

DEVELOPMENT OF A GIS-BASED TOOL FOR EVALUATING AND PREDICTING COASTAL WATER QUALITY ISSUES: THE PEARL RIVER ESTUARY

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ABSTRACT

In this study, a GIS-based tool has been developed to evaluate and predict coastal water quality issues for the Pearl River Estuary (PRE). The developed system consists of three key components. The first component is a database of hydrodynamic and water quality data collected from various public domains. This database is linked with the GIS for efficient retrieval, display, and analysis of historic hydrodynamic and water quality conditions. The second component is the integration of the GIS with a hydrodynamic-water quality numerical model. The system is customized to handle the model pre-processing and post-processing requirements through the GIS interface. Finally, the third component is an Environmental Impact Assessment (EIA) tool. The EIA module is designed to examine water quality conditions in spatial context and more specifically, to identify the region subjected to the most severe water quality impact. The module combines spatial layers of various water quality parameters, whereas created from field data or generated from model results, into a single spatial layer of water quality index using the GIS Map Algebra technique.

KEY WORDS

Geographic Information System, Water quality, Hydrodynamic model integration, Environmental Impact Assessment, Pearl River Estuary

INTRODUCTION

The Pearl River Estuary (PRE), located in the southern part of Guangdong province in China, is a triangular-shaped estuary which receives freshwater from the Pearl River Delta (PRD) and drains into the South China Sea (see Figure 1). The estuary covers an area of more than

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2000 km², and is exposed to effluent from four major river outlets at the northwest side, namely, Humen, Jiaomen, Hongqilimen, Hengmen, resulting in a total annual average freshwater runoff of $1.742 \times 10^8 \text{ m}^3$ and an average annual discharge of 5300 m³/s (e.g., Chen and Heinke 2001). In the past decades, due to the massive economic and industrial development in the PRD region, the PRE is experiencing serious water quality deterioration. To address this issue, a tool has been developed to enhance coastal management in the PRE by applying Geographic Information System (GIS) technology in hydrodynamic/water quality modelling.

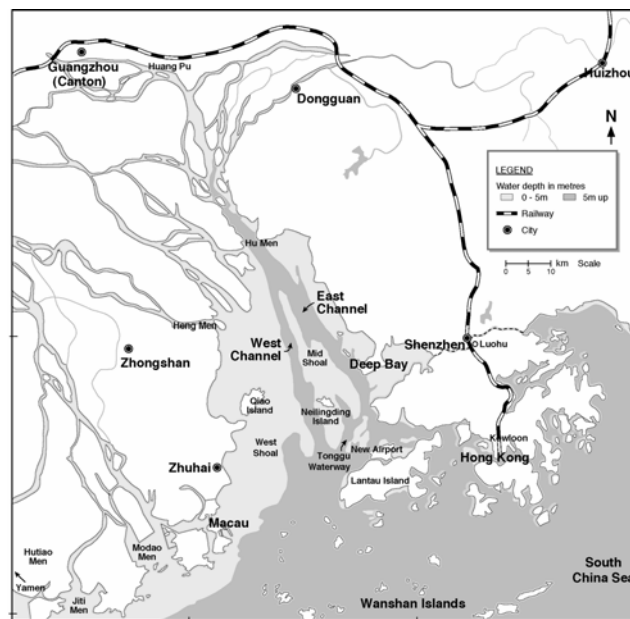


Figure 1: Pearl River Estuary (Figure 1.1 in Ng 2005)

DEVELOPMENT OF A GIS-BASED TOOL FOR HYDRODYNAMIC

In this study, a GIS-based tool has been developed to support retrieval, display, and interpretation of both field-collected and model-simulated datasets as well as for environmental impact assessment (EIA). Figure 2 shows a conceptual diagram of the GIS-based hydrodynamic system. The integrated system links together three key system components: 1) a database for storing field-collected data, 2) a pair of connections with a hydrodynamic-water quality coupled model, one for data exchange with model inputs and the other for retrieval of outputs, and 3) a module for EIA application, to a single operation platform.

