

# **ENVIRONMENTAL MANAGEMENT OF SEAPORT WATER BODIES USING GEOGRAPHIC INFORMATION SYSTEMS**

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## **ABSTRACT**

ROM 5.1 is a methodological procedure directed to complement the suite of tools that would be adopted by Spanish and European ports in order to satisfy the requirements established by the Water Framework Directive (WFD, 2000/60/EC). In agreement with the volume of data managed by this methodological procedure, a spatial database system has been used to integrate the entire information. This paper introduces a practical case of the usefulness of Geographic Information Systems and Spatial Databases to carry out the management of seaport water quality. Results show how this approach improves information management and environmental results analyses.

**DBMS, ENVIRONMENTAL MANAGEMENT, GIS, PORT, WATER QUALITY.**

## **INTRODUCTION**

The coastal zone is subject of major environmental pressures, not only for its limited surface of high economic and natural value, but also because around two thirds of the world's population live in this space. The convergence of uses in such a limited space have generated important conflicts that have been growing as well as the activities that origin them. In this process of coastal zones exploitation, there have been forgotten the basic principles of every environmental management system: environmental sustainable actions, economically affordable, technically feasible, legal, administratively achievable and, by last, socially desirable (Elliot, 2002).

Within the coastal zones, the port spaces are characterized by being well defined elements, with direct or indirect effects in all the sectors, that is why the port activity has been prevailed over other kind of activities (Barragán, 2003). Ports are integrated into population nucleus that promote the trend to rearrange the spaces occupied by them, in order to strengthen their activities minimizing the possible conflicts derived of the different uses that converge in this zones (Ondiviela, 2006). Nowadays, the port traffic in the European Union represents the 90% of the trade with the rest of the world, and the 35% of the internal trade (European Sea Ports Organisation (ESPO), 2003)

The Spanish Ports, along with the rest of the ports of the European Union, have been working since the start of the 90s in the port environment field. The aim of this involvement was to contribute to the sustainability of the transport, harmonizing the environmental policies and the development of tools enabling the identification and reduction of the port environment

impacts, better prevention, control and management of the environmental risks, in short, a more flexible adaptation of the ports to the demands and requirements of the extensive environmental regulation that is being introduced. In this context, the approval of the Directive 2000/60/EC of the European Parliament and Council 23rd October 2000 should be highlighted, known as the Water Framework Directive (WFD), through which a Community-wide framework in the water policy area is established. Ports are obviously within the scope of application of the WFD as coastal and transitional waters are within their objectives of protection (Puertos del Estado, In press).

For these reasons, the Spanish National Port Administration considered it both essential and urgent develop a first methodological and technical tool for the integral management of port water bodies. This methodological procedure was developed within the well known Spanish standardization programme in the field of ports (ROM programme) under the denomination of “ROM 5.1. Quality of Coastal Waters in Port Areas” (Puertos del Estado, 2005). ROM 5.1 makes available some scientific and technical methodologies that could contribute to the integral port water bodies management (Revilla et al, 2006).

ROM 5.1 (available at [http://www.puertos.es/es/programa\\_rom/rom\\_51\\_05.html](http://www.puertos.es/es/programa_rom/rom_51_05.html)) is a very useful technical and methodological tool for port administrations to manage, in terms of water quality, its geographical area of jurisdiction in an integral way. In accordance with the contents of its programmes it is clear that even when ROM 5.1 is an entire tool by itself, it demands and generates a lot of information that needs to be managed. For this reason, it may be complemented and strengthened by the use of other technical tools as Data Base Management Systems (DBMS) and Geographic Information Systems (GIS) that working together allow to calculate, storage, and manage a lot of valuable information for decision makers to solve environmental problems efficiently. In this work, it is shown through an application example to the Port of Gijón (North of Spain coastal zone) how are satisfied the input and output information management demands during the application of ROM 5.1 using Structure Query Languages (SQL) and DBMS as a management and calculating supporting tool and a GIS as the integrator environment.

