Erosion Negril Beach

Kingston, December 2006

Authors

Daniel ten Ham B.Sc.

Johan Henrotte B.Sc.

Rudi Kraaijeveld

Mirza Milosevic

Pieter Smit B.Sc.

Preface

This report is the result of a combined research made by a group of five students from the faculty of Civil Engineering at the Delft University of Technology (DUT) in the Netherlands with the Jamaican Coastal Engineering firm Smith Warner International Ltd (SWIL).

The collaboration between the group of students with the firm Smith Warner International Ltd. originates from the course *'Multidisciplinary-Master-Project (CT4061)'*. This is an elective course in the curriculum of the Civil Engineering MSc-Programme. The aim of this course is to participate in the solving of an actual and recent civil engineering problem in a multidisciplinary team. A project alongside with a traineeship for the group of students has been made possible by Smith Warner International Ltd.

The project described in this report is located at the West-Coast of Jamaica, near the town Negril, specifically the beaches of Long Bay and Bloody Bay. The project has been initiated by the hotel owners and consists of making a literary study, collection of missing data and finding feasible solutions for the beach erosion problem of Negril.

To help finance our travel to and stay in Kingston we addressed different engineering companies, contractors and organizations, from which we received several sponsor donations. Our sponsors were;

TU Delft — Delft University of Technology

Digital Hydraulics Holland — experts in wave modelling

Smith Warner International — Coastal Environment

Royal Boskalis Westminster nv

We would like to thank our mentors David, Phil, Jamel and Henk-Jan. Liz deserves special thanks for looking after us and organizing a lot of our non-work related trips. Finally we want to thank Beatriz, Chris, Corinne, Dionne, Graham, Leighton, Roberto and Veronique for supporting us during different phases of the project and for accepting us as part of the team.

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TU Delft students
Daniel ten Ham BSc
Johan Henrotte BSc
Rudi Kraaijeveld
Mirza Milosevic
Pieter Smit BSc

Smith Warner International Ltd.
Dr. David A.Y. Smith
Mr. Philip Warner
Jamel Banton MSc

Summary

The ongoing erosion of the Negril Beach has become worse the past decade. In most places along the coast line, the beach will be gone in approximately 10 years. This will result in a major decrease of incomes that are made by the local tourist sector.

To prevent the erosion this study has been performed to find a feasible and affordable solution. An important part of the study is the literature research since several other parties had investigated different aspects of the erosion problem recently. Before any solutions can be brought up different aspects have to be investigated. These are a clear view of the actual problem, a good knowledge of the environment, profiles of the coastline, current patterns and sea grass locations to avoid environmental damage as much as possible.

Data was collected during two field trips to Negril in the end of 2006. After collecting this data an analysis was made using different computer models as LITPACK (sediment transport), SWAN (waves) and RMA (currents). The data analysis shows that the primary concern is the erosion at Long Bay since the erosion in Bloody Bay is not that severe.

Possible solutions are generated and their validity has been checked. Five alternatives can be distinguished: zero-alternative, nourishment, series of near-shore breakwaters, off shore reef extension and a combination of all.

Using a Multi Criteria Analyses (MCA), that ranks solutions by their desired effects (without including costs), objectively the 'best' solution is found. The solution that scores best at our criteria is beach nourishment along Long Bay. When costs are taken into account, this solution seems to be the most efficient. Costs are estimated US$7,000,000.

The final recommendation is to execute beach nourishment only at Long Bay. This solution is relatively affordable and shows the highest score in the MCA. The implementation of this solution results in a minimum beach width of about 10 meters for 20 years, about 30 meters in the year of execution. According to local divers the required sand can be found 2km offshore at the beginning of the outer shell.

Beside of that it is recommended to perform a separate investigation concerning the water quality to deal with the algae contamination.

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1. Introduction

In the last several years the erosion of the Negril beaches has received a lot of media attention. The economical importance of the beaches for Jamaica has initiated a cooperation between the hotels and several studies concerning this problem have already been made. They were however all focused on different parts and separate issues of the Negril beaches.

In this report an all combining integrated study is presented on the occurring erosion mechanisms and feasible solutions to preserve the beach.

This report is divided in eight chapters. The appendices are bound together in a separate document.

The report starts in **chapter 2** with a description of the project location, an explanation of the actual problem is given and the goal of the project is defined.

Chapter 3 begins with an overview of the existing data gaps. The data collection methods are explained followed by a presentation of the results.
Hereafter, the collected data is analyzed in **chapter 4**. Different computer models are generated to give an impression of the several occurring mechanisms. The chapter finishes with conclusions about the system behavior.

The most applicable and reasonable options are discussed in **chapter 5**.

Chapter 6 contains recommendations on the choice of solutions. This choice is made trough a Multi Criteria Analysis. After this the costs are taken into account and the final recommendation to solve the problem is given in **chapter 7**.
The report finishes with the references in **chapter 8.**

2. Problem Analysis

Before any data can be collected and possible solutions for the erosion problem examined, the project characteristics are first investigated.

This chapter will start with an overview of the project location. After this the problem can be described which then results in the determination of the project goal.

2.1. Location description

The project site is located at the West coast of Jamaica, near the town of Negril. The coast consists of two carbonate beaches [5] with a total length of 9km; Long Bay in the South and Bloody Bay in the North.

The shoreline of Long Bay is 7km long and has a beach varying in width from North to South with the widest parts generally located in the middle of the bay. All kinds of establishments are situated on the beach. Establishments include but are not limited to hotels, restaurants and large resorts. Additional a road is found at the back (East) of these establishments.

Bloody Bay has a continues beach stretching out for 2.1km. In the North and South big hotels are located. The original forest cover is still present in the middle part of the bay. The road continues northwards through the forest.

The two bays are separated by a rocky peninsula and a small island called Booby Cay.

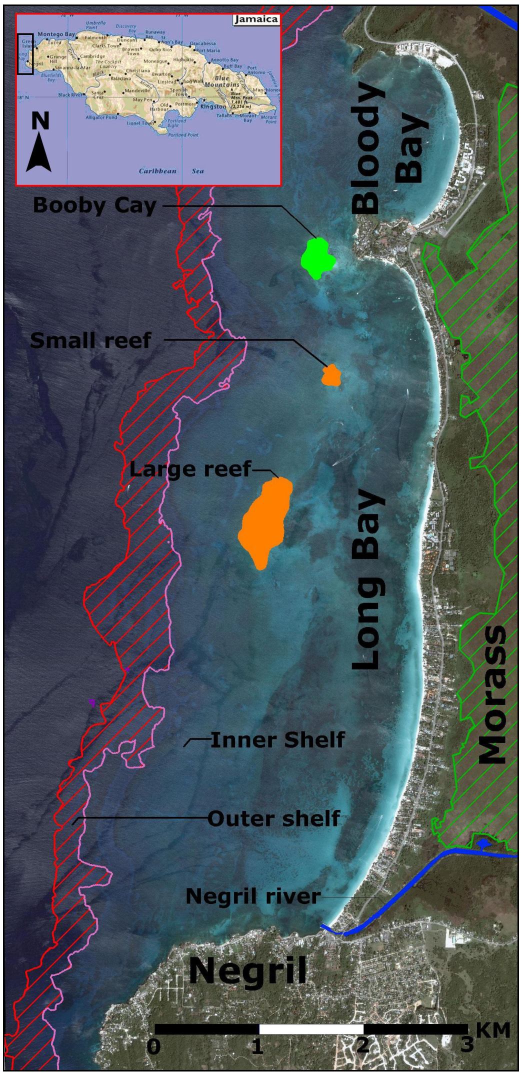


Figure 2.1:Location of Negril beach

South to Long Bay and North to Bloody Bay the area is bordered by headlands.

The area in front of the beach of both bays is shallow with a mild slope. The inner shelf (0-20m depth contour) reaches till 1-2km off-shore, and is then followed by the outer shelf (20-50m depth contour). An extensive line of fringing reefs is situated on the edge of the outer shelf parallel to the shore at a distance between 2-3km from the coast. After this outer shelf the bottom drops down abruptly.

In the middle of Long Bay some coral reefs are located in shallow water. The largest reef has a length of approximately 500m from North to South at a distance of 1,5km from the shore.

At the East of the road the great morass of Negril is found. The sandy barrier lying close to the coast of Negril separates the morass from the Caribbean Sea.

Finally the area has two waterways. The Negril River which runs through the morass and passes a waste water treatment facility, flows out in the South of Long Bay where it is guided by two groynes. At the North of Bloody Bay a canal functions as a drainage system for the morass.

2.2. Description of Problem

The beautiful white beach of Negril is without any doubt one of the main tourist attractions of Jamaica. For the last 15 years it has been noticed that the beach is slowly disappearing. The Negril shoreline appears to have retreated at a rate of 1-2 meters per year.

The tourism industry is currently one of the largest earners of foreign exchange to the Jamaican economy, and in 2001 earned more than US$ 1.2 billion. The resources of Negril and in particular those found along the beach, form a significant part of Jamaica's tourism product, reportedly providing more than 25% of these earnings.

To ensure Jamaica's economical development, this ongoing erosive trend is not a situation that should be allowed to persist in the long term.

2.3. Goal

The goal of this project is to generate a feasible solution or combination of solutions for the erosion problem of the Negril beach that can be implemented and effective in a short period of time.

3. Data Collection

After the problem analysis an inventory was made of past reports and available information about the Negril erosion problem. From this inventory a list of remaining data gaps could be derived (Table 3-1). This chapter describes the data collection methods used for the different data gaps and also the acquired results. The data has been collected in the second week of October 2006 and in the third week of November 2006.

Known gap	Method
Terrain survey	Bathymetry of the area and beach profile measurements.
Current patterns	Placement and retrieving of current meter. Following drogues by boat while determining GPS location.
Coastal structures	Photo with digital cameras and determining location by GPS.
Meteorology	Placement and retrieving of measurement devices.
Sediments	Taking sand samples along the coast.
Tides and Waves	Placement and retrieving of a current meter.

Table 3-1: Data gaps

3.1. Terrain survey

To get the required knowledge of the existing wave climate, local currents and the transport of sediment, detailed information about the bottom of the sea is needed. The obtained information about the terrain forms an important input factor in several computer models.

The gathering of this data is divided in two methods. The first method is used to obtain the profile out on the sea and the second method is used to obtain the profile near shore and of the beach. Both methods will be described in more detail in the following sections.

3.1.1. Bathymetry

To collect the depth profile data out on the sea a boat-based bathymetric survey was done, with the use of an echo-sounder and a GPS device.

With the echo-sounder (which was attached to the boat) the depths were measured at pre-programmed tracks. The GPS recorded at the same time the positions of the echo-sounder. With the use of a palmtop the time data from both devices was synchronized to obtain the depths at a certain positions (Figure 3.1).

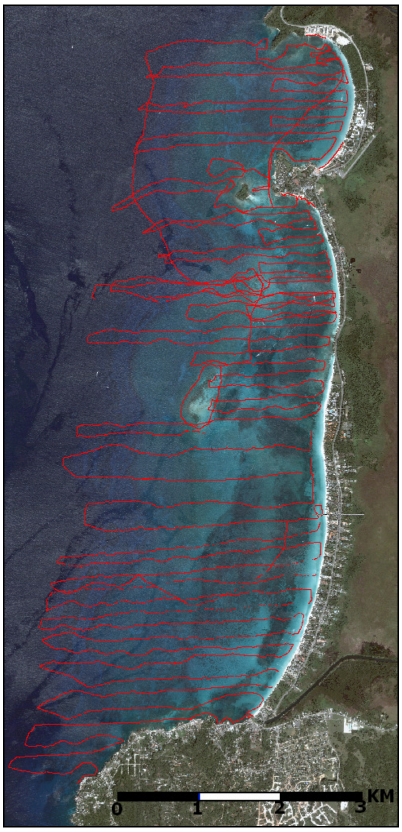


Figure 3.1:Bathymetry track

3.1.2. Beach profiles

The near shore profiling was done by taking cross-sections of the beach every 100m with a level (Figure 3.2 and Figure 3.3). The sections include the beach and run into the water for about 30m. Sometimes these lines were limited by the inaccessibility or depth of the sea.

The water level height is correlated with data from a tide meter, which was placed in the sea. The collected beach profiles are finally added to the bathymetric survey. All the locations of the cross-sections and their results can be viewed in appendix 1.

Figure 3.2:Cross-sections 1–15

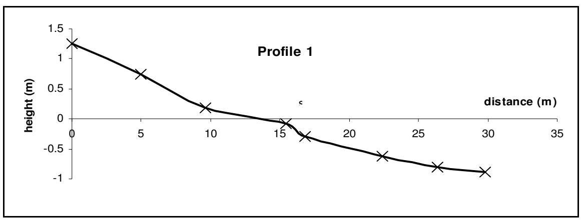


Figure 3.3:Profile 1

3.1.3. Results bathymetry and beach profiles

The bathymetry and the beach profiles were combined with several other aspects such as the shoreline, coastal structures, the location of Booby Cay, headlands, etc. From this a contour map of the entire area could be created (Figure 3.4)

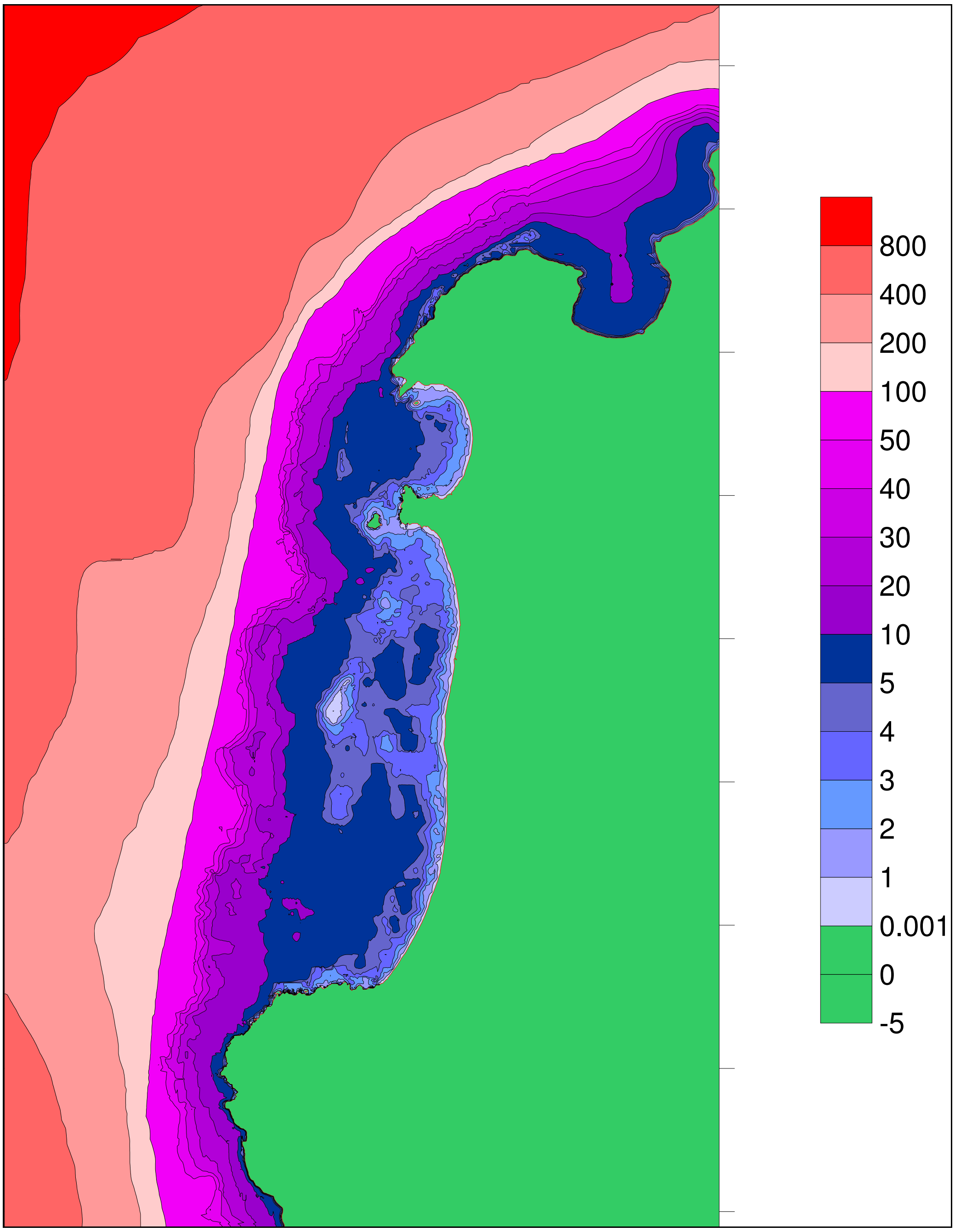


Figure 3.4:Contour map of Long and Bloody Bay (depth in meters)

3.2. Shoreline survey

During the shoreline survey a map was created of the present shape of the shoreline. Combined with this mapping an inventory was also made of interesting features that were noticed along the shoreline. The documentation of the shoreline consists of a map, a brief text description and several photographs.

3.2.1. Shoreline mapping

The exact position and shape of the shoreline was obtained by slowly walking the waterline with a GPS. Every second the GPS registered its position (Figure 3.5).

3.2.2. Shoreline inventory

For a clear overview of the shoreline inventory, the total area of the Negril Beach is divided in four regions (Figure 3.5). The different characteristics of each region are shortly described. A detailed review and a description of all collected waypoints with matching photographs can be found in appendix 2.

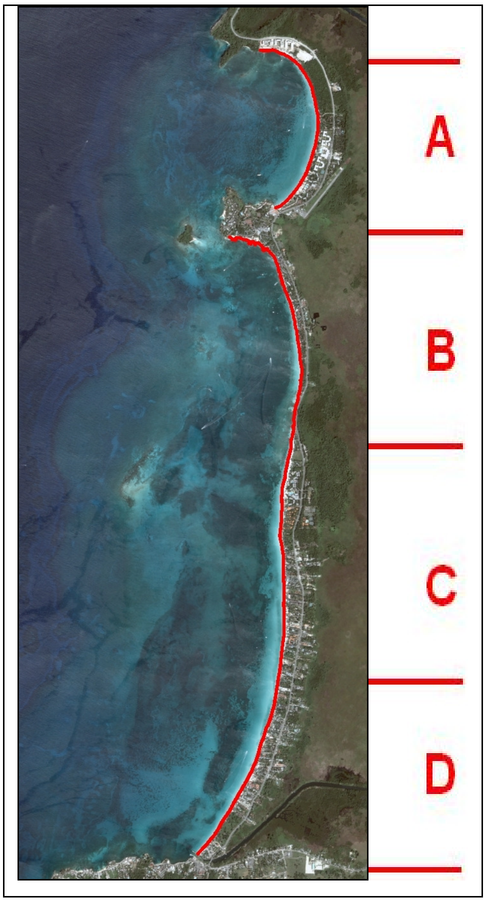


Figure 3.5:Shoreline map 2006

Bloody Bay (Region A)

Along the beach of Bloody Bay a few trees can be found that are standing near the waterline (Figure 3.6). Furthermore there are many drains constructed for rain water from hotel roofs and streets. These drains are probably sometimes used for waste water by small bars situated near or on the beach (Figure 3.7). The southern corner of Bloody Bay contains a lot of algae (Figure 3.8).

Figure 3.6:North of Bloody Bay

Figure 3.7:North of Bloody Bay

Figure 3.8:South of Bloody Bay

Northern part of Long Bay (Region B)

In the northern part of Long Bay the bigger hotels have built their own coastal structures, such as breakwaters, groynes, and a jetty for boats (Figure 3.9). To maintain the beach several seawalls are situated along the coast of these hotels as well (Figure 3.10). In this section the beaches have an average width of 20m consisting of probably nourished sand. The beach In front of the hotel Sandals and the public beach more to the south contain a lot of algae.

After this part the beach becomes quite narrow and sometimes disappears completely. There's a ridge of 1m height with vegetation that consists of grass and trees (Figure 3.11:)

Figure 3.9:North of Long Bay (Hedonism2)

Figure 3.10:North of Long Bay (Hedonism2, Sandals)

Figure 3.11:Middle of Long Bay

Middle part of Long Bay (Region C)

In the middle part of Long Bay the beach increases abruptly in width to 30m. This width remains constant in this part of Long Bay (Figure 3.12). Down to the South there are several little bars and restaurants near or at the waterline (Figure 3.13). The width of the beach increases again in the direction of the hotel Charela Inn.

Figure 3.12:Middle of Long Bay near Beaches

Figure 3.13:Middle of Long Bay

Southern part of Long Bay (Region D)

From the Charela Inn to the South the beach is again constant in width (about 20m) for quite a distance (Figure 3.14). More southwards a little ridge develops to a height of approximately 0.75m (Figure 3.15). At the most southern part the river is guided by two groynes (Figure 3.16). This is also the place where the beach ends. After this the coast only consists of rocks and cliffs.

