SUSTAINABLE MANAGEMENT OF CONTAMINATED SEDIMENT IN PUERTO DOCK SUD - ARGENTINA

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KEYWORDS: CONTAMINATION, SEDIMENT, SUSTAINABLE, PORT, DEVELOPMENT

ABSTRACT

The Río Matanza-Riachuelo carries large volumes of contaminated sediment to the Port of Dock Sud at the mouth of the river. The dredging of this contaminated sediment requires special handling and forms a major constraint for the port in becoming sustainable and enabling future growth. Efficient methods of handling the sediment and implementation in the port’s master plan are required for future development. The Master Thesis “Sustainable Management of the Contaminated Sediment in Puerto Dock Sud” (Croonen 2008) investigates the problem and provides a guideline for sustainable development of the port, with special regard to the contaminated sediment. This paper provides a triptych of this study. First it gives the context of the issue: the capacity growth and potential of the port. Secondly the way of handling contaminated sediment when it is in your port. And thirdly the long term action for solving the issues of contaminated sediment.

1. INTRODUCTION

For more than a hundred years Buenos Aires has been struggling with cleaning the major river that runs through its city, the Río Matanza-Riachuelo. Throughout the past century the contamination in the river proved to be one of the biggest environmental challenges the city has encountered and although various projects were executed, the river is still contaminated. And because of the expanding industries and the growing population, the problems increased over the years. While the situation in the river deteriorates and the neighbouring population experiences negative consequences on daily basis, like bad odour and elevated illness numbers, the authorities try to control the pollution and clean the river. But this social and economical problem shows hard to be solved.

While environmental groups are taking the case to the High Court to force the authorities to start source control and come up with firm results, the Port of Dock Sud is managing the contaminated sediments in their port basins for a decade. To protect the population and environment, legislation prohibits the port to freely relocate the dredged sediments.

Because of the growth in global shipping and the strong recovery of Argentina’s economy after the 2001 crisis, there is an increasing demand for good port facilities; which trend is likely to continue in the future (this study did not include the effects of the recent economical crisis, which consequences are still not clear). The Port of Dock Sud is seen as an attractive location for expansion and in 2007 a Master Plan (EGIP 2007) was prepared by the Postgraduate School of Port Engineering of the Engineering Faculty of the University of Buenos Aires. This master plan introduced the roadmap to prepare Dock Sud for the future and to maintain its position as a major port in Argentina. Although the master plan marks the issue of the contaminated sediment as one of the key obstacles for Dock Sud’s future, it does not analyse the problem or come forth with solutions.

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1.1 The Port of Dock Sud and the Catchment Area of Matanza-Riachuelo

The Río Matanza-Riachuelo is a 64 km long river which originates in the Province of Buenos Aires and runs in northeast direction to the federal capital, from where it runs along its south border to the Río de la Plata. The catchment area has a surface of 2,238 km² and has 4.88 million inhabitants. The first half of the river runs through a rural area, where the river has relative normal environmental conditions. From about 30 km off the coast the population gets denser and more industries are present. The density of population and industries grows the more the river approaches the city. The average water discharge is 67 m³ per second, while the annual carried sediment is estimated at 320,000 m³. The water and sediment discharges in the Río de la Plata by the Riachuelo are heavily contaminated.

FIGURE 1 Greater Buenos Aires & catchment Area Matanza-riachuelo

There are two main ports that serve Greater Buenos Aires; Puerto de Buenos Aires and Puerto Dock Sud. Both ports form a 14 km long area that stretches along the coast of the city, from the domestic airport (John Newberry Airport) in the west to Canal Sarandí in the east. The border between the two ports, with different port authorities, is also the province border, which is indicated by the Riachuelo.

The port of concern in this paper is Puerto Dock Sud and is the largest petrochemical port and the second container port in the country. Furthermore it has side activities in sand mining, chemicals and general cargo. Puerto Dock Sud takes a vital position in Argentina’s international shipping with an interesting future potential.

FIGURE 2 Port of Dock sud – buenos aires

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2. ISSUES OF CONTAMINATED SEDIMENT IN THE PORT OF DOCK SUD

Contaminants are discharged in the Río Matanza and Riachuelo by thousands of industries and millions of residents on the river banks. These contaminants are carried along with the water downstream. During the journey to the mouth of the river the contaminants meet suspended sediment particles to which the greater part of the contaminants attaches. After a cycle of settling and re-suspending, sediment particles arrive at the mouth of the Riachuelo, where the increase in cross section causes a decrease in flow velocity and settlement of suspended particles. Rivers tend to compensate increasing widths by decreasing in depth through sedimentation. The sedimentation continues until a new equilibrium is found and the flow velocity is strong enough to drag particles along. But the port in Dock Sud requires larger depths to receive international shipping vessels. Therefore maintenance dredging is performed to remove sediment and keep the port’s basins on depth. The contaminants have been in these sediments for a long time, but since the end of the 20th century, relocating the dredged material freely to the Río de la Plata is no longer allowed for environmental and health risks.

2.1 Contamination

Various institutes, including C&D Laboratories (2005), analyzed the quality of the port sediments. 24 samples were taken by C&D Laboratories on various spots within the port area and tested for 41 contaminants. In order to determine the risks of free location to society and nature, the concentrations are compared to Dutch limits that are used in the Dutch legislation on dredged material.

The Netherlands is performing studies on contaminated sediments since the seventies. The Port of Rotterdam yearly had to dredge large volumes of sediment in order to keep their port accessible to vessels, while the River Rhine transported new sediment to the port. This sediment was heavily contaminated by industries from Germany, France, Swiss and The Netherlands. When risks of relocating contaminated sediment became known, countermeasures were taken. A large Confined Disposal Facility was created at the new land reclamation of the port and a successful program was executed to stop the contaminant discharge of industries upstream.

