Planning and technical feasibility study deepwater port
'Zona Portuaria Simon Bolivar'
in Tablazo Bay, Venezuela

MSc Thesis

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Preface

This report is the master thesis of Sander van Poeteren, student at Delft University of Technology, Faculty of Civil Engineering and Geosciences.

This thesis is my last project of the study Civil Engineering. My specialization is Hydraulic Engineering, Port and Inland Waterways.

The subject of this report is the planning and technical feasibility study of a deepwater port in Tablazo Bay, Venezuela.

The project has been carried out under guidance of a graduation committee.

I would like to thank the members of my graduation committee for their comments and support during my master thesis. The members of this committee are:

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Furthermore I would like to thank Mr Vis (Alkyon), Mr Adema (Alkyon), Mr Onderwater, Mr van der Leer (EMO), Maurice Derks and J.E. Stein Callenfels (Corus) and Mr Hartveld (Visafslag Scheveningen) as well, for their advice and useful reports. Finally I would like to thank my family and friends for their support during the years I spent in Delft and especially the months I spent on my thesis.

Sander van Poeteren

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Summary

Background Information

Lake Maracaibo is the main lake of Venezuela. The expectations of the government of Venezuela for Lake Maracaibo are high. Venezuela does not have a main port in the region of Lake Maracaibo. In the current situation, there are many small ports that are positioned at different locations.

The government of Venezuela would like to construct one main port in the region of the island of Pájaros. The island of Pájaros is located between the Gulf of Venezuela and Tablazo Bay as presented in figure-1. The future port has to contribute to the necessary economic growth and at the same time, the environmental conditions of Lake Maracaibo have to be improved.
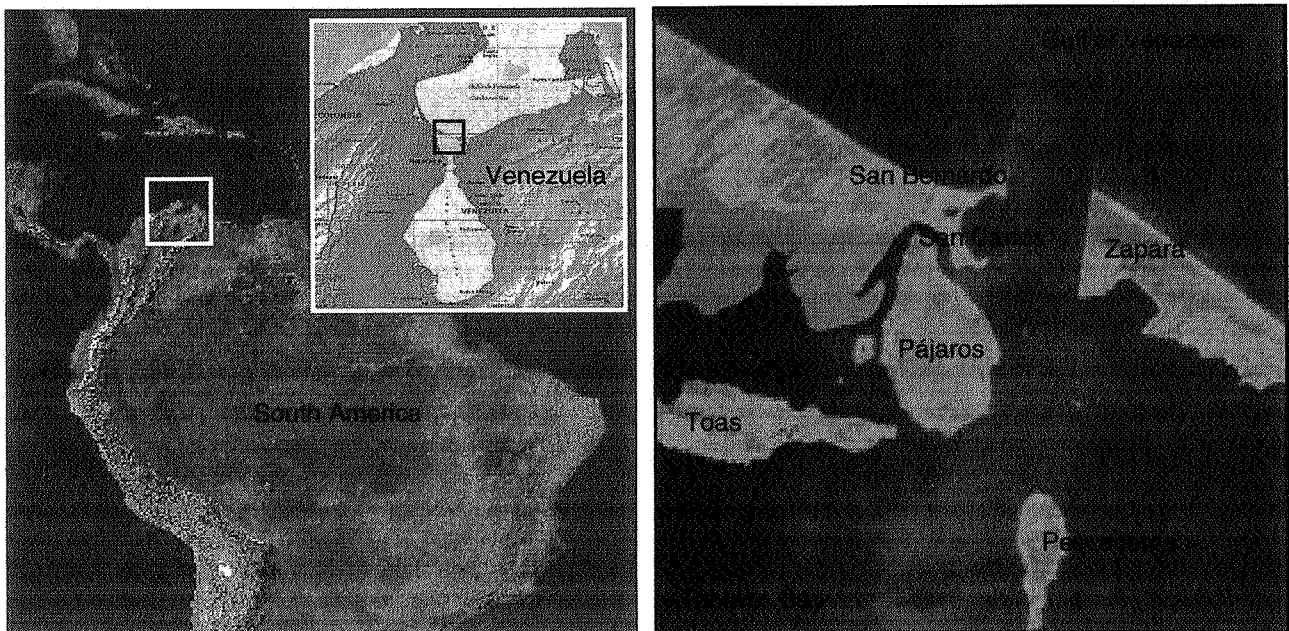

Figure 1: Locations and names concerning the project area 'Zona Portuaria Simon Bolivar'

The capacity of some terminals in the Maracaibo region are not sufficient to keep up with the economic growth from 60 Mtons at present times up to 90-120 Mtons in the next 20-25 years. To stop the contamination of salinity into Lake Maracaibo, the navigation channel must be closed between the entrance of Tablazo Bay and Lake Maracaibo. To gain more throughputs and reduce contamination of salinity, a deep water port needs to be created in the Tablazo Bay area. By creating a deep water port, cargo such as oil, coal, iron ore, petrochemicals, cement grain, other dry bulk and containers is converged and can be transported in larger consignments. Due to converged cargo and larger consignments, the export volumes are considered to increase.

The need for a new feasibility study

As a solution to the economic growth possibilities in Venezuela and to reduce the contamination of salinity, in 2002 a masterplan was created by Alkyon called 'Puerto America'. The terminal sites in the masterplan were located on Zapara and San Bernardo. The estimated costs for this project were too high due to the large amount of landfill area at the north site of San Bernardo. For that reason the port has to be positioned at another location. This study includes the planning and technical feasibility of the deep water port on 'Zona Portuaria Simon Bolivar', that is partly located at the island of Pájaros, Zapara and San Bernardo.

Traffic forecast per phase

A lot of different commodities will be handled at the deep water port. Some of these commodities will be handled at the same terminal area. Finally, six terminals are created to handle all the commodities in the port area. The six terminals are:

Containers
General cargo
Cement related products
Cereals
Coal
Oil

The expected cargo throughput for 'Simon Bolivar' is determined for three phases (2008, 2010, 2018) and for the year 2028. Phase-1 includes only the start of the coal terminal with little throughput. In this phase, the amount of coal is delivered by truck. In the other phases all terminals become operational and the main amount of coal is delivered by train. The traffic forecast for containers, coal and oil is presented in the table below.

	Containers	Coal	Oil
Phase-1 2008	-	13.5 Mtons	-
Phase-2 2010	142,000 TEU	16.7 Mtons	62,000,000 m³
Phase-3 2018	790,000 TEU	24 Mtons	66,000,000 m³
Year 2028	1,288,000 TEU	26 Mtons	66,000,000 m³

Dimensions of the port

The traffic forecast is based on a maximum depth of the port basin of 47 ft. This is a required basin depth for a Panamax container vessel. Using the queuing theory, the necessary quay length for the sea going vessels and the necessary quay length for barges are determined for the different development phases. The extra sailing time through the channel is included in this method. For the large oil tankers and coal carriers the channel will be a one-way channel section and a two-way section for the remaining smaller vessels.

3

The tide difference between mean high and mean low water is 0.88 m. It is possible to implement a tidal window. In that case, vessels can only enter the channel during the high water period in the tidal window. In the remaining time no vessels will be able to enter or leave the port. This will result in a decrease of throughput. Implementing a tidal window will accommodate somewhat larger vessels to enter the port because of the extra channel depth. However, it is expected that this will not compensate the decrease of throughput caused by the extra average waiting times. As a result, no tidal window will be implemented.

The required quay length for the sea going vessels and the barges during phase-2, 3 and the year 2028 are presented in table-1.

	Sea quays		Barge quays	
	Numb of berths	Quay length (m)	Numb of berths	Quay length (m)
Fase-2 (2010)				
Containers	2	340	1	142
General cargo/Break bulk	2	378	-	-
Crude oil/Petroleums/Chemicals	5	-	6	-
Coal	2	-	2	-
Cereals	1	230	1	142
Cement related/Other dry bulk	2	310	1(other dry bulk)	120
Fase-3 (2018)				
Containers	3	650	3	395
General cargo/Break bulk	2	378	-	-
Crude oil/Petroleums/Chemicals	5	-	6	-
Coal	2	-	2	270
Cereals	1	230	1	142
Cement related/Other dry bulk	2	310	1(other dry bulk)	120
Steel factory	-	-	1	142
Year (2028)	Numb of berths	Quay length (m)	Numb of berths	Quay length (m)
Containers	4	860	4	521
General cargo/Break bulk	2	378	-	-
Crude oil/Petroleums/Chemicals	5	-	6	-
Coal	2	-	2	-
Cereals	1	230	1	142
Cement related/Other dry bulk	2	310	1(other dry bulk)	120
Steel factory	-	-	1	142

Table-1: Number of berths and lengths of the sea and barge quays.

For all three phases and the year 2028 the required terminal areas are determined. Together with the quay lengths, the harbour lay-outs are determined. An important factor in determining the location is the possibility of future terminal extension in two directions.

Multi Criteria Evaluation

Four alternative harbour lay-outs are created. A rough estimation is made of the dredging costs, landfill costs and breakwater costs per alternative. A Multi Criteria Evaluation (MCE) is carried out to determine which alternative is most suitable based on criteria like functionality, environment, adaptability, preservation and future development.

In the MCE the qualitative criteria are non-cost related and independent of each other. At the end of the evaluation the value-cost ratio is determined. When looked at the individual value ratio points and the value-cost ratio, alternative-2 is most favourable. Based on the MCE alternative-2 is selected. Alternative-2 is presented in appendix 5.

Optimum width of coal and oil basin

The relation between trestle costs and dredging costs per m^1 over a period of 20 years is found. These optimum trestle lengths and the safety distance between the passing vessels and the berthed oil tankers or coal carriers determine the basin width of the two basins.

Together with the channel, main basin and tide data, the siltation and sedimentation rates are determined for the barge harbour and the main harbour basin for the sea going vessels. If these rates become too high a lot of dredging is required. As a result of the dredging, hindrance of the arriving vessels occurs. The result is more down time for the vessels.

Current velocities and sedimentation

To determine the current velocities in the harbour basins, the new situation and bathymetry of alternative 2 is implemented in Delft 3D. Finally the current speed-time graphs are plotted for several observation points in the basins.

The sedimentation in the two basins is approximated with the van Rijn transport formula and the Eysink-Vermaas formula. It became clear that the estimation of the average sedimentation in the barge harbour basin will approximately be in the order of magnitude of 0.80 m per year. This is an acceptable value. The sedimentation in the main harbour basin will be in the order of magnitude 1.40 m per year. This is 20% higher than in the present situation. The costs for maintenance dredging are also acceptable and resulting down time of the vessels is minimal.

It can be concluded that it is feasible to create a new port on the island of Pájaros.
However, it must be noted that many risks are involved in the total project. The main risk in the whole project is the economical growth of all commodities except oil and coal. These two products are exported and are in favour. Because of the uncertainties concerning economical growth, this project is constructed and designed in phases. This way the port development will be able to adapt to the economical growth of Venezuela.
The only thing that is certain is that the predicted amount of cargo throughput will be reached. The only question is: when?

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1   Introduction

This thesis covers the planning and technical feasibility study of a deepwater port 'Zona Portuaria Simon Bolivar' on the island of Pájaros, San Bernardo and Zapara, Venezuela.
To gain a good insight into the contents of the feasibility study in this first chapter the problem analysis, assumptions and the background of the study will be discussed.
The problem analysis, resulting from the problems described in the following sections and development in the region of Lake Maracaibo, will be discussed in section 1.1. A description of the project area where the deepwater port will be located is also described in this section.
After the description of the main assumptions in section 1.2, the history of the economical growth and the industries, problems and future plans around the Maracaibo Basin area are described in section 1.3. Furthermore, ecological and economical problems will be explained for this region. The remedy for these problems and the future development of the Maracaibo Basin area will be described in the following sections. At the end of this chapter the structure of the study of the planning and technical feasibility study will be further discussed in section 1.4.

1.1   Problem analysis

The expectations of Venezuela for Lake Maracaibo and the new deepwater port 'Zona Portuaria Simon Bolivar' are as follows:
Firstly, Lake Maracaibo has to recover in an ecological way. This problem can only be solved if the access channel will no longer be navigable for ships with great depth.
Secondly, the coal industry will construct a coal export terminal on San Bernardo. It is expected that a deepwater port nearby the coal terminal will cause large economical benefits for different industries in the Lake Maracaibo region.
The present throughput of all the ports in the nearby area of Lake Maracaibo is about 60 million tons per year. The prediction for the cargo throughput in the next 20-25 years is in the order of 90-120 million tons per year [Masterplan 'Puerto America', Alkyon 2002]. This can only be realized with the development of the 'Zona Portuaria Simon Bolivar' deepwater port.

1.1.1   Problem definition

Considering the cargo forecast of the different modes of transport and the desired ecological improvement of Lake Maracaibo, the government of the State of Zulia gave order to develop a Masterplan "Puerto America" in the year 1998. The government of Zulia gave some basic assumptions at the beginning of the project. In this masterplan, developed by Alkyon, the harbour was situated on San Bernardo.
Eventually the overall costs of the Puerto America Masterplan became too high. This lead to a new assumption as location regards. A new feasibility study must be performed, concerning a deepwater port at the island Pájaros.
figure1-1 shows all locations and names concerning the project area. This figure shows the location of the Puerto America masterplan at San Bernardo, the location for the new feasibility study 'Zona Portuaria Simon Bolivar' at Pájaros and the surrounding islands.
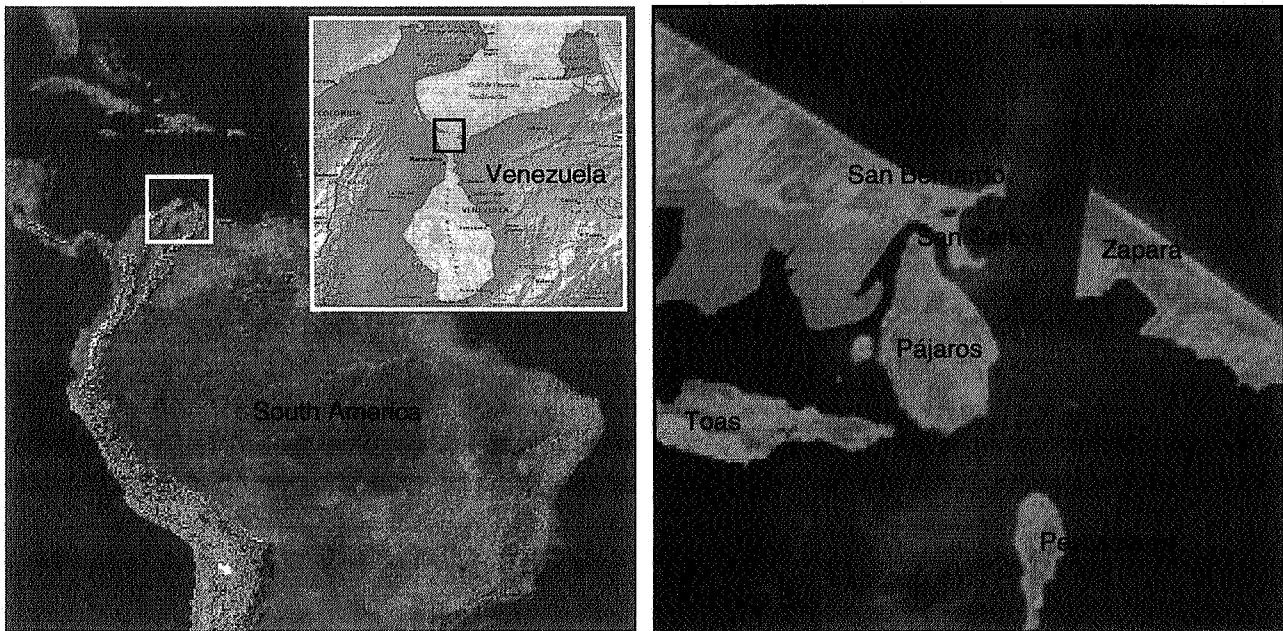
figure1-1: Locations and names concerning the project area 'Zona Portuaria Simon Bolivar'

The old location of "Puerto America" at San Bernardo is situated at the western side of the northern connection between the Gulf of Venezuela and Lake Maracaibo. The island of Pájaros is situated south of the little town San Carlos.

In this study the planning and technical feasibility of the port lay-out at the island of Pájaros, Zapara and San Bernardo is evaluated.

This feasibility study is written for Delft University of Technology and Alkyon Hydraulic Consultancy & Research.

1.1.2   Objective

The main objective for this study is the planning and technical feasibility of a deepwater port at the Island of Pájaros, Zapara and San Bernardo. During the feasibility study a clear understanding will be needed of the following matters:

- Is the development of a deepwater port at the Island of Pájaros viable?
- What are the most important influences and risks during the design of the port lay-out?
- What kind of hinterland connections for the different cargo flows will be required?
- What will be the final port lay-out?
- Does the final port lay-out satisfy the preliminary assumptions?

1.2   Assumptions

The main assumptions of the feasibility study are:

- The location for the development of the new deepwater port "Zona Portuaria Simon Bolivar" will be on the Island of Pájaros, the opposite Island of Zapara and San Bernardo.
- One of the export commodities is coal. The coal terminal will be located at San Bernardo.

- Another export commodity is oil. The location of the oil storage terminal will be at the island of Zapara.

- Some arrangements need to be made for the local fishermen on the island of Zapara.

- Considering the available space at the island of Pájaros, all remaining terminal areas and industries will be located on this island.

- A steel factory and the accompanying iron ore stockyard, which produces steel plates, will be part of the feasibility study.

- There may be future potential for cruise shipping. A location needs to be reserved nearby the port. Nowadays it is too early to develop a plan for such activities. For that reason this report does not include a feasibility study for a cruise terminal. Only a reservation is made for a jetty.

- The hinterland connection from San Bernardo will be connected to the highway between Sinemaica and Maracaibo with minimum impact on the mangroves in the area.

- The future channel depth must be sufficient enough for Panamax container vessels of about 4400 TEU. This results in partly loaded coal carriers and oil tankers.

- An extensive data collection is available from the finished [Masterplan "Puerto America" Alkyon, June 2002] at San Bernardo. These data cover another location but can also be used for the planning and technical feasibility study for the deep see port at the island of Pájaros, just south of San Carlos.

- The trade and traffic forecast of the 'Puerto America' project was developed for three different phases, starting with phase-1 in the year 2005. As a result of the change in port location, phase-1 of the 'Zona Portuaria Simon Bolivar' project starts in 2008. Every phase starts 3 years later in the new situation.

- In phase-1 only a small coal terminal will be operational. Phase-2 is the beginning of the year 2010 where all the remaining terminals need to be operational and the coal throughput is increased in relation to phase-1. Phase-3, in the beginning of the year 2018 and all throughput for the different commodities have increased in relation to phase-2.

- The oil terminal will be operational on the island of Zapara from phase-2. All the oil tankers will berth at the island of Zapara and depart fully loaded to their over-seas location. For that reason the tankers do not sail their present route anymore after the year 2010.

1.3   Background of this study

1.3.1   Project area

The project area is located in north-western Venezuela nearby Maracaibo City, capital of Zulia State. The area is located on the western shore of a channel linking Lake Maracaibo and the Gulf of Venezuela (an arm of the Caribbean Sea).

As shown in figure1-1 Venezuela is located at the northern most end of South America. The Country is surrounded on the north by the Caribbean Sea and the Atlantic Ocean, on the east by Guyana, on the south by Brazil, and on the west by Colombia.

The location for the development of a deepwater port is an area located on the island of Pájaros, the nearby located island of Zapara and San Bernardo. Between Zapara and San Bernardo lies the channel from the Gulf of Venezuela to Lake Maracaibo. This channel provides the access for ocean going vessels to the different port facilities. A further detailed description of the project area is presented in appendix-1 (Information about the project site, page 2).

1.3.2   History and present situation

Maracaibo City is the main seaport and industrial centre for the petroleum-rich of Lake Maracaibo.
It is Venezuela's second largest city, a commercial and industrial centre, and the oil capital of South America.
Besides crude oil and petroleum products exports include mainly cement, coal, Natural gas and petrochemicals.
Cabimas and the port of Maracaibo are the principal cities situated by the lake. figure 1-2 shows an overview of these cities and the surrounding ports.
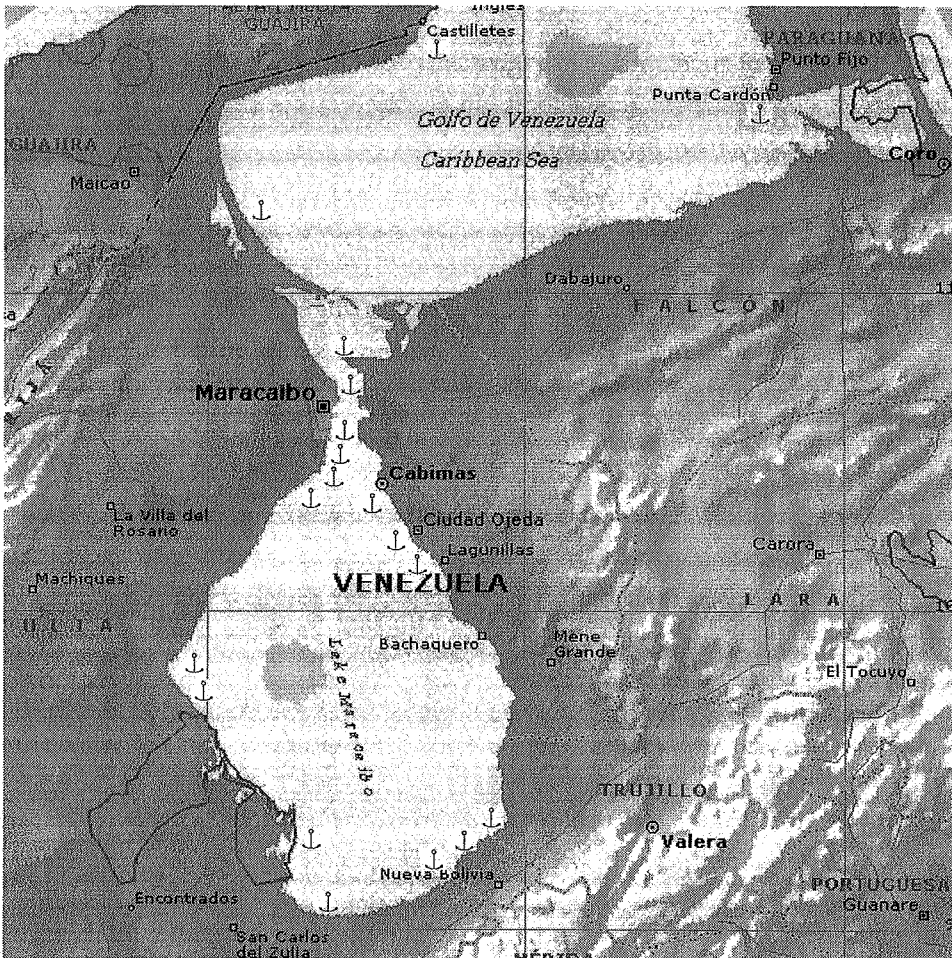
figure 1-2: Overview of cities and neighbouring ports

The economical growth of commercial oil drilling from 1917 until present times is described in appendix-1 (Economical growth, page 2). Due to the economical development and foreign investments the petroleum, natural gas/petrochemical and mining industries are still growing consistently.
The development of these industries will be further discussed in appendix-1 (History of industries, page 3).

1.3.3   Problems

A forest of metal towers rise throughout nearly half of the 12,000 square km of Lake Maracaibo. This is a result of 90 years continued extraction of crude oil in South America's largest oil field. The lake, connected to the Caribbean Sea via a canal with the Gulf of Venezuela, suffers the multiple contaminations of salinity, oil spills

and sewage.

Biologist Gonzalo Godoy, president of the regional management commission, said; "The lake is very contaminated, but stable [http://www.gasandoil.com]. Its waters are renewed every five years and it is recoverable as a source of sustainable development for the millions of inhabitants living in the Maracaibo basin".

Fifty years ago, when the oil industry deemed it necessary to create a route for ocean going vessels, a navigation canal was dredged. figure 1-3 shows the access channel.
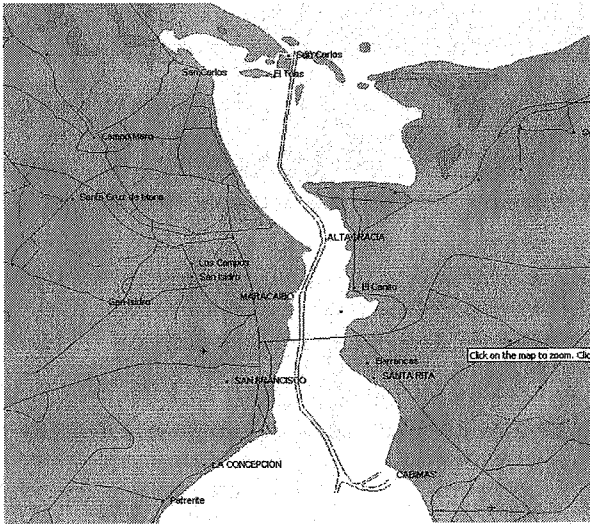
figure 1-3: Location of dredged channel

The salt water slowly intruded the lake through the channel. Problems caused by the salinity of the lake, contamination caused by the oil industry and the sewage which is dumped into the lake are discussed in appendix-1 (Problems, page 9).

1.3.4   Future plans

Environmental progress

To clean up the lake in the first half of the 21st century, so that its shoreline can be enjoyed and its water can be used for irrigation, requires three steps:

1.   The closure of the current navigation canal would reduce salinity within just a few years and would move the heavier, oxygen-rich water to the lake's depths.

2.   Moving the petroleum shipment operations to the sea coast, building sewage treatment plants in at least six lakeshore cities, and thereby reducing oil spills and the flow of wastewater from industry, farming and livestock into the lake.

3.   It is essential to control deforestation and agricultural expansion because they produce runoff into the rivers that feed the lake.

Economical development in the future

The state oil company of Venezuela, PDVSA, has begun a five year initiative that aims to optimize the country's oil production. This initiative is a response to the increasing global demand.

The goal is to increase the oil production from the current 3.2 million barrels a day to 5 million barrels a day in 2009. To produce this amount of oil, 3800 new wells will be needed, 5000 jobs will be needed and more than 100 rigs need to be operational [http://www.oilonline.com].

Much of this activity will be onshore-focused and will involve heavy oil operations. The PDVSA has emphasized that the offshore activity will play a key role in the country's future. Although Venezuela's offshore acreage has been relatively unexplored, with only around 100 wells drilled to date, the company believes the offshore holds huge potential with possible reserves in the range of 18 billion barrels of oil and 95 trillion cubic feet (tcf) of gas. The PDVSA was licensing some of its offshore areas in September or October 2004, beginning with around seven or eight blocks in the Gulf of Venezuela.

An important issue for the PDVSA at the moment and what it hopes will galvanize the country's future development is gas. With the growing gas demand in the US and fact that Venezuela is relatively nearby, the country has been more than eager to develop gas projects. Much of the country's gas supply presently lay off its east coast in a five-block sector known as Plataforma Venezuela Deltana. This offshore location south east of Trinidad is estimated to hold 38 tcf.

When gas is extracted from the Gulf of Venezuela it will be piped to a future Liquefied Natural Gas (LNG) plant on 'Zona Portuaria Simon Bolivar'. The LNG plant is not part of this feasibility study. Only a possible location is assumed on the island of Zapara.

