Wissenschaftlich-technische Zusammenarbeit mit Brasilien

BMBF-Verbundprojekt

Nachhaltiges Umweltmanagement in brasilianischen Häfen

Fallstudie Paranaguá

FKZ 03F0452A-C, 03F0452E-F, 03F0454A
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A. Allgemeiner Teil

Vorbemerkung

Das Forschungsvorhaben „Nachhaltiges Umweltmanagement in brasilianischen Häfen" ist ein Verbundprojekt des Bundesministers für Bildung und Forschung (BMBF), welches im Zeitraum 01.11.2006 - 31.10.2009 (FKZ 03F0452B-C, 03F0452E-F, 03F0454A) bzw. 01.11.2006 - 31.12.2009 (FKZ 03F0452A) gefördert wurde. Es liefert einen anwendungsbezogenen Beitrag zu der deutsch-brasilianischen Zusammenarbeit in Wissenschaft und Technologie (WTZ), welche 1996 in einem Rahmenabkommen beider Länder aktualisiert wurde. Thematische Schwerpunkte der bilateralen Zusammenarbeit sind u.a. die Bereiche Umwelt und Nachhaltigkeit sowie Hochschulbildung. Vor allem die Bedeutung der Forschungsbereiche mit Bezug zur Nachhaltigkeit wird für die WTZ der beiden Länder betont. Eine Intensivierung der Kooperation im Bereich der meeres- und küstenbezogenen Umweltforschung wurde im Juli 2004 in einem Abkommen zwischen dem BMBF und dem brasilianischen Ministerium für Wissenschaft und Technologie (MCT) vereinbart. Hierbei wurden vier prioritäre Forschungsfelder definiert, i.e. die Themenbereiche Küstenzonenmanagement, Verschmutzung, lebende marine Ressourcen und Hafenentwicklung.

Zentrales Thema des vorliegenden Verbundvorhabens ist die Entwicklung von Strategien für ein nachhaltiges Hafenmanagement. Sämtliche der o.g. vier Forschungsprioritäten sind dieser Themenstellung folglich inhärent. Eine weitere wichtige Zielsetzung des bilateralen Abkommens mit Brasilien, die Förderung der Hochschulbildung, wurde im Rahmen der Projektaktivitäten im Modul Training und Capacity Building aufgegriffen. Die gemeinsam durchgeführten Forschungsarbeiten, die Organisation von Gastforscheraufenthalten brasilianischer Wissenschaftler an den beteiligten deutschen Universitäten, mehrmonatige Trainingskurse für brasilianische Masterstudenten in Deutschland und themenzentrierte Workshops führten zu einem deutlichen Wissens- und Kompetenzfortschritt der beteiligten brasilianischen Arbeitsgruppen. Die studentische Ausbildung im Rahmen des Projektes erreichte, gemessen an der Anzahl abgeschlossener und laufender Examensarbeiten auf Seiten beider Partner, eine beachtliche Effizienz.

Die im nachfolgenden Ergebnisbericht beschriebenen Untersuchungen wurden am Beispiel des Großhafens von Paranaguá, Südbrasilien, durchgeführt. Der Hafen liegt im weitverzweigten, subtropischen Ästuarkomplex von Paranaguá, welcher von ausgedehnten Naturschutzgebieten, vorwiegend Mangrovenwäldern, umgeben ist. Die Ergebnisse des vorliegenden Verbundprojektes tragen zum generellen Verständnis der ästuarinen Strukturen und Prozesse im

Buchtenkomplex von Paranaguá bei, sie sind jedoch vor allem relevant für Entscheidungsträger aus Küstenraumplanung, Hafen- und Umweltmanagement. Als Projektergebnis liegen Instrumente, Entscheidungshilfen und eine umfangreiche Datengrundlage vor, die für die Entwicklung wissenschaftlich begründeter Leitlinien und die zukünftige Erstellung detaillierter Umweltleitpläne herangezogen werden können. Daher wurden schon frühzeitig nationale und bundesstaatliche brasilianische Institutionen in das Projekt einbezogen, die sich mit Themen des Hafen- und Umweltmanagements befassen. Es entstand eine für beide Seiten sehr wertvolle Zusammenarbeit. Die Behörden unterstützten die Projektarbeiten durch die Bereitstellung von Informationen und Datensätzen, die den Erfolg des Vorhabens wesentlich beförderten. Fortschritt und Ergebnisse des Projektes wurden auf mehreren gemeinsamen Treffen und Workshops mit den Behördenvertretern vorgestellt und diskutiert.

Unter der Federführung des Forschungs- und Technologiezentrums Westküste der Universität Kiel waren auf deutscher Seite folgende Institutionen an dem Vorhaben beteiligt: Technische Universität Darmstadt (TU Darmstadt), Institut für Chemie und Biologie des Meeres der Universität Oldenburg (ICBM), Inros Lackner AG, Bremen, GKSS Forschungszentrum Geesthacht, 4H-Jena GmbH sowie die Bundesanstalt für Wasserbau (BAW), Hamburg. Koordinator und Hauptpartner auf brasilianischer Seite war das Centro de Estudos do Mar (CEM) der Universität von Paraná. Eine dem Verbundprojekt angegliederte Untersuchung der Universität der Bundeswehr in München befasste sich mit dem Aufbau eines Modellierungssystems zur Analyse der Strömungen und Transportprozesse in der Patos Lagune und dem Hafen von Rio Grande. Die Schwerpunktsetzung in dem genannten Vorhaben unterscheidet sich jedoch von derjenigen der vorliegenden Untersuchungen in Paranaguá, so dass eine Darstellung beider Vorhaben in getrennten Schlussberichten als sinnvoll erachtet wurde.

Der nachfolgende Berichtsteil ist aus Gründen der besseren Kommunikation mit den brasilianischen Projektpartnern in englischer Sprache abgefasst. Er gibt eine Übersicht zur generellen Projektstruktur, zu Zielen, Vorgehensweise, ausgewählten Forschungsergebnissen, den hieraus resultierenden Schlussfolgerungen, den Aktivitäten und Ertrag des Verbundvorhabens.

Im Anschluss erfolgt die Darstellung der einzelnen Teilvorhaben gemäß den Gliederungsvorgaben des BMBF und der förmlichen Berichtspflicht.

Dem BMBF sei an dieser Stelle für die Förderung des Vorhabens gedankt. Besonderer Dank gebührt auch dem Projektträger Jülich, Bereich System Erde - MGS in Warnemünde, für die sachkundige und konstruktive Projektbetreuung.

Development of Strategies for the Sustainable Environmental Management of Harbours

Case Study Paranaguá Harbour

1. Introduction

This report summarizes the aims, strategies, main findings and deliverables of the joint-research project entitled "Development of strategies for the sustainable environmental management of Brazilian harbours – Case study Paranaguá Harbour".

The overall aim of the project is the design and assessment of the effectiveness of a state-of-the-art strategy for handling the most relevant issues of environmental sustainability in harbours. Attention is given to water and sediment pollution, siltation, dumping, dredging, hazards and monitoring. The technological advancements in this field to render standardized strategies which can be applied to the assessment of the impacts in harbours worldwide are emphasized.

The project is coordinated by the Research and Technology Centre Westcoast of the University of Kiel on the German side and the Centro de Estudos do Mar of the University of Paraná on the Brazilian side. Funding was provided by the German Ministry of Education and Research (BMBF) and the Brazilian Ministry of Science and Technology (MCT) from 2006 to 2009.

The project relies extensively on close cooperation between several research institutes, private companies and agencies in Germany and Brazil, with a pooling of expertise, efforts and resources. The project team comprises of experts in the fields of engineering, oceanography, chemistry, geology and sedimentology, ecology and meteorology with expertise in experimental and modelling fields.

The investigations have been focussed on the harbour of Paranaguá, which is situated within the Paranaguá Estuarine Complex (PEC) in the South of Brazil. Results of the investigations are summarized below.

2. Background and Synthesis of Results

2.1 Study area

The study area Paranaguá Harbour (fig. 1) was selected since the majority of the issues concerning environmental sustainability are present there. From the logistic viewpoint it can easily be accessed from the Centro de Estudos do Mar in Pontal do Sul, which helped in realising measuring campaigns and monitoring activities. Other arguments for choosing this specific area were related to the availability of suitable measurement data kindly provided by the harbour authorities and of data sets collected during own previous investigations.

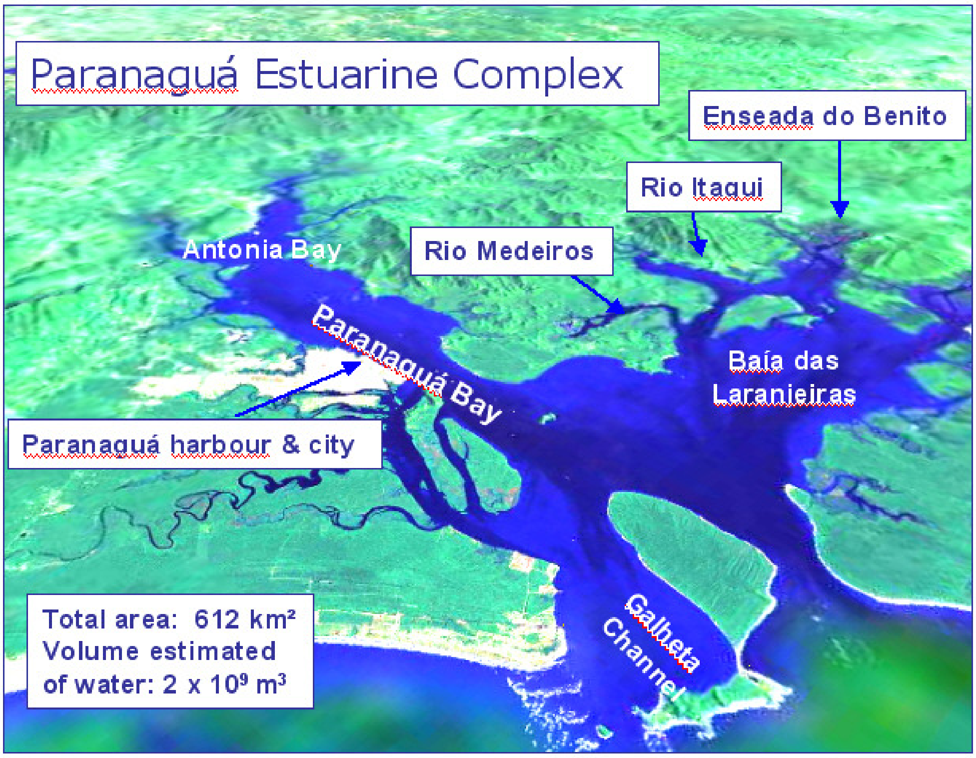

Fig. 1: Paranaguá Estuarine Complex

The harbour of Paranaguá is situated on the coast of the State of Paraná, about 25 km inside the Paranaguá Estuarine Complex (PEC). PEC is part of a large interconnected subtropical estuarine system that also includes the Laranjeiras Bay at the southern coast of the State of São Paulo. The estuarine system connects to the Atlantic Ocean through three channels, via the North, Southeast and South (Galheta Channel).

Paranaguá Harbour is one of the most important harbours in Brazil and the biggest one for grain export. Increasing productivity, as well as new markets in Brazil and in neighbouring countries prompted his activities to expand rapidly. As a result, expansion of the docking area is currently envisaged. This plan implies a major threat to the adjacent protected areas. However, little information is available on the water pollution in the PEC representing a point at issue between city officials and harbour authorities. It is estimated that the untreated sewage discharged into the estuarine system amounts to 48,000 m^3/day with a total organic load of about 14,300 kg. Industrial discharges, losses from cargo handling at the harbour and from oil terminals as well as agrochemical contamination constitute further sources of pollution to the bay. Due to the lack of adequate contingency plans and facilities to handle oil spill accidents the Petrobras oil terminal may also represent a major threat to the environment. The harbour basin, navigation channel and entrance to the PEC are areas of sedimentation and require frequent maintenance dredging to guarantee safe navigational depths. Since the areas around the bay are under nature protection by law, the management of dredged material constitutes a major problem for the port authority.

2.2 Project partners and working packages

The names of the participants involved in this case study are listed in table 1. Table 2 lists the harbour and environmental agencies taking part in the project. Research and development activities have been subdivided into five working groups as shown in table 3 and figure 2: (1) Assessment of the harbour infrastructure and operation, (2) Morphodynamics, siltation, dredging and dumping; (3) Water and sediment quality; (4) Automated monitoring and (5) Data handling and dissemination of information.

Tab. 1: List of participants – Case Study Paranaguá Harbour

Research Centres	
	Centro de Estudos do Mar (CEM), Universidade Federal do Paraná (UFPr) Brazil Prof. Dr. E. Marone
	Research & Technology Centre Westcoast in Büsum (FTZ), University of Kiel (CAU), Germany Prof. Dr. R. Mayerle
	Institute for Chemistry and Biology of the Marine Environment – (ICBM) - Terramare, University of Oldenburg, Germany Prof. Dr. G. Liebezeit
	Technical University of Darmstadt (TU Darmstadt), Germany Prof. Dr. U. Zanke
	Institute for Coastal Research (GKSS) Research Centre, Germany Dr. W. Petersen
	Federal Agency for Hydraulic Engineering (BAW), Germany Dr. R. Lehfeldt
Companies	
	4 H Jena Engineering, Germany Dipl.-Ing. M. Koch
	Inros Lackner AG, Germany Dr. Bergmann
	Engenharia e Consultoria LTDA. Recursos Hidricos e Ambientais, Brazil Dipl.-Ing. L. Cunha

Tab. 2: List of participants - Brazilian agencies involved in the project

Agencies	
	Agencia National de Transportes Aquaviários (ANTAQ)
	Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA)
	Administração dos Portos de Paranaguá e Antonina (APPA)
	Secretaria de Estado de Meio Ambiente e Recursos Hídricos (SEMA/PR)
	Centro de informacoes de Recursos Ambientais e de Hidrometeorologia de Santa Catarina (EPAGRI)

Tab. 3: Case study Paranaguá - working packages and organizations

Working Packages (WP)	**German Organization**	**Brazilian Organization**
WP 1: Assessment of the harbour infrastructure and operation	Inros Lackner FTZ	CEM APPA ANTAQ
WP 2: Morphodynamics, siltation, dredging, dumping	FTZ TU Darmstadt ICBM-Terramare	CEM APPA
WP 3: Water and sediment quality	FTZ ICBM-Terramare Poremba Consulting Inros Lackner	CEM APPA
WP 4: Automated monitoring for the detection of short-term events	GKSS 4H Jena FTZ	CEM APPA EPAGRI
WP 5: Data and information management	BAW Data supply from all partners	CEM Data supply from all partners

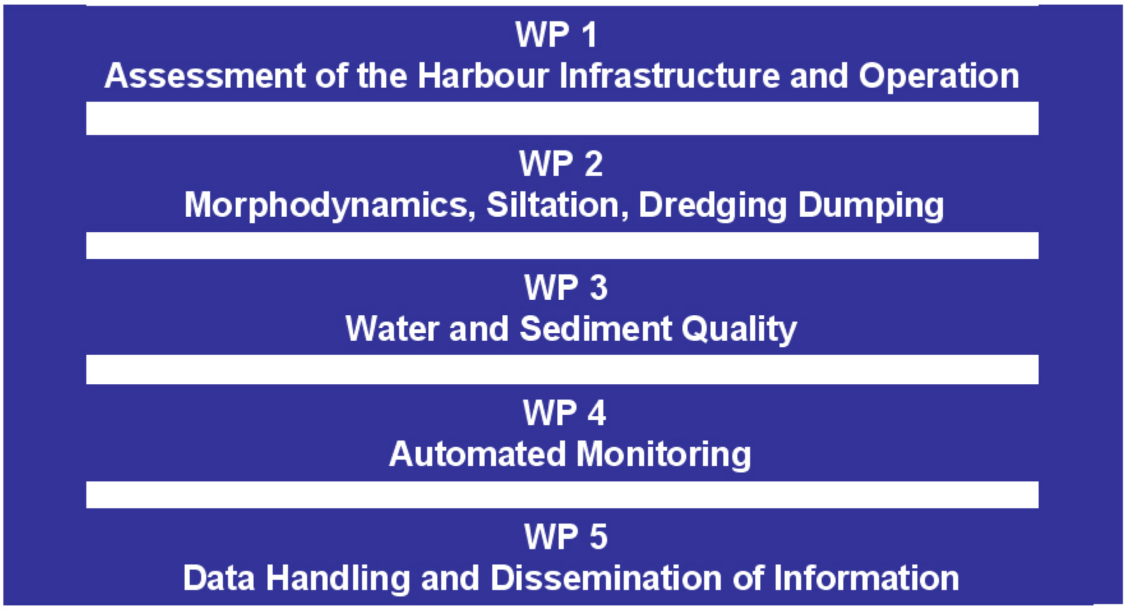

Fig. 2: Case study Paranaguá - Working packages

2.3 Proposed strategy

On the basis of the results achieved a generalized strategy to handle the various issues of environmental sustainability in harbours was proposed. Figure 3 shows the relevant fields and issues of concern. Attention was given primarily to the harbour infrastructure and operation, conditions along the navigation channel and conflicts between city officials and harbour authorities. In this study issues related to water and sediment pollution, siltation, effects of dredging and dumping as well as accidental hazards and operational monitoring were emphasised.

Fig. 3: Issues covered by the strategy

A description of the proposed strategy, which is applicable to a variety of harbour lay-outs and environmental settings, follows. Figure 4 displays a structural overview of the proposed strategy.

Step 1 - Environmental auditing: In the first step the harbour infrastructure, operation as well as the environmental settings taking into account the applicable environmental legislation are assessed. Environmental risks and deficits are identified and priorities for the harbour in question are established.

Step 2 - Development of the Decision System Systems: In a second step the available data are analysed and the gaps of information with emphasis on data required for the development of process based models are identified. Specially designed field measurements for the calibration and validation of the modeling system as well as for the supply of data on water and sediment pollution are conducted. Process based models for simulation of flow, waves, sediment transport, water quality and morphodynamics are developed. Emphasis is given to the estimation of the predictive capabilities of the models using field measurements. Finally the Decision Support Systems (DSS) for assisting the decision making process with respect to the main issues of environmental sustainability in harbour operation and management are set-up.

Step 3 - Application of the system and diagnosis: In the third step the DSS is applied to evaluate the deficits related to environmental sustainability. In this step the effectiveness of alternatives for mitigation of pollution are checked, alternatives to reduce siltation are identified, the effects of different options in dredging, dumping and of harbour expansions are investigated and monitoring strategies are defined.

Step 4 - Recommendations for the Environmental Master Plan: Finally, on the basis of the results obtained, diagnostics with respect to an optimized harbour infrastructure and operation concerning the most relevant environmental issues are made.

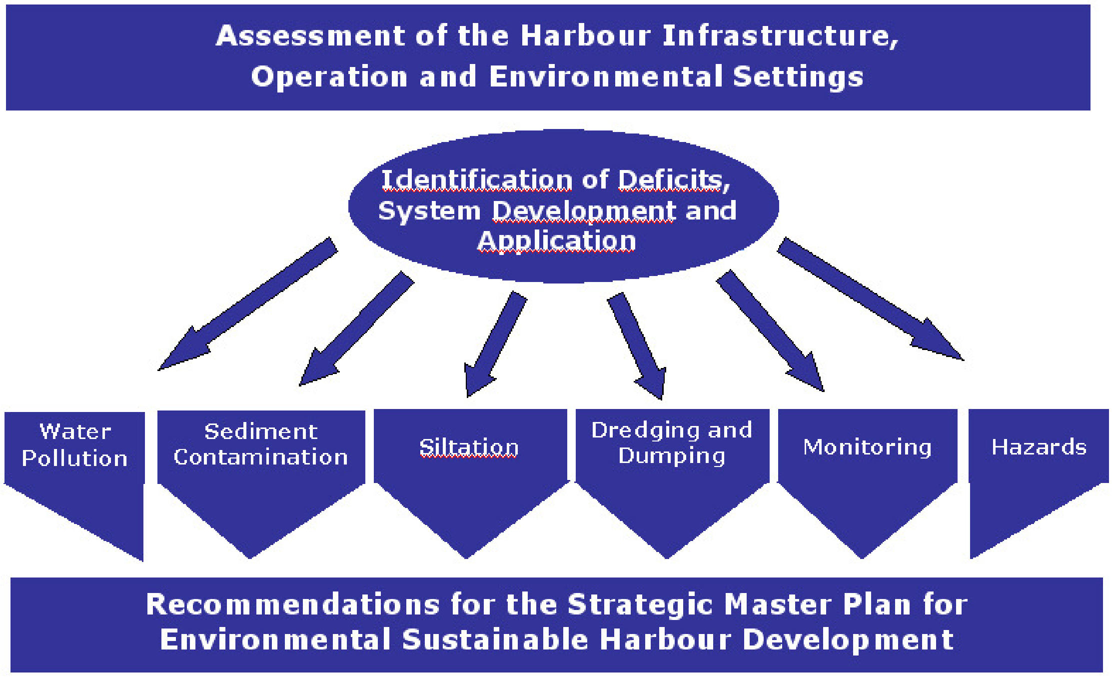

Fig. 4: Structural overview of the proposed strategy

2.4 Effectiveness of strategies

In order to prove the effectiveness of the proposed strategy, results from its application to the Paranaguá Harbour are summarised hereafter.

Step 1: Environmental auditing for the Paranaguá Harbour: Initially an environmental auditing was conducted. The existing port conditions, including infrastructure, port operations, management, national and local legal regulatory framework with respect to the harbour organization and the environmental settings were analysed in detail. The potential sources of pollutants, such as cargo handling at the quay, cargo spillage in port and access roads, cargo losses during road transportation, sewage systems and storm drainage were identified. The main deficits and weaknesses concerning the harbour infrastructure and operation were identified. The existing Master Plan was found to be outdated; no regular maintenance dredging has been going on and as a result the port was found to be congested. Due to the outdated (open) loading equipment there is pollution from cargo handling, mostly from bulk cargo such as soy products and fertilizers. There are risks of accidents due to improper storage. Also segregation of conventional and ballast water reception facilities are missing. A conflict between the harbour authorities and the city officials concerns the water quality. There is no doubt that the city sewage, the harbour operation and river discharge contribute to the pollution in the PEC. However, the relative importance of these sources of pollution is unclear at this step of the strategy, and there are still some uncertainties about the exact location of some sources of pollution.

Step 2: Development of the Decision Support System for the PEC: Existing information and data sets from local authorities and from previous studies were assessed for their relevance and the gaps of data were identified. Intensive field measurements specially designed for the development of the process based models were carried out in the summer and winter periods covering both neap and spring tidal cycles. These included measurements of salinity and temperature distribution, current velocities, suspended sediment concentration, nutrient concentration and bathymetries at several locations covering several cross sections and areas along the PEC. Continuous information on water level variation was provided by a set of tidal gauges installed at different locations in the bay. In order to provide continuous data of physico-chemical parameters at the outlet of the bay, an *in situ* automated flow-through sensor system called "FerryBox" was installed near Pontal. Figure 5 gives an overview of the locations and types of field measurements carried out in the PEC and close to the harbour. Due to the lack of data on the fresh water inflow, the stream flow and rainfall volumes between 1976 and 2007 were estimated. Hydrographic profiles taking from aboard a vessel implemented with a mobile FerryBox were used to adjust the fresh water input, in particular in the areas along the PEC in which there was lack of gauge stations. Furthermore a study to produce gridded wind field hourly data for the PEC over the 2002-2008 period was undertaken. The wind data were used as input for the hydrodynamic models in order to simulate the wind induced currents and waves associated with the different tidal conditions. Wave and current data from a S4-buoy from the Centre of Marine Studies (CEM) were used for the development of the morphodynamic model for the coastal area at the entrance to the bay. Based on the results of bottom sampling covering the entire PEC the sediment distribution was mapped in order improve the accuracies of the sediment transport predictions. To enable simulations with the water quality model, a monthly monitoring of the dissolved inorganic nutrient load from the main river mouths discharging into the bay and from the city sewage was carried out. Diffuse nutrient input to the bay from cargo losses at the harbour was estimated on the basis of monthly throughput data of fertilizer and soy products obtained from the harbour authorities and degradation experiments with soy flour. The data was used for the development of the models, the definition of model accuracies and for the elaboration of the scenarios.

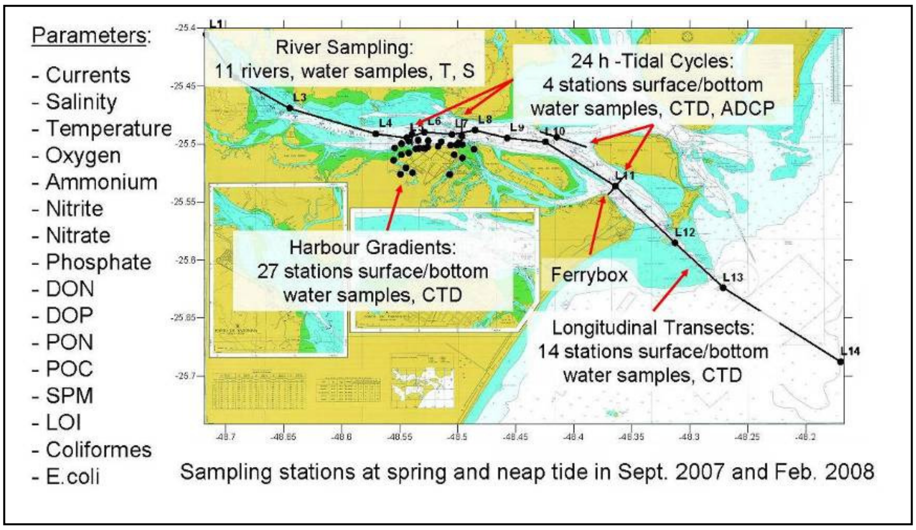

Fig. 5: Overview of the field measurements for water analysis

In addition to the measurements used for model development a thorough investigation of contaminant levels in surface sediments of the PEC, the adjacent coastal area and the main rivers was carried out in order to assess the potential anthropogenic impact of dumping and discharges from the harbour (fig. 6).

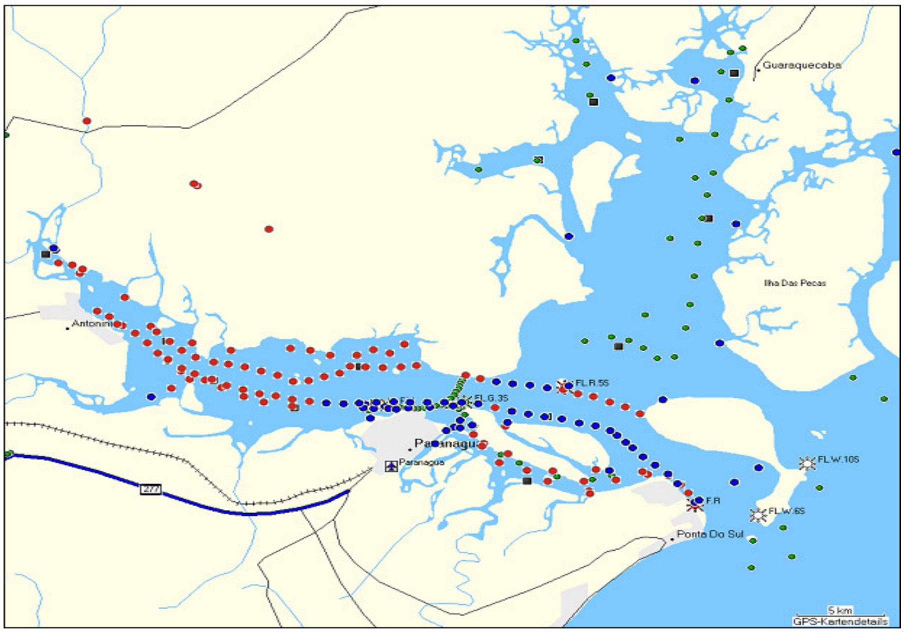

Fig. 6: Location of sediment sampling (red and blue dots = 2007; green dots and black squares = 2008)

Contents of heavy metals (Cu, Pb, Zn, Hg), polycyclic aromatic hydrocarbons, total organic carbon and organochlorine compounds were determined. Besides, tissues from selected biota were analyzed for organochlorine compounds (DDT, DDE, DDD, PCBs). For the evaluation of impacts of waste water input on hygienic water quality, the discharge and distribution of total coliform bacteria and *E. coli* was assessed around the harbour and the city of Paranaguá and in the central part of the PEC.

Parallel to the field measurements, the modelling system for the PEC for the simulation of flow, waves, sediment transport, water quality and morphological developments on the short and medium terms was developed. This procedure implied the model set-up, sensitivity studies, model calibration and model validation. Figure 7 shows the model grid adapted to the PEC. To be able to describe the flow and transport processes in the harbour area with good accuracy, a fine grid spacing of about 20 m was implemented. To assess the significance of density stratification of the water both two-dimensional depth-integrated (2DH) and three dimensional (3D) models have been developed. Bed roughness maps were prepared following a procedure, which accounts for the bed dimensions. In figure 8 an overview of the DSS applied to the PEC is given. Results of the sediment transport model simulations using the DSS for handling dredging and dumping are shown in figure 9. This model predicts the amount of sediment in movement as bed load and suspension load. It is used to investigate the effect of dumping and to optimize the dumping locations.

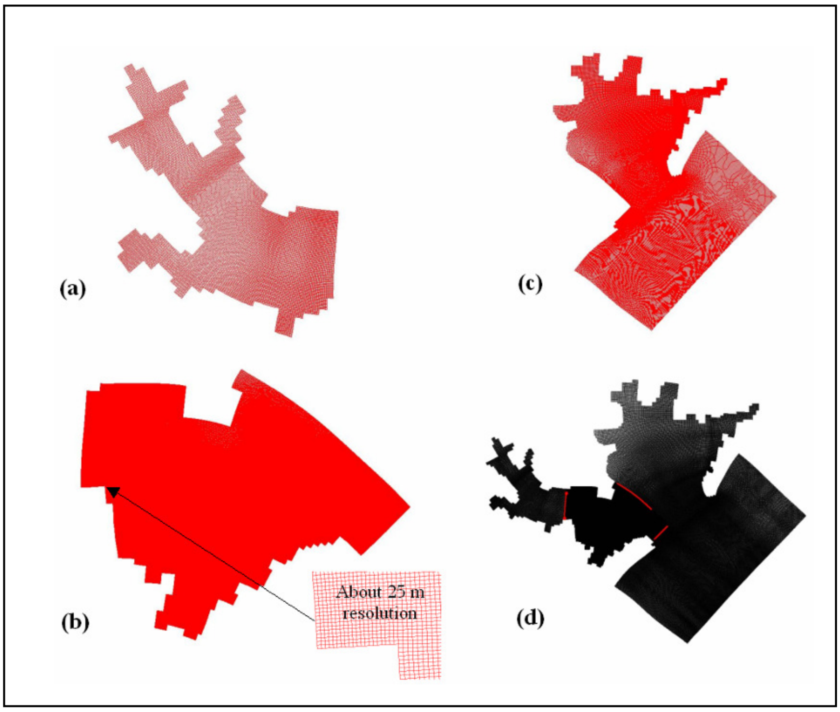

Fig. 7: Grid of the process based models of the PEC

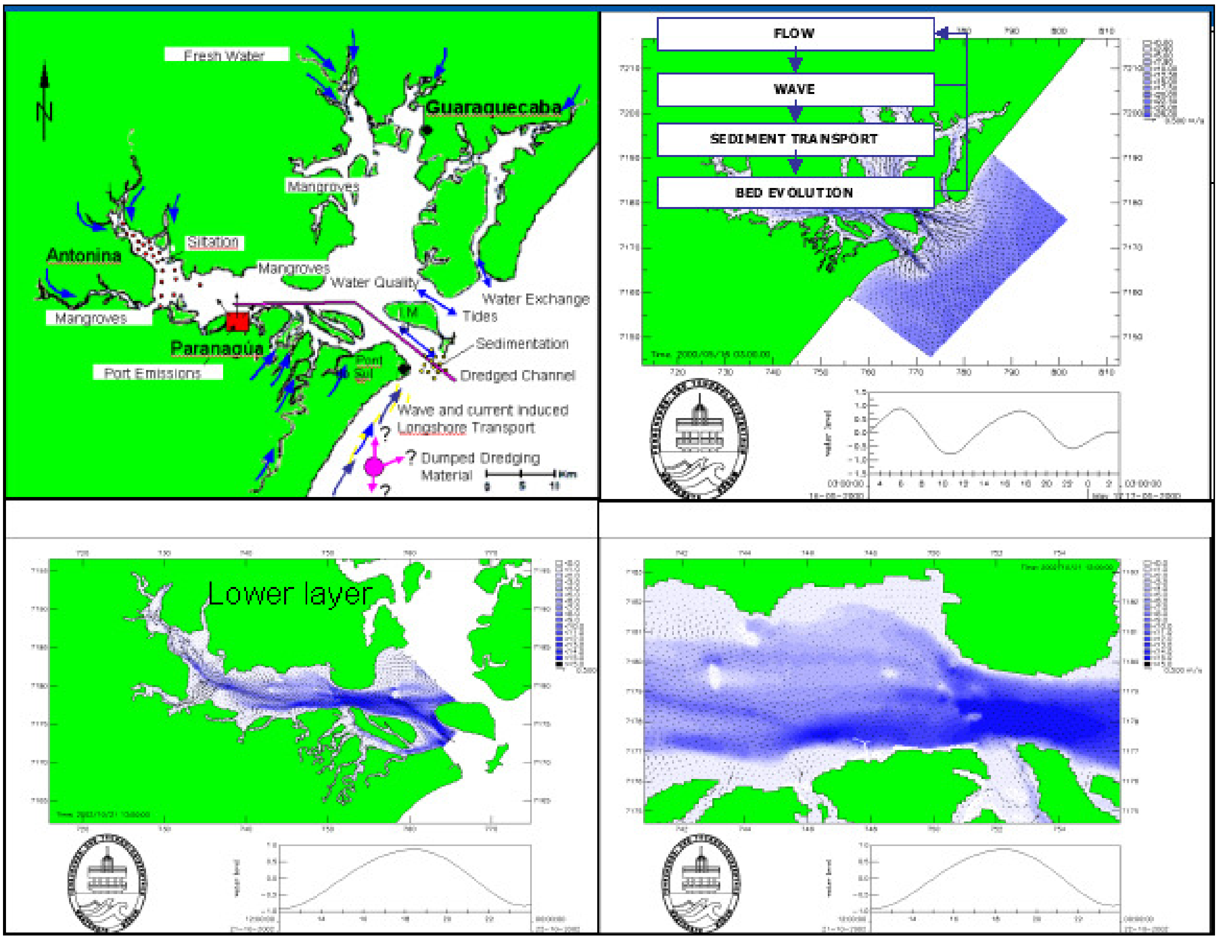

Fig. 8: DSS for Paranaguá Harbour

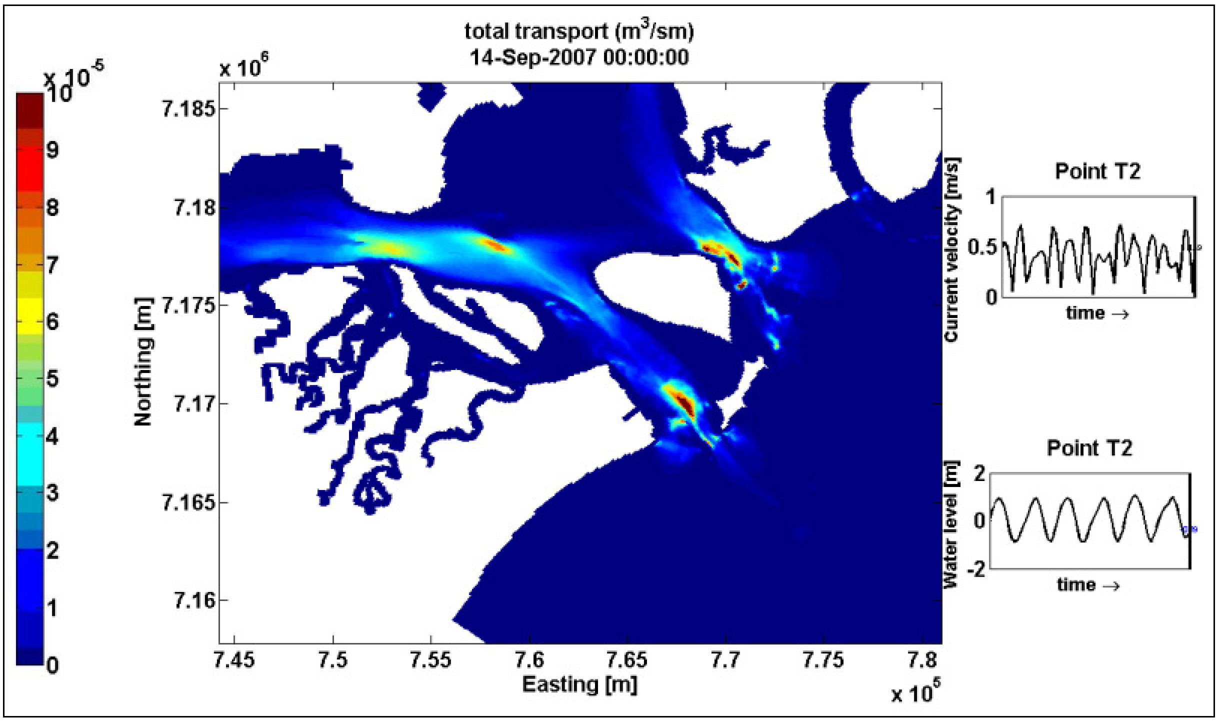

Fig. 9: Sediment Transport Model

As the modelling results play a major role in the decision making process it is important to estimate the models accuracies for predicting water levels, current velocities, water quality parameters and sediment concentration. As an example, figure 10 shows a comparison of measured and modelled current velocities at the Galheta Channel. The existing quality standards for assessing the performance of the models taking into account the accuracy of the measuring devices under field conditions were adopted. In general, the predictive capability according to the standards usually adopted ranges between good and excellent.

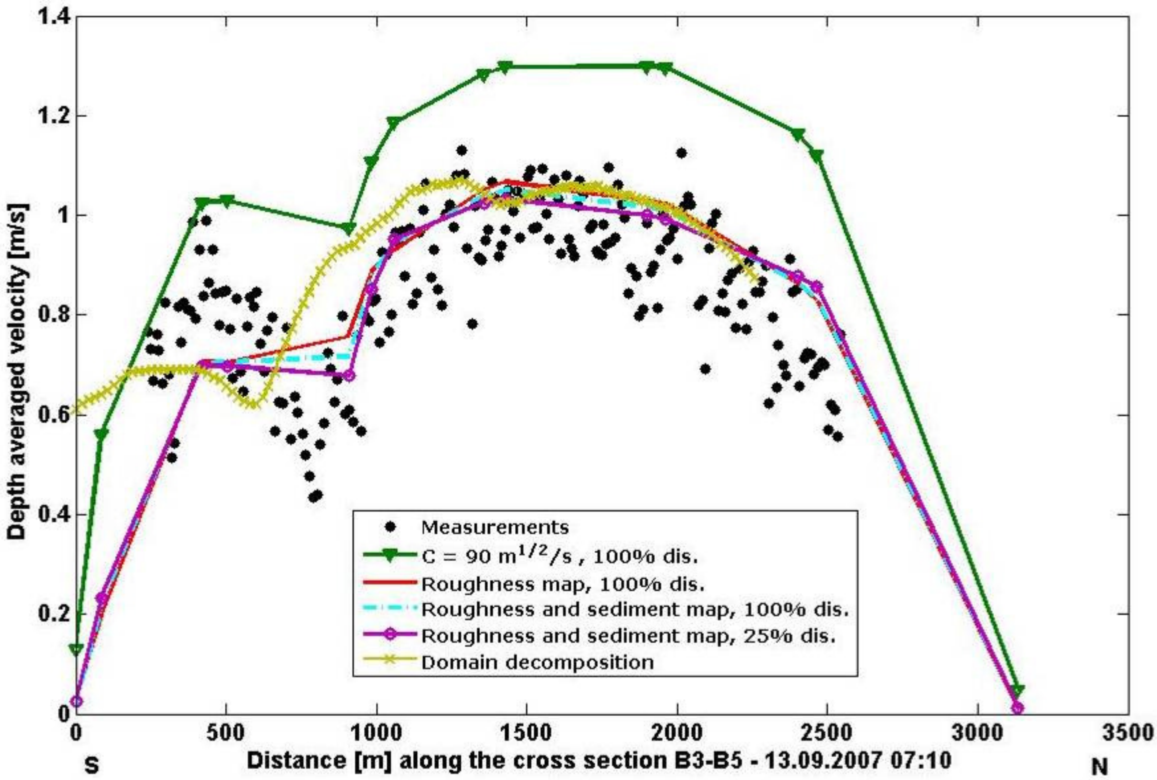

Fig. 10: Comparison of measured and modelled current velocities

<u>Step 3: Application of the DSS and diagnosis:</u> In the third step the DSSs are applied for investigating the various issues related to the environmental sustainability of the Paranaguá Harbour. For the sake of compactness of this report, only a short overview of the main investigations and results obtained is given below. For further details the reader is referred to the final reports of the individual subprojects and the publications.

(1) Water pollution: Figures 11 and 12 show respectively the measured dissolved inorganic nutrient and fecal bacteria discharge from drainage channels at the harbour and the city, and the estimated losses of nutrients due to cargo handling. Simulations covering different tidal conditions for the different sources of inorganic nutrient pollution were carried out.

Figures 13 and 14 show results of simulations respectively in terms of ammonium and phosphate concentrations for the following scenarios: a) no sources of pollution from the city and harbour; b) only harbour losses, c) only losses from the city sewer system and d) all sources of pollution. Considering ammonium the city effluents shape up as the main pollution source of the area in question. Regarding phosphorus the harbour turned out to be the main pollutant. Further simulations were done in order to check the effectiveness of a planned decentralized waste water treatment system for retaining contamination off the coastal areas close to Paranaguá. It can be traced from the simulation results shown in figure 15 that the sewer system in operation would cause a significant reduction in the ammonium levels near the terminals.

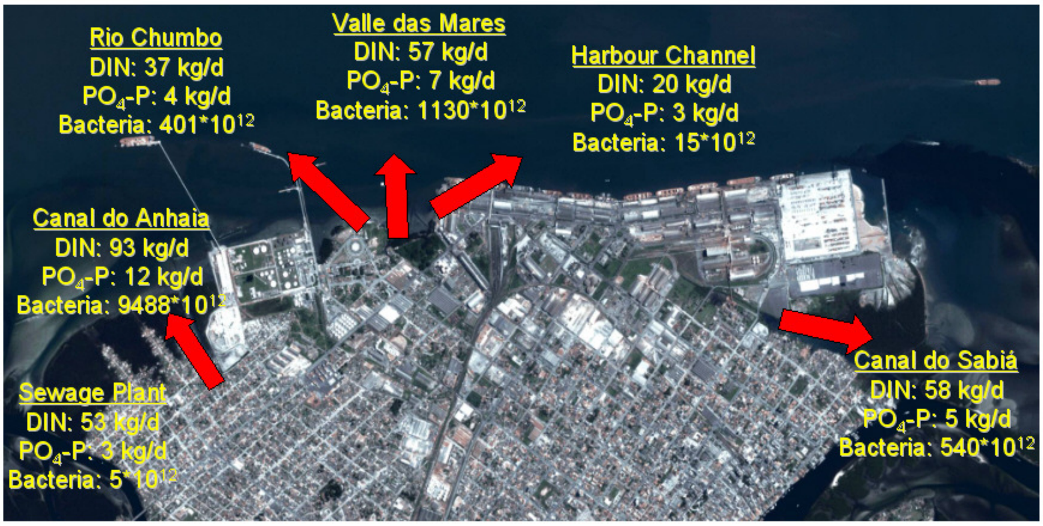

Fig 11: Pollutant loads at the main locations of sewage discharge

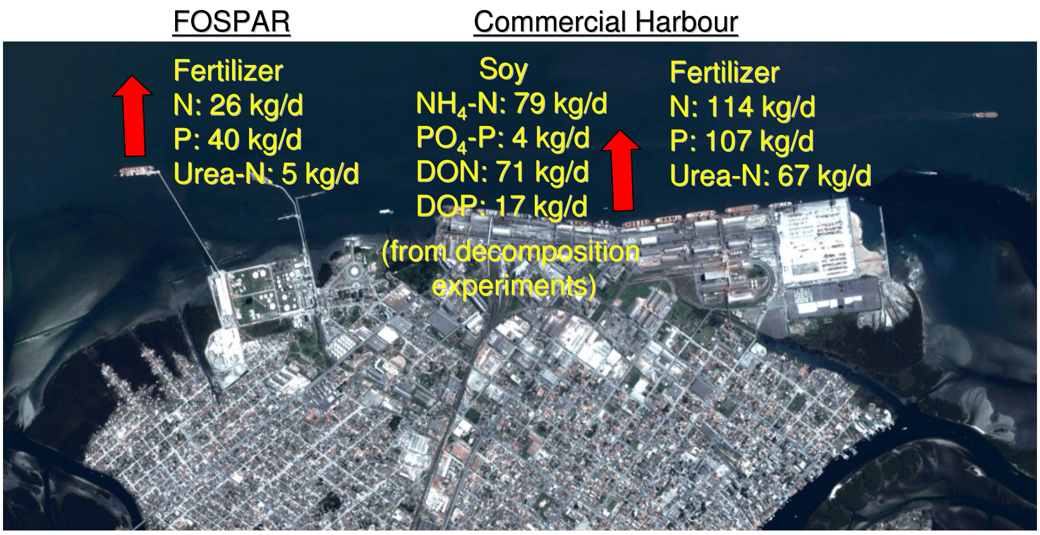

Fig. 12: Estimations of losses due to cargo handling

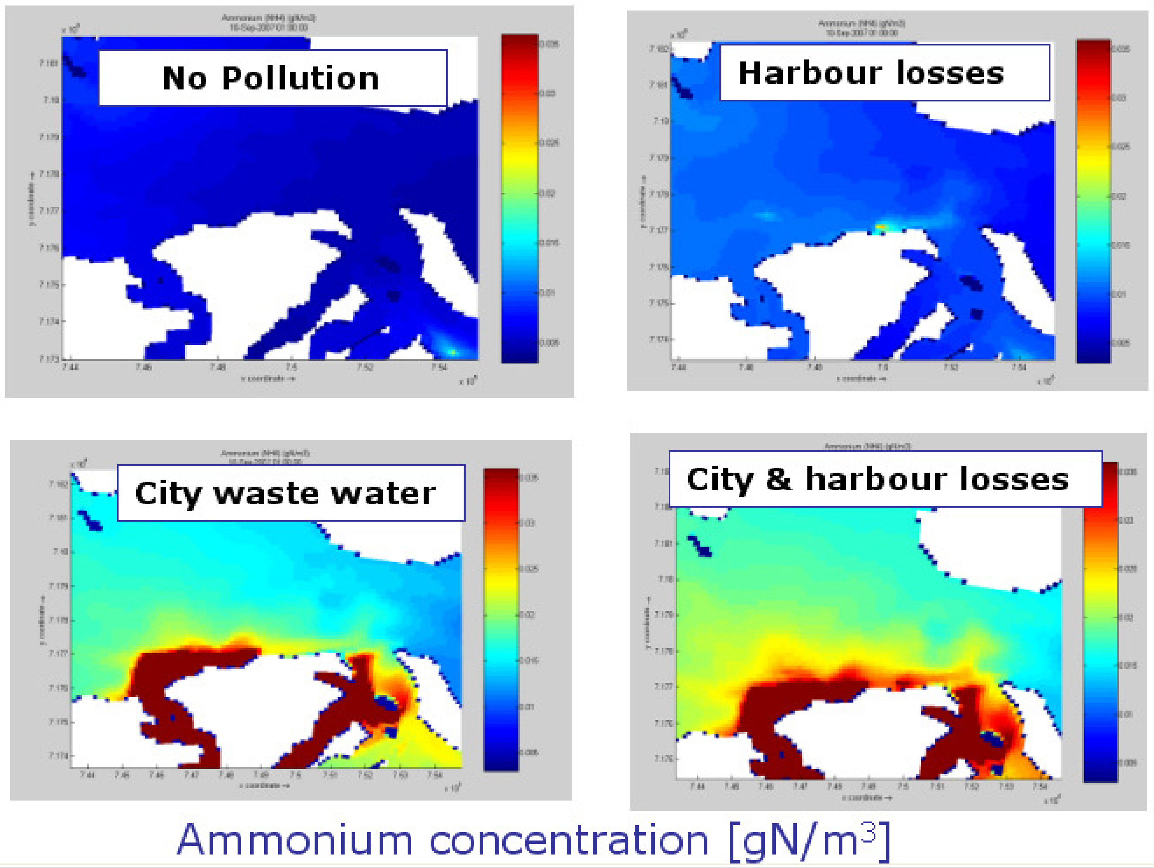

Fig. 13: Simulated spatial distribution of ammonium for different scenarios

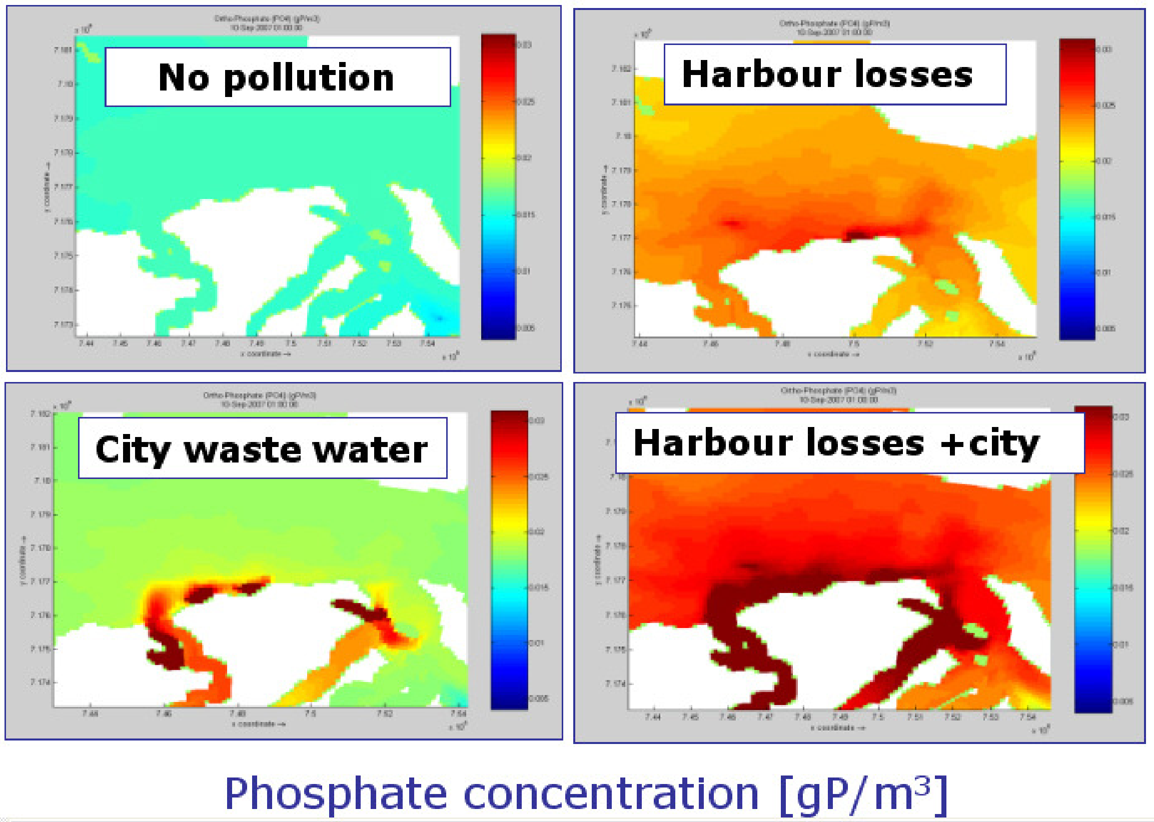

Fig. 14: Simulated spatial distribution of phosphate for different scenarios

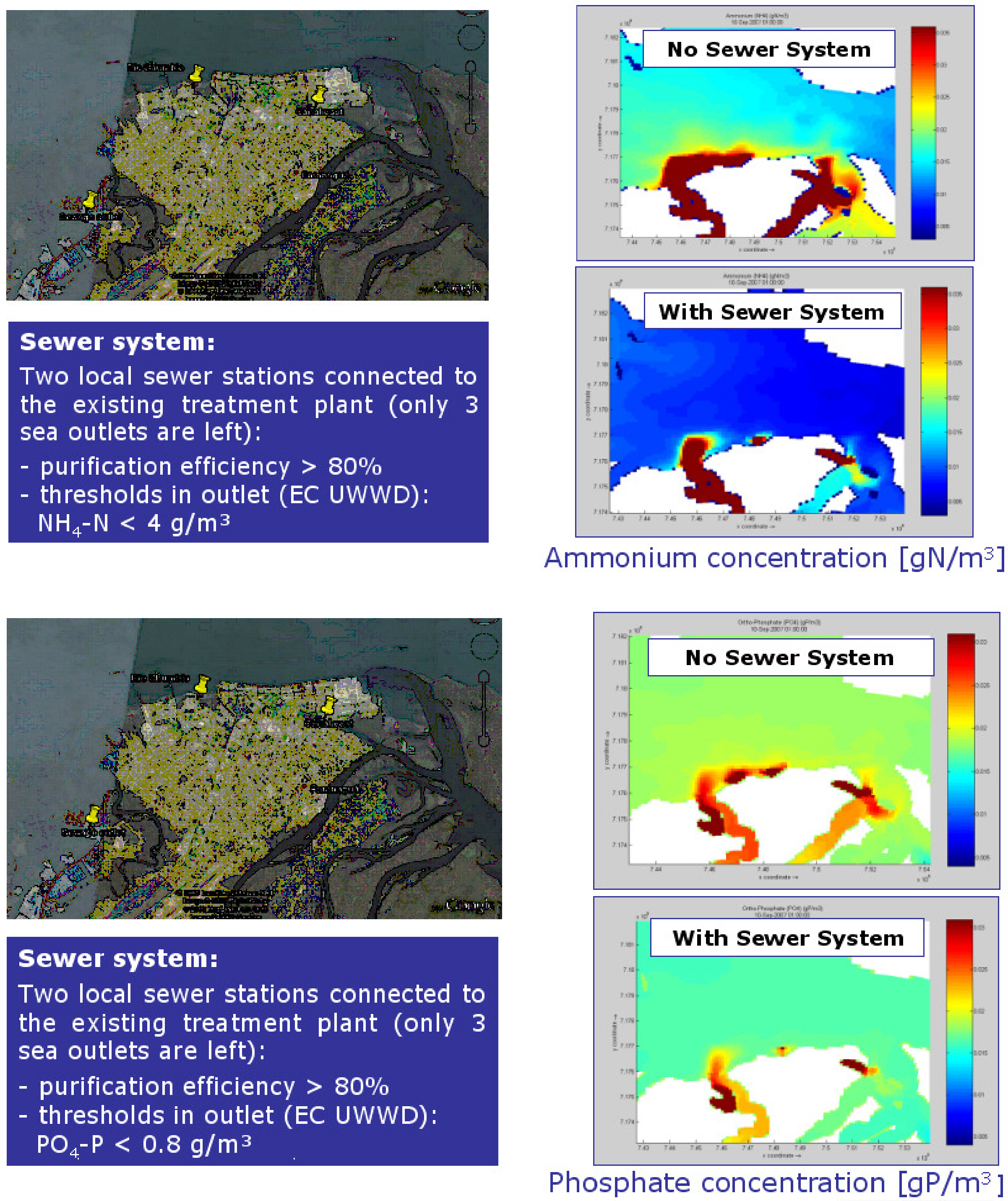

Fig. 15: Effectiveness of the proposed sewer system

(2) Sediment quality: The investigation of sediment quality focused on contaminants assumed to have a critical potential of pollution in the study area. Results indicate that the harbour activities do not impact considerably the contaminant levels at the sediment surface. Concentrations of the investigated heavy metal species, polycyclic aromatic hydrocarbons and polychlorinated biphenyls are with a few exceptions far below critical thresholds as defined by the Brazilian CONAMA regulations. However, organo-tin biocides from antifoulings associated

with a high degree of imposex in gastropods have been detected in the vicinity of the harbour. Data available so far on other antifouling biocides such as Irgarol and Diuron indicate that these compounds are present, albeit with low contents. Harbour activities are evident, too, when the organic matter (OM) content of the sediments is considered. High OM contents which do not fit the general < 63 μm-fraction/organic carbon relation were observed in the harbour area and the turbidity maximum zone NE of the harbour (fig. 16).