## **ZONE UNDER STUDY**

The Port of Gijón is the study area of this work. This port is immersed within the city of Gijón in the North of Spain. Concretely, the zone under study is the geographical area of jurisdiction of the Port of Gijón, named Port Service Zone and defined like the space of land and water necessary to guarantee the development of port uses and activities (Spanish Law 48/2003). Their limits are included between the following meridians and parallels: Length 5° 42,52' W and 5° 38' W and Latitude 43° 37' N and 43° 33' N (Figure 1).

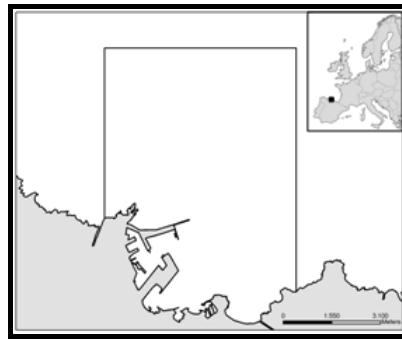


Figure 1. Site under study, geographical area of jurisdiction of the Port of Gijón, located in the North coast of Spain, in the Cantabrian Sea.

Nowadays, the Port of Gijón is more than a basic node of transport system, is a centre of activities, which ranged from the transport of dangerous cargo to recreational use in bathing waters. The surface water of the space scope, with 2950 hectares approximately, is predominantly coastal with protected areas and heavily modified water bodies.

### ROM 5.1 METHODOLOGICAL APPROACH

ROM 5.1 is structured in four large working areas: the programme of delimitation of uses and characterization of water bodies, the programme of assessment and management of environmental risks, the programme of environmental monitoring and the programme of management of contaminant episodes.

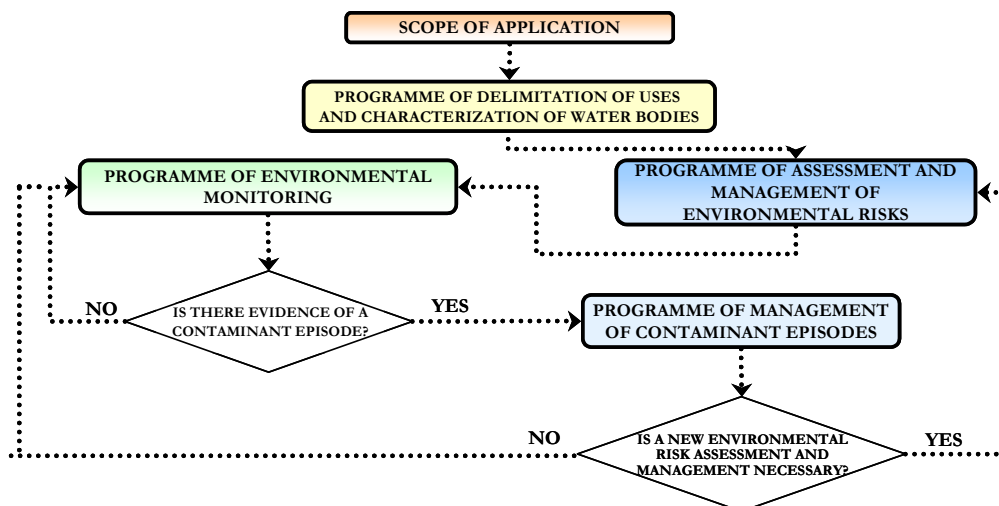


Figure 2. Diagram for application of the ROM .5.1.

At first place, the management of water quality in a specific port environment requires the establishment of methods and procedures for delimitation and characterization of its different water bodies. In the application of the ROM, this programme is based on the following tasks: delimitation of uses of the aquatic environment, establishment of categories of the water bodies, and assignment of types to the water bodies.

The delimitation of uses basically lays on the analysis of the specific activities existent in the port, since they are a direct influence for the water bodies quality. This way, the water bodies could be classified as non modified or modified in accordance with the procedure proposed by ROM 5.1 for the assignation of modified water bodies. For the characterization of the non modified water bodies there is taken into consideration their salinity characteristics (transitional or coastal waters) and the kind of substrate (sandy or rocky sea bottoms). On the other hand, for the characterization of the modified water bodies there is taken into consideration the kind of substrate and the flushing time (low or acceptable). This characterization allows to assign a specific type to each water body.

