New south exit channel in Río de la Plata: A preliminary design study

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PREFACE

During the Master of Civil Engineering at the TU Delft students can participate in a Multidisciplinary Project as part of their study curriculum. Student with different study backgrounds work together, simulating a small engineering consulting firm. Different aspects of a problem are regarded and a solution needs to be presented in a time-scope of 8 weeks. This project is often executed abroad. We took the opportunity to take this course and found a project in Buenos Aires, Argentina.

During these two months we were able to apply our gained theoretical knowledge in a real time project setting. We experienced working and living in a in country with a significant culture difference. Argentina differs with the Netherlands in quite some areas, for example: Language, politics, economy and lifestyle. We had a great time being here working on the project as well as living in Buenos Aires.

We would like to thank Ir. H.J. Verhagen (TU Delft) for getting us in touch with the University of Buenos Aires and for his project and content advise. Our supervisors, Eng. R. Escalante (Hídrovia S.A./UBA) in Buenos Aires, Ir. H. Verheij (TU Delft) and Prof. Ir. T. Vellinga (TU Delft) in The Netherlands, have been of great support providing the project group with advice and insights. We also had dinner with Dutch people in the Argentine water sector. A few names of the people who were there where are Niek Boot, Paul Braeken, Tiedo Vellinga and Henk-Jan Verhagen. In Argentina, Leonel Temer (Hidrovía S.A.), Sebastián Garcia (Hidrovía S.A.) and Paul Augustijn (Jan de Nul) gave us a lot of data and advice.

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Buenos Aires, October 2015

SUMMARY

The authorities of Argentina wish to improve the accessibility of the ports located in the Río de la Plata and upstream to the Paraná River. The water depth in the Río de la Plata is very shallow and did not suffice for vessels to navigate. Therefore navigation channels have been dredged. Ship drafts have increased in time and nowadays there is a need to be able to accommodate vessels with higher drafts. This report provides possible solutions to increase the accessibility by researching the influence of the expansion of these channels. In particular, the construction of the Magdalena Channel: an additional channel that bifurcates in the point named 'El Codillo'. This channel does not cross from the Argentinean coast to the Uruguayan coast, but continues along the Argentinean coast towards the Atlantic Ocean. This results in a southbound exit.

To conclude the best solution for the posed problem, the following method has been implemented: A shipping prediction is made to estimate the future traffic intensity on the navigation channels. With the obtained information, a design ship is selected. By combining different design vessels and channel layouts, six alternatives were created. With the selected design ships and the available data, concept designs were elaborated using the PIANC manual: Approach channels (2014) as a guide line. For these channel dimensions, both capital and annual maintenance dredging volumes are estimated. The costs and benefits of all the alternatives have been considered and together with a Multi Criteria Analysis recommendation regarding the waterway infrastructure improvements are presented.

At the moment the current channel is designed for a ship design draft of 34 feet. Bulk carriers, tankers and containers vessels were indicated as the most important vessels navigating the Río de la Plata. Their expected growth, from 2013 till 2035, is respectively 54.6%, 38.7% and 91.6% for vessels with a draft bigger than 34 feet. From the shipping prediction it resulted that about 10% of the outgoing ships headed towards the south. The design ship for the new Magdalena Channel has in most alternatives length, width and draft dimensions of a New Panamax vessel (Length 352 m, width 48 m, depth 11 m & 12.8 m). In one case the design ship is a bulk carrier (Length 255 m, width 36 m, depth 11 m).

In total six alternatives have been developed, excluding the current situation. The current situation implies that the Punta Indio Channel will remain at 34 feet and that there will be no Magdalena Channel constructed, set at Alternative 0. For the remaining alternatives, the table below gives an overview of the design drafts of both the Punta Indio Channel and the Magdalena Channel.

Alternative	Design draft Punta Indio [ft]	Design draft Magdalena [ft]	Width Magdalena based on
0 – current situation	34	-	-
1	36	-	Container ships
2A	36	36	Bulk carriers
2B	36	36	Container ships
3	34	36	Container ships
4A	-	36	Container ships
4B	-	42	Container ships

For the 36 feet design draft, a channel dredging depth of 14.16 meters is designed for both container ships and bulk carriers. For the 42 feet design draft, a channel dredging depth of 16.36 meters is calculated. The width is 144 meters, which is the same for the 36 and 42 feet design draft for container ships. For the bulk carriers at 36 feet, the channel width is set at 117 meters. The slope of the channels is 1:20.

From the results of the Multi Criteria Analysis, Alternative 0 with Punta Indio at 34 feet and no Magdalena channel came out best. However, it does not give ships a larger draft to enter or exit Río de la Plata. When it is suitable to have a deeper channel, Alternative 1 and Alternative 3 are the best options.

The conclusion of the Cost Benefit Analysis is that none of the alternatives will generate revenue in the considered time period of 20 years. However, compared to the current situation (Alternative 0), Alternative 1 has a higher Net Present Value. In Alternative 1 the Punta Indio channel will be deepened to 36 feet and the Magdalena channel will not be constructed.

The data of the Multi Criteria Analysis and the Cost Benefit Analysis are combined. The result is that Alternative 3 scores less on the Cost Benefit Analysis, but scores the same on the Multi Criteria Analysis as Alternative 1. Therefore Alternative 1 is more favorable than Alternative 3 and the other alternatives.

This leads to the conclusion that the construction of the new Magdalena channel at 36 or 42 feet is not considered feasible, both economically and financial.

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1. PROBLEM DESCRIPTION

Ports and harbors are important shackles in the logistic chain. Their accessibility is crucial to national economies. This is also the case for Argentina, where the port of Buenos Aires for example serves the largest part of foreign trade of Argentina. Ports further inland like the one in Rosario are important for the export of agricultural products. Before the current infrastructure was build, it was hard for ships to get near Buenos Aires or further upstream. The heavy silt deposits from the Paraná and Uruguay river have been causing the waters in the Río de la Plata to stay very shallow, which only allowed ships with minimal draft to enter the estuary (Luqui Lagleyze, 2005).

With the fast increasing prosperity in the second half of the 19th century more and more ships were visiting Buenos Aires, which led to the incremental expansion of the port to the size as it is known today (Díaz Alejandro, 1970). Even though the economy of Argentina has had its ups and downs since the 1930's, the port still is one of the busiest in South America handling around 1.5 million TEU containers (AAPA, 2013). Next to that Argentina is a large exporter of agricultural products like wheat, soybeans and meat, while more than 14 percent of Argentinian lands is still available for cultivation according to the United Nations (Frayssinet, 2015). Ports inland near Rosario are frequently used by bulk carriers or tankers to ship agricultural products towards other destinations. Containerships mostly drop of their last cargo in the port of Buenos Aires before heading back to the ocean.

The ports in Argentina can be seen as the end point of the South American eastside before ships head back via Brazil on towards North America, Europe or Asia. Since Argentina is isolated in the south, it is vital to have good water infrastructure so goods can be brought in by ship rather than more expensive modes of transport like road or train. Because the shallow waters in the Río de la Plata estuary make it insufficient for containerships and bulk carriers to sail, Buenos Aires and Argentina's hinterland are only accessible via navigation channels as shown in the below.

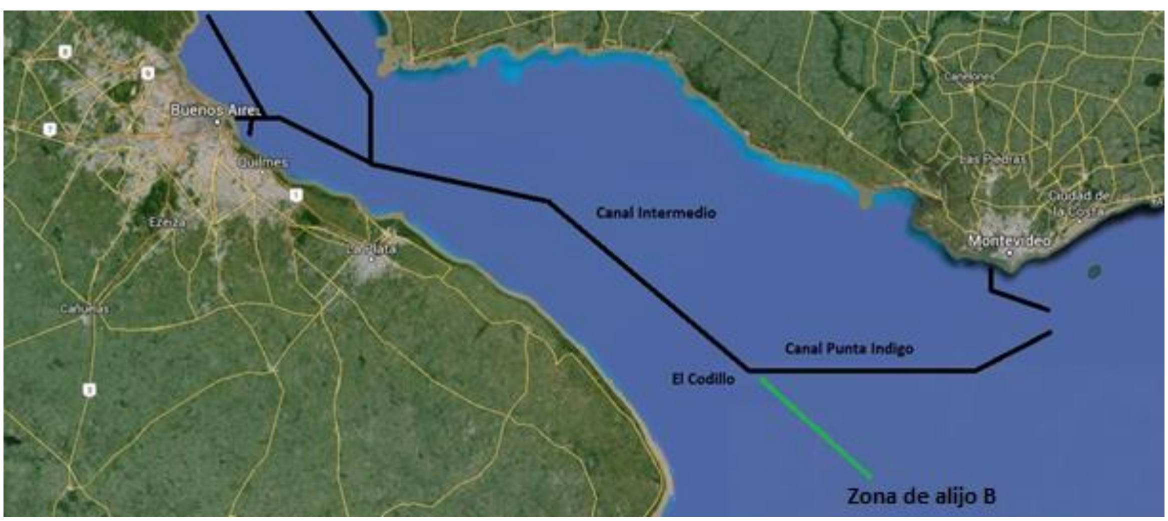

FIGURE 1: OVERVIEW OF THE NAVIGATION CHANNELS IN THE RÍO DE LA PLATA ESTUARY.

The figure gives an overview of the entrance channels. The port of Buenos Aires is currently connected to the Atlantic Ocean via Canal Intermedio. Two ramifications are seen attached to the channel, which are routes leading further upstream to the Parana and Uruguay river. At El Codillo (Spanish for the elbow) Intermedio bends away from the Argentinean shore. From there the Canal Punta Indio starts, going towards Montevideo. Currently this is the only entrance to the Río de la Plata estuary. However, to improve the accessibility of Buenos Aires and other ports in Argentina, Canal Intermedio may be extended from El Codillo towards deeper navigable waters near area

Zona de Alijo B (labelled green in the figure). In this report this new channel will be called Magdalena channel. The current Magdalena is just a small part near the village Magdalena, so it could be seen as an extension of the current Magdalena channel.

Apart from creating more capacity with the new channel, ships that go to the southern part of Argentina can take a route that is approximately 200 kilometers shorter. Furthermore a deeper channel might be needed to compete with the port of Montevideo for container traffic. Therefore it is required to have a channel of at least 36 feet instead of the current 34 feet, which is seen as a bottleneck for containerships with a deeper design draft. Apart from this it must be an economically feasible solution on the short and long term.

This report will give the government of Argentina an insight of the possibilities to improve the accessibility of the Río de la Plata with the Magdalena channel. Different alternatives will be discussed, including the construction of a whole new channel and the deepening of the current channel. The research will include a concept design of the new channel according to the latest PIANC guidelines (PIANC, 2014). The economic feasibility of creating a new channel will be compared to the deepening of the current channel. With the data provided by Hidrovía S.A. it is estimated which ships are willing to take the new route along with the maximum width, length and draft. Using this information the design ship for the new channel is estimated. With this estimation the design is determined, after which a cost-benefit analysis will be made for every alternative.

2. DEVELOPMENT OF SHIP TRAFFIC & DIMENSIONS

To determine the traffic expected to make use of the new channel and to make predictions for future ship traffic, it is required to have a clear indication on the traffic development in the past years. The amount of ships entering the channel from the ocean have been recorded by Hidrovía S.A. since 1996 up until 2013 (Hidrovía S.A., 2014). Since this means that only one way has been counted, movements in the channels should be at least twice as high.

The ships taken into account have a minimum draft of 15 feet, because this is the minimum for which a ship has to make use of the channel. A sub category has been made for ships with a design draft that is larger than the channel depth of 32 feet. Since the channels have been deepened from 32 feet to 34 feet in 2006, this is also done within the data, upscaling the ship design draft from 'larger than 32 feet' towards 'larger than 34 feet' in 2006. The subcategory is a fraction of the total amount above 15 feet. Additionally the percentage of ships with a draft deeper than 32/34 feet have been calculated to see if the ratio between the different draft categories changes over time.

2.1 TOTAL TRAFFIC

There are numerous types of ships currently navigating the channel through the Río de la Plata. The majority of these ships can be classified in different types and shares in 2013 shown in Figure 2 (Hidrovía S.A., 2014).

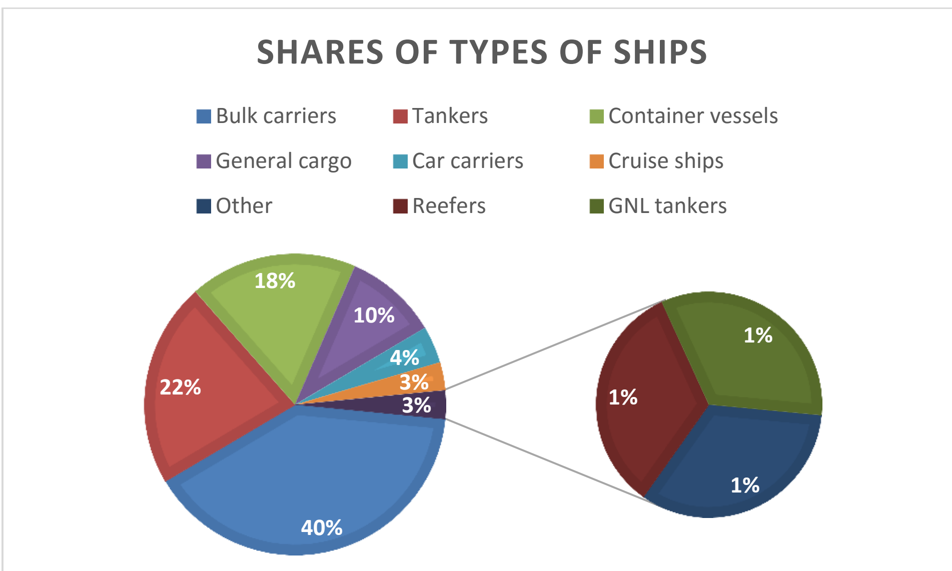

FIGURE 2: SHARE PER TYPE OF SHIP IN 2013.

Figure 3 on the next page gives the total amount of ships from the period of 1996 until 2013. It can be seen that traffic was growing steadily until 1998 but has since been declining until 2002 when 3781 ships arrived at the Río de la Plata. This decline can be explained by the huge financial crisis in Argentina during 1998-2002, which was the worst in the country's history (Cibils, Weisbrot, & Kar, 2002). On top of that came the dotcom-bubble, which had big effects on both imports and exports. When Argentina started to recover from the crisis, the country's growth was so strong it had one of the highest yearly growth percentages in the world (The World Bank, 2015). As a result traffic started to grow again with over 5100 ships arriving in 2008. However, just as most other countries in the world, Argentina has been hit hard by the 2008 financial crisis, causing a plummeting of worldwide trading. The amount of ships entering Río de la Plata fell with more than 600 during 2008-2009. After that the traffic numbers kept fluctuating because of the unstable situation in the country.

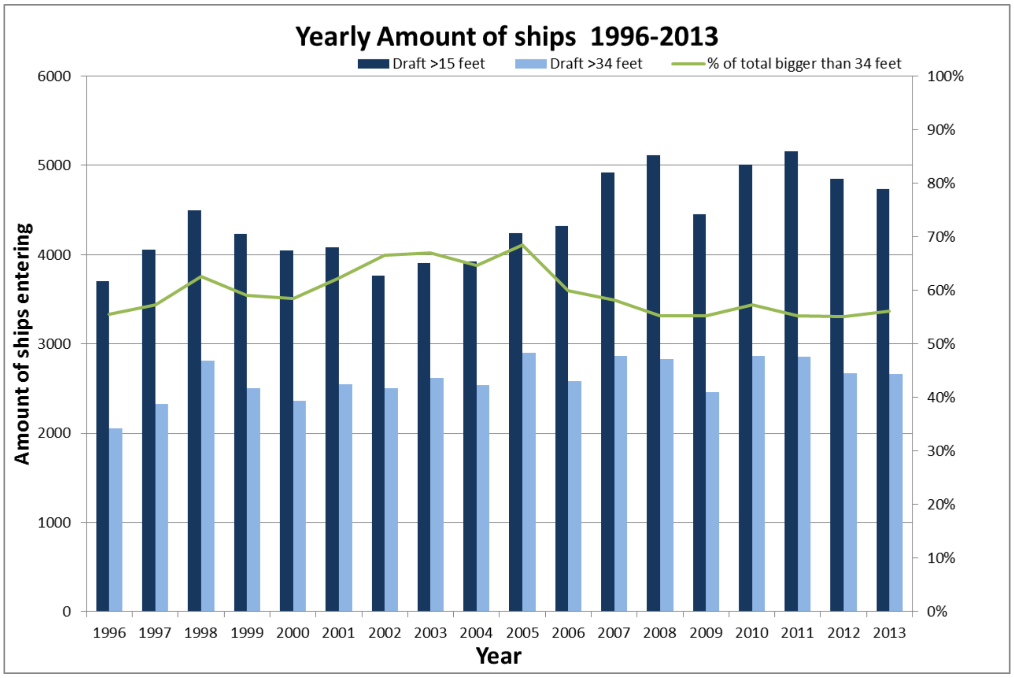

FIGURE 3: TOTAL AMOUNT OF SHIPS LARGER THAN 15 FEET ENTERING RÍO DE LA PLATA.

One surprising thing which can be noted when looking at the ratio between design drafts is that until 2005 when the channel draft was still 32 feet, the ratio was still increasing. After the increase to 34 feet in 2006 it is expected that the amount of ships in this category are smaller, but quite surprisingly the percentages keep more or less stable after that instead of further increasing. This means that the amount of ships with a smaller draft than 34 feet grow about as fast as the ones with a bigger draft.

To make it easier to see if there are clear deviations in growth between different types of ships, the traffic has also been subdivided by different categories. The most important types are bulk carriers, tankers and container ships. Amongst the smaller categories belong general cargo, cruise ships, car carriers and reefers, together combined under 'other traffic'. Figure 4 on the next page gives the ratio between different types of ships on a yearly basis. While containerships and tankers are relatively staying at the same percentages throughout the years, the share of 'other traffic' is declining with more than 15%. Bulk carriers are picking up a larger share over the years, with an increase of more than 10% in 2013 compared to 1996.

Appendix A: Traffic analysis will further zoom in on the traffic per ship type and the shares between small and large ship drafts, analyzing the development on a yearly basis and the factors behind it.

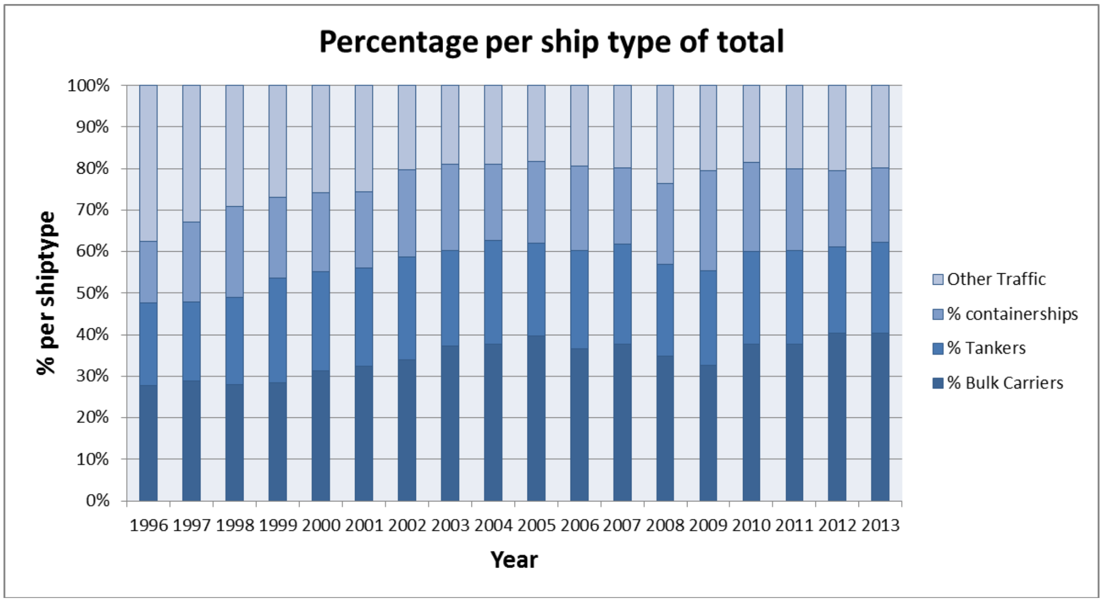

FIGURE 4: SHARES IN TOTAL TRAFFIC PER SHIP TYPE.

2.2 TRAFFIC HEADING SOUTH

Most traffic going into Río de la Plata have a destination in this area which is 'end of the line'. When they have unloaded their cargo they will head back towards the north past Brazil, heading for Europe, North America or Asia. This traffic would not have immediate advantage of the Magdalena channel, but there is also a portion of traffic that has to head south towards Quequén, Bahía Blanca or Ushuaia. This traffic, mostly existing out of bulk carriers and tankers, is heading this way to fill up their ships with grain, soybeans, or bio oil. This could not be done in ports like Rosario or Buenos Aires because of the inadequate depth of the channels.

This part will analyze traffic which is sailing between destinations in Río de la Plata and the southern ports of Quequén and Bahía Blanca. Table 1 below gives the amount of ships taking the southern route in the years 2012, 2013 and 2014. The numbers of Quequén are not known for 2012, so this year does not give a complete image of the total. In 2013 around 500 ships left the Río de la Plata estuary to go south. This is 10.5 percent of the total ships. For 2014 it is know that 444 ships were heading south. The total number for 2014 are determined on 4513 ships, resulting in 9.8% of the ships going south in that year.

Amount of ships/year		2012	2013	2014
Origin Río de la P.	Quequén	-	102	118
	Bahía Blanca	375	401	326
	total	*375*	*503*	*444*
	% of total	-	*10,6%*	*9.8%*

TABLE 1: AMOUNT OF REGISTERED SHIPS MOVING FROM AND TO THE SOUTH OF ARGENTINA.

The amount of ships returning to the Río de la Plata estuary after visiting Bahía Blanca or Quequén are 158 in 2013 and 149 in 2014 (Table 2 on the next page). Since the total ships are only counted one-way this should also be the case for the ships going to the south and heading back. Thus the returning ships are not counted towards the total.

Amount of ships returning to Río de la Plata estuary		2012	2013	2014
Destination Río de la P.	Quequén	-	15	18
	Bahía Blanca	104	143	131
	total	*104*	*158*	*149*

TABLE 2: AMOUNT OF SHIPS FROM THE SOUTH HAVING A DESTINATION IN RÍO DE LA PLATA.

This is made clear with Figure 5 below, which represents the flow of ships heading to the south in 2013. The arrows indicate the flow direction and the number next to it gives the amount of ships taking this direction. 401 ships have

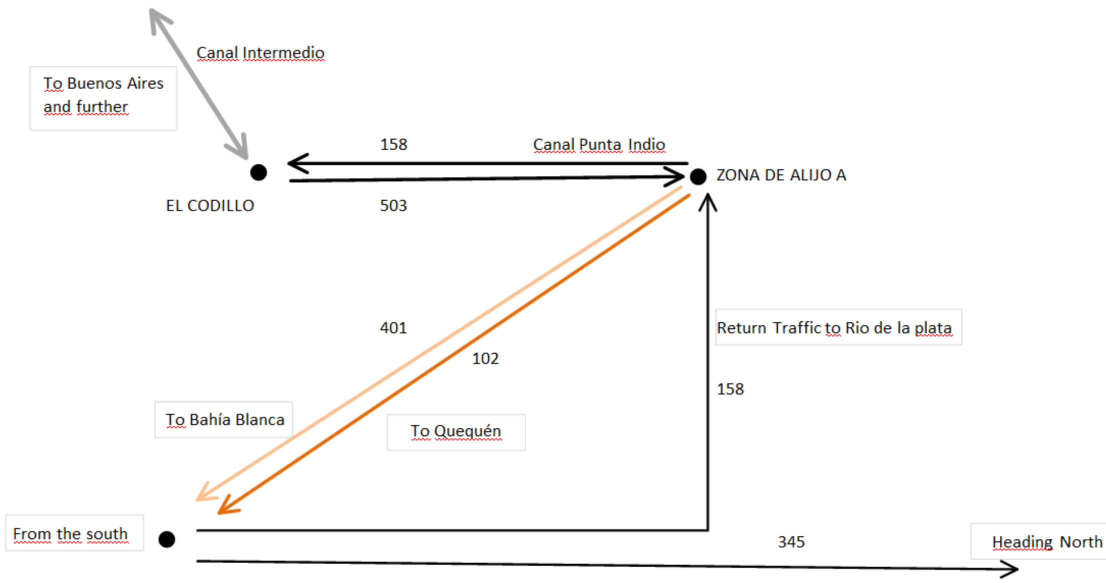

FIGURE 5: TRAFFIC FLOWS OF SHIPS GOING TO AND COMING FROM THE SOUTH.

set sail for Bahía Blanca, while 102 ships headed for Quequén. Of the 503 ships that go to the south, only 158 directly return afterwards, while 345 ships head towards the north (N. America, Europe, Asia or Africa).

The numbers at the arrows of Canal Punta Indio summed together give the potential movements through the new Magdalena channel, being 661 in 2013, or 1 to 2 ships passing the channel each day. This is only for traffic heading southbound. When the depth or width of the new channel has more advantages over the old channel it could get more attractive for ships heading to the north as well. Multiple factors are influencing this decision like efficiency, costs and safety.

Table 3 below gives the amount of ships going south in 2014. It can clearly been seen that these are mostly consisting of bulk carriers and tankers. Only 26 ships are other types like container or reefer ships.

Ship type	Bulk carrier	tankers	others	**Total**
Amount	144	156	26	*326*
Percentage	*44.2%*	*47.8%*	*8%*	*100%*

TABLE 3: AMOUNT OF SHIPS PER TYPE GOING SOUTH (2014).

2.3 FUTURE GROWTH OF SHIPS

The feasibility of a new channel is partly depending on the future demand for ships. The growth of traffic can influence the effect of different alternatives. When traffic growth is very high for example, it will lead to capacity problems for the Punta Indio channel in which case a new channel is highly recommended to reduce pressure on the current channel. If the size and depth of ships keep increasing in the upcoming years it could be an option to increase the depth of the channel even further to 42 feet. This part will further elaborate on how future traffic is determined and what is expected based on the calculations. After this analysis it is possible to give an indication which vessel is going to use what channel.

2.3.1 DETERMINING GROWTH RATES

The available data gives the amount of ships ranging from 1996 till 2013. This is used to extrapolate towards 2035, using a first order linear equation. The total amount of ships is shown in Figure 6 below. Looking at the ships larger than 15 feet, the growth throughout the years is rather steady were the deviations are having a steady bandwidth around the linear line. The same goes for ships larger than 34 feet where the deviation is even less, although the average line is climbing less steep. This implies that the growth of ships larger than 34 feet is smaller than those

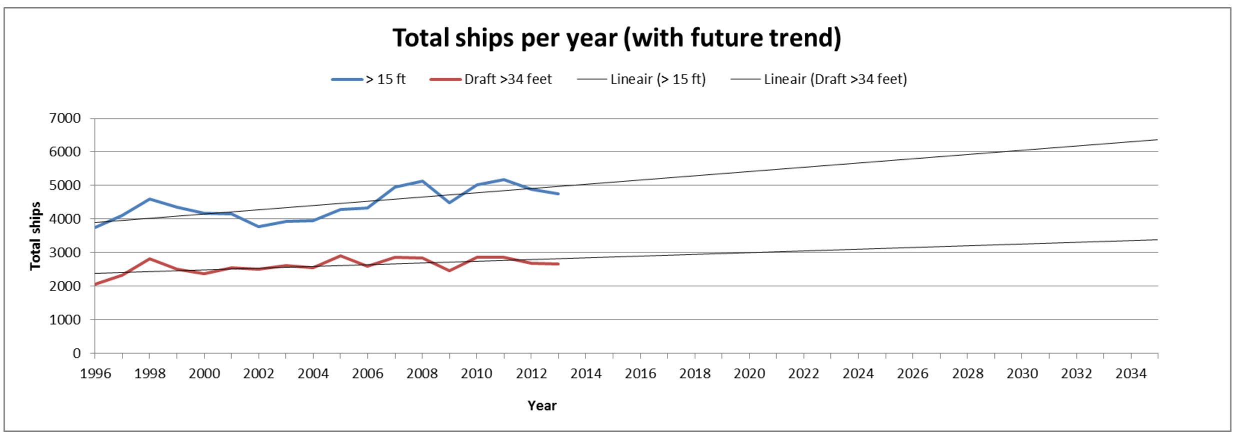

FIGURE 6: GRAPH OF THE TOTAL AMOUNT OF SHIPS PER YEAR WITH AN ADDED TREND LINE.

While this figure gives a broad overview of the development of ships, it is not enough to determine the routes that ships take. Bulk carriers and tankers for example have different dimensions, destinations and costs involved with their travel compared with container ships. The sizes within different ship types also have influence on the costs and choices of routes. To further zoom in on this, ship types have been divided in bulk carriers, tankers, containerships and other traffic and for each of these types the growth rate has been determined for both the 15-34 feet and the >34 feet group. After this the types were further divided into eleven subclasses for different design drafts and the determined growth rates have been extrapolated towards 2035.

2.3.2 GROWTH RATES PER TYPE OF SHIP

The growth rates are determined with the trend line function in Microsoft Excel. Using an exponential trend line with the formula:

$y = \alpha e^{\beta x}$, with β being the average growth percentage which is determined by Excel.

This way it can quickly be seen what the average growth over a certain period has been. As an example the graph for the development of bulk carrier traffic has been given below (Figure 7). The blue line indicates all traffic above 15 feet and the red line is the amount of bulk carriers above 34 feet, with the corresponding exponential trend lines and its formulas. As can be seen the β has been determined, which corresponds to an average growth rate of 3.6% (0.0356) per year when looking at all ships in this category, while the growth of bulk carriers with drafts deeper than 34 feet have a growth rate of 1.9% (0.0187) per year. For the bulk carriers it can be concluded that the amount of smaller ships is growing relatively faster than the amount of >34 feet carriers, since the gap between the two lines is getting bigger. Graphs with trend lines of other ship types are located in *appendix A.6 Determined future growth of ships*.

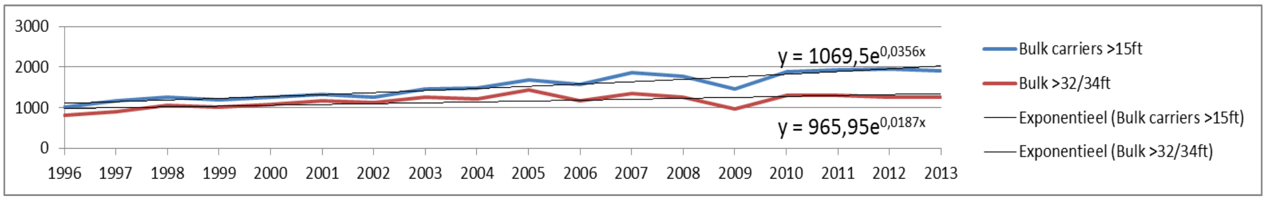

FIGURE 7: YEARLY BULK CARRIER TRAFFIC WITH AN ADDED EXPONENTIAL TREND LINE INDICATING THE GROWTH RATE OVER THE YEARS.

The growth percentages of the other categories are shown in Table 4 on the right. The tankers are the slowest growing type compared to containerships or bulk carriers. The growth of larger and smaller ships is about the same. Containerships have had some adjustments in the growth rates. Nowadays al the ships that are built in this category have a design draft larger than 34 feet. Maybe a few exceptions can be found, but the actual trend is to keep building bigger ships. This can also be seen in this case, where the growth of plus 34 feet ships is much larger (3.5%) while the amount of smaller ships is barely growing. In fact when extrapolating the data, eventually only large containerships will remain. As it is likely that at least a few ships of smaller size will stay available because of containers that have to be shipped over shorter distances like between Ushuaia and Buenos Aires, the growth of this category has been set to null so that it will stay the same in the future regardless of the growth of larger ships.

Type of ship	Growth percentage (%)
Bulk carrier	
>15 feet	*3.5%*
>34 feet	*2.0%*
Tanker	
>15 feet	*1.7%*
>34 feet	*1.5%*
Container ship	
>15 feet	*0.0%*
>34 feet	*3.0%*
Other ships	
>15 feet	*-1,5%*
>34 feet	*-9,5%*

TABLE 4: AVERAGE YEARLY GROWTH PERCENTAGE PER SHIP TYPE.

The other ships like general cargo, reefers, car carriers and cruise ships have been put together in one category. Over the years the amount of ships greatly decreases, certainly when looking at the bigger ships. The ratio of bigger ships is greatly declining since 1996. The reason for this can be in the fact that more and more cargo is being containerized nowadays, which leads to less general cargo and reefers. Only the smaller ones are still in use probably to ship products over small distances within Argentina or to neighboring countries.

With knowing the growth it is possible to further differentiate the types into smaller categories depending on the design draft of the ships. This is described in further detail in *appendix A.6 Determined future growth of ships*.

2.4 EFFECT OF GROWTH SCENARIOS ON THE TOTAL AMOUNT OF SHIPS

The growth rates used in the previous paragraphs are an extrapolation of the average growth rate from 1996 until 2013. The uncertainty of the predictions gets higher when looking further in time. There could be a totally different situation in 2035 than predicted. Because of this the predictions have been extended with two extra scenarios next to the normal one: low growth rate and high growth rate. Economics have not been involved in this, it is just a matter of adjusting the growth rates with 1.5% up or down for every type of ship. Figure 8 below gives the normal growth (blue line), the high growth (green line) and the low growth (red line). It is reasonable to assume that the future growth of traffic will be somewhere in between the green and red line.

The impact of these different scenarios can be quite large. If growth is low, it will be less likely that a new channel is needed, while high growth could lead to the necessity of two channels to be able to maintain enough capacity. *Appendix A.7 Growth sheets* has more data from the scenarios regarding the growth per ship type and draft calculated per year for the different scenarios.

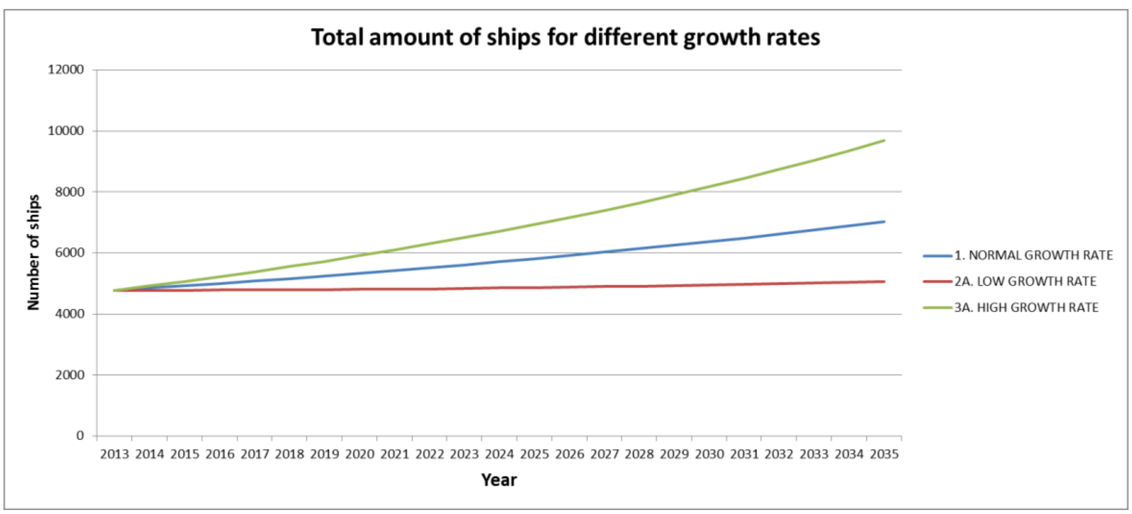

FIGURE 8: TOTAL AMOUNT OF SHIPS FOR DIFFERENT GROWTH SCENARIOS.

3. DESIGN SHIP

Following the guidelines for approach channels stated by PIANC (2014), the design ship method is used to determine the design parameters of the new channel. The most simple and direct approach is to use the largest ship which has to pass the channel and design the channel based on this design ship. However in the case of the Magdalena channel there are some reasons not to use this “naïve” approach. First of all, the economic feasibility might be very low when the channel is designed for a ship which only passes the channel once a year partially loaded. Furthermore a prediction of the expected ships in the future is required to design the channel for an extended period of time. The main characteristics of the design ship to be considered are: maneuverability (depends on type), draft, beam, length, speed and surfaces. In the next paragraphs these characteristics are discussed, after which the design ship parameter is chosen and motivated.

3.1 TYPES OF SHIPS

It is important to know which ships will be using the south-bound Magdalena channel in the future. A detailed analysis of the traffic share and the types of ships heading south is given in chapter: shipping prediction. The type of ships found in the analysis determines the maneuverability margins required for the channel. These will eventually result in the determination of the width and other design characteristics of the channel.

The previous chapter analyzed that a south bound Magdalena channel will mostly be used by Bulk carriers carrying grains and bi-products of grains such as bio-oils exiting the estuary. Depending on the economic circumstances the number of bulk carriers heading south varies from time to time. At the moment bulk carriers with a design draft of over 38 feet. will travel to the deep sea ports to be topped off (Escalante, personal communication, September, 2015) but this can change depending on the economic circumstances and costs of shipping. Bulk carriers and tankers have a poorer maneuverability then for example cruise liners or container vessels (PIANC, 2014). These safety factors must therefore be taken into account when determining the channel dimensions. Since bulk carriers and tankers have the poorest maneuverability, the safety margins should be sufficient for all types of ships. However it should be bear in mind that the channel might also be used by very large containerships (New-Panamax size), with a poorer maneuverability than the bulk carriers. This might occur in case the current channel does not offer sufficient draft or is inaccessible for some other reason.

Also when an alternative is chosen which comprehends that the existing Punta Indio channel can be used only for one-way traffic, the Magdalena channel must allow navigation of all types of ships entering or exiting the Río de la Plata estuary. This means the design ship will be based on a New Panamax size container vessel. The trend is that the number of New Panamax vessels is increasing over the world and referring back to chapter 2 it is expected that more of these vessels will visit the Buenos Aires in the coming years when the new panama canal is finished.

3.1.1 DESIGN DRAFT

For the vertical dimensions of the approach channel the design draft is required. In the current economic situation, the draft seems not to be a limiting factor for the growth of shipping in the region (Escalante, personal communication, September, 2015). Most vessels entering the Río de la Plata are in ballast and therefore not require additional dredging. In the future however, in case the economy grows a larger draft will be necessary to accommodate larger (container)vessels entering the Río de la Plata without having to transship at the port of Montevideo. Considering these factors it is very important to determine the correct design draft of the ship. And it will eventually have a large impact on the feasibility of the channel. Figure 9 below gives the amount of ships for different design drafts.

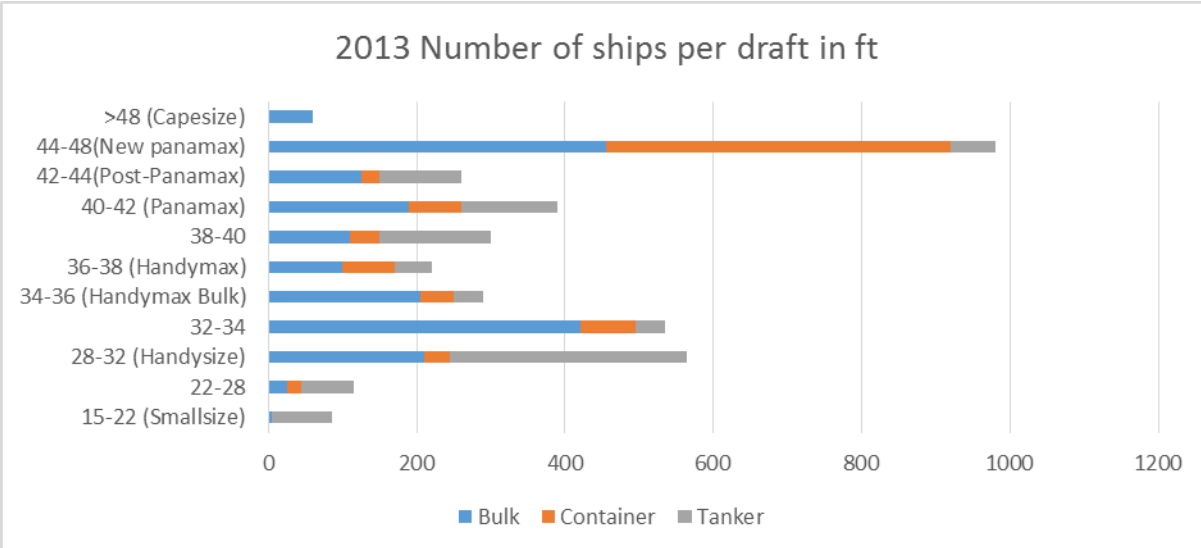

FIGURE 9: NUMBER OF SHIPS PER DRAFT (HIDROVÍA S.A., 2014).

It can be derived from the chart in 2013 about 60 Capesize vessels have navigated the current channel of 34 feet. This implicates that the actual draft of these ships was at least 12 feet less, compensated for tides. As stated in chapter 2 they navigated the channel partially loaded and where later topped off at the deep sea bulk ports of Bahía Blanca and Quequén. In case the current channel would be deeper, these vessels do not have to visit the southern ports before navigating to their final destinations, mostly in North-America, Europe and Asia.

The most simple and direct approach to determine the draft of the design ship is to take the vessel which has the largest draft. In this case it would be a Bulk carrier with a design draft of more than 48 feet. Referring back to Figure 9 it can also be seen that the New Panamax size draft is present in large numbers (Hidrovía S.A., 2014). This would be a better size to aim the design ship on since a Capesize ship is not abundant in large numbers.

3.1.2 BEAM

The PIANC approach channel design guidelines also mention that the beam (or width of the hull) of the ship is an important characteristic to determine the dimensions of the channel, especially concerning the width. Analyzing the beam of the ships passing the channel from 1996 to 2013 (see *Appendix B: Design ship* for further reference) a trend becomes visible: the container vessels are the only type of vessels with a substantially increasing beam over the years. It is not expected that the beam in the future fleet of bulk carriers will change considerably, as the current trend seems to level off around 36 meters. Depending on the main function of the channel, it can be considered to have different design ships for the width. The channel could be designed for the prospected main user of bulk carriers and tankers going south (chapter 2), or to accommodate bigger containerships. For the second one a design beam of 48 meters should be chosen, to accommodate these New Panamax vessels (see Figure 10).

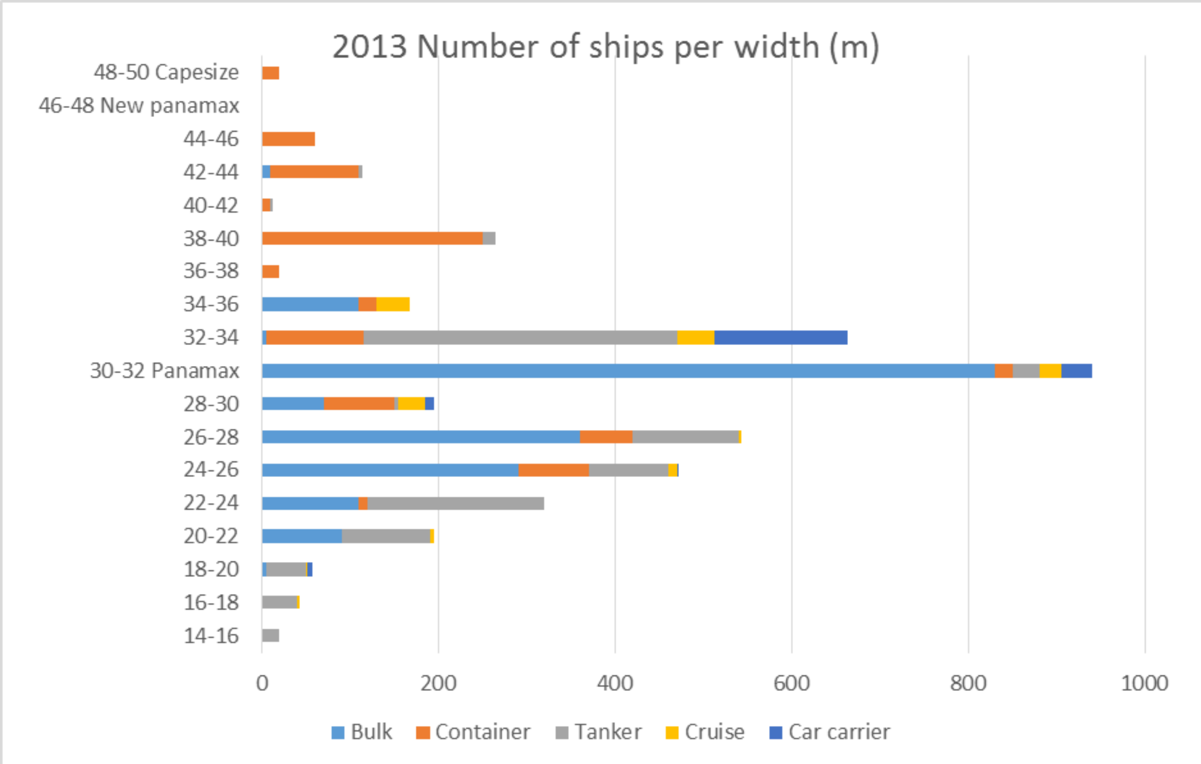

FIGURE 10: NUMBER OF SHIPS PER WIDTH (HIDROVÍA S.A., 2014).

3.1.3 LENGTH

The length off the design ship is important to determine the width of the channel. The length determines the manoeuvrability margins needed for the channel. Deriving from Figure 11 it can be concluded that most ships have

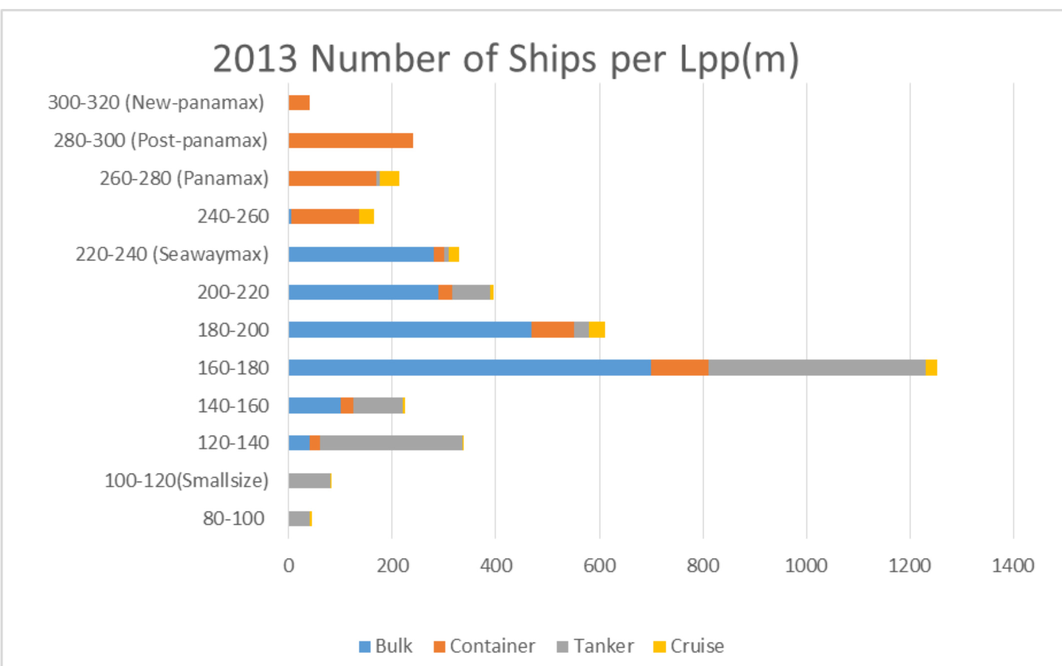

FIGURE 11: NUMBER OF SHIPS PER LENGTH (HIDROVÍA S.A., 2014).

a length bigger than 160 meters. Looking at the expected traffic, the majority of ships using the Magdalena channel consists of large bulk carriers or tankers. The maximum length of these vessels is 240 meters, Length between perpendiculars (Lpp) and is not expected to increase in the coming years due to the accessibility of the ports inland. This corresponds with an overall length (Loa) of 255 meters.

If the length of the design vessel should be consistent with New Panama container vessels it should be put at 320 meters (Lpp). This is consistent with an overall length (Loa) of 352 meters.

3.1.4 SPEED

The design ship speed is an important factor for determining the safety margins of the channel, both in the horizontal and vertical dimensions. The PIANC approach channel manual describes three vessel speed classes in respect to the water:

Vessel speed	*Classification*
Vs ≥ 12 kts	Fast
8 kts ≤ Vs < 12 kts	Moderate
5 kts ≤ Vs < 8 kts	Slow

TABLE 5: SPEED CLASSIFICATION ACCORDING TO PIANC GUIDELINES (PIANC, 2014).

A GPS-survey of all types of ships passing through the current Río de la Plata channel via marinetraffic.com (Marinetraffic, 2015) reveals an average ground-speed of around 12 knots. The ships surveyed are navigating both upstream and downstream to mitigate the effect of tides or currents on the average measurement and can therefore be considered as the ships relative speed to the water.

This puts the design vessel in either the moderate or fast speed classification. It is chosen to design the channel for a maximum speed of 12 knots and put a speed restriction on the channel so the channel can be designed according to the moderate speed classification, allowing for a narrower channel.

3.1.5 SURFACES

The surface of the design ship, lateral and frontal, is needed in order to determine the safety margins of the channel. The maneuvering of the ship to compensate for wind effects, requires extra safety margins in the design of the channel.

The surfaces of the ships depend on the vessel size and type. As mentioned in earlier paragraphs, all types of ships are currently passing through the channel. When it is assumed that only bulk carriers and tankers will use the channel, the surfaces of a typical bulk carrier in the 80.000 DWT class is used. When considering a New Panamax container vessel, a larger surface than the Bulk carrier ship is required. The surface areas are given in Table 6 below.

Type	*A Frontal m^2*	*A Lateral m^2*
Bulk carrier 80.000DWT	573	2003
Container vessel New Panamax	1697	9727

TABLE 6: AVERAGE SURFACE AREA FOR BULK CARRIERS AND NEW PANAMAX CONTAINERSHIPS.

3.2 DETERMINING THE DESIGN SHIP

For this study, it is assumed that the Intermedio and the Inferior channel section are deepened to 36 feet. This will therefore be the starting point for our preliminary design study, in order to make a comparison for the construction of a new channel against deepening of the Punta Indio channel. It means that when aiming for the New Panamax the design ship has a draft which is higher than the eventual depth of the channel.

Since there are multiple options possible it is interesting to compare them to each other. The research will focus on three different design ships for the channel. The first one will aim for bulk carriers and tankers heading south towards Bahía Blanca and Quequén. The design vessel for the new Magdalena channel is therefore chosen to be the maximum beam of a bulk carrier with a width of 36 meters.

For the second design ship, the 48 meter beam is chosen to anticipate for trends in the ship width (*Appendix B: Design ship*). It is expected that the number of New Panama class container vessels will increase. It is expected that when the new channel has 2 feet more draft compared to the 34 feet canal of Punta Indio it gets beneficial for some of the larger vessels, even if they have to make a detour.

To look further ahead, taking into account future growth of the Argentinian economy, this report will have another option by looking at a 42 feet channel. So there are two design draft of 36 and 42 feet respectively, while two different beams have been chosen (36 and 48 meters). The final design ships are given in Table 7 below:

Design ship N°	*Depth (feet)*	*Beam (m)*	*Length (m)*
1	36	36	255
2	36	48	352
3	42	48	352

TABLE 7: CHOSEN DESIGN SHIPS USED FOR FURTHER ANALYSIS.

4. PROGRAM OF REQUIREMENTS & ALTERNATIVES

Appendix C: Physical Environmental Data Analysis has an detailed description of the physical environmental circumstances in the project area. Together with this data and the determined design ship a program of requirements is composed. The program of requirements summarizes the functional requirements, design ship, boundary conditions, hydraulic conditions and soil conditions required for the conceptual design. The first paragraph will give the starting points for the design (width, depth, etc. of the channel).

4.1 PROGRAM OF REQUIREMENTS AND BOUNDARY CONDITIONS

Functional requirements

- South exit of Río de la Plata estuary.
- Aids to navigation system.

Design Ships

- Depth 36 feet (10.97m), width 36m, length 255m (Loa).
- Depth 36 feet (10.97m), width 48m, length 352m (Loa).
- Depth 42 feet (12.80m), width 48m, length 352m (Loa).

Boundary conditions

- Water density is 1025 kg/m^3.
- The governing wind is coming equally from N, S and SE with a speed of 10 m/s, this occurs 0.9% of the time.
- The chances on ice in the channel are negligible.

Hydraulic conditions

- Main wave direction is SSE with 59% of occurrence.
- The significant wave height is between 0.6-1.4 m, 80 % of occurrences
- The significant wave height of 4.04 m has a return period of once per year in case of a storm.
- At Banco Piedras the governing current has a velocity of 1.3 knot and a direction of 141.4°.
- At Banco Piedras the governing current towards the opposite direction has a velocity of 1.1 knot and a direction of 331.3°.
- At the ocean side the governing current has a velocity of 0.6 knot and a direction of 286.5°.

Soil conditions

- Soil type A is the upper layer which has to be dredged, it consists out of sand and silt.
- Soil type B is the lower layer which consists out of compacted harder clayey silt.

Assumptions

- Water density has no seasonal variations.
- Currents have no seasonal variations.
- Currents are only driven by the tide.

4.2 ALTERNATIVES

Based on the program of requirements that have been determined in the previous section, seven alternatives are considered for further research. All alternatives are comprising a design of the new south exit channel of Río de la Plata with the same specifications, but with different situations regarding the Punta Indio channel. Next to that the current situation has been taken into account to compare the other alternatives with.

Alternative 0 Current situation – Punta Indio at 34 feet, no Magdalena channel.
In the 'as is' situation the Punta Indio channel will stay the only entrance/exit to the Río de la Plata. For this situation data is available from the last twenty years, giving a good indication on the costs and benefits of the channel. It is mainly used as a reference for the other alternatives.

Alternative 1 – Punta Indio at 36 feet, width is based on container ships. No Magdalena Channel.
There are plans to deepen Canal Punta Indio to 36 feet. Vessels can increase in draft when this channel is deeper. The current plans do not include a new channel.

Alternative 2A– Magdalena at 36 feet, width is based on bulk carriers, Punta Indio at 36 feet.
This channel is specifically designed for traffic going to the south of Argentina. This traffic consists mostly out of bulk carriers and tankers.

Alternative 2B – Magdalena at 36 feet, width based on container ship, Punta Indio at 36 feet.
If both channels are at 36 feet a lot of dredging is needed, but in the long term it could have a positive effect on the capacity. Because if the number of large ships are increasing, it is possible to use both channels when this is needed. This means that the new channel should be designed to the widest container vessel. Another advantage is the shorter route for the vessels going southwards.

Alternative 3 – Magdalena at 36 feet, Punta Indio at 34 feet.
This alternative will make the Magdalena channel a main entry for ships with a larger draft than 34 feet, since the Punta Indio channel will stay at the same design draft. Ships coming from or going to Brazilian coast which are sailing with a draft of 34 or less will still use the old channel as this will still be the faster route. Southbound ships will most probably always use the new channel as it can spare them a number of hours of sailing.

Alternative 4A – Magdalena at 36 feet, Punta Indio closed.
This alternative is chosen to investigate the possibility of the current channel being closed down. A disadvantage are the longer sailing times for ships coming from and going to the Brazilian coast and Montevideo. It is expected that the only advantages of this alternative are the low maintenance costs and the shorter route for south bound traffic.

Alternative 4B – Magdalena at 42 feet, Punta Indio closed.
This is an extreme alternative. Ships can take more cargo with them, but the channel will be deeper and longer. This results in very high capital dredging costs and high maintenance dredging costs. Also the detour will bring the same costs as in 4B.

5. CONCEPT DESIGN

With the determination of the alternatives, the concept of the channel can be designed. This is done according to the PIANC manual "Harbour Approach Channels Design Guidelines 2014" (PIANC, 2014). Design criteria and considerations are based upon this manual. For a preliminary design, the sections have been decoupled. Then fine tuning between sections took place, resulting in definitive concepts.

5.1 WATER REFERENCE LEVELS

Data has been obtained from different sources, which each measure depths from different reference levels. In this paragraph an overview is presented which connects the difference reference levels.

In Figure 12 the different reference levels are illustrated:

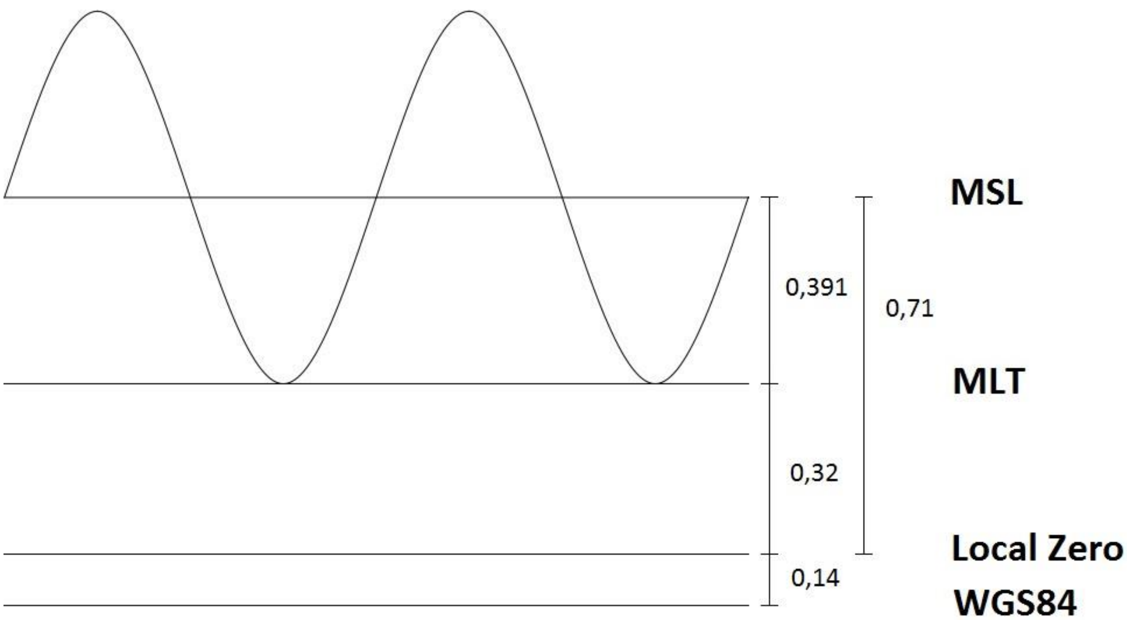

FIGURE 12: DIFFERENT REFERENCE LEVELS FOR WATER IN RÍO DE LA PLATA.

MSL is the abbreviation of Mean Sea Level. From the nautical chart provided by the Servicio de Hidrografía Naval (SHN, 2015) , information is obtained that the mean sea level lies 0,85 meter above the WGS84 vertical reference system.

From a study by Hidrovía, (Hidrovía S.A., 1997b) , the MLT (Mean Low Tide), and the Local Zero (Cero Local) were determined. For a period of 27 days, measurements have been taken every 10 minutes without interruptions to determine these values. The MLT was set 0.391 meter lower than the MSL, and a standard deviation of 0.32 meter was observed. The Local Zero was then set as the MLT minus one standard deviation, which results in a difference of 0.71 meter with the MSL. Bathymetry data provided in this report uses the Local Zero reference system.

Charts of Navionics (Navionics Webapp, 2015) are used for determining bathymetry as well. The depths in Navionics are presented with respect to the WGS84 reference system.

5.2 LAYOUT

At first, two preliminary alignments have been considered, see *Appendix D: Preliminary layout*. After more information was available regarding channel dimensions and shipping routes, the concept layout was designed.

The determination of the channel alignment will be done according to criteria stated by the PIANC:

- Channel length
- Boundary conditions (e.g. basins), etc. at both channel ends
- Ease of construction and maintenance of the channel
- Prevailing winds, currents and waves
- Curvature of the channel
- Environmental damage and/or disturbance at the channel ends

Integration of the different technical channel aspects led to two layouts. These are based on the required dredging depths for 36 feet (14.16 meter) and 42 feet (16.36 meter) design draughts and the available data regarding bed levels. The channel is classified as an outer channel, because the Río de la Plata is comparable to open water with respect to waves that can produce significant vertical ship motions of heave, pitch and roll.