Figure 3.14:Middle of Long Bay (Charela Inn)

Figure 3.15:South of Long Bay

Figure 3.16:South of Long Bay (Negril river)

3.3. Photographic survey

3.3.1. Shoreline photos

In the data collection phase two shoreline mappings were undertaken within a four week interval. The first mapping was made under calm weather conditions in the second week of October of 2006. During the second mapping in the third week of November 2006, the weather changed drastically along the coast of Negril. The temperature dropped, clouds came in and the wind speeds picked up.

The pictures which were taken before and after this three day storm event show a drastic change of the beach shoreline. Below a few interesting points are shown listed from the south (Negril River) to the north (Point Village).

The Figure 3.17 and Figure 3.18 show a loss of almost 1.5m sand in front of the groynes of the Negril River in only a couple of days. Between the two groynes, a lot of sediment was dropped during the storm, making it very difficult for boats to pass.

Figure 3.17:Groyne Negril River (November 19th 2006)

Figure 3.18:Groyne Negril River (November 22nd 2006)

More to the North an almost 1m thick layer of sand was eroded from the beach during the storm event (Figure 3.19 till Figure 3.22)

Figure 3.19:South of Long Bay (November 19th 2006)

Figure 3.20:South of Long Bay (November 19th 2006)

Figure 3.21:Wall, South of Long Bay (November 19th 2006)

Figure 3.22:Wall, South of Long Bay (November 19th 2006)

In the middle of Long Bay, in front of the Charela Inn hotel the beach was relatively unchanged.

Figure 3.23:Charela Inn (October 22^{nd} 2006)

Figure 3.24:Charela Inn (November 22^{nd} 2006)

Figure 3.25 till Figure 3.28 show a lot of algae and sea grass contamination on the beach after the storm, although the beach profile seemed to remain in tact.

Figure 3.25:Seasplash, middle of Long Bay (October 22^{nd} 2006)

Figure 3.26:Seasplash, middle of Long Bay (November 22^{nd} 2006)

Figure 3.27:North of Long Bay (October 22nd 2006)

Figure 3.28:North of Long Bay (November 22nd 2006)

In the North of Long Bay, in front of the Sandals resort, the pictures show again 1m erosion, resulting in exposed roots of the trees (Figure 3.29 and Figure 3.30).

Figure 3.29:Sandals, North of Long Bay (October 20th 2006)

Figure 3.30:Sandals, North of Long Bay (November 22nd 2006)

The conclusion from the pictures is that the middle part of Long Bay did not change very much during the storm, while in the North and South a lot of erosion took place. Along the whole beach of Long Bay there were no signs of any sedimentation.

3.3.2. Historical data

In order to get a clear picture of the long term erosion pattern, historical data in the form of aerial and satellite photos has been compared.

Aerial photos from 1968, 1980 and 1991 were compared with a satellite image from 2003 and the shoreline which was mapped in October 2006. Although the aerial photographs have a somewhat poor quality, the long term erosion trend is clearly visible. Detailed images about the shoreline changes can be found in appendix 3.

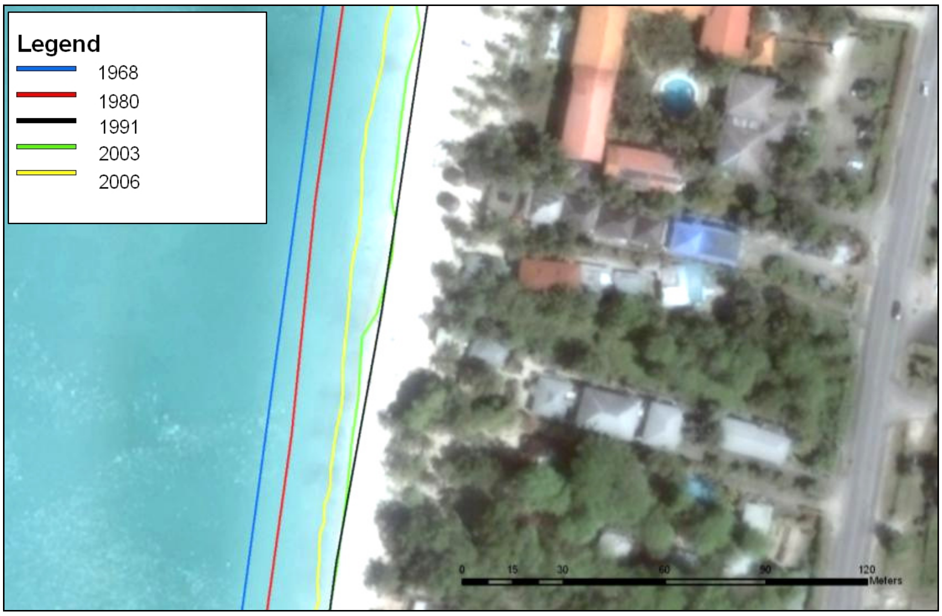


Figure 3.31:Changes in shoreline in the middle of Long Bay (Charela Inn)

The aerial photo from 1968 shows a beach with an average width from the waterline to the vegetation of 30-40m all across Long Bay and Bloody Bay. Between 1968 and 1980 there have been several changes in the width of the beach. The northern part of Bloody Bay has lost around 15m of beach. The beach in the southern part of Bloody Bay remained the same. The beach of Long Bay showed an overall erosive trend of about 10m.

There is again a difference visible in the width of the beach on the photograph from 1980 and 1991. Now the northern part of Bloody Bay stayed the same, but the southern part showed an erosive trend of about 15m. In this period of time the middle part of Long Bay lost about 20m of beach. The northern and southern part had smaller signs of erosion. Here the beach on some places only lost about 10m.

Between 1991 and 2003 the width of the beach of Bloody Bay almost stayed the same. Only a little erosive trend of less than 5m is visible. In Long Bay the overall width of the beach had also hardly changed. There were some areas that showed an erosion of 10m, but there were also places found where the beach had increased for 10m. This took place in the middle part of Long Bay.

The satellite image from 2003 was also compared with the result of the shoreline mapping of 2006 and this showed that the beach in Bloody Bay did not change much. Only in the southern part a small increase of width could be noticed. The beach of Long Bay showed in this period several places that had gained 10m of beach and several areas that had lost about 10m of beach.

Year	Erosion rate Long Bay (m/yr)	Erosion rate Bloody Bay (m/yr)
1968-1980	0.80	1.25
1980-1991	1-2	1.25
1991-2006	1	0.30
1968-2006	1	0.50

Table 3-2:Erosion rates

3.3.3. Anecdotal evidence from locals

During the field work in Negril there was a lot of information obtained by talking to locals. Although the information was not always reliable due to personal motives and opinions, on one thing they all agreed. The beach used to be significantly wider in the past, maybe even as much as 50m.

Furthermore several people said that it was normal for the beach to erode and to recover again after a big storm. What they all did notice was that in the past ten years the beach has been recovering less and less.

3.4. Sediment characteristics

To get some information about the sediment characteristics along the two bays, several sand samples were taken. At different locations in Long Bay and Bloody Bay two samples were taken at each location: one close at the waterline and the other 5m into the sea. Photographs of the sand samples have been made to get an impression of their consistency.

The samples were analyzed by an external laboratory to determine their grain size distributions, which will be used in the sediment transport model LITPACK. The pictures of the samples together with their exact location and more details about the grain size distributions are shown in appendix 4.

3.5. Waves and tides

A wave recorder (InterOcean S4ADW) was deployed off-shore in the northern part of Long Bay to record wave heights, periods and directions. The tidal information will be used to reference the beach profiles which were taken to the mean sea level. Tidal results are shown in appendix 6.

3.6. Current patterns

The current data for Long Bay and Bloody Bay has been collected by a current meter and with the use of so called drogues.

A drogue is a cross-shaped 3-dimensional device that is lowered beneath the water level and that moves with the current as shown in Figure 3.32. With a GPS the position of the drogue was measured in time steps of 10-15 minutes. The speed and direction of the movement are derived from this. The drogues were deployed in sets of three in a line perpendicular to the coast so that several measurements could be done at the same time.

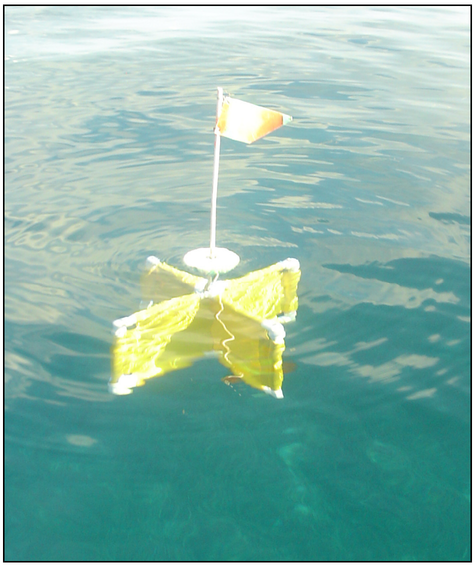


Figure 3.32:Drogue

3.6.1. Current meter

The current meter was placed at a depth of about 8 meters behind the big coral reef, looking from shore.

The meter has recorded the tide during the period starting on 10/20/2006 until 11/28/2006. Figure 3.33 gives an overview of the water depth during this period. The computed mean sea level (MSL) is 7.58m.

The two red areas display the two periods wherein drogue tracking measurements have been held. For more details reference is made to appendix 6.

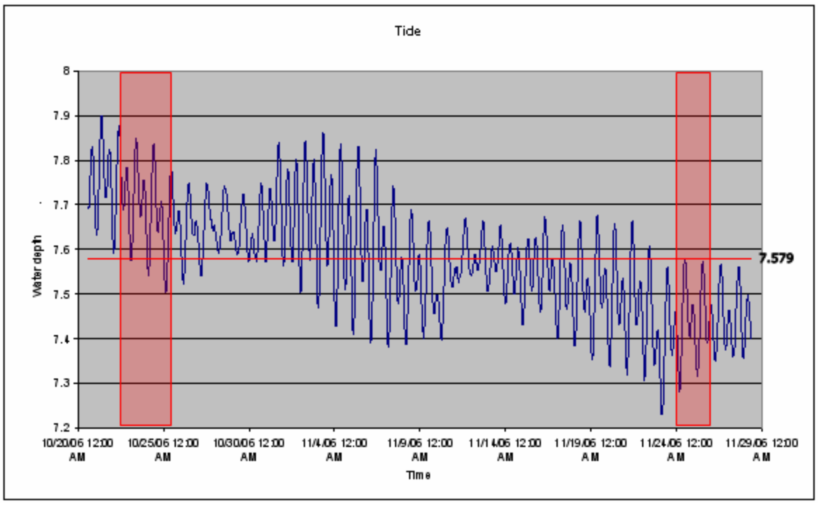


Figure 3.33:Tides recorded by current meter

3.6.2. Drogues

Drogue tracking has been performed on October 23-25 and November 24 and 25 2006. Minimum time span per drogue is one hour unless stated different. Table 3-3 gives an overview of the velocities subtracted out of the appendix 6.

Morning [m/s]

Drogue series	*Near shore*	*Mid. shore*	*Far shore*
1	-	-	-
2[3]	0.085	0.093	0.075
3[1]	0.039	0.036	0.055
4[1]	0.040	0.035	0.045
5	-	-	-
6[7]	-	0.068	0.041
7[4]	0.090	0.085	0.072
8[4]	0.076	0.097*	0.097
10bb[7]	0.044	0.051	0.075
11bb[7]	0.048	0.036	0.054
12[9]	0.130	0.162	0.113
13[11]	0.113	0.100	0.159
14	-	-	-
15[11]	-	0.171*	0.143*
16bb	-	-	-

Afternoon [m/s]

Drogue series	*Near shore*	*Mid. shore*	*Far shore*
1	-	-	-
2[5]	0.120	0.097	0.087
3[2]	0.064*	0.094*	0.115*
4[2]	0.104	0.066	0.082
5	-	-	-
6[6]	0.064	0.051	0.028
7[8]	-0.001	0.009	0.041
8	-	-	-
10bb	-	-	-
11bb[8]	-	-	-
12[12]	0.086*	0.063*	0.069*
13[10]	0.096	0.087	0.067
14[10]	-	0.067*	0.065*
15	-	-	-
16bb[12]	0.058	0.026	0.141

* Significantly less than 1 hour time span

Table 3-3:Average velocities drogues (morning/afternoon) in m/s

Each superscript corresponds with the time period wherein the measurement has been taken and can be found in appendix 6. The purple line in these tide graphs shows the computed mean sea level (MSL).

3.7. Sea grass

There is a premise which implies that the sea grass degradation has led to the beach erosion. The implication is that a decrease in the amount of sea grass would lead to a decrease in the presence of coralline algae such as *Halimeda opuntia* which is a contributor to the production of sediment. As a result of the years of erosion and the various views on the cause of this erosion, it was important to do a benthic assessment which involved examining the sea grass beds along the Bloody Bay and Long Bay sections of Negril.

3.7.1. Methodology

Due to the expanse of the area, approximately 10km of beach, it was difficult to map each sea grass bed along the Long Bay and Bloody Bay area. A process of ground-truthing was therefore undertaken. A satellite image of the area from 2003 was used to outline areas that were suspected to be sea grass beds. Sixty points were chosen randomly within these outlined areas, and were examined to ascertain whether sea grass was still present or not. Also photographs were taken at some of the points to get an impression of the composure of the sea grass beds.

3.7.2. Results

Figure 3.34 gives a fairly accurate representation of the sea grass beds located in the Bloody Bay and Long Bay area with beds growing as deep as 10m to 17m. The most predominant type of sea grass observed in the specified area is Thalassia testidium with some Syringodium filiforme mixed in the beds, see Figure 3.35.The area is characterized by fairly dense and very healthy sea grass beds interspersed with sandy areas. As can be seen in Figure 3.34, few areas (points 10, 25 and 38) did not have any sea grass. Points 44, 45, 48, and 51 show signs of new growth of Thalassia testidium. These points are highlighted on Figure 3.34 below with a color key. Sand patches interspersed with patches of sea grass were observed at locations circled in yellow (49, 50). Halimeda opuntia was also found to be present in the sea grass beds. The Halimeda opuntia is circled in red in Figure 3.36. This is a calcified type of coralline green algae that is jointed. In the area nearer to the river outfall, the water was very cloudy which made it very difficult to confirm what was present.

A table containing the results from the truthing process and showing the present species in the area can be found in appendix 7.

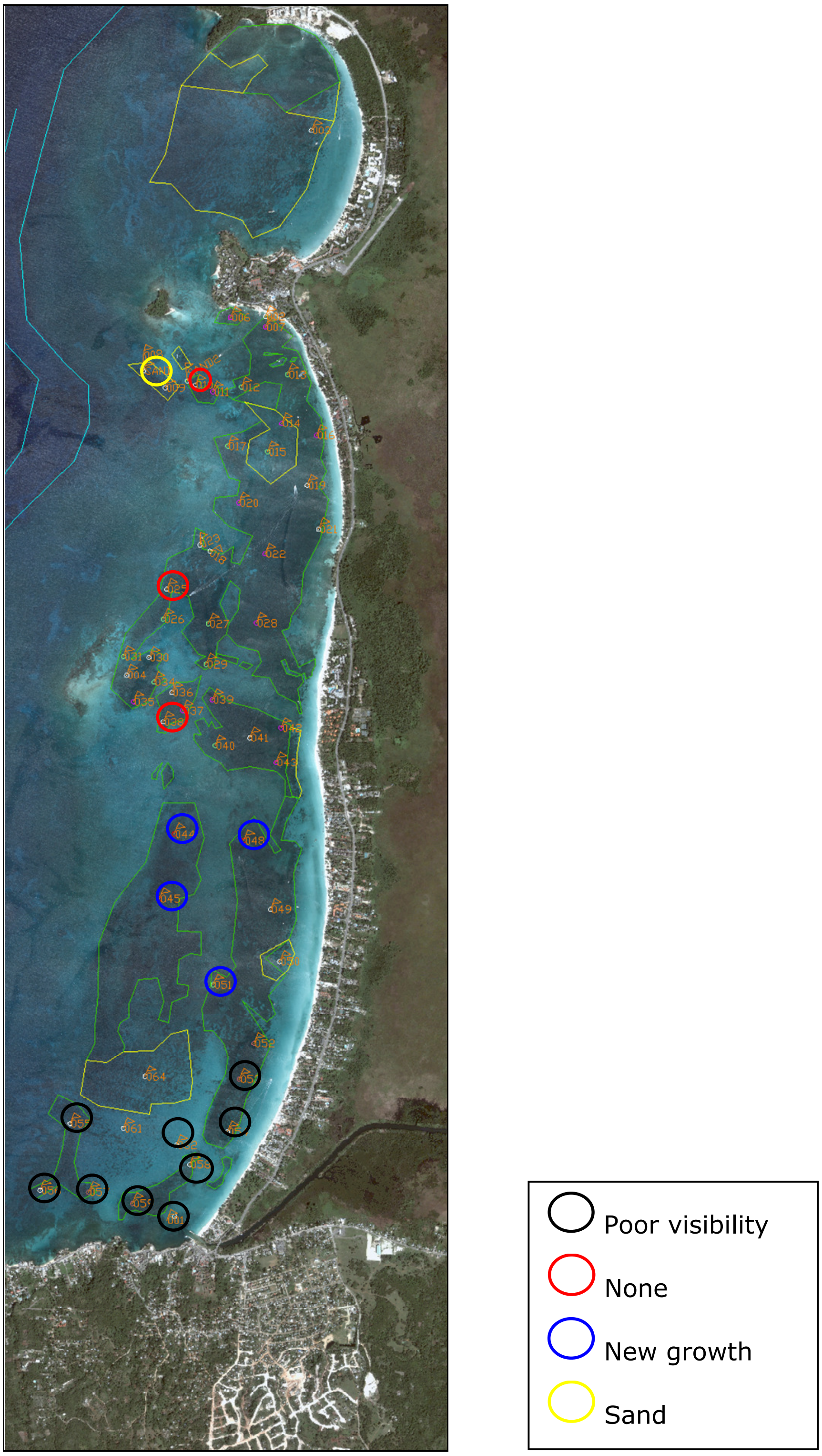


Figure 3.34:Sea grass mapping

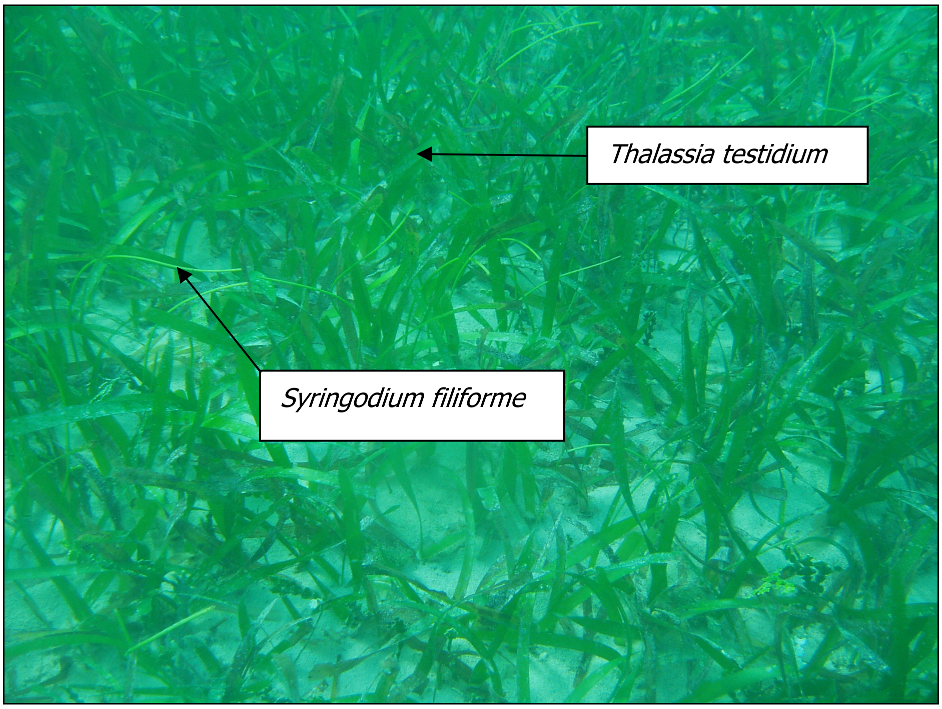


Figure 3.35:Thalassia testidium and Syringodium filiforme

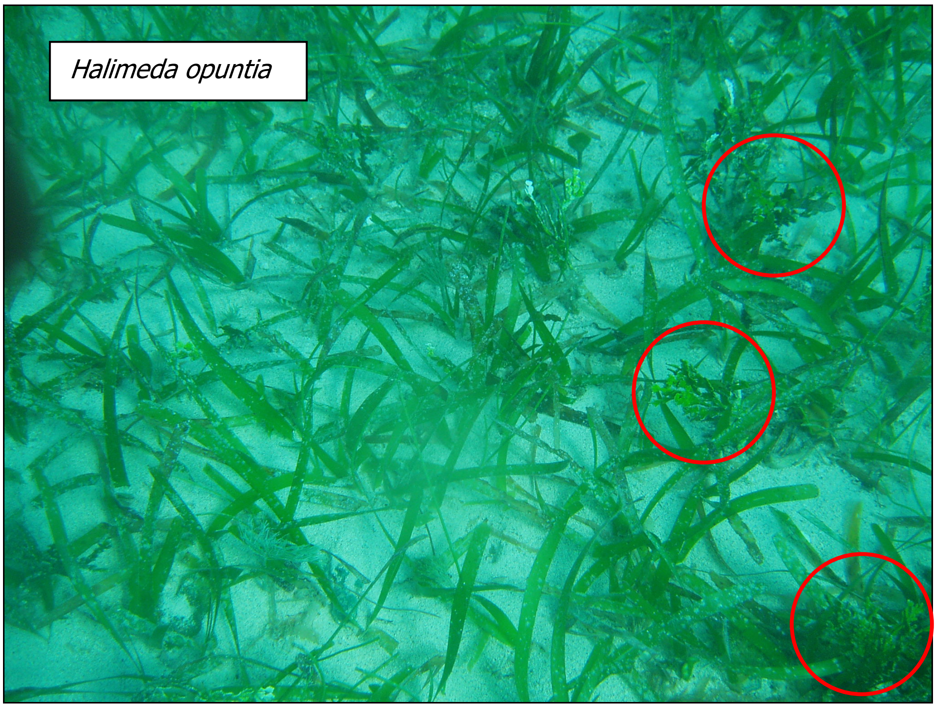


Figure 3.36:Halimeda opuntia

3.8. Meteorology

To obtain information about the weather conditions in Negril a weather station was placed in the middle of Long Bay on top of one of the buildings of the hotel Charela Inn. Data will be collected about the wind speed and wind direction, the air pressure, the quantity of rain, the temperature and the quantity of sunshine. This weather station has to be put up for at least a month to obtain useful data and after this period a detailed description of the weather conditions can be derived. The weather station has been collecting data since the end of November 2006 which is not yet available.