Because of the large coal reserves in the mines of Venezuela, the production of coal can be increased. This can only be done when a deepwater port is available to provide greater depth for bigger bulk carriers. The present level of production is about 10 million tons and the prediction for phase-2 is 24 million tons of coal. Venezuela wants to increase the country's export production in response to an increasing global demand. The country can generate an overall wealth by expanding and promoting its natural resources.

The new deepwater port and its facilities will be able to facilitate larger vessels in 'Zona Portuaria Simon Bolivar'. This offers great opportunities for the different economical sectors. Especially the coal mining industry will benefit from this situation due to the expected increase in production.

Enlargement of the ship size will enable the petroleum industry to sell its crude oil to refineries with deepwater ports all over the world.

The strengthened market position in the future of the new container port and the import of cereals will lead to a new attractive location for import and export. All the business at the south and east coast of Lake Maracaibo should re-route their goods from Puerto Cabello or La Guaira to the new terminals at 'Zona Portuaria Simon Bolivar'.

The site location of 'Zona Portuaria Simon Bolivar' on Zapara Island and the island of Pájaros is determined by the following facts. Zapara Island and the island of Pájaros are situated directly next to the navigation channel. One of the most important commodity flows is coal. The coal mines, which produce most of the exported coal, are located in west Venezuela. The transportation costs will be low due to the short distance from the mines to the coal terminal. Another important commodity is oil. The production facilities will not be moved to 'Zona Portuaria Simon Bolivar' but stay at their present locations. Only storage facilities for the oil and petrochemical products will be placed on Zapara. Mooring facilities for the coal carriers and oil tankers will be constructed nearby the terminals.

The production location of the oil lie somewhat further than the coal mines but the difference is not too big. The difference in transport costs between the two commodities will be minimal. When the present harbour facilities in Tablazo Bay and Lake Maracaibo will be relocated at 'Zona Portuaria Simon Bolivar', the maintenance dredging of the access channel from the island of Pájaros up to Maracaibo can be stopped until the depth of the channel is not sufficient anymore for the barges to sail in due to sedimentation. It is predicted by Alkyon that this will take 6 or 7 years to occur.

Less channel depth will result in ecological improvement for Lake Maracaibo because of the decrease of salinity in the Lake.

The convergence of all the cargo flows, such as oil, coal, iron ore, petrochemicals, cement, grain, other dry bulk, break bulk and containers, to 'Zona Portuaria Simon Bolivar' will increase the feasibility of this project.

1.4   Structure of feasibility study

In the next chapter 2, the data relating to the project site like geography, site conditions, cargo flows and ship sizes are described. Chapter 3 covers the modal split for the different commodities. On the basis of these data the dimensions are calculated of the quay length, terminal areas and channel dimensions in chapter 4. As a result of the dimensions and assumptions, four rough lay-outs have been designed for phase-1 in the year 2015 and phase-2 in the year 2025. These alternatives differ in barge channel location, terminal location, basin location, landfill/dredging ratio, construction works, morphology etc.

2 Data relating to the project

2.1 Introduction

In this chapter the data collection for the project site is described. The data is divided into four categories and described in section 2.2-2.5. The categories are economy, geography, site conditions and the history and developments of the industries.

Most of the data, concerning the feasibility study of the deepwater port at the island of Pájaros, is collected from [Masterplan Puerto America Alkyon, June 2002].

2.2 Economy

The historical growth of the Gross Domestic Product (GDP) of Venezuela fluctuated a lot. The GDP is strongly related to the fluctuations in the crude oil prices. The average annual growth of the GDP, over the period 1983-1993 was 3.1 percent. Due to the growth of the population, the GDP per capita increased with 0.6 percent. During the following years, 1993-2003, the GDP decreased with 0.4 percent annually which resulted in a decrease of the GDP per capita of 2.3 percent. Decreasing oil prices, the policy of Venezuela to a have a low oil production strategy like OPEC is an explanation of this decrease. The neighbouring countries in Latin America and the Caribbean performed better and produced steady rates of 3.5 percent increase in GDP. These developments have lead to negative growth for the overall economy and resulted in a strong reduction in the construction market. Because of this reason the demand for cement decreased, leading to a shift in exports in the Port of Maracaibo.

In 1998 most of the experts expected a recovery in the economy in the nearby future and the Economist Intelligence Unit (EIU) foresaw an improvement of the economic situation, resulting in growth rates of about 4 percent for 2000 and 2001.

At the beginning of Appendix-2 (Economy, page 2), the growth rate of the GDP from March 1995 until March 2004 will be described and then the development of the GDP for a low, medium and high scenario will be described.

2.3 Geography

2.3.1 Present situation

In the early 50s the navigation channel was dredged, 36 ft deep. Simultaneously the eastern breakwater, called the Malecon Oriental, was constructed. From the year 1957 to 1963 the channel was deepened to 45 ft and widened to a two lane channel. The dimensions of the outer channel were 300 m and the inner dimensions were 240 m. The overall length of the navigation channel was 100 km.

In 1974 a sand dam was build between the former island of San Carlos and the former island of San Bernardo. The goal of this project was to decrease the cross currents in the channel just south of the island of Zapara. Due to this project the currents went more parallel to the channel axis. This caused significant erosion to the eastern part of the island of San Bernardo. For this reason the western Breakwater, called Malecon

Occidental, was constructed to keep the erosion under control and present situation stable. Appendix-2 (bathymetry) shows the bathymetry for the present situation.

The vegetation all around the project site consists mainly of mangroves and the water depth in the surrounding area is shallow. Appendix-2 (Map of the site location) shows the map of the area nearby the project site and a picture of the mangroves.

2.3.2   Surrounding ports and terminals

The port of Maracaibo is one of the biggest in Venezuela, together with Puerto Cabello, La Guaira, Guanta and Puerto Ordaz, located on the Orinoco river east in the country. Appendix-2 (Port locations) shows these port locations. The big distances between the ports every port has its own hinterland area. Almost all the same commodities will be handled by these ports due to this reason. For instance, wheat and maze imported from Canada and the US is shipped in consignments of 30,000 tons and partly unloaded in Puerto Cabello (20,000 tons), Guanta (5,000 tons) and the remaining 5,000 tons is unloaded in Maracaibo.

The port of Maracaibo has a capability of handling vessels at the 8 berths with an overall quay length of 1400 m. Maracaibo Port has a total of 23.400 m^2 of land with warehouses on it and 78.700 m^2 of open storage. figure 2-1 shows the port of Maracaibo.
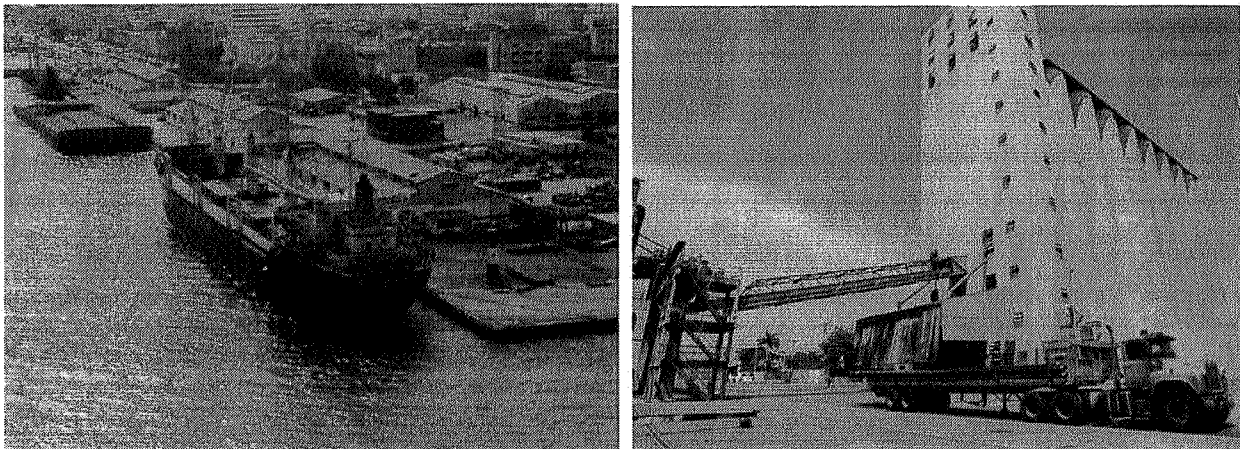
figure 2-1: Port of Maracaibo.

The maximum draft of the vessels is 6.4 metres in the south berth and 11.3 metres at the floating dock.

The port of Maracaibo has an organization that comes close to a Landlord Port, the port authority owns the land and gives concessions to private sector companies for provisions of cargo handling and storage service. All the areas are leased to private companies. These are mostly small companies, which act on their own and which are for instance operating in a number of small container yards. These containers are stacked mostly by reachstackers or frontloaders. The port of Maracaibo owns a grain silo also shown in figure 2-1.

The port of Maracaibo and the industrial terminals located around Lake Maracaibo are playing a dominant role in the export and import for the western part of Venezuela.

The port operates in a modern working regime of 24 hours a day and 7 days a week.

An overview of the most important ports, terminals and industrial facilities is presented in table 2-1. This table also shows the distance to 'Zona Portuaria Simon Bolivar'.

Industrial sector	Distance to SB (km)	Sign
Cement:		
Cementos Catatumbo Plant	120 (by road)	Cem-1
Cementos Catatumbo Terminal	32 (straight)	Cem-1T
Vencemos Mara Plant	50 (by road)	Cem-2
Vencemos Mara Terminal	35 (straight)	Cem-T2
Cemento Surandino Plant	192 (by road)	Cem-3
Cemento Surandino Terminal		Cem-3T
Coal:		
Guasare Mining area	85 (by road)	Coal-1
Guajira mining area	135 (by road)	Coal-1
Tachira mining area	435 (by road)	Coal-2
Norte Santander mining area	350 (by road)	Coal-3
Casigua mining area	87 (straight)	Coal-4
Santa Cruz de Mare Terminal	15 (straight)	Coal-T1
San Francisco Terminal	32 (straight)	Coal-T2
Palmarejo Terminal	41 (straight)	Coal-T3
Grain/Cereals silo	55 (by road)	Gr/Co
Petrochemicals:		
Pequiven	20 (straight)	Chem-1
Pralca-Etoxyl	34 (straight)	Chem-2
Crude oil and Petroleum products:		
Terminal Puerto Miranda	15 (straight)	Oil-T1
Terminal La Salina	44 (straight)	Oil-T2
Terminal Bajo Grande/ Punta de Palmas	44 (straight)	Oil-T3
Containers and breakbulk from Maracaibo	50 (by road)	Gr/Co

table 2-1: General location of the facilities.

All of the above mentioned locations are provided with signs in appendix-2 (General location of the facilities).

2.3.3   The hinterland of Maracaibo

As presented in chapter-1, Zulia state is the biggest part of western Venezuela. The hinterland of the port of Maracaibo is restricted to the area around Maracaibo and the Straight of Maracaibo with the petrochemical industries. These industries can be reached by the bridge across the channel. The rest of the industries, at the east side of Venezuela, are reached by Puerto Cabello and La Guaira.

A total of 682 km railway track is available. A big stretch of the track is badly neglected. Nowadays 248 km of the existing railway system is privately owned. The condition of the track is improved. New hinterland

connections are required for a possible dedicated rail track for the coal transport between the mines and the coal terminal, transportation of containers and other cargo in the future.

A railway service for passengers is non existent. However, a National Railways Plan, intended to provide a significant railway system, has been initiated in 2001.

The total length of highways is estimated at 97.000 km in 1997 of which 33.000 was paved. Appendix-2 (roads nearby the Maracaibo city) shows the roads nearby the Maracaibo city and around Lake Maracaibo. Cargo can be transported on these paved main roads. The only problem will be the connection from the present infra structure to the new port area on the Island of Pájaros.

If the services in the competitive ports are better than in Maracaibo, the hinterland will shift towards them.

All this applies in particular to the container throughput of the port. At this moment only 6 percent of the total throughput of containers is handled in the port of Maracaibo. If the 'Zona Portuaria Simon Bolivar' project will be finished, the hinterland will be enlarged to a very big area. This will be all of Venezuela west of the imaginary line from north to south across Barguisimeto. Because of this hinterland extension, almost 20 percent of the container throughput will be handled in 'Zona Portuaria Simon Bolivar'. Also other products will increase there percentages. These enlargements will lead to a decrease in inland transportation costs.

The deepwater port 'Zona Portuaria Simon Bolivar' will be able to accommodate much larger vessels than in present times. This will bring Maracaibo and Venezuela into the world markets all over the world. This will be especially the case for the coal market and the world wide container shipping industry.

2.4   Site conditions

Developments due to earlier interventions:

To reduce the velocity of the cross current in the dredged channel nearby the island of San Bernardo and Zapara a sand dam has been constructed between the two islands because the natural channel crossed the dredged channel. Due to the construction of the sand dam between the 'former' islands of San Carlos and San Bernardo, the size of the island of San Bernardo has reduced tremendously. As a result the northern part of San Bernardo eroded. For this reason the Malecon Occidental dam has been build.

To stop the large sedimentation of the channel caused by the west going sand transport due to the average north-western wind direction, the Malecon Oriental has been build. Since then the the northern coastline of Zapara has moved over a distance of 350 metre in seaward direction. A number of coastal defense structures have been build between1978 and 1985. The defense structures have stabilized the coastline.

A more profound description is given in appendix-2 (Site conditions, page 30).

Climate conditions:

Venezuela lies within the tropics, its climate varies from tropical humid to alpine, depending on the elevation, topography, and the direction and intensity of prevailing winds. Most of the country has a distinct rainy season (430 millimetres). The rainy period (May through November) is commonly referred to as winter and the remainder of the year as summer. The yearly averages ranging periods in the project area are between 26° C and 28° C. A more profound description is given in appendix-2 (Climate conditions, page 30).

Tides and water levels:

All the different tidal levels are measured in Malecon and refer to Zero Zapara Level. Malecon is the northern part of Zapara Island. All calculated depths in this study are related to Zero Zapara Level.

Table 2-2 shows the tidal levels in Malecon, just north of Zapara.

Tidal level		Height with respect to Zero Zapara (m)
Mean high water Spring	MHWS	1.41
Mean high water	MHW	1.32
Mean sea level	MSL	0.88
Mean Low Water	MLW	0.44
Mean Low Water Spring	MLWS	0.23
Mean Monthly minimum	MMM	0.02
Zero Zapara	ZZ	0.00

Table 2-2: Tidal levels in Malecon

A more profound description is given in appendix-2 (Tides and water levels, page 32).

Currents:

The information on currents in the Tablazo Bay and the southern part of the Gulf of Venezuela is obtained by the tidal wave propagation simulation.

For the San Bernardo area during Spring tide, the results of the detailed model are presented in the form of time series of water levels, currents and velocity vector fields. The pictures in figure-5 (appendix-2) shows the velocity vector field for maximum flood and ebb during spring tide conditions. The maximum flow velocity is during flood and is approximately 1.2-1.4 m/s.

This velocity only occurs in the middle of the channel between Zapara and San Carlos.

All remaining velocities are described in appendix-2 (Currents, page 32).

Wind:

In the northern regions of the Gulf of Venezuela, most of the wind conditions are trade winds from east. These dominant trade winds generally blow between the directions north east and south east for all year season. figure 2-2 shows the windrose in the Gulf of Venezuela for all year season.
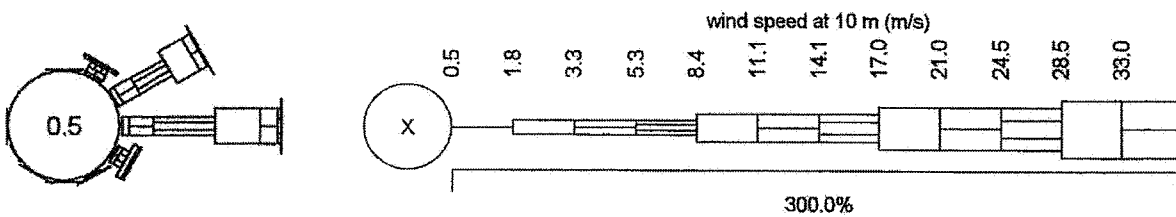
figure 2-2: Windrose in the Gulf of Venezuela for all year season [Masterplan 'Puerto America', Alkyon 2002].

A more profound description with a table of the probability of accidence of wind in the given classes for all year conditions, is given in appendix-2 (Wind, page 34).

Waves:

The wave climate for the location at the seaward end of the access channel, approximately 24 km from the island of Zapara is shown in figure 2-3.
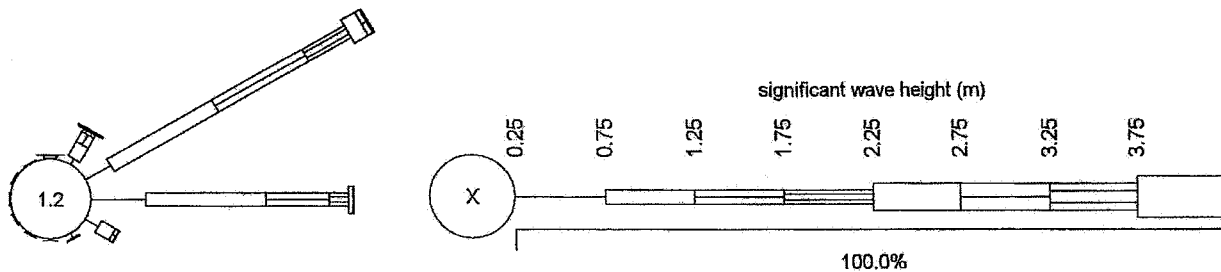
figure 2-3: Wave climate for the location at the seaward end of the access channel [Masterplan 'Puerto America', Alkyon 2002].

A more profound description of several wave climates along the access channel and just north of the Zapara and San Bernardo with frequency of occurrence tables are given in appendix-2, page 37).

Geotechnical data:

The soil layers in the Gulf of Venezuela North of San Bernardo and Zapara consist of fine to very fine sand. It contains silty sand and clay with high percentages of fines. Dredged material in this area will be good dredgeable but cannot be used for reclamation purposes. The soil conditions get coarser when you get closer to the islands San Bernardo or Zapara. The soil close to and in the channel consists of very fine material such as silt and clayey silt. It is therefore not useable for land reclamation.

A natural channel was running through Tablazo Bay, before the present channel has been dredged. The original course of this channel was east of the Island of Pescaderos. During these times, at the inner bend of the channel a lot of sediment was settled. This happened east and north of Pescaderos. The sedimentation area that we are talking of is more than 2.25 km^2. The upper part in this region has a layer of approximately 4 m. and consists mostly of sand with a very low percentage of fines.

Suitable material for reclamation purposes can be gained from this area if the quality somewhere else is not sufficient enough. It is therefore useable for land reclamation purposes.

A more profound description for several locations is given in appendix-2 (Geotechnical data, page 40).

Sedimentation:

The measured sedimentation volumes, between 1977 and 1987 along the access channel, is as follows:

Along the inner channel from the future turning circle (discussed in chapter 5) and southwards is $4.0*10^6$ m^3/y been measured due to maintenance dredging.

Along the outer channel between the turning circle and the end of the channel section northwards, $2.9*10^6$ m^3/y has been measured.

A more profound description of the quantities and sediment characteristics along the access channel is given in appendix-2 (Geotechnical data, page 41).

2.5   History and developments of the industries

2.5.1   Introduction

The present situation of the Port of Maracaibo and the industrial terminals situated around the Lake of Maracaibo is as follows:

The industrial terminals play a dominant role for the sea-born transport of the Western part of Venezuela. These ports consist of a common user port in the city of Maracaibo, industrial terminals located nearby the Strait of Maracaibo and the Port of La Ceiba. The total trade and traffic volumes in 1999 consisted of 1154 calls by tankers and 1347 calls by dry cargo ships. The cargo flows of $60.5*10^6$ Mton dominated by crude oil, coal, oil products, petro-chemicals and cement production related goods.

The 'Zona Portuaria Simon Bolivar' project causes the relocation of all terminals from their present location at the

Strait of Lake Maracaibo to a new location on the Island of Pájaros, Zapara and San Bernardo.

For some industrial sectors the relocation will impact on their long term decisions on expansion, allocation or contraction of production and consumption.

The impact on these industrial sectors is discussed in appendix-2 (Impact industrial sectors, page 3).

The future developments will be uncertain. For this reason cargo flows have been reflected as a "high", "medium" and a "low" scenario. The forecast presented as the medium scenario for the years 2005, 2007, 2010, 2015 and 2025 is assumed to be most likely. This is a basic assumption for the feasibility study.

The history of all the different kind of industries until 1998, the forecast until 2025 and the future vessel sizes in 'Zona Portuaria Simon Bolivar' will be discussed in the following sections.

2.5.2   Cargo flows

The history and the forecasts of the following industries are discussed in appendix-2 (History and development of cargo flows, page 5):

- Containers
- General cargo
- Crude oil/Petroleum
- Coal
- Cereals
- Petrochemicals
- Cement related products
- Other dry bulk

A summary of the forecasts per industry are discussed in section 2.5.4.

2.5.3   Future vessel sizes and number of ship calls per industry

The envisaged future vessel sizes and number of ship calls per industry are discussed in appendix-2 (Future vessel sizes and number of future ship calls, page 19). A summary of the future vessel sizes and the number of ship calls per industry are also discussed in section 2.5.4.

2.5.4   Summary of all the cargo flows and vessel movements

It is expected that all the cargo flows together will increase to an amount to $100*10^6$ ton per year in 2018 and to $107*10^6$ ton in the year 2028.

The amount of vessels that will call 'Zona Portuaria Simon Bolivar' will increase from 2200 nowadays to approximately 4000 in 2018 and 4700 in the year 2028. These assumptions are all based on the fact that the port will be dredged to 47 ft of depth (presented in section 4.4.1).

Table 2-3 shows a summary of all the cargo flows and vessel movements in the future for the medium scenario. The forecast of the cargo flows for the different phases are based on vessel with a maximum draft of 42 ft. This results in less vessel calls if larger vessels will call the deepwater port.

Cargo flows: Medium scenario		Dim.			
			phase-2	phase-3	yr.2028
1a	Containers	(1000 TEU)	142	790	1288
1b	Containers	(1000 tons)	1184	6581	10720
2	Other general cargo	(1000 tons)	574	622	687
3	Cereals	(1000 tons)	875	1331	1787
4a	Crude oil	(1000 m^3)	59776	65580	65580
4b	Crude oil	(1000 tons)	53798	59022	59022
5a	Oil products	(1000 m^3)	2000	2000	2000
5b	Oil products	(1000 tons)	1800	1800	1800
6	Coal	(1000 tons)	16700	24000	26000
7	Petro-chemicals	(1000 m^3)	1390	1262	1134
8	Cement related	(1000 tons)	943	1373	2237
9	Other dry bulk	(1000 tons)	401	418	438
No. of ships [a] based on maximum 42 ft draft					
1	Container ships	-	650	1573	2002
2	General cargo ships	-	234	254	280
3	Grain carriers	-	144	182	245
4	Crude oil carriers	-	937	1028	1028
5	Product carriers	-	143	143	143
6	Coal carriers	-	277	398	431
7	Chemical tankers	-	99	79	65
8	Bulk carriers cement	-	157	229	373
9	Other dry bulk carriers	-	123	150	193

Note a) The movements of the non-cargo carrying ships are not included.

Table 2-3: Summary of all the future cargo flows and vessel movements [Masterplan 'Puerto America', Alkyon 2002].

2.5.5   Other activities

The other activities are a home-base function for the fishery industry, shipbuilding and ship repairs, processing activities or cruise shipping. The possibility of shipbuilding and ship repairs is not likely in the nearby future. Nowadays it is too early to develop a plan for such activities. A location for the jetty of the cruise ship is reserved in the port (presented in chapter 5). A new fishery port will be constructed for the local fishermen, living on the island of Zapara. The fishery port is part of the feasibility study of 'Zona Portuaria Simon Bolivar'.

3 Modal split

3.1 Introduction

The development of the new outer port at the islands of San Bernardo and Zapara will greatly influence the transportation modes of each of the sectors that are presently making use of Puerto Maracaibo and private terminals.

This chapter describes the different transport modes (barge, road, rail and pipeline) of the following sectors: container, general cargo, oil, coal, cereal, petro-chemical, cement and other dry bulk.

For the new situation the transport modes of the different plants and sectors and the accompanying distances are presented. The change in port location from the 'Puerto America' project site into the 'Zona Portuaria Simon Bolivar' project site does not cause a modal shift. The hinterland connections are almost the same, accept the new connection from San Bernardo to the island of Zapara. Due to these two facts, no changes in the modal split of the 'Zona Portuaria Simon Bolivar' project will occur in comparison to the old project. At the end of appendix-3 (table-8), a summary of the modal split in quantities for all products movements is shown for phase-3.

3.2 Container throughput

A barge system will be developed when the lake will be closed. This system will be developed especially for the container transport between the terminals around the lake and the new port. Based on the population forecast, densities in the hinterland of Maracaibo, 50% of the future container throughput will be transported by barge and the other 50% by truck. These trucks can be loaded by a maximum amount of weight of 30 ton. The barge system includes container barges with a capacity of 100 TEU. 1/3 of containers in TEU is 20' and 2/3 of containers in TEU is 40'. The average distance from 'Zona Portuaria Simon Bolivar' to the terminals round the lake is approximately 100 km and the transportation speed is about 10km per hour for a barge. The time for a complete roundtrip, including loading and unloading of the barge, is one full day. The average distance by truck is 50 km.

The container terminal at the Island of Pájaros will be connected to Maracaibo by road. It is also possible to make a connection to Maracaibo by railroad. The railroad could be developed from the mines in Rio Guasare to San Bernardo. This is not envisaged in the model split.

Appendix-3 (table-1) shows a summary of the modal split.

3.3 General cargo throughput

The breakbulk and general cargo throughput varies in sizes and weight. Also the physical appearance of breakbulk changes all the time. Because of the relatively small distances, mainly to Maracaibo, it is foreseen that the future flows of breakbulk shall be transported by truck.

Appendix-3 (table-2) shows a summary of the modal split.

3.4 Crude oil and petroleum throughput

The forecast for the total throughput of crude oils is $66*10^6$ m³ during phase-3 up to the year 2028. This quantity is exported from 'Zona Portuaria Simon Bolivar' to different overseas destinations. There will be no

import of crude oils at the 'Zona Portuaria Simon Bolivar' terminal. Only storage facilities are located on the island of Zapara. All crude oil and petroleum production facilities in the Maracaibo area, like the Puerto Miranda facility, will stay at their present location.

There are different ways to transfer crude oils and other materials from the existing terminals to 'Zona Portuaria Simon Bolivar'. The characteristics of the materials determine the transportation possibilities. Nowadays the most reliable way is to transport these goods overland by pipelines. Transportation by underwater pipelines, above water pipelines and barges is also possible. Due to the limited depth in Lake Maracaibo, the barges have a limited carrying capacity of 2500 metric tons. In Table 3-1 the quantities from and to 'Zona Portuaria Simon Bolivar' are presented. This figure also includes the transport of crude oil and petroleum products by barge. The average distance to the existing terminals is about 50 to 60 km. With an average sailing speed of 10 km/h, a service time for loading or unloading of 4.7 hours (see section 4.2.3) and all barges are 80 percent of the year operational, the amount of barges that is necessary during phase-3 will be:

- 13 barges for boscan.
- 6 barges for black, white and refrigerated products and chemical imports.
- 1 barge for asphalt.

Appendix-3 (table-3) shows a summary of the modal split.