The customization of GIS software is carried out using ArcView's built-in Visual Basic for Application (VBA) scripting capabilities for manipulation of ArcObjects. Other more advanced tools are developed using Active Dynamic Link Library (DLL) in Visual Basic (VB) and registered into the system. Furthermore, building upon a menu-driven interface, the system allows users with minimal backgrounds in the use of GIS software to access and analyze hydrodynamic and water quality information.

GIS DATABASE FOR FIELD DATA

Hydrodynamic and water quality data of the PRE have been acquired from a number of public domains and compiled into a database system using the Microsoft (MS) Access software. The collected data encompasses various physical, chemical, and biological parameters, including temperature, current velocity, pH, salinity, turbidity, dissolved oxygen, nutrients (nitrogen and phosphorus compounds), metals, organics and coliform bacteria. The developed database system is linked with the GIS for efficient retrieval and display of information.

STRUCTURE OF DATABASE SYSTEM

Within the database system, the collected data are organized into a collection of station and measurement tables. For most of the field surveys, measurement data were taken at several monitoring stations of fixed locations. The station tables are for storing the geographic positions of the fixed stations, while the measurement tables contain the actual measurement records. For each field survey, there are typical one station table and several measurement tables and “one-to-many” relationships are established between the core station table and each subordinate measurement table (see Figure 3).

DATA RETRIEVAL AND DISPLAY

In general, there are three basic methods to display raw measurement data (see Figure 4). The simplest data display method using GIS is a spatial snapshot in the horizontal direction at a specified time depth. As marine environment is essentially three-dimensional and dynamic, pertinent data exhibit variations not only in location, but also through depth and time (e.g., Lucas 2000). For this reason, time series plot and vertical profile display are also incorporated into the system.

Data retrieval process is carried out based on the Structured Query Language (SQL) procedures. As shown in the single spatial layer dialog box in Figure 5, a spatial layer can be created by specifying a list of input parameters including the data source, the dataset, the measurement table, the hydrodynamic or water quality parameter, the measurement depth level (e.g. surface, middle, bottom) or depth range (i.e. from a specific distance from water surface to another), and the measurement time period. In addition, as the user chooses among the measurement tables, the dialog box provides a description detailing the station table name, measurement time period and interval, and the measurement depth interval. Based upon the selection criteria, the GIS performs SQL queries to extract the information needed to create a spatial layer. For efficiency in creating multiple layers, creating of spatial layers can also be done using batch model.

Similar querying operation applies for creating time series and profile plots. Graphing displays for time series and profile are developed using the MS Office Chart Component. The output of the time series function is an x-y scatter plot with time given in the x-axis and the specified hydrodynamic or water quality parameter in the y-axis (see Figure 6). Profile is for display of parameter along a vertical water column. Additional options of time series and profile include display of more than one curve for comparison of the same parameter at

different survey stations or at different time instants, and the use of trendlines to enhance visibility of information.

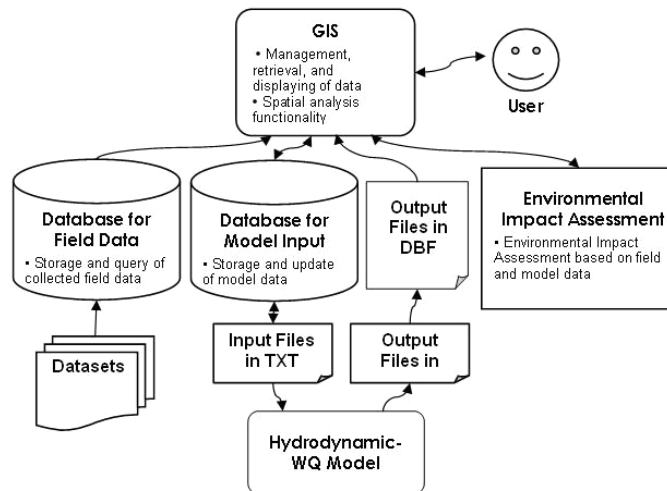


Figure 2: Conceptual Diagram of the GIS-hydrodynamic Integrated System (Figure 2.1 in Ng 2005)