5.2.1 LAYOUT 36 FEET

In Figure 13 the layout of the 36 feet channel is illustrated. Note that the depth on the charts, which are provided by Navionics (Navionics Webapp, 2015)**,** refer to a standard level named WGS84. The mean water level in the Río de la Plata lies 0.85 meter above this standard level. The dredging bed level is 14.16 meter and the channel has a length of 62 kilometres.

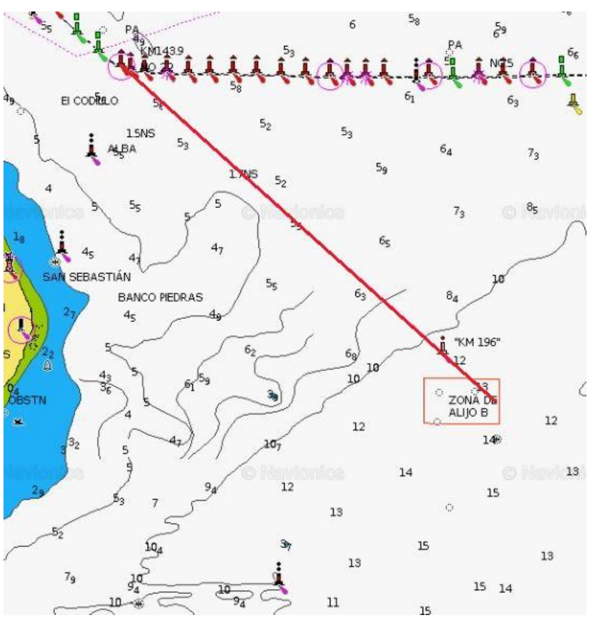

FIGURE 13: LAYOUT OF THE 36 FEET CHANNEL.

5.2.2 LAYOUT 42 FEET

In Figure 14 the layout of the 42 feet channel is illustrated.

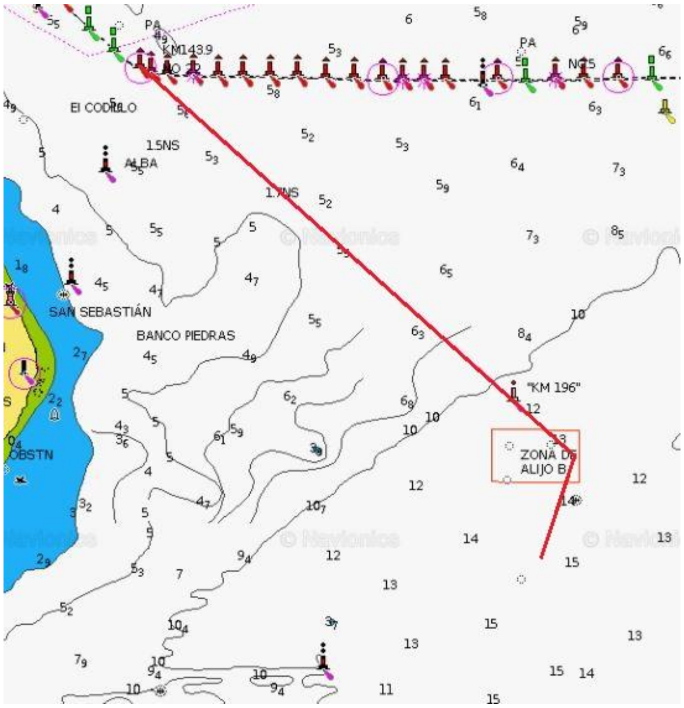

FIGURE 14: LAYOUT OF THE 42 FEET CHANNEL.

The dredging bed level is 16.36 meter. The channel has a length of 72.3 kilometres.

An important feature of this layout is the bend. This bend is located at the end of the 62 kilometres mark. This is the endpoint of the 36 feet alternative. It will be favourable when the 36 feet channel will be constructed first, after which it has the possibility to expand to 42 feet later on. The calculation is located in *Appendix E: Bend configuration*.

NOTES

The presented layouts are based on a channel depth calculated in Appendix H: Depth based on PIANC guidelines, which are 14.33 and 16.17 meters for respectively the 36 and 42 feet design draft. The client requested that the channel would be designed according to the PIANC concept design (PIANC, 2014) *at a later stage in the design process. Hence, the layout was already completed. Due to the time scope of this project, only the depths have been adjusted; the layout and channel length characteristics were fixed at the depth calculated in section (depth based in PIANC guidelines).*

5.3 SHIPPING ROUTES

When the new channel is created ships need to follow new routes. These are different for going south or heading east seen from Buenos Aires. All the routes have starting point El Codillo where the two channels connect to channel Intermedio.

5.3.1 SOUTH ROUTE

Most of the ships going south are bulk carriers and tankers, which will not make a stopover in Montevideo. The new route south will have a length of 206 kilometer to the point near Punta Medanos (Figure 15). The current route has a length of 355 kilometer, making the new route 149 kilometer shorter in total. The design depth is not relevant in this case, because the new channel will be at least as deep as canal Punta Indio.

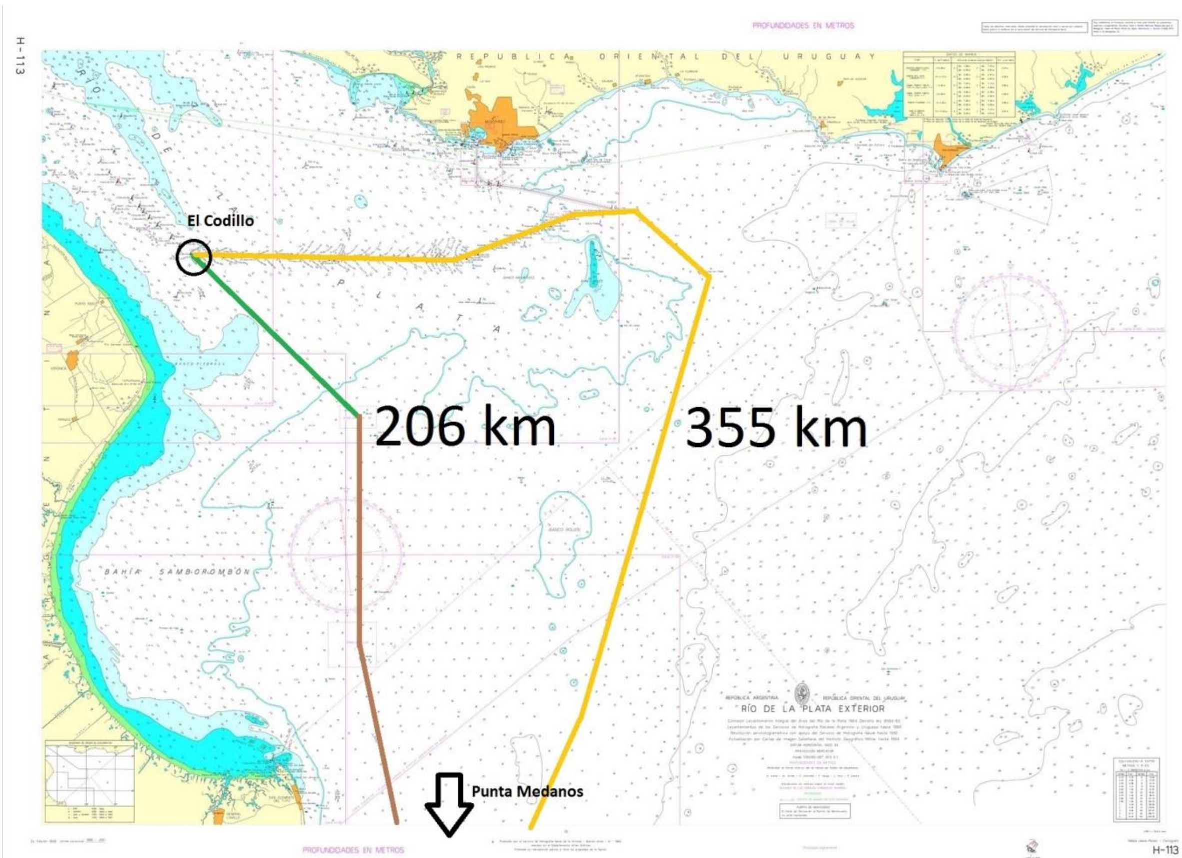

FIGURE 15: SHIPPING ROUTE TOWARDS SOUTH ARGENTINA.

5.3.2 EAST ROUTE TOWARDS THE COAST OF BRAZIL AND ATLANTIC DESTINATIONS

There are two possibilities for ships going east. Those ships can make a stopover in Montevideo or choose not to do that. Bulk carriers and Tankers are not likely to do so, as stated in the chapter Design ship.

A stopover can be interesting for the containerships with a higher draft than 36 feet. If they have too much containers causing a draft that is deeper than the channels in Río de la Plata, they have to drop off containers in Montevideo. Depending on the alternative they have to sail around the shallow parts in the Río de la Plata exterior towards the new 36 feet Magdalena channel if Canal Punta Indio is not deepened to 36 feet. This trip will take 380 km before arriving at Punta Indio (Figure 16). If the current channel of Punta Indio is dredged to 36 feet they can still use this one. This route is only 152 km, making the new route more than twice as long with a difference of 228 km.

For ships without a stop in Montevideo, the new shipping route from the point east of Punta del Este to El Codillo is 356 km, while the current route is 231 km (Figure 16). The difference is 126 km, with a vessel speed of 12 knot, the route will take approximately 5.5 hours longer. For alternative 4B with a depth of 42 feet, ships can take almost the same route as with a new channel of 36 feet. Only the very deep ships have to go a few kilometers more south to reach additional depths. This only slightly affects the 356 km to be a few more.

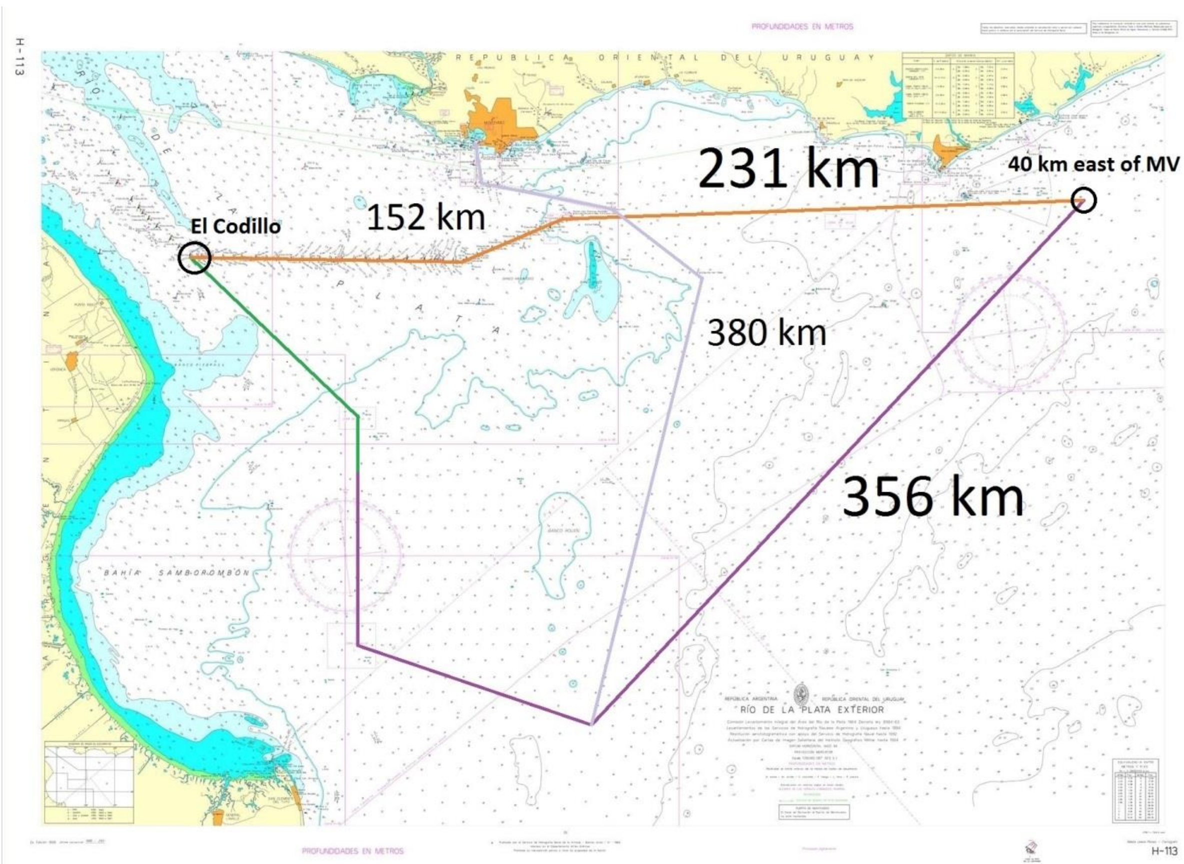

FIGURE 16: EAST ROUTE, SMALLER NUMBERS ARE FROM EL CODILLO TO MONTEVIDEO, BIGGER NUMBERS FROM EL CODILLO TO THE EAST.

5.4 WIDTH

For the channel width design, PIANC offers general design guidelines (PIANC, 2014). They also give a brief overview of Spanish and Japanese design standards. These methods should be used when designing channels in those countries. For the scope of this report, the general design guidelines given by the PIANC suffice.

First, the general formula is presented. Then factors influencing channel width are treated. An overview of the input data is given at the end for the stated alternatives, resulting in conceptual channel widths for the alternatives.

The general formula used to determine the width of straight, one-way channels given by PIANC is:

$$W = W_{BM} + \sum W_i + W_{BR} + W_{BG}$$

For a two-way channel, the following formula is given:

$$W = 2W_{BM} + 2\sum W_i + W_{BR} + W_{BG} + \sum W_p$$

W_{BR}= width of basic maneuvering lane as a multiple of the design ship´s beam B
$\sum W_i$= additional widths to allow for the effects of environmental forces and boundaries, AtoN (Aids to Navigation) and channel depth
W_{BR}, W_{BG} = bank clearance on the ‘red’ and ‘green’ sides of the channel
$\sum W_p$ = passing distance, comprising the sum of a separation distance between both maneuvering lanes W_m and an additional distance for traffic density

The width elements are illustrated in Figure 17 (PIANC, 2014). The total width W is defined as the channel width, shown in Figure 18.

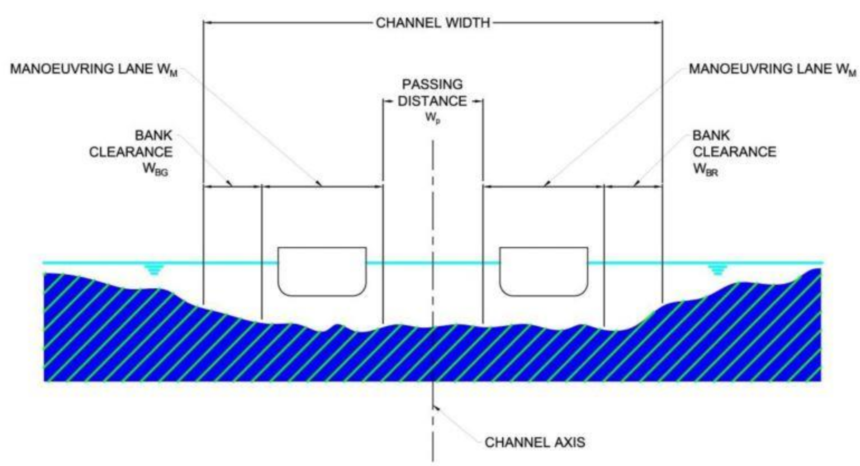

FIGURE 17: ELEMENTS OF CHANNEL WIDTH.

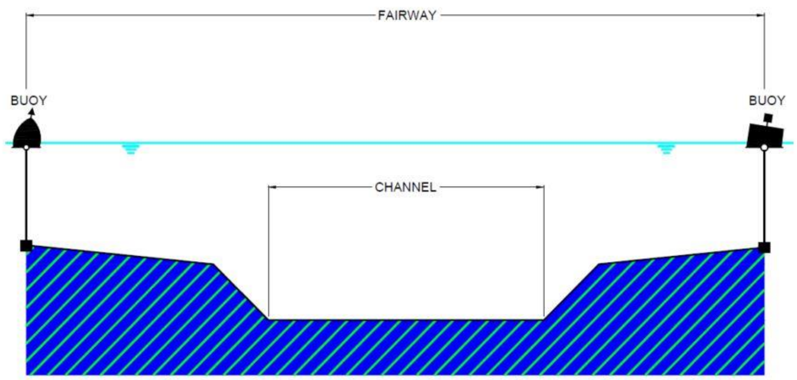

FIGURE 18: CHANNEL AND FAIRWAY DEFINITION.

The factors of width are based on the design beam B. A distinction is made between inner and outer channels in the design process. Inner channels are located in protected waters, like in harbor basins behind breakwaters. Outer channels are located more offshore and ships here are more prone to environmental conditions like currents and waves. Due to the location of our channel, it is regarded as an outer channel.

5.4.1 BASIC MANEUVERING LANE

The basic maneuvering lane depends on the maneuverability of the ship. Different types of vessels have different levels of maneuverability. In general, maneuverability of tankers and bulk carriers are considered poor. Container vessels, car carriers, Ro-Ro vessels, LNG and LPG vessels are regarded moderate. Twin-propeller ships, ferries and cruise vessels are considered to have a good maneuverability.

5.4.2 BANK CLEARANCE AND ADDITIONAL WIDTH FOR PASSING DISTANCE IN TWO-WAY TRAFFIC

A ship in motion will experience asymmetrical later forces due to the restricted flow around a ship. Due to this phenomenon ships may be sucked towards the banks, or to each other. Additional channel width is therefore required. In Figure 19 (PIANC, 2014) this additional width is illustrated, next to the maneuvering lane.

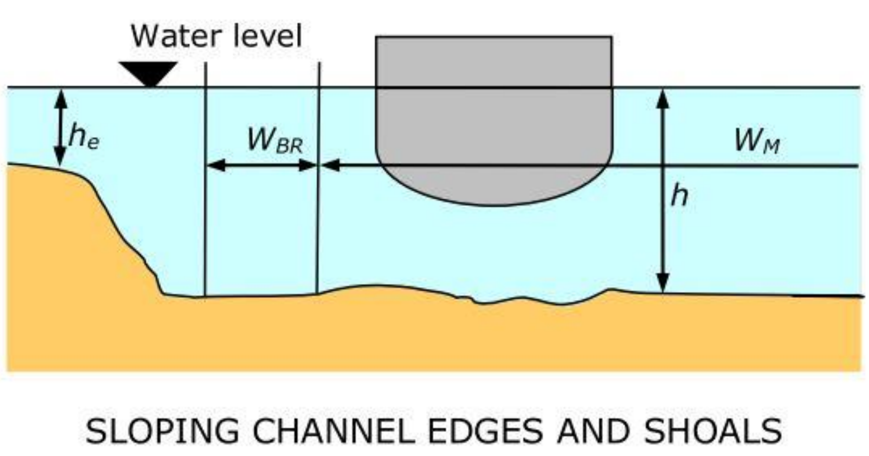

FIGURE 19: BANK CLEARANCE

5.4.3 ADDITIONAL WIDTHS

Environmental forces like currents, winds, waves and tides have influence on the maneuverability of the ship. Hence, extra width has to be taken into account accordingly. For most of these influences, additional widths are based on the vessel speed relative to the water and the channel exposure to waves. Other influence factors are briefly described in the following part.

- The higher the prevailing cross wind, the bigger the additional width. PIANC gives guidelines for a balanced ratio between windage surface and lateral underwater area. The following ships are regarded: tankers, bulk carriers/OBOs in full load or ballast condition, containerships, cargo vessels, car carriers and LNG/LPG vessels. For cruise liners, Ro-Ro vessels and car carriers with higher ratios of windage area a supplementary width should be added. However, this width is 20% of the design ship's beam, which is expected to be much bigger than the stated vessels which require this additional width. Also, they are not as frequent on the Río de la Plata as the other vessels are. Therefore this additional width for high windage area vessels is not taken into account.

- The prevailing cross and longitudinal currents are considered equal over the stretch of the to be designed channel. Incoming waves impact the maneuverability of the ship. Depending on the angle of the waves with the ship direction, additional width should be taken into account.

- The Aids to Navigation support ships while navigating the channel. The better the quality of the AtoN, the less additional width has to be added.

- If the bottom is close to the draught of the vessels, it may be possible that the vessels will be grounding against the bottom of the waterway. It is possible to navigate through some mud, but it will decrease the ships maneuverability. If the channel is regarded as a shallow channel, additional width should be added.

- For high cargo hazards, in general no additional width needs to be accounted. It is advised to take additional safety measures. For instance, speed reduction for vessels containing high cargo hazards, in combination with VTS assistance and patrol vessels. Another option is to choose a 2-way channel to guarantee safe access and exit of the high cargo hazard vessels.

- When a large tidal range in combination with strong currents and steep underwater banks on both sides of the channel, additional width should be considered given to the possibility of a vessel blocking the channel. When a tidal range is larger than 4 meters, it can be considered a large tidal range. The hydraulic environment in the Río de la Plata does not possess such extreme tidal range, hence no additional width for this component is required.

5.4.4 ADDITIONAL BEND WIDTH 42 FEET CHANNEL

For the 42 feet alternative, a bend will be constructed to minimize the channel length.

In a bend the swept path of a vessel will increase. Bends require extra length due to two conditions. First: an additional width due to drift angle. Second: an additional width due to response time. This width is required to compensate the time delay of the vessel which is made when the course is altered.

The PIANC guidelines (PIANC, 2014) provides a simplified formula for the additional width due to drift angle, which may be used in the concept design phase.

$$\Delta W_{DA} = \frac{L_{oa}^2}{a * R_c}$$

ΔW_{DA} = additional width of the vessel's path swept due to drift angle in a curved channel section
R_C = bend radius
L_{oa} = length overall
a = factor depending on the ship type

For a, the factor depending on the ship type, a = 8 for normal ships and a = 4.5 for larger displacement ships with $C_B \geq 0.8$.

For the additional width due to response time, the following formula is presented:

$$\Delta W_{RT} = 0.4B$$

ΔW_{RT} = additional width due to response time.

5.4.5 BOUNDARY CONDITIONS DEFINITION FOR WIDTH DETERMINATION

The parameters on which the PIANC manual Harbour Approach Channels Design Guidelines (2014) bases its channel width are presented in this section. Then an overview of the set parameters is given. The calculations are presented in *Appendix F: Boundary conditions width calculation*, where some the following parameters are elaborated:

- Design ship dimensions and type
- Vessel speed V_s [kn] with respect to the water
- Prevailing cross wind V_{cw} [kn]
- Prevailing cross-current V_{cc} [kn]
- Prevailing longitudinal current V_{lc}
- Beam and stern quartering wave height H_s [m]
- Quality of Aids to Navigation (AtoN)
- Depth h [m]
- Water depth above embankment h_e [m]

For bends, additional parameters are used:

- Bend radius R_c [m]
- Factor a, depending on ship type

An overview of the parameters is given in Table 8**:**

Ship type	Container		Bulk/tanker
L_{oa} [m]	352		255
W [m]	48		36
D [ft]	36/42		
D [m]	10.97/12.8		
V_{cw} [kt]	14.45		
V_{cc} [kt]	0.36		
V_{lc} [kt]	1.28		
H_s [m]	0.6-1.2		
AtoN	Excellent		
h [m]	14.16/16.36		
h_e [m]	See section Bathymetry in *Appendix Environmental data analysis*		
V_s [kt]	fast	moderate	moderate

TABLE 8: WIDTH CALCULATION PARAMETERS.

5.4.6 CALCULATED CHANNEL WIDTHS

For the container ship, the width is calculated for two speed regimes: fast and moderate. When nautical traffic speed lies between 10 and 12 knots the vessel speed is considered moderate. Above 12 knots the vessel speed is considered fast. Vessel speed has been observed on Marine traffic (Marinetraffic, 2015) for one week. Containerships were classified as fast paced vessels. Bulk carriers and tankers were classified as moderate paced vessels. However, if vessel speed is restricted to 12 knots with regulations, a smaller channel width can be realized. This design is specified for a one-way channel.

In Table 9 the channel widths are presented for the design vessels:

Ship type		Container								Bulk			
L_oa	[m]	352								255			
W	[m]	48								36			
T	[ft]	36				42				36		42	
Dredge level	[m]	14,16				16,36				14,16		16,36	
Velocity	[-]	fast		moderate		fast		moderate		moderate		moderate	
Slope	1:x	1:20	1:10	1:20	1:10	1:20	1:10	1:20	1:10	1:20	1:10	1:20	1:10
Channel length	[m]	62000	62000	62000	62000	74400	74400	74400	74400	62000	62000	74400	74400
Channel depth	[m]	14,16	14,16	14,16	14,16	16,36	16,36	16,36	16,36	14,16	14,16	16,36	16,36
Channel width	[m]	144	144	141,6	141,6	144	144	141,6	141,6	117	117	117	117
Add. Bend width	[m]	25,5	25,5	25,5	25,5	25,5	25,5	25,5	25,5	23,8	23,8	23,8	23,8

TABLE 9: OVERVIEW CHANNEL WIDTHS ONE-WAY CHANNEL.

Different design parameters have been considered: type of design vessel with their corresponding widths, fast and moderate speed regimes and slope angles of 1:10 and 1:20. For the calculations, see *Appendix G: Width calculation* sheet.

The bulk carriers and tankers do not need a width which is broader than the width required by the container vessels. For the above channel widths, dredging volumes are calculated in the section Dredging.

5.4.7 BEND CONFIGURATION

For the 42 feet design draft depth, a bend occurs in the designed channel. The configuration is shown in Figure 20. For design considerations and calculations, see *Appendix E: Bend configuration.*

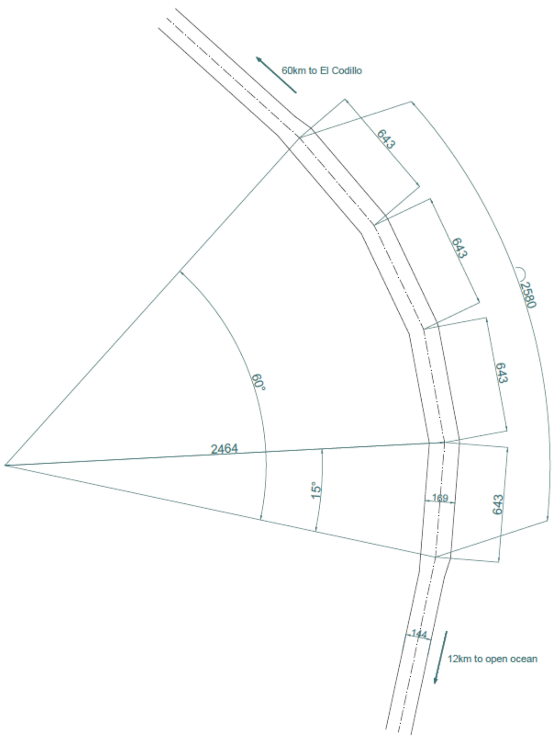

FIGURE 20: BEND CONFIGURATION

After the bend, the alignment of the channel with respect to the prevailing conditions differs. New calculations of the boundary conditions are needed to exactly determine the channel width for this section. For the scope of this project, the boundary conditions are assumed to be identical as for the 132 degrees orientated part of the channel (PIANC, 2014).

5.4.8 RECOMMENDATIONS FOR FURTHER INVESTIGATION (DETAILED WIDTH DESIGN)

The concept width design gives a good estimate of the final design. The concept width is based on tables and formulas provided by PIANC (PIANC, 2014). A more accurate estimation can be elaborated in a detailed design with the usage of advanced techniques. In this section a recommendation is presented regarding specifications of the techniques to be used for the detailed design.

5.5 DEPTH

There are several ways to determine the channel depth. It is always a consideration between computational time and accuracy. The channel design is a concept and therefore it does not need to be most accurate with the use of computer models and extensive calculations. The most basic and fast way to get an answer is to use rules of thumb. All factors influencing draught and depth are lumped together. It gives however an initial value of how deep the channel needs to be. For sheltered water the depth over draught ratio is taken to be 1.1 and in waves up to one meter height the ratio is 1.3. Higher waves give a ratio of 1.5 to be sure of sufficient depth in the channel (Ligteringen & Velsink, 2014).

The PIANC guidelines (PIANC, 2014) give a better approximation for the concept design of a channel. It is a very fast method where some data of the area and traffic has to be known. Calculations however are still absent. These PIANC guidelines for a concept design are used to determine the depth of the channel.

In the book *Ports and Terminals* by H. Ligteringen and H. Velsink (Ligteringen & Velsink, 2014) a more detailed formula is given based on PIANC guidelines. More variables are taken into account which reduces the uncertainty. It can be seen as an intermediate calculation between concept and detailed design. Calculations have been made using this formula, but are purely indicative and are not used for further use.

For the most accurate calculation PIANC gives formulas for a detailed design. All factors are treated extensively and the use of computer models may be needed. This is however far too detailed and extensive for the scope of the project and are therefore not used.

5.5.1 PIANC CONCEPT DESIGN

A channel has to be designed for safe use and easy navigability. To achieve the required level of safety, depth factors are taken into account treating water level-, ship- and bottom factors. Of those ship related factors are most influential on vertical channel design. For the concept design all ship related factors are combined into one factor F_s, rather than to calculate each and every single factor separately. PIANC uses Table 10 (on the next page) to determine the combined value for squat, dynamic heel and wave response. The approximation depends on the ship speed, intensity of wave effects and the channel type with its draught.

Description	Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel
Ship Related Factors F_s					
Depth *h*	≤ 10 kts	None		1.10 *T*	
	10 - 15 kts			1.12 *T*	
	> 15 kts			1.15 *T*	
	All	Low swell ($H_s < 1$ m)			1.15 *T* to 1.2 *T*
		Moderate swell (1 m $< H_s <$ 2 m)			1.2 *T* to 1.3 *T*
		Heavy swell ($H_s > 2$ m)			1.3 *T* to 1.4 *T*
	Add for Channel Bottom Type				
	All	All	Mud	None	None
			Sand/clay	0.4 m	0.5 m
			Rock/coral	0.6 m	1.0 m
Air Draught Clearance (ADC)					
ADC	All	All		0.05 H_{st}	0.05 H_{st} + 0.4 *T*

Notes:
1. For Ship Related Factors: Assumes $T > 10$ m. If $T < 10$ m, use value for $T =$ 10m
2. Swell means waves with peak periods T_p greater than 10 s
3. For Outer Channel swell values, use lower value for smaller swell wave periods and higher value for larger swell periods
4. Value of significant wave height H_s is dependent on required operation, design ship type, level of accessibility, wave period and relative wave direction
5. H_{st} is the distance from the sea surface to the top of the ship
6. Seawater density assumed for *T*. Additional adjustments required if fresh water.

TABLE 10: PIANC CHANNEL DEPTH COMPONENTS FOR CONCEPT DESIGN (PIANC, 2014).

The vessel speed lies between 10 – 15 knots and there is a low to moderate swell regime with significant wave heights ranging between 0.40 m and 1.40 m. For the inner channel this leads to 1.12 times the draught of the ship and for the outer channel 1.2 T. In a report of Hidrovía (Hidrovía S.A., 2013) swell waves are recorded with peak periods higher than 6 seconds, while PIANC states swell waves should exist longer than 10 seconds. In the case of shorter or longer periods than 10 seconds the weighing factors should be adjusted somewhat according to PIANC, but for the Magdalena channel this is not needed. The factor is determined on the most frequent peak periods of 10 seconds and a significant wave height of 0.9 m. (PIANC, 2014)

The bottom of the existing channel is consisting of mud due to the high sediment discharges of the rivers combined with the tide, short waves and low water depth. When a new channel is dredged there will be however mostly clay and silt material beneath a small layer of mud. An additional draught of 0.4 m is added to the inner channel and 0.5 m to the outer channel.

The air draught clearance (ADC) is the vertical distance between the top of the ship and overhead structures. However, in the channel running through the Río de la Plata there are no overhead structures like bridges, powerlines or cables and therefore air draught can be ignored in the design.

As mentioned in the last note of Table 10, the Río de la Plata is a mix between salt and fresh water with a salt wedge into the estuary. These waters have different densities and therefore different buoyancy forces. A ship will have a higher draught in fresh water, because of a smaller density. The table is based on salt water conditions, but the channel has a mix of lower salt water layers and upper fresh water layers. The difference in draught is approximately between 2% and 5%. In *appendix C.8 Salinity of the Río de la Plata* about Seawater effects it is calculated that the draught difference is indeed very small (0.5% and 1.6%) and therefore salinity influences are neglected.

The channel is classified as an outer channel, because the Río de la Plata is comparable to open water with respect to waves that can produce significant vertical ship motions of heave, pitch and roll. Adding up all factors gives a ship related factor F_s of $1.2T + 1.0m$.

In case the design vessel is a container ship or car carrier, it is wise to add a separate estimate for dynamic heel. For these types of ships heeling due to crosswinds can be quite significant and can be calculated with $S_k = F_k(\frac{B}{2} sin\Phi_{wr})$. A conservative estimate according to PIANC for the roll angle due to turning and windage is $\Phi_{wr} = 1 - 2\ degrees$. The keel factor F_k takes into account the curvature of the keel and lies typically around 0,76 and 0,90. The larger and more safer value 0.90 is used for the concept design. The value for heeling should be included if the calculated value has a significant contribution (>5%) to the determined ship factor. A container ship is found to be the design vessel and it has a beam of 48m:

$$S_k = 0.90\left(\frac{48}{2}\sin(1.5)\right) = 0.57m$$

The channel depth can now be calculated with the following formula:

$$h = 1.2T + 1.0m \qquad [m]$$

For a 36ft (10,97m) ship design draught this leads to a depth of $h = 14{,}16m$ and for 42ft (12,80m) it results in $h = 16{,}36m$. Dynamic heel equals $100 * 0{,}57m/14{,}16m = 4{,}03\%$ and $100 * 0{,}57m/16{,}36m = 3{,}48\%$. This is lower than 5% and will therefore not be included in the channel depth.

$$h_{36ft} = 14.16m \ \text{ or } \ 46.5ft$$

$$h_{42ft} = 16.36m \ \text{ or } \ 53.7ft$$

The depth is relative to MSL, the midpoint between the average high tide and the average low tide. Over the entire channel stretch the MSL has the same value, else a fixed reference plane like the 'Cero Local' or WGS84 needs to be used. Choosing the reference plane at MSL and ignore tidal effects will mean that 50% of the time ships with the maximum allowed draught have to wait, because low tide causes the channel to have insufficient depth. It is an acceptable assumption due to the low traffic intensity in the Río de la Plata. Nowadays ships also have to wait in the existing channels and the long distances to dredge don't way up to the amount of ships passing the channel.

5.5.2 SIDE SLOPE

The PIANC does not give a guideline for slope design. The slope is defined as vertical displacement divided by a horizontal displacement.

The current situation in the Río de la Plata channels from the ocean to Buenos Aires is the following:

Name	km (from)	km (to)	width (m)	Side Slope
Extensión Punta Indio	246.8	205.3	100	1/20
Canal Punta Indio	205.3	121.0	100	1/20
Canal Intermedio	121.0	81.0	100	1/20
Banco Chico	81.0	57.0	100	1/20
Radar Exterior	57.0	37.0	100	1/20
Canal de Acceso	37.0	17.0	100	1/20
	17.0	16.6	100	1/20 to 1/16
	16.6	14.6	100	1/16
	14.6	14.2	100	1/16 to 1/12
	14.2	12.4	100	1/12
	12.4	12.0	100	1/12 to 1/8

TABLE 11: CHANNEL SLOPES IN RÍO DE LA PLATA IN 2015.

The river further upstream near Rosario has slopes of 1/5 (Gained from an illustration of Hidrovía S.A.).

The soil determines the slopes that can give a natural equilibrium. Negative feedback mechanisms will lead to changes in the slope until an equilibrium is reached. These slopes are the results of their soil material. Upstream at Rosario are found other soil conditions then in the Río de la Plata exterior. The angle of repose is different at these locations. As can be seen from the table above, from km 17.0 which is near Buenos Aires there is already a side slope of 1/20.

If in the new channel a design slope would be chosen of 1:10 the channel will need a few years to adapt to the equilibrium state. During this period there is a lot of maintenance necessary to keep the channel at the desired width. It is possible to put the slope at 1:10 or less, but a detailed study (Delft3D model e.g.) needs to be done to investigate the effects of these slopes. It is easier to put the channel to 1/20, because the equilibrium state will be reached the fastest. The width at ground surface will be more than when a less steep slope will be used at first, but in the end the slope will go to around 1/20, which is very mild.

5.6 AIDS TO NAVIGATION

In the channel it is necessary to have some navigational aids for the ships like pilots, buoys or a vessel traffic service. This paragraph will further elaborate on those three aspects.

5.6.1 VESSEL TRAFFIC SERVICE

At the moment there is a Vessel Traffic Service (VTS) in the Río de la Plata area. It consists of 4 sectors in the estuary, with the 4th going from Recalada Pilot Station (Figure 21) at the right until around Paso Banco Chico (km 57). The other sectors are more land inwards. The new channel will get the same VTS as the rest of Río de la Plata, with possibly a new sector. This suits best for the current situation and is a safe option.

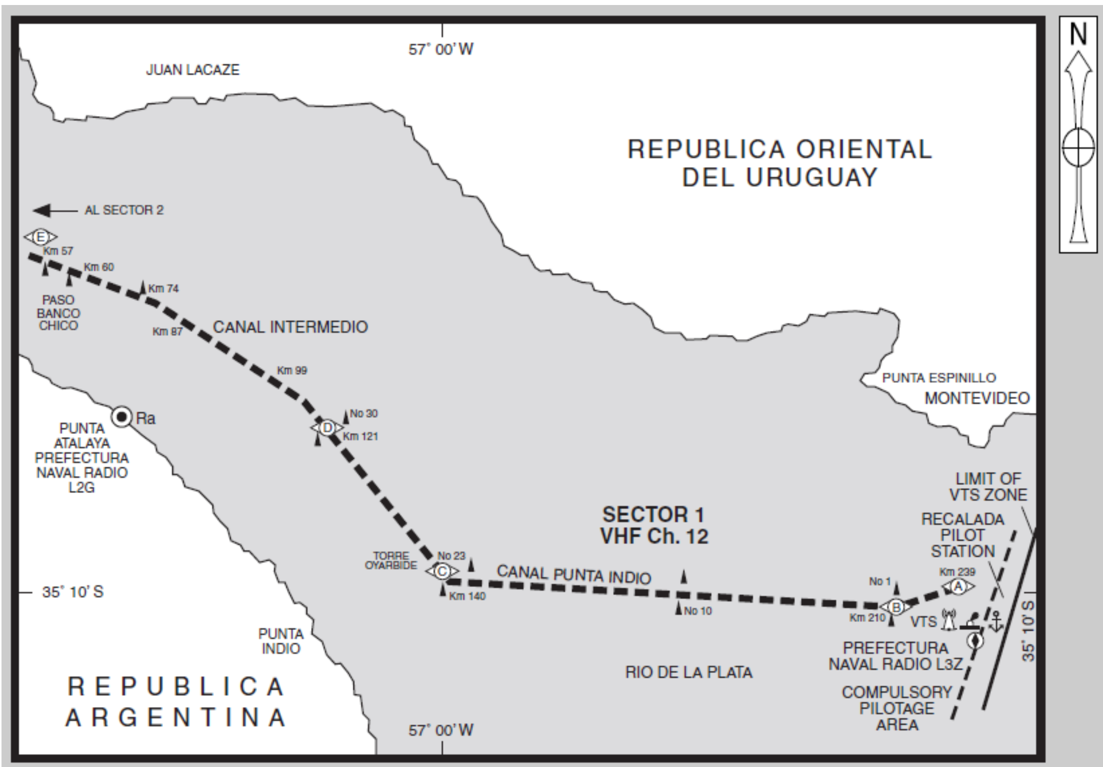

FIGURE 21: VESSEL TRAFFIC SERVICE RÍO DE LA PLATA.

5.6.2 PILOTAGE

Río de la Plata has a compulsory pilotage, with pilotage area. This can be seen in Figure 22 on the next page. This will also be the case in new channel. There should be a station like Recalada Pilot Station at the end of the new channel. Pilots transfer from the ships to this station and vice versa.

FIGURE 22: RECALADA PILOT STATION.

5.6.3 BUOY SYSTEM

The system of lateral buoys currently used in Río de la Plata will be used in the new channel as well. To design a new buoy system would take much time and is not in the scope of this study.

On the straight part of the Punta Indio channel a total of 19 pairs of buoys are in place over a length of 54,6 kilometer. This is a buoy every 2870 meter , which is also taken as the reference for the new channel (Figure 23). There will be red and green buoys as prescribed by the IALA. On each buoy there will be a light signal as well. Every 10 km there will be a PRR (Spanish name) on a buoy, this is a radar reflecting steel object. At the bifurcation in the north will be a cardinal buoy indicating the bifurcation.

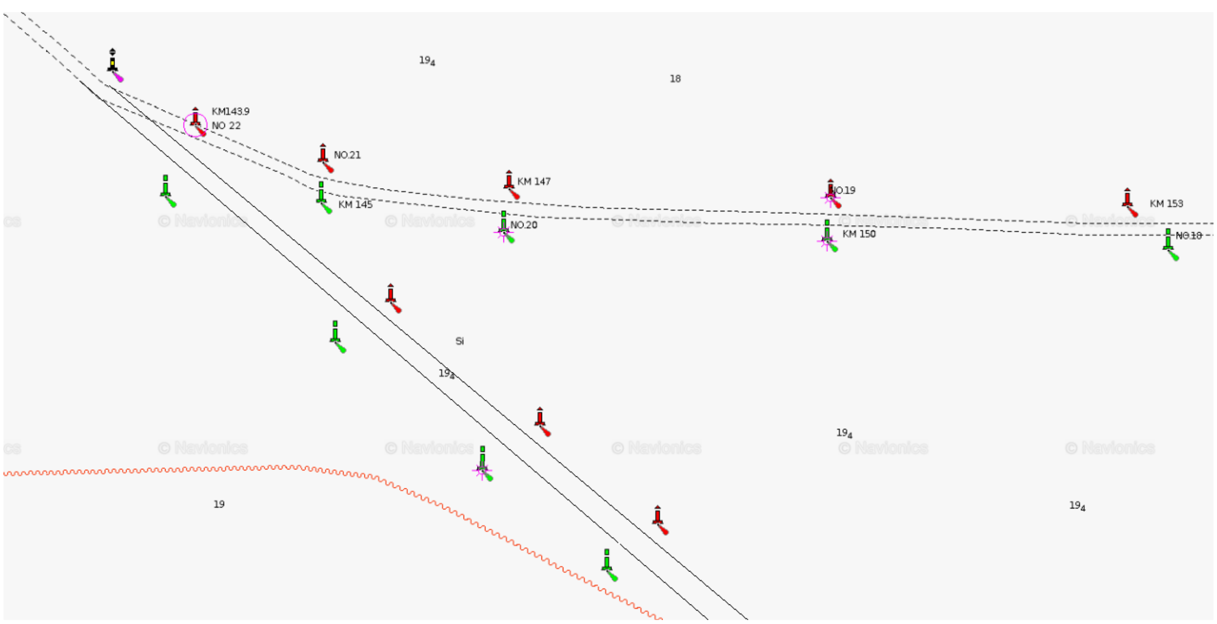

FIGURE 23: BUOYS (ADAPTED FIGURE TAKEN FROM NAVIONICS WEBAPP EDIT WITH THE NEW CHANNEL CONNECTED TO CANAL PUNTA INDIO).

At the end of the channel on the ocean side, there will be a Safe Water Mark. This also serves as the point where the channel starts, seen from the ocean perspective. This mark could be in the ground as a beacon or placed as a buoy.

FIGURE 24: EXAMPLE OF A SAFE WATER MARK.

5.7 OVERVIEW CONCEPT DESIGNS

Table 12 gives an overview of the design specifications for all alternatives. In this report only the Magdalena channel is designed. Punta Indio is only considered as a comparison regarding costs and benefits. There are two visualizations of a front view sections on the next page, one for the 36 feet channel (Figure 25) and one for the 42 feet channel (Figure 26).

Alternative		0	1	2A	2B	3	4A	4B
Punta Indio								
Design draft	[ft]	34	36	36	36	34	-	-
Dredging depth	[m]	10,82	14,16	14,16	14,16	10,82	-	-
Channel width	[m]	120	120	120	120	120	-	-
Channel length	[m]	96.000	96.000	96.000	96.000	96.000	-	-
Magdalena								
Design draft	[ft]	-	-	36	36	36	36	42
Dredging depth	[ft]/[m]	-	-	14,16	14,16	14,16	14,16	16,36
Channel width	[m]	-	-	117	144	144	144	144
Channel width bend	[m]	-	-	-	-	-	-	169,5
Channel length	[m]	-	-	62.000	62.000	62.000	62.000	62.000
Slope	[-]	1:20	1:20	1:20	1:20	1:20	1:20	1:20

TABLE 12: OVERVIEW DESIGN SPECIFICATIONS ALTERNATIVES.

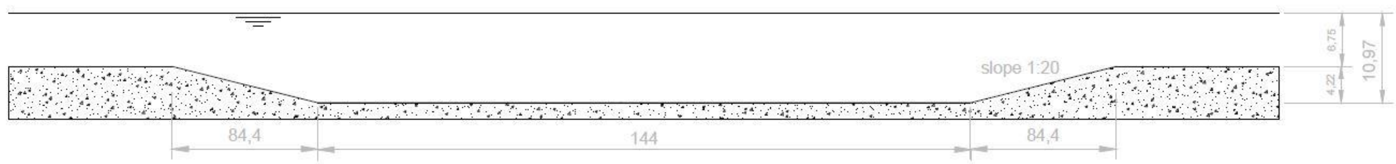

FIGURE 25: 36 FEET MAGDALENA CHANNEL DIMENSIONS AT EL CODILLO

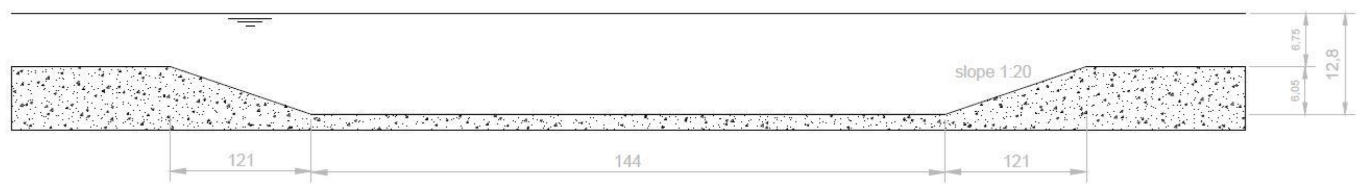

FIGURE 26: 42 FEET MAGDALENA CHANNEL DIMENSIONS AT EL CODILLO

6. DREDGING

The costs for the realization of navigation channels consists for the biggest part of dredging works. To get an estimate of the dredging costs and construction time, dredging volumes are determined. In this section the capital and the maintenance dredging volumes are elaborated. Then, an estimation of the dredging costs is presented.

6.1 CAPITAL DREDGING VOLUMES

The biggest initial costs for the realization of a channel are the capital dredging costs. Capital dredging is the excavation of soil to create new structures like a channel. A good estimation of the capital dredging is required in order to make a good cost estimation for the Magdalena Channel. This section will present the estimated capital dredging volumes for the Magdalena Channel. The capital dredging volumes for the Magdalena channel are calculated for different sets of parameters. This is in accordance with the resulting widths from the section Width.

The additional volume in the bend due to additional width is not calculated because its contribution to the total capital dredging volume is not considered significant.

The capital dredging volumes are presented in Table 13 for different channel dimensions relevant to the alternatives. For the calculations and used method, see *Appendix O: Capital dredging calculation method.*

Magdalena Channel				
Ship type		Container		Bulk
L_{oa}	[m]	352		255
Width	[m]	48		36
Velocity	[-]	fast		moderate
Design draft	[ft]	36	42	36
Slope	1:x	1:20	1:20	1:20
Channel length	[m]	62000	74400	62000
Channel depth	[m]	14,16	16,36	14,16
Channel width	[m]	144	144	117
Add. Bend width	[m]	25,5	25,5	23,8
Dredging volume type A	$[m^3]*10^6$	88,9	115,1	80,9
Dredging volume type B	$[m^3]*10^6$	17,5	50	15,1
Total dredging volume	$[m^3]*10^6$	106,4	165,1	96

TABLE 13: CAPITAL DREDGING VOLUMES MAGDALENA CHANNEL.

In Table 14 the capital dredging volume is presented for a deepening from 34 feet to 36 feet design draft for Canal Punta Indio.

Canal Punta Indio		
Design draft	[ft]	36
Total dredging volume	$[m^3]*10^6$	9,2

TABLE 14: CAPITAL DREDGING VOLUME CANAL PUNTA INDIO.

6.2 MAINTENANCE DREDGING VOLUMES

The upper rivers of the Río de la Plata transport sediment to the estuary. This sediment moves up and down through the estuary due to tidal currents. The construction of the channel disrupts the flat bottom of the estuary and hence is prone to sedimentation. Over time, the channel will clog due to settling suspended particles. This natural process decreases the depth of the channel and slopes. To counteract this, maintenance dredging is required. In this section the amount of sedimentation in the channels is predicted, so the expected yearly maintenance dredging volumes can be approximated.

Hidrovía S.A. performed a study regarding sedimentation predictions of the Canal Punta Indio and the Magdalena Channel (Hidrovía S.A., 2000). A model predicted the annual sedimentation for the Canal Punta Indio and the Canal Magdalena for design depths of 32, 36 and 40 feet. In this report their corresponding dredging depths are provided: for all of the design depths 0.5 meter is added. These depths are extrapolated to the dredging depths for the designed Magdalena channel in the concept design. The sedimentation volumes calculated in the model are based on a channel width of 120 meter for both Canal Punta Indio and Canal Magdalena. The slopes for the new designed channel have the same angle, 1:20, as the slopes used in the model. Hence, the assumption is made that linear scaling in both depth and width is admissible.

However, data regarding obtained dredging volume measurements (Hidrovía S.A., 2015a) give dredging volumes less than predicted. This might be due to the auto dredging effect according to R. Escalante (personal communication, October 6 2015). This is the phenomenon that the ships propellers induce currents which makes the sediment at the bottom suspend. Because the main current in the Río de la Plata is at an angle with the channel direction, the suspended particles might be transported out of the channel. For this reason, the actual measured data will be used for the Punta Indio channel.

Channel Magdalena, as described in the model, is not constructed so no actual measurements are available. Canal Magdalena lies almost parallel to the tidal current direction. If particles are suspended and transported due to the current, they might settle out in the channel once again. Hence, the model predictions for the Canal Magdalena and Canal Punta Indio are used to calibrate the expected dredging volumes.

The above reasoning resulted in a model which is used to approximate the dredging volume.

$S_{Magdalena} = \alpha_1 \alpha_2 \alpha_3 \gamma S_{Punta\ Indio}$, With:

$$S_{Magdalena} = Annual\ sedimentation\ estimation\ in\ the\ Magdalena\ Channel\ [\frac{m^3}{year}]$$
$$\alpha_1 = Depth\ extraplation\ parameter$$
$$\alpha_2 = Width\ extraplation\ parameter$$
$$\alpha_3 = Length\ extraplation\ parameter$$
$$\gamma = Model\ extraplation\ parameter$$
$$S_{Punta\ Indio} = Measured\ annual\ sedimetation\ in\ Canal\ Punta\ Indio\ [\frac{m^3}{year}]$$

The model resulted in approximate values for the future maintenance dredging. Table 15 gives an overview of the results, with data used from the model for the Magdalena channel. The recent measurement data for Canal Punta Indio is presented in Table 16. These are the values used for the estimation of the maintenance dredging volumes. For calculations and elaborations of the model, see *Appendix J: Sedimentation estimation.*

Design draft Magdalena [feet]	36	36	42
Design vessel	Bulk	Container	Container
Sedimentation [m^3/year]*10^6	3,1	2,3	3,1

TABLE 15: OVERVIEW EXPECTED REQUIRED MAINTENANCE DREDGING MAGDALENA CHANNEL.

Design draft Punta Indo	34	36
Sedimentation [m/year]*10^6	5,4	5,9

TABLE 16: OVERVIEW EXPECTED REQUIRED MAINTANCE DREDGING PUNTA INDIO.

6.3 DREDGING COSTS

The price per cubic meter of dredged material is based on various factors. The number of workable weeks per year and the output per week are determining how much can be dredged and thus on what the price per cubic meter is based on. Factors defining the costs are capital investment, fuel, crew, insurance and various smaller expenses (IHC Beaver dredgers, n.d.).

Efficiencies have increased in time trough modernization of key components like pumps, pipelines and other equipment. This caused the price per cubic meter of dredged material to decline in the last 15 years. The most significant reason for the decline in price is by the increasing size of dredging vessels. Economy of scales and higher efficiency caused the price range to go between $3 and $6 US dollars per m3 (Cohen, et al., 2011; Owen & Park).

To determine the price of dredging in the Río de la Plata the previously mentioned factors are determined based on the book “A guide to cost standards for dredging equipment 2009” by R.N. Bray. Two existing dredging vessels were chosen as a reference for the project. These vessels are the Trailing Suction Hopper Dredger (TSHD) “Alexander von Humboldt” of Jan de Nul (see Figure 27) and the Cutter Suction Dredger (CSD) “Castor” of Van Oord (see Figure 28). In Van Oord fleet (TSHD’s and CSD’s) all TSHD’s and CSD’s in the fleet of Van Oord are shown. Van Oord is, next to Jan de Nul, China Harbour Engineering, DEME and Boskalis, one of the five biggest dredging companies according to Rabobank Dredging outlook (Rabobank, 2013). The types of dredging work are nearly the same for all companies and therefore the fleet shown in the appendix is representative for current dredging vessels in the market.

FIGURE 27: TRAILING SUCTION HOPPER DREDGER “ALEXANDER VON HUMBOLDT (JAN DE NUL)”.

FIGURE 28: CUTTER SUCTION DREDGER “CASTOR (VAN OORD)”

Comparing the results of *Appendix K: Dredging costs* for the new Magdalena channel suggests that the use of a CSD would be cheaper. This would agree with the fact that a large volume needs to be dredged and CSD’s have a larger production compared to TSHD’s. However, the circumstances in the Río de la Plata can be too rough for the Cutter Suction Dredger and tugboats. The operational hours/week is lower than for TSHD’s, but this downtime could be even higher for the Río de la Plata. On top of that, the nearest port for tugboats to get safe during storms is very far from the new Magdalena channel. This combination makes it a difficult operational task and the preference is given to Trailing Suction Hopper Dredgers.

Trailing Suction Hopper Dredgers also have difficulties in the Río de la Plata. It is a very shallow estuary and even if the vessels could sail everywhere, fully loaded with sediment almost none of them can. The TSHD “Capitan Nunez” is currently maintaining the Punta Indio channel plus Canal Intermedio and is specifically designed for a low draught. Other TSHD’s mostly don’t have this low draught. Therefore small dredgers need to be used or the hopper must be filled less, both resulting in higher dredging costs.

In Table 17 all channel variants for the Río de la Plata estuary have been described with their corresponding costs. These variants are a combination of the new Magdalena channel and possible deepening of the existing Punta Indio channel. Deepening of the current Punta Indio channel will be done with TSHD’s. These dredgers do not completely block the one-way channel during dredging while ships are still sailing through and the dredging volumes are less making it more favorable for Trailing Suction Hopper Dredgers.

Dredging costs [€ million]	*Alternative*						
	0	**1**	**2A**	**2B**	**3**	**4A**	**4B**
Capital dredging	0,0	21,5	257,0	282,0	260,5	260,5	399,5
Maintenance dredging	13,2	14,6	19,1	20,1	18,7	5,6	7,7

TABLE 17: DREDGING COSTS [€ MILLION] OF ALL VARIANTS.

7. ENVIRONMENTAL IMPACT ANALYSIS

When a large infrastructural project takes place, there is an impact on the environment. How large the impact will be or what the effects will be depend on the type of project, the scale and the environment. There can be both local effects: pollution, erosion, ecological, etc. as well as global effects such as the emission of greenhouse gasses. In order to compare alternatives and their environmental impact, the effects can be put into monetary terms, based on common accepted values in scientific studies. In the case of dredging, this is not different. The PIANC environmental commission (EnviCom) has stated guidelines on how an environmental impact assessment should take place for dredging projects (PIANC, 2006). It follows four steps:

1. Problem formulation
2. Effects assessment
3. Exposure assessment
4. Risk characterization

Since this is a preliminary design study, the environmental impact will mostly be assessed qualitatively indicating the various effects and estimated effects, when a detailed design is made it will require a more detailed analysis of the environmental effects.

7.1 PROBLEM FORMULATION

The environmental effects in the case a new channel needs to be dredged are difficult to assess. However an estimation of the impact can be made. There can be a significant effect on the food chain and eventually on the livability of the Río de la Plata area. Below a general conceptual model is given of the environmental impact of dredging operations in a certain area.

This model given in *Appendix I: Environmental Impact analysis* indicates the sources (sediment), the transport mechanisms, exposure pathways, exposure routes and the receptors. In the case of the Magdalena channel the receptors are the population eating fish and using water from the Río de la Plata. The population of the fish species in the Río de la Plata estuary can be an important issue, both ecological as socio-economic. The Río de la Plata is home to a lot of ecological wildlife including the rare La Plata dolphin, which is a protected species (New world encyclopedia, 2015). It is also considered as the main fishing ground in the area for both Argentina and Uruguay. Dredging activities might cause fish populations to migrate, causing a loss of income for fishermen and welfare in the region.

7.2 EFFECTS ASSESSMENT

Figure 73 of *Appendix I: Environmental Impact analysis* gives an idea about the effects generated by dredging in general. These effects will be discussed in the next paragraphs. In the Magdalena channel case, some of these effects are less relevant and will therefore not be discussed in detail. Also the effect of the disposal of dredged material from the Magdalena channel is discussed later.

7.2.1 BED ALTERATION

By performing dredging operations the composition of the river bed changes. This causes the removal of organisms and habitat in the dredged area. Which has the final effect that birds and fish have less places to forage. Since the Río de la Plata estuary is the widest river in the world with a surface of 30,362 km^2 and since the Magdalena channel will have a surface of about 10 km^2, the effects of bed alteration by dredging on the fauna in the area can be neglected.

7.2.2 BATHYMETRIC CHANGES

As a result of dredging, the bathymetry of the Río de la Plata changes. The final impact on the environment depends on various factors such as the lay-out of the channel, the composition of the bed etc. An effect of dredging on the bathymetry is erosion: by dredging a channel erosion takes place on the beds of the channel when material is removed. Whether this has a large effect on the environment depends on the lay-out of the channel. Since the Magdalena channel is located in the middle of the estuary, all erosion will be under water, not on the banks of the estuary. This has the effect that it might influence the sedimentary flow patterns in the area. Which in turn has effect on the benthic communities in the area. Since this not only affects the dredged area, but also the surroundings, the effects on the environment should not be neglected and therefore be estimated.

7.2.3 INCREASED TURBIDITY

Dredging operations causes sediment to get separated from the bottom and to mix up with the water. On what scale this happens depends on a lot of factors such as the dredging method and the consistency of the dredged material. Turbidity causes less sunlight to travel through the water affecting the natural growth of plankton and other organisms negatively. There is also an effect on the fish themselves, as their behavior can change. The impact depends on the scale, the spread and the concentration of the suspended particle clouds.

In order to assess the scale of the suspended particle clouds under water, a computational modelling study has been performed on four study spots: A1 to A4 allong the layout of the Magdalena channel (see *Appendix I: Environmental Impact analysis* Figure 75). The study uses data of currents and material properties in order to estimate the contours, location and concentration of the turbidity at multiple time steps (see *Appendix I: Environmental Impact analysis* Figure 77 & Figure 78).

As can be seen in the figures, the concentration of the particles decreases and increases over time at the different measurement points. This is due to the currents in the area which displaces the suspended particles over time. After about 24 hours the concentration of the suspended particles becomes neglible. The area where the cloud spreads is shown in Figure 29.

