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Studies of channel sediments contaminated with organics and heavy metals

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Abstract

The paper discusses the geo-environmental studies carried out to revitalise a silted up channel in Guanabara Bay. A dredging operation has been planned to remove about 1.5 million cubic meters of contaminated sediment. Investigations were performed to characterise the sediment in terms of its physical and chemical properties and to evaluate the presence of heavy metals and organic compounds, particularly polycyclic aromatic hydrocarbons PAH. Finally, dredging and disposal schemes are briefly outlined based on measured contamination levels.

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

1. Introduction

Dredging and disposal of fine sediments is a major issue today in the state of Rio de Janeiro, Brazil. The geography and the tropical climate (intense rainfalls at summer) favours erosion in the highlands, transportation of sediments by the rivers into the lowlands, towards the sea, and deposition at discharge areas in lagoons and bays (Barbosa and Almeida [1]). Urbanisation intensifies the natural processes, resulting very often in silted bodies of water that contribute to water floods in the summer and general degradation of the coastal environment. The Fundão Channel dredging project is an example of this situation, involving highly contaminated sediments.

The Fundão Island, in Guanabara Bay, State of Rio de Janeiro, and shown in Fig. 1, was formed in the period 1949–1952 by reclamation works joining eight islands, with the purpose to build the Campus of the Federal University of Rio de Janeiro.

In mid 1970s the Osvaldo Cruz (OC) Bridge was built, (Fig. 2), causing obstruction of the Fundão Channel. The reclamation works for the construction of both the Fundão Island and the OC Bridge affected irreversibly the water flow in Fundão Channel. In addition, this channel in the past decades has received different types of wastes and garbage, and also domestic and industrial effluents without adequate treatment from a number of industries and housing nearby. The Cunha Channel, shown in Fig. 2, was dredged in late 1980s and is also quite polluted. In the early nineties an important expressway was built along the Fundão Channel, as shown in Fig. 2.

In 1997, a study was commissioned to revitalise this highly silted up and contaminated channel, so that free water circulation could return to this region of Guanabara Bay. The revitalisation of the Fundão Channel is within the scope of a major program for the overall clean up of Guanabara Bay (PDBG [2]).

The studies for the revitalisation of the Fundão Channel have three main topics: a hydrodynamic study of the water movement in the channel; a geo-technical stability study of the channel border following dredging; and a geo-environmental study for the characterisation of the dredging sediment and its disposal, considering the degree of contamination.

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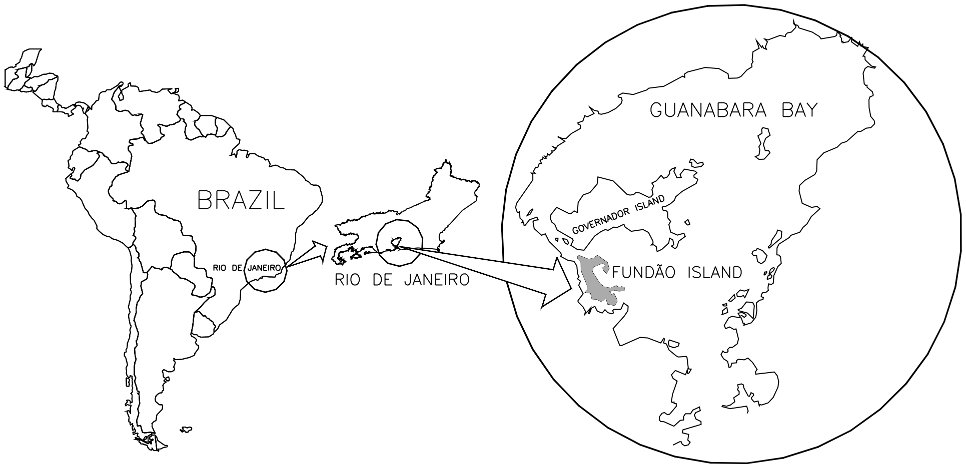


Fig. 1. Fundão Island in Guanabara Bay.

The present paper concentrates on the third topic. Field and laboratory studies of the sediment contamination will be reported. The proposed dredging strategy and disposal conditions of the contaminated sediment is briefly outlined.

2. The project and preliminary studies

Field studies were carried out in nine cross-sections shown in Fig. 2. These studies included batimetry and topography surveys, SPT boreholes, and sampling of the channel sediments.

At the time of the survey (1997), the water depth in Fundão Channel was found to be in the range 0.0–2.0 m. Consequently, hydrodynamic studies indicated that the water velocity between the two bridges (Fig. 2) was negligible and concluded that the channel sediments should be dredged to attain 4.25 m water depth in order to restore the adequate water flow in the channel. The required hydraulic section of the channel was found to be 300 m^2 (Rosman [3], in Rosman and Lacerda [4]).

Typical results of the hydrodynamic modelling studies are reproduced from Rosman [3] in Fig. 3, comparing the existing (Fig. 3a) and the expected (Fig. 3b) water circulation patterns of Fundão Channel at the same condition of descending half tide. The divergent current arrows in that area in Fig. 3a point out the stagnation of the water flow between the two bridges. After dredging, the water will flow continuously along the channel, around the island, towards Guanabara Bay (Fig. 3b).

