erosion of 10 m.

The impact of hurricane Dean (August 2007) was more significant in the northern section of the Bay which experienced erosion averaging 15 m as against the southern section where erosion as low as 4 m was recorded at the Community Public Beach (**Table 2**).

2.2. Recovery Levels

During the months following the passage of hurricane Mitch, the Long Bay Beach consistently showed a trend towards recovery. Over the three year period between hurricane Michelle and hurricane Ivan, average accretion ranged between 10 m in the south to16.5 m in the north of the Bay (**Figure 4**). At three sites; Sandals Hotel to Mohagany Inn, Cherella Inn and the Community Public Beach, the MHWM had advanced/accreted more than the pre Hurricane Michelle position.

Recovery of the beach was more even and consistent along the entire length of the beach during the one year period between hurricane Ivan and hurricane Wilma (**Figure 5**). The Beach was able to recover 12 m of beach during this period.

Only three sites; Sandals Hotel, Mahogany Inn

Table 2: Erosion and Recovery of Beach Pre and Post Hurricane

Hurricane	Average Erosion	Average Recovery	Net change
Hurricane Michelle (October 2001)	14 m - Between 11 m in the north to 16 m in the south of the bay	14 m - Between 10 m in the south to16.5 m in the north	0 m
Hurricane Ivan (September 2004)	16 m	12 m	-4 m
Hurricane Wilma (October 2005)	19 m	18 m - 23 m in the north to a low of 7 m in the south	-1 m
Hurricane Dean (August 2007)	11 m - Between 15 m in the north to 7 m in the south		

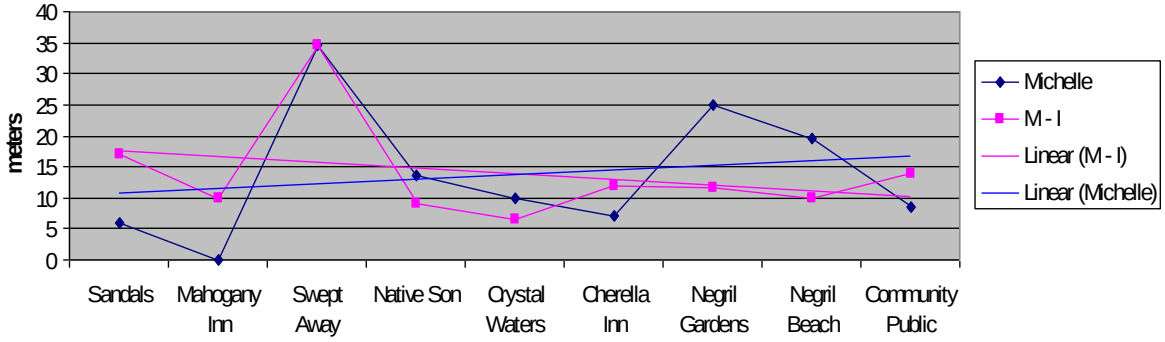

Figure 4. The level of erosion at the nine sites following Hurricane Michelle and the level of accretion (M-I) during the intervening period between Hurricanes Michelle and Ivan. The trendlines show the trend in erosion (linear (Michelle)) and accretion (linear (M-I)) from Sandals in the north of the bay to the Community Beach in the south.

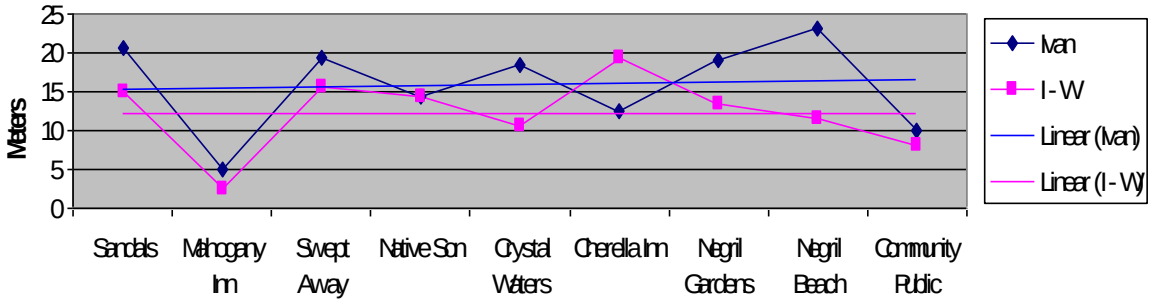

Figure 5. The level of erosion at the nine sites following Hurricane Ivan and the level of accretion (I-W) during the intervening period between Hurricanes Ivan and Wilma. The trendlines show the trend in erosion [linear (Ivan)] and accretion [linear (I-W)] from Sandals in the north of the bay to the Community Beach in the south.