FIGURE 29: TURBIDITY CLOUDS CAUSED BY DREDGING OPERATIONS

The turbidity clouds stretch over a large area, a rough estimation gives an area of approximately 60 km x 8 km = 480 km^2. This area is 48 times larger than the dredged area and is approximately 1.5% of the area of the Río de la Plata. The effects of the turbity should not be underestimated and therefore futher study on the final impact should take place.

7.2.4 LIBERATION OF MATERIALS

The liberation of materials due to dredging can also have an impact on the environment. Contaminants like heavy metals coming from ships can be suspended into the water and carried on for long distances, when ships are passing through or when maintenance dredging takes place. This can have negative effects on the quality of the water (Hidrovía S.A., 1998a). A study at the impact of dredging the alternative Magdalena was done by Hidrovía in 1998, including the impact concerning the heavy metals. In this study is concluded that the impact of the heavy metals being suspended in the water on the ecological system due to the dredging is small.

7.2.5 OTHER ENVIRONMENTAL EFFECTS

There are also other environmental effects indirectly caused by dredging the channel. For example the effect that more capacity will allow for more ships to visit Buenos Aires over time and therefore increase the air pollution in the area, also the less or extra greenhouse gasses emitted by ships need to be taken into account when a detailed quantitative analysis is performed. Besides this, important to mention are the effects of exotic ballast water being discharged in the ports of Buenos Aires and inland ports. Due to the dredging of a deeper channel some empty ships entering the Río de la Plata might take in more ballast water for a more stable ship, increasing the chance of exotic species nestling in the Río de la Plata and displace the local species. However these effects are considered not to be significantly different than the current effects.

7.3 EXPOSURE ASSESSMENT

The assessment of the exposure to contaminants of concern (COCs) is considered by PIANC to be a quantitative analysis of the effects on the receptors. In this preliminary design study, the environmental impact will be assessed qualitatively so it will deviate from the PIANC guidelines on this point. As a result of this, of the three steps, only step 1 will be done.

The analysis will follow the conceptual model stated by the PIANC (PIANC, 2006). The conceptual exposure model of COCs for the Río de la Plata can be found in *Appendix I: Environmental Impact analysis* Figure 80.

The exposure as a result of the COCs being suspended due to dredging along the channel is found to be minimal. It should be noticed that the study (Hidrovía S.A., 1997a) states that some measurements cannot be considered reliable enough to draw definitive conclusions, so in order to confirm the conclusions made in the study, these measurements should be done over in order to verficitate the study.

7.3.1 ADDITIONAL REMARKS

Other studies show that the Río de la Plata is allready contaminated with heavy metals at certain areas, which is caused by the sediment transport from rivers into the basin. The exposure treshhold level for these areas is crossed according to the Canadian water quality standards used in the study (Ronco et al, 2008) The effects of exposure to COCs in the Río de la Plata can therefore not be neglected, but the effect of dredging the new channel is limited compared to the other pollution sources.

7.3.2 RISK ASSESSMENT

In order to assess the risks regarding a new navigation channel all kinds of aspects need to be analyzed. The risks regarding the dredging itself as well as the risks of the future shipping in the channel need to be assessed. In the next paragraphs these risks will be explained in a qualitative approach. The EnviCom approach uses a risk quotient approach in order to assess the risks of dredging a new channel, which requires the use of quantitative data about exposure and statistics.

7.3.3 ECOLOGICAL RISKS OF DREDGING

The ecological risks can be assessed by studying the exposure and the area of exposure. The area of exposure caused by the dredging is roughly found by taking the area of the turbidity clouds and the exposure zone of the disposal site of dredged material. Both of these areas together are considered to be around 2% maximum of the area of the Río de la Plata. These areas are not at the banks of the Río de la Plata so the risk of humans coming in direct contact to the dredged materials is very low. Fish and mammals living in the Río de la Plata are at risk to come in direct contact with the sediment. But since the overall contamination of the Río de la Plata is already high, no significant extra risks are expected at this point. Although further research on the exact migration areas of fishes and mitigating measures of the contaminated sediments should be investigated in further detailed studies.

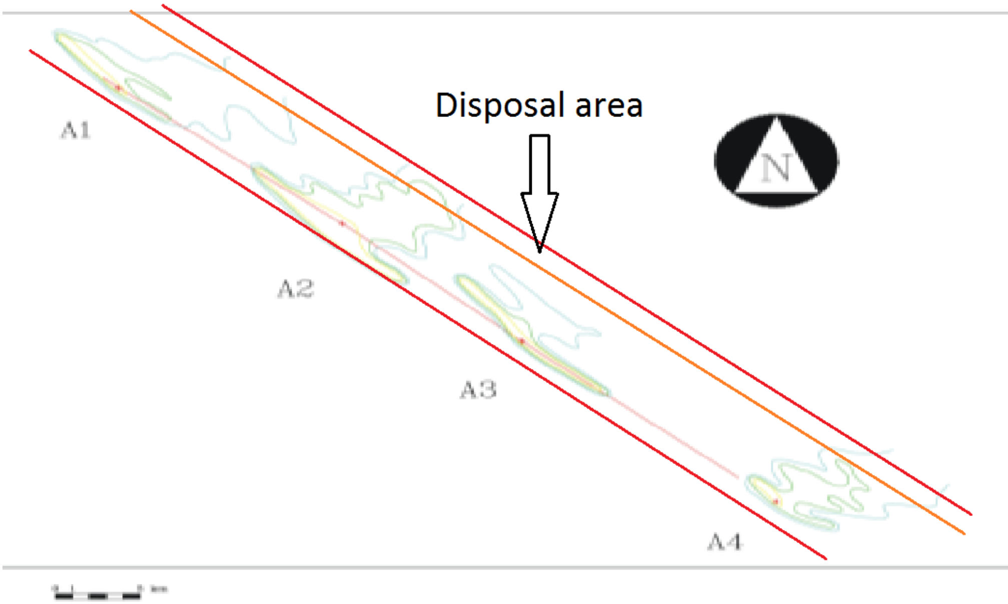

FIGURE 30: DISPOSAL AREA ALONG THE CHANNEL.

7.3.4 ECOLOGICAL RISKS OF SHIPPING

Besides the ecological effects due to dredging, described by the PIANC (PIANC, 2006). Also the risks of shipping accidents in the channel need to be assessed. This can best be done using quantitative analyses and simulation studies, which are very time consuming and expensive. A rough estimation can be made on the chance and impact of ships carrying dangerous materials colliding and the chance of a ship running at ground in the channel.

7.4 MAINTENANCE DREDGING SEDIMENT WASTE DISPOSAL

With maintenance dredging comes in sediment that has to be relocated to another location. It has to be dumped away far enough from the channel to prevent it from getting back inside the channel due to waves or currents (Figure 30). Navigation channel sediments get contaminated over time due to pollution of ships sailing in the channels or particles flowing along with tidal streams and currents. Pollutants can be heavy metals like copper, cadmium, nickel, zinc, chrome or mercury coming from the hull (paint) of the ship or due to industrial activity. Other pollutants can be for example petrol related products, organic waste or plastics. Depending on the severity of pollution in sediments additional steps should be considered when it is expected to be harmful to the environment.

7.4.1 SITUATION IN RÍO DE LA PLATA

To get an indication on the requirements for sediment waste disposal of the new channel, it is important to know the current situation in the Río de la Plata estuary.

The estuary supplies water to more than 10 million people living in the surrounding area. The waters are also home to numerous fish species, including some very distinctive ones like turtles and La Plata dolphins. The fish are a source of food for people living near the river and, being a very important for the water supply, the river is vital for the people living in the area. Nonetheless it is very polluted, being ranked by the World Wildlife Fund (WWF) to be third most polluted river in the world (Evans & McDonnell, 2010). In 2010 there were over 340 open trash dumps depositing their industrial, chemical and household waste in the Matanza river, which is flowing through Buenos Aires directly into the Río de la Plata (Jones, 2014).There have been attempts by the Argentinian government to reduce pollution in the area, but most of them have been in vain due to lack of commitment from the different parties involved. Even more difficult is the fact that the la Plata basin goes through multiple countries, making it a problem on an international scale. The issue has gained more attention the last few years, but not much has been done.

The fact that the environmental situation has become worse throughout the years can also be seen in the way the current navigation channels are dredged. Waste sediments of the Punta Indio channel for example are now simply disposed along the seaside of the channel about three kilometer from the channels edge, ready to get flushed away further towards the ocean. The most probable reason for this is that the sediments are not very polluted, or at least not any worse than the water itself, thus not having a great impact on the overall environmental situation.

A study conducted by Hidrovía (Hidrovía S.A., 1997a) shows that all the sediments samples taken from specific points had heavy metal values lower than the Dutch guide levels for water sediments quality (article 15 and 16, 6th section , Besluit kwaliteitseisen en monitoring water 2009). This can be explained by the fact that most pollution of heavy metals (and other sorts of pollution as well) are mostly in effect at the ports, while the point of El Codillo is between 50 and 150 km away depending on the port's location. Thus the pollution caused by the ports has already decreased significantly at this point.

7.4.2 POSSIBILITIES FOR SEDIMENT DISPOSAL

PIANC (PIANC, 2006) describes multiple options for dredged material management, including the use of confined disposal facilities (CDF) which is depicted in Figure 31.

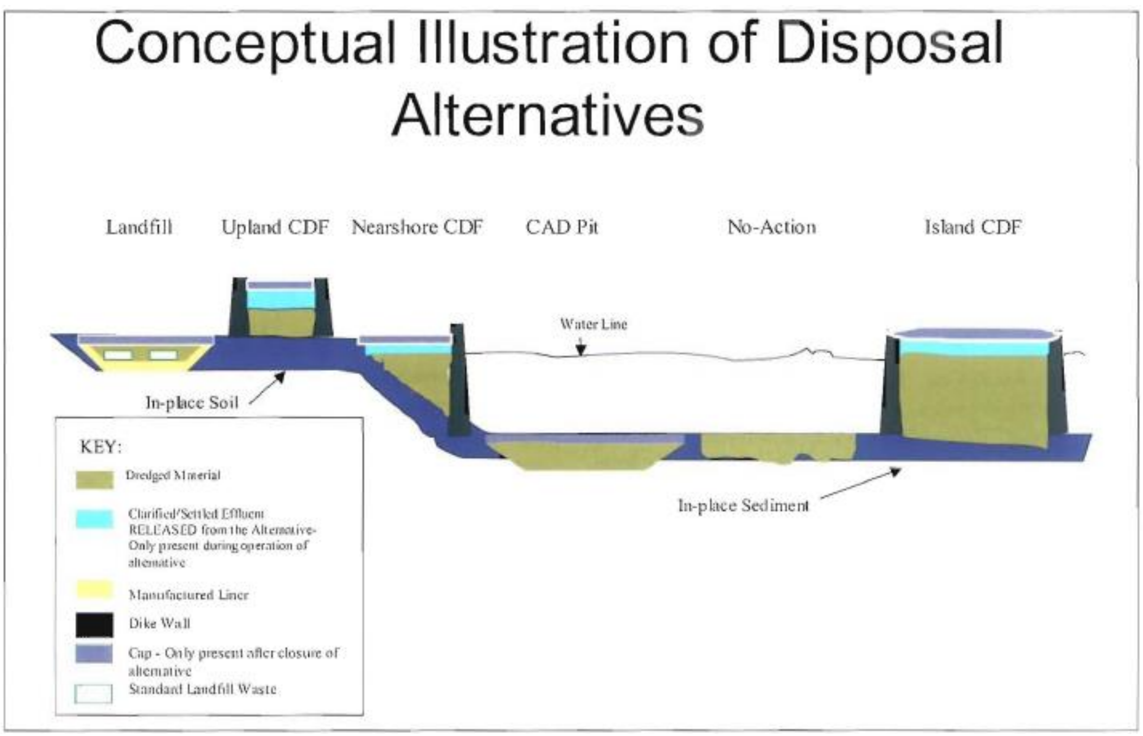

FIGURE 31: SIX DREDGED MATERIALS MANAGEMENT ALTERNATIVES SUBJECT TO A COMPARATIVE RISK ASSESSMENT OF CONTAMINATED MATERIAL (PIANC, 2006).

The different options will be briefly discussed in terms of usability for the maintenance for the Magdalena channel.

7.4.3 LANDFILL, UPLAND CDF OR ISLAND CDF

The first two on the left side: Landfill and upland CDF are considered not feasible due to the distances between the shore and the channel's stretch. At minimum it is about 22 kilometers wide, making the transport of sediments too expensive to be a serious option, certainly with the current environmental situation in the Río de la Plata. The Island CDF is also considered as a less preferred option, because it would mean the construction of an island in somewhere in the middle of the estuary. Ships with low drafts that can sail outside the channel could be hindered by this and it possibly also has a negative impact on aesthetics, flow of currents, and aquatic life in the water.

7.4.4 NO ACTION OR CAD PIT

The remaining options are the most probable options. The disposable sediment is not expected to be significantly more or less contaminated than the water itself. Therefore the easiest and cheapest option in the current situation is to replace the sediment towards locations three kilometers out of the channel on its sides, without containing or cleaning it. This would involve no extra costs other than the actual dredging itself like already happening at the Punta Indio or Intermedio channel. Downturn is that it can hinder wildlife that is disturbed by sounds or dust clouds in the water.

A CAD pit (Confined Aquatic Disposal) or Subaquatic CDF is another option to consider when the sediments are more contaminated than the water itself. The water itself could get less polluted when laws and guidelines change in the upcoming years to tackle water pollution. If this is the case and the sediment actually is more polluted compared to the water, then it is necessary to take additional action. With a CAD pit it is possible to contain the contaminated dredged material by finding a part in the estuary near the channel where physical conditions are relatively calm. Otherwise it is required to dig a hole where the sediment is getting dumped. After the hole is filled with the contaminated sediment, a cap layer is placed in top to prevent the sediments from moving due to water motions above. At the same time the contact with the waterbody above is the biggest concern, since the cap is only placed over the sediment after the hole is filled. In the meantime aquatic organisms can come in contact with contaminated material, so this has to be taken into concern (PIANC, 2002).

7.4.5 NEARSHORE CDF

The excavation of a CAD pit is expensive compared to another option: a nearshore CDF. With the subaquatic pit one cubic unit excavated means one cubic unit of sediment disposal. A nearshore CDF with dikes can give 3 cubic units per cubic unit excavated (PIANC, 2002). Knowing that the costs of a cubic meter of CDF costs 10 dollar or even more (PIANC, 2009) it is obvious that a nearshore CDF can save a lot of money. The choice depends on other factors of course, like the distance, dredging costs or (expected long-term) fuel prices and should be taken into account when making a choice.

7.5 CONCLUDING REMARKS

Considering all effects and risks involved the extra environmental impact of dredging the Magdalena channel is thought to be low compared to the current situation. There might be some effects on the species living and foraging in the area but these effects are not certain until the channel has been dredged. Therefore further research must be done after the channel has been dredged and the ecological situation should be assessed regularly and if necessary, mitigating measures regarding the disposal of dredged materials or turbidity clouds should be taken.

Considering that in the upcoming years nothing will change in the quality of the water, the best option would be to work the same way as it is done in the Intermedio and Punta Indio channel. It is always possible to look at the situation from year to year, although changing to other options will inevitably lead to higher costs.

In case the channel project gets in a more detailed design phase, quantitative research of the environmental impact should be done according to the steps described in the PIANC EnviCom manual (2006).

8. COSTS AND BENEFITS

In this chapter the costs and benefits of the different alternatives will be analysed and discussed. The method to analyse the cost and benefits are based on the Net Present Value (NPV) and the Internal rate of return (IRR). This comprehends that a discount rate is applied to costs and benefits in the future.

8.1 INFLATION AND DISCOUNT RATES

As a cost benefit analysis applies to multiple years, there is an influence of inflation and discount on the costs and benefits over time. It is assumed that all payments and costs are in US dollars (USD) and since the economic situation in Argentina is very unpredictable over longer periods of time, especially with inflation rates and discount rates, average inflation rates are therefore taken from the Eurozone area over the last 10 years, since most dredging companies are based in Europe it is likely for them to adjust prices according to European inflation rates and their investment decision also depends on the common European discount rates for large infrastructure investments.

Concerning the inflation rate, the average inflation rate in the Eurozone is taken from the last 10 years. This mean inflation value is around 1.75% (Trading economics, 2015). In a detailed cost study a more detailed analysis of the local inflation rate is recommended.

The common discount rates for large infrastructural projects in the Netherlands are between 2.50% and 5.00% depending on the risk and economic situation (KiM, 2012). In this study a value of 3.50% is assumed for the cost benefit analysis. Again in a detailed cost study this value should be determined more carefully, or if needed based on Argentinian discount rates.

8.2 COSTS

The costs for dredging a channel are composed of capital dredging and maintenance dredging. These costs are in turn based on a large variety of other costs such as equipment, fuel costs, crew salaries and insurances. These costs have been calculated extensively in chapter 6. The costs of dredging per alternative can now be calculated in Table 18 below. The combination of all costs can be found in the *Appendix L: Cost benefit analysis*.

Alternatives	Capital dredging costs	Maintenance dredging costs/year
0	USD -	USD 13.175.164
1	USD 21.513.550	USD 14.551.673
2A	USD 256.996.209	USD 19.069.575
2B	USD 282.026.510	USD 20.111.789
3	USD 260.512.960	USD 18.735.279
4A	USD 260.512.960	USD 5.560.116
4B	USD 399.487.446	USD 7.705.996

TABLE 18: CAPITAL AND MAINTENANCE DREDGING COSTS PER ALTERNATIVE.

As can be seen in Table 18 the maintenance dredging costs for the new channel are relatively low compared to the current dredging costs. This is because the new channel is shorter than the current one. The combination of two channels will have the highest maintenance costs as expected. Also dredging a new channel will have the highest capital costs, compared to deepening the current channel.

In the cost benefit analysis the costs of maintenance dredging are discounted over the years. The capital dredging costs will remain fixed.

8.3 BENEFITS

The benefits of the navigation channel consists of two types of benefits: benefits for the ship owner and for the channel owner. The benefit for the channel owner is not taken into account, because this is determined after the channel is constructed and is an agreement between different stakeholders. The benefits of the ship-owner will eventually turn out into benefits for the economy of Argentina and are therefore part of the consideration for the decision maker to construct the channel. The benefits of the ship-owner are therefore taken into account for the Cost-Benefit Analysis (CBA). In the next paragraphs the benefits for the ships will be calculated by determining the cost of shipping and the revenue gained by carrying more cargo.

8.3.1 SHIP CHOICE FOR A CHANNEL

If a ship comes from the Brazilian coast or other destinations around the world like Rotterdam, and goes to Buenos Aires or further upstream, the ship can choose between Canal Punta Indio and Magdalena channel.. In this part it is estimated which ships will go through which channels and how many. If it is known which ships will navigate through what channel an estimation can be made regarding the shipping benefits. To know exactly what kind of ships and how many will be taking the different channels is hard to estimate. A lot of factors contribute to this, and this study does use a few assumptions for this. There are three scenarios for the growth of the number of ships. All ship types have their own growth percentages. More information about the calculations can be found in *Appendix L: Cost benefit analysis*.

8.3.2 ASSUMPTIONS

Some assumptions have been made for the determination of costs and income for the ships:

- Fuel bunker prices are $700/ton.
- Ships will be loaded as much as possible.
- Other ships than tankers, bulk carrier & containerships will take Magdalena when going south and will take Punta Indio when going to the Brazilian Coast and further.
- Extra revenue for a larger draft at bulk ships is estimated to be 15 USD/ton, which is the average of the routes China – Rotterdam (capsize) & Rotterdam – Buenos Aires (Panamax)
- Extra revenue for a larger draft at tankers is estimated to be 30 USD/ton, which is the average of the routes China – Rotterdam (capsize) & Rotterdam – Buenos Aires (Panamax)
- Extra revenue for a larger draft at container vessels is estimated by using the shipping price per container (2970 USD), average shipping time between ports and the number of additional containers on a ship type.

Furthermore the study takes into account:

- 3 ship types: Bulk carriers, tankers & Containerships.
- 11 sizes (different drafts) of each type
- Vessel speeds for each ship
- Operating costs per ship type
- Fuel consumption per ship type
- Ships going south & coming from the Brazilian coast or Atlantic destinations.

8.3.3 NUMBER OF SHIPS IN EACH CHANNEL

The calculated numbers of ships per channel for 2016 are summarized below (Table 19). Next to that percentages of traffic per channel for each alternative are given in Table 20 on the next page.

Punta Indio	0 PI	34 PI	36 PI
0 Mag		5005	5005
36 Mag		3736	4469
42 Mag		4469	4469

Magdalena	0 PI	34 PI	36 PI
0 Mag			
36 Mag	5005	1268	536
42 Mag	5005	536	536

TABLE 19: NUMBER OF SHIPS PER CHANNEL FOR EACH ALTERNATIVE.

Alternative 0 and 1 have a logical outcome of 0% taking the Magdalena channel, because this channel simply is not available for these alternatives. For alternative 2A and 2B the number of ships are the same, as both channels of both alternatives will be 36 feet, making containerships always take Punta Indio channel. Only bulk carriers and tankers heading to the south will take the Magdalena channel in both case. In the case ships can choose between taking more cargo or a shorter route, like in alternative 3, then 25% of the ships will take Magdalena. This are mostly bulk carriers and tankers heading south, or large containerships which can take an extra amount of containers making it profitable for them to make a detour, even while it involves extra costs. Alternatives 4A an B are 100%, because all traffic is forced to go through the Magdalena channel, since Punta Indio is closed in these alternatives.

Alternative	Magdalena [ft]	Punta Indio [ft]	Percentage of ships in Magdalena
Alternative 0	0	34	0.0%
Alternative 1	0	36	0.0%
Alternative 2A	36	36	10.7%
Alternative 2B	36	36	10.7%
Alternative 3	36	34	25.3%
Alternative 4A	36	0	100.0%
Alternative 4B	42	0	100.0%

TABLE 20: SHARE OF THE TOTAL AMOUNT OF SHIPS TAKING THE NEW MAGDALENA CHANNEL.

8.3.4 BENEFITS FOR SHIPPING

The final benefits for shipping are of importance for the decision whether to build the channel or not. The benefits of shipping are taken into account in the cost benefit analysis for the channel owner, but are of importance for the decision maker to invest in the channel if this has an indirect effect on the development of the region. Below the benefits for shippers are given in terms of revenue for extra cargo and cost of detours see Table 21, note that only bulk, container and tanker vessels are taken into account for the calculation, the calculation can be found in *Appendix L: Cost benefit analysis***Fout! Verwijzingsbron niet gevonden.**

TABLE 21 BENEFITS FOR SHIPPING RELATIVE TO THE CURRENT SITUATION

Alternatives	*Possible yearly benefits for shipping in 2016**	
0 current situation	USD	-
1 Punta Indio to 36ft	USD	12.286.238
2a Magdalena channel for bulk PI 36 feet	USD	20.395.672
2b Magdalena channel for container PI 36 feet	USD	20.395.672
3 Magdalena to 36 feet PI 34 feet	USD	8.333.213
4a PI closed, Magdalena channel 36 feet	USD	-7.735.528
4b PI closed Magdalena channel 42 feet	USD	37.382.486**

**There are some assumptions made determining the possible benefits above. It is for example assumed that all ships are loaded to their maximum capacity allowed in the channel. In reality most ships entering the Río de la Plata are in ballast, since it is the end of the route.*

***This gives a high benefit for alternative 4b since the extra revenue for container ships is very high although in reality the draft will not reach 42 feet. In case the container vessels are not taken into account, the benefits are actually negative in this alternative.*

The benefits might be over-estimated in general. Therefore the table above should be seen as a relative comparison between the alternatives in terms of the benefits for shipping. In a detailed design study also other factors than revenue and cost of detours should be taken into account, for example the costs of delays and pilotage and the realistic revenue gains of the ships. Some of these factors are accounted for in the Multiple Criteria Analysis.

8.4 NET PRESENT VALUE OF ALL ALTERNATIVES AND SCENARIOS

When all relevant costs and benefits are indicated, the Net Present Value (NPV) can be calculated per year and eventually the total Net present value can be determined for all alternatives and scenarios. The costs of dredging and the benefits of shipping are taken into account. For maintenance dredging and the benefits, a discount rate is applied in order to determine the total NPV until 2035.

TABLE 22: ABSOLUTE VALUES OF NPV.

2016-2035	Normal growth	Low growth	High growth
Scenarios	2,26%	0,834%	3,829%
ALT	*Net result NPV*	*Net result NPV*	*Net result NPV*
0	USD -205.467.769	USD -205.467.769	USD -205.467.769
1	USD -118.305.320	USD -128.102.331	USD -106.195.195
2a	USD -338.345.313	USD -354.608.765	USD -318.241.996
2b	USD -379.629.034	USD -395.892.486	USD -347.057.009
3	USD -464.421.089	USD -471.065.970	USD -456.207.326
4a	USD -429.162.512	USD -422.994.224	USD -436.787.158
4b	USD -123.686.659	USD -153.495.349	USD -86.840.020

**Note that the colour indicators are relative.*

Above the absolute NPV is given for all alternatives, however this might give a non-balanced view on the situation since the benefits of the current channel are hard to measure and therefore 0, but the costs are absolute. Therefore the Cost-benefit analysis in Table 23 has been made relative to the current situation. So the benefits and the maintenance costs of the current situation are considered to be 0. When the costs are higher, the maintenance costs are negative. When the benefits are higher the benefits are positive and vice versa. The CBA calculation is also given in the *Appendix L: Cost benefit analysis*.

TABLE 23: RELATIVE COST BENEFIT ANALYSIS TO CURRENT SITUATION

2016-2035	Normal growth	Low growth	High growth
Scenarios	2,26%	0,834%	3,829%
ALT	*Net result NPV*	*Net result NPV*	*Net result NPV*
0	USD -	USD -	USD -
1	USD 87.162.449	USD 77.365.437	USD 99.272.574
2a	USD -132.877.544	USD -149.140.996	USD -112.774.227
2b	USD -174.161.266	USD -190.424.717	USD -154.057.948
3	USD -258.953.321	USD -265.598.201	USD -250.739.557
4a	USD -223.694.743	USD -217.526.455	USD -231.319.389
4b	USD 81.781.109	USD 51.972.420	USD 118.627.749

The zero and first alternative score the best in the CBA due to the low investments and maintenance cost while maintaining toll income. The maintenance costs for the two-channel alternatives are relatively high, although the new channel has a much lower maintenance cost than the current channel. As can be seen, only *alternative 1 and 4b* have a positive NPV relative to the current situation. As mentioned earlier 4b should not be taken into account as a feasible alternative due to the over-estimation of the shipping benefits.

The results given in Table 23 do not necessarily mean that the most financially favourable option from this analysis is also the most favourable option in general for all stakeholders involved. Therefore next to the CBA, a Multiple Criteria Analysis (MCA) will be made (chapter 9) in order to include other factors into the consideration.

8.5 INTERNAL RATE OF RETURN

In addition to the Net Present Value, the internal rate of return (IRR) for all alternatives is calculated as well. It describes the profitability on investments over time. In Table 24 below the absolute rates of return are given. Again this can give an unbalanced view on the situation but it is necessary to understand that none of the alternatives will be financially feasible over time.

TABLE 24: INTERNAL RATE OF RETURN IN ABSOLUTE NUMBERS.

2016-2035			
Scenarios	Normal	Low	High
ALT	*IRR*	*IRR*	*IRR*
0	N/A	N/A	N/A
1	-3,7%	-3,7%	-3,1%
2a	-4,4%	-4,4%	-4,0%
2b	-4,5%	-4,9%	-3,7%
3	-8,6%	-9,1%	-8,1%
4a	N/A	N/A	N/A
4b	-1,1%	-1,4%	-0,7%

In Table 25 below all IRR values relative to the current situation are given per alternative and for all scenarios.

TABLE 25: INTERNAL RATE OF RETURN RELATIVE TO CURRENT SITUATION

2016-2035			
Scenarios	Normal	Low	High
Alternatives	*IRR*	*IRR*	*IRR*
0	N/A	N/A	N/A
1	5,1%	4,4%	5,5%
2a	-2,0%	-2,1%	-1,6%
2b	-2,4%	-2,7%	-2,0%
3	-5,6%	-6,0%	-5,2%
4a	N/A	N/A	N/A
4b	0,8%	0,5%	1,1%

For most of the alternatives the outcome is negative, since the high investment costs and maintenance costs do not result in enough revenue for shipping. For the first alternative an IRR of 5.1% is found for the normal growth scenario, which is the highest and therefore the most profitable investment. For *alternative 4a* no IRR is found due to the fact that no positive revenue is made from the first year. All other alternatives including alternative 4b are considered not profitable compared to the current situation. 4b has overestimated benefits, as mentioned in the first paragraph and is therefore not considered profitable.

8.6 CONCLUDING REMARKS

Considering all the results from the NPV and the IRR analysis, it can be concluded that none of the alternatives will eventually be profitable from an financial perspective. However from a relative point of view from the current situation, there is improvement to be gained which eventually result in lower costs. The first alternative is considered to be the most favourable from an economical point of view. Alternatives 3 and 4a are considered to be economical infeasible, 4b might also be considered infeasible due to the overestimated shipping benefits. The other alternatives do not have a direct economic advantage over the current situation but could be considered, when for example the political situation in the area changes. This will be considered in the Multiple Criteria Analysis (MCA) in the next chapter.

In a more detailed cost benefit study, the load factors of ships should be determined more precisely and incorporated in the revenues. Also the discount and inflation rates should be chosen more carefully regarding the economic situation.

9. MULTI CRITERIA ANALYSIS (MCA)

The multi criteria analysis is a method to compare different alternatives. To make a proper comparison, there has to be a weight factor to determine the certain importance of the criteria. It is not certain which weighting factors are the most important to the client. Therefore three possible Preferences for weights have been chosen. The used criteria have different values for every preference to make one aspect more important than the other.

In the first called 'economic' the most important criteria is the average time for the ships to go through the area. In the second one, called 'sustainability', the impact on the environment is deemed most important. The third criterion which will be seen as most important is 'construction'. These different Preferences will give different outcomes to the MCA, although it can still lead to the same outcome (e.g. which alternative as the most favorable).

Every alternative gets a score for each criterion on a scale of 1-5 (higher the better). This rating will be multiplied with the weighting factor, to give the ratio between the criteria. The score which will remain, is the total score for that alternative. The alternative with the highest number scores best on the criteria.

9.1 CRITERIA

The criteria which will be used are:

A Time - The vessels have to get from the ocean to inside Río de la Plata. This could for example be to Buenos Aires or Rosario. This study is about the section from the Atlantic ocean to El Codillo. From an economic point of view vessels want to get to their destination as fast as possible keeping waiting time as low as possible. Ships from the south will be much faster though the Magdalena channel.

B Capacity - At this moment there is not any problem with the capacity of the channels, but the new Magdalena channel could give extra capacity needed for the future.

C Navigation & Piloting costs - These costs are not included in the cost-benefit analysis, because they are too complicated to give a good estimation. But relative to the alternatives they can be estimated quite well. A longer channel will have higher piloting and navigation costs than a shorter one.

D Sustainability - In the environmental impact analysis this part is investigated. Creating a new channel will harm the environment more than deepening the current channel.

E Construction – This criterion has the following things taken into consideration: risks while dredging, risks of delays and slope stabilization in the first years (which can lead to a lot of additional sedimentation. There needs to be a certain time for the equilibrium situation to develop. this might take a couple of years).

In Table 26 and Table 27 on the next page weightings and scores are given respectively. All the calculations of the score can be found in *Appendix M: Multi Criteria Analysis.*

		Weighting Possibilities					
	Criterion	Preference 'economic'		Preference 'construction'		Preference 'sustainability'	
Time to get through area	A	5	0.33	4	0.27	3	0.20
Capacity	B	3	0.20	2	0.13	1	0.07
Costs for navigation & pilotage	C	2	0.13	3	0.20	2	0.13
Sustainability	D	1	0.07	1	0.07	5	0.33
Construction (time & possible complications)	E	4	0.27	5	0.33	4	0.27
	∑	15	1	15	1	15	1

TABLE 26: WEIGHTING POSSIBILITIES MCA.

Score							
	Alternative 0	Alternative 1	Alternative 2A	Alternative 2B	Alternative 3	Alternative 4A	Alternative 4B
A	2	2	5	5	5	1	1
B	3	3	4	5	4	4	4
C	4	4	1	1	2	5	5
D	5	4	1	1	2	3	2
E	5	4	2	2	2	2	1

TABLE 27: SCORES MCA.

9.2 RESULTS

The results of the MCA are given in Table 28 on the next page. For all three of the preferences Alternative 0 comes out best. It mainly gives the highest score because there are no risks nor changes for the environment. Also there will only be one channel, which gives relative low navigation & piloting costs. However, this alternative does not lead to an better accessibility for ships with a higher design draft. Alternative 4B (PI closed, MA 42) scores lowest on every preference. This can lead to the conclusion that this alternative is not feasible.

When not taking alternative 0 into account, alternative 2B and 3 are the ones with the highest score when looking at the economic preference. The construction and sustainability preferences both have Alternative 1 (deepening Punta Indio) with the highest score.

When choosing for an alternative with a channel of at least 36 feet, alternative 1, 2B and 3 are possibilities. Alternative 2A scores lower on each preference, making it the least attractive. Alternative 1, 2B and 3 have comparable scores, but 2B score slightly lower than the other two. Therefore alternative 1 and 3 both seem to be the best alternatives in this analysis.

	Alt 0	Alt 1	Alt 2A	Alt 2B	Alt 3	Alt 4A	Alt 4B
Punta Indio [ft]	34	36	36	36	34	0	0
Magdalena [ft]	0	0	36	36	36	36	42
Preference 'economic'	**347**	313	320	**340**	**340**	253	220
Preference 'construction'	**373**	**333**	280	293	307	267	227
Preference 'sustainability'	**413**	**353**	227	233	273	267	207

TABLE 28: RESULTS MCA.

10. CONCLUSION AND RECOMMENDATIONS

CONCLUSION

The construction of the Magdalena Channel is economically infeasible. This is supported by the following assessment tools.

- The result of the Multi Criteria Analysis indicates that Alternative 0-current situation is the best alternative. In this alternative the Punta Indio Channel remains at 34 feet and the Magdalena Channel will not be constructed.
- The Cost Benefit Analysis concludes that none of the alternatives will generate revenue in the considered time period of 20 years. However, compared to the current situation alternative 1 has a higher net present value. In Alternative 1 the Punta Indio Channel will be excavated till 36 feet and the Magdalena Channel will not be constructed.
-

RECOMMENDATIONS

To ensure that the ports of Argentina will be accessible by the predicted ships in the upcoming future, the following actions are recommended:

1. *Design the Punta Indio Channel with the PIANC approach channel guidelines to 36 feet*
   Due to the scope of this report, no detailed design has been developed for the Punta Indio Channel. Making a detailed design will give accurate insights in channel dimensions, hence costs.
2. *Execute a more detailed research regarding the benefits of the Punta Indio Channel*
   The current benefits regarding extra revenue estimations were in a preliminary setting in this report.
3. *A detailed design study regarding the possible new south exit channel in the Río de la Plata is considered obsolete*
   If a detailed design gives more beneficial design specifications for the new Magdalena Channel, it still will not be significant enough to be feasible in the considered time span till 2035.

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APPENDIX A: TRAFFIC ANALYSIS

A.1 BULK CARRIERS

Figure 32 below shows the yearly amount of bulk carriers that has been entering de Punta Indio channel.

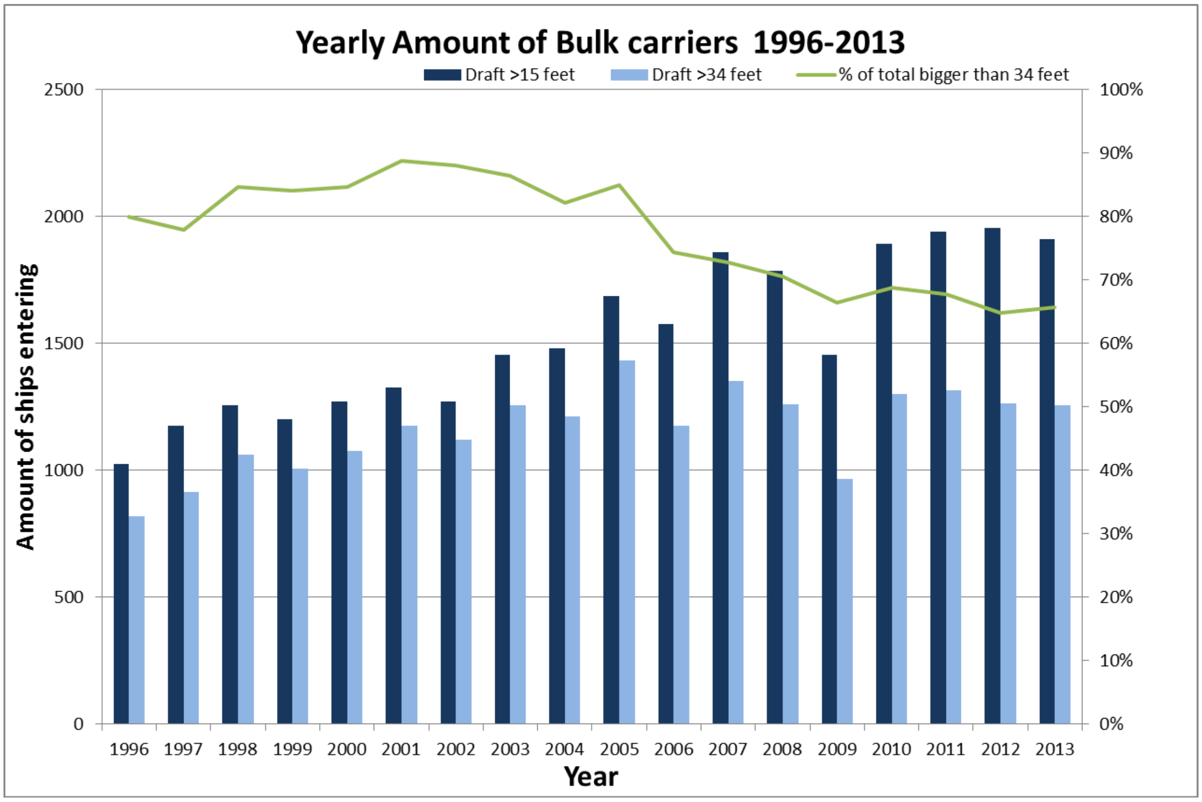


FIGURE 32: AMOUNT OF BULK CARRIERS LARGER THAN 15 FEET ENTERING RÍO DE LA PLATA.

It can clearly been seen that the 1998-2002 crisis in Argentina has had little effect on the bulk carrier traffic. It did stagnate a bit, but this is due to the fact that the dotcom-bubble slowed demand growth in the rest of the world. Since Argentina is a large exporter of agricultural products, most bulk carriers come to Argentina to pick up for example grain or soybeans after which they leave for destination elsewhere around the world. Therefore the crisis in Argentina had much more effect on the import than export and thus having less effect on bulk carrier traffic.

The fact that bulk carrier traffic has doubled since 1996 is not only due to higher exports. Starting from 2006 when 74% of bulk carriers still had a draft larger than 34 feet, this has slowly decreased towards 66%. This implies that the amount of bulk carriers with a lower design draft than 34 feet have been growing faster than the ones with a larger draft, probably because the demand for smaller draft ships has been higher. This could be related with the fact that the channel of Punta Indio is only 34 feet deep, making it more profitable to have a ship with a design draft which is the same or lower as that of the channel. In that case the ship can be fully loaded and does not have to go south again to fill up, saving a lot of time and money.

A.2 CONTAINERSHIPS

The fact that the crisis in Argentina had far more effect on the imports becomes clear when comparing it with containership traffic in Figure 33 below, which has much more variation when looking from year to year than bulk traffic.

Since Argentina is importing a lot of goods coming with containers, container traffic is much more dependent on the economic situation inside the country. Therefore the 1998-2001 crisis lead to a sharp decrease of container traffic and it took until 2008 before the amount of containerships was back on the 1998 level. Although the 2008

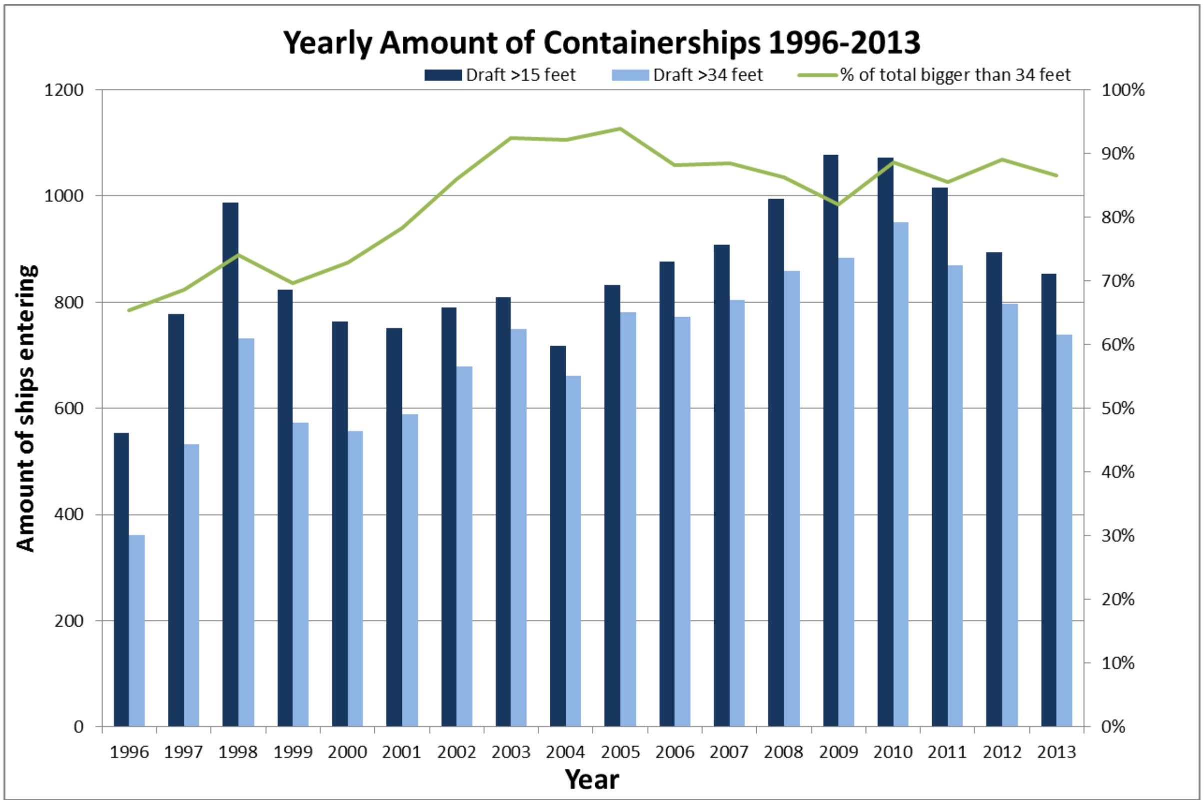


FIGURE 33: AMOUNT OF CONTAINERSHIPS LARGER THAN 15 FEET ENTERING RÍO DE LA PLATA.

crisis did not seem to have a very big impact on the Argentinian imports at first, it has been shrinking since 2011 following the declining national economy of the last few years. In 2013 the amount of container vessels had already descended back to the number it was ten years earlier.

Furthermore it must be noted that the percentage of containerships having a design draft larger than 32/34 feet has sharply risen since 1996. While it was only 65% during that year, nowadays around 90% has a draft deeper than 34 feet. This means that only ten percent of the containerships can enter the Río de la Plata estuary being fully loaded. This is not a big problem for most ships, since Buenos Aires is the last point where they drop off containers before heading back to the north. Still it can be very inconvenient in terms of planning and efficiency, which can make the port of Buenos Aires less attractive for large containerships.

A.3 TANKERS

The economic changes had less effect on the amount of tankers visiting Río de la Plata each year Figure 34. When the crisis started the amount of ships did decline a little bit, but the impact is not as big as with container ships. After the Argentinian crisis the traffic steadily grew towards a number fluctuating between 1050-1200 ships a year and keeps between this range since 2007. The tankers did not change a lot in terms of draft, where the amount of ships above or over 34 feet have an 50/50 spread throughout the years.

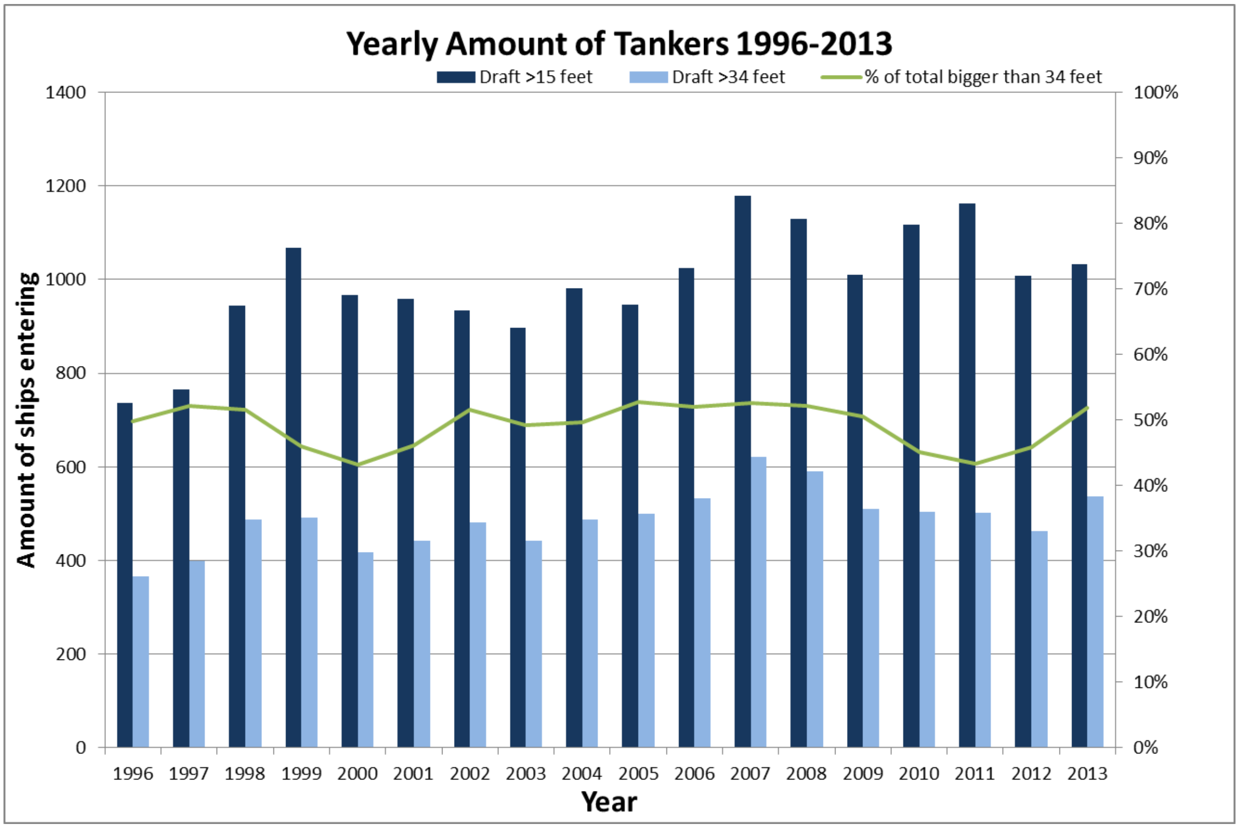


FIGURE 34: AMOUNT OF TANKERS LARGER THAN 15 FEET ENTERING RIO DE LA PLATA.

A.4 GENERAL CARGO

General cargo is part of the traffic gathered under other traffic, but because it has a high impact on the total within this group it will be analyzed under a separate paragraph. The developments can be seen at the general cargo in Figure 35 on the next page. After the crisis of 1998-2002 the amount of general cargo kept shrinking until the bottom was reached in 2005 when the cargo traffic more than halved from 940 to 387. From that year traffic started to recover, until the crisis of 2008 started. From that year on the amount of ships have been oscillating around 500 per year, but has not been near the record of 940 in 1996. The explanation could be in the fact that more and more cargo is containerized, which is much cheaper to transport. There are no remarkable changes noticed in draft. Only that most ships have a draft below 34 feet. This can be derived from the sudden decline in the ratio between 2005 and 2006. This is the year that the channel was deepened to 34 feet and the data was adjusted to this number as well. The amount of ships with a draft over 34 feet has been steady around 15-20% since 2006.

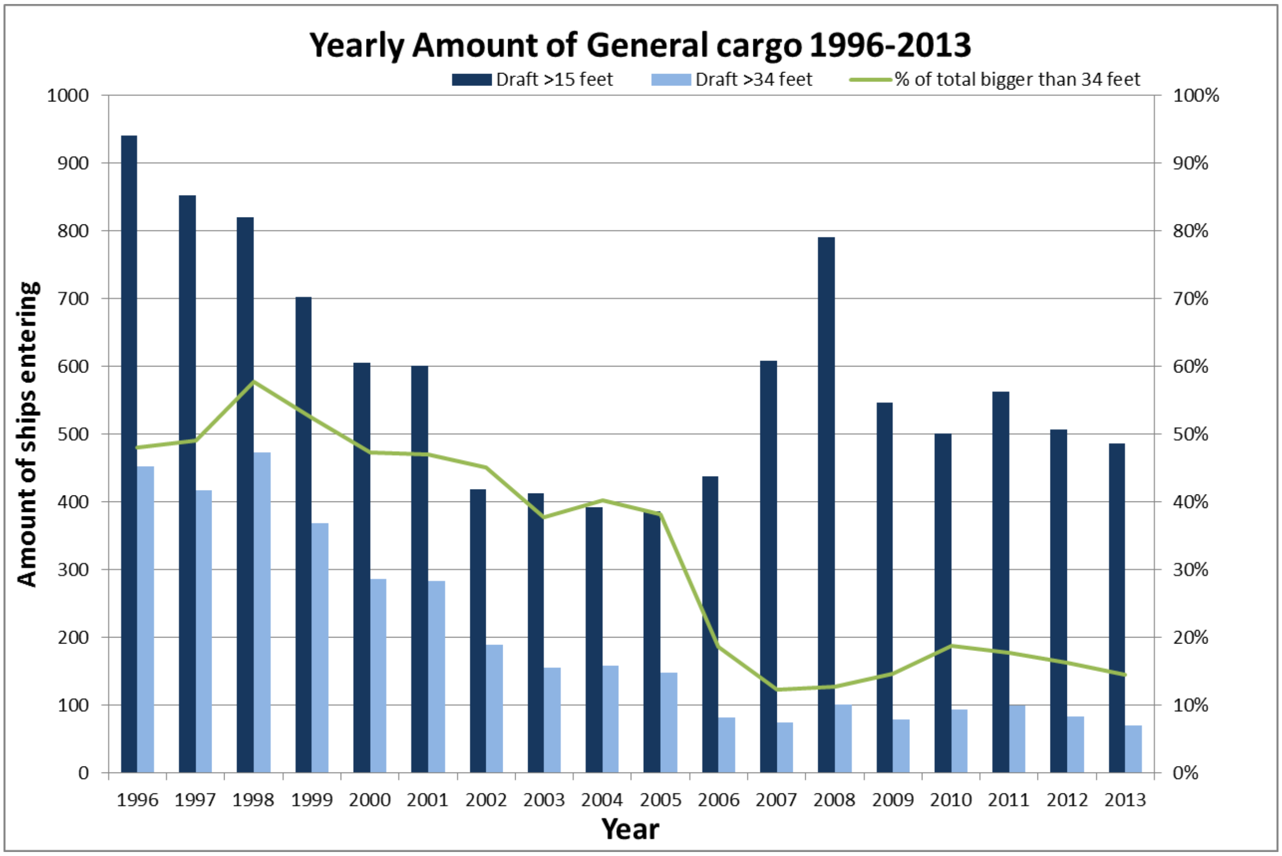


FIGURE 35: AMOUNT OF GENERAL CARGO LARGER THAN 15 FEET ENTERING RIO DE LA PLATA.

A.5 OTHER TRAFFIC

Cruise ships, reefers, car carriers or LNG carrier are other sorts of traffic which make use of the channels. The amount of ships in these categories are relatively small compared to the total. In 2013 it composed less than 10% of total traffic and except for the LNG carriers most ships were within the 15-34 feet range. Cruise ships do not have a large draft, width or length compared to cargo ships, but are much higher. Since height is not relevant to the project it will not be further discussed.

LNG has around 70% with a draft higher than 34 feet (Table 29). This is because the ships carry liquefied gasses, which have an high density and thus are quite heavy. Furthermore the liquids should have a center of gravity that is in line with the water level to prevent the ship from capsizing. This causes the draft of such ships to be relatively high (see Figure 36).

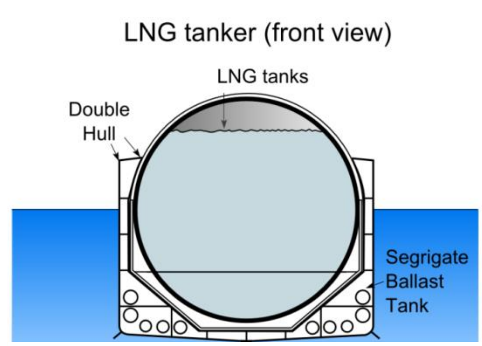


FIGURE 36: SECTION VIEW FROM THE FRONT OF AN LNG TANKER (TOSAKA, N.D.)

The amount of reefers and car carriers has been declining through the years. This is probably because of more containerization in refrigerated containers which can transport perishable products, replacing conventional reefers. Reefers then become unnecessary to transport goods over longer distances and will be a more common sight for local transportation. The decline in car carriers can partly be explained by the declining economy of Argentina. The demand for vehicles will get lower as people do have less money to buy new ones, trying to keep their old vehicles as long as possible.

Amount of LNG tankers			
Draft in feet/Year	2011	2012	2013
> 15 ft	42	53	58
> 34 ft	32	40	40
% of total >34ft	*76%*	*75%*	*69%*

TABLE 29: AMOUNT OF LNG TANKERS LARGER THAN 15 FEET ENTERING RÍO DE LA PLATA.

Amount of cruise ships per year										
Draft in feet	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
> 15 ft	27	46	55	51	60	57	57	62	48	59
> 32 ft	0	5	9	4	0	0	0	0	0	0
% of total >32ft	*0%*	*11%*	*16%*	*8%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**		
> 15 ft	73	85	102	123	143	141	160	159		
> 34 ft	0	0	0	0	0	0	0	0		
% of total >34ft	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*		

TABLE 30: AMOUNT OF CRUISE SHIPS LARGER THAN 15 FEET ENTERING RÍO DE LA PLATA.

Amount of reefers/car carrier/other traffic per year										
Draft in feet	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
> 15 ft	420	438	438	390	384	389	289	267	305	332
> 32 ft	57	55	50	55	30	56	33	12	17	44
% of total >32ft	*14%*	*13%*	*11%*	*14%*	*8%*	*14%*	*11%*	*4%*	*6%*	*13%*
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**		
> 15 ft	329	284	310	243	284	294	275	235		
> 34 ft	27	12	19	22	20	34	24	17		
% of total >34ft	*8%*	*4%*	*6%*	*9%*	*7%*	*12%*	*9%*	*7%*		

TABLE 31: AMOUNT OF OTHER SHIPS LARGER THAN 15 FEET ENTERING RÍO DE LA PLATA.

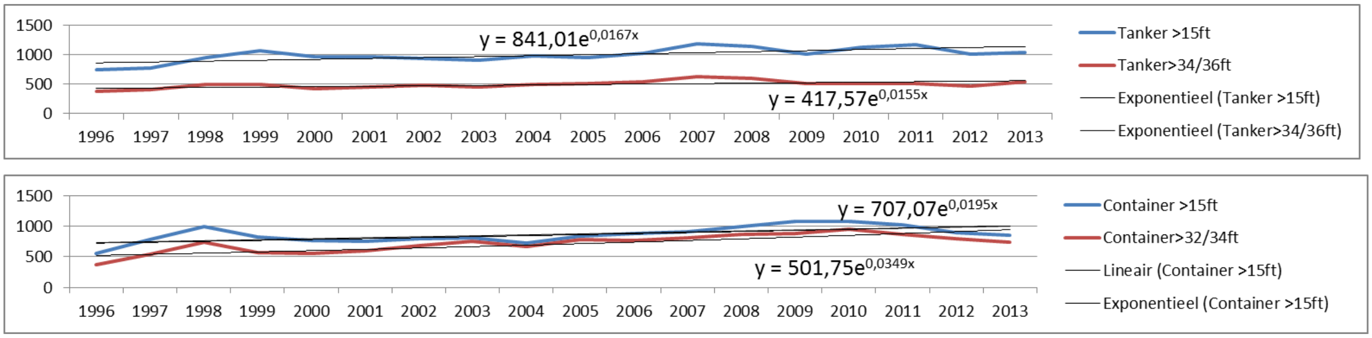


FIGURE 37: DETERMINED YEARLY GROWTH PERCENTAGES FOR TANKERS AND CONTAINER VESSELS.

Future bulk carrier traffic

Argentina is a large exporter of agricultural products like grain and soybeans. The export has been steadily growing as seen in Figure 38 below, which gives the development of the most important agricultural products from 2009 until 2013. This is reflected in the fact that of all ship types bulk traffic has the largest growth rate throughout the years.

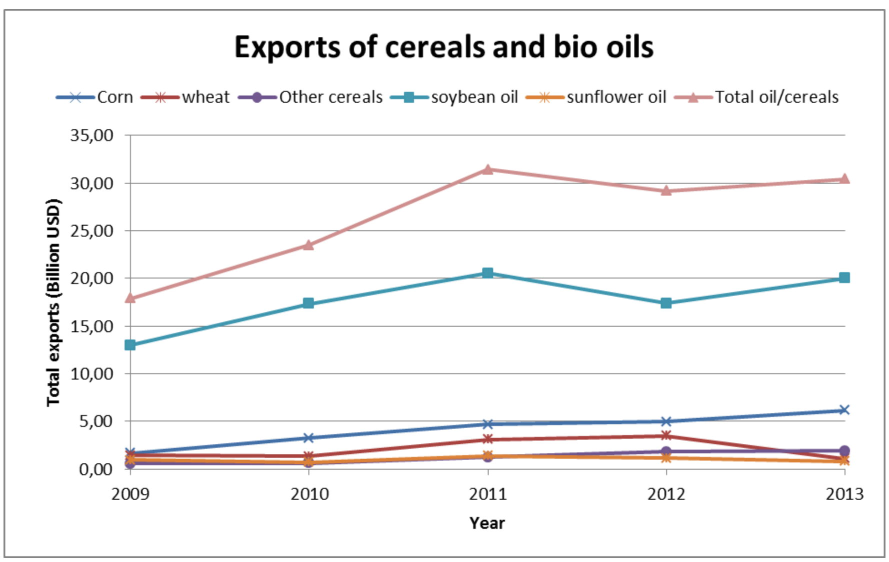


FIGURE 38: ARGENTINIAN EXPORTS OF CEREALS AND BIO OILS BETWEEN 2009 AND 2013 (INDEC, 2014).

The future output of agricultural products will largely influence the development of bulk traffic. It is anticipated that the output will increase over the upcoming years, so a steady growth of ships is a reasonable expectation. In 2035 it is expected that the amount of ships is increasing with more than 1000 (Table 32 on the next page). This is over 70% more traffic than in 2013. The percentage of ships with a design draft deeper than 34 feet is lower in 2035, because it is expected that the amount of smaller bulk carriers is growing faster. Since 17% of bulk traffic is assumed to go southwards it will grow proportional to the growth of the total traffic. *A.7 Growth sheets* has more data on the growth per year per draft.

Draft/year	**2013**	**2035**	**% growth**
Total >34ft	1245	1925	*54.6%*
TOTAL >15ft	1905	3332	*74.9%*
% >34ft	*65%*	*58%*	-

TABLE 32: COMPARISON BETWEEN THE NUMBERS OF BASE YEAR 2013 AND THE PREDICTED NUMBERS OF 2035 FOR BULK CARRIERS.

Future tanker traffic

Tankers are one of the slower growing type of ships. Even so, the amount of tankers has increased more than 40% by 2035 (Table 33). The growth of large draft and smaller draft tankers is comparable, which is why the ratio keeps steady around 50%. Referring back to Figure 38 from the previous paragraph it can be seen that soybean oil is growing quite fast. This growth is expected to keep momentum for a while. It is also possible that more crude oil will be exported or imported, depending on the economic situation. *A.7 Growth sheets* has more data on the growth per year per draft.