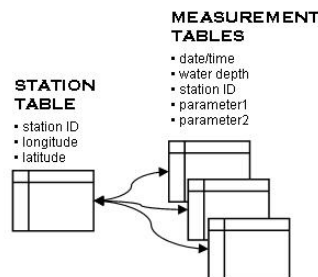


Figure 3: Database Relationship Diagram – Field Data (Figure 3.1 in Ng 2005)

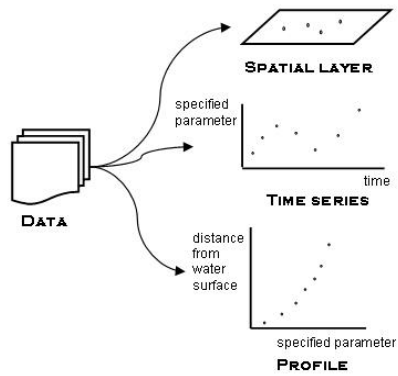


Figure 4: Data Displays (Figure 4.4 in Ng 2005)

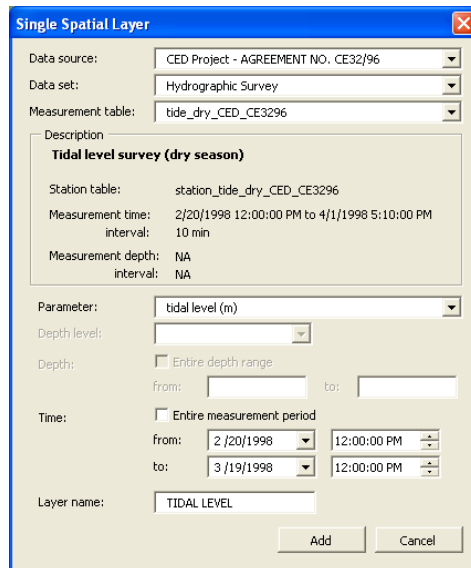


Figure 5: Dialog Box for Creating Single Spatial Layer (Figure 4.5 in Ng 2005)

