Project Walvis Bay

Integrated approach for the long-term development of the Port of Walvis Bay

October 2012

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Preface

This report is the result of a ten-week project process, performed by the undersigned students within the curriculum of their Civil Engineering master track at the Technical University of Delft.

First of all, we would like to thank the people at WSP Africa Coastal Engineers for accommodating and supporting us at their office in Stellenbosch, South-Africa. For initiating this contact, we would like to thank ir. H.J. Verhagen.

Regarding the project content, we would like to thank Prof.ir. T. Vellinga and ir. P. Taneja for sharing their expertise on port development. Prof.ir. A.Q.C. van der Horst is thanked for giving his input on how to approach the project in general.

Our gratitude goes out to all of our sponsors for contributing to our project financially. Special thanks go out to Boskalis for being main sponsor and assisting us with technical aspects.

We want to make clear to the reader that the contents of this report are all based on the view of the project team, and are not influenced by any of the sponsors and/or partners.

Stellenbosch, 19 October 2012

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Summary

This report contains the summary of the results of a ten-week project process, performed by the undersigned students within the curriculum of their Civil Engineering master track at the Technical University of Delft. The numbering of the sections below corresponds to the respective chapters in the main report.

1 Introduction

The Port of Walvis Bay has seen years of steeply inclining throughput figures, up until the beginning of the global financial crisis back in 2008. Volumes are however picking up again, making it likely that the throughput will reach the limit of the port's handling capacity within the foreseeable future.

The objective of the project is to '*develop a financially- and technically feasible development strategy for the Port of Walvis Bay, taking account of the uncertainties of future events'*. As there is a high degree of uncertainty in the future demands for services, the attention is focussed on designing a development strategy that maximizes the flexibility of the port.

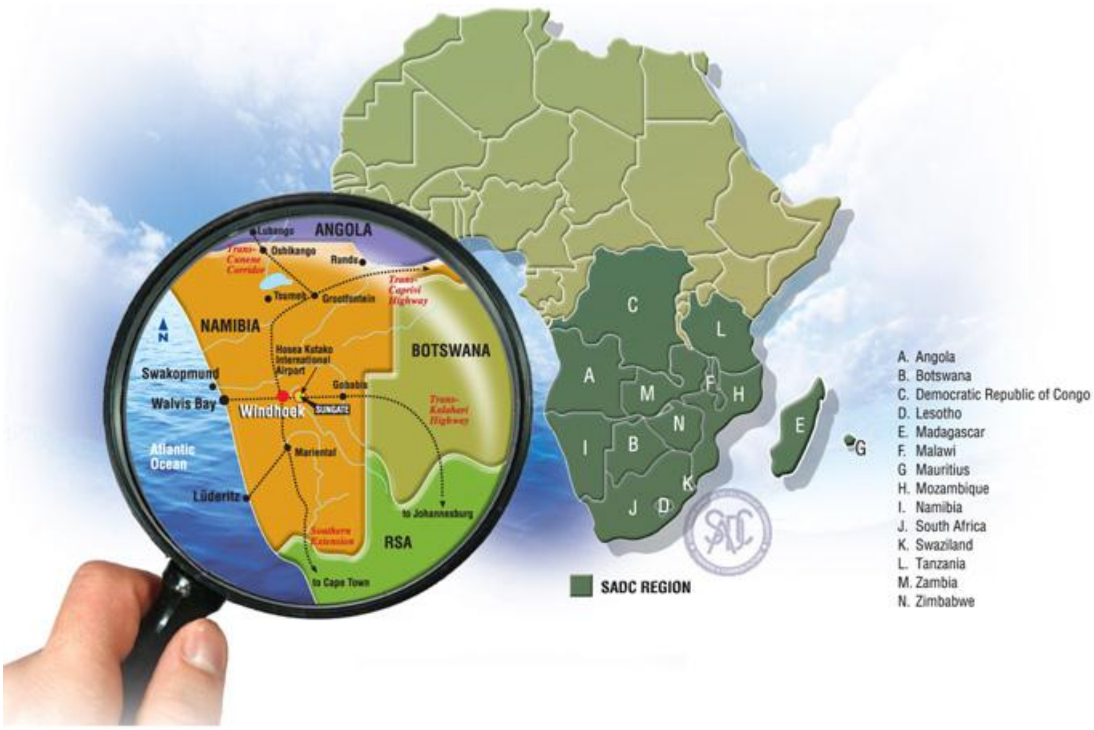

Figure 1: Location of Walvis Bay in the SADC region

2 Current situation

The city of Walvis Bay is positioned about halfway along the coast of Namibia, and accommodates the largest port of the country. There is a direct connection to the major maritime routes to and from Europe, South America and Asia. This strategic location makes the port the natural gateway for international trade to and from the South African Development Community (SADC) region to the rest of the world. The port also plays an important role as a regional container transhipment hub for trade to central and southern Africa, a position that the Namibian Port Authority (NamPort) pursues to strengthen.

Southern expansion

In order to do so, NamPort announced plans for expanding the port back in 2008, after which construction of the first phase should have commenced in 2011. However, due to reluctance of investors, the project's Engineering, Procurement and Construction (EPC) phase has been cancelled indefinitely by the port authority. NamPort is now accepting new tenderers to both build and finance the expansion. They are confident that the construction phase will begin in early 2013, targeting full operation in 2016. The expansion will accommodate a container terminal, eventually quadrupling the port's handling capacity up to one million TEU's annually.

Long-term development

According to container throughput forecasts, the demand for services may however reach the increased handling capacity as soon as 2019/2020. The objective of this project is to recommend a strategy on how to develop the port on the long-term, scoping at a design lifetime of half a century.

3 Economic analysis

In order to be able to make estimates of future service demands, an analysis of the commercial market of the port is performed. The understanding of a rapidly growing economy is established after investigating the performances of the SADC region and the major ports within these countries.

Mining and infrastructure

Trends in mining and infrastructural investments are investigated, showing that there are some tremendous opportunities for the Port of Walvis Bay. Southern Africa is known to possess large stakes of global mineral resources, of which emerging countries as China, India and Brazil seem to have an insatiable desire for. Most promising potential comes from Botswana's coal reserves, mining of which is expected to commence within a decade. The governments of Namibia and Botswana are in negotiatons about transporting the coal through the Port of Walvis Bay. Large investments are required in both the transportation corridor and the new coal terminal, making it still very uncertain if the deal gets sealed.

Long-term scenarios

There appears to be a strong correlation between throughput figures and certain economic indicators of the commercial market, both valid for cargo and im- and exported containers. Using this correlation along with long-term economic estimates of the market, the throughput figures are extrapolated over the design lifetime of the project. Throughput scenarios are extracted from the results, representing the likelihood of certain volumes to be handled in different timeframes. Together with the volumes expected from the uncertain mining projects, these trends form the most important requirements in terms of handling capacity for the future development of the port.

4 Port requirements and conditions

In order to meet the demand for services in time, the development of the port should fulfil certain functional requirements in terms of handling capacity, nautical accessibility and hinterland connections. As there is a high degree of uncertainty regarding the throughput volumes, flexibility of the port is one of the main criterions for expansion phases. This is reflected in the formulation of the different functional requirements. The development should be designed such that the port is financially feasible in the lower limit scenario, while being able to easily expand to accommodate the upper limit scenario.

Social, technical and natural conditions impose boundaries on the design of the port expansion projects. Together with the functional requirement they form the domain in which an efficient development strategy has to be engineered.

Boundary conditions

The topographical conditions in the port's domain are of vital importance to the conceptual designs of expansions. As can be seen from the figure, there are two obvious locations for the port to expand its activities; indicated as the northern and the southern expansion sites.

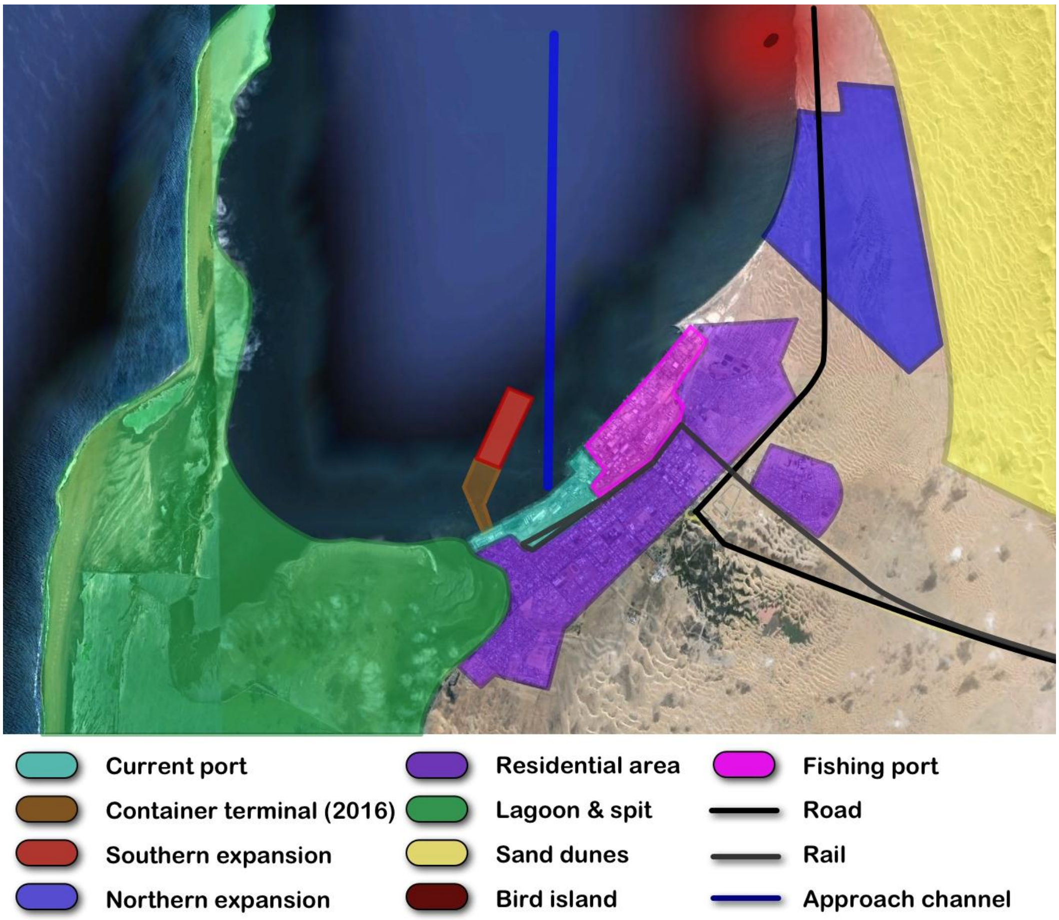

Figure 2: Topographical boundary conditions within the project domain

The southern expansion possibility involves expanding the port's peninsula, elongating a patch of reclaimed land that is yet to be built. It would be a consecutive expansion to the one that is targeted to be finished in 2016.

The northern expansion site is made available by the government of Namibia, and may be used as expansion ground for the port. The area has a gigantic footprint available, however none of the required infrastructure is present yet.

The bay and lagoon area are fragile ecosystems, which have a high biodiversity and attract tourism. Also the sand dunes on the east side of the northern site are of great importance to the city. Special attention should be given to their preservation.

5 Expansion alternatives

The functional requirements are translated into design indicators, describing required quay lengths, terminal footprints and dimensions for the wet infrastructure of an expansion. Using these quantifications, general designs for the terminal layout and major civil works can be drafted that are in compliance with the requirements and conditions. As the functional requirements change in time, the designs have a phased character. The following expansion alternatives are however just presented as a proof of concept; showing that the sites are eventually able to comply with the functional requirements set for a high economic development towards the year 2050.

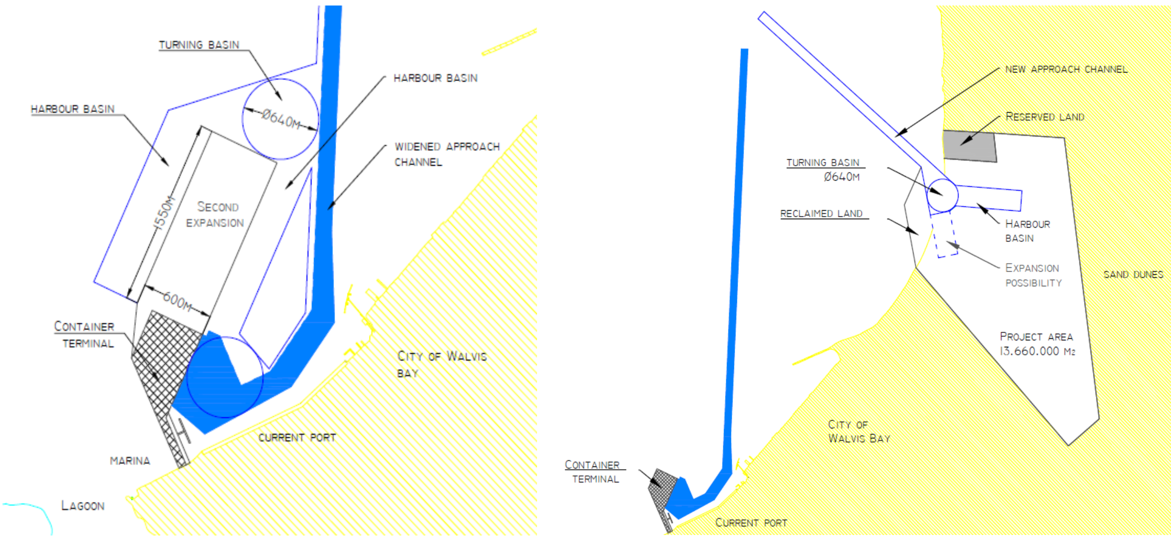

Figure 3: Conceptual designs for southern- and northern expansion sites

Southern expansion

Excessively widening the peninsula is not within the options, as a disrupted water flow in the lagoon may be induce siltation and negatively affect its unique ecosystem. The expansion of the peninsula is furthermore bounded by the port's existing wet infrastructure. These conditions enforce an elongation of the peninsula, in which the design indicators can be fit as displayed in Figure 3. The high-scenario design features a second harbour basin at the west side of the peninsula, needed to be able to fulfil the quay length requirements. The approach channel and harbour basins are dredged up to a depth of respectively 16.25 and 15.75 meter below chart datum, enabling the accommodation Post-Panamax class vessels.

The major disadvantage of the southern site is the inability to further expand on the longer-term, or to accommodate the large coal-terminals required if Botswana decides to export their coal through Walvis Bay. In that event, there is no other option than to divert to the more spacious northern site.

Northern expansion
Expanding at the northern site basically means constructing a totally new harbour on the assigned area. Some facilities can probably be shared with the current port, however all of the infrastructure and terminals are newly developed.

With the project area having an enormous footprint, space is not a limiting factor for the expandability on the long-term. Furthermore, a high degree of flexibility can be built into the initial design and layout, making it relatively easy to expand in stages if the port outperforms its expectations.

6 Development strategies

It is clear that the initial investments for the alternatives are far apart; the southern site can rely on existing infrastructure and gradually expand, whereas the northern site initially requires a tremendous amount of civil works. The choice for either of the development sites highly depends on the willingness of investors to take risks. A distinction is made between two types of investors, having either a risk-aversive or a risk-seeking investment strategy.

Risk-aversive strategy
A risk-aversive investment strategy aims on minimizing the initial investments, lowering the risk of losing large sums of money. The investor will wait for a high service demand to happen before initiating the expansion process, reacting on growth rather than anticipating on it. This strategy is therefore not the most profitable if the service demand develops in a brighter way than anticipated for, as the capacity of the port will be insufficient. The investor risks not utilizing the market’s full potential.

A phased expansion of at the southern site fits this investment strategy, as only minor investments are required. The total investment over time will however be higher, as a phased construction implies more preparation costs, double work and call-out charges of subcontractors. This is especially true if Botswana as yet decides to export its coal through Walvis Bay, forcing a consecutive expansion at the northern site. In this case, both the southern- and northern expansions are developed, which is relatively cost inefficient.

Risk-seeking strategy
Risk-seeking investors have a relatively high confidence in the economic development of the port’s market. This confidence makes them to assess the investment risk as acceptable. Therefore they are willing to invest a relatively large sum of money to assure the port has enough capacity to grow for the long-term. This will avoid them from having to expand in multiple phases, minimizing the total investment. If the throughput indeed develops as anticipated for, the highest profits are gained for investors. If the figures are however disappointing, the potential of the port expansion is not fully utilized and project may not even be profitable.

When anticipating on high growth and coal from Botswana, it makes no sense to invest in a southern expansion as it is incapable of accommodating the required capacity when fully developed. Therefore, one immediately starts constructing the entire wet infrastructure required for the highest scenario at the northern site. The construction and expansion of terminals will however follow the demand for capacity, as their technology quickly age and require additional maintenance.

Financial evaluation

In order to financially evaluate the two different development strategies, their respective investments and expected revenues are used as an input to construct a decision tree. This tool can be used by investors to choose the strategy fitting their risk profile, and evaluate the financial consequences of their decisions. Progressive insights in the economy can be incorporated into the tree by adapting the event probabilities, drastically affecting the outcome. In order for investors choose the development strategy matching their risk profile, decision criterions are drawn.

The so-called 'maximax criterion' fits a risk-seeking profile, as it is a strategy which maximizes the gain while omitting any potential loss. This type of investor would choose to instantaneously develop the northern expansion site, anticipating on high growth and a coal-deal with Botswana.

The 'minimax criterion' fits a risk-aversive profile, aimed at minimizing the maximum loss. This type of investor would choose for a staged expansion at the south site.

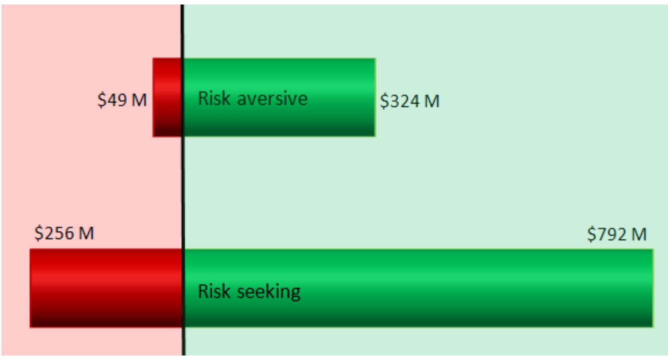

Figure 4: Potential profits and losses by the year 2050 for two different investment strategies

General evaluation

Besides financial aspects, there are more general aspects that are often undervalued in the conceptual design phase of projects. If these aspects are given equal weight in the decision process for different strategies, a higher added value over the complete service life of the project can be generated. These general values are however usually conflicting with the financial ones. A compromise has to be found between both the financial and the non-financial aspects of the project, optimizing the added value over the service life and the range of stakeholders.

Due to the high degree of uncertainty regarding future service demands, special attention is paid to the flexibility and expandability of the port design. As the northern expansion is designed from scratch, this concept can be integrated in the conceptual designs. This freedom is however limited for the southern expansion, due to the shape of the peninsula and the connection to the existing container terminal. Also regarding the accessibility of the port, the northern alternative is prevailing. The hinterland connections coming from the southern site traverse the city of Walvis Bay, limiting their flexibility and expandability.

Environmental evaluation

If possible, any disturbance of the ecosystem should be prevented by selecting appropriate locations, materials and execution methods. If complete prevention is not within the possibilities, any disturbance inflicted during construction or utilization of the expansion should be mitigated. The building materials and construction technologies that are being used should be selected very carefully for this purpose. However, the location of construction is obviously the most critical factor as it comes to disturbing the surrounding.

The most critical factors to be respected are the bay, the lagoon and the sand dunes. These all sustain ecosystems which are susceptible to sudden changes, and are highly important to the city and its tourism. As the southern site is very close to the lagoon and the northern site to the sand dunes, the alternatives will have different environmental impacts. The risk to the lagoon is however less predictable, while its ecosystem is expected to be more unique and fragile.

Also regarding hindrance and exposure to hazards for the residents of Walvis Bay, the northern expansion site is preferable, as it is located outside the city's boundaries.

Decision

It seems that the highest added value for the majority of the stakeholders is created by choosing for an expansion of the port at the northern site. Together with its higher possible financial profits, the choice for this strategy seems evident. The port is however very dependent of the economic climate and the willingness of investors to take risks. This willingness seems to be small these days, as there is a low degree of confidence in the global economy. Smaller investments that are most certain to at least pay back their investments are prioritized above large scaled projects, even though they have higher expected return rates.

Involving the stakeholders in the conceptual design phase of the project leads to a broadly supported development strategy, increasing the probability of actually being implemented. The stakeholders with the highest influence all share the same interest; creating a profit. The financial aspect will therefore be decisive in the decision for the northern of southern alternative. As the decision for the northern of southern expansion is highly dependent on the risk profile of the attracted investors, no alternative is picked.

7 Design aspects

The construction and layout of an elongation of the southern peninsula is more or less self-evident. The northern expansion plan is however still very unclear, and offers many opportunities for the implementation of efficient en flexible designs. Therefore, general alternatives for the terminal layout, the quay walls, revetments and a liquid bulk berthing facility are considered and evaluated.

General layout

The northern site offers a much larger footprint than required to offer the capacity of the projected demand in 2050. Therefore only a small part is developed, while anticipating on future upgrades. As the wet infrastructure is generally the bottleneck in port upgrades, it is chosen to design the entrance and turning basin of the port to be sufficiently large and deep for future generation vessels. This way, during the upgrade, just a second harbour basin has to be constructed to be able to accommodate these vessels at the quays. This basin will extend to the south, where it will conflict with the General Cargo and Ro-ro terminal. This terminal does not require any advanced or fixed equipment and structures, making it relatively easy to be repositioned during the upgrade. Also the rail- and road infrastructure has been positioned in a way that does not require repositioning, while still being expendable. The different terminal facilities are indicated in the figure. The hatched areas resemble the initial terminal footprint, while the surrounding areas indicate in which direction they can expand if the service demands require so. One can see that the rough bulk terminal has an unproportionally large area to expand in, which is necessary to open the possibility of handling coal from Botswana.

A new liquid bulk terminal is constructed at the northern port, as the current liquid bulk jetty has passed its design service life and requires excessive maintenance. Furthermore, the location is safer with respect to the residents of Walvis Bay.

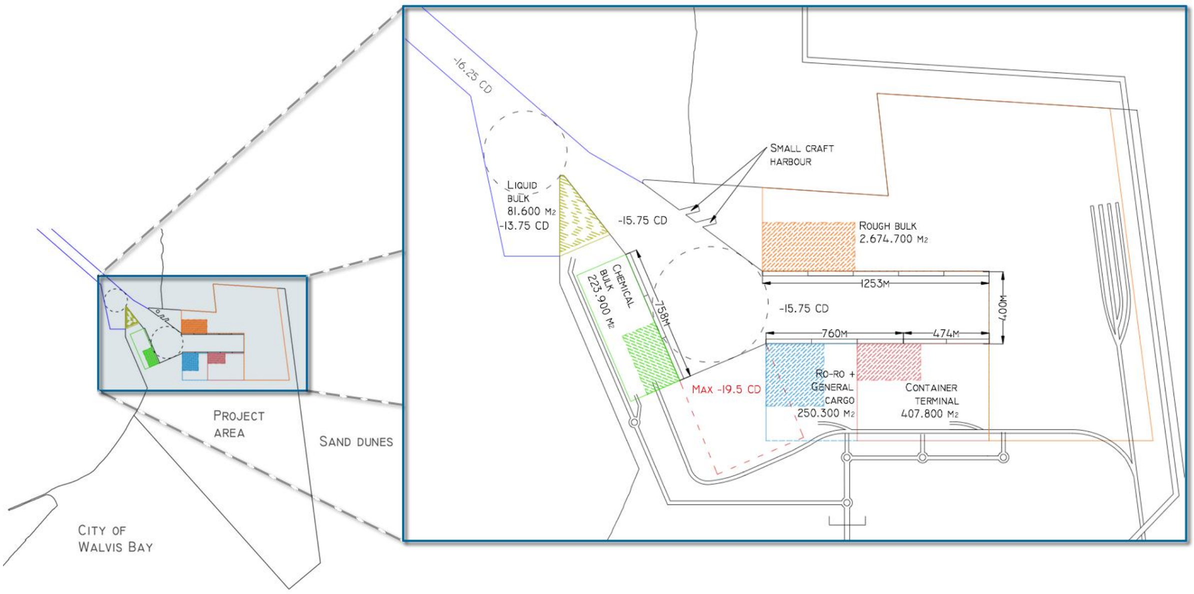

Figure 5: General layout for northern port expansion alternative

Quay walls

The conceptual design of quay walls is highly influenced by the presence of randomly located boulders in the area, complicating the process of drilling sheet piles. Gravity based structures offer a durable solution to retaining the soil. It is chosen to apply caissons along the perimeter of the wet infrastructure inside the harbour. These structures are very labour intensive, but efficient in the use of materials. Furthermore, they don’t require much maintenance. As labour in Namibia is inexpensive compared to construction materials, caissons offer the best value for their price.

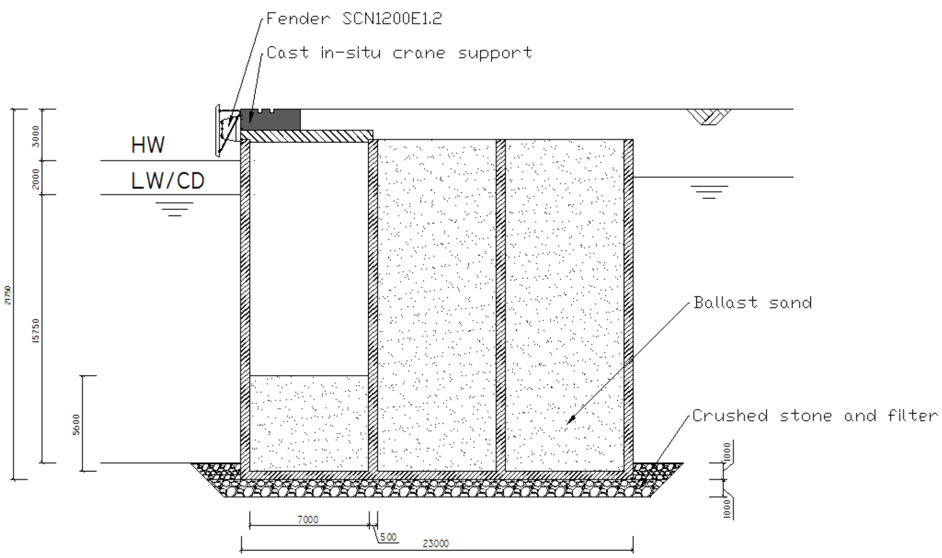

Figure 6: Design for caisson-based quay walls

8 Method statement and planning

The execution methods and planning of the project are important factors in the conceptual design phase of civil works. Special attention should be paid to the availability of specific equipment, knowledge and skilled labour when evaluating design alternatives. It may be more efficient to choose for less advanced methods rather than hiring knowledge and equipment.

By determining the quantities of major civil works and their execution methods, durations of the different processes are estimated. By arranging the processes in a smart way, the critical path of planning can be optimized. This optimization must be done with respect to both the total duration and risk of delay, as certain activities may high uncertainties in productivity and possible downtime.

Without any excessive delays, the presented expansion project should be able to be completed within a timeframe of six years.

9 Conclusions and recommendations

After analysing the Port of Walvis Bay and assessing its potential, a long-term development strategy and accompanying general expansion designs were presented. During this process certain conclusions were drawn, on basis of which recommendations are made.

Conclusions

The Port of Walvis Bay seems to have a lot of potential, considering the economic developments of its commercial market and the upcoming natural resource projects. There is however a high degree of uncertainty regarding the throughput volumes associated with these developments.

As a reaction to the changing demand for capacity on the short-term, vacant patches of land are used to extend terminals that are highly stressed. This has resulted in a fragmented layout of the terminals, which reduces the productivity of the port as a whole.

Tourism is an important social-economic factor to the city of Walvis Bay, and depends on the preservation of the fragile ecosystems of the bay, the lagoon and the sand dunes. Construction and operation of port expansions may negatively affect them.

The port has difficulties in attracting investors for their expansion activities, as a result of the low degree of confidence in the global economy. This reluctance of investors may be expected to persist within the near-future.

Recommendations

Consecutive expansion phases, after completion of the container terminal, are required to be able to utilize the port's full potential on the long-term. It is recommended to continue investigating long-term development strategies.

Expansions should have an integrated character with respect to the current port, in order to decrease fragmentation of terminals. The overall productivity of the port will benefit from an integrated approach. Furthermore, as estimates for future service demands have a high degree of uncertainty, the focus of expansion projects should be on flexibility and expandability.

Thoroughly investigate the morphological effects of the shape and size of the southern peninsula on the lagoon. Widening the peninsula would be a cost-efficient way of increasing the port's footprint.

Involve all stakeholders in the conceptual design phase of port expansions, increasing the probability of actually being implemented. As the stakeholders with the highest influence all share the same interest, creating a profit, the financial aspect will be decisive in the decision making process.

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APPENDICES

1 Introduction

The Port of Walvis Bay has seen years of steeply inclining throughput figures, up until the beginning of the global financial crisis back in 2008. Volumes are however picking up again; making it likely that the throughput will reach the limit of the port's handling capacity within the foreseeable future. In order to cope with the increasing demand, a new container terminal is shortly planned to be constructed on reclaimed land at the southern end of the port, eventually quadrupling the current capacity. Plans for consecutive expansion phases are already drafted, as the port tries to become the major container transhipment hub of Africa's west coast.

Our project focuses on the long-term development strategies of the port, scoping at a time span of half a century. As there is a high degree of uncertainty in the future demands for services, upper- and lower scenarios are used throughout the report. A well-designed port is defined to be feasible in the lower limit scenario, while being able to easily expand to accommodate the upper limit. Because of this philosophy, the attention is focussed on designing a development strategy that maximizes the flexibility of the port.

The objective of the project is to 'develop a financially- and technically feasible development strategy for the Port of Walvis Bay, taking account of the uncertainties of future events'.

Chapter 2 of this report will introduce the reader to the current state of the port, describing its scale, services and conditions. Also the port's southern expansion accommodating the new container terminal is introduced in this chapter, as it is not within the long-term scope of this project.

Chapter 3 clarifies the economic conditions of the commercial market in which the port operates. Historical throughput data is investigated and the state of competitive ports, infrastructure and mines is identified. On the basis of this analysis, the development of annual throughput figures is estimated and future scenarios are extracted.

Chapter 4 establishes the design space in which future developments of the port can be engineered. Handling capacity, stacking space, nautical requirements and hinterland connections define the functional requirements that an expansion has to be in compliance with. Social, technical and natural conditions on the other hand impose boundaries to the design. Furthermore, concerns and interests of stakeholders are investigated to be able to address them in the conceptual design.

Chapter 5 translates the functional requirement into design indicators, quantifying the terminal footprints, berthing facilities and infrastructure required to cope with the throughput scenarios. Basic expansion alternatives that are able to accommodate the required indicators are presented.

Chapter 6 reviews the development of the port from a consulting point of view. After describing different risk profiles of investors and presenting development strategies fitting them, their implications with respect to both financial and general aspects are evaluated. In order to create added value with the project and increase the likelihood of its continuation, the preferences of stakeholders are considered. The last paragraph formulates recommendations on how to act regarding future expansions.

Chapter 7 presents recommendations for the design of the major civil works and terminal facilities for a newly developed port expansion.

Chapter 8 discusses the physical development the expansion project. Execution methods and a global planning for the major civil works are presented.

Chapter 9 gives an overview of the drawn conclusions and corresponding recommendations regarding the port's future development.

A list of books, papers, reports and websites used as a reference in creating this report is presented in the bibliography, included at the last few pages of this report.

2 Current situation

This chapter gives an overview of the current state and activities of the Port of Walvis Bay, which define the initial conditions. After describing the important aspects of the port, an overview of the corridors facilitating the inland connection is given. The third paragraph outlines the current expansion plans of the Port Authority, needed to cope with the increasing demand.

2.1 Port of Walvis Bay

The city of Walvis Bay is positioned about halfway along the coast of Namibia, and accommodates the largest port of the country. The natural bay at which the city is located has been used as a deep-water anchorage for sailing vessels in the 1800s, because of its protection against waves by the natural 'Pelican Point' sand spit. There is a direct connection to the major maritime routes to and from Europe, South America and Asia. This strategic location makes the port the natural gateway for international trade to and from the South African Development Community (SADC) region to the rest of the world. The port also plays an important role as a regional transhipment hub for trade to central and southern Africa.

Figure 2-1: Location of Walvis Bay in the SADC region

2.1.1 Performance

The government-owned corporation that owns and is responsible for the operations of the port is the Namibian Ports Authority, Namport. They manage the port facilities and initiate developments for future demands. The strategic goal of Namport is to consolidate the Port of Walvis Bay as a regional gateway, operating as a reliable and efficient interface for import and export to and from the SADC region, the west coast of Africa and other sub-Saharan countries. Corridors connected to the port make it possible to transport the SADC region import- and export- seaborne cargo. The port currently has the capacity to handle 7 to 8 million tons of bulk cargo and 250.000 twenty-foot equivalent units (TEU's) per year, and it claims to be one of Africa's most efficient and best-equipped ports. Last year's results show that the container capacity has been exceeded by about 20%, which was possible by arranging temporary stacking space. The bulk terminal handled an amount of bulk equal to about 80% of its capacity; a total of 5,2 million tons, comprising 2,9 million tons import, 1,4 million tons export and another 0,9 million tons of transhipped goods. The commodity split for in- and export of non-containerized cargo can be seen from Figure 2-2 and Figure 2-3.

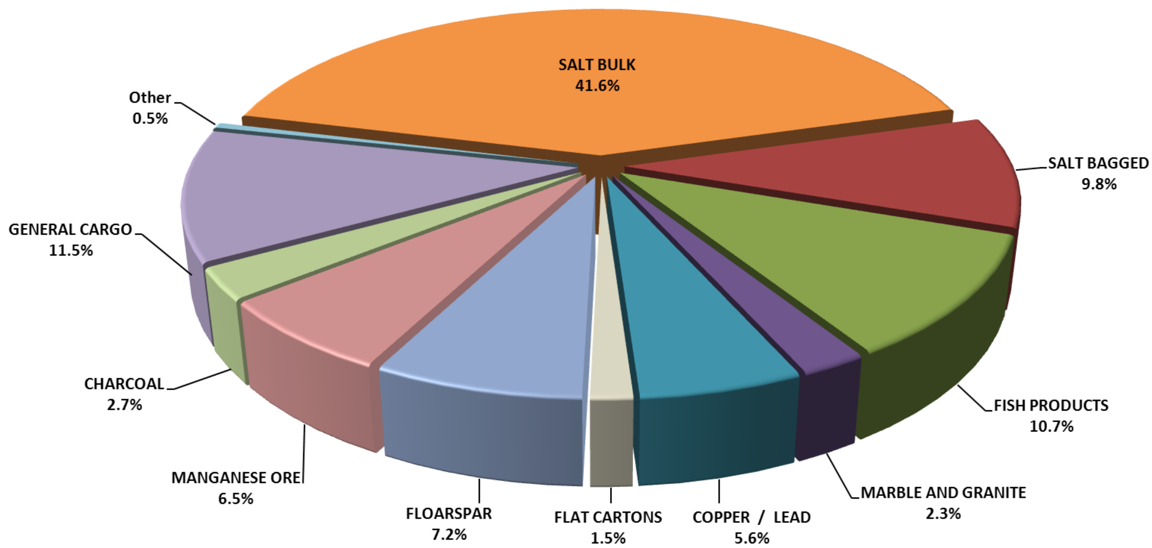

Figure 2-2: Exported non-containerized cargo commodity split of 1,4 million FT

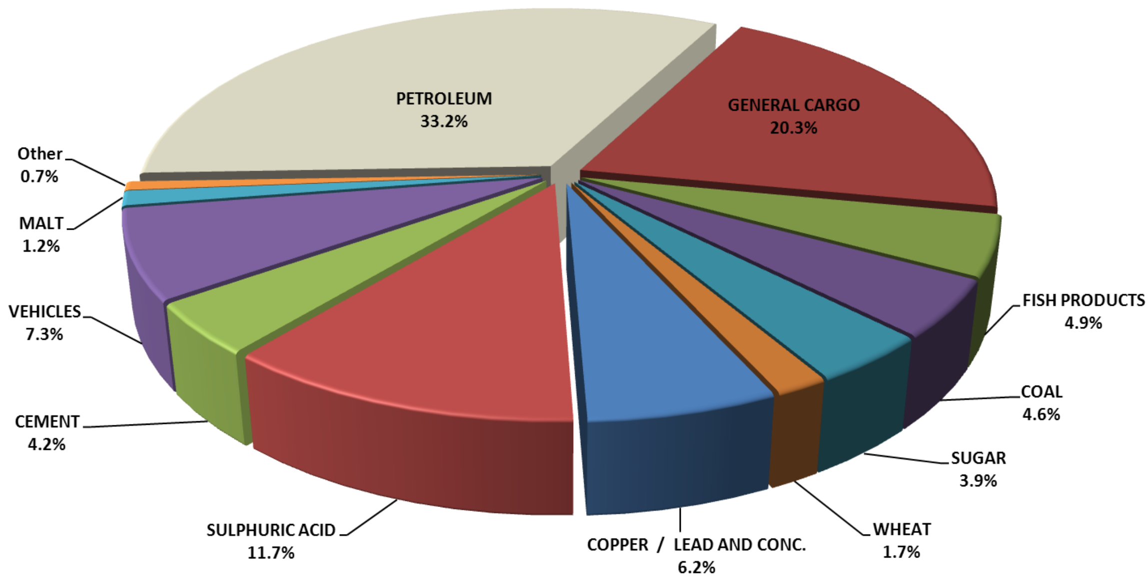

Figure 2-3: Imported non-containerized cargo commodity split of 2,9 million FT

Although the global financial crisis has slowed down the progress since 2008, the economies in the Southern part of Africa has seen sustained growth over the last decade. This trend resulted in congestion in several major ports along the coast of Africa, making it a bottleneck to the growth potential. Reports have shown that cargo vessels heading to Cape Town and Durban may have to wait up till five days before being allowed into the harbour, whereas Walvis Bay offers waiting times of around 12 to 15 hours. However, due to scarcity of stacking space, the port may not be able to maintain this service for very long. To avoid this, several patches of land have already been given different purposes while repositioning functionalities. This has resulted in a fragmented distribution of functionalities over the port area, reducing overall efficiency. Namport is currently making efforts to merge patches of land to harmonize the processes in the port.

2.1.2 Layout

The total footprint of the port's domain is divided into different facilities as displayed in Figure 2-4 and in listed in Table 2-1. All handled cargo is stored behind the berths; separated in containerized cargo, commercial cold storage, break bulk, clean break bulk, bulk and chemicals. Container stacking is done in the area behind berths 1-3 and additional empty stacking at the southern end of the port. The bulk terminals, which are privately operated, are located behind berths 4-8. Liquid bulk handled at the offshore tanker berth is stored in the tanks situated in the areas indicated with blue. The most northern part of the port, indicated with pink, facilitates ship repair facilities (Synchrolift and two dry-docks) and provides jetties for small craft such as tugboats.

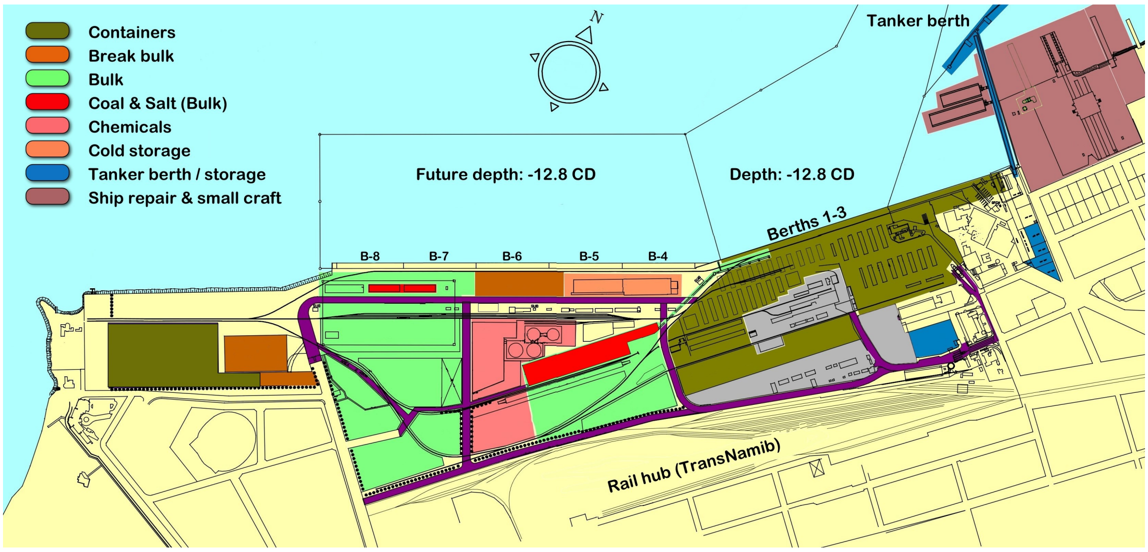

Figure 2-4: Current layout of Port of Walvis Bay

Next to the berths, terminals and storage facilities, there are also workshops, offices and roads (listed as 'other'). This brings the total area of the port up to 780.000 m2.

	Area [1000 m^2]
Container terminal	141.4
Bulk terminals	178.5
Rail hub (TransNamib)	36.5
Salt terminal	16.2
Cold storage facility	15.0
Ro-Ro (car park)	55.0
Liquid bulk storage	74.0
Other	263.4
Total	**780.0**

Table 2-1: Breakdown of the port's domain into facility footprints

2.1.3 Berthing facilities

The port offers eight berthing quays for dry cargo handling, and one tanker berth to handle liquid bulk. An overview of their properties and functions is given in Table 2-2.

	Draught [m]	Length [m]	Cargo Handled
Berth 1	12.8	154.4	Containerised cargo
Berth 2			Containerised cargo, Fluorspar in bulk
Berth 3			Containerised cargo, Fluorspar, salt in bulk, Ro-Ro
Berth 4	10.6	198	Cold Storage (fish)
Berth 5		182	Cold Storage (fish), Sulphuric Acid
Berth 6		182	General Cargo, break bulk, Ro-Ro
Berth 7		182	General Cargo, break bulk, coal in bulk
Berth 8		167	General Cargo, break bulk, manganese and lead concentrates
Tanker Berth	10.0	192	Tankers, Liquid bulk petroleum products

Table 2-2: Overview of properties and functions of the port's berths

The containerized cargo at berths 1 to 3 is handled by quayside mobile tower cranes. Reach stackers and gantry cranes are used for the handling and moving of the containers. An overview of the available equipment is listed in Table 2-3

	Maximum size [ton]	Amount
Mobile Harbour Crane	140	6
Reach Stacker	45	12
Empty Handler	9	2
Forklift	45	26
Hauler	75	37
Container Trailer	60	39
MHC Spreader	50	9
MHC Grab	40	2
Wharf Crane	4	7
Gantry Crane	25	2
RTG's	51	6
Front End Loader	-	2
Tractor	-	2

Table 2-3: Available cargo handling equipment

2.1.4 Vessels

Since the last couple of years, berths 1-3 are usually used by two vessels at a time instead of three. The reason is the increasing ship dimensions, outgrowing the berths. Table 2-4 gives an overview of the number of ships and the average gross tonnage per ship, in the book year 2010/2011. A gross ton is a dimensionless quantity related to the total inner volume of the ship, used by the port to determine the harbour fees. Another frequently used quantity to represent the size of a ship is deadweight tonnage (DWT); this quantity represents the total amount of cargo, crew and fuel a ship can carry. In case of DWT a ton represents one thousand kilograms. Both these quantities will be used to determine the dimensions of the vessels calling at the port. Conversion between the two quantities and the approximation of the average ship sizes is done by using relation graphs. This method of determining the average ship size will only give an approximation; a more accurate representation would be gained by analysing a harbour log of all the ships calling the port. Unfortunately, this information is not available.

Container vessels

The average GT of all container vessels calling at the port in 2010/2011 was just over 20.000 tonnes. Conversion into DWT results in a ship of approximately 23.000 tonnes. Container vessels with such a DWT will be able to carry about 2.000 TEU. The ship will be around 190 m long, 28 m wide and have a maximal draft of 11 m.

