Transhipment Port
in the
Rio de la Plata

Los Gauchos del Puerto

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Project Definition

The research and design in this report are made for the fourth year course CIE4061-09 "Multidisciplinary Project" for the faculty of Civil Engineering & Geosciences at Delft University of Technology. This project is a multidisciplinary project done by students of different specialisations within the master track Hydraulic Engineering.

The project is about the design of a transhipment port in the Rio de la Plata between Argentina and Uruguay in order to improve logistics of the grain export of Argentina.

Buenos Aires, November 2012

Sponsors

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Preface

During the Master track at Delft University of Technology, students are given the chance to do a project abroad. The four of us took this opportunity to go to Buenos Aires, Argentina to do such a project in cooperation with Royal Boskalis Westminster NV.

After contact with Ingrid Karelse (Recruitment Boskalis) and Ing. Tako de Veth (Manager Boskalis Argentina) we were given the assignment to design a port of transhipment in the Rio de la Plata. Our project supervisors of Civil Engineering and Geo-Sciences, DUT; Ir. J. van Overeem (Department Coastal Engineering), Prof. Ir. T. Vellinga (Professor Ports and Waterways) and Ir. A van der Toorn (Lecturer Hydraulic Engineering) helped us to ensure the quality and academic level of our report, for which we want to thank them.

During our stay in Buenos Aires, we met people from Boskalis who helped us with our project. First of all we want to thank Ing. Tako de Veth for giving us this project, providing us with information and contacts and for the office and trips he granted us. Furthermore we want to thank Ir. Sergio Cetera (Representative Boskalis Argentina) for giving us a clear project description and providing us with information and feedback during the project. We also want to thank Ir. Alberto Palomar (Consultant Boskalis Argentina) for providing information for the project and giving feedback on our report.

Besides contacts from Boskalis Argentina, we met some other people who helped us. We want to thank Paul Louer (Retired manager Riovia S.A. Uruguay), who told us a lot about the Rio Paraná system and gave feedback on our report, as well as Ing. Rafeal Seizar (Contractor Riovia S.A. Uruguay) who provided us with technical information for our project. We also want to thank Niek Boot (Owner Satecna Costa Afuera S.A.) for letting us use a part of his office during our stay and helping us with our project where needed.

Last of all we want to thank our sponsors. Our main sponsor, Royal Boskalis Westminister NV and our other sponsor Ingenieursbureau Den Haag, as well as the STuD fund and the Section Hydraulic Engineering, Civil Engineering and Geosciences, DUT, for their financial support.

During these two and a half months we worked as a team, applied the gathered knowledge of the past years and gained new, learned what it is to work and live abroad and got to know a lot about the Argentine politics, economy and lifestyle, which is a lot different from that in the Netherlands. We enjoyed working on this project and hope you will too when reading this report.

Los Gauchos del Puerto

Buenos Aires, November 2012

Summary

Currently the transport of agricultural products over the Rio Paraná and the Rio de la Plata consists of a transport stream towards and from the Rosario area. The transport to the area is done by trucks coming from up to 1000 kilometres inland, hinterland connections by rail and barges coming from the upstream area of the Rio Paraná (Argentina, Paraguay, Bolivia). The transport from the area towards the rest of the world is done by ocean going vessels ranging in size from Handysize to Panamax and an occasional Capesize vessel. The grain that is transported to the Rosario area is partially transhipped into these ocean going vessels and partially processed by the local crushing industry, where it is turned into meal and oil before being shipped by ocean vessels.

The restrictions in depth in the Rio Paraná and, mostly, the Rio de la Plata (32 feet for vessels going upstream in the Martin Garcia canal and 34 feet for vessels going downstream in Emilio Mitre) cause for most of these ships to not be able to fully utilise their loading capacity. The additional loading of the ships has to be done in the deeper coastal ports of Bahia Blanca, Quequén and Paranagua, meaning they have to sail an additional distance and make an additional stop before they become fully efficient. On top of the inefficient use of ocean vessels on the river, there are also significant dredging costs involved to keep the river and the estuary at their required depth. The costs of this dredging are paid by the shipping system in that they have to pay a significant amount of toll to be allowed to sail through the canals and river.

The predictions for the future foretell an increase of the amount of exported grain over the Rio Paraná/Rio de la Plata system of 63% in 2030. Besides this, the new Panama locks will be finished in 2015. Seeing as the current shipping standard is largely determined by the Panama locks, the general expectation is that the vessel dimensions will increase to a standard size that complies with the new locks. It is evident that the increase in maximum draft of these vessels makes the depth restrictions in the Rio de la Plata cut into their efficiency even harder. It is a reasonable assumption that something has to be done in order to keep the Rio Paraná system from collapsing.

There are numerous types of solutions that could be applied for this problem. The chosen solution in this case is the construction of a new port somewhere in the Rio de la Plata. This port would serve as a transhipment station where inland vessels deliver the cargo from ports along Rio Paraná and where it gets transhipped into ocean going vessels with a New Panamax size, which have a maximum draft of 54 feet, for shipment across the ocean. This solution means that the ocean going vessels can fully utilise their maximum draft for the entire duration of their trip. Furthermore it means that, as far as the grain industry is concerned, the requirement for maintaining an artificial depth of 34 feet in the Rio de la Plata past the port is no longer required.

The final design of the previously described port consists of an artificial island on Banco Chico off the coast of Magdalena in the Rio de la Plata. This location has been chosen due to political, environmental and cost related motivations and is located right next to the already existing shipping channel, making the required access channel for the port's ocean basin shorter. The port is designed to be capable of receiving anything up to fully loaded New Panamax sized vessels and partially loaded Capesize vessels. On the river side of the port the system is designed to make use of tug/barge combinations with a loading capacity of 5600 tons and a draft of 14 feet. This draft means they can freely sail on most of the Rio de la Plata and do not necessarily require the maintained channels. The island itself gives room for (temporary) storage of commodities in between unloading and loading to ensure a constant supply of grain to load the ocean vessels and thus reduces the service time.

All in all the construction of a transhipment port on an artificial island in the Rio de la Plata is a preliminarily feasible solution to the described problem. This does, however, mean that all the assumptions that have been made in the design phase will either have to be true, or false in a non-critical fashion. On top of that there are still numerous risks that could harm the operational feasibility of the port and make sure it will never exist. As long as sufficient research is done into the more critical aspects of these risks and assumptions, a lot of economic benefit could be gained from embarking on a new system.

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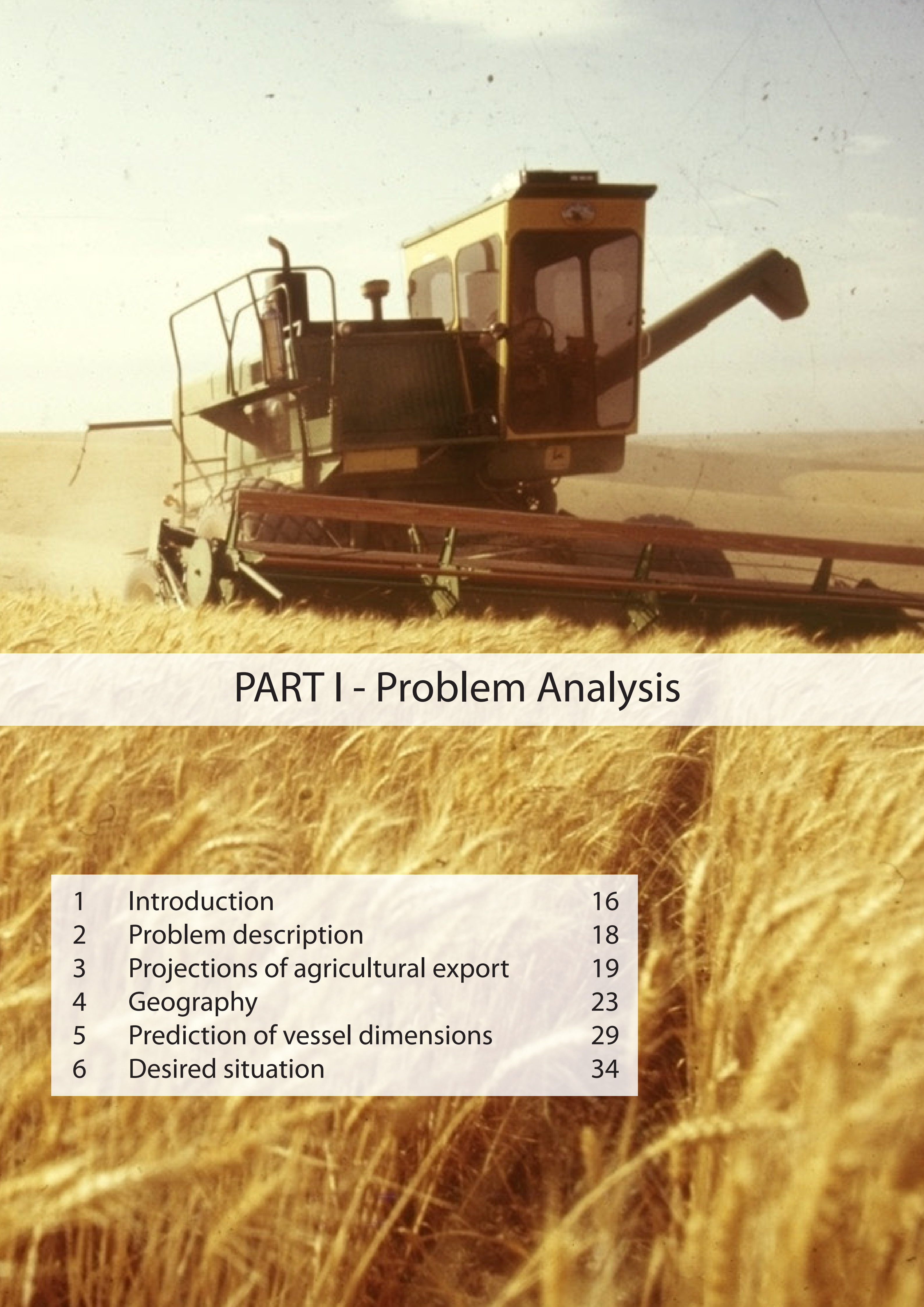
In this part a description of the current agricultural export system and its problems are given. Projections are made of the increase of this export, the enlargement of the vessel dimensions and the restrictions the river is giving to those. This results in a desired situation for 2030.



PART I - Problem Analysis

1 Introduction

In this chapter an explanation of the current situation, considering export over the Rio Paraná and the Rio de la Plata will be given. The Rio de la Plata estuary forms the mouth of two rivers, the Rio Paraná and the Rio Uruguay, in the Atlantic Ocean. The catchment area of the Rio de la Plata consists of Northern Argentina, the South-Eastern part of Bolivia, central Brazil and large parts of Uruguay and Paraguay.

The Rio de la Plata plays an important role in the export and import of cargo from Argentina. The port of Buenos Aires and Montevideo are situated along the Rio de la Plata. The two main cargo streams are the export of agricultural products as bulk and the export of containers. Container transport goes mainly via the port of Buenos Aires and Montevideo. The containers to these ports are mainly delivered by land, but also by sea transport.

The biggest part of the agricultural products, mainly grain and grain by-products, originates from the Northern part of Argentina. The grain is transported to ports along the Rio Paraná, the Rio Uruguay and the Argentine coast by truck and by rail. Another part of the products comes from Paraguay. This cargo is transported via the Rio Paraná by convoys of Mississippi type push barges to ports in the Rosario-San Martin area. In these river and coastal ports the agricultural products are loaded on ocean going vessels sailing all over the world. The export of agricultural products gives a large contribution to the Argentine economy.

An overview of the waterways is given in Figure 1, which is enlarged in Appendix A: Maps.

Figure 1 - Overview of the ports

The ports along the Atlantic coast, Bahia Blanca and Quequén, have a large water depth and can accommodate fully loaded Panamax vessels. The ports along the Rio Paraná, however, only allow vessels with a limited draught because of depth restrictions on the Rio Paraná. To reach the ports along the Rio Paraná ships have to sail via navigation channels in the Rio de la Plata.

To reach the Rio Paraná, vessels can choose between two routes, as can be seen in Figure 2. The route Emilio Mitre - Paraná de las Palmas, next to the Argentine coast, has an allowable draft of 34 feet. This route and the rest of the Rio Paraná are dredged to keep them at this draft. Another route is the Martin Garcia channel. This channel is located more to the north, along the Uruguayan coast and has an allowable draft of 32 feet which is maintained by dredging as well. The difference between both channels is that the Emilio Mitre route is shorter and allows vessels with a larger draft. However, it is a busier one and contains some sharp curves, limiting the maximum ship length. The Martin Garcia route, however, has no speed restriction, which the Emilio Mitre route does have. Therefore the sailing time of both routes is the same.

In the current system the Martin Garcia route is mainly used for empty vessels to sail upstream, while for sailing downstream the Emilio Mitre route is mainly used.

Figure 2 - Navigation channels

2 Problem description

After the Second World War Liberty class ships were sailing to ports along the Rio Paraná. They could sail the Rio Paraná without a problem, but from 1955-1960 the amount of dry cargo and the size of bulk carriers started growing. More inland ports were being built. The ships kept growing until the size of the Panamax dry bulk carrier. Argentina decided to deepen the navigation channels and the Rio Paraná. This was done in stages, 15 years ago the allowable draft was 32 feet, which has increased to 34 feet and currently it is being analysed if the allowable draft could become 36 feet.

At this moment even an even larger depth is needed, because vessels have to go to coastal ports in Argentina or Brazil to top off their cargo to reach their maximum draft of 45 feet. This system is not logical, because vessels cannot be loaded to their full capacity and have to sail an additional distance to reach their full capacity. On top of this the channels in the Rio de la Plata and the Rio Paraná have to be dredged constantly, resulting in high maintenance costs to keep the system navigable. Besides the problem of the depth, the navigation channels in the delta of the Rio Parana contain sharp curves limiting the length of the vessels.

In the future the grain export of Argentina and the countries upriver may grow as a result of the rising food demands all over the world and an increase in farming efficiency. With the building of the new Panamax-locks and the growing export amounts the size of ocean vessels may grow. When the draught of the vessels will increase, the current system will become even more inefficient. The high costs may make it unattractive to import agricultural products from Argentina and may have a negative influence on the economy of Argentina.

3 Projections of agricultural export

To be able to design the transhipment port, first the amount of cargo that has to be transhipped, needs to be known. In this chapter a projection for the agricultural export over the Rio de la Plata for 2030 is made and an analyses of the need for container export. The data illustrated in the figures below can be found in Appendix D: Cargo analysis as well.

3.1 Export Rio de la Plata

Using the data from the annual report of the ports of Argentina (Globalports, 2008) the part of the total grain export that is shipped over the Rio de la Plata as part of the total export of Argentina has been calculated. A part of the production on land directly goes to the coast because of a smaller distance for traffic by road or rail and thus does not pass the Rio de la Plata. It is expected that the increase in production does equally increase in both zones and that the calculated percentage can be applied in the future as well.

This appears to be on average 71% of the grain, 94% of the by-products and 90% of the vegetable oils over the period 2003 to 2007, see Figure 3.

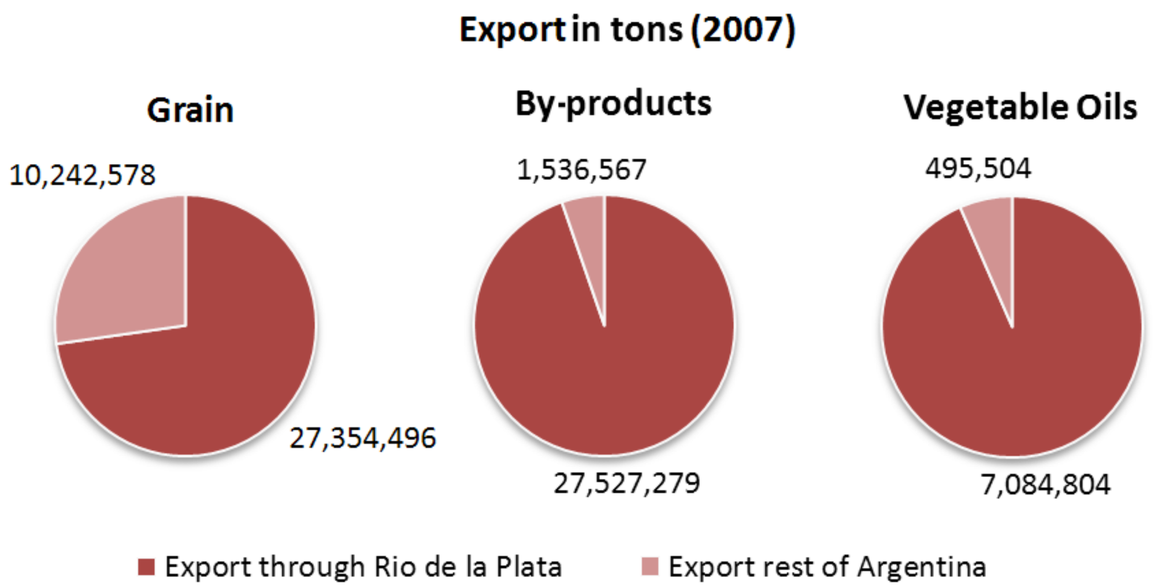


Figure 3 - Export over the Rio de la Plata

3.1.1 Data of the past years

Using the history of the total export data of the agricultural export of Argentina(Argicultural Ministry of Argentina, 2010) and the already calculated share that is exported through the Rio de la Plata, the export values for the period 1993 to 2010 have been found.

3.1.2 Projections up to 2021

To make an accurate graph of the future, the data of the USDA of, what they think, will be the export up to 2021 has been used(USDA, 2012). Since the data by the USDA was seasonal (e.g. 2010/2011) and the other data is given in normal years (e.g. 2010) the data has been converted using 9/12 of the previous season (e.g. 2009/2010) and 3/12 of the following season (2010/2011). This division gives the most accurate approximation.

3.1.3 Commodities split

USDA data also provided an excellent source to show what the commodities consist of, as is presented in Figure 4.

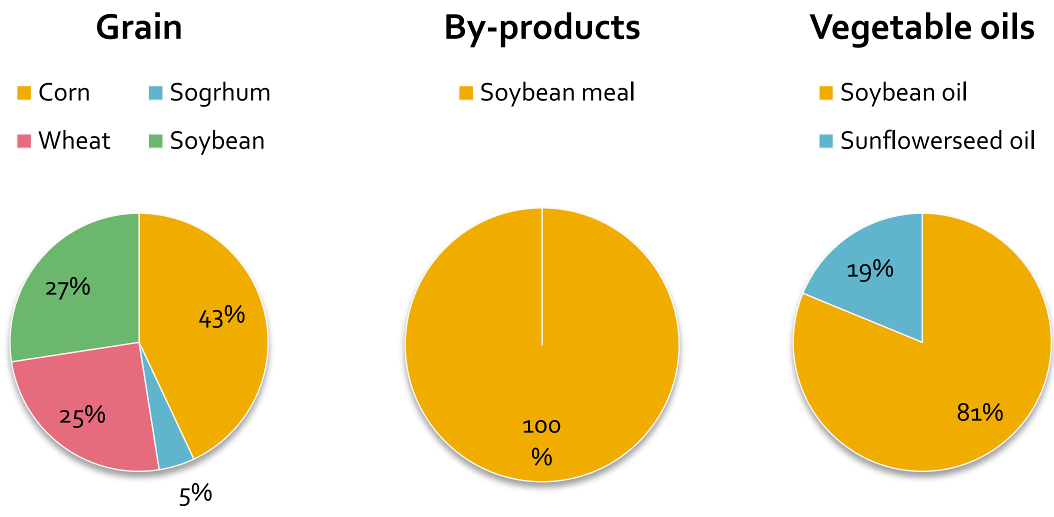


Figure 4 - Commodities

3.2 Comparison with GDP

A comparison with the GDP of Argentina (World Bank) and the export of commodities is made and there seems to be little to no correlation, see Figure 5. There is a correlation between the dips in export and GDP, but there is no clear correlation between the growth of the export and the growth of the GDP, so it will not be used in the projection.

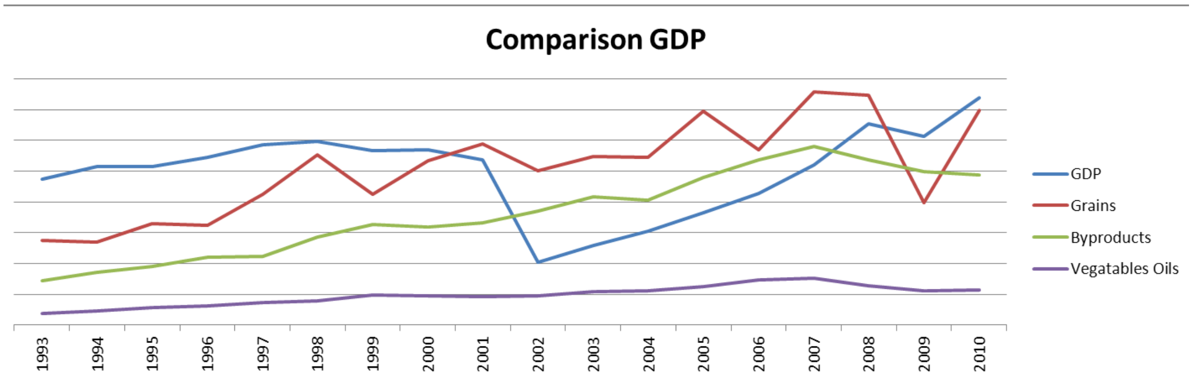


Figure 5 - Comparison GDP

3.3 Projections up to 2030

A trend line is fitted through all the collected data. The best fitting trend line for the grains is a linear trend line, as can be seen in Figure 6.

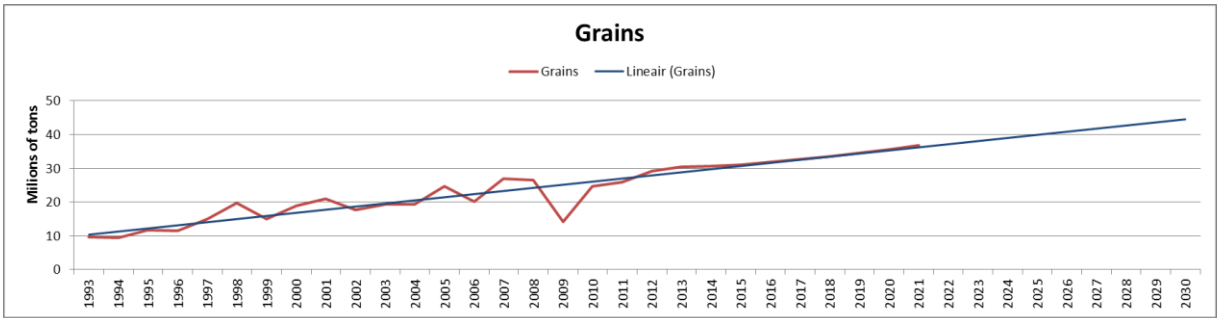


Figure 6 - Prediction of grains

For by-products the best fit is a third order polynomial, as Figure 7 shows.

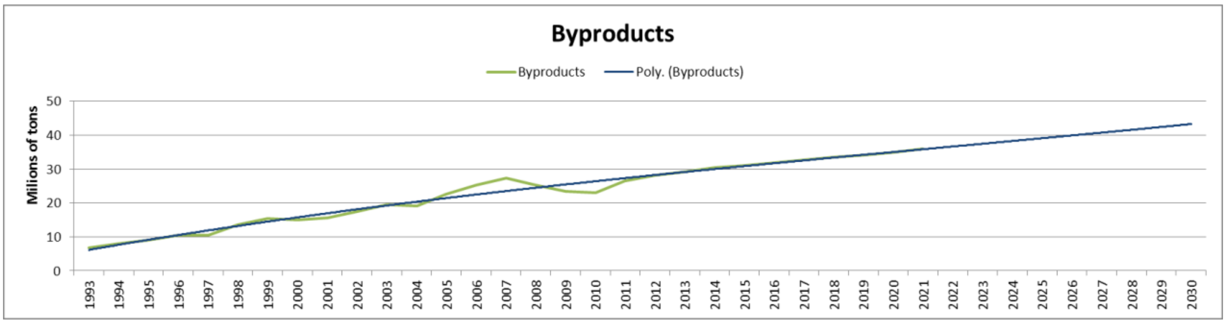


Figure 7 - Prediction of by-products

For vegetable oils only a projection of the soybeans by the USDA is given. Since the split with the sunflower seed is known, this data is used to make a prediction of the total. A logarithmic trend line gives the best fit, as can be seen in Figure 8.

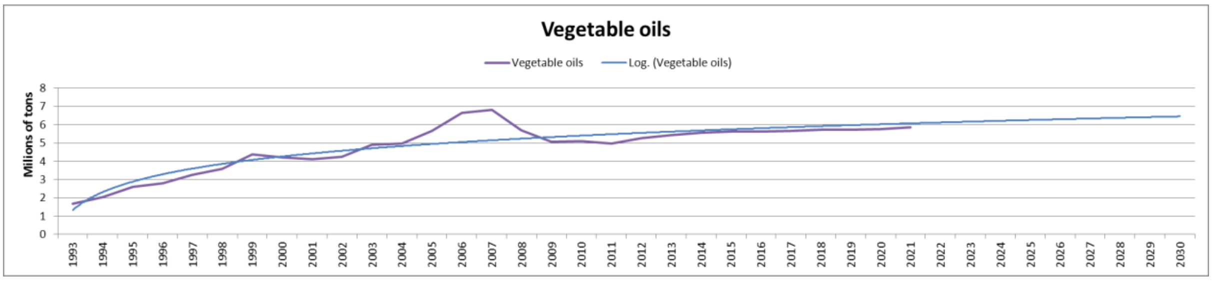


Figure 8 - Predictions of vegetable oils

Although the used trend lines are the best fit for the historic data, there are still many circumstances that can lead to a significant deviation of this extrapolation. Possible reasons for a change in the growth could be the stagnation of the growth due to the limiting capacity of the rail and road infrastructure or a collapse of the economy and the currency making export less attractive. However, in this study none of these events are assumed to happen and the trend lines used above are assumed to be accurate enough for this port.

Using these trend lines the projection of the total export via the Rio de la Plata is:

Grains:	44.6 million metric tons
By-products:	43.3 million metric tons
Vegetable oil:	6.5 million metric tons
Total export:	**94.4 million metric tons**

3.4 Other export

Besides the export of agricultural products, Argentina also exports containers and iron ore.

3.4.1 Export by containers

A minor part of Argentina's export is done by containers. Also in this sector major increases are expected, in the past it went from 1 million TEU in 2002 to 1.8 million TEU in 2007. Almost 95% of the container export is directly done by the port of Buenos Aires and thus there is no need of a transhipment port for containers in the Rio de la Plata due to little container import and export over the Rio Paraná.

In the future it might not be possible to further expand the port of Buenos Aires at its current location and in that case the port of transhipment could be used to increase the capacity of Argentina. However, this is only possible if it is located at a location with (possible) land connections to the hinterland. Since the necessary quays and facilities of a container terminal differ greatly from that of a bulk terminal, it is probably more economical to build the port extension at a different location.

3.4.2 Export of iron ore

A minor part of the Argentine export consists of iron ore. This iron ore comes mainly from an ore mine in Brazil and is also exported via the Rio Paraná and the Rio de la Plata, by barges and by bulk carriers in the deeper parts. These bulk carriers will also not be able to reach the inland ports if the system changes and an alternative for the export of iron ore has to be found.

There are plans to build a deep water port for iron ore export in Uruguay and the assumption is made that the iron ore is transhipped at this port from small coaster vessels to ocean going vessels. There are plans to build a railway for the export of iron ore in Uruguay, so there is also the possibility to transport the iron ore to this port over land.

4 Geography

The Rio Paraná is one of the main export channels for the export of Argentina (see chapter 3.1). The restrictions of this waterway are described in this chapter.

4.1 Depth restrictions

In the current situation the Rio Paraná and the Rio de la Plata have a concession in place where Hidrovía S.A. (which Jan de Nul dredging company makes part of) takes care of the complete dredging works of the Rio de la Plata and Rio Paraná (with the exception of the Canal Martin García on the Uruguayan side of the Rio de la Plata). The concession, involving the Rio Paraná, consists of a number of channels in the Rio de la Plata and the Rio Paraná itself. The channels, as illustrated in Figure 2, and their according guaranteed drafts are illustrated in Table 1 (de Veth, 2012):

Channel Name	Guaranteed draft [feet]
Punta Indio channel	34
Intermedio channel	34
Paso Banco Chico	34
Rada Exterior	34
Emilio Mitre Channel	34
Martin Garcia Channel	32
Rio Paraná up to Rosario	34
Rio Paraná up to Santa Fé	24

Table 1 - Guaranteed draft of channels

In order to obtain a proper assessment of the current Rio Paraná system and its flaws it is also necessary to look at the water depths the current system has further upstream. For this assessment data is used of a part of the Argentine ministry of planning (SSPYVN), which has been collected on a monthly base during the course of 2011. Figure 9 illustrates the maximum and the minimum values of the water depth over the various river sections upstream from Rosario until Posadas. The Rio Paraná flows downstream from Rosario towards Buenos Aires and the mouth of the Rio de la Plata at depths that are equal to or larger than those of the Rosario – Santa Fé river section. Once the Rio de la Plata has been reached, the allowable draft is artificially maintained at 34 feet for the Emilio Mitre route and 32 feet for the Martin Garcia route. This means that the allowable draft for ocean going vessels coming from Rosario is not affected by the maximum allowable draft in the Rosario – San Martin river section, because the Rio de la Plata cannot support vessels of this draft anyhow.

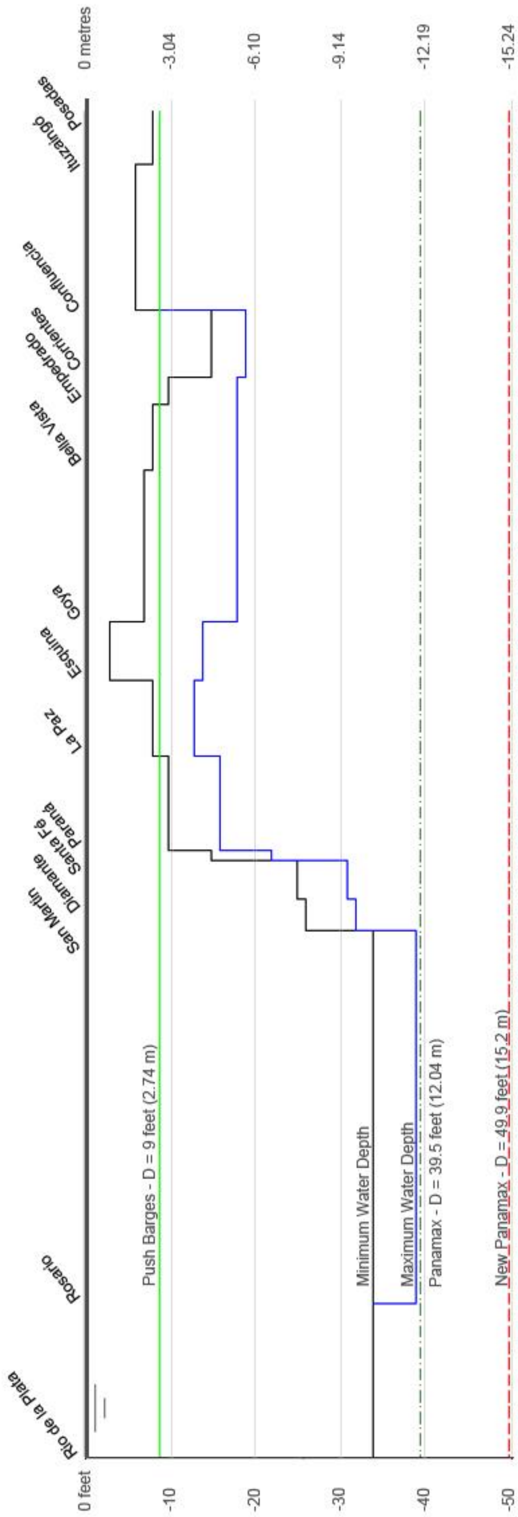


Figure 9 - Depths of the Rio Paraná

One can clearly see that the system barely suffices for the use of the current standard of Panamax size vessels in the section downstream of Santa Fé. In fact, the current system requires for Panamax size vessels to sail the Rio Paraná and Rio de la Plata only partially loaded due to the depth restrictions of the system. It is only when the ships reach the Atlantic ports of Bahia Blanca, Quequén and Brazilian ports that they are loaded to their maximum capacity.

The red line in Figure 9 shows the draught of the to be expected new standard New Panamax size vessels (as described in chapter 5.1.3). One can clearly observe that the current system is far from capable of facilitating these types of vessel as far as depth restrictions are concerned. An additional dredging of at least 11 feet would be required in the section between Rosario and Santa Fé to make New Panamax shipping possible at full capacity, and to be able to reach further upstream ports this additional dredging would only increase. As the current system provides a port of transhipment from ocean vessels to inland barges in the Rosario area, the system upstream of Santa Fé would not be affected by the size of ocean faring vessels.

When looking at the green line, representing the draught of push barges, it is noticed that a very large part of the system has the required water depth needed for this type of transport. The only restriction is the La Paz – Empedrado section, which does not suffice for fully loaded barges in the dry season, but is well sufficient for barge transport during periods when there is no severe drought. Considering the limited amount of maintenance dredging currently done upstream of Santa Fé, one might expect that a similar amount of maintenance would suffice for keeping the Rosario – Santa Fé section at sufficient depth for barge transport.

4.2 Curve restrictions

Besides the depth, also the width is a limiting factor when it comes to allowing bigger ships in the Rio Paraná. Naturally, many parameters play a role in the determination of the width of the channel. The frequency of overtaking and encounter manoeuvres, the wave and wind conditions, the river discharge and the extra width needed in the curves are several of the many parameters that are used in calculation of the channel width. The curves in the Rio Paraná delta are, however, very narrow and are determining for the maximum allowable ship length.

4.2.1 Channel Restrictions

Restrictions are given on what ships are allowed on the Rio Paraná. For most part of the Rio Paraná a maximum length of 290 metre and a beam of 50 metre are permitted as long as the ship is equipped with radar for rivers and under normal weather conditions. Only for the Rio Paraná de las Palmas those values are reduced to a length of 236 metre and a beam of 50 metre (Prefectura Naval Argentina, 1982). Although these values might be influenced by sea ports and a greater ship length might be possible if it has the proper equipment, these rules are not likely to be changed.

4.2.2 Ocean Vessels

As an extra check the necessary width in the limiting curves is also calculated. The limiting curves in the Rio Paraná (and Rio the la Plata) are listed in Table 2 below (SSPYVN, 2011).

Name of river section	Radius of smallest curve [m]	Channel width at curve [m]	Number of small curves R<1000 m
Rio de la Plata, subsección I.1 (up to Buenos Aires)	2754	100	0
Rio de la Plata, subsección I.2 (Buenos Aires to the delta)	1624	100	0
Paraná de las Palmas (Delta to intersection)	444	262	15
Paraná Inferior (intersection to San Martin)	586	128	3
Paraná Medio (San Martin to Santa Fé)	814	116	2

Table 2 - Limiting curves

Unfortunately, the radiuses of the curves in the route via the Martin Garcia channel through the Paraná Guazu or Bravo are unknown. This is no problem though, since this route is primary used for empty vessels due to the lower channel depth. Empty vessels sailing upstream have a smaller relative speed and thus a smaller additional width needed in the curves; they are, however, more influenced by wind forces, but since the width of this channel is considerably larger than the Paraná de las Palmas, this channel will not be governing.

Currently the maximum vessel is the Panamax vessel with a width of 32 metre and a length of 235 metre. To determine the width needed for a vessel for taking the curves, the formula of Schäle is used(Groeneveld, 2002):

$$B_{curve} = B_{ship} + \Delta B = B_{ship} + \left(0.035 \cdot V_s + 0.125 \cdot \left(1 - \frac{R}{1000}\right)\right) \cdot \frac{L^2}{R}$$

In this formula the additional width ΔB is calculated by using the relative vessel speed (V_S), radius of the curve (R) and the length of the ship (L). Using a maximum downstream speed of 12 knots (22 km/h) compared to the river bank, gives a required width of 137 m for the Paraná de las Palmas and a width of 110 m for the Paraná Inferior. This last width is already exceeding the current width available and only includes the downstream lane.

This shows that the current system is already unsafe or the vessel needs to reduce speed at the limiting curves. An increase of the maximum vessel size would only be possible if the width of the channel would be considerably increased.

4.2.3 Push Barges

Currently push barges are used in the upper part of the Rio Paraná, although the river upstream of Santa Fé can still use improvements(World Bank, 2010) to prevent convoys of push barges from having to disconnect and reconnect before and after curves. Further downstream restrictions have to be implemented on the maximum size of the push barge convoys to allow safe sailing.

4.3 Spatial analysis

To make a proper assessment of the possibilities for building a new port in the Rio de la Plata, it is important to make a spatial analysis. This spatial analysis will show where it is and isn't possible to build something, and where other possibly important obstructions arise.

Figure 10 shows the spatial analysis as it has been applied on the system, where the green parts are already existing port areas along the Rio Paraná, Rio de la Plata and Rio Uruguay, blue areas show the current cities along the Rio de la Plata (the cities upstream on the Rio Paraná and the Rio Uruguay are irrelevant for the port construction as the port will need to be constructed in the Rio de la Plata). Furthermore there are red areas where current anchor places are located. Anchor places can in theory easily be moved elsewhere, as it doesn't really matter where the ships queue up for port entrance. These places often show large amounts of debris, anchor chains and cut anchors at the bottom, which would make clean-up of the area necessary to make it ready for construction. The orange lines show the shipping lanes where currently dredging is done in order to make the ports of Montevideo, Buenos Aires and those further up the Rio Paraná and Rio Uruguay accessible.

The yellow zones indicate the zones of exclusive jurisdiction as determined in the Treaty concerning the Rio de la Plata(Governments of Argentina and Uruguay, 1973). The requirement for the port to be governed by Argentina, as it mostly includes their goods being exported, makes it undesirable for the port to be built in the exclusive zone of Uruguay. The economic benefits Argentina would gain from operating the port themselves should be evident, and a positioning of a port for export of Argentine grain under Uruguayan command would mean they would miss out on yielding an optimal profit from their own crop. Besides that, already much of the Argentine container transport is relocating to Montevideo due to more favourable business conditions, causing the Argentine government to become more protective in regards to their own export policy. It would be in the line of expectation that the Argentine government would do everything in its power to prevent the export of Argentine grain through a Uruguayan port, making the new port essentially useless. Therefore, construction in the zone of Uruguayan exclusive jurisdiction is unthinkable for the practical application of this port.

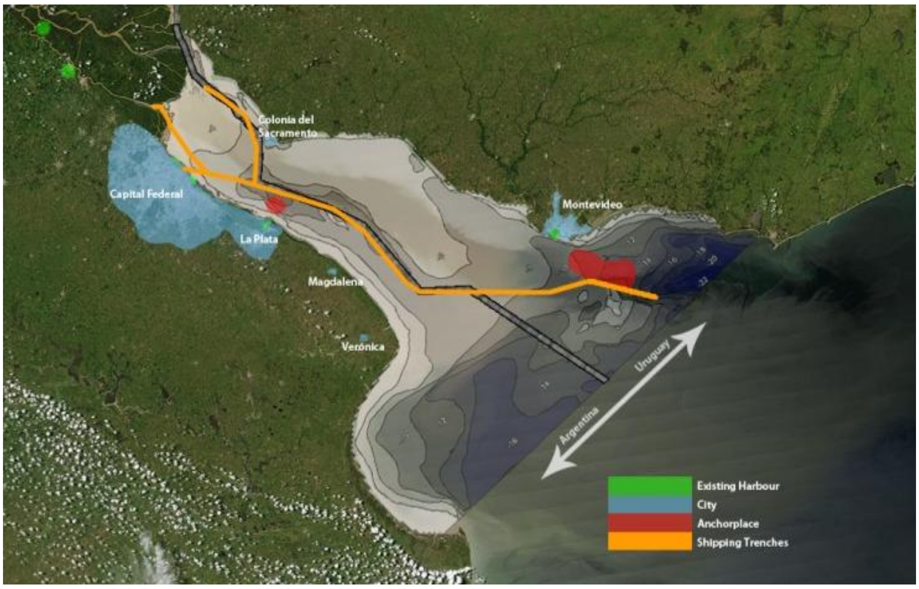


Figure 10 - Spatial Analysis of the Rio de la Plata area

4.4 Transport in the Rio Paraná system

There are some notes on the Rio Paraná system, concerning the vessels on the river, the transhipment ports in the Rosario area and the inland water transport.

4.4.1 Ocean going vessels on the Rio Paraná

The current Rio Paraná system has a set of rules and regulations in place that may affect the future situation of the to be created transhipment port in de Rio de la Plata area. For starters, the current system is already not capable of facilitating fully loaded Panamax vessels (32% of the ships on the Rio Paraná are of this size) and even most of the Handymax (41%) and some of the Handysize vessels (27%) are not capable of loading up to full capacity. These types of vessels sail upstream towards Rosario with limited cargo or in ballast, and are subsequently loaded with grain to the point where they reach the maximum allowable draught for the Rosario – Rio de la Plata river section (34 feet in fresh water). From here on the ships sail down the Rio Paraná and via the Rio de la Plata towards Bahía Blanca, Quequén or Paranágua to top off their cargo. It goes without saying that this system is highly inefficient.

4.4.2 Transhipment ports in the Rosario area

The ports in the Rosario area in this system are a main contributor to the export. Greater Rosario houses a large soy bean crushing industry that relies on the Rio Paraná system to export its goods. The goods Rosario needs for this industry reach the city partially by truck transport from up to 1000 km inland, and partially through barges that travel up the Rio Paraná to grain producing areas further upstream. Part of this grain is subsequently transhipped into ocean going vessels, and part is processed before doing the same (see chapter 3.1 for more detailed information). The total transhipment area of the Rio Paraná where cargo is transhipped from inland barges and trucks to ocean faring vessels stretches from Santa Fé to Rosario, further upstream depth requirements are therefore limited.

4.4.3 Inland water transport

Due to trade union regulations in Argentina, ship owners do not want to fly the Argentine flag. This causes issues for transporting parties to tranship cargo between ports in Argentina, as cabotage is forbidden for any vessel that is not flying the Argentine flag. This regulation could have a large impact on the design of a new transhipment port in the Rio de la Plata, as inland vessels from Rosario flying anything but the Argentine flag would not be allowed to tranship any goods to any Argentine port downstream. Even now cargo destined for the downstream Argentine ports often travels through a Uruguayan port prior to delivering its cargo at its destination to circumvent the current regulations (Dutch-Argentina Chamber of Commerce, 2009).

5 Prediction of vessel dimensions

In this chapter a research will be conducted to determine the future size of bulk carriers, which will be used to transport grain and grain by-products in the future.

5.1 Predictions of ocean going vessels

The ocean going vessel size will be determining for the depth of the port and the access channels, so it is necessary to make a prediction of this size.

5.1.1 Current situation

At present export of grain and grain by-products out of Argentina is done by Panamax and Handy size vessels or smaller and a few Capesize vessels. The Panamax size vessels on the Rio Paraná cannot be fully loaded, because the fully loaded draught of the vessels is larger than the available depth, which has been further elaborated in chapter 4.1. In the future the size of vessels is expected to grow. If this expectation becomes reality, the Rio Paraná transport system will become even more uneconomical, as it becomes too expensive to accommodate larger ships in the Rio Paraná and the inland ports. This is mainly caused by the rising dredging costs of the Rio Paraná in case of deepening the navigation channels even further. If larger vessels than Panamax size vessels want to enter the system, the navigation channels should be deepened, which could make for an inefficient system.

To make a prediction of the vessel size in 2030, first an analysis of the current export countries of Argentina is made. In Figure 11 the regions of the world, which import from Argentina are shown (Indec, 2010).

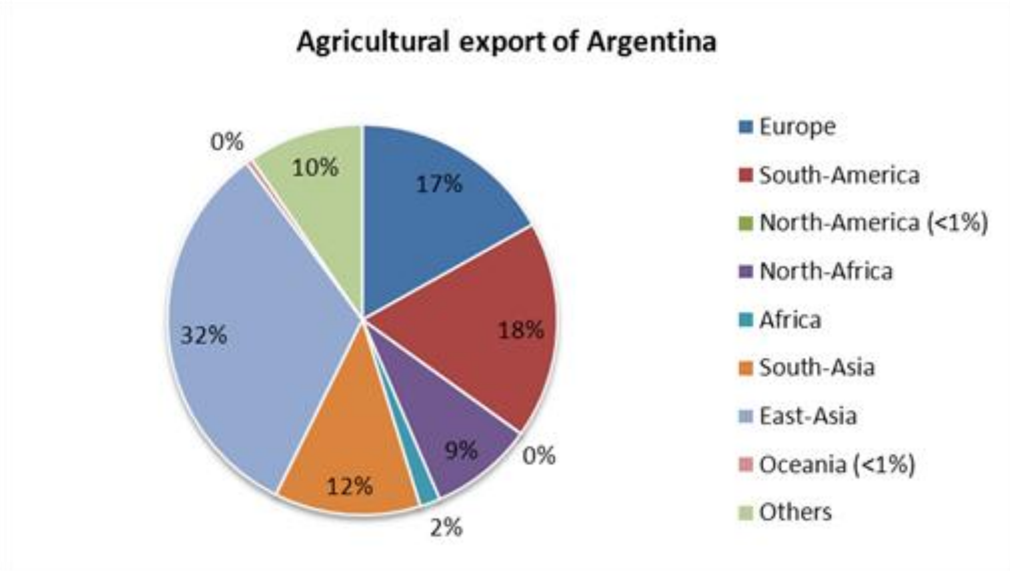


Figure 11 - Agricultural export of Argentina

This analysis is used to take a closer look at ports which possibly import grain from Argentina. Cross-references are made between the export countries of Argentina and the possible grain import ports of the export countries. After an analysis of these ports in Appendix E: Exports ports, it can be concluded that most of these ports can accommodate Panamax size vessels, but there are only few ports capable of receiving larger vessels of New Panamax size or Capesize(G-ports).

5.1.2 Shipping routes

The main shipping routes between de Rio de la Plata and the export countries of Argentina are the route to Europe and the route to Asia. The route from Argentina to Asia is the "Far East — South America East Coast (ECSA) via Cape of Good Hope" route. From Argentina to Europe the trade route is "Europe — South America" (Lam, 2010). On both of these routes there are no canals or locks that have to be bypassed and thus do not create any restrictions for the vessel size.

5.1.3 Future ocean going vessel size

The cascading effect (economics of scale) in maritime transport causes the large vessels to replace the smaller vessels, because of an increase in transport volume and lower costs/ton transported. The transport of grain will increase, because the world grain demand grows due to world population growth. Due to the cascading effect vessels are expected to grow in size, thus replacing the Panamax size vessels by larger ones.

This could be Capesize vessels, the largest bulk carriers at present, but currently only used for transporting iron ore and coals. The current grain ports in the world are only able of facilitating Panamax size vessels and will have to make large investments to be able to accommodate Capesize vessels. Due to these large investments and the difficulty to make a port able to facilitate Capesize vessels it is not likely these vessels will become the new standard by 2030(Vellinga, 2012).

In 2015 the new locks of the Panama Canal will be ready, which will be able to facilitate bigger ships than the current Panamax size vessels. This development will cause bulk carriers to grow to a new size, the New Panamax size, which will most likely become the standard vessel instead of the Panamax size vessel (Schuylenburg, 2012). In Table 3 the sizes of the named vessels are listed.

Vessel	DWT	Length [m]	Beam [m]	Draft [m]
Panamax	50,000-80,000	235	32	12
New Panamax	60,000-200,000	366	49	15,2
Capesize	130,000+	366+	50-77,5	20,1+

Table 3 - Vessel sizes

In conclusion, the vessel size is expected to grow due larger grain demand and the cascading effect. Because of the difficulty to make receiving ports able to accommodate Capesize vessels and the fact that the new Panama locks will be ready in 2015, the expected preferred vessel size is most likely to be the New Panamax type.

5.2 Prediction of river-sea transport

The prediction of the feeder vessels for the transhipment port is needed to assess the amount of vessels which will need to access to port and to determine the size of the port basin for inland vessels.

5.2.1 Current system

In the current system push barges are used to transport bulk from far upstream (Bolivia, Paraguay) to ports in Rosario and surroundings. The push barges are of a Mississippi type, their characteristics are (Dutch-Argentina Chamber of Commerce, 2009), (Caria) as can be seen in Table 4.

Characteristics	
Length barge [m]	60
Beam barge [m]	11
Loading capacity [ton/barge]	1500
Maximum draught [m]	3

Table 4 - Characteristics Mississippi barges

Depending on the navigation conditions along the river a different barge sailing layout is applied (Prefectura Naval Argentina, 1982).

At this moment new barges are built, to replace the older Mississippi type of barges. The size of them is about 60 x 15 metres, a convoy will contain at most 16 barges.

In the desired situation cargo should be transported from Rosario to the port in the Rio de la Plata. The draught of the vessels should preferably be as small as possible resulting in low maintenance costs of the Rio Paraná. The depth of the Rio Paraná will without dredging be about 5 m (Louer, 2012). In order to prevent the cargo to be transhipped twice the vessels should also be able to transport the cargo from the mouth of the Rio Paraná to the port in the estuary. Compared to the Rio Paraná the estuary has very different sailing conditions, like higher waves, more wind and no curve restrictions.

Both parts of the transport line require different types of vessels: a river vessel with a limited draught sailing in quiet water for the Rio Paraná and a sea vessel being able to resist waves. Sea vessels often have a large draught compared to river vessels.

5.2.2 Possible solutions

Convoys of the current Mississippi type push barges would be a good solution for the Rio Paraná, because of the large loading capacity and the limited draught. As far as known these barges aren't seaworthy.

A possible solution would be a river-sea vessel. This type of vessels has a limited draught and is able to sail at sea. Some examples of river-sea vessels are shown in Table 5 (TIL 5050 – Interdisciplinary project, 2010), (Egrrov & Ilnitskyy, 2006).

Name	Frisium	Arklow Surf	Heydar Aliyev
Draft [m]	3,7	4,7	4,6
LOA [m]	87	90	140
Beam [m]	12,5	12,6	16,5
DWT	2355	3100	6670
Sailing region	The Netherlands	Ireland	Mediterranean Sea

Table 5 - Examples of river-sea vessels

Another solution is a push barge system, but with adapted push barges. The push barges are adapted to sea conditions by increasing the freeboard and the shape of the hull. As an example the push barge in Table 6 is considered (MCKeil).

	Niagara Spirit
Draft [m]	4,3
LOA [m]	100
Beam [m]	23,8
DWT	7800
NRT	2770
Sailing region	St Lawrence river, Canada

Table 6 - Adapted push barge

5.2.3 Conclusion

Two possible options for the transport by vessel remain: a river sea ship like the Heydar Aliyev with a DWT of about 6700 or a push barge with a DWT of about 7800.
For this project the push barge is chosen because of its smaller length, smaller draught and higher loading capacity. The beam, however, is larger.

5.3 Expected fleet

As calculated in Appendix D: Cargo analysis a total of 94.4 million tons is expected as throughput in the year 2030. Since the daily peak can be significantly higher than the daily average throughput, as an assumption a factor of 150% is applied to accommodate this. With 350 operational days a year the daily peak is 0.4 million tons.

The total fleet consists of an inland fleet sailing towards the Rio Paraná and an ocean going fleet. As an assumption the ships that are used are given in Table 7. The division of the fleet is also estimated, which is given in Table 8, including also the calculated number of ships that arrive daily. This estimation is loosely based on the prediction of the fleet on the Rio de la Plata by Frima (Frima, 2004) Due to their high capacity only barges are taken into account as inland vessels. The DWT of the ocean vessels is converted to NRT using a factor which can be found in Appendix G: NRT factor vessels.

	DWT	NRT	Length [m]	Beam [m]	Draft [m]
Barges	7,800	2,770	100	23.8	4.3
Handymax	45,000	15,000	190	29	10
Panamax	75,000	25,000	294	32	12.0
New Panamax[2]	120,000	40,000	366	49	15.2
Capesize	150,000	50,000	400	60	25

Table 7 - Average dimensions of ships [2]:(Stott, 2012)

Inland fleet	Division in % of ships	Division in number	Ocean going fleet	Division in % of ships	Division in number
Barges	100%	72	**Handymax**	5%	0.3
Coasters	0%	0	**Panamax**	40%	2.4
			New Panamax	54%	3.3
			Capesize	1%	0.1

Table 8 - Division of the inland and ocean going fleet and number of ships per day

6 Desired situation

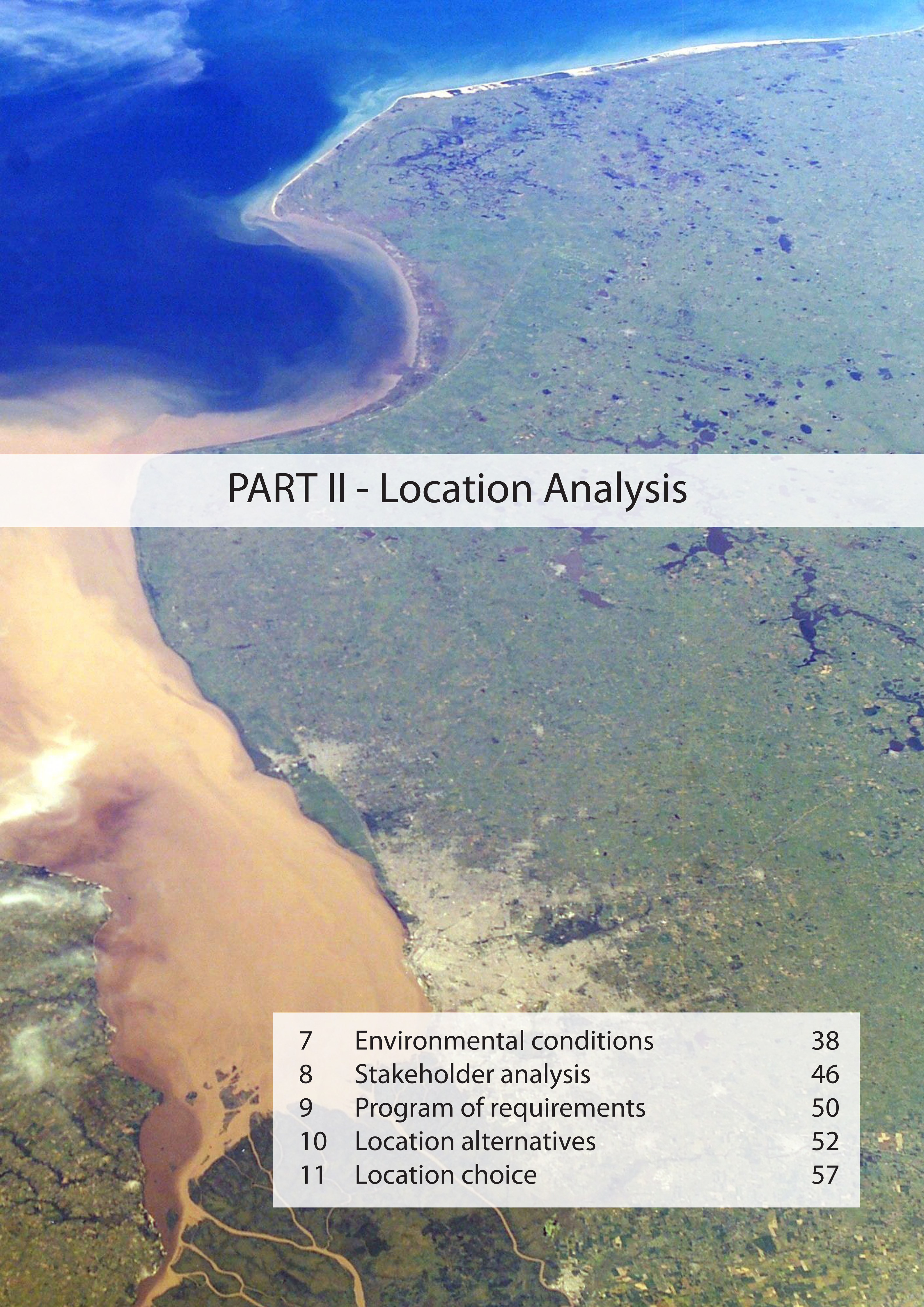
The future situation that would be considered desirable presents a solution for the earlier described problem in a way that the expectations of the dimensions of future vessels and the increase in grain production are taken into account. It becomes clear from the previous chapters that the prospected new vessel dimensions are determined by the newly constructed Panama Canal, which will be finished in 2015, and that the current lay-out of the Rio Paraná with its depth restrictions and curves is not capable of facilitating these vessel sizes.

Realising this, it becomes clear that something needs to happen if Argentina is to keep, or expand, on its position on the global market. Large amounts of money are being invested in keeping the Rio Paraná accessible for ocean vessels in the current system, and in the future system this would only increase due to increasing vessel sizes. The most logical solution to prevent these costs from escalating would be to keep too large vessels out of the Rio Paraná and tranship their cargo somewhere on the ocean side of the Paraná system.

To achieve this transhipment some drastic changes will have to be made to the prospected transhipment area, namely that a port of transhipment would have to be installed. River vessels would collect the grain in the upper areas of the Rio Paraná (Rosario area, Santa Fé and further upstream) and transport it to the Rio de la Plata transhipment port, where it would be transhipped to ocean vessels to distribute it to the global market. This newly constructed port could either be on an artificial island or somewhere along the coastline. Moreover, it should be able to facilitate New Panamax size vessels and inland waterway transport vessels.

To come to this desired solution it has been assumed that buoy to buoy transport is not a feasible solution for the transhipment of 94.4 million tons of dry bulk. Besides that, it has been determined that possibly feasible alternatives such as a rail connection from Rosario to Bahia Blanca/Quequén or from Nueva Palmira to a new deep sea port on the Atlantic coast of Uruguay will be cast aside for the duration of this investigation. So only the solution with a transhipment port is investigated in this report. At a later stage it will be investigated whether the possibility of constructing a new port will outweigh the possibility of further excavating the current Rio Paraná system to make it suitable for New Panamax size vessels or the possibility of keeping the system operational in its current configuration.

For the port, described in the desired situation, a location is sought. Based on an analysis of the environmental conditions and a stakeholder analysis a program of requirements is made. Using these criteria a comparison is made between four alternative locations resulting in the final location.



PART II - Location Analysis

7 Environmental conditions

To be able to determine the port location, the environmental conditions have to known. The environmental conditions have a major influence on choice for the location of the port. In this chapter the sedimentation and the advancing data are discussed, as well as the wind and wave data on the Rio de la Plata.

7.1 Sediment

In order to get a good estimate of the possibilities of both shipping and construction in the Rio de la Plata, the climate of currents and sediment transport in the estuary has to be investigated. The origin of the sediment that is present in the Rio de la Plata lies in the Rio Paraná (and to a lesser degree also the Rio Uruguay) and is created in the Andes where the Rio Paraná springs. This presence alone, however, is not the cause of sedimentation deposition in the Rio de la Plata, this phenomena is caused by differences in flow speed. In order to get a good picture of this, a research from 2011 by the University of Western Australia regarding the flow patterns and current velocities in the Rio de la Plata has been used (Resources Rio de la Plata, 2011). Figure 12 shows that the velocities of the currents in the Rio de la Plata are the highest at the Canal Martin García, where the Rio Uruguay enters the Rio de la Plata, and that the rest of the estuary encounters average flow speeds in the order of 0.2 m/s, which is a relatively low value for the flow speed. It can also be seen that the flow patterns of the water from and to the mouth of the Rios Paraná and Uruguay pretty much follow the coastal line of the Argentine coast, with the exception of the water that is closest to the Uruguayan coast line. The currents have a large impact on the sediment transport because of the fact that the areas with larger flow velocities will transport more sediment (because $s{\sim}m \cdot u^n$). The sediment transport is therefore expected to be large near the Martin García channel, mostly due to the plume of the Paraná Guazu branch.

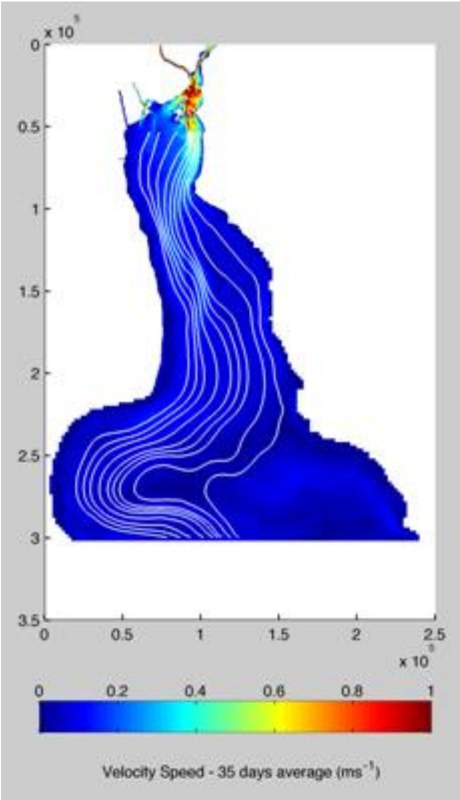


Figure 12 - Plot of the flow velocities in the Rio de la Plata

This large velocity and the according change in velocity towards the rest of the Rio de la Plata cause for sedimentation of the upper area of the Rio de la Plata. Accordingly the relatively larger velocities along the Argentine coast, and the slowing down of the water towards the edge of the basin, cause for sedimentation along the coastline. On top of that, the current around the Uruguayan side of the estuary creates a large bank in the "international" (see chapter 4.3) waters near Montevideo (see Figure 13) called Banco Inglés (with water depths as low as 0.9 metres). Other banks that have been created are Banco Chico near Magdalena (3m depth), Banco Piedras near Punto Piedras (5m depth) and in the delta itself Playa Honda with an average water depth of 2 to 3 metres.

