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An integrated database manager to forecast estuarine dynamics and water quality in the Guadalquivir river (Spain)

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ABSTRACT: Estuaries are complex water bodies where seawater and freshwater mix to generate a dynamic gradient from marine to fluvial conditions. These environments need to be monitored and modeled with a multidisciplinary approach which considers the different spatial and temporal scales of the undergoing processes and the non-linear effects of their interaction. The Guadalquivir River estuary is a representative example of human modification of the natural flow regime from both the fluvial and the sea. Boat navigation, metal and salt mine exploitation, agricultural transformation, fluvial regulation throughout the catchment area and, more recently, aquaculture practices, have not only strongly modified the tidal prism and the fluvial regime, but also affected the sediment supply and transport dynamics with dramatic intermittent or prolonged growth in the resulting turbidity and marked oxygen depletion during long periods. This study presents a multidisciplinary integrated database manager, created to characterize the coupled dynamics of water, sediment, salts, nutrients, pollutants and meteorological forcing in the Guadalquivir estuary. The database manager incorporates data from over 100 measurement stations allowing for not only the visualization of the variable evolution, but also complex analysis techniques for monitoring estuarine processes and forecasting the short-term and long-term evolution of water quality.

Keywords: Estuary dynamics, Data management

1 INTRODUCTION

The Guadalquivir Estuary is located in Southern Spain, with the river mouth exiting into the Atlantic Ocean. It receives inflow from a 57400 km^2 catchment area, with a freshwater discharge mainly originating from the Alcalá del Rio dam. It is a channel like, convergent estuary, with a mean water depth of 7.1m, maintained by periodic dredging. Figure 1 and Figure 2 show the location of the study site and the Guadalquivir river catchment area, respectively.

The Estuary form and area are constantly altered by the erosion and deposition of sediment along its extent, both of which are strongly affected by variations in the sea level at different time scales. Its wide range of forms is the result of the complex interaction between riverine and marine processes. Estuaries are continually evolving, changing their shape, adapting to changes in river flow and weather patterns, changing the phase and amplitude of the input signals, with effects on salinity, temperature, suspended sediments and nutrients distribution in water in time and space (Dyer, 2000).

Most of the estuaries along developed countries coastlines are strongly modified by upstream dam regulation and socioeconomically use of the estuary area, such as agriculture, aquiculture and tourism. An integrated management not only of water resource but also of soil use in their contributing area is a necessary approach to restore and preserve the diversity of life and nutrient fluxes in our estuaries. The Guadalquivir River Estuary in Southern Spain is a good example of such a demanding situation, which has experienced a large reduction of freshwater input due to the upstream regulation system along the river, periodic dredging labors to maintain navigation lanes to the Seville Port, and aquiculture systems and large downstream rice crop areas which require low suspended sediment concentration and moderate levels of salinity in water, respectively.

In order to evaluate the Guadalquivir estuary current state and trends, and to simulate future states under different management strategies and/or subject to sea level rise and climate variability trends, a grand volume of data from the system must be processed to include all relevant processes in the analysis and to feed and calibrate the final models (Hardisty, 2007).

This work presents a data management tool, under the Matlab programming language, developed for the monitoring system of the Guadalquivir Estuary in the framework of the Project *Method Proposal for the Diagnosis and Prognosis of Human Actions Consequences on the Guadalquivir Estuary*, financed by the Port Authority of Seville and coordinated by the ICMAN, (Andalucian Institute of Marine Sciences) and the GDFA (Environmental Fluid Dynamics Group).