The biggest containership that ever moored in the port is of the West African-max class; a 4.500 TEU, 250 m long, 37 m wide vessel with a maximum draught of 13.5 m. The current port would not able to accommodate this ship in case it is fully loaded; the depth of the entrance channel and at the quay walls is not sufficient with its 12.8 meters.

Ro-Ro vessels

Determining the average size of the Ro-Ro vessels is difficult, because it's not known whether all Ro-Ro vessels are Ro-Ro only, or combined Ro-Ro container/general cargo vessels. Assumed is the Ro-Ro vessels are Ro-Ro only. The average GT of the vessels in 2010/2011 was about 48.000 tonnes, having an approximate DWT of 15.500 tonnes. This corresponds to a 180 m long and 30 m wide average vessel, having a maximum draught of 8 meters. These vessels are capable of transporting 5000 car equivalent units.

Bulk vessels

Both the liquid and dry bulk vessels have an average size of around 16.000 GT. This implies for dry bulk ships a DWT between 20.000-25.000 tonnes on average. This results in 'handysize' bulk vessels of around 160 m long, 25 m wide and a draught of 10 m. For liquid bulk vessels this results in vessels with a DWT of around 25.000-30.000 tonnes. The ship dimensions will be in the magnitude of 180 m long, 30 m wide and a draught of 10 m.

General cargo vessels

The average DWT for the general cargo vessels is between 8.000 and 9.000 tonnes; this number is relatively high because a lot of cargo is stored on the deck of the ship. This space is not taken into account in the determination of the gross tonnage. The ship dimensions corresponding to this DWT are around 120 m length, 17 m width and a draught of 8 m.

Other vessels

The category other vessels includes fishing boots, tugs and research vessels. These vessels are relatively small and have their own mooring facilities away from the other berths.

	Known data		Approximated vessel statistics			
	Number of ships	Average gross tonnage	Dead Weight Tonnage	Length [m]	Width [m]	Draught [m]
Container	572	20.010	23.000	190	28	11
Ro-Ro	38	48.164	15.500	180	30	8
Dry Bulk	79	15.901	25.000	160	25	10
Liquid Bulk	81	16.459	30.000	180	30	10
General	92	5.214	9.000	120	17	8
Other	268	788	-	-	-	-

Table 2-4: Vessel statistics calling at the port in 2010/2011

2.1.5 Further transport

The port of Walvis Bay is a main container transhipment hub at the west coast of Africa, and has envisioned to strengthen this position. Currently, 65% of the containers that are handled in the port are transhipped while the other 35% is transported through the land corridors, as described in chapter 2.2. In that last category, only about 5% of the containers is transported by rail while the rest handled by trucks. The main reason for this off balance modal split is the unreliability and inefficiency of the railway connection, caused by the following facts:

- Two main railways (Trans-Caprivi to Zambia and the Trans-Kalahari to Botswana) do not continue at the border of Namibia; containers have to be loaded on trucks for the last part of their journey
- The railways are sometimes unserviceable due to accumulation of sand on the tracks, originating from the surrounding sand dunes.
- The railway parastatal of Namibia, TransNamib, suffers repeatedly from strikes

Namport desires a more equal distribution of road/rail transport, as this would release pressure on the road networks while improving feasibility of the rail connections.

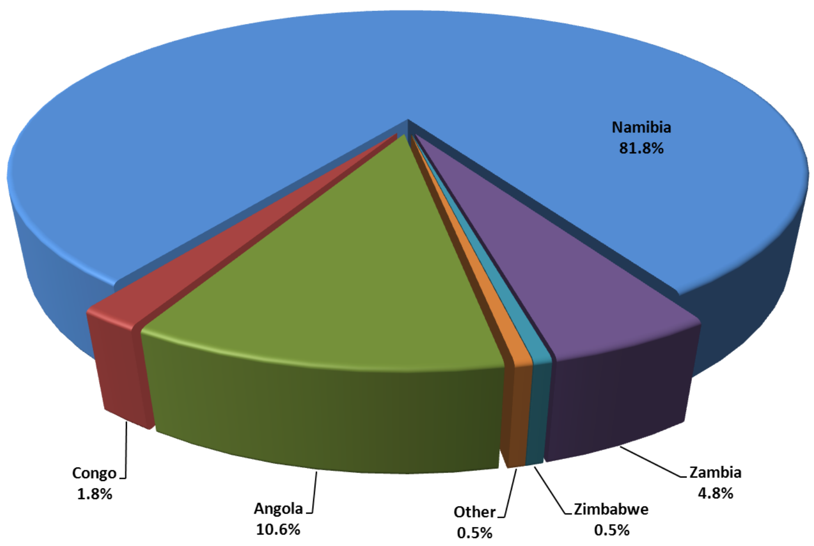

Figure 2-5: Final destination of landed containers

2.1.6 Wet infrastructure

All the ships and vessels wishing to enter the Port of Walvis first orientate themselves on the Pelican Point lighthouse, which is located on a large spit that protects the port from waves coming from the south-west. The approach channel starts about six kilometers east of the spit, traversing the bay towards berths 1-3. The channel has the following dimensions; a length of 6200 m, a width of 134 m and a depth of -12.8 m CD. The channel extends into a basin having a width of 400 meters, large enough for vessels to turn. It can happen that all the berths are occupied, than the ships have to anchor. There are two special anchor places, at each side of the approach channel. At this location, the vessels are protected by the bay against waves. Both anchor places have a footprint of four square kilometers and a depth of -11m to -18m CD. They are situated approximately two kilometers from the approach channel.

2.1.7 Fishing wharfs

The city of Walvis Bay thrived on the fishing industry, which is nowadays still the cornerstone of the city's economy generating about 10% of the GDP of Namibia. Fish processing industries stretch along more than two kilometres of quays at the north side of the port, and are all privately owned companies. The port authority is not responsible for any of their activities and does not maintain structures; the fishing wharfs are not part of ports responsibility or property. However, major design changes in or around the fishing wharfs have to be approved by Namport as they may affect the port's activities.

For the last couple of years the number of private fisheries is declining, as the production decreases due to overfishing and governmental regulations. The remaining fisheries also make less use of the harbour as more and more of them tranship their catch offshore to ships that are anchored in the bay, saving time and money. Just recently, Namport has incorporated the property of a fishing company that went bankrupt, about one kilometre outside of the current port's boundaries. After demolishing the existing structures, the land will be used to house dry docks to expand the port's ship repair facilities.

2.1.8 Ship maintenance facilities

Offering maintenance for vessels is one of the key businesses of Namport, as Walvis Bay is one of only few places where this service is offered along the African west coast. Namport operates two dry docks and a syncrolift, capable of processing up to fifty vessels a month with a maximum of 2000 tons of deadweight, 80 meters long and 12 meters wide.

The docking and undocking of the vessels is managed and operated by Namport, whereas private companies and individuals do the actual maintenance work. The facilities are an important factor for the local repair and engineering companies, attracting skilled employees and stimulating entrepreneurship. With national unemployment rates up to 38%, it is of big importance that the government keeps investing in the service industry. At this moment the syncrolift is being used up to 85% of its handling capacity, but is in need of renovation.

Additional dry docks will be constructed on purchased land within the fishing wharfs area, boosting the maintenance service capacity.

2.2 Corridors

The majority of the container cargo handled at the Port of Walvis Bay is mostly transit and transhipment and the minority is imports and exports of Namibia. The hinterland of the Port of Walvis Bay is not limited to Namibia itself, but also includes parts of surrounding countries for transit such as Angola, Zambia, Zimbabwe, Botswana and South Africa. Particularly the landlocked countries Zambia, Zimbabwe and Botswana are strategically essential hinterland because they overlap the hinterland of competitive ports such as Cape Town, Durban, Beira, Maputo and Dar es Salaam. These competitive ports are sharing the container cargo market of these landlocked countries with the Port of Walvis Bay.

Corridors are tracts of land in which at least one main line for transport, be it rail, road or canal, has been built. It connects for example a port to its hinterland. Five corridors traverse Namibia; two of them are directly connected to The Port of Walvis Bay. The five corridors in Namibia are:

- 1: Tripoli-Windhoek corridor
- 5: Trans-Cunene corridor
- 6: Trans-Kalahari corridor (directly connected to Walvis Bay)
- 7: Trans-Caprivi corridor (directly connected to Walvis Bay)
- 8: Trans-Oranje corridor

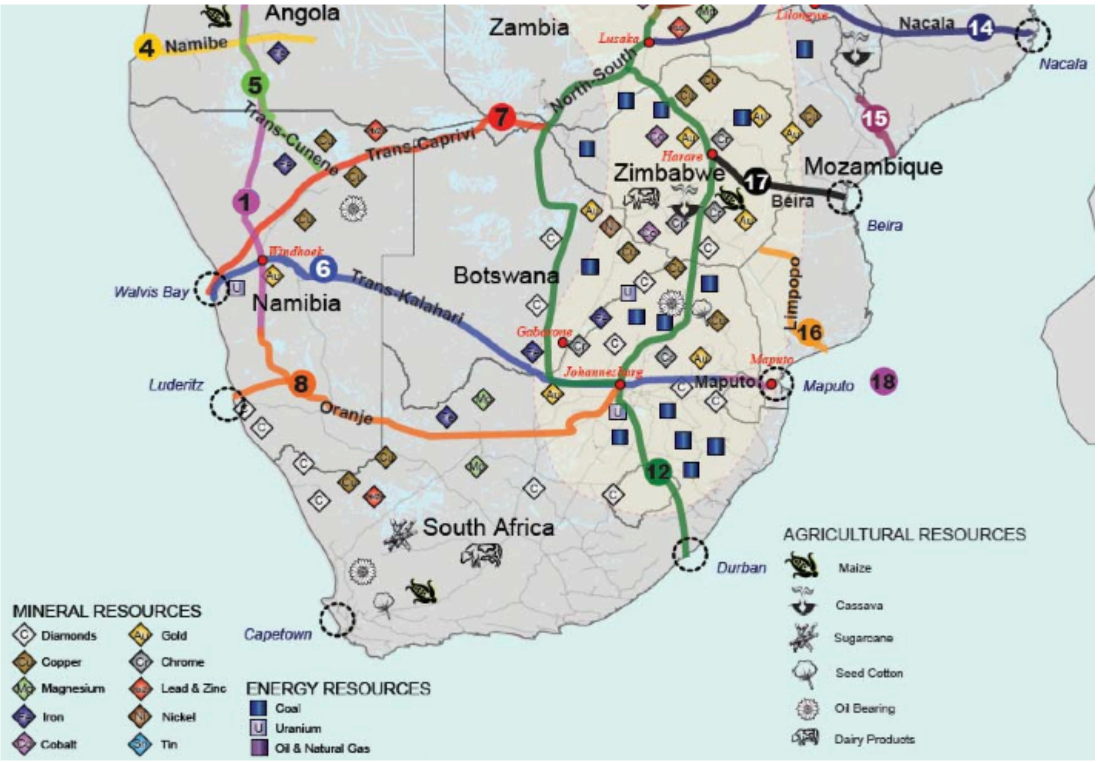

Figure 2-6: Corridors traversing Namibia (JICA, 2010)

To support the port to its growing potential, these corridors will become more and more important in the future. Creating or extending existing corridors makes it possible to attract transport of new goods to the Port of Walvis Bay, e.g. the production of Uranium.

2.2.1 Tripoli-Windhoek corridor

The Tripoli-Windhoek corridor comprises a 9600 kilometre long road, running from Tripoli in Libya to Windhoek in Namibia. It mainly crosses not densely populated areas with no significant economic importance. The quality of the road is good in Namibia itself but in Angola and further to the north some sections are not that well maintained.

In contrast to the other corridors in Namibia, the Tripoli-Windhoek corridor does not connect to large mineral resources. It is mainly used for interregional trade and is therefore not of great importance to the port of Walvis Bay.

2.2.2 Trans-Cunene corridor

The Trans-Cunene Corridor connects the Port of Walvis Bay in Namibia with Lubango in south Angola. It consists of a road infrastructure, supported by the Namibian northern railway line, with a total length of 1600 km. These roads are being maintained by both the Government of Angola and Namibia, because this corridor is of great importance to both countries. The corridor handles the largest percentage of cargo volume that is transferred through the port of Walvis Bay.

The crossing border between Namibia and Angola along this road corridor is at the city of Oshikango, where a wholesaling and retail centre for trade with Angola is positioned.

2.2.3 Trans-Kalahari corridor

The Trans-Kalahari corridor is a roadway that connects the port of Walvis Bay in Namibia with the rest of southern Africa. It stretches over 1900 km from Walvis Bay to Maputo in South Africa via Botswana. It forms a transport corridor from West to East in Southern Africa.

There is also a railway connection between the port of Walvis Bay and Gobabis in Namibia. This railway is part of the corridor system but it's not used a lot for transporting cargo because its length is very limited. There are plans to extend this railway connection to Botswana, where large quantities of coal can be exploited and transported via Walvis Bay. By extending the railway connection it becomes much easier to export the coal from Botswana.

2.2.4 Trans-Caprivi corridor

The Trans-Caprivi corridor links the Port of Walvis Bay to the inland areas of Zambia and the South-Eastern part of Democratic Republic of Congo via a highway. Between Walvis Bay and Grootfontein there is also a railway line available. Since the completion of the bridge crossing the Zambezi River between Namibia and Zambia, the marketing activities via the Trans-Caprivi corridor have accelerated resulting in larger imports and exports through the Port of Walvis Bay.

The present bottleneck in this corridor is the capacity of the container terminal in the Port of Walvis Bay. Congestion at the terminal is expected in the near future, as the limit of handling capacity is imminent. Developing a new terminal therefore has the priority, after which the extension of the railway line from Grootfontein in Namibia to Zambia would be beneficial.

2.2.5 Trans-Oranje corridor

The Trans-Oranje corridor highway is a tar road linking the Western part of Namibia to the Northern Cape province of South Africa. It stretches from the Port of Luderitz, the second largest port in Namibia, and the Port of Walvis Bay to Johannesburg. There are also railway connections between Windhoek and Keetmanshoop and between Luderitz and Keetmanshoop, however some sections have not been completed yet. The main transported resources are lead and zinc.

Since the large iron ore mines at Sishen (South Africa) are already served by the dedicated Sishen-Saldanah railway line, the potential benefits from developing this corridor may not be as high as others.

2.2.6 Overview

After analysing the five corridors that connect to Walvis Bay, it becomes clear that the Tripoli-Windhoek and the Trans-Oranje corridors are currently of minor importance for the port of Walvis Bay. The Trans-Cunene corridor transfers the largest volume of cargo to the port of Walvis Bay at this moment and is therefore of great importance. This corridor has sufficient capacity for now, but may have to be expanded in the future to satisfy the growing demand of northern Namibia and southern Angola. No new projects are planned surrounding this corridor.

The transport of cargo from and to Zambia and the South-Eastern part of the Democratic of Congo has accelerated since 2008 after the completion of the bridge crossing the Zambezi River. The Trans-Caprivi corridor is sufficient for the transport, making the port of Walvis Bay the bottleneck of this corridor.

	Current situation	**Development possibilities**
Tripoli-Windhoek	- Mainly used for regional trade; limited importance	- Construct missing links in road network
Trans-Cunene	- Major volume of freight traffic from port of Walvis Bay to Angola. - Only an available railway in northern Namibia.	- Expanding of the current corridor when maximum capacity is reached.
Trans-Kalahari	- Only a railway between port of Walvis Bay and Gobabanis in Namibia. - Increasing container traffic, which is expected to exceed the current terminal capacity.	- Extend the railway along the corridor. - Development of a container and a coal terminal at the port.
Trans-Caprivi	- Available railway from the port of Walvis Bay till Grootfontein. - Expected congestion at the container terminal of the port of Walvis Bay.	- Construction of the railway to Zambia. - Expansion of a container handling capacity at Walvis Bay.
Trans-Oranje	- Not of great use, due to the Sishen-Saldanah railway line.	- Completing missing sections of railway between Luderitz and Keetmanshoop

Table 2-5: Overview of corridors and their development possibilities

2.3 Southern expansion

Although the port has been optimised substantially in the last decade, it is nearing its handling capacity rapidly. In order to cope with the increasing demand the port will be expanded on a patch of reclaimed land, which is connected to the mainland at the southern end of the current port area. The first phase of expansion will increase the handling capacity from around 250.000 TEU to 1.000.000 TEU after completion. Consecutive phases may further increase the capacity up to 2.000.000 TEU, depending on future demand and feasibility. Due to repositioning of port facilities, the bulk handling capacity is also increased alongside.

Namport announced their plans for expansion of the port back in 2008, after which construction of the first phase should have commenced in 2011. However, due to reluctance of investors, the project's Engineering, Procurement and Construction (EPC) phase has been cancelled indefinitely by the port authority. Namport is now accepting new tenderers to both build and finance the expansion. They are confident that the construction phase will begin in early 2013, targeting full operation in 2016.

2.3.1 Expansion details

The location of the expansion is chosen in a way that the existing approach channel can be used, minimizing the dredging quantity and thus making the construction most economically feasible. The approach channel only has to be deepened from -12.8m to -14.1m CD, making it penetrable for post-Panamax vessels. The current width of 134 meters is considered sufficient and remains unchanged. An additional turning basin is required to facilitate the manoeuvring of vessels, dimensioned with a diameter of 450 meters at a depth of -13.5 m. The dredging material resulting from these operations may be used to reclaim the patch of land, if not contaminated. The layout of the southern expansion, as it is tendered for construction phase, is displayed in Figure 2-7.

The area of the newly reclaimed land consists of a 400 by 400 meters square patch, and a triangular annex of about 56.000 m^2, adding up to a total footprint of 216.000 m^2. The expansion will merely be used as a container terminal, increasing the handling capacity by an additional 650.000 TEU per annum. The two new berths have a total length of 550 meters, making the terminal capable of accommodating a Panamax and a 2.000 TEU class container vessel simultaneously.

To load and unload containers from vessels, six quay gantry cranes will be installed. Over the stacking area, eight rubber-tired gantry cranes are initially available for placing and picking up containers. The connection with the current port will be made possible by a 500 meter long and 100 meter wide section of land, facilitating four truck lanes, three rail tracks and a pedestrian lane. The connection is located at the most southern part of the current port, to minimize the interference with current activities. Next to the dike, a small craft jetty will be constructed to accommodate tugboats and other small crafts.

The infrastructure within the port will drastically be altered to handle the growing container throughput. The plans include two new roundabouts, separated entrance and exit gates, an automated customs scanner and a state-of-the-art routing system. To avoid congestion, all transport will be one-way. The current rail tracks are extended to the new terminal, including cranes to load and offload carriages. This will make rail transport more accessible, possibly resulting in a more favourable modal split (see section 2.1.5).

The construction of the container terminal creates new storage space for containers, releasing the pressure of the current port. Because of this, functionalities can be repositioned in the current port's area, enhancing bulk and other cargo capacity along. Furthermore, the current container terminal will be made more efficient. Along with the enhancements of the infrastructure, this is estimated to boost the handling capacity from its current 250.000 up to 350.000 TUE per annum. Together with the new terminal, the total container capacity after expansion adds up to 1.000.000 TUE's that can be handled per year; quadrupling the port's current capacity.

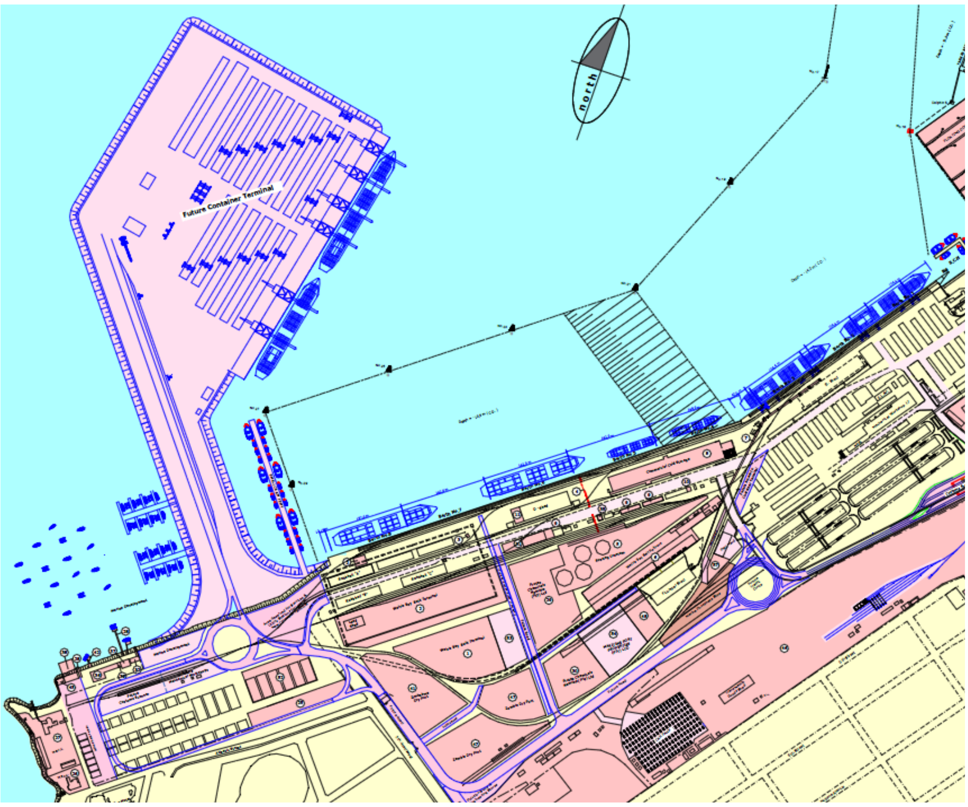

Figure 2-7: Master plan for southern expansion, including infrastructural enhancements

2.3.2 Consecutive expansions

According to container throughput forecasts based on positive scenarios, the new maximum handling capacity of 1.000.000 TEU will be reached as soon as 2019/2020. This means that there is a time span of only 3-4 years for the port authority to find a tenderer for a designing and constructing (and possibly financing) a consecutive expansion, if they don't want to disappoint customers with congestion. There are many possibilities to achieve this, all having their pros and cons with respect to finances, risks, expandability, flexibility, accessibility and sustainability. In chapter 6 of this report, several consecutive expansion possibilities are elaborated and assessed with respect to these aspects, leading to a substantiated recommendation for the future development strategies of the port of Walvis Bay.

3 Economic analysis

In order to be able to make realistic estimates of future service demands for the port, a thorough economic analysis is essential. Predictions can only be fundamental after investigating the (macro-) economy of the region of Southern Africa, and Namibia in particular. Consecutively, competitive ports and their visions should be analysed. The paragraphs in this chapter each handle one of these aspects.

3.1 Namibian economy

In 1993, three years after achieving complete independence from South Africa, Namibia introduced its own currency; the Namibian Dollar (N$). It is linked to the South African Rand at a fixed exchange rate of 1:1. Furthermore, the Namibian economy remains integrated with the economy of South Africa, as 85% of Namibia's imports originate here and 33% of Namibian exports are destined for the South African market.

The country's sophisticated formal economy is based on capital-intensive industry and farming. However, Namibia's economy is heavily dependent on the earnings generated from primary commodity exports in a few vital sectors, including minerals (especially diamonds), livestock and processed fish. The clean, cold South Atlantic waters off the coast of Namibia are home to some of the richest fishing grounds in the world. Namibia's fishing infrastructure is most heavily concentrated in the Port of Walvis Bay.

Several key macroeconomic indicators show the sustained growth of the economy of Namibia. Most importantly, the average GDP grew with 5% annually in the past decade.

	IMF published data								IMF estimates		
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Population [*1000 persons]	1860	1891	1923	1957	1992	2028	2065	2103	2120	2138	2156
GDP current prices [Billion US$]	3.37	4.93	6.62	7.26	7.98	8.81	8.83	8.93	11.12	12.46	12.72
GDP purchasing-power-parity [Billion US$]	8.19	8.71	9.94	10.83	11.97	12.98	13.71	13.80	14.88	15.74	16.59
GDP growth [% change]	4.8	4.3	12.3	2.5	7.1	5.4	3.4	-0.4	6.6	3.6	4.0
Consumer price inflation [% change]	11.3	7.2	4.1	2.3	5.1	6.7	10.4	8.8	4.5	5.8	6.7
Volume of imports of goods [Billion US$]	1.7	1.4	1.4	1.5	2.4	2.5	3.5	4.5	5.2	-	-
Volume of exports of goods [Billion US$]	1.6	1.2	1.1	1.4	2.0	2.3	2.8	3.5	4.3	-	-
Total investment [% of GDP]	18.5	19.4	19.1	19.7	22.3	23.7	28.2	29.4	28.1	32.4	30.4
Government gross debt [% of GDP]	21.8	24.9	27.5	26.0	23.8	19.1	17.7	15.9	18.8	21.9	25.3
Current account balance [Billion US$]	0.12	0.30	0.46	0.34	1.11	0.81	0.24	0.17	-0.20	-0.78	-0.56

Table 3-1: Macroeconomic indicators of Namibia, 2002 – 2012. [IMF World Economic Outlook database]

For Namibia and some of its surrounding countries, the 90s were a troubled period of conflicts, such as the Caprivi conflict, the Angolan civil war and the Second Congo War. These conflicts had their effects on the economic competency of the whole southern African region and thus on the Namibian economy as well during that period. During the early 2000s the economy was catching up again with 2004 as a peak year. The global financial crisis also affected Namibia showing a decrease of GDP in 2009. After the crisis, the Namibian economy started picking up again in 2009, showing a solid growth for the last two years. The country's investments are increasing; the government is for example investing in developing and constructing the Trans-Caprivi and Trans-Kalahari corridors, which will open up the region's access to the Port of Walvis Bay.

3.2 Economic situation of Southern Africa

Besides Namibia, the other countries in the Southern African region also perform well compared to the global economic development. Figure 3-1 shows the development of both the global and the southern African gross domestic product (NB. logarithmic GDP scale). This indicator gives a good impression of development of the economies that depend on the services of the port. It is clear that the region's economy has substantially grown in the past decade, and this trend is predicted to continue towards the year 2017.

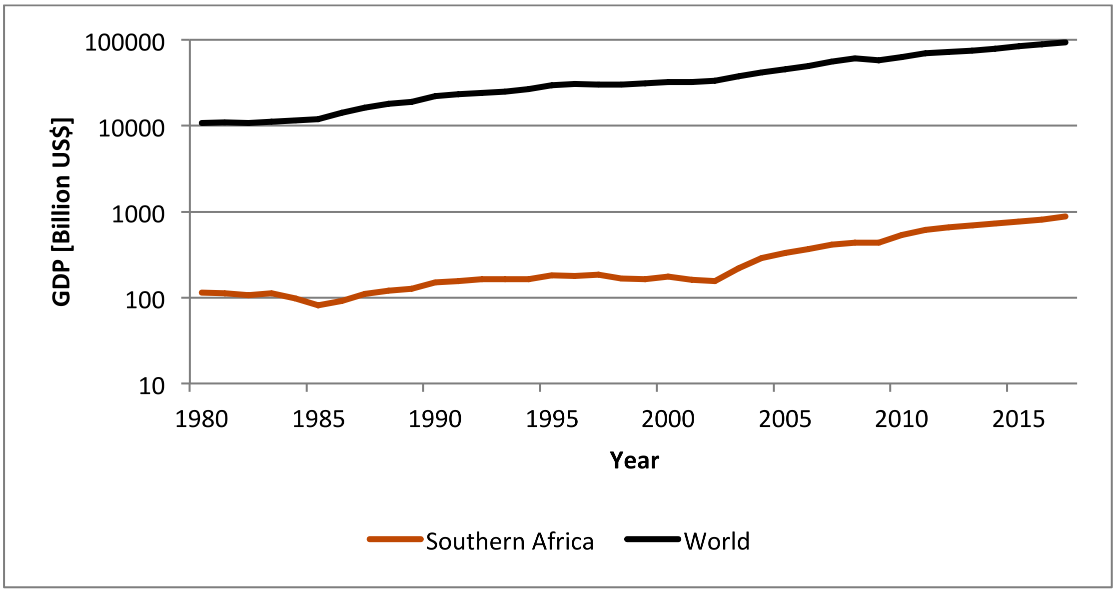

Figure 3-1: Development of global and Southern African GDP

In Figure 3-2 the GDP development of the countries around Namibia is presented. It becomes clear that in the 80's and early 90's, most economies in the region were quite stable. There was not much growth, except for in South-Africa, which has always been the most developed economy in the sub-Saharan region. This trend is clearly broken around the millennium, after which the average economy has about doubled within a decade. Especially Angola has seen a spectacular rise, after its civil war had reached an end in the year 2002. The expectation is that exploitation of untouched reserves of mainly oil, gas and diamonds will drive Angola's economy even further in near future, making it the most important commercial market for the Port of Walvis Bay. As can be seen from Figure 2-5, already about three-quarter of all exported containers landed at the port is destined for Angola. One of the reasons is the absence of a decent port to handle their own import of goods.

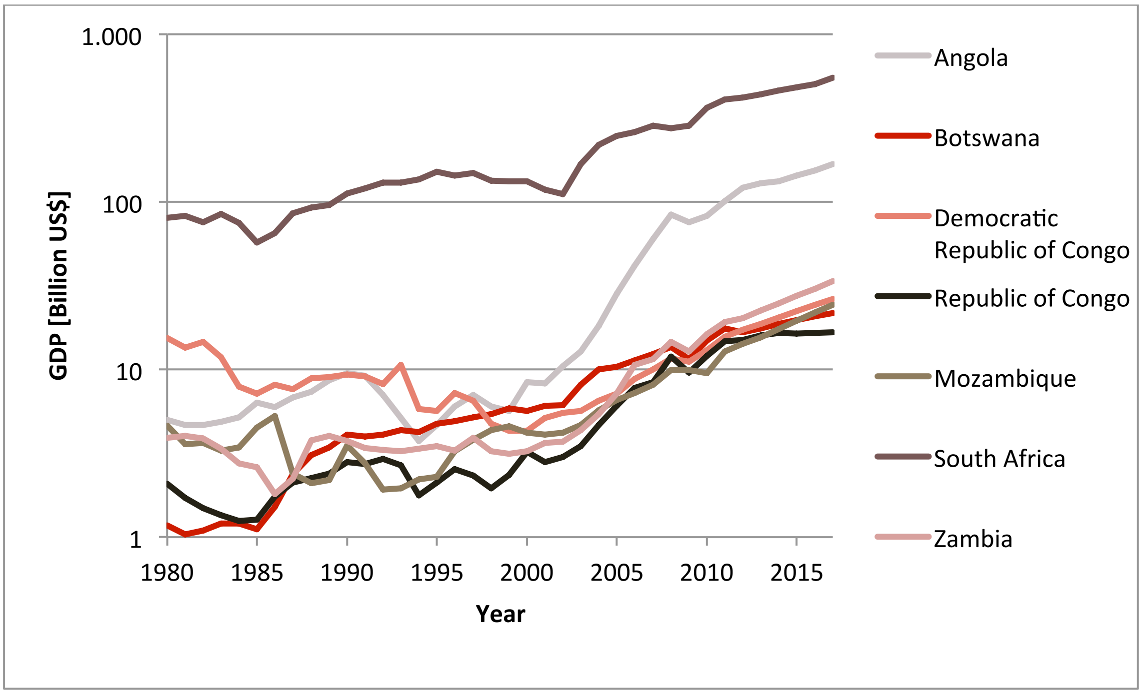

Figure 3-2: GDP of countries adjacent to Namibia, in billions of US$

3.3 Throughput analysis

Both container and cargo throughput of the port have steadily grown for the last decade, up until the global crisis in 2009. The global trade volumes declined by 12%, affecting Walvis Bay's volume figures dramatically. This effect was more noticeable in container figures than in cargo, as China's insatiable desire for resources mitigates the volume drop. Container volumes were below previous years for seven months in a row, stabilizing after declining by 18%. Since the last quarter of 2009 however, volumes have restored and are growing faster than ever before.

3.3.1 Container throughput

The total throughput for import, export and transhipped containers for the past decade is plotted in Figure 3-3. The throughput volumes are measured from September until August. One can see the strong increase in transhipped container throughput, as Walvis Bay has transformed into an important transhipment hub along the west coast of Africa. The port features an excellent location for transhipment activities, and benefits from congestion at competitive ports.

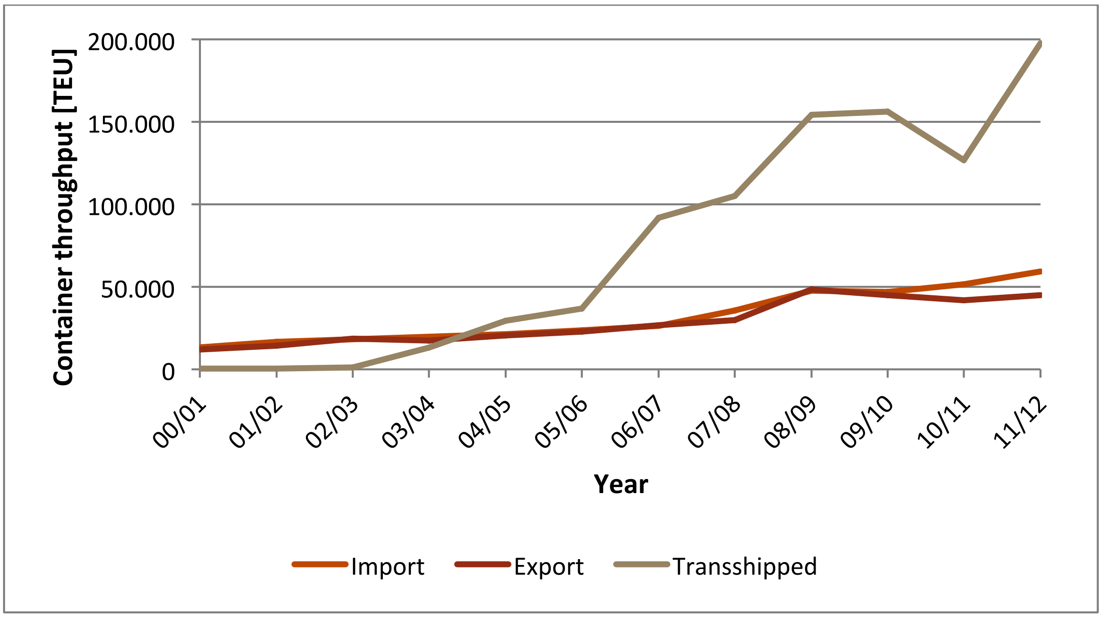

Figure 3-3: Container throughput Port of Walvis Bay 2000/2001 – 2011/2012.

A detailed outline of the container throughput, reefers and empties is given in Appendix A.1.1.

3.3.2 Cargo throughput

Also the cargo throughput has grown substantially since the early 2000s. Especially general cargo shows a significant volume growth.

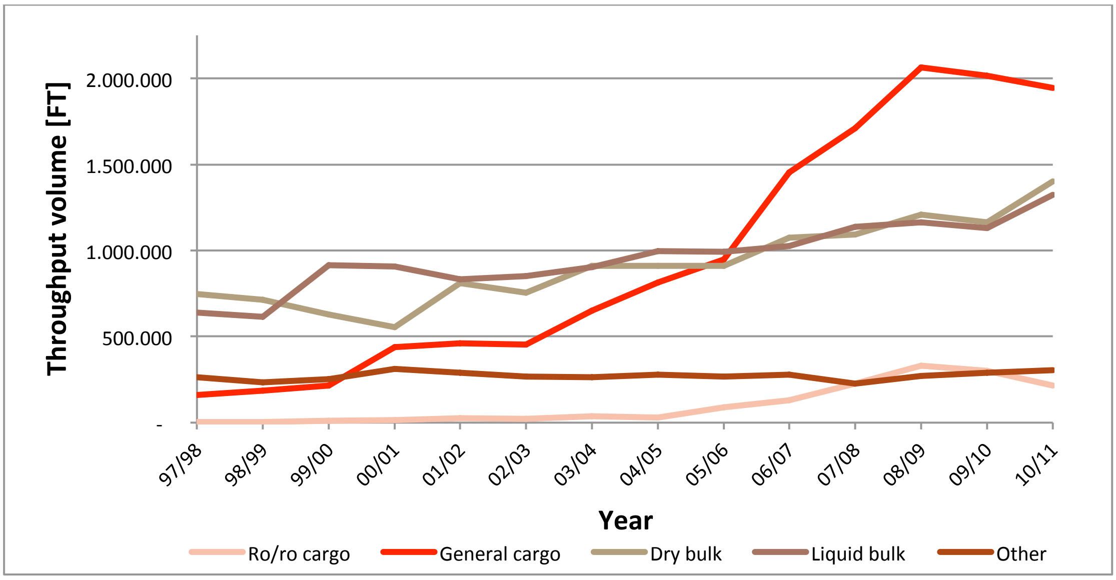

Figure 3-4: Cargo throughput Port of Walvis Bay 1997/1998 – 2010/2011.

One can see a decrease in general cargo transport in the last two years and an increase in dry and liquid bulk Projections container throughput for different scenarios transport. This is because the bulk terminal has increased in size at the expense of the general cargo terminal. The current port is now almost operating at its capacity so the throughput cannot grow much further without expanding the port.

A detailed survey of the cargo commodities is given in Appendix A.2.1.

3.4 Competitive ports

The economies in the Southern part of Africa have seen sustained growth over the last decade. As a result, transportation of containers and cargo has been growing faster than the handling capacity of the ports situated in Southern Africa, resulting in congestion. This creates opportunities for Walvis Bay to be able to grow with relatively small financial risks attached. An insight in the most important competitive ports and their developments is essential to this extend.

Figure 3-5: Major ports of Southern Africa

3.4.1 Port of Lüderitz

The port of Walvis Bay is the largest port in Namibia. The only other port in the country is the port of Lüderitz, in the southern region. Accommodating fishing industry and shipping cargo for the mining industry are the main functions of the port of Lüderitz. Containers are handled, but only in very small quantities compared to Walvis Bay; 2.600 versus 300.000 TEU in 2011/2012. The total throughput of the port in was 340.000 freight ton compared to 5.2 million freight ton in the port of Walvis Bay. Both ports are exploited and maintained by Namport, so cooperation instead of competition should be pursued.

3.4.2 South-African ports

Most of the major competitive ports can be found in neighbouring country South-Africa. The port of Durban is the largest port of Southern Africa, handling 2.7 million TEU, of which 0.5 million TEU transhipment, and a total of 78 million tonnes of cargo (excluding containers) annually. The port has good rail and road connections to neighbouring countries. Nevertheless the port of Durban is suffering from congestions; the port is simply unable to keep up with the growing demand. The second biggest port in South-Africa is the port of Cape Town, handling 0.79 million TEU and 3.8 million tonnes of cargo (excluding containers) per year. The port is of big importance for the export of fruit. Both South-African ports are competing with Walvis Bay for the transhipment market of Southern Africa. A third harbour also targeting this market is the harbour of Ngqura. This is a complete new harbour at the east coast of South-Africa taken in service at the end of 2009. The depth in the harbour is

16.5 m, making it possible to accommodate larger container vessels than any other port in Southern Africa. After completing all the phases, the container will be capable of handling approximately 2.0 million TEU per year, a big part of which will be transhipment.

South Africa has got two other major ports; Richards Bay at the east coast about 150 km north east of Durban and Saldanha Bay at the west coast just over 100 km north of Cape Town. Both ports are primarily dedicated to transporting bulk cargo. Saldanha Bay handled over 57 million tonnes of bulk cargo last year of which the majority was iron ore. This resource is mined at the Sishen mines located about 800 km north east, a special railway is constructed for the transport. The entrance channel is dredged to a depth 23 meters; this enables the port to accommodate cape size ore carriers. Richards Bay's main cargo is coal; it exported over 63 million tonnes of coal last year. The terminal has been upgraded to the capacity of 91 million tonnes per year making it one of the biggest coal terminals worldwide. Both ports can be serious competitors for the bulk cargo export of the landlocked countries, or even for bulk cargo produced in Namibia itself.

3.4.3 Angolan ports

In Angola, the other sea bordering neighbouring country, just minor ports are in operation. Most important reason is the years of civil war the country was in; this resulted in underdeveloped and poorly maintained infrastructure both inside and outside of the ports. The three main ports of Angola are situated in Luanda, Namibe and Lobito, and are primarily focussed on handling cargo for Angola itself. At the moment not much cargo is transported from and to the landlocked countries like Zimbabwe, Malawi and Zambia. However attention should be paid to the development of these ports in the future; a lot of money is invested to renovate and build new port facilities. When these ports are well functioning and the infrastructure towards the landlocked countries is improved, Angola can become an important rival for shipping cargo from these countries.

3.4.4 Port of Maputo

For the transport of cargo of the landlocked countries in Southern Africa, the port of Maputo in Mozambique is an important competitor. The total amount of cargo shipped from this port is currently around 14 million tonnes per year, mainly consisting of bulk cargo. Plans are made to expand the throughput capacity of the coal terminal, making the port the main competitor for the export of bulk cargo from Botswana.

3.4.5 Overview

An overview of annual container and cargo handling of the main ports in the region is presented in the table below.

	Containers [1000 TEU]			Cargo excluding containers [1000 Metric Tonnes]		
	Import	Export	Tranship	Import	Export	Tranship
Cape Town	390	400	65	2.453	1.325	74
Port Elizabeth	82	66	152	*2.006	*5.660	*35
East London	26	28	-	1.234	688	18
Saldanha Bay	-	-	-	4.690	53.576	-
Richards Bay	-	-	-	5.888	83.113	-
Durban	1.121	1.077	450	30.147	11.071	458
Maputo	50	34	6	*2.860	*3.700	*60
Beira	48	38	19	*346	*486	*6

Table 3-2: Throughput figures for major ports of Southern Africa [* = data between 5-10 years old]

3.5 Mining and infrastructural developments

Southern Africa is known to possess large stakes of global mineral resources such as Copper (22%), Platinum (87%), Cobalt (40%), Chrome (40%) and Diamond (58%). Dozens of mines have been designated as 'depleted', as exploitation was no longer economically feasible. However, due to steady increase of metal prices, these abandoned mines become interesting again since infrastructure is already more or less available. The export volumes of resources are expected to grow along with the global economy, but especially local projects can drastically boost trade through Walvis Bay. Some of the most important projects are highlighted in the next paragraphs.

3.5.1 Coal from Botswana

Botswana has a very large coal reserve at the Mmamabula Coalfields, indicated in Figure 3-6. According to estimations there is a reserve of 212 billion tons of coal. The price of coal has risen in the past which makes it more attractive to invest in these coal reserves. Also the demand for coal is still expanding, due to the growing amount of thermal coal plants in China and India. The multi-product beneficiation plants that will be built at the Mmamabula Coalfield are expected to accommodate the production of 24 million tons per year for 35 years, possibly peaking at 100 million tons per year.

At present there is not a good connection to transport the coal towards any port. The government of Botswana has to decide whether to construct a railway to the port of Walvis Bay or to Southern Mozambique. Both railways have their pros and cons.

The railway through Zimbabwe to the Indian Ocean in southern Mozambique is a route of 1100 kilometers, which is about 400 kilometers shorter compared to the distance to Walvis Bay. The location on the Indian Atlantic is also preferred, because the major coal markets are India and China. The Zimbabwean part of the route however raises some concerns, since the political instability of this country may cause problems and holds off investors.

Using the Trans Kalahari route to Namibia, a distance of around 1500 kilometers has to be crossed, however the relation between Botswana and Namibia is better and more stable than with Zimbabwe.

The government of Botswana has favoured the Trans Kalahari Rail line to the Port of Walvis Bay above the Zimbabwean connection, and permission for the construction of a new coal terminal has been given by Namport. However, there seem to be second thoughts about the deal and Zimbabwe is still a serious option. If the port of Walvis Bay is indeed chosen as transportation hub, this will have a major impact on the harbour considering the average estimated production of 24 million tons per year. To put this into perspective; the Port of Richards Bay in South Africa handled about 63 million tons of coal in 2011 and has recently increased its capacity to handle 91 million tons per year.

3.5.2 Iron ore from Namibia

About one and a half year ago a large iron ore field was discovered in the Opuwo area in the North of Namibia, as indicated in Figure 3-6. It is expected that there is a reserve of at least 2 billion tons of iron ore, which could start being produced by 2016. The production of the plant is estimated to be around 5 million tons per year. All the iron ore will probably be transported through the port of Walvis Bay, using the Tripoli-Windhoek corridor which is located 250 kilometres east of the mines in Opuwo. Unfortunately this corridor consists of a highway and not a railway. Considering the large amounts of iron ore that will be transported over the years, it can be beneficial to construct a railway next to the Tripoli-Windhoek corridor. To put this into perspective; the Port of Saldanha Bay in South Africa handled about 50 million tons of iron ore in 2011.