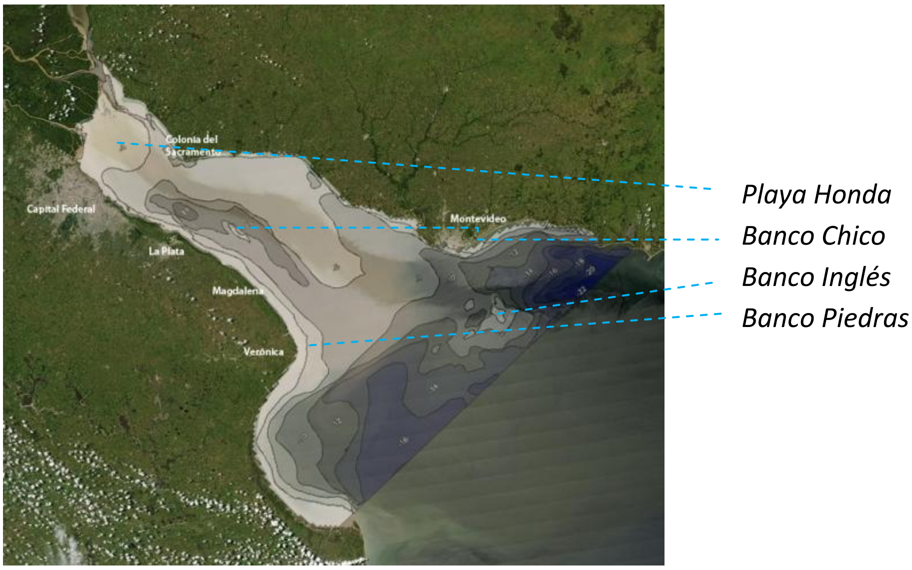


Figure 13 - Bathymetry of the Rio de la Plata

An other important aspect of the Rio de la Plata that has to be taken into account is the advancement of the Paraná delta. The upstream branches of the Paraná and Paraguay rivers originate in the Andes, and pick up large amounts of sediment in this area. The finer parts of sediment travel all the way down into the Rio de la Plata and float around there making the estuary have its characteristic brown colour. The bigger particles of the sediment load, however, settle as soon as the Rio Paraná widens into the Rio de la Plata where there is a large deceleration and therefore a negative sediment transport gradient), causing the creation of a delta. This delta has advanced by approximately 30 km over the past three centuries (as can be seen in Figure 14).

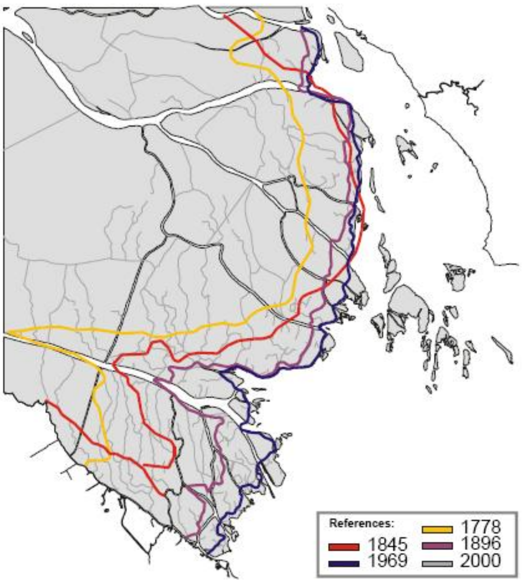


Figure 14 - Advancement of the Paraná delta

Research done by the University of Buenos Aires (Menéndez & Sarubbi, 2007) shows that the Paraná delta will continue to grow due to the consistent sediment transportation by the Rio Paraná. “Worst case scenario” predictions even show that the sedimentation may reach the city of Buenos Aires as soon as the year 2119 (see Figure 15). However, it has to be noted that the model used by the UBA shows a strong bias towards extension in the southern part of the delta (as seen in Figure 15).

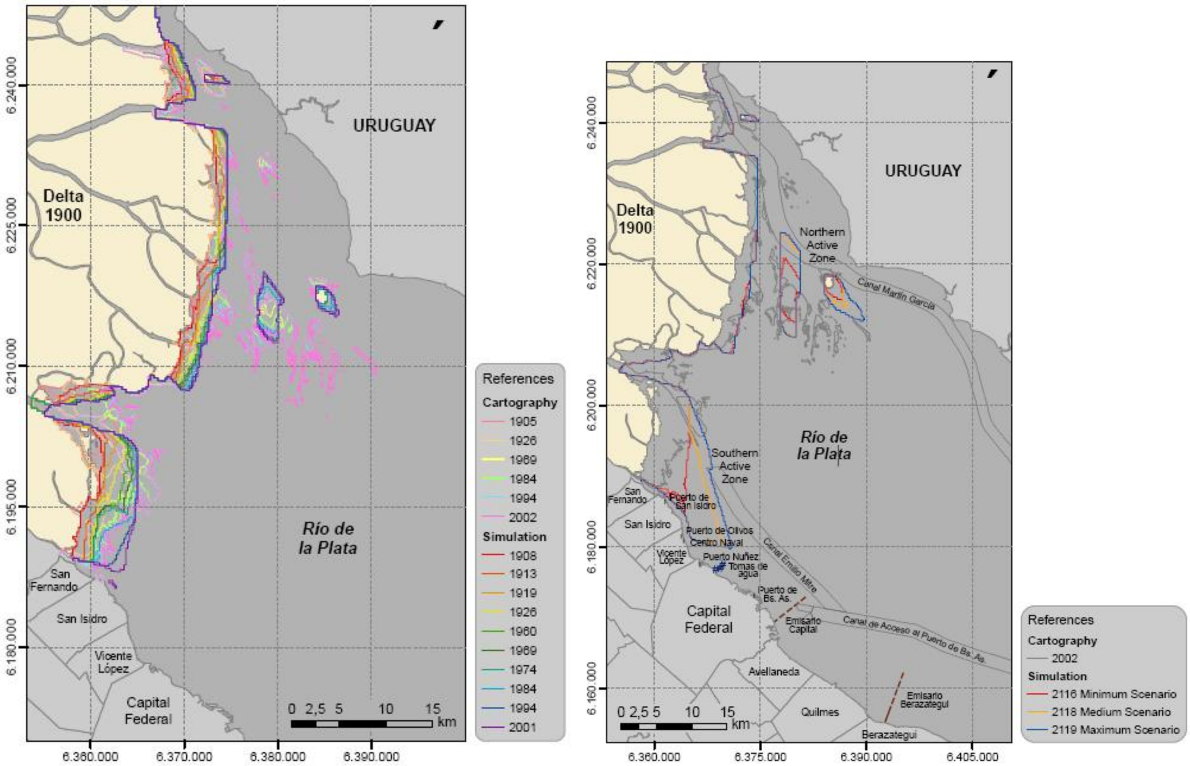


Figure 15 - Advancement of the Paraná delta in the future (l) and compared with the present (r)

7.2 Wind and waves

The Rio de la Plata is such a wide river or, a better way to call it, an estuary that the wind can generate waves of reasonable height on its surface and it is influenced by the wave climate of the Atlantic Ocean. The location choice for the port will partially depend on the wave and wind climate in the Rio de la Plata. This climate will be discussed in the following paragraphs, starting with general data from the Rio de la Plata and followed by more detailed data on two sections of the Rio de la Plata (Wave Climate). All data and calculations can be found in Appendix I: Wind and waves Rio de la Plata.

7.2.1 General wind and waves

For a first understanding of the wave and wind climate in the Rio de la Plata, it is useful to look at the global wave and wind data available.

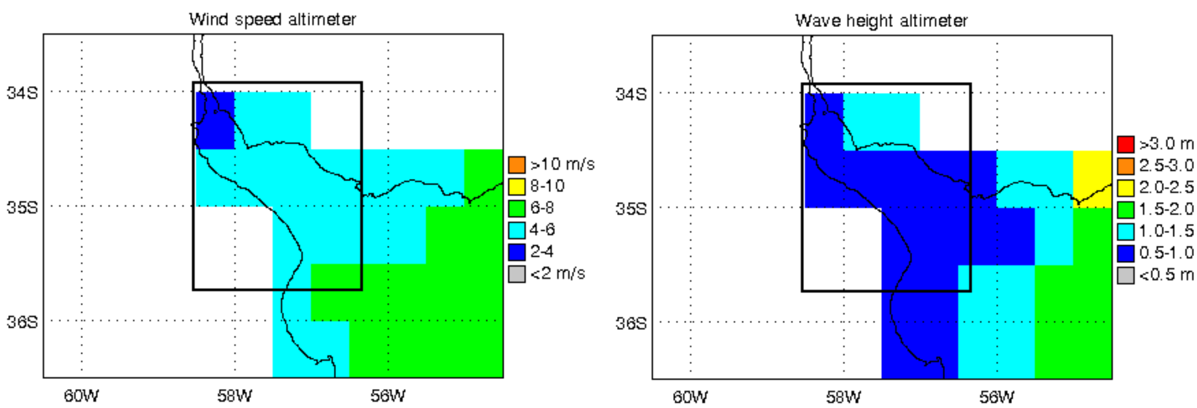


Figure 16 - Wind and waves in the Rio de la Plata

In Figure 16 two charts are visible, the left one displays the wind speeds on the Rio de la Plata and the right one the wave heights. From these charts it is possible to conclude that the average wind speed is 4-6 m/s and the average wave height is 0.5-1.0 metres. Due to its shape and the fading influence of the Atlantic Ocean, the wave climate near the mouth of the Rio de la Plata will differ slightly from the wave climate more land inward. In order to see this difference, data of the western and eastern part will be analysed.

7.2.2 Wind and waves in the western part of the Rio de la Plata

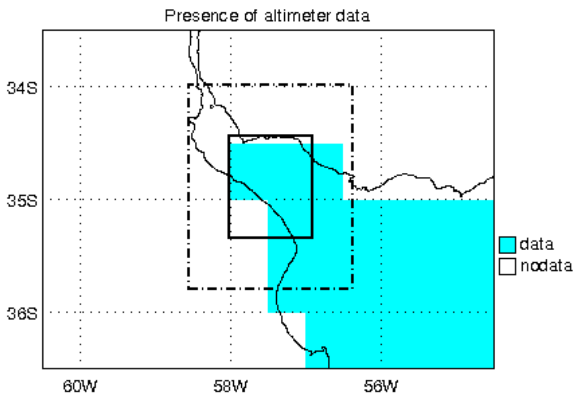


Figure 17 - Location of the western part

Figure 17 shows the location of the western part of the Rio de la Plata. This is the most western location where detailed data was available. A first impression of the wave and wind climate in this part of the Rio de la Plata is given by the wind and wave roses in Figure 18.

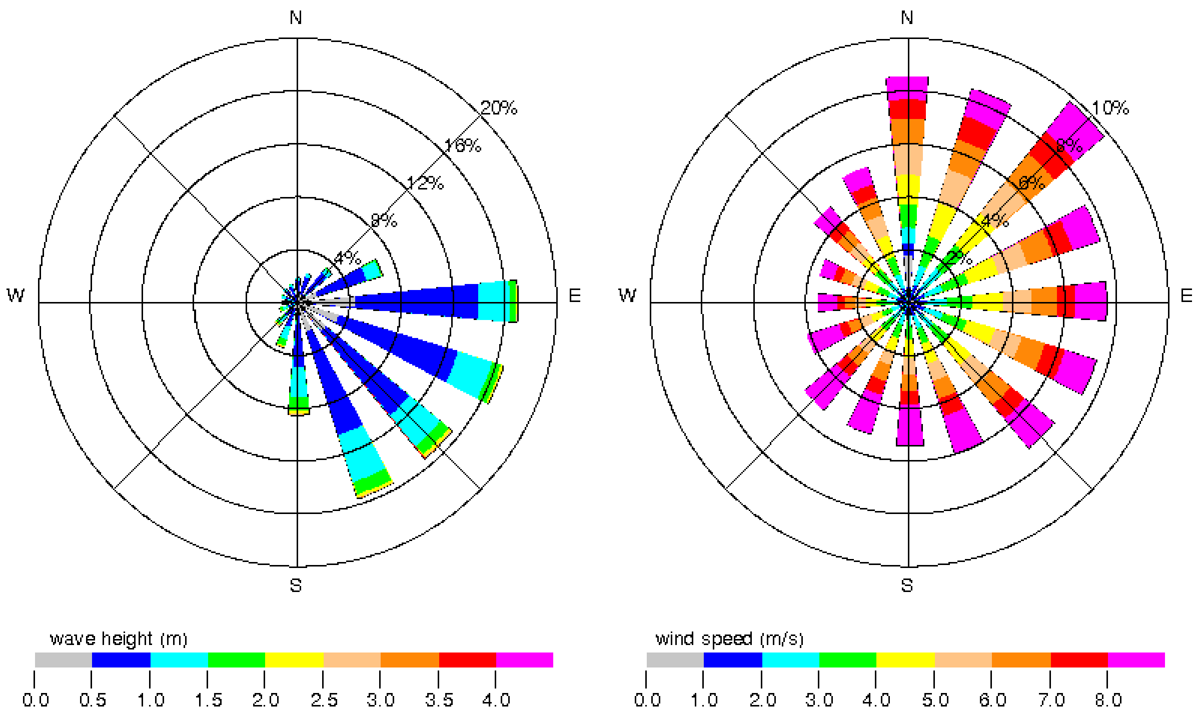


Figure 18 - Wave and wind rose western part

The waves in this part of the Rio de la Plata come mainly from the South-East. This is explained by the fact that most waves are generated on the Atlantic Ocean and the wider part of the Rio de la Plata near the mouth, which are both located to the South-East of this location. The main directions of the wind in the western part are mainly North-East and East.

Using more detailed data, the average wind speed and the average wave data can be estimated, which can be seen in Table 9. Also the percentage of exceedance of the wind speed larger than 25 km/h is given.

Parameter	Value
Average wind speed [m/s]	6.3
Wind speed > 25 km/h [% of time]	28.8
Significant wave height [m]	1.2
Peak period [s]	4.0

Table 9 - Wind and wave data western part

7.2.3 Wind and waves in the eastern part of the Rio de la Plata

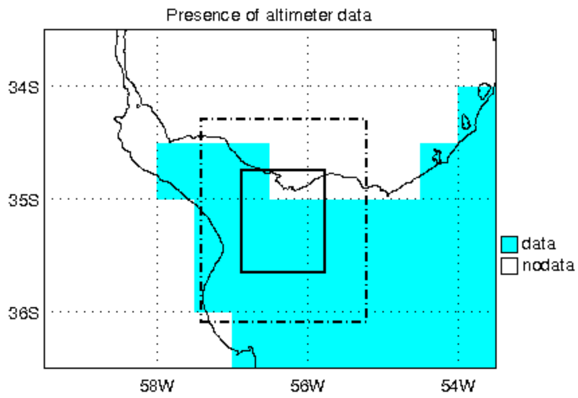


Figure 19 - Location of the eastern part

Figure 19 shows the location of the eastern part of the Rio de la Plata. A first impression of the wave and wind climate in this part of the Rio de la Plata is given by the wind and wave roses in Figure 20.

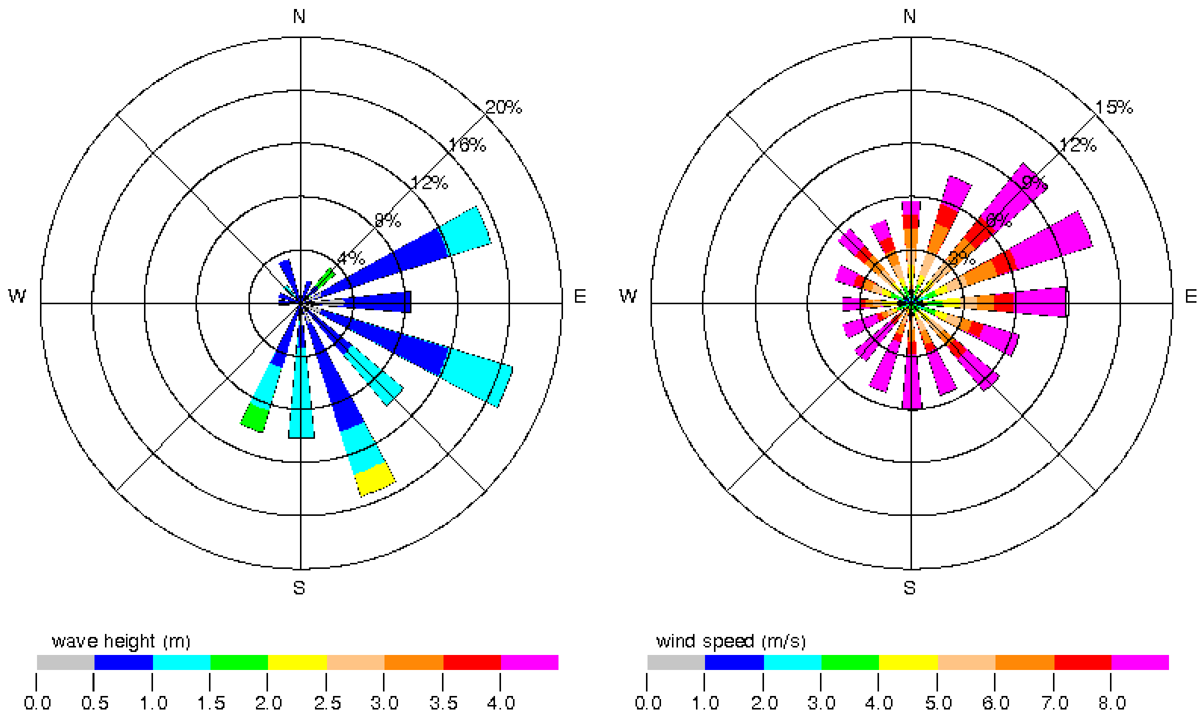


Figure 20 - Wave and wind rose eastern part

The waves in this part of the Rio de la Plata come from a slightly broader direction range than the western part, because the Rio de la Plata is wider in the east. The main direction of the wind in this part is mainly North-East.

Using more detailed data, the average wind speed and the average wave data can be estimated, which can be seen in Table 10. Also the percentage of exceedance of the wind speed larger than 25 km/h is given.

Parameter	Value
Average wind speed [m/s]	6.5
Wind speed > 25 km/h [% of time]	32.2
Significant wave height [m]	1.3
Peak period [s]	4.1

Table 10 - Wind and wave data eastern part

8 Stakeholder analysis

Another important thing for the port location, are the stakeholders, their wishes and demands have to be considered. After conversations with several (former) employees in the nautical sector a list is made of all relevant stakeholders involved in the building and running of a port of transhipment in the Rio de la Plata. In Table 11 an overview is given of these stakeholders. In this table each stakeholder is represented with a numerical value indicating up to what extent they are interested in this port and in what area this interest is, their main goal and to what extent they are able to influence the project. Below the table a detailed description can be found about the stakeholders and their interests. In this table an interest of 5 is high and an interest of 1 is low.

Stakeholder	Interest [1-5]		Goal	Influence [--/-/0/+/++]
Users				
Agricultural sector	5	Financial	Reduce costs of total exporting process	+
Barge Sailors	3	Financial	Increase of sailing market	++
Exporters	4	Financial	Fast done in country	+
Tug boats	2	Financial	Biggest profit	0
Unions	4	Workers	Best work environment	+
Dredging companies				
Hidrovía	5	Financial	Not reducing the depth to be dredged	+
Riovia	4	Financial	Increasing their market	-
Local dredgers	3	Financial	Keeping their market on dredging	-
Competitors				
Transhipment ports	3	Financial	Making highest profit	+
Coastal ports	3	Financial	Improving transhipment	-
Local ports	1	Financial	Keeping their container market	+
Governmental organisations				
Argentina	5	Economical	Improving Argentina's economy	++
Uruguay	3	Economical	Improving Uruguay's economy	0
Neighbouring cities	2	Economical, Environment	Increase cities economy and reduce disturbances	+
Other				
Residents	3	Environment	Reduce disturbances	-
Environmental organisations	4	Environment	Improving the environment	0
Archaeological institutes	3	Environment	Conservation or research of discoveries	0

Table 11 - Stakeholder Overview

Users

Agricultural sector: This is a wide range including all the actors that play part in the export of agricultural products up to the waterfront. This system has as objective to reduce the total costs involved in the export so the products become more attractive and the profit of the involved actors can increase. For the construction of the port they are probably needed as investor.

Barge sailors: The barges are currently being sailed on the Rio Paraná upstream of Santa Fé. Most barges are currently not sailing under the Argentine flag since they are coming from Paraguay and Brazil. With changes of the system the sailing distance and total market might increase, which will influence the demand of barges. Since it is not allowed to sail with a foreign ship between two internal ports Argentine barges should be build.

Exporters: These are the exporters that sail the larger vessels like Panamax size and sail the goods to the rest of the world. Currently these are sailing up to the Rosario area, but with a port of transhipment they have no longer need to sail the Rio Paraná.

Tug boats: Tug boats assist in berthing of the vessels and will have an increase in their market with an increase of larger vessels that could be in need of assistance.

Unions The unions of both the construction workers and the stevedores are very powerful and can order the port employees to seize the activities in the port if a disagreement occurs.

Dredging companies

Hidrovia: Hidrovia, part of Jan de Nul, is the main dredging company of the Rio Paraná and dredges a total length of about 1500 km from the ocean all the way upstream. Their income is based on the toll they ask for ships per NRT, maximum draft and allowable draft. With the creation of a transhipment port the necessary depth to be dredged can be reduced and the tollage will reduce as well. The ground within 250 metres on both sides of the dredged channel is part of the concession of Hidrovia.

Riovia: Riovia is the daughter company of Boskalis and is in charge of the Martin Garcia channel. The building of a transhipment port will reduce their dredging to the Rio Paraná.

Local dredgers: Other local dredgers (as well as some smaller international) also have an interest in the keeping of their market with the arrival of a new port.

Competitors

Transhipment ports:	These include all ports in the Rosario area as well as Nueva Palmira, where currently transhipment is being done from barges to vessels and also have an industry in handling of some commodities.
Local ports:	These include the ports of Buenos Aires and Montevideo which both mainly consist of container terminals. A transhipment port thus will not be a direct competitor.
Coastal ports:	At the moment vessels are partly filled at the Rio Paraná and topped of at coastal ports of e.g. Bahia Blanca. This topping of will no longer be needed, but the total export will not change.

Governmental organisations

Argentina:	The Argentine government is currently paying for some dredging done by different companies. The government will benefit from a reduction in dredging costs and also from an increase of the export in the agricultural sector. The Argentine government currently has strict import rules and is taking measure to increase the local economy by reducing the influence of foreign companies.
Uruguay:	Uruguay is a considerably smaller country then Argentina, and besides having a container terminal in Montevideo their import share is lower as well. For the area between the Uruguayan and Argentine zone of exclusive jurisdiction both parties should get a concession about the port. The building of a port could under no circumstances take place in Uruguay waters or land.
Neighbouring cities:	Cities close to the location of the port gain an increase in their local economy due to the extra work and the passing ships. They could, however, also experiences problems with disturbances of air, view or noise.

Others

Residents: Just as the cities, nearby residents also get problems with disturbances.

Environmental organisations: The construction of the port of transhipment will have a negative influence on the local environment and possibly also influences the currents. It, however, also reduces the necessary dredging which will improve the environment at the Rio Paraná.

Archaeology institutes: If at the construction side historical building or artefacts are found, this could be reduced by research or conversation operations for archaeological purposes.

The influence and interest of each actor are plotted in Figure 21. To the right of this figure the most important stakeholders are listed.

5				Hidrovia Govern. Uruguay Agricultural sector	Govern. Argentina
4		Riovia	Environment	Exporters Unions	
3		Local dredgers Coastal ports Residents	Archaeology	Transhipment ports	Barge sailors
2				Neighbouring cities	
1		Local ports	Tug boats		
	--	-	0	+	++

Interest of stakeholders →

Influence of stakeholders →

Figure 21 - Stakeholder grid

With the help of this figure it can easily be seen what the important stakeholders are. The further to the right and the top, the more the interest of the actors have to be taken into account.

9 Program of requirements

In the program of requirements the demands and wishes for the project are listed combined with the demands of the important stakeholders of the previous chapter. This results in a list of requirements split into functional and spatial requirements that will have to be satisfied in the design and a list of wishes that are optional to take into account in the port design.

9.1 Functional requirements

- The port of transhipment needs to have a transhipping capacity in 2030 of 44.6 mln. MT (Metric Ton) grains, 43.3 mln. MT by-products and 6.5 mln. MT vegetable oil as described in chapter 3.
- The port needs to have a lifetime of 100 years.
- The probability of exceedance for the port and port components is 1/1000 as is calculated in Appendix H: Probability of exceedance.
- Possibility to expand the port to cope with a rising demand during the entire lifetime.
- There needs to be a possibility to temporarily store commodities between unloading and loading.
- Berthing for exporters has to be possible 99% of the year.
- Berthing for barges has to be possible 95% of the year.
- There have to be resting quays for barges during periods of storm when they are unable to sail over the Rio de la Plata.
- Refuelling facilities for tug boats and ocean vessels.
- Overnight facilities for barge sailors have to be available.
- The port has to be built by 2020.
- For construction workers and stevedores good facilities have to be present.
- For construction workers and stevedores good connection to their homes has to be possible.
- Minimal construction and maintenance costs over the designed lifetime.

9.2 Spatial requirements

- The required dredging depth in the Rio Paraná has to be greatly reduced after the construction of the port.
- To assure a good design of the new transhipment port, the existing transhipment ports in Argentina should be involved early in the design process.
- Before building, a scan for archaeological artefacts should be done to prevent delays during the construction phase.
- The port may not be constructed on Uruguayan water or land.

- The disturbance to neighbouring cities and residents should be minimised during the construction and operating of the port.
- The current navigation channels may not be hindered during construction.

9.3 Program of preferences

- A connection to the hinterland.
- If a connection with land is available, the port could have the possibility to be an extension or replacement of the container terminal of Buenos Aires.
- As an island it would be useful if the port is able to provide for its own electricity (preferably green energy).
- As a possible extension it can be considered to do a part of the processing of the commodities, as already happens at some ports upstream on the Rio Paraná.
- Repair facilities for the barges.

10 Location alternatives

After determining the program of requirements for the port, a location can be determined. Within the framework of the Rio de la Plata four locations are chosen to further examine. To achieve a list of possible construction sites it has been determined that a set of locations have to be chosen with significantly different characteristics. Influencing factors in this are: Proximity to the shore, proximity to the ocean, proximity to the Rio Paraná and the use of existing banks. Analyses in the previous chapters give us information about possible construction sites, and accordingly four have been picked. The chosen locations, as shown in Figure 22, differ greatly in accessibility, construction dredging, maintenance dredging and water conditions on which they will later be examined in the Multi Criteria Analysis (chapter 11.1). Below the figure a description is given of the characteristics of every location.

Figure 22 - Overview of all locations

10.1 Variant Banco Inglés

Banco Inglés (the English Bank) is a naturally formed sandbank in the Rio de la Plata (Figure 23). It is located on the Atlantic Ocean side of the estuary just off the coast of Montevideo and outside the zone of exclusive jurisdiction of Uruguay. Water depths on the bank vary from 0.9 to 5 metres making it a very economical solution as far as land reclamation is concerned. The location is also fairly close to the currently existing shipping channels, so that either a dredged canal to the existing channel or the ocean would suffice for making the port accessibly for large draught vessels. The proximity to the open ocean also makes sure that ocean-faring vessels do not have to sail far up the Rio de la Plata to get to the port. Downside of this is, however, that river vessels will have to sail further towards the ocean, where sailing conditions are more difficult.

Another downside of choosing Banco Inglés is that there is no possibility for any land based form of hinterland connection. This complicates the possibility for a future container based extension as replacement for the current port of Buenos Aires. It also means that construction workers and stevedores will experience more difficulties reaching the port than with a land connected port. The port would be solely capable of handling transhipment. The location being as close to the ocean as it is would also mean that the more severe weather conditions would cause the need of stronger sea defence structures such as breakwaters and shoreline protection.

The size of Banco Inglés makes sure that any possible future extension of the port is still possible. Whether it be extra grain terminals or container terminals doesn't really matter as there is plenty space available without causing an obstruction to any current transport routes. The only requirement is that the extension is for transhipment, as there is no possibility for land based transport from the port onward unless significant investments are made in the infrastructure (i.e. a bridge or tunnel connection) to Uruguayan land.

Figure 23 - Location of the Banco Inglés

10.2 Variant Banco Chico

The second chosen variant is located closer to the delta, halfway between the delta and the ocean, and is also located on a naturally formed sandbank (Figure 24). The sandbank called 'Banco Chico' (the Small Bank) at a distance of 16 km to 23 km of the coast of Argentina and is at an average depth of 3 metre below low water over a length of 20 km.

The bank is located parallel and close to the navigation channel and will have very little extra need for dredging of additional navigation channels. By moving further into the Rio de la Plata, the hydraulic conditions improve and will make the port better accessible for push barges, while still having great accessibility for the ocean going vessels. However, the inland vessels still need to sail a fair distance over the over the Rio de la Plata, so they might still be encountering problems with the weather conditions. Also the wave conditions for construction and operation of the port improve, making the construction and berthing conditions saver and less strong shoreline protection and breakwaters will be required. Since the width of the Rio de la Plata is reduced, the current slightly increases and there is also a slight increase in the sedimentation due to the advancing delta. However, since there still is a significant distance from the delta of the Rio Paraná, this won't become a problem in the next century.

Banco Chico has a surface that is larger than the necessary transhipment, so it gives an excellent location for possible extension. However, since a road- or railroad-connection to the hinterland is only possible with the construction of extra infrastructure over or under water, a container terminal will be hard to achieve. Furthermore the distance to the coast is a problem for the construction workers and the stevedores who need to be transported to the artificial island.

Figure 24 - Location of the Banco Chico

10.3 Variant Playa Honda

Playa Honda is shallow underwater plain in the mouth of the Paraná delta (Figure 25). The depth varies from 0 metres near the coast to about 2-4 metres in the middle.

The mouth of the Rio Paraná is located at a distance of about 15 km. For river vessels this will be a good location, because they have to sail only a small distance across the estuary of the Rio de la Plata. Since the location is also at an increased distance to the ocean, the wave climate has become milder and this may, under favourable weather conditions, even enable push barges to reach the port.

For ocean vessels it's harder to reach the port because of the larger distance to the ocean. In comparison with other variants the current navigation channels in the Rio de la Plata, including the Emilio Mitre channel, will therefore have to be maintained and even deepened in order to receive bigger vessels. No new channels will have to be dredged because the port is located at the Emilio Mitre channel.

In comparison with other variants the reclamation costs will be small because of the very shallow water. Because of the small distance to the Paraná the advancing delta may be a problem for this variant. In the future it may even be surrounded by new land. However, there will always be a channel to the port because of the flowing river.

The port will be an artificial island, so there won't be a connection with the land. There is, however, plenty of room for the expanding of the port with more transhipment capacity, however, because of the absence of a connection with the hinterland a container terminal is a problem.

Figure 25 - Location of Playa Honda

10.4 Coastal variant

Another option for a transhipment port in the Rio de la Plata is to locate the port on the banks of the Rio de la Plata (Figure 26). The port will be located on the Argentine coast of the Rio de la Plata, between La Plata and Verónica. The depth of the water ranges from 0 metres at the coast to approximately 4-6 metres at about 7 miles from the coast.

There are two options to make a port at the coast. One way to do it is to create artificial land in front of the coast; the second way to do it is to dig channels and basins into the coast. A balance between these two options is also a possibility.

The main advantage of a port which is connected with the coast is the direct connection to infrastructure on land. This connection is useful during the construction phase and is an easy way for employees to get to the port when it is operational. But the main advantage of a land connection is that it can be used to directly transport commodities to the port over the land. This can be used to transport grain from regions close to the port over land and load it directly onto ocean-going vessels.

In the future the port might expand, due to rising export of grains. Another possibility for expansion is to take over a part of the container export of the port of Buenos Aires, when this port has reached its maximum capacity or is no longer accessible due to sedimentation. The availability of a land connection is an advantage it that case.

Due to the low water depth in the coastal region, the amount of sand needed to create artificial land is lower than a port in the centre of the Rio de la Plata. A disadvantage of this low water depth is the fact that deep access channels will have to be dredged in order to give New Panamax vessels access to the port. This channel will need to have a length of approximately 13 miles from the coast, because there the main access channel of the Rio de la Plata is located.

River going vessels should be able to reach the port without too many problems, although the water conditions depend on the distance from the delta. The more the port is located toward the Atlantic Ocean, the rougher the water gets. Due to its location on the Argentine coast, the main currents of the Rio de la Plata will pass the port from west to east, which could create problems for vessels trying to enter the port.

Figure 26 - Location of the coastal variant

11 Location choice

The location choice, between the four given locations, will depend on a Multi Criteria Analysis (MCA), the costs and risk of each location. After these are assessed, the location will be chosen, depending on the outcome of these analyses.

11.1 MCA

The MCA phase requires us to judge the variant by certain aspects that are deemed important for the location the port will be designed for. The value of each aspect has been determined by cross checking each aspect against each other for importance. The results can be found in Appendix J: MCA criteria location. Table 12 shows the results of the MCA, a 5 is the highest score and a 1 the lowest score. Under the table the motivation for each grade has been noted.

	Durability (8.5)	Sustainability (2.0)	Influence of Advancing Delta (7.5)	Ability to transport by land (10.0)	Accessibility for ocean vessels (13.5)	Accessibility for river vessels (13.5)	Accessibility for workers (2.0)	Construction related dredging (7.5)	Dredging navigation channels (5.5)	Maintenance Dredging (7.5)	Influence of currents (7.0)	Influence of waves (3.5)	Expandability (12.0)	Obstruction for existing traffic (5.0)	**Final score**
Banco Inglés	3	3	5	1	5	1	2	4	4	5	4	2	3	2	**3.19**
Banco Chico	5	3	3	2	3	3	3	4	2	2	3	3	3	2	**2.97**
Playa Honda	2	2	1	2	1	5	3	4	1	1	2	4	3	4	**2.50**
Coastal Variant	4	5	3	5	2	3	5	4	2	1	3	4	4	2	**3.20**

Table 12 - MCA location choice

11.1.1 Durability

Concerning the durability, the biggest influencing factors are the advancing delta of the Paraná, as the sedimentation this involves would swallow the port and make it unusable. On top op that an influencing factor is the rougher wave climate near the ocean, which would be a severe load on the port constructions. These factors make Banco Chico score best, as it is outside of the influence of both the delta and the ocean. The coastal variant is near the shore, where more sedimentation applies, and therefore scores slightly worse. On top of that the coastal variant also experiences influence from land related strains. Banco Inglés is right in the middle of the oceanic rough zone, and therefore scores below the coastal variant on this aspect. Playa Honda is very close to the delta and is therefore in the least durable position.

11.1.2 Sustainability

For sustainability the primary concern is the (harmful) influence on the surrounding environment. This means that the effect the newly constructed port has on the Paraná delta (a rich natural environment) and the amount of allocated sand required for construction is taken into account. All this accounts for the coastal variant to score best, as it is not near the delta, and it is fairly possible to get a beneficial cut/fill-ratio. Playa Honda is expected to be right in the middle of the delta within approximately 100 years, and would therefore affect the wildlife in that system within the prospected lifespan. For both Banco Chico and Banco Inglés there is a significant amount of prospected sand allocation, which makes their score on this aspect go down a bit. Furthermore it has been taken into consideration that the same distance an ocean vessel travels as a river vessel does, is more efficient for the ocean vessel, causing less exhaust per unit of carried cargo. This benefits locations closer to the delta, making the coastal variant score the best over all the considered influences.

11.1.3 Influence of advancing delta

As mentioned before, and in chapter 7.1, the delta of the Paraná is expected to advance further into the Rio de la Plata over the next centuries. It is therefore an important aspect to take into account when designing a civil work that is expected to be used for some time ahead. Locations closer to the current delta are affected sooner, and therefore score lower on this aspect. Locations further from the delta automatically score better. This makes for Banco Inglés to score the best on this, and Playa Honda to score the worst. The coastal location and Banco Chico are at approximately the same distance from the river, and therefore score the same.

11.1.4 Ability to transport by land

With the advancing delta and the need for construction workers and stevedores to reach the port, it's a beneficial aspect to have a connection to land. Moreover that the possible extension into a container terminal requires this to be present, or it would be a futile exercise to construct it. It goes without saying that only the coastal variant really provides for good land connection. From there on Banco Chico and Playa Honda score slightly better than Banco Inglés due to the much longer distance Banco Inglés has from the mainland.

11.1.5 Accessibility ocean vessels

The accessibility for ocean vessels is one of the two primary concerns for the port. It can easily be seen that the most accessible port area is that of Banco Inglés, as it's practically in the ocean and needs very little approach channel in order to become operational. Playa Honda scores the worst as it's all the way down to the delta of the Paraná and ships would have to sail a significant distance before reaching it. In between those locations Banco Chico scores better than the coastal variant, as Chico is right next door to the already existing channel in use for the port of Buenos Aires. The coastal variant, however, would still require a new access channel to be dug, extending the distance required for ocean vessels to reach the port.

11.1.6 Accessibility for river vessels

The accessibility for river vessels is more or less inversely proportional with the accessibility for ocean vessels. Banco Inglés therefore scores badly, as it's difficult for river vessels to travel all the way up the Rio de la Plata during bad weather. Playa Honda, however, is close to the delta, and therefore excellently accessible for river vessels. The coastal variant and Banco Chico score equally and averagely.

11.1.7 Accessibility for workers

In order for workers to have easy access to the port it is required for the port to either have a land connection, or be fairly close to the land so ships can easily reach it. This means that the Banco Inglés variant automatically gets a bad score as the closest Argentine shore (where the workers would have to come from) is 120 km away. The coastal variant is actually on the shore, and therefore gets the highest score for this aspect. Playa Honda and Banco Chico are not on the shore, and therefore not as good as the coastal variant, but they are also not as far away as Banco Inglés and therefore they score higher than that variant.

11.1.8 Construction related dredging

To create the artificial island or shore based port, a significant amount of capital dredging will have to be done. This dredging involves both the dredging of the basins, as well as the land reclamation to create the quay walls and terminal areas. Seeing as all variants require a possible significant amount of capital dredging, none of them score the highest score. Then again, there is not enough difference between the amounts of dredging to really call a notable difference between the variants either. Therefore all variants get an equal score.

11.1.9 Dredging navigation channels

In order to make the port accessible, access channels will have to be dredged. On top of that, the current navigation channels in the Rio de la Plata have to be deepened. Banco Inglés seems to be practically in the ocean already. Also the access channel is rather short and located in an area where the bottom is deep, so this variant scores well. The coastal variants need a long access channel through a shallow area. Also half of the current navigation channels in the Rio de la Plata have to be deepened. The same goes for Banco Chico, but here the access channel is very short. Playa Honda scores the worst, because all the navigation channels of the Rio de la Plata have to be deepened.

11.1.10 Maintenance related dredging

The amount of maintenance dredging is related with the length of the navigation channels. Also the orientation of the channels plays a role: channels perpendicular to the currents will catch more sediment than channels parallel to the currents. Banco Ingles scores the best because of the small length of the navigation channels. Playa Honda and the Coastal variants score the lowest because of the large length of navigation channels for Playa Honda and the cross-current access channel for the Coastal variant. Banco Chico scores a little better because of the short access channel and the moderate length of the navigation channels.

11.1.11 Influence of currents

The figures in chapter 7 show that the currents in the Rio de la Plata are quite constant and not so big over the complete stretch of the estuary. This means that the Banco Inglés and the Banco Chico variants will score well on this aspect. The coastal variant is subject to some coastal currents, and therefore scores slightly less good than the two other variants closer to the ocean. Playa Honda is fairly close to the mouths of the Rio Uruguay and the northern branch of the Rio Paraná. These branches have high flow speeds and cause large currents, making Playa Honda score worse in this comparison.

11.1.12 Influence of waves

For the influence of waves two aspects have been taken into account. Firstly the actual size of the waves, which makes Banco Inglés stand out as the hardest hit variant. Secondly we're looking at the amount of sides affected by the waves. All the offshore variants are subject to attacks from every direction, whereas the coastal variant can be protected more easily seeing as it's only attacked from one side. This means that Banco Inglés scores the worst score, and the coastal variant has the best one.

11.1.13 Expendability

The expandability is affected by two different things. Firstly there is the actual space to put an expansion, which puts only the coastal variant at a slight disadvantage as there is some space limitation along the coastline. All the offshore variants have plenty of space on their respective banks and therefore score well on this part. The second part, however, puts things into a different perspective, as the offshore variants cannot be expanded into being a container port in the future whereas the coastal variant can. The combination of the two puts the coastal variant slightly ahead of the other three variants.

11.1.14 Obstruction for existing traffic

The obstruction for traffic is not only influenced by the actual position of the variant, but also by the transport streams it generates over the Rio de la Plata. The only variant that doesn't influence anything is the Playa Honda variant. The inland vessels heading for Banco Inglés cross with the routes for the Montevideo port, and Banco Chico and the coastal variant cross with the route to Buenos Aires. Furthermore, Banco Inglés is practically located on top of the anchor place for Montevideo. All this puts only Playa Honda ahead as scoring well on this aspect, the others score significantly worse.

11.2 Cost Analysis

In Appendix K: Location costs analysis the costs that differ over the variants are calculated. A summation of all costs is given in Table 13. It is a summation of all cost that differ in all four locations and costs included in all ports (e.g. port construction costs) are excluded. For all annual costs the 100 year lifetime of the port is used recalculated to the year 2020 with the use of the Net Present Value. Included are the costs to transport workers to the island over the lifetime of the port, the costs to create and maintain breakwaters, the costs for the initial reclamation of the artificial island and the dredging of the basins. Besides these also the capital costs for deepening the channel and the annual costs for maintaining this new depth.

Since the port is designed as an optimisation of the entire export system, also the shipping costs are calculated, which are the costs that the ships are making for the sailing of a set boundary between the Rio Paraná and the ocean. For the different locations the sailing distance for river and ocean vessels change and having different costs per km, the total shipping cost also differ between locations. The total lifetime costs, including these shipping costs is also given in Table 13.

	Banco Inglés	Banco Chico	Playa Honda	Coastal Variant
Transport of workers	94.7	86.5	24.0	0.0
Breakwaters	107.7	70.7	31.5	35.4
Construction Reclamation and Dredging	207.3	197.2	199.8	212.5
Channel Capital Dredging	505.4	2106.7	3035.8	2180.6
Channel Maintenance Dredging	51.2	760.6	1387.0	1740.6
Total lifetime costs	**966.3**	**3221.7**	**4678.1**	**4169.0**
Shipping transport	861.7	726.0	665.6	737.6
Total lifetime costs incl. shipping	**1828.1**	**3947.6**	**5343.6**	**4906.6**

Table 13 - Total lifetime costs (in million USD) of port and shipping transport

11.3 Risk assessment

A well substantiated choice for a location for the port can only be made after a risk assessment has been made. Per possible location the risks will be described.

11.3.1 Banco Inglés

- **Shipwrecks; could cause additional construction costs**
  - On the nautical charts shipwrecks are shown on Banco Inglés. These wrecks are covered by the riverbed, but might be revealed when the access channels and basins for the port will be dredged. If a wreck is encountered, this will have to be removed first in order to continue construction, which will generate extra costs for the port construction.
- **On the Uruguayan side of the border; Uruguay might forbid the port**
  - Banco Inglés is located in the Rio de la Plata on the Uruguayan side of the border. Although it is outside the area of exclusive jurisdiction of Uruguay, it may cause severe political problems because Banco Inglés is so close to Uruguay.
- **Bad weather conditions; could result in bad accessibility for the port**
  - Banco Inglés is the location which is closest to the Atlantic Ocean and thus subjected to the influences of the wave and wind climate of the ocean. This could result in worse weather conditions than the other locations and thus the port could be more often inaccessible for inland vessels.
- **Interference with the existing container traffic; could cause delays for inland/ocean vessels**
  - The inland traffic will cross the access channel of Montevideo, which could cause delays for inland vessels and container vessels.

11.3.2 Banco Chico

- **Shipwrecks; could cause additional construction costs**
  - Like Banco Inglés, some shipwrecks are shown on the nautical charts of Banco Chico, causing the same problems as Banco Inglés could encounter.
- **In shared territory of Argentina and Uruguay; Uruguay might cause problems**
  - If the port is located on Banco Chico, the port is outside the area of exclusive jurisdiction of Argentina and Uruguay has a say if the port is being build or not. However, the port will be closer to Argentina than to Uruguay and on the Argentine side of the border, so the expected problems with Uruguay won't be major.
- **Bad subsoil; could cause additional construction costs**
  Lack of geological surveys in the Rio de la Plata makes it difficult to assess whether the subsoil is suitable to support the port island. When the subsoil can't support the island, either the subsoil has to be improved or removed till better soil is available, making for extra construction costs for the port.
- **Interference with the existing container traffic; could cause delays for inland/ocean vessels**
  - Just like Banco Inglés, the routes for the transhipment port and container port interfere.

11.3.3 Playa Honda

- **Close to Paraná delta; could reduce the life time of the port**
  - Playa Honda is close to the Paraná delta, this delta is known to grow into the Rio de la Plata. The projections of this growth in chapter 7.1 show that the life time of Playa Honda will be limited due to the growth of the delta.
- **In shared territory of Argentina and Uruguay; Uruguay might cause problems**
  Playa Honda has the same problem as Banco Chico, because it is also outside the area of exclusive jurisdiction of Argentina, but just like Banco Chico, the expected problems won't be major.

- **Bad subsoil; could cause additional construction costs**
  - Just as Banco Chico, it is not certain what the subsoil consists of.

11.3.4 Coastal Variant

- **Bad subsoil; could cause additional construction costs**
  - Just as Banco Chico, it is not certain what the subsoil consists of.
- **Interference with the existing container traffic; could cause delays for inland/ocean vessels**
  Just like Banco Inglés, the routes for the transhipment port and container port interfere.

11.4 Conclusion

In Table 14 the conclusions of the previous chapters are combined. By dividing the score of the MCA by the total costs or the total costs including the export system, two scores are acquired on which basis the conclusion for the optimal location can be made.

	Banco Inglés	Banco Chico	Playa Honda	Coastal Variant
MCA score	3.19	2.97	2.50	3.20
Lifetime costs [in mln. USD] (excl. shipping)	966.3	3221.7	4678.1	4169.0
MCA score/Costs (excl. shipping)	**33.0**	**9.2**	**5.3**	**7.7**
Lifetime costs [in mln. USD] (incl. shipping)	1828.1	3947.6	5343.6	4906.6
MCA score/Costs (incl. shipping)	**17.4**	**7.5**	**4.7**	**6.5**

Table 14 - MCA Conclusion

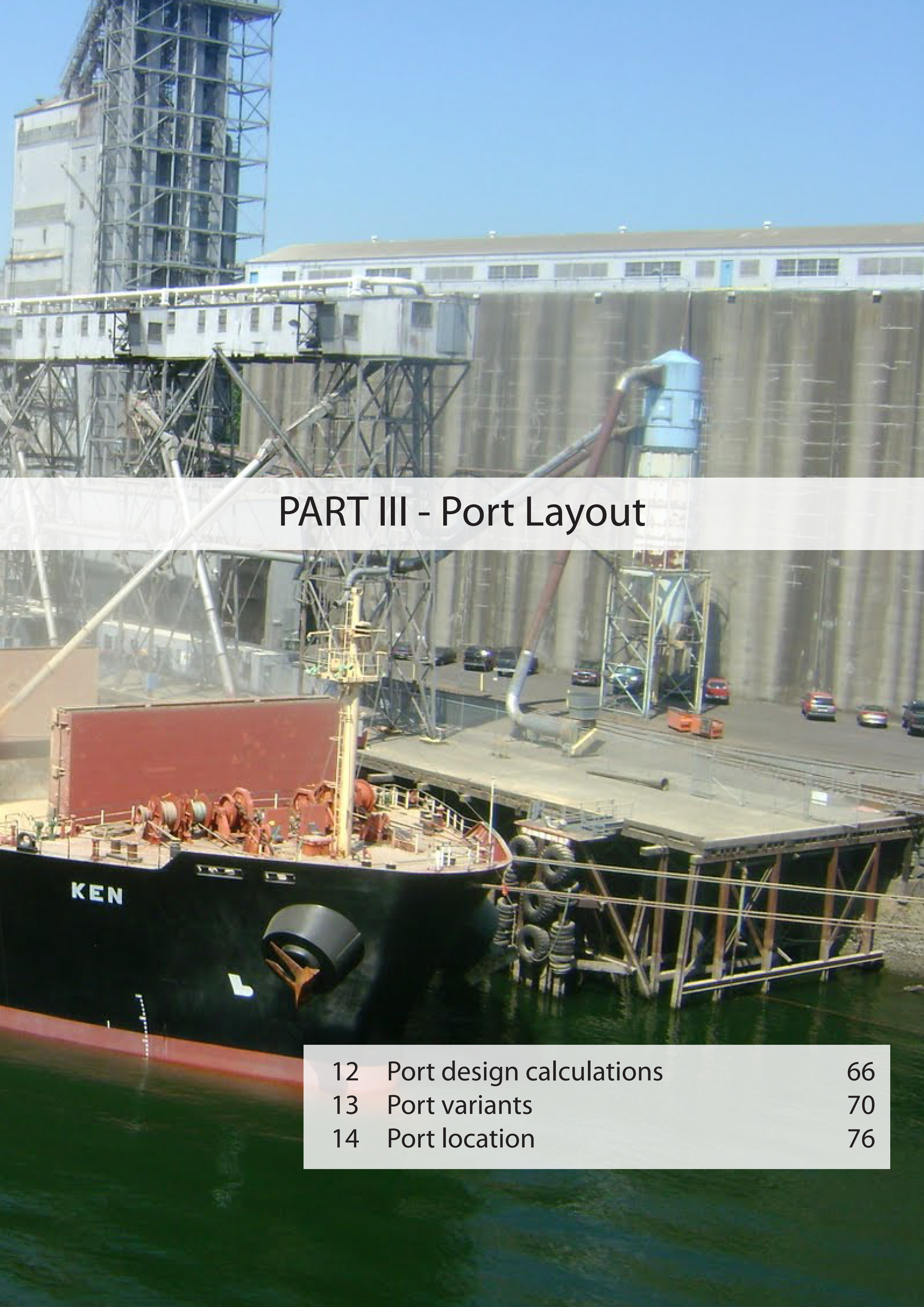
As can be seen in the table, the MCA score for Banco Ingles and the Coastal Variant are the highest, followed by Banco Chico and Playa Honda with still acceptable scores.. The costs on the other hand differ greatly and Banco Inglés is, mainly due to the dredging costs, the cheapest option. Including the shipping costs, the costs of the different locations converge a little as Banco Inglés needs barges to sail a significant distance over the Rio de la Plata.

Looking at the MCA Score/Costs ratio (including shipping costs) Banco Inglés has the best score, followed by Banco Chico, the Coastal Variant and Playa Honda. Even though this would conclude Banco Inglés as best location, the risk assessment changes this result.

Due to its distance of the coast of Argentina the work environment for Banco Inglés is very different. Stevedores have to make a long trip and it will not be possible to return during the week. They will have to stay overnight on the island and will have to rest the week afterwards, making the total demand on stevedores higher. Even worse are the political problems that arise at Banco Inglés as it is not located on Argentine territory, but in Uruguayan waters, making the construction of an Argentine port in the current political situation impossible. As a third downside the ship wrecks are mentioned, which are significantly higher in number then at Banco Chico.

As a conclusion not Banco Inglés but Banco Chico is chosen as location for the port of transhipment. Having an average score, average construction costs, good shipping costs and no big risks makes it the best of those four locations.

For the chosen location the size of different port components is calculated. Six global port layouts including these components are designed and a decision is made for the most ideal. For this layout the location and orientation are subsequently optimized.



PART III - Port Layout

12 Port design calculations

Before a port can be designed, first some calculations have to be made. It is necessary to know how large the storage area is, how many berths are necessary and the length of the berths and the area for other facilities, as well as the basin size and channel width and depth.

12.1 Calculation of berths

With the use of queuing theory the number of berths for both the inland basin and the ocean going basin are calculated. By first calculating the number of ships, the inter arrival time and inter arrival rate are found. Using the equipment listed in Appendix L: Port equipment, the service time and service rate are calculated. With this information the number of berths can be calculated with the use of the queuing theory. In the last paragraph, the dimensions of the berths and depth of the basin are calculated.

12.1.1 More detailed calculation of the fleet

The detailed calculation is started with calculating the number of vessels that will be using the port every year. Using the predicted throughput in 2030 of 94.4 million MT and the estimated grain capacity per type of vessel that was made in chapter 5.3 (and using the stowage factors in Table 62) and also the used assumption of the fleet, the number of vessels per year are calculated and listed in Table 15.

Inland Fleet	Grain Capacity [MT]	Vessels per year	
Barges	5,619	**100%**	16,801
Coasters	2,718	**0%**	0
Ocean Going Fleet			
Handymax	30,426	**5%**	71
Panamax	50,710	**40%**	567
New Panamax	81,136	**54%**	765
Capesize	101,420	**1%**	14

Table 15 - Estimated number of vessels

12.1.2 Calculation of inter arrival and service rate

The arrival rate can now easily be calculated by dividing the number of ships through the number of hours per year. As listed in the program of requirements, the port should be operational 99% of the year. This is similar with 360 days per year and 24 hours per day, as listed in (Ligteringen, 2000). The inter arrival time can be calculated by dividing the numbers of ships by the number of hours per year.

The service time is calculated by using the equipment of Appendix L: Port equipment and adding to this the berthing and unberthing time. For the inland fleet a total of unberthing and berthing time of 1 hour is used and for the ocean going fleet a total of 4 hours is used, this adds up to a total of 4 hours (Thoresen, 2010). The results can be seen in Table 16.

	Ships per year	Inter Arrival Time $[1/\lambda]$ [h]	Inter Arrival Rate $[\lambda]$	Service Time $[1/\mu]$ [h]	Service Rate $[\mu]$
Inland Fleet	16,801	0.51	**1.9**	5.5	**0.18**
Ocean Going Fleet	1,417	6.1	**0.16**	22	**0.046**

Table 16 - Inter arrival and service rate

Since the distribution of the inter arrival rate is not known, it is advised to use the Negative Exponential Distribution (M) (Groenveld, 2001). The service rate is distributed as an Erlang-K distribution (E_k), in which k is the number of added negative exponential distributions. The E_2 is chosen, as it has a clear average compared to the E_1, but still has more variation then the higher order Erlang distributions to show the difference between the different vessels.

12.1.3 Queuing theory

As a last step before applying the queuing theory the maximum average waiting time is needed. As also assumed in (Bosch, 2000) this is taken as 0.15 in units of average service time.

The utilisation can be calculated by dividing the inter arrival rate with the number of berths and service time:

$$u = \frac{\lambda}{n \cdot \mu}$$

In Table 17 and Table 18 for different number of berths the utilisations is calculated and in table IV in (Groenveld, 2001) the waiting time can be read. Using the maximum waiting time of 0.15 as given above, the number of required inland berths is 13 and the number of required ocean going berths is 6.

Number of berths	Utilisation	Waiting time	Waiting time [h]
12	0.89	0.18	0.35
13	0.82	0.14	0.27
14	0.76	0.06	0.11

Table 17 - Queuing theory for the inland berths

Number of berths	Utilisation	Waiting Time	Waiting time [h]
5	0.71	0.29	6.33
6	0.59	0.06	1.21
7	0.50	0.02	0.43

Table 18 - Queuing theory for the ocean going berths

12.1.4 Berth dimensions

The calculation of the dimensions of the basins is similar with the calculation that was made in Appendix K: Location costs analysis. Again the length of the berth is calculated by $1.1 \cdot L_{ship}$ and the width of the basin by $8 \cdot B_{ship} + 50$ for the inland basin and $5 \cdot B_{ship} + 100$ for the ocean going basin. For the depth a detailed calculation of the squat is now done and included in Appendix M: Channel design. The total dimensions of the berths are listed in Table 19.

Basin	Number of berths	Length/berth [m]	Width [m]	Depth [m]
Inland vessels	13	110	242	5.6
Ocean going vessels	6	403	345	16.3

Table 19 - Basin dimensions

12.2 Channel width

The port will be reached by the vessels via access channels. In the port different basins for inland and ocean going vessels are calculated and these basins will have separate access channels to avoid interference between the inland and ocean going vessels. In Appendix M: Channel design the width of these channels is calculated. The access channel for the inland vessels will be a two way channel of at least 254 metres width. For the ocean vessels a one way access channel of at least 230 metres width will be sufficient.

12.3 Calculation of storage area

For calculating the necessary storage area the assumption is made that the storage is 5% of the throughput (WorleyParsons Westmar Corp., 2008). The storage is split into the grains and the oils as both will be stored in different ways. A calculation of the silos and tanks is given in Appendix L: Port equipment the resulting capacity and area is given in Table 20.

Storage of grains	4,395,000	MT	**Storage of oils**	325,000	MT
Ton/Silo	9,426	MT	**Ton/tank**	11,584	MT
Number of silos	467	Silos	**Number of tanks**	29	Tanks
Area of silos	206,559	m^2	**Area of tanks**	12,827	m^2

Table 20 - Area of silos and tanks

The total necessary land surface for the port facilities exists on average for 60% of storage facilities (WorleyParsons Westmar Corp., 2008) making the total land area approximately 366,000 m^2.

12.4 Calculation of other facilities

Next to these main port components also some smaller facilities are calculated.

12.4.1 Tug boats

As written guidelines for the number of tug boats are not available, information was given by a local tugboat owner (Boot, 2012). Under normal weather conditions a New-Panamax vessel with non-hazardous cargo, two tug boats will be sufficient. For the unberthing for similar conditions a single tug boat will be sufficient. At times that one of the tug boats is being repaired, a backup tug boat should be available to not increase the waiting times.

As a conclusion of these guidelines 4 tug boats are chosen, so it is possible to unberth and berth at the same time and also have a tugboat as a backup. In heavier weather conditions it will also be possible to use all 4 tug boats for the berthing or unberthing process.

The total bollard pull is derived from the ship size by means of the following expression (Ligteringen, 2000) in which Δ is the ship displacement.

$$T_B = \frac{\Delta}{100,000} \cdot 60 + 40$$

For a Capesize ship of 200,000 DWT, this gives a total bollard pull 160 ton. This can be achieved by 2 80-ton tug boats. As an example the dimensions of the tug boats by Delta Marine are used, which have a length of 37.5 m, giving a total necessary berth length of 48 metre per tug (Marine). At the berths of the tug boats, also land surface has to be available for their equipment. A land surface of 465 m^2 is needed for two tugs, giving a total of 930 m^2 for all four (PB Towage, 2009).

12.4.2 Ferry terminal

Since a ferry is used to transport the stevedores to the land also a terminal has to be taken in the design. A small ferry with the capacity of 260 passengers has a length of about 30 metre, giving a berth length of 43 metre (Tacoma Scene, 2006).

12.4.3 Smaller facilities

Other facilities such as a place to sleep and eat, as well as the port office are in size negligible compared to the storage area.

12.5 Expandability

In the design of the port, the expandability is also taken into account. Although projections further then 2030 are unrealistic with the method used in chapter 3 it gives an impression about the possible rate of expansion. By extrapolating the trend lines given in Figure 6, Figure 7 and Figure 8 up to 2050, there is an increase of cargo of 44% compared to the earlier listed projections of 2030. This also results in a traffic increase of 44% and, by taking the assumption that the unloading and loading capacity of the vessels will be sustained at the current rate, the number of berths will increase. The number of inland berths will increase up to 17 (+4) and the number of ocean going berths will increase to 7 (+1). The increase of necessary land surface is expected to be possible by more efficient use of the storage area, since the calculation given in Appendix K: Location costs analysis is conservative and a higher throughput/area is possible.

Although these numbers are subject to more parameters than given above, this gives an impression of what could be happening in the 30 years after the construction of the port and will be partly taken into account in the design.

13 Port variants

One of the most important aspects of a port is its layout, because it is the basis for a detailed port design. After the calculations for the port design have been made, a layout can be chosen.

13.1 Boundary Conditions

To come to a good port layout first the contents of the port have to be determined. This means the amount of berths will have to be known for ocean going vessels, river barges, tugboats, and ferry services and the amount of required storage area and space for other facilities will have to be known. After this a puzzle will have to be made to give all the berths enough space to handle their respective ships in an economical fashion. The data required to make the puzzle is presented in Table 21. The explanation for the components' dimensions can be found in chapter 12.

Component	Quantity	Dimension
Berth ocean going vessels (Basin width)	6	L = 403 m (W = 345 m)
Berth inland vessels (Basin width)	13	L = 110 m (W = 242 m)
Berth tugboats (Basin width)	4	L = 48 m (W = 345 m)
Berth ferry vessel (Basin width)	1	L = 43 m (W = 345 m)
Land surface		366,000 m^2

Table 21 - Port Components

When making the port layout it is assumed that berths are allowed to share a basin, as long as the ship using the basin is not hindered by a ship parked at another berth. Furthermore it has been attempted to make the entry channels be affected by wave and current conditions as few as possible. It has been determined that the use of jetties is preferred over the use of quay walls. This is due to the fact that space is not an issue for the artificial island, and it is more expensive to build a quay wall in weak ground than it is to have a sloped side of the island. The jetty will be built over the slope until the required depth is reached where the ships can dock. The following four layout designs have subsequently been made.

13.2 Layouts

Now that the boundary conditions have been determined it is possible to look into different proposals for port configurations.

13.2.1 Port 1

The first port design houses the barges inside the artificial island, and has the ocean going vessels berth outside this protective area. The barges are unable to dock in the port with the expected wind and wave conditions and therefore require a protected basin to make port. It is most cost effective to combine the protection area with the berthing spaces as it would be very expensive to make separate breakwaters for the cause of protecting the berths. Some breakwater structures will still have to be constructed in order to protect the berths. The land mass in this variant is, however, fully functional in either a breakwater purpose or land bound port facilities. The ocean going vessels will be attached to the "mainland" through similar jetty constructions, where the corners will be placed in a perpendicular fashion as to make optimal use of the required basin space. An overview is given in Figure 27.

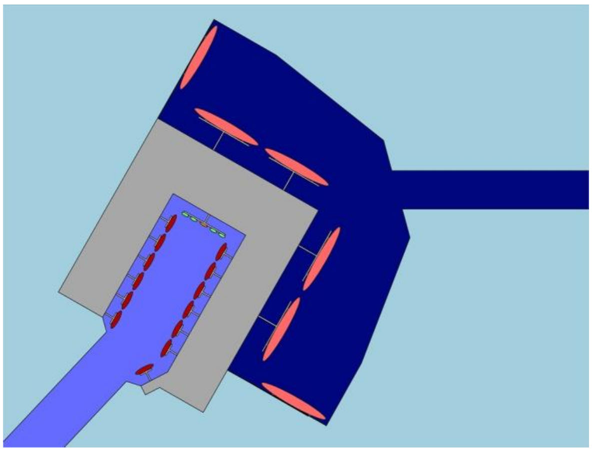


Figure 27 - Port 1 layout

13.2.2 Port 2

The design of port 2 is based on a similar philosophy as that of port 1. The barges are docked in a sheltered basin whereas the ocean going vessels are parked outside the port structure. The main difference between the two is that the storage area is made in a more square form, and the ocean going vessels have a more condensed layout. The corner jetties now house two ships, making all the ocean going vessels be close to the centred storage area. An overview is given in Figure 28.