Total amounts of products	Ton per yr. in phase-3	Type of product
Import		
Fuel select	374,236	Oil (black)
RC 250/ Diluent	53,781	Oil (black)
Gasoil	73,064	Oil (white)
Styrene	31,700	Petrochemical
Cyclohexane	2,984	Petrochemical
Propane	166,000	Petrochemical (refrigerated)
Butene-1	9,851	Petrochemical (refrigerated)
Total Import	711,616	
Export		
Boscan	8,795,906	Oil, crude, heated
Asphalt	288,272	Oil, asphalt, heated
Gasoline	512,229	Oil (white)
MGO	27,054	Oil (white)
IFO 180/380	127.125	Oil (black)
Butane	84,000	Petrochemical (refrigerated)
Total Export	9,834,586	

Table 3-1: Types and quantities transported by Barges [Masterplan 'Puerto America', Alkyon 2002].

3.5   Coal throughput

In the last few years, the production volumes increased gradually from less than $1*10^6$ ton per year to about $8*10^6$ ton at present, all for export. Only small quantities are consumed locally. A barge system in the South West of the Lake will transport all coal from the Tachira area and the area of Norte Santander to 'Zona

Portuaria Simon Bolivar'. When all terminals are realized on 'Zona Portuaria Simon Bolivar', a total of $24*10^6$ tons is expected to go through 'Zona Portuaria Simon Bolivar' during phase-3. It is forecasted that $4*10^6$ ton of coal is transported by barge and the rest by railroad based on the origin of coal mining areas. This is based on the medium growth scenario during phase-3.

The distance they will have to sail is approximately 120 km. With an average sailing speed of 10 km/hr, a service time for loading of 2 hours and unloading of 5 hours (see section 4.2.4) and all barges are 90 percent of the year operational, the amount of barges that are necessary during phase-3 will be 6 with a capacity of 3.500 dwt. Table 3-2 shows the dimensions of such a coal barge.

Principal dimensions of the barge	
Dead weight	3500 dwt
Length	79.2 m
Width	20.5 m
Depth	5.6 m
Draught	3.5 m

Table 3-2: Principal dimensions coal barge.

Appendix-3 (table-4) shows a summary of the modal split.

3.6   Cereals throughput

Nowadays all of the grain and cereals are imported via the port of Maracaibo. The imports are mainly maize, wheat, barley and soya beans. The companies that imports grain and cereals are located all over the South West of Lake Maracaibo. This distance from the Rosario de Perija area to 'Zona Portuaria Simon Bolivar' is approximately 50 to 60 km.

The throughputs are based on the medium scenario of the trade and traffic forecast. Table 3-3 shows the throughputs.

Year	1999	2008	2010	2013	2018	2028
Throughput (1000 ton)	557	660	875	1146	1331	1787

Table 3-3: Future throughput Cereals 'Zona Portuaria Simon Bolivar' [Masterplan 'Puerto America', Alkyon 2002].

When the expected traffic, caused by the new facilities on 'Zona Portuaria Simon Bolivar', is predicted, the transportation by barge will be approximately 50% and the other 50% is envisaged for transportation by truck. In the new situation, the transportation distance is 120 km on average. This is approximately 60 km more than before. Also with an average sailing speed of 10 km/hr, a service time for loading of 10 hours and unloading of 5 hours (see section 4.2.5) and all barges are 90 percent of the year operational, the amount of 2 barges with a capacity of 3.500 dwt will be necessary during phase-3.

Appendix-3 (table 5) shows a summary of the modal split.

3.7   Petrochemicals throughput

As mentioned before, the petro chemical industries in the Maracaibo hinterland are located in the El Tablazo chemical complex and concern Pequiven El Tablazo and Pralca Etoxyl. Due to the new port 'Zona Portuaria

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Simon Bolivar', the product mix of these sites will be changing from bulk chemicals to speciality chemicals. The closure of the Maracaibo Lake leads to accessibility of the El Tablazo complex of barge tankers with a maximum capacity of 2500 dwt.

The prediction of the future export capacity of chemicals from El Tablazo is shown in Table 3-4.

Product	Format	Transport direction	Transport ton per year
Plastics	solid (bags)	Export	328.000
PVOH	solid (bags)	Export	293.333
PVAC	solid (bags)	Export	293.333
Propylene	refrigerated liquid	Export	105.000
Propylene trimer/tetramer	liquid	Export	80.000
EDC/MVC	liquid	Export	22.000
Acetic acid (Liquid)	liquid	Export	12.016

Table 3-4: Estimate of future export of from El Tablazo after shift to production of speciality chemicals [Masterplan 'Puerto America', Alkyon 2002].

The forecast for the containerized cargo includes all solids in bags and solids in bulk that will be exported through 'Zona Portuaria Simon Bolivar'. The construction of a pipeline system is too expensive due to the fact that the quantity of the liquids is too small. The export of fine chemicals will be done by barges. It is envisaged that fine chemicals are exported directly to the clients. The local demand will be served by trucks directly from the plants. This means that no transportation is predicted directly for the liquid petrochemical products through 'Zona Portuaria Simon Bolivar'.

In contrary, imports for the chemical production are envisaged through 'Zona Portuaria Simon Bolivar'. This will be a total amount of 295.000 tons per year. This quantity is derived from the petrochemical products shown in Table 3-1. Because of the small quantity it can be transported with one chemical barge through the year. The tanker barge that will be used must be suitable for both the imported chemicals and white oil products. This is possible when the tanks on the tanker can be filled separately.

3.8   Cement products throughput

In the Maracaibo port hinterland, cement is produced by Vencemos Mara, Cementos Catatumbo and Cemento Surandino. All of these ship a considerable share of their inputs and outputs through the respective dedicated terminals.

In the future, it is expected that exports will mainly originate from the Cementos Catatumbo, since the raw material at Isla de Toas will be exhausted. It is feasible that the capacity will be expanded in the neighbourhood of the existing Catatumbo plant, by one of the cement industrial groups. This new plant will be oriented towards the new port. For Cementos Catatumbo this means that they will have to shift from exports of cement in bags to cement in bulk. For Cementos Catatumbo and the assumed new plant, implementing the new port system will imply that the clinker and cement will no longer be transported to the San Francisco terminal and the storage in Puerto Maracaibo, but will be transported directly to 'Zona Portuaria Simon Bolivar' by road.

From the Surandino plant, the import of gypsum will switch from direct vessel loading and unloading to direct truck transport to 'Zona Portuaria Simon Bolivar'. The transport will be by truck since the annual quantities are

small: 25,000 ton per year. An overview of the amount of traffic forecast and summary of the modal split is presented in Appendix-3 (table 6).

3.9   Other dry bulk throughput

This group of commodities includes bulk shipments, at present going through the port of Maracaibo, such as shipments of products like baryte and bentonite and some shipments of salt. There are also some shipments presently going through the terminal of La Ceiba. The volumes shipped through Maracaibo, however, are small.

The present quantities are 32,000 ton of Baryte and Bentonite. For phase-3, the envisaged amounts are 44,000 of Baryte and Bentonite and 300,000 tons of Salt. The Baryte and Bentonite are transported by truck, with an average transportation distance of 50 km. The future Salt streams are expected to be transported by barge over a distance of approximate 30 km. Because of the small quantity it can also be transported with one barge through the year. Appendix-3 shows a summary of the modal split (table 7).

3.10   Transportation modes

The following presents an overview of the modal split of the different type of cargoes and the corresponding quantities from the traffic forecast. Analysis of US maritime statistic data of 3690 barge tank vessels indicates that the closure of the channel up to a maximum of 15 feet implicates that the maximum possible barge tankers are those with a capacity up to 2,500 DWT maximum [Masterplan 'Puerto America', Alkyon 2002]. For the transportation of cargo over the roads, the maximum allowable tonnage by truck is 30 ton.

The following Table 3-5 shows an overview of the total ton transported for each commodity and the mode of transport.

Capacity of coal barges	3500	ton
Capacity of barges for containers	100	TEU/barge
Capacity of remaining barges	2500	ton
Containers per TEU	TEU/1.6	
Capacity of trucks	15	ton
Capacity of trucks	1.5	TEU/truck
Capacity of trains	100	ton/wagon
Cement in bulk	50%	
Cement in bags	50%	

Table 3-5: Required capacity per transportation mode.

4 Number of berths, terminal areas & wet infrastructure

4.1 Introduction

In chapter 3 is the modal split discussed. Together with the loading and unloading rates of the different commodities, vessel dimensions, loading capacity etc, the calculation of the quay length for all different terminal facilities are calculated. This is described in this chapter.

These lengths have been estimated with these data and the queuing theory in section 4.2. In the following sections, the development of cargo throughput in the year 2028 will be the basic assumption for the terminal area calculations. The terminal dimensions will be evaluated in section 4.3 and at the end this chapter in section 4.4 the dimensions of the water area components will be determined. In the next chapter the location of the different terminals and the positioning of the barge terminal will be determined.

4.2 Number of berths and quay length

In this section the number of berths and the following quay length needed for the future throughput will be determined for all the individual commodities. The number of berths and the quay length will be determined for the sea going vessels and the barges in three phases: In phase-1 (2008) only a small coal terminal will be operational. Phase-2 is the beginning of the year 2010 where all the remaining terminals need to be operational and the coal throughput is increased in relation to phase-1. Phase-3 is the beginning of the year 2018 and all throughput for the different commodities have increased in relation to phase-2.

The Panamax container vessels that will visit 'Zona Portuaria Simon Bolivar' have an average draught of approximately 42 ft. The bulk carriers of the western coal importers (90% of the Venezuelan export locations) with a capacity of 170.000 dwt have an average draught of about 59 ft. In the case of 59 ft, the dredging costs are very high. To evaluate the most economical situation for minimum dredging costs and maximum profit for Venezuela, a financial and economical analysis has to be made with an Economic Internal Rate of Return (EIRR) and the Net Present Value per draft alternative. This is not included in this feasibility study.

No tidal window is assumed in this feasibility study (see section 4.4.1) and for that reason manual calculations can be performed for the required number of berths and final quay length by the queuing theory.

During the first rough estimations for the number of berths and quay length, a basin depth of 47 ft (see section 4.4.1) has been assumed with corresponding maximum load factors for the coal carriers and the oil tankers.

4.2.1 Containers

Phase-2: year 2010
The total forecasted throughput in phase-2 for 'Zona Portuaria Simon Bolivar' is about 142,000 TEU. From this quantity 2/3 is import and 1/3 is export. If the export and import is divided into full and empties, 90 percent of the import containers is full and the rest is empty. The export containers can be divided into 30 percent full and 70 percent empty.

The imported containers that will be distributed by barge is 50 percent of the total import (47,350 TEU). The other 50 percent will be transported by truck (47,350 TEU). The amount of containers, that will be exported via 'Zona Portuaria Simon Bolivar' and will be delivered by barge, covers also 50 percent of the container export (23,675 TEU). The remaining 50 percent will be transported by truck (23,675 TEU). figure 4-1shows the modal split of the container cargo for phase-2.
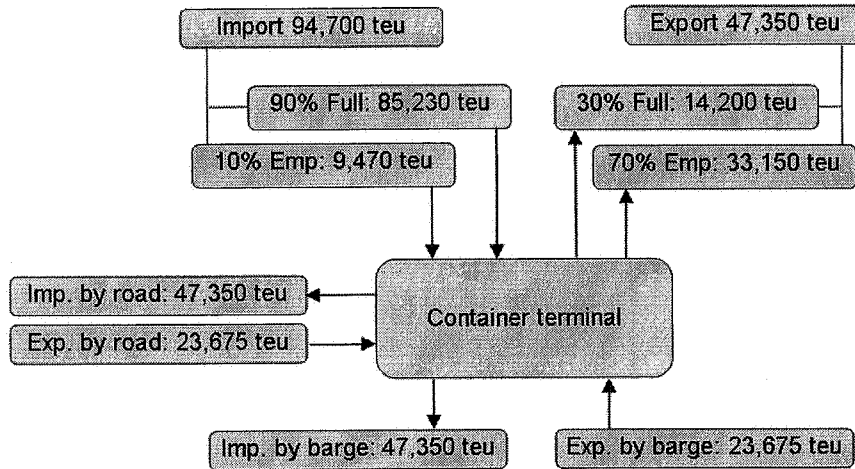
figure 4-1: Modal split container cargo phase-2 [Masterplan 'Puerto America', Alkyon 2002].

The TEU-factor $f = \frac{N20'+2 \cdot N40'}{Ntot}$. Due to the fact that 1/3 of all containers are TEU's and the rest are FEU's, the TEU- factor will be 5/3.

A description is given of the used symbols:

λ = arrival rate of the vessels

μ = service rate of customers

φ = average utilisation of the berths

The following values have been taken for the 'Zona Portuaria Simon Bolivar' container port during phase-2:

- The average additional service time for berthing and departure is about 2 hours.

- The number of cranes that will be able to work along side the vessel is two.

- These cranes can reach 25 moves in an hour.

It is forecasted that about 110,000 TEU are handled by sea going vessels with an average parcel size of 187 TEU and the rest are handled by sea going vessels with an average parcel size of 440 TEU. The vessel movements are all together 679 vessel movements with an average of 218 TEU.

The time to load and unload the containers is $\frac{(218 \cdot \frac{5}{3})}{2 \cdot 25} = 2.6$ hours per visit.

The necessary time for the vessels to sail the 44 km channel section with a maximum speed of 15 kn is 1.6 hours. This high speed is possible because it is assumed that the vessels sail with a 10 minutes notice. This means when a vessel crosses another vessel, 10 minutes in advance the vessel speed is reduced for a safe crossing. An extra 1.6 hours of service time is required for the sailing time of the vessel if the access channel is a two-way channel for container vessels (see section 4.4.2).

The total amount of average service time is 2+2.6+1.6 = 6.2 hours. Hereby is taken into account that there are no limitations in the approach and departure for the vessels.

λ = The arrival rate per hour = $\dfrac{\text{The total amount of throughput in TEU / Parcel size}}{\text{Workable hours per year}}$

$\lambda = \dfrac{(\frac{142000}{218})}{360 \cdot 24} = 0.075$ vessels/hr.

$\frac{1}{\mu}$ = the total amount of service hours per vessel = 6.2 hr.

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$$\rho = \lambda \cdot \frac{1}{\mu} = 0.467$$

The average waiting time for the container vessels from the Gulf of Venezuela in units of the average service time is assumed to be a maximum of about 15 percent.

The Erlang probability distribution function for the queue system is used. The $E_2/E_2/n$ queue system is used because of the rather regular inter arrival times and service rates.

In table-5 of [Service systems in ports and inland waterways, 2002] the average waiting time in units of average service time is presented.

The utilisation for 1 berth is 0.467. The factor weighting times in units of average service times (w/s) for one berth is much higher than 0.15.

The utilisation for 2 berths is 0.233. The factor (w/s) for two berths is 0.012. This value is much lower than the maximum of 15 percent. For that reason two berths will fulfil the necessary requirements to avoid long average waiting times.

For multiple berths at a straight continues quay front, the quay length is based on the average vessel length.

$$L_q = 1{,}1 \cdot n \cdot (\bar{L}_s + 15) + 15 .$$

During phase-2, 595 Feeder type vessels with an average parcel size of 187 TEU and 84 vessels with 1000 TEU will visit 'Zona Portuaria Simon Bolivar'. The average vessel length will be 133 m.

The quay length for this sea going container vessels is:

$$L_q = 1.1 \cdot 2 \cdot (133 + 15) + 15 = 340 \, \text{m}.$$

The construction of the quay, with a length of 340 meter, has to be finished by the year 2010.

The next thing to determine is the necessary quay length for the container barges.

The amount of TEU imported through 'Zona Portuaria Simon Bolivar' by barge is 47,350 and the amount exported is 23,675 TEU during phase-2. By then, the barge terminal for containers should be designed for a throughput of 71,025 TEU. Due to the depth of the surrounding waters, the container barges have a maximum capacity of about 100 TEU. The length of these barges is 100 m. Only two mobile Jib cranes with a capacity of 32 TEU per hour (20 containers per hour) are loading and unloading the barges at the same time. The loading and unloading process only occurs during 12 hours a day.

The containers to be imported by barge are the maximum amount of 100 TEU per vessel. The amount of containers to be exported by barge to 'Zona Portuaria Simon Bolivar' is half the size of the amount of import. The total amount of TEU's to be handled per barge is 150 TEU.

$$\lambda = \text{The arrival rate per hour} = \frac{\text{The total amount of throughput in TEU} / \text{Parcel size}}{\text{Workable hours per year}}$$

$$\lambda = \frac{71{,}025 / 150}{360 \cdot 12} = 0.109 \quad \text{vessels/hr.}$$

$$\text{The service hours for one barge} = \frac{Parcelsize}{n_{cranes} \cdot f \cdot p} = \frac{150}{2 \cdot 5/3 \cdot 20} = 2.25 \, \text{hr.}$$

The total amount of service hours, for berthing, loading and departure is estimated to be 3 hours.

$$\frac{1}{\mu} = 3 \, \text{hr.} \rightarrow \rho = \lambda \cdot \frac{1}{\mu} = 0.327$$

The average waiting time for the container barges from Lake Maracaibo in units of the average service time is preferred to be about 15 percent. The $E_2/E_2/n$ queue system will be used again.

The utilisation for 1 berth is 0.327.

The factor (w/s) for one berth has a value of 0.16. An average waiting time of 28 minutes is good enough for handling the container barges during phase-2.

$$L_q = 1.1 \cdot 1 \cdot (100+15)+15 = 142 \text{ m.}$$

The construction of the barge quay, with a length of 142 meter, has to be finished by the year 2010.

Phase-3: year 2018

All the assumptions that were made for phase-2 also apply for phase-3. The things that differ are presented in this section.

The total forecasted throughput during phase-3 for 'Zona Portuaria Simon Bolivar' is about 790.000 TEU. The imported containers that will be distributed by barge is 50 percent of the total import (263.500 TEU). The other 50 percent will be transported by truck (263.500 TEU). The amount of containers, that will be exported via 'Zona Portuaria Simon Bolivar' and will be delivered by barge, covers also 50 percent of the container export (131.500). The remaining 50 percent will be transported by truck (131.500 TEU). In figure 4-2 the modal split of the container cargo is presented for phase-3.
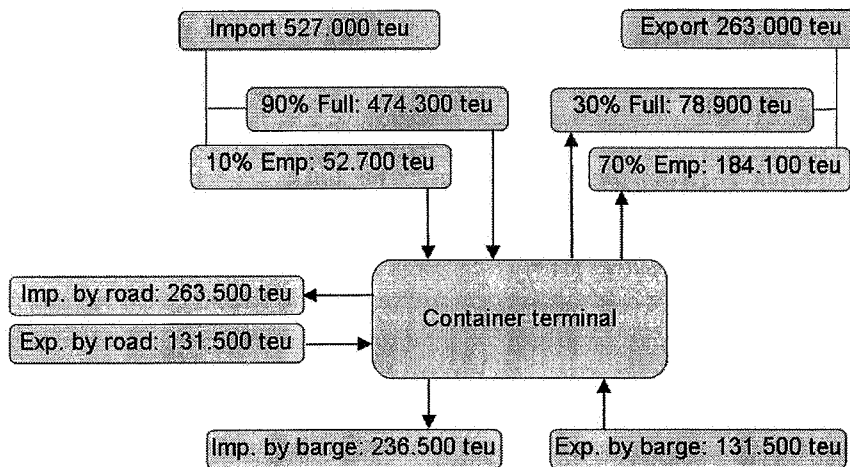
figure 4-2: Modal split container cargo phase-3 [Masterplan 'Puerto America', Alkyon 2002].

A summary is given below of the amount required quay length for the sea going container vessels and the barge harbour during phase-3. The calculations of the data are presented in appendix-4 (Containers, page 2). The quay length for sea going container vessels is:

$$L_q = 1.1 \cdot 3 \cdot (177+15)+15 = 650 \text{ m.}$$

The construction of the quay, with a length of 650 meter, has to be finished by the year 2018.

The amount of TEU imported through 'Zona Portuaria Simon Bolivar' by barge is 263.500 and the amount exported is 131.500 TEU in the year 2018. By then, the barge terminal for containers should be designed for a throughput of 395.000 TEU.

The construction of a barge quay, with a length of 395 meter, has to be finished by the year 2018.

Year 2028:

All the assumptions that were made for phase-2 also apply for the year 2028. The things that differ are presented in this section.

The total forecasted throughput in the year 2028 for 'Zona Portuaria Simon Bolivar' is about 1.288.000 TEU. The amount of imported containers that will be distributed by barge is 300.545 TEU. The other part will be transported by truck (558.155 TEU). The amount of containers that will be exported via 'Zona Portuaria Simon Bolivar' and will be delivered by barge is 150.255 TEU. The remaining part will be transported by truck (279.045 TEU).

A summary is given below of the amount required quay length for the sea going container vessels and the barge harbour in the year 2028. The calculations of the data are presented in appendix-4 (Containers, page 3). The quay length for sea going container vessels is:

$$L_q = 1.1 \cdot 4 \cdot (177 + 15) + 15 = 860 \text{ m}.$$

The quay length of 650 m. for the sea going vessels of phase-3 has to be lengthened to 860 m. in the year 2028.

The amount of TEU imported through 'Zona Portuaria Simon Bolivar' by barge to the hinterland is 429,350 and the amount exported is 214,650 TEU in the year 2028. By then, the barge terminal for containers should be designed for a throughput of 644.000 TEU.

The construction of a barge quay, with a length of 521 meter, has to be finished by the year 2028.

4.2.2   General cargo / break bulk

In the trade and traffic forecast, a total amount of 635,000 tons of break bulk for phase-2 and 696,000 tons for phase-3, is foreseen. Due to the little difference in amount of throughput between phase-2 and 3, the required facilities for the two phases are based on 696,000 tons of throughput.

A summary is given below of the amount required quay length for the sea going vessels during phase-2 and 3. The calculations of these data are presented in appendix-4 (General cargo / break bulk, page 5).

The quay length for sea going general cargo / break bulk vessels is: $L_q = 1.1 \cdot 2 \cdot (150 + 15) + 15 = 378 \text{ m}.$

4.2.3   Crude oil, petroleum and petrochemicals

Sea quays:

The Crude oil, petroleum and petrochemical throughput are discussed at the same time because all these vessels are handled at the same terminal on Zapara. The predicted amount of oil that will be exported through 'Zona Portuaria Simon Bolivar' during phase-2 is and phase-3 is 65,580,000 m^3. The total throughput which includes oil products and petrochemicals is 66,260,600 m^3. figure 4-3 shows the commodity flows of crude oil, petroleum and petrochemical during phase-2 and phase-3.
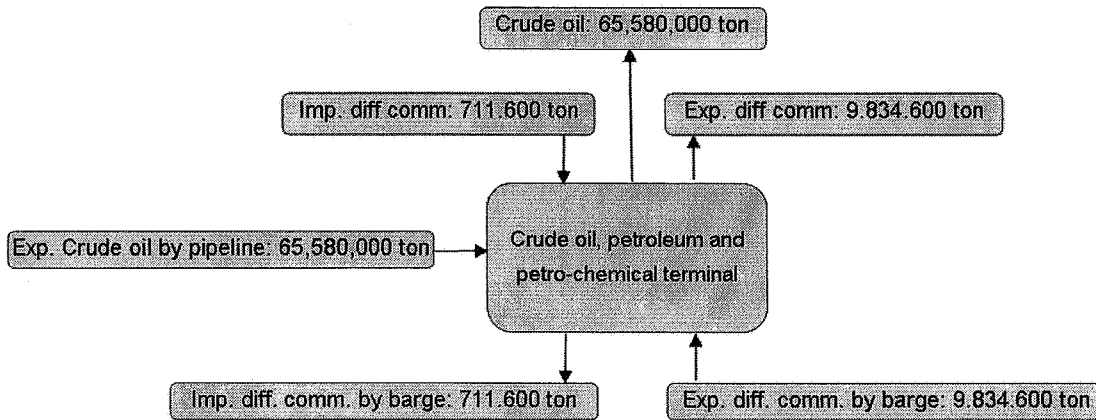
figure 4-3: Commodity flows of crude oil, petroleum and petrochemical during phase-2 and phase-3 [Masterplan 'Puerto America', Alkyon 2002].

The import and export of the different type of commodities by barges are presented in Table 3-1 (section 3.4). The oil shipments, which have small consignments in relation to the oil tankers with draught limitations, are exporting about 5 percent of the total throughput. This volume is shipped in small consignments of approximately 16,000 m^3. Due to the small ship sizes for oil, petroleum products and chemicals, one small berth is needed. Four big jetties for the large oil tankers are required to handle the big tankers. The amount of berths required in the barge harbour is six.

The calculations of these data are presented in appendix-4 (Crude oil, petroleum and petrochemicals / break bulk, page 6).

4.2.4   Coal

Sea quays:

The predicted amount of coal that will be exported through 'Zona Portuaria Simon Bolivar' during phase-2 is 16,700,000 tons and during phase-3 is 24,000,000 tons. As presented in the modal split (chapter, 3) the transportation modes are shown in figure 4-4.

In the earlier phase-1, coal will be the first and only commodity to be exported. This coal terminal will be placed on San Bernardo as soon as possible. In order to keep the cash flow going, the first phase of the coal throughput will be approximately the same as in present times. The coal will be delivered to the terminal by trucks and is loaded into the carriers with one radial-travel shiploader. When the coal throughput is growing, the transport will gradually change from truck to barge and rail transportation in the years 2010 and 2018.
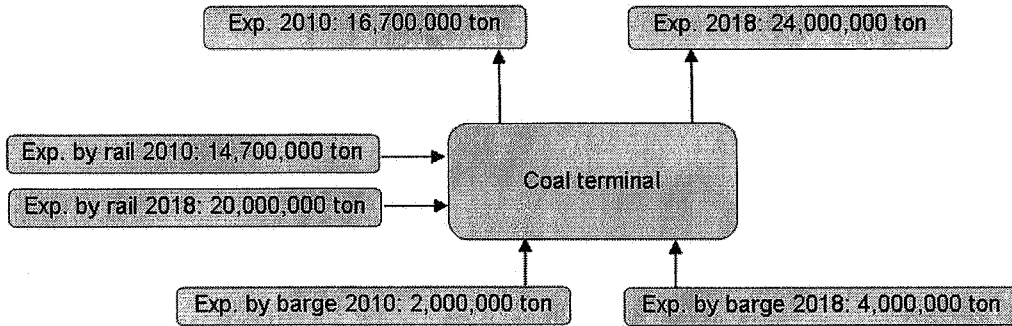
figure 4-4: Modal split of coal for the years 2010 and 2018 [Masterplan 'Puerto America', Alkyon 2002].

The amount of berths required during phase-1 is one and during phase-2 and 3 are two.
The calculations of these data are presented in appendix-4 (Coal, page 10).

4.2.5   Cereals

Sea quays:
Most of the agricultural sectors in Venezuela are not self sufficient. All the cereals needed for human consumption and animal feed are imported. The throughput of cereals is 1.331.000 tons during phase-3 and 1.787.000 tons in the year 2028. The possible location of the cereal terminal is located between two other terminal areas (see chapter 5). It is not possible to increase the quay length due to future growth of the throughput. The sea quay length will therefore be determined for the throughput in the year 2028.
Bulk trucks and barges will transport the cereals to the hinterland of Maracaibo.
Figure 4-5 shows the modal split of cereals for the years 2018 and 2028.
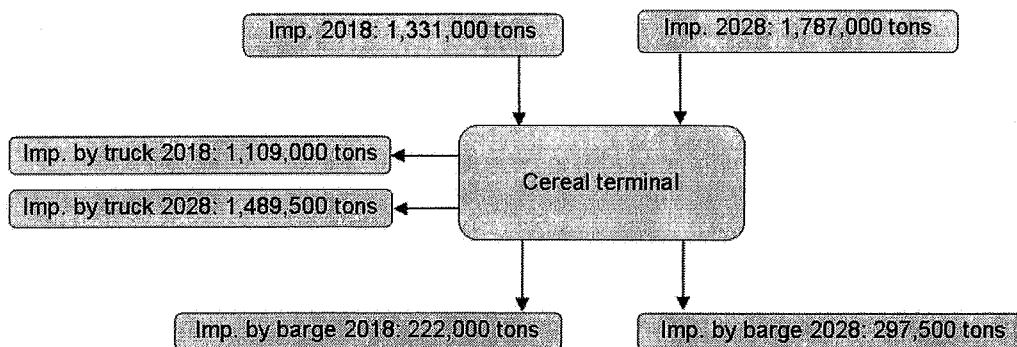
figure 4-5: Modal split cereals for the years 2018 and 2028 [Masterplan 'Puerto America', Alkyon 2002].