The huge amount of studies performed over the last 35 years provided the Netherlands much knowledge and understanding on the topic. This resulted in well advanced legislation and good norm system for handling contaminated sediments, which is used and referred to by countries all over the world.

Because the Argentine experience on the handling of contaminated sediments is limited, international knowledge is used for evaluating the contamination. This study applies the Dutch Norms (Zoute-Bagger-Toets; Ministry of Transport, Public Works and Water Management). to decide if sediment is clean enough for free relocation to sea or if special handling is required. The Dutch norms consist of concentration limits for contaminants, which may not be exceeded for relocation to sea.

A summary of the investigation on contaminant concentrations in the Port of Dock Sud compared to the Dutch norms gave the following results:

- 7 out of 41 tested contaminant types show elevated concentrations in at least one sample. The contaminants are the Sum of Mineral Oils and the heavy metals Chrome, Copper, Zinc, Lead, Mercury and Cadmium. The first five show the highest concentrations at the mouth of the Riachuelo. The latter two only show elevated concentrations in only 1 sample within the port basins.

- Chrome, Mineral Oils and Copper show the most exceeded concentrations with respectively 10, 8 and 2.5 times the Dutch limit.

Most sediment settles in the entrance channel ‘Canal Sur Interior’. Dredged material from this location is not allowed to be freely relocated and needs special handling according to Dutch norm.
2.2 Disposal Site ‘Yarará’

Since the prohibition of free relocation of contaminated sediment, dredged material has been placed at the disposal site ‘Yarará’. The site is located at the shore of Dock Sud, between the LPG berth and the refineries of Shell. This site has an area of 30 Ha.

In an interview with former director of the DNVN\(^5\) three main issues about the disposal site were addressed and were confirmed during a site visit. A first problem with the site is the limited storage capacity. Approximately 200,000 m\(^3\) is available as storage volume in the current site. This is rapidly filled with the current dredging activities. After this compartment is filled, a next section of the disposal site needs to be constructed. Based on the site visit the storage depth is estimated on 5 m, which means an annual site expansion of 6.4 Ha in the coming years and a probable increase to 10 Ha. If the trend continues the site will occupy an area of 225 Ha in 2030; almost 5 times the size of the container terminal operated by Exolgan. The only available expansion area is in direction of the estuary, which complicates the construction of dikes on its soft soil and claim an even larger part of the potential port expansion.

The second concern is the containment dike of Yarará. The dike is constructed out of dewatered contaminated material from earlier parts of the disposal site and approximately 3 m high, with slopes of 1:2 and a crown width of 3 m. The dikes have no revetments and are constructed directly on a muddy beach, making the dike vulnerable for severe wave attacks. The risk of a breach and erosion of the site is present. The confinement of the dike is hard to estimate, because the permeability of the construction material is not known to this study. If the impermeability or confinement properties of the dike are not known at all, it is recommended to study this and assess the dispersion pathways.

The third issue is the limited settlement time for the dredged material. The dredged material is transported by pipeline under turbulent conditions with addition of water and high pressures. Most particles leave the pipeline in suspension and need time to settle. If the effluent water moves too rapid to the outlet weir without providing particles sufficient time to settle, particles are discharged together with the effluent water back into the LPG basin. This results in a major loss pathway of contaminants. The result of discharging effluent water with a high amount of particles can be seen around the outlet in the LPG basin. The discharged water is brown turning the area around the discharge pipe dark.

When visiting the site another aspect was noticed. The dewatered dredged material was very dry and dusty. It was remarkable that eyes were irritated after the site visit of half an hour.

The thesis study recommends a change in handling of contaminated sediment. The present way of storage has too many negative consequences for the future, because of dispersion of contaminants and blocking port expansion possibilities.

Investigating and evaluating the loss pathways of contaminants is recommended when it is not known to the port authorities. The thesis study continues with the basic assumption that risks concerning disposal site ‘Yarará’ are acceptable when closed. If the disposal site is no longer filled and covered by a layer of soil, effluent water and volatilization halts. When the port is expanded into the Río de la Plata, sufficient protection is provided for wave attack. Although it is not assumed, relocation should be kept in mind if risks prove to be too high.

2.3 Port Development

The contaminated sediment constrains the port in two ways. The first constrain is the high costs of dredging contaminated sediment. Since the DNVN obligates the port to handle dredged material with restrictions, dredging costs increased. The continuous expansion of ‘Yarará’ remains an uncertain cost factor for the dredging works and carries a potential risk for health and environment.

Ports are required to be sustainable nowadays. Lagging behind on sustainable developments and environmental legislation gives the port an uncertain character with unpredictable costs. Sustainable ports preparing for the future are attractive to settle and invest in. If all parties are investing in this port, the potential and stability of the port increases. A sustainable handling of contaminated sediment is

\(^5\) Dirección Nacional de Vías Navegables - National Direction of Waterways
one of the keys to making a reliable port, because a sustainable port requires a sustainable surrounding.

The second constrain is the disposal site growth in the direction of the Río de la Plata. This area is assigned for the potential port expansion. Puerto Dock Sud is located in one of the densest populated areas in the world, which makes land valuable. The population is pushing the port from the landside and citizens already settled within the port territory. Landside expanding of large areas of wet infrastructure and terminals is financially and socially not feasible. The shallow estuary provides an excellent possibility to develop new port area, but new terminals require a connection with Canal Sur. The current disposal site is claiming more valuable shore every year. If studies prove that “Yararará” could be reused as terminal area, this should be integrated. But unlimited expansion of “Yararará” without a master plan increase investment costs in the future. Excavation of large volumes of contaminated material to create new wet infrastructure could become a very expensive operation.