3.9. Environmental issues

3.9.1. Coral reefs

Observations during the storm in week 3 of November 2006 show the importance of the reefs in Long Bay as a natural breakwater. It seems that the higher waves break on the reef and loose energy before they break near the shoreline.

From anecdotal evidence of locals was also derived that the protective nature of the reef was much greater in the past. People said that over the years the length and width of the reefs was diminished, partially due to fishermen using explosions near the reef to catch fish more easily.

3.9.2. Pollution

Signs of pollution are mostly observed in the form of algae at various locations along Long and Bloody Bay. There are a few sources of pollution within the system boundaries.

The first one is the increase of tourists in the area. They tend to leave their waste at the beach, what contributes to the total pollution in the area.

The second source for pollution appears after storms when a lot of sea grass is deposited on the beach. The sea grass is mostly buried under a layer of sand and is left to rot. This could probably enable a nutrient flow into the sea what should be examined by biologist.

Another source of pollution is the dirt and waste from the watershed of the Negril River which end up at the river mouth. After heavy rainfall the diminished quality of the water is visible because the water is brown colored.

The last pollution source involves also the flood water run-off but now specific around the hotels. The density of buildings along the coastline of Negril is increasing. As a result there are more paved areas that stimulate a fast run-off of flood water.

4. Data Analysis

After the data collection phase the acquired data was processed and analyzed. This chapter describes the wave, sediment transport and current models that were used, together with their input parameters and their results.

4.1. Wave modeling

It is common practice in coastal engineering to distinguish two types of wave climates. One, the day to day wave climate, occurs during the whole year and as such can probably have an influence in transporting sediments. The other occurs during special events, such as storms and hurricanes. The most dramatic changes happen during storms and the largest visual impact is often caused by these types of weather conditions. In order to be able to model the sediment transport we need to know the significant wave heights which occur along the coast.

4.1.1. Day to day wave climate

To help gather information a current meter was deployed to record a times series of wave data. Unfortunately the period of recording is to short (about 1 month) to use this data to produce a reliable wave climate in the area of Negril. This means that the wave data was acquired from a different source.

The wave data was bought from the UKMO (United Kingdom Meteorological Office). This data consist of significant wave heights, peak periods and directions in a 6 hour interval taken over a 3 year period. Unfortunately no data was available in front of the West coast of Jamaica, and as such data was taken from the North side.

The data consisted of two different wave components, sea and swell. Sea waves are waves which are locally generated by the wind, while swell waves are waves which are generated by distant storms. Generally speaking swell waves have longer periods and wave lengths than sea waves. An overview of the data sorted in directional bins of sea and swell can be seen in Figure 4.1.

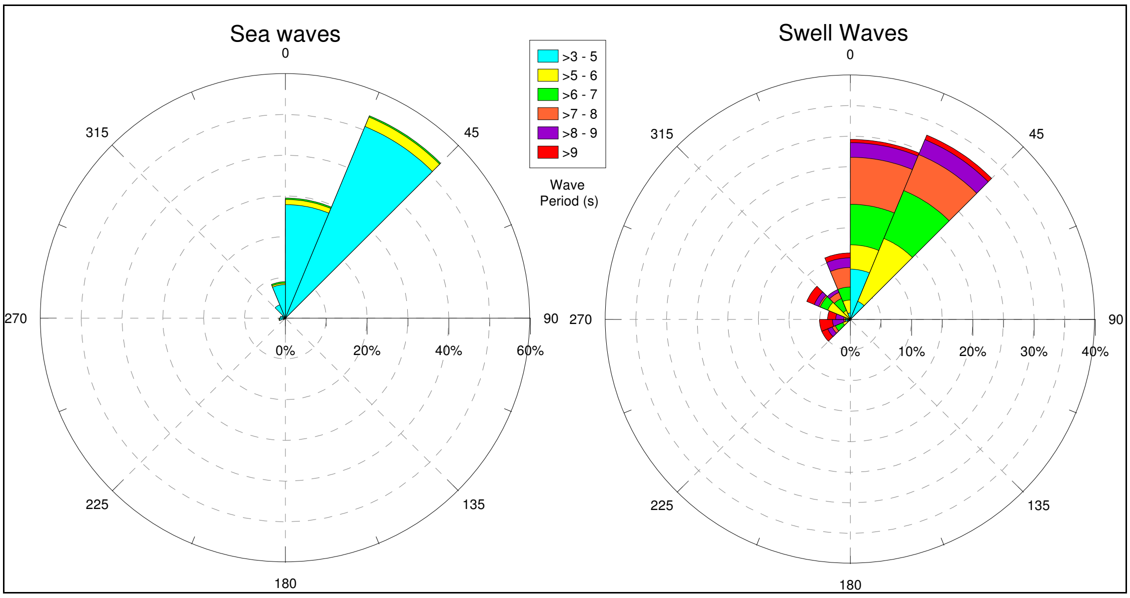


Figure 4.1:Wave periods of sea and swell waves

From the directional data it can be seen that most of the sea waves come from the North-Eastern direction. This dominant wind is responsible for the generation of these waves. The swell waves approach from more different angles, but again predominantly come from the North-Eastern direction.

The data in its current form is however not ready for use in the sediment transport model since the wave information is given in deep water conditions between Cuba and Negril. Thus this data needs to be transformed to local wave heights and periods. In order to achieve this, the wave model SWAN was used.

Transforming wave data

Due to the large amount of day to day information available (4 years in 6 hours intervals) a choice had to be made which conditions would be modeled. A first choice can be made based on the directional information. Since the wave information applies to deep water conditions between Cuba and Jamaica waves approaching from the South-West, South and South-East travel away from the problem area and can thus safely be ignored. Based on this it is tempting to also ignore waves from the North, North-East and East since these waves cannot reach Negril in a straight line from the deep water location. It is however important to realize that these waves will be influenced by the shallow coastal areas and refract around Jamaica and thus they could influence the Negril coast.

With the dominant North-Eastern winds the directional filtering did not result in a significant enough reduction of data to begin modeling. A further reduction of data was achieved by making a distinction between sea waves and swell waves.

Almost all of the sea waves are generated by the dominant North-Eastern winds. These waves are generally shorter in wave length than swell waves traveling in the same direction. Since waves with longer periods refract to a larger extent the swell waves from North to North-East might influence the Negril coast while the shorter sea waves would not be affected by the shallow areas. In order to determine if these waves could be safely ignored a test run was done. Results from these test runs can be seen in Figure 4.2.

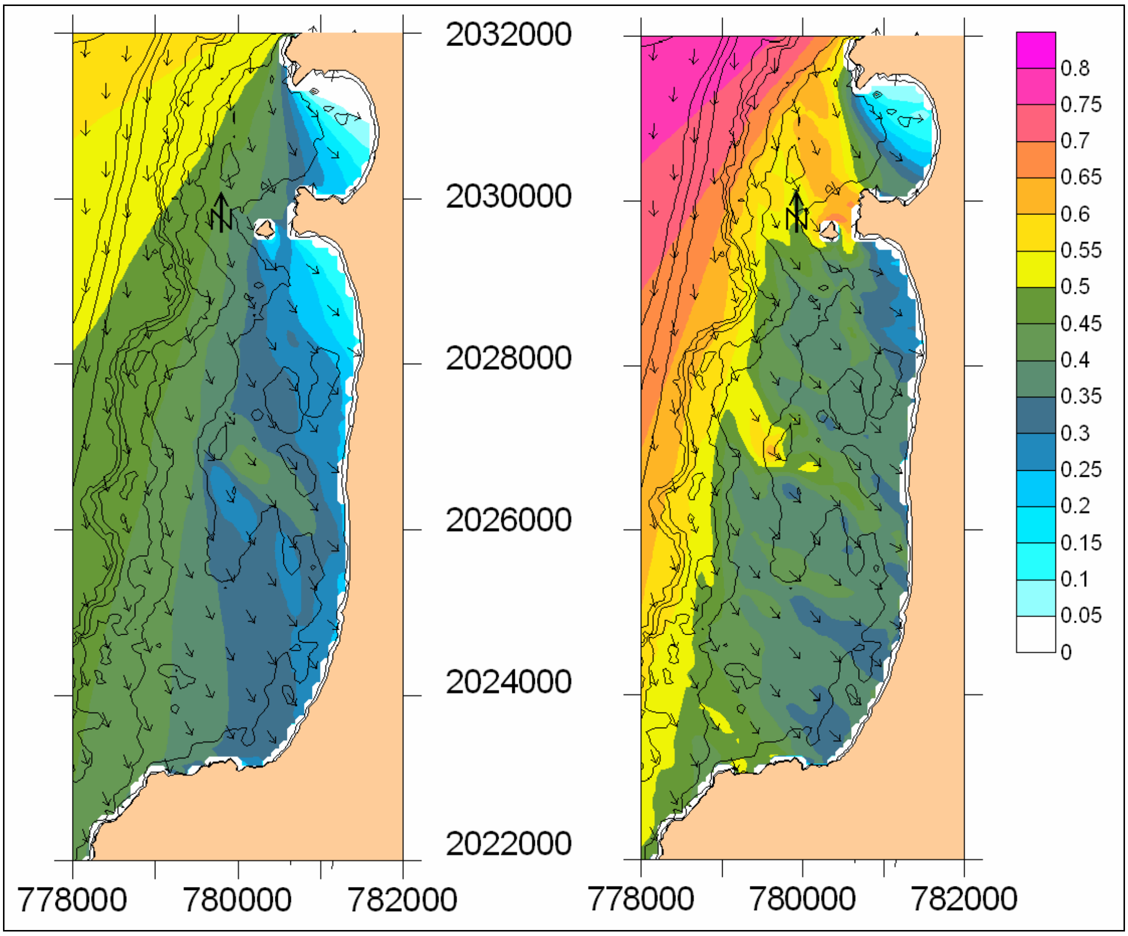


Figure 4.2:Difference in refraction of sea vs. swell waves, left figure depicts sea waves while the right side shows the swell waves.

In the test run identical wave heights and directions were taken at the boundaries. Only the wave period was varied with 3s for sea waves and 6s for the swell waves. These are the average periods from the dataset seen in Figure 4.1.

The figure shows that the longer swell waves refract more and thus lead to higher wave conditions near the coast than the shorter sea waves. Since the input scenario used was favorable towards the sea waves in direction and period it can be concluded that these waves can be safely excluded from the input data.

Using only the swell climate from the North-West to the East each of the resulting wave conditions were modeled and wave conditions on 20 points near the Negril coast were obtained. Figure 4.3 shows the wave height and directions of the waves. For example, almost 45 percent of all waves had a significant wave height smaller than 0.3m and traveling to a direction between 315 and 337.5 degrees.

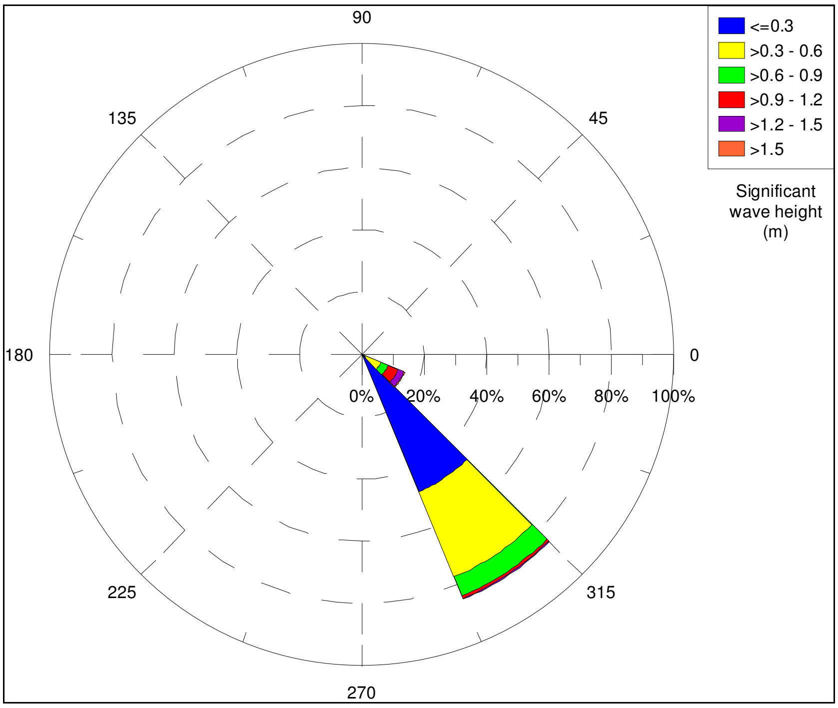


Figure 4.3:Wave directions and height at a point near the South side of the bay

These results will be used in the sediment transport model which is described later on in this chapter. For the results of all the points you are referred to appendix 5.

To further clarify the results of how the waves interact with the shallow foreshore a plan view is given of waves approaching from the North-East with a wave height of 2.8m and a period of 8.7s. This can be seen in Figure 4.4.

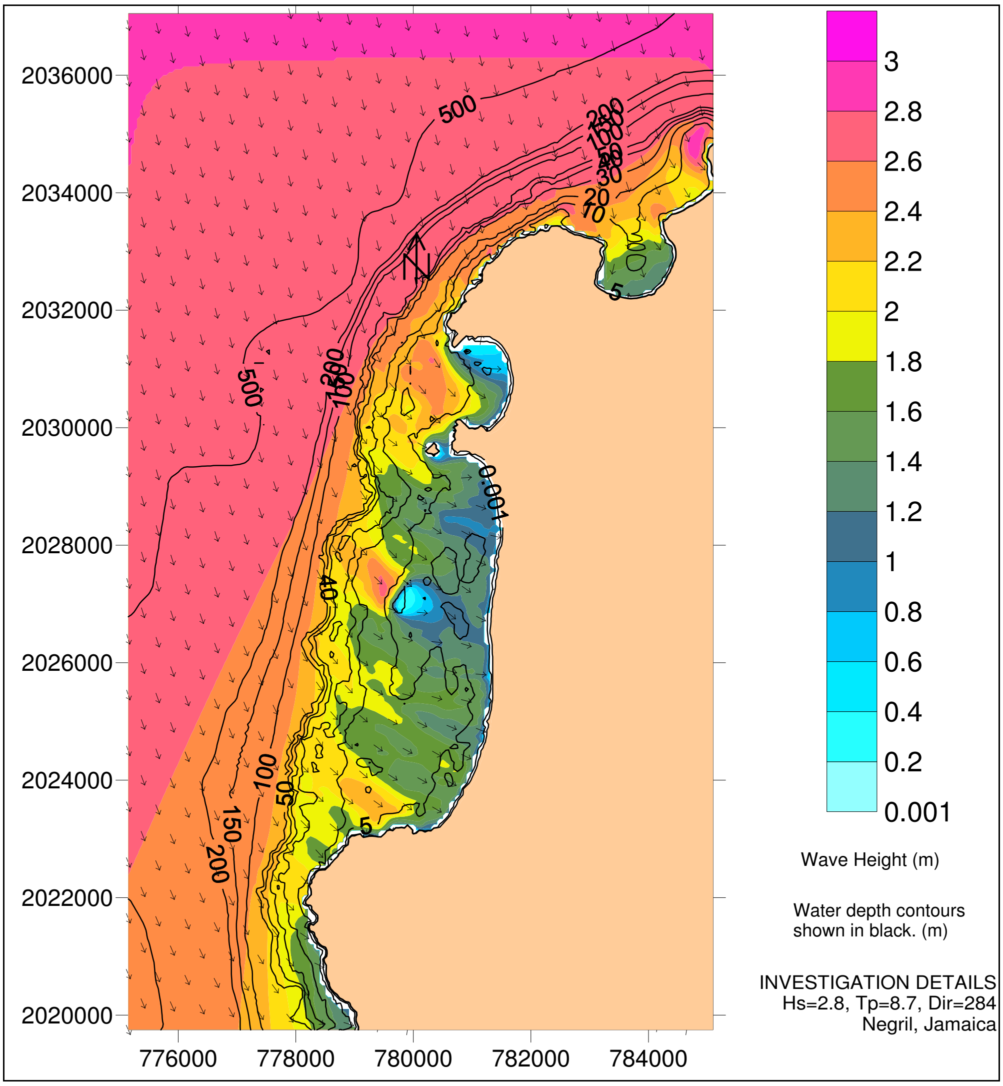


Figure 4.4: Waves approaching from the North-West, the sheltering which the reef provides can be clearly seen.

These waves represent the higher part of the wave climate and are comparable to the waves found during the 21 November storm event. The sheltering provided by the reef can be seen in the middle part of the figure. Another interesting fact is that most waves approach the coast almost perpendicular. This is probably due to the extensive shallow foreshore.

4.1.2. Hurricane wave climate

Hurwave

To generate a hurricane wave climate near Negril a program called Hurwave by Mr. Jamel Banton was used. This program hind casts wave conditions near a specified point using a database of all past Hurricanes in the Caribbean. An example track is given in the picture below (Figure 4.5).

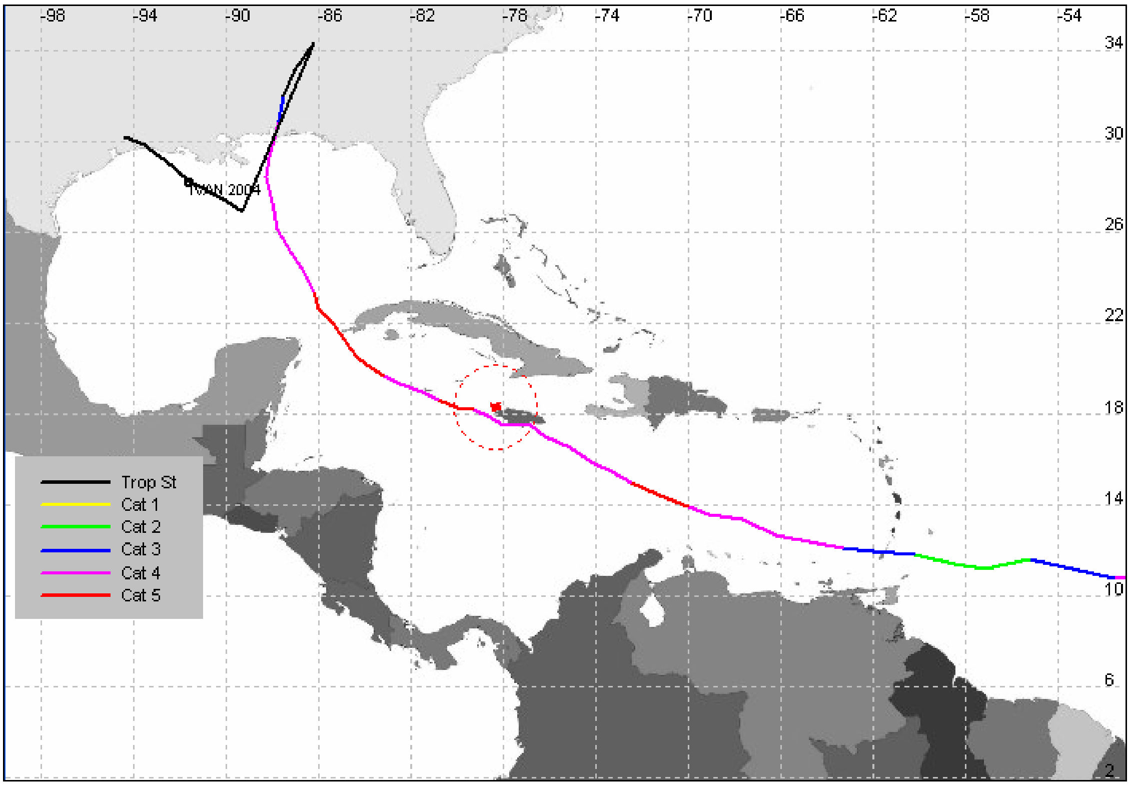


Figure 4.5:Hurwave example

Using the recorded tracks hurricanes and tropical storms passing the Negril area in a radius of 300km were included at a center point with a longitude of -78.37 and latitude of 18.32. Hurricanes within this radius generate waves higher than day to day waves. If the Hurricane passes at a distance further than 300km its influence will be included in the day to day spectra, here these waves are represented by the swell waves.

