UMHLANGA ROCKS COASTAL DEFENSE

The sustainable coastline of the future

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Preface

This report presents the results of a Multi-disciplinary project, as a master course for students from Delft University of Technology in the Netherlands. The main purpose of the project is to give students the chance to gain knowledge and experience from different disciplines, during their stay abroad. Because of the different viewpoints taken, a complex problem is addressed fully, providing solutions, which suit the area and are socially accepted. The group of this project consists of two MSc Coastal Engineering students, two MSc Structural Engineers and two students from the Construction Management & Engineering's master's degree. The project has been executed in a period of 2 months, starting from the 1st September 2014 to 31st October 2014. When accomplished with sufficient result it provides each student with 10 ECTS.

The multidisciplinary project of this research concentrated on the coastal erosion problem in Umhlanga Rocks in the province of Kwazulu-Natal, South Africa. The project is made possible through ir. Henk Jan Verhagen from Costal engineering at TU Delft and his close relations with eThekwini Municipality in Durban, South Africa.

Firstly, we would like to express our sincere gratitude to Clinton Chrystal for his shared knowledge and supervision during the research project. At the same time we would like to thank Godfrey Vella for having us at eThekwini Municipality and giving us this chance of a lifetime.

Last but not least we would like to thank our main supervisors ir. H.J. Verhagen, ir. A.J.M. Schmets and Drs.ir. J.G.Verlaan for their expert judgement and supervision during the project. Thanks to prof. Derek Stretch from Kwazulu-Natal University, Talia Feigenbaum from Urban-Econ, Peter Rose from Umhlanga Tourist Information and Brian Wright from Umhlanga UIP for finding time in their busy agenda's for meeting us and providing us with different perspectives on the problem. Furthermore we would like to tank to Tandi Breetzka and Royal HaskoningDHV for their corporation and financial support.

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Summary

The eThekwini coastline is a vulnerable coastline subject to chronic erosion and damage due to sea level rise. In 2007 a severe storm caused major physical and economic damage along the coastline, proving the need for action. Umhlanga Rocks is a densely populated premium holiday destination on the eThekwini coastline suffering from similar problems due to its narrow beaches and lack of dunes in certain places. Interference with the coast of Umhlanga can entice fierce resistance from different groups of stakeholders, which makes finding a suitable solution more difficult. The above leads to the following problem definition:

Due to erosion and extreme weather conditions the coastline of Umhlanga Rocks is shifting on shore, causing narrow beaches, decrease of tourism and increased risk of failures of the coastal structures. The current situation requires a new long term safety strategy, taking into account the social, economic and environmental vitality of the Umhlanga Rocks area as well.

To solve the problem definition the main question states:

How can the eThekwini municipality create a sustainable Umhlanga coastline while adding value to the area?

To answer the main question many different elements, varying from conventional coastal protection measures to experimental ideas that would increase local business, were formulated during a brainstorm session. These elements are ranked on their cost, added value and technological feasibility. From the highest ranked elements in each category 11 different alternatives are created. By performing a multi criteria analysis these 11 alternatives are narrowed down to three alternatives and an additional `do nothing' option is included. This gives the following 4 possible alternatives:

- Do nothing
- Bar retaining sill
- Nourishment
- Submerged breakwater

All these options are designed up to preliminary design level. This includes a stakeholder analysis, net present value calculation (over 50 years), structural design and a Delft3d model.

The do nothing option assumes that the beach will be completely gone in 30-40 years. It is further assumed Umhlanga Rocks recreational businesses are coupled to the beach and property values will drop by 12% once the beach is gone. This gives a NPV of R.15,000,000,000.

It is suspected that the equilibrium that normally exists in the cross shore sediment transport is disturbed and more sediment moves offshore than onshore. The sill is designed to prevent the sediment form moving too far offshore and thus to create a new equilibrium. The bar retaining sill consists of prefab concrete elements located just outside the surf zone. From the Delft3D model it followed that the beach stays roughly the same size after construction of the sill. The NPV bases the

cost of the sill on reference projects. With the beach maintaining its current size the total NPV amounts to R.116,000,000,000.

The nourishment option adds enough sand to the beach to compensate for erosion and add 15 meters of beach according to the Delft3D model. It is assumed the nearby sand depot can be used to perform the nourishment. The nourishment itself will be done using a dredger connected to a floating pipeline to pump the sand to the beach. Shovels will be used to divide the sand over the beach area. The cost of the nourishment is based on the cost of a similar project, with the benefit of the added beach area the total NPV is R.142,000,000,000.

The submerged breakwater creates a calmer wave climate near the coast and will thereby reduce erosion and increase beach growth. The Delft3D model suggests an average beach growth of 20 meters. For the breakwater design different materials are considered. Geotextile systems look very promising and have several advantages over a rock or concrete breakwater. A design with geotextile bags and one with geotextile tubes is made for the Umhlanga Rocks area. The NPV of the breakwater amounts to R.131,000,000,000.

A second multi criteria analysis is performed to determine the overall best option. According to this analysis the construction of a submerged breakwater made of geotextile tubes provides the best solution to the problem from social and technical preferences. Social preferences include perceptions of stakeholders involved like environmental groups and property owners, but take the construction and maintenance costs of the alternative into account as well. In this case the geotextile tube breakwater uses conforming materials, does not cause any visual horizon pollution and seems to deliver the best benefits for the price involved. At the same time the results from the 3D simulations have shown that the breakwater is able to perform well on the technical preferences including the breakage of waves offshore and increase of beach width.

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1 Introduction

1.1 Problem definition

The eThekwini coast has a mean CVI (coastal vulnerability Index) of 21, resulting in the coast being categorised as high risk. This section of the coast is considered to be vulnerable to erosion and damage through sea level rise. This vulnerability is the result of low beach width (48m mean), dune width (5m mean) and a lack of vegetation behind the back beach. This results in 51% of the coastline being defined as moderate risk and 49% as high risk (Oceanographic Research Institute, 2011, p.1). The necessity for action was further proven by a severe storm in 2007 that caused major physical and economic damage along the coast of eThekwini. Over the last few years different storm events have contributed to a fast changing coast line in the area of eThekwini. This process not only directly affects the coast itself, but also indirectly affects the activities in the surrounding areas. Umhlanga Rocks is a densely populated premium holiday destination on the eThekwini coastline that is already suffering from similar problems due to its narrow beaches and lack of dunes in certain places.

Interference with the coast of Umhlanga can entice fierce resistance from different user groups. In fact such user groups have blocked earlier investigation into measures like a tidal pool to protect the beach. Besides concerns with the pressure on the infrastructure, that improved swimming conditions could bring, concerns vary from over crowdedness to loss of high-end appeal and environmental concerns. The rocky outcrops of Umhlanga are a nursing ground for a multitude of fish species and the rocks are a key visual reminder of the regions name. Obstruction of views, severe alterations of the beach's usefulness and/or alterations to the region's ecological functions will likely foster concerns with important stakeholders. Umhlanga Rocks will continue to experience the threat in the coming years. The area is exposed to erosion that narrows the beaches further and decreases the value of the area. The problem definition therefore states:

Due to erosion and extreme weather conditions the coastline of Umhlanga Rocks is shifting on shore, causing narrow beaches, decrease of tourism and increased risk of failures of the coastal structures. The current situation requires a new long-term safety strategy, taking into account the social, economic and environmental vitality of the Umhlanga Rocks area as well.

1.2 Research question

Answering the following main and sub questions solves the problem.

How can the eThekwini municipality create a sustainable Umhlanga coastline while adding value to the area?

When evaluating the sustainability of the coastline more attention is devoted to the social and economic aspects, while aspiring to a solution that is most equitable. To obtain a sustainable coastline the following criteria are considered.

From a financial point of view the technical costs for the whole lifetime of the project should be bearable by the municipality. From a technical point of view the design should comply with the applicable design codes and a certain amount of robustness is preferred. To minimize the risk it is important to take into account the uncertainties of the future. When a high risk of failure of the project is discovered, the solution is considered to be not sustainable. A lower risk means a higher sustainability.

To add value to the area the total sum of the criteria listed below will be considered: economic, financial, social, ecological, aesthetics and export-potential. These criteria will have different weight factors when the added value is calculated.

To answer the main question the following sub questions are answered first:

What is required to make the Umhlanga coastline sustainable?

What are the possible solutions that fulfil the requirements?

How do these solutions add value?

What solutions best fulfil the social and technical preferences?

1.3 Principles, goals and objectives

To come up with a sustainable solution for the current and possible future problems in the Umhlanga Rocks area the principles of eThekwini municipality are followed. The principles are based on an approach, which takes from the 'designing with coastal processes and ecosystems, and not against them' perspective (Department of Environmental Affairs and Tourism CSIR, 2000, p.58) for a solution that takes in mind the integral, innovative and sustainable approach that will also respect the area's social economic value. The main goal of the project is to provide a sustainable solution for the coastal problems at Umhlanga Rocks with as much added value to the area as possible. The goal should be achieved using the following objectives (Department of Environmental Affairs and Tourism CSIR, 2000, p.60):

- Providing and maintaining a beach for the tourists and inhabitants of the area
- Providing sufficient protection against erosion and storm surges
- Preserving the economic activities of Umhlanga Rocks
- Protecting indigenous flora and fauna

The eThekwini municipality has already come up with various options. However, the conflicting interests of the stakeholders involved have obstructed acceptation and implementation of these options. It can be assumed that a new solution cannot easily be integrated in the area. Therefore the aim is to find a new, innovative solution where the social aspects are highly taken into account. Thinking in and out of the box and eliminating the variants that are not suitable achieve this.

1.4 Method

In this section, the method needed for reaching the main goal and objectives of the project is discussed. The research is executed in several phases. Each phase provides an answer to a sub question.

In the analysis of the current situation the problem at hand is described together with the context in which it is situated. The main source of information is the eThekwini municipality. Secondly, a literature study, based on the current situation and on reference projects is performed. This provides a comprehensive overview of the situation, needed for a scope definition and the requirements for a sustainable coastline.

The synthesis phase starts with a stakeholder analysis. Brainstorm sessions within the team of experts and interviews with stakeholders, together with the knowledge gained from the reference projects are used as input for the search of alternatives. The alternatives are technically evaluated on a conceptual design level. After this different solutions to the problem are defined.

During the simulation phase the various alternatives are evaluated based on technical feasibility and hydraulic effects. A SWOT analysis and a Multi Criteria Analysis complete the evaluation. The end product of the simulation is a small number of alternatives generating the best value.

The evaluation phase presents the best alternative according to the research performed. These alternatives, wave conditions and sand transport and possible structural interventions are described on a design level using calculations and modeling. This phase may not generate one best solution. In this case a combination of alternatives is to be considered.

Net present value

The net present value calculates the difference between costs and benefits over time. It incorporates required returns and thus devaluation and inflation. The final NPV gives a measure for the benefits for the municipality over the course of fifty years.

The net present value is calculated as follows

$$NPV = \sum b - c \div (1 + r)^t$$

The costs of the measures are comprised of the construction costs, maintenance costs and usage costs. In the different measures proposed most costs are incorporated in standard prices. Therefore not all costs mentioned above are specified in the NPV.

Benefits

The benefits that contribute most to the overall NPV are the recreational benefits. For this report the recreational benefits are taken from a report by Urban-Econ, which used the economic impact method for ascertaining the value of the beach. These total benefits are divided by the available beach are to get a measurement of the value of available beach per m^2. This value is used to determine the recreational value of added beach. Other benefits include added property ownership rates and employment benefits.

The calculations of decrease or increase in property values are usually done through hedonic analyses (Landry et. al, 2003). This process includes reducing the value of the properties to their characteristics and comparing these to similar cases. Through regression analyses a probable change in value can be determined. In this study there is not enough time to perform this full analysis.

The value of a residential or commercial property significantly depends on the area where the property is and the conditions of this area. The value of waterfront properties is related to the beach in terms of beach width, proximity to the beach, loss of beachfront property and the beach protection (Kirkpatrick, 2012).

Fout! Verwijzingsbron niet gevonden., showing the relation between increasing property values, the distance of the property from the beach and increased beach and an average price of property of $169.110 (USD1983), together with information from Pompe and Rhinehart (1994, p. 283) is used to determine the relation between increasing beach width and property value in percentages shown in **Fout! Verwijzingsbron niet gevonden.**.1.

Distance from the beach	Increased width 21-24m	Increased width 21-30m	Increased width 21-38m
80m	3.79 %	11.47%	20.84%
508m	1.72%	5.17%	9.49%
1.19km	1.13%	3.82%	7.00%

TABLE 1.1 RELATION BETWEEN DISTANCE FROM BEACH, INCREASED BEACH WIDTH AND PROPERTY VALUE INCREASE (ADJUSTED FROM KIRKPATRICK, 2012)

In the case of Umhlanga the distance between the buildings that are part of our project area and the low water line is roughly 100 meters. Therefore the top row of percentages in table x is used, and a linear progression for beach width is used.

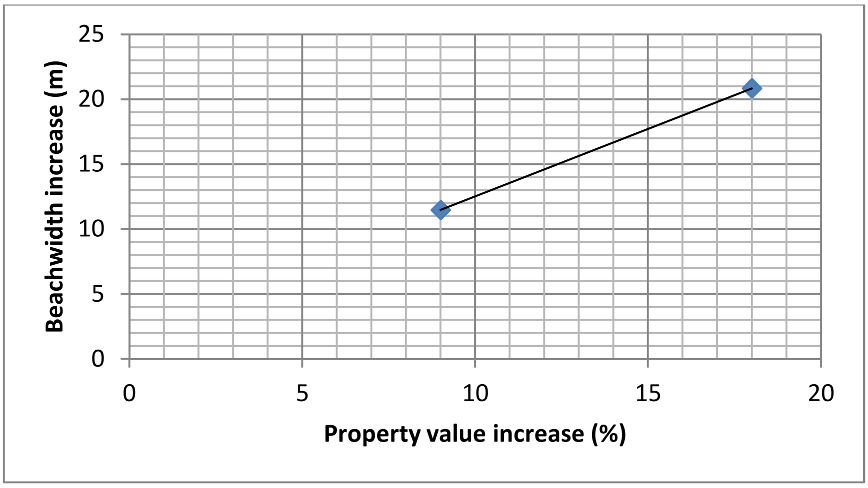

FIGURE 1.1 RELATION BETWEEN BEACH WIDTH INCREASE AND PROPERTY VALUE

Employment benefits are difficult to determine, other benefits for Umhlanga are generated through job creation and increased income. Having more space on the beach makes it possible to build new facilities like restaurants and hotels and create a busier environment where jobs are created. Since South African unemployment rate is 25% (Trading Economics, 2014) added benefits from job creation could be substantial.

The actual benefits of added jobs are very hard to determine. Labour-based construction (Watermeyer, 1993) states that in the case of community based construction retention of construction costs could vary between 37 and 50 % (Watermeyer, 1993). In this case, retention is the transfer of funds from construction costs to benefits. The correct percentage is unknown because, as said in labor costs that coastal engineering is differently treated, especially coastal engineering.

Coastal engineering is however a specialist job, the case with job creation in a field that requires expertise is that mostly jobs are shifted from one location to another. This means that jobs added do not contribute as benefits.

Added jobs from new additions to businesses on the beachfront are highly dependent on approval from the municipality and interest by the UIP. In an interview with Peter Rose he mentioned obstructions in the acquisition of additional licenses for street venders. This obstruction may be caused by a fear for reduction of the high-end atmosphere of Umhlanga. Future development of small businesses may suffer from a similar fear. The benefits can therefore not be predicted.

Delft3d

To give an idea of the hydraulic effects in the area, Delft3D is used. Delft3d is a computational program developed by Deltares. It is used to model the behaviour of the waves, the flows and the sediment transport in the three-dimensional frame over time. In this way it is possible to predict how the coast will react to a certain structure or how it will develop when nothing is done. It consists out of two parts: the wave model and flow model. When they are coupled the morphodynamics can be derived. In this project Delft3D is mainly used to give an idea about the effects. Because the project has a broad view several assumptions and simplifications have to be made. These assumptions also help to keep the project within the scope. Wind is not taken into account in the model; only wave and tidal influences are taken into account. Furthermore, only one layer in the vertical plane is used. When using more layers, a more precise prediction could be given, but it would take much more computational effort to do so.

Wave setup

To make a good prediction of the wave behaviour, the wave model first has to be calibrated to ensure the parameters are set correctly. This is done by the data of the far offshore located NCEP and the ADCP data near Umhlanga. The real-time NCEP data is used as wave input for the model. The model output is derived at the location of the ADCP. This output is compared to the real-time data of the ADCP. After each run different parameters can be changed in order to reduce the deviation of the wave height and the direction between the model and the ADCP data. When the deviation is in an acceptable range the wave model is calibrated.

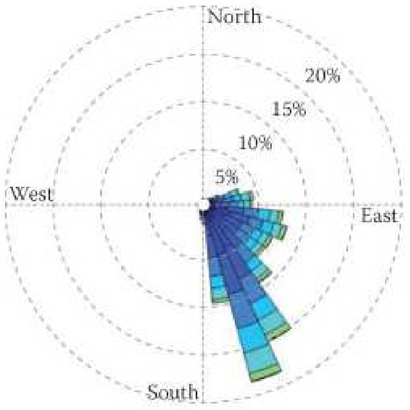

FIGURE 1.2 WAVE CLIMATE OF KWAZULU-NATAL

[1]

To model the waves in the final model, not the above data is used, but data from the eThekwini waverider. There is more data available and it is near the project location. Three years of data from the eThekwini waverider is used. This is a large set of measurements. When these are all used in the model, it would take a lot of time to run. Therefore the whole set of data is reduced to 14 wave conditions. These 14 conditions represent all the other wave conditions in wave height, wave direction, peak period and persistence. In Table 1.2 it is shown which parameters in the wave model are changed compared to the default values. In appendix A1, A2, A3 and A4 an extensive explanation is given of how these parameters are derived.

Parameter	Default	Used	Unity
JONSWAP PeF	3,3	2	[-]
Directional spread	4	14	[-]
Gravity	9,81	9,79	[m/s2]
Bottom friction	Jonswap: 0,067	Madsen: 0,005	[m2s-3]

TABLE 1.2 PARAMETERS WAVE MODEL

Coupled flow-wave setup

When the wave model is calibrated, it can be coupled with the flow model. The coupled model has to be calibrated as well. This is done by changing parameters within the flow model. The flow model is harder than the wave model to calibrate. It is hardly possible to compare the model to real-time data. To stay within the timeframe of the project, it is chosen to calibrate the model until it gives reliable results based on expert judgement. In Table 1.3 the main parameters that are changed can be seen. Especially the change in the sediment transport formula is an important one. The van Rijn formula gives very unlikely results, making the slope of the bed level very steep. After this is changed, the rest of the parameters are set during a series of calibration runs. In appendix A5 and A6 this is more extensively illustrated.

