A tool for the management of seaport water bodies quality. "ROM 5.1. Quality of coastal waters in port areas".

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Abstract

In order to "establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater", in the year 2000 the European Parliament published Directive 2000/60/EC (henceforth Water Framework Directive or WFD).

The management policies established by the WFD define a unique performance framework for watersheds. Furthermore, in this new framework of management, it is possible to identify singular elements, such as ports, whose peculiarities justify the development of control and monitoring programmes specific and adequate to their characteristics (operational monitoring programmes in WFD terms).

With these objectives, the paper introduces the first methodological and technical tool for integral management of seaport water quality, with direct incidence in design, evaluation and environmental monitoring of infrastructure works, activities and port operations. This tool included in the Spanish standardisation programme of ports (ROM PROGRAMME) was published in 2005 under the denomination of "ROM 5.1. Quality of coastal waters in port areas".

1. Introduction

The overall goal of the European Water Framework Directive for surface water bodies is to achieve "good ecological status" by 2015. However, numerous water bodies in the EC may not be able to achieve this goal (European Commission, 2003b). The cause of this lack of fulfilment is related to one principal origin: the usage of water bodies. Because the manner in which water bodies are used may not limit its natural development the Directive introduced the figure of heavily modified water bodies (HMWB): bodies substantially changed in character to maintain specific uses. In a general form, WFD recognises as specific uses those that require hydromorphological changes in water bodies of such scale that restoration to "good ecological status" may not be achievable even in the long-term without preventing the continuation of a specific use (Ondiviela, 2006). The great contribution of this new approach is that instead of using "good ecological status" for natural water bodies, HMWB ecological assessment will be based on "good ecological potential" (Irmer & Rechemberg, 2004).

The recognition of HMWB and the definition of environmental objectives in coherece with its physical alteration have allowed the continuation of uses which provide valuable social and economic benefits. In any case, this optional designation is not an opportunity to avoid achieving ecological and chemical objectives, since good ecological potential may be often, in itself, challenging to achieve (Estrela *et al.*, 2004).

The complexity and diversity of environmental problems are determined by the specific peculiarities of each port. Aspects such as their location, the type of activities pursued and the interactions arising from the confluence of these with other uses developed determine the type of actions required to halt their environmental deterioration (Puertos del Estado, 2005). A number of anthropogenic activities and uses with potential negative environmental impacts take place in ports (Borrego *et al.*, In Press). Although port emissions to the aquatic environment have been reduced considerably in the late years as control measures were implemented (Casado-Martinez *et al.*, 2006; PIANC, 1997), the results of the application of the WFD in the Atlantic ecoregion confirm ports are at a significant risk of failing to meet their environmental objectives (CEDEX, 2005; GESHA, 2005).

The consideration of ports as one of the uses that has special economic and social relevance in the EC has allowed to adapt its environmental objectives to others more coherent with their hydromorphological characteristics, with their current uses and with the impacts produced by its uses (Ondiviela, 2006). Nevertheless WFD recognises that in numerous cases environmental problems are not solved by just reducing requirement standards but by establishing specific operational monitoring in order to assess the ecological status of bodies at risk and to evaluate changes resulting from measures programmes (European Parliament and the Council, 2000).

Nowadays neither in Europe nor Spain there is a specific nation-wide regulation for the environmental management of port water bodies (ESPO, 2003) and many administrations and organisations in the port sector have repeatedly shown concern due to the significant medium to long term effects in water bodies quality. With the purpose of developing an instrument to carry out a sustainable environmental management programme in port areas and to satisfy the operational monitoring requirements of water bodies at risk of failing to meet their environmental objectives established by WFD, Spanish National Ports Administration promoted a participatory process (port authorities, consultants, marine scientists). The result has been a tool included in the Spanish Standardization of Maritime Works (ROM Programme), under the denomination of “ROM 5.1. Quality of coastal waters in port areas” (Spanish National Ports Administration, In Press). Even though this instrument is currently being tested at different Spanish ports, in the Mediterranean, the Atlantic, the Biscay Gulf and the Canary Island coastal areas, the goal of this contribution is to introduce the methodological scheme of the first tool developed in Europe for management seaport water bodies quality in an integral way.

2. Description of ROM 5.1. methodology

The goal of this methodological procedure was to perform a conceptual model to manage ports water bodies quality, scientifically rigorous, simple in its design and interpretation, easily integrated into port schemes, sensitive to port singularities, and sustained on a public draft procedure. The first step in the development process was to design a scheme to answer three main questions:

What has to be protected?