Draft/year	**2013**	**2035**	**% growth**
Total >34ft	540	749	*38.7%*
TOTAL >15ft	1050	1488	*41.7%*
% >34ft	*51%*	*50%*	-

TABLE 33: COMPARISON TANKER NUMBERS OF BASE YEAR 2013 AND THE PREDICTED NUMBERS OF 2035 FOR TANKERS.

Future containership traffic

Container traffic is particularly fast growing in the segment of design drafts above 34 feet. In fact it was found out that the growth of large ships can be held accountable for almost all growth that is apparent in the container sector. Looking at *appendix A.2 Containerships* the portion of smaller ships is vastly decreasing, but it is assumed that at least a small portion will remain. For example on shorter routes or when capacity for a certain destination is low. To correct this for the future, growth has been set to zero for the group of ships smaller than 34 feet. The amount for ships larger than 34 feet has increased with more than 90% in 2035 (See

Table 34) below. Since the smaller ships do not increase in amount, this means that from 2013 until 2035 the ratio of >34 feet ships is increasing from 85% to 91%. *A.7 Growth sheets* has more data on the growth per year per draft.

Draft/year	**2013**	**2035**	**% growth**
Total >34ft	715	1.370	*91.6%*
TOTAL >15ft	845	1500	*77.5%*
% >34ft	*85%*	*91%*	-

TABLE 34: COMPARISON BETWEEN THE NUMBERS OF BASE YEAR 2013 AND THE PREDICTED NUMBERS OF 2035 FOR CONTAINERSHIPS.

Large containerships could be important for the effectiveness of alternatives. These ships can make much more revenue when they are able to take more containers. Even if they have to make a detour which takes more time, it could still be more profitable for them if they can take more containers.

Other traffic

Other traffic is decreasing rapidly, especially when looking at the bigger ships. While in 2013 there were still 128 ships with a draft larger than 34 feet, this will have decreased to less than 20 in 2035. As told earlier on this is probably due to more containerization, while smaller ships take care of distributing goods not traveling with container. Most presumably on short distances towards surrounding areas. The only two which are growing are LNG tankers and Cruise ships, but these numbers are considered too small to make a real impact on the usage of the channels.

Draft/year	**2013**	**2035**	**% growth**
Total >34ft	128	14	*-914%*
TOTAL >15ft	983	705	*-28.3%*
% >34ft	*13%*	*2%*	-

TABLE 35: COMPARISON BETWEEN THE NUMBERS OF BASE YEAR 2013 AND THE PREDICTED NUMBERS OF 2035 FOR CONTAINERSHIPS.

A.7 GROWTH SHEETS

							1. NORMAL GROWTH RATE																	
Bulk draft (f	*Averag*	**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22	3,50%	5	5	5	6	6	6	6	6	7	7	7	7	8	8	8	8	9	9	9	10	10	10	11
22-28	3,50%	25	26	27	28	29	30	31	32	33	34	35	36	38	39	40	42	43	45	46	48	50	51	53
28-32	3,50%	210	217	225	233	241	249	258	267	277	286	296	307	317	328	340	352	364	377	390	404	418	432	448
32-34	3,50%	420	435	450	466	482	499	516	534	553	572	592	613	635	657	680	704	728	754	780	807	836	865	895
34-36	2,00%	205	209	213	218	222	226	231	235	240	245	250	255	260	265	270	276	281	287	293	299	305	311	317
36-38	2,00%	100	102	104	106	108	110	113	115	117	120	122	124	127	129	132	135	137	140	143	146	149	152	155
38-40	2,00%	110	112	114	117	119	121	124	126	129	131	134	137	140	142	145	148	151	154	157	160	163	167	170
40-42	2,00%	190	194	198	202	206	210	214	218	223	227	232	236	241	246	251	256	261	266	271	277	282	288	294
42-44	2,00%	125	128	130	133	135	138	141	144	146	149	152	155	159	162	165	168	172	175	179	182	186	189	193
44-48	2,00%	455	464	473	483	493	502	512	523	533	544	555	566	577	589	600	612	625	637	650	663	676	690	703
>48	2,00%	60	61	62	64	65	66	68	69	70	72	73	75	76	78	79	81	82	84	86	87	89	91	93
Total >34ft		**1245**	**1270**	**1295**	**1321**	**1348**	**1375**	**1402**	**1430**	**1459**	**1488**	**1518**	**1548**	**1579**	**1611**	**1643**	**1676**	**1709**	**1743**	**1778**	**1814**	**1850**	**1887**	**1925**
TOTAL >15ft		**1905**	**1953**	**2002**	**2053**	**2105**	**2158**	**2213**	**2270**	**2328**	**2387**	**2449**	**2512**	**2576**	**2643**	**2711**	**2781**	**2854**	**2928**	**3004**	**3083**	**3163**	**3246**	**3332**
% >34ft		*65%*	*65%*	*65%*	*64%*	*64%*	*64%*	*63%*	*63%*	*63%*	*62%*	*62%*	*62%*	*61%*	*61%*	*61%*	*60%*	*60%*	*60%*	*59%*	*59%*	*58%*	*58%*	*58%*
Tanker	*Averag*	**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22	1,70%	80	81	83	84	86	87	89	90	92	93	95	96	98	100	101	103	105	107	108	110	112	114	116
22-28	1,70%	70	71	72	74	75	76	77	79	80	81	83	84	86	87	89	90	92	93	95	96	98	100	101
28-32	1,70%	320	325	331	337	342	348	354	360	366	372	379	385	392	398	405	412	419	426	433	441	448	456	464
32-34	1,70%	40	41	41	42	43	44	44	45	46	47	47	48	49	50	51	52	52	53	54	55	56	57	58
34-36	1,50%	40	41	41	42	42	43	44	44	45	46	46	47	48	49	49	50	51	52	52	53	54	55	56
36-38	1,50%	50	51	52	52	53	54	55	55	56	57	58	59	60	61	62	63	63	64	65	66	67	68	69
38-40	1,50%	150	152	155	157	159	162	164	166	169	172	174	177	179	182	185	188	190	193	196	199	202	205	208
40-42	1,50%	130	132	134	136	138	140	142	144	146	149	151	153	155	158	160	163	165	167	170	173	175	178	180
42-44	1,50%	110	112	113	115	117	119	120	122	124	126	128	130	132	133	135	138	140	142	144	146	148	150	153
44-48	1,50%	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	80	81	82	83
>48	1,50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total >34ft		**540**	**548**	**556**	**565**	**573**	**582**	**590**	**599**	**608**	**617**	**627**	**636**	**646**	**655**	**665**	**675**	**685**	**696**	**706**	**717**	**727**	**738**	**749**
TOTAL >15ft		**1050**	**1067**	**1084**	**1101**	**1119**	**1137**	**1155**	**1173**	**1192**	**1211**	**1230**	**1250**	**1270**	**1290**	**1311**	**1332**	**1353**	**1375**	**1397**	**1419**	**1442**	**1465**	**1488**
% >34ft		*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*50%*	*50%*	*50%*	*50%*
Container dr	*Averag*	**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22	0,00%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-28	0,00%	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
28-32	0,00%	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
32-34	0,00%	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
34-36	3,00%	45	46	48	49	51	52	54	55	57	59	60	62	64	66	68	70	72	74	77	79	81	84	86
36-38	3,00%	70	72	74	76	79	81	84	86	89	91	94	97	100	103	106	109	112	116	119	123	126	130	134
38-40	3,00%	40	41	42	44	45	46	48	49	51	52	54	55	57	59	61	62	64	66	68	70	72	74	77
40-42	3,00%	70	72	74	76	79	81	84	86	89	91	94	97	100	103	106	109	112	116	119	123	126	130	134
42-44	3,00%	25	26	27	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	43	44	45	47	48
44-48	3,00%	465	479	493	508	523	539	555	572	589	607	625	644	663	683	703	724	746	769	792	815	840	865	891
>48	3,00%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total >34ft		**715**	**736**	**759**	**781**	**805**	**829**	**854**	**879**	**906**	**933**	**961**	**990**	**1.019**	**1.050**	**1.082**	**1.114**	**1.147**	**1.182**	**1.217**	**1.254**	**1.291**	**1.330**	**1.370**
TOTAL >15ft		**845**	**866**	**889**	**911**	**935**	**959**	**984**	**1009**	**1036**	**1063**	**1091**	**1120**	**1149**	**1180**	**1212**	**1244**	**1277**	**1312**	**1347**	**1384**	**1421**	**1460**	**1500**
% >34ft		*85%*	*85%*	*85%*	*86%*	*86%*	*86%*	*87%*	*87%*	*87%*	*88%*	*88%*	*88%*	*89%*	*89%*	*89%*	*90%*	*90%*	*90%*	*90%*	*91%*	*91%*	*91%*	*91%*
Others draft (feet)		**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
Total >34ft	-9,5%	128	116	105	95	86	78	70	64	58	52	47	43	39	35	32	29	26	23	21	19	17	16	14
TOTAL >15ft	-1,5%	983	968	954	939	925	911	898	884	871	858	845	832	820	808	796	784	772	760	749	738	727	716	705
% >34ft		13%	12%	11%	10%	9%	9%	8%	7%	7%	6%	6%	5%	5%	4%	4%	4%	3%	3%	3%	3%	2%	2%	2%
TOTALS		**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22		85	87	88	90	91	93	95	96	98	100	102	104	105	107	109	111	113	116	118	120	122	124	127
22-28		115	117	119	121	124	126	128	131	133	136	138	141	143	146	149	152	155	158	161	164	168	171	175
28-32		565	578	591	604	618	633	647	662	678	694	710	727	744	762	780	799	818	838	859	880	901	923	946
32-34		535	550	566	583	600	617	636	654	674	694	715	736	759	782	805	830	856	882	909	938	967	997	1028
34-36		290	296	302	309	315	322	328	335	342	349	357	364	372	380	388	396	404	413	422	431	440	449	459
36-38		220	225	230	235	240	245	251	256	262	268	274	280	286	293	299	306	313	320	327	335	342	350	358
38-40		300	306	311	317	323	329	336	342	349	355	362	369	376	383	390	398	406	413	421	429	438	446	455
40-42		390	398	406	414	422	431	440	449	458	467	477	486	496	506	517	527	538	549	560	572	584	596	608
42-44		260	265	270	275	280	285	291	296	302	308	314	320	326	332	338	345	351	358	365	372	379	386	394
44-48		980	1004	1029	1054	1080	1106	1133	1161	1190	1219	1249	1280	1312	1344	1378	1412	1447	1483	1520	1558	1597	1637	1678
>48		60	61	62	64	65	66	68	69	70	72	73	75	76	78	79	81	82	84	86	87	89	91	93
Total >34ft		**2628**	**2670**	**2715**	**2762**	**2811**	**2863**	**2917**	**2972**	**3030**	**3090**	**3152**	**3217**	**3283**	**3351**	**3421**	**3493**	**3568**	**3644**	**3723**	**3803**	**3886**	**3971**	**4058**
TOTAL >15ft		**4783**	**4854**	**4928**	**5005**	**5084**	**5165**	**5250**	**5337**	**5427**	**5519**	**5615**	**5714**	**5816**	**5921**	**6029**	**6141**	**6256**	**6375**	**6497**	**6623**	**6753**	**6887**	**7025**
% >34ft		*55%*	*55%*	*55%*	*55%*	*55%*	*55%*	*56%*	*56%*	*56%*	*56%*	*56%*	*56%*	*56%*	*57%*	*57%*	*57%*	*57%*	*57%*	*57%*	*57%*	*58%*	*58%*	*58%*

FIGURE 39: NORMAL GROWTH RATE CALCULATION SHEET UNTIL 2035.

2A. LOW GROWTH RATE 15-34 -1,50% >34 -1,50%

Bulk dr	Average	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
15-22	2,00%	5	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	8	8
22-28	2,00%	25	26	26	27	27	28	28	29	29	30	30	31	32	32	33	34	34	35	36	36	37	38	39
28-32	2,00%	210	214	218	223	227	232	236	241	246	251	256	261	266	272	277	283	288	294	300	306	312	318	325
32-34	2,00%	420	428	437	446	455	464	473	482	492	502	512	522	533	543	554	565	577	588	600	612	624	637	649
34-36	0,50%	205	206	207	208	209	210	211	212	213	214	215	217	218	219	220	221	222	223	224	225	227	228	229
36-38	0,50%	100	101	101	102	102	103	103	104	104	105	105	106	106	107	107	108	108	109	109	110	110	111	112
38-40	0,50%	110	111	111	112	112	113	113	114	114	115	116	116	117	117	118	119	119	120	120	121	122	122	123
40-42	0,50%	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
42-44	0,50%	125	126	126	127	128	128	129	129	130	131	131	132	133	133	134	135	135	136	137	137	138	139	139
44-48	0,50%	455	457	460	462	464	466	469	471	474	476	478	481	483	485	488	490	493	495	498	500	503	505	508
>48	0,50%	60	60	61	61	61	62	62	62	62	63	63	63	64	64	64	65	65	65	66	66	66	67	67
Total >34ft		**1245**	**1251**	**1257**	**1264**	**1270**	**1276**	**1283**	**1289**	**1296**	**1302**	**1309**	**1315**	**1322**	**1328**	**1335**	**1342**	**1348**	**1355**	**1362**	**1369**	**1376**	**1382**	**1389**
TOTAL >15ft		**2285**	**1924**	**1944**	**1964**	**1984**	**2005**	**2026**	**2047**	**2069**	**2091**	**2113**	**2136**	**2159**	**2182**	**2206**	**2230**	**2254**	**2279**	**2305**	**2330**	**2356**	**2383**	**2410**
% >34ft		**4470**	*65%*	*65%*	*64%*	*64%*	*64%*	*63%*	*63%*	*63%*	*62%*	*62%*	*62%*	*61%*	*61%*	*61%*	*60%*	*60%*	*59%*	*59%*	*59%*	*58%*	*58%*	*58%*
Tanker	*Average*	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
15-22	0,20%	80	80	80	80	81	81	81	81	81	81	82	82	82	82	82	82	83	83	83	83	83	83	84
22-28	0,20%	70	70	70	70	71	71	71	71	71	71	71	72	72	72	72	72	72	72	73	73	73	73	73
28-32	0,20%	320	321	321	322	323	323	324	325	325	326	326	327	328	328	329	330	330	331	332	332	333	334	334
32-34	0,20%	40	40	40	40	40	40	40	41	41	41	41	41	41	41	41	41	41	41	41	42	42	42	42
34-36	0,00%	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
36-38	0,00%	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
38-40	0,00%	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
40-42	0,00%	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
42-44	0,00%	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
44-48	0,00%	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
>48	0,00%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total >34ft		**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**	**540**
TOTAL >15ft		**1050**	**1051**	**1052**	**1053**	**1054**	**1055**	**1056**	**1057**	**1058**	**1059**	**1060**	**1061**	**1062**	**1063**	**1064**	**1066**	**1067**	**1068**	**1069**	**1070**	**1071**	**1072**	**1073**
% >34ft		*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*50%*	*50%*	*50%*	*50%*
Contai	*Average*	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
15-22	-1,50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-28	-1,50%	20	20	19	19	19	19	18	18	18	17	17	17	17	16	16	16	16	15	15	15	15	15	14
28-32	-1,50%	35	34	34	33	33	32	32	31	31	31	30	30	29	29	28	28	27	27	27	26	26	25	25
32-34	-1,50%	75	74	73	72	71	70	68	67	66	65	64	64	63	62	61	60	59	58	57	56	55	55	54
34-36	1,50%	45	46	46	47	48	48	49	50	51	51	52	53	54	55	55	56	57	58	59	60	61	62	62
36-38	1,50%	70	71	72	73	74	75	77	78	79	80	81	82	84	85	86	88	89	90	92	93	94	96	97
38-40	1,50%	40	41	41	42	42	43	44	44	45	46	46	47	48	49	49	50	51	52	52	53	54	55	56
40-42	1,50%	70	71	72	73	74	75	77	78	79	80	81	82	84	85	86	88	89	90	92	93	94	96	97
42-44	1,50%	25	25	26	26	27	27	27	28	28	29	29	29	30	30	31	31	32	32	33	33	34	34	35
44-48	1,50%	465	472	479	486	494	501	508	516	524	532	540	548	556	564	573	581	590	599	608	617	626	636	645
>48	1,50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total >34ft		**715**	**726**	**737**	**748**	**759**	**770**	**782**	**794**	**805**	**818**	**830**	**842**	**855**	**868**	**881**	**894**	**907**	**921**	**935**	**949**	**963**	**977**	**992**
TOTAL >15ft		**845**	**854**	**863**	**872**	**881**	**891**	**901**	**910**	**921**	**931**	**942**	**952**	**963**	**975**	**986**	**998**	**1009**	**1021**	**1034**	**1046**	**1059**	**1072**	**1085**
% >34ft		*85%*	*85%*	*85%*	*86%*	*86%*	*86%*	*87%*	*87%*	*87%*	*88%*	*88%*	*88%*	*89%*	*89%*	*89%*	*90%*	*90%*	*90%*	*90%*	*91%*	*91%*	*91%*	*91%*
Others draft (fee		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Total >	-11,00%	128	114	101	90	80	71	64	57	50	45	40	36	32	28	25	22	20	18	16	14	12	11	10
TOTAL	-3,00%	983	954	925	897	870	844	819	794	770	747	725	703	682	662	642	622	604	586	568	551	535	519	503
% >34ft		13%	12%	11%	10%	9%	8%	8%	7%	7%	6%	6%	5%	5%	4%	4%	4%	3%	3%	3%	3%	2%	2%	2%
TOTALS		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
15-22		85	85	86	86	86	86	87	87	87	87	88	88	88	89	89	89	89	90	90	90	91	91	91
22-28		115	115	116	116	116	117	117	118	118	119	119	120	120	121	121	122	122	123	124	124	125	125	126
28-32		565	569	574	578	583	588	592	597	602	607	613	618	623	629	634	640	646	652	658	665	671	677	684
32-34		535	542	550	558	566	574	582	590	599	608	617	627	636	646	656	666	677	687	698	710	721	733	745
34-36		290	292	293	295	297	299	300	302	304	306	308	310	311	313	315	317	319	321	323	325	327	329	331
36-38		220	222	223	225	226	228	230	231	233	235	236	238	240	242	243	245	247	249	251	253	255	257	259
38-40		300	301	302	303	305	306	307	308	310	311	312	313	315	316	317	319	320	321	323	324	325	327	328
40-42		390	392	394	396	398	400	402	404	407	409	411	413	415	418	420	422	425	427	429	432	434	437	439
42-44		260	261	262	263	264	265	266	267	268	269	270	271	273	274	275	276	277	278	279	281	282	283	284
44-48		980	989	999	1008	1018	1027	1037	1047	1057	1068	1078	1088	1099	1110	1121	1132	1143	1154	1166	1177	1189	1201	1213
>48		60	60	61	61	61	62	62	62	62	63	63	63	64	64	64	65	65	65	66	66	66	67	67
Total >34ft		**2628**	**2631**	**2635**	**2642**	**2649**	**2658**	**2668**	**2679**	**2692**	**2705**	**2718**	**2733**	**2748**	**2764**	**2781**	**2798**	**2816**	**2834**	**2852**	**2872**	**2891**	**2911**	**2931**
TOTAL >15ft		**4783**	**4783**	**4784**	**4786**	**4790**	**4795**	**4802**	**4809**	**4818**	**4828**	**4840**	**4853**	**4867**	**4882**	**4898**	**4916**	**4934**	**4954**	**4975**	**4997**	**5021**	**5045**	**5071**
% >34ft		*55%*	*55%*	*55%*	*55%*	*55%*	*55%*	*56%*	*56%*	*56%*	*56%*	*56%*	*56%*	*56%*	*57%*	*57%*	*57%*	*57%*	*57%*	*57%*	*57%*	*58%*	*58%*	*58%*

FIGURE 40: LOW GROWTH RATE CALCULATION SHEET UNTIL 2035.

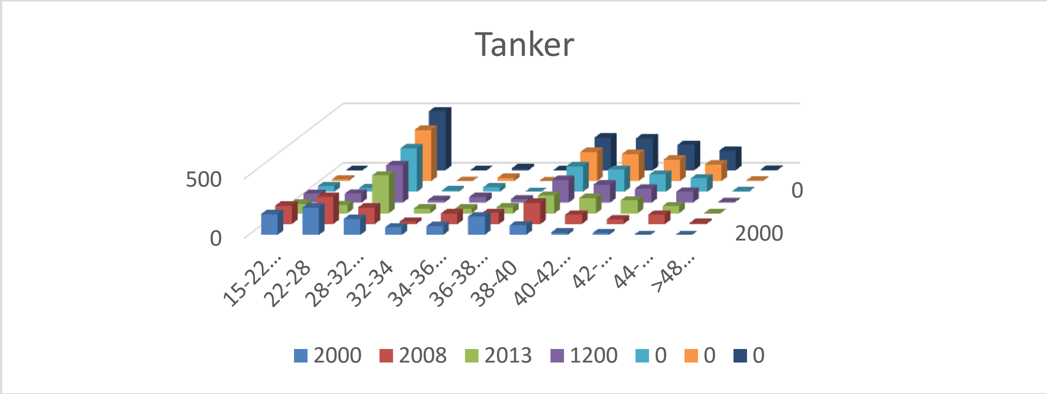
3A. HIGH GROWTH RATE 15-34 1,50% >34 1,50%

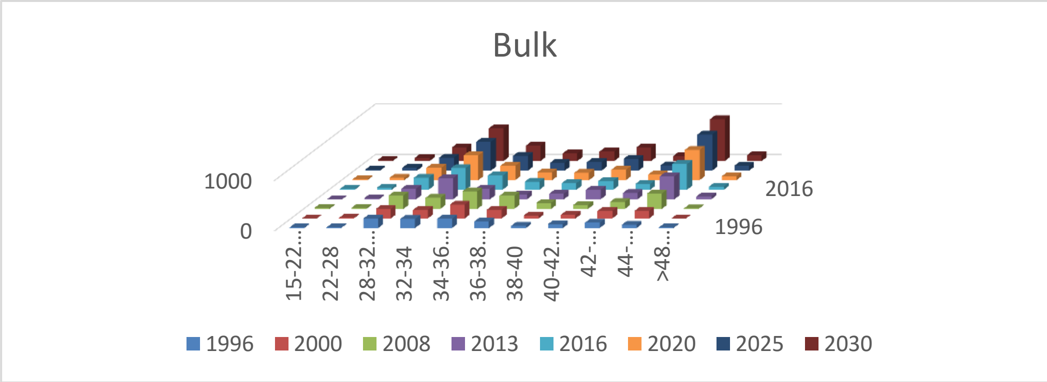
Bulk dr Averag		**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22	5,00%	5	5	6	6	6	6	7	7	7	8	8	9	9	9	10	10	11	11	12	13	13	14	15
22-28	5,00%	25	26	28	29	30	32	34	35	37	39	41	43	45	47	49	52	55	57	60	63	66	70	73
28-32	5,00%	210	221	232	243	255	268	281	295	310	326	342	359	377	396	416	437	458	481	505	531	557	585	614
32-34	5,00%	420	441	463	486	511	536	563	591	621	652	684	718	754	792	832	873	917	963	1.011	1.061	1.114	1.170	1.229
34-36	3,50%	205	212	220	227	235	243	252	261	270	279	289	299	310	321	332	343	355	368	381	394	408	422	437
36-38	3,50%	100	104	107	111	115	119	123	127	132	136	141	146	151	156	162	168	173	179	186	192	199	206	213
38-40	3,50%	110	114	118	122	126	131	135	140	145	150	155	161	166	172	178	184	191	197	204	211	219	227	234
40-42	3,50%	190	197	204	211	218	226	234	242	250	259	268	277	287	297	308	318	329	341	353	365	378	391	405
42-44	3,50%	125	129	134	139	143	148	154	159	165	170	176	182	189	195	202	209	217	224	232	240	249	257	266
44-48	3,50%	455	471	487	504	522	540	559	579	599	620	642	664	688	712	737	762	789	817	845	875	905	937	970
>48	3,50%	60	62	64	67	69	71	74	76	79	82	85	88	91	94	97	101	104	108	111	115	119	124	128
Total >34ft		**1245**	**1289**	**1334**	**1380**	**1429**	**1479**	**1530**	**1584**	**1639**	**1697**	**1756**	**1818**	**1881**	**1947**	**2015**	**2086**	**2159**	**2234**	**2313**	**2394**	**2477**	**2564**	**2654**
TOTAL >15ft		**1905**	**1982**	**2061**	**2144**	**2231**	**2321**	**2415**	**2513**	**2615**	**2721**	**2831**	**2946**	**3067**	**3192**	**3322**	**3458**	**3600**	**3747**	**3901**	**4061**	**4228**	**4403**	**4584**
% >34ft		*65%*	*65%*	*65%*	*64%*	*64%*	*64%*	*63%*	*63%*	*63%*	*62%*	*62%*	*62%*	*61%*	*61%*	*61%*	*60%*	*60%*	*60%*	*59%*	*59%*	*59%*	*58%*	*58%*
Tanker Averag		**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22	3,20%	80	83	85	88	91	94	97	100	103	106	110	113	117	120	124	128	132	137	141	146	150	155	160
22-28	3,20%	70	72	75	77	79	82	85	87	90	93	96	99	102	105	109	112	116	120	123	127	131	136	140
28-32	3,20%	320	330	341	352	363	375	387	399	412	425	438	453	467	482	497	513	530	547	564	582	601	620	640
32-34	3,20%	40	41	43	44	45	47	48	50	51	53	55	57	58	60	62	64	66	68	71	73	75	78	80
34-36	3,00%	40	41	42	44	45	46	48	49	51	52	54	55	57	59	61	62	64	66	68	70	72	74	77
36-38	3,00%	50	52	53	55	56	58	60	61	63	65	67	69	71	73	76	78	80	83	85	88	90	93	96
38-40	3,00%	150	155	159	164	169	174	179	184	190	196	202	208	214	220	227	234	241	248	255	263	271	279	287
40-42	3,00%	130	134	138	142	146	151	155	160	165	170	175	180	185	191	197	203	209	215	221	228	235	242	249
42-44	3,00%	110	113	117	120	124	128	131	135	139	144	148	152	157	162	166	171	177	182	187	193	199	205	211
44-48	3,00%	60	62	64	66	68	70	72	74	76	78	81	83	86	88	91	93	96	99	102	105	108	112	115
>48	3,00%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total >34ft		**540**	**556**	**573**	**590**	**608**	**626**	**645**	**664**	**684**	**705**	**726**	**747**	**770**	**793**	**817**	**841**	**867**	**893**	**919**	**947**	**975**	**1005**	**1035**
TOTAL >15ft		**1050**	**1083**	**1116**	**1151**	**1186**	**1223**	**1261**	**1300**	**1340**	**1382**	**1425**	**1469**	**1514**	**1561**	**1609**	**1659**	**1711**	**1764**	**1818**	**1875**	**1933**	**1993**	**2055**
% >34ft		*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*51%*	*50%*	*50%*	*50%*
Contai Averag		**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22	1,50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-28	1,50%	20	20	21	21	21	22	22	22	23	23	23	24	24	24	25	25	25	26	26	27	27	27	28
28-32	1,50%	35	36	36	37	37	38	38	39	39	40	41	41	42	42	43	44	44	45	46	46	47	48	49
32-34	1,50%	75	76	77	78	80	81	82	83	84	86	87	88	90	91	92	94	95	97	98	100	101	103	104
34-36	4,50%	45	47	49	51	54	56	59	61	64	67	70	73	76	80	83	87	91	95	99	104	109	113	119
36-38	4,50%	70	73	76	80	83	87	91	95	100	104	109	114	119	124	130	135	142	148	155	162	169	176	184
38-40	4,50%	40	42	44	46	48	50	52	54	57	59	62	65	68	71	74	77	81	85	88	92	96	101	105
40-42	4,50%	70	73	76	80	83	87	91	95	100	104	109	114	119	124	130	135	142	148	155	162	169	176	184
42-44	4,50%	25	26	27	29	30	31	33	34	36	37	39	41	42	44	46	48	51	53	55	58	60	63	66
44-48	4,50%	465	486	508	531	555	579	606	633	661	691	722	755	789	824	861	900	940	983	1.027	1.073	1.121	1.172	1.225
>48	4,50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total >34ft		**715**	**747**	**781**	**816**	**853**	**891**	**931**	**973**	**1.017**	**1.063**	**1.110**	**1.160**	**1.213**	**1.267**	**1.324**	**1.384**	**1.446**	**1.511**	**1.579**	**1.650**	**1.724**	**1.802**	**1.883**
TOTAL >15ft		**845**	**879**	**915**	**952**	**991**	**1031**	**1073**	**1117**	**1163**	**1211**	**1261**	**1313**	**1368**	**1425**	**1484**	**1546**	**1611**	**1679**	**1749**	**1823**	**1899**	**1980**	**2063**
% >34ft		*85%*	*85%*	*85%*	*86%*	*86%*	*86%*	*87%*	*87%*	*87%*	*88%*	*88%*	*88%*	*89%*	*89%*	*89%*	*89%*	*90%*	*90%*	*90%*	*91%*	*91%*	*91%*	*91%*
Others draft (fe		**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
Total >	-8,00%	128	118	108	100	92	84	78	71	66	60	56	51	47	43	40	37	34	31	29	26	24	22	20
TOTAL	0,00%	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983	983
% >34ft		13%	12%	11%	10%	9%	9%	8%	7%	7%	6%	6%	5%	5%	4%	4%	4%	3%	3%	3%	3%	2%	2%	2%
TOTALS		**2013**	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
15-22		85	88	91	94	97	100	103	107	110	114	118	122	126	130	134	139	143	148	153	158	163	169	175
22-28		115	119	123	127	131	135	140	145	150	155	160	165	171	177	183	189	196	203	210	217	225	233	241
28-32		565	586	608	631	655	680	706	733	761	791	821	853	886	920	956	994	1033	1073	1115	1159	1205	1253	1303
32-34		535	558	583	609	635	664	693	724	756	790	826	863	902	943	986	1031	1078	1128	1179	1234	1291	1350	1413
34-36		290	300	311	322	334	346	358	371	385	398	413	428	443	459	476	493	511	529	548	568	589	610	632
36-38		220	228	237	245	255	264	274	284	295	306	317	329	341	354	367	381	395	410	425	441	458	475	493
38-40		300	310	321	332	343	354	366	379	392	405	419	433	448	463	479	495	512	530	548	567	586	606	627
40-42		390	404	418	433	448	464	480	497	514	533	551	571	591	612	634	656	680	704	729	755	782	810	838
42-44		260	269	278	287	297	307	318	328	339	351	363	375	388	401	415	429	444	459	475	491	508	525	543
44-48		980	1019	1059	1101	1144	1189	1237	1285	1336	1389	1445	1502	1562	1624	1688	1756	1826	1898	1974	2053	2135	2221	2309
>48		60	62	64	67	69	71	74	76	79	82	85	88	91	94	97	101	104	108	111	115	119	124	128
Total >34ft		**2628**	**2710**	**2796**	**2886**	**2981**	**3080**	**3184**	**3293**	**3406**	**3524**	**3648**	**3777**	**3911**	**4051**	**4196**	**4347**	**4505**	**4669**	**4839**	**5017**	**5201**	**5393**	**5592**
TOTAL >15ft		**4783**	**4926**	**5075**	**5230**	**5391**	**5558**	**5732**	**5913**	**6101**	**6297**	**6500**	**6712**	**6932**	**7161**	**7399**	**7646**	**7904**	**8172**	**8451**	**8742**	**9044**	**9358**	**9685**
% >34ft		*55%*	*55%*	*55%*	*55%*	*55%*	*55%*	*56%*	*56%*	*56%*	*56%*	*56%*	*56%*	*56%*	*57%*	*57%*	*57%*	*57%*	*57%*	*57%*	*57%*	*58%*	*58%*	*58%*

FIGURE 41: HIGH GROWTH RATE CALCULATION SHEET UNTIL 2035.

APPENDIX B: DESIGN SHIP

B.1 FUTURE DRAFT ESTIMATION: NUMBER OF SHIPS





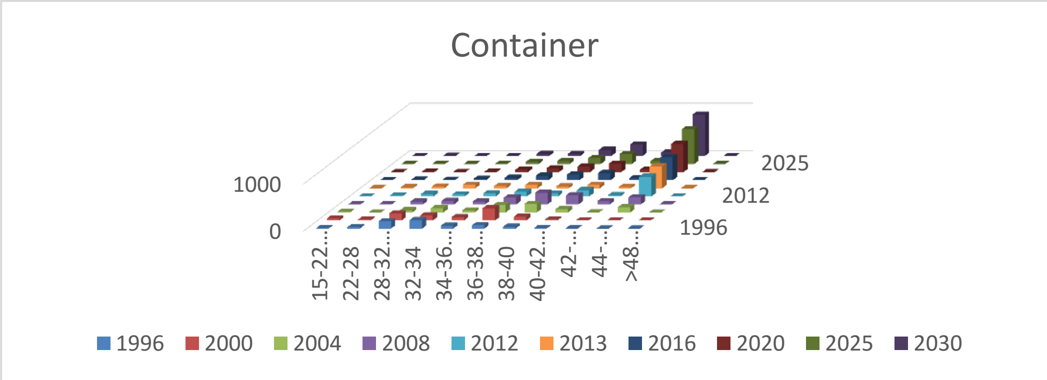


FIGURE 42: FUTURE DRAFT ESTIMATION FOR TANKERS, BULK CARRIERS AND CONTAINERSHIPS.

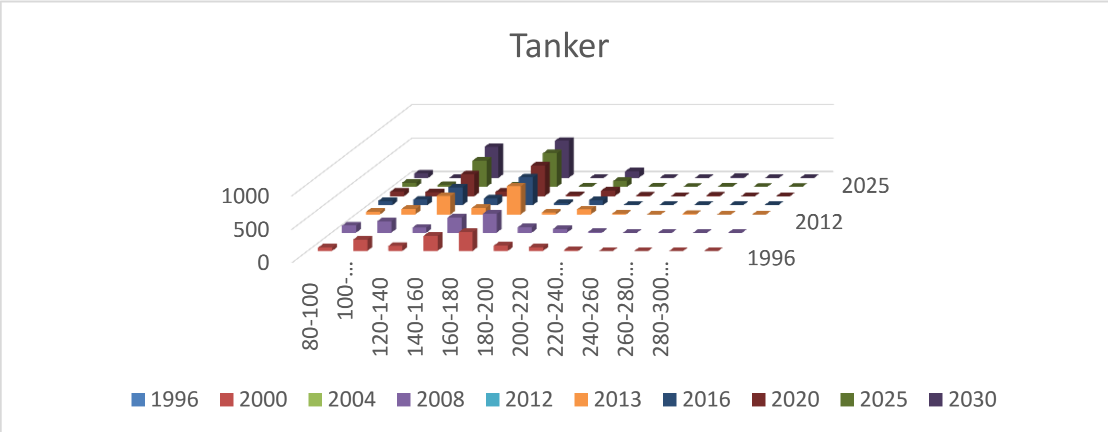
B.2 FUTURE BEAM ESTIMATION: NUMBER OF SHIPS

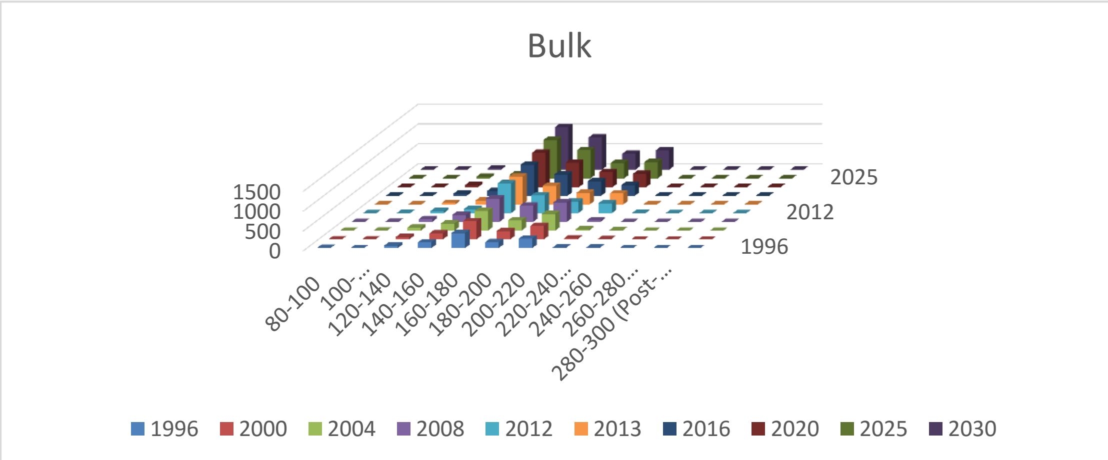
Future BULK	1996	2000	2004	2008	2012	2013	2016	2020	2025	2030
14-16	15	10	10	1	10	0	2	0	0	0
16-18	12	5	15	20	10	0	8	7	6	4
18-20	40	30	20	5	2	5	0	0	0	0
20-22	250	280	200	220	110	90	64	10	0	0
22-24	150	150	205	190	130	110	122	106	86	66
24-26	180	180	220	270	290	290	325	360	404	447
26-28	80	120	110	170	330	360	389	469	569	668
28-30	80	100	110	170	100	70	98	93	86	80
30-32 Panamax	200	380	510	690	780	830	934	1072	1244	1416
32-34	5	2	10	10	0	0	1	0	0	0
34-36	2	0	0	0	110	110	125	163	210	257
36-38	2	1	0	0	0	0	0	0	0	0
38-40	1	1	2	0	0	0	0	0	0	0
40-42	0	0	1	0	5	10	9	11	14	18
42-44	0	0	0	0	2	0	1	1	2	2
44-46	0	0	0	0	0	0	0	0	0	0
46-48 New panamax	0	0	0	0	0	0	0	0	0	0
48-50 Capesize	0	0	0	0	0	0	0	0	0	0

Future CONTAINER	1996	2000	2004	2008	2012	2013	2016	2020	2025	2030
14-16	20	5	0	0	0	0	0	0	0	0
16-18	25	40	30	0	0	0	0	0	0	0
18-20	120	70	75	0	0	0	0	0	0	0
20-22	150	180	70	0	0	0	0	0	0	0
22-24	90	190	100	20	50	10	3	0	0	0
24-26	20	60	20	70	40	80	71	79	90	101
26-28	80	160	360	70	50	60	73	52	25	0
28-30	0	0	0	120	90	80	117	143	176	208
30-32 Panamax	0	0	50	50	25	20	41	47	55	63
32-34	0	0	0	560	230	110	322	387	469	551
34-36	0	0	0	0	20	20	20	25	31	37
36-38	0	0	0	0	10	20	15	19	23	28
38-40	0	0	0	80	230	250	258	321	399	478
40-42	0	0	0	0	25	10	17	21	26	31
42-44	0	0	0	0	0	100	51	64	81	97
44-46	0	0	0	0	0	**60**	31	39	49	58
46-48 New panamax	0	0	0	0	0	0	0	0	0	0
48-50 Capesize	0	0	0	0	0	20	10	13	16	19

Future TANKER	1996	2000	2004	2008	2012	2013	2016	2020	2025	2030
14-16	55	30	10	30	0	20	2	0	0	0
16-18	60	40	60	60	50	40	47	45	43	40
18-20	100	130	125	165	90	45	85	76	65	53
20-22	50	95	140	75	70	100	97	100	104	108
22-24	75	190	50	70	180	200	174	192	214	237
24-26	110	110	90	65	100	90	80	75	69	62
26-28	50	60	130	115	100	120	134	149	168	186
28-30	30	80	80	60	10	5	17	6	0	0
30-32 Panamax	20	30	40	60	25	30	40	42	45	47
32-34	70	90	180	340	300	**355**	409	480	568	657
34-36	30	20	10	0	5	0	0	0	0	0
36-38	40	55	0	0	0	0	0	0	0	0
38-40	0	0	0	20	0	15	13	16	20	23
40-42	0	0	0	10	0	2	4	5	5	6
42-44	0	0	0	0	0	**4**	2	3	3	4
44-46	0	0	0	0	0	0	0	0	0	0
46-48 New panamax	0	0	0	0	0	0	0	0	0	0
48-50 Capesize	0	0	0	0	0	0	0	0	0	0

FIGURE 43: FUTURE BEAM ESTIMATION FOR TANKERS, BULK CARRIERS AND CONTAINERSHIPS.





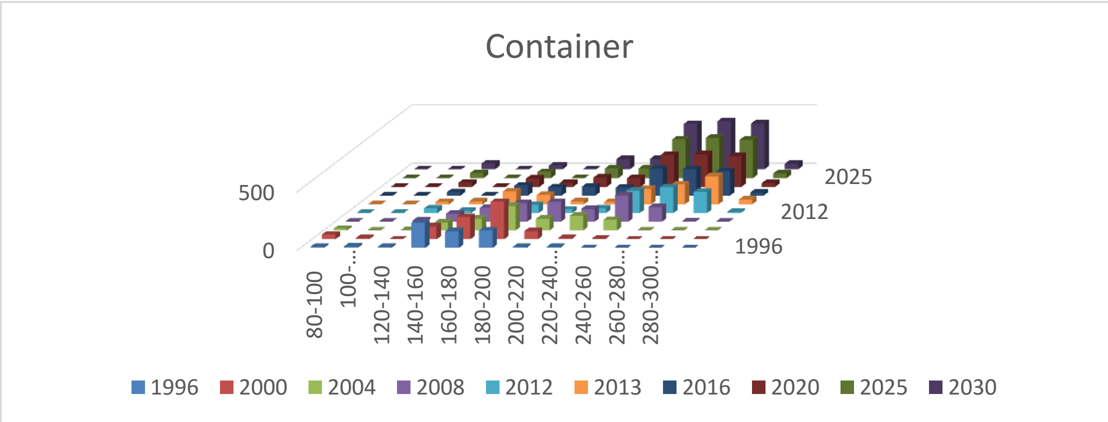


FIGURE 44: FUTURE LENGTH ESTIMATION FOR TANKERS, BULK CARRIERS AND CONTAINERSHIPS.

B.4 TYPICAL SHIP CHARACTERISTICS FROM ROM 3.1(PIANC, 2014),

ROM 3.1(PIANC, 2014)							3		Surface		Speed in RDP		Cannot navigate in cu
Tanker	DWTx1000	Deltamx1C	Loa(m)	Lpp(m)	B(m)	T(draft r	Draft fee	Cb	Av frontal	Av latera	kn	Load	Can navigate only pa
ULCC	500	590	415	392	73	24	79	0,84	1481	5446	12		Can navigate through
ULCC	400	475	380	358	68	23	75	0,83	1332	4809	12		
ULCC	350	420	365	345	65,5	22	72	0,82	1251	4463	12		
VLCC	300	365	350	330	63	21	69	0,82	1162	4095	12		
VLCC	275	335	340	321	61	20,5	67	0,81	1116	3901	12		
VLCC	250	305	330	312	59	19,9	65	0,81	1066	3699	12		
VLCC	225	277	320	303	57	19,3	63	0,81	1014	3488	12		
VLCC	200	246	310	294	55	18,5	61	0,8	959	3266	12		
Tankers	175	217	300	285	52,5	17,7	58	0,8	900	3032	12		
Tankers	150	186	285	270	49,5	16,9	55	0,8	837	2782	12		
Suezmax	125	156	270	255	46,5	16	52	0,8	768	2513	12		
New-Panamax	100	125	250	236	43	15,1	50	0,8	691	2219	12		
Aframax	80	102	235	223	40	14	46	0,8	621	1959	12		
Aframax	70	90	225	213	38	13,5	44	0,8	583	1818	12		
Aframax	60	78	217	206	36	13	43	0,79	542	1668	12		
Panamax	50	66	210	200	32,2	12,6	41	0,79	497	1507	12		
Seawaymax Chem	40	54	200	190	30	11,8	39	0,78	447	1330	12		
Seawaymax Chem	30	42	188	178	28	10,8	35	0,76	390	1133	12		
Seawaymax Chem	20	29	174	165	24,5	9,8	32	0,71	322	904	12		
Seawaymax Chem	10	15	145	137	19	7,8	26	0,72	232	614	12		
Chem tanker	5	8	110	104	15	7	23	0,71	167	417	12		
Chem tanker	3	4,9	90	85	13	6	20	0,72	131	314	12		
Bulk	DWTx1000	Deltamx1C	Loa(m)	Lpp(m)	B(m)	T(draft r	T feet	Cb	Av frontal	Av lateral		Load	
Chinamax	400	464	375	356	62,5	24	79	0,85	1039	3970	13		
Capesize	350	406	362	344	59	23	75	0,85	989	3751	13		
Capesize	300	350	350	333	56	21,8	72	0,84	934	3513	13		
Capesize	250	292	335	318	52,5	20,5	67	0,83	873	3251	13		
Capesize	200	236	315	300	48,5	19	62	0,83	804	2957	13		
Capesize	150	179	290	276	44	17,5	57	0,82	723	2617	13		
Capesize	125	150	275	262	41,5	16,5	54	0,82	676	2422	13	42%	
New panamax	**100**	**121**	**255**	**242**	**39**	**15,3**	**50**	**0,82**	**622**	**2203**	**13**	**50%**	
New panamax	**80**	**98**	**240**	**228**	**36,5**	**14**	**46**	**0,82**	**573**	**2003**	**13**	**56%**	
Panamax	60	74	220	210	33,5	12,8	42	0,8	515	1773	13	75%	
Handymax	40	50	195	185	29	11,5	38	0,79	443	1492	13	88%	
Handysize bulk	20	26	160	152	23,5	9,3	31	0,76	343	1111	13		
Handysize bulk	10	13	130	124	18	7,5	25	0,76	265	828	13		
LNG carrier	125	175	345	333	55	12	39	0,78	676	2422	13	84%	
LNG carrier	97	141	315	303	50	12	39	0,76	615	2174	13	84%	
LNG carrier	90	120	298	285	46	11,8	39	0,76	598	2106	13	84%	
LNG carrier	80	100	280	268,8	43,4	11,4	37	0,73	573	2003	13	92%	
LNG carrier	52	58	247,3	231	34,8	9,5	31	0,74	488	1668	13		
LNG carrier	27	40	207,8	196	29,3	9,2	30	0,74	383	1263	13		
LPG carrier	60	95	265	245	42,2	13,5	44	0,66	515	1773	13		
LPG carrier	50	80	248	238	39	12,9	42	0,65	481	1641	13		
LPG carrier	40	65	240	230	35,2	12,3	40	0,64	443	1492	13		
LPG carrier	30	49	226	216	32,4	11,2	37	0,61	398	1320	13		
LPG carrier	20	33	207	197	26,8	10,6	35	0,58	343	1111	13		
LPG carrier	10	17	160	152	21,1	9,3	31	0,56	265	828	13		
LPG carrier	5	8,8	134	126	16	8,1	27	0,53	205	617	13		
LPG carrier	3	5,5	116	110	13,3	7	23	0,52	170	496	13		
Container ships	DWTx1000	Deltamx1C	Loa(m)	Lpp(m)	B(m)	T(draft r	T feet	Cb	TEU x 100	Av front	Av latera	Speed	
ULCV	245	340	470	446	60	18	59	0,69	22	2621	16065	14	
ULCV	200	260	400	385	59	16,5	54	0,68	18	2316	13929	14	
ULCV	195	250	418	395	56,4	16	52	0,68	14,5	2281	13684	14	
New-panamax no beam	165	215	398	376	*56,4*	15	49	0,66	12,2	2060	12167	14	
New-panamax	125	174	370	351	**45,8**	15	49	0,7	10	1739	10010	14	
New-panamax	**120**	**158**	**352**	**335**	**45,6**	**14,8**	**49**	**0,68**	**9**	**1697**	**9727**	**14**	
Post-panamax	110	145	340	**323**	43,2	14,5	48	0,7	8	1609	9150	14	
Post-panamax	100	140	326	310	42,8	14,5	48	0,71	7,5	1518	8557	14	
Post-panamax	90	126	313	298	42,8	14,5	48	0,66	7	1424	7946	14	
Post-panamax	80	112	300	284	40,3	14,5	48	0,66	6,5	1326	7314	14	
Post-panamax	70	100	280	266	41,8	13,8	45	0,64	6	1222	6659	14	
Post-panamax	65	92	274	260	41,2	13,5	44	0,62	5,6	1168	6321	14	
Post-panamax	60	84	268	255	39,8	13,2	43	0,61	5,2	1112	5975	14	
Post-panamax	55	76,5	261	248	38,3	12,8	42	0,61	4,8	1055	5621	14	
Panamax	60	83	290	275	32,2	13,2	43	0,69	5	1112	5975	14	
Panamax	**55**	**75,5**	**278**	**264**	**32,2**	**12,8**	**42**	**0,68**	**4,5**	**1055**	**5621**	**14**	
Panamax	50	68	267	253	32,2	12,5	41	0,65	4	996	5256	14	
Panamax	45	61	255	242	32,2	12,2	40	0,63	3,5	934	4881	14	
Feedermax	40	54	237	225	32,2	11,7	38	0,62	3	869	4493	14	
Feedermax	35	47,5	222	211	32,2	11,1	36	0,61	2,6	801	4091	14	
Feedermax	30	40,5	210	200	30	10,7	35	0,62	2,2	729	3670	14	
Feeder	25	33,5	195	185	28,5	10,1	33	0,61	1,8	653	3229	14	
Feeder	20	27	174	165	26,2	9,2	30	0,66	1,5	570	2760	14	
Feeder	15	20	152	144	23,7	8,5	28	0,67	1,1	478	2255	14	
Small feeder	10	13,5	130	124	21,2	7,3	24	0,69	0,75	374	1696	14	
Cruise liners	DWTx1000	Deltamx1C	Loa(m)	Lpp(m)	B(m)	T(draft r	T feet	Cb	PAX	Avf	Avl		
Post-panamax	220	115	360	333	55	9,2	30	0,67	5,400 / 7,500	1669	16695	14	
Post-panamax	160	84	339	313,6	43,7	9	30	0,66	3,700 / 5,000	1457	13444	14	
Post-panamax	135	71	333	308	37,9	8,8	29	0,67	3,200 / 4,500	1355	11977	14	
Post-panamax	115	61	313,4	290	36	8,6	28	0,66	3,000 / 4,200	1266	10740	14	
Post-panamax	105	56	294	272	35	8,5	28	0,67	2,700 / 3,500	1218	10096	14	
Post-panamax	95	51	295	273	33	8,3	27	0,67	2,400 / 3,000	1167	9431	14	
Post-panamax	80	44	272	231	35	8	26	0,66	2,000 / 2,800	1085	8391	14	
Panamax	90	48	294	272	32,2	8	26	0,67	2,000 / 2,800	1140	9091	14	
Panamax	80	43	280	248,7	32,2	7,9	26	0,66	1,800 / 2,500	1085	8391	14	
Panamax	70	38	265	225	32,2	7,8	26	0,66	1,700 / 2,400	1025	7663	14	
Panamax	60	34	252	214	32,2	7,6	25	0,63	1,600 / 2,200	959	6900	14	
Panamax	60	34	251,2	232,4	28,8	7,6	25	0,65	1,600 / 2,200	959	6900	14	
Panamax	50	29	234	199	32,2	7,1	23	0,62	1,400 / 1,800	888	6096	14	
Panamax	50	29	232	212	28	7,4	24	0,64	1,400 / 1,800	888	6096	14	
Panamax	40	24	212	180	32,2	6,5	21	0,62	1,200 / 1,600	807	5238	14	
Panamax	40	24	210	192,8	27,1	7	23	0,64	1,200 / 1,600	807	5238	14	
Panamax	35	21	192	164	32	6,3	21	0,62	1,000 / 1,400	763	4783	14	
Panamax	35	21	205	188	26,3	6,8	22	0,61	1,000 / 1,400	763	4783	14	
Panamax	30	18,2	190	175	25	6,7	22	0,61	850 / 1,200	714	4307	14	
Panamax	25	16,2	180	165	24	6,6	22	0,6	700 / 1,000	661	3805	14	
Panamax	20	14	169	155	22,5	6,5	21	0,6	600 / 800	601	3269	14	
Panamax	15	11,5	152	140	21	6,4	21	0,6	350 / 500	532	2688	14	
Panamax	10	8	134	123	18,5	5,8	19	0,59	280 / 400	447	2040	14	
Panamax	5	5	100	90	16,5	5,6	18	0,59	200 / 300	333	1274	14	
Car carriers	DWTx1000	Deltamx1000	Loa(m)	Lpp(m)	B(m)	T(draft m)	T feet	Cb	CEU	Avf	Avl		
Car carriers	70	52	228	210	32,2	11,3	37	0,66	8000	1371	5031	13	
Car carriers	65	48	220	205	32,2	11	36	0,64	7000	1327	4860	13	
Car carriers	57	42	205	189	32,2	10,9	36	0,62	6000	1253	4573	13	
Car carriers	45	35,5	198	182	32,2	10	33	0,59	5000	1131	4098	13	
Car carriers	36	28,5	190	175	32,2	9	30	0,55	4000	1026	3695	13	
Car carriers	27	22	175	167	28	8,4	28	0,55	3000	906	3233	13	
Car carriers	18	13,5	150	143	22,7	7,4	24	0,55	2000	759	2679	13	
Car carriers	13	8	130	124	18,8	6,2	20	0,54	1000	659	2303	13	
Car carriers	8	4,3	100	95	17	4,9	16	0,53	700	533	1839	13	

FIGURE 45: EXCEL SHEETS WITH SHIP CHARACTERISTICS.

C.1 BATHYMETRY

For a channel design, a map of the sea bottom where possible channels may be located is required. The channel alignment may be based on this data.

Hidrovía S.A. executed measurements in the Río de la Plata (Hidrovía S.A., 1997b). These are presented below. The measurements are with respect to the Local Zero reference level, which lies 0.71 meter below the mean sea level (for elaboration, see Appendix Reference Levels).

Additional depths were taken from Navionics (Navionics Webapp, 2015) if they were not provided by the study of Hidrovía S.A.. The reference level used by Navionics is WGS84, which lies 0.14 meter below the Local Zero reference level.

Servicio de Hidrografía Naval has provided these depths to Navionics.

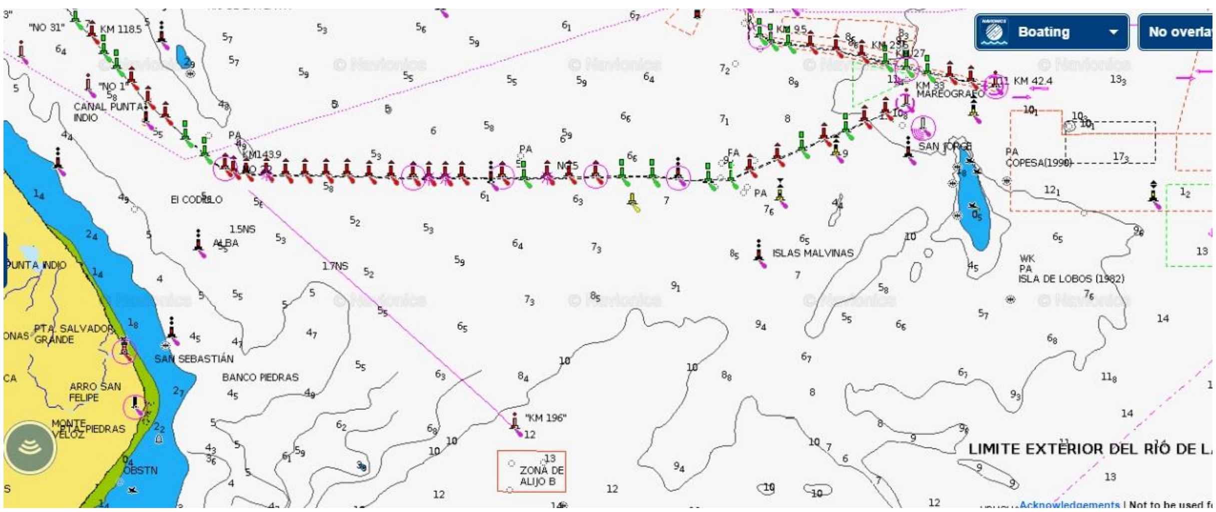


FIGURE 46: NAVIONICS MAP WITH DEPTHS.

In the following Table 36 (next page), the depths measured by the survey from Hidrovía S.A. (Hidrovía S.A., 1997b) are presented for extended stretch from Canal Intermedio, from El Codillo to Zona Beta.

#	= measurement number
a_j	= measured depth [m], from the Local Zero
along line	= distance from El Codillo [m]

#	a_j	along line	#	a_j	along line	#	a_j	along line
1	10,64	101	34	6,21	7100	67	5,77	14184
2	9,23	234	35	6,16	7309	68	5,79	14395
3	7,57	445	36	6,22	7530	69	5,76	14608
4	7,57	660	37	6,16	7742	70	5,91	14828
5	7,47	874	38	6,1	7955	71	5,77	15039
6	7,22	1097	39	6,75	8165	72	6,99	15260
7	7,14	1310	40	6,15	8385	73	5,72	15472
8	7,14	1529	41	6,22	8597	74	5,65	15685
9	7,02	1738	42	7,07	8808	75	5,68	15907
10	6,93	1960	43	6,03	9028	76	5,91	16120
11	6,89	2171	44	6,06	9236	77	5,67	16333
12	6,82	2382	45	6	9456	78	5,68	16556
13	6,89	2604	46	6,02	9671	79	5,64	16770
14	6,95	2814	47	6,08	9883	80	5,74	16984
15	6,76	3034	48	6	10102	81	5,67	17206
16	7,57	3251	49	5,99	10311	82	5,68	17419
17	6,6	3461	50	5,96	10525	83	5,61	17638
18	7,53	3674	51	5,94	10747	84	5,65	17847
19	6,53	3894	52	5,92	10956	85	5,69	18068
20	6,44	4103	53	5,94	11172	86	5,64	18282
21	6,41	4323	54	5,96	11390	87	5,62	18503
22	6,43	4536	55	6,73	11604	88	6,18	18714
23	6,41	4745	56	6,18	11814	89	5,55	18928
24	6,42	4963	57	6,02	12025	90	6,12	19151
25	6,36	5176	58	5,94	12248	91	6,4	19362
26	6,38	5386	59	5,88	12460	92	5,53	19575
27	6,35	5604	60	6,68	12669	93	5,48	19797
28	6,31	5812	61	5,96	12888	94	5,51	20006
29	6,35	6034	62	5,84	13108	95	5,53	20221
30	6,21	6244	63	5,85	13321	96	5,51	20444
31	6,26	6454	64	6,25	13532	97	5,66	20658
32	6,19	6670	65	5,96	13751	98	5,47	20870
33	6,21	6889	66	5,91	13962	99	5,48	21093

#	a_j	along line	#	a_j	along line	#	a_j	along line
100	5,44	21310	144	5,65	31401	188	7,1	41675
101	5,95	21525	145	5,63	31612	189	6,82	41885
102	6,53	21740	146	5,84	31833	190	6,94	42110
103	5,56	21959	147	5,64	32046	191	7,11	42319
104	5,46	22166	148	5,55	32255	192	7,24	42541

105	5,34	22382	149	5,67	32469	193	7,23	42756
106	5,41	23243	150	5,73	32682	194	7,14	42972
107	5,44	23466	151	5,72	32894	195	7,27	43197
108	5,49	23677	152	5,76	33112	196	7,35	43404
109	5,4	23891	153	5,79	33325	197	7,37	43628
110	5,45	24109	154	5,82	33535	198	7,44	43843
111	5,42	24322	155	5,64	33754	199	7,47	44061
112	5,45	24536	156	5,76	33967	200	7,68	44277
113	5,47	24758	157	5,8	34176	201	7,71	44497
114	5,38	24970	158	5,85	34398	202	7,79	44717
115	5,66	25182	159	5,88	34613	203	7,79	44936
116	5,56	25398	160	5,87	34828	204	7,79	45145
117	5,45	25611	161	5,93	35034	205	7,93	45363
118	5,63	25825	162	5,94	35248	206	7,92	45590
119	5,55	26046	163	5,89	35467	207	8,05	45800
120	5,53	26261	164	6,05	35681	208	8,03	46017
121	5,56	26474	165	6,27	35890	209	8,14	46237
122	5,46	26692	166	6,01	36110	210	8,22	46455
123	5,48	26905	167	6,64	36321	211	8,32	46681
124	5,47	27120	168	6,11	37171	212	8,7	46896
125	5,51	27335	169	6,28	37391	213	8,44	47113
126	5,54	27548	170	6,18	37603	214	8,47	47331
127	5,48	27761	171	6,26	37813	215	8,88	47550
128	5,46	27974	172	6,31	38031	216	8,69	47764
129	5,55	28187	173	6,72	38243	217	8,89	47987
130	5,5	28407	174	6,2	38458	218	9,13	48200
131	5,52	28620	175	6,29	38674	219	9,09	48414
132	5,53	28834	176	6,41	38886	220	9,54	49263
133	6,36	29048	177	6,35	39099	221	9,78	49473
134	5,57	29263	178	6,56	39309	222	9,75	49685
135	6,11	29477	179	6,44	39525	223	10,17	49898
136	5,56	29688	180	6,7	39948	224	9,93	50091
137	5,54	29898	181	6,59	40164			
138	5,62	30116	182	6,56	40383			
139	5,65	30336	183	6,71	40594			
140	5,56	30550	184	6,75	40809			
141	5,62	30761	185	6,85	41031			
142	5,6	30976	186	6,83	41244			
143	5,58	31189	187	6,96	41459			

TABLE 36: DEPTH MEASUREMENTS

The data provides not all the necessary depths for the complete layout. Other depths are approximated by Navionics (Navionics Webapp, 2015). As a result, distance between measurement points is bigger. The values are presented in Table 36, with the measurements measured from El Codillo till 62.000 meters downward the channel. Then, the direction of the measurement lines changes to 192 degrees in the cardinal system, following the alignment for the 42 feet alternative.