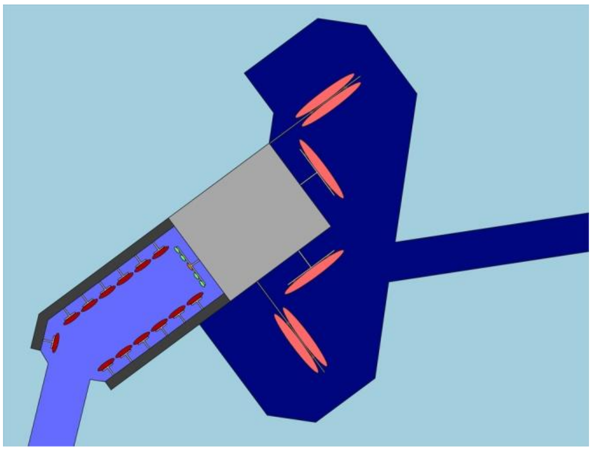


Figure 28 - Port 2 layout

13.2.3 Port 3

The layout of port 3 does carry the same philosophy for the inland vessels as the previous two layouts did, yet for the oceangoing vessels it deviates. In this variant the ocean going vessels are given a sheltered basin as well, for the situation where the outside wave and wind conditions would not allow for them to berth outside the port. The towboats are given shelter in between the ocean going vessels in this variant as it has now become a sheltered basin. An overview is given in Figure 29.

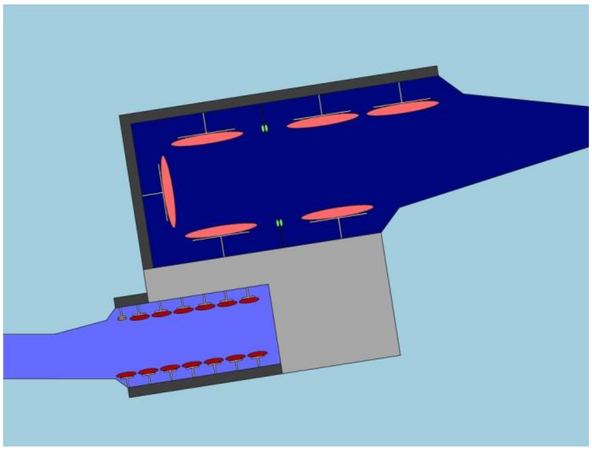


Figure 29 - Port 3 layout

13.2.4 Port 4

The layout for the fourth port design has been based on making the transport routes between barges and ocean going vessels short. This means a more longitudinal orientation of the storage area has been chosen, and the basins are duly affected. The barges are still protected and share their basin with the tugboats and the ferry berth, and the ocean going vessels are berthed in an L shaped configuration on the canal side of the structure. An overview is given in Figure 30.

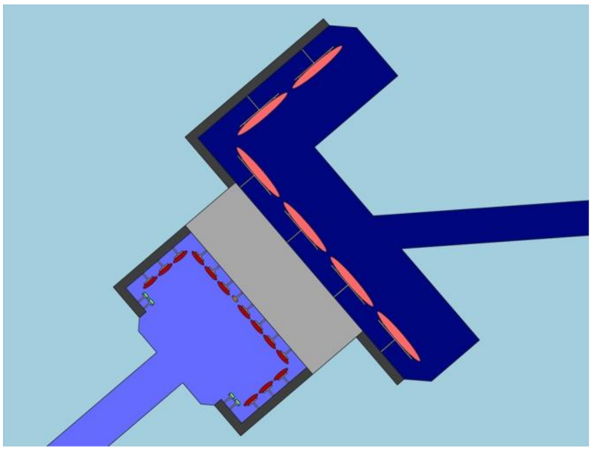


Figure 30 - Port 4 layout

13.2.5 Port 5

The fifth port design is also designed mainly for ideal cargo transport distances. The barges are all connected straight to the storage area and therefore arriving goods do not have to travel much distance in order to be stored. Furthermore the ocean going vessels are all connected to the storage area via jetties extending into the Oceanside basin. The storage area is mainly made up of the triangular areas next to the barge basin, and completed by the area between the ocean basin and the barge basin. This means the barges berth fairly close to the ocean vessels and do not have to travel long distances to be transhipped. An overview is given in Figure 31.

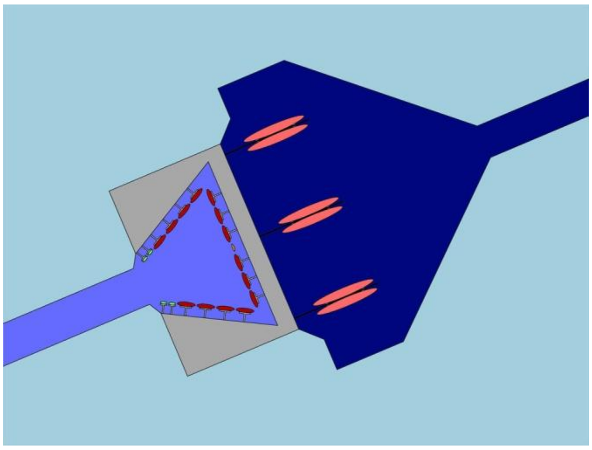


Figure 31 - Port 5 layout

13.2.6 Port 6

In the design of port 6 the main philosophy is also based on minimising the distance needed to travel between the various components of the transhipment port. The storage area here is placed more towards the ocean going vessels than to the barges, and the orientation of the ocean vessels is more alongshore than in the previous variant. An overview is given in Figure 32.

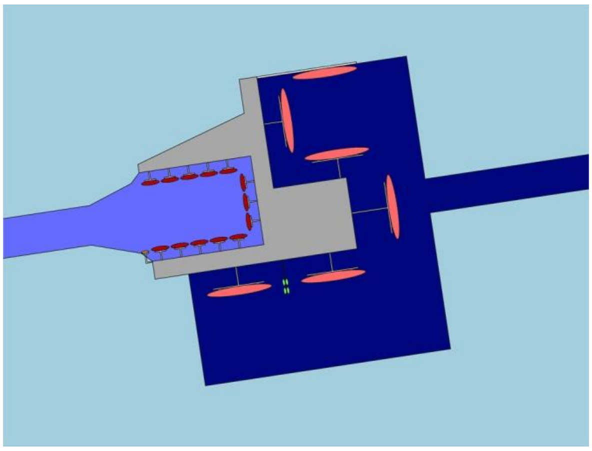


Figure 32 - Port 6 layout

13.3 Dredging/Reclamation volumes

To properly assess the difference between the variants it is relevant to look at the amount of dredging and reclamation that has to be done for each one. To attain good values for this a 3D model of the bathymetry has been made in the 3D rendering software SolidWorks. Subsequently simplified 3D models of the ports have been made and placed in this bathymetry. By using the subtract (for reclamation, subtracting the bathymetry from the port gives the amount that still needs to be reclaimed) and common (for the basins, the amount of volume the water bodies have in common with the bathymetry gives the required volume to be dredged) features the volumes of required sand movement have been determined and presented in Table 22.

Variant	Reclamation [m3]	Dredging [m3]	Moved Volume [m3]
Port 1	4,700,030	22,759,430	27,459,460
Port 2	4,943,030	24,356,640	29,299,670
Port 3	7,185,570	17,417,430	24,603,000
Port 4	6,893,770	19,178,010	26,071,780
Port 5	4,578,660	20,850,480	25,429,140
Port 6	4,415,000	27,190,480	31,605,480

Table 22 - Moved volume of dredged material

13.4 MCA

To make a choice between the various port designs an MCA has been chosen to be used as decision tool. The criteria that have been determined as important for the port layout and their according weight are presented in Appendix N: MCA port layout.

Having determined the weight factors of the contributing aspects grades can be given to the different port layouts, according to their description. The intent of the MCA is that a general layout is chosen, and that good aspects of a specific design are used in the "winning" layout as to optimise it into a best possible compromise. Table 23 shows the result of the constructed MCA sequence.

	Expandability storage area (1.5)	Expandability inland berths (4.5)	Expandability ocean berths (2.5)	Availability (3.5)	Cargo efficiency (5.0)	Dredging (7.0)	Reclamation (4.0)	**Final score**
Port 1	3	5	2	5	7	4	6	**4.88**
Port 2	6	5	4	3	5	3	5	**4.21**
Port 3	8	7	3	8	2	8	2	**5.46**
Port 4	8	8	6	5	7	6	3	**6.05**
Port 5	7	2	4	3	7	5	7	**4.93**
Port 6	3	6	2	6	8	2	8	**5.13**

Table 23 - MCA layouts

It shows that, despite requiring a relatively large amount of reclamation work, Port 4 scores among the best on nearly every considered aspect. Its only other weak spot is the availability, but due to the covered nature of the ocean berths in Port 3 it is impossible to adopt that into Port 4's design. Another variant that has port 4 beat on the availability aspect is Port 6 due to the sheltered nature of some of that variant's berths. This aspect is somewhat importable into Port 4's design. After adding this addition and inserting a turning basin for the ocean going vessels the definitive layout is presented in Figure 33.

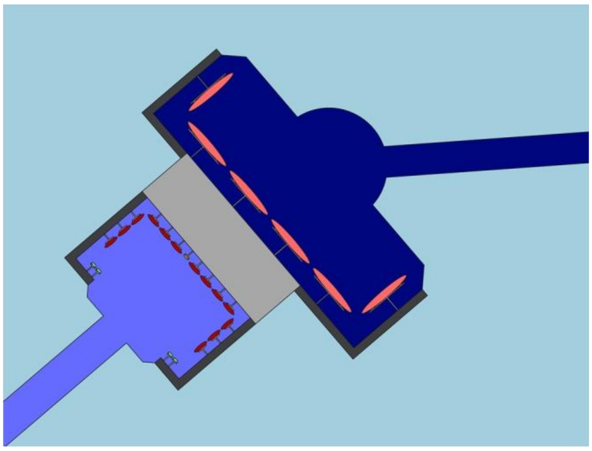


Figure 33 - Final port layout design

14 Port location

The final stage in the location optimization is to give the port its definitive location and orientation on the bank. This process is mainly based on a trial-and-error approach in which the rotation and placement are tried in such a way that dredging costs are minimized, and in the meantime the orientation of the access channels does not become too hard to construct. For the calculation of the dredging amount the same method has been used as in chapter 13.3 where the required dredging volumes for the ocean basin (including access channel), the river basin (including access channel) and the reclamation works are determined independently. The result of the trial and error phase is the orientation as shown in Figure 34.

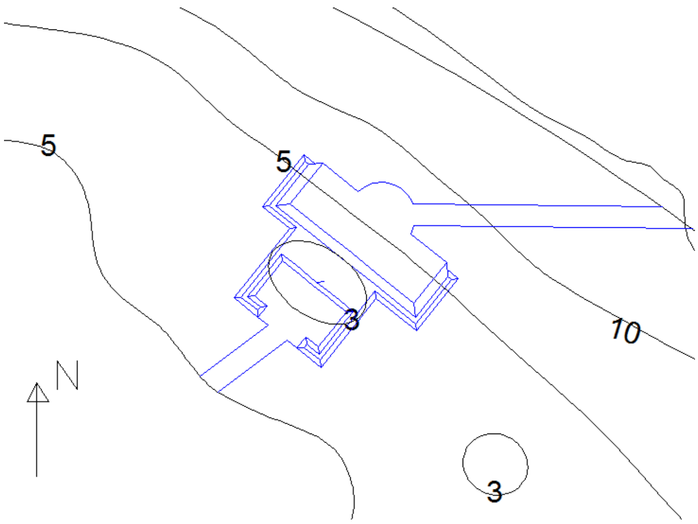


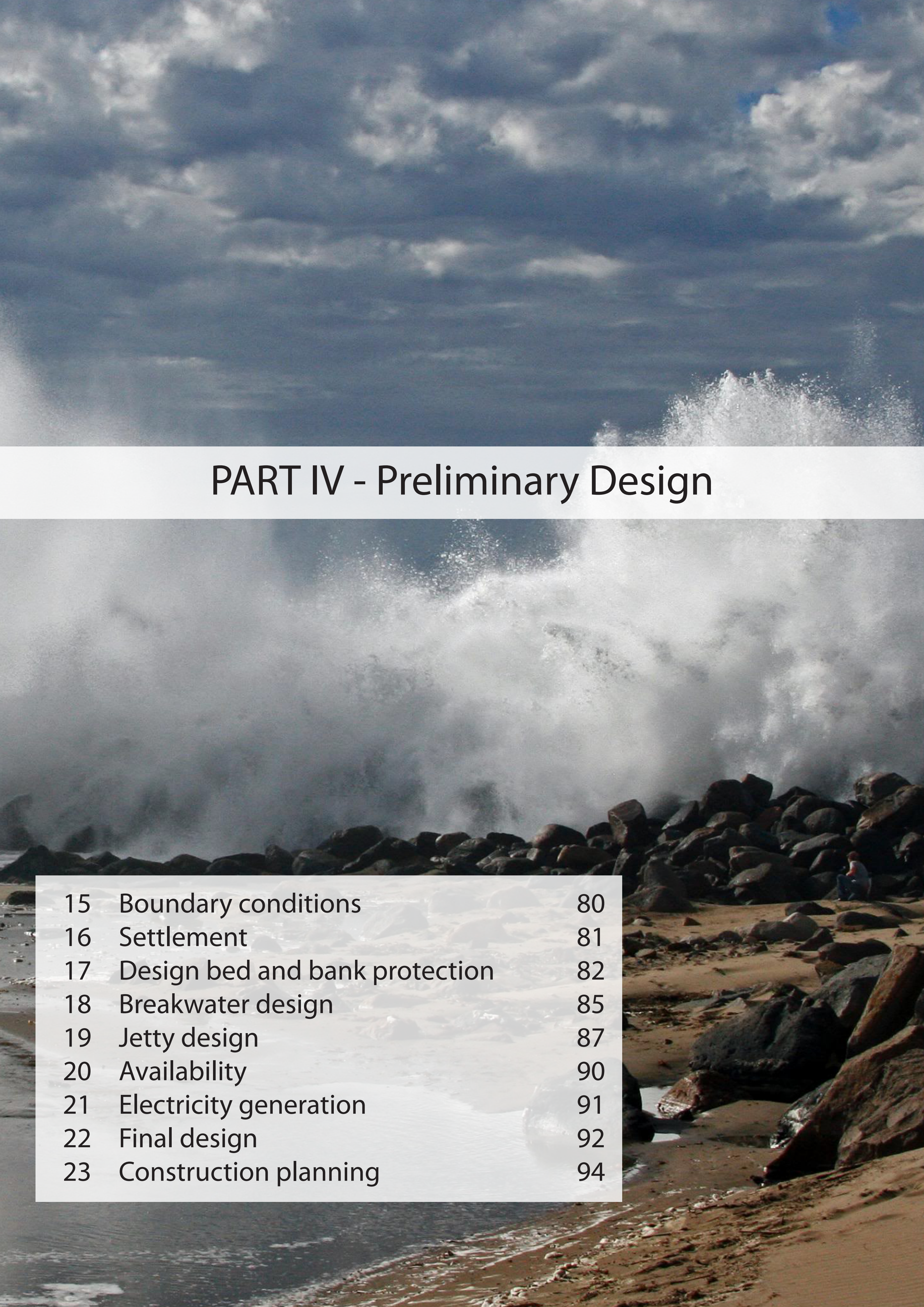
Figure 34 - Definitive orientation

The main philosophy behind this orientation is that as much of the artificial island as possible is located on the highest part of the bank, so that reclamation volumes can be minimized. This is desirable as the costs for reclamation are about 1.5 times as high as those for dredging. Subsequently the ocean basin should be as deep as possible because it needs to be dredged to a depth of more than 16 metres. The results for the dredging volumes for the determined configuration are shown in Table 24.

Type	Subtype	Volume [m^3]
Reclamation		$9.9 \cdot 10^6$
Dredging	River basin	$1.3 \cdot 10^6$
	Ocean basin	$18.7 \cdot 10^6$

Table 24 - Dredging volumes final configuration

For the chosen port layout the boundary conditions and the settlement are assorted. With these parameters a design of different components is made starting with the design of the bed and bank protection, the design of the breakwater and the design of the jetties. After that the annual availability of the port and an analysis of different possibilities for renewable electricity generation is made. This concludes in the exact design of the port and the planning for its construction.



PART IV - Preliminary Design

15 Boundary conditions

In order to make a preliminary design for the port, the boundary conditions have to be known. The height of the port area and the strength of the breakwater for example are dependant of these conditions. In Appendix H: Probability of exceedance, the design criterion has been calculated and is 1/1000. This probability is used to calculate the design conditions for the port. In Appendices P: Water levels, Q: Currents and R: Waves and wind at Banco Chico, the calculation for each condition can be found, in Table 25 these conditions are summed up. Another boundary condition is the subsoil, below a few metres of sand a clay layer with a thickness of 24 metres is assumed to be under Banco Chico. The analysis of the subsoil is further elaborated in Appendix O: Subsoil.

Condition	Value
Extreme water level (1/1000)	2.86 m + LIMB
MWL	0.76 m + LIMB
Average current velocity ebb	0.40 m/s
Maximum current velocity ebb	0.60 m/s
Current direction ebb	129 º
Current velocity flood	0.27 m/s
Maximum current velocity flood	0.50 m/s
Current direction flood	303 º
Design wave height	1.92 m
Peak period waves	4.98 s
Mean period waves	4.66 s
Wave direction design waves	112 º
Design wind speed	13.9 m/s
Wind direction design wind speed	34 º

Table 25 - Boundary conditions

16 Settlement

With the given boundary conditions, the settlements after the land reclamation for the port can be calculated.

Because of the thick layer of clay under Banco Chico, large settlements are expected when a load is put on top of it. For two different locations the settlements are calculated, see Figure 35. The calculations can be found in Appendix S: Settlement.

The first location is at the point where the current bed level is at -6 m LIMB. The final settlement over here is 6.95 m. The calculated value at this location is an upper bound, because no reduction of the increase in vertical effective stress over the depth has been taken into account. The settlement at the second location, where the bed level is at -3 m LIMB, is 4.10 m. The settlement at the first location is higher, because of the larger amount of sand on top of the clay layer (at the centre of Banco Chico, so at location two, there is a sand layer of a few metres, this is not the case at location one). Settlements of other parts of the island are somewhere between both calculated values.

The load on the island after construction hasn't been taken into account for this calculation. Because of the large amount of grain storage, this may result in large settlements. To prevent this to occur, the area can be preloaded during the settlement period.

To counterbalance the settlements extra sand has to be reclaimed. Construction of the civil works on the island can start when the remaining settlements are less than 1.00 m. This doesn't apply for the constructions, because they are limited to relative settlements of the foundation. When drains with a distance of 5 m are applied, the civil works can start about 4.5 years after reclamation. The final settlement is reached after 7.1 years for location one and 5.3 years for the second location.

17 Design bed and bank protection

Bed and bank protections are necessary to prevent erosion of the island, mainly caused by waves and currents. The listed protections are based on Appendix T: Design bed and bank protection.

17.1 Design height

First of all the design height of the island has been determined. Taking into account the design water level, supplements because of high water rise and local increase of water level, and the wave-run-up the design height of the island has been determined at 5.35 m + LIMB.

A slope of 1:4 resulted in the least amount of bank protection and was chosen as slope for the inner and outer banks. Not the whole island is located at + 5.35 m LIMB, but only the crests of the dikes. The rest of the island is located at +3.00 m LIMB, being about the design high water level + the supplement of high water rise. This is done to decrease the amount of sand to be reclaimed.

17.2 Bank protection

Two different bank protections are designed: one for the sides most attacked by storms (the red banks in Figure 35) and one for the other sides (the green banks in Figure 35). Chosen is for a rip-rap bank protection with stone classes as listed in Table 26. Under the top layer two filter layers are applied, to prevent erosion of the sand.

Description	Revetment 1	Revetment 2
Top layer		
dn_{50}	0.59 m	0.38 m
Stone class	HMA 300-1000	LMA 60-300
Thickness	0.90 m	0.60 m
Filter Layer 1		
dn_{50}	0.063 m	0.040 m
Thickness	0.30 m	0.30 m
Filter layer 2		
dn_{50}	0.004 m	0.0267 m
Thickness	0.30 m	0.30 m

Table 26 - Top and filter layers revetments

17.3 Bed protection

Bed protections are applied under the mooring places of the vessels to prevent scour holes near the jetties and banks, because of the propeller wash of mooring and un-mooring vessels. Chosen is for a mattress instead of rip-rap, because of the heavy stone class necessary.

According to a stability calculation the propeller wash doesn't have influence on the stability of the stones of the bank protection.

A cross section of a part of the island has been made, showing the bed and bank protections, see Figure 36.

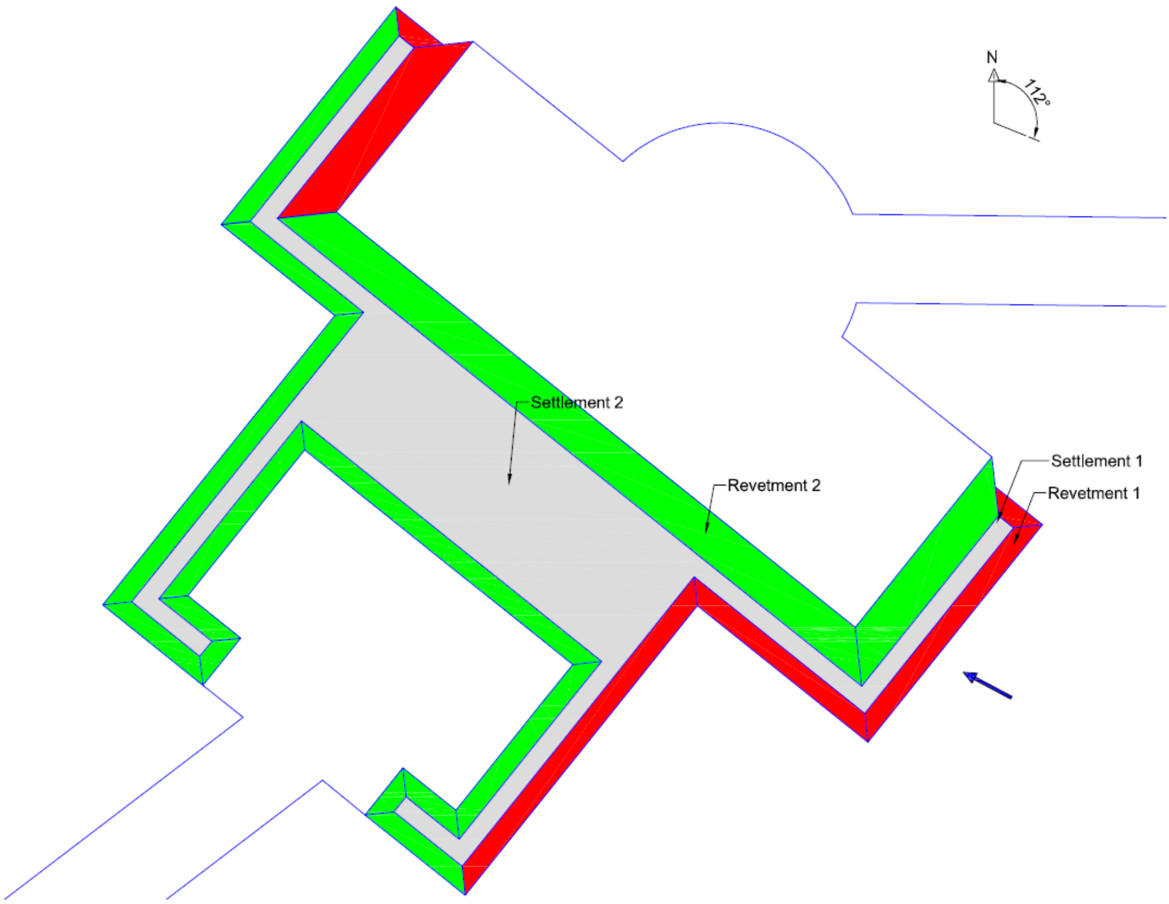


Figure 35 - Bank protections

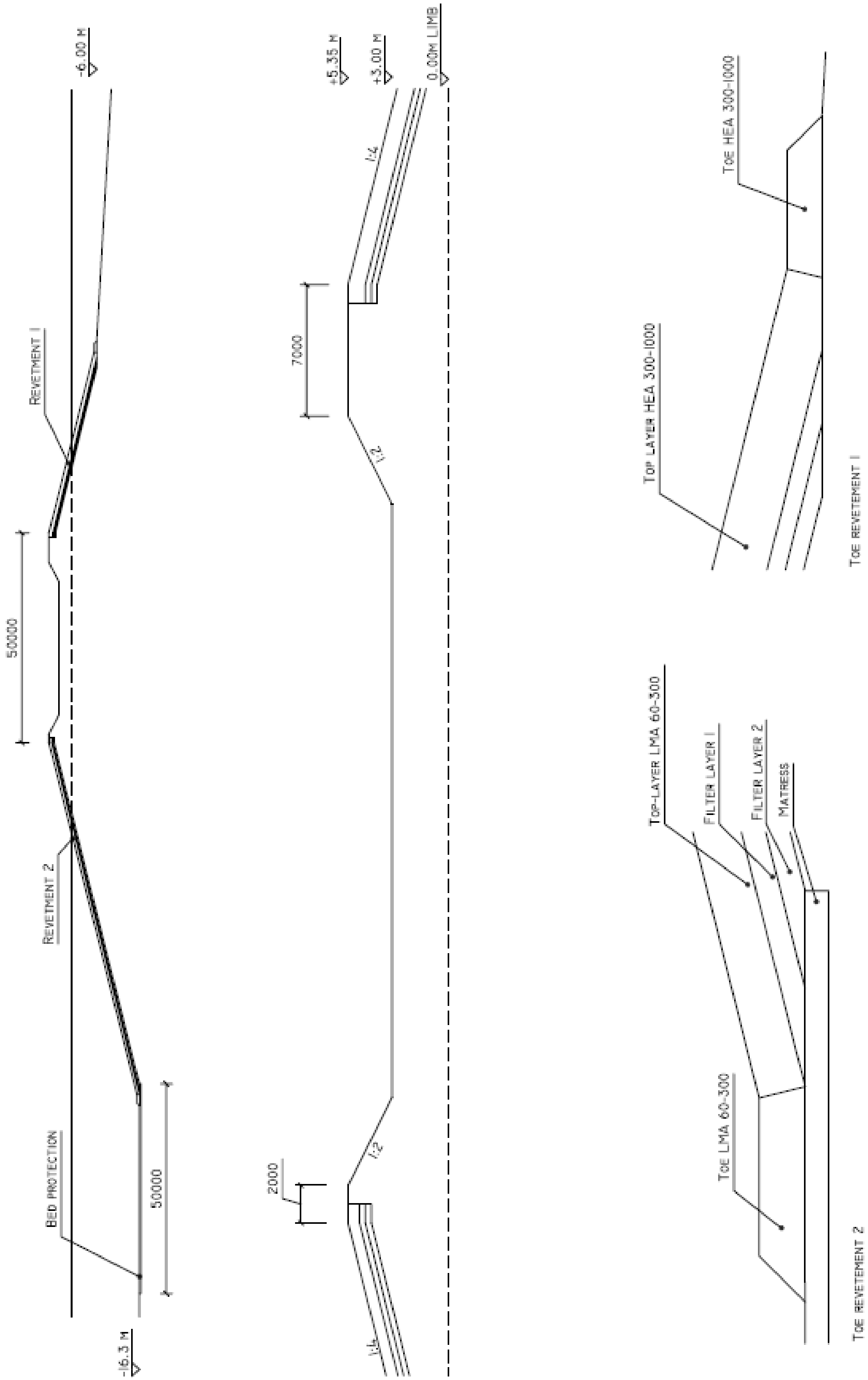


Figure 36 - Cross section of bed and bank protections

18 Breakwater design

The barges and tugboats berthed in the inland basin have to be protected against waves. This protection is needed to reduce downtime because of too high waves in the basin and to create a safe harbour when there are storm conditions on the Rio de la Plata.

Before a breakwater can be designed, first a choice of the type of breakwater has to be made. According to Burcharth (Burchart, 2011) the best choice for a location where stone materials are easily accessible, water depth is not very large, bed soils are relatively weak and soft, restrictions on wave reflection are necessary and there is no need for mooring behind the breakwater, is a rubble mound structure. This type of breakwater has been used to design the breakwater in more detail. The design of the breakwater is based on the calculations made in Appendix U: Breakwater design. The total height of the breakwater will be 10.83 metres, including a crest free board of 2.34 metres and the width at the bottom will be approximately 42.2 metres, giving the breakwater a slope of approximately 3:4. The crest width is chosen to be 7 metres, so it is possible to construct a part of the breakwater with trucks. A cross section of the breakwater is given in Figure 37.

For the construction of the breakwater approximately 399 tons stones of stone per metre length is needed. This gives a total amount of stones of approximately 179,000 tons

18.1 Rock layers

The armour layer on the sea and port side of the breakwater, the crest and the toes on both sides of the breakwater all require a stone size of a d_{n50} around 0.5 metres. In order to reduce the need for a lot of different stone sizes, the armour layer at the seaward and port side and the crest will use the same rocks, a d_{n50} of 0.52 metres, a stone class of 300-1000 kg and a layer thickness of 1.04 metres. The toes on both side of the breakwater will also be made of this stone class and have a height of 0.95 metres.

The head of the breakwater generally is more vulnerable to wave attack than the seaward slope of the breakwater, due to the curvature. In order to account for this vulnerability, the stone size can be increased, the slope can be decreased or the density of the stones can be increased. Since the d_{50} of the armour layer is low for the chosen stone class, it is assumed that this stone class will also be sufficient for the head of the breakwater.

To make a transition between the armour layer and the core material and to protect the core material below the toe of the armour layer from propeller wash, an under layer has to be constructed. The under layer will have a d_{n50} of 0.21 metres, a stone class of 10-60 kg and a layer thickness of 0.42 metres. The toe on the bottom of the port side slope will also use this stone class and has a height of 0.42 metres.

The core will use a stone class of 63/180 mm (W_{50} is 2.2 kg) with a d_{n50} of 0.08 metres. The filter layer between the core layer and the sand will consist of stones with a d_{n50} of approximately 5.7 mm and a grading of 4.

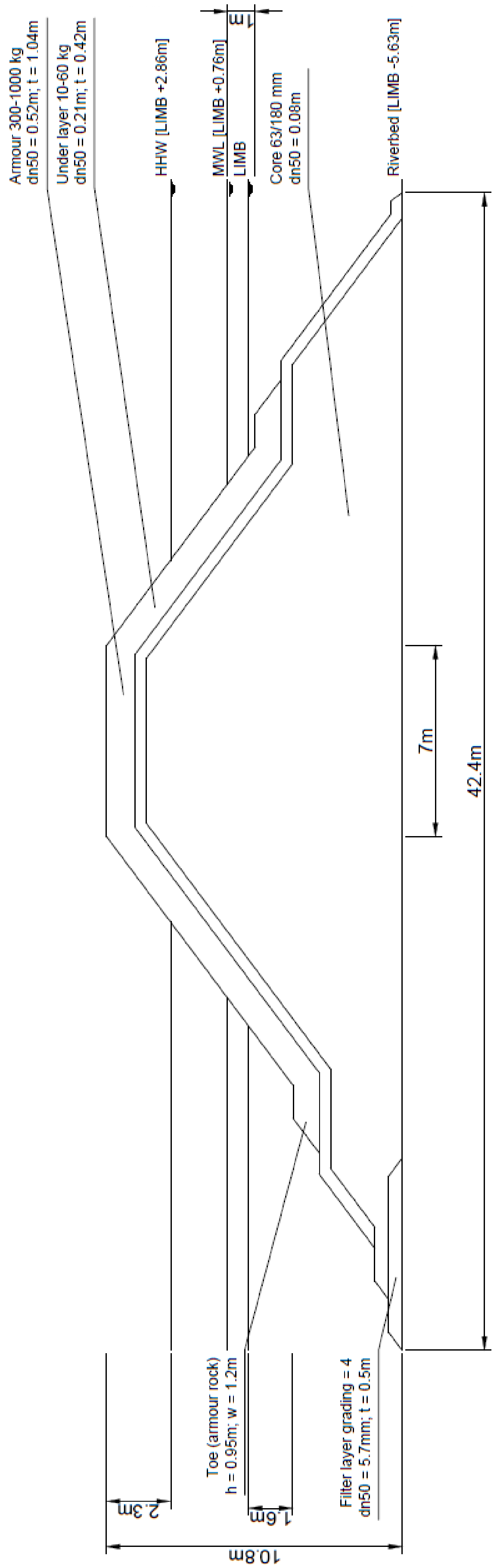


Figure 37 - Cross section breakwater

19 Jetty design

The vessels which enter the port have to be berthed in order to load or unload them. The jetties which are used for berthing are designed in this chapter.

19.1 Layout of the ocean going basin

The design of the dolphins is based on the guidelines provided (PIANC, 1997), (Ligteringen, 2000). For the layout three design vessels are taken into account: the Panamax, New-Panamax and the Capesize vessels. Each of the vessels has to be able to connect two spring lines with a maximum horizontal angle of 10° in order to function most efficient in restraining the surge motion. For the mooring lines a maximum angle of 15° with the normal of the ship is needed to most efficient prevent the lateral movements. Besides that the mooring dolphins are placed at a distance of 50 metre to also reduce the vertical angle. The design shown in Figure 38 satisfies all these conditions for the different vessels. Instead of the minimum of four mooring dolphins, a total of six mooring dolphins are placed, to better accommodate all design vessels. The two main breasting dolphins are at a distance of 94 metre of each other to support the hull of all ships in the 0.25-0.4 LOA range. An extra breasting dolphin is placed in between for Handymax vessels, as the distance between the outer two dolphins is higher than 0.4 LOA for this vessel.

In this design also the catwalks can be seen, which are used during the berthing and unberthing process. The combination of the jetty head and the approach bridge is called a T-jetty, where the approach bridge is aligned in the centre of the jetty head. The loading platform has an extra-large width to accommodate two cranes (marked as shaded areas) as well as a system of conveyor belts leading towards the storage area.

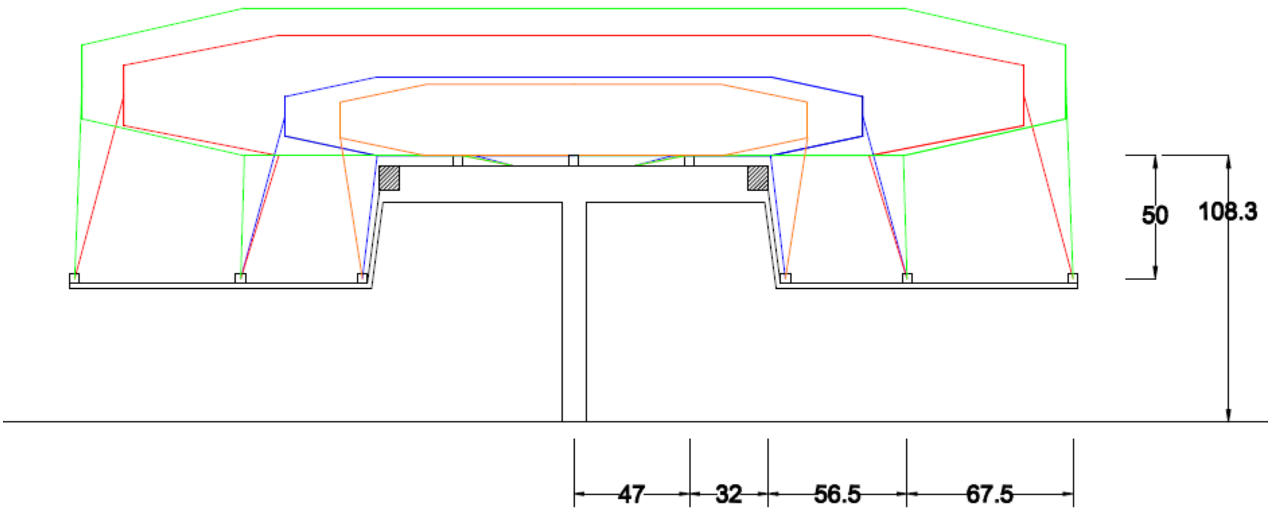


Figure 38 - Design of the dolphins for ocean going basin

For the height of both the breasting and mooring dolphins, the freeboard of the vessels is estimated at a minimum of +4 metre LIMB for loaded vessels at low water. The highest height above LIMB will occur when an empty Capesize vessel is moored during high water. Using Archimedes' principle, it can be calculated that a Capesize vessel will rise 6.25 metre compared to sailing fully loaded and assuming a free board of 5 metre and, the maximum height of the ship deck is at +13 metre LIMB. In the guidelines listed above a maximum angle of 25° is specified, which can be managed by using a breasting dolphin at a height of +7 m LIMB. For the mooring dolphins, at a distance of 50 metre, the guideline also prescribes 25° as a maximum angle and using also a height of +7 m LIMB for those will satisfy.

In Appendix V: Design of breasting and mooring dolphins, a calculation of the berthing force is done to calculate the fenders and dimensions of the breasting dolphins. All three dolphins are designed equally, though the middle dolphin will only be used for the mooring of Handymax vessels. Using high capacity fenders with dimensions of 2.7 x 5.5 metre gives a reaction force of 4.0 MN on the breasting dolphin (Urethane Products Corporation (UPC)). Allowing a maximum deflection of 1% (or 233 mm), the minimum dimensions of a cylinder shaped dolphin are a radius of 1100 mm and a thickness of 100 mm. The force on the mooring dolphins is estimated on 2.0 MN and these dolphins will require a radius of 950 mm and a thickness of 80 mm. Both dolphins are shown in Figure 39.

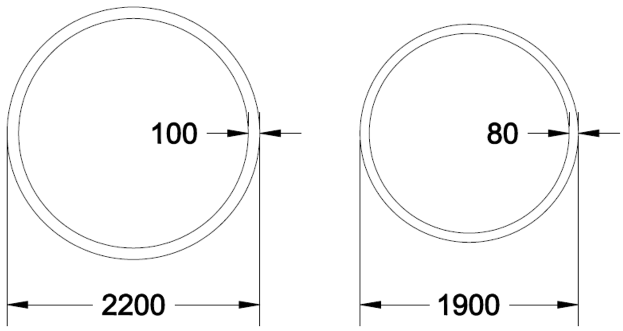


Figure 39 - Dimensions of the breasting (l) and mooring dolphin (r) of the ocean basin in mm

The depth of both dolphins is calculated in the same appendix with the method of Blum. As the top layer consists only of a weak clay layer they both need to be founded in the sand layer beneath. To resist the horizontal forces the breasting dolphins need a depth of 31.1 m below and the mooring dolphins need a depth of 25.5 m.

19.2 Layout of the inland basin

For the inland basin a similar design as the ocean going basin can be made. As the barge is the only design vessel the placing of the breasting and mooring dolphins is based on those dimensions using the guidelines again (PIANC, 1997), (Ligteringen, 2000). This concludes in the following design as shown in Figure 40.

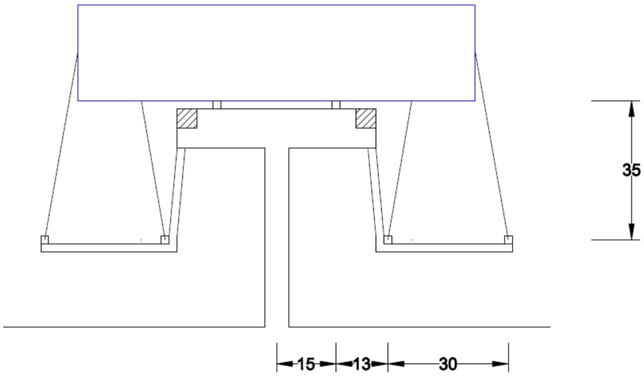


Figure 40 - Design of the dolphins for the inland basin

The level of the deck is at its minimum at low water for a fully loaded barge and estimated at +1 m LIMB, the maximum deck level is calculated again using Archimedes' principle at high water and is +7 m LIMB. The height of both breasting and mooring dolphins is chosen at the average of +4 m LIMB.

The governing force on the breasting dolphin is again the berthing ship. Using the calculation of the kinetic energy and a standard capacity fender of (Urethane Products Corporation (UPC)) with dimensions of 1.2 x 4.9 metre, gives a reaction force of 928 kN on the mooring dolphin and the barge. Using the same 1% allowed deflection results in a radius of 500 mm and a thickness of 50 mm. The mooring dolphins need to bear a mooring force of 283 kN, resulting in a radius of 350 mm and a thickness of 40 mm. Both cylinders are shown in Figure 41.

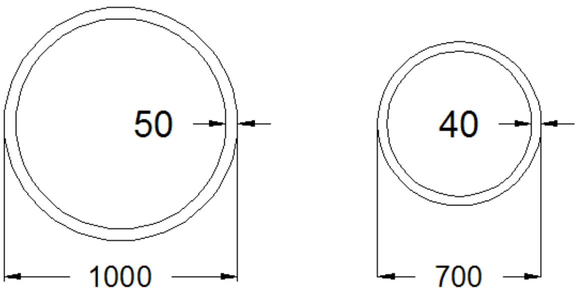


Figure 41 - Dimensions of the breasting (l) and mooring dolphin (r) of the inland basin in mm

The depth is again calculated with the method of Blum. The forces are lower compared to the ocean basin, resulting in piles that are founded in the clay layer. As a necessary depth for the breasting dolphin 17.1 metre is found and for the mooring dolphin a depth of 12.1 metre is found. Since the clay layer is expected to settle it might be required to still base the pile foundation on the sand layer, however, a more detailed calculation would be required.

20 Availability

In chapter 9.1 demands are listed for the minimum availabilities for both the ocean and inland basin. After the design for the port has been made, this availability can be calculated. In Appendix W: Availability an overview is made of all events that can reduce the availability. The total availability is split in the, partly overlapping, navigational availability and the operational availability (Thoresen, 2010). The results are given in Table 27.

Ocean basin	
Navigational availability	99.1 %
Operational availability **(waves at 45° - 90° of berth)**	96.2 %
Operational availability **(waves at 0° of berth)**	99.1 %
Total availability	**95.7 %**

Inland basin	
Navigational availability	96.7 %
Operational availability	98.5 %
Total availability	**96.2 %**

Table 27 - Availability

It can be seen that for inland vessels the availability of the basin of 95% is possible, due to the presence of breakwaters. For the ocean vessels an availability of 99% was the demand, but due to limiting wave heights after which loading is no longer possible, the berths at an angle of 45° to 90° compared to the wave direction are not able to fulfil this demand. However, both the navigational availability as the operational availability of the other berths are within the boundaries of the program of requirements and this is considered acceptable.

21 Electricity generation

One of the desires for the port project is that it will be capable of providing for its own electricity demand. On top of this it has been considered desirable to make this electricity generation occur in an environmentally friendly and renewable fashion. The electricity demand of a yet to be constructed port is evidently not known. Therefore a reference project (the port of Corpus Christi, U.S.) with a similar yearly throughput has been used to determine an annual energy consumption of 8,100,000 MWh (Port Corpus Christi, 2012). To achieve this goal three different types of renewable energy generation are investigated in Appendix X: Electricity generation: wind turbines, hydropower and solar energy. Of those types of energy a calculation is made of the installed power that can be generated. A short summary of is presented in Table 28.

Energy plant	Annual revenue [MWh]	Required to supply demand
Wind turbines	35,040 per turbine	232 turbines (49.5 km^2)
WEC	106 m^{-1}	77 km
Dynamic Tidal Power	34,164	insufficient
Photovoltaic solar panels	0.246 m^{-2}	32.9 km^2
Thermal solar panels	0.32 m^{-2}	25.3 m^2

Table 28 - Summary of energy types

It is clear to see that the only the only form of energy really capable of somewhat realistically providing for the required energy by itself are the Wind turbines. The other forms of energy may still be plausible, but would require a combination with other forms of electricity generation in order to be a plausible solution. Considering the large capital investment required for the Dynamic Tidal Power plant it is safe to say that this form of energy isn't a feasible solution unless there would be severe other reasons to build a hinterland connection.

In order to make a reasonable assessment of the preferred layout of energy generation on the island it needs to be determined how much of each green energy variant can be installed without too much effort. The useable circumference for wave energy is 1,410 m' in the dominant wave direction as well as an equal amount on the opposite direction with a large fetch. On top of that a circumference of 940 metres can be found in the shore oriented direction. Assuming that the dominant direction has 100% revenue, the anti-dominant direction 50% and the shore oriented side 0% a yield of $1.5 \cdot 1410 \cdot 106 = 224{,}190 MW$ can be generated annually from wave energy.
The island has a total surface of 273,801 m^2, but naturally not all this area can be used for solar power harvesting. The areas that would be eligible for solar installations are the rooftops of the silos, terminals and the hotel. It is estimated that this constitutes as 10% of the total surface area of the port making it 27,380 m^2. By combining the photovoltaic and thermal panels (so called PV-T panels (Marsh, 2010)) this area can be used most efficiently. With an efficiency of 85% this equation gives an annual result of $0.85 \cdot 27380 \cdot (0.246 + 0.32) = 13{,}173\ MW$.

This means that an annual energy shortage of $8{,}100{,}000[MW] - 224{,}190[MW] - 13{,}173[MW] = 7{,}862{,}637[MW]$ will have to be delivered by either wind turbines or non-renewable forms of energy. In regards to wind energy the only limiting factor is the costs and the required amount would be 225. It may be concluded that a reduction of 7 turbines at the cost of installing solar and wave plants is negligible.

22 Final design

To conclude the design of the artificial island, a layout of the final configuration is made. In this layout all the previously determined components will be given their place and some essential components that have not been a part of the calculations will also be presented. Figure 42 shows this final design, a larger version of this design can be found in Appendix Y: Port design.

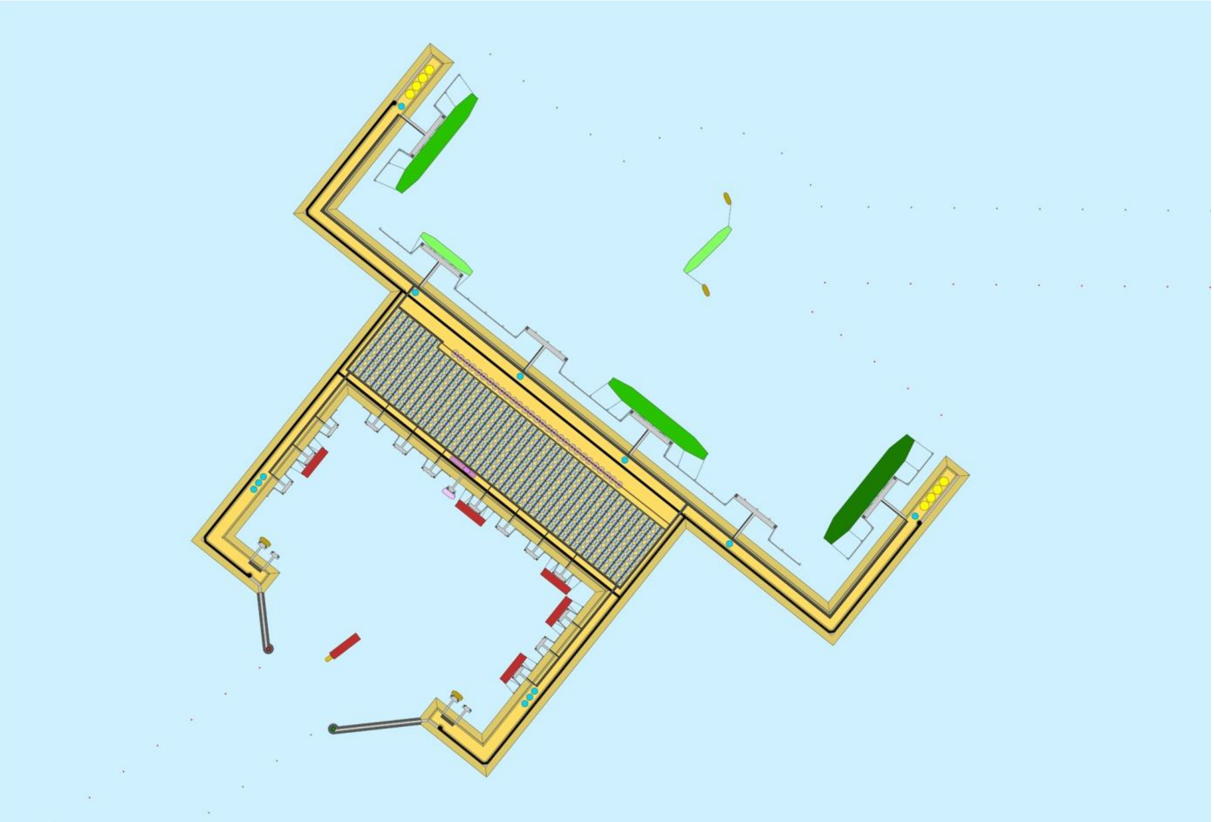


Figure 42 - The final design of the artificial island

It can be seen that the breakwaters have now been given their place at the entrance of the river basin where they extend until the borders of the shipping channel and give a place for lighthouses to be installed on the heads of the breakwaters. Extending into the Rio de la Plata from the breakwaters some buoys indicating the access channel can also be noticed. Similarly buoys have been placed to indicate the outskirts of the ocean basin and the according access channel. In the inland basin the 13 jetties for barge traffic have been placed, as well as the 4 berths for the tugboats. The ferry is located in the centre of the basin and where it meets the land some port infrastructure has been placed. This involves the port office, the ferry terminal and the hotel. At the berths for tugboats, near the breakwaters, the shore bound tugboat areas have been placed on the inner side of the protective dike ring. This dike ring is elevated to 5.35 metres above sea level and 2.35 metres above the level of the inner island, which has been placed at LIMB + 3 metres as to decrease the required amount of land reclamation.

On the main body of the island the silos for grain (467 of them) and oil (29) have been placed. These silos are connected to the berths on both sides of the island through respectively conveyor belts and pipelines, which have also been drawn in Figure 42. On the ocean side of the port space has been reserved for the 7 ocean vessel berths which are usable for ships up to cape size dimensions. The outer most sections of the arms house the fuel storage facilities, as any possible accident would cause the least damage to the port as a whole when located there. The transport of the fuel will be done underground and can therefore not be seen in the top view. The fresh water that is required for the ships' bunkering period will be stored in tanks close to the ocean jetties, seeing as they require a lot of fresh water each bunker period. For the barges (and the tugboats related to those) the storage will be done on converged places on the arms of the inland basin. Transport of this commodity will be done in a subterranean fashion as well. Getting around the island has been made possible by creating a road system that gives access to every berth in the port.

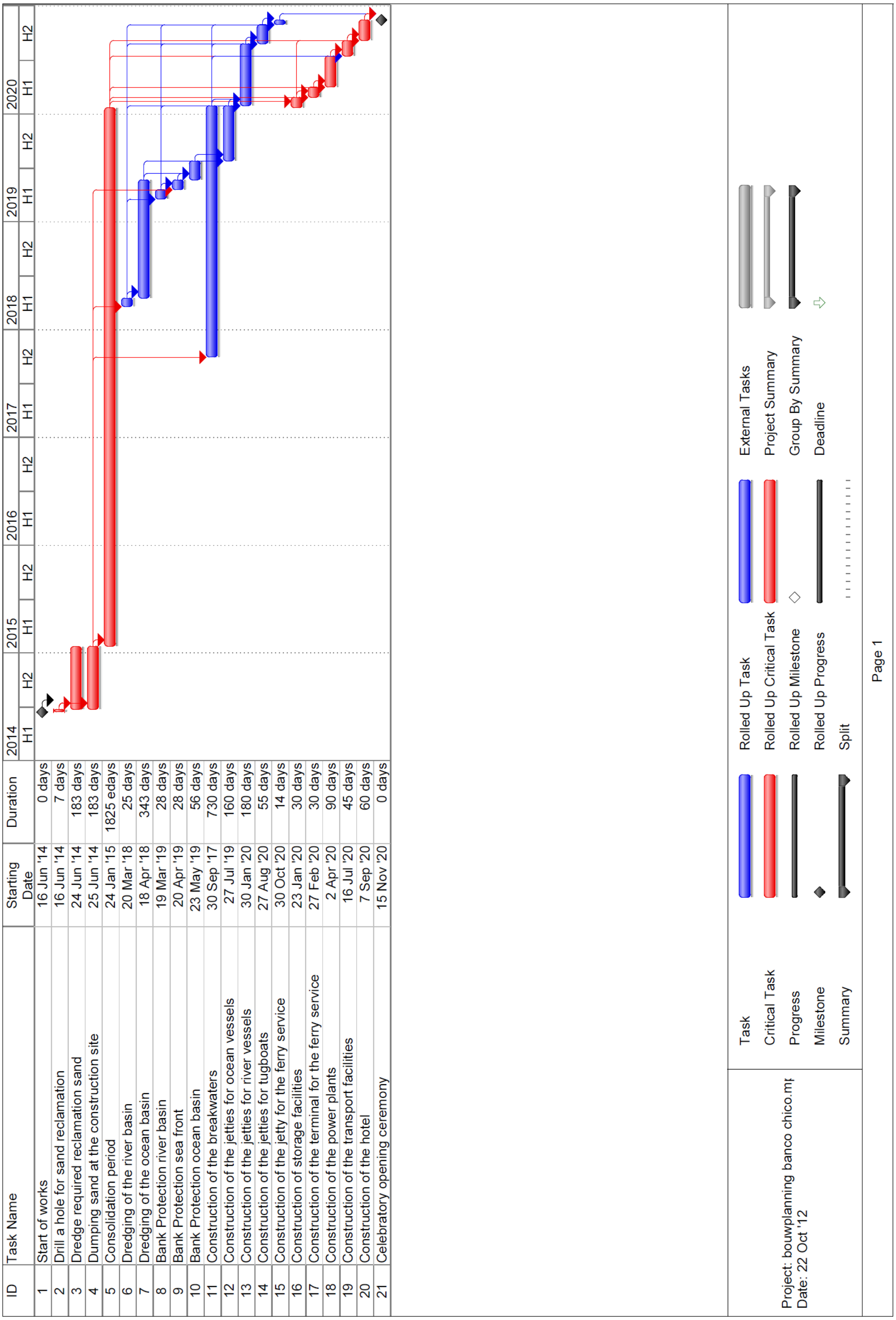
23 Construction planning

Now all the port components have been designed, a construction planning for the port can be made. In this phase an estimate will be made about how much time is required to build each component of the port structure, and how the durations of these times affect the construction of other components. The result of the construction planning is presented in Figure 43. For an explanation of the different components see Appendix Z: Construction planning.

23.1 Labour distribution

To save money on having to fund different sets of equipment and training, not all constructions will be built at the same time. Labour forces will be distributed over the structures and build them one after the other. In this distribution two sets of labour forces are distinguished: the Jetty work force and the Facilities work force. The Jetty work force will start by building the ocean jetties and, once they're done with those, subsequently build the river jetties, the tug jetties and the ferry jetty. The Facilities work force will do a same path but for relatively the storage facilities, ferry terminal, power plant, transport facilities and lastly the hotel.

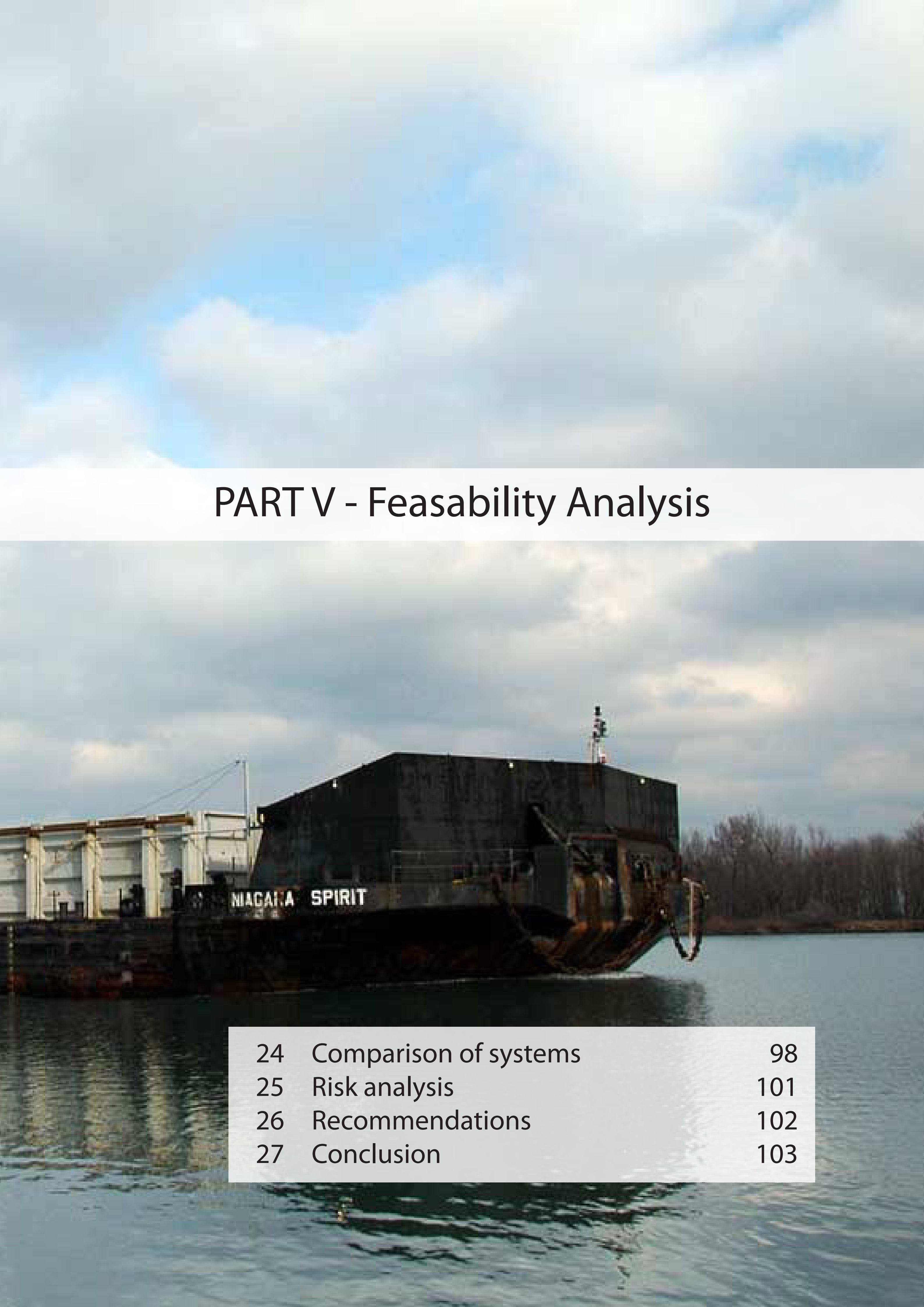
The same principle also applies to the dredging works. It is assumed that one dredging vessel will be used to do all the dredging for the port. Given that the consolidation of the main island takes a significant amount of time this is not a critically time consuming choice. It also means that the ocean basin and the inland basin, as well as the adjoining access channels cannot be dredged simultaneously and will have to be done one after the other.



ID	Task Name	Starting Date	Duration
1	Start of works	16 Jun '14	0 days
2	Drill a hole for sand reclamation	16 Jun '14	7 days
3	Dredge required reclamation sand	24 Jun '14	183 days
4	Dumping sand at the construction site	25 Jun '14	183 days
5	Consolidation period	24 Jan '15	1825 edays
6	Dredging of the river basin	20 Mar '18	25 days
7	Dredging of the ocean basin	18 Apr '18	343 days
8	Bank Protection river basin	19 Mar '19	28 days
9	Bank Protection sea front	20 Apr '19	28 days
10	Bank Protection ocean basin	23 May '19	56 days
11	Construction of the breakwaters	30 Sep '17	730 days
12	Construction of the jetties for ocean vessels	27 Jul '19	160 days
13	Construction of the jetties for river vessels	30 Jan '20	180 days
14	Construction of the jetties for tugboats	27 Aug '20	55 days
15	Construction of the jetty for the ferry service	30 Oct '20	14 days
16	Construction of storage facilities	23 Jan '20	30 days
17	Construction of the terminal for the ferry service	27 Feb '20	30 days
18	Construction of the power plants	2 Apr '20	90 days
19	Construction of the transport facilities	16 Jul '20	45 days
20	Construction of the hotel	7 Sep '20	60 days
21	Celebratory opening ceremony	15 Nov '20	0 days

Figure 43 - Construction Planning

Now the design is finished, the construction of the port can be compared with two situations in which the system would continue as it is. The total initial and annual costs are compared, as well as the risks for the construction of the port. This results in a set of recommendations and the final conclusion.



PART V - Feasability Analysis

24 Comparison of systems

For the financial feasibility of the port of transhipment a comparison is made between three systems. For each system the total nautical costs of the grain export are calculated, as this is the only part of the grain export system that will be considered to change with the creation of the port of transhipment. It starts at the loading ports on the Rio Paraná near Rosario and finishes at the coastal import port over the ocean. At the end the total annual costs are compared with the total construction costs of the port.

System 1: Current system without changes

In this system the current system will not be changed and the allowable draft on the Rio Paraná will be maintained at 34 feet. The simplification is done that only Panamax vessel will be used which will sail the Rio de la Plata and will be partly filled. They will continue to a coastal port where they will be topped of before they continue their journey to their final destination. In the most negative case the rest of the world will be able to accommodate larger vessels and import of agricultural products from Argentina will become less attractive, causing export to reduce. However, this is not taken account in this comparison.

System 2: Current system with maximum dredging

The second system is based on the predictions as they are done now for the Rio Paraná system. It is expected that dredging can be increased up to a maximum of 38 feet (Louer, 2012). With the increased depth it is also possible for New Panamax vessels to sail up to Rosario, although both the Panamax and the New Panamax vessels can still not be loaded up to their maximum capacity and have to visit a coastal port before sailing onto the ocean. Also in this case the negative consequences for the export of Argentina are not taken into account.