Within the program the improved Young model was used to generate wave heights from the recorded wind speeds. Furthermore, only waves in the direction of the Negril coast were included into the statistical analysis.

The output of this program was a significant wave height and peak period for a design energy spectrum. These were used to construct a JONSWAP spectrum. The results are summarized in the following table.

Return period (year)	Significant wave height (m)	Peak period (s)
5	4.68	8.73
10	6.43	10.66
25	8.15	12.38
50	9.23	13.39
100	10.20	14.25
150	10.72	14.71

Table 4-1:Results Hurwave

These results will be entered into the wave model SWAN to calculate the near shore transformations of the spectrum.

Modeling Hurricane waves

Using the information obtained with Hurwave two different Hurricane scenarios were run. For further modeling with the sediment transport model especially the more frequent storms are interesting as these still may occur often enough to have a systematic impact. These are represented by storms with a 10 year return period.

The solution might encompass several structures which will be erected. Since the design conditions ask for a 50 year return period the storms with a return period of 50 years were modeled as well. The results are summarized in Figure 4.6. Please be aware that the color scales in the two figures are different. Full page versions of the images are included in appendix 5.

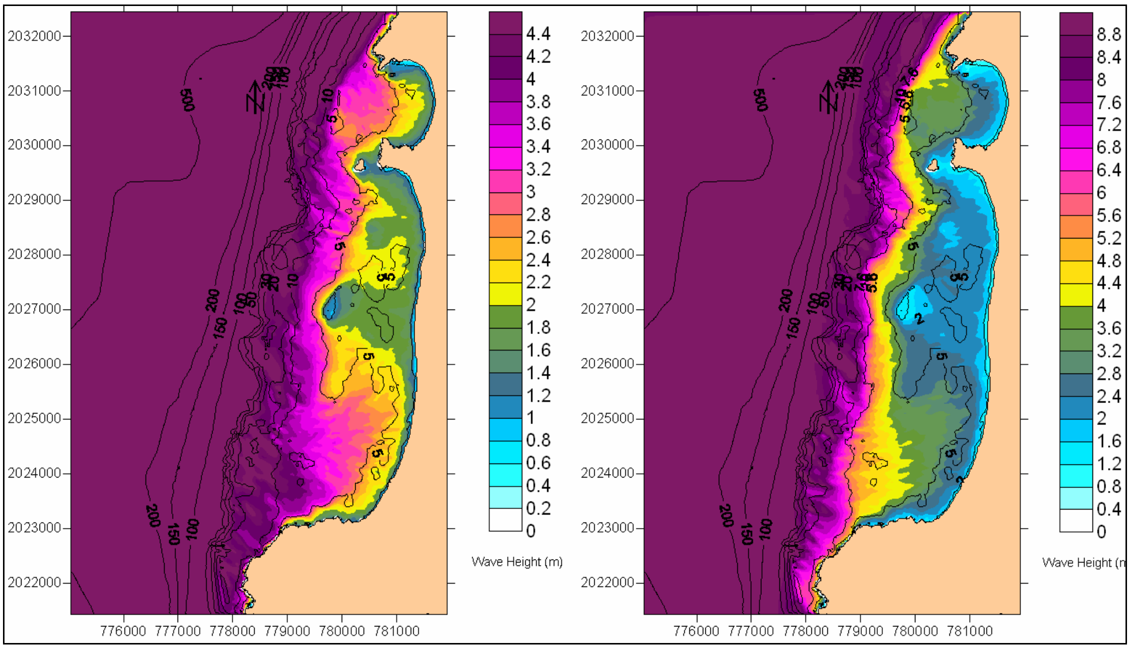


Figure 4.6:On the left side the significant wave height resulting from a storm with a return period of 10 years. On the right the significant wave height with a return period of 50 years.

4.2. Sediment transport modeling

Waves usually do not approach the shoreline exactly perpendicular. Instead they make varying angles with a normal to the coast. This drives a longshore current which has the potential to transport sediment. An indication for the yearly amount of sediments transported through a series of cross-sections would be useful to estimate the importance of this mechanism.

The sediment transport model LITPACK from DHI (Danish Hydraulic Institute) was used to model the longshore and cross-shore movement of sediments. In addition to this a measured storm event was rerun to see profile reactions on such a storm.

4.2.1. Model setup

The modeling of waves resulted in twenty points in which the significant wave height, peak period and direction of the waves is known as a function of time. These points will function as a starting point for the modeling of sediment transport.

Using the bathymetry created from the depth soundings and measured beach profiles 20 cross-sections were taken. These cross-sections start in the points where the wave climate is known and end perpendicular to the coast. Figure 4.7 shows the 20 profiles.

Due to the shape of Long Bay and Bloody Bay the North and South cross-sections in both bays are directed to the North and South. An unfortunate consequence of this is that these profiles are not always perpendicular to the depth lines at these locations. This results in distortions in the modeling of these lines since the sediment transport model always assumes perpendicular depth lines to each part of the profile.

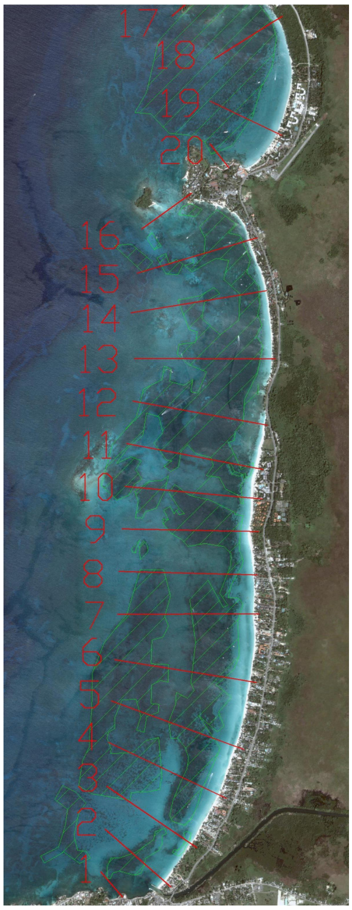


Figure 4.7:Cross-sections for sediment transport modeling

The wave propagation through these profiles is thus affected and not accurately modeled. Profiles 1, 16, 17 and 20 will suffer the most from these distortions and no conclusions can therefore be based on these profiles.

An important feature of the Negril coast is the extensive sea grass beds in front of the shoreline. These sea grass beds resist erosion far better then bare sand layers. To model this resistance to erosion the sand characteristics were modified at those locations in the profiles where these non-erodable sections occurred to an infinite grain size. This prevented erosion from these locations while still allowing sedimentation on these sections. The same procedure was applied to rocky sections of the coast (Figure 4.8)

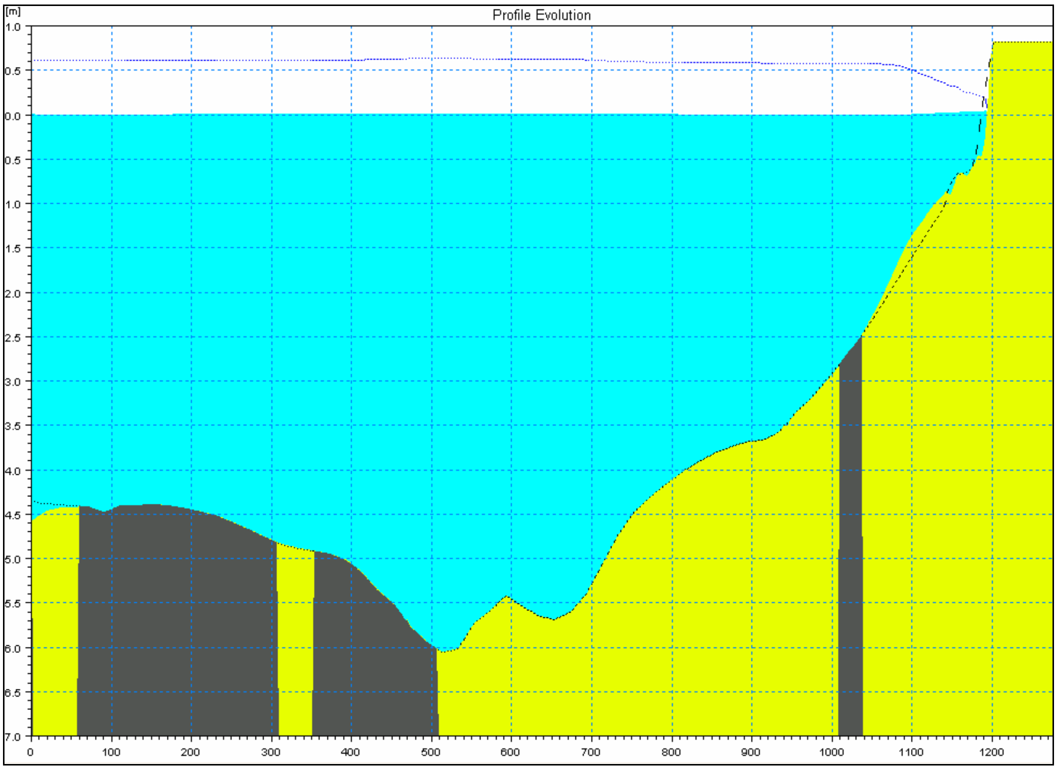


Figure 4.8:Sample cross-section for input into the sediment transport model. The yellow areas indicate sand while the darker parts indicate non-erodable layers.

Sediment characteristics for the erodable part of the profile were obtained from the sediment samples taken in Negril. From these the nearest sample to a particular cross-section taken on shore was chosen as a representative sample in that area. For a list of sediment samples and their locations please look at appendices 4 and 8.

4.2.2. Longshore transport modeling

Using the cross-sections and the previously calculated wave climate (paragraph 4.1) a longshore model was run. In the model all of the sections were modeled as a single profile of an infinite coastline. No morphological changes were included.
The results of the longshore transport modeling are summarized in Table 4-2.

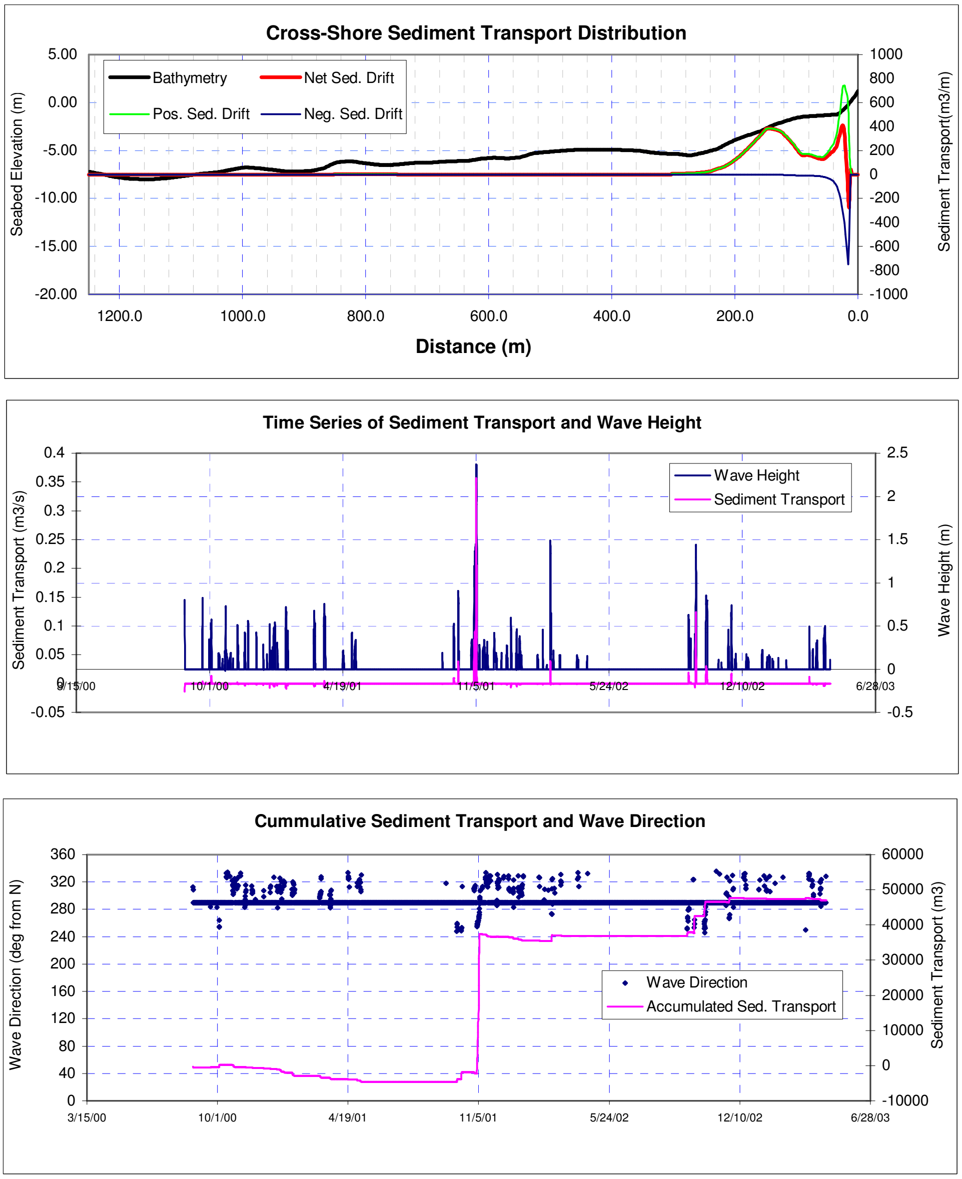
Profile nr	Net transport (m^3/year)	Gross transport (m^3/year)	Comment
1	1805.2830	2287.9245	South of Long Bay
2	12875.4717	13886.7925	
3	9430.1887	11400.0000	
4	18845.2830	23430.1887	
5	17739.6226	25003.7736	
6	1336.9811	13784.9057	
7	-9245.2830	15558.4906	
8	-9200.0000	13215.0943	
9	-4916.9811	19513.2075	
10	-6173.5849	21452.8302	
11	-19324.5283	20630.1887	
12	-9381.1321	13430.1887	
13	0.0000	0.0000	
14	-25905.6604	26128.3019	
15	-14105.6604	14283.0189	
16	-6471.6981	6471.6981	North of Long Bay
17	0.0000	0.0000	North of Bloody Bay
18	-14279.2453	14279.2453	
19	633.5849	6977.3585	
20	1775.4717	2721.1321	South of Bloody Bay

Table 4-2:Yearly sediment transport per profile (positive transport to the North and negative transport to the South)

There are two reasons for the relatively small amount of transport through the profiles. The first one is the sheltered location of both bays to the waves approaching from the North-West, which is the dominant wind direction in this region. The second is the long shallow area in front of the coastline which ensures that the waves have plenty of time to refract and approach the coast in an almost perpendicular direction.

Below (Figure 4.9) a detailed overview of the sediment transport in profile 5 is given, for the results of other profiles reference is made to appendix 8.

These figures show that the sediment is being transported near the shore in the breaker zone. This is also predicted in theory as this is the region where the waves transfer most of their energy.



Project:	Negril Beach, Jamaica		Prepared by:	Johan Henrotte
Title:	Litdrift Model Results		Date:	Dec-06
Profile:	Number:	**5**	Notes: Positive transport is towards the north and negative transport is towards the south	
	Location:	**Negril Beach**		
Wave Climate:	Source:	SWAN		
	Period:	**24/08/2000 - 21/04/2003**		

Figure 4.9:Longshore sediment transport in profile 5.

Figure 4.10 gives an indication of the direction and size of the longshore transport in each profile. Longer arrows indicate larger transport rates than shorter arrows.

The first interesting feature of the transport is the difference in direction between profiles located at the North and profiles located at the South side of the bays. Profiles at the North generally transport in a southward direction while at the South the transport is prominently northward. This is most likely due to incoming waves from North-Western directions and the shape of the bay and the profile orientation.

A second interesting feature is the lack of a net sediment transport through profile 13. This can only be explained by the extensive sea grass beds which protect a large part of the profile and the small angle the incoming waves make with a normal to the shoreline in the breaker zone. This small angle is a result of wave refraction over the large shallow areas in front of the coast.

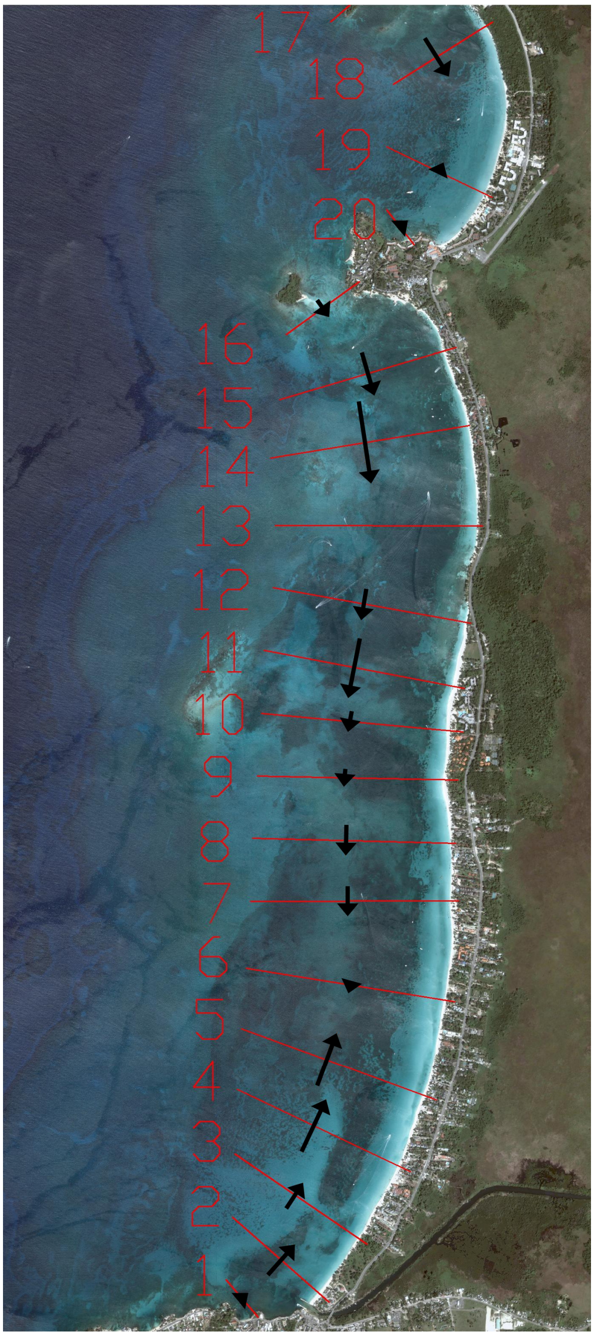


Figure 4.10:Indication of longshore transport direction and size. Longer arrows indicate higher transport.

The effect of sea grass is not confined to profile 13, but found throughout the bay. This makes transport not only a function of angle and profile orientation but also dependent on the amount of sea grass coverage. Especially the near shore distribution of sea grass is important to the amount of longshore transport.

Most of the longshore transport is directed towards the middle of the bay. From a morphological perspective especially the difference in transport capacity is important, which is given is Figure 4.11 (positive is sedimentation, negative is erosion).