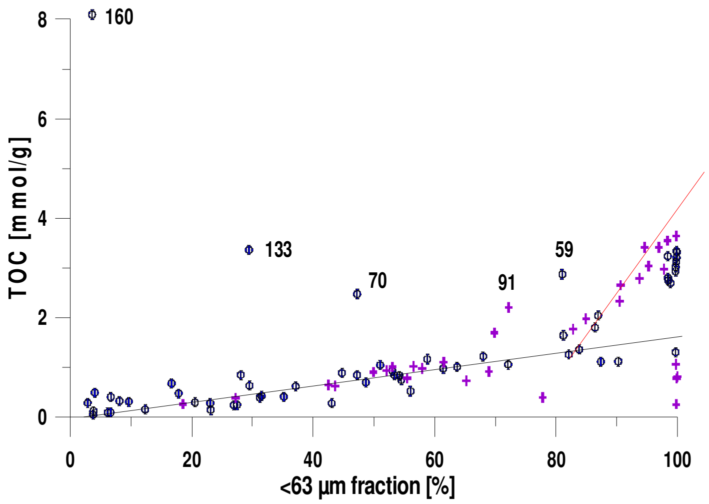

Fig. 16: Relation between the fine fraction and organic carbon content (dots = 2007, crosses = 2008; samples deviating from the black line are located in the harbour area or the turbidity maximum zone)

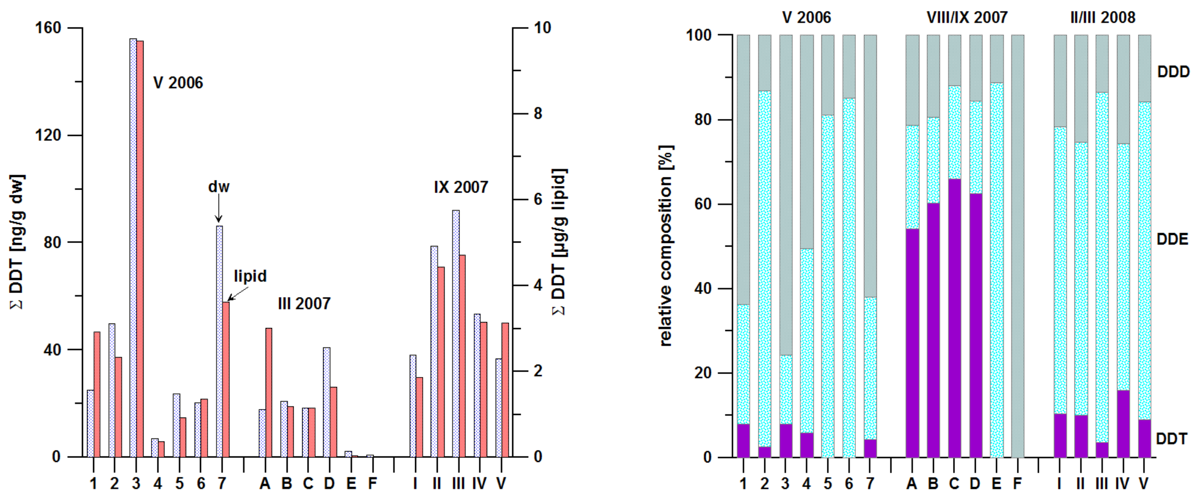

Fig. 17: Σ DDT in mussels, oysters and other biota (left) and composition of the DDT pool (right)

These were associated with high organic phosphorus contents. At the same time pronounced anoxia was observed at the sediment surface layers in front of the harbour bulk terminals. These findings suggest significant losses from soy and grain handling. On the other hand, pollution from urban sources has become evident from the analysis of biotic tissue. Here, *de novo* input of DDT could be detected in early 2007 (fig. 17). Previously and later in the year degradation products (DDE and DDD) dominated. Hotspots were located in the vicinity of Paranaguá City. Finally, there are indications that inputs from untreated wastewater affect the malformation rate of macrozoobenthic organisms (polychaetes) in front of the city and harbour of Paranaguá.

(3) Siltation: Another environmental issue of particular concern to the Paranaguá harbour is the siltation at the mouth of the estuary. About 2 million cubic meters of sediments have to be dredged annually close to the mouth, in the harbour basin and in the navigation channel to maintain navigational depths. Since the areas around PEC are protected by environmental law, the disposal of the dredged material is an issue of major concern to the port authority and the environmental agencies. Therefore, an investigation of the causes of siltation and the alternatives for their reduction was carried out in the framework of the project. A DSS comprising of flow, wave, sediment transport and morphodynamic models was set up and applied to the coastal areas and entrance to the PEC. Amongst others a training structure along the outer navigation channel was simulated in order to check the effectiveness of such a structure to minimize sedimentation in the channel.

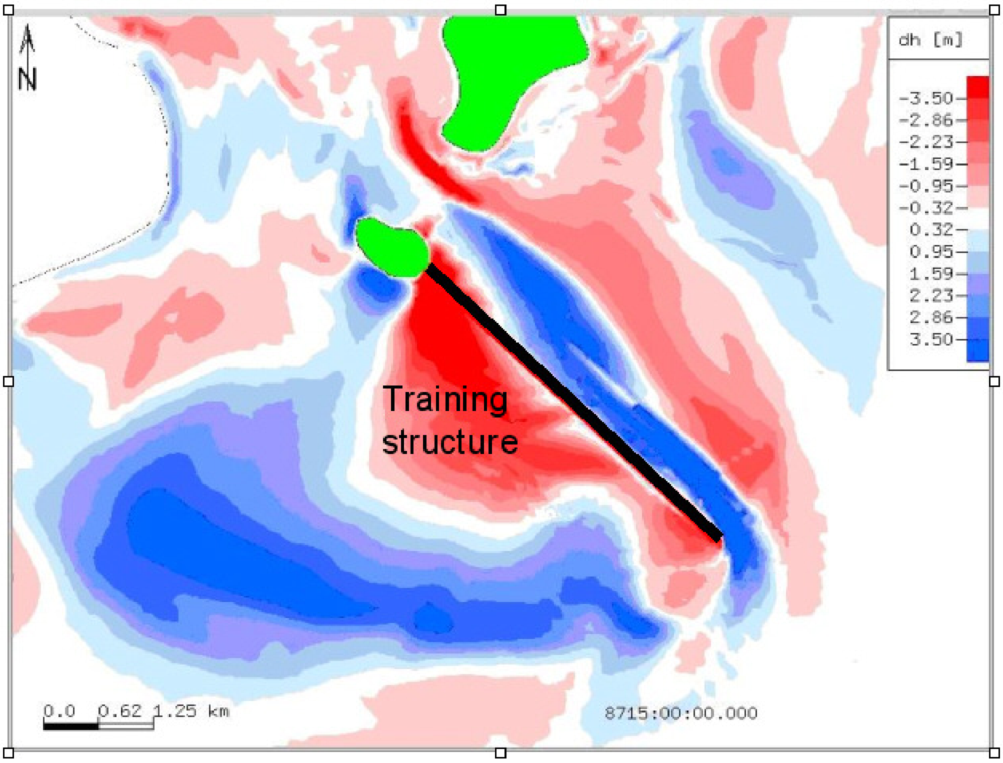

Fig. 18: Investigation of the effect of a training structure on sedimentation in the outer navigation channel: Depth differences with and without training wall

Figure 18 shows the changes in the bathymetry as a result of a training wall of a heigth of 1.5 m above sea level. The structure considerably reduces the sedimentation in the channel. Further simulations were carried out for analysing different lay-outs of the training structures. Conclusions concerning the best alternatives for reducing siltation were drawn.

(4) Dredging and dumping: Investigations to assess the effect of the dredging (mouth, harbour basin and navigation channel) on water levels, current velocities and salinities were carried out. This was done by comparing the results of the simulations with and without dredging. Due to the large dimensions of the PEC the effects on the water levels, current velocities and salinities were found to be negligible. Investigations leading to the optimization of the dumping locations were also performed using the DSS (fig. 19). In this case the dispersion of the dumped material from a site near the harbour of Paranaguá was studied. The most adequate periods for carrying out the dumping activities were then identified in terms of the simulated sediment concentrations. Simulations to compare different dumping grounds in order to find sites from which the dumped material is not transported back to the navigation channel were also conducted for the area in front of the bay's entrance (fig. 20).

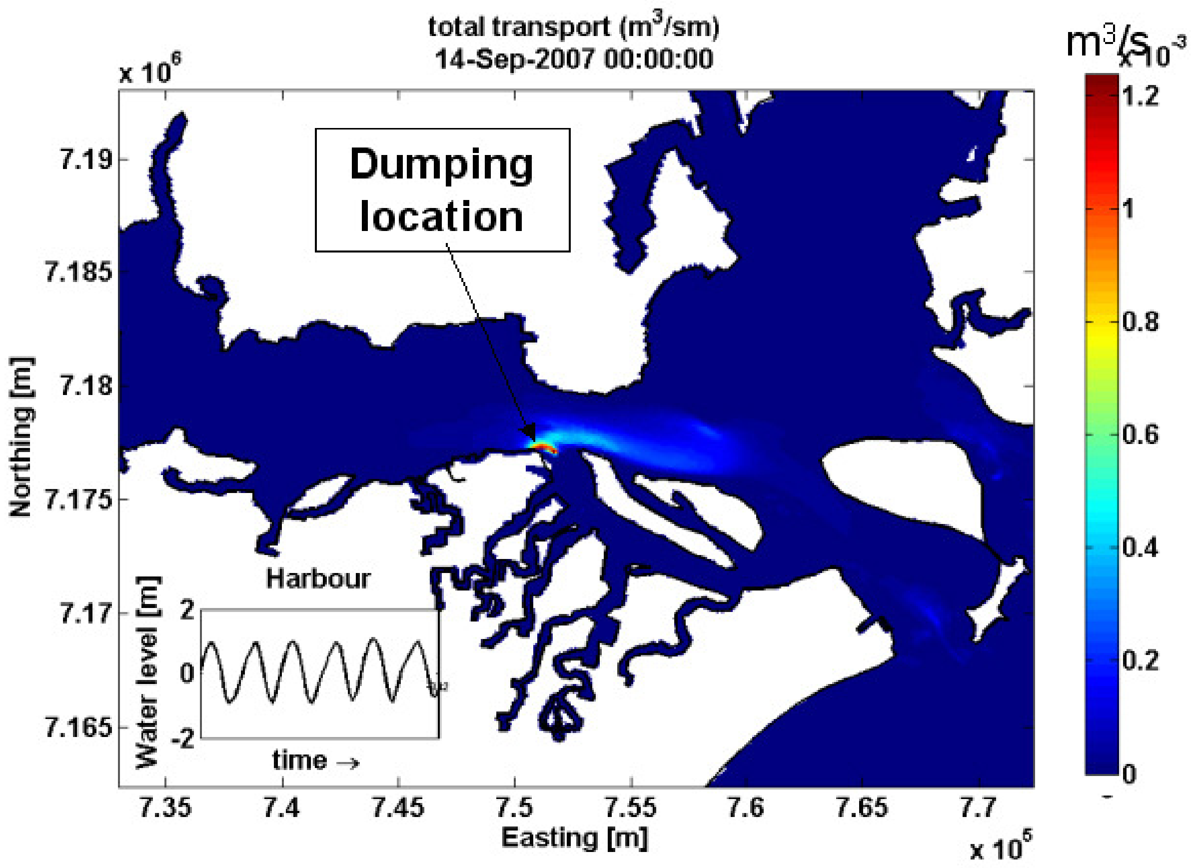

Fig. 19: DSS for dredging and dumping

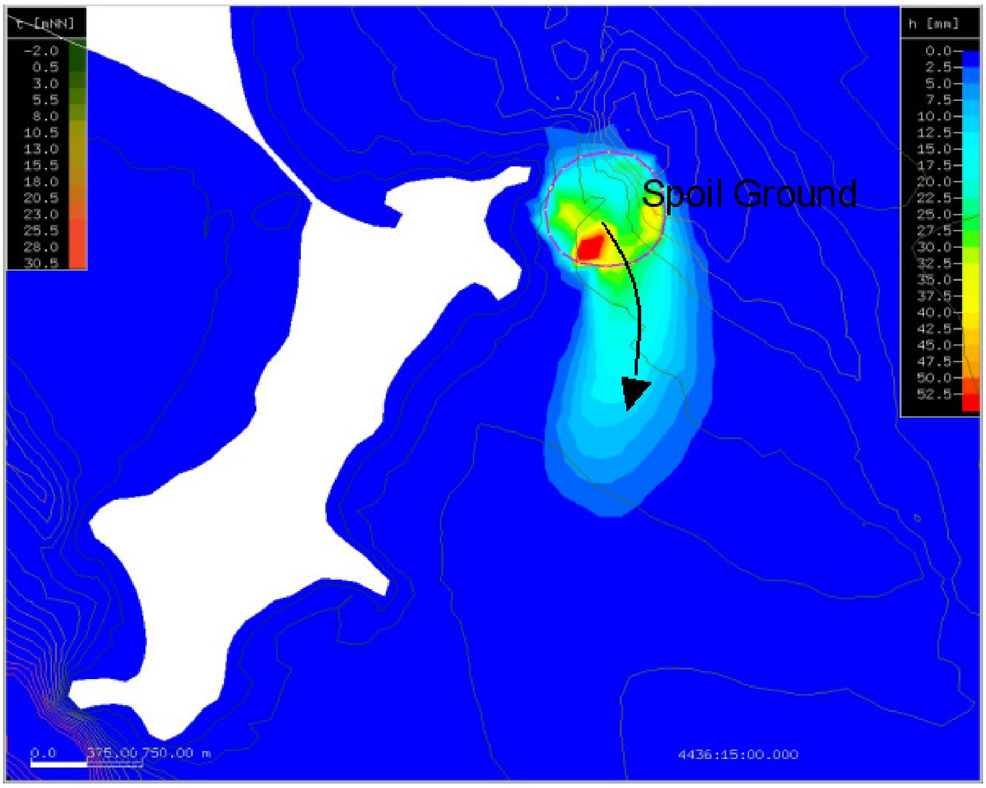

Fig. 20: Investigations of the dumping near the navigation channel

(5) Monitoring: The effectiveness of the application of the automated *in situ* measuring device "FerryBox" (fig. 21) for carrying out on-line monitoring of several physical, chemical and biological parameters was tested. The stationary as well as the mobile system proved to be useful and time saving considering the monitoring of basic water quality parameters in high resolution. Especially the effect of sporadic short-term and extreme events such as storms, anthropogenic impacts etc. on water characteristics (salinity, temperature, pH, dissolved oxygen, turbidity, chlorophyll, colored dissolved organic matter) can be traced in real-time with telemetric data transmission to the internet. Telemetry also allowed for remote control of the system. Figures 22 and 23 respectively display the location of the stationary FerryBox system at the entrance of the bay as well as FerryBox time series measurements of chlorophyll and water level covering two typical periods in the rainy and dry season. Additional investigations aimed at identifying the most adequate Environmental Pressure Indicators and their location. The selection of the indicators was achieved by way of investigating the changes in the physico-chemical parameters using the DSS. Recommendations for the establishment of a monitoring strategy complying with the governmental regulation have been provided.

Fig. 21: FerryBox System

Fig. 22: Location of the FerryBox System

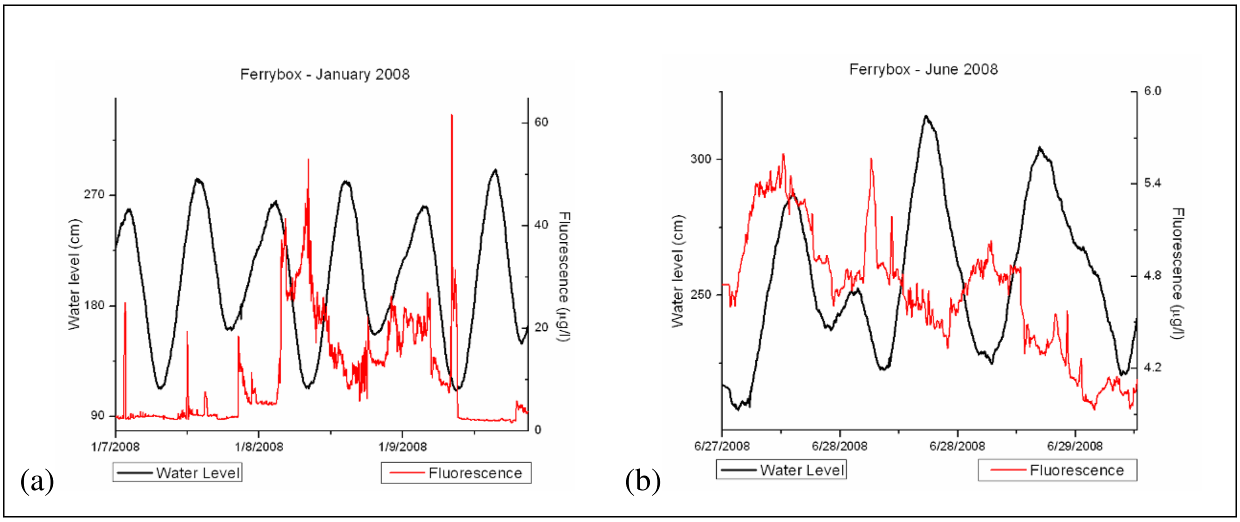

Fig. 23: Stationary FerryBox measurements of chlorophyll and water level:

(a) rainy period exemplified by observations during January 2008 and

(b) dry period represented by information from June 2008

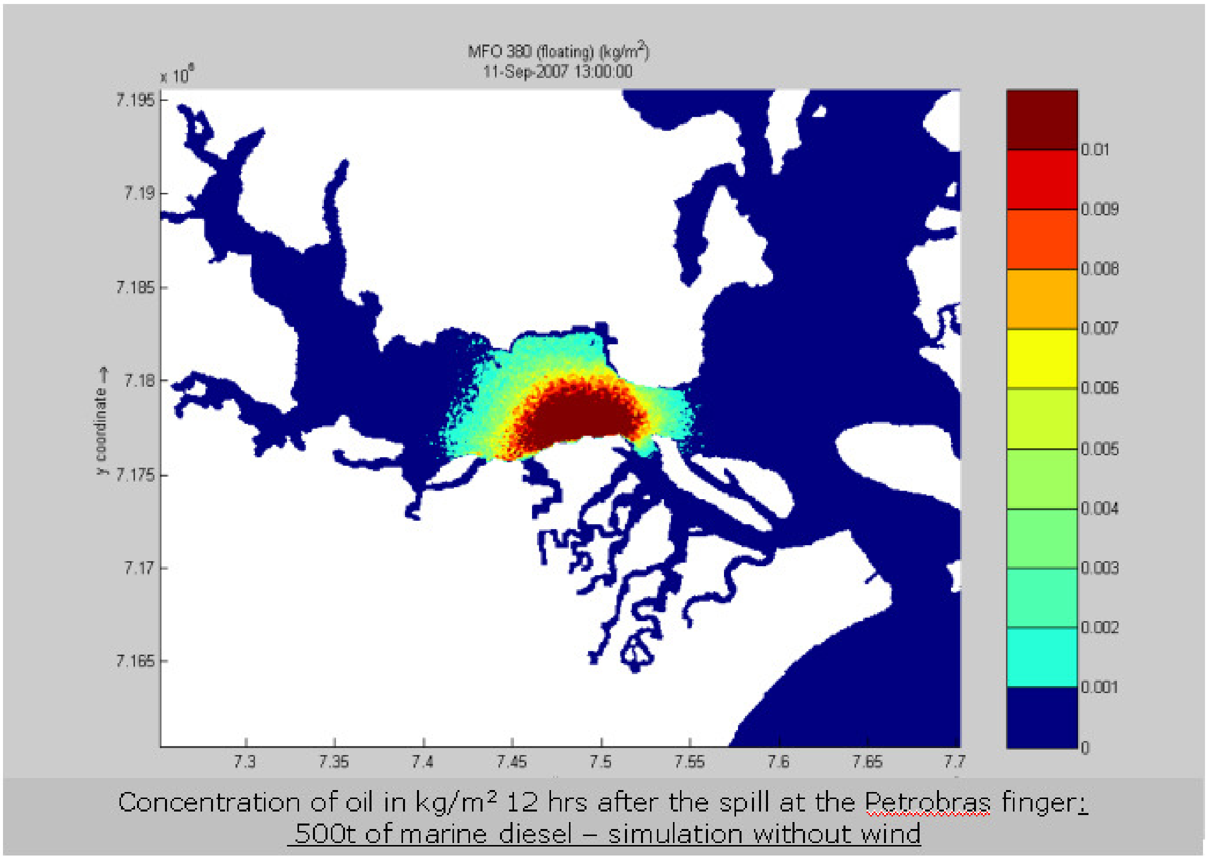

Fig. 24: Results of the application of the DSS for the simulation of oil spills

(6) Oil spills: As already mentioned the Petrobras oil terminal may be a major threat to the environment in case of accidental oil spills. After the recent accidents in the bay the lack of adequate contingency planning to manage oil spill accidents became evident. In such cases

the time for taking adequate counter measures is short and requires fast and effective decision support. Therefore a DSS for the simulation of the dispersion and fate of a spill was set-up. Investigations were carried out for a wide range of conditions and oil types. They also include the most recent accident of the Vessel Vicuna. Results of the simulation of an oil spill at the Petrobras Pier in the Paranaguá Harbour are shown in figure 24. Bearing in mind that there will be not enough time to carry out model simulations in the course of such an accident, a large number of scenarios covering the whole tidal ranges, wind conditions (magnitude and directions) and types of oil has to be simulated beforehand. Results of the different simulation runs should be stored in a database to be ready for use for the identification of suitable counter measures in case of any hazard. In conjunction with on-line measurements of the tidal and wind conditions taking into account rough estimates of the soiled volumes this database will enable a quick assessment of the fate of the oil thus supporting the contingency plans.

Step 4: Recommendations for the Environmental Master Plan: Finally on the basis of the results and diagnosis obtained, recommendations for the development of an Environmental Master Plan of the Paranaguá Harbour are given. The recommendations for the Paranaguá Harbour concerning the various issues are as follows:

(1) Due to the lack of regular maintenance dredging along the Galheta Channel, the port was found to be congested. To resolve this problem, a regular maintenance dredging should be carried out following the results of the simulations with the DSS for the mouth of the PEC. A feasibility study to verify the cost-effectiveness of the tested training structures at the Galheta Channel should be carried out. Moreover it is recommended to investigate the possibility of navigation along the Southeast channel;
(2) Additional dumping locations within and outside the PEC for environmental sustainability should be identified using the DSS for sediment transport. It is recommended to define favourable conditions in terms of tidal ranges and winds for conducting dumping activities;
(3) The loading equipment for bulk cargo (soy, grain, fertilizer) should be updated to diminish pollution from cargo handling and to improve the oxygen conditions in the harbour sediments. A major source of contaminants, however, is the city of Paranaguá itself rather than the harbour. In order to minimize water and sediment pollution it is recommended to implement the decentralized waste water treatment system and to combat in a more stringent manner the illegal use of DDT;

(4) The environmental management structure of the harbour was found to be outdated and requires significant improvements concerning its budget, infrastructure and organisation. The establishment of a service club to handle port operation is recommended;

(5) A more effective monitoring of the main key parameters should be set-up to enable a more detail quantification of the impacts of various harbour activities. The selection of the Environmental Pressure Indicators for environmental sustainability and their locations should be done on the basis of the DSS;

(6) To minimize the effects of oil spills, contingency plans should be optimized on the basis of the simulations with the DSS. A state-of-the-art system, usually employed by oil companies, should be implemented to help in the decision making process during accidents;

(7) A central data base for handling the main environmental issues should be established;

2.5 Data management and dissemination of information

As a result of the investigations a large number of information consisting of thematic data sets, maps, simulation results and logistic items has been created. In order to support the data collection process in the PEC and to provide a central platform for the dissemination and exchange of information for the project's team members and the interested community, a web-based information infrastructure to manage data, metadata and Web services has been established. This activity is in keeping with current efforts worldwide to implement geospatial information infrastructures as resources for coastal zone management. The information infrastructure established for the data collection of the Paranaguá Estuarine Complex relies on ISO19115 metadata and uses Open Geospatial Consortium (OGC) conform web map services to access data repositories. In order to bridge any language barriers, a multilingual working environment has been created, offering English, German and Portuguese as an interface language (fig. 25).

Making use of the web interface of catalogue services CSW for automated procedures in networked environments the user requests are passed to the online metadata base which returns an according hit list where each item contains a geographic reference element for the location that can be displayed on a map. Web services also handle interactive access to the metadata for each location as shown in figure 26. All or selected items from the metadata records can be displayed to provide the user with details on the chosen items.

Fig. 25: User interface for creating ISO19115 metadata for the Coastal Zone Metadata Profile

Fig. 26: Dynamically produced composite map which displays the location of gauges taken from the hit list items and additional metadata

2.6 Conclusions from the project results

In this case study a strategy for enhancing the sustainable environmental management of harbours has been proposed and its effectiveness to handle a wide range of issues of environmental sustainability for the Paranaguá Harbour in the South of Brazil was verified.

The following conclusions can be drawn:

(1) The application of the strategy to the Paranaguá Harbour proved its effectiveness and led to the identification of the main harbour deficits and their relevance, alternatives for their mitigation as well as to recommendations for the harbour's Master Plan. A wide range of issues of environmental sustainability in harbours were handled quite effectively. The strategy was set up in such a way to cover additional issues. To prove the effectiveness of the strategy for a wider range of conditions it is recommended its application to additional different harbour sites with different layouts and environmental settings along the coast of Brazil;

(2) For handling most of the issues of sustainable environmental management in harbours a combination of field measurements and process based models embedded into Decision Support Systems (DSS) is used. Measuring techniques for most of the quantities have advanced quite significantly during the last years. The main limitations are the available techniques for measuring sediment concentration and transport close to the sea bed which are needed for calibration of the sediment transport models and the laborious non-automated methods for assessing most of the sediment and water quality parameters. Moreover, direct measurements are quite expensive particularly in regions of difficult access accounting for most of the costs in the application of the strategy. The use of high frequency radars may provide an alternative for the direct measurements of current velocities and wave fields and hence for reducing the costs of model development. As the effectiveness of such techniques to provide data for calibration and validation of hydrodynamic models in harbours has not been proved thoroughly further investigations are needed;

(3) The investigations of sediment quality originally focused on the potential impacts from harbour operation should be extended to a more comprehensive assessment of the pollution status of the sediments and biota in the Paranaguá Estuarine System taking into account a more detailed evaluation of the different pollutant inputs from cargo handling in the harbour, agriculture (predominantly via rivers) and untreated waste water. Both organic matter and organic pollutants in sediments are closely related to the fine grain size fraction. Since the surface sediments in the PEC show a dominance of sand and silt with only minor contributions of clay, low organic loadings could be expected. This would also indicate either export of riverine clay-sized material to the coastal ocean or low contents in river sources. At least seasonal sampling of riverine sources is needed to answer this question. The experience from the sediment investigations has shown that in order to render the assessment of sediment quality more cost–effective and time-saving,

a stepwise procedure should be followed. First a screening should be applied to the area in question consisting of a coarse sampling grid defined on the basis of bathymetries and results of flow simulations. Simple biotests such as the bacterial luminescent inhibition test or other fast inhibition tests (Ecotox, AChE-inhibition test) should be employed allowing for the identification of hotspots of potential toxicity. In a second step, in depth analyses for the most relevant types of contaminants as expected from the coastal uses should be performed;

(4) Process based models have also advanced rapidly during the last decades and have been applied successfully to a wide range of problems in harbours. The simulations of flow and waves have become standard. On the other hand the development of models for sediment transport and morphodynamics remains in the infancy. Although such models are able to capture trends quite well, they usually fail to predict the sediment concentrations, sediment transport and morphological changes in good agreement with observations. To improve the predictive ability of the sediment transport and morphodynamic models further research is needed. Emphasis should be given to the enhancement of the techniques for providing better descriptions of the input data required to simulate sediment transport and morphodynamics on the short and medium term;

(5) The modelling of water quality has been restricted to the main dissolved inorganic nutrient pollutants ammonium and phosphate with nitrification as the only biochemical transformation process. Nevertheless model results and field data were in reasonable accordance and in good agreement in the central area of the bay adjacent to the city of Paranaguá. However, for a more refined simulation of nutrient dynamics in the entire PEC further transformation processes, such as denitrification, ammonification, nutrient uptake and remineralisation have to be taken into account. Information on the quantitative importance of these processes in the PEC, which are decisive for the self-cleaning capacity of the area, is missing until now. Hence, for the purpose of model improvement, the relevant processes have to be assessed in the field and a three-dimensional (3D) modelling has to be applied to the study area;

(6) Another area that requires further attention is the integration of online measurements with process based models for nowcasting. Nowcasting Modelling Systems can enhance the operation of harbours quite significantly as water levels, current velocities, waves and other quantities are predicted in real time and can be used for example in the elaboration of contingency plans. In the case of the Paranaguá Harbour this implementation would be facilitated by combining the measurements from the stationary FerryBox located near the inlet to the PEC with the existing flow model. Preliminary investigations

to check the adequacy of the cross-section at which the device was installed were carried out;

(7) Harbours worldwide will be increasingly subjected to pressures due to climate changes and sea level rise. More severe wind and thus wave climate will impact negatively on the coast and maritime activities leading to the necessity of predicting future trends and their effects on harbours. To mitigate these detrimental impacts, research should be increasingly directed at an improved understanding of the existing conditions and what is likely to happen as climate change intensifies as well as about the adaptation options. For the coastal area around Paranaguá, a secular trend in sea level rise of 0.5 m has been predicted by the IPCC. Further investigations are needed in order to assess the potential impact of this process on the harbour and the surrounding areas and to test the effectiveness of the proposed techniques to handle such issues.

3. Developed Activities

The main activities carried out within the framework of the project including project meetings and workshops, training courses, exchange visits of scientists, students and authorities, coordination meetings, joint measurement campaigns as well as project presentations are listed in table 4 in chronological order:

Tab. 4: Developed activities

Kickoff-meeting in Florianopolis (Brazil), November 2006
Workshop in Büsum (Germany): "Design and preparation of the first joint Intensive Field Campaign in Paranaguá Bay", June 2007
Implementation of the 1st joint Intensive Field Campaign in the Bay of Paranaguá, September 2007
Workshop in Pontal do Sul (Brazil): "Evaluation of the field campaign and first results", September 2007
Training of two students from CEM at Kiel University, 2007
Training of a student from CEM at Darmstadt University, 2007
Presentation of first results at Young scientists meeting in Kassel (Germany): "JuWi-Meeting 2007"
Seminar in Kiel: "Metadata for the Coastal Zone", November 2007
Visit of Brazilian project coordinator to Germany (Kiel University, GKSS), Nov. 2007
Plenum Workshop of German teams in Hamburg: "Preliminary results of the project partners and preparation of the 2nd joint Intensive Field Campaign in Paranaguá Bay", Jan. 2008
Implementation of the2nd Intensive Field Campaign in the Bay of Paranaguá, Febr. 2008
Visit of APPA technical director to project coordinator and involved institutions in Ger-

many. Visit to harbour authorities in Hamburg and Bremerhaven in order to exchange information on harbour management, March 2008
Guest researcher from CEM at Kiel University, August-September 2008
Seminar in Kiel: “Historical development and forecast of Paranaguá harbour”, August-September 2008
Workshop in Kiel: “Data acquisition and exchange”, September 2008
Training course in Büsum: “Introduction to metadata editor of NOKIS data management system”, November 2008
Visit of project coordinators and representative of PtJ to CNPq, ANTAQ, IBAMA, CEMA and APPA, November 2008
Presentation of results at Chinese-German Joint Symposium on Hydraulic and Ocean Engineering 2008, Darmstadt, Germany
Presentation of results at Young scientists meeting in Innsbruck (Austria): “JuWi-Meeting 2008”
Presentation of results at Congresso Brasileiro de Oceanografia in Fortaleza (Ceará, Brazil): “In-situ Monitoring: FerryBox Measurements in Paranaguá Bay, Paraná, Brazil”, 2008
Presentation of results at Oceanology Congress in London: “The Pocket FerryBox”, 2008
Seminar in Kiel: “Standards and Web Services for the Coastal Zone”, 2008
Plenum workshop of German teams in Darmstadt: “Results achieved and present state of data analysis”, March 2009
Thematic workshop in Büsum: “Water and sediment quality in the bay of Paranaguá”, May 2009
Presentation of results at conference in Concepción (Chile): “Hydroinformatics”, 2009
Presentation of results at workshop in Venice (Italy): “Numerical modeling”, 2009
Presentation of results at Congress in Vancouver (Canada): 33rd IAHR Congress (Internat. Association for Hydraulic Research), 2009
Visit of project coordinator to ANTAQ and APPA, April 2009
Presentation of the results at the First Hemispheric Convention on Environmental Port Protection, Foz do Iguaçu, Brazil, July 21-24, 2009
Joint evaluation seminar in Curitiba, September 2009

4. Benefits derived from the Project

The bilateral research activities conducted within the present project strengthened the scientific and technological cooperation between Brazil and Germany. The development of sustainable strategies for the marine environment is one of the central objectives of the Brazilian policies in science and technology. Both countries emphasize the relevance of applied research in their cooperation. Socio-economic impacts of the project results and capacity building have high priority in the partnership.

4.1 Relevance and applicability of the results

Harbours are essential for the international trade and promoters of regional development. However, as a result of their operation, expansions and new implementations they usually bring about a wide range of environmental risks and conflicts. In many countries, port infrastructure and management do not cope with the rapid expansion of markets due to globalization. As a result of the outdated infrastructure and inadequate management and operation, risks of environmental impacts and hazards may increase. To more adequately handle these issues and to resolve conflicts among the stakeholders, state-of-the-art tools should be used. Despite the fact that advancements have been made in this field there is a lack of a strategy capable of handling the wide range of environmental issues usually faced in harbours.

Within the framework of the present project the effectiveness of a general strategy to enhance environmental sustainability in harbours has been tested. Attention was given to issues related to harbour infrastructure, pollution, dredging and dumping, siltation, contingency planning and operational monitoring. As already mentioned the proposed strategy has been effectively applied and recommendations for the Environmental Master Plan of the Paranaguá harbour have been made. Above all, however, the strategy can be extended to handle a wider range of problems related to port activities. Moreover it can be applied to different harbour layouts and environmental settings.

4.2 Impacts of the project for the involved institutions, the region and society

In addition to the traditional scientific and technical goals of such research cooperation, one of the main objectives of the project conception was to intensify the development of new capacities at the Brazilian institutions in the use of the most advanced techniques and methodologies in the related fields. The significant increase of the local capacity building was not only restricted to the academic component of the project, but also of benefit to agencies and institutions directly and indirectly involved with the project.

At the academic level, it is necessary to highlight that the Brazilian group had no full capacity in several of the scientific fields that were approached during the cooperation. Due to the joint research activities carried out in the framework of the project and to the experience shared between the partners their capacity was increased significantly. This especially holds true with respect to analytical and automated monitoring methodologies and the use of numerical modeling techniques, the latter of which gave rise to a new growing group with students and researchers working on that issue at CEM. Several students at PhD, MSc and undergraduate level were formed or have been trained in Germany. The students involved in the project got hands-on experience in performing investigations and preparing their thesis in the framework of a multidisciplinary project. The full impact on the increase of the local capacity can be estimated by the number of students at all levels that have been working within the project.

The results of the project have been presented to agencies directly involved with issues concerning the environmental sustainability in harbours. The relevance of the topic and their interest in the intensification of the ongoing activities and cooperation has been stressed. ANTAQ is particularly interested in setting standards for conducting investigations leading to recommendations for the establishment of Environmental Master Plans for the major harbours in Brazil. As already pointed out the application of the proposed strategy to additional harbour sites would facilitate the decision making concerning future actions to be taken towards the improvement of the environmental sustainability. IBAMA on the other hand stressed its interest with respect to the limitations and accuracies of the process based models usually employed to study the effect of dredging and dumping activities as well as of harbour expansions. As the environmental licenses rely to a great extent on the results of such simulations a clear understanding of such issues is of major concern. Moreover the differences between the environmental regulations of the two countries and their enforcement as well as the ongoing activities related the operational monitoring are of great relevance to this agency. On the other hand, the environmental agency of the State of Paraná (SEMA) pointed out the relevance of the strategy to enhance the environmental sustainability concerning issues of nature protection which are currently under investigation. The fact that the proposed strategy can be extended to other fields would facilitate such implementations.

The Administration of the Ports of Paranaguá and Antonina (APPA) is the major user of the project's expertise. APPA´s support and involvement in the project facilitated the activities tremendously. It is expected that the results of the application of the decision support systems and proposed solutions may lead to improvements in the environmental sustainability and cost effectiveness of the harbour operation. One of the preconditions for obtaining the operating license of the Paranaguá harbour is the establishment of a sound Environmental Master Plan and the deliverables of the project constitute a major step in this direction. The implementation of the proposed measures are bound to improve the environmental conditions in the region and foster the competitiveness of the harbour. As a consequence the socio-economic living standards of the inhabitants of the city of Paranaguá and surroundings are also expected to improve.

4.3 Relevant contribution for scientific and technological development of the project's theme

Within the framework of the project substantial knowledge related to the environmental status and underlying processes and problems of the Paranaguá Estuarine Complex (PEC) has been acquired. The comprehensive and synoptic data sets gathered within the project form a sound basis for conducting a wide range of scientific or technological activities. The process based models developed in the course of the project are currently being used by the Center for Marine Studies of the Federal University of Paraná. Similarly the web based information structure storing the metadata from the investigations is being used quite effectively at CEM. Moreover the bilateral transfer of expertise and technology in the field of applied marine science has been intensified. Several exchange visits of scientists and authorities took place in the course of the project. Additional PhD scholars supported by CNPq/DAAD are scheduled to join the University of Kiel to undergo their studies in topics related to the project's theme. Efforts to establish a double degree program involving the Federal University of Paraná and the Kiel University are currently underway.

4.4 Strategy for the dissemination of the results

Results of the project have been presented at various conferences and workshops. In addition to the papers already published, a series of publications are currently in preparation to be published in a special issue of the "Journal of Ocean Dynamics". To enhance the dissemination of data as well as of the main findings and achievements to the project community, authorities and to the public in general a web-based information structure comprising a working environment in several languages (English, German and Portuguese) has been set up (see http://harbours.wtz-brasilien.org/). The final report of the joint cooperation will be disseminated throughout institutions and authorities involved in the project.

4.5 Prospective analysis of the developed products

There are 34 major ports along the Brazilian coastal areas which are responsible for about 98 % of the foreign trade throughput. The majority of these harbours are currently facing environmental problems and do not implement proper Environmental Management Plan. The stepwise application of the proposed strategy to these harbours would enable the National Agency of Water Transport (ANTAQ) of the Brazilian Ministry of Transport to set up priorities concerning future actions and investments to be taken.

4.6 Identification of new actions produced from the original project

To achieve the goals of the project the following additional activities were carried out in the course of the project:

- Estimation of the freshwater input to the PEC on the basis of the characteristics of the catchments areas and precipitation rates (contract with RHA LTDA.)
- Comprehensive study of wind forcing to produce griddling wind field data for the PEC to be used in the hydrodynamic model simulations
- Monthly monitoring of nutrient discharges from main rivers along the PEC
- Comparison between the Brazilian and German dredging regulations
- Decomposition experiments with soy flour
- Intensification of FerryBox maintenance activities due to hazards and biofouling
- Intensification of capacity building

4.7 Interactions with other research areas

The project is multidisciplinary and involved experts in the fields of engineering, oceanography, marine chemistry, geology and sedimentology, ecology and meteorology with expertise in experimental and modeling fields. Thematic links to the socio-economic field became evident from the activities related to harbour auditing.

4.8 Interaction with the productive sector

Several private companies have been involved in the project. The involvement of the companies and close cooperation with the agencies proved to be essential for the successful execution of the activities and thus for reaching the goals of the project. In addition, opportunities to access new markets and to establish contacts with potential contractors have been provided through the project's activities**.** One example is the cooperation of the German company 4H-JENA and the Brazilian company Sistemas de Medição e Controle. As a result of the cooperation this company is currently representative for the FerryBox system in Brazil.

5. Research Targets which could not be achieved

The main goals of the project have been achieved. It should be mentioned that, due to the low resolution and coverage of satellite images in the coastal and estuarine area of the PEC and to signal errors related to the seabed proximity, the application of monitoring real-time data to calibrate satellite images of chlorophyll-a and suspended matter proved to be ineffective. In the course of the project it turned out that the high content of colored dissolved organic matter (CDOM) in the bay interfered with the measurements of the nitrate UV-sensor in the FerryBox system under conditions of low nitrate concentrations. Therefore the nitrate UV-sensor was not implemented. Instead, a CDOM sensor was installed in the FerryBox.

6. Changes to the Working Schedule and Financial Plan

Some adjustments to the initial working plan were needed. In particular the schedule of the first joint measuring campaign and installation of the FerryBox system at the PEC required some modifications. These activities were slightly delayed primarily due to difficulties in custom clearance. However, logistic support has been effectively provided by the Brazilian counterpart. In few cases and for various reasons the recruitment of scientific coworkers could not be done in accordance to the time scheduled in the original proposal. However, it was possible to accommodate these delays in the course of the project. With respect to the project's finances a supplementary increase of the budget has been approved in order to guarantee the proper maintenance of the FerryBox system at its exposed location near Pontal do Sul.

7. Outlook for a Continuation of the Cooperation

A follow-up project is envisaged to advance the developments in several areas. The amount of data on the Brazilian side and the ongoing model developments and applications in Germany constitute a sound basis for a future cooperation. In addition to more comprehensive and multidisciplinar investigations in the PEC, topics of relevance for the follow-up phase are: (1) process based studies on sources, transport and transformation of matter and refinement of the models for sediment transport and water quality (2) application of advanced technologies for reducing the costs of field measurements; (3) the inclusion of new themes, as the potential impacts of global warming and sea level changes in harbour areas (4) the application of technological advancements for enhancing harbour operation; (5) the verification of the effectiveness of the proposed strategy to other harbour sites as pointed out by ANTAQ.

Acknowledgement

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B. Schlussberichte der Teilprojekte

Schlussbericht

TP1 Transportprozesse, Morphodynamik und Wasserqualität
bei Paranaguá

Gesamtkoordination im Verbundprojekt

Nachhaltiges Umweltmanagement in brasilianischen Häfen

Forschungs- und Technologiezentrum Westküste
Christian-Albrechts-Universität zu Kiel

BMBF-Förderkennzeichen: 03F0452A

Zuwendungempfänger: **Christian-Albrechts-Universität zu Kiel Forschungs- und Technologiezentrum Westküste**	Förderkennzeichen: **03F0452A**
Vorhabenbezeichnung: **TP1 Transportprozesse, Morphodynamik und Wasserqualität bei Paranaguà / Gesamtkoordination im Verbundprojekt**	
Laufzeit des Vorhabens: **01.11.2006 - 31.12.2009**	
Berichtszeitraum: **01.11.2006 - 31.12.2009**	
Projektleiter: **Prof. Dr. Roberto Mayerle** Projektbeteiligte: **Dr. Karl-Jürgen Hesse, Dr. Norbert Ladwig, Dr. Knut Poremba, Dipl.-Phys. Robert Osinski, Techn. Ass. Daniela Koch**	

I. SCHLUSSBERICHT

1. Aufgabenstellung

Ziel des Teilprojektes war die Charakterisierung von hydrodynamischen Prozessen, des Sedimenttransportes, der Morphodynamik und von wichtigen Aspekten der Wasserqualität im Bereich des Hafens und der zentralen Bucht von Paranaguá/Südbrasilien. Ein zentrales Anliegen hierbei war die Untersuchung potentieller Auswirkungen anthropogener Einträge aus dem Hafenumfeld von Paranaguá auf die Wasserqualität sowie Folgeabschätzungen von Unterhaltungsbaggerei und Baggergutverklappung für die Sediment- und Morphodynamik des Gebietes.

Auf Basis von prozessorientierten Felduntersuchungen und bestehenden Datensätzen sollten numerische Modelle zur Simulation von Hydrodynamik, Sedimenttransport, Morphodynamik, Nährstoffausbreitung und Ölunfällen entwickelt und aus Szenarienrechnungen Optimierungsstrategien für ein nachhaltiges Umweltmanagement des Hafenstandortes Paranaguá abgeleitet werden. Die Arbeiten des vorliegenden Teilprojektes bilden somit einen zentralen Baustein für die übergreifende Zielstellung des Verbundvorhabens.

Weiterhin übernahm das vorliegende Teilprojekt die Gesamtkoordination für die deutschen Partner des Verbundvorhabens.

2. Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

Das Teilprojekt stellt ein Modul des bilateralen Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ dar, welches im Rahmen der bilateralen WTZ mit Brasilien im Bereich Meeresforschung im Zeitraum 01.11.2006 bis 31.12.2009 aus Mitteln des

Bundesministeriums für Bildung und Forschung gefördert wurde. Die logistischen Herausforderungen für die umfangreichen Feldmesskampagnen im Ästuarsystem von Paranaguá konnten jedoch nur durch Bereitstellung zusätzlichen Personals aus Eigenleistung bewältigt werden. Ergänzend zu der wissenschaftlichen Zielsetzung leistete das Vorhaben einen wichtigen Beitrag zur Postgraduiertenausbildung an der Universität Kiel. Spezielle Fragestellungen wurden im Rahmen des internationalen Ausbildungsprogramms „Coastal Geosciences and Engineering“ mit seinen M.Sc.- und Ph.D.-Ausbildungslinien thematisiert und bearbeitet.

Als besonders förderlich auf die Durchführung des Projektes wirkte sich die einschlägige Auslandserfahrung des Projektteams aus. So bestanden bereits lange vor Projektbeginn enge Kontakte zu brasilianischen Forschungseinrichtungen und Kollegen, und es wurden in der Vergangenheit bereits mehrere kleinere Forschungsarbeiten in Brasilien durchgeführt. Dementsprechend verlief die Zusammenarbeit mit den brasilianischen Partnern zwar nicht immer problemlos, jedoch insgesamt erfolgreich. Der wissenschaftliche Austausch, Capacity Building und Training waren integrative Bestandteile des Vorhabens. So wurden mehrmonatige Gastforscheraufenthalte brasilianischer Wissenschaftler am CORELAB der Universität Kiel im Laufe des Projektes ermöglicht. Ergänzend hierzu erfolgte ein dreimonatiges Training von Masterstudenten des Centro de Estudos do Mar der Universität Paraná in der Abteilung CORELAB des Forschungs- und Technologiezentrums Westküste.

Erheblich erleichtert wurden die Forschungsarbeiten dadurch, dass nunmehr zur Durchführung der Messungen in Brasilien keine Forschungsgenehmigungen und Visa seitens der brasilianischen Behörden erforderlich sind. Die temporäre Einfuhr der benötigten Geräteausstattung per Luftfracht nach Curitiba war zwar mit einem nicht unerheblichen verwaltungstechnischen Aufwand verbunden, es wurde allerdings seitens der Einfuhrabteilung der Universität Paraná gute Unterstützung geleistet.

3. Planung und Ablauf des Vorhabens

Die übergreifende Planung des Vorhabens sowie die Bildung von thematischen Arbeitsgruppen wurden auf einem Implementationstreffen aller Projektpartner in Florianopolis im November 2006 festgelegt. Hieran nahmen auch Vertreter von nationalen und bundesstaatlichen Hafen- und Umweltbehörden, des CNPq und des brasilianischen Ministeriums für Wissenschaft und Technologie (MCT) teil.

Als Untersuchungsobjekt für die Entwicklung eines Entscheidungsfindungssystems zum umweltgerechten Hafenmanagement wurde der Großhafen und der Ästuarkomplex von Paranaguá im Bundesstaat Paraná (Südbrasilien) ausgewählt. Die F&E-Arbeiten des Teilprojektes gliederten sich in die Bereiche a) Feldmessungen (Hydrographie, Hydrodynamik und Wasserqualität) und b) Numerische Modellierung.

a) Feldmessungen

Im Rahmen zweier Intensivmesskampagnen, die je im September 2007 (Trockenzeit) sowie im Februar 2008 (Regenzeit) stattfanden, wurden umfangreiche Datensätze zur Hydrographie, Hydrodynamik und Wasserqualität (Einträge und Verteilung von Schweb- und Nährstoffen, Enterobakterien, Sauerstoff) in der Bucht von Paranaguá erhoben (Fig. 1).

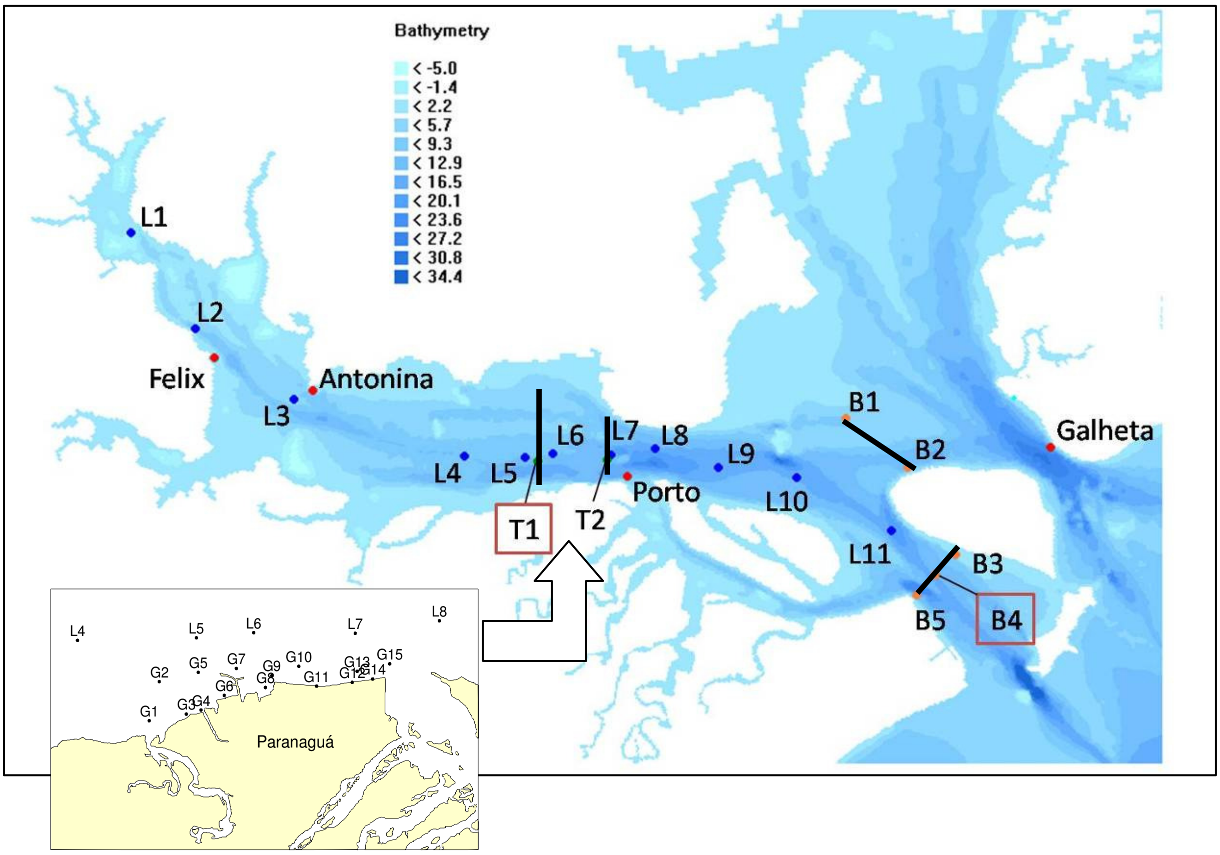

Fig. 1: Stationsnetz der Messkampagnen im TP1 (Felix, Antonina, Porto, Galheta = Pegel; L = Längsschnitt durch die Bucht; B = Transekte an den Modellgrenzen; T = Transekte in Hafennähe; G = flächenhafte Beprobung in Hafen- und Stadtnähe)

Neben ihrem Eigenwert zur Beschreibung der Stoffverteilung und Eintragsmengen im Untersuchungsgebiet lieferten die Felddaten die Grundlage für den Aufbau und Betrieb von numerischen Modellen für Strömung, Sedimenttransport, Morphodynamik und ausgewählten Aspekten der Wasserqualität. Um weitreichend synoptische Datensätze zu erhalten, wurden bei den Messkampagnen mitunter drei Schiffe simultan eingesetzt. Zusätzlich wurden Beprobungen der Einleiter von Land aus vorgenommen. Schon frühzeitig im Projektverlauf wurde

in den Randgebieten der Bucht ein Pegelmessnetz installiert, das über einen längeren Projektzeitraum kontinuierlich Daten über die Wasserstände lieferte.
Da nur für wenige Flüsse Messdaten zu den Frischwassereinträgen vorliegen, wurde eine Studie zur Berechnung der monatlichen Abflussmengen auf Basis der Niederschlagsmengen und Topographie der Einzugsgebiete durchgeführt. Die Daten waren sowohl für die Modellierung der Hydrodynamik und des Sedimenttransportes als auch für die Bilanzierung der Nährstoffeinträge unabdingbar.

b) Modellierung

Auf Grundlage eines bereits vorliegenden Zirkulationsmodells für die Bucht von Paranaguá wurde ein hochauflösendes, gekoppeltes Modellsystem mit Modulen für Strömung, Sedimenttransport, Morphodynamik und Wasserqualität (Nährstoffausbreitung, Ölunfälle) erstellt. Hierfür wurde die Delft3D-Software von Delft Hydraulics (The Netherlands) verwendet. Durch Domain-Decomposition-Verfahren wurde der Gitterabstand des vorliegenden großskaligen Zirkulationsmodells auf ca. 20 m im zentralen Bereich der Bucht im Vorfeld des Hafens von Paranaguá verfeinert. So können vor allem die kleinräumigen Prozesse im sensiblen Bereich des Hafenumfeldes gut erfasst werden. Verschiedene Nesting-Verfahren wurden für das hochauflösende Modell appliziert und mit tidenzyklischen Feldmessungen analysiert. Um die Prognosefähigkeit des Modells zu optimieren, wurden detaillierte Karten der Bodenrauhigkeit erstellt, welche die Strömungsbedingungen und Sedimentcharakteristika berücksichtigen. Hierfür wurden Daten aus vorhandenen Sedimentuntersuchungen und neue Messungen des TP 3 (Sediment- und Wasserqualität) digitalisiert. Ebenso wurden die neu erhaltenen Informationen zu den Durchflussraten der kontinentalen Frischwassereinträge in den Modellen berücksichtigt.
Das hydrodynamische Modell wurde mit den Modellmodulen für Sedimenttransport, Morphodynamik, Wasserqualität und Öldrift gekoppelt. An allen Modellmodulen wurden Sensitivitätsanalysen durchgeführt. Die Modelle für Hydrodynamik, Sedimenttransport, Morphodynamik und Wasserqualität (Ammoniumverteilung) wurden anhand von Feldmessungen kalibriert und validiert. Mit den erstellten Modellen wurden Szenarien u.a. im Hinblick auf optionale Maßnahmen der Baggerei und Baggergutverbringung, der Nährstoffeinleitungen aus dem Hafen und der Stadt von Paranaguá und für potentielle Ölunfälle am Pier von Petrobras simuliert. Die Ergebnisse bilden die Grundlage für die Formulierung von Handlungsempfehlungen für ein nachhaltiges Hafenmanagement.
Im Laufe des Vorhabens wurden regelmäßige Arbeitstreffen der Projektteilnehmer durchgeführt, auf denen der aktuelle Sachstand und Fortgang der Arbeiten sowie die Planung gemein-

samer Messkampagnen vorgestellt bzw. diskutiert wurden. Die folgende Tabelle 1 gibt eine Übersicht über die im Rahmen des vorliegenden Teilprojektes durchgeführten Workshops, Trainingkurse, wissenschaftlichen Gastaufenthalte, Präsentationen und Koordinationsreisen.