[1] Stretch, wave climate of kwazulu natal coast

Parameter	Default	Used	Unity
Sed. transport formula	v Rijn	Bijker	[-]
Time step	1	0,05	[min]
Time frame	-	15	[days]
Gravity	9,81	9,79	[m/s2]
Water density	1000	1025	[kg/m3]
Median sediment diameter (D50)	-	380	[µm]
Additional parameters			
Gammax	2	0,55	[-]
Cstbnd	no	yes	[-]

TABLE 1.3 PARAMETERS FLOW MODEL

Parameter	value	Unity
calibration coefficient b for shallow water BS	5	[-]
calibration coefficient b for deep water BD	2	[-]
shallow water (h_w/h) criterion C_s	0,4	[-]
deep water (h_w/h) criterion C_d	0,05	[-]
D90 grain size	570	[µm]
bed roughness height r_c	0,15	[m]
settling velocity w	0,031	[m/s]
porosity ε	0,4	[-]
wave period T_{user}	9	[s]

TABLE 1.4 PARAMETERS BIJKER FORMULA

Determining of the results

To derive good results out of Delft3D, one is very dependent on the time the model can run. It takes a lot of computational effort to run a dignified and accurate model. Because different scenarios have to be modelled, the computational time has to be minimized. In order to do so, the grid is redefined in both the wave and flow model. Furthermore, the running time is set on 15 days. In this way all the wave conditions and the tidal conditions are taken into account, but the time is as short as possible. The outcome of the model is not a long-term effect. To look at the long-term the output is compared to real measurements of the beach. After the output is known relative to the real data, it is extrapolated at a longer time-span. These 15 days of running time are thus interpreted as several years, which will probably not give a reliable result. However it is chosen to do so, to spare computational time.

2 Current situation analysis

2.1 Problem demarcation

Time

The timespan of the project will be 50 years. The value of the area demand a long lifespan of the solution but after 50 years the forecasts are not relevant anymore.

Organizational

As mentioned in chapter 1 information provided by the eThekwini municipality is used as a main source of information. Sources before 2000 are seen as out-dated and will be left out. Technical data related to major storm surges before 2000 could be admitted. Special attention is paid to sources related to the 2007 storm. Technical data is mainly sourced from peer-reviewed articles. For the social aspects municipal documents are utilised, including but not limited to interviews and surveys.

Geographic

The project concentrates on the Umhlanga Rocks area in Durban, South Africa from Umhlanga lagoon nature reserve at the north to the Durban view park at the south. The project boundary is physically bounded by the promenade and by the sea as well. Economic effects of the strategies on stakeholders reach further than the physical boundaries of the project and are taken into account for the Umhlanga Rocks but Umhlanga Ridge is not included. Since the coastline of KwaZulu-Natal is exposed to similar problems, solutions might be extrapolated to more areas than the Umhlanga Rocks area demarcated in this case. Umdloti, further to the north is used an example of such extrapolation.

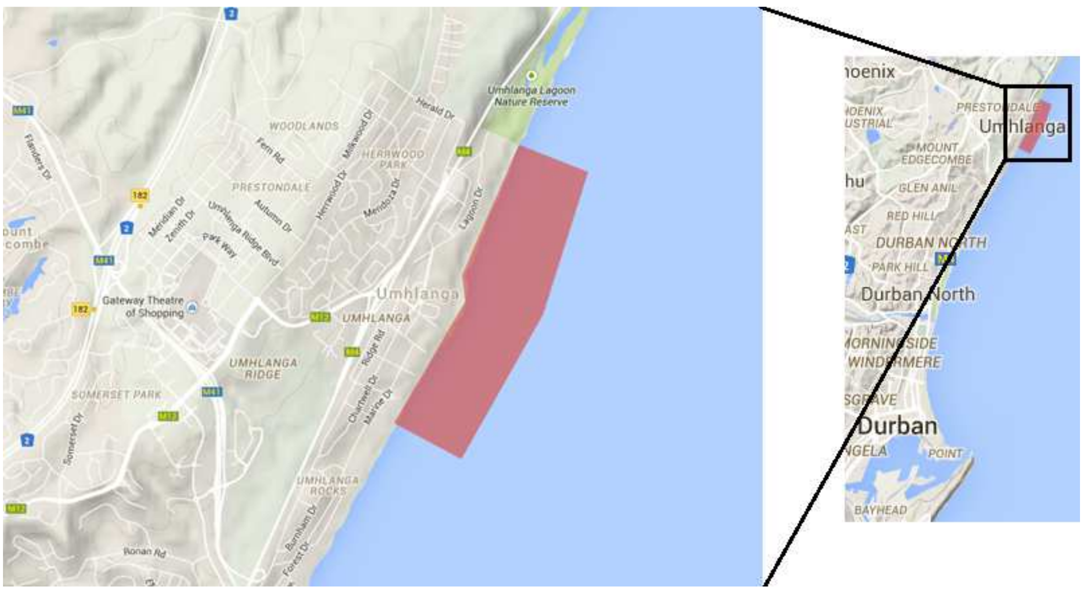

FIGURE 2.1 GEOGRAPHIC DEMARCATION

Tidal pool

Because the negative opinion of the local businesses and residents the option to build a tidal pool will be left out of the projects scope. Extensive research about a tidal pool is already done. The focus of this project will therefore be on other solutions.

Modelling

The structures are designed up to the level of preliminary design. The hydraulic and structural models used to compute the dimensions of the measurements will be on the level of preliminary design as well.

Materials

A lot of new materials are used these days to construct. To encourage innovative solutions there are no restrictions about the use of materials in the solutions.

Secondary effects

Only the first order effects of the solutions will be taken into account. The second order effects will be for further investigation. A couple of examples are given:

When the beach gets larger the possible wind erosion is not taken into account. Or when the number of tourists grows, due to the larger beach, there will be no research done on the capability of the infrastructure in Umhlanga to handle the increased traffic flow. When looking at environmental aspects only direct effects of the alternatives to the flora and fauna life and landscapes within the Umhlanga Rocks system are taken into account.

Social

From management point of view social interactions between stakeholders are mapped, together with legal aspects that obstruct the choice and implementation of an eventual solution. Process designs and/or solution strategies for these obstructions fall outside the scope of this project.

Financial

The cost of the solution will be computed using the level of indicators prices and reference projects.

Legal

All Legal aspects that are required for the implementation of the project are considered. The purpose of the legal section of this report is to define the obstructing power of current legislation. On a national level close attention is paid to the Integrated coastal management act (Ministry of Environmental Affairs, 2013) and the National environmental management act (Ministry of Environmental Affairs, vol.288, 2014). Other relevant provincial regulations are taken into account as well if necessary.

2.2 Stakeholder analysis

The main purpose of the stakeholder analysis is to map out the stakeholders involved in the project, their power and problem perceptions and to find a solution, which aligns their wishes. In case of Umhlanga the stakeholder analysis is mainly used as input for the creation of alternative solutions. Secondly it is used as input for defining the criteria on which the solution is evaluated. Problem perceptions that are defined through stakeholder analysis influence weight factors of criteria. Thirdly the stakeholder analysis is used to map out the stakeholders opposing or behaving neutral to the alternatives from the simulation phase. The end result is a recommendation to the client, based on actions of how to involve or collaborate with certain stakeholder with main purpose of convincing or satisfying.

There are several reasons for excluding an extensive process design as described by De Bruijn and Ten Heuvelhof (2010). First of all, the legislation involved in the Umhlanga problem is quiet complex. At the same time the limited time available does not make it possible to filter the strategic behaviour of stakeholders and find out their real problem perceptions and wishes. Creating a complete process design with the information available is then based on a lot of assumptions and for this reason inappropriate for implementation in this case. Stakeholder analysis is based on a literature study, interviews performed with Brian Wright (see appendix B1) and Pieter Rose (see appendix B2) and information provided by the client, eThekwini.

Stakeholders involved

In this section explanation about the stakeholders involved according to **Fout! Verwijzingsbron niet gevonden.** and their irreplaceability, importance, dependency, relevant resources, dedication and criticality (see appendix B3 Stakeholder analysis) is given. As explained above the stakeholder analysis is mainly used as input for determination of alternatives and their weight factors in the Multi Criteria Analyses (Chapter 4 and 9).

Players

eThekwini municipality

eThekwini municipality is the main authority responsible for the protection of the coastline. Since they are the main decision makers they are considered as a stakeholder with high power. Their main concern is the unsustainable coastline, which will suffer from more erosion due to lower sediment supply, sea level rise and the increase of storm frequency and intensity. eThekwini municipality's main goal is to find a suitable safety solution, while at the same time satisfying as many stakeholders as possible since previous alternatives did not receive the support expected. At the same time eThekwini is dependent on the property values and commercial businesses due to the rates they receive.

Timeshare

Timeshare or the so called shared vacation ownership makes it possible for consumer to use a property for certain period of time. Timeshare in Umhlanga Rocks is present in the form of two very large timeshare resorts and numerous shared apartments around Umhlanga Village. These are mainly used by domestic visitors, although internationals pay more attention to this option of accommodation as well. Users of timeshare are especially interested in family oriented activities on the beach and are for this reason considered as stakeholders with high interest (Urban-Econ, 2013). Since timeshare is an essential part of the tourism industry in Umhlanga, the economic value of the properties would decrease dramatically if the beach remains narrow or retreats. Resources like money, high dependency and importance allow timeshare to fulfil the role of a player.

Business community: bars/restaurants/pharmacy Umhlanga

Umhlanga is a first class holiday destination, providing various tourist oriented facilities like restaurants, bars and shopping centres. Although visiting the beach is considered as the main reason for tourists to visit Umhlanga, the nightlife opportunities and restaurants influence the image and attractiveness of the area.

Residents Umhlanga

A lot of properties in Umhlanga are directly placed on the beach and have experienced or probably will experience the effects of the coastal erosion on their properties. Although some of them have been influenced by earlier storms people forget about the consequences and the damage very soon. For this reason they might oppose to pay extra for better protection. There are two types of residents in Umhlanga: the wealthy residents and the ones with fixes income. They are considered to have the same amount of power and interests. The difference between the wealthy and the fixed income residents is that the first group consider their property more of an investment.

Umhlanga UIP

Umhlanga Urban Improvement Precincts has been established by property owners with the purpose of creating an environment in the area, which improves safety and quality of life. At the same time Umhlanga UIP helps maintain existing business investments and create new ones (UIP, 2014). Since the economic value of Umhlanga depends a lot on the properties in the area, this organization is considered an important player. Because of their irreplaceability, high important and dedication Umhlanga UIP is a critical player. Umhlanga UIP works closely with eThekwini Municipality to ensure the key interests of the stakeholders are in line with the plans of the municipality.

Tourists

Tourists are the driving market force in Umhlanga Rocks. The lack of facilities on the beach and the fact that almost no beach is available are their main problems perceptions. Since they have a lot of influence in the area and the economic value of Umhlanga would decrease dramatically, they are considered as a player with high power and high interests. A distinction could be made between tourists staying in the 5 stars hotels like Beverly Hills and the Oyster Box. This differentiation is based on the fact that wealthy want a beach only from aesthetics reasons. Their 5 star accommodations actually provide enough facilities for sunbathing and swimming. Tourists from other hotels have different perception on the problem since they don't have a lot of exclusive facilities and depend more on the beach for their recreational activities. The same distinction in interests could be also made between the 5 star hotels and the remaining ones, because they represent the interests of their clients.

5 star-Hotels: Oyster Box, Beverly Hills

Three 5 star accommodations on the beachfront of Umhlanga determine the image of the area and are the main accommodations for business visitors. Finding a solution for the area is highly dependent on the wishes of these stakeholders since a dramatic change in the coastline would influence the view and experience of the tourists and could cause loss of income for these hotels and for Umhlanga in general.

Hotels Umhlanga Rocks

Compared to the 5-star hotels explained above these hotels are more dependent on the beach, since not all of them have extra facilities like a swimming pool for their visitors. For this reason they are considered as stakeholders with higher interest, but lower power than the 5-star hotels. Loss of income for these actors could influence the economic value of the area even more.

Coastal property owners/developers

Coastal property owners wish to develop and/or maintain their property, thus ensuring growth for their investment. Their main interest is protecting this investment from natural or socio-economical threats. They have relatively large influence on the UIP and the community and a high interest. This makes them a player

Coastal lease holders

Coastal leaseholders are present on the coast of Umhlanga in the form of bars or restaurants. They use permits on coastal public property to develop their business. Their interests are maintaining their lease and expanding possibilities for their businesses along the beach. They rely heavily on beach going clientele that will mostly consist of day-trippers.

Context setters

Coastal Watch/KZN Wildlife/ WESSA

WESSA is the Wildlife and Environmental society of South Africa. Their goal is to promote and support environmental and wildlife projects that promote public participation in caring for the earth. (Wessa,2014). They are a high power NGO with strong ties to legislative bodies and the community. This gives them significant lobbying power. They could use this power to prevent measures that damage the environment or the wildlife in the Umhlanga region.

Coastal Watch is a local NGO, with relatively large power in Kwazulu-Natal. Their objective is to protect the coastline of KwaZulu-Natal. They have high power within the local community and could obstruct project that they feel are harmful to the coast

KZN wildlife is a governmental organization charged with the protection of wildlife in KwaZulu-Natal. They maintain and exploit several wildlife parks on land and in the Indian Ocean. The environmentally protected areas near Umhlanga are under their care. Therefore they are a high power stakeholder that should be taken into account.

Residents in Durban

Residents in Durban use the beaches at Umhlanga for recreational purposes but also experience competition with their own beaches at Durban centre. At the Umhlanga beaches facilities at the beachfront are limited. This reduces the value of the beach for Durban city residents.

KwaZulu-Natal Provincial Government

The KwaZulu-Natal Provincial Government is in charge of preventing or remedying adverse effects on the coastal environment adopt a coastal management program and affect it (Ministry of environmental affairs, 2013). Within these duties the provincial government can direct a municipality that is not taking adequate measures to take specific measures. The MEC in turn can delegate powers to several factions of provincial or traditional authority, like the provincial lead agency that every province must appoint to enact the provincial coastal management problem.

National Government

The national government through the minister of environmental affairs is the author of the integrated coastal management act. This act governs most of the coastal related issues, and responsibilities of the different government bodies. The Minister holds executive power over all aspects of the coastal management act. She can delegate these tasks, but withdraw this delegation at any time.

Port Authorities

The port authorities have access to a dredger needed to perform a variation of coastal management options. Secondly the main sand deposit sits outside the harbour and requires port cooperation to attain. Shipping lanes go past the Umhlanga beach but are so far out at sea they fall beyond our scope.

Surfers and/or other recreational ocean users

Surfers in particular have evolved to an affluent and potentially well organised group that could pose serious resistance when wave heights or other desirable wave aspects are altered. Other recreational group hold potentially less power.

The lifesaving club

The lifesaving club is an association in Durban, defending the interests of all recreational users of the beach. This stakeholder has primary lobbying power and medium interest in having a safe coastline. Because of the influence this association has on the local area and users they are considered as an important context setter, whose wishes should be taken into account. Involving them actively in the design process is not necessary since they don't have a lot of power.

Subjects

Surveyors are stakeholders involved in the project since they collect data for the municipality. Together with potential building contractor they are considered as subjects since they don't have high power but are interested in the project, which generates work for them. They don't have a clear problem perception. Operators of ocean trips will be directly influenced if the amount of tourists in Umhlanga changes. For this reason they have medium interest in the creation of a sustainable coastline and are for this reason considered as subject.

Crowd

Consultants are very often asked for advice in engineering projects in South Africa. Although they don't have power as individuals they generate work for themselves by making noise during the initial phases of the construction projects. Daily people in Umhlanga influence the revenue and economic value but are highly replaceable and cannot really use any kind of power or obstruct the project. This is the case as well for recreational ocean users others than surfers and beach users.

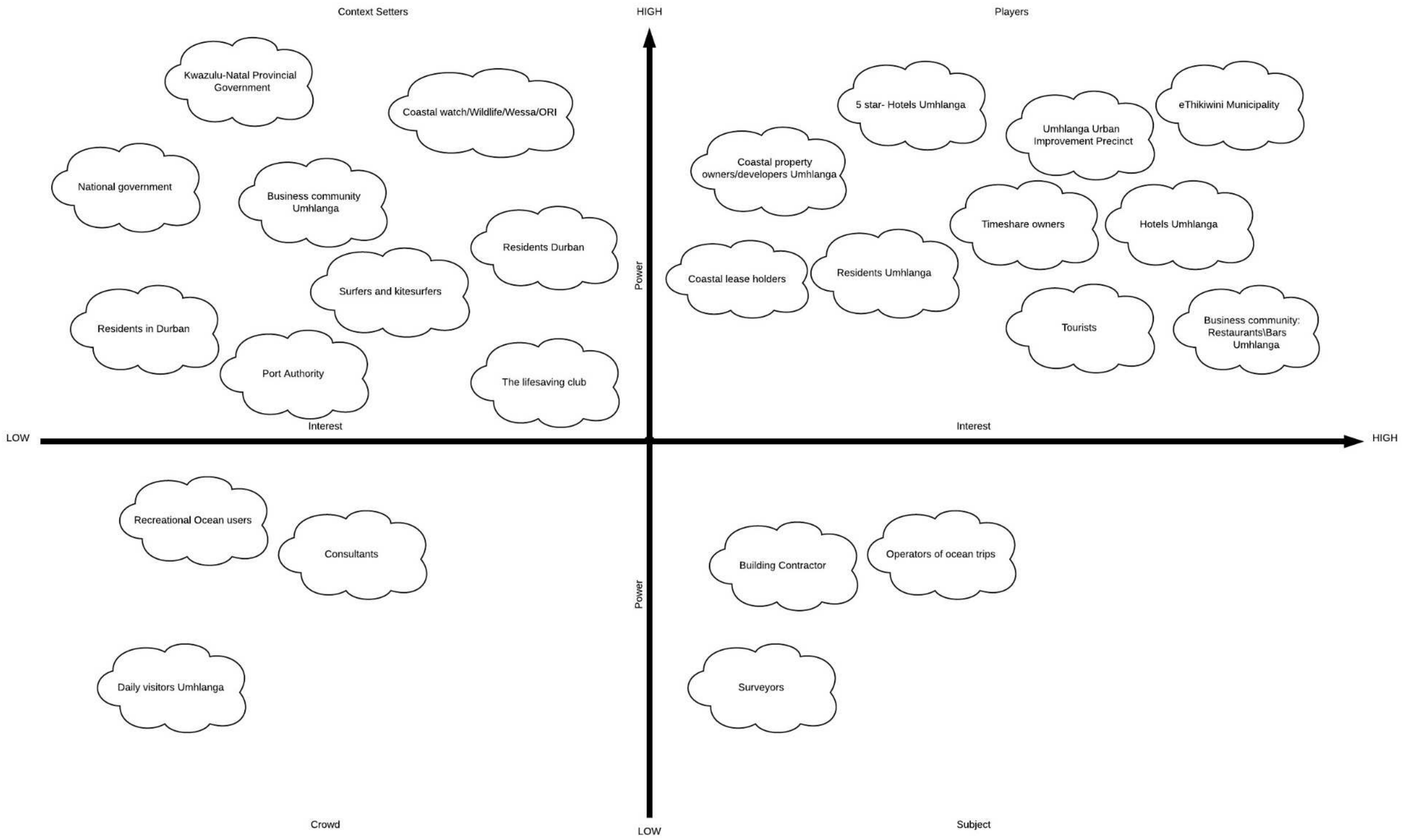

FIGURE 2.2 POWER GRID INTEREST

2.3 Design criteria

Surfzone

- The net sediment transport at the boundaries of the system should not change significantly.
- Rip current velocity should not exceed 1 m/s.

Beach

- The current high water shoreline should not retreat.

Hydraulic structures

- Any hydraulic structure should be designed so it can withstand a storm with a return period of 30 years without suffering damage.
- The lifetime of all structures should be 20 years.