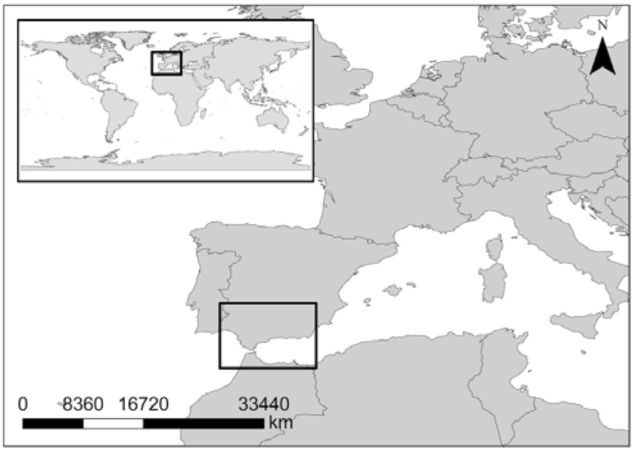

Figure 1. Location of study site.

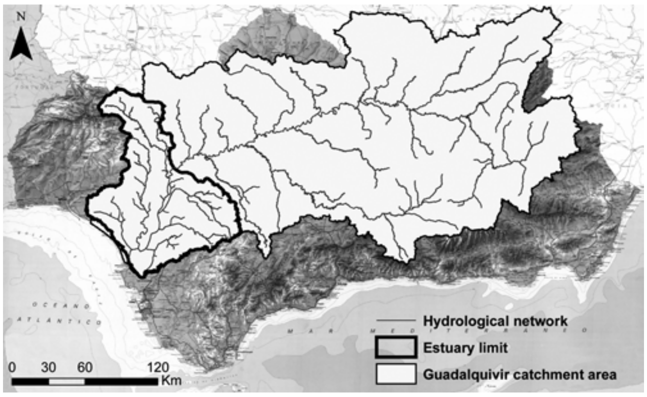

Figure 2. Guadalquivir River catchment area.

2 MONITORING SYSTEM

The monitoring network and data necessary for the estuary analysis and modeling comprises several sources and databases (Navarro et al., 2009; Diez et al., 2009):

- Meteorological data from the automatic station network provided by the regional government of Andalucia (hourly information of precipitation, humidity, air temperature, radiation, wind speed and direction).
- Water level and current meter velocity, from eleven doppler profiling stations (ADCP) and nine additional pressure sensors (Tide Gauges) from different sources (Federal Ports Authority, ICMAN and GDFA). Profiling stations are moored on buoys at the free surface along the estuary, pointing in a downward direction. At each position, profiles are obtained with 15 minute intervals with a cell size of 1m.
- Deep water wave and wind characteristics obtained from WANA points provided by the Federal Ports Authority, Spain and the AEMET (Federal Meteorological Agency). Each WANA point contains daily series of forecast wave (WAM wave model) and wind data (HIRLAM model) since 1996.
- Water quality data from the government of Andalucia periodic (1-7days) measurements along the estuary, comprising of suspended matter concentration, turbidity and conductivity.
- Water quality data from the Guadalquivir Water Administration ICA network (Water Quality Integrated Network). This network provides, since January 1981, laboratory analysis of monthly surface water samples collected along the estuary, including information about chemical, physical and microbiological parameters, such us pH, water temperature, conductivity, concentration of nitrates, nitrites, ammonium, phosphates, total phosphorus, herbicides, suspended particles, etc.
- Water quality data from the Guadalquivir Water Administration, SAICA network (Automatic Water Quality Measurement System). Each station provides real time records of water depth, turbidity, conductivity, pH, temperature, dissolved oxygen concentration, and at particular locations along the estuary also ammonium and organic matter concentrations.
- Within the Guadalquivir estuary, high frequency continuous records of turbidity, salinity, temperature and water quality parameters are obtained from seven CTD stations controlled by ICMAN.
- Daily water discharges from the Alcala del Rio dam and other contributing rivers to the estuary from SAIH (Automatic Hydraulic Information Measurement System).
- Current and wave monitoring points in the continental shelf provided by the GDFA

from doppler profilers (a NORTEK acoustic wave and current meter AWAC, two NORTEK and two SONTEK acoustic current meters comprising of temperature, compass, tilt and pressure sensors). The instruments are positioned outside of the river mouth and fixed at the sea bed, pointing upwards. The devices are programmed to hourly measure 1024 samples of the water surface elevation, pressure and orbital velocities with a sample rate of 1Hz. For the remaining time within the hour, water current profiles are obtained with a sampling time of 20 minutes and an averaging interval of 120s.