Tab. 1: Chronologische Übersicht der Aktivitäten im TP 1

Kickoff-meeting in Florianopolis (Brazil), November 2006
Workshop in Büsum (Germany): "Design and preparation of the first joint Intensive Field Campaign in Paranaguá Bay", June 2007
Implementation of the 1st joint Intensive Field Campaign in the Bay of Paranaguá, September 2007
Workshop in Pontal do Sul (Brazil): "Evaluation of the field campaign and first results", September 2007
Training of two students from CEM at Kiel University, 2007
Seminar in Kiel: "Metadata for the Coastal Zone", November 2007
Visit of Brazilian project coordinator to Germany (Kiel University, GKSS), November 2007
Plenum Workshop of German teams in Hamburg: "Preliminary results of the project partners and preparation of the 2nd joint Intensive Field Campaign in Paranaguá Bay", January 2008
Implementation of the 2nd Intensive Field Campaign in the Bay of Paranaguá, February 2008
Visit of APPA technical director to project coordinator and involved institutions in Germany. Visit to harbour authorities in Hamburg and Bremerhaven in order to exchange information on harbour management, March 2008
Guest researcher from CEM at Kiel University, August-September 2008
Seminar in Kiel: "Historical development and forecast of Paranaguá harbour", August-September 2008
Workshop in Kiel: "Data acquisition and exchange", September 2008
Training course in Büsum: "Introduction to metadata editor of NOKIS data management system", November 2008
Visit of project coordinators and representative of PtJ to CNPq, ANTAQ, IBAMA, CEMA and APPA, November 2008
Seminar in Kiel: "Standards and Web Services for the Coastal Zone", 2008
Plenum workshop of German teams in Darmstadt: "Results achieved and present state of data analysis", March 2009

Thematic workshop in Büsum: “Water and sediment quality in the bay of Paranaguá”, May 2009
Visit of project coordinator to ANTAQ and APPA, April 2009
Presentation of the results at the First Hemispheric Convention on Environmental Port Protection, Foz do Iguaçu, Brazil, July 21-24, 2009
Joint evaluation seminar in Curitiba, September 2009

4. Wissenschaftlicher und technischer Stand, an dem angeknüpft wurde sowie Angabe der verwendeten Fachliteratur sowie der benutzten Informations- und Dokumentationsdienste

Die Felduntersuchungen wurden nach internationalem Standard für Meerwasseranalytik (Grasshoff et al., 2002) durchgeführt. Die Modellierungsarbeiten erfolgten auf Grundlage der Delft3D-Modellsoftware (WL/Delft Hydraulics, the Netherlands, 2006).

Topographie und Bathymetrie der Modellgebiete wurden aus vorhandenem nautischen Kartenmaterial, letzteres auch aus TM-Landsat-Daten, Messungen der Hafenbehörde APPA (Administration of Ports of Paranaguá and Antonina) und eigenen Erhebungen erstellt. APPA stellte weiterhin operationelle Pegeldaten zur Verfügung, die die eigenen Wasserstandsmessungen ergänzten. Daten zu Windrichtung und -geschwindigkeit wurden von der meteorologischen Station des Centro de Estudos do Mar in Pontal do Sul zur Verfügung gestellt. Zur Beschreibung der Sedimentcharakteristik wurden neben neuen Erhebungen u.a. Daten von Lamour et al. (2004, 2007) verwendet.

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GRASSHOFF, K., K. KREMLING, M. EHRHARDT, 2002: Methods of Seawater Analysis, 3rd Edition. Wiley-VCH, 600pp.

HERRLING, G., 2003: Development of a numerical model for the Paranaguá Bay in Brazil. Master Thesis, Coastal Research Laboratory Research and Technology Centre Christian-Albrechts-University Kiel, Germany.

LAMOUR, M.R., C.R. SOARES, J.C. CARRILHO, 2004: Mapas dos parametros texturais dos sedimentos de fundo do Complexo Estuarino de Paranaguá. Pr. Bolet. Parana. De Geosciencas, no. 55, p. 77-82.

CONSELHO NACIONAL DO MEIO AMBIENTE, 2005: Resolução Nº 357, de 17 de Março de 2005 (CONAMA Resolution No. 357/2005).

CASTELLA, R.M.B., P.R. CASTELLA, D.C. DOS SANTOS FIGUEIREDO, S.M.P. DE QUEIROZ, 2006: Paraná – Mar e costa. Subsidios ao Ordenamento das Áreas Estuarina e Costeira do Paraná. Governo de Estado do Paraná, 143pp.

DELFT HYDRAULICS, 2006: Delft 3D - GPP User Manual. Delft Hydraulics, The Netherlands.

DELFT HYDRAULICS, 2006: Delft 3D - WAQ User Manual. Delft Hydraulics, The Netherlands.

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DELFT HYDRAULICS, 2007b: Delft 3D - Quickin User Manual. Delft Hydraulics, The Netherlands.

DELFT HYDRAULICS, 2007c: Delft 3D - Wave User Manual. Delft Hydraulics, The Netherlands.

LAMOUR, M., R. ANGULO, C. SOARES, 2007: Bathymetrical Evolution of Critical Shoaling Sectors on Galheta Channel, Navigable Access to Paranaguá Bay, Brazil. Journal of Coastal Research 23: 49-58.

SOARES, C.R., M.A. NOERNBERG, 2007: Dragagens Portuárias no Brasil Licenciamento e Monitoramento Ambiental, 192-202.

5. Zusammenarbeit mit anderen Stellen

In Ergänzung zu der engen Zusammenarbeit der Antragsteller im eigentlichen Projektverbund bestand ein intensiver Erfahrungs- und Informationsaustausch mit verschiedenen regionalen und nationalen Behörden und Institutionen auf brasilianischer Seite. Dazu zählten insbesondere die bereits erwähnten Hafenbehörden des Bundesstaates von Paraná (APPA), sowie die für Häfen und Schifffahrt verantwortliche Bundesbehörde ANTAQ (Agencia National de Transportes Aquaviários), die staatliche Umweltbehörde IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis), sowie die bundesstaatliche Umweltbehörde SEMA (Secretaria de Estado de Meio Ambiente e Recursos Hídricos). Projektergebnisse wurden anlässlich mehrerer Treffen mit Behördenvertretern vorgestellt und diskutiert. Hierbei wurden auch Planungsziele zum Management und Ausbau der Häfen, zu Regelwerken der Umweltverträglichkeit und der Grenzwertproblematik thematisiert. Ohne die seitens der Behörden geleistete Unterstützung u.a. in Form von detaillierten Informationen und Datensätzen wäre die Durchführung des Vorhabens wesentlich erschwert worden.

Der technische Direktor der Hafenbehörde APPA besuchte im März 2008 Deutschland, um sich an den Hafenstandorten Kiel, Bremen und Hamburg über das deutsche Hafenmanagement zu informieren. In diesem Rahmen fand ein Informationsaustausch u.a. mit der Fa. Inros-Lackner AG, Bremenports GmbH, Hamburg Port Authority und der BAW statt.

Die Wassergesellschaft der Stadt Paranaguá „Aguas de Paranaguá“ unterstützte mit Informationen und technischen Daten zur derzeitigen kommunalen Abwasserentsorgung und deren zukünftigen Ausbauplanung und gestattete die Beprobung der örtlichen Abwasseraufbereitungsanlage und Vorfluter. Die Fa. FOSPAR S.A. (Fertilizantes Fosfatados do Paraná) lieferte

Daten zu Düngemittelumschlag und -zusammensetzung im firmeneigenen Terminal von Paranaguá.

6. Eingehende Darstellung der erzielten Ergebnisse

Im nachstehenden Berichtsteil III sind die im vorliegenden Teilvorhaben erzielten Ergebnisse dargestellt, soweit sie nicht bereits im übergreifenden Bericht des Verbundvorhabens beschrieben sind. Zwecks einer besseren Kommunikation mit den brasilianischen Partnern ist der wissenschaftliche Ergebnisbericht in englischer Sprache abgefasst.

7. Nutzen und Verwertbarkeit des Ergebnisses

Die im Laufe des Vorhabens erarbeiteten Felddatensätze und Modellergebnisse stellen auch unabhängig vom Kontext der eigentlichen Zielstellung des Projektes eine wertvolle Erkenntnis- und Datengrundlage für den noch nicht systematisch untersuchten Ästuarkomplex von Paranaguá dar, die künftige Forschungsaktivitäten zur Küstenozeanographie des Gebietes sicherlich befördern und unterstützen werden. Der wesentliche Nutzen der Projektergebnisse besteht jedoch darin, dass sie ein zentrales Instrument für die Entwicklung wissenschaftlich begründeter Leitlinien im Hafen- und Küstenmanagement liefern. Mit den entwickelten Modellsystemen konnten Simulationen zu Folgeabschätzungen verschiedener Maßnahmen im Baggerei- und Abwassermanagement, zur Bedeutung anthropogener Nährstoffeintragsquellen und zu potentiellen Ölunfällen im Hafen durchgeführt werden, deren Ergebnisse eine fundierte Entscheidungsgrundlage für die Hafen- und Umweltbehörden bieten. Die Anwendung der Modelle ist jedoch nicht auf die bislang untersuchten Themenfelder beschränkt. Vielmehr eröffnet sich nun die Möglichkeit, auf Basis der kalibrierten und validierten Modelle auch andere, zukunftsträchtige Szenarien der Küstenraumplanung, e.g. im Hafenausbau, Küstenschutz und Emissionsmanagement, zu simulieren und somit deren Effekt zu prognostizieren.
Ergebnisse des Teilprojektes wurden den brasilianischen Behörden mehrfach vorgestellt und stießen auf großes Interesse. Insbesondere die für Häfen und Schifffahrt zuständige Bundesbehörde ANTAQ würde es begrüßen, wenn die Untersuchungen auch auf andere Großhäfen Brasiliens ausgeweitet werden, um somit Grundlagen für einen Umweltleitplan der Häfen zu schaffen. Die für die Genehmigung von Umweltlizenzen verantwortliche, staatliche Umweltbehörde IBAMA zeigt starkes Interesse an der Anwendung der Modelle für die Umweltverträglichkeitsprüfung von Baggerei-, Dumping- und Ausbaumaßnahmen. Hauptnutzer der Ergebnisse wird jedoch die Hafenbehörde APPA sein. Eine entscheidende Voraussetzung für die (noch nicht erteilte) Betriebsgenehmigung des Hafens von Paranaguá ist die Erstellung

eines detaillierten Umweltleitplans, zu dem die vorliegenden Erkenntnisse einen wichtigen Beitrag liefern.

Letztendlich konnte das Projekt zur Schaffung neuer Forschungskapazitäten beim brasilianischen Partner, dem Centro de Estudos do Mar (CEM) der Universität von Paraná, wichtige Beiträge liefern. Das Modellsystem ist am CEM etabliert worden. Es fanden mehrmonatige Trainingsaufenthalte brasilianischer Masterstudenten am CORELAB der Universität Kiel statt, in denen u.a. grundlegende numerische Modellierungstechniken erlernt wurden. Eine Vielzahl brasilianischer Studenten führte ihre Examensarbeiten mit Themenstellungen im Rahmen des Projektes durch. Capacity Building und Transfer von wissenschaftlicher und technologischer Expertise wurde zudem durch Gastforscheraufenthalte brasilianischer Wissenschaftler am FTZ der Universität Kiel befördert. Derzeit werden Gespräche zur Einrichtung eines Double Degree Masterstudienganges in Coastal Geosciences and Engineering zwischen der Universität Kiel und der Universität von Paraná geführt, zu denen die im Laufe des Vorhabens gewachsenen Kontakte sehr beigetragen haben.

8. Während der Durchführung des Vorhabens dem Zuwendungsempfänger bekanntgewordenen Fortschritts auf dem Gebiet bei anderen Stellen

entfällt

9. Erfolgte oder geplante Publikationen

Schriften

siehe Literaturverzeichnis im englischsprachigen Berichtsteil S. 42ff

Poster

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LADWIG, N., K. POREMBA, G. BRUSS, K.-J. HESSE, D. KOCH, 2007: Measurement Campaign Paranaguá Bay – First results from the sampling programme in September 2007. Workshop in Pontal do Sul, Brazil, 24.09.2007.

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MAYERLE, R., 2009: Advances in the development of strategies for the sustainable environmental management of Brazilian harbours, ANTAQ Brasilia, April 2009.

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Examensarbeiten

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DIETRICH, ENNO: Set up of a morphodynamic model of Paranaguá Bay, Brazil. University of Kiel.

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HAKIM, ARADEA RAMADHAN: 2Dh Morphodynamics Modelling in Paranaguá Bay, Brazil. University of Kiel.

HAYATININGSIH, INTAN: Development of a three dimensional flow model for Paranaguá Bay in Brazil. University of Kiel.

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II. ERFOLGSKONTROLLBERICHT

1. Bezug zu den förderpolitischen Zielen

Das vorliegende Teilprojekt stellt einen anwendungsbezogenen Beitrag zu der deutsch-brasilianischen Zusammenarbeit in Wissenschaft und Technik im Bereich der Meeresforschung dar, welche im Juli 2004 in einem bilateralen Abkommen zwischen BMBF und MCT festgeschrieben wurde. Die WTZ auf dem Gebiet der Meeresforschung setzt Schwerpunkte in den Bereichen Küstenzonenmanagement, lebende marine Ressourcen, Verschmutzung und Hafenentwicklung. Die vorliegenden Untersuchungen fokussieren auf den Bereich Hafenentwicklung, tangiert jedoch sämtliche der o.g. Schwerpunktthemen. Eine weitere Zielsetzung des bilateralen Abkommens mit Brasilien lag in dem Bereich Training und Capacity Building, welcher ebenfalls im Rahmen der Projektaktivitäten aufgegriffen wurde und zu einer Kompetenzstärkung der beteiligten brasilianischen Arbeitsgruppen führte.

2. Wissenschaftlicher Erfolg des Vorhabens

Als ein wichtiges Ergebnis des Teilprojektes liegt ein Modellsystem vor, welches im Rahmen der durchgeführten Untersuchungen für Fragestellungen im Bereich des Baggerei- und des Abwassermanagements sowie der Notfallplanung bei Ölunfällen eingesetzt wurde. Dieses prognostische Werkzeug stellt einen wesentlichen Beitrag zum Gesamtziel des Verbundvorhabens, i.e. der Entwicklung von Strategien für ein nachhaltiges Umweltmanagement in brasilianischen Häfen, dar. Auf Grundlage der erstellten Modelle lassen sich zukünftig auch weitere angewandte Problemstellungen des Umwelt- und Hafenmanagements bearbeiten und Optionen zur Entscheidungsfindung ableiten.

Darüber hinaus liegen nunmehr umfangreiche, kohärente Datensätze und Karten zu hydrographischen, nährstoffchemischen und enterobakteriellen Parametern für das sensible und bislang noch wenig untersuchte ästuarine Ökosystem von Paranaguá vor. Diese Informationen bilden somit eine Grundlage für weiterführende Forschungsaktivitäten, die eine Beschreibung der komplexen Prozesse und des ökologischen Gefährdungspotenzials im Ästuarsystem von Paranaguá anstreben.

Insgesamt konnten die im Teilprojektantrag gesteckten Ziele, auch in Bezug auf die Aufgabenstellung im Bereich Capacity Building, Training und Wissenstransfer, innerhalb der Laufzeit erreicht werden. Ein Erfolg des Teilvorhabens liegt auch in der erreichten Ausbildungseffizienz: Aus den Aktivitäten des vorliegenden Teilprojektes resultierten allein auf deutscher Seite neun Masterarbeiten.

3. Einhaltung des Finanzierungs- und Zeitplans

Die Arbeits- und Zeitplanung konnte, wie ursprünglich vorgesehen, i.W. eingehalten werden. Der Termin der ersten gemeinsamen Messkampagne wurde auf Wunsch der brasilianischen Partner geringfügig (um 8 Wochen) verschoben. Bezüglich der Finanzplanung bzw. des Mittelbedarfs wurde Mitte 2008 im Rahmen der bei dem vorliegenden TP angesiedelten Gesamtkoordination des Verbundvorhabens ein Antrag auf Mittelaufstockung gestellt, um die Funktionsfähigkeit des automatischen FerryBox-Systems am isolierten Standort Pontal do Sul zu sichern. Kosten zur Sicherstellung der Funktionsfähigkeit der FerryBox waren in der ursprünglichen Planung der hiermit befassten Teilprojekte (GKSS/4H-Jena) nicht vorgesehen. Umwidmungen der Mittelverwendung waren nicht erforderlich. Es wurde jedoch eine kostenneutrale Verlängerung von zwei Doktorandenstellen bis zum Laufzeitende, d.h. um jeweils 2 Monate, bewilligt. Hierdurch konnte sichergestellt werden, dass die noch anstehenden Auswerte- und Analysearbeiten des Projektes erfolgreich zu Ende geführt wurden.

4. Verwertbarkeit der Ergebnisse

Verwertbarkeit und Nutzen der Projektergebnisse sind in §7 des Schlussberichtes ausführlich dargestellt. Die entwickelten Modelle, Szenarienrechnungen und Datensätze bilden im Rahmen des Verbundprojektes eine strategische Grundlage für die Entwicklung von Handlungsoptionen für ein ökologisch nachhaltiges Hafenmanagement am Beispiel des Großhafens von Paranaguá. Die im Projekt eingebundenen Hafen- und Umweltbehörden auf bundesstaatlicher und nationaler Ebene profitieren unmittelbar von den Ergebnissen und Empfehlungen. Training- und Capacity-Building-Aktivitäten waren integrativer Bestandteil des Vorhabens und führten zu einer deutlichen Kompetenzsteigerung und einem Wissensfortschritt auf Seiten der brasilianischen Partner. Es ist geplant, die wissenschaftlichen Erkenntnisse des Projektes u.a. in einer Publikationsserie der Zeitschrift „Ocean Dynamics" zu publizieren.

5. Erfindungen und Schutzrechtsanmeldungen

entfällt

6. Arbeiten, die zu keiner Lösung geführt haben

Es ist allgemein bekannt, dass ein Forschungsergebnis viele neue Fragen aufwirft, und das vorliegende Projekt stellt in diesem Zusammenhang keine Ausnahme dar. Im Fazit des Projekterfolges gibt es weniger geplante Aufgabenstellungen, die letztendlich nicht gelöst werden konnten, als vielmehr eine Reihe von Erkenntnissen zu neuem Forschungsbedarf, die erst aus den Projektaktivitäten resultierten. Dies betrifft u.a. eine bessere Beschreibung des Sedimenttransportes und der morphodynamischen Prozesse, die Berücksichtigung weiterer biogeochemischer Transformationsprozesse in der Modellierung der Nährstoffdynamik, als auch eine verbesserte Prognosefähigkeit der Modelle vor dem Hintergrund künftiger klimatischer Veränderungen.

ZUSAMMENFASSUNG

Auf Basis von prozessorientierten Feldmessungen und hochauflösenden numerischen Modellen wurden Transportprozesse, morphodynamische Entwicklungen und Aspekte der Wasserqualität im Bereich des Hafens und der zentralen Bucht von Paranaguá/Südbrasilien untersucht. Die kalibrierten und validierten Modelle wurden für Szenarienrechnungen im Hinblick auf Optionen der Baggerei und Baggergutverbringung, der Nährstoffeinleitungen aus dem Hafen und der Stadt von Paranaguá sowie für potentielle Ölunfälle am Pier von Petrobras angewandt. Die Ergebnisse der Modellsimulationen bilden zusammen mit den Erkenntnissen aus den Felduntersuchungen die Grundlage für die Formulierung von Handlungsempfehlungen und Krisenplänen für ein nachhaltiges Hafenmanagement.

III. MAIN RESULTS OF THE RESEARCH

The activities carried out in subproject 1 aimed at the investigation of hydrodynamic transport processes, morphodynamics and aspects of water quality in the central bay of Paranaguá. Emphasis was given to the effects of dredging and dumping on sediment and morphodynamics, to anthropogenic nutrient pollution from the harbour and the city of Paranaguá and to fecal bacteria discharges from untreated sewage.

The investigations rely on extensive field measurements conducted during two multi-ship measuring campaigns and on the development and application of a set of process-based numerical models for the simulation of flow, waves, sediment transport, morphodynamics, oil spills and nutrient distribution in the bay. A variety of scenarios were simulated to study the effects of different options in dredging and dumping and mitigation of nutrient pollution. From the results of the scenario runs recommendations are given for assisting the decision making process related to sustainable harbour operation.

The specially designed field measurements primarily aimed at providing the data basis required for the development, calibration and validation of the process based models. Apart from this important role, the comprehensive field studies also provided valuable insights into the characteristic hydrographic features and related processes of the bay.

The first section of the following report is devoted to a description of selected results from the two intensive measuring campaigns focusing on the estuarine gradients and nutrient loads of the bay. In the subsequent section, the developed process based models for the simulation of hydrodynamics, sediment transport, morphodynamics, water quality and hazards are introduced and the main results from the simulation of optional scenarios for assisting the decision making process are presented.

Results of Field Measurements

1. Hydrography

Hydrographic characteristics of a water body can amplify or mitigate eutrophication effects i.a. by improving the light supply for photoautotrophic primary producers or influencing the oxygen regime of deep waters. The hydrography inside the bay of Paranaguá is dominated by two main water types. Comparatively warm freshwater is discharged by rivers at different sites around the bay. Cold saline and hence denser water of the Southern Atlantic Ocean enters the bay at the eastern part, north and south of Ilha do Mel. Depending on the tide and seasonal differences in river runoff, these water bodies form a complex variable thermohaline stratification pattern inside the bay.

During flood phase in the dry season, vertically mixed oceanic water with high salinities > 29 PSU (Practical Salinity Units) enters the bay from the east and retains freshwater runoff in inner parts of the estuary (fig. 2). Hence, the vertical stratification of the water column is less pronounced when compared to the ebb phase in the rainy season. A vertical haline stratification is detectable in the middle section of the bay between stations L4 to L10, i.e. close to the city and harbour of Paranaguá, which is located between stations L5 to L7.

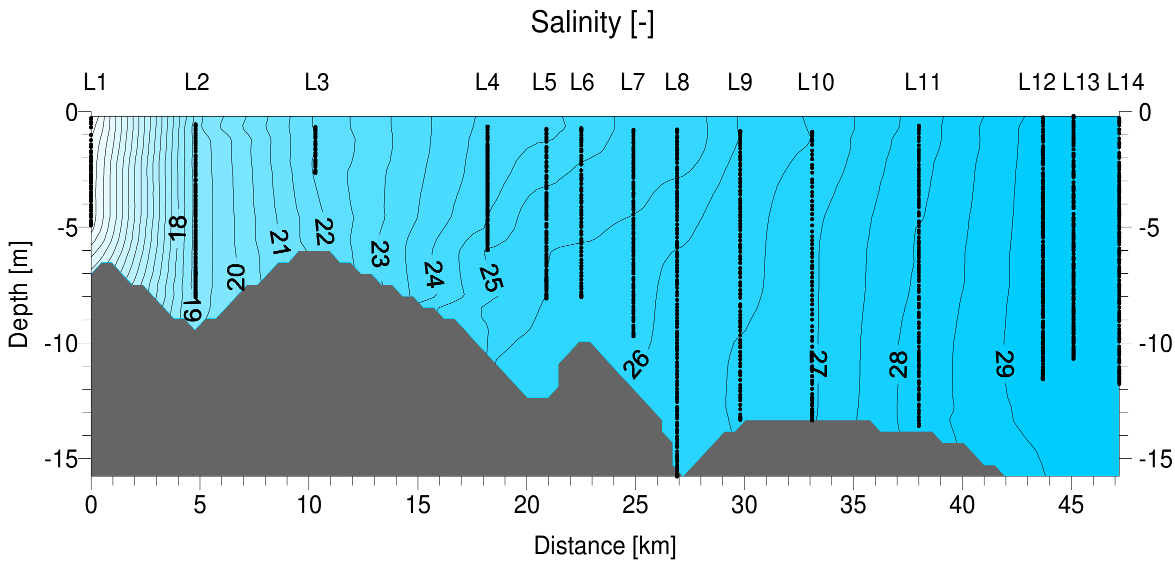

Fig. 2: Interpolated vertical salinity profiles on a longitudinal transect through the bay of Paranaguá in September 2007 during flood phase in the dry season (measurements at stations L1 (western part of the bay) to L14 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

During ebb phase in the rainy season, the fraction of freshwater inside the bay is higher when compared to flood in the dry season (fig. 3). Riverine water flows at the surface from the western to the eastern part of the bay, layering over oceanic deep water with higher salinities. Vertical salinity gradients increase so that haline stratification is enhanced. Moreover, thermal heating of surface waters amplifies the stratification process in both seasons (figs. 4-5). Maximum temperature differences between surface and deep waters are about 2 Kelvin and lead to an additional thermal stratification of the water column. The subsequent thermohaline stratification results in pronounced vertical density gradients, especially from station L4 to station L10 (figs. 6-7). A maximum sigma difference between surface and deep waters of 6 kg/m³ can be detected at L4 during ebb phase in the rainy season (fig. 7).

Both stratification patterns described may support the development of eutrophication effects by improving the light supply for phytoplankton, especially in the middle section of the bay close to Paranaguá. Moreover, the vertical transport of oxygen may be hindered by thermohaline stratification of the water body.

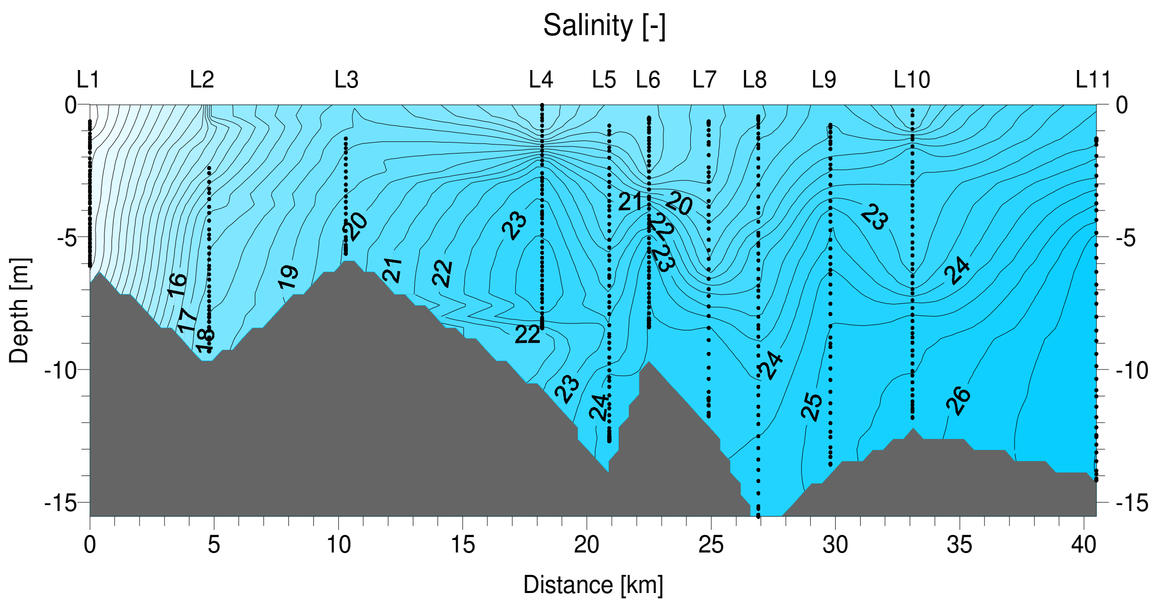

Fig. 3: Interpolated vertical salinity profiles on a longitudinal transect through the bay of Paranaguá in February 2008 during ebb phase in the rainy season (measurements at stations L1 (western part of the bay) to L11 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

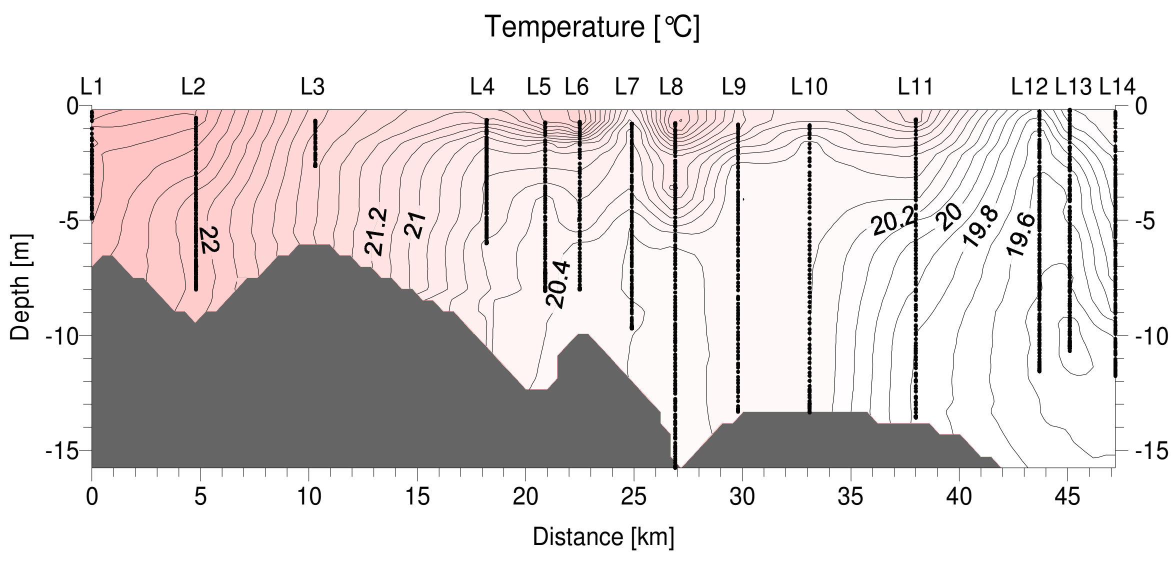

Fig. 4: Interpolated vertical temperature profiles on a longitudinal transect through the bay of Paranaguá in September 2007, springtime in southern hemisphere (measurements at stations L1 (western part of the bay) to L14 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

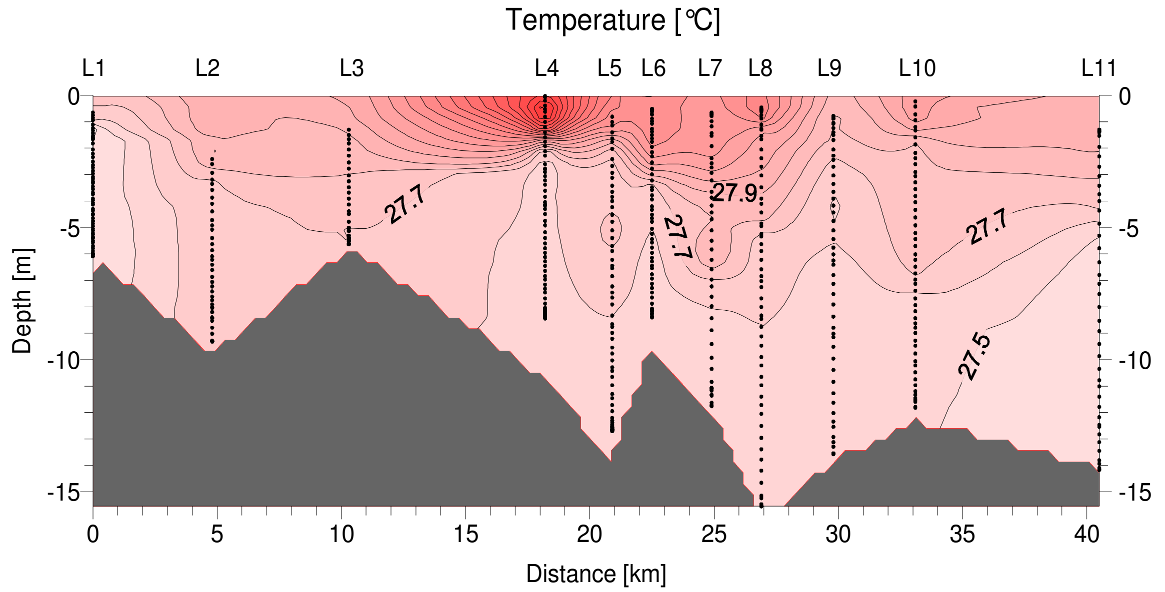

Fig. 5: Interpolated vertical temperature profiles on a longitudinal transect through the bay of Paranaguá in February 2008, summer in southern hemisphere (measurements at stations L1 (western part of the bay) to L11 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

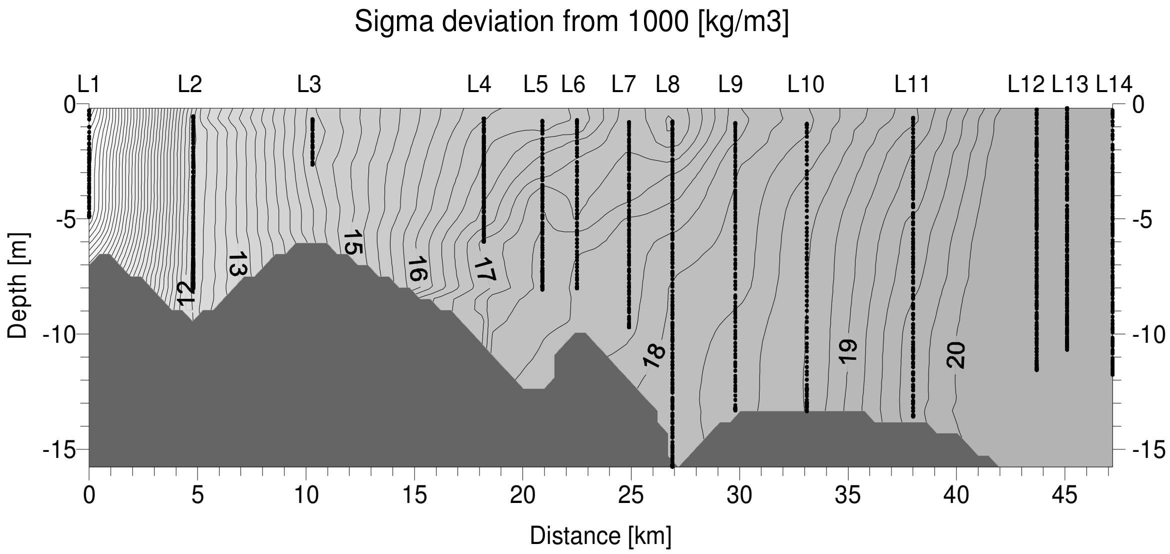

Fig. 6: Interpolated vertical density profiles (as deviation from 1000 kg/m³) on a longitudinal transect through the bay of Paranaguá in September 2007 (measurements at stations L1 (western part of the bay) to L14 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

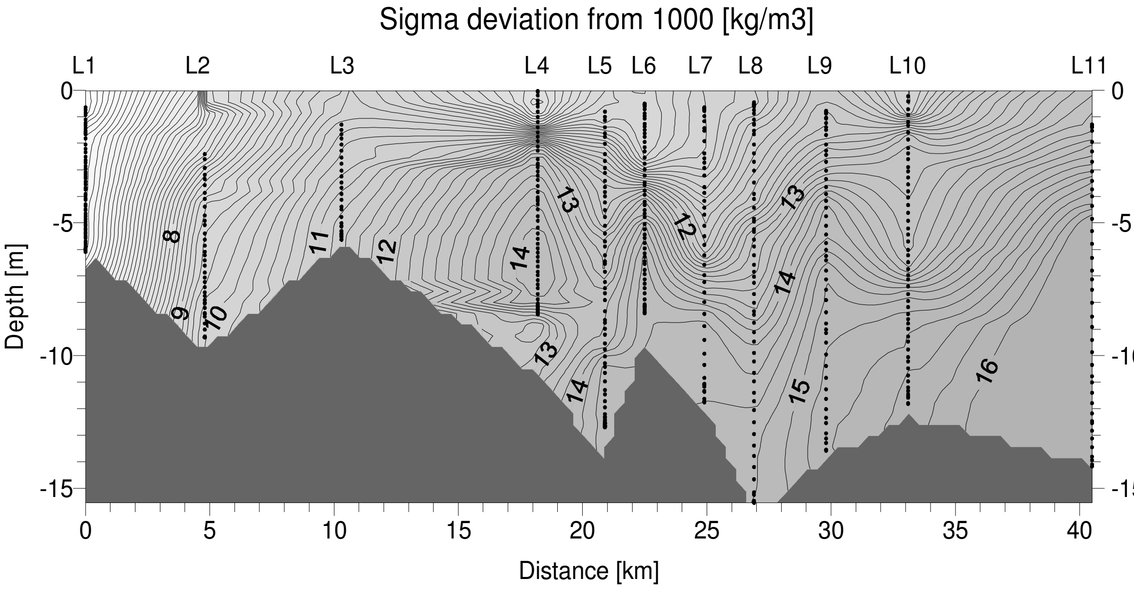

Fig. 7: Interpolated vertical density profiles (as deviation from 1000 kg/m³) on a longitudinal transect through the bay of Paranaguá in February 2008 (measurements at stations L1 (western part of the bay) to L11 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

2. Dissolved nutrients

In general, a typical distribution of dissolved inorganic nutrients (DIN, PO_4) can be observed along a longitudinal transect inside the bay of Paranaguá, especially during the rainy season. Higher concentrations can be found close to rivers and lower concentrations close to the mouth of the bay where nutrient inputs are diluted by incoming oceanic water.

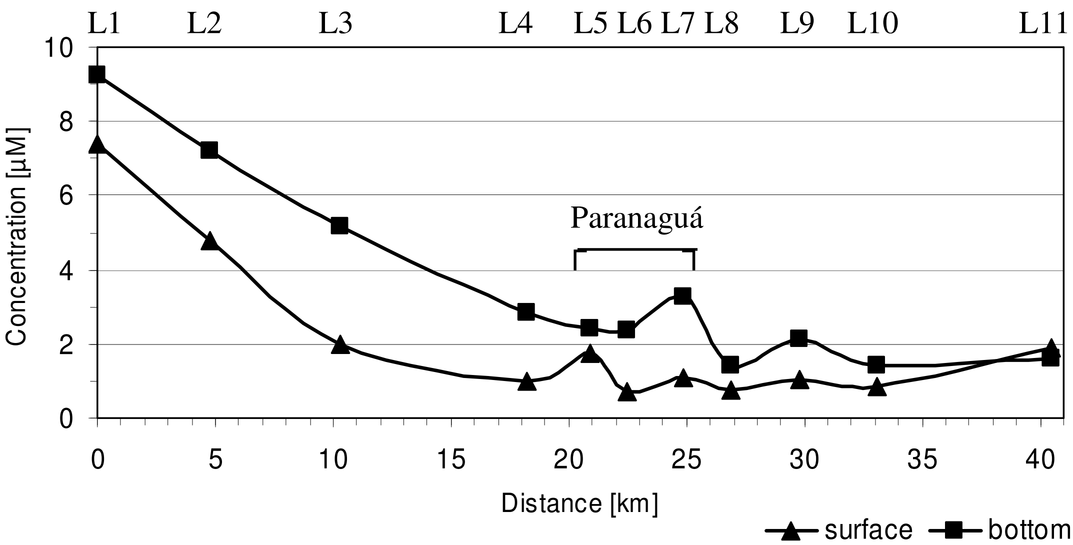

Fig. 8: DIN concentrations on a longitudinal transect through the bay of Paranaguá in February 2008, rainy season (surface = 1 m depth; bottom = 1-2 m above sediment surface)

At station L1, in the inner part of the estuary, dissolved inorganic nitrogen concentrations are about 7 µM DIN at the water surface and 9 µM DIN in deeper waters (fig. 8). Riverine inputs are diluted progressively along the bay so that DIN concentrations decrease down to less than 2 µM DIN at the seaward side of the transect. At L5 (surface) and L7 (bottom) DIN concentrations are slightly higher than the neighbouring values in the curve progression, which is supposed to be due to emissions from the city and harbour of Paranaguá. Especially ammonium concentrations increase by about 1 µM NH_4 in front of Paranaguá (fig. 9).

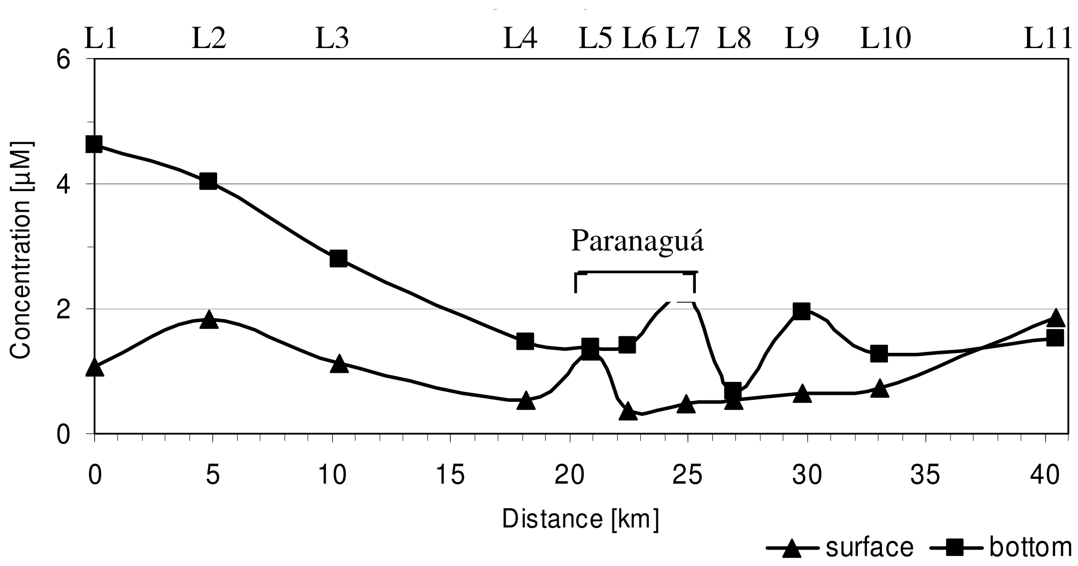

Fig. 9: Ammonium concentrations on a longitudinal transect through the bay of Paranaguá in February 2008, rainy season (surface = 1 m depth; bottom = 1-2 m above sediment surface)

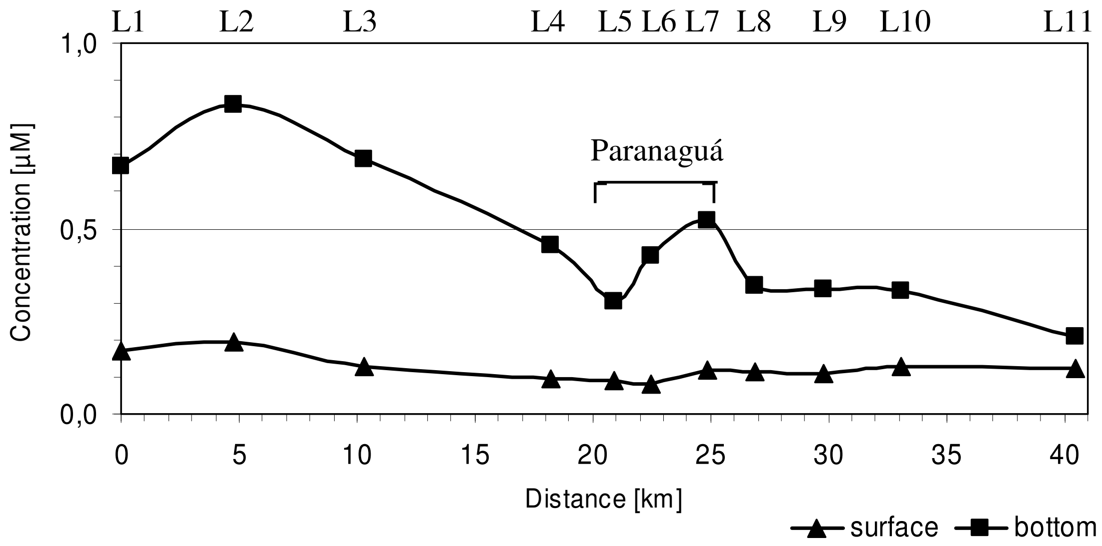

Fig. 10: Phosphate concentrations on a longitudinal transect through the bay of Paranaguá in February 2008, rainy season (surface = 1 m depth; bottom = 1-2 m above sediment surface)

In the case of phosphate concentrations, an increase close to Paranaguá is obvious especially in the deep water from 0.3 µM PO_4 at station L5 to 0.5 µM PO_4 at station L7 (fig. 10).

3. Particulate Matter

As in the case of nutrient distribution, the spatial gradients of suspended matter (SPM) and particulate carbon (POC) suggest an emission from the harbour of Paranaguá. Close to the soy terminals at the commercial harbour, the suspended matter concentration of the deep water ranges from 58-65 mg/l SPM (fig. 11) and the particulate organic carbon content exceeds 3000 µg/l POC (fig. 12). Moreover, particulate organic nitrogen concentrations in this area are about 400 µg/l PON (fig. 13). The results are consistant with the findings of subproject 3, where enhanced TOC concentrations of the sediment were found in the same area.

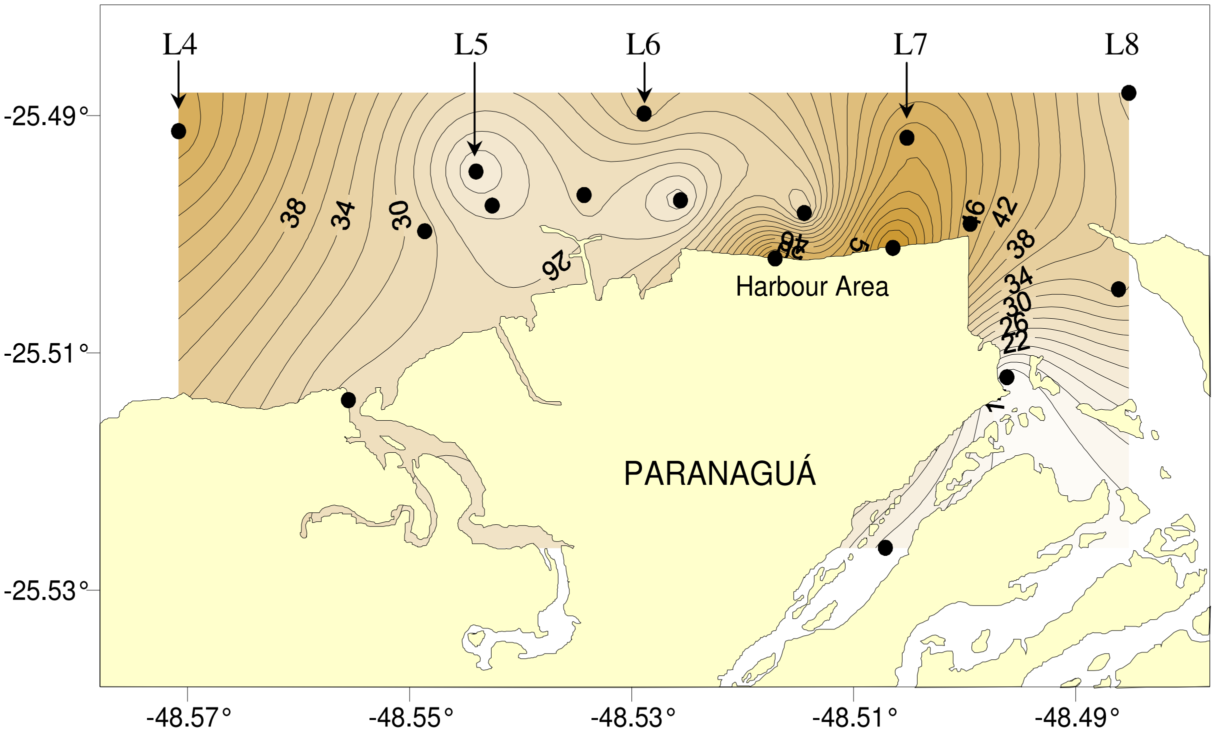

Fig. 11: Suspended matter concentration (SPM) [mg/l] of deep water samples close to Paranaguá in February 2008 (black dots = sampling stations; L4-L8 = from longitudinal transect)

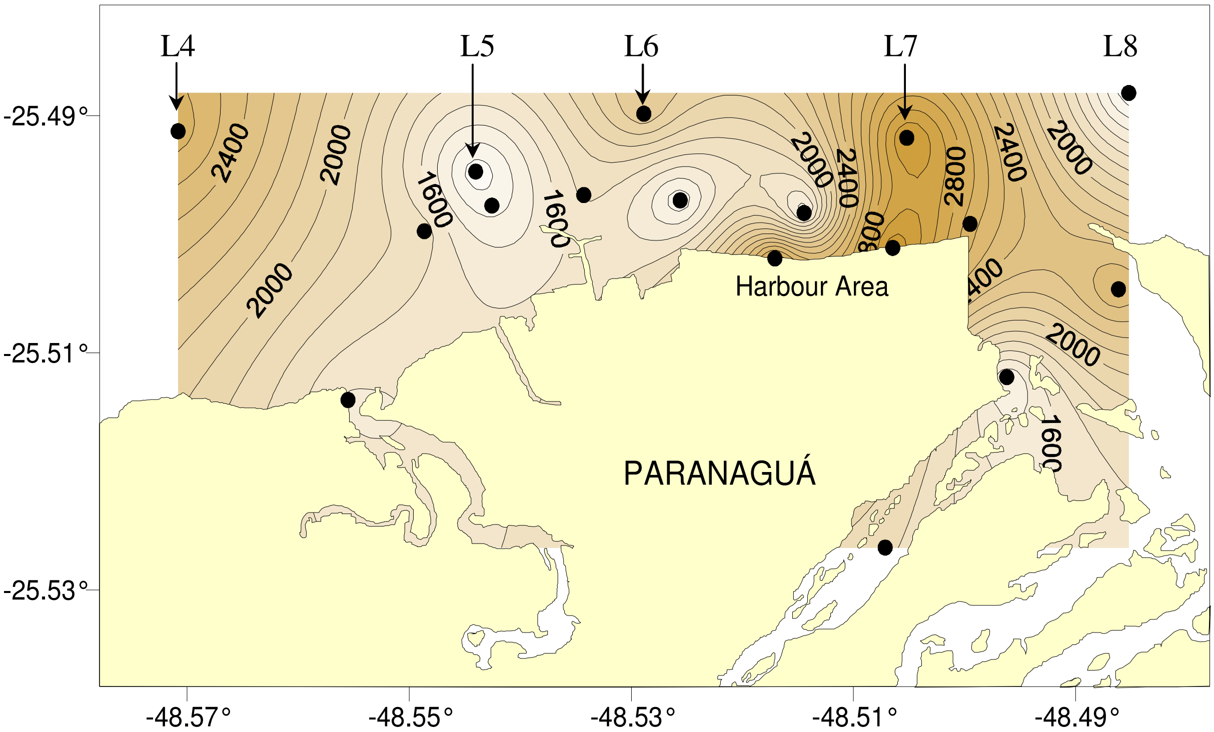

Fig. 12: Particulate organic carbon (POC) [µg/l] of deep water samples close to Paranaguá in February 2008 (black dots = sampling stations; L4-L8 = from longitudinal transect)

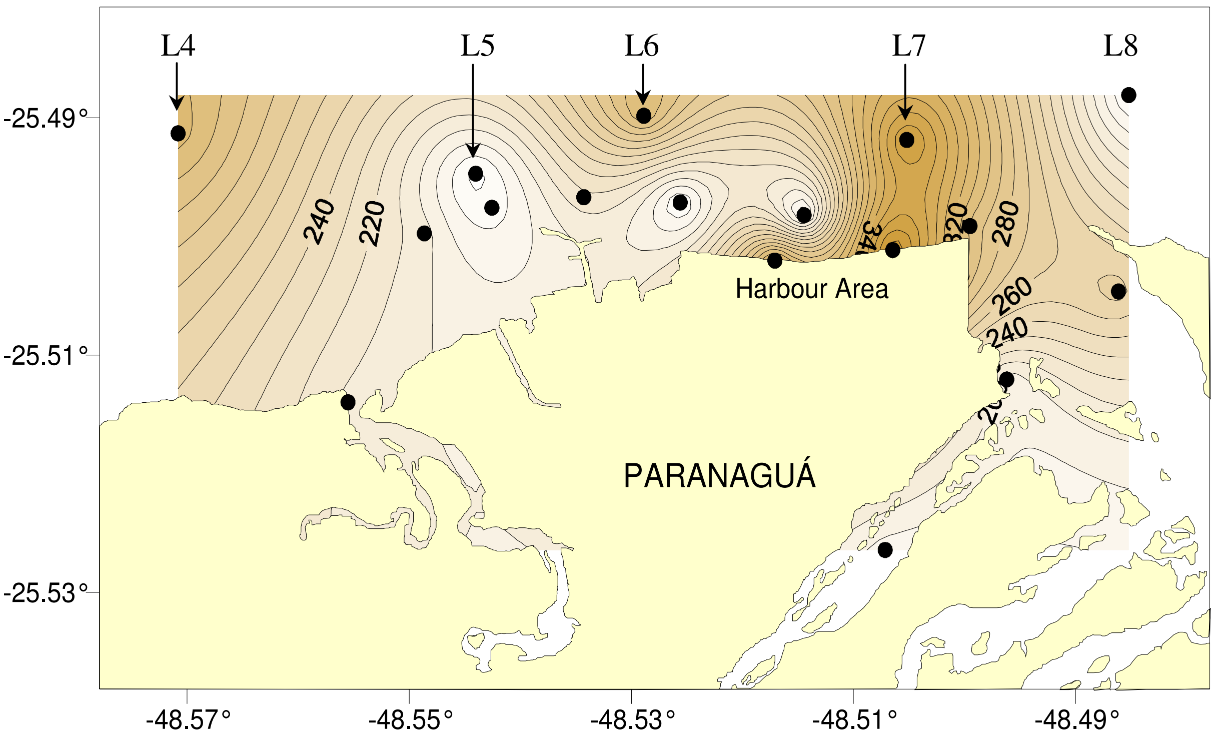

Fig. 13: Particulate organic nitrogen (PON) [µg/l] of deep water samples close to Paranaguá in February 2008 (black dots = sampling stations; L4-L8 = from longitudinal transect)

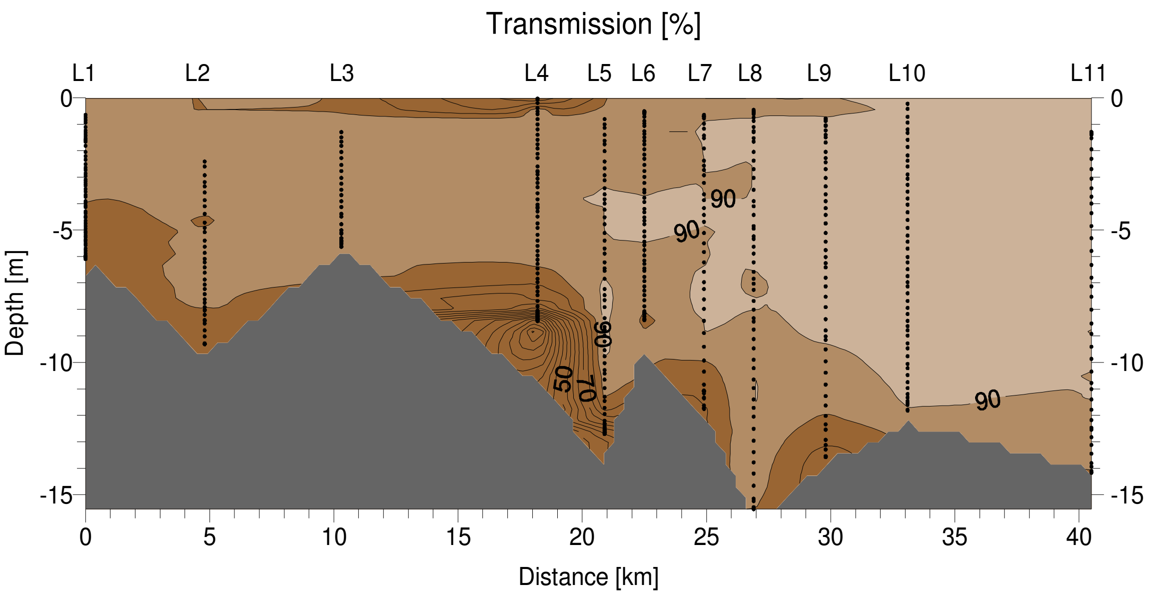

Fig. 14: Interpolated vertical transmission profiles on a longitudinal transect through the bay of Paranaguá in February 2008 (measurements at stations L1 (western part of the bay) to L11 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

Vertical transmission profiles on a longitudinal transect through the bay in February 2008 show that the near bottom water is subject to enhanced turbidity (fig. 14) with a minimum transmission of < 15 % at station L4 corresponding with a decreased transmission of 70 % at the surface. This feature represents the MTZ (Maximum Turbidity Zone) of the bay, where mixing processes of marine and freshwater cause enhanced sedimentation of particulate matter. Besides this estuarine phenomenon, the transmission is also decreased in the deep water at station L7, which is in accordance with the findings of higher SPM, POC and PON concentrations and thus probably due to particulate emissions from the harbour.

