FINAL RAPPORT 12/12/2011

Appendix

Coastal Protection Plan

Table of Contents

Appendix A Morphology

The coastal morphology is often not well understood because of its complex system. The morphological system involves various aspects. In order to keep an overview, the aspects of the morphology have been categorized as follows:

- Wave, tide and wind conditions.
- Physical features.

1.1 Wave, tide and wind conditions

Firstly, the general wind and wave conditions will be assessed; because the wave and wind conditions have a large influence on the coastal features (rivers and sediments also have influence).

1.1.1 *Wind*

Wind induced waves are of paramount importance for the condition of the wave climate. From a global point of view the metropolitan area of Recife experiences primarily tropical doldrums (Coastal Dynamics 2011) influenced by trade winds and low pressures area from the South-Atlantic Ocean. The coast receives east coast swell from storms that are generated in the South-Atlantic Ocean. The winds are strongest in May to July due to the fact that the temperature difference of the landmass and the oceans is at its highest (MAI, 2009).

- From February to September the wind is mainly North-West directed. With velocities ranging from 2.6 to 4 m/s.
- From October to January the wind is mainly West, North-West directed. With velocities ranging from 3 to 3.2 m/s.
- From November to December the wind is mainly West, South-West directed. With velocities ranging from 2 to 2.1 m/s.

For a more detailed overview of the wind conditions see Appendix B

1.1.2 *Tide*

Tidal propagation along the coast of Pernambuco is a response to astronomical forcing. There are contributions from non-periodic components of metrological origin but they are negligible when held in comparison to regular components (MAI, 2009). In the area of the Port of Recife, the tides display semi-diurnal behavior with a form factor of F=0.09 and an average period of 12 hours and 25 minutes. There are two high waters and two low waters in the lunar tide with little daily inequality (MAI, 2009). The average tidal range is approximately 1.76 m. The quadratic average height is 0.97 m and syzygy height is 2.07 m.

Tidal Characteristics Recife Metropolitan area	
Form factor	F=0.09
Tidal Period	12 hours and 25 minutes
Tidal Range average	1.76 m
Tidal syzygy	2.8 (Navy – Pernambuco)
Tidal quadratic average height	0.97 m

Table 1: Tidal characteristics Recife Metropolitan area (MAI, 2009)

1.1.3 *Wave*

Surface waves are a result of the transfer of wind energy from local and offshore sources to the surface of the oceans. When waves reach shallow waters near the coast the energy is rapidly released which generates currents and directly influences the sediment transport and morphology of the coastline. Coastal structures affect the waves in mechanics such as refraction, breaking, reflection and diffraction which makes understanding of the coastal hydrodynamics of paramount importance to the execution of coastal engineering projects.

According to results obtained by the project MAI (2009), analysis of the time series obtained for the studied area, in regard to gravity waves, waves are present with a significant height average of 0.60 m to 0.97 m in coastal areas of Jaboatão dos Guararapes, Recife and Olinda.

The average significant wave height in Paulista ranged from 0.27 to 0.29 m (MAI 2009). Periods of significant ripples in the stations ranged between 5.1 and 6.8 seconds, with the largest wave heights occurring in Recife's region of which a significant wave height of 1.57 m is observed, in the stronger wind periods in the end of October. Table 2 and Table 3 resents the findings of the report of the project (MAI, 2009)

General Wave characteristics Metropolitan area Recife	
Periods of Ripples	5.1 s – 6.8 s
Maximum Significant wave height in data series	1.57 m
Average significant wave height Jaboatão dos Guararapes, Recife and Olinda	0.60 m – 0.97 m
Average significant wave height Paulista	0.27 – 0.29 m

Table 2: General Wave characteristics Metropolitan area Recife (MAI, 2009)

Municipality	**Hs [m]**	**Hmax [m]**	**Ts [s]**	**Tp [s]**	**Dir [°Az]**
Jaboatão dos Guararapes	0.61 / 0.44	0.98 / 0.71	6.34 / 6.81	8.57 / 8.58	119 (097-140) / 119 (079-148)
Recife	0.97 / 0.66	1.57 / 1.07	5.97 / 5.88	9.50 / 8.45	131 (116–152) / 124 (052-157)
Olinda	0.60 / 0.61	0.97 / 0.99	5.55 / 6.04	8.73 / 10.85	129 (087–335) / 126 (093-313)
Paulista	0.29 / 0.27	0.47 / 0.44	5.12 / 5.53	6.86 / 7.69	185 (098–335) / 154 (124-312)

Table 3: Wave heights at 4 municipalities (MAI, 2009)

LOCAL	Hs (m)	Hmax (m)	Ts (s)	Tp (s)	Dirs (ºAz)
Jaboatão	0,61 / 0,44	0,98 / 0,71	6,34 / 6,81	8,57 / 8,58	119 (097–140) / 119 (079-148)
Recife	0,97 / 0,66	1,57 / 1,07	5,97 / 5,88	9,50 / 8,45	131 (116–152) / 124 (052-157)
Olinda	0,60 / 0,61	0,97 / 0,99	5,55 / 6,04	8,73 /10,85	129 (087–335) / 126 (093-313)
Paulista	0,29 / 0,27	0,47 / 0,44	5,12 / 5,53	6,86 / 7,69	185 (098–335) / 154 (124-312)

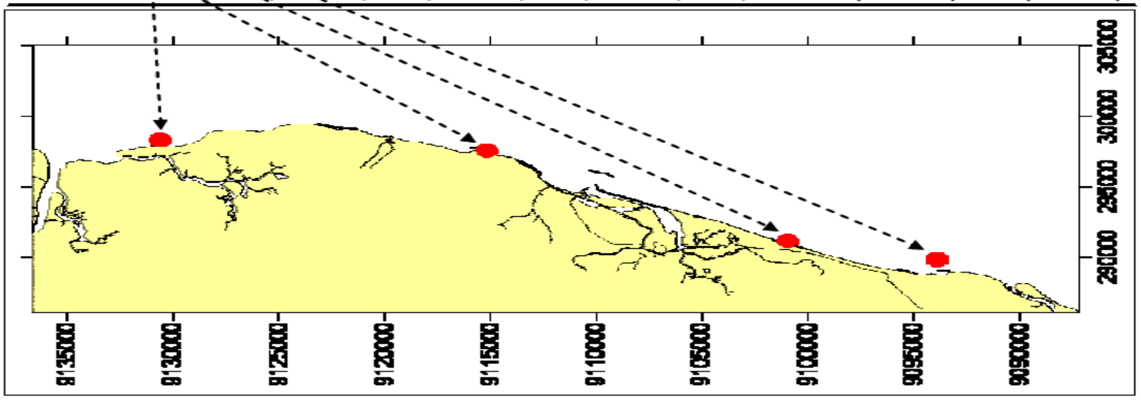

Figure 1: Wave height at 4 municipalities (MAI, 2009)

The wave data analysis showed significant differences in spatial patterns of wave characteristics which can primarily be attributed to the presence of the reefs acting as submerged breakwaters (PROCOSTA, 2010). The wave height is strongly dependent on the tidal stage. The reefs, fulfilling the role of submerged breakwaters are capable of dissipating significant quantities of wave energy. Data analysis produced average wave heights of 0.27 m to 1.28 m in outer measuring stations of the coast of the Recife Metropolitan area and 0.15 m to 0.58 m in internal stations sheltered by the reefs at Jaboatão dos Guararapes Recife, during the rainy season (PROCOSTA,2010). During the drought records showed significant wave heights of 0.25 m to 0.33 m in the inner stations of Boa Viagem.

Wave heights Recife Metropolitan coast	Inner stations wave heights (m)	Outer stations wave heights(m)
Rainy season	0.15-0.58	0.27-1.28
Dry season	0.25 -0.33	NA

Table 4: Wave heights on both sides of the reef (PROCOSTA 2010)

In the internal stations protected by the submerged reefs (BVI, FOZ and CANI) the significant wave height is not only smaller than those recorded by the external measuring devices. Variations on a time scale of 6 h with well-defined cycles of 12 hours are observed and the magnitude of these periods suggests a modulation wave caused by the tide with minima and maxima occurring in the stages of ebb and spring. In Boa Viagem the significant wave heights observed during the stages of low tide where 0.50 m and stages of high tide the average value was 0.72 m. In Candeias, during low tide, the significant wave height obtained an average value of 0.07 to 0.27 m (PROCOSTA, 2010).

Tidal Characteristics Recife	
Significant wave height Boa Viagem low tide	0.50 m
Significant wave height Boa Viagem high tide	0.72 m
Significant wave height Boa Viagem low tide	0.07 – 0.27 m

Table 5: Tidal characteristics of Recife PROCOSTA 2010

The maximum elevation of water level registered in Boa Viagem beach (BVI = Boa Viagem inside reef protection and BVE = Boa Viagem outside the reefs protections) during July and August 2009 was 2.32 m and the minimum was 0.29 m, with an average height of the tide observed during this period being around 1.24 m. The period from 22 to 30 March 2009, data (PROCOSTA 2010) presented maximum water levels in BVI and BVE of 2.55 m and the minimum was 0 m. The average height of the tide during this period was 1.24 m.

Elevations Registered in BVI and BVE July-august 2009	
Maximum elevation BVI and BVE July-august 2009	2.32 m
Minimum elevation BVI and BVE – march 2009	0.29 m
Average height of tide BVI BVE – march 2009	1.24 m

Table 6: Elevation measured in BVI and BVE PROCOSTA 2010

Records of the tidal heights observed in Candeias Beach (CANE = Candeias outside reefs protection, CANI = Candeias inside reefs protection) during the period 18-21 September 2009, spring tide conditions were 2.58 m and the minimum was -0.05 m and the average tidal heights was 1.20 m. The values obtained by the S4 mooring at the river mouth Jaboatão during the period of 29th June to 5th of July showed a maximum elevation of the tide of approximately 1.95 | 0.59 m with an average rise of the tide of 1.22 between measurements (PROCOSTA,2010).

Records tidal heights Candeias beach	
Maximum water level elevation 18-21 sep 2009	2.58 m
Minimum water level elevation 18-21 sep 2009	-0.05 m
Average tidal heights 18-21 sep 2009	1.20 m
Maximum water level elevation 29 June- 5 July 2009	1.95 m
Minimum water level elevation 29 June- 5 July 2009	0.59 m
Average water level elevation	1.22 m

Table 7: Records of tidal heights at Candeias beach PROCOSTA 2010

According to what was reported in (PROCOSTA,2010) in Boa Viagem wave attenuation was between 40 and 60 per cent, however, in Candeias the attenuation of the wave reaches values between the range of 1 % and 90% in steps of high and low tide for the two locations. The modulation of the tidal wave was clearer in Candeias due to the geometry of the reef. The length above the reef is merely 0.5 m during low tide which created a surf zone on the site (approximately 700 m from the shoreline). In Boa Viagem, the top of the reef is about 5.5 m during the low tide and the dissipation process by wave breaking isn't evident, given that the depth limit isn't reached. The wave attenuation is primarily due to friction in the background (PROCOSTA, 2010)

At the mouth of the river Jaboatão, during the low seas significant wave heights reach small values in the range of 0.06 m neap tide and 0.58 m at high tide. This region is under the protection of the reef which allows for the formation of sand banks which attributes to the attenuation of incident waves (PROCOSTA, 2010).

Characteristics Mouth River Jaboatão	
Significant wave heights low tide	0.06 m
Significant wave height high tide	0.58 m

Table 8: Characteristics at the river mouth of Jaboatão PROCOSTA 2010

1.1.4 *Currents*

Collected data suggests that the current directions are narrowly connected to the dynamics of the tides, being generally more intensified in parts protected by reefs. According to (PROCOSTA,2010) the measurements of currents observed at a depth of 11 m, collected at Boa Viagem during the months July and August 2009, had a maximum speed of 0.153 m/s, with a mean of approximately 0.032 m/s. The currents tend to stream towards the North and North-East under the influential tidal dynamics. During the month of March 2010, the maximum speed of the current was around 0.112 m/s with a mean of approximately 0.048 m/s according to (PROCOSTA, 2010)

Characteristics current Recife metropolitan Coast – Collected at Boa Viagem	
Depth measuring device	11 m
Primary Direction	N-NE
Maximum velocity July-August 2009	0.153 m/s
Mean velocity July-August 2009	0.032 m/s
Maximum velocity March 2010	0.112 m/s
Minimum Velocity March 2010	0.048 m/s

Table 9: Characteristic currents for the Recife metropolitan area PROCOSTA 2010

The current data found in the internal measurement device (BVI) Boa Viagem at a depth of 7 m, during July to August 2009 have a preferential direction towards the NE and SW, associated with the tidal dynamics. The maximum speeds during this period were significantly higher than in July and August. The maximum measured speed was 0.226 m/s and the mean was 0.054 m/s. The series measured during March 2010 showed the maximum speed of 0.202 m/s and at least 0.011 m/s. The average velocity was around 0.114 m/s according to (PROCOSTA, 2010).

Measurements currents BVI	
Depth collection	7 m
Primary direction	NE SW
Maximum measured velocity July –august 2009	0.226 m/s
Mean Measured velocity July –august 2009	0.054 m/s
Maximum velocity March 2010	0.202 m/s
Minimum velocity March 2010	0.011 m/s
Average Velocity March 2010	0.114 m/s

Table 10: Current velocities at BVI PROCOSTA 2010

The measurements of the velocities collected at a depth of 1 m in Candeias Beach (interior point) during the same period indicated that the currents presented with directions associated with tidal dynamics for N and SE. The maximum speed observed was approximately 0.161 m/s resulting in an average velocity of 0.044 m/s.

Measurements currents Candeias Beach	
Depth collection	1 m
Primary direction	N - SE
Maximum measured velocity July –august 2009	0.161 m/s
Mean Measured velocity July –august 2009	0.044m/s

Table 11: Currents velocities at Candeias beach PROCOSTA 2010

In June and July 2009 currents observed near the river mouth of Jaboatão with a water depth of 3 m had a velocity maximum of 0.832 m/s and a minimum velocity of 0.007 m/s with an average velocity of 0.33 m/s. In this area the directional tendency of the current was also primarily influenced by the dynamics of the tide.

Measurements currents mouth of Jaboatão	
Depth collection	3 m
Maximum velocity June-July 2009	0.832 m/s
Mean velocity June-July 2009	0.33 m/s

Table 12: Current velocities at the mouth of Jaboatão PROCOSTA 2010

Measurements of the currents were also measured in (MAI, 2009). The project was executed to characterize the coastal circulation in the study area covering area with a profiler current ADCP. Numerical models for the currents were also written and published in (MAI, 2009).

The velocity field of the currents, both the bottom and surface currents during the high tide and low tide, were measured and are reported in (MAI, 2009). During the majority of the year, prevailing winds cover the area from the S-SE, particularly during the rainy season when stronger winds are prevalent which results in long shore currents from N-NE. Under windows from non-E-SE winds of the E-NE the incident waves on the coast result in prevailing long shore to the south, throughout the area (MAI, 2009). The currents can be found in Appendix C Currents.

1.2 Physical features

1.2.1 *Geology*

The study area falls within the basins of Paraiba and Pernambuco. These basins have different geological backgrounds. Both basins find their origin from the separation of the African and American continental plates. The cities of Paulista and Olinda are located in the Paraiba basin while the city of Recife and Jaboatão dos Guararapes are located in the Pernambuco basin (Figure 2). The fact that the basin of Paraiba was a land bridge between Africa and South-America in the upper cretaceous, may explain the differences of the two basins (MAI, 2009). The Paraiba basin has an averaged width of 25 km, a depth of maximal 400 m and a slope varying between 5 to 25 m/km.

During the last 1.8 million years (the Quartair) the Brazilian coast has experienced different kind of processes due to sea level rise and fall. The sea level varies because of the different ice ages present at the time. In total 8 cycles of sea level rise and fall can be determined, which influence the Brazilian coast. See (MAI volume 1 2009) for more information on these processes. During the Pleistocene transgression took place that deposited primarily sand (quartz). The marine sediments where dissolved due to certain acids that were present. These sediments are primarily deposited in the inner part of the coastal plane, with a width varying from 0.5 to 1 km. The Holocene witnessed the last transgression which deposited sediments consisting of sand (quartz) and mollusks. These sediments were deposited on the outer coastal plane and can have a width of 2 km.

Figure 2: Map with among other the Paraiba and Pernambuco basin (MAI, 2009).

1.2.2 *Material properties and supply*

The main sediment supply for the coast of the metropolitan area of Recife comes from the shallow deposits done in the Pleistocene and Holocene. These shallows have a tendency to create an environment which favors sediment deposition to the coast (estuaries, deltas, mangroves and sandy beaches). Some marine deposits may be found here as well. Another source is the rivers in the area.

However due to human intervention in these rivers the sediment supply is limited and contains more mud than before the human intervention.[1]

Along the coast of the metropolitan area of Recife the sediment characteristics differ vastly. In the study (CPE, 2011): samples collected all over the metropolitan coastline have been studied and reported, the results can be seen in Appendix F Material characteristics. In the CPE study the following material characteristics has been denoted:

- The value of the average diameter in Wentworth scale (WENTWORTH, 1922);
- The standard deviation [-];
- Asymmetry [-];
- Kurtosis [-];
- The friction angle Phi [-].

1.2.3 *Sediment transport*

The coastal region of Pernambuco is 187 km long and has a high population concentration. Intense erosion is evident along the coastline of the state. Many of the stretches of coastline are stable; however some areas are presenting progressive coastal erosion (CPRH, 1998 apud Souza, 2006). The erosion can be faulted to the lack of sediment supply due to absence of major rivers and a narrow continental shelf. Other reasons may also be: small sediment storage areas and presence of the reefs which hinder mobilization of the sediment. Finally occupation of the beach environment can make it difficult for beaches and dunes to recover.

The processes that govern the coastal sediment dynamics are forced by a combination of physical and geological features such as currents generated by both the tide and wind waves from the SE and NE. Other features such as particle size from the beach, classified between medium and coarse sand in most of the areas and also a complex bathymetry of the inner shelf play an equally important role. In (MAI, 2009) the idea is enforced that coastal erosion of the beaches is directly related to the increase of irregular occupation of the coastal line.

The primary factors influencing the creation or erosion of a sandy beach are waves, currents, sediment availability and sediment transport along the coast. Calculation of the sediment transport is a complex undertaking and becomes extremely complex, primarily by uncertainties in the calculation of the long shore drifts. During incidental erosion events large amounts of sands can be eroded from the beach and transferred into offshore sinks. The sediment rarely returns to the beach under normal conditions. Understanding of the transport mechanisms of sediment on the coast is paramount to the execution of successful coastal protection projects.

Erosion factors

The relative contribution of erosion factors is poorly understood, however, it can easily be concluded that the occupation of the beach environment by buildings has been detrimental for the erosion (MAI, 2009). Moreover, many of these works (buildings, retention walls, roads etc.) have been constructed on the back shore which is essential for the supply of sediment. Their construction has undermined the sediment supply of several stretches of beach which are currently under strong erosion (Souza, 2006).

[1] See 2

Throughout the Metropolitan Region of Recife, the management of this problem has been addressed by the construction of adhering revetments and breakwaters in critically affected areas without proper input from the coastal engineering discipline (MAI, 2010). These measures resulted in failures or sometimes in intensification of the erosion problem in local or adjacent area.

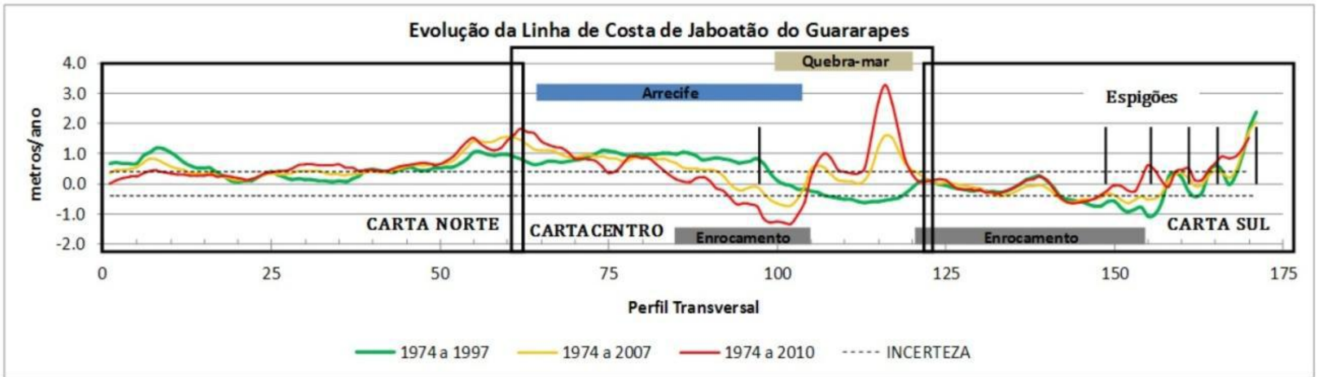

Figure 3: Pattern of coastal evolution of Jaboatão do Guararapes (MAI, 2010)

The coastal erosion of Jaboatão do Guararapes is visible in the image Figure 3. The green line represents the rate of change of the coastline in 1997 before most hard coastal measures were taken. In yellow the coastal line is shown in 2007 when most hard measures were already taken. The coastline in 2010 is drawn in red. It can clearly be seen that some areas have heavily eroded; however, some areas have heavily accreted. The previous phenomenon is testament to the magnitude of the problem.

An assessment of the sediment transport and morphological changes was made in (CPE, 2011) for the coastal region of Recife using Delft3D-Wave, Delft-3D-Flow and Delft3D-MOR. The simulation used morphological tide forcing and 12 representative cases of the local wave climate. Each of the cases had three tidal cycles which therefore included its influence on all levels. The simulations were performed for two coastal interventions in each region and the results have been reported in (CPE, 2011). The area was simulated for an area for up to 5 years. Aside from Recife, the areas Jaboatão do Guararapes, Olinda and Paulista were also simulated. About 500 $m^3/m/y$ is the expected maximum long shore transport in the system boundary.

The longshore transport is responsible for the problematic erosion of the metropolitan coast of Recife. Recife does not have to endure large storms and thus cross shore transport is not the main problem. The rest of the report will therefore focus more on the longshore transport.

Transport direction

The general transport direction of sediment for the entire area is likely towards the North-East because the strongest currents are directed towards the North-East as well. The transport is directly dependent on the direction of the current and this is therefore a fair conclusion. However, locally there may be differences. In (CPE, 2010) the transport through the area was modeled with DELFT3D. The primary direction was clearly toward the northeast in areas such as Boa Viagem. See Figure 4.

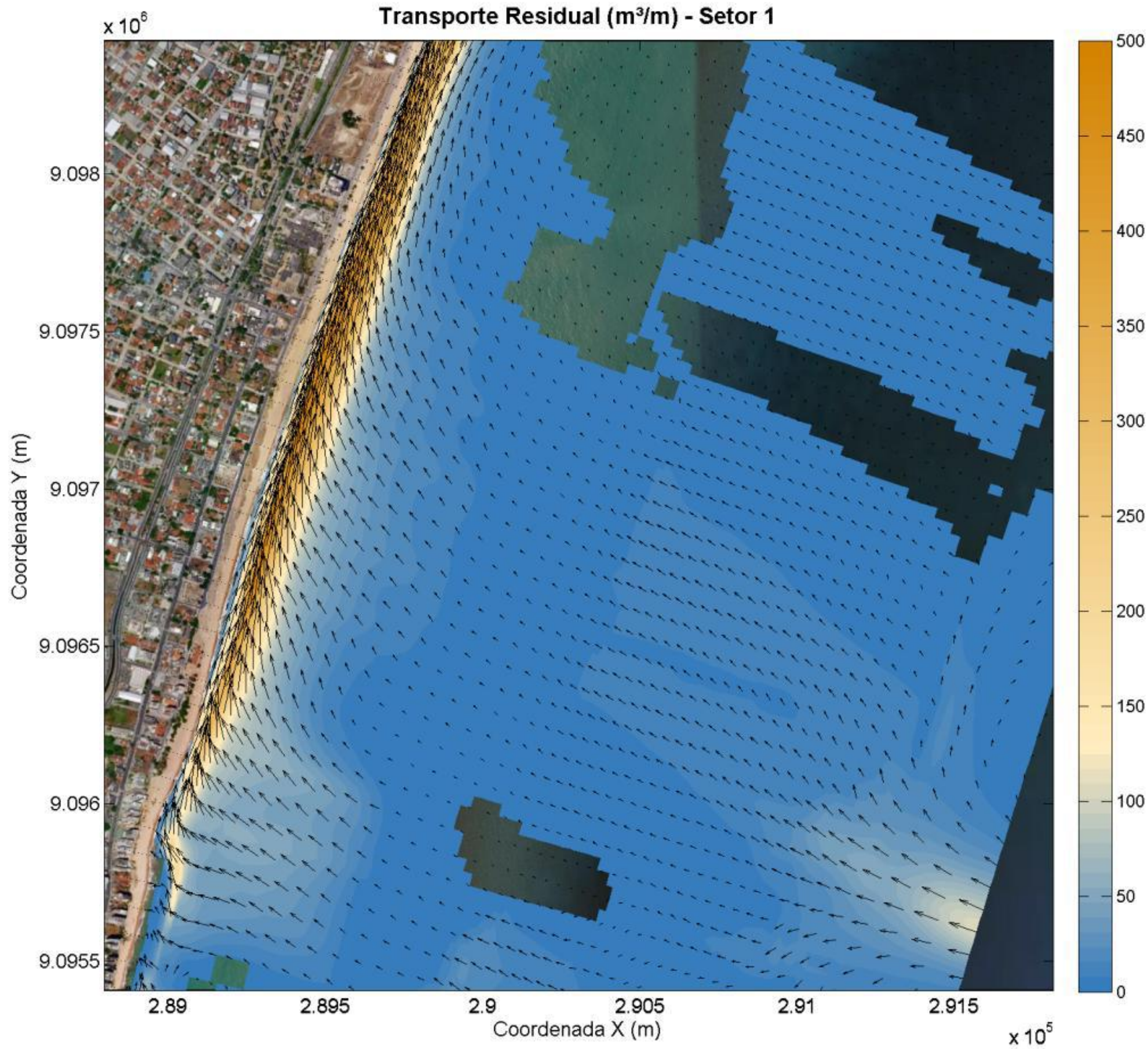

Figure 4: Annualized sediment Transport Recife sector 1 ($m^3/m/y$), (CPE, 2010)

However, in other areas the transport is significantly more complex, such as Olinda. It can be observed that the transport direction isn't clearly directed towards the North-East, however, in Olinda there are several large breakwaters and not to forget the complex reefs in front of the coast, which are probably affecting the natural flow of sediment unlike Boa Viagem in Recife (see Figure 5). There are several areas which each have their own varying field of sediment transport in the area and the NE direction isn't always applicable. Many stretches of the coasts are shielded by the reefs in front of the coast and diffraction can easily change the sediment transport patterns.

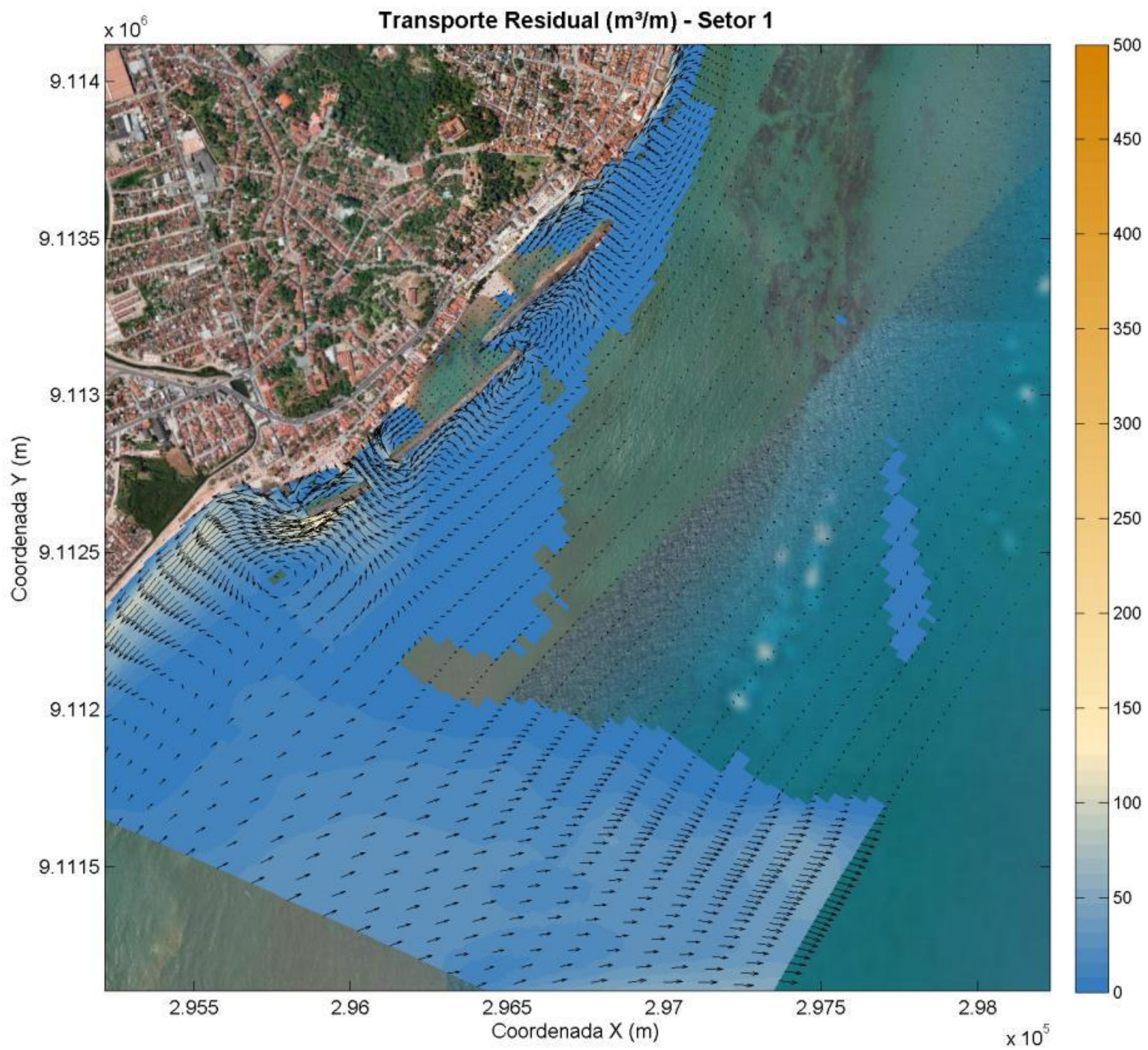

Figure 5: Annualized Residual Sediment transport Olinda sector 1 (CPE, 2011)

1.2.4 *Bathymetry*

The North-Eastern coast of Brazil does not have a very large continental shelf. The width of the shelf at Recife is approximately 30 km. The continental shelf has an averaged depth of about 50 meters. The depth of the ocean directly after the continental shelf is about 500 meters. See Figure 13 and Figure 14 for a map displaying the continental shelf. (CPE 2011)

The metropolitan area of Recife consists of a total of 48,135 m of coastline. 51% of these coasts have beaches. At the beaches of Pina and Boa Viagem there is a channel present between the coast and the reef. One can easily see this channel in the black box in Figure 6. The channel lies parallel to the coast and has a depth of about 7 meters. Further to the south the depth diminishes, at Piedade the depth is reduced to about 4 meters and at the beach of Candeias the channel can no longer be found. At Brasilia and the Northern part of Pina there is a second reef present, at 100 m from the coast. At Boa Viagem the main reef is situated about 1000 m out of the coast and the water depth is about 7 meters before the reef. The bathymetry of Olinda is different to the cities to the south; it has several submerged reefs with tops at two to ten meters. At Paulista the bathometry looks similar to that of Pina, with a reef and a channel in between. To the north there is a reef formation at the low water line, leading to a shallow area between the coast and the reef. Outside of the reef depths of about 15 meters are easily reached. At the mouth of the estuary on the northern border there is a high deposition of sediments. These sediments form sand banks that migrate seasonally (MAI, 2009). For examples of cross sections of the bathymetry see Appendix D Bathymetry.

