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Dredging and disposal of fine sediments in the state of Rio de Janeiro, Brazil

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Abstract

Dredging is employed quite frequently in the state of Rio de Janeiro, especially for the installation and upkeep of commercial ports and rehabilitation of the hydraulic section of silted bodies of water. Until recently, all dredged material with no economic use was destined for marine disposal or stored at the edge of the water body. Since the 1990s, however, a new approach has been adopted for dredging as a result of pressure from the environmental organisations, encouraging closer interaction in Rio de Janeiro between the local and state public authorities and the universities on issues relating to licensing of this kind of activity. The recent experiments of the Civil and Ocean Engineering Programs of COPPE-UFRJ (Federal University of Rio de Janeiro) described herein are included in this context. The state of Rio de Janeiro has three bays, several coastal lagoon systems and a number of small and medium sized rivers in or close to urban areas, with a gentle slope as they near the sea. This is, then, a region highly susceptible to silting processes of water bodies, and therefore, to maintenance and/or environmental rehabilitation. As discussed in the article, fine and almost always organic sediments prevail, which is a considerable obstacle to the end disposal and possibility of reuse.

Keywords: Dredging; Organic fine sediments; Land disposal; Contaminated sediments

1. Introduction

The Civil and Ocean Engineering Programs of COPPE-UFRJ have been involved in dredging projects in the city of Rio de Janeiro since 1996. Several teaching staff members, post-graduate and under-graduate students have taken part in these projects.

In addition to the projects themselves, some staff members have also had the opportunity to join a group formed in 1998 to discuss the creation of "Guidelines on Dredging and

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Disposal of Sediments in the state of Rio de Janeiro", a document expected to be put into practice in the state, in 2000.

This article provides a summary of the accumulated experience and discussion on geotechnical and environmental aspects of dredging and disposal of fine sediments in an urban environment. This subject has already been much debated in a number of countries (see US Army Corps of Engineers [29]; Herbich [20]; IADC/CEDA [21,22]; Kamon et al. [23]), but it has only now become relevant in government agencies, and consequently, in the technical sphere in Brazil.

In this respect, a federal document is currently being prepared under the co-ordination of IBAMA (Brazilian Institute for the Environment and Renewable Resources), in an agreement with Holland. That document, however, will necessarily be of a more general nature, and is not intended to be a discussion of specific questions for each environment, which is the aim of the article herein with regard to the state of Rio de Janeiro.

2. Recent dredging projects in the state of Rio de Janeiro

The state of Rio de Janeiro has more than 70% of its population living along the coastline, which is very relevant economically, because of tourism, petroleum exploitation and refining, and the presence of important ports. Within the state limits there are three very distinct bays, one of them, Guanabara Bay, has being occupied for centuries, being the birth place of the cities of Rio de Janeiro and Niterói. Tropical coastal lagoon systems are also very common in the state, and one of them is located in the expansion zone of Rio, in the Jacarepaguá Basin, in the West side of the city. Therefore, surface water bodies are very important natural resources for the state, either for water consuming (rivers) or recreation and/or navigation uses (lagoons and sea).

Fig. 1 shows the five most relevant projects in the state of Rio de Janeiro in the 1990s, some of which have already been accomplished and others are still under study.

In the case of Sepetiba Port (no.1 in Fig. 1) this was an installation dredging involving a large volume of material, part of which was contaminated with heavy metals. Its dredging was started in 1996 and concluded in 1998.

Rio de Janeiro Port (no.3 in Fig. 1) requires periodic dredging to keep the access channel open. On each occasion a new license must be requested, but an agreement with the state environmental agency permits disposal of dredged material in a specific area inside Guanabara Bay.

Areas no. 4 and 5 (Fig. 1), Fundão Channel and the mouth of the Iguaçu river are part of the Guanabara Bay depollution plan (PDBG), an environmental rehabilitation project of the Rio de Janeiro state government funded by the World Bank.

In both areas, dredging is to recover reasonable water circulation conditions and remove the more polluted layers of bottom sediment. To understand the importance of these areas, it is worth mentioning that the Petrobras Duque de Caxias refinery and a group of petrochemical plants are on the left bank of the river Iguaçu, and on the right bank there is the largest urban waste landfill in metropolitan Rio de Janeiro, named Gramacho landfill (6000 t per day of waste). Moreover, practically all rivers in the region flowing into the bay are in the last stages of degradation.

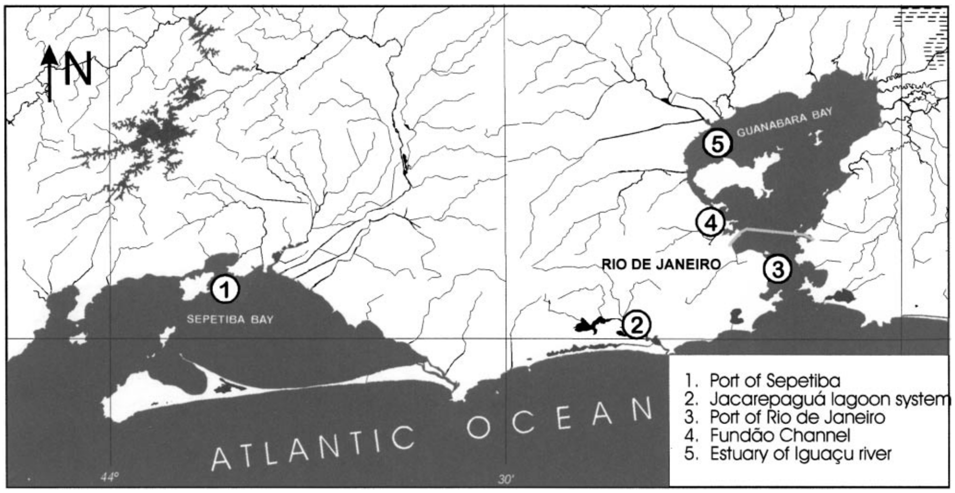


Fig. 1. Recent major dredging areas in Rio de Janeiro (apud Ramos [28]).

Jacarepaguá Basin (no.2 in Fig. 1) today is the subject of a widespread environmental rehabilitation project by the Secretariat for the Environment of the city of Rio de Janeiro (SMAC). This project involves various aspects, one of which is the dredging of the rivers and the lagoon system.

Table 1 shows a general comparison of the dredging of Sepetiba Port, Fundão Channel and Jacarepaguá Basin. COPPE-UFRJ has been directly involved in the last two projects. The data on Sepetiba is given only for the purpose of comparison, based on the environmental

Table 1
Table comparing quantities of some dredging areas in Rio de Janeiro

Site and year	Objective	Volume (m^3)	Level below average sea water	Responsible
Sepetiba Bay, 1996	Implementation of Sepetiba Port	25000000	−19 m (today: 10–17 m)	Compamhia Docas do Rio de Janeiro
Guanabara Bay (under study)	Maintenance and environmental dredging — Fundão Channel	1500000	−4.25 m	SERLA and state of Rio de Janeiro (PDBG)
Jacarepaguá Basin, 1996–2000	Emergency maintenance dredging — Camorim, 1996	600000	−2.00 m	SMAC (local Rio government) and SERLA (state)
	Flood control — Rivers (1998–1999)	4000000	Variable	SMAC (local Rio government)
	Maintenance and environmental — Tijuca (under study)	3200000	−1.54 m	SMAC (local Rio government)

impact assessment reports (EIA-RIMA) (MultiService and Cia. Docas do Rio de Janeiro [26]).

3. The dredging project

There are four large dredging groups with different objectives: (a) installation dredging, for opening channels in virgin areas; (b) maintenance dredging, to recover the water depth of silted bodies of water; (c) mining dredging, to extract material for economic purposes (sand, gravel, ores); and (d) environmental dredging, when the goal is to remove polluted sediments from a body of water.

Currently, dredging projects involving a volume of more than 25,000 m^3 and/or special conditions, such as environmental preservation sites or a high degree of contamination, must undergo a series of investigation and analysis stages.