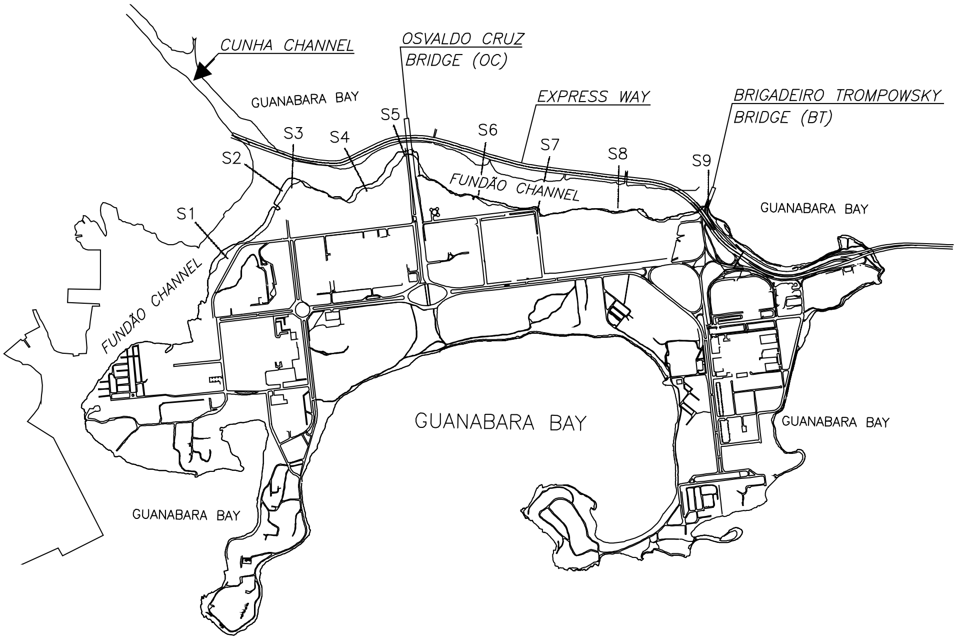
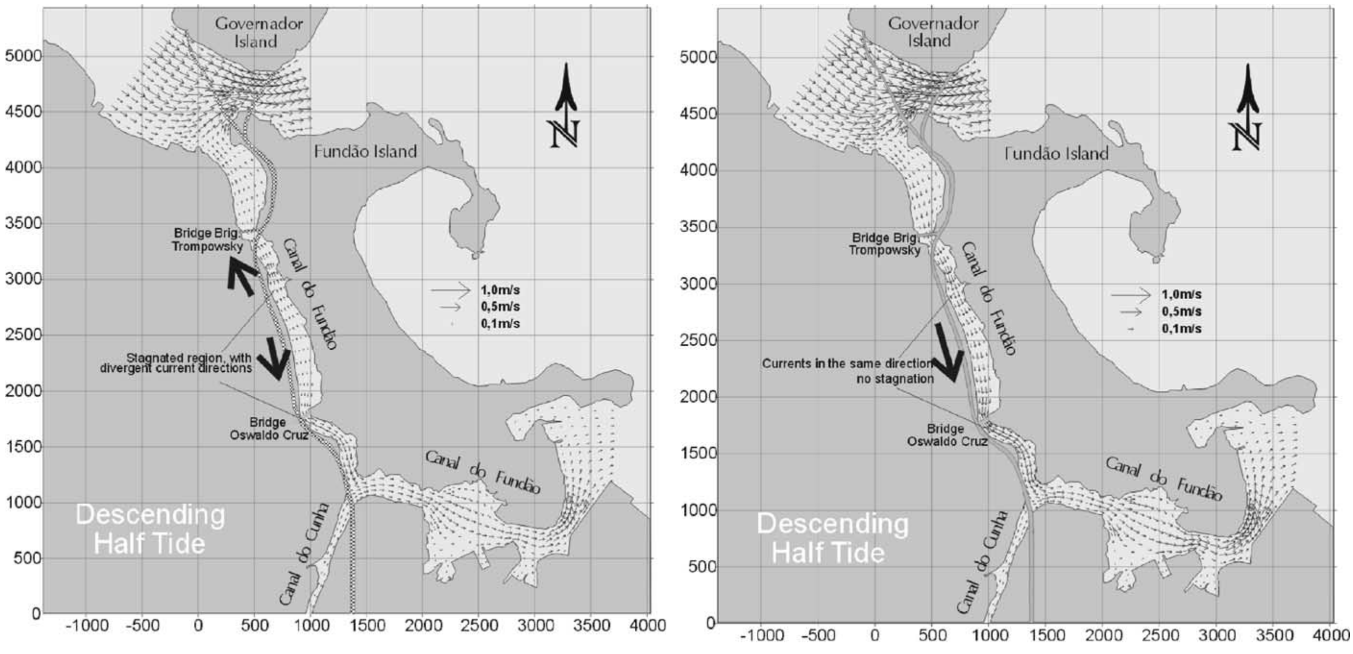


Fig. 2. The Fundão Channel and the cross-sections studied.



(a) (b)

Fig. 3. Typical results of hydrodynamic modelling of Fundão Channel at descending half tide condition. (a) Present silted situation, (b) expected after dredging (adapted from Rosman [3]).