- Meteorological data (wind, atmospheric pressure, temperature, radiation) recorded at the entrance to the estuary at 10m height, sampled every 10 minutes.
- Additional information from field campaigns including a current meter mounted on a body-board to capture the 3D tidal structure at specific cross sections in the river.

Figure 3 shows the locations of the principal measurement stations, which continuously measure maritime, fluvial and climate conditions, including temperature, salinity, turbidity, current and surface elevation variations at several points.

The network of measurement stations can be organized into three main groups. Firstly, 16 maritime stations are located outside of the river mouth at different water depths. Secondly, 66 fluvial stations are present along the main channel of the river and different tributaries to the estuary. Finally, 28 climate stations are located within the estuary catchment area. In total 110 data stations have been compiled from 20 different networks, resulting in the continuous quasi-real time monitoring of forcing agents in the estuary, together with the state variables.

Due to the characteristics of every dataset (frequency, time series extent, data source, file format), a huge amount of work deals with data validation, filtering, preprocessing, and format conversion, including standard statistical methods for automatically detecting outliers and errors.

After one year of data collecting and analysis, the need for a management tool was patent, together with the need for up-to-date continuous access to the entire dataset from every member in the research group. Because of this, it quickly became clear that a single management tool was necessary to collect, validate, and format the data into a single, global, database.

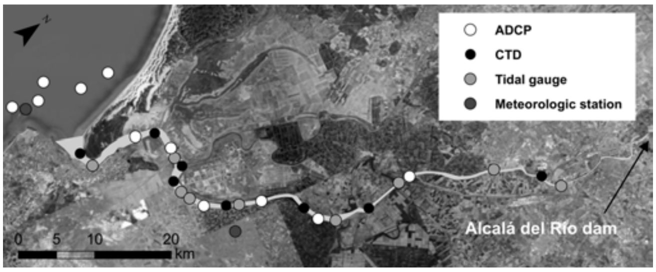

Figure 3. Principal measurement station locations.

3 DATA MANAGEMENT STRUCTURE

To facilitate this, a software tool is being developed within Matlab with a user interface. The data management organization chart is presented in Figure 4. The data originates from three basic sources: Firstly, from an ftp server, controlled by ICMAN, which is automatically downloaded into the database at the beginning of each month; secondly, directly from equipment deployed by the GDFA, and thirdly, from publicly controlled institutions, which are periodically inputted as the data becomes available.

The data is first screened through a quality control program and later saved within a structured format, which contains all relevant information pertaining to the measurement station. In the past we have stored data in matrix form or multiple text files, however in this way details about the measurement parameters and units were stored separately from the time series files. It became clear that as the number of stations increased the possibility of introducing errors due to miscommunication of measurement parameters became large.

To eliminate this possibility, the database is built using a structured format, which includes all necessary text and numeric information within the one file. For example the structure includes station identification, including name, network, latitude, longitude and altitude or depth.

Three basic data formats are available:

1. Time-series, which are separated for each deployment time interval. This facilitates deployments with different sample frequencies and measurement parameters.

2. Profile data, for example water current profiles by ADCP and AWAC sensors, and salinity and turbidity profiles by the CTD buoys, where each profile is separated according to date.

3. Free surface data, collected at the outer platform by the ADCP and AWAC sensors, obtained from 17 minute bursts at the

start of each hour, where each measurement burst is separated according to date.

This fills a global database library which contains all 110 stations, from which it is possible to compile smaller sub-databases for specific applications by using the station selection module presented in Figure 5. Each sub-database contains all information relating to the selected stations within one single file for ease of transfer between colleagues.