One berth is required for the cereal carriers during phase-2 and 3.
The required quay length for the cereal carriers is 230 m.
One berth is required for the barges during phase-2 and 3.
The required quay length for the barges during phase-2 and 3 is 142 m.
The calculations of these data are presented in appendix-4 (Cereals, page 13).

4.2.6   Cement related products

The location of the cement terminal is in alternative-2 and 4 located between the general cargo terminal and the cereal terminal (see appendix-5). It is not possible to increase the quay length due to future growth of the throughput. The amount of throughput for the terminal during phase-2 is almost the same as during phase-3. The sea quay length will be determined for the throughput during phase-3 and the year 2028.

Cement related products that will be exported through 'Zona Portuaria Simon Bolivar' are cement, clinker, gypsum and iron ore.

Two berths are required for the throughput of all the commodities during phase-3 and the year 2028.

The required quay length is 310 m.

No quay length will be needed in the barge harbour for handling these goods because everything will be transported from and to 'Zona Portuaria Simon Bolivar' by truck or rail.

The calculations of these data are presented in appendix-4 (Cement related products, page 15).

4.2.7   Steel factory

State Zulia is studying the economical feasibility of a steel factory in 'Zona Portuaria Simon Bolivar' in the year 2028.

In the feasibility study of the project 'Zona Portuaria Simon Bolivar', the rough lay out of the terminal location, hinterland connection, arrival of raw materials and departure of the final product is evaluated.

Most likely the plant is located on the island of Pájaros because all infrastructure to and from the other terminal can be used.

The initial information of State Zulia concerning the type of plant was aiming at an old fashioned blast furnace process. This blast furnace process and additional factories are described in appendix-4 (Blast furnace process, page 16).

As a result of the characteristics of the cocking coals, which are not high enough, and because the iron ore is very fine material a cokes, pallet and sinter factory has to build on the Island of Pájaros. All three factories and especially the cokes factory, are not very environmentally friendly.

To minimize the land reclamation costs and develop an environmentally friendly steel factory, a direct reduced iron (DRI) method is used. No cokes, pallet and sinter factories are required for this kind of steel making process. The only thing that is required is enough power and iron ore pallets with a minimum of 70 percent iron. Pick iron will be made directly in the Electric Arc Furnace (EAF).

The location of the pallet factory is assumed close to the iron ore mine. This way the remains of the pallet production can easily be taken care of.

When 700,000 tons of cokes will be used for the pick iron production, a final quantity of $\frac{700,000}{0,6} = 1,166,667$ tons

will be produced. To produce such an amount of pick iron with the DRI method, $\frac{1,166,667}{0,7} = 1,666,667$ tons of iron ore pallets are required. The pallet factory is not only dependant on the iron ore pallets required for the steel factory but these pallets can be exported. The export market area is excellent for this product.

A lot of uncertainties make the required area for the steel factory hard to predict. A feasibility study for a steel factory with the same production method and throughput of pick iron has been looked at. The required area will be approximately 100,000 m^2.

The extra occupancy rate of the general cargo quay, due to the steel plate carriers, is little. The total amount of throughput can be handled by a quay length of 378 m during phase-3 and the year 2028.

The quay length that will be needed in the barge harbour for handling the iron ore pallets is 142 m.

The calculations of these data are presented in appendix-4 (Steel factory, page 17).

4.2.8   Other dry bulk

The main quantity of 'other dry bulk' that will be transported through 'Zona Portuaria Simon Bolivar' in phase-2, phase-3 and in the year 2028 is salt. About 300,000 tons of salt will be exported. Baryte and bentonite will be imported in quantities of 44,000 tons per year.

The vessels, which transport the salt, have an average lotsize of 40,000 tons and will be loaded with a capacity of 1,000 tons per hour. The other dry bulk products, baryte and bentonite, will be imported in average parcel sizes of 4,000 tons. Like iron ore, also baryte and bentonite are unloaded with a capacity of 300 tons per hour by crabcrane.

The baryte and bentonite are imported and distributed only by truck but the total amount of exported salt is transported by barges to 'Zona Portuaria Simon Bolivar'.

One berth is required for all the commodities salt, baryte and bentonite carriers during phase-2, 3 and the year 2028. The required quay length is 275 m.

Also one berth is required for the barges during phase-2, 3 and the year 2028.

The calculations of these data are presented in appendix-4 (Other dry bulk, page 18).

4.2.9   Summary of berths and quay length

In this section an overview is given of the different sea quays and barge quays of all the different commodities. Some commodities can be handled at the same quay, such as cement related products and the other dry bulk. It may be possible to fulfil the requirements of the throughput of these commodities with less than 3 berths.

The (w/s) factor for all the 'cement related products' and the 'other dry bulk' commodities like salt, baryte and bentonite with the same M/M/n queue system is:

The utilization is $0.46 + 0.068 = 0.528 \rightarrow$ (w/s) with two berths is 0.08. Two berths with a total length of 310 m will fulfil the requirements during phase-3 and the year 2028.

For phase-2, the utilization of the cement related products' vessels is 0.49 and the utilization of the 'other dry bulk' vessels is 0.4. The (w/s) with two berths is 0.26.

In this case, the two commodities can be handled at two berths. The required quay length for this seldom arriving salt vessel (220 m) is 275 m. This vessel can berth easily at the quay length for two vessels of 165 m. shows the number of berths and lengths of the sea and barge quays.

As a result of the different commodities, which can be handled at the same berths, the total length of the quays will decrease. Table 4-1 shows the resulting number of berths and lengths of the sea and barge quays.

	Sea quays		Barge quays	
	Numb of berths	Quay length (m)	Numb of berths	Quay length (m)
Fase-2 (2010)				
Containers	2	340	1	142
General cargo/Break bulk	2	378	-	-
Crude oil/Petroleums/Chemicals	5	-	6	-
Coal	2	-	2	-
Cereals	1	230	1	142
Cement related/Other dry bulk	2	310	1(other dry bulk)	120
Fase-3 (2018)				
Containers	3	650	3	395
General cargo/Break bulk	2	378	-	-
Crude oil/Petroleums/Chemicals	5	-	6	-
Coal	2	-	2	270
Cereals	1	230	1	142
Cement related/Other dry bulk	2	310	1(other dry bulk)	120
Steel factory	-	-	1	142
Year (2028)	Numr of berths	Quay length (m)	Numb of berths	Quay length (m)
Containers	4	860	4	521
General cargo/Break bulk	2	378	-	-
Crude oil/Petroleums/Chemicals	5	-	6	-
Coal	2	-	2	-
Cereals	1	230	1	142
Cement related/Other dry bulk	2	310	1(other dry bulk)	120
Steel factory	-	-	1	142

Table 4-1: Number of berths and lengths of the sea and barge quays.

4.3   Terminal area

In this section the basic dimensions of the different terminal areas are determined. In this phase of the design, areas such as offices, infra structure, parking areas and custom areas are not designed yet. The area required for safe traffic on the terminals and the amount of square meters for the buildings are assumed.

4.3.1   Container terminal

Phase-2:

The container terminal at 'Zona Portuaria Simon Bolivar' will have a quay length of 340 meters with two berths. First the apron area is determined. This part of the sea side area consists out of the service lane, crane track spacing, space behind the landward rail and the traffic lane. The service lane is the amount of space between the coping and the sea side rail of the cranes (5 m). For a good stability of the cranes, a distance of 30 meters is assumed for the crane track spacing. If special or hazardous cargo has to be picked up and directly transported to the special site, the required space to do so is approximately 15 meters. At last but not less important, the traffic lane for the transportation of the containers from and to the storage yard has to be determined. When the terminal has to be designed in more detail, the width of the traffic lane has to be adjusted to the traffic system. In this stage of the design, the same width as the distance between the crane rails is assumed (30m). Eventually, the apron area will have a width of 80 meters. In the assumption that the quay is a straight line, the apron area is 27,000 m^2.

Secondly, due to the separate tracks, the overall storage yard must be divided into areas for export, import, hazardous cargo, empty containers and the Container Freight Station (CFS). The amount of reefers is not known but they are included in the amount of import and export containers. All the values that have been assumed are values of modern western container terminals.

The calculation [Ports and terminals, 2000] is presented in appendix-4 (Calculation container terminal area, page 20).

A summary of the container terminal area for phase-2 is shown in Table 4-2.

Type of area	Area (m^2)
Import	13.100
Export	2,200
Empties	16,700
Hazardous	1,500
Container Freight Station	10,000
Apron area	27,000
Roads/offices/parking/transfer areas	10,000
Total phase-2	80,500

Table 4-2: Summary container terminal area phase-2.

Phase-3:

The container terminal at 'Zona Portuaria Simon Bolivar' will have a quay length of 650 meters with three berths. First the apron area is determined. This part of the sea side area consists out of the service lane, crane

track spacing, space behind the landward rail and the traffic lane. The service lane is the amount of space between the coping and the sea side rail of the cranes (5 m). For a good stability of the cranes, a distance of 30 meters is assumed for the crane track spacing. If special or hazardous cargo has to be picked up and directly transported to the special site, the required space to do so is approximately 15 meters. At last but not less important, the traffic lane for the transportation of the containers from and to the storage yard has to be determined. When the terminal has to be designed in more detail, the width of the traffic lane has to be adjusted to the traffic system. In this stage of the design, the same width as the distance between the crane rails is assumed (30m). Eventually, the apron area will have a width of 80 meters. In the assumption that the quay is a straight line, the apron area is 52.000 m^2.

Secondly, due to the separate tracks, the overall storage yard must be divided into areas for export, import, hazardous cargo, empty containers and the Container Freight Station (CFS). The amount of reefers is not known but they are included in the amount of import and export containers. All the values that have been assumed are values of modern western container terminals.

The calculation [Ports and terminals, 2000] is presented in appendix-4 (Calculation container terminal area page 23). A summary of the container terminal area for phase-3 is shown in Table 4-3

Type of area	Area (m^2)
Import	72,800
Export	12,200
Empties	92,700
Hazardous	8,600
Container Freight Station	56.000
Apron area	52.000
Roads/offices/parking/transfer areas	55,900
Total phase-3	350,200

Table 4-3: Summary container terminal area phase-3.

Year 2028:

In the year 2028, the container terminal at 'Zona Portuaria Simon Bolivar' will have a quay length of 860 meters with four berths. The apron area will have a width of 80 meters and an area of 68,800 m^2.
This calculation is also presented in appendix-4 (Calculation container terminal area, page 23).
A summary of the container terminal area for for the year 2028 is shown in Table 4-4.

Type of area	Area (m^2)
Import	118,700
Export	21,700
Empties	151,200
Hazardous	14,000
Container Freight Station	86,300
Apron area	68,800
Roads/offices/parking/transfer areas	91,700
Total year 2028	552,400

Table 4-4: Summary container terminal area year 2028.

4.3.2 General cargo and break bulk terminal

The general cargo terminal at 'Zona Portuaria Simon Bolivar' will have a quay length of 378 meters with two berths. A total of 635,000 tons of break bulk for phase-2 and 696,000 tons for phase-3 is foreseen.
Due to this small difference in throughput, the terminal area will be determined for phase-3.
The apron area is smaller than the one by the container terminal because there are no huge container cranes on the quay. This quay-apron width is 25 meters at minimum but it should be better to make it approximately 30 m wide to load and unload the vessels.
The total terminal area is split up into transit sheds, open storage, infra structure, offices and car parks.
A few basic assumptions have been made. The average dwell time of the general cargo is about 3 weeks and ½ of the cargo requires covered storage and ½ open storage.
All the values that have been assumed are values of modern western general cargo terminals.
The calculation [Ports and terminals, 2000] and the rest of the assumptions are presented in appendix-4 (Calculation general cargo terminal area, page 24).
A summary of the container terminal area is shown in Table 4-5.

Type of area	Area (m^2)
Transit shed	42,900
Open storage	42,900
Apron area	11,300
Central delivery area	17,000
Infra structure ect.	22,900
Total	137,000

Table 4-5: Summary general cargo terminal area.

4.3.3 Crude oil, petroleum and petrochemical terminal

All the products like crude oil, petroleum and petro-chemical products will be stored on the island of Zapara.
The required area on the island is divided into barge terminal, crude oil storage, product storage, refrigerated storage, asphalt and fuel storage, buildings and future expansions. In this section, these individual required areas will be presented for the throughput during phase-3 and the year 2028. The throughput differ not much for these phases.
For the storage of crude oil, including the safety quantity, 24 storage tanks with a capacity of 220,000 m^3 each will be required [Masterplan 'Puerto America', Alkyon 2002]. These values are estimated on view soil samples of the island. If the load carrying capacity of the soil is higher than assumed, the storage tanks will be made higher and less wide. The required area in which a storage tank is positioned is 150x150 m (2.25 ha) [Masterplan 'Puerto America', Alkyon 2002]. The total amount of required area for the storage tank park is 54 ha. For all petroleum products, except asphalt and gasoline, two product tanks per product are needed with an average storage capacity per tank of about 16,500 m^3. These 16 tanks, with a required area of 5,600 m^2 (75x75 m) per tank, have a total area of 9 ha. [Masterplan 'Puerto America', Alkyon 2002].
It is assumed that the storage of the fuel and the asphalt will take 3.7 ha and the storage of refrigerated products about 4.9 ha. [Masterplan 'Puerto America', Alkyon 2002].

Taken all the above mentioned into account, the total area becomes 88 ha.

When all roads, warehouses, required spaces for pipelines etc. are included it is assumed that the 88 ha will be multiplied by a factor 1.4. The total required area on the island of Zapara is approximately 123 ha.

4.3.4   Coal terminal

The amount of coal that will be exported through 'Zona Portuaria Simon Bolivar' during phase-3 is 24 Mtons and in the year 2028, 26 Mtons. As earlier mentioned, the terminal will be placed on San Bernardo. The required area will be determined for the throughput in the year 2028. The most important issue to determine is the minimum quantity of coal on the terminal area. This quantity must be enough for the loading of several carriers with short inter arrival times due to a assumed Negative Exponential Distributed (N.E.D.) distribution. In phase-3 and the year 2028, the only way coal is transported to the terminal is by barge and rail. Every day approximately 3.5 barges will arrive at 'Zona Portuaria Simon Bolivar'. The train that will be unloaded consists of 100 cars with a capacity up to 60 tons. These values have been taken as an average between the EMO import terminal in the Netherlands (throughput of 22 Mtons of coal transported by trains with 44 cars and a capacity per car of 63 tons) and terminals in South Africa (throughput of 60 Mtons of coal transported by trains with 200 cars and a capacity per car of 85 tons). With an amount of 7777 workable hours per year, per hour, 0.47 trains will arrive in the year 2028. Due to the dumper systems (one for during repair of the other) under the rails where two cars can be unloaded at the same time, the necessary time to unload 100 wagons is about 1.5 hour. The occupancy rate of the dumpers is high and the distance to the mines, where most of the coal is coming from in future times, is about 100 km. Transportation with 5 trains and a steady loading rate by the coal mines makes the inter arrival time of the trains almost deterministic.

With the earlier mentioned information a rough stockpile quantity can be determined. If the arriving trains and barges are not regulated in relation with the minimum or maximum amount of coal on the terminal area, the maximum amount of coal will be much too big. The maximum amount of coal will then approximately be 8 Mtons.

This value is relatively high in comparison to the present coal terminals and their export volumes. Table 4-6 shows several export terminals with their yearly throughput and stockpiles.

Terminals	Yearly throughput (Mtons)	Stockpile (Mtons)
Port Waratah (Australia)	74.0	3.0
AG Tana (australia)	40.0	4.2
Westshore (Canada)	21.0	2.0
Richardsbay (South Africa)	72.0	6.7

Table 4-6: Coal terminals with their export rates [World coal magazine, June 2004].

The big difference between the 8 Mtons and the quantities in Table 4-6 is the presence of a safety stock nearby the mines. When looked at the average stockpiles of the existing present terminal throughputs and their stockpiles an average stockpile quantity of approximately 2 Mtons is usually taken for the daily throughput and a safety stock that is big enough to load all the trains if extra capacity is required.

This capacity must be sufficient to deliver coal to the terminal at such a capacity rate that the stockpile can be replenished in time to fulfil the export demands of the coal carriers. Such a situation will arise when successively short inter arrival times occur. For further detailed design of the transportation logistics, this train capacity must be evaluated.

When the maximum capacity of the stockpiles is assumed at 2 Mtons, the coal delivery to the terminal must be stopped from time to time when the inter arrival time of the vessels will be longer than usual. Due to this stockpile maximum the amount of times that the minimum values became low or even zero will increase. During this period of time, the peak capacity of the trains must be about the same as the total amount of coal that will be dumped at a maximum rate into the two coal carriers per hour. One train will carry 6,000 tons of coal. If the stockpiles are empty and two carriers need to be loaded, a capacity of 7,000 tons per hour is required. This amount can be delivered by 28 trains per day (1.17 trains per hour) when the barge capacity is excluded because of the low capacity rate per hour. With the unloading time of 1.5 hour per train, there will be two double dumper systems needed. The occupancy rate for the dumper systems will be high. The occurring waiting times of the trains will be no problem.

In the detailed design phase, a computer model has to be developed to optimize the maximum train capacity.

Due to the 3 or 4 different coal qualities from the different coal mines, 3 or 4 stockpiles are required. A terminal area like the EMO-terminal with several stockpiles and different qualities of coal, has an average of 5 tons per m^2. If only one quality of coal is present per stockpile, an average of 10 tons per m^2 is possible.

It is assumed that the stockpiles will have a span of 80 m and a height of 23 m. These values are the same as the EMO and other terminals with the same coal throughput. In the detailed design phase, the type of coal has to be investigated. As a result of this investigation, the stockpile height has to be determined to exclude possible heating which can lead to spontaneous combustion of the coal. Another important phenomenon is dust nuisance. This must be controlled by the use of water sprays at the critical discharge positions. Nowadays it is possible to spray a cellulose substance on the stockpile like a thin plastic layer. Then the dust production caused by the wind will be almost zero. It is required that the conveyor belts are closed and enclosed transfer points. figure 4-6 shows an example of enclosed conveyor belts and transfer points.
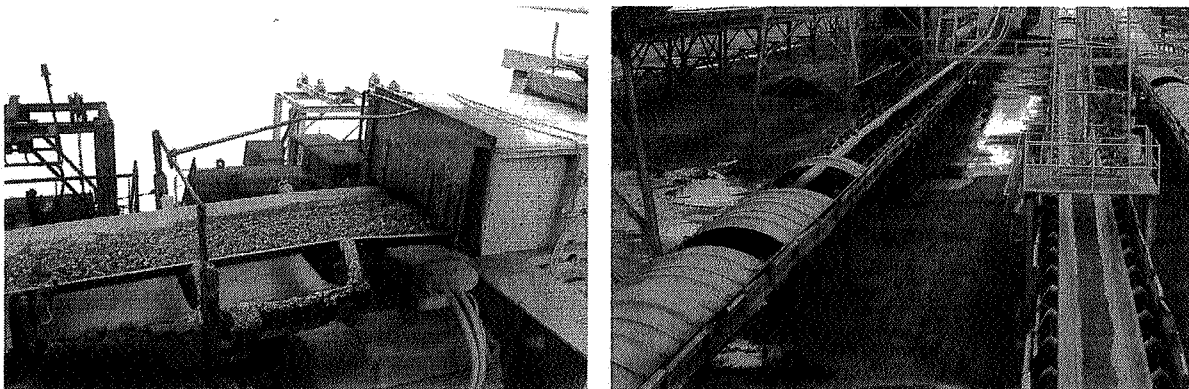
figure 4-6: Enclosed conveyor belt and transfer point.

The earlier assumed dimensions of the stockpiles and big stacker-reclaimers with a span of 49 m are required for future expansions of the coal terminal and its increase of coal throughput. Such a stacker-reclaimer, which is fully automatic due to the 3-D scanner and GPS technology, is shown in figure 4-7. Nowadays it is possible to give the stacker-reclaimer an order via the computer and it will automatically reclaim the required amount of coal.

figure 4-7: Stacker-reclaimer (EMO-terminal in Rotterdam).

The angle of the stockpile is between 38 and 40 degrees. With 10 tons per m^2 and a stockpile width of 80 m, a stockpile length of 2500 m is required. Two options are possible: two stockpiles with a length of 1250 m each or three stockpiles with a length of 840 m each. Two stockpiles are preferred because enough space is available for the stockpiles at the west side of the terminal area. At the north side of the terminal area land reclamation is required to locate a third stockpile.

The total width of a stockpile, which includes area for roads, conveyor belts and the stacker-reclaimer, is 100 m. When these distances are translated to the required stockpile area, the stockpile area will be approximately 25 ha.

No space is reserved for quay facilities such as big grab cranes because the coal terminal is only exporting the coal. Because the coal will only exported, the coal can be loaded with two radial-travel shiploaders or a linear shiploader with an average capacity of 7,000 tons per hour. It is possible to transport the coal with conveyor belts to these loaders. As a result of this and the fact that a jetty is much cheaper to construct, the carriers will be moored at two jetties. figure 4-8 shows such a facility.
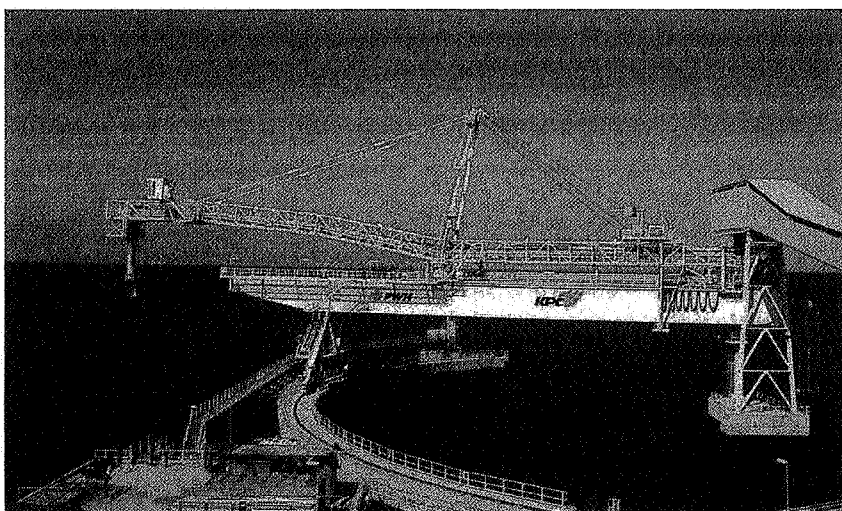
figure 4-8: Radial shiploader.

When all the conveyor belts, roads, train unloading areas with dumper systems and buildings are included, the total amount of required area for the coal terminal will be about 35 ha.

4.3.5   Cereal terminal

The handling and storage of cereals is assumed as follows. As already discussed in section 4.2.5, the average parcel sizes of 35,000 tons will be unloaded with a capacity of 600 tons per hour by pneumatic unloaders such as the Siwertell as shown in figure 4-9.

figure 4-9: Pneumatic Siwertell unloader.

When the cereals are unloaded, they will be transported by conveyor belts to the storage building. It is assumed that the storage requirements will only be influenced by the loading rate of the barges and the trucks (see modal split). Because the barges and the trucks are loaded at a rate of 300 tons per hour due to the maximum conveyor capacity, the stockpile can be controlled very well. The storage requirements will be approximately 40,000 tons, which is about 48,000 m^3 in total. This quantity will be stored in one big shed. A stockpile length of 240 m will be used with a base of 40 m and a height of 10 m. Because the stockpile will be positioned perpendicular to the quay (due to the length of the stockpile), the width of the terminal area is the same as the length of the quay.
For the movable Siwertell unloader a working space of about 30 m between the storage shed and the quay is required. At the end of the shed about 100 m is needed for arrival of trucks, conveyor belts to the barges, buildings etc. The total harbour area for the cereal throughput is about 10 ha.

4.3.6   Cement related products and other dry bulk terminal

For the total amount of combined cement and dry bulk terminal area, the different commodities are divided over the terminal area. Cement in bulk is exported with parcels of 6,000 tons. As a result of the high loading rate of the silo's and the fact that the average arrival rate is once in the 2.3 days in 2028, the required stock is about 8,000 tons (6,000 m^3). Three big silo's with a diameter of 12 meter and a height of 28 meter will be able to store this quantity of cement. The total amount of terminal area required for the roads, facilities for unloading of the trucks and loading of the conveyor belts, silo's etc. will be about 1.25 ha.
Cement in bags is stored and handled on pallets (1.2x1.0x1.8m) with a capacity of 2.5 tons. It is assumed that they will be stored two pallets high. The vessels which transport the pallets have average payloads of 5,000 tons. The required stockpile weight is assumed to be 8,000 tons. About $8,000/_{2.5 \cdot 2} = 1920$ m^2 is needed only to

store the pallets. The forklift trucks also need space to transport the pallets. The same factor 1.3 (like in the transit shed of the container terminal) is taken to include the roads in the shed. Due to this factor the total storage area will be approximately 2,500 m². In this case the total amount of terminal area required for the roads, shed, area's for unloading the trucks and the apron area for loading the vessels will be approximately twice the storage of 0.25 ha, 0.5 ha.

During phase-3, 626,000 tons and in the year 2028 1,020,000 tons of clinker will be exported with average parcel sizes of 5,000 tons. Due to the average arrival rate of once in the 1.8 days and the loading rated the storage building by trucks is equal or less than 1.8 days, the clinker buffer will be about 9,000 tons (8,000 m³). Also in this shed the stockpile base width is 40 m, the height is 10 m and the length is 50 m. The required storage area in the open air will be about 2,500 m². For the same reason as by the cement terminal area, the required area will be 0.5 ha.

In phase-3, an amount of 127,000 tons of gypsum will be imported and another 206,000 tons in the year 2028. The average parcel size is 8,000 tons of the delivered gypsum. Because of the low average arrival rate, once in the 14 days, the storage capacity will be exactly 8,000 tons (6,000 m³). For the stockpile an area of 20x10x100 m is required. The area for the shed will be 3,000 m² and the total amount of terminal area to include all activities is 0.6 ha.

During phase-3 and in the year 2028, 300,000 tons of salt will be exported in vessels with an average lot size of 40,000 tons (34,000 m³). Once in the 50 days a vessel will arrive. Also in this case, the stockpile will have the same volume as the maximum lotsize of about 40,000 m³. The base width of the stockpile will be 30 m, the height 15 m and the length 200 m. The area required for the shed will be 10,000 m². All terminal area's together, which includes the conveyor belts, the reclaimer area along the salt stockpile and the area between the shed and the quay, will be approximately 2.0 ha.

Iron ore, which is needed for the cement industry, will be stored on the storage area of the steel making factory. No separate area will be required to store the little amount of 6,000 tons of iron ore.