After the assignation of specific types to the water bodies, the programme of assessment and management of environmental risks is carried out. The quality of the waters in the port area will be conditioned by the set of interactions of the activities. Therefore, ROM establishes procedures to evaluate environmental risks associated with the different contaminant emissions impacting on the port area. To this end, the risk attributable to each emission is evaluated on the basis of the likelihood of its occurring, the ensuing consequences and the vulnerability of the waters potentially affected. Depending upon the tolerability of the emission, appropriate preventive and corrective measures are applied in order to minimize the environmental repercussions of these contaminant emissions.

Then, the programme of environmental monitoring is carried out as the tool through which the evolution of the ecological status of the non modified water bodies or the ecological potential of the modified water bodies, and chemical quality of all of them can be evaluated. This programme remains active continuously in time. Its application enables the proof of reduction in quality of the water bodies, the failure and omissions of the programme of assessment and management of environmental risks and the activation of the programme of management of contaminant episodes.

Finally, the programme of management of contaminant episodes is the procedure leading to the mitigation of the quality deficits detected in the water bodies by the programme of environmental monitoring. Its development is based on the following working steps: identification of origin, adoption of corrective measures, and verification of the results. The aim of this programme will be to reduce the adverse effects of contaminant episodes through the application of corrective measures.

## **DBMS AND GIS IN PORT AQUATIC SYSTEMS MANAGEMENT**

As we discussed above, due to the huge quantity of generated information through the application of ROM 5.1 to the ports, it is necessary to involve an information management system that allows to process and storage all this information in order to be easily and effectively consulted and used.

Since most of the information has a spatial component, it is essential to have a connection with a cartographic system. This task could be gotten through the utilization of a specific designed Geodatabase System which would combine SQL Procedures and a GIS.

A particular application has been developed to allow users to get quickly and easily the input forms and the output reports through windows with menus and submenus. This tool allows to make or to consult technical reports based on the stored information (characterization of water bodies, calculation of water and sediment quality indexes, estimation and evaluation of environmental risk, management of contaminant episodes information, and so on). Furthermore, the incorporation use of the GIS allows to visualize graphically the different aspects studied by ROM 5.1 that involves a spatial distribution (delimitation of the water bodies, potential risk areas, spilling points, sampling points, an so on).

In accordance with ROM 5.1 structure, the developed spatial database is capable to handle and manage all the collected information and also would allow the possibility to connect with the corresponding GIS project. ROM 5.1 application is carried out solving some tasks derived from its programmes (Figure 2).

- Development of the Delimitation of uses and characterization of the water bodies programme

In order to characterize the water bodies, a GIS is used to manage the concrete spatial information necessary: the visualization of the study area, the establishment of the exact location and surface occupied by each use existent in the port, and the establishment of the water bodies kind of substrate, salinity and flushing time. To establish the kind of substrate it is necessary to introduce in the GIS project a layer that contains information about the morphology of the sea bottoms of the zone. GIS allows to calculate within each water body the extensions covered with sand and with rock to classify the substrate as “soft” or “hard”, respectively. The salinity of the non modified water bodies is established in function of the predominant coastal or transitional water body character. The flushing time of the modified water bodies is calculated with numerical models (H2D, H2DZ and RENOVA ) (Gómez et al, 2006; Gómez et al, 2007; Sámano et al, 2007). On the one hand, its usefulness lays on the capability of overlaying spatial information and the possibility to make a connection with interoperable Web Map Services to have a more realistic visualization and then, a better evaluation of the study zone. On the other hand, its importance lies on the fact that starting from this point is possible to establish the limits and specific types of the water bodies.

With all this information (delimited non modified and modified water bodies, kind of substrate, salinity and flushing time) the developed spatial database allows to establish the water bodies specific types. This basic information feeds the input demands of the first database’s module. The corresponding output is the automatic assignation of one specific type that involves the water body distinctive characteristics.

- Development of the Assessment and management of environmental risk programme

All the environmental risk related information is also located through a GIS in order to know which are the prone points to suffer contaminant emissions, and what kind of contaminants may be expected to be present at this locations in accordance with the existent detected activities. In order to complete the estimation and evaluation of the environmental risk, it is used another numerical model (EMITE) (Revilla et al, 2006) to estimate the consequences of each emission in terms of water body’s affected surface obtaining a concentration map that could be imported by the GIS (García et al, 2007). Moreover, the GIS capabilities to join

information allow to establish the impact of an emission by combining the affection of different substances. Using a GIS is also helpful for the estimation of the vulnerability of the water bodies in function of their ecological value.