2.4 Handling and Management of Contaminated Sediment

Handling contaminated sediments and minimizing potential risks is the right step to take. International experience is available to optimize the handling and provide new solutions.

But if input of contaminants is not stopped, handling takes forever. Management of contaminated sediments is essential on the long run. Source control is the key to sustainable management. When the input of new contaminants is stopped and present contaminants are treated or isolated, only than does the threat to the health of the population and environment disappear.

The management of the contaminated sediment stretches beyond the direct influence area of the port authorities and involves various authorities, polluting parties, the population of Greater Buenos Aires and environmental groups. Notwithstanding the large number of parties, a key role can be taken by Puerto Dock Sud. A successful approach of the Port of Rotterdam proves that ports can play a key role in cleaning entire rivers.

3. PORT EXPANSION

Master Plan Dock Sud (EGIP 2005) gives predictions for the growth potential of the four main activities of the port; container, oil & gas, sand and chemical transport. The predictions of the throughput in Puerto Dock Sud for 2010, 2020 and 2030 are given in the table below. The operation of a new LNG terminal is a potential business for the port in addition to the four existing sectors.

<table>
<thead>
<tr>
<th>Year</th>
<th>Container (TEU)</th>
<th>Oil and Gas (m³)</th>
<th>Sand (ton)</th>
<th>Chemical (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>400,000</td>
<td>4,800,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>600,000</td>
<td>9,500,000</td>
<td>2,500,000</td>
<td>500,000</td>
</tr>
<tr>
<td>2020</td>
<td>1,000,000</td>
<td>12,000,000</td>
<td>3,700,000</td>
<td>500,000</td>
</tr>
<tr>
<td>2030</td>
<td>1,500,000</td>
<td>14,500,000</td>
<td>5,000,000</td>
<td>500,000</td>
</tr>
</tbody>
</table>

**TABLE 1** Throughput Predictions for Puerto Dock Sud

The Master Plan of EGIP mentions land reclamation at the shore of Dock Sud as the possible location for the new terminal activities, but does not give a size indication of terminals or basins. The thesis calculated the size of this expansion into the Río de la Plata in order to be able to create an integral plan with the contaminated sediment handling. The areas for the new terminal concerning the port expansion in Dock Sud are given with surface areas in the following table.

<table>
<thead>
<tr>
<th>Cargo Type</th>
<th>Surface Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container Terminal</td>
<td>45 Ha</td>
</tr>
<tr>
<td>Oil &amp; Gas Terminal</td>
<td>27 Ha</td>
</tr>
<tr>
<td>Sand Terminal</td>
<td>14 Ha</td>
</tr>
<tr>
<td>Chemical Terminal</td>
<td>4 Ha</td>
</tr>
<tr>
<td>LNG Terminal</td>
<td>15 Ha</td>
</tr>
</tbody>
</table>

**TABLE 2** Surface Area Terminal Expansion per Cargo Type
3.1 Expansion Area

The location for the container, oil & gas and LNG terminal has to satisfy certain requirements. First of all there has to be a market for importing and exporting products. The market evaluation is done in Master Plan Dock Sud with predicted market growth. These predictions are used as a basic assumption for this study.

The second requirement is the availability of space. Since Puerto Dock Sud is located in Buenos Aires, one of the densest populated areas in the world, this gives very limited possibilities on land. Nevertheless, the shallow Río de la Plata estuary provides enough space for expansion.

A third important issue is the water depth. The basins of Puerto Dock Sud and the Via Navegable Troncal have limited depth and therefore the port does not profit from the economy of scale larger vessels provide worldwide. Increasing the depth and receiving larger vessels is attractive for the port. Dredging is a good solution to create larger depth and the past proved that shipping is still a very competitive way of transport from and to Buenos Aires, despite of large dredging investments. The port should discuss deepening the Via Navegable Troncal in order to increase the competitiveness of Buenos Aires.

Safety and reliability is a fourth requirement of the location. Nautical conditions proved to be good as long as the Via Navegable Troncal and other waterways are dredged and ships can find a safe haven in the ports in the Buenos Aires region. The operational safety is always important in dense populated areas. Oil and LPG have been operated for more than a half century in Puerto Dock Sud and the risks seem to be acceptable for these two products. The introduction of a LNG terminal brings new risks to society. But the Río de la Plata provides a lot of space for safety distances and LNG has proven to be very safe. In 44 years of LNG shipping and over 47,000 LNG voyages, there has never been a major spill, no containment system has been breached and no crew member has ever been killed as a result of a cargo incident (LNG World Shipping newsletter (2006)).

The landside transport is the fifth requirement. The port has rail and road connection that has relative low congestions compared to Puerto Nuevo and many other ports in big agglomerations around the globe. The new terminals at the shore of Dock Sud are connectable with the road and rail system without significant difficulties.

3.2 Confined Disposal Facility

The final addition to the requirements of this port expansion is the Confined Disposal Facility (CDF). The special handling of contaminated sediment in Puerto Dock Sud is a problem, which needs to be solved. Therefore there is an area reservation taken up in the port expansion plan for the CDF. The surface area for the reservation is 35 Ha, as calculated in the thesis.

3.3 Wet infrastructure

The new terminals need access to the Via Navegable Troncal by wet infrastructure. The approach channel, Canal Sur, exists but needs to be accessible to vessels of 12 m draft as well.

Ligteringen (2007) gives vessel size increases over the past century and a prediction of future sizes can be made for a two-way channel. Although with a variability, because of the uncertainty of developments. This results for the normative container vessel in a width of 110 m. It is advisable to consider a two-way channel because of the limited waiting areas outside Canal Sur.