3.5.3 Uranium from Namibia

Namibia is the fourth largest producer of uranium oxide in the world, making it the prime export resource of the country. Uranium is moved in high-value, low volume containers. The production of uranium is an important source of income; it represents ten per cent of the total export of Namibia. Production of uranium oxide is expected to grow to 23.500 tonnes in 2015 compared to 3.500 tonnes in 2011, as the number of mines in the region is planned to expand from three to possibly sixteen.

For the mining and processing of uranium, specific chemicals are needed such as sulphuric acid and alkaline chemicals. The need for these chemicals will grow along with the increasing mining and processing activities, possibly six folding the total volumes. The chemicals are not produced in Namibia, but they are all imported through the port of Walvis Bay.

	Transportation method	Used in 2012 [1000 ton/y]	Needed in 2022 [1000 ton/y]
Sulphuric acid	Liquid bulk	250	1600
Bicarbonate	Dry bulk	60	210
Soda Ash	Dry bulk	40	390
Caustic soda	Dry bulk	10	90
Uranium oxide	Break bulk	3.5	23.5

Table 3-3: Expected increase of liquid and break bulk throughput

Gecko Vision Industrial Park

With its current capacity, the port of Walvis Bay will not be able to cope with such an increase of bulk cargo. There are two main options to solve the problem; enlarge the port's throughput capacity of these chemicals, or start producing them yourself. This second solution is under consideration, and has been called the 'Gecko Vision Industrial Park'. A series of chemical plants would be built to produce the chemicals needed for mining uranium, including a: sulphuric acid plant, soda ash, bicarbonate plant, caustic plant, phosphoric plant and a phosphoric acid plant.

Building the Industrial Park has got more positive impacts for the region apart from the production of the chemicals used in the mining business. The project will create jobs, and an opportunity to produce and export phosphoric concentrates. The waste heat of the sulphuric acid plant can be used to produce fresh water from sea water in a desalination plant. The decision which of the solutions is preferable is up to the Namibian government in collaboration with the mining companies and other important stakeholders.

The implications of building the chemical park for the throughput of different commodities is given in the table below. A conversion has been made to freight ton.

	Gecko project is constructed		
	Throughput [1000 FT/y]	Origin	Destination
Coal	94	Gecko	Import
Sulphur	300	Gecko	Import
Phosphoric ore	2.400	Reserves	Gecko
Phosphate	2.644	Gecko	Export
Uranium oxide	15	Mines	Export
TOTAL	**5.452**		

	Gecko project is not constructed		
	Throughput [1000 FT/y]	Origin	Destination
Sulphuric acid	1.480	Import	Mines
Bicarbonate	247	Import	Mines
Soda ash	507	Import	Mines
Caustic soda	68	Import	Mines
Uranium oxide	15	Mines	Export
TOTAL	**2.316**		

Table 3-4: Additional throughput from Gecko project

3.5.4 Power plant in Namibia

Because of economic growth a power shortage arose in Namibia. The country is depending on import of electricity, mainly from South-Africa. NamPower, the Namibian national power utility company, has set the goal to provide its own demand for electricity in 2016. In order to meet this goal several power stations are upgraded, and a couple of new energy projects are planned for the coming years.

One of the projects, a coal fired power station planned just outside Arandis, may influence the cargo throughput of the port of Walvis Bay. The power station will produce 300 MW when put in use in 2016, in the future the output of the factory can be upgraded to 800 MW. The 1,100,000 tonnes of coal per year needed to operate the 300 MW power plant will be imported through the port of Walvis Bay, after which transport will be taken care of by trains on the Trans Namib rail line. In case of a future upgrade of the power station 2,700,000 tonnes of coal per annum will be needed for operation.

The current coal terminal is able to expand within the current port's domain to be able to cope with the additional amount of coal, needed to operate the 300 MW station. In fact, NamPort has promised NamPower to facilitate the import as soon as it's needed. This would imply the coal throughput will be tenfold of what is currently being handled; 136.000 FT now versus 1.346.000 FT after commissioning.

The demand for coal after future upgrades of the power plant can however not be facilitated without more radical expansion of the capacity; a totally new bulk terminal would in that case be inevitable.

3.5.5 Corridor investments

The success of the port of Walvis Bay depends largely on the quality of its hinterland connections, as explained in chapter 2.2. In the current state these connections are far from ideal, lacking maintenance and efficiency. Especially at border crossings, where clearance times can reach up to five days, or railways may not even continue. Improving the corridors would attract investment companies in mineral and agricultural resources in Southern Africa.

It seems like mining investors are waiting for the governments to improve the corridors to ports like Walvis Bay, while governments are awaiting investors before improving. This vicious circle could be broken by cooperating, which is for example attempted by an organization called the 'Walvis Bay Corridor Group'. Since its founding in the year 2000 it has accomplished more harmonised procedures for customs along some of the corridors, boosting their utilisation. Other important improvements that would be beneficial to the port of Walvis Bay are listed in Table 2-5.

The most promising investment is considered to be the extension of the Trans-Kalahari railway corridor to Botswana's coal fields. Becoming the export hub for Botswana's coal production is a major goal for Namport, as it would generate an estimated average increase in dry bulk throughput of 24 million tons per year.

Another important goal is creating a rail corridor between Namibia's own iron ore reserves and the port, which is estimated to generate another 5 million tons of export per year. A substantial investment is needed, since the present Tripoli-Windhoek corridor presently only comprises road infrastructure.

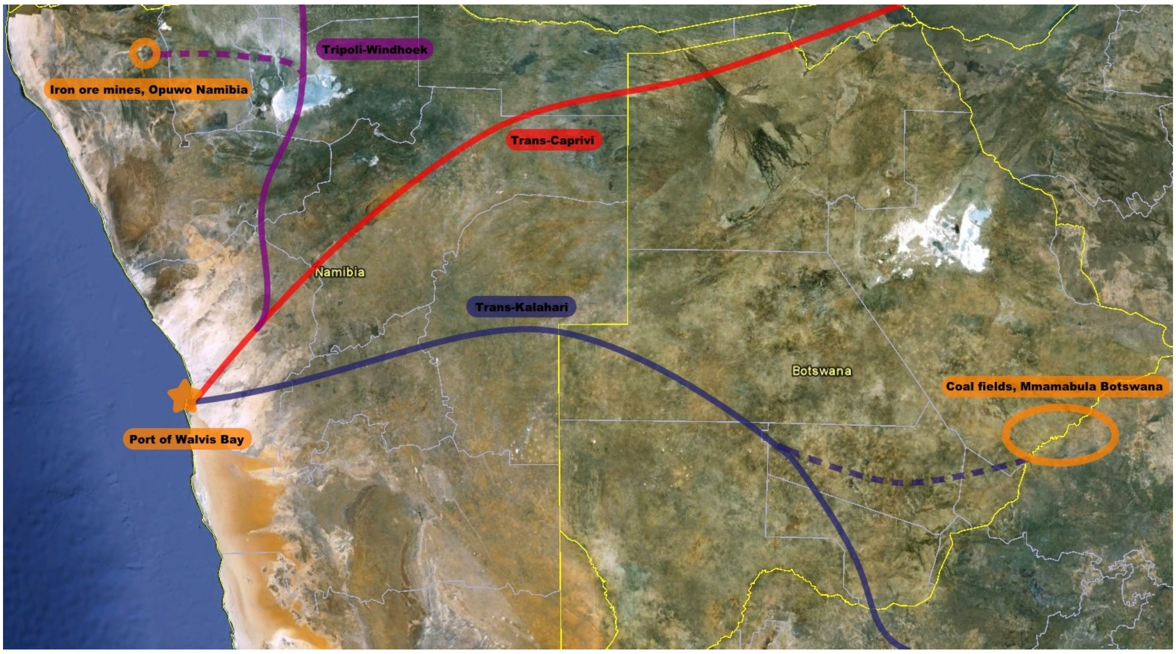

Figure 3-6: Directly connected corridors of Walvis Bay and suggested developments

3.5.6 Overview

An overview of the throughput volumes of what mining and local projects would additionally provide is presented in the following tables. The volumes in freight ton per annum are derived by applying stowage factors to the specified metric tonnes.

	Possible throughput [1000 FT/year]	Origin/Destination	Destination	Conditions
Iron ore	2.375	Opuwo, Namibia	Export	Needs Tripoli-Windhoek railway
Coal	26.396	Mmamabula, Botswana	Export	Needs trans-Kalahari railway
Coal	1.210	Powerplant	Import	No conditions
Coal	1.760	Powerplant	Import	Needs expansion of coal power plant
Coal	94	Gecko	Import	Gecko project is constructed
Sulphur	300	Gecko	Import	Gecko project is constructed
Phosphoric ore	2.400	Reserves	Import	Gecko project is constructed
Phosphate	2.644	Gecko	Export	Gecko project is constructed
Uranium oxide	15	Mines	Export	Gecko project is constructed
TOTAL	**37.194**			

Table 3-5: Additional throughput of commodities for mining and local projects

3.6 Scenarios

Predicting the future is a very tricky but inevitable step in any design process. To be able to pin any assumptions regarding the estimations, one must search for proportionalities between the design parameters and known historical data. Consecutively, these must somehow be extrapolated over the design lifespan of the structure, anticipating on as many uncertainties as possible. This operation results in a probability distribution of which a number of scenarios is extracted. The effectiveness of the final design should be optimized with respect to these scenarios and corresponding likelihood.

3.6.1 Throughput-GDP correlation

There appears to be a strong correlation between throughput figures and the gross domestic product of the port's commercial market; the southern African region. Plotting container and cargo volumes together with the market's GDP in time results in Figure 3-7 and Figure 3-8 respectively. Although the lines in the graphs represent a totally different quantity, the results hint on their dependency.

Container

For container throughput, a distinction is made between transhipment and in- and export. The last category follows the regional GDP quite nicely, whereas transhipment grows unproportionally. This is mainly due to the fact that Walvis Bay filled a void in transhipment capacity after deepening the harbour back in 2000. The transhipment figures grew exponent tially as pressure was being released from competitive ports in South Africa. Namport has the ambition to turn Walvis Bay into a main hub port in the near future, making it plausible that this trend continues.

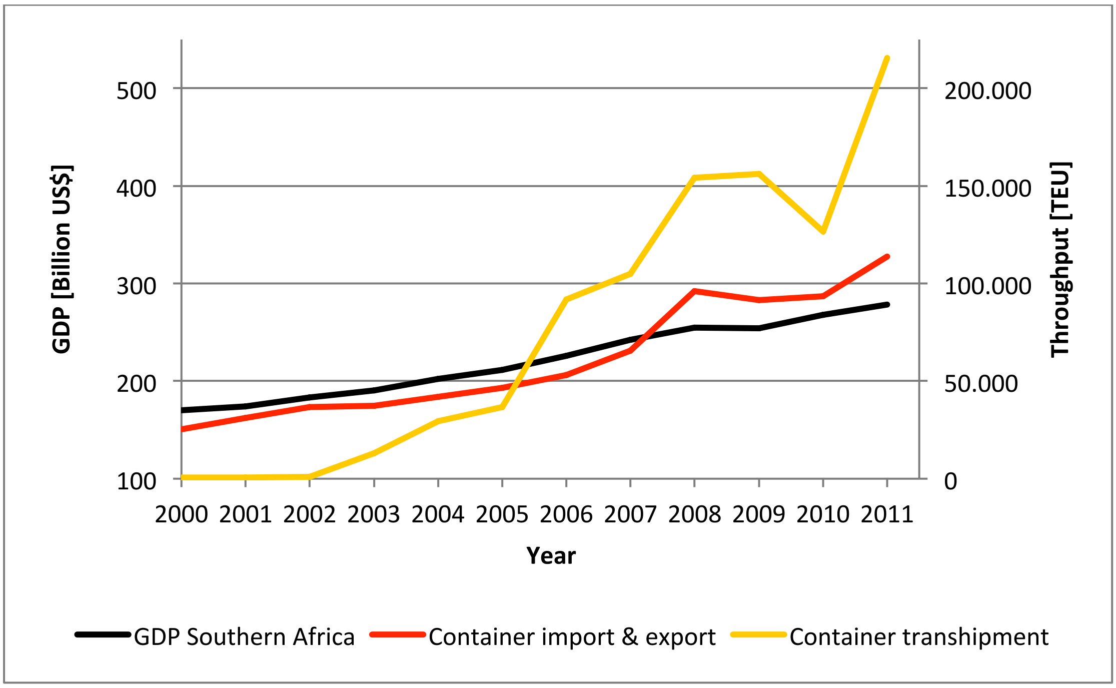

Figure 3-7: GDP of Walvis Bay's business market versus container throughput

Cargo

The same correlation is clearly visible for cargo volumes.

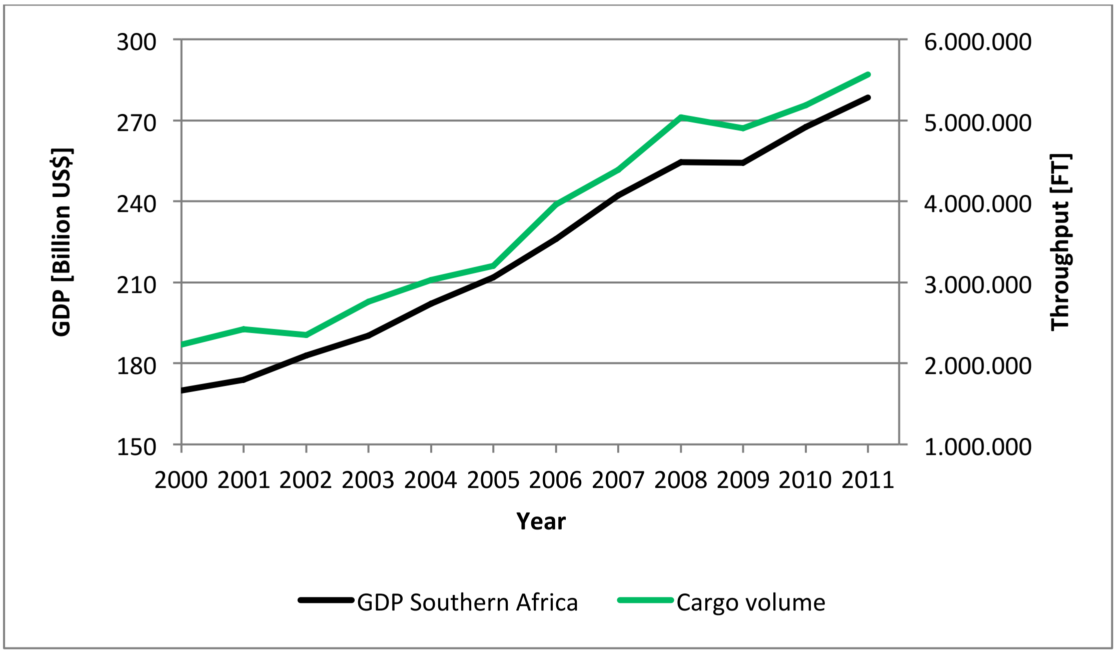

Figure 3-8: GDP of Walvis Bay's commercial market versus cargo throughput

3.6.2 Projections

Since throughput figures are correlated to the regional GDP, they can be extrapolated using economic predictions. The International Monetary Fund has modelled and published GDP estimates for the region up to 2017, making this operation possible. The numbers can further be estimated until 2050 using Namport's predictions that the first container port expansion project in the southern part will reach its maximum capacity in 2019. Because the financial resources for the consecutive expansion phase have to be earned with the southern expansion's revenues, this phase is likely to be finished not earlier than 2025.

In the graphs the capacities at different stages of the port are marked with dashed horizontal lines. The throughput predictions converge to these boundaries towards 2025, as the capacity is no longer in compliance with the demand. After completion of the consecutive phase, sustainable growth is possible until at least 2050. The three projected scenarios (low, medium and high growth) are linked to uncertainties in economic growth. They will be used as an input for the port's development strategies. A detailed survey of methods used for predicting throughput volumes is given in Appendix A.

Container

Container transhipment is clearly prevailing import and export, and Namport is determined to take this to the next level. Nowadays the total of transhipped containers is about double of what is im- and exported, while the vision is to increase this ratio to four. This is used to determine the total container throughput as shown in Figure 3-9. The milestones on which the predictions are based are listed below.

- 2016: Southern container terminal expansion operative
- 2019: Total container throughput reaches port's capacity
- 2025: Consecutive expansion operative

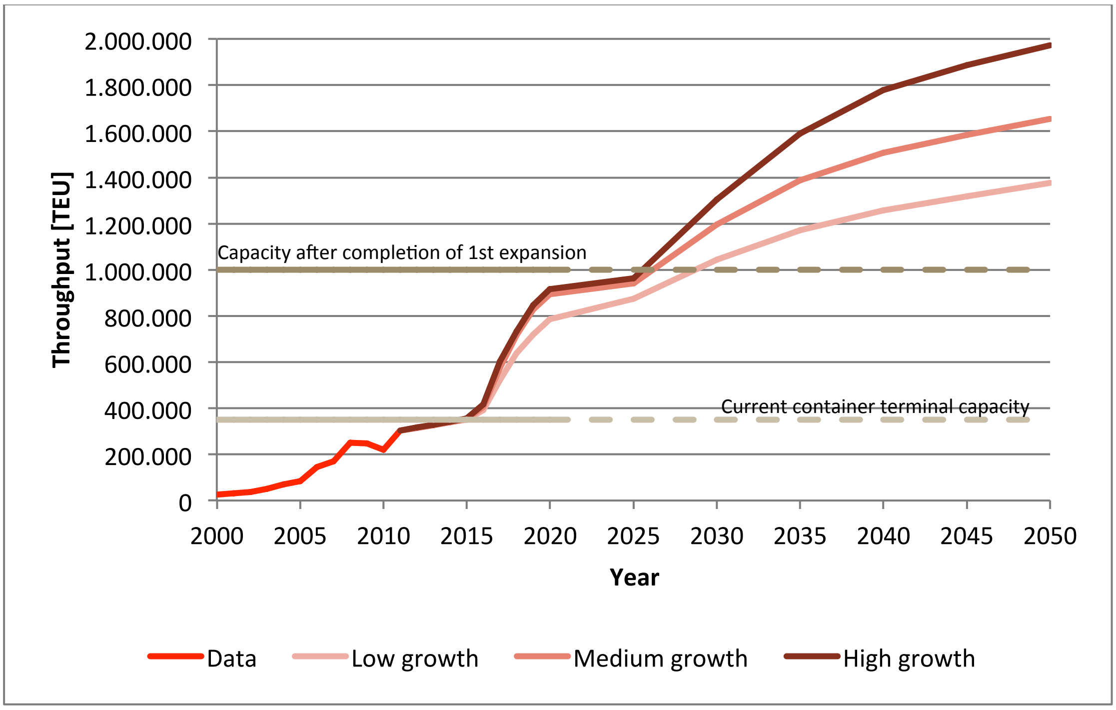

Figure 3-9: Future container throughput projection

The projected container throughput for different design timeframes and different grow scenarios can be extracted from the figure.

	Projected container throughput [1000 TEU]								
	2025			2035			2050		
	Low	Med	High	Low	Med	High	Low	Med	High
Import	131	141	145	161	193	223	167	203	244
Export	89	95	97	106	123	140	109	129	151
Tranship	656	706	724	906	1.073	1.229	1.101	1.324	1.580
TOTAL	**875**	**941**	**965**	**1.173**	**1.388**	**1.590**	**1.376**	**1.655**	**1.974**

Table 3-6: Projected container throughput for different timeframes and scenarios

By subtracting the port's current container throughput capacity from the extracted required ones, the additionally required capacity of the expansion is obtained. The current container terminal capacity is 350.000 TEU, and will be increased in 2016 to 1.000.000 TEU after completion of the southern expansion. The capacity split resembles the ratio between transhipment and im- and export, which tends to become larger in each expansion phase.

	Current [1000 TEU]		Additionally required capacity [1000 TEU]								
			2025			2035			2050		
	Now	2016	Low	Med	High	Low	Med	High	Low	Med	High
Import	63	157	0	0	0	4	36	66	10	46	87
Export	48	107	0	0	0	0	16	33	2	22	44
Tranship	241	737	0	0	0	169	336	492	364	587	843
TOTAL	**350**	**1.000**	**0**	**0**	**0**	**172**	**388**	**591**	**376**	**655**	**974**

Table 3-7: Required additional container capacities for projected throughput

Cargo

The cargo trend of the port has been steady for many years and is closely correlated to the GDP growth of the market, making the predictions more reliable. These predictions do not incorporate sudden changes in demand by the opening of new mines or local projects; these are separately listed in paragraph 3.5.6. The cargo throughput is however affected by the completion of the southern expansion of 2016, as container handling will mainly shift to this new terminal, clearing new area for cargo handling. A detailed survey of predicted cargo throughput volumes is given in Appendix A.2.2.

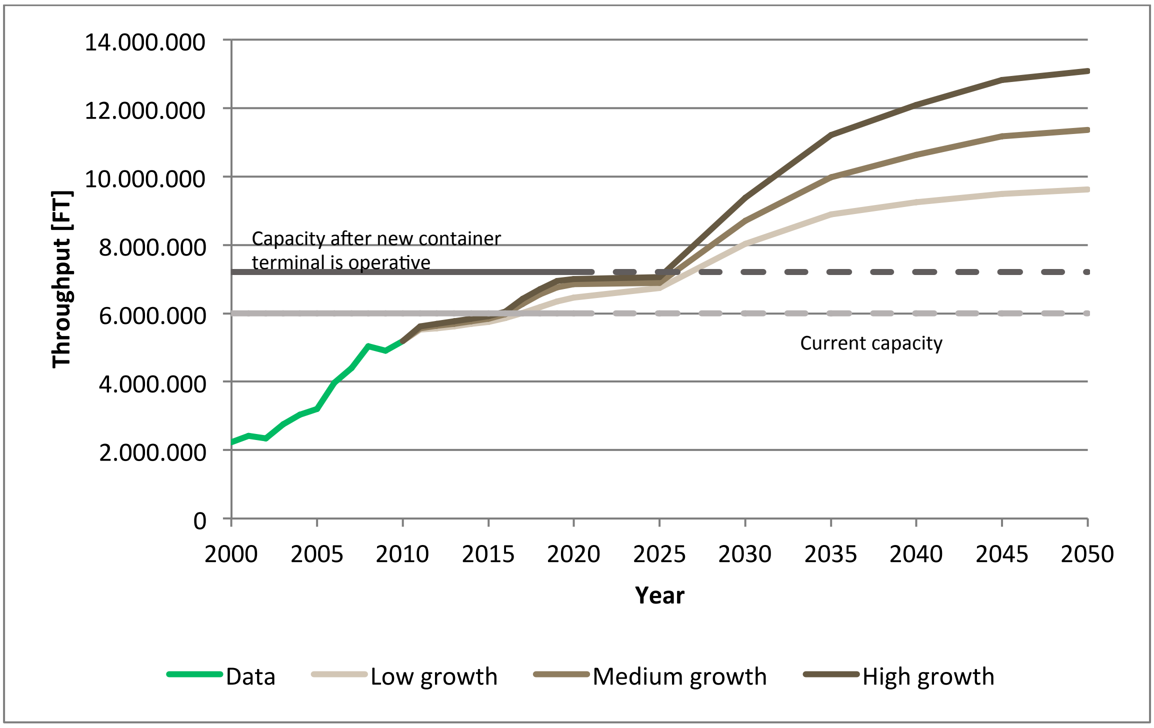

Figure 3-10: Future cargo throughput projection

Within dry bulk a division is made between four cargo classes; rough, food, chemical and salt bulk. This is done because rough bulk like coal, manganese ore and copper will be handled with another unloading facility than food bulk (sugar, wheat etc), chemical bulk (fluorspar, sulphur etc) and salt bulk. These four cargo classes all need their separate unloading facility.

	Projected cargo throughput [1000 FT]								
	2025			**2035**			**2050**		
	Low	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
Ro-Ro	489	517	549	1.092	1.454	1.913	1.347	2.000	2.732
General	2.420	2.469	2.521	2.743	2.904	3.068	2.834	3.052	3.246
Dry bulk	1.958	2.007	2.064	2.876	3.305	3.789	3.175	3.855	4.506
- rough bulk	*839*	*878*	*911*	*1.364*	*1.684*	*1.983*	*1.530*	*2.027*	*2.430*
- food bulk	*334*	*343*	*357*	*648*	*616*	*752*	*770*	*732*	*910*
- chemical bulk	*188*	*184*	*190*	*258*	*394*	*437*	*267*	*483*	*548*
- salt bulk	*599*	*604*	*608*	*606*	*612*	*617*	*608*	*614*	*620*
Liquid bulk	1.532	1.548	1.567	1.794	1.902	2.013	1.870	2.026	2.162
Other	349	353	357	398	419	439	412	441	466
TOTAL	**6.747**	**6.892**	**7.056**	**8.901**	**9.981**	**11.220**	**9.636**	**11.372**	**13.109**

Table 3-8: Projected cargo throughput for different timeframes and scenarios

The current cargo capacity is around 5.900.000 FT, and is expected by Namport to increase to 7.200.000 FT after completion of the first container terminal. By subtracting the port's current container throughput capacity from the extracted required ones, the additionally required capacity of the expansion is obtained.

	Current [1000 FT]		**Additionally required capacity [1000 FT]**								
			2025			**2035**			**2050**		
	Now	**2016**	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
Ro/ro	354	424	65	93	125	668	1.030	1.489	923	1.576	2.308
General	2.259	2.710	0	0	0	33	194	358	124	342	536
Dry bulk	1.412	1.692	266	315	372	1.184	1.613	2.097	1.483	2.163	2.814
- rough bulk	*539*	*646*	*193*	*232*	*265*	*718*	*1.038*	*1.337*	*884*	*1.381*	*1.784*
- food bulk	*219*	*262*	*72*	*81*	*95*	*386*	*354*	*490*	*508*	*470*	*648*
- chemical bulk	*127*	*152*	*36*	*32*	*38*	*106*	*242*	*285*	*115*	*331*	*396*
- salt bulk	*527*	*632*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Liquid bulk	1.508	1.960	0	0	0	0	0	53	0	66	202
Other	361	469	0	0	0	0	0	0	0	0	0
TOTAL	**5.894**	**7.255**	**331**	**408**	**497**	**1.885**	**2.837**	**3.997**	**2.530**	**4.147**	**5.860**

Table 3-9: Required additional cargo capacities for projected throughput

4 Port requirements and conditions

The development of the port should ideally maximize the added value of its stakeholders. The design of expansions of the port should reflect this request. In order to do so, functional requirements are drafted that are expected to maximize the added value function in time. They comprise certain standards for cargo and container capacities, handling of vessels and hinterland connections. The designs must be in compliance with these requirements in order to maximize the projects profit. Together with the initial costs, this defines the economic feasibility of the expansion.

The design space is however bounded by conditions imposed by social, technical or natural conditions. The most optimal solution in terms of costs may for example not be accepted due to environmental restrictions. Therefore it is of the essence to clearly state what is needed and what is possible prior to starting the design process.

4.1 Functional requirements

The functional requirements define what the port should be able to handle at different points in the future, regarding throughput capacity, vessel types and hinterland connections.

4.1.1 Throughput capacity

It is impossible to design a port with just the right capacity, as the predictions of the future have a high degree of uncertainty. This means the port will either have a capacity that is too small or too large. In the latter case, the investments are higher than strictly needed, leading to a lower return rate for investors. If the capacity however proves to be insufficient, the full potential of the port is not utilized. The initial design should be such that consecutive expansions are accounted for, without having to invest disproportionally. The most important functional requirement can be expressed as:

"The port must be economically feasible in the lower limit throughput scenario, while allowing to feasibly expand to accommodate the upper limit scenario."

In section 3.6 three different scenarios have been presented. These scenarios give an impression of the expected cargo flow in the future. Besides this gradual growth of throughput, driven by economic development of the region, there is also the possibility of attracting demand from new mining and local projects as described in section 3.5.6.

Using this data, upper- and lower limits of cargo throughput can be constructed in different points in time. It is chosen to do so for both 2035 and 2050, as they represent the design span of the first and second expansion phases. The 2025 expansion will accommodate the requirements to handle the 2035's throughput, and in 2035 the terminals will expand to the demand of 2050.

The lower limit is the sum of lowest economic growth, no extra projects and no Gecko project. The highest growth scenario is the combination of highest economic growth; the maximum developed extra projects and a fully completed Gecko project. In Table 4-1 and Table 4-2 the estimated cargo flows are presented. The figures exclude the flows through the current port; they merely represent what the capacity of the expansion should be.

	2035		2050	
	Lower	Upper	Lower	Upper
Import	4.000	66.000	10.000	87.000
Export	0	33.000	2.000	44.000
Transhipment	169.000	492.000	364.000	843.000
TOTAL	**173.000**	**591.000**	**376.000**	**974.000**

Table 4-1: Upper- and lower limits container throughput scenarios [TEU]

	2035		2050	
	Lower	Upper	Lower	Upper
Ro-Ro	668.000	1.489.000	923.000	2.308.000
General cargo	48.000	373.000	139.000	551.000
Dry bulk	2.032.000	39.291.000	2.329.000	40.007.000
- rough bulk	*718.000*	*35.872.000*	*884.000*	*36.319.000*
- food bulk	*386.000*	*490.000*	*508.000*	*648.000*
- chemical bulk	*928.000*	*2.929.000*	*937.000*	*3.040.000*
- salt bulk	*0*	*0*	*0*	*0*
Liquid bulk	1.314.000	53.000	1.390.000	202.000
Other	0	0	0	0
Total	**4.062.000**	**41.206.000**	**4.781.000**	**43.068.000**

Table 4-2: Upper- and lower limits cargo throughput scenarios [FT]

4.1.2 Nautical requirements

In order to be able to compete with the largest ports of Southern Africa, the port of Walvis Bay should have a high standard as it comes to accommodating vessels. Standards are draft regarding both vessel dimensions and number of calls per year.

Dimensions

After expansion it is assumed that the largest container vessel interested in entering the port will be of post-Panama class, carrying 8000 TEU. In the table below the range of capacities and corresponding maximum dimensions are given.

	Capacity [TEU]	Length [m]	Beam [m]	Draught [m]
Panamax	3.500 – 4.500	240	32.0	12.0
Post Panamax	4.500 – 8.000	320	42.8	14.5
Suezmax	Up to 13.000	397	56.0	15.5

Table 4-3: Container vessel classes

The post-Panamax container vessel defines what the port should minimally be able to accommodate. However, for the design process, the average ship dimensions are just as important. There is not much information available on this topic. A rough first-order estimation is to assume the average vessel length to be two-third of the maximum vessel length; 210 meters.

The largest dry bulk vessels are also assumed to be of the Post-Panamax class, having a length of 320 meters. If the large mining projects will continue to develop, it is likely that the vessel sizes increase as well. The main mining product exported through the port is coal. The largest coal vessels are in the so-called 'Cape size' class. It's probable that there will be a demand for Cape sized class vessels to enter the port of Walvis Bay in the future. To give an impression, the largest dry bulk vessel (Very Large Ore Carrier) is presented in the table below as well.

	Capacity [DWT]	Length [m]	Beam [m]	Draught [m]
Post Panamax	90.000 – 130.000	320	42.8	14.5
Cape-size	80.000 – 200.000	330	45.0	17.5
Very Large Ore Carrier	Up to 400.000	380	63.0	23.0

Table 4-4: Dry bulk vessel classes

The largest liquid bulk vessels calling at the port are assumed to be of the Panamax class, as the throughput volumes are insufficient to make it feasible to accommodate larger vessels. The dimensions of the largest liquid bulk vessels to be expected are listed below.

	Capacity [m³]	Length [m]	Beam [m]	Draught [m]
Panamax	75.000	230	32.0	12.0

Table 4-5: Liquid bulk vessel classes

Quantities

The average capacities of the calling vessels will increase due to the increasing allowed draught in the harbour. This is especially expected for container vessels, increasing their average capacity from 2000 TEU now towards 5000 TEU in 2035. The increase for cargo ships is expected to increase more gradually. In the table below the expected development of the vessel size is presented.

	Now	2016	2035	2050
Container [TEU]	2000	3000	5000	5000
Ro-Ro [1000 FT]	100.0	110.0	130.0	140.0
General cargo [1000 FT]	27.5	30.3	35.8	38.5
Dry bulk [1000 FT]	48.0	52.8	101.4	109.2
Liquid bulk [1000 FT]	48.0	52.8	62.4	67.2
Other [1000 FT]	2.6	2.9	3.4	3.7

Table 4-6: Average vessel capacity development

The amount of vessels calling at the port obviously depends on the throughput scenarios. For this requirement, the same holds as for the throughput capacity:

“The port must be able to accommodate the amount of vessels in the lower limit throughput scenario, while allowing to feasibly expand to accommodate the upper limit scenario.”

	Current [-]		Additionally required capacity [-]			
			2035		2050	
	Now	2016	Lower	Upper	Lower	Upper
Container	700	1333	938	1274	1102	1580
Ro-Ro	18	19	42	74	48	98
General cargo	411	448	386	431	370	424
Dry bulk	292	339	278	1226	272	1168
Liquid bulk	79	93	131	81	125	80
Other	139	164	118	130	113	128
Total	**1638**	**2396**	**1893**	**3216**	**2030**	**3478**

Table 4-7: Required vessel capacities per year for different scenarios

The quantities are calculated using the estimated average vessel capacities from Table 4-6. Since the vessels do not transfer all of their containers/goods at the port, a ratio is assumed for their actual transferred load. For containers this ratio is assumed to be 25%, but it is up to 100% for fish and salt.

One can see that the expected amount of vessels decreases for the lower scenarios, even though the throughput is significantly higher. The vessel size effect compensated the increased throughput, made possible by the deepening of the harbour.

4.1.3 Hinterland connections

The port of Walvis Bay has the ambition to become a major transhipment hub in Southern Africa, visioning an 80% transhipment percentage. The other 20% has to be transported by rail or road to their final destination inland. In order to avoid congestion of the city's road network, a more balanced modal split between rail and road is anticipated; ideally going towards a 50-50 split for containers. The modal split for cargo is highly dependent of the type of commodities that are transported. The high scenarios include large amounts of coal, which will be transported by rail.

	Current		Total port			
	Now	2016	2035		2050	
			Lower	Upper	Lower	Upper
	CONTAINER [1000 TEU]					
Road	88 [80%]	212 [80%]	187 [70%]	255 [70%]	166 [60%]	237 [60%]
Rail	22 [20%]	53 [20%]	44 [30%]	49 [30%]	111 [40%]	158 [40%]
	CARGO [1000 FT]					
Road	3.345 [57%]	4.122 [57%]	5.760 [51%]	6.269 [13%]	6.237 [52%]	7.440 [15%]
Rail	2.550 [43%]	3.133 [43%]	5.460 [49%]	42.147 [87%]	5.719 [48%]	42.689 [85%]

Table 4-8: Required hinterland connection capacities for different scenarios

For this requirement, the same holds as for vessels:

"The port's hinterland connections must be able to accommodate the inland transport of the throughput quantities of the lower limit throughput scenario, while allowing to feasibly expand to accommodate the upper limit scenario."

4.2 Boundary conditions

Expansion designs must be in compliance with boundary conditions imposed by social, technical or natural conditions. The most important ones are investigated and presented in this section.

4.2.1 Topographical

The location for the expansion of the port is physically bounded by several other functions in the region of Walvis Bay, as can clearly be seen from Figure 4-1. The red dot at the top of the map is a protected man-made platform called the “Bird Island”, which serves as a breeding ground for birds and is used to harvest guano. No motorised vessels are allowed close by, making the underlying shoreline unsuitable. Also, expanding the existing port (light blue) to the south is not an option due to the lagoon and area around it, which is assigned to be “Nature Reserve” (green).

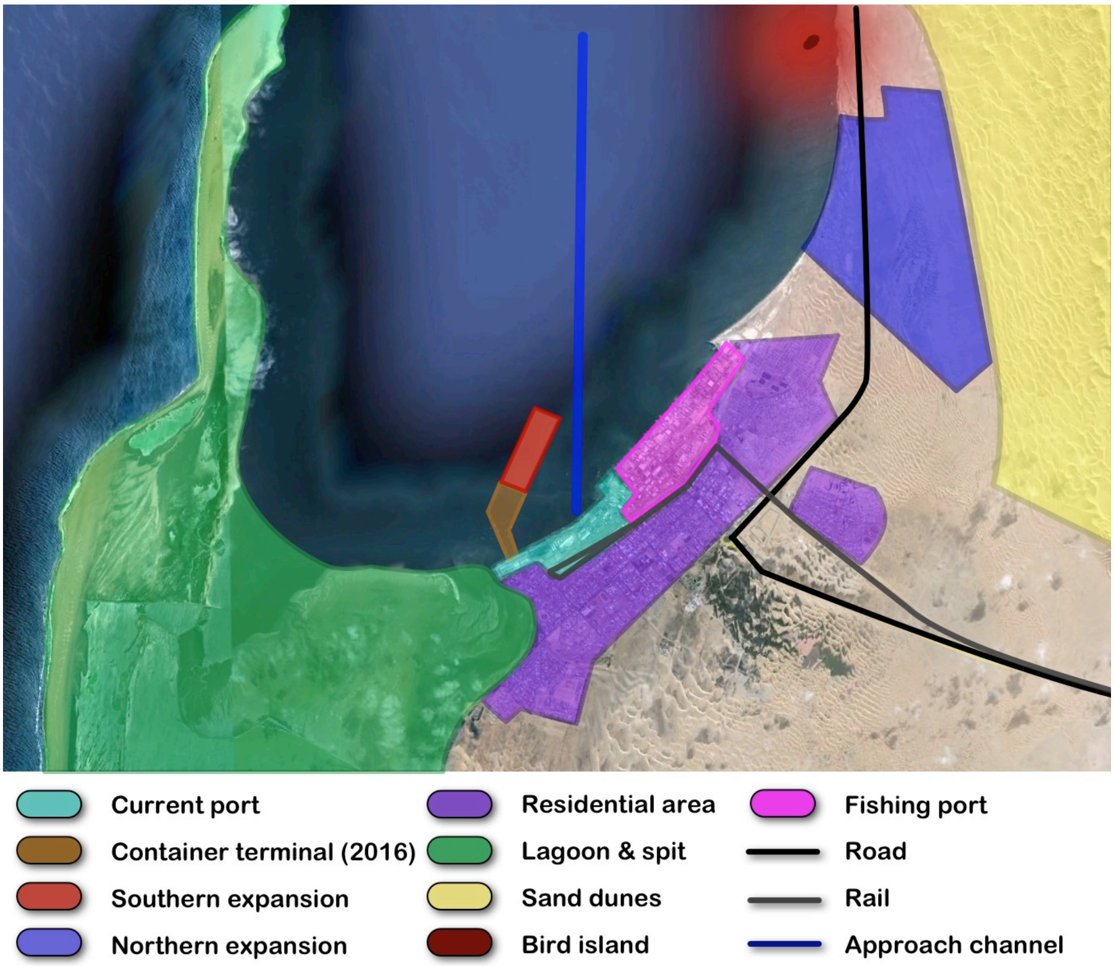

Figure 4-1: Topographical boundary conditions for expansion

The southern expansion, planned for 2016, is indicated with brown. The red rectangular area north of it indicates a possible expansion area; more details on this are given in section 5.3.1. The blue area has been made available by the government of Namibia to use as expansion site; this patch of land is hereafter called ‘Northern expansion’. Its surface is currently uncultivated and composed of small sand dunes. A main tar road between Walvis Bay and Swakopmund runs straight through the site. The area is bounded by residential area on the one hand, and protected sand dunes on the other.

4.2.2 Meteorological

Walvis Bay features an arid climate but it almost never experiences extreme cold or heat. This is mainly because of cold offshore currents in Walvis Bay. The city experiences on average 10 millimetres of precipitation per year, which makes it extremely dry. The precipitation that does occur can create gullies in the sand, often causing damage to pavements.

Walvis Bay experiences a relatively windy climate that can blow over relatively large distances, hence locally generated wind waves are considered to be important. Hourly measurement operations for over six years have resulted in wind roses and exceedance probabilities, displayed in

Figure 4-2. It clearly shows a dominant wind coming from the South-South-East direction, even though the strongest winds (up to 15 meters per second) are coming from the South-South-West.

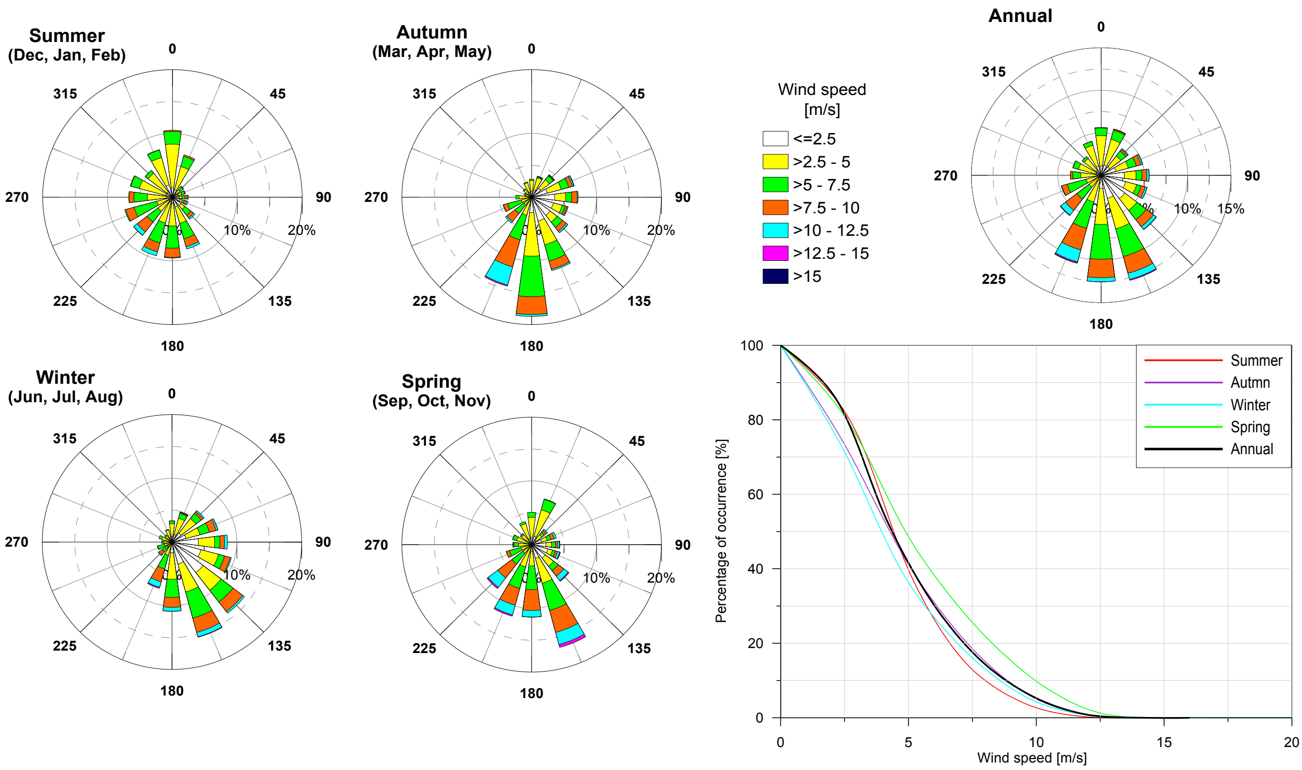

Figure 4-2: Seasonal and annual wind roses, with probabilities of exceedance

4.2.3 Hydraulic conditions

Wind- and tidal waves are separately considered to describe the hydraulic conditions in the bay, in which the port and its wet infrastructure are situated. Furthermore, a water depth profile of the bay is presented.

Wind waves

The port of Walvis Bay is well protected the Pelican point sand spit, which is a naturally shaped land tongue at the west side of the bay. Both swell waves and locally generated wind waves from southern and western direction cannot penetrate completely into the bay. The current port is located in the most protected area of the bay. The area designated for the Northern expansion is however less protected. The sand spit is vital to the conditions in the port. In near future the sand spit may suffer from wave attacks and overtopping, but that phenomenon is not investigated in this study.