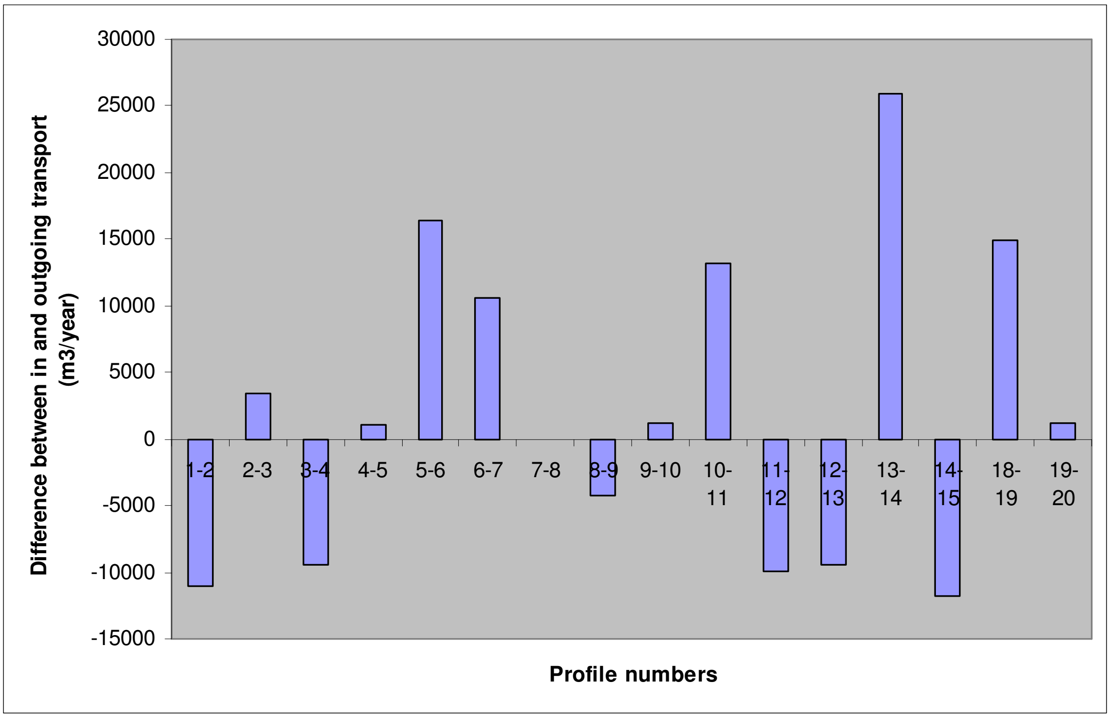


Figure 4.11:Difference in longshore transport between profiles

Behind the reef there is a significant drop in transport capacity, which results in sediment being deposited here. This is also the case between profile 5 and 7. Due to the lack of transport through profile 13 there is a large accumulation of sediment between profile 13 and 14. However there is no evidence to support the accumulation of material here from which we conclude that the modeling of profile 13 is not reliable. The same can be said for the profiles located at the edges of the bays. Which results in exclusion of profile 1, 2, 13, 16, 17 and 20. Excluding these profiles results in Figure 4.12.

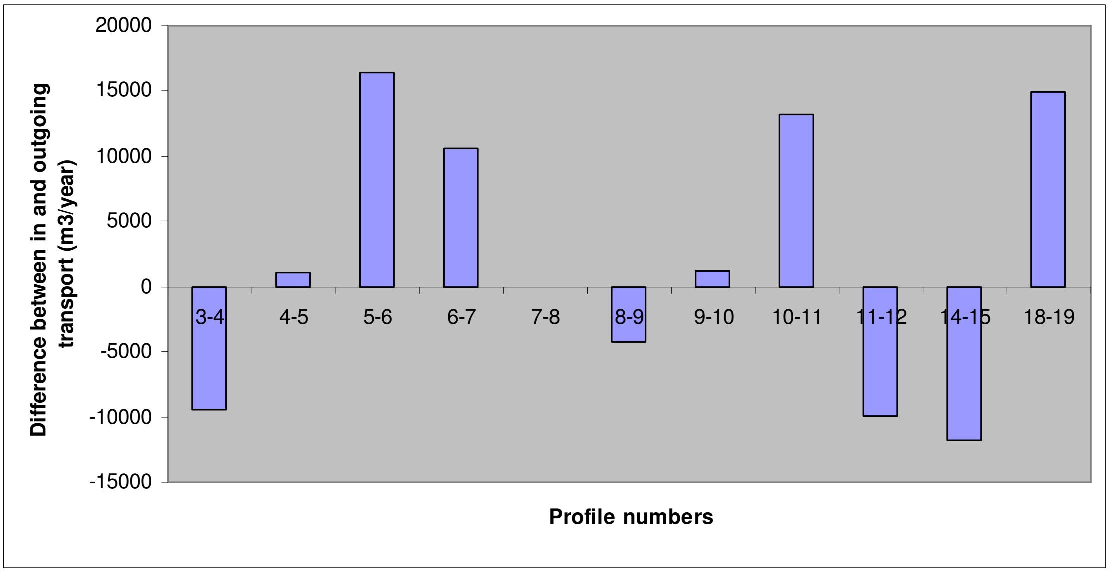


Figure 4.12:Difference in longshore transport (m^3/yr) between profiles without the unreliable results

From Figure 4.12 it can be conclude that there is a surplus of material being transported between profile 5-7, behind the reef (profile 10-11) and in the middle of bloody bay (profile 18-19).

More important is however that there seems to be no transport out of the system due to the longshore transport. These graphs only depict the net transport, so there might be wave conditions under which there is transport to the boundaries of the system. But because there are no signs of sedimentation on the edges of the bay and the rocky headlands, which prevent sediment from escaping the bay, it can be conclude that the sediment will remain in the system.

4.2.3. Cross-shore transport modeling

To model the cross-shore transport of both bays, the same profiles were used as in the longshore modeling. Due to the limitations of the model, which only models accurately up to one month, it was decided to re-run the measured storm which occurred the last week of November.

Unfortunately the profiles were measured after the storm occurred, which means that no pre-storm profiles were available. Because of this, pre-storm profiles were assumed. With these pre-storm profiles the model was run, and calibrated toward the (measured) after-storm profiles (Figure 4.13).

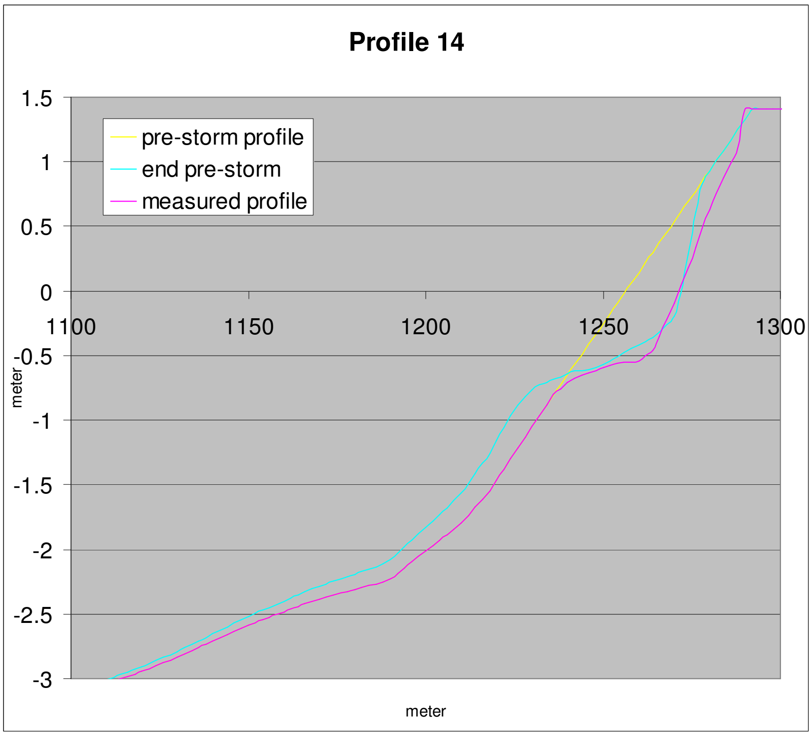


Figure 4.13:Cross-shore transport profile 14

Because of some problems with the model and inaccurate calibration, it was decided to run only a few of the twenty profiles to get an indication of the cross-shore sediment movement. The results of this can be found in appendix 8.

4.2.4. Conclusion

Longshore transport modeling indicates that this mechanism is only responsible for redistributing sediment through the bays. It does not result in sediment being lost from the system. But from historical data an erosive trend can be clearly seen which means that cross-shore transport must be responsible for the loss of sediment. The cross-shore modeling indicates there is a substantial movement of sediment which makes the aforementioned conclusion plausible.

Most of the sediment is lost during the larger swell events when the bigger waves transport some of the material beyond the outer shelf. If this happens the sand is lost to the system.

The reef functions as a natural breakwater, breaking the biggest of waves and thus creating a calmer climate behind it. This explains the reduced rate of erosion behind the reef. Besides the calmer climate there is also a net longshore transport towards this area which also reduces the erosion. This is also visible in the shape of the bay.

There was also a net longshore transport towards the area between profiles 5 and 7. However, the shelf in this region is less deep then towards the North of long bay. This means that more of the wave energy reaches this part of the coastline (see Figure 3.4). As most of the longshore transport occurs during the swell events, the sand transported towards this region is carried away to deeper regions by cross-shore transport. This explains the lack of sedimentation in this area.

In the North the shelf is shallower and therefore the wave attack is smaller then near the river. However, there is still a net loss of sediment due to both long and cross-shore transport. This was confirmed by the shoreline mapping after the storm, when there was still a substantial amount of erosion, but significantly less then the erosion which occurred near the river.

4.3. Hydrodynamic modeling

4.3.1. Introduction

Hydrodynamic modeling using RMA software is used to get an insight in the currents near the coast of Negril. This model can be used for instance to model pollution distributions. Using the output of the current meter (tidal information) an overview has been made of the tides and velocities behind the reef (see appendix 6). Together with the information gathered by drogue tracking the model will be calibrated.

4.3.2. Model input

To setup the model the following input parameters are required:

- Tide information
- Bathymetry

The figure below gives an overview of an example input of the model. The blue lines represent flow patterns (finite elements method).

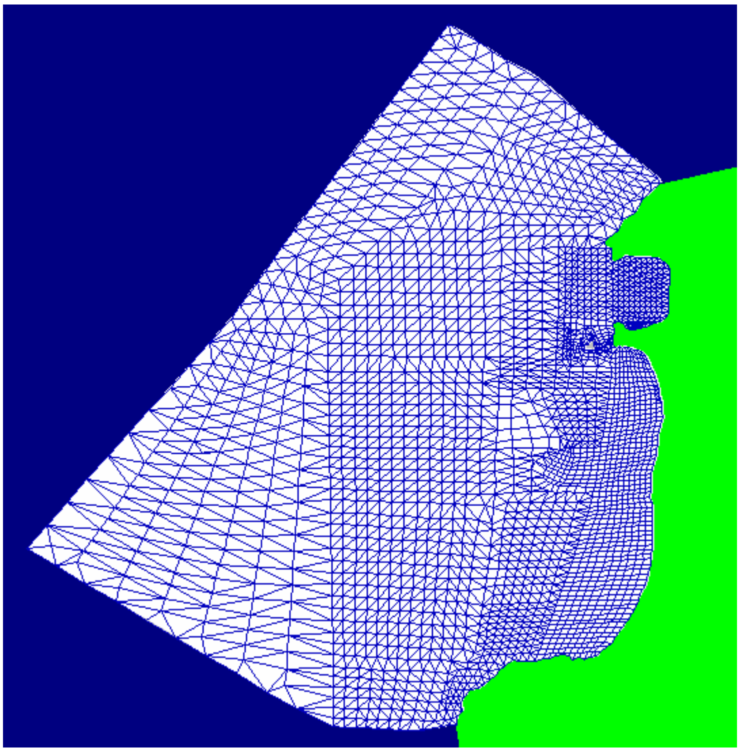


Figure 4.14:Overview finite elements input

4.3.3. Calibration

During the calibration phase several problems occurred. The current patterns near the boundaries keep showing turbulent flows as can be seen in the example image below.

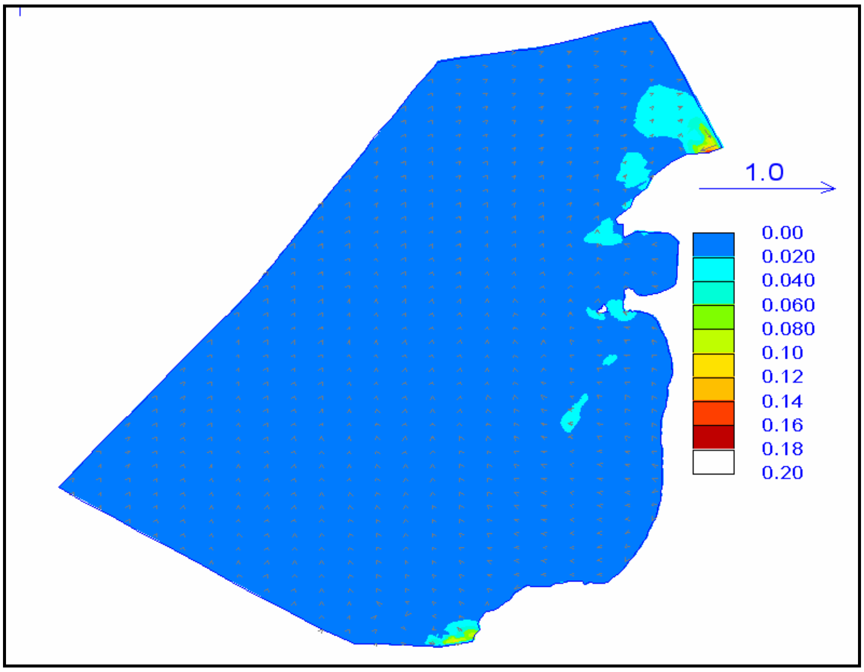


Figure 4.15:Example starting boundary conditions (bath6.rm1)

Playing with the R10 input file using *HCN lines* did not have any effect on the boundary conditions. The problem seems to concentrate around the second or third one node from the top at the right-hand side. Smoothing the lower right corner shows some improvement but still the problem occurs.

These turbulent flows show high velocities and is affecting the system during the whole simulation. Most times the model crashes. The HCN lines in the R10 file seem to have a little effect.

4.3.4. Model output

Because of the aforementioned problems, the results of the modeling are not yet available.

4.4. Sediment production

To get an estimation of the quantity of produced sand in the sea grass beds near Negril, a study is performed by Shakira A. Khan & Edward Robinson [6]. The field investigation shows that the most predominant type of sea grass is Thalassia testidium. The most common contributor that is present within these beds is Halimeda opuntia. This knowledge, combined with the information from the study report mentioned above, the sand production of the sea grass beds at the coast of Negril can be set to 79 $g/m^2/yr$.

From the 2003 satellite image the locations of the sea grass beds were mapped. During the field investigation these areas were confirmed to contain sea grass. The total area is estimated by taking the global dimensions of these sea grass beds. The two main sea grass fields located in the South and North of Long Bay cover each approximately 2.000.000m^2. The sea grass bed in Bloody Bay covers an area of 1.000.000m^2.

Therefore the total size of the area of the sea grass beds comes to 5.000.000m^2. These beds produce together 395.000kg sand. According to a density of 2200kg/m^3 the total volume of sand being produced comes to an amount of 180m^3/yr.

4.5. Conclusions

From the results of the data analysis, several conclusions are made about the erosion mechanisms, nutrient levels and sea grass beds.

4.5.1. System behavior

From the aerial photographs a trend appears of a general retreat along the entire coastline, with little to no sedimentation in either of the bays. Over the last four decades Bloody Bay has lost an average of about 20 meters while Long bay lost about 40 meters. This results in an average erosion of 0.5 meters in Bloody Bay and 1.0m in Long Bay. The erosion does not appear to be constant in time, with periods of faster erosion and periods of relative stability. However the overall trend remains one of a retreating coastline.

The modeling of the wave climate suggests that locally generated waves are not responsible for this erosive trend. This is mostly due to the predominantly North-Eastern winds and the sheltered locations of both bays to waves coming from this direction. This was verified on-site where during the calm periods little to no wave action could be observed along the beach. These waves do play an important role in the recovery of the beach after storm events as they slowly built up the beach to a pre storm profile.

It are the waves generated by distant storms, or swell waves, which are responsible for the erosion. Created by the low pressure areas along the North American coast during the winter months, these are long period waves coming from the West forming a direct attack on the shoreline of Negril. To a lesser extent swell events originating in the North-East play a role. Although Negril is sheltered from this direction these waves are long enough to refract enough to influence the shoreline.

The impact of swell waves originating from the West was observed between the 21st and 23rd of November when waves with a significant wave height of 2.4m were recorded in front of the reef by the current meter. In this period more than 1.5m of sand was lost near the river mouth, while about 0.5m was lost at the northern part of Long Bay.

The lack of any built up of sediment at either sides of the bay suggests that the longshore transport is not the transporting mechanism which causes the loss of sediment. With the bay enclosed by two rocky headlands the longshore mechanism can only redistribute the sediment, but not cause any loss.

This is further confirmed by the modeling of the longshore transport with LITPACK in which the transport at the edges of the bay is minimal. And most of the longshore transport is directed towards the middle of the bays due to their shape. More than 90% of this transport occurs during the storm events with little to no transport in the calmer periods.

It appears therefore that the dominant mechanism in the Negril case is the cross-shore transport of sediment during prolonged exposure to larger swell events. During these events large portions of sand are washed away and deposited further off-shore. During calmer periods the beach recovers from these events to approximately its former state. However after the bigger swell events some of the material is carried beyond the outer shelf. Due to this the sediment is lost from the system. Since there is virtually no transport of sediments from the ocean into the system this leads to a loss of sediment.

This is further amplified by the Hurricanes which occur at the West coast of Jamaica. For a storm with a 10 year return period, the significant wave height in deep water is about 6.5m. These kinds of waves transform the profile far more drastically than the swell waves and severely redistribute the sediment. The infrequent appearance of these storms suggests that they are not the cause of the long term erosive trend, but merely exaggerate it.

4.5.2. Nutrient levels

Not only after the storm, but also in the first data collection period, a lot of areas were contaminated by algae. The presence of algae can point out that the area has to deal with a lot of nutrients in the water. The source of nutrients is not only the pollution, but also by the digesting of buried dead sea grass along the shoreline.

It is not clear, and it goes beyond the limit of this project, to see if the high level of nutrients and the presence of algae have an influence on the quality and quantity of sea grass. Further investigation can be done by taking water samples to see if there is really a high nutrients level. Also research has to be done by biologists to see if there is a link between algae and high nutrient levels on one side, and the sea grass beds on the other side. The outcomes of this investigation may reveal that the increasing pollution during the last decades and the burying of the sea grass partially contribute to the global erosion problem.

4.5.3. Sea grass beds

The sea grass beds along the coast of Long and Bloody Bay produce only a mere 180m^3 of sand per year and are therefore not a major source of sand for the beach. They are however of great importance for keeping the sand in the system. They hold on to the sand and prevent it from being swept away to the outer shelf. It is only the big waves and fast currents that can take the sand across these beds out of the system. The sea grass beds should therefore be preserved as much as possible.

5. Possible Solutions

The goal of this project is to generate a feasible solution or combination of solutions to the erosion problem of the Negril beach that can be implemented and effective in a short period. This chapter describes the most applicable options for the problem at hand and their pros and cons.

The choice between the solutions or a combination of these will be made in the chapter 'Recommendations'.

The type of solutions which are available can be divided into two sub-categories, hard and soft solutions.

- Hard solutions
  a) Series of Breakwaters
  b) Extension of the reef
  c) Series of Groynes
- Soft solutions
  a) Beach nourishment
  b) Strengthening the sea grass beds

The primary cause of the erosion, are the incoming waves on the Negril coast. It seems therefore reasonable to assume that good solutions would try to reduce the waves and thus provide protection for the Negril beach.

This would automatically lead to the hard solutions, since these are designed to provide shelter to the beach from the higher waves. It are also these structures which have the largest visual impact on the beach. For this criterion alone the groynes could be excluded, as these would divide the beach into sections, an effect which is deemed undesirable. Since the primary cause of erosion is the cross-shore transport groynes would not be effective anyway, as they primarily interrupt the longshore transport of material.

The soft solutions, especially beach nourishment, has proven an economical alternative to coastal structures around the world and should therefore be included.

The amount of sea grass beds in the area is already quite large. Further increase of these areas will still not sufficiently contribute to a solution for the erosion problem and can therefore be excluded.

From these fundamental solutions the following alternatives where chosen, which are shortly listed below.

- 0-alternative
- Beach nourishment
- Series of submerged breakwaters
- Extension of the reef
- Integrated solution

The first alternative would be the cheapest as well, just leave the situation as it is. As it stands this would ultimately lead to the disappearing of the beach. This will only be used as a reference case.