The contractor is legally responsible for dredging and disposal or use of the dredged material. In the state of Rio de Janeiro dredging associated to implementation and maintenance of sea ports is undertaken by the Rio dock authorities (Companhia Docas do Rio de Janeiro).

Maintenance and environmental dredging are almost always public works. As inland waters are involved, the dredging is contracted by or with the participation of SERLA (Rio de Janeiro State Operating Department for Rivers and Lagoons). Very often the responsibility for flood control and environmental rehabilitation of degraded areas is either the state or local Secretariat for the Environment or Works.

In the case of mining dredging, contractors are almost always private. The only exceptions are sand dredging to add to beaches or undertake marine landfills in public works.

In Brazil, licensing is the task of each state environmental agency, in Rio de Janeiro it is the task of the State Environmental Engineering Foundation (FEEMA). As dredging in the state is so frequent and widespread, in 1997 FEEMA organised a document to instruct and guide the contractors on how to prepare and submit the EIA-RIMA reports (FEEMA/GTZ [18]). In 1998, a second document with wider coverage was discussed and rewritten as a guide for the contractors on the overall dredging and disposal design (FEEMA/SERLA/GTZ [19]).

The purpose of these initiatives was to regulate the licensing of the dredging process in the state of Rio de Janeiro, fixing a priori the guidelines of the environmental agency for the contractor, so that the latter could plan the investigations and analyses required in the project.

4. Comparative analysis of some case studies

The first reference in Brazil to a geotechnical study on dredging, including an analysis of sediment contamination, was the paper by Boscov et al. [9] on dredging the river Tietê, in the city of São Paulo. This involved dredging a sandy sediment, in which the principal sources of contamination were untreated sewage and domestic waste.

Around the same time (1996) dredging was initiated at the access channel to Sepetiba Port in Itaguaí, in the state of Rio de Janeiro, and an emergency dredging of Camorim lagoon, in

Jacarepaguá Basin, Rio de Janeiro, was implemented, the latter involving COPPE-UFRJ. Both cases consisted of dredging fine sediments, which complicates disposal and/or use of the dredged material. In late 1997, studies began on the Fundão Channel dredging project, for SERLA. In 1998 a new study was made on sediment dredging and disposal from Tijuca lagoon in Jacarepaguá, for SMAC.

The results of these studies considered most relevant are presented and discussed herein. Although the state government engineering offices and most contractors have a significant practical experience on dredging works, until now there was little or no concern on the environmental aspects of the design, particularly when related to the final disposal of dredged material. The knowledge of the type of waste generated and the type and degree of contamination involved is, thus very important for a better planning of such works in the state.

4.1. Quantitative parameters

The bottom elevation for a dredging project is defined differently according to the end purpose of the work. In dredging for implementing and upkeep of harbors, the site and bottom elevation are defined to meet the requirements of the vessel's draft and maneuvers. In mining dredging, these parameters are based on the occurrence of the material which is to be exploited and/or the requirements of use if the objective is to procure building material. In environmental dredging, the extent and depth of the dredging depend on the contaminated sediments to be removed.

The main objective of all dredging discussed herein, is to recover the hydrodynamic conditions of circulation of the body of water. The quantitative parameters, therefore, such as the depth, extent and volume of the dredging, must be reached in hydrodynamic model studies. These studies have been conducted by the Ocean Engineering Program of COPPE-UFRJ, both for the Fundão Channel and the lagoon system of Jacarepaguá.

Fig. 2 shows the lagoon system of Jacarepaguá, in Rio de Janeiro, with the contributing rivers and points of sample collection and percussion drilling performed in 1996.

It is clear that accumulation of sediments in the Tijuca lagoon represents an obstacle for seaward drainage of the rivers flowing into the lagoons of Jacarepaguá and Camorim. This condition has resulted in the occurrence of increasingly widespread and frequent summer flooding upstream from the lagoons. As this is quite a populated region, the consequences of these floods are disastrous.

Three dredging alternatives have been studied (de Almeida et al. [12]) for the site, leaving the local government to take the final decision. The quantities presented herein (Table 1) refer to the intermediary dredging alternative as far as the elevation 1.54 m below average sea water level in Rio, corresponding to an average water depth of 1.30 m after dredging.

Fig. 3 reproduces the hydrodynamic model of the Fundão Channel, as in current bathymetry, for an outgoing tide condition. The model shows the region of stagnant water between the strangulation points at Brigadeiro Trompowski and Oswaldo Cruz bridges. It is worth mentioning that Fundão Island was created by a group of islands that had been linked to each other by a hydraulic landfill in the 50 s. The Fundão Channel did not exist before. Because of these interventions, a silting process was initiated and is developing very fast.

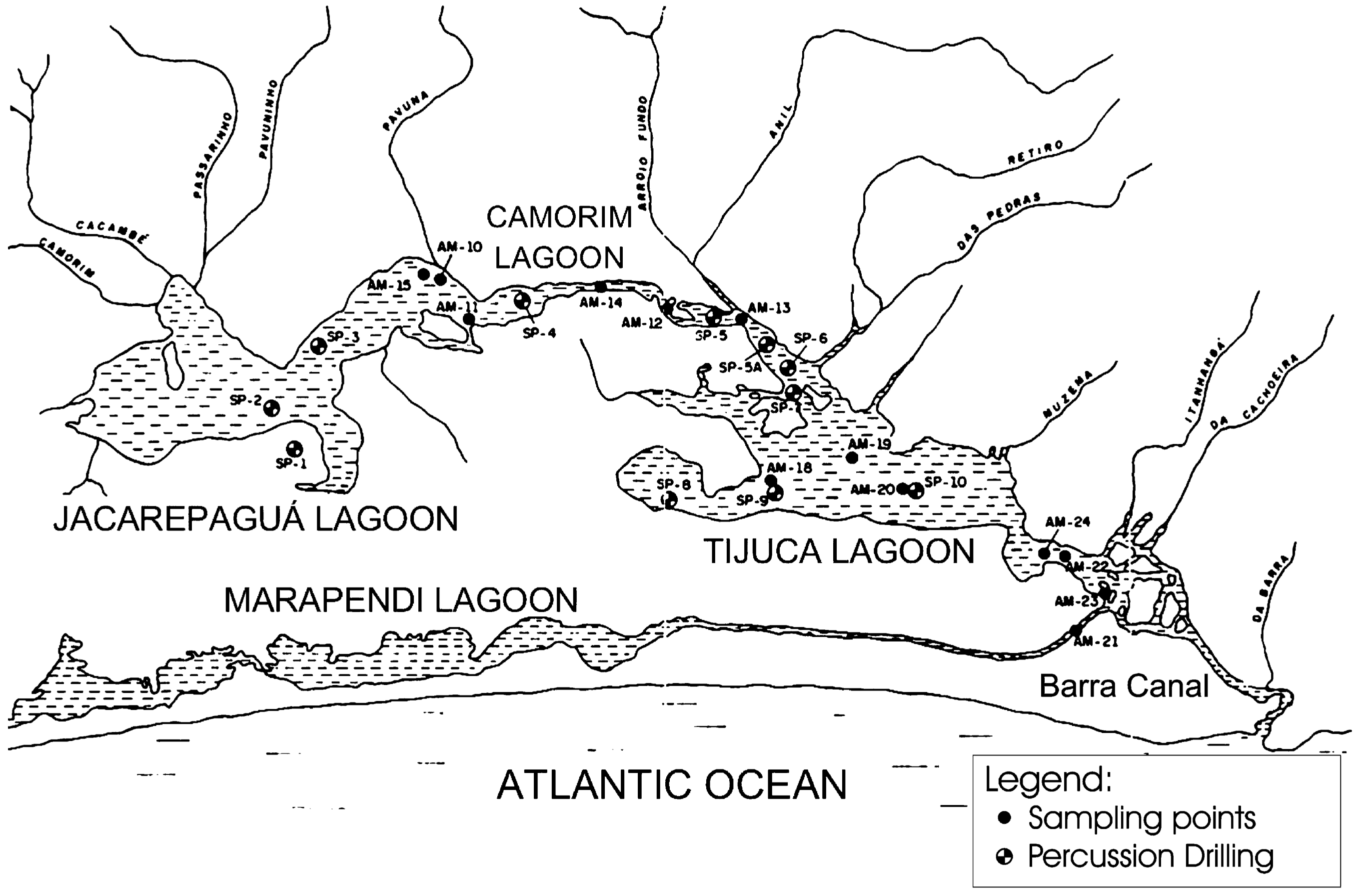


Fig. 2. Jacarepaguá lagoon system, apud de Almeida et al. [10].

