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Full Length Research Paper

Environmental port management: Conceptual model development and use of tools to evaluate and monitor dredging activities in the Port of Rio Grande, Brazil

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This work concerns assessing and monitoring of dredging activities in the Port of Rio Grande, Brazil. The subject is presented to address the major problems related to the dredging process itself and sediment disposal options. From the dredging works carried out in 1998, 2000 and 2003 on the Port of Rio Grande, different data were gathered and used to develop a preliminary conceptual model of this process. The conceptual model elaborated and presented in this study consists of technical, ecological and socio-economic aspects of dredging. This model, which is an analysis of the major points to be considered when dealing with dredging projects at the Port of Rio Grande, highlights the importance of monitoring these activities from all aspects. The main points to be considered are: Selecting the type of dredge and the method of management and disposal of the sediments; monitoring the impacts within the environment (plants, animals, water and sediment quality), and the operational and monitoring costs of these activities. Another point that should be considered is about the disposal options or beneficial reuse of the dredged material.

Key words: Brazil, dredging, environmental impacts, modeling, monitoring.

INTRODUCTION

One important research field in developed and developing countries is the improvement of ports and channels by the use of dredging activities. These activities produce a certain level of impacts and a monitoring program should always be considered to evaluate their environmental consequences.

Most of the ports worldwide have been established in rivers, estuaries and lagoons in highly populated industrial centers. The navigation channels in the entrance of these ports and estuaries suffer shoaling processes requiring frequent dredging to maintain their depth. However, the sediments present at the bottom of industrialized ports are usually contaminated with trace metals and organic compounds. Thus, the dredged material must be carefully handled and disposed at proper sites. Therefore, dredging activities demand correct planning and decision making on the process itself, as well as on the handling and disposal of the dredged material.

In developing countries such as Brazil, there is a lack of information related to dredging works (Torres and Calliari, 2004). In many cases, existing information are not presented to the community, being held by the port administration they belong to or research institutes that do not publish them. In a worse situation, very few of the ports and channels that require dredging have any kind of environmental monitoring and evaluation program. The first Brazilian legislation dealing with the dredging process was approved in March, 2004 and addressed the characterization of the sediment in order to decide the disposal options in coastal areas and monitoring the disposal site, with several physical, chemical and ecotoxi-cological parameters (CONAMA, 2004).

Environmental impacts associated to the dredging process and spoil disposal can be characterized by direct effects over organisms and habitats and indirect effects attributed to alterations in water quality (Kennish, 1994, 1996). Physical disturbances associated to removal and re-location of sediments are considered direct effects and

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provoke the destruction of benthic habitats, increasing mortality of these organisms. Indirect effects are associated with the resuspension of bottom sediments with remobilization of contaminants and nutrients affecting the water quality and the increase of turbidity and decrease on the conditions of light dispersion.

According to Davis et al. (1990) and Bray et al. (1997), the impacts of dredging can be divided into several categories: 1. Dispersion and deposition of resuspended sediments; 2. Depth alterations; 3. Effects and changes in coastline configurations; 4. Loss of habitats on bottom sediments and water column, as well as fishing resources; 5. Noise; 6. Odor and 7. Changes in overall environmental quality (both in the dredging site and disposal site).

Environmental monitoring, by definition, consists on making specific measurements and observations of some indicators and parameters with the purpose of verifying if the required environmental impacts are happening, their intensity and to help choose and evaluate which mitigating procedures can be taken (Araújo, 2006).

In the case of dredging operations, the variables to be monitored according to IADC/CEDA (1998) and USEPA (1998) are related to depth control, suspended sediments generation, spill generation, density in the pipeline and/or disposal site, physical and chemical characteristics and biological parameters.