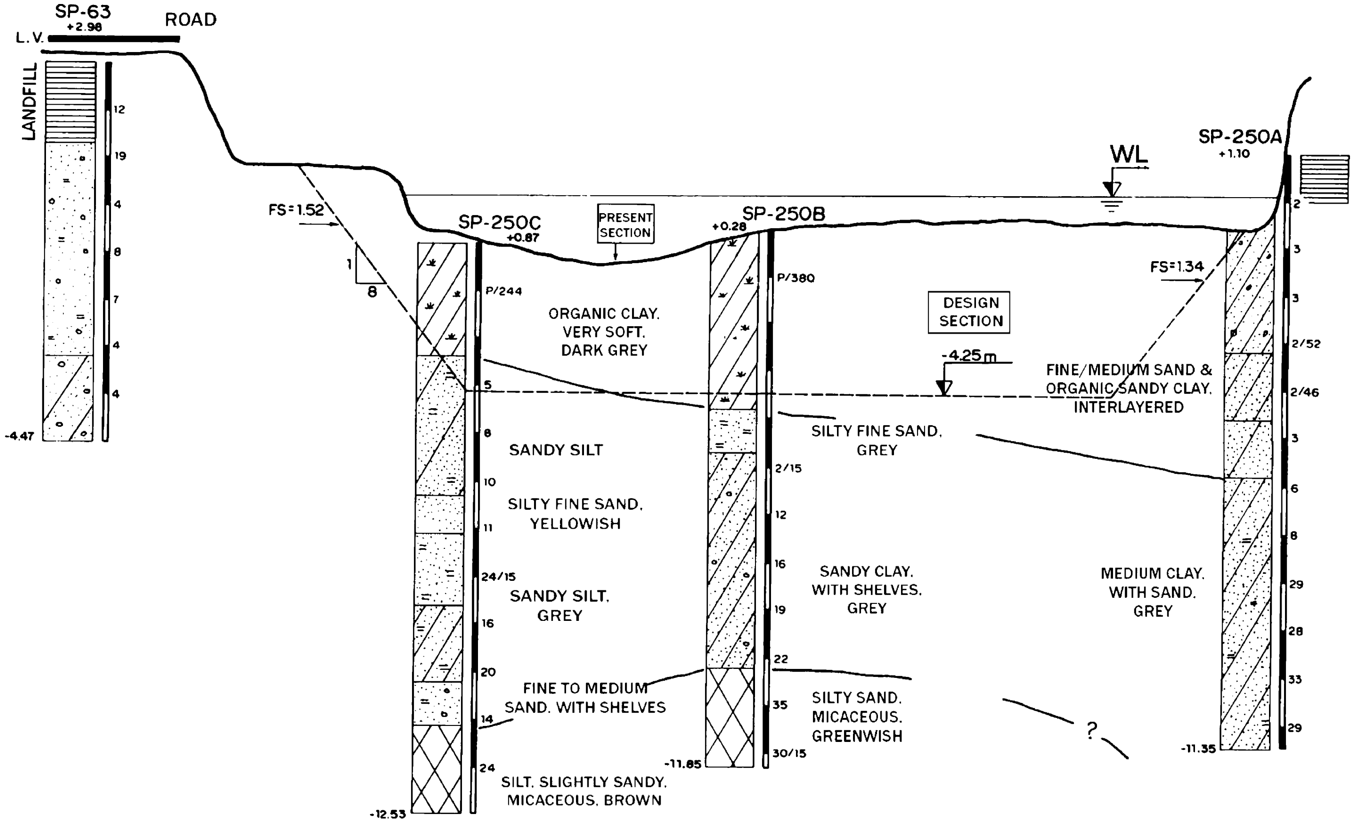


Fig. 4. Channel cross-section: present and future situations.

Limit equilibrium stability analyses of channel border, assuming the bottom channel depth 4.25 m, were carried out for the nine cross-sections indicated in Fig. 2. A typical channel cross-section is shown in Fig. 4, where the situation in 1998 and the future situation following dredging are indicated. The narrowest hydraulic section is located at the OC Bridge and for this section underwater retaining structures at both sides of the channel have been designed to provide the adequate water flow.

3. Characterisation of the sediment

3.1. Sediment characterisation

In order to study the physical and chemical characteristics of the sediments, a number of sediment specimens were collected at 0.40 m intervals, using a closed helicoid auger. The procedure is described in Barbosa and Almeida [1]. Sampling was stopped when soil recover became impossible. Each specimen was kept in polyethylene bags and taken to the laboratory located at the university campus, and stored in the special room maintained at 10 °C to minimise biologic actions.

Results of physical characterisation of the sediments are shown in Table 1, in terms of plasticity index I_P, percentage of the finer fraction $<63\%$ μm), organic matter content and soil activity index A_c. It is observed in most sampling points that sediments found at the shallow depths have usually higher plasticity and greater amount of fines. This pattern is observed at all points South of the OC Bridge (S1–S5), and also for the sampling point (S6) immediately North of the bridge. The remaining three sampling points (S7–S9) between the two bridges, where the water flow velocity is quite low, showed similar plasticity index and amount of fines at all depths.