Beach nourishment would encompass a plan for a series of nourishments continued over time to replenish the lost sand. This would continue indefinitely since the cause of erosion is not tackled, however might prove cost effective.

A series of breakwaters would require the construction of submerged breakwaters near the most vulnerable stretches of the beach. Combined with one time beach nourishment this would protect the beach for a 50 year time period.

Finally extending the reef extends the protective influence of the reef by construction of a submerged breakwater parallel to the coast at both sides of the reef. Again this would be combined with a one time nourishment to restore the beach. In the next paragraphs each of these solutions will be presented in a more detailed manner.

Prices are in US-dollar.

5.1. Beach nourishment

The desired beach width can be derived from the total number of hotel rooms along the beach. Out of data received from NEPA the following information is subtracted.

Tourist accommodation	2000	2001	2002	2003
<=50rooms	1,008	1,036	1,084	1,076
51-100	694	694	694	823
101-200	472	272	272	272
>200rooms	1,284	1,890	1,890	1,918
Hotels	3,458	3,892	3,940	4,089
Guesthouses	907	916	916	953
Resort villas	691	724	740	758
Apartments	36	36	51	51
Total	5,092	5,568	5,647	5,851

Table 5-1:Negril demographics

Since most guesthouses, resort villas and apartments are located at the cliffs below the Negril South River, these numbers will not be included in the beach demand. Total amount of rooms will then be 4.089 in 2003. From 2000 until 2003 the average growth was 5.08%. Assuming the same growth during the next 3 years, in 2006 the amount of rooms will be 4297. Capturing growth during the upcoming years and including available space at the strip, further calculations will be made using an amount of 5000 rooms. Using the rule of thumb of 12 m^2 beach/room the total beach demand will become 60,000m^2.

Since both bays consist of about 9km of beach the ideal width would be around 7m wide. This means that large parts of the coastline would already fulfill this width and no nourishment would be necessary here.

However, since there is an ongoing process of erosion it seems wiser to extend the beach to a wider state in order to guarantee sufficient width for the years to come. The aerial photos taken suggest that there was a loss of beach in Long Bay of about 40m is the last 4 decades. For Bloody Bay this resulted in a total of 20m. This means that the average rate of erosion was about 1m/year in Long Bay and 0.5m/year in Bloody Bay. For a lifespan of 20 years after nourishment in Long Bay there should be 27 meters of beach and in Bloody Bay 17 meters. The beaches of Long and Bloody Bay should be extended to these lines.

A safety margin of 10% will also be included to ensure that the beaches will have the desired width for the full 20 years. This results in around 30m of beach in Long Bay and about 19m in Bloody Bay.

To calculate the quantity of needed sand for the nourishment the beach profiles are used. The beach is divided in sections with the same properties. The taken beach profiles in one section are then compared to get the most likely profile over the whole section. With this profile and the desired beach width the total amount of sand needed for this particular section is calculated. The beach of Long Bay was divided in 33 sections. The beach of Bloody Bay is continuous for long distances, so this part was only divided in 4 sections. The outcomes of the calculation:

Sand needed for Long Bay: 248.000 m^3

Sand needed for Bloody Bay: 12.000 m^3

Detailed information about this calculation can be found in appendix 9.

For the beach nourishment solution two sources of sand can be identified.

The first is the outer shelf of Long and Bloody Bay. According to local divers from the Negril Coral Reef Protection Society (NCRPS) there are expected to be sand layers between the 20 and 50m depth lines (Figure 5.1). The area that is considered is probably about 7km long and 200-600 m wide, which means that the dredging will be for about 1 meter deep. The costs for dredging near shore are approximately $20-30 per cubic meter. Dredging these parts must also occur with a lot of care to ensure that the delicate environment is not damaged. The corals and the sea grass beds add not only to the stability of the two bays, but are also important for maintaining the water quality in the bays and they form the habitat for wild life.

Figure 5.1:Possible sand source near shore

The second source of sand is acquisition from a third party. These sources are located far away, which means an increase of the transportation costs.

Another influence on the costs is the fact that the type of sand should also match the rare type found in Negril, because this is Jamaica's trademark. The acquisition costs of sand are estimated to be about $60-120 per cubic meter.

It is therefore recommended to use the outer shelf as source, because it will be more cost effective and the type of sand is the same as on the beach. If the outer shelf is used as source the total costs would be in the range of:

Costs for Long Bay: $5mln- $7.5mln

Costs for Bloody Bay: $240.000- $360.000

Further investigation will be necessary to ensure the availability and thickness of the sand layers. It is possible that just one or two series of nourishments are possible and that after that a third party is still needed.

5.2. Series of breakwaters

A different approach to nourishing the beach is to try and stop the cause of erosion, the wave action. This is possible using a series of off-shore breakwaters to dissipate the wave energy. In this two principle variants are at our disposal:

- Emerging breakwaters
- Submerged breakwaters

The main difference between the two is that the submerged breakwater breaks the waves, but does not stop the waves. While the breakwater with the crest above mean sea level stops most waves from affecting the shoreline.

5.2.1. Erosion rate along the shore

There is about a factor 2 difference between the erosion rate in Bloody Bay and Long Bay. With an average erosion rate of 1m/year in Long Bay and about 0.5m/year in Bloody Bay over the last 40 years. However it seems that the Bloody Bay coastline is becoming more stable, while the erosion in Long bay stays a problem. With this in mind it seems wise to restrict the construction of structures to Long Bay and use soft solutions in Bloody Bay.

5.2.2. Emerging near shore breakwaters

An example can be seen in Figure 5.2, where a series of near shore breakwaters was used to stop erosion. If applied in the Negril situation they would probably be effective in the reduction of cross-shore transport as the wave climate at the coast would be significantly reduced. However, as can be seen in Figure 5.2, the visual impact of these is quite profound.

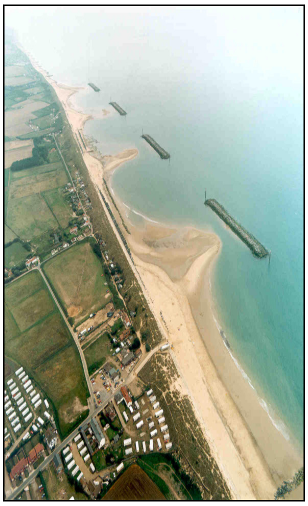


Figure 5.2:Emerging breakwaters

This raises an important question, is this an acceptable degradation of the quality of the beach, or should other alternatives be explored. If we look at what makes the Negril beach attractive, it is the long stretch of sand and the open view to the ocean this provides. To place structures to obstruct this would significantly reduce the attractiveness of the beach and is therefore not acceptable as an alternative.

5.2.3. Submerged near shore breakwaters

An alternative to the emerging breakwaters are the submerged breakwaters which have their crest below mean sea level and thus cannot be seen from the shoreline. This means that they are acceptable in terms of preserving the look of the Negril beach, as their visual impact is less than emerging breakwaters.

It is important to remember that after construction of these structures there will be a response from the coastline. Generally speaking there are three manners in which it will respond. These are:

- Formation of a tombolo
- Formation of a salient
- No visual response.

An example of salient formation can be seen in Figure 5.2 where there is accumulation of sand behind the breakwaters and the coastline grows towards the breakwater due to the hampered transporting capability behind it. If the sedimentation would continue and the breakwater would be connected to the land it would be a tombolo.

Since it was important that the Negril beach remained a more or less undisturbed beach in appearance the creating of a fully grown tombolo or large salient is unwanted. Some response is however unavoidable and accepted.

Most of the sediment movement happens in the zone where the waves brake and thus a lot of turbulence occurs. The construction of a submerged breakwater should be outside the zone where the sediment moves. From the modeling tests it was concluded that sediment movement occurred to a depth of about 3.1m, adding a meter for safety this puts the breakwater at a depth of about 4.1 meters (appendix 11, determining depth of closure). This depth is the starting point from which a design will be produced.

Crest height

As was previously mentioned an important criteria in this project is that the structures have as little visual impact as possible. This means that the breakwaters should be submerged all the time. With a tidal range of about 0.6m this means that the breakwaters should be constructed below -0.3m +MSL.

There are also a lot of small recreational crafts along the beaches in Negril. These mainly consist of Jet Ski's, small sailing vessels and glass bottom boats. All of these vessels have a relatively small draught with a maximum of about 0.3m. Since a lot of these are steered by inexperienced tourists there is a risk of accidents when the breakwaters are constructed at low tide level. Special lanes for these crafts to manoeuver around the breakwaters and buoys to mark these lanes are not an option due to the inexperience. For now a clearance of 0.4m water is taken to be sufficient which results in the construction of the breakwaters at -0.7m +MSL. In a later stage the amount and type of pleasure crafts should be further investigated to come to a final decision on this.

Crest width

The goal of the breakwater structures is to dissipate the incoming energy. For this to happen the idea is that the waves break on the structure and subsequently loose their energy while progressing over the structure. If the crest of the submerged breakwater is too small there is a risk that the breaking waves will plunge over the structure and transfer most of their energy in the area right behind the structure.

To avoid this, a 5m will be used to ensure that the waves loose most of their energy on the structure, and not behind it. Further enlargement of the width did not seem to provide a significant reduction in the amount of transferred energy.

Locations

As mentioned earlier the submerged breakwater will be placed along the 4.1 meter depth contour. However there are other considerations to be made. The large sea grass beds along the coast help keep the sediment from going into suspension and provide good protection against the attack of waves. If the breakwaters are constructed within these beds the possibility arises that the construction activities will destroy large portions of the sea grass beds. It might take a long time for the beds to recover from the initial construction period. The sea grass beds are also considered an important environmental asset. For these reasons construction within the sea grass beds should be avoided if possible.

Further constrictions on the locations of the submerged breakwaters are the reefs in Long and Bloody Bay. These should not be disturbed and no construction activity is allowed around these. Since the shadow zones of the reef already provide protection no additional breakwaters are needed behind these, which reduces the construction costs. Finally it is most cost effective to build in as shallow water as possible.

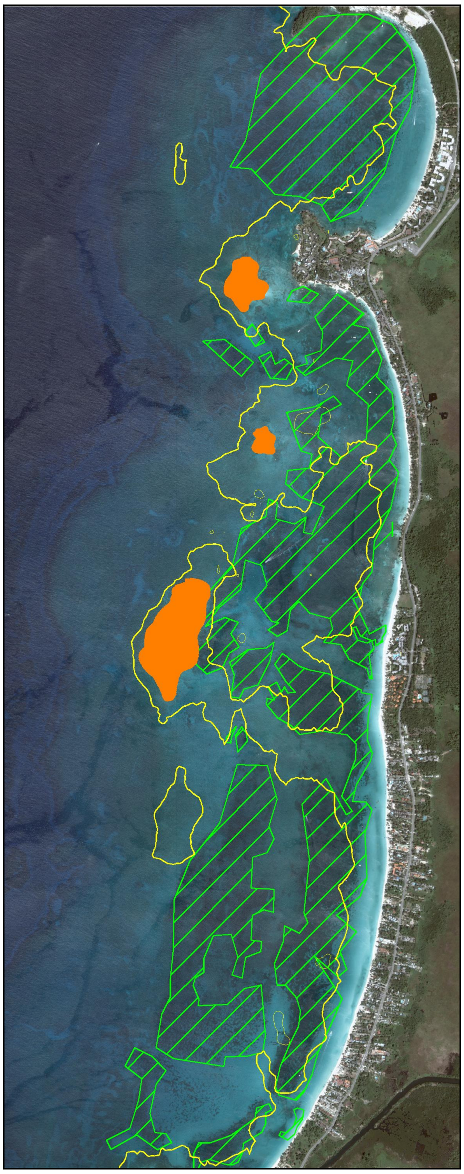


Figure 5.3:Overview of the reefs and booby cay in orange, with the 4.1m detph line in yellow and the sea grass in green.

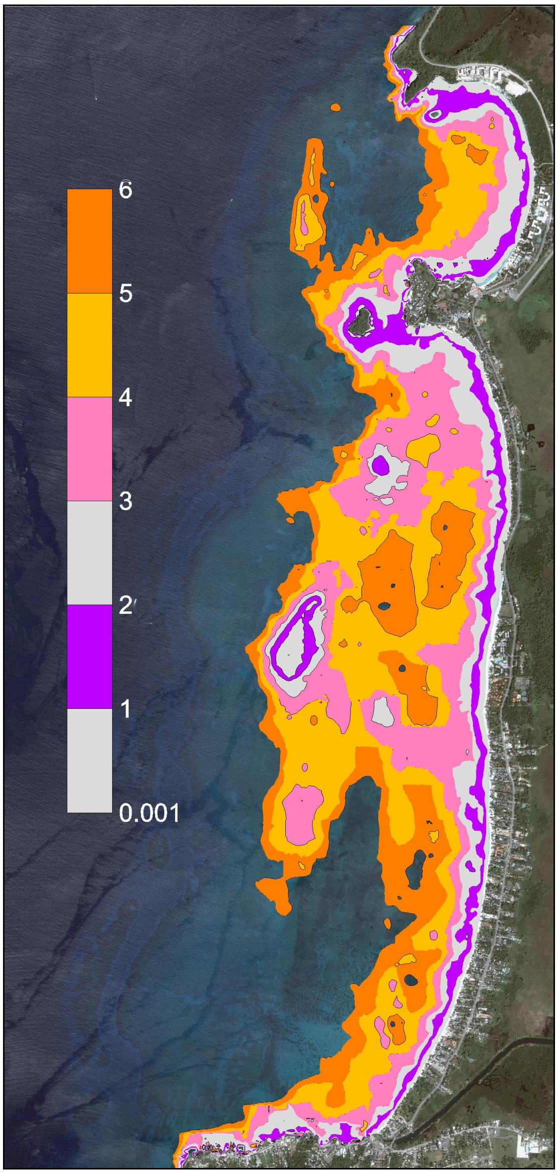


Figure 5.4:Overview of the depth lines

All these conditions are summarized in Figure 5.3and Figure 5.4 which depict the possibilities for construction of submerged breakwaters.

Layout

Using the 4.1m depth line as a starting point the structures where placed as close to shore as possible without disturbing the sea grass beds to much. With a known distance to the shoreline, the length of the structure can be calculated (appendix 11). Using a gap between the breakwaters of about 100m and the locations as defined in the previous paragraphs a possible layout for the protection of the shoreline was generated. Figure 5.5 shows the result of this.

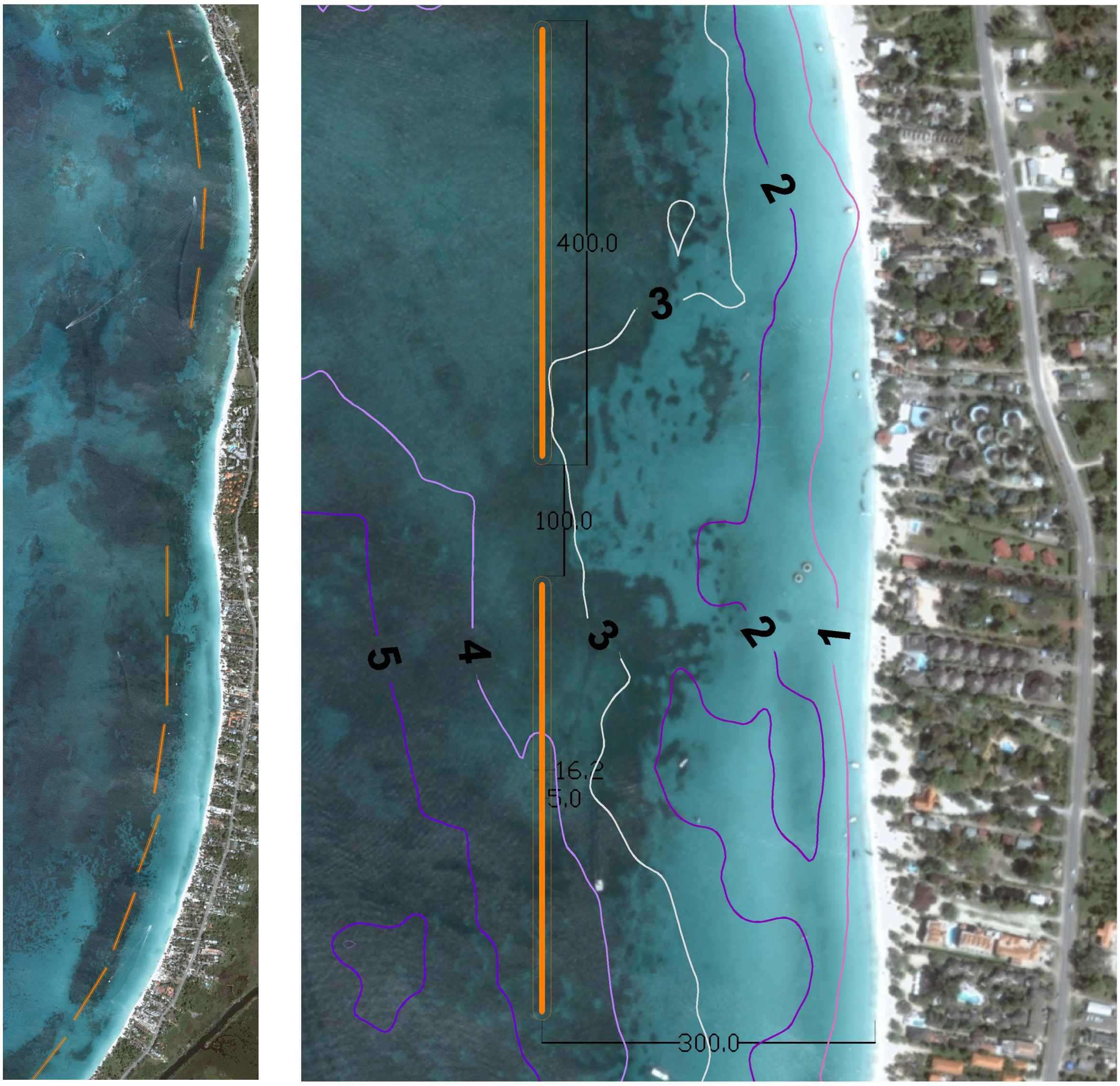


Figure 5.5:Locations of breakwaters in long bay and an enlarged view of the middle section.

This means that 11 submerged breakwaters (8 submerged breakwaters of 350m and 3 of 400m) will be constructed along the Negril shoreline, totaling 4000m of breakwaters. Behind the reef no extra structures are needed due to its protective influence. In Bloody Bay only beach nourishment will be applied, no structures are necessary here.

5.2.4. Potential problems

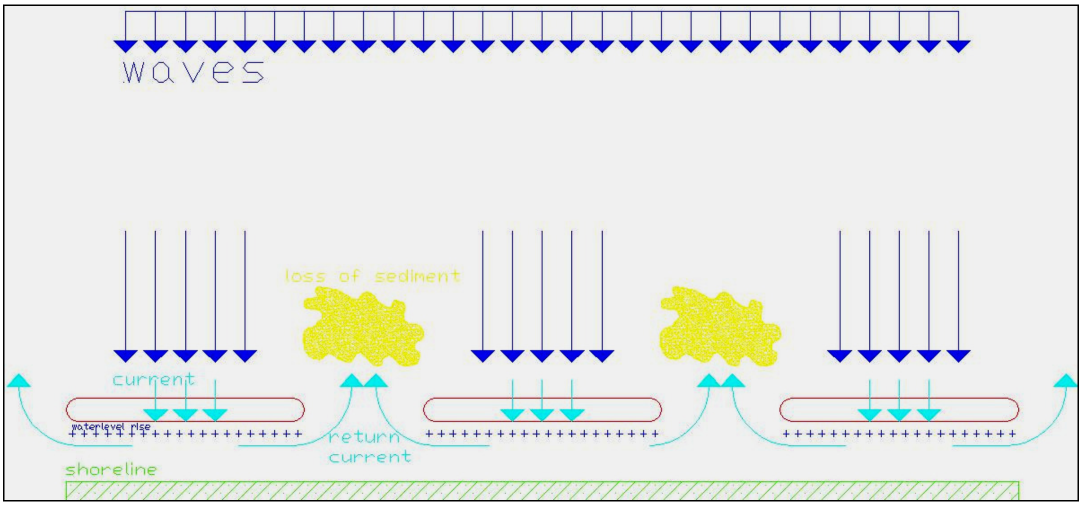


Figure 5.6:Return currents in case of submerged breakwaters

Near shore submerged breakwaters are not without problems. Very big concerns are the return currents which might be produced by waves in the gaps or around the edges of these breakwaters. Since waves break due to the reduced water depth on top of the structure they dissipate their energy there. In doing so, they keep on transferring water over the breakwater into the calmer areas behind it. This transfer of mass leads to an increase in the water level behind the submerged breakwaters. The excess water level tries to return through the gaps between, or around the end(s) of the breakwater(s). This leads to larger currents than those which would have been produced by the natural undertow which is present during wave conditions without the breakwater. There have been reported cases (Dean 1997) where after the construction of submerged breakwaters this phenomenon resulted in more erosion than there was before the construction.