	WGS84	Zero Local	
#	a_j	a_j + 0,14	along line
0	10,64	10,78	0
1	6	6,14	1360
2	5,5	5,64	30490
3	6	6,14	35180
4	6,5	6,64	37650
5	7	7,14	39490
6	7,5	7,64	43470
7	8	8,14	43970
8	8,5	8,64	45760
9	9	9,14	47850
10	9,5	9,64	49400
11	10	10,14	50720
12	10,5	10,64	51550
13	11	11,14	52750
14	11,5	11,64	54040
15	12	12,14	55380
16	12,5	12,64	57470
17	13	13,14	59900
18	13,25	13,39	62000
19	13,5	13,64	62840
20	14	14,14	65000
21	14,5	14,64	69670
22	15	15,14	74400

TABLE 37: NAVIONICS DEPTHS

In Figure 47 the bathymetry data from HDRV/10 is plotted in the green line. Along the same stretch, depths from Navionics are plotted in the light blue line. These depths comply for a big part with the data from HDRV/10, hence it is acceptable to use depths obtained from Navionics for the stretch where there is no data available from HDRV/10. In red, the dredging depth for the 36 feet design draft is plotted. In dark blue, the dredging depth for the 42 feet design draft is plotted. The top layer indicates soil type A, from the brown line downwards indicates soil type B. See Appendix Physical environmental data analysis section Geobed technics for the soil layer specifications. In Figure 48 the boundary of these soils is approximated, where yB indicates the boundary between soil layer A and B. This approximation is used in the capital dredging calculations, see Appendix Dredging calculation method. Layer B is located at 10.9 meter depth for the stretch of 0-35 kilometers, and 14.1 for the stretch of 35-74.4 kilometers. The depths refer to the local zero level, see section Water Reference Levels.

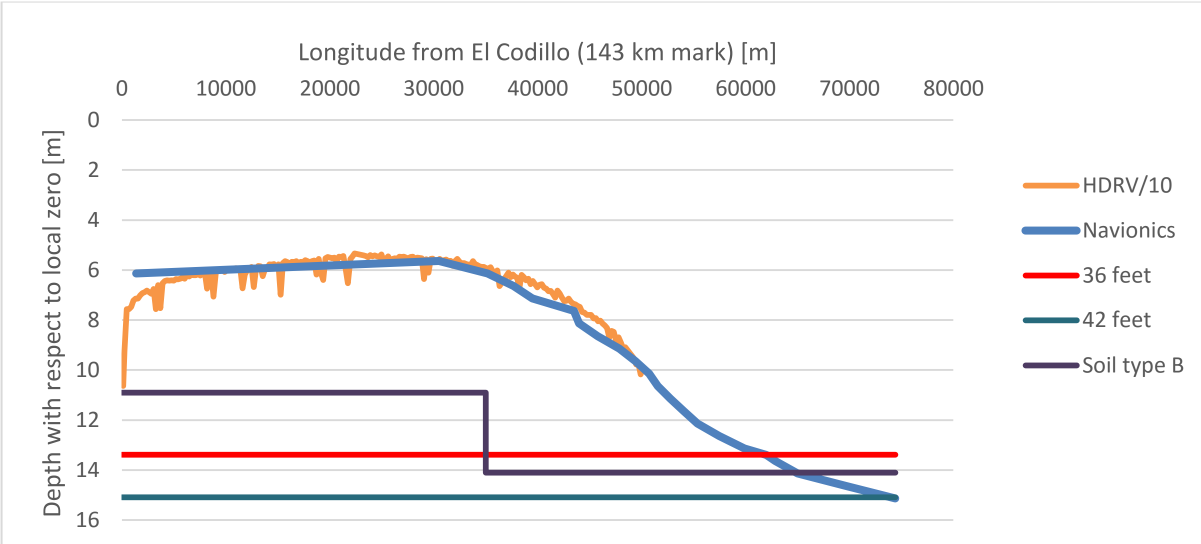


FIGURE 47: BATHYMETRY DATA AND APPROXIMATE POSITION SOIL LAYERS.

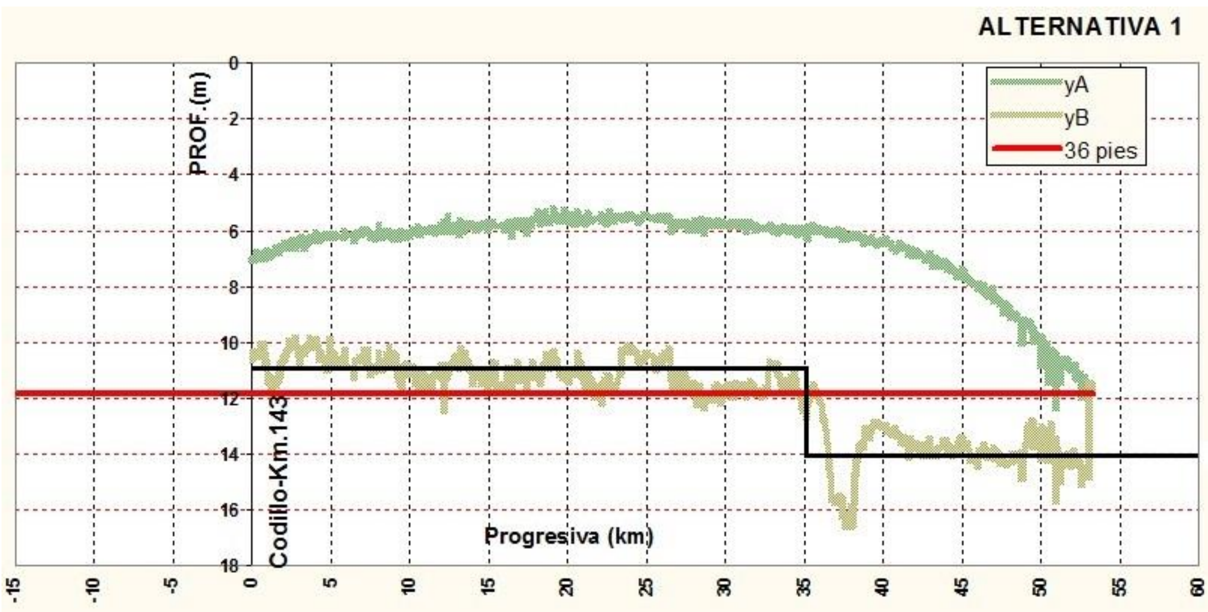


FIGURE 48: APPROXIMATION BOUNDARIES SOIL LAYERS.

C.2 WIND

Measurements for wind data were obtained from (Envioware, 2014) which are up-to-date weather reports from airports. Based on this information a wind rose for the year 2014 could be constructed with information coming from the Punta Indio airport, located at the Río de la Plata. This is the closes point of measurement to the investigating area.

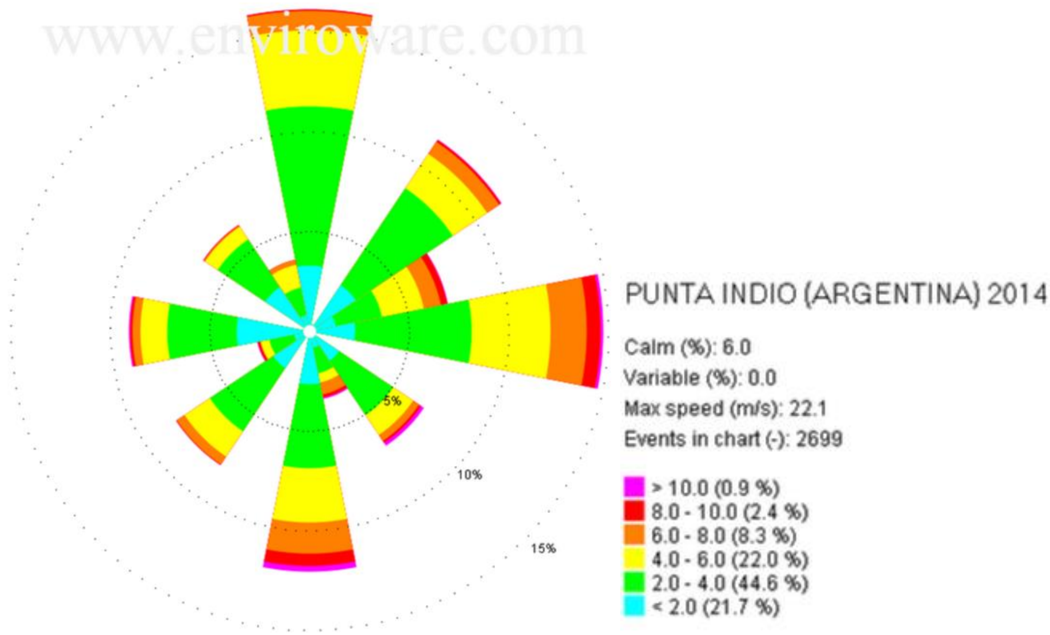


FIGURE 49: 2014 WIND DATA FOR PUNTA INDIO.

Measurements from Hidrovía S.A. were not used, because this wind data was taken at the Port of Montevideo. Our alternative shipping channel lies closer to Punta Indio and on top of that the METAR data has a full year coverage and Hidrovía S.A. only measured from June to November.

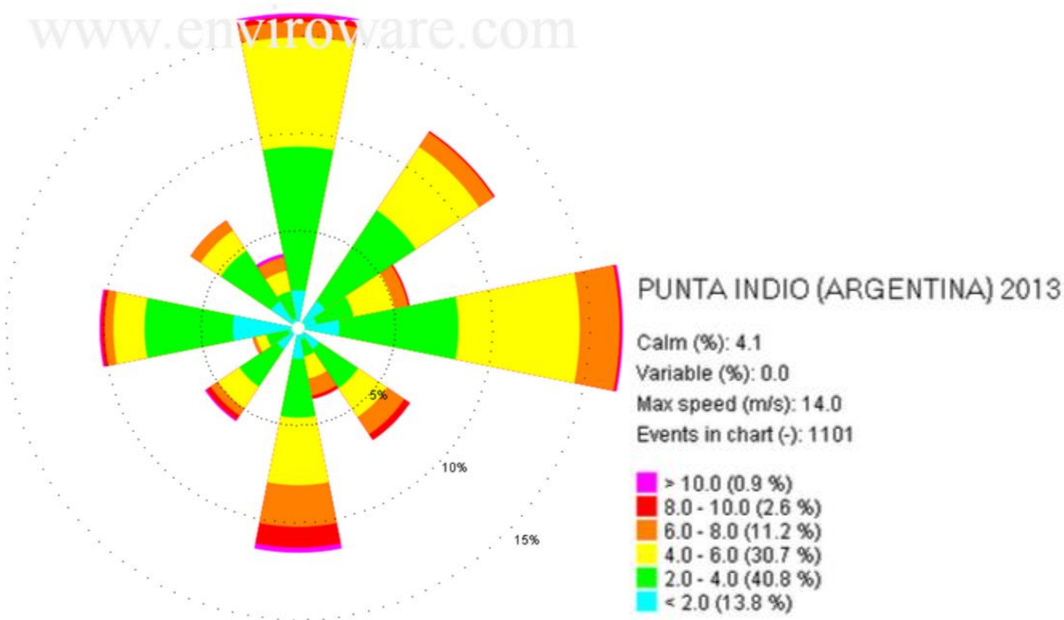


FIGURE 50: 2013 WIND DATA FOR PUNTA INDIO (ENVIOWARE, 2013).

Wind has a large influence on the surface elevation. Intensity and persistency determine the amount to which the water level can rise. The wind blowing from the south to southwest (*Pampero*) pushes the water inlands increasing the water level in Buenos Aires and the Paraná delta with possible flooding. Winds blowing from the southeast (*Sudestada*) cause the water to be pushed up at the Uruguayan coast. The levels to which the water can rise are considerable, but they are not really relevant to our design of the channel. The wind has to come from a specific direction and based on this you can't introduce a sort of tidal window from which you gain an advantage (Britannica, 2014).

C.3 WAVES

A wave study was performed by Hídrovia S.A. in the Río de la Plata exterior in the period 1996 – 2009. The conclusions will be summarized below. (Hidrovía S.A., 2013) The database is acquired by an oligrafo in the outer Río de la Plata.

From the series of waves a statistical description of the most common values is obtained. The wave fronts have predominantly significant heights ranging from 0.6m to 1.4m (80% of occurrences), and less than 1% of the value exceeded the value of Hs = 3 m.

Half of the peak periods are under 6 seconds, the other 50% peak periods represent the value between 6 and 21 seconds. For the direction, there is a clear predominance of waves coming from the SE (31.6%), after that it is E (18%) and to a lesser extent ESE (12.1%) and SSE (10.7%).

Waves consist of ocean waves and/or local generated waves, called respectively Swell and Wind waves. Based on the observation of the parameters of the waves is determined that the separation occurs between periods greater of smaller than 6 seconds. The analysis preformed determined that the most frequent state is represented by a combination of Swell and Wind waves (43.3%).

There was always influence of Swell at all measurements. The state of pure Swell only occurred 0.8% of the occurrences. From the analysis, it is determined that the waves spread mainly form SSE quadrant (59% of occurrences). The swell states come mostly from this sector (76% of occurrences), while Wind waves can also come from the E or N-NW (42% of occurrences).

The Sudestadas, a phenomenon in Río de la Plata, which comes with heavy rain and high waves. The wave period is between 8 and 12 seconds. The significant wave height remains above 2 m and 3 m for a whole day, reaching 4 m at the peak of the storm.

The Pampero is less intense than the Sudestadas and has a shorter duration. It was observed that the wave heights are between 1 and 3m, with periods of less than 8s. The fronts are propagating from the SW.

The analysis of the extreme values of the wave heights has been done with multiple formulas. These are Pareto, Gumbel and Weibull. Tr is the return period of each peak wave height.

Tr	Pareto	Gumbel	Weibull	Total max
(años)	Hs (m)	Hs (m)	Hs (m)	Hs (m)
1	4.04	3.34	3.37	4.04
2	4.30	3.95	4.05	4.30
5	4.58	4.53	4.45	4.58
10	4.76	4.92	4.63	4.92
20	4.91	5.29	4.76	5.29
50	5.07	5.76	4.87	5.76
100	5.18	6.12	4.94	6.12

TABLE 38: EXTREME VALUES OF SIGNIFICANT WAVE HEIGHTS.

C.4 CURRENTS

The currents at the possible location of the channel are predicted by the Servicio de Hidrografía Naval (SHN, 2015). The currents occur due to the tides only. The discharge of the rivers which is around 25,000 m^3/s will give a low current, due to the huge cross section area. The order will be at the channel at most 0.05 m/s. This is negligible relative to the current due to tide. There will be 2 points used for this study. One at the Banco Piedras, which is more at the side of Buenos Aires, the other in the mouth of the estuary, at the side of the ocean. This second point is just outside of the area where the channel will be constructed. It is not perfectly suitable, but useful though. At the locations a maximum current velocity and direction is given. This is almost every 12 hours and 25 minutes, sometimes less.

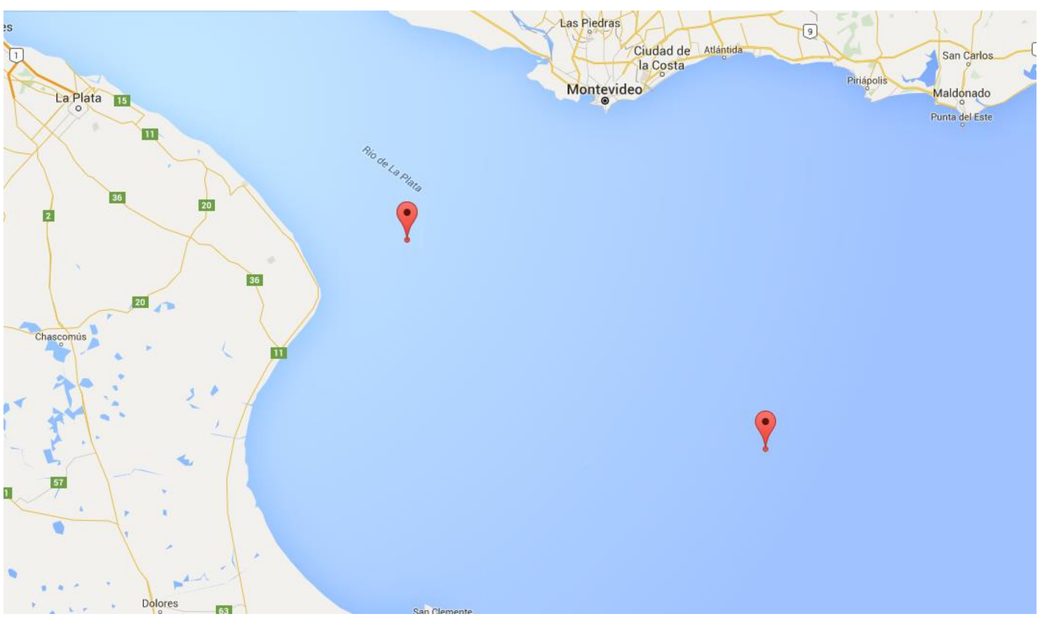


FIGURE 51: LOCATIONS OF THE VALUES OBTAINED.

Banco Piedras	Velocity (knot)	Velocity (m/s)	Direction (degree)	% of cases in that direction
SE direction	1.0	1.9	141.2	47%
	1.1	2.1	141.3	37%
	1.2	2.3	141.3	21%
	1.3	2.5	141.4	7%
	1.4	2.7	0.0	0%
NW direction				
	0.8	1.6	334.4	30%
	0.9	1.7	332.9	19%
	1.0	1.9	332.0	11%
	1.1	2.1	331.3	4%
	1.2	2.3	0.0	0%

TABLE 39: CURRENTS FROM JULY TO OCTOBER 2014 AT BANCO PIEDRAS (SHN, 2015).

Boca Río de la Plata	Velocity (knot)	Velocity (m/s)	Direction (degree)	% of cases in that direction
SE direction	0.2	0.4	123.6	91%
	0.3	0.6	126.8	55%
	0.4	0.8	0.0	0%
NW direction				
	0.2	0.4	275.3	100%
	0.3	0.6	276.5	92%
	0.4	0.8	280.2	62%
	0.5	1.0	282.5	21%
	0.6	1.2	286.5	1%

TABLE 40: CURRENTS FROM JULY TO OCTOBER 2014 AT THE BOCA RÍO DE LA PLATA (SHN, 2015).

At Banco Piedras the governing current has a velocity of 1.3 knot and a direction of 141,4°.
At Banco Piedras the governing current in the other direction has a velocity of 1.1 knot and a direction of 331.3°.
At the ocean side the governing current has a velocity of 0.6 knot and a direction of 286.5°.

C.5 TIDE

Tidal oscillations of the water level are created by astronomical influences. Gravitational pull of the moon, and to a lesser extent the sun, act on the waters in the estuary and cause it to rise or decline. The combination of the moon and the sun can dampen out or amplify the water level elevation as can be seen in Figure 52.The amount to which the water will rise or fall is totally different for each location on earth and is dependent on water depth, distance to the equator and the presence and shape of land masses. Another factor influencing the water level is the weather were wind speeds and pressure zones also have the ability the lift or push the water away. The highest elevation of the water surface is during storms in combination with high tide, but this has negative consequences for maneuverability and vision so ships will not have any advantage in this situation.

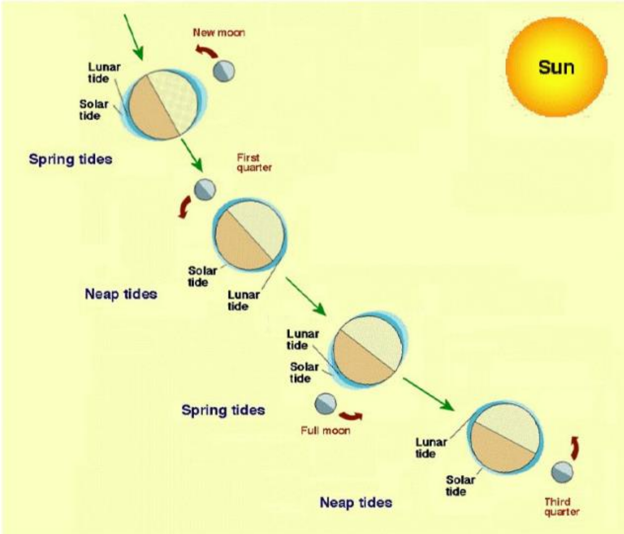


FIGURE 52: MOON EFFECTS ON TIDE (HAGERMAN, G, 2005).

The rivers flowing into the Río de la Plata do not influence the water level. They are widely distributed and due to the great width of the estuary the incoming water is spread out in such extend that elevation of the estuary can be neglected (Britannica, 2014).

ASTRONOMICAL TIDE

The following tidal elevations are solely due to astronomical influences and weather circumstances are not taken into account here. (SHN, 2015)

High tide		**Low tide**	
Maximum	Average	Minimum	Average
1,46 m	1,18m	0,02 m	0,47 m

TABLE 41: MAXIMUM TIDES 2015 AT TORRE OYARVIDE.

High tide		**Low tide**	
Maximum	Average	Minimum	Average
1,50 m	1,18 m	0,03 m	0,47 m

TABLE 42: MAXIMUM TIDES 2014 AT TORRE OYARVIDE.

Measurements were made at the Torre Oyarvide station in the upper left corner of the Punta Indio Channel.

The Río de la Plata is semi diurnal, dominated by the M2 component and O1 component. Every day there are two high and two low waters with a duration of 12 hours and 25 minutes, with an average elevation of 0.83 meter (Pedocchi & Fossati, 2012).

In Figure 53 every single tidal elevation can be seen for the months September till November 2014. The tidal range is somewhat higher in the Punta Indio channel over the port of Buenos Aires.

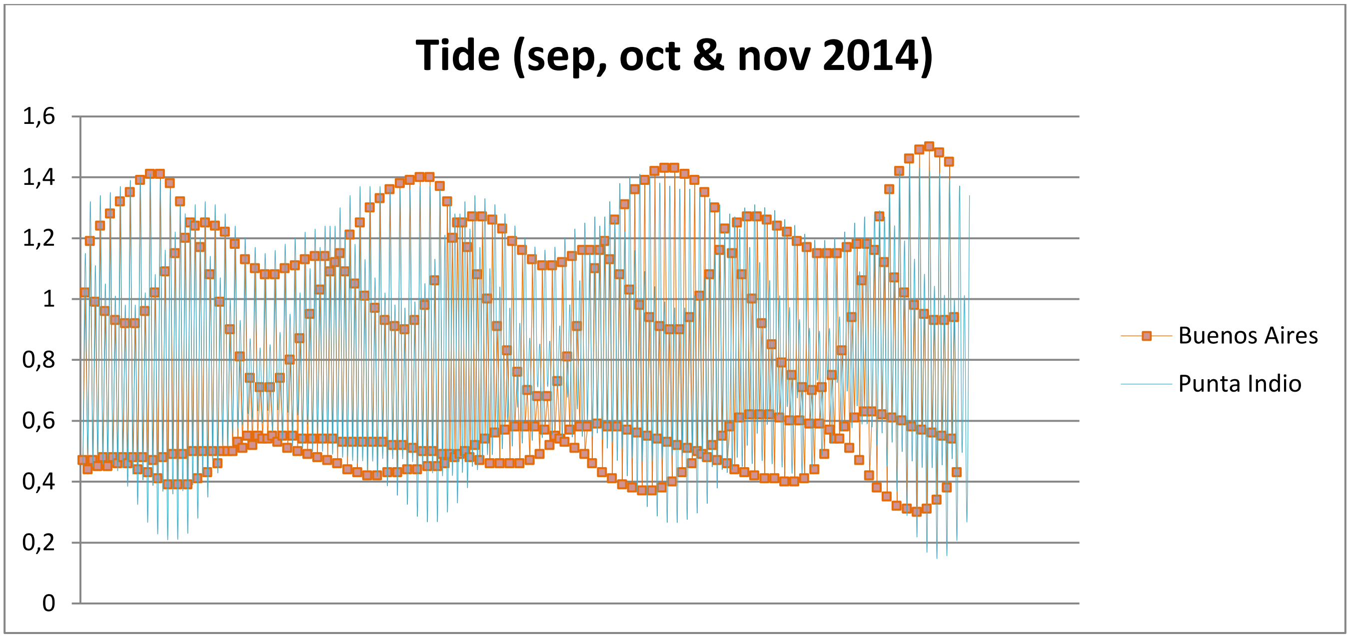


FIGURE 53: TIDES IN SEP, OCT AND NOV 2014.

C.6 SEABED GEOTECHNICS

Studies have been carried out by Hidrovía S.A. regarding geotechnical and geophysical properties of the soil in the Magdalena stretch. The information presented here is based on these reports (Hidrovía S.A., 1998b) (Hidrovía S.A., 1999)

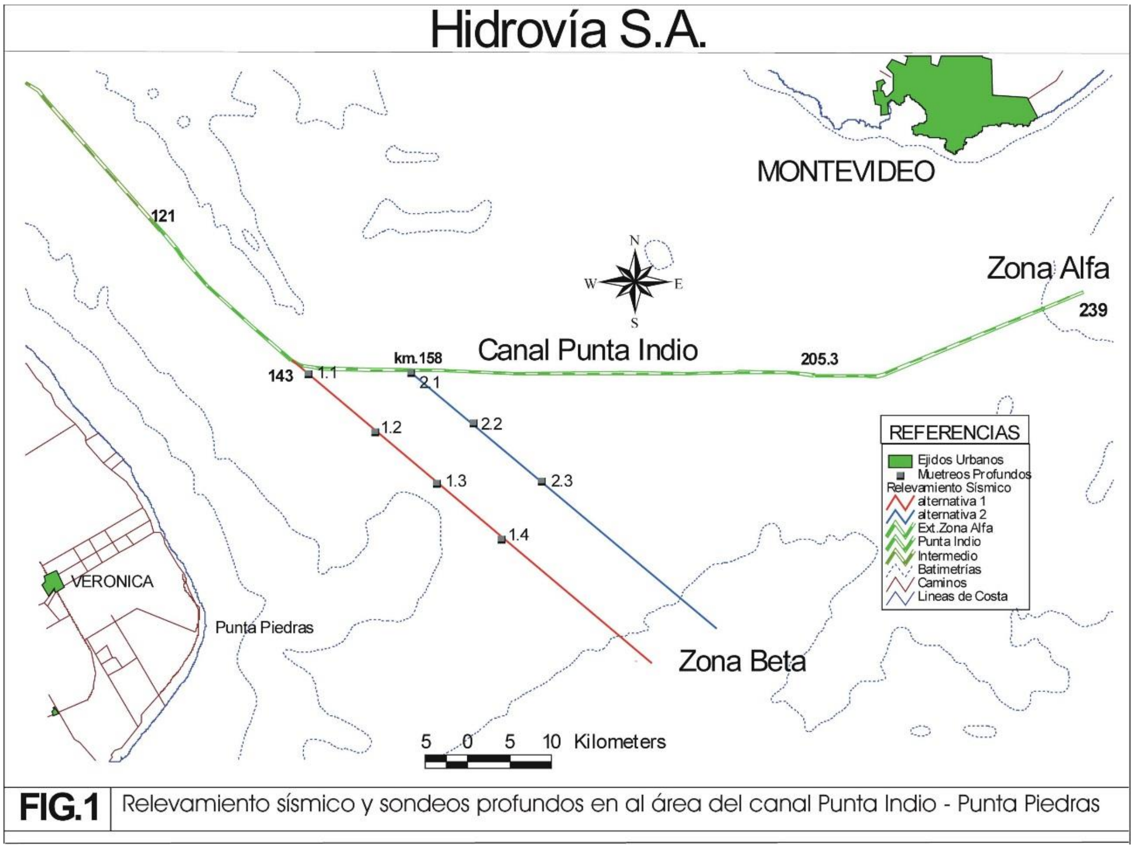


FIGURE 54: OVERVIEW OF GATHERINGPOINTS FOR GEOTECHNICAL AND GEOPHYSICAL PROPERTIES.

Position	Coordinates
1.1	35° 10’ .5746 S 56° 51’ .4127 W
1.2	35° 13’ .8605 S 56° 54’ .0585 W
1.3	35° 17’ .0144 S 56° 49’ .0624 W
1.4	35° 20’ .0671 S 56° 44’ .0431 W

TABLE 43: COORDINATES MEASUREMENT POSITIONS.

Position	Depth [m]	Dry density [kg/m^3]	Wet density [kg/m^3]	Shear Strength test [kPa]	Vane test [kg/cm^3]
1.1	2.4-2.7	1601	2093	150	
1.2	5.7-6	730	1108		
1.3	5.15-5.45	1738	2136		1.5
1.4	4.7-5	670	1070		

TABLE 44: PROPERTIES OF SAMPLES.

The classification of the soil in the following tables is based on the Unified Soil Classification System (USC).

Monster [#]	Depth [m]	Description	Liquid limit [%]	Plastic Limit [%]	Plasticity Index [%]	Classification
1	1,00	Clayey fluid, dark grey	65,12	26,10	39,02	CL-ML
2	2,50	Clayey fluid, dark grey	65,12	26,10	39,02	CL
3	3,00	Clayey with brown nodules	51,92	25,14	26,78	

TABLE 45: MONSTER SPECIFICATIONS AT POSITION 1.1.

Monster [#]	Depth [m]	Description	Liquid limit [%]	Plastic Limit [%]	Plasticity Index [%]	Classification
1	1,00	Dark grey clayey fluid with rests of shells	59,23	23,80	35,44	CL-ML
2	1,90	Dark grey clayey fluid with rests of shells	59,23	23,80	35,43	CL
3	3,00	Dark grey clayey fluid with rests of shells	46,00	19,72	26,27	
4	3,85	Clayey with shells, dark grey	46,00	19,72	26,28	
5	5,00	Clayey with shells, dark grey	37,43	17,20	20,22	
6	6,00	Clayey with shells, dark grey	37,43	17,20	20,23	

TABLE 46: MONSTER SPECIFICATIONS AT POSITION 1.2.

Monster [#]	Depth [m]	Description	Liquid limit [%]	Plastic Limit [%]	Plasticity Index [%]	Classification
1	1,00	Dark grey clayey fluid with rests of shells	71,22	33,06	38,15	CL-ML
2	2,00	Dark grey clayey fluid with rests of shells	71,22	33,06	38,15	CL
3	2,85	Dark grey clayey fluid with rests of shells	56,33	26,42	29,91	
4	3,85	Clayey with fine sand sheets, dark grey	32,21	13,53	18,68	

5	4,60	Clayey with fine sand sheets, dark grey	32,21	13,53	32,21	
6	5,45	Clayey with brown limestone nodules	32,54	15,19	17,35	

TABLE 47: MONSTER SPECIFICATIONS AT POSITION 1.3.

Monster [#]	Depth [m]	Description	Liquid limit [%]	Plastic Limit [%]	Plasticity Index [%]	Classification
1	0,85	Dark grey clayey fluid with rests of shells	67,06	29,53	37,52	CL-ML
2	2,00	Dark grey clayey fluid with rests of shells	66,01	27,16	38,85	CL
3	2,85	Dark grey clayey fluid with rests of shells	66,01	27,16	66,01	
4	4,00	Clayey with fine sand sheets	66,01	27,16	38,85	
5	4,85	Clayey with fine sand sheets	39,39	16,79	22,60	
6	5,50	Dark grey clayey	31,14	18,47	12,68	

TABLE 48: MONSTER SPECIFICATIONS AT POSITION 1.4.

An analysis of the survey concluded that the soil of the Río de la Plata can be categorized, for dredging purposes, in two soil types. These are classified as soil type A and soil type B.

Soil type A is characterized by fine homogeneous sediment. It has a uniform thickness of about 4 to 6 meters. In the last one third of the trace, the layer thickness increases to about 9 meters. Soil type A is subdivided in two subunits: A1 and A2.

Subunit A1 is the top layer. It consists of very soft and plastic clays which are colored dark greyish brown. It contains small proportions of silt, shells and gravel. At the bed level, there is a small layer of mud which has a thickness of a few centimeters. The thickness of this layer is, with very few exceptions, not more than 3 or 4 meter.

Subunit A2 is the layer below A1 and in general is much thinner than A1. In general, it does not surpasses a thickness of 2.5 meters. The clay has the same composition as in subunit A1, but at the base of the layer silt and sand with a very fine thickness.

Soil type B has a homogenous thickness between 20 and 30 meters. Throughout the layer there several layers present. These can be categorized, for dredging purposes, in two main categories: B1 and B2.

Subunit B1 is present in the northern half in the area while in the south it almost completely disappears. It consists of greenish brown clayey silt with limestone boulders.

Subunit B2 starts getting bigger thicknesses towards the south, while it is not very apparent in the north of the area. It consists of clayey silt which is very compacted and partly cemented.

In Figure 55, the depth contours of soil A and soil B are visualized. The green line yA corresponds with the depth of soil type A, and the brown line yB corresponds with the depth of soil type B. The depth data is available from El Codillo towards Zona Beta, over a stretch of 50091 meter.

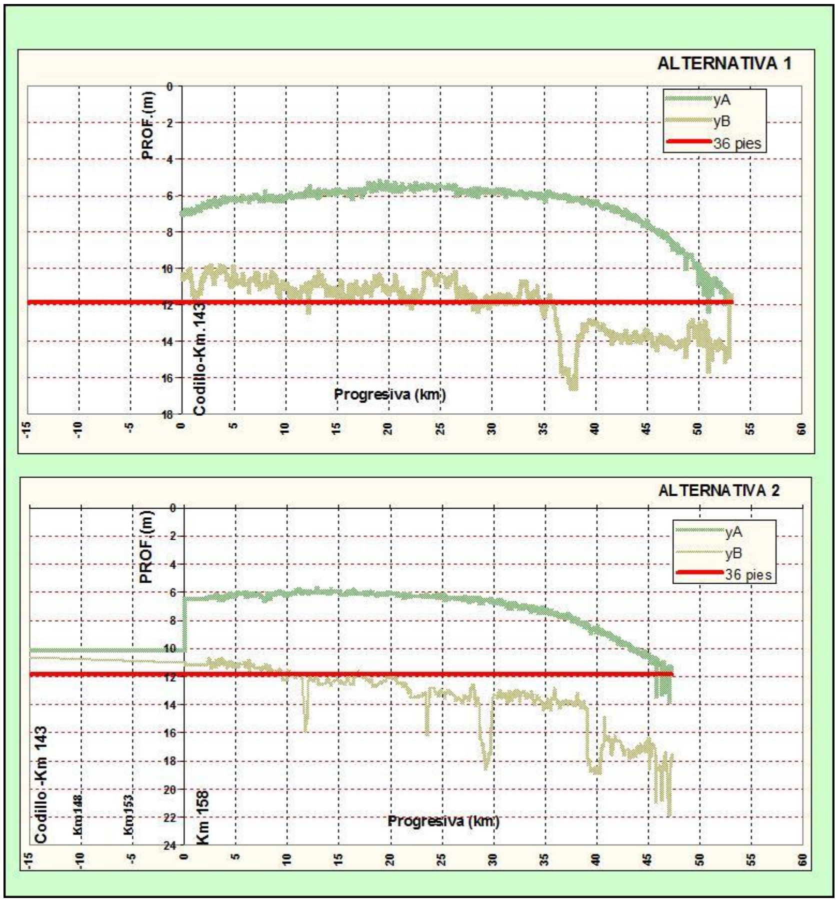
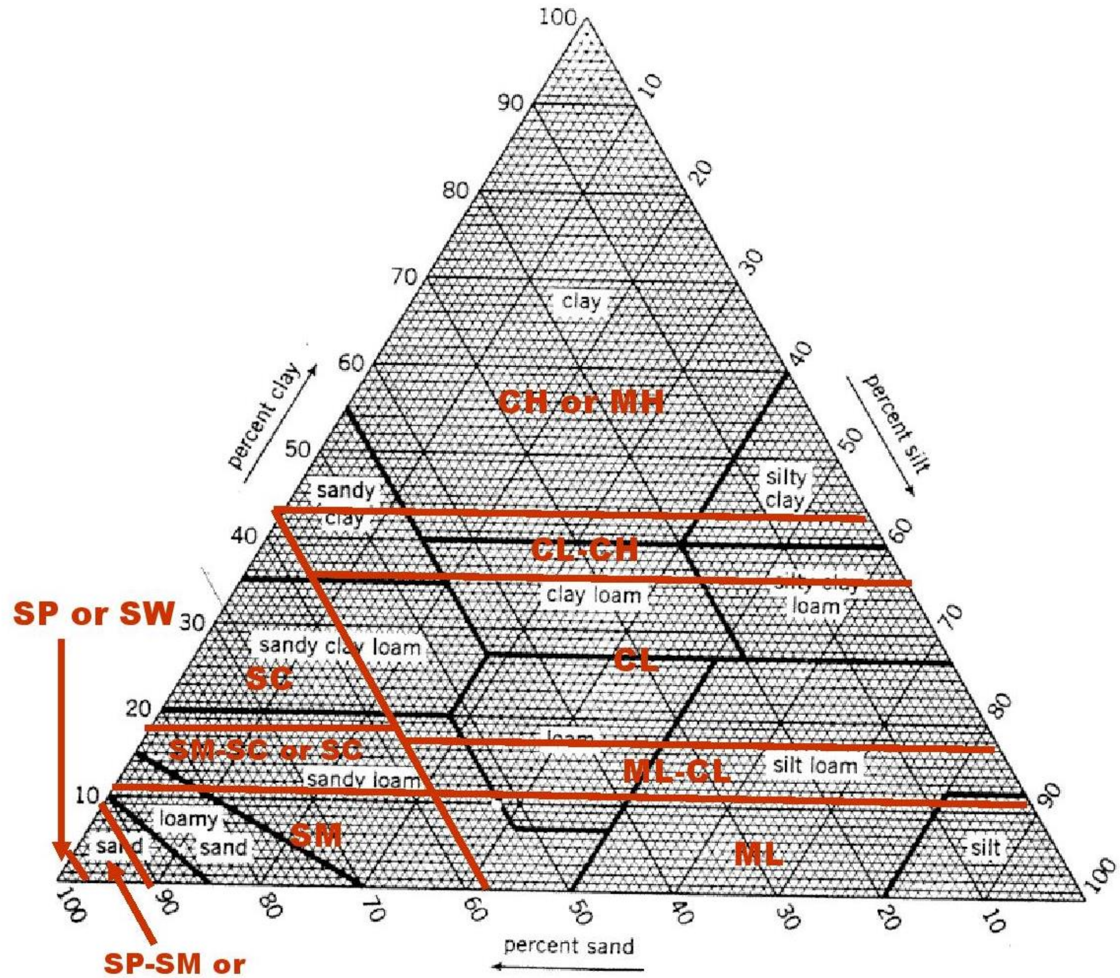


FIGURE 55: CONTOURS OF SOIL TYPE A AND B.

C.7 UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)



Unified Soil Classification System (USCS)—Generalized

Well-Graded (many sizes):	Gravels	GW	Well-graded gravel
	Sands	SW	Well-graded sand
Poorly-Graded (uniform size)	Gravels	GP	Poorly-graded gravel
	Sands	SP	Poorly-graded sand
Sands with enough fines to stain a wet palm:			
	SW-SM		Well-graded sand with silt
	SW-SC		Well-graded sand with clay
	SP-SM		Poorly-graded sand with silt
	SP-SC		Poorly-graded sand with clay
Sandy loamy soils:			
	Non-sticky/Non-Plastic	SM	Silty sand
	Sticky/Plastic	SC	Clayey sand
Fine-Grained Soils:			
	Average NC clays	CL	Lean clay
	Average NC silts	ML	Lean silt
	Very heavy/sticky/plastic clays	CH	Heavy clay
	Very heavy/sticky/plastic silts	MH	Heavy silt

FIGURE 56: UNIFIED SOIL CLASSIFICATION SYSTEM.

C.8 SALINITY OF THE RÍO DE LA PLATA

The to be designed channel will lie in an estuary where sweet and salt water mix. The location of the salt wedge with respect to the navigation channel alignment is important. The salinity is not constant, hence there are different water densities present over the length of the estuary. Archimedes law states that this will result in different buoyant forces. Hence, the draught of a ship in low density waters (e.g. fresh water) is deeper than in higher density waters (e.g. saline and brine water). Note that salinity is not the only influence on water density, but it is the most significant one in the Río de la Plata estuary. Other factors like temperature are important on a seasonal scale but otherwise only displays small gradients in density (Cabreira, 2006).

An acoustic study of the Río de la Plata estuarine front has been conducted by Cabreira (2006). They have managed to produce a map of the salinity of the Río de la Plata with the use of acoustic technique. In Figure 57, the acoustic transect is indicated by the black line and the Barra del Indio shoal is indicated by the dotted line.

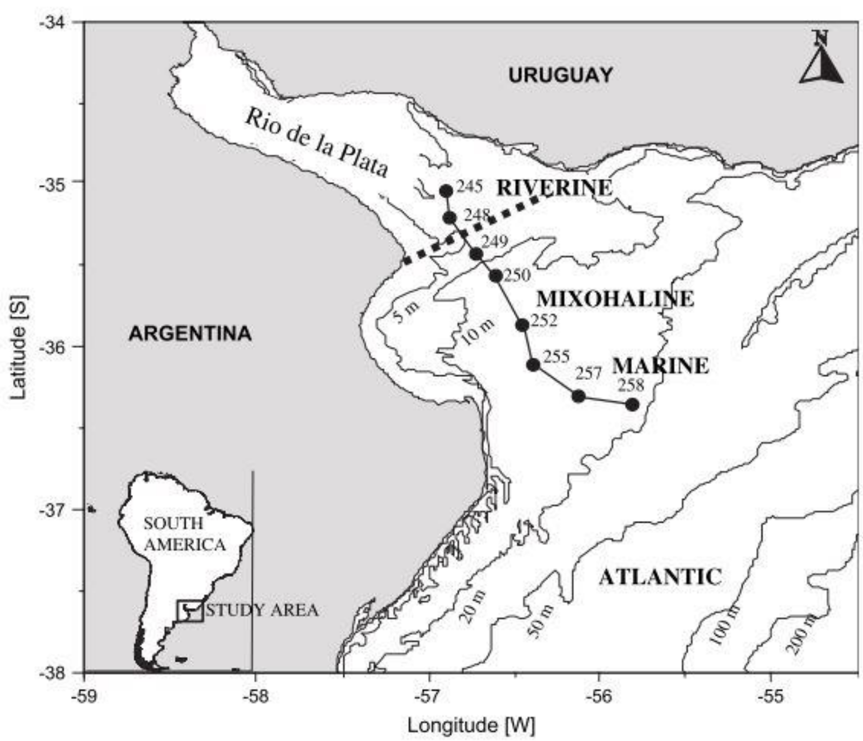


FIGURE 57: MAP OF STUDY AREA.

At the Barra del Indio shoal, the sea bottom rapidly decreases by approximately ten meters over a length of twenty kilometers. The study found that “this bar functions as a barrier and that the maximum upriver penetration of the salt wedge is controlled by this submerged bar. This results in a well-developed bottom salinity front”. (Cabreira, 2006)

In Figure 58 on the next page, the isohalines (contour lines of constant salinity) are shown.

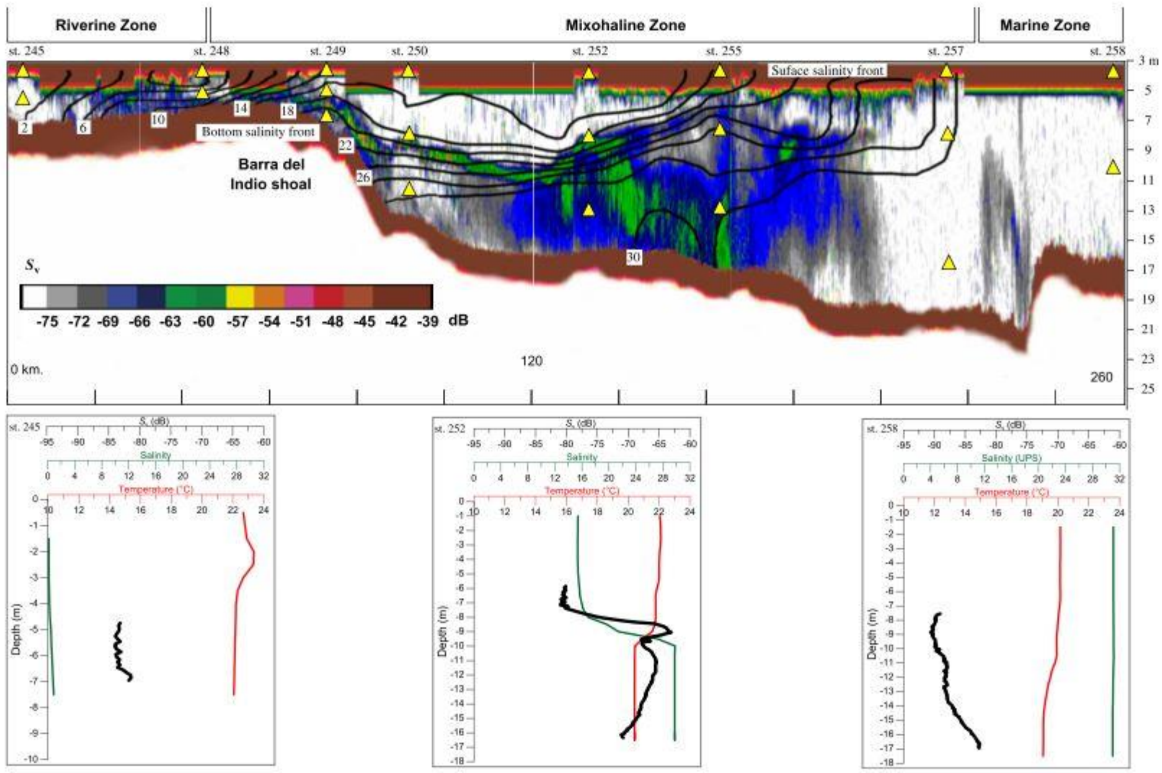


FIGURE 58: SALINITY CROSS-SECTION OF THE RÍO DE LA PLATA.

The new navigation channel will end around st. 252: it probably will not exceed this point. The salinity is expressed as grams of salt per kilogram of water. At st. 252 a salinity of 16 was measured for the first 8 meters from the sea surface level. Then from the 10 meter mark and onwards a salinity of about 29 was found. For passing ships, most part of the draught will lie in water with a salinity of 16.

Salinity distribution is dependent on wind direction and seasonality (Cabreira, 2006)

As can be seen in Figure 58 the grams of salt per kilo water are 18 at the 252 point till a depth of 8 meters. Till a depth of 11m it increases to 28 grams/kg. Normal seawater has around 35 grams of salt per kilogram water. The different variants for the channel have design draughts of 34 feet (10.4m) and 42 feet (12.8m). This gives the following amounts of salt:

$$\frac{8m * 18g/kg + 2{,}4m * \frac{1}{2}(18g/kg + 26g/kg)}{10{,}4m} = 18{,}9g/kg$$

$$\frac{8m * 18g/kg + 3m * \frac{1}{2}(18g/kg + 28g/kg) + 1{,}8m * 28g/kg}{12{,}8m} = 20{,}6g/kg$$

Sea water has a density of 1025kg/m3 and fresh water 1000kg/m3. When the relation between amounts of salt and density are linear, this gives densities of 1013,5kg/m^3 and 1014,7kg/m^3.

$$1000kg/m^3 + \frac{18{,}9g/kg}{35g/kg} * 25kg/m^3 = 1013{,}5kg/m^3$$

$$1000kg/m^3 + \frac{20,6g/kg}{35g/kg} * 25kg/m^3 = 1014,7kg/m^3$$

The percentage difference (less buoyancy) is:

$$\frac{1013,5kg/m^3 - 1025kg/m^3}{1025kg/m^3} * 100\% = -1,6\%$$

$$\frac{1014,7kg/m^3 - 1025kg/m^3}{1025kg/m^3} * 100\% = -0,52\%$$

For a design draught of 10.4m this will lead to an extra depth of 0.17m. The other variant with a draught of 12.8m will have an extra draught of 0.07m. This is calculated for the location with the highest fresh water concentration to have an indication of the negative effects. The differences are so little that salinity effects will be neglected at further depth calculations.

C.9 ICE

Ice in Río de la Plata has never been seen. This is due to high water temperature in this area. For example in Río de la Plata the water temperatures in the winter do not go below 10°, giving no chance to the forming of ice.

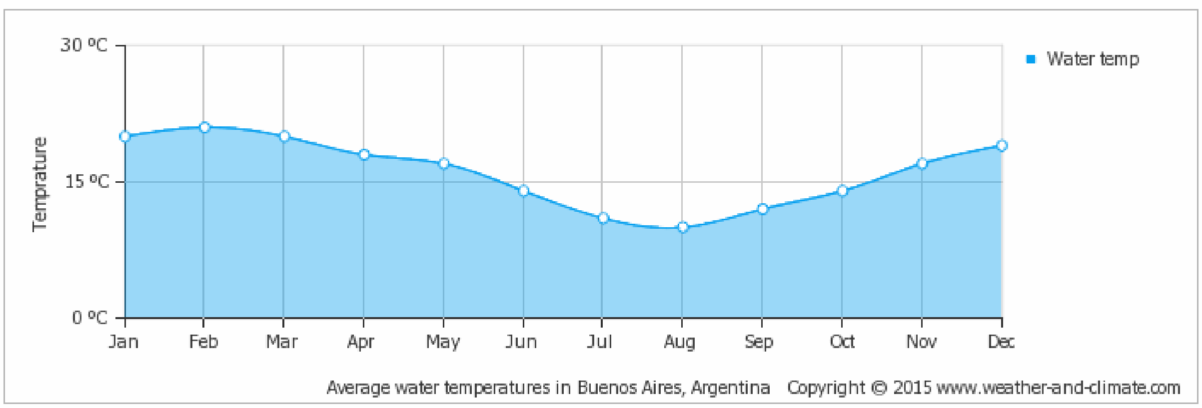


FIGURE 59: AVERAGE WATER TEMPERATURE IN BUENOS AIRES.

APPENDIX D: PRELIMINARY LAYOUT

Two alignments are being considered, see Figure 60: Alignment A and Figure 61: Alignment B in the next sections, where the possible alignments are marked in red. The map is made available by Navionics (Navionics Webapp, 2015). The reason for alignment A is that it is a straight extension of the Canal Intermedio. Also, soil data is available for both stretches, that is why alignment B is located at the 158 km mark in the Canal Punta Indio, measured from the port of Buenos Aires, and not at another connection point with the Canal Punta Indo.

The main difference is their length and their connection point to the Canal Punta Indio; alignment A connects at the El Codillo nod, while alignment B connects in the fairway in the Canal Punta Indio. This results in different junctions. The actual alignment could be between these two alternatives.

First an estimate which alignment suits better between alignment A and B is made for the concept design. The length will linearly increase towards alignment A. Compared with the junction construction costs will result in a preferred alignment. If the result is small, an optimized alignment may be designed between these two extremes.

The perpendicular distance between alignment A and alignment B is about 10 kilometers. From the 158 kilometers mark, the width of the estuary is about 100 kilometers. Hence, the assumption that winds, currents and waves do not differ significantly is made. Also that the environmental impact at the channel ends due to ships leaving the channel is assumed to not differ significantly.

It is assumed that the aids to navigation implemented will be the same for both alignments so no alignment will have an additional advantage in navigability due to different aids to navigation.

D.1 ALIGNMENT A

The following figure shows alignment A, which is an extension of the Canal Intermedio.

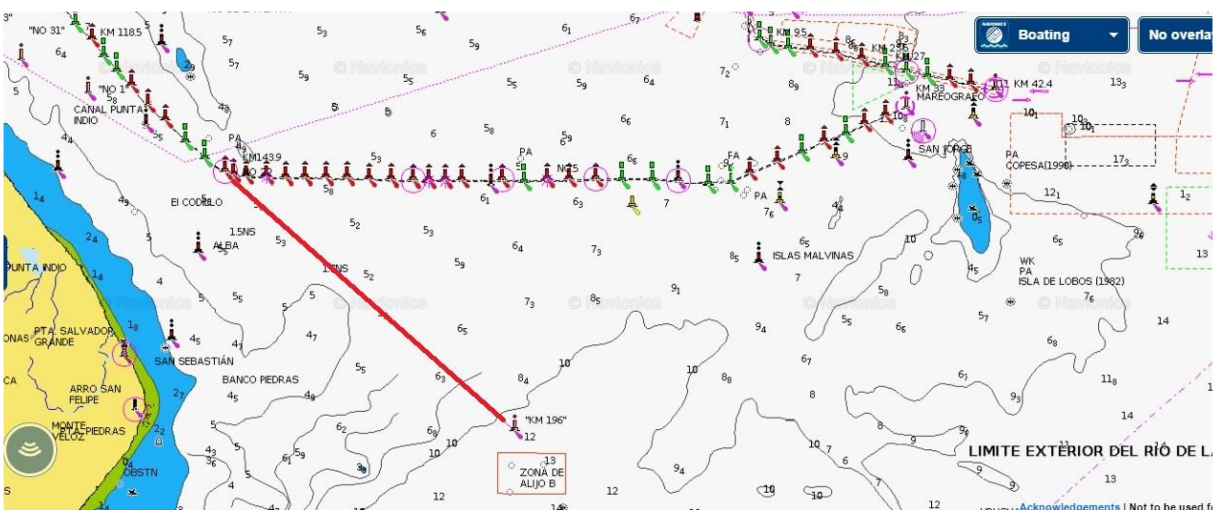


FIGURE 60: ALIGNMENT A.

The length is about 52.5 kilometers. With respect to the cardinal system, the angle made by the channel is 312 degrees clockwise. Thus it stretches in approximately from northwest direction to southeast direction. The depth fluctuates from 5 meters to 6 meters of depth the first 40 kilometers. The last 12.5 kilometers, the depth increases from 6 meters to 12 meters.

The ease of construction is mainly related to the subsoil. Other factors which influence construction like currents and prevailing winds are not taken into account: their influence is not big enough and the differences between the alignments are not significant.

As found in the section Seabed Geotechnics, the soil can be divided in three main layers. We consider now the top layer A and the second layer B. Layer B is harder to dredge than layer A and will be harder to dredge, hence increasing costs. In *Appendix K: Dredging costs* the calculations of the volume estimations are showed. It is important to recognize that these are based on a 36 feet nominal channel bed level, based on studies of Hidrovía (Hidrovía S.A., 1999)

The nominal channel bed level for the designed channel has not been determined yet.

For alignment A approximately a volume of 219,000 m^3 and 51,000 m^3 of soil type A and soil type B respectively has to be dredged. This is for the channel bed excluding the slopes.

D.2 ALIGNMENT B

The following figure shows alignment B. This channel starts at a junction with Canal Punta Indio, heading to the deeper waters.

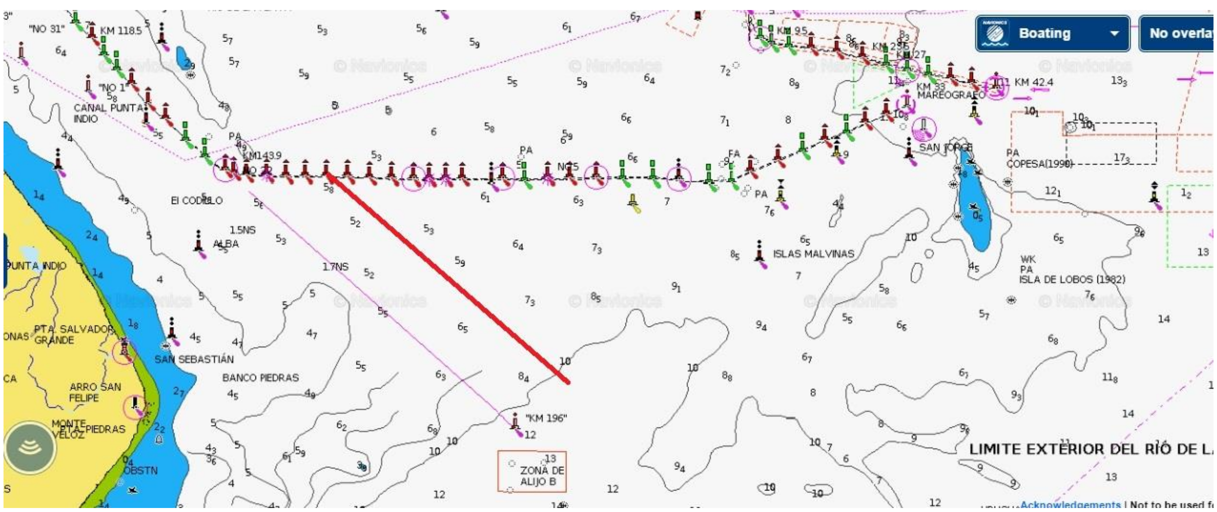


FIGURE 61: ALIGNMENT B.

The length of alignment B is about 47.5 kilometers. The channel position is parallel to alignment A, so it also stretches approximately from northwest direction to southeast. The depth fluctuates around 6 meters of depth the first 27.5 kilometers. The last 20 kilometers, the depth increases from 6 meters to 12 meters.

It should be noted that ships will use the new channel to head southwards. So while alignment B is shorter, the navigation distance is increased. To reach the exit point at alignment A, ships have to travel a distance of 50 kilometers with alignment A and 65 kilometers with alignment B.

For alignment B approximately a volume of 207,500 m^3 and 32,500 m^3 of soil type A and soil type B respectively has to be dredged. This is for the channel bed excluding the slopes. Because the channels are parallel, sedimentation is considered equal for the layout design. Hence, maintenance dredging is assumed proportional to channel depth.

D.3 PRELIMINARY LAYOUT CHOICE

With two preliminary layouts, a choice is made for the preliminary layout. The following criteria have been selected:

- Costs
- Ship travel distance towards south
- Navigability
- Ease of construction

These are derived from the design criteria designed given by PIANC because of their commonalities.

Geography wise the channels alignments are not located far from each other. That is why prevailing winds, currents, waves and environmental impact differences are considered insignificant.

	Alignment A	Alignment B
Channel length	52,5 km	47,5 km
Estimated dredging volume soil type A	219.000 m^3/m width	207.500 m^3/m width
Estimated dredging volume soil type B	51.000 m^3/m width	32.500 m^3/m width
Travel distance towards south	50	65
Junctions	Straight channel expansion	Bend is required
Navigability	Straight channel, easy	Bend, increasing difficulty

TABLE 49: PRELIMINARY LAYOUT CHOICE.

Further design will be based on Alignment A, after the dredging depths were calculated in more detail. These are 14.16 and 16.36 meter dredging depths for design draughts of 36 and 42 feet, respectively. It required Alignment B to turn southwards to deeper depths, increasing its channel length to roughly the same as Alignment A.