With the aim of having a more concrete estimation and evaluation of the environmental risk, the developed spatial database is able to calculate and evaluate the risk of every contaminant emission. For feeding the database it is required for each contaminant emission detected within, or nearby the port area, to declare its localization and characterization (type of contaminant, concentration and flow). Then the database presents a multiple choice input form that allows to select the appropriate statement in order to satisfy the information input demands such as likelihood of occurrence, accessibility, extent (previously calculated with a GIS) and social repercussion of the contaminant emission, hazard posed by the contaminant emission, efficiency of the working procedures and recovery potential of the water bodies. The output of this module is the automatic numerical estimation of the environmental risk as well as its evaluation. This form is followed by a second one in which could be described the preventive and corrective measures that should be applied.

- Development of the Environmental monitoring programme

A GIS project allows the visualization of the monitoring stations along the port area. Furthermore, the management of all the field surveys information under a GIS environment, make it possible to have very useful interpolations, plots, statistics and so on.

In order to know the chemical quality of the pelagic environment of the water bodies, it is necessary to compare each measured parameter with the established quality standards in order to know if the parameters fulfil this demands. To know the chemical quality of the benthic environment, in absence of concrete quality standards, it is necessary to fix a base line which will be taken as a reference in the future to establish the chemical quality of the port sea bottoms.

In order to know the ecological/potential status of the water bodies, it is necessary to calculate the quality indexes from the field surveys data. For the calculation of these indexes, the corresponding module of the database system is divided in two kinds of blocks: one to insert the data resulting from field surveys, and another one to make queries. The input form requires before inserting the data, to declare the water body under analysis and the sampling station, as well as it is focused on water or in sediment. On the other hand, to consult all the raw or processed data and the calculated indexes it is enough to select the water body of interest, and to provide basic information such as the year. It is important to highlight that the developed database calculates the annual media data, and then it also standardizes them as a previous requirement for the quality indexes calculations.

- Development of the Management of contaminant episodes programme

Throughout the management of the contaminant episodes information there have been mixed the localization and visualization advantages of a GIS, determining the most prone zones to suffer contaminant episodes, and the database storage capacity. The last module of the developed database is dedicated to the compilation of all the available information of each

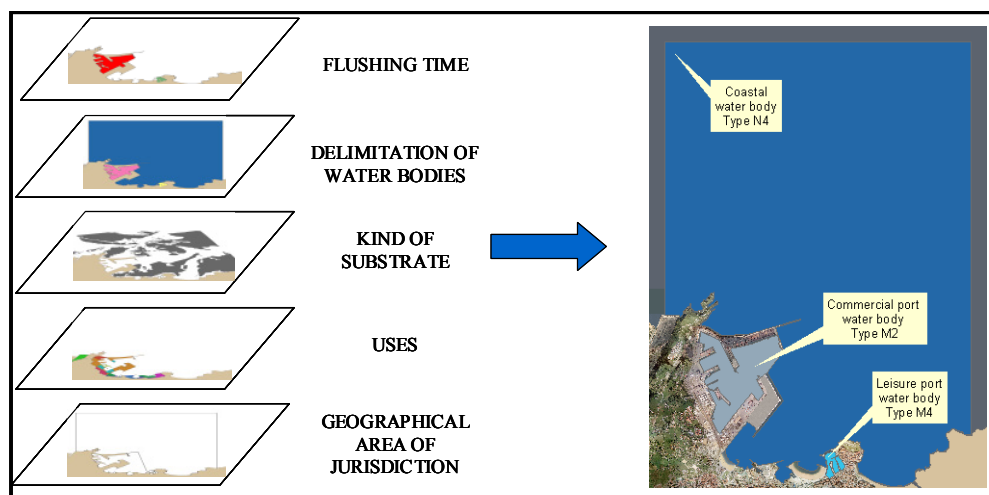
contaminant episode occurred within the port area in order to identify, control, and verify the results gotten after the application of the appropriate corrective measures.