4. Nutrient inputs from the harbour and city of Paranaguá

Handling of bulk cargo is usually associated with freight-specific losses. On the basis of annual throughput data and consultants estimates for loss rates derived from subproject 6, the amount of cargo losses of fertilisers and soy was assessed with respect to nitrogen and phosphorus inputs to the marine environment.

4.1 Fertilisers

In 2007, about 4 mio. tons of (inorganic) mineral fertilisers containing both nitrogen (N) and phosphorus (P) compounds and 0.7 mio. tons of (organic) urea fertilisers containing nitrogen were handled at the harbour of Paranaguá (tab. 2). Nitrogen and phosphorus losses to the marine environment were calculated on the basis of a 0.01 % cargo loss rate of which a fraction of 75 % reaches the marine environment (Bergmann, pers. com.). The estimated annual nutrient loads from mineral fertilizer handling account for 50.9 t N and 53.9 t P, equaling a daily nutrient input of 139.5 kg N and 147.7 kg P to the bay. Moreover, 26.2 t/a N from urea fertilisers were estimated to be introduced to the bay, i.e. 71.8 kg per day.

Tab. 2: Annual fertiliser throughput at the harbour of Paranaguá in 2007 and estimated N- and P-losses to the bay

	Throughput [mio. t/a]	N-loss to the water [t/a]	P-loss to the water [t/a]
Mineral N&P-Fertiliser[1]	4.0	50.9	53.9
Urea Fertiliser	0.7	26.2	-

4.2 Soy products

The throughput of soy products accounted for 9.2 mio. tons in 2006, i.e. 7.2 mio. tons of soy beans and soy bean meal and 2.0 mio. tons of soy bean pellets (tab. 3). A loss rate of 0.015 % was applied for soy beans and soy bean meal, and 0.025 % for soy bean pellets respectively. A fraction of 50 % of lost soy products is assumed to be introduced to the marine environment, which leads to a total input of 790 tons of soy into the bay of Paranaguá.

Tab. 3: Annual throughput of soy products at the harbour of Paranaguá in 2006 and estimated loss of soy introduced to the marine environment

	Throughput [mio. t/a]	Loss [t/a]
Soy Beans & Soy Bean Meal	7.2	540
Soy Bean Pellets	2.0	250
Total	9.2	790

A laboratory experiment was conducted in order to estimate the nutrient release from decomposition of grinded soy products. The analysis showed that mainly ammonium (NH_4), dis-

[1] without insoluble phosphate rock

solved organic nitrogen (DON), dissolved organic phosphorus (DOP) and phosphate (PO_4) are released, while nitrate (NO_3) and nitrite (NO_2) are negligible. After an incubation time of 34 days a concentration of 1464 µM NH_4, 1313 µM DON, 139 µM DOP and 66 µM PO_4 was measured (fig. 15).

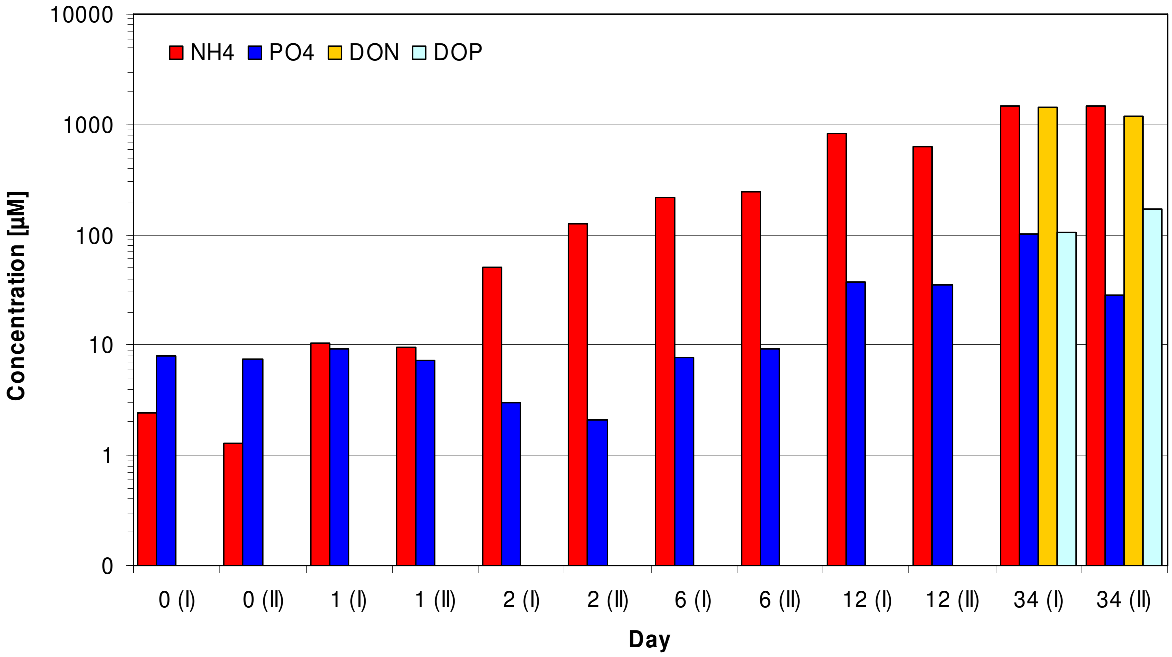

Fig. 15: Nutrient release from decomposition of 0.5 g pestled soy mixed in 1 litre destilled water during a laboratory experiment over 34 days (repeat determination I and II; DON and DOP concentrations exclusively determined on day 34; log scale on ordinate)

From the amount of soy products lost to the harbour water during cargo handling and the rate of nutrients released during the decomposition of soy the daily input of nutrients to the sea was estimated to amount to 79.4 kg NH_4-N, 71.2 kg DON, 16.6 kg DOP and 7.9 kg PO_4-P, i.e. 150.6 kg N and 24.5 kg P (tab. 4).

Tab. 4: Daily N- and P-release from soy lost during cargo handling

	Release from lost soy [kg/d]
Ammonium (NH_4-N)	79.4
Dissolved Organic Nitrogen (DON)	71.2
Dissolved Organic Phosphorus (DOP)	16.6
Phosphate (PO_4-P)	7.9

4.3 Comparison of inorganic nutrient inputs

The dissolved inorganic nutrient loads deriving from local sewage inputs from the city of Paranaguá, which have been assessed during the field campaign in February 2008, add to those from cargo handling. Altogether, anthropogenic dissolved inorganic nutrient inputs from fertilisers, soy and local sewage discharge account for 536.7 kg/d N and 185.5 kg/d P (tab. 5). For comparison, at the same time the daily nutrient loads of 11 main rivers of Paranaguá Bay accounted for 2352 kg DIN and 277 kg PO_4-P.

Tab. 5: Estimated daily inputs of inorganic nutrients from anthropogenic sources

	Nitrogen [kg/d]	Phosphorus [kg/d]
Local Sources	317.8	33.7
Mineral N&P-Fertilisers	139.5	147.7
Soy Products	79.4	4.1
Total	536.7	185.5

Dissolved inorganic nutrients are essential for phytoplankton growth. Based on the stoichiometric Redfield ratio (C:N:P = 106:16:1), an anthropogenic inorganic nitrogen input of 536.7 kg/d would allow for a daily phytoplankton primary production of 3 tons of phytoplankton carbon.

5. Phytoplankton biomass

Nutrient inputs as well as the thermohaline stratification favour growth conditions for the phytoplankton in the upper layer of the central part of the bay. In September 2007, maximum chlorophyll-*a* concentrations[2] of 4 µg/l were observed from stations L4 to L8 (fig. 16). In February 2008, a maximum concentration of 11 µg/l chlorophyll-*a* was observed at station L4 (fig. 17). Although, at least at the moment of the field surveys, these maxima are not in the order of magnitude of nuisance “High Biomass Blooms” (HBB), they form consistent patterns in the surface waters close to Paranaguá and may give rise to enhanced sedimentation of organic material with subsequent oxygen deficiency in the sediment. The occurrence of harmful algae blooms in Paranaguá Bay has been reported several times (Junior et al., 2006; Negri et al., 2004; Fernandes et al., 2001).

[2] as an indicator for phytoplankton biomass

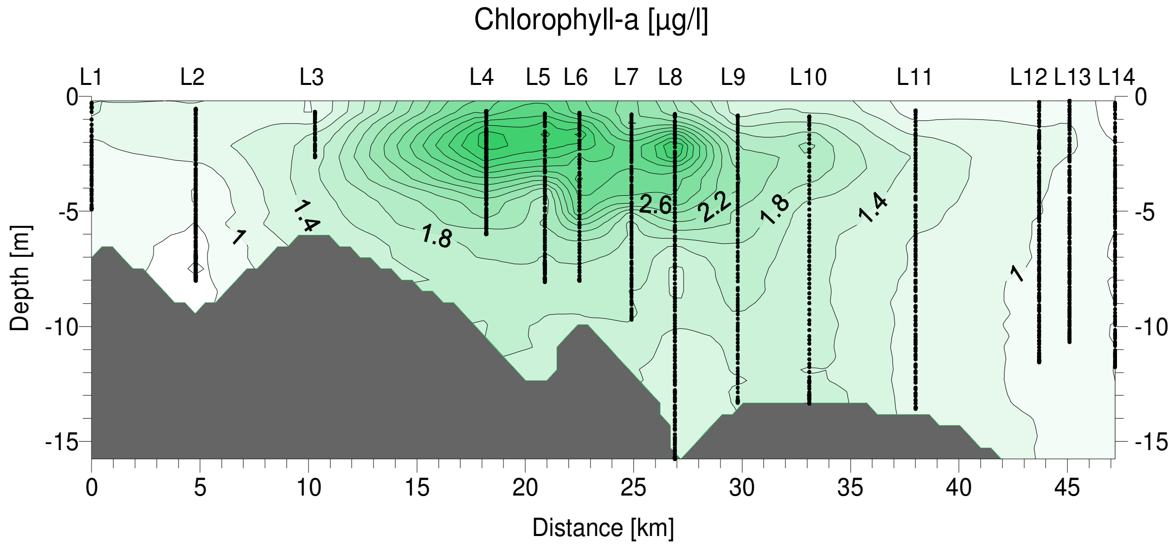

Fig. 16: Interpolated vertical chlorophyll-*a* profiles on a longitudinal transect through the bay of Paranaguá in September 2007 (measurements at stations L1 (western part of the bay) to L14 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

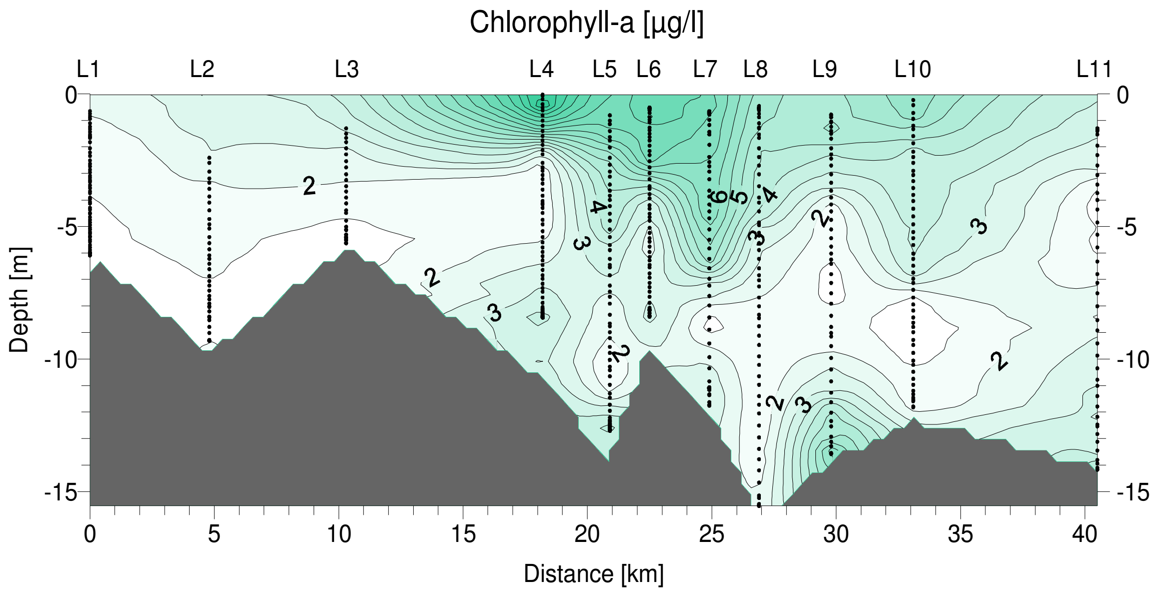

Fig. 17: Interpolated vertical chlorophyll-*a* profiles on a longitudinal transect through the bay of Paranaguá in February 2008 (measurements at stations L1 (western part of the bay) to L11 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

6. Oxygen regime

In September 2007, the oxygen saturation exceeded 100 % all over the bay, even in deep waters (fig. 18). Especially at sites of enhanced chlorophyll-*a* concentrations the oxygen regime was oversaturated due to strong photosynthesic activity. In February 2008, at some stations close to the "Maximum Turbidity Zone" (MTZ), the oxygen saturation fell below 80 % in the deep water, corresponding to areas with enhanced thermohaline stratification (fig. 19). Although the oxygen regime does not seem to be critical e.g. for fish, the measurements show that the deep water is subject to decreased oxygen saturation in some areas, especially in the inner part of the estuary.

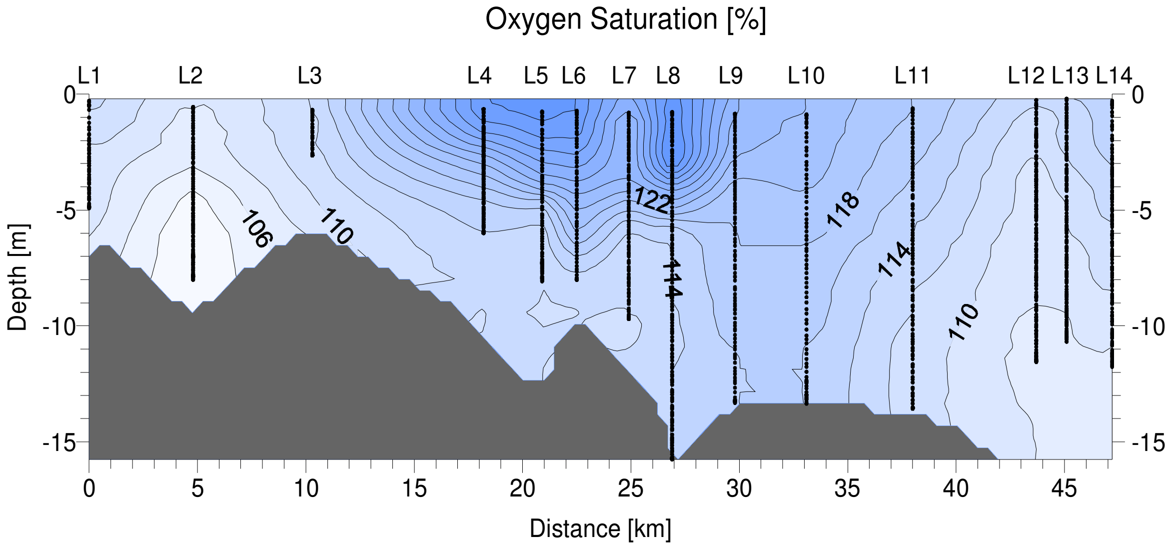

Fig. 18: Interpolated vertical oxygen saturation profiles on a longitudinal transect through the bay of Paranaguá in September 2007 (measurements at stations L1 (western part of the bay) to L11 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

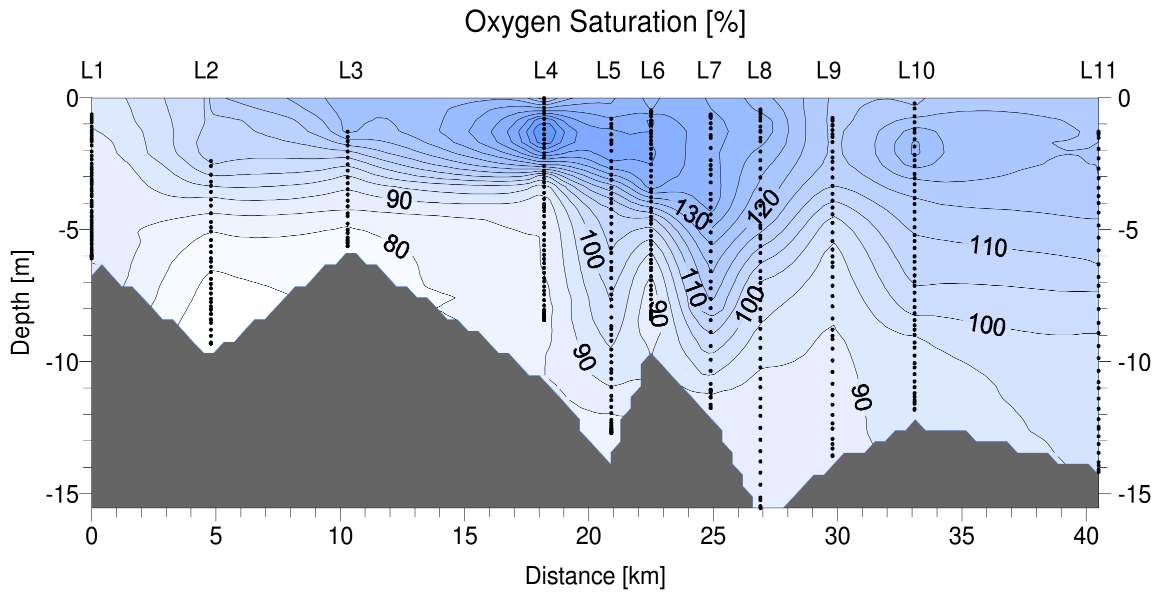

Fig. 19: Interpolated vertical oxygen saturation profiles on a longitudinal transect through the bay of Paranaguá in February 2008 (measurements at stations L1 (western part of the bay) to L11 (eastern part) are indicated by black dots; sediment surface indicated by dark grey area; profile superelevated 1:1000)

7. Conclusions

Anthropogenic nutrient immissions deriving from fertiliser and soy handling at the harbour and from sewage loaded local sources at Paranaguá are significant. Compared to the main rivers entering the bay, the anthropogenic inorganic nitrogen and phosphorus inputs account for a percentage of 23 % DIN and 67 % PO_4 of riverine inputs in the rainy season of February 2008. The percentage may vary with the season, but will even be higher in dry periods because of lesser river runoff. Although eutrophication effects were not detected during *in situ* measurements, anthropogenic nutrient inputs represent a substantial surplus in the nutrient budget of the bay and enhance the nutrient availability for primary producers like the phytoplankton.

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Results of Numerical Modelling

8. Numerical Modeling for the PEC

This section sums up development phases of a modelling system for the simulation of water levels, current velocities, waves, sediment transport, water quality and morphodynamics in the Paranaguá Estuarine Complex (PEC) in the South of Brazil. Both, two-dimensional depth-integrated (2DH) and three-dimensional (3D) models based on the Delft3D Modelling System developed by Delft Hydraulics in the Netherlands were developed. A coupled modelling system implementing a curvilinear grid with grid resolution in the horizontal varying from about 180 m in the outer parts to up to 20 m in the vicinity of the Paranaguá Harbour was developed (fig. 20). Over the vertical up to 10 layers have been used.

The strategy adopted in the development of the coupled modelling system was as follows: Initially, the flow and wave models were developed. At the same time the effectiveness of meteorological forcing for driving the process-based models was investigated. Wind gridded fields derived on the basis of wind measurement data at several locations along the PEC were imposed in the simulations. The flow and wave models were then used to set-up the sediment transport model. Finally, the various process based models for simulating bed evolution on the short and medium term covering periods of up to several years were coupled. In order to achieve high predictive capability for the full range of conditions typical to the study area, special attention was given to the development and performance of the models with the aid of field data. Selective measurements of sediment characteristics, bed forms, water levels, current velocities, suspended sediment concentrations and nutrient concentrations with a dense spatial and temporal coverage were used for this purpose. Moreover, existing quality standards for checking the performance of the models were adopted (Walstra et al., 2001; Van Rijn et al., 2002).

The models applied in the investigation area were nested with a larger scale model covering the entire PEC and part of the coastal area. Figure 20 shows the nesting sequence. The flow model covering the entire domain is a 2DH model driven by water levels resulting from field measurements and/or from several main astronomical constituents along the open sea boundaries and by wind fields covering the entire model domain (fig. 20d). A domain decomposition implementing higher resolution grids to enable accurate predictions in the vicinity of the harbour was set-up (fig. 20b).

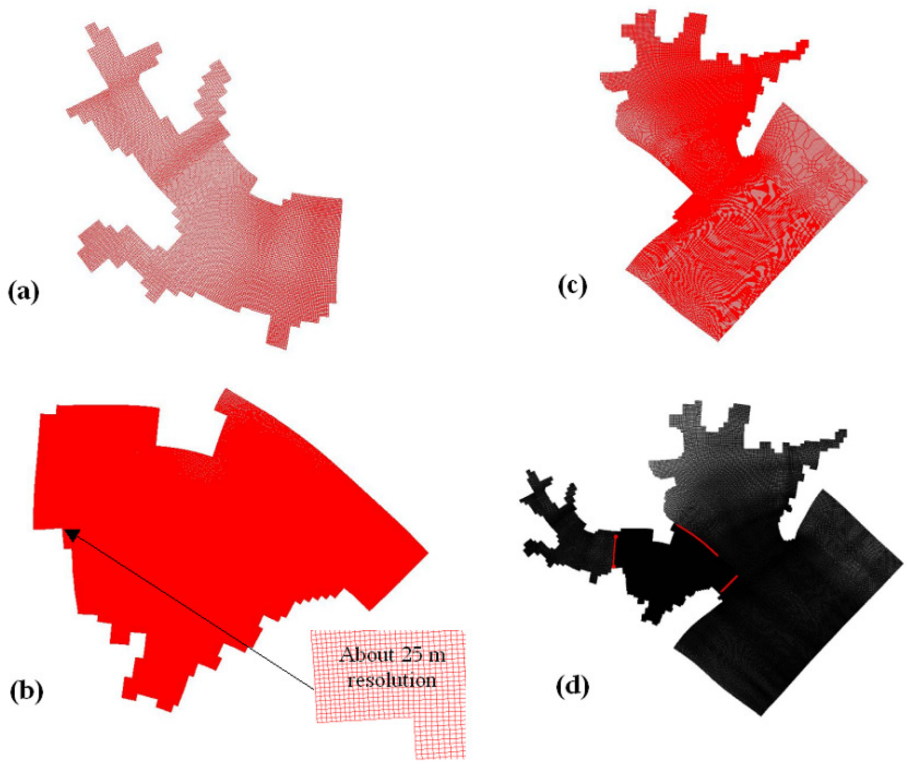

Fig. 20: Model nesting for the PEC

9. Flow model

Two-dimensional depth-integrated and a three-dimensional flow model were developed for the PEC. The model set-up as well as sensitivity studies and model calibration and validation procedures were carried out. Measurements of water levels, current velocities using acoustic profilers and salinity data with a good spatial coverage were used for this purpose. A numerical procedure for predicting bed-form dimensions and the associated bed roughness taking into account the flow conditions and sediment characteristics was applied. Figure 21 shows the resulting bed roughness for the PEC. The effect of spatially variable bed roughness on the flow was found to be quite significant. The resulting flow field in the study area is exemplified in figure 22. The effect of river discharges on the flow was found to be negligible. Adjustments of the estimated river discharges using salinity measurements were carried out in areas in which direct discharge measurements are not available. The validation results showed that the model is capable of reproducing water levels, current velocities and salinities in fair agreement with observations. Comparisons between modelled and computed water levels at two locations within the PEC are shown in figure 23. Figure 24 shows a comparison between modelled and measured depth-averaged current velocities at one transect across the navigation channel. It can be seen that the agreement between model results and measurements resulted quite good. A clear stratification of the flow is observed in the vicinity of the harbour. In general, the predictive ability of the flow model is better in the area between the harbour and the entrance to the system and during spring tides. On the basis of quality standards usually adopted, the performance of the model with regard to water levels and current velocity predictions was found to be good.

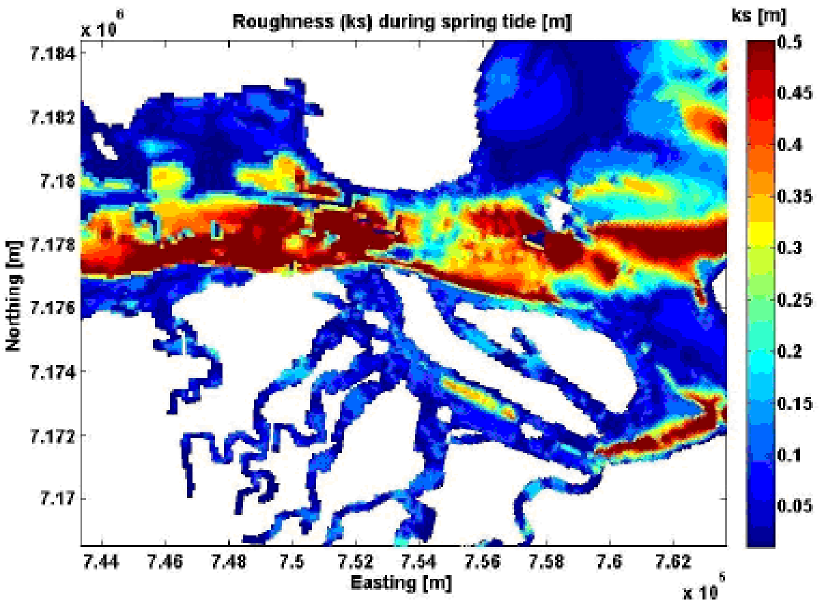

Fig. 21: Bed roughness map

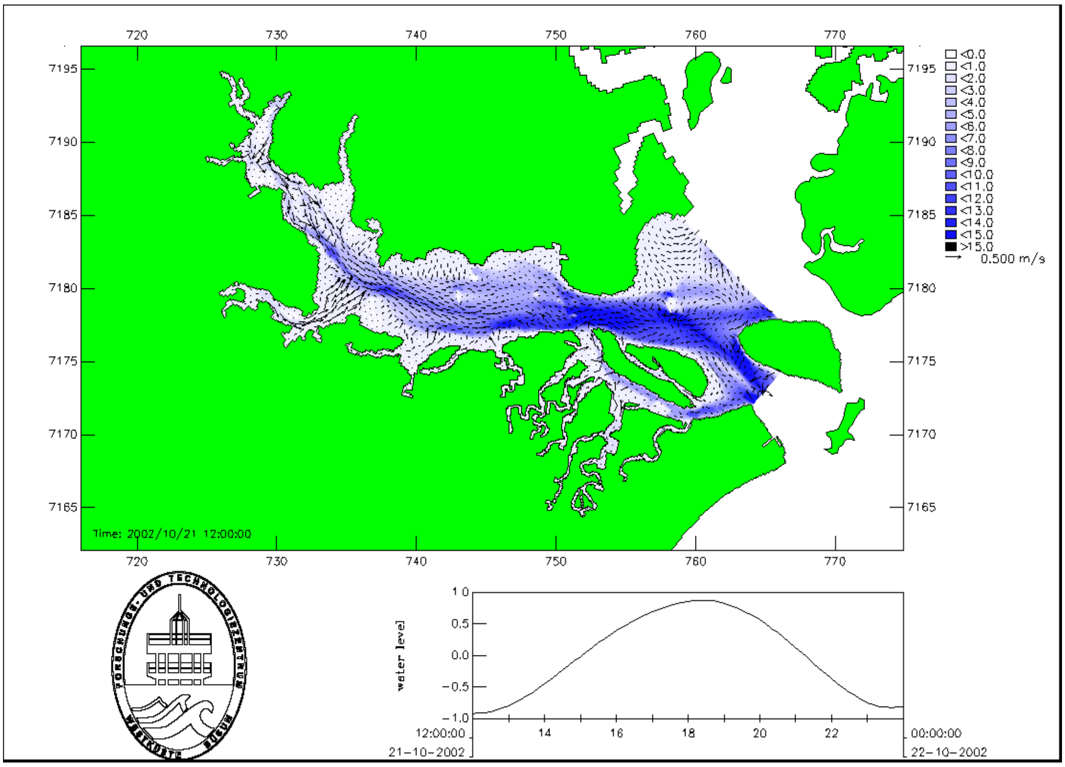

Fig. 22: Modelled flow field in the PEC

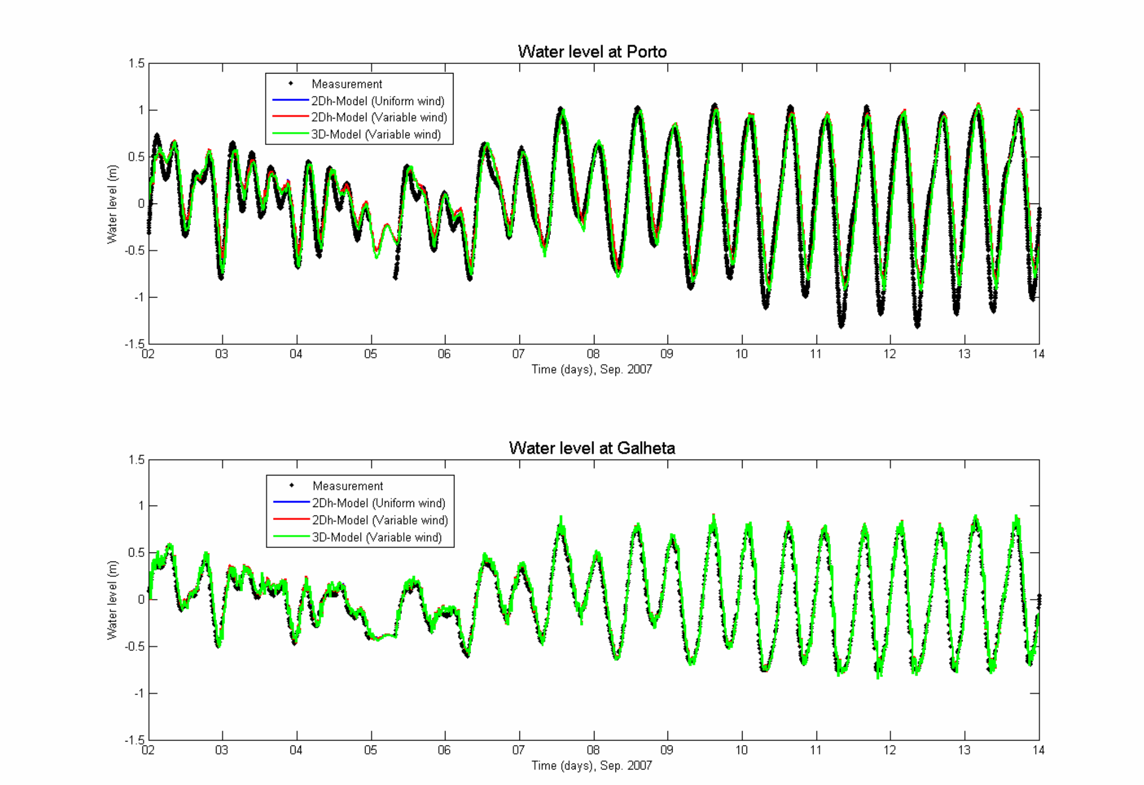

Fig. 23: Comparison between modelled and measured water levels

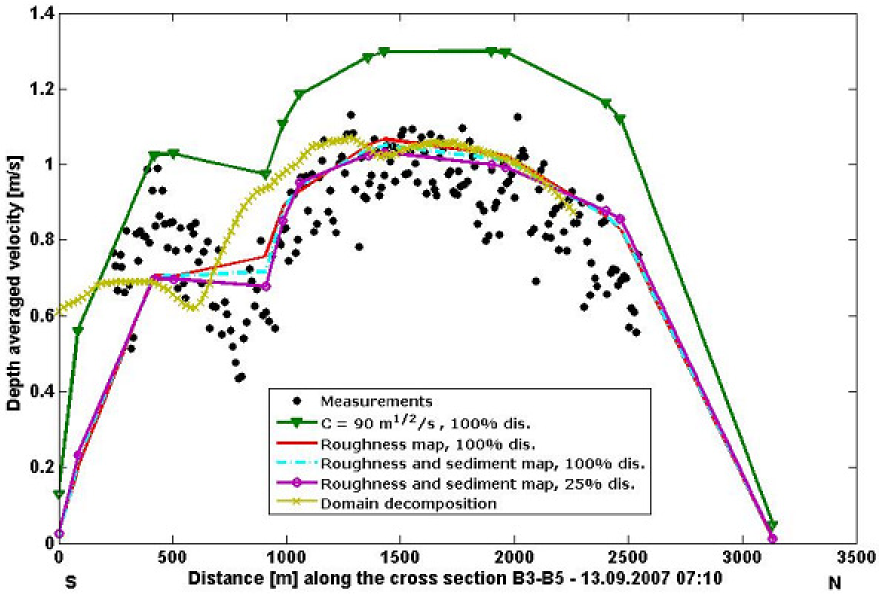

Fig. 24: Comparison between modelled and measured depth-averaged current velocities across the navigation channel

10. Wave model

To improve the understanding about the wave conditions in the PEC a wave model was developed. In this study the phase-averaged wave model SWAN, developed at the Delft University of Technology, the Netherlands, was set-up and applied to the PEC. SWAN is a third generation model, capable of simulating wave propagation, refraction, shoaling, wind-induced generation and dissipation due to white-capping, depth-induced wave breaking, bottom friction and wave-wave interactions. The same grid implemented in the flow model was used.

The relevance of the main processes affecting wave generation and dissipation was investigated in the framework of the project. Focus was given to the wave conditions in the vicinity of the harbour. The wave conditions during the most adverse weather conditions observed from April 2002 to September 2007 was investigated in detail. The fetch was found to have a major effect on wave generation in the study area. Wave model simulations as stand-alone were carried out initially for selected storms. The spatial variation in the significant wave heights (Hs) and resulting mean wave directions during the establishment of the maximum wave heights for the storm in April 2004 are shown respectively in figures 25 and 26. Significant wave heights up to about 0.6 m resulted near the harbour during the storms.

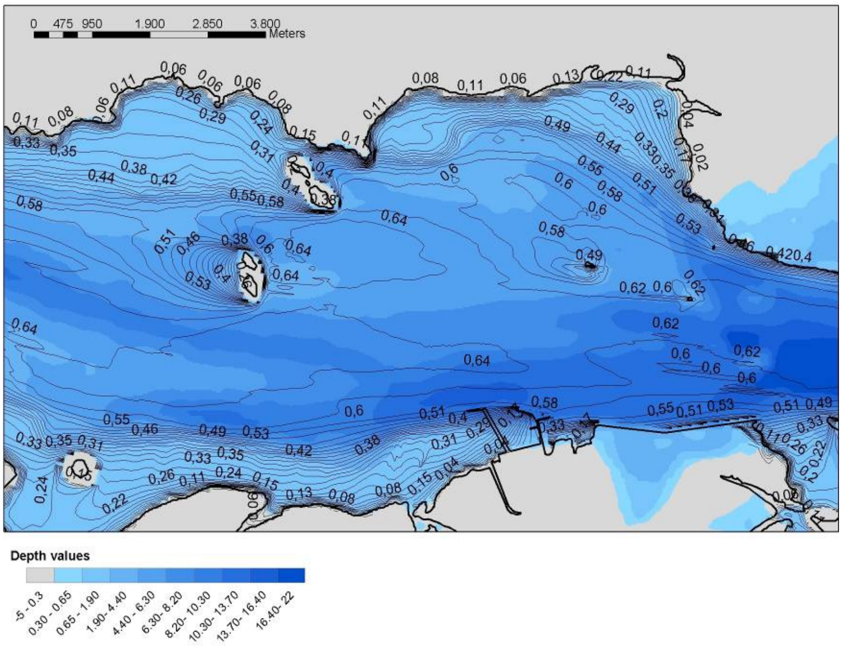

Fig. 25: Maximum wave heights (Hs) during the storm in April 2004

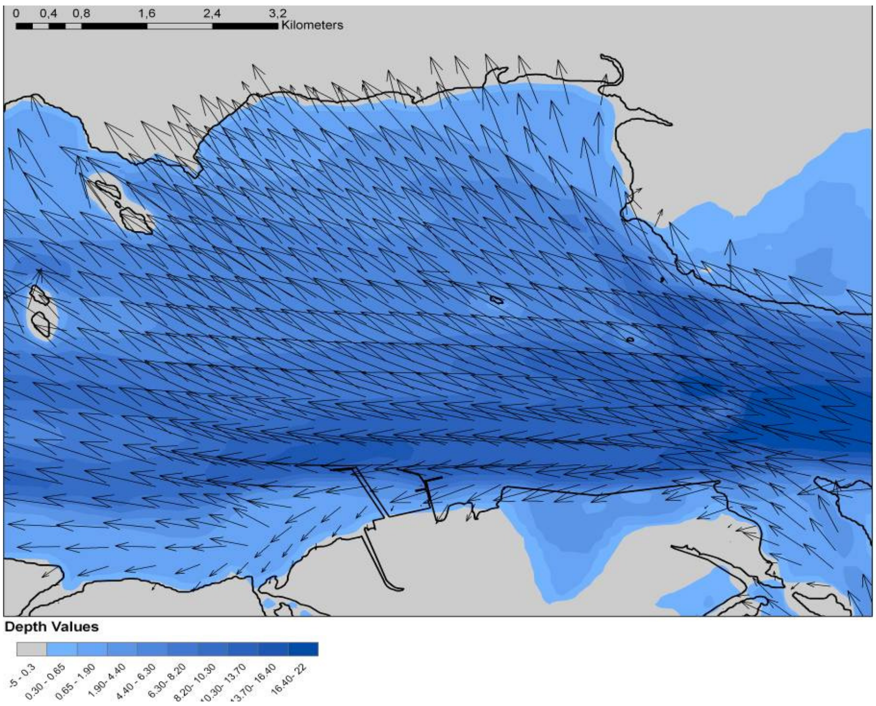

Fig. 26: Mean wave directions during the maximum wave heights (Hs) - storm in April 2004

The results obtained helped in advancing the development of the coupled process-based models for simulation of flow, waves and sediment transport in the PEC. It was found that although currents have a certain influence on the wave heights, the effect of the tidal variation resulted more significant. Moreover, waves were found to affect the current velocities in shallow water areas and should therefore be included for enhancing the predictions of sediment transport rates particularly for more adverse wind conditions.

11. Sediment transport model

Some results of the development phases and the application of the sediment transport model for the PEC are presented in this chapter. A two-dimensional depth-integrated sediment transport model was employed. Measurements of suspended sediment concentrations with a good spatial coverage were used for this purpose. The sediment transport model solves an empirical equation for the bed load and the convective-diffusion equation for the suspended sediment concentration and transport. Both, non-cohesive and cohesive sediment fractions are accounted for. Maps of sediment characteristics and percentages of muddy and sandy sediments obtained from extensive field measurements were used (fig. 27).

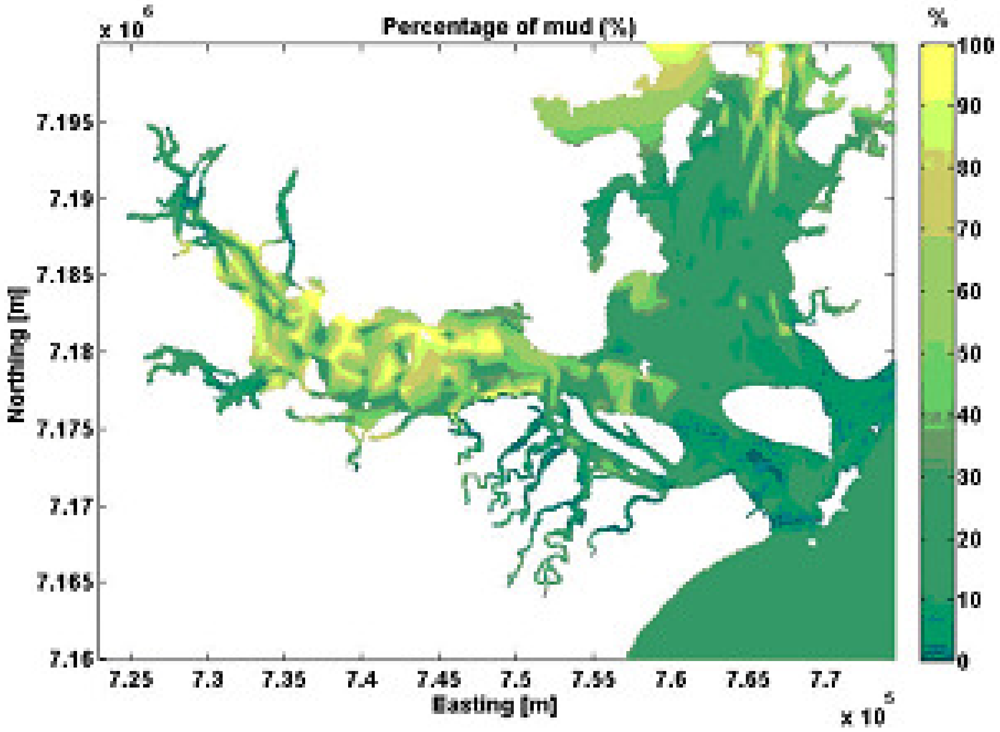

Fig. 27: Percentage of mud in the PEC

The model uses spatial variable bed roughness sizes taking into account the flow conditions and sediment characteristics. The results clearly indicated the relevance of bed roughness with respect to sediment transport predictions. The selection of the parameters in particular for cohesive sediments is strongly dependent on the tidal range. The validation results showed that the model is capable of reproducing suspended sediment concentrations in fair agreement with observations (fig. 28).

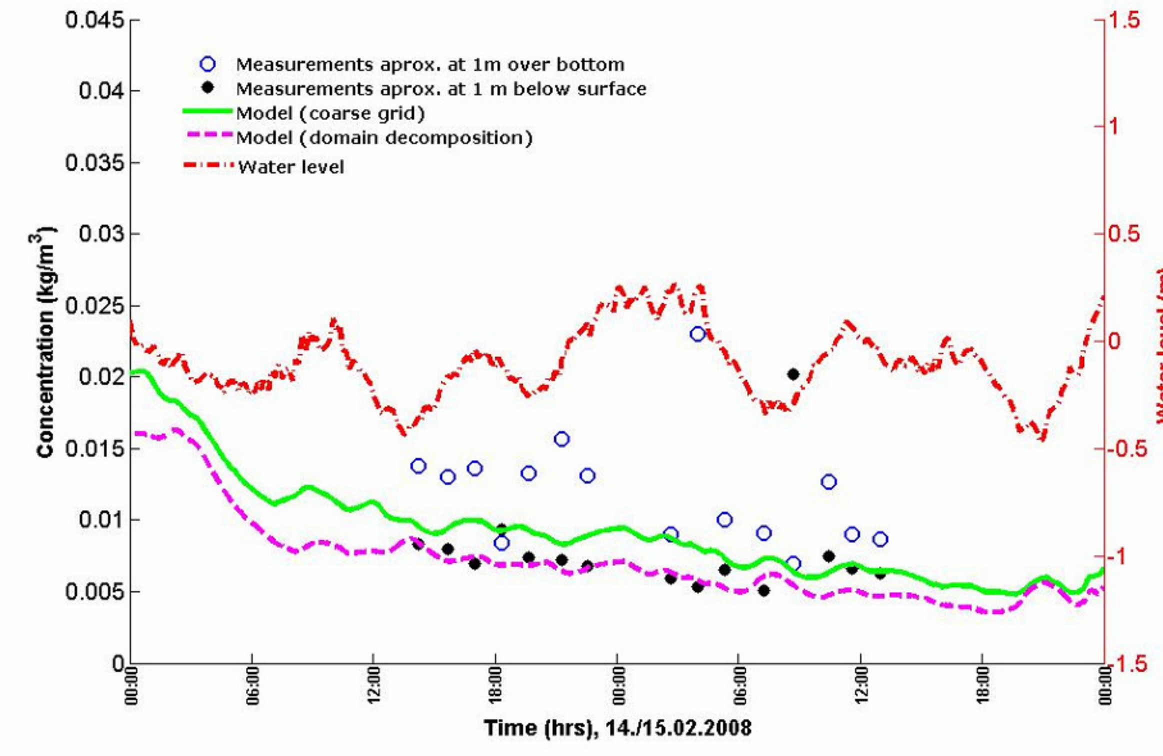

Fig. 28: Comparison between measured and modelled suspended sediment concentrations across the navigation channel (station B4) during neap tide

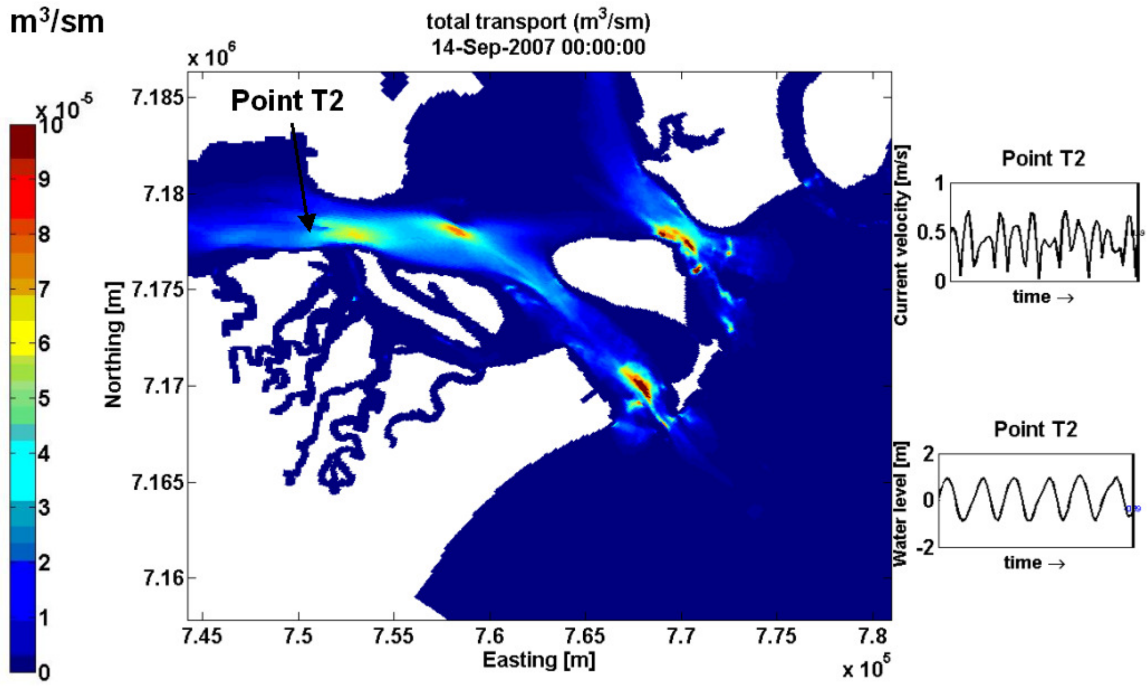

Fig. 29: Sediment transport along the navigation channel

Similar to the flow model, in general, the predictive ability of the sediment transport model is better in the outer parts of the estuarine system and during spring tides. On the basis of quality standards usually adopted, the performance of the model in predicting suspended sediment concentrations was found to range between reasonable and good. Results of the simulated sediment transport rates are shown in figure 29. The sediment transport model has been used quite effectively in optimizing the dumping locations in the study area. Applications of the model for optimization of the dumping locations in the PEC are presented in the overview to the joint project (Part A).

12. Water quality model

Selected results from the development phases and application of a water quality model for the Paranaguá Estuarine Complex are condensed in the following. In this study a two-dimensional depth-integrated model is used. Measurements of salinity and inorganic nutrient concentrations at the river mouths, the entrance to the bay and throughout the entire model domain were used respectively as boundary conditions and for calibration and validation of the model. Special designed measuring campaigns for assessing loads from sources of nutrient pollution were carried out. Emphasis was given to the predictive ability of the model in the vicinity of Paranaguá Harbour. In this study, phosphate was modelled as a conservative substance while simulations of ammonium took into account nitrification processes.

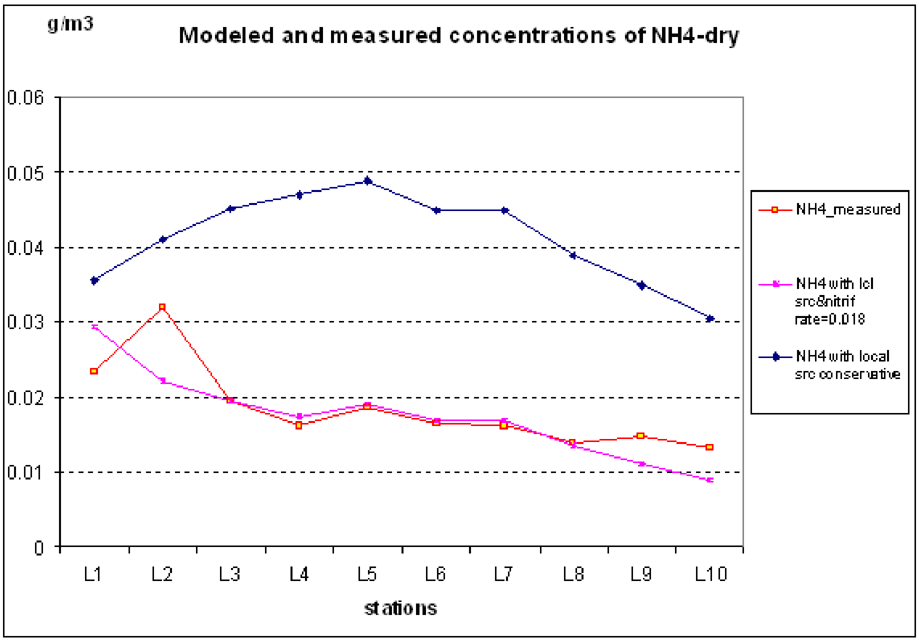

Fig. 30: Comparison between measured and modelled concentrations of NH_4-N along the navigation channel during the dry season

The nitrification rate was estimated on the basis of model calibration using measured ammonium concentrations along a transect from the coastal water towards the end of the bay. Results of the model validation indicate that the model is capable of describing the levels of nutrients in the area in good agreement with observations (fig. 30). The model has been used to assess the effect of pollution due to waste water input from Paranaguá city and fertilizer handling in the harbour (fig. 31). It was found that the city sewage is responsible for the high levels of ammonium in the vicinity of the harbour. However, ammonium levels in the bay are distinctly suppressed by the nitrification process. The harbour losses on the other hand lead to a significant increase in the levels of phosphate. Simulations assuming the implemantation of a planned, decentralized sewer system for the city reveals the effectiveness of this mitigation strategy.

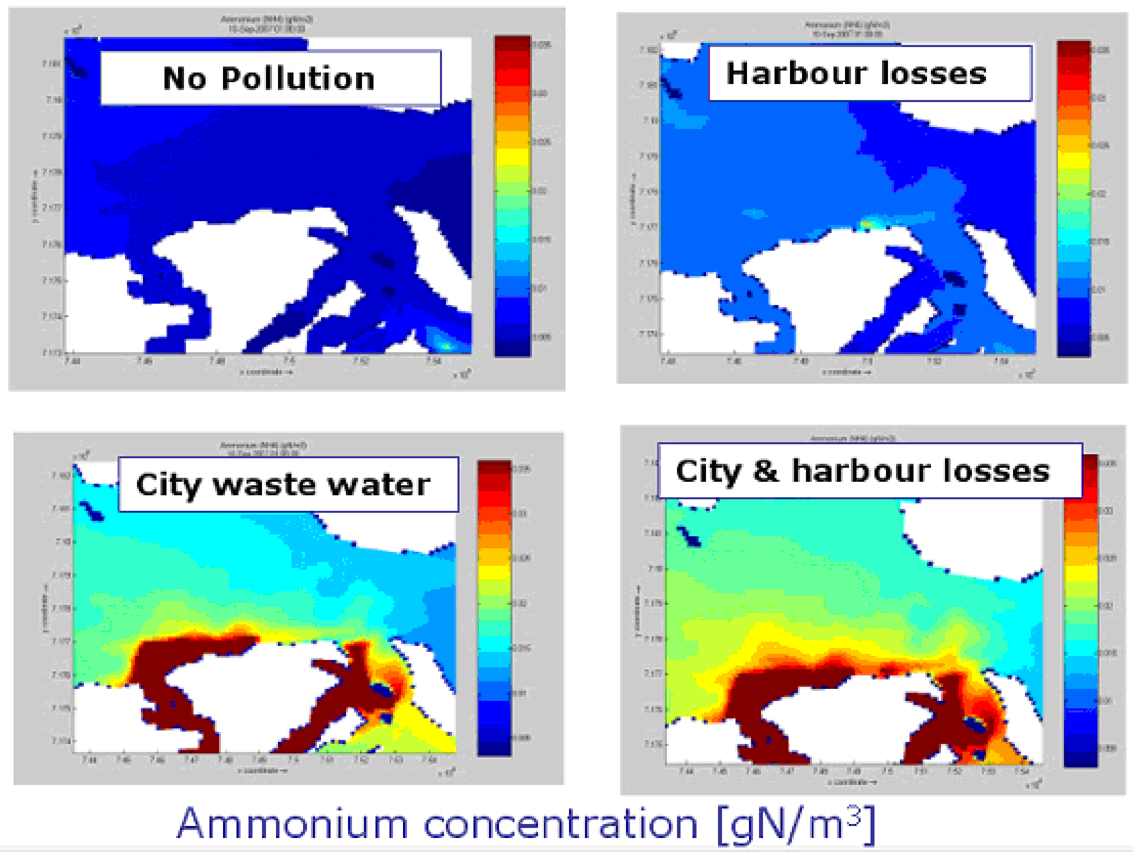

Fig. 31: Application of the model for the verification of the relevance of the various sources of pollution

13. Morphodynamic model

On the basis of extensively calibrated and validated models for simulation of tides, waves and sediment transport, a two-dimensional depth-integrated morphodynamic model for the PEC has been developed. Approaches were defined for input and process filtering techniques. A morphological accelerating factor in combination with a representative computational period was used. The model is calibrated and validated on the basis of volumetric analysis for several sub-domains along the navigation channel (fig. 32). Measurements of bathymetry along the navigation channel between 2004 and 2006 were used for this purpose. The volumetric analysis yielded objective and qualitative comparisons between computed and observed morphological changes covering periods of about one year (fig. 33).

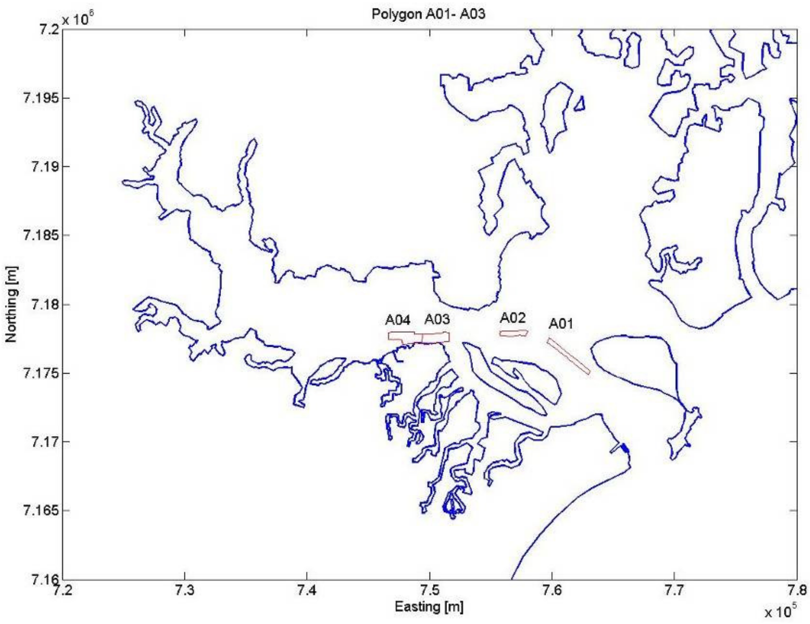

Fig. 32: Locations along the navigation channel taken for validation of the morphodynamic model

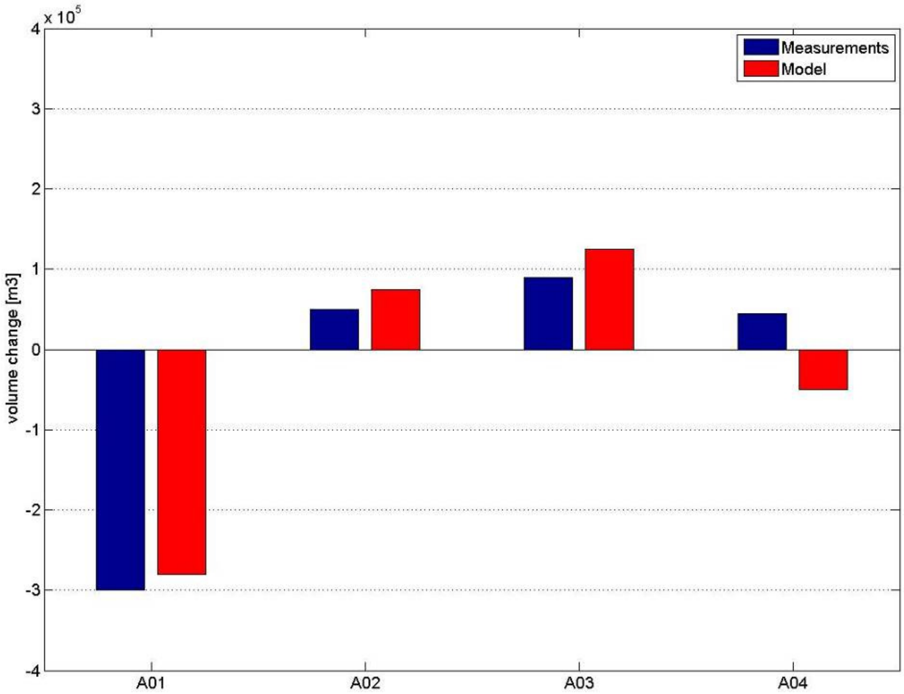

Fig. 33: Comparison of measured and computed volumetric changes along the navigation channel

Resorting to bulk volumes integrated over larger spatial scales, the model clearly has skill in predicting the overall effects of the sedimentation along the navigation channel. Similar to the flow and sediment transport models the predictive ability of the morphodynamic model is better between the mouth of the estuarine system and the harbour. The model has been used quite effectively to investigate the patterns of sedimentation along the navigation channel and near the harbour.