What does it have to be protected from?

How can it be protected?

Therefore elements to recognise and classify environmental units, to analyse general pressures and to assess and control the impacts were considered. This conceptual model was used to develop an assessment tool structured in three main working areas: (i) Characterization of waters bodies, (ii) Environmental Risk Assessment (iii) and Environmental Monitoring (Figure 1).

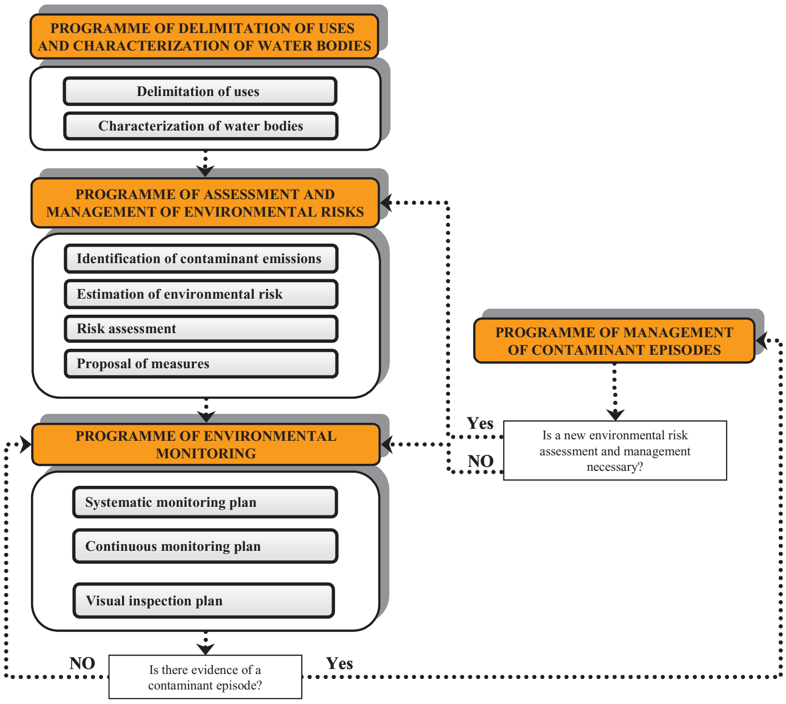

Figure 1. Methodological procedure of "ROM 5.1. Quality of coastal waters in port areas".

2.2. Characterization of water bodies

In agreement with the WFD, water bodies are the units used for reporting and assessing compliance with environmental objectives (European Commission, 2003a). Therefore water bodies identification is a tool not an objective itself. In a general form, ROM 5.1 define water bodies as discrete, homogeneous, significant, clearly differentiated and perfectly delimited, including both the water column and the sea-beds.

Water bodies characterization is based on descriptors and classification systems comprised in a system that is arranged hierarchically (Figure 2). Different classification characteristics (uses) and variables (physical descriptors) are used on various levels, achieving gradually an increasingly detailed level of description of a water body. Since the areas defined by marine uses and activities are characterised by being units subjected to the same type of pressure, the conditions prevailing in these areas could be considered as homogenous.

A number of abiotic descriptors were selected based on the most important physical factors: Hydromorphological features (non modified water bodies or heavily modified water bodies), residence time (low or high residence time), salinity fluctuations (transitional or coastal waters) and substratum (hard or sediment) (Figure 2). The combination of these descriptor results in a classification system which allows to recognise four possible types of non modified water bodies (N1-N4), and another four types of heavily modified water bodies (M1-M4).

Hydromorphological alteration: Ports are characterized by a great heterogeneity of uses and physical environments. In order to perform an objective method of classification to recognise heavily modified (HMWB) and non modified (WB) water bodies a group of suitable descriptors were selected. Attending to WFD heavily modified water bodies are defined as "bodies of surface water which as a result of physical alterations by human activity are substantially changed in character and cannot meet a good ecological status" (WFD, 2000/60/EC). Nevertheless, in order to achieve ROM 5.1 objectives the generality of this approximation is insufficient. As far as the ROM 5.1 is concerned all the water bodies physically confined are considered as HMWB. Furthermore, all those waters which are dredged or have demonstrated that they have undergone a substantial change in their physical or hydromorphological conditions, will also be classified as HMWB.