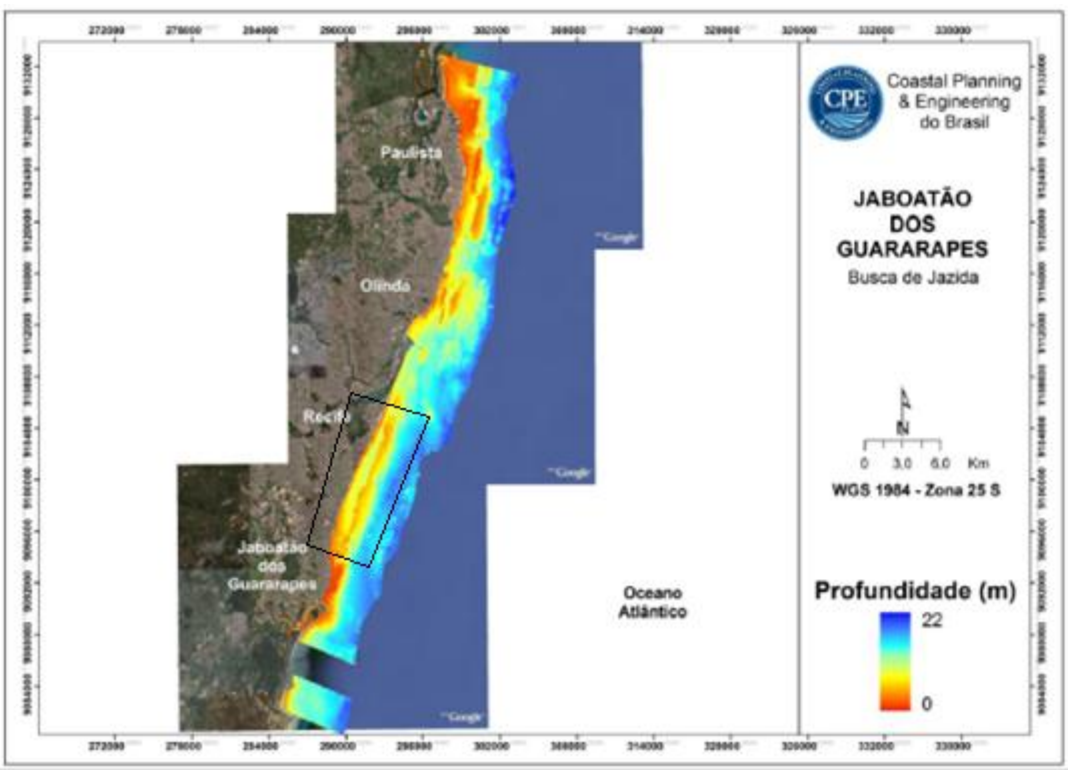

Figure 6: Bathymetry of the metropolitan area of Recife (MAI, 2009). (profundiade means water depth)

Reef types

In the metropolitan area of Recife one can physically categorize three kinds of reef types:

- Barrier type
- Fringing type
- Sandbar type

Barrier type

The barrier type of reef is located offshore and can reach levels above sea level (see Figure 7). These reefs can reach widths of up to 800 meters. The name barrier explains what role these reef types play on the coast. They shelter the coast from wave action and they can ensure that sediments do not escape easily offshore.

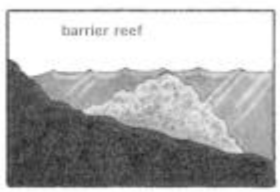

Figure 7: Barrier type of reef

Fringing type

The fringing type of reef run all the way up to the shore, see Figure 8. They create a relative flat and shallow area in front of the beach. Because of the flat area the waves will break further off the coast, thus sheltering the coast.

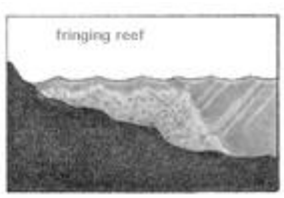

Figure 8: Fringing type of reef

Sandbar type
The sandbar type of reef is very narrow and is oriented in a line, see Figure 9. They are similar to a sandbar except that they can be higher, steeper and are fixed to their location. It is possible for the sandbar types of reef to be higher than the water level. These types of reefs are found relatively close to the shore.

Figure 9: Sandbar type of reef

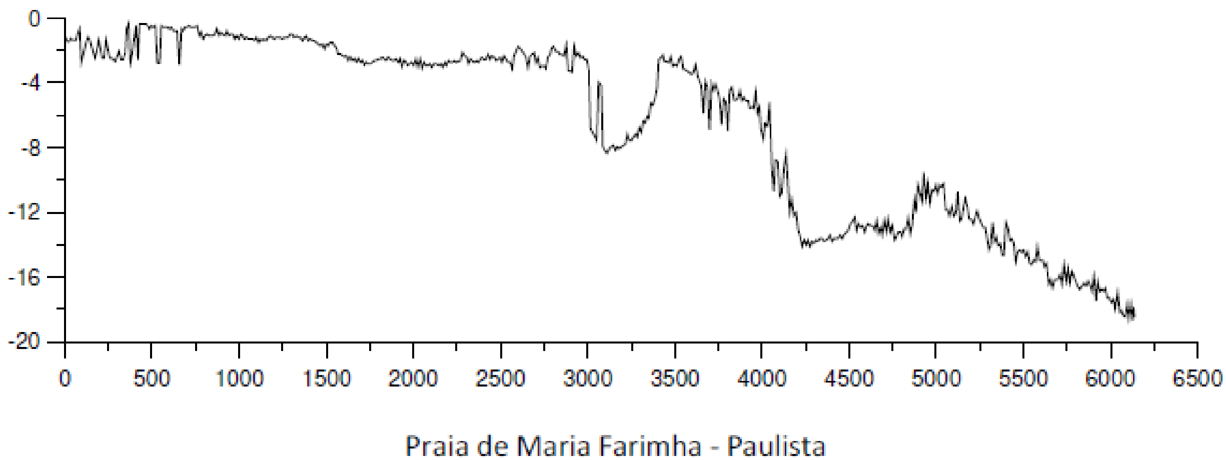

Figure 10: Representative cross sections for Paulista.

In Figure 10 the cross section of the bathymetry of the beach of Maria Farimha in Paulista can be found. In the figure one can see very clearly that at a distance of 3000 meters a fringing type of reef starts.

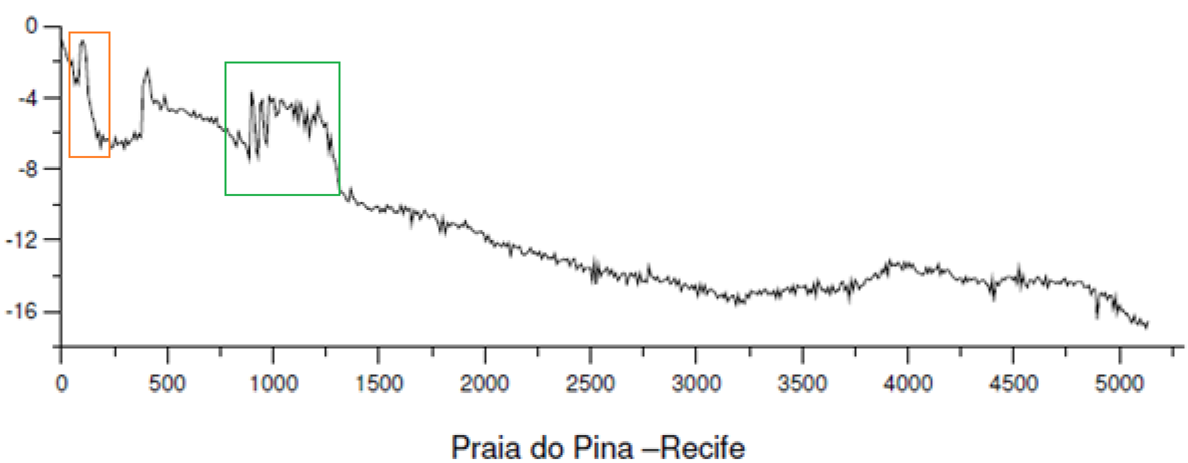

Figure 11: Representative cross sections for Recife.

In Figure 11 the cross section of the bathymetry of the beach of do Pina in Recife can be found. Inside the green box one can see a barrier type of reef. In the orange box a sandbar type of reef can be seen.

1.2.5 *Large time scale (30 years) beach variations*

During the last 3 decennia the changes of the shoreline position have been monitored by the (CPE, 2011). An analysis was performed that entails the coastal changes with respect to its initial position within the last 36 years (1974-2010).

In this study it was shown that the changes in the coastal development of recent years were related to the installation of coastal structures. More pronounced variations were caused by the presence of structures such as the natural rigid, the coral reef, or man-made structures such as breakwaters and groynes.

A striking observation is that there were vast variations in the same area, e.g. in the coastal area of Olinda: where a shift of the coastline towards the sea occurred of +0.79 m/year and a shift of the coastline towards the mainland of -13.32 m/years. The local places where erosion was very large, so called “hot spots”, the coastline decreased. The places where sedimentation was very large, there was a pro-gradation of the coastline.

At some places where structures are built there are peaks of accretion, which are very local. The revetments prevent erosion. See Figure 12 for an example of the results of the study. At the location that shows large relative accretion there is a breakwater, note that because of the revetments of the adjacent beaches shoreline does not erode. The accretion or erosion of the shore of the metropolitan area or Recife depends very much on the location. See Appendix E Long time scale variation of the coast for more detailed information of the other areas in the system boundary (CPE 2010 Volume 2).

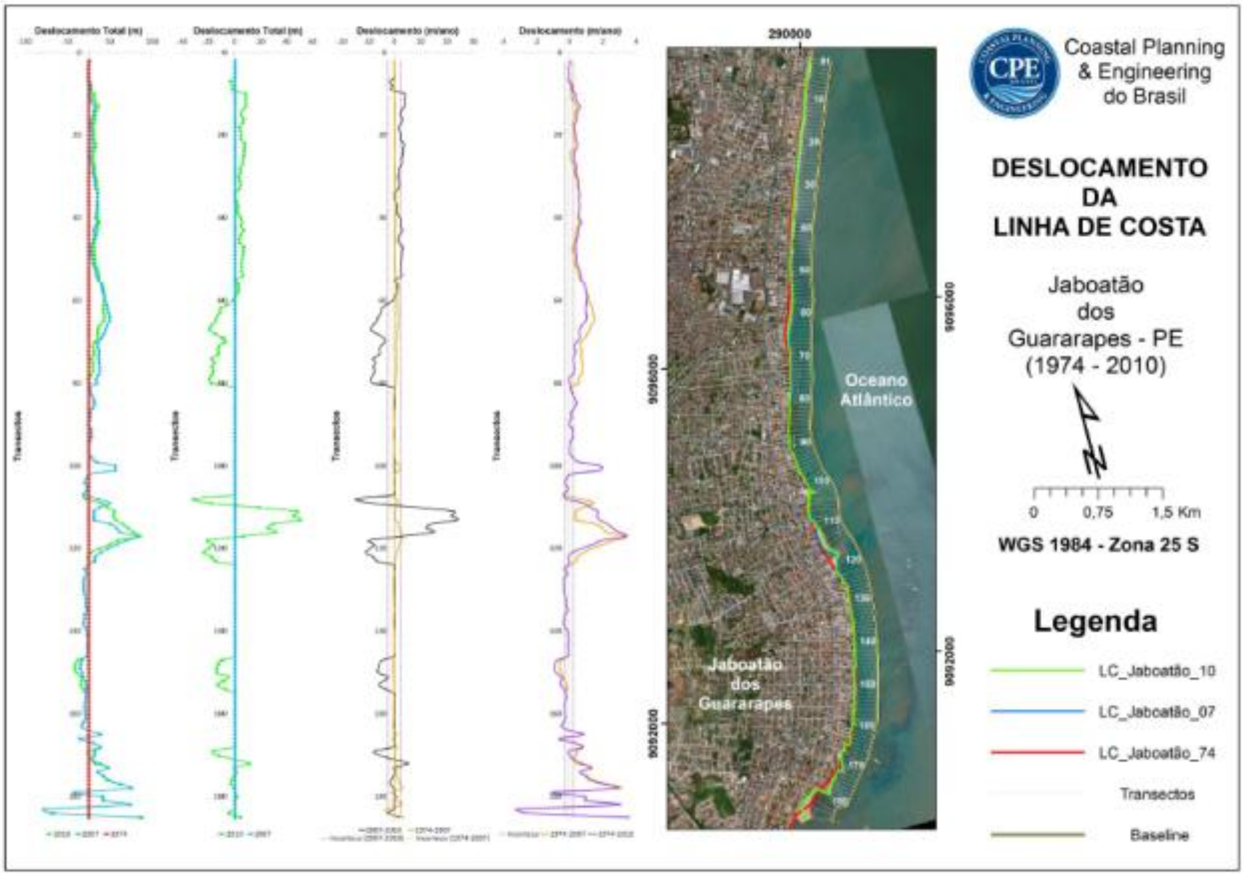

Figure 12: Total coastline variation of the coast of Jaboatão dos Guararapes. (transecots means cross section and deslocamento means displacement)

1.2.6 *Short time scale (one year) beach variations*

Studies in (CPE 2009) have shown that on a yearly basis the coast of the metropolitan area of Recife has not only shown erosion. The area of Jaboatão dos Guararapes, Recife and Paulista has shown a progressive trend. Most of the lost sediments return to the beach profiles. However some areas in Jaboatão dos Guararapes and Paulista showed erosion. The erosion in this area can be ascribed as consequences of human constructions works (MAI, 2009).

The beach profiles on the Carmo beach (Olinda) shows an unequal distribution of sedimentation due to the breakwaters present. The breakwaters are not equally effective. The erosion behind some breakwaters comes up as accretion behind others. The beaches of Bairro Novo in Olinda have a stable shoreline due to revetments. However the beach does not have enough space for healthy coastal processes. The upper beach is too short to store sediments and to let transport take place. The northern part of the shore of Olinda does not show any big changes. Studies have shown that the waves are responsible for changes in the beach profile in this area. Since there is little or no change in this area, one concludes that the wave action in this area is too small to cause major changes to the beach profile (MAI, 2009). For more detailed information on the short time scale beach profile see (MAI 2009).
The conclusions of the short time scale beach variations can be misleading. The fact that a beach is stable or accreting does not mean that the respective beach is healthy or desired. It is possible that the

beach was already too small when the small scale measurement started. If the beach was then concluded to be stable means, that it will remain this (undesirable) size.

1.3 Coast classification

1.3.1 *Continental coastal classification*

The continents are classified as the uppermost layer of the earth (containing the crust) that is called lithosphere. By the 1960's it was found that the earth's crust is divided into 12 large, tightly fitting plates and several smaller ones. In (Inman et al, 1971) it was recognized that broad coastal characteristics such as shelf width and coastal topography are connected to the position of the dynamic plates. The classification which was used in (Inman et al, 1971) placed the coast into three categories. The classifications were a leading edge coast, trailing-edge coast ad marginal sea coast.

The Eastern coast of South-America is a trailing edge coast according to (Coastal Dynamics 1 by Stive). The trailing edge coasts are located at a relatively large distance from plate boundaries contrary to leading edge coasts and are generally tectonically stable. The trailing edge coast also has wide continental shelves. Recife differs from the general classification trailing edge coast because despite being a trailing edge, the continental shelf is quite narrow (CPRH, 1998 apud Souza, 2006). Figure 13 in which Recife has been marked in red. See Figure 14 for a closer inspection on the bathymetry and composition of the beach.

Figure 13: Continental shelf width of South America

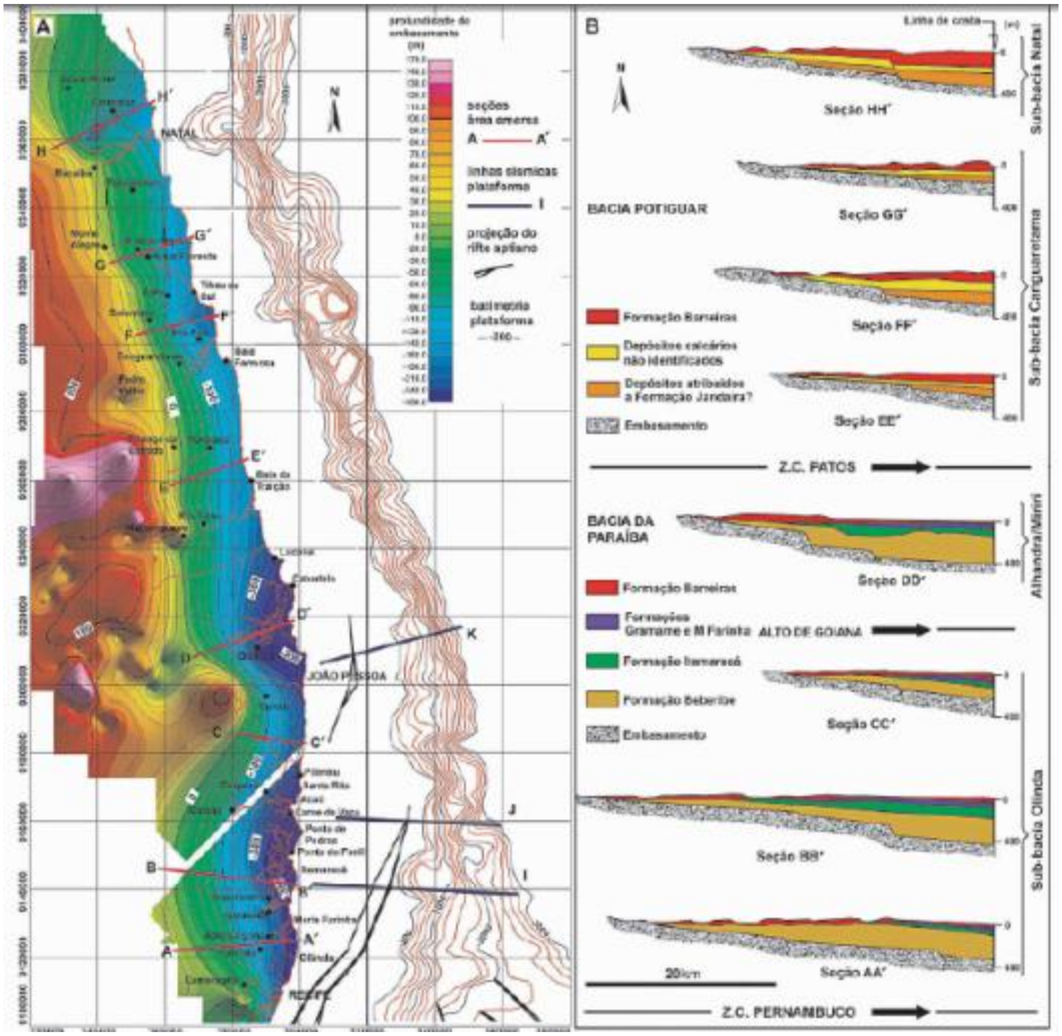

Figure 14: Continental Shelf Pernambuco

The narrow continental shelf width has an effect on the hydrodynamic conditions. A wide shelf allows for strong storm surge elevations due to larger fetch distances.

Wind waves are higher on narrow shelves since the waves are permitted to keep their height because there is less bottom depth to dampen their height. Wider shelves have more frictional dampening of the waves and thus less energy. Trailing edge coasts have been tectonically stable for millions of years during which erosion processes have taken place and converted hills and cliffs into coastal submarine plains. Along these coasts large amount of sediment can be found. The coast is shaped and reshaped by currents, winds and waves into barrier islands, deltas and other sedimentary shapes. Trailing edge coast have fine sediment and leading edge coasts have coarser sediment and even rocks and pebbles.

Recife has a flat but narrow coast which is somewhat contrary to the general description of the trailing edge coast. This makes the metropolitan area of Recife a particularly interesting and complicated area in regards to its erosion problems. The metropolitan area of Recife also faces interesting environmental excitation because the narrow and flat continental shelves allows for more wave energy to reach the

coast than a wide and flat continental shelf would normally allow for. The sediment on the coast is that of a trailing edge coast because it is composed of relatively fine sand according to (CPE, 2011).
The reefs present on the coast of the Metropolitan area of Recife therefore play an instrumental role in the coastal protection of the area because their presence heavily reduces the wave energy resulting is weaker currents and less sediment transport.

1.3.2 *Wave energy*

Another characterization of the coast is based on the wave energy. In (Coastal Dynamics, 2010) the classifications used for global wave environments are:

- Low wave energy (Hs is smaller than 0.6 m)
- Medium wave energy (Hs lies between 0,6 m and 1.5 m)
- Strong wave energy (Hs is larger than 1.5 m)

The metropolitan area of Recife can be classified as a medium wave energy environment because the significant wave heights generally occur in the general vicinity of 0.6 m and 1.5 meters (MAI, 2009; CPE, 2011).

Two types of breakers are prevalent on wide and flat beaches which are found in the metropolitan area of Recife. Spilling breakers are usually found along flat beaches. These waves begin breaking at a great distance from shore and break gradually as they approach shallower water (COASTAL DYNAMICS 1, 2010). There is very little wave reflection back towards the sea. However, the author has observed plunging breakers. The curling top of the wave was clearly visible in field observations. Post-breaking of the curling top over the lower part of the wave, significant energy is dissipated into turbulence of which some is reflected back at sea and some transmitted towards the coast.

1.3.3 *Beach states*

Another method of coastal classification focuses on the beach states. The two extreme ends of the spectrum in the beach state sequence can be a reflective and dissipative beach.

Reflective beaches are characterized by relatively steep and narrow beach faces with a berm and a narrow surf zone without bars. The sandy material is relatively coarse (COASTAL DYNAMICS 1, 2010).

Dissipative beaches are characterized by wide and flat sandy coastal zones with one or more bars and dunes backing a wide beach. A dissipative beach is the result of high energy waves which start breaking far offshore. These high energy and short waves are typical for a storm wave climate and the associated variability results in highly dynamic profiles.

The continental shelf is flat and narrow and it also has a large reef heavily attenuating wave action on the beaches. The classification of the beach of the metropolitan area of Recife as a dissipative or reflective is quite complex due to the reef and narrow continental shelf despite being a trailing edge coast.

1.3.4 *Process dominated classification*

Process dominated classification is based upon the dominant process that shapes the coast. There are three basic processes that shape the coast:

- Waves
- Tides
- Rivers

Wave dominated coasts typically have a very smooth shoreline with well-developed beaches and dunes. The waves tend to distribute the available sediment along the coast. A tide dominated coast is more interrupted and where a river meets the coast a delta forms which resembles an estuary. River dominated coast have a large supply of sediments which is not smeared along the coast due to absence of wave and tides.
Most parts of the coast are smooth indicating wave domination. There are no big sedimentations at the rivers discarding river dominance.

The metropolitan coast of Recife can be classified as a wave dominated system (Coastal Processes Geomorphology, 2003).

1.3.5 *Conclusion*

The morphology of the metropolitan area of Recife is very complex. The coast of Recife is a unique one because of the presence of the reef. There are different types of reefs present and there are at some places three reef lines distinguishable. The rivers in the area contribute to this complexity. The morphology does not solely depend on a single factor, but on multiple factors and their interaction with each other. The wind and wave conditions show seasonality, the rivers at the northern and southern boundary of the system, the presence of the many reef lines and the many structures, the complex bathymetry and human interventions all contribute to the complexity of the problem.

The shoreline has not developed uniformly. Some parts have shown erosion; meanwhile other parts have shown accretion. Most of the accretion is very local and due to the presence of structures, reefs and rivers. Adjacent coasts have shown extra erosion. The metropolitan area of Recife has a segmented coast, where each part shows different characteristics.

Appendix B Winds

In Figure 15 one can see the dominant wind directions and velocities averaged per month. The data was collected between the years 2002 to 2007[2].

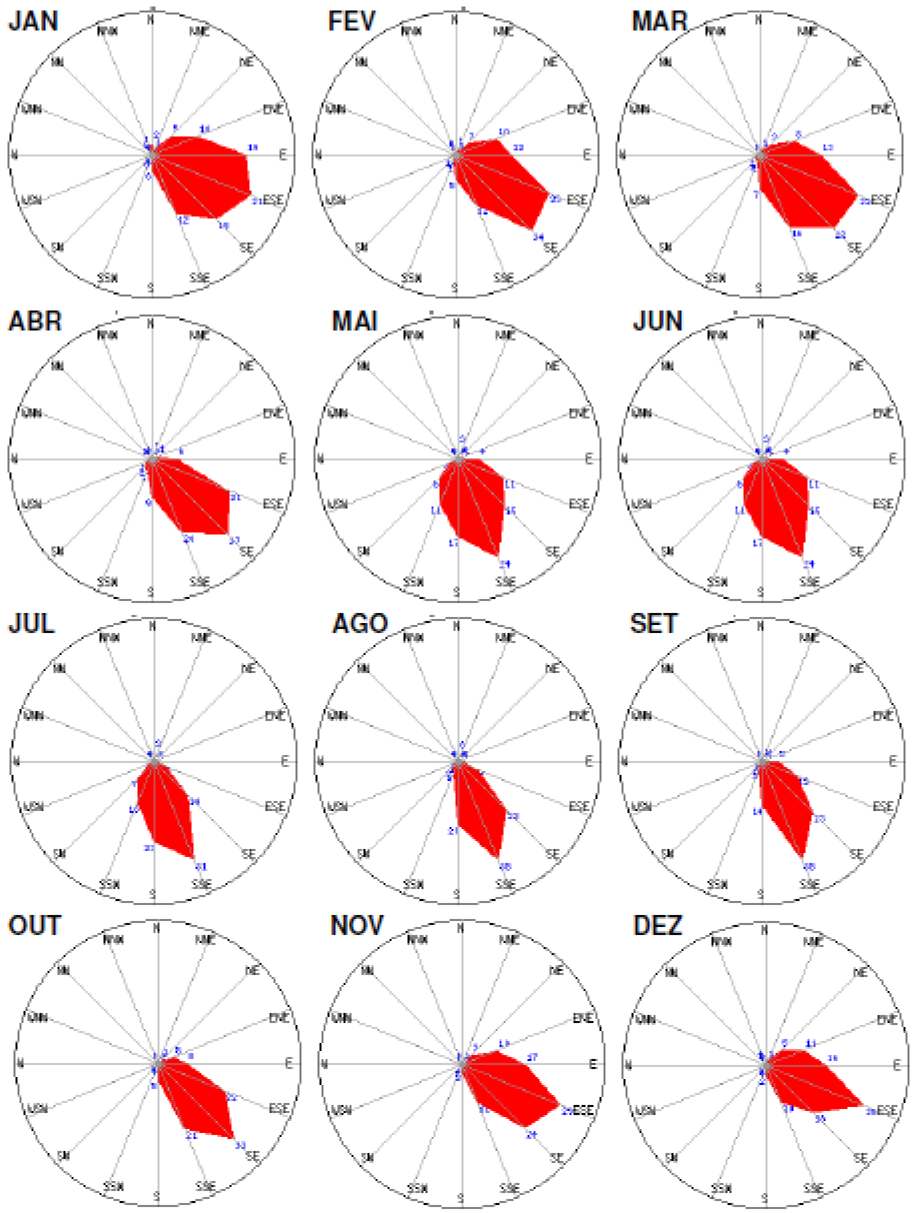

Figure 15: Monthly pattern of prevailing winds. Weather Station of the Airport Guararapes, measured in 2002 to 2007

[2] See 1

Appendix C Currents

Stream velocities and directions (MAI, 2009)

The project was executed to characterize the coastal circulation in the study area covering area with a profiler current ADCP. Numerical models for the currents were also written and published in (MAI, 2009).

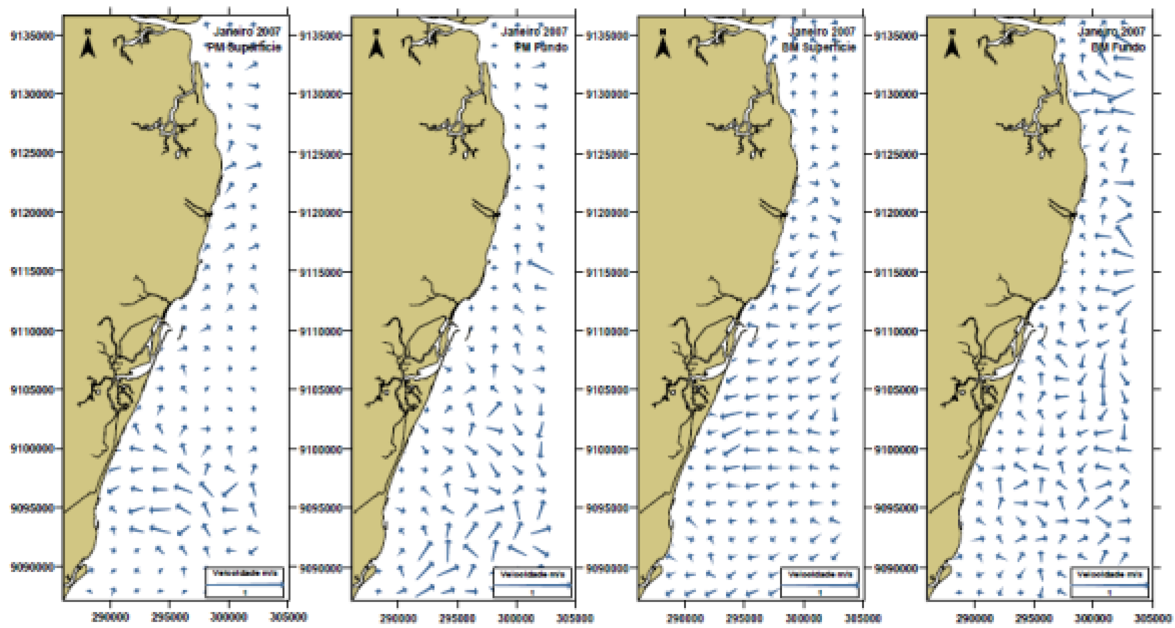

Figure 16: January 2009 - Current Velocity field - (MAI, 2009) – Superficie=surface and Fundo= bottom.