In order to determine the local wave height, a SWAN model was used to model the area of interest. Offshore wave data were used and with the SWAN model the local near shore wave height was determined. Offshore data for the significant wave height with a 0.1% probability of exceedance were used. This wave has a significant wave height of 5.6m offshore. A probability of exceedance of 0.03% corresponds roughly to a wave with a return period of 1 year. Therefore the 0.1% probability of exceedance seems a reasonable design wave for the port as limited downtime is allowed.

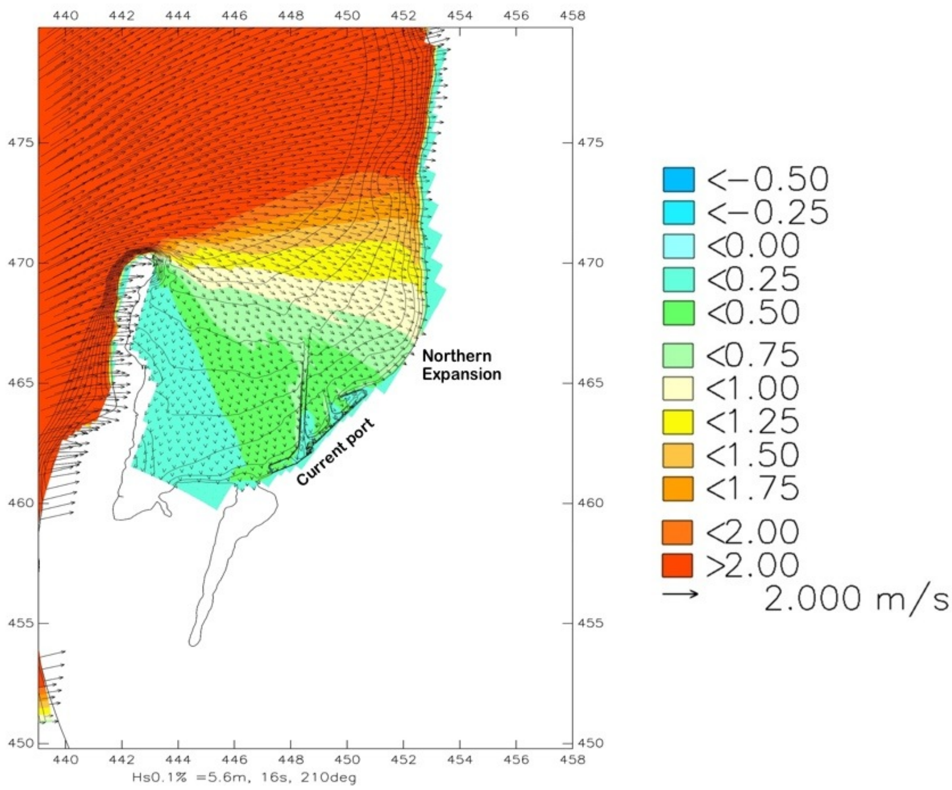

Figure 4-3 Wave height in Walvis Bay with a 0.1% probability of exceedance wave

The SWAN model only takes the waves coming from outside of the bay into account. Wind waves which are generated in the bay occur as well, but those are not considered in the model.

Tidal waves

Walvis Bay features a semi-diurnal tide which implies two high and low waters a day. The tidal characteristics are listed in the following table.

	Height CD [m]
Lowest Astronomical Tide (LAT)	0.00
Highest Astronomical Tide (HAT)	LAT +1.97
Mean Level (ML)	LAT +0.98
Mean High Water Spring Tide (MHWS)	LAT +1.69
Mean Low Water Spring Tide (MLWST)	LAT +0.27

Table 4-9: Tidal heights relative to Chart Datum (CD)

The tidal currents are considered to be ‘slow’ as they have a velocity of about 0.5 m/s. Near the entrance of the lagoon the tidal flow velocities can become up to 2 m/s. As this study focuses on the long term, it might be important to take sea level rise into account. In 2050 the sea level is expected to be 20 to 50 cm higher compared to the 2000 level. It’s recommended to measure the sea level development in time as it gives valuable information and doesn’t require expensive instruments.

Hydrographic map

The natural depths of the bay area are essential when designing the wet infrastructure as optimum length and directions can be derived from it, limiting the dredging volumes. The hydrographic map of the project area can be found in Appendix B.

4.2.4 Geotechnical conditions

The geotechnical conditions are important for both the foundation of structures and dredging activities. Since the soil layers are completely different at the current port and the Northern expansion, a distinction is made between them.

Current port

The port of Walvis Bay is located in an area which consists mainly of sand, finding its origin in the South African Orange River. Some research was done at the project site of the southern expansion of the port; boreholes have been drilled to determine the properties of the soil. Inter- and extrapolation of these samples suggests that the dense sand layer on which the quays are founded is descending rapidly below surface towards the sea. In line with the southern expansion, this sandy layer is estimated to only exist at around -60 to -100 meters CD.

Depth [m CD]	Soil description	Soil consistency	Typical dry density [kN/m^3]	SPT N-value	Effective cohesion [kPa]	Effective friction angle [deg]
-4 to -20	Silt/slightly clayey sandy silt	Very soft to very stiff	14.0 – 17.0	1 – 29	10	18 – 28
-20 to -60/-100	Slightly silty fine quartzite sand	Dense to very dense	17.5 – 19.5	30 – 80	0	35 – 40
from -60/-100	Fine quartzite sand	Very dense	17.5 – 19.5	50 – 80	0	40 – 45

Table 4-10: Indication of soil properties in line of southern expansion of the port

Northern expansion site

The location of the Northern expansion was once the estuary of a prehistoric river. There is no soil data available; however geologists assume that the river has eroded a rocky soil layer to an estimated depth of around -30 meters CD. The soil above this rocky layer consists of clayed sandy silt. Boulders are spread over the area, which are non-inventoried.

Dredging aspects

The bay is known to occasionally release large quantities of H_2S gas, leaving the city in a distinctive smell. This gas is trapped as pockets inside the silt soil layers. Apart from the smell, the gas in the city is harmless to human beings or the environment. However, in high concentrations, people may faint or actually suffocate as a result of breathing it. This is a very important issue to account for regarding dredging activities, as high concentrations of H_2S gas are released in the surrounding of the dredging vessel. It's recommended to do research into the location of these pockets and to take measures during dredging activities.

The silt layers close to the seabed can be stirred up quite easily while the deeper silt layers are more cohesive. The material is expected to arrive as slurry in the hopper or disposal site so it is expected not to have a negative effect on the dredgeability. However, large boulders spread around the sea bottom may be a problem to overcome while dredging. Repositioning or even blowing them up with explosives are costly operations.

For the reclamation activities it's assumed that 50% of the dredged material is suitable for reclamation use, as the first layers of clayey silt do not possess appropriate properties.

4.2.5 Environmental conditions

The government of Namibia has established a Directorate of Environmental Affairs within the Ministry of Environment and Tourism to ensure that sustainable development is achieved. An expansion of the port of Walvis Bay will also be subject to this law, enforcing the design to be sustainable. The United Nations describes sustainable development as: "development that meets the need of the present, without compromising the ability of future generations to meet their own needs".

If possible, any disturbance of the ecosystem should be prevented by selecting appropriate locations, materials and execution methods. If complete prevention is not within the possibilities, any disturbance inflicted during construction or utilization of the expansion should be mitigated. Mitigated damages should furthermore be compensated or restored.

Walvis Bay and lagoon

An area of 12.600 hectares of wetlands, which forms the habitat for thousands of migratory birds, is located just south of the port. This wetland is one of 1950 RAMSAR-registered areas, an international treaty for the protection of wetlands worldwide. Wetlands are delicate ecosystems; a small change in water flows or quality can have devastating consequences for its flora and fauna. Attention should be paid to the level of disturbance of the flow from and towards the wetlands when designing the port's expansion. Furthermore, a low southward tidal and wind wave driven sediment flow is observed in the bay. If a lot of fine sediments are supplemented within the grasp of this flow, the wetland might silt up. This is another thing to account for when reclaiming land in the bay. Both issues will have consequences for the design and construction of the port expansion.

The bay also accommodates lots of oyster farms, which forms an important source of income for the local populations. Certain standards for flow velocities and water quality are vital to grow oysters. These conditions must not be jeopardised any construction activities.

Sand dunes

North-East of the designated Northern expansion site, there is a widely stretched area of sand dunes. Besides being a unique natural area, its preservation is also important for tourism in Walvis Bay and Swakopmund. Hosting desert tours is one of the ways for local people to earn a living. As the principle wind direction along the coast is northward, attention should be paid to avoid pollution getting end up in this area.

City of Walvis Bay

Not only the natural areas surrounding the port of Walvis Bay should be taken into account when looking at the environmental impact of a port, also the city itself should be considered. The port is surrounded by urban area, which inhabitants living standards will directly be influenced by emissions in the form of noise, smell and light. Furthermore, there is the risk of being exposed to hazards like toxic gases and explosions. Great attention should be paid to this aspect in both the construction and utilisation phase of the port expansion.

	Key issues
Ecology	Migration and breeding pattern birds Biodiversity in the lagoon and bay Dune area north-east of existing port
Pollution	Suspension of fine sediments in lagoon Water quality inside the bay; acidification Emission of greenhouse gasses, fine dust, heavy metals and toxic components
Health and safety	Noise, smell and light hindrance for residents Exposure to hazards Safe working conditions
Socio-economic	Salt works inside the lagoon Oyster farms and fisheries inside the bay Maintaining touristic value of the area surrounding Walvis Bay

Table 4-11: Key issues regarding social and ecological aspects

4.2.6 Labour and skills

Construction and utilization of a project in the developing country of Namibia imposes special conditions to the design of the expansion. One has to deal with certain price and quality standards for construction materials, equipment and labour. These aspects should be accounted for in the conceptual design phase, as they are of great influence on the overall costs and construction method.

Cost drivers

Namibia does not maintain a national minimum wage; however estimates suggest an average income of €1725 per year [36]. Materials and equipment are however only marginally less expensive compared to western countries. This makes that the labour/material cost ratio radically differs. It makes sense to design any project such that the demand for materials is minimalized, even if this would require a lot more man-hours. The problem with material efficient designs is that they often require specialized skills and equipment. If these are not available close by, engineers and equipment may have to be flown in, involving high costs. It is clear that the design should be optimized with respect to costs, driven by required materials, equipment, labour and skills.

Skilled professions

As a governmental institution, the National Port Authority has the task to 'Uplift and support the communities in which they operate'. Besides being the largest employer of Walvis Bay in sheer numbers, their activities also attract skilled professions to the city. To stimulate this, Namport has set the goal the push the ship repair and maintenance facilities in the port. Knowledge and skills required to execute this profession can be trained by Namport, creating more valuable employees.

4.3 Stakeholders

All individuals or groups that affect or are affected by the port of Walvis Bay and its expansion (the stakeholders) should be determined, and their interests should be assessed, in order to be able to create the largest added value possible for the project. In the tables presented below the stakeholders are sorted according to the impact of action on them, and their impact on action (interest and power).

	Interest/concern	Power
Namibian government	Sustainable stimulation of the country's economy by creating jobs and increase export	++
Namibian Port Authority (Namport)	- Sustainable growth of profit - Ability to easily expand activities - Uplift and support the community	++
Ministry of Environment and Tourism	Preservation of environment and tourism around Walvis Bay	+
Municipality	- Support local economy - Hindrance and exposure to hazards	+
Walvis Bay Corridor Group	- Stimulate the corridor cargo flow - Harmonize custom procedures	+
Investors	- High return rates - Low investment risks	+
Leaseholders of quays	- Efficient loading equipment - Sufficient stacking space - Low lease prices	+
Maritime operators	Increasing efficiency of service procedures (both costs and handling times)	+
Governments of adjacent countries	- Stimulate their economies by enhancing trade with Namibia	-
Mining industry	- Increase efficiency and flexibility of export	-
Contractor	Realize a prestigious project and make a profit (short term)	-
Fishing industry	- Preserve water quality - Increasing efficiency of export facilities	-
Salt refinery	- Preserve water quality - Increasing efficiency of export facilities	-
Tourist industry	- Preservation of environment - Increase efficiency of passenger hub	-
Owner of Bird Island	- Minimizing close approaches of vessels	-
Residents of Walvis Bay	- Minimizing hindrance and hazards due construction and utilization of the port - Increase amount of jobs	-
Environmentalists	Preservation of ecosystem in the bay, lagoon and sand dunes	-

Table 4-12: Stakeholders of the Port of Walvis Bay and its expansion

5 Expansion alternatives

After having established the requirements and conditions of the development of the port, multiple solutions can be engineered to anticipate on the future. The message from the requirements is that the port should develop in such a way that, even for slow economic development, its operations remain profitable. On the other hand, the port should be able to easily adapt to a more progressive development of the economy. A lower and upper throughput limit has been defined for this purpose. The two main uncertainties in these limits are the economic development and the ability to attract coal from Botswana.

This chapter gives estimations of what key units are needed to be able to handle the capacities and vessels in lower- and upper throughput limits, as stated in section 4.1. These conversions are done by using rules of thumb and looking at reference projects.

5.1 Footprints and berthing facilities

Terminals are key facilities in a port; the transhipment between the different transport modes, storage and occasionally value adding takes place in these areas. To be able to handle the required volumes and quantities, they should comprise certain minimal footprints and berthing facilities.

In this section basic rules of thumbs and simple formulas are used for a first estimate of these indicators. A couple of simplifications are made, for instance the precise layout of the infrastructure inside the terminals is not determined. Instead a factor is used to correct for the needed infrastructure. The areas found by these calculations are useful for a first rough design of the port, not for detailed design of the terminals itself. The indicators of the terminals are determined for the lower- and upper limits in both 2035 and 2050.

5.1.1 Containers

An important part of the world trade is shipped in containers. The port of Walvis Bay is aiming on becoming an important transhipment hub for the West-African coast, and the trade between Europe and Asia. In order to be able to become a transhipment hub, a well-functioning container terminal without congestions is essential. A forecast of the required additional container throughput in time is given in Table 5-1.

	2035		2050	
	Lower	**Upper**	**Lower**	**Upper**
Import	4.000	66.000	10.000	87.000
Export	0	33.000	2.000	44.000
Transhipped	169.000	492.000	364.000	843.000
TOTAL	**173.000**	**591.000**	**376.000**	**974.000**

Table 5-1: Required container throughput new harbour expansion [TEU]

Footprint

In a container terminal it is most efficient to store containers for import and export in separated yards. Also reefers, cooled containers, and empties are stored in separate parts of the terminal. Assumed is the percentage of these special containers stays constant in time, as indicated in Table 5-2. These assumptions have been derived from historical data.

	2035	2050
	REEFERS	
Import	27%	27%
Export	28%	28%
Transhipment	25%	25%
	EMPTIES	
Import	32%	32%
Export	52%	52%

Table 5-2: Percentages reefers and empties

Using the following formula the required areas for the different parts of the container terminal can be determined.

$$A = \frac{C_i \cdot \bar{t_d} \cdot F}{r \cdot 365 \cdot m_i} \quad [5\text{-}1]$$

In which:

A	Area required	$[\mathrm{m}^2]$
C_i	Number of container movements per year	$[\mathrm{TEU}/\mathrm{yr}]$
$\bar{t_d}$	Dwell time	[days]
F	Area per TEU including equipment travelling lanes	$[\mathrm{m}^2]$
r	Average/nominal stacking height	$[-]$
m_i	Acceptable average occupancy	$[-]$

The dwell time of containers is estimated to be 5 days for import, 2 days for export and 15 days for transhipment; conform the current dwell times. In the existing harbour the stacking of the containers is done by RTG with a stacking height of 4 containers. Having the same stacking system in the whole port has great benefits in terms of maintenance and training of employees. Furthermore, RTG's achieve a high stacking efficiency of around $10\ \mathrm{m}^2$ per TEU. Assuming stacking height and occupancy factors of respectively $r = 0.6$ and $m_i = 0.7$ results in the footprints shown below.

	2035		2050	
	Lower	**Upper**	**Lower**	**Upper**
Import	500	8.800	1.300	11.600
Export	0	900	100	1.200
Transhipment	62.000	180.500	133.600	309.300
Reefers	7.200	28.900	15.900	46.000
Empties	1.000	30.000	3.300	39.700
TOTAL	**70.800**	**249.100**	**154.200**	**407.800**

Table 5-3: Required footprints for container terminal functions $[\mathrm{m}^2]$

Berthing facilities

The container terminal also needs berths for the loading and offloading of the container ships. Calculating required the number of berths and corresponding quay lengths is done using the following formulas.

$$n = \frac{C_s}{p \cdot f \cdot N_b \cdot t_n \cdot M_b} \qquad [5\text{-}2]$$

In which:

n	Number of berths	$[-]$
C_S	Annual number of TEU throughput	$[{}^{TEU}/_{yr}]$
p	Gross production per crane	$[moves/hr]$
f	TEU-factor	$[-]$
N_b	Number of cranes per berth	$[-]$
t_n	Number of operational hours per year	$[hrs/yr]$
m_b	Average Berth occupancy	$[-]$

$$L_{quay} = \begin{cases} 1.1 \cdot n \cdot \left(L_{ship,avg} + 15\right) + 15 & \text{(multiple berths)} \\ L_{ship,max} + 2 \cdot 15 & \text{(single berth)} \end{cases} \qquad [5\text{-}3]$$

In which:

L_{quay}	Quay length	$[m]$
$L_{ship,avg}$	Average ship length	$[m]$
$L_{ship,max}$	Length design ship	$[m]$

The following assumptions are made taking into account the fact it concerns a newly constructed modern harbour. On each berth there are three cranes with each a gross production of 25 movements per hour; modern equipment is installed. The TEU-factor is assumed to be 1.5. The initial number of operational hours is 360 days a year with two shifts of 8 hours. If the demand requests the container capacity to be enlarged, operational hours can be switched to 24 a day. The average berth occupancy is taken to be 60%. This might seem rather high for just one or two berths, however one must keep in mind that there is already a number of berths existent in the current port and southern expansion. The design vessel is 320 meters long and the average ship length is 210 meters, as described in section 4.1.2. The results of calculations are shown in the following table.

	2035		2050	
	Lower	Upper	Lower	Upper
Number of berths [-]	1	2	1	3
Total berth length [m]	350	510	350	757.5

Table 5-4: Berth requirements container terminal

5.1.2 Dry bulk

The transport and storage of different kinds of dry bulk should be well separated. For instance coal and sugar should not be transported on the same conveyor belt to prevent contamination. The following four categories should have their own transport and storage:

- Rough bulk: coal, manganese ore, copper, lead and iron ore
- Food: sugar, wheat and malt
- Chemicals: fluorspar, caustic soda, soda ash, bicarbonate and sulphur
- Salt

The handling capacity requirements of the different bulk categories in the upper and lower scenarios were presented in Table 4-2. To be able to give more accurate indicators, the throughput figures for import and export have been separated and presented in the table below.

	Current	Additionally required capacity							
	Until	2035 Lower		2035 Upper		2050 Lower		2050 Upper	
	2025	Import	Export	Import	Export	Import	Export	Import	Export
Rough bulk	646	489	230	6.886	28.987	624	261	7.143	29.176
Food bulk	262	386	0	490	0	508	0	648	0
Chemical bulk	152	706	222	2.513	415	707	230	2.518	522
Salt bulk	632	0	0	0	0	0	0	0	0
TOTAL	**1.692**	**1.581**	**452**	**9.889**	**29.402**	**1.839**	**491**	**10.309**	**29.698**

Table 5-5: Im- and export handling capacity requirements for scenarios [1000 FT]

Footprints

A first estimation for the required footprint of the dry bulk terminal is made using a rule of thumb to convert throughput figures to areas. According to this rule, the throughput capacity per square meter dry bulk terminal is $20\ \mathrm{metric\ ton/year/m^2}$. By converting the freight tons into metric tons, using the respective average specific weights of the commodities, the rule of thumb can be used to derive the required footprints. The average specific weights of the bulk categories will not be constant as time develops, since the composition of the categories may change. This change is neglected, but should be taken into account in a more detailed design step.

The commodity footprints of the current bulk terminals are also presented to be able to make a choice on combining current and future terminals or not.

	Avg. Specific weight $[\mathrm{kg/m^2}]$	Current $[\mathrm{m^2}]$	Additionally required footprints $[\mathrm{m^2}]$			
		Until 2025	2035		2050	
			Lower	Upper	Lower	Upper
Rough bulk	1.300	47.500	53.000	2.641.900	65.200	2.674.700
Food bulk	750	11.200	16.400	20.800	21.600	27.500
Chemical bulk	1.300	11.200	68.300	215.600	69.000	223.900
Salt bulk	1000	34.500	0	0	0	0
TOTAL	-	**104.400**	**137.700**	**2.878.300**	**155.800**	**2.926.100**

Table 5-6: Current and additionally required bulk footprints

Berthing facilities

The different groups of dry bulk can share one berth, but each group should have its own loading and offloading equipment. For bulk there is a big difference between loading and offloading a ship. The equipment used and productivity is significantly different. The loading of a ship can be done much faster and with only a movable conveyor belt. For the offloading of a ship either a crane or a pneumatic system is needed. Sometimes ships have their own unloading equipment, this is however neglected in calculating the berth indicators.

The offloading of coal bulk is assumed to be done by grabbing cranes; the costs per ton of moved material is relatively low for this type of equipment. The food and chemical bulk will be offloaded using pneumatic systems, preventing contamination of the surroundings and the product itself. Loading and offloading productivity rates for different bulk commodities are given in the table below.

	Offloading	Loading
Rough bulk	1.500	8.000
Food bulk	500	500
Chemical bulk	500	1.000
Salt bulk	1.000	1.000

Table 5-7: Productivity rates bulk cranes for different commodities [ton/hour]

Using these productivity rates and assuming a berth occupation percentage of 50%, the required number of berths can be determined using an equation equivalent to [5-2]. The results are listed in the tables below. A distinction is made between required number of berths for the just the expansion (additional throughput) and for the port as a whole (total throughput), as berths may be combined and relocated.

	2035 Lower		2035 Upper		2050 Lower		2050 Upper	
	Import	Export	Import	Export	Import	Export	Import	Export
Rough bulk	0,17	0,01	2,35	1,85	0,21	0,02	2,43	1,86
Food bulk	0,23	0	0,29	0	0,3	0	0,38	0
Chemical bulk	0,72	0,11	2,57	0,21	0,73	0,13	2,57	0,27
Salt bulk	0	0	0	0	0	0	0	0
TOTAL	**1,12**	**0,12**	**5,21**	**2,06**	**1,24**	**0,15**	**5,38**	**2,13**

Table 5-8: Number of required bulk berths for the expansion (additional throughput)

	2035 Lower		2035 Upper		2050 Lower		2050 Upper	
	Import	Export	Import	Export	Import	Export	Import	Export
Rough bulk	0,32	0,03	2,39	1,87	0,37	0,03	2,48	1,9
Food bulk	0,38	0	0,44	0	0,45	0	0,54	0
Chemical bulk	0,84	0,13	2,7	0,22	0,84	0,14	2,7	0,28
Salt bulk	0	0,24	0	0,24	0	0,24	0	0,24
TOTAL	**1,54**	**0,4**	**5,53**	**2,33**	**1,66**	**0,41**	**5,72**	**2,42**

Table 5-9: Number of required bulk berths for port as a whole (total throughput)

There are a lot of opportunities for combining berths. Berths can be used for different bulk cargo groups, or import and export can be combined. Furthermore, the bulk terminal situated the current port could be repositioned and combined with the new one. Because of this freedom of combination, total required berths cannot be determined before layout designs are made. The required quay lengths can be calculated if the number of berths is determined, using equation [5-3].

5.1.3 Liquid bulk

The throughput capacity required for the liquid bulk terminal strongly depends on whether the Gecko Vision Industrial Park, as described in section 3.5.3, is launched or not. In case Gecko is not built, a lot of extra liquid bulk needs to be imported. Otherwise, the liquid bulk throughput is not expected to grow much. Table 5-10 shows the liquid bulk throughput predictions for the different scenarios.

Footprint

Calculating the required storage area and quay wall length for liquid bulk is done in a similar way as dry bulk, but using different assumptions. The average specific weight of liquids is assumed to be $1000\ \mathrm{kg/m^3}$, the storage capacity $30\ \mathrm{metric\ ton/year/m^2}$ and the crane/pump productivity $3000\ \mathrm{tonnes/hour}$.

	Current	Additionally required capacity				Additional if Gecko is not built
	Until 2025	2035		2050		
		Lower	Upper	Lower	Upper	
Liquid bulk [1000 FT]	1.960	0	53	0	202	1.480
Area [$\mathrm{m^2}$]	74.000	0	2.000	0	7.600	55.900

Table 5-10: Liquid bulk throughput and required additional footprints

Berthing facilities

The liquid berth is currently dimensioned for Panamax vessels. This is sufficient for future use; the liquid throughput is not high enough to make it financially interesting to accommodate bigger vessels. The current pump capacity is however not enough to handle the throughput growth. As newer pump systems have a higher production rate, upgrading the current berth with new equipment would suffice in each of the scenarios. The current berth however requires a lot of maintenance nowadays, as it is reaching its design lifespan. A study should verify if upgrading or constructing a new berth is the best solution.

5.1.4 General cargo and Ro-Ro

The port is currently handling quite a big amount of general cargo. Its growth is however expected to slow down, since there is a global trend of the containerizing transported goods. Ro-Ro is however growing steadily, as loads of used cars are being imported for the SADC-countries. The throughput predictions for general cargo and Ro-Ro are presented in the following table.

	Current	Additionally required capacity [1000 FT]			
	Until 2025	2035		2035	
		Lower	Upper	Lower	Upper
General Cargo	2.710	48	373	139	551
Ro-Ro	424	668	1.489	923	2.308

Table 5-11: Current and additionally required throughput capacities General cargo and Ro-Ro

Footprints

To improve the efficiency of Ro-Ro handling, it is advised to use two patches of land for its storage. The first area is used to temporarily park vehicles that just rolled off the ship, and should be close to the quay to load and offload the ship as fast as possible. This area should be big enough to store the total amount of vehicles of one ship. Ships will usually don't load or offload their total capacity at one port, therefore a car park with the capacity of an average ship is assumed to be sufficient instead of the biggest ship capacity; 5.000 car equivalent units (CEU). The second area is the storage area where vehicles can be parked here for a longer amount time; assumed is an average period of three weeks. Dimensions of a CEU are $(\mathrm{L} \cdot \mathrm{B} \cdot \mathrm{H}) = (4.5 \cdot 2.5 \cdot 2)$. The space needed per CEU including roads inside the parking lot is assumed to be $15\ \mathrm{m}^2$. This is a relatively small footprint, as cars can be parked much closer to each other than on normal parking lots.

Calculating the required area for general cargo is done assuming a storage capacity ratio of $5\ \mathrm{metric\ ton/year/m}^2$. The average density of the cargo is assumed to be $600\ \mathrm{kg/m}^3$.

	Current	Additionally required footprints $[\mathrm{m}^2]$			
	Until 2025	2035		2050	
		Lower	Upper	Lower	Upper
General Cargo	368.500	6.500	50.700	18.900	75.000
Ro-Ro temporary	55.000	75.000	75.000	75.000	75.000
Ro-Ro storage		29.000	64.700	40.100	100.300

Table 5-12: Current and additionally required footprints for General cargo and Ro-Ro

Berthing facilities

The port doesn't have berths fully dedicated to Ro-Ro cargo; the general cargo berths are used for this purpose. Ro-Ro and general cargo often share berths, as most general cargo ships incorporate a Ro-Ro deck. Dedicated Ro-Ro ships can quite easily use different berths because the tidal difference in the port small (less than two meters) and the ships feature their own ramps.

For the berths, three cranes with a productivity rate of $40\ \mathrm{metric\ ton/hour}$ is taken. An occupancy percentage of 75% can be achieved. This rate looks rather high compared to the occupancy of the other berths. The reason for this is the relatively long time it takes to unload a general cargo ship; several days is no exception. Because of these long unloading times, waiting for a berth to become available is less of a problem. The total average load- and unload timespan for Ro-Ro vessels is assumed to be half a day. Using the expected vessel quantities as specified in section 4.1.2, the required number of berths and their lengths can be derived.

	Current	Additionally required			
	Until 2025	2035		2050	
		Lower	Upper	Lower	Upper
Number of berths	3	1	2	1	2
Quay length [m]	531	320	474	320	474

Table 5-13: Current and additionally required berth facilities General cargo and Ro-Ro

5.1.5 Overview

An overview of the additionally required footprints and berthing facilities per cargo category for the lower- and upper scenarios is given in the tables below. These indicators are, together with the boundary conditions, the input for designing alternatives. Since the indicators depend largely on the presence or absence of the coal throughput from Botswana, a distinction is made in these options in the two high growth scenarios.

Footprints

The additionally required footprints per cargo category for the lower- and upper scenarios are given in the following table. These figures do not include footprints in the current port layout.

	2035			2050		
	Lower	Upper		Lower	Upper	
		With coal	Without coal		With coal	Without coal
Container	70.800	249.100	249.100	154.200	407.800	407.800
Dry bulk	137.700	2.878.300	236.400	155.800	2.926.100	251.400
Liquid bulk	0	2.000	2.000	0	7.600	7.600
General cargo + Ro-Ro	110.500	190.400	190.400	134.000	250.300	250.300
TOTAL	**319.000**	**3.319.800**	**677.900**	**444.000**	**3.591.800**	**917.100**

Table 5-14: Additionally required footprints per cargo category in lower- and upper scenarios

Berthing facilities

The additionally required berthing facilities per cargo category for the lower- and upper scenarios are given in the following table. These figures do not include berths in the current port layout.

	2035			2050		
	Lower	Upper		Lower	Upper	
		With coal	Without coal		With coal	Without coal
Container	350	510	510	350	760	760
Dry bulk	510	1.995	1.500	510	1.995	1.500
Liquid bulk	0	260	260	0	260	260
General cargo + Ro-Ro	320	474	474	320	474	474
TOTAL	**1.180**	**3.239**	**2.744**	**1.180**	**3.489**	**2.994**

Table 5-15: Additionally required berthing facilities per cargo category in lower- and upper scenarios

5.2 Wet infrastructure

Based on the nautical requirements and the boundary conditions that apply to the port's expansion, the dimensions of the wet infrastructure can be determined. The design vessel is of the Post-Panamax class, and has the following dimensions:

Length: $L_{ship,max} = 320 \text{ m}$
Beam: $B_{ship,max} = 42.8 \text{ m}$
Draught: $D_{ship,max} = 14.5 \text{ m}$

5.2.1 Harbour basin

The minimal width of the basins is determined using a rule of thumb:

$$W_{basin} \geq 8 \cdot B_{ship,max} + 50 \quad [5\text{-}4]$$

This formula applies to basins which are designed in such a way that vessels can turn within the basin. Applying the dimensions of the design vessel results in a minimum basin width of about 400 meters.

5.2.2 Turning basin

The dimensions of the harbour basin depend highly on the vessel dimensions. The length of the basin is determined by the quay length, as discussed in chapter **Fout! Verwijzingsbron niet gevonden.**. The width and depth of the harbour basin are discussed in this section.

Width

The minimal width of the basins is determined using a rule of thumb:

$$W_{basin} \geq 8 \cdot B_{ship,max} + 50 \quad [5\text{-}5]$$

This formula applies to basins which are designed in such a way that vessels can turn within the basin. Applying the dimensions of the design vessel results in a minimum basin width of about 400 meters.

Depth

The depth of the basin can be determined with the following requirement:

$$d > D_{ship,max} - T + s + r + m \quad [5\text{-}6]$$

In which:

d	Guaranteed channel depth	[m]
$D_{ship,max}$	Draught of design vessel	[m]
T	Tidal elevation above reference level, below which no entrance is allowed	[m]
s	Maximum sinkage due to squat and trim	[m]
r	Vertical motion due to wave response (half the wave height)	[m]
m	Remaining safety margin or net under keel clearance	[m]

The reference water level is equal to the lowest tidal level in the bay area, implying $\mathrm{T} = 0$. As ships maintain low speeds in the basin, a reasonable assumption for a maximum sinkage height would be $\mathrm{s} = 0.25$ meters. From Figure 4-3 can be seen that the wind wave height with an exceedance probability of 0.1% in the bay area is smaller than 1.0 meters, so $r = 0.5$ meters is taken. The sandy bottom of the channel imposes a safety margin of $m = 0.5$ meters. Applying these boundary conditions and nautical requirements as parameters in the formula gives a minimum required harbour basin depth of $\mathrm{d} = 15.75$ meters.

5.2.3 Approach channel

The calculation of the minimum dimensions for the approach channel is quite elaborate, as it is influenced by many factors.

Directionality

The approach channel can be designed for uni- or bidirectional traffic, having a crucial impact on the required width and thus the dredging expenses. Frequently visited ports use approach channels designed for bidirectional traffic in order to prevent long waiting times. The current Port of Walvis Bay is equipped with a unidirectional approach channel, sufficient for its 1600 vessel calls per year; an average of little over four a day.

The expansion of the port will attract more cargo throughput, however the transport capacity of the vessels is also expected to quickly increase. A projection of the development of vessel quantities is given in section 4.1.2; the highest scenario of 2050 predicts an amount of ten vessels calling at the port daily. It takes about half an hour to traverse the governing southern expansion approach channel, resulting in a channel occupancy of ten hours a day. This can easily fit within normal operational hours, implying that a unidirectional channel is sufficient to meet the future traffic intensity.

Width

The minimum width of the approach channel can be determined using a method developed by the PIANC group. According to this method, the width of a unidirectional channel should fulfil the following requirement:

$$W \geq W_{BM} + \sum W_i + 2 \cdot W_B \qquad [5\text{-}7]$$

The parameters are quantified using the conditions in the bay, as presented in the table below.

Width component	Conditions	Width implication
Basic width W_{BM}	Good manoeuvrability	$1.3 \cdot B_{ship,max}$
Additional widths W_i		
- Prevailing cross-winds	25 knots → Moderate	$0.4 \cdot B_{ship,max}$
- Prevailing cross-current	0.4 knots → Low	$0.2 \cdot B_{ship,max}$
- Prevailing wave height	$0 < H_s < 1$ meter → Negligible	0
- Aids to navigation	Good VTS available	$0.1 \cdot B_{ship,max}$
- Seabed characteristics	Soft	$0.1 \cdot B_{ship,max}$
- Cargo hazard	Chemicals → High	$1.0 \cdot B_{ship,max}$
- Depth of waterway	$d < 1.25 \cdot D_{ship,max}$	$0.2 \cdot B_{ship,max}$
- Bottom surface	Smooth and soft	$0.1 \cdot B_{ship,max}$
Bank clearance W_B	Sloping edge	$0.5 \cdot B_{ship,max}$
TOTAL	-	$\mathbf{4.4 \cdot B_{ship,max}}$

Table 5-16: Channel width components used in the PIANC method

Substituting these parameters in the requirement leads to a minimum approach channel width of $4.4 \cdot \mathrm{B_{ship,max}}$ equalling 188 meters.

Depth

The minimum channel depth can be calculated by applying the same requirement as for the harbour basin and the approach channel:

$$d > D_{ship,max} - T + s + r + m \quad [5\text{-}8]$$

The only parameter that has a different value for the approach channel is the value for s. In this case $s = 0.75$ m, this is because the ship has a higher velocity in the approach channel. Due to this increased velocity the movements of the ship increase as well, thus a larger depth is required. Applying these boundary conditions and nautical requirements as parameters in the formula gives a minimum required channel depth of $d = 16.25$ meters.

Length

The length of the approach channel should be large enough to fulfil the following actions within its length:

- Slowing down the vessel from entrance speed to limited port speed (L_1)
- Tying up the tugboat while advancing with limited port speed (L_2)
- Completely stopping the vessel to approach the quay (L_3)

The length of the approach channel should thus fulfil the following requirement:

$$L > L_1 + L_2 + L_3 \quad [5\text{-}9]$$

$$L_1 = (v_{entrance} - v_{port}) \cdot \left(\frac{3}{4} \cdot L_{ship,max}\right) \quad [5\text{-}10]$$

$$L_2 = t_{tug} \cdot v_{port} \quad [5\text{-}11]$$

$$L_3 = 1.5 \cdot L_{ship,max} \quad [5\text{-}12]$$

In which:

$v_{entrance}$	Vessel entrance speed	$[\mathrm{m/s}]$
v_{port}	Vessel speed inside port's domain	$[\mathrm{m/s}]$
t_{tug}	Tying-up time for tugboats	$[\mathrm{s}]$
$L_{ship,max}$	Length of design vessel	$[\mathrm{m}]$

The speed of vessels entering the bay area is assumed to be $4.5\ \mathrm{m/s}$, whereas the speed limit inside the port's domain is $2\ \mathrm{m/s}$. Tugboats usually require about ten minutes per vessel for tying up.

Applying these parameters leads to a minimum approach channel length of 2280 meters.

The water depth at this distance out of the port is however not enough for the design vessels. Hence the approach channel must be dredged up to the location where the natural depth equals the required depth for vessels, which is at 16.25 meters. This location can be determined by using the hydrographical map, as included in Appendix B. The actual length of the approach channel depends on its direction, and can therefore not yet be precisely determined. It is however clear from the map that it is in the order of magnitude of respectively nine and five kilometres for the current port and the Northern expansion site.

5.3 Expansion sites

Looking at the topographical boundaries of the bay area from Figure 4-1, it is clear there are two obvious sites that qualify for physical expansion of the port. First of all, there is the possibility of developing consecutive expansion phases elaborating on the southern expansion of 2016. By reclaiming land around the southern expansion, one could enlarge its footprint. Secondly, there is the Northern site that is reserved for port expansion by the municipality of Walvis Bay. Both sites have their up- and downsides, which will be evaluated in the the section 'Development strategies'. The two next paragraphs describe both expansion sites without judging their values.

5.3.1 Southern expansion site

The enlargement of the container terminal, to be finished in 2016, is the most obvious way to expand the port's available footprint and berths. It has however not been subject to extensive studies, as the focus has so far been on the container terminal.

The location of the outer perimeter of the port's peninsula is limited at each side. Southwards, both a marina and the lagoon's entrance are located that prevent expanding in that direction. Eastwards, there is the port's wet infrastructure that needs to remain intact to be able to accommodate vessels. Expanding westwards seems a possibility at first sight, however due to environmental aspects the peninsula is not allowed to become much wider. The only option seems to be elongating in line with the container terminal, until it starts conflicting with the current approach channel.

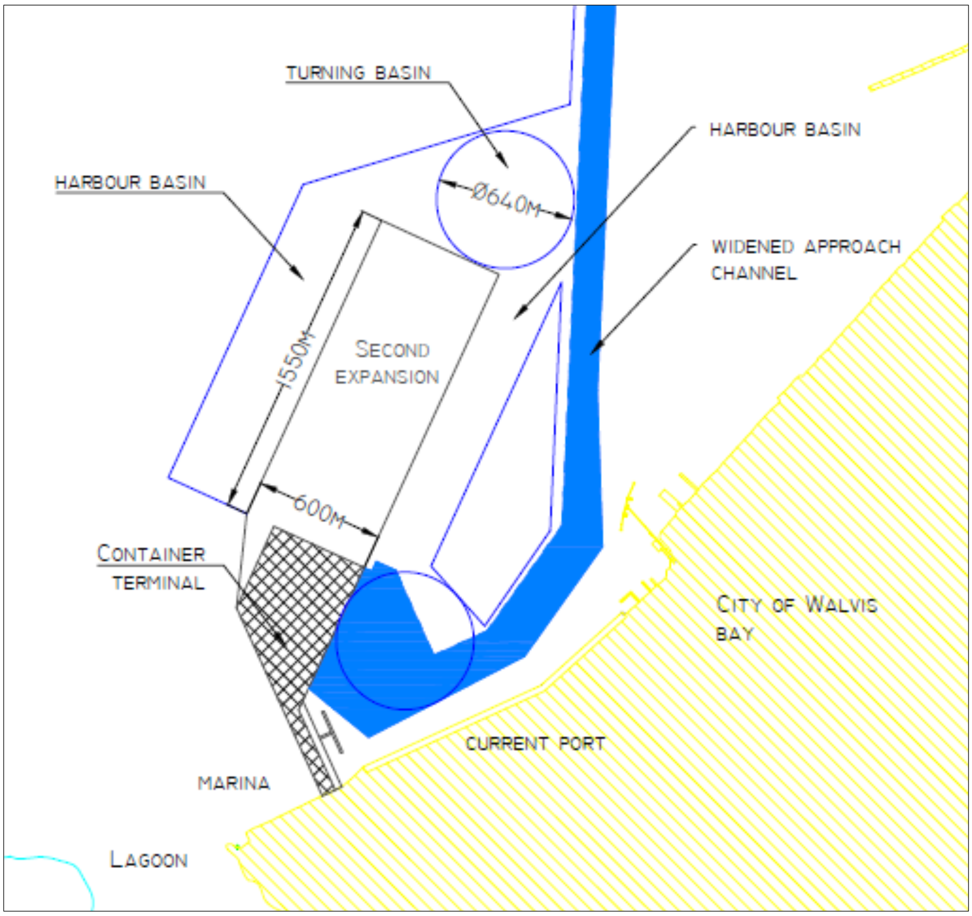

Figure 5-1: Concept for southern expansion

Footprint and quay length

The most effective dimensions of the extension were derived in a process in which the footprint and the available running meters for quays were optimized with respect to the functional requirements. The governing requirement is that, after several expansion phases, the footprint and available quay lengths should be sufficient to meet the need of the upper scenario of 2050. The result is displayed in

Figure 5-1, in which the blue lines indicate the dredging works that have to be executed. As can be seen from the figure, the elongation could have extended for at least another 600 meters before reaching the approach channel, creating an even larger footprint. Doing this would however prevent the construction of a turning basin at the head of the peninsula. Therefore the western side could not have been used to moor vessels, making it unable to fulfil the requirements regarding the available running meters of quay.

	Available after expansion	Required for 2050 Upper	Additionally required for coal
Quay lengths [m]	3.100	2.994	483
Footprint [m^2]	930.000	917.100	2.674.700

Table 5-17: Available and required footprints and quay lengths at southern expansion

The design is only partly in compliance with the functional requirements. It can handle the upper growth scenario for the year 2050, however it is not able to accommodate the enormous additional footprint required for the coal terminal if Botswana decides to transport its coal via Walvis Bay. There is also no option left to expand the port for this purpose without compromising the environmental boundary conditions.

Wet infrastructure

The approach channel that is currently used for the port will be deepened to -14.1 CD during the construction of the container terminal in 2016, while remaining its current width of 135 meter. For the consecutive expansion the approach channel needs to be upgraded according to the requirements defined in section 5.2.3; deepened to -16.25 CD and widened to 188 meters. Furthermore, the channel has to be elongated towards the point where the natural depth of the bay is sufficient for the design vessel.

The diameter of the existing turning basin will need to be enlarged from 450 meter to 640 meter to be able to accommodate larger vessels. At the head of the peninsula a second turning basin will be constructed to be able to reach the harbour basin and berths at the western side.

5.3.2 Northern expansion site

Expanding at the northern site basically means constructing a totally new harbour on the assigned area. Some facilities can probably be shared, however all of the infrastructure and terminals are newly developed.

Footprint and quay length

With the project area having a total footprint of 13.660.000 m^2, space is not an issue. The quays can be built in such a way that they offer enough running meters to handle the cargo in all scenarios. Furthermore, if the port outperforms the expectations, its initial design can be easily adapted to increase the handling capacity.

Wet infrastructure

A concept for the wet infrastructure of the northern expansion is displayed in Figure 5-2. The approach channel is positioned in such a way that its length is minimalized, reducing dredging costs. The turning basin in combination with two separate basins enables the opportunity to easily expand the berthing facilities. A patch of newly reclaimed land is positioned at the west side of the project area to maintain a better cut and fill balance, and to minimize the dredging works for the channel and basins.