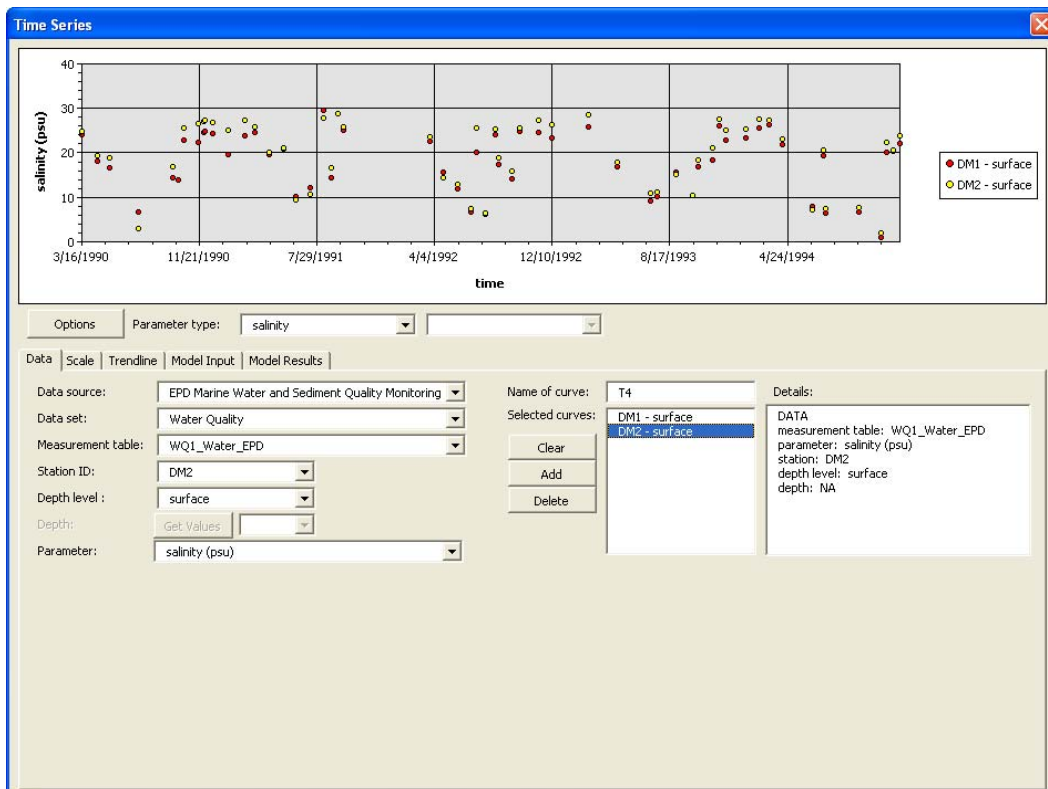


Figure 6: Dialog Box for Creating Time Series (Figure 4.7 in Ng 2005)

INTEGRATION WITH HYDRODYNAMIC-WATER QUALITY NUMERICAL MODEL

The GIS has been integrated with a three-dimensional hydrodynamic-water quality numerical model. The model was initially developed by Wai and Lu (2000) to simulate sediment-water transport processes using a parallel-processing algorithm, and was later modified by Jiang (2003) to include fate and transport of cohesive sediment and heavy metals modelling. Based on the interface integration method (e.g., Shamsi 2002), pre-processing and post-processing components have been incorporated into the system to allow model input and output procedures to be carried out entirely within the GIS interface.

PRE-PROCESSING COMPONENT

The pre-processing component is designed for retrieval, manipulation, editing, display, and export of model input data through the GIS interface. The data input requirements for the model include bathymetry of the study area, inflow and outflow for source elements, suspended and bed sediment parameters, tidal flat drying and flooding control variables, initial conditions and boundary conditions of tidal elevation, salinity, current velocity, sediment concentration, and metal (or water quality) concentration, as well as mesh grid configuration.

Model Input Update

A separate relational database has been developed specifically for model inputs (refer to Figure 2) also using the MS Access software. The placement of model input into relational database software is essential not only for efficient management of data but also for establishment of a direct linkage between the model input and the GIS user interface. The tables of input data in the database can be embedded into the pivot tables in the user input dialog boxes. In this way, the user not only can view the data from the database, but also can update input data through the dialog boxes (see Figure 7).

Model Input Display

The retrieval and display of model input are in strong parallel with that of field data. Model input can be visualized in forms of spatial layer, time series, or profile display. As shown in the dialog box from Figure 8, a spatial layer can be created simply by specifying the parameter and the layer number. And upon execution, the GIS will perform a SQL query to extract the information from the model input database, and create a spatial layer.

The incorporation of model input display allows for quick and easy interpretation of model input. Figure 9 is a single spatial layer of water depth created using the model input display command. The color of the nodal points gradates from light to dark as the water depth varies from shallow to depth. So at a glance, the user can acquire a comprehensive picture of a specified model input variable.

The only input variable at open boundary which varies with time and thus requires time series display is tidal level. All other variables, such as sediment concentration, salinity, and metal concentration, are assumed to be constant with time. The time series display for tidal level are included as part of the same dialog box for field data. This will allow comparison of field-collected and model data through the same graphic display. Referring back to Figure 6, time series of model input can be created by selecting the *Model Input* tab. The input requirements simply include the measurement time period and the open boundary node number. Profile display can be created for both initial and boundary conditions of all variables except tidal level and water depth. Similarly, the profile display for model input are incorporated into the same dialog box for field data.