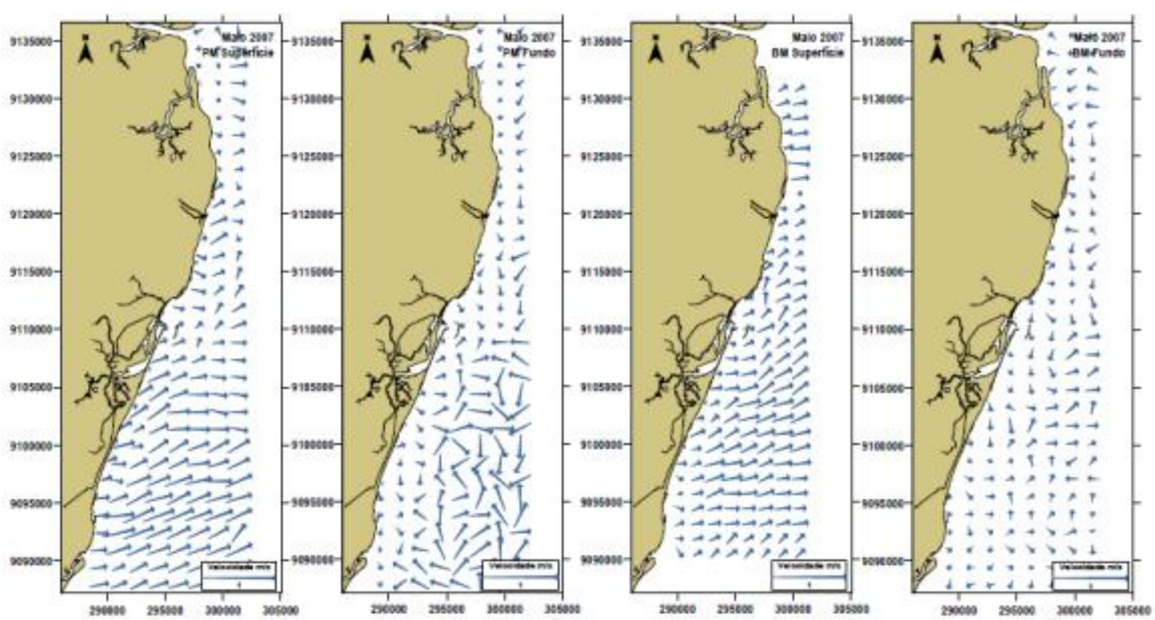

Figure 17: March 2007 - Current Velocity field - (MAI, 2009)

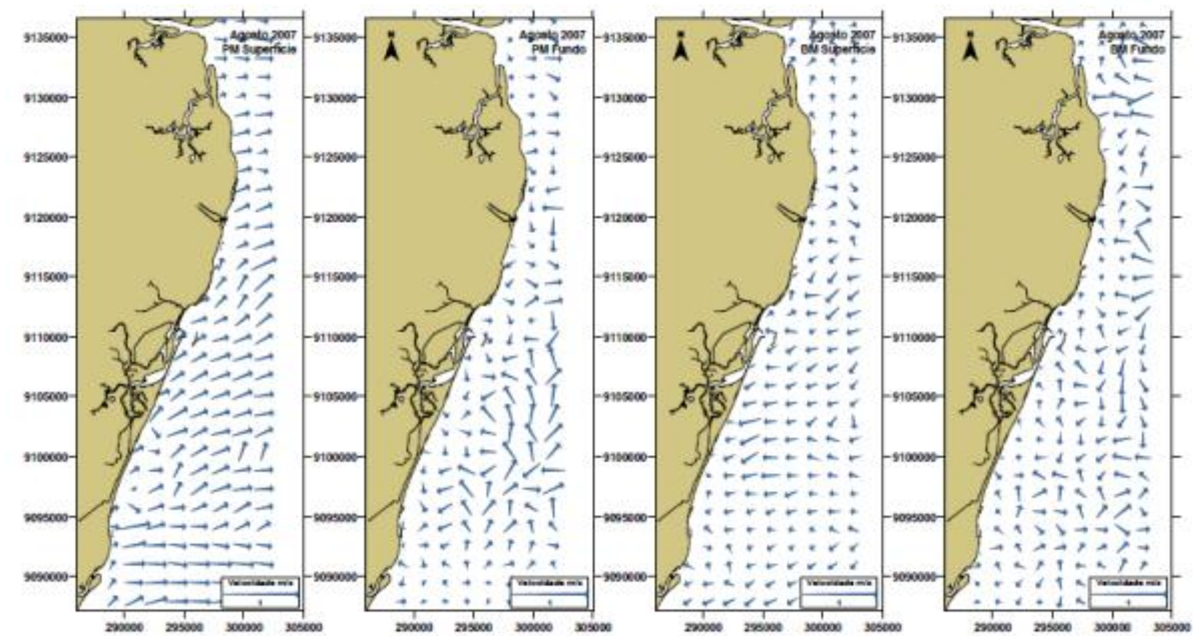

Figure 18: August 2007 - Current Velocity field - (MAI, 2009)

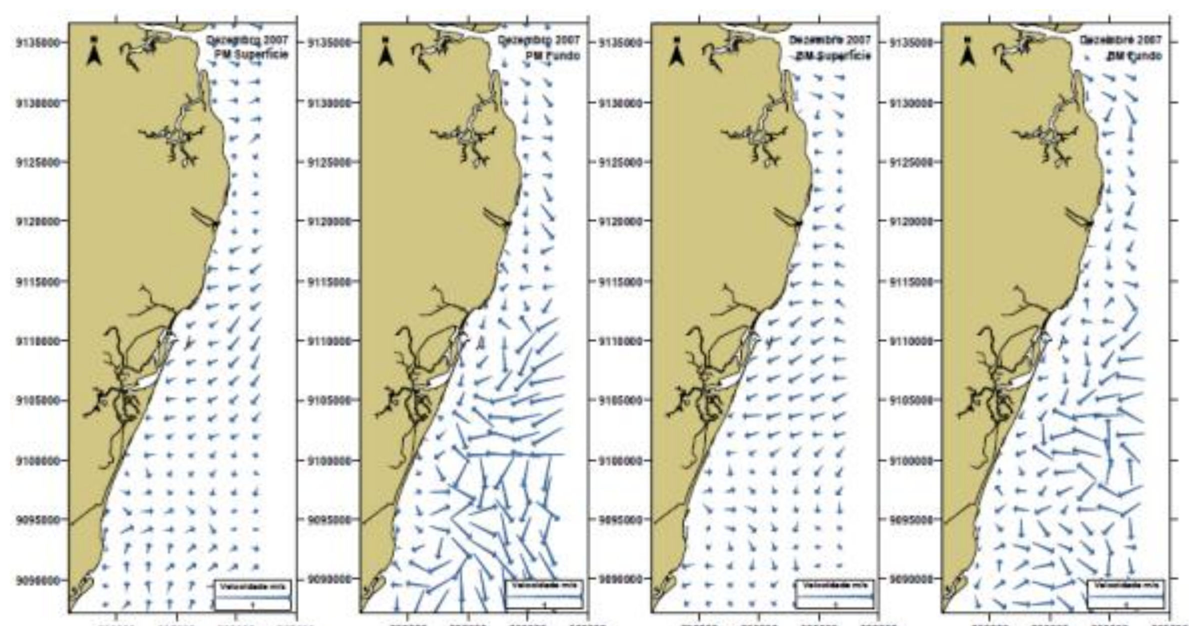

Figure 19: December 2007 - Current Velocity field - (MAI, 2009)

Appendix D Bathymetry

The figures below show example cross section which are representative for the respective area (MAI 2009).

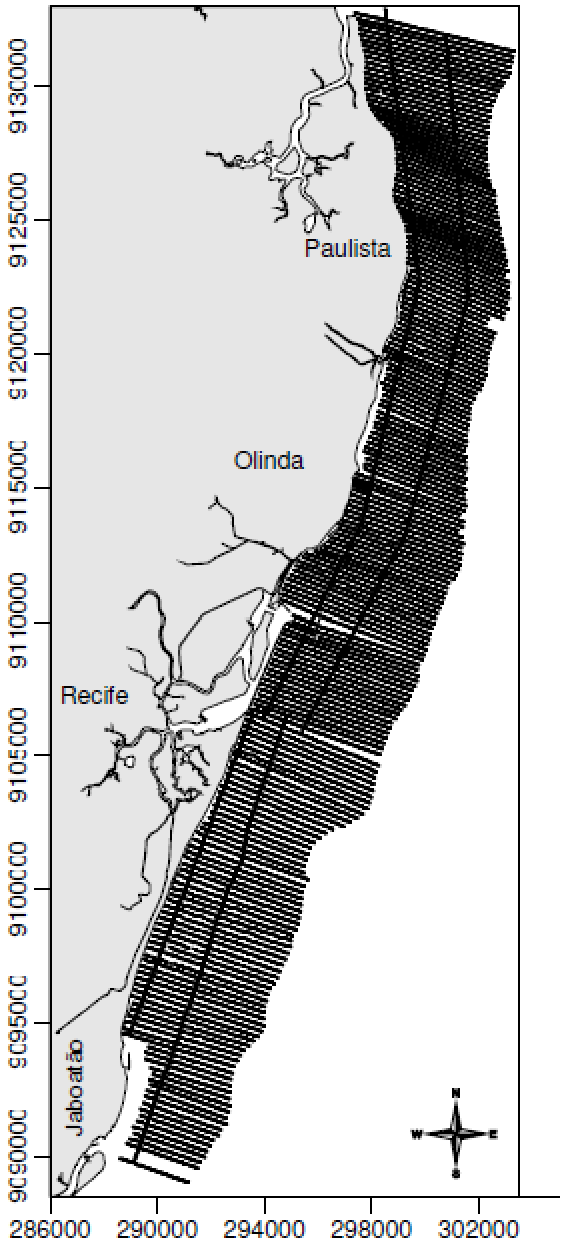

Figure 20: Paths of measurements (MAI 2009)

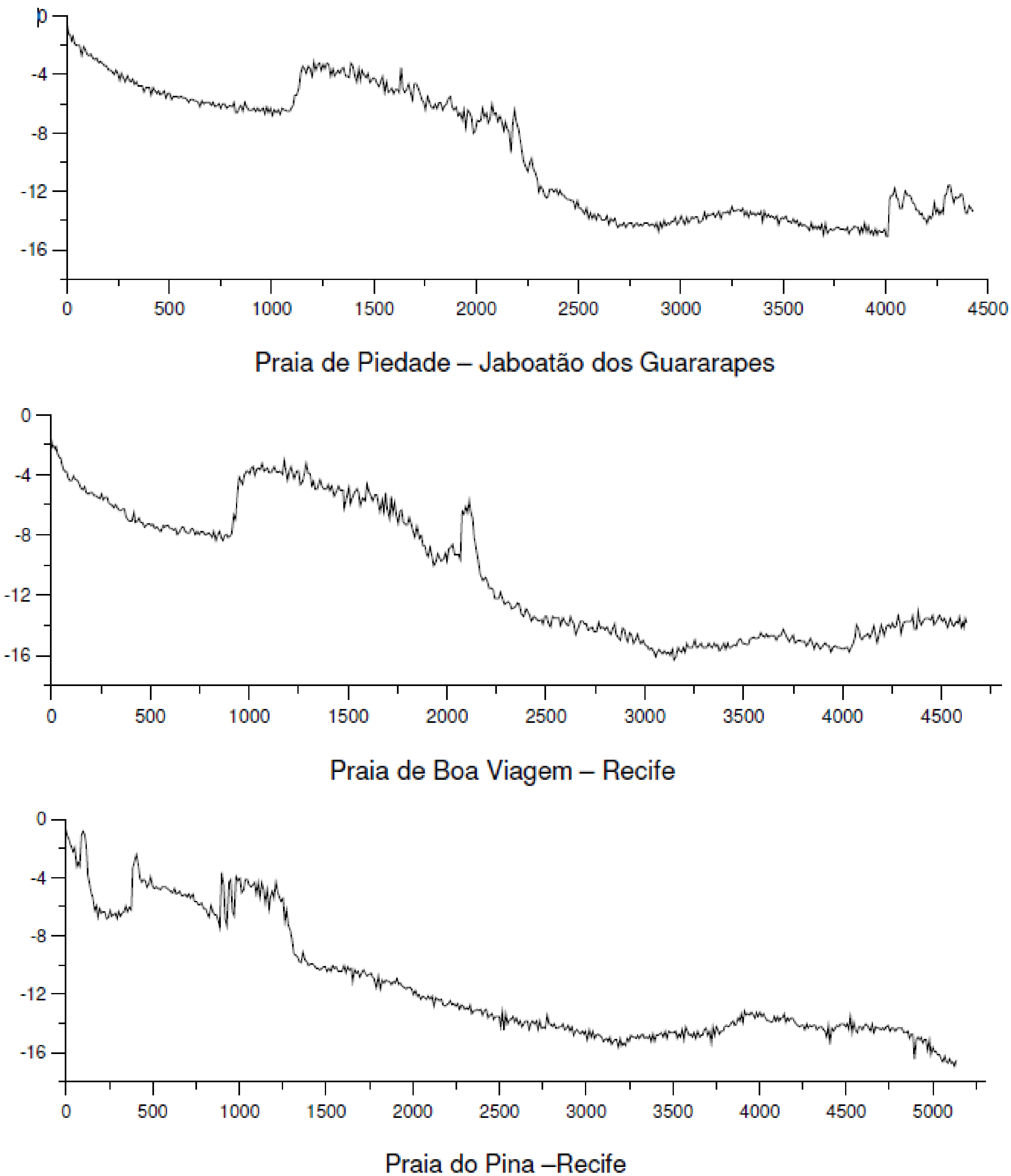

Figure 21: representative cross sections for Jaboatao dos Guararapes, Boa Viagem and Pina.

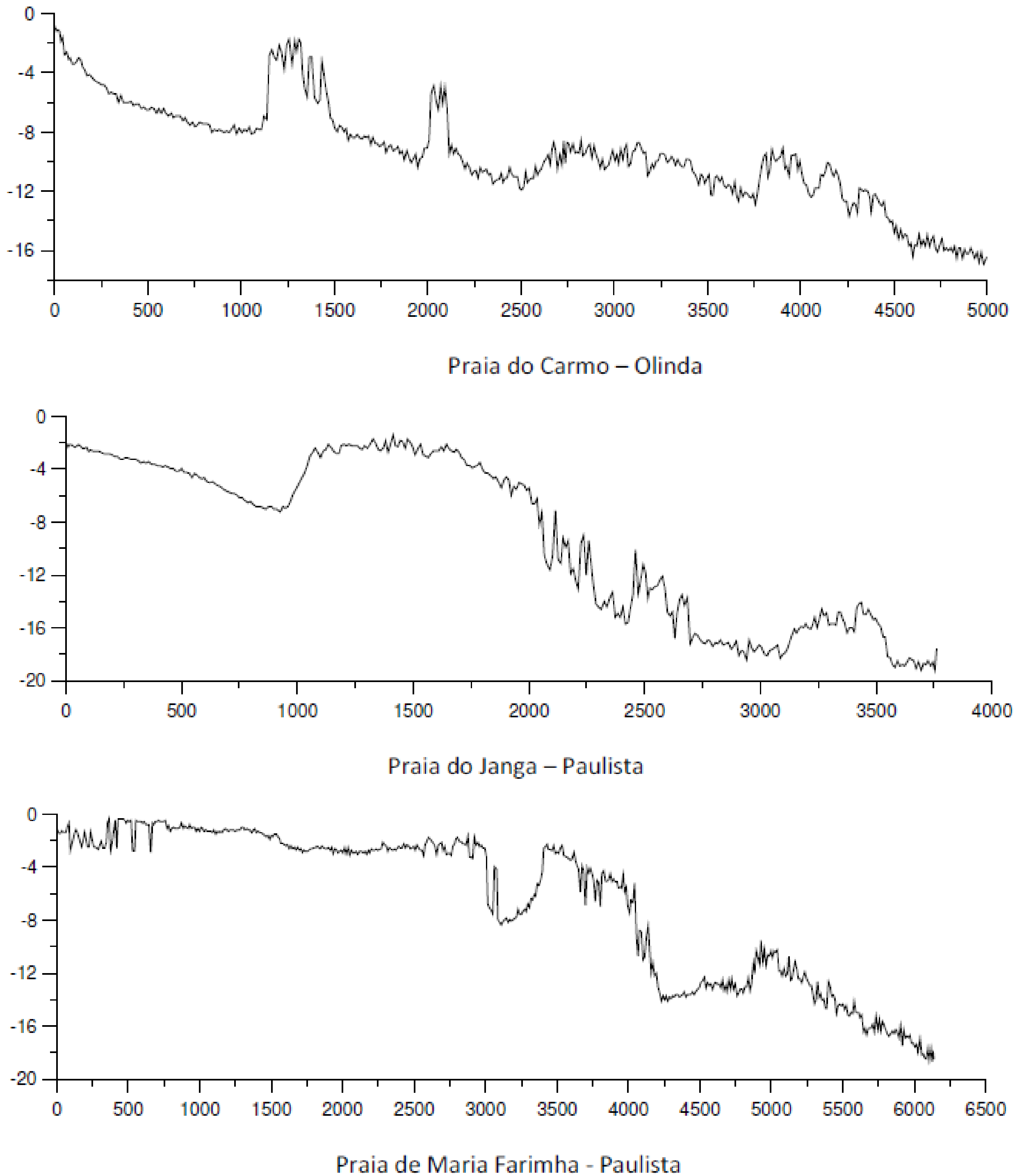

Figure 22: representative cross sections for Olinda and Paulista.

Appendix E Long time scale variation of the coast

The figures below show the results of the study done in (CPE 2010 volume 2).

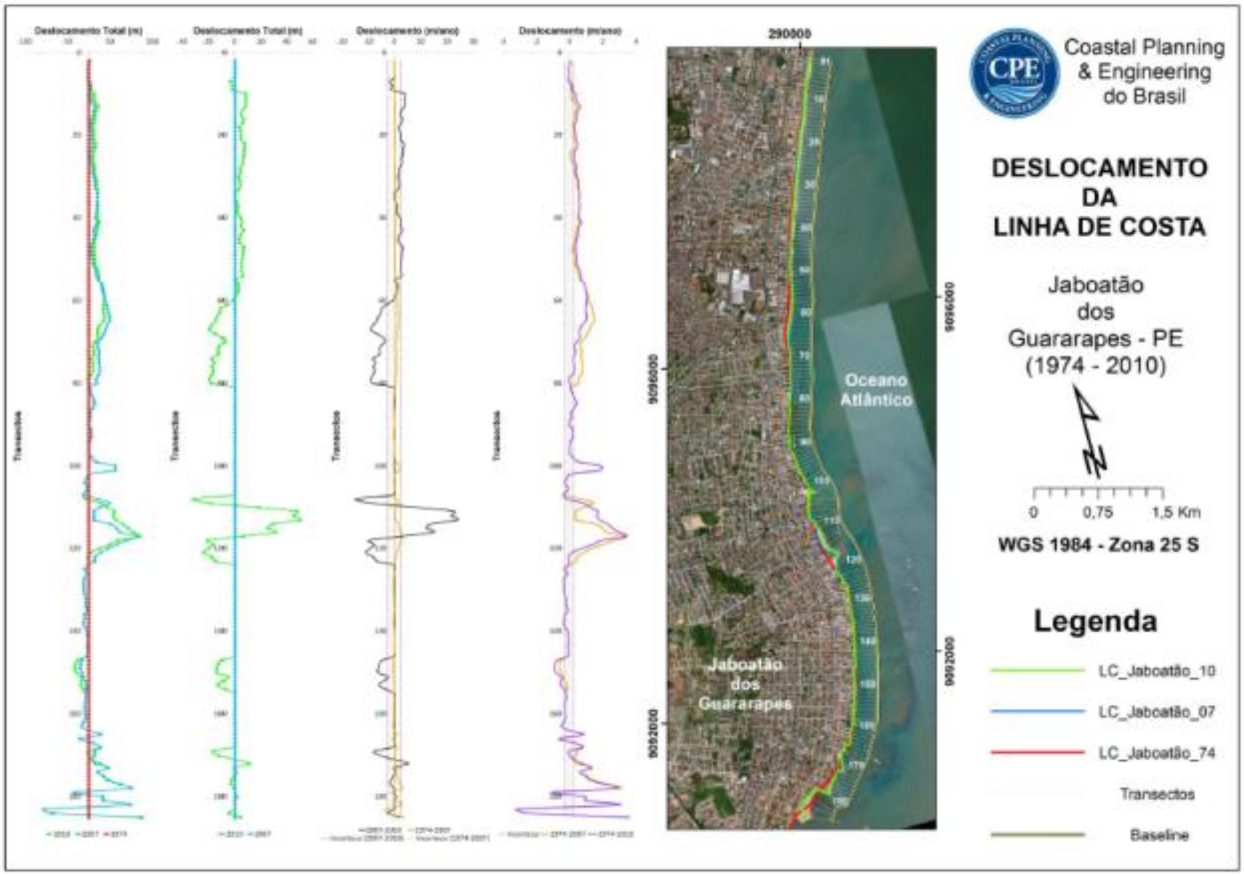

Figure 23: total coastline variation of the coast of Jaboatão dos Guararapes. (transecots means cross section and deslocamento means displacement)

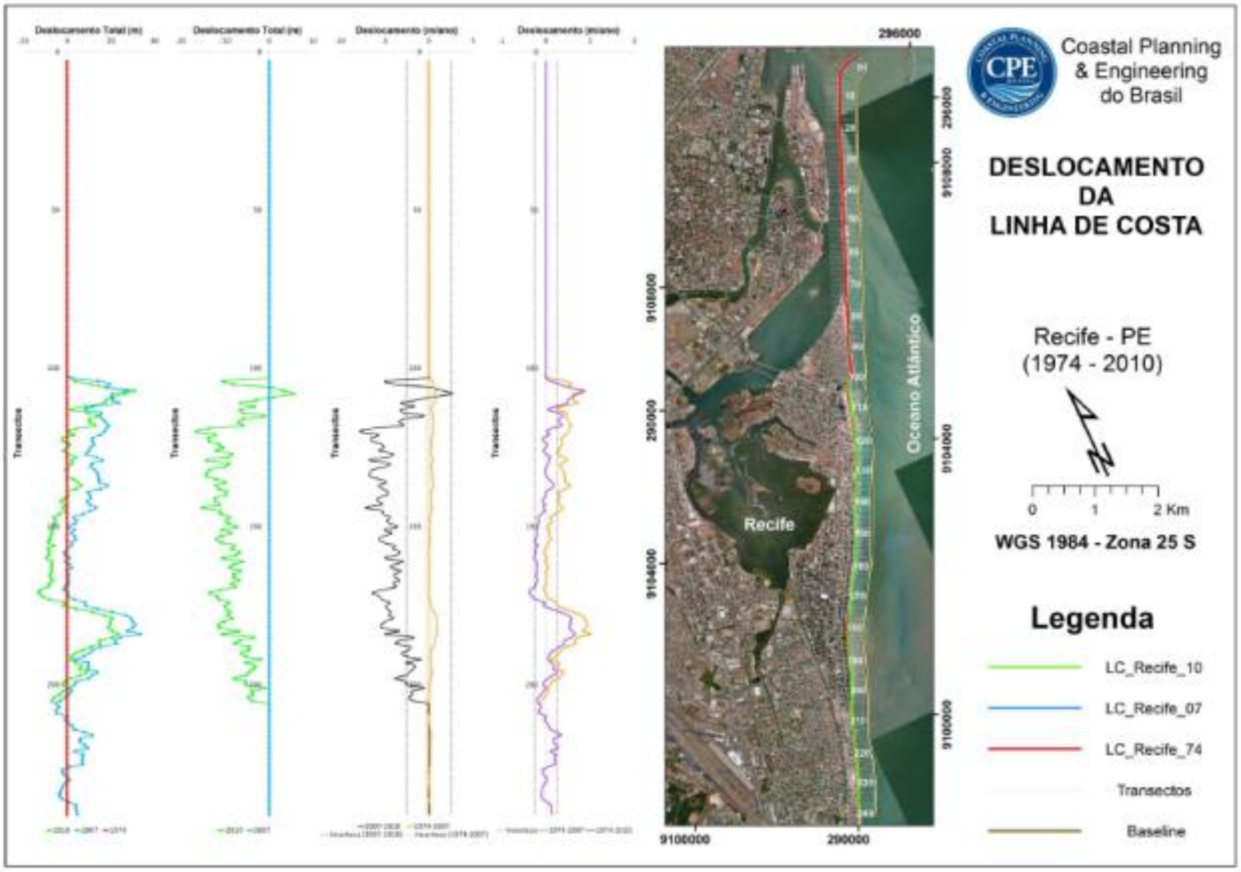

Figure 24: total coastline variation of the coast of Recife. (transecots means cross section and deslocamento means displacement)

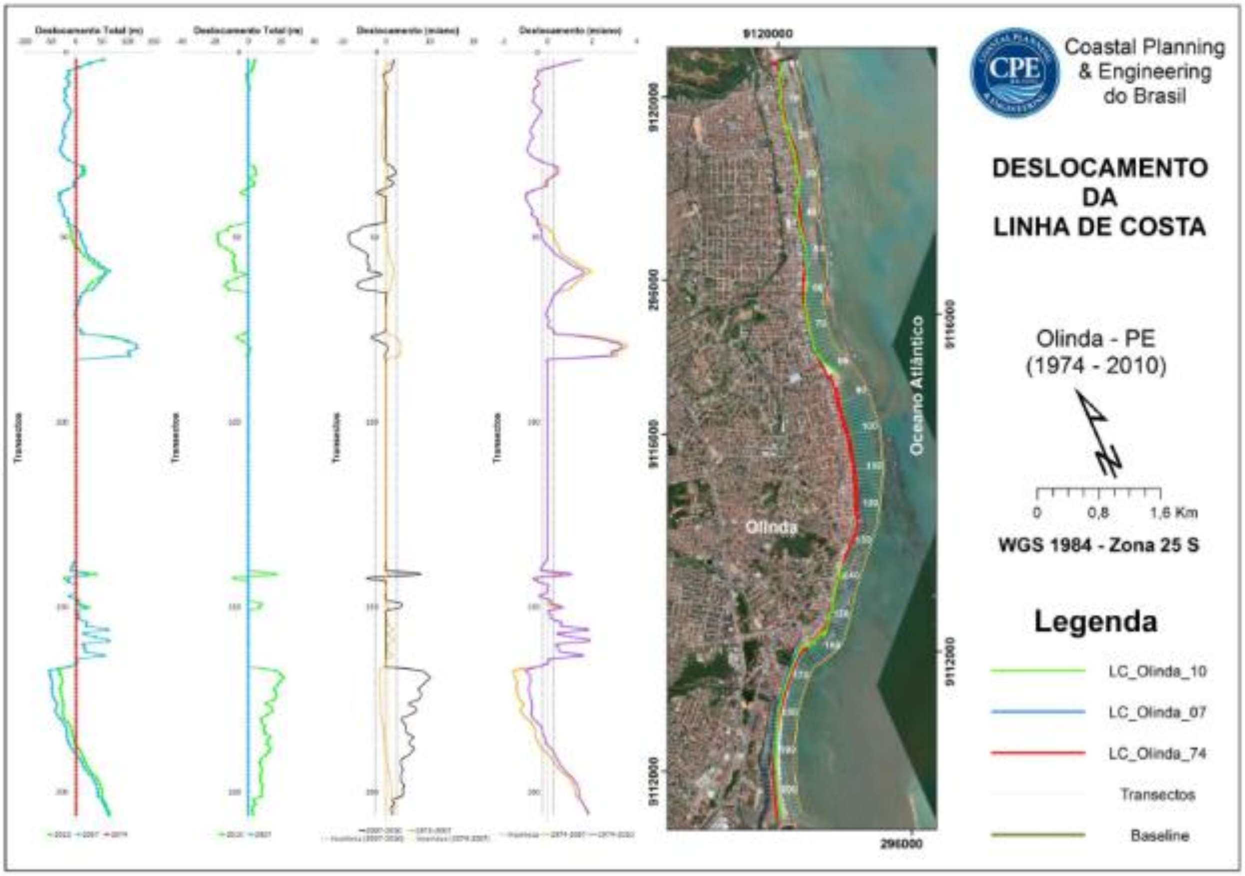

Figure 25: total coastline variation of the coast of Olinda. (transecots means cross section and deslocamento means displacement)

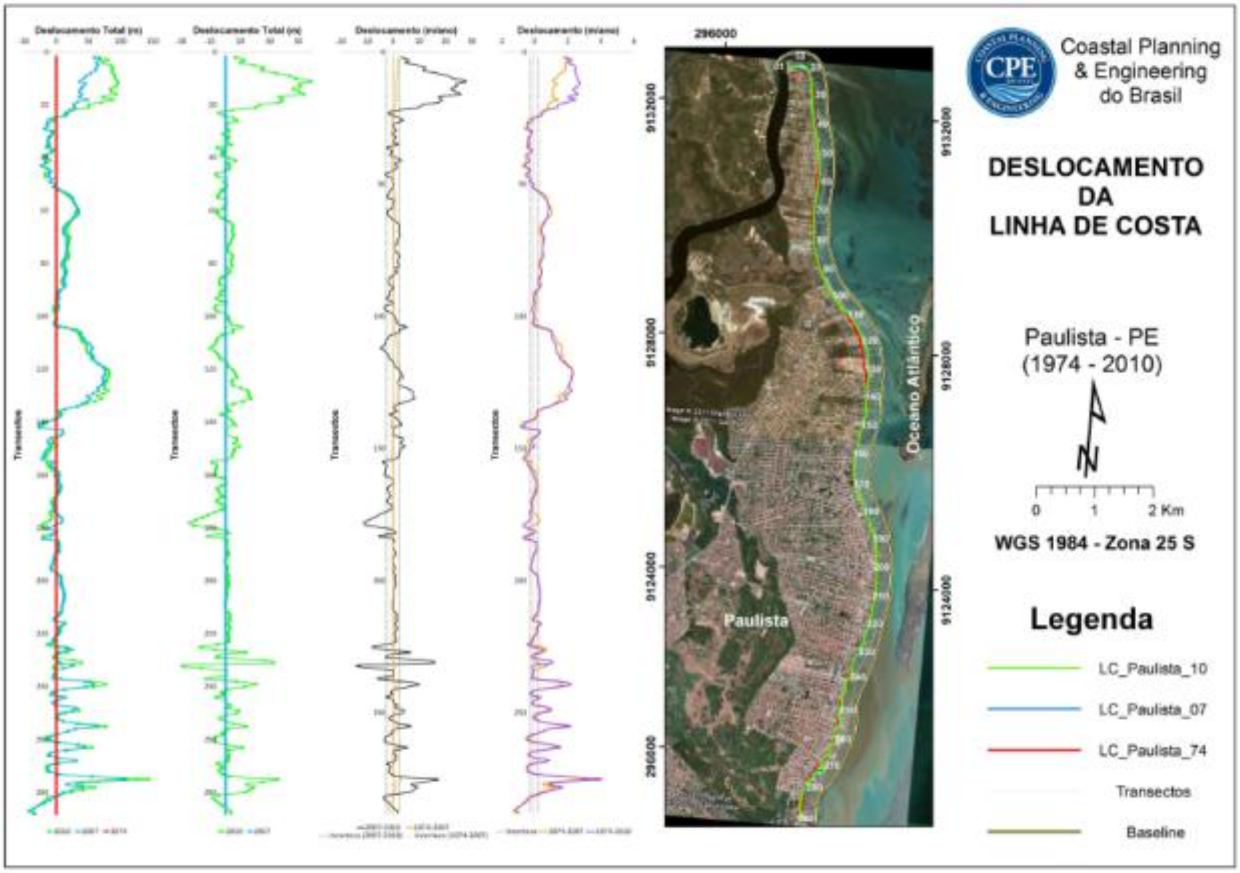

Figure 26: total coastline variation of the coast of Paulista. (transecots means cross section and deslocamento means displacement)

Appendix F Material characteristics

The determination of average diameter of the sediment has been conducted by geologists and therefore the scale is different (Wentworth scale)[3]. The value of the Wentworth scale value can be transformed to a true diameter with the aid of the Wentworth formula:

$D = D_0 \cdot 2^{-\phi}$

Where:

- D = true diameter [mm]
- D_0= reference diameter equal to 1 [mm]
- ϕ = Wentworth scale value [-]

Later in this paper the metropolitan area has been sub divided into 6 regions. The material characteristics of each of these regions have been denoted below. Note that kurtosis have been left out since it is not of the essence for this project.