Residence time: In a general approach, water bodies processes are controlled by a wide variety of physical settings. Nevertheless in HMWB water exchange rates have important implications for many variables and site-specific parameters (Painting *et al.*, 2007). The descriptor chosen to estimate water exchange rates has been water residence time (Table 1). In ROM 5.1 water residence time is defined as the time necessary to reduce the average concentration of a conservative tracer by 90%. Its calculation is based on the methodology proposed by Gómez et al (2006).

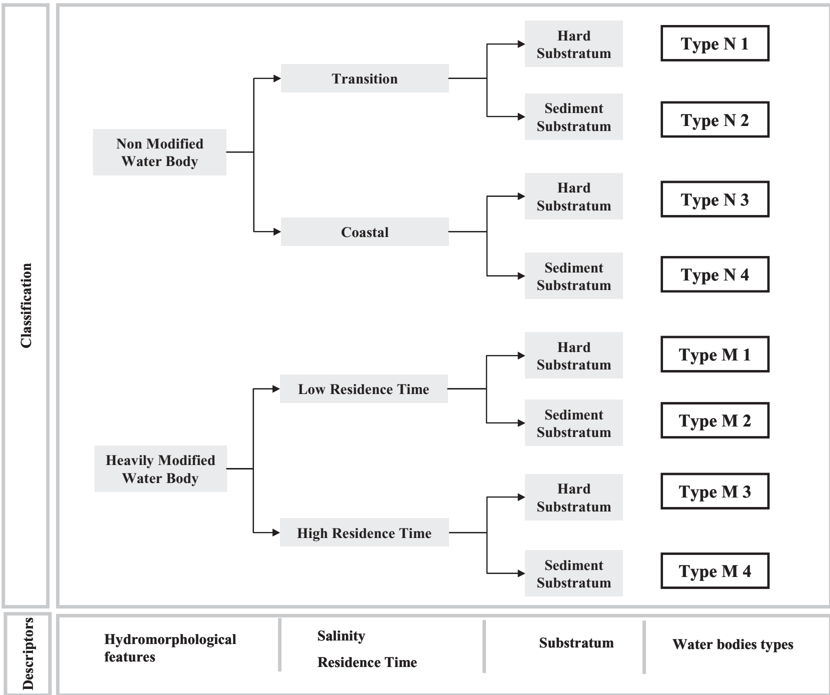

Figure 2. Hierarchic arrangement to classify port water bodies (N1-N4: Non modified water bodies; M1-M4: Heavily modified water bodies).

Salinity: This variable is the descriptor used by WFD to distinguish continental, transitional and coastal aquatic systems. Initially, differences between these zones were set at WFD. Nevertheless, its definition is not clear enough and finally the limit has been establish in the virtual line that defines a river mouth. Waters placed from this line towards the interior of the estuary will be transitional waters and from this line towards the exterior coastal waters (Table 1).

Substratum: Substratum reflects a significant part of the functional and structural variability found in benthic communities. So, the criteria used in the classification system is the dominant substratum and two classifications have been established: rocky substratum (rock making up more than 50% of the surface) and sedimentary substratum (sediment making up more than 50% of the surface) (Table 1).

Descriptor	Class boundaries	Classification
Hydromorphological alteration	Physical confinement or dredged Not Physical confinement or dredged	Heavily modified water bodies Non modified water bodies
Residence time	<7 days >7 days	Low residence High residence
Salinity	Brackish waters Salt waters	Transitional waters Coastal waters
Substratum	Rock making up more than 50% of the surface Sediment making up more than 50% of the surface	Rocky substratum Sedimentary substratum

Table 1. Descriptors and class boundaries defined to classify water bodies.

2.3. Environmental Risk Assessment (ERA)

Any environmental risk assessment process must be based on the analysis of hazards. If the objective of management is the aquatic system and the feature to protect is its quality, hazards to work on should be contaminant emissions, principal contaminant elements in the coastal fringe. But when is a contaminant emission a hazard? and when is it necessary to assess its environmental risk?. While an effluent discharge permit is an authorization for established conditions to guarantee the maintenance of the water quality, contaminant emissions are supposed to be a hazard when these conditions are infringed. Therefore, point emissions only represents a hazard for water bodies quality when its authorization is violated. Similarly diffuse emissions always represents a hazard for lacking authorization.