Mesh Grid Configuration

The configuration of model mesh grid can also be implemented within the GIS interface. Programming routines have been developed for generating the setup of model mesh grid as well as carrying out refinements. There are basically two ways to reposition the locations of existing nodal points. One is by modifying the values or the geographic coordinates in the nodal coordinate table (see Figure 9), and the other is by moving nodal points through the GIS display.

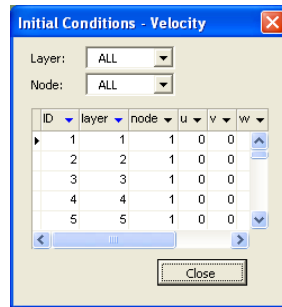


Figure 7: Dialog Box for Initial Conditions of Velocity (Figure 5.2 in Ng 2005)

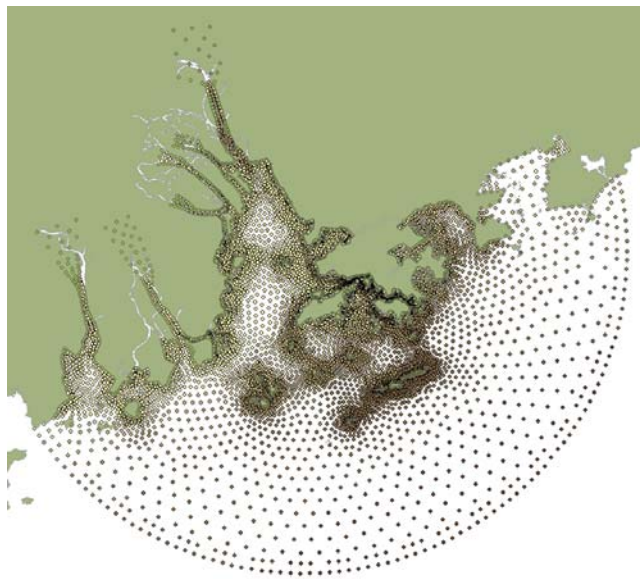


Figure 8: Display of a Spatial Point Layer of Water Depth from Model Input in GIS (Figure 5.10 in Ng 2005)

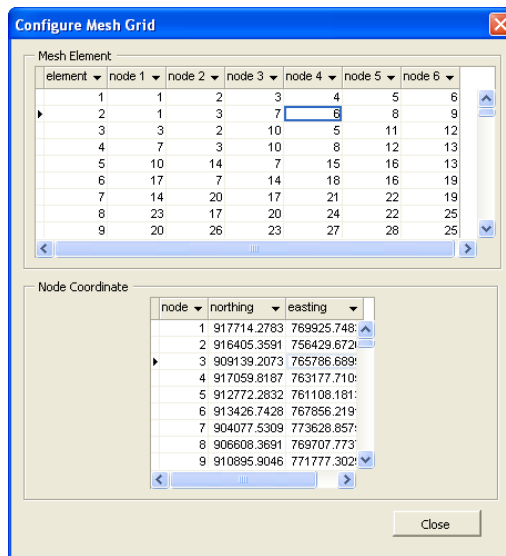


Figure 9: Dialog Box for Configuring Mesh Grid (Figure 5.14 in Ng 2005)

POST-PROCESSING COMPONENT

Likewise, the data displaying methods for model output are fundamentally the same as those for field data and model input (i.e. spatial layer, time series, and profile). However, since model output involves a large amount of output files of the same format, the files can be directly retrieved from the DBF output files. To create a spatial layer, the user must specify the hydrodynamic or water quality parameter, the time instant of simulation, and the water depth layer. For display of a time series plot, the user must specify the hydrodynamic or water quality parameter, the nodal number, and the water depth layer. The required input parameters for creating a profile are the hydrodynamic or water quality parameter, the nodal number, and the time instant of simulation.