The design depth of the approach channel is 13.5 m under MLLW with a normative draft of 12 m. No tidal window is considered for Puerto Dock Sud, since tide differences are limited and the approach channel relative long. At the end of the approach channel the vessels have a turning basin to make the turn to the new terminal area. A turning basin requires twice the normative vessel length; 600 m in case of Puerto Dock Sud.
3.4 Future Port Layout

The various areas of the new terminals have connections with each other, the open sea and the hinterland. Keeping these connections in mind, the terminal areas can be placed strategically in order to optimize the port. The layout design of the terminal areas is to be executed on various levels, from rough to detail. The study only treats the first step of this port planning and suggests and shows that the “Branch Along Coast” layout scores best on nine criteria (Approach Channel, Manoeuvrability, Sedimentation/Morphology, Cut/Fill, Dike, Future Port Expansion, Land Transport Connections, LNG Safety Distances and Confined Disposal Facility). Next figure depicts the layout of this plan.

![Future Port Layout](image)

**FIGURE 3** Future port layout: ‘branch along coast’ (grey zones are present port)

4. Handling Contaminated Sediment

The risk of free relocating contaminated dredged material from Puerto Dock Sud is too high and requires special handling. This is also stated by law and leaves the Port of Dock Sud with two options of handling its sediment as stated by Vellinga (1997):

- **Treatment**  Cleaning the dredged material and return it to the ecosystem
- **Storage**  Isolate the material in a Confined Disposal Facility

Keilor (2007) states that treatment diminishes the negative effects of the contaminants and produces relative clean sediments or products. Clean enough for relocation to the ecosystem or for beneficial use. Although the results are promising, the disadvantages are significant. It requires a sensitive investigation of the contaminants in order to find the right treatment process. Various processes are required since the contamination in the sediment concerns a mix of heavy metals and mineral oils. This makes the costly treatment processes even more costly. Based on reference projects in Europe
and United States of America is the treatment of contaminated sediment at least a factor 10 more costly than confined storage. Price indications by European companies are set between 125 and 200 USD per m$^3$ (ENVICOM report 2002 and 2006).

Storage of contaminated sediment proves to be an effective remediation measure on various locations in Europe, Japan and North America. The relocation of dredged material into the Confined Storage Facility isolates the contaminants and diminishes the social and environmental impact risks. Due to the high confinement of the material itself, the isolating dikes and the aquatic storage is the mobility of the heavy metals and mineral oils almost nil. Confinement needs to be achieved by soil or synthetic liners. Immobilisation measures by injecting binding supplements are difficult and often not effective because of the mixture of heavy metals and mineral oils. Current techniques that immobilise heavy metals do not prevent the mobilisation of mineral oils. The costs estimation of aquatic storage in a CDF, based on reference projects around the globe, gives 12 USD per m$^3$. Including the more expensive upland storage it is estimated on 22 USD per m$^3$ (see summary Master Thesis).

Treatment is often performed in combination with confined storage. The clean sandy part of the dredged material is cleaned, separated and used, while the remainder is stored in a CDF. Because the dredged material consists for more than 80% of clay and silt, this procedure is not feasible.

So it can be concluded that treatment can potentially clean the sediment to acceptable levels, but costs approximately 10 times more than storage. Storage in a CDF isolates the contaminants and diminishes the risks of the contamination. Note that the impact of the measure on the total amount of contaminants is limited, since approximately 50% of the contaminated sediment passes the port basins to the Río de la Plata without being dredged.

4.1 Confined Disposal Facility

Constructing a CDF concerns many factors of importance and an assessment is required for its features, like storage volume, CDF type, location, geometry, dike/structure, isolation features, logistics, treatment and monitoring. Especially the location turned out to be difficult in the dense populated area and a construction in the Río de la Plata estuary provides the most feasible location. However, the estuary has a soil with very limited strength and excavation of the weak soil is necessary and a main cost factor. An overview of the alternatives is given of an elaborate study of the thesis report.

The design volume for the CDF that is primary meant to store the dredged material from the port is 4,760,000 m$^3$. There are two locations for the CDF: ‘shore’ and ‘estuary’. The shore location is from the coast to 1 km into the Río de la Plata and the estuary location from 1 km up to 5 km. Off course this a rough schematization and a soil investigation should provide more detailed data. Secondly the CDF can vary in being attached to the coast or port area and being standalone, in case of the ‘shore’ location. Next figures gives possible location of the CDF.
**CDF Alternative 1: Attached to coast at Shore**

The CDF is attached to the coast or another port area. The CDF is able to use the existing coast or another dike for containment of the dredged material. Therefore the dike ring length will decrease because of the synergy, but the shape will not be circular in order to optimize this synergy. The required pipeline infrastructure is estimated on 2 km, because a nearshore CDF cannot be built attached to Canal Sur, for port expansion reasons. The only possible location is reserved for the access to the new port area. The next table gives the properties of CDF alternative 1.

<table>
<thead>
<tr>
<th>CDF Alternative 1</th>
<th>Attached to coast at Shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape Factor</td>
<td>1.3</td>
</tr>
<tr>
<td>Dike Ring Length</td>
<td>1,700 m</td>
</tr>
<tr>
<td>Dike Construction Depth</td>
<td>-5.75 m MSL</td>
</tr>
<tr>
<td>Total Dike Height</td>
<td>12 m</td>
</tr>
<tr>
<td>Storage Depth</td>
<td>-18 m MSL</td>
</tr>
<tr>
<td>Transport Distance</td>
<td>2 km</td>
</tr>
</tbody>
</table>

**TABLE 3 CDF Alternative 1 Properties**

**CDF Alternative 2: Standalone at Shore**

The CDF is not attached to the coast, but forms an island at the shore. To minimize the dike length, the CDF will be circular. The required pipeline infrastructure is estimated on 2 km, because the shore CDF cannot be built attached to Canal Sur, for port expansion reasons. The only possible location is reserved for the access to the new port area. The next table gives the properties of CDF alternative 2.