The approach developed in ROM 5.1 to estimate environmental risk for each emission *Ri* is based on the model adopted by the Spanish standardized norm UNE 150.008 (AENOR, 2000) according to equation (1):

$$R_i = P_i \, x \, V_i \, x \, C_i \qquad (1)$$

where P_i is the probability factor of a contaminant emission, V_i is the vulnerability factor of the waters in respect to a contaminant emission and C_i is the consequence magnitude factor of a contaminant emission. The Probability factor calculates the frequency a hazard *i* represents a risk for water bodies. In point emission the value of probability is calculated as the time between two violations of the discharge permit. Otherwise, in diffuse emissions probability represents the time between two successive emissions. Assessment of this factor will be based on an exhaustive collection of information on activities with the potential to generate unacceptable contaminant emissions, whether they are point or diffuse. The main source of information to calculate this factor will be the Programme of management of contaminant episodes. This programme represents a complementary working area to detect any contaminant episode or contaminant emission able to produce a reduction in the quality.

The Vulnerability factor of the aquatic system affected by an emission is calculated as follows:

$$V_i = \frac{1}{10}\left[5 \cdot Fs + 3 \cdot Fa + 2 \cdot Fe\right] \qquad (2)$$

where *Fs* is the susceptibility of the waters to the contaminant emission and is evaluated in agreement with the type of bodies affected by the emission (e.g. modified, protected, etc), *Fa* is the accessibility of the contaminant emission and is assessed by the availability of detection, control or protection systems and *Fe* is the efficiency of the working procedures and quantifies the possibility that the preventive and corrective measures taken against the contaminant emission will achieve their objectives. The value of the Consequence factor is predicted by:

$$C_i = \frac{1}{4}\left[2 \cdot Fp + Fg + 2Fr\right] \cdot Fc \qquad (3)$$

where *Fp* is the hazard posed by the contaminant emission and assess pollutant potential to affect the chemical and ecological quality, the human health or the established usage, *Fg* is the extent of the contaminant emission and evaluates the percentage of bodies affected by the emission, *Fr* is the recovery potential of the water bodies following the contaminant emission and quantifies the time before water bodies recover the environmental quality they had prior to the contaminant emission, if this is possible, and *Fc* is the social repercussion of the contaminant emission.

This evaluation procedure allows the differentiation between unacceptable, correctable or acceptable contaminant emissions. From here preventive and corrective measures applied in order to reduce the risk to acceptable levels will be specific of each contaminant emission.

2.4. Environmental monitoring

Environmental monitoring is the tool which makes it possible to verify the status and evolution of water bodies quality. The application of this concept to port environment has meant to design a procedure integrated by metrics to identify chemical and ecological variations due to man-related disturbances.

Chemical quality

In agreement with WFD chemical quality assessment is based on the list of 33 priority substances of Directive 2000/60/EC (European Parliament and of the Council, 2001). Indicators selected to assess the chemical value of water bodies are those priority substances whose presence has been detected in some contaminant emission. The assessment is performed by the comparison of the average annual values of the indicators with the reference values established in the standards (quality guidelines). Water bodies chemical quality is obtained by integrating the results of all the substances considered and applying the principle "*one out all out*" established by WFD. If one of the substances detected in a body infringes its chemical guideline quality will be classify as unacceptable.

Ecological quality

The indexes here developed are based on that first proposed by Juanes *et al* (2001) for water quality and Grall *et al* (2003), CEDEX (1994) and Holland Directorate General for Environmental Protection (1994) for soft bottom quality. In order to reflect objectively port water bodies structure and functioning, a selection of indicators were based on a combination of data analysis, scientific studies, publications and expert judgement. The result has been an assessment procedure integrated by one index to evaluate water quality, I_{AG} and another one to evaluate soft bottom quality, I_{SED}. Both indexes have been performed to be used on annual basis. In order to use annual means it was assumed that these values were representative of the whole variability of the variables. For assessing the ecological quality of water bodies default values were set up in accordance with its physical characteristics: heavily modified or non modified; low or high residence time; coastal or transitional; rocky or sedimentary. Therefore a specific assessment approach is available for each type of water body (N1-N4, M1-M4).

For the assessment of the water quality at a particular port water body in a year period a new index (I_{AG}) is proposed:

$$I_{AG} = \frac{(3.5C_{SAT} + 3C_{TURB} + 3.5C_{CLA})x(C_{HT} \, . \, C_{DET})}{10} \quad (4)$$

where C_{SAT}, C_{TURB}, C_{CLA}, C_{HT} and C_{DET} are the standardised values of average annual oxygen saturation, turbidity, chlorophyll 'a', total hydrocarbon and detergents respectively.