The soil activity, defined by the ratio between I_p and the clay content ($<2\%$ μm, not shown in Table 1), is an important indication of the likely soil-contaminant interaction. In Table 1 all but one specimen have activity values in the range 1.25–3.15. The single exception is specimen S3 (0.0–0.4 m) with $A_c = 0.79$. Values of A_c greater than 1.25 indicate a highly active soil. Activity values for smectite are in the range 1–7, and the typical A_c value for kaolinite is 0.5 (Mitchell [5]). Mineralogical analyses in the finer fraction ($<63\%$ μm) were performed in specimens S3 (depth 0.40–0.80 m) and S8 (depth 0.80–1.20 m) using difractometer Seifert model XRD7. The following clay minerals have

Table 1
Physical characterisation of the sediments

Vertical sampling point	Water column during sampling (m)	Sample denomination	Sample depth (m)	I_P (%)	$<63\%$ μm	Organic matter content (%)	Soil activity index, A_c
S1	2.20	E2	0.40–0.80	37	45.6	14.8	2.52
		E3	0.80–1.20	NP	14.4	14.9	–
S2	1.90	B3	0.80–1.20	46.8	40.4	17.3	2.44
		B5	1.60–2.00	NP	56.6	26.6	–
S3	0.85	B1	0.00–0.40	13.0	47.3	25.3	0.79
		B3	0.80–1.20	22.6	43.7	15.2	2.31
		B4	1.20–1.60	NP	45.6	–	–
		B5	1.60–1.80	NP	30.8	20.9	–
S4	0.80	A2	0.40–0.80	58.0	71.3	8.1	2.26
		A4	1.20–1.60	50.3	88.8	16.5	1.64
		A6	2.00–2.40	48.5	81.2	21.0	2.02
		A7	2.40–2.60	NP	42.3	–	–
S5	1.20	A2	0.40–0.80	55.3	87.6	9.7	1.60
		A4	1.20–1.60	NP	42.0	–	–
S6	0.75	B2	0.40–0.80	81.4	97.7	–	3.12
		B4	1.20–1.60	70.7	97.5	20.6	1.59
		B6	2.00–2.20	42.4	66.9	20.1	1.42
		B7	2.20–2.40	NP	16.9	–	–
S7	0.90	B2	0.40–0.80	35.2	53.0	16.7	1.51
		B4	1.20–1.60	68.1	90.3	19.1	1.25
		B6	2.00–2.40	75.9	87.7	19.0	3.15
S8	1.20	B2	0.40–0.80	51.2	65.2	24.5	2.13
		B4	1.20–1.60	65.3	82.7	18.8	1.56
		B6	2.00–2.40	55.2	83.5	9.1	1.36
S9	1.60	B2	0.40–0.80	44.3	68.3	12.4	2.95
		B4	1.20–1.60	51.7	79.6	12.5	2.57
		B8	2.80–3.20	74.8	95.1	8.0	1.62

been identified in these two specimens: kaolinite, biotite and smectite. However the high activity measured indicates the key role of the smectite as a clay mineral.

3.2. *CEC and organic matter content*

Physico-chemical analyses have been performed in the air-dried soil. Values of the cation exchange capacity (CEC) obtained from these analyses were 13.4 and 17.6 cmol/100 g, respectively for specimens S3 (depth 0.40–0.80 m) and S8 (depth 0.80–1.20 m).

The organic matter content (OMC) was obtained by measuring the amount of organic carbon present in the dried soil. The organic carbon content is composed by a variety of organic compounds, either natural, or from domestic and industrial effluents. As shown in Table 1, the OMC is equally high in all specimens and does not correlate with either plasticity index I_P or the content of fines (<63% μm).

For example, samples S1-E3 (0.80–1.20 m), S2-B5 (1.60–2.00 m) and S3-B5 (1.60–1.80 m), presented a non-plastic (NP) behaviour, despite the very high OMC measured (in the range 15–27%). The natural organic matter substantially increases the overall soil plasticity index, even in small amounts such as 5% of dry weight. Therefore, the only explanation for the non-correlation between the plasticity index and the OMC parameters in the sediment samples is the presence of organic contaminants, instead of natural organic matter. These compounds are measured as organic carbon content but are not capable of providing plasticity to the soil.

4. Analysis of contamination

4.1. *Contamination by heavy metals*

A number of heavy metals have been analysed in 16 specimens listed in Table 2. The first two digits of the specimen denomination refer to its location (see Fig. 2).

Heavy metals were measured in the sediment by total extraction method and each tested specimen was analysed in duplicate using Atomic Mass Absorption spectrometer. A summary of minimum, maximum and average concentration values of heavy metals measured in 16 specimens collected in verticals (S1–S8, see Fig. 2) is presented in Table 3.

Table 4 presents a comparison of the maximum values of heavy metals measured in Fundão Channel with corresponding values measured in the sediments of Guanabara Bay at different locations outside the channel in 1992 (JICA [6]), and suggested bagkground values by Rebello et al. [7]. It is observed in Table 4 that only Cu, Zn and Ni concentrations are significantly higher in the channel when compared to the general pattern observed in the sediments of Guanabara Bay. Other metals present concentration levels within present limits in this particular region.