<table>
<thead>
<tr>
<th>CDF Alternative 1</th>
<th>Attached to coast at Shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape Factor</td>
<td>1.0</td>
</tr>
<tr>
<td>Dike Ring Length</td>
<td>2,200 m</td>
</tr>
<tr>
<td>Dike Construction Depth</td>
<td>-5.75 m MSL</td>
</tr>
<tr>
<td>Total Dike Height</td>
<td>12 m</td>
</tr>
<tr>
<td>Storage Depth</td>
<td>-18 m MSL</td>
</tr>
<tr>
<td>Transport Distance</td>
<td>2 km</td>
</tr>
</tbody>
</table>

**TABLE 4 CDF Alternative 2 Properties**

**CDF Alternative 3: Standalone in Estuary**

Circular island CDF in estuary between 1 km and 5 km from Puerto Dock Sud. No pipeline is required because the CDF can be built directly next to Canal Sur. The next table gives the properties of CDF alternative 2.

<table>
<thead>
<tr>
<th>CDF Alternative 1</th>
<th>Attached to coast at Shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape Factor</td>
<td>1.0</td>
</tr>
<tr>
<td>Dike Ring Length</td>
<td>2,200 m</td>
</tr>
<tr>
<td>Dike Construction Depth</td>
<td>-14.75 m MSL</td>
</tr>
<tr>
<td>Total Dike Height</td>
<td>22 m</td>
</tr>
<tr>
<td>Storage Depth</td>
<td>-18 m MSL</td>
</tr>
<tr>
<td>Transport Distance</td>
<td>5 km</td>
</tr>
</tbody>
</table>

**TABLE 5 CDF Alternative 3 Properties**
Multi Criteria Analysis

The three alternatives are all potential solutions to the problem. Further investigation should provide more information on the details of the alternatives. Secondly the port authorities and other involved administrations have to specify the development of the area and the plan for all the contaminated dredged material in the region. If those demands are clear, the final design can be made for the CDF.

For now a first evaluation is made based on the available information. The criteria to which the alternatives are evaluated are given in the overview below. TABLE 6 provides the quantitative and qualitative criteria and the criteria that are not taken up in the MCA because they are the same for each alternative.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dike Construction</td>
<td>Quantitative</td>
<td>Material and placement costs of dike</td>
</tr>
<tr>
<td>Dike Excavation</td>
<td>Quantitative</td>
<td>Dredging costs construction pit</td>
</tr>
<tr>
<td>Storage Excavation</td>
<td>Quantitative</td>
<td>Dredging costs storage pit</td>
</tr>
<tr>
<td>Pipeline Infrastructure</td>
<td>Quantitative</td>
<td>Infrastructure costs pipeline</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Qualitative</td>
<td>Flexibility for new port areas</td>
</tr>
<tr>
<td>Integration</td>
<td>Qualitative</td>
<td>Integration in new port areas</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Qualitative</td>
<td>Accessibility by land</td>
</tr>
<tr>
<td>Facilities Area</td>
<td>Qualitative</td>
<td>Costs of extra land reclamation</td>
</tr>
<tr>
<td>Maintenance/Operation</td>
<td>Similar</td>
<td>Alternatives have similar maintenance/operation costs</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Similar</td>
<td>Alternatives have similar storage effectiveness</td>
</tr>
<tr>
<td>Treatment</td>
<td>Similar</td>
<td>Alternatives have similar treatment facilities</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Similar</td>
<td>Alternatives have similar monitoring program</td>
</tr>
<tr>
<td>Extra Storage</td>
<td>Similar</td>
<td>Alternatives can all increase storage for sediment from outside Puerto Dock Sud</td>
</tr>
</tbody>
</table>

TABLE 6 Criteria MCA

Construction Material

A selection of the most suitable construction material cannot be made in this thesis. All three materials (sand, Tosca clay and geotubes/containers) satisfy the requirements. The choice will be based on the construction costs and the prices are not known of each material.

- Sand is available, but needs to be transported over large distances (200 km). The volume per running meter is for a sand dike at the ‘shore’ 1,460 m$^2$ and at the estuary 4,830 m$^2$.

- Clayey sand is available in the neighbourhood (10 to 40 km) and is a good fill material for geotubes. However, the costs of the filling procedures and placing of the geotube are not known. The volume per running meter is for a geotube dike at the ‘shore’ 340 m$^2$ and at the estuary 1,050 m$^2$.

- Tosca clay is suggested by Jan de Nul Argentina and costs 5.0 USD per m$^3$, including transport to Buenos Aires. This does not include placement. The volume per running meter is for a clay dike at the ‘shore’ 760 m$^2$ and at the estuary 2,470 m$^2$.

Tosca gives the best price indications and is therefore used for the multi criteria analysis.

Quantitative

Construction volumes and prices are given per alternative in the next table. The price of Tosca is set on 5.0 USD per m$^3$ and the price of excavating by TSHD is set on 275,000 USD per 50,000 m$^3$, which corresponds to 5.5 USD per m$^3$.

The dredged material can be transported by barge in case the CDF is close to a waterway and there is a mooring station. Hydraulic transport requires a semi-permanent infrastructure of pipelines. Semi-permanent signifies that the pipeline is required as long as the filling period of the CDF. An island CDF in the ‘estuary’ is assumed to be constructed next to a waterway, while the ‘shore’ CDFs roughly need a 2.0 km pipeline. Jan de Nul Argentina estimates the costs of a pipeline at 550 USD per m, which means the shore CDFs require a pipeline of 1.1 mln USD.
Note that the table does not include all the costs, but only some quantifiable aspects. The placement of the Tosca clay is also an important costs factor, but is not included. This will increase the dike costs for all three alternatives.