Any recreational structure or area will be classified as permanent (class 1), semi-permanent/low economic value (class 2) or temporary (class 3). The following requirements are applicable to the safety classes.

	Class 1	Class 2	Class 3
Withstand a storm with a return period of:	50 years	10 years	1 year
Overtopping of 200 l/m/s limited to:	1/ 50 year	1/10 year	1/1 year
Overtopping of 10 l/m/s limited to:	1/10 year	50/1 year	-
Overtopping of 0.1 l/m/s limited to:	1/1 year	-	-
Maximum amount of storm events per year that render the structure unusable:	1	50	120

TABLE 2.1 SAFETY CLASSES AND OVERTOPPING

Promenade and inland structures

- The promenade is a permanent structure and follows the requirements for a class 1 recreational structure.

Environmental

- If it is deemed necessary to harm nature it is required to compensate for this.

Preferences

- No harm shall be done to endangered species.
- Enrich the local ecosystem by making the area more suitable for marine life.
- Create more square meters of beach.
- Maintain or create a wave climate that is favourable towards surfers.
- More facilities like bars and restaurants with seafront view
- More facilities generating extra economic value through entertainment in the high season
- Aesthetical design satisfying the wishes of current tourists and generating new ones.

3 Alternatives

Before coming up with different alternatives, various elements have been determined during a brainstorm session. All the elements and a short description are included in appendix C1. These elements have been ranked on three criteria, cost, added value and technological feasibility. This ranking is included in appendix C2. Technological feasibility includes both cost and risk. The best scoring elements have been combined. This leads to 11 different alternatives. An extensive description of those alternatives is included in appendix C3, an overview of the different alternatives and their performance is given in table 3.1.

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Variant	Elements	Costs	Added value	Risk	performance	Positive	negative
Detached breakwater	- Detached breakwater - Beach small business - Expand promenade On current Beach - 1 time nourishment	$$$$	***	!	+++++	- It will be a safe beach to swim over the full length. - A larger beach is expected - The small business will be on the beach and the enlarged promenade. - Because of the nourishment the small businesses profit immediately	- Rip currents - No surfing - Horizon pollution
the Durban	- groynes - reinforce current promenade - small business - nourishment	$$$	**	!	+++++	- It will be a safe beach to swim over the full length. - A larger beach is expected - The small business will be on the beach and the enlarged promenade.	- Rip currents - No surfing - Horizon pollution - There is no nourishment so the beach has to grow before small businesses can profit
little mermaid	- Submerged breakwater - Beach small business - 1 time nourishment	$$	***	!!	+++	- No influence on view - Added beach - Good for surfers - Relative rough sea	- At high water the breakwater could lose its function
Eco Island	- Island - Living shoreline - Island retaining wall	$$$$$	***(extra eco)	!!!	++++	- Positive view - High ecological value - easy swimming water - export potation - large beach - extra nature	- Just after completion there is no storm protection without the vegetation - there will be no surfing possible

Pleasure Island	- Island - Marina - Beach Small business - Pier/jetty	$$$$$	*****	!!!!	+++	- More economic value - Good marina will attract rich people - Safe swimming (at lee side of the island)	- Horizon pollution - Keep it classy - High damage after storm due to the business on the island
Venice in KwaZulu-Natal	- Removable breakwater - Beach small business - (nourishments)	$$$$$	****	!!!!	++	- No influence on view - Export potential - No surf interference - Swimming conditions are adaptable	- High maintenance - High probability of failure - No good swimming
Promenade d'Umhlanga	- Expand promenade on beach - Pier/jetty	$$	**	!!	+++	- Nice outdoor beach cafe's - Room to get a lot of business - No swimming accidents	- No surfing - No beach - No swimming - There is no other defence mechanism - High probability of overtopping (might want a flood pump)
sand savoir	- Beach small business - Sand retaining berm - Scheduled nourishment	$$$	***	!!	?	- Bigger beach - No horizon pollution - Export potation - No alongshore sediment interference	- No good swimming - No hard coastal defence - Beach has to grow to protect Umhlanga
FANCY	- Submerged walkway - Artificial reef	$$$$$	*****	!!!!!	++	- Tourist attraction - No horizon pollution - Diving/ fishing potential - Export potential	- High risk (high probability of failure and consequences) - A lot of exits because the tunnels escape routes can't be too long

Promenade protection	- Beach small business - Artificial reef - Reinforced current promenade-Scheduled nourishment - Promenade flood pump	$$$	***	!!	+++	- Good for surfers - No horizon pollution - Calm swimming environment - Provides an enriched diving environment	- At high water the artificial reef provides not enough protection - Rip currents
Nourish, nourish, nourish	- Scheduled nourishment	$$$	**	!!	++++	- No horizon pollution - Immediate profit from increased beach size	- No heavy storm protection

TABLE 3.1 DESCRIPTION ALTERNATIVES

4 Multi criteria analysis #1

This chapter presents the first evaluation round, where a selection is made from eleven to three best alternatives through a Multi-criteria analysis (MCA). The first paragraph describes the different criteria that are chosen. The second paragraph, describes the weight factors that are given to the criteria. The end result of this chapter is the choice of three best alternatives, based on the weighted score of the alternatives on each criteria and a sensitivity analysis.

4.1 Evaluation criteria

One method for determination of the criteria is the use of a goal tree. The goal tree represents the concrete and specific goals of the client and results in the establishment of indicators or criteria against which the degree of goal achievement is measured. Underlying goals or sub-goals in the goal tree define the parent goals. On the lowest level of the goal tree there are measurable criteria with a unit. It is important that criteria included in the evaluation are independent. When the criteria are not independent of each other, there is chance of double counting when these criteria are given scores. The end result of the goal tree can be found in appendix D1 Goal Tree. The criteria are derived in three categories being socio-economic, structural and hydraulic. A description of each of them is given in appendix D2 Description of criteria. Since not all criteria are used for the evaluation of alternatives, more information on the choice of criteria can be found in append D3 Selection of criteria.

An overview of the criteria that are used in the scoring is given below:

- More use of new technology
- Low visual horizon pollution
- More beach facilities
- Low investment cost
- Low maintenance and usage cost
- More use of conforming materials
- Load combinations
- Larger outflow Umdloti
- Larger beach
- Lower rip current velocity
- Amount overtopping
- Frequency overtopping

4.2 Weight factors

Each group member determines the weight factors first. Each group member assigns a weight factor that is suitable according to him or her. These results are subsequently compared and discussed within the group. An important discussion was for example by how many criteria represented each discipline. Since the structural criteria had been combined into load combinations a weight of 1.0 seems suitable against a sum of 2.35 for the socio-economic criteria *(1.35 without costs)* and 1.6 of hydraulic criteria's. Although the socio-economic aspects of the project play an important role the main idea behind the weight factors is that when costs are neglected finding a solution for the hydraulic problems of the area is more important. This is considered to be the case because if no solution is found sooner or later no beach is expected to be left and safety issues will be prioritized.

In terms of the socio-economic criteria costs are considered the most important ones. If these do not fit into the budget available probably the project won't be executed without external financial support. Investment costs are considered more important because of the pressure that is involved with getting the amount needed. However as explained earlier investments costs are strongly related to maintenance and usage costs. Horizon pollution (interview Peter Rose) and use of more conforming materials (interview Brian Wright) are considered as essential as well for acceptation of the project and actually executing it. More beach facilities is not a hard criterion but is seen as an important wish, as more facilities will directly benefit tourism. The use of more technology is given the lowest factor since its contribution to a high value coastline is considered to be less important.

The hydraulic criteria give a larger beach the highest weight factor. The reason for this is that a large beach contributes directly to better protection of the buildings it attracts more tourists and creates more space for extra facilities. Amount of overtopping is more important than the frequency because more overtopping at one time causes more damages than less overtopping on a more frequent basis. Lower rip current velocity and larger outflow to Umdloti are two criteria that have a strong relation with the stable amount of sand staying in the Umhlanga system and the way this influences the beach width.

Category	Criterium	Factor
Social economic	More use of new technology	0.15
	Low visual horizon pollution	0.4
	More beach facilities	0.3
	Low investment cost	0.6
	Low maintenance and usage cost	0.5
	More use of conforming materials	0.4
Structural	Load combinations • Storm + high water+ wind • Maximum vehicle load • Long term permanent load • Collision load • Mooring load	1.0
Hydraulic	Larger outflow Umdloti	0.3
	Larger beach	0.6
	Lower rip current velocity	0.3
	Amount overtopping	0.25
	Frequency overtopping	0.15

TABLE 4.1 WEIGHT FACTORS ON CRITERIA

4.3 Criteria scores

In order to score the different criteria per alternative, 55 points per criteria are divided over the eleven alternatives. This method gives a more accurate depiction of the level of expected success of the alternative per variable. This feature is used to take the mean of the scores of all group members in order to mitigate outliers.

Socio-economic

More use of new technology

The most innovative alternatives are the ‘Pleasure Island’, ‘Venice in KZN’ and the ‘Fancy’ option. These options rewarded with 8, 9 and 10 points respectively. With 5 points per alternative, this means these alternatives are considered to be significantly above average in terms of use of new technology. All these options have been implemented before. Dubai is most famous for its use of artificial islands, and movable barriers have been used in Venice and Kampen in the Netherlands. All alternatives are however in very different circumstances and on a much smaller scale.

The ‘Detached breakwater’, ‘Durban’ and ‘Promenade d’Umhlanga’ options are considered to be the least innovative. Expanding the current promenade or expanding the solutions implemented in Durban would not require any new technology. The detached breakwater could implement new technology but these would not be strictly necessary.

Low visual horizon pollution

Therefore alternatives that are less of an infringement upon the views will be awarded with more points. Since all alternatives will have some impact on the views none are awarded with more than ten points. Those alternatives that interfere below the waterline are awarded the most. ‘Promenade d’Umhlanga’ is awarded the most points because it does not include any construction in the sea. The island options and the breakwater are awarded the least points because they interfere most with the view.

More beach facilities

Alternatives that add extra space to either the beachfront or the boulevard will be awarded with more points. ‘Eco Island’ creates more space, but this space is not meant for facilities. An assumption is made that the beach will grow naturally along the coast, but since this is an uncertainty eco island receives a low score on more beach facilities. The same goes for ‘Venice in KZN’ and the ‘Sand Saviour’. These alternatives do not directly contribute to more facilities. On the other side ‘Pleasure Island and ‘Promenade d’Umhlanga’ are two alternatives which create more space for entertainment in all different forms like casino’s, concerts or restaurants.

Low investment cost

The lowest scores for low investment costs were given to ‘Eco Island, ‘Pleasure island’ and ‘Fancy’. The two islands need very high investments for the land reclamation. The submerged walkway is an expensive investment since it is underwater and uses non-established technology. ‘Sand saviour’ is a quiet simple technique, primary consisting of the concrete sill. For this reason it has been given a high score in low investments costs. Nourishment has already been performed very often at the eThekwini municipality. No high investments are needed, since the current dredger can be used if available.

Low maintenance and usage cost

The medium investments costs for the construction of the detached breakwater are compensated by one of the lowest maintenance and usage costs. The barrier forms a permanent construction in the water and needs to be maintained by divers but with a low frequency. The same is the case for the 'Eco Island', which once build does not really need any maintenance. On the other hand the lowest scores on low maintenance and usage costs are given to 'Venice in KZN' and 'Fancy' option. Those alternatives are permanently on the sea bottom and for this reason need to be maintained more than the detached breakwater for example. Especially the 'Fancy' option with the submerged walkway needs a lot of maintenance to make it attractive for visitors and make it possible to have a clear view from the inside.

More use of conforming materials

For 'Eco Island' no hard materials are expected to be used. The island itself will be reclaimed by sand and made stable by flora. For this reason it is seen as an alternative with quiet confirming materials, which fit in the natural appeal of the area. Same is the case for nourishment since this alternative only includes the use of sand. For the use of the 'Venice in KZN' alternative a very strong barrier underwater will be needed, probably made of steal. 'Promenade d'Umhlanga' will actually increase the use of non-conforming materials like concrete and decrease the availability of current conforming materials by reducing the beach. The 'Fancy' variant would include the construction of a harbour, which does not really use confirming materials. The same counts for the 'Venice in KZN' breakwater which is seen as a 'foreign' and 'disturbing' material into the water. Although 'Promenade d'Umhlanga' does not include any alien material or construction into the water it changes the view drastically by replacing the beach by a promenade. For this reason this alternatives scores low for the use of confirming materials.

Structural

The eleven variants are marked between 0 and 10 for their resistance against the load combinations. A high mark means good resistance against a load combination. The load combinations are not considered to be equivalent therefore a weighting factor is introduced. The resistance against load combination 2 is considered as the most important one followed by combination 1. Combination 3 is considered to be the least import one because this is an extreme combination that does not occur frequently. Based on the structural behaviour of the variants, described in Chapter 3 Synthesis the marks are given.

Evaluating the variants on load combination 1; a long-term permanent load, the highest marks are given to the variants with structures which are the least sensitive to settlements. These are the options with a distributed load on the seabed like an island a reef and a submerged breakwater.

High marks for the protection of the Umhlanga coastline are given to the offshore breakwater and both of the islands. These options will reflect the incoming waves and will reduce the hydraulic load on the shore seriously.

Damage in case of collision can be limited by constructing the structures from several elements. The marks are shown in the table 4.2.

Load combination	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
1long-term permanent (foundation) (2)	5	7	7	8	7	6	5	8	7	8	Nvt
2 permanent + storm + high water + wind (3)	9	5	3,5	7,5	2,5	7,5	7,5	2	2	6,5	2
4 permanent + collision (1)	9	8	9	9	3	2	6	9	1	9	Nvt
Total score	46	37	33,5	47,5	24,5	36,5	38,5	31	21	44,5	2
weighted score	7,7	6,2	5,6	7,9	4,1	6,1	6,4	5,2	3,5	7,4	2,0
score out of 55	**7**	**5**	**5**	**7**	**4**	**5**	**6**	**5**	**3**	**7**	**2**

TABLE 4.2 LOAD COMBINATION SCORES

Hydraulic

Larger outflow Umdloti

The alternatives that interfere the least with the longshore transport have the highest score. The movable breakwater and the expanded promenade don't have structures that influences the longshore sediment transport consistantly. The promenade won't interfere at all. The movable breakwater only interferes for short amounts of time which are negligible. The nourishment option will only make more sand available to be transported to Umdloti. Therefore this one has the highest score. Both the islands have the lowest score, because they can possibly block the entire littoral drift, causing that the outflow to cease.

Larger beach

The nourishment option will have a direct effect of increasing the beach. Therefore this option has again the highest score. The breakwaters and groynes will let the beach grow over time when designed properly. On the other hand, the expanded promenade will let the beach naturally erode and eventually disappear, therefore it has the lowest score possible.

Lower rip current velocity

The options that have continuous structures or no structures at all in the water have the highest score, because no rip currents are caused. This is the case for the expanded promenade, the berm retaining sill and the nourishment option. The movable breakwater has the same score, because most of the time the structure will not influence the wave climate. Both the breakwaters have the lowest score. They consist out of several smaller structures. The water will flow in between them, causing strong currents.

Overtopping

The scores of the amount and the frequency of overtopping are mostly the same. The highest scores are mainly given to the ones that influence the wave climate. These are the detached breakwaters and the eco island. The pleasure island on the other hand has one of the lowest score, because there is a high economic activity on the island, causing it to be vulnerable to overtopping.

Table 4.2, the end result of the scoring, shows that alternatives submerged breakwater, sand retaining sill and nourishment perform the best on the selected criteria. These three alternatives, together with the 'Do Nothing option" are further designed during the simulation phase of Chapter 5 to 8.

Category	Criteria	Unit	Factor	V1.	V2.	V3.	V4.	V5.	V6.	V7.	V8.	V9.	V10.	V11.
Social economic	More use of new technology	[number of users technology]	0.15	2	2	6	7	8	9	2	7	10	1	1
	Low visual horizon pollution	[% obstructed horizon]	0.4	2	3	7	4	2	8	2	8	7	5	7
	More beach facilities	[facilities/m2]	0.3	5	5	4	2	9	3	8	3	5	4	7
	Low investment cost	[euro]	0.6		5	7	2	1	4	6	9	2	5	9
	Low maintenance and usage cost	[euro/y]	0.5		6	6	8	3	2	6	6	2	5	4
	More use of conforming materials	[% of total volume]	0.4	4	6	5	8	4	3	3	6	2	6	8
Structural	Functional failure		1	7	5	5	7	4	5	6	5	3	7	2
Hydraulic	Larger outflow Umdloti	[m3/s]	0.3	3	3	6	2	3	7	7	6	5	4	9
	Larger beach	[m2]	0.6	7	7	6	5	5	3	0	3	5	5	9
	Lower rip current velocity	[m/s]; max 1m/s	0.3	2	3	2	5	6	7	7	7	5	4	7
	Amount overtopping	L/m/s	0.25	8	6	5	8	3	7	3		4	5	3
	Frequency overtopping	1/y	0.15	8	5	6	7	2	5	3	4	5	6	4
Total score				**59.8**	**56.5**	**65.0**	**65.0**	**49.6**	**63.4**	**52.7**	**66.6**	**55.1**	**56.6**	**69.8**
Weight score				**26.4**	**25.1**	**27.2**	**26.8**	**18.8**	**23.9**	**22.4**	**27.6**	**19.7**	**25.4**	**29.0**

TABLE 4.3 SCORES OF DIFFERENT ALTERNATIVES

4.4 Sensitivity analysis

A sensitivity analysis is performed to check whether the initial given weight factor really represent the best alternatives. For this reason a differentiation of weight factors is used four times, each time neglecting some of the criteria, by changing their weight factor and analysing the influence of the change on the weighted score. An extensive overview of the sensitivity analysis and the new scores is given in appendix D4.

When there are no budget constraints and investment, maintenance and usage costs are given lower *scores (change from 0.6 and 0.5 to 0.3 and 0.2)* the sand-retaining sill is no longer in between the best alternatives, while the submerged breakwater and nourishment are. Instead of the sand retaining sill, Eco-island joins the best three alternatives.

When the functional failure is paid more attention *(given a weight factor 2 instead of 1)* Eco-island, detached breakwater, the submerged breakwater and the sill give the best results.

If the weight factor of larger beach is doubled *(from 0.6 to 1.2)* then the detached breakwater, the submerged breakwater and nourishment receive the highest scores.

When less attention is paid to visual pollution and the use of conforming materials and their factors are changed *(0.4 to 0.1 and 0.4 to 0.1)* the detached breakwater, the submerged breakwater and nourishment come out as the best alternatives.

The sensitivity analysis shows that in three of the four cases nourishment stays on top, the submerged breakwater in all cases and the sill in only one of the cases, when more attention is paid to functional failure. Two other alternatives that score quiet well during the sensitivity analysis are the Eco-island and the detached breakwater. However both alternatives cause a drastic change in the view of Umhlanga. The sensitivity analysis shows quiet well that change of weight factors still delivers the submerged breakwater, the sand retaining sill and nourishment as the best options. Because of this and the diversity of alternatives desirable it is chosen to go further with this original setting of alternatives in the simulation phase.

5 Do nothing option

5.1 General information

Assumptions

The fourth alternative considered for the Umhlanga problem is the “Do nothing” option. This one considers no construction or nourishment, with continuous beach erosion as a consequence. The purpose of considering this option is to give eThekwini municipality a well examined solution for the Umhlanga erosion problem by taking into account the costs and benefits that would occur if nothing is done. The “Do nothing option” is considered through, the stakeholder perception of doing nothing and the costs and benefits that would probably occur with different scenarios of erosion.