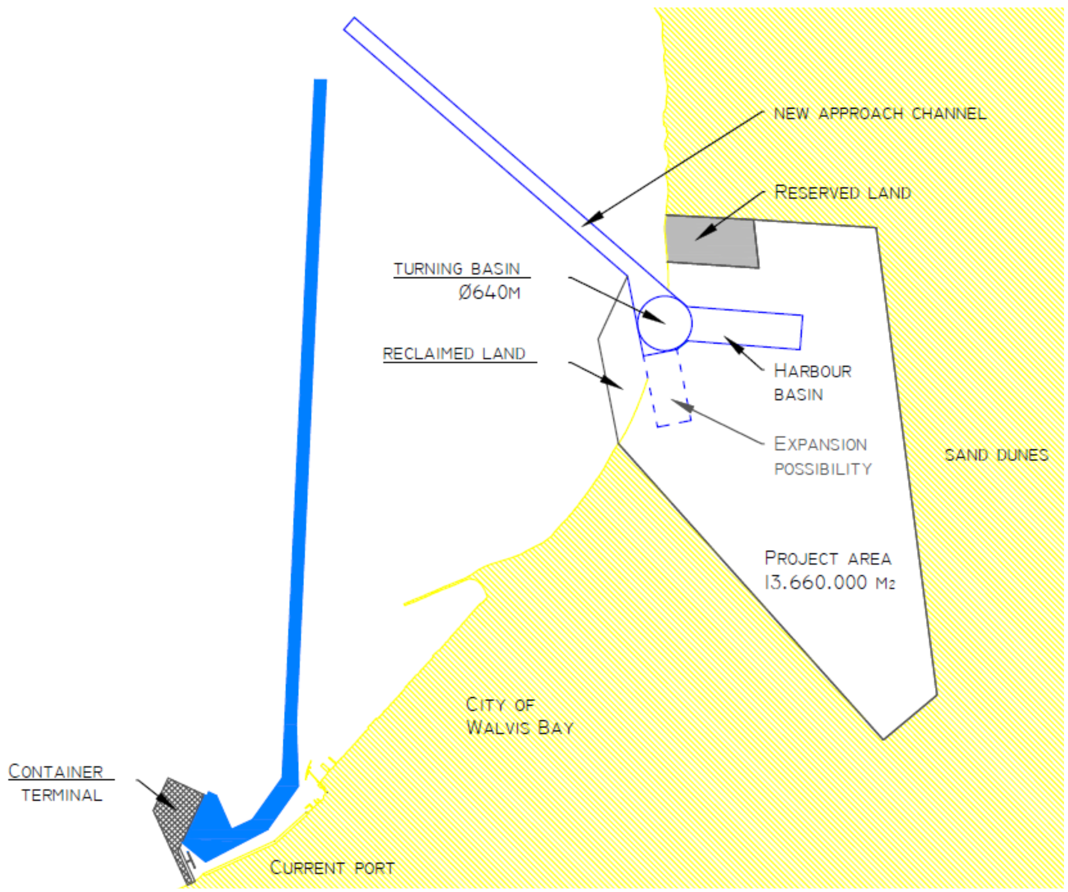

Figure 5-2: Concept for northern expansion

6 Development strategies

After having translated the functional requirements and boundary conditions into two expansion alternatives for the port, these must be evaluated and optimized with respect to their added value for the stakeholders. These values comprise both financial and non-financial aspects, describing its usefulness for different stakeholders over time. On basis of these evaluations, a recommended future development strategy is drafted.

6.1 Financial aspects

The stakeholders with the most influence in the project all share the same interest; creating a profit. This value is therefore considered the most important. Profit can only be generated after investing a sum of money, which apparently is not that easily available. As discussed in section 2.3, investors are nowadays very reluctant as it comes to projects of this scale. A compromise has to be found between the investment sum and the return rates in time.

6.1.1 Risk profile

Countless solutions can be engineered to anticipate on the future; however the future is still very uncertain and susceptible to fluctuations. Estimates with sufficient accuracy can only be made for the short term, whereas expansion plans are made for the long term due to the high investment sum. This discrepancy between what is known and what is anticipated for creates a financial risk to investors.

Investors pursue projects that generate high return rates and accompany a low risk of losing their investment. These two interests are however usually conflicting, which forces investors to reach a compromise between the two. If a high return rate is preferred over low risks the investor is risk-seeking, while the other way around is called risk-averse.

Risk-aversive strategy

Investors tend to be more reluctant towards large projects as a result of the global economic crisis, making them have less confidence in the economic development. By minimizing the initial investments they lower the risk of losing large sums of money. This strategy is however not the most profitable if the throughput develops in a brighter way than anticipated for. The investor will wait for a high demand to happen before expanding, reacting on growth rather than anticipating for it.

A risk-aversive strategy can be applied to the expansion of the port of Walvis Bay. The lowest initial expansion costs are obviously achieved when expanding at the southern expansion site, as all (wet) infrastructure is already available. The first phase of expansion is finished in 2025, and anticipates on a low economic growth scenario and no Botswana coal to minimize the investment. Once this expansion has reached its capacity and appears to be profitable, a consecutive phase is designed and constructed between 2025 and 2035. At that time the economic predictions for 2050 can be made more accurately, and it is certain whether the coal will come or not. The design will be adjusted to fit the needs, which may be possibly mean that both the southern and northern sites are have to be developed.

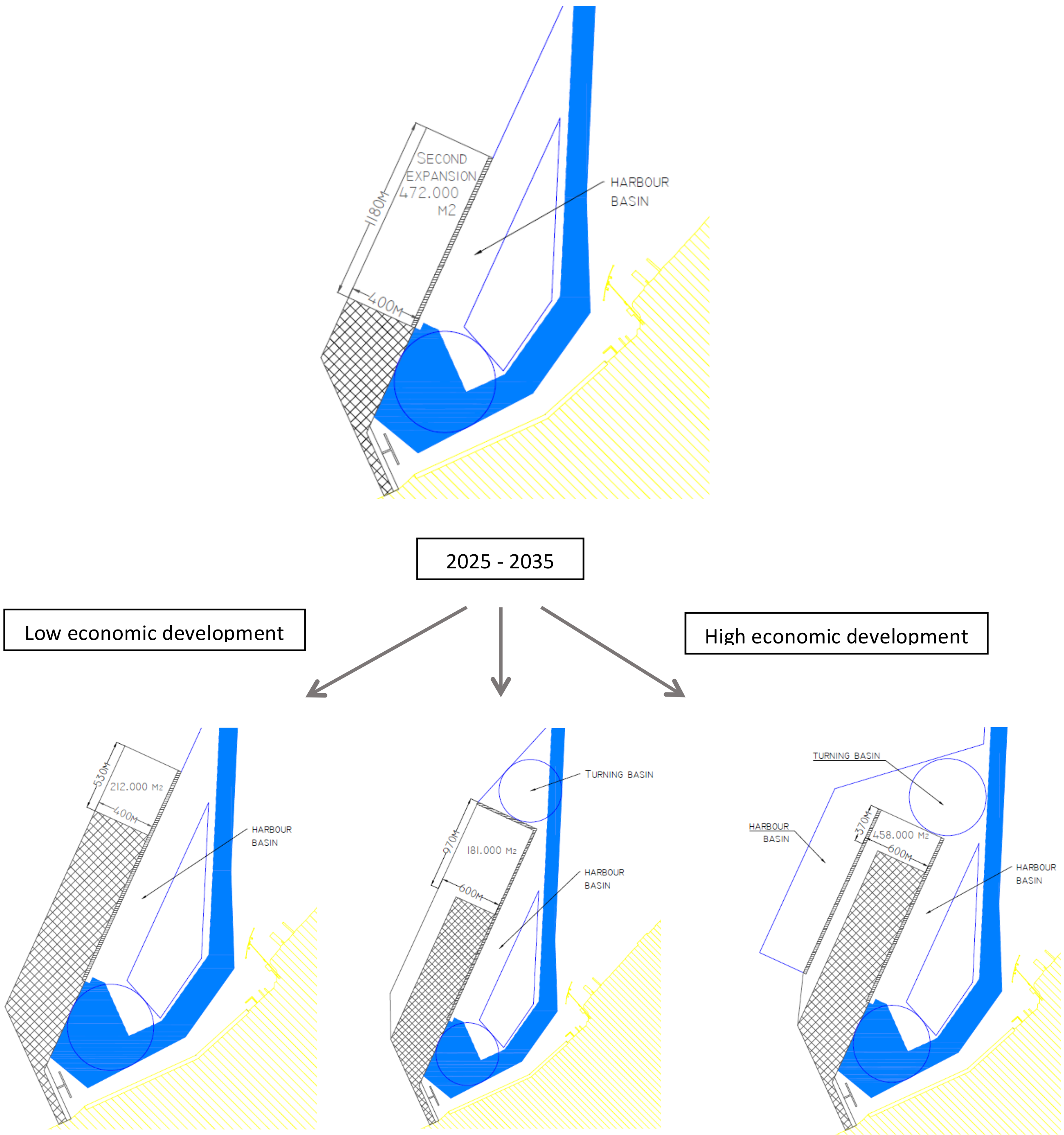

Figure 6-1: Development of southern expansion used for risk-aversive strategy

If the throughput growth sustains, the port will develop in two expansion phases. Due to preparation costs, double work and call-out charges of subcontractors, the total investment will be much higher compared to constructing all at once. This difference in costs is especially very high if the coal from Botswana does get exported through Walvis Bay. The necessary coal terminal would never fit on the southern expansion site, making it inevitable to as yet develop a port at the northern site.

Risk-seeking strategy

Risk-seeking investors have a relatively high confidence in the economic development of the port's commercial market. They anticipate on a steep increase of throughput figures, and deem the likelihood of Botswana exporting its coal through Walvis Bay high. This confidence makes them to assess the investment risk as acceptable. Therefore they are willing to invest a relatively large sum of money to assure the port has enough capacity to grow until at least 2050. This will avoid them from having to expand in multiple phases, cancelling out the 2035 expansion and thus minimizing the total investment.

When anticipating on high growth and coal from Botswana, it makes no sense to invest in a southern expansion as it is incapable of accommodating the required capacity when fully developed. Therefore, one immediately starts constructing the entire wet infrastructure required for the highest scenario at the northern site. The construction and expansion of terminals will however follow the demand for capacity, as these will age quickly.

If the throughput indeed develops as anticipated for, the highest profits are gained for investors. If the figures are however disappointing, the potential of the port expansion is not fully utilized and project may not even be profitable.

6.1.2 Investment

The two development strategies as described above entail different investments. The risk-aversive strategy comes with several investments in time, whereas the risk-seeking strategy has just one large initial investment. The major cost components for both strategies are assessed by estimating the amount of civil works and assuming unit rates. The costs are divided in the following expenses:

- Dredging; including approach channels, harbour basins and reclaiming land
- Quay wall structures
- Bank protection
- Bed protection near quay walls
- Pavement
- Equipment
- Maintenance

Dredging

According to the nautical requirements the new approach channels have to be dredged up to a level of -16.25 meter CD and their width is required to be 188 meter. Using a bottom depth hydrographical map of the bay, the water depths at the harbour side of the approach channel are determined. It is assumed dredging is possible at a slope of 1:5. Using this input, the total dredging volumes for the approach channel and basins can be calculated for both the southern and northern expansion.

	Northern site	Southern site				
	Initial 2025	Initial 2025	Additional for 2035 – 2050			
			Low no coal	High no coal	Low coal	High coal
Approach channel – north	6.109	0	0	0	6.109	6.109
Approach channel – south	7.710	7.710	0	0	0	0
Harbour basin	21.777	6.553	0	2.451	5.712	8.163
TOTAL	**35.596**	**14.263**	**0**	**2.451**	**11.821**	**14.272**

Table 6-1: Dredging volumes for southern and northern expansion [1000 m^3]

It is assumed that the percentage of non-polluted dredging material that is reusable for land reclamation is 50%. It is clear the cut-and-fill balance is especially in the northern expansion not in balance, more attention will be given in the next design step. For the northern expansion the volume of the southern approach channel is assumed to be non-reusable, since this channel deepening will be carried out in phases separately from the expansion's construction works.

	Northern site	Southern site				
	Initial 2025	Initial 2025	Additional for 2035 – 2050			
			Low no coal	High no coal	Low coal	High coal
Reusable dredged material	*13.943	7.132	0	1.226	5.910	7.136
Reclaim volume	5.588	3.800	0	1.301	1.781	3.081
Cut-and-fill balance	2.49	1.88	-	0.94	1.92	1.47

Table 6-2: Land reclamation volumes [1000 m^3] – (* = Volume without southern approach channel)

It is clear that the southern expansion requires less dredging works and has a better cut-and-fill balance than the northern expansion. In terms of re-use of material the southern alternative is thus favourable, except in case of anticipating on high economic growth without coal. Then the volume of reusable dredged material is not enough to cover the whole reclaimed volume, so it has to be dredged offshore.

The dredging vessels are assumed to sail fifteen kilometres offshore in order to dump the dredged material safely without affecting the coastal system. Hence the costs for this offshore dumping are higher than directly reusing the dredged material for land reclamation. The unit cost for dredging and directly reclaiming is assumed to be 5 $/m^3, whereas dredging and dumping offshore costs 7 $/m^3. The call-out charges for mobilizing and demobilizing the suction hopper dredgers are assumed to be $ 1.500.000 per dredging operation. For an overview of the costs for each expansion site, see Table 6-6.

Quay walls

The construction of quay walls is, next to the excavation of the approach channel and harbour basins, another major civil work that has to be done. For the southern expansion, first the land has to be reclaimed, before the quay walls can be constructed. At the project area in the north, the quay walls can be constructed onshore, while the dredging works are taking place. This can save time and is therefore an advantage for the northern alternative. The difference in the geotechnical conditions for both locations has a big influence on the designs of the quay walls and the amount of work that has to be done for the construction. The soil bearing layer in the south is at -60 meter CD, while in the north this layer is present at just -30 meter CD. The depth of this layer has a decisive impact on the conceptual design of the quay wall structures that can be applied. For the northern site there are several kinds of designs possible, but for the south a decent foundation for the quay walls is problematic as the bearing soil layer is too deep.

	Northern site	Southern site				
	Initial 2025	Initial 2025	Additional for 2035 – 2050			
			Low no coal	High no coal	Low coal	High coal
Quay length north	3.489	0	0	0	510	914
Quay length south	0	1.180	0	510	0	0

Table 6-3: Required quay lengths [m]

To be able to assess a cost estimation for both quay wall constructions, their price is expressed using the unit costs for combiwalls. This price is assumed to be 1000 $\$/m^2$ (per meter depth per running meter quay wall). Total overhead costs include for example the call-out charge of the subcontractor, and is weighed at $200.000 per construction activity.

Bank protection

The land reclamation boundaries where no quay is applied have to be protected. A reliable bank protection prevents the eroding of the reclaimed land.

	Northern site	Southern site				
	Initial 2025	Initial 2025	Additional for 2035 – 2050			
			Low no coal	High no coal	Low coal	High coal
Bank protection length	2.150	1.640	0	404	2.440	2.844

Table 6-4: Bank protection lengths [m]

Unit costs for this riprap protection are estimated to be 50 $\$/m^2$ for a 0.5 m thick layer. Overhead costs for the trucks and cranes are set at $100.000 per construction activity.

Bed protection

To prevent vessel propeller induced scouring near the quay walls, a bed protection needs to be applied. This type of protection needs to reach as far from the quay as to the ship's width; about 40 meters. The costs for this riprap bed protection depend on the required quay length (see Table 6-3), and is estimated to cost $1000/m quay. Its overhead costs concern the mobilization of the dumping vessels and is weighed in at $100.000 per activity.

Pavement

The total terminal footprint has to be strengthened and paved to bear the load of stored goods and transport vehicles. The table below lists the sum of all terminal footprints.

	Northern site	Southern site				
	Initial 2025	Initial 2025	Additional for 2035 – 2050			
			Low no coal	High no coal	Low coal	High coal
Total terminal footprint	3.591.800	319.000	125.000	364.200	2.799.700	2.913.900

Table 6-5: Total terminal footprints [m^2]

The costs for pavement are assumed to be $5/m^2 terminal area and its overhead costs are set at $20.000 per activity.

Equipment

The purchase costs of required equipment is estimated using two unit costs; one per running meter of quay (for hoisting cranes and portainers) and one per square meter of stacking space (for transport vehicles, conveyor belts etc.). The costs are estimated to be $80/m quay and $5/m^2 terminal area. No overhead costs are taken into account.

Maintenance

Maintenance costs are assumed to take 1% of the expansion’s total construction costs per year. So for the period of 2025 – 2035 it takes 10% of the total investment. For the period 2035 – 2050 the total maintenance costs are the sum of the costs incurred during 2025 – 2035 period and 15% of the additional construction costs.

Total cost survey

Summing all the costs as described above shows the investment required for the different development strategies. The first two columns show the construction costs for the decision to be taken in 2016 (regarding the 2025 – 2035 scenarios). The latter four columns show the consecutive investments to be done in 2025 when adapting the design for the future.

	Northern site	Southern site				
	Initial 2025	Initial 2025	Additional for 2035 – 2050			
			Low no coal	High no coal	Low coal	High coal
Dredging works	239,5	93,7	0	16,6	80,7	95,2
Quay walls	104,9	71,0	0	30,8	15,5	27,6
Bank protection	2,7	2,1	0	0,6	3,0	3,5
Bed protection	3,6	1,3	0	0,6	0,6	1,0
Pavement	18,0	1,6	0,6	1,8	14,0	14,6
Equipment	87,2	29,5	0	12,8	12,8	22,9
Maintenance (2025-2035)	45,6	19,9	-	-	-	-
Maintenance (2035-2050)	68,4	-	30,0	39,4	48,9	54,6
Total (2025-2035)	501,4	219,1	219,1	219,1	219,1	219,1
Total additional (2035-2050)	68,4	-	30,6	102,5	175,5	219,4
TOTAL	**569,8**	**219,1**	**249,7**	**321,7**	**394,6**	**438,6**

Table 6-6: Total investment costs for different development strategies [1.000.000 $]

6.1.3 Operational profit

In order to be able to determine the feasibility of the port expansion in the different scenarios it is necessary to determine the generated income. The port has got three major sources of revenue; marine services, cargo handling and leasing of storage space. In this chapter revenues of ship repair facilities and the charges for freshwater and petrol supply are neglected.

Marine services

The revenue of vessels calling at the port is divided into separate parts; the height of the charges depends on the ship's gross tonnage and length. To calculate the revenues, the income of an average ship is multiplied by the number of ships calling per year. This is done separately for container, dry bulk, liquid bulk, general cargo and Ro-Ro vessels. For the calculation of the income per ship the current standard harbour tariffs are used. Discounts for regular calling shipping lines or special fees are not taken into account. A calculation example for the revenues of an average container vessel (210 meters long, 29.000 Gross Tonnage) is done in Table 6-7. The same method is used to calculate the income for the other ship categories.

	Unit	Rate [$/unit]	Quantity / ship	Income [$]
Port dues	100 GT	10.7	290	3,103
Light	100 GT	6.7	290	1,943
Berthing	6 hours 100 GT	3.4	580	1,972
Tug assistance	1 movement	2352	2	4,704
Berthing service	1 movement	454.2	2	908
Pilotage services	1 movement	1153.4	2	2,307
Channel levy	1 meter	0.8	210	168
TOTAL (per ship)	-	-	-	**15,105**

Table 6-7: Revenues per average container vessel

Applying the same method for other ships, and multiplying by the expected amount of calls for each scenario results in Table 6-8. The average sizes and number of calls can be found in section 4.1.2.

	Economic scenarios				Bulk projects		
	2035		2050		Gecko	Gecko	Botswana
	Lower	Upper	Lower	Upper	built	not built	Coal
Container	14.175	19.238	16.640	23.866			
Ro/Ro	924	1.619	1.059	2.147			
GC	7.497	8.381	7.191	8.231			
Dry Bulk	5.656	7.431	5.524	6.157	3.715	561	16.261
Liquid Bulk	801	848	732	846		579	
Other	58	64	56	63			
TOTAL	**29.111**	**37.581**	**31.201**	**41.310**	**3.715**	**1.141**	**16.261**

Table 6-8: Revenues from maritime services per year for different scenarios [1000 $]

Cargo handling

The handling of cargo at the quay is the responsibility of the port authority, for which fees are charged per TEU of ton. As the throughput volumes increase, also the efficiency of the port does. In order to strengthening the competitive position of the port, the unit price for handling cargo will drop along with the rise of efficiency. In this calculation, it is assumed that the price of all cargo handling activities will drop by 25 percent compared to the current rates. In reality this percentage might be vary for different commodities. Bulk projects, such as the Gecko Vision Industrial Park, are of such magnitude that the price for handling these bulk commodities is assumed to be even halved. The following table shows the expected revenues earned by cargo handling activities, derived from current prizes and projected throughput volumes.

		Economic scenarios				Bulk projects		
	Rate	2035		2050		Gecko	Gecko	Botswana
	[$/unit]	Lower	Upper	Lower	Upper	built	not built	coal
Containers								
- import	49,4	10.589	14.612	10.959	16.050			
- export	49,4	6.940	9.160	7.146	9.925			
- tranship	105,5	63.675	86.351	77.369	111.006			
- reefers	29,1	7.535	10.219	8.647	12.406			
Ro-Ro	3,6	524	918	646	1.311			
GC	3,6	8.999	10.060	9.296	10.641			
Dry bulk								
- import	6,3	22.334	28.297	26.201	34.217	77.016	11.642	
- export	2,7	7.917	10.913	8.075	12.740			129.669
Liquid bulk	7,5	20.324	22.799	21.179	24.492		16.768	
Other	1,7	991	1.094	1.026	1.161			
TOTAL	**-**	**112.372**	**145.817**	**127.907**	**175.461**	**38.508**	**14.205**	**129.669**

Table 6-9: Revenues from cargo handling services per year for different scenarios [$1000]

Land lease

The storage yards at the port will be privately operated; the land is leased by private companies from port authority. The advantage for this kind of port organisation is the cut in initial costs for the expansion. Namport does not have to invest in terminal equipment used at the storage yards. The lease contracts will be for a long term, giving the port a secure income and thereby lowering the unit price per year. Lease locations will have different prices depending on the location and accessibility; an average price of $2 per m^2/year is assumed. The following table gives an overview of the required storage area and the revenues from leasing the land.

	Economic scenarios				Bulk projects		
	2035		2050		Gecko	Gecko	Botswana
	Lower	Upper	Lower	Upper	built	not built	coal
Required area [1000 m^2]	1.359	1.504	1.487	1.777	400	116	2.247
Revenue [$1000]	2.718	3.008	2.974	3.553	801	233	4.495

Table 6-10: Revenues from land lease per year for different scenarios.

Overview

The increased cargo throughput generated by the harbour expansion will not only result in extra revenues but also in higher operational costs. For instance staffing and energy costs will rise along with higher volumes. Subtracting these costs from the revenues shows the operational profits that can be expected per year.

The last ten fiscal years show an average operational profit margin of 22.5% of the total generated turnover. By upscaling the port activities the efficiency of the port may be expected to grow, allowing for a higher profit margin. However, to be able to strengthen the competitive position of the port, this margin is assumed to be capped allowing unit handling rates to decrease.

Table 6-11 gives an overview of the total expected revenues and operating profit generated by the expansion solely. In the sections above, revenues were described for the entire port; including its current activities.

	Economic scenarios				Bulk projects		
	2035		2050		Gecko	Gecko	Botswana
	Lower	Upper	Lower	Upper	built	not built	coal
Revenue per year	43.497	85.701	61.377	119.619	43.023	15.578	150.425
Operating profit per year	9.780	19.270	13.800	26.896	9.674	3.503	33.823

Table 6-11: Total revenues and operating profit per year for the port expansion [$1000]

6.1.4 Decision tree

In order to evaluate the development strategies, the investments and expected revenues are used as an input to construct a decision tree. The outcome of this tool can be used by investors to determine the financial consequences of a certain risk profile. Due to the many rough assumptions made, the outcome may not be very precise. It does however give a good insight in how different input parameters affect the outcome, and should thus be used as a decision tool rather than method of predicting revenues. It is advised to regularly inspect Appendix C in order to follow the steps explaining the tree’s structure.

The tree is based on the two development strategies as defined in section 6.1.1; a risk-aversive and a risk-seeking strategy.

First decision moment: 2016-2025

The first split of branches represents the decision and construction of both development strategies. The corresponding investments for the construction are displayed in red underneath the branches. This expansion is planned to be finished in 2025 and will thus not start to generate income before that year.

The lower branch represents the risk-aversive strategy in which an extension of the southern peninsula is constructed, able to comply with the capacity demand of the lower 2035 scenario. The major cost component of the investment is from upgrading of the approach channel and reclaiming land. A detailed overview of the expenses regarding this strategy is given in the second column of Table 6-6.

The upper branch represents a risk-seeking strategy, in which the entire wet infrastructure is constructed at once to be able to accommodate growth towards a high scenario in 2050. This is done at the northern expansion site, as the southern site cannot provide the footprint required in this scenario. This obviously requires a much higher initial investment, since none of this infrastructure is existent. A detailed overview of the expenses regarding this strategy is given in the first column of Table 6-6.

First event period: 2025-2035

Between this period of time, revenues are generated by exploiting the expansions. These revenues highly depend on the throughput volumes, which are linked to the economic development of the port’s commercial market. Furthermore, there is the event of Botswana accepting or rejecting Walvis Bay as their coal export hub, which is also expected in this timeframe. These two events are considered to be correlated. The chance of signing the coal deal is higher in case the economy performs well, but also will the transport of coal positively affects the economy. The following probability matrix is used for the events:

		Economy	
		High	Low
Coal	Yes	35%	15%
	No	15%	35%

Table 6-12: Event probability matrix 2025-2035

The risk-aversive strategy always generates the same amount of revenue between the event period of 2025-2035, as it is only able to accommodate the ‘low growth, no-coal scenario’. In case of a high economic development the expansion will quickly reach its capacity limit. There is also no space to handle the coal, preventing the opportunity to gain extra revenue. Within this timespan, the port authority should decide how they want to develop the port to handle the required capacity for 2050. If the coal contract gets signed, there is no other option than still to use the northern expansion site, involving a high investment. If no coal is coming, consecutive expansions can be constructed at the southern site. Two designs are drafted for this decision, either anticipating on high or low economic growth between 2035 and 2050 (see Figure 6-1). The different investments are again showed in red below the respective decisions. A detailed overview of the expenses regarding these strategies is given in the last four columns of Table 6-6.

The risk-seeking strategy on the other hand is able to handle any of the four events, generating different revenues. The only investment that has to be done is expanding the terminals along with the throughput growth, which have initially been dimensioned to handle low growth and no coal. No decision on expanding the port is required, as there are sufficient footprints and berthing facilities available to grow towards a high economic development in 2035-2050.

Second event period: 2035-2050

In the second event period, revenues are highly dependent on the way the economy develops. Again, the probability of the economic scenarios is assumed to be correlated to whether the coal is being exported though Namibia or not. Consecutive expansions in the north may be designed in this period, however this is beyond the scope of this project. There is however the possibility to dig a second harbour basin to expand the availability of quays and to be able to accommodate vessels with larger draughts.

		Economy 2035-2050	
		High	Low
Event period 2025-2035	Low Growth – No Coal	30%	70%
	High Growth – No Coal	50%	50%
	Low Growth – Coal	50%	50%
	High Growth – Coal	70%	30%

Table 6-13: Event probability matrix 2035-2050

Decision

As stated before, this tool can be used by investors to choose the strategy that fits their risk profile. In order to pick the right strategy, decision criterions exist to match certain risk profiles.

The so-called ‘maximax criterion’ fits a risk-seeking profile, as it is a strategy which maximizes the gain while omitting any potential loss. This type of investor would choose to go for the northern expansion in 2016, while constructing quays and terminals anticipating for the high growth scenario of 2050. A maximum gain of 792 million dollars can be achieved in 2050.

The ‘minimax criterion’ fits a risk-aversive profile, aimed at minimizing the maximum loss. This type of investor would choose for a staged expansion at the south site. By doing this the maximum loss is minimized from 286 million to 49 million dollars in 2050.

A third strategy would be the ‘minimax regret criterion’, in which the investor seeks to minimize the maximum possible regret. Regret is defined at the opportunity cost that will be missed out as a result of having made the wrong decision. This strategy fits a risk-neutral profile, which is not used in this evaluation. This type of investor could also look at the expected value of the profit, by multiplying the profits with their respective event probabilities. Doing so shows that expanding at the southern site provides a slightly higher expected profit value, as can be seen from Table 6-14.

		Total profit as of 2050		
		Minimum	Maximum	Expected
Expanding at	Southern site	-$49 M	$324 M	$283 M
	Northern site	-$256 M	$792 M	$268 M

Table 6-14: Minimum, maximum and expected profit values for the two development strategies

The investor is however not really interested in the profit as gained by the year 2050, since the expansion will generate profits on the longer run. It does however give a good insight in what both strategies imply in terms of investment and revenues. To complete the evaluation, the annual operational profits are included in the last column of the event tree.

6.2 General aspects

Besides financial aspects, there are more general values that are often undervalued in the conceptual design phase of projects. If these aspects are given equal weight in the decision process for different strategies, a higher added value over the complete service life of the project can be generated. These general values are however usually conflicting with the financial ones. A compromise has to be found between both the financial and the non-financial aspects of the project, optimizing the added value over the service life and the range of stakeholders.

6.2.1 Expandability

The first phase of the expansion has to be finished by 2025 and is designed to handle the cargo throughput capacity of 2035. This is quite a limited time span, making it inevitable to think about future expansion phases. Not only should there be enough space to be able to expand, the actual layout of the area should be such that repositioning of terminals and infrastructure is minimized.

Southern site

The main issue with the southern site is the inability to accommodate a terminal to handle coal coming from Botswana. Expansion possibilities are limited by the current port's infrastructure and the lagoon, causing the maximum available footprint to be too small. However also without a coal deal the demand is likely to approach the capacity within several decades, forcing the port to as yet expand at the northern site. The associated investment will however be less risky, as the upscaling is of a much smaller proportion.

Northern site

The available footprint at the northern site is incredibly large, making it possible to design the facilities in such a way that it is very easy to expand. By anticipating on the major civil works associated with future expansions, the terminals can be positioned in a way that no repositioning is required whatsoever. In order to achieve this, every terminal must have a center of growth from which it can expand in a certain direction that does not interfere with future projects. The disadvantage of this approach is the widespread character of the initial terminal layout, making it relatively inefficient.

6.2.2 Flexibility

In order to prevent this inefficient widespread character of terminals, a high degree of flexibility should be pursued. By doing so terminals can be positioned closed together initially, while taking over each other's functionality when expanding. A high degree of flexibility can be achieved by limiting the use of specialized and fixed equipment; for example using rubber-tired instead of rail-based equipment. Facilities that naturally have a flexible character, such a Ro-Ro stacking, should initially be positioned at a central location in the layout. Their space can easily be taken over by other functions after repositioning.

Southern site

The degree of flexibility that can be achieved at the southern site is low due to the very limited space available. Different terminals have to be positioned in a line right next to each other, making it very laborious to reposition functions. Doing so will also cause relatively much downtime of port functionalities, as no temporary facilities are available. The lack of space will increase the fragmentation of the port's facilities, having a negative impact on its efficiency.

Northern site

The northern expansion can flexibly be designed from scratch. If this potential flexibility in the physical infrastructure is combined with smart service systems and port management, the northern expansion has the ability to easily adapt to different future scenarios. The connection between the current port and the northern site can however cause problems, as the port will be divided into two large sections.

6.2.3 Accessibility

The infrastructure in and around the port has a great influence on the expansion possibilities. The cargo throughput is expected to substantially grow in the next decades, implying a lot more cargo needs to be transported in and out of the port. This requires a well organised broad infrastructure in the port. Especially with the possibility of having to export millions of tons of coal, the upgrade of the Trans-Kalahari corridor has to be taken into account in the conceptual design of the port layout.

Southern site

The southern container terminal serves as a convenient basis for the consecutive expansion phases, but also forms a limiting factor for the growing possibilities. All cargo intended for im- and export has to go past the existing terminals, sharing the same transportation network. This network runs along a 100 meter wide section of land connecting the peninsula to the main land. Subsequently, traffic has to go through the city of Walvis Bay towards the connections to the main corridors. Although road infrastructure of the city has a very spacious design, the many non-priority junctions are probably going to form a bottleneck. As to the rail connection, there is only track connected to the southern site which runs straight through the city. There is no option to easily reposition its course without having to demolish existing structures.

Northern site

The northern project site is located at several hundred meters from the outer city boundary, avoiding congestion problems. Within the project area, the infrastructural system is designed from scratch. The design should be flexible to allow for future developments. Practically this means that the main road- and rail connections should be designed for many decades to come, avoiding repositioning. Due to the location at the north side of the city, the access to the main corridors is relatively easy. Due to the absence of structures, future upgrades can be accounted for. One concern is the need for entrance gates and custom services at both the current port and the northern site, probably making these functions less efficient.

6.2.4 Sustainability

If possible, any disturbance of the ecosystem should be prevented by selecting appropriate locations, materials and execution methods. If complete prevention is not within the possibilities, any disturbance inflicted during construction or utilization of the expansion should be mitigated. The building materials and construction technologies that are being used should be selected very carefully for this purpose. However, the location of construction is obviously the most critical factor as it comes to disturbing the surrounding. The major environmental concerns related to the expansion of the port have been discussed in section 4.2.5, and should be assessed for both the northern and southern site.

Ecology

There is a large diversity of flora and fauna in the bay and lagoon. Special attention should be given to the risks that are involved with the construction of the expansion regarding the ecological system.

As the southern site is located close to the entrance of the lagoon, the risk of a negative influence on the biodiversity in the lagoon is considerable. The migration and breeding pattern of birds may be affected by constructing this alternative. Furthermore, the water flow in and out of the lagoon could be disturbed by the peninsula. This may affect the water quality, which may be destructive for the biodiversity.

The construction of the northern alternative will induce vessel traffic from east to west in the bay. This can have a considerable influence on the flora and fauna in the bay. The influence on the birdlife can be considerable, as the approach channel is located close to Bird Island. The influence on the lagoon however much is less than for the southern alternative. The northern alternative is located along a protected dune area, which biodiversity may be disturbed due to noise hindrance.

Pollution
The most important pollution matters comprise the water quality in the bay, the suspension of fine sediments in the lagoon and the emission of gasses, fine dust and toxic components.

The southern expansion is located close to the entrance of the lagoon. Due to the excessive dredging works required at this location and the presence of a tidal flow the risk of suspension of fine sediment particles in the lagoon is considerable. Especially due to the fact that silt layers are present in this area. Furthermore, due to the location close to the lagoon entrance, any polluted material in the water may reach the lagoon fairly easy. In Walvis Bay the dominant wind is coming from the south. Therefore there is a considerable risk of fine dust pollution in the residential area during utilization.

Construction of the northern expansion requires more dredging works compared to the southern site. However there is less fine sediment present in this location and the area around the expansion site is less sensitive than the lagoon in the south. Due to the southern wind the risk of fine dust pollution in the residential area is not as high as for the southern alternative. As there is more construction work required for this alternative than for the southern one, making that the CO_2 emission for construction will be higher as well.

Health and safety
A lot of the problems in ports in general are related to health and safety issues. Attention is given to hindrance for residents, exposure to certain hazards and the safety of the working conditions.

The southern alternative is located next to a residential area. For this reason the hindrance to residents will be larger than for the northern alternative. The residential area is also more exposed to hazards that play a role in port activities, such as storing and handling hazardous cargo.

The northern alternative is located further away from the residential area; hence the hindrance to the residents and the exposure to hazards is smaller. The safety of the working conditions will probably be about the same for the northern and southern alternative.

Socio-economic
The construction of a port expansion can have far going influences on the socio-economic system of both the city and the country. Special attention should be paid on the continuation of salt works in the lagoon, the oyster farms and fisheries in the bay, the touristic value of Walvis Bay and the creation of jobs.

The southern expansion site is located close the salt production facilities in the lagoon. Suspension of fine sediment or polluted material can be a threat to their continued existence. The impact on the oyster farms is probably not very large as they are located in the western part of the Bay, near Pelican point. The marina of Walvis Bay is located at the southern end of the port. The recreational value is probably reduced by increasing vessel activities in the port.

The northern alternative has less (if any) influence on the lagoon, so the salt works are not endangered. Due to the increased vessel traffic in east-west direction in the bay, the fishing activities might be influenced. Probably the influence on the oyster farms is not much as they are not located near the approach channel. The influence on the marina activities will be less than for the southern alternative. Furthermore the northern expansion requires more construction work to be done. This implies more jobs are created for local residents, lowering the high unemployment rate.

6.3 Stakeholders

The stakeholders and their interests or concerns regarding the expansion and utilization of the port have been listed in section 4.3. The evaluation of the financial and general aspects will help them form a preference towards either the northern of the southern expansion alternative. Expectations of their preferences are listed in the table below. Consultation should be performed to confirm these expectations in order to avoid conflicts along the way.

	Preference	Reason
Namibian government	North	No risk of approaching capacity limits, and missing out on the port's full potential
Namibian Port Authority (Namport)	North	- No downtime in current port - Possibility to easily expand activities - Prestigious project
Ministry of Environment and Tourism	North	- Minimal environmental impact in bay and lagoon area - Minimal disturbance of marina tourist attractions
Municipality	North	- Higher job creation in construction phase - Minimal hindrance and exposure to hazards
Walvis Bay Corridor Group	North	Improved accessibility and expandability of infrastructure
Investors	-	Depending on their risk-profile
Leaseholders of quays	North	Improved flexibility of terminals
Maritime operators	South	Less complications due to having a single approach channel
Governments of adjacent countries	North	Improved infrastructural connection to the port
Mining industry	North	Higher degree of flexibility makes them able to export as much as requested by the market
Contractor	North	- Less hindrance by current port activities gives more freedom - Prestigious project
Fishing industry	South	- Better access to port from fishing quays - Less vessel hindrance due to single approach channel
Salt refinery	North	No effects on the water quality in lagoon
Tourist industry	North	Less negative effects regarding flora and fauna, and disturbance of marina tourist attractions
Residents of Walvis Bay	North	Less hindrance and hazards due location outside the city
Owner of Bird Island	South	Less vessels and dredging operations near the island
Environmentalists	North	Minimal environmental impact in bay and lagoon area

The majority of the stakeholders are expected to have a preference for the northern alternative. The others may have to be compensated for any inconveniences.

6.4 Strategy decision

It seems that the highest added value for the majority of the stakeholders is created by choosing for an expansion of the port at the northern site. Together with its higher possible financial profits, the choice for this strategy seems evident. The port is however very dependent of the economic climate and the willingness of investors to take risks. This willingness seems to be small these days, as there is a low degree of confidence in the global economy. Smaller investments that are most certain to at least pay back their investments are prioritized above large scaled projects, even though they have higher expected return rates.

Involving the stakeholders in the conceptual design phase of the project leads to a broadly supported development strategy, increasing the probability of actually being implemented. The stakeholders with the highest influence all share the same interest; creating a profit. The financial aspect will therefore be decisive in the decision for the northern of southern alternative. As the decision for the northern of southern expansion is highly dependent on the risk profile of the attracted investors, no alternative can be recommended as yet.

7 Design aspects

As outlined in chapter 6, the choice for port development at the northern or southern expansion site highly depends on the type of investor that is attracted. The construction and layout of an elongation of the southern peninsula is more or less self-evident. The northern expansion plan is however still very unclear, and offers many opportunities for the implementation of efficient en flexible designs. Therefore it's chosen to make conceptual designs for the northern site, focussing at the general terminal layout, a liquid bulk berthing facility, the quay walls and revetments.

7.1 General layout of the expansion

Up to now, the alternative has only been globally sketched without going into detail of the layout of the expansion. In this section, the design aspects will be translated into a general layout, including the wet and dry infrastructure, terminal arrangement and the expansion possibilities after 2050.

7.1.1 Wet infrastructure

The approach channel, harbour basin and the turning basin have to be designed according to the following minimum required dimensions obtained in section 5.2. The liquid bulk vessels calling at the port have a lower draught than other vessels; therefore its harbour basin is dredged two meters shallower.

	Length [m]	Width [m]	Depth [m]
Approach channel	2280	188	-16.25 CD
Harbour basin	-	400	-15.75 CD
Harbour basin – liquid bulk terminal	-	400	-13.75 CD
Turning basin	640	640	-15.75 CD

Table 7-1: Wet infrastructure dimensions

These minimum required dimensions will be applied to the complete wet infrastructure; only the final length of the approach channel and the orientation of the harbour basin has to be determined.

Approach channel

In order to minimize the required dredging activities, the approach channel is orientated in such a way that it has an optimum length and is slightly non-parallel to the dominant wave direction. The prevailing waves are relatively small; the significant wave height hardly exceeds one meter near shore. Hence the probability of downtime due to wave conditions is very small, therefore no breakwaters are required. The channel has an orientation of 131 degrees relative to the absolute north. This orientation implies a required length of 4.650 meters to reach a depth of -16.25 meter CD. By using this orientation, there are no conflicts with the approach channel of the current port, as is shown in

Figure 7-1.

Harbour basins

The expansion at the northern site is based on the risk-seeking strategy, which includes investors anticipating on high economic growth and exporting the coal from Botswana through Walvis Bay. This strategy has a big influence on the general layout of the harbour basin, as the whole basin and the associated 3.239 meters of quay wall have to be constructed at once to accommodate the number of vessels for the high growth scenario of 2035. The difference in the amount of required quay lengths is only 250 meters between the 2035 and 2050 scenario, making a onetime investment for the construction of the 3.489 meters of quay wall favourable over expanding in multiple phases. At the west side of the reclaimed land, there is second harbour basin with a corresponding turning basin, used to reach the liquid bulk terminal. The orientation of the harbour basin depends on the terminal arrangement, and is further elaborated in section 7.1.2.

Dredging aspects

The expansion on the north side requires dredging of the wet infrastructure and levelling of the land for the terminals around the harbour basin. The amount of soil that has to be dredged is not in balance with the amount of land that has to be used for the levelling. In order to attain a more desirable cut-and-fill balance, two patches of land will be reclaimed on both sides of the port entrance. This brings the cut-and-fill balance down to a ratio of 1.24 (see chapter 8.1)

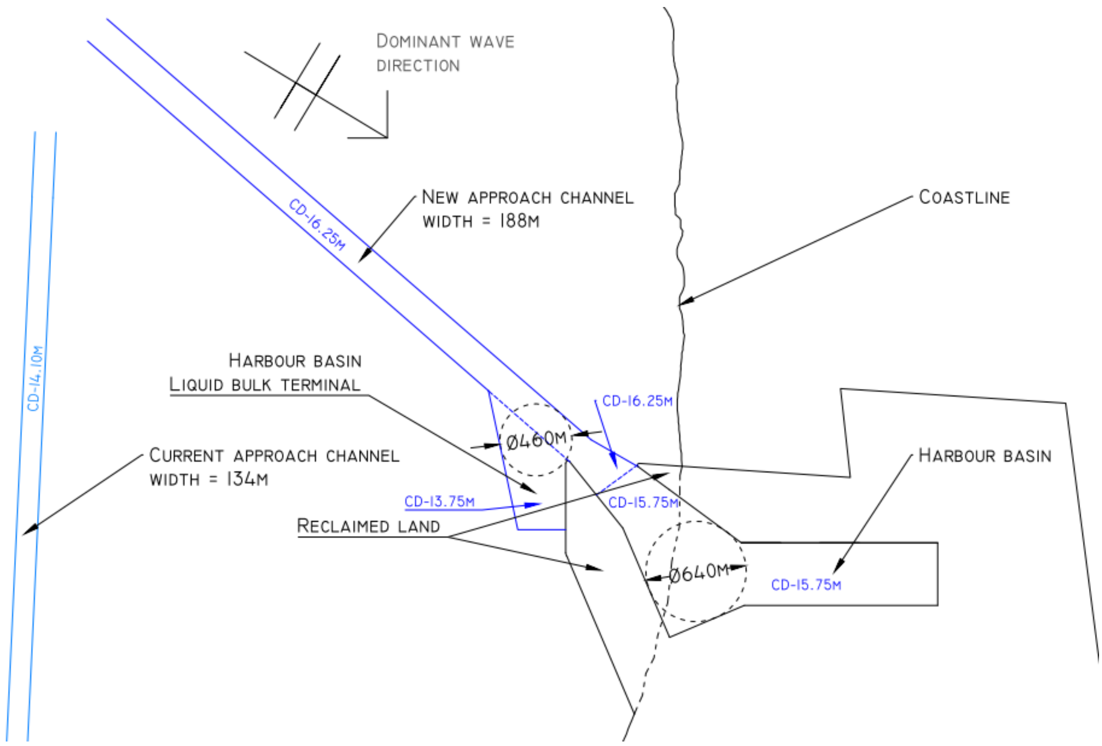

Figure 7-1: Wet infrastructure

7.1.2 Terminal arrangement

As described above, all of the wet infrastructure will be constructed at once for the high growth scenario of 2050, but this is unnecessary for the construction of the terminals. As there is still a high degree of uncertainty regarding future cargo flow, special attention is paid to the expandability and flexibility of the terminal arrangement. The initial terminals are constructed anticipating on low economic growth and no coal transport from Botswana. The liquid bulk terminal is relocated from the existing port to the northern port for two reasons; the current liquid bulk jetty already has to be replaced in the near future and at the new location the liquid bulk facilities are further away from residential areas. This terminal is placed on the north part of the reclaimed land, due to safety reasons. The berth facility is located on the west side, so it does not interfere with the approach channel. The space that freed up by this relocation from the current port may be used to store the entire food bulk. The initial storage footprints for different commodities in the northern port are shown in Table 7-2.