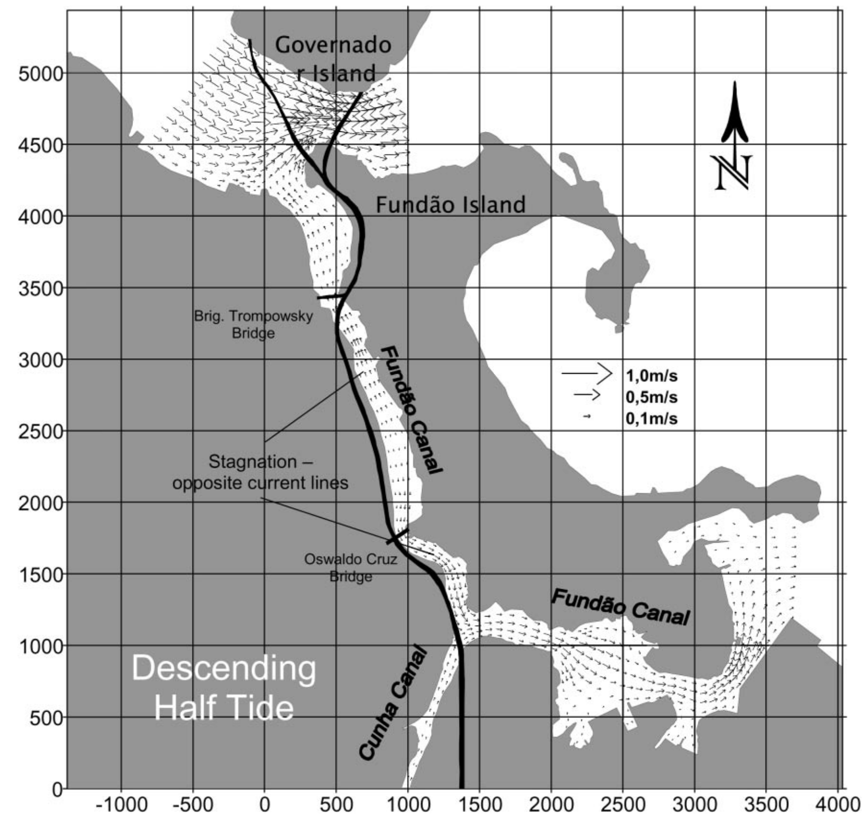


Fig. 3. Field of currents in the Fundão Channel at outgoing tide, as the sedimentation was in 1998 (Lacerda et al. [11]).

There are only two alternatives: to close the channel definitely, or dredging and recovering a hydraulic stable condition for the site.

Table 1 shows the different volumes involved in these two areas plus the dredging work developed for the Sepetiba Port. The latter is strikingly greater, and finding suitable disposal alternatives for this particular site was very difficult and caused a lot of discussion among the contractor, the state environmental agency, FEEMA, and the public.

4.2. Site characteristics

In both Fundão Channel and Jacarepaguá lagoons, the status of aggradation is so severe that only shallow dredges can operate. In both situations, the sediment comes to the surface in the more critical stretches, and the water depth is generally no more than 2.0 m.

Domestic waste is spread at the bottom in both places. In the Fundão Channel, the waste actually covers a vast area of the sea floor, and at some points large heavy objects can be seen, such as a concrete slab abandoned next to Oswaldo Cruz bridge.

There does exist, however, some major differences between the two sites. Fundão Channel can be reached at both ends from Guanabara Bay, thereby permitting free access for vessels and dredges. In Tijuca lagoon, access by water of craft from the Barra Canal is blocked soon after the beginning by a low bridge. In 1996, the dredge was carried overland, assembled and deposited on the Camorim lagoon from a temporary wharf.

Another major difference is the tidal influence, which is significant in Fundão Channel and quite mild in Jacarepaguá. This has an influence on the type of dredge to use in each site.

For purposes of comparison, the original water depths in Sepetiba Bay were 10–17 m along the access channel to the harbor, and the project had planned to dredge to 19 m deep (Table 1). As it is bay environment, the presence of waves and currents was an important influence. For the Sepetiba works, therefore, it was possible, and necessary, to use highly productive large-scale equipment, in a condition totally different from the Fundão Channel and Jacarepaguá lagoons.

4.3. Assessment of material to be dredged

4.3.1. Geologic–geotechnical sections

Percussion drilling and standard penetration tests (SPT) were required to investigate the stratigraphy within the limits of the dredging works planned at each site. Only quaternary marine and/or fluvial marine sediments were involved, and the SPT values are useful as indexes of these sediments consistency.

The geologic–geotechnical sections along the lagoon system of Jacarepaguá are shown in Fig. 4, based on the project data (de Almeida et al. [10]). The bottom sediment layer almost throughout the system consists of a very soft organic clay, eventually overlying a

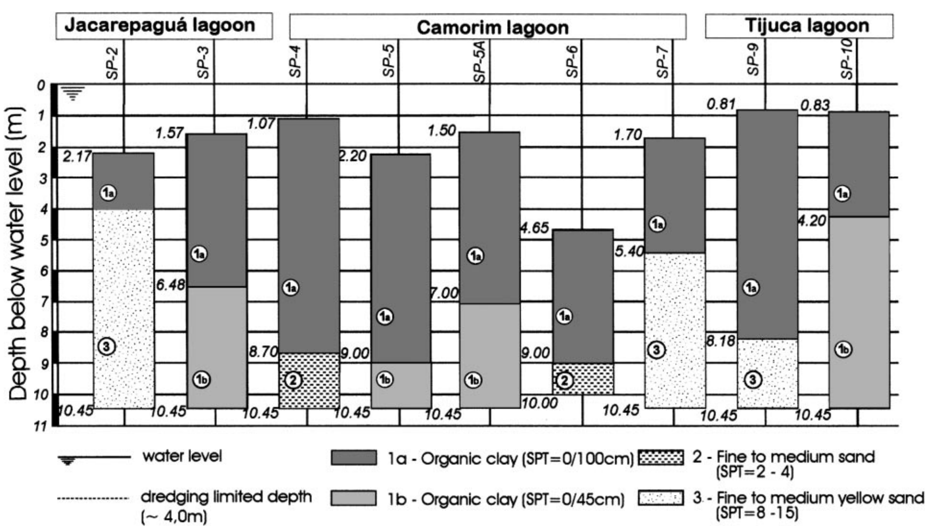


Fig. 4. Geologic–geotechnical profile along the Jacarepaguá lagoon system (apud de Almeida et al. [10]).

layer of sand. Although it is not shown in the profile, the bottom sediment layer is sandy near the Barra Canal where the current velocities are faster. This data is from 1996 and prior to the dredging of Camorim lagoon.

The figure also shows the maximum dredging limit permitted by SERLA for the lagoon system: the water depth cannot be more than 4.0 m. This is an environmental restraint to preserve acceptable conditions of luminosity and oxygenation of the aquatic environment in tropical coastal lagoons, such as those of Jacarepaguá.

Drilling was performed in nine cross-sections in the Fundão Channel. These sections were sited in accordance with the Linha Vermelha highway pile system (Lacerda et al. [11]), and the drilling profiles performed on the occasion of Linha Vermelha construction works were also included in the analysis. A typical section is reproduced in Fig. 5. Borehole SP-63 was taken from the investigations of the Linha Vermelha highway and the other holes drilled in 1997 for the dredging project.

In addition to the borehole logs, the bathymetric section for 1997/1998, design section and safety factors regarding the geotechnical stability of the lateral slopes of the dredged channel are shown in the figure. It is worth mentioning that, like Jacarepaguá, the dredging will essentially remove the topmost layer of very soft organic clay, not affecting the underlying sandy layers.