Casa Caiada			
Parameter	**Value**	**Definition**	**True Diameter [mm]**
Average Diameter	1.187	Medium Sand	0.439215234
Standard Deviation	0.9685		
Asymmetry	0.0165	Nearly Symmetrical	
Phi(Φ)	1<X<2		

Table 13: Sediment characteristics Casa Caiada

Bairro Novo			
Parameter	**Value**	**Definition**	**True Diameter [mm]**
Average Diameter	1.168	Medium Sand	0.445037867
Standard Deviation	0.9494		
Asymmetry	0.0879	Nearly Symmetrical	
Phi(Φ)	1<X<2		

Table 14: Sediment characteristics Bairro Nove

Fortim			
Parameter	**Value**	**Definition**	**True Diameter [mm]**
Average Diameter	0.072	Big Sand	0.951318276
Standard Deviation	0.8846		
Asymmetry	0.0709	Nearly Symmetrical	
Phi(Φ)	-0.5<X<1		

Table 15: Sediment characteristics Fortim

[3] http://en.wikipedia.org/wiki/Particle_size_(grain_size)

Boa Viagem			
Parameter	**Value**	**Definition**	**True Diameter [mm]**
Average Diameter	2.034	Fine Sand	0.244177132
Standard Deviation	0.8097		
Asymmetry	-0.0057	Nearly Symmetrical	
Phi(Φ)	2<X<3		

Table 16: Sediment characteristics Fortim

Candeias			
Parameter	**Value**	**Definition**	**True Diameter [mm]**
Average Diameter	3.313	Very Fine Sand	0.100620767
Standard Deviation	0.5835		
Asymmetry	0.0614	Nearly Symmetrical	
Phi(Φ)	3.5		

Table 17: Sediment characteristics Candeias

Appendix G Design Guidelines

1.1 Groynes

Groynes should only be constructed along coasts with recession rates exceeding 2 m/year and dominant long shore transport processes and that groynes are most effective at coarse-grained beaches (0.3 to 1 mm) along swell-dominated coasts.

There are several parameters of importance when designing a groyne; however two parameters are decisive for designing a groyne field:

- The groyne length;
- The distance between two successive groynes.

1.1.1 *Groyne length*

According to (Stive 2011) the length of the groyne should be 40 to 60 per cent of the width of the surf zone to trap enough sediment. This is a rule of thumb for designing the groynes' length, this rule has for simplicity been abbreviated to RoTg. Generally the surf zone stretches from where the waves start to break up to the beach (see Figure 27). Note that when a groyne is too long, there will be no sediment bypass, having a negative effect on the downstream area.

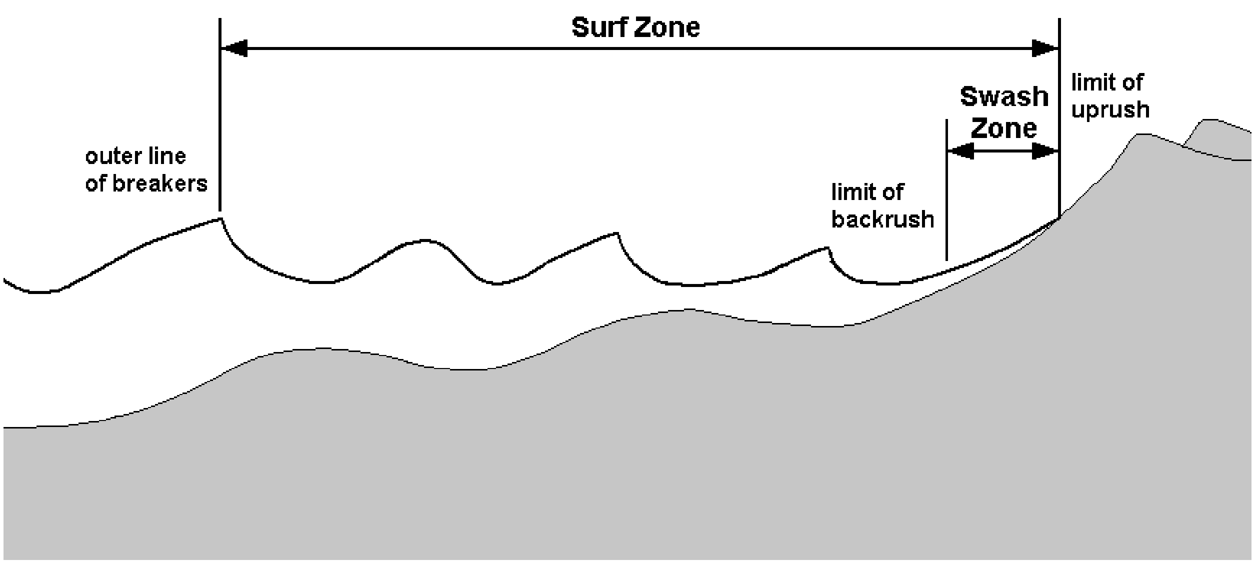

Figure 27: definition of the surf zone

1.1.2 *Distance between two successive groynes*

Creating a healthy beach not only depends on the length of the groynes, but also on its mutual distance. If the groynes are too closely situated to each other the sediments are transported offshore. When placed too far to each other, the next compartment will suffer from scour erosion (see Figure 28). The rule of thumb states that the gap between two successive groynes should be 3 times the length of the groyne (van Rijn 2010).

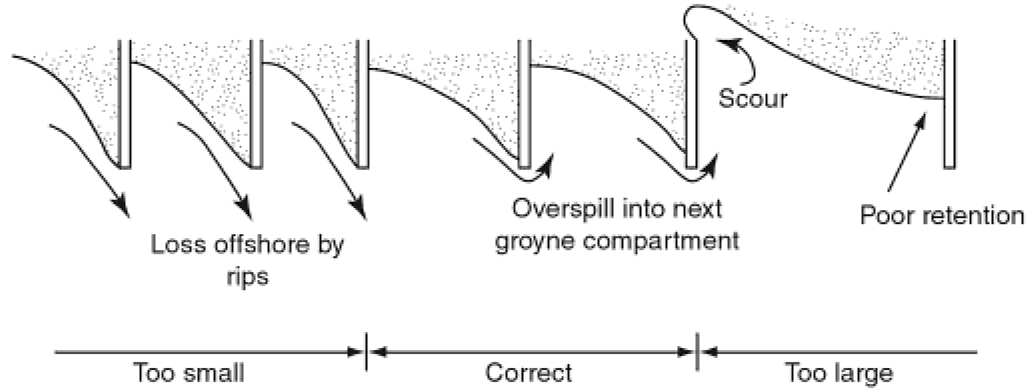

Figure 28: Schematic view of the consequences of the distance between successive groynes.

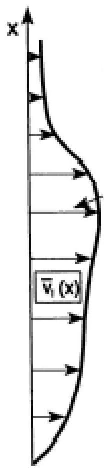

Figure 29: Distribution of long shore sediment transport (van Rijn 2010 http://www.conscience-eu.net/documents/deliverable13a-controlling.pdf)

1.1.3 *Other parameters*

Impermeable groynes tend to block the entire long shore transport along the entire length of the groyne. If there is one clear dominant wave direction, a saw-tooth like beach shape can be expected. In a severe wave climate with two but adversary wave direction and fine sediment (0.2 mm) erosion can be expected inside the cells resulting in a narrow beach. Permeable groynes act as resistance to flow; they do not create cells and do a worse job of slowing down the erosion than impermeable groynes. Because of the low sediment transport it is advised to use impermeable groynes. It is not expected to have a big saw-tooth like beach as the sediments are of medium size and wave action is limited and from different directions.

The height of the groyne should be about +1 MSL (mean sea level) to allow for enough sediment bypassing during storms and high tide conditions. High crest levels are unattractive if the beach will be used for recreation.

After a construction of a compartment it will take a relative long time to fill the compartment to its capacity due to the low transport rates in the area. It is therefore advised to fill the cell compartments to their capacity to avoid big erosion at the down drift side of the groyne field.
T or L head groynes can be used to increase the effectiveness of the groynes. T and L head groynes are used at very exposed eroding coasts to reduce the wave energy in the compartment (van Rijn 2010).

1.2 Breakwaters

For the design of offshore breakwaters, there are different design guidelines; this paper uses guidelines from ("COASTAL DYNAMICS, 2011").

These guidelines propose limits between the ratio between the length of the structure and its distance to the coast. There are 2 general guidelines for the dimensions of breakwaters.

1. Tombolo formation: $D_{offshore} < 0,8\ L_{breakwater}$
2. Salient Formation: $0.8\ L_{breakwater} < D_{offshor\ e} < 2\ L_{breakwater}$

For both these design rules there is a limitation which is as follows:

3. $L_{gap} < 1\ L_{breakwater}$ to $1.5\ L_{breakwater}$

See *Figure 30* for the symbols.

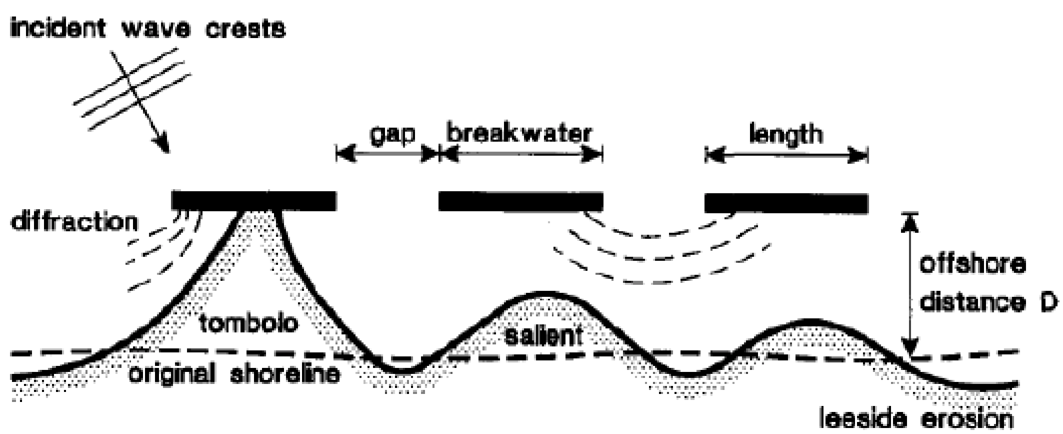

Figure 30: Schematic Drawing Symbols used in (Coastal Dynamics, 2010)

The second guideline for the design of breakwaters was defined in (Ahrens, 1990), which uses the parameter Is to define the response of the beach, see *Figure 31*. The symbols can be found in Figure 32.

$$Is = e^{(1{,}72 - 0{,}41 \frac{L_S}{Y})}$$

Is	1	Permanent formation of a Tombolo
Is	2	Periodic formation of a Tombolo
Is	3	Well Developed Salient
Is	4	Not fully Developed Salient
Is	5	Without sinuosity.

Figure 31: Responses back of the breakwater depending on Is (Ahrens, 1990)

The guidelines of Ahrens will be used to predict the response of the coastline.
There are many other factors which influence the coastal response behind a breakwater beside its dimensions. It was seen before that the formation of a tombolo upstream in a series of breakwaters can adversely affect the long shore transport and diminish the rate of formation of tombolos behind downstream breakwaters. Aside from the dimensions of the structure, the sediment supply and transportation plays a vital role.

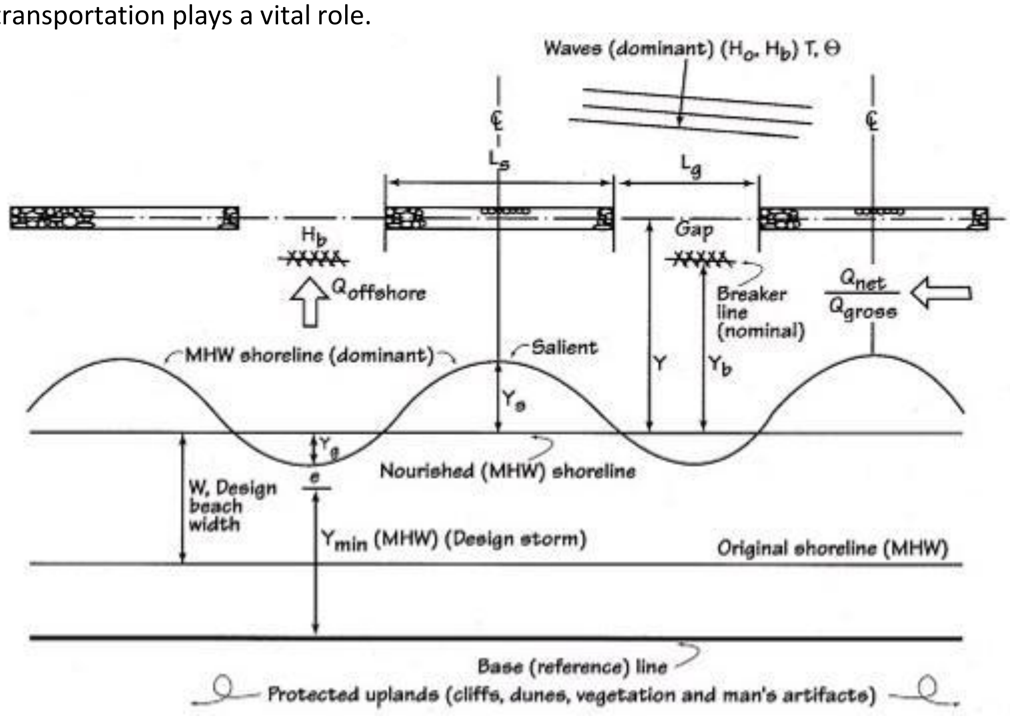

Figure 32: Schematic drawing of the variables used in the formulations of Dally and Pope (1986), Pope and Dean (1986) and Ahrens and Cox (1990).

Appendix H Candeias

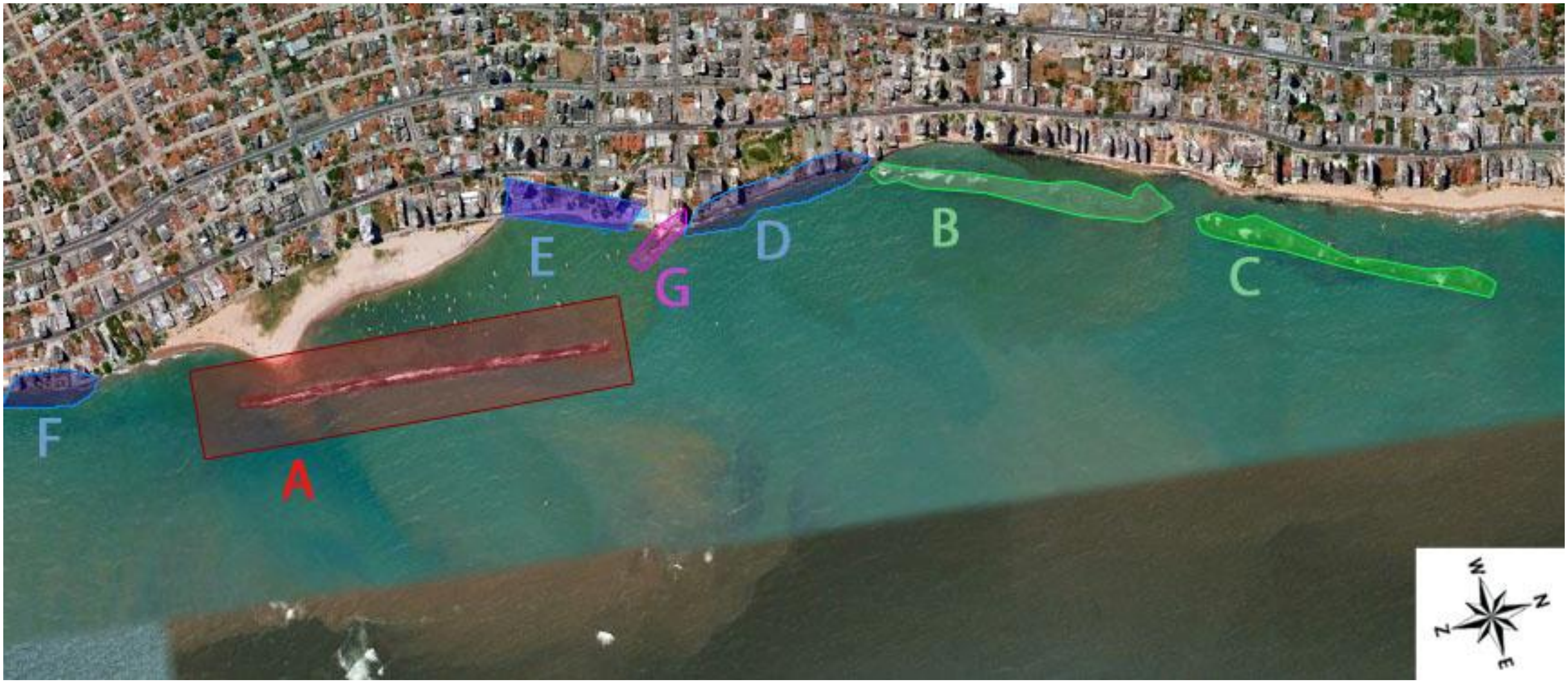

Figure 33: Overview Candeias (Source: Google Earth) (red: breakwaters, green: distinctive reefs, blue: revetments, purple: groynes)

1.1 Preliminary Assessment

1.1.1 *Breakwater*

The only breakwater A in the area is a huge one which is an influential structure in the total area. On the landward side of the breakwater there is a huge salient which is wide and long. The salient has the same length of the breakwater but lies 200 meters more to the south.

Breakwater	Length [m]	Width [m]	Distance offshore [m]
A	752	24	287

Table 18: Breakwaters in Candeias

1.1.2 *Reef*

Two particular locations of the reef can be distinguished in this area. They are north of the breakwater and very close to the coastline. Behind reef C a healthy beach is present. On the landward side of reef B revetments are built and here is hardly any beach.

Reef	Length [m]	Width [m]	Distance offshore [m]
B	585	28	111
C	580	29	65

Table 19: Reefs in Candeias

1.1.3 *Revetment*

Revetment D is a relatively long one and starts near reef C and continues until groyne G. Along the revetments no beaches can be observed.

Revetments	Length [m]
D	1150
E	310
F	115

Table 20 Revetments in Candeias

1.1.4 *Groyne*

There is one structure that can be interpreted as a groyne (groyne G) while it is not entirely clear what its function here is. The groyne is angled towards the breakwater and is very short in length. It doesn't hold any sediment so there's virtually no beach north or south of the groyne.

Groyne	Length [m]	Angle [degrees] to coast
G	83	53

Table 21: Groynes in Candeias

1.1.5 *Photos of current situation*

Figure 34: Revetments at the start of the breakwater

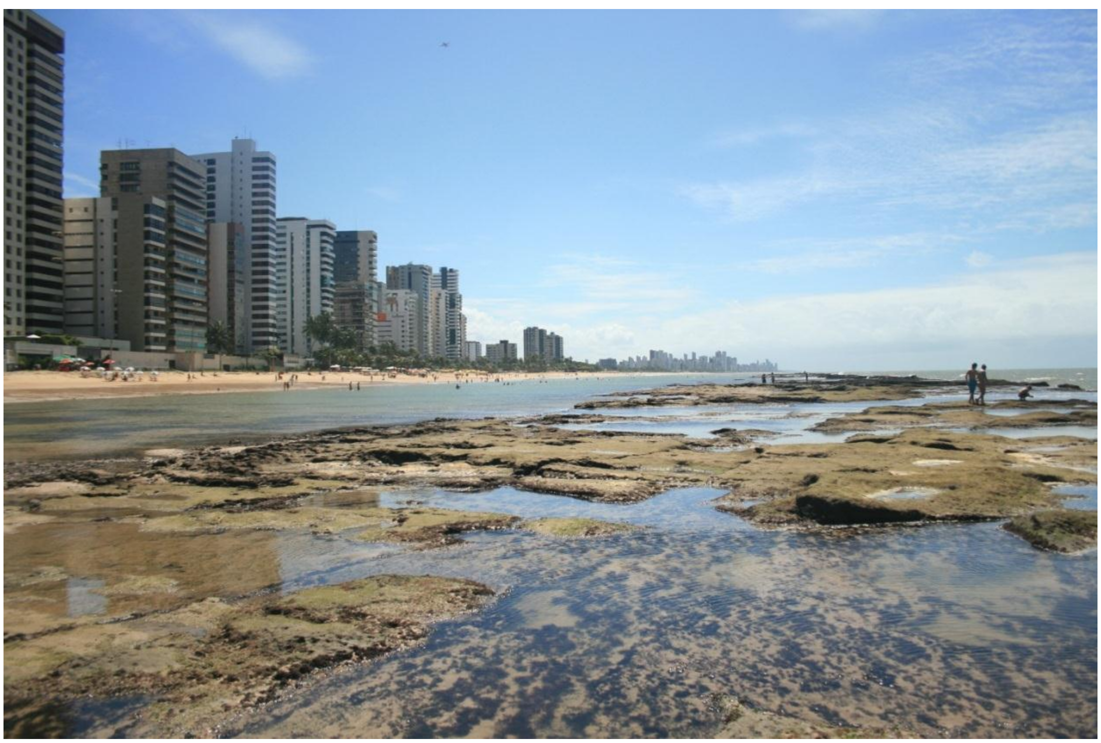

Figure 35: Reef C at the north of Candeias

1.1.6 *Summary of Candeias*

This area has many problems with the coastline. Actually, the only place where some beach can be observed is behind the huge breakwater. North or south of the breakwater there are revetments built in order to stop the erosion process. Behind the revetments there seems to have been an avenue that is destroyed probably before the construction of the revetments. Now there is only a revetment that separates the buildings from the ocean. The same holds for the revetment in the south after the breakwater. Overall the quality of the revetments is very bad. The rocks seem to have been simply dumped without preparation works or finishing works.

1.2 Problem Assessment

1.2.1 *Elementary information*

Additional information about Candeias is shown in Table 22

Additional information Candeias	
Wave direction	119° Az
significant wave height	0.61 m
significant wave period	6.34 sec
Sediment direction	North
Accretion/erosion rate	Accretion of 2.83 m^3/m/month
Sediment sinks	Yes
Tidal range	1.76 m

Table 22: Additional information Candeias

More information concerning the wave and tidal conditions can be found in Appendix A.

Sediment transport: In a study done (MAI, 2009) the beach profiles have been measured for about one year. From these beach profiles it is possible to calculate the amount of sediments lost or gained. The amount of sediments lost or gained on the beach circled in Figure 36 will be representative for the Candeias area.

Figure 36: Position of measurement Candeias

1.3 General Solutions

1.3.1 *Length of surf zone*

For the Candeias area it is necessary to obtain information about the surf zone, in order to determine the length of the groynes for alternative 2. Determining where the waves start to break is done by field observations in combination with the bathymetry results. This way the length of the surf zone is determined to be about 110 meters offshore at the north in Candeias. In this south this length is equal to about 90 meters, see *Figure 37*.

Figure 37: Length of surf zone

Appendix I Piedade

Figure 38: Overview Piedade beach (Google Earth)

1.1 Preliminary Assessment

Since there are no structures in Piedade, this preliminary assessment consists of onsite photos.

1.1.1 *Photos of current situation*

Figure 39: Looking south at Piedade beach

Figure 40: Beach halfway at Piedade Beach

1.1.2 *Summary*

The coastline in Piedade has almost no curvatures and continues along a straight line. This area has a long, healthy beach along the entire coastline.

1.2 Problem assessment

1.2.1 *Elementary Information*

Specifications Janga Beach	
Wave direction	119° Az
significant wave height	0.97 m
significant wave period	5.97 sec
Sediment direction	Clearly North
Sediment sinks	No
Tidal range	1.76 m

Table 23 Elementary information about Piedade

Appendix J Boa Viagem

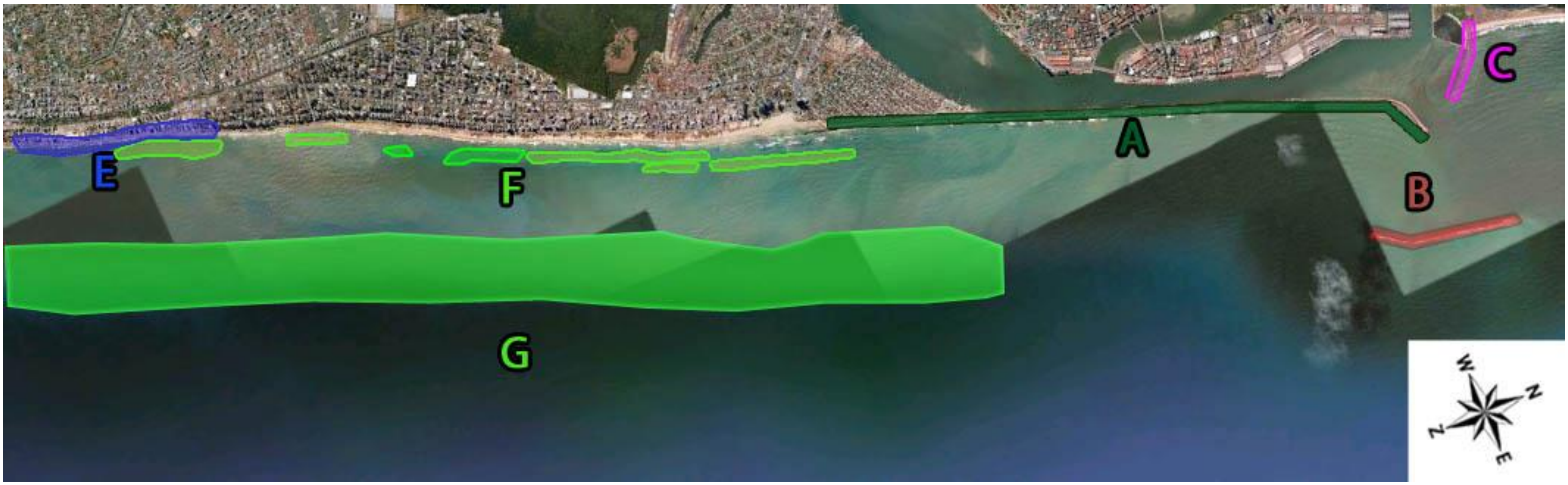

Figure 41: Overview Boa Viagem (red: breakwaters green: distinctive reefs, blue: revetments, purple: groynes, dark green: seawall) (Google Earth)

1.1 Introduction

In the appendix of Candeias one can find extra information on the Candeias area as well as more detailed information on the work brief. The structure this appendix is structured as followed:

- Preliminary assessment
- Problem assessment appendix
- Solutions appendix

1.2 Preliminary assessment

1.2.1 *Introduction*

The coast along the area of Boa Viagem has a length of 12.212 meter (see Figure 41). This area is divided in smaller parts since this area is relatively long. Each area can be recognized by its own features. The whole area is divided in three sub-areas. The first area located in the northern part of Boa Viagem consists of a seawall (A), a jetty (C) and a breakwater (B) in front of the mouth of the harbour. The seawall has been built to protect the (old) harbor. The length of the seawall along the (old) harbor is 4 km. In front of the entire area there are pieces of reef (F). Where the reef ends a revetment (E) will continue until the beach starts.
The second part consists of the middle part which has beach, so from seawall A till revetment E. The whole second area exists of beaches with variable widths. The beaches, with a length of 5.1 km, have for the most part a reef in front of it which runs parallel to the coast. The third part starts where the revetment can be seen.