Table 2
Sample location and depth

Sample	Depth (m)
S1-1	0.00–0.40
S2-B2	0.40–0.80
S3-B1	0.00–0.40
S3-B3	0.80–1.20
S3-B6[a]	0.00–0.10
S3-B7[a]	0.10–0.20
S3-B8[a]	0.20–0.30
S3-B9[a]	0.30–0.40
S4-A1	0.00–0.40
S4-A6	2.00–2.40
S5-A1	0.00–0.40
S6-B1	0.00–0.40
S6-B6	2.00–2.20
S7-B1	0.00–0.40
S8-B1	0.00–0.40
S8-B6	2.00–2.40

[a] Specimen taken using a special continuous sampler.

Table 3
Summary of heavy metals data measured in the sediments

Heavy metals	Concentration (mg/kg)		
	Minimum value	Maximum value	Average value
Cd	<0.01	<0.01	<0.01
Cu	100	300	195
Ni	186	357	276
Pb	101	198	145
Zn	266	825	660
Cr	23	136	91
Hg	1.0	2.3	1.4

The background values suggested by Rebello et al. [7] are substantially lower than any value measured in the bay sediments in the past decades. Since the land surrounding this particular bay has being occupied by man since the foundation of the City of Rio de Janeiro in 1565, one cannot expect to achieve these background values anywhere in Guanabara Bay, in particular for sediments collected close to urban areas.

The values of heavy metals measured at the 16 specimens listed in Table 2 are compared in Fig. 5 to reference values

Table 4
Comparison of heavy metals concentration in Guanabara Bay

Heavy metals	Total Concentration (ppm)		
	Fundão Channel[a]	Guanabara Bay[b]	Possible background[c]
Hg	2.30	0.01–3	0.07
Cd	<0.01	0.01–3	0.02
Pb	198	20–180	3.6
Cu	300	10–120	2.4
Cr	136	40–285	3.5
Zn	825	0–660	–
Ni	357	15–40	–

[a] See Almeida [11].
[b] See JICA [6].
[c] See Rebello et al. [7].

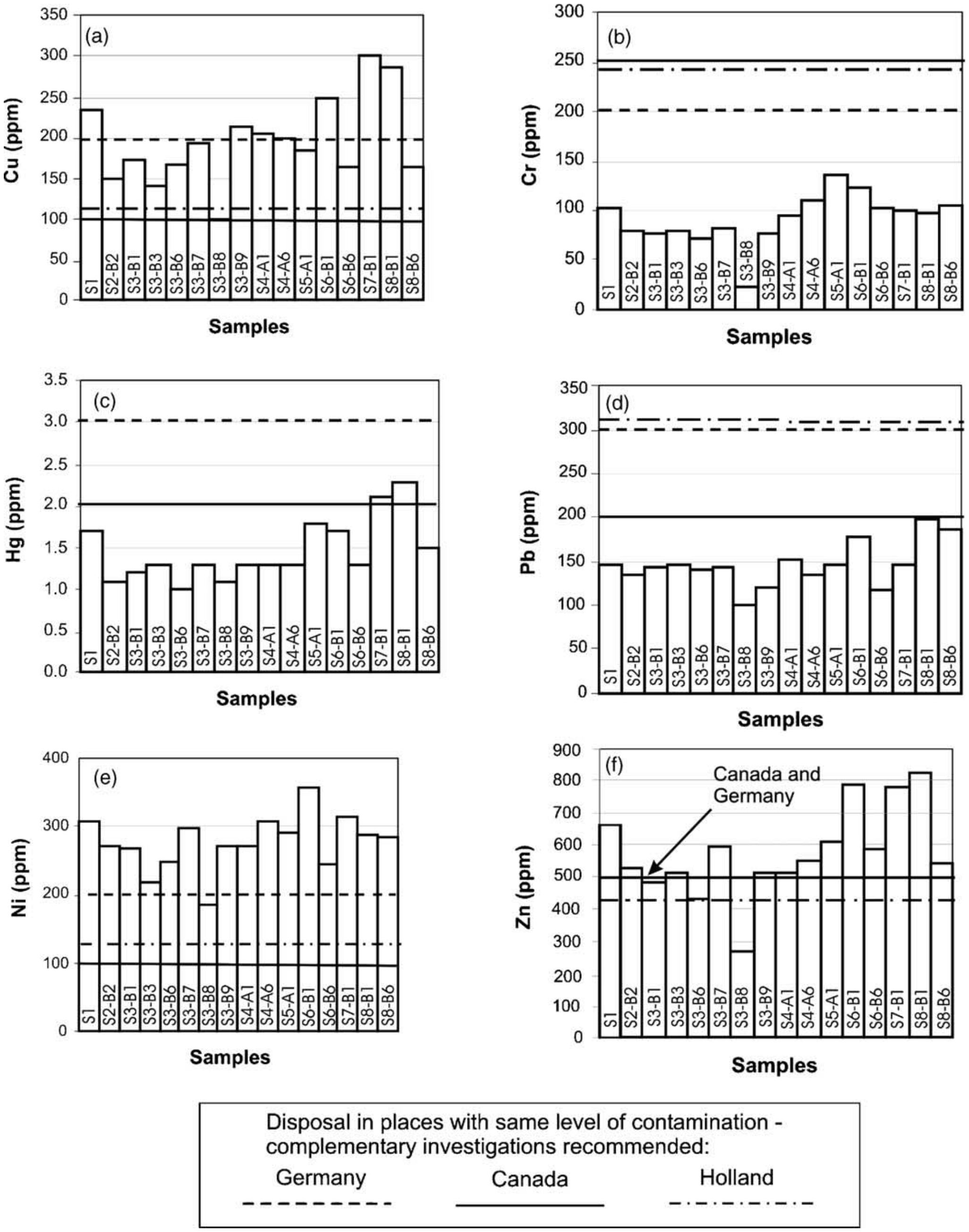


Fig. 5. Heavy metals concentrations in the sediments.

proposed in Canada, Germany and Holland for careful disposal (IADC/CEDA [8]). It is observed that Ni, Zn and Cu are the heavy metals that contribute with the highest degree of contamination, followed by Hg, and that Pb and Cr are below critical contamination level.