4.3.2. Sampling and sediment characterisation

The criterion used was sampling the soil in similar conditions to the dredged material. In other words, mixing the sediments from different depths at the same point of collection and with the column of water was acceptable, and sampling was controlled by depth bands (0–30, 30–60 cm, and so on).

This option means that the water content and on-site density cannot be measured, while the chemical analyses of the interstitial water and solids represent, in fact, the conditions of the mix and not the conditions existing on-site. Accuracy is also lost in the variation profiles of parameters with depth. However, these factors are only relevant when defining the original geotechnical and geochemical environment, and are not representative of the material as dredged.

Based on this criterion, a closed helicoid auger was used (Mendes [25]) for sampling sediments in the Fundão Channel and Jacarepaguá lagoons, and clamshells for sampling river sediments when available on site.

The sampling process is described in the projects reports and discussed in Ramos [28]. The samples are 30 cm in height and the process permits reasonable depth control by penetrating the sampler rod. Manual rotary drilling is used and the maximum depth reached is around 40 cm in sand, limited only by the rod length available in clay sediments.

For Jacarepaguá Basin (lagoons and rivers) 36 sediment samples were collected and analysed, from 23 sampling points (see Fig. 2 for location). For the Fundão Channel, 58 samples were collected at nine points along the channel course and 27 selected for analysis.

The grain size distributions obtained for Jacarepaguá lagoon sediments are shown in Fig. 6, based on project data (de Almeida and coworkers [1,2,10]). The more clayey group A prevails almost throughout the lagoon system. The more sandy group B occurs close to the Barra Canal. The corresponding physical indices are shown in the actual figure caption.

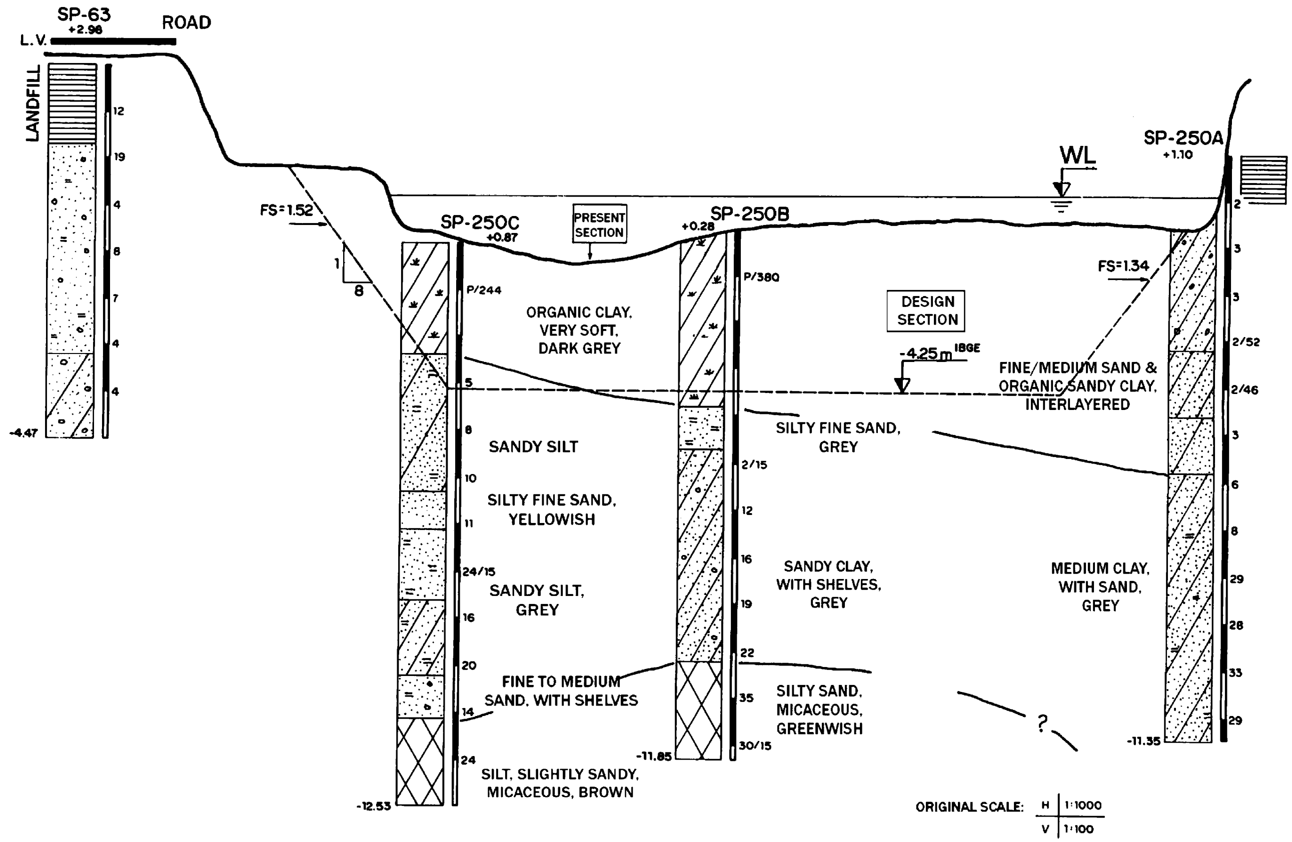


Fig. 5. Geologic–geotechnical section of the Fundão Channel at Pile 250 of the Linha Vermelha highway (Lacerda et al [11]).

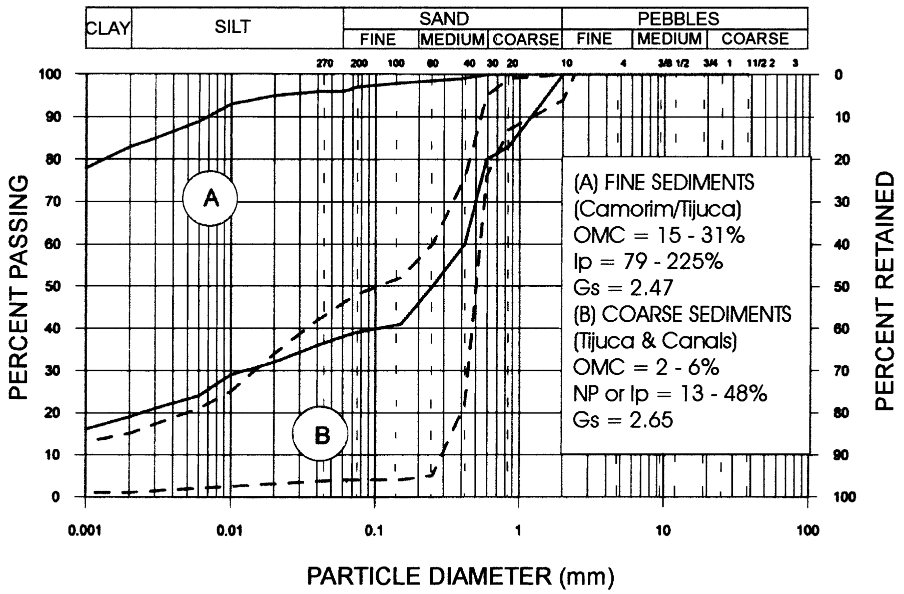


Fig. 6. Grain size distribution and physical indices of Jacarepaguá lagoon sediments, Rio de Janeiro (de Almeida et al. [10]).

The results of the liquid and plastic limits are shown in the plasticity chart in Fig. 7, where the plasticity of Jacarepaguá lagoon sediments is seen to be a direct result of the organic matter content and not of the percentage of fines. This behaviour is indicative of mineral clays with little activity (kaolinite), which has been confirmed in mineralogical analyses. The Atterberg limits tests were performed in non-dried soil samples, as recommended for organic soils.

The grading curves of the bottom sediment layer from the Fundão Channel are shown together in Fig. 8 (Lacerda et al. [11], de Almeida [13]). Although the predominant material is also clayey, sediments from the Fundão Channel generally have higher percentages of sand than the Jacarepaguá lagoon sediments. In the Fundão Channel the organic matter content varies widely between samples, both in position and depth. Unlike Jacarepaguá, the plasticity is correlated with the percentage of fines and not with the organic matter content (Lacerda et al. [11], de Almeida [13]).