14. Oil spill model

An oil spill model developed by coupling the existing flow model with a particle-tracking model for simulation of the fate of oil spills in the bay was set-up. The model was applied to the simulation of oil spill accidents in the vicinity of the oil terminal. The selection of the model parameters was based on the main environmental settings, port infrastructure and oil types taking into account the Brazilian legislation applicable to contingency plans. Spill scenarios were modelled for a wide range of meteorological and hydrodynamic conditions in order to give best estimates of the trajectories as to help in the decision making for spill response planning.

Figures 34 and 35 show results of simulations considering the release of 500 t of Marine Fuel Oil-380 (MFO-380) at the pier of PETROBRAS in the Paranaguá Harbour. The fate of oil is shown respectively 4 hrs and 12 hrs after the release during the flood phase of a spring tidal cycle with winds of 5 m/s from the South. Although the extension of the slick with and without winds is of the same order after 4 hrs, the wind tends to deflect the slick to the North. Oil sheens drift towards the northern shore and the inner islands are encircled by the oil. Only little amount of oil reaches the shoreline. That means that within 4 hrs it would still be possible to contain most of the oil spilled if appropriate measures were taken. 12 hrs after the spill the slick moves towards the northern coast (fig. 35). The impact of the slick on the southern shoreline is small and the amount of oil sticking is low even though the oil slick and the highest concentration are located right in front of the northern shore. Having this in mind, an oil spill response team could contain the slick at the northern shore to avoid further damage in other parts of the bay.

Figure 36 shows the fate of oil after 12 hrs for the same conditions as above without wind. The influence of the wind on the slick is quite evident. The shape and extension of the fate of oil is significantly affected despite the low wind velocities. The results of the simulations with no wind show that the lateral extension of the fate reaches from the Isle of Cotinga in the East to the Isle Guararema in the West. The fate extends in north-south direction from the harbour to the northern shore. Over 20 % of the oil sticks to land. Compared to the scenario with wind (fig. 35), the amount of oil sticking to land after 12 hrs is much higher. This may be due to the proximity of the release point to the southern shore and due to the presence of mangrove channels which enlarge the area that may be affected by oil beaching.

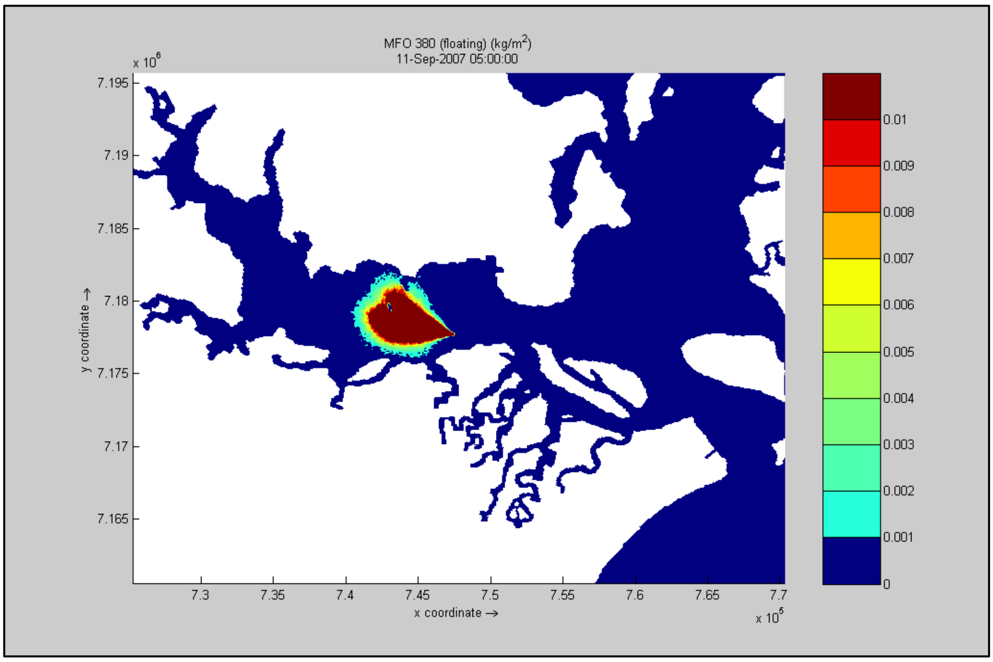

Fig. 34: Concentration of oil in kg/m^2 4 hrs after the spill: 500.900 kg floating, 2.835 kg evaporated, 249 kg beached

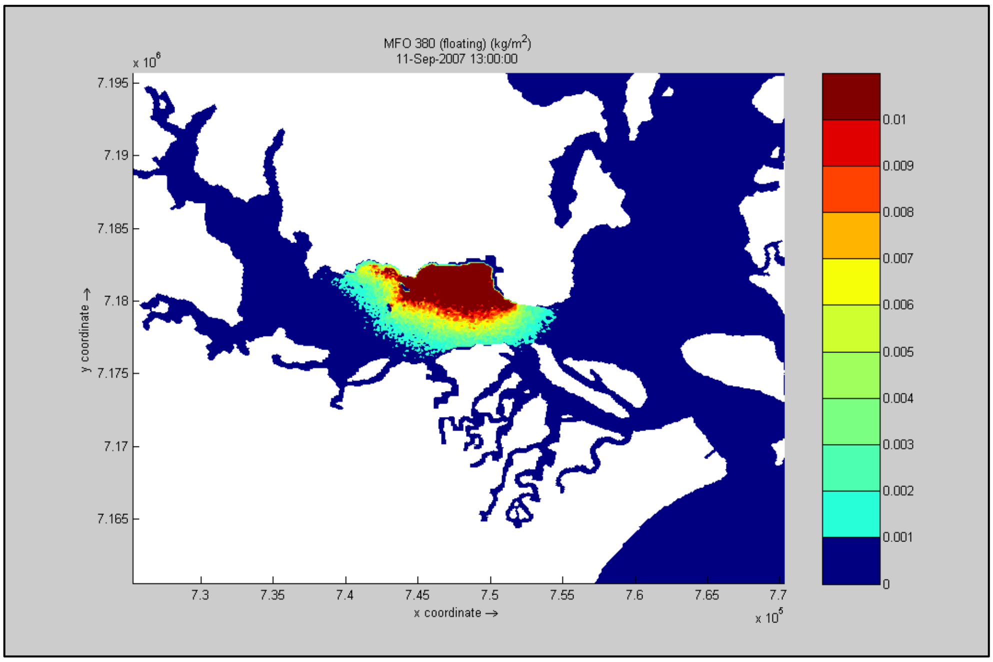

Fig. 35: Concentration of oil in kg/m^2 12 hrs after the spill: 459.000 kg floating, 9.591 kg evaporated, 35.360 kg beached

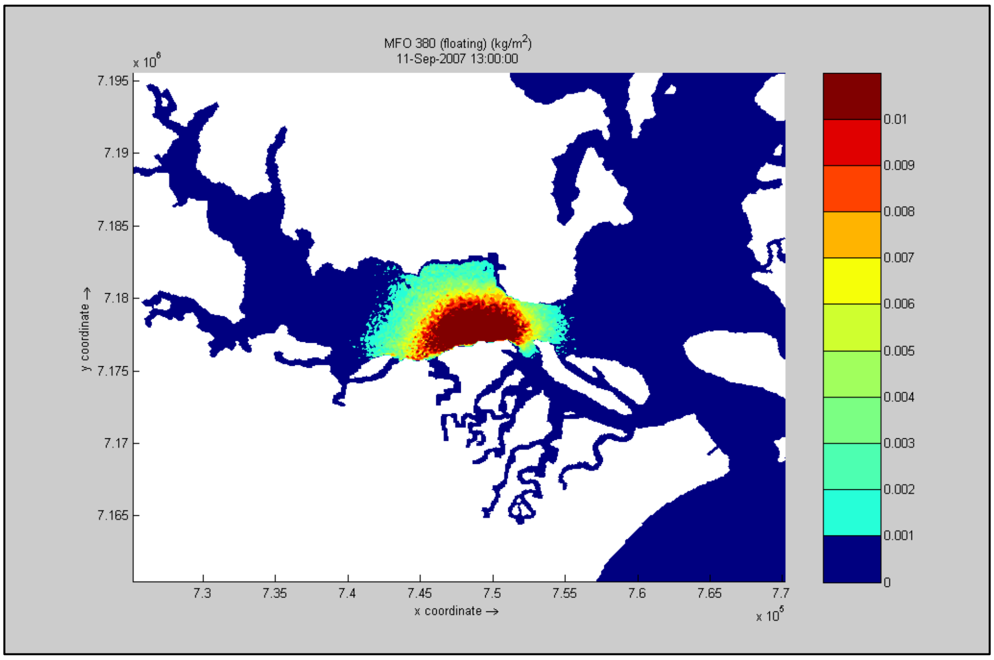

Fig.36: Concentration of oil in kg/m^2 12 hrs after spill-no wind: 392.800 kg floating, 8.895 kg evaporated, 102.400 kg beached

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18. abstract
Transport processes, morphodynamics and aspects of water quality in the vicinity of the harbour and central bay of Paranaguá/Southern Brazil were analysed on the basis of field measurements and high-resolution numeric models. Calibrated and validated models were applied for scenario simulations with focus on options for dredging and dumping, nutrient emissions from the harbour and city of Paranaguá and potential oil spills at the Petrobras pier. Along with the findings derived from field measurements, results from model simulations represent the basis for the development of contingency plans and recommendations for a sustainable harbour management.

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Schlussbericht

TP2 Numerische hydro- und morphodynamische Modellierung der Sedimentbewegung am Eingang des Ästuarsystems von Paranaguá

im Verbundprojekt

Nachhaltiges Umweltmanagement in brasilianischen Häfen

TECHNISCHE UNIVERSITÄT DARMSTADT

Institut für Wasserbau

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Vorhabenbezeichnung: **TP2 Numerische hydro- und morphodynamische Modellierung der Sedimentbewegung am Eingang des Ästuarsystems von Paranaguá**	
Laufzeit des Vorhabens: **01.11.2006 - 31.10.2009**	
Berichtszeitraum: **01.11.2006 - 31.10.2009**	
Projektleiter: **Prof. Dr.-Ing. habil, Prof. h.c. Ulrich C. E. Zanke** Projektbeteiligte: **Dipl.-Ing. Jan-Gregor Dahlem**	

I. SCHLUSSBERICHT

1. Aufgabenstellung

Der Hafen von Paranaguá sowie die Fahrwasser zum Hafen ab der Isla do Galheta vor dem Eingang zur Bucht von Paranaguá müssen immer wieder gebaggert werden, um die für die Schifffahrt notwendigen Wassertiefen zu gewährleisten. Aus diesem Grund müssen jährlich etwa 2 Millionen m³ Sediment gebaggert werden. Dies ist nicht nur sehr kostenintensiv, sondern auch ein Eingriff in die Natur. Zwar kann der größte Teil des Sediments auf dem Kontinentalschelf verklappt werden, jedoch sind hierzu lange Transportwege erforderlich, was wiederum zu hohen Kosten führt.

Neben den ökologisch unbedenklichen Sedimenten sind auch belastete Sedimente zu erwarten. Besonders im unmittelbaren Hafenbereich ist durch das Verladen von Düngemitteln mit Belastungen zu rechnen. Auch Belastungen mit Schwermetallen und Ölen sind nicht auszuschließen.

Das Teilprojekt 2 hat zum Ziel, die Bagger- und Verklappungsprozesse zu optimieren, um negative Umwelteinflüsse zu minimieren und Kosten zu senken.

2. Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

Das TP wurde im Rahmen des bilateralen Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ durchgeführt

3. Planung und Ablauf des Vorhabens

Das Teilprojekt 2 sollte im 2. Quartal 2006 starten. Prof. Zanke und Dr. Mewis waren zum Kick-Off-Meeting in Pontal do Sul. Erste bereits vorhandene Daten konnten gesammelt und Problemstellungen vor Ort diskutiert werden. Die Stelle des Wissenschaftlers (BAT IIa) konnte aufgrund der kurzfristigen Bewilligung und der Marktsituation erst zum 01. Januar 2007 besetzt werden.

Das hydrodynamische Modell wurde in der ersten Hälfte 2007 aufgesetzt, das morphodynamische Modell lief, gekoppelt mit dem Wellenmodell, erstmals Ende 2007. An der ersten Messkampagne im September 2007 nahm Dipl.-Ing. Gregor Dahlem teil. Er führte Tiefenmessungen im Bereiche der Barre am Eingang der Bucht durch, um die Datengrundlage des Modells zu verbessern. Bei der zweiten Messkampagne nahm wiederum Dipl.-Ing. Gregor Dahlem teil. Es wurden Strömungs- und Wellenmessungen im Eingangbereich der Bucht durchgeführt.

Die gewonnenen Daten dienten im weiteren Projektverlauf der Kalibrierung und Validierung der Modelle.

4. Wissenschaftlicher und technischer Stand, an den das Vorhaben angeknüpft wurde

Die Computersimulationen wurden mit dem an der TU Darmstadt entwickelten Programm TIMOR3 (Morphodynamik), welches mit dem Wellenmodell WWM gekoppelt wurde, durchgeführt.

5. Zusammenarbeit mit anderen Stellen

Die Zusammenarbeit erfolgte auf brasilianischer Seite in erster Linie mit Prof. Marone und seinen Mitarbeitern vom CEM. Auf deutscher Seite wurde vor allem wegen ähnlicher Fragestellungen mit dem Forschungs- und Technologiezentrum Weatküste kooperiert. Aber auch mit dem Forschungszentrum Terramare.

6. Publikationen

DAHLEM, G., U. ZANKE, A. ROLAND: Gekoppelte Modellierung von Morphodynamik und Seegang am Beispiel der Bucht von Paranaguá, 2009, Hansa (April 2009), p.104f.

DAHLEM, G.: Jungwissenschaftlertreffen Kassel 2007: Morphodynamische Modellierung am Eingang zum Ästuarsystem von Paranaguá.

DAHLEM, G., U. ZANKE, A. ROLAND, P. MEWIS: Proceedings to the Chinese-German Joint Symposium on Hydraulic and Ocean Engineering 2008 : Coupled Sediment and Wave Modeling – A Morphodynamic-Numerical-Simulation of the Paranaguá Bay.

DAHLEM, G., A. ROLAND, U. ZANKE, P. MEWIS: Coupled Sediment and Wave Modeling – A Case Study of Paranaguá Bay, Brazil, Proceedings to thr Hydroinformatics Conference, 2009, Concepcion, Chile.

DAHLEM, G., U. ZANKE, M. GANDOR, E. MARONE: Morphodynamics at the Mouth of the Paranaguá Estuarine System in Brazil, Ocean Dynamics (in Vorbereitung).

GANDOR, M., E. MARONE, G. DAHLEM, U. ZANKE: Wave Climate at Paraná State, Southern Brazilian Coast, Ocean Dynamics (in Vorbereitung).

II. ERFOLGSKONTROLLBERICHT

Der Zeitplan konnte, bis auf den unter I. genannten leicht verzögerten Beginn, eingehalten werden.

Die Mittel wurden wie beantragt eingesetzt. Jedoch gab es, im Rahmen des vom BMBF zugelassenen Anteils, eine Verschiebung hin zu den Personalkosten.

Das im Vorhaben erstellen morphodynamische Modell kann für weitere Untersuchungen in der Bucht von den brasilianischen Projektpartnern genutzt werden. Die innerhalb des Vorhabens erzielten Ergebnisse zu den simulierten Baggerungen und Verklappungen können von den lokalen Verantwortlichen aufgegriffen werden, um das Baggergutmanagement entsprechend anzupassen.

Von der TU Darmstadt wurden im Rahmen des Projektes keine Erfindungen gemacht und keine Schutzrechtsanmeldungen vorgenommen.

III. DETAILED DESCRIPTION

The dredging as well as the dumping of sediments in the area is simulated with the coupled models. Furthermore it is investigated whether a training structure along the outer navigation channel can reduce the amount of the material that has to be dredged.

The project area is located at the Atlantic coast of the state of Paraná in southern Brazil. The Bay of Paranaguá has an overall water area of about 600 km² and consists of two sub-systems. These are the real Bay of Paranaguá with a west-east orientation and the Bay of Laranjeiras with a north-south orientation (fig. 1). The port of Paranaguá is located inside the bay of Paranaguá. It can only be reached by bigger ships through the navigation channel between Isla do Mel and Isla de Galheta. To enable shipping in the navigation channel extensive maintenance dredging has to be undertaken. The channel is dredged to a depth of 12 m.

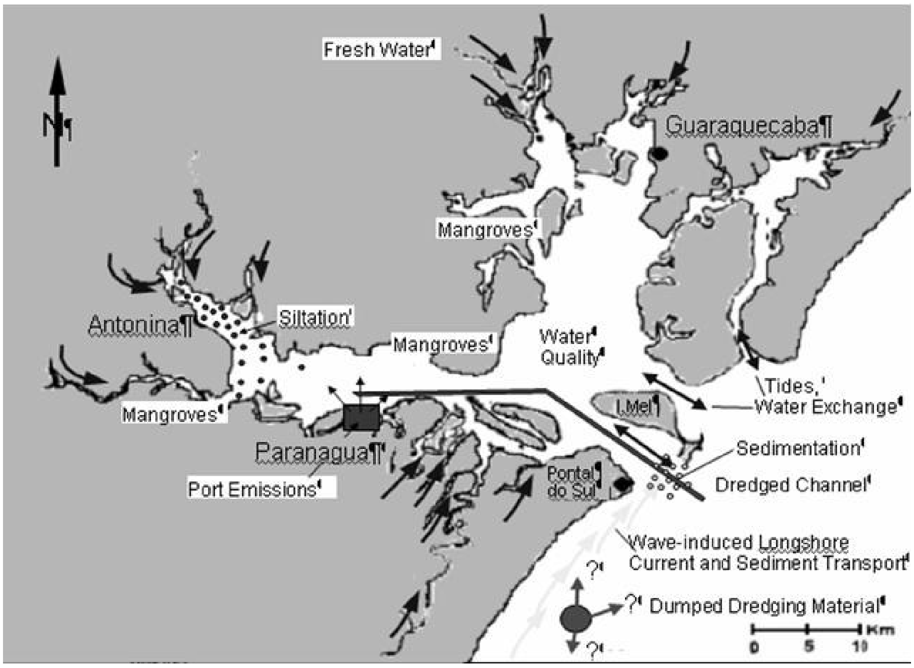

Fig. 1: Map of the Bay of Paranaguá with main processes

The sediments in the estuary are fine and middle sands at the coastline. More inland the portion of mud is increasing. South of the entrance a bar is located that is cut through by the navigation channel. This is the region of the highest sedimentations.

1. TIMOR3 (Tidal Morphodynamics)

The morphodynamic model TIMOR3 solves on unstructured triangular meshes the SWE (Shallow Water Equation) using the hydrodynamic model bubble. The advection-diffusion equation for the suspended matter or the Exner equation is solved either with an upwind characteristic method or using fluctuation splitting schemes. On the basis of the calculated flow velocities it is possible to determine the ground level velocities and hence the shear stresses. The model is able to resolve the ground in many layers each with up to 24 mineral size fractions. On the one hand it is possible to simulate the change of the ground level (erosion or sedimentation) on the other hand the way of the sediments can be tracked. So it is possible to make predictions about the whereabouts of dumped material.

2. WWM (Wind Wave Model)

The WWM solves the WAE (Wave Action Equation) on unstructured meshes. The WAE describing the advection and refraction of waves due to depths and currents (computed by the hydrodynamic model) and can be written for Cartesian coordinates as follows:

(1) $$\underbrace{\frac{\partial}{\partial t}N}_{\text{Change in Time}} + \underbrace{\nabla_{,\vec{x}} \cdot \left(c_{\vec{x}} N\right)}_{\text{Advection in spatial space}} + \underbrace{\frac{\partial}{\partial \sigma}\left(c_\sigma N\right) + \frac{\partial}{\partial \theta}\left(c_\theta N\right)}_{\text{Intra-spectral propagation}} = \underbrace{S_{tot}}_{\text{Total Source Term}}$$

where N = N(t,x,y,σ,θ) is the wave action density spectrum; t is the time; cx and cy are the wave propagation velocities in x and y space, respectively; cσ and cθ are the wave propagation velocities in σ and θ space, respectively; σ is the discrete relative frequency and θ is the wave propagation direction.

The communication between TIMOR3 and the WWM II is based on FIFO (First In First Out) files. These are special files in UNIX/LINUX systems, which allow two processes to communicate with each other during the runtime of each code. The advantage of using FIFO files is that both processes are automatically synchronized when each of the processes writes/reads to the FIFO file. The data are not written to the file system, but are passed internally over the kernel of the operating system to the calling process using the system memory. The use of FIFO files for the data exchange provides both models with a universal interface to any other wave/current model. The FIFO file concept is also available under Dos/Windows type machines however, it is not considered here. Beside the wave induced forces the orbital velocities and the wave induced momentum transfer in terms of stokes drift are passed to TIMOR3. The initial bathymetry for the model comes from different series of measurements from different times. These measurements were provided by the Brazilian Partners. The depths south west of the entrance of the bay were measured during the second measuring campaign in February 2008.

The calculated water levels match well with the measurements at the Galheta gauge (fig. 2).

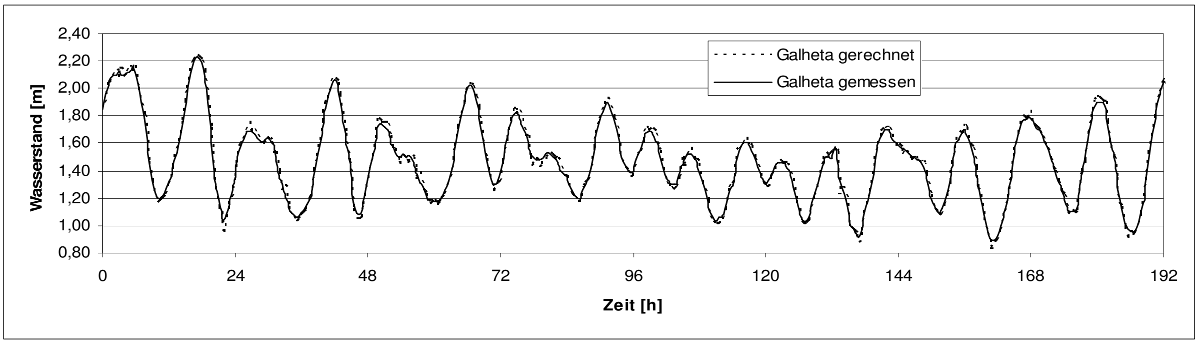

Fig. 2: Calculated and measured water levels

The initial corn size distribution in such a big area can not be measured without extravagant expenses. So it turned out that it is reasonable to calculate the initial grain size distribution by using an average tide and calculating the flow velocities within the model area. So in areas with high flow velocities the software distributes bigger grains than in areas with low velocities where we find finer sediments. During this process the grain size distribution changes but not the bathymetry.

After preparing the initial grain size distribution the coupled model was started with an average tide at the seaside boundary. With a morphodynamic factor of 35 a period of 3 month was simulated and the rearranged sediments stated.

To find the best dumping area for sediments dredged in the navigation channel different dumping grounds (fig. 3) were investigated with the model and the results compared. At each dumping ground 100,000 m³ of sediment per month were continuously dumped. This material has an average particle size of 0.3 mm. This is about the same size as in the navigation channel. The dumping grounds investigated in this project correspond to the areas displayed as spoil grounds in the nautical charts.

In another calculation a training structure along the outer navigation channel was simulated. It was investigated if such a structure can minimize the sedimentations in the outer channel. The training structure was realised as two lines of nodes on a level of 1.5 m above sea level. These nodes can not be eroded. This means that they are normally dry but can be flooded when a high high water occurs. In the outer navigation channel the depth was set to 12 m. If sedimentations occur in this area and the depth comes below 12 m the model automatically starts “dredging”. The amount of the dredged material is logged by the program. This enables the user to make statements about the effectiveness of such a measure.

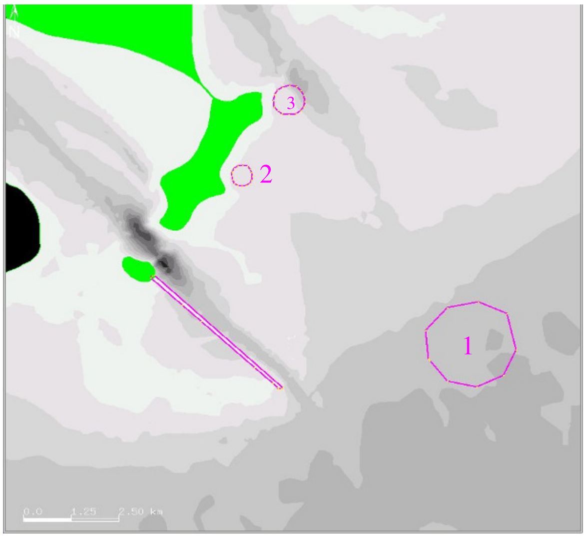

Fig. 3: Location of spoil grounds and training structure

All simulations are done with a mean tide as seaward boundary (an event from year 2000) and constant wind of vwind10 = 10 m/s from southeast in the whole area. In addition at the seaward boundary a wave height HS = 2 m was forced. The waves also come from a southeast direction with a spreading of 20 degrees and a wave period of 8 seconds. The inlets from inland are not included in this simulation. Prior calculations showed that their impact on the flow at the bay entrance can be neglected.

The grain size distribution calculated by the model is shown in figure 3. The calculated and measured grain sizes match quite well. But this comparison can only be made at a few points where sediment samples have been taken. For example in the navigation channel a soil sample had an average diameter of about 0.3 mm. The model calculates for the same region a diameter of 0.23-0.35 mm. Also the calculated bathymetry after 3 months matches well with measurements (fig. 4).

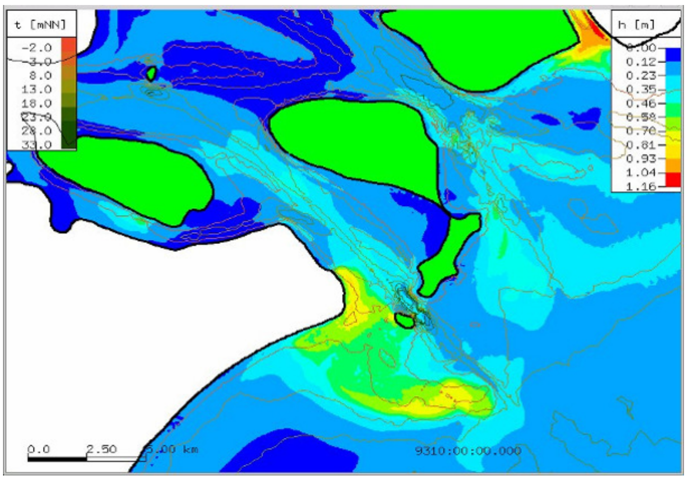

Fig. 4: Calculated grain size distribution

The calculations provide a stable morphologic system which has only at a few places differences to the reality. Because these places are not located in the area of interest the differences are not of importance to the further calculations. The differences can be ascribed to different soil types such as rock which is not erodable.

The comparison of the different dumping areas shows that particularly at dumping ground 2 only low transportation of the dumped sediments occur. The disadvantage of this location is the minor depth of 5 meters why big hopper dredger can not navigate to this place. The same applies partly to dumping ground 3 (fig. 5). But here we have depths up to 14 m at the seaward side. But due to the location at the northern entrance to the Bay of Paranaguá the flow velocities are much higher and hence there is a higher drifting of the dumped material. The transport is mainly southward, but is not very strong. Dumping ground 1 is easy to reach for ships but has the big disadvantage that the dumped sediments are transported along the coastal southwest-northeast-axis in both directions. So parts of the dredged sediments are transported back to the navigation channel.

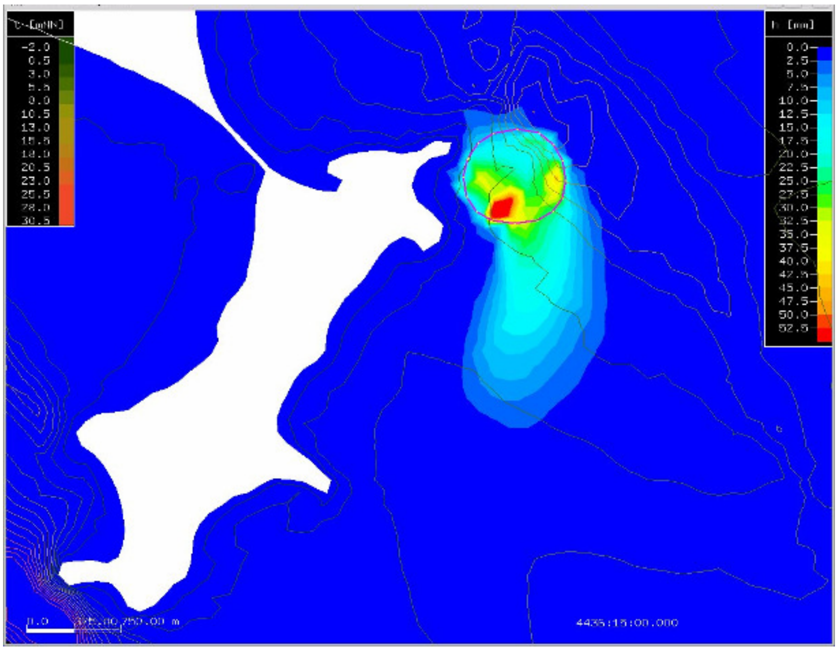

Fig. 5: Drifting of sediments from dumping ground 3

The effect of the simulated training structure on the sedimentations is very positive. In figure 6 the effect of the training structure can be seen. Increasing depths are shown in blue colour, decreasing depths in red. Northeast of the structure the depth is increasing because of the structure, while southwest the material is accumulating. The decreasing depth between Isla do Mel and Isla de Galheta is at the first glance surprising but can be explained by the depth in this area. Between the islands are depths of about 40 m, whereas the depths nearby are more shallow. This leads to sedimentations. The sedimentations in the channel are strongly decreasing. In the simulated time span of 3 month the amount of material that has to be dredged to ensure a depth of 12m is about 125,500 m³ without training structure. With training structure only about 33,500 m³ of sediments have to be dredged.

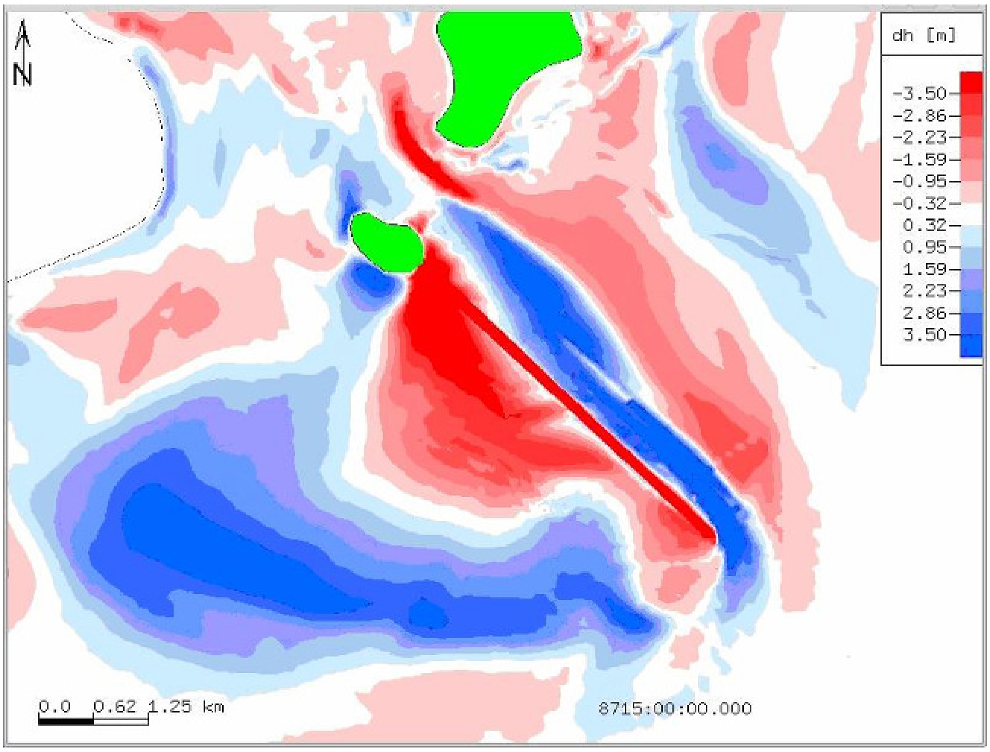

Fig. 6: Depth differences between simulations with and without training structure after 3 months

The development of the amount of dredged material from the outer navigation channel can be seen in figure 7. These numbers are coming from simulations and have to be dealt with very carefully. An exact prediction is not possible, but different simulations give a good feeling for the system response to structural measures.

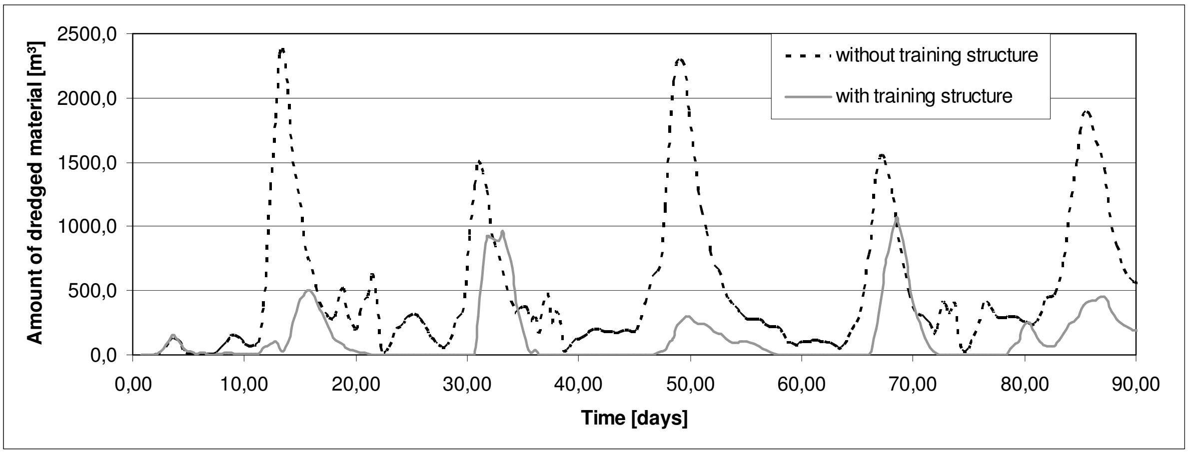

Fig. 7: Amount of dredged material in the outer navigation channel

The decrease of the sedimentation can be put down to two facts. On the one hand the entry of sediments from southwest is prevented by the training structure on the other hand the flow velocities in the channel are higher, which leads to an increased clearance by the current.
Parameters like wind direction, wind velocity, wave direction and wave height have to be varied to confirm or confine the results.
For a final assessment of the measures a cost-benefit analysis has to be prepared to compare the cost effectiveness of the investigated variants.
By now it can be said that coupled models are effective tools to simulate the system wave-current-morphodynamic. The coupling of wave and morphodynamic simulation tools works well and leads to very good results. Trough the application of such simulation systems extensive cost reductions of the maintenance works is possible.

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18. Kurzfassung Im Teilprojekt 2 des Verbundprojekte „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ wurden die hydro- und morphodynamischen Vorgänge im Eingangsbereich der Bucht von Paranaguá simuliert. Bei den Simulationen kam das morphodynamische Modell TIMOR3 zum Einsatz, welches mit dem Wellenenergiemodell WWM gekoppelt wurde. Es wurden verschiedene Klappstellen vor der Bucht verglichen und die Simulationsergebnisse bewertet, um günstige Klappstellen zu ermitteln. Auch die Auswirkungen eines Leitwerks entlang der äußeren Fahrrinne wurden simuliert. Dieses würde sich durchaus günstig auf die Sedimentationen im Außenbereich der Fahrrinne auswirken. Jedoch wären weitere Auswirkungen wie z.B. auf den Küstenverlauf genauer zu untersuchen. Auch eine Wirtschaftlichkeitsbetrachtung müsste noch durchgeführt werden.	
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Schlussbericht

TP3 Wasser- und Sedimentqualität

im Verbundprojekt

Nachhaltiges Umweltmanagement in brasilianischen Häfen

Institut für Chemie und Biologie des Meeres
Carl von Ossietzky Universität Oldenburg

BMBF Förderkennzeichen: 03F0452C

Zuwendungempfänger: **Carl von Ossietzky Universität Oldenburg** **Institut für Chemie und Biologie des Meeres**	Förderkennzeichen: **03F0452C**
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Laufzeit des Vorhabens: **01.11.2006 - 31.08.2009**	
Berichtszeitraum: **01.11.2006 - 31.08.2009**	
Projektleiter: **Prof. Dr. Gerd Liebezeit** Projektbeteiligte: **Dr. Daniela Brepohl**	

I. SCHLUSSBERICHT

1. Aufgabenstellung des Teilprojektes 3

Im TP „Wasser- und Sedimentqualität" sollten Umweltbelastungen, die aus den Hafenaktivitäten in der Bucht von Paranaguá resultieren, untersucht werden. Hier waren besonders chlorierte organische Schadstoffe und polycyclische aromatische Kohlenwasserstoffe von Interesse.

2. Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

Das TP wurde im Rahmen des bilateralen Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen" durchgeführt.

3. Planung und Ablauf des Vorhabens

Die Feldarbeiten wurden in enger Abstimmung mit den am Vorhaben beteiligten brasilianischen und deutschen Gruppen durchgeführt.

4. Wissenschaftlicher und technischer Stand, an den angeknüpft wurde

Von brasilianischer Seite lagen umfangreiche Untersuchen zur Belastungssituation vor allem im Bereich des Schifffahrtswegs vor. Die abgestimmten Probennahmen ergänzten diese Daten räumlich und erlauben, Aussagen über die gesamte Bucht zu machen.

5. Zusammenarbeit mit anderen Stellen

Das Vorhaben wurde im Rahmen des Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ durchgeführt. Besonders hervorzuheben ist die Kooperation mit der Arbeitsgruppe von Prof. Dr. E. Machado am CEM.

II. ERFOLGSKONTROLLBERICHT

1. Beitrag des Ergebnisses zu den förderpolitischen Zielen des Förderprogramms

siehe dazu den Beitrag im Gesamtbericht

2. Wissenschaftlicher oder technischer Erfolg des Vorhabens

Die durchgeführten Arbeiten ergänzen vorliegende Datensätze und erlauben damit eine umfassende Bewertung der Umweltsituation der Bucht von Paranaguá.

3. Einhaltung des Finanzierungs- und Zeitplans

Sowohl Zeit- als auch Finanzierungsplan wurden eingehalten.

4. Verwertbarkeit der Ergebnisse

Die erhaltenen Daten stellen den brasilianischen Behörden die notwendigen Daten zur Verfügung, um entsprechende Regelungen zur spezifischen Reduktion der Belastung aus städtischen Quellen und dem Hafenbetrieb zu treffen.

Die Ergebnisse werden in internationalen Zeitschriften publiziert.

5. Vom Zuwendungsempfänger gemachte oder in Anspruch genommene Erfindungen, Schutzrechtsanmeldungen etc.

entfällt

6. Arbeiten, die zu keiner Lösung geführt haben

entfällt

III. SCIENTIFIC RESULTS

1. Sampling

A total of 19 stations was sampled in March 2007 to which another 140 stations were added in August/September 2007 (fig. 1). The latter included a series of river stations. In addition, in autumn surface water samples were taken for PAH analysis.

Fig. 1: Sampling stations in 2007 (upper map) and 2008 (lower map), (dots = surface samples; squares = cores)

In 2008, 95 surface sediments including river samples and 15 cores were sampled.
Surface sediments were obtained with a 150 cm van Veen-type grab. For corina 100 * 8 cm gravity corer modified after Rumohr and Meischner (1974) was used.

2. Sediments

2.1 Grain size distribution

Grain size analysis by laser diffraction shows that the sediments range from sands to silts with little clay contributions (fig. 2 left). Sands have relatively higher clay contents than silts. These data compare well with the sediment distribution maps provided by Lamour et al. (2004).

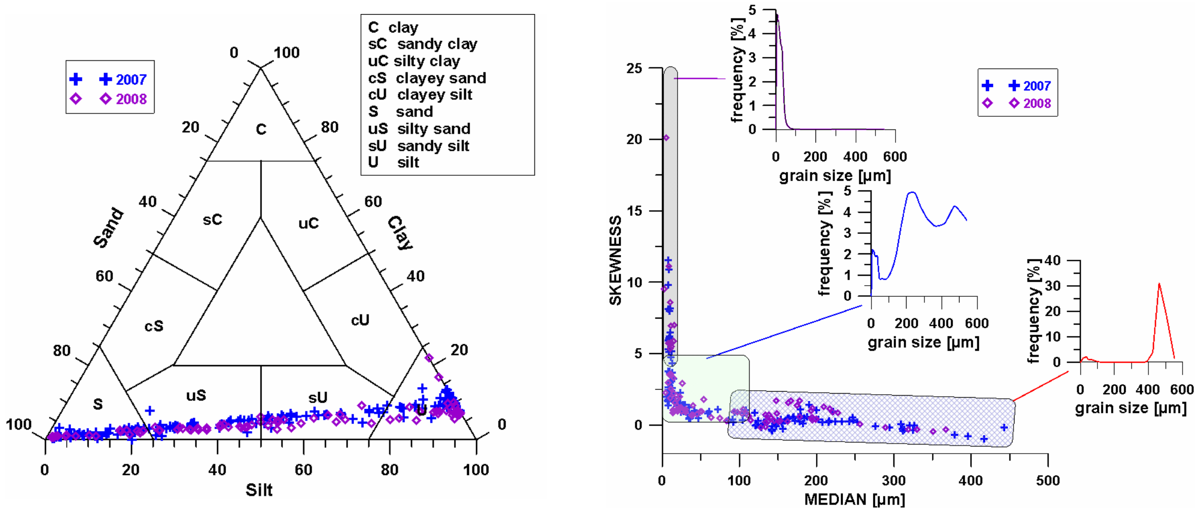

Fig. 2: Shepard plot of the sediments analysed (left) and skewness-median plot (right)

Analysis of grain size data suggests, as expected, two dominant modes of transport: in suspension (low median, high positive skewness) and as bedload (high median, low positive to low negative skewness): A third intermediate group combines both transport modes.
Along the axis of the bay there are two trends recognisable in grain size composition (fig. 3). All samples with median values in the silt fraction are to be found from 25° 21' W to 25° 42' W, i.e. east and west of the harbour area. As the turbidity maximum is also to be found here this suggests that sedimentation of silty material takes place predominantly here. Given the known association of the <63 µm fraction with organic carbon and also contaminants it can be expected that an input of these compounds would be recorded particularly in this area.

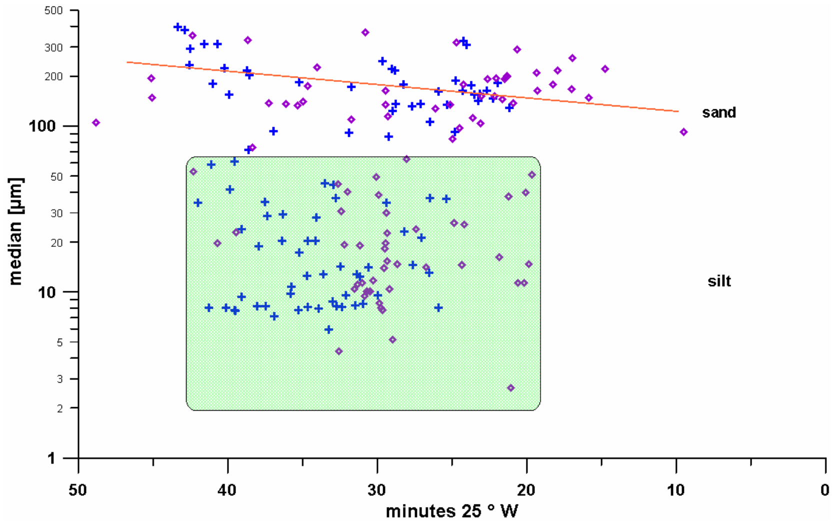

Fig. 3: Median grain size as function of longitude (2007/2008 labelling as in figure 2)

The second group of sediment encompasses sands showing a weakly pronounced fining towards the mouth of the bay.

2.2 Elemental composition

Elemental analysis of the samples taken in March 2007 indicates a dominance of quartz with minor carbonate contributions (fig. 4).

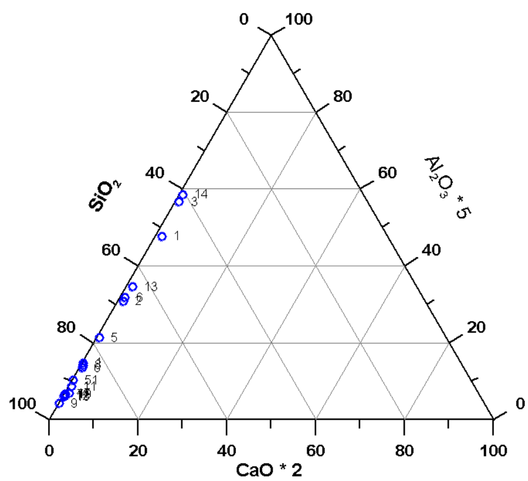

Fig. 4: Ternary plot of Si (quartz), Al (clay minerals) and Ca (carbonate)

Similarly, the overall elemental signatures available do not provide evidence of unusually high contents of heavy metals (fig. 5). This is in line with data already provided by Sá et al. (2007). The exception here are barium and zirconium with higher contents. These anomalies, found in the inner part of Antonina Bay, are most probably due to higher contents of these two elements in the terrestrial sources.

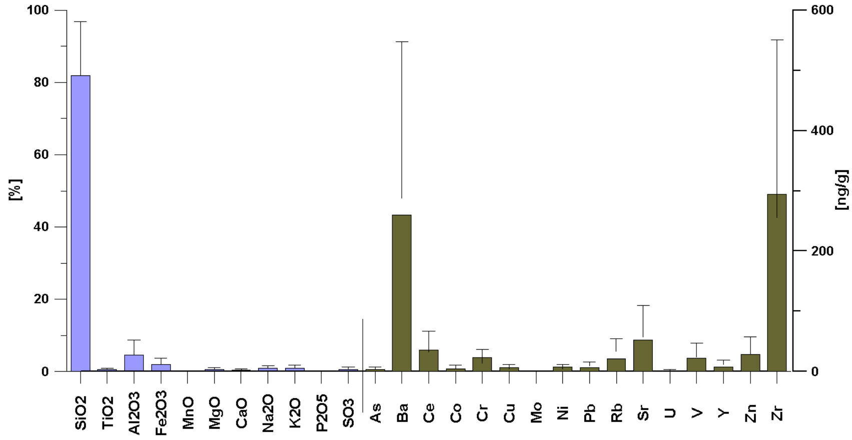

Fig. 5: Mean major and minor element composition (n = 19)

Mercury has been investigated in this context more closely. With the exception of station 129 in the port area it shows, as expected and frequently reported in the literature, a positive relationship both with the fine grain size fraction (fig. 6) and total carbon (fig. 7). Absolute Hg values are with one exception below the Brazilian action level. Thus, there are no significant mercury sources both in the drainage area and the bay itself.

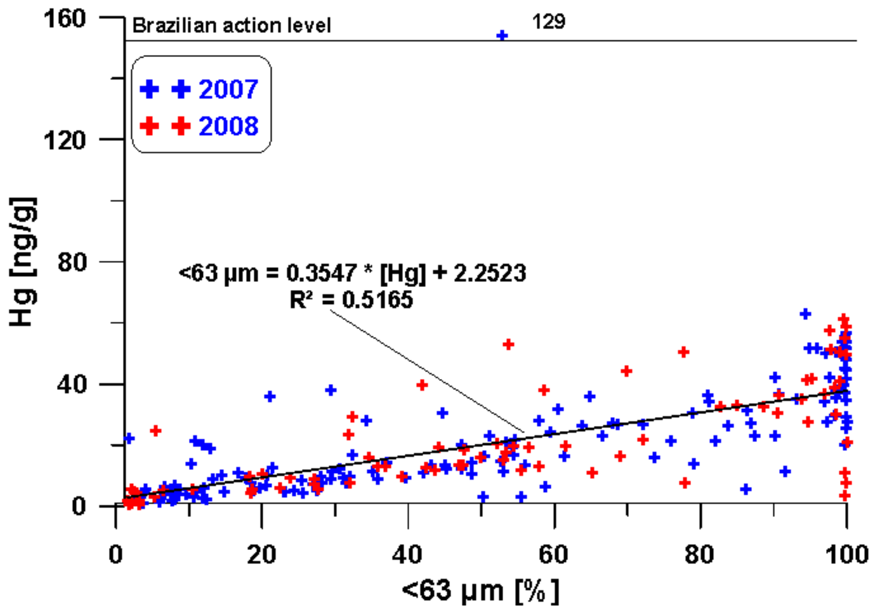

Fig. 6: Mercury contents as function of relative fine fraction content

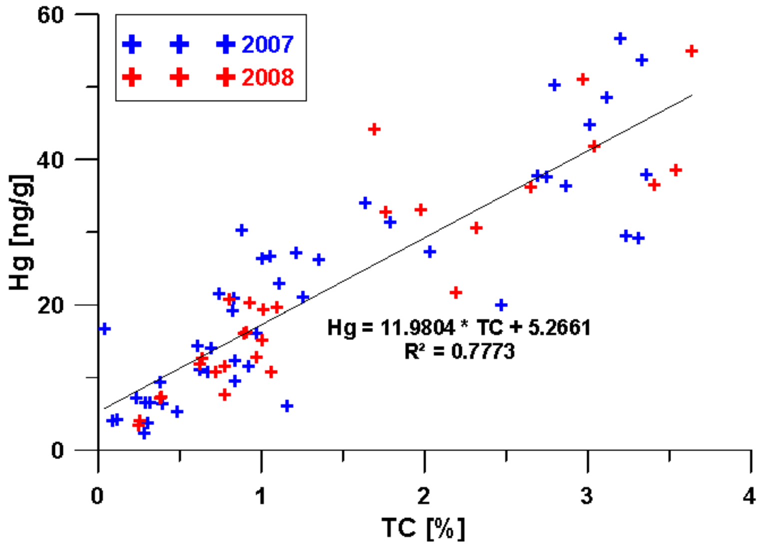

Fig. 7: Mercury contents as function of total carbon content

Using grain size normalised data only few stations with elevated mercury contents become evident (fig. 8). The outer bay and offshore stations are characterised by low >63 µm contents. Hence a given contaminant load becomes associated with relatively small mud contents thereby resulting in high normalised contents.

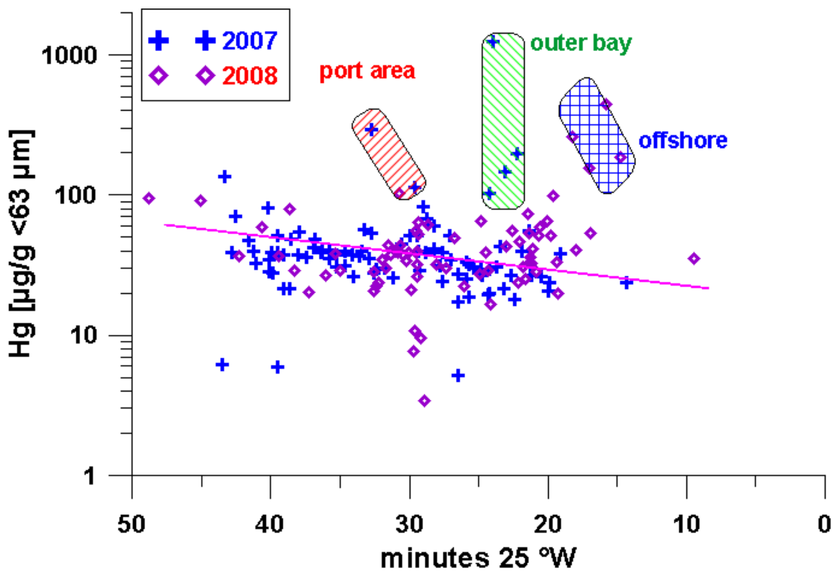

Fig. 8: Fine fraction normalised mercury contents as function of geographical longitude

Furthermore, figure 8 indicates that the major source of mercury is located in the drainag area. This is in accordance with data of Sá and da Costa Machado (2007) for other metals. Thus, trace metals in general show low contents below Brazilian actions levels and originate from the drainage area. Port based or urban sources cannot be identified.

It should, however, be pointed out that contamination by organotin compounds has been found (Moscardo dos Santos, 2008) with marked effects on biota, e.g. imposex has been reported to occur by de Castro et al. (2007). This phenomenon ranged from 85 to 100 % in the access channel to the port and in the port while it was only 36 % at a station in the coastal Atlantic. Although the snail species investigated, *Stramonita haemastoma*, is not commonly employed in this type of study the data indicate a significant influence of the harbour here. Furthermore, Moscardo dos Santos (2008) reported the occurrence of not only butyltin compouds but also phenyltin ones which suggests an input from agricultural activities in the drainage area.

2.3 Total carbon (TC) and total organic carbon (TOC)

Total organic carbon accounted on the average for 97.2 % of total carbon (n = 19) indicating that little inorganic carbon is present in the surface sediments sampled. This is supported by field observations that only occasionally showed living or dead shell bearing organisms. Thus in the following TC values will be discussed only.

TC concentrations range from 0.04 to 2.92 mmol/g. With few exceptions a positve relation between TC and fine fraction content is observed (fig. 9) following the equation TC = $e^{0.0283}$ * 0.1625 <63 µm (R^2 = 0.8372). Both high TC concentrations at low to medium fine fration contents and low TC concentrations at high fine fraction contents were found at isolated stations in the middle part of the bay. These phenonema cannot be related to any particulare features of the stations although it would be reasonable to assume organic detritus to be responsible for the high TC values.