Therefore, there is a need to develop monitoring techniques of these activities aiming to align projects in accordance with the existing policy, which can be complemented by international laws on dredging and disposal. The evaluation of the techniques used in projects around the world could help in implementing mechanisms that better represent the reality of the Brazilian ports (Fredette and French, 2004). The multidisciplinarity involved in dredging activities which include port, naval and ocean engineering, oceanographic processes (comprising physical, chemical, geological and biological oceanography) and environmental, ecological, economical, social and legal aspects to which the dredging operations are closely related must be considered in designing a monitoring program.

The objective of this work is to present an overview of the dredging activity in the Port of Rio Grande and develop a conceptual model giving emphasis on aspects that should be considered in the management of a dredging activity, from the environmental, technical and socio-economical point of view. Also, from this conceptual model, some tools for the environmental monitoring process of the activity can be commented.

MATERIALS AND METHODS

Study area

The Port of Rio Grande is the southernmost port of Brazil (Figure 1) and is located at the west margin of the North Channel (considered the natural drainage of the Patos Lagoon Hydrographic Basin). Its geographic location and the extent of protected waters make it ideal for the flow of commerce from the Rio Grande State and the North of Argentina, presenting great importance to the economy of the region. It is the third most important Brazilian port, after the ports of Santos and Rio de Janeiro (Torres, 2000).

The city of Rio Grande is locate in the margins of the estuarine region of the Patos Lagoon, in a peninsula limited to the south and northeast by shallow bays ("Saco da Mangueira, Saco do Martins and Saco do Justino"); to the north by the North Channel; and to the east by the Access Channel to the Patos Lagoon and the Atlantic Ocean ("Canal do Rio Grande"; Figure 1).

The estuarine region is located between the latitudes of 31°30'S and 32°30'S and longitudes 51°55'W and 52°15'W and consists of the transition area that has some influence from salt water and the fresher lagoon waters. The Patos Lagoon estuary is classified as a coastal plain estuary or bar estuary according to Fairbridge (1980) (in Hartmann, 1996). Kjerfve (1994) also denotes this estuary as choked (strangled) because it is a narrow and long lagoon, composed of elliptic cells connected with each other and with a long and narrow channel linking to the ocean.

With the increasing importance of the Port of Rio Grande, the improvements on the navigation conditions of the Patos Lagoon inlet took place with the construction of the "Molhes da Barra" (two 2 mile long jetties at the entrance of the Lagoon). This construction, which started in 1898 and finished in 1915, is one of the biggest coastal engineering works in Brazil. These jetties fixed the bar, allowing a natural deepening of the channel from 2.5 to 6 m. Lately, with the dredging works to open the Rio Grande Canal, in 1972, ships with a greater draft were able to enter the estuary. The main periodic dredging every two to three years (Hartmann, 1996).

Mainly suspended matter is a major contributor makes up of the sediments contribution to in the Patos Lagoon and estuarine area. Baisch (1994) estimated that the solid discharge from the Guaíba system and Camaquã River are about 5.3 million meter cube per year, of which about 82% is from the Guaíba and 18% from the Camaquã. According to this author, only 25% of this volume reaches the estuarine region, or a total of 1.2 million meter cube. Adding to the total is the amount of sediment exported from the Mirim Lagoon through the São Gonçalo Channel, this volume comes to about 2 million meter cube of suspended matter all contributing to the shoaling process in the navigation channels.

According to the available data, maintenance dredging of the Rio Grande Port is about 1.4 million cubic meters per year, divided in three distinct areas: Rio Grande Canal, approximately 1,040,000 m^3/year; Access Channel to Porto Novo, 75,000 m^3/year, and; Evolution Basin of Porto Novo, 285,000 m^3/year (Portobrás, 1979).

Model development

The dredging operation in the Port of Rio Grande that took place from March to August 1998 was accompanied and previously evaluated biological, physical, chemical and geological characteristics of the area such as biological and hydrological cycles, water and sediment quality and socio-economical aspects of the region present in Torres (2000) were gathered in order to develop a conceptual model based on energy fluxes according to Odum (1971, 1994) regarding environmental, technical and socio-economic aspects as well as the information on the techniques that is normally used in dredging projects.