### Qualitative

Operation, maintenance, flexibility, integration and external use are costs/benefits that are finally also expressible in currency, but not in this stage of the design. Therefore they are quantified qualitative.

- Only alternative 1 is accessible by land. Alternative 2 and 3 require barges.
- The flexibility of an island CDF, alternative 2 and 3, is higher than a nearshore CDF. It is placed independent of other structures or coast and can therefore easier be adjusted.
- The nearshore CDF, alternative 1, can be easily integrated in a new port area and even be turned into a terminal area once the CDF is filled and covered. Alternative 2 can also be used as land reclamation, but has higher requests from the new port area, because this area cannot be used anymore as waterway or basin. Alternative 3 is too far away from the coast to be integrated.
- Facility areas require land reclamations next to the CDF. This includes facilities for treatment, logistics and workshops. The deeper the constructions bottom of the land reclamation the higher the costs. These costs are not yet expressed in currency in this stage.

The weighing factors of the qualitative criteria are given in TABLE 8. All criteria are compared to each other and if one criterion is more important than the other, it obtains 1 point. All criteria have the starting value of 1; expressed in the number in the grey box.

- Integration has the highest weighing score, because it can result in large benefits of land reclamation.
- Flexibility is weighed second, because if the layout of the new port layout changes, the CDF can become an obstacle.
- Facility area is weighed third. Costs are limited.
- Accessibility is weighed fourth. The extra costs of transport by boat or barge is limited, but land transport of soils is not the primary purpose of the CDF.
TABLE 9 Qualitative Evaluation

The next table gives the criteria with weighing factors and scores. The advantages and disadvantages are discussed on the previous page and expressed in scores from 1 to 10.

<table>
<thead>
<tr>
<th>CDF Alternative</th>
<th>w.f.</th>
<th>CDF 1</th>
<th>sc.*w.f.</th>
<th>CDF 2</th>
<th>sc.*w.f.</th>
<th>CDF 3</th>
<th>sc.*w.f.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td>6</td>
<td>18</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Integration</td>
<td>4</td>
<td>8</td>
<td>32</td>
<td>6</td>
<td>24</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Accessibility</td>
<td>1</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Facility Area</td>
<td>2</td>
<td>7</td>
<td>14</td>
<td>7</td>
<td>14</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Final Score</td>
<td>-</td>
<td>-</td>
<td>69</td>
<td>-</td>
<td>61</td>
<td>-</td>
<td>52</td>
</tr>
</tbody>
</table>

The quantities and qualitative evaluation of the alternatives are visualised in the next figure. The evaluation does not include all costs or characteristics, but points at the differences of the alternatives.

Concluded from this analysis is that the CDF in the estuary is more expensive than the CDFs at the shore. Alternative 1 is slightly more cost effective than alternative 2, but the costs should be worked out more detailed. Alternative 1 and 2 give opportunities for integration and beneficial use of the CDF as land reclamation for new port areas, while alternative 3 is 'standalone' and therefore provides more flexibility for alterations in the area. The CDF is less likely to provide a terrain conflict if for instance the new port layout alters.

This thesis suggests developing a CDF at the shore of Dock Sud and not farther away in the estuary. The future plans for the whole area should determine if a nearshore CDF or island CDF should be constructed. In the opinion of this thesis provides the nearshore CDF the better opportunities.

Sensitivity Multi Criteria Analysis

The evaluation as carried out in this section works with fixed numbers. These numbers are fixed with a certain assumption, but can vary. In a next study with more detailed information a MCA can be repeated.
5. Management of Contaminated Sediment and the Role of a Port

The storage of the contaminated sediment in a Confined Disposal Facility on Dock Sud’s shore is an appropriate solution for the port in the short and middle long period. The contaminants are isolated from the ecosystem by the containment dike and bottom in order to minimize the risks for the population and environment. Once the dredged material is clean enough to relocate to sea, the CDF can be covered by a soil layer and the land can beneficially be used for port expansion. This way a burden of the port is converted into an opportunity to generate sustainability and economic potential for the Buenos Aires region.

But the principal is based on temporary storage of contaminated sediment in the port. The limited dimensions of the CDF are not capable to store sediment perpetually. After the filling period, new CDFs are required until the input of contaminants stops. Thus the port is obliged to keep investing in costly storage of their sediments, while other parties have the benefits of illegal polluting. This situation has to change to prevent that the port pays part of the problems of the industries upstream.

This requires a change. It is in the port’s best interest to involve all responsible parties in the issue and move the problem and costs back to the polluting parties. If the sources of the contamination make the switch to become clean, this will bring sustainability to the whole issue. Source control is therefore the key in the sustainable solution for this problem.

The contamination is not only affecting the port, but the whole of Buenos Aires and its surroundings. The area is not only socially affected, but also economical.

5.1 Society & Environment

The social consequences of the contamination in the Río Matanza-Riachuelo are large. Amongst the 4.8 million residents in the area are to the poorest citizens of Argentina. Because of the lack of a sewer system, 1.7 million residents depend for their domestic waste water on ‘disposal wells’, called ‘Pozos Ciegos’ in Castilian. If possible these wells are leaking to the aquifer in order to minimize costs for pump trucks that have to empty the ‘well’ once in a while. Although leakage of the ‘disposal well’ saves money for the owner, it is a main source of contaminants into the aquifer and indirect to the river. The other way round are many persons dependent on this aquifer for their daily consumption of water by other wells.