System 3: Building of a transhipment port

This is the system in which the port as designed in this report is built at the Banco Chico location in the Rio de la Plata. The shipping upriver is only done by barges and it is assumed that dredging of the Rio Paraná up to Rosario will no longer be necessary. The simplification is made that transport over the ocean is only done by the efficient New Panamax vessels and it is assumed that all destination ports have the option to accommodate these vessels.

Total costs

The different costs per system are calculated in appendices and summarised in Table 29. The port construction costs, port maintenance costs and port operating costs are all costs directly associated with the port of transhipment as it is designed in this report. These costs are given in Appendix AA: Costs of systems.

The capital dredging costs consists of the costs that are needed for the increasing of the draft in System 2 and the construction of the short connection to the ocean. In System 3 they consist of the dredging of the access channels to the port, the construction of the short connection to the ocean, and the deepening of a part of the current navigation channels. These costs are explained in Appendix AA: Costs of systems. The toll costs are based on the calculation for the annual maintenance dredging costs given in this same appendix. The annual dredging costs are the summation of all the dredging that occurs to maintain the necessary draft in the Rio Paraná and in the access channels in the Rio de la Plata. The toll costs are based on the profit currently made on the dredging and are fully calculated in Appendix AA: Costs of systems.

The last and most determinant costs in the table are the shipping costs. In the shipping costs all costs are included that are made for the transport of the commodities over water. It includes the fuel consumption during berthing and sailing and the crew costs. These are given in Appendix AA: Costs of systems.

	System 1	System 2	System 3
Port construction costs	-	-	1,390
Capital dredging costs	-	2,350	4,018
Total initial costs	**-**	**2,350**	**5,409**
Port maintenance costs	-	-	47
Port operating costs	-	-	167
Toll costs	158	235	120
Shipping costs	5,027	4,940	4,340
Annual costs	**5,184**	**5,175**	**4,674**

Table 29 - Total initial and annual costs in million USD

Net Present Value

Using the Net Present Value method the sum of all present values is added and plotted in Figure 44. By using the intersections of the systems, the number of years needed until a system has lower total cost compared to another system is found. These intersections are also given in Table 30. It can be seen that System 1, within the current assumptions, never exceeds the Net Present Value of System 2, so the extra dredging to allow Panamax and New Panamax vessel in a better way is not favourable due to the high initial dredging costs. System 3, however, is concluded as a better system than both System 1 and System 2 and has a lower total costs in respectively 2035 and 2028.

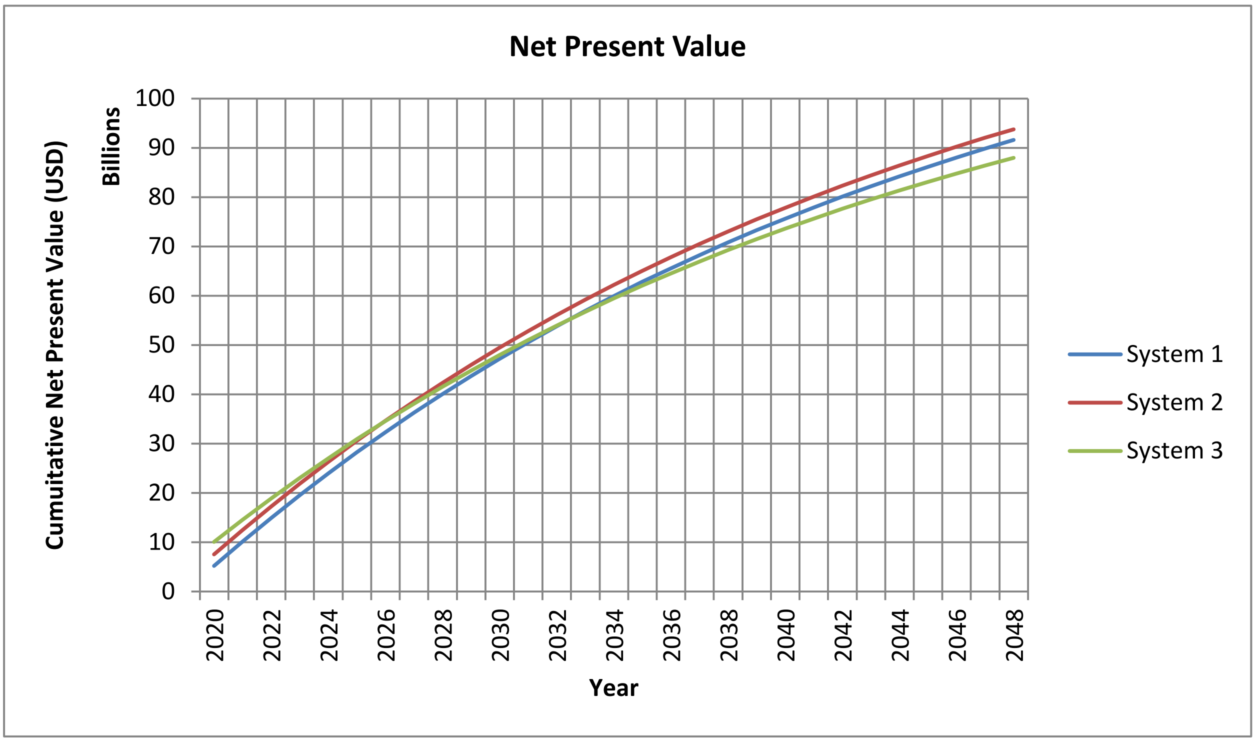


Figure 44 - Net present value

	Number of years until intersection	Year at which total costs are lower
System 3 > System 1	12.4	2033
System 3 > System 2	5.8	2026
System 2 > System 1	Never	Never

Table 30 - Intersections of the NPV of the systems

25 Risk analysis

In this section a look will be taken at the risks that could endanger the project during its design stage and its lifetime. These risks are separated into risks for the system, which make the port lose its function as a (operational) transhipment port and risks for the port itself, which damage (parts) of the port and makes these parts unusable.

25.1 System Risks

A list of risks that affect the port on a system levels is as follows:

- Political reasons
  - Internal politics
  - Foreign politics
  - Hidrovía S.A. concession extended
- Economic reasons
  - Collapse of the grain industry
  - Collapse of the sea transport industry
  - Trading partners no longer demand Argentine grain
  - Creation of a competitive port nearby
  - Creation of a competitive alternative farm-ocean transport system
  - Global fleet size does not increase
  - Fleet beam increases but not their draft
  - Dredging costs significantly decrease
  - Costs of inland transport drastically increases
  - Insufficient investing parties
  - Exporting companies stick to old habits
  - Inland infrastructure not sufficient
- Geographic reasons
  - Increase in natural depth in the Rio Paraná
  - Decrease in natural depth in the Rio Paraná
  - Increase of wind and wave conditions in the Rio de la Plata

A more detailed description of each risk is given in Appendix BB: Risk analysis.

25.2 Port risks

Apart from the risks that threaten the system as a whole, there are also risks that threaten the operational capabilities of the port itself.

- Damage due to accidents
  - Ship collision
  - Explosion of a fuel tank
- Terrorist attack
- Uncontrollable sedimentation
- Malfunctioning equipment
- Severe storms
  - Damage
  - Unavailability

A more detailed description of each risk is given in Appendix BB: Risk analysis.

26 Recommendations

As a result of this research, some recommendations for future research regarding the system and the port design can be made.

26.1 Regarding the system

- A more accurate prediction of the grain export of Argentina can be made, which should include a more detailed analysis of the export of Paraguay and Bolivia over the Rio Paraná. Also an investigation of the inland transport streams can be done to find out what the most optimal way of transport is to a possible port of transhipment.
- Besides grain, an analysis of the expected ore export over the Rio Paraná should be made and taken into account in the new system.
- The import into the Rio de la Plata and the Rio Paraná from across the ocean, especially LNG, should be analysed and a solution for this transport should be found if the allowable draft exceeds the limiting draft.
- An LNG terminal is located in San Nicolas. It may be necessary to find an alternative for the transport to this port.
- A thorough study of the shipping costs in the different systems should be made.
- An economic analysis should be made to determine the most economical, and probable, vessel to transport grain over the Rio Paraná to the new port.
- A thorough study for the dredging costs of the different systems should be made and the maximum dredging depth should be assessed in more detail.
- The movements of the barges in different weather conditions should be modelled or investigated, in order to know what the maximum conditions in which the barges can sail are.

26.2 Regarding the transhipment port

- A more economical analysis of the location choice and optimization can be made in order to determine the economically most attractive location.
- An unused gas pipeline is on the bottom of the Rio de la Plata between La Plata en Colonia, which can be used as an alternative solution for the LNG transport to San Nicolas.
- An ore transhipment terminal could generate more revenue for the port on top of the grain transhipment.
- The ship movements at berths should be modelled in order to make a better berth design and calculation of the availability.
- A study into the logistics of the proposed port should be made in order to have a better understanding of its efficiency and have more detailed figures for the port equipment.
- The construction, maintenance and operating costs of the port can be determined in more detail.
- At the location of the port of transhipment a soil investigation should be performed.
- An investigation into the environmental effects of the new transhipment port should be executed in order to determine if there are any negative effects on the environment.

27 Conclusion

After predicting the expected throughput of the system in 2030, designing a new transhipment port and comparing this with two other systems, the null-variant and the New Panamax adaption, a conclusion can be drawn regarding the export system.

This report has as a preliminary conclusion that a system with a transhipment port is an economically feasible solution to transport the expected grain export of Argentina over the Rio Paraná and should be able to reduce the shipping costs for the system. There are, however, some remarks which have to be taken into account for this system. First of all, all the recommendations given in chapter 25 have to be taken into consideration in order to do a more thorough research and reach a better founded conclusion, a better or other port design, another port location or even another feasible export system.

There are, however, also risks (see chapter 25) which have to be taken into account. There are a few things which have a major influence in the decision if the port is going to be build or not. First of all, there are political constrains. As long as there is no urgent need for the port, the government will never make the decision to build the port and adapt the system. So only when it is really necessary, the whole system will be made to change. Apart from the domestic politics, there is also the political friction between Uruguay and Argentina. A consensus has to be reached between these two countries before the port will be allowed to be build.

Secondly, the current export companies, stevedores and shipping companies will have to agree with and support the construction of the new port and the subsequent change of the export system. Since they have to invest a lot of money to change the current system to the new one, their support is vital. Besides the fact that they have to support the new system, they will also have to reach an agreement with their competitors in order for the system to be changed. If some of the companies do not want to change the system, it becomes difficult to do so.

Another important stakeholder is Hidrovía S.A., they currently maintain the Rio Paraná and a large part of the Rio de la Plata. If their concession gets extended when the new port should become operational, this might pose a major threat for the port, since they can refuse to cooperate and even influence the usage of the new port. This, though, is also related to the domestic politics, since they decide if Hidrovía S.A. will have consent to continue their concession, and to what degree, after the port is constructed.

From the above it can be concluded that there are a lot of major issues which have to be resolved before the new system has a chance of being put in place. So the likelihood of the change from the current to the new system is fairly small and depends mainly on the existence of an utmost necessity to change the current system.

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A Maps

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Source:
Map 1: (Dutch-Argentina Chamber of Commerce, 2009)
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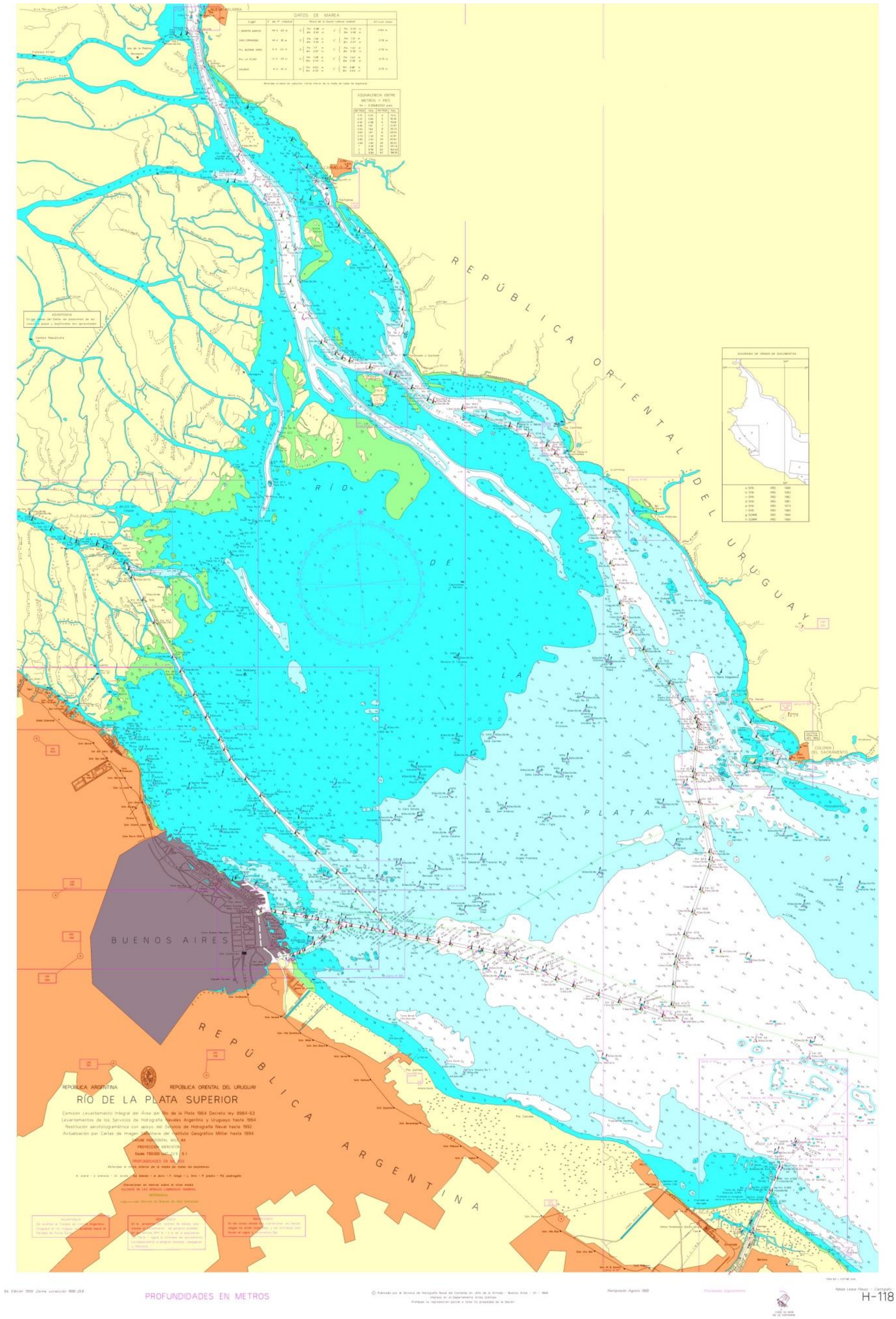
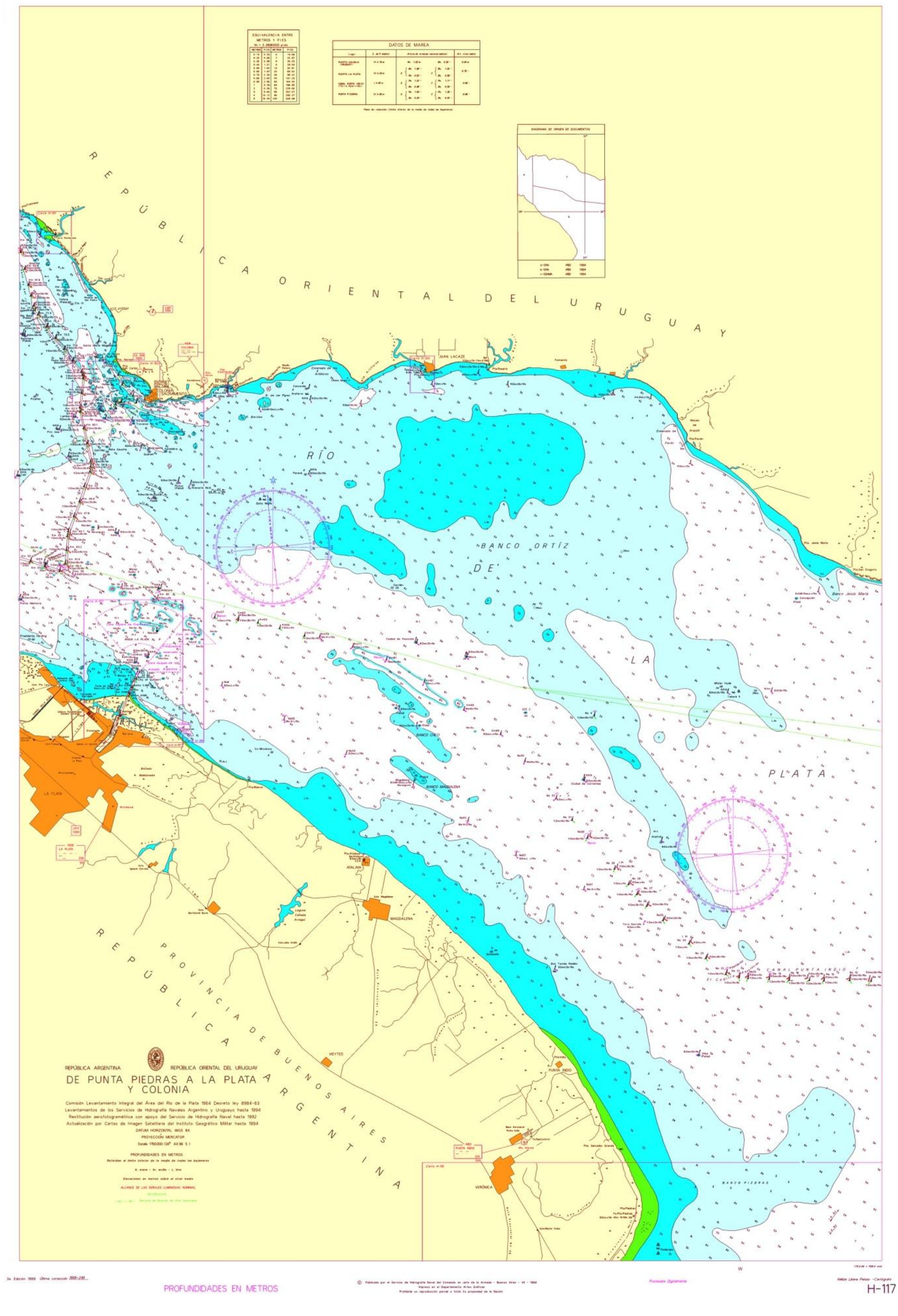
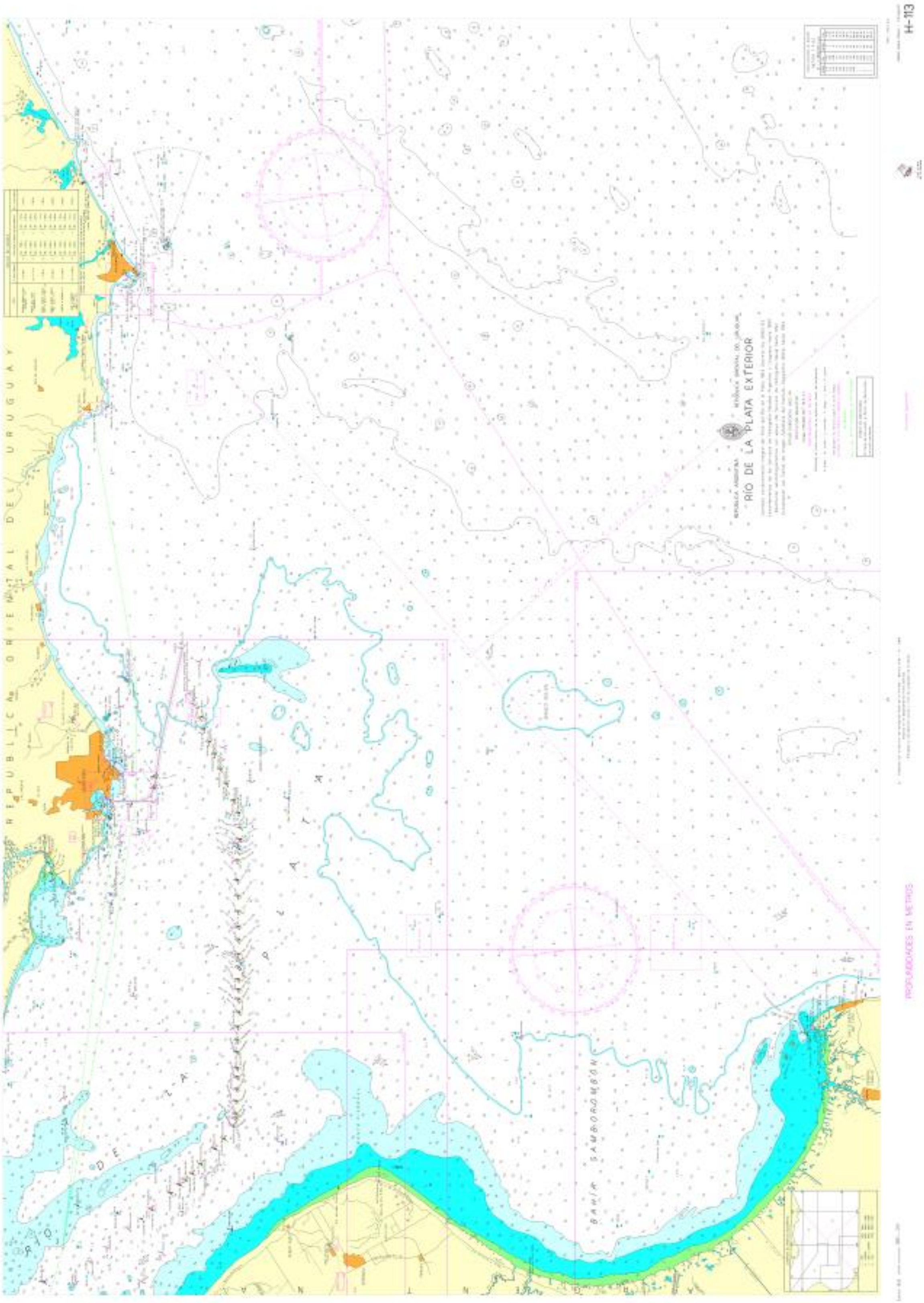
Map 1 - Argentina: Puertos de Embarque para Cereales, Oleaginosas y Subproductos



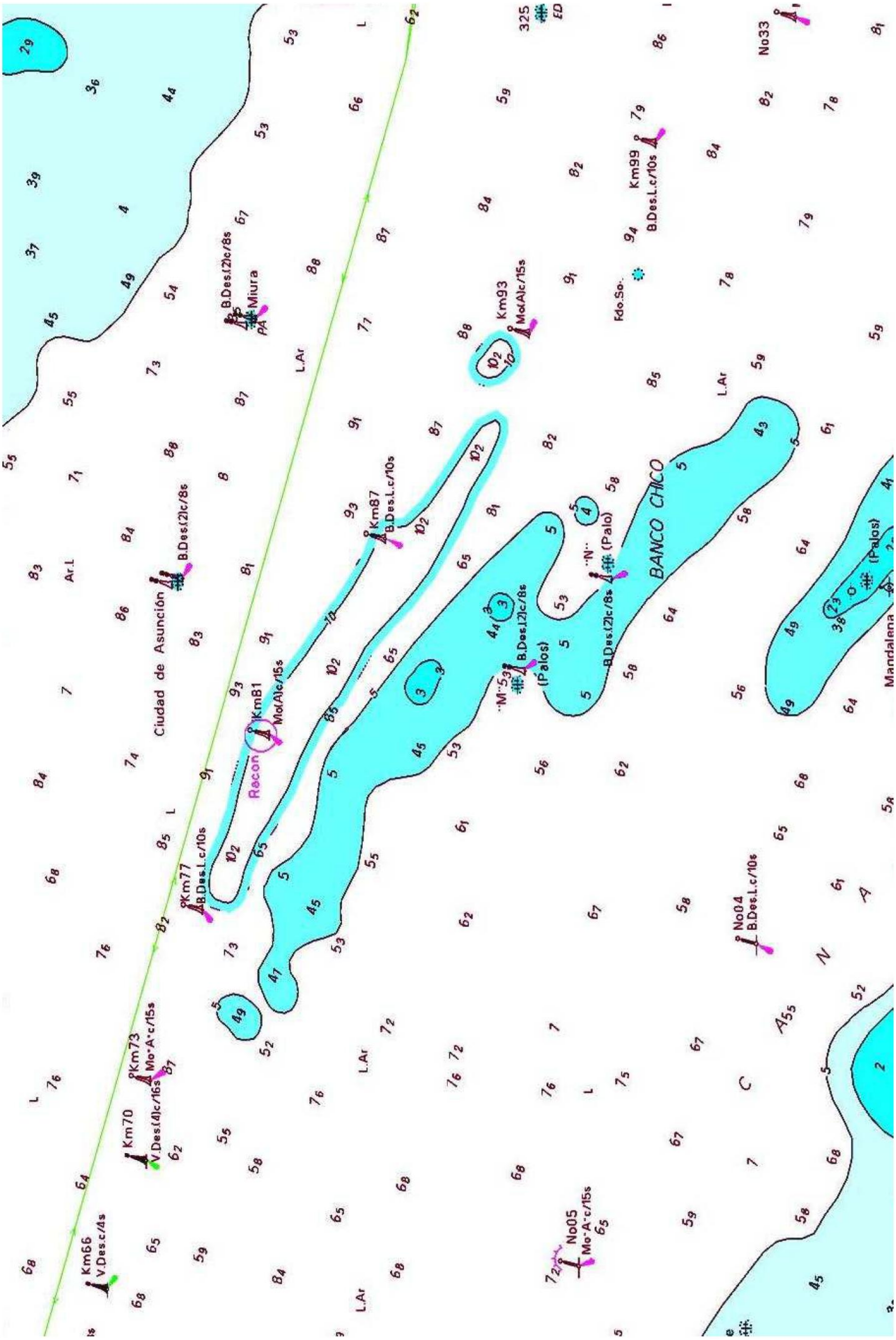
Map 2 - H118: Rio de la Plata Superior



Map 3 - H117: De Punta Piedras a La Plata y Colonia



Map 4 - H113: Rio de la Plata exterior



Map 5 - Part of H117: Banco Chico

B Reference levels

In and around the Rio de la Plata several reference levels exist, all used by different institutions and/or countries. To be able to compare those values, a table is made with the different levels. The main reference level used on maps is the local low water level, which is called LIMB. It can be referred to the Ex-Warton level in Montevideo by the data in Figure 45.

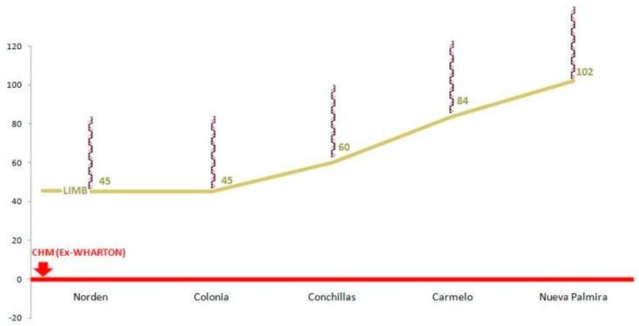


Figure 45 - LIMB Reference Level (Riovia)

In Figure 46 a comparison is made between towards the Cero IGM and the Cero del Riachuelo.

Figure 46 - Reference levels Argentina (SSPYVN)

For a location within the Rio de la Plata this is summarized in Table 31, taking the Cero Wharton as reference level.

Cero I.G.M.	0.6925 m
LIMB	0.45 m
Cero del Riachuelo	0.1367 m
Cero Wharton	0 m

Table 31 - Reference levels in Rio de la Plata

C Financial aspects

Exchange rates

For converting all currencies to USD exchange rates are given in Table 32 (Wisselkoers.nl).

Currency	In USD	
Euro	€ 1 =	$ 1.29
Argentine Peso	$ 1 =	$ 0.21
Uruguayan Peso	$ 1 =	$ 0.05

Table 32 - Exchange rates

Inflation

In order to calculate the costs in 2020 the inflation of the unit prices have to be taken into. This is done by using an inflation of 4% per year. The unit price in 2020 is calculated by:

$$U_{2020} = U \cdot 1.04^{(2020-Y_U)}$$

In which U_{2020} is the unit price in 2020, U is the unit price of Y_U, and Y_U is the year in which the unit price has been determined.

Net Present Value

To calculate the net present value of the maintenance costs an estimation of the rate of return is made of 4%. Since the periodic maintenance is equal every year, it can be calculated by the formula below. As an example the yearly costs (C) are set on 1.

$$NPV = \frac{C}{i}\left[1-\frac{1}{(1+i)^n}\right] = \frac{1}{0.04}\left[1-\frac{1}{1.04^{100}}\right] = 24.5$$

So the NPV over 100 year is 24.5% of the total maintenance costs.

D Cargo analysis

Export of the Rio de la Plata

Port	Volume of grain export in tons				
	2003	2004	2005	2006	2007
Buenos Aires	433,498	257,353	374,803	437,166	439,797
Concep. Del Uruguay	12,643				
Diamante	748,967	488,351	499,225	254,380	458,100
Lima	662,961	759,712	772,760	843,951	1,019,971
Ramallo				1,187,542	1,339,924
Rosario	6,770,606	7,268,937	9,331,226	7,402,810	10,762,541
San Lorenzo-San Martín	9,927,368	9,464,060	11,469,662	8,562,452	12,677,829
San Nicolas	712,447	304,727	485,129	390,336	264,900
San Pedro	639,714	396,909	737,614	435,917	366,901
Sante Fe	81,396	21,985			
Villa Constitucion	117,320	35,685	13,200	28,579	24,533
Others				789,890	
Subtotal Rio de la Plata	20,106,920	18,997,719	23,683,619	20,333,023	27,354,496
Bahia Blanca	4,462,922	4,543,381	6,981,896	5,779,476	7,102,182
Mar del Plata		107,526	23,357		
Necochea	2,833,699	3,657,557	3,433,958	3,221,082	3,140,396
Total	27,403,541	27,306,183	34,122,830	29,333,581	37,597,074
R. de la P. of Total	73.37%	69.57%	69.41%	69.32%	72.76%

Table 33 - Export of grain over the Rio de la Plata(Globalports, 2008)

Port	Volume of by-products export in tons				
	2003	2004	2005	2006	2007
Buenos Aires	470	669	10,010	1,220	
Ramallo				6,600	5,721
Rosario	3,735,813	3,301,713	3,042,649	3,864,050	5,187,631
San Lorenzo-San Martín	15,830,814	15,673,465	19,311,034	21,626,049	22,333,927
San Nicolas	4,002	6,203			
Others				163,373	
Total Rio de la Plata	19,571,099	18,982,050	22,363,693	25,661,292	27,527,279
Bahia Blanca	856,483	893,796	1,101,302	889,196	980,991
Necochea	374,960	450,320	470,783	464,572	555,576
Total	20,802,542	20,326,166	23,935,778	27,015,060	29,063,846
R. de la P. of Total	94.08%	93.39%	93.43%	94.99%	94.71%

Table 34 - Export of by-products over the Rio de la Plata (Globalports, 2008)

Port	Volume of vegetable oils in tons				
	2003	2004	2005	2006	2007
Buenos Aires	132,934	114,685	149,009	143,042	105,393
Rosario	1,158,463	953,700	1,086,117	1,135,781	1,501,219
San Lorenzo-San Martín	3,505,688	3,769,350	4,394,932	5,515,750	5,478,192
Total Rio de la Plata	4,797,085	4,837,735	5,630,058	6,794,573	7,084,804
Bahia Blanca	371,585	391,547	407,969	336,563	261,351
Necochea	282,090	310,866	315,023	263,829	234,153
Total	5,450,760	5,540,148	6,353,050	7,394,965	7,580,308
R. de la P. of Total	88.01%	87.32%	88.62%	91.88%	93.46%

Table 35 - Export of vegetable oils over the Rio de la Plata (Globalports, 2008)

Port	Container transport in TEU						
	2001	2002	2003	2004	2005	2006	2007
Buenos Aires inc. Dock Sud	962,965	745,658	897,123	1,138,503	1,255,000	1,567,000	1,709,000
Rosario	601		8,481	20,782	18,258	19,879	26,109
Deseado	16,004	16,292	16,431	16,822	17,632		16,910
Zarate	17,674	26,424	56,089	40,370	17,025	20,397	22,900
Total Rio de la Plata	981,240	772,082	961,693	1,199,655	1,290,283	1,607,276	1,758,009
Bahia Blanca	5,059	6,247	9,591	13,275	11,217	9,162	10,314
Madryn	16,707	23,071	24,173	21,190	21,778	24,196	20,808
Ushuaia			13,167	21,735	28,611	26,441	32,485
Total	1,019,010	817,692	1,025,055	1,272,677	1,369,521	1,667,075	1,838,526
R. de la P. of Total	96.29%	94.42%	93.82%	94.26%	94.21%	96.41%	95.62%

Table 36 - Export of containers over the Rio de la Plata (Globalports, 2008)

On average the export over the Rio de la Plata compared to the country:

Grain: 70.89%
By-products: 94.12%
Vegetable oils: 89.86%
Containers: 96.25%

Export of the past

Commodity	1993	1994	1995	1996	1997	1998
Grains	13,723,940	13,423,380	16,504,900	16,233,130	21,280,450	27,711,170
By-products	7,162,650	8,525,830	9,508,640	11,033,100	11,211,480	14,314,630
Vegetable oils	1,850,030	2,280,950	2,881,340	3,120,600	3,636,460	3,976,170
Commodity	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Grains	21,270,290	26,727,710	29,478,990	25,076,330	27,403,550	27,298,000
By-products	16,377,370	15,901,090	16,571,490	18,523,430	20,801,970	20,324,770
Vegetable oils	4,868,120	4,703,570	4,582,920	4,729,120	5,441,750	5,527,650
Commodity	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Grains	34,719,970	28,513,400	37,868,450	37,345,790	19,931,990	34,854,670
By-products	23,990,340	26,851,740	29,065,270	26,895,090	24,992,470	24,366,130
Vegetable oils	6,299,080	7,380,290	7,570,810	6,345,980	5,649,650	5,687,660

Table 37: Statistics of export (Ministerio de Agricultura, Ganaderiá y Pesca)

Export Predictions by USDA

	2011	2012	2013	2014	2015	
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
Grains						
Corn	15,000,000	20,000,000	20,100,000	20,200,000	20,000,000	20,000,000
Sorghum	1,900,000	2,200,000	2,300,000	2,500,000	2,800,000	2,900,000
Wheat	9,300,000	7,500,000	8,200,000	8,300,000	8,400,000	8,700,000
Soybean	9,200,000	10,800,000	12,200,000	12,200,000	12,200,000	13,000,000
Total	**35,400,000**	**40,500,000**	**42,800,000**	**43,200,000**	**43,400,000**	**44,600,000**
Conversion		**36,675,000**	**41,075,000**	**42,900,000**	**43,250,000**	**43,700,000**
By-products						
Soybean meal	27,500,000	29,800,000	30,600,000	32,000,000	32,900,000	33,600,000
Total	**27,500,000**	**29,800,000**	**30,600,000**	**32,000,000**	**32,900,000**	**33,600,000**
Conversion		**28,075,000**	**30,000,000**	**30,950,000**	**32,225,000**	**33,075,000**
Vegetable oils						
Soybean oil	4,500,000	4,800,000	5,000,000	5,100,000	5,200,000	5,200,000
+20% for sunflower seed	921,687	983,133	1,024,096	1,044,578	1,065,060	1,065,060
Total	**5,421,687**	**5,783,133**	**6,024,096**	**6,144,578**	**6,265,060**	**6,265,060**
Conversion		**5,512,048**	**5,843,373**	**6,054,217**	**6,174,699**	**6,265,060**

	2016	2017	2018	2019	2020	2021
	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22
Grains						
Corn	20,100,000	20,500,000	20,800,000	21,300,000	21,900,000	22,600,000
Sorghum	3,100,000	3,200,000	3,300,000	3,300,000	3,400,000	3,500,000
Wheat	8,900,000	9,100,000	9,400,000	9,600,000	9,800,000	10,000,000
Soybean	13,600,000	14,200,000	15,000,000	15,700,000	16,300,000	16,900,000
Total	**45,700,000**	**47,000,000**	**48,500,000**	**49,900,000**	**51,400,000**	**53,000,000**
Conversion	**44,875,000**	**46,025,000**	**47,375,000**	**48,850,000**	**50,275,000**	**51,800,000**
By-products						
Soybean meal	34,500,000	35,300,000	36,100,000	37,000,000	37,900,000	39,000,000
Total	**34,500,000**	**35,300,000**	**36,100,000**	**37,000,000**	**37,900,000**	**39,000,000**
Conversion	**33,825,000**	**34,700,000**	**35,500,000**	**36,325,000**	**37,225,000**	**38,175,000**
Vegetable oils						
Soybean oil	5,200,000	5,300,000	5,300,000	5,300,000	5,400,000	5,400,000
+20% for sunflowerseed	1,065,060	1,085,542	1,085,542	1,085,542	1,106,024	1,106,024
Total	**6,265,060**	**6,385,542**	**6,385,542**	**6,385,542**	**6,506,024**	**6,506,024**
Conversion	**6,265,060**	**6,295,181**	**6,385,542**	**6,385,542**	**6,415,663**	**6,506,024**

Table 38: Predictions by USDA, original data by (USDA, 2012)

E Exports ports

With port info by (Global Ports & SSY) a comparison of the allowed vessel draft, length, beam and DWT of ports around the world is made in Table 39.

Port	Draft [m]	Length [m]	Beam [m]	DWT [MT]
Algeria, Algiers	9.8	190		
Algeria, Bejaia	11.6	200		
Algeria, Djen Djen	18			
Bangladesh, Chittagong	9.2	186		
Brasil, Rio de Janeiro	10.9			
China, Beihai	12.4	300	34	
China, Chiwan	12.5	280	35	75000
China, Fuqing	11.4	190	35	85000
China, Fuzhou	9	170	30	20000
China, Jingtang	11.8	230	34	
China, Lianyungang	15	280	35	35000
China, Luoyuan	12	190	35	52000
China, Ningbo	14			76000
China, Rizhao	15	354		
China, Tangshan	11.8	230	34	
Egypt, Abu Qir	8	250		
Egypt, Adabiya	12.5	200		
Egypt, Alexandria	12.8	335.28		
Egypt, Safaga	12.5	250		
India, Kandla	12.5	240		65000
Italy, Bari	11.58	230		
Italy, Cagliari	12			
Italy, Manfredonia	9.75			25000
Japan, Chiba	10.8	238		
Japan, Osaka	9.1	198		65000
Japan, Yokohama	16.8	300		150000
Malaysia, Lumut	9.3	185	27	35000
Malaysia, Pasir Gudang	12			90000
Malaysia, Port Klang	14.5			80000
Netherlands, Rotterdam	18.65	300		150000
Taiwan, Kaohsiung	12.5	300		
Taiwan, Keelung	10.5	260		
Taiwan, Taichung	12.5	230		

Table 39 - Comparison of allowed vessels in ports

F Reference of grain terminals

Terminal Name	Effective Area (Acre)	Throughput capacity (Tons/Year)	Throughput (Tons/Year)	Storage Capacity (tons)	Berth Length (ft.)	Draft (ft.)	Targeted Turn Ratio (Times/Year)	Turn Ratio (Times/Year)	Targeted Tons / Gross Acre	Tons / Gross Acre
Colonel's Island Terminal, Georgia, US	45	3000000	1324525	80000	1 @ 925	40	37.5	16.6	66667	29434
Westwego Elevator, New Orleans, US	42	n/a	n/a	100000	3 @ 1800	49	n/a	n/a	n/a	n/a
Ilyichevsk Com. Seaport, Il., Ukraine	22	5000000	n/a	380000	1 @ 925	46	13.2	n/a	227273	n/a
Outer Harbor, Adelaide, AU	20	2500000	2250000	65000	2 @ 1050	45.5	38.5	34.6	125000	112500
Kembla Grain Terminal, Kembla, AU	21	5000000	n/a	260000	1 @ 1033	52	19.2	n/a	238095	n/a
Port of Montreal, Quebec, CA	10	n/a	2400000	262000	1 @ 700	35	n/a	9.2	n/a	240000
Cascadia Terminal, Vancouver, CA	15	10500000	5000000	280000	1 @ 900	49	37.5	17.9	700000	333333
Euro-Silo NV, Belgium	n/a	14000000	40000/day	650000	n/a	n/a	21.5	n/a	n/a	n/a
Tilbury FreePort, Tilbury, UK	21	2000000	n/a	120000	1 @ 850	41	16.7	n/a	95238	n/a
Sovena Oilseeds, Lisbon, Portugal	n/a	n/a	1500000	55000	n/a	n/a	n/a	27.3	n/a	n/a
J. Richardson Int. Terminal, Vancouver, CA	28	n/a	3000000	100000	1 @ 355	50	n/a	30.0	n/a	107143

Table 40 - Grain Terminal References (WorleyParsons Westmar Corp., 2008)

G NRT factor vessels

The vessels used to design the port all have a known DWT. In order to make calculations for the amount of ships needed to transport all the grain, the service time and the amount of berths, the amount of cargo each vessel can transport had to be known. The amount of cargo a vessel can transport is given in NRT (Net Register Tonnage). One NRT is the equivalent of 100 cubic feet of space for cargo in the holds.

The NRT is not as easily determined for a vessel as the DWT. The DWT of each class of vessels is well known, but the NRT depends on the facilities on board. A ship's NRT is its GRT (Gross Register Tonnage) reduced by the volume of non revenue earning spaces (not available to carry cargo), like engine rooms, fuel tanks and crew quarters. The GRT is a ship's total internal volume expressed in register tons, which are as well 100 cubic feet. The GRT is calculated from the total permanently enclosed capacity of a vessel.

In order to determine the NRT for the design vessels, existing vessels are analysed to obtain a factor for DWT/NRT. This is done for inland vessels and the ocean going vessels.
For the ocean going vessels, Table 41 gives a factor for several vessels (Golden Ocean), (Herlumindo). The average of these factors gives a DWT/NRT factor of 3 for ocean going vessels.

	DWT [mt]	GRT [100 cu ft]	NRT [100 cu ft]	LOA [m]	Beam [m]	Draft [m]	DWT /NRT
Golden Opportunity	75500	42785	25809	224.9	32.25	14.1	2.9
Golden Bull	75000	41596	25292	224.9	32.25	12.4	3.0
Golden Enterprise	79463	43498	27819	229	32.26	14.6	2.9
Golden Zhoushan	175835	91971	59546	291.8	45	18.2	3.0
Golden Beijing	176000	91971	59546	292	45	18.2	3.0
Golden Feng	169232	89510	56668	290.5	45	17.9	3.0
Gulf Pearl	74999	42443	21863	228.19	32.24	14.4	3.4
MV XINYU	63988	30868	23842	224.55	32.2		2.7
MV Grand Rise	64169	35208	21282	224.5	32.2	17.8	3.0

Table 41 - NRT factor ocean going vessels

H Probability of exceedance

In order to determine the design conditions for the port and the port components, first the acceptable probability of exceedance has to be calculated. This is done using this formula (Verhagen, d'Angremond, & Roode, 2009):

$$f = -\frac{1}{T_L}\ln(1-p)$$

In this formula T_L represents the life time of a construction and p the probability of failure. In this case the life time is set to 100 years and the probability of failure is chosen to be 0.1. This high value is chosen, because the breakwater does not protect inhabited areas, thus if it fails, the consequences of flooding are not that severe. Using these numbers to fill in the formula, the probability of exceedance becomes:

$$f = -\frac{1}{100}\ln(1-0.1) = 0.001$$

This gives a probability of exceedance of 1/1000 for the design conditions.

I Wind and waves Rio de la Plata

Data by (BMT Argoss).

Offshore location	34° 50'S, 57° 26'W	Size of offshore area for satellite data	200x200 km
Offshore model point	35° 00'S, 56° 15'W		

Wind speed altimeter

A global distribution of average wind speed, based on all altimeter observations in the database (Figure 47).

Wind speed scatterometer

A global vector field of average wind speed and wind direction, based on all scatterometer observations in the database (Figure 47).

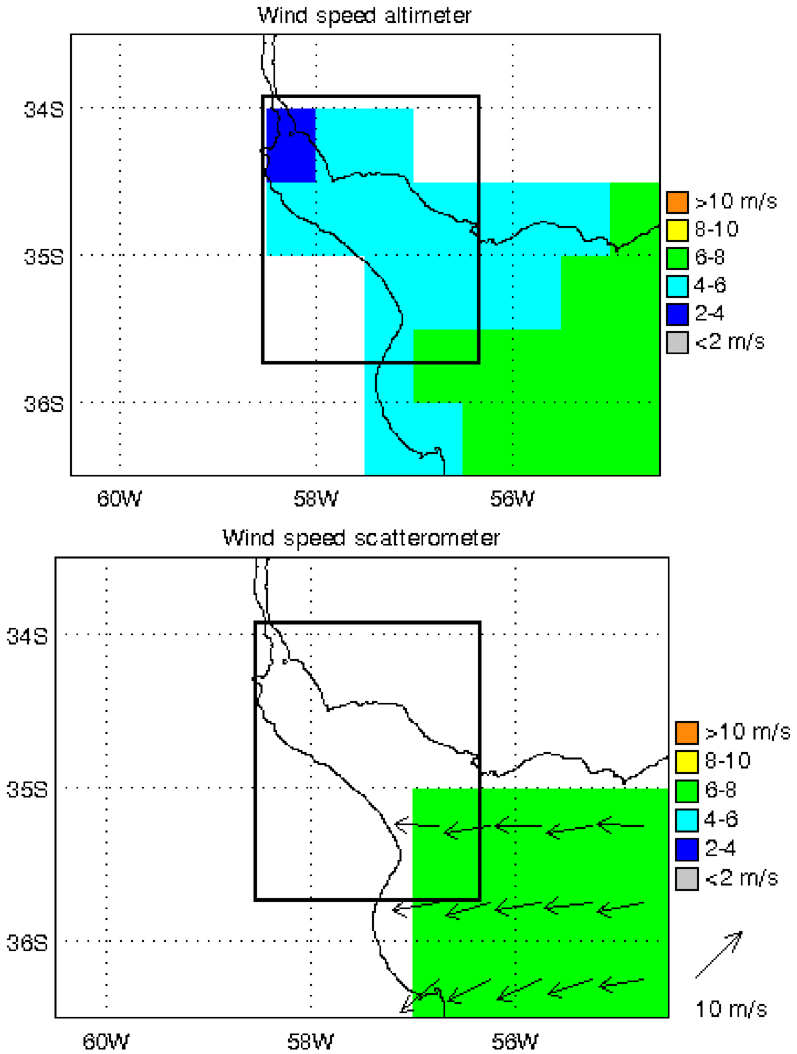


Figure 47 - Wind speed altimeter and scatterometer

Wave height altimeter

A global distribution of average significant wave height, based on all altimeter observations in the database. Mind that the coloured areas in this chart do not ensure the availability of data. They only indicate the wave height classes (Figure 48).

Wave height SAR

A global vector field of average significant wave heights, based on the swell part all ERS-SAR spectra in the database. Only cells containing at least 5 samples are shown (Figure 48).

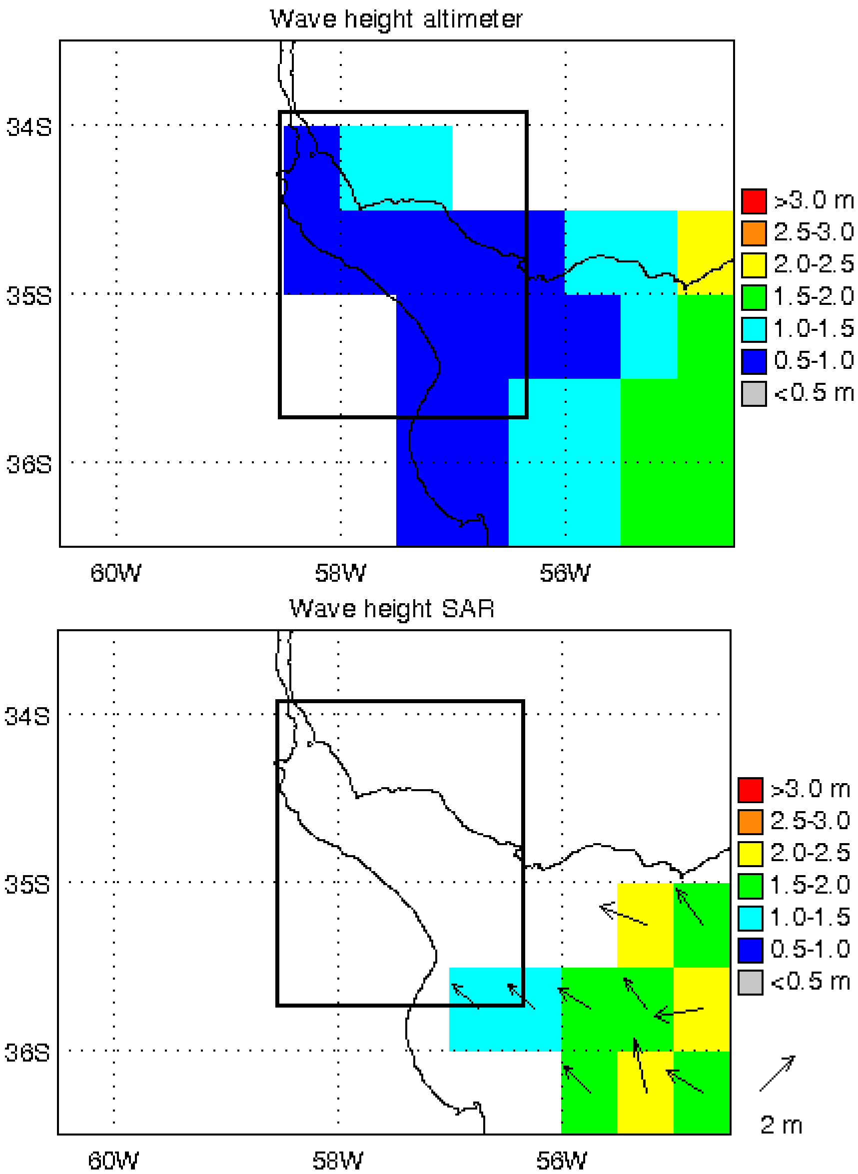


Figure 48 - Wave height altimeter and SAR

Wave height swell SAR

A global vector field of average swell, based on the swell part all ERS-SAR spectra in the database. Only cells containing at least 5 samples are shown (Figure 49).

Wave height wind sea SAR

A global vector field of average wind sea, based on the wind sea part of all ERS-SAR spectra in the database. Only cells containing at least 5 samples are shown (Figure 49).

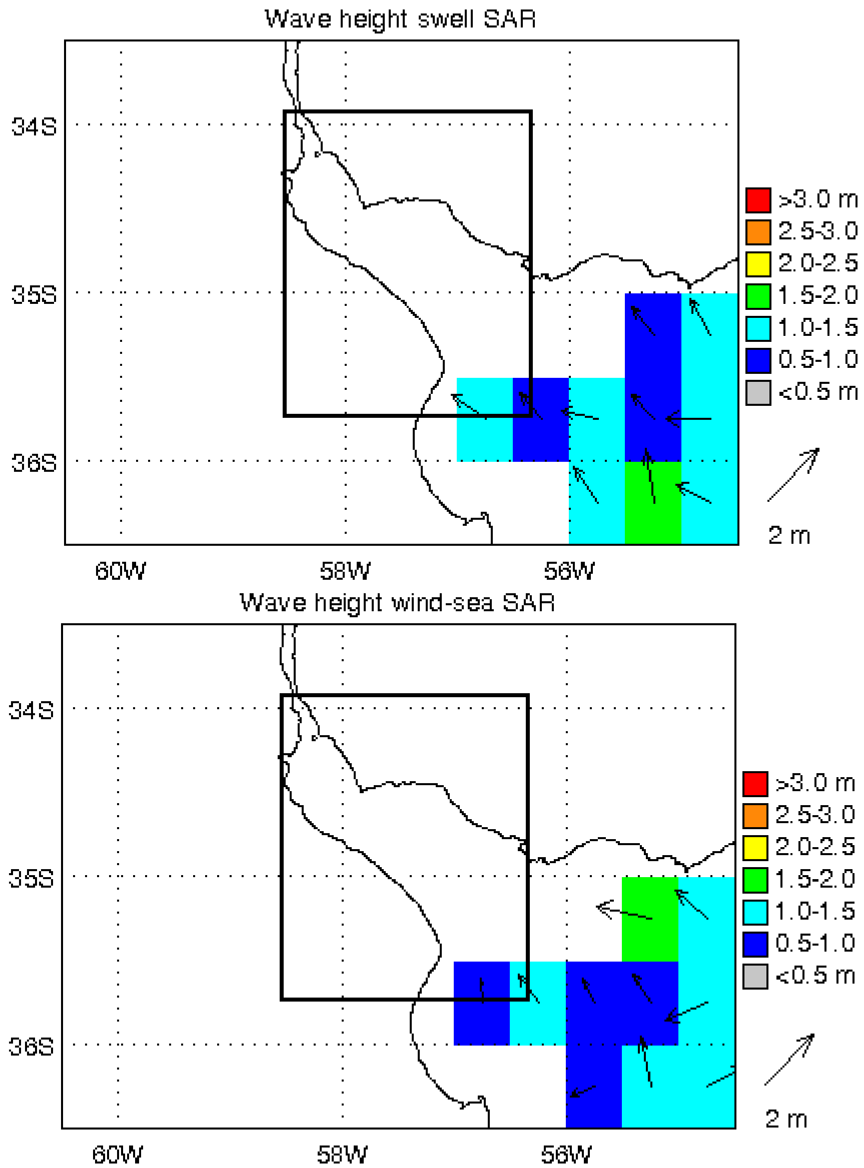


Figure 49 - Wave height swell SAR and wind sea SAR

Wave period SAR

A global distribution of average wave period, based on all ERS-SAR observations in the database. Average period is T_{m-10}, derived from the total spectrum. Only cells containing at least 5 samples are shown (Figure 50).

Wave period swell SAR

A global distribution of average swell period, based on all ERS-SAR observations in the database. Average period is Tm-10, derived from the swell part of the spectrum. Only cells containing at least 5 samples are shown (Figure 50).

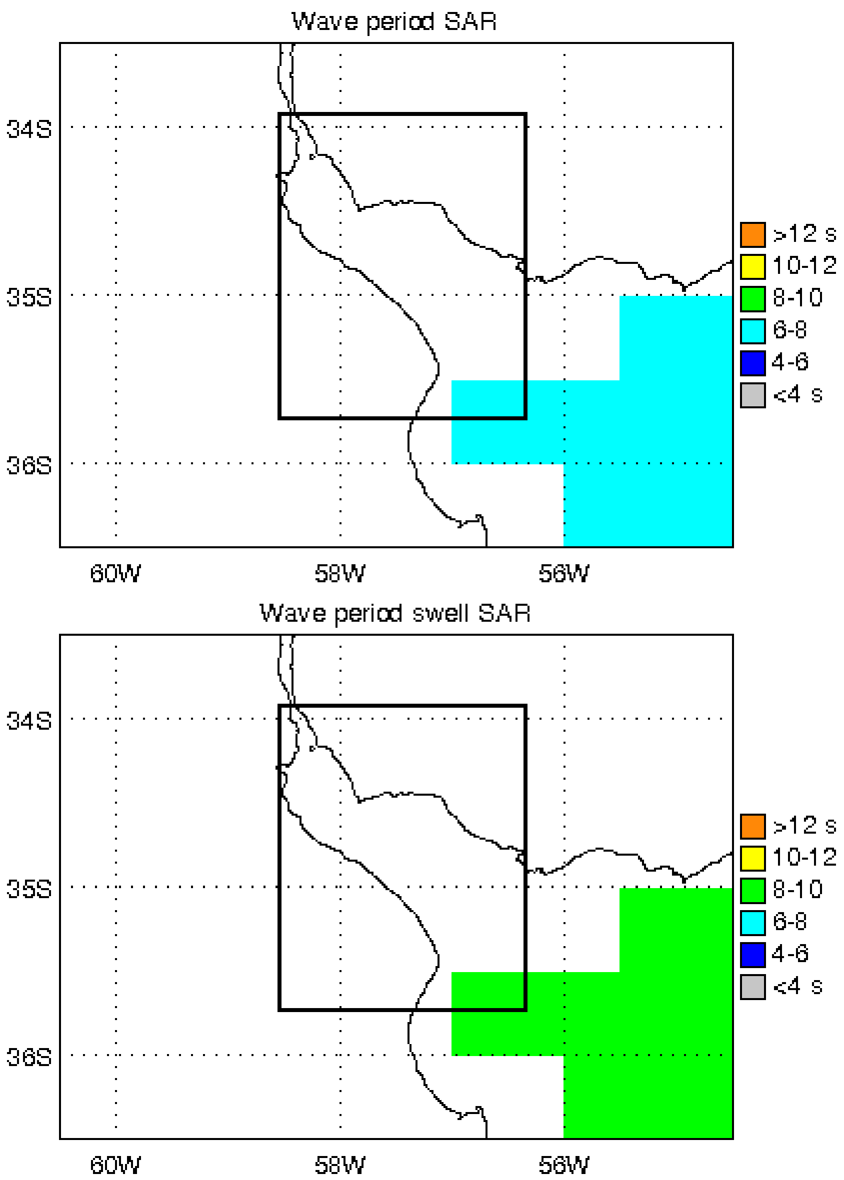


Figure 50 - Wave period SAR and wave period swell SAR

Wave period wind sea SAR

A global distribution of average wind sea period, based on all ERS-SAR observations in the database. Average period is T_{m-10}, derived from the wind sea part of the spectrum. Only cells containing at least 5 samples are shown (Figure 51).

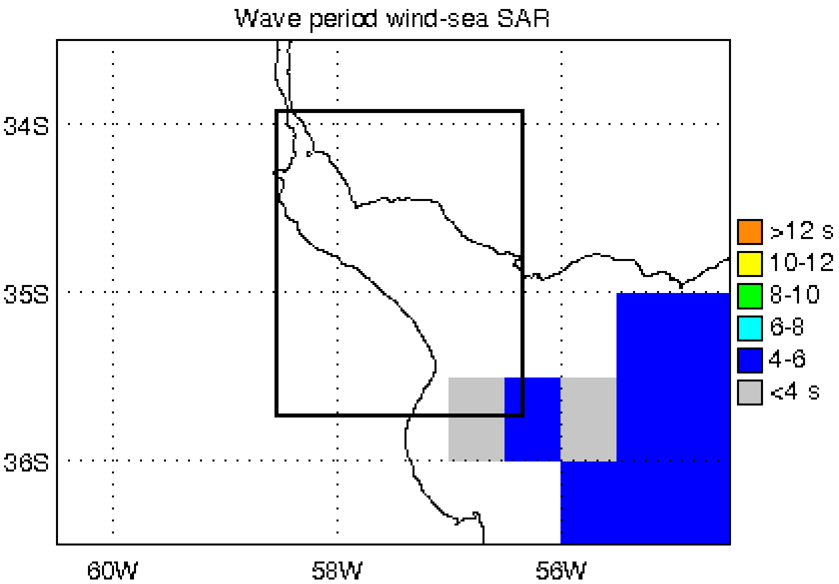


Figure 51 - Wave period wind sea SAR

Location 1 & 2

Tables

The monthly distribution table gives the relative distribution of wave height or wind speed over all months of the year: January until December. Each table entry contains the percentage or the absolute number of samples falling inside the related wave height or wind speed class. Colours indicate the highest entries: the red cells show the modus for each month. Per month, the second and third highest cells are yellow and the fourth and fifth highest cells are orange. White means 'really' zero. Next to the table the probability of occurrence per year of a wave class is given and the probability of exceedance of these classes.

Plots

The seasonality plot shows the monthly averages (thick red line) of wave height or wind speed against the months of the year. Interannual variation is indicated by the minimum and maximum monthly average over the years (thin red lines). In addition, the 90% confidence interval for the values in a particular month (orange) is given.

Rose

The length of each colours spoke in the directional wave rose above is related to the percentage of time that the waves arrive from that particular direction. Each concentric circle represents a different frequency, emanating from zero at the centre to increasing frequencies at the outer circles. Each spoke is broken down into colour-coded bands that show wave height ranges. Directions follow the nautical convention.

Location 1 - Western Rio de la Plata

Offshore location	34° 54'S, 57° 28'W	Size of area for satellite data
Offshore model point	35° 00'S, 56° 15'W	100x100 km

Wave height

The table of wave heights is used to calculate the significant wave height (H_s) and the peak period (T_p). H_s is approximated by calculating the $H_{13,5\%}$.