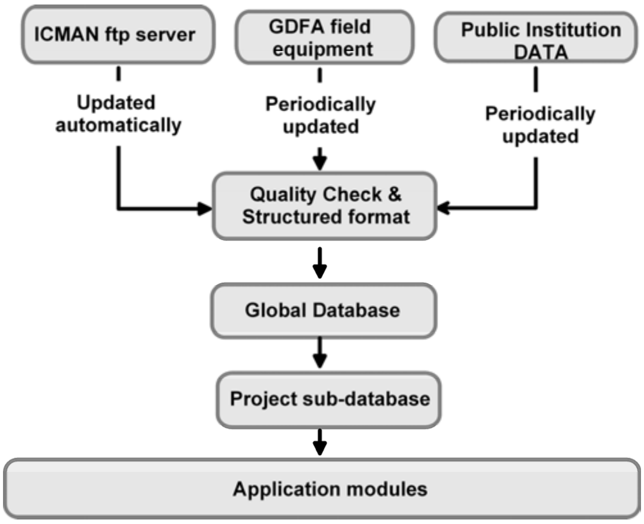

Figure 4. Data management organization chart.

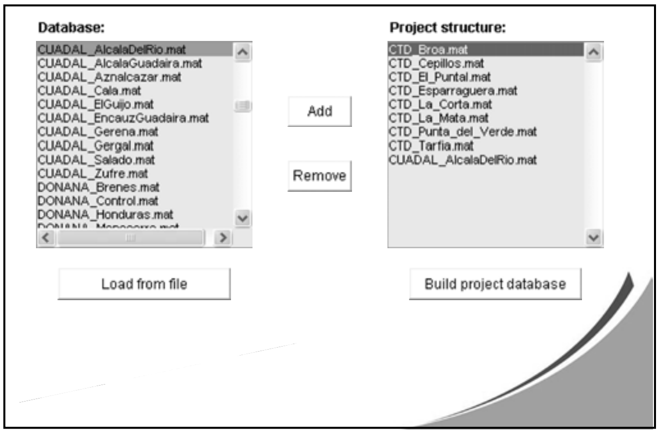

Figure 5. Measurement station selection module.

4 APPLICATION MODULES

Various application modules have been developed for the project, ranging from simple data visualization applications to complex data analysis

The basic visualization module allows plotting of multiple variables collected from different stations. The user can select the date of representation, with the option of extracting the selected data into a text file with a common time step. This extracted data can be used to feed and calibrate the various numerical and analytical models used within the project. Other visualization tools include the profile visualization module, which allows the user to easily scroll through the various profile measurements according to measurement parameter (salinity, turbidity, temperature, currents, etc.) and date.

Data analysis modules provide time series analysis (spectral and harmonic analysis), filtering and signal processing, spatial correlation, mean flux of water, salt and sediments (Tidal prism, Eulerian and Langrangian current), wave statistics (univariate, extreme value, mean climate) and wind statistics (wind rose, weibull, extreme value).

The wave statistics module shown in Figure 6 provides the mean climate and extreme event analysis, using the peaks over threshold technique. The module separates the time-series from any selected measurement station into individual storm events which can be later exported for input into external numerical propagation modeling programs, for example SWAN and REF-DIFF.

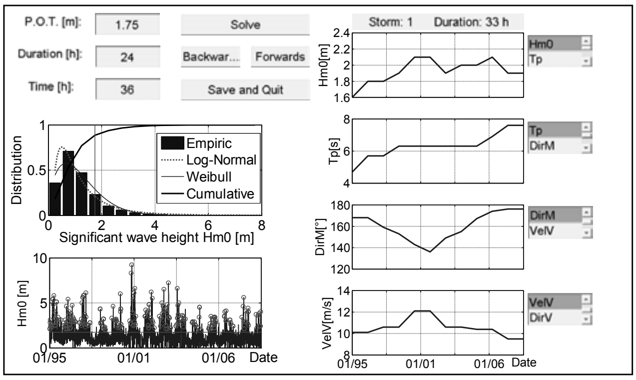

Figure 6. Mean climate and extreme events analysis module.

The wind rose and statistics modules in Figures 7 and 8 provide the wind rose, for determining the seasonal and daily variations in the wind speed and directionality, in addition to representing the parent probability distribution through a weibull fit, according to wind direction, season and time of day.