	Initial storage footprints
Container	70.800
Rough bulk	137.700
Liquid bulk	76.000
General cargo + Ro-Ro	110.500
Chemical bulk	68.300

Table 7-2: Terminal storage footprints [m^2]

These initial terminals are indicated in Figure 7-2 by the hatched sections. All the terminals are located in such a way that they can easily expand without conflicting with each other. As stated before, the construction of the terminals will follow the demand for capacity. If the coal contract gets signed, then the rough bulk terminals will immediately be prepared to handle the increasing storage capacity up to 2.674.400 m^2. All the other terminals have the space to grow towards a high economic development in multiple phases, as can be seen in the figure. The required quay walls and the berthing facility for liquid bulk are elaborated in sections 7.2 and 7.3. The northern part of the reclaimed land offers space to for offices and a small craft harbour to accommodate the tugboats. The Vessel Traffic Service tower (VTS) is also located at this strip of land.

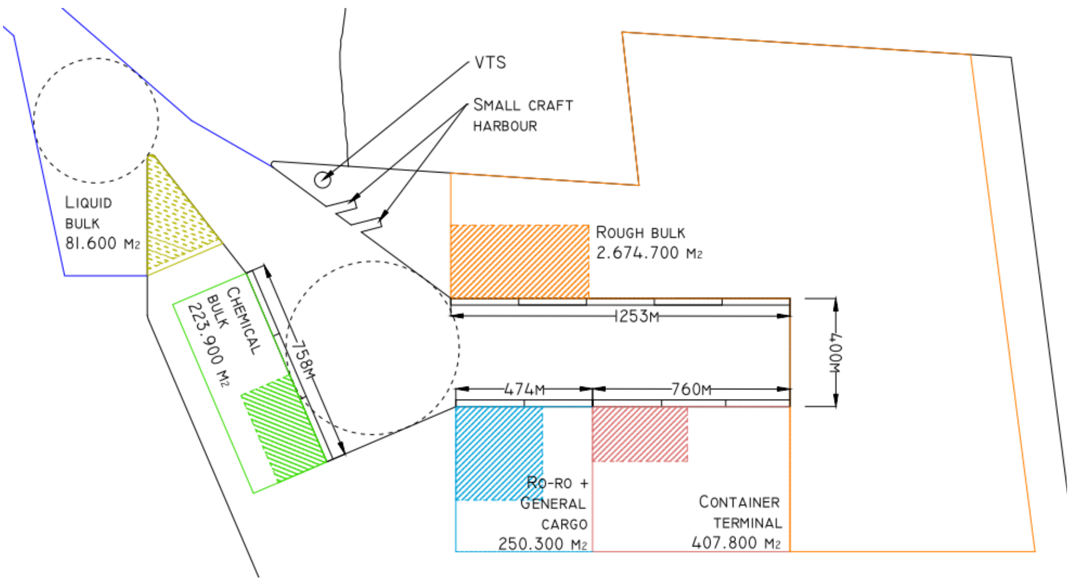

Figure 7-2: Initial terminal arrangement (hatched) and expansion possibilities

7.1.3 Hinterland connections

The expansion of the port will increase the cargo throughput, which has to be transported by rail or road either to the port or to their destination inland. The (rail)roads accessing the port should be connected to the current infrastructural system outside of Walvis Bay, to avoid congestion of the city's road network. Both rail and road will be designed to accommodate the throughput quantities for a low growth scenario, with the ability to expand to accommodate the high growth scenario. The infrastructure is designed from the hinterland to the terminals. The transport inside the terminal areas is not described.

Railroad

As stated before, nowadays the modal split is such that only 5% of the containers is transported by rail, whereas the other 95% is handled by trucks. A more equal distribution is desired by Namport, so it is important to develop a good connection to the current railway. The new railway (see Figure 7-3, in red) will be connected to the current railway at the east side of Walvis Bay. Here the railway goes up to the north and splits into the different corridors, like the Trans-Kalahari to Botswana. The majority of handled cargo will comprise containers and rough bulk, making it efficient to let the railway will enter the port close to these terminals.

Road

The current road from Walvis Bay to the north is located through the project area. This road will need to be relocated to the east, positioned next to the dunes. It leads around the northern port where it is connected to the current road on the north side. The new roads (indicated with brown) will enter the port at the main entrance on the south side, where the same automated customs scanner and routing systems will be installed as in the current port. From here the roads will be constructed to the different terminals, as can be seen in Figure 7-3.

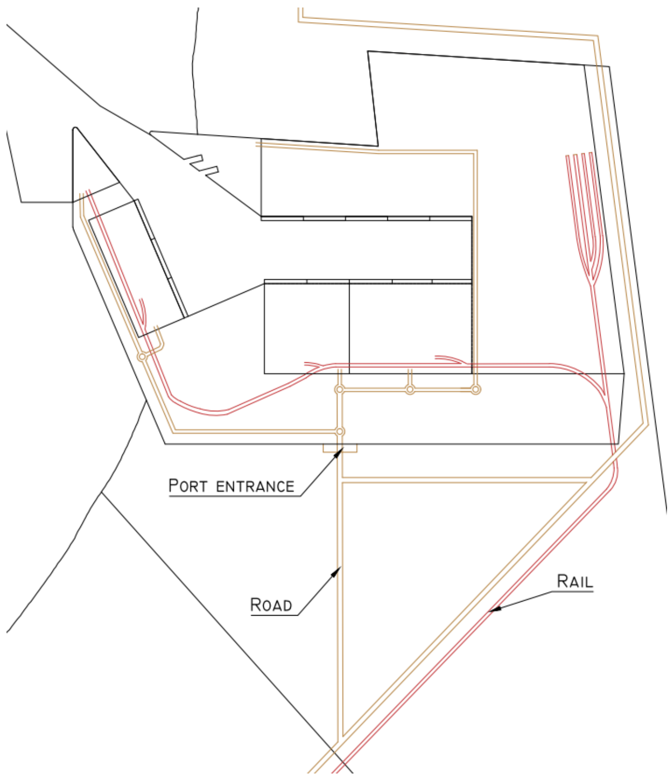

Figure 7-3: Hinterland connections

7.1.4 Expendability

The expansion of the port is designed to handle the future cargo flow up to 2050. After that there might be a demand for larger terminals and/or more berthing facilities if the cargo flows and the size of the vessels continue to grow. Based on the Capesize vessel (see section 4.1.2), it is estimated that only the vessel's draught will substantially increase after 2050.

Future dimensions

For the future port to be able to cope with the dimensions of Capesize vessels after 2050, the approach channel and the harbour basin have to be excavated to approximately -19.5 meter CD. Dredging of the approach channel can be done by the time it is necessary, but a further excavation of the harbour basin has to be taken into account when designing the quay walls (see section 7.3). It is assumed that it is sufficient to only dredge the turning basin and the new harbour basin up to the required depth to accommodate Capesize vessels. The 'old' the harbour basin for rough bulk, containerized and general cargo is kept at a depth of -15.75 meter CD.

Expansion of harbour basin

An area between the chemical bulk and the general cargo terminal has been kept undeveloped, to be able to enlarge the harbour basin and generate more berthing facilities. The basin can be enlarged for 500 meters before it conflicts with the railroad in the port, as can be seen in Figure 7-4. The only terminal that has to be (partly) replaced is the General Cargo terminal, which is relatively easy to move as it does not have much advanced structures or equipment. In order to expand the other terminals, the roads in the port have to be relocated. This is assumed to be a minor issue as these roads probably have to be reconstructed due to deterioration by that time.

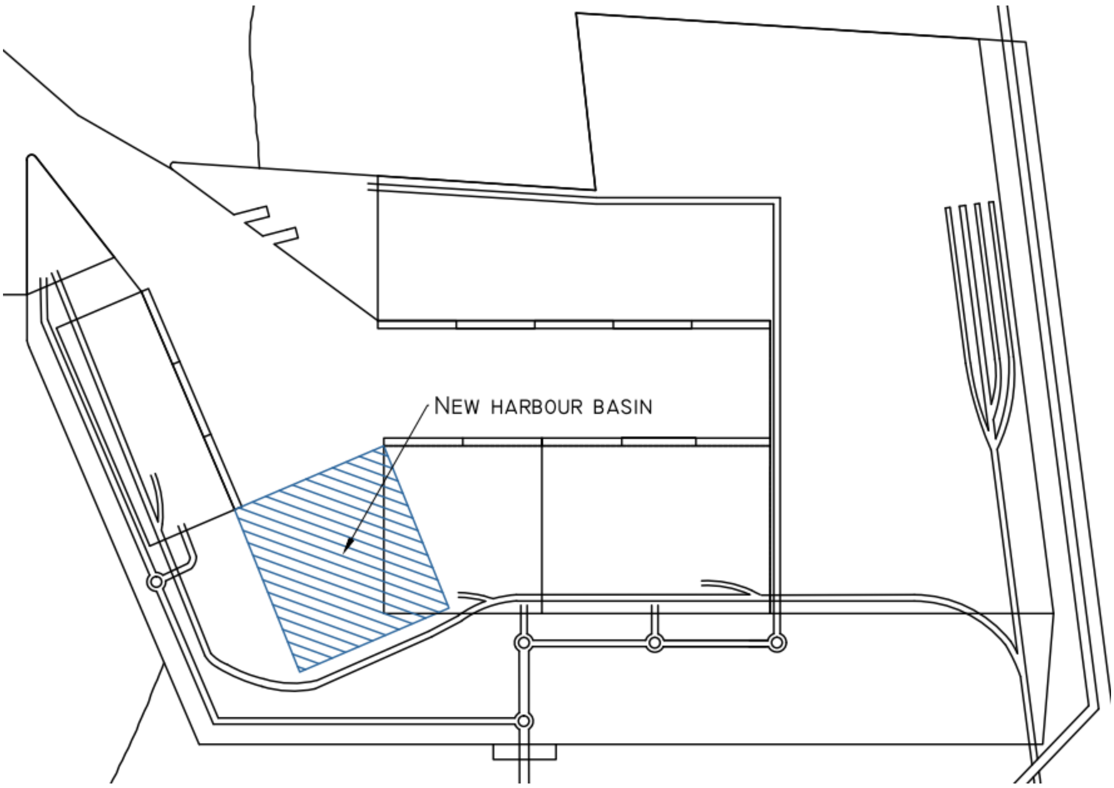

Figure 7-4: Expansion after 2050

7.2 Liquid bulk berthing facility

Liquid bulk comprises the following commodities: crude oil, oil products, fluid chemical products, liquefied natural gases and vegetable oils. For the port of Walvis Bay this means the commodities that have to be transported via a liquid bulk terminal are petroleum and sulphuric acid. These are imported goods so the berthing facility only needs to do the unloading of liquid bulk. These bulk goods are classified as 'dangerous', implying special safety requirements. The unloading occurs through one central manifold on the ship, placed more or less in the middle of the vessel. Just constructing a jetty seems to be the best solution for this job, but there are other alternatives. In this section, next to a description of a jetty, the possibilities and side effects of two alternative berthing facilities are evaluated; a Multiple Buoy Mooring (MBM) and a Single Buoy Mooring (SBM) facility.

7.2.1 Jetty in port expansion

A jetty is a structure consisting of an approach bridge, jetty head, mooring dolphins, berthing dolphins and a bottom scour protection. The approach bridge is a 2.5 to 3.5 meter wide roadway combined with a pipe track plus service ducts, lighting and guard rails. The length of the approach bridge can vary between tens to hundreds of meters. The jetty head is a platform with the (un)loading arms, jetty crane and service area. The mooring dolphins are used to fasten the transverse mooring lines and the berthing dolphins serve to absorb the ship's kinetic energy, hold the vessel in position during onshore wind and fasten the spring lines of the vessel. Constructing a jetty inside the sheltered area of the port expansion always poses a collision risk with possible devastating consequences. Therefore it has got its own harbour basin outside the regular harbour basin, as seen in Figure 7-2. By doing so, the collision probability is reduced to a minimum.

Aquacultural activities in the bay, which are of social and economic importance to the Walvis Bay community, will experience a lot of hindrance from eventual spills. However, unlike to an offshore mooring system, an eventual spill is noticed immediately limiting the possible consequences of a spill.

Costs

A rough cost estimate for a jetty able to serve the required Panamax vessels is around $16.000.000, including costs for additional dredging and bank protection. [50]: (WSP Africa, 2009).

Figure 7-5: Example illustration of tanker jetty with storage facilities

7.2.2 Offshore buoy mooring system

Multiple or single point moorings are unloading structures anchored offshore and serve as a mooring point for tankers to offload liquid or gas bulk products. First an overview of two offshore buoy systems is given, followed by a comparison with the jetty construction.

Multiple Buoy Mooring

The simplest offshore berth facility is the Multiple Buoy Mooring (MBM). More mooring points are used to prevent the ship from rotating around the mooring point. Flexible hoses connected to pipelines on the seabed run to or from the tank farms on land. When no vessel is at berth, the flexible hoses are set down on the seabed, with pick-up rigging connecting the end of the hose to a surface marker buoy. Upon arrival the ship uses its own anchor lines and often additional wires, connected to surface buoys (which are in turn anchored by chains to pile anchors in the seabed). Having moored, the vessel uses its manifold derrick or crane to attach the pick-up rigging and lift the flexible hose in order to connect it to the vessel's manifold. When the sea is rough it is not possible to connect the hose to the manifold. The limiting wave height is one meter, meeting the annual maximum wave heights in the sheltered area of the bay.

Figure 7-6: Example of Multiple Buoy Mooring

Single Buoy Mooring

The advantage of a Single Buoy Mooring (SBM) is that the ship can always take the most favourable position in relation to the combination of wind, current and waves. It has a high operability, ships can be (un)loaded up to wave heights of 2.5 meters. The SBM is attractive for its simplicity and low investment costs. On the other hand, the maintenance costs for SBM's are considerably higher than for jetties. In particular the hoses and floating houses require strict inspection and frequent replacement. Because of the low pump capacity the service time is quite high. In general, for small to moderate annual throughputs SBM's are more economical than jetties.

Figure 7-7: Example of Single Buoy Mooring

The offshore buoy mooring and the pipeline structure will potentially expose fish in the area to increased concentration of pollution and thereby cause contaminants to bio-accumulate up the food chain. A special concern is the likelihood of seals, dolphins, whales and seabirds that can get entangled in the structures.

Buoy location

An offshore mooring location is in the bay, near the entrance of the southern approach channel. The location is 5.5 kilometers offshore where the water depth amounts 15 meters, sufficient for the largest liquid bulk vessels. The location is a sheltered area behind the Pelican Point spit. The occurring wave heights will reach up to 1.0 meters, not limiting the berthing accessibility of an MBM or SBM.

The pipeline will run for 5500 meter undersea towards the liquid bulk terminal in the port expansion area. It has to avoid the port's wet infrastructure as this brings a risk of pipeline damage. Wave exposure on the pipeline can be significant; it therefore has to be well protected.

The proposed site could be regarded by the public as it is interfering with ecotourism and aquaculture activities such as oyster farms. These are reliant on unpolluted water. The growing aquaculture industry is of social and economic importance to the Walvis Bay community. A mooring facility for tankers in this area will have a negative impact on the environment due to an increased disturbance of the marine life, noise pollution and a possible increase in the risk of sea life collisions. The site is unique due to the rocky shores and reefs in the surrounding. It contains the highest concentration of bird life along the Namibian coast and the shores sustain a high biodiversity, which would be severely affected in the event of chemical spills.

Costs

A pipe with diameter of 46 cm is assumed to be sufficient to transport all liquid bulk to the terminal. Rough cost estimation sets the unit price for the underwater pipeline at $350 per running meter. [50]: (WSP Africa, 2009).

	MBM	SBM
Supply and install buoy	$ 4.500.000	$ 6.000.000
Pipeline under water (5500m)	$ 1.925.000	$ 1.925.000
TOTAL	**$ 6.425.000**	**$ 7.925.000**

Table 7-3: MBM and SBM costs

7.2.3 Overview

An evaluation of which berthing facility fits the best in this project location is done according to their functional features, differences in service time, costs and environmental impacts.

Functional features

The following table gives an overview of the functional features of the three mooring systems. [48]: (Maari, 1977)

	Jetty	Offshore mooring	
		MBM	SBM
Access from shore	Direct	By sea	By sea
No. of hoses	1 – 8	1 – 4	1 – 3
Mooring time	2 hours	5 hours	2 hours
Demooring time	0.5 hour	1 hour	0.5 hour
Mooring possible with waves of	1.0 – 2.0 m	1.0 m	2.0 – 2.5 m
Oil unloading possible with waves of	1.5 – 2.0 m	2.0 – 2.5 m	3.0 – 4.5 m
Ship has to leave berth with waves higher than	-	2.0 – 3.0 m	3.5 – 5.0 m
Possible tidal effects	Yes	No	No
Damage sensitive parts	Fenders	Buoy chains	Hoses
Preference regarding ease of (de)berthing	2	3	1
Assistance during berthing/mooring	Tugs and flats	Flats	Flats
Assistance for departure	Tugs and flats	Flats	None

Table 7-4: Functional features per mooring system

Service time

Since liquid bulk is only imported, just the unloading rate of the vessels is of importance to the Walvis Bay liquid bulk terminal. Assuming a maximum pump capacity of 1500 m^3/hour/hose the unloading time of three alternatives can be evaluated. According to Table 4-5 the average vessel capacity in 2050 is around 75.000 m^3. Combined with the time it takes to (de)moor a vessel the total service time is obtained.

	Jetty	Offshore mooring	
		MBM	SBM
Unloading rate [m^3/hr]	12000	6000	4500
Mooring + Demooring	2.5 hours	6 hours	2.5 hours
Total service time	8.4 hours	17.8 hours	18.2 hours
Operational hours per year [1]	5760	5536	5536
Max. number of ships annually [2]	686	311	304

Table 7-5: Service time for jetty, MBM and SBM

[1] MBM and SBM's operational hours per year are lower because of downtime due to maintenance (approx. two weeks per year).
[2] Maximum number of ships annually at an occupancy rate of 100%.

From the table above it is clear that each alternative, using its maximum number of pumps, is easily able to facilitate the total number of vessel calls per year of for liquid bulk (see Table 4-7).

Conclusion

Although constructing an MBM is cheaper than an SBM system, the SBM has a lot more beneficial characteristics that make it worth investing in. The MBM beats the SBM on its unloading speed, but the long (de)mooring time outweighs this time saving. Disadvantage of the SBM is the vulnerability of the hoses. However, if one decides to build an offshore unloading facility, the SBM is the best alternative.

Constructing an SBM is about two-third of the costs for a jetty. However, the environmental cons that come with an SBM and the amount of maintenance needed make it an unfavourable alternative. Constructing a jetty seems the best way to go for the expansion of Walvis Bay. In the next sections the jetty is further designed, starting with the fender characteristics.

7.2.4 Fender design

To determine what kind of fender has to be used, the berthing energy first has to be calculated. The calculation should take into account the least favourable combinations of vessel displacement, velocity and angle as well as the various coefficients. After the berthing energy is calculated, the reaction force can be read from a PIANC table about different fender types. Next, using the maximum hull pressure, the required fender panel area is calculated.

Berthing energy

The total energy depends on the vessel's water displacement m_s, the approach velocity v_B and several coefficients. C_H is the hydrodynamic coefficient, C_E the eccentricity coefficient, C_C the berth configuration coefficient and C_S the softness coefficient. The total normal berthing energy to be absorbed by the fender in formula:

$$E_N = 0.5 \cdot m_s \cdot v_B^2 \cdot C_H \cdot C_E \cdot C_C \cdot C_S \qquad [7\text{-}1]$$

It is assumed that the maximum vessel's water displacement is 80.000 metric tonnes. Berthing speeds depend on the ease of difficulty of the approach, the exposure of the berth and the vessel's size. According to PIANC standard the approach velocity for these conditions is 0.15 m/s.

The hydrodynamic coefficient is in fact simply the ratio between the mass of the ship plus the water moving with the ship and the mass of the ship:

$$C_H = \frac{m_s + m_w}{m_s} = \frac{m_s + \rho \cdot L_s \cdot 0.25 \cdot \pi \cdot D_s^2}{m_s} \qquad [7\text{-}2]$$

Where:

$\rho = 1025\ kg/m^3$	Density of seawater
$L_s = 230\ m$	Vessel length
$D_s = 12.0\ m$	Vessel draught

Inserting all parameters in formula [7-2] gives the hydrodynamic coefficient: $C_H = 1.33$.

The coefficient of eccentricity C_E takes into account the energy dissipation caused by the yawing of the ship when it moors eccentrically against the structure.

$$C_E = \frac{k^2 + r^2 \cos^2 \gamma}{k^2 + r^2} \qquad [7\text{-}3]$$

Where k is the radius of gyration which depends on the block coefficient C_B (function of the hull's shape) and the vessel length.

$$k = (0.19 \cdot C_B + 0.11) \cdot L_s \quad [7\text{-}4]$$

$$C_B = \frac{m_s}{L_s \cdot B_s \cdot D_s \cdot \rho} \quad [7\text{-}5]$$

Where B_S is the design vessel's width of 32 meter.

The radius r is the distance between the centre of mass of the ship and the point of collision between the ship and the structure. The angle γ is the angle between radius r and the velocity of the ship. See figure below.

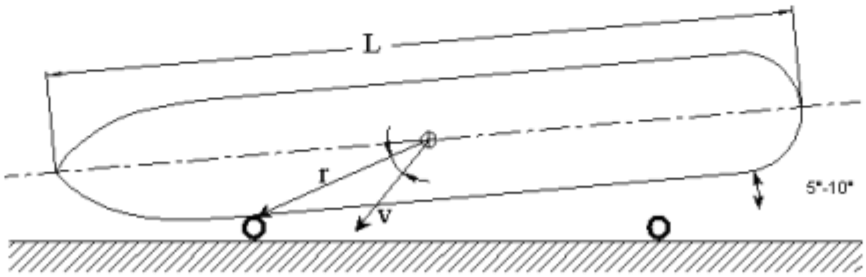

Figure 7-8: Berthing eccentrically (Hydraulic Engineering Department TU Delft, 2011)

Substituting equations [7-4] and [7-5] in [7-3] gives a coefficient of eccentricity $C_E = 0.77$.

The configuration coefficient C_C takes into account the hydrodynamic friction. This is caused by the water mass between the ship and the structure. For a jetty this hydrodynamic damping will not occur, resulting in a value of $C_C = 1.0$.

The softness coefficient C_S takes into account the elasticity of the ship's side. This coefficient depends on the stiffness of the structure and that of the ship's shell and takes into account the part that is taken on by the structure. For soft fenders $C_S = 1.0$.

Substituting all values in [7-1] gives the normal berthing energy to be absorbed by the fender:

$$E_N = 933\ kNm \quad [7\text{-}6]$$

Abnormal impacts arise when the normal energy is exceeded. Causes may include human error, malfunctions, exceptional weather conditions or a combination of these factors. The characteristic value of the so called abnormal energy to be absorbed by the fender is calculated by multiplying the normal berthing energy with a safety factor for abnormal berthings. For the largest vessel this factor is $F_s = 1.25$

$$E_A = E_N \cdot F_s = 1165\ kNm \quad [7\text{-}7]$$

Reaction force in fender

For resisting the berthing force at the liquid bulk jetty a cone fender is chosen. These are cell fenders with a conical body which stays stable even at large compression angles. According to the tables and graphs, an SCN1400 fender with rubber quality E1.5 results in the lowest reaction force with the given abnormal berthing energy. The resulting reaction force F_r = 1613 kN, the deflection is δ = 1008 mm. See figure below. [47]: (Trelleborg, 2008)

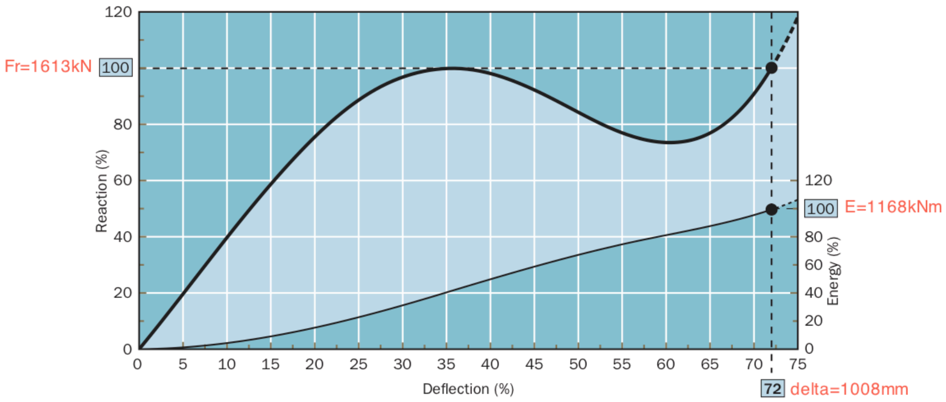

Figure 7-9: Berthing energy versus reaction force F_r and maximum deflection δ for SCN1400 cone fender, rubber quality E1.5.

Panel dimensions

The panel dimensions depend on the maximum hull pressure and the acting fender reaction force. The maximum allowable hull pressure for oil tankers is $P_{f,max}$ = 150 kN/m^2. For the design of the panels it's assumed the panels will distribute the reaction force of F_r = 923 kN over their full face. The minimum panel dimensions are:

$$A_{panel} = \frac{F_R}{P_{f,max}} = 10.75\ m^2 \quad \rightarrow \quad H_{panel} = 4.7\ m, \quad W_{panel} = 2.3\ m \qquad [7\text{-}8]$$

7.2.5 Breasting dolphins

Breasting or berthing dolphins serve to absorb the kinetic energy of the ship and hold the vessel during on-shore wind.

Position

The position of the breasting dolphins is determined by the design criteria from the next figure. The distance between the two dolphins (indicated in blue) must lie between 0.25 and 0.4 times the ship's length; say 0.3. This results in a breast dolphin distance of 69.0 meter.

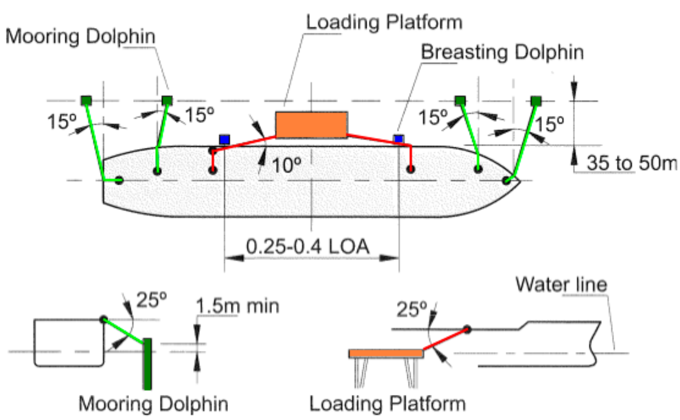

Figure 7-10: Guidelines for hawser cables and dolphin positions. (OCIMF, 1997)

Design

The breasting dolphins are driven raked or inclined into the ground, constituting yokes that are relatively stiff. The horizontal berthing load is mainly transferred into compression and tension forces in the piles. The heavy concrete dolphin head will reduce the tensile forces in the inclined piles. Unfortunately the exact data about the subsoil is unavailable, so the soil reactions cannot be calculated. However, using an existing dolphin as an example the next drawings are made.

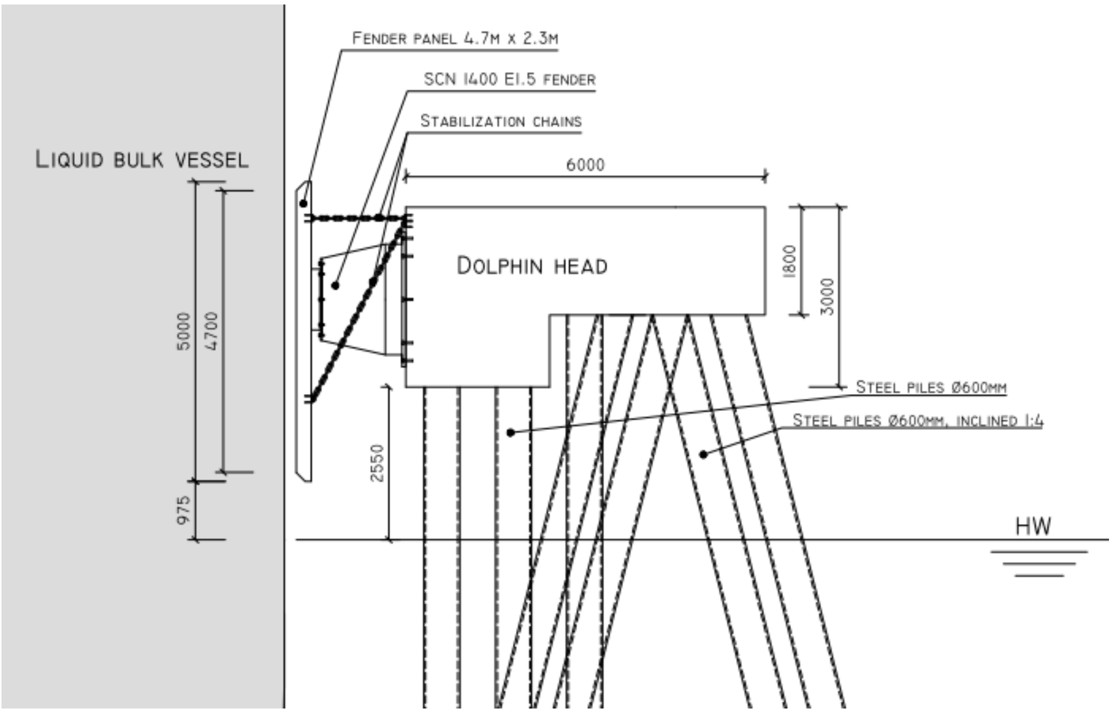

Figure 7-11: Side view breasting dolphin. Units: mm

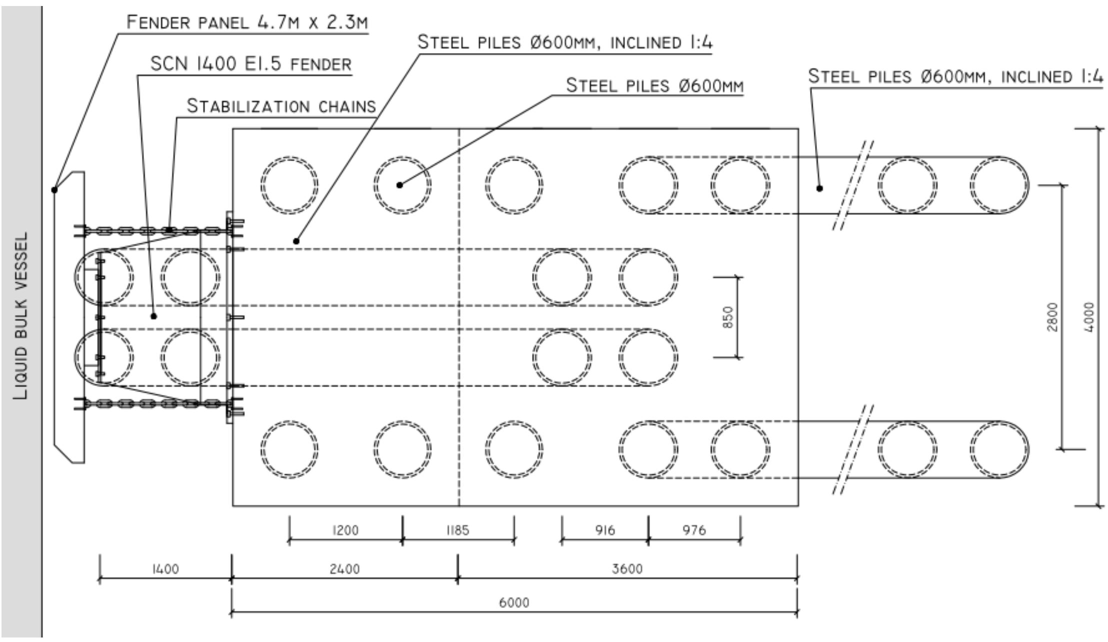

Figure 7-12: Top view breasting dolphin. Units: mm

7.2.6 Mooring dolphins

The mooring dolphins are used to fasten the transverse mooring lines (see Figure 7-10, indicated in green) which are connected to bollards on top of the dolphins. First the mooring dolphin positions are determined.

Position

According to the guidelines in Figure 7-6 a proper perpendicular distance between the mooring dolphins and the vessel is 40 meters. The maximum distance between the two outer dolphins is 240 meters for the largest vessel; a distance of 230 meters meets this requirement. The walkway between the breasting dolphin and the first mooring dolphin is oriented at an angle of 45 degrees with respect to the coastline. The width of the walkways is 1.5 meters.

Mooring bollard

The required bollard dimensions depend on the mooring force to be transferred. For seagoing vessels of 80.000 tonnes a mooring force of 92 tonnes can be assumed, including a safety factor [43]. A 100-ton bollard will be able to resist this mooring force.

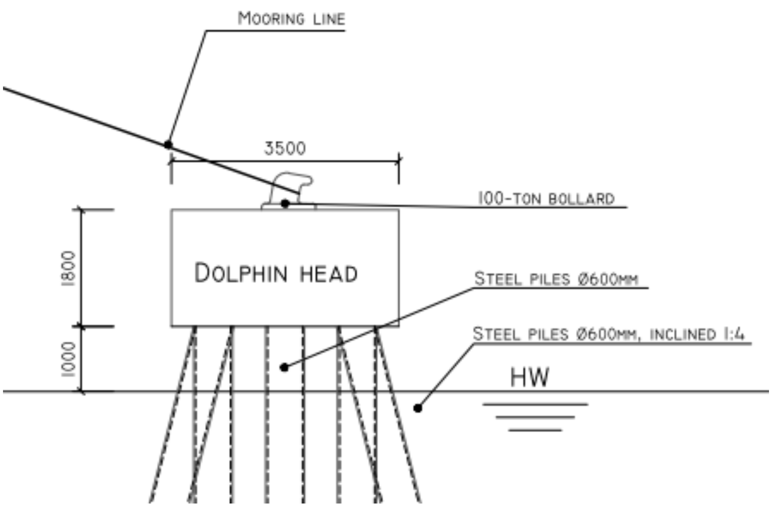

Figure 7-13: Side view mooring dolphin. Units: mm

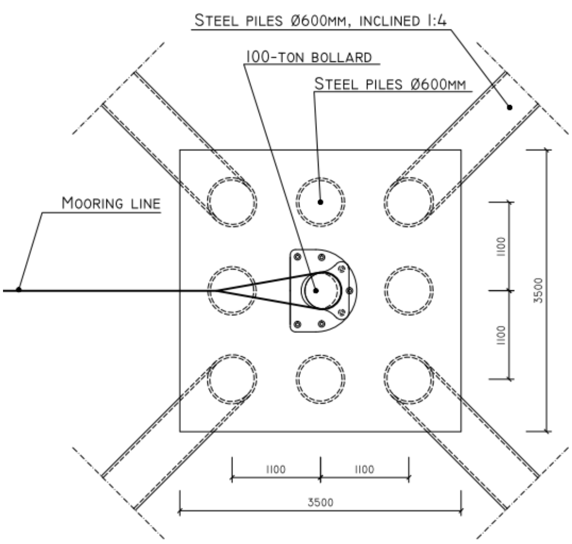

Figure 7-14: Top view mooring dolphin. Units: mm

7.2.7 Jetty head and approach bridge

The jetty head consists of a platform with oil unloading facilities and for example a service area, a service building and a fire fighting tower. It is connected to the main land and the liquid bulk terminal via the approach bridge. The approach bridge gives space to a roadway, a pipe track (right next to the roadway), service ducts, lighting and guard rails. The heaviest vehicle passing the roadway is assumed to be a 15 ton truck. The approach bridge and jetty head are quite simple structures for which local building regulations apply. This is not further discussed here; just a global layout is given of the jetty top view in Figure 7-15.

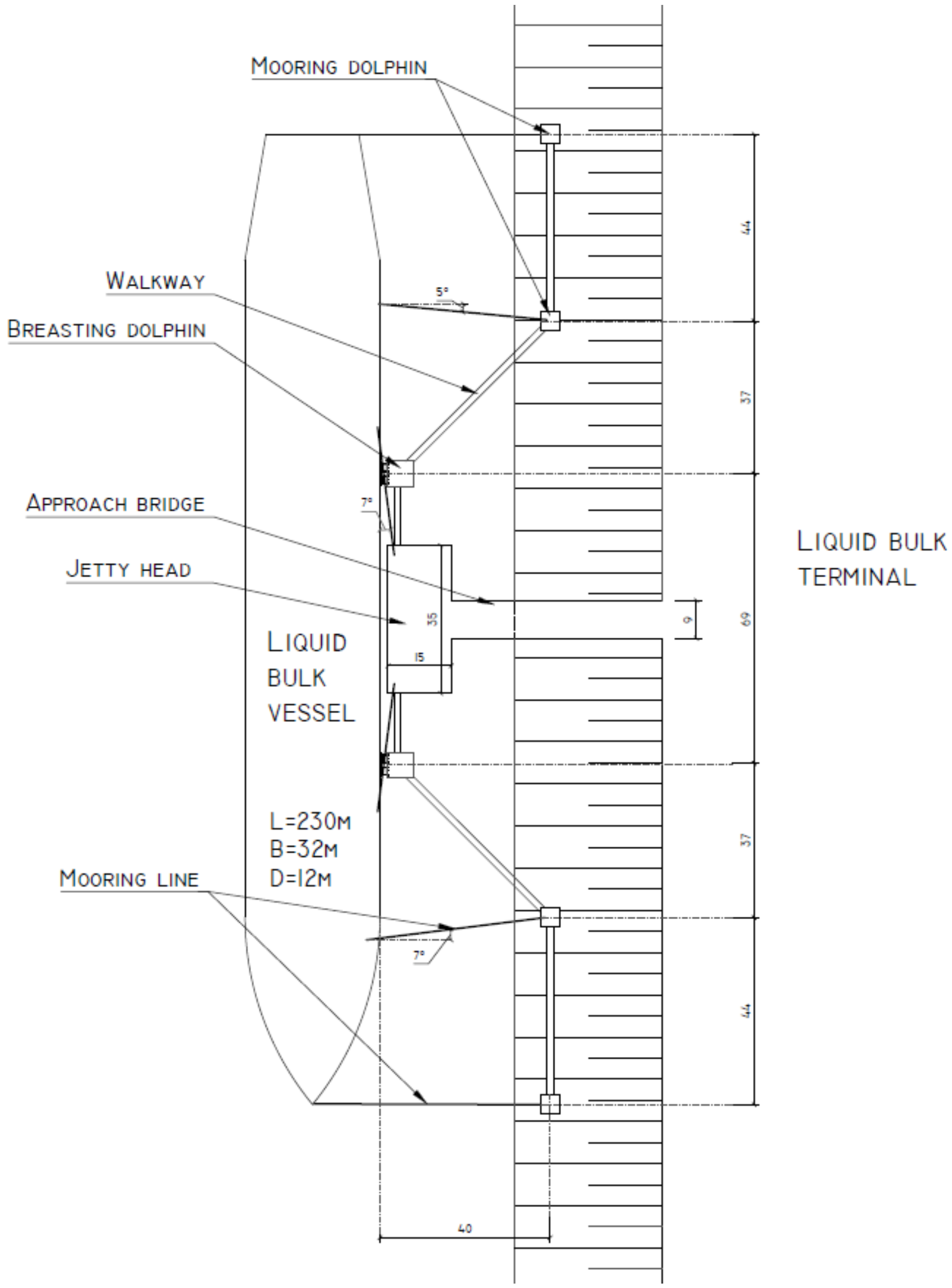

Figure 7-15: Jetty top view. Units: m

7.3 Quay walls

Quay walls have three main functions:

- Retaining; the quay wall has to retain soil and water
- Bearing; loads imposed by cranes, traffic and stored goods
- Mooring; ships must be able to moor safely to load or unload cargo

A lot of conditions influence the quay wall design, for instance: number and size of ships calling, labour and material costs, wind, waves and ice conditions. The most important conditions are the soil conditions and the loading of the quay wall. In the area of the port expansion not a lot of geographical data is available, geologist expect a solid rock layer at around 30 meters below CD. Above this rock layer there are different soil layers; most are expected to consist of clayed sandy silts. In this layer also boulders are expected, size and location of which is unknown.

An aim of the new expansion is to be flexible in the future in terms of layout changes. If the commodity shipped at a certain quay is changed, the requirements for the quay wall may change as well. This is the easiest if all quay walls are identical and can all bear the governing loads. Having identical quay walls will also lower the construction and maintenance costs. Besides a higher repetition factor can be achieved, increasing efficiency.

There are lots of different types of quay walls, which can be divided into three main categories; sheet piles, open structures and gravity structures. Each of these structures has its own advantages and disadvantages, which will be elaborated in the coming sections.

7.3.1 Sheet pile structure

Sheet piles are a straightforward way of creating a retaining wall. A sheet of steel is drilled into the ground and held in its place by anchors if necessary. Often a relieving floor is installed on top of the sheet pile to lower the horizontal ground pressure on the sheet piles. Retaining the soil is not the only function of sheet piling; it also bears part of the weight of for instance cranes at the quay wall. Attention should be paid to corrosion of the steel and leakage between the sheet piles. In case of leakage the sand behind the retaining wall washes away, if the leakage is not observed in time this could result in quay wall failure. Figure 7-16 shows one of the possible designs of a sheet pile quay with relieving floor.

Advantages

The sheet pile quay wall structures are usable for all of the quay walls. Sheet piling is possible in soil layers with low bearing capacity.

Disadvantages

Sheet pile walls require relatively much maintenance, repairs are relatively costly because most of the work must be done by divers or even a construction pit could be necessary for big repairs. The randomly placed rocks will impose a big challenge drilling the sheet piles. Removing all rocks and installing sheet pilling afterwards will be relatively expensive and time consuming.

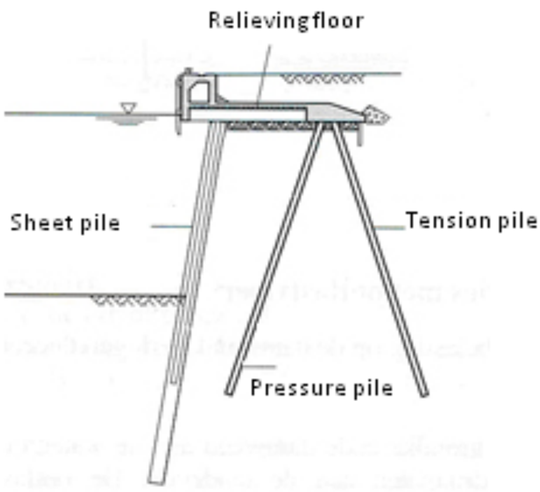

Figure 7-16: Sheet pile with relieving floow

7.3.2 Open quay structures

Open quay structures have much in common with jetty structures. The stability of the structure depends on the bearing capacity of the piles. In contrast to gravity type and sheet pile structures there is no vertical wall separating the land and water, bed protection is used to protect the sloped embankment. They are easy to construct in deeper water and a flexible design is possible in case of unexpected obstacles. The structures are also flexible in the sense that they are able to absorb energy, for example in case of earthquakes. Open quay structures are often used in areas where there is a soft top layer and a solid base layer at reasonable depth. Figure 7-17 shows a possible design.

Advantages

Because of the flexible design, the rocks in the soil will only have a minor effect on construction. In general the construction costs are relatively low.

Disadvantages

The structure has a limited load bearing capacity (not to be applied for general cargo and container handling), is vulnerable to abnormal berthing and lacks flexibility in receivable vessels. In general open quay structures require more maintenance than regular quay walls.