An estimate of the magnitude of these return currents is not easy to make and this needs to be modeled by either a scale model or more advanced computer models. This is however beyond the scope of this research and should only be investigated when the decision is made to implement these structures. If the return currents prove to be a problem a possible solution is to place the breakwaters in a staggered fashion and thus creating more space for the flow.

5.2.5. Sand nourishment

As mentioned in the introduction of this chapter the construction of breakwaters alone will not suffice. There needs to be some nourishment in order to bring the beach back into an acceptable state with on top of that some extra sand to deal with future erosion since the submerged breakwaters will not stop the problem in its entirety.

In the previous paragraph the design lifetime of the beach was assumed to be 20 years between successive nourishment operations. In principle this would reduce the amount of nourishment significantly in case of the construction of breakwaters because the amount of erosion is reduced. However, since there will be a long period of construction along the beach it seems better to keep the amount of nourishment constant to extend the lifetime of the beach.

5.2.6. Construction costs

With a slope of 1/2 and an average depth of 4.1m, the volume per meter breakwater is estimated at 40 m^3/m (see Figure 5.7).

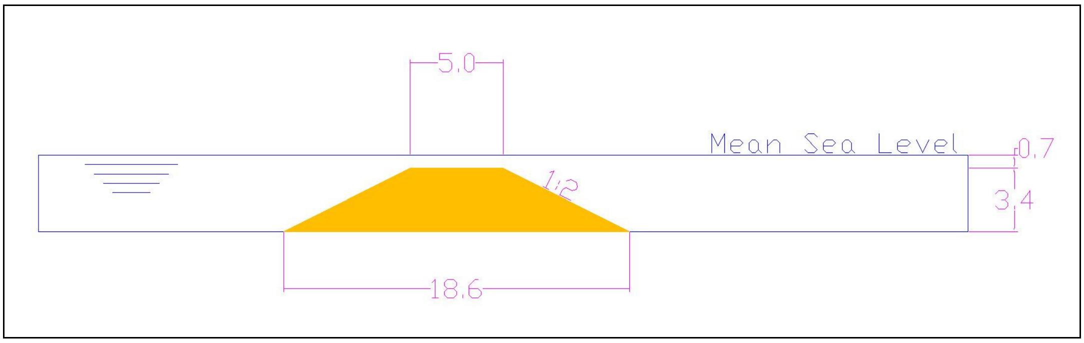


Figure 5.7:Example cross-section of the submerged breakwater

Using locally acquired rock with a W_{50} of 6000kg and local labour the construction costs per cubic meter rock amount to about $85. This means that the breakwaters would cost about $4565 per meter breakwater. With a total length of 4000m the total construction costs will be around $13.6mln. Combining this with the nourishment costs of $7mln, brings the total cost of this option to $20.7mln.

5.2.7. Modeling

Using the same input parameters as in the previous modeling runs the sediment transport and the wave model were run again but now with the included structures to see what the effect of the breakwaters would be. The wave model was run with the storm data gathered from the current meter during the storm of November 2006.

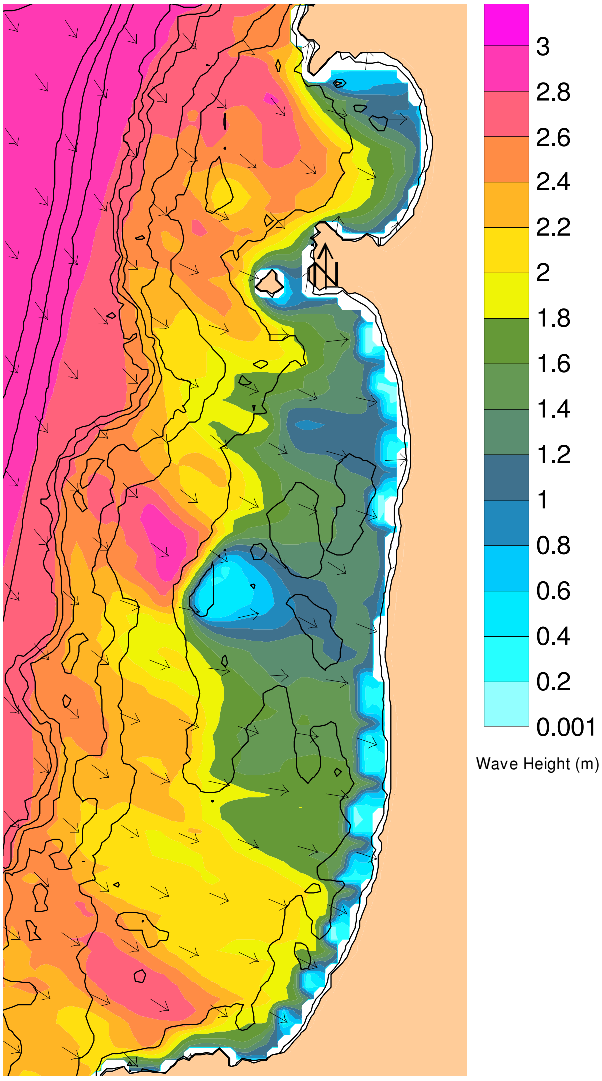


Figure 5.8:The significant wave height during the November 2006 storm if the breakwaters would have been present.

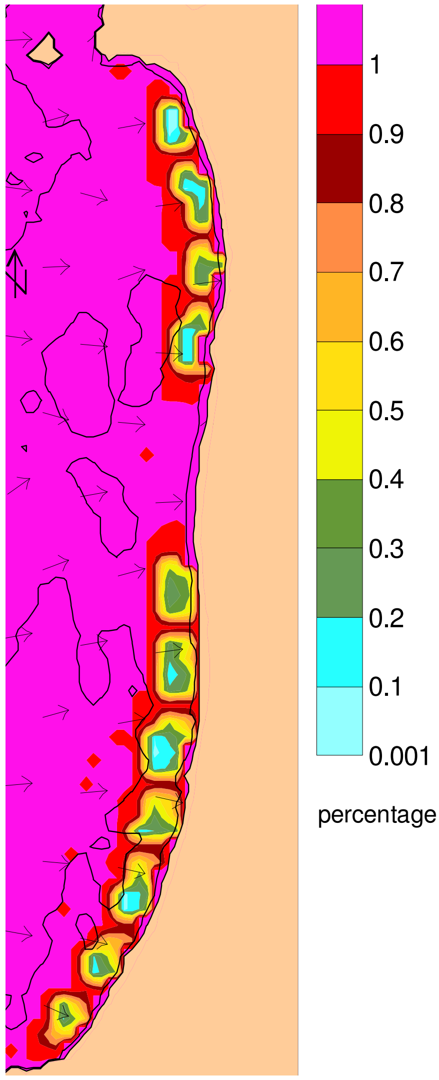


Figure 5.9:The wave height during the storm with breakwaters divided by the wave height without breakwaters.

The result of the wave model is seen in Figure 5.8 and Figure 5.9. The effect of the breakwaters can be seen near the shore where the wave heights are significantly reduced behind the structures. In Figure 5.9 the significant wave height at each location was divided by the significant wave height without the structures. During the wave modeling no diffraction was modeled which means that the wave heights behind the structures are somewhat underestimated.

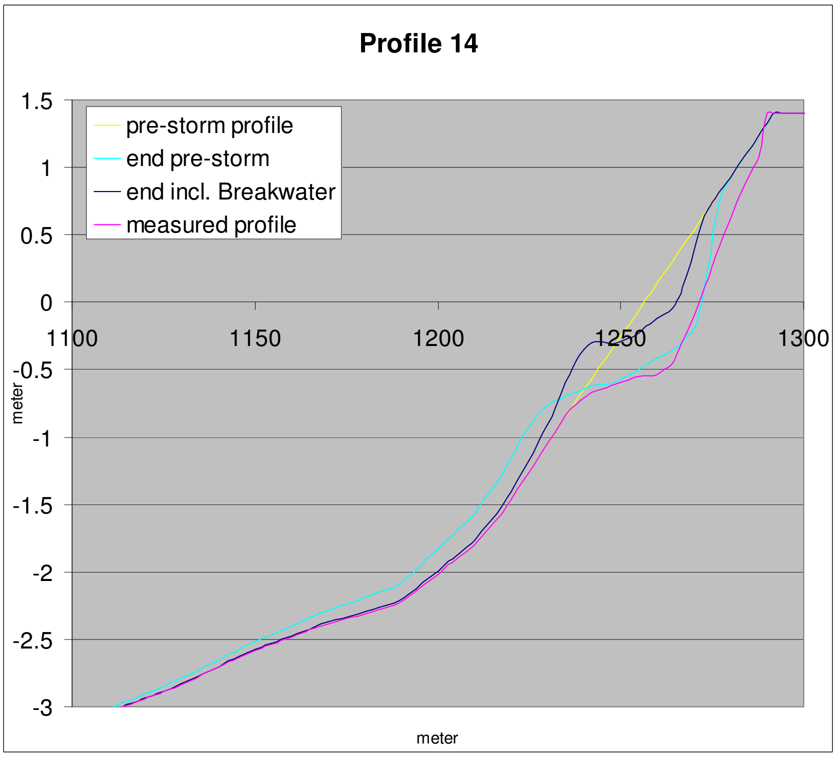


Figure 5.10:Profile evolution model output (profile 14)

The profile evolution model also was rerun for the storm but now with breakwaters. Figure 5.10 shows a result of this, the full results for all profiles can be found in appendix 8. The profiles show that the placement of a breakwater has a significant effect in reducing the cross-shore movement of material. Due to the uncertainties in the cross-shore model the net sediment transport as a figure is unreliable, but the shape and amount and differences do give an indication on the effect of the structure. The waterline retreats about 50% less. But more important is that the sediment that is removed stays at higher locations in the profile. This means that more recovery will take place after the storm with the breakwater then without.

5.3. Reef extension

Another option that can be investigated is the extension of the reef by a submerged breakwater. Since waves that can cause a lot of damage to the beach are broken by the reef it seems like a reasonable alternative. Depending on the type of breakwater this structure can contribute to coral growth and establish an environment for fish and recreation (diving).

Since the location of the reef is about 1.5 km off-shore the average depth of the sea is bigger than using conventional solutions like the earlier mentioned series of submerged breakwaters. Looking at the geometry of the structure the depth will be the determinative factor in relation to total costs.

5.3.1. Geometry

The geometry of the large submerged breakwater will not differ much from the series of breakwaters except that the dept will be bigger. Since the stability has to be granted the slope of the breakwater will be 1:2. An example is given below.

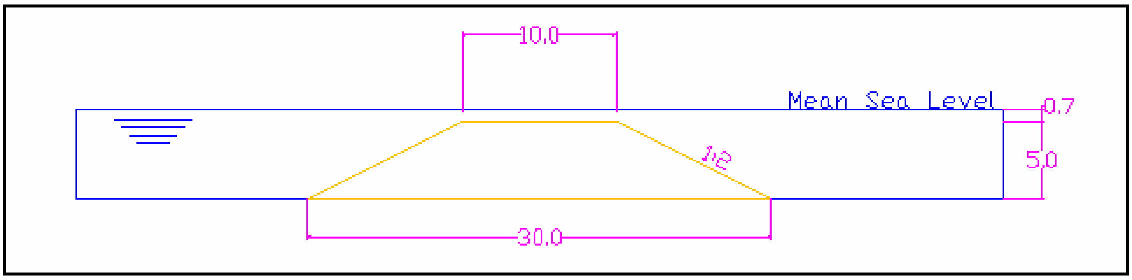


Figure 5.11:Example breakwater slope 1:2

The crest will be about 0.7m below MSL as can be read in the chapter about series of breakwaters. The footprint of the structure is determined by the slope and the depth. For every meter breakwater in vertical direction 2m of ground is needed. To save as much environment as possible shallow waters are required. Also the location of sea grass has to be included in the design process.

When looking at the project area one can distinguish the area in sea grass locations and the bathymetry. The image below gives an overview of the area and two possible solutions for the submerged breakwater. This image gives an *indication* of the location of the submerged breakwater.

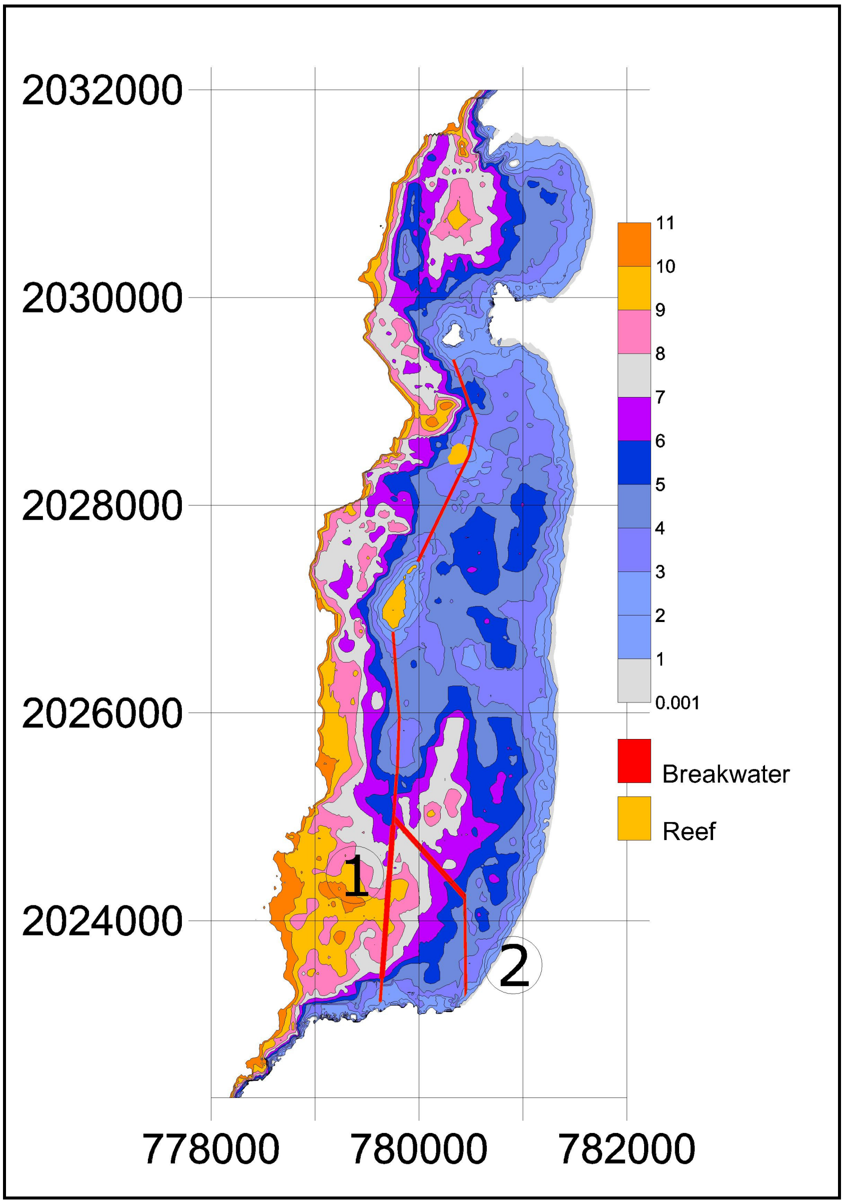


Figure 5.12:Overview reef extension - bathymetry

The difference between the two solutions can be found in the south. One can choose to continue the breakwater at the same distance from shore in deeper water (1) or try to minimize the deeper parts of the sea (2).

The exact length and location can be determined by running computer models and by analyzing the outcomes.

The image below shows the same alternatives in relation to the location of sea grass.

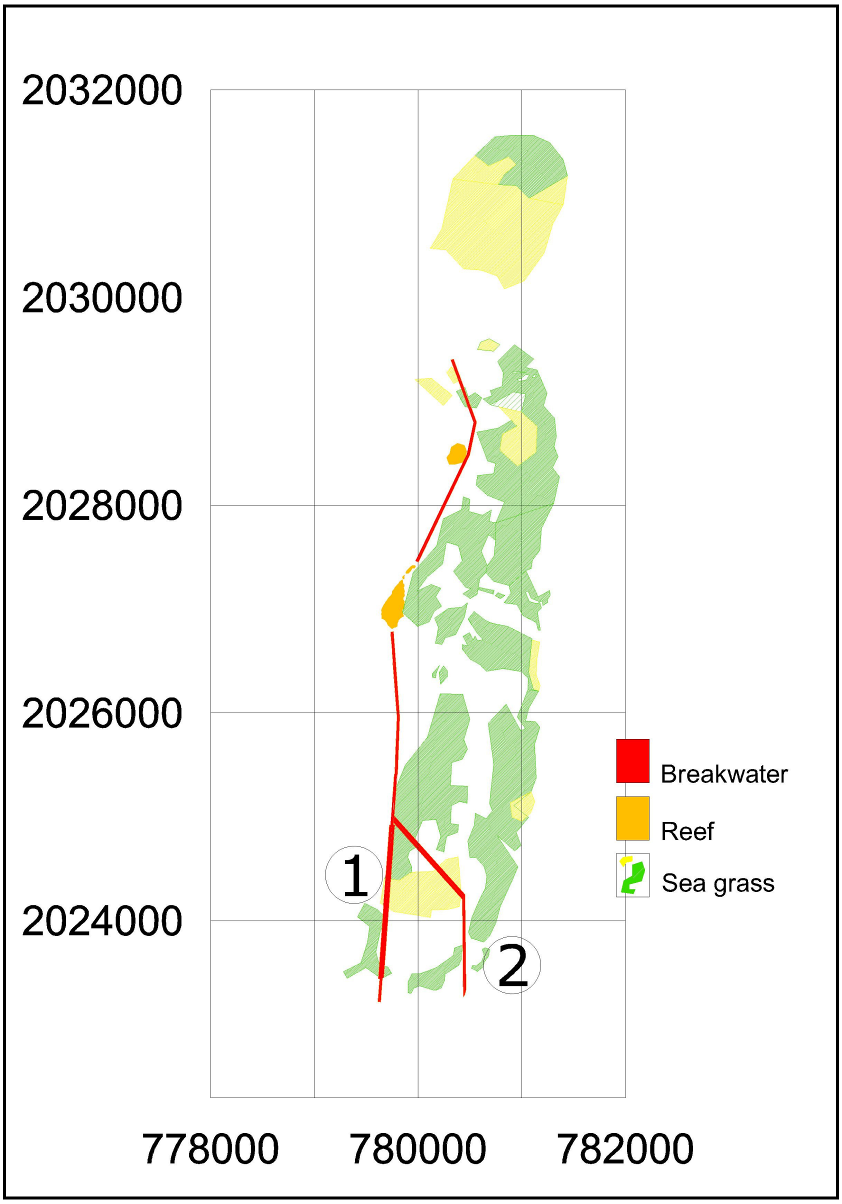


Figure 5.13:Overview reef extension – sea grass

As can be seen in Figure 5.13, the 'shared component' of the two solutions avoids most sea grass except a little in the north. The big difference can be found in the south. Alternative one is laid just beside the sea grass and relatively doesn't damage a lot of grass. However, alternative two crosses two large sea grass beds as can be seen in the table below that describes the characteristics of both alternatives. A detailed calculation can be found in appendix 10.

Alternative	Length [m]	volume [m3]	Seagrass surface [m2]	% of total seagrass
Alt1	5654	465667	12628	0.25
Alt2	5881	358461	23873	0.48

Table 5-2:Overview alternatives reef extension

As can be seen, alternative two will be the most cost efficient method due to 23% less required construction material compared to alternative one. However the amount of sea grass destroyed by this alternative is twice as much as by alternative one. Since sea grass plays a very important role in the ecology as well as erosion, it is advised to maintain as much sea grass as possible. Including this in the consult it is advised to implement alternative one above alternative two.

5.3.2. Reef balls

To extent the existing reef an artificial reef can be implemented instead of a conventional breakwater made of rocks. This reef can be made using Reef Balls as can be seen in the images below.

Figure 5.14:Reef balls

Since these artificial reefs are very expensive (approximately $ 3.000/m3) an implementation of a reef along the whole coast is not realistic ($ 1.1+ billion). It is realistic however to implement small parts of the breakwater as Reef Balls. This will contribute to a durable and sustainable environment as well as to recreational activities.

5.3.3. Cost estimation

Appendix 10 shows a detailed description of the information below. Using the bathymetry per depth the total length of structure is determined. With this result the total volume and costs can be determined per alternative: the shared component in the north, alternative one and two both with and without use of Reef Balls.

Alternative	*Costs*	*Total costs*
Shared	$20.0	
Alt1	$26.6	$46.6
Alt2	$15.9	$35.9
Alt1-RB		$1,397
Alt2-RB		$1,075

Table 5-3:Total costs of reef extension per alternative in million US dollar

A reasonable estimation will then be between 55 and 65 million dollar implementing alternative one with a few sections of Reef Balls.