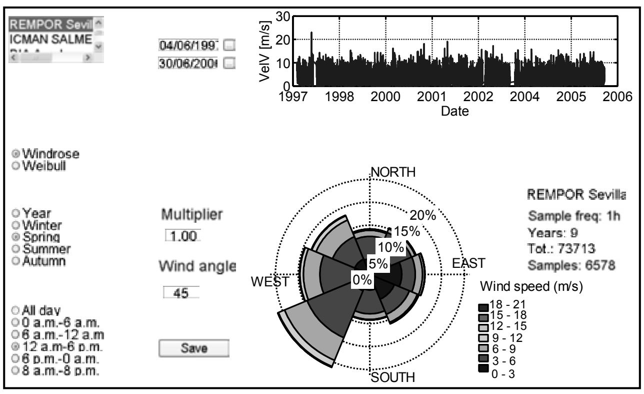

Figure 7. Windrose module.

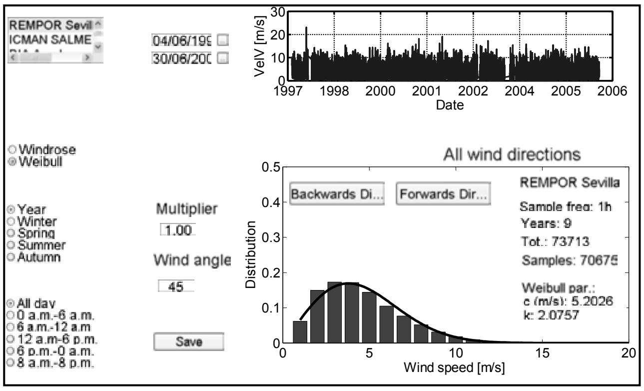

Figure 8. Wind statistics analysis module.

The spatial analysis module analyzes the effect of the discharge from the upstream dam on the location of the mixing zone. Figure 9 represents on the x axis, the distance from the mouth of the river, and on the y axis the mean daily river discharge from the Alcala del Rio dam. The contour lines represent the tidal averaged salinity isolines.

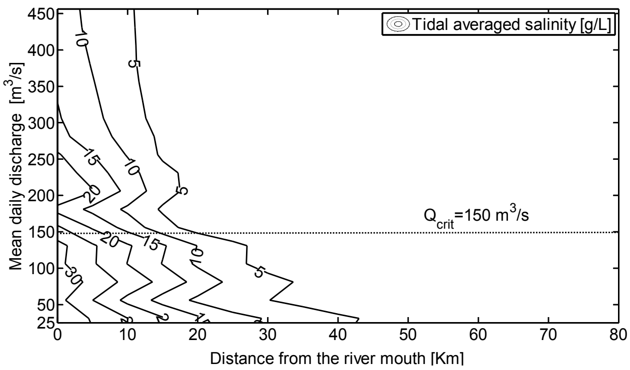

Figure 9. Spatial data analysis module.

The Figure 9 shows the presence of a clear discharge limit of 150 m^3/s. For a discharge below this, the mixing zone, based on a tidal averaged Salinity of between 5 and 10 g/L, is located approximately 30 km from the river mouth. However, for discharges above this limit, the mixing zone is clearly shifted by 20 km towards the river mouth.

Figure 11 is obtained from the basic visualization module displaying various measured parameters during the period between April 4th to June 4th, 2008. From top to bottom, the Figure 11 presents: daily discharge from the Alcalá del Rio dam, hourly precipitation at the station RIA Lebrija 1, tidal variation in Bonanza Harbor, significant wave height, peak period and mean direction, wind velocity and mean direction (simulated in the WANA point from the Spanish Harbor Administration), and finally, the salinity and turbidity measured at 1 m from the surface at two CTDs located in Cepillos and Esparraguera. The station locations are presented in Figure 10.