APPENDIX E: BEND CONFIGURATION

At the alternative 4B with the Magdalena channel at 42 feet design level there will be a bend toward the southwest. The channel of 36ft does not have a bend, because it reaches depths that are deep enough after 62 km already. The bend is 62 km from El Codillo and 12 km to the end of the channel. Following the PIANC manual approach channels (2014) the distances below are calculated.

In table 3.8 in Harbour approach channels (PIANC, 2014) the turning radius R_c is given as a function of the ship type. For container vessels over Panamax size the R_c is 7 times the L_{oa}.

$$R_C = 7L_{oa} = 7 * 352 = 2464\ m$$

The channel makes a bend of 60°. This gives a theoretical curvature length of $2\pi \cdot Rc \cdot \frac{60}{360} = 2580m$.

The channel will be composed of 4 smaller bends of 15°. The distance between those parts is evenly spread: 643m.

This might be an underestimation for the curvature, because 4 small bends are not the same as a constant big one. But the smaller ships have no problem with the turning. Also the biggest ships can still take the constant bend in the channel.

In **Fout! Verwijzingsbron niet gevonden.** a drawing of the bend is shown.

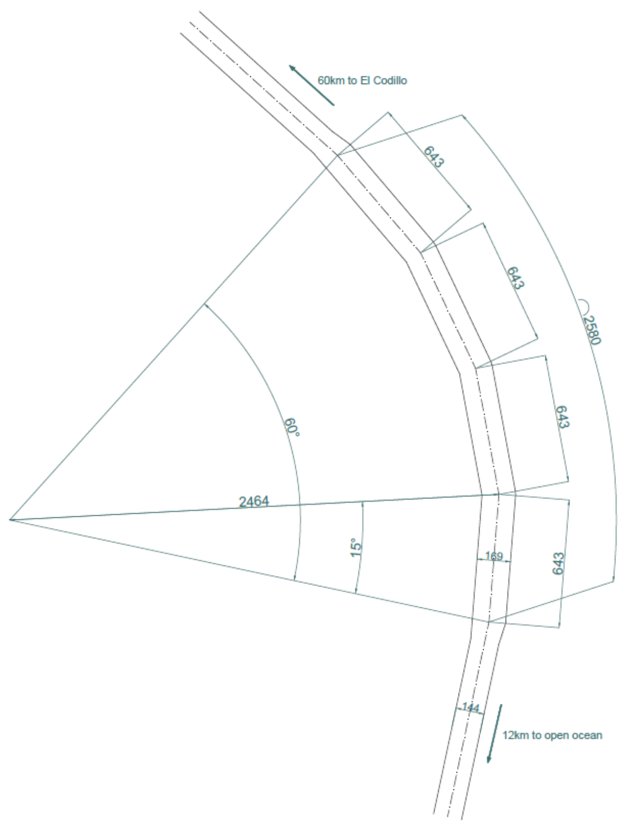


FIGURE 62: BEND CONFIGURATION.

APPENDIX F: BOUNDARY CONDITIONS WIDTH CALCULATION

The following parameters are used for the width calculation:

- Design ship dimensions and type
- Vessel speed V_s [kt] with respect to the water
- Prevailing cross wind V_{cw} [kt]
- Prevailing cross-current V_{cc} [kt]
- Prevailing longitudinal current V_{lc} [kt]
- Beam and stern quartering wave height H_s [m]
- Quality of Aids to Navigation (AtoN)
- Depth h [m]
- Water depth above embankment h_e [m]

In this appendix elaborations of the parameter calculations are presented. Also, their category is presented according to the PIANC manual (PIANC, 2014).

The channel direction is 312 degrees with respect to the cardinal system, see Section Layout.

The governing wind is coming equally from N, S and SE (respectively 0/360, 180 and 225 degrees) with a speed of 10 m/s (19.44 kt.). The cross wind is the wind perpendicular to the channel direction. The biggest component perpendicular to the channel will be from a northern or a southern wind, which have the same longitude due to their orientation to the channel.

$$V_{cw} = 19.44 * \sin 48\,° = 14.45\ [kt]$$

Prevailing crosswinds below 15 knots are considered mild. Hence, the prevailing cross wind is considered mild.

At Banco Piedras, there are two prevailing currents observed: one of 1.3 knot with a direction of 141.4° (current I) and one of 1.1 knot with a direction of 331.3° (current II). The angles made with the channels are respectively 141.4-132 = 9.4° and 331.3-312 = 19.3°. There is data available at the ocean side, but this value is small compared to the presented values.

$$longitudinal\ current\ I \rightarrow 1{,}3 * \cos 9{,}4° = 1{,}28\ kt$$
$$cross\ current\ I \rightarrow 1{,}3 * \sin 9{,}4° = 0{,}21\ \mathrm{kt}$$
$$longitudinal\ current\ II \rightarrow 1{,}1 * \cos 19{,}3° = 1{,}04\ \mathrm{kt}$$

$$cross\ current\ II \rightarrow 1{,}1 * \sin 19{,}3° = 0{,}36\ kt$$

$$V_{cc} = 0{,}36\ ;\ V_{lc} = 1{,}28$$

Prevailing cross currents between 0.2 and 0.5 knots are considered low. Hence, the cross current is considered low. Prevailing longitudinal currents below 1.5 knots are considered low. Hence, the longitudinal current is considered low.

The significant wave height is between 0.6-1.4 m with 80% of occurrences. The main wave direction is SSE with 59% of occurrences. The angle with the channel is 109.5°/70.5°. So these waves which can be regarded as beam waves, mainly induce roll effect which affect the under keel clearance and drifting motion of the ship. There are three categories, and the choice of the middle category is made. In this category wave heights between 1 and 3 meters are considered.

The ratio between depth and draught is used to determine if additional width is needed due to contact with the bottom surface or depth of the waterway. After iterative calculations, an elaborated concept design has been reached. For the elaborated concept design, two channel depth are calculated. For the 36 and 42 feet channels, a dredging channel depth of 14.16 and 16.36 meters are calculated with h/T ratios of 1.29 and 1.28, respectively. Hence, the channel depth – draft ratio would fall into the category 1.5 T > h ≥ 1.25 T.

APPENDIX G: WIDTH CALCULATION SHEET

The channel widths are calculated using Excel, based on the PIANC guidelines (PIANC, 2014) In this section tables are presented, as well as the general formula to determine channel width, used to calculate the width for one specific parameter set. Other widths were calculated with the same sheet but with other parameter sets. Then the formulas and calculations for the additional width due to the channel curvature are presented.

The general formula used to determine the width of straight, one-way channels given by PIANC is:

$$W = W_{BM} + \sum W_i + W_{BR} + W_{BG}$$

For a two-way channel, the following formula is given:

$$W = 2W_{BM} + 2\sum W_i + W_{BR} + W_{BG} + \sum W_p$$

W_{BR}= width of basic manoeuvring lane as a multiple of the design ship´s beam B
$\sum W_i$= additional widths to allow for the effects of environmental forces and boundaries, AtoN (Aids to Navigation) and channel depth
W_{BR}, W_{BG} = bank clearance on the 'red' and 'green' sides of the channel
$\sum W_p$ = passing distance, comprising the sum of a separation distance between both maneuvering lanes W_m and an additional distance for traffic density

The following tables calculate the channel width for the following parameter set:

- Containership (moderate maneuverability)
- Fast vessel speed
- Beam width = 48 meters
- L_{oa} = 352 meters
- Slope 1:20
- One-way channel

For the boundary conditions, see Appendix Boundary conditions width calculation. In the presented tables, the red boxed cell indicates the value used for the additional width.

In Table 50: Basic maneuvering lane, the widths of the basic maneuvering lane is set. The container ship's maneuverability is regarded moderate (PIANC, 2014).

Basic Maneuvering Lane (W_BM)		
Good	Moderate	Poor
62,4	72	86,4

TABLE 50: BASIC MANEUVERING LANE.

In Table 51 the basic additional widths are presented. Outer ch., both ch. and inner ch. are abbreviations for respectively outer channel, both channels and inner channels. The channel regarded is an outer channel.

Additional Widths W_i		Outer ch.	Both ch.	Iner ch.	Chosen
(a) Vessel speed (kts with resp to the water)					
V_s ≥ 12 kts	fast		4,8		4,8
8 kts ≤ V_s < 12 kts	mod		0		
5 kts ≤ V_s < 8 kts	slow		0		
(b) Prevailing cross wind V_cw					
Mild	fast		4,8		4,8
V_cw < 15 kts	mod		9,6		
(< Beaufort 4)	slow		14,4		
Moderate	fast		14,4		
15 kts ≤ V_cw < 33 kts	mod		19,2		
(Beafort 4 - Beaufort 7)	slow		28,8		
Strong	fast		24		
33 kts ≤ V_cw < 48 kts	mod		33,6		
(Beafort 7 - Beaufort 9)	slow		52,8		
(c) Prevailing cross-curren V_cc					
Neglegible					
V_cc < 0,2 kts	all	0		0	9,6
Low	fast	9,6		4,8	
0,2 kts ≤ V_cc < 0,5 kts	mod	12		9,6	
	slow	14,4		14,4	
Moderate	fast	24		19,2	
0,5 kts ≤ V_cc < 1,5 kts	mod	33,6		28,8	
	slow	48		38,4	
Strong	fast	48		-	
1,5 kts ≤ V_cc < 2,0 kts	mod	57,6		-	
	slow	76,8		-	
(d) Prevaling longtudinal current V_ic					
Low					
V_ic < 1,5 kts	all		0		0

Moderate	fast			0		
1,5 kts ≤ V_{ic} < 3 kts	mod			4,8		
	slow			9,6		
Strong	fast			4,8		
V_{ic} ≥ 3 kts	mod			9,6		
	slow			19,2		
(e) Beam and stern quartering wave height H_s						
- H_s ≤ 1 m	all	0			0	24
-1 m < H_s ≤ 3 m	all	24			-	
- H_s ≥ 3 m	all	48			-	
(f) Aids to Navigation (AtoN)						
Excellent				0		0
Good				9,6		
Moderate				19,2		
(g) Bottom surface						
-if depth h ≥ 1.5 T				0		4,8
-if depth h < 1.5 T then						
-smooth and soft				4,8		
-rough and hard				9,6		
(h) Depth of waterway h						
	h ≥ 1,5 T	0	h ≥ 1,5 T		0	4,8
	1.5 T > h ≥ 1.25 T	4,8	1.5 T > h ≥ 1.15 T		9,6	
	h < 1.25 T	9,6	h < 1.15 T		19,2	
(i) High cargo hazards		0			0	
Total						52,8

Table 51: Additional widths for straight channel sections.

In Table 52 on the previous page the additional width for blank clearance is presented (PIANC, 2014).

Bank Clearance (W_BR, W_BG)			
Widt for bank clearance	Vessel Speed	Outer channel	Inner Channel
1:10 or less	fast	9,6	9,6
	moderate	4,8	4,8
	slow	0	0
Sloping channel edges and shoals	fast	33,6	33,6
	moderate	24	24
	slow	14,4	14,4
Steep and hard embankments, structures	fast	62,4	62,4
	moderate	48	48
	slow	24	24

TABLE 52: BANK CLEARANCES.

For a bend, additional width is required to take into account. The PIANC guidelines (PIANC, 2014) provides a simplified formula for the additional width due to drift angle, which may be used in the concept design phase.

$$\Delta W_{DA} = \frac{L_{oa}^2}{a * R_c}$$

ΔW_{DA} = additional width of the vessel's path swept due to drift angle in a curved channel section
R_C = bend radius
L_{oa} = length overall
a = factor depending on the ship type

For a, the factor depending on the ship type, a = 8 for normal ships and a = 4.5 for larger displacement ships with $C_B \geq 0.8$.

For the additional width due to response time, the following formula is presented:

$$\Delta W_{RT} = 0.4B$$

ΔW_{RT} = additional width due to response time

In table 3.8 PIANC Approach channels design guidelines (PIANC, 2014), the turning radius R_c is given as a function of the ship type. For container vessels over Panamax size the R_c is 7 times the L_{oa}. For bulk carriers and tankers, the R_c is 6 times the L_{oa}.

$$R_C\ container = 7L_{oa} = 7 * 352 = 2464\ m$$
$$R_C\ bulk/container = 6L_{oa} = 6 * 255 = 1530\ m$$

The block coefficient C_B for the containerships is 0.68 and 0.82 for the bulk vessels. Hence or the factor a, respectively 8 and 4.5 are given.

The additional width of the vessel's path swept due to drift angle is then calculated with the formula presented earlier in this appendix. The results are presented in Table 53:

Drift angle	Table 3.8	
	Container	Bulk
a	8	4,5
R_c	2464	1530
W_DA	6,285714	9,444444

TABLE 53: DRIFT ANGLE EXTRA WIDTH.

The additional width due to response time is presented in Table 54**.** The additional width due to response time is calculated with the formula presented earlier in this appendix.

Response time			
Container (B=48m)		Bulk(B=36m)	
19,2	m	14,4	m

TABLE 54: RESPONSE TIME.

The results of the additional widths due to the bend are presented in Table 55**.**

	Container	**Bulk**
ΔW_{DA}	6,3	9,4
ΔW_{RT}	19,2	14,4
Total addition bend width	25,5	23,8

TABLE 55: ADDITIONAL BEND WIDTH.

Adding up all the calculated widths results in the total channel width. In Table 56, the additional widths are summed for the total channel width (= 144 meters), as well the total channel width in the bend (169.5 meters).

One-way channel		
W_BM	72	m
W_BR	9,6	m
W_BG	9,6	m
W_i	52,8	m
W_channel	144	m
W_additionalbend	25,5	m
W_channelbend	169,5	m

TABLE 56: OVERVIEW CALCULATED CHANNEL WIDTHS.

APPENDIX H: DEPTH BASED ON PIANC GUIDELINES

H.1 CHANNEL DEPTH CALCULATION

To get a better view of the processes in the channel, a more detailed formula has been worked out as a reference to the concept design depth of PIANC. Aspects like water density, wave response, dredging tolerances, squat and tidal influences are treated more extensively to get a better understanding of the channel and to give recommendations on a better channel design. In Figure 63 all relevant factors for the channel depth can be seen. Each of these factors is further explained in H.15 Depth factors - explanation

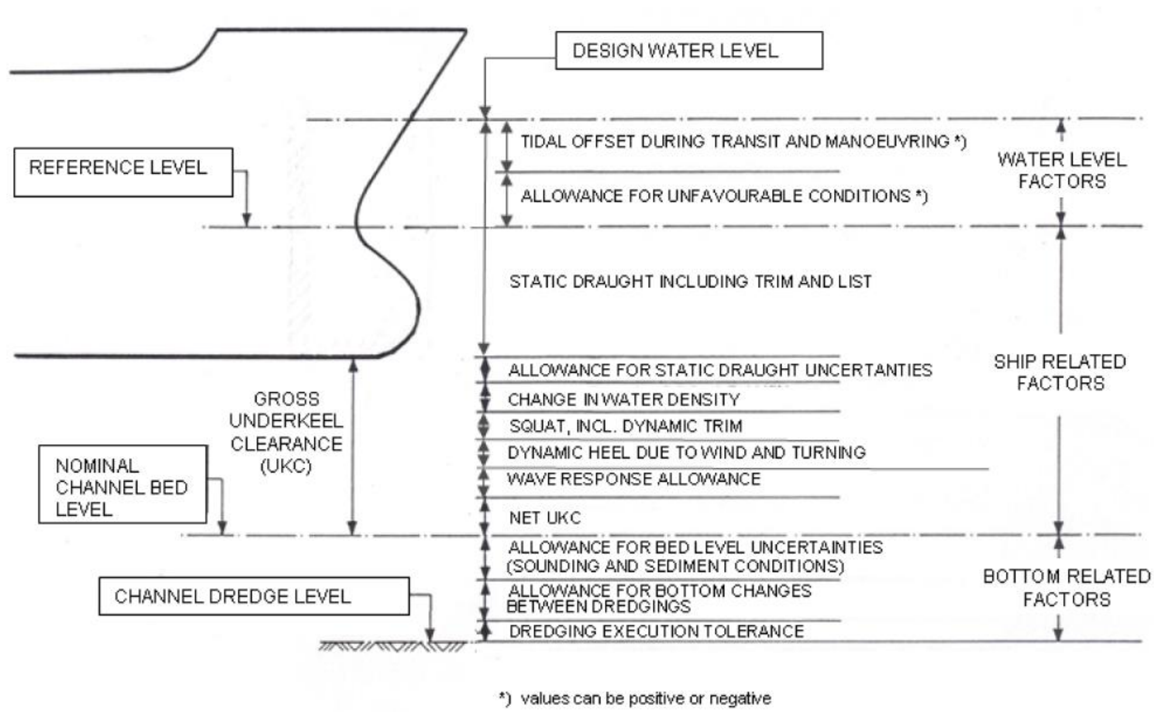


FIGURE 63: PIANC CHANNEL DEPTH FACTORS.

The following formula for channel depth is given by H. Ligteringen and H. Velsink (Ligteringen & Velsink, 2014).

$$h_{gd} = D - h_t + s_{max} + a + h_{net}$$

In which:

h_{gd}	=	nominal channel depth (with respect to a specified reference level)
D	=	draught design ship
h_t	=	tidal elevation above reference level, below which no entrance is allowed
s_{max}	=	maximum squat (fore or aft) due to sinkage and trim
a	=	vertical motion due to wave response
h_{net}	=	net under keel clearance

H.2 TIDAL ELEVATION

The mean water level for Punta Indio (Torre Oyarvide) is +0.85m above reference plane WGS84 5.1 Water reference levels. All tidal elevations can be seen. Like mentioned in paragraph 5.5.1 PIANC Concept Design, the traffic intensity in the Río de la Plata is relatively low and doesn't compensate for the dredging costs. Therefore the channel will have MSL as a reference plane and tidal influences are not taken into account, so some ships have to wait at specific waiting areas during low tide. The accessibility is 50%.

When a higher accessibility is wished for and on the other hand not be over dimensioning, the level for high tide is chosen to be at +1.33m and for low tide at +0.38m. With these values 10% of time low tide is larger than permitted. The tidal range becomes hereby +1.33m – +0.38m = +0.95m, which is not quite significant. The length of the channel is 200 km and it is calculated in *appendix H.17 Tidal window* that this distance is too long to be used for a tidal window. Vessels will encounter more than half the wavelength and therefore the whole advantage of high tide disappears. Waiting areas are therefore still needed, but less than with 50% accessibility. Taking a 90% accessibility results in an absolute level of +0.38m and $h_t = +0.85m - +0.38m = +0.47m$. When the accessibility needs to be increased from 50% to 90% this will give an extra dredging depth of 0.47m, leaving all other relevant factors on design depth out.

MSL is taken as plane of reference and tidal influences are neglected, so it is possible to compare the PIANC concept design depth with the more detailed formula given by *Ports & Terminals* (Ligteringen & Velsink, 2014). Over the entire channel stretch the MSL has the same value, otherwise a fixed reference plane like the 'Cero Local' or WGS84 needs to be used.

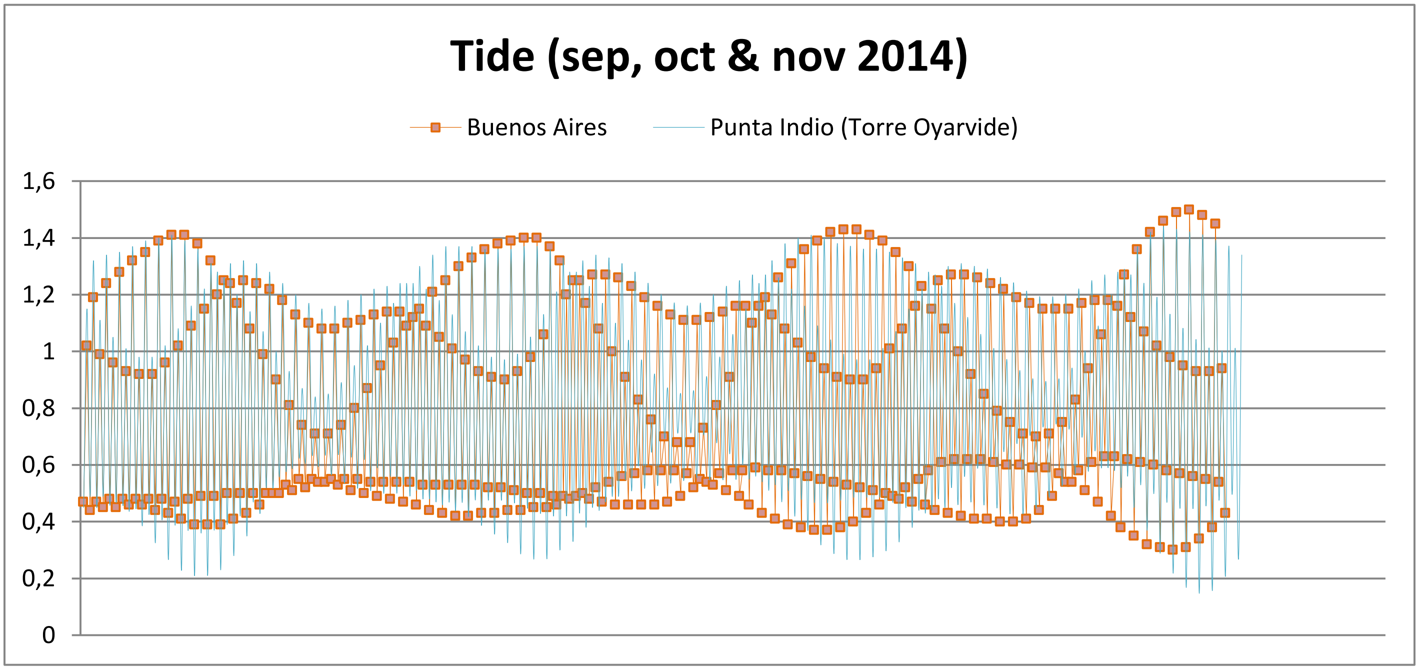


FIGURE 64: TIDAL ELEVATIONS SEPT, OCT AND NOV 2014; DATA FROM SERVICIO DE HIDROGRAFÍA NAVAL.

H.3 MAXIMUM SQUAT (FORE AND AFT) DUE TO SINKAGE AND TRIM

Ship squat depends on ship characteristics and channel configurations. The ship draught T, hull shape C_b and ship speed V_s all have influence on the amount of squat. Ship speed V_s has the most influence, which represents the speed of the ship relative to the water. Other factors influencing squat are the distance between fore and aft in length and width direction, the presence of a bulbous bow and the shape of stern-transoms (surface that forms the stern of a vessel). The main channel factors influencing squat is the proximity to the channel sides and bottom. If a ship is not in relatively shallow water with a small UKC, the effect of squat is usually negligible. The ratio water depth over ship draught h/T is considered safe from squat when greater than 1.5 (deep water conditions). There will still be squat, but to a lesser extent and the risk of groundings is low.

Ship squat has always existed, but could always be neglected due to small vessels, slow speeds and relatively deep channels. Nowadays there are bigger vessels, higher vessel speeds and shallower channels with less UKC so the amount of squat has increased. It has become an important part in channel design. High dredging costs and higher chances of groundings made it important to come to an accurate squat value.

There are several empirical formulas that can be used to calculate squat. As mentioned in the PIANC manual (PIANC, 2014) the formula of Barrass3, Yoshimura and ICORELS are simple to use and therefore good for a concept design. The formulas are based on ships in the center of a symmetrical channel. Because the channels are one-way this does not give problems. When overtaking, one of the ships will be at a waiting or overtaking area while the other ship passes. The ship may be sailing somewhat out of the center of the channel, but this won't have large influences on squat and will be neglected. Also the speed of the ships relative to the water won't increase, because one of the ships will be waiting in the waiting area. For a two-way channel these would have resulted into larger squat values.

Due to the very mild slopes of 1:20 the designed channel is considered to be unrestricted. Barrass has made a formula defining when a channel is unrestricted.

$$W_{eff} = \left[\frac{7{,}04}{C_B^{0{,}85}}\right] B$$

To be an unrestricted channel W_{eff} must be at least 8*B. Container vessels have a blockage coefficient of 0.68 with a width of 48 m. Bulk carriers have a blockage coefficient of 0.82 and a width of 36 m. The block coefficient is used to describe the hull shape. It is a measure of how streamlined a ship is compared to an equivalent rectangular volume with the same dimensions.

The block coefficient value C_b is given for fully loaded ships. This is not always the case in the Río de la Plata as mentioned in chapter Design ship. Ships which are not fully loaded have a lower draught, lay higher in the water and therefore have a slightly smaller C_b value. The actual C_b value is very hard to determine and is based on the weight of cargo and the weight/shape of the ship. The difference in C_b is small and would be an estimation, therefore the C_b for fully loaded ships is used.

$$W_{eff} = \left[\frac{7{,}04}{0{,}68^{0{,}85}}\right] * 48 = 469m$$
$$W_{eff} = \left[\frac{7{,}04}{0{,}82^{0{,}85}}\right] * 36 = 300m$$

Container vessels satisfy the condition with 469m/48m=9,77*B and bulk carriers with 300m/36m=8,33*B. Therefore the channel can be categorized as an unrestricted channel. See Figure 65.

For open or unrestricted channels ICORELS has been historically a good choice according to PIANC (PIANC, 2014). Therefore Barrass3 and Yoshimura will be mentioned, but ICORELS will be used for further calculations. In Table 57 can be seen in which circumstances the formulas may be used and under what constraints.

Formula	Channel type			Constraints							
	U	R	C	F_{nh}	C_B	S	B/T	h/T	h_t/h	L/B	L/T
Barrass3	Yes	Yes	Yes	V^2	0,5 – 0,85	0,1 – 0,25		1,1 – 1,4			
Yoshimura	Yes	Yes	Yes	V^2	0,55 – 0,8		2,5 – 5,5	$\geq 1,2$		3,7 – 6,0	
ICORELS	Yes	(Y)*		$0,7 \leq V_{cr}$	0,6 – 0,8		2,19 – 3,5	1,1 – 2,0	0,22 – 0,81	5,5 – 8,5	16,1 – 20,2

TABLE 57: CHANNEL CONFIGURATIONS AND PARAMETER CONSTRAINTS FOR SQUAT FORMULA, PAGE 191 (PIANC, 2014).

In which:
U = Unrestricted channel
R = Restricted channel
C = Canal
**ICORELS sometimes used in restricted channels although originally developed for unrestricted channels. Use with caution in this case.*

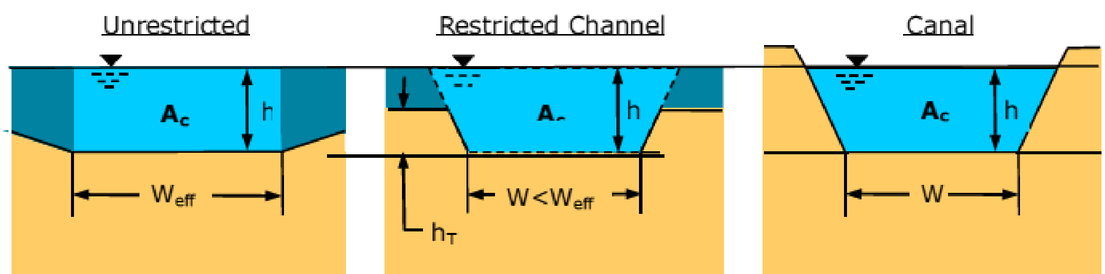


FIGURE 65: CHANNEL CONFIGURATIONS: UNRESTRICTED (OPEN), RESTRICTED (TRENCH) AND CANAL, PAGE 28 (PIANC, 2014).

H.4 FORMULA OF BARRASS3

The formula of Barrass for maximum squat S_{max} can be used for all channel types and can be divided into squat at the bow and stern. It is dependent on blockage coefficient Cb, vessel speed Vk (knots) and the channel's dimensionless blockage coefficient S.

$$S_{max,B3} = \frac{C_B * V_K^2}{100/K}$$
$$K = 5,74 * S^{0,76}$$

$$S_{m,B3} = K_m * S_{max,B3}$$
$$K_m = [1 - 20(0,7 - C_B)^2]$$

$$S_{t,B3} = K_t * S_{max,B3}$$

$$K_t = 40(0{,}7 - C_B)^2$$

In which:

S_{max}	=	maximum squat for all channel configurations [m]
S_m	=	mean body sinkage [m]
S_t	=	dynamic trim [m]
V_K	=	vessel speed [knots]
C_B	=	block coefficient [-]
K	=	dimensionless coefficient [-]

For open or unrestricted waters a blockage factor of S=0,10 is used which results in K=1. For restricted channels this is S=0,25 and K=2. Constraints of these equations are $1{,}10 \leq h/T \leq 1{,}40$ and $0{,}10 \leq S \leq 0{,}25$. Container vessels have C_b=0,68 and a sailing speed of 14 knots:

$$S_{max,B3} = \frac{0.68 * 14^2}{100} = 1{,}33m$$

$$K_m = [1 - 20(0{,}7 - 0{,}68)^2] = 0{,}992$$
$$S_{m,B3} = 0{,}992 * 1{,}33m = 1{,}32m$$

$$K_t = 40(0{,}7 - 0{,}68)^2 = 0{,}016$$
$$S_{t,B3} = 0{,}016 * 1{,}33m = 0{,}02m$$

For bulk carriers with C_b=0,82 and a sailing speed of 12 knots:

$$S_{max,B3} = \frac{0.82 * 12^2}{100} = 1{,}18m$$

$$K_m = [1 - 20(0{,}7 - 0{,}82)^2] = 0{,}712$$
$$S_{m,B3} = 0{,}712 * 1{,}18m = 0{,}84m$$

$$K_t = 40(0{,}7 - 0{,}82)^2 = 0{,}576$$
$$S_{t,B3} = 0{,}016 * 1{,}18m = 0{,}68m$$

Because Barrass3 uses the same blockage factor S for unrestricted channels, unrelated to draught and depth of the channel, squat has the same value for all channel depths. This is 1,33m for container vessels and 1,18m for bulk carriers.

H.5 FORMULA OF YOSHIMURA

Yoshimura suggest that squat is a quadratic function of ship's speed that changes with the blockage factor S for restricted and unrestricted channels, but ignores the effect of a critical speed V_{cr}. The formula for bow squat $S_{b,y}$ generally has the same value as the other PIANC squat formulas regardless of ship type:

$$S_{b,y} = \left[(0{,}7 + 1{,}5\frac{1}{h/T})(\frac{C_B}{L_{pp}/B}) + 15\frac{1}{h/T}(\frac{C_B}{L_{pp}/B})^3\right]\frac{V_e^2}{g}$$

With:

$$V_e = \begin{cases} V_s & U \\ \dfrac{V_s}{(1-S)} & R, C \end{cases}$$

Filling in this equation with $V_e = \ V_s$ for unrestricted channels gives for container vessels with Cb=0.68, Lpp=335m, B=48m and for bulk carriers with Cb=0.82, Lpp=228m, B=36m:

	Squat (Yoshimura)	
Variants	Container ship	Bulk carrier
Punta Indio 34ft	1,36m	1,20m
Punta Indio 36ft	1,05m	1,07m
Magdalena 36ft	1,05m	1,07m
Magdalena 42ft	1,06m	1,09m

TABLE 58:RESULTS FOR SQUAT CALCULATIONS USING YOSHIMURAS FORMULA.

H.6 ICORELS FORMULA

The formula of ICORELS for bow squat $S_{b,l}$ was initially developed for unrestricted channels and increases more than quadratic with increasing speed. For restricted channels it should be used with caution.

$$S_{b,l} = C_s \frac{\nabla}{L_{pp}^2} \frac{F_{nh}^2}{\sqrt{1 - F_{nh}^2}}$$

With:

$$C_s = \begin{cases} 1{,}7 & C_B < 0{,}70 \\ 2{,}0 & 0{,}70 \leq C_B < 0{,}80 \\ 2{,}4 & C_B \geq 0{,}80 \end{cases}$$

The ship's volume displacement is defined as $\nabla = C_B L_{pp} B T$, which gives for the container ship design vessel $\nabla = 0{,}68 * 335m * 48m * 10{,}97m = 119.950m^3$ for 36ft and $\nabla = 0{,}68 * 335m * 48m * 12{,}80m = 139.960m^3$ for 42ft. With different draughts L_{pp} and C_B will change somewhat, but this is very hard to determine and will not have a big influence. Therefore this difference will be neglected. The constant C_s is 1.7 because the blockage coefficient is 0.68. The depth Froude Number in the ICORELS formula contains the channel depth h and therefore the guaranteed channel depth h_{gd} needs to be solved iteratively. The elaboration of the depth Froude Number is done in *appendix H.11 Depth Froude Number.*

For bulk carriers the volume displacement is $\nabla = 0{,}82 * 228m * 36m * 10{,}97m = 73.834m^3$ for 36ft and $\nabla = 0{,}82 * 228m * 36m * 12{,}80m = 86.151m^3$ for 42ft, with a constant C_s of 2.4.

For the current Punta Indio channel at 34ft nominal channel bed level plus 0.5m dredging tolerance, the draught of ships is 34ft. Calculations are done with Matlab, the written code can be seen in *Appendix N: Matlab code for iteratively determining channel depth* and results are shown in Table 59.

	Squat (ICORELS)	
Variants	Container ship	Bulk carrier
Punta Indio 34ft	1,17m	1,46m
Punta Indio 36ft	0,92m	1,16m
Magdalena 36ft	0,92m	1,16m
Magdalena 42ft	0,91m	1,17m

TABLE 59: RESULTS OF SQUIAT CALCULATIONS USING ICORELS FORMULA.

It can be immediately seen that for the current Punta Indio channel the squat is bigger than 0.5 m dredging tolerance. This means that ships would need lower static draughts or the sailing speed would have to be much lower, else the ships would get stuck in the channel. Due to the soft silt/clay bottom this would not lead to (much) damage of the ships, but can cause large delays/blocking for other ships passing the one-way Punta Indio channel.

In the channel design a fast traffic regime is chosen. This has large consequences for the channel depth because of high squat values. For further research a lower vessel speed could be investigated, because this has large influences on the channel dimensions and, unlike the current situation with high vessel speeds, the traffic intensity is low and therefore a medium or even low sailing speed is acceptable.

H.7 VERTICAL MOTION DUE TO WAVE RESPONSE

The significant wave height Hs is the average of the highest one-third (33%) of the measured waves from through to crest in a given period. In Figure 66 the significant wave height Hm0 is used. This is estimated from the variance of the recorded waves or with an integral of the variance from the spectrum. It is an estimate, but in many cases very accurate and therefore much used in data analysis. Hm0 slightly overestimates Hs with approximately 5%, but since the determination of the significant wave height is a choice of the designer and not a hard criteria this difference is found neglectable. Waves between Hm0 = 0.6m and 1.4m have an occurrence of 80%, waves exceeding Hm0 = 3.0m occur less than 1%. For the channel design a significant wave height of Hm0 = 2.0m has been chosen. There are a few occurrences in which the significant wave height exceeds this value and because the calculation is with an average value some individual waves will be higher, but otherwise the channel would be over dimensioned. When higher waves do occur, there is still a safety margin and the soft bottom does not likely give damage to the ship. Based on this argumentation Hm0 = 2.0m is chosen. It is measured from through to crest, so therefore the vertical motion due to wave response is $a = \frac{2{,}0m}{2} = 1.0m$. Only the level beneath the still water level is relevant to the depth of the channel.

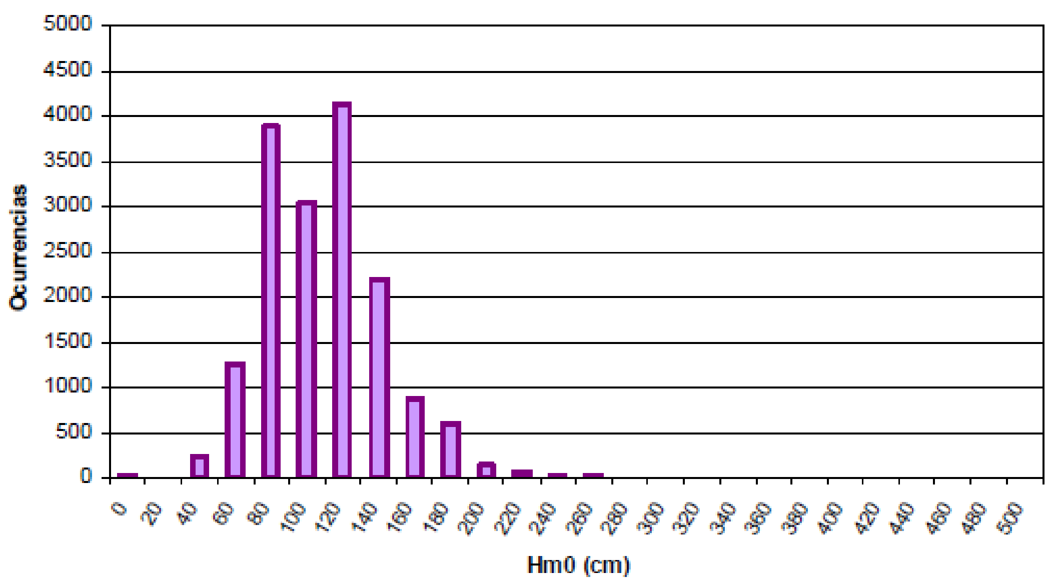


FIGURE 66: SEA WAVES: SIGNIFICANT WAVE HEIGHTS OCCURRENCES, 1996-2009, TORRE OYARVIDE (HIDROVÍA S.A., 2013).

H.8 NET UNDER KEEL CLEARANCE

The net under keel clearance (UKC_{net}) is used for the concept design phase. It can be seen as the minimum margin remaining between the keel of the ship and the nominal channel bed level, while the ship is sailing under the highest allowable wind and wave conditions. The distance after subtracting all factors leaves a safety margin to the nominal channel bed level. ICORELS wrote that the UKC_{net} should be based on type and size of the ship, commodities, environmental consequences, density of traffic etc. A value of at least 0.5m is recommended but can be increased to 1.0m when the consequences of touching the bottom would have major effects.

Because the bottom of the channel is soft, traffic intensity is low and the consequences are not that high the net under keel clearance is selected at 0.5m (PIANC, 2014).

H.9 DREDGING TOLERANCES

The PIANC manual doesn't give hard criteria for dredging tolerances, because it is very difficult to determine due to the different site specific circumstances. A minimal allowance for bed level uncertainty of at least 0.1m is recommended. For bottom changes between dredging a minimal allowance of 0.2m or 1% of channel depth is recommended. And at last; a typical dredging execution tolerance between 0.2m and 0.5m is common, depending on the bottom- and dredger type (PIANC, 2014).

In the existing channels a lot of mud is deposited and maintenance dredging needs to counteract this. The amounts of deposited mud are dependent on the local circumstances. Nowadays ships push their draught to the maximum, resulting in propellers of the vessels very close to the ground. The sediments are stirred up and in the case of the Punta Indio channel crossing the Río de la Plata the horizontal tide takes the suspended sediments away. For the Intermedio channel and the new Magdalena channel this is not the case, because the channels lay in the same direction as the horizontal tide. The sediments are stirred up, but now it is transported through the channel and not out of it. Weather influences the sedimentation also. In times of rough weather and high wind speeds, short waves are present which stir up the sediment. Mostly in places where the water depth is most shallow and the waves are closest to the bottom. In times of calmer weather the sediment has the chance to settle again, especially in the lower parts. The Río de la Plata wants to get back to its natural equilibrium.

The Río de la Plata is mainly consisting of silt, sand and mud as can be seen in *Appendix C: Physical Environmental Data Analysis*. It is soft material and can be measured quite well. A minimal bed level uncertainty and minimal execution tolerance of 0.1 m and 0.2 m are used, because grounding probably won't result in any damages and the shipping intensity is not that high. Studies and experience differ in the amount of deposited sediments. For the new channel caution is required and on top of that mud that's depositing shifts and moves much faster than for instance sand. Therefore the allowance for bottom changes between dredging is chosen to be 0.4 m. This sums up to a tolerance of:

$$\text{dredging tolerances} = 0{,}1m + 0{,}2m + 0{,}4m = 0{,}7m$$

H.10 RESULTS

Filling in all abovementioned factors into the formula of H. Ligteringen and H. Velsink (Ligteringen & Velsink, 2014) gives the guaranteed channel depth. This is relative to MSL, the midpoint between the average high tide and the average low tide. The nominal channel depth is calculated iteratively using Matlab for the new Magdalena channel with a container ship as design vessel with 36 feet draught. See *Appendix N: Matlab code for iteratively determining channel depth* for the Matlab code used.

$$h_{gd} = 10{,}97m + 0m + S_{b,l} + 1{,}0m + 0{,}5m$$

$$S_{b,l} = 1{,}7 * \frac{119.950m^3}{(335m)^2} \frac{F_{nh}^2}{\sqrt{1 - F_{nh}^2}}$$

$$F_{nh,container} = \frac{V_s}{\sqrt{gh}} = \frac{7{,}2m/s}{\sqrt{9{,}81\frac{m}{s^2} * h}}$$

$$h_{gd} = 13{,}39m$$

To get the channel dredge level the dredging tolerance of 0.7m has to be added. This gives:

$$h = 14.09m$$

The other variants lead to the following channel depths:

	Channel dredge level	
Variants	Container ship	Bulk carrier
Punta Indio 34ft	(10,86m)	(10,86m)
Punta Indio 36ft	14,09m	14,33m
Magdalena 36ft	14,09m	14,33m
Magdalena 42ft	15,91m	16,17m

TABLE 60: CHANNEL DREDGE LEVELS.

H.11 DEPTH FROUDE NUMBER

The depth Froude Number is a measure of the ships resistance to motion in shallow water. The value is a combination between ship and channel parameters and is dependent on ship speed V_s and water depth h.

$$F_{nh} = \frac{V_s}{\sqrt{gh}}$$

For container ships a vessel speed of 14 knots (7.2m/s) is used, for bulk carriers 12 knots (6.2m/s). The ship speed is relative to the water, so to achieve the most unfavorable situation the current has to flow opposite to the ship to achieve the highest Froude number. The longitudinal current is 1.28 knots (0.7m/s] *Appendix G: Width calculation sheet*. The vessel types have specific boundaries where the resistance to motion increases such that the vessels do not have sufficient power to increase in speed. Usually the threshold for container vessels is $F_{nh,container} < 0.7$ and for bulk carriers $F_{nh,container} < 0.6$.

$$F_{nh,container} = \frac{7{,}2m/s + 0{,}7m/s}{\sqrt{9{,}81\frac{m}{s^2} * h}}$$

$$F_{nh,bulk} = \frac{6{,}2m/s + 0{,}7m/s}{\sqrt{9{,}81\frac{m}{s^2} * h}}$$

	Depth Froude Number F_{nh}	
Variants	Container ship	Bulk carrier
Punta Indio 34ft	0,77	0,67
Punta Indio 36ft	0,68	0,59
Magdalena 36ft	0,68	0,59
Magdalena 42ft	0,64	0,55

TABLE 61: DEPTH FROUDE NUMBERS.

All newly designed channel depths are consistent with the mentioned threshold for container vessels $F_{nh,container} < 0.7$ and for bulk carriers $F_{nh,container} < 0.6$, except for the current Punta Indio channel with a nominal channel depth of 34 feet. The channel dredge level is 0.5 m lower than the nominal channel depth.

Filling in this equation with $V_e = V_s$ for unrestricted channels gives for container vessels with Cb=0.68, Lpp=335m, B=48m and for bulk carriers with Cb=0.82, Lpp=228m, B=36m:

	Squat (Yoshimura)	
Variants	Container ship	Bulk carrier
Punta Indio 34ft	1,36m	1,20m
Punta Indio 36ft	1,05m	1,07m
Magdalena 36ft	1,05m	1,07m
Magdalena 42ft	1,06m	1,09m

TABLE 62: RESULTS OF SQUIAT CALCULATIONS USING YOSHIMURAS FORMULA.

In the ICORELS Formula the squat is bigger than this dredging tolerance. This means, together with the data of the depth Froude Number, that the vessels sailing in the existing Punta Indio channel can't have a static draught of 34 feet or else they will get stuck at sailing. The other values of the depth Froude number comply with the given restrictions.

H.12 CRITICAL SPEED VCR

In a restricted channel or canal the motion of a ship sailing will cause a return flow. Due to Bernoulli's Law the water level will drop, causing the cross-section of the waterway to reduce and enhancing the return flow even more. Because of this effect ship squat will increase more as a quadratic function of the vessel speed Vs. A stationary situation for the return flow is only possible when the ship's speed is lower than the critical velocity Vcr:

$$\frac{V_{Cr}}{\sqrt{gh_m}} = \left[\frac{2}{3}(1 - S + \frac{V_{Cr}^2}{2gh_m})\right]^{1,5}$$

This can also be solved explicit by rearranging some of the terms:

$$\frac{V_{Cr}}{\sqrt{gh_m}} = K_c = \left[2 * \sin\left(\frac{\arcsin(1-S)}{3}\right)\right]^{1,5} = \left[2 * \cos\left(\frac{\pi}{3} + \frac{\arccos(1-S)}{3}\right)\right]^{1,5}$$

THE MEAN WATER DEPTH H_M IS ONLY REQUIRED FOR RESTRICTED CHANNELS AND CANALS. THE DESIGNED CHANNEL IS CONSIDERED UNRESTRICTED, SEE FIGURE 64: TIDAL ELEVATIONS SEPT, OCT AND NOV 2014; DATA FROM SERVICIO DE HIDROGRAFÍA NAVAL.

H.3 Maximum squat (fore and aft) due to sinkage and trim, and therefore h_m is equal to water depth h.

In unrestricted shallow water S=0, which gives Kc=1. This means that the critical speed V_{Cr} equals $\sqrt{gh_m} = \sqrt{9{,}81m/s^2 * 14.64m} = 11.98m/s$ or 39.3knots. When the blockage S increases somewhat, the critical speed V_{Cr} will increase very rapidly in the beginning. See Figure 67. A very small S=0.03 already results in $V_{Cr} \approx 0.8\sqrt{gh_m}$. As previously mentioned the channel may be characterized as an unrestricted channel, but for a safe approximation the second critical speed will be used as a maximum. This is $V_{Cr} \approx 0.8\sqrt{gh_m} = 0.8 * \sqrt{9{,}81m/s^2 * 14.64m} = 9{,}59m/s$ or 31,45knots. This is way higher than the used 12 knots and 14 knots in the current channel, but for more restricted channels this maximum can be much lower.

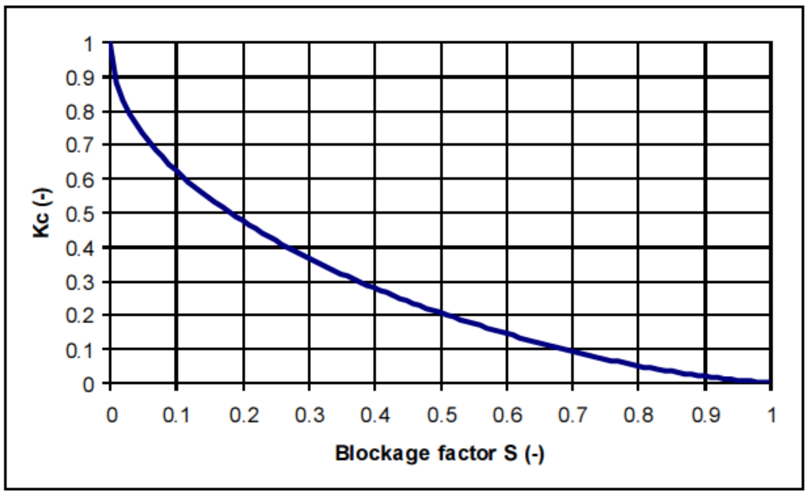


FIGURE 67: KC VALUE VS. BLOCKAGE FACTOR S (PIANC, 2014).

H.13 MANEUVERABILITY MARGIN

The maneuverability margin (MM) is used to define the time-averaged clearance under the ship. Maneuverability may be defined as specific maneuvers of the pilot/ship without the help of tugboats. When the distance between the channel bottom and the ship's keel decreases the ability to maneuver at the design speed also decreases. It can even become insufficient and not enough water flows below and around the ship. The ship can no longer maneuver properly and has to sail slower. PIANC introduced this margin to keep sufficient distance between the lowest average level of the ship's keel and channel bottom.

Wave-induced oscillations like heave, pitch and roll generally have not much effect on maneuverability. Therefore only calculations which effect the lowest average position of the ships bottom are taken into account. The following formula follows:

$$MM = depth - draught - squat - heel$$

The minimal value for MM depends on ship type, ship traffic (one-way or two-way) and channel dimensions plus alignment. For most ship sizes and channel types it has been found that a minimal MM of 5% of draught or 0.6m, whichever is greater, is found to be sufficient for proper maneuverability.

The calculation for minimum maneuverability margin is separate from the calculations of net UKC that includes wave response allowance. In practice, MM is determinative over UKC for inner harbor basins and outer harbor sections with low swell conditions. If there is tug assistance and waves are not too high, the value of MM will decrease.

See for squat ICORELS formula and for dynamic heel the calculation below for both container and bulk vessels. Filling in the maneuverability margin with the now known factors for 36ft gives:

$$S_{k,container} = 0{,}90\left(\frac{48}{2}\sin(1{,}5)\right) = 0{,}57m \qquad S_{k,bulk} = 0{,}90\left(\frac{36}{2}\sin(1{,}5)\right) = 0{,}42m$$

$$MM_{36ft,container} = 14{,}33m - 10{,}97m - 0{,}92m - 0{,}57m$$

$$MM_{36ft,container} = 1{,}78m$$

$$MM_{36ft,bulk} = 14{,}33m - 10{,}97m - 1{,}16m - 0{,}42m$$

$$MM_{36ft,bulk} = 1{,}78m$$

And for the 42ft variant it results in:

$$MM_{42ft,container} = 16{,}17m - 12{,}80m - 0{,}92m - 0{,}57m$$

$$MM_{42ft,container} = 1{,}88m$$

$$MM_{42ft,bulk} = 16{,}17m - 12{,}80m - 1{,}16m - 0{,}42m$$

$$MM_{42ft,bulk} = 1{,}79m$$

The requirement of a minimum 5% draught of the channel gives $0{,}05 * 14{,}33m = 0{,}72m$ for 36ft and $0{,}05 * 16{,}17m = 0{,}81m$ for 42ft. On top of that there is a minimum of 0,6m. The calculated maneuverability margin is bigger than both given requirements for the two variants, therefore the ships won't have any trouble navigating and the channel doesn't needs to be adapted. (PIANC, 2014)

H.14 MUDDY CHANNEL BEDS

Many navigational channels are covered with muddy suspensions with somewhat higher densities than water (1050 – 1300 kg/m3), but with comparable rheological properties. Contact with the keel of the ship and the upper part of the fluid mud suspension would probably not damage the ship and have minimal influence on maneuverability. This would increase navigable depth and reduce dredging frequency.

The definition of the "bottom" is now hard and difficult to make. Measurements can only show the top of the suspension and some distance into the hard bottom, but not the exact place of the hard bottom. Taking the top of the suspension would be safe, but gives problems to navigation due to tidal and seasonal variations. This makes it hard to maintain a certain depth trough dredging. Choosing the lower boundary could lead to damage of the ship, loss of control and would threaten safety.

If there is a mud layer present, this will always increase the maximum sinkage of the ship. To include this effect the water level above the mud suspension must be used in the squat formula.

The concept design for the channel is for a first approximation quick and easy to calculate. This results in a conservative design with an adequate level of navigational safety. For better and more accurate results further studies have to be done to create a smaller channel still functioning to the level of safety.

H.15 DEPTH FACTORS - EXPLANATION

WATER RELATED FACTORS:

Tidal elevation: Due to tides the water level fluctuates and consequently also the UKC. This can be positive (high tide, the ship sails higher) or negative (low tide). During channel design the tide has to be taken into account if this has a large amplitude compared to the channel depth. Larger vessels can enter the port during high tide, but at low tide vessels can get grounded.

(Un)favorable conditions: In case of *sudestadas* the water level in the Río de la Plata is rising. This is however not always favorable. Mostly these winds are part of a storm, where high waves and high wind speeds make navigation more difficult.

SHIP RELATED FACTORS:

(Static) Draught: There is equilibrium between the total weight of a stationary ship and the weight of the water that is displaced. The vertical distance below water level that is needed to displace this amount of water is known as static draught or draught.

Draught uncertainties: The draught is measured with limited accuracy at the port of departure and can lead to uncertainties. The port of arrival could have a different water density resulting in a different draught. Furthermore, the mark on the ship to determine the draught could be difficult to read because of wave action. When the ship is unevenly loaded the mark could lay more or less deep in the water resulting in a wrong determination of the draught.

Sinkage: A ship sailing through shallow water is being sucked to the bottom by a low pressure zone. This is because the water in front of the ship has to be squeezed in between the hull of the ship and the seabed, so the water has a higher resistance and is therefore flowing faster creating a low pressure zone.

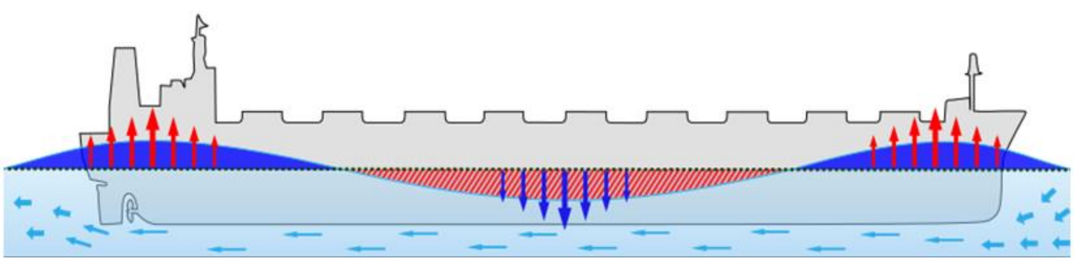


FIGURE 68: SINKAGE (WIKIPEDIA, 2008)

Trim: The flow of water as mentioned above, between the hull and bottom, is also transferring a rotational force to the ship causing it to tilt back or forth. This can be (partly) adjusted by ballast water tanks. Some prefer to lean back, so the rudder and propeller lay deeper in the water and the maneuverability is better. Others prefer to lean forward, so the bulb of the ship lies deeper in the water and the resistance will decline. Trim is the difference between draught at the bow and stern.

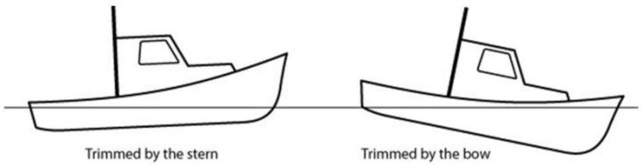


FIGURE 69: VESSEL TRIM.

Squat: The combined effect of sinkage and trim due to the same water stream flowing between the ship's hull and the bottom of the channel.

Heel: The same movement as rolling, but now it's not arising from oscillating waves but by non-oscillating winds and currents. When a ship turns it also heels and ads to the draught. Factors influencing heel are the rate of turning, windage, ship speed, metacentric height and tugboat forces.

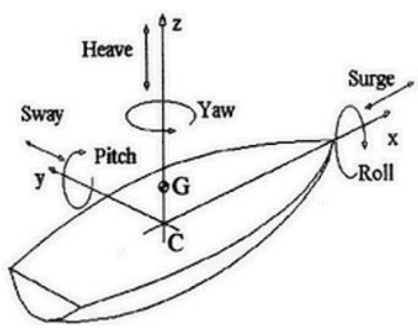


FIGURE 70: VESSEL MOTIONS

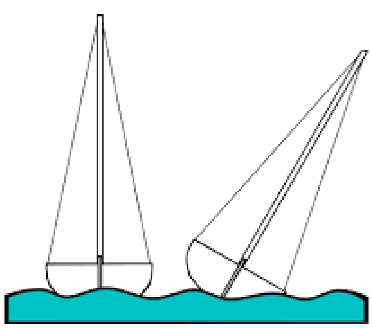


FIGURE 71: VESSEL HEEL EXAMPLE

Wave-induced vertical motions: The up/downward movement due to wave action.

Net UKC: The minimum distance remaining between keel and bottom after subtracting all other factors. The net UKC is the distance what is left and can be seen as a 'safety' margin.

H.16 BOTTOM RELATED FACTORS:

Bed level uncertainties: This is the difference between the actual depth and the measured depth of the bottom. Measurement devices have a built-in tolerance or uncertainty and this has to be accounted for.

Bottom changes between dredging: After dredging operations there will almost certainly be sedimentation filling up the channel. To anticipate on this there will be dredged slightly deeper to avoid continuously dredging.

Dredging execution tolerance: The bottom after dredging will not be completely flat, so there will be dredged extra to ensure a specific nominal depth.

Variations in the abovementioned factors can occur which affect the ships draught even more. This can be due to a variety in water density, sailing speed, rate of turning or computational uncertainties.

H.17 TIDAL WINDOW

In the case of large tidal amplitudes it may be an option to use a tidal window. With this measure dredging can be limited and the tidal elevation is used to create sufficient water depth. A disadvantage is that usability of the channel is also limited.

Ships moving in the same direction as the tide profit most of the tidal elevation. This can be seen in Figure 72. This would be the case for ships coming from the Atlantic Ocean. Ships sailing in the opposite direction of the tidal wave, thus leaving the Río de la Plata, profit the least and are therefore determinative for the channel design.

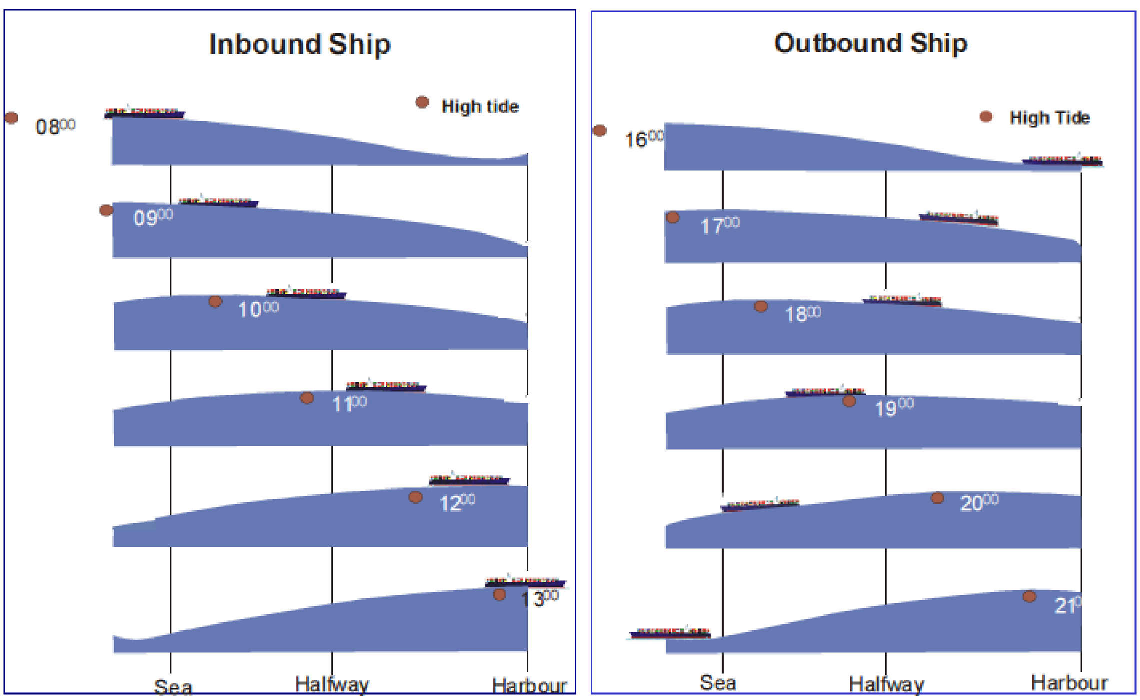


FIGURE 72: INBOUND & OUTBOUND SHIPS WITH TIDE (PIANC, 2014).

Ships sailing in the Río de la Plata estuary have a speed between 8 and 14 knots, or 4 and 7m/s. (Marinetraffic, 2015) The distance ships have to travel to get from the port of Buenos Aires to the South Atlantic Ocean is around 200km. The first part from the port of Buenos Aires to El Codillo is 144km long and lies in exactly the same direction as the tide propagation. The second part is the alternative Magdalena channel with a length of around 50km and also lies in the same direction as the tidal propagation. With this information it can be determined how much the ships can benefit from the tidal elevation.