In conclusion, from both points of view, comparison to Guanabara Bay range of metals concentrations in the sediments or comparison to some national guides for contaminated soil evaluation, the sediments to be dredged from Fundão Channel can be considered contaminated by Cu, Ni and Zn metals at an intermediate risk level.

It must be observed that these two criteria are usually not coincident, and if they do not match each other, the analysis has to be expanded before decision, either by performing deeper investigations, either by taking into consideration other aspects involved (impact on costs, relevance of the differences obtained, etc.). By chance, in this particular site both criteria led to the same conclusion.

4.2. Contamination by organic compounds

Contamination by organic compounds was analysed both in the sediment (solid and liquid phases) and in the wa-

Table 5
Summary of PAH and O & G measured in the channel sediments (solid and extracted liquid phases) and in water column samples

Location	Depth (m)	PAHs			O & G		
		Sediment[a]		Water column (ppb)	Sediment[a]		Water column (ppm)
		Solid (ppm)	Extracted (ppb)		Solid (ppm)	Extracted (ppm)	
S1	0.00–0.40	863	34.0	–	20240	2.0	–
S2	0.00–0.40	276	64.4	–	2211	<1	–
S3	1.20–1.60	839	43.2	307	14206	<1	7.4
S4	0.00–0.40	447	45.2	–	4759	3.4	–
S5	0.00–0.40	355	90.6	30	4202	<1	3.3
S6	0.00–0.40	1212	37.2	–	20603	1.8	–
S7	0.00–0.40	1257	113.8	–	17599	6.5	–
S8	0.00–0.40	1783	1008.8	–	19380	33.5	–
S9	0.00–0.40	633	134.3	95	6738	5.6	6.3

[a] The soil sample was centrifuged at 4000 rpm for 10 min, separating the liquid and the solid phases. Each phase was analysed individually.

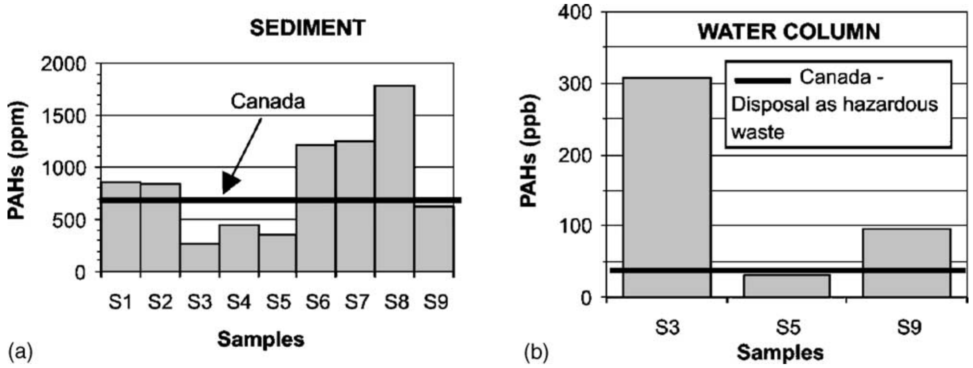


Fig. 6. PAH concentrations in sediment and water column samples.

ter column. Analyses have been made for the concentration of polycyclic aromatic hydrocarbons PAH and for oils and greases (O & G), based on recommendations of the local public environmental agency (FEEMA[1]) considering local potential sources of pollution. Phenol compounds were also suggested and analysed, but the results were below detection limits, both in the sediment and water column samples. PAH compounds have a series of benzene rings and result from the incomplete combustion of fossil products. Benzene is carcinogen and skin irritant and can affect the central nervous system. Consequently, PAH is considered a hazardous contaminant. O & G is just an index parameter that includes all types of organic contaminants. The results are presented in Table 5.

Analyses of the samples for PAH and O & G were carried out in specimens S1–S9 and comparisons have been made to the Canadian recommendations for hazardous wastes. Data shown in Fig. 6a indicates that the high concentrations of PAH measured in all samples characterise the Fundão Channel dredging sediments as a hazardous material. As far as O & G is concerned, the concentration level measured in six out of the nine samples characterise the sediment as a hazardous material, when compared to reference values proposed in Quebec, Canada (MEC/MENVIQ [9]) (see Fig. 7a).

4.3. *Interpretation of contamination processes*

The channel water was tested in three locations S3, S5 and S9 (see Fig. 2) with the purpose of comparison with the sediment contamination for PAH and O & G. Data of PAH and O & G for the water column are presented in Figs. 6b and 7b and compared to reference values proposed in Quebec, Canada (MEC/MENVIQ [9]). The locations were selected to represent different hydrodynamic conditions: S3 is at the mouth of Cunha Channel, which is the major transportation agent of sediments and contaminants into the site; S5 is at OC Bridge, at the beginning of the stagnated region; S9 is close to the BT Bridge, just outside the critical area.