T_p is calculated with the formula $T_p = 3.6 \cdot \sqrt{Hs}$

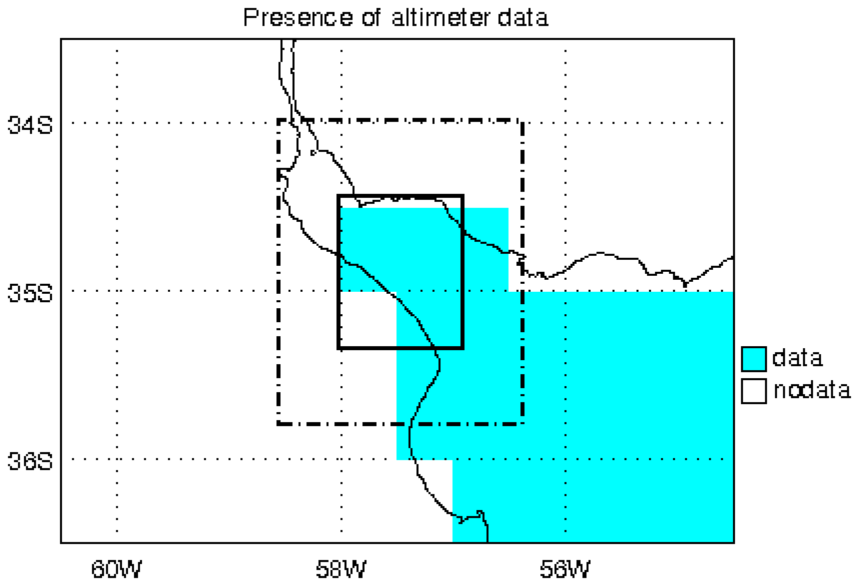


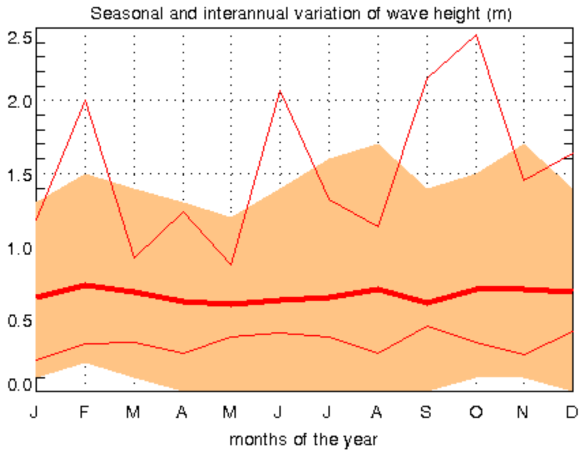
Figure 52 - Location 1

Monthly distribution of wave height (m)

lower	upper	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total	%	P of exceedance
0.0	0.5	32,819	27,734	33,693	39,370	36,818	41,435	41,064	35,076	41,190	29,901	35,609	30,090	424,799	35,40%	64,60%
0.5	1.0	51,544	46,094	43,629	41,732	47,955	39,583	42,128	44,227	40,503	50,495	40,959	51,171	540,020	45,00%	19,60%
1.0	1.5	12,162	20,312	18,359	15,157	11,591	15,509	10,426	14,161	13,959	13,861	16,790	13,874	176,161	14,68%	4,92%
1.5	2.0	2,703	4,102	3,024	2,165	2,727	1,389	3,404	3,050	2,288	3,960	4,059	3,604	36,475	3,04%	1,88%
2.0	2.5	0,193	0,391	0,864	0,984	0,227	1,157	1,277	1,525	1,144	0,792	1,661	0,721	10,936	0,91%	0,97%
2.5	3.0	0,579	0,586	0,432	0,394	0,682	0,926	1,489	1,307	0,915	0,594	0,738	0,360	9,002	0,75%	0,22%
3.0	3.5	0,000	0,586	0,000	0,197	0,000	0,000	0,213	0,436	0,000	0,396	0,185	0,180	2,193	0,18%	0,03%
3.5	4.0	0,000	0,195	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,195	0,02%	0,02%
4.0	4.5	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,218	0,000	0,000	0,000	0,000	0,218	0,02%	0,00%
4.5	5.0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,00%
total		100	100	100	100	100	100	100	100	100	100	100	100	1200,00	100,00%	

H_s (m)	T_p (s)
1,21	3,96

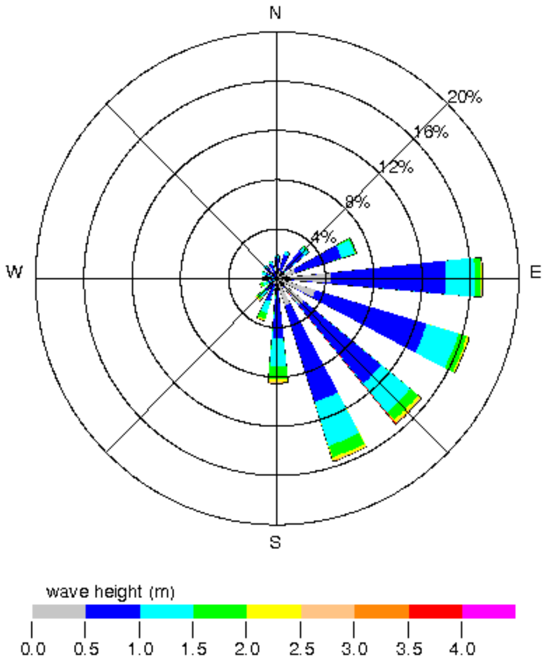
Table 42 - Distribution of wave height location 1



Copyright ARGOSS, September 2012

Your choices :

Centre of area is at 34° 54'S, 57° 28'W
Size of area is 100x100 km
Season is all year
First and last year analysed 1985-2011
Variable iswave height (m)
Data source is altimeter
Results are based on 5841 samples from 1184 passes



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Your choices :

Model output point is 35° 00'S, 56° 15'W
Season is all year
First and last year analysed 1992-2011
Variables are wave height (m) and wave direction (deg)
Data source is wavemodel
Results are based on 58440 model records
Direction convention is "coming from"

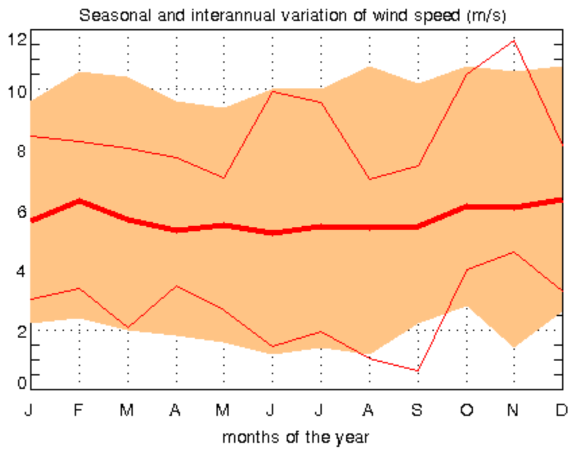
Figure 53 - Wave height distribution and wave rose

Wind speed

		Monthly distribution of wind speed (m/s)														
lower	upper	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total	%	P of exceedance
0	1	1,509	0,840	0,701	1,815	1,822	3,148	1,923	2,961	1,831	0,000	1,533	0,559	18,642	1,55%	98,45%
1	2	1,509	2,521	3,505	4,839	4,556	7,748	4,701	7,973	1,831	2,355	4,598	2,421	48,557	4,05%	94,40%
2	3	10,129	5,252	8,178	9,476	5,923	11,864	11,325	11,162	10,984	4,069	5,939	4,842	99,143	8,26%	86,14%
3	4	10,560	8,193	14,019	14,113	11,390	10,896	13,675	12,756	15,103	11,135	9,579	9,870	141,289	11,77%	74,36%
4	5	15,302	12,605	16,121	13,306	15,262	11,138	11,538	8,656	16,705	10,493	12,644	7,263	151,033	12,59%	61,78%
5	6	18,966	15,126	15,421	19,758	20,957	18,402	16,239	11,390	16,018	21,627	14,368	17,318	205,590	17,13%	44,65%
6	7	15,733	15,966	14,953	14,718	16,856	14,770	12,821	14,579	12,357	18,201	17,816	21,974	190,744	15,90%	28,75%
7	8	10,345	13,655	7,944	7,863	10,706	6,053	11,538	12,756	7,323	14,989	11,303	13,780	128,255	10,69%	18,06%
8	9	8,405	9,664	7,009	5,040	5,239	4,600	7,692	7,062	6,865	7,495	10,345	10,056	89,472	7,46%	10,61%
9	10	4,526	7,983	5,841	5,040	3,872	6,053	3,205	3,872	4,348	2,998	5,939	3,911	57,588	4,80%	5,81%
10	11	0,862	4,622	2,336	3,427	1,595	2,906	1,709	2,278	4,805	1,927	1,533	3,352	31,352	2,61%	3,19%
11	12	0,647	3,151	1,869	0,403	0,911	0,484	2,137	4,100	0,915	1,285	1,724	2,607	20,233	1,69%	1,51%
12	13	1,078	0,420	1,402	0,202	0,456	1,211	0,641	0,456	0,458	2,998	0,383	1,117	10,822	0,90%	0,61%
13	14	0,431	0,000	0,701	0,000	0,000	0,726	0,855	0,000	0,229	0,428	0,192	0,186	3,748	0,31%	0,29%
14	15	0,000	0,000	0,000	0,000	0,228	0,000	0,000	0,000	0,229	0,000	0,575	0,186	1,218	0,10%	0,19%
15	16	0,000	0,000	0,000	0,000	0,228	0,000	0,000	0,000	0,000	0,000	0,766	0,000	0,994	0,08%	0,11%
16	17	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,11%
17	18	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,383	0,000	0,383	0,03%	0,08%
18	19	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,192	0,186	0,378	0,03%	0,05%
19	20	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,192	0,000	0,192	0,02%	0,03%
20	21	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,03%
21	22	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,03%
22	23	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,03%
23	24	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,03%
24	25	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,03%
25	26	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,372	0,372	0,03%	0,00%
26	27	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,00%
total		100	100	100	100	100	100	100	100	100	100	100	100	1200,00	100,00%	

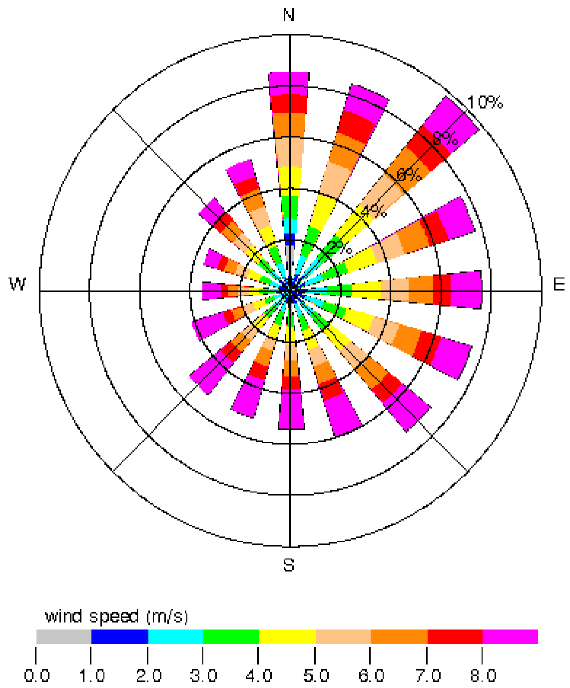
Average (m/s)	> 25 km/h
6,50	32,24%

Table 43 - Wind speed location 1



Your choices :

Centre of area is at 34° 54'S, 57° 28'W
Size of area is 100x100 km
Season is all year
First and last year analysed 1992-2011
Variable iswind speed (m/s)
Data source is altimeter
Results are based on 5586 samples from 1150 passes



Your choices :

Model output point is 35° 00'S, 56° 15'W
Season is all year
First and last year analysed 1992-2011
Variables are wind speed (m/s) and wind direction (deg)
Data source is wavemodel
Results are based on 58440 model records
Direction convention is "coming from"

Figure 54 - Wind speed distribution and wind rose

Location 2 - Eastern Rio de la Plata

Offshore location	35° 12'S, 56° 19'W	Size of offshore area for satellite data
Offshore model point	35° 00'S, 56° 15'W	100x100 km

Wave height

The table of wave heights is used to calculate the significant wave height (H_s) and the peak period (T_p). H_s is approximated by calculating the $H_{13,5\%}$.

T_p is calculated with the formula $T_p = 3.6 \cdot \sqrt{Hs}$

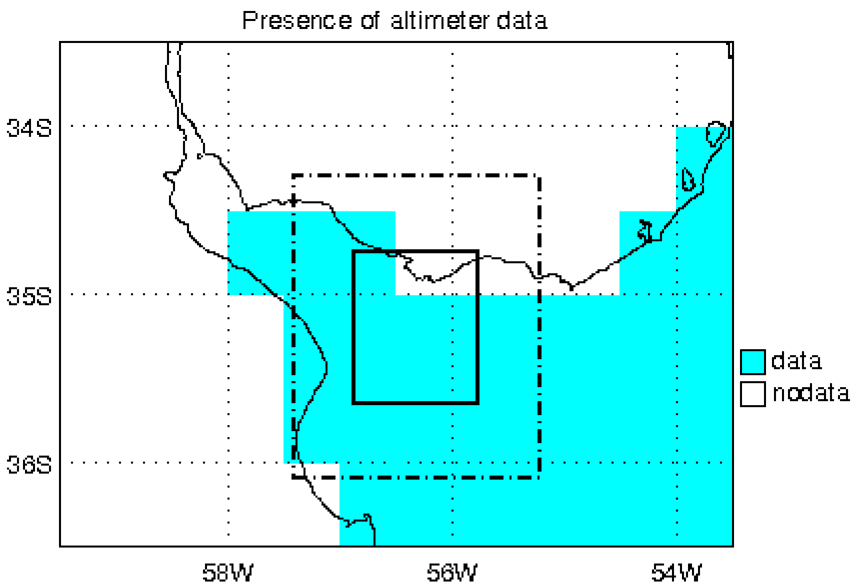


Figure 55 - Location 2

Monthly distribution of wave height (m)

lower	upper	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total	%	P of exceedance
0.0	0.5	23,384	25,166	29,072	33,538	35,981	31,791	35,763	33,961	27,447	27,053	23,952	23,195	350,303	29,19%	70,81%
0.5	1.0	50,051	43,805	47,336	43,984	41,939	45,346	39,504	40,853	44,501	48,116	46,524	50,349	542,308	45,19%	25,62%
1.0	1.5	23,283	24,889	18,569	16,948	15,981	16,113	17,638	14,774	22,654	19,469	19,476	20,820	230,614	19,22%	6,40%
1.5	2.0	2,374	4,425	4,008	3,891	3,830	5,553	5,296	6,495	4,238	4,348	5,762	4,006	54,226	4,52%	1,88%
2.0	2.5	0,455	0,996	0,761	0,819	1,513	0,599	1,166	2,380	0,605	0,580	1,810	1,211	12,895	1,07%	0,80%
2.5	3.0	0,253	0,221	0,152	0,666	0,520	0,381	0,534	1,190	0,404	0,435	1,286	0,326	6,368	0,53%	0,27%
3.0	3.5	0,152	0,387	0,101	0,154	0,189	0,054	0,049	0,297	0,151	0,000	1,095	0,093	2,722	0,23%	0,05%
3.5	4.0	0,000	0,111	0,000	0,000	0,000	0,054	0,049	0,050	0,000	0,000	0,048	0,000	0,312	0,03%	0,02%
4.0	4.5	0,000	0,000	0,000	0,000	0,047	0,054	0,000	0,000	0,000	0,000	0,048	0,000	0,149	0,01%	0,01%
4.5	5.0	0,000	0,000	0,000	0,000	0,000	0,054	0,000	0,000	0,000	0,000	0,000	0,000	0,054	0,00%	0,00%
5.0	5.5	0,051	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,051	0,00%	0,00%
total		100	100	100	100	100	100	100	100	100	100	100	100	1200,00	100,00%	

H_s (m)	T_p (s)
1,32	4,13

Table 44 - Wave height distribution location 2

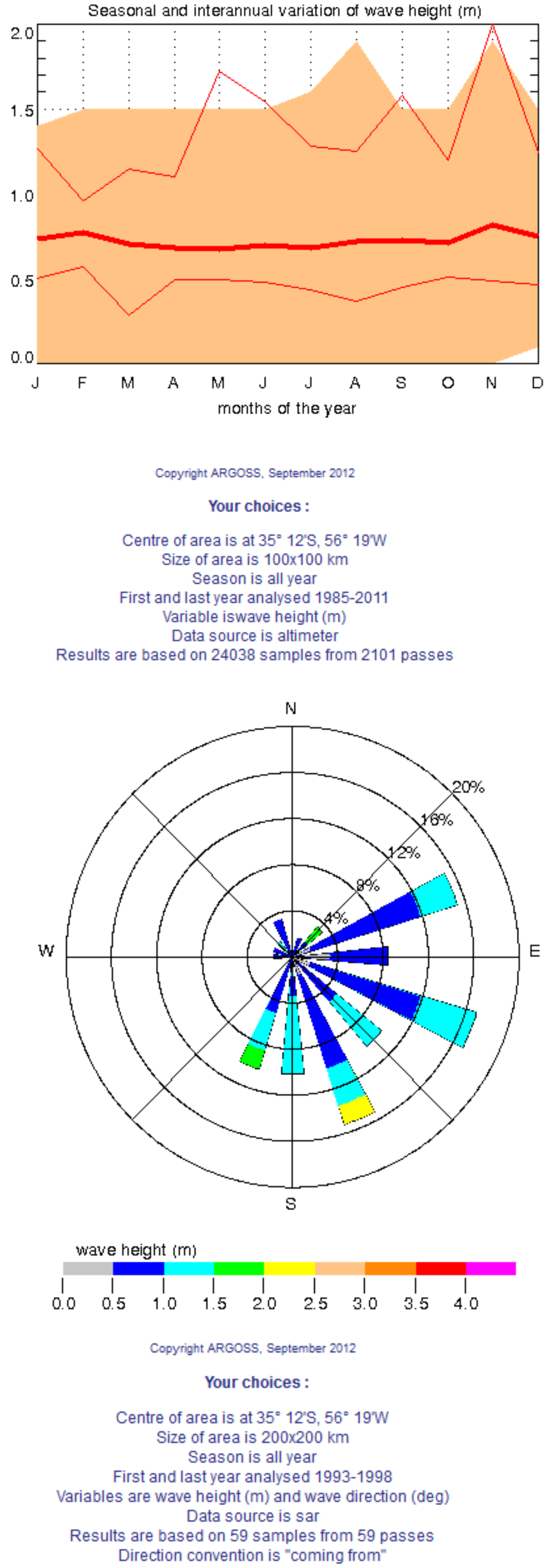
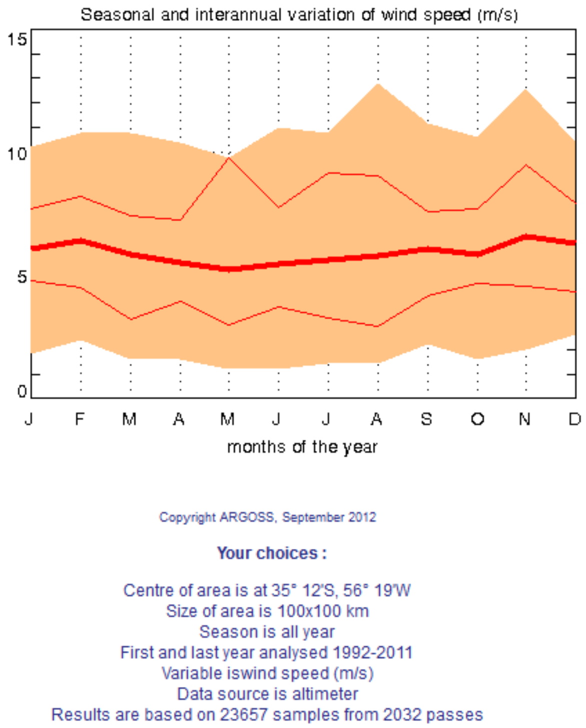


Figure 56 - Wave height distribution and wave rose

Wind speed

Monthly distribution of wind speed (m/s)																
lower	upper	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total	%	P of exceedance
0	1	0,823	1,350	2,022	2,397	2,255	3,941	2,687	2,087	2,151	1,666	1,602	0,711	23,692	1,97%	98,03%
1	2	4,272	1,912	4,095	5,107	7,630	6,240	5,471	5,293	2,048	5,047	2,864	2,226	52,205	4,35%	93,68%
2	3	5,816	7,312	4,925	7,817	11,996	7,663	7,474	10,687	7,578	8,182	4,903	4,121	88,474	7,37%	86,30%
3	4	9,007	7,368	10,109	11,933	10,605	14,012	15,340	13,842	10,548	9,554	8,010	8,669	128,997	10,75%	75,55%
4	5	10,654	10,799	15,759	16,311	14,107	12,261	14,851	13,791	13,722	13,082	11,262	12,080	158,679	13,22%	62,33%
5	6	15,594	15,017	17,107	16,571	17,131	13,738	13,630	13,639	15,105	16,805	15,146	15,917	185,400	15,45%	46,88%
6	7	15,800	14,792	16,071	14,591	12,956	17,077	10,601	12,214	12,494	14,062	16,553	18,475	175,686	14,64%	32,24%
7	8	14,874	12,598	9,953	9,745	8,157	9,524	8,891	7,277	12,340	10,142	13,641	14,543	131,685	10,97%	21,27%
8	9	14,050	11,417	7,465	5,003	6,670	4,433	8,451	6,005	10,241	7,251	9,369	9,569	99,924	8,33%	12,94%
9	10	3,397	8,549	3,733	3,387	3,839	3,065	5,471	2,952	4,301	7,006	5,485	5,969	57,154	4,76%	8,18%
10	11	1,801	4,274	4,406	4,117	1,344	2,737	2,247	2,850	3,687	2,891	2,573	4,027	36,954	3,08%	5,10%
11	12	1,698	2,531	2,903	1,199	1,871	2,737	1,026	2,697	3,840	1,911	1,845	2,653	26,911	2,24%	2,85%
12	13	1,132	0,956	1,296	0,261	0,768	0,930	1,417	1,730	0,870	0,833	2,379	0,758	13,330	1,11%	1,74%
13	14	0,669	0,225	0,052	0,417	0,192	0,438	0,928	1,934	0,256	0,833	0,777	0,095	6,816	0,57%	1,17%
14	15	0,206	0,337	0,104	0,730	0,048	0,985	1,124	0,712	0,819	0,637	0,243	0,095	6,040	0,50%	0,67%
15	16	0,154	0,112	0,000	0,313	0,384	0,219	0,342	0,712	0,000	0,049	0,777	0,047	3,109	0,26%	0,41%
16	17	0,000	0,112	0,000	0,000	0,048	0,000	0,049	0,712	0,000	0,049	1,553	0,047	2,570	0,21%	0,20%
17	18	0,000	0,112	0,000	0,000	0,000	0,000	0,000	0,458	0,000	0,000	0,631	0,000	1,201	0,10%	0,10%
18	19	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,153	0,000	0,000	0,388	0,000	0,541	0,05%	0,05%
19	20	0,051	0,056	0,000	0,052	0,000	0,000	0,000	0,102	0,000	0,000	0,000	0,000	0,261	0,02%	0,03%
20	21	0,000	0,112	0,000	0,052	0,000	0,000	0,000	0,102	0,000	0,000	0,000	0,000	0,266	0,02%	0,01%
21	22	0,000	0,056	0,000	0,000	0,000	0,000	0,000	0,051	0,000	0,000	0,000	0,000	0,107	0,01%	0,00%
22	23	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00%	0,00%
total		100	100	100	100	100	100	100	100	100	100	100	100	1200,00	100,00%	
Average (m/s)																
6,50																

Table 45 - Wind speed distribution location 2



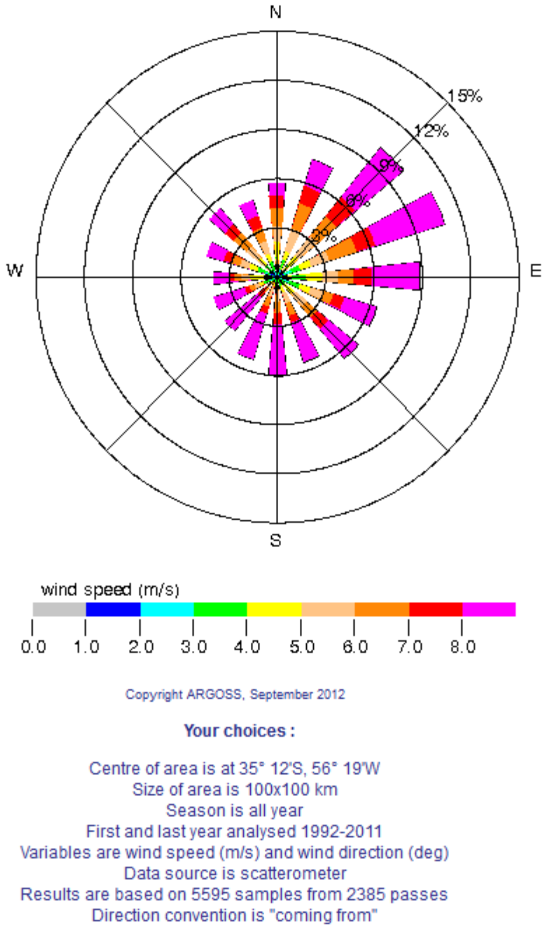


Figure 57 - Wind speed distribution and wind ros

J MCA criteria location

The following list shows the various aspects that are considered of significant influence on the choice of the port's location. The weight that is assigned to every aspect can be found between the brackets and is determined through individual comparison between the aspects. The complete chart of this procedure can be found in Table 46.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	**Durability**		0.5	1.0	1.0	0.0	0.0	0.5	1.0	1.0	0.5	1.0	1.0	0.0	0.0	**8.5**
2	**Sustainability**	0.5		0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.0**
3	**Influence of advancing delta**	0.0	1.0		0.0	0.0	0.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	0.5	**7.5**
4	**Ability to transport by land**	0.0	1.0	1.0		0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	**10.0**
5	**Accessibility for ocean vessels**	1.0	1.0	1.0	1.0		0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**13.5**
6	**Accessibility for river vessels**	1.0	1.0	1.0	1.0	0.5		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**13.5**
7	**Accessibility for workers**	0.5	0.5	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.0**
8	**Construction related dredging**	0.0	1.0	1.0	0.0	0.0	0.0	1.0		0.5	0.0	1.0	1.0	0.0	1.0	**7.5**
9	**Dredging navigation channels**	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.5		0.0	0.0	1.0	0.0	1.0	**5.5**
10	**Maintenance dredging**	0.5	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0		0.0	1.0	0.0	1.0	**7.5**
11	**Influence of currents**	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0		1.0	0.0	1.0	**7.0**
12	**Influence of waves**	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0		0.0	0.5	**3.5**
13	**Expandability**	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	**12.0**
14	**Obstruction for existing traffic**	1.0	1.0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.5	0.0		**5.0**
																105.0

Table 46 - MCA criteria location choice

Durability (8.5)

The time which the port will be able to operate before the boundary conditions change in such a way that the port becomes obsolete or unusable. This aspect is considered quite important, as the lifespan of the port is a significant influence on the possible revenue of the structure.

Sustainability (2.0)

The matter in which the structure or parts of the structure cause damage to the environment. Naturally it is not desirable to cause harm to the surroundings of the structure, but it is not one of the main aspects that need to be considered when determining where to place the structure. In the actual design phase it will play a more significant role.

Influence of advancing delta (7.5)

The manner in which sediment will clog up the port, or enclose the port in a delta. The delta advancing past the port's location would mean that it becomes unusable, or at the least very costly to keep it operational. It is therefore of some importance to keep in mind with the choice of location that the advancing delta does not reach it too quickly.

Ability to transport by land (10.0)

The manner in which it is possible to transport goods to the hinterland by land. In the future it may be desirable to use the newly constructed port to replace the current container terminals of Buenos Aires. The advancing delta may cause issues for the accessibility of that port, and the land at which it is built now could provide better income with other purposes. This container terminal would require a connection to the hinterland by land, and therefore the port, if it were to be suitable for gaining the extra feature that Buenos Aires fulfils now, would require a land connection. This land connection may also cause a shift in the grain export system and move some transport from the Bahia Blanca and Quequén ports to the newly constructed one.

Accessibility for ocean vessels (13.5)

The manner in which ocean vessels can easily reach the port (read: proximity to ocean). It is essential for the port to be accessible for ocean vessels, as without those, there would be no point to building the port in the first place. Therefore it gets the highest possible importance.

Accessibility for river vessels (13.5)

The manner in which river vessels can easily reach the port (read: proximity to river). It is essential for the port to be accessible for river vessels, as without those, there would be no point to building the port in the first place. Therefore it gets the highest possible importance.

Accessibility for workers (2.0)

The manner in which construction workers and stevedores can easily reach the port. Workers will find ways to get to their jobs quite easily, whether it be by air transport, sea transport or accommodation on the island itself. It is therefore not deemed an all too important aspect to keep into consideration when determining the location of the port.

Construction related dredging (7.5)

The amount of dredging that is required to construct the port. This amount is largely influenced by the current water depth at the desired building location. The shallower it is, the fewer dredging will have to be done. Seeing as it requires a lot of effort to do extra dredging, and effort costs money, it is considered of some importance that the construction related dredging is kept to a minimum.

Dredging navigation channels (5.5)

The amount of dredging that is required to make the port accessible for the vessels that will be using it. Dredging consist of the access channel to a port and deepening of the navigation channels in the Rio de la Plata. With this aspect the same goes as with construction related, less is better. Considering that the transport related dredging will likely be fewer than the construction related dredging, it is slightly less weighty than that.

Maintenance dredging (7.5)

The amount of dredging that is required to keep the port operational. This is a significant aspect to take into account. The sedimentation of the port,the access channels and the navigation channels could cause severe complications for the usage phase as well as the construction phase of the project. Due to its lasting influence it is considered of quite some importance.

Influence of currents (7.0)

The manner in which the currents in the system influence the port and the transport to and from the port. Large currents cause for ships to sway in their lane and experience difficulties properly approaching the access channel. This may cause accidents if the conditions are too severe. On top of that, large currents may wash away the newly created land and move sediment into the shipping lanes. It is therefore considered a large influence on the choice of the location.

Influence of waves (3.5)

The manner in which the waves in the system influence the port and the transport to and from the port. Waves are of influence on the erosion of the construction's shores, as well as, to a certain degree, the stability of approaching ships. Seeing as the ocean vessels are designed for much worse conditions than the Rio de la Plata can provide, and the construction can be protected against erosion using shoreline protection, it is considered a manageable aspect and therefore of not too large an influence on the choice of the location.

Expandability (12.0)

The manner in which It is possible to, in the future, add more terminals of any kind to the port. As mentioned before in the section about the land connection, there may be a future desire to add container terminals to the port. In top of that, increasing export numbers in grain may cause the need for extra dry bulk terminals as well. These aspects make it a very big influence to check of the port can be expanded in the future when the market asks for it.

Obstruction for existing traffic (5.0)

The manner in which the structure causes hindrance to currently existing transport lines. The existing lines of transport in the Rio de la Plata are of some importance to the country's economy and therefore the primary shipping lanes are already deemed unavailable for any constructions. On top of that the consideration in the location variants should include other, lesser important, lines of transport that currently inhabit the Rio de la Plata. Given that the primary transport is already taken into account, however, we can conclude that the other lines are of lesser influence.

K Location costs analysis

Reclamation and construction dredging costs

For making an estimation of the costs for land-reclamation and basin-dredging a rough calculation of necessary basins and land surface is necessary. To calculate this, the estimation for the peak traffic in chapter 5.3 is used.

Estimation of basins

For calculating the size of the basin, the total berth length is needed. A first estimation is made by calculating the service time per ship and calculating the daily amount of hours a fleet needs. Dividing this by an operating day and multiplying by the length of the ships gives the berth length.
For calculating the service time an estimation of the (un)loading rate is based on information in (WorleyParsons Westmar Corp., 2008) and(Ligteringen, 2000). Estimated are an unloading rate of 850 tons per hour for inland vessels and a loading rate of 10,000 tons per hour for ocean going vessels. This value is increased by 1 hour for berthing and unberthing for inland vessels and 2 hours for ocean going vessels.

Multiplying the amount of ships per day by the service time, gives the time a fleet needs per day. Dividing this by an operating day of 16 hours gives the maximum average ships in the port at any time. Those values are given in Table 47.

	Ships per day	Service time [h]	Time per day [h]	Avg. ships at any time
Barges	72	7.6	548	34.2
Handymax	0.3	5.0	12.2	0.8
Panamax	2.4	7.1	17.2	1.1
New Panamax	3.3	10.1	33.2	2.1
Capesize	0.1	12.1	0.7	0.04

Table 47 - Calculating of average ships at any time

The berth length, which is taken to be the same as the basin length, can now easily be calculated by using the formula $L = 1.1 \cdot \Sigma n_s(L_s + 15) + 15$, in which n_s is the number of ships and L_s the ship length. The width of the basin is 8B+50 for the inland basin and 5B+100 for the ocean going basin, where B is the beam of the design vessel (Ligteringen, 2000).

The depth of the basin and also for the access channel can be calculated with:
$D - T + s_{max} + r + m$. Where D is the draft of the ship, T the tidal window, s_{max} the maximum sinkage due to squat and trim, r the vertical motion due to wave response and m the net under keel clearance. For the inland terminal the depth of the barges is used, no tidal window is applied and the proposed values for sinkage (0.5) and vertical motion ($H_s/2 = 1.32/2 = 0.66$) are used. The clearance is 0.3 due to the soft mud as soil. For the ocean going terminal, the depth of the New Panamax is used and the depth of the Capesize is not taken into account. If Capesize vessels visit the port, they will have to load only partly to have a reduced draft. By still taking the beam of Capesize into account, there is a better possibility to extend the depth at a later point in time. The rest of the parameters will be equal to the New Panamax vessels. This gives the basin dimensions as given in Table 48.

	Length [m]	Width [m]	Depth [m]	Area [m^2]
Inland basin	4,298	242	6.1	1,040,092
Ocean going basin	1,270	345	16.7	438,003

Table 48 - Dimensions of terminals

Estimation of land surface

The land surface is estimated based on the values given in (WorleyParsons Westmar Corp., 2008). In their design they compare a number of grain terminals and draw some conclusions. The full list of the terminals is also included in Appendix F: Reference of grain terminals.

By dividing the throughput with the effective area the targeted tons per gross area is calculated. This value indicates the area that is needed per ton throughput. This value differs a lot for all ports and the most efficient port is the Cascadia Terminal in Vancouver, Canada. They have a value of 333,333 tons/gross area and expect a targeted 700,000 tons/gross area in the near future. The Cascadia Terminal is specialised in handling over 100 grades of grain. These characteristics are similar with the transhipment port being designed and therefore it is expected that the same efficient tons/gross area can be reached. Since the expected value has not been reached so far, a conservative choice is made by using 333,333 tons/gross area.

This gives a total land surface of 94.4 mln. / 333,333 = 283 acre, or 1,146,072 m^2.

Construction costs

The volumes of necessary dredging can now be calculated by comparing the depth of the location with the necessary depth of the basins. As the height of the port, a comparison is made with the design of AeroIsla (Boskalis AeroIsla), a land reclamation project in the Rio de la Plata for an airfield. The design height is here calculated to be 5 metres above Cero del Riachuelo. As explained in Appendix B: Reference levels, this gives a height of 4.7 m above low water (LIMB) in which the local depth is measured.

Besides the raw land or water surface, also the slope of both has to be taken into account. A slope of 1:4 is used for all dredging, as is currently done for all channels in de Rio de la Plata (SSPYVN, 2011) and a slope for the land reclamation of 1:5 is used, as is given in (Verhagen, d'Angremond, & Roode, 2009).

The reclamation volume can be calculated by assuming a square island. This island will have a circumference of $\mathrm{P} = 4 \cdot \sqrt{1146072} = 4282\mathrm{m}$ and the reclamation volume is

$$V_{recl} = (d + 4.7) \cdot A + P \cdot \frac{d + 4.7}{1/5} \cdot \frac{d + 4.7}{2}$$

The dredging volume is calculated similarly for both basins, but instead of using the circumference, the berth length can now be used.

$$V_{dred} = (d_{basin} - d) \cdot A + 2 \cdot L \cdot \frac{d_{basin} - d}{1/4} \cdot \frac{d_{basin} - d}{2}$$

Prices for dredging are, according to (de Veth, 2012), around \$10 per m^3. Although the sand that is dredged for the basins can as well be used for reclamation, the costs for rainbowing is higher than for the dumping and it is assumed that the reclamation also costs \$10 per m^3. The total construction costs per variant are given in Table 49.

	Avg. depth [m]	Reclamation volume [m^3]	Dredging volume [m^3]	Costs [USD]
Banco Inglés	0.9	6,736,891	13,988,877	207,257,681
Banco Chico	3	9,442,048	10,274,368	197,164,162
Playa Honda	2.4	8,659,511	11,315,613	199,751,247
Coastal Variant	0	5,606,443	15,640,938	212,473,810

Table 49 - Construction Costs

Dredging and maintenance costs of access channels

The dredging and maintenance costs of the access channels are an important part of the total expected costs of a port.

Construction Costs

In order to be able to sail to each variant, new navigation channels will have to be dredged. Also the current navigation channels in the Rio de la Plata will have to be deepened.

In Figure 58 the location of the access channels is drawn. For each variant the length of the access channel is determined, as can be found in Table 51. Banco Inglés and the Coastal variants have a distance to the current navigation channels of relatively 15 and 18 km. Banco Chico and Playa Honda have a distance of 2 km.

Figure 58 - New situation

In the new situation the current navigation channel near the Atlantic Ocean has to be extended with 30 km, see the green line in Figure 58. When the point where this channel stops is taken as a base point, the distances to the variants are as in Table 50.

Variant	Distance excl. access channel [km]	Distance incl. access channel [km]
Banco Inglés	30	45
Banco Chico	188	190
Playa Honda	271	273
Coatal variant	115 – 212	133 - 230

Table 50 - Sailing distance to Atlantic Ocean

For each access canal the average bottom depth of the area is determined. The average bottom depth next to the current navigation channels of the Rio de la Plata is assumed to be 6 m, in order to simplify the calculation. Only for the Emilio Mitre channel this simplification isn't completely valid, because the average bottom depth is smaller than 6 m. So the calculated dredging volume for the Playa Honda variant will be an underestimation.

The navigation channels in the Rio de la Plata have a depth of about 10.5 m in the current situation. In the new situation the depth of the channels has to be 17 m (Table 48). So the dredging height of the navigation channels will increase to 11 m. The dredging height of the access channels can also be found in the table.

Variant	Part	Length channel (km)	Average bottom depth (m)	Current dredging height (m)	New dredging height (m)	Cross-sectional area (m^2)	Dredging volume x 10^6 (m^3)	Total dredging volume x 10^6 (m^3)	Total dredging costs x 10^6 (USD)
Banco Inglés	Access channel D=17m	15	9.0		8.0	1456	21.8	63.2	505
	Deepening navigation channel D=17 m	30	6.0	4.5	11.0	1378	41.3		
Banco Chico	Access channel D=17m	2	6.0		11.0	2134	4.3	263.3	2,107
	Deepening navigation channel D=17 m	188	6.0	4.5	11.0	1378	259.1		
Playa Honda	Access channel D=17m	2	2.5		14.5	3016	6.0	379.5	3,036
	Deepening navigation channel D=17 m	271	6.0	4.5	11.0	1378	373.4		
Coastal	Access channel D=17m	18	4.0		13.0	2626	47.3	272.6	2,181
	Deepening navigation channel D=17 m	163.5	6.0	4.5	11.0	1378	225.3		

Table 51 - Costs of construction dredging

The width of the channels is assumed to be 150 m, in order to receive Post Panamax vessels. With a bottom width of 150 m and a slope of 1:4 the cross sectional area of the channel that has to be dredged is calculated. For the access channels this is just the area of the canal profile. For the navigation channels to be deepened, the current area of the canal profile is extracted from the area of the new canal profile.

Multiplied with the length of the channel parts, the result is the dredging volume. The soil to be dredged is assumed to consist completely of sand. For sand the dredging costs for construction are between 7 and 10 USD/m^3 (de Veth, 2012). Chosen is a value of 8 USD/m^3. The total construction costs for the dredging of the channels of each variant are shown in Table 51. There seems to be a rather big difference in construction costs between Banco Inglés and the other variants. Mainly caused by the relative short length of the navigation channels to be deepened for this variant. The deepening of the navigation channels turns out to be dominant in comparison with the dredging of the access channels.

Maintenance costs

The access channels do not only have to be constructed but also have to be maintained. Because of the high amounts of silt in the Rio Paraná a lot of sediment reaches the Rio de la Plata. Without maintenance dredging the access channels will silt up very soon. In order to determine the amount of maintenance dredging, reference projects are viewed. The amounts of dredged material are listed in Table 52. The dredged volume of the Martin Garcia channel is an average of 14 years of dredging (Saizar, 2012). Only the part perpendicular to the current is taken. The dredging volumes of the other channels are based on a dataset of 1 year (Local expert, 2012).

Navigation Channel	Dredging volume [m^3/y]	Depth channel [m]	Depth bottom [m]	Length [km]	Dredging volume [m^3/m/y]	Dredging height [m]	W_{ch} [m]
Martin Garcia	3,150,000	9.4	6	24.5	128,571	3.4	90
C.Ing.E.Mitre	4,584,000	10.5	6	36	127,333	4.5	110
C. Acceso	525,000	10.5	6	37	14,189	4.5	90
C.Intermed.	0	10.5	6	40	0	4.5	200
R.Ext./B.Chico	10,000	10.5	6	44	227	4.5	130
C.P.Indio	4,872,000	10.5	6	90	54,133	4.5	250
Extensión Punta Indio	1,219,000	10.5	6	28	43,536	4.5	250

Table 52 - Maintenance dredging current navigation channels

As can be seen from the data channel Martin Garcia and the Emilio Mitre channel have the highest amount of sedimentation. Emilio Mitre probably because it is located close to the mouth of the Paraná. Martin Garcia is located perpendicular to the flow patterns as in Figure 12 and will therefore have more sedimentation than Canal Acceso, which is located more or less parallel to the flow pattern. In case of Martin Garcia the velocity suddenly drops over a wide area and will thus result in a lot of sedimentation. In case of a channel parallel to the flow pattern this area is rather small.

All the variants are located in the neighbourhood of a reference project. The only difference is the depth and the width of the channel compared with the reference project.

To calculate the dredging costs for the different locations, two correction factors are applied on the original data: one for the difference in dredging height and one for the difference in channel width. The correction factor for the dredging height is calculated by dividing the dredging height of the new navigation channel (11 m) by the current dredging height (4.5 m). The same goes for the channel width. By multiplying the dredging volume of Table 52 with the correction factors the dredging volumes for the maintenance of the new navigation channels are calculated, see Table 53.

Navigation Channel	Correction factor dredging height [-]	Correction factor channel width [-]	Dredging volume future navigation channel [m^3/y]
Emilio Mitre	2.44	1.36	15,280,000
Canal de Acceso	2.44	1.67	2,138,889
Intermedio	2.44	0.75	0
R.Ext./B.Chico	2.44	1.15	28,205
Punto Indio	2.44	0.60	7,145,600
Extensión Punta Indio	2.44	0.60	1,787,867

Table 53 - Maintenance dredging future navigation channels

The access channel to Banco Inglés is located perpendicular to the Extension of the Punta Indio channel, but both make aren't in an area of the flow pattern. So the same dredging volume is expected. The amount of maintenance dredging for the access channel can be calculated by multiplying the dredging volumes of Table 52 with correction factors for the dredging height and the channel width. The same goes for Banco Chico, Playa Honda and the Coastal variants (access channels parallel to Martin Garcia channel). See Table 54 for the maintenance dredging volume.

Variant	Part	Correction factor dredging height [-]	Correction factor channel width [-]	Dredging volume x 10^6 (m^3)	Total dredging volume x 10^6 (m^3)	Total dredging costs x 10^6 (USD)
Banco Inglés	Access channel D=17m	1.8	0.6	0.7	70	51
	Deepening navigation channel D=17 m			0		
Banco Chico	Access channel D=17m	3.2	1.67	1.4	1,035	761
	Deepening navigation channel D=17 m			9		
Playa Honda	Access channel D=17m	4.3	1.67	1.8	1,887	1,387
	Deepening navigation channel D=17 m			17		
Coastal	Access channel D=17m	3.8	1.67	14.8	2,368	1,741
	Deepening navigation channel D=17 m			8.9		

Table 54 - Maintenance costs

With a life time of 100 years the total amount of maintenance dredging for this period is determined. The costs of maintenance dredging are about 3 times as small as for construction dredging (Louer, 2012), so resulting in 3 USD/m^3. Because the maintenance costs are spread over 100 years, the Net Present Value (NPV) has to be included (see Appendix C: Financial aspects). The total maintenance costs of each variant for the total life time are listed in Table 54.

Transport of workers

Another important aspect of the different variants is the distance construction workers and stevedores would have to travel in order to reach the port. This travelling motion obviously costs money as ships, cars and possibly airborne vehicles will have to bring the workers and stevedores to the port area. To make a comparison the following is assumed.

Separate housing facilities will have to be installed at Banco Inglés to provide housing for the stevedores, so the construction workers can live on the island in barracks. It is assumed every worker will have to travel back and forth to land once a week.

The workers for the Banco Chico variant can live in La Plata, as it's reasonably accessible by ship from the La Plata port. The workers for the Playa Honda variant can live in Buenos Aires for similar reasons as the Banco Chico variant. The workers for the coastal variant can live in the coastal towns La Plata, Magdalena and Veronica and get to work by car easily. This gives Table 55 for the distance workers have to travel to the port.

Variant	Distance [km]
Banco Inglés	114
Banco Chico	42
Playa Honda	9
Coastal variant	0

Table 55 - Distance from variant to shore

From this distance the cost associated with the transfer of workers from their homes to the port can be deducted. Naturally the cost for Banco Inglés will be affected by the construction costs of the workers' living quarters. The cost of living quarters has been estimated at USD 71,189.73 which makes the stevedores have single houses which will be constructed to achieve a so called gold label for green construction (Stripes). For the transport of the workers it is envisioned that a ferry transport system will have to be put in place with the capacity to transport workers from and to the island on a daily base (weekly for the Banco Inglés variant). This involves some capital investments for terminals and ships, as well as operational costs. A research (State of Washington) done by the state of Washington, U.S., shows us that terminals and ships together will cost roughly USD 7 million and the annual maintenance and operational cost will be USD 0.065 per km per day. It is estimated that approximately 800 stevedores will be included in the port's operational personnel (downscaling of 2^{nd} Maasvlakte projected workforce by area). The total costs for the transport of workers are presented in Table 56.

Variant	Transport of workers [USD]
Banco Inglés	94,699,696
Banco Chico	86,548,555
Playa Honda	24,029,540
Coastal variant	0

Table 56 - Cost to transport workers during life time

It shows that the Banco Inglés variant is quite expensive due to its distance from shore regardless of the fewer transport movements. Chico is more expensive due to the many required movements, and the coastal variant is free because workers can drive there by land.

Costs breakwater

A part of the costs for the new port is the construction of breakwaters to protect the vessels and port area from waves. In order to make an estimation of these costs, first the design wave height has been estimated, after which the length of the breakwater is estimated. Using a table which gives the price of a breakwater per running metre and design wave height, the total costs are estimated.

Design wave height

The design wave height is determined using the wind and wave data in Appendix I: Wind and waves Rio de la Plata and the probability of exceedance given in Appendix H: Probability of exceedance. Using the data, the probability of exceedance of each wave class is plotted versus this wave class. Using a logarithmic trend line, a formula for the design wave height is calculated, in Figure 59 presented as the y-formulas.

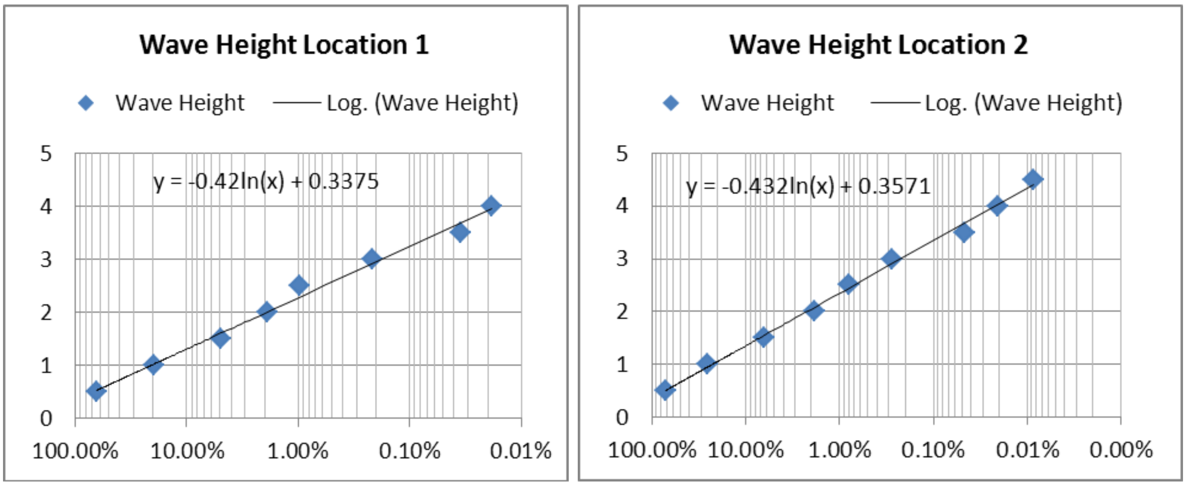


Figure 59 - Design wave height location 1 & location 2 in the Rio de la Plata

When the calculated probability of exceedance is filled in to these formulas, the design wave height for these locations is calculated. This gives a design wave height for location 1 of 3.21 m and a design wave height for location 2 of 3.32 m. Using these wave heights, the design wave heights for the different port locations are estimated, as can be seen in Table 57. The design wave height for Playa Honda has been slightly reduced, due to the lower water depth in that area.

Location	H_d [m]
Banco Inglés	3.3
Banco Chico	3.2
Playa Honda	2.6
Coastal Variant	3.2

Table 57 - Design wave heights

Length of the breakwaters

The different locations require different lengths of breakwaters, due to different directions of wave attack. The location which requires the most breakwaters is Banco Inglés, because this location is close to the Atlantic Ocean and has a large fetch of the river on the West and South side of the port. It is estimated that approximately three quarters of the circumference of this location will have to be protected by breakwaters.

Banco Chico has less exposure to waves, due to the fact that it is close to the coast and further up river. It is exposed to waves coming from the East and North. Therefore the length of these breakwaters is estimated to be approximately half of the circumference of the port.

Playa Honda and the Coastal Variant have the least exposure to waves, due to their natural shelter of a part of the port. Playa Honda only has wave attack from the East and the Coastal Variant is mostly protected by land. Therefore these locations have an estimated length of a quarter of the circumference of the port.

The total circumference (CF) of the port is estimated to be 4282 m, which will be used to calculate the length of the breakwaters, as can be seen in Table 59.

Costs per breakwater

To estimate the cost of breakwaters for the port, a unit price is determined. The unit price for design wave heights from 4 till 6 metres is known(Verhagen, d’Angremond, & Roode, 2009). The unit prices for the lower design wave heights have extrapolated from the known prices, resulting in Table 58. The price consists of two parts, one part for the core of the breakwater and the other part for the armour layer.

Design wave height H_d [m]	Initial Costs Breakwater [€/m]	Initial Costs Armour Layer [€/m]
2.0	11260	2640
2.5	11920	3300
3.0	12580	3960
3.5	13240	4620
4.0	13900	5280
5.0	15220	6600
5.5	15900	7280
6.0	16540	7920

Table 58 - Unit prices breakwaters

Using the above information, the total costs for the breakwaters per location can be estimated. To take the maintenance of the breakwater into account, the total costs are estimated to be 150% of the construction costs. The unit prices are converted to USD. The outcome can be found in Table 59.

Location	Part of CF	Length [m]	IC Breakwater [USD]	IC Armour Layer [USD]	Total [USD]
Banco Inglés	0.75	3211	53,759,811	18,046,990	**107,710,201**
Banco Chico	0.50	2141	35,475,288	11,666,741	**70,713,044**
Playa Honda	0.25	1070	16,461,594	4,557,321	**31,528,373**
Coastal Variant	0.25	1070	17,737,644	5,833,370	**35,356,522**

Table 59 - Total costs breakwaters (per location)

Shipping cost

To obtain a proper comparison between the costs of vessel movement between the source of the goods and its destination an assessment will have to be made about the distances the ships travel compared to each other. In order to achieve this, points have been chosen which all transport movements have in common, and from there the distances to the respective ports are compared. For the river vessel the chosen point is in the Rio Paraná at San Pedro. This point has been chosen because both the vessels that go through the Martín Garcia and the vessels that go through the Paraná de las Palmas will have to pass this point. Table 60 shows the distances as they've been determined. In this assessment a spread has been considered for the location of the coastal variant along the coast between La Plata and Veronica.

Variant	Distance through Martin Garcia [km]	Distance through Paraná [km]
Banco Inglés	455	451
Banco Chico	295	289
Playa Honda	218	201
Coastal Variant	281 – 383	275 – 377

Table 60 - Distances to port from San Pedro

For ocean vessels a similar assessment has been made. For this comparison the entry point into the dredged system is being taken as representative point. The obtained distances are the same as in Table 50.

Following this assessment the next step is to look into the cost difference between ocean transport and sea transport, and what the costs are for the transport. The determining factor in this calculation is chosen to be the personnel cost. Subsequently this cost has been multiplied by respectively 10 for ocean going vessels (Drewry Shipping Consultants Ltd.) and 0.26 for inland vessels (PIANC, 1991). It has been deducted that an inland vessel requires 4 employees(St-AB, 2009) and a Panamax vessel requires 26(FSB). Subsequently it has been determined that the average crewmember receives a wage of USD 1548,- per month (De-SalarisIndicatie.nl) and a captain earns twice this amount and two captains are required per vessel to keep it operational. This means that for the transport of one Panamax equivalent amount of cargo (50,710 NRT) an amount of salary units of 28 is required for the Panamax vessel, and a total of 58 for the inland vessels. Furthermore the speed of a Panamax vessel is determined to be 25.92 km/h and that of an inland vessel to be 11.36 km/h.

Knowing the distances that are required for each variant for both river vessel transport and ocean going vessel, the shipping costs can now be calculated.

Variant	Time ocean [h]	Time river [h]	Costs 50,710 MT eq. [USD]	Total 94.4 mln MT 100 yr incl. NPV [USD]
Banco Inglés	1.7	39.9	1,889,455	861,749,606
Banco Chico	7.3	26.0	1,591,724	725,959,125
Playa Honda	10.5	18.4	1,459,356	665,588,521
Coastal Variant	7.0	26.7	1,617,302	737,625,051

Table 61 - Cost per transported ton for each variant

It can be seen that the Banco Inglés variant is quite expensive due to the long distance (inefficient) river vessels have to travel before reaching the port, whereas the Playa Honda variant scores quite well because the commodities can stay aboard more efficient ocean vessels longer.

L Port equipment

Unloading equipment

There are different types of unloading equipment available. Chosen should be between several grabbing crane unloaders, pneumatic elevators, chain/screw/spiral conveyors and bucket elevators. Aiming at reaching the highest capacity for grain a comparison is made between mechanical ship conveyors and pneumatic elevators. A pro of the pneumatic system is the reduced cleaning as the system itself is able to unload a larger part of the grain. However, since the capacity of the mechanical ship conveyors is significantly higher, the best results will be achieved by this system.
As an example product it is decided to look at the Simporter of Vigan and more specifically the system of 2 mechanical unloaders of 750 tons/hour each that are used in Ulsan, South Korea which are shown in Figure 61(Vigan, 2011). This peak capacity can, however, not be reached during the complete unloading process. In Figure 60 an estimate is made about the process of the unloading speed as a function of the time, based on measurements of the grabbing crane unloader of Corux in IJmuiden (Ligteringen, 2000). On average an unloading capacity of 640 tons/hour per crane is reached, making the total used effective capacity 1250 tons/hour.
In order to also unload the vegetable oils, some berths can be outfitted with a oil unloading system.

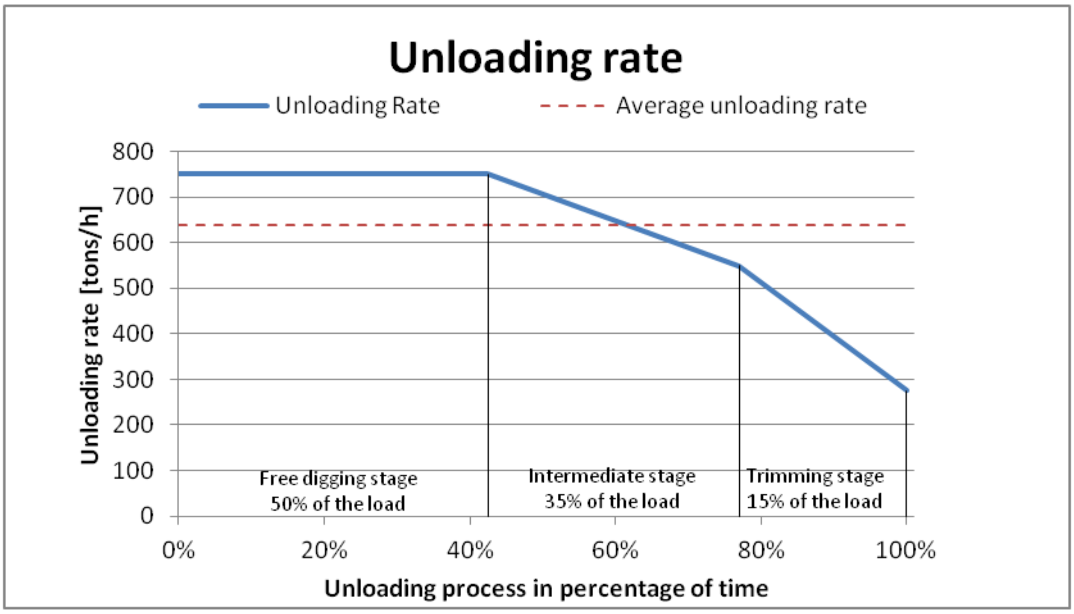


Figure 60 - Unloading rate per crane

Loading equipment

For the loading of the ocean going vessels different equipment is used. With a mechanical conveyor again the highest capacity can be reached. An example product is now found in the Portaload by Bühler (Bühler, 2006). It has a capacity of 2000 tons/hour and two of those will be placed at the loading berths. Loading will be able to load for most of the time with the peak capacity and only near the end will it have to reduce its rate to finish the process. As an estimate an effective capacity of 95% or 1900 tons/hour is used, given the berth a total capacity of 3800 tons/hour.
To be able to load the vegetable oil into the vessels, some berths can be outfitted with a oil loading system.

Figure 61 - Left: Multibelt ship unloader [Neuero]. Right: Portaload ship loader [Bühler]

Transport equipment

Conveyors up to 2000 tons/hour are possible as an example we have taken a look at the Roller Through Belt Conveyors of Bühler. With a width of 1.6 metre these have a capacity of 2000 tons/hour (Bühler, 2012), an impression is given in Figure 62.

Figure 62 - Roller Through Belt Conveyors [Bühler]

The storage of both the grains and the oils is done in silos. Reclaiming of the first category is optimized by using a Track-Driven Silo Reclaim Systems of Laidig as shown in Figure 63. A capacity of 400 CFM or 500 ton/h can be reached (Laidig, 2008).

Figure 63 - Track-Driven Silo Reclaim Systems [Laidig, website]

This reclaiming system can handle silos of a maximum diameter of 21 metres. This is used to calculate the silo and tank capacity.

Silo and tank capacity

Before calculating the capacity of the silo, the average stowage factors of the grains has to be calculated using Table 62 (RC-NOLA).

Stowage factors Grains	
Soybean Meal	1.5 m^3/MT
Soybean Meal Pellets	1.6 m^3/MT
Soybeans	1.4 m^3/MT
Corn	1.3 m^3/MT
Wheat	1.2 m^3/MT
Average	**1.4 m^3/MT**

Table 62 - Stowage factors grains

Using a diameter of 21 metre as given by the reclaimer and a height of twice the width, gives the dimensions for the silos in Table 63 (Powder Bulk Solids).

Storage Silo Grains		
Hopper Height	0	m
Hopper Volume	0	m^3
Straight Wall Height	41.1	m
Diameter	21.0	m
Shell Volume	14294	m^3
Level Full Capacity	14294	m^3
Working Capacity	13159	m^3
Tons / Silo	**9426**	**MT**
Repose Height	4.9	m
Springline Elevation	0.9	m
Area (square area) per silo	**442.3**	**m^2**

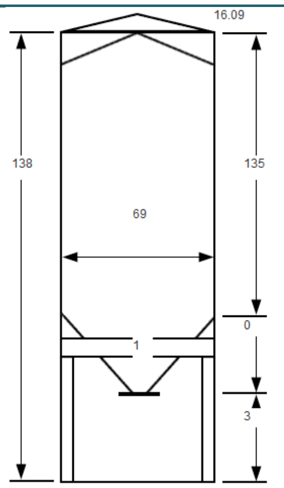


Table 63 - Storage silo grains

A similar calculation can be made for the oil tanks, by first calculating the average density using Table 64 (SIMetric).

Density Oils	
Sunflower oil	0.920 kg/MT
Soya bean oil	0.924 kg/MT
Average	**0.922 kg/MT**

Table 64 - Density oils

These can be used to calculate the storage of a tank with equal dimensions as the tank for the grains, as can be seen in Table 65 (Powder Bulk Solids).

Storage Tank Oil		
Hopper Height	5.9	m
Hopper Volume	703	m^3
Straight Wall Height	34.6	m
Diameter	21.0	m
Shell Volume	12020	m^3
Level Full Capacity	12723	m^3
Working Capacity	12564	m^3
Tons / Tank	**11584**	**MT**
Springline Elevation	7.5	m
Area (square area) per tank	**442.3**	**m^2**

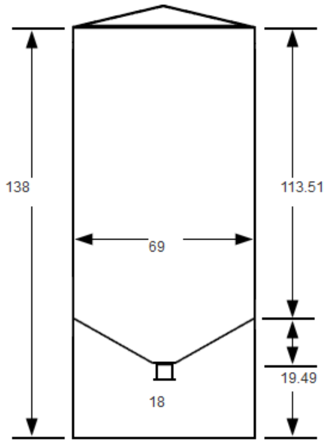


Table 65 - Storage tank oil

Conclusion

Each silo can store up to 9426 MT, giving a total number of silos of 467. To store the oil, 29 silos of 11584 MT each are necessary. Each silo has a representative area of 442.3 m^2. With this information the total storage area for grains and oils can be calculated, which gives an area of 206559 m^2 for grain storage and an area of 12827 m^2 for oil storage.

M Channel design

Channel width

The calculation of the width of the access channel is based on PIANC guidelines (PIANC, 1996). Two approach channels will be used, one heading inland for the barges, and one heading towards the ocean for the ocean going vessels.

For the ocean going vessels a one-way channel is used wherefore the formula below applies. In this formula w_{BM} is the Basic Manoeuvring Lane, Σw_i are the additional widths and w_{Br} and w_{Bg} are the bank clearances on the 'red' and 'green' sides of the channel.

$$w = w_{BM} + \Sigma w_i + w_{Br} + w_{Bl}$$

The individual components, their conditions and the concluding widths are given in Table 66. For the New Panamax ships with an expected width of 49 metre a channel width of 5.1 B or 230 metre is necessary. This is higher than the current access channels in the Rio de la Plata, which have a width of 100 m, but are not yet able to comfortably accommodate this new generation of ships.