This model comprises the sources of energy (represented by the objects outside the dashed rectangles), the pathways of the energy inside and across each different compartment and the final destination of this energy. To help evaluate and refine this model, the two subsequent dredging projects (in 2000/2001 and 2003/

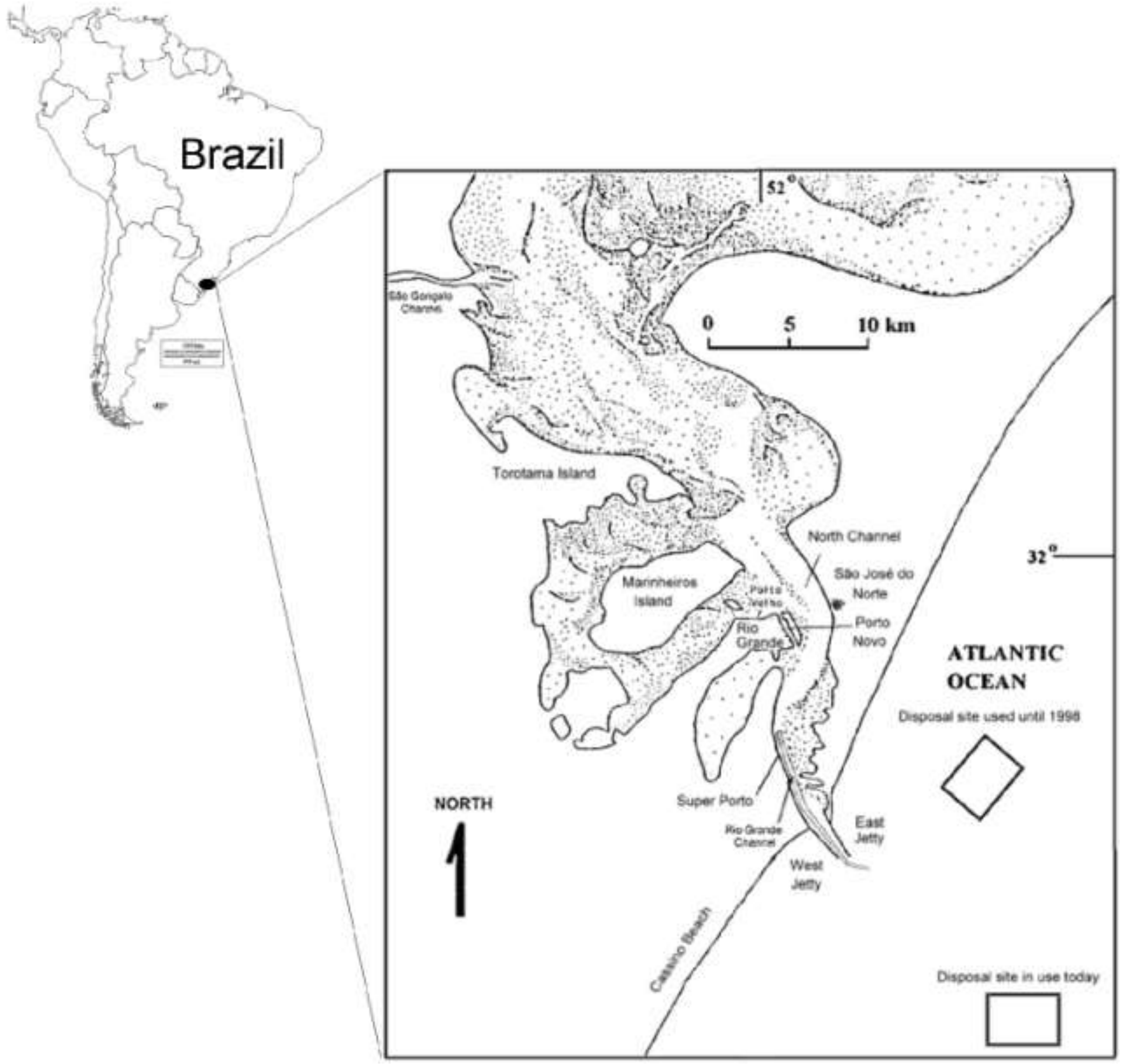

Figure 1. Rio Grande region map showing the port areas, the navigation channels and the disposal site used until 1998 and the current site [modified from Hartmann (1996)].