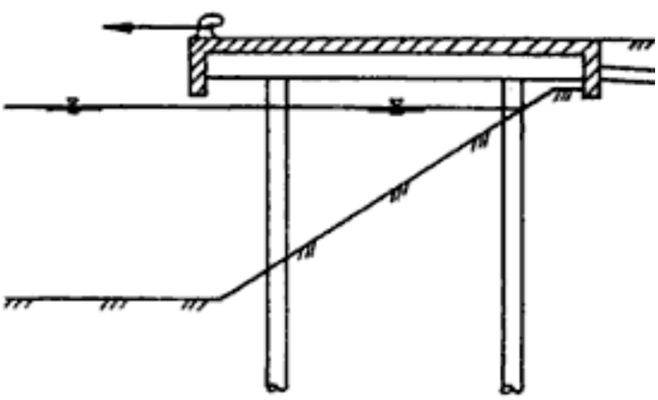

Figure 7-17: Open quay structure

7.3.3 Gravity type structures

This type of quay wall primarily uses its own weight to resist the loads acting on the structure. Most common types are the block-wall, caisson and L-wall. The structures are characterized as robust and durable. Gravity type structures are often used in harsh environments, for instance with big temperature differences, salt water, large waves, heavy ice loads and soil layers which are unsuitable for pile driving. The large deadweight of the structure makes good bearing subsoil necessary. The majority of gravity type structures is low-tech, needs a lot of material and is labour intensive. Construction can both be constructed in situ or prefabricated. Figure 7-18 shows a block-wall, a typical gravity type structure.

Advantages

All quay walls can be built the same way. The randomly placed rocks form a minor obstacle because for construction an excavation of the area is needed; encountered rocks can easily be removed. The labour intensiveness – which makes this technique often not feasible – is less of a problem in Namibia due to low labour costs. Moreover, the large amount of labour needed is beneficial for the creation of jobs, making it an important advantage of these structures. Very little maintenance is needed.

Disadvantage

Relatively much material is needed for construction. Soil improvements are necessary.

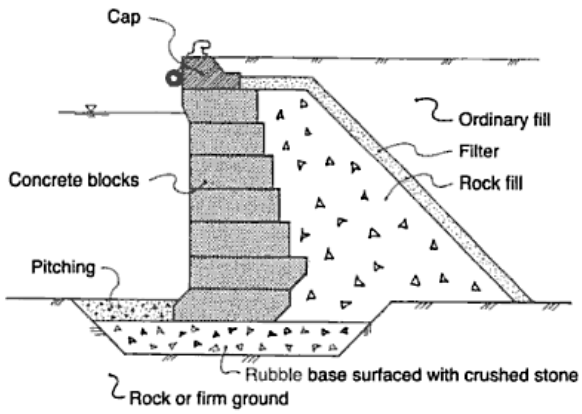

Figure 7-18: Block wall

7.3.4 Quay wall design

Considering the (dis)advantages of the different design alternatives, the gravity based structure seems to fit the local requirements best, mainly due to the existence of randomly located boulders. There are multiple gravity based designs possible; the block-wall, caissons and L-walls are the most common types. The caisson alternative is the best since it requires a relatively low bearing capacity of the soil, it is material efficient and no special lifting equipment is necessary.

Expandability

As explained in section 7.1.4, the requirements in terms of retaining height are not the same for all quay walls. The reason is the future expandability of the port; it should be possible to deepen the basin in front of the quay walls. As a future harbour basin should be deeper, also the present turning basin should be dimensioned at this depth. In order not to have to reconstruct these walls during the upgrade of the wet infrastructure, they are designed at this depth from the initial construction. Over a length of 785 meters, a depth of 19.5 meter below CD has to be maintained, hereafter referred to as $CD_{19.5}$. The other 2487 meters of quay length have to be dimensioned just to minus 15.75 m CD, hereafter referred to as $CD_{15.75}$. For both dimensions a design is made and checked for failure mechanisms.

Loads

The quay wall structure is loaded by different loads in different situations. Figure 7-19 shows the possible loads and Table 7-6 their magnitude. The berthing and mooring forces are calculated in the same manner as done in section 7.2.4. A container crane with a span of 45 meters is assumed, the support of the rear crane track is not designed. The water level behind the caisson is in the middle of low and high water. Because of the low waves of 0.5 meter, the simplification of hydrostatic pressure underneath the wave is assumed to be sufficient. The ground pressure depends on the top loading behind the caisson and the total high and low water pressure. The latter depends in turn on the design height of the caisson. The angle of internal friction of the sand is assumed to be 30 degrees.

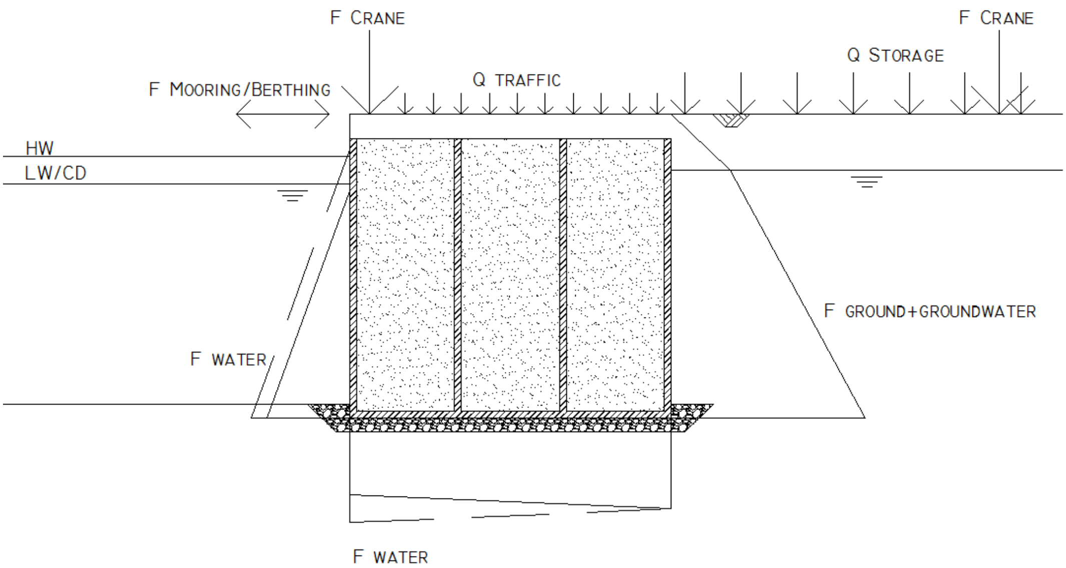

Figure 7-19: Loads on caisson

	Magnitude
Crane load [kN]	8000
Traffic load [kN/m^2]	10
Storage load [kN/m^2]	40
Berthing force [kN]	1100
Mooring force [kN]	1050

Table 7-6: Load magnitudes on caisson

Caisson dimensions

Caissons are usually constructed from cells with dimensions of 5 to 7 meters, to reduce the required wall thickness. In this design reinforced concrete walls with a thickness of 0.5 meter are assumed sufficient for the first design, which will later on be checked. In order to choose the length of the caisson, one should take into account that the caissons have manageable sizes, but the number of caissons should not be too large. Also the required quay length is important; preferably the caissons all have the same size. Taken these factors in account a caisson with 24 cells in the longitudinal direction and a length of 156.5 meters seems optimal for both quay walls.

The other dimensions are determined using an iterative design process. The height of the quay wall is composed of two parts, first part is the caisson and second part is an in-situ cast top structure. These parts are separated to ensure the top structure is completely flat for the cranes and other equipment, as the caissons may settle unproportionally after placement. Table 7-7 lists the dimensions of the two caisson designs. Figure 7-20 and Figure 7-21 show cross-sections of both designs.

	$CD_{15.75}$	$CD_{19.5}$
Outer dimensions (LxWxH)	156.5 x 23 x 20	156.5 x 30.5 x 23.75
Compartment dimension (LxWxH)	6 x 7 x 19.5	6 x 7 x 23.25
Compartment numbers (LxW)	3 x 24	4 x 24
Wall thickness	0.5	0.5
Floor thickness	0.5	0.5
Height top structure	1.75	1.75

Table 7-7: Caisson dimensions [m]

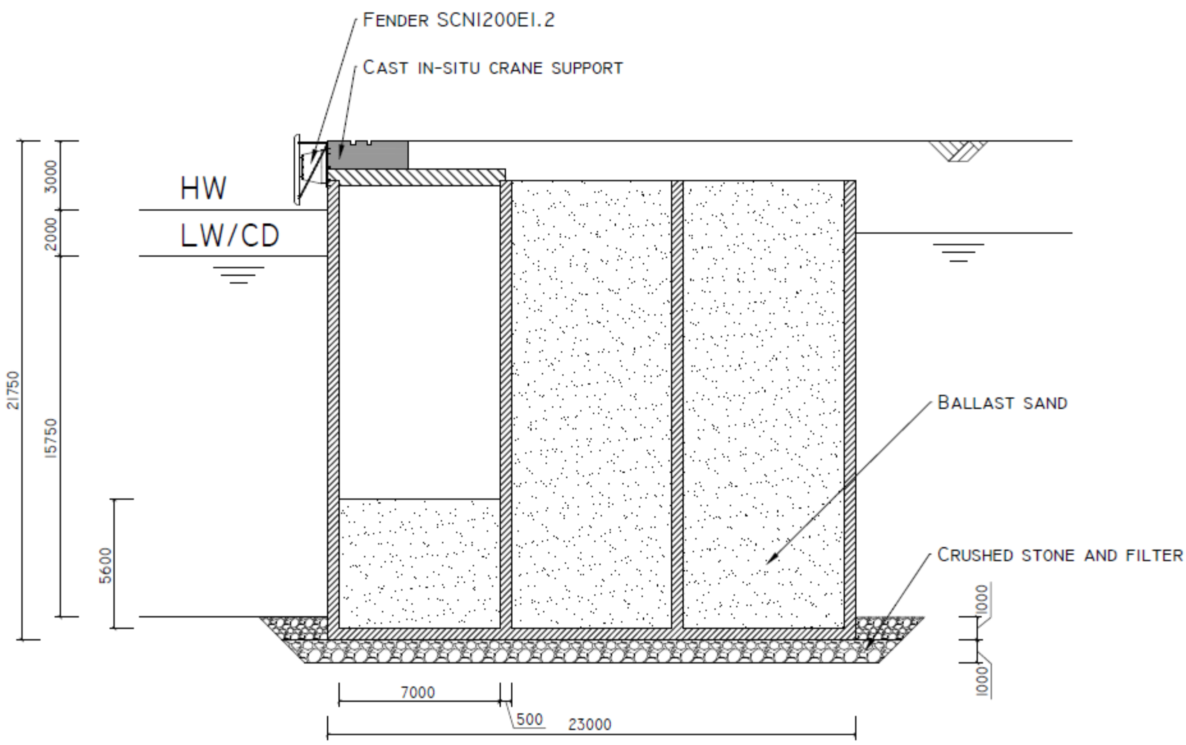

Figure 7-20: Design of caisson $CD_{15.75}$dimensions: mm

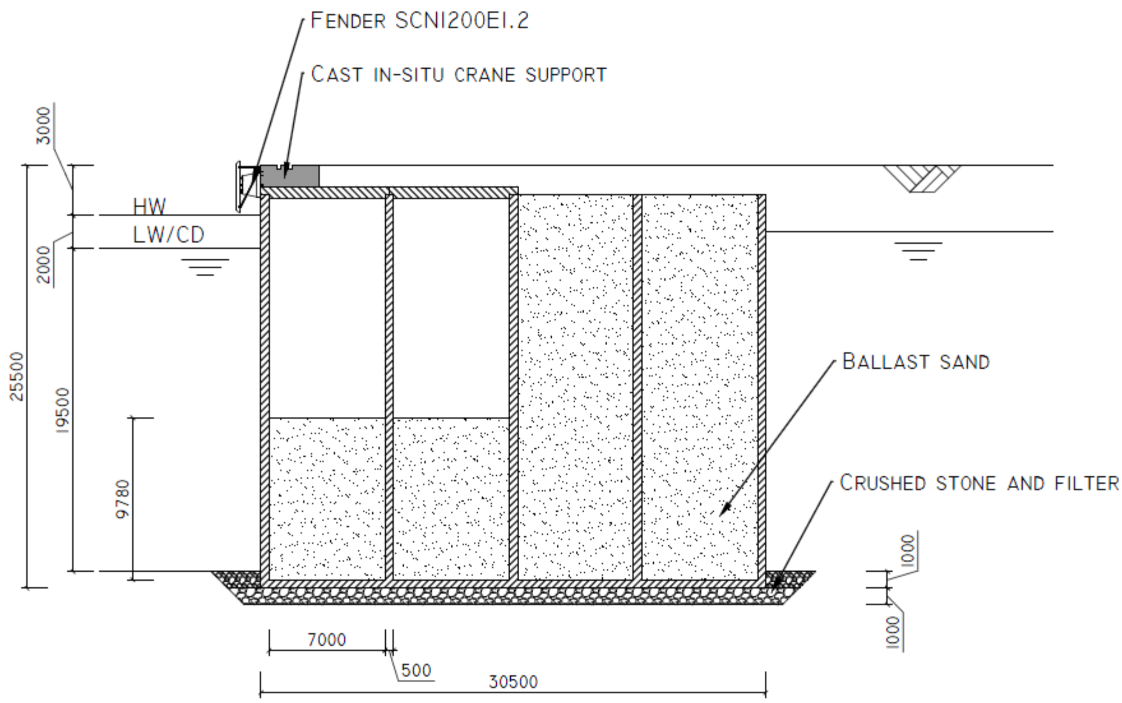

Figure 7-21: Design of caisson $CD_{19.5}$ dimensions: mm

7.3.5 Quay wall simulation

The designs presented in the section above need to be tested to whether they fulfil the requirements concerning different failure mechanisms. The failure mechanisms taken into account are draught, floating stability, shear between caisson and subsoil, turning over and soil bearing capacity. The wall thicknesses will also be checked whether the reinforcement percentage is economical.

Draught

The caissons are constructed in a dry dock, located at the head of the southern container terminal expansion. In order to transport them to their final location, the caissons have to be able to float. The allowed draught of the caissons is restricted to 14.5 meter because of the limited depth of the approach channel at the southern part of the port. For the calculation of the draught the law of Archimedes is used; the specific weight of the concrete is 25 $\mathrm{kN/m^3}$ and the water in the bay is salt, resulting in a draught of 9.0 meter for $CD_{15.75,}$ and 10.2 meter for $CD_{19.5}$. Both draughts remain within what is maximally allowed.

Floating stability

For the transport of the caisson draught is not the only requirement. The caisson must also be stable while floating, in other words the caisson must not turn over when put slightly out of balance by for instance a small wave or towing forces. The restoring ability of the caissons is expressed in metacentric height: the higher the metacentric height the more stable the caisson. The height is required to be at least 0.5 meter. The formula to calculate the metacentric height is the following:

$$h_m = \overline{KB} + \overline{BM} - \overline{KG} \qquad [7\text{-}9]$$

Where:

h_m	Metacentric height	[m]
$\overline{KB}$	Height of centre of buoyancy	[m]
$\overline{KG}$	Height of centre of gravity	[m]
$\overline{BM}$	Distance between the centre of pressure and the meta centre	[m]

Calculations result in a metacentric height of 0.53 meter and 2.0 meter for $CD_{15.75}$ and $CD_{19.5}$ respectively. Both designs satisfy the floating stability criteria.

Shear caisson – subsoil

The caisson is lowered onto the foundation using ballast sand with a specific weight of $18\ kN/m^3$. In order to ensure the caisson doesn't move horizontally under different loading conditions enough ballast sand must be added. The needed amount of ballast sand is determined using the shear stress requirement:

$$\frac{\Sigma V \cdot f}{\Sigma H} > 1 \quad [7\text{-}10]$$

Where:

f	Friction coefficient between caisson and foundation (0.5)	$[-]$
ΣV	Sum of vertical forces	[kN]
ΣH	Sum of horizontal forces	[kN]

The critical loading conditions are: low water, a ship mooring, maximum distributed load just behind the caisson and no load on top of the caisson (see Table 7-6). In order to fulfil the shear criterion, the required volumes of ballast sand are $44.4 \cdot 10^3\ \mathrm{m}^3$ for $CD_{15.75}$ and $66.5 \cdot 10^3\ \mathrm{m}^3$ for $CD_{19.5}$. Both designs have enough internal space to accommodate the required amount of ballast.

Turning over

For the stability of the caissons, no tensile stresses are allowed in the subsoil. Sand and gravel foundations cannot provide tensile stress because of their very poor adhesive and cohesive properties. This results in the following requirement:

$$\frac{\sum M}{\sum V} \leq \frac{1}{6} W \ \rightarrow \ \frac{W \cdot \Sigma V}{6 \cdot \Sigma M} > 1 \quad [7\text{-}11]$$

Where:

ΣM	Sum of moments around midpoint base	[kNm]
ΣV	Sum of vertical forces	[kN]
W	Width of the caisson base	[m]

The governing conditions are: low water, a ship mooring, a crane on top of the caisson, only a traffic load on the sea side of the caisson and a maximum storage load just behind the caisson (see Table 7-6). In this situation the overturning moment maximized. The calculations show both designs meet this requirement, the $CD_{15.75}$ has a unity check of 6.9 and $CD_{19.5}$ of even 55. The reason for this high value is the large width of the caisson and the ballast sand is placed in such a way it counteracts the moment created by the ground pressure.

Soil bearing capacity
The stability of the quay wall can only be guaranteed if the forces applied to the foundation do not exceed the bearing capacity of the soil. The bearing capacity of the ground after installing the rubble foundation is assumed to be at least $200\ \mathrm{kN/m^2}$. The following formula is used to calculate the maximum soil pressure:

$$\sigma_{max} = \frac{F}{A} + \frac{M}{W} = \frac{\sum V}{W \cdot L} + \frac{\sum M}{\frac{1}{6} \cdot L \cdot W^2} \qquad [7\text{-}12]$$

Where:

ΣM	Sum of moments around midpoint base	$[\mathrm{kNm}]$
ΣV	Sum of vertical forces	$[\mathrm{kN}]$
W	Width of the caisson base	$[\mathrm{m}]$
L	Length of the caisson	$[\mathrm{m}]$

Two situations can be governing; the same load situation as used for the overturning criteria or the same load conditions but the traffic load over the whole caisson. The maximum soil pressure for $CD_{15.75}$ is 180 $\mathrm{kN/m^2}$ and for $CD_{19.5}$ a pressure of 140 $\mathrm{kN/m^2}$ is found. Both values stay well below the limit bearing capacity.

Wall strength
The caisson as a whole is stable, but also wall strength is an important requirement. Both caissons are made with 0.5 meter thick walls. The required reinforcement percentage is calculated, if this percentage is higher than the economical percentage margin of 0.5-1.5% a slightly bigger wall can be favourable.

The highest transversal load on the front wall is the water pressure just above the ballast sand; the berthing fenders are placed in front of the internal walls. The depth at that place is the highest in the $CD_{15.75}$ design; in case of high water the depth is 12.6 meters. Using the low water as a static load and the difference in pressure between low and high water a dynamic distributed load of $158\ \mathrm{kN/m^2}$ is found (safety factors taken into account). The wall is modelled as if it is a continuous beam, resulting in a moment of:

$$M_{ED} = \frac{1}{10} \cdot q \cdot l^2 \qquad [7\text{-}13]$$

Where:

M_{ED}	Forcing moment	$[\mathrm{kNm}]$
q	Distributed load	$[\mathrm{kN/m}]$
l	Span	$[\mathrm{m}]$

The governing bending moment is $569\ \mathrm{kNm}$, defining a minimum requirement for the bending moment resistance of the wall. A first estimate of the moment resistance of the beam can be calculated using the following formula:

$$M_{Rd} = 0.9 \cdot d \cdot f_{YD} \cdot A_s \qquad [7\text{-}14]$$

Where:

M_{Rd}	Moment resistance	$[\mathrm{kNm}]$
d	Effective depth of cross-section ($= 0.9 \cdot h$)	$[\mathrm{m}]$
h	Wall thickness	$[\mathrm{m}]$
f_{YD}	Minimum yield strength reinforcement steel	$[\mathrm{kN/m}]$
A_s	Minimum area of reinforcement steel	[m]

Reinforcement steel of the S235 quality is assumed, resulting in a minimum amount of reinforcement; just below $6000\ \mathrm{mm/m}$. This is in accordance with a reinforcement percentage of 1.2%. The same calculation is performed to check whether the walls of the $CD_{19.5}$ design are not too big, resulting in a reinforcement percentage of 1.1%. Both front walls thus have an economic reinforcement. The internal walls of the caisson however are loaded less than the front wall; probably slightly thinner walls inside the caisson are possible. Further research should give the most economical dimensions of these walls.

Due to the hostile environmental conditions (class XS3), a nominal concrete cover of 30 millimetres is applied at all walls. This cover is thick enough to protect the reinforcement steel from chloride attacks, while being thin enough to avoid initial cracks that would permit the ingress of seawater.

7.4 Revetments

The new port will partly consist of land that is reclaimed. The side of this reclaimed land that is facing the bay will be attacked by waves and this will cause erosion. In order to prevent erosion of the reclaimed land, revetments have to be constructed. In this chapter the governing revetments, located on the border of the port with the bay, are discussed. In the port itself there are also revetments required, however they are not discussed in detail. In the method statement in chapter 8 the planning aspects of these revetments will be discussed.

7.4.1 Materials and dimensions

The material that is being used in the revetment has a large influence on its dimensions. As there are granite mines relatively close to Walvis Bay, it's chosen to use granite for the armour layer. The existing breakwater in the port is also constructed with granite. For riprap type of coastal structures the van der Meer formula is used to calculate the required stone diameter and weight. An important input parameter in this formula is the wave height. A one in hundred year wave is selected as the design wave. This wave has an offshore wave height of about 6.5 meter, which results in a significant wave height near the port of up to 1.5 meter. The slope of the revetment is chosen at 1:3, which is a good optimum between stability and the amount of rock required for the structure. Furthermore there is a geotextile present and therefore the notional permeability is expected to be 0.2. Subsequently one can check whether one needs the formula for surging or plunging waves using the next formula:

$$\xi_{cr} = \left[6.2 \cdot P^{0.31} \cdot \sqrt{\tan\alpha}\right]^{\frac{1}{P+0.5}} \qquad [7\text{-}15]$$

Where:

ξ_{cr}	Transition point between surging and plunging waves	$[-]$
P	Notional permeability	$[-]$
α	Slope angle of the revetment	$[-]$

It turns out the value for $\xi_{cr} = 1.72$. The surf similarity parameter, or Iribarren number, is defined as:

$$\xi_m = \frac{\tan\alpha}{\frac{H_s}{L}} \qquad [7\text{-}16]$$

Where:

ξ_m	Surf similarity parameter	$[-]$
H_s	Significant wave height	$[\mathrm{m}]$
L	Wave length	$[\mathrm{m}]$
α	Slope angle of the revetment	$[-]$

The surf similarity parameter is a measure for the steepness of the slope compared to the wave steepness. In this case $\xi_m = 4.1$, this value is larger than the value for $\xi_{cr} = 1.72$, so it concerns surging waves.

Stone diameter and weight

Now that the wave breaking type is known, one can calculate the required stone size. The formula to calculate the required stone size for surging waves is:

$$\frac{H_s}{\Delta \cdot D_{n,50}} = P^{-0.13} \cdot \left(\frac{S}{\sqrt{N}}\right)^{0.2} \cdot \sqrt{\cot\alpha} \cdot \xi_m^P \qquad [7\text{-}17]$$

Where:

Δ	Relative density	$[-]$
$D_{n,50}$	Diameter of the stone in the armour layer	$[\mathrm{m}]$
S	Damage parameter	$[-]$
N	Number of waves for the design event	$[-]$

The relative density of granite has a value of about 1.65. It is assumed the design storm has a duration of half a day and the wave period is 12 seconds. This results in about 4000 waves in the design event. Furthermore a little damage ($S = 4$) is allowed as it's relatively easy to repair some possible damage to the revetment due to the mild wave climate. Using these parameters, one finds a stone diameter of 0.56 meter, which is a stone with a weight of approximately 520 kilograms. For the under layer it is assumed that this layer consists of stones with a diameter which is 2.2 times smaller than the stones in the armour layer. This corresponds to a stone diameter of $D_{n,50} \approx 0.26m$ which has a weight of approximately 25 kilograms. The values for the diameter and weights as presented here are only the theoretical values. In reality it won't be possible to mine stones with exactly the theoretical weight and size. In practice the stones are available in a certain class with a certain range of diameter and weight.

Layer thickness

The thickness of the layers has to be equal to $2 \cdot k_t \cdot D_{n,50}$, in which k_t is the so called layer thickness coefficient. For riprap this coefficient is assumed to be 0.8. The minimum thickness of a layer is 0.5 meter. For the armour layer this results in a thickness of 0.9 meter and for the under layer a thickness of 0.5 meter is required.

Crest freeboard

It's important the revetment is able to protect the hinterland area against the waves. Behind the revetment is a port terminal; overtopping waves can be a threat to this area. Therefore an overtopping criterion is set: the overtopping discharge may not exceed 1 l/s/m. If the overtopping discharge would exceed this value then some damage to buildings might occur. Using the overtopping manual [58] the required crest freeboard is calculated. It turns out the crest freeboard has to be at least 2.6 meter. The highest tidal elevation is +2.0 meter CD. Hence the crest has to be constructed at +4.6 meter CD.

Toe protection

The revetment has to be stabilised near the bed, in order to guarantee the stability of the structure. The toe protection consist of a two stones wide armour layer on top of the under layer. The under layer is extended by a three stones wide section, for more details see Figure 7-23.

7.4.2 Design

In the figure below the governing revetment locations are indicated.

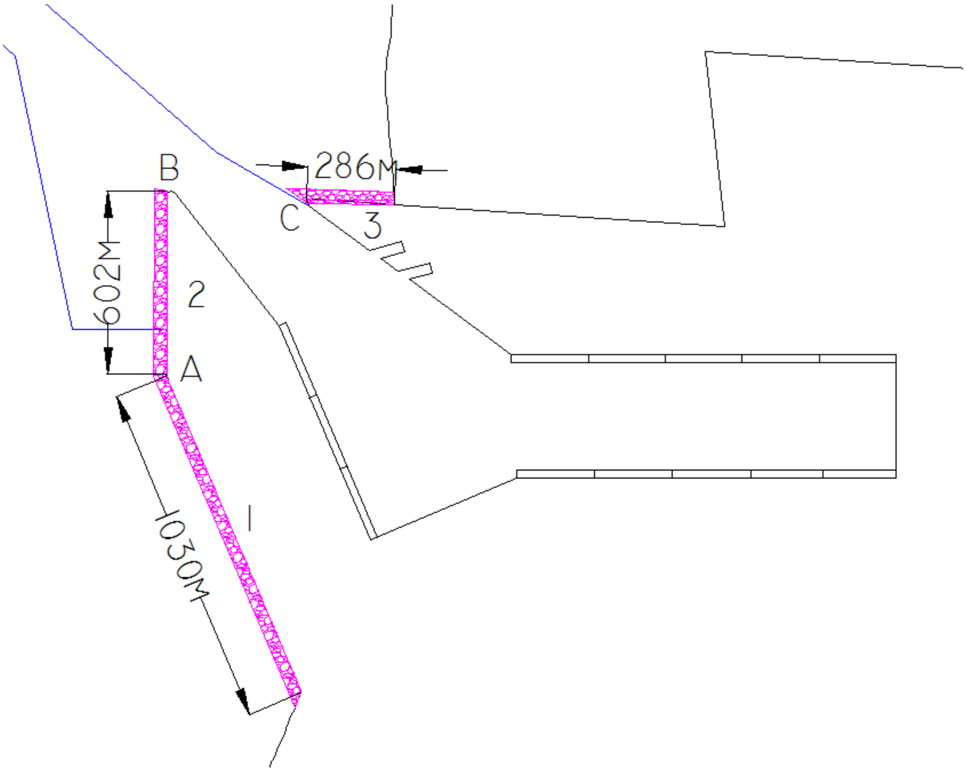

Figure 7-22: Northern project area with the governing revetment locations indicated in pink

The depths in point A, B and C are -6.5, -8.0 and -5.0 meter CD respectively. The depth in this area changes quite gradually so it's assumed that one can interpolate the depths between these points linearly. In the figure below a cross section of the revetment in point A is presented.

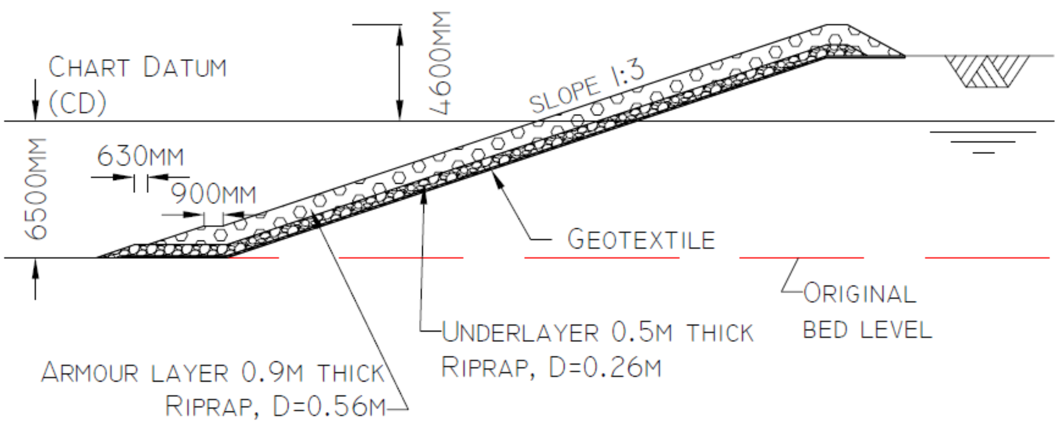

Figure 7-23: Cross section of the revetment at a water depth of -6.5 meter CD

Now that the dimensions are defined, one can calculate the amount of material required for the construction of the revetments. It's assumed that the porosity of the riprap layers is about 40%, thus 60% of the riprap layers is assumed to be granite rock. Furthermore the depth is assumed to vary linearly between the points A, B, C and the coastline. The shape of the revetment does not change along the crest; only the slope length varies with the depth. In the table below the required amounts of material for the three revetment sections are presented.

	Armour layer material [ton]	Under layer material [ton]	Geotextile $[m^2]$
Section 1	26.359	15.370	20.261
Section 2	35.431	20.601	27.086
Section 3	9.195	5.772	7.162
TOTAL	**70.984**	**41.743**	**54.509**

Table 7-8: Material required for different revetment sections

8 Method statement and planning

The execution methods and planning of the project are important factors in the design phase of civil works. Special attention should be paid to the availability of specific equipment, knowledge and skilled labour when evaluating design alternatives. It may be more efficient to choose for less advanced methods rather than hiring knowledge and equipment.

By determining the quantities of major civil works and their execution methods, durations of the different processes are estimated. By arranging the processes in a smart way, the critical path of planning can be optimized. This optimization must be done with respect to both the total duration and risk of delay, as certain activities may high uncertainties in productivity and possible downtime.

The construction works are divided into the following categories:

- Dredging, excavation and reclamation and raising land
- Liquid bulk berthing facility
- Caissons
- Revetment
- Infrastructure works and terminal facilities

For each of these works a separate construction method will be treated in the sections below, resulting in construction times for the separate works. These construction methods will lead to a general project planning, presented in section 8.6.

8.1 Dredging, excavation and reclamation works

The dredging and reclamation activities form a large part of the total construction works for the port expansion. The dredging works are divided into the dredging of the approach channel and the harbour basin. Before dredging of the harbour basin can start the area has to be excavated to mean sea level. Almost half of the dredged soil will be used for reclamation. The dredging, reclamation and disposal is done in phases, because these activities are highly related to the placement of the caissons. In section 8.6.2 these phases are discussed in more detail.

8.1.1 Dredging of the approach channel

The construction of the approach channel is one of the major dredging activities. Below the construction process is explained resulting in a construction time for the approach channel.

Construction method

Construction of the approach channel will be done with a Trailing Suction Hopper Dredger (TSHD). This vessel is capable of dredging up to a large depth and is highly manoeuvrable. Therefore it's suitable to dredge the approach channel. This vessel removes the soil by trailing a suction pipe over the seabed, filling up the hopper inside the ship. Once the hopper is full it has to discharge the load. The dredged material will be disposed offshore. The operating schedule of the TSHD can be interpreted as a cycle. One cycle of the operating TSHD looks as follows:

1. Dredging the sediment and thereby loading of the hopper
2. Sailing to the disposal site
3. Discharging the sediment in the hopper
4. Sailing back to the construction site

Quantities

The channel has a required depth of 16.25m, a length of 4650m and a width of 188m. The total amount of soil that has to be dredged is 6.1 million m^3. A medium sized TSHD is assumed, with a hopper volume of 10,000 m^3. The loading of the hopper takes about one hour. The TSHD sails with a speed of about 5 m/s to the disposal site. The trip to and from the disposal site will take a bit more than half an hour. The discharging of the hopper load does not take a lot of time. The discharging is done by simply opening the bottom doors of the TSHD. The time for one cycle is a bit more than two hours; let's say two hours and fifteen minutes. The TSHD will be operational 24 hours a day, thus it can do $10.6\ \mathrm{cycles/day}$. It's important to mention that there is a probability of running into boulders. Therefore 15% downtime is taken into account. Furthermore an efficiency-rate of 0.5 is assumed. Now one can calculate the production rate which has a value of 53.333 $\mathrm{m}^3/\mathrm{day}$. In the table below the most important quantities are given:

	Dredged volume $[\mathrm{m}^3]$	Efficiency	Production rate $[\mathrm{m}^3/\mathrm{day}]$
TSHD	6.100.000	0.5	53.333

Table 8-1: Most important quantities for dredging the approach channel

Timeframe

Dividing the volume that has to be dredged by the production rate, results in a construction time for the approach channel of 132 days. Important restriction for the TSHD is the five meters of water depth necessary to be able to operate. The shallow part of the approach channel close to the shore has to be, at least partially, dredged by a Cutter Suction Dredger as this device can operate in very shallow water.

8.1.2 Excavation of the harbour basin

Before the harbour basin can be dredged, it has to be excavated up to mean sea level. As this area is located 3m above sea level this activity is quite time consuming. A total of 2.84 million m^3 sand has to be excavated. Excavation is done by loaders and dump trucks. A productivity of 10.000 $\mathrm{m}^3/\mathrm{day}$ is assumed, resulting in a total duration for this event of 284 days. The sand will be re-used to raise the surface level of the terminals in the port.

8.1.3 Dredging of the harbour basin

The harbour basin has to be dredged in three phases, as this is the most efficient way of combining the dredging works and the placing of the caissons. In section 8.6.2 this will be discussed in more detail.

Construction method

Construction of the harbour basin will be done with a Cutter Suction Dredger (CSD). This vessel is capable of dredging in very shallow water and is thus suitable for the dredging works. The CSD has a different way of working than a TSHD. The CSD removes the material and discharges it immediately through a pipeline. This pipeline is a floating pipe which connects the CSD with the reclamation site or the offshore disposal site. In this manner the CDS is slowly working its way into the harbour basin.

Quantities

In total a volume of nearly 19 million m^3 of soil has to be dredged to construct the harbour basin. It's assumed that the CSD has a productivity of 50.000 $\mathrm{m}^3/\mathrm{day}$. 15% downtime has to be taken into account, due to the possible presence of rocky layers. The offshore disposal site, to where the floating pipeline has to be build, is located ten kilometers away from the harbour basin. For the floating pipeline it's assumed that installing it goes with a speed of 500 m/day. In the table below the most important quantities are given:

	Dredged volume $[\mathrm{m}^3]$	Production rate $[\mathrm{m}^3/\mathrm{day}]$
CSD	18.960.000	50.000

Table 8-2: Most important quantities for dredging the harbour basin

Timeframe

Dividing the amount of soil to be dredged by the production rate and correcting it for the downtime gives a total construction time for the harbour basin of 437 days. Installing the pipeline to the offshore disposal site takes 20 days. The dredging of the harbour basin can start at any moment due to the capability of the CSD to operate in very shallow water.

8.1.4 Reclaiming and raising land

A new section of land has to be constructed and the surface level of all the terminals has to be raised from 3 to 5 meters above CD. The sand dredged from the approach channel is not used; reclaiming and raising land next to an area which still has to be dredged, results in a lot of material that has to be dredged twice.

Construction method

The reclamation and raising of land is done using the sand dredged by the CSD. It discharges the dredged sand in a mix with water through a pipeline on to the edge of the reclaimed land. Loaders and other land moving equipment direct the flow of water and sand in such a way as much sand as possible ends up on the reclaimed land. Despite of these efforts part of the sand will wash back into the sea.

Quantities

In total 10 million m^3 of sand is required for reclamation and raising the land. The production rate for reclamation and raising land is lower than the productivity of dredging due to sand washing back into sea. Another factor is higher compacting of sand on dry land than on the seabed. Because of those two factors a productivity of 40.000 $\mathrm{m}^3/\mathrm{day}$ is assumed. The downtime of the dredging equipment due to the probability of presence of rocks has to be taken into account as well.

Timeframe

Dividing the amount of soil required for reclamation by the production rate and correcting it for the downtime gives a total construction time for reclamation and raising land of 288 days.

8.1.5 Levelling the land

When the amount of sand is deposited in the right area, it has to be levelled in order to construct the pavements and other infrastructure works. The total area of all terminals and infrastructure needs to be levelled, in total 2.9 million m^2. It's assumed that one hectare (10.000 m^2) can be levelled per day. The total time required for levelling is 290 days.

8.2 Liquid bulk berthing facility

In this section the construction sequence of the liquid bulk berthing facility is treated. As described in section 7.2 the berthing facility will consist of a jetty.

Construction method

The jetty will be located on the bay side of the reclaimed land in the western part of the expansion. The following construction phases are required for building the jetty and securing the slope underneath the jetty:

1. The land the jetty will be connecting to is reclaimed using dredged sand from the harbour basin as described in the section above.
2. The water in front of the jetty is dredged to the required 13.75 meter depth using a TSHD.
3. Prefab piles supporting the breasting and mooring dolphins and the jetty itself are driven into the soil using equipment on a floating barge.
4. After all the piles are in place the revetment can be placed. The piles protrude above water making it difficult to place the revetment using boats, land based equipment is used.
5. The top structure of the breasting and mooring dolphins is cast in-situ. In-situ is preferred over prefab solutions because of the little space between the driven piles and the problems fitting prefab units in case small inaccuracies occur driving the piles.
6. The top structure of the jetty is prefab the spacing between the piles is much bigger and the piles are not driven inclined, making it easy to fit prefab elements. Placing of the prefab elements is done using land based equipment.
7. Last part of construction is placing the fenders, bollards and all equipment needed to unload the ships like pumps, hoses and fire fighting equipment.

Quantities

The total structure has two breasting and four mooring dolphins, as can be seen in Figure 7-15. Each mooring dolphin has four inclined and four straight supporting piles. The breasting dolphin has eight inclined and six straight piles. The approach bridge of the jetty is 50 meters long and 9 meters wide, the head of the jetty is 15 by 35 meters.

Time frame

Driving the piles is assumed to take eight weeks. Placing the 250 meter of revetment around the jetty will take ten weeks according to the construction rate described in section 8.4. Placing the prefab jetty parts and casting the dolphin heads will take four weeks. Placement of the fenders bollards and unloading equipment takes another four weeks. The total construction time of the jetty adds up to 26 weeks.

8.3 Caissons

The caissons which will form the quays are a very important element in the port. In this section first the construction of the caissons will be discussed. The placing process of the caissons will be discussed in section 8.6.2

Construction method

Construction of the caissons will take place in a floating dry dock. The dry dock will be built by a specialised company which installs in at the north east side of the southern expansion of the harbour. This location is chosen because of the sheltered location from big waves, the free space available close to infrastructure and the access to the deep water of the approach channel. The floating dock must be secured with anchors or sliding poles and a ramp should give excess to the floating dock. Side preparation and installation of the dry dock is assumed to take four weeks. Further detailing of construction and transport of the dry dock falls outside the scope of this report.

When the dry dock is ready for use the building the caissons can start. The different construction phases are:

1. First a permeable layer is installed on the floor, to make sure the caissons will float when the dock is flooded.
2. Installation of plywood for the bottom slab of the caisson. The horizontal plywood can be placed on top of the permeable layer; the vertical plywood has to be supported by struts to resist the forces of the poured concrete. One side of the formwork has to be installed after phase 3 to allow access to the worksite.
3. Installing and fixating the rebar for the bottom slab and the strands for the reinforcement for the walls. The caissons are placed in a hostile environment, thus special attention should be paid to the concrete cover. A nominal cover of 30 millimeters is used in the design, and should be checked during construction.
4. Pouring of the bottom slab, the whole slab will be cast at ones. This can only start after the concrete mix passes a quality check. Attention should be paid to the dropping height of the concrete, if the drop is too large segregation of the mix might occur. The concrete has to be compacted with vibrators in order to remove air bubbles inside the concrete. After the pouring the concrete has to harden for two days before considered strong enough to start constructing the walls.
5. The walls of the caissons are 19.5 and 23.25 m high; these heights can’t be poured in a single pour using regular formwork. There are different methods to pour walls of these heights. The first method is slip forming; a continuous casting method, the formwork slowly climbs while the concrete is hardening. The second method is casting the walls in different phases using climbing formwork. The first method needs more expensive equipment, the second method is more labour intensive. With the relative low labour costs in Namibia casting multiple times using climbing formwork is most economical. Special attention has to be given to the connection of concrete layers between different pouring stages. The cycle for casting the walls is the same every time, big advantage of this repetition is an increase of productivity; everybody knows what has to be done and how. The cycle for the casting of the walls is as follows: installing the formwork, placing the prefab reinforcement

meshes, casting and compacting of the concrete, wait two days for the concrete to harden, removing the formwork, clean and reuse them for the next cycle.

6. After the walls are casted temporary bollards have to be installed to make it possible to tow the caissons out of the dry dock. The temporary bollards will be bolted on threaded rebar sticking out of the walls. The bollards will be placed at the points where an inner wall connects to the outer wall; these are the strongest points of the caisson.
7. After al equipment is removed and all personnel have left, the dry dock can be flooded and the caisson can be towed out.
8. The last step is closing the dry dock and pump out all the water. The cycle is repeated 21 times to finish the construction of one caisson.

Quantities

For the calculation of the construction time an approach with indicating quantities is used. The key quantities used for the construction of the caissons are amount of rebar, concrete volume of floors and walls and area of formwork. The amount the reinforcement needed at the highest loaded point is 1.2%, see section 7.3.5, an average percentage of 0.5% is assumed for the caisson in total. This implies the use of small diameter rebar to make sure the spacing is not too big, to prevent cracking of the concrete. The table below shows the required quantities per caisson for the different caisson designs.

	Caisson $CD_{15.75}$	Caisson $CD_{19.5}$
Number constructed	16	5
Volume floor [m^3]	1.800	2.400
Volume walls [m^3]	11.200	17.200
Area of formwork [m^2]	47.200	71.700
Rebar [ton]	508	765

Table 8-3: Required quantities per caisson design

Timeframe

To estimate the construction time of the caissons the quantities found in the previous section are translated into working hours using indicators. Dividing the working hours by the number of working hours in a day and the number of workers gives the number of days needed for construction. Assumed are two shifts per day, resulting in 16 working hours a day. Per shift on average 50 people are working. The table below gives the required number of working hours and days per caisson.

	Productivity	Caisson $CD_{15.75}$	Caisson $CD_{19.5}$
Volume floor	0.1 [hour/m^3]	180	240
Volume walls	0.2 [hour/m^3]	2.240	3.440
Area of formwork	0.5 [hour/m^2]	23.600	35.850
Rebar	10 [hour/ton]	5.080	7.650
TOTAL [hours]	-	31.100	47.180
TOTAL [days]	-	39	59

Table 8-4: Required working per caisson

Downtime is not yet taken into account. Assumed is a downtime of 10% for both first caissons of each design, and 5% for the rest of the caissons. The first caissons will encounter more downtime because all the challenges are new and solutions have to be found, much of these challenges can be avoided or dealt with faster during the construction of the following caissons. Between the constructions of the caissons three days are reserved for cleaning up, towing out the caisson and preparation for the new build. Assuming a work week of 6 days this results in a construction time of 55 weeks for the $CD_{19.5}$ caissons and 118 weeks for the $CD_{15.75}$ caissons.