This behaviour is consistent with the results of the mineralogical X-ray diffraction analyses, which revealed traces of smectite, and of the contamination research, which discovered substantial quantities of industrially produced organic compounds. These compounds do not give plasticity to the soil but appear as organic carbon in the analysis of the organic matter content.

Table 2 gives a summary of the characterisation of Jacarepaguá lagoon and river and Fundão Channel sediments. There are signs in Jacarepaguá lagoons of increasing salinity towards the channel to the sea, reflecting the penetration of salt water according to tidal movement.

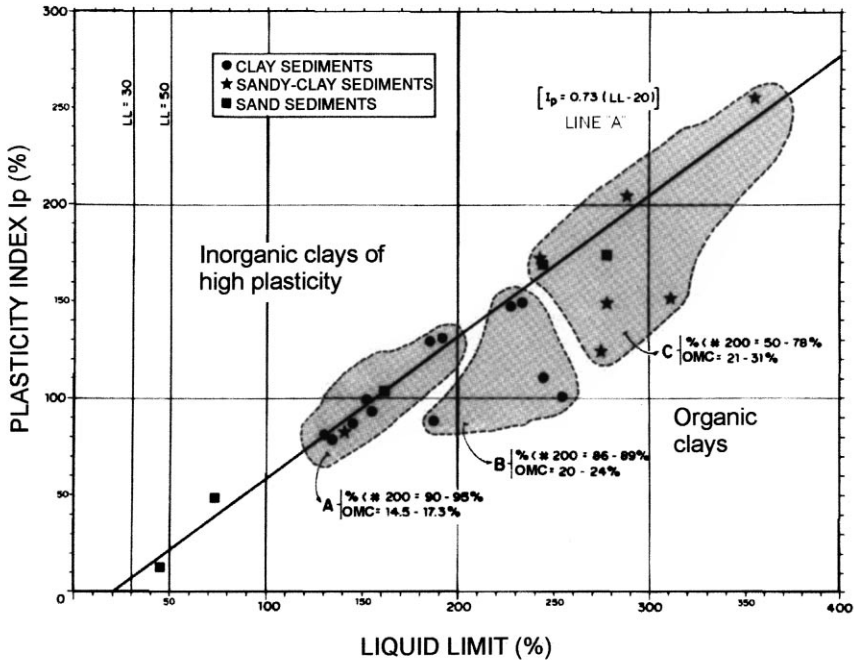


Fig. 7. Plasticity chart of Jacarepaguá lagoon sediments, Rio de Janeiro (de Almeida et al. [10]).

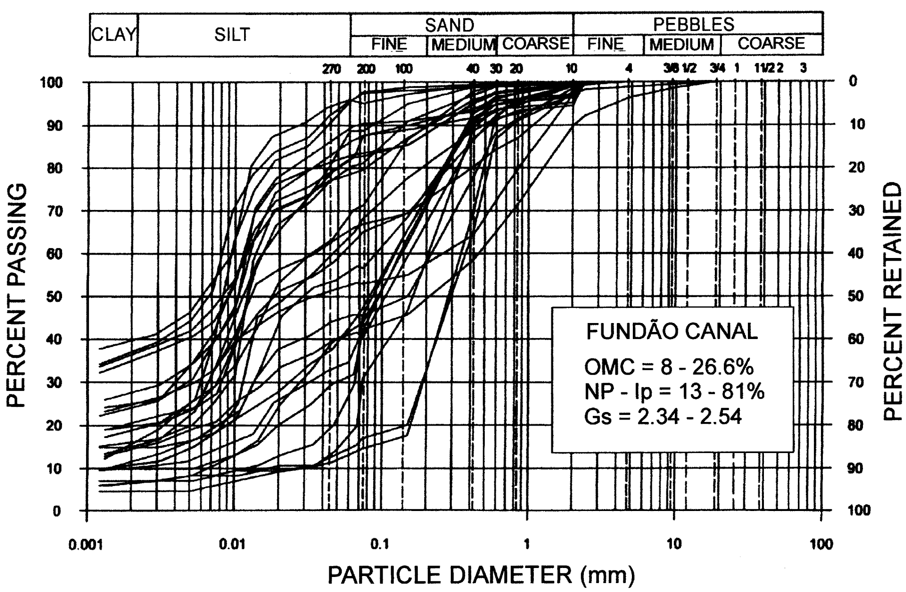


Fig. 8. Grain size distribution and physical indices of bottom sediment layers of the Fundão Channel, Guanabara Bay, Rio de Janeiro (Lacerda et al [11]).

Table 2
Table comparing sediments of the Fundão Channel and Jacarepaguá Basin, Rio de Janeiro

Site	Predominant material	Secondary material	<2 µm (%)	OMC[a] (%)	SEC[b] (mS/cm)	Fine fraction mineralogy
Jacarepaguá lagoons	Clays and organic silts	Sands: only near the Barra Canal	19–83	15–31 (uniform)	11.5–23.6 (gradual variation)	Kaolinite Interstr. Illite pyrite (FeS_2) gypsum ($CaSO_4{\cdot}2H_2O$)
Jacarepaguá rivers	Sands and clayey-silt sands	–	0–34	0.3–7.8	0.8–3.0	Kaolinite Illite
Fundão Channel, Guanabara Bay	Organic clay with fine sand	Sands: greater depth or greater velocities	5–41	8–27 (varies with site and depth)	22.5–25.5 (uniform)	Kaolinite mica/Illite smectite (traces)

[a] OMC: organic matter content.
[b] SEC: specific electric conductivity.

The freshwater environment of the rivers is represented in the low levels of specific electric conductivity measures (SEC in Table 2) and the coarser grading reflects faster flow velocity of the river environment in relation to the lagoon environment. It is worth mentioning that pyrite and gypsum minerals were only found in the lagoon sediments, indicating that they are minerals of authigenic origin, i.e. formed on site.

4.3.3. Contamination study

In every project, contamination studies were planned based on the existing information of the site and assessment of possible contamination sources present in the contribution area.

Jacarepaguá has several studies that were performed in the 1980s by the Geochemistry Department of Federal Fluminense University (UFF) on heavy metals in water bodies in the region, as well as reports on water and sediment analysis by FEEMA (1970s and 1980s) and more recent analyses on suitable bathing conditions of the lagoons by SMAC.

Based on the significant amount of data, heavy metals Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn were chosen as assessment parameters for sediments and chemical oxygen demand (COD) for water, plus fecal and total coliforms counts. The data already existing and values measured by COPPE are provided and discussed in the reports of the 1996 [10] and 1998 [12] projects, as well as in Borma [5] and de Almeida et al. [2].

Excessive nutrients (N,P) intensify the growth of algae and aquatic plants, reducing the level of oxygen dissolved in the column of water, and therefore, the quantity and diversity of the local aquatic fauna.

The main source of contamination in Jacarepaguá is the untreated sewage outfall. The rivers also receive industrial effluents at some points, which are diluted in the water and discharged into the lagoons. Zn and Cu metals are normally associated with sewage emission. The studies have shown that only heavy metals Cu, Ni, Pb and Zn are present in significant quantity and show an enrichment pattern characteristic of contamination. For example, in Fig. 9, by de Almeida et al. [2], a variation in concentrations of these metals appears in sediments in Arroio Fundo along its course toward Camorim lagoon. The other elements analysed (Cd, Cr, Fe, Mn) are either present in very low concentrations or occur naturally in the sediments in the region.

There is no previous local information for the Fundão Channel but only studies relating to Guanabara Bay in general and some tributaries, one of which is the Cunha Channel. Borma [4] provides a review and discussion of the data existing on heavy metals in Guanabara Bay.