2004) and their environmental monitoring programs were analyzed.

RESULTS AND DISCUSSION

The total amount dredged from Rio Grande Port in the 1998 dredging operation was approximately 2,940,000 m^3 in the three sections of the port that was dredged (Rio Grande Channel, Access Channel to Porto Novo and Evolution Basin of Porto Novo). The disposal site was located offshore, in front of the Mar Grosso beach in São José do Norte - Rio Grande's neighbor town - about 5 nautical miles from the east jetty, at a depth of about 13 m. This disposal site was considered unsuitable because it could form sand bars in the beach area, affecting the incidence of waves in the foundation of the east jetty, and it could cause its rupture (Calliari and Tagliani, 1997). This problem was avoided during the 2000/2001 and later dredging operations on which another disposal site started to be used, located about 13 miles offshore with an approximate depth of 20 m (Figure 1) and out of the navigation routes as proposed by Torres (2000).

It is known from prior projects that the sediments from depth of this channel is about 14 m and is maintained through Rio Grande channel are contaminated by trace

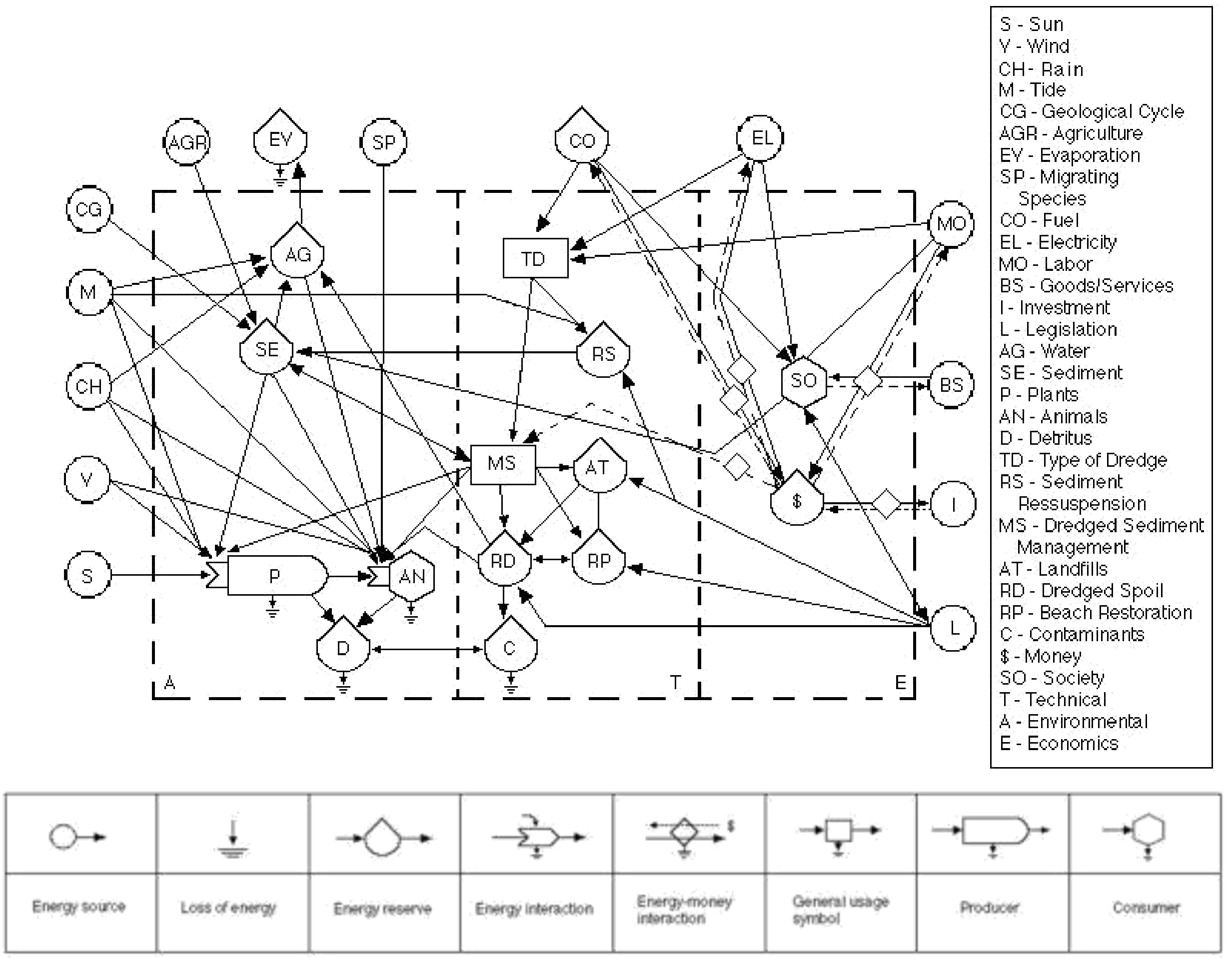

Figure 2. Schematic (conceptual) model presenting the relationship between the various processes related to the dredging activities.

metals and organic contaminants from the port area, from the effluents of the industries based in the Industrial District, especially from the fertilizer industries and from the adjacent sewage effluent from the city (Baisch, 1997). As dredging re-suspends this sediment allowing these contaminants to get back to the water column, it is advisable that these activities should be monitored before, during and after the operations are concluded.

The schematic model shown in Figure 2 was developed by observation of the dredging operation that took place in 1998. As an ecological model, it was based on the energy circuit language designed by Odum (1971, 1994). It takes into account the following major aspects: Environmental/ ecological, technical and socio-economic aspects which are represented by dashed line rectangles. The linkages and relationships between the different compartments of the model can be used to generate information on the design of new dredging projects.