1.2.2 *Seawall*

Seawall	Length [m]	Width above sea level[m]	Distance offshore [m]
A	5300	32	-

Table 24: Harbor seawall in Boa Viagem

1.2.3 *Breakwater*

In front of the mouth of the seawall, breakwater B can be observed, which is curved. The breakwater is likely built to prevent the waves from the Atlantic Ocean from entering the harbour.

Breakwater	Length [m]	Width above sea level [m]	Distance offshore [m]
B	1150	15	1000

Table 25: Breakwaters in Boa Viagem

1.2.4 *Jetty*

Jetty C is at the most northern border of the area. This is actually the entrance of the harbor. Give them the same name as in previous area.

Jetty	Length [m]
C	450

Table 26: Jetty in Boa Viagem

1.2.5 *Revetment*

There is one revetment present in this area. In the south of part 2, revetment E begins, with a length of 1.77 km. It stops at the northern boundary of the Piedade area.
An important observation made at revetment E is that during high tide overtopping occurs (see Figure 45). This overtopping happens along the entire length of the revetment.

Revetment	**Length [m]**
E	1770

Table 27: Revetments in Boa Viagem

1.2.6 *Reef*

In Boa Viagem there can be observed that there is a small reef in front of the beaches. For simplification, the small pieces of reef are seen as a whole given.

Reef	**Length [m]**	**Width [m]**	**Distance offshore [m]**
F	6100	20	90

Table 28: Reefs in Boa Viagem

1.2.7 *Photos of current situation*

Figure 42: (Northern) end of the revetment E in Boa Viagem (also the end of the beach)

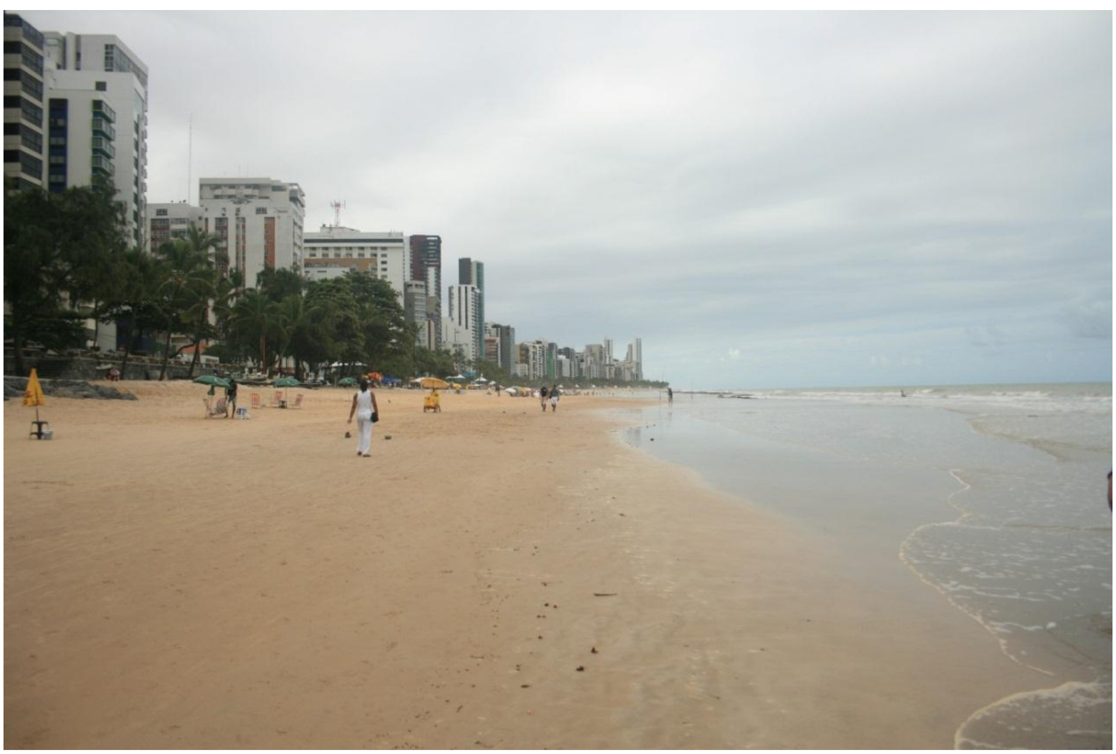

Figure 43: Looking to the north of Boa Viagem towards the healthy part of the beach

Figure 44: Looking to the south of Boa Viagem where revetment E is at low tide.

Figure 45: Overtopping during high tide at revetment E

1.2.8 *Summary of the preliminary assessment*

Boa Viagem is the longest area within the system boundaries. This is also the part with the longest uninterrupted beach. While there is a long beach, the area with large population densities also shows long revetments without any beach in front of this.
An important aspect that has been observed is that overtopping occurs at revetment E during high tide.

1.3 Problems Assessment

1.3.1 *Elementary information about Boa Viagem*

Specifications Janga Beach	
Wave direction	131° Az
significant wave height	0.97 m
significant wave period	5.97 sec
Sediment direction	Generally from South to North
Sediment transport	Accretion of sediment (25 m^3/m/month in some areas)
Sediment sinks	No
Tidal range	1.24 m

Table 29: Elementary information about Boa Viagem

More information concerning the wave and tidal conditions can be found in the Morphology (see Appendix A Morphology).

Sediment transport
The beach profiles have been monitored for about one year (MAI 2009). From these beach profiles it is possible to calculate the amount of sediments lost or gained. The amount of sediments lost or gained on the beach circled in Figure 46 will be representative for the Boa Viagem area.

Figure 46: Locations of the beach profiles measured on the metropolitan coast of Recife.

1.4 Solution

1.4.1 *Beach nourishment*

The basic coastal management approaches are elimination of the cause of erosion or mitigation of the effects. The major cause of erosion on the coast of the metropolitan area of Recife has been thoroughly explained in the section on morphology. However, curing the cause isn't possible because this would require changes above and beyond the ability of engineering. The approach is mitigation of the effects with hard and/or soft measures.

Soft measures such as beach or foreshore nourishment compensate eroded sand. However, the erosion process still continues and therefore must be repeated on a natural basis. Beach nourishments have been proven to effectively mitigate the structural erosion (van Rijn 2009). Another method which can be interesting for the metropolitan area of Recife is By-pass systems. Sediment drained upstream is send back down-drift by pumps.

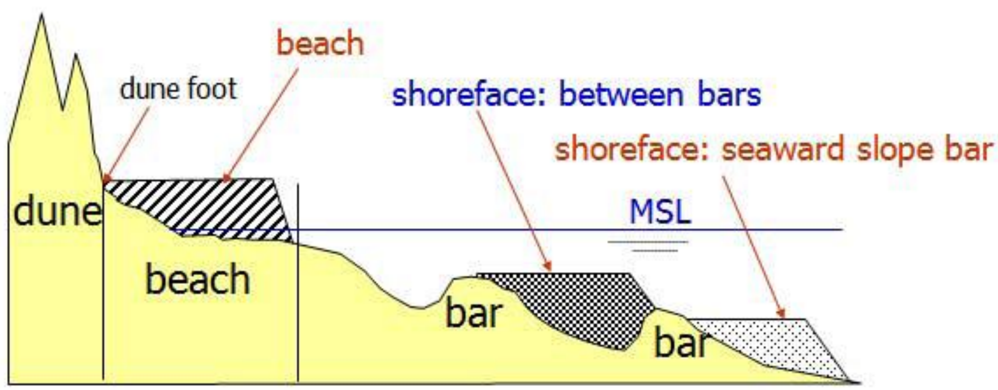

Figure 47: Beach nourishment locations (COASTAL DYNAMICS, 2010)

Beach nourishment is possible on several locations. The beach can be nourished on the landward slope of the dunes, seaward slope of the dunes, on the dry beach and on the shore face. Placing sand on the beach requires dredging equipment to cross the breakwater zone, but a rain-bow method can provide an alternative. Shore face nourishment is placed at the seaward edge of the surf zone where the hopper has sufficient navigational depth. Shore face nourishment may be more economical and friendly to recreation on the beach; however, the efficiency of foreshore nourishment is much less than nourishment on the dry beach.

Foreshore nourishment can be performed for the area; however, placing nourishment directly on the beach may also be possible. The reef is approximately 90 meters from the beach and a rainbow method can possibly have enough range to reach the beach.

Larger volumes of sand are required for shore face nourishment because only 30 % to 50 % (COASTAL DYNAMICS, 2010) will reach the beach zone. The costs per m3 for shore face nourishment are 50% to 70% less (COASTAL DYNAMICS, 2010) which does make it an attractive measure due to cost balance.

Appendix K Fortim

Figure 48: Overview Fortim (red: breakwaters, blue: revetments, purple: groynes, pink: jetty) (Google Earth)

1.1 Introduction

In the appendix of Fortim one can find extra information on the Fortim area as well as more detailed information on the work. The structure of this appendix is structured as followed:

- Preliminary assessment
- Problem assessment
- General Solutions

1.2 Preliminary assessment

- Breakwaters
- Reef
- Revetment
- Groynes
- Jetty
- Photos current situation
- Summary

1.2.1 *Breakwaters*

A short description of the breakwater and the coast at the breakwater will be given.

Structure A: The first breakwater is also the longest one and overlaps breakwater B with 78 meters. Observations show that directly on the landward side of the breakwater some accretion has formed a small beach connected the breakwater. On the coast a large salient has formed that has specifically grown in the last few years. Only a small channel behind the breakwater prevents the salient from becoming a tombolo. The salient is very narrow rather than the desired wide form. Another observation is that the salient has formed near the end of the breakwater and that on each side of the salient revetments have been placed.

Structure B: This breakwater is about the same length as breakwater A. A specific aspect of this breakwater is that it is not parallel to the coast, but under an angle of 10 degrees. The created salient has similar characteristics, though smaller, as on the seaward side of the first breakwater and here too is the salient surrounded by revetments.

Structure C: The last breakwater is a very short one that is parallel to the coast. There is no beach on the coast at the breakwater. On the landward side of the breakwater there is some small revetment built.

Breakwater	Length [m]	Width [m]	Distance offshore [m]
A	544	33	145
B	530	24	155
C	222	22	122

Table 30 Breakwaters at Fortim

1.2.2 *Reef*

There are some scattered reefs in the area like J and K and there is also one big reef which has large influences on the area I.

1.2.3 *Revetment*

Revetment D is located on the landward side of the breakwater A and stretches all the way to the start of the salient. In front of this revetment there is no beach. After the salient, the revetment once again starts and continues on the landward side of the breakwater B, all the way to the salient on the landward side of breakwater B. After this salient the last revetment F starts and goes all the way till the last breakwater C.

Revetment	Length [m]
D	453
E	318
F	272

Table 31: Revetments in Fortim

1.2.4 *Groyne*

There seem, to be one groyne at this location. Groyne G is a very small one and holds no sediment.

Groyne	Length [m]
G	51

Table 32: Groynes in Fortim

1.2.5 *Jetty*

Jetty H is at the most southern border of the area. This is actually the entrance of the harbor.

Jetty	Length [m]
H	450

Table 33: Jetty in Fortim

1.2.6 *Photos of current situation*

Figure 49: Look on breakwater C

Figure 50: Breakwater A and the salient behind it

Figure 51: Revetment F looking into the salient behind breakwater B

1.2.7 *Summary*

This area is full of problems concerning coastal protection. As can be seen in Figure 49 to Figure 51 the revetments are built as last defense against the water. There are several revetments behind the breakwaters that are not parallel to the coast. The only places where some beaches can be seen are behind the breakwater in between the revetments and on the landward side of breakwater A also some beach can be observed. At the area bordering the harbor entrance the beach is long and looks healthy, while there are no structures here.

1.3 Problem description

- Elementary information
- Breakwater and revetments

1.3.1 *Historical information*

The erosion problems of Olinda started reportedly after the expansion of Recife's Harbour in 1909, destroying even houses and streets (Quebra-mar, 1976). The construction of breakwater A and B started in 1959 and was finished in 1962, along with some concrete walls and groyne G (Pereira, 2006).
The last time that any improvements were made was in 1995-1998, during which some reordering of the existing stones were made and the breakwaters were heightened to their current heights.

1.3.2 *Elementary information*

Additional information concerning Fortim	
Wave direction	129° Az
significant wave height	0.6 m
significant wave period	5.55 sec
Sediment direction	Circles, different directions
Sediment transport (at the salient at breakwater A)	Accretion of 0,69 m^3/m/month
Sediment transport (at beach on the landward side of breakwater C)	Erosion of 0,04 m^3/m/month
Sediment sinks	yes
Tidal range	1.76 m

Table 34: Elementary information concerning Fortim

Breakwaters & revetments

On the landward side of breakwater A the coast is sheltered from the high waves. However there are strong currents from the north towards the south that cause a lot of erosion north of revetment D. The transported sediment reduces its speed and can settle only when it's at the salient on the landward side of breakwater A. Here, accumulation of sediment happens and one can see a growth of the salient (see Figure 52). In Figure 53 the sediment transport indicated that leads to the forming of a reverse salient at the landward side of the breakwater.

Figure 52: Salient at breakwater A in 2003 (left) and 2010 (right) (Google Earth)

Figure 53: Transport of sediment at breakwater A

In between breakwater A and breakwater B there is an overlap. This leads to the following diffraction pattern (see Figure 54).

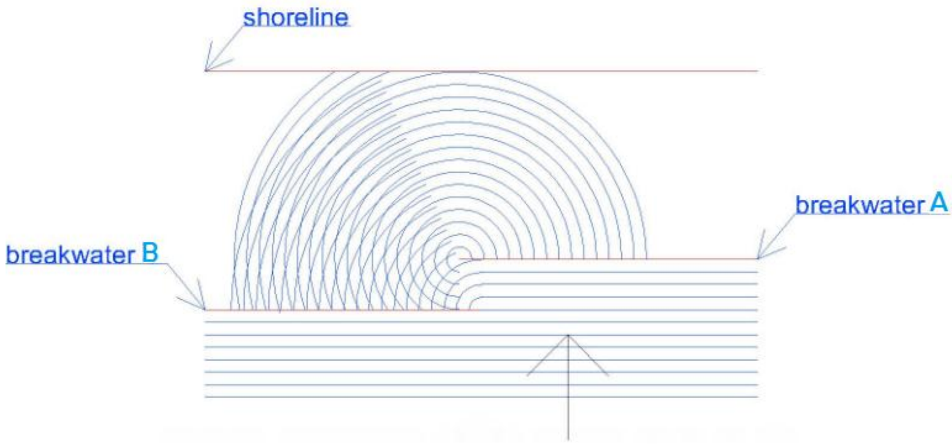

Figure 54: Schematized diffraction pattern between breakwater A and B

In a situation where breakwater B wasn't present, the salient would form at the middle of the breakwater with erosion at both sides of the salient (see Figure 55).

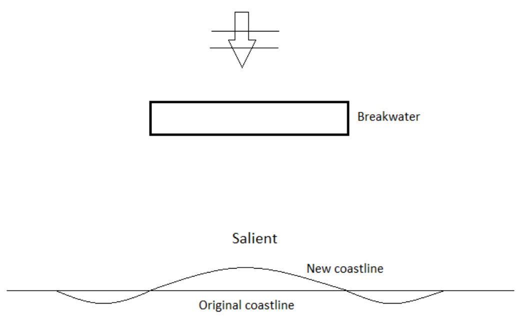

Figure 55: Example of salient formation

Because in this situation breakwater B is next to breakwater A, the diffraction patterns from the left side (the left side in Figure 54) are blocked off. This leads to set up differences in the water level. This process leads to a salient formation which is slightly shifted south (in Figure 53) rather than somewhere in the middle. Another consequence is that the places where erosion would normally take place are shifted towards the south, justifying the relatively long length of revetment D.
The breakwaters are probably built to protect the coast against the high waters and to create beaches on the landward side of the breakwater. The breakwaters fail almost completely in doing this job. The created beaches are steep and narrow and on both outer sides of the salients a lot of erosion takes place that endangers the stability of the revetments. While there is erosion on the outer sides, the salient itself keeps on growing. It is highly likely that the huge steep salient behind breakwater A will form a tombolo. Once the tombolo is formed, sediment transport is blocked for the area behind it. This process is therefore unwanted

1.4 General solution Fortim

- Alternative 1
- Alternative 2
- Comparison CPE

1.4.1 *Alternative 1*

From (see Appendix G Design Guidelines) follows that groynes should only be constructed along coasts with recession rates exceeding 2 m/year and dominant long shore transport processes and that groynes are most effective at coarse-grained beaches (0.3 to 1 mm) along swell-dominated coasts. The average sediment size along the coast is equal to 0.95 mm, as for the recession rate, at the moment it differs along the coastal area (between 0.04 and 0.7 m/year) which would not be a reliable value since the coastal process would entirely change (see Appendix A Morphology). Since without breakwaters one would expect a larger alongshore dominant process, it is assumed that the recession rate exceeds 2m/s. When the structures are present, sediment needs to be pumped into the system in order to create a beach. A rough estimate of the amount of sediment necessary can be calculated with the following factors:

- Equilibrium beach profile
- Original profile
- Initial placed profile

The original profile is the profile at its current state. The equilibrium beach profile is the profile where the system is in its equilibrium state. With nourishments, thus the initial placed profile; one tries to approach the equilibrium profile (Figure 56).

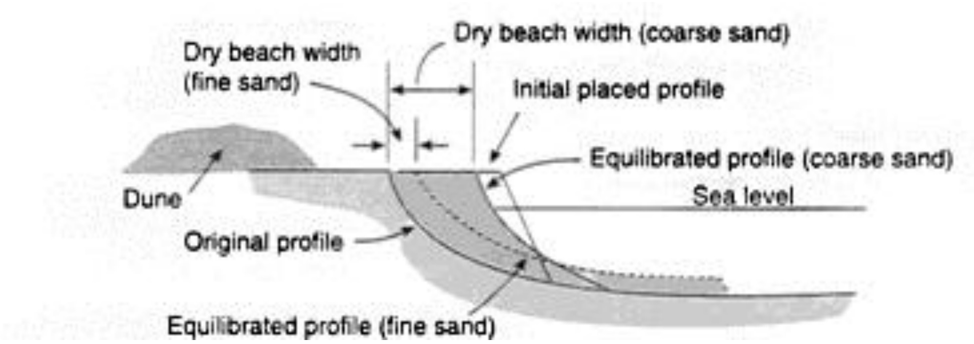

Figure 56: Beach profile (Beach Nourishment and Protection (1995))

1.4.2 *Comparison Alternative 2 with CPE results*

In Figure 57 one can see an alternative solution (CPE, 2011). This alternative shows much resemblance as well as some differences with the alternative 2. The CPE has used numerical models to iteratively come up with their solutions. The most striking difference is the use of groynes in the CPE alternative. In the CPE alternative, breakwater C will be demolished completely, creating the need of the most southern groyne. The salient at breakwater 1' will fulfill the same part as the most southern groyne in the CPE alternative, thus eliminate the need for the groyne. In Figure 58 one can see that most of the long shore sediment transport takes place at the seaward side of the breakwater because of the blockage in the white box, thus making the breakwater less effective and increasing the loss of sediment offshore. To prevent a similar process it was chosen not to put groynes to the north of the breakwaters in alternative 2. The design of the breakwaters of alternative 2 and the CPE alternative look similar only the dimensions differ.

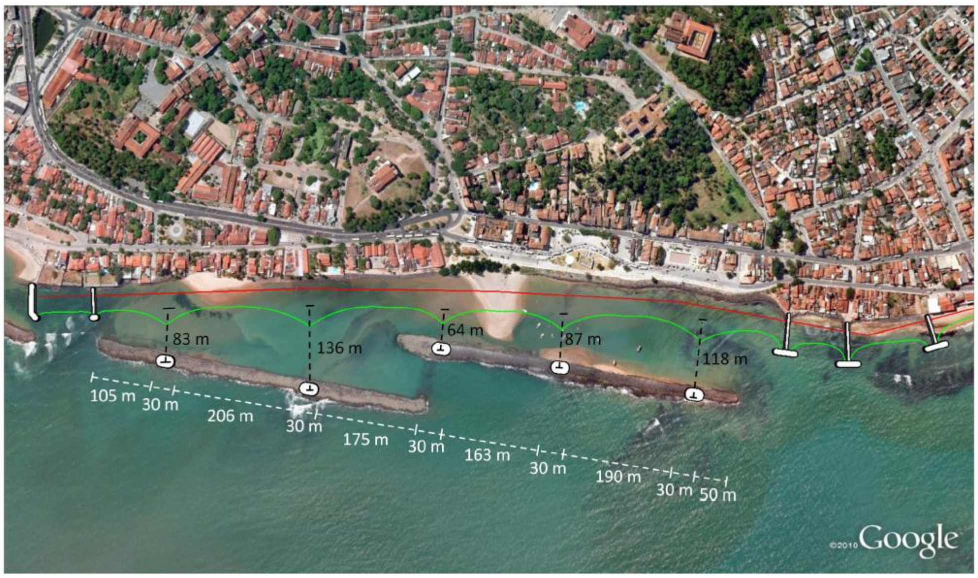

Figure 57: alternative according to (CPE 2011)

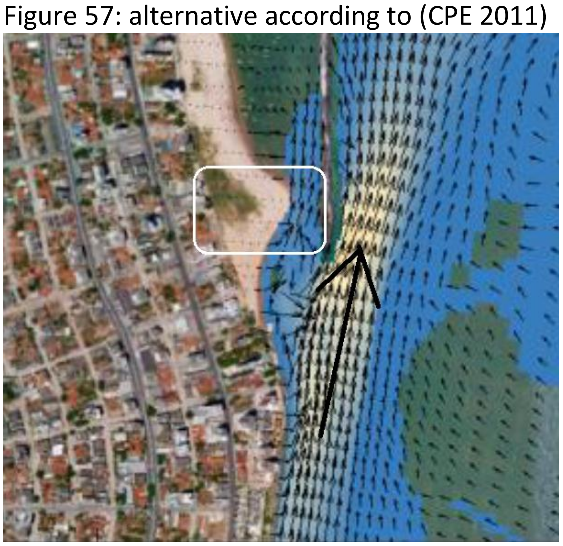

Figure 58: bypass phenomena of sediment transport in the Candeias area

Appendix L Bairro Novo

Figure 59: Overview Bairro Novo (green: distinctive reefs, blue/purple: revetments+ groynes, purple: groynes) (Google Earth)

1.1 Preliminary Assessment

1.1.1 Groynes & Revetment

A short description of the coastal features will be given based on the groynes locations.
To keep a good overview of the area, the area is divided in 4 sub-areas, based on the coastal features and structures in this area.

At part A in the area, the coast is protected by a combination of groynes and revetment. Here a large triangular beach has formed near the long groyne. In this part beaches between the groynes are visible at low tide, some even during high tide.

Part B starts after the 11th groyne (after 700 m).The protection of the coast in this part is also a combination of revetments and groynes. In this part only revetments are visible and no beach between the groynes. These groynes are even shorter than the groynes in the first and last part of the area.

Part B ends after the 22th groyne (after 615 m). This is where part C begins. The beaches between the groynes can be seen once again. One specific observation that can be mentioned is that the reef seems to start where the last groyne stops.

Groynes & Revetment		Length [m]	Averaged length of each groyne [m]
A	Part 1 (1st till 11th groyne)	700	36
B	Part 2 (12th till 22nd groyne)	615	27
C	Part 3 (23rd till 32nd groyne)	820	40
D	Most northern and longest groyne		263

Table 35: Length of the groynes and revetment in Bairro Novo

1.1.2 *Reef*

At the large distance off the coast a long and wide reef can be seen. Reef E is in front of almost the entire coast of Bairro Novo, except for the northern part. The northern part is protected by smaller scattered reefs, of which the largest one is called reef F. Another point of interest is the small strips of reef in front of the southern groynes, reef G and more to the south where the groynes stop, reef H.

Reef	Length [m]	Width [m]	Distance offshore [m]	Depth(averaged) [m]
E	1380	290	370	-4
F	320	140	354	-4.5
G	275	30	54	-3
H	283	56	101	-3

Table 36: Reefs in Bairro Novo

1.1.3 *Photos of current situation*

Figure 60: Groynes at part 2 of Bairro Novo

Figure 61: Picture from the coast of a groyne at part 2 of Bairro Novo

Figure 62: Long groyne D at the northern part of Bairro Novo

1.1.4 *Summary*

The coastline in Bairro Novo is characterized by a combination of short groynes and revetment. Also there is virtually no beach.

1.2 Problem assessment

1.2.1 *Elementary information Bairro Novo*

Additional information on Bairro Novo can be found in Table 37. More information concerning the wave and tidal conditions can be found in the Morphology.

Additional information Bairro Novo	
Wave direction	129° Az
significant wave height	0.6 m
significant wave period	5.55 sec
Sediment direction	Differs in area
Sediment transport	Accretion of -0.4 m^3/m/month
Sediment sinks	No
Tidal range	1.76 m

Table 37 Elementary information Bairro Novo

In the (CPE 2011) the beach profiles have been monitored for about one year. From these beach profiles it is possible to calculate the amount of sediments lost or gained. The amount of sediments lost or gained on the beach circled in will be representative for the Bairro novo area.

Figure 63: Position of measurement Bairro Nova)

1.3 General Solutions

1.3.1 *Groyne length*

The RoTg (see Appendix G Design Guidelines) cannot be simply applied for Bairro Novo due to the complex bathymetry of Bairro Novo: some waves brake on the reef leading to a complex surf zone. This complex surf zone leads to a different sediment transport distribution than indicated in Figure 29.

When one would apply the RoTg to Bairro Novo, the length of the groynes would be about 300 meters, which would not be correct. RoTg cannot be blindly applied to the Bairro Novo area.
Using the net sediment transport one can calculate the percentage sediments to block. However it is unknown what the total sediment transport in and out the system is, but one can make a rough estimate on the basis of known data. The rate of structural erosion is 4.8 m^3/m per year (see 1.2 Problem assessment), which is relatively small value. Erosion rates of 20 m^3/m a year are more common structural erosion amounts (Stive 2011). The relative small structural erosion in combination with the fact that the coast of metropolitan Recife has no big sediment source, one can conclude that the amount of sediments to be trapped is a big percentage of the total sediment transport of the area. Thus when using groynes the length should be as big as possible trapping as much possible sediments, while there is enough bypass, which corresponds to a length of 60 % of the width of the surf zone. It is assumed that a groyne with a length of 60 % of the surf zone and a sediment transport distribution as found in Figure 29 will roughly block 75 % of the sediment transport (see Figure 64).

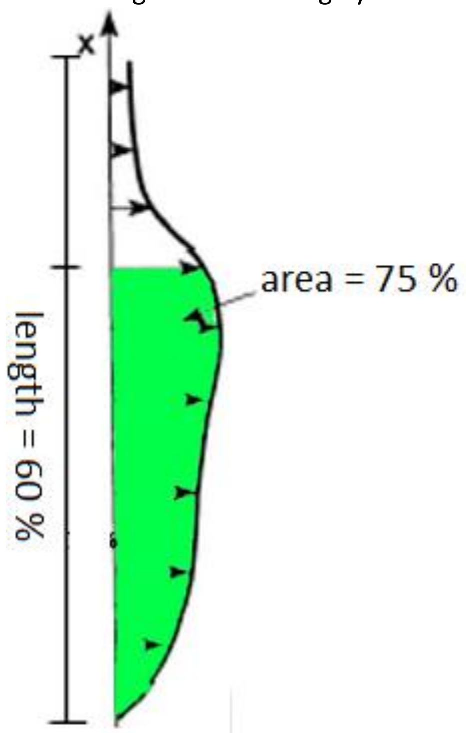

Figure 64: Cross shore distribution of the long shore sediment transport over the surf zone. (Van Rijn 2010)

The groynes at Bairro Novo should block about 75 per cent of the sediments see Figure 64. In order to simplify the design of the length even further, the groyne will be assumed to be impermeable for now.

Groynes B and C can be of equal length, as the widths of the sediment transport zone in front of them are about equal at these groynes (see 1.2 Problem assessment). Groynes B and C should be 70 meters (from the sidewalk) in length to stop 75 % of the sediments transport. At groyne A the width of the zone where the sediment transport takes place is much larger (see 1.2 Problem assessment) what should result in longer groynes. However to reduce the down drift erosion it is possible to shorten the groynes at the down drift side of the groyne field (groyne tapering). It is therefore recommended to maintain the same length of the groynes. Because of the greater width of the sediment transport zone a kind of groyne tapering is applied.

Groyne D is too large: it does not allow proper sediment bypassing (starving Casa Caiada). Groyne D should be shortened so it is of equal length as the other groynes. The Casa Caiada area has small openings which are responsible for the sediments budget of the area, shortening Groyne D will create a large opening and thus have a vast impact on the sediment budget. The shortening of groyne D should be done in accordance with the solution for the Casa Caiada area.

1.3.2 *Groyne Distance*

The existing groynes should have a mutual distance of 100 meters, yet they are about 50 meters apart from each other. If their length is modified as described above their distance should be in the order of 210 meters. Note that if a distance of 210 meters is used, most of the existing groynes will have to be removed.

1.4 (Re-)Nourishment

The coast of Bairro Nova is approximately 2240 meters long. With an erosion rate of 0.4 m^3/m a year, the total erosion will be 900 m^3/year. For the nourishment to be viable a repetition time of at least five years is desirable, in five years 4500 m^3 of sand will be eroded. The nourishment has an effectiveness of 80 %, so the total amount of (maintenance) nourishment every five years is 5400 m^3. Note however that the first nourishment must be of a much larger quantity as it will first have to create the beach, the quantities of this first nourishment are of magnitude of 1.6 million m^3 (CPE 2010), which is of monstrous magnitude but possible.