According to the Argentine newspaper Clarin, does the population on the river banks show an increased level of the diseases leptospirosis, gastrointestinales, tetanus, parasites and dengue. The newspaper assumes that the diseases have a direct connection with the daily discharge of 88,500 m$^3$ of industrial waste water and 368,000 m$^3$ sewer water in the Río Matanza-Riachuelo. It is evident that during visits to the area a heavy pollution odour was noticed and that the river consisted of sludge and was carrying along a lot of garbage. If the river has connections with lower aquifers and with the groundwater, it is likely that the soil of this area is contaminated.

Thus the contamination problems start directly at the discharge location and continue to Puerto Dock Sud. But the social and environmental problems do not stop at port. Approximately 50% of the sediment passes the port and flows directly into the Río de la Plata where it disperses over the southern bank. The FREPLATA (2002) study to the environmental situation of the ‘Río de la Plata and its foreshore’ concluded that the Riachuelo together with Canal Sarandi is the largest contaminants contributor of the southern part of the estuary. Chrome, Lead and Mineral Oil contributions consist of respectively 66%, 53% and 43% of the total input of this area. These contaminants accumulate in the ecosystem and could have far-reaching consequences for future generations of flora, fauna and the human population.
5.2 Economic

Cleaning the Río Matanza-Riachuelo and stopping the pollution requires big investments, but the economic return on investments is often higher. Although the human and environmental harm caused by the pollution is often beyond the expression in money, it is interesting to express the problem economically in a risk assessment. Assessment of the economic losses due to the pollution shows the potential benefits of a cleanup program. In many examples around the globe this approach showed that remediation and cleanup projects are profitable in an economic perspective. In most cases only an assessment of the direct consequences is sufficient to prove that the cleanup is profitable. If an assessment shows that the cleanup is a profitable investment for society, the cleanup is easier justified and sooner executed. This provides administrative organs much more power and support to undertake the necessary measures.

The assessment should include the following items for the firms and communities involved:

- Added health costs for people exposed to toxic chemicals
- Loss in value of the large degraded parts of the environment
- Depressed value of real estate
- Barriers to development of property
- Suppression of recreational activity in polluted areas

If the simple risk assessment of direct items turns out to be not profitable a deeper investigation is needed. Such a deeper research can be done by contingent valuation. The method relies on a survey of informed people to determine their willingness to pay for the cleaning of their waters that will accomplish specific goals. Though it is hard to estimate the spending power of the area in this situation, it is important to know the willingness for action among the population. A proactive population can be a large costs reduction, since the people are part of the contamination problem and work in the industries. Providing information is a key issue to create willingness.

5.3 Role of a Port

Ports take a very special part in the contaminated sediment issue. As no other commercial party, they notice the consequences of the contamination. They are often located at the end of the river and are obliged to remove large amounts of sediments to enable navigation. But they are also closely related to the industries. They move all the products that go from and to the industries in their hinterland, which are often settled within or close to the port territory. In the next example is explained how the Port of Rotterdam played an important role in the cleaning of the River Rhine and how Puerto Dock Sud can learn from this best practise.

5.4 Port of Rotterdam

The Port of Rotterdam is located on the interface between the catchment area of the River Rhine and the North Sea. The catchment area is 185,000 km² Salomons & Gandrass (2001) and consists of major parts of The Netherlands, Germany, Switzerland and Luxemburg, but also includes parts of France, Belgium, Austria, Italy and Liechtenstein. The port requires a depth between 10 and 25 m in order to receive the sea going vessels. The yearly maintenance dredging involves 20,000,000 m³ of sediment that comes for 1/3 from the river and 2/3 from sea.

The port used to relocate the sediments to the North Sea and to upland locations, but in the seventies it became clear that much of the dredged material was contaminated. In these days the environmental awareness was very low in Europe and the River Rhine functioned for many industries as a sewer system for their waste water. As a result the sediment became heavily contaminated and the environment degraded. When the negative consequences of the dredged material for society and environment became known, it did lead to the prohibition of non-contained relocation of contaminated material on land or into sea.

This development made the dredged material a heavy burden for the port and demanded a stout solution. Approximately 50% of the dredged material, 10 million m³, was assumed to be too contaminated and required to be handled specially. In 1986 a Confined Disposal Facility, called 'the
Slufter', was constructed to store the contaminated dredged material with a storage capacity of 150 million m$^3$. The filling period was planned to be 15 years.

In the mean time the port launched the 'Rhine Research Project' (POR), because changes needed to be made to prevent the construction of a new CDF after these 15 years. The project was aimed at point discharges in the river. Water and sediment samples were taking from the river and analysed, after which the polluting companies were identified. The port confronted the Swiss, German and French companies with their discharge and initially faced grave resistance or complete denial. But after negotiations and with the backup of the indisputable proves of their research, agreements were reached on discharge reductions up to 70% to 90%. It resulted in an enormous reduction of contaminants in the River Rhine, illustrated with the return of several fish species that were not encountered in the river for decades. The drop in contaminants in the river sediment and thus in the port too, resulted in a decrease of contaminated dredged material and a reduction of dredged material that had to be stored in the Slufter. Currently 1,000,000 m$^3$ is stored yearly in the CDF, being 5% of the total dredged material and a reduction of 90% compared to the eighties.

The negotiations based on bringing parties together and creating understanding as well as the use of arguments based on clear facts proved to be effective. The result reached beyond the goals of governments, cutting 50% of the pollution discharges. And the major reduction was all realised within a decade by working together and avoiding time consuming lawsuits.

But a complete sustainable situation has not yet been achieved for the River Rhine and so the port started a follow-up research in the beginning of the 21st century, POR II. This research is aimed at the assessment and quantification of the diffusive sources of contaminants. The insights on diffusive sources, as atmosphere, groundwater, pavement run-off and historical sediment should support the future policies and regulatory frameworks on national, European and international level and aim at completely sustainable catchment areas.