Scenarios

In case of Umhlanga the beach width is 26.9m (2012), with an average erosion of 1.1m/ year leading to a beach with of 24 m in 2014. This means that if nothing is done to the beach and erosion takes places, in 24/1.1=22 years there will be no beach at all. For simplification of the calculation an erosion rate of 1.0m/year is calculated with. This erosion rate is used for the first scenario when only coastal erosion occurs, following the trend of the last years. When coastal erosion takes place in combination with storm surge the beach will disappear faster. It is unknown what exactly the erosion rate will be. For this reason an extreme rate of 2m/year is used.

Scenario	Erosion rate
Scenario Coastal erosion	1.0 m/year
Scenario Coastal erosion & Storm surge	2.0 m/year
Scenario Coastal erosion, Storm surge & Failure retaining wall	2.0 m/year

TABLE 5.1 EROSION SCENARIOS

5.2 Delft3D

Model setup

The model setup of the do nothing option is quite trivial. It is a model with only the present bathymetry in it. No structures or manly made bed level changes are made. The model runs for a short period with all the tidal and wave conditions represented.

Results

When looking at the cumulative erosion and sedimentation picture, different patterns can be seen. Several areas of sedimentation occur, but at the bump in the bed level a large spot of erosion occurs. This is a logical pattern. From the picture it looks like there is a lot more sedimentation than erosion, but when looking at the change of the beach area something different can be seen. The beach area is defined as all of the surface above -0,5 SWL. This surface is decreasing over time in the model. This is also what can be seen in reality and what the main problem is to solve in this project. Out of the model it turns out that this beach width is decreased with -0,87 m/m (cross shore direction). It is considered that this value does not fully represent the reality. Therefore this is used relative to other measurements. Reference data gives that the beach width decreases with one meter per year (Urban-econ, 2013). Because of this, it is assumed that the run time of the model represents $0{,}87 * 365 = 317{,}5\ days$ instead of the 15 days it says in the model. All of the other alternatives will also be calculated relative to this.

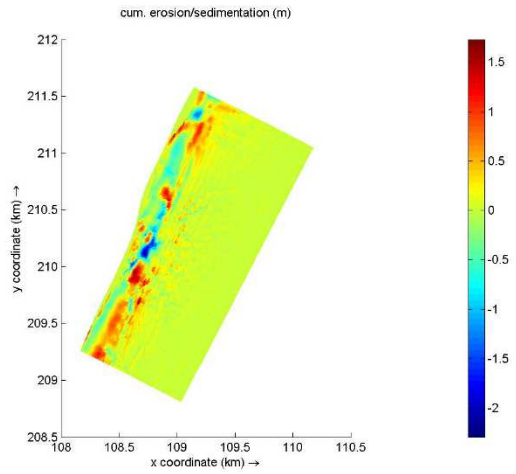


FIGURE 5.1 CUMULATIVE EROSION/SEDIMENTATION DO NOTHING OPTION

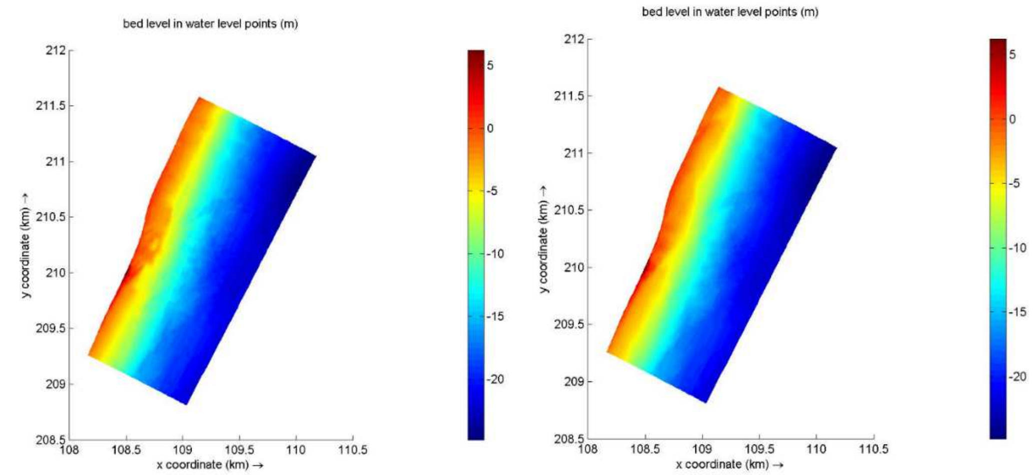


FIGURE 5.2 BED LEVEL CHANGE DO NOTHING OPTION BETWEEN T0 (LEFT) AND T1 (RIGHT)

5.3 Stakeholder perception

According to eThekwini municipality, when full erosion of the coast has taken place and no beach is available any more, the retaining wall and promenade will be strong enough to protect the properties behind. This means that as long as sufficient protection is available eThekwini will not have to take any action. The same is the case for the National and Provincial government. They will be however consulted about possible consequences of taking no measurement about protecting the beach in the short term. Business community, tourists and residents in Umhlanga however are probably going to use their power and protest when nothing is done to protect the beach. Coastal leaseholders and coastal property owners' main concern is damage of their properties when the beach has disappeared and there is no buffer for protection. These opposing parties should be consulted about the consequences that no action will have for them. In this case certain measurement or compensations could be used to minimize the consequences for them.

Inform	Consult
• Port authorities • Residents in Durban • The lifesaving club • Coastal Watch/Wildlife/WESSA/ORI • Surfers and kite surfers • Surveyors • Operators of ocean trips • Building contractor • Consultants • Daily people Umhlanga • Recreational Ocean users: fishers	• Residents Umhlanga • Timeshare owners • Businesscommunity: bars/restaurants/pharmacy • Hotels Umhlanga Rocks • Hotels: Oyster Box, Beverly Hills • Coastal lease holders • Coastal property owners/developers • Umhlanga UIP • Tourists • KwaZulu-Natal Provincial Government (MEC) • National government

TABLE 5.2 STAKEHOLDER ACTION ON THE DO NOTHING OPTION

5.4 NPV

Costs

When doing nothing is considered as an alternative for the Umhlanga problem, no equipment, labour or material costs are needed initially. This alternative is based on repairing damage when this occurs. For proper estimation of the cost benefit ratio and NPV calculations three different scenarios are considered. These scenarios include interpolation of the erosion rates from the past *(2002-2012)* and two more pessimistic options, with one including failure of the promenade.

Maintenance

The weather conditions from 2007 have caused significant damage to the promenade. Additional R70 million was needed to upgrade the promenade, so damage was repaired and significant protection level was ensured for the future ("Umhlanga promenade paved to endure", 2012). According to Kenney (2006) repair costs can increase by 10% due to the corrosive effect of sea water. If nothing is done, continuous maintenance and rebuild costs will be needed when damage occurs. For the NPV it is considered that storm events force maintenance of the same scale as the 2007 event twice over the 50 year span of this project.

Loss of Benefits

When nothing is done against beach erosion, the beach of Umhlanga disappears, leading to loss of recreational benefits because of less tourists visiting, loss of property values, and loss of property rates depending on the property values.

Loss of recreational benefits

Urban-Econ has already calculated the recreational benefit per annum for Umhlanga beach. This amount counts almost R3 billion (from Lighthouse to Umhlanga Main beach) and includes Umhlanga Village and Umhlanga Ridge. Since only Umhlanga Village is considered in the scope of the project, tourism benefit is equal to

$$\begin{aligned} \text{R2 912 286 743} \quad & - \text{ R592 413 250 (Timeshare in Ridge)} \\ & - \text{R67 447 620 (Domestic hotel visitors in Ridge)} \\ & - \text{R22 022 912 (International hotel visitors in Ridge)} \\ & = \text{ R2 230 402 961 per annum (2012)} \ = \ \text{2 294 861 607 (2014)} \end{aligned}$$

Since according to the predictions less beach will be available if nothing is done, recreational benefits will decrease each year with 25 000 ZAR/m^2. When looking at the different scenarios the same amount of recreational benefits is generated. Differences are found only in the period of time for which the calculation is done and so as well for the amount of loss expected.

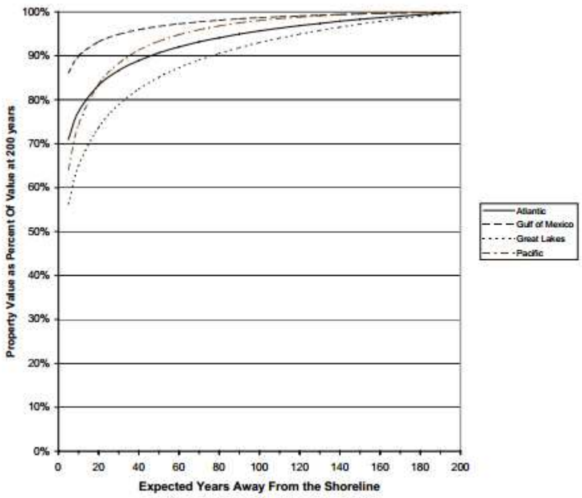
Loss of property values

In areas when there was chance of flooding and flood insurance was unavailable real estate agents stated they would take between 12-25% of the property value reducing the valuation (Kenney, 2006). According to Landry (2003) a property owner could also stabilize his property, while when doing nothing the value of the property decreases with 12%. Looking at Umhlanga 53.4% of the property owners stated that there was a correlation between the sand erosion and there property value, while probably the same 54% had already experienced a decrease of their property value due to sand erosion. From this finding it can be concluded that there is a strong correlation between the decrease of property values and beach erosion. This however does not mean that only 54% of the properties' value actually decreases. Property owners might not have noticed this correlation or might not have paid attention to it.

According to the article of Kenney (2006) recent flood events can reduce the value of a property in UK by 12%. According to an article written by the Heinz Center (2000) there is a strong relation between the decrease of property value and the number of years until the nearest shore is likely to erode and reach the house. For a waterfront property at Atlantic Coast, on distance of 30m from the water and expected to reach the water in 50 years, is according to the article worth about 90% of the value of an identical house also located 30m from the shoreline, but expected to reach the water in 200 years. Similarly, a house estimated to be within 10 to 20 years of an eroding shore is worth 80 % of one located 200 years away. Since 200 years is a long period of time for the simplification of the information it could be stated that the houses, which will erode once in 200 years, will not erode at all. This leads to the assumption that there is 80% value decrease of property when the coast is about to erode in 20 years and 90% when it is about to erode in 50 years. These calculations have been done with an erosion rate of 0.6 to 1m/year and estimation that an average beach front property is on 45m from the waterline. However this research did not consider the increasing sea level (Kriesel, 2000). When taking this one into account the erosion rate could increase with 0.3 m/year.

In case of Umhlanga the beach has eroded with average of 1.1m per year between 2002 and 2012. Although the average distance between property and beach is 100m (and not 45m as in the Heinz article) in Umhlanga, the data of Heinz Center is partly comparable to the Umhlanga case. Based on the assumptions explained above it can be stated that when a property is estimated to reach the waterline within 10 to 20 years its value will decrease with 20%. According to Urban-Econ (2013) when there is no beach at all, property values will decrease with 15%. The percentages according to Urban- Econ and Heinz Center are in the same range. Since Urban-Econ has performed the research specifically for Umhlanga, and 15% is in between the previous found 12% and 20%, 15 % of property loss due to no beach in Umhlanga is considered as the most suitable estimation.

FIGURE S.5 Effect of erosion hazard on typical coastal property value[a]



[a] Property value for otherwise identical waterfront houses, at the same distance from the water today, but with shores eroding at different rates.

FIGURE 5.3 PROPERTY VALUE VS. DISTANCE FROM THE BEACH BY HEINZ CENTER (2000)

When coastal erosion takes place in combination with storm surge the beach will disappear faster, causing more damage and leading to even lower property values. Taking into consideration the graph produced by the Heinz Center around 20% loss of property value is expected to occur.

If rarer storm surges occur, there is a change the retaining wall will fail and damage will be caused to the promenade. In this case it does not seem reasonable to assume that all property value will be lost. For this reason 25% loss of property value is calculated with. An overview of the estimated percentages for the "Do nothing" scenarios is given below:

Scenario	% loss of property value when no beach available
Scenario Coastal erosion	15
Scenario Coastal erosion & Storm surge	20
Scenario Coastal erosion, Storm surge & Failure retaining wall	25

TABLE 5.3: LOSS OF PROPERTY VALUES FOR UMHLANGA BASED ON THREE SCENARIOS

NPV calculation Coastal erosion

The NPV of the "Do nothing option" with scenario coastal erosion is calculated using the following data:

- **No construction costs** since no construction is planned to be built in the short term
- **No maintenance and usage costs** for the same reason as explained above
- **Recreational benefits** are R2 294 861 607 according to Urban-Econ (2013, p.10) as calculated under Loss of recreational benefits

- **Recreational benefits decrease**: each year erosion takes place and the beach width decreases with 1m/year. The length of the project is 2.4km while 1m^2 generates R25 000 of income. This means that each year the recreational benefits decrease with
  $1 \text{ x } 2400 \text{ x } 25\,000 = \text{R}60\,000\,000 \text{ per year}$
- The calculations show that even though in 22 years there will be no beach, only in year 37 there will be zero benefits from tourists.
- **Property values** have been derived in Residential and Business & Commercial. Both sections decrease with 15% until the property has reached the waterline, in 37 years as explained above. After 37 years the property value is expected to stay constant. However the direct difference in property value is not used for the NPV. The difference in property value is used to calculate the loss in rates that eThekwini municipality will experience.
- **Residential property rates** are equal to 0.976 cents to the Rand and Commercial property rates 2.213 cents to the Rand. So in year 1 this gives an income of Residential property rates of $0.976 \text{ x } \text{R}4\,375\,026\,000.00 = \text{R}42\,700\,253.76$
  and Commercial property rates of $2.213 \text{ x } \text{R}94\,450\,000.00 = \text{R}2\,011\,785.00$
- NPV is calculated using the sum of the costs which are zero and the $\frac{benefits}{(1+0.05)^t}$ with t the mount of years.
- The calculations show that when coastal erosion of 1m/year occurs and nothing is done, within 50 years this alternative still has a **positive NPV is R23 559 867 811.76.**

NPV calculation Coastal erosion & Storm surges

The NPV of the "Do nothing option" with scenario coastal erosion & storm surges is calculated using the following data:

- **No construction costs** since no construction is planned to be built in the short term
- **No maintenance and usage costs** for the same reason as explained above
- **Recreational benefits** are R2 294 861 607 according to Urban-Econ (2013, p.10) as calculated under Loss of recreational benefits
- **Recreational benefits decrease**: each year erosion takes place and the beach width decreases with 2m/year. This coastal erosion takes place two times faster than the previous scenario because it is in combination with storm surges. The length of the project is 2.4km while 1m^2 generates R25 000 of income. This means that each year the recreational benefits decrease with $2\ x\ 2400\ x\ 25\ 000\ =\ R120\ 000\ 000\ per\ year$.
- **Property values** have been derived in Residential and Business & Commercial. Both sections decrease with 20% until the property has reached the waterline, in 19 years as explained above. After 19 years the property value is expected to stay constant. However the direct difference in property value is not used for the NPV. The difference in property value is used to calculate the loss in rates that eThekwini municipality will experience.
- **Residential property rates** are equal to 0.976 cents to the Rand and Commercial property rates 2.213 cents to the Rand. So in year 1 this gives an income of Residential property rates of $0.976\ x\ R4\ 375\ 026\ 000.00\ =\ R42\ 700\ 253.76$ and Commercial property rates of $2.213\ x\ R94\ 450\ 000.00\ =\ R2\ 011\ 785.00$
- **NPV is calculated** using the sum of the costs which are zero and the $\frac{benefits}{(1+0.05)^t}$ with t the mount of years.
- The calculations show that when coastal erosion of 2m/year occurs in combination with storm surges and nothing is done, within 50 years this alternative still has a **positive NPV is ZAR 15 825 663 888**

NPV calculation Coastal erosion & Storm surges & Failure promenade

The NPV of the "Do nothing option" with scenario coastal erosion in combination with storm surges and failure promenade is calculated using the following data:

- **No construction costs** since no construction is planned to be built in the short term
- **Maintenance costs** of R70 000 000 for repair of the promenade when this one fails. eThekwini municipality has not been able to provide failure chances about the promenade which makes it difficult to estimate the occurrence of this costs.
- **Recreational benefits** are R2 294 861 607 according to Urban-Econ (2013, p.10) as calculated under Loss of recreational benefits
- **Recreational benefits decrease**: each year erosion takes place and the beach width decreases with 2m/year. This coastal erosion takes place two times faster than the previous scenario because it is in combination with storm surges. The length of the project is 2.4km while

$1m^2$ generates R25 000 of income. This means that each year the recreational benefits decrease with $2\ x\ 2400\ x\ 25\ 000\ =\ R120\ 000\ 000\ per\ year$.

- **Property values** have been derived in Residential and Business & Commercial. Both sections decrease with 25% until the property has reached the waterline, in 19 years as explained above. After 19 years the property value is expected to stay constant. However the direct difference in property value is not used for the NPV. The difference in property value is used to calculate the loss in rates that eThekwini municipality will experience.
- **Residential property rates** are equal to 0.976 cents to the Rand and Commercial property rates 2.213 cents to the Rand. So in year 1 this gives an income of Residential property rates equal to $0.976\ x\ \ R4\ 375\ 026\ 000.00\ =\ \ R42\ 700\ 253.76$
- and Commercial property rates of $2.213\ x\ \ R94\ 450\ 000.00\ =\ \ R2\ 011\ 785.00$
- **NPV is calculated** using the sum of the maintenance costs and the $\frac{benefits}{(1+0.05)^t}$ with t the mount of years.
- The calculations show when coastal erosion of 2m/year occurs in combination of storm surges and failure of the promenade and nothing is done, within 50 years this alternative still has a **positive NPV is ZAR 15,776,585,700**

6 Bar retaining sill

6.1 General information

Cross shore transport

At most beaches erosion occurs under heavy wave conditions and during calmer wave conditions the beach is slowly restored. This eroded sand is temporarily stored in an offshore bar. Normally this bar forms close enough to the shore that it can be brought back to the beach by low waves. It is suspected that at Umhlanga Rocks this bar forms too far offshore and the sand does not return to the beach. Over time this leads to a total loss of sand in the system and chronic beach erosion.

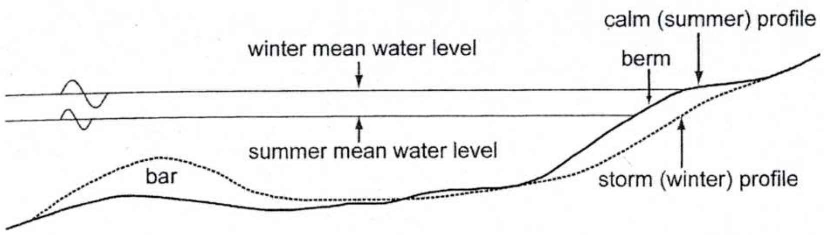


FIGURE 6.1 CROSS SHORE SEDIMENT TRANSPORT

Bar retaining sill

To prevent the bar from moving too far offshore a sill is constructed that is designed in such a way that it can retain the bar. During heavy wave conditions the sediment will settle at the leeside of the sill and calmer wave conditions will now be able to move the bar back to the beach.