This conceptual model can be used to identify which points of the dredging process can be optimized and the model gives a background for future studies on dredging operations of the Rio Grande port and estuarine area, as well as other ports in the Brazilian coast. As such, it represents a comprehensive system representation of cause and effects. The model is designed in order to organize information into a comprehensive representation of the system's important structure (components) and function (processes) and cause-and-effect relationships. The model components and relationships may be used to assess and evaluate changes to the system and effects of management actions, alternatives, and scenarios on the system and system structure and function.

Since most dredging projects are site specific, this conceptual model can be used to identify which points of the dredging process can be optimized and gives a background for future studies on the dredging operations of the Rio Grande port and estuarine area, perhaps it may be adapted and used as bases for other dredging projects in Brazil and other places around the world. The main points to be considered are: Selecting the type of dredge and the method of management and disposal of the sediments; how to make a monitoring plan of the impacts over the environment (plants, animals, water and sedi-ment quality), and the operational costs and monitoring costs of these activities. One aspect that should be emphasized is the volume to be dredged at specific sites, which in many cases can be influenced by geological and climatic cycles of the region, raising or reducing the volume of sediments that reach the estuarine area.

Another point that should be considered is the choice of disposal options or reuse of the dredged material. Some of the techniques used can be dangerous to the environment and human health while others can be beneficial such as the use of these sediments for beach nourishment, landfill or construction material. A pilot project has been conducted in order to reuse the sediments from the area of Porto Novo as material for blocks and cement to be used as construction material (Dias et al., 2004).