8.4 Revetment

A distinction is made between the revetments facing the bay called outer revetments and those located within the port called inner revetments. Figure 8-1 gives more information about the locations of the revetments. Revetments 1 to 3 are outer revetments and 4 to 7 are inner revetments.

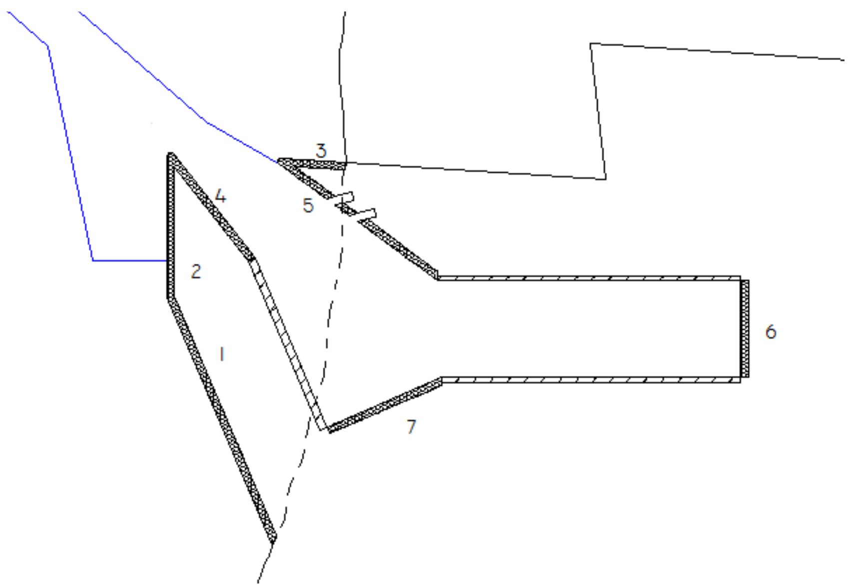

Figure 8-1: Location of the revetments

Construction method

The construction method is the same for both the inner and outer revetments. Only the dimensions of the placed materials are different because of the different loading conditions. The construction of the revetment consists of the following activities:

1. Preparing the site
2. Placing the geotextile
3. Placing the under layer
4. Placing the armour layer

Quantities

For the outer revetment the amounts of stone and geotextile required is calculated in section 7.4.2, and presented in Table 7-8. For the inner revetment the key indicator is meters revetment needed. This distinction is made because the cross sections of all the inner revetments are uniform; there are no differences in depth as is the case with outer revetment.

	Length
Section 4	600
Section 5	865
Section 6	400
Section 7	520
TOTAL	**2.385**

Table 8-5: Lengths of the inner revetments [m]

No distinction is made in the placing of the under and armour layer as they are both from granite rock and have the same placing speed, only the size of the rocks is different. It's assumed that the rock placing can be done with a speed of 500 $\mathrm{m^3/day}$. With a density of 2.65 $\mathrm{ton/m^3}$ and a porosity of 0.4 this results in a placing rate of 315 $\mathrm{ton/day}$. Placing will be done using land-based equipment. The table below shows all the placing speeds assumed:

	Preparing site [m/day]	Placing geotextile [m/day]	Placing riprap [tons/day]	Placing inner revetment [m/day]
Revetment	20	30	315	5

Table 8-6: Assumptions in order to calculate the construction times of the outer revetments

Timeframe

Dividing the amounts needed by the productivity per day results in the days needed to build the revetment. The different sections of revetment are not necessarily built directly after each other. Building revetments is highly depending on dredging and land reclaiming activities. For this reason there is not one total construction time for the revetments as a whole but only for the different sections, these are shown in the table below.

	Construction time
Section 1	133
Section 2	178
Section 3	48
Section 4	120
Section 5	173
Section 6	80
Section 7	104

Table 8-7: Construction time of the different revetment sections [days]

8.5 Infrastructure works and terminal facilities

The infrastructure works and the facilities at the terminal are discussed in this section.

Construction method

A rail, - and roadway are required to transport the cargo from and to the terminals. Both the rail, - and roadway have to connect to the existing network. The road already running through the project side has to be repositioned in order to make place for the port facilities. Construction of the rail, - and roadway start at the connecting point with the existing infrastructure and will work its way into the harbour. Advantage is the machinery and materials needed for construction can use the new build infrastructure. After building the main infrastructure connecting the terminals construction can start on the pavement inside of the terminals. In all terminals except for the rough bulk terminal pavement is installed.

Quantities

The design of the infrastructure is described in section 7.1.3. A short summation of the infrastructure needed is given in the table below.

	Amount
Rail inside port [m]	7.440
Rail outside port [m]	7.000
Road inside port [m]	4.260
Road outside port [m]	9.850
Pavement	
- Container [m^2]	249.100
- Chemical bulk [m^2]	215.600
- General cargo [m^2]	190.400
- Liquid bulk [m^2]	76.000

Table 8-8: Quantities for the required infrastructure works

Timeframe

Both rail, - and roadway have different construction speeds for the different parts of the track. For instance parts of the railway with a lot of railway switches will take more time per meter then straight parts of track. The average construction speed is assumed to be 50 meter per day for railway and 100 meter per day for road.

The pavement of all terminals is assumed to have an average building speed of 50 by 50 meters per day. These production speeds result in the days needed listed in the table below

	Construction time
Rail inside port	149
Rail outside port	140
Road inside port	43
Road outside port	99
Pavement	
- Container	100
- Chemical bulk	87
- General cargo	77
- Liquid bulk	31

Table 8-9: Construction times for infrastructure works [days]

8.5.1 Quay facilities

The (un)loading facilities at the quays are also part of the infrastructure works. The facilities of the liquid bulk terminal are discussed in more detail in section 7.2. For the other terminals the facilities at the quay are discussed below.

Container

For the container berths, three cranes per berth have to be installed. It's assumed that it takes two months to install one crane. As there are three berths, it takes 18 months in total to install these cranes. The cranes can be installed simultaneously per berth, thus 6 months are required per berth to install the cranes.

Rough bulk

For the rough bulk there are four offloading facilities and three loading facilities required. This means two berths are both suitable for loading and offloading the vessels. Offloading is done with grab cranes and loading is done with conveyor belts. It's assumed that installing the conveyor belt takes 30 days and installing the grab cranes takes 60 days.

Chemical bulk

At the chemical bulk terminal pneumatic systems are required. It's assumed that installing them takes 45 days and they can be installed simultaneously at the three berths.

General cargo and Ro-Ro

Ro-Ro does not require specific systems; the boats can unload using the ramp of the ship because of the small tidal difference. The general cargo berths each have three cranes, making a total of six cranes needed. Construction is assumed to take one month per crane, resulting in a construction period of 3 months, on the different berths simultaneous construction is possible.

8.6 Planning

In the previous sections the different construction activities were discussed. In this section the relation between those activities and the planning of the whole project is elaborated.

8.6.1 General construction planning

In the figure below the general construction planning is presented. Planning of the separate parts is discussed in the coming sections. The construction activities start at the beginning of 2019 and they are planned to be finished in the end of 2024.

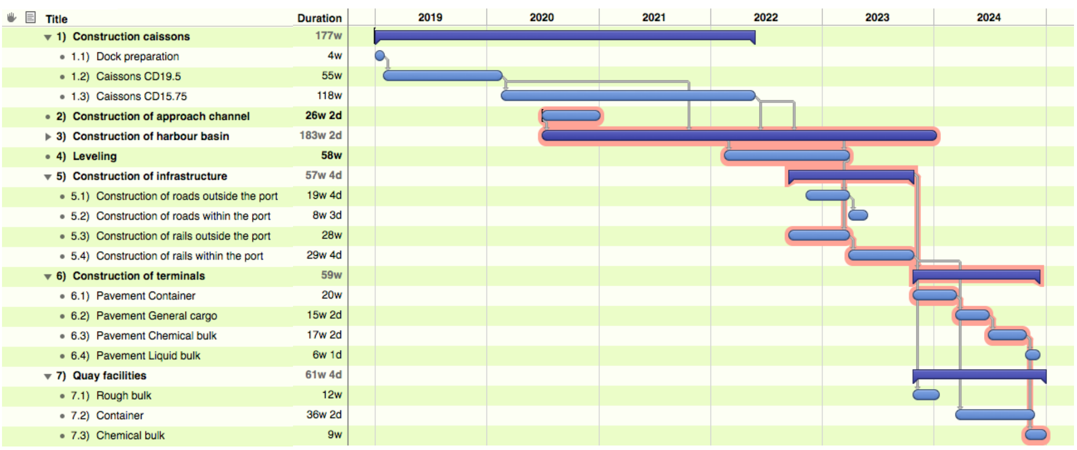

Figure 8-2: Global project planning

A critical timing in the project is building the caissons and dredging the location the caissons are placed. If the caissons are not ready in time sediment transport will make new dredging of the site necessary. This causes a huge loss of time and money. For this reason construction of the caissons is the first activity to begin, in 2019. Caissons ready will be stored in the bay, waiting to get placed.

Dredging of the harbour basin and thereby land reclamation starts halfway 2020 in order to finish dredging at the same time as building the caissons. The construction of the harbour basin is discussed in detail in the section below. When the reclamation is in an advanced state, the levelling of the area starts. When the levelling is ready, the construction of the infrastructure can start. When the road- and railway connections are finished, the construction of the terminals and the quay facilities can start. These activities are the final stage of the construction of the expansion.

8.6.2 Construction of the harbour basin

Construction of the harbour basin is divided into four steps. The steps are numbered in Figure 8-3. The different steps are built up from nearly the same construction activities each time. Main construction activities are the dry excavation, dredging, reclamation, soil improvements for the caissons, caisson placement and revetment construction.

Figure 8-3: Phases in the construction of the harbour basin

The sequence of phases is:

Step 1:

1. Dry excavation of the harbour basin.
2. Dredging the first part of the harbour basin to a depth of -15.75m CD.
3. Reclamation of the first section of land.
4. Construction of revetment section 3.
5. Construction of revetment section 1.
6. Construction of revetment section 5.
7. Deepening of the area where the caissons have to be placed for the chemical bulk terminal up to -21.5m CD and constructing the soil improvements.

Step 2:

8. Sinking and filling the caissons of the chemical bulk terminal.
9. Dredging the second part of the harbour basin to a depth of -10m CD.
10. Reclamation of the area of the chemical bulk terminal and raising the surface level for the other terminals.
11. Driving the piles for the liquid bulk jetty, jetty phase 1.
12. Construction of revetment section 2.
13. Construction of revetment section 4.
14. Construction of revetment section 7.
15. Construction of the top structure of the jetty, jetty phase 2.

Step 3:

16. Deepening of the area where the caissons have to be placed for the rough bulk terminal up to -17.5m CD and constructing the soil improvements.
17. Sinking and filling the caissons of the rough bulk terminal.

Step 4:

18. Deepening of the area where the caissons have to be placed for the general cargo and container terminal up to -17.5m CD and constructing the soil improvements.
19. Sinking and filling the caissons of the general cargo and container terminal.
20. Dredging the second part of the harbour basin to a depth of -15.75m CD.
21. Raising the surface level with the dredged material.
22. Construction of revetment section 6.

A lot of activities can only start when other activities are finished. These relations and the time all activities take are shown in Figure 8-4.

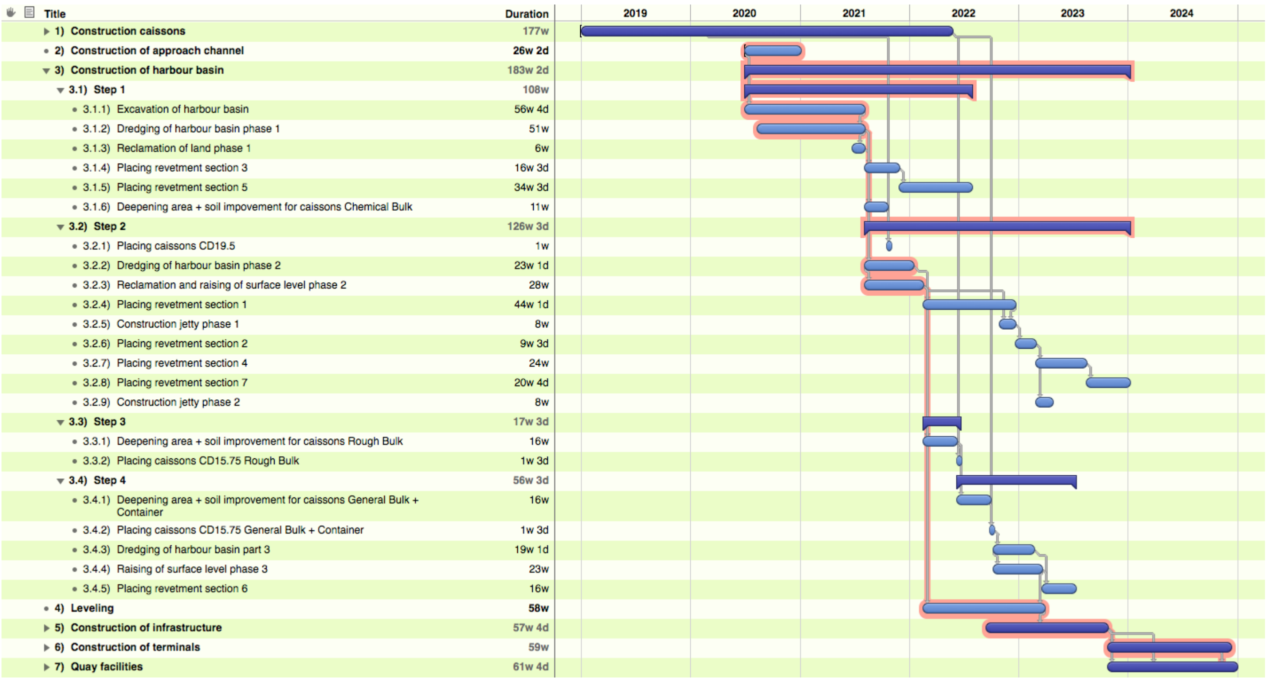

Figure 8-4 Project planning including the construction of the harbour basin

8.6.3 Critical path

The critical path is highlighted in red in the Figure 8-2. If an activity which is part of the critical path takes longer than expected, then the whole project will take longer than expected. Therefore it’s important to identify the critical path and indicate the possible risks. In the planning it’s chosen to start constructing the caissons well before they can be placed. In this way the construction of the caissons is not part of the critical path and thereby the risk of delays is smaller. Below the activities that are part of the critical path and their risks are discussed.

Harbour basin

The first two critical activities are the excavation and dredging of the harbour basin. Dredging takes less time than excavation and can only start in the areas excavation took place. Dredging is however a quite risky activity. Downtime due to rocky layers is taken into account, but the downtime can increase if there are unexpected layers of rock for example. Also the material can cause downtime as dredge pumps and suction heads can break and repairing them can be time consuming.

Two other critical activities are the dredging and reclamation of phase 2. Reclamation is maybe even more risky than dredging from a planning point of view. This is because there are some requirements to the soil that is used for reclamation or to raise the surface level. If the dredged soil does not meet these requirements it will most likely result in downtime.

Levelling

The levelling of the land can have downtime due to several causes such as failing equipment and weather conditions. Levelling the land is relatively straightforward so therefore not much downtime is expected.

Infrastructure
Construction of the railway and roads inside the port can only begin after levelling of the port is completed and the outside railways and roads are ready. Planning is to finish both levelling and construction of the outside railways and roads at the same time. Downtime can be caused by a delay in supply of materials, for example. Also soil conditions can cause downtime. But overall the risks are not too high compared to other construction activities.

Construction of terminals
Construction of the pavements can only start if the infrastructure to the terminals is finished. Thereby the construction of the pavement is part of the critical path. Downtime can be caused by insufficient levelling for example. Also bad weather can have a negative effect.

Quay facilities
The facilities installed at the quay are in general specialised structures and that may introduce a higher risk of downtime. Only the chemical bulk facilities are part of the critical path. This is the last activity to be done in the project so other terminals will not be affected by any downtime at this activity.

9 Conclusions and recommendations

After analysing the Port of Walvis Bay and assessing its potential, a long-term development strategy and accompanying general expansion designs were presented. During this process certain conclusions were drawn, on basis of which recommendations are made.

9.1 Conclusions

The following main conclusions were drawn during the process:

- The current demand for services is reaching the capacity of the Port of Walvis Bay, putting a lot of pressure on its terminals. As a reaction to the changing demand for capacity on the short-term, vacant patches of land are used to extend terminals that are highly stressed. This has resulted in a fragmented layout of the terminals, which reduces the productivity of the port as a whole.
- The port does not suffer from excessive delays, other than competitive ports in the region. Together with its strategic location at the west-coast of Africa, this lack of congestion has made Walvis Bay an attractive alternative for transhipment activities. As a result, the transhipment volumes have risen unproportionally to the economic development of the port's commercial market. The planned container terminal on the reclaimed peninsula at the southern end of the port will strengthen this position as major transhipment hub in the future.
- The mineral resource export projects, predominantly the coal from Botswana, can be decisive in the feasibility of future development projects of the port. The likelihood of attracting these export volumes can however not be determined with much accuracy.
- Based on the economic development of the port's commercial market, the potential of resource export projects and the port's attractiveness as transhipment hub, the likelihood of reaching the limits of handling capacity on long-term is very high.
- The available geotechnical data is not sufficiently accurate to be able to evaluate general designs for civil works and assessing the associated costs. Extrapolation of old data was used to estimate the depth and properties of soil layers.
- Construction and operation of port expansions may negatively affect the fragile ecosystems of the bay, the lagoon and the sand dunes surrounding the project area. This may result in a deterioration of the tourism sector, which is an important social-economic factor for the city of Walvis Bay.
- The port has difficulties in attracting investors for their expansion activities, as a result of the low degree of confidence in the global economy. This reluctance of investors may be expected to persist within the near-future.

9.2 Recommendations

On the basis of the presented conclusions, the following actions are recommended:

- Consecutive expansion phases, after completion of the container terminal, are required to be able to utilize the port's full potential on the long-term. It is recommended to continue investigating long-term development strategies.
- Expansions should have an integrated character with respect to the current port, in order to decrease fragmentation of terminals. The overall productivity of the port will benefit from an integrated approach.
- As the estimates for future service demands have a high degree of uncertainty, the focus of expansion projects should be on flexibility and expandability. Each expansion phase should be financially feasible for the lower limit of the service demand projection, while being able to relatively easily expand towards a design that can accommodate the upper limit. On the long-term, this can be achieved by taking consecutive expansion phases into account in the conceptual design phase. Infrastructure and terminals should be arranged in a way that relocation is minimized during upgrades. On the short-term, critical terminals should be able to be relocated and expanded without inducing excessive fragmentation to the port.
- Establish more accurate geotechnical data. The investment for acquiring the geotechnical data is dwarfed by the financial benefits that can be achieved by engineering smart solutions using the data.
- Thoroughly investigate the morphological effects of the shape and size of the southern peninsula on the lagoon. In the drafted expansion alternatives, it is assumed that the peninsula may not become any wider as this would disturb the flow from and towards the protected wetlands. Furthermore, dredging operations near the entrance of the lagoon are expected to induce silt up. Both effects could have devastating effects to its fragile ecosystem. By exactly determining the conditions for which these effects occur, smart designs and execution methods can be engineered to deal with the problem rather than avoiding it by shifting the focus to the northern expansion site. Widening the peninsula would be a cost-efficient way of increasing the port's footprint.
- Establish more accurate estimations of the required investments for both expansion alternatives, and use these as input for the decision tree as presented in section 6.1.4. Furthermore, assess the likelihoods of events with greater accuracy by involving major resource exporters, like Botswana, in the expansion plans.
- Involve all stakeholders in the conceptual design phase of port expansions. Namport will have less control over the process, however in the end this leads to an expansion strategy that is broadly supported, increasing the probability of actually being implemented. As the stakeholders with the highest influence all share the same interest, creating a profit, the financial aspect will be decisive in the decision making process.

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A list of books, papers, reports and websites used as a reference is presented per chapter. Work that is used throughout the report is listed separately.

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Appendices

A. Chapter 3: Economic analysis

A.1 Containers

A.1.1 Historical data

	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12
Import	13.338	16.814	18.230	19.665	21.312	23.720	26.295	35.669	47.550	46.746	51.721	59.282
Export	11.974	14.208	18.528	17.625	20.585	22.766	26.728	29.892	48.547	44.879	41.734	45.097
Transshipped	456	547	1.057	13.073	29.559	36.777	91.970	105.025	154.165	156.118	126.723	197.583
TOTAL	**25.768**	**31.569**	**37.815**	**50.363**	**71.456**	**83.263**	**144.993**	**170.586**	**250.262**	**247.743**	**220.178**	**301.962**

Table A-1: Walvis Bay historical container throughput [TEU]

	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09
Import	398	214	243	565	2.029	4.177	8.270	7.687	19.043
Export	3.156	3.113	3.212	3.730	5.502	7.296	9.898	9.042	20.204
Transshipped	3.554	3.327	3.455	4.295	7.531	11.473	18.168	16.729	39.247
TOTAL	**7.108**	**6.654**	**6.910**	**8.590**	**15.062**	**22.946**	**36.336**	**33.458**	**78.494**
% of total throughput	27.6%	21.1%	18.3%	17.1%	21.1%	27.6%	25.1%	19.6%	31.4%

Table A-2: Reefer throughput [TEU]

	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09
Import	3.292	5.036	5.149	4.572	6.098	6.278	7.416	15.539	24.984
Export	5.213	5.536	6.208	10.437	8.967	9.260	12.613	23.909	37.924
TOTAL	**8.505**	**10.572**	**11.357**	**15.009**	**15.065**	**15.538**	**20.029**	**39.448**	**62.908**
Import %	24.7%	30.0%	28.2%	23.2%	28.6%	26.5%	28.2%	43.6%	52.5%
Export %	43.5%	39.0%	33.5%	59.2%	43.6%	40.7%	47.2%	80.0%	78.1%
TOTAL %	**33.0%**	**33.5%**	**30.0%**	**29.8%**	**21.1%**	**18.7%**	**13.8%**	**23.1%**	**25.1%**

Table A-3: Empties [TEU]

A.1.2 Projections

	2012	2013	2014	2015	2016 [4]	2017	2018	2019 [5]	2020	2025 [6]	2030	2035	2040	2045	2050
	LOW GROWTH SCENARIO [1a] – [TEU]														
Import	59.543	59.819	60.106	60.385	65.980	86.807	104.228	115.258	122.878	130.403	149.575	160.928	165.404	166.162	166.543
Export	45.266	45.444	45.629	45.810	49.396	62.382	72.885	79.398	83.842	88.191	99.108	105.472	107.963	108.384	108.595
Ratio T/IE [2]	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.0	3.2	3.4	3.6	3.8	4.0
Transhipment [3]	209.617	221.054	232.617	244.247	276.903	372.974	460.496	525.572	578.815	655.782	795.786	905.761	984.122	1.043.275	1.100.549
TOTAL LOW	**314.426**	**326.317**	**338.352**	**350.442**	**392.279**	**522.164**	**637.610**	**720.228**	**785.534**	**874.376**	**1.044.469**	**1.172.162**	**1.257.489**	**1.317.821**	**1.375.687**
	MEDIUM GROWTH SCENARIO [1b] – [TEU]														
Import	59.670	60.081	60.508	60.925	68.579	96.265	117.987	133.308	140.741	140.837	172.617	192.403	200.395	201.758	202.444
Export	45.348	45.614	45.890	46.160	51.057	68.165	81.071	89.960	94.217	94.272	112.121	122.984	127.324	128.062	128.432
Ratio T/IE [2]	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.0	3.2	3.4	3.6	3.8	4.0
Transhipment [3]	210.035	221.959	234.076	246.295	287.126	411.076	517.553	602.824	657.884	705.325	911.161	1.072.317	1.179.786	1.253.317	1.323.505
TOTAL MEDIUM	**315.053**	**327.654**	**340.473**	**353.380**	**406.762**	**575.506**	**716.612**	**826.092**	**892.842**	**940.434**	**1.195.898**	**1.387.704**	**1.507.504**	**1.583.137**	**1.654.381**
	HIGH GROWTH SCENARIO [1c] – [TEU]														
Import	59.794	60.338	60.904	61.458	70.607	100.979	120.761	136.871	144.417	144.547	189.037	222.061	238.533	242.839	243.927
Export	45.429	45.782	46.148	46.506	52.353	71.050	82.771	92.108	96.425	96.499	121.336	139.210	147.978	150.255	150.829
Ratio T/IE [2]	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.0	3.2	3.4	3.6	3.8	4.0
Transhipment [3]	210.446	222.850	235.513	248.318	295.103	430.074	529.183	618.243	674.359	723.136	993.196	1.228.322	1.391.440	1.493.755	1.579.027
TOTAL HIGH	**315.668**	**328.970**	**342.564**	**356.282**	**418.063**	**602.104**	**732.714**	**847.222**	**915.202**	**964.182**	**1.303.569**	**1.589.593**	**1.777.951**	**1.886.849**	**1.973.783**

Table A-4: Projections container throughput for different scenarios

[1] The import and export volumes are adjusted to GDP growth. Historical data is used to determine the ratio between GDP growth and container throughput growth. The average number over the last ten years is used as a prediction towards 2050.
  a. Low growth scenario: import 4%. export 5%
  b. Medium growth scenario: import 7%. export 6%
  c. High growth scenario: import 9%. export 8%

[2] T/IE: ratio between number of transhipped containers and imported + exported containers. Namport has the ambition to become one of the largest hubports in southern Africa. By 2050 transhipment is ought to be 80% of the port's total throughput. The number is currently around 67% and is assumed to increase linearly to 80% in 2050.

[3] Transhipment volumes are calculated by multiplying T/IE ratio by projected import and export volumes.

[4] 2016: Southern container terminal expansion project operational.

[5] 2019: Total container throughput reaches port's capacity including the new southern port expansion.

[6] 2025: Northern port expansion operative

A.2 Cargo

A.2.1 Historical data

	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11
	RO-RO CARGO [FT]							
Vehicles	36.898	29.306	87.571	131.305	224.924	332.115	302.261	214.651
TOTAL RO-RO	**36.898**	**29.306**	**87.571**	**131.305**	**224.924**	**332.115**	**302.261**	**214.651**
	GENERAL CARGO [FT]							
Foodstuffs	1.009	286	0	448	1	0	0	0
Fertilizer (Guano)	1.900	1.229	1.518	990	1.012	1.034	1.210	1.342
Wine/beverages	40.670	40.827	37.214	16.845	11.905	7.480	7.348	1.738
Skins and hides	5.613	4.729	5.962	4.840	1.914	5.500	5.170	4.994
Flat cartons	17.914	11.367	6.792	6.343	3.007	19.304	18.635	19.904
Lubricating oil	1.625	264	242	286	22	506	1.188	3.972
Salt bagged	114.230	122.528	99.423	111.495	121.469	139.060	137.238	134.864
Charcoal	8.521	12.827	15.664	22.286	34.056	42.658	53.768	37.536
Cement	220	18.120	36.066	104.694	162.024	104.782	71.816	123.070
Other	457.983	601.453	744.580	1.187.100	1.375.266	1.744.870	1.718.980	1.616.050
TOTAL GENERAL	**649.685**	**813.629**	**947.461**	**1.455.327**	**1.710.676**	**2.065.194**	**2.015.353**	**1.943.470**
	DRY BULK [FT]							
Coal	55.493	30.495	98.260	117.252	113.178	118.316	64.421	135.934
Sugar	36.543	35.086	56.928	59.835	58.515	92.495	85.689	115.601
Wheat	42.463	37.398	45.911	47.083	30.344	37.900	35.460	50.554
Manganese ore	19.945	70.240	22.116	55.182	63.913	105.040	100.351	105.108
Copper/lead	48.020	59.348	44.225	88.011	79.670	159.689	244.069	259.750
Marble and granite	24.039	18.718	30.773	38.992	41.742	17.709	25.735	31.300
Fluorspar	93.994	106.926	117.337	128.624	111.746	93.351	112.206	98.878
Malt	21.910	25.058	22.241	31.702	29.876	35.134	35.410	35.376
Salt bulk	568.908	529.293	472.526	506.034	563.936	547.576	460.429	570.694
TOTAL DRY	**911.316**	**912.562**	**910.317**	**1.072.715**	**1.092.921**	**1.207.210**	**1.163.769**	**1.403.195**
	LIQUID BULK [FT]							
Petroleum	682.281	791.300	815.687	735.956	756.108	899.618	883.760	979.548
Sulphuric acid	220.954	206.520	177.512	290.047	381.839	264.428	245.328	344.545
TOTAL LIQUID	**903.235**	**997.819**	**993.199**	**1.026.003**	**1.137.946**	**1.164.047**	**1.129.088**	**1.324.094**
	OTHER [FT]							
Fish products	262.313	278.614	269.444	277.781	226.269	269.486	290.699	305.027
TOTAL OTHER	**262.313**	**278.614**	**269.444**	**277.781**	**226.269**	**269.486**	**290.699**	**305.027**
	TOTAL CARGO [FT]							
TOTAL CARGO	**2.763.446**	**3.031.929**	**3.207.991**	**3.963.131**	**4.392.736**	**5.038.052**	**4.901.170**	**5.190.437**

Table A-5: Walvis Bay historical cargo throughput [FT]

A.2.2 Projections

	2011	2012	2013	2014	2015	2016 [3]	2017	2018	2019 [4]	2020	2025 [5]	2030	2035	2040	2045	2050
	LOW GROWTH SCENARIO [1a] – [1000 FT]															
Ro-Ro	252	260	270	280	290	310	339	370	403	425	489	825	1.091	1.212	1.300	1.346
General [2]	2.182	2.193	2.205	2.218	2.230	2.254	2.285	2.316	2.348	2.367	2.419	2.626	2.743	2.788	2.818	2.834
Dry bulk	1.425	1.448	1.473	1.499	1.524	1.575	1.642	1.712	1.785	1.830	1.956	2.514	2.873	3.021	3.124	3.176
Liquid bulk	1.345	1.354	1.363	1.373	1.383	1.401	1.425	1.450	1.475	1.490	1.532	1.698	1.794	1.831	1.856	1.869
Other	313	315	317	318	320	324	329	333	338	341	349	380	398	405	409	411
TOTAL LOW	5.516	5.570	5.628	5.688	5.747	5.864	6.019	6.181	6.349	6.453	6.745	8.043	8.899	9.257	9.507	9.637
	MEDIUM GROWTH SCENARIO [1b] – [1000 FT]															
Ro-Ro	258	268	279	290	302	327	383	440	486	506	516	1.016	1.454	1.705	1.921	1.999
General [2]	2.213	2.227	2.241	2.255	2.270	2.297	2.355	2.408	2.445	2.461	2.468	2.745	2.903	2.977	3.033	3.052
Dry bulk	1.433	1.460	1.489	1.519	1.549	1.607	1.736	1.857	1.948	1.986	2.005	2.780	3.305	3.569	3.780	3.854
Liquid bulk	1.348	1.358	1.369	1.381	1.392	1.413	1.459	1.500	1.530	1.542	1.548	1.771	1.901	1.962	2.009	2.025
Other	314	316	318	321	323	327	336	343	349	351	352	394	418	429	438	441
TOTAL MED	5.567	5.629	5.696	5.766	5.835	5.972	6.269	6.548	6.758	6.846	6.890	8.705	9.981	10.642	11.182	11.371
	HIGH GROWTH SCENARIO [1c] – [1000 FT]															
Ro-Ro	263	275	288	301	315	336	411	470	525	537	549	1.224	1.912	2.285	2.612	2.731
General [2]	2.245	2.260	2.276	2.293	2.310	2.333	2.408	2.459	2.503	2.512	2.521	2.860	3.068	3.155	3.222	3.245
Dry bulk	1.441	1.472	1.505	1.539	1.573	1.624	1.790	1.911	2.017	2.039	2.062	3.048	3.787	4.130	4.408	4.505
Liquid bulk	1.351	1.363	1.375	1.388	1.401	1.419	1.478	1.518	1.552	1.559	1.566	1.840	2.012	2.086	2.142	2.162
Other	316	318	320	323	325	329	340	347	354	355	357	408	439	452	462	466
TOTAL HIGH	5.617	5.688	5.764	5.844	5.924	6.041	6.427	6.705	6.952	7.003	7.054	9.380	11.218	12.108	12.847	13.109

Table A-6: Projections cargo throughput for different scenarios

[1] The import and export volumes are adjusted to GDP growth. Historical data is used to determine the ratio between GDP growth and container throughput growth. The average number over the last ten years is used as a prediction towards 2050.
   a. Low growth scenario: 0.5 * high growth scenario
   b. Medium growth scenario: 0.75 * high growth scenario
   c. High growth scenario: linear relation between historical growth in cargo throughput and GDP growth.

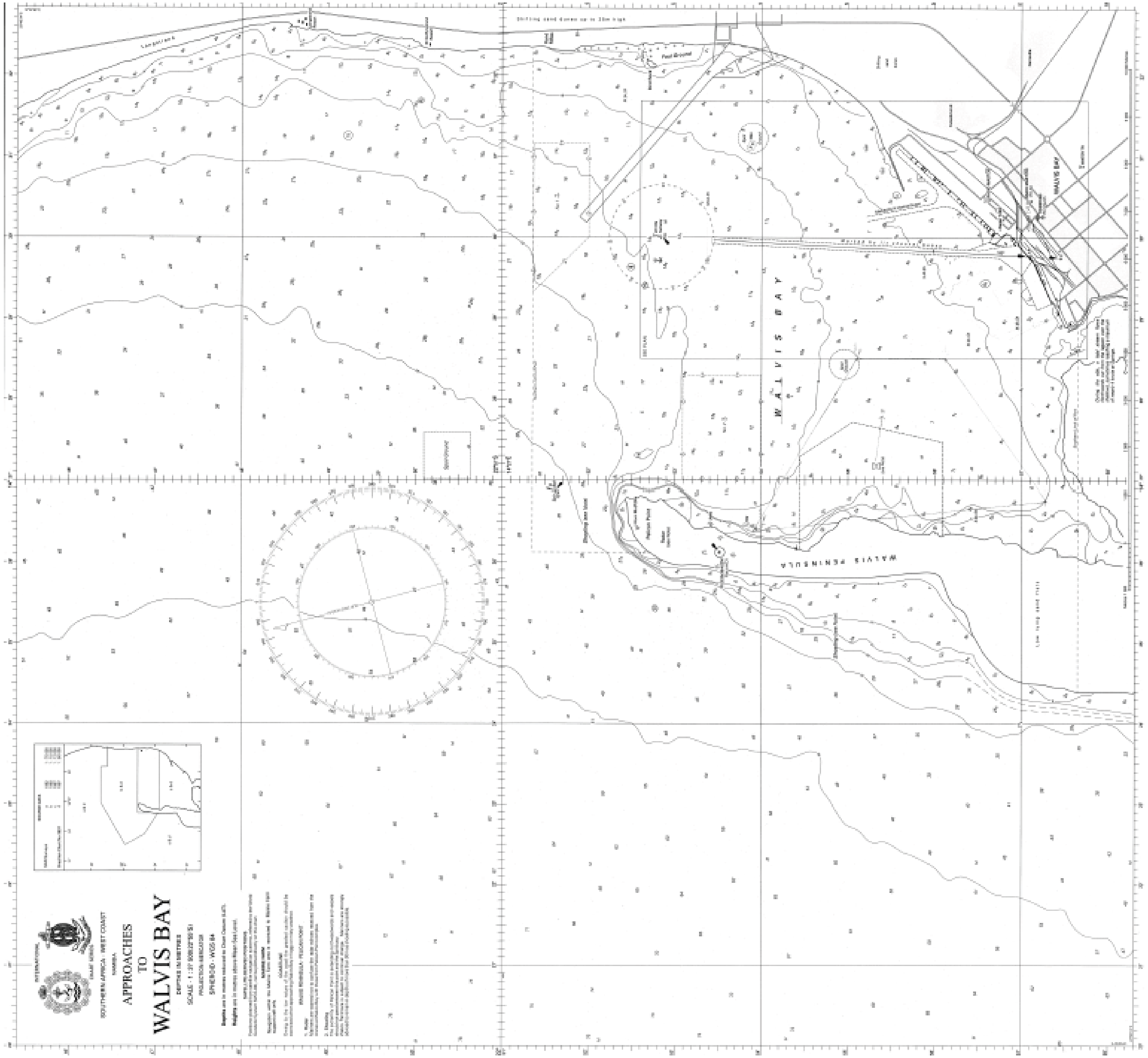
[2] General cargo (GC) throughput growth is assumed to decrease in the future. This is a worldwide trend that hits the African ports later than Western European or Asian ports. Moreover. if the southern container terminal expansion is finished the container throughput will increase. This decreases the GC growth because some GC commodities will be stored in containers.

[3] 2016: Southern container terminal expansion project operational. The cargo throughput also ‘feels’ the completion of the southern container terminal expansion in 2016, because container handling will move completely to this new terminal clearing new area for cargo handling.

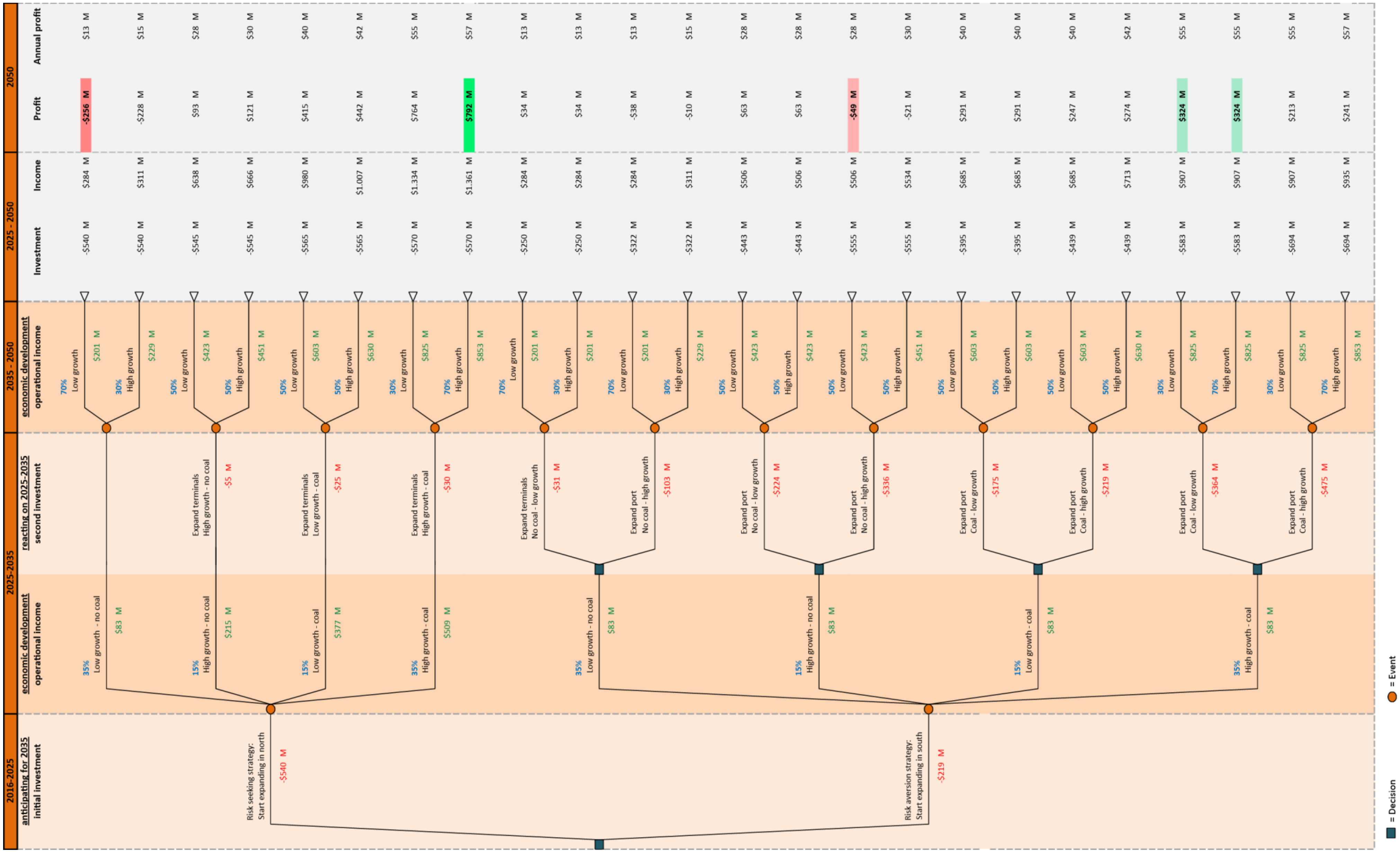
[4] 2019: Total container throughput reaches port’s capacity including the new southern port expansion.

[5] 2025: Northern port expansion operative

B. Hydrographical map of Walvis Bay



C. Decision tree



D. Construction planning

Title	Duration	Start	End
1) **Construction caissons**	177w	01-01-19	23-05-22
1.1) Dock preparation	4w	01-01-19	28-01-19
1.2) Caissons CD19.5	55w	29-01-19	17-02-20
1.3) Caissons CD15.75	118w	18-02-20	23-05-22
2) **Construction of approach channel**	26w 2d	01-07-20	31-12-20
3) **Construction of harbour basin**	157w 2d	01-07-20	06-07-23
3.1) Excavation of harbour basin	56w 4d	01-07-20	02-08-21
3.2) Dredging of harbour basin phase 1	51w	11-08-20	02-08-21
3.3) Reclamation of land phase 1	6w	22-06-21	02-08-21
3.4) Placing revetment section 3	16w 3d	03-08-21	25-11-21
3.5) Placing revetment section 1	44w 1d	26-11-21	30-09-22
3.6) Placing revetment section 5	34w 3d	03-10-22	31-05-23
3.7) Deepening area + soil impovement for caissons Chemical Bulk	11w	03-08-21	18-10-21
3.8) Placing caissons CD19.5	1w	19-10-21	25-10-21
3.9) Dredging of harbour basin phase 2	23w 1d	03-08-21	11-01-22
3.10) Reclamation and raising of surface level phase 2	28w	03-08-21	14-02-22
3.11) Construction jetty phase 1	8w	15-02-22	11-04-22
3.12) Placing revetment section 2	9w 3d	12-04-22	16-06-22
3.13) Placing revetment section 4	24w	17-06-22	01-12-22
3.14) Placing revetment section 7	20w 4d	02-12-22	26-04-23
3.15) Construction jetty phase 2	8w	17-06-22	11-08-22
3.16) Deepening area + soil improvement for caissons Rough Bulk	16w	15-02-22	06-06-22
3.17) Placing caissons CD15.75 Rough Bulk	1w 3d	07-06-22	16-06-22
3.18) Deepening area + soil improvement for caissons General Bulk + Container	16w	07-06-22	26-09-22
3.19) Placing caissons CD15.75 General Bulk + Container	1w 3d	27-09-22	06-10-22
3.20) Dredging of harbour basin part 3	19w 1d	07-10-22	17-02-23
3.21) Raising of surface level phase 3	23w	07-10-22	16-03-23
3.22) Placing revetment section 6	16w	17-03-23	06-07-23
4) **Leveling**	58w	15-02-22	27-03-23
5) **Construction of infrastructure**	57w 4d	13-09-22	20-10-23
5.1) Construction of roads outside the port	19w 4d	09-11-22	27-03-23
5.2) Construction of roads within the port	8w 3d	28-03-23	25-05-23
5.3) Construction of rails outside the port	28w	13-09-22	27-03-23
5.4) Construction of rails within the port	29w 4d	28-03-23	20-10-23
6) **Construction of terminals**	59w	23-10-23	06-12-24
6.1) Pavement Container	20w	23-10-23	08-03-24
6.2) Pavement General cargo	15w 2d	11-03-24	25-06-24
6.3) Pavement Chemical bulk	17w 2d	26-06-24	24-10-24
6.4) Pavement Liquid bulk	6w 1d	25-10-24	06-12-24
7) **Quay facilities**	61w 4d	23-10-23	26-12-24
7.1) Rough bulk	12w	23-10-23	12-01-24
7.2) Container	36w 2d	11-03-24	19-11-24
7.3) Chemical bulk	9w	25-10-24	26-12-24