## RESULTS

At this point we have described ROM 5.1 structure and contents, and the utility of using complementary tools such as DBMS and GIS in order to satisfy data management needs. The results obtained through the application of ROM 5.1 to the Port of Gijón supported with these tools are shown next:

- **Delimitation of uses and characterization of the water bodies programme**

Taking advantage of GIS capability of importing files from another applications and in order to get a specific characterization of water bodies, there were built layers from imported .dwg files that were supplied by Port of Gijón Authority. These layers were managed using a GIS project (Figure 3) and content information about the scope application, the existent uses, the kind of substrate, the proposal of water bodies delimitation, and flushing time.



**Figure 3. Delimitation and characterization of water bodies.**

As a result of this task of overlaying all the information into a GIS, there have been delimited three water bodies. Two of them are modified (Commercial port and Leisure port water bodies), and the third one is a non modified water body (Coastal water body).

The integration of the necessary information (water body category, kind of substrate, salinity and flushing time) through the developed spatial database determined automatically the specific type of each water body. In accordance with the types proposed by ROM 5.1, the “Commercial port” is a M2 water body (modified water body with sandy sea bottoms and low renovation rate), the “Leisure port” is a M4 water body (modified water body with sandy sea bottoms and acceptable renovation rate), and the “Coastal” is a N4 water body (non modified coastal water body with sandy bottoms).

- Assessment and management of environmental risk programme

Using a GIS, there have been detected direct emissions within or nearby the geographical area of jurisdiction of the Port of Gijón. This emissions are product of the different activities performed at the port: capture and selling of seafood, nautical and sport activities, industrial and the wastewater cleaning-up systems. Also, there have been established the affected areas by each contaminant emission. The estimation and evaluation of the environmental risk of each emission is being obtained through the use of the corresponding module of the developed spatial database just answering the input forms on basis on the analyzed information.

As an example was chosen the emission of the wastewater treatment plant (E.D.A.R. La Reguerona) through a submarine outfall. The preliminary estimation and evaluation made to this contaminant emission using the spatial database and numerical models under a GIS environment are shown in Figure 4.



Figure 4. Location of the wastewater treatment plant and extent of the contaminant emission visualization (left). Estimation and evaluation of the emission carried out by the wastewater treatment plant (right).

- Environmental monitoring programme

The port of Gijón is carrying out a monitoring programme that started at May 2005. At these stations are measured, at least, every month, five parameters at different depths for the pelagic environment, and every year, thirteen parameters for the benthic environment, that is, more than 3000 annual data. The final objective for all this information is to obtain an evaluation of the chemical quality and the ecological/potential status of the water bodies. This objective was gotten automatically thanks to the capabilities of the developed database.

On the one hand, to evaluate the chemical quality, the database compared the input data with the established quality standards for the pelagic environment in order to know if the measured values correspond to a fulfilment or to a non fulfilment with regard to the WFD's requirements. On the other hand, for the benthic environment, all the collected data was



stored at the database as the future reference values. The obtained results revealed that just 4 of the 1320 determinations made at the port of Gijón during 2005 campaign did not fulfil de WFD's requirements. The determinations made to the benthic environment allowed to establish the standing still status which will be taken as reference for future evaluations (Ondiviela et al, 2007).

In order to evaluate the ecological/potential status the developed spatial database was used. This way, there were automatically calculated the annual media data for each measured parameter at every monitoring station. Then, these annual media data were standardized in order to have an applicable scale for all the parameters involved. Finally, with the standardized annual media data, there were calculated the quality index for water, and the quality index for sediments that were combined to determine the ecological/potential status for each water body. The developed spatial database allows to get reports of the ecological/potential status as well as each index for every water body (Figure 5). The results obtained by the spatial database for the 2006 campaign data shown that the ecological status of the non modified water body was "Very Good" and the potential status of both modified water bodies were "Good".