According to Asmus and Zamboni (2001) and Asmus et al., (2002), the impacts of the 2000/2001 dredging works on benthic organisms, plankton, fish and fishing resources, vegetation, water and sediment quality, and the overflow activity (discharge of the exceeding water from the interior of the hopper dredge, and which contains fine grained sediments), were monitored in the dredging site and at the disposal site for the first time in the maintenance dredging that happened in the years 2000/2001. From this monitoring activity, it was possible to determine that dredging should be done on the periods that the outflow regime from the Patos Lagoon can carry the re-suspended sediments to the ocean, preventing it to re-settle in the channel. Also, as sediments were contami-nated with trace metals and organic compounds, it required careful management and placement. The main toxic compounds were persistent organic pollutants (POPs), sulfur and nitrogen from the city sewage outlets and phosphorus (P), lead (Pb), copper (Cu), cadmium (Cd), zinc (Zn), chromium (Cr) and nickel (Ni) from the fertilizer industries on the industrial district adjacent to the port area. POPs were not quantified, but some of these metals such as Cu, Pb and Zn have shown violations of the sediment quality guideline called ERL (Effects Range Low), which might present toxic responses to living organisms (Long et al., 1995). Some of these compounds may bioaccumulate in seafood resources, representing some potential harm to human health.

The environmental effects to plants and animals of the estuarine area of the lagoon and nearby coastal zone mainly result from the increase of turbidity, with normal concentration of about 50 mgl^{-1} of suspended sediments reaching up to 15,000 mgl^{-1} in the plume behind the hopper dredge, which represents a reduction in light incidence and reflects on the plant growth and fisheries life cycles. Also, sediment settlement in the channel and disposal site can affect benthic organisms, suffocating them.

During the dredging work of 2003/2004, a monitoring program was also conducted (Asmus and Granato, 2004).

In this particular project, the overflow was controlled. This way, the suspended particles in the plume behind the dredge did not reach the same values as on the previous dredging, remaining below the 500 mgl^{-1} level, even though it is still above safe levels. Also, another action that was taken was related to conducting most of the work during the periods when the discharge from the lagoon to the ocean was larger, pushing the turbidity plume to the sea and preventing the settlement of the sediments back in the channel and estuarine region. This proved to be a good practice to improve the overall conditions of the estuarine and marine area.

Tools for monitoring dredging activities

In the last few decades, a great number of studies regard-ing environmental impacts of dredging have been con-ducted (Fredette and French, 2004). Some of them in Europe, Asia and North America discuss the importance of assessing sediment quality and how it is related to environmental toxicology (USEPA, 1998). Some of these tools for monitoring dredging activities (also known as lines of evidence or LOE) have been characterized as follows:

Physical and chemical characterization: Grain size, total organic carbon (TOC), acid volatile sulfides and simultaneously extracted metals (AVS/SEM), metal speciation and persistent organic pollutants such as poly-cyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and some pesticides (Cesar, 2006; Lotufo, 2006);

Biological characterization: Ecotoxicological assays with whole sediments, water from the interface water-sediment, interstitial water and elutriates, use of Microtox®, histopathology and mutagenicity, evaluation of benthic community structure and bioaccumulation of chemicals by fish and invertebrates (Cesar, 2006; Sáfadi, 2006; Umbuzeiro, 2006).

SUMMARY AND RECOMMENDATIONS

From the information obtained, it was possible to draw the following conclusions and recommendations for future dredging projects and other scientific works regarding dredging and environmental management:

1. The knowledge of natural and anthropogenic shoaling processes of estuarine areas and navigation channels is the first step to understand what happens in the port area.
2. Good assessment of the magnitude of contaminants present in the sediments from the bottom of the channels is necessary in order to prepare safe actions for the

dredging activity and spoil disposal, especially for the fact that dredging can re-mobilize these contaminants.

3. In the Port of Rio Grande, the dredging works should be conducted during periods of water discharge from the lagoon so the re-suspended sediment would be carried out of the estuary. In other ports, the hydrodynamic system of the estuary should be evaluated in order to understand what happens with fine sediments and what would be the best option to reduce recontamination of the estuary.