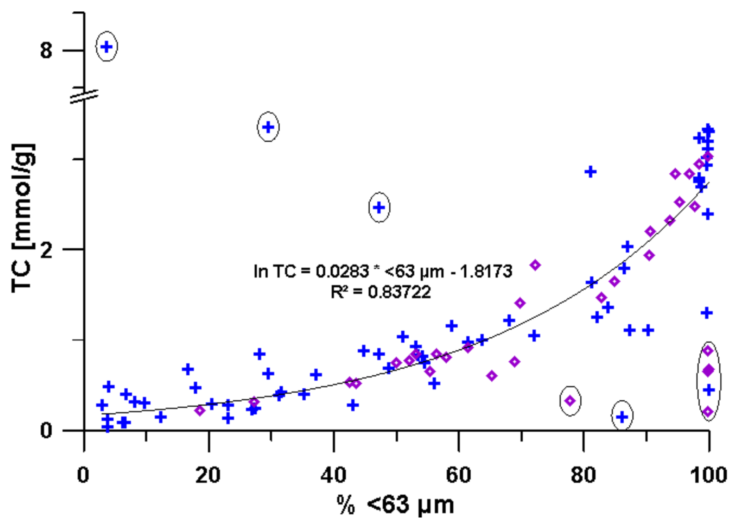

Fig. 9: Relationship between total carbon concentrations and fine fraction contents (2007/2008 labelling as in figure 3; encircled values have not been used for the correlation equation given)

2.4 Polycyclic aromatic hydrocarbons (PAH)

PAHs in marine sediments generally originate from two sources – petrogenic or pyrogenic, i.e. direct input of petroleum or its derivatives or atmospheric input of products of incomplete combustion. In the latter case PAHs are usually strongly associated with soot particles.

PAH contents ranged from 0.4 to 3998 ng/g (mean 205 ng/g ± 30.6 %; n = 61). With three exceptions contents were below 200 ng/g (fig. 10) and thus within the range reported by Fillmann et al. (2007) for Paranaguá Bay. Stations 85 and 59 are located in the port area while station 44 is towards the outer part of the bay within the shipping channel. The former two are located close to station 27 of Fillmann et al. (2007) who found a PAH content of about 700 ng/g here. This suggests a highly localised point of contamination.

There is no clear relation both with the fine grain size fraction fraction and total carbon (figs. 10, 11).

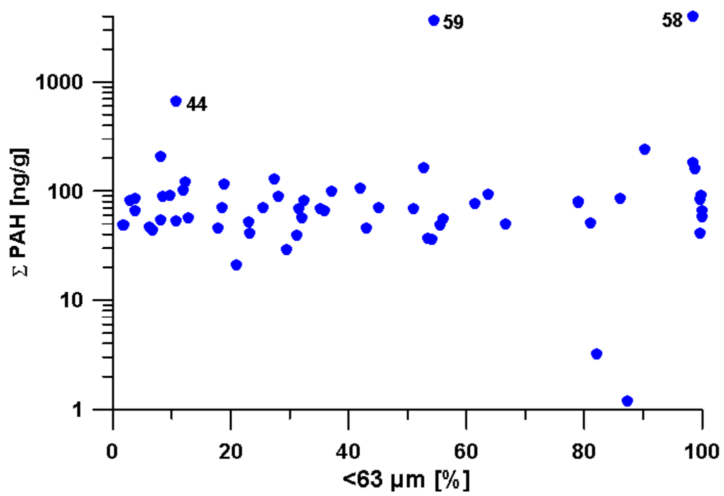

Fig. 10: ΣPAH as function of fine fraction content

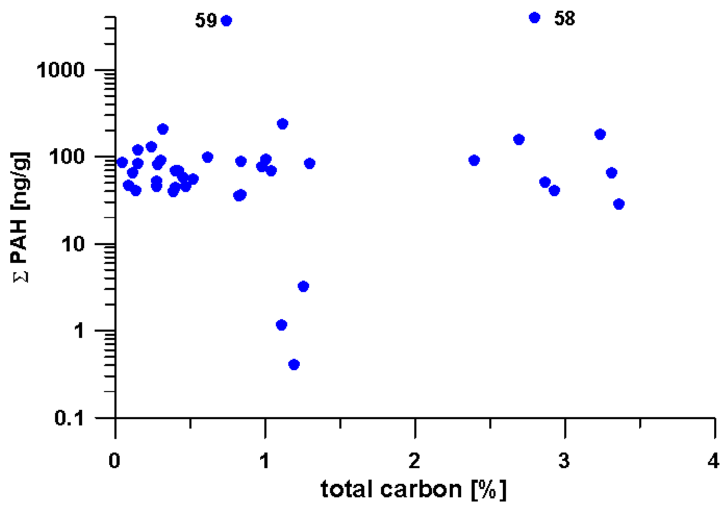

Fig. 11: ΣPAH-TC relationship

A source consideration based on these data indicates a dominant atmospheric input with the exception of stations 58 and 59.

3. Biota

During discussions with the Brazilian colleagues it was decided that it might be worthwhile to extend the scope of the present investigation to biota. To test whether organisms carry indeed high amounts of organic pollutants, mussel (*Mytella guyanensis*) and oyster (*Crassostrea rhizophorae*) samples were collected in 2007. In addition, liver samples from two dead turtles (*Chelonia mydas*), one benthic mussel (*Anomalocardia brasiliana*) and one unidentified sponge were analysed for organochlorine compounds. For comparison data were compared to *Crassostrea rhizophorae* results obtained in 2006. All data are summarised in table 1.

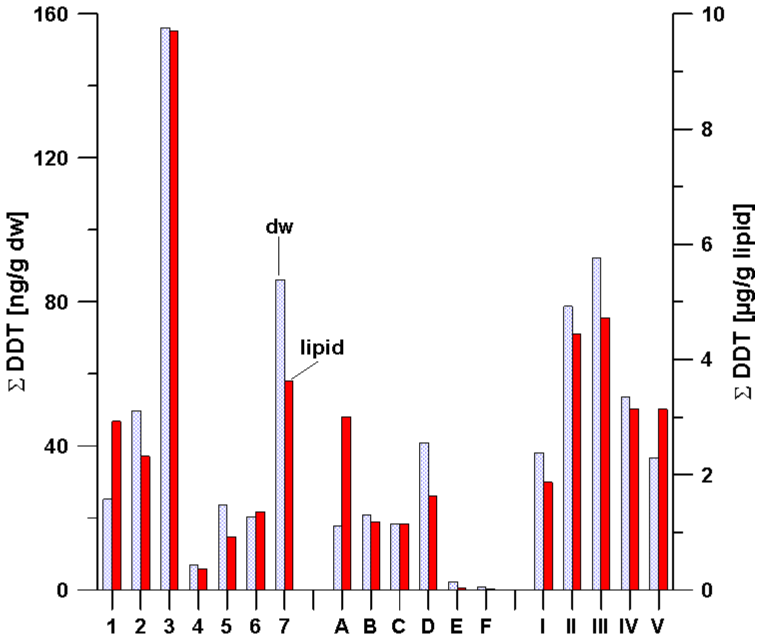

Fig. 12: DDT and its degradation products in unidentified sponge (1), *Mytella guayensis* (2), *Crassostrea rhizophorae* (3, 4) and *Chelonia mydas* livers (5, 6), (for labelling see table 1)

DDT and its degradation products DDE and DDD were found in all samples from Paranaguá Bay (fig. 12). The highest contents, both dry weight based and total lipid normalised, were found for mangrove oysters and *Anomalocardia brasiliana* from Anhaia (samples 3 and II) followed by mangrove oysters at Ilha dos Papagaios (# 7) and the fish species *Cathorops* sp. (# III). Samples D and I, i.e. *Mytella guyanensis* from the Ilha do Mel, sampled at the same location, had comparable ΣDDT contents in September 2007 and March 2008. The turtle liver samples E and F had only extremely low ΣDDT contents (fig. 12).

Tab. 1

date	species	location	label	length	n	% lipid	ΣDDT		DDT/DDE
			(fig. 12)	[cm]			[ng/g dw]	[µg/g lipid]	
May 2006	*Crassostrea rhizophorae* (Ostreidae)	Gererês	1	5.0 ± 0.9	9	0,86	25,2	2,9	0,3
	C. rhizophorae	Ilha Rasa	2	4.9 ± 0.9	13	2,14	49,7	2,3	0,0
	C. rhizophorae	Anhaia	3	5.3 ± 0.7	10	1,61	156,2	9,7	0,5
	C. rhizophorae	Itiberê	4	5.0 ± 0.,6	12	1,90	6,9	0,4	0,1
	C. rhizophorae	Ilha da Cotinga	5	5.8 ± 0.6	9	2,57	23,6	0,9	*
	C. rhizophorae	Itaqui	6	5.4 ± 0.6	12	1,50	20,3	1,4	*
	C. rhizophorae	Ilha dos Papa-gaios	7	4.4 ± 0.6	13	2,38	86,2	3,6	0,1
August/	unidentified sponge	inner bay	A	-	1	0,60	17,9	3,0	2,2
September 2007	*C. rhizophorae*	outer bay	B	3.8 ± 0.4	12	1,78	21,0	1,2	3,0
	C. rhizophorae	Pontal do Sul	C	5.4 ± 0.9	18	1,59	18,4	1,2	3,0
	Mytella guyanensis (Mytilidae)	Ilha do Mel	D	3.1 ± 0.3	20	2,50	40,9	1,6	2,9
	Chelonia mydas (Chelonidae)	outer bay	E		1	5,30	2,2	0,0	*
	C. mydas	outer bay	F		1	5,87	0,7	0,0	*
March 2008	*M. guyanensis*	Ilha do Mel	I	4.2 ± 0.3	14	2,04	38,1	1,9	0,2
	Anomalocardia brasiliana (Ve-neridae)	Anhaia	II	2.1 ± 0.1	12	1,77	78,8	4,4	0,2
	Cathorops sp. (Ariidae)	bay	III	12	1	1,95	92,1	4,7	0,0
	Stellifer brasiliensis (Sciaenidae)	bay	IV	5,5	1	1,70	53,5	3,1	0,3
	Paralonchurus sp. (Sciaenidae)	bay	V	9	1	1,17	36,8	3,1	0,1

* no DDT

The regional distribution pattern indicates that a significant input of DDT compounds occurs at the station Anhaia. This artificial channel discharges untreated sewage through a narrow mangrove belt into an area W of Paranaguá port. *Anomalocardia brasiliana*, a benthic mussel species, was sampled in front of the channel exit and was also found to be highly contaminated. It can thus be safely assumed that sewage or runoff from residential areas are the main sources of ΣDDT at this location. Similarly, station 7 at Ilha dos Papagaios is affected by discharge from the Itiberê River transporting runoff from the city of Paranaguá.

The relative composition is dominated in May 2006 and February/March 2008 by the degradation products DDE and DDD (fig. 13). In August/September 2007, on the other hand, DDT made up 60.7 ± 0.08 % in the filter feeding organisms while it was absent in the turtle samples. Correspondingly mean DDT/DDE ratios were 0.28/0.15 *vs*. 2.76.

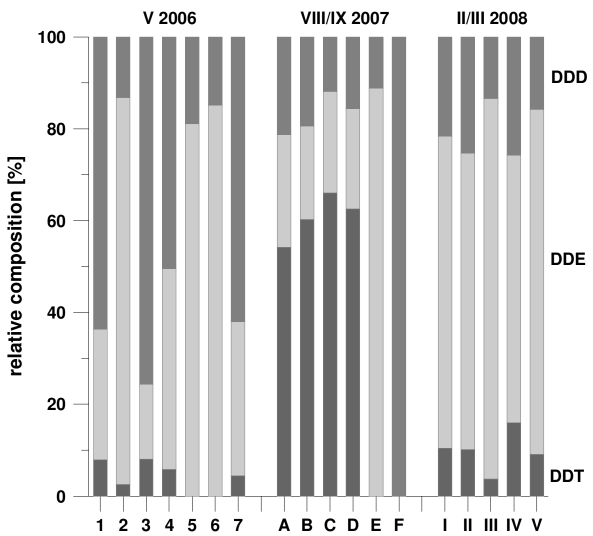

Fig. 13: Relative composition of DDT compounds in biota samples from Paranaguá Bay (labelling according to table 1)

These findings suggest that there is a continuing *de novo* input of DDT into Paranaguá Bay. Recent pesticide input is also in line with findings of da Silva et al. (2008) who suggest continuing usage of hexachlorohexane and heptachlor for the Piracicaba River basin (São Paulo, Brazil) while DDT and its degradation product DDE could not be detected here.

Apparently DDT in Paranaguá Bay is rapidly degraded as is evident from the marked decrease in DDT content of *Mytella guyanensis* sampled on Ilha do Mel from early southern winter to summer. These data also indicate either widespread usage of DDT in the land areas surrounding the bay or rapid distribution from a point source. From hydrographic and inorganic nutrient measurements there is at present no support for the latter explanation (N. Ladwig, pers. comm., 2008). Turtles, albeit also feeding in the bay, are not exposed to high DDT levels in their diet as seagrasses, due to their low lipid content, will not accumulate organochlorines to a significant extent.

Comparison with data from Todos os Santos Bay, NE Brazil, indicates comparable or even higher maximum contents of DDT group compounds (*Brachidontes exustus*; Taveres et al. 1999). These authors point out that comparisons between different taxa have to be viewed with caution as different life histories may give rise to different bioaccumulation factors. Compared to other areas of the Brazilian coast (tab. 2) ΣDDT values in biota of Paranaguá Bay are the highest reported so far.

Tab. 2: ΣDDT in bivalves from Brazilian coastal areas

region	**year**	**ΣDDT**		**reference**
		mean [ng/g dw] *[ng/g fw]*	range [ng/g dw] *[ng/g fw]*	
Paranaguá Bay	2006- 2008	52.6 May 06 26.7 March 07 58.4* Septem- ber 08	20.3 – 156.2 18.4 – 40.9 38.1 – 78.8	this study
Paranaguá Bay	2006	*1.3*	*0.1 – 3.2*	Koike, 2007
Macaé - Rio de Janeiro	1997	1,1**	-	Taniguchi, 2001
Angra dos Reis – Rio de Janeiro	1997	2,3*	1.1 - 3.4	Taniguchi, 2001
Lagoa dos Patos	1999	-	*0.6 - 2.0*	Hermanns, 2004
Baía de Santos	1994-95	*7,4*	<0.3 – 44.0	Tavares et al., 1999
Baia de Guanabara	1996	8.1 August 2.2 December	8.2 – 19.1 0.6 – 10.0	de Brito et al., 2002

* 2 samples

** 1 sample

In Guanabara Bay, Rio de Janeiro, de Brito et al. (2002) found DDT contents in the bivalve *Perna perna* from 5.5 to 16.9 ng/g dw and DDT/DDE ratios from 0.3 to 10.9. There are seasonal effects as reported by de Brito et al. (2002) resulting in higher values during the dry season due to reduced runoff. Although not discussed by the authors the high DDT/DDE ratios also suggest recent input of DDT. In Ribeirão Preto, State of São Paulo State, Brazil, Lopes et al. (1992) found DDT values of 0.19 to 0.65 µg/g for *Anodontites trapesialis* with DDT/DDE ratios of 1 to 5.2. Seasonal effects here were related to agricultural activities.

In blue mussels (*Mytilus edulis*) and Pacific oysters (*C. gigas*) from the Wadden Sea, southern North Sea, the overall levels of the DDT group were 5.0 ± 1.1 ng/g dw with DDT being present in only one sample out of a total of nine (Dörr and Liebezeit, 2009). Here insect control is not an issue in the adjacent terrestrial environment and the DDT ban of 1979 was enforced strictly.

The three fish specimen analysed showed ΣDDT values from 36.8 to 92.1 ng/g dw. This compares with values of 21.8 to 101.5 ng/g dw given by Taniguchi (2001) for four species sampled along the coast of Rio de Janeiro state.

These data together with the data for Paranaguá biota suggest that DDT application is still widespread along the Brazilian coasts. Accordingly, Kajiwara et al. (2004) found up to 150 µg ΣDDT/g lipid in the estuarine dolphin *Sotalia guianensis* indicating significant bioaccumulation of this compound class.

Polychlorinated biphenyls (PCBs) were also found in all biota samples analysed albeit with low contents (fig. 14).

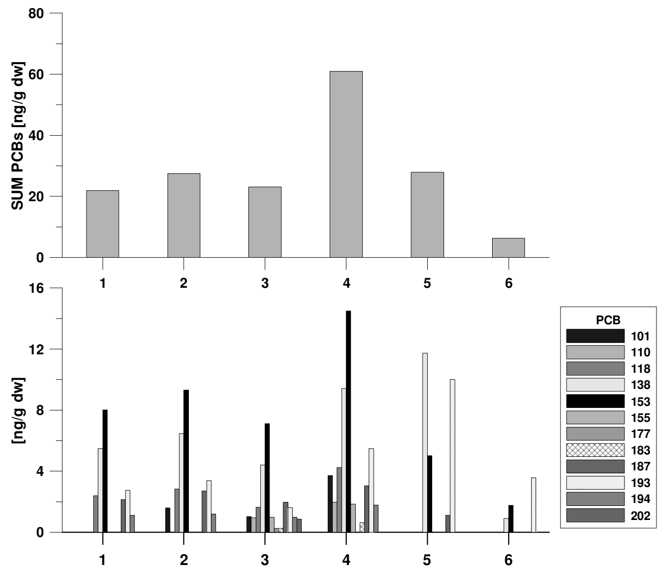

Fig. 14: PCBs in unidentified sponge (1), *Mytella guyanensis* (2), *Crassostrea rhizophorae* (3,4) and *Chelonia mydas* livers (5, 6)

As only compounds with a medium to high degree of chlorination were found (fig. 15) it can be assumed that these are derived from an already degraded source. It can thus be safely assumed that no recent input of PCBs has taken place.

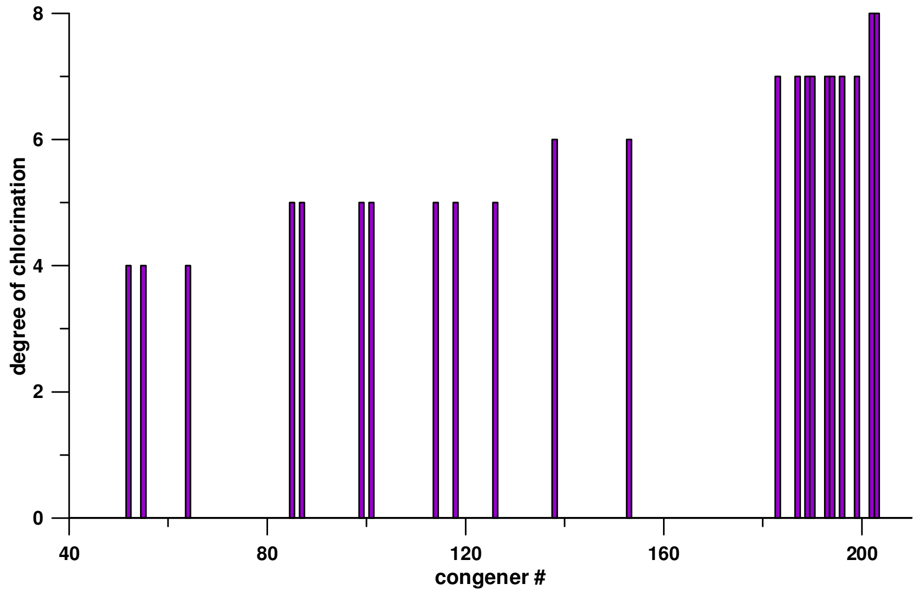

Fig. 15: Degree of chlorination of PCB congeners in biota samples

4. Natural organic loads

During field work it was observed that dust from soy and grain loading was frequently visible along the port. It was thus decided to also analyse phosphorus fractions in sediments of the harbour area to investigate whether input of organic matter from this source could be detected. Stations in the port area and the turbiditiy maximum zone exhibited for the most part normal mud – TC relations with some exceptions (figs. 16, 17). Especially in the direct vicinity of the loading activities higher TC contents were found.

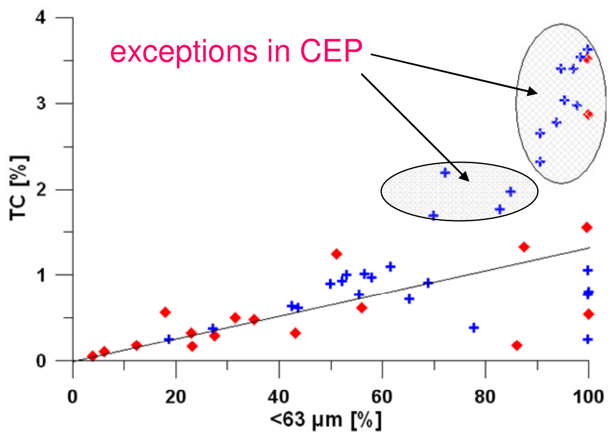

Fig. 16: Mud-TC relationship for samples taken in the port area and the turbidity maximum zone

As in soybeans about 0.6 % phosphorus is present with majority bound to phytic acid (Earle and Milner, 1938; Smith and Rackis, 1957) P fractions were also analysed. Organically bound

P accounted for the majority of samples analysed for up to 95 % of the total P pool (fig. 18). In normal marine sediments this fraction usually does not make up more than 50 % (Liebezeit, 1995). This indicates an additional input of organic material most likely being derived from soy and grain loading with wider areal distribution of the dust via atmospheric transport.

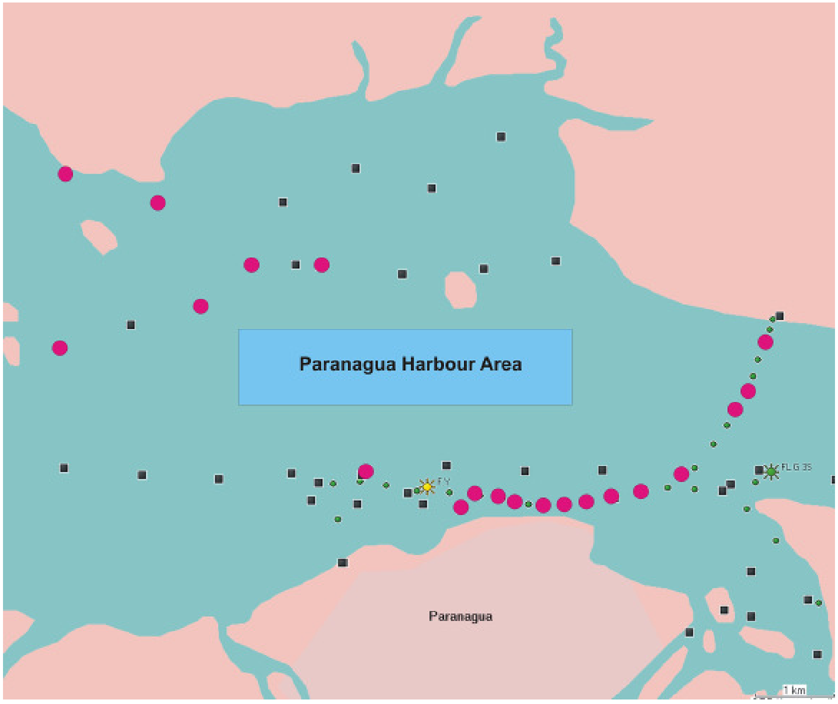

Fig. 17: Areal distribution of exception from the linear relation mud-TC (red dots)

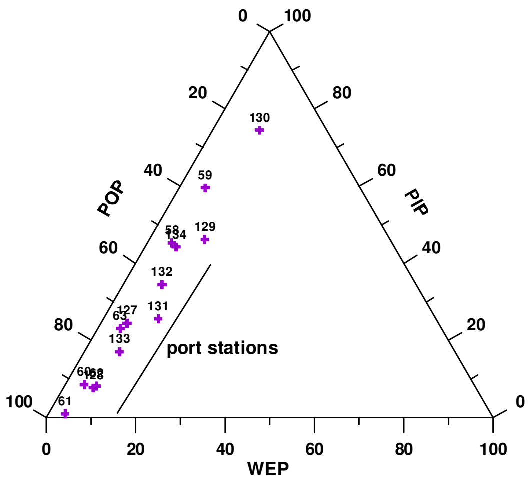

Fig. 18: Ternary plot of three phosphorus fractions (POP = organic P, PIP = inorganic P, WEP = water extractable P)

This high input is also evident from observations during sediment sampling where anoxic conditions were observed up to the sediment surface. As it was similarly noted that screw action of ships manoeuvring in the port led to dispersion and redistribution of surface sediments the P data and the field observations suggest a considerable load of easily degradable organic matter. The developing anoxic conditions will have a strong effect on benthic organisms.

5. Summary

So far there is no evidence that port activities contribute signifantly to the contamination loads of sediments in Paranaguá Bay. However, the present investigation indicates that an input of organic matter may take place leading to increased oxygen consumption in the surface sediment followed by anoxia.

There is, however, evidence from imposex investigations for a significant influence of antifouling biocides on benthic species. Although the detected organotin compounds have been ruled out since 2008 they are highly persistent and will hence remain in the ecosystem for some time. In addition, alternative antifouling biocides may also soon show their mark in Paranaguá Bay.

The main contamination in Paranaguá Bay apparently does not originate from the port itself but from domestic sources. Here, significant inputs of fresh DDT could be detected.

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18. Kurzfassung

Anhand der vorliegenden Daten lässt sich nicht zeigen, dass Aktivitäten im Hafen von Paranaguá die Umweltbelastung der Sedimente der Bucht von Paranaguá in signifikantem Umfang beeinflussen. Es konnte jedoch gezeigt werden, dass ein Eintrag von organischem Material stattfindet, der zu erhöhtem Sauerstoffverbrauch in den Oberflächensedimenten und nachfolgenden anoxischen Bedingungen führt.
Es gibt jedoch Hinweise aus Imposex-Untersuchungen auf einen deutlichen Einfluss von Antifoulingbioziden auf benthische Spezies. Obwohl Organozinnverbindungen seit 2008 verboten sind, dürfte aufgrund ihrer hohen Persistenz zu erwarten sein, dass sie noch längere Zeit im Ökosystem nachweisbar sein werden.
Die wesentliche Kontamination der Bucht von Paranaguá stammt offensichtlich nicht aus den Hafenaktivitäten, sondern aus städtischen Quellen. In diesem Zusammenhang konnten signifikante Einträge von DDT nachgewiesen werden.

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Schlussbericht

TP4 Automatisiertes Monitoring und Detektion
von Kurzzeitereignissen

im Verbundprojekt

Nachhaltiges Umweltmanagement in brasilianischen Häfen

Institut für Küstenforschung
GKSS Forschungszentrum Geesthacht

BMBF Förderkennzeichen: 03F0452E

Zuwendungempfänger: **GKSS Forschungszentrum Geesthacht GmbH** **Institut für Küstenforschung**	Förderkennzeichen: **03F0452E**
Vorhabenbezeichnung: **TP4 Automatisiertes Monitoring und Detektion von Kurzzeitereignissen**	
Laufzeit des Vorhabens: **01.09.2006 - 31.12.2009**	
Berichtszeitraum: **01.09.2006 - 31.12.2009**	
Projektleiter: **Dr. Wilhelm Petersen** Projektbeteiligte: **Dr. Friedhelm Schroeder, MSc. Byanka Mizerkowski**	

I. SCHLUSSBERICHT

1. Aufgabenstellung

Im Rahmen des Verbundprojektes „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ sollte im Teilprojekt TP4 (Automated Monitoring for the Detection of Short-Term Events) eine automatische Messstation zur Erfassung der Gewässergüte in der Paranaguá-Bucht in Brasilen adaptiert und für wissenschaftliche Fragestellungen angewendet werden. Die Station sollte unter anderem dazu genutzt werden, Kurzzeitereignisse zu erkennen und saisonale Trends aufzudecken.

2. Ablauf des Vorhabens

Nach anfänglichen Verzögerungen bedingt durch Zollprobleme bei der Einführung der Messstation inklusive Messcontainer wurde die Station im September 2007 von der Firma 4H Jena Engineering erfolgreich aufgebaut und gemeinsam mit GKSS in Betrieb genommen. Seit der Zeit wurden mit einigen technisch bedingten Unterbrechungen (Blitzschlag, längere Stromausfälle) Messdaten kontinuierlich aufgezeichnet. Im Laufe des Projektes konnten die z.T. aufgetretenen Störungen durch extremen biologischen Bewuchs durch einige technische Verbesserungen der FerryBox-Anlage reduziert werden. Gemessen werden Temperatur, Salzgehalt, Trübung, Chlorophyll-*a*-Fluoreszenz, CDOM (fluorometrisch), Sauerstoff, pH sowie der Pegel und die Globalstrahlung. Alle Daten werden automatisch täglich in eine von GKSS betriebene und über das Internet für jeden frei zugängliche Datenbank (http://tsdata.gkss.de) transferiert. Die Anlage wurde vor Ort durch einen von der GKSS finanziell unterstützen Master-Studenten betreut, wodurch ein kontinuierlicher Betrieb sichergestellt werden konnte.

Parallel zu den Dauermessungen auf der Station wurden vom Schiff aus mehrere Messkampagnen mit kontinuierlichen Messungen und Probenahmen in der gesamten Bucht durchgeführt. Hierfür wurde von der GKSS jeweils eine transportable FerryBox („pocketFerryBox“) zur Verfügung gestellt, die es erlaubt, vom fahrenden Schiff aus die Wasserqualitätsparameter Temperatur, Salinität, Trübung, Sauerstoff, Chlorophyll-Fluoreszenz, pH sowie Algenpigmente (Phycoerythrin & Phycocyanin) zu bestimmen. Einzelheiten und die entsprechenden Auswertungen sind dem beigefügten ausführlichen wissenschaftlichen Bericht zu entnehmen.
Ein Teil der Messkampagnen wurde in enger Kooperation insbesondere mit dem Teilprojekt TP3 (Water and Sediment Quality) durchgeführt. Die Daten der FerryBox wurden auch von brasilianischer Seite vom CEM (Center for Marine Studies, University of Paraná) für eigene Forschungsaufgaben genutzt.

3. Beitrag zu den förderpolitischen Zielen des Förderprogramms

s. Gesamtbericht

II. ERFOLGSKONTROLLBERICHT

1. Wissenschaftlicher Erfolg des Vorhabens

Mit Hilfe der Daten der FerryBox und den Ergebnissen der Messkampagnen konnten neue Erkenntnisse über die Nährstoffdynamik in der Paranaguá Bucht gewonnen werden. Die wesentlichen Quellen der Nährstoffe konnten identifiziert und die wesentlichen Prozesse der Algen- und Nährstoffdynamik konnten qualitativ beschrieben und z.T. auch quantifiziert werden. Weitere Untersuchungen sind allerdings notwendig um die beobachteten extrem hohen biologischen Umsetzungsraten genauer zu verstehen. Die aus dem Projekt finanzierte Dissertation über diese Untersuchungen steht kurz vor dem Abschluss. Aus dieser Dissertation sind mehrere Publikationen in der Vorbereitung bzw. stehen kurz vor dem Abschluss (s. Liste).
Der geplante Vergleich der FerryBox Chlorophyll-Messungen mit entsprechenden Satellitendaten erwies sich für die relativ flache Bucht als zu problematisch. Die Satellitendaten sind aufgrund der Landnähe und der geringen Wassertiefe zu sehr gestört, um sie quantitativ nutzen zu können. Hinzu kommt noch, dass aufgrund der Wolkenabschattung in solch subtropischen Gebieten nur an wenigen Tagen Satellitendaten verfügbar sind.

2. Einhaltung des Finanzierungs- und Zeitplans

Die Sachmittel sind wie in der Kostenplanung vorgesehen beschafft worden. Es gab keine wesentlichen Verschiebungen/Umwidmungen in der Mittelverwertung

3. Verwertbarkeit des Ergebnisses und Zusammenarbeit mit anderen Stellen

Die im Rahmen dieses Projektes gewonnenen Erkenntnisse können als Basis für zukünftige Planungen im Zuge der vorgesehenen zukünftigen Erweiterung des bestehenden Hafens sowie des ebenfalls in Planung befindlichen vorgelagerten Tiefseehafens dienen. Mit den von der stationären FerryBox über mehrere Jahre erfassten Basisdaten kann der jetzige Status gut dokumentiert werden. Für diese Hafenerweiterungen sind zukünftige Umweltverträglichkeitsuntersuchungen erforderlich. Von den für diese Untersuchungen zuständigen Institutionen wurde daher auch schon nachgefragt, inwieweit diese Station weiterhin für solche Untersuchungen zur Verfügung steht.

Mit der Universität von Paraná (CEM) wurde bezüglich der zur Qualitätssicherung notwendigen Vergleichsmessungen im Labor sowie der Messungen der Nährstoffkonzentrationen und der Chlorophyll-*a*-Konzentration von bei den Messkampagnen genommenen Wasserproben erfolgreich zusammen gearbeitet.

4. Publikationen

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MIZERKOWSKI, B., W. PETERSEN, F. SCHROEDER: FerryBox continuous water quality monitoring in Paranaguá Bay. (in Vorbereitung)

MIZERKOWSKI, B. et al: Applying Assessment of Trophic Status (ASSETS) in four estuaries in Southern Brazil. (in Vorbereitung)

Beiträge zu Tagungen etc.:

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MIZERKOWSKI, B., K.-J. HESSE, N. LADWIG, F. SCHROEDER, W. PETERSEN, E.C. MACHADO, R. ROSA, T. ARAUJO, 2009: Sources of nutrients in Paranaguá Bay – Southern Brazil. XIII Congresso Latinoamericano de Ciências do Mar (Latinamerican Conference on Marine Sciences), October 26-30th, Havana, Cuba.

III. NUTRIENT DYNAMICS IN PARANAGUÁ BAY – SOURCES AND DISTRIBUTION

1. Motivation and techniques

Nutrient enrichment is a well recognized evidence of increasing human impacts in the coastal zone. Higher nitrogen and phosphorus contents derive from natural or anthropogenic sources, from diffuse or point discharges. Higher availability of these nutrients can lead to eutrophication processes and affect negatively the ecosystem metabolism. Therefore it is necessary to investigate nutrient dynamics, relating sources and dispersion patterns to the occurrence of environmentally damaged areas in estuaries. The following investigations were carried out in close cooperation with subproject 1.

Estuarine systems that comprise economically important activities related to harbour and occupation are under increasing risk of presenting negative symptoms of eutrophication, such as nuisance/hazard algae blooms, hypoxia and organisms death. Paranaguá Estuarine Complex (PEC) has presented higher levels of development in the past decades. Paranaguá Harbour reached an important position among world´s trade network, especially in the matter of grain exportation. This growth has been followed by the city that comprises the harbour. Besides this activity, Paranaguá Bay is under occupation since the earlier 1600´s. The region is traditionally used by traditional fishery villages, tourisms and recreation, and it is draw up by several environmental protection units. The catchment area of PEC is recognized as one of the largest areas of protection of the Atlantic Rainforest.

PEC comprises two branches: Paranaguá and Antonina Bays (East-West Axis) and Laranjeiras Bay (north-south Axis). The assessment was addressed to the East-West Axis, where the harbours and important cities are placed.

In this area, nutrient enrichment can be related to harbour activities (highlight to soy and fertilizers transportation), illegal occupation in mangrove areas and illegal discharge of untreated sewage, deforestation, small scale agriculture and industry.

To assess nutrients sources, the following draft was assumed (only measurable sources were considered, input by underground water was not estimated):

- Rivers: there are around 9,000 freshwater channels in the whole catchment area of Paranaguá Bay. The logistical effort to sample all the area could not be accomplished. Therefore, only main streams were sampled (Faisqueira, Cachoeira, Cacatu, Sagrado, Nhundiaquara and Guaraguaçú rivers), comprising around 80 % of all estimated freshwater discharge to the system. Discharge data was not available for all the streams. Information based on catchment area and precipitation rates were correlated with proximate regions, with registered daily discharge values, to provide estimations on freshwater discharge.

- Atmosphere: bulk wet deposition was estimated using fixed stations in three locations. The importance of the input is due to the climate of this subtropical region (between 2000 and 3000 mm rain per year) and due to the large water surface area of the system (around 600 km^2). Loads were calculated by nutrients concentration, rainfall rates and area of the estuary.
- Harbour losses: estimation of losses regarding soy and fertilizers was performed based on information provided by harbour authorities. Annual reports about trading goods and losses during shipping activities were compared with the product content. Release of nutrients by soy was estimated with decomposition essays.
- Paranaguá City: comprises around 130,000 inhabitants and only a small portion of the city is covered by the sewage treatment network (around 35 %). Sewage channels are observed along the city, discharging untreated sewage and storm water directly to the estuary and harbour vicinity. These locations were sampled and discharge was estimated through comparison of field measurements and daily potable water consumption.

These sources were assessed (tab. 1) and related to the distribution of nutrients along the estuary body. Therefore, information regarding physical, chemical and biological processes could be analyzed and related to the possible exportation of material to the adjacent coastal area. In summary, the identification and determination of main nutrient sources in Paranaguá Bay was performed considering freshwater, atmospheric, harbour and city inputs. These information were combined with physical-chemical variables analyzed in longitudinal transects (main water body) to verify water quality dynamics, fluctuations and trends in temporal and spatial scales. Chlorophyll-*a* concentrations were used as phytoplankton biomass indicator, aiming the recognition of eutrophic areas and/or situations.

In order to assess the distribution of nutrients in Paranaguá Bay, longitudinal transects were performed in 6 occasions along the main navigation channel of the system (tab. 2). Water samples were taken and Pocket FerryBox information were recorded in order to verify the spatial and temporal fluctuations of water quality parameters. The surveys assessed 10 to 14 sampling points, with 6 concentrated around the harbour area. Besides, a better highlight was given to the harbour vicinity through a gradient mash sampling, in which 18 stations were sampled in the harbour area, named "harbour gradient" survey.

Along with sampling surveys, the FerryBox technology was also applied to supply data regarding water quality parameters in water. A stationary and a Pocket FerryBox were used to an integrated collection of data in continuous measurements and automated functioning. Data were available and accessed on real-time. The stationary system operates near the outlet of Paranaguá Bay since September 2007, collecting basic data (salinity, temperature, pH, dissolved oxygen, fluorescence, turbidity and colored dissolved organic matter-CDOM) that allows the identification of short and long term events such storms and dredging effects over water quality, and plankton blooms. The portable Pocket FerryBox is used in mobile sampling platforms, recording the basic water quality parameters in spatial scale.

Tab. 1: Sampling strategy regarding nutrient sources in Paranaguá Bay

Source	*Periodicity*	*Sampling period*	*Variables*
Rivers	monthly	February 2008-2009	Temperature, dissolved inorganic nutrients, total nitrogen and phosphorus, chlorophyll-*a*, suspended particulate matter
Atmospheric	Monthly (weekly accumulation)	August 2007 – April 2008	Dissolved inorganic nutrients
Harbour	Year rates	2007, 2008	Dissolved inorganic nitrogen and phosphorus
City	6 surveys	see table 2	Dissolved inorganic nutrients, total nitrogen and phosphorus, chlorophyll-*a*, suspended particulate matter

Tab. 2: Sampling dates, corresponding seasonal period and variables analyzed in the longitudinal transect in Paranaguá Bay. *Occasions with harbour gradient sampling

Date	*Period*	*Variables*
September 2007*	Dry	Salinity, temperature, pH, dissolved oxygen, dissolved inorganic nutrients (nitrite, nitrate, ammonium, phosphate, silicate), total nitrogen and phosphorus, organic particulate nitrogen and carbon, chlorophyll-*a*, suspended particulated matter
December 2007	Rainy	
February 2008*	Rainy	
June 2008	Dry	
September 2008	Dry	
January 2009	Rainy	

2. Results

2.1 Sources

River input is represented by relative contribution among rivers and dissolved nutrient forms (fig. 1a in $\mu mol \cdot dm^{-3}$ and fig. 1b in $kg \cdot day^{-1}$) and by discharge ($m^3 \cdot s^{-1}$). Among the dissolved inorganic nitrogen (DIN) entering Paranaguá Bay, 78 % was in the form of nitrate (NO_3^-), 20 % of ammonium (NH_4^+) and 2 % of nitrite (NO_2^-). Cachoeira River is the most important source of nutrients due to a combination of higher discharge and concentration, contributing approximately in the same order as all the other streams summed together.

Seasonality can be described by periods of more (rainy) or less (dry) precipitation. Average rainfall is two times higher in the rainy period and this pattern is followed also by the loads of nitrite, ammonium, phosphate and silicate (tab. 3). Nitrate loads, in terms of $kg \cdot day^{-1}$, are similar between the rainy and dry periods and derive from an inverse behavior between DIN concentrations and discharge along the year. Therefore DIN input, determined by nitrate fluctuations, can be constant along the year and regulated by freshwater (rainfall) dilution. Others nutrients present less fluctuations in concentration, and loads reflect the rainfall increase.

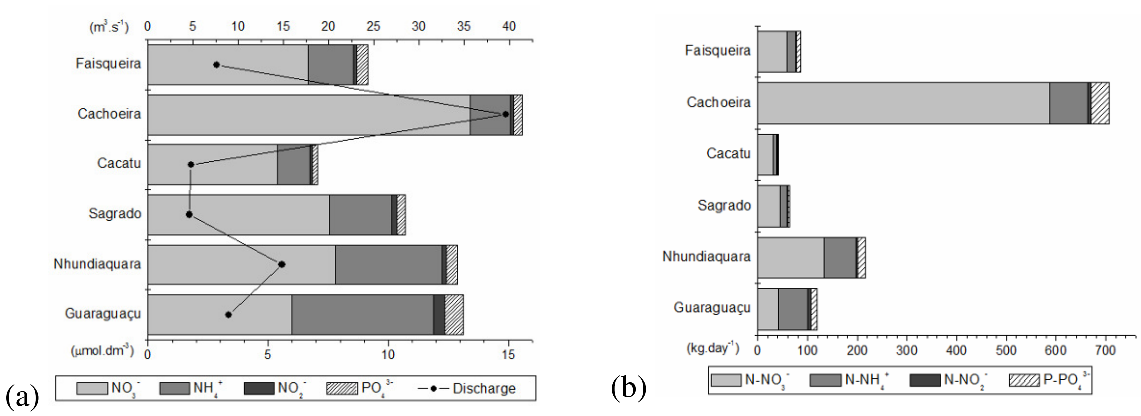


Fig. 1: Nutrient average concentrations (a) and loads (b) for the main rivers of Paranaguá Bay

Tab. 3: Average input from the rivers in the rainy and dry seasons in Paranaguá Bay, and the ratio between rainy:dry seasons. Discharge is given in $m^3 \cdot s^{-1}$ and dissolved inorganic nutrients are presented in $kg \cdot day^{-1}$

	Discharge	Nitrite	Nitrate	Ammonium	DIN	Phosphate	Silicate
Rainy	103.4	24.7	872.3	301.0	1198.0	107.3	23110.2
Dry	51.4	10.4	898.0	158.5	1168.0	54.8	12879.2
Rainy:Dry	2.0	2.4	1.0	1.9	1.1	2.0	1.8

Higher concentrations of nutrients from the atmospheric bulk wet deposition were registered in the middle region of Paranaguá Bay. This region comprises the Paranaguá Harbour and City, possibly the sources of enriched dust to the air. Higher loads were observed in the outer area, close to the mouth of the system. Therefore, concentration is an important factor regulating atmospheric deposition in the middle region, while in the larger area in the outer region is reflected by higher loads. In summary (fig. 2), nitrate and ammonium have a similar contribution for DIN in the rainy period, while is observed a clear decrease for ammonium in the dry season, leading also to lower DIN loads in this season. Phosphate levels were similar in both seasons. Silicate concentrations are not presented, considering that silicate levels are not bio-limiting and always abundant in Paranaguá Bay.

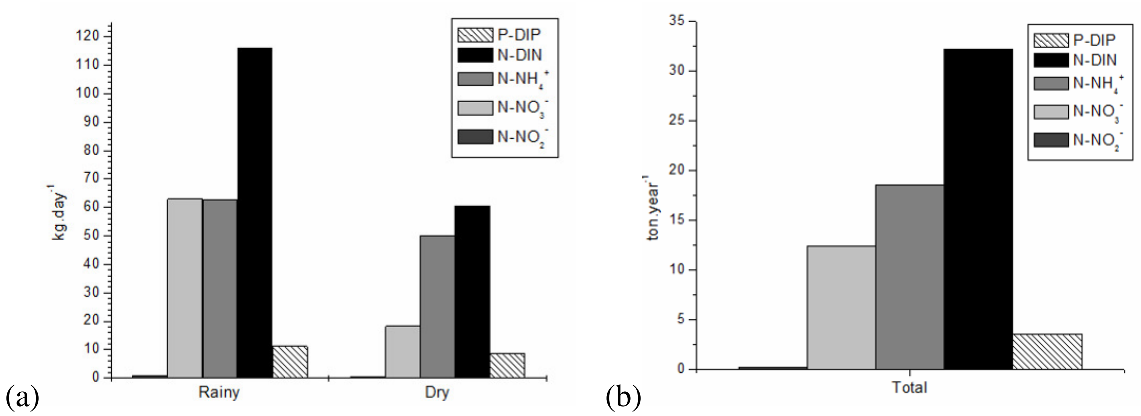


Fig. 2: (a) Atmospheric bulk daily deposition of DIN, and species, and DIP during rainy and dry seasons; (b) Total annual atmospheric bulk deposition of DIN, and species, and DIP

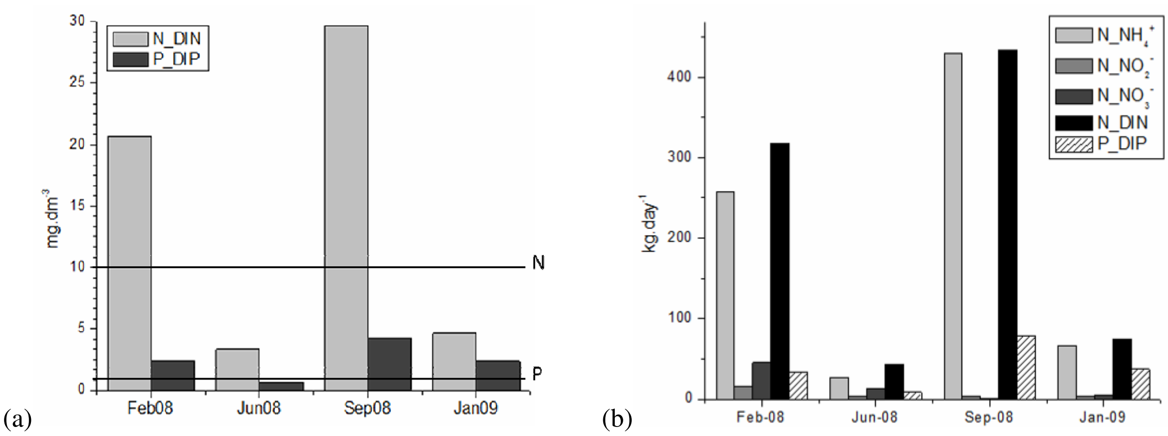


Fig. 3: (a) DIN and DIP average concentrations (mg·dm^{-3}) among sewage channels in Paranaguá Bay and CONAMA 357/05 legislation values for total N and P; (b) Loads of DIN, its species and DIP in kg·day^{-1} for four sampling campaigns

According to the Brazilian environmental legislation (CONAMA 357/05), total nitrogen and phosphorus concentrations in the discharged waters can be maximum 10 mg·dm^{-3} and 1 mg·dm^{-3}. In the channels of Paranaguá City, these limits were already crossed in two occasions for DIN and three times for DIP, as shown in figure 3a, therefore it is likely that the total N and P content can be regularly over the legal values for discharged water. Opposite to the pattern observed for freshwater and atmospheric input, ammonium is the prevalent form in DIN (fig. 3b), totaling from 63 to 98 % of total load of DIN. Fluctuations both in discharge and in concentrations could not be correlated with precipitation; other factors such daily variations in potable water consumption or individual/disperse discharges must be responsible for determining the input from the local sources in Paranaguá City.

Losses from harbour activities (fig. 4) were estimated as year budgets, considering the information about traded goods and percentage of losses provided by annual reports. Ammonium is abundant in fertilizers and no nitrate release was detected in the soy decomposition essays. It is important to mention that release of dissolved organic nitrogen and phosphorus by soy can reach 71.19 kg·day^{-1} and 16.63 kg·day^{-1}, respectively.

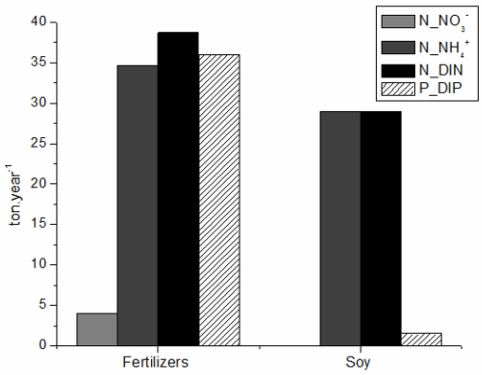


Fig. 4: DIN and DIP loads from harbour losses during shipping of fertilizers and by soy decomposition

Tab. 4: Relative contributions to DIN and DIP loads in Paranaguá Bay considering the measured sources of nutrients

Nutrient Sources	$N\text{-}NH_4^+$		$N\text{-}NO_3^-$		N-DIN		P-DIP	
	ton/year	**%**	**ton/year**	**%**	**ton/year**	**%**	**ton/year**	**%**
Rivers	88	37	339.6	93	434.6	71	32.2	36
Atmospheric	17.1	7	15	4	32.2	5	3.6	4
Fertilizers	34.7	14	4.0	1	38.7	6	36.0	40
Soy	29.0	12	-	-	29.0	5	2.0	4
City	71.2	30	5.8	2	79.4	13	14.4	16
Total	240		364.4		613.9		88.2	

In summary, the comparison of all measured sources (tab. 4) suggests that rivers are responsible for around 71 % of all DIN entering Paranaguá Bay, mostly in the form of nitrate. The contribution in the form of ammonium (56 %) derives from the sum of the sources in the middle region of the estuary (fertilizers, soy and city), revealing an important spot for decomposition resultants. DIP input is also higher in this middle area, where around 60 % results from this sum of sources. Rivers are responsible for 36 % of DIP load. Atmospheric input has presented similar effect over total loads of DIN and DIP (5 % and 4 %, respectively).

2.2 Nutrient dispersion and water quality

Nutrients concentrations followed diverse patterns along the main East-West Axis of Paranaguá Bay. To easy the understanding of processes, the system was divided into three sections (upper, middle, lower) according to the salinity gradients and previous studies (fig. 5).

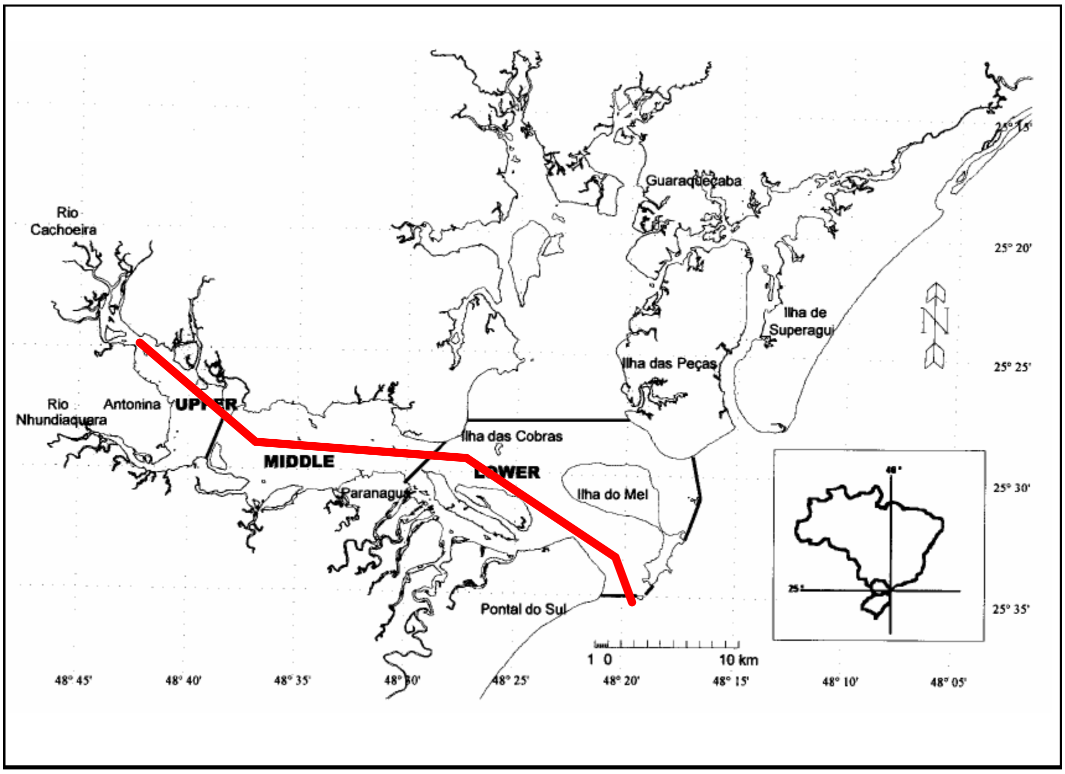
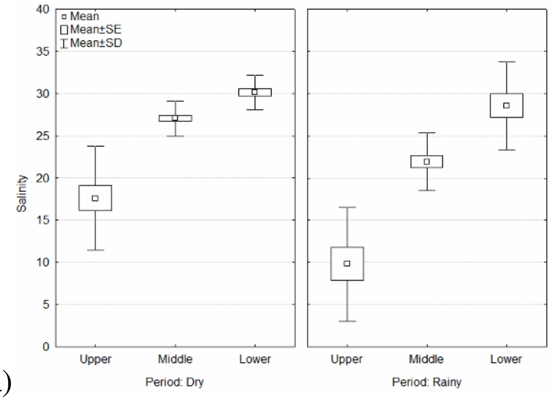


Fig. 5: The Paranaguá Estuarine System and Paranaguá Bay highlighted by the division of three sections, presenting the longitudinal transect (red line) performed in sampling surveys (Source: Marone et al., 2005)

Results are also presented with the distinction between rainy and dry seasons, presenting seasonal fluctuations observed. The salinity gradient among the sections was evident in all samplings as shown by figure 6a. Higher phytoplanktonic biomass (indicated by the increase of chlorophyll-*a* concentrations) is observed during the rainy period (fig. 6b), representing spring/summer season. Primary production in this period can be 4 to 6 times higher compared to the dry period (autumn/winter). Higher concentrations are always observed in the middle region.

(a)



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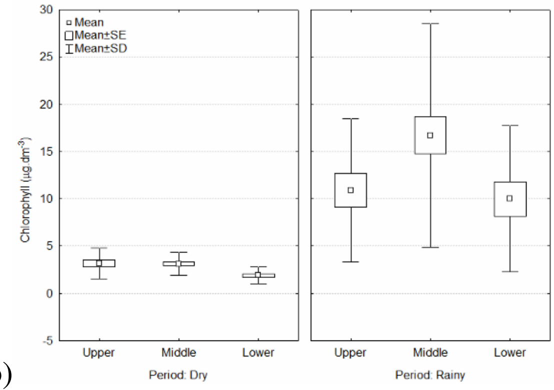


Fig. 6: Salinity (a) and chlorophyll-a (b) average, standard error and standard deviation for the obervations among the three sections (upper, middle and lower) of Paranaguá Bay in dry and rainy periods

DIN concentrations (fig. 7a) are always higher in the Upper section, and no significant difference was observed between seasonal periods. This corroborates that rivers are the main source of DIN and nitrate (fig. 7b) to the system, as discussed in the previous topic.

Moreover, the magnitude of primary production increase during the rainy period (4 to 6 times higher) is slightly reflected by lower concentrations of DIN during this season in the upper and middle sections. In the middle section of the bay, where the city of Paranaguá is located, DIN concentrations are in the range of local background concentrations of about 3-6 $\mu mol \cdot dm^{-3}$ in both seasons. The lower section presents an opposite behavior, with an unexpected increase of DIN during this period that can be due to higher input from the coastal beach area during summer holidays.

Nitrite (fig. 7c) and ammonium (fig. 7d) behavior along the longitudinal transect is not well clear, especially during the rainy period. Nitrite presents picks of concentration around the mouth of Nhundiaquara River and near the eastern margin of harbour area. Ammonium concentrations are even more variable, but three picks are well recognized: near the outlet of Nhundiaquara River, in the harbour area (around the fertilizers pier and the outlet of Anhaia sewage channel, more precisely) and in the outer section. Therefore, the contribution of local sources besides rivers is important in the distribution of these two forms of DIN.