Appendix M Casa Caiada

Figure 65: Overview Casa Caiada (red: breakwaters, green: distinctive reefs, blue: revetments, purple: groynes) (Google Earth)

1.1 Preliminary Assessment

1.1.1 *Breakwaters*

A short description of the coastal features will be given based on the breakwater locations.
Structure A: The most northern breakwater is attached to the jetty at the mouth of the river and therefore has a lot of sediment on the landward side of the breakwater, almost enclosing it. There is a clear overlap of 70 meters with the next breakwater which is placed at least 75 meter closer to shore. Also worth mentioning is that the breakwater seems to be placed on a reef.
Structure B: The second breakwater is closer to the coastline and is also placed on a reef that is wider than the breakwater itself.
Structure C: The third breakwater is not parallel to the coast but is placed under an angle of around 13 degrees to the orientation of the coast. A lot of sediment can be seen on the landward side of the breakwater. This breakwater is also placed upon a reef which is also wider than the breakwater itself.
Structure D: The fourth breakwater is placed parallel to the coast. At the coast one can see a little bit of erosion at the coastline. The reef stops halfway of the breakwater. The same sediment accumulation on the landward side of the breakwater is clearly visible here.
Structure E: At the seaward side of this breakwater there is relative little beach visible. On the landward side of the breakwater there is sedimentation. This one is also probably built upon a reef. The waves clearly break before they hit the breakwater due to the reef.
Structure F: The reverse salient is best visible here with a large amount of sediment on the landward side of the breakwater. The same breaking of waves due to the reef is seen here. There is almost no clear beach on the coast behind the breakwater. The salient that is visible is very close to the previous breakwater, as if there is a shift in the salient formation.
Structure G: Just like breakwater A, this breakwater is almost attached to a long groyne. At the northern side of the groyne a lot of sedimentation can be seen, forming a triangular beach. At the landward side of the breakwater a clear sediment accumulation is visible. The beach is forming on the landward side of the breakwater (on the opposite side of the coast).

Breakwater	Length [m]	Width [m]	Distance offshore [m]
A	490	23	245
B	502	25	218
C	495	32	233
D	862	24	320
E	575	24	162
F	870	28	330
G	577	31	407

Table 38: Breakwaters in Casa Caiada

1.1.2 *Reef*

There are reefs all around and beneath breakwater A, B, C and E. Because the reefs are beneath the breakwaters we take them as part of the breakwaters.
Further offshore there is a longer and wider reef observed.

Reef	Length [m]	Width [m]	Distance offshore [m]	Depth(averaged) [m]
M	1345	100	280	-5

Table 39: Reefs in Casa Caiada

1.1.3 *Revetments*

The revetments in the area are very locally placed to prevent local erosion processes. The revetments start halfway along the length of breakwater 6 and continue till halfway through breakwater G. The revetment is placed on the landward side of the breakwater.

Revetments	Length [m]
I	174
J	690

Table 40: Revetments in Casa Caiada

1.1.4 *Groynes*

The groyne at the boundary between the two areas Casa Caiada and Bairro Novo is now assumed to be at the Casa Caiada area. Since the groyne also influences the other area, the structure is also taken into account there, but note that is it the same structure. The same holds for the groyne between Casa Caiada and Janga.

Groynes	Length [m]
L	263

Table 41: Groynes in Casa Caiada

1.1.5 *Jetty*

There is one jetty present in Casa Caiada. This is at the mouth of a small river and is made up of rocks.

Jetty	Length [m]
K	235

Table 42: jetty in Casa Caiada

1.2 Problem assessment

1.2.1 *Elementary information*

Additional information concerning Casa Caiada	
Wave direction	129° Az
significant wave height	0.6 m
significant wave period	5.55 sec
Sediment direction	Offshore directed
Accretion/erosion rate	Accretion of 0.2 m^3/m/month
Sediment sinks	yes
Tidal range	1.76 m

Table 43: Elementary information of the Casa Caiada area

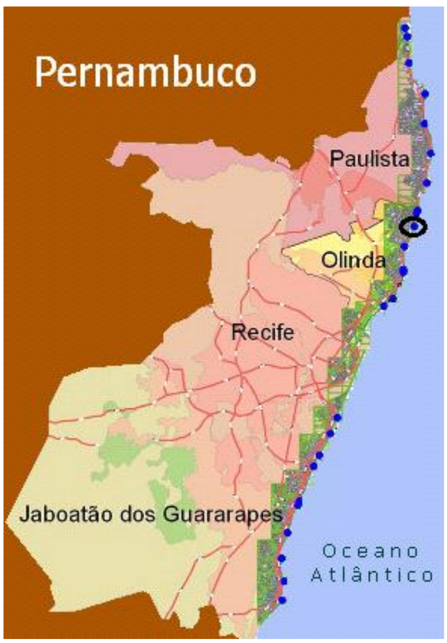

Figure 66: Locations of the beach profiles measured on the metropolitan coast of Recife.

Sediment transport: In the (CPE 2011) the beach profiles have been monitored for about one year. From these beach profiles it is possible to calculate the amount of sediments lost or gained. The amount of sediments lost or gained on the beach circled in Figure 66 will be representative for the Casa Caiada area

1.3 General solutions

1.3.1 *Rule of thumb for breakwaters*

A tombolo will form when the length of the breakwater divided by the distance offshore is higher than 1.3, so $\frac{L}{D} > 1.3$, for example for breakwater A the value is $\frac{490}{245} = 2$. According to these basic rules, it can be predicted that it is highly likely that a tombolo will form at breakwater A.
A salient will form when $0.5 < \frac{L}{D} < 1.3$.

The same is done for the ratio between the length of the gap and the length of the breakwater. In the case that $\frac{L_{gap}}{L} > 1\ to\ 1.5$, erosion will likely occur at the coast. There is actually no gap in between the breakwaters, but instead there is an overlap. So according to the rule of thumb there is no predicted erosion. Erosion spots are clearly visible, especially at the revetments. This can be due to the reason that the Casa Caiada area works as a closed system instead of an open coast.

Breakwater	Length [m]	Distance offshore [m]	L/D ratio
A	490	245	2.00
B	502	218	2.30
C	495	233	2.12
D	862	320	2.69
E	575	162	3.50
F	870	330	2.64
G	577	407	1.42

Table 44 Application of rules of thumb in Casa Caiada

Appendix N Janga

Figure 67: Overview of Janga (red: breakwaters green: distinctive reefs, blue: revetments, purple: Jetty) (Google Earth)

1.1 Preliminary Assessment

As can be seen in *Figure 67*, there are in total 9 separate breakwaters in front of the coast of Janga, each with different dimensions. The breakwaters are made out of rocks of large diameters.

The observed features of this area are shortly explained for each breakwater.
Structure A: The most northern breakwater, indicated with the letter A in Figure 68, is the longest breakwater along the coast (see Table 45). This breakwater is the closest one to the reef. Here one can observe the appearance of two connected salients on the coast. On each side of the salient, revetments are placed to protect the coastline.
Structure B: The second breakwater is curved in the middle and has a large salient which is almost turned into a tombolo. On the northern side of the salient, revetments are placed. South of the salient there are no revetments, only a few rocks can be seen.
Structure C: On the coast at the third breakwater a very small salient is observed.
Structure D: Directly behind the fourth breakwater sediment can be seen as well as a wide salient.
Structure E, F, G: The fifth, sixth and seventh breakwaters have similar sediment profiles. On the landward side of the breakwaters a tombolo is almost formed and the coastline is full of sedimentation.
Structure H: The eight breakwaters have fully developed tombolo.
Structure I: The ninth and smallest breakwater has very little sediment accretion and a small salient. Further south of breakwater I a healthy beach can be observed of 700 meter until it reaches the jetty at the mouth of the river. Here is the northern boundary of the next area, Casa Caiada.
Table 45 gives an overview of characteristics of these breakwaters.

Breakwaters	Length [m]	Height [m]	Top Width [m]	Distance offshore [m]	Distance to previous breakwater [m]
A	640		20	150	-
B	270		20	130	44
C	180		20	192	40
D	240		20	210	36
E	310		20	180	40
F	240		20	170	46
G	204		22	172	45
H	250		21	148	48
I	127		23	143	49

Table 45: Overview breakwaters in Janga

1.1.1 *Reef*

In Janga long and wide reefs can be found and some of the reefs are placed behind each another. There are a lot of small reefs scattered around the area that are too small to mention.
Worth mentioning is reef J. This reef continues where breakwater A stops and can to some degree be seen as the continuation of the breakwater as a submerged breakwater. There is however no beach behind the reef and the coast here has been fixed by relatively long revetments.

Reef	Length [m]	Width (averaged) [m]	Distance offshore [m]	Depth(averaged) [m]
J	1170	62	160	-3.5
K	3244	380	570	-2.5
L	3567	380	1360	-4.0
M	590	44	220	-4.5

Table 46: Reefs in Janga

1.1.2 *Revetments*

There are several revetments built in the area. These revetments are placed in order to preserve the coastline. North of the first breakwater a very long revetment behind is observed of 1864 m long. The ending of this revetment also marks the ending of the area.

Revetment	Length [m]
N	1864
O	235

Table 47: Revetments Janga

1.1.3 *Jetty*

There is also one jetty in the area of Janga. This is at the mouth of a small river and is made up of rocks.

Jetty	Length [m]
P	250

Table 48: Jetty in Janga

1.1.4 *Photos of current situation*

Figure 68: Looking at breakwater H from the coast, with a clear tombolo

Figure 69: Breakwater H (left) and I from the coast

Figure 70: On top of breakwater H

Appendix O Multi Criteria Analysis (MCA)

1.1 Introduction

A *Multi Criteria Analysis* (MCA) will be used to determine the value of the different alternatives. An MCA is a scientific method to evaluate the value of different alternatives in a rational and objective way.
The objectives of an MCA are organizing, increasing the transparency of decision making and supporting decision makers in their choice.
The analysis is based upon different criteria, which are determined based upon the stakeholders analysis and value-variables. These criteria have unequal importance and thus have a different influence on the total project. This factor is called the weight factor and is determined with a *Weight Matrix* (*see* Table 49). For example, it's considered far more important to have wide beaches than to have beautiful structures.

1.2 Criteria

The different criteria that have an influence on the project are explained here. These criteria have been chosen based upon the stakeholder, problems and desired situation for the area. Many aspects are very subjective and educated guesses are needed here to determine their value.

The following criteria will be taken into account here and will be explained later:

- *Construction Time*
- *Constructability*
- *Defense against storms and tides*
- *Defense structural erosion*
- *Beach quality*
- *Durability*
- *Sustainability*
- *Esthetics*
- *Visual obstruction*
- *Physical obstruction*
- *Ecology*
- *Safety feeling*

Construction Time
The construction time is the time required to realize the alternative from start to end of construction. The correlation that the construction time has with the total costs is disregarded here.
E.g. If alternative 2 takes 10 months longer to build than alternative 1, then this extra construction time influences the costs (like more rent of equipment, etc.). This influence is already taken into account under construction costs and doesn't need to be taken into account here again.
Instead, what is meant with construction time are aspects like the extra nuisance the construction works cause, as well as the less time the beach is available due to e.g. nourishment.

Constructability
It is preferable that an alternative is easily constructed. The amount of works that need to be done as well as how complicated these works are determine to a large degree whether an alternative easily constructed.

Defense against storms and tides
The alternatives are largely bases upon the problems that are caused by sediment transport in the longshore direction. This is why they could fail when a large storm or extreme high tide reaches the coast. The alternatives should therefore be assessed based upon the defense they offer against storms and tides.

Defense structural erosion
To limit the structural erosion is one the main reasons of the alternatives. However, one alternative will provide a better defense against structural erosion than other alternatives.

Beach quality

Another main goal for Boa Viagem was to create and ensure the quality of the beaches. The quality of the beaches is dependent on the width and shape of the sediment accumulation. A high quality beach increases the economic potential in the area and offers more defenses against the ocean.

Durability
One problem that is numerously observed in this report is the fact that many ‘recently’ built structures, of some only 10 years old, are failing due to the ocean condition in Recife. This is a clear indication that the structures are not designed to resist the wave/current conditions in Recife. The new solution should therefore be durable enough.

Sustainability
Sustainability is a very extensive term. There are many definitions for sustainability and the word is coined in various situations. The following definition is used here:
"Sustainability integrates natural systems with human patterns and celebrates continuity, uniqueness and place making", (Early, 1993). This means that the structures have to be built with respect to their environment, without straining the resources much and without causing too much damage to the environment.

Esthetics
Esthetics describes the appearance of the area to the people in the society. It is impossible to determine an absolute value for this; however one can understand the relative value, i.e. when an alternative is perceived to be creating an esthetically more beautiful area.

Visual obstruction
E.g. a breakwater that blocks the view on the ocean can be perceived to have a high visual obstruction.

Physical obstruction
With a physical obstruction is meant that a certain object (i.e. structure) blocks passage physically. Examples are boats that cannot pass through the area, but also swimmer who are unable to swim into the ocean because of the physical obstruction of a breakwater.

Recreational value
Recreational value is a term that is used to express the possibilities for recreation. This criterion is correlated with other criterion such as beach quality, physical obstruction but is also determined on aspects like the distance to the highly populated areas.

Ecology
Ecology described the science of the relationship between organisms and their environments. This criterion is highly correlated with terms like water quality and pollution in the area.

Safety feeling
A structure can be designed and constructed to withhold an enormous storm, but when the street is hit with water, people start to get afraid. Putting enormous structures may increase the feeling of safety, but comes at a high cost and could have consequences such as increased erosion due to less overtopping.

1.3 Weight Matrix

How much influence each of the criteria is supposed to have on the choice of alternative is dependent on the weight factor assigned to each criterion. This will be done using a *Weight Matrix* (see Table 49), i.e. *Relation Matrix*. In this matrix each criterion is compared to one another in terms of importance (e.g. durability is appointed 1 and ecology 0 because durability is more important than ecology). After all the comparisons are made, the totals are summed up and divided by the total amount of points.

Weight factor	Construction time	Constructability	Defense against storms and tides	Defense structural erosion	Beach quality	Durability	Sustainability	Esthetics	Visual obstruction	Physical obstruction	Recreational value	Ecology	Safety feeling	Total	Scaled weight factor
Construction time		0	0	0	0	0	0	1	1	1	1	1	0	5	6%
Constructability	1		0	0	0	0	0	1	1	1	0	1	1	6	8%
Defense against storms and tides	1	1		0	1	1	1	1	1	1	1	1	1	11	14%
Defense against structural erosion	1	1	1		1	1	1	1	1	1	1	1	1	12	15%
Beach quality	1	1	0	0		1	1	1	1	1	1	1	1	10	13%
Durability	1	1	0	0	0		1	1	1	1	0	1	0	7	9%
Sustainability	1	1	0	0	0	0		1	1	1	0	0	1	6	8%
Esthetics	0	0	0	0	0	0	0		0	1	0	0	0	1	1%
Visual obstruction	0	0	0	0	0	0	0	1		1	0	1	0	3	4%
Physical obstruction	0	0	0	0	0	0	0	0	0		0	1	0	1	1%
Recreational value	0	1	0	0	0	1	1	1	1	1		1	0	7	9%
Ecology	0	0	0	0	0	0	1	1	0	0	0		0	2	3%
Safety feeling	1	0	0	0	0	1	0	1	1	1	1	1		7	9%
													Total	78	*100%*

Table 49 Criterion Weight Matrix

The values in Table 49 are mainly determined based upon the stakeholders (their wishes, involvement and influence), the problems that are described and the desired situation.
The totals clearly show that the importance of some criteria above others. Criteria like esthetics, ecology visual obstruction are of minor importance (however they do influence the total value), while particularly safety (defense against structural erosion, defense against storms and tides), beach quality, recreational quality and durability are considered important and their score has a large influence on the total value of the alternatives.

1.4 Multi Criteria Analysis

Based upon the criteria and their weight factor, the created value for the different alternatives will now be determined. This will be done for each alternative with a grade, ranging from 1 to 5, where 1 is worst and 5 is best.

The different alternatives with their main characteristics are:

- Alternative 0: Making no changes to the current situation
- Alternative 1: Nourishment at E
- Alternative 2: Nourishment at E + breakwater at E

	Values			Weight factor	Scaled values		
Criterion	**Alternative 0**	**Alternative 1**	**Alternative 2**		**Alternative 0**	**Alternative 1**	**Alternative 2**
Construction time	5	2	1	6%	0.32	0.13	0.06
Constructability	5	4	3	8%	0.38	0.31	0.23
Defense against storms and tides	2	3	4	14%	0.28	0.42	0.56
Defense against structural erosion	1	3	4	15%	0.15	0.46	0.62
Beach quality	1	3	3	13%	0.13	0.38	0.38
Durability	1	3	4	9%	0.09	0.27	0.36
Sustainability	4	4	4	8%	0.31	0.31	0.31
Esthetics	4	4	3	1%	0.05	0.05	0.04
Visual obstruction	5	5	2	4%	0.19	0.19	0.08
Physical obstruction	5	5	3	1%	0.06	0.06	0.04
Recreational value	1	3	3	9%	0.09	0.27	0.27
Ecology	2	3	2	3%	0.05	0.08	0.05
Safety feeling	2	3	4	9%	0.18	0.27	0.36
Total scaled value					2.29	3.21	3.36

Table 50 Multi Criteria Analysis results

The values are defined relative to each other, one gaining far more points if that alternative does so much better than the other one.
From Table 50 one can conclude that Alternative 2, nourishment near revetment E and the construction of a breakwater offshore of E, has the most value. This could be expected, since this solution offers the most extensive defense, using a combination of hard and soft measurements to solve the problems.

However, the real question is whether this alternative created so much more value to compensate for the extra amount of costs (analyzed after this).
As expected, Alternative 0 i.e. doing nothing has the least value. The problems remain the same and this alternative therefore scores badly for the important criteria such as defense and beach quality.

Appendix P Planning

The project planning can be found in Figure 71. Explanations can be found under Figure 71.

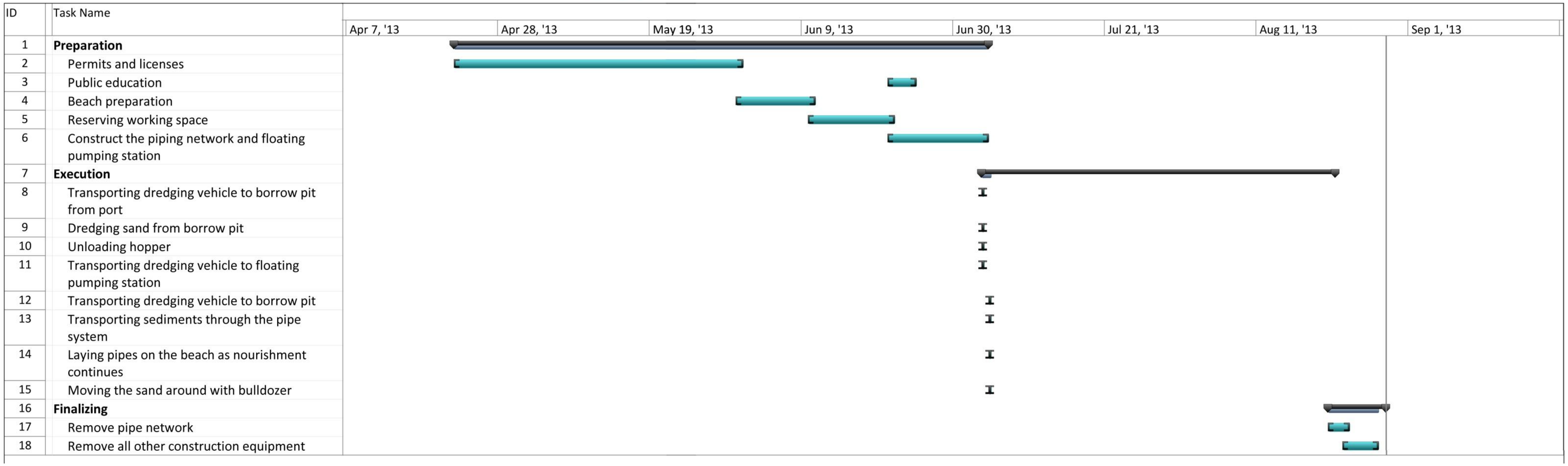

Figure 71: project planning (on the top '2013' should be '2015')

1.1 Preparation *[54 days]*

Before a project can be executed, preparation works have to be done. Further down follows different types of preparation works;

Permits and licenses [30 days]

A project cannot be executed without proper permits and licenses.

Public education [2 days]

A company is obliged to inform the public of upcoming works, in order to educate the people and to have enough support for the project.

Beach preparation [7 days]

The beach will be occupied during the project; therefore the area of occupation will be contained. Signs will be posted to notify the people of the project.

Reserving workspace [10 days]

Workspace has to be reserved for labor and machines. The pipes will be stored on the beach as will other machinery.

Construct a piping network and a floating pump station [10 days]

Nourishment will take place with a piping network, which has to be constructed in advance.

1.2 Execution *[70 days]*

Once the pipe network is ready, one can start the nourishment

1) First a dredging vehicle, the hopper, needs to be transported from the port to the pit [0.1 days].

2) When the hopper has arrived at the pit, it will dredge until it has reached its limit [0.03 days]

   The ship has a capacity of 4480 m^3 and a loading speed of 180 m^3/min, thus resulting in a dredging time of 0.03 days.

3) The hopper sails 7.5 km, from the pit to the floating pumping station and unloads the dredged sediments [0.04 days]

   Top speed of the vessel is 14.4 km. The vessel will take about 30 min to cover the distance taking into account acceleration/deceleration).

4) The pumping station will then pump the sediments though a 2.5 km pipe to the beach [approximately 5 minutes]

   Assumption here is that the sediments move with a speed of 10 m/s through the pipe.

5) Simultaneously with (4), the hopper goes back to the pit [0.04 days] and starts a new *cycle*; this *cycle* repeats itself 262 times.

6) At the beach, the sediments will be spread by a bulldozer and will be flattened by a scraper.

The execution has been visualized in Figure 72.

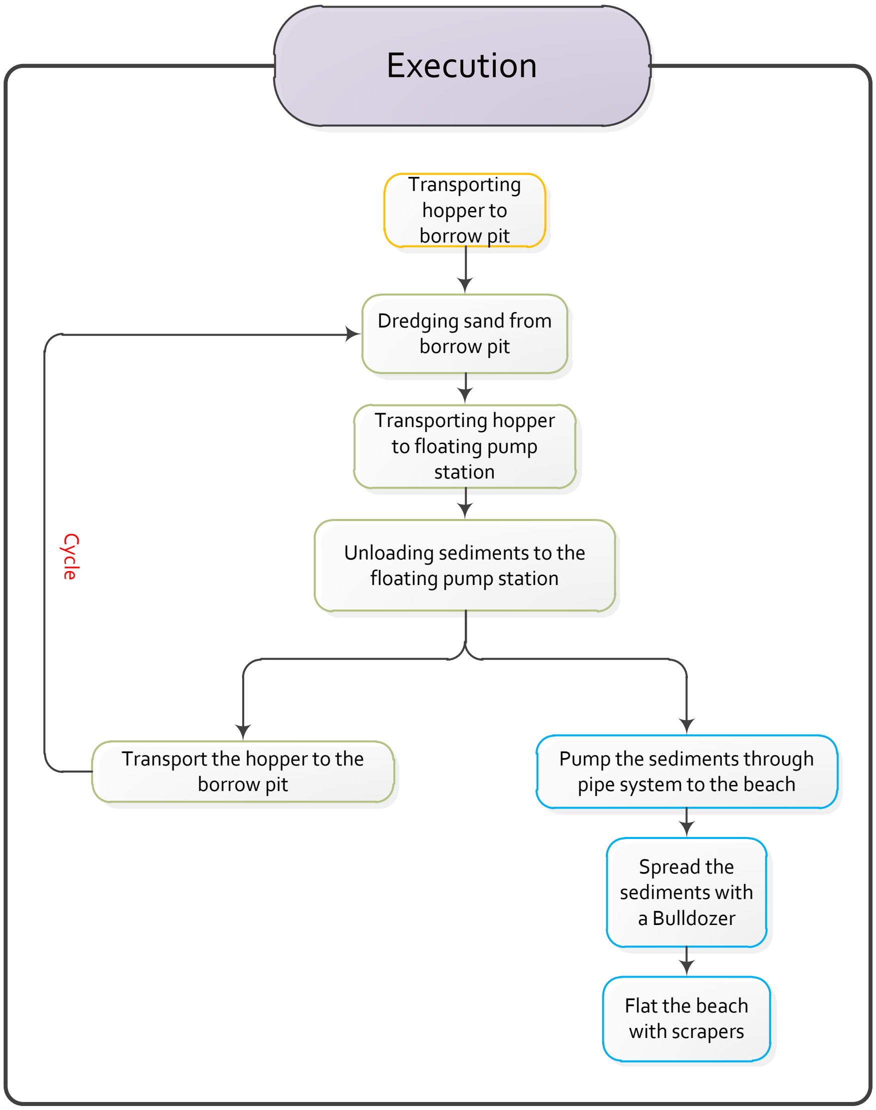

Figure 72: execution

1.3 Finalizing *[6 days]*

Once execution has been completed, one has to remove all project related structures.

Appendix Q Expenditures Model Alternatives

1.1 Introduction

With the use of an expenditures model the costs of the project along the entire project will be looked upon. With the use of this model, different alternatives can be compared on costs. Another advantage is that becomes immediately clear what the best investment time is and what the future value of this investment will become.

The calculations have been made using an Excel-sheet, with which the model is built. The most important information is the total cost that and how these costs are spent along the project duration. Apart from this can be seen what the influence of the economy will be on the project, with a variable time-preference rate, simulating the changes in interest rates, inflation and economic growth in the area.

1.2 Assumptions

1.2.1 *General*

- All costs in a particular year will be spend on 31 December of that year
- No demolition phase or demolition costs
- The time-preference rate is variable, but decisions in the project are based upon a value of 2%

1.2.2 *Planning*

- Project and design phase starts on 1 January 2013
- Designing takes two years
- Building phase starts on 1 January 2015
- Building phase duration can be determined from the building plan
- Operational phase starts immediately after finishing building phase
- Operational phase lasts 50 years
- Project finishes when the operational phase has ended

1.2.3 *Costs*

- Costs for the total design phase are 3% of the total building costs
- Maintenance and exploitation costs per year are 1% of the total building costs for Alternative 1
- Maintenance and exploitation costs per year are 0,5% of the total building costs for Alternative 2, this amount is lower because of the higher initial costs of Alternative 2 and the fact that it is not expected that maintenance of the breakwater will be a high costs. The absolute maintenance costs for Alternative 1 are still quite lower than the maintenance costs for Alternative 2.
- Dispossession is not needed since the beaches are already property of the Brazilian government
- Risk is expressed in a percentage of the total building costs. A low risk percentage of 5% of the total building costs will be taken because the risks for this project are relatively low.

1.3 Time-preference value

The time-preference value (*discontovoet* in Dutch) is the factor that takes into account the drop in value of structures. This can be due to many aspects of economy, among the main factors: inflation, interest, economic growth etc. When determining the costs for this project, this time-preference value must be taken into account because this project is stretched along a relatively long time period.

The time-preference rate is used here to estimate the future costs of activities that are described in the alternatives, i.e. how much extra does it costs to nourish the same amount 40 years later compared to nourishing now?

The Brazilian economy is very vibrant and dynamic at the moment. The increasing growth of the economy in combination with the many risks and dangers of stagnation of the growth make it hard make an estimation for the value of the time-preference rate. This value is therefore chosen to be variable, choosing the following values for different scenarios: 1%, 5% and 10%.

However, when making a comparison between the alternatives, one value has to be chosen to base the choice of the alterative on. This choice of value is largely based upon the international capital market. This can be defended that domestic investment should have the same return as investments that are made abroad on the international market. The time-preference rate in 2011 is equal to 2,5% (Dutch Ministry of Finance, 2011).

1.4 Pricing date

The compare the future value of the different activities of the different alternatives with each other, a specific pricing date must be determined. The values for the activities are adjusted (Dutch: *contanteerd*) to this specific date and this date is called the pricing date. This pricing date is chosen to be 1 January 2015, assuming the building phase will start on the same date.

1.5 Time horizon

The time duration for the exploitation phase is chosen to be 50 years. This duration is reasonable given the structures and activities in the alternatives. In 50 years the effect of the changes made to the area can also be seen and can be judged whether the proposed solution have the desired effect.
Also, this long time span allows for a more fair competition between the alternatives, since their initial and recurrent costs differ vastly.

1.6 Key figures

Key figures are costs per unit of the particular target structure. The values of key figures are usually based upon various reference projects and empirical research. They provide a clear idea about the magnitude of the costs. However, the values should be approached with caution, since the environment and situation for this particular project can be very different from the situation the key figures are based upon. That's why a higher risk percentage is added to the total costs, accounting also for this uncertainty.

Initial nourishment:
According to (CPE, 2011) and (Kengetallen, 2007), the cost of 1 m^3 is equal to 25 R$.

Breakwater:
A global estimation of the costs of the breakwaters is not easy, because the breakwater is a relative complex structure with many different layers. The cost mainly depend on e.g. its location, the water depth, the resistance against waves, the material and dimensions of the breakwater.
As mentioned before, the breakwater consist of different layers which have a different costs. It differs from R$ 50 to R$ 70 per ton (Verhagen, 2011). In this paper a cost of $R 60 per ton has been assumed. Using the dimensions determined in the solutions, one breakwater has an approximate weight of 85000 tons. One breakwater would then cost approximately $R 5.100.000.

Recurrent nourishment: *R$* 1.750.000 / per nourishment
The residual sediment transport will probably change due to the initial nourishment. Whether there is occurrence of erosion or accretion after the initial nourishment is hard to predict without information of numerical models or measurements.
We assume that in the future, maintenance nourishment will be necessary. According to the guidelines (see Appendix G Design Guidelines), a nourishment of a 5 year period is generally applied.
According to the guidelines (see Appendix G Design Guidelines) for maintenance nourishment, the specific area should be closely monitored by measurements. Based upon the results of these measurements, further action can be taken. When looking at (CPE, 2011) erosion/accretion model one can observe that there is erosion-stroke along the stretch of the coast, it is not clear what will happen when this part will be nourished.
Due to lack of measurements/information, it is assumed that only 10 % of the initial nourishment is required as recurrent nourishment.

The Dutch Design Method

Beach nourishment in the Netherlands is designed in an extremely simple way. Experience has shown that this is a very reliable method. The method is very trustworthy, if applicable.

- step 1: Perform coastal measurements (for at least 10 years).
- step 2: Calculate the "loss of sand" in m^3/year per coastal section.
- step 3: Add 40 % loss.
- step 4: Multiply this quantity with a convenient lifetime (for example five years).
- step 5: Put this quantity somewhere on the beach between the low-water-minus-1-meter line and the dune foot.

This method is simple and straightforward. It does not require mathematical models, but good quality profile measurements are absolutely necessary.

Figure 73: The Dutch Design Method for Nourishment

1.7 Costs Alternative 0

The costs for Alternative 0 are zero, since for this alternative nothing will be done.

1.8 Costs Alternative 1

Alternative 1 makes use of primarily initial nourishment and recurrent nourishment. Compared to alternative 2, this alternative uses a larger frequency of recurrent nourishment during the 50 years of exploitation. However, the initial costs are far lower the initial costs for alternative 1. The main activities for Alternative 1 are the initial nourishment and recurrent nourishment.