4. Monitoring the quality of water and sediments as well as the influence of the dredging operations on the biological, chemical and physical processes on the estuarine and marine areas should be conducted before, during and after the dredging work takes place.

5. Dredging activity management should comprise the aspects presented in the conceptual model proposed here and includes the choice of dredging equipment and the best disposal techniques, evaluation of the volume to be dredged, assessment of water and sediment quality, as well as the biological cycles in the port area

6. A model enhancement and testing with data to be collected in new dredging projects may generate hypotheses about uncertain relationships or interactions between components which may be tested and revisions made to the model through an adaptive process;

7. According to recent studies (César, 2006; Lotufo, 2006), some tools for monitoring dredging activities are necessary. These tools are related to physical and chemical characterization as well as biological and ecotoxicological evaluations. These aspects are foreseen on the recent Brazilian legislation CONAMA 344/04 that concerns about the assessment and monitoring of dredging activities in Brazilian jurisdictional waters, which is under evaluation. The conceptual model conceived in this work is important for communication and decision-making that incorporates different disciplines and a range of affected stakeholder and agency groups involved in the dredging activity in Brazil.

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REFERENCES

Araújo N (2006). Curso de Avaliação de Impacto Ambiental (Course of environmental impact assessment). Pró-Ambiente Assessoria Ambiental. p. 46.

Asmus ML, Granato FC (2004). Relatório Técnico Referente às Atividades Desenvolvidas no Monitoramento Ambiental da Operação de Dragagem no Canal de Acesso ao Porto de Rio Grande. (Technical report on environmental monitoring of the activities developed on the dredging operation on Rio Grande Channel). Rio Grande. Relatório final. p. 230.

Asmus ML, Zamboni AJ (2001). Monitoramento ambiental da operação de dragagem do porto de Rio Grande: relatório final - fase 1. (Environmental monitoring of the dredging activity on the Port of Rio Grande: final report – phase 1). Rio Grande. Fundação Universidade Federal do Rio Grande (FURG). p. 197.

Asmus ML, Freitas DM, Zamboni AJ (2002). Monitoramento ambiental da operação de dragagem do porto de Rio Grande: relatório final - fase 2. (Environmental monitoring of the dredging activity on the Port of Rio Grande: final report – phase 2). Rio Grande. Fundação Universidade Federal do Rio Grande (FURG). p.180.

Baisch P (1994). Les oligo-elements metalliques du systeme fluvio-lagunaire dos Patos, Flux et devenir (Bresil). (Trace metals from the fluvial-lagoonair system of the Patos Lagoon, Brazil). Ph.D. thesis. Université de Bordeaux, Bordeaux I. 1136: 345.

Baisch P (1997). Geoquímica. (Geochemistry). In: Tagliani, P.R.A. and M.L. Asmus (Coord.) Estudo do impacto ambiental do Porto de Rio Grande (EIA). (Environmental Impact Assessment of the Port of Rio Grande). Rio Grande. pp. 425-489.

Bray RN, Bates AD, Land JM (1997). Dredging, a Handbook for Engineers. John Wiley & Son, Inc. Second edition. New York. p.434.

Calliari LJ, Tagliani CR (1997). Geologia - Geomorfologia. In: Tagliani, P.R.A. and M.L. Asmus (Coord.). Estudo do impacto ambiental do Porto de Rio Grande (EIA). (Environmental Impact Assessment of the Port of Rio Grande). Rio Grande, pp. 412-425.

César A (2006). Métodos integrados para a avaliação e caracterização ambiental (Integrated methods for environmental assessment and characterization). I Workshop sobre Ferramentas para o Monitoramento das Atividades de Dragagem (I Workshop on tools for Monitoring Dredging Activities). 19 October. São Paulo.