In the absence of more specific information, the solution was to resort to FEEMA's experience on the site to plan the contamination study. Therefore, heavy metals Cd, Cr, Cu, Ni, Pb, Zn and Hg and organic oil and grease analyses, polycyclic aromatic hydrocarbons (PAHs) and phenols were chosen as parameters to assess the sediment. The phenols were later discarded because they were below the detection limit. These same parameters plus dissolved oxygen content (DO), DOC, biochemical oxygen demand (BOD) and total and fecal coliforms counts were analysed for the column of water.

Lacerda et al. [11] and de Almeida [13] analysed the results relating to environmental standards in different countries and concluded that only Ni of the heavy metals analysed is present in sufficient quantity to require extra care in disposal. Concerning oil and grease and PAH levels in the sediment, however, these were about 40 times more (ppm) for oil

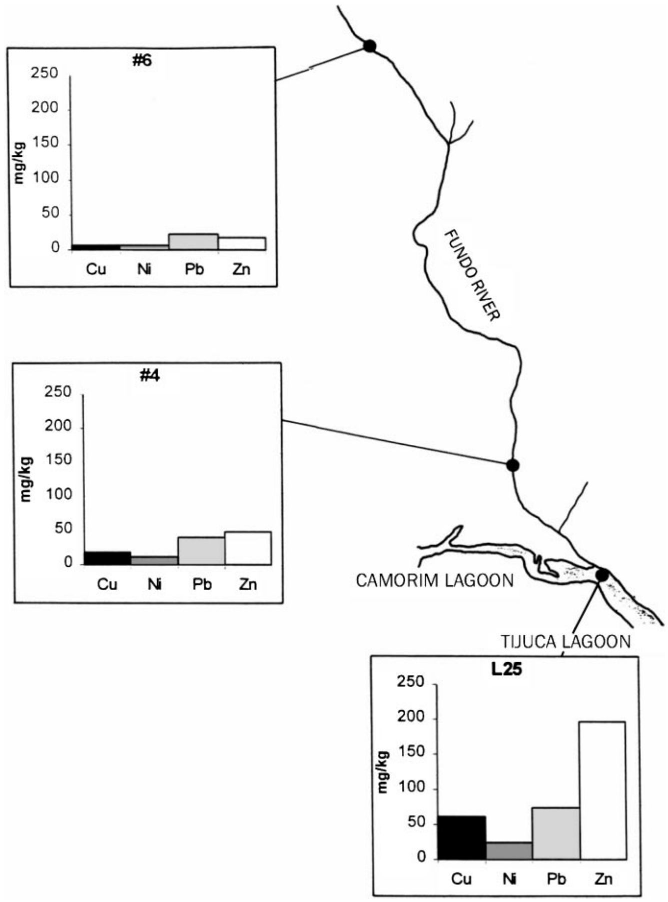
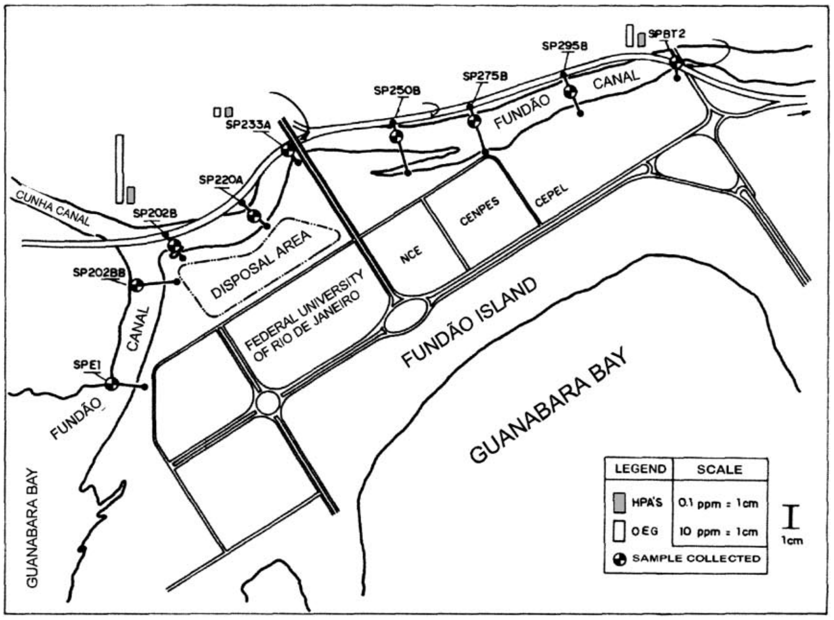


Fig. 9. Total concentration of Cu, Ni, Pb and Zn in Arroio Fundo sediment, Jacarepaguá, Rio de Janeiro (Almeida et al. [2]).

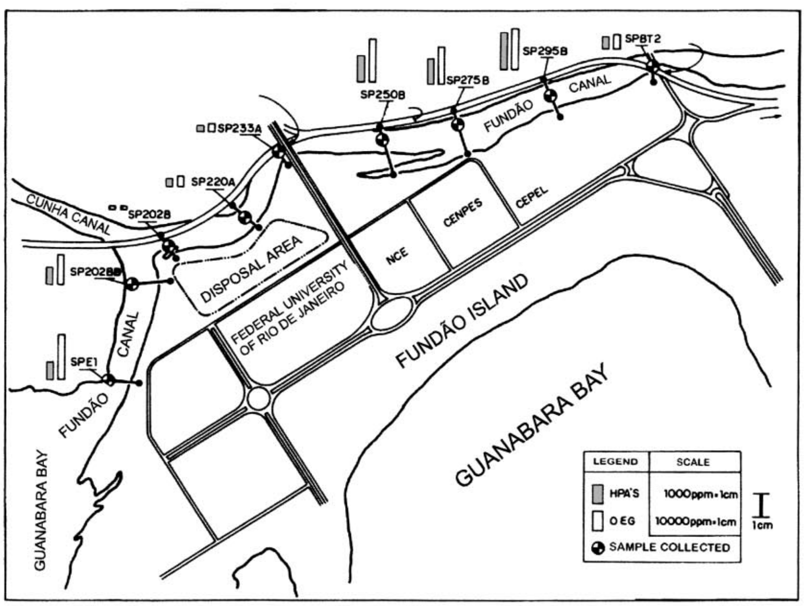
and grease and 80 times more (ppm) for PAH than is admissible at standard levels. The concentrations encountered are particularly high in the region of stagnant water, between the Brigadeiro Trompowski and Oswaldo Cruz bridges.

Fig. 10(a) and (b) in Lacerda et al. [11] show the likely sediment contamination mechanism in the Fundão Channel. Fig. 10(a) shows oil and grease and PAH levels in the channel water, where the highest figures correspond to the Cunha Channel outlet. Fig. 10(b) shows the distribution of these parameters in the sediment, and the highest values occur at the bottom of Fundão Channel, especially in the samples from between the two bridges.

It can then be deduced that the Cunha Channel is the main, although perhaps not the only source of these contaminants, which tend to be deposited on the channel floor as the water velocity diminishes. Thus, the Fundão Channel is acting as an accumulation reservoir over the years, in a process accentuated by the degree of aggradation and low hydrodynamic circulation at the site.



(a) Distribution of organics in column of water.



(b) Distribution of organics in sediment.

Fig. 10. Distribution of oils and grease and PAHs in the column of water and bottom sediment layer of the Fundão Channel, Guanabara Bay, Rio de Janeiro (Lacerda et al [11]).

4.4. Dredged material disposal

Herbich [20], US Army Corps Engineering Manuals [29] and IADC/CEDA guides [21,22] describe various alternatives for dredged material disposal. In general, it may be said that there are two options regarding the disposal method, land and marine, and two options regarding the disposal method, confined and non-confined.

In the state of Rio de Janeiro, the options traditionally adopted have been the non-confined marine disposal or on areas at the edge of the water body itself. However, the pressure from environmental licensing requirements has induced public and private contractors to study more and more alternatives for disposal or reuse.

In 1996, the city authorities used two areas next to the lagoon, shown in Fig. 11 (de Paula [14], de Paula et al. [15]) for the disposal of dredged material from Carmorim lagoon. Suction and pressure dredging was performed, producing a suspension with around 10% solids.