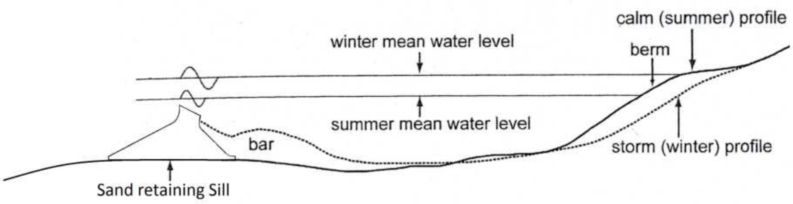


FIGURE 6.2 PRINCIPLE OF BAR RETAINING SILL

6.2 Properties

Location

The sill is located just outside the surfzone, 80 m offshore. The sill will be constructed over the entire project length of 2400 m.

Hydraulic principle

The shape of the sill plays an important role. From reference projects information about different shapes has been obtained. The shape as seen in 6.2 will be applied for this project, since it proved to be the most efficient. The sill itself blocks offshore sediment transport and a bar forms in front of the sill. Due to the return current and the shape of the sill the sediment flow will be forced upwards. Waves will then move this sediment back to the shore.

FIGURE 6.3 EXAMPLE OF A SILL

6.3 Design

Material

Due to the strict requirements on the cross profile of the sill it will be made out of precast reinforced concrete elements. Although seen as a hard engineering solution it is not possible to construct the required shape out of rock, sand or geotextile. The concrete cover should be sufficient, it is recommended to apply a cover of at least 60 mm to resist corrosion of the steel due to salt water. The exact shape of the sill is not known, but it should roughly match the dimensions shown in figure 6.4. The elements have an interlocking system attached to them in longitudinal direction to make sure individual elements are unable to slip away.

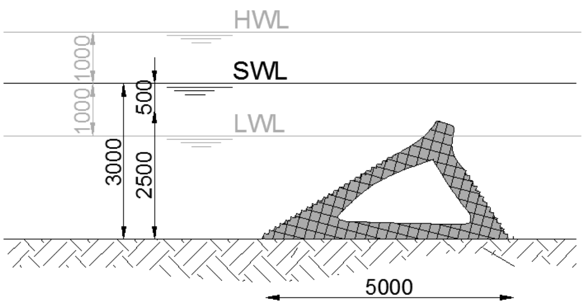


FIGURE 6.4 DIMENSIONS OF SILL

Construction

The sill can be constructed by placing the elements from a barge in the water. Divers will be necessary to guide the elements to the right location and make sure the elements are interlocked to each other in longitudinal direction. Construction time of the sill should be low because the prefab elements do not need any additional treatment on site and are easy to place.

Between the seabed and the sill a geotextile mat has to be placed, in order to prevent scour next to the structure. This mat extends several meters further in both the onshore and offshore direction. At the end of each side an anchor geotextile tube is attached to the mat to make sure it stays at the right place.

6.4 Delft3D

The effect of the sill is modelled using Delft3D. The expectation is that the sill mainly influences the cross-shore sediment transport. Delft3D is never widely used for cross-shore sediment transport and not recommended to do so. It is used however, to compare it with the other alternatives and to give an idea of what may happen when the sill is built.

Model setup

It is not possible to model the exact design of the sill in Delft3D. To approach the real situation the bed level is extended at the location of the sill. The whole sill will have the same crest height, namely 0,5 meter below reference height (Chart datum). This is done over the whole length of the project: 2400 m. The sill is put up in three meter water depth, which is approximately 80 meter offshore (Figure 6.5 cross section bed profile with sill)

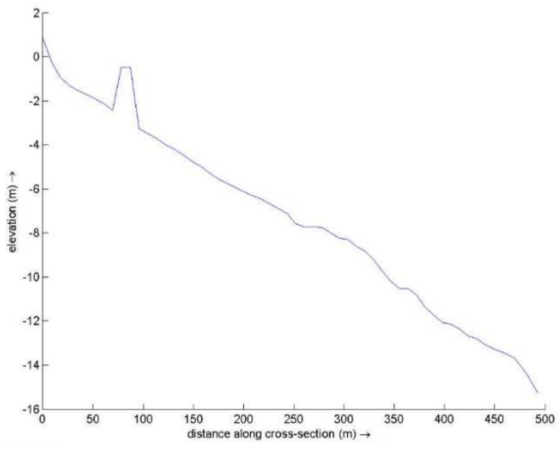


FIGURE 6.5 CROSS SECTION BED PROFILE WITH SILL

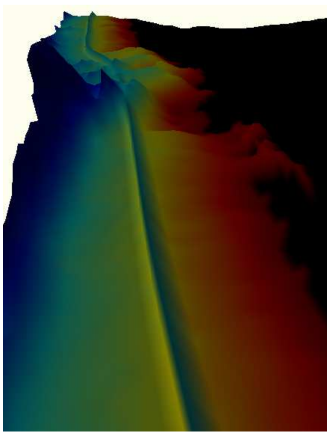


FIGURE 6.6 3D BED PROFILE WITH THE SILL

The extended bed level is modelled in such a way that no erosion can occur at that specific point. It considers it as a hard structure. The rest of the bed level, wave conditions and boundaries are the same as in the initial situation.

Results

The results are distinguished out of a short run where in the entire wave conditions and the tides are present, so that every combination is represented. In Figure 6.7 it can be seen that at the structure itself will not erode nor settlement will occur, as how it is set up in the model. On the seaside of the sill a line of erosion will occur. As said this will be countered using a geotextile mat. On the landside of the structure it can be seen that no erosion will occur. Even sedimentation will occur on some places. Out of these two factors it can be concluded that the sill behaves as expected and works well to contain the beach. However, the model gives some unpredictable results seeing the big red and blue dots in Figure 6.7. Furthermore, as long as the exact design is not modelled, the behaviour of the sill is not certain.

Looking at the bed level, only minor changes occur. This is mostly due to the fact that the model runs for a short period of time. It can be seen however that between the beach and the sill the bed level will stay more or less the same. On the seaside of the sill the bed level is slightly lower, making a steeper slope.

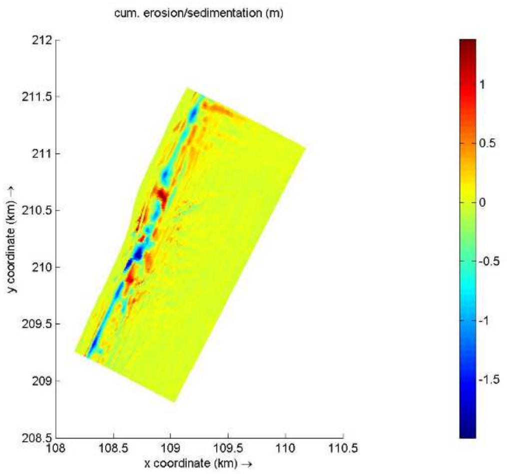


FIGURE 6.7 CUMULATIVE EROSION/SEDIMENTATION SILL OPTION

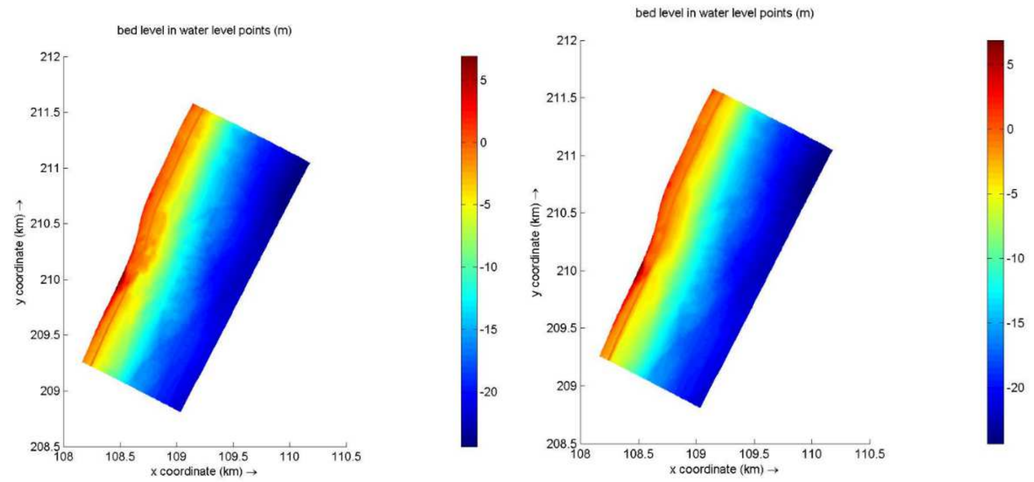


FIGURE 6.8 BED LEVEL CHANGE BETWEEN T0 (LEFT) AND T1 (RIGHT)

6.5 Stakeholders analysis

If a sand retaining wall is to be constructed, more actors are informed than consulted compared to constructing the submerged breakwater. The reason for this is the uncertain effect the sand retaining sill is supposed to bring with it. Actors like coastal leaseholders and coastal property owners are then consulted about the use of extra space in case extra case is expected to be created due to the sill. Because the construction of the sill is a non-established technology, input from consultants, construction company and surveyors is useful as well.

Inform	Consult
• Residents Umhlanga • Timeshare owners • Business community: bars/restaurants/pharmacy • Hotels Umhlanga Rocks • Hotels: Oyster Box, Beverly Hills • Umhlanga UIP • Tourists • KwaZulu-Natal Provincial Government (MEC) • National government • Port authorities • Residents in Durban • The lifesaving club • Surfers and kite surfers • Operators of ocean trips • Daily people Umhlanga • Recreational Ocean users: fishers	• Coastal lease holders • Coastal property owners/developers • Coastal Watch/Wildlife/WESSA/ORI • Surveyors • Building contractor • Consultants

TABLE 6.1 STAKEHOLDER ACTION ON BAR RETAINING SILL OPTION

6.6 NPV

The bar retaining sill is constructed using prefab concrete elements, costing $2000 per meter. Including fixing- and construction costs the total cost of the sill amounts to a little under ZAR 200 million. This amount is spread over the 1.3 years it takes to construct the sill (see appendix F1).

Simulations of the sill in Delft3D do not confirm the suspicion that the sill would aid in accretion of the beach. In the literature one instance was noted where this was the case. For this report it is assumed that the sill retains the beach as it is today.

Benefits

Benefits do not increase in this option. They remain equal to the benefits today. Also no increase in property value occurs since no beach area is added. The current property rates are continued. No benefits from labour are assumed, since the construction of the sill requires highly skilled labour. This labour is most likely currently also being used, meaning that jobs created through constructing the sill are displaced from somewhere else and not added to the local economy.

7 Nourishment

7.1 General information

Assumptions

Nourishments already happen on a regular basis along the Kwazulu-Natal coastline and are a possible solution for the Umhlanga Rocks problem. The two main ways to perform nourishments are by either rainbowing the sand onto the beach or pumping it with pipelines and using shovels to spread it out across the beach. Due to a lack of expertise when it comes to rainbowing it is assumed that any beach nourishment will be done using pipelines. At the edge of the project area there is a possible sand depot, it is assumed it will be possible to use this sand depot for possible nourishment at Umhlanga.

Hydraulic principle

The idea behind nourishment is to add more sand to the beach than the amount that erodes. If enough sand is added this should also create a wider beach. A wider beach should also offer enough resistance against storm, providing protection for the properties located behind the boulevard.

7.2 Nourishment scheme

Execution process

The sand depot is located quite close to the project area, see figure 7.1. A pipeline with a length of 700 m is used to transport the sediment from the depot to the beach. A dredger is used to excavate the sand and pump it to the beach. The sand is stored on the beach in several piles located 200 m apart. This means that after the first pile of sand is placed the pipeline will have to be moved and the dredger will have to move from the sand depot to connect to the pipeline, see figure 7.1. The pipeline itself will be a floating pipeline connected to the beach at one end and a pontoon on the other end. On the beach shovels will be used to flatten out the piles of sand created by the dredger.

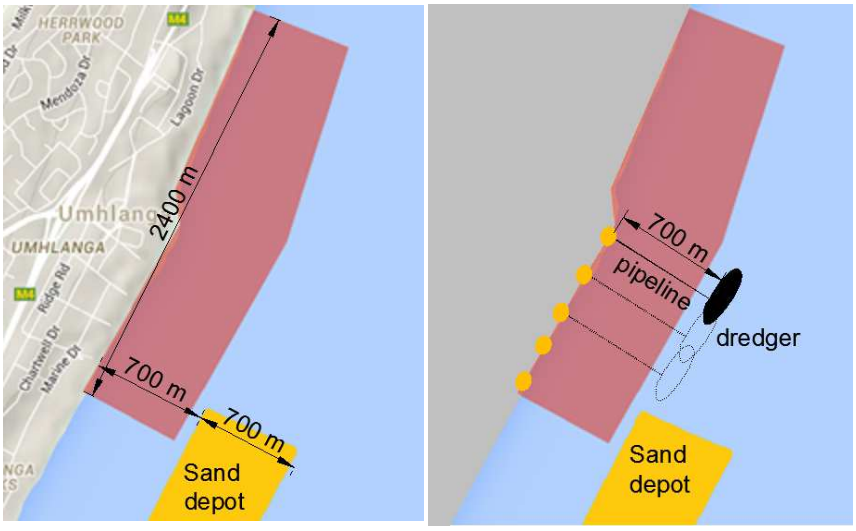


FIGURE 7.1 LOCATION OF SAND DEPOT AND EXECUTION PROCESS

7.3 Delft3D

Model setup

The nourishment model has the same conditions as the initial situation. The only difference is that a three meter layer of sediment is added to the beach. This extra layer has a width of 300 meter extending along the whole length (2400 m) of the project location. After this layer is added, the depth file is smoothed. This is done to prevent problems with an abrupt change in the bed level of three meter.

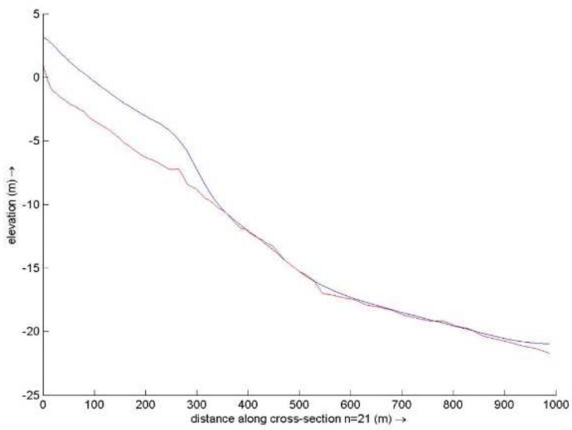


FIGURE 7.2 BED LEVEL BEFORE (RED LINE) AND AFTER (BLUE LINE) NOURISHMENT

Results

The results are derived out of a short run where all the wave and tidal conditions are present. As can be seen in Figure 7.3, two parallel lines of sedimentation and erosion occur. Erosion occurs at the edge of the added sediment. Sedimentation occurs slightly more offshore. These two effects means that the slope of bed level flattens out and that the nourishment is spread out offshore. The two lines of sedimentation and erosion will slowly move to the shore. Eventually all the nourishment will be spread and some of it will be washed further offshore. This will go way faster than in the original situation. Therefore scheduled maintenance is necessary in order to retain the beach.

The beach has an increased width immediately when built. Because the model runs only for a short amount of time, there are no large changes in the model pictures. When looking at the numbers however, it turns out that the beach is eroding quite fast. After extrapolating the result is that after 8,5 years the beach width is back at the original situation.

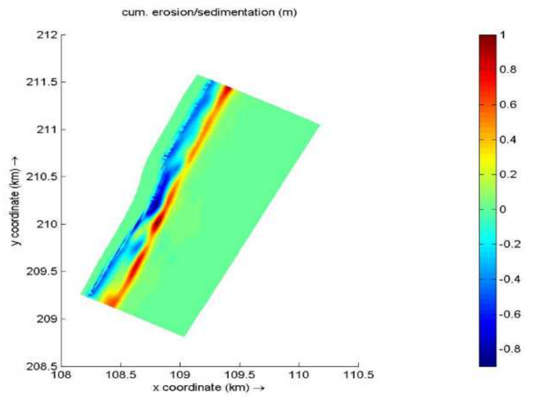


FIGURE 7.3 CUMULATIVE EROSION/SEDIMENTATION NOURISHMENT OPTION

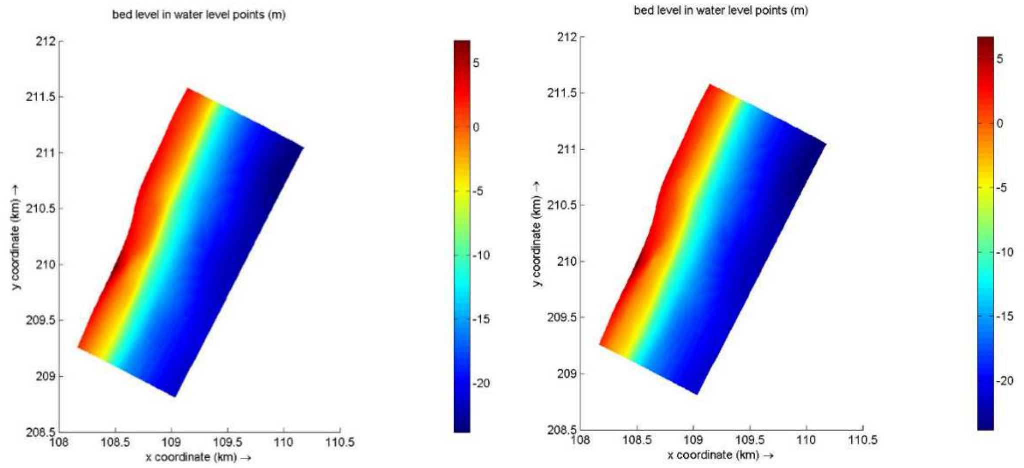


FIGURE 7.4 BED LEVEL CHANGE BETWEEN T0 (LEFT) AND T1 (RIGHT)

7.4 Stakeholder perception

When considering nourishment as an alternative, there is only one stakeholder opposed. These are the environmental groups because of the disturbance nourishment causes to sea life. For this reason they should be consulted about the sand extraction area where the extraction causes least disturbance to the sea life. Port authorities are opposes, only because there is only one dredger available and the dredging activities in the harbour are dependent on it. Coastal leaseholders, Coastal property owners/developers and the lifesaving club should be involved since nourishment takes place directly on the beach and it is necessary to fine-tune the amount of space created and the purpose of use for this space.

Inform	Consult
• Residents in Durban • Surfers and kite surfers • Surveyors • Operators of ocean trips • Building contractor • Consultants • Daily people Umhlanga • Recreational Ocean users: fishers • KwaZulu-Natal Provincial Government (MEC) • National government • Tourists • Umhlanga UIP	• Port authorities • Residents Umhlanga • Timeshare owners • Business community: bars/restaurants/pharmacy • Hotels Umhlanga Rocks • Hotels: Oyster Box, Beverly Hills • Coastal Watch/Wildlife/WESSA/ORI
Involve	
• Coastal lease holders • Coastal property owners/developers • The lifesaving club	

TABLE 7.1 STAKEHOLDER ACTION ON NOURISHMENT OPTION

7.5 NPV

Nourishment consists of pumping sand from an offshore location onto the beach. The required tools are listed in appendix G1. Previously the municipality calculated different solutions for the tidal pool project. The calculations included nourishment of 110 m of beach adding 15 meters of extra beach. This data was initially used to calculate the amount of sand needed to add 15 meters of beach to the entire length of the project area. After further calculations the estimate from urban-econ could not be reproduced. From our own calculations about half the sand from the urban-econ estimate is needed to ensure 15 meters of extra beach, assuming the same 15 meter closure depth as the urban-econ estimate.