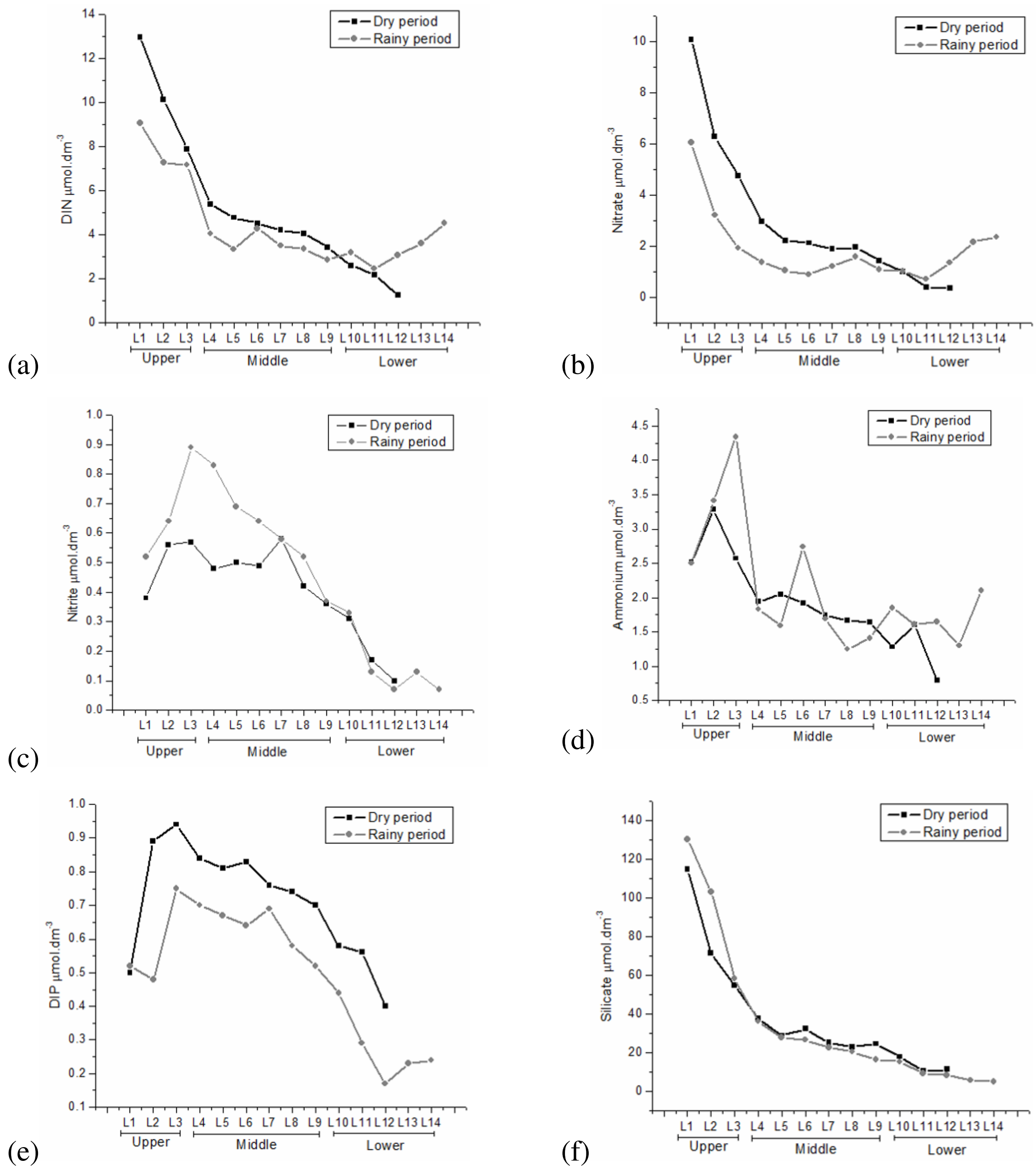


Fig. 7: Concentration [µmol·dm^{-3}] of DIN (a), nitrate (b), nitrite (c), ammonium (d), DIP (e) and silicate (f) along the three sections (upper, middle, lower) of the longitudinal transect in Paranaguá Bay during rainy and dry periods

DIP concentrations (fig. 7e) are clearly enhanced in the middle of the bay, especially around the outlet of Nhundiaquara River and harbour area. In the upper section, DIP concentrations are around 0.5 µmol·dm^{-3}, whereas an increase to almost 1.0 µmol·dm^{-3} can be observed close to the city of Paranaguá during the dry period. The location of the maximum turbidity zone might also play an important role as remobilization of phosphate from sediments in this area. Silicate concentrations (fig. 7f) show a clear gradient that correlates with salinity, indicating the freshwater input of this nutrient. Its distribution must be almost conservative as the salinity content.

The relationship between nutrient availability and primary production is presented by observations of chlorophyll-*a* concentrations and ratio DIN:DIP (fig. 8). The middle section presents best conditions for phytoplankton growth, with two picks of concentration during the rainy period around the harbour vicinity. DIN:DIP ratios show an opposite behavior to chlorophyll-*a* concentrations indicating that phytoplankton growth also effects nutrients concentrations, especially in the rainy period.

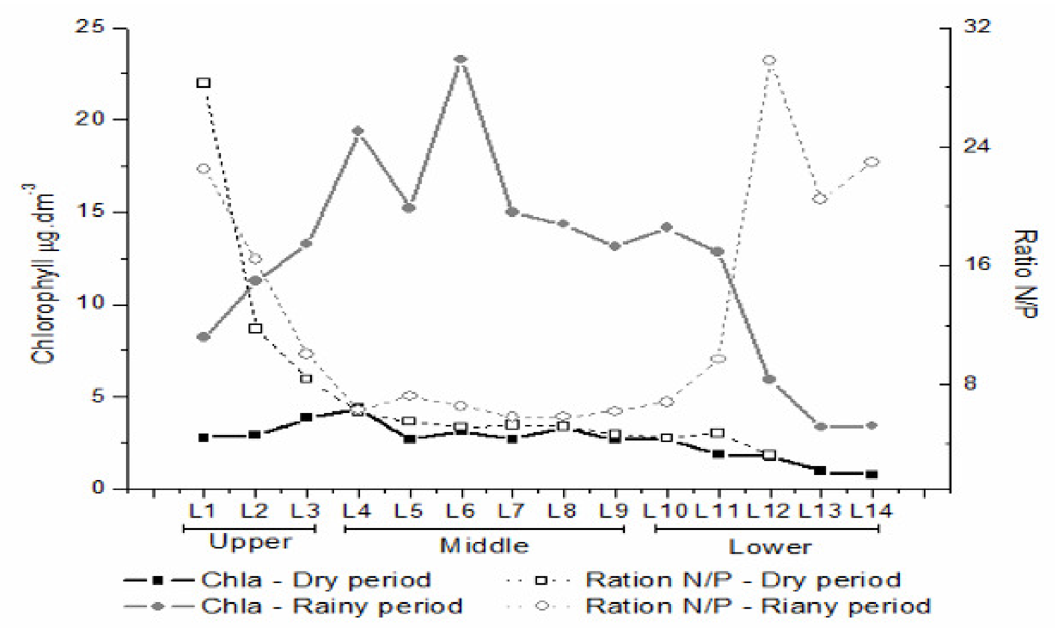


Fig. 8: Chlorophyll-*a* concentrations and ratio DIN:DIP along the three sections (upper, middle and lower) of Paranaguá Bay in rainy and dry periods

DIN, DIP and chlorophyll-*a* concentrations were compared with reference limits, as shown in table 5. The reference limits were determined in order to analyze the trophic status of an estuary, therefore provide information regarding the susceptibility of the system to develop eutrophication negative symptoms. It is recommended that maximum values are considered according to precaution approaches. Nevertheless, average values should also be considered in order to observe if predominant conditions can be also described by extreme situations. Most of the observed measurements can be classified as medium to low in all sections for both seasons, except for the high chlorophyll-*a* maximum concentrations in all sections during the rainy season. Especially in the middle section high maximum chlorophyll-*a* concentrations of 47.6 µg were observed which represent a dense phytoplankton bloom.

Tab. 5: DIN, DIP and chlorophyll-*a* concentrations among the three sections (upper, middle, lower) of Paranaguá Bay in dry and rainy periods, compared with reference limits

Variables		Upper		Middle		Lower		Reference Limits*
		Dry	Rainy	Dry	Rainy	Dry	Rainy	
DIN	Mean	0.15 Medium	0.10 Medium	0.07 Low	0.04 Low	0.03 Low	0.05 Low	High ≥ 1; 1>Medium ≥ 0.1; Low < 0.1
	Max.	0.4 Medium	0.16 Medium	0.12 Medium	0.10 Medium	0.06 Low	0.11 Medium	
DIP	Mean	0.02 Medium	0.01 Medium	0.03 Medium	0.02 Medium	0.02 Medium	0.01 Medium	High ≥ 1; 1> Medium ≥ 0.1; Low < 0.01
	Max.	0.03 Medium	0.03 Medium	0.04 Medium	0.04 Medium	0.03 Medium	0.02 Medium	
Chlorophyll-*a*	Mean	3.3 Low	12.6 Medium	3.5 Low	17.8 Medium	1.8 Low	10.5 Medium	Hypereutrophic > 60; 60 ≥ High > 20; 20 ≥ Medium > 5 Low ≤ 5
	Max.	5.6 Medium	36 High	6.9 Medium	47.6 High	3.4 Low	23.2 High	

* Reference Limits modified from Bricker *et al.* (2003); DIN and DIP in $mg \cdot dm^{-3}$; Chlorophyll-*a* in $\mu g \cdot dm^{-3}$

DIN and DIP plumes are observed in a more detailed assessment in the harbour vicinity, as presented by figure 9. Local maxima in dissolved inorganic nitrogen and phosphorus levels deriving from the highly concentrated sewage discharge were observed in front of the harbour of Paranaguá. However, in keeping with the low water residence time of the bay (around 3 days), the plumes are rapidly diluted. Some effects are observed along the longitudinal transects profiles, but the dilution is evident.

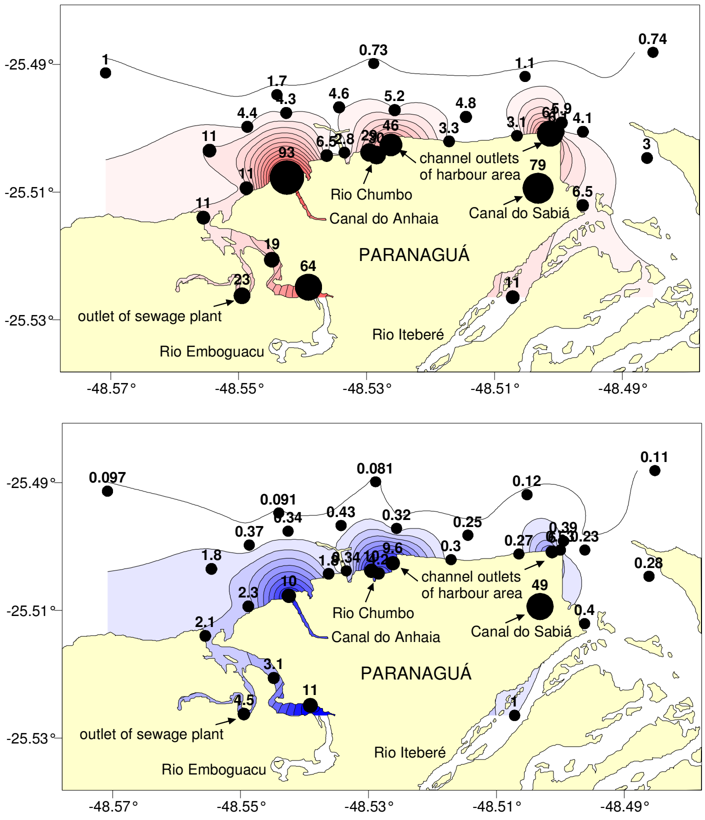


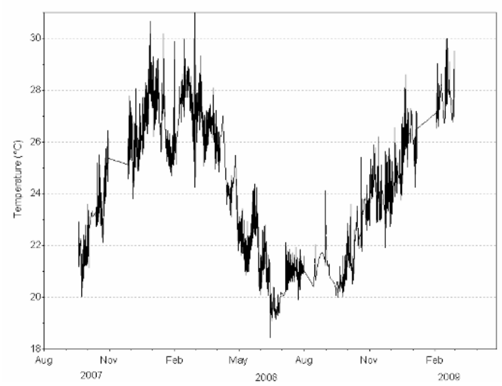
Fig. 9: DIN (a) and DIP (b) concentrations (µmol·dm^{-3}) in the Paranaguá Harbour and City vicinity (Source: Subproject 1)

2.3 Water Quality Monitoring

The Stationary FerryBox operating in Paranaguá Bay since September 2007 provides a long time-series from water quality data. Large scale fluctuation can be observed with high resolution (measurements are made at each minute), such as annual or seasonal variations. Temperature measurements (fig. 10a) show a clear cyclic behavior according to seasons. Short-scale fluctuations, such as daily salinity variation as a tidal effect, are also recorded (fig. 10b). Moreover, the resolution provided by the system would not be reached in the conventional forms of sampling.

The effect of random events, as storms, was indicated by data and an example is presented. There was a severe storm event in March, 12th 2008, when a pick of 150 mm was recorded after 10 days of no rainfall (fig. 11a). Salinity data (fig. 11b) reveal a decrease of salinity after the storm and the subsequent days of rain. Fluorescence levels (fig. 11b) also show the effect of freshwater input. An increase of phytoplanktonic production is observed during the dry days, and a decrease follows the salinity behavior. This indicates that increasing freshwater input with resultant salinity decrease can have an inhibition effect on primary production.

(a)



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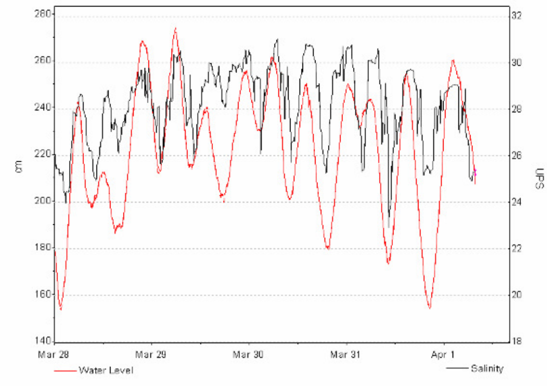
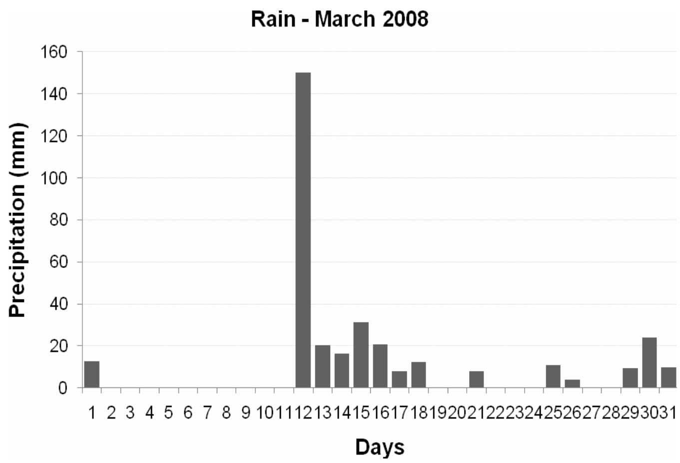
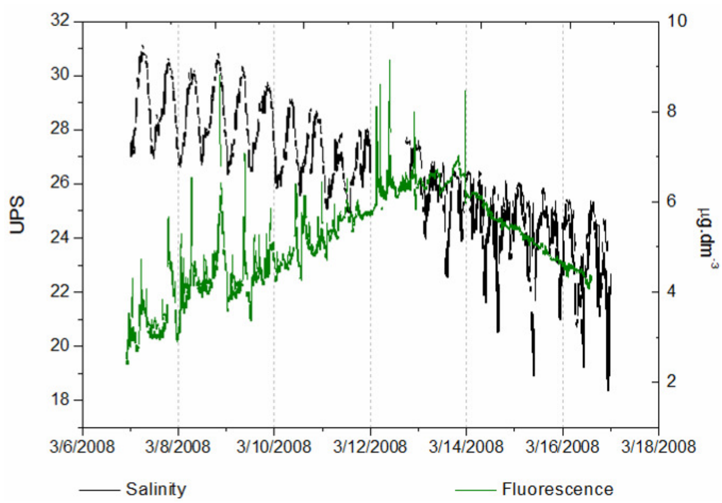


Fig. 10: (a) Temperature measurements from September, 2007 to February, 2009; (b) Water level (tide) and salinity measurements between March, 27th and 31st, 2008



(a)



(b)

Fig. 11: (a) Rainfall daily records during March, 2008; (b) Stationary FerryBox measurements of salinity and fluorescence between March 7th and 17th, 2008

Patches of production is also an important aspect of the distribution of phytoplankton in Paranaguá Bay. The middle section of the estuary presents better conditions for these communities growth, indicated by higher fluorescence measurements used as indicator of chlorophyll concentrations (fig. 12).

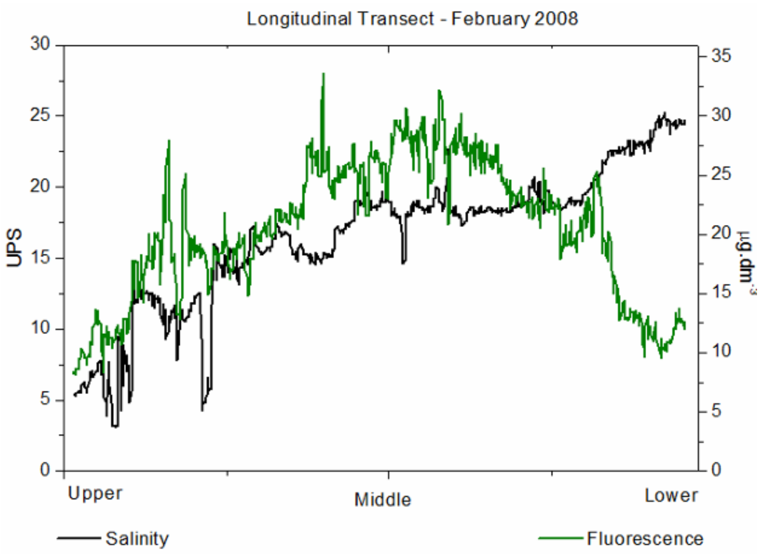


Fig. 12: Salinity and fluorescence measurements in the longitudinal transect of Paranaguá Bay, performed in February, 2008 with the portable Pocket FerryBox

Lower chlorophyll concentrations are observed in the lower area both in dry and rainy periods, where the Stationary FerryBox is placed. Negative correlation is observed between fluorescence and salinity measurements from the monitoring station. Chlorophyll-*a* peaks recorded during low tide (figs 13a, b) indicate that higher primary production patches are transported from inner parts of the estuarine system.

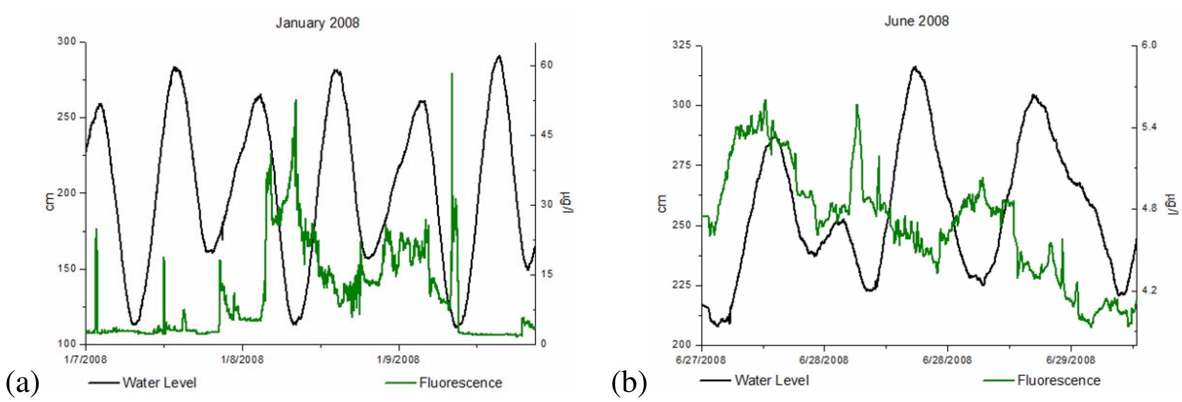


Fig. 13: Stationary FerryBox measurements of water level (tide) and fluorescence in January, 2008 (a) and June, 2008 (b)

2.4 Summary

Main source of DIN in Paranaguá Bay are the rivers (65 % of total inputs), especially in the form of nitrate (93 %). In the middle region of the bay, harbour losses and city input play an important role in the distribution of ammonium and nitrite. DIP enrichment can be related to the cargo handling of fertilizers, soy decomposition and sewage discharge that are responsible for more than 60 % of total loads centralized in the middle section. No clear evidence of nutrient enrichment is verified when observing chlorophyll and nutrients concentrations. Short resident time may act as a dumper of severe eutrophication conditions. The trophic status of Paranaguá Bay can be classified as medium to low with respect to nutrients and chlorophyll-*a* concentrations. However, it is well known that low nutrient and high chlorophyll concentrations are not obligatory causes and symptoms of eutrophication. The occurrence of nuisance or hazard algae blooms is not completely understood. If other environmental factors are favorable, undesired effects can affect phytoplanktonic communities resulting in negative impacts. Even though nutrient concentrations in Paranaguá Bay are considered around medium limits, nuisance algae blooms had already been observed in the system, causing fisheries interruption. Applying nutrient reduction strategies is necessary, especially in the case of subordinate the discharge of untreated sewage to the Brazilian environmental legislation. The implementation of sewage treatment plants and expanding the collecting net is indispensable for Paranaguá City also as public health matter. Losses in the harbour area could be diminished by controlling the handling of cargo, resulting also in less financial losses. Alternative solutions for losses of grains can also be implemented in the city and outside the harbour. The loss of material during the road transport is evident and during harvest periods, all the way leading to the harbour is covered by grains. This material can be collected and used in biodecomposition chambers transforming the organic material into methane and, therefore, energy.The use of a reference pristine area, like the North-South Axis, can be useful to verify natural fluctuations in nutrients concentrations. Moreover, management actions should be addressed to the catchment areas in order to control the input, not only for nutrients but also for sediments causing siltation and reducing the depth in the navigation channel. A better understanding of denitrification and nutrient assimilation by phytoplankton is required to better understand the processes involving nitrogen, phosphorus and carbon cycling in the estuary. Recovery of past information about nuisance algae blooms, quantify and qualify macroalgae banks is also essential to determine primary productions rates and these elements fixation. Monitoring of eutrophication symptoms with the FerryBox systems has shown to be an important tool providing real-time data. Fluorescence measurements are used as phytoplanktonic biomass indicator and dissolved oxygen concentrations can be used to indicate harmful situations to the aerobic organisms. In summary, proposing a continuous environmental plan for Paranaguá Bay would impose monitoring and management actions over the sources of nutrients and the cycles of nitrogen, phosphorus and carbon in the estuarine system.

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18. Kurzfassung

In der Paranaguá Bucht wurden als Hauptquellen für gelösten anorganischen Stickstoff (DIN) die Flüsse (65 % vom Gesamteintrag) identifiziert. Gelöstes Nitrat hat hierbei den Hauptanteil (93 %). Im mittleren Bereich der Bucht spielt der Einfluss des Hafens und der anliegenden Stadt Paranaguá auf die Konzentrationen von Ammonium und Nitrit eine bedeutende Rolle. Für die Anreicherung von gelöstem Phosphor (DIP) in diesem Bereich wird der Verlust beim Transport sowie der Verladung von Düngemitteln und Sojaprodukten angesehen. Die Mineralisierung dieser Stoffe und der Abwassereintrag kann für mehr als 60 % der Frachten verantwortlich gemacht werden.

Es wurde kein eindeutiger Zusammenhang zwischen Nährstoffkonzentrationen und den beobachteten Chlorophyll-*a* Konzentrationen gefunden. Die hohen Wasseraustauschraten in der Bucht verhindern, dass ernsthafte Eutrophierungsprobleme beobachtet werden können. Der Eutrophierungsgrad in der Bucht kann als leicht bis mittel bezüglich der Nährstoff- und Chlorophyll-Konzentrationen klassifiziert werden. Dennoch wird aber das zeitweise Auftreten toxischer Algenblüten mit teilweisem Fischsterben beobachtet.

Im Rahmen der Reduktion der Nährstoffeinträge sollte insbesondere in der Großregion Paranaguá der Eintrag von unbehandelten Abwässern durch entsprechende Kläranlagen reduziert werden. Die durch Verluste bei der Verladung von Soja und Düngemitteln verursachten Einträge aus dem Hafen sollten durch entsprechende Maßnahmen reduziert werden.

Um die Einträge von Biomasse und Nährstoffen in das Ästuar besser zu verstehen, bedarf es noch weiterer Untersuchungen zu den Prozessen der Denitrifizierung und der Nährstoffaufnahme durch Phytoplankton in der Bucht. Der Vergleich der Nährstoffkonzentrationen entlang einer Nord-Süd Achse kann genutzt werden, um natürliche Schwankungen in den Nährstoffkonzentrationen von anthropogen verursachten zu unterscheiden.

Das installierte FerryBox-System hat sich als ein wichtiges Instrument zur Beobachtung von Eutrophierungserscheinungen in Realzeit herausgestellt. So können die Chlorophyll-*a* Fluoreszenzdaten als Indikator für die Phytoplankton-Biomasse genutzt und die Sauerstoffmessungen zur Detektion kritischer Sauerstoffsituationen verwendet werden.

19. Schlagwörter

Paranaguá Bucht, Nährstoffbudget, FerryBox

20. Verlag	21. Preis

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18. abstract
Main source of DIN in Paranaguá Bay are the rivers (65 % of total inputs), especially in the form of nitrate (93 %). In the middle region of the bay, harbour losses and city input play an important role in the distribution of ammonium and nitrite. DIP enrichment can be related to the cargo handling of fertilizers, soy decomposition and sewage discharge that are responsible for more than 60 % of total loads centralized in the middle section.

No clear evidence of nutrient enrichment is verified when observing chlorophyll and nutrient concentrations. Short resident time may act as a dumper of severe eutrophication conditions. The trophic status of Paranaguá Bay can be classified as medium to low with respect to nutrients and chlorophyll-*a* concentrations. However, it is well known that low nutrient and high chlorophyll concentrations are not obligatory causes and symptoms of eutrophication. The occurrence of nuisance or hazard algae blooms is not completely understood. If other environmental factors are favorable, undesired effects can affect phytoplanktonic communities resulting in negative impacts. Even though nutrient concentrations in Paranaguá Bay are considered around medium limits, nuisance algae blooms had already been observed in the system, causing fisheries interruption. Applying nutrient reduction strategies is necessary, especially in the case of subordinate the discharge of untreated sewage to the Brazilian environmental legislation. The implementation of sewage treatment plants and expanding the collecting net is indispensable for Paranaguá City also as public health matter.

Losses in the harbour area could be diminished by controlling the handling of cargo, resulting also in less financial losses. Alternative solutions for losses of grains can also be implemented in the city and outside the harbour. The loss of material during the road transport is evident and during harvest periods, all the way leading to the harbour is covered by grains. This material can be collected and used in bio-decomposition chambers transforming the organic material into methane and, therefore, energy.

The use of a reference pristine area, like the North-South Axis, can be useful to verify natural fluctuations in nutrient concentrations. Moreover, management actions should be addressed to the catchment areas in order to control the input, not only for nutrients but also for sediments causing siltation and reducing the depth in the navigation channel.

A better understanding of denitrification and nutrient assimilation by phytoplankton is required to better understand the processes involving nitrogen, phosphorus and carbon cycling in the estuary. Recovery of past information about nuisance algae blooms, quantify and qualify macroalgae banks is also essential to determine primary production rates and these elements fixation.

Monitoring of eutrophication symptoms with the FerryBox systems has shown to be an important tool providing real-time data. Fluorescence measurements are used as phytoplanktonic biomass indicator and dissolved oxygen concentrations can be used to indicate harmful situations to the aerobic organisms.

In summary, proposing a continuous environmental plan for Paranaguá Bay would impose monitoring and management actions over the sources of nutrients and the cycles of nitrogen, phosphorus and carbon in the estuarine system.

19. keywords
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20. publisher	21. price

Schlussbericht

TP5 Aufbau, Wartung und Weiterentwicklung einer „Stationären FerryBox“

im Verbundprojekt

Nachhaltiges Umweltmanagement in brasilianischen Häfen

-4H- JENA engineering GmbH

BMBF Förderkennzeichen: 03F0452F

Zuwendungempfänger: **-4H-JENA engineering GmbH**	Förderkennzeichen: **03F0452F**

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TP5 Aufbau, Wartung und Weiterentwicklung einer „Stationären FerryBox"

Laufzeit des Vorhabens: **01.10.2006 - 30.09.2009**

Berichtszeitraum: **01.10.2006 - 30.09.2009**

Projektleiter: **Dipl.-Ing. M. Koch**
Projektbeteiligte: **Dr. T. Boehme**

I. SCHLUSSBERICHT

1. Aufgabenstellung

Die Arbeiten im Teilprojekt waren Bestandteil des Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen". Ziel des Teilprojektes war es, eine automatische Messeinrichtung („stationäre FerryBox") zu erstellen, in Paranaguá aufzubauen und den Betrieb mittels regelmäßiger Wartungsarbeiten zu gewährleisten. Mit der Anlage sollten Echtzeitdaten und Langzeitmessreihen zur besseren Bewertung der Umweltbedingungen im Hafen von Paranaguá erfasst werden. Es erfolgte daher eine enge Zusammenarbeit mit TP1 (*Morphodynamik, Verschlickung, Baggerei,* FTZ) und TP4 (*Automatisiertes Monitoring und Detektion von Kurzzeitereignissen*, GKSS).

Die „stationäre FerryBox" wurde in einem klimatisierten Container eingebaut, getestet und in Paranaguá aufgebaut. Zur Anpassung an die spezifischen Gegebenheiten vor Ort war die Entwicklung einer Ansaugeinrichtung mit Pumpen und Sensorik am Ufer der Bucht erforderlich. Die Daten sollten per GSM-Verbindung in ein Büro des brasilianischen Partners CEM übertragen werden. Hier sollte sowohl eine Anbindung an das NOKIS-System als auch eine direkte Anbindung an das Internet erfolgen. Damit könnte weltweit auf die Daten online zugegriffen werden und das System als Frühwarnanlage für außergewöhnliche Ereignisse (Tanker-/Chemikalienunfälle, starke Algenblüten usw.) verwendet werden. Ein wesentlicher Teil der Arbeiten bestand in der regelmäßigen Wartung und Kontrolle der Anlage (Fernüberwachung und Wartungsfahrten nach Brasilien), sowie in einer Kontrolle der Sensorfunktionen (Qualitätssicherung). Weiterentwicklungen für eine Anpassung an die spezifischen Gegebenheiten (Konzentrationsbereiche, spezielle Biofouling-Bedingungen usw.) waren notwendig.

Mit der Anlage wurden die Teilprojekte 1 und 4 in die Lage versetzt, ihre Modelle zu kalibrieren, kurzfristige Ereignisse zu erfassen und damit eine Bewertung der Wasserqualität der Paranaguá-Bucht durchzuführen.
Gleichzeitig sollte die „stationäre FerryBox“ als Referenzanlage in Brasilien dienen und damit die Vermarktungschancen in Südamerika erhöhen.
Beim Aufbau der Anlage standen als FuE-Arbeiten insbesondere die Anpassung der Sensorik an die Verhältnisse des Messgebiets (Konzentrationsbereiche, Biofouling-Bedingungen usw.) sowie die Entwicklung einer an die Messaufgabe angepassten Ansaugeinrichtung im Vordergrund.

2. Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

Das vorliegende Teilprojekt stellte einen anwendungsbezogenen Beitrag zu der deutsch-brasilianischen Zusammenarbeit in Wissenschaft und Technik im Bereich der Meeresforschung dar. Dabei wurde dem Grundgedanken, der die Einbeziehung industrieller Partner vorsieht, im Vorhaben entsprochen. Weiterhin war das Vorhaben in Übereinstimmung mit Vorgaben der Europäischen Kommission, in deren Förderrichtlinien Projekte vorrangig gefördert werden sollen, die zu einer Verbesserung der Lebensqualität, für eine nachhaltige Nutzung von Umwelt und natürlichen Ressourcen sowie zu einer Verbesserung der Wettbewerbsfähigkeit von KMU‘s führen.

3. Planung und Ablauf des Vorhabens

Die Durchführung des Vorhabens erfolgte arbeitsteilig auf der Grundlage von zwischen den beteiligten Einrichtungen eng aufeinander abgestimmten Arbeitsplänen jedes Projektpartners. Im Teilprojekt 5 von 4H JE waren folgende Arbeiten geplant:

- **Entwicklung einer Ansaugeinrichtung mit Pumpe und Sensorik, die dem variablen Wasserstand (Tide, Windstau) folgt**
  Es sollte eine an die örtlichen Gegebenheiten angepasste Ansaugeinrichtung entwickelt und aufgebaut werden. Dies beinhaltete einen beweglichen Sondenträger, der am Ufer befestigt und unterhalb der Wasseroberfläche fixiert ist. Auf dem Sondenträger befindet sich eine Tauchpumpe, die Probenwasser in die FerryBox befördert. Elektronische Sicherungen verhindern ein Trockenlaufen der Pumpe. Zur Reinigung kann der Sondenträger hochgeklappt werden, wobei die Pumpe automatisch abschaltet werden.

- **Aufbau und Inbetriebnahme einer stationären FerryBox unmittelbar am Ufer der Bucht**

  Eine FerryBox mit den unter Pkt. 4 angeführten Sensoren sollte erstellt und in Jena getestet werden. Anschließend sollte die Anlage in einen Container eingebaut werden, der gleichzeitig Reinigungseinrichtungen sowie eine Bedieneinheit mit unterbrechungsfreier Stromversorgung enthalten sollte. Nach erfolgreicher Erprobung des Gesamtsystems sollte der Container nach Paranaguá verschifft und anschließend in Betrieb genommen werden. Parallel dazu war spezifiziert, einen Rechner (Landstation) in einem Büro von CEM zu installieren. Intensive Tests waren angedacht zu:
    - Funktion aller Wassersysteme, einschl. Spülung und Antifouling-Einrichtungen
    - Datenaquisition mit Mittelung und QS-Kontrolle
    - Kalibrierdaten der einzelnen Sensoren
    - Datentelemetrie zur Landstation und Verbindung ins Internet

- **Qualifizierung der FerryBox zur Qualitätssicherung**

  Gemeinsam mit dem wissenschatlichem Partner GKSS (TP4) sollten Vergleichsmessungen durchgeführt werden, um die Qualität der Messdaten festzustellen und zu dokumentieren.

- **Regelmäßige Wartung in Paranaguá**

  Es wurden dreimal jährlich (2009 zweimal) Wartungen in Paranaguá geplant. Diese Arbeiten sollten beinhalten:
    - Überprüfung der Anlage
    - Austausch von Verschleißteilen
    - Überprüfung der Ansaugeinrichtung und ggf. Tausch der Pumpe
    - Neukalibrierung einzelner Sensoren
    - Überprüfung der Hard- und Software im Container und an Land
    - Aufspielen und Testen von Software-Updates
    - Kontrollieren und Bereinigen der Datenbank

- **Komplette Dokumentation der Anlage sowie aller Wartungs-, Kalibrier- und Reparaturarbeiten (QS)**

  Ein wesentlicher Bestandteil der Arbeiten war eine vollständige Dokumentation.

Dies war insbesondere deshalb wichtig, damit die brasilianischen Partner die Anlage bedienen und qualitätsgesichert „fahren“ konnten. Die Arbeiten beinhalteten im Einzelnen:

- Dokumentation aller Geräte und Komponenten
- Dokumentation der Software
- Anleitungen zur Bedienung der Anlage
- Dokumentation aller Wartungsvorgänge
- Lebenslaufblätter für die Sensoren (QS)
- Dokumentation aller Kalibrierungen, Vorbereitung für „Control-Charts“, die vom brasilianischen Bedienpersonal gepflegt werden (QS).

4. Wissenschaftlich-technischer Stand, an den angeknüpft wurde

Mit dem beantragten Vorhaben wurde der bilaterale Technologietransfer speziell auf dem Gebiet der angewandten Umweltforschung zwischen Deutschland und Brasilien intensiviert. Die geplanten Forschungsarbeiten sollten einen Beitrag zur Verbesserung der Umweltstandards im Partnerland leisten und Entwicklungspotenziale für ein nachhaltiges Hafenmanagement aufzeigen.

Die Firma -4H- JENA engineering GmbH entwickelt und fertigt seit mehreren Jahren Sonden und Sondensysteme für die Meeresmesstechnik, die sich durch hohe Stabilität und Messgenauigkeit auszeichnen.

In der Fa. -4H- JENA engineering GmbH existiert sowohl das wissenschaftlich technische, als auch kaufmännische know how, um die im Projekt dargestellten Aufgaben mit hoher Effizienz zu lösen.

Nicht zuletzt die Zertifizierung des Unternehmens nach *DIN EN ISO 9001 6/97* und aktuell nach DIN EN ISO 9001:2008 in 2009 gab und gibt die Gewähr für eine Sicherung der im Projekt abverlangten Qualität.

Das wissenschaftlich-technische Potential der anderen Projektpartner war ein weiterer Grund für die Sicherheit der Antragsteller auf eine erfolgreiche Projektdurchführung.

5. Zusammenarbeit mit anderen Stellen

Die in diesem Verbundvorhaben geplanten Arbeiten wurden in drei eng aufeinander abgestimmten Teilvorhaben gemeinsam den Teilprojekten TP1 und TP4 durchgeführt.

6. Voraussichtlicher Nutzen und Verwertbarkeit der Ergebnisse

Insgesamt kann eingeschätzt werden, dass uns die am Einsatzort gewonnenen Erkenntnisse wesentlich geholfen haben, das Gesamtsystem weiter zu entwickeln.

Die Möglichkeiten des operationellen Monitorings konnten umfassend getestet werden und Erfahrungen im Betrieb an isolierten Standorten gesammelt werden.

Besuche auf Messen in Brasilien haben das System weiter bekannt gemacht.

Vor-Ort-Besichtigungen mit potentiellen Kunden, wie Petrobras, der Hafenbehörde Paranaguá haben gezeigt, dass dieses System für den brasilianischen Markt geeignet ist. Aktuell sind verschiedene Angebote über unseren brasilianischen Partner im Umlauf. Für den brasilianischen Markt konnte zusätzlich eine Vertretung gewonnen werden, welche die Systeme in unserem Namen anbietet, gemeinsam mit uns installiert und vor Ort auch die notwendigen Wartungsarbeiten durchführen kann. Diese Vertretung hat bereits in unserem Namen an der CBO 2008 in Fortaleza vom 19. bis 24. Mai 2008 teilgenommen. Auch dort zeigte insbesondere die Ölindustrie starkes Interesse an dem Messcontainer, was dazu führte, dass entsprechende Angebote ausgearbeitet und übergeben wurden, sowie Besichtigungen vor Ort am Container angeboten und im Dezember 2009 auch durchgeführt wurden.

7. Während der Durchführung des Vorhabens bekannt gewordener Fortschritt bei anderen Stellen

Uns sind keine Fortschritte an anderen Stellen bekannt geworden. Nach wie vor stellt unser System das Einzige System dar welches auch kommerziellen Ansprüchen genügt.

II. ERFOLGSKONTROLLBERICHT

1. Beitrag des Ergebnisses zu den förderpolitischen Zielen

Das Teilprojekt war Bestandteil des Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ und liefert einen technisch orientierten Beitrag zur wissenschaftlich-technologischen Zusammenarbeit des BMBF mit Brasilien. Die WTZ mit Brasilien sieht insbesondere die Einbeziehung industrieller Partner in die bilateralen Forschungsvorhaben vor. Diesem Grundgedanken wurde mit dem vorliegenden Teilprojekt entsprochen.

2. Wissenschaftlich-technisches Ergebnis des Vorhabens, erreichte Nebenergebnisse und gesammelte wesentliche Erfahrungen

Mit dem nahezu automatischen Betrieb des Messcontainers und der installierten FerryBox konnte nachgewiesen werden, dass diese Art Station auch in subtropischen Gebieten dauerhaft eingesetzt werden kann. Diese Erkenntnis im Zusammenhang mit der techn. Umsetzung stellt einen wichtigen Beitrag zum kontinuierlichen Umweltmanagement in diesen Regionen dar.

3. Fortschreibung des Verwertungsplanes

Insgesamt kann eingeschätzt werden, dass uns die am Einsatzort gewonnenen Erkenntnisse wesentlich geholfen haben, das Gesamtsystem weiter zu entwickeln.

Die Möglichkeiten des operationellen Monitorings konnten umfassend getestet und Erfahrungen im Betrieb an isolierten Standorten gesammelt werden.

Besuche auf Messen in Brasilien haben das System weiter bekannt gemacht.

Zu den weiteren Ergebnissen verweisen wir auf unseren Abschlussbericht Abschnitt III.

4. Ungelöste zukünftige Fragestellungen

Im Rahmen der weiteren Qualifizierung des Systems ist die Einbindung weiterer Sensortechnik und Analysesysteme von entscheidender Bedeutung.

Zukünftige Fragestellungen werden sich zunehmend mit der Nährstoffkonzentration im Wasser auseinandersetzen. Hier automatisierte Systeme mit möglichst geringem Betreuungsaufwand ist von zentraler Bedeutung im operationellen Monitoring, speziell an isolierten, schwerzugänglichen Standorten.

5. Einhaltung des Finanzierungs- und Zeitplanes

Der Zeitplan konnte bis auf geringe Abweichungen wie vorgesehen eingehalten werden. Diese Abweichungen waren begründet in Problemen mit der zolltechnischen Abwicklung und dem nachträglichem Umbau der Übertragungsstrecke zwischen Container und Institut auf Grund der vor Ort vorgefundenen umfassender und höher ausgefallenen Vegetation als ursprünglich angenommen. Beide Probleme wurden jedoch in vertretbarem Zeitrahmen gelöst.

Hinsichtlich des Finanzierungsplanes resultierte infolge von unvorhergesehenen Wartungsarbeiten ein Mehrbedarf an Mitteln, der im Rahmen einer Aufstockung zentraler Projektmittel aus dem Teilprojekt 1 bestritten werden konnte.

III. ERZIELTE ERGEBNISSE

Der Aufbau, die Wartung und Weiterentwicklung einer „stationären FerryBox“ war innerhalb des Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ das Teilprojekt der -4H- JENA engineering GmbH. Diese automatische Messstation zur Erfassung der Gewässergüte in der Paranaguá-Bucht war entsprechend den gegebenen örtlichen Umweltbedingungen den Anforderungen für ein nachhaltiges Umweltmanagement anzupassen.

Dazu gehörte die Entwicklung einer Ansaugvorrichtung mit Pumpen für verschiedene Wassertiefen, die Auswahl und der Betrieb geeigneter Sensorik, Entwicklung und Testung eines geeigneten Antifoulingkonzeptes welches für den Betrieb einer stationären FerryBox speziell in subtropischen Gewässern geeignet ist.

Ein weiterer wesentlicher Teil der Arbeiten bestand in der regelmäßigen Wartung und Kontrolle der Anlage (Fernüberwachung und Wartungsfahrten nach Brasilien), sowie in einer Kontrolle der Sensorfunktionen (Qualitätssicherung). Weiterentwicklung für eine Anpassung an die spezifischen Gegebenheiten (Konzentrationsbereiche, spezielle Biofouling-Bedingungen usw.), sowie die Testung von neuentwickelten Sensoren (z.B. Sensor zur Detektion von Öl im Wasser).

Entsprechend den vorhandenen Gegebenheiten musste dafür auch eine geeignete Datenübertragung aufgebaut werden.

Die Arbeiten wurden am 01.10.2006 begonnen, zunächst mit der Auswahl und Festlegung eines geeigneten Standortes und der Entwicklung eines geeigneten Konzeptes für die stationäre FerryBox.

Innerhalb einer Vor-Ort-Besichtigung wurden mit dem Projektpartner GKSS unterschiedliche Standorte in der Bucht von Paranaguá im Hinblick der zu installierenden automatischen Messstation begutachtet. Es wurde als Standort für den Messcontainer eine Kaimauer mit befriedigender Infrastruktur im Mündungsbereich der Bucht ausgewählt (s. Abb. 1).

Durch intensive Zusammenarbeit mit der GKSS wurde die stationäre FerryBox konzeptionell weiterentwickelt und an die Bedingungen des Standortes angepasst. Das Wassersystem wurde entsprechend den wissenschaftlichen Anforderungen spezifiziert und an die technische Machbarkeit angepasst (s. Abb. 5).

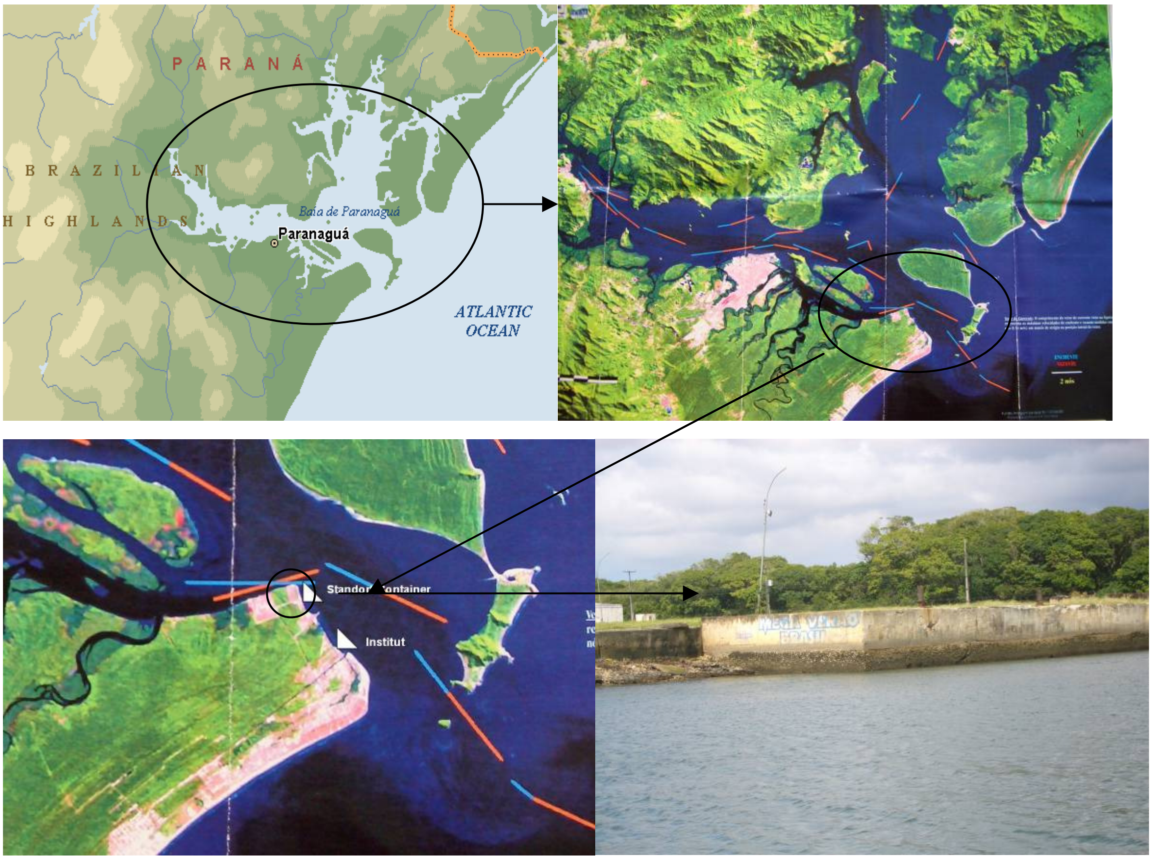

Abb. 1-4: Die Bucht von Paranaguá in unterschiedlichen Vergrößerungen; rechts unten die Kaianlage des gewählten Standortes

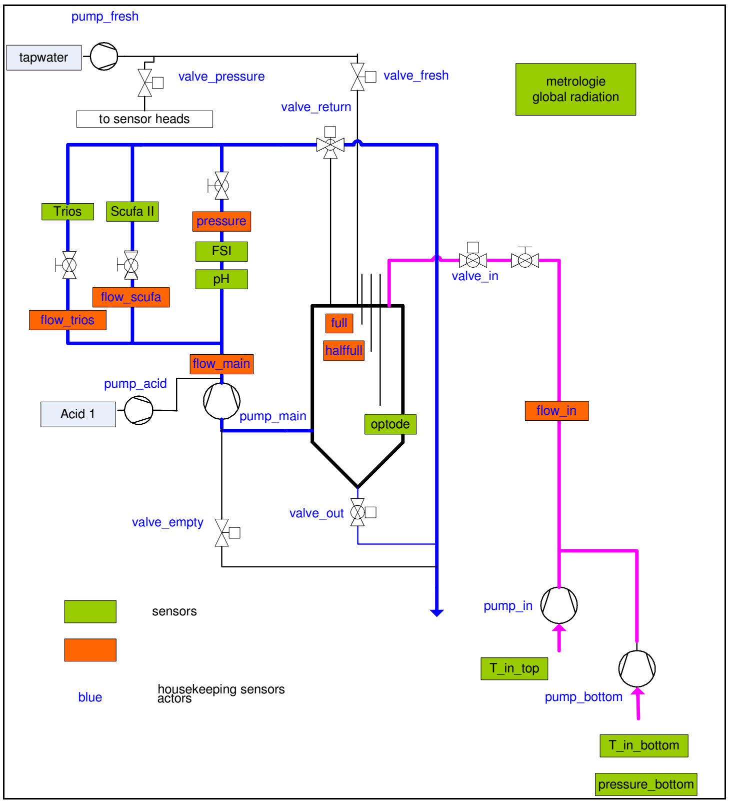

Abb. 5: Schematische Darstellung des Wassersystems

Im Rahmen der Vor-Ort-Besichtigung wurde dann abweichend vom Projektantrag entschieden, das Messwasser aus zwei Tiefen alternierend dem Messsystem zuzuführen. Zum einen wurde aus einer Wassertiefe von ca. 1 m über Grund und zum anderen Oberflächenwasser durch das Messsystem gepumpt. Hintergrund war, dass die Vermutung bestand, dass sich salzarmes und dadurch leichteres Wasser im Oberflächenbereich dem Wasser aus dem atlantischen Ozean überlagert. Durch die Ansaugstellen in den verschiedenen Wasserkörpern konnte abwechselnd deren Qualität bestimmt werden.

Da die Stabilität des Stromnetzes am Aufstellungsort eingeschränkt war, musste versucht werden, eine unterbrechungsfreie Stromversorgung für minimal 15 min zu gewährleisten. Bei längeren Netzstörungen sollte das Rechnersystem geregelt abgeschaltet und ein automatisches Starten des Gesamtsystems sichergestellt werden. Erschwerend kam hinzu, dass im Einsatzgebiet starke Blitzereignisse zu erwarten waren, weshalb ein spezieller Blitzschutz eingerichtet werden musste. Dies ist für eine Vermarktung in Brasilien auch von elementarer Bedeutung.

Der Container in dem das Messsystem installiert wurde, wurde konzeptionell überarbeitet und mit den erforderlichen Öffnungen für Stromversorgung und Wasserein- bzw. -abläufe versehen. Zusätzlich erhielt der Container eine Klimaanlage, um die hohe Luftfeuchtigkeit und die starken Temperaturschwankungen auszugleichen.

Für das benötigte Frischwasser, wurde ein Vorratsbehälter im Container vorgesehen, der mit einer UV-Lampe keimfrei gehalten wurde. Dieses Frischwasser wird für die verschiedenen Reinigungszyklen des Gesamtsystems benötigt.

Nach dem Komplettaufbau des Systems und erfolgreicher Testung und Optimierung in Deutschland wurde es komplett in Kisten verpackt und per Container-Seefracht nach Brasilien verbracht. Nach anfänglichen zolltechnischen Problemen konnte mit dem Aufbau vor Ort im Zeitraum August/September 2007 begonnen werden.

Abb. 6-12: Transport und Aufbau der Messstation

Als problematisch erwies sich die Funkverbindung, da die Baumhöhen doch erheblich von den vorher übermittelten Höhen abwichen und somit die Funkstrecke erheblich gestört und eingeschränkt war. Dieses Problem wurde während einer im Dezember anstehenden Wartung behoben. Es wurde ein zusätzlicher Antennenmast mit einer Höhe von 21 m gesetzt. Dadurch konnte die Funkstrecke optimiert werden.

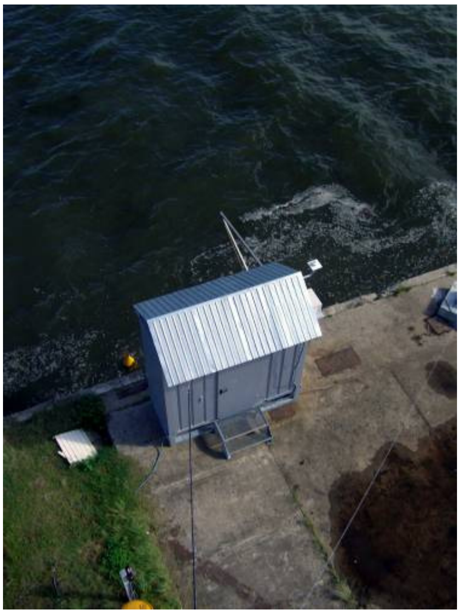

Abb. 13-14: Optimierung der Funkstrecke durch zusätzlichen Antennenmast

Innerhalb des im Messcontainer aufgestellten Wassersystems wurden folgende Messgrößen kontinuierlich aus unterschiedlichen Wassertiefen aufgezeichnet:

- Leitfähigkeit,
- Salzgehalt,
- Temperatur,
- gelöster Sauerstoff,
- Trübung,
- Chlorophyll-*a*-Konzentration,
- pH,
- Detektion von emulgiertem Öl

Zusätzlich wurden außerhalb des Containers die Tide über den Druck, die *in situ*-Wassertemperatur und die Globalstrahlung aufgezeichnet und in das Datenmanagementsystem übertragen. Die Daten waren über die Landstation am Institut CEM in Pontal per Internet abrufbar und wurden zusätzlich in die GKSS-Datenbank eingespeist und dort zur Verfügung gestellt.

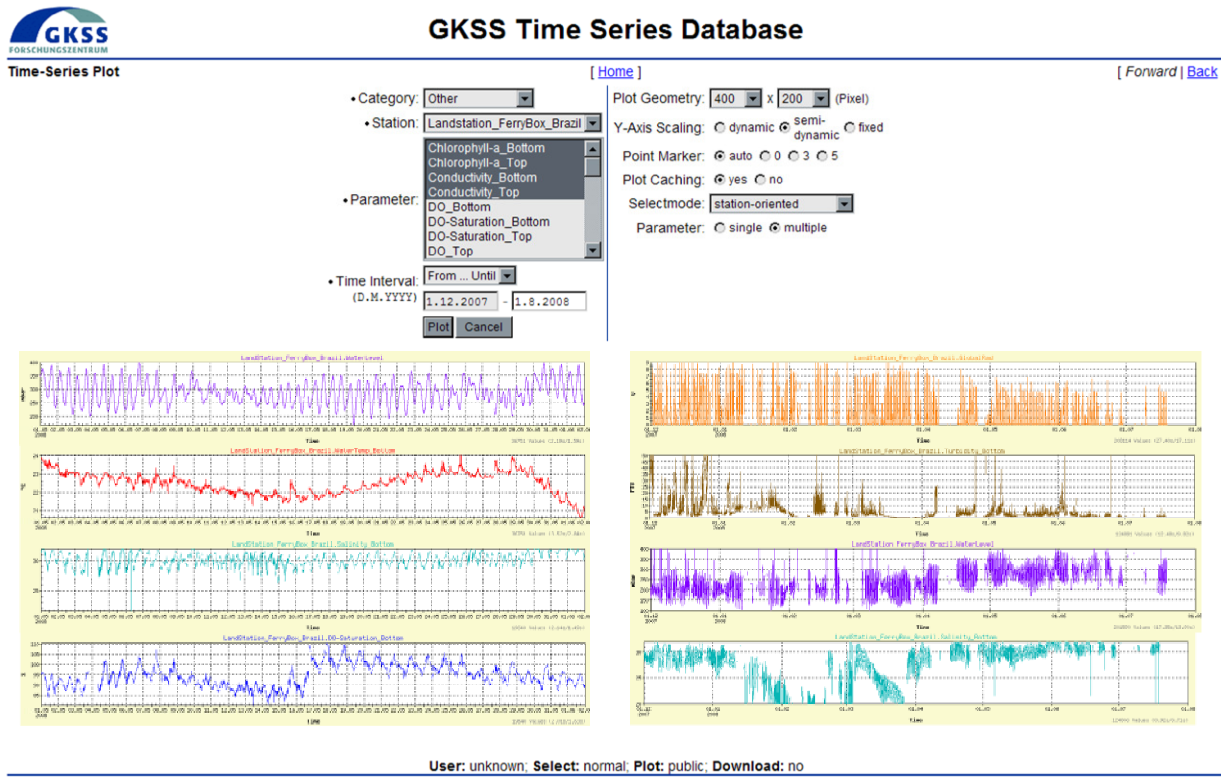

Abb. 15: Auszug aus der GKSS-Datenbank

Mittels des erarbeiteten Wartungsplanes, welcher zum einen Vor-Ort-Einsätze durch die -4H-JENA engineering GmbH vorsah aber auch die Mitarbeiter vor Ort aus dem Institut mit einbezog, war es möglich, die Ausfallzeiten wesentlich zu begrenzen. Die Mitarbeiter des Institutes wurden umfangreich geschult und so in die Lage versetzt, wesentliche Teile der Wartung selbstständig oder unter Anleitung mittels Ferndiagnose durchzuführen. Die während der 3-jährigen Messkampagne gewonnenen Erfahrungen im Betrieb tragen wesentlich zur weiteren Entwicklung der FerryBox bei. Insbesondere die Analyse der hauptsächlichen Ausfallursachen hilft, das System weiter unanfälliger für äußere Einflüsse zu machen.