In area I, with sandy foundations, the confined disposal method for the dredged mud was chosen, with perimetral retaining dikes and spillway for returning the surface water after sedimentation. In area II, where the foundation soil was peat with around 60% organic matter, the disposal was non-confined and the solids were prevented from returning to the lagoon by the actual gallery vegetation. In this case, it was emergency dredging and the dredged material revealed very low contamination rates.

Dredging the Fundão Channel and Tijuca lagoon in Jacarepaguá is still under study, and therefore, the disposal alternatives shown below may be altered. In both cases, so far confined land disposal is being considered, bearing in mind the restraints imposed by FEEMA for marine disposal and the difficulty in using it because of the fine, organic and saline materials.

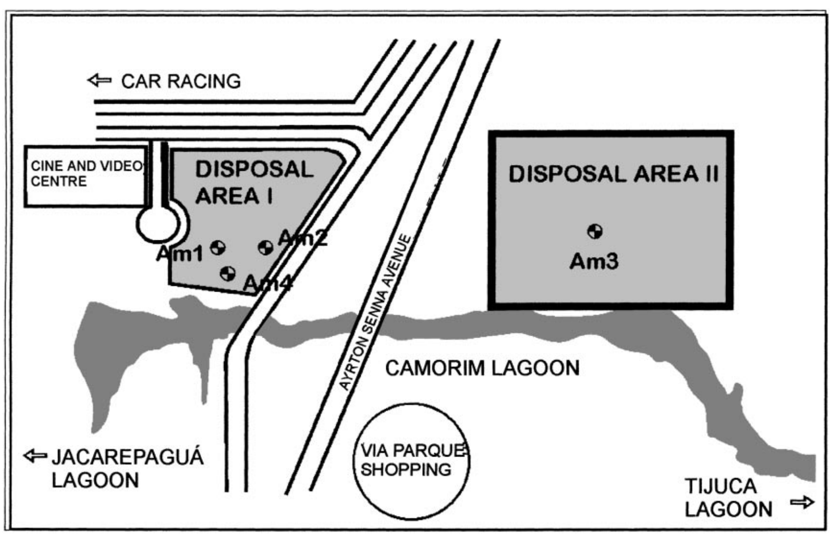


Fig. 11. Dredged material disposal areas in 1996, Camorim lagoon, Jacarepaguá, Rio de Janeiro (de Paula [14]).

Table 3
Calculation of volumes of dredged material for disposal in the Fundão Channel and Jacarepaguá ($B = 1.5$)

Site	Dredging volume (m^3)	Disposal volume (m^3)
Fundão Channel	1500000	2250000
Tijuca lagoon	3200000	4800000

The most likely dredging method in both cases is by suction and pressure, due to the grading characteristics of the sediment and shallow draft required to operate the dredge. The size of the disposal area must consider the capacity of receiving and storing the dredged volume and ensure that there will be no return of solids above a limited figure for the water body. The disposal method must also consider the possible environmental impacts that may arise from this disposal.

The confined land disposal process is similar to the mining mud lagoons. After the suspension flows into the basin, sedimentation of solids occurs, surface water returns to the water body, the dredged material densifies under its own weight and dries up (Herbich [20]; US Army Corps of Engineers [29]).

The volume used for dimensioning the disposal area must, therefore, consider all those processes. In practice, a bulking factor B is adopted, which is the ratio between the end volume after disposal (and after sedimentation) and the on site volume of the dredged material. In the case of coarse sands $B \approx 1$, soft sands tend to densify after dredging and disposal ($B < 1$), and fine sediments (silts and clays) tend to expand ($B > 1$). Several empirical figures are suggested in technical literature. Based on these suggestions, it seems reasonable to adopt $B = 1.5$ for the materials in the Fundão Channel and Jacarepaguá lagoons. The volumes calculated in this way are shown in Table 3.

For Jacarepaguá, an SMAC proposal was studied for managed dredged material disposal from the Tijuca rivers and lagoon in an area belonging to a group of companies. There are plans to build commercial and residential projects in the near future on this site. This area is shown in Fig. 12.

The more sandy material dredged from the rivers is being used for construction of the perimetric dikes, which coincide with the existing street building plan. These dikes then form the cells to receive the mud dredged from Tijuca lagoon.

One important aspect of land disposal of dredged sediment from the Jacarepaguá lagoons lies in the potential acidification and release of heavy metals as a result of the oxidation of sulphides and organic matter. This issue has been investigated by Borma [5] and Pessoa [27]. The results obtained so far are also discussed in Borma and coworkers [6–8] and de Almeida et al. [2,12]. In the event of these released heavy metals, the potential contamination of the subsoil was studied as an experiment by de Paula [14] for area I in Fig. 11.

Another line of research has begun on biological treatment of the sediment after disposal, to reduce the organic matter content in order to facilitate its use in building secondary landfills (Lerner [24]). It has been shown in the project (de Almeida et al. [10]) that the physico-chemical stabilization with lime or cement was not feasible for the existing organic matter content.

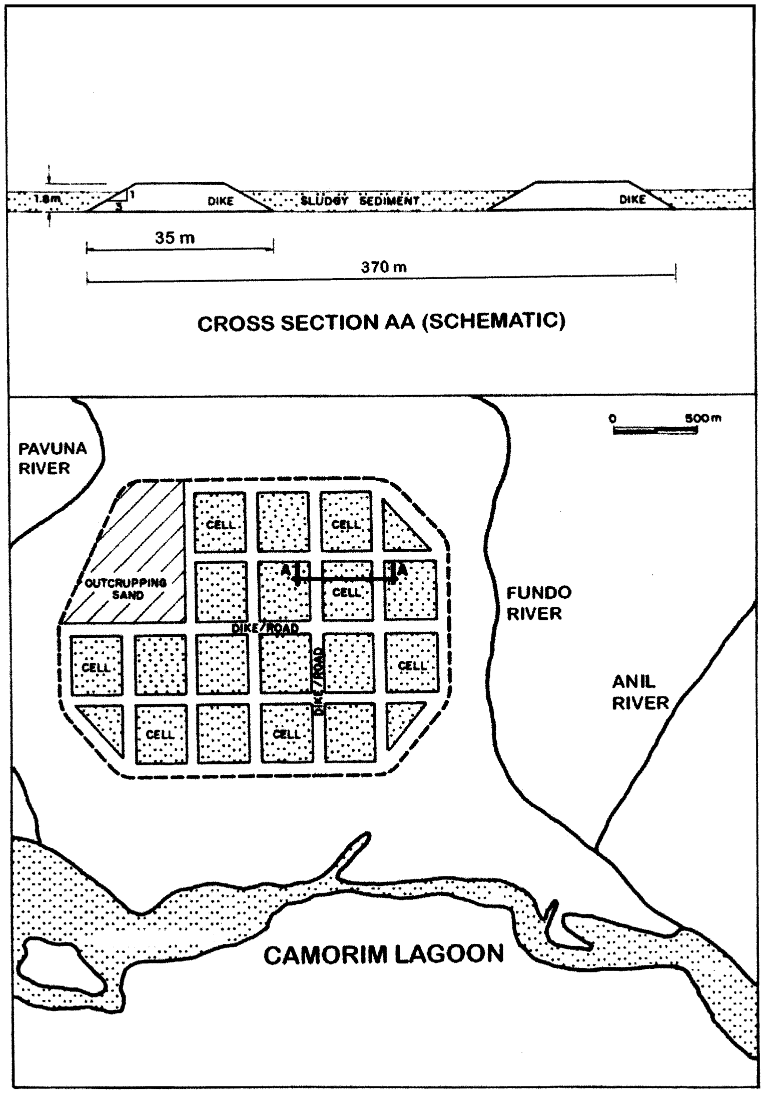


Fig. 12. Proposed site and dredged material disposal method for rivers and lagoons in Jacarepaguá, Rio de Janeiro (de Almeida et al. [2]).

A confined land disposal alternative was studied for the Fundão Channel on Fundão Island, on land assigned by the Federal University Campus administration. Considering, however, the contamination level of the sediment, a barrier with a mix of compacted soil and geomembrane was included in the disposal basin design. Fig. 13 shows a diagram cross-section of this design.