Comparing Fig. 2 (location) to Fig. 3a (hydrodynamic model), it is noticed that location S3 presents the highest water velocities, followed by S9 section and S5 has the lowest values, sometimes approaching zero flow condition. Accordingly, the concentrations of PAH in channel water column obey the following order: $S3 \gg S9 > S5$ (Fig. 6b), and for O & G the sequence is slightly different: $S3 \approx S9 > S5$ (Fig. 7b).

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[1] FEEMA is Fundação Estadual de Engenharia do Meio Ambiente do Rio de Janeiro (*Environmental Engineering Foundation, Government of the State of Rio de Janeiro*).

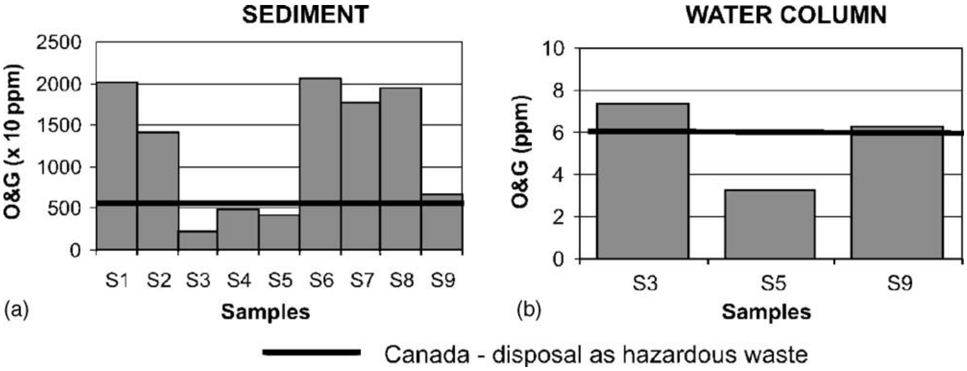

Fig. 7. O & G concentrations in sediment and water column samples.

For sediment samples (Figs. 6a and 7a) the opposite is observed: concentrations are highest in S1/S2 region (South of Fundão Island) and in S6–S8 sections, between the two bridges. A few conclusions can be drawn from these patterns:

(a) The major source of PAH is the Cunha Channel, since S3 water concentration is substantially higher than S9 value, located at the other end of Fundão Channel.
(b) For O & G, both ends of the channel contribute, since S3 and S9 water samples present about the same concentration level.
(c) The concentrations in the water column are higher in locations with higher water flow velocities.
(d) When the water column concentrations are higher, the sediment concentrations are lower, and vice-versa. That means a deposition process related to the decrease of water flow velocity. The PAH species have typically high molecular weight, and when the water flow is no more capable of transporting them, the contaminants are deposited on the channel floor.
(e) In the S1/S2 region, at the South of the island, currents are faster, but the concentrations in the sediment are also high for O & G index (Fig. 7a). This can be explained by an enlargement of the channel section just after the sections analysed (see Fig. 3), causing a decrease in water flow velocity, and also by navigation at both ends of the island, that seems to be the major source of O & G compounds in the water.

Heavy metals are generally transported in the water bodies attached to particulate suspended matter. When the water velocity decreases, the metals are deposited together with the suspended solid matter on the channel floor.

Therefore, both metals (Cu, Ni and Zn) and organic compounds (PAHs) are brought into the site mainly by the discharge of the Cunha Channel, and deposited on the Fundão Channel floor as the flow velocity diminishes. Besides industries contribution, untreated sewage and garbage are also sources of pollution for the site.

This degradation process is going on for decades, and because of progressive siltation of the channel, the rate of deposition is increasing, and so is the degree of contamination. The silted water body has been working as a reservoir for chemical substances for a long time, what explains the high concentrations measured in the sediment.

Besides, the combination of poor quality of sediments and water column, hydraulic stagnation and high average temperature (around 25 °C in 1-year period), led to the increase of micro-organisms populations in the channel environment. Lacerda et al. [10] reported 43 000 to 150 000 *coliforms fecalis* per 100 mL and zero dissolved oxygen in channel water samples. Brazilian standards establishes a maximum of 1000 *coliforms fecalis* per 100 mL and a minimum of 5 g/L of dissolved oxygen for bodies of water such as Guanabara Bay, used for navigation, recreation and fishing activities.

5. Sediment dredging and disposal

5.1. Dredging

The total volume of sediment to be dredged was estimated in 1.5 million cubic metres. However, only the top layer of the sediment is expected to be classified as a hazardous waste due to its degree of contamination with PAH and O & G. On exception of sample S3 (1.20–1.60 m), the sediment samples tested for PAH and O & G were collected between 0.0 and 0.40 m depth, in order to characterise the most recent and probably the worst condition at the site. Table 5 shows that sample S3 presented the same level of PAH and O & G concentrations of the shallow samples.

The deposition rate in the Fundão Channel has been estimated as 4–5 cm per year. If we consider the construction of the Fundão Island in the 50 s as the start up, then we would get about 2.50 m of sediments deposited on the channel floor since then. The oil refinery that is suspected of being the source of the PAH transported by the Cunha Channel exists long before the creation of the island. Therefore, the result of PAH contamination of S3 sample shown in Table 5 is quite reasonable, but it represents only one point tested.