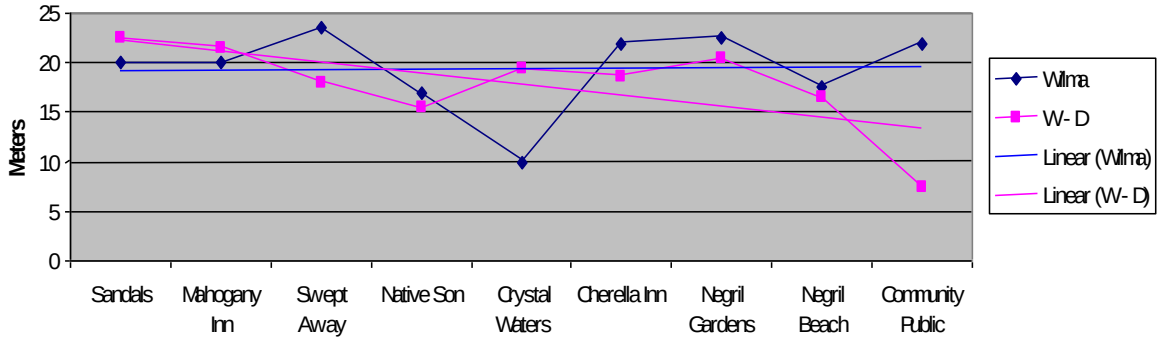

Figure 6. The level of erosion at the nine sites following Hurricane Wilma and the level of accretion (W-D) during the intervening period between Hurricanes Wilma and Dean. The trendlines show the trend in erosion [linear (Wilma)] and accretion [linear (W-D)] from Sandals in the north of the bay to the Community Beach in the south.

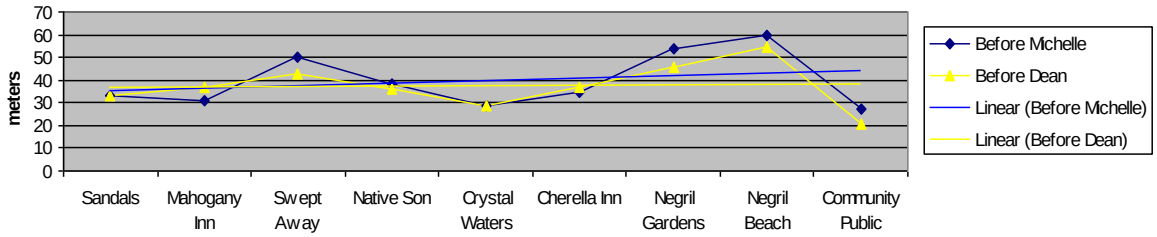

Figure 7. The location of MHWM prior to Hurricanes Michelle and Dean at sites located at Sandals in the north to the Community Public Beach in the south.

and Crystal Waters Hotel, were able to recover to their pre storm positions during the two year period between hurricane Wilma and hurricane Dean. Recovery ranged from 23 m at the Sandals Hotel site in the north to a low of 7 m at the Community Public Beach in the south (**Figure 6**).

3. DISCUSSION

Several physical factors can influence the type and magnitude of storm impacts. Morton (2002) identified several of these factors. They include the alongshore variability of storm processes, geographic location relative to the storm centre, prior storm history, duration of beach inundation by waves, morphology and elevations of the ground surface, density of vegetative cover, and human modifications. Zhang et al. (2001) noted that the fact that barrier beaches along the US East Coast recovered to their long term trend positions after storms regardless of severity; strongly indicate that storms are not responsible for long term beach erosion. They argued that the risk to coastal property is determined both by storm induced and long term beach erosion. They also argued that because short term erosion caused by storms is only a temporary deviation from long term shoreline evolution, and beaches tend to recover to their long term trends; these two processes can be treated independently.

Morton (2002) identified four stages for complete beach recovery: (1) rapid forebeach accretion, (2) backbeach aggradation, (3) dune formation, and (4) dune expansion and vegetation re-colonization. While it would not be possible for the dunes along Long Bay to be fully re-established given the level of coastal development, a more detailed analysis of the beach profiles will be necessary to determine to what extent the beach was able to progress through these stages given the limited time between storm events.

Over the three year period between hurricane Michelle (2001) and hurricane Ivan (2004) the Long Bay beach was able to largely recover to its pre-hurricane Michelle position. Between hurricanes Ivan (2004) and Wilma (2005) and hurricanes Wilma and Dean (2007) however, the Beach experienced a net loss of approximately 5 m (**Table 2**). This is demonstrated in **Figure 7** which shows the location of MHWM at the nine sites just prior to Hurricane Michelle and Hurricane Dean.

Overall the data suggest that the beach requires a minimum of 3-4 years to recover to its pre-storm position following the near passage of a category 4 storm event. Morton et al. (1995) investigated beach and dune recovery at Galveston Island, Texas after hurricane Alicia in 1983. They found that post-storm beach recovery can last 4-5 years or more.

Many coastal areas along the gulf coast of the United States may be accreting in the short term, but the general trend is in the direction of shoreline retreat (Day and Boesch, 2007). Cambers (2009) using data from all eight Caribbean islands shows an overall erosion trend with a retreat rate of 0.5 m yr^{-1} with elevated rates in those islands impacted by a higher number of hurricanes (with the exception of Antigua). This figure (0.5 m yr^{-1}) represents the average change for all measured beaches, including those showing no change or accretion.

Analysis of hurricane trends over the last 50 years suggest possible significant storm impacts during the period 1950-1952 when three late season hurricanes (hurricanes King, Item and Fox) trended close to Negril. Hurricane Hattie (1961-1964 period) another late season storm, should have also caused extensive damage to Negril (note the similarity in storm tracks of both Hurricane Hattie in 1961 and Hurricane Mitch in 1998). It will however be necessary to use hindcast storm surge models to better understand the possible impact of these hurricanes on shoreline change along Long Bay.

Late season tropical storms and hurricanes as demonstrated by hurricanes Mitch, Michelle and Wilma pose a serious threat to the south coast beaches and the Long Bay Beach, Negril in particular. Beach property owners and beach managers in this area must therefore prepare and

implement beach adaptation strategies as a counter to the impact of the storm event.

4. CONCLUSIONS

This study in general illustrates beach responses to storm processes and provides data necessary to develop generic coastal impact forecasts.

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