Baroid and betonite are imported with parcel sizes of 4,000 tons. Eleven vessels per year arrive at 'Zona Portuaria Simon Bolivar' during phase-3 and 2028. Also in the case of baroid and betonite, the minimum volume of the stockpile is 2,000 m³ (4,000 tons). The required open air terminal area is 0.5 ha.

All the terminal area's together for the cement related products and other dry bulk is 15.35 ha.

4.3.7   Fish terminal

In the present situation most fishermen are living on the island of zapara. Fishing grounds of the fishermen are located in Tablazo Bay (approximately 30x30 km). It is not envisaged that the fishermen will extend their fishing grounds towards the Gulf of Venezuela in the nearby future. This home-base small port on the island of Zapara is a simple landing place for fishermen. This point of view will stay the same.

Perhaps in the future, somewhat bigger vessels will be entering the port and it will become a coastal fishery port. There are great fishing opportunities with the Gulf of Venezuela nearby.

Nowadays the vessels have a length of about 10 m.

Due to the planned oil terminal and barge harbour on 'their' island Zapara, the state of Zulia will arrange new facilities for the fishermen and their vessels to compensate for the future oil terminal plans.

In the following sections the current and future situation, the site location and port lay-out, dimensions of the water area and the required facilities are discussed.

Present and future situation

The local fishermen on the island of Zapara possess about 50 wooden vessels. The vessels arrive from

Monday till Friday, at the end of the day, with about 200 kg of fish. Maybe a few will go night fishing, but the rest will stay in the port. The total amount of caught fish will be shipped to St. Rafael, at the west side of Tablazo Bay. St. Rafael is much closer to Zapara than Maracaibo City and the roads towards Maracaibo are well maintained to transport the goods.

Site location and port lay-out

The fishery port is planned at the island of Zapara. The information to be considered for the site location is:

The distance to the fishing grounds remains the same as before (about 15 km).

The north-west area of the island is reserved for the oil terminal. PDVSA-Gas has plans for a gas plant on the island in the future, but these plans are in a preliminary phase. There will be enough space for expansion of the fishery port. The only disadvantage when the gas terminal will be built next to the oil terminal is the dominant wind direction. The wind frequently blows over the gas terminal and the possible toxic gasses may blow straight over the fishery port. When the fishery port is located at the west-side of the island, safety is not guaranteed if a gas leak occurs.

This problem has to be evaluated in a later design phase and is not included in this feasibility study.

The lay-out of two fingerpiers and the ro-ro fishing vessels at the end of the piers reduces the dredging costs to an optimum dredging volume. Two fingerpiers with a required length of 100 m, need an area of about 3.7 ha.

Further information about the site location and the port lay-out is presented in appendix-4 (Site location and port lay-out, page 26).

Required facilities

In this section a summary is given of the required facilities on the island of Zapara as described in appendix-4 (Required facilities, page 27).

At the beginning of the project the small storage shed of 10x30 m is sufficient to cool the fish.

Requirements for the space of small-ice production are about $6m^2$ per ton of ice per day capacity. The required area is 5x5 m.

The required area for the washing machine to clean the boxes and the storage area for the boxes is 20x20m.

The required area for the offices and canteen can be 10x20 m because of the small amount of vessels.

The remaining required facilities for a coastal fishery port are:

1. A servicing area for ship-maintenance and repair. For these small vessels a facility where they rest on keelblocks will be optimal. The tidal range is not enough so a slipway is sufficient for the vessels. Nearby the slipway, workshops are needed to repair the wooden and machinery parts of the vessels.
2. A fishing gear warehouse and drying area for the nets.
3. Fuel storage for the vessels (One main fuel storage together with the oil barges).
4. Roads to and from the port.
5. Parking area for the vehicles.
6. Lot of facilities like electricity, water etc. will be shared with the barge harbour facilities of the oil terminal.
7. A ro-ro facility is needed to transport heavy equipment like vehicles and other materials to and from the island of Zapara. This facility is most likely located in the barge harbour of the oil terminal basin.

4.4   Dimensions of water area

In this section the approximations of the basic wet surface areas will be determined. The real dimensions need to be determined in a phase when more detailed data is available and the layout is determined of the location. These dimensions will be used for the most favourable port layout.

4.4.1   Channel depth

The vessels with the largest maximum draught are fully loaded Panamax container vessels, partly loaded coal carriers and the partly loaded oil tankers. An important factor in the future trade mark between Venezuela and the coal importers in Europe is the vessel capacity. These coal importers will use the largest possible consignments in order to minimise their transport costs. Such vessels are approximately 180.000 dwt with a maximum draft of 18 m. It is assumed that the dredging costs, to allow such a vessel through the channel, are much too high to make this project feasible. It is assumed that these coal carriers and oil tankers will have a maximum load capacity factor. When the load factor has been reached by the coal carriers, the vessels will go to Columbia to load the rest of the cargo. The Length Over All (LOA), Draught and Beam of the Panamax container vessel is (290, 12.5, 32)m. As mentioned in the introduction, a financial and economical analysis has to be made to evaluate the most economical situation for minimum dredging costs and maximum profit for Venezuela.

The fact whether a tidal window would be implemented or not did not influence the trade and traffic forecast for the phases 1, 2, 3 and the year 2028 at the beginning of the project. Because the assumption is made that the Panamax container vessel is the design vessel for the channel depth, the most relevant vessel draught to implement a tidal window for are the coal carriers and the oil tankers. It is possible to do so because the difference between Mean High Water Spring (MHWS) and Mean Monthly Minimum (MMM) is 1.39 m. As a result of this tidal window the coal carriers and oil tankers will be able to increase their amount of cargo. There is also a disadvantage of the implementation of a tidal window. The amount of extra waiting time for the coal carriers and oil tankers until the water level is high enough to sail trough the channel will be higher than without a tidal window.

These two situations need to be modelled for an optimal situation. Because the trade and traffic forecast did not make any difference in the amount of throughput for the coal and oil terminal for different channel depths, no tidal window is assumed in this phase of the feasibility study.

In the appendix of the site conditions, the table is presented of the frequency of the wave height in the Gulf of Venezuela, 8 km north of Malecon Oriental. The significant wave height (H_s) above 2.75 m has an occurrence rate of 1.27 percent in the area with a depth of about 11 m. The significant wave height just offshore of the Gulf of Venezuela is higher than 4.25 m with an occurrence rate of 2.62 percent. It is assumed that the significant wave height at the end of channel section-1 and in sections-2, a depth of about 18 m, is somewhere in between (3.5 m). The channel sections are presented in appendix-4, page 29. The value of H_s between San Bernardo and the Island of Zapara is 0.7 m with an occurrence rate of 0.92 percent.

Only during severe storms and lost hurricanes, like the ones which occurred last few years, no vessels are allowed to sail through the channel. The channel bottom consists of very fine sand with some silt and clay.

The preliminary assessment of the channel depth of the first straight channel section from 'Zona Portuaria Simon Bolivar' and the other section can be determined with the following formula:

$d = D - T + s_{max} + r + m$, in which:

d_0 = The guaranteed depth inside the port (with respect to a specified reference level) [m].

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d_1 = The guaranteed depth at the beginning of channel, nearby the island of

Zapara, section-1 (with respect to a specified reference level) [m].

d_2 = The guaranteed depth at the end of channel section-1 and section-2 (with respect to a specified

reference level) [m].

D = The draught design vessel: Panamax container vessel [12.5 m].

T = The tidal elevation above reference level below which no entrance is allowed [m].

s_{max} = The maximum sinkage (fore or aft) due to squat and trim [0.5 m].

The vertical motion due to wave response is based on the maximum wave height of $2H_s$.

r_0 = The vertical motion due to wave response (H_s) → [0.70 m].

r_1 = The vertical motion due to wave response (H_s) → [2.75 m].

r_2 = The vertical motion due to wave response (H_s) → [3.5 m].

m = The remaining safety margin or net underkeel clearance [0.5 m].

The guaranteed depth of the channel needs to be:

$d_0 = 12.5 - 0 + 0.5 + 0.7 + 0.5 = 14.2$ m (47 ft).

$d_1 = 12.5 - 0 + 0.5 + 2.75 + 0.5 = 16.25$ m (54 ft).

$d_2 = 12.5 - 0 + 0.5 + 3.5 + 0.5 = 17$ m (56 ft).

This depth is relative to Zero Zapara (see section 2.4.3 Tides and water levels).

The required channel depth for the push barge units is 5.1 m and the required channel depth for the chemical barges to the island of Zapara is 4.2 m. The calculation of the channel depths of the shallow channels for the push barge units and for the vessel to the oil barge harbour are presented in appendix-4 (Calculation channel widths and depths, page 30).

4.4.2   Channel width

The design vessel with the largest beam is an oil tanker of 47 m. This oil tanker has a maximum capacity of 169,000 tons and do not enter 'Zona Portuaria Simon Bolivar' very often. The average capacity is 147,000 tons of crude oil. As earlier mentioned, these vessels will also be partly loaded (80%) to be able to enter 'Zona Portuaria Simon Bolivar' through the channel.

An important matter in the determination of the channel width is the amount of lanes. Will a one-lane channel be enough for all the vessel traffic or must a two-lane channel be constructed? The length of the channel will be influenced by the water depth in the Gulf of Venezuela. As presented in this appendix-4 (Channel sections map, page 29), the shortest distance through these shallow areas is as follows:

The first channel section from 'Zona Portuaria Simon Bolivar' is about 44 km and the second channel section is about 30 km.

This total distance is very long for a one-lane channel. Due to the large amount of vessels a two-lane channel will be necessary for the smaller vessels. Perhaps it is possible to use the channel for one way traffic for the coal carriers and the oil tankers. The necessary time for the vessels to sail the 44 km channel section with an average speed of 15 kn is 1.6 hours. The amount of oil tankers (641) and coal carriers (238) will be able to sail through the one way channel section without causing too much delay for the other vessels because an average total of 2.4 tankers and carriers per day will sail the channel. This assumption need to be checked by a simulation model. The maximum width of a one lane channel section for the oil tankers or a two-lane channel

section for the other remaining vessels will be evaluated to determine the final channel width. The design vessel for the two lane section is the Panamax container vessel of 32 m wide.

The projected future channel locations are straight channel sections.

For a one-lane straight channel section, the channel width is described by the PIANC rules with the following formula:

$$W = W_{BM} + \Sigma W_i + 2 \cdot W_B$$

For a two-lane straight channel section, the channel width is described by the following formula:

$$W = 2(W_{BM} + \Sigma W_i + W_B) + W_p \text{, in which;}$$

W_{BM} = Basic width.

ΣW_i = All the additional widths.

W_B = Bank clearance.

W_P = Separation distance due to the two way channel.

When the tidal range exceeds about 4 meters, the minimum width of the channel has to be the length of the design vessel. The vessel can run aground, turn with the tide in the channel, hit the opposite bank and break at falling tide. The tidal range is 1.4 meter, so the earlier mentioned formula will be used to determine the channel width.

W_{BM0} = 1.7B (depth/draught = 1.09)

W_{BM1} = 1.7B (depth/draught = 1.15)

W_{BM2} = 1.7B (depth/draught = 1.18)

ΣW_i :

Prevailing cross-winds:

In chapter-2, the probability of accidence of the wind is presented for the orientation of channel section-1 and 2. Crosswinds for section-1 have to be evaluated between 15 and 75 degrees. The probability of the occurring crosswinds of 11.1 m/s (22 kn) is 6.01 percent between 45 and 75 degrees. → W=0.4B. Crosswinds for section-2 have to be evaluated between -15 and 15 degrees. The probability of the occurring crosswinds of 5.3 m/s (10.6 kn) is 3.4 percent between -15 and 15 degrees. The extra width necessary for cross winds is negligible for channel section-2.

Prevailing cross-currents:

As earlier mentioned in the section of the current site conditions, the current velocities will reach no more than 0.2 m/s (0.4 kn). The extra width necessary for cross currents is therefore negligible.

Prevailing long-currents:

The long currents in the channel sections will be no more than 0.4 kn. This can be concluded due to the fact that the channel depth and the surrounding water depth of channel section-2 do not vary much. The only area where the longitudinal current in the channel will be approximately 2.4 kn is the area between San Bernardo and the island of Zapara. This location is described in the section about the site conditions of the currents. If the long currents of 2.4 kn occur during spring tide, the design vessel will be assisted by tugs. The extra width necessary for long currents is also negligible.

Prevailing wave height:

As mentioned before, the significant wave height between San Bernardo and the Island of Zapara is 0.7 m. The extra width is negligible.

As mentioned before, the significant wave height at the beginning of channel section-1 is 2.75 m. → W=1.0B.

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As mentioned before, the significant wave height at the end of channel section-1 and section-2 is < 3.0 m. →
W=1.0B.

Aids to navigation:

The aids to navigation are good. → W=0.1B.

Seabed characteristics:

The seabed characteristics are soft. → W=0.1B.

Cargo hazard:

The cargo hazard is medium due to the oil tankers. → W=0.5B.

W_B = The bank will have a sloping edge due to the sandy seabed characteristics. → W=0.5B.

W_{P0} = Due to the fact that the vessel speed will be reduced to about 5 kn to keep sufficient rudder control, the separation distance will be negligible.

W_{P1} = Due to the fact that the maximum crosscurrent is 0.4 kn and the vessel speed will be between 5-8 kn at the first part of channel section-1, the separation distance will be → W=1,2B.

W_{P2} = Due to the fact that the maximum crosscurrent is 0.4 kn and the vessel speed will be between 8-12 kn at the last part of channel section-1 and in channel section-2, the separation distance will be → W=1.6B.

The width of a two-lane channel is:

$$W_{inside} = 2(1,7B + 0,1B + 0,5B) = 4,6B = 148 \text{ m.}$$

$$W_1 = 2(1,7B + 2,1B + 0,5B) + 1,2B = 9,8B = 314 \text{ m.}$$

$$W_2 = 2(1,7B + 2,1B + 0,5B) + 1,6B = 10,2B = 326 \text{ m.}$$

The width of the one-lane channel is:

$$(W_{inside} = 1,7B + 0,1B + 2 \cdot 0,5B = 2,8B = 132 \text{ m.})$$

$$W_1 = 1,7B + 2,1B + 2 \cdot 0,5B = 4,8B = 226 \text{ m.}$$

$$W_2 = 1,7B + 2,1B + 2 \cdot 0,5B = 4,8B = 226 \text{ m.}$$

The dimensions of the two-lane channel are required.

Because the channel width W_{inside} is relative small in comparison to the southern basin width of Pájaros and the northern channel width W_2, the width W_{inside} is increased. The difference in the amount of depth is two meters. For that reason the width is increased up to the same width as W_2. It is not possible to widen this channel section W_{inside} at the west side for alternatives 1 and 3 because the breakwater must protect the barges in the barge harbour against waves. figure 4-10 shows the channel widths.
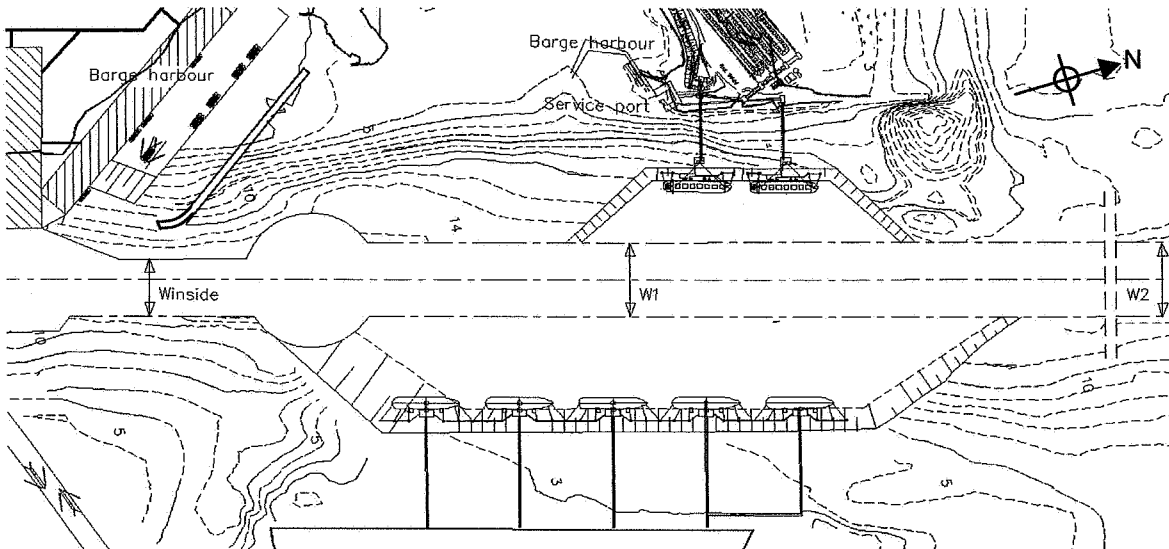
figure 4-10: Channel widths.

The required channel width for the push barge units is 151 m and the required channel width for the chemical and oil barges to the island of Zapara is 86 m. The calculation of these channel widths are presented in appendix-4 (Calculation channel widths and depths, page 30).

4.4.3   Channel length

An important dimension in the berth areas is the length of the channel inside the port in which the vessel has sufficient time to stop. When the vessel enters the port nearby the head of the Malecon Oriental dam, the probability of a significant wave height (H_s) higher than 1.5 m is 13.07 percent. This is a value taken from measurements between 1990 and 1999 as presented in appendix-4 (Waves at harbour entrance, page 34). Values for the possible wave conditions at several locations are predictions of measured data from the actual existing situation and computations of the former harbour lay-out at San Bernardo.

The wave propagation shows that a H_s of 5 meters in the Gulf of Venezuela leads to a wave height 1.5 meters at a specific point between the two dams. This point is presented in appendix-4 (Point of Hs 1.5 m, page 35). As earlier mentioned, the Hs of 5 meters in the Gulf of Venezuela, has an occurrence rate of 0.92 percent (3.5 days per year).

When vessels approach the port, the required minimum vessel speed to maintain sufficient rudder control is 3 or 4 kn without any hindrance of wind or currents. No extra vessel speed is necessary to reduce the cross current influence on the vessels because the cross currents are negligible.

Tug assistance is essential to assist the vessels to the berthing place. Due to the maximum operational conditions for the tugs, the H_s cannot be much higher than 1.5 m. In average circumstances, the time required for tying up the tugboats is approximately 10 minutes. The maximum speed of the vessel to tie up the tugboat is 5 or 6 kn. Due to the main wind direction, which is almost 90 degrees to the axis of the channel, the vessel speed must be 5 kn to maintain sufficient rudder control. This speed becomes 7 kn because of the maximum flow velocity is 2 kn during flood. From the point between the dams, where H_s is less than 1.5 m, the vessel will require 2100 m before the tugs are ready to pull. The actual stopping distance of the vessel with 3 or 4 tugs will be approximately 2 times the vessel length. This will be 580 m for the design coal carrier. The total channel length from the point where Hs do not became higher than 1.5 m (presented in appendix-4, page 35) up to the turning circle is 2680 m.

4.4.4   Basin dimensions

Due to wind speeds higher than 11.1 m/s, with an occurrence rate of 8.38 percent and a direction of 45 degrees north, the bow of the vessels will tan to port. To allow drift angles in the first part of the channel, protected by the two dams, has a length of 2-3 L_s. Over this length (580 m) the width stays 314 m.

When the tugs stop the vessel at the end of the channel, a turning basin is required to turn the vessels and tow them to their berth location. The diameter of this turning basin has to be at least 2 L_s (580 m).

The areas inside the port need to be determined. In this phase of the port design, the layout of the port has not yet been determined but some dimensions can already be calculated.

A sufficient basin width for towing conventional cargo vessels and container ships, while the opposite berth is occupied, is 4 to 5B + 100 m. For big tankers and bulk carriers, such as the design coal carrier, a basin width of 4 to 6B + 100 m is necessary. This width also accounts for two-sided use of the basin. The low value applies to favourable wind conditions and the high value when cross winds are the dominant wind direction.

In case of very long basins, for instance longer than 1 km, it is required that the vessel can be turned in the basin. The basin width will approximately be $L+B+50$ m or $8B+50$ m for the largest vessel that will be handled in the port basin [Ports and terminals, 2000]. The biggest vessels arriving in the port basin of Pájaros are the Panamax container vessel and the Salt bulk carrier. The widths of these two vessels are about 32 m. In lay-out 1, 2 and 4, the barges will pass the port basin east of Pájaros at the east side. If a vessel is manoeuvring in the basin the barges must be able to pass. For this reason the basin width is increased with the barge channel width of 150 meters (see appendix 4, page 30). The basin width in lay-out 3 is 300 meters and the basin width in lay-outs 1, 2 and 4 are 450 m.

The basin width of the oil tankers at the west side of Zapara is determined by the safe passage distance of vessels and the minimum construction and maintenance costs for the oil tanker jetties and the capital and maintenance dredging costs of the basin area. The loading arms of the oil jetties are located 620 m. west of the island Zapara and the width of the basin is 300 m. This evaluation is presented in appendix-4 (Calculation of the oil tanker and coal carrier basin width, page 36).

The basin width of the coal carriers at the east side of San Bernardo is also determined by the safe passage distance of vessels and minimum construction and maintenance costs for the coal tanker jetties and the capital and maintenance dredging costs of the basin area. The berthing line of the coal jetties is located 290 m east of San Bernardo and the width of the basin is 300 m due to the occurring waves and currents caused by the vessels in the channel.

This evaluation is also presented in appendix-4 (Calculation of the oil tanker and coal carrier basin width, page 37).

The required width for the barge harbour basin is as follows: Because the barges (95 m LOA and a width of 11.4 m) must be able to be turned in the basin the width is approximately $L+B+50 = 95+11.4+50 = 160$ m. The total basin width, with a two-sided use caused by the barge harbour and the opposite waiting facilities, is $160+11.4+24 = 195$ m.

4.4.5   Berth orientation

Considering the wave and current conditions, the correct berth orientation is important to ensure safe berthing. Wave heights are reduced by the Malecon Oriental dam and the current conditions are no more than 2.4 kn in the centre of the channel between the island of San Bernardo and Zapara. These current velocities occur during the spring tide. Measured and computed data tell us that the maximum velocity on that place will not exceed 1.25 m/s (2.5 kn).

The computed value is produced by a simulation model while the channel between the end of 'Zona Portuaria Simon Bolivar' and Lake of Maracaibo has not been closed yet. For this design phase, these values have been taken for the preliminary design. A new flow modal will give more detailed information about the currents in the port of 'Zona Portuaria Simon Bolivar'. This flow model is presented in chapter 7, Hydraulic data lay-out-2. Currents along side the berth needs to be limited to a minimum of 3 kn or preferable less than this value and perpendicular to the berth no more than 0.75 kn is allowed. Also for safe berthing, the alignment of the quay is preferred to be within 30 degrees of the prevailing wind direction. The final orientation of the quays and the flow velocities in the port basins are discussed in chapter-5, Harbour lay-outs.

4.4.6   Morphology

Sedimentation is a very important issues for the design of a port layout. Maintenance dredging is a very expensive operation. To minimise these costs and make the port feasible, the location of the basins and channel have to be chosen wisely. It is difficult to predict the influence of changed depth due to the new basins on the currents and morphological aspects. Another phenomenon that will influence the design of a port lay-out is the slow siltation of the access channel from 'Zona Portuaria Simon Bolivar' to the Lake of Maracaibo. The flow velocity will increase a little in the former channel area west of the island of Pescaderos (figure-13, appendix-7) due to the channel closure. Also the flow velocity in the former natural channel east of Pescaderos will increase as a result of the channel closure. The function of the Malecon Oriental dam is to intercept littoral transport from the south east. This littoral sediment transport is caused by the tidal currents and occurring waves in the Gulf of Venezuela. Waves themselves do not introduce a high sediment transport rate. They mainly influence the sediment concentration distribution by stirring up material. The long shore sediment transport at the north side of the islands of San Bernardo and Zapara is caused by waves and the currents parallel to the shore. Most of the time, the currents velocities are not high and the prevailing wave direction has a 90 degrees angle with the shore line. Wave angles different than 90 degrees to the shore causes currents along the shores. Due to the prevailing wave direction, the wave does not increase the little cross currents. This results in little sediment transport north of the islands of San Bernardo and Zapara.

4.4.7   Wave agitation

As earlier mentioned, the wave penetration in 'Zona Portuaria Simon Bolivar' is not very high. The wave propagation, which is simulated and earlier shown in appendix-4 (Point of Hs 1.5 m, page, 35), shows a H_s of no more than 0.8 m close to the coast line of the island of Pájaros. When the future channel will be deepened to 56 ft, the wave height will increase a little. In general terms it is forecasted that this will be negligible. In this preliminary design phase it can be concluded that the wave penetration from the Gulf of Venezuela is small. Another possible wave attack could possibly come from the Tablazo bay area east of Pájaros. The average depth in this area is about 1 m. Small wave heights and wave periods will be developed. Possible wave attack could be developed in the area south of the island of Zapara with an average depth of 2 m over a the first 15 km and 3 m over the last 15 km.

Breaking of a wave occurs because a wave is very steep (on deepwater) or because the water is very shallow as in Tablazo bay. Both limits are described with the breaking criterion by Miche:

$$H_B = 0{,}142 \cdot L \cdot \tanh\left(\frac{2\pi}{L} \cdot h\right)$$, in which h=water depth, L=wave length and H_B =height of the breaking wave,

[Introduction to bed bank and shore protection, 2001]. Due to the shallow foreshore in Tablazo bay and no available wave measurements or computations, the earlier mentioned formula applied to H_s leads to

$\dfrac{H_s}{h} \approx 0.4 - 0.5$. With the upper limit of the ratio, the largest H_s will be approximately 1.5 m. When these waves hit a quay and fully reflect, they become higher than 1.5 m. The resulting wave heights are not translated into ship motions of a moored vessel because these waves have already been reflected against the quay of ship. The next thing to determine in the preliminary design stage is the limiting operational wave heights for the vessels. Table 4-7shows these wave heights.

Vessel type/ Limiting wave heights Hs (m)	0°(head or stern)	45°-90° (beam)
General cargo	1.0	0.8
Container	0.5	< 0.5
Dry bulk (30.000 dwt): loading	1.5	1.0
Tankers (30.000 dwt)	1.5	
Tankers (30.000-200.000 dwt)	1.5-2.5	1.0-1.2
Tankers(>200.000 dwt)	2.5-3.0	1.0-1.5

Table 4-7: Limiting operational wave heights.

With these values it is possible to generate general layouts without taking into account the wave periods and the effect of mooring systems on the ship movements. There will be no limit state conditions allowed in 'Zona Portuaria Simon Bolivar', only operational limit conditions. The limit state conditions will be avoided in the best way possible when designing the port layout.

Not only the operational conditions are of importance, also the allowable ship motions have to fulfil the operational criteria. Different wave heights are allowed for the vessels. For instance, container vessels are more critical because of high precision during container handling while tankers are handled midships with a central manifold. Table 4-8 shows these allowable ship motions [Ports and terminals, 2000].

Type of ship	Surge (m)	Sway (m)	Yaw ()	Heave (m)
Tankers	2.0-3.0	2.0-3.0	1.0	1.5
Bulk carriers	0.5-1.5	0.5-1.0	-	0.3-0.5
Container vessels	0.5	0.3	1.0	0.3

Table 4-8: Allowable ship motions.

4.4.8   Water level rise

The water level rise due to strong winds from the east of Pájaros with a fetch of 30 km is negligible. It is logical that the water level will not to rise because the fetch does not end in a closed basin but in an area where the water can flow in any direction with an average depth of 0.5 m. The only way the water level will rise a little is by maximum flood during spring tide and when Rio Limon has a high discharge rate into the bay west of the island of Pájaros.