Anno 2008 is the Slufter filled by approximately 50% and has a remaining storage capacity of 75 million m$^3$. With the dropping amount of contaminated sediment in the port and the assumption that the river will be sustainable within decades, the Slufter will remain with an overcapacity. Therefore the storage of contaminated sediment is opened for external parties as well. The sediment is stored under strict quality restrictions and for a fee of approximately 15 USD/m$^3$ (website Port of Rotterdam 2008).

### 5.5 Puerto Dock Sud

Puerto Dock Sud can use the example of Rotterdam as a best practice. Contaminated sediment is increasing dredging costs and limiting port developments. If a sustainable river with clean sediments is obtained, it will save the port significant costs and increase its economical potential.

A cleaner river is inevitable. The awareness of the necessity of protecting the environment and the limitation of natural resources is growing. The government created ACUMAR to bring answers, the High Court is pushing the government to produce results and a change of mind is developing amongst the population. Sustainability is coming and this is noticed all over the world. So why not invest to speed up the process and save the port some money?

**Research Project Riachuelo**

The first step is to obtain clear figures on the contamination. The facts should be indisputable to all parties. This is of course not that easy and it is recommended to cooperate with respected institutes for this research. They should sample the river, if possible the discharge outlets too, and do the contaminant analyses.

Secondly the consequences should be linked to the contamination. This can be done by using existing knowledge on the topic from other studies around the globe or doing new bioassays and field inventories.

In the third place the targets should be set for reduction of contaminants. These targets can be based on the legislation for contaminated sediments or could be found by environmental impacts assessments. It should be understood that a contaminant hazard is not directly a risk and that a risk is not directly an impact. The connections between these three should be made in order to reach the potential impact of the contamination. This can aid by the development for better legislation.

The targets, based on the C&D Laboratories report that is used earlier in this study, would indicate reductions for Chrome, Copper, Lead, Zinc and Mineral Oils. Assumed is that sample spot CA1 (see appendix B for location) at the centre of Cuatro Bocas, is the most representative sample for the
sediment in the Riachuelo. This sample is the closest to the Riachuelo and therefore the least mixed with other sediments from the Río de la Plata. The values are compared with the Dutch legislation on relocating sediment to sea, which gives the following target reductions.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>CA1 - Cuatro Bocas</th>
<th>Dutch Limit</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrome</td>
<td>1.159 µg/g</td>
<td>120 µg/g</td>
<td>90%</td>
</tr>
<tr>
<td>Copper</td>
<td>164 µg/g</td>
<td>60 µg/g</td>
<td>63%</td>
</tr>
<tr>
<td>Lead</td>
<td>155 µg/g</td>
<td>110 µg/g</td>
<td>29%</td>
</tr>
<tr>
<td>Zinc</td>
<td>670 µg/g</td>
<td>365 µg/g</td>
<td>46%</td>
</tr>
<tr>
<td>Mineral Oil</td>
<td>9,899 µg/g</td>
<td>1,250 µg/g</td>
<td>87%</td>
</tr>
</tbody>
</table>

TABLE 10 Target Reductions Contaminants Riachuelo

This is based on one sample, but more elaborate researches should result in a more profound target.

**Sustainability**

Subsequently the approach has to be made to the responsible polluters. Locate the dischargers of the target contaminants and confront them with the exceeding concentration levels. If the consequences of the contamination and their discharges are clearly linked, the first step is often overcome in the process to sustainability: denial. Then they only need to be convinced that they are able to make the change and that they should undertake action. If the parties maintain unwilling and will not cooperate, going to court could bring a way out, but be prepared for long-lasting lawsuits. It is better used as a threat. For the Port of Rotterdam in most cases the threat of making the measured direct inputs from the industries known to the general public was regarded the best pressure on industries to reach agreements.

6. CONCLUSION

6.1 Sedimental Port Constrains

The Riachuelo transports heavily contaminated sediment into the Río de la Plata of which annual 320,000 m³ remains in the wet port areas at the river mouth and is to be dredged. The 3,000 industries in the catchment areas are identified as a main source of the pollution next to the urban disposal of 4.8 million inhabitants in the river and the formal port activities.

The sediment is heavily contaminated with heavy metals and mineral oils. Compared to Dutch legislation seven contaminants concentration exceed the norm: chrome, copper, lead, zinc, cadmium, mercury and mineral oils. According to Dutch legislation the dredged material is not allowed to be relocated to sea, unless each of the contaminant concentrations is reduced to the norm.

Argentinean legislation neither allows free relocation of these contaminated sediments. The dredged material is therefore currently stored at a disposal site in front of the shore, which has questionable confinement and an unsuitable location regarding future port expansion.

6.2 Storage and Port Expansion

Storage of contaminated dredged material in a Confined Disposal Facility (CDF) has proven to be an efficient and economical way to minimise the environmental risks and is ten times cheaper than existing treatment methods. The estuary is the place to create a CDF.

The Río de la Plata area is also suitable for port expansion and could provide the port’s answer to the increase in Buenos Aires’ demand in container-, oil & gas- and LNG-terminal capacity. An integral port expansion design with attached or detached CDF provides a solution for growth in a sustainable port.

FIGURE 5 Future Port Layout Dock Sud...?
6.3 Key Role Port

The port requires a sustainable surrounding to develop, but should also play a key role in making the surrounding sustainable. The best case practice of Rotterdam shows the role of the port in achieving a sustainable River Rhine by source control. A source control program and port expansion with CDF prepares the Port of Dock Sud for the future demands of Buenos Aires in the 21st century.

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