So waren die meisten Ursachen für Ausfälle des Systems vor allem in der unstabilen externen Stromversorgung begründet. Nach Starkregen und anderen extremen Wetterereignissen konnte es bis zu mehreren Tagen dauern, bis die externe Stromversorgung wieder hergestellt wurde. Spannungsschwankungen im Netz führten zudem dazu, dass die Schutzeinrichtungen der inneren Containerversorgung auslösten. Diese mussten dann manuell wieder eingeschaltet werden. Diese Schutzeinrichtungen waren jedoch notwendig, um das Messsystem vor größeren Schäden und Zerstörung zu schützen, was sich auch erfolgreich bewährt hat. Die von Anfang an im System integrierten Blitzschutzmodule konnten die Überspannungen durch Blitzeinschläge oder Netzschwankungen abfangen. Die bei Überspannungen zerstörten Blitzschutzmodule und Sicherungen wurden problemlos ausgetauscht und die Betriebsbereitschaft konnte schnell wieder hergestellt werden. Das gesamte System war somit effektiv geschützt.

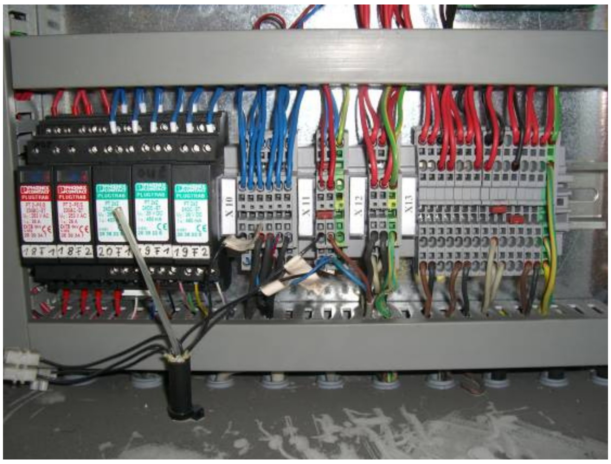

Abb. 16: Blitzschutz Module vor der Stromeinspeisung in die Elektronik des Messcontainers

Die automatische Reinigung und die Antifoulingmaßnahmen wurden in enger Zusammenarbeit mit der GKSS im laufenden Betrieb angepasst, so dass die in der ersten Zeit aufgetretenen Probleme mit Bewuchs weitestgehend abgestellt werden konnten. So wurde auf besser angepasste Waschzyklen und 2 Reinigungen am Tag umgestellt. Des Weiteren wurde eine zusätzliche Säurepumpe in das System gebracht, um nach der Reinigung mit Säure noch einen Zyklus mit Hypochlorit anzuschließen. Diese Maßnahmen haben dazu geführt, dass Ausfälle durch Bewuchs auf ein absolutes Minimum reduziert werden konnten. Probleme mit Bewuchs traten vor allem dann auf, wenn die Strecke durch Stromausfälle längere Zeit nicht in Betrieb war.

Die gesammelten Erkenntnisse aus den getroffenen Antifoulingmaßnahmen können nun für weitere Projekte in ähnlichen Regionen übernommen werden.

Abb. 17: Das Debubbler-Glas ist vollständig mit Seepocken bewachsen

Nach einem halben Jahr Erfahrung mit dem Wassersystem vor Ort zeigte sich, dass die Pumpen öfter durch angesaugte Plastiktüten oder andere Gegenstände verstopften. Eine zusätzliche Funktion im Reinigungsschema, die ferngesteuerte Rückspülung, hat dieses Problem in den meisten Fällen beseitigen können.

Abb. 18-19: Bewuchs auf der oberen (links) und der unteren (rechts) Zulaufpumpe

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18. abstract The installed system is a stationary measuring station for coastal monitoring at the bay of Paranaguá in Brazil. The intention for this subproject was to installed a stationary measuring station for coastal monitoring at the bay of Paranaguá in Brazil. By continuous measurements of the main water quality parameters seasonal trends of the water quality and short-term events will be observed.One of the major advantages of the „FerryBox-module" are its automated control-, cleaning- and anti-fouling capabilities which reduce the necessary maintenance. All data are transferred to a PC in Pontal do Sul by wireless transmission. There the data are stored in a data base which can be accessed by the internet. The cooperation with the other subprojects was also significant. With our data the other sub-projects can validation your models of environmental. The FerryBox is also a reference in Brazil for more systems of this type.	
19. keywords FerryBox, automatic and remote controlled measurement, flow through measuring system for a long-term in situ monitoring of rivers, estuaries, coastal zones	
20. publisher	21. price

Schlussbericht

TP7 Daten- und Informationsmanagement

im Verbundprojekt

Nachhaltiges Umweltmanagement in brasilianischen Häfen

Bundesanstalt für Wasserbau
Dienststelle Hamburg

BMBF Förderkennzeichen: 03F0454A

Zuwendungempfänger: **Bundesanstalt für Wasserbau-Dienststelle Hamburg** **Wedeler Landstraße 157** **22559 Hamburg**	Förderkennzeichen: **03F0454A**
Vorhabenbezeichnung: **TP7 Daten- und Informationsmanagement**	
Laufzeit des Vorhabens: **01.11.2006 - 31.10.2009**	
Projektleiter: **Dr.-Ing. Rainer Lehfeldt** Projektbeteiligte: **Dipl.-Ing. Ronny Beyer**	

I. SCHLUSSBERICHT

1. Vorhabensdarstellung

1.1 Veranlassung und Zielsetzung

Das Vorhaben ist Bestandteil des Verbundprojektes „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ und unterstützt die Kommunikation zwischen den Partnern der Teilprojekte und weiteren Nutzern. Im Sinne von Integriertem Küstenzonenmanagement werden Daten und Projektergebnisse aus der Küstenzone der Bucht von Paranaguá dokumentiert und bereitgestellt.

Die mit Internet-basierter Software-Technologie aufgebaute Informations-Infrastruktur beruht auf internationalen Standards und kann somit leicht in übergeordnete Informationssysteme eingebunden werden.

1.2 Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

Das TP wurde im Rahmen des bilateralen Verbundvorhabens „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ durchgeführt.

1.3 Planung und Ablauf des Vorhabens

Gemäß der Projektplanung wurde ein Webportal für die Bucht von Paranaguá mit einer übergreifenden Darstellung des Daten- und Informationsmaterials aus dem Projekt aufgebaut und kontinuierlich in Zusammenarbeit mit allen Teilprojekten um die neuen Daten aus den Messkampagnen und für die Modellierung ergänzt.

Der NOKIS-Editor wurde zur Erzeugung von standardisierten Metadaten in Deutsch und Portugiesisch in die Projekt-Arbeitsumgebungen eingebunden. Mit den darin enthaltenen Such-

mechanismen ist eine gezielte Recherche nach Projektdaten aus der Bucht von Paranaguá möglich. Die erfassten Daten und Metadaten bleiben dauerhaft verfügbar.
Zu Projektbeginn wurde in Pontal do Sul eine ganztägige Einführungsveranstaltung in Metadaten und Informationssysteme mit Übungen durchgeführt (2.12.2006), an der alle Projektmitarbeiter vom CEM und eine Delegation der FURG in Rio Grande teilgenommen haben. Damit wurden die Grundlagen zur systematischen Metadatenerfassung für die Projektinformationen gelegt und mit der lokalen Installation des NOKIS-Metadaten-Editors technisch unterstützt. Im Anschluss an die Messkampagnen 2007 und 2008 wurden die Daten aus der Bucht von Paranaguá damit dokumentiert.
Neben den Berichten anlässlich der Projektworkshops in Büsum (7.6.2007), Hamburg (24.1.2008) und Darmstadt (13.3.2009) wurden ganztägige Seminare mit praktischen Übungen für Master-Studenten in Kiel („Metadata for the Coastal Zone", 2.1.2007, und „Standards and Web Services for the Coastal Zone", 2.2.2008) durchgeführt. Daraufhin haben die brasilianischen Praktikanten in Kiel an der Metadatenerfassung für die Daten der beiden Messkampagnen und der Fachliteratur aus Paranaguá gearbeitet.

1.4 Wissenschaftlicher und technischer Stand zu Projektbeginn

Mit der weltweiten Vernetzung von Forschungsinstituten, Verwaltungen und Wirtschaftsunternehmen wächst das online Angebot von Daten, Dokumenten und anderen Informationsträgern. Nur mit Hilfe von standardisierten Metadaten können automatisierte Suchverfahren effizient eingesetzt werden, um im Rahmen von Webportalen intersektorale Sichten auf die verfügbaren Quellen zu erzeugen und qualifizierte Recherche-Ergebnisse zu liefern.
Die meisten Ansätze dazu kommen aus dem Geo-Informationsbereich und finden sich national z.B. in der Geodaten-Infrastruktur Deutschlands gdi.de oder europaweit bei INSPIRE. Dabei werden Metadaten-Profile aus dem ISO19115 verwendet, die fachübergreifend eingesetzt werden können. Das Nord- und Ostsee- KüstenInformationsSystem NOKIS (03KIS027 und 03KIS049) hat ein solches Profil für die Küstenzone definiert und stellt einen Editor zur Erzeugung von Metadaten bereit.
Im Rahmen von zwei Forschungsprojekten wurden NOKIS Metadaten-Profile weiterentwickelt und Services nach ISO19119 aufgebaut. Die damit vorhandene Informations-Infrastruktur wurde u.a. in dem EU Projekt FLOODsite (GOCE-CT-2004-505420) zum Daten- und Informationsmanagement genutzt und ist Grundlage für die Arbeiten im Teilprojekt „Daten- und Informationsmanagement".

1.5 Zusammenarbeit mit anderen Stellen

Die Einträge auf der gemeinsamen Website des Projektes im öffentlichen wie im internen Bereich dokumentieren die erfolgreiche Zusammenarbeit mit den Daten bereitstellenden Dienststellen. Insbesondere der Kontakt zu den Hafenbehörden hat sich positiv bei der Interpretation von Pegeldaten während der Messkampagne Herbst 2007 ausgewirkt.

Im März 2008 wurde der Besuch einer Delegation von Vertretern der Hafenbehörden in Paranaguá zum Informationsaustausch mit der Hamburg Port Authority HPA organisiert.

2. Vorhabensergebnisse

2.1 Erzielte Ergebnisse

In der Anlage 1 wird eine ausführliche Darstellung der nachfolgend genannten Stichpunkte in Englisch gegeben:

- Aufbau der Projekt-Website
- Metadatenprofil und Metadatenproduktion
- Web mapping services
- Recherche und Metadaten gesteuerte Dienste
- Datendokumentationen

2.2 Nutzen und Verwertbarkeit der Ergebnisse

Die realisierte Informationsinfrastruktur bietet für brasilianische Forschungseinrichtungen, Behörden und Agenturen ein Instrument zur Kommunikation und Recherche im Sinne von Integriertem Küstenzonenmanagement für die Bucht von Paranaguá. Das zugrunde liegende netzbasierte Informationssystem ist in diesem Teilprojekt des Verbundvorhabens unter Verwendung von Softwaremethoden nach dem neusten Stand der Technik und mit international standardisierten Metadaten nach ISO19115 aufgebaut.

Nach Projektende bleibt das Informationssystem dauerhaft auf dem Server „hosted-by-kfki“ online verfügbar und die erfassten Datensätze und Modellergebnisse können für weitere Forschungsaufgaben und im Rahmen eines nachhaltigen Umweltmanagements verwendet werden. Durch die unmittelbare Einbindung in die NOKIS Arbeitsumgebung stehen alle Weiterentwicklungen von NOKIS bei künftigen Nutzungen zur Verfügung.

Mit den in Brasilien und Deutschland durchgeführten Schulungen zum Umgang mit Metadaten konnte anhand konkreter Projektdaten ein Beitrag geleistet werden, standardisierte Metadaten zur nachhaltigen Dokumentation und zur Qualitätssicherung bei Weitergabe und Nutzung von Daten zu etablieren. Das mehrsprachige Erfassungswerkzeug kann jederzeit online oder bei Bedarf auch als eine lokal zu installierende Instanz verwendet werden.

2.3 Fortschritt auf dem Gebiet des Vorhabens bei anderen Stellen

Sowohl für das Teilprojekt in Rio Grande wie auch in Paranaguá wurden zusätzliche Webseiten an den Universitäten der brasilianischen Partnern mit Hinweisen zu Literatur und weiteren Daten eingerichtet. Diese ergänzenden Informationsquellen verwenden jedoch keine standardisierten Metadaten und sind somit nicht in die strukturierte Recherche eingebunden.

2.4 Publikationen

LEHFELDT, R., H.-C. REIMERS, J. KOHLUS, F. SELLERHOFF, 2008: A Network of Metadata and Web Services for Integrated Coastal Zone Management. Proc. International Conference on Coastal and Port Engineering in Developing Countries COPEDEC VII, Feb.24-28.Dubai, U.A.E. Cyber Proceedings. paper 207, 11p.

LEHFELDT, R., M. CAMARGO, 2009: Data Management and Information Dissemination in Paranaguà Bay, Brazil. Proceedings 33rd IAHR Congress, Vancouver: Water Engineering for a Sustainable Environment. International Association of Hydraulic Engineering & Research (IAHR), pp. 7423-7430.

LEHFELDT, R., M. CAMARGO, 2010: Coastal Zone Data Management in Paranaguá Bay, Brazil. Ocean Dynamics (in prep.).

Vorträge:

- "Introduction to metadata standards and information systems", Ganztägiger Short Course mit Übungen für alle Projektteilnehmer in Pontal do Sul, 02.12.2006
- "Metadata for the Coastal Zone", Seminar mit Übungen für Master-Studenten in Kiel, 02.1.2007
- "Standards and Web Services for the Coastal Zone", Seminar mit Übungen für Master-Studenten in Kiel, 02.02. 2008

II. ERFOLGSKONTROLLBERICHT

1. Beitrag zu den förderpolitischen Zielen des Förderprogramms

Das vorliegende Teilprojekt stellt einen anwendungsbezogenen Beitrag zu der deutsch-brasilianischen Zusammenarbeit in Wissenschaft und Technik im Bereich der Meeresforschung dar, welche im Juli 2004 in einem bilateralen Abkommen zwischen BMBF und MCT festgeschrieben wurde.

Mit den verschiedenen technischen und strukturellen Ansätzen wurde ein Beitrag zur Entwicklung eines interdisziplinären Netzwerkes mit den Hauptkomponenten Daten, Metadaten und Dienste für den Einsatz in Forschung und Verwaltung geleistet. Diese Arbeiten sind im Einklang mit verschiedenen förderpolitischen Schwerpunkten des Rahmenprogramms „Forschung für die Nachhaltigkeit (fona)“ des BMBF. Dabei handelt es sich im Einzelnen um die folgenden:

Aktionsfeld 2: Nachhaltige Nutzungskonzepte für Regionen

Die Informationen der beteiligten Institutionen werden so aufbereitet und vernetzt, dass sie den zuständigen Stellen und der Öffentlichkeit transparent zur Verfügung stehen. Durch die aufgebaute Informations- und Kommunikationsstruktur wird die Verfügbarkeit und Verbreitung von Grundlagen- und Fachwissen verbessert. Auf diese Weise können Verwaltungsentscheidungen und politischen Beschlüsse auf fachlicher Grundlage wissensbasiert und damit nachvollziehbarer für die Öffentlichkeit dokumentiert werden.

Aktionsfeld 3: Konzepte für eine nachhaltige Nutzung von natürlichen Ressourcen

Vernetzte marine Informationen stellen ein grundlegendes Instrument für die Entwicklung von Analyse- und Planungsinstrumenten zur Verfügung. Wichtige Anwendungsfelder sind u.a. der Schutz der Biodiversität der Meere und die Anpassungen an die Auswirkungen des Klimawandels, wie z.B. ein nachhaltiges Hochwassermanagement, ein nachhaltiges Sedimentmanagement, eine nachhaltige Nutzung der marinen Ökosysteme sowie den Schutz der Meeresumwelt.

Rahmenprogramm: Verankerung von Nachhaltigkeit in der Gesellschaft

Die neue Informationsinfrastruktur kann dabei helfen, bestehende Kommunikations- und Transferprobleme zu überwinden. Da sie der breiten Öffentlichkeit über das Internet zugänglich ist, stellt sie einen wichtigen Baustein für die zukünftige Wissensgesellschaft dar.

2. Wissenschaftlicher oder technischer Erfolg des Vorhabens

In der bilateralen Kooperation sind existierende Konzepte für Metadaten aus Deutschland erfolgreich unter Wahrung internationaler Standards auf die Erfordernisse des Projektes in Brasilien angepasst und umgesetzt worden.

Die neue gemeinsam aufgebaute Informationsinfrastruktur für dieses Projekt kann zukünftig dazu genutzt werden, Daten und Berichte aus weiteren Projekten zu verwalten. Dabei handelt es sich im Einzelnen um die aus NOKIS entnommenen bzw. im Bedarfsfall zu entnehmenden Metadaten-Profile, den mehrsprachigen Metadaten-Editor und das Rahmenkonzept zur Visualisierung von Daten.

3. Einhaltung der Ausgaben- und Zeitplanung

Die in der Kostenplanung vorgesehen Personal- und Reisemittel sind antragsgemäß verwendet worden. Die Durchführung des Vorhabens entspricht dem im Arbeits- und Zeitplan vorgesehenen Ablauf.

4. Verwertbarkeit der Ergebnisse

Es besteht auf brasilianischer Seite ein starkes Interesse, die Systematik beim Aufbau der Informationsinfrastruktur auch in anderen Bereichen der universitären Forschungsarbeiten für weitere Kooperationen einzusetzen.

Die durchgängige Spracherweiterung um Portugiesisch im Metadaten-Editor bleibt in diesem zentralen Erfassungswerkzeug, das auch Kernbestandteil der „Marinen Daten-Infrastruktur Deutschland - MDI-DE“ (03KIS089) sein wird, erhalten und steht für weitere internationale Anwendungen zur Verfügung.

5. Arbeiten, die zu keiner Lösung geführt haben

Das Management von Metadaten für Modelle und für die Umweltbeobachtung wird im Projekt „Marine Daten-Infrastruktur Deutschland - MDI-DE“ auch für den Aufbau digitaler Kataloge intensiv weiterentwickelt und für die Nutzung in Internet-basierten Diensten erweitert.

In der bisher für Paranaguá realisierten Informationsinfrastruktur sollten diese neuen Komponenten für die brasilianischen Anwender implementiert werden, um die vorhandenen Daten noch intensiver nutzen zu können.

III. TECHNICAL REPORT ON WORKPACKAGE "DATA MANAGEMENT AND INFORMATION DISSEMINATION"

1. Introduction

The principal objective of "Data Management and Information Dissemination" is to support the data collection process in the Bay of Paranaguá so as to provide sufficient data for the modelling studies of the entire bay and to document the project results. This activity is in keeping with current efforts worldwide to establish geospatial information infrastructures as information resources for coastal zone management. Recently, Green and King (2003) have summarized the main requirements in relation to data and information:

- Ease of access to information
- Capability to do spatial analysis
- Integration of information from different sources
- Presentation of information in different formats
- Knowledge about available information

From the user perspective the information infrastructure should enable project and coastal managers to undertake:

- Spatial analysis
- Query different data at the same time
- View graphically different resources at the same time
- Have the ability to overlay resources spatially
- Isolate areas and look at the relationship between all activities
- Be able to generate basic statistics
- Be able to generate basic business graphics
- Be more responsive and timely to queries
- Query on an ad hoc basis
- Know where information is held and how to access it
- Be able to produce mapped information as well as reports

Longhorn (2003) presents a detailed record of projects, which have recently been carried out in the attempt to provide useful databases for coastal zone management. The main shortcomings of these projects are their lack of standardized metadata, which support the documentation, discovery and use of information, and the lack of interoperability of data. Thus, the essential user requirements for integration of different data bases have not been met by the prototype solutions of the demonstration projects.

Lehfeldt et al. (2008) outline the progress that has been made with respect to metadata and internet based services using metadata within the process of establishing spatial data infrastructures in the European member states. These activities are driven by the INSPIRE directive of the European Parliament and Council (2007) for an **IN**nfrastructure for **S**patial **I**nfo**R**mation in **E**urope, which will integrate the national geospatial data bases. Experiences gained and technologies developed in these activities are applied in the present project.

2. Project Web site

The project Web site summarizes the facts related to the activities carried out in field campaigns and in modeling studies. Figure 1 shows the distributed resources concerning data, reports, modeling results and services, which are contributed by the project partners. An effective information flow and online data access are supported by a (in this case) central repository, where documentation with metadata and tools for services are added to the available data.

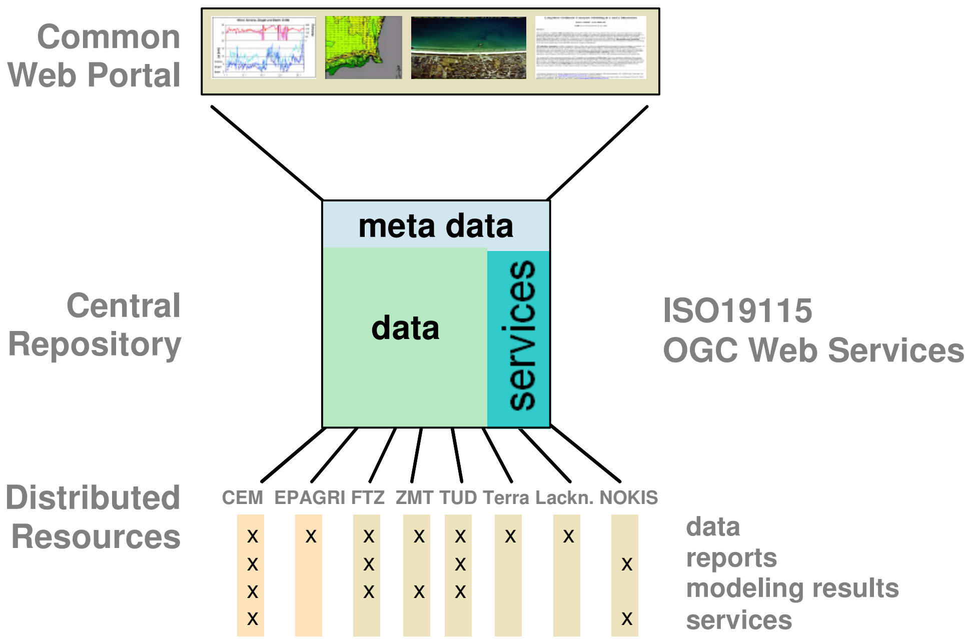


Fig.1: Information management

In order to provide a high level of technical interoperability of the data and metadata collected in the project, both the structured documentation as well as the standardized data access are based on international standards put forward by the International Standard Organization ISO and the Open Geospatial Consortium OGC.

The common Web portal provides information entry points for external users interested in the Case Studies, the Data (Field; Modeling; Published Literature), Metadata (Authoring Tool; Profile) and participating Partners. The internal pages are password protected and serve as data repository for the research community of this project.

The web site is hosted in Hamburg and maintained with the free and open source content management system TYPO3 outlined by Altmann et al. (2006). The different sections are updated as required by the project members. In particular, the metadata authoring tool is integrated in the user interface.

3. Metadata – profiles and production

The motivation for structured descriptions of data resources with standardized metadata is focused on two objectives, which relate to

- sustainable **documentation** of
  - **what** the data represent
  - **who** is responsible for the data
  - **how** to access the data
- better data **discovery** specifications of
  - **where** the data have been collected in space
  - **when** the data have been collected in time

Most of the time, metadata are created in a separate working process for data resources after these have been published. Lehfeldt et al. (2008) present examples where metadata are created automatically during data processing. The above mentioned questions are addressed by metadata elements for

- **title**
- **abstract**
- **keywords**
- **responsible party**
- **location**
- **time**

These entries contain the essential information, which is used in information systems and discovery interfaces.

As outlined by Lehfeldt et al. (2002), the authoring tool called metadata editor is directly related to the metadata schema, which is a profile of the ISO 19115 metadata schema (2002).

The effective metadata schema can be accessed online at “http://harbours.wtz-brasilien.org”. The coastal zone profile used in the German coastal community includes the ISO-core profile, which is the common base of information systems currently being established in the European Union as communicated by the EUROPEAN COMMISSION (2007). Therefore, the created metadata can be made available in any information system without additional effort.

Fig. 2: User interface for creating ISO19115 metadata for the Coastal Zone Metadata Profile

Input forms shown in figure 2 query the structured "data about data" for individual data sets or complete data series. Mandatory metadata are tagged in the authoring tool so as to produce **complete** metadata sets in the sense that the information can be used in discovery services. The editor also guarantees that the metadata is **syntactically correct** through the input mechanisms of the input forms. They take the information given in formats compatible with ISO regulations (e.g. for time, date, language specifications etc.). The validity of a metadata set cannot fully be tested automatically, since there are no means to test semantic correctness. However, the metadata are assumed to be **valid** once the mandatory input areas in the editor forms are filled.

In order to bridge any language barriers, a multilingual working environment has been created. The authoring tool depends on language packs, which offers for the time being German, English and Portuguese for the interface language (see fig. 3). Depending on the locale chosen in the Web browser, the menus, comments and explanations are presented accordingly.

All textual metadata entries can be entered in different languages, which are then registered in individual elements so as to provide the option to evaluate entries by different languagedependant discovery services. It is recommended to always fill in free text in English and provide the same text in the language spoken in the county of data origin.

Fig. 3: Multi-lingual working environment for metadata management according to Web browser locale [pt-br, en-us, de-de]

4. Web mapping services

The information infrastructure established for the data collection of Paranaguá Bay incorporates the technology of Web Map Services WMS in order to display existing and accessible data. Using the Open Geospatial Consortium (OGC, 2004) compliant services for geographical maps which are supplied by various providers like DEMIS (2009), the location of interest can be identified on freely available electronic maps.

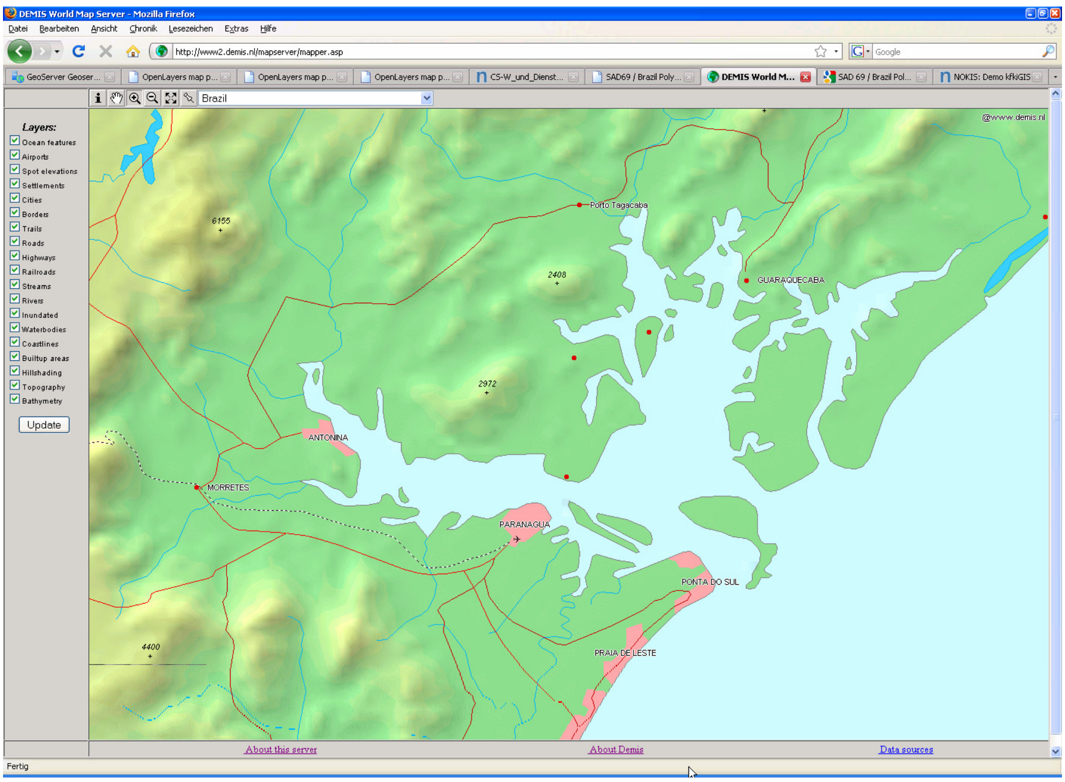


Fig. 4: Map of Paranaguá Bay from DEMIS Map server

Figure 4 shows the map of Paranaguá Bay, which is produced in a Web browser using appropriate parameters for the bounding box and the layers to be displayed:

http://www2.demis.nl/mapserver/wms.asp*?*

VERSION=1.1.0&REQUEST=GetMap&SRS=EPSG:4326&

BBOX*=-48.934060141891,-25.6829753887324,-48.0627316730537,-25.1091904743167&*

WIDTH=1268&HEIGHT=835&

LAYERS*=Bathymetry,Countries,Topography,Hillshading,Builtup+areas,Coastlines,Waterbodies,Inundated,Rivers,Streams,Railroads,Highways,Roads,Trails,Borders,Cities,Settlements,Spot+elevations,Airports,Ocean+features&*

STYLES=,,,,,,,,,,,,,,,,,,,&BGCOLOR=0xCEFFFF&

FORMAT=image/gif&TRANSPARENT=FALSE&WRAPDATELINE=TRUE

The complete parameter list for calling the map server is given in the Web Map Service Implementation Specification (OCG, 2001) with details on the Spatial Reference System SRS, the bounding box BBOX, the applied LAYERS etc. The OGC Web mapping services WMS display maps that are created on demand from data that remain on servers.

This provides the background for project specific data that has been transferred into shape files for use in GIS manner in order to produce composite maps. To this end, a representative number of project data shown in figure 5 have been processed accordingly and listed on the website "http://www.hosted-by-kfki.baw.de/geoserver/mapPreview.do ". For a quick preview this list includes a link to a WMS client, a tool which communicates with OGC conform WMS servers and displays the requested maps.

The information layers provided here by OGC web map services can be loaded into any WMS client like the Gaia (2006) geospatial viewer as shown in figure 6. Individual layers are selected and added to the effective layer list of the current session as presented in figure 7. Thus the input for the composite map consisting of the public background map of Paranaguá Bay, the project bathymetry and the sampling stations of 2007 for harbour monitoring are prepared.

An OGC compliant web map service interface (OCG, 2004) implements the GetCapabilities und GetMap operations. The optional operation GetFeature- Info is also realized in the NOKIS framework of WMS services. If the server supports the GetFeatureInfo operation on a layer, additional information relating to the current pointer position on the selected layer can be retrieved from the metadata. Via this mechanism, the Universally Unique Identifier UUID

(OASIS, 2003), which is created for each metadata set according to the standard for identifiers in software engineering, can also be retrieved for further use in other services.

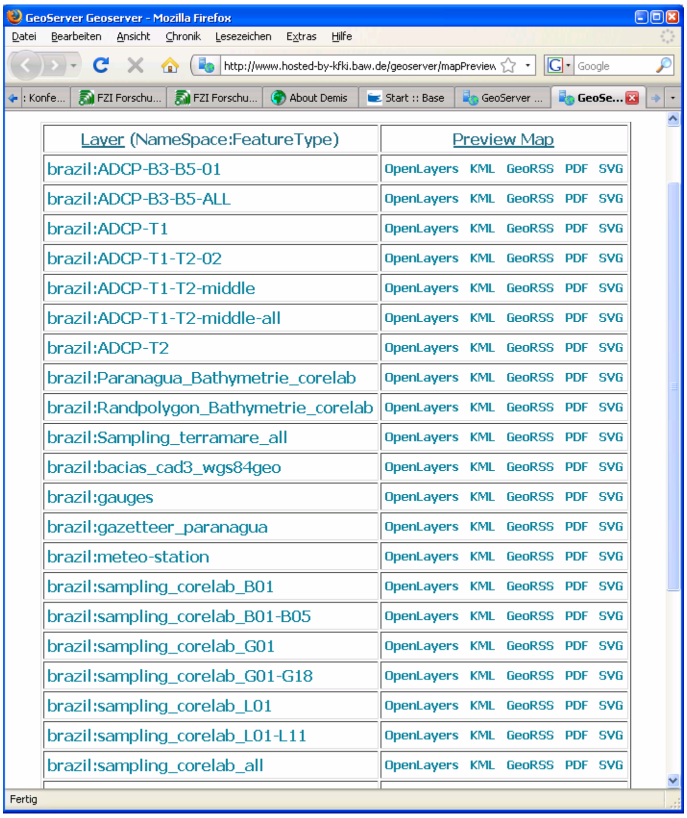


Fig. 5: List of project data provided through a web mapping service

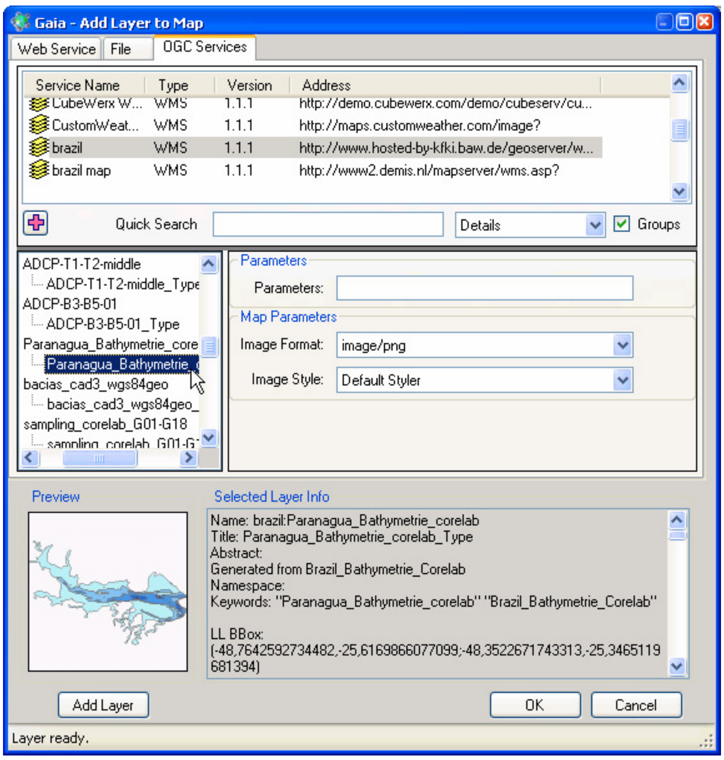


Fig. 6: Loading the Paranaguá Bay bathymetry layer into the Gaia (2006) WMS client

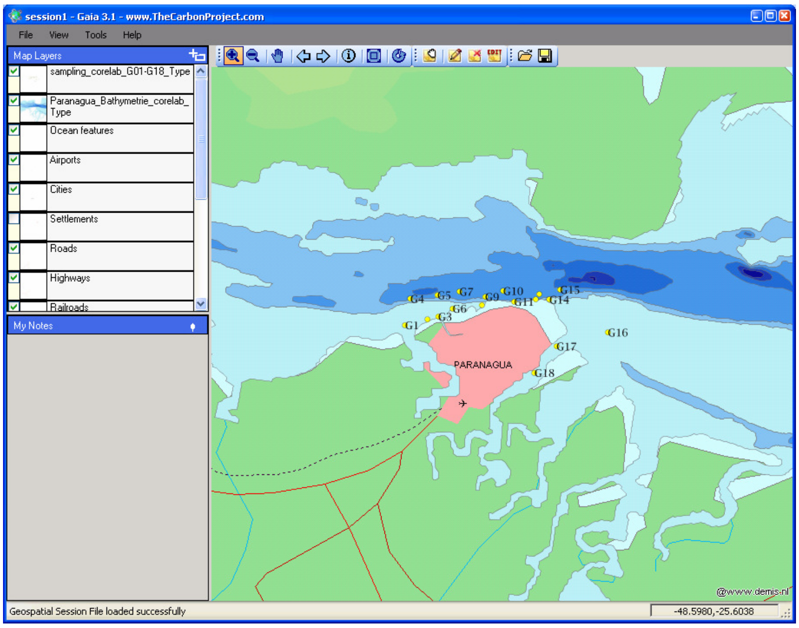


Fig. 7: Effective layer list in the Gaia WMS client and composite map of public background map of Paranaguá Bay, project bathymetry and project locations of sampling stations for harbour gradients in 2007

5. Services based on metadata

An obvious advantage of working with standardized metadata is their application in search interfaces, which are prominent components in information infrastructures and web portals.

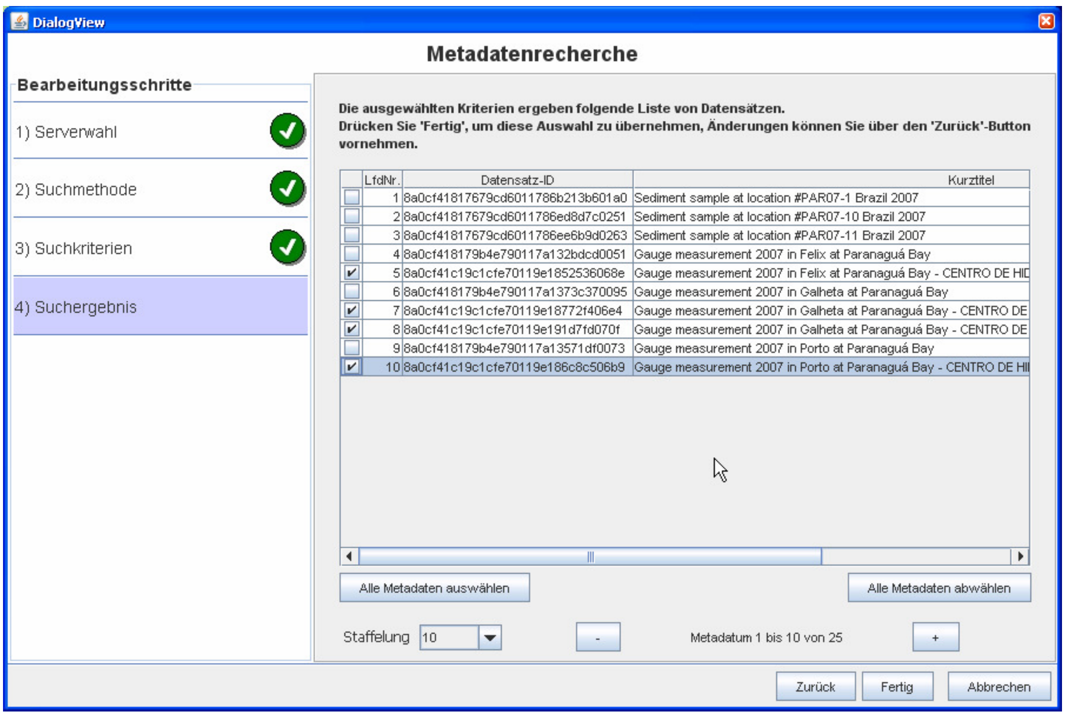


Fig. 8: Search interface with hit list for gauge data documented with ISO19115 metadata

Making use of catalogue services CSW for automated procedures in networked environments (OGC, 2002), the user requests are passed to the online metadata base by the web interface, which returns an according hit list as shown in figure 8.

Each item on this list contains a mandatory geographic reference element for the location that can be displayed on a map. Static clickable maps, operating on the HTML-code of a web page with <map> and <img … usemap=…> tags are a suitable stand alone approach for individual tasks. Dynamically selected information from continuously growing databases is better processed within a standardized framework of services that allows for composite maps, where locations are automatically marked according to metadata.

OCG Web feature services WFS provide context to maps and handle interactive access to e.g. the metadata for each location as shown in figure 9 or trigger further processing clients for coastal engineering data types (visualization, statstics, analysis etc.). All or selected items from the metadata records can be displayed to provide the user with details on the chosen items.

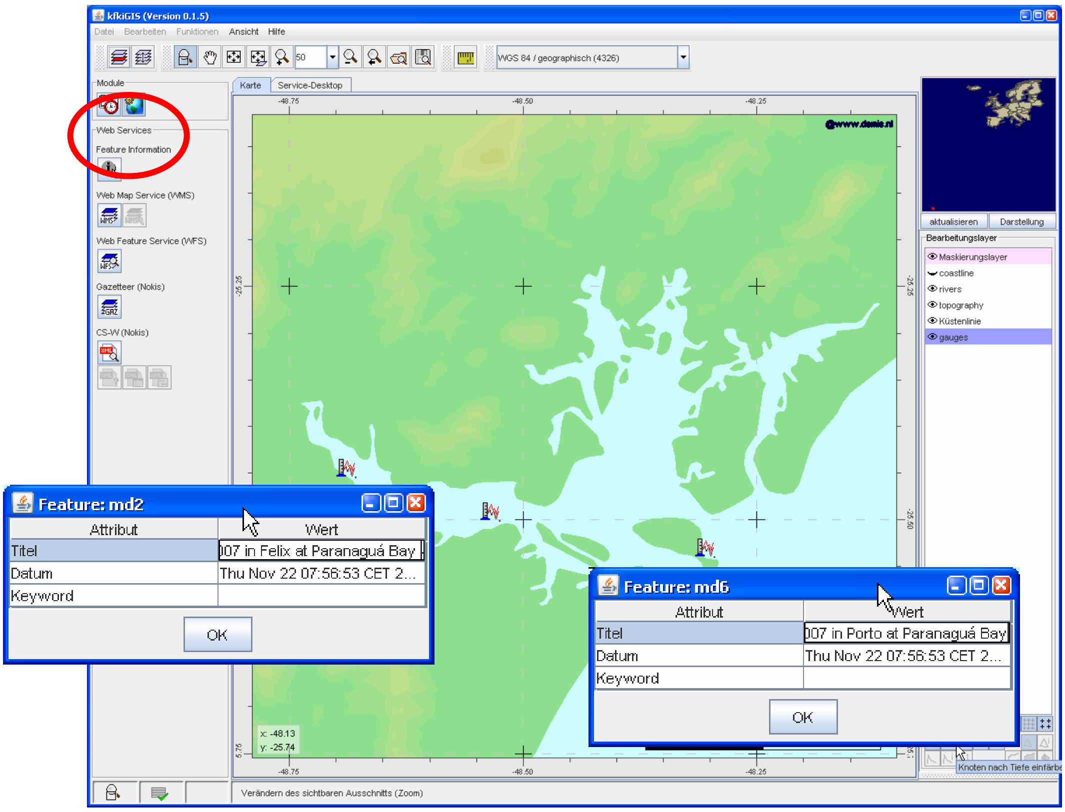
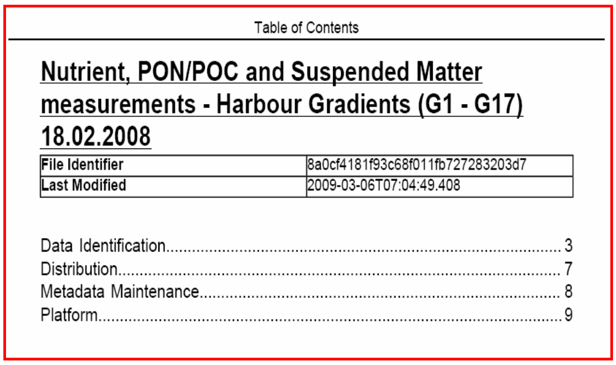


Fig. 9: Dynamically produced composite map (WMS), which displays

- the location of gauges taken from the hit list items (CSW) and
- additional metadata (WFS)

In particular, the coastal-zone-metadata, which has been created with the metadata authoring tool (see fig. 2) and ideally provide a complete description of the data at a given position can be displayed and printed as shown in figure 10. This pdf-document is created on demand from the metadata base through the interaction of web services. Its contents reflects the current status of data documentation and can accompany the data when distributed.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Nutrient, PON/POC and Suspended Matter measurements - Harbour Gradients (G1 - G17) 18.02.2008

File Identifier	8a0cf4181f93c68f011fb727283203d7
Last Modified	2009-03-06T07:04:49.408

Fig. 10: Printed version of metadata created by the NOKIS metadata authoring tool

A large number of field data collected during the campaigns 2007 and 2008 have been processed in a way that preview pictures (see fig. 11) are available, which give a quick impression of the data without previous download.

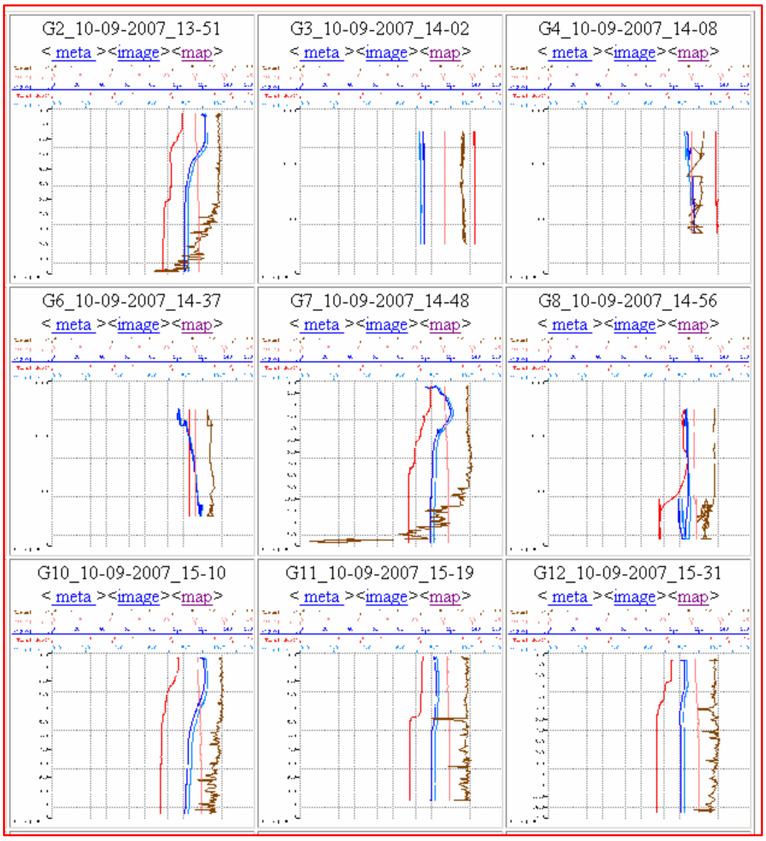

Fig. 11: Preview pictures as part of the documentation with metadata

6. Data documentation

Distributed data from surveying, monitoring and modeling is provided on Web servers of different agencies to be applied on demand for system analysis through integrated views by Web services. A number of use cases (see fig. 12) have been selected to demonstrate the applicability of the chosen concepts and technologies to the project data of Paranaguá Bay.

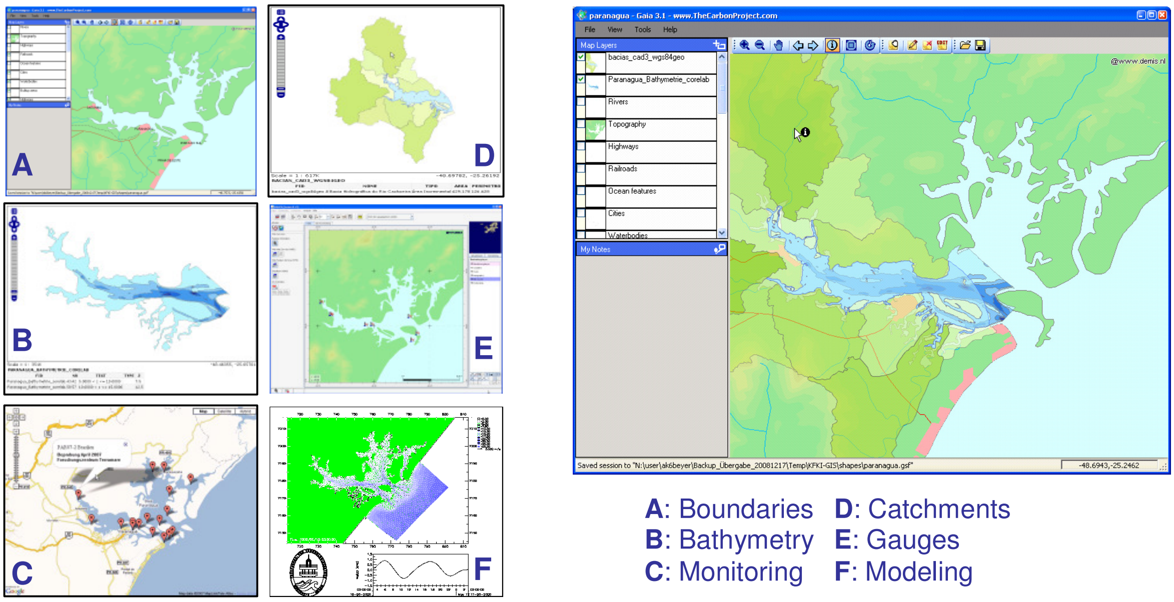

Fig. 12: Composite maps

7. Conclusions

A multi-lingual metadata editor has been implemented as communication tool for a distributed international research team and helps documenting field and project data in the different native languages in a standardized metadata model.

The elements of the "Coastal Zone Metadata Profile" specified from the ISO 19115 metadata schema provide consistent documentation of data that can be used in search interfaces and automated query procedures.

OGC Web Mapping services are applied to dynamically display the locations of sampling stations with coordinates taken from the pertaining metadata.

OGC Web Feature services allow accessing the full metadata set where information about the data proper and further service data can be stored.

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18. Kurzfassung

Das Vorhaben ist Bestandteil des Verbundprojektes „Nachhaltiges Umweltmanagement in brasilianischen Häfen“ und unterstützt die Kommunikation zwischen den Partnern der Teilprojekte und weiteren Nutzern. Im Sinne von Integriertem Küstenzonenmanagement werden Daten und Projektergebnisse aus der Küstenzone der Bucht von Paranaguá dokumentiert und bereitgestellt. Die mit Internet-basierter Software-Technologie aufgebaute Informations-Infrastruktur beruht auf internationalen Standards und kann somit leicht in übergeordnete Informationssysteme eingebunden werden. Mit den verschiedenen technischen und strukturellen Ansätzen wurde ein Beitrag zur Entwicklung eines interdisziplinären Netzwerkes mit den Hauptkomponenten Daten, Metadaten und Dienste für den Einsatz in Forschung und Verwaltung geleistet. Für die Bucht von Paranaguá wurde ein Webportal mit einer übergreifenden Darstellung des Daten- und Informationsmaterials aus dem Projekt aufgebaut und kontinuierlich in Zusammenarbeit mit allen Teilprojekten um die neuen Daten aus den Messkampagnen und für die Modellierung ergänzt. Der NOKIS-Editor wurde zur Erzeugung von standardisierten Metadaten in Deutsch und Portugiesisch in die Projekt-Arbeitsumgebungen eingebunden. Mit den darin enthaltenen Suchmechanismen ist eine gezielte Recherche nach Projektdaten aus der Bucht von Paranaguá möglich. Die erfassten Daten und Metadaten bleiben dauerhaft online verfügbar. Mit den in Brasilien und Deutschland durchgeführten Schulungen zum Umgang mit Metadaten wurden standardisierte Metadaten zur nachhaltigen Dokumentation und zur Qualitätssicherung bei Weitergabe und Nutzung von Daten etabliert. Unter Verwendung von OGC Web mapping services werden zur Modellierung verwendete flächenhafte Daten der Bathymetrie und der Einzugsgebiete sowie die Lage von Messstationen in den Feldkampagnen visualisiert und in einem Gaia WMS Klienten dargestellt. Mit Hilfe von OGC Web feature services werden Kontext-Informationen abgerufen, die aus den standardisierten Metadaten mit Vorschaubildern bestehen und als pdf-Dokumente ausgedruckt werden können. Die vorhandenen Metadaten werden auch direkt zur Recherche über die Katalogschnittstelle CSW angesprochen.

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18. abstract The project is part of the collaborative project "Sustainable Environmental Management in Brazilian Harbours", and supports communication between the partners of the projects and other users. For the purposes of Integrated Coastal Zone Management data and project results from the coastal zone of the bay of Paranaguá are documented and made available. The resulting information infrastructure is using Internet-based software technology, which relies on international standards and can easily be integrated into higher level information systems. With the various technical and structural approaches a contribution to the development of an interdisciplinary network with the main components of data, metadata, and services for use in research and administration is provided. For the Bay of Paranaguá a web portal with a comprehensive representation of the data and information material concerning the project was developed and continuously updated, in collaboration with all subprojects, covering new data from the measurement campaigns and for modeling. The NOKIS editor has been integrated in the project working environments for the generation of standardized metadata in German and Portuguese. Targeted search for project data from the Bay of Paranaguá is possible with the installed search mechanisms regarding the collected data and metadata, which remain permanently available online. The training of dealing with metadata during short courses in Brazil and Germany has established standardized metadata for sustainable data documentation and quality assurance in case of data exchange. Using OGC Web mapping services the areal data of bathymetry and catchment areas used for modeling and the locations of measurement sites in the field campaigns are visualized and displayed in a Gaia WMS client. With the help of OGC Web feature services context information consisting of the standardized metadata including thumbnails is made available, and can be printed out as pdf documents. The existing metadata can also be addressed directly for searching through the CSW Web catalogue service interface.	
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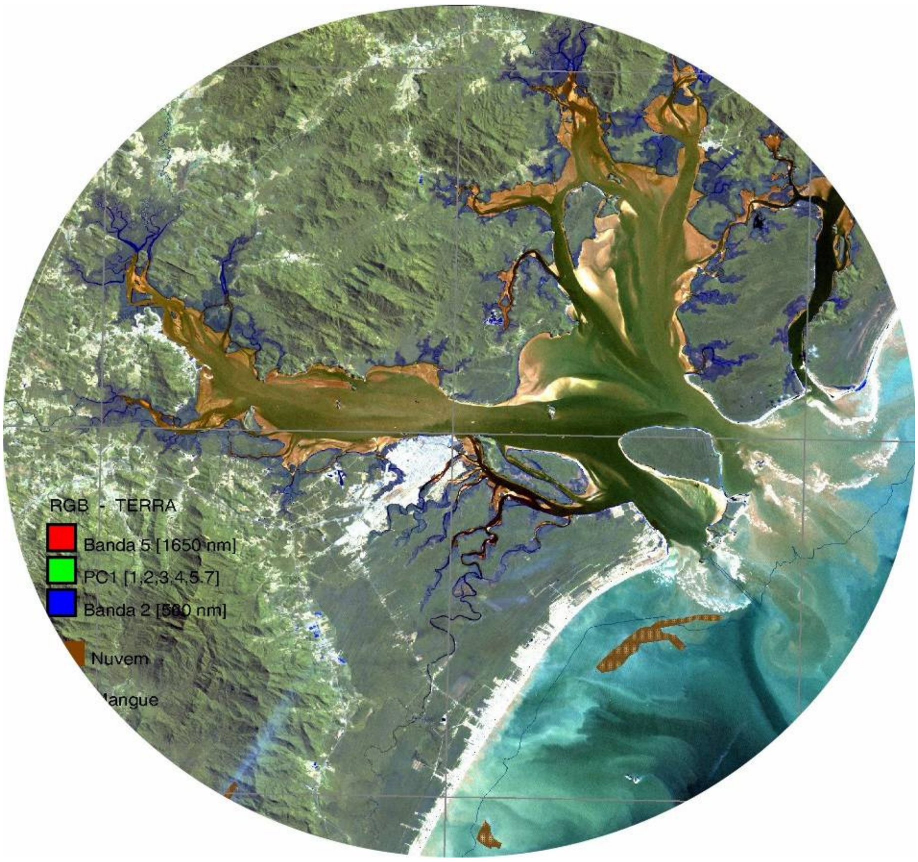

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