7.7 million m^3 of sand will need to be added to the beach resulting in

The total amount is roughly ZAR 380 million in 2012 , adjusted for inflation and divided over 4.82 years equals

$$\frac{(409\ 789\ 754.76)}{4.82} = ZAR85\ million\ a\ year$$

Because nourishment does not reduce the wave climate the beach is still eroding at the same level as before. The loose sand that was freshly nourished is likely to erode even faster. According to the urban-econ report roughly 5% of the originally nourished amount needs to be replaced. 25% of the originally nourished amount will be replaced every 5 years.

Benefits

The benefits from nourishment are mostly dictated by the increased beach size. Because through nourishment the beach increases rapidly and stays enlarged for a long period of time the added benefits are accumulated over a long period and occur early, this is beneficial to the NPV. Other benefits include an increase in property values, that also increase the returns from ownership rates.

8 Breakwater design

8.1 General information

Requirements

This chapter focuses on coming up with a design for a submerged breakwater in front of the Umhlanga Rocks coastline. The breakwater should reduce wave energy and hereby prevent erosion from taking place. This should extend the beach by a significant amount and provide enough protection during storms. To reach these goals the following requirements have been set:

- To prevent horizon pollution a statically stable submerged breakwater will be considered, with the crest of the structure under the still water level.
- A salient is the preferred shoreline response on the submerged breakwater for this project. A salient allows for littoral sediment transport to continue through the project area to the downstream beaches. Therefore the breakwater needs to be built sufficiently far from the shore.
- The submerged breakwater will be designed in such a way that it takes away part of the incoming wave energy by reducing the wave height. The transmitted wave height should be unable to cause severe erosion.
- 40 to 50 m beach at high tide is desirable. At this beach width it is assumed that there is sufficient amount of sand in front of the retaining wall to prevent any storm from causing severe damage to any structures located behind the beach.
- For the design of the submerged breakwater a storm with a return period of 30 years will be considered. This is based on the requirements formulated in the design criteria.

Design process

To come up with a design that matches the above mentioned criteria the following procedure will be followed. First a storm with a return period of 30 years will be defined. Wave heights at which beach erosion occurs will be determined. From this the wave transmission factor (Kt) can be calculated. From the Kt factor and the fact that it is desirable to minimize littoral sediment transport, the location of the submerged breakwater can be determined. The materials used for this design will be looked further into. The materials that will be considered are: rocks, geotextile bags and geotextile tubes.

Design storm 30 year return period and tidal range

There are many different ways to determine the properties of a storm with a return period of 30 years. However since the focus of this design is not on the wave properties and because there are some excellent articles available on the wave climate near Umhlanga rocks it was decided to use this data. From the article on the wave climate on the KwaZulu-Natal coast of South Africa (Corbella S; Stretch D, 2012) it is concluded that a storm with a return period of 30 years has the following significant wave height and period.

$H_s = 8.5\ m$

$T_p = 16\ s$

These wave heights have been measured at a depth of 22 meters. By using delft3D the corresponding significant wave height at the toe of the breakwater is calculated. The following wave height is used for modelling the breakwater:

$H_s = 4.75\ m$

$T_p = 14.5\ s$

For the tidal range historic data was reviewed and it was decided to use a tidal range of 2 meters. Varying from SWL -1 at low tide to SWL +1 at high tide.

A sea level rise in Durban of 2.7 mm ± 0.05 mm per year at a 95% confidence level is expected (Mather, 2007). This means an increase of circa 8 cm during the lifetime of 30 years. The increase of 8 cm is negligible compared to the significant wave height of 4.75 m and will not be taken into account.

The wave direction is taken perpendicular to the coast. This leads to the highest wave load on the breakwater and a safe design.

Erosion

To design the submerged breakwater there should be a requirement on the wave height on the leeside of the breakwater. The design criterion was that there should be no severe erosion on the Umhlanga beach. Due to the limited time available for the project it was decided to determine the wave height at which serious erosion occurs from historic data. From this it was concluded that beach erosion starts from a significant wave height of 3.5 m. The breakwater will be designed to reduce the significant wave height of 4.75 m from a storm with a return period of 30 years to 3.5 m. This should limit the amount of erosion by a sufficient amount to create a stable coastline.

8.2 Properties

Transmission coefficient Kt

A submerged breakwater, with the crest of the structure below the still water level, allows overtopping and transmission. The submerged breakwater will reduce the energy of incoming waves by a certain amount. This is taken into account by the transmission coefficient Kt. From the incoming and transmitted significant wave height the required Kt factor is calculated and included in appendix H1. To reduce the transmitted wave height from 4.75 to 3.5 m, the transmission coefficient may not exceed 0.74.

Breakwater dimensions and location

With the transmission coefficient known the relation between crest height, width and slope can be calculated. This has been done for several combinations for both a permeable breakwater and an impermeable breakwater; a table with the different dimensions and corresponding transmission coefficient is included in the appendix H1. From this table the optimal design was chosen by calculating the area of the cross section of the breakwaters that had a Kt factor of about 0.74. The dimensions that gave the lowest area (lowest amount of material required) was considered to be the most optimal design. Another requirement was that the breakwater should remain below the waterline most of the time. To reach this goal the breakwater is positioned below the low tide water level. During a storm at high tide the crest will be at least 2 meters below the water level. The chosen dimensions of the breakwater are:

For a permeable breakwater:	For an impermeable breakwater:
$B = 3\ m$	$B = 5\ m$
$Rc = -2\ m$	$Rc = -2\ m$
$tan\alpha = 1{:}2$	$tan\alpha = 1{:}2$
$Rc = 0.69$	$Rc = 0.72$

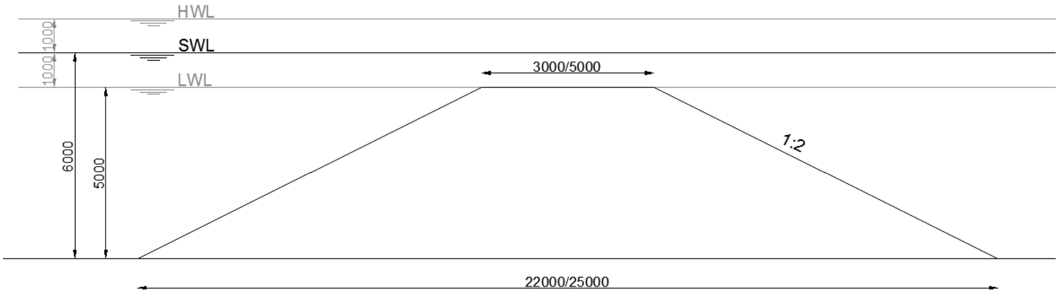


FIGURE 8.1 CROSS SECTION BREAKWATER

To maximize beach growth the breakwater will be constructed just outside the surf zone according to figure 8.2. From aerial photographs it has been estimated the surf zone extends about 93 meter seawards. This leads to the breakwater being located 100 m offshore. From the cross shore profiles provided by the municipality of Durban at an offshore distance from 100 m measured at the pier the depth is 6 m. Although the depth also varies in longitudinal direction the breakwater will be dimensioned for a water depth of 6 m.

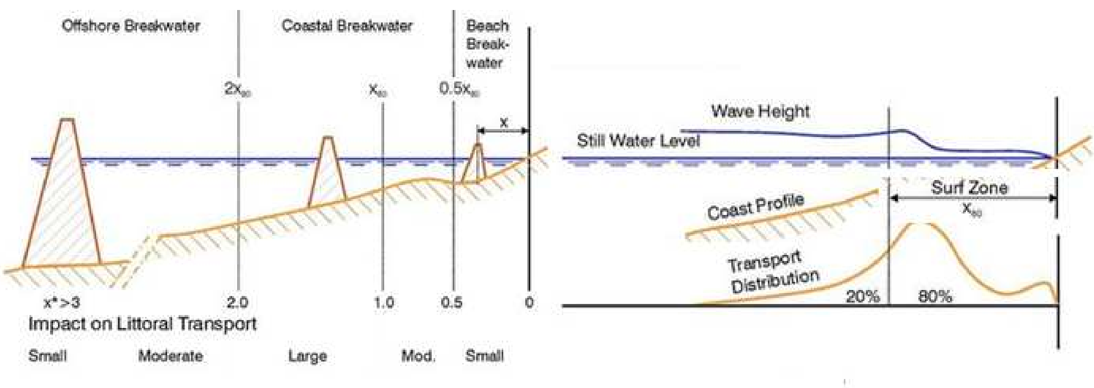


FIGURE 8.2 PLACEMENT OF BREAKWATER AND SEDIMENT TRANSPORT

The project area includes 2.4 km of shoreline so multiple breakwaters have to be constructed. The determination of the dimensions is included in appendix H2. The requirements, assuming a salient, for the offshore location and length of the breakwater are given below.

$$L_s < 385\ m$$

$$111\ m < G < 307\ m$$

$$G > 1.3 * 10^{-3} * L_s^2$$

To get a most economical design a minimal amount of breakwaters is preferred with a maximum gap width. A maximum gap width will also give lowest possible currents that can lead to dangerous situations for swimmers. Considering that the project area has a length of 2400 m the following length and gap width seem most optimal. The dimensions are given in the 8.3.

$$L_s = 380\ m$$

$$G = 300\ m$$

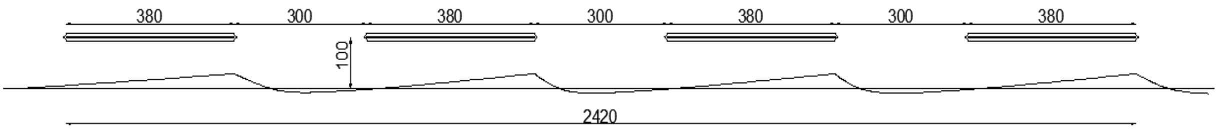


FIGURE 8.3 TOP VIEW BREAKWATER PLACEMENT

Materials

To reach a proper design for the breakwater, different materials are considered: rock, geotextile bags and geotextile tubes. Rock is considered a hard engineering solution, while geotextile systems are considered a soft solution. In the next chapters a preliminary design is made for these materials.

8.3 Rock breakwater design

Rock is one of the most common materials used for constructing breakwaters. Before looking into more experimental materials like geotextile bags and tubes, an armour layer made out of rock is calculated. This is done using the Van Der Meer equations and can be found in appendix H3.

For the armour layer a stone weight of 8 ton is needed. This stone size is unacceptably large. A more detailed design could lead to a smaller stone size; however obtaining rocks and transporting them to the location would be very expensive. The transport of the rocks would lead to very high traffic load at Umhlanga during the construction of the breakwater, which is an undesirable situation. It will also be very difficult to remove or adjust the breakwater once it is placed.

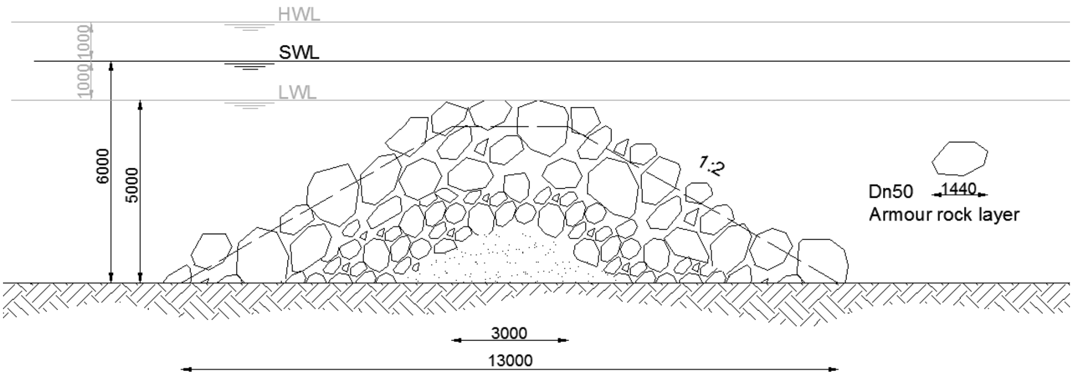


FIGURE 8.4 CROSS SECTION ROCK BREAKWATER

8.4 Geotextile systems

For the situation at Umhlanga Rocks the use of a geotextile system for a submerged breakwater looks very promising. This can be done with either geotextile bags or tubes filled with sand. This part of the report will focus on designing a submerged breakwater made out of geotextile bags and one out of geotextile tubes. This system is especially fit for the Umhlanga Rocks area. Geotextile bags have already been used extensively in the area and have proven to provide a sustainable solution as retaining walls and dune reinforcement. In general these bags are seen as a soft engineering solution because they can easily be removed by cutting the bags. For this project it was much preferred to use materials that blend in with the surroundings, geotextile systems match this criteria. For construction only the transport of the bags is needed, they can be filled at the location, either above or below water.

Design process geotextile systems

For the geotextile bags and tubes use will be made of the *Geosystems: design rules and applications and Geosynthetics* and *Geosystems in Hydraulic Engineering and Coastal Engineering*. Additional use will be made of papers concerning the stability of bags and tubes to come to a solid design (Kriel, 2012). With the cross section from the previous chapter the amount of bags or tubes needed can be determined. This will lead to two designs, one for geotextile bags and one for tubes. An event tree is set up to determine the possible failure mechanisms and conditions required for these mechanisms. From this the design rules in the manual and papers can be applied to come to a safe design.

Load

Wave induced forces

To determine the stability of the geotextile bags and tubes a trapezoidal distribution of the wave load is assumed along the breakwater (Pilarczyk, 2000). The decisive load is from a wave with a significant wave height of 4.75 meters. The formula for determining wave load is as follows:

$$wave\ load = \frac{3}{4}(1+k)H_s * \rho_w * h * g$$

$$h = height\ of\ structure\ exposed\ to\ wave\ load$$

$H_s = 4.75\ m$

$\rho_w = 1030\ \frac{kg}{m^3}$

$g = 9.81\ \frac{m}{s^2}\ gravitational\ constant$

$k = 0.45\ reflection\ coefficient$

Self-weight

The weight of the bags or tubes is the most important factor in resisting the wave induced forces and plays an important role in determining the overall stability.

Load during constructing

The highest tensile loads on the geotextile elements occur during construction of the breakwater due to the filling, positioning and dumping of the tubes respectively bags.

During constructing a reduced wave height is assumed. When the significant wave height of the incoming waves exceeds 1m, no tubes or bags should be placed.

Failure mechanisms

A failure tree is created to find all the possible failure mechanisms of the geotextile systems. The failure tree is included in appendix H4. The design is checked on inadequate stability, inadequate strength of the geotextile and ship collision. For certain failure mechanisms a calculation is not relevant, these are mentioned below.

Internal stability of the filling material only becomes a problem at high filling ratios. The filling ratios are all over 75%, so internal stability should not be a problem. No further checks on this failure mechanism are performed.

Depending on the size of the ship major damage could be caused in case of collision. Safety measures should be taken to prevent any ship from colliding with the breakwater. This can be done by marking the area with buoys. In case large ships collide with the breakwater it will be heavily damaged and new tubes will have to be installed.

The rocky underground in front of the Umhlanga coastline provides a solid foundation for a geotextile breakwater. Special care should be taken during installation with sharp rocks, to prevent rupture or puncture of the geotextile. This problem can be reduced by applying an apron mat underneath the breakwater.

Puncture of the geotextile can also occur when the breakwater is exposed to a wave attack. Objects in the in the water can penetrate the geotextile. Due to the penetration, the soil and geotextile will deform what gives local tensile stresses on the geotextile skin. To resist these local stresses, the tension and elongation properties of the geotextile should be sufficient. If the geotextile is not able to resist the local stresses a load-spreading layer can be used. The use of a woven geotextile will limit the effect of the puncture.

The geotextile skin must remain intact during the lifetime of the breakwater. The properties of the geotextile can change over time due to; UV-radiation, creep, hydrolysis and ageing, which can lead to a reduction of the strength of the geotextile.

Because the breakwater has been carried out as a submerged breakwater there is less UV exposure. When there is less UV exposure and the geotextiles are manufactured from polyester with high strength properties, the decrease of strength from the geotextile due to hydrolysis is negligible. Also decline due to ageing remains limited due to the limited exposure to UV-radiation.

The highest tensile loads on the geotextile elements occur during construction of the breakwater. After the construction phase the tensile stresses in het geotextile are often very small so the effects of creep are limited. Even if the effect of creep is considered, the decline of strength due creep is included in the material reduction factor.

To increase the durability of the geotextile and to provide better protection against puncture of the geotextile, the geotextile skin can be manufactured double layered.

Design

Geotextile tubes

Geotextile tubes have been used on several locations around the world to construct an emerged or submerged breakwater, mainly around Australia and New Zealand. Some have been installed in similar wave conditions as Umhlanga Rocks. The municipality has some experience with constructing geotextile tubes. On one occasion a tube was installed, however, the filling process proved to be difficult and eventually the costs exceeded that of a geotextile bag design. With more experience and better construction process it is expected a more cost efficient design is possible, therefore a geotextile tube design is considered. To reach the required Kt factor and dimensions the following cross section is considered:

$B = 5\ m$

$Rc = -2\ m$

$tan\alpha = 1{:}2$

$Rc = 0.72$

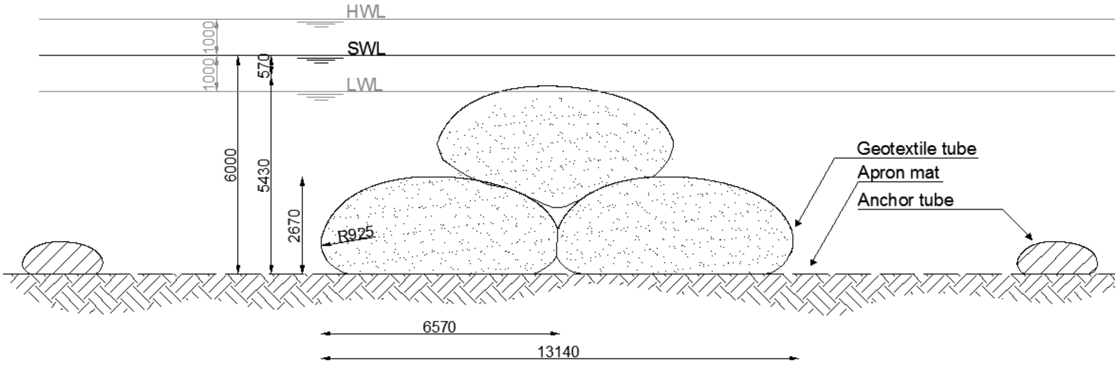


FIGURE 8.5 CROSS SECTION GEOTEXTILE TUBE BREAKWATER

Geotextile bags

Geotextile bags have been applied on several occasions along the KwaZulu-Natal coastline. The municipality of Durban has a lot of experience with using this system. It was decided to make use of this experience instead of coming up with a new design. T make sure the bags are stable the slope needs to be adjusted to a 1:1 slope. To meet the requirements on the Kt factor the cross section for the geotextile bags needs to be adjusted to the following:

$B = 10\ m$

$Rc = -2\ m$

$tan\alpha = 1:1$

$Rc = 0.74$

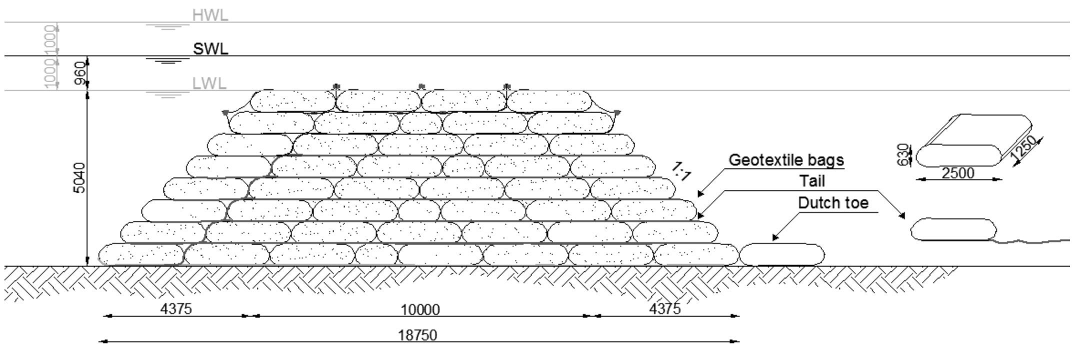


FIGURE 8.6 CROSS SECTION GEOTEXTILE BAG BREAKWATER

To avoid the top bags sliding off, several bags will have to be sewed together. The bags on the slope of the breakwater will have a tail attached to them to increase their resistance against slip and pull out failure mechanism. This is further explained in the stability calculations. To determine the factor of safety against slip circle failure use has been made of the program GEOSTUDIO 2012.