It is found that the water depth $d = 5.5m$, as this is the average depth of the Río de la Plata (Navionics Webapp, 2015). Substituting the depth and gravitational acceleration $g = 9.81m/s^2$ into the wave celerity equation with shallow water conditions gives:

$$c = \sqrt{gd} = \sqrt{9{,}81 * 5{,}5} = 7{,}35m/s$$

The period of M2 tide is 12h25m (or 12,417h). This gives the tidal wave a length of:

$$L = \sqrt{gd}T = \sqrt{9{,}81 * 5{,}5} * 12{,}417 * 3600 = 328km$$

Ships sailing at 4m/s will travel t seconds to get through the entire 200km channel:

$$t_{channel,4} = \frac{200 * 10^3 m}{4\ m/s} = 50.000s = 13{,}9h$$

Ships sailing at 7m/s will travel t seconds to get through the entire 200km channel:

$$t_{channel,7} = \frac{200 * 10^3 m}{7\ m/s} = 27.210s = 7{,}56h$$

H.18 OUTGOING SHIPS

When a ship leaves the port of Buenos Aires at zero tidal elevation, it takes x meters and t seconds to reach high or low tide (1/4 wave length), dependent on which time the tide passes:

$$t_{tide,4} = \frac{0{,}25 * 328km}{4\ m/s\ + 7{,}35\ m/s} = 7225s = 2h$$

$$x_4 = 4\ m/s\ * 7225s = 28{,}9km$$

$$t_{tide,7} = \frac{0{,}25 * 328km}{7\ m/s\ + 7{,}35\ m/s} = 5715s = 1{,}6h$$

$$x_7 = 7\ m/s\ * 5715s = 40{,}0km$$

To determine when another zero tidal elevation or high/low tides is reached it takes multiples of the calculated times and distances above. The alternative channel has a length of approximately 50 km. As can be seen above, the distances ships and tides travel in opposite direction during this timeframe are smaller than half the wavelength (2*28.9 km and 2*40.0 km < 0.5*328 km). Therefore ships may benefit from tidal elevations if they sail during specific times. Sailing faster further increases the advantage of the tidal wave because you can use the top of the tidal wave more.

Seen over the entire channel from the port of Buenos Aires to the Atlantic Ocean there are several times a ship meets low water, despite its sailing speed. A tidal window can still be maintained, but several parts of the route will have to be dredged somewhat further to maintain sufficient depth during low water.

The Punta Indio channel is longer than the Magdalena channel and has an angle with the tidal direction. Therefore it will take even more time to pass the Río de la Plata. The previous mentioned extra depth sections can still be applied to overcome this issue and to make use of a tidal window.

H.19 INCOMING SHIPS

Container ships are more loaded entering the port of Buenos Aires compared to when they are leaving. When these ships are coming from the Atlantic Ocean in to the Río de la Plata they have a higher draught, but can take advantage of the tidal wave propagating into the same direction. Leaving the Río de la Plata is disadvantageous from a tidal point of view but since the container ships are now less loaded it could compensate for the low tidal Periods. Therefore the tidal wave for incoming ships is also calculated.

When a ship enters the Río de la Plata at zero tidal elevation, it takes x meters and t seconds to reach high or low tide (1/4 wave length), dependent on which time the tide passes:

$$t_{tide,4} = \frac{0{,}25 * 328km}{7{,}35\ m/s\ - 4\ m/s} = 24.478s = 6{,}8h$$

$$x_{tide,4} = 4\ m/s\ * 24.478s = 98km$$

$$t_{tide,7} = \frac{0{,}25 * 328km}{7{,}35\ m/s\ - 7\ m/s} = 234.286s = 65{,}1h$$

$$x_{tide,7} = 7\ m/s\ * 234.286s = 1640km$$

To profit from the tide ships have to sail the channel within half a wave length; the time tide is above average tidal elevation. For the entire range of sailing speeds it can be seen that the distance travelled by ships is greater than the distance travelled by the tidal wave (2*98 km and 2*1640 km > 0.5*328 km). This means that incoming ships benefit from high tide if they enter the channel at the right time.

If the ships enter at the Punta Indio channel, it will take more time because of the longer distance and the angle with the tidal wave. The Punta Indio channel is 92 km long and makes an angle of around 45 degrees. This means that the speed in the direction of the tidal wave equals $\frac{4m/s}{\sqrt{2}} = 2.83$m/s or $\frac{7m/s}{\sqrt{2}} = 4.95$ m/s. The time it takes ships to sail through Punta Indio channel to the port of Buenos Aires equals:

$$t_{channel,4} = \frac{92km}{2{,}83\ m/s} + \frac{144km}{4\ m/s} = 32.509s + 36.000s = 9{,}0h + 10{,}0h = 19{,}0h$$

$$t_{channel,7} = \frac{92km}{4{,}95\ m/s} + \frac{144km}{4\ m/s} = 18.586s\ +\ 36.000s = 5{,}2h + 10{,}0h = 15{,}2h$$

In this time ships have sailed 92km + 144km = 236km. The tide has advanced:

$$x_{tide,4} = 7{,}35m/s\ * (32.509s + 36.000s) = 503{,}5km$$

$$x_{tide,7} = 7{,}35m/s * (18.586s + 36.000s) = 401.2km$$

The difference in travelled distance between tide and ship is more than half the wave length:

$$503{,}5km - 236km = \mathbf{267,5km} > \mathbf{164km} = 0{,}5 * 328km$$

$$401.2km - 236km = \mathbf{165.2km} > \mathbf{164km} = 0{,}5 * 328km$$

Therefore incoming ships sailing through the Punta Indio channel can't take advantage of high tide. Incoming ships sailing through the Magdalena channel concept can take advantage of high tide as previously mentioned, if they sail at specific times.

APPENDIX I: ENVIRONMENTAL IMPACT ANALYSIS

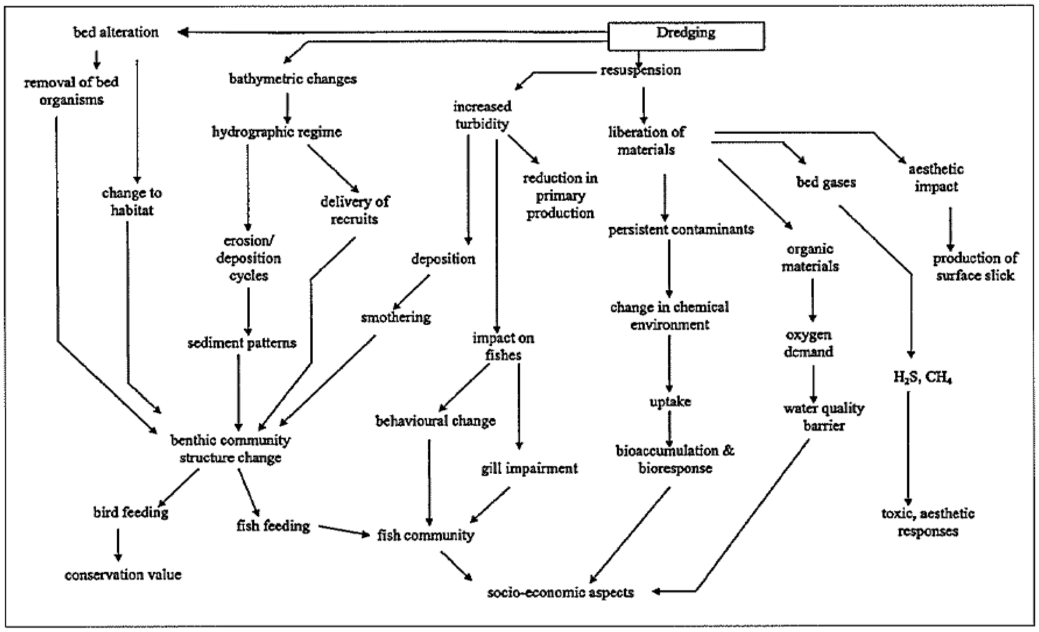


FIGURE 73: EFFECTS CAUSED BY DREDGING OPERATION (PIANC, 2006).

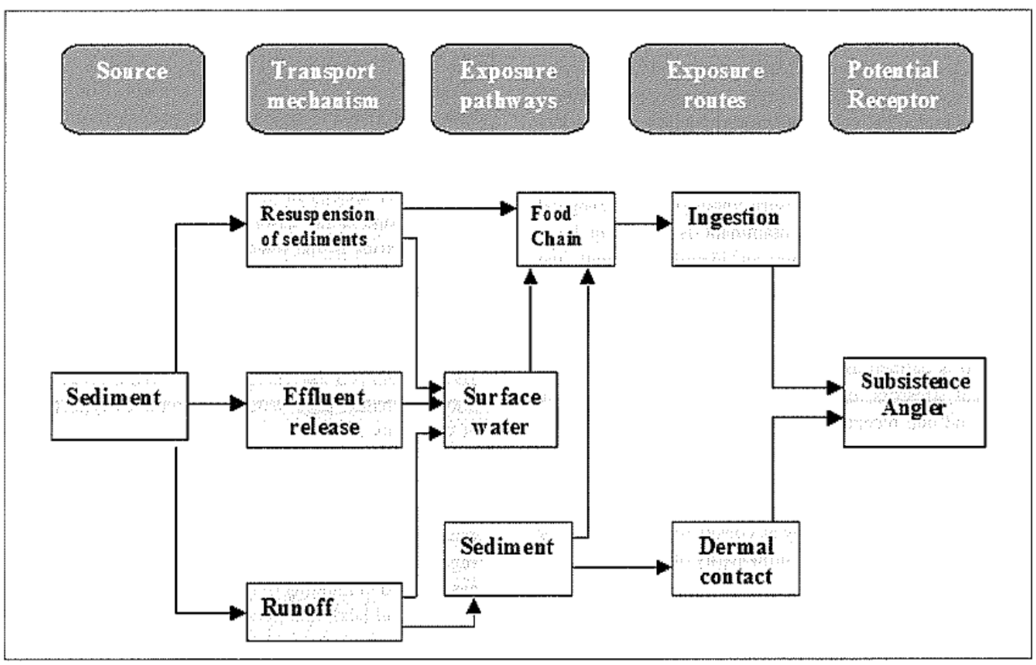


FIGURE 74: CONCEPTUAL MODEL 1.

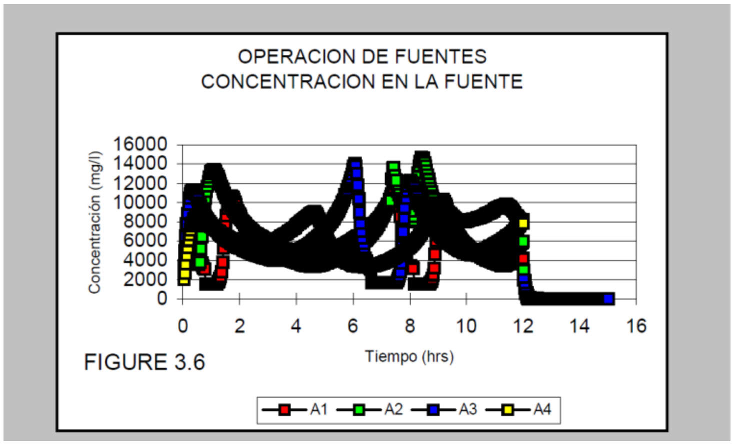


FIGURE 75: CONCENTRATION OF SUSPENDED PARTICLES IN THE CLOUD OVER TIME.

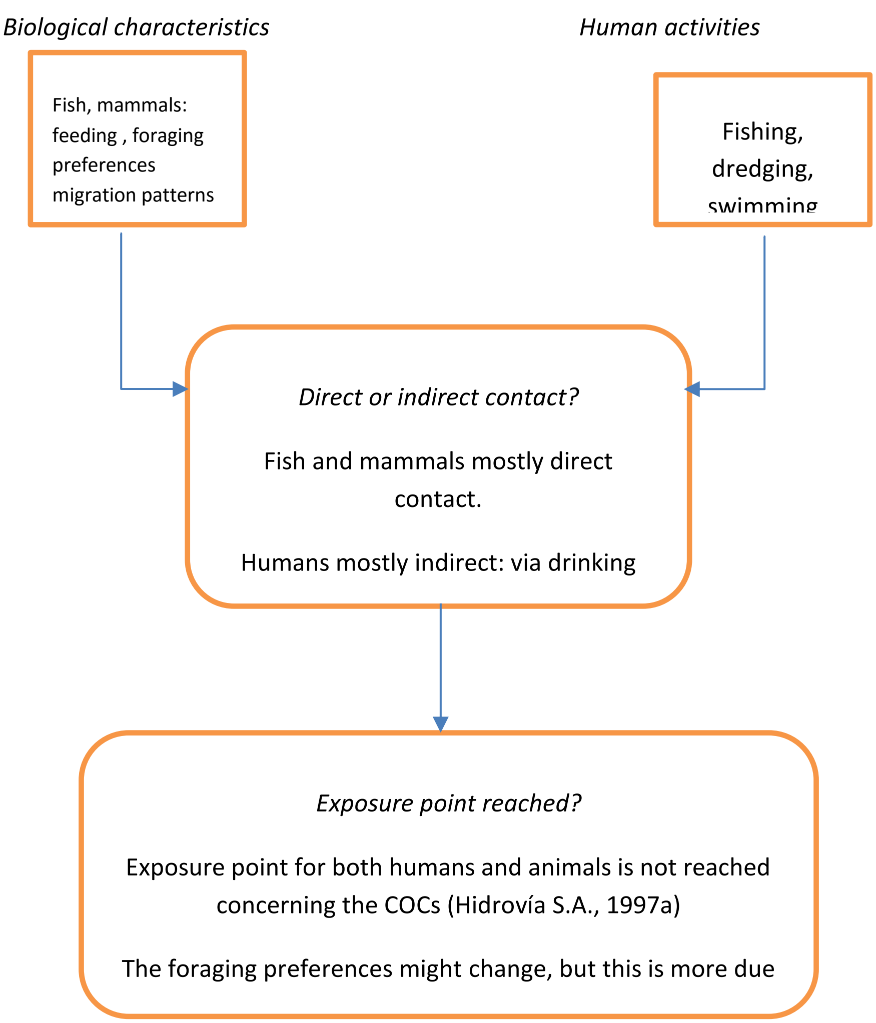


FIGURE 76: THE CONCEPTUAL EXPOSURE MODEL OF COCS FOR THE RIO DE LA PLATA..

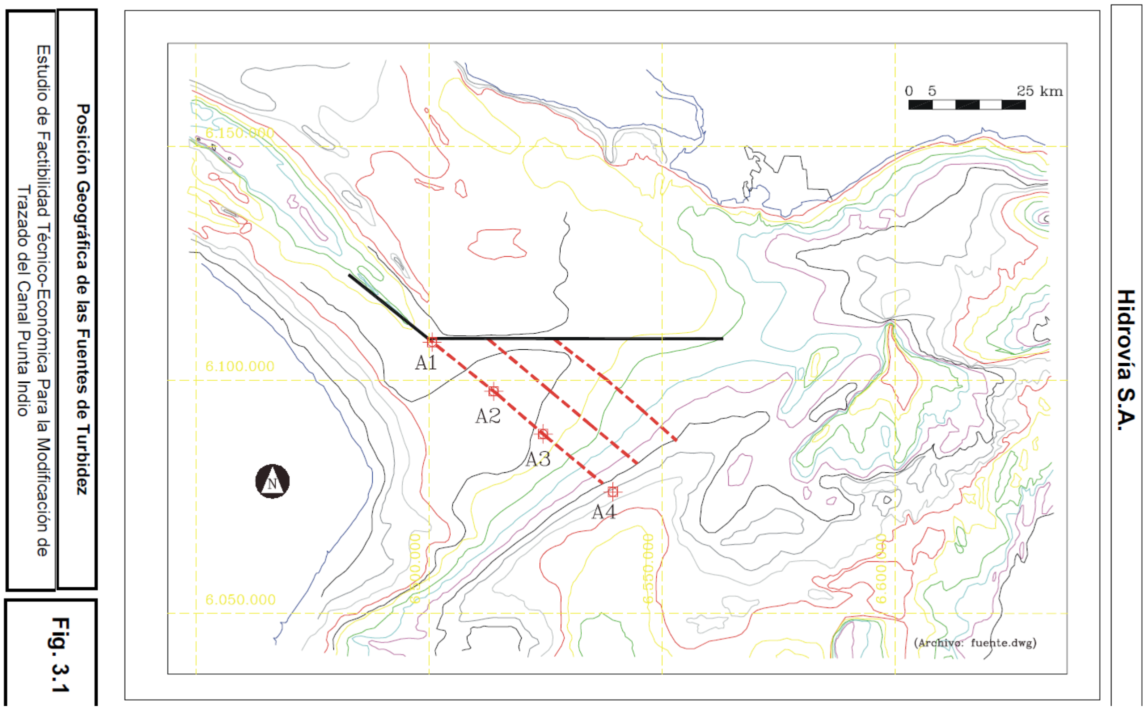


FIGURE 77: LOCATIONS OF THE COMPUTATIONAL MODELLING STUDY.

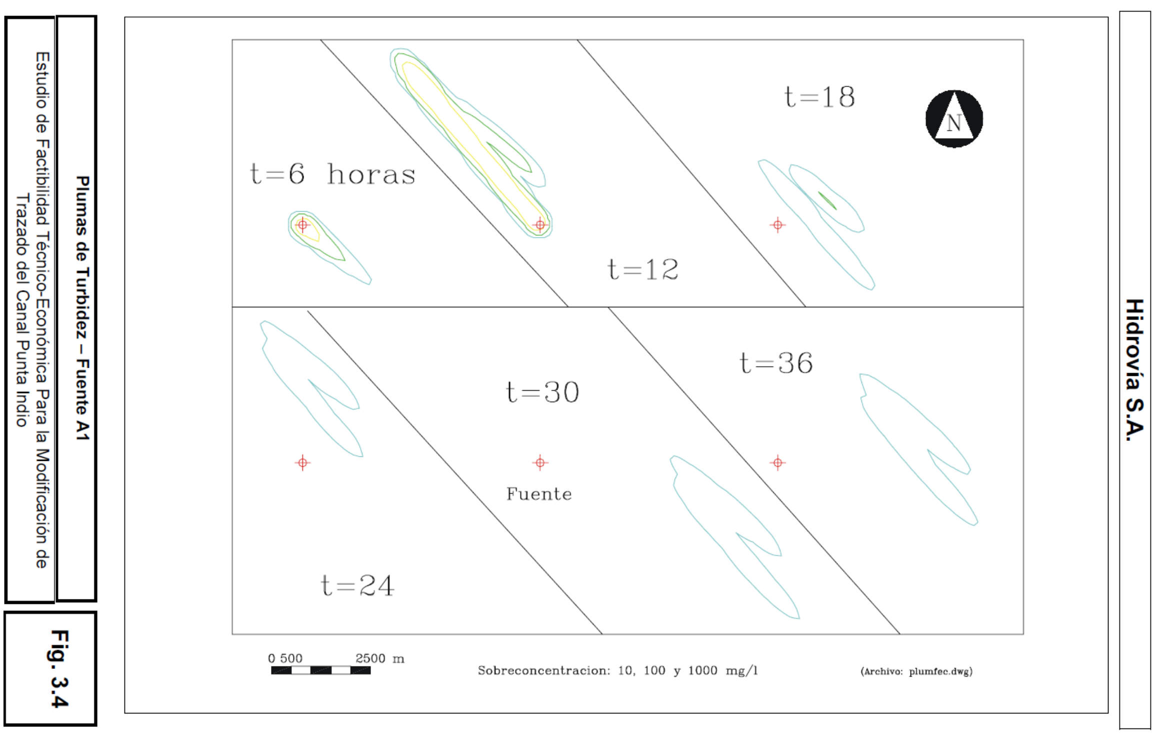


FIGURE 78: RESULTS OF COMPUTATIONAL MODELLING WITH DIFFERENT TIME STEPS.

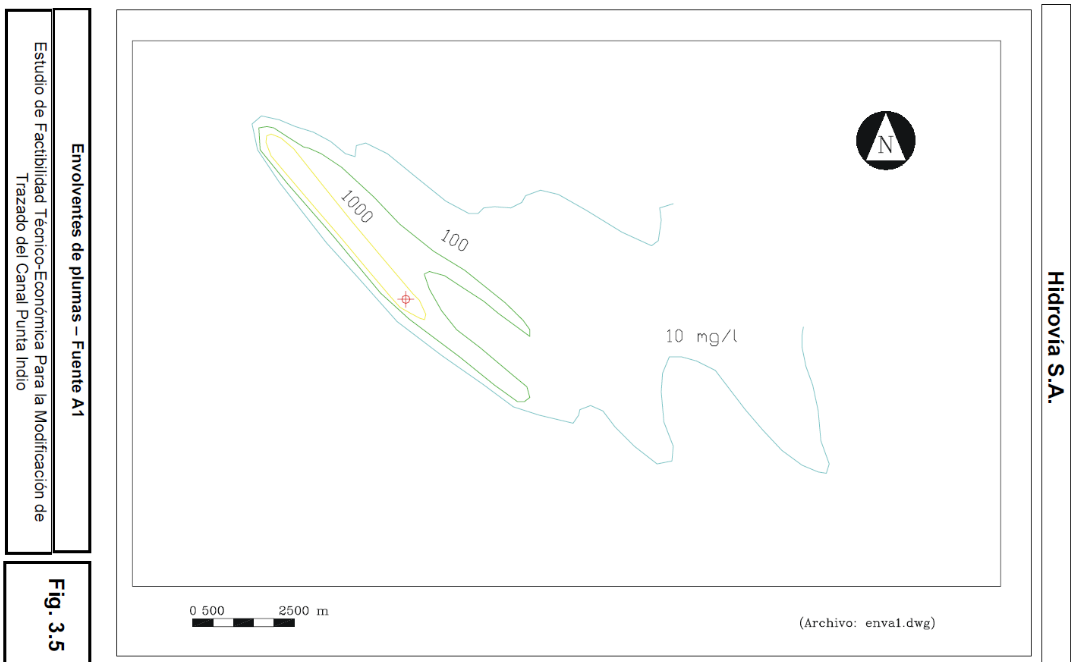


FIGURE 79: CONCENTRATION AND CONTOURS OF SUSPENDED PARTICLES.

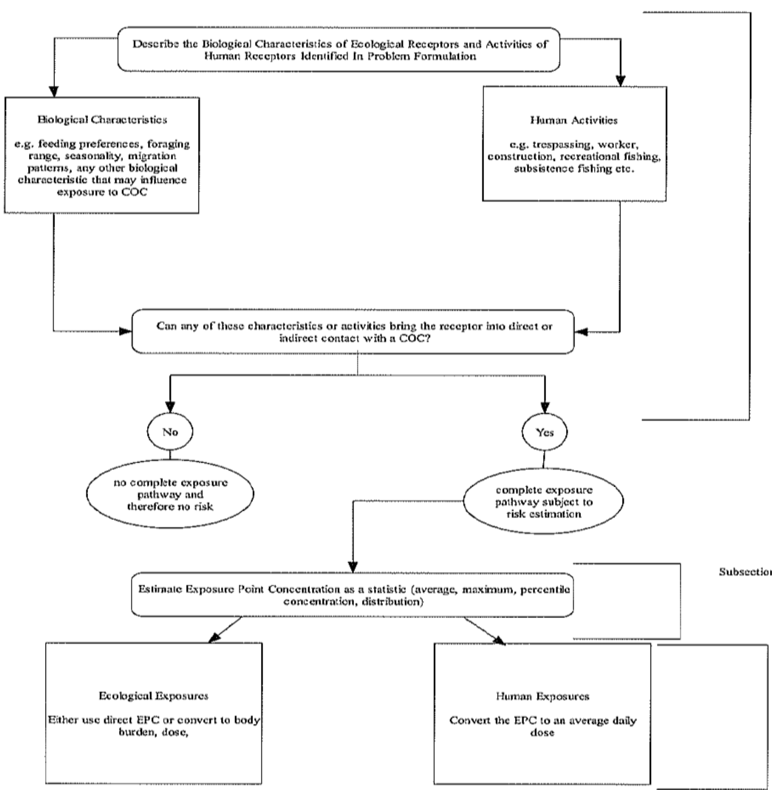


FIGURE 80: CONCEPTUAL MODEL 2.

APPENDIX J: SEDIMENTATION ESTIMATION

In this section the sedimentation for the Magdalena channel is estimated. Two models have been developed, which will be elaborated in different sections. Estimation II is chosen to approximate the annual sedimentation rates, because it relies on more recent data, together with calibrations from Estimation I. Last, model uncertainties and suggestions are presented.

J.1 ESTIMATION I

The sediment transport equations used are called EIH-AD32. This model is created by EIH Estudio de Ingeniería Hidráulica S.A., an Argentine based company. It solves a transportation equation using an algorithm of third order finite differences. An additional control algorithm avoids numerical diffusion, thus transport of any substance can be modeled fairly accurately (Hidrovía S.A., 2000).

The data in Table 63 is obtained from the model. The report gives the predicted annual sedimentation for different dredging depth levels. The sedimentation is predicted for the stretch from El Codillo (143 km mark) till the exit of the channel (239 km mark).

Report model	**Magdalena (Beta)**		
Design depth	Dredging depth [m]	Dredging depth [ft]	Sedimentation [m^3/y]
32 feet [33]	10,0584	33	1616083
36 feet [37,5]	11,43	37,5	2113812
40 feet [41,5]	12,6492	41,5	2576754
Report model	**Punta Indio (Alpha)**		
Design depth	Dredging depth [m]	Dredging depth [ft]	Sedimentation [m^3/y]
32 feet [33]	10,0584	33	4316176
36 feet [37,5]	11,43	37,5	5587416
40 feet [41,5]	12,6492	41,5	6509913

TABLE 63: DATA PROVIDED (HIDROVÍA S.A., 2000)

The data is plotted and extrapolated to the designed dredging depths of the Magdalena channel. This is illustrated in Figure 81: Sedimentation Estimation I, depth extrapolation.

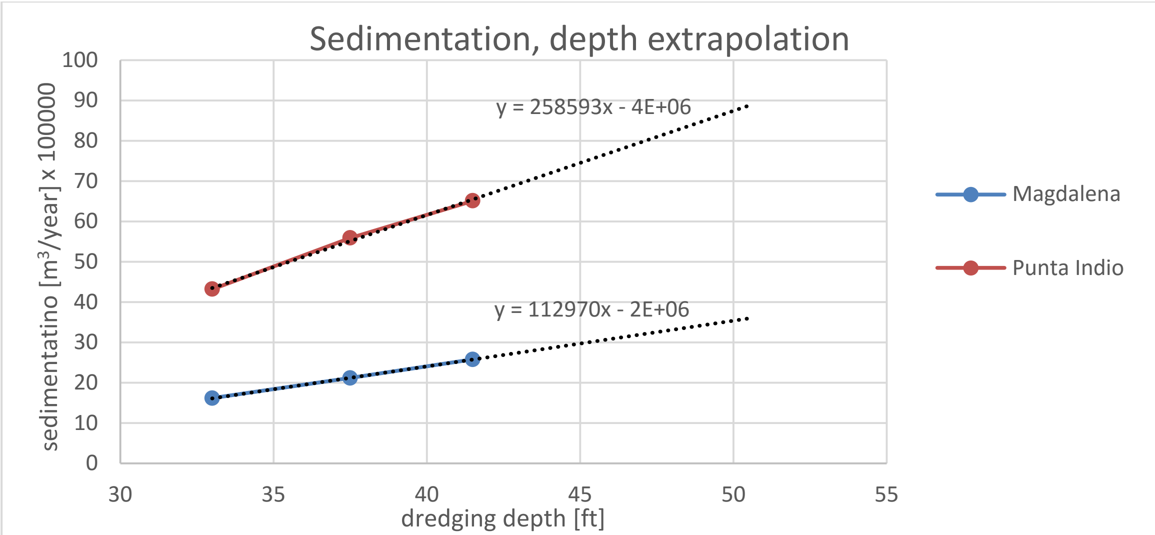


FIGURE 81: SEDIMENTATION ESTIMATION I, DEPTH EXTRAPOLATION MODEL (HIDROVÍA S.A., 2000).

The formulas used for the depth extrapolation, with x in feet are:

$$Yearly\ sedimentation\ in\ \frac{m^3}{year}\ for\ Magdalena: 112970x - 2000000$$
$$Yearly\ sedimentation\ in\ \frac{m^3}{year}\ for\ Punta\ Indio: 258593x - 4000000$$

In Table 64 the results of the extrapolation are presented. Headings with report model indicate data used from the report (Hidrovía S.A., 2000) whilst new design indicates the extrapolation values. For the depth extrapolations the above formulas have been used. For the width extrapolation, the ratio of the widths used in the model and in the new design is calculated. This ratio is multiplied with the depth extrapolation for the Magdalena channel.

Report model	Magdalena (Beta)		Depth extrapolation		
Design depth	Dredging depth [ft]	Bottom Width [m]	Sedimentation [m^3/y]*10^6		
32 feet [33]	33	120	1,616083		
36 feet [37,5]	37,5	120	2,113812		
40 feet [41,5]	41,5	120	2,576754		
New design	**Magdalena (Beta)**		**Depth extrapolation**		**Width extrapolation**
Design depth	Dredging depth [ft]	Bottom Width [m]	Sedimentation [m^3/y]*10^6	width ratio	Sedimentation [m^3/y]*10^6
36 feet [46,47]	46,47	144	3,2497159	1,20	3,899659
42 feet [53,67]	53,67	144	4,0630999	1,20	4,875720
36 feet [46,47]	46,47	117	3,2497159	0,98	3,168473
Report model	**Punta Indio (Alpha)**		**Depth extrapolation**		
Design depth	Dredging depth [ft]	Bottom Width [m]	Sedimentation [m^3/y]*10^6		
32 feet [33]	33	120	4,3161760		
36 feet [37,5]	37,5	120	5,5874160		
40 feet [41,5]	41,5	120	6,5099130		
New design	**Punta Indio (Alpha)**		**Depth extrapolation**		
Design depth	Dredging depth [ft]	Bottom Width [m]	Sedimentation [m^3/y]*10^6		
34 [35,5]	35,5	120	5,1800515		

TABLE 64: CALCULATIONS OF DEPTH AND WIDTH EXTRAPOLATION.

However, due to the auto-dredging phenomena, measured maintenance dredging volumes are probable lower than the predicted ones (Hidrovía S.A., 2015a)**.** This is the phenomenon that the ships propellers induce currents which makes the sediment at the bottom suspend. Because the main (tidal) current in the Río de la Plata is at an angle with the channel direction, the suspended particles will be transported out of the channel. For this reason, the actual measured data will be used for the Punta Indio channel. However, Channel Magdalena as described in the model is not constructed so no actual measurements are available. Channel Magdalena lies almost parallel to the current direction. If particles are suspended and transported due to the current, they will settle out in the channel once again, so the prediction on Magdalena channel is probably more accurate. Hence, the model predictions for the Channel Magdalena are used for dredging volumes estimation.

In Table 65 the dredging volume data of the past 8 years is (Hidrovía S.A., 2015a). The stretch 143-239 is significant, because it reaches from El Codillo, the start of the Magdalena Channel, to the exit of Punta Indio. Data was available for the stretch of 121-239. For one year (2013), data was available for the stretch of 121-239 and 143-239. The ratio of these 2 stretches is used to approximate the dredging volumes for stretch 143-239. Also note, that the dredged volume actually differs from the sediment volume: a bulk factor of 0.5 is used to convert the dredged volume (a mixture of sediment and water) to sediment volumes. The ratio of the volume dredged from 143-239 to 121-239 is used to approximate the dredging volumes for the stretch 143-239 for the rest of the years.

$$stretch\ 121km - 239km = 5{,}180{,}000\ m^3$$
$$stretch\ 143km - 239km = 824{,}000\ m^3$$
$$ratio = \frac{5{,}180{,}000 - 824{,}000}{5{,}180{,}000} = 0{,}840927$$

	Dredged volume [m^3/year]		Sediment volume [m^3/year]
Year	Stretch: 121-239	Stretch: 143-239	Stretch: 143-239
2006/07	6224000	5233927	2616964
2007/08	6801000	5719142	2859571
2008/09	9172000	7712979	3856490
2009/10	4987000	4193701	2096851
2010/11	6927000	5825099	2912549
2011/12	6604000	5553480	2776740
2012/13	4278000	3597484	1798742
2013/14	5373000	4518299	2259149
Mean	6295750	5294264	2647132
Mean*10^6	6,3	5,3	2,6

TABLE 65: MEASURED DREDGING VOLUMES.

J.2 ESTIMATION II

Difficulty arises when attempting to create a very accurate sedimentation model. This is due to the many factors and complex theory influencing sedimentation rates. Measurements of maintenance dredging volumes in Channel Punta Indio at 34 feet design draft indicated that the sedimentation is lower than expected. This might be due to the auto dredging phenomenon. Vessels crossing the channel induce a suspension which may alter sedimentation rates. With this knowledge, new predictions for deepening of the Channel Punta Indio to 36 feet design draft have been calculated (Hidrovía S.A., 2015b). Combining the old (Hidrovía S.A., 2000)and the new models, a model is created to estimate the sedimentation rates of the designed Magdalena Channel.

The following model is used to predict the annual maintenance dredging volumes:

$$S_{Magdalena} = \alpha_1 \alpha_2 \alpha_3 \gamma S_{Punta\ Indio}$$

With:

$$S_{Magdalena} = Annual\ sedimentation\ estimation\ in\ the\ Magdalena\ Channel\ [\frac{m^3}{year}]$$
$$\alpha_1 = Depth\ extraplation\ parameter$$
$$\alpha_2 = Width\ extraplation\ parameter$$
$$\alpha_3 = Length\ extraplation\ parameter$$

$$\gamma = Model\ extraplation\ parameter$$

$$S_{Punta\ Indio} = Measured\ annual\ sedimetation\ in\ Canal\ Punta\ Indio\ [\frac{m^3}{year}]$$

Data is available regarding measured maintenance dredging volumes (Hidrovía S.A., 2015b) see Table 66.

Punta Indio		
Design depth [ft] (Dreding depth [ft])	34 (35,64)	36 (37,64)
Area section	Sedimentation [m^3/y]	Sedimentation [m^3/y]
Río de la plata Exterior		
239-205	0	360210
205-191	785882	817477
060-172	1984167	2143321
172-158	1165323	1165551
158-145	1428992	1429272
Total Sedimentation [m^3/year]	5364364	5915831
Total Sedimentation [m^3/year]*10^6	5,364364	5,915831

TABLE 66: MEASURED SEDIMENTATION RATES IN CHANNEL PUNTA INDIO.

The γ factor is computed with the data from the model dating from 2000 (Hidrovía S.A., 2000).

Model HDRV/27/00 **(Hidrovía S.A., 2000)**		
Sedimentation Alpha 36 feet [m^3/y]	5587416	
Sedimentation Beta 36 feet [m^3/y]	2113812	
Design draft/dredging depth PI [ft]	32	33
	36	37,5
	40	41,5
Length Punta Indio [km]	60	
Length Magdalena [km]	58	
γ	0,39	

TABLE 67: DATA FOR COMPUTATION Γ.

$$\gamma = \frac{Sedimentation\ Beta\ 36\ feet}{Sedimentation\ Alpha\ 36\ feet} * \frac{Length\ Punta\ Indio}{Length\ Magdalena} = \frac{2113812}{5587416} * \frac{60}{58} = 0.041$$

The α factors are calculated by dividing the designed value for the designed Magdalena Channel by the value of the Channel Punta Indio (depth, width and length). They are presented in Table 68, together with the expected sedimentation rates.

HDRV/189/2015				
Punta Indio	Design depth [ft]	36		
	Dredging depth [m]	11,47		
	Dredging depth [ft]	37,64		
	Width	120		
Designed Magdalena		36	42	36
	Dredging depth [m]	14,16	16,36	14,16
	Dredging depth [ft]	46,47	53,67	46,47
	α1	1,23	1,43	1,23
	Width [m]	117	144	144
	α2	0,975	1,2	1,2
	Channel length [km]	62	74,4	62
	α3	0,66	0,79	0,66
Result sedimentation estimation				
Sedimentation [m^3/y]		1838171	3135470	2262364,1
Sedimentation [m^3/y]*10^6		1,8	3,1	2,3

TABLE 68: ESTIMATED ANNUAL SEDIMENTATION VOLUMES FOR MAGDALENA

J.3 CONCLUSION

For the design, the annual sedimentation volumes presented in Table 69 are used. These are a combination of the extrapolated values calculated by the presented model for the Magdalena Channel and the measured volumes and prediction presented by the (Hidrovía S.A., 2015b).

Design draft Magdalena [ft]	36	36	42
Design vessel	Bulk	Container	Container
Sedimentation [m^3/y]*10^6	1,8	2,3	3,1
Design draft Punta Indo [ft]	34	36	
Sedimentation [m^3/y]*10^6	5,4	5,9	

TABLE 69: FINAL ANNUAL SEDIMENTATION VOLUMES FOR PUNTA INDIO AND MAGDALENA.

J.4 MODEL UNCERTAINTIES AND SUGGESTIONS

The h/T ratio is higher for the newly designed channel: the under keel clearance will be bigger. Hence, the auto dredging effect may be lower if the propellers of the vessels induce less particles in suspension. If it turns out that maintenance dredging costs are of crucial impact on the cost-benefit analysis, it is suggested to further investigate annual sedimentation rates with more accurate models.

APPENDIX K: DREDGING COSTS

K.1 TRAILING SUCTION HOPPER DREDGER (TSHD)

A Trailing Suction Hopper Dredger is a ship that can suck up sand, clay, silt and even gravel from the bottom with powerful pumps. The ship sails slowly while one or two lowered drag heads mounted on suction tubes slide along the bottom like a large vacuum cleaner. The sucked up sediment is being stored in its "hopper" and can be emptied again in different ways. The material can be dumped by opening the bottom doors, it can be transported through pipes or it can be jetted from the bow of the ship. The last mentioned possibility is called "rainbowing", see Figure 82.

FIGURE 82: TRAILING SUCTION HOPPER DREDGER "UTRECHT".

K.2 CUTTER SUCTION DREDGER (CSD)

A Cutter Suction Dredger can be stationary or self-propelled and has a rotating cutter head in front of the ship. The cutter head is mounted on a ladder with a suction mouth, where the sediment is sucked up by centrifugal pumps. Simultaneously the sediment is further being transported by pipelines or the material is loaded onto barges, because a CSD does not have any storage space like a TSHD. On the stern of the ship there are two spud poles. One pole is penetrated in the bottom and the ship makes a circular movement around it dredging a part of bottom. Once a partly circular move is completed the second spud pole is lowered so the ship stays in place, the first spud pole is lifted and shifts to the center of the ship. The first spud pole is then lowered again, the second pole is lifted, and the ship can push itself forward to make a new circular movement to dredge. The circular motion is possible by steel wires connecting the ladder and cutter head to anchors on the side. Putting a force on these wires creates the needed lateral force.

FIGURE 83: CUTTER SUCTION DREDGER "HAM218".

Cutter Suction Dredgers (CSD) are usually used for capital dredging to create new harbors, berths or waterways. These projects often involve high volumes and hard sediments. Trailing Suction Hopper Dredgers (TSHD) are more used for maintenance dredging to maintain or increase the depth of existing channels and waterways. The deposited sediment is dredged and dumped on another location. This material is often easier to move and has smaller volumes. There is also the possibility that material is too hard to dredge. In this case the bottom is blown up with dynamite and the created chunks are then dredged.

K.3 CALCULATION DREDGING COSTS

To determine the costs of dredging a lot of references are done to the reader "Dredging Technology" by G.L.M. van der Schrieck. In combination with tables of costs given by the book "A guide to cost standards for dredging equipment 2009" by R.N. Bray the total costs of dredging are determined for both dredging firms and customers. Each specific subject adding to the costs is treated below, see for a full explanation *Appendix K: Dredging costs*.

K.4 STANDARD VALUE

Formula for the standard value of Trailing Suction Hopper Dredgers:

$$V_{TSHD} = 6.000 * W + 1.212.000 * W^{0,35} - 6.464.000 + 1.900 * P_t + 785 * J_t + 910 * S$$

$$V_{TSHD,Alexander\ von\ Humboldt} = 6.000 * 5.635 + 1.212.000 * 5.635^{0,35} - 6.464.000 + 1.900 * 7.500 + 785 * 3.100 + 910 * (2 * 5.280) = € \ 78.545.760$$

Formula for the standard value of Cutter Suction Dredgers:

$$V_{CSD} = 3.800 * C + 20.000 * W_{cgb} + 1.400 * (P + J) + 9.050 * W + 15.000 * W^{0,35}$$

$$V_{CSD,Castor} = 3.800 * 3.680 + 20.000 * 100 + 1.400 * (2 * 2.794 + 1.766) + 9.050 * 6.340 + 15.000 * 6.340^{0,35} = € \ 83.688.723$$

** The weight of the cutter gearbox of the CSD Castor is unknown. A value of 100 tonnes is used, based on the gearbox tonnage of a 3700kW cutter motor as can be seen in Table 77. The lightweight tonnage is also based on this cutter motor power and gives 6340 tonnes. The same table is used.*

***The lightweight metric tonnes of the TSHD Alexander von Humboldt is unknown. A value of 5.635 tonnes is used based on a hopper volume of 9.100 cubic meters. The information is taken out of Table 76.* (Bray, 2009)

K.5 INDEXATION

The book 'A Guide to Cost Standards for Dredging Equipment' is written in 2009 and since that time prices have changed. Therefore the standard value of dredging vessels is adjusted by means of an indexation. For TSHD's this is 106 and for CSD's 108 per 1-1-2015. This results in the following standard values:

$$V_{TSHD,Alexander\ von\ Humboldt} = € \ 78.545.760 * 1,06 = € \ 83.258.506$$

$$V_{CSD,Castor} = € \ 83.688.723 * 1,08 = € \ 90.383.821$$

K.6 DEPRECIATION AND INTEREST

The amount of depreciation and interest is dependent on the investment, the period of depreciation and the interest on the capital market. It is taken as a weekly percentage of the value norm V, based on an interest rate i of 7% and a residual value of 10% at the end of the vessels lifetime.

In Table 76 depreciation and interest is given to be 0,292%/week for Trailing Suction Hopper Dredgers. For Cutter Suction Dredgers the value is 0,371%/week, see Table 78. Multiplied by the standard values calculated in the previous paragraph this results in €243.115/week for TSHD's and €335.324/week for CSD's. (Bray, 2009)

K.7 MAINTENANCE AND REPAIR

The costs for maintenance and repair consist of all the expenses needed to keep the vessel running. The percentage is based on normal project circumstances, service life, residual value, the yearly utilization period and depreciation plus interest.

Maintenance and repair is not easy to calculate. It is however dependent on the production of the ship and from practice expenses are known. For TSHD's with a hopper volume of 9100m^3 maintenance and repair equals €79.967/week. CSD's with a cutter power of 3700kW have maintenance and repair expenses of €112.535/week. See Table 76 and Table 78.

Applying indexation for 2015 gives €84.765/week for TSHD's and €121.538/week for CSD's. (Bray, 2009) &

K.8 WEAR AND TEAR

The costs for wear and tear on dredger vessels are not determined, because this is really project specific and therefore has a large spread. It is difficult to determine and has no standard formula. To get a proper view, dredging contractors or consulting engineers should be asked. These costs should be accounted for, but both the reader (Schrieck, 2015) and the book (Bray, 2009) don't give values. Therefore wear and tear costs are assumed to be a part of the 10% extra expenses as can be seen in Table 71.

K.9 CREWMEMBERS SALARY

A Dutch crew member costs around € 3000,- a week. This includes all costs like plane tickets, pay during leave, local housing and health insurance. The costs for local crewmembers (seamen, welders etc.) is approximately € 1000,- a week. The TSHD Alexander von Humboldt accommodates 31 crewmembers. The accommodation of the CSD Castor is not precisely known, but for the size of the ship around 17 crewmembers are usual. There is worked in 3 shifts, which means that 2 shifts are on board and 1 shift is on leave. This only applies for expats, local crew does not have shifts off. (Schrieck, 2015)

Trailing Suction Hopper Dredger (17+8) * € 3000 + 14 * € 1000 = € 89.000/week

Cutter Suction Dredger (17+8) * € 3000 + 5 * € 1000 = € 80.000/week

K.10 FUEL EXPENSES AND LUBRICANTS

Modern diesel engines have a fuel consumption of approximately 0,2 liters/HP/hour. The average price of marine diesel is around €0,25 per liter. For lubricants 10% in costs are added as a rule of thumb. The operational hours represent an average situation including downtime for weather conditions and location (soil type, waves, wind and currents). (Schrieck, 2015)

	Trailing Suction Hopper Dredger	**Cutter Suction Dredger**
Workable power (kW)	13.980	14.261
Consumption (liters/hour)	2.796	2.852
Service hours (hours/week)	168	168
Minus:		
Mechanical downtime	-11	-17
Operational downtime	-22	-46
	___________________	___________________
Operational hours/week	135	105
Weekly fuel expenses	€ 94.365	€ 74.865
Lubricants 10%	€ 9.437	€ 7.487
	+	+
Total	€ 103.802	€ 82.352

TABLE 70: FUEL EXPENSES AND LUBRICANTS (SCHRIECK, 2015).

K.11 INSURANCE EXPENSES

A common value for insurance expenses is 0.04% of the value norm for weekly insurance expenses. When in case of an accident the insurance also pays for own damage, the percentage must be increased to 0.07%. In the calculation a rate of 0.07% is used (Schrieck, 2015).

Trailing Hopper Suction Dredger value norm € 83.258.506 € 58.281/week

Cutter Suction Dredger value norm € 90.383.821 € 63.269/week

K.12 WEEKLY COSTS

Adding up all previously mentioned factors lead to Table 71 on the next page with weekly costs for a dredging company (Schrieck, 2015) :

Weekly costs	Trailing Suction Hopper Dredger *"Alexander von Humboldt"*	Cutter Suction Dredger *"Castor"*
Depreciation and interest D + i	€ 243.115	€ 335.324
Maintenance and repair M + R	€ 84.765	€ 121.538
Crew	€ 89.000	€ 80.000
Fuel and lubricants	€ 103.802	€ 82.352
Insurance	€ 58.281	€ 63.269
Other expenses approx. 10%	€ 57.896	€ 68.248
	+	+
Total weekly costs 168 hours	€ 636.859	€ 750.731

TABLE 71: WEEKLY COSTS TSHD AND CSD FOR A DREDGING COMPANY (SCHRIECK, 2015).

K.13 GENERAL OVERHEAD

General overhead for profit and risk is added to the total weekly costs. Companies have to make a profit and usually charge 20% on top of the costs, but this margin may vary from project to project. Adding 20% means an extra €127,372 for the TSHD and €150,146 for the CSD, making a total of €764,231 and €900,877. (Schrieck, 2015)

K.14 (DE)MOBILIZATION

Furthermore (dredging) vessels have to sail to the project site and equipment has to be assembled. The same holds for the end of the project, were equipment has to be dismounted and the vessels sail to the next project site. During this time there is no production, but the weekly expenses are still present. Mobilization in 1 week and demobilization in 0.5 week are common periods, resulting in expenses of €955,289 for the TSHD and €1,126,097 for the CSD. In these periods there is very little risk compared to the production period and therefore general overhead is not added to these expenses. Dependent on how many dredgers are needed and in what period the project has to be executed, the expenses have to be multiplied by the number of ships. (Schrieck, 2015)

K.15 HOPPER CONTENTS AND CYCLE TIME (TSHD)

One very crucial aspect of Trailing Suction Hopper Dredgers is the production of the actual dredged volume. The hopper content of the vessel is never completely filled with only cubic meters of sediment. It is always a mixture with water, though always as low as possible. Another possibility is that the dredged material is compressed and will expand once it is sucked up and enters the vessel. These are reasons why the dredged material does not have to be equal to the material that has to be dredged for achieving the desired channel dimensions.

As mentioned in paragraph the sediment to be dredged is made out of two layers. The upper layer consists of soft and plastic clays with sand and silt fractions and a harder lower layer consisting of clayey silt which is compacted and partly cemented. Silt has a very low efficient volume, because it mixes very well with water. To reduce the water fraction and improve efficient volume overflowing could be applied. This is however not possible, because the part flowing over would have the same density as the silt/water mixture sucked into the hopper. The result is a very low efficient volume. For the dredged upper layer it will be around 50% and for the lower compacter layer around 55%. (Garcia, personal communication, 2015).

The hopper capacity of the Alexander von Humboldt is 9000 m3. Using the efficient volume this leads to sediment volumes of 4500 m3 and 4950 m3 per fully loaded cycle. The time to load the vessel takes around 50 minutes. It then has to sail to its location of dumping. The Alexander von Humboldt has a maximum sailing speed of 14 knots, but a more realistic sailing speed would be 7 knots (3m/s = 13km/h). The vessels have to sail 3.5 km perpendicular to the channel to dump its load, so the dumped sediment won't fall back into the channel and at the same time vessels have the shortest distance to move the load. Dumping the sediment through the vessels bottom doors will take 5 to 10 minutes. On top of these actions vessels have delays due to accelerating, stopping and turning. The distance to move the sediment is short and therefore the delays have a relatively large influence on the sailing time. To account for this and other delays 15% is added to the cycle time.

Cycle time TSHD "Alexander von Humboldt"	
Loading time	50 minutes
Sailing full	16 minutes
Unloading time	10 minutes
Sailing empty	16 minutes
Delays (*15%*)	14 minutes
Total	**106 minutes**

TABLE 72: CYCLE TIME TSHD "ALEXANDER VON HUMBOLDT".

A working week consists of 168 hours, in which 11 hours are lost to mechanical downtime and 22 hours are lost to operational downtime. See Table 71. In 135 operational hours/week the TSHD can make $(135 * 60\text{min})/106min = 76$ trips. Translating this into dredged effective volumes of sediment per week gives:

Upper layer: $76\ cycles * 4500m^3/cycle = 342.000m^3$ per week

Lower layer: $76\ cycles * 4950m^3/cycle = 376.200m^3$ per week

**The actual production rate should be lower for the lower layer. It is true that the effective hopper volume is higher for more compact sediment, and therefore the production rate is higher, but it will also take more time to dredge. This is not mentioned and two cycle time tables should have been used. One for each sediment layer.*

K.16 COSTS (TSHD)

For the new Magdalena channel a total volume of 106.4 million for 36 feet design draught or 165.1 million cubic meters of sediment for the 42 feet design draught has to be dredged. If the first variant of 36 feet is dredged in 2 years, the costs will be:

Upper layer: $€\ 764.231/342.000m^3 * 88.900.000m^3 = €\ 198.655.368$

Lower Layer: $€\ 764.231/376.000m^3 * 17.500.000m^3 = €\ \ 35.569.262$

(De)mobilization $€\ 636.859 * 1{,}5\ \text{week} * 3\ \text{vessels} \quad = €\ \quad 2.865.866$

Total: $= €\ \mathbf{237.090.496}$

If the second variant of 42ft design draught is dredged in 2 years and 3 months, the costs will be:

Upper layer: $€\ 764.231/342.000m^3 * 115.100.000m^3 = €\ 257.201.720$

Lower Layer: $€\ 764.231/376.000m^3 * 50.000.000m^3 \ = €\ \ 101.626.463$

(De)mobilization $€\ 636.859 * 1{,}5 \text{ week} * 4 \text{ vessels} \qquad = € \quad 3.821.154$

Total: $= € \mathbf{362.649.337}$

K.17 FLOATING DISCHARGE PIPELINES (CSD)

In the Río de la Plata the discharge of a CSD would be done by pipelines. The distances to overcome are relatively small (2.5km) and don't need any boosters. The power of the dredging vessel is sufficient. The floating pipelines are subject to wear and the costs can be determined with Table 73. The CSD Castor has a discharge diameter of 850 mm. Taking the average of 800 mm and 900 mm pipelines gives a 12m section value of €30,913 and D + i of €175.35/12 m. Taking the entire 2,5km trace gives a value of €9,026,596 with a D + i of €51,202. Here the distance of 2.5km is different from the case with TSHD's. This is because TSHD's have to sail more than the absolute distance, while pipelines are (nearly) straight in the direction wished for.

Maintenance and repair is completely dependent on the soil types and quantities. The costs are not mentioned in Table 73 because of the high spread.

Grain diameter (µm)	m^3 soil per 10mm wear ($x10^6$)
100	45
200	42
300	26
400	20

TABLE 73: WEAR OF PIPELINES BY VARIOUS GRAIN DIAMETERS (SCHRIECK, 2015)

The table above is given for indication of wear. Silt is very fine sediment with a grain diameter between 2 µm and 63 µm. The wear costs for this type of sediment can be determined very precise and do not vary more than a few cents. The table is based on round grains in a pipeline diameter of 800 mm. Sharp or angular sand has approximately 30% higher wear, but this is not relevant for the new channel. The chosen pipelines have a new wall thickness of 20 mm and are used till a thickness of 8 mm. The amount of sediment is chosen somewhat higher because of a smaller grain diameter than 100 µm and a slightly larger pipe diameter of 850 mm. This results in $12mm * 50 * 10^6 m^3/10mm = 60$ million m3.

Over the entire project 106.4 million m3 has to be dredged for the 36 feetvariant and 165.1 million m3 for the 42 feet variant of the new Magdalena channel. Disregarding depreciation and interest because of the small values and only taking into account the section values gives $106{,}4 * 10^6 m^3/60 * 10^6 m^3 = 1{,}77$ times and $165{,}1 * 10^6 m^3/60 * 10^6 m^3 = 2{,}75$ times a complete set of pipelines. Expressed in costs these are;

36ft: $1{,}77 * €\ 9.026.596 = €\ 15.977.075$

42ft: $2{,}75 * €\ 9.026.596 = €\ 24.823.139$

K.18 PRODUCTION (CSD)

In the reader (Schrieck, 2015) Table 74, production values are given for different cutter powers. The reference vessel Castor has a cutter power of 3700kW. Extrapolating this value linearly results in 5700m3/hour for weak clay or loose soil. Production values may be non-linear at these rates, but this is not known and therefore a logic linear relation is assumed.

Production Values Cutter Suction Dredgers (CSD) [m3/hour]				
Cutter power	**500 [kW]**	**1000 [kW]**	**2000 [kW]**	**3000 [kW]**
Compact soil/ hard clay	400	700	1200	1600
Loose soil/ weak clay	1800	3000	4000	5000

TABLE 74: PRODUCTION VALUES OF CSD'S TO CUTTER POWER AND SOIL TYPE (SCHRIECK, 2015).

Because the production rate is per hour, shifting of the spud poles is already taken into account. In Table 70 is mentioned that the number of workable hours per week for CSD's is 105. This gives a production rate of 598,500m3/week.

K.19 TUGBOATS (CSD)

A non-self-propelled CSD like the Castor must be put into place with tugboats. After that the dredger can move on its own with his spud poles and side anchors. Assistance of tugboats may however still be needed for bigger CSD and they can carry staff to and from the vessel. In case of heavy storms the dredger needs to be towed to safer waters. The pipelines used to transport the sediment also need tugs for constant replacement. The assumption is made to use 2 tug boats with a propulsion power of 2 x 300kW at all time. The costs for depreciation and interest D + i and maintenance and repair M + R are taken into account, fuel expenses are assumed to be low and are therefore neglected:

$$€\ 6.543/week/tugboat$$

K.20 COSTS (CSD)

The construction of the new Magdalena channel to 36 feetdesign draught consists of 106.4 million cubic meters dredging. If the work is done with two Cutter Suction Dredgers in 1.7 year the costs will become:

Sediment layer: $€\ 900.877/598.500m^3 * 106.400.000m^3 = €\ 160.155.911$

(De)mobilization $€\ 750.731 * 1{,}5 \text{ week} * 2 \text{ vessels} = €\ 2.252.193$

Tugboats $€\ 6.543 * 89 \text{ weeks} * 2 \text{ tugboats} = €\ 1.164.654$

Pipelines $= €\ 15.977.075$

Total: $= €\ \mathbf{179.549.833}$

The construction of the new Magdalena channel to 42 feet consists of 165,1 million cubic meters of sediment. Here the assumption is made to use three tugboats and use three CSD's, then it will take 1.8 year and the costs will be:

Sediment layer: $€\ 900.877/598.500m^3 * 165.100.000m^3 = €\ 248.512.603$

(De)mobilization $€\ 750.731 * 1{,}5 \text{ week} * 3 \text{ vessels} = €\ 3.378.290$

Tugboats	€ $6.543 * 92$ weeks $* 3$ tugboats	$= €$ 1.805.868
Pipelines		$= €$ 24.823.139
Total:		$= €$ **278.519.900**

K.21 DREDGING COST FACTORS – EXPLANATION

Standard value (V)

The standard value (V) of the plant, whatever the age, is the current price to replace the item. This is done for the increasing costs of spare parts due to maintenance and to give the company sufficient budget to replace the plant at the end of its lifetime.

Indexation

Indexation will keep the given values in the book up-to-date. The document "Cost standard indexation 2015" adjusts costs to the current situation.

Service life (N)

The service life N (years) reflects the time between purchase and amortization. A piece of equipment can get inefficient for technical or economic reasons and is therefore no longer used. Major renovation can expand the service life of the item.

Utilization (weeks/year)

Utilization period (weeks/year) is the time equipment is in use for a project including interruptions in work and mobilization. Inspections, major repairs and lying idle waiting for a job are not part of this time. Utilization periods may differ in categories and service life of equipment.

K.22 DEPRECIATION AND INTEREST (D+I)

Depreciation (D) and interest (i) gives insight into future cash flows. The method chosen for depreciation is the annuity method, which results in a constant amount of money per year. It is calculated by taking a percentage of the standard value (V) minus the residual cash value of the item.

$$A_n = p^n * \frac{p-1}{p^n - 1} * 100$$

$$C = A_n * \frac{1}{100 * u} * \left(1 - \frac{z}{100 * p_n}\right) * V$$

$$D + i = \frac{(i/100)}{p_n - 1} * \frac{100}{u} * \left(p_n - \frac{z}{100}\right) \quad [as\ a\ \%\ of\ V]$$

Where:

An = annuity [%]
U = utilization [weeks/year]
C = weekly costs in respect of D + i [€]
V = standard value [€]
N = service life [years]
p = 1 + (i/100) = 1,07
i = interest rate = 7 [%/year]
z = residual value at the end of the service life [% of V]

The interest rate (i) is taken 7 percent. This is a generally accepted business return on capital, but can vary from time to time.

Equipment that is older than the standard service time cannot be compared with new equipment in terms of production capacity. A reduction has to be applied to the value D + i for every year that the equipment is older than the standard service life (N).

K.23 MAINTENANCE AND REPAIR COSTS (M+R)

Maintenance (M) and repair (R) are all the costs needed to keep an item in a technical state to function properly. The costs are based on service hours as mentioned before. The actual service hours are the period of production minus small delays and interruptions. Wear and tear of the components that come into direct contact with the soil is not taken into the maintenance and repair calculation. Furthermore the costs are based on normal soil and working conditions in Europe. Extreme conditions and working in other continents could lead to extra maintenance and repair costs.

Wear and tear of soil conveying parts should be determined for each specific project. A list of all consumed components is recorded between start and end of the project. The nature of the soil has significant consequences for the amount of wear and tear. Other factors are mixture velocity and concentration, pipe diameter, grade of steel, resistance to wear, production method, swell, turning pipes from time to time and pipe alignment.

Working outside Europa could lead to the following factors which increases the costs: geographical location and infrastructure, distance to closest (air)port, climate conditions, local technical equipment, availability of technical components, local price levels, freight costs for spare parts, import duties, legal requirements, competence of local technical support.

K.24 DIFFERENT SERVICE HOURS/WEEK

Of the maintenance and repair costs 40% is considered to be fixed and the other 60% are costs that vary with the number of service hours of the vessel. If the number of service hours is different from the amount showed in Table 75, the value for M + R should be multiplied with a factor F which can be determined by using the following equation:

$$F = 1 + 0{,}6 * (A - H)/H$$

F = multiplication factor for M + R
A = number of actual service hours
H = standard service hours as mentioned in the table for CSD and TSHD

For 42, 84 and 168 service hours this gives the following multiplication factor F:

Multiplication factor (F)		**Actual service hours schedule (A)**		
		42	84	168
Standard service hours schedule (H)	42	1	1,6	2,8
	84	0,7	1	1,6
	168	0,55	0,7	1

TABLE 75: MULTIPLICATION FACTOR F FOR ACTUAL SERVICE HOURS (BRAY, 2009).