5.3.4. Modeling

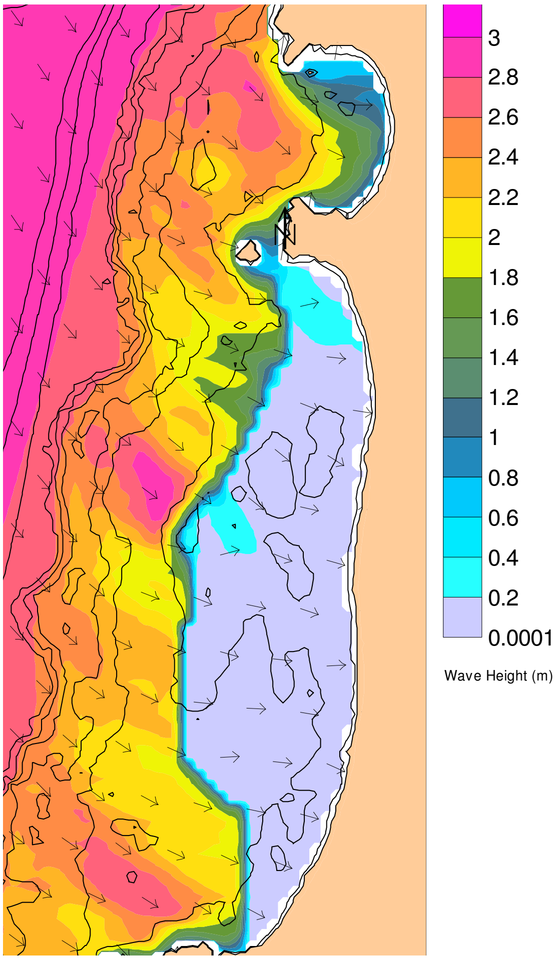


Figure 5.15:The significant wave height during the November 2006 storm if the reef extension would have been present.

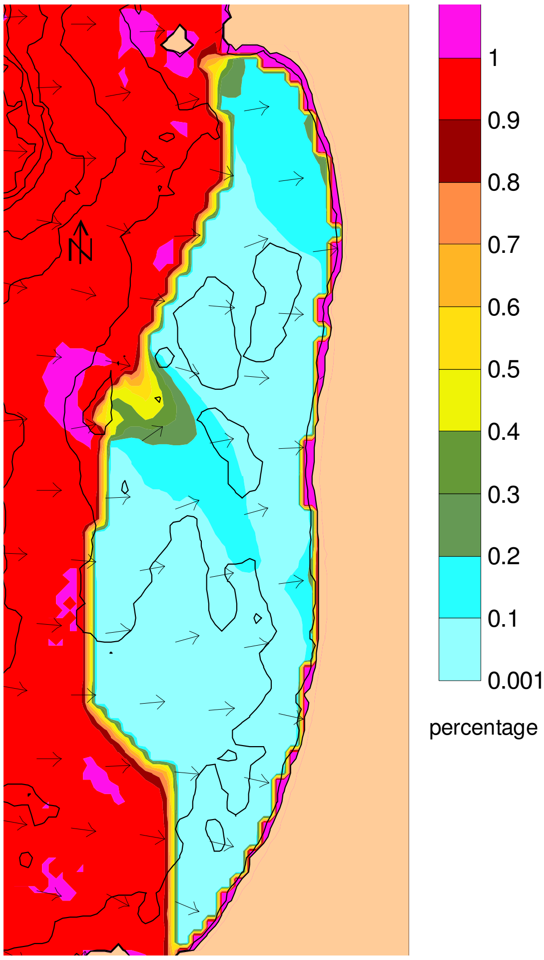


Figure 5.16:The wave height during the storm with breakwaters divided by the wave height without the reef extension.

Alternative 2 was put into the wave modeling software which resulted in the output of Figure 5.15 and Figure 5.16. The results show that behind the extended reef the wave action is almost non-existent. This however is most likely a limitation of the wave model or an error in the formulation of the model. Unfortunately this could not be corrected and no conclusion can be based on the model output. It is however safe to say that the barrier will decrease the wave action considerably. The sediment transport model was not run for the extended reef as the profile lines didn't extent far enough.

5.4. Integrated solution

Using the previous alternatives a final alternative was generated which integrates the sand nourishment, series of breakwaters and reef extension. This alternative tries to keep the best part of each solution.

5.4.1. Description

The "series of breakwaters alternative" placed the breakwaters in near shore locations and thus did not make full use of the shallow areas near the reefs. The reef extension on the other hand tried too much to extend the reef even in deeper waters, what made it a costly alternative. The depth charts of the area suggest a solution in which breakwaters are placed close to the shore in the South, while in the middle and the north of long bay the breakwaters can be placed further off-shore extending the reef there and making use of the smaller reef located between Booby Cay and the large reef.

In this alternative the same dimensions for the submerged breakwater were used. This means that the crest height remains -0.7m +MSL, crest width of 5m and a slope of 1/2. Figure 5.17 shows the locations of the submerged structures with respect to the depth. In Figure 5.18 the sea grass, corals and breakwaters are shown. The sea grass beds remain relatively untouched by the construction of the breakwaters. Only on the South side the breakwaters are built within the sea grass beds. At the North the breakwaters are generally outside the sea grass beds with only the last breakwater crossing some sea grass.

Around the coral reefs there arises a problem as the precise beginning of the reefs are unknown. For this reason the breakwaters are not built right at the reef, but in somewhat deeper water.

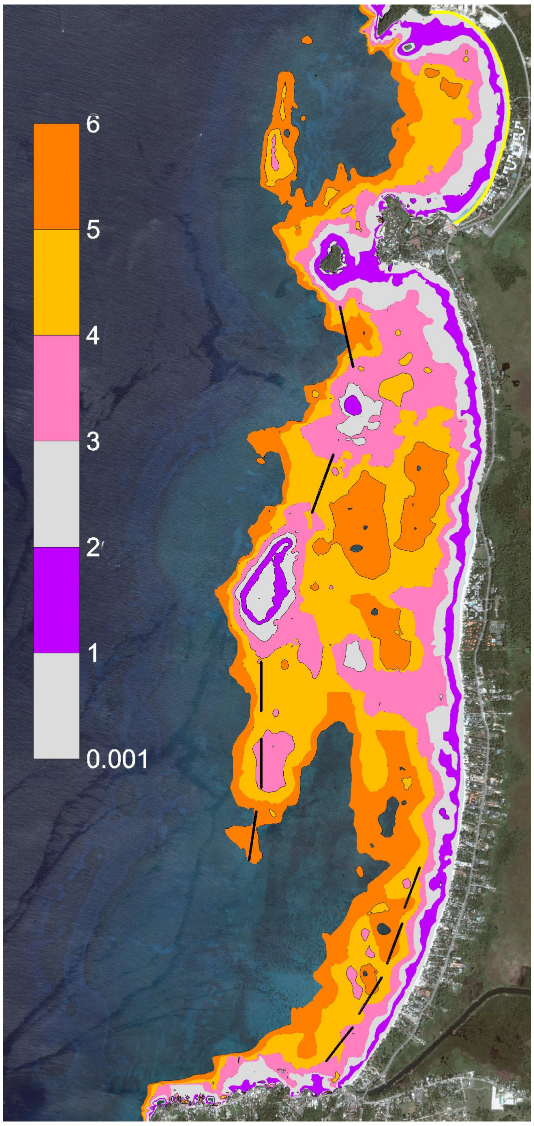


Figure 5.17:Locations of the breakwaters with the 1 to 6m depth lines.

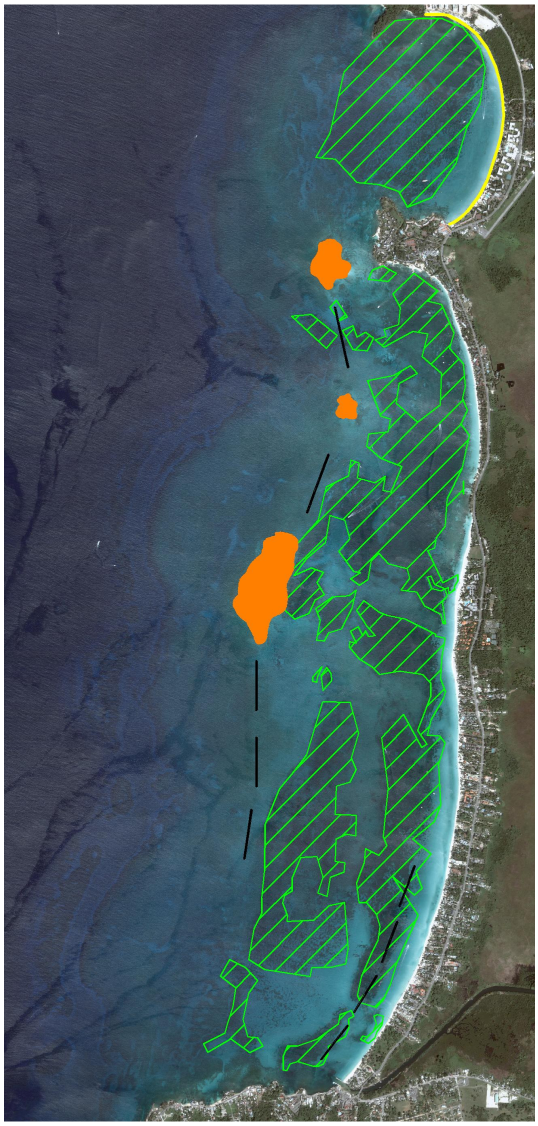


Figure 5.18:The breakwaters and their impact on the sea grass beds.

5.4.2. Costs

In this layout a total of nine structures will be built varying in length from 350m to 500m. The average depth amounts to about 4.7m. Again the price of rock is placed at \$85/m^3 . This would bring the total costs of the construction of the breakwaters to \$15.4mln. Combining this with the nourishment gives a total price of around \$22.4mln. Table 5-4 gives a more detailed overview of the costs.

nr (from south to north)	Height (m)	Length (m)	Volume (m3)	Appr cost (millions)
1	4.1	350	14875	$1.26
2	4.5	350	16625	$1.41
3	5	350	18812.5	$1.60
4	4.5	350	16625	$1.41
5	6	400	26500	$2.25
6	3.7	400	15000	$1.28
7	4.8	400	20500	$1.74
8	4.7	500	25000	$2.13
9	5	500	26875	$2.28
			Total	**$15.37**

Table 5-4:Breakdown of the costs of construction.

5.4.3. Effectiveness

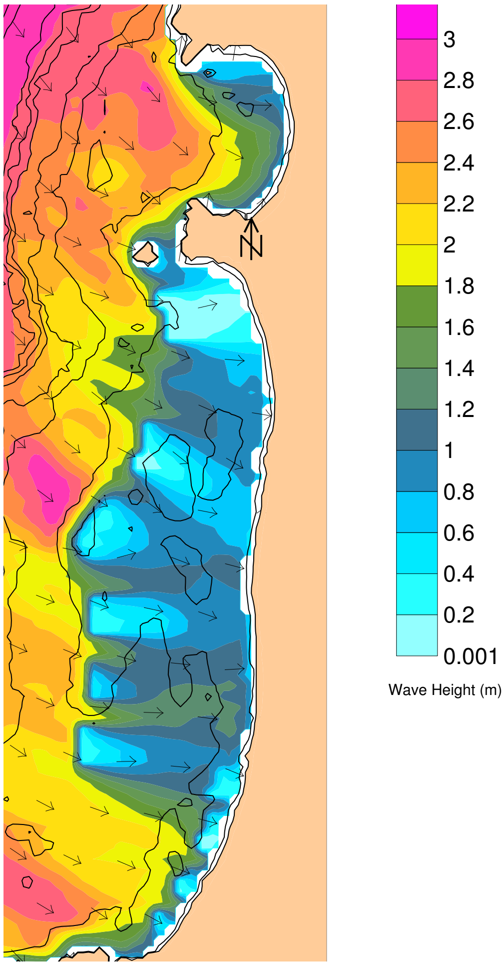


Figure 5.19:The significant wave height during the November 2006 storm if the breakwaters would have been present.

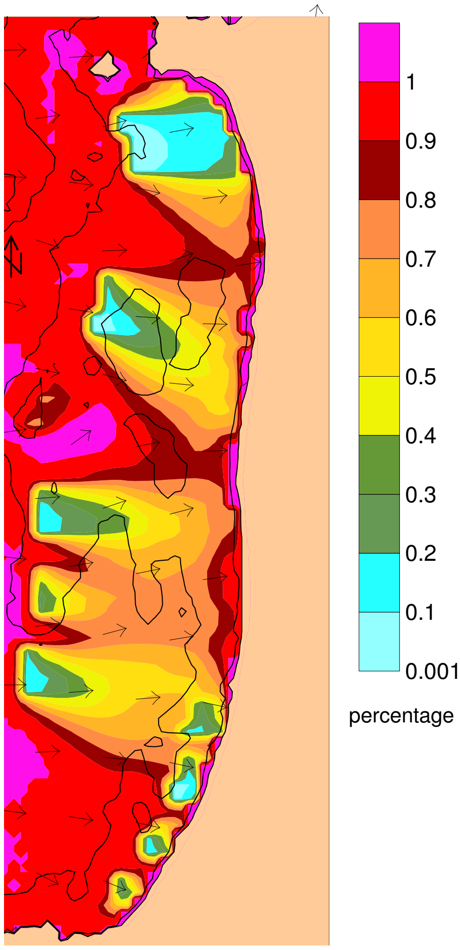


Figure 5.20:The wave height during the storm with breakwaters divided by the wave height without breakwaters.

Again the breakwaters and their locations were entered into the wave modeling profile using the November 2006 storm conditions as input. The significant wave height and direction can be seen in Figure 5.20. The effect of the breakwaters can be clearly seen, as the wave heights drop considerably after the breakwaters. Figure 5.20 shows the relative changes between the significant wave heights with and without the integrated solution. Behind the structures the wave conditions vary from 20-80 percent. However between the breakwaters there is still a transfer of wave energy into the area. Behind the reef there is little change, which is to be expected as no structures were placed here. The wave conditions at the coast vary from no change to an 80% reduction. This is expected to be somewhat exaggerated since no diffraction was modeled.

A remark has to be made on the direction of the approaching waves. They were modeled as waves coming in almost from the West, which is the dominant angle of attack for the larger wave events. It is also a more favorable angle for the integrated solution. Waves approaching from the South-West could potentially travel between the breakwaters near the south and the breakwaters near the reef and still transfer their full energy at the coast.

The breakwaters in the south had the same configuration as the breakwaters in the series of breakwater solution. As such their profile evolution figures are identical to the earlier modeled ones. Unfortunately the other breakwaters couldn't be run for their current location. The previously run profiles do give an indication of the influence they could have.

6. MCA

In this chapter the different solutions will be rated to pre-set criteria. After this the costs are taken into account. When these two aspects are combined the final recommendation can be made.

6.1. Multi criteria analysis (MCA)

A multi criteria analysis is a decision-making tool. An objective score can be determined for each solution by the set up of criteria.

The possible solutions that are considered:

- 0-alternative
- Sand nourishment
- Series of breakwaters
- Extension of the reef
- Integrated solution

The criteria that play a role:

- **Effectiveness** to prevent the erosion of the beach and durability
- **Ease of construction** of the solution
- **Construction time** of the solution
- **Morphological response** of the coast (salient formation)
- **Environmental impact** of the solution on corals, sea grass and refreshment of the water (currents)

The first step is to compare the importance of different criteria with each other. When for example 'effectiveness' is judged to be more important than 'construction time', a 1 is filled in. The scored points are summarized and a percentage is determined for the importance of all criteria, relative to each other (Table 6-1).

	Effect.	Ease of Co	Constr. time	Morph. Resp.	Env. Imp.	SUM	SUM2	Percentages
Effectiveness		1	1	1	1	4	8	34.783
Ease of construction	0		0	0	0	0	1	4.348
Contruction time	0	1		1	0	2	4	17.391
Morph. Resp.	0	1	1		0	2	4	17.391
Environmental impact	0	1	1	1		3	6	26.087
						11	23	100.000

Table 6-1:Comparison criteria

The second step is to give each solution a score in the range of 1-10 for each criterion, where a 10 is the highest score (Table 6-2). Basic assumption is an effective time span of 50 years. Since sand nourishment by itself lasts for about 25 years this action should be executed twice.

Table 6-2 is then multiplied by the percentages calculated in Table 6-1. From this the final mark is determined per solution (Table 6-3).

	Effect.	Ease of Constr.	Constr. time	Morph. Res	Env. Imp.
0-alternative	2	10	10	4	8
Sand nourishment	6	7	8	8	7
Series of breakwaters	7	6	6	3	5
Reef extension	8	3	3	9	7
Integrated solution	7	5	5	6	6

Table 6-2:Scores per solution per factor

	Effect.	Ease of Co	Constr. time	Morph. Resp.	Env. Imp.	SUM
0-alternative	69.57	43.48	173.91	69.57	208.70	**565**
Sand nourishment	208.70	30.43	139.13	139.13	182.61	**700**
Series of breakwaters	243.48	26.09	104.35	52.17	130.43	**557**
Reef extension	278.26	13.04	52.17	156.52	182.61	**683**
Integrated	243.48	21.74	86.96	104.35	156.52	**613**

Table 6-3:Final mark (best score, best solution).

Sand nourishment is objectively the best solution but is closely followed by reef extension. Then the integrated solution shows the best score. Finally the series of breakwaters and the 0-alternative score the least.

6.2. Cost analysis

In the comparison before, costs are not taken into account. Since this is perhaps the most important factor, an efficiency estimation is made. The table below shows the amount of money that needs to be invested per point earned in the MCA per alternative. The costs of the 0-alternative are unknown since no good estimations can be made of the financial damage for the hotels due to fewer tourists.

	Costs (US$)	Score	Efficiency ($/pnt)	Weighted Score
0-alternative	unknown	565	infinite	infinite
Sand nourishment	15000000	700	21429	1
Series of breakwaters	20700000	557	37195	1.74
Reef extension	65000000	683	95223	4.44
Integrated	22400000	613	36539	1.71

Table 6-4:Cost efficiency per alternative

The last column shows the relative score in comparison to the most efficient alternative; sand nourishment.

6.3. Conclusion

Sand nourishment is estimated as the most feasible solution. The list below shows the solutions and their (costs) efficiency compared to sand nourishment.

1. Sand nourishment 100%
2. Integrated solution 165%
3. Series of breakwaters 173%
4. Reef extension 416%
5. 0-alternative infinite

7. Recommendations

The most feasible solution for the erosion in Negril is beach nourishment. Although other options exist they do not generate the same value. A few points are to be kept in mind. While dredging occurs it can rather have a visual on impact on the beach. Annoyance can also come from the noise and the possible stench. Dredging should therefore not regularly be repeated, but should be done approximately every 20 years.

About 250.000m^3 of carbonate sand is needed. If possible the source of material is the outer shelf, between the 20m and 50m depth lines. Divers confirm the existence of sand pockets there, however the exact quantity and thickness of the layers are still unknown factors. These outer sand layers should be surveyed to determine their suitability as a source.

The best time to undertake the dredging operations seems to be right after the winter season, and before the summer season starts. In these months the weather is calm and the nuisance to tourists is kept minimal. However, this is best decided in cooperation with the dredging company as other factors such as the availability of ships play a role.

To cope with the sand nourishment costs a dredging fund could be set up. If every hotel room in Negril is charged $ 1 US more and this is put a side in a dredging fund it can provide $ 800.000 US a year. In twenty years there would be more than enough money to finance the dredging.

The study also indicates the importance of the sea grass beds in minimizing the impact of storms and swell events. Although there is some production by the beds their primary importance lies in their protective capabilities. The preservation of the sea grass beds should therefore be taken seriously.

Some other problems came to our attention which were beyond the scope of the project but deserve a mentioning as they might prove to be important to the tourism sector.

The pollution of algae along the coast, especially after bad weather, seems to be getting worse. At some locations (for example near Sandals) there was a thick layer in front of the beach. Although only the first ten meters were polluted it deterred some tourists from entering the water. If this increases further it might prove disastrous for the tourism sector as a clean and wide beach is of most importance for this industry. It is recommended that a separate investigation on the quality of the water is made by biologists.

Besides the algae after storms, there are also large quantities of sea grass deposited on the beach, which produce an unpleasant odour. This is unavoidable due to the extensive sea grass beds in front of the coast. However the practice of burying the dead sea grass on the beach might not be the best way to deal with this. The decomposing sea grass might release nutrients in the water which raise the nutrient levels and accelerate the growth of algae. The best way to deal with the residue could be taken into account together with a study to the quality of the water.

Coping with the erosion and ensuring a good water quality is the best way to ensure that Negril remains an attractive tourist destination for years to come.

8. References

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