Stability

Geotextile tubes

From the failure tree it can be seen that there are various ways the tubes can fail when it comes to stability. The main loads that lead to these failure mechanisms are wave induced forces and and self-weight of the bags. The following stability mechanisms are checked, the complete calculations are included in appendix H5. The coefficient of interaction plays an important role when determining the stability of geotextile tubes and bags. For this coefficient the following formula is used (Nielsen & Mostyn, 2011):

$$CI = \frac{tan\varphi_{sg}}{tan\varphi_s} = 0.75$$

$\varphi_{sg} = 25\ degrees\ friction\ angle\ geotextile$

$\varphi_s = 32\ degrees\ friction\ angle\ loose\ sand$

-Overturning of a tube, is checked by comparing overturning moment caused by wave loading to the resisting moment from the self-weight of the tube. Safety factor=1.31

-Slip of top tube. The top tube is most vulnerable to slipping, because there are no other tubes behind it to resist the hydraulic loading. Safety factor=1.07, additional safety measures might be need here.

-Slip of entire tube structure. Safety factor=2.41

-Slip circle of the back and top tube. Failure of the structure where the back row slides downwards due to self-weight and hydraulic loading. Safety factor=1.28

Geotextile bags

The same failure mechanisms as geotextile tubes are checked for the geotextile bags. All calculations are included in appendix H6.

-Overturning of a bag, is checked by comparing overturning moment caused by wave loading to the resisting moment from the self-weight of the tube. To resist the overturning moment Safety factor=1.82

-Slip of top bags. The top bags are most vulnerable to slipping. It is assumed the top four bags are connected. Safety factor=1.45

-Slip of entire bag structure. Safety factor=2.01

-Slip of back row of the structure due to self-weight and hydraulic loading. Safety factor=1.47

-Slip circle failure of entire structure. Calculated by using GEOSTUDIO 2012, tails will have to be applied to the outer bags. Safety factor=7.44

Material properties

Geotextile skin

The geotextile skin must satisfy several requirements. The geotextile needs sufficient tensile strength and strain to withstand the deformations and the changes of shape over time. The geotextile must satisfy the requirement to resist the load during filling, to prevent erosion of the filling material and needs to fulfill the requirements regarding durability to remain intact over the design life of the tube.

Material	*Unit weight [kg/m^3]*	*Tensile strength [N/mm^2]*	*Elastic modulus [N/mm^2]*	*Maximum strain [%]*
Polyester (PET)	1380	800–1200	12000–18000	8–20
Polypropylene (PP)	920	400–800	2000–8000	6–25
Polyethylene (PE)	900–930	350–600	600–6000	10–30

TABLE 8.1 GEOTEXTILE DESIGN RULES AND APPLICATIONS

The geotextile skin of the tubes is manufactured using a woven polymeric yarn. Selection can be made between the use of polyester or polypropylene.

For the calculations geotextile type GT 750M is used with a tensile strength of 120 kN/m. The maximum stain is assumed to be 15% at breaking. The pore size (O_{90}) of the geotextile is assumed to be 250 µm. The specifications of the geotextile are included in appendix H7.

Material reduction factor

For the design of the geotextile tubes several safety factors are used. During the filling of the tube, the geotextile can be weakened by the abrasion of the sand-water mixture. This is taken into account by the strength-reduction factor ϒd. For the decline of the strength due to creep for polyester a reduction factor of 1.4 is used. The seams are often the weakest point in a geotextile system therefore a strength-reduction factor of 2 is used.

γd =1.25

γcreep = 1.4

γseams =2

The different strength-reduction factors give an overall material reduction factor of 3.5.

Strength of geotextile skin

Geotextile tubes

The required tensile strength of the geotextile can be determined by taking the loads on the geotextile during filling. The ultimate load depends on the degree of filling, the pumping speed, the fill material and the shape of the geotextile. The location where the highest curvature occurs is at the sides of the geotextile tubes. There you will find the highest stress in the geotextile.

The circumferential force is much larger than the axial force and therefore decisive for the strength of the geotextile. High tensile stresses also occur at the connection of the filling ports, to withstand those stresses measures needs to be taken. Calculations can be found in appendix H8.

The geotextile tubes must meet the strength requirements in all places. The seams are required to resist the tensile load without the seams tearing which would allow loss of fill material. A minimum of the circumferential tension is found at the bottom of the geotextile tube (*10-15% of the maximum circumferential tension*). Therefor the seams in the geotextile tubes should be at the bottom side of the tube.

- The strength of the skin is checked to resist the circumferential force in the geotextile. Safety factor = 1.14
- The longitudinal seams are checked to resist the circumferential force working in the skin of the tube. Safety factor = 3.8

Geotextile bags

The highest tensile stresses in the geotextile bags occur while dumping and lifting of the bags during construction.

When dumping the geotextile bags on the required location, the bags are subjected to an increased load and deformation while they hit the bottom. To resist this load the strength and strain of the geotextile needs to be sufficient. While lifting the bags from the vessel to the required location the weight of the fill material will be transferred through the geotextile into the bands of the crane. Calculations can be found in appendix H9.

- Safety against dumping. The geotextile skin is checked to resist the increased load and deformation while the bags hit the bottom. Safety factor = 1.21
- The bag is checked to resist the tensile load in the geotextile caused by lifting of the bags. Safety factor 1.13

Loss of fill material

The use of a woven geotextile provides a soil retaining, water permeable tube. To prevent erosion by sand washing out of the tubes a maximum pore size for the geotextile can be estimated.

The pore size of the geotextile does not exceed the sieve size trough which 90% fraction of the sand can't pass. Thereby the geotextile skin fulfils the requirements

Risk of failure

While geotextile systems have been used in many projects around the world, there are still a lot of unknowns. Little information about the failure of geotextile systems is available, however from reference projects, some things can be said. Puncture or rupture of the geotextile leading to loss of fill material is the most common problem. For bags the total loss is limited to the volume of the bags. For tubes it seems that rupture only leads to sand loss locally and if repaired in time the damage can be limited. Some excellent repair methods are available that can be used to quickly repair any holes in the tubes. Regular inspections are needed to make sure repairs happen in time.

Construction aspects

Geotextile tubes

The geotextile tubes are executed with a scour apron and anchor tubes to prevent undermining of the tubes. On the scour apron the geotextile can be unrolled on the exact location, 100 m offshore. The geotextile tube will be filled hydraulically with a sand-water mixture of 20% using pumps. To prevent the geotextile tube rolling laterally during filling, the geotextile tube must be temporarily secured horizontally.

With a pump diameter of 0.4 m and a pump speed of 4.46 m/s the tubes can be filled with 27.4 m^1/hr (see appendix H10). The distance between in and outlet ports can be estimate based on the velocity of the sand to settle out the sand and water mixture. The distance between the ports should roughly be 15m.

Each of the breakwaters has a total length of 380 m. The breakwaters are divided in 4 separate geotextile tubes with a length of 95 m. The separate tubes have to be prepared and filled during one construction cycle. If the filling process is disrupted and the sand has settled it is not possible to continue filling the tube to the desired 75% fill ratio. Because of this each tube has four filling ports along the crest of the tube, meaning the tube can be filled within one hour.

Geotextile bags

The geotextile bags are placed one by one on the required location using a crane situated on a barge. Filling of the geotextile bags can be performed on the barge. When the crane lowers a geotextile bag, divers will move the bags to the required position.

The outer bags are constructed with tails. On top of those tails the rest of the breakwater layer is positioned to prevent the outer bags to wash away during a wave attack. The bags on the crest of the structure have been carried out with and an overlay to sew the bags together. Seaming of the bags is done under water, before the overlaying layer of geotextile bags is placed. To support the geotextile bags and to ensure the bags stay in position during construction, concrete blocks can temporarily be placed on the bottom to use as anchor blocks.

8.5 Delft3D

Model setup

The dimensions of the breakwater are known out of the hand calculations. These dimensions are approached in the model by rising the bed level on the right locations. This is done at the six meter water depth line. This line is mainly situated 170 meter offshore.

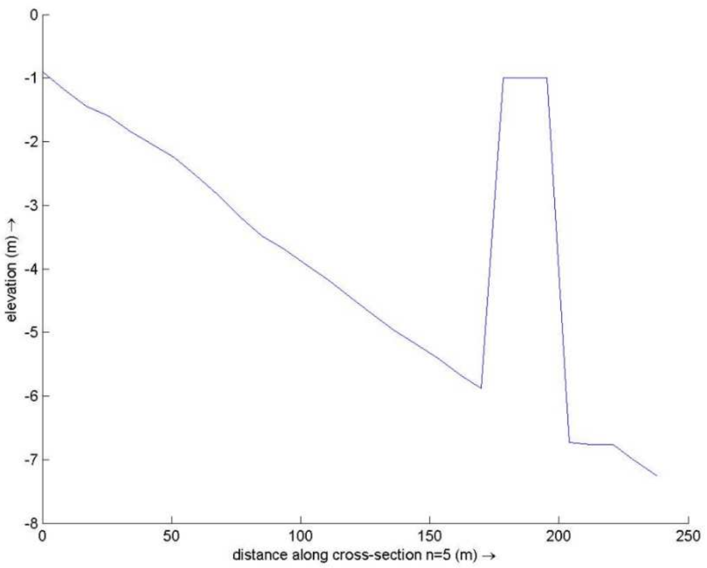


FIGURE 8.7 CROSS SECTION BED PROFILE WITH BREAKWATER

The bed level is extended up to -1 m SWL. The crest width of the breakwater is ten meter. The second breakwater from the south is placed further offshore, because there is a bump in the bed level. The six meter depth contour line is located further offshore. Because Delft3D works with a grid with a certain density, some values had to be rounded. The effects of this are neglected.

In the model there is no sediment available on the breakwaters, so that delft3d considers it as a hard structure which will not erode.

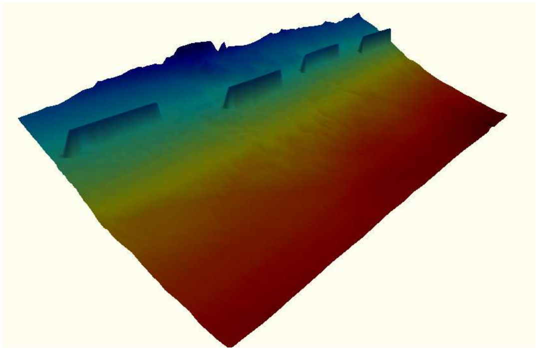


FIGURE 8.8 3D BED PROFILE WITH THE BREAKWATERS

Results

The results of the Delft3D model come from a short run where all the tidal influences and all the wave conditions are taken into account. When looking at Figure 8.9, different areas where erosion and sedimentation occurs are present. This is a pattern that can be expected by breakwaters. Sedimentation occurs at the leeside of the breakwaters and erosion in between the breakwaters. Sedimentation is mainly caused by the strong return currents induced by the submerged breakwaters. At the north and south boundary a lot of sedimentation occurs next to the breakwaters. In reality this is very unlikely. The model cannot cope with the boundary conditions in this configuration. Extending the grid and moving the boundaries so that they are not in the area of influence of the breakwaters anymore can probably solve this.

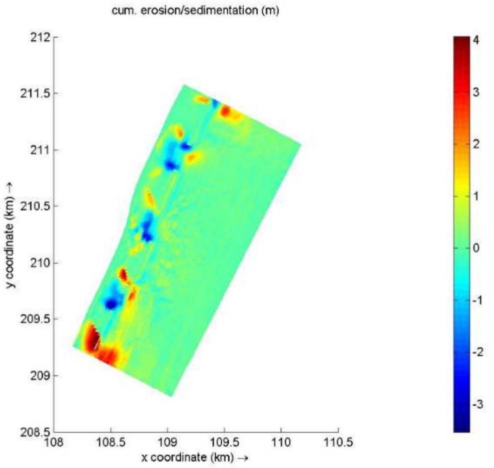


FIGURE 8.9 CUMULATIVE EROSION/SEDIMENTATION BREAKWATER OPTION

When looking at the bed level, one can see a big rise just behind the points of the breakwaters. This shape of the beach is not as expected and not usually seen in reality. It is assumed that this is caused by the wave input. All the wave conditions are taken into account in the wave input, but they are all reduced to only 14 wave conditions to reduce the computational effort. This probably resulted in two main wave directions, namely from the north-east and the south. This would cause the two different bumps at a breakwater instead of one big accretion in the middle of the breakwater. However, the final outcome is a positive result in means of beach growth. The area of accretion at the water level is larger than that of the eroding area. This means that the beach has grown over time.

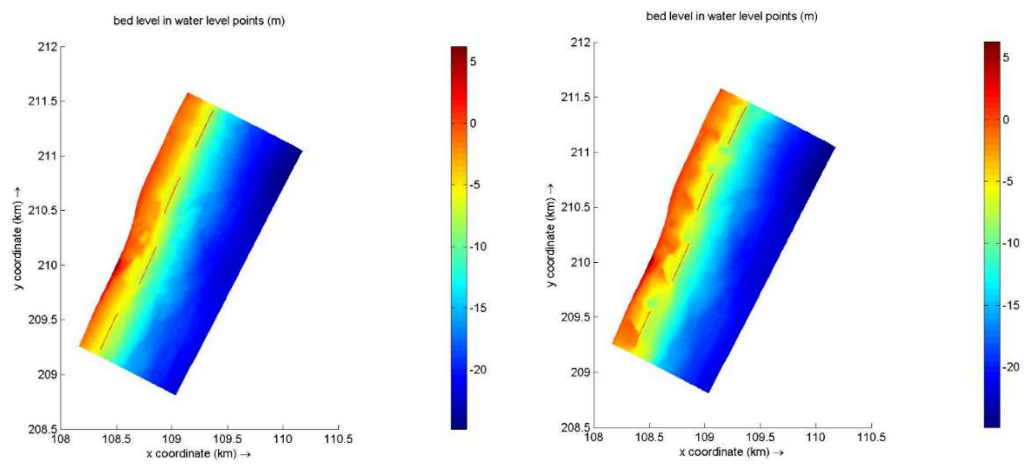


FIGURE 8.10 BED LEVEL CHANGE BREAKWATER OPTION BETWEEN T0 (LEFT) AND T1 (RIGHT)

8.6 Stakeholders perception

If the submerged breakwater is to be build, the environmental groups are seen as the most important opponents. However, the impact of the breakwater to the environment is insecure and results from environmental survey were not regained on time for processing them in the report. The reason 5-star hotels should be involved is although the construction evolves a submerged breakwater it is desirable to minimize disturbance of the tourists during the construction process. To minimize the effects of the breakwater to the swimming conditions and to monitor the effect of the breakwater to Umhlanga as a whole, UIP is collaborated with during the design, construction and use phase.

Inform	Consult
• Port authorities • Residents in Durban • The lifesaving club • Surfers and kite surfers • Surveyors • Operators of ocean trips • Daily people Umhlanga • Recreational Ocean users: fishers	• Residents Umhlanga • Timeshare owners • Business community: bars/restaurants/pharmacy • Hotels Umhlanga Rocks • Coastal lease holders • Coastal property owners/developers • Building contractor • Tourists • KwaZulu-Natal Provincial Government (MEC) • National government
Involve	**Collaborate**
• Hotels: Oyster Box, Beverly Hills • Coastal Watch/Wildlife/WESSA/ORI	• Umhlanga UIP

TABLE 8.2 STAKEHOLDER ACTION FOR NOURISHMENT OPTION

8.7 NPV

Geotextile bags

The geotextile bags are 2,5 x 1,25 x 0.63m with 1,25m being the length in the longitudinal direction. Each bag has a volume of 2m^3 and weights 4 ton when filled up with sand. According to the calculations, 4 breakwaters each 380m long are constructed, each cross section consisting of 44 bags. In total

$$4\ x\ \frac{380}{1.25}\ x\ 44 = 53504\ bags\ are\ needed$$

Information about the installation of the bags has been taken from the reinforcement of the North pier in Durban, where because of weather conditions on good days 20-30 bags a day where placed. In case of Umhlanga

$$\frac{53504}{30} = 1783\ days\ are\ needed$$

With 200 workable days this makes

$$\frac{1783}{200} = 8.91\ years.$$

With four breakwaters constructed simultaneously

$$\frac{8.91}{4} = 2.23 years$$

Then $30x200 = 6000\ bags$ could be placed a year.

$$6000\ bags\ a\ year\ x\ ZAR5000/bag\ =\ 30\ million\ per\ year\ in\ costs\ for\ placement\ of\ the\ bags.$$

The general construction costs are the total construction costs per hour from the table:

$$ZAR1600\ x\ 1600\ hours\ a\ year\ x\ 4\ breakwaters = ZAR10\ 240\ 000.00\ a\ year\ for\ two\ years\ long\ and$$

$$0.23\ x\ ZAR10\ 240\ 000.00\ for\ the\ third\ year = ZAR355\ 200.00\ (see\ appendix\ H11)$$

Geotextile tubes

The cross section of the breakwater made of tubes consists of 3 tubes with height of 95m. When placing the tubes each hour 27,4m of longitudinal direction can installed.

According to Worley (2005) tubes costs $2400 ($3077 in 2014 dollars at 2,8% inflation) for 14 diameter *30,5 land tube 4695 m^3 volume . This gives $0,50/m^3 of volume of bag for $953 dollars per tube, $953 equals $1221 in 2014 given 2,8% inflation $1241 = R13 750.

In the same article Worley refers to a different calculation coming down to $13,50/m^3 (Worley et al 2005). In the calculations used in the report the first calculation is assumed together with costs for crew and dive teams. The costs in the report of Worley are based on land filling and placement, so costs including equipment and divers to place underwater are much higher. This is why the first calculation is used see apppendix H11.

Benefits

Benefits from the breakwater come in the form of added beach space, in the amount of 30 meters over the course of fifty years. This added beach is interpolated linearly after the construction of the breakwater finishes. In terms of added beach space there is no difference in the bag or tube breakwater. Benefits amount to ZAR 25.000 per m^2 of added beach space.