APPLICATION FOR EIA

Spatial layers, whether generated from field data or model output, can be useful for EIA. An EIA module, based on the concept of Water Quality Index (WQI) has been developed for quantifying water quality conditions. A WQI integrates a selected set of measured parameters into a single unitless value (e.g. one number from 0 to 100, with 0 for the worst condition and 100 for the best condition) for water quality evaluation. The mathematical procedure involves first converting values of each parameter into a subindex score, and then combining the subindex scores into a single WQI using an aggregation function. The manipulation of raster layer of different water quality parameters for creating a single layer of WQI can be carried out using the GIS Map Algebra technique.

Figure 10 shows the dialog box for creating WQI layers. The input process involves first identifying the water quality parameters to be included, their respective rating curve, raster layer, and weight if applicable, and then selecting an aggregation function type. On the right side of the dialog box is a display of the rating curves in graphic format. A wide selection of

rating curves taken from literatures (e.g., Cude 2001, Dinius 1987, Liou et al. 2004, Schierow and Chesters 1998, Smith 1990, Stambuk-Giljanovic 1999) is available. Furthermore, five aggregation functions, namely, weighted arithmetic mean, weighted geometric mean, harmonic mean of square, minimum operator, and Swamee and Tyagi (2000) are included into the system.

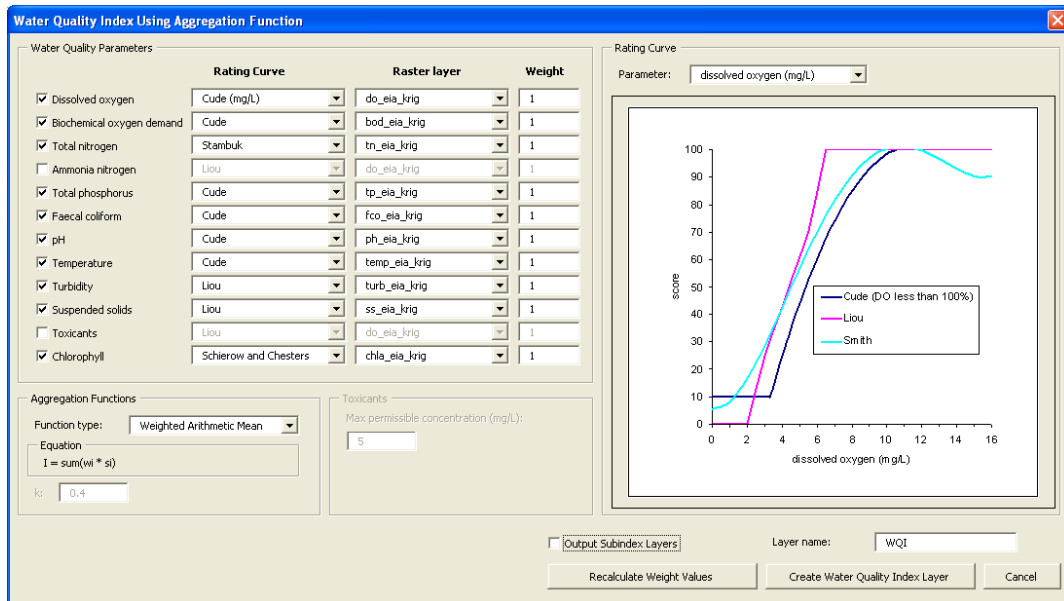


Figure 10: Dialog Box for Creating WQI layer (Figure 7.15 in Ng 2005)

CONCLUSIONS

This paper has presented a GIS-based tool, which integrates together data collected from field and those generated by a hydrodynamic-water quality model for efficient retrieval, display manipulation, and analysis information. The integration not only allows information comparison through various data displaying functions such as spatial layer, time series, and profile, but also extends the use of field data for model inputs. Furthermore, an EIA component making use of the GIS Map Algebra technique has been discussed. The module integrates spatial layers of water quality parameters in different measurement dimensions into a single spatial layer of water quality index. This provides a comprehensive spatial outlook for identifying areas that are acceptable and those potentially at risk. Though the initial intention of developing this GIS is to tackle the serious water quality issues at the PRE, the developed data display and retrieval tools can essentially be applied for any water body system.

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