The significant wave height presented in Figure 11(d) shows the arrival of two storms, both with significant wave heights greater than 2m, proceeding from the Atlantic Ocean. During the two storm events, north-westerly winds of up to 10 m/s are present in the region, inducing precipitations of up to 10 mm/h. As a consequence, the Alcalá del Rio dam releases two significant discharges of over 500 m^3/s. The occurrence of the two discharges correlates well with the observed reduction in salinity along the length of the estuary (Sandford et al., 2001).

The effect of both discharges on the estuary turbidity varies with the tidal characteristic: the first discharge occurs in conjunction with a neap tide and the river flow is capable of contrasting the tidal flow (Geyer et al., 2001) resulting in little variation in the level of turbidity at both CTD measurement locations. In contrast, the second discharge coincides with a spring tide, inducing an increased level of turbidity in the Esparraguera zone as the sediments transported by the river exceeds the tidal push. The behavior of the turbidity correlates well with the tidal variations resulting in a maximum turbidity during spring tide and a minimum during neap tide.

Conversely in the Cepillos Zone, near the river mouth, the velocity reduction near the bed caused by the increase in the transversal river section width and the existence of moderate winds rotating 360^o from North to West, increases the mixing of estuarine turbidity water with the cleaner ocean water, and contributes to reduce the value of the global local turbidity.

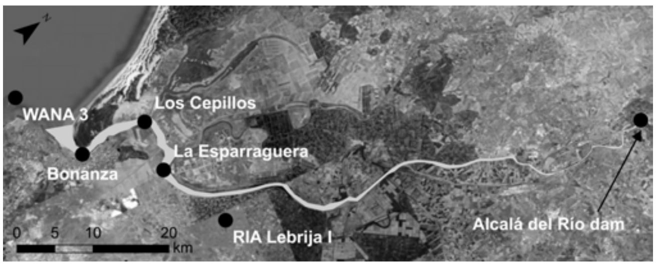

Figure 10. Location of the CTDs (Los Cepillos, La Esparraguera), meteorological station (RIA Lebrija 1), Bonanza tidal gauge, WANA3 and the discharge measurement point at Alcalá del Rio.