The water level changes between the present situation and the future situation of the new lay-out are computed and presented in figures 6-25 (appendix-7). The observation points are presented in figures 3a,b and 4 (appendix-7, page 3,4,5).

4.4.9   Port basin resonance

Wave attack and flow velocity are not the only things that may lead to severe problems for ships at berth. If a port basin is rectangular shaped and has a uniform depth, the natural periods of oscillation can be the same as the incoming waves. This phenomenon leads to much higher water levels in some areas in the port basin. The design formula for closed and open basins is:

$$T_{n(open)} = \frac{4L_B}{(1+2n)} \cdot \frac{1}{\sqrt{gD}}$$. Most problems occur when T_n is close to long swell periods of 10-16 seconds or long

waves with periods of 30 to 300 seconds. When the port layout has been chosen, simulation modals can be used to ensure the precise frequencies of the port basins. Similar frequencies of the waves and the natural frequencies of the basins must be avoided. A way to avoid problems is to design no regular shapes in the basins. Due to the surrounding water depths of about 0.5 or 1.0 m and the sloping edge of the basins, the oscillating effect will be damped and is assumed to be negligible.

5 Harbour lay-outs

5.1 Introduction

In the previous section the required dimensions has been presented. In this chapter a number of possible harbour lay-outs will be discussed. The two main issues that differ in these lay-outs are the different terminal locations, barge harbour locations and routes of the access channel for the barges.

During the evaluation of the lay-outs, the maximum allowable wind, current and wave conditions for the vessels will be discussed. Use will be made of the results of the wave propagation simulation model in Swan, which is produced by Alkyon Hydraulic Consultancy & Research for the Puerto America project. The output of this wave propagation model presents the wave propagation from the Gulf of Venezuela and current condition into the former harbour lay-out of Puerto America, with the future port basin and closed access channel. The waves caused by the wind are measured nearby the project site and are shown in appendix-5, table 1 and 2. These values are discussed in the following sections. When all these data are put together, the different lay-outs are determined and their individual disadvantages are discussed. In the following sections the final wind, wave and current condition will be discussed for all the different lay-outs. Because the wave penetration and the different current conditions are not precisely known in the phase where the several harbour lay-outs need to be evaluated. When a particular alternative is chosen to be designed in further detail, the flow velocities and wave penetration will than be simulated. The flow velocities for the chosen lay-out are presented in chapter-7. The wave penetration in the future lay-out need to be further investigated and is not included in this feasibility study. Until that phase, the flow velocities and wave penetration data of the Puerto America project will be used for the 'Simon Bolivar' project.

In all four lay-outs the commodities of coal and oil will be located in the area numbers 1 and 2. All areas are presented in the figure below. The remaining commodities will be located in area number 3 on the island of Pájaros. The basin of the oil tankers and coal carriers will be located in area number 4 and the other ocean going vessels will be berthed in area number 5. The position of these areas is the same for all four alternatives.
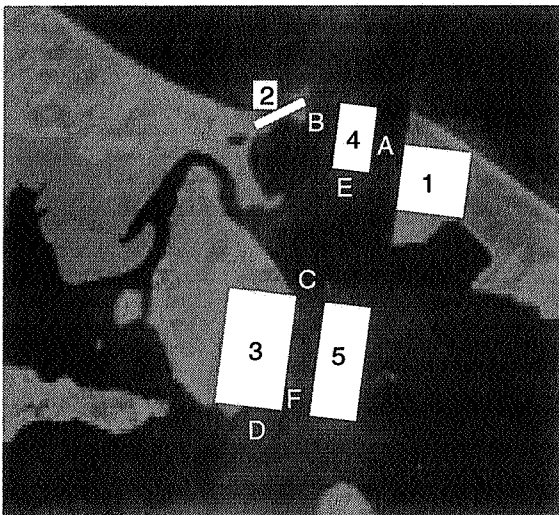

Figure: Location of commodities and locations of the basins.

Some important question during the design process will be:

1.   Can the different types of vessels and barges stay at their berths during occurring wind, waves and current forces?

2.   Can the different types of vessels and barges manoeuvre in a safe way to their berth location?

3.   Is the maximum downtime for the different types of vessel permitted?

4.   Is the sedimentation rate allowable in the basins and channels?

During the design of the possible lay-outs, these questions need to be taken into account. At the end of the lay-out determination, these questions need to be evaluated by simulation models and calculations of the future harbour lay-out. In this feasibility study the future flow velocity is simulated in Delft 3D (Chapter-7) and the sedimentation in the barge harbour basin and the basin east of Pájaros is evaluated. A nautical study is required for the future harbour lay-out and a simulation model need to be produced to determine whether the average waiting times of the vessels are not too high. Both two studies are not included in this feasibility study.

5.2   Wave agitation at possible berths

All values for the possible wave conditions at several locations are predictions of measured data from the actual existing situation and computations of the former harbour lay-out at San Bernardo. The four locations which are evaluated are shown in the figure at page 50:

A.   The Berth location for the Oil tankers at the west side of the Island of Zapara.

The result of the wave propagation model, produced by Alkyon, is shown in appendix-4 (Point where Hs<1,5 m, page 35). In this figure the location where the wave height is between 1.0-1.5 m is presented during a significant wave height of 5 m in the Gulf of Venezuela. Measured data shows the H_s will be approximately 0.5-0.6 m in 3.57 percent of the time (13 days per year) as shown in tables of appendix-2 (table-31, page 38). Because this is measured wave height in the middle of the basin, the significant wave height nearby the berths of the oil tankers will be less. The presented values in section 4.4.7. of a maximum H_s of 1.5 m will not be exceeded.

B.   The Berth location for the Coal carriers at the east side of San Bernardo.

The same H_s as for the oil tanker basin is forecasted for the berth location of the oil tankers. Perhaps the wave penetration will be somewhat higher than by the oil tankers caused by the waves generated by the dominant wind from the north east over a distance of a few hundred meters. This will be negligible. The presented values in section 4.4.7 of a maximum H_s of 1.0 m will not be exceeded.

C.   The north east side of the Island of Pájaros.

As presented in appendix-2, the computed wave heights caused by penetrated waves (H_s = 5 m) from the Gulf of Venezuela are about 0.2 m. Measurements of the H_s at the north east side of the Island of Pájaros show that H_s is 0.4 m with a probability of 0.48 percent (1.7 days per year).

Another phenomenon is the local wave growth caused by the wind blowing from the dominant wind direction. This wind speed is 14.1 m/s from 15-165 degrees during 0.62 percent of the total time per year (2,3 days per year). The maximum wave height caused by this wind speed over a fetch length of about 3 km and an average depth of 2-3 m will be 0.6 m with a probability of 1.18 percent (4.3 days per year). Al the above discussed data is shown in appendix-5, table-3 (Local wave growth).

D.   The south east side of the Island of Pájaros.

There will be no wave penetration from the Gulf of Venezuela. Only small and short waves will arrive from areas with a depth of about 2 m. At this location the same local condition are occurring as at the north east side of the Island of Pájaros.

At the end of design phase, the final port lay-out and the wave agitation must be simulated to check whether the assumptions are correct.

5.3   Currents

The same situation accounts for the occurring currents in the future situation. As earlier mentioned, the computed situation for the deepwater basin between San Bernardo and the Island of Zapara is representative for the future situation. The average flow velocity during spring tide at location E (figure, page 50) is about 0.8 m/s. Such a flow velocity is acceptable during manoeuvring of the coal carriers and oil tankers. Prevailing velocities nearby the breasting and mooring dolphins will be less than 0.8 m/s. The shallow areas surrounding the port basin and the current velocities through the channel during ebb causes an eddy in the port basin nearby the moored vessels location F (figure, page 50). When the oil tankers are listing to port, velocities of about 0.3 m/s occur, with an angle of 60 degrees perpendicular to starboard side, during spring tide.

The flow velocity in the port basin east of the island of Pájaros has not been computed yet. At present times, the flow velocity is maximum 1.0 m/s in the channel. The increase of depth at the future basin location will decrease the flow velocity in this area.

At the end of design phase, also the final port lay-out and the current velocities must be simulated to check whether the assumptions are correct.

5.4   Winds

As presented in chapter-2, the prevailing wind direction just offshore the Gulf of Venezuela is 75-105 degrees. A wind velocity of 11.15-14.15 m/s occurs in 5.56 percent of the time (20 days per year) at a height of 10 m. Nearby 'Zona Portuaria Simon Bolivar', at Cano Paijana, wind measurements are available for the years 1995 and 1996. During 0.48 percent of the time (1.7 days per year) a wind speed of 14.1 m/s between 45-75 degrees occurred. The possible down time of for instance the container vessels is not much due to the low percentage of occurrence of high winds.

5.5   Lay-out assumptions

The lay-out assumptions in relation to the terminal areas are:

1. The coal terminal will be situated on San Bernardo. This location is selected because the prevailing wind direction is parallel to the stockpile length. Due to the hot and dry environment in the 'Zona Portuaria Simon Bolivar' area, this terminal orientation will minimize the dust nuisance. To further decrease this nuisance, water or a thin layer of glucose can be sprayed over the stockpiles. Another main influence on the location determination is the fact the hinterland connections for rails and roads can be constructed properly without difficult passages. An aerial view of the coal terminal location is shown in figure 5-1. For the orientation, this picture is taken to north western direction. The coal terminal will be placed on the uninhabited area at the north east side as close as possible to the port entrance. The other location, at the south side of the peninsula, is not acceptable because a small town called San Carlos is located here with local beaches on the east side of the town.
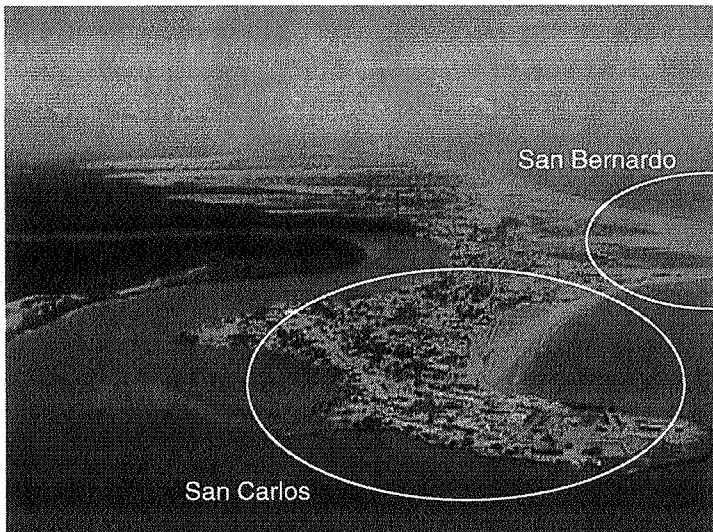
figure 5-1: Aerial view of San Bernardo and San Carlos.

Another argument for positioning of the coal terminal location is the short distance to the port entrance and the berthing locations of the coal carriers. The berth facilities will be one jetty in phase-1 and two jetties in phase-. A jetty for such coal carriers, with a depth of about 45 ft, will be much cheaper than a quay construction. Also the currents during spring tide, between San Bernardo and the Island of Zapara, will be much lower because the current will flow underneath the jetty.

2.   The oil terminal will be located at the Island of Zapara. For the new oil terminal and possible future LNG-LPG plant the location has to be situated as near to the seaside harbour entrance as possible. Because of the major quantities of hazardous cargos to be handled, the location should be isolated from the rest of the harbour and far from residential areas, passenger terminals and other facilities [Dangerous cargoes in ports, 2000]. Another reason for the assumption of the site location is also the great draught of the tankers. Like the coal carriers, the berths of the tankers will be directly parallel to the access channel at the port entrance. As described earlier, the assumption is made that the oil tankers will berth alongside a jetty. Another possibility is the use of Single Buoy Moorings (SBM's). The advantages of SBM's [Dangerous cargoes in ports, 2000] are: Vessels always take the most favourable position in relation to the combination of wind, current and waves. The use of SBM's is attractive because of the simplicity of the system and low investment costs.

No expanses will have to be made because no tug assistance of the oil tankers is required. For the use of SBM's, a single mooring launch is sufficient.

A rough estimation of the investment costs for VLCC jetties, fully equipped including local dredging, is about 2.5 times as high as a SBM with a 36" submarine pipeline of 5 km length.

On the other hand, the distance for enough depth for a SBM is much more than 5 km and the investment costs will be much higher. The maintenance costs of SBM's are considerably higher than for jetties. For example the hoses under water between pipeline and buoy and the floating hoses between buoy and vessel require still inspections and frequent replacement. Another important disadvantage of an SBM is that the loading capacity of the oil tankers is less than when a jetty is used.

The most important reason not to use SBM's is the fact that use can be made of the present access channel without too much extra dredging of the channel.

In general, for a small and moderate throughput per year, SBM's will be a better choice than jetties. It will be more economical profitable with the VLCC in 'Zona Portuaria Simon Bolivar' with large throughputs to assume 5 jetties at the west side of the island of Zapara in the sheltered area.

Other lay-out assumptions in relation to the barge waterways are:

1. One possible route of the barges is the old natural channel at the south side of the island Zapara and at the east side of the island of Pescaderos. This old natural channel needs to be dredged in some areas but the amount of material will not be much because the water from and to Tablazo Bay still runs through the old natural channel.

2. Another possibility for barges arriving from and departing to the lake of Maracaibo is to use the present channel west of Pescaderos until the channel depth becomes less than the required depth for the barges as a result of sedimentation. Maintenance dredging will be required afterwards.

5.6   Background of the four lay-outs

In the following two sections, the background information is discussed which will lead to the four lay-outs.

5.6.1   Wet infra structure

All different routes of the barges and the sea going vessels must fulfil the requirements of safety. The wave and current conditions must not endanger the workability of the barges and the sea going vessels. Another safety issue is the number of crossing between barges and other sea going vessels. If these numbers are too high, precautions will have to be made. A waiting area for the barges in a relatively sheltered area can be constructed for example. The flow velocity data and wave penetration data are taken, as discussed in section 5.1, from the former master plan of Puerto America produced by Alkyon. When a final lay-out has been selected, new simulations of the wave penetration and currents in the harbour need to be performed. This has to be done in order to check whether the waves cause the barges to move in their own frequency and whether the flow velocity is not too high for ship and barge manoeuvring.

When all these data are known, a nautical simulation needs to be developed, in order to check whether the vessels and barges can make safe manoeuvres during these wind, waves and current conditions. This nautical study is not included in this feasibility study

All four lay-outs have the same access channel lay-out position of the turning basin. These dimensions are presented in chapter 4. The port basins for the different terminals are close to the present channel. Due to the shallow water area (except oil, coal and iron ore) it is possible to reclaim up to the required quay position or dredge the basin until the required basin width is accomplished. The best compromise between these two options results in a good landfill-dredging ratio. The port basin will now use a part of the present depth of the channel. The positions of the jetties for the coal carriers and oil tankers are as close as possible, but at a safe distance from the access channel. The amount of material to be dredged will be as little as possible. On the other hand, the construction costs will increase when the length of the jetties increase. Further investigation is needed to determine the optimum between dredging and jetty costs. The berthed vessels lay parallel with the access channel. The waves and current attack from about zero degrees head. This is not entirely correct for the oil tankers due to the possible eddy in the harbour basin of the oil terminal.

A separate berth location is required for the pilot boats, tug boats and coast guard vessels. It is preferable to locate this small basin close to the port entrance. The wave agitation must be low and the basin area must be well protected because the vessels are relatively small. Many different locations are possible. Only locations in relation to their wave penetration characteristics, extension possibilities of the surrounding terminals, maintenance dredging, location close to the port entrance and port location will be taken into account. One of

the possible locations, in the sheltered area of the island of Zapara, is no option on forehand. Although all characteristics as mentioned earlier are excellent, the accessibility to the port is a problem. For this reason, this location will not be discusses as an option.

5.6.2   Dry infrastructure

The space that is required for the different terminal areas is discussed in chapter 4. As mentioned earlier, the terminals (except the steel plant) are located on the east side of the island of Pájaros. New soil samples are needed for further research on the soil conditions, to decide which transportation system will be used. Firm soil conditions are needed to use Rubber Tyred Gantry (RTG), otherwise Rail Mounted Gantry (RMG) cranes can be used with foundation to prevent any soil settlment. For the general cargo terminal several mobile cranes will be needed to load and unload the vessels. Some vessels will be unloaded by their own ship's derricks. A special type of crane will be needed to load the steel plates from the steel factory into the coasters. Such a steel plate weights about 40 tons. Depending on the steel production of the plant, several steel plates of 40 tons will be transported from the steel factory to the general cargo terminal, as earlier mentioned, the steel production of the plant is about $1.2*10^6$ MTPA. This will be approximately 3300 tons of steel per day. To transport these 80 steel plates per day, two options are possible. The first option is a train with 40 wagons with a carrying capacity of 100 tons, the second options is the use of 80 trucks which transport the steel plates to the general cargo terminal. Three or four trucks per hour will arrive at the terminal. This is acceptable, and no major investment costs have to be made for a separate rail transportation system.

A part of the transportation to and from the island of Pájaros will be through the barge harbour. Another way to transport the goods is by trucks.

The position of the barge harbour for all the different barges is located on the north or south side of the island of Pájaros. A Multi Trailer System (MTS) or Automated Guided Vehicles (AGV) will be used to transport the containers between the barge harbour and the container terminal. The arriving iron ore pallets for the steel factory in barges will be transported by conveyor bells to the storage facility of the steel factory.

No barges will be handled at the quays for the sea going vessels due to the already high occupancy rate in the year 2028. However, it is possible to build the barges harbour in a later phase because the occupancy rate will not be that high in phase 1. A disadvantage of the barges berthing at the quays are the waves produced by the passing sea going vessels and the down time due to the occurring wave climate.

In phase 2, all the transportation of cereal cargo, cement related products and general cargo between the barge harbour and the terminals will be done by trucks. All gates are central elements on the terminals where all exported cargo arrives and imported cargo leaves. Customs will record all these entrees and arrivals. When the final terminal areas are designed, it is important to reserve enough space for customs, required offices and parking.

One main highway will be constructed from the hinterland to the island. Three factors play an important role in the location of a crossover from the mainland to the island.
- Disturbance of the mangroves at the west side of the island.
- River between San Bernardo and the island of Pájaros.
- Location of the little town called San Carlos.

The dedicated railway for the coal wagons end at San Bernardo, just north of Pájaros across the river. Most of the mangroves are located at the west side of the island of Pájaros. Due to these two factors, it is assumed that the highway will be positioned parallel to the railway and will cross the river to Pájaros at the north side of the island. Further research on the soil conditions and river characteristics should be done before it can be

decided on which location the bridge will be build. The location of the crossing is the same for all four lay-outs and is shown figure 5-2.
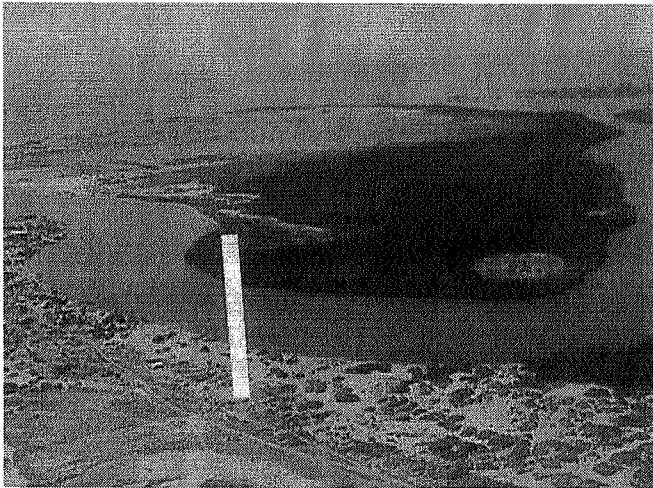
figure 5-2: Location of bridge between San Carlos and Pájaros.

Positioning the terminals from north to south on the island of Pájaros will be influenced by many factors, like:
- Soil characteristics, for the required bearing capacity of the terminal stockpiles and handling equipment.
- The maximum required depth for the vessels. It is not wise to place a terminal for vessels with little draught between two others which require larger basin depths.
- Main wind direction, for disturbance caused by dust of the coal, clinker, iron ore or cement related terminals.
- Dust production will occur during (un)loading of the vessels, barges, trains and trucks.
- Possible future terminal extensions and the extension of the quay length.
- Traffic intensity to and from the different terminals.
- Possible location of the service port.

These factors are now discussed in further detail:
Several soil samples are required to determine the bearing capacity of the terminal area's for the stockpiles, handling equipment, buildings etc. These data are not yet available. For this reason, these data are not yet available and will not be taken into account.
A big influence on the decision is the required decreasing vessel depth per terminal from north to south. The maximum vessel draught of the container and cereal terminal will be about 42 ft, the depth of the cement related vessels will be 43 ft and the maximum depth of a general cargo vessel will be about 27 ft. As a result of this decreasing necessary basin depth it would be logical to position the general cargo terminal of the south side of the island of Pájaros. On the other hand, it is wise to position the general cargo terminal next to the container terminal. When the terminals are operational for a few years, the general cargo terminal can shift their transportation more to container handling. This is an uncertain factor and therefore the required container terminal area for phase-2 and 3 will not be reduced as a result of the possible extra container throughput by the general cargo terminal.
As a result of the dominant wind direction, the cement related terminal will be positioned south of the cereal terminal due to possible cement dust hindrance on the cereal terminal.

The possible future extensions of the quay length and the terminal area are of importance for the harbour lay-out. As a result of the number of berths and quay length for phase-1 and phase-2, two possible locations are

determined. The quay length for container the container terminal needs to be lengthened from 438m to 989m, and the quay length of the cement related/other dry bulk terminal needs to be lengthened from 165m to 310m. Two locations are possible when the terminals and quays are placed next to each other at the east side of the island of Pájaros. These locations will be at the far north and far south side of the island.

The position of the container terminal is preferred close to the barge harbour, because a lot of containers will be transported (450.000 TEU in the year 2028). The location of the cereal terminal is preferred north of the cement related terminal due to the dust production of the cereal terminal.

Another important matter is the traffic intensity which passes the different terminals. To generate little traffic intensity past the cement, cereal and general cargo terminals, it is wise to position the terminals in such a way that the terminal with the lowest traffic intensity is located at the end of the main road on the south side of the island. Table 5-1 shows the traffic intensity by road between the hinterland and the traffic intensity between the barge harbour and the terminals.

Terminal	Individual throughput per terminal to and from hinterland				Individual throughput per terminal to and from barge harbour on Pájaros		
	year 2018		year 2028		year 2018		year 2028
	# trucks	# barges	# trucks	# barges	# trucks		# trucks
container	336.000	2.860	547.667	4.665	263.333		429.333
breakbulk	46.378	-	52.114	-	-		-
cereals	73.933	89	99.300	119	34.800		39.833
dry bulk	2.933	120	2.933	120	-		-
cement	72.159	-	117.500	-	-		-
oil	-	3.934	-	3.934	-		-
coal	-	1.143	-	1.143	-		-
total	531.403	8.146	819.514	9.981	298.133		469.166

Table 5-1: Traffic intensity by road to and from the different terminals.

The amount of passing trucks per hour will be different for the terminals in each lay-out.

In the four harbour lay-outs, two locations for the barge harbour have been chosen, as discussed in the section about the wet infrastructure. The location will also be determined by the nautical requirements. Another important issue by this determination is the connection from the barge harbour to the different terminal areas. The most favourable situation is short infrastructure connections between the barge harbour and the terminals. In the next section the four lay-outs will be described separately. During the explanation of the different lay-outs in the next section, the traffic intensity caused by trucks from and to the hinterland, terminals and the barge harbour will be discussed.

5.7   Different harbour lay-outs

5.7.1   In general

In this section the different possible lay-outs will be evaluated. During the evaluation of the different lay-outs, the following general information will be discussed.

- Arrival and departure safety of the vessels and the barges.
- Terminal positioning and future extensions.
- Environmental loads on the vessels/barges and possible down time.
- Land fill/dredging ratio.
- Hinterland connections and infrastructure.
- Dredging volumes for the lay-outs and sedimentation.
- Environmental issues.

The developed lay-outs all fulfil the requirements of the earlier calculated terminal areas, quay length and required channel and basin dimensions. All these dimensions and different drawings of the lay-outs are shown in appendix-5.
Before discussing the different lay-out options, general information that applies for all the different lay-outs will be discussed. The facilities, services and safety requirements are implemented all implemented in the different lay-outs but not worked out in detail.
In the following sections the lay-out assumptions for each lay-out are the same.

5.7.2   Lay-out 1

The first alternative is an alternative with a barge channel at the same location as the present channel. The lay-out is shown in appendix-5 (Drawing lay-out 1). All arriving barges from Lake Maracaibo will sail in the channel up to the north east side of the island of Pájaros. From this point the oil and chemical related barges will go to the island of Zapara and the rest will go to the barge harbour north of the island of Pájaros. These arriving and leaving barges from Pájaros will cross the sea going vessels. In the worst case scenario, the oil tankers are still sailing through the present channel during phase 1,2,3 and the year 2028 because the start of the oil terminal is uncertain.
In that case, the number of sea going vessels that cross the sailing route of the barges is 6035 and is presented in appendix-5, table-4.
In phase 2, the amount of barges that will cross the sea going vessels per year is 10,334 and is presented in appendix-5, table-5.
The number of encounterings per hour is low (0.69 ocean going vessels per hour and 1.18 barges per hour). With a good Vessel Traffic System, the crossing of barges and vessels can be controlled in a safe manner. Probably one main problem is the occurring flow velocity perpendicular to the channel section to Zapara and the lack of information considering the morphology and sedimentation transport nearby the channel section. The basin of the barge harbour is located at the north east side of Pájaros. In this basin the flow velocity is low, but the barges will sail perpendicular to the current nearby the basin. Also the dominant wind direction is perpendicular to the quay of the basin. It needs to be checked if these conditions do not influence the manoeuvring capabilities of the barges too much. This evaluation is not included in this feasibility study.
Waves coming from the Gulf of Venezuela and the local generated waves cause downtime for the barge harbour. It might be possible to construct a small breakwater at the north east side of the basin. The incoming waves will not reach the barge harbour and the current will be possibly even less. If the flow velocity and the waves are less in the basin, maintenance dredging will also decrease. For now it is assumed that extra measures should be taken to protect the barge harbour basin on the island of Pájaros. No measures are taken to protect the barge harbour on the island of Zapara because of the sheltered area south west of the island. The terminal location from north to south on the island of Pájaros is: container terminal, general cargo terminal, cereal terminal and the cement related products terminal.

A big advantage of this terminal lay-out is the short distance from the container terminal to the barge harbour. Table 5-2 shows a summary of the traffic intensity which pas the terminals to the barge harbour and the hinterland.

Terminal	Container	General Cargo	Cereals	Cement
yr. 2018	531.403	230.203	183.825	75.092
yr. 2028	819.514	311.680	259.566	120.433

Table 5-2: Amount of trucks passing the individual terminals in 2028.

Because the container terminal is positioned at the most northern location, the traffic intensity on the main road at the west side of the terminal is low. The amount of 859.347 trucks passing the gate of the container terminal is 1.63 trucks per minute. This is acceptable.

After phase 2 it is likely to assume that more general cargo will be transported by containers. This development can be seen in the rest of the world. In case of large capacity growth, the container terminal quays must be extended southwards and the terminal area to the west. As a result of this, the general terminal area is not positioned next to the container terminal area but somewhat more to the south to sustain future extension possibilities for the container terminal.