The highly contaminated layer should be dredged in separate of the remaining sediment, in order to minimise the volume of hazardous waste to be disposed off. For that reason, a complemental series of investigations is strongly recommended before starting the project execution, to establish a more reliable frontier between hazardous and non-hazardous dredging sediments along the channel (Lacerda et al. [10]).

Considering that PAHs are predominantly attached to the solid phase, the dredging procedure has to be carefully chosen in order to minimise the liberation of the PAH to the water column. Therefore, hydraulic type dredger equipments with suction and pipeline are preferable than mechanical dredgers (e.g. bucket or dipper), which allow return of the liquid phase to the water body during operation.

A three step dredging procedure was suggested in the preliminary design (Rosman and Lacerda [4] and Almeida [11]):

1. Mechanical dredging for removing the garbage layer that covers the channel floor and part of the big, heavy individual pieces like concrete slabs abandoned in the channel. The material removed would be transported on trucks to the city MSW landfill.
2. Careful hydraulic dredging of the hazardous sediment layer. The material would be pumped to a specially prepared disposal basin for sedimentation and confinement.
3. Hydraulic dredging of the remaining layers of sediment according to the design. The final disposal of this material would not require the same degree of protection as the previous hazardous dredged sediment.

5.2. *Final disposal*

Kamon et al. [12] outline the assessment of potential hazards of dredged materials for final disposal design, for both land and underwater disposal solutions. The appropriate underwater disposal technique described for heavily contaminated sediments was considered too expensive for the amount of financial resources available in Rio de Janeiro for this particular project. Therefore, only the land disposal alternative was taken into consideration in the design, at least for the contaminated sediment layer to be dredged in Fundão Channel.

The land disposal is generally the more economical solution in Rio de Janeiro, since underwater disposal is not allowed in the bay itself, and dredged material should be transported to the sea, beyond the entrance of Guanabara Bay. The transportation costs are usually prohibitive.

The Fundão Island is the closest option for land disposal, but it belongs to the Federal University of Rio de Janeiro, and final decision depends on the agreement of the University community. This alternative is still under negotiation.

Independent of the site, some disposal conditions have been outlined in the design and are briefly discussed herein:

1. The dredged material consists mainly of fine organic sediments, with smectites as the governing clay mineral. In addition, hydraulic dredging implies that the material will be initially deposited as a suspension with only 10 to 15% solids. This material will then remain in the basin for sedimentation and consolidation under own weight before the area can be covered with regular soil and re-urbanised.
2. The designed disposal facilities are quite similar for hazardous and non-hazardous sediments, consisting in excavated reservoirs surrounded by earth dikes, provided with an outlet for the supernatant discharge back into the bay after the sedimentation stage. The difference is the presence at the hazardous waste facility of a barrier system composed of an HDPE geomembrane enveloped in two compacted clay soil layers, and drainage systems to collect the water resulting from the waste consolidation with time (Almeida [11]).
3. A very important practical question is how long the material will take to consolidate and permit the use of the site. Due to the sediment physical and mineralogical characteristics, a long time is expected. Therefore research has been performed aside from the project to quantify the sedimentation and self-weight consolidation processes for this particular material and to investigate possible solutions to accelerate them in the field. The results are presented in Santos [13] and briefly described in Santos et al. [14]. The addition of non-ionic polymers' into the suspension has proved to be quite efficient in the laboratory experiments, and does not produce any significant environmental impact.
4. Barbosa and Almeida [1] present some comments on acid drainage generation related to oxidation of sulphides after land disposal in Rio de Janeiro of dredged sediments rich in FeS_2 and organic matter. But the material to be dredged in the Fundão Channel was analysed for sulphides and the result was negative. Natural pH is neutral to slightly alkaline (7.5–8.3), in agreement with the marine environment.
5. The conditions at the disposal site are favourable to the immobilisation of both heavy metals and organics within the confined dredged material. If only confinement is adopted, the final soil cover and the landscape design at the hazardous waste disposal site will have to be planned not to cause any disturbance to the protective liner system (soil and HDPE geo-membrane layers). But to permit future use of the areas, the possibility of bio or fitoremediation is being considered for the hazardous waste deposit, concerning the PAH contamination.

6. Conclusions

The dredged sediment of the Fundão Channel has been sampled in a number of locations and depths for a careful characterisation of its physical and chemical properties. The sediment consists predominantly of a material with a large amount of fines and high plasticity. Organic matter content has been found in virtually all samples including the coarser non-plastic sediment material. Therefore these are organic carbon content due to the presence of organic compounds.

A number of heavy metals were found in the sediment, in concentration levels that require careful disposal. However the organic compounds (PAH and O & G) were measured in concentration levels that characterise the sediment as a hazardous waste. Besides, degradation of channel sediment and water column led to biological contamination. Dredging and disposal operations have to be made taking these important aspects into consideration.

The comparative analysis of hydrodynamic conditions and spatial variations in degree of contamination of sediment and water column samples allowed determining the mechanism of contamination at the site. The investigations showed that simple techniques and procedures can be very efficient if carefully planned and adequate interpretation is carried on.

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