K.25 COST STANDARD TABLES

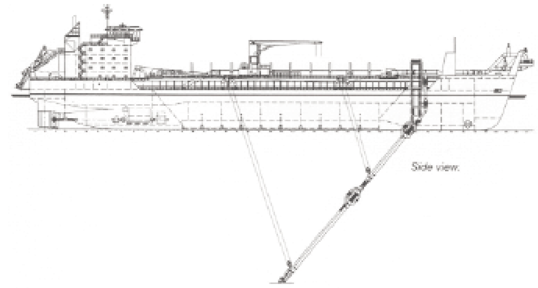
Abbreviations used in the equations:

C = electric or hydraulic power of the cutter motors (kW)
I = total installed diesel power (kW)
J = power on the jet pumps and/or soil dilution system (kW)
J_t = jet pump power on the trailing heads (kW)
NH = net hoisting capacity (metric tonnes)
P = power on the dredge pumps (kW)
P_t = power on the dredge pumps during trailing (kW)
S = propulsion power free-sailing (kW)
S_b = bow and stern thrusters power (kW)
V = standard value (euro, €)
W = lightweight (metric tonnes)
W_{cgb} = weight of the cutter gear box incl. thrust-bearing (metric tonnes)

Other abbreviations used in determining the standard value are:

DE = diesel-electric main drivers namely cutter, dredge and jet pumps and, if applicable, propulsion
FSC = flexible spud carrier
UWP = underwater pump

Table 100 Trailing suction hopper dredgers



With certificate for unrestricted navigation area [a]

Unloading through bottom doors, valves or sliding doors with or without shore discharge

Service life	18 years
Service hours	168 hours per week
Residual value	10 % of V
Utilisation period	33 weeks
D+i	9.647 % of V per year or 0.292 % per week
Standard value	$V = 6000 \times W + 1\,212\,000 \times W^{0.35} - 6\,464\,000 + 1900 \times P_t + 785 \times J_t + 910 \times S$

Hopper volume	Displacement at dredging mark [b]	Lightweight (W)	Power dredge pumps during suction (P_t) [b]	Power jet pumps on draghead (J_t)	Free sailing propulsion power (S)	Value (V) [d]	Costs per week D+i	Costs per week M+R	M+R/ week
cu.m	t	t	kW	kW	kW	€	€	€	% of V
900	2000	635	350	220	950	10 600 000	30 952	21 917	0.2068
1300	3000	945	600	300	1550	15 300 000	44 676	30 508	0.1994
1800	4000	1260	880	360	2200	19 800 000	57 816	38 734	0.1956
2400	5200	1640	1000	660	2500	24 200 000	70 664	42 625	0.1761
2700	5800	1800	1250	660	3550	27 200 000	79 424	45 142	0.1660
3500	7600	2400	1550	760	4000	33 600 000	98 112	50 513	0.1503
4700	9900	3050	1950	800	5100	40 900 000	119 428	56 639	0.1385
6200	13 000	3925	2400	850	6450	50 100 000	146 292	64 359	0.1285
7700	16 000	4780	2600	1000	7350	58 100 000	169 652	71 072	0.1223
9100	19 000	5635	3500	1600	9400	68 700 000	200 604	79 967	0.1164
11 000	23 000	6830	4320	1600	10 800	80 400 000	234 768	89 786	0.1117
12 500	26 000	7610	5200	1600	13 000	89 800 000	262 216	97 674	0.1088
13 500	29 000	8685	5200	1800	13 000	97 700 000	285 284	104 303	0.1068
18 000	40 000	12 100	6680	2000	16 700	128 000 000	373 760	129 730	0.1014
19 000	42 000	13 750	7000	2000	17 500	141 000 000	411 720	140 639	0.0997
22 500	48 000	15 950	7200	3000	18 000	157 000 000	458 440	154 066	0.0981
24 000	60 000	18 250	9600	4000	24 000	184 000 000	537 280	176 723	0.0960
35 000	83 000	22 440	9600	4000	24 000	212 000 000	619 040	200 220	0.0944
45 000	105 000	27 000	13 000	4500	38 000	261 000 000	762 120	241 339	0.0925

a For trailing suction hopper dredgers without a certificate for unrestricted navigation area, V should be decreased by 10 per cent. For further explanation about class, see Section A1.3.

b Displacement on dredging mark = lightweight W + deadweight.

c Unless dredge pumps during trailing have their own power supply that cannot be used for other applications, P_t is defined as 40 per cent of the main engine power but not exceeding the mechanical limitation of the dredge pump drive.

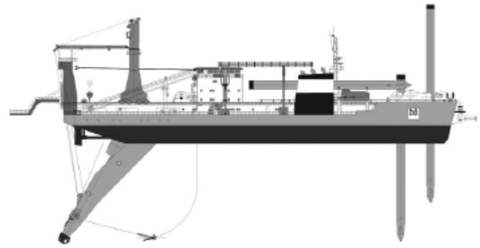
d Standard values for large TSHDs exhibit a different trend to the smaller vessels because of the inclusion of extra equipment, such as extended pipes and submerged dredge pumps.

TABLE 76: COSTS TRAILING SUCTION HOPPER DREDGERS (BRAY, 2009)

M + R for dredgers of more than 35,000 m3 hopper volume are extrapolated on the basis of trends, due to the recent construction of these vessels there are insufficient data to base these figures on actual records.

In case where there is a different value of V than given in the table, interpolate M + R linearly.

Table 200 Cutter suction dredgers, self propelled



With certificate for unrestricted navigation area [a]

Service life 18 years

Service hours 168 hours per week

Residual value 10 % of V

Utilisation period 26 weeks

D+i 9.647 % of V per year or 0.371 % per week

Standard value $V = 2000 \times C + 80\,000 \times W_{cgb} + 1400 \times (P + J) + 8500 \times W + 141\,000 \times W^{0.35} + 950 \times S$

Power cutter motors	Weight of cutter gearbox	Power dredge and jet pumps	Lightweight	Propulsion power	Remarks	Value	Costs per week		M+R/ week
(C)	(W_{cgb})	(P+J)	(W)	(S)		(V)	D+i	M+R	
kW	t	kW	t	kW		€	€	€	% of V
1750	50	8000	4300	1750		59 500 000	220 745	79 351	0.1334
2000	55	8500	4700	2000		64 900 000	240 779	84 198	0.1297
2500	75	8000	5100	3500		71 700 000	266 007	90 302	0.1259
3000	80	7000	6250	3000		81 200 000	301 252	98 830	0.1217
4000	105	9600	6050	7400	FSC [b]	93 100 000	345 401	109 512	0.1176
6000	145	16 000	10 650	7400	FSC [b]	150 000 000	556 500	160 588	0.1071
6000	150	15 000	11 000	7000	DE [c]	158 000 000	589 890	168 667	0.1068
7600	220	16 000	13 700	7600	DE [c]	194 000 000	727 160	201 880	0.1041

a For cutter suction dredgers without a certificate for unrestricted navigation area, V should be decreased by 10 per cent. For explanation about class, see Section A1.3.

b In cases where the dredger is equipped with a flexible spud carrier, two per cent is added to the value derived from the equation.

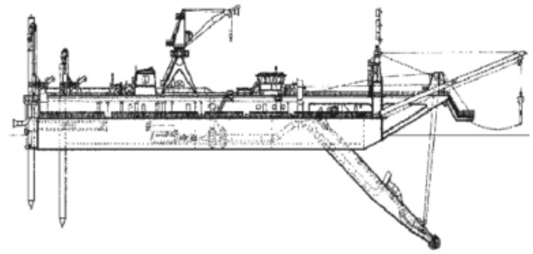
c In cases where the dredgers' main drives are diesel-electric, six per cent is added to the value derived from the equation.

TABLE 77: COSTS CUTTER SUCTION DREDGERS, SELF-PROPELLED (BRAY, 2009).

M + R for dredgers having a cutter power in excess of 5000kW are extrapolated from trends, due to the recent construction of these vessels there are insufficient data to base these figures on actual records.

In case where there is a different value of V than given in the table, interpolate M + R linearly.

Table 201 Cutter suction dredgers, not self propelled



With certificate for unrestricted navigation area [a]

Dredgers with a lightweight >250 tons and cutter power >200 kW

Service life	18 years
Service hours	168 hours per week
Residual value	10 % of V
Utilisation period	26 weeks
D+i	9.647 % of V per year or 0.371 % per week
Standard value	$V = 3800 \times C + 20\,000 \times W_{cgb} + 1400 \times (P + J) + 9050 \times W + 15\,000 \times W^{0.35}$

Power cutter motors	Weight of cutter gearbox	Power dredge and jet pumps	Lightweight	Remarks	Value	Costs per week		M+R/ week
(C)	(W_{cgb})	(P+J)	(W)		(V)	D+i	M+R	
kW	t	kW	t		€	€	€	% of V
250	8	850	360	–	5 680 000	17 882	20 786	0.3660
250	10	1000	380	–	6 110 000	20 405	22 026	0.3605
350	0	1675	400	–	7 420 000	27 528	25 567	0.3446
550	0	1700	520	–	9 310 000	34 540	30 103	0.3233
750	0	3300	1050	–	17 100 000	63 441	40 830	0.2388
750	30	4100	1370	–	21 800 000	80 878	46 580	0.2137
900	33	4000	2000	–	28 000 000	103 880	53 400	0.1907
1100	34	6000	2500	–	36 100 000	133 931	61 517	0.1704
1300	44	6400	2650	–	39 000 000	144 690	64 330	0.1649
1500	50	6500	2850	–	41 800 000	155 078	66 923	0.1601
1700	55	7000	3200	–	46 600 000	172 886	71 250	0.1529
2500	57	7000	3400	–	51 500 000	191 065	75 667	0.1469
3000	80	7000	4900	–	67 400 000	250 054	90 000	0.1335
3300	90	9600	6000	FSC [b]	84 040 000	311 788	104 999	0.1249
3700	100	9000	6340	DE [c]	91 540 000	342 804	112 535	0.1229

a In cases where the dredger has a certificate for restricted navigation area (coastal), V should be decreased by five per cent. Without a class certificate, V must be decreased by 10 per cent. For explanation about class, see Section A1.3.

b In cases where the dredger is equipped with a flexible spud carrier, two per cent is added to the value V.

c In cases where the dredgers' main drives are diesel-electric, six per cent is added to the value V.

TABLE 78: COSTS CUTTER SUCTION DREDGER, NOT SELF-PROPELLED (BRAY, 2009).

In case where there is a different value of V than given in the table, interpolate M + R linearly.

Table 940 Floating pipelines

Pipeline consisting of one polyester floatation body and 12 m steel pipe, sections are filled with foam for use with rubber pressure hoses or self floating rubber line excluding assembling and disassembling costs, excluding anchorage, including bolts and nuts

Residual value	In-and-out survey
Utilisation period	26 weeks
i	7.0 % of V per year or 0.269 % per week for pipeline
D+i	10.0 % of V per year or 0.385 % per week for flotation body
M+R	Related to type and quantity of the soil
Standard value	According to table of examples

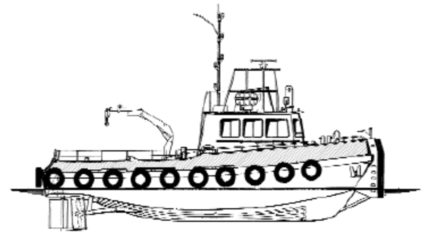
Nominal diameter	New wall thickness	Rejection thickness	Line	Floatation body	Section value (V)	i per week	D[a] per week	D [a] + i per week
mm	mm	mm	€ / 12 m	€ / pp	€ per section	€	€	€
400	12	4	1900	8750	10 650	28.60	33.70	62.30
500	13	5	2600	10 800	13 400	36.00	41.60	77.60
600	16	6	3800	13 900	17 700	47.60	53.50	101.10
700	20	6	4450	17 000	21 450	57.70	65.50	123.20
800	20	8	5925	21 100	27 025	72.70	81.20	153.90
900	25	8	8000	26 800	34 800	93.60	103.20	196.80
1000	25	8	9100	34 600	43 700	117.60	133.20	250.80
1100	25	8	10 000	43 250	53 250	143.20	166.50	309.70

a Depreciation excludes the pipeline

TABLE 79: COSTS FLOATING PIPELINES (BRAY, 2009).

Service life and M + R are related to type and quantity of the soil. Depreciation of pipeline and M + R of whole combination should be settled based on an in-and-out survey. For use of detachable polyethylene flotation units, increase V of floats by 20 per cent.

Table 830 Tugboats



With certificate for restricted navigation area (30 miles) [a]

Service life	18 years
Service hours	84 hours per week
Residual value	5 % of V
Utilisation period	26 weeks
D+i	9.794 % of V per year or 0.377 % per week
M+R	9.10 % of V per year or 0.350 % per week
Standard value	V = 1500 × S

Propulsion power	Length	Value (V)	Costs per week D+i	Costs per week M+R	M+R/week
kW	m	€	€	€	% of V
2 × 283	17	849 000	3201	2972	0.350
2 × 295	16	885 000	3336	3098	0.350
2 × 300	17	900 000	3393	3150	0.350
2 × 350	17	1 050 000	3959	3675	0.350

a In cases where the tugboat has a certificate for 15 miles, use Table 831. Without a class certificate, use Table 832. For explanation about class, see Section A1.3.

TABLE 80: COSTS TUGBOATS (BRAY, 2009).

With towing hook and push bow.

VAN OORD FLEET (TSHD'S AND CSD'S)

Trailing suction hopper dredgers

Name	Total power installed (kW)	Hopper capacity (m³)	Maximum dredging depth (m)
HAM 318	28,636	39,467	70/101
Vox Máxima	31,309	31,387	70/125
Rotterdam	27,470	21,665	60/94
Volvox Terranova	29,563	20,046	40/70/101
Utrecht	23,807	18,292	60/74
HAM 310	13,522	13,392	48
Volvox Asia	21,453	10,834	35
Lelystad	15,976	10,329	38/50
Geopotes 15	12,445	9,931	53
HAM 316	11,890	9,535	40
Volvox Delta	11,028	7,788	51
Geopotes 14	11,326	7,423	42
Volvox Iberia	12,073	6,038	50
Volvox Olympia	6,542	4,870	32
Volvox Atalanta	6,633	4,692	30
HAM 317	6,132	4,497	37
HAM 312	5,504	3,738	30
HAM 311	5,317	3,702	30
Dravo Costa Dorada	4,271	2,548	28
Volvox Anglia	2,500	1,202	18
Pelican	1,813	965	20

TABLE 81: TRAILING SUCTION HOPPER DREDGER FLEET VAN OORD.

Cutter suction dredgers

Name	Total power installed (kW)	Power cutter (kW)	Maximum dredging depth (m)	Discharge pipe (mm)
Artemis	24,702	7,100	31	1,000
Athena	24,702	7,100	31	1,000
Castor	14,261	3,680	25	850
Hector	10,823	1,177	28	850
HAM 218	10,660	1,618	25	850
HAM 217	8,775	1,324	23	850
Hercules	8,539	1,472	20	750
Zeeland II	6,284	883	25	750
Haarlem	6,102	736	21	750
Noordzee	5,965	1,100	19	750
Zeeland/Riekerpolder	4,087	552	16	600
HAM 219	3,583	540	22	700
Merwede	3,261	552	20	750
Calabar River	2,672	552	16	650
Aegir	2,025	368	19	600
HAM 250	1,427	250	14	500
Laurum	1,181	100	48	350
Ajax	1,009	100/140	45	350
Kruipnix	698	70	28.5	300
Gooiboog	453	30	9.5	250

TABLE 82: CUTTER SUCTION DREDGER FLEET VAN OORD.

K.26 JAN DE NUL TSHD "ALEXANDER VON HUMBOLDT"

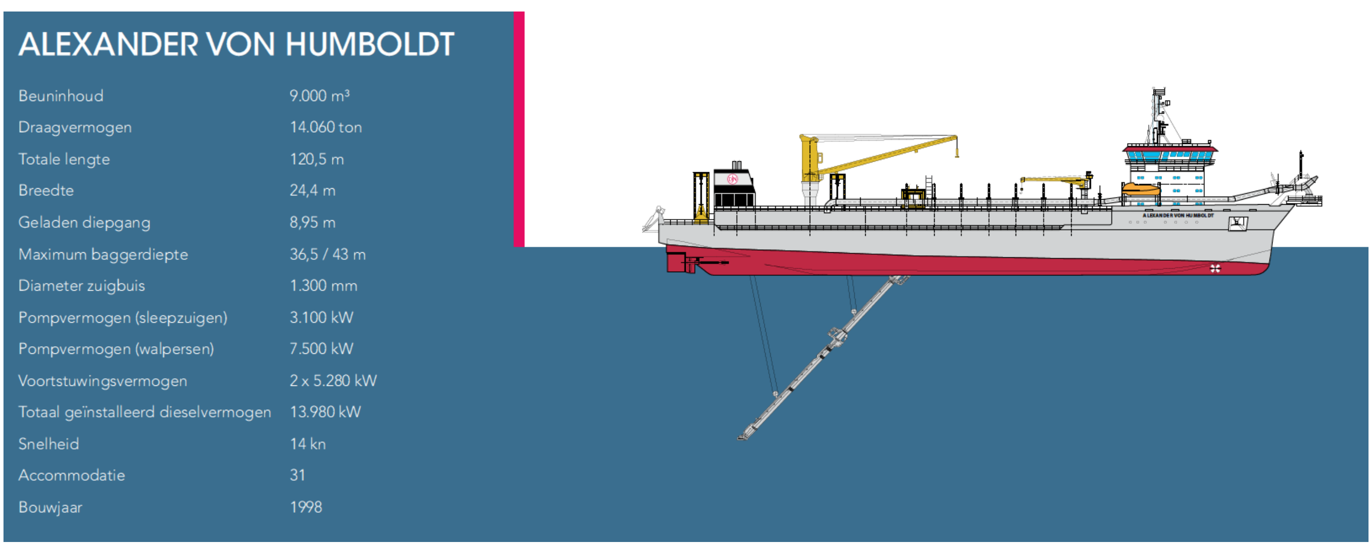


FIGURE 84: SPECIFICATIONS TRAILING SUCTION HOPPER DREDGER "ALEXANDER VON HUMBOLDT" [DUTCH, SEE FOR ENGLISH TABLE 83]

Table translated into English:

ALEXANDER VON HUMBOLDT	
Hopper volume	9.000m3
Deadweight	14.060 ton
Total length	120,5m
Width	24,4m
Loaded draft	8,95m
Maximum dredging depth	36,5m / 43m
Diameter suction tube	1.300mm
Pump power (trailing)	3.100kW
Pump power (discharge pipe)	7.500kW
Propulsion power	2 x 5.280kW
Total installed diesel power	13.980kW
Speed	14kn
Accomodation	31
Year	1998

TABLE 83: SPECIFICATIONS TRAILING SUCTION HOPPER DREDGER "ALEXANDER VON HUMBOLDT (JAN DE NUL)" [ENGLISH].

APPENDIX L: COST BENEFIT ANALYSIS

A model has been made in Excel to calculate the costs and income for ships when making use of the channels in the new situations. This is done for bulk carriers, tankers and container vessels. Other vessels have been excluded because those are having a minor impact on the total.

L.1 TRAVEL TIME OF DIFFERENT ROUTES

First of all the travel time per channel has to be determined for every type and size. This is a simple calculation by taking the length of each route and divide this by the average speed of a vessel. The routes were already determined in chapter 5 for both the new Magdalena channel and Punta Indio channel. Table 84 below gives those distances in kilometer. It can be derived that when ships need to head south it is almost 150 km shorter when using the new channel. On the other hand the route via channel Magdalena is 125 kilometer longer compared with Punta Indio when heading towards Brazil or the Atlantic Ocean.

Route lengths (km)		
	Magdalena	Punta Indio
Direction Atlantic	356	231
Direction South	206	355

TABLE 84: ROUTE LENGTHS FOR DIFFERENT CHANNELS WHEN HEADING SOUTH OR TOWARDS BRAZIL/ATLANTIC.

	Cruise speed (knts)	Cruise speed (km/hour)
bulk		
15-22 (Smallsize)	14,5	26,9
22-28	14,5	26,9
28-32 (Handysize)	14,5	26,9
32-34	14,5	26,9
34-36 (Handymax Bu	14,5	26,9
36-38 (Handymax)	14,5	26,9
38-40	14,5	26,9
40-42 (Panamax)	14,5	26,9
42-44(Post-Panamax	14,5	26,9
44-48(New panamax	14,5	26,9
>48 (Capesize)	14,5	26,9
tanker		
15-22 (Smallsize)	14	25,9
22-28	14,3	26,5
28-32	14,8	27,4
32-34	15,1	28,0
34-36 (handysize-pro	15,1	28,0
36-38 (Handymax)	15,1	28,0
38-40	15,1	28,0
40-42 (Panamax)	15,1	28,0
42-44(Post-Panamax,	15,1	28,0
44-48(New panamax	15,1	28,0
>48 (Capesize)	15,1	28,0
container		
15-22	13,8	25,6
22-28	16,4	30,4
28-32 (feedermax?)	17	31,5
32-34	18,5	34,3
34-36 (Container ship	20,5	38,0
36-38	23	42,6
38-40	23	42,6
40-42 (Panamax, mai	22,2	41,1
42-44(Post-Panamax	24	44,4
44-48(New panamax	23	42,6
>48 (ULCV)	23	42,6

FIGURE 85: SPEEDS PER SHIP SIZE AND TYPE.

The speeds have been determined by using average speeds in knots for different sizes and types of ships retrieved from Pocuca (2006). After this they have been converted to kilometer per hour (Figure 85 on the left).

Now it is possible to calculate the travel times per channel and destination. After this the differences in travel times between the channels have been given. A positive number indicates that the Magdalena route is longer, while a negative number means that the Magdalena route is shorter. A print screen of these numbers have been given in Figure 86 on the next page.

	Traveltime					
	North			South		
bulk	**Magdalena**	**Punta Indio**	*Difference in time*	**Magdalena**	**Punta Indio**	*Difference in time*
15-22 (Smallsize)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
22-28	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
28-32 (Handysize)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
32-34	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
34-36 (Handymax Bulk)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
36-38 (Handymax)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
38-40	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
40-42 (Panamax)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
42-44(Post-Panamax)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
44-48(New panamax)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
>48 (Capesize)	13,3	8,6	*4,7*	7,7	13,2	*-5,5*
	North			South		
Tanker (feet)	**Magdalena**	**Punta Indio**	*Difference in time*	**Magdalena**	**Punta Indio**	*Difference in time*
15-22 (Smallsize)	13,7	8,9	*4,8*	7,9	13,7	*-5,7*
22-28	13,4	8,7	*4,7*	7,8	13,4	*-5,6*
28-32	13,0	8,4	*4,6*	7,5	13,0	*-5,4*
32-34	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
34-36 (handysize-product)	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
36-38 (Handymax)	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
38-40	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
40-42 (Panamax)	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
42-44(Post-Panamax/Aframa	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
44-48(New panamax)	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
>48 (Capesize)	12,7	8,3	*4,5*	7,4	12,7	*-5,3*
	North			South		
Container ship (feet)	**Magdalena**	**Punta Indio**	*Difference in time*	**Magdalena**	**Punta Indio**	*Difference in time*
15-22	13,9	9,0	*4,9*	8,1	13,9	*-5,8*
22-28	11,7	7,6	*4,1*	6,8	11,7	*-4,9*
28-32 (feedermax?)	11,3	7,3	*4,0*	6,5	11,3	*-4,7*
32-34	10,4	6,7	*3,6*	6,0	10,4	*-4,3*
34-36 (Container ship)	9,4	6,1	*3,3*	5,4	9,4	*-3,9*
36-38	8,4	5,4	*2,9*	4,8	8,3	*-3,5*
38-40	8,4	5,4	*2,9*	4,8	8,3	*-3,5*
40-42 (Panamax, main liner)	8,7	5,6	*3,0*	5,0	8,6	*-3,6*
42-44(Post-Panamax)	8,0	5,2	*2,8*	4,6	8,0	*-3,4*
44-48(New panamax)	8,4	5,4	*2,9*	4,8	8,3	*-3,5*

FIGURE 86: OVERVIEW OF TRAVEL TIMES PER VESSEL SIZE AND TYPE, FOR PUNTA INDIO AND MAGDALENA CHANNEL.

L.2 COSTS OF DIFFERENT ROUTES

The costs are determined by two separate variables: the fuel costs and the operational costs. Fuel is one of the largest expenses when operating a ship and therefore the most important variable In this equation. The fuel costs are calculated by taking a standard fuel price. At the time of writing this report it is around 550 dollar per metric ton. Since this is one of the lowest prices in years and not considered reasonable for the long term, the price for calculations has been set on 800 dollar per metric ton, which is an average over the period from 2009 until 2014

(Marcon, 2015). Furthermore the fuel consumption for the different ships are needed for different speeds and sizes based on data of UNCTAD (2012). Multiplying these two with the travel time per route gives the fuel usage per ship type over the indicated time.

In the model the operational costs are calculated in dollar per hour. These costs can be divided in crew costs, stores (for lubricating oils, etc), repairs and maintenance, insurance, administration and drydocking. Just like the fuel consumption the data for the operational costs are taken from the data of UNCTAD (2012). Multiplying the hourly operation costs with the travel time and adding this number to the fuel costs gives the total costs of traveling a certain route.

The results of the model are given in Figure 87 below. The difference in costs between the routes are also calculated, where a positve number indicate additional costs for taking the Magdalena channel, while a negative number means that the Magdalena route is cheaper.

		Costs				
	North			South		
Bulk draft (feet)	**Magdalena**	**Punta Indio**	*Difference in costs*	**Magdalena**	**Punta Indio**	*Difference in costs*
15-22 (Smallsize)	12130	7871	*4259*	7019	12096	*-5077*
22-28	12130	7871	*4259*	7019	12096	*-5077*
28-32 (Handysize)	13164	8542	*4622*	7617	13127	*-5510*
32-34	14278	9264	*5013*	8262	14238	*-5976*
34-36 (Handymax B	16783	10890	*5893*	9712	16736	*-7024*
36-38 (Handymax)	16783	10890	*5893*	9712	16736	*-7024*
38-40	18334	11897	*6438*	10609	18283	*-7674*
40-42 (Panamax)	20349	13204	*7145*	11775	20292	*-8517*
42-44(Post-Panama	22351	14503	*7848*	12933	22288	*-9355*
44-48(New panama	22497	14598	*7899*	13018	22434	*-9416*
>48 (Capesize)	25427	16499	*8928*	14713	25355	*-10642*
	North			South		
Tanker (feet)	**Magdalena**	**Punta Indio**	*Difference in costs*	**Magdalena**	**Punta Indio**	*Difference in costs*
15-22 (Smallsize)	12769	8286	*4484*	7389	12733	*-5344*
22-28	12985	8426	*4559*	7514	12949	*-5435*
28-32 (Handysize)	14832	9624	*5208*	8583	14791	*-6208*
32-34	16600	10771	*5829*	9606	16553	*-6948*
34-36 (Handymax B	16613	10780	*5833*	9613	16566	*-6953*
36-38 (Handymax)	18395	11936	*6459*	10644	18343	*-7699*
38-40	19553	12688	*6866*	11315	19499	*-8184*
40-42 (Panamax)	20534	13324	*7210*	11882	20476	*-8594*
42-44(Post-Panama	22660	14703	*7956*	13112	22596	*-9484*
44-48(New panama	25473	16529	*8944*	14740	25401	*-10661*
>48 (Capesize)	26733	17347	*9387*	15469	26658	*-11189*
	North			South		
Container ship (feet	**Magdalena**	**Punta Indio**	*Difference in costs*	**Magdalena**	**Punta Indio**	*Difference in costs*
15-22	8775	5694	*3081*	5078	8751	*-3673*
22-28	12952	8404	*4548*	7495	12915	*-5421*
28-32 (feedermax?)	17945	11644	*6301*	10384	17894	*-7511*
32-34	20303	13174	*7129*	11748	20246	*-8498*
34-36 (Container sh	22420	14548	*7872*	12973	22357	*-9384*
36-38	24789	16085	*8704*	14344	24719	*-10375*
38-40	25031	16242	*8789*	14484	24961	*-10476*
40-42 (Panamax, m	30003	19468	*10535*	17361	29918	*-12557*
42-44(Post-Panama	40319	26162	*14157*	23331	40206	*-16875*
44-48(New panama	45549	29556	*15993*	26357	45421	*-19064*
>48 (ULCV)	50037	32468	*17569*	28954	49896	*-20942*

FIGURE 87: OVERVIEW OF COSTS PER VESSEL SIZE AND TYPE, FOR PUNTA INDIO AND MAGDALENA CHANNEL.

L.3 INCOME FOR DIFFERENT ROUTES

A few assumptions had to be made in the model for the calculations of the income per ship type. The first one is that all ships that make use of a channel are loaded to their maximum design draft or the maximum draft allowed by the channel (thus 36 and 42 feet). This automatically means that the income for a certain vessel on a certain route depends on the draft of that same vessel. Therefore ships with a design draft of 34 feet or lower will not have any advantage of a deeper channel and could only profit or have additional costs due to shorter or longer travel times respectively.

Hidrovía S.A. has made calculations of the average additional tonnage a ship can take when the channel is 2 feet deeper (Hidrovía S.A., 2001). This is given for bulk carriers, tankers and containerships and the numbers are used as a reference in this report (see Figure 88 below). An assumption for the containerships is that the income is measured by multiplying the travel costs per container with the additional containers that can be transported. The weight per container is 26 metric-tons (which is almost fully loaded). This is important for the additional amount of containers for a certain containership since the extra cargo that can be transported with an additional 2 feet are given in tons.

The calculations of the shipping costs differ for containerships from bulk carriers and tankers. Therefore it is best to explain them separately.

Additional tonnage for 2 feet (ton)	Additional containers for 2 feet (ton)
2973,3	
3294,2	
3615,1	
3936	
4256,9	
4577,8	
4898,7	
2495,1	
2679,7	
2864,3	
3048,9	
3233,5	
3418,1	
3602,7	
	150
	233
	317
	400
	483
	567
	650

FIGURE 88: ADDITIONAL TONNAGE FOR 2 FEET.

L.4 SHIPPING COSTS FOR BULK CARRIERS AND TANKER

Prices for the bulk carriers and tankers are very difficult to determine per hour. They vary a lot over time and it depends on the route. However, it is known what the costs are for chartering a whole ship for one day. These costs have been provided in Figure 89 below, both for a Capesize and a Panamax vessels.

Route	Charter (USD/day)	Traveltime (days)	Total costs	Price per ton
Bulk				
china - BA (cape)	22250	38,2	849950	21,2
Rotterdam - BA (panamax)	10750	23,3	250475	6,3
average		30,8		13,8
Tanker				
china - BA (cape)	45000	36,7	1651500	41,3
Rotterdam - BA (panamax)	35000	20,4	714000	17,9
		28,55		29,6

FIGURE 89: CHARTER RATES (DRYSHIPS, 2015) (KÖNIG & CIE, 2015), TRAVEL TIME FOR SPECIFIC ROUTES, TOTAL COSTS FOR THAT ROUTE AND THE PRICE PER TON, SOURCES:

The travel times of some busy routes have been determined to get some indication on the price per hour. Although prices greatly vary per route it is used as an reference. This leads to the price per ton per hour. The average of both routes has been used for further calculations.

It must be noted that the charter prizes are on an all-time low. Since it is not expected to stay this low in the future, the price is multiplied with 2 making it more in line with the average from 2000 until 2015.

The price per ton is multiplied with the amount of tons that can be shipped with an additional 2 feet of draft. This number is divided by the amount hours that are needed to finish one of the indicated routes and then multiplied by the time it takes to go through Punta Indio. This gives an indication on what the travel through Punta Indio is worth. The same calculation is not done for the Magdalena channel, because Punta Indio is seen as the reference travel time. The additional cargo that they can take stays the same for both routes, only Magdalena is more expensive in travel costs when going towards the Atlantic Ocean.

Bulk draft (feet)	*Extra income from cargo (36ft)*	*Extra income from cargo (42ft)*
15-22 (Smallsize)	0	0
22-28	0	0
28-32 (Handysize)	0	0
32-34	0	0
34-36 (Handymax Bulk)	476,7	476,7
36-38 (Handymax)	528,2	1056,3
38-40	579,6	1738,8
40-42 (Panamax)	631,1	2524,2
42-44(Post-Panamax)	682,5	2730,0
44-48(New panamax)	734,0	2935,9
>48 (Capesize)	785,4	3141,7
	Going North	
Tanker (feet)	*Extra income from cargo (36ft)*	*Extra income from cargo (42ft)*
15-22 (Smallsize)	0	0
22-28	0	0
28-32 (Handysize)	0	0
32-34	0	0
34-36 (Handymax Bulk)	1241,9	536,9
36-38 (Handymax)	1333,8	1153,3
38-40	1425,7	1849,1
40-42 (Panamax)	1517,5	2624,3
42-44(Post-Panamax)	1609,4	2783,2
44-48(New panamax)	1701,3	2942,1
>48 (Capesize)	1793,2	3101,0

FIGURE 90: INCOME FOR TANKERS AND BULK CARRIERS ON DIFFERENT ROUTES.

L.5 SHIPPING COSTS FOR CONTAINERSHIPS

The only difference for containerships regarding the calculation is that the prices per container on a certain route are known. With this it is possible to calculate the hourly income for one container and then multiply it with the travel time in the channel and the amount of extra containers. The prices are stated below in Table 85:

Route	**Price per cont. ($)**	**Traveltime (days)**
Rotterdam - BA	2657	14,2
US - BA	1904	13,3
china - BA	4357	23,5
Average	2972,7	17

TABLE 85: PRICES PER CONTAINER AND TRAVELTIME FOR SOME SPECIFIC ROUTES.

It leads to the following income:

	Going North	
Container ship (feet)	*Extra income from cargo (36ft)*	*Extra income from cargo (42ft)*
15-22	0	0
22-28	0	0
28-32 (feedermax?)	0	0
32-34	0	0
34-36 (Container ship)	6650	6650
36-38	9218	18436
38-40	12510	37529
40-42 (Panamax, main liner)	16370	65481
42-44(Post-Panamax)	18297	73187
44-48(New panamax)	22384	89534
>48 (ULCV)	25675	102700

FIGURE 91: INCOME FOR CONTAINERSHIPS FOR DIFFERENT ROUTES.

When knowing the ships that go south or north it can be calculated how much the ships together will profit or loose from an alternative.

The ship choice for a channel is calculated in the following way for the alternative with 2 channels, Punta Indio at 34ft and Magdalena at 36ft. The extra benefit for ships is the extra income for the increase in draft. This is 34 feet in this case. Also there is a difference in toll in Magdalena. This is scaled to the length of the channel. So Magdalena channel has lower toll, because it is shorter. Those two benefits are summed up and then the costs for the detour are subtracted. If the result is positive, ships will take the deeper Magdalena channel.

bulk	Atlantic route Costs via Magdalen	Costs via Punta	Revenu extra cargo	South route Costs via Magdalena	Costs via Punta	Brazilian coast	Southern Argentina
15-22 (Smallsize)	12,130	7,871	-	7,019	12,096	-4,259	5,077
22-28	12,130	7,871	-	7,019	12,096	-4,259	5,077
28-32 (Handysize)	13,164	8,542	-	7,617	13,127	-4,622	5,510
32-34	14,278	9,264	-	8,262	14,238	-5,013	5,976
34-36 (Handymax Bulk)	16,783	10,890	520	9,712	16,736	-5,373	7,544
36-38 (Handymax)	16,783	10,890	576	9,712	16,736	-5,317	7,600
38-40	18,334	11,897	632	10,609	18,283	-5,806	8,306
40-42 (Panamax)	20,349	13,204	688	11,775	20,292	-6,457	9,205
42-44(Post-Panamax)	22,351	14,503	744	12,933	22,288	-7,104	10,099
44-48(New panamax)	22,497	14,598	800	13,018	22,434	-7,099	10,216
>48 (Capesize)	25,427	16,499	856	14,713	25,355	-8,071	11,499
tanker							
15-22 (Smallsize)	12,769	8,286	-	7,389	12,733	-4,484	5,344
22-28	12,985	8,426	-	7,514	12,949	-4,559	5,435
28-32	14,832	9,624	-	8,583	14,791	-5,208	6,208
32-34	16,600	10,771	-	9,606	16,553	-5,829	6,948
34-36 (handysize-produ	16,613	10,780	1,053	9,613	16,566	-4,780	8,006
36-38 (Handymax)	18,395	11,936	1,131	10,644	18,343	-5,328	8,830
38-40	19,553	12,688	1,209	11,315	19,499	-5,657	9,392
40-42 (Panamax)	20,534	13,324	1,286	11,882	20,476	-5,923	9,881
42-44(Post-Panamax/A	22,660	14,703	1,364	13,112	22,596	-6,592	10,848
44-48(New panamax)	25,473	16,529	1,442	14,740	25,401	-7,502	12,104
>48 (Capesize)	26,733	17,347	1,520	15,469	26,658	-7,867	12,709
container							
15-22	8,775	5,694	-	5,078	8,751	-3,081	3,673
22-28	12,952	8,404	-	7,495	12,915	-4,548	5,421
28-32 (feedermax)	17,945	11,644	-	10,384	17,894	-6,301	7,511
32-34	20,303	13,174	-	11,748	20,246	-7,129	8,498
34-36 (Container ship)	22,420	14,548	6,650	12,973	22,357	-1,223	16,033
36-38	24,789	16,085	9,218	14,344	24,719	514	19,593
38-40	25,031	16,242	12,510	14,484	24,961	3,721	22,986
40-42 (Panamax, main l	30,003	19,468	16,370	17,361	29,918	5,836	28,928
42-44(Post-Panamax)	40,319	26,162	18,297	23,331	40,206	4,140	35,172
44-48(New panamax)	45,549	29,556	22,384	26,357	45,421	6,390	41,448
>48 (ULCV)	50,037	32,468	25,675	28,954	49,896	8,106	46,617

FIGURE 92 SHIPS CHOICE FOR CHANNEL, HERE 34 FT PUNTA INDIO AND 36 FT MAGDALENA. (GREEN IS THOUGH MAGDALENA).

L.6 NET PRESENT VALUE AND INTERNAL RATE OF RETURN

TABLE 86: ABSOLUTE VALUES NPV & IRR.

	Capital dredging cost		Maintainance dredging cost/year		Benefits shipping intitial year	
Alternatives						
0	USD -		USD -13.175.164		$ -	
1	USD -21.513.550		USD -14.551.673		$ 12.286.238	
2a	USD -256.996.209		USD -19.069.575		$ 20.395.672	
2b	USD -282.026.510		USD -20.111.789		$ 20.395.672	
3	USD -260.512.960		USD -18.735.279		$ 8.333.213	
4a	USD -260.512.960		USD -5.560.116		$ -7.735.528	
4b	USD -399.487.446		USD -7.705.996		$ 37.382.486	

Kolom1	Kolom2	Kolom3	Kolom4	Kolom5	Kolom6	Kolom7
2016-2035	Normal growth		Low growth		High growth	
Scenarios	2,26%		0,834%		3,829%	
ALT	*Net result NPV*	*IRR*	*Net result NPV*	*IRR*	*Net result NPV*	*IRR*
0	USD -205.467.769	#GETAL!	USD -205.467.769	#GETAL!	USD -205.467.769	#GETAL!
1	USD -118.305.320	-3,7%	USD -128.102.331	-3,7%	USD -106.195.195	-3,1%
2a	USD -338.345.313	-4,4%	USD -354.608.765	-4,4%	USD -318.241.996	-4,0%
2b	USD -379.629.034	-4,5%	USD -395.892.486	-4,9%	USD -347.057.009	-3,7%
3	USD -464.421.089	-8,6%	USD -471.065.970	-9,1%	USD -456.207.326	-8,1%
4a	USD -429.162.512	#GETAL!	USD -422.994.224	#GETAL!	USD -436.787.158	#GETAL!
4b	USD -123.686.659	-1,1%	USD -153.495.349	-1,4%	USD -86.840.020	-0,7%

Inflation rate	1,75%
Nominal discount rate	3,50%
Real discount rate	1,75%

TABLE 87: RELATIVE VALUES NPV & IRR.

	Capital dredging cost		Maintainance dredging cost/year	Relative Maint costs	Benefits shipping intitial year	
Alternatives						
0	USD -		USD -13.175.164	USD -	$ -	
1	USD -21.513.550		USD -14.551.673	USD -1.376.510	$ 12.286.238	
2a	USD -256.996.209		USD -19.069.575	USD -5.894.411	$ 20.395.672	
2b	USD -282.026.510		USD -20.111.789	USD -6.936.625	$ 20.395.672	
3	USD -260.512.960		USD -18.735.279	USD -5.560.116	$ 8.333.213	
4a	USD -260.512.960		USD -5.560.116	USD 7.615.048	$ -7.735.528	
4b	USD -399.487.446		USD -7.705.996	USD 5.469.168	$ 37.382.486	

Kolom1	Kolom2	Kolom3	Kolom4	Kolom5	Kolom6	Kolom7
2016-2035	Normal growth		Low growth		High growth	
Scenarios	2,26%		0,834%		3,829%	
ALT	*Net result NPV*	*IRR*	*Net result NPV*	*IRR*	*Net result NPV*	*IRR*
0	USD -	#GETAL!	USD -	#GETAL!	USD -	#GETAL!
1	USD 87.162.449	5,1%	USD 77.365.437	4,4%	USD 99.272.574	5,5%
2a	USD -132.877.544	-2,0%	USD -149.140.996	-2,1%	USD -112.774.227	-1,6%
2b	USD -174.161.266	-2,4%	USD -190.424.717	-2,7%	USD -154.057.948	-2,0%
3	USD -258.953.321	-5,6%	USD -265.598.201	-6,0%	USD -250.739.557	-5,2%
4a	USD -223.694.743	#GETAL!	USD -217.526.455	#GETAL!	USD -231.319.389	#GETAL!
4b	USD 81.781.109	0,8%	USD 51.972.420	0,5%	USD 118.627.749	1,1%

Inflation rate	1,75%
Nominal discount rate	3,50%
Real discount rate	1,75%

APPENDIX M: MULTI CRITERIA ANALYSIS

M.1 PREFERENCES AND CRITERIA

A time
B capacity
C Navigation & Piloting costs
D Sustainability
E Construction

Preference economic								
	Weight *100	Alt 0	Alt 1	Alt 2A	Alt 2B	Alt 3	Alt 4A	Alt 4B
A	33.33	66.67	66.67	166.67	166.67	166.67	33.33	33.33
B	20.00	60.00	60.00	80.00	100.00	80.00	80.00	80.00
C	13.33	53.33	53.33	13.33	13.33	26.67	66.67	66.67
D	6.67	33.33	26.67	6.67	6.67	13.33	20.00	13.33
E	26.67	133.33	106.67	53.33	53.33	53.33	53.33	26.67
Score	100	347	313	320	340	340	253	220

TABLE 88: TOTAL SCORES FOR DIFFERENT ALTERNIATIVES ON PREFERENCE ECONOMIC.

Preference Construction								
	Weight *100	Alt 0	Alt 1	Alt 2A	Alt 2B	Alt 3	Alt 4A	Alt 4B
A	26.67	53.33	53.33	133.33	133.33	133.33	26.67	26.67
B	13.33	40.00	40.00	53.33	66.67	53.33	53.33	53.33
C	20.00	80.00	80.00	20.00	20.00	40.00	100.00	100.00
D	6.67	33.33	26.67	6.67	6.67	13.33	20.00	13.33
E	33.33	166.67	133.33	66.67	66.67	66.67	66.67	33.33
Score	100	373	333	280	293	307	267	227

TABLE 89: TOTAL SCORES FOR DIFFERENT ALTERNIATIVES ON PREFERENCE CONSTRUCTION.

Preference Sustainability								
	Weight *100	Alt 0	Alt 1	Alt 2A	Alt 2B	Alt 3	Alt 4A	Alt 4B
A	20.00	40.00	40.00	100.00	100.00	100.00	20.00	20.00
B	6.67	20.00	20.00	26.67	33.33	26.67	26.67	26.67
C	13.33	53.33	53.33	13.33	13.33	26.67	66.67	66.67
D	33.33	166.67	133.33	33.33	33.33	66.67	100.00	66.67
E	26.67	133.33	106.67	53.33	53.33	53.33	53.33	26.67
Score	100	413	353	227	233	273	267	207

TABLE 90: TOTAL SCORES FOR DIFFERENT ALTERNIATIVES ON PREFERENCE SUSTAINABILITY.

M.2 SCORES

Score							
	Alternative 0	Alternative 1	Alternative 2A	Alternative 2B	Alternative 3	Alternative 4A	Alternative 4B
A	2	2	5	5	5	1	1
B	3	3	4	5	4	4	4
C	4	4	1	1	2	5	5
D	5	4	1	1	2	3	2
E	5	4	2	2	2	2	1

TABLE 91: SCORES FOR EVERY CRITERION ON EACH ALTERNATIVE.

A Time – Alternative 0 can be seen as the standard situation, because it is the current situation. This is given a score of 2. Alternative 4A & 4B will both take more time most ships, because they have to go round the banks Río de la Plata Exterior. In this case there is no Punta Indio. In Alternative 2 and 3 there are two channels so ships will be faster at their destination.

B Capacity – When there are two channels the capacity is increased. A roundabout can be created in the case of 2B. At 2B there is no possibility for this, because containerships can only take Punta Indio. In case of only 1 channel, the Magdalena will be wider than Punta Indio. This is due it's design (22m wider at the bottom) that the capacity is slightly higher.

C Navigation & Piloting Costs – The longer the channel, the higher the navigation & piloting costs. Two channels are more expensive than one on navigation. On piloting they are in between the two single channels. That is why there is a big difference in the values

D Sustainability - In the environmental impact analysis this part is investigated. Creating a new channel will harm de environment more than not creating it. To have two channels is relative the worst for the environment, but as can be seen in the Environmental Impact Assessment, it is still minimal on an absolute scale. Holding only the current Punta Indio is seen as the best option.

E Construction – This criterion has the following thing taken into consideration: risks while dredging, risks of delays. Also the slopes in the first years can get a lot of sedimentation. There needs to be a certain time for the equilibrium situation to develop. This might take a long time. The construction of the deepest, 4B has the biggest risks and therefore has the lowest score. In the other cases with a new channel the value is 2. In Alternative 0 there are no risks and no construction, so it score very high.

APPENDIX N: MATLAB CODE FOR ITERATIVELY DETERMINING CHANNEL DEPTH

N.1 YOSHIMURA CODE

```
Yoshimura
clc
clear all
close all

B=36;
Lpp=228;
Cb=0.82;
d=42; %feet
D=d*0.3048; %meters
T=D;
% Vs=7.2; %container
Vs=6.2; %bulk

% Punta Indio channel 34ft
% h=35.64*0.3048
% Sbl=((0.7+1.5*T/h)*(Cb*B/Lpp)+(15*T/h)*(Cb*B/Lpp)^3)*(Vs^2)/9.81

% Punta Indio channel 36ft & Magdalena channel 36ft/42ft
h=20;
h2=5;
while abs(h-h2)>eps(h)
   Sbl=((0.7+1.5*T/h)*(Cb*B/Lpp)+(15*T/h)*(Cb*B/Lpp)^3)*(Vs^2)/9.81
   h2=h;
   h=D+0+Sbl+1.0+0.5;
end
Hdredge=h+0.7;
```

N.2 ICORELS CODE

```
ICORELS
clc
clear all
close all

B=48;
Lpp=335;
Cb=0.68;
Cs=1.7;
d=36; %feet
D=d*0.3048; %meters
T=D;
Vs=7.2; %container
%Vs=6.2; %bulk

V=Cb*Lpp*B*T;

% Punta Indio channel 34ft
h=35.5*0.3048
Fnh=Vs/sqrt(9.81*h)
Sbl=Cs*(V/(Lpp^2))*((Fnh^2)/sqrt(1-(Fnh^2)))

% Punta Indio channel 36ft & Magdalena channel 36ft/42ft
h=20;
h2=5;
while abs(h-h2)>eps(h)
   Fnh=Vs/sqrt(9.81*h)
   Sbl=Cs*(V/(Lpp^2))*((Fnh^2)/sqrt(1-(Fnh^2)))
   h2=h;
   h=D+0+Sbl+1.0+0.5
end
Hdredge=h+0.7
```

APPENDIX O: CAPITAL DREDGING CALCULATION METHOD

In this appendix the capital dredging calculations are elaborated. First, the calculation method for the Magdalena Channel is explained. Then the input data is given (soil elevation). The results of the calculations are presented. For the Punta Indio channel a different approach is used to calculate the depth increment from 34 feet to 36 feet design draft. Then, a conclusion is stated at the end.

Model variables:

$$h = depth\ waterway\ [m]$$
$$h_e = waterdepth\ [m]$$
$$\Delta h = h - h_e\ [m]$$
$$x = slope\ steepness\ 1{:}x$$
$$W = bottom\ width\ [m]$$
$$W_{slope} = x * \Delta h = Width\ slope\ [m]$$

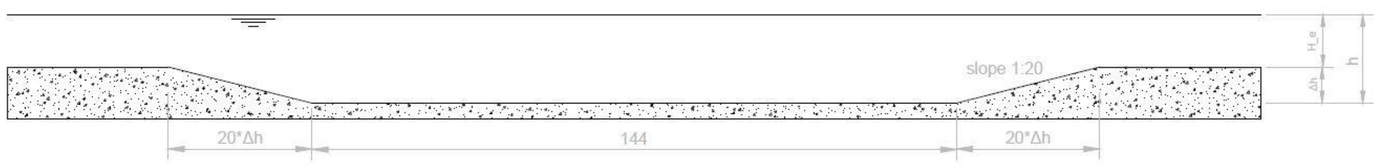


FIGURE 93: EXAMPLE DREDGING CALCULATION

$$Area\ cross - section = \Delta h * W + \Delta h * W_{slope} = \Delta h W + \Delta h^2 x = \Delta h(W + \Delta h x)$$

Measurement data is available: this consists of depth and longitude coordinates along the stretch of the channel starting from El Codillo. See Appendix Bathymetry data for the data and the used reference level.

The total dredging volume is calculated as the sum of calculated smaller volumes.

$$Total\ capital\ dredging\ volume = \sum v_j = \sum A_j \Delta s_j$$

$$A_j = \Delta h_j (W + \Delta h_j)$$
$$\Delta h_j = h - h_{e,j} = h - \frac{a_j + a_{j+1}}{2}$$
$$a_j = depth\ at\ measurement\ point\ j$$
$$\Delta s_j = x_{j+1} - x_j$$

For each measurement number j, there is a depth measurement a_j and a length coordinate x_j. The cell length is Δs_j. The mean depth Δh_j in this cell is used to calculate the cross section, which in turn is used to calculate the volume of the cell.

In Figure 94 the bathymetry data is plotted. For elaboration of this graph, see Appendix Bathymetry data. The soil is split into two layers, layer A and layer B. Layer B, positioned below the brown line named ‘Soil type B’, has different geotechnical properties than the above layer. This results in different costs to dredge layer A and layer B.

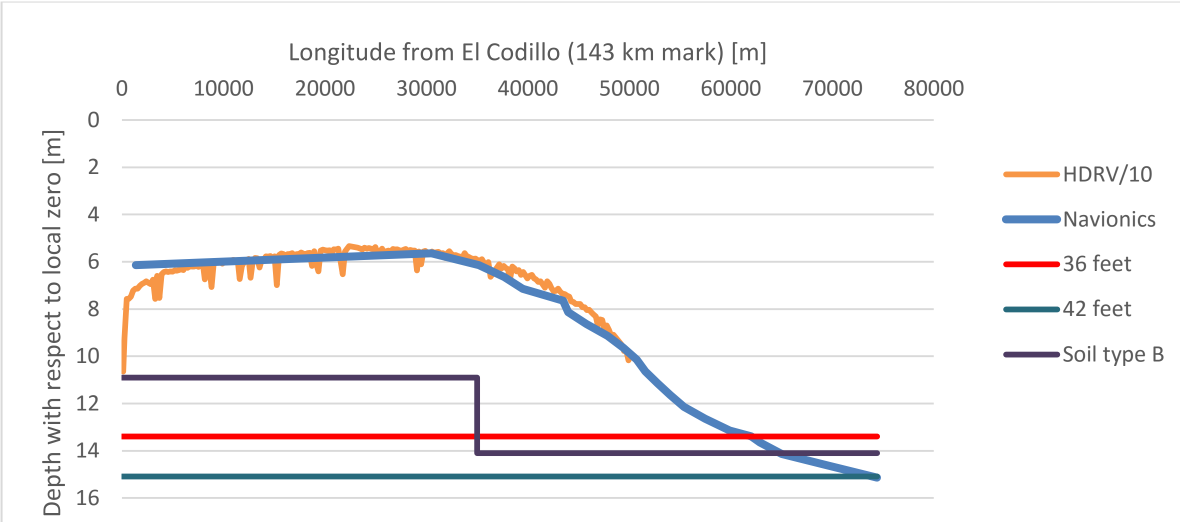


FIGURE 94: BATHYMETRY DATA USED FOR THE CAPITAL DREDGING CALCULATIONS.

In Table 92 an overview of the calculated dredging volumes for the Magdalena Channel is presented. This has been done for a variety of parameters: two ship types, two dredging depths, two velocities and two slopes which results in different channel widths. The additional volume in the bend due to additional width is not calculated.

Ship type		**Container**								**Bulk**	
L_{oa}	[m]	352								255	
W	[m]	48								36	
T	[ft]	36				42				36	
Dredging depth	[m]	14,16				16,36				14,16	
Velocity	[-]	fast			moderate	fast		moderate		moderate	
Slope	1:x	1:20	1:10	1:20	1:10	1:20	1:10	1:20	1:10	1:20	1:10
Channel length	[m]	62000	62000	62000	62000	74400	74400	74400	74400	62000	62000
Channel depth	[m]	14,16	14,16	14,16	14,16	16,36	16,36	16,36	16,36	14,16	14,16
Channel width	[m]	144	144	141,6	141,6	144	144	141,6	141,6	117	117
Total dredging volume	$[m^3]*10^6$	106,4	80,9	105,5	80	165,1	120,1	163,8	118,8	96	70,6
Dredging volume type A	$[m^3]*10^6$	88,9	65,7	88,2	65	115,1	78,9	114,4	78,2	80,9	57,8
Dredging volume type B	$[m^3]*10^6$	17,5	15,2	17,3	15	50	41,2	49,4	40,6	15,1	12,8

TABLE 92: OVERVIEW CALCULATED DREDGING VOLUMES.

O.1 CANAL PUNTA INDIO CAPITAL DREDGING

In 2001 Hidrovía performed a study on dredging Canal Punta Indio. (Hidrovía S.A., 2001) The aim for this report was to give an insight in the volume of deepening the Canal Punta Indio channel to 36 feet from 32 feet. This is a total of 17,268,000 m^3. Currently the depth is 34 feet. So the dredging volumes to 34 feet need to be determined, before continuing to 36 feet. That 17 million cubic meter of sand need to be divided in two parts: from 32ft to 34ft and from 34ft to 36ft. To make the calculation to determine the two volumes, the dredging levels need to be known. Which levels are used it not given in the report. But in the report the depths for dredge levels do are used. Not the design depths as shown below, dredging depths are in reality more because of dredging inaccuracies/tolerances. But is gives a good estimation in the distribution. The figure and calculation below gives estimation on how the 17 million cubic meters of sediment can be split.

FIGURE 95: SKETCH OF THE PUNTA INDIO CROSS-SECTION.

The difference in length of the slope can be seen in the figure above. Therefore the slopes of the cross-section have different areas. The yellow part is the difference in area between the 2 parts, the black is from 32 to 34 feet and grey from 34 to 36 feet.

First the yellow area needs to be calculated. The height is 2 feet, with a slope of 1/20 this gives a length of 40 feet and there are 2 sides, gives $2 \cdot 2 \cdot 40 = 160\ ft^2$.

The total area of 32 to 34 ft is as follows:

- Bottom: 120m=394ft; deepened 2 ft: $394 \cdot 2 = 788\ ft^2$
- Sides: 2 sides; average depth Río de la Plata at Canal Punta Indio: 28ft, with 3 ft overdepth gives 7 ft to dredge to 32 ft; slope of 1/20, so slope can be seen as a rectangular area; $2 \cdot (2 \cdot (7 \cdot 20)) = 560 ft^2$
- Total area of 32 to 34 is $560 + 788 = 1348\ ft^2$
- Total area of 34 to 36 is $1348 + 160 = 1508\ ft^2$
- Total area of 32 to 36 is $1508 + 1348 = 2856 ft^2$
- Percentage of total volume that is used for 34 to 36ft = $\frac{1508}{2856} \cdot 100\% = 53\%$
- 53% of 17.268.000 = 9.152.040m^3

So to be dredged volume for deepening the channel from 34 to 36 feet is 9,152,040m^3

O.2 CONCLUSION

In Table 93 the dredging volumes for the Magdalena Channel concept design are presented. For Punta Indio, the increment from 34 feet to 36 feet results in a dredging volume of $9.1*10^6$ m^3. This soil volume is classified as soil type A.

Ship type		Container		Bulk
L_oa	[m]	352		255
W	[m]	48		36
T	[ft]	36	42	36
Velocity	[-]	fast	fast	moderate
Slope	1:x	1:20	1:20	1:20
Channel length	[m]	62000	74400	62000
Channel depth	[m]	14,16	16,36	14,16
Channel width	[m]	144	144	117
Add. Bend width	[m]	25,5	25,5	23,8
Capital dredging total soil	$[m^3]*10^6$	106,4	165,1	96
Capital dredging soil type A	$[m^3]*10^6$	88,9	115,1	80,9
Capital dredging soil type B	$[m^3]*10^6$	17,5	50	15,1

TABLE 93: DREDGING VOLUMES FOR THE CONCEPT DESIGN.

APPENDIX P: REFLECTION

P.1 REFLECTION ON THE REPORT

Substantively there are some points of improvement regarding the report. For multiple analyses in the report, assumptions have been used like for the dredging, environmental and economic analysis. Especially for the economic analysis these assumptions, such as the discount rate and the shipping revenues are important to be recognized, since they have a large impact on the outcome of the final analysis such as the cost benefit analysis and multi criteria analysis. These factors are hard to estimate accurately in this case and need to be estimated correctly for the local situation in order to represent the realistic circumstances.

As mentioned in the report itself the presented layouts are based on the channel depth calculated, later the client requested for the channel to be designed according to the concept PIANC guidelines at a later stage in the design process. Hence the layout was already completed. Due to the time scope of this project, only the depths have been adjusted to the PIANC manual; the layout and length characteristics where fixed at the depth based on PIANC guidelines.

Overall, the preliminary design study satisfies the steps stated in the PIANC approach channels manual. Some steps are actually examined using a method with a higher detail than the method used in the manual.

P.2 REFLECTION ON THE GROUP PROCES

Looking back at the process of the project in general, it can be said that the project process went well overall and that everybody has put in the effort which was requested. When we were making preparations to go to Buenos Aires, we have made an overview of the different skills and knowledge every group member had. This helped us ahead in the first few weeks, because we already had a clear view which member should search for what specific data. Knowing which data someone needed we could also help each other ahead.

The downturn was that the first few weeks were possessed with personal matters. Most of us were plagued with different illnesses in the first two weeks, while someone else had to fly back to the Netherlands for a weekend because of family matters .

However, even though we had some setbacks the first few weeks and the fact that most data provided was in Spanish, with some adjustments in the project planning we were able to start calculations and analyses in the third week. This was only slightly later than intended. The weeks after that we have made full days to get back on track and finally finished the project within the intended time.

One of the difficult parts was to cope with the demands and requirements made by our supervisors in Delft and out supervisor in Buenos Aires. While Mr. Verhagen and Mr. Verheij were urging us to keep things on wide perspective with multiple alternatives, Mr. Escalante wanted us to go more into depth focusing on one specific alternative. We tried to satisfy both, but this lead to some confusion within the group sometimes, due to changes in which alternatives were taken into account in the report. The fact that we had many alternatives to analyze did make it even more unclear. This sometimes lead to necessary adjustments which could take a lot of additional time.

Sometimes this also lead to frustration between different group members and although this sometimes could lead to a fierce (but healthy) discussion, we were always capable of clearing the air and find a solution. It were only minor things mostly of which we regard it as a normal thing within a group.

Most important was that we had an good cohesion within the group which made it easy to work together. Outside the project we have seen a lot of the city, met a lot of new people and the great vibe within the group leads to the conclusion that we have had a great time in Buenos Aires overall.