The other terminal with possible capacity growth after 2028 will be the cement related/ other dry bulk terminal. The quays can be extended southwards. Land reclamation will be needed at the south side of the island of Pájaros.

Nearby the barge harbour of the assumed coal terminal, the service port is located. Possible wave penetration of waves from the Gulf of Venezuela and wind waves are low.

The pilot services and tug assistance can assist the vessels immediately when they enter the port. The total amount of area required for the service port need to be evaluated. This is not calculated in this feasibility study.

5.7.3   Lay-out 2

This second alternative is the alternative with the same access channel for the barges as the first alternative. The main difference is the position of the barge harbour and the sequence of the terminals on Pájaros. Extra basin width is created at the east side of the basin (presented with a 5 in the figure on page 50) to allow the oil barges to pass the ocean going vessels at a safe distance. Because the barge harbours are situated at the south side of Pájaros and the south side of Pájaros, no barges and sea going vessels will cross each other if the oil terminal and jetties are already be used. The lay-out is shown in appendix-5 (Drawing lay-out 2).

The same problem can occur as in the first alternative, namely the flow velocity perpendicular to the channel section nearby Zapara used by the oil barges.

At the south side of the island of Pájaros the barge harbour is situated. This location for the moored barges is a sheltered area. The incoming waves from the Gulf of Venezuela and wind waves from other than the dominant wind direction are negligible. Information concerning the current increase causes by the change in depth between the basin at the east side of the island of Pájaros and the barge harbour basin needs to be gathered. This information is important for the manoeuvring capabilities of the barges.

The terminal location from north to south is; cereal, cement related/dry bulk, general cargo and the container terminal. Like the first terminal lay-out, the barge harbour is situated next to the container terminal for a short transportation route of the containers. There will be no hindrance of other transported commodities.

A disadvantage of the container terminal location is the increase of traffic intensity past the other terminals. Table 5-3 shows the amount of trucks passing the individual terminals.

The traffic intensity past the terminals at the south side of the island is increased due to the container terminal.

Terminal	Cereals	Cement	General Cargo	Container
yr. 2018	336.000	492.270	417.178	370.800
yr. 2028	263.333	760.047	639.614	587.500

Table 5-3: Amount of trucks passing the individual terminals in 2028.

Also in alternative 2 the container terminal can extend towards the general cargo area in the north and to the west. If extensive container throughput growth occurs after the year 2028 it is possible, but expensive, to relocate the barge harbour more to the south and extend the quay of the container terminal.

At the north side of the cereal terminal the service port is located. The wind waves and penetrating waves from the Gulf of Venezuela are presented in section 5.2. The Hs of 0.4 m is small enough for the small boats when they are moored in a sheltered position inside the service port. The service port location is close to the turning basin but about 2 km away from the port entry.

5.7.4   Lay-out 3

This third alternative is a alternative with a barge channel at the east side of the island of Pescaderos. This lay-out is only feasible when the oil terminal is situated on the island of Zapara and the oil tankers do not sail through the present channel anymore. Otherwise the barges will be able to sail through the present channel in the future. The lay-out is shown in appendix-5 (Drawing lay-out 3).

The terminal location from north to south is the same as in alternative 1. For that reason, all barges, except the oil related ones, cross the channel nearby the north east of Pájaros. The amount of barges that will cross the sea going vessels in 2028 is the as in alternative 1.

Table 5-4 shows the same traffic intensity past the terminals due to the same terminal locations.

Terminal	Container	General Cargo	Cereals	Cement
yr. 2018	531.403	230.203	183.825	75.092
yr. 2028	819.514	311.680	259.566	120.433

Table 5-4: Amount of trucks passing the individual terminals in 2028.

If the maintenance dredging is stopped, the present channel section at the west side of Pescaderos will silt up. The old natural channel at the east side of Pescaderos is deep enough in some sections to sail in. The remaining parts need to be dredged. An advantage of the channel section from the main channel towards the oil barge harbour is the low flow velocity in this area. On the other hand, the dominant wind direction is perpendicular to the axis of the channel and can cause nautical problems for the barges.

In this alternative, the remaining lay-out of the wet infra structure is the same as in alternative 1.

5.7.5   Lay-out 4

This fourth alternative is the alternative with the access channel for all barges through the old natural channel at the east side of Pescaderos, like in alternative 3. The main difference is that there will be no crossing with

sea going vessels because the barge harbour is located at the most southern part of Zapara, like in alternative 2. The lay-out is shown in appendix-5 (Drawing lay-out 4).

All barges, except the coal and oil related ones, sail round the island to the barge harbour at the south side. In this way, the barges and sea going vessels do not disturb each other if the oil tankers do not sail through the present channel in future times. The barge harbour is located in a sheltered area. For now, it is assumed that the maintenance dredging for this basin area is low. The occurring flow velocity explained in alternative 2, needs to be simulated because it can cause sedimentation in the barge harbour basin and nautical problems for the barges.

The terminal locations from north to south are the same as in alternative 2. Also the service port is located north of the cereal terminal. All extension possibilities of the quay lengths, terminal areas and traffic intensity past the terminals, are described in section 5.7.3.

6 Multi Criteria Evaluation

6.1 Introduction

In the former chapter four different lay-outs are described. To evaluate these four alternatives a Multi Criteria Evaluation (MCE) is used. In a MCE the alternatives are analysed by different criteria. These criteria are not of equal importance. For that reason different weighting factors are used for all the different criteria. To decide what weighting factor each criteria must have, an average factor must be chosen. This includes all interest in 'Zona Portuaria Simon Bolivar'. The way to determine the weighting factors is to place the criteria in a matrix and decide which criteria of the two is more important. This is done with a 0 or a 1.

When the weighting factors are determined, the individual scores of each criteria per alternative are determined. The total score of the value per alternative is known. The alternative with the highest value ranking is favourable over all criteria.

The earlier mentioned criteria do not include the costs. The costs have a large influence on the final choice of the lay-out. To separate the costs of the other value, three different ways to evaluate the alternatives are possible [Integraal ontwerpen in de civiele techniek, 2004]:

- Value ranking
- Costs ranking
- Costs per value point ratio

The above mentioned steps to produce these three ratio's are described in the following sections.

6.2 Qualitative characteristics of criteria

All characteristics of the criteria must be non-cost related and independent of each other. Only the criteria which get different scores per alternative are included in the MCE. Five main groups are introduced which cover all possible non-cost related criteria for the four alternatives of 'Zona Portuaria Simon Bolivar'. The criteria per main group are described in the following sections.

6.2.1 Functionality

(Accessibility, user friendly, extendible, re-arrangable, safety)
The accessibility of the port contains nautical and the hinterland transportation functionality. This is an important criteria in the MCE.

User friendly is a criteria which is influenced by the location of the terminals and the barge harbour related to each other. The user friendliness of a lay-out is evaluated only by its location, berth orientation and hinterland connections.

Another important criteria is the extendibility of the terminal areas in future times. For instance, the total amount of required terminal area and quay length must increase during all phases.

The function of the general cargo terminal is likely to change slowly over time into a container terminal. Re-arrangement of the general cargo terminal is possible if located next to the container terminal and is therefore a functionality criteria in the MCE.

Safety is an important criteria for the different alternatives. The amount of crossings between sea going vessels and barges, berth orientations in relation to each other, the port basin and the access channel are evaluated.

6.2.2   Environment

(Disturbances, Environmental harm, Aesthetics)
The physical, visual and noise disturbance caused by the port is evaluated for each alternative. The disturbances is of great importance for the people living on the islands of Toas and San Carlos.
In the environmental harm criteria the distance between the mangroves and the port activities is evaluated. Other important question in the lay-out choice is: Does the port lay-out have a prestigious, presentable and nice character. This is very subjective criteria. There are no major differences in the port lay-outs and port locations. For that reason the aesthetics are not evaluated for the port authority point of view but through the eyes of the present inhabitants who live or work on San Carlos and Toas.

6.2.3   Adaptability

(Modification)
During this phase in the port design it is not known whether the oil terminal is operational in the nearby future. It is assumed that during the time the oil terminal is not operational, the oil tankers will sail through the present channel. If the oil tankers use the present channel in the future, the barges are likely to sail through the same channel and not through a new dredged channel east of Pescaderos. The possibility of change in economical growth or political situation in Venezuela can lead to less investment. The modification of the port lay-out to such modifications is evaluated.

6.2.4   Preservation

(Hindrance)
Are the different alternatives recoverable, repairable and in what way can the alternatives be maintained? These criteria are not evaluated by the costs but by the qualitative characteristics. For example a lot of maintenance for a certain alternative can cause possible down time for the terminals. The possible hindrance per alternative is evaluated in the MCE.

6.2.5   Development

(Phasing)
The construction phases are part of the development of 'Zona Portuaria Simon Bolivar'. There are three phases and the year 2028. In these phases the amount of throughput increases a lot. The required terminal area and quay length need to expand during each phase. The possibility of these expansions is evaluated.

6.3   Evaluation of the criteria

6.3.1   Mutual weight of the criteria

Not all of the criteria have the same importance. For that reason the mutual weight of the criteria are determined. For a clear evaluation of these mutual weights, the criteria are put into a matrix. If a criteria is of more importance than the other one, a 1 is given and a 0 is given the other way around. If all the weights are summed up, the mutual weights of the criteria are determined. A problem has occurred. The aesthetics did not get any points at all. If this criteria does not get a score it looks like aesthetics do not play a role in the final evaluation. For that reason the criteria will get a score of 1. To show the difference in mutual weight between aesthetics and the other criteria, the mutual weight of all criteria except aesthetics are multiplied by 5. It is possible to multiply the remaining mutual weight with a lower number. A multiplying factor of 5 is chosen to show the big difference in weight between aesthetics and the other criteria. Appendix-6 shows the table of the mutual weights in table-1.

6.3.2   Score per lay-out

In this section the different scores are determined for the four different lay-outs. The scores are given for each lay-out per qualitative characteristic. Marks are appointed on a scale between 1 and 10. Appendix-6 shows the scores per lay-out in table-2.
Now the mutual weights and the score per qualitative characteristic per lay-out are is known, these two are multiplied. Appendix-6 shows the results of all four lay-outs in table-3. The value ranking of lay-out-2 scores best.

6.4   Costs

As described in section 6.1, the costs are considered separately. The terminal facilities, roads, quay constructions and equipment are assumed the same for the four alternatives. The main difference between the alternatives is the construction of breakwaters, capital and maintenance dredging costs between the four lay-outs. The dredging costs differ much because of the different access channels and basin areas [Baggertechniek, 2002]. In the next section the dimensions and volumes of the alternatives are described. These volumes are determined with an application of Delft-3D, called Quickin. The profile of the present situation can be loaded into this program. After the implementation of the channel sections and the basin areas in Quickin, the precise amount of capital dredging and landfill is known.
Because no layout has been chosen yet, no modelling has been performed to gain information about the current speed and resulting sedimentation rates. If the channel section or basin area are located close by areas in the 'Puerto America' Masterplan project, data regarding sedimentation is used in the 'Zona Portuaria Simon Bolivar' project. If the basin areas are elsewhere located, an average sedimentation rate is assumed just like the surrounding waters.

6.4.1   Dimensions and volumes

As a result of the earlier discussed dimensions of the basins, channel sections and terminal areas in section 4.4, the volumes for the amount of landfill and capital dredging needed are presented in Table 6-1. These

precise amount of volumes are determined in Quickin. This program is an application for an input file of Delft 3D-flow.

Area/Alternative		Dim.	Lay-out-1	Lay-out-2	Lay-out-3	Lay-out-4
Landfill wet area	Volume	m³	2,856,000	2,538,000	2,856,000	2,538,000
dry area	Volume	m³	3,818,000	3,860,000	3,818,000	3,860,000
coal carrier basin &	Volume	m³	8,480,000	8,480,000	8,480,000	8,480,000
oil tanker basin &	Area	m²	1,934,000	1,934,000	1,934,000	1,934,000
the channel section in between.						
Basin east of Pájaros	Volume	m³	1,594,000	1,594,000	1,594,000	1,594,000
	Area	m²	159,000	159,000	159,000	159,000
Barge basin	Volume	m³	716,000	1,080,000	716,000	1,080,000
	Area	m²	187,700	318,500	187,700	318,500
Turning cycle	Volume	m³	222,500	222,500	222,500	222,500
	Area	m²	264,000	264,000	264,000	264,000
Main access channel	Volume	m³	25,430,000	25,430,000	25,430,000	25,430,000
(towards the port entrance)	Area	m²	1,408,000	1,408,000	1,408,000	1,408,000
Barge channel to Zapara &	Volume	m³	782,000	782,000	3,314,000	3,314,000
barge harbour oil terminal	Area	m²	298,000	298,000	1,537,000	1,537,000

Table 6-1: Volumes for the amount of landfill and capital dredging.

Another important phenomenon is the required maintenance dredging for the reference period of 30 years. The port facilities will last much longer than 30 years but this time duration is chosen for the final port lay-out. Table 6-2 shows the required amount of maintenance dredging in the access channel for the sea going vessels, barge access channel up to the west side of Pescaderos, the access channel east of Pescaderos and the basin areas.

Area/Alternative	Amount of maintenance dredging per year				
	Dim.	Lay-out-1	Lay-out-2	Lay-out-3	Lay-out-4
coal carrier basin & oil tanker basin & channel section in between.	m³/yr	1,200,000	1,200,000	1,200,000	1,200,000
Basin east of Pájaros	m³/yr	172,000	172,000	172,000	172,000
Barge basin	m³/yr	64,700	318,500	64,700	318,500
Main access channel (towards the port entrance)	m³/yr	5,000,000	5,000,000	5,000,000	5,000,000
Inner barge channels (after 13 years)	m³/yr	600,000	600,000	260,000	260,000

Table 6-2: Required amount of maintenance dredging per year.

The net present value approach is used to translate the total costs per year in the future to the base year in which the maintenance dredging starts. In the costs for the different alternatives, the breakwaters are also included. As a result of the dimensions in Table 6-1 and Table 6-2, the costs per variant are described in appendix-6 (table-4 and 5). The calculation of the material needed for the breakwaters and the related investment costs are described in appendix-6. The input and output parameters for the van der Meer formula [Introduction to bed, bank and shore protection, 2001] required for the final stone diameter is shown in table-6, appendix-6, page 4. The calculation of the total investment costs per m^1 breakwater and the overall costs for the different breakwaters is shown in table-7, 8 and 9 in appendix-6.

The required amount of dredging and landfill costs per lay-out are described in appendix-6, page 6 and the costs for maintenance dredging are assumed at €3 per m^3.

6.5   Final evaluation

Column 2 shows that lay-out-1 requires the lowest investment costs. The determined costs of all four alternatives are almost the same. For that reason the ratio of the qualitative characteristics per alternative influences the final lay-out choice a lot.

Column 3 shows that lay-out-2 offers the highest ratio points and column 4 shows that lay-out-2 offers the highest scores in the costs per value point ratio.

	nr.	Total costs	nr.	value points	nr.	costs per value point ratio
Layout-1	1	€ 441,598,500	4	540	4	817,775
Layout-2	2	€ 443,339,500	1	688	1	644,389
Layout-3	3	€ 451,692,500	2	576	2	784,188
Layout-4	4	€ 453,433,500	3	570	3	795,497

Table 6-3: Evaluation of the lay-outs.

In the following chart these values are plotted. As a result of this, lay-out-2 is overall most favourable.
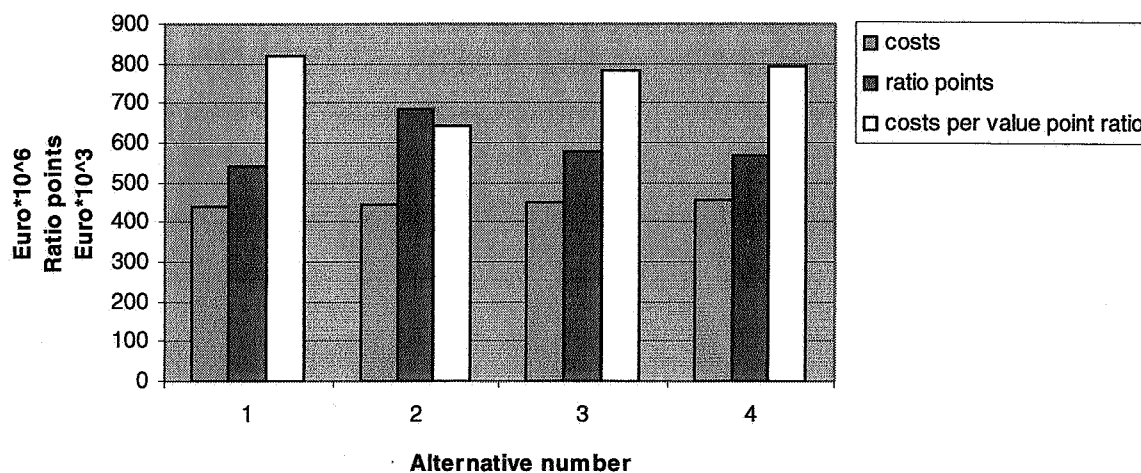
7   Hydraulic data lay-out-2

7.1   Introduction

In this section hydraulic data of the overall most favourable alternative 2 is evaluated.

It is important that the future flow velocities in the lay out of alternative 2 are not too high, especially in the areas where vessels are manoeuvring towards and from their berthing place. Another important phenomenon is the possible sedimentation in the new port basins and access channels. The amount of sedimentation and following maintenance dredging in the basins is expensive and also gives extra down time for the vessels during maintenance work in the basins. The nautical conditions need to be adequate to make a controlled entry towards and in the basins.

To determine the sedimentation rates in the basins, the current speeds and flow patterns during an average tide cycle need to be determined for the present situation and the future situation.

In this chapter the modelling in Delft 3D of these flow velocities and flow patterns for the present situation and the future situation of alternative 2 are discussed. The future sedimentation rates are described in chapter 8.

7.2   Delft 3D Input

In this section the simulation steps are described for two runs in Delft 3D. These two runs are:

- Simulation of the present situation.
- Simulation of the future port lay-out during an average tide.

The methodology of the process is described in the following sections.

7.2.1   User interface

The user interface of Delft-3D is presented in figure-1 (appendix-7, page 2). The grid, bathymetry, outer model limits and starting values are implemented in the Delft 3D model of the Puerto America Masterplan project. The hydrodynamic flow module in Delft 3D must be changed to implement the new land boundaries or dry points, new observation points, new breakwaters and the new bathymetry of the future port lay-out. These changes in the hydrodynamic flow module are discussed in section 7.2.2 to 7.2.5.

7.2.2   Dry points

New landfill areas nearby the island of Pájaros need to be implemented in the Delft 3D model. These areas can be assigned to the grid with so called dry points. A dry point is an area with a minimum size of the length between two grid points. The main function of a dry point is to point out the areas where no water can flow. This way, the quays and new terminal areas on the island of Pájaros are implemented into the model. Figure-2 (appendix-7, page 2) shows in green the dry points in the visualisation area in the Delft 3D user interface.

7.2.3   Observation points

To gain sufficient information about certain points in the port area, observation points are appointed to some grid locations. The most important areas are located in the areas where the vessels are moored, nautical difficulties can be expected and areas where high sedimentation rates can be expected. In the barge harbour

basin high sedimentation rates are expected and in the area between the islands of Pájaros and Pescaderos high flow velocities are expected caused by the new quay facilities. When the model data are available, flow velocity-time figures can be plotted for these individual observation points. These data are needed for further investigation about sedimentation rates, discussed in chapter 8.

Figures 3a,b and figure 4 (appendix-7, page 3,4 and 5) shows the locations and grid coordinates of the most important observation points.

7.2.4   Bathymetry

As earlier mentioned in section 6.4 the bathymetry can be visualised and data like water volumes and sediment volumes can be measured in an area with an application of Delft-3D, called Quickin. Not only the bathymetry of the project site can be looked at but the bathymetry can also be adjusted.

The present bathymetry is presented in figure-5 (appendix-7, page-6).

The new depths of the basins of the future project site of alternative 2 are adapted in the present bathymetry. These new depths are presented in the drawing of alternative-2 in appendix-5.

figure 7-1 shows the future situation of the bathymetry of alternative 2 in the Quickin application.

The following five areas are presented in figure 7-1:

1. Harbour basin of the Zapara oil terminal.
2. Harbour basin of the San Bernardo coal terminal.
3. Harbour basin of the Pájaros port terminals.
4. Harbour basin for the barge harbour area.
5. Access channels.

figure 7-1: Future situation of the bathymetry of alternative-2 nearby Pájaros.

When all the discussed adjustments and implementations are ready the mdf-file can be saved in Delft 3D and the model can be run. The final mdf-file is shown in appendix-7, page 7.

7.3   Delft 3D output

After running the computer, the output files contain a 1.5 Gbyte field information definition file and data file. To translate these data into a flow velocity vector plot or a time dependant plot during the critical moments in which the flow velocity is highest, the data are put into a program called Tekagx. The adjustments to the Delft 3D output data file, to gain the required input files for Tekagx, are discussed in appendix, page-10.

7.4   Data plots of observation points

Twenty two plots are produced of different observation points. In each plot the water level is related to MSL, the flow velocity and the direction of the current are presented for a period of 24 hours during an average tide. In every plot the present situation is presented with a continuous line and the future situation is presented with a dashed line. Several observation points are plotted in the barge harbour basin, the harbour basin east of Pájaros, the oil and coal carrier basin and the access channel west of Pescaderos. These observation points with grid coordinates are presented in appendix-7 (figures 3a,b and 4, pages 3,4,5).

Figures-6,-25 (appendix-7) shows the results of all observation points for the present and future flow velocity, direction and water level during an average tide.

The process of adapting the data files and the data input for the final data plots of the observation points are described in appendix-7, page 10.

7.5   Maximum flow velocity plots during the average tide

Two plots are produced, one of the present situation and one of the future situation. To gain good insight into the current velocities and directions in the whole area, one plot of each situation is produced. Figure-26 (appendix-7) shows the results of the present maximum flow velocity during average ebb and figure-27 (appendix-7) shows the results of the future maximum flow velocity during average ebb in the new lay-out of alternative-2. Before the output file Trim.dat can be put into the graphical program 'Tekagx' the data must be adapted to sustainable input file of Tekagx.

The process of adapting the data files and the data input are described in appendix-7, page 10.

7.6   Results

As a result of the future lay-out of alternative 2 and the new depth of the access channels and port basins, the flow velocities change in the port basins.

Figures 6-10 in appendix-7 show that the flow velocities in the barge harbour basin observation points (appendix-7, page 3) at the east side of the basin are somewhat higher than at the west side in the present and future situation. This is logical because of the divergent flow pattern at the east side of the barge harbour basin. The future flow velocity at the most west located observation point (257,437) will decrease with about 50 percent. This is not representative for the change in flow velocity in the barge harbour basin because the observation point is located just outside the barge harbour basin. Figures 7-10 (appendix-7) show the increase of the average flow velocity from approximately 0.5 m/s to approximately 0.57 m/s (in the order of magnitude of 15 percent) in the 4 observation points during ebb and flood.

Figures 14-17 in appendix-7 show that the average flow velocities in the observation points (appendix-7, page 4) in the harbour basin east of Pájaros will decrease from approximately 0.5 m/s to approximately 0.42 m/s in the future situation. The flow velocity in the observation point (300,443), at the most southwest end of the basin, will decrease more compared to the three other observation points in the basin. This can be explained by the eddy which occurs in the area of observation point (300,443) during an ebb current. Figures 15-17 (appendix-7) also show the decrease of the average flow velocity in the order of magnitude of 15 percent in the 3 observation points over the full length of 3 km during ebb.

Figures 21-25 in appendix-7 show that the flow velocities in the observation points (appendix-7, page 5) in the coal carrier and oil tanker basins will decrease in the future situation. These figures show a present maximum flow velocity of 1 m/s during an average ebb period and 0.75 m/s during the future ebb period in the lay-out of alternative-2. The future average flow velocity during ebb and flood in alternative 2 will decrease in the order of magnitude of 20 percent in the five observation points.

The sedimentation rates in the basins and the nautical situation in the harbour need to evaluated to determine whether the lay-out alternative 2 must be adapted or not. Extra measures, like breakwaters, can also be taken to change the flow velocity or sedimentation rate to create a safe harbour for nautical and operational conditions. These aspects are not further investigated in this study. Another important matter is the amount of sedimentation in the basins. To much interference of the vessels, caused by dredging activities in the channels and basins, can create extra downtime for the vessels.
The sedimentation rates in the barge harbour basin and the basin east of Pájaros are predicted in the next chapter 8. A nautical research is required to evaluate the vessel manoeuvring of alternative 2.

8   Sedimentation harbour basins east and west of Pájaros

In this chapter the sedimentation is predicted in the barge harbour basin south of Pájaros and in the main basin east of Pájaros of alternative 2. The sediment in the project area consists of different fractions I. The fractions differ from gravel (2-10mm) to fine sand (0.06-0.6mm) and silt (<0.06mm). Because of the variety of the mixture of sand and silt in the area it is hard to predict the exact amount of sedimentation in the two harbour basins. For that reason a rough estimation is produced for the sedimentation in the barge harbour basin and the basin east of Pájaros.

The barge harbour is not located in a sheltered area with respect to the ebb current. The current runs over the full length through the barge harbour basin. A part of the silt and sand transport will not be deposited in the main channel but will first run through this barge harbour basin. Because of the difference in flow velocity between the barge harbour basin and the surrounding area, the sand and silt transport will behave differently. The total amount of sedimentation in the barge harbour basin is important for future maintenance dredging costs and the following down time of the barges. The down time of the barges is created by the hindrance of the barges caused by the maintenance dredging works.

To determine whether measures need to be taken to prevent high maintenance costs and occurring extra down times for the sea going vessels, the sedimentation rate in the barge harbour basin and the harbour basin east of Pájaros needs to be predicted.

Section 8.4 evaluates the amount of sedimentation per year inside the barge harbour basin and section 8.5 evaluates the situation inside the main basin east of Pájaros.

In the following 3 sections a process description, the available data and the used sediment transport formula is described.

The objective of this chapter is to predict the sedimentation rates and take extra measures, if necessary, to prevent sedimentation rates which are too high.

8.1   Process description

To determine the amount of sediment transport in a certain area the sediment transport formula of Meyer-Peter Müller or Engelund and Hansen can be used. A disadvantage of these two formula's is that they describe the total sediment transport. The transport formula of van Rijn makes a distinction between the bedload and suspended load. These data are required to make a more accurate estimation about the future situation. The total amount of sedimentation cannot be estimated only with the van Rijn transport formula, as discussed in section 8.3. The combination of the van Rijn formula [Rivierwaterbouwkunde, 2001], measured sediment data and the Eysink Vermaas formula [Principles of sediment transport in rivers, estuaries and coastal seas,1990] the total amount sedimentation can be estimated for the future barge harbour basin and the harbour basin east of Pájaros.

The steps of estimating the sedimentation in the barge harbour basin and the basin east of Pájaros are as follows:

The length of the channel section east of Pájaros, in which almost none sediment is deposited other than originating from the area between the south east of Pájaros and Pescaderos, is estimated. This channel section is the hatched section presented in figure-1, appendix-8.

The deposited sediment in this channel section is transported through the area between the south east of Pájaros and Pescaderos as presented in figure-1, appendix-8. The sediment transport through the section

between Pájaros and Pescaderos caused by the ebb current crosses the barge harbour basin (1/4 of the total transport, see figure-1, appendix-8).

There are two different ways of estimating the sedimentation in the barge harbour basin and in the basin east of Pájaros.