Residential value will increase because of the increased beach width. Increase in residential is according to Pompe (2005) (see appendix x). The beach width is expected to increase by 30 meters. However the beach does not grow evenly and grows more around the edges of the breakwater, with incremental decreases in beach in between because of increased currents. Therefore an overall beach width increase of 20m is assumed. This results in an increase of 17% over the course of 50 years. The increase in property value in turn increases the return of property rates for the municipality.

9 Evaluation of alternatives

In this chapter the choice between the four alternatives of submerged breakwater, bar retaining sill, nourishment and “Do Nothing” is done. First the choice of analysis is substantiated. After this the criteria on which the analysis is based on are explained, together with their weights and the scores given. This chapter is used as input for the final recommendation of alternative for the coastal erosion problem in Umhlanga Rocks.

9.1 MCA vs. Permutation method

For the evaluation of the alternatives the permutation method has been considered. This method is based on the principle that every possible arrangement of choices can be tested on the degree of accordance with the effectiveness scores and the criteria weights. The order of alternatives that occurs most can be deduced by using a simultaneous treatment of preference scores and ordinal solutions through a series of permutations. (Verhaegen, TU Delft). The evaluation through a permutation method consists of three steps:

- Evaluation of each alternative based on determined criteria
- Measuring the values of the effects with regard to the criteria in ordinal scales
- Valuation of importance of each criteria by ordinal weights

For a problem with n alternatives there are n! possibilities to arrange the alternatives, which in this case results in 24 orders. However this method becomes quiet time-consuming when there are more than three alternatives involved. In this case the procedure of scoring in Excel becomes exceedingly difficult. For this reason the use of MCA is chosen once again.

9.2 Choice of criteria

During the choice of criteria taking **aesthetic value** into consideration is discussed but left out. The reason for this is that aesthetics played an essential role already in the simulation phase where it was given a high weight factor. As a consequence the three construction alternatives of nourishment, sand retaining sill and submerged breakwater came out from the simulation phase. As well as the geotextile bags as the tubes and the sand retaining sill are submerged and do not disturb the view. Nourishment does cause some changes, but sand is considered to be a natural material. Since the alternatives are submerged their aesthetic value is difficult to be distinguished from one another and to be scored. For this reason aesthetic value is not taken into account as a criterion.

Taking into account the cost benefit ratio and the internal rate of return as criteria in the MCA is considered. However Cost Benefit Ratio, NPV and IRR are three dependant variables, so just taking one of them into account is enough. Cost Benefit Ratio only gives information about the ratio between costs and benefits and does not give any information about the amount of money involved. The IRR is the interest rate that makes the Net Present Value zero. In this case however, the discount rate is not of a great importance, because it cannot be influenced. The **NPV** however gives an idea about the amounts of benefits and costs created, taking into account the different construction durations as well. Beside the NPV **the initial investment** needed for realization of the project is chosen as a criterion as well since eThekwini is a public party and has to consider budget constraints.

The criteria chosen for the evaluation of the alternatives are:

- **Net present value**
- **Initial investment**
- **Amount of beach created**
- **Stakeholders' perspective**
- **Environment Friendly**
- **Technological feasibility**
- **Robustness**
- **Construction time**

Since benefits are mainly created through the **creation of more beach**, which is seen as the main aim of the project, the beach surface created is seen as a separate criterion. **The stakeholder's perspective** scores are given based on stakeholder analysis performed and the resistance from these stakeholders against each alternative. Because of the marine life involved and probably influences through the construction of a project in Umhlanga, the **environmental impact** of the alternatives is scored as well. Another reason for adding this criterion is that the environmental impact was difficult to predict and for this reason, not given any monetary value and excluded from the NPV calculation.

Whether the project chosen uses established technologies is important as well. Non-established technologies are uncertain and bring more risks within their use. This element is included in the evaluation through the technical feasibility criterion. Same counts for the **robustness** of the alternatives. This criterion determines whether the alternatives meet the structural and hydraulic requirements of the design criteria. Although the **construction time** is indirectly involved in the calculation of the NPV, this criterion represents the construction time from a stakeholders' perspective, since longer construction time causes disturbance to the tourists and inhabitants of Umhlanga.

9.3 Weight factors

The weight factors are between 0.1 and 1, where a weight factor of 0.1 is considered as low and 1 as having essential influence on the final choice of alternative.

Net present value is given a weight factor of 0.4 because it is a very broad criterion, including initial investment, construction time, maintenance costs and benefits generated.

Initial investment: even if a project has a positive NPV, the amount of money needed at initial phase might be very high. When initial investment is high and eThekwini takes budget constrains into account, the implementation of the project might become difficult.

Amount of beach created is seen as the most important criterion, because it directly creates a buffer against erosion and generates benefits. For this reason it has been given a weight factor of 1.

Stakeholders' perspective receives a weight factor 0.7, because stakeholders opposing can use their power to obstruct the project. At the same time when environmental organizations are against a certain project eThekwini is convinced that the project's implementation is not going to be put through (eThekwini, 2014).

Environment Friendly receives a low weight factor of 0.2 because of the environmental perspectives are already partly included in the stakeholder's perspective.

Technological feasibility is important and is given a 0.7 as weight factor. When certain technology is not established or uncertain, this brings a lot of risks and eventually extra investments with it. At the same time expectations might not be achieved, which influences stakeholder's perspectives as well and creates conflicts.

Robustness: when a project is executed it is supposed to fulfil its function. In case of Umhlanga the project should not only generate benefits, but provide a good buffer for the erosion problem as well. For this reason robustness is given a high weight factor, equal to 0.8

Construction time is indirectly already included in the MCA through the NPV. However, a long construction time has negative effect on the surroundings since it causes temporary disturbance of view, noise and infrastructure pressure due to supply of materials. However since construction of any of the projects (beside the "Do nothing" option) is desired by the area because of its benefits, this criterion is given a low weight factor.

9.4 Scoring

Since there are four alternatives, including the "Do Nothing" option, and each alternative can be given 5 points, $4x5 = 20$ points are divided for each criterion.

Net present value

The results from the CBA have an NPV of R 133 943 413 204.19 for the geotextile tubes, R 116 047 784 420.46 for the sand retaining sill, R 142 110 738 758.75 for nourishment according to eThekwini 's report and R 142 705 465 863.42 for nourishment according to own calculations, R 23 559 867 811.76 for coastal erosion based on data from the past years for the "Do Nothing option". The NPV calculations show that nourishment has the highest so the best NPV. The difference in NPV between nourishment and geotextile tubes is only around R8 billion, so they are given quiet similar scores of 7 and 6. The lowest score of 2 points is given to the "Do nothing option", because it has the lowest NPV due to the disappearance of the beach. The remaining 4 points are given to the sand retaining sill.

Initial investment

The initial investment of the breakwater is R15 million for the geotextile tubes and R90million for the geotextile bags, R88.4 million for the sill, and R820 million for nourishment according to Urban-Econ estimates and R200 million according to own calculations. When nothing is done, no initial investment is needed, which receives the highest score. After this the breakwater is the cheapest in order, followed by the sill and nourishment with the highest investment and the lowest score given.

Amount of beach created

When nothing is done the beach is eroding and will eventually disappear. This alternative is given the lowest score. Nourishment creates directly the most amount of beach and received the highest score, followed by the breakwater. Since the simulation in 3D did not provide any useful results about the amount of beach created due to the sill it is considered that this alternative just maintains the current beach width. Because no beach is added the sand retaining sill does not score high on this criterion.

Stakeholders' perspective

When nothing is done, stakeholders might show their dissatisfaction because of the negative effects on the beach. However these effects will be noticed on the long term. When the sand retaining sill is constructed, environmental groups are not going to approve the concrete construction and might use their obstructing power. However, for other stakeholders' reaction on the sand retaining sill is quiet neutral since it just maintains the current situation. For this reason it is given the same score as well nothing is done. Nourishment is expected to cause opposition by the environmental groups and change the appearance of the area, although just by sand dumping. The breakwater is expected to receive the most support from the stakeholders since it is submerged, made of a conforming material and brings less uncertainties.

Environment Friendly

An environmental survey about the influence of the alternatives has been prepared and send to representative groups. However the results are not collected on time and for this reason not processed in this report. This score is based on common sense. Nourishment is expected to have the worst influence on the environment because of the direct disturbance of sea life due to modification of the seabed. Although the sill is expected to have similar influence as the geotextile tubes, the sill is made of concrete which is seen as a non-conforming material compared to the geotextile tubes. When nothing is done the environment is not experiencing any disturbance and for this reason this alternative is given the highest score.

Technological feasibility

Doing nothing as an alternative receives the lowest score because no construction is to be build. Nourishment receives the highest score because eThekwini already has enough experience with the nourishment of the Durban beaches. A breakwater made of geotextile bags is as well a used measurement by eThekwini although the sand bags are placed on the beach and not into the water. However eThekwini already has done research on making geotextile tubes as well. Since construction of the sand retaining sill is the most uncertain technique due to its method and expected effects it received the lowest score for technical feasibility.

Robustness

Doing nothing is not a robust solution at all since the beach is going to disappear. For this reason it is given the lowest score compared to the other options. Although nourishment creates a buffer for the beach, still a lot of sand is taken during storms and needs to be replenished to maintain the beach width. Creating a sill however is not robust since it only maintains the current beach width and does not provide a better solution. Constructing the breakwater made of tubes or sand bags however is the most robust solution, since it breaks the waves offshore and contribute to a wider beach.

Construction time

The Do nothing option is given a score of 1 since no construction is planned and no disturbance is expected. Constructing the submerged breakwater by tubes takes place in 2.6 years, the sand retaining sill in 1.4 years and nourishment 4.8 years. Since the sill is constructed quickly it is given a high score, followed by the breakwater. Nourishment takes significant longer time compared to the other two constructions and for this reason is given a low score of 2. Another reason for this low score is the presence of pipes on the beach and the temporary horizon pollution by the dredger.

9.5 Result

The result of the MCA is shown in the table 9.1.

	Factor	Breakwater	Sand retaining sill	Nourishment	Do Nothing
Net present value	0.4	6	5	7	2
Initial investment	0.5	7	4	1	8
Amount of beach created	1	7	4	8	1
Stakeholders' perspective	0.7	9	5	4	5
Environment Friendly	0.2	6	4	3	7
Technological feasibility	0.7	7	2	10	1
Robustness	0.8	9	4	5	2
Construction time	0.2	8	9	2	1
Weighted score		34.1	18.7	26.1	13.2

TABLE 9.1 RESULT OF MCA

Combining the criteria, with their weights and he scores given shows that according to the MCA, constructing the submerged breakwater, followed by nourishment, the sand retaining sill and the “Do nothing option” is the best rank of alternatives for eThekwini. This result is based on the fact that the submerged breakwater was quiet cheap and did generate some benefits, while nourishment was more expensive but generated the benefits sooner. Sand retaining sill's low score is due to the uncertainty involved, while doing nothing is considered to be the worst option because of fully disappearance of the beach on the long term, loss of property values and recreational benefits once the beach has disappeared.

10 Conclusion

This chapter represents the conclusion of the report, by giving answers to the sub-questions, as well as to the main research question.

What is required to make the Umhlanga coastline sustainable?

To make the Umhlanga Rocks coastline sustainable it is important to use natural resources like local materials and minimize the import of others. At the same time it is wishful to create more natural area through an environment in which marine life can flourish.

What are the possible solutions that fulfil the requirements?

The possible solutions that have been considered in this report are a submerged breakwater, bar retaining sill and nourishment. Beside this the alternative of doing nothing has been examined. However, if nothing is done it is expected that due to coastal erosion the beach will eventually disappear and bring the recreational benefits to zero, together with some decrease in property values in Umhlanga.

How do these solutions add value?

Value is added by the execution of the alternatives to the Umhlanga Rocks mainly through the direct creation of more beach area through nourishment, the creation of extra beach in the course of time through the submerged breakwater or through maintaining the current beach width through the bar retaining sill. The construction of the breakwater using geotextiles provides a habitat for aquatic life and is expected to improve the marine life and biodiversity.

What solutions best fulfil the social and technical preferences?

According to this research the construction of a submerged breakwater made of geotextile tubes provides the best solution to the problem from social and technical preferences. Social preferences include perceptions of stakeholders involved like environmental groups and property owners, but take the construction and maintenance costs of the alternative into account as well. In this case the geotextile tube breakwater uses conforming materials, does not cause any visual horizon pollution and seems to deliver the best benefits for the price involved. At the same time the results from the 3D simulations have shown that the breakwater is able to perform well on the technical preferences including the breakage of waves offshore and increase of beach width.

Reflecting to the main research question stating:

How can the eThekwini municipality create a sustainable Umhlanga coastline while adding value to the area?

The construction of a submerged breakwater consisting out of geotextile tubes in front of the Umhlanga coastline will prevent chronic erosion from taking place and offer protection against future storms. The construction is located below the low water line, so it does not obstruct the view. The breakwater is constructed out of sand, which is locally available, and geotextile tubes, which are easy to transport, making it a soft engineering solution that is much desired by the community. By maximizing the use of natural materials the environmental impact will be limited. Extra meters of beach width will be added that can be exploited by local businesses and will increase property value; this in combination with the low construction cost of the geotextile tube system will lead to a large net present value of the entire project. Taking into account social, technical and economic benefits in a multi criteria analysis the breakwater proves to be the best overall solution.

11 Recommendations

A well designed submerged breakwater could fix the coastal problems Umhlanga Rocks is currently facing and provide a sustainable solution for the future. However the focus of this report was to deliver a preliminary design and a lot of optimization can still be done. Below are several options that can be considered when further research is performed on the construction and modelling of a submerged breakwater or any other construction.

General Delft3D

First of all, for each solution only one scenario is modeled, assuming that it is the best option. In further research, more scenarios with different configurations of the structures should be modeled. With doing so, a scenario can be optimized and a more founded recommendation can be made.

Beside this, In this project a short time step is modeled. To give an estimation for several decades, the output is extrapolated. There are actually a lot of uncertainties in this. To lower these uncertainties, a longer time step can be modeled. This will however also increase the computational time. Furthermore a morphology factor can be used to give a better estimation for the future.

A wave data set of three years is used for modeling. Large amounts of measurements are taken into account. Within these three years are no severe wave conditions measured. Therefore these conditions are not modeled and it is not clear what the influence is of extreme waves. These conditions can be modeled separately or a more extended set of data can be used. Wind is not taken into account in this project. However the influence of the wind may be considered very low, this is not proven. To prove this and to take it into account, the wind can be put in the model as well.

Delft3D is mostly used to model long-shore sediment transport. The sill however mainly influences the cross shore transport. It is not proven that Delft3D give reliable results with this type of structures. Therefore another model like Xbeach will most likely give more reliable results. The sole purpose of this program is to model cross-shore sediment transport.

Calibration coupled flow-wave model and wave model

In further research, more calibration of the coupled model should be done in order to derive a more accurate output. In that way the output numbers are more realistic and could be used to give a real estimation of the amount of sand that is moved. In order to do so, real time data should be compared with the model. The wave model is calibrated using another wave data than where the scenarios are being modeled with. When however the same wave data is used for the calibration, it will give a more reliable wave model.

Boundaries of the model

The boundaries seem to have a large effect on the output of the model. Especially in case of the breakwater. Large local variations in bed levels are seen, which was not expected. This can be handled by making the area bigger so that the boundaries do not influence the project area anymore. Furthermore the grid can be refined close to the boundaries. At the breakwater and the sill, there are steep variations in the bed level. Therefore it is useful to use a fine grid at that exact location. In this way the shape of the breakwater can be modeled in a more realistic way. This fine grid is not everywhere needed. The computational time would increase very much when the grid is refined everywhere.

The model in this project used only one layer in the vertical plane, so that everything is depth-averaged. In the real situation this is not averaged. More sediment is transported along the bottom than along the top of the depth. This can influence the results, especially when structures are modeled which are not depth-averaged like the breakwater and the sill. To counter this problem, multiple layers in the vertical plane can be used in Delft3D.

Socio- economic factors

There are several difficulties with the solutions proposed from a construction management viewpoint. The main issue is the large price tag of the solutions. The nourishment option can be reconsidered, if another dredger with higher capacity than the current one can be used for the project. All solutions have a positive NPV over the course of 50 years, however the initial investments are substantial.

The eThekwini municipality has shown that it is willing to make significant investments to protect and improve the shoreline. The current boulevard has been constructed at the costs of R. 100 000 000 and offers some protection, as do the reinforcements with geotextile bags. These reinforcements and the boulevard are constructed on private land however and a contribution from the owners is deemed necessary. The solutions range in price from 13 million Rand to 409 million Rand. So exploring ways to secure financing from commercial sources is paramount.

Secondly the dependence of these solutions to increased beach size overstates the importance of the beach for the economy of Umhlanga rocks. Increasing the share of other activities in the area could decrease the dependence on the beach. This would decrease the need for drastic action regarding the beach, and would create extra revenue to fund future action required.

Therefore recommendations for future research are to focus on adding additional revenue streams to the Umhlanga area, and making the area less dependent on the beach. Secondly the raising of funds to have the different solution financed by private parties.

Material options

As mentioned in the report, the use of rock is not recommended due to various reasons. The use of a geotextile system looks very promising, especially the use of geotextile tubes. By using the tubes as a submerged breakwater the risk of vandalism, which has been a serious issue in reference projects, will be reduced a lot. The need for UV protection is also limited. These factors should contribute to a longer lifespan of the tube, more research on the lifespan of the tube is recommended if this design is chosen. A geotextile tube has already been used in the past and the filling of the tube to the desired level proved to be quite difficult. A large number of geotextile tubes will be needed for a submerged breakwater and special attention should be paid to make sure the filling process proceeds smoothly to ensure an economic design.

The use of geotextile bags has the advantage that it has already been successfully applied on several projects along the KwaZulu-Natal coastline. However it has not yet been applied as a submerged breakwater where it will be subject to higher wave loads. Sewing bags together and attaching tails to the bags could potentially lead to a stable design, but this will require a lot of additional work and quality control to ensure a safe design. Compared to the tubes the cost will be higher.

Other solutions

While studying literature and reference projects (see appendix K1) several other systems that could be used were encountered. Geotextile bags could be filled with cement instead of sand. If filled with cement the bags can be coupled to each other using rebars. The higher weight of cement compared to sand and the reinforcement will lead to a much more stable and robust design. Disadvantages are increased costs and the loss of the ability to easily remove the breakwater by cutting the bags.

Another option could be to only fill the top two rows of geotextile bags with cement and coupling them with rebars. This option combines the benefits of cement and sand filled bags. The top of the structure is most vulnerable to sliding and overturning, the cement filled bags will offer better resistance against these failure modes. The overall structure will still consist mainly of sand and can still be removed quite easily. A third option is to use geotextile tubes instead of bags in the top two or three rows. This has similar benefits as using cement filled bags.

Geotextile containers are another geotextile system that could be applied. The containers are a lot bigger than the bags. The cross section of the breakwater would most likely consist of just one container, limiting stability issues. The containers can be dumped onto the bottom using a split barge.

Instead of a breakwater an artificial surf reef could be built. A reef has much larger cross shore dimensions than a breakwater and is therefore more expensive. The advantage is the possibility to create optimal surfing waves leading to more aqua tourism. The reef could also produce a more rich marine life environment. Examples of successful application of a surf reef are the Narrowneck reef in Australia and the Boscombe reef in the UK.

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