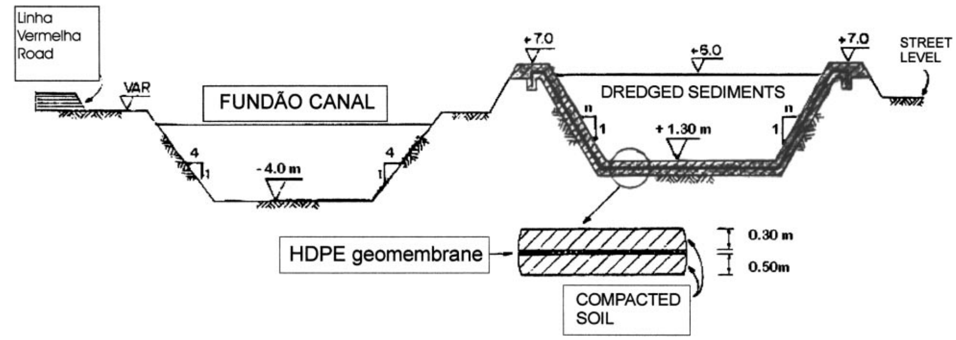


Fig. 13. Proposed dredged material disposal, Fundão Channel, Guanabara Bay, Rio de Janeiro (de Almeida [13]).

4.5. Geotechnical studies

4.5.1. Stability studies

Stability studies only were required for the dredging project of the Fundão Channel, considering its proximity to the Linha Vermelha highway, one of the main thoroughfares in to the city of Rio de Janeiro. The scope of the required hydraulic section (Lacerda et al. [11]) was based on the slopes geotechnically defined, which varied between 1V:8H in the more critical stretches and 1V:4H in the rest of the channel (see Fig. 5).

To recover the channel's hydrodynamic circulation conditions, it is necessary to increase the width of the section at the Oswaldo Cruz bridge, removing part of the landfill on which the foundation slab is based on the bank corresponding to Fundão Island (see Fig. 3). The project then includes the construction of vertical retaining structures on both banks, anchored in the ground using root piles (Lacerda et al. [11]), and continuing with the current structure foundations.

4.5.2. Sedimentation and consolidation studies

After disposal, the dredged mud undergoes the phases of sedimentation, consolidation under its own weight (after removing surface water) and drying. The sedimentation stage is the most important in dredging projects, since it determines the waiting time required to release the return of the surface water to the water body.

In some cases, it can take so long that it makes the land disposal alternative unfeasible. If necessary, the sedimentation process may be accelerated by adding chemical flocculants. This type of treatment has been studied, for academic purposes, in the cases of mud from Jacarepaguá by dos Santos [17], and the results are also presented in Alves et al. [3]. Nevertheless, sedimentation tests performed for the project (de Almeida et al. [10]; dos Santos [16]) and the 1996 dredging work on Camorim lagoon have shown that the sedimentation time for the Jacarepaguá lagoon dredged material is very fast. In the laboratory, the material took around 40 min to begin consolidation under its own weight, as shown in Fig. 14, presenting an average sedimentation rate of 6.5 mm/min, with no flocculant added.

These results were later confirmed in Lerner [24], who also observed in laboratory that the surface liquid showed at this point a concentration of solids (in weight) of 0.3%. This

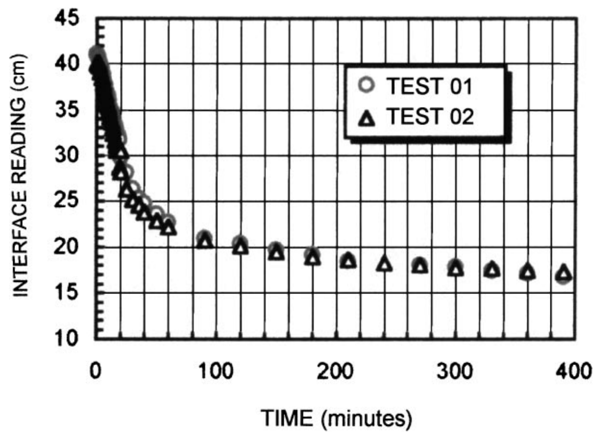


Fig. 14. Sedimentation tests of dredged slurry from Jacarepaguá lagoons (dos Santos [16]).

figure is perfectly acceptable for the supernatant being returned to the water body, since 0.5% (5 g/l) is generally adopted as an admissible limit for the effluent outflow.

A much longer sedimentation time is expected because of the presence of smectites in the Fundão Channel sediments, but experiment results are not yet available.

5. Discussion

In the state of Rio de Janeiro, maintenance dredging in silted water bodies in urban areas is predominant. In this kind of environment, the main contamination sources are sewage and domestic waste outfalls. The most frequent contaminants, therefore, are the associated organic load, which consumes the oxygen available in the column of water, pathogenic agents indicated by the presence of coliforms and heavy metals, particularly Zn and Cu. Depending on the site, industrial contaminants may also be found, such as other heavy metals and recalcitrants organic compounds.

Aggradation favours the deposit of fine sediments with a high organic matter content and anoxic environment. In coastal cities, such as Rio de Janeiro, the proximity to the sea produces abundant sulphates, which tend to become sulphides in this type of environment, creating hazards of acid drainage formed by oxidation in the alternative of land disposal of dredged material.

Although the dredged material must be considered waste, due to its continuing increase in contamination, the environmental hazard analysis using leaching tests recommended in the standards for the analysis of solid waste is not efficient. This ineffectiveness is shown in Borma [5] in the case of Jacarepaguá lagoon sediments. A reliable analysis of environmental impact must include information of the dredging and disposal sites, contamination mechanisms and mineralogy of the sediment to be dredged.

One of the major problems found in those studies has been the lack of proper guidelines in Brazil to classify the dredged material with regard to the degree of contamination present.

Guidelines from various countries have been adopted but none has been a successful substitute for environmental hazard analyses focusing on the local environmental and operating conditions.

The definition of admissible values for land or marine disposal depends on the conditions of the disposal environment. A general guideline may have negative effects because it is based on average values of very different environments. Taking the state of Rio de Janeiro as an example, the current levels of contamination in Guanabara Bay are quite high, while Ilha Grande Bay has the inverse situation. Therefore, a value appropriate for Guanabara Bay conditions would be detrimental with regard to disposal in Ilha Grande Bay. On the other hand, the value that would be suitable for the latter's conditions would be anti-economical and unrealistic concerning disposal in Guanabara Bay.

From the geotechnical point of view, the most interesting aspect is the mechanical behaviour of the material after land disposal, whether for future use of the area or for the potential reuse of the deposited material. Techniques for treating the deposited material with predominant fine and organic sediments must be developed or enhanced to make one of these alternatives economically feasible.

6. Conclusions

The experience gained in the dredging projects described herein has resulted in some progress in understanding physical and environmental aspects of dredging in the state of Rio de Janeiro and has helped identify the principal deficiencies of the current status of technical, know how and prevailing criteria for environmental control in these kinds of jobs.

- The exchange between public authorities, contractors and universities has proved very rewarding. Through it, more advanced technological, know how can be adapted to the physical, economic and strategic conditions of the region.
- The studies have shown the importance of the multidisciplinary approach together with a more detailed knowledge of the environments in question. Mere application of standards and general environmental guidelines does not produce satisfactory results.
- Accumulated experience shows that regional criteria are potentially more efficient than federal criteria, due to the diversity of environments in question.
- The silted water bodies in the state of Rio de Janeiro have acted as "reservoirs" for various contaminants. The removal of the contaminated layers by dredging is only a temporary solution for the problem. Control of the contaminating sources and degradation of the water body is essential for effective environmental rehabilitation of the area.
- More in-depth knowledge of the effective impacts of disposal on the water body itself for the different environments in the state of Rio de Janeiro (bays, lagoons, open sea) is vital.
- Three aspects require the continuity of the studies in relation to alternative land disposal: mechanical behaviour after disposal (sedimentation, consolidation and drying), potential generation of acid drainage through oxidation in sulphide-rich sediments, and treatment techniques for reusing the dredged material.

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