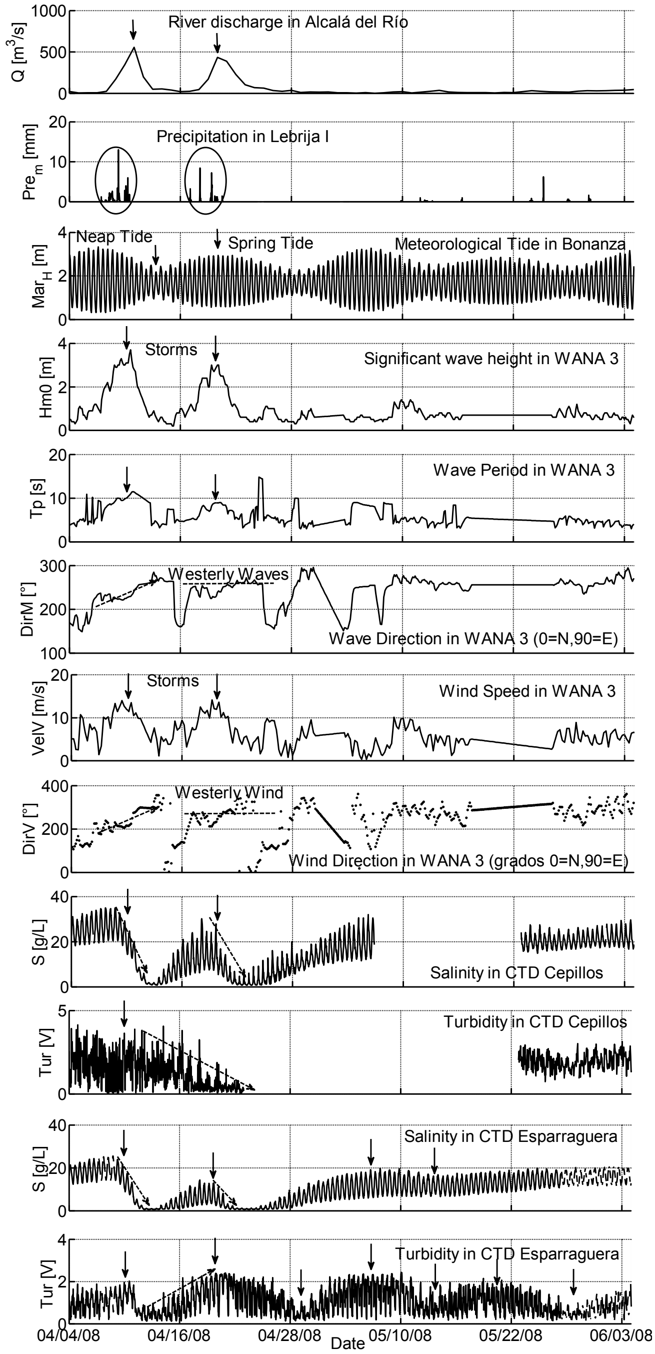

Figura 11. Fluvial, maritime and climatic variables in the Guadalquivir estuary along with salinity and turbidity in Los Cepillos y La Esparraguera CTDs, for the time period between April 4th to June 4th, 2008.

5 CONCLUSIONS

The complex and multi-scale processes that describe the Guadalquivir estuary require an integrated monitoring tool to compile a wide variety of environmental variables from different sources. The dataset management tool has been efficiently structured to provide the intra-university research group with a common validated dataset and a simple user interface analysis package to visualize and further process the data. In the future, the database and management tool will be accessible from the internet for public use, under the maintenance of the research group.

The monitoring system installed in the estuary provides the information necessary for characterizing the estuary dynamics by observing the differential behavior of the physical variables such as salinity, temperature, suspended sediment concentration (turbidity), in function with the location within the estuary, tidal cycle, river discharge, and river mouth conditions with respect to the meteorological atmospheric forcing and the consequent wave height.

Through the management tool, the multiple processes are collated and verified before constructing numerical models of the estuary dynamics for forecasting the short-term and long-term evolution of water quality.

The management tool is readily applicable to monitoring plans in coastal and transitional systems (estuarine and lagoonal system subject to the European Union Water Framework Directive, WFD, 2000) in which water quality, conservation areas and human uses may easily relate. Specifically, it will be applied to selected littoral Andalusian areas to meet the WFD requirements for control and monitoring points in water bodies. This relates to hydromorphological parameters in coastal and transitional water zones, such as tidal elevation, waves, fresh water discharge, turbidity, salinity, dissolved oxygen content.

REFERENCES

Díez-Minguito, M., García-Contreras, D., Bramato, S., Ruiz, J. and Losada, M.A. 2009. Modelo de circulación mareal y submareal en el estuario del Guadalquivir. Proceeding of X Jornadas de Costas y Puertos, 28-29 May, Santander (Spain), 291-300.

Dyer, K.R. 2000. Estuaries: A Physical Introduction, Wiley, Chichester.

Hardisty, J. 2007. Estuaries. Monitoring and modeling the physical system, Blackwell, Singapore.

Geyer, W., Woodruff J., Traykovski, P. 2001. Sediment Transport and Trapping in the Hudson River Estuary. Estuaries, 24(5), 670-679.

Navarro, G., Gutiérrez, F.J., Roque, D., García, R., Fernández, J.L., Losada, M.A. and Ruiz, J. 2009. Red de monitorización en tiempo real de las propiedades hidráulicas y de calidad ambiental de las aguas portuarias de Sevilla. Proceeding of X Jornadas de Costas y Puertos, 28-29 May, Santander (Spain), 349-358.

Sandford, L., Suttles, S., Halka, J. 2001. Reconsidering the Physics of the Chesapeake Bay Estuarine Turbidity Maximum. Estuaries. 24(5), 655-669.

WFD. 2000. Available from:
http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:327:0001:0072:EN:PDF.