Initial nourishment: *R$* 17.500.000
The area that needs to be nourished is roughly in the same order of the amount that needs to be nourished in the solution in the (CPE, 2011). The amount of initial nourishment is approximately equal to 700.000 m^3 (CPE, 2011). Using the key figure of R$ 25 per m3 nourishment, the total value can be obtained.

Recurrent nourishment: *R$* 1.750.000 / per nourishment
Using the 10% of the initial nourishment number, the costs for one time of recurrent nourishment can be calculated as *R$* 1.750.000 / per nourishment.
For an exploitation period of 50 years, this means that the amount of recurrent nourishments for this alternative is equal to 10 times.

Apart from these costs, the design and maintenance costs are added as a percentage of the total building costs. In Table 51 is shown how the costs add up along the development of Alternative 1. In the last columns, the totals for different time-preference rates are shown to present situations where the economy doesn't not act the anticipated time-preference rate of 2,5%.
How the costs develop in time for Alternative 1 is presented in a graph in Figure 74.

Alternative 1					Time-preference rate	2,5%	1%	5%	10%
	year	year of project	Expenditures	Cumulative balance without time-preference	Expenditure incl. time-preference	Cumulative costs with time-preference	Cumulative costs with time-preference	Cumulative costs with time-preference	Cumulative costs with time-preference
Start design phase	2013	1	R$ 262.500,00	R$ 262.500,00	R$ 275.789,06	R$ 275.789,06	R$ 267.776,25	R$ 289.406,25	R$ 317.625,00
	2014	2	R$ 262.500,00	R$ 525.000,00	R$ 269.062,50	R$ 544.851,56	R$ 532.901,25	R$ 565.031,25	R$ 606.375,00
Start building phase	2015	3	R$ 17.500.000,00	R$ 18.025.000,00	R$ 17.500.000,00	R$ 18.044.851,56	R$ 18.032.901,25	R$ 18.065.031,25	R$ 18.106.375,00
Start exploitation phase	2016	4	R$ 175.000,00	R$ 18.200.000,00	R$ 170.731,71	R$ 18.215.583,27	R$ 18.206.168,58	R$ 18.231.697,92	R$ 18.265.465,91
	2017	5	R$ 175.000,00	R$ 18.375.000,00	R$ 166.567,52	R$ 18.382.150,79	R$ 18.377.720,39	R$ 18.390.428,08	R$ 18.410.094,01
	2018	6	R$ 175.000,00	R$ 18.550.000,00	R$ 162.504,90	R$ 18.544.655,69	R$ 18.547.573,66	R$ 18.541.599,66	R$ 18.541.574,10
	2019	7	R$ 175.000,00	R$ 18.725.000,00	R$ 158.541,36	R$ 18.703.197,05	R$ 18.715.745,22	R$ 18.685.572,59	R$ 18.661.101,45
	2020	8	R$ 1.925.000,00	R$ 20.650.000,00	R$ 1.701.419,50	R$ 20.404.616,55	R$ 20.547.316,67	R$ 20.193.860,46	R$ 19.856.375,00
	2021	9	R$ 175.000,00	R$ 20.825.000,00	R$ 150.901,95	R$ 20.555.518,50	R$ 20.712.174,59	R$ 20.324.448,15	R$ 19.955.157,94
	2022	10	R$ 175.000,00	R$ 21.000.000,00	R$ 147.221,42	R$ 20.702.739,92	R$ 20.875.400,25	R$ 20.448.817,39	R$ 20.044.960,61
	2023	11	R$ 175.000,00	R$ 21.175.000,00	R$ 143.630,65	R$ 20.846.370,57	R$ 21.037.009,81	R$ 20.567.264,27	R$ 20.126.599,40
	2024	12	R$ 175.000,00	R$ 21.350.000,00	R$ 140.127,46	R$ 20.986.498,03	R$ 21.197.019,28	R$ 20.680.070,83	R$ 20.200.816,48
	2025	13	R$ 1.925.000,00	R$ 23.275.000,00	R$ 1.503.806,92	R$ 22.490.304,96	R$ 22.939.696,67	R$ 21.861.853,85	R$ 20.942.987,32
	2026	14	R$ 175.000,00	R$ 23.450.000,00	R$ 133.375,34	R$ 22.623.680,29	R$ 23.096.553,32	R$ 21.964.172,72	R$ 21.004.323,75
	2027	15	R$ 175.000,00	R$ 23.625.000,00	R$ 130.122,28	R$ 22.753.802,57	R$ 23.251.856,93	R$ 22.061.619,27	R$ 21.060.084,14
	2028	16	R$ 175.000,00	R$ 23.800.000,00	R$ 126.948,57	R$ 22.880.751,14	R$ 23.405.622,89	R$ 22.154.425,51	R$ 21.110.775,41
	2029	17	R$ 175.000,00	R$ 23.975.000,00	R$ 123.852,26	R$ 23.004.603,40	R$ 23.557.866,41	R$ 22.242.812,40	R$ 21.156.858,38
	2030	18	R$ 1.925.000,00	R$ 25.900.000,00	R$ 1.329.146,20	R$ 24.333.749,60	R$ 25.215.964,15	R$ 23.168.770,31	R$ 21.617.688,07
	2031	19	R$ 175.000,00	R$ 26.075.000,00	R$ 117.884,36	R$ 24.451.633,96	R$ 25.365.207,87	R$ 23.248.939,83	R$ 21.655.773,17
	2032	20	R$ 175.000,00	R$ 26.250.000,00	R$ 115.009,13	R$ 24.566.643,09	R$ 25.512.973,93	R$ 23.325.291,75	R$ 21.690.395,99
	2033	21	R$ 175.000,00	R$ 26.425.000,00	R$ 112.204,03	R$ 24.678.847,13	R$ 25.659.276,96	R$ 23.398.007,86	R$ 21.721.871,28
	2034	22	R$ 175.000,00	R$ 26.600.000,00	R$ 109.467,35	R$ 24.788.314,48	R$ 25.804.131,44	R$ 23.467.261,31	R$ 21.750.485,17
	2035	23	R$ 1.925.000,00	R$ 28.525.000,00	R$ 1.174.771,57	R$ 25.963.086,04	R$ 27.381.754,55	R$ 24.192.773,56	R$ 22.036.624,16
	2036	24	R$ 175.000,00	R$ 28.700.000,00	R$ 104.192,60	R$ 26.067.278,64	R$ 27.523.754,83	R$ 24.255.588,48	R$ 22.060.272,01
	2037	25	R$ 175.000,00	R$ 28.875.000,00	R$ 101.651,32	R$ 26.168.929,96	R$ 27.664.349,16	R$ 24.315.412,20	R$ 22.081.770,05
	2038	26	R$ 175.000,00	R$ 29.050.000,00	R$ 99.172,02	R$ 26.268.101,98	R$ 27.803.551,48	R$ 24.372.387,18	R$ 22.101.313,73
	2039	27	R$ 175.000,00	R$ 29.225.000,00	R$ 96.753,19	R$ 26.364.855,16	R$ 27.941.375,55	R$ 24.426.649,07	R$ 22.119.080,71
	2040	28	R$ 1.925.000,00	R$ 31.150.000,00	R$ 1.038.326,88	R$ 27.403.182,05	R$ 29.442.429,80	R$ 24.995.106,90	R$ 22.296.750,51
	2041	29	R$ 175.000,00	R$ 31.325.000,00	R$ 92.091,08	R$ 27.495.273,12	R$ 29.577.538,19	R$ 25.044.324,03	R$ 22.311.433,96
	2042	30	R$ 175.000,00	R$ 31.500.000,00	R$ 89.844,95	R$ 27.585.118,08	R$ 29.711.308,88	R$ 25.091.197,49	R$ 22.324.782,56
	2043	31	R$ 175.000,00	R$ 31.675.000,00	R$ 87.653,61	R$ 27.672.771,69	R$ 29.843.755,11	R$ 25.135.838,87	R$ 22.336.917,64
	2044	32	R$ 175.000,00	R$ 31.850.000,00	R$ 85.515,72	R$ 27.758.287,41	R$ 29.974.889,98	R$ 25.178.354,48	R$ 22.347.949,54
	2045	33	R$ 1.925.000,00	R$ 33.775.000,00	R$ 917.729,67	R$ 28.676.017,08	R$ 31.403.091,60	R$ 25.623.756,07	R$ 22.458.268,50
	2046	34	R$ 175.000,00	R$ 33.950.000,00	R$ 81.395,09	R$ 28.757.412,17	R$ 31.531.642,60	R$ 25.662.318,98	R$ 22.467.385,77
	2047	35	R$ 175.000,00	R$ 34.125.000,00	R$ 79.409,85	R$ 28.836.822,02	R$ 31.658.920,82	R$ 25.699.045,55	R$ 22.475.674,20
	2048	36	R$ 175.000,00	R$ 34.300.000,00	R$ 77.473,02	R$ 28.914.295,04	R$ 31.784.938,86	R$ 25.734.023,25	R$ 22.483.209,13
	2049	37	R$ 175.000,00	R$ 34.475.000,00	R$ 75.583,44	R$ 28.989.878,47	R$ 31.909.709,19	R$ 25.767.335,34	R$ 22.490.059,07
	2050	38	R$ 1.925.000,00	R$ 36.400.000,00	R$ 811.139,30	R$ 29.801.017,78	R$ 33.268.594,02	R$ 26.116.319,14	R$ 22.558.558,47
	2051	39	R$ 175.000,00	R$ 36.575.000,00	R$ 71.941,40	R$ 29.872.959,18	R$ 33.390.905,89	R$ 26.146.534,19	R$ 22.564.219,58
	2052	40	R$ 175.000,00	R$ 36.750.000,00	R$ 70.186,73	R$ 29.943.145,91	R$ 33.512.006,75	R$ 26.175.310,42	R$ 22.569.366,04
	2053	41	R$ 175.000,00	R$ 36.925.000,00	R$ 68.474,86	R$ 30.011.620,77	R$ 33.631.908,59	R$ 26.202.716,36	R$ 22.574.044,64
	2054	42	R$ 175.000,00	R$ 37.100.000,00	R$ 66.804,74	R$ 30.078.425,52	R$ 33.750.623,28	R$ 26.228.817,25	R$ 22.578.297,92
	2055	43	R$ 1.925.000,00	R$ 39.025.000,00	R$ 716.928,95	R$ 30.795.354,47	R$ 35.043.555,57	R$ 26.502.255,19	R$ 22.620.830,65
	2056	44	R$ 175.000,00	R$ 39.200.000,00	R$ 63.585,72	R$ 30.858.940,18	R$ 35.159.931,11	R$ 26.525.929,47	R$ 22.624.345,75
	2057	45	R$ 175.000,00	R$ 39.375.000,00	R$ 62.034,85	R$ 30.920.975,03	R$ 35.275.154,43	R$ 26.548.476,41	R$ 22.627.541,30
	2058	46	R$ 175.000,00	R$ 39.550.000,00	R$ 60.521,80	R$ 30.981.496,83	R$ 35.389.236,91	R$ 26.569.949,68	R$ 22.630.446,34
	2059	47	R$ 175.000,00	R$ 39.725.000,00	R$ 59.045,66	R$ 31.040.542,49	R$ 35.502.189,87	R$ 26.590.400,41	R$ 22.633.087,29
	2060	48	R$ 1.925.000,00	R$ 41.650.000,00	R$ 633.660,73	R$ 31.674.203,21	R$ 36.732.370,58	R$ 26.804.646,19	R$ 22.659.496,78
	2061	49	R$ 175.000,00	R$ 41.825.000,00	R$ 56.200,51	R$ 31.730.403,72	R$ 36.843.097,92	R$ 26.823.195,61	R$ 22.661.679,38
	2062	50	R$ 175.000,00	R$ 42.000.000,00	R$ 54.829,76	R$ 31.785.233,48	R$ 36.952.728,94	R$ 26.840.861,72	R$ 22.663.663,56
	2063	51	R$ 175.000,00	R$ 42.175.000,00	R$ 53.492,45	R$ 31.838.725,94	R$ 37.061.274,51	R$ 26.857.686,59	R$ 22.665.467,37
	2064	52	R$ 175.000,00	R$ 42.350.000,00	R$ 52.187,76	R$ 31.890.913,70	R$ 37.168.745,38	R$ 26.873.710,27	R$ 22.667.107,19
	2065	53	R$ 1.925.000,00	R$ 44.275.000,00	R$ 560.063,75	R$ 32.450.977,45	R$ 38.339.220,11	R$ 27.041.577,45	R$ 22.683.505,40
		Total initial		R$ 17.500.000,00		R$ 18.044.851,56			
		Total recurrent		R$ 26.250.000,00		R$ 14.406.125,88			
		Total		R$ 43.750.000,00		R$ 32.450.977,45	R$ 38.339.220,11	R$ 27.041.577,45	R$ 22.683.505,40

Table 51 Costs Alternative 1

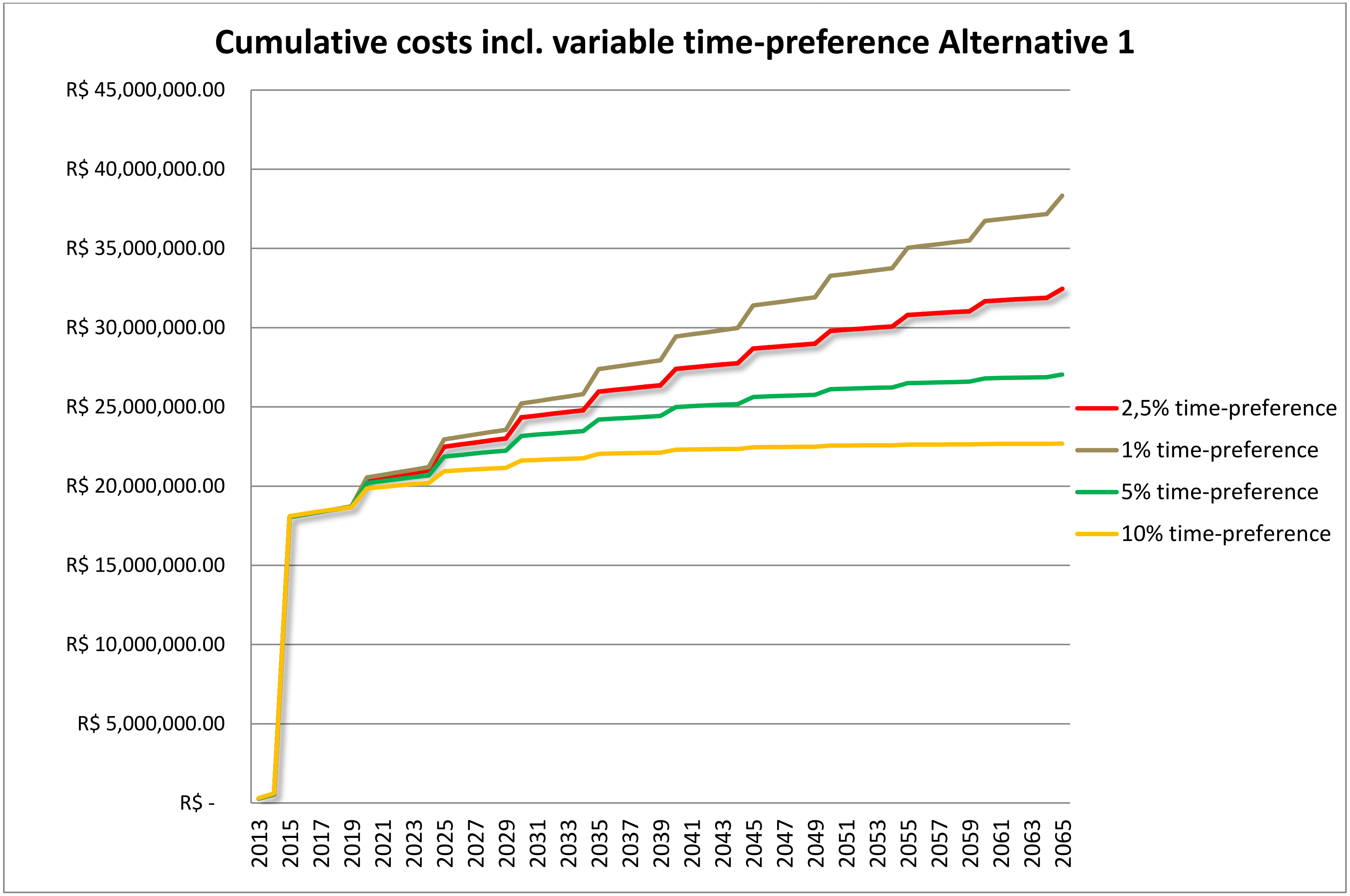

Figure 74 Graph of costs development for Alternative 1

1.9 Costs Alternative 2

Initial nourishment: *R$* 17.500.000
The area that needs to be nourished is roughly in the same order of the amount that needs to be nourished in the solution in the (CPE, 2011). The amount of initial nourishment is approximately equal to 700.000 m^3 (CPE, 2011). Using the key figure of R$ 25 per m3 nourishment, the total value can be obtained.

Breakwater: *R$* 25.500.000
A global estimation of the costs of the breakwaters is not easy, because the breakwater is a relative complex structure with many different layers. The cost mainly depend on e.g. its location, the water depth, the resistance against waves, the material and dimensions of the breakwater.
With the key figure of 60 R$ per ton the total costs can be calculated. Using the dimensions determined in the solutions, one breakwater has an approximate weight of 85000 tons. One breakwater would then cost approximately $R 5.100.000.

Recurrent nourishment: *R$* 1.750.000 / per nourishment
Using the 10% of the initial nourishment number, the costs for one time of recurrent nourishment can be calculated as *R$* 1.750.000 / per nourishment.
For alternative 2 due to the presence of the breakwaters, it is assumed that the erosion rate will decrease. The frequency of the nourishments required will therefore also decrease. It is assumed that the maintenance period will increase from 5 to 8 years. This means that for a total period of 50 years the nourishment frequency is 6 times.

Apart from these costs, the design and maintenance costs are added as a percentage of the total building costs. In Table 52 is shown how the costs add up along the development of Alternative 2. In the last columns, the totals for different time-preference rates are shown to present situations where the economy doesn't not act the anticipated time-preference rate of 2,5%.
How the costs develop in time for Alternative 2 is presented in a graph in Figure 75.

Alternative 2	year	year of project	Expenditures	Cumulative balance without time-preference	Time-preference rate Expenditure incl. time-preference	2,5% Cumulative costs with time-preference	1% Cumulative costs with time-preference	5% Cumulative costs with time-preference	10% Cumulative costs with time-preference
Start design phase	2013	1	R$ 645.000,00	R$ 645.000,00	R$ 677.653,13	R$ 677.653,13	R$ 657.964,50	R$ 711.112,50	R$ 780.450,00
	2014	2	R$ 645.000,00	R$ 1.290.000,00	R$ 661.125,00	R$ 1.338.778,13	R$ 1.309.414,50	R$ 1.388.362,50	R$ 1.489.950,00
Start building phase	2015	3	R$ 43.000.000,00	R$ 44.290.000,00	R$ 43.000.000,00	R$ 44.338.778,13	R$ 44.309.414,50	R$ 44.388.362,50	R$ 44.489.950,00
Start exploitation	2016	4	R$ 215.000,00	R$ 44.505.000,00	R$ 209.756,10	R$ 44.548.534,22	R$ 44.522.285,79	R$ 44.593.124,40	R$ 44.685.404,55
	2017	5	R$ 215.000,00	R$ 44.720.000,00	R$ 204.640,10	R$ 44.753.174,32	R$ 44.733.049,44	R$ 44.788.135,74	R$ 44.863.090,50
	2018	6	R$ 215.000,00	R$ 44.935.000,00	R$ 199.648,87	R$ 44.952.823,19	R$ 44.941.726,32	R$ 44.973.860,83	R$ 45.024.623,18
	2019	7	R$ 215.000,00	R$ 45.150.000,00	R$ 194.779,39	R$ 45.147.602,58	R$ 45.148.337,09	R$ 45.150.741,86	R$ 45.171.471,07
	2020	8	R$ 215.000,00	R$ 45.365.000,00	R$ 190.028,67	R$ 45.337.631,25	R$ 45.352.902,22	R$ 45.319.199,98	R$ 45.304.969,16
	2021	9	R$ 215.000,00	R$ 45.580.000,00	R$ 185.393,83	R$ 45.523.025,08	R$ 45.555.441,94	R$ 45.479.636,29	R$ 45.426.331,05
	2022	10	R$ 215.000,00	R$ 45.795.000,00	R$ 180.872,03	R$ 45.703.897,10	R$ 45.755.976,32	R$ 45.632.432,78	R$ 45.536.660,05
	2023	11	R$ 1.965.000,00	R$ 47.760.000,00	R$ 1.612.767,01	R$ 47.316.664,11	R$ 47.570.620,86	R$ 46.962.422,13	R$ 46.453.347,05
	2024	12	R$ 215.000,00	R$ 47.975.000,00	R$ 172.156,60	R$ 47.488.820,71	R$ 47.767.203,92	R$ 47.101.013,04	R$ 46.544.528,04
	2025	13	R$ 215.000,00	R$ 48.190.000,00	R$ 167.957,66	R$ 47.656.778,37	R$ 47.961.840,61	R$ 47.233.004,39	R$ 46.627.419,84
	2026	14	R$ 215.000,00	R$ 48.405.000,00	R$ 163.861,13	R$ 47.820.639,50	R$ 48.154.550,21	R$ 47.358.710,44	R$ 46.702.776,03
	2027	15	R$ 215.000,00	R$ 48.620.000,00	R$ 159.864,52	R$ 47.980.504,01	R$ 48.345.351,80	R$ 47.478.430,49	R$ 46.771.281,66
	2028	16	R$ 215.000,00	R$ 48.835.000,00	R$ 155.965,38	R$ 48.136.469,39	R$ 48.534.264,25	R$ 47.592.449,58	R$ 46.833.559,50
	2029	17	R$ 215.000,00	R$ 49.050.000,00	R$ 152.161,35	R$ 48.288.630,74	R$ 48.721.306,29	R$ 47.701.039,19	R$ 46.890.175,72
	2030	18	R$ 215.000,00	R$ 49.265.000,00	R$ 148.450,09	R$ 48.437.080,84	R$ 48.906.496,43	R$ 47.804.457,86	R$ 46.941.645,01
	2031	19	R$ 2.180.000,00	R$ 51.445.000,00	R$ 1.468.502,36	R$ 49.905.583,19	R$ 50.765.646,78	R$ 48.803.140,98	R$ 47.416.076,53
	2032	20	R$ 215.000,00	R$ 51.660.000,00	R$ 141.296,94	R$ 50.046.880,13	R$ 50.947.187,94	R$ 48.896.944,77	R$ 47.458.613,13
	2033	21	R$ 215.000,00	R$ 51.875.000,00	R$ 137.850,67	R$ 50.184.730,80	R$ 51.126.931,66	R$ 48.986.281,71	R$ 47.497.282,77
	2034	22	R$ 215.000,00	R$ 52.090.000,00	R$ 134.488,46	R$ 50.319.219,26	R$ 51.304.895,75	R$ 49.071.364,51	R$ 47.532.436,99
	2035	23	R$ 215.000,00	R$ 52.305.000,00	R$ 131.208,25	R$ 50.450.427,51	R$ 51.481.097,81	R$ 49.152.395,75	R$ 47.564.395,37
	2036	24	R$ 215.000,00	R$ 52.520.000,00	R$ 128.008,05	R$ 50.578.435,56	R$ 51.655.555,29	R$ 49.229.568,36	R$ 47.593.448,44
	2037	25	R$ 215.000,00	R$ 52.735.000,00	R$ 124.885,90	R$ 50.703.321,46	R$ 51.828.285,48	R$ 49.303.066,08	R$ 47.619.860,32
	2038	26	R$ 215.000,00	R$ 52.950.000,00	R$ 121.839,91	R$ 50.825.161,37	R$ 51.999.305,46	R$ 49.373.063,91	R$ 47.643.871,13
	2039	27	R$ 2.180.000,00	R$ 55.130.000,00	R$ 1.205.268,27	R$ 52.030.429,64	R$ 53.716.199,62	R$ 50.049.011,95	R$ 47.865.196,93
	2040	28	R$ 215.000,00	R$ 55.345.000,00	R$ 115.968,98	R$ 52.146.398,62	R$ 53.883.849,84	R$ 50.112.502,05	R$ 47.885.040,57
	2041	29	R$ 215.000,00	R$ 55.560.000,00	R$ 113.140,47	R$ 52.259.539,09	R$ 54.049.840,15	R$ 50.172.968,81	R$ 47.903.080,24
	2042	30	R$ 215.000,00	R$ 55.775.000,00	R$ 110.380,94	R$ 52.369.920,03	R$ 54.214.186,99	R$ 50.230.556,20	R$ 47.919.479,95
	2043	31	R$ 215.000,00	R$ 55.990.000,00	R$ 107.688,72	R$ 52.477.608,75	R$ 54.376.906,64	R$ 50.285.401,33	R$ 47.934.388,77
	2044	32	R$ 215.000,00	R$ 56.205.000,00	R$ 105.062,17	R$ 52.582.670,92	R$ 54.538.015,20	R$ 50.337.634,79	R$ 47.947.942,24
	2045	33	R$ 215.000,00	R$ 56.420.000,00	R$ 102.499,68	R$ 52.685.170,60	R$ 54.697.528,63	R$ 50.387.380,94	R$ 47.960.263,58
	2046	34	R$ 215.000,00	R$ 56.635.000,00	R$ 99.999,69	R$ 52.785.170,28	R$ 54.855.462,71	R$ 50.434.758,23	R$ 47.971.464,79
	2047	35	R$ 2.180.000,00	R$ 58.815.000,00	R$ 989.219,80	R$ 53.774.390,08	R$ 56.440.985,66	R$ 50.892.266,47	R$ 48.074.714,92
	2048	36	R$ 215.000,00	R$ 59.030.000,00	R$ 95.181,14	R$ 53.869.571,22	R$ 56.595.807,82	R$ 50.935.239,07	R$ 48.083.972,12
	2049	37	R$ 215.000,00	R$ 59.245.000,00	R$ 92.859,65	R$ 53.962.430,87	R$ 56.749.097,09	R$ 50.976.165,35	R$ 48.092.387,76
	2050	38	R$ 215.000,00	R$ 59.460.000,00	R$ 90.594,78	R$ 54.053.025,65	R$ 56.900.868,65	R$ 51.015.142,76	R$ 48.100.038,34
	2051	39	R$ 215.000,00	R$ 59.675.000,00	R$ 88.385,15	R$ 54.141.410,80	R$ 57.051.137,51	R$ 51.052.264,10	R$ 48.106.993,42
	2052	40	R$ 215.000,00	R$ 59.890.000,00	R$ 86.229,42	R$ 54.227.640,22	R$ 57.199.918,56	R$ 51.087.617,76	R$ 48.113.316,21
	2053	41	R$ 215.000,00	R$ 60.105.000,00	R$ 84.126,26	R$ 54.311.766,48	R$ 57.347.226,54	R$ 51.121.287,92	R$ 48.119.064,21
	2054	42	R$ 215.000,00	R$ 60.320.000,00	R$ 82.074,40	R$ 54.393.840,87	R$ 57.493.076,02	R$ 51.153.354,73	R$ 48.124.289,66
	2055	43	R$ 2.180.000,00	R$ 62.500.000,00	R$ 811.898,76	R$ 55.205.739,63	R$ 58.957.279,86	R$ 51.463.014,32	R$ 48.172.456,60
	2056	44	R$ 215.000,00	R$ 62.715.000,00	R$ 78.119,59	R$ 55.283.859,23	R$ 59.100.255,53	R$ 51.492.099,86	R$ 48.176.775,16
	2057	45	R$ 215.000,00	R$ 62.930.000,00	R$ 76.214,24	R$ 55.360.073,47	R$ 59.241.815,59	R$ 51.519.800,38	R$ 48.180.701,11
	2058	46	R$ 215.000,00	R$ 63.145.000,00	R$ 74.355,35	R$ 55.434.428,82	R$ 59.381.974,08	R$ 51.546.181,83	R$ 48.184.270,17
	2059	47	R$ 215.000,00	R$ 63.360.000,00	R$ 72.541,81	R$ 55.506.970,63	R$ 59.520.744,85	R$ 51.571.307,01	R$ 48.187.514,76
	2060	48	R$ 215.000,00	R$ 63.575.000,00	R$ 70.772,50	R$ 55.577.743,13	R$ 59.658.141,66	R$ 51.595.235,76	R$ 48.190.464,39
	2061	49	R$ 215.000,00	R$ 63.790.000,00	R$ 69.046,34	R$ 55.646.789,46	R$ 59.794.178,10	R$ 51.618.025,05	R$ 48.193.145,87
	2062	50	R$ 215.000,00	R$ 64.005.000,00	R$ 67.362,28	R$ 55.714.151,75	R$ 59.928.867,65	R$ 51.639.729,13	R$ 48.195.583,58
	2063	51	R$ 2.180.000,00	R$ 66.185.000,00	R$ 666.363,12	R$ 56.380.514,87	R$ 61.281.035,33	R$ 51.849.318,93	R$ 48.218.053,82
	2064	52	R$ 215.000,00	R$ 66.400.000,00	R$ 64.116,39	R$ 56.444.631,26	R$ 61.413.070,96	R$ 51.869.005,17	R$ 48.220.068,46
	2065	53	R$ 215.000,00	R$ 66.615.000,00	R$ 62.552,57	R$ 56.507.183,83	R$ 61.543.799,31	R$ 51.887.753,97	R$ 48.221.899,95
		Total initial		R$ 43.000.000,00		R$ 44.338.778,13			
		Total recurrent		R$ 22.325.000,00		R$ 12.168.405,71			
		Total		R$ 65.325.000,00		R$ 56.507.183,83	R$ 61.543.799,31	R$ 51.887.753,97	R$ 48.221.899,95

Table 52 Costs Alternative 2

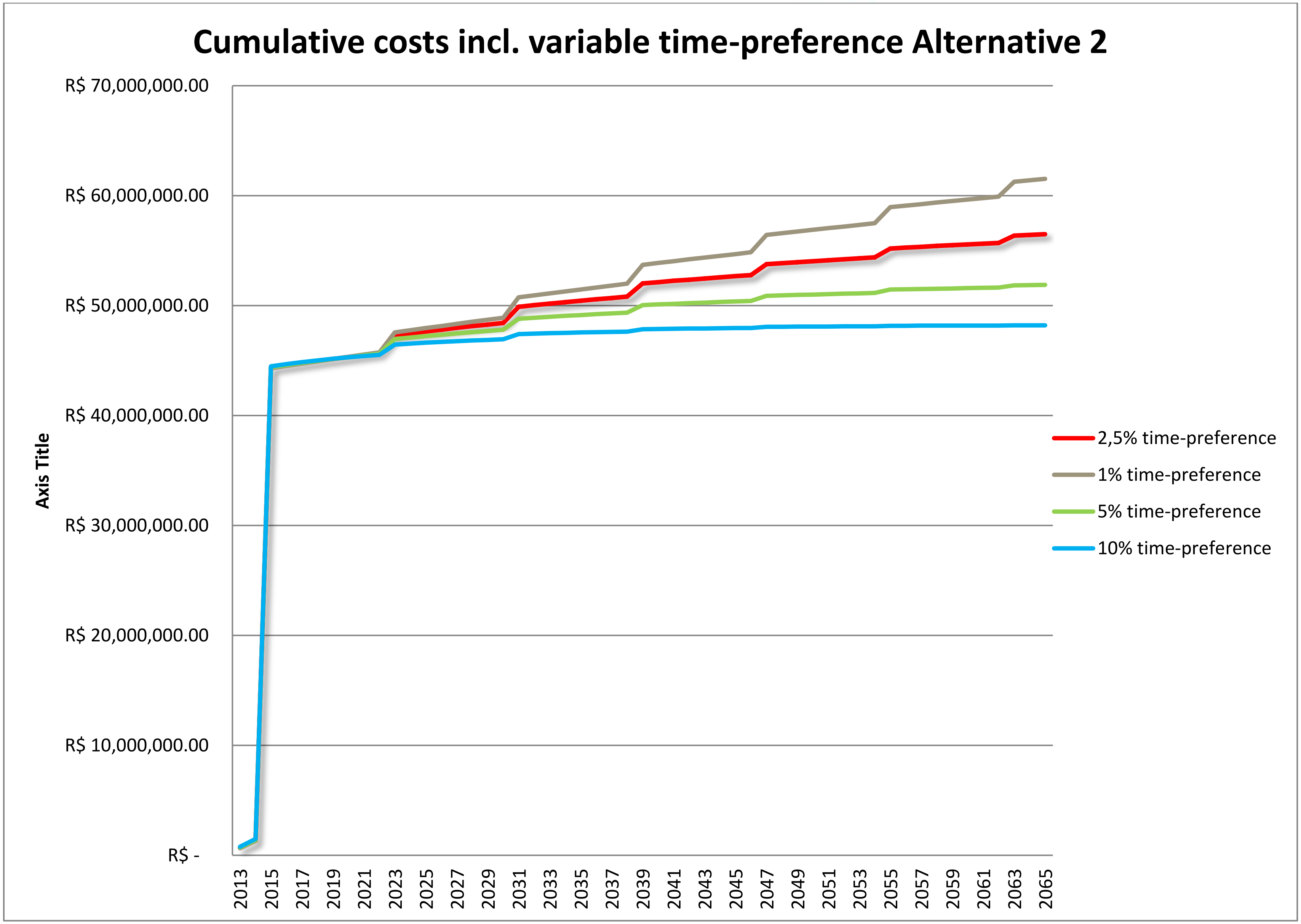

Figure 75 Graph of costs development for Alternative 2

1.10 Summary

The total costs of the different alternatives have been put beneath one another in Table 53.

alternative	Costs
Alternative 0	R$ 0
Alternative 1	R$ 32.500.000
Alternative 2	R$ 56.500.000

Table 53 Costs incl. time-preference for the alternatives for the given time horizon

Clearly is visible that Alternative 0 is the most economic option, where nothing is done. The most expensive one is Alternative 2.