The hypothesis used in the formulation of the index to assess soft bottom quality was that hydromorphological altered areas as port water bodies information supplied by the combination of physico-chemical and organic characteristics, could reflect the health status of benthic communities (Grall *et al.*, 2003). The index performed to assess the quality of sediments, I_{SED}, is based on an exhaustive review of the environmental problems in port areas (Caeiro *et al.*, 2005; Chapman *et al.*, 2002; Chapman & Mann, 1999; Hamer & Karius, 2005; Hartmann *et al.*, 2004; Stronkhorst *et al.*, 2003; Sundberg *et al.*, 2005); (Alzieu *et al.*, 2003; Glemarec & Hily, 1981; Grall *et al.*, 2003; Lehtoranta *et al.*, 2004) and is integrated as the arithmetic mean of two specific indexes that estimate chemical I_{CQ} (equation 6) and organic I_{CO} contamination (equation 7), repectively:

$$I_{SED} = I_{CQ} + I_{CO} \quad (5)$$

The formula to calculate chemical contamination, I_{CQ} is:

$$I_{CQ} = \frac{1}{6}\left(C_{MP} + C_{PCB} + C_{HAP}\right) \quad (6)$$

where C_{MP}, C_{PCB} and C_{HAP} are the standardised values of the average annual concentration of heavy metals, Polychlorinated Biphenyls and Polycyclic Aromatic Hydrocarbons, respectively.

The expression developed to calculate organic contamination I_{CO} is:

$$I_{CO} = \frac{1}{2}\left(C_{COT} + C_{NTK} + C_{PT}\right) \quad (7)$$

where C_{COT}, C_{NTK} and C_{PT} are the standardised values of the average annual concentration of Total Organic Carbon, Total Kjeldahl Nitrogen and Total Phosphorus. The quality of rocky sea-beds is calculated using the percentage of rocky surface covered by flora and fauna characteristics communities.

In order to detect in advance any possible damaging effects environmental monitoring in water bodies subjected to greatest pressure of port activities could be complemented with the incorporation of "measures in real time" systems (continuous monitoring plan) and with the visual inspection of the water bodies.

3. Discussion

ROM 5.1 has developed a number of approaches to provide port authorities a unique, standardised and coherent tool to satisfy the operational monitoring demanded by Water Framework Directive to bodies at risk of failing environmental objectives. In a general analysis ports can be considered as significant pressures to water bodies and therefore with potential to fail its environmental objectives. Nevertheless, this is not a simple task to solve. In port areas environmental situation respond to the concurrence of interests and activities which produce a complex environmental challenge (Ondiviela, 2006). Nowadays the absence of legal procedures to regulate environmental quality in port areas (Goulielmos, 2000) is being replaced by initiatives promoted from the port organization directed to achieve the sustainability of its activities. That is the case of ROM 5.1. a methodology promoted by the Spanish National Ports Administration to help port authorities to be objective about environmental management and to explore sustainable development in port areas in terms of protection and improvement of the aquatic environment (Puertos del Estado, 2005). In agreement with WFD operational monitoring shall be undertaken in order to establish the status of those water bodies identified as being at risk of failing to meet their environmental objectives, and assess any changes in the status of such bodies resulting from the programmes of measures (European Parliament and the Council, 2000). Although literature offers numerous methodologies to analyse port environmental problems (Darbra *et al.*, 2005; Eide *et al.*, 2007; Jones *et al.*, 2005; Peris-Mora *et al.*, 2005; Ronza *et al.*, 2006; Ronza *et al.*, 2003; Wang *et al.*, 2004) neither of them manage sea port aquatic systems in an integral form. With this objective ROM 5.1 recognises physical singularities in seaport aquatic systems, gives evidences of significant pressures caused or induced by port activities, assesses its effects in water bodies quality but also proposes prevention, protection and control measures for water quality. This knowledge will contribute to identify where are the problems and which are the measures to be applied. In other words to identify the relations between antrophic disturbances and environmental attributes (Pearson & Rosemberg, 1978).

Nevertheless environmental impacts will differ from place to place depending upon the variations of geography, hydrology, geology, ecology types of shipping industrialization and urbanization (Gupta *et al.*, 2005). Hence, ROM 5.1. is currently being tested at different Spanish ports, in the Mediterranean, the Atlantic, the Biscay Gulf and the Canary Island coastal areas in order to create baseline studies able to establish a strong scientific background.

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