	Width component	**Condition**	**Width**	**Width [m]**
w_{BM}	Basic manoeuvring lane	Poor ship manoeuvrability	1.8 B	88.2
Σw_i	Vessel speed	Slow: 5-8 knots	0 B	0
	Prevailing cross wind	Moderate: 15 - 33 knots	0.5 B	24.5
	Prevailing cross current	Moderate: 0.5 - 1.5 knots	1 B	49
	Prevailing longitudinal current	Low: < 1.5 knots	0 B	9.8
	Significant wave height	1 > H_s > 3m and $\lambda = L$	0.5 B	24.5
	Aids to navigation	VTS	0 B	0
	Seabed characteristics	Soft	0.1 B	4.9
	Depth of waterway	< 1.25 D	0.2 B	9.8
	Cargo hazard level	Low	0 B	0
w_{Br}	Bank Clearance, red side	Sloping Edge	0.3 B	14.7
w_{Bg}	Bank Clearance, green side	Sloping Edge	0.3 B	14.7
	Total Channel Width of ocean going channel		**4.7 B**	**230**

Table 66 - Total channel width of ocean going channel

The inland channel will be made as a two-way channel and can be calculated by the formula below in which also the passing distance is taken into account by the term Σw_p.

$$w = 2w_{BM} + 2\Sigma w_i + w_{Br} + w_{Bg} + \Sigma w_p$$

In Table 67 the components for the inland channel are listed, giving a total width of 9.2 B or 220.8 m for barges with a beam of 24 metre.

	Width component	**Condition**	**Width**	**Width [m]**
$2 \cdot w_{BM}$	Basic manoeuvring lane	Moderate ship manoeuvrability	$2 \cdot 1.5$ B	$2 \cdot 36$
$2 \cdot \Sigma w_i$	Vessel speed	Moderate: 5-8 knots	0 B	0
	Prevailing cross wind	Moderate: 15 - 33 knots	$2 \cdot 0.4$ B	$2 \cdot 9.6$
	Prevailing cross current	Moderate: 0.5 - 1.5 knots	$2 \cdot 0.7$ B	$2 \cdot 16.8$
	Prevailing longitudinal current	Low: < 1.5 knots	0 B	0
	Significant wave height	$1 > H_s > 3$m and $\lambda = L$	$2 \cdot 1.0$ B	$2 \cdot 24$
	Aids to navigation	VTS	0 B	0
	Seabed characteristics	Soft	$2 \cdot 0.1$ B	$2 \cdot 2.4$
	Depth of waterway	$1.25D < d < 1.5D$	$2 \cdot 0.1$ B	$2 \cdot 2.4$
	Cargo hazard level	Low	0 B	0
Σw_p	Vessel Speed	Moderate: 5-8 knots	1.6 B	38.4
	Traffic Intensity	Moderate: 1-3 ships/h	0.2 B	4.8
w_{Br}	Bank Clearance, red side	Sloping Edge	0.5 B	12
w_{Bg}	Bank Clearance, green side	Sloping Edge	0.5 B	12
	Total Channel Width of inland channel		**10.6 B**	**254**

Table 67 - Total channel width of inland channel

Channel and basin depth

For all depth calculations below the formula below is used (Ligteringen, 2000).

$$d = D - T + s_{\max} + r + m$$

In which:

- d = total depth [m]
- D = maximum ship draft [m]
- T = tidal window [m]
- $s_{\max}$ = squat of governing ship
- r = vertical motion due to wave response
- m = underkeel clearance

To calculate the maximum squat of the governing ship a general formula for shallow water is given by (Barras, 1979):

$$s_{\max} = \frac{C_B}{30} \cdot S_2^{2/3} \cdot v_s^{2.08}$$

In which:

- s = squat [m]
- v_s = vessel speed [kn]
- C_B = block coefficient [-]
- S_2 = S/(1-S) [-]
- S = blockage factor = A_s/A_{ch} [-]

The vertical motion of the ships can be calculated by assuming an Response Amplitude Operator (RAO) of 1, which gives the simple formula: $r = \frac{H_s}{2}$.

Ocean going basin and channel

Governing for the ocean going basin are the New Panamax vessels, their parameters are given in Table 68.

Parameters	Value
C_B	0.9
A_{ch}	6952 m^2
A_s	670 m^2
V_s	4 knots
H_s	1.32 m

Table 68 - Design parameters ocean vessels

This gives a maximum squat of 0.11 m, this results in a total depth given in Table 69.

Parameters	Value [m]	
D	15.2	
T	0	No tidal window
s_{max}	0.11	
r	0.66	
m	0.3	(soft mud)
Total depth	**16.3**	

Table 69 - Depth ocean vessels

Inland going basin and channel

For the inland basin the coasters are the governing ship type. Even though we are not expecting those ships to be used, the extra depth needed to accommodate these ships is small and will increase the accessibility, their parameters are given in Table 70.

Parameters	Value
C_B	0.9
A_{ch}	1512 m^2
A_s	68.3 m^2
V_s	4 knots
H_s	1.32 m

Table 70 - Design parameters inland vessels

This gives a maximum squat of 0.07 m and a total depth given Table 71.

Parameters	Value [m]	
D	4.6	
T	0	No tidal window
s_{max}	0.07	
r	0.66	
m	0.3	(soft mud)
Total depth	**5.6**	

Table 71 - Depth inland vessels

N MCA port layout

To be able to assess which port layout is the most suitable layout for the transhipment port, some criteria are used to choose this layout. The importance of each criterion is determined by comparing them to one another, as Table 72 shows.

		1	2	3	4	5	6	7	
1	Expandability storage area		0.0	0.0	0.0	0.5	0.0	0.0	1.5
2	Expandability inland berths	1.0		1.0	1.0	0.0	0.0	0.5	4.5
3	Expandability ocean berths	1.0	0.0		0.5	0.0	0.0	0.0	2.5
4	Availability	1.0	0.0	0.5		0.5	0.0	0.5	3.5
5	Cargo efficiency	0.5	1.0	1.0	0.5		0.0	1.0	5.0
6	Dredging	1.0	1.0	1.0	1.0	1.0		1.0	7.0
7	Reclamation	1.0	0.5	1.0	0.5	0.0	0.0		4.0
									28.0

Table 72 - MCA criteria port layout

Expandability of storage area (1.5)

The storage capacity of the transhipment port is based on the throughput of the port in 2030. As the throughput is expected to increase after 2030 it may be necessary to increase the storage capacity of the port. It is therefore import to take the possibility for expansion of the storage area of the different layouts into account.

Expandability of inland berths (4.5)

As for the same reason the storage area needs to have to possibility to expand, the amount of inland berths should be able to increase. There is an expected increase of four berths by 2050. Port layouts are graded on the easiness of this increase in inland berths.

Expandability of ocean berths (2.5)

As for the same reason the storage area needs to have to possibility to expand, the amount of inland berths should be able to increase. By 2050 one extra berth is expected to be necessary. Port layouts are graded on the possibility to add an extra ocean berth.

Availability (3.5)

According to the functional requirements, the port should be 99% of the time available for ocean vessels and 95% of the time for inland vessels. By taking the orientation of the basins and channels, as well as the directions of currents, waves and wind into account, each port layout is given a grade for this criterion.

Cargo efficiency (5.0)

It is preferred to have a minimum transport distance between the inland and ocean berths, as it reduces the length of the conveyor belts in the port. A smaller distance gives a better score for a layout.

Dredging (7.0)

The main cost for the construction of the transhipment port is caused by the necessary dredging. Access channels and basins have to be dredged and maintained, the less this seems to be for a port layout, the better the score.

Reclamation (4.0)

The port area has to be above the water level, thus it is necessary to reclaim land on Banco Chico. A large port area needs more reclamation than a smaller port area, thus a large port area gets a lower score.

O Subsoil

One of the boundary conditions is the subsoil. In general CPT's (cone-penetration tests) or boreholes are performed to make a map of the different soil layers in an area. None such investigations have been performed for the area around Banco Chico.

Therefore an estimation of the soil profile is made by using two cross sections of the Rio de la Plata. One of those maps is a cross section of the Rio de la Plata. The other one is a longitudinal cross section, see Figure 64. Both studies don't contain information about the reference level, therefore the LIMB is assumed. Because the difference in reference levels is small compared with the accuracy of the figures, this assumption is justified.

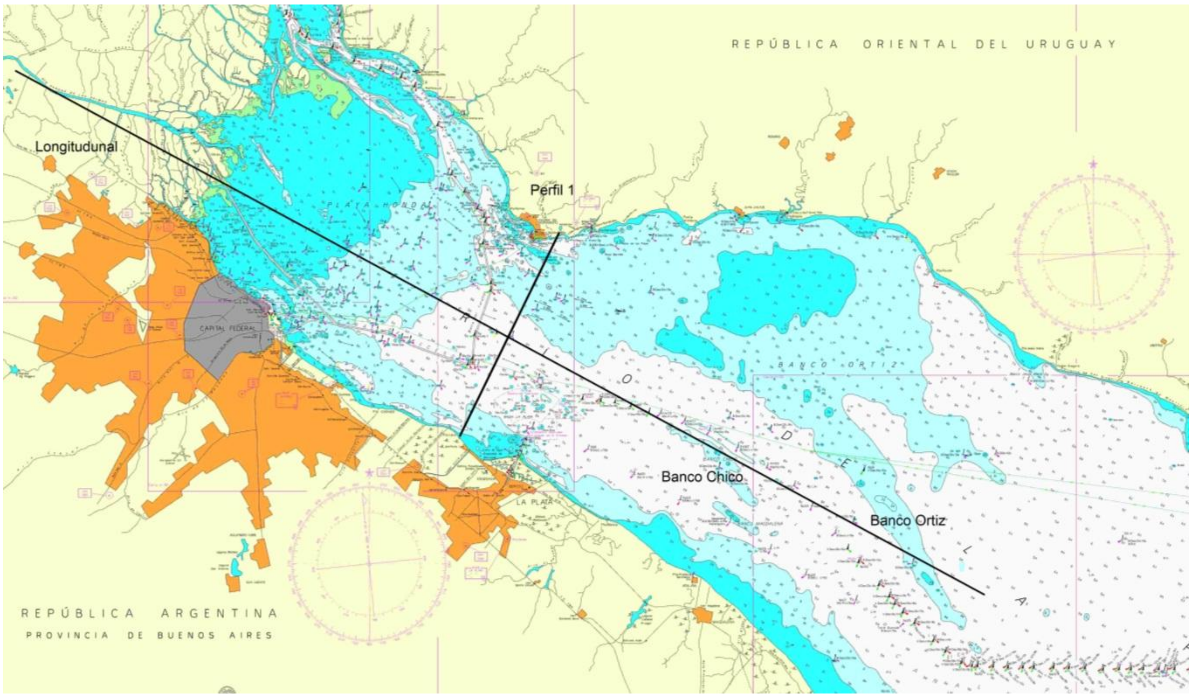
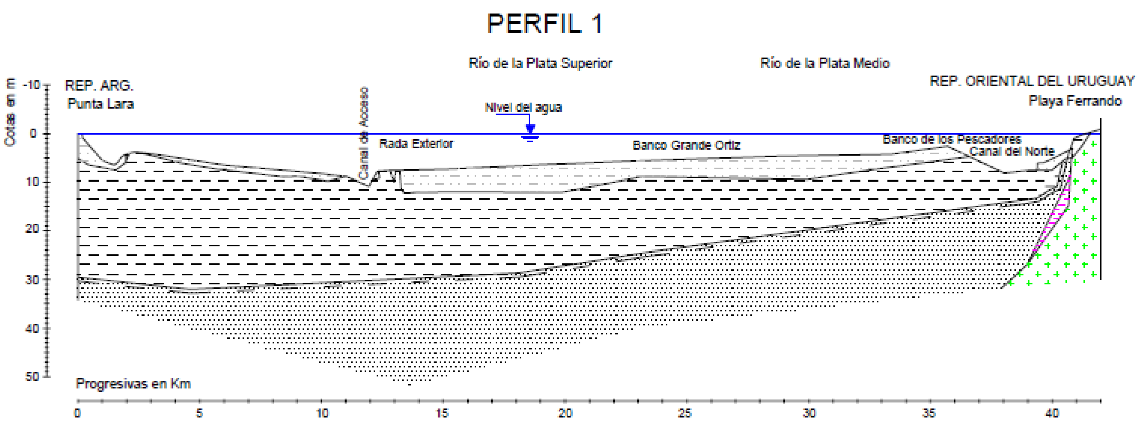


Figure 64 - Overview intersections

The cross sectional map, Perfil 1 (Víctor A. Rinaldi, 2006), is part of a series of cross sections. Perfil 1 is, with a distance of about 40 km, the closest to Banco Chico. Figure 65 shows there is a sand layer at about -30 m Puelches formation) with on top of that a layer of about 20 m consisting of clay (Atalaya formation).



REFERENCIAS	Formación	Edad		Litología	Unidad geotécnica
	FM Playa Honda	HOLOCENO	Sup	Arenas y fangos aluvionales	Limos y arenas muy sueltos
	Fm Atalaya		Medio	Arcillas marinas	Arcillas muy blandas
	Pampeano	PLEISTOCENO		Limos y limos arcillosos consolidados	Limos y arcillas muy compactos
	Fm Puelches		Inferior	Arenas finas densas	Arenas finas densas
	Fm Paraná	MIOCENO		Arcillas verdes	Arcillas muy compactas
	Basamento Cristalino	PRECÁMBRICO	Medio	Granitos, granitoides y gneisses frescos y alterados	Roca cristalina

Figure 65 - Cross section

The study also gives the soil parameters of the Playa Honda and the Atalaya formation layers, see Table 73.

Formación	Parámetro	Descripción	
Playa Honda (Horizonte de formación Fluvial)	CU	CL , ML, SM	(1)
	IP (%)	10 – 20 IP = 0,72 (w_L -14,7)	(1)
	LL (%)	20 – 40	(1)
	w_n (%)	20 – 50 (generalmente w_n > LL)	(1)
	γ_d (kN/m^3)	11.5 - 14.5	(1)
	γ_s (kN/m^3)	17 - 20	(1)
	k (cm/s)	$10^{-5} – 10^{-6}$	(2)
	N (SPT)	N < 10	(1)
	s_u (kPa)	20 – 40	(1)
	φ´ (º)	25 -30	(2)
	E_u (kPa)	~ 2000	(2)
	C_c	0,20 – 0,30	(2)
	V_s (m/s)	150 – 200 $V_s = 40\,(\sigma_o´)^{0.35}$	(3)
	ρ (Ohm-m)	12 – 20	(4)
Atalaya (Horizonte de formación Marina)	CU	CH	(1)
	IP (%)	50 – 70 IP = 0,72 (w_L -14,7)	(1)
	LL (%)	60 – 110	(1)
	w_n (%)	80 – 90	(1)
	γ_d (kN/m^3)	7 – 10	(1)
	γ_s (kN/m^3)	14 - 16	(1)
	k (cm/s)	$10^{-6} – 10^{-8}$	(1) (2)
	N (SPT)	N < 5	(1)
	s_u (kPa)	10 – 35 s_u = 1,82 z + 3,91	(3)
	φ´ (º)	20	(2)
	E_u (kPa)	1500 – 3000 (1) Eu = 490 C_u	(3)
	C_c	0.45 1,10 C_c = 0,009 (w_L – 10) C_c = 0,38 e_o – 0,15)	(1) (3) (3)
	V_s (m/s)	100 – 150 $V_s = 24\,(\sigma_o)^{0.40}$;σ_o (kPa)	(4)
	ρ (Ohm-m)	1.2 – 3	(5)

Table 73 - Soil parameters Playa Honda and Atalaya layer

Both the study of Rinaldi (Víctor A. Rinaldi, 2006) and AeroIsla (Boskalis AeroIsla) give soil parameters for the Atalaya layer. For the calculations in this report the parameters in Table 74 are used.

Formation	Parameter	Symbol	Value
Atalaya	Specific wet weight	γ_s	15 [kN/m^3]
	Angle of internal friction	ϕ'	20 [°]
	primary compression coefficient	C'_p	8 [-]
	secondary compression coefficient	C'_s	80 [-]
	Primary compression coefficient	C_c	0.45 C_c=0.38 e_0-0.15
	Permeability	k	10^{-9} [m/s]
	Porosity	n	61 [%]

Table 74 - Assumed soil parameters Atalaya formation

The porosity n can be calculated with $n = \dfrac{e}{1+e}$ (Verruijt, 2010) where e is the pore value.

To calculate the porosity the initial pore value e_0 is calculated from C_c=0.38 e_0-0.15=0.45 resulting in e_0 = 1.58. Now the porosity n=61%.

The longitudinal cross section (Asociacíon Geológica Argentina) can be found in Figure 66. Between Playa Honda and Banco Chico a part of the map is missing. Assumed is that the sandy layer (Arenas; Holoceno inf.) stays at about the same depth as left of Playa Honda. The lowest line under Banco Chico at -30 m is assumed to be the bottom of the clay layer (Arcillas; Holoceno inf.) and the top of the sandy layer.

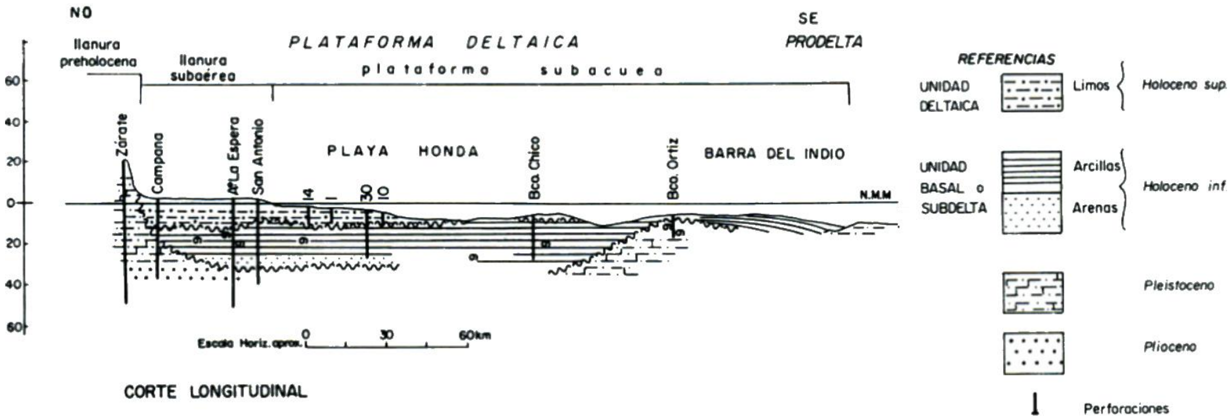


Figure 66 - Longitudinal cross section

Combining the cross sectional map and the longitudinal cross section one can make a prediction of the soil layers under Banco Chico. The cross sectional study gives more detailed information about the type of soil and the soil parameters. The longitudinal cross section shows that the sand layer stays at about the same depth and that there is also a clay layer under Banco Chico.
For further calculations the soil is schematised as in Figure 67.

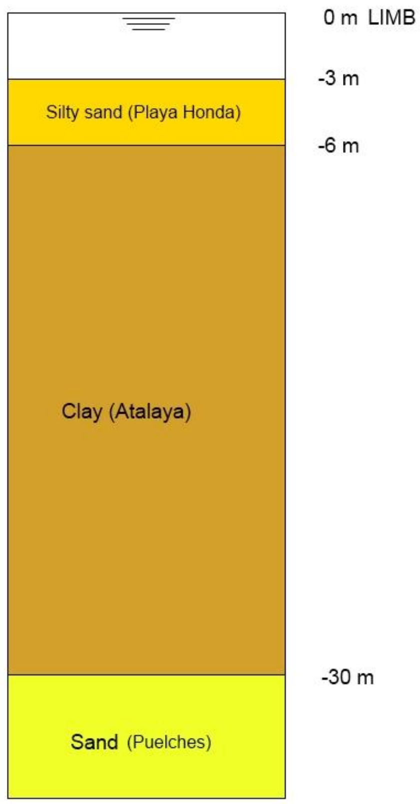


Figure 67 - Soil schematisation

The upper sand layer is assumed to be of the same kind as the Playa Honda formation. The clay layer is of the Atalaya formation. Soil parameters can be found in Table 73. Below -30 m only solid sand layers exist. The same layer as from Perfil 1 (the Puelches formation) is assumed to be under Banco Chico as well. No soil parameters known about this formation. The only given fact is that the sand layer is very densely packed. The parameters in Table 75 can be used as an assumption for a densely packed sand layer (Prof.Ir.Drs. J.K. Vrijling et al, 2011).

Formation	Parameter	Symbol	Value
Puelches	Soil type		Solid, clean
	Specific dry weight	γ_{dry}	19 [kN/m^3]
	Specific wet weight	γ_{wet}	21 [kN/m^3]
	Angle of internal friction	ϕ'	37.5 [°]
	Nominal diameter exceeded by 50% of the weight	d_{n50}	0.3 [mm]
	Gradation	d_{85}/d_{15}	3 [-]

Table 75 – Assumed soil parameters Puelches formation

Assumed is that the sand has a d_{n50} of 0.3 mm and a gradation of d_{85}/d_{15} of 3.

As can be seen from the soil profile there is a deep layer of clay under Banco Chico. Such a clay layer causes large settlements when loaded. A reference is made to the Aeroisla project where the clay layer under the island was also very thick. To prevent large settlements after construction, the soil was preloaded with sand. To speed up the settlements, drains were used. After about 3 years of preloading construction of the structural elements could start. The final settlement was expected to be 5.8m(Universidad Nacional de Rosario, 2011).

P Water levels

The water levels near Banco Chico are formed by two components: the tide and a wind setup.
In order to determine the maximum water level for 1/1000 year tidal information can be calculated and added with a setup calculation. Another approach is to use measurements from buoys. In this case two buoys were available (Boskalis, 2012): one in the port of La Plata and one near the Martin Garcia channel, also named Norden, see Figure 68.

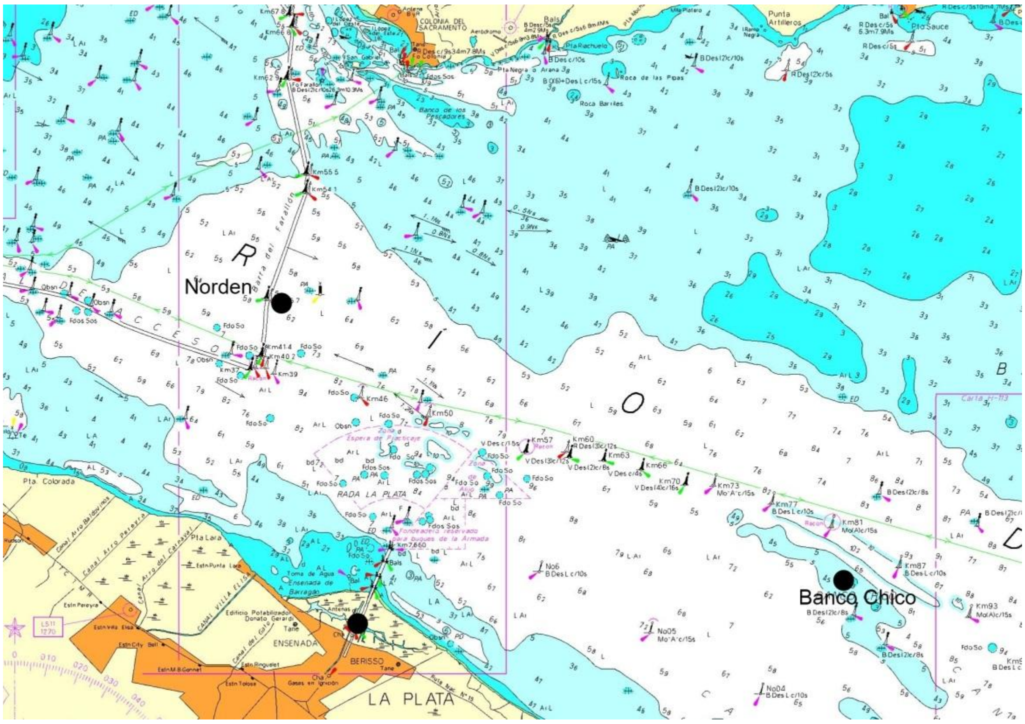


Figure 68 - Location of the buoys

The distance from La Plata to Banco Chico is 35 km. Norden is located 47 km from Banco Chico. Measurements of both buoys are compared. La Plata contains data from 2003 to 2008 with a measurement of the water level every 20 minutes, resulting in about 140,000 data points. The data points of Norden are from 2004 to 2010 with a measurement every 5 minutes, resulting in about 746,000 data points. All the data points are categorized in classes of 10 cm of water level. For La Plata the distribution is given in Figure 69.

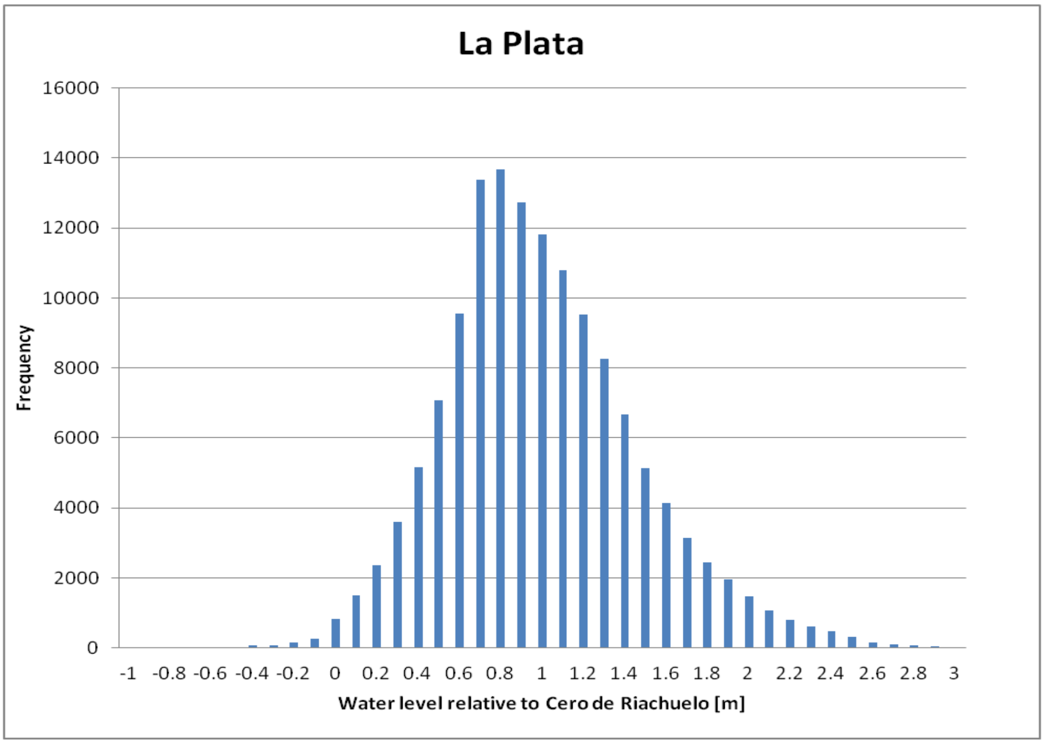


Figure 69 - Water levels La Plata

It turned out that some extremely high or low values of the water level were measured, which definitely had to be a failure of the buoy. These values were removed from the further analysis. After categorizing the probability of exceedance of each class was determined.

Several distributions were fitted on the data. The Gumbel distribution turned out to be the best fitting one as can be seen in Figure 70.

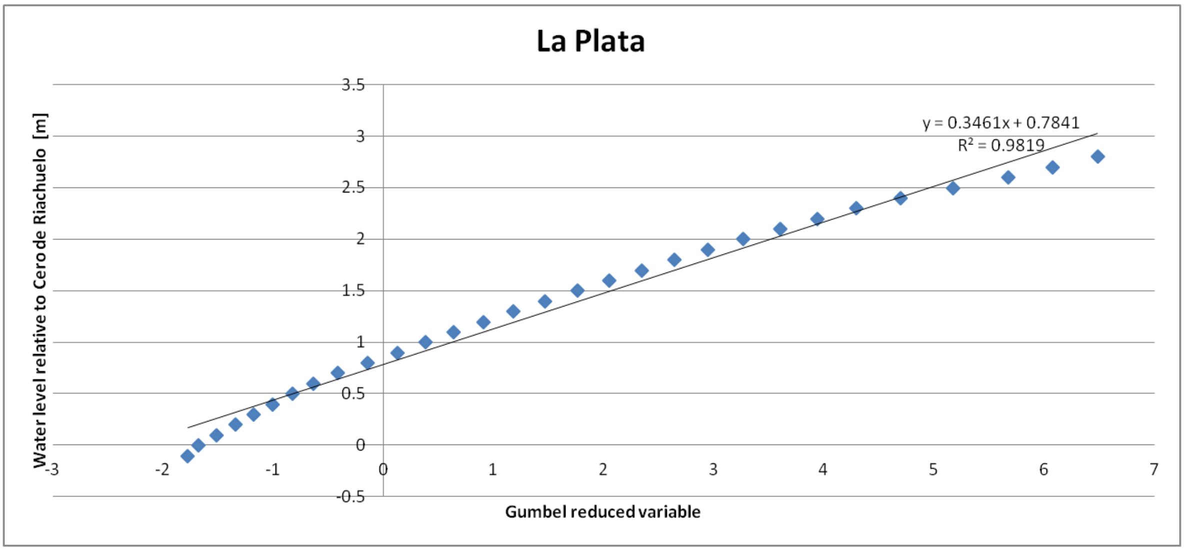


Figure 70 - Gumbel distribution

The Gumbel reduced variable G is calculated with:

$$G = -\ln\left(\ln\frac{1}{1-Q}\right)$$

Where Q is the probability of exceedance of a water level.

For G also the next formula applies: $G = AH - B$ which can be rewritten to $H = \beta G + \gamma$ where $\beta = 1/A$ and $\gamma = \beta B$. For the Gumbel distribution the water level is plotted against the Gumbel reduced variable, see Figure 70. A linear trend line is fitted through all the data points. In order to make a proper fitting line some of the data has been left out of the calculation (about 500 for both locations).

The values of β and γ are determined from the trend line, where γ is the slope of the trend line and β the crossing point with the vertical axis. The measurements of La Plata have Cero de Riachuelo as a reference level, so to transform the values to LIMB a value of 0.3133 is subtracted from γ. Norden has LIMB as reference level. With the calculated values for β and γ, the water level for a probability of exceedance Q of 1/1000 years can be determined with:

$$H = \gamma - \beta\ln\left(\ln\frac{1}{1-Q}\right)$$

This results in Table 76.

Location	Water level 1/1000 year relative to Limb [m]
La Plata	2.86
Norden	2.73

Table 76 - Waterlevel

There seems to be a difference in the calculated 1/1000 year water level of both buoys. The difference is, however, not very big. A cause for the difference may be the location of the buoys: the buoy of La Plata is located in a port and near the coast. Because of resonance of this basin the water levels may have a wider range than in Norden.

As a conservative approach the calculated 1/1000 water level of La Plata is assumed to be the same for Banco Chico, so a value of 2.86 m relative to LIMB. The MWL is taken to be the average water level of all data points and is 0.76 m relative to LIMB

Q Currents

To be able to design for example the access channel, the velocities and directions of the currents around Banco Chico have to be known. Unfortunately no current velocities and directions are measured at Banco Chico, however, there are other measurement stations near Banco Chico: Canal de la Magdalena, Quebrada del Banco Ortiz and Canal Intermedio, as can be seen Figure 71.

Figure 71 - Current measurement stations

The data from these measurement stations is available on the website of Servicio de Hidrografia Naval. Data is available from November 2011 until September 2012, during this period there are 3 to 4 measurements per day (Servicio de Hidrografia Naval). Due to this frequency of measurements, it is possible to distinguish ebb velocities and flood velocities. As the current velocities also include the river flow, the ebb velocity is higher than the flood velocities, because the ebb flow has the same direction as the river flow and the flood flow is opposite of the river flow. Using this information, the data is analysed.

The data from each measurement station is divided in ebb and flood velocities and directions. For each direction the maximum, minimum and average velocities are calculated, as well as the direction maximum, minimum and average. The result of this analysis can be seen in Table 77.

Canal de la Magdalena (Prox. Boya N°04)
Latitude: 34° 53' S
Longitude: 57° 34' W

Ebb flow + River flow			**Flood Flow - River Flow**		
Min. Velocity	0.3	knots	Min. Velocity	0.1	knots
Max. Velocity	1.1	knots	Max. Velocity	0.9	knots
Average	**0.74**	**knots**	**Average**	**0.51**	**knots**
Direction min.	113	°	Direction min.	293	°
Direction max.	119	°	Direction max.	330	°
Average	**117**	**°**	**Average**	**300**	**°**

Quebrada del Banco Ortiz (Ext. Occidental)
Latitude: 34° 49' S
Longitude: 57° 19' W

Ebb flow + River flow			**Flood Flow - River Flow**		
Min. Velocity	0.2	knots	Min. Velocity	0.1	knots
Max. Velocity	1.3	knots	Max. Velocity	0.8	knots
Average	**0.83**	**knots**	**Average**	**0.44**	**knots**
Direction min.	129	°	Direction min.	246	°
Direction max.	137	°	Direction max.	316	°
Average	**134**	**°**	**Average**	**304**	**°**

Canal Intermedio (Prox. Km.121 / ex Par N°30)
Latitude: 34° 59' S
Longitude: 57° 20' W

Ebb flow + River flow			**Flood Flow - River Flow**		
Min. Velocity	0.4	knots	Min. Velocity	0.1	knots
Max. Velocity	1.1	knots	Max. Velocity	1.2	knots
Average	**0.78**	**knots**	**Average**	**0.63**	**knots**
Direction min.	115	°	Direction min.	197	°
Direction max.	161	°	Direction max.	377	°
Average	**137**	**°**	**Average**	**305**	**°**

Table 77 - Current velocities and directions

The goal of this analysis is to obtain current information for Banco Chico. The data from the measurement stations does not show large differences between them and thus it is possible to calculate the velocities and velocity directions for Banco Chico, by averaging between the different stations. The result of this calculation can be seen in Table 78. This table gives the velocities in both knots and metres per second.

Ebb flow + river flow				
Average direction	129	°		
Average velocity	0.78	knots	0.40	m/s
Maximum velocity	1.2	knots	0.60	m/s
Minimum velocity	0.3	knots	0.15	m/s
Flood Flow - river Flow				
Average direction	303	°		
Average velocity	0.53	knots	0.27	m/s
Maximum velocity	1.0	knots	0.50	m/s
Minimum velocity	0.1	knots	0.05	m/s

Table 78 - Currents Banco Chico

R Waves and wind at Banco Chico

The heights of the port area, breakwaters and berths, as well as the required strength of the coastal protection, depend on the design wave height at the port location. In order to obtain the design wave height for the port, wave data is needed.

Wave data for this specific location has been collected (BMT Argoss). The data available on ARGOSS gives at its best, data for an area of 50x50 km. For the design of the port, more specific wave data for Banco Chico is necessary. ARGOSS offers the possibility to model the wave height at a near shore location, using data from offshore locations and taking into account bathymetry, wave breaking, refraction and local growth of the waves by wind. This model is called a Ray model.
Besides the exact location, this model needs the water level above LAT as another parameter. Using the analysis of the design water level in Appendix Q: Currents and the assumption that LAT is the same as LIMB at this location, the water level is LAT +3 metres (The model only uses whole metres for the water level). The input for the ray model is given in Figure 72.

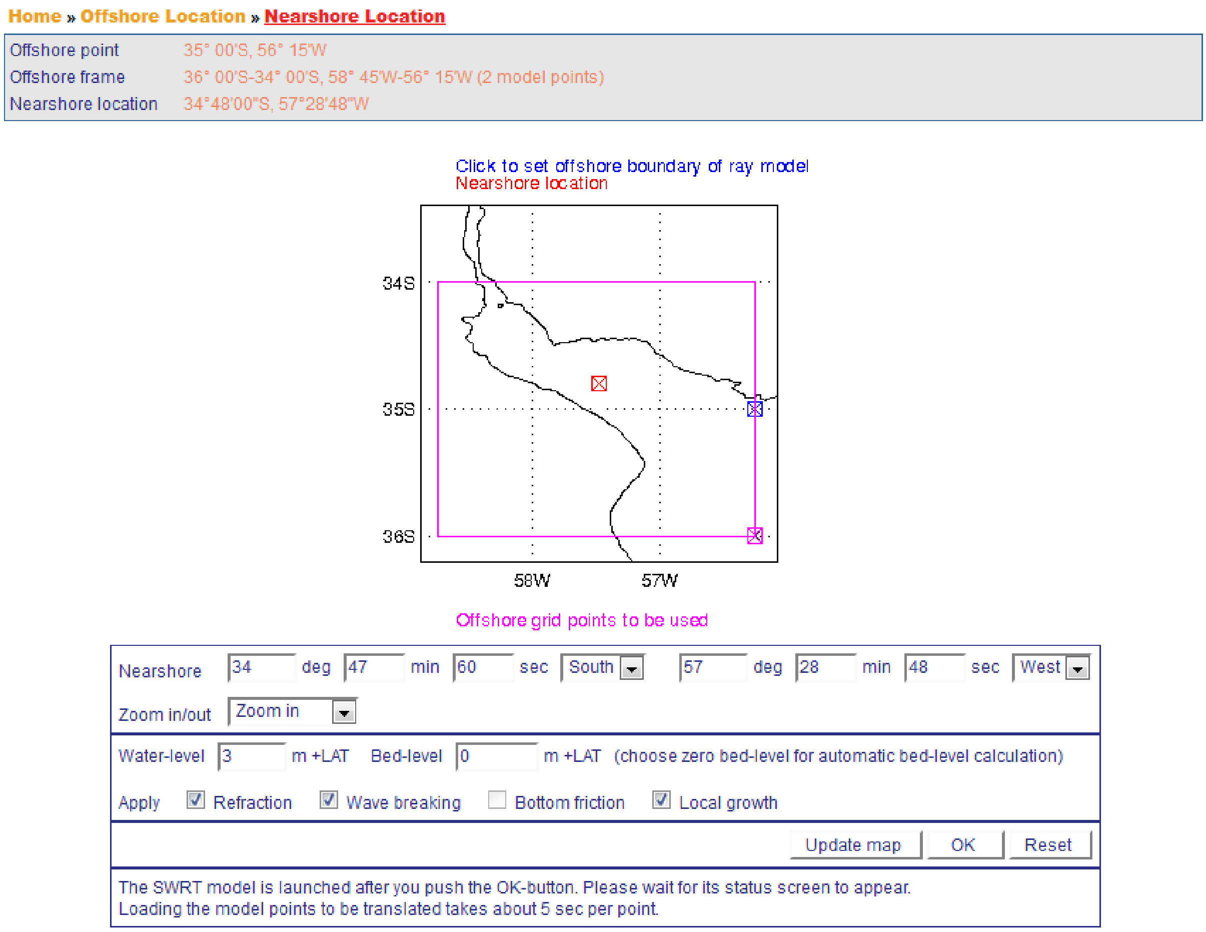


Figure 72 - Input ray model

The ray model gives the bathymetry and used wave rays as first output, as can be seen in Figure 73.

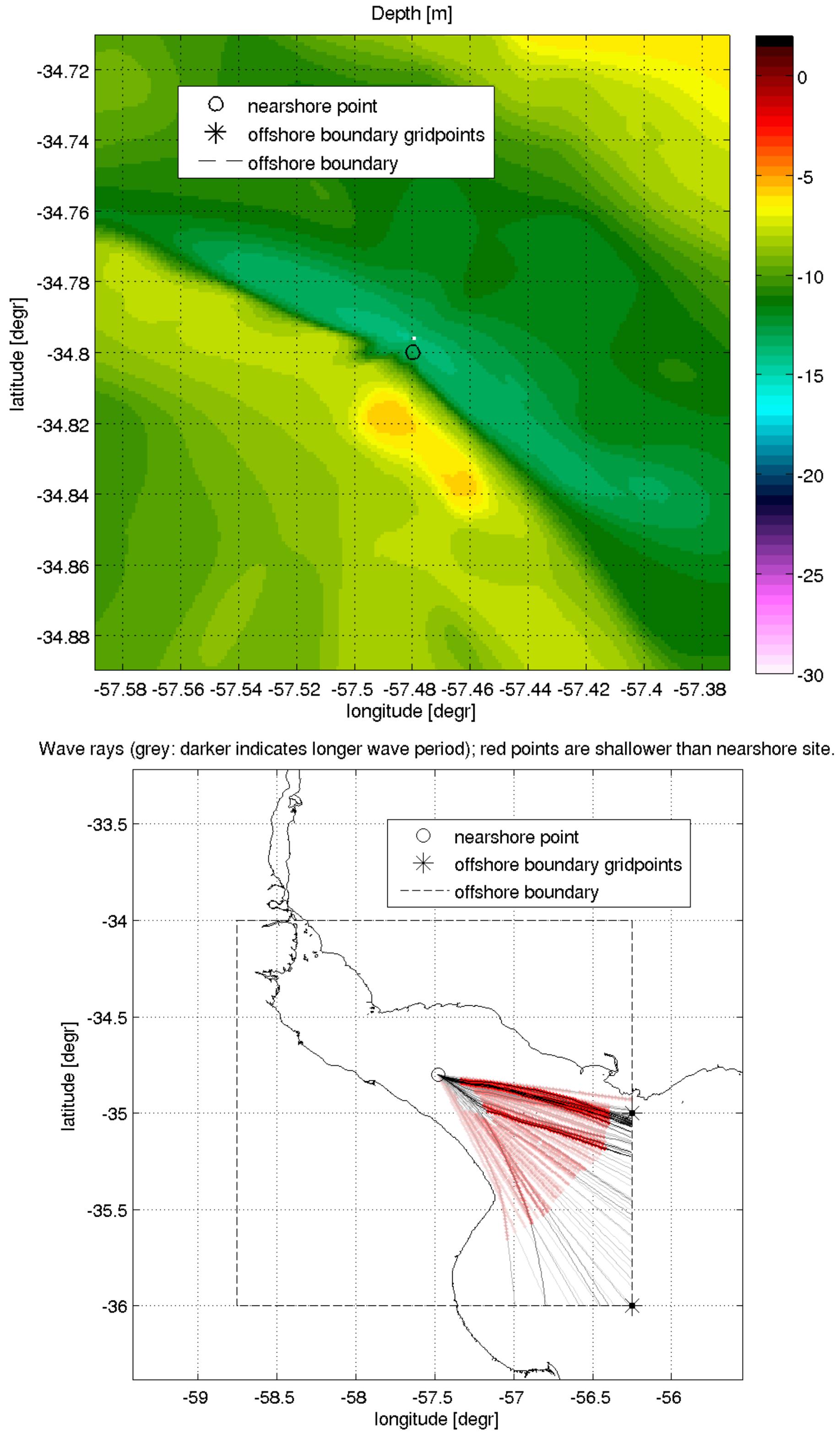


Figure 73 - Output ray model

In Table 79 the wave height classes versus the directions classes are given. Each coloured cell gives the percentage of occurrence of a wave height class in a specific direction. This data is used to calculate the design wave height and dominant wave direction.

	lower	355	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165
lower	upper	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175
0	0.5	0.693	0.717	0.763	0.741	0.88	0.835	0.859	1.047	1.196	1.631	2.471	14.685	12.873	2.916	1.071	0.731	0.616	0.453
0.5	1	0.931	1.025	1.087	1.242	1.287	1.396	1.343	1.472	1.73	1.949	2.182	4.954	3.195	1.064	1.182	1.194	1.015	0.939
1	1.5	0.094	0.077	0.08	0.092	0.123	0.152	0.205	0.234	0.294	0.469	0.453	0.578	0.166	0.159	0.202	0.293	0.282	0.221
1.5	2	0	0.002	0.002	0	0.003	0.005	0	0.009	0.021	0.05	0.051	0.029	0.007	0.021	0.019	0.015	0.036	0.019
2	2.5	0	0	0	0	0	0	0	0	0.002	0.005	0.009	0.002	0	0	0.002	0.002	0.002	0
2.5	3	0	0	0	0	0	0	0	0	0	0	0.003	0.005	0	0	0	0	0	0
3	3.5	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0
3.5	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total		1.718	1.821	1.932	2.076	2.293	2.389	2.408	2.762	3.243	4.103	5.169	20.255	16.241	4.16	2.476	2.235	1.951	1.632

	lower	175	185	195	205	215	225	235	245	255	265	275	285	295	305	315	325	335	345
lower	upper	185	195	205	215	225	235	245	255	265	275	285	295	305	315	325	335	345	355
0	0.5	0.448	0.433	0.404	0.38	0.318	0.363	0.315	0.298	0.238	0.236	0.296	0.306	0.287	0.296	0.37	0.495	0.549	0.659
0.5	1	0.741	0.688	0.661	0.657	0.667	0.679	0.621	0.595	0.464	0.392	0.428	0.483	0.534	0.541	0.666	0.749	0.744	0.854
1	1.5	0.217	0.159	0.147	0.145	0.145	0.181	0.214	0.222	0.205	0.157	0.173	0.149	0.224	0.209	0.188	0.121	0.098	0.07
1.5	2	0.009	0.012	0.002	0.005	0.003	0.01	0.012	0.014	0.019	0.029	0.033	0.041	0.022	0.029	0.012	0	0	0.002
2	2.5	0	0	0	0	0	0	0	0	0	0.002	0	0.002	0	0	0	0	0	0
2.5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total		1.415	1.292	1.213	1.188	1.134	1.234	1.162	1.129	0.926	0.816	0.929	0.98	1.068	1.075	1.235	1.366	1.391	1.585

Table 79 - Distribution wave heights Banco Chico

Wave direction

A first estimate of the dominant wave direction can be made using a wave rose of the above data. As can be seen in the wave rose in Figure 74, the dominant wave direction is approximately East-South-East.

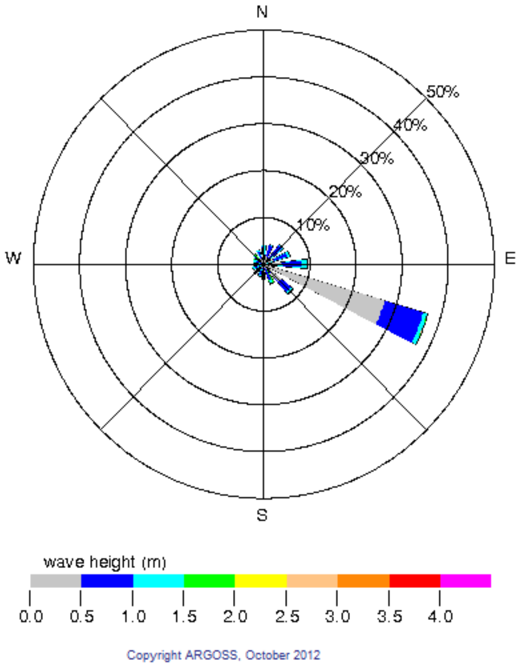


Figure 74 - Wave rose Banco Chico

In order to calculate the design wave height, first the relevant directions are chosen, based on the wave rose. The dominant wave direction is the average of the directions in Table 80 and is 112 ^{o}.

Wave direction [^{o}]	Occurrence
80	3.243
90	4.103
100	5.169
110	20.255
120	16.241
130	4.16
140	2.476

Table 80 - Wave direction Banco Chico

Design wave height

For the calculation of the design wave height, only the percentages of occurrences of wave classes of the relevant directions are taken into account. The first step for calculating the design wave height is determining the probability (P) and probability of exceedance (1-P), the result is given in Table 81.

Wave height [m]	Probability	Probability of exceedance
0.5	0.6621	0.3379
1	0.9542	0.0458
1.5	0.9959	0.0041
2	0.9995	0.0005
2.5	0.9998	0.0002

Table 81 - Probability of exceedance of wave heights

To obtain a formula to calculate the design wave height, the wave height classes are plotted versus the probability of exceedance (logarithmic scale) and a logarithmic trend line is plotted between the data points, see Figure 75.

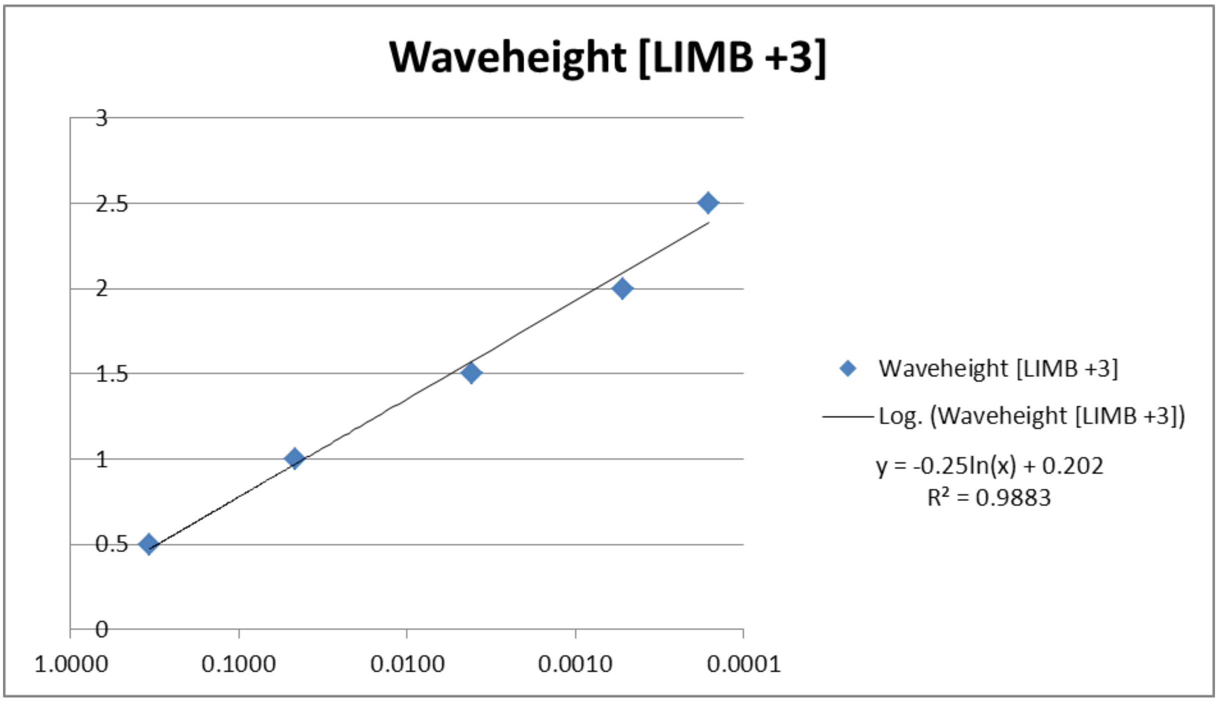


Figure 75 - Wave height Banco Chico

The formula of the logarithmic trend line gives the significant wave height (H_s) as a function of the probability of failure (F): $H_s = -0.25 \cdot \ln(F) + 0.202$. The probability of failure has already been calculated in Appendix H: Probability of exceedance and is 1/1000. Using this probability of failure and the formula of the logarithmic trend line the design wave height and peak period (using a wave steepness of 0.05) can be calculated:

$\mathbf{H_d}$	**= 1.92 m**
$\mathbf{T_p}$	**= 4.98 s**
$\mathbf{T_m}$	**= 4.66 s**
$\mathbf{T_{m-1,0}}$	**= 4.53 s**
$\mathbf{T_{1/3}}$	**= 4.66 s**

The different wave periods are calculated using these formulas:

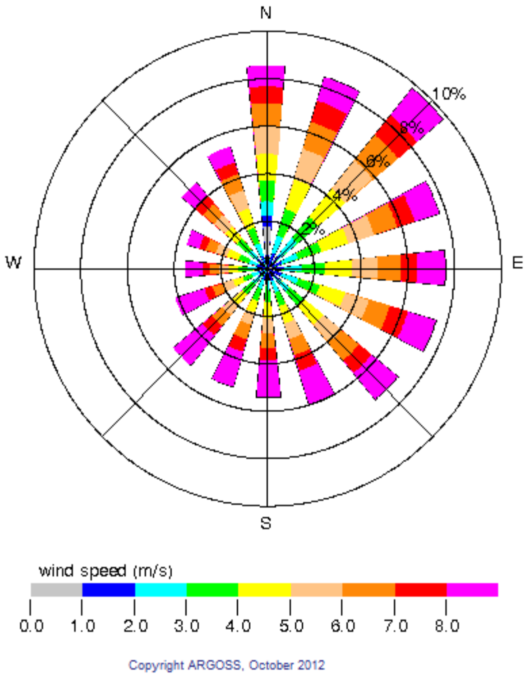
$T_p = T_{m0}$

$T_p = 1.07 T_{1/3}$ (Johnswap) so $T_{1/3} = T_m = \frac{T_p}{1.07}$ (Verhagen, d'Angremond, & Roode, 2009)

$T_p = 1.1 T_{m-1,0}$ (Taw v/d Meer) $T_{m-1,0} = \frac{T_p}{1.1}$ (Verhagen, d'Angremond, & Roode, 2009)

Wind direction and speed

The model also gives output for wind data, resulting in the wave rose and table in Figure 76.



Wind direction	Occurrence
0	4.728
10	3.487
20	3.792
30	4.057
40	4.192
50	3.994
60	3.67
70	3.467

Figure 76 - Wave rose and wave directions

Using the wave rose and wind data, the average wind direction is approximately North-East or 34 ^{o}. For the wind speed the probability and probability of exceedance are calculated in the same way as has been done with the wave heights, of which Table 82 shows the result.

Wind speed [m/s]	Probability	Probability of exceedance
1	0.0753	0.9247
2	0.1267	0.8733
3	0.2136	0.7864
4	0.3357	0.6643
5	0.4854	0.5146
6	0.6369	0.3631
7	0.7695	0.2305
8	0.8706	0.1294
9	0.9370	0.0630
10	0.9733	0.0267
11	0.9886	0.0114
12	0.9947	0.0053
13	0.9976	0.0024
14	0.9988	0.0012
15	0.9995	0.0005
16	0.9999	0.0001

Table 82 - Probability of exceedance of wind speed

The wind speed and probability of exceedance are plotted versus each other in order to obtain the formula to calculate the design wind speed, see Figure 77.

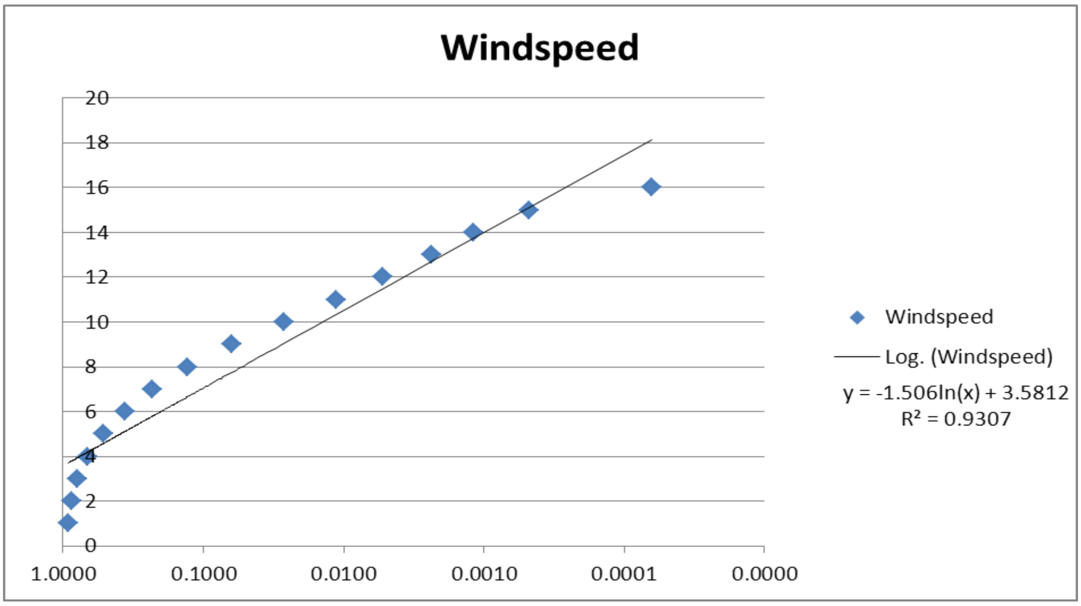


Figure 77 - Wind speed Banco Chico

A logarithmic trend line is used again and gives the formula: v = -1.506·ln(F)+3.5812. Using the same probability of failure as used for the design wave height (1/1000), the design wind speed becomes 13.9 m/s.

S Settlement

Because of the clay layer, large settlements are expected to occur when a load is placed on top of it. The settlements are caused by the consolidation of the clay layer. For the calculation of the settlements 2 different locations are viewed: Location 1 at the tip of the arms of the ocean basin and location 2 at the centre of the island.
The soil depth at location 1 is -6 m LIMB and -3 m LIMB for location 2 (Figure 78).

The settlements are calculated using the formula of Koppejan (Prof.Ir.Drs. J.K. Vrijling et al, 2011) where the strain of a soil layer is equal to: $\varepsilon_i = \left(\frac{1}{C_p^{'}} + \frac{1}{C_s^{'}} \log(t) \right) \cdot \ln \left(\frac{\sigma_{v;i}^{'} + \Delta\sigma_{v;i}^{'}}{\sigma_{v;i}^{'}} \right)$

where:

C'_p = primary compression coefficient [-]

C'_s = secondary compression coefficient [-]

t = time in days [d]

$\Delta\sigma_{v;i}^{'}$ = increase of the vertical effective stress in the weak layer [kPa]

$\sigma_{v;i}^{'}$ = initial vertical effective stress [kPa]

The values for the compression coefficients of the clay layer follow from Appendix O: Subsoil: C'_p=8, C'_s=80. The time t is put at 40,000 days (about 100 years).
The clay layer is divided in layers of 1 m. For each layer the initial vertical effective stress $\sigma_{v;i}^{'}$ is calculated. The increase in vertical effective stress is caused by the reclamation of the sand, and can be calculated with the formula for the vertical stress distribution:

$\Delta\sigma_{v;i}^{'} = \frac{b_0}{b_i} q$ where b_0 is the width of the load at the current bottom, b_i the width of the load at layer i and q the load in kPa (Prof.Ir.Drs. J.K. Vrijling et al, 2011). The width b_i can be estimated with $b_i = b_0 + 2d_i$ where d_i is the distance from the bottom to the centre of a soil layer i.

When the width of the loaded area is large compared to the depth of the clay layer, $\frac{b_0}{b_i}$ goes to 1. In that case the next simplification can be applied:

$$\Delta\sigma_{v;i}^{'} = q = \gamma_{s;d} h_d + (\gamma_{s;w} - \gamma_w) h_w$$

where:

$\gamma_{s;d}$ = the specific self-weight of dry sand

h_d = the height of the dry part of the reclaimed sand

$\gamma_{s;w}$ = the specific self-weight of wet sand

h_w = the height of the wet part of the reclaimed sand

For location 2 the simplification is valid, because $b_0 \approx 400$ m and b_i is on average 430 m ($\overline{d}_i$=15 m), resulting in $\frac{b_0}{b_i}$=0.93 ≈ 1.

For location 1 $b_0 \approx 70$ m and b_i is on average 94 m ($\overline{d}_i$=12 m), resulting in $\frac{b_0}{b_i} \approx 0.75$. Here the simplification isn't really valid any more. However, the simplification gives an upper bound for the settlement and consolidation period and is as such calculated with. See Table 83 for the values of $\Delta\sigma'_{v;i}$. The water level is putted at MWL (0.76 m + LIMB) (see chapter 15), and the top level of the sand at + 5.35 m LIMB. This level is only applied for the dikes (see chapter 17). The rest of the island is located at + 3.00 m LIMB, resulting in less settlements. So, the calculated values are upper bounds.

Next, for each layer the total strain is calculated. The settlement of a layer is:
$\Delta H_i = \varepsilon_i H_i$, where H_i = 1 m is the thickness of an individual clay layer.
The total settlement $\Sigma\Delta H_i$ is the sum of the settlements of each individual layer. The total settlement is 6.95 m for location 1 and 4.10 m for location 2, see Table 83.
The average strain $\overline{\varepsilon}$ is equal to $\frac{\Sigma\Delta H_i}{H}$ where H=24 m is the thickness of the clay layer.

	Location 1	Location 2
h_d [m]	4.59	4.59
h_w [m]	6.76	3.76
$\Delta\sigma'_{v;i}$ [kPa]	161.57	128.57
$\Sigma\Delta H_i$ [m]	6.95	4.10
$\overline{\varepsilon}$ [-]	0.29	0.17

Table 83 - Settlements

Consolidation

The degree of consolidation is expressed with the consolidation coefficient U, where 0<U<1. The time when the consolidation is finished and U=1, and as such also the settlement had reached its maximum, can be calculated with:

$$t_{99\%} = \frac{2h^2}{c_v}$$

Where $t_{99\%}$ is the consolidation time in seconds, h the drainage height in metres and c_v the vertical consolidation coefficient:

$c_v = \frac{k_v}{\gamma_w m_v}$ where k_v is the vertical permeability (assumed at 10^{-9} m/s) and m_v the vertical soil stiffness:

$$m_v = \frac{\overline{\varepsilon}}{\Delta\sigma'_{v;i}}$$

The drainage height h is 0.5H= 12 m, because outflow of the water can take place at the top and at the bottom of the clay layer. The results for the consolidation time are shown in Table 84.
As can be seen it takes 164 year for location 1 to reach its final settlement and 121 year for location 2.

When drainage is applied the duration of the settlement can be decreased. When for example every 5 m a drain is installed, the drainage length is decreased from 12 m (maximum distance to the border) to 2.5 m (maximum distance to the drain), resulting is drainage length being 4.8 time as small as before. The consolidation time $t_{99\%}$ is now decreased with a factor 4.8^2.

	Location 1	Location 2
m_v **[1/kPa]**	0.00179	0.00133
c_v	5.58 E-08	7.53 E-08
$t_{99\%}$ **[year]**	164	121
$t_{99\%\_\mathrm{drains}}$ **[year]**	7.1	5.3
t_{1mleft_drains} **[year]**	2.5	1.3

Table 84 - Consolidation

The assumption is mad that construction of the civil works can start when the settlements are smaller than 1.00 m (Boskalis AeroIsla).The corresponding consolidation coefficient U can be calculated with:

$U = \frac{\Delta H}{\Sigma \Delta H_i}$ where ΔH is the expired settlement and $\Sigma \Delta H_i$ the total settlement. For location 1 the result is U = 0.86 and for location 2 U = 0.76. The corresponding time can be determined from:

$$t \approx \frac{\ln\left(\frac{(1-U)\pi^2}{8}\right)}{-\frac{\pi^2}{4}\frac{c_v}{h^2}} \quad \text{(if U>0.5)}$$

Where t is the time in seconds.