CONAMA (Conselho Nacional do Meio Ambiente – National Environmental Council) 2004. Norma 344 de 25 de março de 2004. Diretrizes gerais para a avaliação do material a ser dragado em águas jurisdicionais brasileiras, visando o gerenciamento de sua disposição. (Policy 344 – March 25, 2004 – General Guidelines for the assessment and management of dredged material suitable to be disposed on Brazilian jurisdictional waters).

Davis JD, MacKnight S, IMO staff (1990). Environmental Considerations for Port and Harbor Developments. World Bank Technical Paper, (126): 83.

Dias CRR, Kerstner VWT, Dias CRC 2004. Bacias de Despejos de dragagens em Rio Grande: I - Implantação e Estudos Iniciais. (Disposal sites of dredged material in Rio Grande: I – implementation and initial studies). *Revista Vetor*, Rio Grande, 14(1): 79-97.

Fredette TJ, French GT (2004). Understanding the physical and environmental consequences of dredged material disposal: history in New England and current perspectives. Mar. Poll. Bull. 49:93-102.

Hartmann C (1996). Dinâmica, distribuição e composição do material em suspensão na região sul da Laguna dos Patos. (Dynamics, distribution and composition of suspended matter on the south region of the Patos Lagoon). Doctorate Dissertation. UFRGS. Porto Alegre. p. 363.

IADC (International Association of Dredging Companies) / CEDA (Central Dredging Association) (1998). Machines, Methods and Mitigation. Environmental Aspects of Dredging Series, 4: 80.

Kennish MJ (1994). Practical Handbook of Marine Science. John Wiley & Sons, Inc. New York . p. 562 .

Kennish MJ (1996). Practical Handbook of Estuarine and Marine Pollution. John Wiley & Sons, Inc. New York. p.524.

Kjerfve B (1994). Coastal Lagoons. In B. Kjerfve (ed.). Coastal Lagoon Processes. Elsevier Oceanogr. 60: 1-8.

Long ER, MacDonald DD, Smith SL, Calder FD (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ. Manage., 19(1): 81-97.

Lotufo G (2006). The use of bioacumulation evaluation in dredged sediment disposal site monitoring. I Workshop on tools for Monitoring Dredging Activities. 19 October. São Paulo.

Odum HT (1971). Environment, power and society. J. Wiley & Sons. New York. p. 33.

Odum HT (1994). Ecological and general systems: an introduction to systems ecology. John Wiley & Sons. New York. p. 644.

Portobrás - Empresa de Portos do Brasil, SA (1979). Plano diretor portuário do Brasil. Parte A. Cadastro. Porto de Rio Grande -

RS. (Director Plan of Brazilian Ports. Part A. Port of Rio Grande). p.270.

Sáfadi RS (2006). Ensaios ecotoxicológicos aplicados à avaliação de sedimentos marinhos e estuarinos: problemas e propostas de soluções (Ecotoxicological assays applied to the evaluation of marine and estuarine sediments: problems and proposals for solutions). I Workshop sobre Ferramentas para o Monitoramento das Atividades de Dragagem (I Workshop on tools for Monitoring Dredging Activities). 19 de outubro. São Paulo.

Torres RJ (2000). A preliminary appraisal of the dredging process on the Port of Rio Grande, RS. M.Sc. thesis on Ocean Engineering. Fundação Universidade Federal do Rio Grande – FURG p.190.

Torres RJ, Calliari L (2004). Evaluation of dredging activities in developing countries – overview of Brazilian ports. World Dredging Congress XVII (WODCON XVII). Hamburg, Germany, 27 September to 01 October.

Umbuzeiro G (2006). Ensaios de mutagenicidade: tendências atuais e uso como ferramenta de monitoramento (Mutagenesis bioassays: real tendencies and use as tools for monitoring). I Workshop sobre Ferramentas para o Monitoramento das Atividades de Dragagem (I Workshop on tools for Monitoring Dredging Activities). 19 de outubro. São Paulo.

United States Environmental Protection Agency (USEPA) (1998). Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual. USEPA/USACE EPA-823-B-98-004. p. 176.