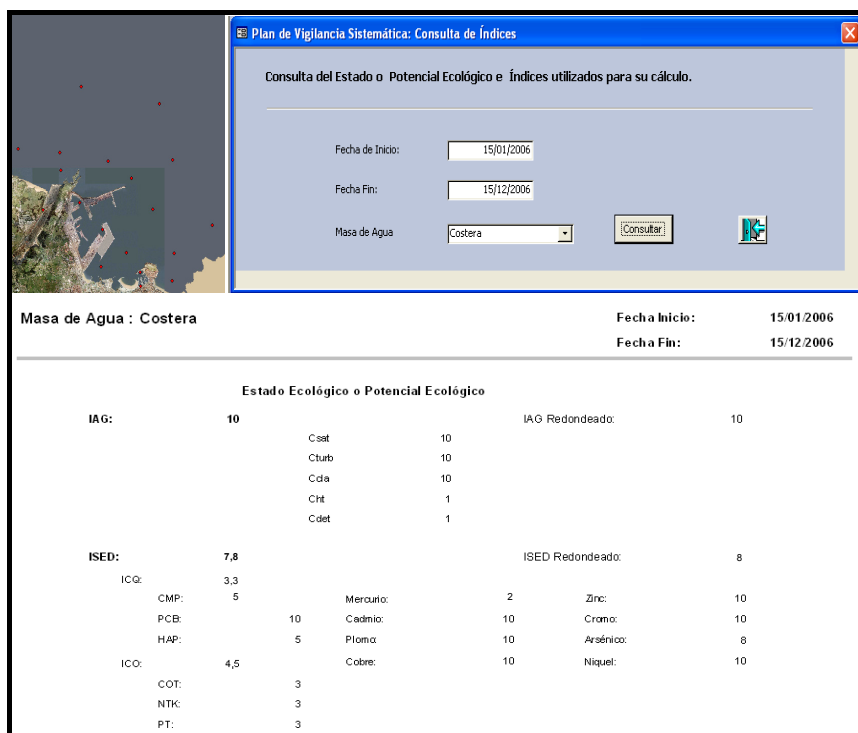


Figure 5. Location of the sampling stations and requesting information window (up). Example of an output report (down).

- Management of contaminant episodes programme

Through the analysis of the contaminant episodes occurred during more than four years at the Port of Gijón, there were located some critical points more prone to suffer contaminant episodes making use of the GIS visualization capabilities. Also, there were stored all the contaminant episodes information in different records of the database system in order to have all this information organized and available for future consults (Figure 6).

**PROGRAMA DE GESTIÓN DE EPISODIOS CONTAMINANTES**

Nombre del episodio: 154    Turno: Segundo    Equipo:    Episodio Cerrado

Fecha: 06/04/2002    Hora: 15:10

Sistema de detección: Plan de Inspección Visual    Especificar: Se observa mancha de aceite

Localización del episodio: Frente al centro de control    Evidencia Gráfica

Origen del episodio: Se sospecha que pueden haber sido las grúas de la empresa X

Plan de Contingencia:    Descripción del Plan activado:

**PROPIESTA DE MEDIDAS**

Tipo medidas	Fecha adopción	Medidas propuestas	Observaciones

Registro: 14 de 1

**COMPROBACIÓN DE RESULTADOS**

Responsable	Fecha	Modo de Comprobación	Observaciones

Registro: 14 de 67

Figure 6. Example of output report that contains data of a contaminant episode.

## CONCLUSIONS

ROM 5.1 application involves the integration of a large amount of information from different data sources, data handling methods and data formats. For these reasons, two powerful tools have been used: Geographic Information Systems and Data Base Management Systems in order to generate, storage and handle all the existent data under the ROM 5.1 methodological proposal. Supporting all ROM 5.1 programmes by a GIS and a database system will provide the best and most complete information available to the decision makers in order to get a more efficient water quality management.

The most remarkable advantage of using a GIS consists in its capability to manage and storage any information with spatial components. There are also notable its visualization capabilities that allows the superposition of all the available information making possible to perform a global analysis.

It is advisable to use a DBMS in the ROM 5.1 application because all its programmes, specially the Environmental monitoring programme, demands the manage of huge quantities of data. Handling this data by hand increases the probability of making a mistake as well as it becomes more complicate and takes much longer. It also allows to get reports with processed and organized information.

Integrating both supporting tools (GIS and DBMS) in a Geodatabase system would allow the possibilities of combining the capacity to storage the collected information and the visualization of all these data and their interrelation.

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