The high costs of Alternative 2 can be appointed mainly to the high initial costs. One would expect that even though this alternative has high initial costs, this would even out and even be cheaper in comparison to Alternative 1, especially for the high time-preference rates. Alternative 1 makes use of more recurrent nourishments, costing a lot of money especially in the later stages of the project. However, one factor that is not regarded in this way of thinking are the costs for designing and maintenance. These are annual costs and are a percentage of the initial costs. So, if it is planned to construct many structures initially, this automatically influences the costs of the alternative annually. These annual costs do influence the costs a lot, again, especially in the later stages of the project.

Appendix R Expenditures Model Detailed

Here the detailed costs of the chosen alternative are further elaborated. The main difference from the previous calculation is that there is now more information about the construction techniques, the ships that will be used and there is a detailed planning of all of the works. The project consists of initial costs (the initial execution) and costs over time (re-nourishment execution).

The same assumptions, time-preference rates, pricing date and time horizon is used for the evaluation of the detailed costs. For these values, see Appendix Q Expenditures Model Alternatives.

1.1 Initial and recurrent costs

The initial execution cost with belonging processes have been given in Initial execution costs Table 54. These costs have been expanded into different aspects of the execution.

For each aspect different key figures are used (Van Oord, 2011). These are explained below and the values are given in Table 54.

Hopper

The costs for the hopper need to be divided into different parts. The first are the mobilization costs, which are the costs to get the hopper crewed up and ready to perform activities. Vice versa the demobilization costs are the costs to demobilize the hopper. The third costs are the rent of the hopper itself.

Pumping station

Since the nourishment is done by pumping the sand onshore from an offshore location, pumping stations are needed to perform this action. For this is calculated that 3 booster stations are needed (see Appendix P Planning)

Bulldozers, labor and site supplies

After the sand is deposited onto the shore, it can be spread on the beach. For this process bulldozer and scrapers will be us. The labor costs and site supplies are self-explanatory.

Profit + risk, finance & administration, tax

These costs account for the profit of the contractor as well as some costs reserved for anything unanticipated, the risk costs. Apart from this, the costs for administration and financial team are added. Due to the high tax rates in Brazil, the costs for tax are relatively high.

Task	Comments	Cost/wk (€)	Cost/wk (R$)	Time (weeks)		Total cost	Relative
Laying Land lines	2,8 km required					R$ 2.587.500	11.21%
Laying Sinker lines	2,5 km required					R$ 375.000	1.63%
Mobilization costs hopper	-	€ 1.300.000	R$ 2.990.000	1		R$ 2.990.000	12.96%
Demobilization costs hopper	-	€ 1.500.000	R$ 3.450.000	1		R$ 3.450.000	14.95%
Renting hopper	-	€ 650.000	R$ 1.495.000	5		R$ 7.475.000	32.40%
Renting linking ship	-	€ 65.000	R$ 149.500	5		R$ 747.500	3.24%
Renting pumping station (booster station III)	3 booster stations required to pump an additional 2,3 km	€ 225.000	R$ 517.500	5		R$ 2.587.500	11.21%
Renting pipesystem	landlines 1000 m = € 5000 /wk; sinkerlines 2000 m = 20000 euro	€ 39.000	R$ 89.700	6		R$ 538.200	2.33%
Renting Bulldozers & Scrapers	Bulldozers & Scrapers	€ 45.000	R$ 103.500	5		R$ 517.500	2.24%
Site Office	Management etc	€ 24.000	R$ 55.200	5		R$ 276.000	1.20%
Renting nourish-labor	-	€ 50.000	R$ 115.000	5		R$ 575.000	2.49%
Staff survey	-	€ 60.000	R$ 138.000	5		R$ 690.000	2.99%
Wear and tear damage		115000	264500			R$ 264.500	1.15%
Profit + Risk	15%						
Finance	2%						
General expenses	5%						
Escalate	2%						
TAX	26%	+					
	50%						
Estimated Unit Price per m3 nourishment According to CPE							
Calculated Unit Price per m3 nourishment							
					Direct Costs	R$ 23.073.700	
					Indirect Costs	R$ 7.516.983	
					Costs unit price	R$ 26.600.59393	
					Total Costs	R$ 30.590.683	
					Total Costs	€13.300.297	

Table 54: Initial execution costs

Task	Comments	Cost/wk (€)	Cost/wk (R$)	Time (weeks)		Total cost	Relative
Laying land lines	-					R$ 1.035.000	5.04%
Laying Sinker lines							
Mobilization costs hopper	-	€ 1.300.000	R$ 2.990.000	1		R$ 2.990.000	14.56%
Demobilization costs hopper	-	€ 1.500.000	R$ 3.450.000	1		R$ 3.450.000	16.80%
Renting hopper	-	€ 650.000	R$ 1.495.000	2		R$ 2.990.000	14.56%
Renting linking ship (4 weeks)	-	€ 65.000	R$ 149.500	2		R$ 299.000	1.46%
Renting pumping station (booster station III) (4 weeks)	Every 1000 m pipe: € 75000/wk; (2.5 km + 2.8km)*75000= €397,500 /wk	€ 397.500	R$ 914.250	2		R$ 1.828.500	8.90%
Renting pipesystem (5 weeks)	1000 m = € 5000 /wk; 5300 m = € 26,500 /wk	€ 26.500	R$ 60.950	3		R$ 182.850	0.89%
Renting Bulldozer (4 weeks)	2007 CAT D6K XL = € 1500 /wk; 3 x bulldozers = € 4500 /wk	€ 4.500	R$ 10.350	2		R$ 20.700	0.10%
Renting Scraper (4 weeks)	1999 CAT 615C = € 3000 /wk ; 3 x scrapers = € 9000 /wk	€ 9.000	R$ 20.700	2		R$ 41.400	0.20%
Renting nourish-labor (5 weeks)	-	€ 50.000	R$ 115.000	3		R$ 345.000	1.68%
Staff survey (5 weeks)	-	€ 60.000	R$ 138.000	3		R$ 414.000	2.02%
Wear and tear damage (5 weeks)	€ 0.10 /m3; 405,000 m3 = € 40,500					R$ 93.150	0.45%
Profit + Risk	15%						
Finance	2%						
Escalate	5%						
TAX	2%	+					
	26%						
	50%					R$ 51	
						R$ 20.534.400	
						€8.928.000	

Table 55 Recurrent nourishment costs

Evaluation of the numbers (Table 54 & Table 55)

The relative influence of each cost on the total costs is also expressed in Table 54. This provides a well insight into which aspects influence the costs mostly. It can be observed that *Renting the hopper* amounts to almost one third of all the costs. So when designing and planning the execution of the building works, it is important to keep the nourishment time minimal and work as efficiently as possible. The nourishment time has already been optimized here, like explained in the planning (see Appendix P Planning).

Another important point of interest is the cost per unit value. One can see that for the initial nourishment the total costs per cubic meter of sand is R$ **26,60**.
This calculation is also made for the recurrent nourishment, for which the value is R$ **51.** This high number can be explained as follows:
The ship that is used is a large ship and the costs for this are high. Especially the mobilization costs for such a ship add up greatly to the total costs. It is true that the amount of sand that needs to be nourished is much smaller than the initial stage; however one still needs to mobilize such a ship. So these cost a constant for each operation, regardless of the amount of nourishment

This number is very high and it is practically unfeasible to do a project based upon this. So a recommendation can be made already in this stage of the expenditures model:
When re-nourishing, nourish as many areas as possible. So don't only re-nourish Boa Viagem, but also do nourish Fortim, Casa Caiada and Janga together.

Comparison with CPE
This number is slightly higher than the number posed in the CPE, which is R$ **25** (CPE, 2011). This can have several reasons, of which the most important are put here:

- The key figures used in the CPE are based upon other numbers. Which key figures are used is not known, since these are not available.
- The CPE has no made no possible project execution plan, i.e. building method. Because one cannot build with ordinary techniques, these costs are more than regular. It could be that the CPE didn't account for this.

year	project year	Design costs	Initial nourishment	Recurrent nourishment		Totaal
2013	1	R$ 458.860.25				R$ 458.860.25
2014	2	R$ 458.860.25				R$ 458.860.25
2015	3		R$ 30.590.683.01			R$ 30.590.683.01
2016	4					R$ 0.00
2017	5					R$ 0.00
2018	6					R$ 0.00
2019	7					R$ 0.00
2020	8			R$ 20.534.400.00		R$ 20.534.400.00
2021	9					R$ 0.00
2022	10					R$ 0.00
2023	11					R$ 0.00
2024	12					R$ 0.00
2025	13			R$ 20.534.400.00		R$ 20.534.400.00
2026	14					R$ 0.00
2027	15					R$ 0.00
2028	16					R$ 0.00
2029	17					R$ 0.00
2030	18			R$ 20.534.400.00		R$ 20.534.400.00
2031	19					R$ 0.00
2032	20					R$ 0.00
2033	21					R$ 0.00
2034	22					R$ 0.00
2035	23			R$ 20.534.400.00		R$ 20.534.400.00
2036	24					R$ 0.00
2037	25					R$ 0.00
2038	26					R$ 0.00
2039	27					R$ 0.00
2040	28			R$ 20.534.400.00		R$ 20.534.400.00
2041	29					R$ 0.00
2042	30					R$ 0.00
2043	31					R$ 0.00
2044	32					R$ 0.00
2045	33			R$ 20.534.400.00		R$ 20.534.400.00
2046	34					R$ 0.00
2047	35					R$ 0.00
2048	36					R$ 0.00
2049	37					R$ 0.00
2050	38			R$ 20.534.400.00		R$ 20.534.400.00
2051	39					R$ 0.00
2052	40					R$ 0.00
2053	41					R$ 0.00
2054	42					R$ 0.00
2055	43			R$ 20.534.400.00		R$ 20.534.400.00
2056	44					R$ 0.00
2057	45					R$ 0.00
2058	46					R$ 0.00
2059	47					R$ 0.00
2060	48			R$ 20.534.400.00		R$ 20.534.400.00
2061	49					R$ 0.00
2062	50					R$ 0.00
2063	51					R$ 0.00
2064	52					R$ 0.00
2065	53			R$ 20.534.400.00		R$ 20.534.400.00
						R$ 0.00
	Totaal	R$ 917.720.49	R$ 30.590.683.01	R$ 205.344.000.00	R$ 0.00	R$ 236.852.403.50

Table 56 Costs divided into aspects

In Table 56 the costs along the entire project are put, without looking into the effect of time on the costs (the effect of the time-preference rate). This table is therefore only created to see when the costs are made. In Table 57 this effect is taken into account and one can see the development of the costs in time during the entire duration of the project.

1.2 Total costs

The total costs development in time is represented in Table 57. Here can be seen how the costs develop in time during the entire project duration. This is better shown in Figure 76 which is plotted for different time-preference rates.

The costs are plotted for different time-preference rates in order to see the effect of a constantly changing economy on this project. If this picture is not available, it could happen that the costs turn out very different in i.e. 40 years from now. This puts the project in danger, since this unaccounted money has to come from somewhere. This report will use the time-preference rate of 2,5% as a constant for the entire project duration.

The project starts in 2013 with the designing phase. This phase will take 2 years after which the building phase starts in 2015. This is also the pricing date of all the costs for the project (see Appendix Q Expenditures Model Alternatives). The costs for the design phase are about R$ **450.000** per year, R$ **900.000** total.

What can be seen is that the total project costs for this rate are R$ **142.500.000.** These can be divided into:

- R$ **31.500.000** of initial investment
- R$ **111.000.000** of recurrent investment, consisting of 10 re-nourishments of each costing R$ **20.500.000.** Including the effect of time on money, this number adds up to the total costs of recurrent nourishments.

Explanation of the high costs relative to the primary costs calculation
In the alternative phase, the costs for nourishing the area are calculated using a key figure which is regularly used in the initial phase. With this calculation, the total costs were calculated to be R$ **32.500.000**.
For the detailed design this number is calculated to be R$ **142.500.000.** This difference is huge and needs some explanation.

The costs for the detailed design are staggering and can be appointed largely to the costs of the recurrent nourishments. Like explained in the chapter before, these recurrent nourishments costs are not feasible for such a low amount of nourishment. Instead, the re-nourishments will have to be done for the complete metropolitan area.
This is however beyond the scope of this project, which is only looking at Boa Viagem in detail.

Alternative 1					Time-preference	2.5%	1.0%	5.0%	10.0%
	year	year of project	Expenditures	Cumulative costs without time-preference	Expenditure incl. time-preference	Cumulative balance with time-preference	Cumulative balance with time-preference	Cumulative balance with time-preference	Cumulative balance with time-preference
Start design phase	2013	1	R$ 458.860.25	R$ 458.860.25	R$ 482.090.05	R$ 482.090.05	R$ 468.083.34	R$ 505.893.42	R$ 555.220.90
	2014	2	R$ 458.860.25	R$ 917.720.49	R$ 470.331.75	R$ 952.421.80	R$ 931.532.18	R$ 987.696.68	R$ 1.059.967.17
Start building phase	2015	3	R$ 30.590.683.01	R$ 31.508.403.50	R$ 30.590.683.01	R$ 31.543.104.81	R$ 31.522.215.20	R$ 31.578.379.69	R$ 31.650.650.18
Start exploitation phase	2016	4	R$ -	R$ 31.508.403.50	R$ -	R$ 31.543.104.81	R$ 31.522.215.20	R$ 31.578.379.69	R$ 31.650.650.18
	2017	5	R$ -	R$ 31.508.403.50	R$ -	R$ 31.543.104.81	R$ 31.522.215.20	R$ 31.578.379.69	R$ 31.650.650.18
	2018	6	R$ -	R$ 31.508.403.50	R$ -	R$ 31.543.104.81	R$ 31.522.215.20	R$ 31.578.379.69	R$ 31.650.650.18
	2019	7	R$ -	R$ 31.508.403.50	R$ -	R$ 31.543.104.81	R$ 31.522.215.20	R$ 31.578.379.69	R$ 31.650.650.18
	2020	8	R$ 20.534.400.00	R$ 52.042.803.50	R$ 18.149.417.48	R$ 49.692.522.29	R$ 51.059.992.21	R$ 47.667.619.40	R$ 44.400.897.00
	2021	9	R$ -	R$ 52.042.803.50	R$ -	R$ 49.692.522.29	R$ 51.059.992.21	R$ 47.667.619.40	R$ 44.400.897.00
	2022	10	R$ -	R$ 52.042.803.50	R$ -	R$ 49.692.522.29	R$ 51.059.992.21	R$ 47.667.619.40	R$ 44.400.897.00
	2023	11	R$ -	R$ 52.042.803.50	R$ -	R$ 49.692.522.29	R$ 51.059.992.21	R$ 47.667.619.40	R$ 44.400.897.00
	2024	12	R$ -	R$ 52.042.803.50	R$ -	R$ 49.692.522.29	R$ 51.059.992.21	R$ 47.667.619.40	R$ 44.400.897.00
	2025	13	R$ 20.534.400.00	R$ 72.577.203.50	R$ 16.041.440.46	R$ 65.733.962.75	R$ 69.649.516.66	R$ 60.273.959.72	R$ 52.317.797.12
	2026	14	R$ -	R$ 72.577.203.50	R$ -	R$ 65.733.962.75	R$ 69.649.516.66	R$ 60.273.959.72	R$ 52.317.797.12
	2027	15	R$ -	R$ 72.577.203.50	R$ -	R$ 65.733.962.75	R$ 69.649.516.66	R$ 60.273.959.72	R$ 52.317.797.12
	2028	16	R$ -	R$ 72.577.203.50	R$ -	R$ 65.733.962.75	R$ 69.649.516.66	R$ 60.273.959.72	R$ 52.317.797.12
	2029	17	R$ -	R$ 72.577.203.50	R$ -	R$ 65.733.962.75	R$ 69.649.516.66	R$ 60.273.959.72	R$ 52.317.797.12
	2030	18	R$ 20.534.400.00	R$ 93.111.603.50	R$ 14.178.295.93	R$ 79.912.258.68	R$ 87.336.811.31	R$ 70.151.357.22	R$ 57.233.569.22
	2031	19	R$ -	R$ 93.111.603.50	R$ -	R$ 79.912.258.68	R$ 87.336.811.31	R$ 70.151.357.22	R$ 57.233.569.22
	2032	20	R$ -	R$ 93.111.603.50	R$ -	R$ 79.912.258.68	R$ 87.336.811.31	R$ 70.151.357.22	R$ 57.233.569.22
	2033	21	R$ -	R$ 93.111.603.50	R$ -	R$ 79.912.258.68	R$ 87.336.811.31	R$ 70.151.357.22	R$ 57.233.569.22
	2034	22	R$ -	R$ 93.111.603.50	R$ -	R$ 79.912.258.68	R$ 87.336.811.31	R$ 70.151.357.22	R$ 57.233.569.22
	2035	23	R$ 20.534.400.00	R$ 113.646.003.50	R$ 12.531.547.65	R$ 92.443.806.33	R$ 104.165.665.28	R$ 77.890.556.61	R$ 60.285.876.93
	2036	24	R$ -	R$ 113.646.003.50	R$ -	R$ 92.443.806.33	R$ 104.165.665.28	R$ 77.890.556.61	R$ 60.285.876.93
	2037	25	R$ -	R$ 113.646.003.50	R$ -	R$ 92.443.806.33	R$ 104.165.665.28	R$ 77.890.556.61	R$ 60.285.876.93
	2038	26	R$ -	R$ 113.646.003.50	R$ -	R$ 92.443.806.33	R$ 104.165.665.28	R$ 77.890.556.61	R$ 60.285.876.93
	2039	27	R$ -	R$ 113.646.003.50	R$ -	R$ 92.443.806.33	R$ 104.165.665.28	R$ 77.890.556.61	R$ 60.285.876.93
	2040	28	R$ 20.534.400.00	R$ 134.180.403.50	R$ 11.076.062.12	R$ 103.519.868.45	R$ 120.177.742.40	R$ 83.954.421.85	R$ 62.181.119.88
	2041	29	R$ -	R$ 134.180.403.50	R$ -	R$ 103.519.868.45	R$ 120.177.742.40	R$ 83.954.421.85	R$ 62.181.119.88
	2042	30	R$ -	R$ 134.180.403.50	R$ -	R$ 103.519.868.45	R$ 120.177.742.40	R$ 83.954.421.85	R$ 62.181.119.88
	2043	31	R$ -	R$ 134.180.403.50	R$ -	R$ 103.519.868.45	R$ 120.177.742.40	R$ 83.954.421.85	R$ 62.181.119.88
	2044	32	R$ -	R$ 134.180.403.50	R$ -	R$ 103.519.868.45	R$ 120.177.742.40	R$ 83.954.421.85	R$ 62.181.119.88
	2045	33	R$ 20.534.400.00	R$ 154.714.803.50	R$ 9.789.624.99	R$ 113.309.493.45	R$ 135.412.684.36	R$ 88.705.618.93	R$ 63.357.916.63
	2046	34	R$ -	R$ 154.714.803.50	R$ -	R$ 113.309.493.45	R$ 135.412.684.36	R$ 88.705.618.93	R$ 63.357.916.63
	2047	35	R$ -	R$ 154.714.803.50	R$ -	R$ 113.309.493.45	R$ 135.412.684.36	R$ 88.705.618.93	R$ 63.357.916.63
	2048	36	R$ -	R$ 154.714.803.50	R$ -	R$ 113.309.493.45	R$ 135.412.684.36	R$ 88.705.618.93	R$ 63.357.916.63
	2049	37	R$ -	R$ 154.714.803.50	R$ -	R$ 113.309.493.45	R$ 135.412.684.36	R$ 88.705.618.93	R$ 63.357.916.63
	2050	38	R$ 20.534.400.00	R$ 175.249.203.50	R$ 8.652.602.03	R$ 121.962.095.47	R$ 149.908.208.89	R$ 92.428.306.17	R$ 64.088.614.83
	2051	39	R$ -	R$ 175.249.203.50	R$ -	R$ 121.962.095.47	R$ 149.908.208.89	R$ 92.428.306.17	R$ 64.088.614.83
	2052	40	R$ -	R$ 175.249.203.50	R$ -	R$ 121.962.095.47	R$ 149.908.208.89	R$ 92.428.306.17	R$ 64.088.614.83
	2053	41	R$ -	R$ 175.249.203.50	R$ -	R$ 121.962.095.47	R$ 149.908.208.89	R$ 92.428.306.17	R$ 64.088.614.83
	2054	42	R$ -	R$ 175.249.203.50	R$ -	R$ 121.962.095.47	R$ 149.908.208.89	R$ 92.428.306.17	R$ 64.088.614.83
	2055	43	R$ 20.534.400.00	R$ 195.783.603.50	R$ 7.647.639.40	R$ 129.609.734.87	R$ 163.700.203.11	R$ 95.345.129.03	R$ 64.542.320.93
	2056	44	R$ -	R$ 195.783.603.50	R$ -	R$ 129.609.734.87	R$ 163.700.203.11	R$ 95.345.129.03	R$ 64.542.320.93
	2057	45	R$ -	R$ 195.783.603.50	R$ -	R$ 129.609.734.87	R$ 163.700.203.11	R$ 95.345.129.03	R$ 64.542.320.93
	2058	46	R$ -	R$ 195.783.603.50	R$ -	R$ 129.609.734.87	R$ 163.700.203.11	R$ 95.345.129.03	R$ 64.542.320.93
	2059	47	R$ -	R$ 195.783.603.50	R$ -	R$ 129.609.734.87	R$ 163.700.203.11	R$ 95.345.129.03	R$ 64.542.320.93
	2060	48	R$ 20.534.400.00	R$ 216.318.003.50	R$ 6.759.398.87	R$ 136.369.133.75	R$ 176.822.812.37	R$ 97.630.536.06	R$ 64.824.036.71
	2061	49	R$ -	R$ 216.318.003.50	R$ -	R$ 136.369.133.75	R$ 176.822.812.37	R$ 97.630.536.06	R$ 64.824.036.71
	2062	50	R$ -	R$ 216.318.003.50	R$ -	R$ 136.369.133.75	R$ 176.822.812.37	R$ 97.630.536.06	R$ 64.824.036.71
	2063	51	R$ -	R$ 216.318.003.50	R$ -	R$ 136.369.133.75	R$ 176.822.812.37	R$ 97.630.536.06	R$ 64.824.036.71
	2064	52	R$ -	R$ 216.318.003.50	R$ -	R$ 136.369.133.75	R$ 176.822.812.37	R$ 97.630.536.06	R$ 64.824.036.71
	2065	53	R$ 20.534.400.00	R$ 236.852.403.50	R$ 5.974.323.68	R$ 142.343.457.42	R$ 189.308.524.81	R$ 99.421.212.27	R$ 64.998.960.05
		Total initial		R$ 30.590.683.01		R$ 31.543.104.81			
		Total recurrent		R$ 205.344.000.00		R$ 110.800.352.61			
		Total		R$ 235.934.683.01		R$ 142.343.457.42	R$ 189.308.524.81	R$ 99.421.212.27	R$ 64.998.960.05

Table 57 Total costs for Alternative 1

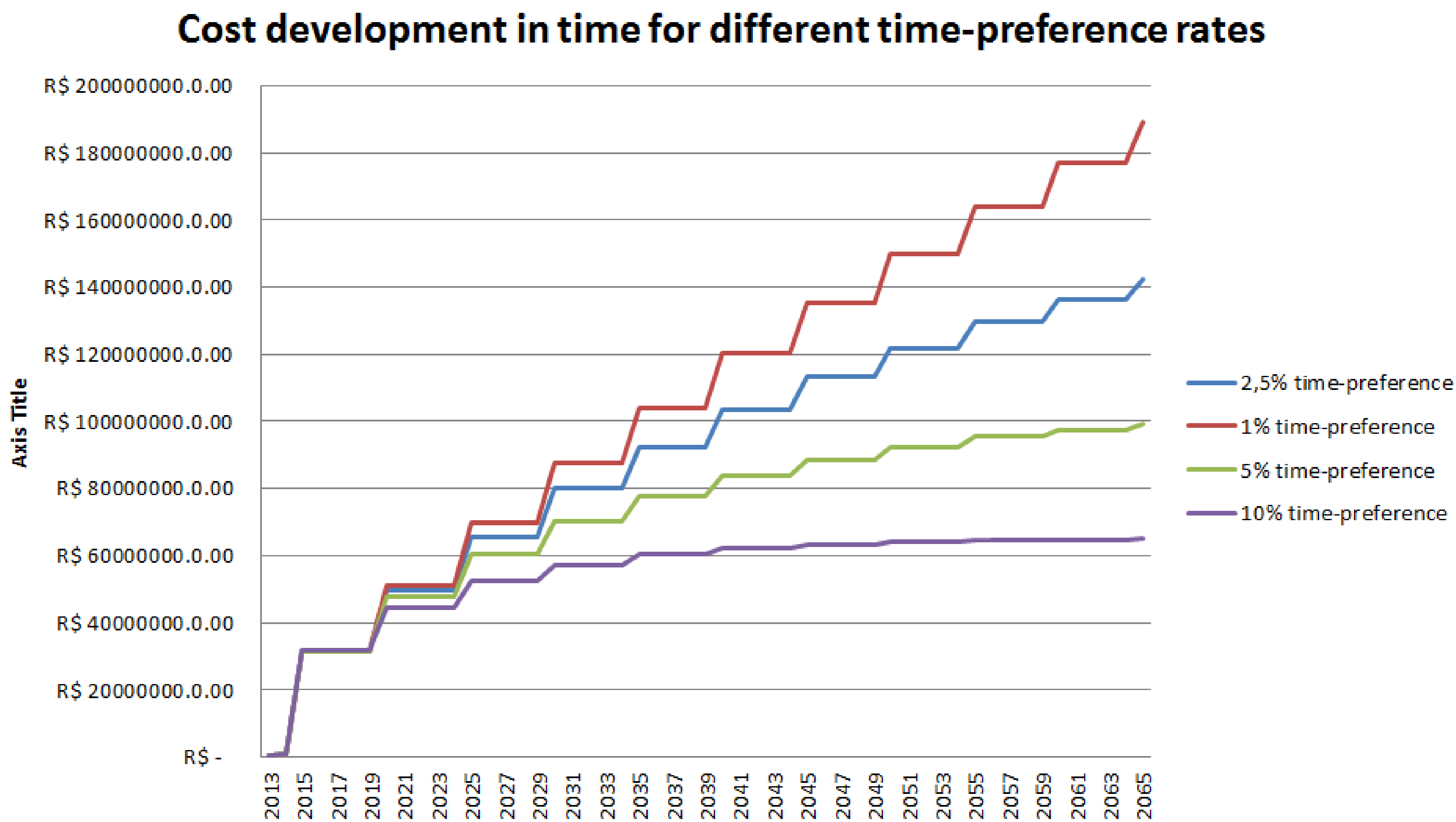

Figure 76 Cost development of Alternative in time for different time-preference rates

List of figures

List of Tables