As can be seen from Table 84 building of the civil works can start 4.5 years after reclamation at location 1 and 4 years at location 2. The value for location 1 is an upper bound because of the simplification of the formula for the vertical stress distribution.

T Design bed and bank protection

Design height

When looking at the design height of the island, the South-Eastern part is the governing side, because storms come from the South-East, see Figure 78.

The design height of the island depends on:

- Tides and wind setup (resulting in design high water level)
- Supplement for high water rise (0.25 metre)
- Supplement for local increase of water level (0.25 metre)
- Wave run-up

Tides and wind setup

The water level from tides and wind setup results in the design high water level. From Appendix P: Water levels follows that the design high water level with an occurrence of 1/1000 year is 2.86 m + LIMB.

Supplement for high water rise

This supplement is the expected increase of high water levels during the expected lifetime of the structure.

Supplement for local increase of water level

This supplement compensates for an increase in water levels because of gust bumps (a single wave resulting from a sudden violent rush of wind), or seiches.

A value of at least 0.5 m for the supplement for high water rise and the local increase of water levels together is suggested (Tonneijck & Weijers, 2008). This value matches with the values used for the AeroIsla project (Boskalis AeroIsla).

Wave run-up

The wave run up is the vertical distance between the design high water level + both supplements and the highest point on a slope reached by water running up the slope. A wave run-up exceeded by 2% of the waves is generally applied. The wave run-up depends on the wave height and period, the shape of the dike, and the roughness and permeability of the dike protection.

Using the van der Meer equation, the wave run-up can be calculated with:

$R_{2\%} = 1.75\gamma_b \gamma_f \gamma_\beta \xi_{m-1,0} H_{m0}$ where $\xi_{m-1,0}$ is the breaker parameter:

$$\xi_{m-1,0} = \frac{\tan\alpha}{\sqrt{H_s / (1.56 T_{m-1,0}^2)}}$$

$H_s \approx H_{m0}$ is the significant wave height, having a value of 1.92m and the spectral wave period $T_{m-1,0} = 4.53s$ (see chapter 15). With a slope of the dike of 1:4 ($\tan\alpha$ =0.25), the breaker parameter has a value of $\xi_{m-1,0}$ = 1.02. γ_b is a reduction factor for a berm. No berm is applied, so this value is equal to 1. The reduction factor for the roughness γ_f is equal to 0.6 when rip-rap is used. For γ_β, reduction for the angle of incidence, applies: $1-0.0022\beta$, where β is the angle of wave attack: the angle between the direction of propagation of the waves and the axis perpendicular to the dike.

The direction of the waves is 112° N during the governing storm. The axis perpendicular to the dike makes an angle of 129° N, resulting in a β of 17°. So the reduction factor γ_β =0.96.

With these values $R_{2\%}$ = 1.98 m.

Crest level dike

The crest level of the dike has a value of 2.86 m + LIMB + supplements + run-up ≈ 5.35 m + LIMB

Bank protection

For the bank protection two different revetments are investigated: revetment 1 and 2. Revetment 1 is applied to all the banks viewing the south-east. For all the other banks revetment 2 is applied, see Figure 78.

The dike, built up from sand, has to be protected from erosion by waves and currents. A choice can be made between the type of protections:

1. Loose grains, rip-rap (permeable)
2. Placed block revetment (semi-permeable)
3. Impervious layer

A choice is made for the rip-rap protection, mainly because rip-rap is available in the area and a rip-rap protection is relative easy to install. Another benefit is the permeability. A loose grain protection consist of a top layer (rip-rap) and a filter layer to prevent erosion of the core of the dike.

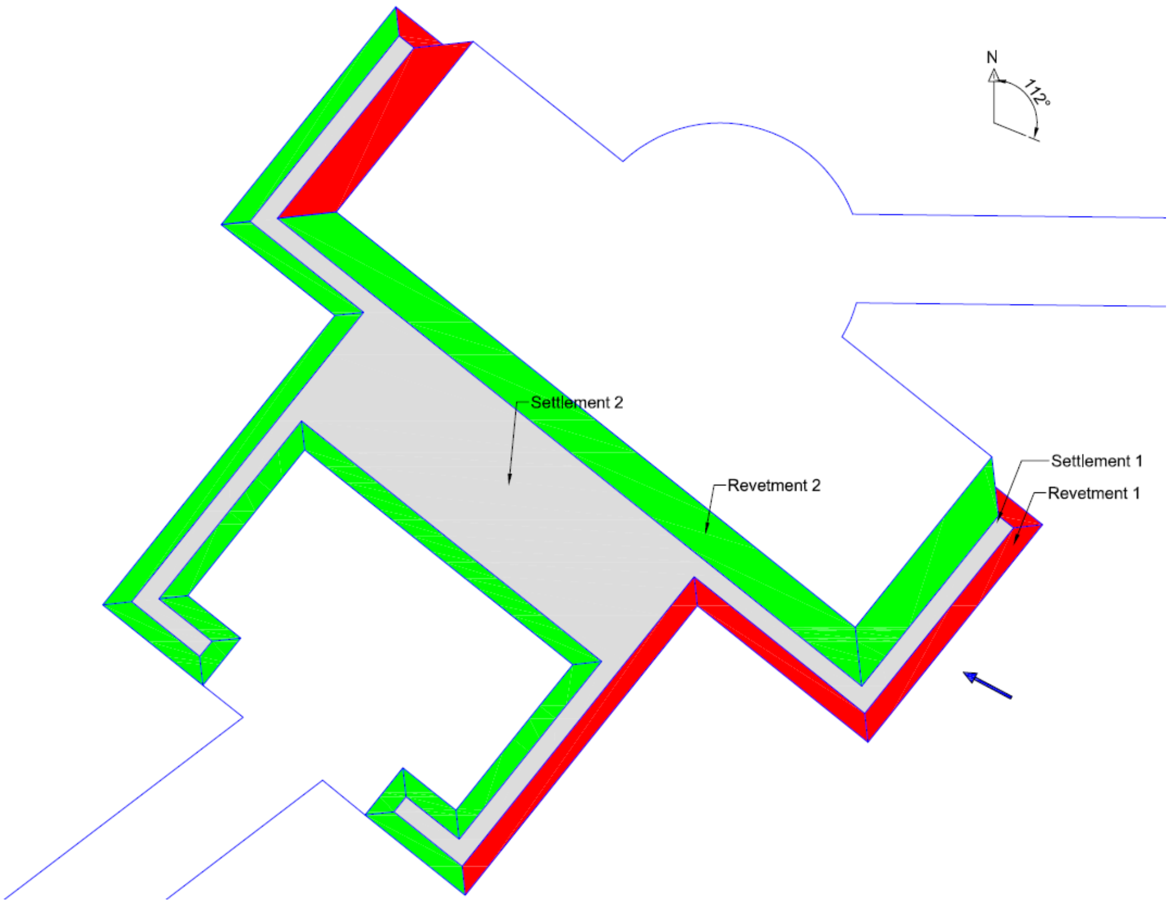


Figure 78 - Overview bank revetments

Revetment 1

Top-layer

The stone size of the top-layer can be calculated with the van der Meer formula (Schiereck & Verhagen, 2012). Assuming a plunging breaker:

$$\frac{H_s}{\Delta d_{n50}} = 6.2P^{0.18}\left(\frac{S}{\sqrt{N}}\right)^{0.2} \xi_m^{-0.5}$$

With H_s=1.92m the significant wave height, Δ=1.65 the relative density (fresh water, ρ_s=2650 kg/m^3), P=0.1 the permeability of a sand core with a permeable layer, S=2 the damage level (little damage), N=3000 the number of waves (some maintenance necessary after a storm) and ξ the Iribarren number:

$$\xi_m = \frac{\tan\alpha}{\sqrt{H_s/(1.56T_m^2)}} = 1.05$$

With a slope of 1:4 ($\tan\alpha$ =0.25) and a mean period T_m = 4.66 s (see chapter 15).
The assumption for plunging breakers is justified if

$$\xi_m < \xi_{transition} = \left(6.2P^{0.31}\sqrt{\tan\alpha}\right)^{\left(\frac{1}{P+0.5}\right)} = 2.01$$

This is true, so the formula for plunging breakers is valid and results in a nominal stone diameter of d_{n50}=0.56 m. The mass of a stone element that is exceeded by 50% of the stone elements W_{50}=477 kg.

According to the Eurocode this matches with a stone class HMA 300-1000 kg, having a d_{n50} of 0.59 m (Eurocode, 2004). The minimum layer thickness is 1.5 d_{n50} with a minimum of 0.30 m because of practical reasons (Schiereck & Verhagen, 2012).The result is a top-layer of 0.90 m thick.

Filter-layer

For the filter-layer a distinction can be made between a geometrically open or close filter, or a geotextile. A geotextile is not a very good solution in this case because no guarantees can be given for a lifetime of 100 years. Another disadvantage of a geotextile is that it's very hard to install under water.

A geometrically closed filter is built up from layers where each layer is coarser than the previous one. Each layer has a minimum thickness relative to the previous layer to prevent wash out and because of practical reasons for installation. A geometrically closed filter consist of less filter layers than a geometrically open filter. Particles of the subsoil can in principle move upwards through the rock bed, but the hydraulic loads on a particle are reduced in such a way that it cannot move entirely through the rock bed. Because of this, a geometrically open filter is often less thick than a closed filter.

A geometrically open filter would result in a less thick layer, but the basic principle turns out to be only valid for a protection mainly subjected to uniform currents. In this case the protection is subjected to waves. Therefore the application of a geometrically open filter is not allowed.

A geometrically closed filter is designed between the borders of stability and permeability:

Stability: $\frac{d_{15F}}{d_{85B}} < 5$ Internal stability: $\frac{d_{60}}{d_{10}} < 10$ Permeability: $\frac{d_{15F}}{d_{15B}} > 5$ (Schiereck & Verhagen, 2012) Where $d_{x,X}$ is the sieve diameter of the layer which is passed by only x% of the mass of the grains. The subscript X stands for the filter (F) or for the Base layer (B).

With sand with a d_{n50} of 0.3 mm (see Appendix O: Subsoil) the next filter layers are necessary, see Table 85.

Description	Value
Top layer	
dn_{50}	0.59 m
Stone class	HMA 300-1000
d_{15}-d_{85}	0.50-0.70 m
Thickness	0.90 m
Filter Layer 1	
dn_{50}	0.063 m
d_{85}-d_{15}	0.033-0.010 m
Thickness	0.30 m
Filter layer 2	
dn_{50}	0.004 m
d_{85}-d_{15}	0.007-0.002 m
Thickness	0.30 m

Table 85 - Top and filter layers revetment 1

Revetment 2

For revetment 2 the same approach is applied as for revetment 1. The wave height is smaller than at revetment because of the smaller fetch. The significant wave height for 1/1000 year at revetment is 1.47 m. The peak period T_m=4.09 s.

The most optimal slope depends amongst others of the amount of stones necessary. For different slopes the minimal d_{n50} has been determined. Using (Eurocode, 2004) the best fitting stone class has been determined. The different slopes result in different amounts of rock, see Table 86.

Slope [1:x]	3	4	5
Minimal d_{n50} [m]	0.5	0.43	0.39
Applied d_{n50}[m]	0.59	0.38	0.38
Dumping quantity [kg/m^2]	1325	950	950
Length protection [m]	68.1	88.9	109.9
Amount of rock [kg/m]	**1393**	**1039**	**1060**

Table 86 - Amount of rock per slope

As can be seen from the table a slope 1:4 requires the least amount of rock. With respect to a slope of 1:3 more sand is needed, but this will probably not outweigh the difference in the amount of rock. So a slope of 1:4 and a stone class LMA 60-300 with a d_{n50} of 0.38 m is chosen for this protection.

The filter layers are calculated in the same way as for revetment 1. The layers of the protection are listed in Table 87.

Description	Value
Top layer	
dn_{50}	0.38 m
Stone class	LMA 60-300
d_{15}-d_{85}	0.30 – 0.45 m
Thickness	0.60 m
Filter Layer 1	
dn_{50}	0.040 m
d_{85}-d_{15}	0.020 – 0.060 m
Thickness	0.30 m
Filter layer 2	
dn_{50}	0.0267 m
d_{85}-d_{15}	0.001 – 0.004 m
Thickness	0.30 m

Table 87 - Top and filter layers revetment 2

Propeller wash

When a vessel sails through a canal or through a port the jet from the propeller can cause significant erosion of the bottom. Depending on the scour depth and the place of occurrence this may be a problem.

Flow velocities

The amount of erosion depends amongst others of the outflow velocity u_0 of the propeller. The outflow velocity for a normal propeller can be calculated with:

$$u_0 = 1.15\left(\frac{P}{\rho(0.7d)^2}\right)^{1/3}$$

Where P is the power of the engine in W, ρ = 1000 kg/m^3 the density of water and d the the propeller diameter in metre. The power of a Post-Panamax vessel is estimated from reference vessels. The 'Dimitris L' is a Panamax vessel with a power of 13,900 kW (Vrontados).Misubushi Heavy Industries has designed a Post-Panamax vessel with a power of 15,400 kW (Mitsubishi Heavy Industries, 2010). An upper bound of 16,000 kW is used for this calculation.

The propeller diameter is also estimated from reference vessels. Wärtsilä uses a propeller diameter of 7.2 m for an Aframax vessel with a loading capacity of 80,000 – 120,000 DWT and a diameter of 8.2 m for a Capesize vessel with a loading capacity of 100,000 – 210,000 DWT (Wärtsilä, 2011). The propeller diameter of a New Panamax vessel, with a loading capacity of 120,000 DWT, is assumed to be 7.7 m. The result is an outflow velocity u_0=9.4 m/s.

The velocity near the bottom depends on the outflow velocity u_0, the distance z_b from the propeller axis to the bottom, and the horizontal distance to the propeller. The maximum velocity near the bottom can be calculated with:

$$u_{b-\max} = 0.3u_0\frac{0.7d}{z_b}$$

The distance z_b is equal to half the diameter of the propeller + the keel clearance. The depth of the canals and basins is 16.7 m, while the maximum draught of a vessel is 15.2 m, resulting in a keel clearance of 1.5 m. The value for z_b is equal to 5.35 m. The maximum velocity near the bottom u_{b-max} =2.8 m/s.

Bed protection

When no measures are taken a scour hole will develop near the jetties and the bank protection during the mooring and un-mooring of the vessel. This may cause instability of the jetty and the bank protection.

A solution is to apply a rip-rap bed protection near the jetty and the toe of the bank protection. The dimensions of the stones for a flat bed protection can be calculated with:

$$d_{n50} = 2.5 \frac{u_b^{\,2}}{2g\Delta}$$

where $u_b = u_{b-max}$. The result is a d_{n50} of 0.63 m. This matches with a stone class HMA 1000-3000, resulting in large stones. An alternative solution is the application of a matrass, consisting of coherent material instead of loose stones. This solution will probably be cheaper and is therefore chosen as bed protection.

The mattress is applied along the border of the toe of the bank protection in the ocean basin. The width is about the width of the vessel, say 50 m (Verhagen H. , 2006).

Outside the area where the bed protection is applied erosion will take place. The critical flow velocity of the clay particles on the bottom of the basin and the navigation channel is for soft clay with a porosity of 60% about 0.1 – 0.4 m/s (Schiereck & Verhagen, 2012). This is less than the maximum flow velocity near the bottom, so erosion will occur.

Bank protection

When a vessel uses its main propeller and bow thrusters for mooring and unmooring the bank protection, as calculated for the bank protection of revetment 2, may become unstable.

Assumed is that the governing situation occurs when the main propeller is directed towards the bank protection. The flow velocity can be calculated with:

$$u(r,x) = \frac{2.8u_0}{\left(\frac{x}{d}\right)} \exp\left(-15.7\left(\frac{r}{x}\right)^2\right)$$

Where x is the horizontal distance on the centre line of the propeller, d the diameter of the propeller and r the vertical distance from the centre line. The assumption is made that the angle of the vessel towards the bank can’t be larger than 45°. The distance x now isn't the shortest distance to the bank (perpendicular to the vessel), but has to be transformed under an angle of 45°.

In this case the shortest distance to the bank is equal to 20 m (considering a vessel with a width of 40 m), resulting in a distance under 45° of $20\sqrt{2} \approx 28$ m. The velocity also depends on the vertical distance to the centre line, being maximum $r=z_b$= 5.35 m near the toe.

In order to find out where the maximum velocities occur the flow velocity has been plotted to r and x, where x>28 m, see Figure 79.

Along the flow line of the propeller jet, the angle of the bank is equal to $\alpha_{45} = \arctan\left(\frac{1}{2}\frac{\sqrt{2}}{x}\right)$

where 1:x is the slope of the revetment. The slope is 1:4, so in the above formula x=4. The result for α_{45} =0.175 rad.

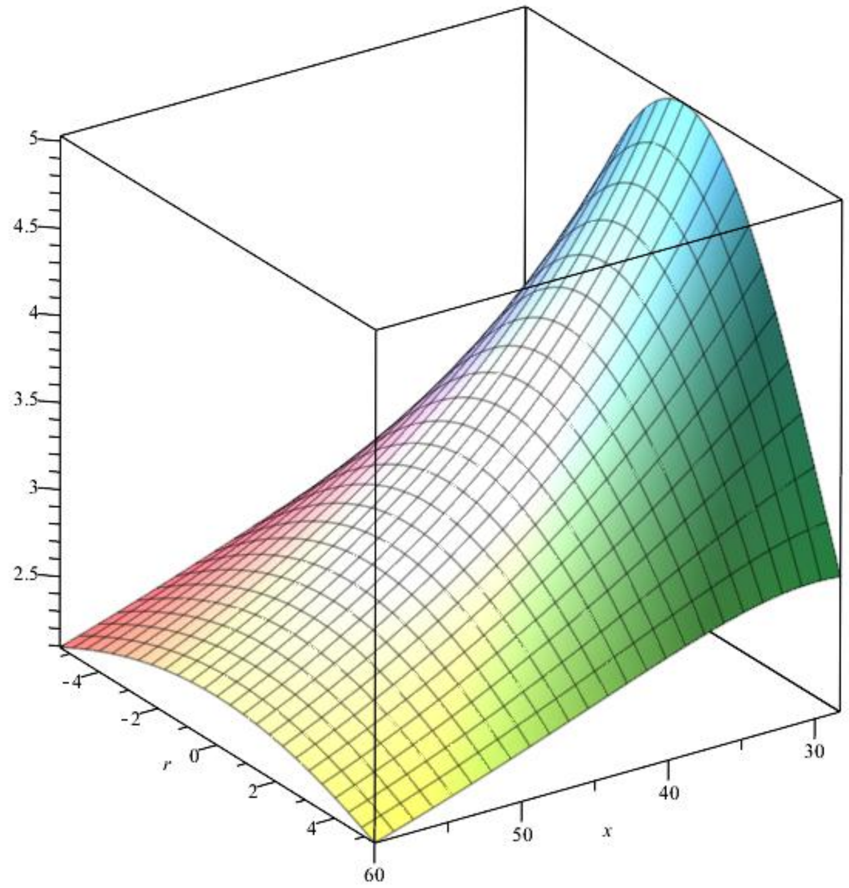


Figure 79 - Flow velocity as function of r and x

R and x can be expressed in each other by: $r = -0.177x + 10.31$. For different corresponding values of r and x the values of u(r,x) have been calculated in Table 88.

x	r	u(r,x)
28	5.34	2.86
33	4.47	3.23
38	3.58	3.26
43	2.70	3.11
48	1.81	2.90

Table 88 - Flow velocity propeller wash

The maximum value appears to be about 3.5 m/s.

According to Izbash for a stone on a slope parallel to the flow direction:

$$d_{n50} = \frac{0.7{u_c}^2}{\Delta 2g} \frac{1}{\frac{\sin(\phi - \alpha_{45})}{\sin \phi}}$$

Where ϕ is the angle of repose of the bed protection (40° for rip-rap) and α_{45} = 0.175 rad. the angle of the slope parallel to the flow direction.

With these values the minimal d_{n50} is equal to 0.34 m, being less than the applied 0.38 m for revetment 2. The conclusion is that no heavier stone class has to be applied because of the propeller wash.

U Breakwater design

The design of the breakwater is based on formulas, tables and figures from Breakwaters & Closure dams (Verhagen, d'Angremond, & Roode, 2009).

Design parameters

The design of the breakwater depends on a few design parameters, listed in Table 89 (see chapter 15).

Parameter	Unit
Reference water depth	LIMB -5.63 m
Mean water level (MWL)	LIMB +0.76 m
Design water level	LIMB +2.86 m
Design wave height (H_s)	1.92 m
Highest 2% wave height ($H_{2\%} = 1.25 \cdot H_s$)	2.39 m
Peak period design wave (T_p)	4.98 s
Spectral wave period ($T_{m-1,0}$)	4.53 s
Water density (ρ_w)	1000 kg/m^3
Stone density (ρ_s)	2650 kg/m^3
Relative density (Δ)	1.65
d_{n50}/ d_{50}	0.84

Table 89 - Design parameters breakwater

Design height

An important parameter for the breakwater design is the design height. The design height of a breakwater is the sum of the design water depth and the crest freeboard. The design water depth is the sum of the reference water depth and the design water level, which gives a depth of 5.63 + 2.86 = 8.49 m. The crest freeboard can be determined with the following formula:

$$\frac{q}{\sqrt{gH_s^{\,3}}} = 0.2\exp\left(-2.3\frac{R_c}{H_s\gamma_f\gamma_\beta}\right)$$

In which:

q (allowable overtopping discharge) = 0.01 m^3/s/m

γ_f (friction factor) = 0.55

γ_β (angle of wave incidence factor, β =0) = 1-0.0063·β = 1

From this formula the crest freeboard (R_c) is calculated and is 2.34 m, making for a total design height of 10.83 metres.

Rock layers

A rubble mound breakwater is made of rock. The most economical way to design the breakwater is to use sufficient large rocks on the outer and inner slope, which are stable under the design conditions and to use smaller rocks to create an under layer and the core of the breakwater. To complete the design of the breakwater, also a toe and filter have to be designed.

Armour layer

The armour layer is the most important rock layer of the breakwater as it protects the breakwater from the waves. To calculate the required rock size for the armour layer, the Van der Meer formula has to be used. There are two main formulas from Van der Meer, a formula for surging waves and one for plunging waves. To assess if the waves are surging or plunging the Iribarren number has to be calculated: $\xi = \tan(\alpha)/\sqrt{Tp}$, where tan(α) is the slope of the breakwater. The slope of the breakwater is chosen to be tan(α) = 0.75 (or cot(α) = 1.33), which is a common slope for breakwaters, making for an Iribarren number of 0.3. Waves with an Iribarren number of 0.3 can be classified as plunging waves, which gives the following Van der Meer formula:

$$\frac{H_{2\%}}{\Delta d_{n50}} = c_{pl} P^{0.18} \left(\frac{S}{\sqrt{N}}\right)^{0.2} (s_{m-1,0})^{0.25} \sqrt{\cot(\alpha)}$$

In which:

c_{pl} (plunging factor) = 7.25
P (permeability, under layer and core) = 0.4
S (damage number, only initial damage) = 2
N (number of waves during a storm) = 3000
$S_{m-1,0}$ (fictitious wave steepness: $2\pi H_{2\%}/(gT_{m-1,0})$ =0.339

Using this formula, the nominal median block diameter d_{n50} can be calculated and the stone class can be determined (Schiereck & Verhagen, 2012),(Eurocode, 2004), as is listed in Table 90.

Parameter	Unit
d_{n50}	0.52 m
d_{50}	0.62m
Weight class	300-1000 kg
W_{50}	600 kg
Grading (d_{85}/d_{15})	1.4

Table 90 - Armour layer

The minimum layer thickness for the armour layer is 1.5· d_{n50}, but for safety and practical reasons, this has to be 2·d_{n50}, which gives a layer thickness of 1.04 metres.

Under layer

Under the armour layer an under layer is present, to make a transition between the armour layer and the core of the breakwater. The size of the rocks in the under layer depends on a ratio between the d_{n50} of the armour layer (d_{n50A}) and the d_{n50} of the under layer (d_{n50U}) (CIRIA, 2007):

$$\frac{d_{n50A}}{d_{n50U}} = 2.50$$

From this ratio the nominal median block diameter d_{n50} and the stone class can be determined (Schiereck & Verhagen, 2012),(Eurocode, 2004), as can be seen in Table 91.

Parameter	Unit
d_{n50}	0.21 m
d_{50}	0.25m
Weight class	10-60 kg
W_{50}	45 kg
Grading (d_{85}/d_{15})	1.5

Table 91 - Under layer

The minimum layer thickness should again be 1.5· d_{n50}, but for practical reasons, this has to be 2·d_{n50}, which gives a layer thickness of 0.42 metres. Because of the relative large rock size of the under layer, the core will consists of smaller rocks to make the breakwater less expensive.

Core

The size of the rocks for the core depends on the same ratio as the size of the rocks in the under layer, giving the nominal median block diameter d_{n50} and the stone class, as given in Table 92.

Parameter	Unit
d_{n50}	0.08 m
d_{50}	0.11 m
Class	63/180 mm
W_{50}	2.2 kg
Grading (d_{85}/d_{15})	3.5

Table 92 - Core

Toe

The toe of the breakwater supports the end of the armour layer. The armour layer does not have to run all the way down to the bed level, therefore a toe has to be places were the armour layer ends. The formulas to calculate the required stone size for the toe are only valid for a ratio of the depth above the toe divided by the wave height, h_t/H_s ,smaller than 2. This reduces the maximum water depth above the toe to approximately 3.8 metres, whereas the total maximum water depth (h) in front of the breakwater is 8.5 metres. The formula that will be used to calculate the toe stability is valid for $0.4 < h_t/h < 0.9$ and is:

$$\frac{H_s}{\Delta d_{n50}} = \left(6.2\left(\frac{h_t}{h}\right)^{2.7} + 2\right) N_{od}^{\ 0.15}$$

In this formula only N_{od} is yet unknown, which is the damage number, for start of damage N_{od} is 0.5. After calculating the d_{n50}, the rock parameters are given in Table 93 (Schiereck & Verhagen, 2012),(Eurocode, 2004).

Parameter	Unit
d_{n50}	0.48 m
d_{50}	0.57m
Weight class	300-1000 kg
W_{50}	600 kg
Grading (d_{85}/d_{15})	1.4

Table 93 - Toe

The layer thickness is again 2·d_{n50}, which gives a thickness of 0.95 metres. The guidelines for the height and width of the toe are: $\frac{h_{toe}}{d_{n50}} = 2-3, \quad \frac{w_{toe}}{d_{n50}} = 3-5$

In order to toe give the slope of the toe the same slope as the rest of the breakwater, these ratios are chosen to be 2 and 3. This gives a height of the toe of 0.95 metres (which is in compliance with the layer thickness) and a width of the toe of 1.43 metres. This toe width is the minimal width, if the toe would have a triangular shape, which is not practical, thus the toe has to be wider. Therefore a toe crest width of 1.2 metres is chosen, as this is the minimum width for this stone class.

Depth of the toe

The depth of the toe should be a maximum of 3.8 metres below the design water level. Generally the toe is at a depth one wave height below the water level. If 3.8 metres should be used, the toe could become unstable in less severe conditions, because the depth of the toe is not sufficient. Therefore other values for the depth of the toe will be chosen. However, a distinction between the depth of the toe at the seaward side and port side can be made, because of difference in wave attack.

At the port side a depth of 1.10 metres below MWL, or 0.25 metres below LIMB, has been chosen, as this is the transmitted wave height of the design wave (see calculation transmitted wave height), this is, however, a conservative value. At the seaward side the design wave height in a water depth equal to LIMB is chosen to be depth level of the toe. This wave height is 1.63 metres and thus the depth is 1.63 below LIMB.

Rear slope armour

The rock dimensions of the armour layer of the rear slope depend on maximum velocity at the rear side of the crest during a wave overtopping event(Delft Hydraulics, 2005):

$$d_{n50} = 0.008\left(\frac{u_{1\%}T_{m-1,0}}{\Delta^{0.5}}\left(\frac{S}{\sqrt{N}}\right)\right)^{-1/6} \cdot \cot(\alpha)^{2.5/6} \cdot \left(1+10\exp\left(\frac{-R_c}{H_s}\right)\right)^{1/6}$$

$$u_{1\%} = 1.7\left(g\gamma_{f-c}\right)^{0.5} \cdot \frac{\left(\left(Z_{1\%}-R_c\right)/\gamma_f\right)^{0.5}}{1+0.1B_c/H_s}$$

$Z_{1\%}$ depends on the surf-similarity parameter, which is calculated with:

$$\xi_{s,-1} = \tan(\alpha)/\sqrt{s_{m-1,0}} = 1.29$$
$$Z_{1\%} = 1.45\xi_{s,-1} \cdot \gamma_\beta H_s = 3.58$$

Other parameters which have to be known are:

S (damage number, only initial damage) = 2

N (number of waves during a storm)	= 3000
Rc (crest freeboard)	= 2.34 m
γ_f (roughness of seaward slope, rock slope)	= 0.55
γ_{f-c} (roughness of crest, rock crest)	= 0.55
γ_β (angle of wave incidence factor, β =0)	= 1-0.0063·β = 1
B_c (Crest width)	= 7 m

This gives a $u_{1\%}$ of 4.34 m/s if the crest width is chosen to be 7 metres. This width is chosen to allow construction vehicles to drive over the breakwater during construction. This reduces the need for maritime construction equipment. From this calculation the d_{n50} and stone classes follow and are given in Table 94 (Schiereck & Verhagen, 2012),(Eurocode, 2004).

Parameter	Unit
d_{n50}	0.38 m
d_{50}	0.45m
Weight class	60-300 kg
W_{50}	200 kg
Grading (d_{85}/d_{15})	1.5

Table 94 - Rear slope armour

For this layer again a thickness of $2 \cdot d_{n50}$ applies, which gives a layer thickness of 0.75 metres.

Protection of the rear slope against propeller wash

The tugboats for the ocean going vessels, which are berthed in the inland basin, will make regular trips from the inland basin to an ocean going vessel in the ocean basin or access channel. Every time they make such a trip, they will pass the breakwater. Since the draft of these tugboats is not deep, there is a possibility these tugboats will sail close to the breakwater (Marine)Because of this, it is necessary to check the stability of the rear slope against propeller wash. This is done using the calculation method and formulas of (Schiereck & Verhagen, 2012) and the data from (Marine). There a two ways to calculate the required stone size to ensure stability in propeller wash. It is possible to calculate the required stone size directly beneath the tugboat or the stone size a bit to the side of the tugboat. A general rule for the second calculation is that vessels keep a distance of 1B (B is beam) from the bank, resulting in a distance from the toe of the breakwater of approximately 0.5B. For both methods the first step is to calculate the speed of the jet directly near the propeller:

$$u_0 = 1.15\left(\frac{P}{\rho d^2}\right)^{1/3}$$

In which:

P (engine power) = 3600 kW
ρ (density of water) = 1000 kg/m^3
d (propeller diameter) = 0.7*0.7*D = 1.96 m

This gives a u_0 of 11.25 m/s. This is used to either calculate the speed $u_{b\text{-max}}$ at the bottom directly under the tugboat or the speed u_t at the toe at the bottom of the breakwater:

$$u_{b-\max} = 0.3u_0\frac{d}{z_b}, \quad u_t = \frac{2.8u_0}{x/d}\exp\left(-15.7\left(\frac{z_b}{x}\right)^2\right)$$

In which:

d (propeller diameter) = 0.7*0.7*D = 1.96 m
z_b (vertical distance propeller to bottom) = 3 m
x (horizontal distance propeller to toe) = 0.5B = 7 m

These formulas give a $u_{b\text{-max}}$ of 2.19 m/s and a u_t of 0.47 m/s. $u_{b\text{-max}}$ should be reduced with the vessels speed, which is assumed to be 4 knots or 2.1 m/s (lowest speed in the access channel), giving a u_b of 1.16 m/s. u_b and u_t will be used to calculate the required stone size, with this formula:

$$d_{n50} = 2.5\frac{u^2}{2g}\cdot\frac{1}{\sqrt{1-\frac{\sin^2\alpha}{\sin^2\phi}}}\cdot\frac{1}{\Delta}$$

In which:

u (speed at the breakwater u_b or u_t) = 1.16 or 0.47 m/s

α (slope of the breakwater) = 37°

Φ (internal angle of repose) = 42°

Δ (relative density) = 1.65

This gives a d_{n50} for u_b of 0.23 metres and a d_{n50} of u_t of 0.04 metres. As it is possible for a tugboat to float directly above the breakwater, the conservative value of d_{n50} of 0.23 metres is assumed. Since this is approximately the same d_{n50} as the under layer of the breakwater, it is chosen to let the under layer continue at the rear side of the breakwater all the way to the bottom.

Filter layer

Underneath the seaward toe of the breakwater, a filter should be present in order to prevent the subsoil from washing away from under the breakwater. In order to prevent this, a geometrically closed filter can be used. A geometrically closed filter is designed between the borders of stability and permeability:

Stability: $\frac{d_{15F}}{d_{85B}} < 5$ Internal stability: $\frac{d_{85}}{d_{15}} < 12$ Permeability: $\frac{d_{15F}}{d_{15B}} > 5$ (Schiereck & Verhagen, 2012). Where $d_{x,X}$ is the sieve diameter of the layer which is passed by only x% of the mass of the grains. The subscript X stands for the Filter (F) or for the Base layer (B). It is assumed that underneath the breakwater a layer of sand will be placed in order to improve the subsoil.

This sand has a d_{n50} of 0.3 mm (see Appendix O: Subsoil). Using these filter rules, it is necessary to construct one filter layer between the sand and the core material, as Table 95 shows.

Sand			
D_{15}	0.00015 m	D_{50}	0.00036 m
D_{85}	0.00045 m	D_{n50}	0.00030 m
Filter layer 1			
D_{15}	0.00270 m	Stability	4.99
D_{85}	0.01053 m	Internal stability	4
D_{50}	0.00662 m	Permeability	14.5
D_{n50}	0.00556 m	Grading	4
Filter layer 2 = Core			
D_{15}	0.05378 m	Stability	4.99
D_{85}	0.15060 m	Internal stability	2.8
D_{50}	0.10219 m	Permeability	20.0
D_{n50}	0.08584 m	Grading	2.8

Table 95 - Filter layers

To be able to construct this filter layer underwater, the layer thickness should at least be 0.5 metres.

Wave-structure interactions

When the breakwater is constructed, it will have interaction with the waves. The breakwater is permeable, so it will allow wave transmission trough the structure and waves will also reflect of the breakwater.

Wave transmission

The wave transmission can be calculated with the following formula:

$$K_t = 0.4\frac{R_c}{H_{si}} + 0.64\left(\frac{B}{H_{si}}\right)^{-0.31} \cdot \left(1 - \exp\left(-0.5\xi\right)\right)$$

In which:

R_c (crest freeboard) = 2.34 m
H_{si} (incoming wave height) = 1.92 m
B (crest width) = 7 m
ξ (Iribarren number) = 0.3

Width these parameters the transmission coefficient K_t can be calculated, which is 0.56. This means that during the design condition, the wave height behind the breakwater is 0.56 times the design wave height, which gives a wave height of 1.06 metres.

Wave reflection

The wave height of the waves which are reflected from the breakwater can be calculated with these formulas:

$$K_r = \tanh(a\xi_{m-1,0}{}^{b})$$
$$a = 0.167\left(1 - \exp\left(-3.2\gamma_f\right)\right)$$
$$b = 1.49(\gamma_f - 0.38)^2 + 0.86$$

In which $\xi_{m-1,0} = \tan(\alpha) / \sqrt{H_s / (1.56T^2_{m-1,0})}$ is 3.07 and γ_f is 0.55, making for a reflection coefficient K_r of 0.36. The reflected waves will be 0.36 times as high as the incoming waves, giving a reflected wave height of 0.70 metres during the design condition.

V Design of breasting and mooring dolphins

Layout of dolphins

As an addition of the detailed drawing in chapter 19, a sketch of the cranes is made to give an impression of the unloading process in Figure 80. The vessel in the figure is the New Panamax vessel.

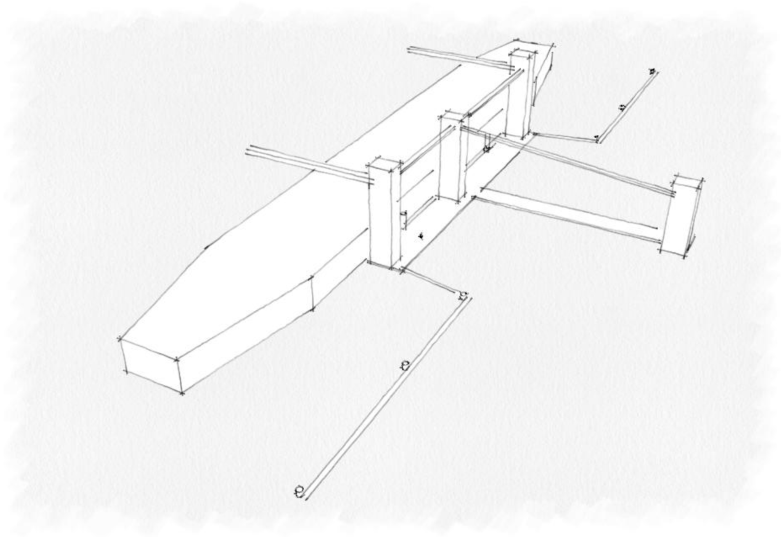


Figure 80 - Impression of the crane positions

Breasting dolphin of ocean basin

Both breasting dolphins are designed to fully absorb the forces of a berthing ship. Although this is not the only force on the dolphin, the forces transmitted by the ship exposed to wind, waves and current are less and not determining for the design. The total of kinetic energy is equal to the formula below. The parameters are explained in the text below the formula (Prof.Ir.Drs. J.K. Vrijling et al, 2011).

$$E_{kin} = \frac{1}{2} m_s v_s^2 C_H C_E C_S C_C$$

The mass of the ship (m_s) is multiplied with the hydrodynamic coefficient (C_H).

$$m_s \cdot C_H = m_s \cdot \frac{m_s + m_v}{m_s} = m_s + m_v$$

In this case the maximum design vessel is a New Panamax vessel as it since the expected Capesize vessel will not be fully loaded and due to its lower depth has a higher C_H value. The mass of the ship can be calculated with

$$m_s = \rho LDBC_B$$

In which ρ is the density of the water (1000 kg/m^3 for fresh water) and L D and B are the dimensions of the vessel. The block coefficient (C_B) is comparable to the bigger container vessels and is estimated on 0.95. This gives a total mass of $260 \cdot 10^6$ kg

The added water mass can be calculated with the Stelson Mavils' equation:

$$m_w = \rho L \frac{1}{4} \pi D^2$$

This gives a value of $66 \cdot 10^6$ kg or $C_H = 1.23$.
The second parameter is the vessel speed (v_s) and can be chosen as 0.15 m/s since the weather conditions in the port are temperate and guidance of the vessels is done with a several tugboats.

C_E is the eccentricity coefficient and takes into account the energy dissipation caused by the yawning of the ship when it turns eccentrically against the structure (see Figure 81). It can be calculated by:

$$C_E = \frac{k^2 + r^2 \cos^2(\gamma)}{k^2 + r^2}$$

In which k is the radius of gyration of the ship and can be approximated by $= (C_B + 0.11)L$. Using the values above gives $k = 106\ m$. r is the radius between the centre of mass of the ship and the point of collision between the ship and the structure and is 49.6 metre in this design. γ is the angle between the radius and the velocity of the ship and is, considering an angle of 5° of the berthing ship, estimated to 86°. This gives an eccentricity coefficient of 0.82.

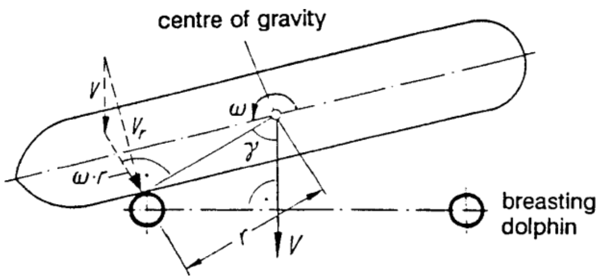


Figure 81 - Calculation of eccentricity coefficient

C_S is the softness coefficient is taken into account the elasticity of the ships side. It depends on both the stiffness of the structure and of the ship. For a relatively stiff structure as this jetty, the ship's shell will take a minor deflection and the coefficient of 0.9 can be used.

The last coefficient is the configuration coefficient (C_C) which takes into account the hydrodynamic friction which is caused by the water mass between the ship and the structure. Since the structure of this jetty is open, the water will simply flow away and will not reduce the kinetic energy of the ship, resulting in a factor of 1.0.

This gives a total kinetic energy of 2.7 MJ.

On impact the berthing energy will result into deflection of the dolphin and compression of the fender mounted on the dolphin. For the piles the relation between the deflection and the force is linear, but most elastomeric fenders show a non-linear force deflection curve. This is summarised in the formula below(Ligteringen, 2000).

$$E = \frac{1}{2} F \cdot y_p + \int_0^{y_f} F \cdot y_f \ dy$$

Since the deflection of the dolphin is only small compared to the compression of the fender, this is usually neglected and a fender is chosen based on the total energy. In this case using the extra high capacity fenders foam filled fenders this results in dimensions of 2.7 x 5.5 metre (Urethane Products Corporation (UPC)). At this design berthing a compression of 60% will occur and a reaction force of 3.6 MN.

For the design of the breasting dolphin itself the force calculated above is added by an additional 0.5F parallel to the berthing line and will be based on the resultant of those forces. The angle between those forces is assumed to be 90°, giving a total force of 1.1F or 4.0 MN.

The breasting dolphin is designed as a steel cylindrical pile driven in the bottom. The dimensions are designed using the assumption that a maximum deflection of $0.01 \cdot L$ is possible using the assumption that bottom is a fixed-moment connection. The pile crosses the bottom at a depth of -16.3 m LIMB, making the moment arm 23.3 m, so the assumed allowed deflection is 233 mm. Since the bottom is not a fully fixed-moment connection and the clay is able to be compressed, the final deflection might be higher; however, it is assumed that this extra deflection due to the clay is negligible.

Using the formula below the necessary moment of inertia (I) is calculated using a modulus of elasticity (E) for steel of 210,000 N/mm^2. The moment of inertia is $345 \cdot 10^9 \ mm^4$ (Hartsuijker, 2001).

$$I = \frac{Fl^3}{3E \cdot w}$$

The moment of inertia of a cylinder can be calculated using the formula below in which r is the (outer) radius and t is the thickness of the cylinder.

$$I = \frac{1}{4} \pi \left(r^4 - (r-t)^4 \right)$$

As a conclusion a cylinder with a radius of 1100 mm and a thickness of 100 mm is chosen, which has a moment of inertia of $365 \cdot 10^9 \ mm^4$.

Mooring forces ocean going basin

During the mooring of a ship all lateral forces are transmitted to the mooring dolphins. All loads on the ship such as wind, current and water level differences are translated to those by the mooring lines, which in their turn are connected to the mooring dolphin by quick release hooks. Quick release hooks will automatically release the mooring lines if a maximum force is exceeded and will thus protect the mooring dolphin of high forces. As an assumption in this preliminary design a force of 2.0 MN is used (Prof.Ir.Drs. J.K. Vrijling et al, 2011).

Using the same calculation as used for the breasting dolphins a minimum moment of inertia of $1.72 \cdot 10^9\ mm^4$ is needed. This can be achieved by using a cylinder with a radius of 950 mm and a thickness of 80 mm, having a total moment of inertia of $1.90 \cdot 10^9\ mm^4$.

Breasting dolphins inland basin

For the calculation of the inland basin dolphins, the same formulas as the previous dolphins are used. The design vessel in these formulas is the default barge with dimensions as mentioned in Table 7. The parameters are nearly the same and thus only the results are given in Table 96. The speed of the barges is considered higher than those of the ocean vessels, because they are only moored with a single tug boat and at a higher rate, making it more likely that this higher mooring speed occurs.

Parameter	Value
m_s	$9.3 \cdot 10^6$ kg
v_s	0.25 m/s
C_H	1.16
C_E	0.8
C_S	0.9
C_C	1

Table 96 - Parameters kinetic energy of the inland breasting dolphin

This results in a total kinetic energy of 0.25 MJ.

Using the standard capacity of foam filled fenders (Urethane Products Corporation (UPC)) results in fender dimensions of 1.2 x 4.9 metre. The fenders will have a compression of 60% at this energy level and will have a reaction force of 843 kN which gives a total force of 928 kN on the mooring dolphin and the ship.

Using a maximum deflection of 1% and a height of 9.6 m (5.6 + 4), gives a minimum necessary moment of inertia of $1.36 \cdot 10^{10}$ mm^4. This can be achieved by using a cylindrical dolphin with a radius of 500 mm and a thickness of 50 mm, which has a moment of inertia of $1.69 \cdot 10^{10}\ mm^4$.

Mooring dolphins inland basin

For barges with a water displacement of 9300 ton, the mooring force is approximately 283 kN (Urethane Products Corporation (UPC)). Using the same calculation as used for the breasting dolphins a minimum moment of inertia of $4.13 \cdot 10^8\ mm^4$ is needed. This can be achieved by using a cylinder with a radius of 350 mm and a thickness of 40 mm, having a total moment of inertia of $4.53 \cdot 10^9\ mm^4$.

Depth calculations

The soil pressure is derived by using the formulas of Blum. These are meant for the deformation of a pile in homogenous ground, but using conservative assumptions, it is used here to give a good estimation of the depth of the piles. Blum schematises the soil pressure as given in the Figure 82 (Prof.Ir.Drs. J.K. Vrijling et al, 2011).

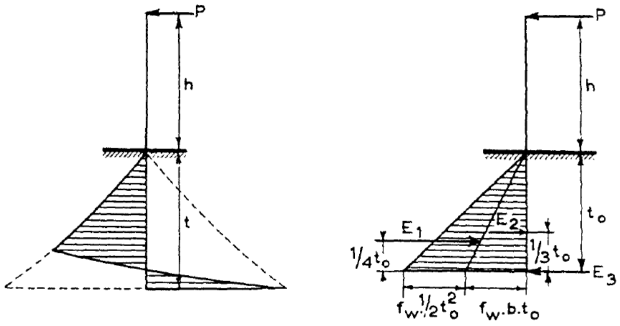


Figure 82 - Schematization of Blum

The total force consists of two components: the force absorbed by the passive ground right in front of the pile (E_2) and the force absorbed by the passive ground behind side wedges (E_1). Blum assumes balance of moments at a point at a depth $t_0 = t/1.2$.

$$F_{E_2} = \frac{1}{2} t_0^2 b \gamma' K_p$$

$$F_{E_1} = \frac{t_0^3}{6} \gamma' K_p$$

Using the soil parameters as given in Appendix O: Subsoil, the passive soil pressure coefficient can be calculated by the analytical formulas of Coulomb (Verruijt, 2010).

$$K_p = \frac{\sin^2(\alpha - \phi)}{\sin^2 \alpha \sin(\alpha - \delta)\left[1 - \sqrt{\{\sin(\phi - \delta)\sin(\phi + \beta)\} / \{\sin(\alpha - \delta)\sin(\alpha + \beta)\}}\right]^2}$$

Since δ and β are 0° and $= 90°$, this can be simplified to

$$K_p = \frac{1 + \sin(\phi)}{1 - \sin(\phi)}$$

An overview of the soil parameters is given in Table 97.

Clay layer	$\phi = 20°$	$K_p = 2.040$	$\gamma_s = 15\ kN/m^3$
Sand layer	$\phi = 37°$	$K_p = 4.023$	$\gamma_s = 21\ kN/m^3$

Table 97 - Soil parameters

Using these, the forces can be calculated, for a depth of 31.1 m these are listed in the Table 98. For the E_1 force and arm of the sand layer the assumption is done that it only consists of a side wedge of the additional soil pressure in the sand layer, and it does not take into account that this wedge will continue as a wider wedge to the surface and also should take the soil pressure of the clay layer into account. The E_1 forces are there for an underestimation.

Layer	F	Force [kN]	Moment arm [m]
Clay layer	E_2	2,106	19.0
	E_1	4,371	17.8
Sand layer	E_2	14,492	5.5
	E_1	21,947	3.6
Total Moment			**197 MNm**
Horizontal force			**4.0 MN**

Table 98 - Soil forces on the breasting dolphin (ocean basin)

From this table can be concluded that the pile will be able to resist the horizontal force if it has a depth of 31.1 m. The same calculation can be done for the other mooring dolphin (see Table 99), which will need a depth of 25.5 m (see Figure 83).

Layer	F	Force [kN]	Moment arm [m]
Clay layer	E_2	1,819	12.1
	E_1	4,371	11.0
Sand layer	E_2	4,401	3.1
	E_1	3,174	1.9
Total Moment			**90 MNm**
Horizontal force			**2.0 MN**

Table 99 - Soil forces on the mooring dolphin (ocean basin)

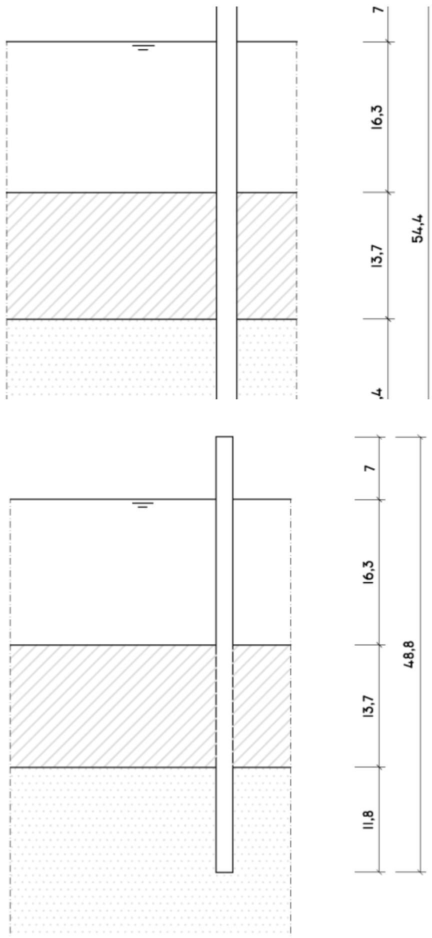


Figure 83 - Depth of the breasting (l) and mooring dolphin (r) of the ocean going basin

For the inland basin the height and the forces on the pile are lower and the pile will not have the need to be founded deeper than the clay layer. The correct method of Blum can now be used since there is only one homogenous layer.

For the breasting dolphins a horizontal force of 928 kN has to be covered. This can be managed with a depth of 17.1 metre (see Table 100).

Layer	F	Force [kN]	Moment arm [m]
Clay layer	E_2	1036	4.8
	E_1	4919	3.6
Total Moment			**22 MNm**
Horizontal force			**941 kN**

Table 100 - Soil forces on the breasting dolphin (inland basin)

The mooring dolphins of the inland basin need to resist a horizontal force of 283 kN, for which a depth of 12.1 metre (see Table 101).

Layer	F	Force [kN]	Moment arm [m]
Clay layer	E_2	363	3.4
	E_1	1743	2.5
Total Moment			**5.6 MNm**
Horizontal force			**285 kN**

Table 101 - Soil forces on the mooring dolphin (inland basin)

The position of the piles is plotted in Figure 84.

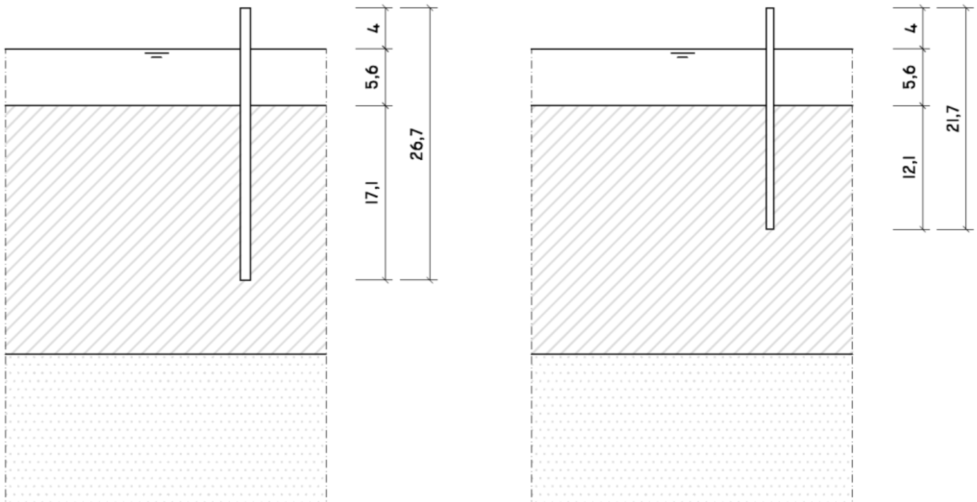


Figure 84 - Depth of the breasting dolphin (left) and mooring dolphin (right) of the inland basin

W Availability

The availability can be split into a navigational and an operational availability. In Table 102 and Table 103 all events resulting in downtime of the port are given. Below the tables the different events are explained (Thoresen, 2010).

Event	Downtime
Ice Problems	0 %
Current	0 %
Wind above 15 m/s, which will stop tugboat assistance	0.05 %
Waves above 1.5 m, which will stop tugboat assistance	0.3 %
Visibility less than 1000m	0.01 %
Tugboat non-availability	0.5 %
Navigational availability	**99.1 %**
Snow	0 %
Wind above 15 m/s, unloading equipment	0.05 %
Waves above 1.0 m at 45 to 90°, stop unloading	3.2 %
(or) Waves above 1.5 m at 0°, stop unloading	0.3 %
Maintenance on berth structure	0.5 %
Operational availability of berths at 45 – 90° of waves	**96.2 %**
Operational availability of berths at 0° of waves	**99.1 %**
Total availability	**95.7 %**

Table 102 - Availability of ocean basin

Event	Downtime
Ice Problems	0 %
Current	0 %
Wind above 15 m/s, push barges cant sail	0.05 %
Waves above 1.0 m, push barges cant sail	3.2 %
Visibility less than 1000m	0.01 %
Navigational availability	**96.7%**
Snow	0 %
Wind above 15 m/s, unloading equipment	0.05 %
Waves above 0.7 m	0.9 %
Maintenance on berth structure	0.5 %
Operational availability	**98.5 %**
Total availability	**96.2 %**

Table 103 - Availability of inland basin

Ice

The northern areas of Argentina are very temperate with an average temperature of 3 to 8° and a lowest ever recorded temperature of -5.4° in Buenos Aires. Next to that the Rio de la Plata is always has a current and a tidal variations so it will not get problems with the navigational availability due to ice (Servicio Meteorológico Nacional).

Snow

A heavy snowfall would also be able to make a terminal unusable. In 2007 a storm of this proportion past, but as it was the only significant snowstorm in the last decennia, the influence on the availability is negligible (BBC).

Fog

Fog is defined as a weather condition in which the visibility is less than 1000 m. If the visibility is less, the sailing is no longer allowed by the Prefectura Naval Argentina and the current ports will close. However, no clear data about the fog is available and the data available mostly contradicts each other. Therefor the interpretation of (Frima, 2004) is used in which a total of 20 periods of fog with an average of 3.5 hours is used.

Currents

Currents in the river change influence the availability of the port, because vessels need a minimum of 6 knots for sufficient steering ability. However, since the barges are protected by a breakwater and the ocean vessels are manoeuvred with tugboats, the vessel speed can be well controlled and since the currents are only small no problems due to current are expected.

Tugboat availability

Under normal conditions only 3 tugboats are operational, creating a chance that a vessel will have to wait on available tug boats at arrival. For the tug boats the total process per vessel is estimated in Table 104 on 31 minutes.

Connect	10	min
Sail to berth	8	min
Berthing en disconnect	10	min
Sail to next ship	3	min
Total	**31**	**min**

Table 104 - Berthing process

Using queuing theory with this service time of 0.5 hour for the total berthing process, gives an average waiting time of 2 minutes.

Wind and waves

Wind generates problems for both the navigational and operational availability as is a high wind generates problems for both the (un)loading equipment and the berthing or tugboat conditions. The limiting conditions for the ocean vessels are given in (Thoresen, 2010). For tug boats the limit at which they start to lose efficiency in controlling ships are a wind of 15 m/s and waves up to 1.5 m (Ligteringen, 2000). The loading conditions are limited to waves up to 1.0 m at an angle of 45 to 90° to the ship and 1.5 m for berths at an angle of 0°. The maximum allowed wind during loading is 15 m/s.

The limiting conditions for the inland vessels are not known, as the barges are not tested on those conditions. It is, however, assumed that the navigational conditions are determined by the capabilities of the tugboats of the barges and are 15 m/s for the wind and 1.0 m for the wave heights. The unloading conditions are however stricter and the wave height is estimated on 0.7 m based on the allowed unloading wave heights of small general cargo carriers and an estimated wind wave height of also 15 m/s.

The chance this wave height of 0.7 m occurs within the breakwaters is calculated by dividing by the transmission coefficient of the breakwater (0.55) and calculating the occurrence of the resulting wave height of 1.3 m in the Rio de la Plata.

Maintenance

Every now and then maintenance of the berths has to be done. The downtime by this is estimated on 0.5% (Thoresen, 2010).

X Electricity generation

Wind Energy

Being on the relatively open plains that the Rio de la Plata creates around the artificial island, makes for ideal conditions for wind build up. Long fetches can be achieved from the direction of the ocean, and the average wind speed builds up to 6.29 m/s. The wind can be converted into usable energy through the following formula:

$$P_{wind} = \frac{1}{2} \cdot A \cdot \rho \cdot v^3 \cdot \eta$$

This means that, considering the average wind speed and air density (1.2041 kg/m^3) are already known, the only variables left to determine are the efficiency and the swept area. Seeing as the wind direction is mostly known, it is unnecessary to make use of hexagonal blade constructions. Therefore the Siemens SWT-6.0-154 is considered to be the desired mill due to its large swept area of 18,600m^2 (Siemens, 2011).The last variable to solve is the efficiency. Betz' Law dictates that the maximum achievable efficiency in wind power harvesting is 59% and considering the use of state of the art equipment it will be assumed that this value can be achieved. Assuming the height of a wind mill is approximately 1.5 times the diameter of the rotors a mill height of 231 metres is achieved(including the rotor height at its highest point). From existing wind farms the distance between mills is estimated to be 2 times the mill length, making it a required 462 metres in between mills.

Now that all the variables are known the installed power of a wind turbine can be calculated:

$$P_{wind} = \frac{1}{2} \cdot 18{,}600 \cdot 1.2041 \cdot 6.29^3 \cdot 0{,}59 = 3{,}983{,}958W \approx 4MW$$

Converting this into an annual electricity production a value of 35,040 MWh per turbine can be harvested.

Hydropower

The second form of power generation that will be investigated is the power of the surrounding water. In this subject two different types of hydropower are distinguished, namely that of the waves (harvested through a Wave Energy Converter or WEC) and that of the tides.

Wave energy

The energy stored in waves is practically delivered to the port for free, as waves roll onto the shores of the structure almost continuously. There are several methods of extracting energy from the waves, but in this case the Salter's Duck will be taken into consideration as it has a fairly high theoretical efficiency of 90% (McGrath), but as an assumption a practical efficiency of 70% is chosen. The principle of this "duck" is that the passing wave makes it rotate around an axis, which in turn powers a generator for electricity (as illustrated in Figure 85).

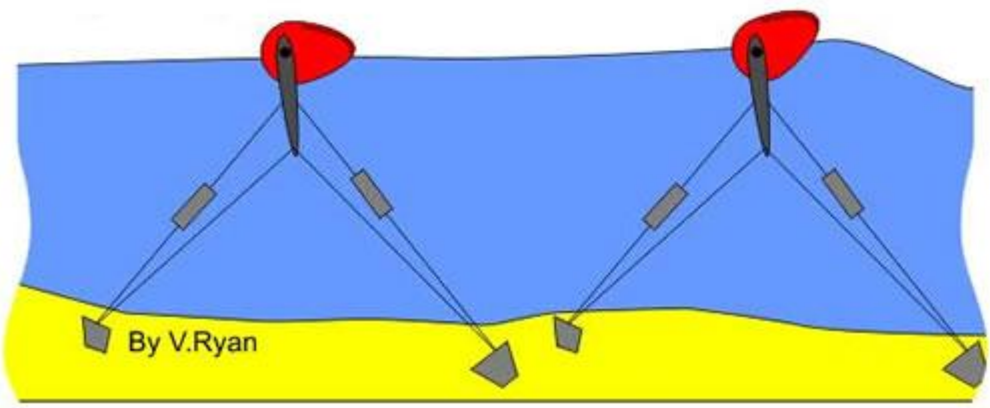


Figure 85 - Impression of a Salter's Duck (Ryan, 2005)

The energy stored in a wave front can be expressed in terms of the wave's crest width and is given by:

$$E = \frac{1}{8} \cdot \rho \cdot g \cdot H^2 \cdot \lambda$$

In which E is the stored energy, ρ and g are the density of the water and the gravity constant, H is the significant wave height and λ is the wave length. Since the Rio de la Plata still consists of fresh water at the location of the port structure, ρ is 1000 kg/m^3. The significant wave height has been determined before in chapter Wind and waves7.2 and is 1.32 metres. λ, however, has not been determined yet and will require some extra effort. To obtain the wave length the formula $\lambda = \frac{v}{f} = v \cdot T$ will be used. T has been predetermined as being 4.98s and for v the formula $\sqrt{gh}$ is used where we generalise the average water depth as being 5 metres. This obtains a value for λ of $\sqrt{9.81 \cdot 5} \cdot 4.98 = 34.8m$.

Now that all the variables of the wave energy harvesting have been determined, the installed power per unit width can be calculated:

$$P = \frac{E}{T} \cdot \eta = \frac{\frac{1}{8} \cdot 1000 \cdot 9.81 \cdot 1.32^2 \cdot 34.8}{4.98} \cdot 0.7 = 10{,}474 \, {}^{W}/_{m'} = 10.4 \, {}^{kW}/_{m'}$$

This yields an annual energy output of 91.1MWh/m'.