1. The assumption is made that 100% of the transported sand into the barge harbour basin will be deposited here and that the amount of silt deposited in the barge harbour basin will be equal with that of the basin east of Pájaros. The amount of sand transported into the basin east of Pájaros will also deposited for 100% in the basin. The amount of silt deposited in the basin east of Pájaros, with respect to the present situation, will be estimated with the Eysink Vermaas formula. The resulting sedimentation rates are an upper bound of the estimated values.

2. The assumption is made that not all the sand which is transported into the barge harbour basin will be deposited there. A part of the suspended sand transport in the barge harbour basin, which is not deposited, will be transported into the basin east of Pájaros. The transport of silt into and out of the barge harbour basin will happen the same way. The estimation of the sedimentation of the silt and the sand in the basin east of Pájaros is determined with the Eysink Vermaas formula. The resulting sedimentation rates are a lower bound of the estimated values.

It is assumed that sediment transport only occurs during ebb because the slope between the barge harbour basin and the basin east of Pájaros is too steep for sediment transport during flood into the barge harbour basin. With historical data concerning the total amount of dredged material per year in this channel section, the sedimentation rate is known.

The sediment transport is divided into the sand bedload transport, suspended sand transport and the transport of silt. With all this information the sand transport is estimated with the van Rijn formula and the deposition of the suspended silt as a function of the flow velocity in the barge harbour basin, in respect to the present situation, is determined with the Eysink Vermaas formula. Finally the total amount of maintenance dredging volumes in the barge harbour basin and the harbour basin east of Pájaros are estimated in the two different ways.

8.2   Available data

The determination of the sedimentation area (Length and width) is as follows. It is assumed that the surrounding water depth nearby the channel remains in an equilibrium state and that the sedimentation in the channel is mainly caused by the sediment transport between the islands Pájaros and Pescaderos. The channel section is 240 m wide and starts at the north-west side of Pescaderos and ends 3 km north. This channel section area is hatched and presented in figure-1 (appendix-8). From this point on to the north, the sedimentation which is deposited north of the 3 km channel section is originating from the area north of Pájaros and from the old natural channel.

The measured amount of dredged sediment in the 3 km channel section is 759,000 m^3 (1986-1987). This quantity contains silt and sand.

The sedimentation characteristics along the access channel is presented in figure-2, appendix-8.

8.3   Approach with van Rijn transport formula

The van Rijn transport formula is used to estimate the suspended and bedload transport in the area south of Pájaros. This calculation is made to estimate the percentage of suspended sand transport and the bedload

transport of sand. If the calculation of the total amount of sand transport per year with the van Rijn transport formula is in the same order of magnitude as the measured sand transport, the sand transport in the two basins can be estimated with the van Rijn transport formula. With the knowledge of the difference in sand transport between the area south of Pájaros and the basins the sedimentation rate of the sand can be estimated.

Before the sedimentation rate is estimated some notes are made in relation to the outcome of the van Rijn transport formula:

The van Rijn transport formula is applicable in a situation with only sand and a steady state flow condition. In the present situation the soil contains different kinds of sediment characteristics and no tidal area with daily current fluctuation during spring tide and neap tide has been taken into account. The flow velocity of the average tide is used for the calculation of the sedimentation rate.

A few parameters in the formula are assumed, like an average flow velocity. This assumption can cause big changes in the final outcome of the calculated sand transport per year because the changing flow velocities (ebb, flood) are not taken into account in the van Rijn transport formula.

The transport formula of van Rijn is:

$S = S_b + S_s$ [kg/yr]; Total amount of suspended and bedload transport.

$S_s = F \cdot u \cdot h \cdot c_a$ [kg/yr]; Suspended bedload.

$$F = \frac{\left(\frac{a}{h}\right)^{Z'} - \left(\frac{a}{h}\right)^{1.2}}{\left(1 - \left(\frac{a}{h}\right)\right)^{Z'} \cdot (1.2 - Z')}$$ [-]; Integration factor.

$$Z' = \frac{w_s}{\left(1 + 2\left(\frac{w_s}{u_*}\right)^2\right) \cdot \kappa \cdot u_*} + 2.5 \cdot \left(\frac{w_s}{u_*}\right)^{0.8} \cdot \left(\frac{c_a}{1 - \varepsilon_p}\right)^{0.4}$$ voor $0.01 \le \frac{w_s}{u_*} \le 1$ [-]

The particle velocity w_s is calculated from the representative particle diameter in suspension D_s.

$$\frac{D_s}{D_{50}} = 1 + 0.011 \cdot \left(\frac{1}{2}\left(\frac{D_{84}}{D_{50}} + \frac{D_{50}}{D_{16}}\right) - 1\right)(T - 25)$$ [-]

$w_s = \dfrac{\Delta \cdot g \cdot D^2}{18 \cdot \nu}$ when $1 \le D \le 100 \mu m$ [m/s]; particle velocity.

u = Depth average speed [m/s]

h = water depth [m]

c_a = Sediment concentration on reference level a measured from bottom.

$c_a = 0.015 \cdot \left(\dfrac{D_{50}}{a} \cdot \dfrac{T^{1.5}}{D_*^{0.3}}\right)$ [-] with $D_* = D_{50} \cdot \left(\dfrac{\Delta \cdot g}{\nu^2}\right)^{\frac{1}{3}}$ [-]

$T = \dfrac{\tau_b' - \tau_{b\,cr}}{\tau_{b\,cr}}$ [-]; bottom friction parameter.

$\tau_b' = \left(\dfrac{C}{C'}\right)^2 \cdot \tau_b$ with $C' = C_{90} = 18\log\dfrac{12h}{D_{90}}$ [-]; particle related bottom friction.

τ_b' = Sediment related bottom friction. [N/m²]

$\tau_{b\,cr}$ = Critical bottom friction for the beginning of movement by Shields. [N/m²]; critical bottom friction for the movements by Shields.

$S_b = \phi_b \cdot \sqrt{g \cdot \Delta \cdot D_{50}^3}$ [m³/yr] Suspended bedload, with ;

$$\phi_b = 0.053 \cdot \frac{T^{2.1}}{D_*^{0.3}} \quad \text{for } T \le 3 \text{ [-]}$$

$$\phi_b = 0.1 \cdot \frac{T^{1.5}}{D_*^{0.3}} \quad \text{for } T \ge 3 \text{ [-]}$$

The actual calculation is presented in table-1, appendix-8. Table 8-1 shows the estimation of the final amount of sand sedimentation between the island of Pájaros and Pescaderos calculated with the van Rijn formula.

Section width	1,750	m		
time	18,396,000	sec		
Sedimentation Sb	5,400	m³/yr	8,600,000	kg/yr
Sedimentation Ss	40,000	m³/yr	64,000,000 +	kg/yr
Total sand sedimentation			72,600,000	kg/yr

Table 8-1: Total amount of sand sedimentation calculated with the van Rijn formula.

8.4   Sedimentation barge harbour basin

The area of the present channel section between the south east of Pájaros and 3 km to the north is 720,000 m². This section contains the sediment transported through the section presented in figure-1, appendix-8. It is assumed that almost all the sand and silt transportation into the channel section east of Pájaros is coming from the south side area of Pájaros. Because the current pattern is parallel to the channel section over a length of 3 km, no extra sediment is transported into this channel section. The sediment transport between the island of Pájaros and Pescaderos is about the same as the amount of dredged material per year from this channel section over a length of 3 km. Measured sedimentation during the year 1986-1987 shows 759,000 m³ per year [Masterplan Puerto America Alkyon, 2002]. This results in an average bottom level rise of 1.05 meters per year.

Figure-2 in appendix-8 shows data of samples taken from the bottom of the channel in percentage of fraction. With the following formula the weight of an average m³ of sediment in the channel is calculated:

$$\varphi_{dry} = \varphi_{silt} + (\varphi_{sand} - \varphi_{silt}) \cdot P_{sand\%}^2$$

The total access channel is divided in several sections with different sediment percentages per km[1] as presented in figure-2 (appendix-8). The channel section of 3 km covers section 3,4 and 5.

Table 8-2 shows the sediment percentages for the different channel part in the channel section.

Section	Sand	Silt
3	40%	60%
4	20%	80%
5	40%	60%
average	33%	66%

Table 8-2: Sediment percentages per channel section.

$$\varphi_{dry} = 350 + (1600 - 350) \cdot 0.33^2 = 490 \text{ kg/m}^3.$$

The total amount of sand and silt which is transported through the section between the two islands is estimated at:

$S_{sand} = 122 \cdot 10^6$ kg/yr.

$S_{silt} = 245 \cdot 10^6$ kg/yr.

The total amount of calculated sand transport per year with the van Rijn transport formula is approximately 60 percent of the measured sand transport.

The different results can be caused by two things:

1. The assumption that the sediment transport between the island of Pájaros and Pescaderos mainly cause the sedimentation rate in the channel of 3km long and 245 m wide is not correct.

2. Some parameters in the van Rijn transport formula can cause big changes in the final outcome of the calculated sand transport per year.

It is more likely that the calculated results of the sand transport, with the van Rijn formula, cause changes in relation to the actual sand transport.

Because of the different outcomes, the sand transport in the two basins cannot be estimated with the van Rijn transport formula.

Lower bound estimation:

The sedimentation rate in the two basins is now estimated with the assumption that the sedimentation rate in the channel of 3 km long and 245 m wide is mainly caused by the sand and silt in suspension between the island of Pájaros and Pescaderos. The only thing that is not taken into account is the sand bedload. The bedload is in the order of magnitude of a few percent of the suspended load. As a result of this the final sedimentation rate in the basins must be estimated a few percent higher. Because the sedimentation rates in the basins are estimated, the few percent extra sedimentation is negligible.

Figure-1 in appendix-8 shows the future situation of the current pattern around the south east side of Pájaros. In this figure can be seen that about ¼ of the total sediment transport will pass the barge harbour basin. This means that about $30 \cdot 10^6$ kg of sand and $61 \cdot 10^6$ kg of silt will be transported in the basin.

The flow velocity in the area south of Pájaros has an average velocity of about 0.42 m/s during an average tide. In the area nearby and in the barge harbour basin the current is in 75 percent of the time flowing east and the maximum velocity is 0.75 m/s during an average tide.

The relation between the suspended sediment transport and the flow velocity is described with the Eysink-Vermaas formula:

The backfilling rate of a channel section is Δs

$$\Delta s = \left[\left(\left(\frac{b_0}{b_1} \cdot q_{s,0} \right) - q_{s,1} \right) \cdot \left(1 - \exp\left(-A \cdot \left(\frac{B}{h_1 \cdot \sin\alpha_1} \right) \right) \right) \right] \sin\alpha_1 \quad \text{with} \quad b_0 = b_1$$

$$A = 0.015 \cdot \left(\frac{2 \cdot w_s}{u_{*,1}} \right) \cdot \left(1 + \frac{2 \cdot w_s}{u_{*,1}} \right) \cdot \left(1 + 4.1 \left(\frac{k_s}{h_1} \right)^{0.25} \right)$$

Δs = Sedimentation rate (kg/s)

$q_{s,0}$ = Suspended sediment transport outside the channel (kg/s)

$q_{s,1}$ = Suspended sediment transport inside the channel (kg/s)

B = Basin length (m)

h_1 = Water depth in channel (m)

α = Angle of current approach parallel with the channel

w_s = Particle fall velocity (m/s)

$u_{*,1}$ = Shear stress velocity (m/s)

k_s = Bed roughness (m)

To calculate the deposition of the sand and silt as a function of the flow velocity in the barge harbour basin the basin length is implemented as the channel length and the basin width is assumed as the unit channel width in the Eysink-Vermaas formula. These assumptions are possible because the current flows almost parallel with the basin length.

Figures 6-9 in appendix-7 shows that the current velocities in the 4 observation points increases with an average rate of about 15 percent during the tide. The deposition of the sand and silt as a function of the flow velocity is calculated in an excel sheet and is presented in table-2, appendix-8. figure 8-1 shows the sedimentation rate of the suspended sand transport for several current velocities.
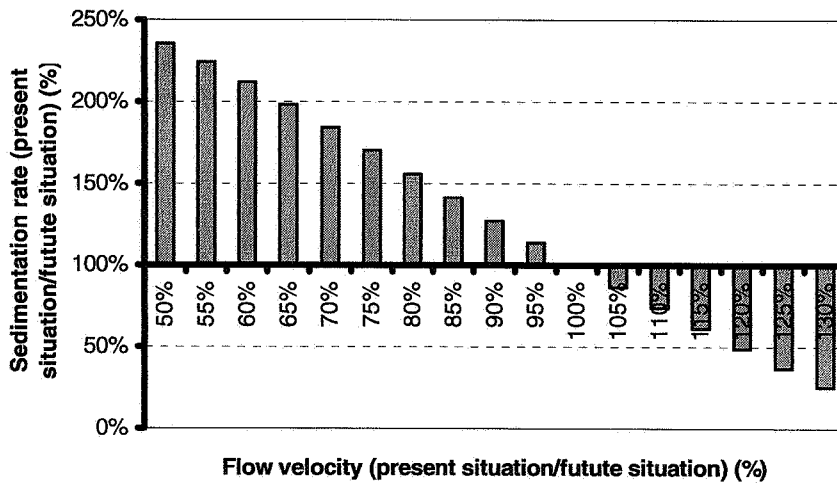

figure 8-1: Deposition of sand as a function of the flow velocity.

The flow velocity increases with 15 percent. As a result the suspended sedimentation rate in the barge harbour basin decreases with 39 percent.

The suspended sediment rate in the barge harbour basin will be 61 percent of the estimated sedimentation rate, which is ¼*0.61*122*10^6= 18.6*10^6 kg/yr.

The amount of silt transport through the barge harbour basin is also 25 percent of the total silt transport between the islands Pájaros and Pescaderos. figure 8-2 shows the sedimentation rate of the suspended silt transport for several current velocities.
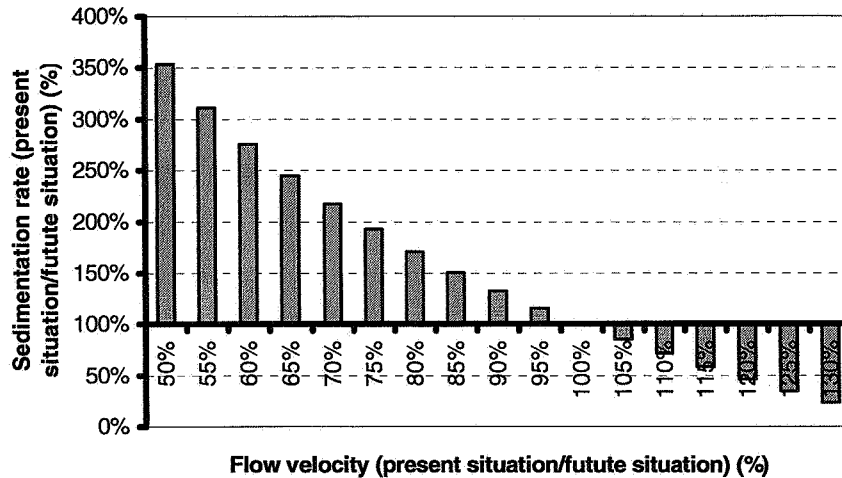
figure 8-2: Deposition of silt as a function of the flow velocity.

The sedimentation rate will decrease with 41 percent. As a result the amount of silt in the barge harbour basin will be $\frac{1}{4}*0.59*245*10^6$= 36.1*$10^6$ kg/yr.

It is assumed that during flood the current southwards deposits almost no sand and silt in the barge harbour basin. The difference in depth is too much for the current to transport any sediment from the basin east of Pájaros (47 ft) up to the barge harbour basin (17 ft).
The total amount of silt and sand deposited in the barge harbour basin will be:
18.6*10^6 + 36.1*10^6 = 54.7*10^6 kg/yr. The weight of this sediment mixture is:
350+(1600-350)*(18.6*10^6/54.7*10^6)^2= 494 kg/m^3.

The volume of the total amount of deposited sediment per year in the barge harbour basin will be:
54.7*10^6 / 494 = 110,000 m^3.
The average amount of maintenance dredging in the barge harbour basin will be in the order of magnitude of 110,000 m^3 / (190 m * 800 m) = 0.70 m per year.

Upper bound estimation:
The amount of deposited sand in the barge harbour basin will be $\frac{1}{4}*122*10^6$ kg/yr = 30.5*10^6 kg/yr. The amount of deposited silt in the basin east of Pájaros is not estimated with the Eysink-Vermaas formula. It is assumed that the sedimentation rate of silt in the barge harbour basin is the same as the sedimentation rate in the main harbour basin east of Pájaros. The As a result of this assumption, the sedimentation rate in the barge harbour basin will be 0.9 m.

8.5   Sedimentation main harbour basin east of Pájaros

Lower bound estimation:
The sedimentation in the basin where the container, general cargo, salt and cereal carriers are manoeuvring is important for future maintenance dredging costs and the following down time of the vessels.
As a result of the suspended sediment rate in the barge harbour basin of 61 percent of the estimated sedimentation rate south of Pájaros, the remaining 39 percent of the suspended sand will deposit in the harbour basin east of Pájaros. This will be $\frac{1}{4}*122*10^6*0.39$ = 11.9*10^6 kg/yr.

It is assumed that the suspended bedload transport of sand through the ¾ section, as presented in figure-1 (appendix-8), is all deposited over the full length of the basin. This is $3/4*122*10^6 = 91.5*10^6$ kg/yr.

The total amount of suspended sand transport into the basin is $11.9*10^6 + 91.5*10^6 = 103.4*10^6$ kg/yr.

The flow velocity in the basin decreases with an average rate of 15 percent over the full length of 3 km. This is concluded from figures 14-17 in appendix-7. As a result the suspended sand transport rate in the harbour basin increases with 28 percent, calculated with the Eysink-Vermaas formula.

The suspended sand sediment rate in the southern part of the main harbour basin will be 72 percent of the total amount of $103.4*10^6$ kg sediment transported per year. This will be:

$103.4*10^6 * 0.72 = 74.4*10^6$ kg/yr.

As a result of the suspended sediment rate of silt in the barge harbour basin of 61 percent of the estimated sedimentation rate south of Pájaros, the remaining 39 percent of the suspended silt will deposit in the harbour basin east of Pájaros. This will be $¼*245*10^6*0.39 = 23.9*10^6$ kg/yr.

It is assumed that the suspended bedload transport of silt through the ¾ section, as presented in figure-1 (appendix-8), is all deposited over the full length of the basin. This is $3/4*245*10^6 = 184*10^6$ kg/yr.

The total amount of suspended silt transport into the basin is $23.9*10^6 + 184*10^6 = 207.9*10^6$ kg/yr.

As a result of the decreasing flow velocity in the basin with 15 percent over the full length of 3 km, the suspended silt transport rate in the main harbour basin increases with 35 percent.

The estimation of the total amount of silt deposited in the southern part of the main harbour basin will be:

$1.35*207.9*10^6 = 281*10^6$ kg/yr.

The total amount of silt and sand deposited in the main harbour basin will be:

$74.4*10^6 + 281*10^6 = 355.4*10^6$ kg/yr. The weight of this sediment mixture is:

$350+(1600-350)*(74.4*10^6 /355.4*10^6)^2 = 405$ kg/m³.

The volume of the total amount of deposited sediment per year in the harbour basin east of Pájaros will be:

$355.4*10^6 / 405 = 877,000$ m³.

The average amount of maintenance dredging in the harbour basin east of Pájaros will be in the order of magnitude of 877,000 m³ / (245 m * 3000 m) = 1.20 m per year.

Upper bound estimation:

The amount of deposited sand in the basin east of Pájaros will be $¾*122*10^6$ kg/yr $= 91.5*10^6$ kg/yr. The amount of deposited silt in the basin east of Pájaros is estimated with the Eysink-Vermaas formula.

As a result of the decreasing flow velocity in the basin with 15 percent over the full length of 3 km, the silt transport rate in the main harbour basin increases with 35 percent.

The estimation of the total amount of silt deposited in the main harbour basin east of Pájaros will be:

$1.35*245*10^6 = 330*10^6$ kg/yr.

The total amount of silt and sand deposited in the main harbour basin will be:

$91.5*10^6 + 330*10^6 = 421.5*10^6$ kg/yr. The weight of this sediment mixture is:

$350+(1600-350)*(91.5*10^6 /421.5*10^6)^2 = 409$ kg/m³.

The volume of the total amount of deposited sediment per year in the harbour basin east of Pájaros will be:

$421.5*10^6 / 409 = 1.03*10^6$ m³.

The average amount of maintenance dredging in the harbour basin east of Pájaros will be in the order of magnitude of $1.03*10^6$ m³ / (245 m * 3000 m) = 1.40 m per year.

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An important area in the harbour basin east of Pájaros is the south-west area of the basin. This area is the transition between the deepwater basin and the more shallow area of the barge channel and the barge harbour basin. As mentioned earlier, most of the sedimentation occurs in this area. The flow velocity in this south-west side of the basin is very low during ebb because this basin area contains a large eddy. Figure-1 in appendix-8 shows this situation.

On the contrary, the current pattern runs parallel with the future quay construction during flood. Part of the sediment will be transported southwards but will eventually be trapped in the area where the slope towards the barge channel and the barge harbour starts. Together with the reduced flow velocity in the eddy during ebb, the sedimentation in this part of the basin will be higher than in other parts of the harbour basin east of Pájaros.

Further research is needed to predict the amount of sedimentation in this basin area.

8.6   Conclusion

As a result of the two different ways of estimating the sedimentation rates in the barge harbour basin and in the harbour basin east of Pájaros, the upper bound and lower bound are determined. These bounds are presented in the following table:

	Sedimentation rate barge harbour	Sedimentation rate basin east of Pájaros
Lower bound	0.7 m/yr	1.2 m/yr
Upper bound	0.9 m/yr	1.4 m/yr

Table: lower and upperbound of sedimentation rates in the basins

The estimated sedimentation rates in the two basins will probably lay somewhere in between.

Conclusions and recommendations

8.7   Introduction

The main objective of this study is to determine the planning and the technical feasibility of a deepwater port at the island of Pájaros, Zapara and San Bernardo. In the nearby future a considerable growth of the international and domestic trade is expected. The development of the deepwater port is divided in three phases (2008, 2010, 2018) and in the year 2028. In phase one the coal terminal will be operational. This is the start of the whole 'Zona Portuaria Simon Bolivar' project. During this first phase a relatively small amount of coal is exported with one jetty. The throughput of coal will grow gradually, depending on the capacity growth of the coal mines, which are available nearby the project site. As a result of the expected export growth, the coal terminal will be able to extend in northern direction. In the second and third phase the remaining the other terminals become operational. Also the container trade will grow relatively fast compared to the other commodities like general cargo, cement related products, cereals and oil, because of the consistent growth of container trade worldwide. For that reason the container terminal area covers a big part of the island of Pájaros during all phases. The terminal areas are positioned in such way that it is possible to extend the terminals in two directions in the future.
A Panamax container vessel of 4400 TEU is chosen as the design vessel for the required depth of the main port basin and the entrance channel. As a result of the choice to use the Panamax design vessel, the coal carriers and the oil tankers will be partly loaded.
The entrance channel is a two-way channel for vessels less wide than the Panamax container vessel. Only the coal carriers and the oil tankers are wider. For these vessels the channel is a one-way channel. The extra resulting waiting times caused by the one-way channel section for coal carriers and oil tankers are included in the queuing theory used for determining the number of berths per commodity.
Two possible lay-outs for the terminals on Pájaros are considered. Also two possible lay-outs for the barge channels are evaluated. As a result 4 alternatives, have been developed, which are evaluated with a Multi Criteria Evaluation (MCE).

The conclusions of this study are presented in section 9.2 and recommendations are made in section 9.3, which can be used for further research and other harbour feasibility studies.

8.8   Conclusions

Alternative 2 is most suitable. The costs of all four alternatives are almost the same because the volumes of capital and maintenance dredging of the basins and channel sections are almost equal for each alternative. Also the amount of landfill is approximately the same for each alternative. The value ranking of the MCE for alternative 2 is much higher than for the other alternatives because the criteria on the extension possibility, safety and phasing in alternative 2 scores high. Also, alternative 2 offers the highest scores in the costs per value point ratio. The total costs of alternative 2 are estimated at € 443,500,000.
To determine whether the sediment rates in the chosen alternative are not too high, the current velocities in the different harbour and basin areas are determined. In alternative 2, the average sedimentation in the barge harbour basin will be in the order of magnitude of 0.80 m per year and the sedimentation in the main harbour basin east of Pájaros is approximately 1.30 m per year.

The amount of maintenance dredging in the main basin and the barge harbour basin does not cause hindrance for the passing vessels and does not create too much down time for the vessels. The berth location of the coal carriers is exposed to wave penetration from the Gulf of Venezuela. It is possible that the penetrating waves enable carriers to be loaded. However, a maximum H_s of 1.0 m will not be exceeded. The penetrating waves will have less effect on the other berth locations in the harbour.

In general, wind hindrance can cause negative effects for the loading and unloading of container vessels. The possible down time of the container vessels is not much due to the low percentage of occurrence of high winds (11.15-14.15 m/s occurs in 5.56 percent of the time).

As a result of the location of the barge harbour basin and the current, running through the basin, a sedimentation problem was assumed in the early design phase. Because the sedimentation is approximately 0.80 m per year no breakwater need to be constructed to lead the current around the basin and keep the sediment out of the basin.

The flood creates an eddy at the south side of the of the main harbour basin nearby the quay. As a result, the average siltation and sedimentation is higher in this part of the basin than in the other parts of the basin. During ebb, this sediment cannot be washed away because of the slope between the south side of the main harbour basin and the barge channel / barge harbour basin. It can be concluded that further research is needed to predict the exact amount of sedimentation in this area.

The main objective for this study is the planning and technical feasibility of a deepwater port at the Island of Pájaros. Finally it can be concluded that the 'Zona Portuaria Simon Bolivar' project is technical feasible. However an economical study is also required to determine whether the project in total is feasible, taking into account that the project must be profitable and can keep up with world wide economical growth.

8.9   Recommendations

It is important to keep the assumptions that were made in mind during the design phase of the port lay-out. It is possible that one of the assumptions must be changed due to new developments in future times. If such a situation occurs it is required to make a profound investigation where to restart the design. It is wise to create a data file with all available and calculated data. All decisions which have been made in relation to the outcome of the data must be collected and put into the data file. This way, it is easy to maintain a good overview on the progression of the total port design phase.

More geotechnical data is required to make more accurate judgements about technical feasibilities and the resulting costs.

A probabilistic design is required to determine the exact depth of the access channel.

The possibilities of a floating accommodation as a base for the pilots at the end of the 44 km long access channel need to be considered. In this situation the pilot boats will berth at this floating accommodation. The pilots do not need to sail up and down to the beginning of the entrance channel.

A simulation model is required of the wet infra structure of the harbour. The system of all the different terminals with individual service times and the one / two-way channel section for the different vessels is a complex system. To optimise the quay lengths and determine the occurring waiting times of the different vessel types, this simulation model will be used.

With the above mentioned simulation model a most favourable situation can be found. For instance: What is the optimum situation between no tidal window at all, which created no waiting times for the vessels at all, or a tidal window which allow larger vessels into the port.

To determine the break-even point and the accompanying time scale of the investment costs and the benefits of the project, an economical and financial analysis is required.

The precise location of the crossing between San Bernardo and the island of Pájaros need to be determined. In the design all transportation between Pájaros and the hinterland does proceed by barge or by road. The other hinterland transport by railroad can be connected to the railroad used by the coal terminal. The precise location of the track from the terminals to the connection need to be worked out in further detail. Also the maximum allowable capacity of the railroad used by the trains transporting coal and all other future commodities transported by rail.

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