Dynamic Tidal Power

A relatively new and as of yet untested concept is that of the Dynamic Tidal power plant. The principle of this form of power generation is that a large "dam" (it's actually more of a pier or breakwater) in the order of 30 kilometres is built into a shore area where there are tidal influences, and that the added distance the tide will have to travel creates a head difference over the sides of the dam. This head difference can subsequently be used to generate electricity with (see Figure 86 for an impression).

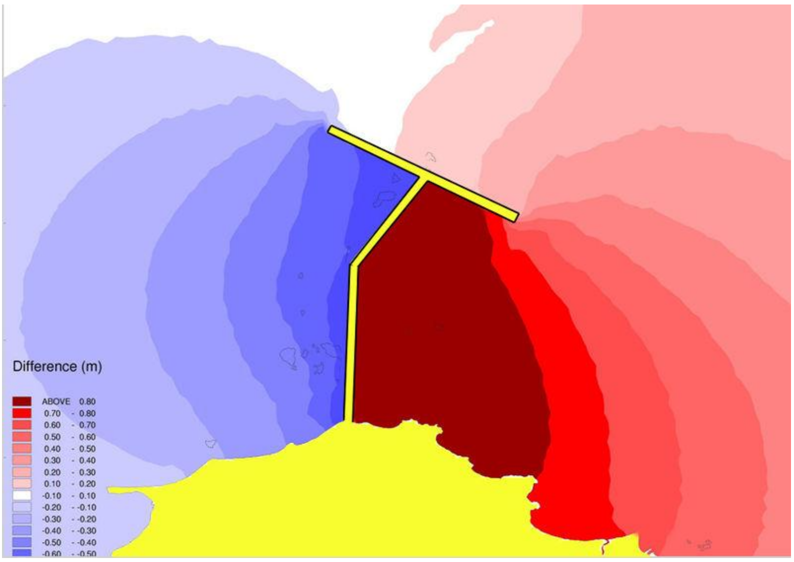


Figure 86 - Dynamic Tidal Power principle (Wikipedia)

Because the port structure in this project is an offshore project located at 20 kilometres from the shore and the Rio de la Plata is subject to a tidal motion, this form of energy generation could be a feasible one for the area. On top of that it would create another desired (yet not required) aspect in a hinterland connection.

For the calculation of the revenue of this hydropower plant it is assumed that the determining factor for the water level difference is the time that is required to flow around the top dam structure. The design dimensions are such that the dam structure runs from the shoreline to the port structure (20km) and then 5km in each direction parallel to the shore. This means that, once the basin on one side has been filled, a distance of 10km (5 along the structure and another 5 into the basin) will have to be travelled.

Having determined the design it is important to know what the tidal window looks like. Realising that there is no (or at the very best a negligible) Kelvin wave present in the Rio de la Plata's tidal system it can be deducted that the tidal information (Kaplan, 1998) from Buenos Aires and Torre Oyarvide is representative for the Banco Chico area. This information gives the following tidal graph:

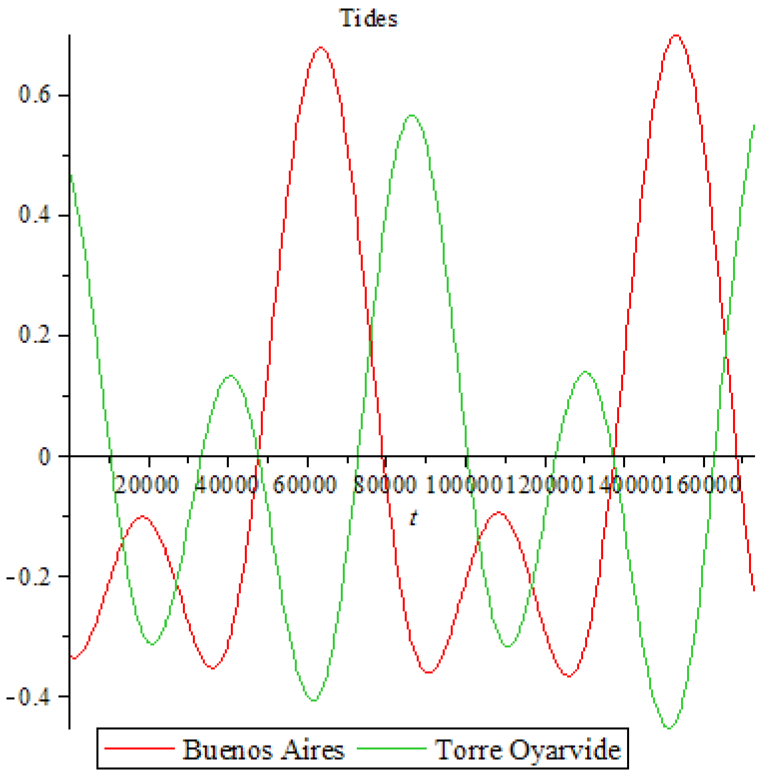


Figure 87 - Tidal charts for Buenos Aires and Torre Oyarvide

The important aspects that can be deducted from the graphs in Figure 87 (through derivation) are listed in Table 105.

Tidal wave crest velocity	6.5 m/s
Maximum water level velocity	0.000061 m/s

Table 105 - Tidal wave data

The formula that we will be trying to apply is the general formula for generating hydroelectricity and is given by $P = \eta \cdot g \cdot \rho \cdot Q \cdot h$. The gravity constant (g = 9.81m/s^2) and the density (ρ = 1000 kg/m^3) are the only evident constants in this equation, the rest require further investigation.
The data from Table 105 can provide more information about the head difference that will be created by the passing tidal wave. It has already been determined that the distance that needs to be travelled is 10 kilometres, so the question that needs to be answered is related to the amount of water level rise in the period that the facing side of the dam is already flooded, and the other side is not yet reached by the tide. This figure can be calculated by $\frac{10000}{6.5} \cdot 0.000061 = 0.094m$. So a head difference of 0.094 metres is what can be expected over the dam. The next thing that needs to be determined is the discharge over the structure. Assuming an equal distribution of the discharge over the Rio de la Plata (which isn't realistic, but necessary due to a lack of data) it can be deducted that the discharge over the newly created dam will be $\frac{20}{71} \cdot 22000 = 6200$m^3/s.
The final factor that needs evaluation is the capacity factor. To estimate this factor a look will have to be taken at the tidal motion, and from that an evaluation of when the plant can and cannot be used. The tide in Buenos Aires is considered to be a sufficient reference to determine the occupancy of the structure as only the amplitude changes along the Argentine coastline.

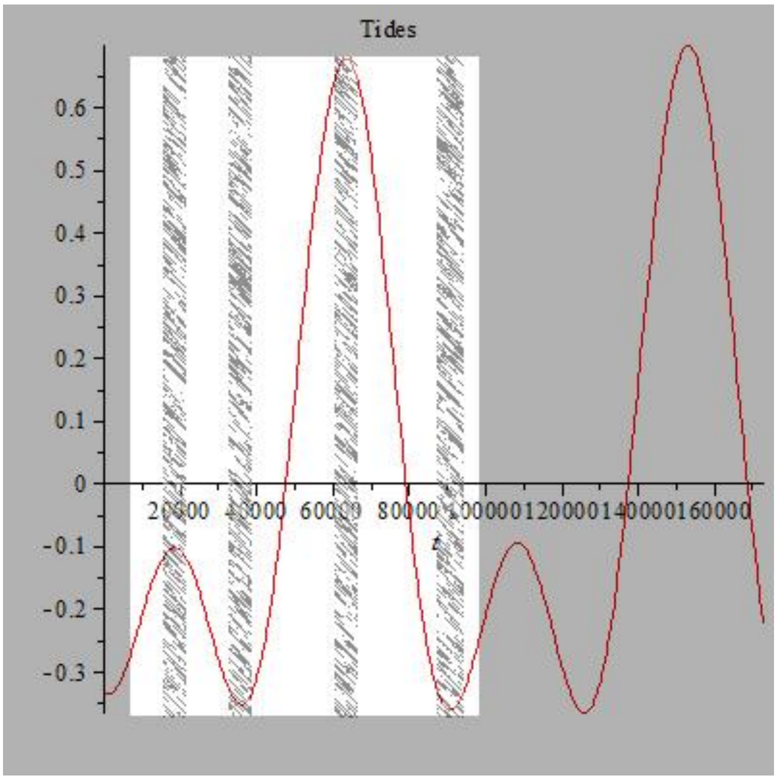


Figure 88 - Usable tidal window

The grey areas in Figure 88 indicate the timeframes in which it is not or negligibly possible to operate the plant. A qualitative analysis of this figure teaches us a capacity factor of 68.75% can be achieved. The installed power therefore becomes:

$$P = 0.6875 \cdot 9.81 \cdot 1000 \cdot 6200 \cdot 0.094 = 3930kW = 3.9MW$$

Annually this yields an output of 34,164MWh.

Solar Energy

The final form of energy that will be considered is a solar energy. Solar energy can be harvested in two ways: photovoltaic and thermal.

Photovoltaic

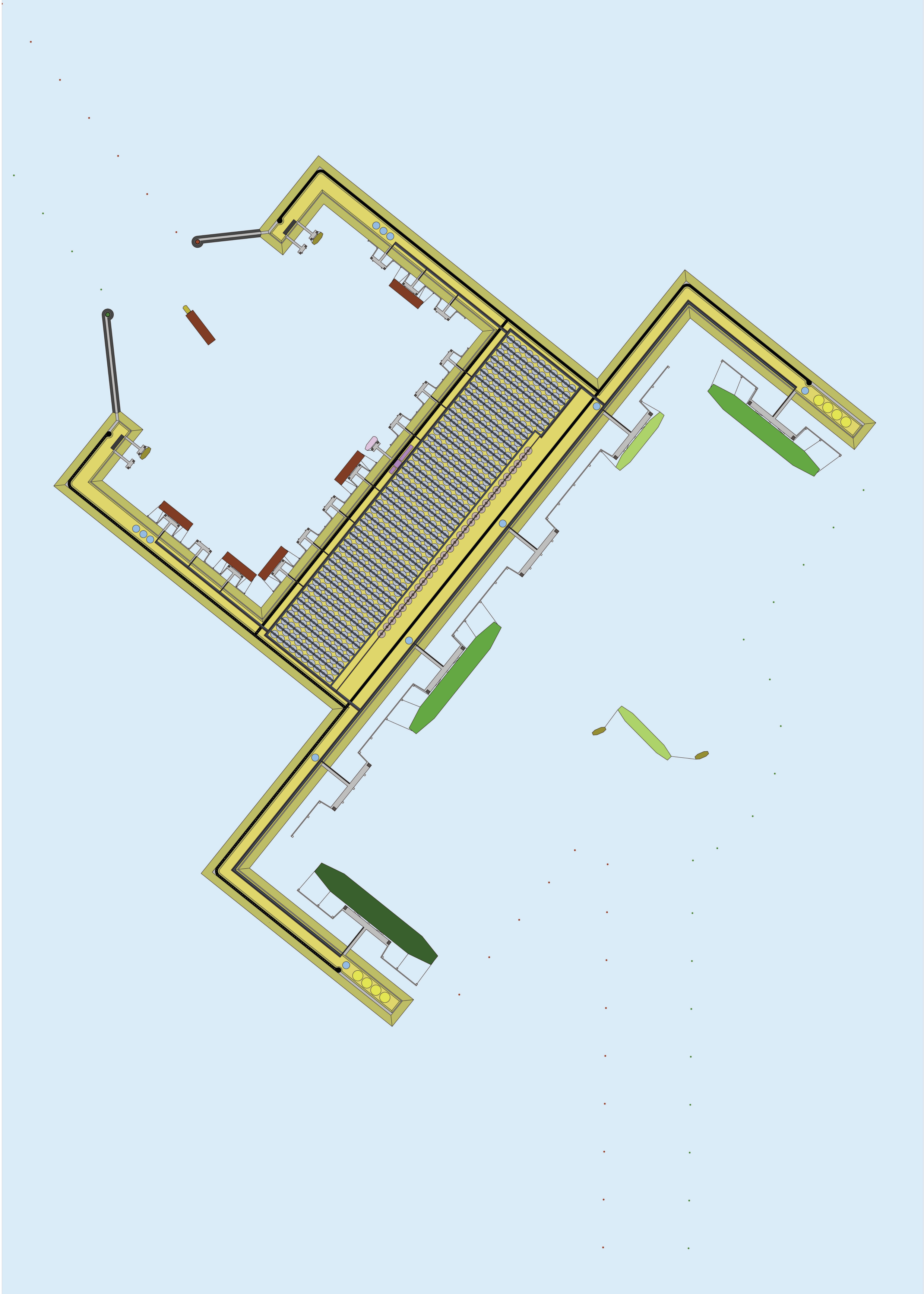
Solar panels can be installed at various locations in the port such as rooftops or unused areas. These panels use the energy stored in the sun's moving photons to create an electrical current in the panel, which can be transferred to the electric grid for power. The electrical output of solar panels is in the order magnitude of 140 W/m^2 (Wikipedia). Giving them an annual output, including a 20% capacity factor, of 0.246 MWh/m^2.

Thermal

Thermal solar power uses the heat of the sun's radiation to create energy. Panels capture the heat and transfer it to a tube that runs underneath the panel. From there it is transported to a conversion facility where the thermal energy is harvested from the heat in the pipelines and converted into useable electricity. The capacity of these panels is related to the solar power at the location and the efficiency of the plant. A regular solar thermal plant has an annual efficiency of approximately 20% (Wikidot) and the solar power on the Rio de la Plata is 1600 kWh/m^2/year(Sunmark). This means the annual revenue is 0.32 MWh/m^2.

Y Port design

An overview of the final layout of the port can be seen on the next page.



Z Construction planning

To further explain the components of the construction planning, a short summary will be made of what each component embodies and why it has been given a certain construction time.

Start of works

Evidentially this is where the construction starts, according to the planning this will be on the June 16th in 2014.

Drill a hole for sand reclamation

The reclamation sand will be dug up from under the Rio de la Plata in the proximity of the port. In order to reach this sand a hole will have to be dug through the clay, from which the sand can be extracted and the replacement material can be injected. The required amount of time for this phase is estimated to be 7 days.

Dredge required reclamation sand

Once the hole has been dug, the process of extracting the required sand can begin. The time estimation of this process has been made using regular dredging cycles and is based on a vessel transporting a weekly amount of 382,000 m^3 (including bunker times and dredging) (Velde, 2010). This method yields a dredging time of 183 days for the required 9.9 million m^3 of reclamation material.

Dumping sand at the construction site

This component is an addition to the previously acquired sand and involves the rainbowing of it over the construction site. For the time required a factor 0.5 has been used over the time required for dredging as there is less ocean time involved. This results in a required dumping time of 92 days. Seeing as, however, the sand cannot be dumped before it is dredged, the effective time required is 183 days, the same as is required for the dredging, but with a 1 day transfer delay.

Consolidation period

The time required for letting the sand consolidate to 83% of its total consolidation (1 metre left to sink) is about 5 years (see Appendix S: Settlement).

Dredging of the river basin

The dredging of the river basin is based on the same data as what has been used in the section for the reclamation of sand. In this case an amount of 1.3 million m^3 will have to be dredged resulting in a required dredging time of 25 days.

Dredging of the ocean basin

The dredging of the river basin is based on the same data as what has been used in the section for the reclamation of sand. In this case an amount of 18.7 million m^3 will have to be dredged resulting in a required dredging time of 343 days.

Bank Protection

The general creation of bank protection has been estimated to be 4 weeks. For the river basin and the sea shore this has been applied, the ocean basin is twice as deep and therefore a construction time of 8 weeks has been determined.

Construction of the breakwaters

The duration of the construction of the breakwaters has been based on a reference project In India. The construction of the breakwaters in the port of Ennore (Bijen, 2000) took 3 years, this value has been used to estimate the construction time of the breakwaters, which is 2 years.

Construction of the jetties

For the construction time of jetties a reference project on the Solomon Islands has been taken and scaled to the level of the present jetties (Namosuaia, 2010). In the case of the ocean vessels the required depth is more than for the other jetties as well as the jetties themselves are larger. Therefore the amount of time required per jetty is larger. For barges, tugboats and ferries the time required per jetty is equal. This results in a total time for ocean jetties of 160 days, for barges of 180 days, tugboats of 55 days and for the ferry jetty of 14 days.

Construction of facilities

The construction times of the basic facilities are based on rough estimated and references to previous construction works. These estimates indicate that the storage facilities will take 30 days to be constructed, the ferry terminal will take 30 days as well, the power plants will take approximately 90 days all together, the transport facilities (conveyor belts etc.) will take 45 days and the hotel will take 60 days.

Celebratory opening ceremony

The port will open its berths to vessels on the 15th of November in 2020.

AA Costs of systems

Costs transhipment port

The costs of the transhipment port are the initial construction costs and the yearly maintenance and operating cost.

Construction costs

First a calculation for the construction costs is made. The result of these calculations can be seen in Table 106. The total construction costs are USD 1.4 billion. Al unit prices are corrected for the price level of 2020, as described in Appendix C: Financial aspects.

Nr.	Construction	Amount	Unit	Unit price [USD]	Total costs [USD]
1	Reclamation	9,900,000	m3	16	162,586,003
2	Breakwaters	178,000	ton	456	81,168,000
3	Bed & bank protection	9,428	m	44,890	424,822,522
4	Dredging ocean basin & channel	18,700,000	m3	11	204,737,930
4	Dredging inland basin & channel	1,300,000	m3	11	14,233,118
5	Ocean berths	6	berth	30,374,114	182,244,681
5	Inland berths	13	berth	8,298,938	107,886,196
5	Tugboat berths	4	berth	3,621,355	14,485,419
5	Ferry berth	1	berth	3,244,130	3,244,130
6	Grain silos	467	silo	109,556	51,162,725
6	Oil tank	29	tank	438,225	12,708,514
6	Conveyor belts	19	pc	1,095,562	20,815,670
6	Loading equipment	12	crane	1,095,562	13,146,739
6	Unloading equipment	26	crane	1,095,562	28,484,601
6	Other facilities	2	pc	1,205,118	2,410,235
7	Unforeseen costs	5%	of TCC		66,206,824
	Total costs				**1,390,343,309**

Table 106 - Construction costs

Calculation of costs:

1. The reclamation costs are 1.5 times as high as dredging costs per m^3 (de Veth, 2012). The total reclamation volume is multiplied by this unit price
2. A cost calculation for the breakwaters is made based on the amount of rock and using (Tutuarima & d'Angremond, 1998) for unit prices.
3. For the bed and bank protection a price per m^2 of is used (Sepa, 2008), which is converted to a unit price per m’ bed and bank protection.

4. The dredging costs are based on a unit price per m^3 of (de Veth, 2012).
5. The cost of an ocean berth is calculated by using the price of a berth (Mehaute, 1974). This price is lowered using the length of the different berths as a scaling factor.
6. For the different storage, transport and other facilities, the costs from a transport study are used as a reference(DOTD, 2010).
7. The unforeseen costs are estimated to be 5% of the total construction costs.

Maintenance costs

The port and the channels have to be maintained. The calculation for the dredging and other maintenance costs can be found in Table 107 and are USD 39 million per year.

Nr.	Maintenance	Amount/year	Unit	Unit price [USD]	Cost/year [USD]
1	Reclamation	0	-	-	-
2	Breakwaters	447	m	7,149	3,195,603
2	Bed & bank protection	9,428	m	3,041	28,670,548
3	Ocean berths	0.15%	of CC	-	273,367
3	Inland berths	0.15%	of CC	-	161,829
3	Tugboat berths	0.15%	of CC	-	21,728
3	Ferry berth	0.15%	of CC	-	4,866
4	Grain silos	2.00%	of CC	-	1,023,255
4	Oil tank	2.00%	of CC	-	254,170
5	Conveyor belts	3.00%	of CC	-	624,470
5	Loading equipment	3.00%	of CC	-	394,402
5	Unloading equipment	3.00%	of CC	-	854,538
6	Other facilities	1.00%	of CC	-	24,102
7	Unforeseen costs	10%	of TMC	-	3,550,288
	Maintenance costs				**39,053,167**

Table 107 - Maintenance costs

Maintenance cost:

1. It is assumed that there will be no maintenance costs for the reclamation.
2. The maintenance costs per year of the breakwaters and bed and bank protection are based on the cost estimation from Breakwater & Closure dams (Verhagen, d'Angremond, & Roode, 2009). These costs are calculated using the unit price for the significant wave height and using the stone sizes as a scaling factor.
3. The maintenance costs for the berth are a percentage of the construction cost (Mehaute, 1974).A value of 0.15% is chosen, because the berths are in slightly polluted water.
4. For the storage facilities this percentage is 2%, because it moderately used equipment.
5. The loading, unloading and transport equipment is frequently used and therefore a percentage of 3% is applied.

6. For the other facilities, which are stationary, a percentage of 1% is used.
7. The unforeseen costs are estimated to be 10% of the total maintenance costs.

Operating costs

When the port is in operation, it will generate costs. In order to calculate the operating costs of the port, reference ports have been used, as can be seen in Table 108. For each reference port the costs per metric ton of throughput per year are calculated. This value is averaged and multiplied with the expected throughput of the transhipment port, to acquire the operating costs per year. These costs are USD 167 million per year.

Nr.	Port	Throughput [MT]	Costs/year [USD]	Cost/MT/Y (2020) [USD]
1	Port of Virginia	49,108,150	72,300,000	2.18
2	Port of Rotterdam	434,550,000	125,370,000	0.41
3	Adani Port	64,010,000	107,369,000	2.30
4	Greater Baton Rouge Port	27,471,822	7,250,929	0.49
5	Port of San Francisco	28,804,000	58,603,000	3.01
6	Port of Seattle	19,822,000	30,542,000	2.19
	Average			**1.76**
	Operating costs	94,400,000	**166,530,761**	

Table 108 - Operating costs

1. (Port of Virginia, 2011)
2. (Port of Rotterdam, 2011)
3. (Adani Port, 2012)
4. (Greater Baton Rouge Port, 2005)
5. (Port of San Francisco, 2010)
6. (Port of Seattle, 2012)

Dredging costs

The dredging costs of each situation consist of capital and maintenance dredging. The most upstream border of the system is taken at San Martin, from where on the draught of the vessels is limited to less than 34 feet. No Panamax or New-Panamax receiving ports are located upstream of this point. The most downstream border is the point where the navigation channel of the Rio de la Plata reaches the Atlantic Ocean.

The amount of required maintenance dredging is based on the values in Table 109, the channels can be seen in Figure 89. The amount of channel Martin Garcia is based on 14 years of data collection (Saizar, 2012). The other amounts are based on a dataset of 1 year (Local expert, 2012). The values seem reasonable, because the total amount of maintenance dredging on the Hidrovia system is about 24 million m^3 (Jan de Nul, 2007).

Figure 89 - Channels in the Rio de la Plata

Navigation Channel	Maintenance Dredging $*10^6$ [m^3/year]
C. M. Garcia	4.18
C. Intermedio	0.00
C. P.Indio	4.87
Ext. Punta Indio	1.22
C. Ing.E.Mitre	4.58
C. Acceso	0.53
R.Ext./B.Chico	0.01
Par.Palmas	5.13
Par.Inferior	8.36
Par.Medio	3.90

Table 109 - Current amount of maintenance dredging

Situation 1

In this situation the system isn't adapted, so there is no capital dredging. The costs for maintenance dredging are deduced from the dredged amounts.
The amount of maintenance dredging for the system from the most downstream till the most upstream border is about 25 million m^3/year (see Table 109).

Situation 2

In this situation the navigation channels in the Rio de la Plata and the Rio Paraná up to San Martin are dredged until a depth of 38 feet (11.6 m) (Louer, 2012). The keel-clearance of vessels is not taken into account for the calculation of the required depth. -. [Empty New Panamax vessels have a draught of 10.2 m. With a keel clearance of 0.5 m, they can only increase their draft with 0.9 m. So, the system isn't capable to receive New Panamax vessels. The Martin Garcia channel should allow empty Panamax vessels to sail upstream, and should therefore have a depth of at least 4.5 m (unloaded Panamax vessel) + 0.5 m = 5.0 m. The Martin Garcia channel has a current depth of 32 feet (9.6 m), so no capital dredging will be necessary for this part. The minimal bottom depth along the Martin Garcia has a minimal value of 5.5 m, so no maintenance dredging will be necessary.

Capital dredging

The calculation for the amount of capital dredging is split in two parts: the Rio de la Plata and the Rio Paraná. This is done because the bottom of the Rio Paraná has a lot of bumps and only some shallow parts. The Rio de la Plata, however, is assumed not to have those bumps and has to be dredged equally over the length of the channel.

The slopes of the banks of the navigation channels in the Rio de la Plata are assumed to be 1:12 (Smets, Jacobs, & Catteau, 1997). The depth of the channels in the Rio de la Plata is assumed to have a constant value of 34 feet (10.2 m), except for the Martin Garcia channel where the depth is assumed to have a constant value of 32 feet (9.6 m). The width of the new navigation channels is 230 metres (see Appendix M: Channel design). In practice some wider areas in the channel are necessary to allow vessels to pass each other, but these are not taken into account for this calculation. Along each channel the average bottom depth is determined.

To calculate the amount of capital dredging for the Rio de la Plata, the same approach as in Appendix K: Location costs analysis is used:

First the current dredged area of the channels is calculated, using the current depth of the channels, the slope, the width and the average bottom level, see Table 110.
Next the area to be dredged is calculated, using the new depth, the new width, the slope and the average bottom level. The result is the cross sectional area to be dredged. Multiplied with the length of each channel the total dredging volume is obtained.
The total amount of capital dredging necessary to allow vessels with a draft of 38 feet in the Rio de la Plata is 193 million m^3. This amount of construction dredging is rather high. This is mainly caused by the widening of the channels to 230 m. If for example the new width would be 150 m, the total dredging volume would be 77 million m^3, a new width of 100 m gives a dredging volume of 34 million m^3.

Part	Length channel [km]	Average bottom depth [m]	Width channel [m]	New cross sectional area [m^2]	Current cross sectional area [m^2]	Cross sectional area to be dredged [m^2]	Dredging volume * 10^6 [m^3]
C. Ing.E.Mitre	36	2.0	110	3317	1709	1608	57.9
C. Acceso	37	6.0	100	1666	632	1034	38.3
C. Radar Exterior	20	7.5	110	1146	384	761	15.2
B. Chico	24	7.0	150	1313	603	710	17.1
C. Intermedio	40	8.5	200	829	375	455	18.2
C. P.Indio	90	6.1	250	1648	1244	404	36.3
Ext. Punta Indio	28	9.0	250	680	317	363	10.2

Table 110 - Capital dredging Rio de la Plata

The considered part of the Rio Paraná consist of the Paraná de las Palmas and the Paraná Inferior. The length of each section and the amount of maintenance dredging can be found in Table 111 (SSPYVN, 2011). The upstream border of the system is located at km. 448, see Figure 90.

Part	From km.	Till km.	Length [km]	Maintenance dredging *10^6 [m^3]
Par.Palmas	48	180	132	5.13
Par.Inferior	233	462	229	8.36
Par.Medio	458	586	128	3.90

Table 111 - Length river sections

Figure 90 - Channel kilometres

To find out how much capital dredging is necessary a comparance is made with the deepening of the Parana River in 1996 from 28 to 32 feet. According to (Smets, Jacobs, & Catteau, 1997), the amount of capital dredging between km. 279 and km. 448 was 10 million m^3. For every kilometre length and metre of dredging depth this is 49,310 m^3/km/m.

The length of the part in the Rio Paraná is about 350 km (from km. 49 till km. 448 with a jump of about 50 km in the km counting between the Paraná Las Palmas and Inferior, see Table 111). With an increase in dredging depth of 4 feet (1.2 m), the amount of capital dredging is about 21 million m^3.

Maintenance dredging

When a channel is deepened more sedimentation will occur. The amount of sedimentation in a channel is calculated using the next formula (Ligteringen, 2000):

$$V_d = C_r \cdot W_{ch} \cdot h_0$$

With:

V_d = average annual volume of resiltation per unit length [m^2/year]

C_r = resiltation factor [1/year]

W_{ch} = channel width [m]

h_0 = over depth, being the dredged height [m]

For each navigation channel in the Rio de la Plata the resiltation factor can be determined by dividing the amount of maintenance dredging by the total volume once dredged (the capital dredging).

Using the same approach as for Table 110, the amount of capital dredging for a channel is calculated.
The resiltation factors can be found in Table 112.

Navigation Channel	Channel depth [m]	Channel width [m]	Length [km]	Average bottom depth [m]	Dredged height [m]	Dredged cross sectional area [m^2]	Capital dredging $*10^6$ [m^3]	Current maintenance Dredging [m^3/year]	Cw [1/year]
C. Intermedio	10.2	200	40	8.5	1.70	375	14.99	0.00	0.000
C. P.Indio	10.2	250	90	6.1	4.15	1244	111.98	4.87	0.044
Ext. Punta Indio	10.2	250	28	9.0	1.20	317	8.88	1.22	0.137
C. Ing.E.Mitre	10.2	110	36	2	8.20	1709	61.52	4.58	0.075
C. Acceso	10.2	100	37	6	4.20	632	23.37	0.53	0.022
R.Ext./B.Chico	10.2	150	44	7.3	2.95	547	24.06	0.01	0.000

Table 112 - Resiltation factors

The resiltation factor can be seen as a ratio between the amount of capital dredging and maintenance dredging.

The total amount of capital dredging is the new cross sectional area from Table 110 multiplied by the length of a channel. The amount of maintenance dredging is the resiltation factor multiplied by the amount of capital dredging, see Table 113.

Part	Length [km]	Total area [m^2]	Total volume dredged [m^2]	Cw [1/year]	Maintenace dredging [m^3/year]
C.Ing.E.Mitre	36	3317	119.4	0.075	8.9
C. Acceso	37	1666	61.6	0.022	1.4
Radar Exterior	20	1146	22.9	0.000	0.0
B.Chico	24	1313	31.5	0.000	0.0
C.Intermed.	40	829	33.2	0.000	0.0
C.P.Indio	90	1648	148.3	0.044	6.5
Ext. Punta Indio	28	680	19.0	0.137	2.6

Table 113 - Maintenance dredging Rio de la Plata

The amount of maintenance dredging increases from 11.2 million m^3 to 19.4 million m^3/year.

The amount of maintenance dredging in the Rio de la Plata increases on average with a factor 1.7. For the Rio Paraná the same factor is assumed.
The current amount of maintenance dredging in the Paraná de las Palmas and the Paraná Inferior is 13.5 million m^3/year, see Table 111. The new amount of maintenance dredging then becomes 23.0 million m^3/year.
For both the Rio de la Plata and the Rio Paraná the amount of maintenance dredging for this situation becomes about 42 million m^3/year.

Situation 3

In this situation the transhipment port in the Rio de la Plata demands a deepening of the navigation channels to 16.3 m depth from the downstream boundary at the Atlantic to the port of transhipment. Upstream from the port the draught should be at least 5.6 m.

Capital dredging

Only the channels from the Atlantic to the port of transhipment are deepened. The rest of the channels isn't deepened, because only barges will sail on them. With the current 10.4 m of depth this is deep enough for the barges that need a draught of 5.6 m.
The amount of capital dredging is calculated in the same way as for situation 2, see Table 114
The total amount of capital dredging for the navigation channels in this situation is equal to about 365 million m^3. Here the biggest part is caused by the deepening of the channels. A new width of 100 m would for example still result in a capital dredging of 247 million m^3.

Channel	New depth [m]	Length [km]	Current channel width [m]	Average bottom depth [m]	New cross sectional area [m^2]	Current cross sectional dredged area [m^2]	Cross sectional area to be dredged [m^2]	Dredging volume * 10^6 [m^3]
Ext. to D=16.3m	16.3	30	0	14.0	593		593	17.8
Ext. P.Indio	16.3	28	250	9.0	2321	317	2003	56.1
C.P.Indio	16.3	90	250	6.1	3621	1244	2377	213.9
C.Intermedio	16.3	36	200	8.5	2526	375	2152	77.5

Table 114 - Capital dredging Rio de la Plata

Maintenance dredging
For the channels in the Rio de la Plata the same approach is used as for system 2. The amount of maintenance dredging for the extension to D=16.3 m is deduced from the amount of maintenance dredging in channel Extension Punto Indio, because it is located in the same area, and also has more or less the same direction.

The same goes for the access channel for inland vessels, but here the dredging amount is deducted from the Martin Garcia channel. Only the cross current part is taken, having a length of 24.5 km and a maintenance dredging of 3.16 million m^3/year, resulting in a resiltation factor of 0.269.
The results can be found in Table 115. Assumed is that the Rio Paraná and the Martin Garcia channel won't need any maintenance dredging any more. The same goes for the Banco Chico, Radar Exterior and the Accesso channel, because the average bottom depth along all those channels is larger than 5.6 m.

Variant	Part	New depth [m]	Reference channel	Area cross section [m^2]	Volume * 10^6 [m^3/year]	Cw [1/year]	Maintenance dredging * 10^6 [m^3/year]
Navigation channels	Extension to D=16.3m	16.3	Ext. P. Indio	593	17.8	0.137	2.4
	Ext. P. Indio	16.3	Ext P. Indio	2321	65.0	0.137	8.9
	C. P.Indio	16.3	P. Indio	3621	325.9	0.044	14.2
	C.Intermedio	16.3	Intermedio	2526	91.0	0.000	0.0
	C.Ing.E.Mitre	5.6	C.Ing.E.Mitre	994	35.8	0.075	2.7
Banco Chico	Ocean channel	16.3	P. Indio	2321	6.7	0.044	0.3
	Inland channel	5.6	M. Garcia	276	0.2	0.269	0.1

Table 115 - Maintenance dredging situation 3

The total amount of maintenance dredging for this system is about 29 million m^3.

Overview
A final overview of the dredging amounts can be found in Table 116.

In order to be able the dredging costs, the prices per unit are determined. For capital dredging a price of 8 USD/m^3 is used, for maintenance dredging 3 USD/m^3 (de Veth, 2012). When these values are transposed to the year 2020, the values become 11 and 4 USD/m^3.

System	Capital dredging $*10^6$[m3]	Costs million [USD]	Maintenance dredging * 10^6 [m3/year]	Costs million [USD/year]
1	0	0	25	99
2	214	2,350	42	169
3	365	4,018	29	114

Table 116 – Overview dredging amounts and costs

Short connection
Instead of deepening the current Navigation channels in the Rio de la Plata a cheaper option may be to make a shorter connection to the Atlantic, see Figure 91.

Figure 91 - Shorter connection

To reach a depth of 11.6 m, the channel needs to have a length of about 50 km. For a depth of 16.3 m, a length of about 100 km is necessary. The depth of the area can be split in two parts: the first 50 km has an average depth of about 6.5 m, the last 50 km an average depth of about 14 m.

For situation 2 and 3 the amounts of capital dredging for the short connection is calculated as listed in Table 117. The total dredging volume of the other variant (from km. 144 till km. 239 or km. 269) is also listed in the table. The amount of capital dredging from km. 144 till km. 211 is downscaled from the total amount of capital dredging of channel Punta Indio (see Table 110).

Situation	Part	Dredging volume * 10^6 [m^3]	Total Dredging volume * 10^6 [m^3]	Short connection * 10^6 [m^3]	Benefit * 10^6 [m^3]
Situation 2	C.P. Indio (part)	27.0			
	Ext Pt. Indio	10.2	37.2	74.3	-37.1
Situation 3	C.P. Indio (part)	159.3			
	Ext Pt. Indio	56.1			
	Extension to D=16.3m	17.8	233.2	192.7	40.4

Table 117 - Capital dredging

As can be seen the short connection results in less capital dredging for situation 3 and more for situation 2.
For the maintenance dredging about the same approach is applied. However, for channel Punta Indio it is assumed that all the maintenance dredging takes place between km. 144 and km. 211, because the first part of the channel is parallel to the flow pattern (see Figure 12).

In the new situation the channels aren't parallel to the flow pattern either. They make about the same angle with it as channel Punta Indio, so assumed is that per kilometre length the same amount of siltation will occur. The results can be found in Table 118. As can be seen the short connection is beneficial for both systems when it comes to maintenance dredging.

Situation	Part	Dredging volume * 10^6 [m^3/year]	Total Dredging volume * 10^6 [m^3/year]	Short connection * 10^6 [m^3/year]	Benefit * 10^6 [m^3/year]
Situation 2	C.P. Indio (part)	6.5			
	Ext Pt. Indio	2.6	9.1	3.6	5.5
Situation 3	C.P. Indio (part)	14.2			
	Ext Pt. Indio	8.9			
	Extension to D=16.3m	2.4	25.5	15.8	9.8

Table 118 - Maintenance dredging

Overview

The costs for capital and maintenance dredging for all systems, using the short connection, are now listed in Table 119. The costs are based on the year 2020.

System	Capital dredging *10^6[m3]	Costs million [USD]	Maintenance dredging * 10^6 [m3/year]	Cost million [USD/year]
1	0	0	25	99
2	251	2,759	37	147
3	325	3,573	19	75

Table 119 - Overview dredged amounts and costs short connection

The conclusion is that for system 3 the short connection results in less dredging and will be a cheaper option. It saves 445 million USD on capital dredging and 39 million USD/year on maintenance dredging. With a NCW of 24.5% the total lifetime costs decrease with 1.4 billion USD. For system 2 the decrease in maintenance costs may counterbalance the increase in capital dredging. When the total costs of the system are calculated this seems to be the case, but the differences are very small (0.1 billion USD for the total lifetime costs). So, for system 2 it doesn't matter very much which connection is chosen. The dredging of a short connection to the Atlantic seems to be more beneficial for the system than the deepening of the current navigation channels. So, for both systems 2 and 3 this option is chosen.

Toll costs

The maintenance of the channels and the rivers is done through concessions. In the current system these concessions are run by Riovia S.A. (the Martin Garcia channel) and Hidrovia S.A. (the rest). In the future this system of concessions is expected to stay in place, but the income from the tolls is expected to change. There should be a connection between the amount of maintenance dredging and the amount of collected toll. In the current system, however, this connection has gone missing. For the sake of research it has been assumed that there in fact is a relation and that the desired percentage profit in the future will remain equal.

For the calculation of toll the following formula applies (Riovia S.A.):

$$T_p = T_b \cdot NRT + T_d \cdot NRT \cdot FC$$

Where; T_p is the toll for a vessel, T_b is the factor for navigational aids, T_d is the dredging factor and FC is the compensation factor for the ship's draft (see Table 121 for these values), NRT is the Net Register Tonnage of the vessel. This correction factor is influenced by the ship's maximum draft, the channel depth and a reference draught of 15 feet. The formula for calculating FC is $(C - 15)/C_b$; where C_b is the maximum design draft of the vessel and C depends on the ship's draft (for $C_b < 15$: C = 15; for $C_d > C_b > 15$: C = C_b; for $C_b > C_d$: C = C_d; C_d = channel depth).

To be able to do the required calculations, first the characteristics of the included vessel types have to be known. These are shown in Table 120.

Ship type	NRT	Draft [ft]	FC 34 feet	FC 38 feet	FC 54 feet
Handysize	10,000	33	0.545	0.545	0.545
Handymax	15,000	36	0.528	0.583	0.583
Panamax	25,000	40	0.475	0.575	0.625

Table 120 - Ship characteristics

Section	T_b	T_d
1.1	USD 2.25 · 44.44%	USD 2.25 · 2.61%
1.2	USD 2.25 · 17.06%	USD 2.25 · 3.80%
1.3	USD 2.25 · 38.50%	USD 2.25 · 1.96%

Table 121 - Compensation factor per river section

In order to get a good picture of which river section is located where, Figure 92 is included.

Figure 92 - Section map

Now that the characteristics of the vessels and river sections are known a look can be taken at the annual revenues for both concessions. In this comparison it is considered that ships use the Martin Garcia Channel in section 1.2 upstream and the Emilio Mitre route downstream. Data from 2007 (Dutch-Argentina Chamber of Commerce, 2009) has been used to get accurate traffic data resulting in the total concessions incomes given in Table 122.

Ship type	Amount	Toll revenue Hidrovia S.A. [USD]	Toll revenue Riovia S.A. [USD]
Handysize	502	24,689,735.57	2,288,733.06
Handymax	752	51,489,086.13	4,833,798.50
Panamax	582	60,755,361.32	5,796,625.14
	total	136,934,183.02	12,919,156.70

Table 122 - Concession incomes in 2007

In order to make a proper estimation of the future systems, it is required to know the dredging volumes in the channels. These have been calculated before and are presented in Table 123.

Section	Canal	Maintenance volume [m^3]	Costs [USD]
Section 1.1	Punta Indio	4,870,000	14,610,000
	Canal Intermedio	0	-
	Extension Punta Indio	1,220,000	3,660,000
Section 1.2	Canal Accesso	530,000	1,590,000
	Canal Emilio Mitre	4,580,000	13,740,000
	Canal Martin Garcia	4,180,000	12,540,000
	Radar Exterior	10,000	30,000
Section 1.3	Parana de las Palmas	5,130,000	15,390,000
	Parana Inferior	8,360,000	25,080,000
	Parana Medio	3,900,000	11,700,000

Table 123 - Maintenance costs

Having calculated both the costs and the revenues, the next logical step is to get a value for the profit. The profit is calculated in a value as well as a percentage and displayed in Table 124.

Concession	Maintenance costs [USD]	Toll revenue [USD]	Profit [USD]
Hidrovia S.A.	85,800,000	136,934,183	51,134,183 (60%)
Riovia S.A.	12,540,000	12,919,156	379,156.70 (3%)

Table 124 - Concession profit

It is assumed that the profit can be scaled up to the new maintenance situations for the river sections. The maintenance dredging which has been calculated before, already shows the specific maintenance requirements for each section under the new circumstances. The profit margin of Hidrovia S.A. is used as a base of reference because Riovia S.A. is partly subsidised by the governments of Argentina and Uruguay and therefore not a realistic measurement tool in this comparison. This means that 60% of the calculated maintenance costs are added to these same maintenance costs in order to obtain the approximate annual toll costs for the system. The results are shown in Table 125.

System	Maintenance costs [USD]	Approximate toll costs [USD]
1	99,000,000	158,000,000
2	147,000,000	235,000,000
3	75,000,000	120,000,000

Table 125 - Total toll cost estimation

Shipping costs

The shipping costs are one of the main reasons for the construction of the port. With a port of transhipment in the Rio de la Plata larger vessels could be fully filled without having to visit more than one port in Argentina. For the three systems the total costs from the (first) shipping of the grain to the final destination are calculated.

Calculation of distances

As a first step the distances are acquired. Rosario is taken as the centre at which the loading of all the commodities occurs to either the (New) Panamax vessels or the barges. In the case of System 3 the next stop is made at the transhipment port at Banco Chico at a distance of 450 km (SSPYVN, 2011). In System 1 and 2 the vessels sail to the coastal ports of Argentina for topping-off their cargo. This average distance is calculated in Table 126 by continuing the previous calculation to Banco Chico up to the coastal ports and is on average 1140 km.

Coastal port	Distance [km]
Bahia Blanca	1,280
Quequen	1,000
Average	**1,140**

Table 126 - Distance from Rosario to the Argentine coastal ports

From Banco Chico or the coastal port, the ships will sail to their final destination. In Table 127 an overview is given of the continents and the part they receive of the export of Argentina. For each continent the distance is calculated to the largest importing city or region and of all these value the weighted average is calculated to be about 13,000 km.

Continent	%	Distance		Taken city
Europe	17%	11,000	km	(Rotterdam)
South-America	18%	5,000	km	(Rio / Colombia)
North-America	0%	10,000	km	(USA)
North-Africa	9%	10,000	km	(Algeria)
Africa	2%	7,000	km	(South-Africa)
South-Asia	12%	16,000	km	(Indonesia)
East-Asia	33%	18,000	km	(China)
Oceania	1%	14,000	km	(Australia)
Others	10%			
Weighted Average distance		**13,000**	**km**	

Table 127 - Calculation of oversea distance

Calculation of the operational costs of the design vessels

For the calculation of the operational cost of a tugboat + barge combination at first a representative tugboat for the transport of the 7,800 DWT barge is found. In Table 128 an overview is given of some tug boats with the possible barges that can be transported (Deena Schipping). As an average engine power a value of 2,674 BHP is found.

Tugboat	Engine power (BHP)	Barge	Dimensions	DWT
Melana 68	2,034	Linau 75	91.4m x 24.39m x 6.10m	8,176
Danum 49	4,000	Danum 16	100.6m x 24.4m x 5.5m	7,184
Oceanline I	2,000	Oceanline II	110m x 24.40m x 6.10m	8,746
Danum 92	2,700	Danum 55	100.6m x 25.6m x 6.1m	8,975
Gemiddeld	**2,684**			

Table 128 - BHP of tugboats and corresponding barges

It can be found that the daily operating costs of tug boats in the range of 2800-3,400 BHP are as given in Table 129 (USACE, 2004). In 2020 this results in a total average daily cost of USD 10,947 for a tug-barge combination

	High Power Use	Actual Power Use
Daily costs Tug [USD]	7,383	5,736
Daily costs Barge [USD]	108	108
Daily costs (2004) [USD]	7,491	5,844
Daily costs (2020) [USD]	**14,031**	**10,947**

Table 129 - Daily operating costs of tug-barge combinations

The daily operating costs of Panamax vessels and New Panamax vessels are calculated based on the annual operating costs as given in Table 130 (AECOM, 2012). However, the engine as used to calculate the total yearly fuel costs seems to be overpowered by far when comparing to reference projects. Also the operating speed is considered to be higher than economical attractive and the Panama Canal Toll is not used on the shipping routes of the vessels for this design, while these costs are included in Table 130. It is therefore chosen to change the calculation for a slower vessel speed and a lower engine power and to remove the Toll costs.

	Panamax vessel	New Panamax
DWT	4,000	12,000
Average Main Engine Power Rating [kW]	38,000	72,240
Average operating speed [knots]	20	20
Total vessel costs per year [USD]	**54,908,090**	**106,054,472**

Table 130 - Annual vessel costs

For the improved operating costs the operating costs of Panamax and New Panamax vessels are calculated for both sailing on the Rio Paraná with a reduced speed of 10 knots and for sailing on the ocean with an economic speed of 15 knots (Rodrigue, Notteboom, & Slack).
The engine power of the design vessels is estimated based on the propulsion trends in bulk carriers and is 11,500 for the Panamax vessel and 15,500 for the New Panamax vessel (Man, 2010). It is assumed that the engine is used at full capacity while sailing at sea. While the vessels are sailing the Rio de la Plata and Rio Paraná the speed is reduced to 10 knots (18.5 km/h) and the engine will not be used at full capacity. The main engine load factor is calculated by extrapolating the engine values plotted in Figure 93 (Notteboom & Carriou, 2009). Using an exponential distribution this gives a main engine load factor of 45.4% for the Panamax vessels and 46.2% for the New Panamax vessels when sailing at 10 instead of 15 knots.

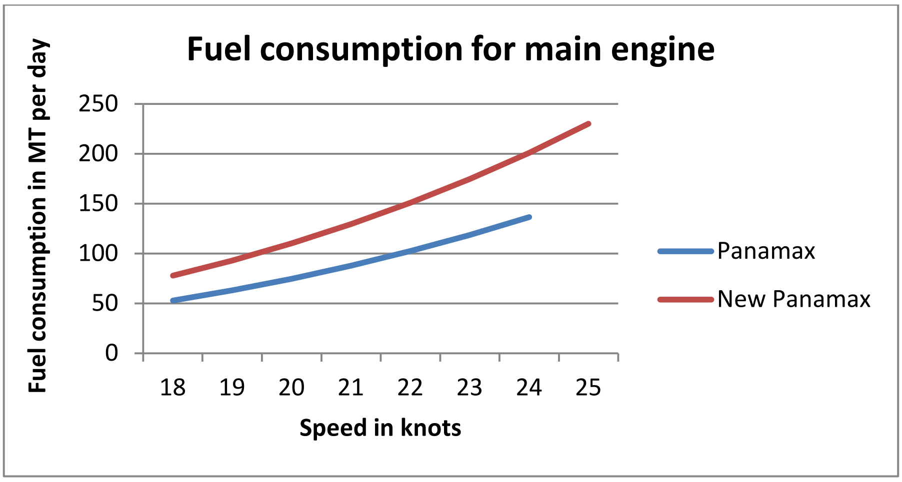


Figure 93 - Fuel consumption for main engine compared with vessel speed

As specific fuel content- a value of 290 g/kWh is used and also the same values for fuel consumption at berth, days as sea, crew costs and capital are used (AECOM, 2012). This results in annual operational costs as given in Table 131.

	Panamax vessel		New Panamax vessel	
Speed [km/h]	27.8	18.5	27.8	18.5
Engine Power [kW]	11500	11500	15500	15500
Main Engine load factor	100%	45.4%	100%	46.2%
Energy per day [kWh]	**276000**	**125304**	**372000**	**171864**
Main Engine fuel per day at sea [MT]	**80.0**	**36.3**	**107.9**	**49.8**
Auxiliary Engine Power usage at sea [kW]	1400	1400	1834	1834
Auxiliary Engine fuel per day at sea [MT]	**9.7**	**9.7**	**12.8**	**12.8**
Total fuel consumption at sea per day [MT]	**89.8**	**46.1**	**120.6**	**62.6**
Total fuel consumption at berth per day [MT]	**12.6**	**12.6**	**22.3**	**22.3**
Fuel unit cost per MT [USD]	700	700	700	700
Days at sea	292	292	292	292
Days on berth	73	73	73	73
Fuel costs per year [USD]	**18,995,710**	**10,063,054**	**25,799,294**	**13,936,033**
Crew costs [USD]	1,314,000	1,314,000	1,314,000	1,314,000
Capital costs [USD]	4,358,935	4,358,935	8,717,869	8,717,869
Total costs per year (2012) [USD]	**24,668,645**	**15,735,989**	**35,831,163**	**23,967,902**
Total costs per year (2020) [USD]	**33,760,744**	**21,535,787**	**49,037,421**	**32,801,729**
Total costs per day (2020) [USD]	**115,619**	**73,753**	**167,936**	**112,335**

Table 131 - Operating costs per day of Panamax and New Panamax vessels

Capacity with reduced draft

As the depth in System 1 and 2 does not allow fully loaded vessels, the draft has to be reduced by not using the full capacity. Using Archimedes' Law for both the Panamax and New Panamax design vessels and an assumed shape coefficient of 0.9 the capacity reduction can be calculated resulting in the possible capacities as given in Table 132 (World Bank, 2010). It is assumed that when the vessels are fully loaded with grain that they are also loaded up to their maximum draft.

		System 1		System 2	
	Full capacity	**Draft reduction**	**Possible capacity**	**Draft reduction**	**Possible capacity**
Panamax	50,710 MT	1.6 m	**39,632 MT**	0.4 m	**47,884 MT**
New Panamax	81,136 MT	4.8 m	**3,067 MT**	3.6 m	**22,746 MT**

Table 132 - Possible capacities

Calculation of the total shipping costs

For the total shipping costs the amount of days of sailing are calculated. This is multiplied with the daily costs to obtain the total shipping costs per type of vessel. For the ocean vessels only the one-way distance is included, as the vessels are able to transport a different commodity back to South America. Forsailing on the Rio Paraná this cannot be assumed since only loading occurs at these ports and the sailing distance is doubled to gain the total sailing distance. As already shown in Table 132 the capacity of the New Panamax is even in the case of a maximum dredged channel (System 2) very small and in the comparison it shows that it is not economically attractive to sail the Rio Paraná with New Panamax vessels. For that reason it is assumed that the system will allow New Panamax vessels, but most vessels are still Panamax size which, due to the increased draft, have a major capacity increase. It is assumed that 95% of all vessels are Panamax vessels. The calculations of all shipping costs are given for System 1 in Table 133, System 2 in Table 134 and System 3 in Table 135.

System 1	**River transport**	**Ocean transport**
	Panamax vessels	**Panamax vessels**
Transport throughput [MT]	94,400,000	94,400,000
Capacity [MT]	39,632	50,710
Number of vessels	2,382	1,862
Sailing distance [km]	2,100	13,000
Average vessel speed [km/h]	19	28
Total hours per trip	113	468
Total days	11,254	36,298
Costs per day [USD]	73,753	115,619
Total costs [USD]	**829,985,080**	**4,196,701,531**

Table 133 - Total shipping costs of System 1

System 2	River transport		Ocean transport	
	Panamax vessels	New Panamax vessels	Panamax vessels	New Panamax vessels
Transport throughput [MT]	89,667,359	4,732,641	89,667,359	4,732,641
Capacity [MT]	47,884	22,746	50,710	81,136
Number of vessels	1,873	208	1,768	58
Sailing distance [km]	2,100	2,100	13,000	13,000
Average vessel speed [km/h]	19	19	28	28
Total hours per trip	113	113	468	468
Total days	8,847	983	34,478	1,137
Costs per day [USD]	73,753	112,335	115,619	167,936
Total costs [USD]	**652,518,009**	**110,429,723**	**3,986,304,475**	**191,000,849**

Table 134 - Total shipping costs of System 2

System 3	River transport	Ocean transport
	Barges	New Panamax vessels
Transport throughput [MT]	94,400,000	94,400,000
Capacity [MT]	5,619	81,136
Number of vessels	16,801	1,163
Sailing distance [km]	900	13,000
Average vessel speed [km/h]	13	28
Total hours per trip	69	468
Total days	48,465	22,686
Costs per day [USD]	10,947	167,936
Total costs [USD]	**530,544,941**	**3,809,813,550**

Table 135 - Total shipping costs of System 3

The total shipping costs can now be calculated by adding all river transport and ocean transport costs of the different systems. These totals are given in Table 136.

	System 1	System 2	System 3
River transport [USD]	829,985,080	762,947,732	530,544,941
Ocean transport [USD]	4,196,701,531	4,177,305,324	3,809,813,550
Total shipping costs [USD]	**5,026,686,610**	**4,940,253,056**	**4,340,358,492**

Table 136 - Comparison of all annual shipping costs

BB Risk analysis

Political situation

A not to be underestimated aspect of designing a project abroad is the political situation in the area of operation. In this specific situation there are two main factors that play a role in the design and construction of the transhipment port.

Internal politics

Firstly there is the internal situation in Argentina. This situation involves the earlier mentioned cabotage rules (see chapter 4.4.3), but also some other aspects that are important to take into consideration. Doing business in Argentina can be very slow and bureaucratic. Whether it is a towing vessel you wish to sell, or simply the moving of a registered vessel you own yourself from Argentina to another country, it is virtually impossible to do so without putting a significant amount of effort into it. It is not uncommon for Argentine construction works to be built several decades after they have become essential to the system. Naturally this affects the current project of the transhipment port. A change, as explained in chapter 2 is not yet essential (albeit recommended) in the current state. The current system (barely) suffices for the situation as it is, and only the predictions for the coming decades require the situation to be altered in a way that the transhipment port would become an ultimate necessity. The lack of vision on the future in Argentina makes it difficult for any new project to really kick off.

Foreign politics

The relation with Uruguay is not exactly in a good shape. The two countries are pursuing considerably different global mindsets where Uruguay is taking a more internationally oriented stance, and Argentina is turning itself more and more away from anything foreign. This protectorate regime of Argentina has its effect on the internal shipping possibilities (see chapter 4.4.3), and thereby the possibilities of successfully operating a port. On top of that it makes it more attractive for shipping companies to do business with Uruguay than with Argentina (noticeable in the increasing popularity of the Montevideo container terminal over the Buenos Aires one).
Aside these issues, there is the situation with the Treaty Concerning the Rio de la Plata (chapter 4.3). This treaty involves a requirement for any construction Argentina wishes to build outside its own zone of exclusive jurisdiction to be accorded by Uruguay. This would in practice probably only be possible if Uruguay would benefit from the newly constructed port as well.

Hidrovía S.A. concession extended

The current concession that Hidrovía S.A. has for the system of canals in the Rio de la Plata and Rio Paraná expires in 2021, meaning that if a new system were to be in place by that time (as is the intend of the considered transhipment port) this concession may not need to be fully extended for the grain industry. If, however, this concession were to be extended for other reasons, it may still be more interesting for relatively more efficient ships to bypass the port and sail further up the river.

Economic reasons

Apart from the political risks there are also economic risks to take into account.

Collapse of the grain industry

If, for some reason, the Argentine grain industry does not live up to the expectations of producing the calculated amounts of grain in the future, or even decreases its annual output, the reasons for the transhipment port to be built will diminish.

Collapse of the sea transport industry

If transport by sea would stop being an economical solution for transporting grain and i.e. air, road or rail transport would become more attractive, the need to ship by seaport would be non-existent. This would also mean that there would be no need for this transhipment port anymore.

Trading partners no longer demand Argentine grain

If the position of Argentina on the global market would deteriorate to the point where there no longer is a desire or need to buy Argentine agricultural (by-)products, the oceangoing transport would obviously collapse as well. This would mean that there would no longer be a need for a transhipment port in the Rio de la Plata.

Creation of a competitive port nearby

Far going plans are currently in the making regarding a deep sea port on the east coast of Uruguay. This port would primarily be needed to export the ore that is located in Uruguay and the throughput of ore from Brazil. The network required for this includes a rail network stretching from Nueva Palmira across Uruguay to the new port. It would not be unthinkable that, in the future, this network would also be used for the export of grain from the Argentine hinterland to the global market. It goes without saying that this would not at all be beneficial for a new port in the Rio de la Plata, as it would circumvent the cabotage rules among others.

Creation of a competitive alternative farm-ocean transport system

Apart from the previously mentioned “new port network” it would also be possible that an alternative way of transporting goods to the ocean through Argentina was developed. In this one could think about an improvement of the road network or a new railway. If this new system were to be economically more attractive it would threaten the new ports right of existence.

Global fleet size does not increase

A large part of justifying the new port is based on the increase of global fleet standards from Panamax to New Panamax. If this increase in size were to keep from happening it would also mean that this means of justifying the port would fall short.

Fleet beam increases but not their draft

The assumption that is made is that the New Panamax ship dimensions are such that they fill the newly constructed Panama canal. This is, however, not necessarily true. It would also be possible that they grow in beam, and do not grow (or decrease even) in draft. A decrease in draft would suddenly mean that there might be a possibility for the ships to sail further up the Rio Paraná when filled to maximum capacity, making an extra transhipment in the Rio de la Plata obsolete.

Dredging costs significantly decrease

An advantage of the newly created port would be that there would be a requirement for quite a few less dredging in the Hidrovía system. This advantage is based on the costs of dredging that are currently valid, but may not always be valid in the future. If the dredging process were to become more efficient, the costs would go down, and the "old" system would be a lot less costly.

Costs of inland transport drastically increases

The envisioned system is based on a large part of the ocean – Rosario transport to be done by barges. It is already a less cost efficient way than using ocean vessels, but considering the costs of maintaining the inland system for ocean going vessels it may overall be cheaper. If the costs of this transport, however, were to increase, it may have catastrophic effects for any transhipment plans in the Rio de la Plata.

Insufficient investing parties

Considering the large costs involved in the construction of the new port, and the upgrade of the existing channels to New Panamax draft, a significant participation of companies would be required. If this investment were not to come, it would severely jeopardise the feasibility of the project.

Exporting companies stick to old habits

It would be a possibility that the exporting companies prefer to keep things the old way, even if it costs a bit more money. This way they would save themselves the effort of switching to a new system and make the newly constructed port obsolete.

Inland infrastructure not sufficient

The current system of inland transport is modelled to the export standards of several decades ago. Roads are barely capable of handling the large amounts of annual truck movements associated with the export of agricultural products and are in bad shape as it is. It could be that the projected increase in grain export could never be achieved simply because the hinterland connections do not have enough capacity.

Geographic Reasons

Apart from human related causes there could also be natural causes that make for the port to be unnecessary.

Increase in natural depth in the Rio Paraná

A structural increase in precipitation in the Rio Paraná catchment area could cause for a systematic increase in the system's water level. If this increase were to be significant enough it could mean that sailing up to Rosario would become a natural possibility for ocean faring vessels.

Decrease in natural depth in the Rio Paraná

Equally as before a decrease in precipitation could mean that the new system would not even be capable of handling barges in the Rio Paraná, meaning significant amounts of dredging would have to be done still or a transport system by land would be more economically attractive.

Increase of wind and wave conditions in the Rio de la Plata

The port layout design is based on the ocean going vessels not needing protection from the elements when berthed, and the inland vessels being able to sail on the Rio de la Plata. If a change in weather conditions would make the wind and wave conditions more severe, the envisioned barge transport and the layout of the ocean berths may not suffice anymore. The port design is not easily able to provide the required changes.

Damage due to accidents

Accidents can always happen and with a port structure this is no different. Some accidents are minor and do not influence the operational capabilities of the port (much), but some are scaled quite larger and do affect day to day operations.

Ship collision

A ship colliding with another ship in the port, or with a port structure like a jetty, can cause significant disturbances to the operational capabilities of the port. The collided ships could block an entrance channel (more likely to happen in the two way barge channel than in the one way ocean channel) or destroy a berth.

Explosion of a fuel tank

The fuel storage tanks are situated in a remote area of the port, but an explosion of them could still lead to significant consequences. Firstly there would be the damage done to the pier they are built on, and possibly the adjoining berth. Secondly there would also be a shortage of fuel and fuel storage capacity until a new tank can be installed.

Terrorist attack

In times of political turmoil it is possible that an economic hotspot like a port becomes the target of terrorism. History has shown that ports are strategic targets in war, so it would be a reasonable assumption that this port could become a target of some sort if such a situation would arise.

Uncontrollable sedimentation

In a situation where the sediment transport in the Rio Paraná drastically increases there could be a situation where it would settle so fast in the port area that not enough dredging can be done in time and the port becomes inoperative due to too shallow water depths.

Malfunctioning equipment

The port depends on large amounts of equipment in order to stay operational. Cranes, conveyor belts, pipelines (and the connected pump system), etc. Any of these things could malfunction or break down over time, and this would mean that the port loses some of its capacity. In case of vital aspects (electricity i.e.) or many pieces of equipment malfunctioning it could render the entire port idle.

Severe storms

Large storms can affect the port in various manners.

Damage

Firstly it can damage the port to a degree where it becomes inoperative. The waves could overtop the dike ring and flood the port area. Strong wind and waves could also damage or destroy some of the more exposed port facilities (such as the ocean berths for instance).

Unavailability

The conditions on the Rio de la Plata could be so severe that barges can no longer sail on the estuary. This would mean the grain would have no way to reach the port and, if it would persevere long enough, stocks could run out and transhipment would come to a hold.